EUMETSAT Satellite Application Facility on Climate Monitoring

The EUMETSAT Network of Satellite Application Facilities

CM SAF Climate Monitoring

CM SAF Cloud, Albedo, Radiation dataset, AVHRR-based, Edition 1 (CLARA-A1)

Cloud Products

Product User Manual

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Fractional Cloud Cover	**CM-05**
Joint Cloud property histogram	**CM-11**
Cloud Top level	**CM-17**
Cloud Optical Thickness	**CM-34**
Cloud Phase	**CM-38**
Liquid Water Path	**CM-43**
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AD 2	CM SAF Service Specification Document	SAF/CM/DWD/SeSp/1.9
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RD 3	Algorithm Theoretical Basis Document NWCSAF/PPP “Cloud mask”	SAF-NWC-CDOP-SMHI-PPS-SCI-ATBD-3_v2_3_3
RD 4	Algorithm Theoretical Basis Document NWCSAF/PPS “Cloud top Temperature, Pressure, Height”	SAF-NWC-CDOP-SMHI-PPS-SCI-ATBD-3_v2_3_1
RD 5	Algorithm Theoretical Basis Document Cloud physical products CLARA-A1	SAF/CM/KNMI/ATBD/GAC/CPP/1.1
RD 6	Algorithm Theoretical Basis Document Joint Cloud property Histograms AVHRR/SEVIRI	SAF/CM/SMHI/ATBD/JCH/1.1

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1 The EUMETSAT SAF on Climate Monitoring (CM SAF)

The importance of climate monitoring with satellites was recognized in 2000 by EUMETSAT Member States when they amended the EUMETSAT Convention to affirm that the EUMETSAT mandate is also to “contribute to the operational monitoring of the climate and the detection of global climatic changes". Following this, EUMETSAT established within its Satellite Application Facility (SAF) network a dedicated centre, the SAF on Climate Monitoring (CM SAF, http://www.cmsaf.eu).
The consortium of CM SAF currently comprises the Deutscher Wetterdienst (DWD) as host institute, and the partners from the Royal Meteorological Institute of Belgium (RMIB), the Finnish Meteorological Institute (FMI), the Royal Meteorological Institute of the Netherlands (KNMI), the Swedish Meteorological and Hydrological Institute (SMHI), the Meteorological Service of Switzerland (MeteoSwiss), and the Meteorological Service of the United Kingdom (UK MetOffice). Since the beginning in 1999, the EUMETSAT Satellite Application Facility on Climate Monitoring (CM SAF) has developed and will continue to develop capabilities for a sustained generation and provision of Climate Data Records (CDR’s) derived from operational meteorological satellites.
In particular the generation of long-term data sets is pursued. The ultimate aim is to make the resulting data sets suitable for the analysis of climate variability and potentially the detection of climate trends. CM SAF works in close collaboration with the EUMETSAT Central Facility and liaises with other satellite operators to advance the availability, quality and usability of Fundamental Climate Data Records (FCDRs) as defined by the Global Climate Observing System (GCOS). As a major task the CM-SAF utilizes FCDRs to produce records of Essential Climate Variables (ECVs) as defined by GCOS. Thematically, the focus of CM SAF is on ECVs associated with the global energy and water cycle.

Another essential task of CM SAF is to produce data sets that can serve applications related to the new Global Framework of Climate Services initiated by the WMO World Climate Conference-3 in 2009. CM SAF is supporting climate services at national meteorological and hydrological services (NMHSs) with long-term data records but also with data sets produced close to real time that can be used to prepare monthly/annual updates of the state of the climate. Both types of products together allow for a consistent description of mean values, anomalies, variability and potential trends for the chosen ECVs. CM SAF ECV data sets also serve the improvement of climate models both at global and regional scale.
As an essential partner in the related international frameworks, in particular WMO SCOPE-CM (Sustained COordinated Processing of Environmental satellite data for Climate Monitoring), the CM SAF - together with the EUMETSAT Central Facility, assumes the role as main implementer of EUMETSAT’s commitments in support to global climate monitoring. This is achieved through:

- Application of highest standards and guidelines as lined out by GCOS for the satellite data processing,
- Processing of satellite data within a true international collaboration benefiting from developments at international level and pollinating the partnership with own ideas and standards,
- Intensive validation and improvement of the CM SAF climate data records,
- Taking a major role in data set assessments performed by research organisations such as WCRP. This role provides the CM SAF with deep contacts to research organizations that form a substantial user group for the CM SAF CDRs,
- Maintaining and providing an operational and sustained infrastructure that can serve the community within the transition of mature CDR products from the research community into operational environments.

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

2 Introduction

This CM SAF Product User Manual provides information on the CM SAF GAC Edition 1 data sets derived from Advanced Very High Resolution Radiometer (AVHRR) observations onboard the NOAA satellites. The covered time period ranges from 1982 (first satellite NOAA-7) to 2009 (last satellite NOAA-18). For the last years 2007-2009 also AVHRR data from the EUMETSAT METOP satellite has been used.

This manual briefly describes the historical development of CM SAF, the GAC data set and the current and upcoming versioning for GAC products. A technical description of the data sets including information on the file format as well as on the data access is provided. Furthermore details on the implementation of the retrieval processing chain, and individual algorithm descriptions are available in the Algorithm Theoretical Basis Document [RD 2]. Basic accuracy requirements are defined in the product requirements document [AD 1]. A detailed validation of the GAC based parameters is available in the Validation report [RD 1].

3 Historical overview of the AVHRR GAC data set

Measurements from the Advanced Very High Resolution Radiometer (AVHRR) radiometer onboard the polar orbiting NOAA satellites and the EUMETSAT METOP satellites have been performed since 1978. Figure 3.1 gives an overview over all satellites carrying the AVHRR instrument until 2009 (the final year covered by the new CM SAF GAC dataset). Notice that also data from NOAA-19 and Metop-A has been used for the last two years in the CM SAF dataset (not included in Figure 3.1). The instrument only measured in four spectral bands in the beginning (AVHRR/1) but from 1982 a fifth channel was added (AVHRR/2) and in 1998 even a sixth channel was made available (AVHRR/3), although only accessible if switched with the previous third channel at 3.7 micron.

Table 3.1 describes the AVHRR instrument, its various versions and the satellites carrying them. The AVHRR instrument measures at a horizontal resolution close to 1 km at nadir but only data at a reduced resolution of approximately 4 km are permanently archived and available with global coverage since the beginning of measurements. This dataset is denoted Global Area Coverage (GAC) AVHRR data.

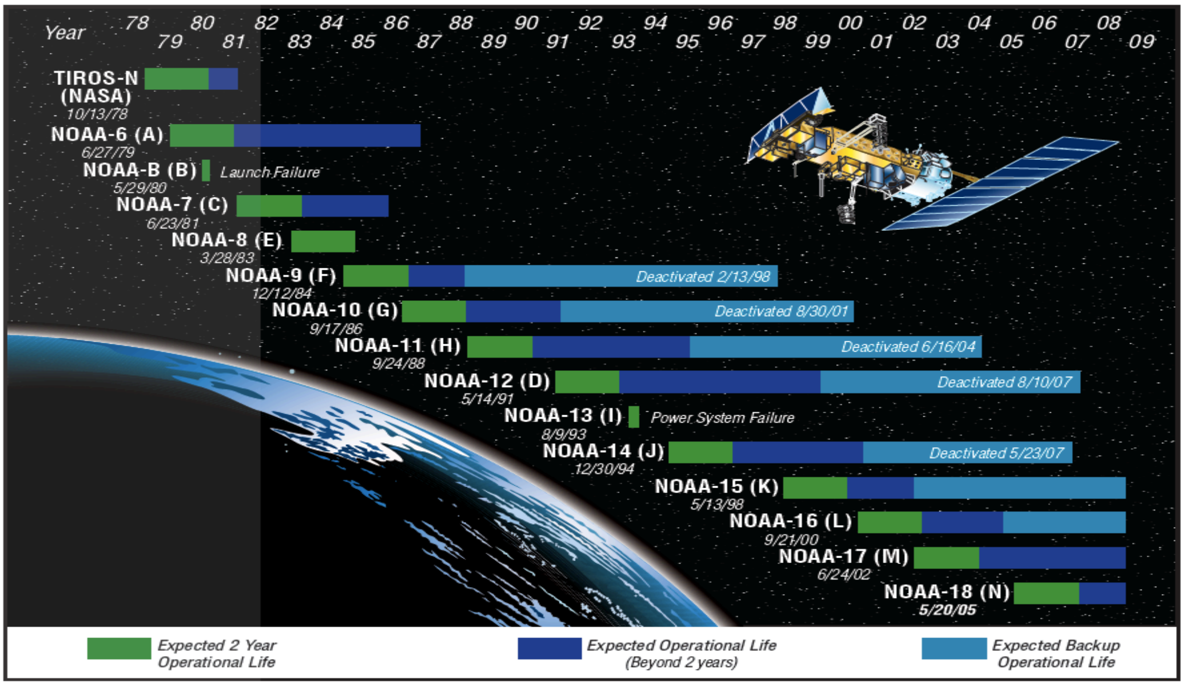

Figure 3.1 *Historic overview of all NOAA satellites available in the covered period until 2009. (Courtesy of Andrew Heidinger, NOAA)*

Table 3.1 *Spectral channels of the Advanced Very High Resolution Radiometer (AVHRR). The three different versions of the instrument are described as well as the corresponding satellites.*

Channel Number	Wavelength (micrometers) AVHRR/1 NOAA-6,8,10	Wavelength (micrometers) AVHRR/2 NOAA-7,9,11,12,14	Wavelength (micrometers) AVHRR/3 NOAA-15,16,17,18 NOAA-19, Metop-A
1	0.58-0.68	0.58-0.68	0.58-0.68
2	0.725-1.10	0.725-1.10	0.725-1.10
3A	-	-	1.58-1.64
3B	3.55-3.93	3.55-3.93	3.55-3.93
4	10.50-11.50	10.50-11.50	10.50-11.50
5	Channel 4 repeated	11.5-12.5	11.5-12.5

Table 3.2 *Channel 3A and 3B activity for the AVHRR/3 instruments during daytime.*

Satellite	Channel 3a active	Channel 3b active
NOAA-15		06/1998 – 12/2009
NOAA-16	10/2000 – 04/2003	05/2003 – 12/2009
NOAA-17	07/2002 – 12/2009	
NOAA-18		09/2005 – 12/2009
NOAA-19		06/2009 – 12/2009
Metop-A	09/2007 – 12/2009	

4 Compilation of the CM SAF GAC cloud dataset

The GAC dataset of global cloud products retrieved by CM SAF cloud retrieval methods spans the time period 1982-2009. Retrieval methods have been dependent on the access to two infrared (split-window) channels at 11 and 12 microns meaning that only data from satellites carrying the AVHRR/2 or AVHRR/3 instruments have been used (see Table 3.1). The retrieval of cloud physical properties (in particular particle effective radius and liquid/ice water path) is sensitive to the shortwave infrared channel being used. As noted in Section 2, data from only one of the channels 3A and 3B can be transmitted at the same time. Table 3.2 summarizes when either of the two channels have been active on the AVHRR/3 instruments.

Figure 4.1 describes the coverage of observations from each individual satellite over the entire period. Notice that the limitations to the use of AVHRR/2 and AVHRR/3 instruments leads to poorer time sampling (i.e., only one satellite available for daily observations) between 1982 and 1991. On the other hand, from 2001 and onwards more than two satellites are available for daily observations.

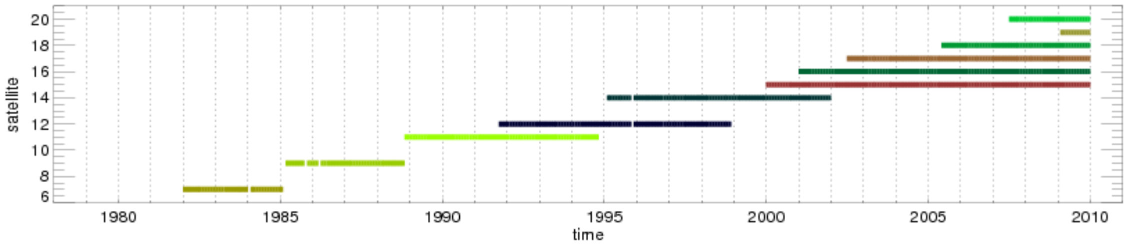

Figure 4.1 *Visualisation of the used NOAA-satellites showing satellite numbers on Y-axis and the length of the observation period for each satellite. Notice that number 20 denotes Metop-A. Some data gaps are present but only for some isolated months for NOAA-7, NOAA-9, NOAA-12 and NOAA-14.*

Observations from polar orbiting sun synchronous satellites are made at the same local solar time at each latitude band. Normally, satellites are classified into observation nodes according to the local solar time when crossing the equator during daytime (illuminated conditions). For the NOAA satellite observations, a system with one **morning observation node** and one **afternoon observation node** has been utilised as the fundamental polar orbiting observation system. This guarantees four almost equally distributed observations per day (if including the complementary observation times at night and in the evening when the satellite passes again 12 hours later). Equator crossing times have unfortunately varied slightly between satellites meaning that the desired equal distribution of observations has not always been fulfilled. Morning satellites have generally been confined to the local solar time interval 07:00-08:00 and afternoon satellites to the interval 13:30-14:30. However, a change was introduced for the morning satellites NOAA-17 and Metop-A, now being defined in a so-called mid-morning orbit with equator crossing times close to 10:00. A specific problem with the observation nodes for the NOAA satellites has been the difficulty to keep observation times stable for each individual satellite (e.g., as described by Ignatov et al., 2004). This is illustrated further in Figure 4.2 for all NOAA satellites. Some compensation for this has been attempted in the CM SAF dataset but not for all parameters.

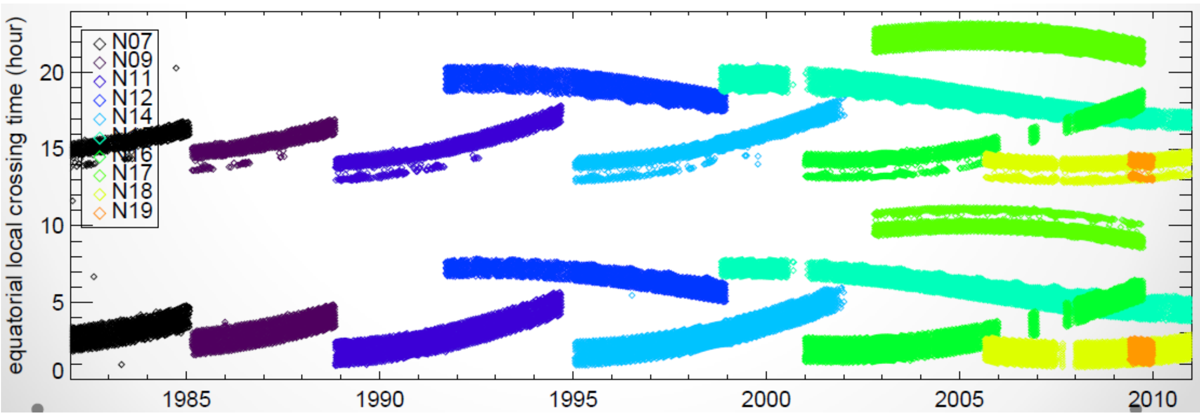

Figure 4.2 *Local solar times at equator observations for all NOAA satellites from NOAA7 to NOAA19. (Courtesy of M. Foster, NOAA). Notice that the figure shows both ascending (northbound) and ascending (southbound) equator crossing times for each satellite separated 12 hours apart.*

An important aspect for any product-based climate dataset (formally denoted Thematic Climate Data Records – TCDRs) is that retrieved products have been derived from accurately calibrated and homogenized radiances (formally denoted Fundamental Climate Data Records – FCDRs). For the CM SAF dataset we have used an AVHRR FCDR prepared by NOAA (Heidinger et al., 2010). This FCDR was prepared for the compilation of the "NOAA Pathfinder Atmospheres – Extended" (PATMOS-x) dataset (for full description, see http://cimss.ssec.wisc.edu/patmosx/overview.html). This FCDR focussed in particular on homogenization of the AVHRR visible reflectances (now available for download at NOAA's National Climate Centre, NCDC - see available datasets at http://www.ncdc.noaa.gov/cdr/operationalcdrs.html). The calibration of infrared AVHRR channels is basically left untouched since the use of onboard blackbody calibration targets have been found to provide stable and reliable results. However, future upgrades of the AVHRR FCDR need to address remaining issues here also for the infrared channels (e.g., recognising the work of Mittaz et al., 2009).

5 Product definitions

The CM SAF GAC cloud data set from AVHRR provides global coverage of a number of cloud parameters. Instantaneous AVHRR GAC retrievals at original swath level are used to derive the spatio-temporally averaged data sets. The products are available as daily and monthly composites for each satellite on a regular latitude/longitude grid with a spatial resolution of 0.25° × 0.25° degrees.

In addition, results are available on two equal-area polar grids at 25 km resolution for the Arctic and Antarctic regions, respectively. These grids are centred at the poles and cover areas of 1000km x 1000km. However, this only concerns the two cloud parameters Fractional Cloud Coverage and Cloud Top Level.

The monthly averages are also available in aggregated form (i.e., merging all satellites). Acknowledging the different observation capabilities during night and during day and also taking into account existing diurnal variations in cloudiness, a further separation of results into daytime and night-time portions has also been done. Here, all observations made under twilight conditions (solar zenith angles between 80-95 degrees) have been excluded in order to avoid being affected by specific cloud detection problems occurring in the twilight zone.

The temporal coverage of the data sets ranges from January 1982 to December 2009. Notice again (as mentioned in Section 3 and visualised in Figure 4.1 and Figure 4.2) that for the first years in the series (1982-1989) only the afternoon satellites are included.

The total set of cloud products are the following (with formal product numbers and abbreviations to the right):

Fractional Cloud Cover	CM-05	(CFC)
Cloud Top level	CM-17	(CTO)
Cloud Optical Thickness	CM-34	(COT)
Cloud Phase	CM-38	(CPH)
Liquid Water Path	CM-43	(LWP)
Ice Water Path	CM-47	(IWP)
Joint Cloud property histogram	CM-11	(JCH)

For each cloud parameter, also various meta data and information about selected statistical parameter distributions in each grid point is available in addition to the main product content described above. For example, one-dimensional histograms of parameter value frequencies at the original 0.05 degree resolution are given for all monthly means (except for the Fractional Cloud Cover parameter) at every grid point. Details on how to access this information is given in Section 6.

A complete description of the retrieval methods for each individual product is given in the Algorithm Theoretical Basis Documents [RD 3, RD 4, RD 5, RD 6]. The general methods for AVHRR calibration and calculation of Level 3 products are described in [RD 2].

All products have been developed and evaluated with respect to requirement goals defined in [AD 1]. The finally achieved product accuracies are described in [AD 2]. Of specific interest here are requirements in [AD 3] as outlined by the Global Climate Observing System (GCOS) community and issued by the United Nations World Meteorological Organisation (WMO) in 2012. All products in the GAC cloud dataset fulfil GCOS requirements regarding the horizontal resolution which is mainly explained by the desire to serve also applications in regional climate modelling and in regional climate monitoring. The GCOS requirement on a temporal resolution of 3 hours is not reachable globally for a dataset based on polar orbiting satellite data. This resolution is only achieved for high-latitudes and for the Polar Regions. In the tropical region the temporal resolution is close to 6 hours. All GCOS accuracy requirements are generally fulfilled for all cloud products (detailed results to be described further below) but the requirements on stability have yet to be assessed.

In the following, each cloud product is shortly described regarding retrieval methods, information content and limitations. Validation results are also described shortly for each cloud product. It should be noted that all validation results refer to the mean error (bias). A summary of all validation results can also be found at the end of this document (Section 9). More details on achieved validation results are given (e.g., more detailed information on accuracy and precision studies) in [RD 1]. At the end of each product description a short statement on recommended applications areas is also given.

5.1 Parameter Retrievals

5.1.1 Fractional cloud cover – CFC

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 grid square compared to the total number of analysed pixels in the grid square. Fractional cloud cover is expressed in percent.

Short Algorithm description

This product is calculated using the NWC SAF PPS (Polar Platform System) cloud mask algorithm (see http://NWC_SAF.inm.es/ for details on the NWC-SAF project). The algorithm (detailed by Dybbroe et al., 2005) is based on a multi-spectral thresholding technique applied to every 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.

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 – here, the ERA-Interim dataset, see Dee et al, 2011 and http://www.ecmwf.int/research/era/do/get/era-interim). Also ancillary information about surface status (e.g. land use categories and surface emissivities) is taken into account. Thus, thresholds are dynamically defined and therefore unique for each individual pixel.

A detailed description is given in [RD 3].

Highlights

- Cloud screening is based on information from all AVHRR channels
- Thin Cirrus clouds are identified using split-window infrared channels (not utilised by traditional VIS/IR methods)
- Water clouds with cloud temperatures close to surface temperatures are identified at night using 3.7 micron channel information (often not identified by traditional IR methods)
- Observation frequency is high in polar areas – 14 observations per day per satellite
- Cloud detection in polar summer in the Arctic and Antarctic regions shown to be comparable with MODIS cloud datasets (Karlsson and Dybbroe, 2010) - thus, the advantage here is the very long observation period
- Efficient polar summer cloud screening allows high-quality estimations of surface albedo (e.g., at the time of minimum ice extent in the Arctic region)
- Daytime conditions with good illumination (i.e., conditions enabling access to information in all spectral channels) provide best cloud screening results

Limitations

- Not all clouds will be detected due to inherent limitations of the AVHRR imager as being a passive radiometer with a rather coarse field of view (here about 5 km in size). This can be compared to actively probing instruments (like cloud lidars and radars) with a much higher cloud detection sensitivity. The current estimation is that clouds with optical thicknesses below 0.3 are generally not detected in AVHRR GAC datasets.
- Some thin clouds (particularly, ice clouds) over cold ground surfaces may remain undetected even if having cloud optical thicknesses higher than the above mentioned detection limit
- Twilight conditions are especially challenging to AVHRR cloud screening methods leading to some systematic underestimation of cloud amounts (especially for morning-evening satellites)
- CFC results over the Arctic and Antarctic regions during the polar winter are very unreliable and generally largely underestimated (-20 % or more in absolute units as shown in comparisons with CALIPSO-CALIOP observations)
- The above deficiencies indicates that overall global CFC estimations are slightly negatively biased
- The same deficiencies and the fact that observation density related to the availability of morning-evening and afternoon-night satellites changes over the years (best density in observations the last ten years with some dominance of observations at morning-evening), leads to artificial (decreasing) trends in global cloud cover over the full GAC period.
- If separating daytime and night-time results, no specific trends in global cloud cover is seen in the respective results (see [RD 1])
- A daytime cloud screening error has been identified in the transition zone between deserts and tropical vegetated regions leading to regional overestimation (+10-20 %) of CFC in semi-arid regions
- A less significant but regionally important (e.g. over Australia) cloud screening error has been identified at night, caused by errors in used ancillary datasets on surface emissivity

The latter two listed errors are well understood and solutions will be implemented for the generation of the next edition of the GAC cloud dataset.

Validation

The CFC product has been evaluated against two independent observation datasets; global synoptical cloud observations in the period 1982-2009 and cloud observations from the CALIPSO-CALIOP instrument in the period 2006-2009. Globally averaged results showed some overestimation in comparison with synoptical observations (+3.6 %) while a significant underestimation (-10 %) was seen when comparing with CALIPSO-CALIOP. The difference in results reflect mainly the higher sensitivity to cloud detection in the CALIPSO-CALIOP dataset but there are also aspects related to data availability to consider (e.g., synoptical observations are mainly available over land in densely populated areas). Consistency checks were also made with datasets from PATMOS-x (v05r02; based on GAC-AVHRR data), MODIS (collection 5.1), and ISCCP (D1). Here, overall results pointed at a general negative deviation between 0-15 percentage points. Figure 5.1 illustrates the relation to other datasets for afternoon observations (ascending orbits, local solar time 13:30) for one year (2007). We notice that the CMSAF dataset has generally lower cloud amounts for this particular year with the largest spread of results near the poles. Results look a bit different for nighttime and twilight observations (see [RD 1] for more details).

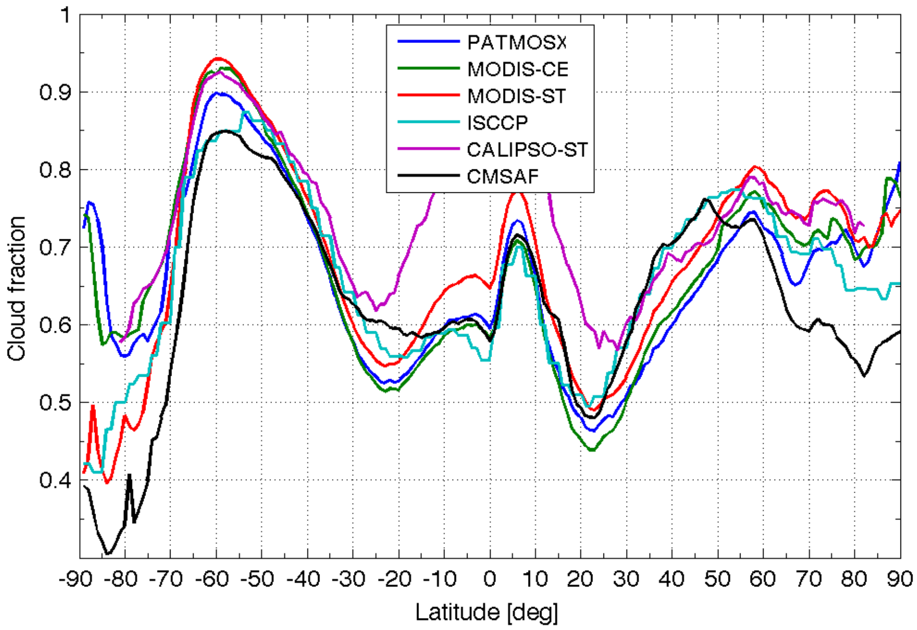

Figure 5.1 *Inter-comparison between six global cloud fraction datasets (from the GEWEX Cloud Assessment database) for the year 2007 for afternoon observations (local solar time 13:30).*

Recommended applications

Despite efforts for inter-calibration and homogenisation, the CMSAF CFC dataset is still not of sufficient quality for offering global climate trend analysis. More work is needed before this status can be reached (see also concluding discussion in section 5). However, for some regions validation efforts have shown very good results. It concerns in particular mid-latitude and high-latitude regions (except near-polar regions). For the Polar Regions polar winter conditions still remains a very big challenge for AVHRR cloud retrievals. Nevertheless, results during the Polar summer appear to be of good quality and studies related to cloud-sea ice interaction in the Polar summer are encouraged.

Further reading

More details on the product retrieval are given in [RD 2] and [RD 3]. Information on the achieved accuracy of the product is found in the CM SAF GAC validation report [RD 1] and SeSp [AD 2].

5.1.2 Cloud Top level – CTO

Three versions of the CM SAF Cloud Top product exist:

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

Notice that the cloud altitude given by CTH is defined as the mean cloud altitude relative to the topography (GTOPO30) and not relative to the mean sea level. The used topography data set is available to users as an ancillary dataset.

The final daily and monthly average products are calculated by averaging the original algorithm output in GAC pixel resolution for all available orbits over the selected grid. All products are averaged arithmetically (linearly) but for the Cloud Top Pressure product also a geometric mean (i.e., average of the logarithm of cloud top pressure) is available.

Short Algorithm description

For the determination of cloud top information, the CM SAF is once again using the NWC SAF algorithms. The CTO product is derived using two algorithms, one for opaque and one for fractional and semitransparent clouds, and it is applied to all cloudy pixels as identified by the PPS cloud mask product. Semi-transparent or fractional (no distinction between the two is made) clouds are identified as clouds having significant (threshold-based) brightness temperature differences between AVHRR channels 3b, 4 and 5 (i.e., at 3.7 micron, 11 micron and 12 micron).

The opaque algorithm use simulated cloud free and cloudy TOA 11 µm radiances which are compared and matched to measured radiances. Cloudy radiances are simulated assuming "black-body"-clouds at various levels.

The semi-transparent algorithm is applied to all pixels classified as semi-transparent cirrus or fractional water cloud. This classification is based on the analysis of brightness temperature differences of the 11 micron and 12 micron (split window) channels noting that this difference is generally small or negligible for opaque clouds. Also brightness temperatures at 3.7 micron are studied in this process. A histogram technique is applied based on the construction of two dimensional histograms using AVHRR channel 4 and 5 brightness temperatures composed over larger segments. 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 ERA-Interim profiles) are retrieved.

Highlights

- Cloud top heights are determined using the closest reference profiles available from the ERA-Interim dataset
- The semi-transparent correction attempts to find the physically correct cloud top level as opposed to the radiatively efficient cloud top level achieved if only matching brightness temperatures to reference profiles

Limitations

- Both cloud retrieval methods are unreliable in the presence of strong temperature inversions in the troposphere
- The previous circumstance leads to unreliable cloud top estimations in the polar winter near the poles and over cold land surfaces.
- Cloud top level estimations near the poles in the polar summer have often a positive bias, sometimes larger than 1000 m, due to problems with resolving boundary layer inversions in reference profiles from ancillary datasets (ERA-Interim)
- Problems may also occur for the same reason for marine stratus/stratocumulus clouds formed and capped in boundary layer inversions – normally leading to overestimation of cloud top (geometric) heights up to 1000 m
- As mentioned for the CFC product, optically very thin clouds may not be detected at all. Even if being detected, it is very difficult to assign a correct cloud top level for the thinnest clouds (see next bullet).
- The semi-transparency correction method works only in cases of single-layer clouds meaning that a significant fraction (up to about 20 % of all clouds) may be left without a valid CTO value (e.g., multi-layer cloud cases)
- Clouds interpreted as being opaque are in reality often diffuse or multi-layered in their upper portions – this often leads to an underestimation of the true cloud top of up to 2000 m

Validation

The CTO product has been evaluated against one independent observation datasets; global cloud observations from the CALIPSO-CALIOP instrument in the period 2006-2009. Globally averaged results showed a general and large underestimation of cloud top levels (-2661 m). However, these results were based on CALIPSO observations of the uppermost detected cloud (highest cloud boundary). If taking into account that AVHRR measurements are not valid for the absolutely highest cloud boundary but instead for a level a bit lower and deeper (expressed by an optical thickness penetration depth of 0.3) into the cloud (i.e., the radiatively efficient cloud height) results improved considerably (-433 m). Inter-comparisons with other datasets based on passive imagery (PATMOS-X, MODIS, ISCCP) showed small deviations (generally within 50 hPa of cloud top pressure).

Recommended applications

For CTO, similar recommendations as for the CFC products (see above) are given. However, it is clear that many cloud tops of boundary layer clouds appear to be overestimated, mainly because of problems in having good enough background reference profiles available from NWP reanalysis datasets. This concerns in particular cloud tops in the Polar Regions and in the Polar summer. Thus, CFC results in the Polar Regions are good in the Polar summer but CTO values have to be used with caution.

Further reading

More details on the product retrieval are given in [RD 2] and [RD 4]. Information on the achieved accuracy of the product is found in the CM SAF GAC validation report [RD 1] and the CM SAF service specification [AD 2].

5.1.3 Cloud Optical Thickness – COT

Short Algorithm description

The central principle of the method 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 little dependence on particle effective radius (r_e), whereas the reflectance of clouds at an absorbing wavelength in the near-infrared region (1.6 or 3.7 μm) is strongly dependent on effective radius (Nakajima and King, 1992).

In the CPP algorithm (Roebeling et al. 2006), 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-/3.7-μm top-of-atmosphere reflectances as a function of viewing geometry, cloud optical thickness, effective radius, and cloud phase. These simulated reflectances are stored in a look-up table (LUT).

COT and r_e are retrieved for cloudy pixels in an iterative manner by simultaneously comparing satellite-observed reflectances to the LUT of RTM-simulated reflectances. The iteration process continues until the retrieved cloud optical thickness converges to a stable value.

Highlights

- An estimate of the COT retrieval error is reported.
- The effect of absorption by trace gases in the atmosphere on narrowband reflectances is taken into account using MODTRAN (Berk et al. 2000) simulations (Meirink et al. 2009).

Limitations

The main limitations of the COT retrieval are:

- The derivation of cloud physical properties from reflected solar radiation is dependent on the availability of daylight. This means that no retrievals can be done during night time. In practice a maximum solar zenith angle of 72 degrees is allowed.
- The retrieval is highly problematic over very bright surfaces, particularly ice and snow, as the visible reflectance from clouds is similar to that from the surface.
- Cloud property retrievals are performed assuming that clouds are plane parallel. Two prominent examples of cases for which this assumption is violated are: (1) three-dimensional radiative effects become important if large sub-pixel variations in cloud-top height occur, and particularly if the solar zenith angle is large; (2) retrievals for broken clouds are affected by a reflectance contribution from the surface, usually leading to an underestimation in COT compared to the cloudy portion of the pixel.
- Aerosols are not considered in the CPP retrieval. This assumption is usually justified because aerosols reside below or within the cloud and their optical thickness is small compared to that of the cloud. However, if the aerosols reside above the cloud and if they are sufficiently absorbing, they can significantly lower the visible reflectance. This leads to an underestimation of COT.

Validation results

The COT product has been evaluated using three existing global cloud property datasets: PATMOS-x (v05r02; based on GAC-AVHRR data), MODIS (collection 5.1), and ISCCP (D1). The overall biases of CMSAF COT relative to these datasets were 3 to 20%, -5 to -10% and 50 to 60%, respectively. Thus, the target accuracy of 15% is achieved compared to PATMOS-x and MODIS. In contrast, there is a large positive bias compared to ISCCP. It is hypothesized that this is due to the lower spatial resolution of that dataset.

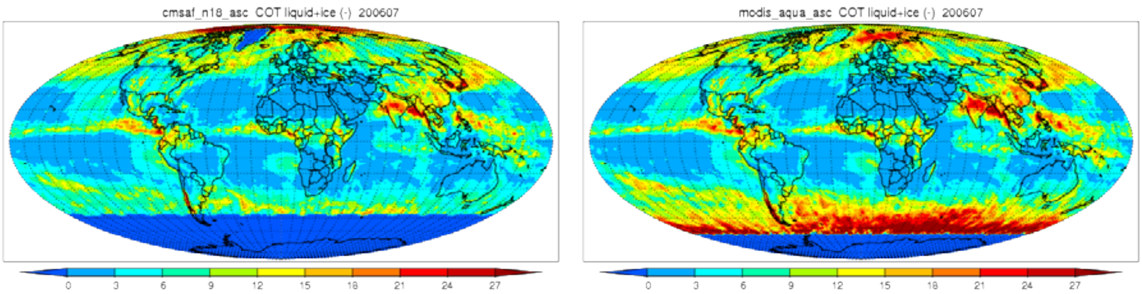

Figure 5.2 *All-sky mean COT for CMSAF (NOAA18-AVHRR) and MODIS (EOS-Aqua) for the month July 2006.*

Figure 5.2 shows an example of global COT distributions for July 2006 obtained from the CM SAF (NOAA-18) and MODIS-Aqua datasets. Overall, the spatial patterns compare very well. The sharp increases in COT towards higher northern hemispheric latitudes (CM SAF) and higher southern hemispheric latitudes (MODIS) are probably artefacts related to the presence of sea ice and low solar elevation, respectively.

Recommended applications

The COT dataset is most reliable at lower latitudes, or (better said) lower solar zenith angles (below about 65 degrees). In addition, high latitudes are frequently affected by snow and ice cover. In these cases retrievals are problematic, even more because our ancillary database currently does not represent snow and ice cover well. Care should be taken when using the dataset for long-term trend analysis. Despite extensive calibration efforts, inter-satellite discontinuities are observed, and trend analysis is further complicated by the orbital drift of the satellites.

Further reading
More details on the product retrieval are given in [RD 2] and [RD 5]. Information on the achieved accuracy of the product is found in the CM SAF GAC validation report [RD 1] and the CM SAF service specification [AD 2].

5.1.4 Cloud Phase – CPH

Short Algorithm description
Cloud phase is interpreted primarily using reflected solar radiation in the 0.6 and 1.6/3.7 µm channels. 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 and 3.7 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, these channels are 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 1.6/3.7-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 (CTT) check, based on measured 10.8-µm brightness temperature, was included. The CTT is not taken from the official CM SAF product because this contains no-data values for some cloudy pixels. Instead, 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). If 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.: *mixed* phase is not retrieved by this method.

Highlights
- The algorithm uses near-infrared reflectances and an additional cloud-top temperature check to detect cloud phase.
- The algorithm performs well in comparison with ground-based observed cloud phase over Cabauw, The Netherlands (Wolters et al. 2008).

Limitations
The main limitations of the CPH retrieval are:

- The derivation of cloud physical properties from reflected solar radiation is dependent on the availability of daylight. This means that no retrievals can be done during night time. In practice a maximum solar zenith angle of 72 degrees is allowed.
- The retrieval is highly problematic over very bright surfaces, particularly ice and snow, as the visible reflectance from clouds is similar to that from the surface.
- 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* labeling. 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.

- Erroneous ice phase retrievals might occur in case of broken or inhomogeneous overcast clouds, in particular over ocean surfaces. However, this concerns only about 3% of the cloud-phase retrievals (Wolters et al., 2010).

Validation

The CPH product has been evaluated using three existing global cloud property datasets: PATMOS-x (v05r02; based on GAC-AVHRR data), MODIS (collection 5.1), and ISCCP (D1). The overall biases of CMSAF CPH, in terms of the liquid water cloud fraction, relative to these datasets were 7 to 15%, 3 to 20% and 12-15%, respectively. In the case of MODIS, the bias compared to the IR cloud phase product is around 3%, meaning that the target accuracy is achieved. In contrast, the bias compared to the optical properties cloud phase product exceeds 10% (the threshold accuracy). Compared to the PATMOS-x and ISCCP datasets the threshold accuracy is (almost) achieved.

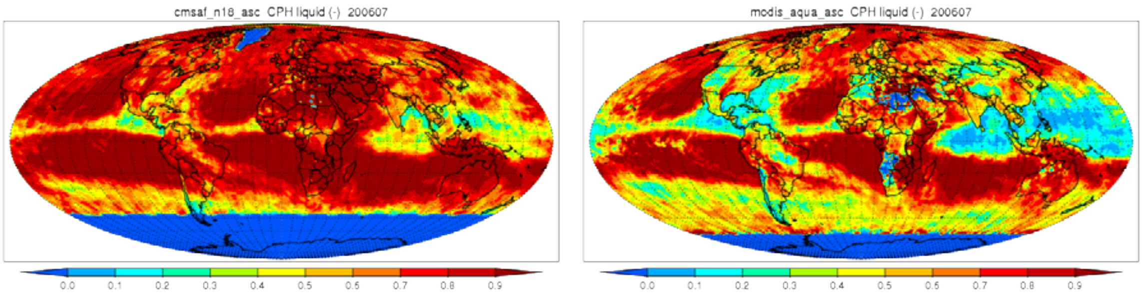

Figure 5.3 *All-sky mean fraction of liquid water clouds for CMSAF (NOAA18-AVHRR) and MODIS (EOS-Aqua) for the month July 2006.*

Figure 5.3 shows an example of global CPH distributions for July 2006 obtained from the CM SAF (NOAA-18) and MODIS-Aqua datasets. The spatial patterns compare well, but CM SAF has an overall higher fraction of liquid water clouds.

Recommended applications

The CPH dataset is most reliable at lower latitudes, or (better said) lower solar zenith angles (below about 65 degrees). In addition, high latitudes are frequently affected by snow and ice cover. In these cases retrievals are problematic, even more because our ancillary database currently does not represent snow and ice cover well. Care should be taken when using the dataset for long-term trend analysis. Despite extensive calibration efforts, inter-satellite discontinuities are observed, and trend analysis is further complicated by the orbital drift of the satellites.

Further reading

More details on the product retrieval are given in [RD 2] and [RD 5]. Information on the achieved accuracy of the product is found in the CM SAF GAC validation report [RD 1] and the CM SAF service specification [AD 2].

5.1.5 Liquid Water Path – LWP

Short Algorithm description

Cloud optical thickness (τ) and droplet effective radius (r_e) are retrieved simultaneously using CPP. 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):

$$CWP = 2/3\ \rho_l \tau\ r_{e,}$$

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

Highlights

- LWP is calculated from the product of the COT and cloud particle effective radius retrieval.
- An estimate of the LWP retrieval error is reported.
- Evaluation with ground-based microwave radiometer-derived LWP at CloudNet sites showed good agreement (Roebeling et al., 2008).

Limitations

The main limitations of the LWP retrieval are:

- The derivation of cloud physical properties from reflected solar radiation is dependent on the availability of daylight. This means that no retrievals can be done during night time. In practice a maximum solar zenith angle of 72 degrees is allowed.
- LWP is calculated from COT and r_e. This implies that all limitations for COT mentioned in Section 4.1.3 are also limitations for LWP.
- Unlike active satellite instruments, which can derive cloud profile information, retrievals from passive satellite instruments are limited by the fact that the obtained signal emanates from the integrated profile. Since near-infrared radiation is only penetrating into the cloud to a certain depth (due to absorption by cloud particles), the retrieved cloud phase and effective radius are representative for the upper part of the cloud (Platnick 2001). The penetration depth depends on the amount of absorption by cloud particles, which is increasing with wavelength. This means that the retrieved CPH and r_e depend on which NIR spectral channel is used (in our case 1.6 or 3.7 µm).
- In the derivation of Equation (2) for LWP it is assumed that the cloud particle effective radius does not vary with height. In reality this assumption is not satisfied. For example, liquid water clouds often obey adiabatic theory leading to a slightly different relation for LWP, in which the factor 2/3 is replaced by 5/9.
- Regarding the case of aerosol layers above clouds, the effect of these aerosols on the retrievals depends on the channel combination used and on the aerosol properties (Haywood et al. 2004). The impact is strongest for the 1.6-µm channel, with a possible underestimation of r_e by several microns. For the 3.7-µm channel, the impact is smaller and can be an overestimation of r_e.
- Because the retrieval of effective radius becomes unreliable for thin clouds, weighting with a climatological average r_e is performed for clouds with COT < 8 (COT < 5) in case the 1.6-µm (3.7-µm) channel is used. Although this stabilizes the retrieval results, it does not take away the inherent uncertainty in r_e retrievals for thin clouds.

Validation

The LWP product has been evaluated using three existing global cloud property datasets: PATMOS-x (v05r02; based on GAC-AVHRR data), MODIS (collection 5.1), and ISCCP (D1). The overall biases of CMSAF LWP relative to these datasets were -60 to 30%, 0 to 15% and 30 to 50%, respectively. The threshold accuracy of 30% is largely achieved compared to PATMOS-x (except for the NOAA-17 instrument), while compared to MODIS the target accuracy of 15% is achieved. In contrast, there is a large positive bias compared to ISCCP. It is hypothesized that this is due to the lower spatial resolution of that dataset. Additional validation with a fully independent passive-microwave based LWP dataset compiled by the University of Wisconsin was performed. This validation could be performed for regions covered by liquid water clouds only, which are in practice the stratocumulus regions. CM SAF LWP had an average negative bias of 5 to 10%, and threshold requirements were achieved for (nearly) all individual regions and instruments.

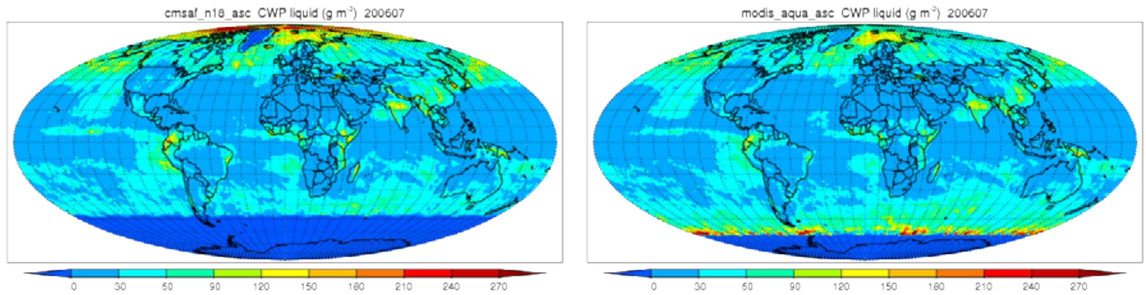

Figure 5.4 *All-sky mean LWP for CMSAF (NOAA18-AVHRR) and MODIS (EOS-Aqua) for the month July 2006.*

Figure 5.4 shows an example of global LWP distributions for July 2006 obtained from the CM SAF (NOAA-18) and MODIS-Aqua datasets. Overall, the spatial patterns compare very well. The sharp increases in COT towards higher northern hemispheric latitudes (CM SAF) and higher southern hemispheric latitudes (MODIS) are probably artefacts related to the presence of sea ice and low solar elevation, respectively.

Recommended applications

The LWP dataset is most reliable at lower latitudes, or (better said) lower solar zenith angles (below about 65 degrees). In addition, high latitudes are frequently affected by snow and ice cover. In these cases retrievals are problematic, even more because our ancillary database currently does not represent snow and ice cover well. Care should be taken when using the dataset for long-term trend analysis. Despite extensive calibration efforts, inter-satellite discontinuities are observed, and trend analysis is further complicated by the orbital drift of the satellites. Significant differences are observed between the parts of the dataset relying on the 1.6-µm and 3.7-µm channels (see Table 3.2). It is recommended that those parts are not combined but used separately for analyses.

Further reading

More details on the product retrieval are given in [RD 2] and [RD 5]. Information on the achieved accuracy of the product is found in the CM SAF GAC validation report [RD 1] and the CM SAF service specification [AD 2].

5.1.6 Ice Water Path – IWP

Short Algorithm description

The CWP for ice clouds (or Ice Water Path, IWP) is approximated using the same relation as for LWP 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.

Highlights

- The use of imperfect hexagonal ice crystals gives reasonably adequate simulations of total and polarized reflectance of ice clouds, outperforming more complex ice crystal habits in many cases (Knap et al. 2005).
- An estimate of the IWP retrieval error is reported.

Limitations

The same limitations as for LWP hold also for IWP. In addition, the r_e retrieval for ice clouds is considerably more uncertain than for water clouds, because particle shapes and roughness vary widely and are not well known. The assumptions on ice crystal habits used to generate the LUTs (in our case imperfect hexagons are assumed) have a profound impact on the retrieved r_e and IWP.

Validation

The IWP product has been evaluated using three existing global cloud property datasets: PATMOS-x (v05r02; based on GAC-AVHRR data), MODIS (collection 5.1), and ISCCP (D1). The overall biases of CMSAF IWP relative to these datasets were -120 to 0%, -80 to 0% and 30 to 50%, respectively. The threshold accuracy of 40% is generally not achieved compared to PATMOS-x and MODIS, whereas it is achieved compared to ISCCP.

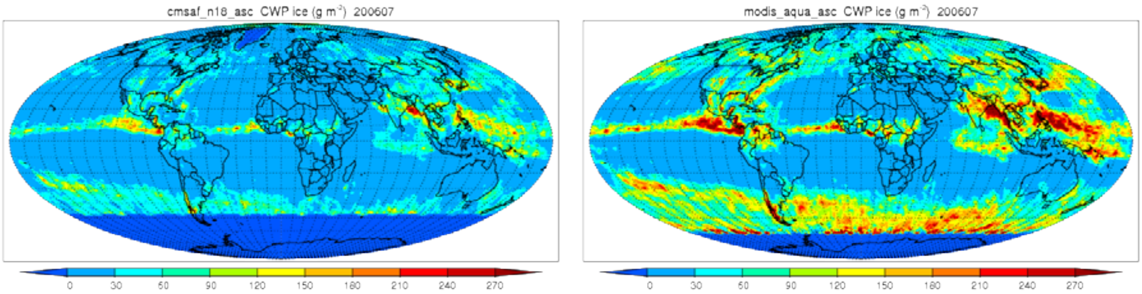

Figure 5.5 *All-sky mean IWP for CMSAF (NOAA18-AVHRR) and MODIS (EOS-Aqua) for the month July 2006.*

Figure 5.5 shows an example of global IWP distributions for July 2006 obtained from the CM SAF (NOAA-18) and MODIS-Aqua datasets. While the spatial patterns compare well, the CM SAF IWP is generally much lower than MODIS IWP.

Recommended applications

The IWP dataset is most reliable at lower latitudes, or (better said) lower solar zenith angles (below about 65 degrees). In addition, high latitudes are frequently affected by snow and ice cover. In these cases retrievals are problematic, even more because our ancillary database currently does not represent snow and ice cover well. Care should be taken when using the dataset for long-term trend analysis. Despite extensive calibration efforts, inter-satellite discontinuities are observed, and trend analysis is further complicated by the orbital drift of the satellites. Significant differences are observed between the parts of the dataset relying on the 1.6-µm and 3.7-µm channels (see Table 3.2). It is recommended that those parts are not combined but used separately for analyses.

Further reading

More details on the product retrieval are given in [RD 2] and [RD 5]. Information on the achieved accuracy of the product is found in the CM SAF GAC validation report [RD 1] and the CM SAF service specification [AD 2].

5.1.7 Joint Cloud property Histograms – JCH

Short Algorithm description

The JCH product is a combined histogram of CTP and COT covering the solution space of both parameters. This two-dimensional histogram gives the absolute numbers of occurrences for specific COT and CTP combinations defined by specific bins. Notice that the product is defined in a slightly coarser grid (1x1 degree resolution) in order to get higher statistical significance and more efficient data storage. More details on this product can be found in [RD 6].

Highlights

- The product adds value to the single standard Level 3 products of CTP and COT by showing how the two parameters vary together
- The histograms are given for each grid point which means that a user can aggregate results over any local or regional domain in order to analyse typical cloud regimes (or types)
- The use of joint histograms is common in applications for evaluating climate models (see http://cfmip.metoffice.com/COSP.html)

Limitations

- The product is only available during daytime since the COT parameter is not retrieved at night
- A portion of the thinnest detected clouds is not given a valid CTP estimation – thus, the JCH distribution is not able to fully describe the true distribution of clouds

An example of a global visualisation (i.e., summed over all grid points) of the JCH product for one month is given in Figure 5.6together with corresponding plots for the ISCCP dataset. Notice the higher binning resolution for the CM SAF dataset.

More details on the product retrieval are given in [RD 2] and [RD 6]. Information on the achieved accuracy of the product is found in the CM SAF GAC validation report [RD 1] and the CM SAF service specification [AD 2].

CM SAF **ISCCP**

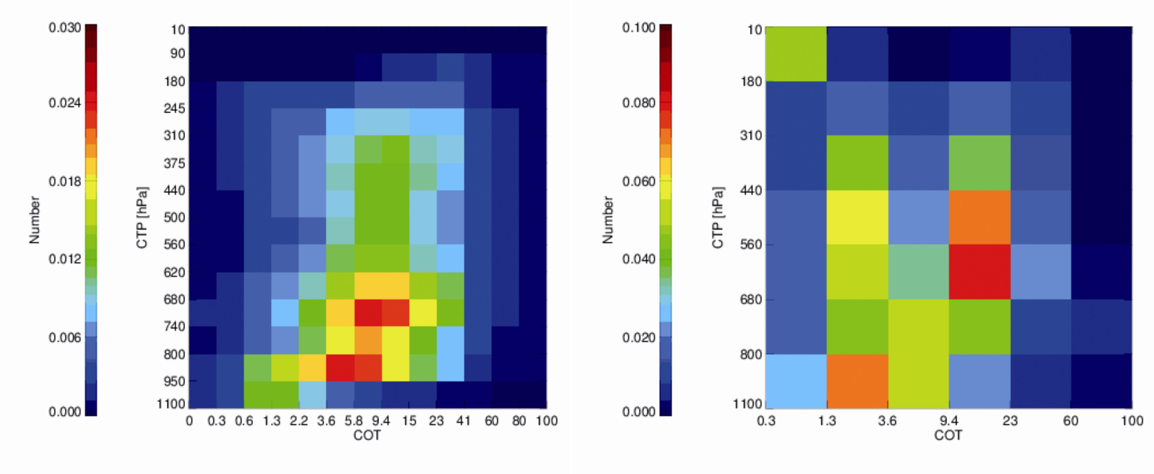

Figure 5.6 *Cloud Top Pressure (CTP) – Cloud Optical Thickness (COT) histograms of CMSAF (left) and ISCCP (right) for all clouds for March 2007. The histograms are presented in relative numbers.*

6 Outlook

The CM SAF GAC Edition 1 is the result of the first reprocessing effort of global AVHRR data in the CM SAF project. Since the processing effort in itself represented an effort being on a level that is several magnitudes larger than what had been experienced before, some specific limitations and shortcomings were consequently encountered. The most important are described by the following:

1. The amount of data to be processed (more than 15 TB) did not permit any full test run based on all data prior to the final processing. Thus, some unexpected features in the results were discovered which were not possible to fully understand from initial tests based exclusively on sub-sampled data.
2. These unexpected features were related to both technical and scientific shortcomings (for the latter related to algorithm weaknesses).
3. The following technical shortcomings should be listed:

    - The GAC dataset includes periods for some satellites when data were corrupt or partly missing in individual files (the latter including data for one full orbit). One example is data from the satellite NOAA-15 in 1999 and 2000 but also other satellites have periods when the data coverage is limited for technical reasons.
    - Even though most of these missing or corrupt data were flagged correctly in original Level 1b files, not all of the involved algorithms were adapted to handle this part of the dataset in a proper way.
    - For the first years of the series (1982-1990) only data from afternoon satellites were used. This means that inconsistencies due to different sampling of the diurnal cycle were introduced.

4. The following scientific shortcomings should be listed:

- Cloud detection over semi-arid areas was found to lead to unrealistically high cloud amounts. This was identified as an insufficient relaxation of visible and near-infrared thresholds between pure desert regions and tropical vegetation-covered regions.
- Improper ancillary datasets on surface emissivities were found to create too many clouds over some regions at night (e.g. over Australia).
- Global cloud amounts were found to be generally lower than most of the other referenced cloud datasets based on passive imagers (except over semi-arid regions). This feature is most pronounced over the Polar areas during the Polar winter.
- Cloud top level estimations are still found to be challenging from passive radiometers. A dual-feature in the deviations is present: Cloud top estimations for low-level clouds are overestimated while the opposite is seen for high-level clouds.

Regarding the technical limitations, the most serious defects (e.g. handling of corrupt data) were taken care of satisfactorily before the dataset was released. However, it is still motivated for upcoming editions to again go through the original Level 1b dataset together with NOAA to clearly identify and document all inherent data failure issues.

The mentioned scientific issues will be the prioritised ones addressed during the preparation of the next GAC reprocessing effort taking place within the next three years. The next release, Edition 2, is planned for release in 2015. For that release, planned improvements will also concern improvements of ancillary datasets (e.g. surface emissivity), introduction of probabilistic approaches for cloud screening and upgraded methods for cloud physical products (CPH, COT, LWP and IWP).

At the end of the upcoming CDOP 2 phase, a third release, Edition 3 is planned taking into account even further upgrades of methods and calibration information. For this edition, more mature methods for the probabilistic cloud information will be utilised and attempts will be made to tackle the problems with orbital drifts for satellites prior to the NOAA-K,L,M,N,N' era (i.e., approximately before year 2000). Also, the covered period will be extended with data from satellites carrying the first generation of the AVHRR instrument (i.e., AVHRR/1 for years between 1978 and 1991).

7 Data format description

CM SAF's AVHRR GAC products are provided as NetCDF (Network Common Data Format) files (http://www.unidata.ucar.edu/software/netcdf/). The data files are created following NetCDF Climate and Forecast (CF) Metadata Convention version 1.5 (http://cf-pcmdi.llnl.gov/) and NetCDF Attribute Convention for Dataset Discovery version 1.0.

For data processing and conversion to various graphical packages input format, CM SAF recommends the usage of the climate data operators (CDO), available under GNU Public License (GPL) from MPI-M (http://www.mpimet.mpg.de/~cdo).

7.1 Data file contents

A common NetCDF file consists of dimensions, variables, and attributes. These components can be used together to capture the meaning of data and relations among data. All CM SAF GAC products files are built following the same design principles. All files contain general variables, which are common for all files, and product specific variables. The latter are three-dimensional, except for the Joint Cloud property histograms. Dimension of all three-dimensional fields are named *time*, *lon*, *lat*. For the JCHs, additional two dimensions for COT and CTP bin are included. General variables of each file are *time*, *time_bnds*, *lat*, and *lon* (see section 7.2). All data fields, which are described in section 7.4, also contain specific attributes as given in section 7.3. Global attributes of each file are reported in section 7.5.

7.2 General variables

time

start of averaging/composite time period
[days counted from 1970-01-01]

time_bnds

two-dimensional array defining the averaging/composite time period
[days counted from 1970-01-01]

lat

geographical latitude of grid-box centre [degree_north]

lon

geographical longitude of grid-box centre [degree_east]

Note, the files containing the equal-area polar grid data provide two-dimensional *lat* and *lon* fields due to the deviation from regular grids.

7.3 Attributes

Table 7.1 summarizes the attributes which are assigned to each data fields in the NetCDF files.

Table 7.1 *Attributes assigned to variables.*

Name	Description
long_name	long descriptive name
standard_name	standard name that references a description of a variable's content in the CF standard name table
units	physical unit [udunits standards]
valid_min	smallest valid value of a variable
valid_max	largest valid value of a variable
scale_factor	The data are to be multiplied by this factor after it is read.

Name	Description
add_offset	This number is to be added to the data after it is read. If scale_factor is present, the data are first scaled before the offset is added.
_FillValue	This number represent missing or undefined data. Missing values are to be filtered before scaling.
missing	same as _FillValue
cell_methods	method used to derive data that represents cell values (optional)
scaled	indicator if data field is scaled (optional)

7.4 Product specific data fields

7.4.1 Fractional cloud coverage

cfc(time, lat, lon)
field containing the mean cloud fractional coverage value given in percent, valid range is between 0 and 100;
cfc_nobs(time, lat, lon)
field containing the number of observations used to create mean CFC
cfc_day(time, lat, lon)
field containing the mean daytime cloud fractional coverage given in percent, valid range is between 0 and 100;
cfc_day_nobs(time, lat, lon)
field containing the number of observations used to create mean daytime CFC
cfc_night(time, lat, lon)
field containing the mean nighttime cloud fractional coverage given in percent, valid range is between 0 and 100;
cfc_night_nobs(time, lat, lon)
field containing the number of observations used to create mean nighttime CFC

7.4.2 Cloud phase

cph(time, lat, lon)
field containing the mean liquid cloud fraction given in percent, valid range is between 0 and 100;
cph_nobs(time, lat, lon)
field containing the number of observations used to create mean CPH

7.4.3 Cloud top level

ctp_arith_mean(time, lat, lon)
field containing the arithmetical mean cloud top pressure, valid range is between 0 and 1050 hPa
ctp_geometric_mean(time, lat, lon)
field containing the geometrical (logarithmic) mean cloud top pressure, valid range is between 0 and 1050 hPa
ctp_arith_stdv(time, lat, lon)
field containing the standard deviation over CTP values used to calculated arithmetical mean CTP
cth_arith_mean(time, lat, lon)
field containing the arithmetical mean cloud top height, valid range is between 0 and 15000 meter

cth_arith_stdv(time, lat, lon)
field containing the standard deviation over CTH values used to calculated arithmetical mean CTH

ctt_arith_mean(time, lat, lon)
field containing the arithmetical mean cloud top temperature, valid range is between 0 and 15000 meter

ctt_arith_stdv(time, lat, lon)
field containing the standard deviation over CTT values used to calculated arithmetical mean CTT

nobs(time, lat, lon)
field containing the number of observations used to create CTO

7.4.4 Cloud optical thickness

cot(time, lat, lon)
field containing the mean cloud optical thickness (COT), considering all clouds

cot_stdv(time, lat, lon)
field containing the COT standard deviation, considering all clouds

cot_err(time, lat, lon)
field containing the mean COT retrieval error, considering all clouds

cot_nobs(time, lat, lon)
field containing the number of observations, considering all clouds

cot_liq(time, lat, lon)
field containing the mean cloud optical thickness (COT), considering liquid clouds

cot_liq_stdv(time, lat, lon)
field containing the COT standard deviation, considering liquid clouds

cot_liq_err(time, lat, lon)
field containing the mean COT retrieval error, considering liquid clouds

cot_liq_nobs(time, lat, lon)
field containing the number of observations, considering liquid clouds

cot_ice(time, lat, lon)
field containing the mean cloud optical thickness (COT), considering ice clouds

cot_ice_stdv(time, lat, lon)
field containing the COT standard deviation, considering ice clouds

cot_ice_err(time, lat, lon)
field containing the mean COT retrieval error, considering ice clouds

cot_ice_nobs(time, lat, lon)
field containing the number of observations, considering ice clouds

7.4.5 Liquid water path

lwp(time, lat, lon)
field containing the mean liquid water path

stdv(time, lat, lon)
field containing the standard deviation over LWP values used to calculated mean LWP

err(time, lat, lon)
field containing the mean LWP retrieval error

nobs(time, lat, lon)
field containing the number of observations used to calculate mean IWP

7.4.6 Ice water path

iwp(time, lat, lon)
field containing the mean ice water path

stdv(time, lat, lon)

field containing the standard deviation over IWP values used to calculated mean IWP

err(time, lat, lon)

field containing the mean IWP retrieval error

nobs(time, lat, lon)

field containing the number of observations used to calculate mean IWP

7.4.7 Joint Cloud property Histograms

jch_liq(time, nctp, ncot, lat, lon)

field containing the number of occurrences of specific combinations of COT and CTP ranges for liquid clouds at given spatial location.

jch_ice(time, nctp, ncot, lat, lon)

field containing the number of occurrences of specific combinations of COT and CTP ranges for ice clouds at given spatial location. In the notation above, *ncot* and *nctp* give the number of COT and CTP bins. The Joint Cloud property Histograms are defined on coarser spatial resolution (1.0°) compared to all other products (0.25°).

7.4.8 One-dimensional histograms

ctp1dhist(time, nctp, lat, lon),
cot1dhist(time, ncot, lat, lon),
iwp1dhist(time, niwp, lat, lon),
lwp1dhist(time, nlwp, lat, lon)

fields containing the number of occurrences of specific CTP, COT, IWP and LWP ranges at given spatial location. In the notation above, *nctp*, *ncot*, *niwp* and *nlwp* give the number of CTP, COT, IWP and LWP bins.

7.5 Global attributes

Table 7.2 contains the global attributes of CM SAF AVHRR GAC final product files. Possible values of the attributes are also given as well as explanations.

Table 7.2 *Overview of global attributes of NetCDF files of CM SAF GAC cloud products and possible corresponding values.*

Name	Description
title	CM SAF cloud, Albedo and RAdiation dataset, AVHRR-based, edition 1 (CLARA-A1)
summary	This file contains AVHRR GAC Thematic Climate Data Records (TCDR) produced by the Satellite Application Facility on Climate Monitoring (CM SAF).
product_class	Cloud products, monthly means / daily means / monthly histograms
Conventions	conventions followed, "CF-1.5" for all files
Metadata_Convention	conventions followed, "Unidata Dataset Discovery v1.0" for all files

Name	Description
institution	EUMETSAT Satellite Application Facility on Climate Monitoring (CM SAF)
Digital_Object_Identifier	DOI:10.5676/EUM_SAF_CM/CLARA_A/V001
creator_url	http://www.cmsaf.eu
creator_email	contact.cmsaf@dwd.de
references	http://www.cmsaf.eu
source	AVHRR GAC edition 1.0
cdm_data_type	grid
filename	*original filename*(case dependent)
time_coverage_start	*temporal coverage start of the data [ISO8601 date]* (case dependent)
time_coverage_end	*temporal coverage end of the data [ISO8601 date]* (case dependent)
time_coverage_duration	*temporal coverage duration of the data [ISO8601 duration]* (case dependent)
time_coverage_resolution	*temporal coverage resolution of the data [ISO8601 duration]* (case dependent)
geospatial_lat_units	*latitude attributes unit*(degree_north)
geospatial_lat_resolution	*latitude grid resolution(0.25f/1.0f)*
geospatial_lat_min	*latitude bounding box minimum*(-90.f)
geospatial_lat_max	*latitude bounding box maximum* (90.f)
geospatial_lon_units	*longitude attributes unit* (degree_east)
geospatial_lon_resolution	*longitude grid resolution(0.25f/1.0f)*
geospatial_lon_min	*longitude bounding box minimum* (-180.f)
geospatial_lon_max	*longitude bounding box maximum* (180.f)
dataset_version	*dataset version*
gac_major_version_number	*GAC major release version*
gac_minor_version_number	*GAC minor release version*
gac_parameter_name	*GAC parameter name*
gac_parameter_id	*CAC parameter ID*
processed_satellites	*satellites id's processed for this mean and corresponding orbits*
processed_orbit_nodes	*satellite orbit nodes processed for this mean "ascending, descending" for all files*
CM SAF_parameter_id	*CM SAF product identifier*
CM SAF_parameter_code	*CM SAF product name*
L3_processor	*L3 processor version used to create L3 products*
L2_processors	*L2 processor version used to create L2 products*
L1_intercalibration	*intercalibration version applied*
reference_documents	*Reference documents products*

8 Data ordering via the Web User Interface (WUI)

The internet address http://wui.cmsaf.eu allows direct access to the CM SAF data ordering interface. On this webpage a detailed description how to use it for product search and ordering is given. We refer the user to this description since it is the central and most up to date documentation. However, some of the key features and services are briefly described in the following sections.
Further user service including information and documentation about CM SAF and the CM SAF products are available from the CM SAF home page (http://www.cmsaf.eu).

8.1 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 (Please not the copyright disclaimer given in section 10.1). After the selection of the product, the desired way of data transfer can be chosen. This is either via a temporary ftp account (the default setting), or by CD/DVD or email. Each order will be confirmed via email, and the user will get another email once the data have been prepared. If the ftp data transfer was selected, this second email will provide the information on how to access the ftp server.

8.2 Contact User Help Desk staff

In case of questions the contact information of the User Help Desk (e-mail address contact.cmsaf@dwd.de) are available via the CM SAF home webpage (www.cmsaf.eu) or the home page of the Web User Interface (http://wui.cmsaf.eu).

8.3 User Problem Report

Users of CM SAF products and services are encouraged to provide feedback on the CM SAF product and services to the CM SAF team. Users can either contact the User Help Desk (see section 8.2) or use the “User Problem Report” page. A link to the “User Problem Report” is available either from the CM SAF home page (www.cmsaf.eu) or the Web User Interface home page (http://wui.cmsaf.eu).

8.4 Service Messages / log of changes

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

9 Feedback

9.1 User feedback

Users of CM SAF products and services are encouraged to provide feedback on the CM SAF product and services to the CM SAF team. We are keen to learn of what use the CM SAF data are. So please feedback your experiences as well as your application area of the CM SAF data.

EUMETSAT CM SAF is an user driven service and is committed to consider the needs and requirements of its users in the planning for product improvements and additions. Please provide your feedback e.g. to our User Help Desk (e-mail address contact.cmsaf@dwd.de).

9.2 Specific requirements for future products

Beside your general feedback you are cordially invited to provide your specific requirements on future products for your applications. Please provide your requirements e.g. to our staff or via our User Help Desk (e-mail address contact.cmsaf@dwd.de).

9.3 User Workshops

CM SAF is organizing on regular basis training workshops in order to facilitate the use of our data. Furthermore through our regular (approximately every four years) user's workshop we revisit our product baseline. Your participation in any of these workshops is highly appreciated. Please have a look at on the CM SAF home web page (www.cmsaf.eu) to get the latest news on upcoming events.

10 Copyright and Disclaimer

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

10.1 Copyright

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

10.2 Acknowledgement and Identification

When exploiting EUMETSAT/CM SAF data you are kindly requested to acknowledge this contribution accordingly and make reference to the CM SAF, e.g. by stating "The work performed was done (i.a.) by using data from EUMETSAT's Satellite Application Facility on Climate Monitoring (CM SAF)". It is highly recommended to clearly identify the product version used. An effective way to do this is the citation of CM SAF data records via the digital object identifier (doi). All information can be retrieved through (http://www.cmsaf.eu/DOI).
The DOI for this data set is provided on the title page of this document.

10.3 Re-distribution of CM SAF data

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

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12 Glossary

ATBD	Algorithm Theoretical Baseline Document
AVHRR	Advanced Very High Resolution Radiometer
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
CALIOP	Cloud-Aerosol Lidar with Orthogonal Polarisation (CALIPSO)
CDO	Climate Data Operators
CDOP	Continuous Development and Operations Phase
CDR	Climate Data Record
CFC	Fractional Cloud Cover
CM SAF	Satellite Application Facility on Climate Monitoring
CPH	Cloud Phase
COT	Cloud Optical Thickness
CTH	Cloud Top Height
CTO	Cloud Top product
CTP	Cloud Top Pressure
CTT	Cloud Top Temperature
DRI	Delivery Readiness Inspection
DWD	Deutscher Wetterdienst (German MetService)
EASE	Equal-Area Scalable Earth Grid (http://nsidc.org/data/ease/)
ECMWF	European Centre for Medium Range Forecast
ECV	Essential Climate Variable
EPS	European Polar System
ERA-40	First ECMWF Re-Analysis dataset
ERA-Interim	Second ECMWF Re-Analysis dataset
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FCDR	Fundamental Climate Data Record
GAC	Global Area Coverage (AVHRR)
GCOS	Global Climate Observing System
HOAPS	Hamburg Ocean Atmosphere Parameters and Fluxes from Satellite Data
ISCCP	International Satellite Cloud Climatology Project
IWP	Ice Water Path
JCH	Joint Cloud properties Histogram
KNMI	Koninklijk Nederlands Meteorologisch Institut
LUT	Look-Up Table
LWP	Liquid Water Path
MODIS	Moderate Resolution Imaging Spectroradiometer
NCDC	National Climate Data Centre (NOAA)
NetCDF	Network Common Data Format
NMHS	National Meteorological and Hydrological Service
NOAA	National Oceanic & Atmospheric Administration
NWC SAF	SAF on Nowcasting and Very Short Range Forecasting
NWP	Numerical Weather Prediction

PATMOS-x	Pathfinder Atmospheres – Extended dataset (NOAA)
PPS	Polar Platform System (NWC SAF polar cloud software package)
PRD	Product Requirement Document
PUM	Product User Manual
RTM	Radiative Transfer Model
SAF	Satellite Application Facility
SMHI	Swedish Meteorological and Hydrological Institute
TCDR	Thematic Climate Data Record
TOA	Top Of Atmosphere

13 Summary table of validation results regarding product accuracy

Table 13.1shows the achieved accuracies of the cloud products as discussed in [RD 1]. The acronyms used are: SYNOP = Synoptical surface observations, CALIPSO = Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation, PATMOS-x = AVHRR Pathfinder Atmospheres – Extended, MODIS = Moderate Resolution Imaging Spectroradiometer, ISCCP = International Satellite Cloud Climatology Project and UWisc = climatology based on passive microwave observations derived at University of Wisconsin. All references are described in detail in [RD 1].

Table 13.1 *Summary table of validation results as given in [*RD 1*]. For CFC and CPH (being defined as percentage values), results are given as absolute values (not relative). In contrast, results for LWP and IWP are given as relative errors.*

Product		**Achieved accuracies (mean error)**
Cloud Fractional Cover	(CFC)	3.6 % (SYNOP) -10 % (CALIPSO) -4.1 % (PATMOS-x) -10 % to -20 % (MODIS) 0 % to -12 % (ISCCP)
Cloud Top Height	(CTH)	-2661 m (CALIPSO)
Cloud Top Pressure	(CTP)	-20 to 60 hPa (PATMOS-X) -40 to -50 hPa (MODIS) -20 to 60 hPa (ISCCP)
Cloud Optical Thickness	(COT)	3-20 % (PATMOS-x) -5 % to -10 % (MODIS) 50-60 % (ISCCP)
Cloud Phase	(CPH)	7-15 % (PATMOS-x) 3-20 % (MODIS) 12-15 % (ISCCP)
Liquid Water Path	(LWP)	0-30 % (PATMOS-x) 15 % (MODIS) 30-50 % (ISCCP) +15 % to -26 % (UWisc)
Ice Water Path	(IWP)	0 % to -120 % (PATMOS-x) 0 % to -80 % (MODIS) 30-50 % (ISCCP)
Joint Cloud Histogram	(JCH)	n/a