ESA Cloud_cci
Product User Guide (PUG)

(Applicable to Cloud_cci version 2.0 products)

Issue 4 Revision 0

06 March 2018

Deliverable No.:	D-3.3
ESRIN/Contract No.:	4000109870/13/I-NB

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DOIs of Cloud_cci datasets:	DOI: 10.5676/DWD/ESA_Cloud_cci/AVHRR-PM/V002 DOI: 10.5676/DWD/ESA_Cloud_cci/AVHRR-AM/V002 DOI: 10.5676/DWD/ESA_Cloud_cci/MODIS-Aqua/V002 DOI: 10.5676/DWD/ESA_Cloud_cci/MODIS-Terra/V002 DOI: 10.5676/DWD/ESA_Cloud_cci/ATSR2-AATSR/V002 DOI: 10.5676/DWD/ESA_Cloud_cci/MERIS+AATSR/V002

Document Change Record

Document, Version	Date	Changes	Originator
PUGv3.0_submitted	12/12/2016	Submitted version	Martin Stengel, Stefan Stapelberg, Cintia Carbajal Henken, Caroline Poulsen, Rainer Hollmann
PUGv3.1_trackchange	31/03/2017	Revision after ESA review	M. Stengel
PUGv3.1	18/04/2017	Approved and issued version	M. Stengel
PUGv4.0	06/03/2018	Minor corrections and updates. Adding Appendix C, which described the uncertainty propagation to higher level products based on Level-3 uncertainties.	M. Stengel

Purpose

The purpose of this document is to provide user guidance for Cloud_cci cloud property datasets, their scientific and technical characteristics and the corresponding data access.

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Terms and conditions for use of Cloud_cci data:

The Cloud_cci datasets may be used by any user for any purpose, with the following terms and conditions:

1) Users of the CCI data are required to acknowledge the ESA Climate Change Initiative and Cloud_cci together with the individual data providers if the data are used in a presentation or publication. Please also cite any relevant dataset DOIs (see example citation text below).
2) Users of the CCI data are encouraged to interact with the CCI programme on use of the products, and to provide a copy of all reports and publications using the dataset. An offer of co-authorship should be considered, if the CCI data constitute a major component of a scientific publication.
3) Intellectual property rights (IPR) in the CCI data lie with the researchers and organisations producing the data.
4) Liability: No warranty is given as to the quality or the accuracy of the CCI data or its suitability for any use. All implied conditions relating to the quality or suitability of the information, and all liabilities arising from the supply of the information (including any liability arising in negligence) are excluded to the fullest extent permitted by law.

Citing the scientific content of the datasets:

Stengel, M., Stapelberg, S., Sus, O., Schlundt, C., Poulsen, C., Thomas, G., Christensen, M., Carbajal Henken, C., Preusker, R., Fischer, J., Devasthale, A., Willén, U., Karlsson, K.-G., McGarragh, G. R., Proud, S., Povey, A. C., Grainger, R. G., Meirink, J. F., Feofilov, A., Bennartz, R., Bojanowski, J. S., and Hollmann, R.: Cloud property datasets retrieved from AVHRR, MODIS, AATSR and MERIS in the framework of the Cloud_cci project, Earth Syst. Sci. Data, 9, 881-904, https://doi.org/10.5194/essd-9-881-2017, 2017.

Citing the datasets:

Cloud_cci **AVHRR-PM, AVHRR-AM, MODIS-Aqua, MODIS-Terra** datasets:

Stengel M., Sus O., Stapelberg S., Schlundt C., Poulsen C., Hollmann R. (2017): ESA Cloud Climate Change Initiative (ESA Cloud_cci) data: Cloud_cci [*AVHRR-PM, AVHRR-AM, MODIS-Aqua, MODIS-Terra*] L3C/L3U CLD_PRODUCTS v2.0, Deutscher Wetterdienst (DWD), DOI:10.5676/DWD/ESA_Cloud_cci/[*AVHRR-PM, AVHRR-AM, MODIS-Aqua, MODIS-Terra*]/V002

Cloud_cci **ATSR2-AATSR** dataset:

Poulsen C., McGarragh G., Thomas G., Christensen M., Povey A., Grainger D., Proud S., Hollmann R. (2017): ESA Cloud Climate Change Initiative (ESA Cloud_cci) data: Cloud_cci ATSR2-AATSR L3C/L3U/L2 CLD_PRODUCTS v2.0, Deutscher Wetterdienst (DWD) and Rutherford Appleton Laboratory (Dataset Producer), DOI:10.5676/DWD/ESA_Cloud_cci/ATSR2-AATSR/V002

Cloud_cci **MERIS+AATSR** datasets:

Carbajal Henken C.K., Preusker R., Fischer F., Hollmann R. (2017): ESA Cloud Climate Change Initiative (ESA Cloud_cci) data: Cloud_cci MERIS+AATSR L3C/L3U CLD_PRODUCTS v2.0, Deutscher Wetterdienst (DWD) and Freie Universität Berlin (Dataset Producer), DOI:10.5676/DWD/ESA_Cloud_cci/MERIS+AATSR/V002

1. Introduction

1.1 The ESA Cloud_cci project

The ESA Cloud_cci project covers the cloud component in the European Space Agency's (ESA) Climate Change Initiative (CCI) programme (Hollmann et al., 2013). In the ESA Cloud_cci project, long-term and coherent cloud property datasets have been generated exploiting the synergic capabilities of different Earth observation missions (European and non-European) allowing for improved accuracies and enhanced temporal and spatial sampling better than those provided by the single sources.

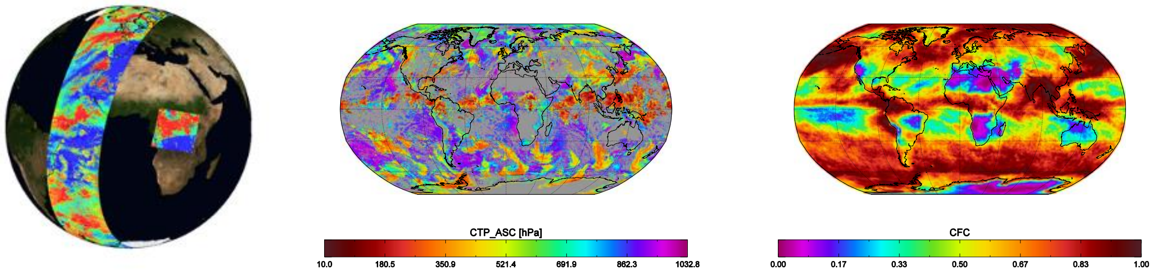

Figure 1-1 *Examples of Cloud_cci cloud products. Left: Pixel-based (Level 2), middle: daily composite on a global grid (Level 3U), right: monthly averaged on a global grid (Level 3C)*

To make the Cloud_cci datasets improved compared to existing ones, the following two essential steps were undertaken:

1) Revisit the measurement data (Level-1) and corresponding calibration performance and development of a carefully inter-calibrated and rigorously quality checked radiance data sets for AVHRR, so called Fundamental Climate Data Record (FCDR). Within this effort the calibration of AVHRR, MODIS and AATSR was compared and characterized. Please see the ATBDv5 for more information about all sensors used and their imaging characteristics. More information on the AVHRR FCDR produced and used is available in RAFCDRv1.0.

2) Development of two state-of-the-art physical retrieval systems that use the optimal estimation technique for a simultaneous, spectrally consistent retrieval of cloud properties including pixel-based uncertainty measures. The first retrieval framework is the Community Cloud retrieval for Climate (CC4CL; Sus et al., 2017; McGarragh et al., 2017) which is applied to AVHRR and AVHRR-heritage channels (i.e. channels which are available from all sensors) of MODIS and AATSR. The second retrieval framework is the Freie Universität Berlin AATSR MERIS Cloud retrieval (FAME-C; Carbajal Henken et al., 2014) and is applied to synergistic MERIS and AATSR measurements on-board of ENVISAT.

Based on these developments, six multi-annual, global datasets of cloud properties were generated using the passive imager satellite sensors AVHRR, MODIS, (A)ATSR and MERIS. These datasets were comprehensively evaluated (1) by using accurate reference observations of ground stations and space-based Lidar measurements and (2) by comparisons to existing and well-established global cloud property datasets.

All parts of the datasets generation effort were properly documented with the major components being the Algorithm Theoretical Baseline Documents (ATBD; ATBDv5, ATBD-FAME-Cv5, ATBD-CC4CLv5), the Product Validation and Intercomparisons Report (PVIR; PVIRv4.1) and this Product User Guide (PUGv3.1).

Furthermore, to facilitate the utilization for evaluation of regional and global atmospheric models, the development of a satellite simulator package for Cloud_cci datasets were fostered, which is planned to be part of one of the upcoming releases of the CFMIP Observation Simulator Package (COSP, Bodas-Salcedo et al. 2011).

1.2 The Cloud_cci datasets

In Cloud_cci two families of global cloud property datasets have been generated. The first family comprises datasets for individual sensor groups such as AVHRR, MODIS, ATSR2/AATSR, for which the AVHRR-heritage channels (0.6, 0.8, 1.6/3.7, 10.8, 12.0 μm) were utilized to retrieve cloud properties using the CC4CL algorithm. The second family comprises a dataset of cloud properties retrieved from simultaneous usage of AATSR and MERIS sensors (both mounted on ENVISAT) by applying the FAME-C algorithm. Since MODIS and AVHRR sensors are separated into morning and afternoon orbits, 6 distinct Cloud_cci datasets exist, which can be seen in Figure 1-2. In addition,

Table 1-1 summarizes the algorithms, sensors and satellites used for each dataset. The official versions of the datasets, as released under the issued Digital Object Identifies (DOIs, see Table 1-2), do not contain any diurnal cycle or satellite drift correction. Potential methods for such a drift correction were investigated for AVHRR and were documented in RODCv1.0. In Figure 1-3 the local observation time of each individual sensor considered are visualized. This information is often essential for properly characterizing time series of cloud properties derived from the satellite-based climate datasets. Other important aspects are the imaging properties. The sensors differ in terms of native footprint resolution (1x1km² for ATSR2, AATSR, MERIS, MODIS; 5x1km² for AVHRR). This, together with the sensor swath width, lead to very different observation frequency and spatial coverage. The latter is visualized in Figure A-18. While MODIS and AVHRR have a complete global coverage within a day, the AATSR sensor needs about 3 days to accomplish this, however, with a higher spatial resolution compared to AVHRR.

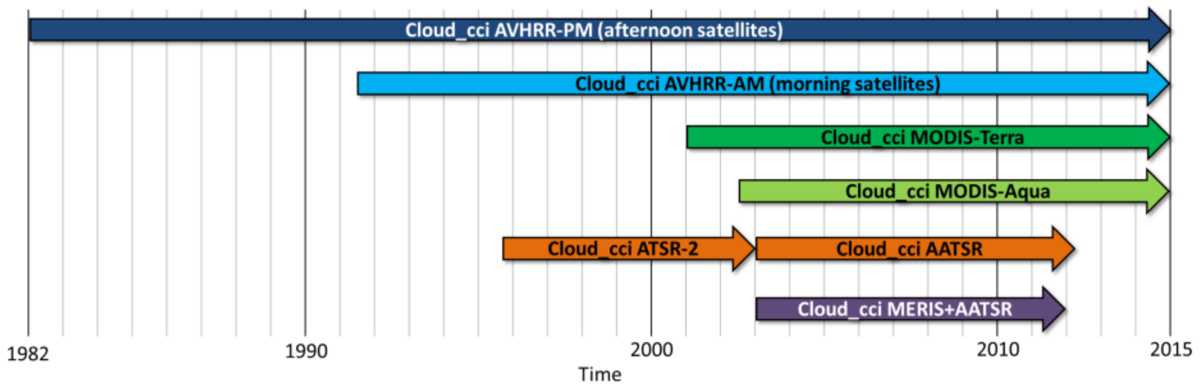

Figure 1-2 *Overview of Cloud_cci datasets and the time periods they cover.*

All datasets contain identical sets of cloud properties: cloud mask/fraction (CMA/CFC), cloud phase/liquid cloud fraction (CPH), cloud top pressure/height/temperature (CTP/CTH/CTT), cloud effective radius (CER), cloud optical thickness (COT), spectral cloud albedo at two wave lengths (CLA) and liquid/ice water path (LWP/IWP). The data is presented at different processing levels ranging from pixel-based retrieval products (Level-2), which are additionally projected (sampling – no averaging) onto a global Latitude-Longitude grid of 0.05° resolution (global composite, Level-3U), to monthly data summarizes including averages, standard deviation and histograms - all defined on a global Latitude-Longitude grid of 0.5° resolution (Level-3C). See Section 1.3 for more details.

All cloud properties (except CPH) are accompanied by uncertainty measures at all processing levels, which range from optimal estimation based uncertainty on pixel level (Level-2 and Level-3U) to propagated uncertainties in the monthly Level-3C products. See Section 1.2 for more information.

In addition to the passive imager based datasets mentioned so far, in Cloud_cci an IASI-based demonstrator dataset has been created, with more details to be found in Feofilov et al. (2017) and Stubenrauch et al. (2017).

Key strengths of Cloud_cci datasets:

- The Cloud_cci datasets are based on two newly-developed, state-of-the art retrieval systems named CC4CL and FAME-C that use the optimal estimation (OE) technique and are applied to passive imager sensors of current and past European and non-European satellite missions.
- The measurement records of the utilized sensors have been revisited, re-characterized and, in case of AVHRR, re-calibrated.
- Two special features of CC4CL and FAME-C are, among others, their applicability to multiple sensors: ATSR2, AATSR, MODIS, AVHRR (CC4CL) and the simultaneous utilization of AATSR and MERIS measurements (FAME-C, i.e. utilizing the O2-A band of MERIS) down to spatial footprint resolutions of 1km.
- Radiative consistency of derived cloud parameters is achieved by the OE-based, iterative fitting of a physically consistent cloud model (and radiative transfer simulations therefrom) to the sensor measurements in the visible and thermal infrared spectral range.
- Pixel-level uncertainty characterization is facilitated by the OE technique, which is physically consistent (1) with the uncertainties of the input data (e.g. measurements, a-priori) and (2) among the retrieved variables. These pixel-level uncertainties are further propagated into the monthly products using a developed sound mathematical framework.
- Potential to combine AVHRR-heritage datasets to achieve increased temporal resolution by including multiple polar-orbiting satellite instruments, which also allows for mature cloud property histograms on 0.5° resolution due to highly increased sampling rate.
- Comprehensive assessment and documentation of the retrieval schemes and the derived cloud property datasets, including possibilities of drift- and diurnal cycle corrections.
- Availability of a developed Cloud_cci satellite simulator facilitating the applicability of Cloud_cci data in regional and global climate models evaluation efforts.
- All datasets are available in netcdf (v4) format and fulfil high CCI-internal and external data standards (e.g. Climate and Forecast – CF conventions).

Table 1-1 *Cloud_cci datasets with the algorithms, sensor(s) and satellite(s) used and the time periods they cover. The Digital Object Identifiers (DOI) of all datasets are also listed.*

Dataset name	Sensor(s)	Satellite(s)	Time period	Algorithm
Cloud_cci AVHRR-PM DOI:10.5676/DWD/ESA_Cloud_cci/AVHRR-PM/V002	AVHRR-2/-3	NOAA-7,-9,-11,-14,-16,-18,-19	1982-2014	CC4CL
Cloud_cci AVHRR-AM DOI:10.5676/DWD/ESA_Cloud_cci/AVHRR-AM/V002	AVHRR-2/-3	NOAA-12,-15,-17, Metop-A	1991-2014	CC4CL
Cloud_cci MODIS-Terra DOI:10.5676/DWD/ESA_Cloud_cci/MODIS-Terra/V002	MODIS	Terra	2000-2014	CC4CL
Cloud_cci MODIS-Aqua DOI:10.5676/DWD/ESA_Cloud_cci/MODIS-Aqua/V002	MODIS	Aqua	2002-2014	CC4CL
Cloud_cci ATSR2-AATSR DOI:10.5676/DWD/ESA_Cloud_cci/ATSR2-AATSR/V002	ATSR2, AATSR	ERS2, ENVISAT	1995-2012	CC4CL
Cloud_cci MERIS+AATSR DOI:10.5676/DWD/ESA_Cloud_cci/MERIS+AATSR/V002	MERIS, AATSR	ENVISAT	2003-2011	FAME-C

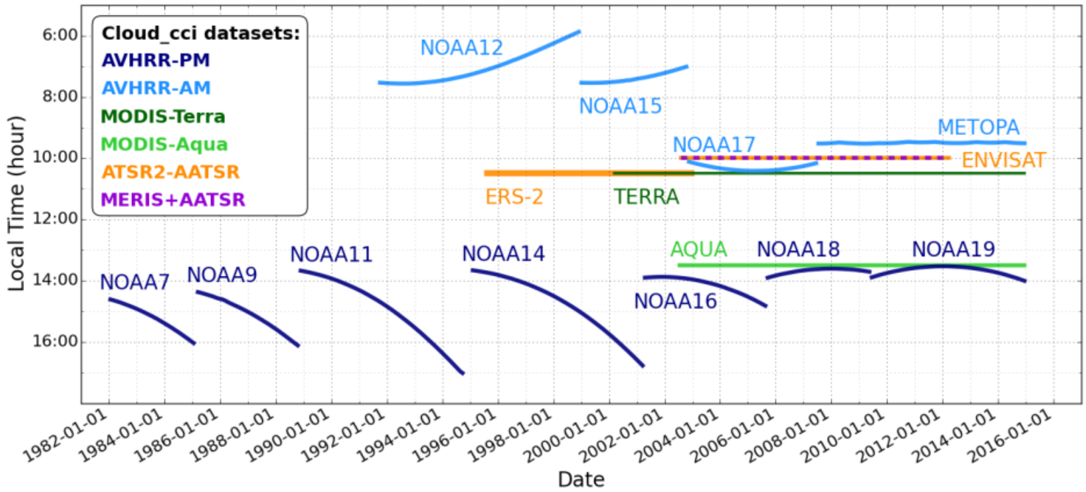

Figure 1-3 *Time periods and local observation times (equator crossing times) of each satellite sensor considered in Cloud_cci. Figure is taken from Stengel et al. (2017).*

1.3 Cloud_cci cloud products

The cloud properties derived on pixel level of each utilized sensor are listed in Table 1-2. It is important to note that the properties CLA, LWP, IWP are not directly retrieved, but rather determined from retrieved COT and CER in a post processing step. The same applies to CTH and CTT, which are inferred from the retrieved CTP. Based on these pixel level retrievals the data is further processed into different processing levels as summarized in Table 1-3. Level-3U denotes a composite on a global Latitude-Longitude grid (of 0.05° resolution) onto which the Level-2 data is sampled (see ATBDv5 for more details on Level-3U sampling). Level-3C products are also defined on Latitude-Longitude grid (here 0.5° resolution) onto which the properties are averaged or their frequency collected (histograms). Further separation of cloud properties in Level-3C in e.g. day/night, liquid/ice, were made wherever suitable (see Table 1-4). Level-3S products are generated merging the Level-3C of all individual sensors. Using Level-3S products requires careful consideration of the partly large and time-varying discrepancies between the used sensors. Please contact the Cloud_cci team for more information (http://www.esa-cloud-cci.org/?q=support).

Table 1-2 *List of generated cloud properties. CMA/CFC and CPH are derived in a pre-processing step. In the next step, COT, CER and CTP are retrieved simultaneously by fitting a physically consistent cloud/atmosphere/surface model to the satellite observations using optimal estimation (OE). Moreover, LWP and IWP are obtained from COT and CER. In addition, spectral cloud albedo (CLA) for two visible channels are derived.*

Variable	Abbrev.	Definition
Cloud mask / Cloud fraction	CMA/ CFC	A binary cloud mask per pixel (L2, L3U) and therefrom derived monthly total cloud fractional coverage (L3C, L3S) and separation into 3 vertical classes (high, mid-level, low clouds) following ISCCP classification (Rossow and Schiffer, 1999).
Cloud phase	CPH	The thermodynamic phase of the retrieved cloud (binary: liquid or ice; in L2, L3U) and the therefrom derived monthly liquid cloud fraction (L3C, L3S).

Variable	Abbrev.	Definition
Cloud optical thickness	COT	The line integral of the absorption coefficient and the scattering coefficient (at 0.55µm wavelength) along the vertical in cloudy pixels.
Cloud effective radius	CER	The area-weighted radius of the cloud drop and crystal particles, respectively.
Cloud top pressure/ height/ temperature	CTP/ CTH/ CTT	The air pressure [hPa] /height [m] /temperature [K] of the uppermost cloud layer that could be identified by the retrieval system.
Cloud lLiquid water path/ Ice water path	LWP/ IWP	The vertical integrated liquid/ice water content of existing cloud layers; derived from CER and COT. LWP and IWP together represent the cloud water path (CWP)
Joint cloud property histogram	JCH	This product is a spatially resolved two-dimensional histogram of combinations of COT and CTP for each spatial grid box.
Spectral cloud albedo	CLA	The blacksky cloud albedo derived for channel 1 (0.67 µm) and 2 (0.87 µm), respectively (experimental product)

Table 1-3 *Processing levels of Cloud_cci data products. Level-3U, Level-3C and Level-3S are each directly derived from Level-2.*

Processing level	Spatial resolution	Description
Level-2 (L2)	MODIS: 1km AATSR: 1km AVHRR: 5 km MERIS+ AATSR: 1km	Retrieved cloud variables at satellite sensor pixel level, thus with the same resolution and location as the sensor measurements (Level-1)
Level-3U (L3U)	Latitude-Longitude grid at 0.05° res. (MODIS-Europe: 0.02°)	Cloud properties of Level-2 orbits projected onto a global space grid without combining any observations of overlapping orbits. Only subsampling is done. Common notation for this processing level is also L2b. Temporal coverage is 24 hours (0-23:59 UTC).
Level-3C (L3C)	Latitude-Longitude grid at 0.5° res.	Cloud properties of Level-2 orbits of one single sensor combined (averaged / sampled for histograms) on a global space grid. Temporal coverage of this product is 1 month.
Level-3S (L3S)	Latitude-Longitude grid at 0.5° res.	Cloud properties of Level-2 orbits of all available single sensors combined (averaged / sampled for histograms) on a global space grid. Temporal coverage of this product is 1 month.

Table 1-4 *Cloud_cci product features incl. day and night separation, liquid water and ice as well as histogram representation. Level-3U refers to the non averaged, pixel-based cloud retrievals sampled onto a global Latitude-Longitude (lat/lon) grid. [1]CMA in Level-2 and Level-3U is a binary cloud mask. All products listed exist in each dataset listed above.*

	Level 2 swath based 1km/5km	**Level-3U daily sampled global** 0.05° lat/lon grid	**Level-3C monthly averages global** 0.5° lat/lon grid	**Level-3C monthly histograms global** 0.5° lat/lon grid
CMA/CFC	✓ as CMA[1]	✓ as CMA[1]	✓day/night/high/mid/low	-
CTP, CTH, CTT	✓	✓	✓	✓ liquid/ice
CPH	✓	✓	✓ day/night	-
COT	✓	✓	✓ liquid/ice	✓ liquid/ice
CER	✓	✓	✓ liquid/ice	✓ liquid/ice
LWP	✓ as CWP	✓ as CWP	✓	✓ as CWP
IWP			✓	
CLA	✓ 0.6/0.8µm	✓ 0.6/0.8µm	✓ 0.6/0.8µm	✓ 0.6/0.8µm/liquid/ice
JCH	-	-	-	✓ liquid/ice

1.4 Uncertainties

The retrieved cloud properties CMA, CTP, CTT, CTH, COT, CER, LWP and IWP (for CC4CL also CLA) are accompanied by pixel-based (Level-2) uncertainties, which are output of the OE technique and represent a rigorous propagation of the uncertainties in the input data, e.g. a-priori information, measurements, radiative transfer. These uncertainties values represent the 68% confidence interval of the true value being within the retrieved value ± uncertainty. These Level-2 uncertainties are also given in Level3U and further propagated into Level-3C. For this a sound mathematical framework has been developed and implemented taking into account the retrieval uncertainties but also the uncertainty correlations. The framework allows an estimation of both the real variability of the observed property and the uncertainty of the calculated mean. Determine and utilizing the uncertainty correlation is a particular key point for an appropriate propagation of Level-2 uncertainties into higher-level products (e.g. Level-3C). Please see the Comprehensive Error Characterization Report (CECRv3) and Stengel et al. (2017) for further details on the uncertainty measures provided.

2. Product description and guidance

This section summarizes the core cloud properties derived in Cloud_cci. These properties are common among all Cloud_cci datasets.

2.1 Cloud mask & fraction

The used cloud detection schemes outputs a binary clouds mask (0: clear, 1: cloudy) on pixel level (Level-2) and for globally subsampled data products (Level-3U, 0.05°). The binary information is averaged to infer monthly mean cloud fraction (Level-3C, 0.5°). Examples of Level-3U and Level-3C are shown in Figure 2-1.

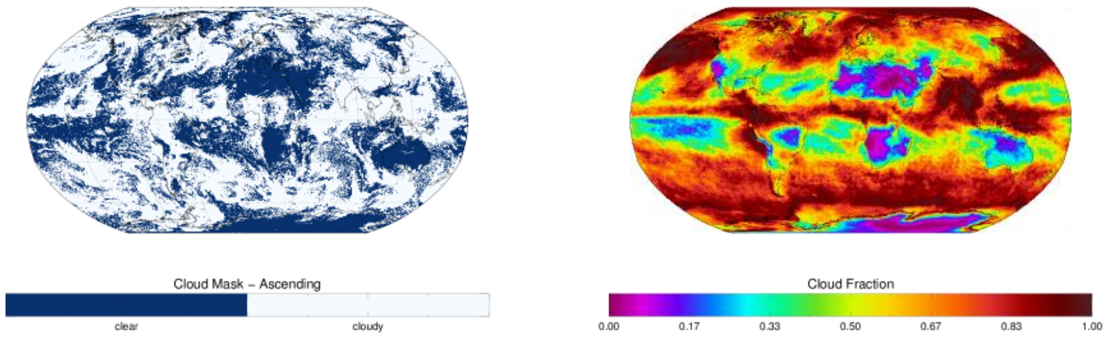

Figure 2-1 *Left: Global map of Cloud_cci L3U cloud mask for 2008/06/21. Right: Global map of Cloud_cci monthly mean total cloud fraction for 2008/06. (Both examples are taken from the AVHRR-PM dataset. Examples of all datasets are shown in Annex A)*

Short algorithm description:

AVHRR-PM, AVHRR-AM, MODIS-Aqua, MODIS-Terra, ATSR2-AATSR (CC4CL) datasets:

Cloud detection in CC4CL is based on a neural network with which CALIOP optical thickness is approximated, followed by an application of scene-dependent thresholds. Please see Sus et al. (2017) for more details.

MERIS+AATSR (FAME-C):

Cloud detection in FAME-C is based on a Bayesian method in which a feature set consisting of several channel combinations from both the MERIS and AATSR instrument are used. The resulting cloud probability is then converted into a binary cloud mask. Please see Hollstein et al. (2015) for more details.

Uncertainty information:

AVHRR-PM, AVHRR-AM, MODIS-Aqua, MODIS-Terra, ATSR2-AATSR (CC4CL) datasets:

- Cloud detection uncertainty on pixel level (Level-2, Level-3U) originates from quantifying the agreement to CALIOP cloud mask as a function of used threshold. The uncertainty values provided on Level-2 are to be interpreted as probability (in %) that the given cloud mask information is not correct (e.g. higher value -> higher uncertainty).
- Level-3 uncertainties provided for cloud fraction are arithmetically averaged Level-2 uncertainties and can, together with the standard deviation provided, serve as qualitative measure for grid boxes with higher/lower uncertainty of the mean cloud fraction.

MERIS+AATSR (FAME-C):

- No direct cloud detection uncertainty exists in the present FAME-C Level-2 data. For Level-3 products the standard deviation over all pixels considered is provided.

Known limitations:

All datasets:

- Discrimination of heavy aerosol and cloudy is not optimal, thus aerosol is sometimes flagged as clouds in such conditions. It is advised to be careful in the interpretation cloudiness in periods with dust / volcanic ash outbreaks. Cloudiness is overestimated in these conditions.
- Problematic cloud detection over mountaneous regions (also applies to all other cloud properties)

AVHRR-PM, AVHRR-AM, MODIS-Aqua, MODIS-Terra, ATSR2-AATSR (CC4CL) datasets:

- Cloud detection during polar night over snow and ice is generally difficult. Comparisons to other AVHRR datasets reveal that the CC4CL cloud detection has also some shortcoming during polar day although it performs better than during polar night.
- Cloud detection in twilight conditions is of rather poor quality due to the small number of channels used. Due to the orbit constellation, this issue is impacting most significantly the AVHRR-AM set before 1999.
- AVHRR-PM/AM time series of CFC should not be used for trend analysis without performing a proper satellite drift correction first.
- The ATSR2-AATSR cloud detection consistency between ATSR2 and AATSR is currently poor because of a missing spectral shift adjustment for ATSR2
- Due to a limitation of passive imagers, the cloud fraction is usually biased toward lower values, compared to example CALIOP.

MERIS+AATSR (FAME-C):

- Overestimation of cloudiness in desert region, especially in Africa and Middle-East region.
- Underestimation of cloudiness above ocean related to inhomogeneous cloud fields with small clouds.
- Some problems occur in the discrimination of heavy aerosol loading with cloud, as mentioned above.
- Underestimation of cloudiness for optically thin, high cirrus clouds in tropical regions
- Overestimation of cloudiness above snow and ice surfaces.

Cloud mask/fraction - data fields* and descriptions:

Product level	Data field name	Description
Level-2	*cc_total*	Cloud mask (0: cloud free; 1: cloudy)
Level-3U	*cmask_asc* *cmask_desc*	Cloud mask, ascending node of orbit Cloud mask, descending node of orbit
Level-3U	*cmask_asc_unc* *cmask_desc_unc*	Cloud mask uncertainty, ascending node Cloud mask uncertainty, descending node
Level-3C	*cfc*	Total cloud fraction using all available observations
Level-3C	*cfc_unc*	Uncertainty of total cloud fraction using all available observations
Level-3C	*cfc_day* *cfc_night* *cfc_twi*	Daytime cloud fraction Nighttime cloud fraction Twilight cloud fraction
Level-3C	*cfc_low* *cfc_mid* *cfc_high*	Cloud fraction of low clouds Cloud fraction of mid-level clouds Cloud fraction of high clouds Separation according to cloud top pressure limits 680 hPa and 440 hPa

* Complete list of data fields is given in Annex B

2.2 Cloud phase & liquid cloud fraction

Cloud phase in Level-2 and Level-3U products is a binary information if the detected cloud is of liquid or ice type. In Level-3 products, this is converted to the fraction of liquid clouds with respect to all detected clouds. Examples of Level-3U and Level-3C are shown in Figure 2-2.

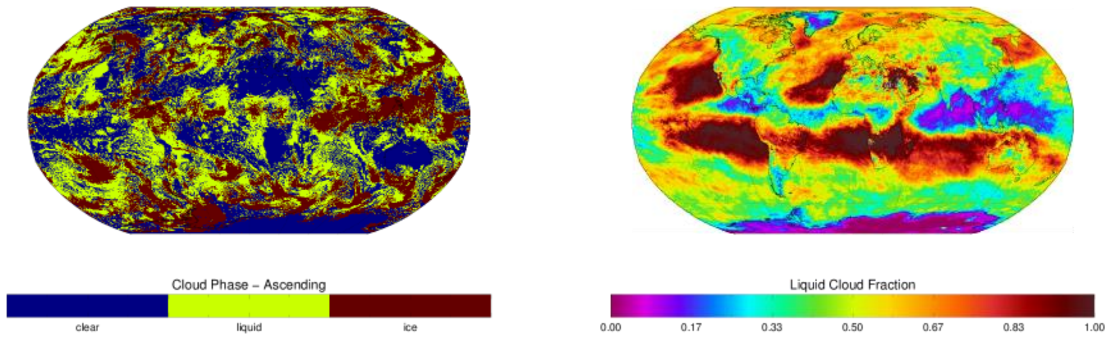

Figure 2-2 *Left: Global map of Cloud_cci L3U cloud phase for 2008/06/21. Right: Global map of Cloud_cci monthly mean liquid cloud fraction for 2008/06. (Both examples are taken from the AVHRR-PM dataset. Examples of all datasets are shown in Annex A)*

Short algorithm approach description:

All datasets:

The Pavolonis et al. (2005) scheme (including some modifications, see ATBD-CC4CLv5 and ATBD-FAMECv5), which is a series of threshold tests, is applied for cloud typing, resulting in 9 types (see data field description table below) with 4 liquid cloud types and 5 ice cloud types. These two groups of types are used to infer the binary cloud phase information.

Uncertainty information:

All datasets:

- No pixel level uncertainty information is provided.
- For Level-3C products the standard deviation over all pixels considered is provided. Assuming a Gaussian distribution of the observations and bias-free monthly mean value, the standard deviation can be used (when multipled with $1/\sqrt{N}$; N being the number of observations) to determine the sampling error for retrieving the correct mean. Also, when assuming that correlation between the retrieval uncertainties and the retrieved values is negligible, the provided standard deviation reflects the natural variability of the observed variable. This argumentation applied to all cloud properties in this report.

Known limitations:

- MODIS-Aqua phase data biased towards liquid phase and should be used carefully.
- AVHRR-PM/AM time series of CFC should not be used for trend analysis without performing a proper satellite drift correction first.
- ATSR-2/AATSR is biased towards ice phase and should be used carefully.
- No pixel-based and propagated uncertainties.

Cloud phase / liquid cloud fraction - data fields* and descriptions:

Product level	Data field name	Description
Level-2	*phase*	Cloud thermodynamic phase (1: water cloud, 2: ice cloud)
Level-2	*phase_pavolonis*	Cloud type (0: clear,1: switched to liquid, 2: fog, 3: liquid, 4: supercooled, 5: switched to ice, 6: opaque ice, 7: cirrus, 8: overlapping, 9: probably opaque ice)
Level-3U	*cph_asc* *cph_desc*	Cloud thermodynamic phase, ascending node of orbit Cloud thermodynamic phase, descending node of orbit
Level-3U	*cty_asc* *cty_desc*	Cloud type, ascending node of orbit Cloud type, descending node of orbit (0: clear,1: switched to liquid, 2: fog, 3: liquid, 4: supercooled, 5: switched to ice, 6: opaque ice, 7: cirrus, 8: overlapping, 9: probably opaque ice)
Level-3C	*cph*	Liquid cloud fraction using all available observations
Level-3C	*cph_std*	Standard deviation over all Level 2 phase retrievals
Level-3C	*cph_day*	Liquid cloud fraction using daytime observations only
Level-3C	*cph_day_std*	Standard deviation over all daytime Level 2 phase retrievals

* Complete list of data fields is given in Annex B

2.3 Cloud optical thickness

The cloud optical thickness (COT) describes the line integral of the absorption coefficient and the scattering coefficient along the instruments line of sight in cloudy pixels (Level-2 and Level-3U). Level-3C contains the monthly arithmetical (and logarithmic) averages together with standard deviation and separations into liquid and ice clouds. Also, 1-dimensional histograms of COT exist in Level-3C. Examples of Level-3U and Level-3C are shown in Figure 2-3.

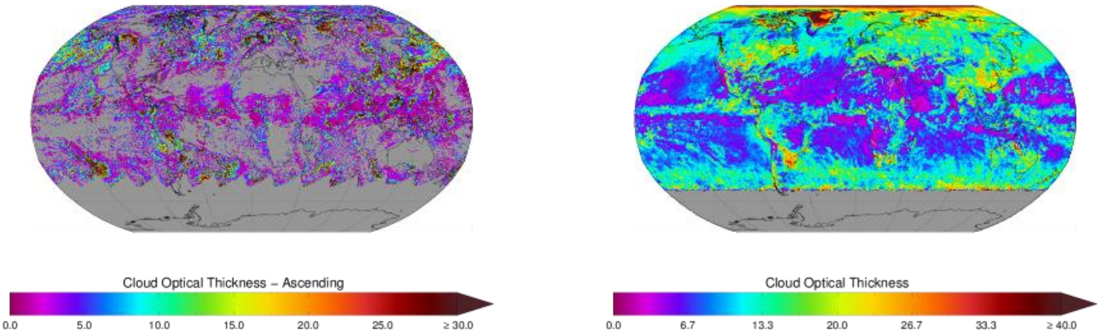

Figure 2-3 *Left: Global map of Cloud_cci L3U cloud optical thickness for 2008/06/21. Right: Global map of Cloud_cci monthly mean cloud topical thickness for 2008/06. (Both examples are taken from the AVHRR-PM dataset. Examples of all datasets are shown in Annex A)*

Short algorithm approach description:

AVHRR-PM, AVHRR-AM, MODIS-Aqua, MODIS-Terra, ATSR2-AATSR (CC4CL) datasets:

Cloud optical thickness is direct output of the optimal estimation retrieval CC4CL (McGarragh et al., 2017; Sus et al., 2017) in which a physical model of the cloud is systematically altered until the corresponding resulting simulated radiances fit the measurements. Simulations look up tables (LUTs) strongly depend on the pre-determined cloud phase.

MERIS+AATSR (FAME-C) dataset:

Cloud optical thickness is direct output of the optical estimation retrieval FAME-C DCOMP (Daytime Cloud Optical and Microphysical Properties) (Carbajal Henken et al., 2014) in which a physical model of the cloud is systematically altered until the corresponding resulting simulated radiances fit the measurements both for an AATSR channel at visible wavelengths and at near-infrared wavelengths. The LUTs strongly depend on the pre-determined cloud phase.

Uncertainty information:

All datasets:

- Along with the COT retrieval, the OE framework provides COT uncertainty on Level-2 (also in Level-3U) which is based on rigorous uncertainty propagation of the input data. According to OE theory the COT uncertainty describes the 68.2% confidence interval around the retrieved COT. This uncertainty is also propagated into the Level-3C products.
- The uncertainty is strongly dependent on the surface BRDF hence high BRDF surfaces will result in high values of uncertainty, e.g. over snow and ice.

Known limitations:

All datasets:

- COT is a daytime product only.
- In cases of wrong phase assigned, the optical thickness is likely to have significant errors.
- In the case of incorrectly assigned surface BRDF the optical depth is likely to be biased. Too high BRDF the COT will be biased low. Too low BRDF the COT will be biased high.
- In case of sub-pixel clouds or cloud borders the COT is likely to have significant errors.
- In case of optically thin clouds above (especially poorly) defined highly reflecting surface, the COT retrieval might be problematic.
- For very optically thick clouds, the measurements go into saturation and thus the sensitivity of the measurement to the COT is small. Those values should be accompanied by large uncertainty values.

Cloud optical thickness - data fields* and descriptions:

Product level	Data field name	Description
Level-2	*cot*	Cloud optical thickness
Level-2	*cot_unc*	Cloud optical thickness uncertainty
Level-3U	*cot_asc* *cot_desc*	Cloud optical thickness, ascending node of orbit Cloud optical thickness, descending node of orbit
Level-3U	*cot_asc_unc* *cot_desc_unc*	Cloud optical thickness uncertainty, ascending Cloud optical thickness uncertainty, descending
Level-3C	*cot*	Cloud optical thickness, mean of individual pixel retrievals
Level-3C	*cot_log*	Cloud optical thickness, logarithmic mean of individual pixel retrievals
Level-3C	*cot_unc*	Cloud optical thickness - mean of individual pixel uncertainties
Level-3C	*cot_std*	Cloud optical thickness - standard deviation of individual pixel retrievals
Level-3C	*cot_prop_unc*	Cloud optical thickness - propagated uncertainty: total uncertainty from individual pixel uncertainty added in quadrature
Level-3C	*cot_corr_unc*	Cloud optical thickness - correlated uncertainty assuming correlation of 0.1
Level-3C	*cot_liq* *cot_ice*	Liquid/ice cloud optical thickness - mean of individual pixel retrievals

Product level	Data field name	Description
Level-3C	*cot_liq_std* *cot_ice_std*	Liquid/ice cloud optical thickness - standard deviation of individual pixel retrievals
Level-3C	*cot_liq_unc* *cot_ice_unc*	Liquid/ice cloud optical thickness - mean of individual pixel uncertainties
Level-3C	*cot_liq_prop_unc* *cot_ice_prop_unc*	Liquid cloud optical thickness - propagated uncertainty
Level-3C	*cot_liq_corr_unc* *cot_ice_corr_unc*	Liquid/ice cloud optical thickness - correlated uncertainty assuming correlation of 0.1
Level-3C	*hist1d_cot*	Cloud optical thickness - histogram

* Complete list of data fields is given in Annex B

2.4 Cloud effective radius

The cloud effective radius (CER) describes the area weighted radius of the cloud droplet and crystal particles, respectively (Level-2 and Level-3U). Level-3C contains the monthly arithmetical averages together with standard deviation and separations into liquid and ice clouds. Also, 1-dimensional histograms exist in Level-3C. Examples of Level-3U and Level-3C are shown in Figure 2-4.

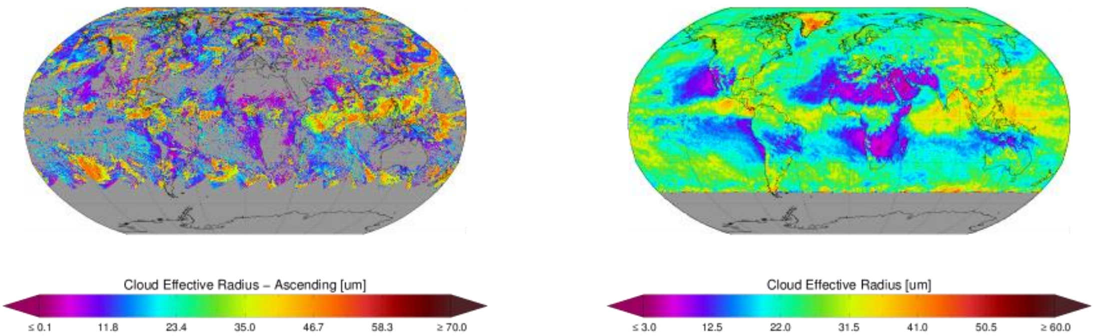

Figure 2-4 *Left: Global map of Cloud_cci L3U cloud effective radius for 2008/06/21. Right: Global map of Cloud_cci monthly mean cloud effective radius for 2008/06. (Both examples are taken from the AVHRR-PM dataset. Examples of all datasets are shown in Annex A)*

Short algorithm approach description:

AVHRR-PM, AVHRR-AM, MODIS-Aqua, MODIS-Terra, ATSR2-AATSR (CC4CL) datasets:

Cloud effective radius is direct output of the optimal estimation retrieval CC4CL (McGarragh et al., 2017; Sus et al., 2017) in which a physical model of the cloud is systematically altered until the corresponding resulting simulated radiances fit the measurements. Simulations look up tables (LUTs) strongly depend on the pre-determined cloud phase.

MERIS+AATSR (FAME-C) dataset:

Cloud effective radius is direct output of the optical estimation retrieval FAME-C DCOMP (Daytime Cloud Optical and Microphysical Properties) (Carbajal Henken et al., 2014) in which a physical model of the cloud is systematically altered until the corresponding resulting simulated radiances fit the measurements both for an AATSR channel at visible wavelengths and at near-infrared wavelengths. The LUTs strongly depend on the pre-determined cloud phase.

Uncertainty information:

All datasets:

- Along with the CER retrieval, the OE framework provides CER uncertainty on Level-2 (also in Level-3U) which is based on rigorous uncertainty propagation of the input data. According to OE theory the CER uncertainty describes the 68.2% confidence interval around the retrieved CER. This uncertainty is also propagated into the Level-3C products.
- The uncertainty is strongly dependent on the surface BRDF hence high BRDF surfaces will result in high values of uncertainty, e.g. over snow and ice.
- The uncertainty in the underlying ice optical model is currently not propagated into the final result. As a significant uncertainty in ice optical models can be assumed, the currently reported CER uncertainty is likely to be too low.

Known limitations:

All datasets:

- CER is a daytime product only
- In cases of wrong phase assigned, the effective radius is likely to have significant errors.
- In case of sub-pixel clouds or cloud boarders, the effective radius is likely to have significant errors.

AVHRR-PM, AVHRR-AM, MODIS-Aqua, MODIS-Terra, ATSR2-AATSR (CC4CL) datasets:

- Due to a bug in the ice LUTs for 3.7μm, the ice affective radii are systematically too high. This affected nearly all datasets, with the exception of the MERIS+AATSR dataset and the AVHRR-AM dataset after mid of 2002.

MERIS+AATSR (FAME-C) dataset:

- In FAME-C the near-infrared channel at 1.6 micron is used. These measurements are affected by 3-d cloud structures, which are not accounted for in the physical cloud model used in the retrieval, and have a penetration depth into the cloud.

Cloud effective radius - data fields* and descriptions:

Product level	Data field name	Description
Level-2	*cer*	Cloud effective radius
Level-2	*cer_unc*	Cloud effective radius uncertainty
Level-3U	*cer_asc* *cer_desc*	Cloud effective radius, ascending node of orbit Cloud effective radius descending node of orbit
Level-3U	*cer_asc_unc* *cer_desc_unc*	Cloud effective radius uncertainty, ascending Cloud effective radius uncertainty, descending
Level-3C	*cer*	Cloud effective radius, mean of individual pixel retrievals
Level-3C	*cer_unc*	Cloud effective radius - mean of individual pixel uncertainties
Level-3C	*cer_std*	Cloud effective radius - standard deviation of individual pixel retrievals
Level-3C	*cer_prop_unc*	Cloud effective radius - propagated uncertainty: total uncertainty from individual pixel uncertainty added in quadrature
Level-3C	*cer_corr_unc*	Cloud effective radius - correlated uncertainty assuming correlation of 0.1
Level-3C	*cer_liq* *cer_ice*	Liquid/ice cloud effective radius - mean of individual pixel retrievals

Product level	Data field name	Description
Level-3C	*cer_liq_std* *cer_ice_std*	Liquid/ice cloud effective radius - standard deviation of individual pixel retrievals
Level-3C	*cer_liq_unc* *cer_ice_unc*	Liquid/ice cloud effective radius - mean of individual pixel uncertainties
Level-3C	*cer_liq_prop_unc* *cer_ice_prop_unc*	Liquid/ice cloud effective radius - propagated uncertainty
Level-3C	*cot_liq_corr_unc* *cot_ice_corr_unc*	Liquid/ice cloud optical thickness - correlated uncertainty assuming correlation of 0.1
Level-3C	*hist1d_cer*	Cloud effective radius - histogram

* Complete list of data fields is given in Annex B

2.5 Cloud top pressure/height/temperature

The cloud top pressure (CTP) refers to the atmospheric pressure at the vertical position of the cloud top. CTP is directly retrieved at pixel level (Level-2, also contained in Level-3U); cloud top height (CTH) and cloud top temperature (CTT) are inferred from CTP using collocated model profiles of temperature, height and pressure. Level-3C contains the monthly arithmetical averages together with standard deviation and separations into liquid and ice clouds. Also, 1-dimensional histograms of CTP and CTT exist in Level-3C. Examples of Level-3U and Level-3C are shown in Figure 2-5.

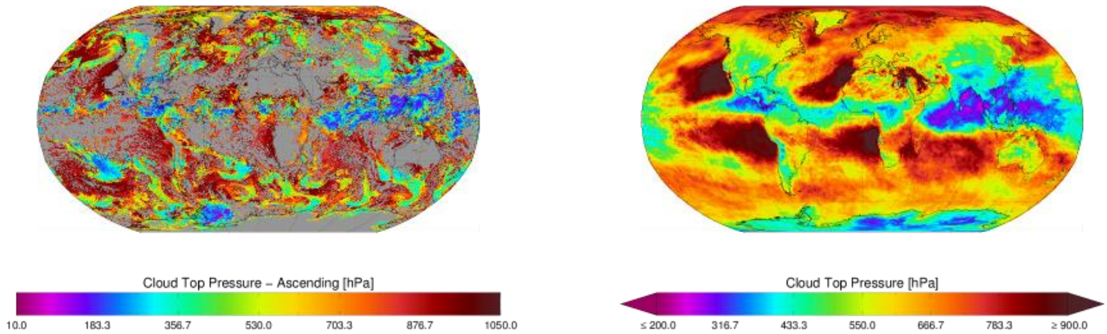

Figure 2-5 *Left: Global map of Cloud_cci L3U cloud top pressure (0: clear; 1: cloudy) for 2008/06/21. Right: Global map of Cloud_cci monthly mean cloud top pressure for 2008/06. (Both examples are taken from the AVHRR-PM dataset. Examples of all datasets are shown in Annex A)*

Short algorithm approach description:

AVHRR-PM, AVHRR-AM, MODIS-Aqua, MODIS-Terra, ATSR2-AATSR (CC4CL) datasets:

Cloud top pressure is direct output of the optimal estimation retrieval CC4CL (McGarragh et al., 2017; Sus et al., 2017) in which a physical model of the cloud is systematically altered until the corresponding resulting simulated radiances fit the measurements. Simulations look up tables (LUTs) strongly depend on the pre-determined cloud phase. Cloud top pressure is also converted to cloud top height and temperature using model profiles. Based on estimated cloud transmissivity, a correction to CTP, CTH and CTT is done and provided in separate fields. In these corrected fields the systematic underestimation of CTH (overestimation for CTP and CTT) occurring for high, semi-transparent clouds is reduced compared to the uncorrected values. For CTP the aggregation to monthly averages is additionally done logarithmically. Based on radiance ratio of the two infrared channels at 10.8 and 12.0 µm, post-processed corrected cloud top pressure, height, temperature are calculated and provided.

MERIS+AATSR (FAME-C) dataset:

Cloud top pressure is direct output of the optical estimation retrieval FAME-C DCHP-A (Daytime Cloud Height Property AATSR) (Carbajal Henken et al., 2014) and a second retrieval FAME-C DCHP-M (Daytime Cloud Height Property MERIS), in which a physical model of the cloud is systematically altered until the corresponding resulting simulated radiances fit the measurements. In the former retrieval brightness temperatures from thermal infrared measurements from AATSR are fitted. In the latter the radiance ratio of the MERIS Oxygen-A absorption band and a near-by window channel is fitted. The so called forward models depend on the pre-determined cloud phase in the former retrieval (DCHP-A). For the former retrieval, the actual retrieved Cloud Top Temperature (CTT) is also converted to cloud top height and CTP using model profiles. For the latter retrieval, the CTP is converted to CTH and CTT using model profiles.

Uncertainty information:

AVHRR-PM, AVHRR-AM, MODIS-Aqua, MODIS-Terra, ATSR2-AATSR (CC4CL) datasets:

- Along with the CTP retrieval, the OE framework provides CTP uncertainty on Level-2 (also in Level-3U) which is based on rigorous uncertainty propagation of the input data. According to OE theory the CTP uncertainty describes the 68.2% confidence interval around the retrieved CTP. The CTP uncertainty is also propagated into uncertainties of CTH and CTT, and also into the Level-3C products.
- The uncertainty has been validated using Calipso/Cloudsat data to be truth and found to well represent the actual uncertainty.

MERIS+AATSR (FAME-C) dataset:

- Along with the CTP and CTT retrieval, the OE framework provides CTP and CTT uncertainty on Level-2 (also in Level-3U) which is based on rigorous uncertainty propagation of the input data. According to OE theory the CTP uncertainty describes the 68.2% confidence interval around the retrieved CTP. The CTP and CTT uncertainty is also propagated into uncertainties of CTH and CTT, and CTH and CTP, respectively, and also into the Level-3C products.

Known limitations:

All datasets:

- In semi-transparent (ice) cloud conditions, the cloud top will be assigned too low. This is caused by the very small impact that optically thin clouds have on the infared radiation, which is primarily used to determine the vertical placement of clouds. In such cases the measured radiance is a mixure of signals coming from the emission of the thin clouds and emission from below the cloud (i.e. lower level clouds or surface), thus the corrected vertical placement of the clouds is very difficult and usually too low.
- Multi-layer clouds are not modelled hence the CTH for cases of an upper layer of thin cirrus will effectively retrieve a radiative height (approx. 1 optical depth into the cloud).

AVHRR-PM, AVHRR-AM, MODIS-Aqua, MODIS-Terra, ATSR2-AATSR (CC4CL) datasets:

- The corrected cloud top pressure/height/temperature retrievals are not radiatively consistent with the retrieved COT and CER, which means that radiative simulations do not fit the measurements anymore, while they do when using the uncorrected retrievals.

MERIS+AATSR (FAME-C) dataset:

- For a significant part of cloudy pixels the OE does not reach a successful CTT retrieval (no convergence reached). This is in cases where the forward model did not lead to successful fitting of simulated radiances to observed radiances. This happens for example in cases of optically thin clouds or multi-layer cloud situations. These pixels are set to the undefined value.
- In case of temperature inversions the wrong CTH and CTP might be assigned due to ambiguous values or due to wrong model profiles.
- In case of very low clouds sometimes no successful retrieval can be performed due to observed radiance ratios which do not occur in the simulated radiances. This might be related to stray light correction and/or slightly inaccurate simulations of absorption in the Oxygen-A band. These pixels are set to the undefined value.
- Due to the sensitivity of the CTP retrieval to the cloud vertical extinction profile, which is unknown, a large overestimation or underestimation of CTP might occur.

Cloud top pressure/height/temperature - data fields* and descriptions:

Product level	Data field name	Description
Level-2	*ctp/cth/ctt*	Cloud top pressure/height/temperature
Level-2	*ctp/cth/ctt_uncertainty*	Cloud top pressure/height/temperature uncertainty
Level-2	*ctp/cth/ctt_corrected*	Corrected Cloud top pressure/ height/temperature uncertainty
Level-2	*ctp/cth/ctt_corrected_unc*	Corrected cloud top pressure/height/ temperature uncertainty
Level-3U	*ctp/cth/ctt_asc* *ctp/cth/ctt_desc*	Cloud top pressure/height/temperature, ascending node of orbit Cloud top pressure/height/temperature, descending node of orbit
Level-3U	*ctp/cth/ctt_asc_unc* *ctp/cth/ctt_desc_unc*	Cloud top pressure/height/temperature uncertainty, ascending node of orbit Cloud top pressure/height/temperature uncertainty, descending node of orbit
Level-3U	*ctp/cth/ctt_corrected_asc* *ctp/cth/ctt_corrected_desc*	Corrected cloud top pressure/height/ temperature, ascending node of orbit Corrected cloud top pressure/height/ temperature, descending node of orbit
Level-3U	*ctp/cth/ctt_corrected_asc_unc* *ctp/cth/ctt_corrected_desc_unc*	Corrected cloud top pressure/height/temp. uncertainty, ascending node of orbit Corrected cloud top pressure/height/temp. uncertainty, descending node of orbit
Level-3C	*ctp/cth/ctt*	Cloud top pressure/height/temperature, mean of individual pixel retrievals
Level-3C	*ctp/cth/ctt_std*	Cloud top pressure/height/temp. - standard deviation of individual pixel retrievals
Level-3C	*ctp/cth/ctt_unc*	Cloud top pressure/height/temperature - mean of individual pixel uncertainties
Level-3C	*ctp/cth/ctt_corrected*	Corrected cloud top pressure/height/ temperature, mean of individual pixel retrievals
Level-3C	*ctp/cth/ctt_corrected_std*	Corrected cloud top pressure/height/ temperature, standard deviation of individual pixel retrievals

Product level	Data field name	Description
Level-3C	*ctp/cth/ctt_prop_unc*	Cloud top pressure/height/temperature - propagated uncertainty: total uncertainty from individual pixel uncertainty added in quadrature
Level-3C	*ctp/cth/ctt_corr_unc*	Cloud top pressure/height/temperature - correlated uncertainty assuming correlation of 0.1
Level-3C	*ctp/cth/ctt_corrected_prop_unc*	Corrected cloud top pressure/height/temperature - propagated uncertainty: total uncertainty from individual pixel uncertainty added in quadrature
Level-3C	*ctp/cth/ctt_corrected_corr_unc*	Corrected cloud top pressure/height/temperature - correlated uncertainty assuming correlation of 0.1
Level-3C	*hist1d_ctp/hist1d_ctt*	Cloud top pressure/temperature - histogram

* Complete list of data fields is given in Annex B

2.6 Cloud liquid water path

The vertical integrated cloud water content in liquid cloud pixels (LWP, cloud liquid water path) is calculated from optical thickness and effective radius. It exists as cloud water path (in liquid cloud pixels) in Level-2 and Level-3U and is averaged to monthly mean liquid water path in Level-3C. Level-3C also holds 1-dimensional histograms of liquid water path. Examples of Level-3U (cloud water path is shown) and Level-3C are shown in Figure 2-6.

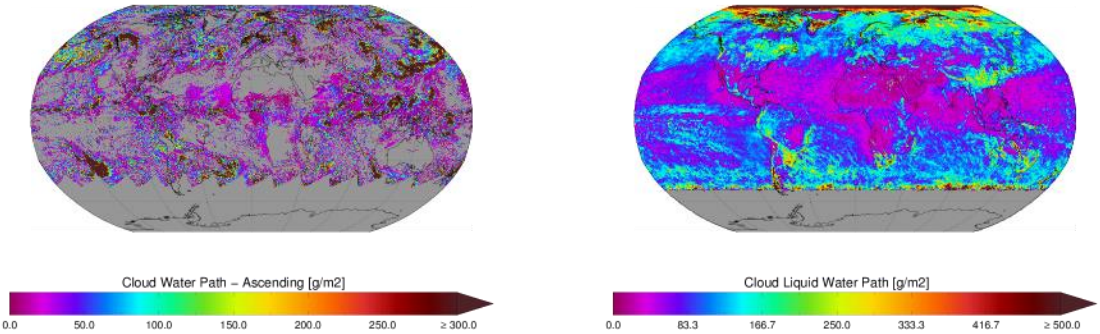

Figure 2-6 *Left: Global map of Cloud_cci L3U cloud water path for 2008/06/21. Right: Global map of Cloud_cci monthly mean liquid water path for 2008/06. (Both examples are taken from the AVHRR-PM dataset. Examples of all datasets are shown in Annex A)*

Short algorithm approach description:

All datasets:

Cloud water path (LWP) is diagnosed from retrieved COT and CER using the Stephens (1978) relation (More details in ATBD-FAME-Cv5 and ATBD-CC4CLv5). Vertically homogeneous clouds are assumed, thus a factor of 2/3 is used in the Stephens formula.

Uncertainty information:

All datasets:

- The OE framework provides pixel-based uncertainty estimates for COT and CER which are propagated through the Stephens (1978) formula. The resulting LWP uncertainty for Level-2 (also in Level-3U) therefore described the 68.2% confidence interval around the diagnosed LWP. The LWP uncertainty is also propagated into the Level-3C products.

MERIS+AATSR (FAME-C) dataset:

- Additionally, uncertain phase assignment for a certain brightness temperature range is taken into account.

Known limitations:

All datasets:

- LWP is a daytime product only
- Since LWP is computed from retrieved COT and CER, same limitations as for COT and CER apply for LWP.
- The method used assumes vertically homogeneous clouds, which might deviate from truth. In case of vertically inhomogeneous cloud layers, e.g. multi-layer clouds, the LWP retrieval is likely to show large errors, since the CER is retrieved from the most upper cloud layers and may not be representative for the entire vertical column.
- In cases of wrongly assigned cloud phase, i.e. ice cloud is treated as liquid cloud, the retrieved LWP will show large errors.

ATSR-2-AATSR (FAME-C) dataset:

- The LWP is currently biased too high as the phase selection for this dataset is biased towards ice.

Cloud liquid water path - data fields* and descriptions:

Product level	Data field name	Description
Level-2	*cwp*	Cloud water path
Level-2	*cwp_uncertainty*	Cloud water path uncertainty
Level-3U	*cwp_asc* *cwp_desc*	Cloud water path, ascending node of orbit Cloud water path, descending node of orbit
Level-3U	*cwp_asc_unc* *cwp_desc_unc*	Cloud water path uncertainty, ascending Cloud water path uncertainty, descending
Level-3C	*lwp*	Cloud liquid water path, mean of individual pixel retrievals
Level-3C	*lwp_unc*	Cloud liquid water path - mean of individual pixel uncertainties
Level-3C	*lwp_std*	Cloud liquid water path - standard deviation of individual pixel retrievals
Level-3C	*lwp_prop_unc*	Cloud liquid water path - propagated uncertainty: total uncertainty from individual pixel uncertainty added in quadrature
Level-3C	*lwp_corr_unc*	Cloud liquid water path - correlated uncertainty assuming correlation of 0.1
Level-3C	*lwp_allsky*	Cloud liquid water path all-sky - grid box mean of individual pixel retrievals, including clear-sky pixels
Level-3C	*hist1d_cwp*	Cloud water path - histogram

* Complete list of data fields is given in Annex B

2.7 Cloud ice water path

The vertical integrated cloud water content in ice cloud pixels (IWP, cloud ice water path) is calculated from optical thickness and effective radius. It exists as cloud water path (in ice cloud pixels) in Level-2 and Level-3U and is averaged to monthly mean ice water path in Level-3C. Level-3C also holds 1-dimensional histograms of ice water path. Examples of Level-3U (cloud water path is shown) and Level-3C are shown in Figure 2-7.

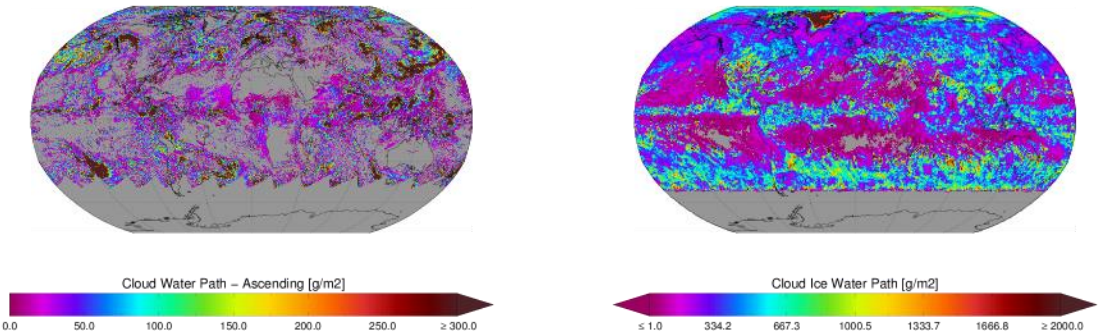

Figure 2-7 *Left: Global map of Cloud_cci L3U cloud water path for 2008/06/21. Right: Global map of Cloud_cci monthly mean ice water path for 2008/06. (Both examples are taken from the AVHRR-PM dataset)*

Short algorithm approach description:

All datasets:

Cloud ice path (IWP) is diagnosed from retrieved COT and CER using the Stephens (1978) relation (More details in ATBD-FAME-Cv5 and ATBD-CC4CLv5)

MERIS+AATSR (FAME-C) dataset:

Cloud ice path (IWP) is diagnosed from retrieved COT and CER using the Stephens (1978) relation for optically thick clouds (More details in ATBD-FAME-Cv5).

For optically thin clouds with COT < 7 (or pixels identified as cirrus clouds from the Pavolonis et al. (2005) cloud typing) the IWP is diagnosed from retrieved COT and CER using the Heymsfield (2003) relation.

Uncertainty information:

All datasets:

- The OE framework provides pixel-based uncertainty estimates for COT and CER which are propagated through the Stephens (1978) formula. The resulting IWP uncertainty for Level-2 (also in Level-3U) therefore described the 68.2% confidence interval around the diagnosed IWP. The IWP uncertainty is also propagated into the Level-3C products.

MERIS+AATSR (FAME-C) dataset:

- The OE framework provides pixel-based uncertainty estimates for COT and CER which are propagated through the Stephens (1978) or Heymsfield (2003) formula. The resulting IWP uncertainty for Level-2 (also in Level-3U) therefore described the 68.2% confidence interval around the diagnosed IWP. The IWP uncertainty is also propagated into the Level-3C products.

Known limitations:

All datasets:

- IWP is a daytime product only
- Similar limitations as mentioned for Cloud liquid water path (see Section 2.6)

MERIS+AATSR (FAME-C) dataset:

- Coefficients used in Heymsfield (2003) are based on observations for mid-latitude cirrus clouds. It is not exactly known how large the introduced error for deviating cloud conditions is.

Cloud ice water path - data fields and descriptions:

Product level	Data field name	Description
Level-2	*cwp*	Cloud water path
Level-2	*cwp_uncertainty*	Cloud water path uncertainty
Level-3U	*cwp_asc* *cwp_desc*	Cloud water path, ascending node of orbit Cloud water path, descending node of orbit
Level-3U	*cwp_asc_unc* *cwp_desc_unc*	Cloud water path uncertainty, ascending Cloud water path uncertainty, descending
Level-3C	*iwp*	Cloud ice water path, mean of individual pixel retrievals
Level-3C	*iwp_unc*	Cloud ice water path - mean of individual pixel uncertainties
Level-3C	*iwp_std*	Cloud ice water path - standard deviation of individual pixel retrievals
Level-3C	*iwp_prop_unc*	Cloud ice water path - propagated uncertainty: total uncertainty from individual pixel uncertainty added in quadrature
Level-3C	*iwp_corr_unc*	Cloud ice water path - correlated uncertainty assuming correlation of 0.1
Level-3C	*iwp_allsky*	Cloud ice water path all-sky - grid box mean of individual pixel retrievals, including clear-sky pixels
Level-3C	*hist1d_cwp*	Cloud water path - histogram

2.8 Spectral cloud albedo

The black-sky spectral cloud albedo (CLA) describes the directional hemispherical reflectance of the cloud at the current solar zenith angle. The CLA is calculated for channel 1 (0.67 µm) and channel 2 (0.87 µm), respectively. This product exists on pixel level in Level-2, globally gridded but unaveraged (Level-3U) and is averaged to monthly mean cloud albedo (Level-3C). Level-3C also holds 1-dimensional histograms of the two albedos. Examples of Level-3U and Level-3C are shown in Figure 2-8.

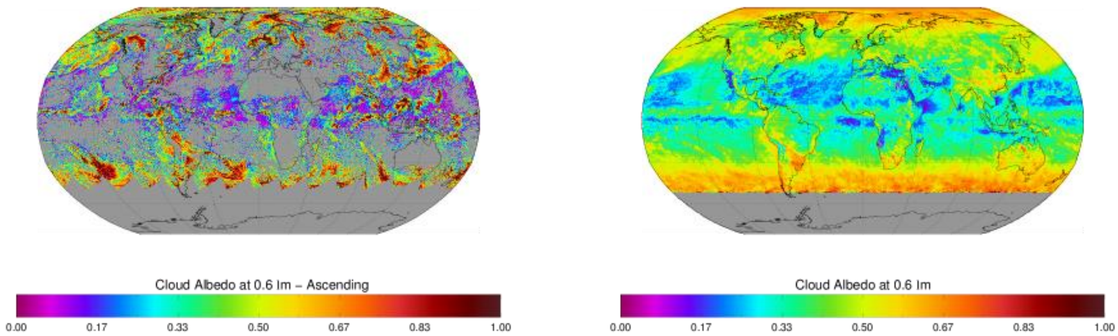

Figure 2-8 *Left: Global map of Cloud_cci L3U spectral cloud albedo at 600nm for 2008/06/21. Right: Global map of Cloud_cci monthly mean spectral cloud albedo at 600nm for 2008/06. (Both examples are taken from the AVHRR-PM dataset. Examples of all datasets are shown in Annex A)*

Short algorithm approach description:

<u>AVHRR-PM, AVHRR-AM, MODIS-Aqua, MODIS-Terra, ATSR2-AATSR (CC4CL) datasets</u>:

The cloud albedo is derived for each of the visible/near infrared channels. The spectral albedo is interpolated from the LUTs for the corresponding retrieved CER and COT

<u>MERIS+AATSR (FAME-C) dataset:</u>

The spectral visible and near-infrared cloud albedo is part of the LUT used in the COT-CER retrieval. It is therefore retrieved implicitly.

Uncertainty information:

<u>AVHRR-PM, AVHRR-AM, MODIS-Aqua, MODIS-Terra, ATSR2-AATSR (CC4CL) datasets</u>:

- The uncertainty of the cloud albedo is calculated using the derivative of the LUT with respect to COT and CER.

<u>MERIS+AATSR (FAME-C) dataset:</u>

- No uncertainty information

Known Limitations:

<u>All datasets:</u>

- CLA is a daytime product only
- The uncertainty will be high over bright/snow covered surfaces.
- Similar limitations as for COT and CER apply

MERIS+AATSR (FAME-C) dataset:

- No pixel-based and propagated uncertainties.

Spectral cloud albedo - data fields* and descriptions:

Product level	Data field name	Description
Level-2	*cloud_albedo_in_channel_no_1/2*	Cloud albedo at 0.6µm/0.8µm
Level-2	*cloud_albedo_uncertainty_in_channel_no_1/2*	Cloud albedo at 0.6µm/0.8µm uncertainty
Level-3U	*cla_vis006/008_asc* *cla_vis006/008_desc*	Cloud albedo at 0.6µm/0.8µm, ascending node of orbit Cloud albedo at 0.6µm/0.8µm, descending node of orbit
Level-3U	*cla_vis006/008_asc_unc* *cla_vis006/008_desc_unc*	Cloud albedo at 0.6µm/0.8µm uncertainty, ascending node of orbit Cloud albedo at 0.6µm/0.8µm uncertainty, descending node of orbit
Level-3C	*cla_vis006/008*	Cloud albedo at 0.6µm/0.8µm - mean of individual pixel retrievals
Level-3C	*cla_vis006/008_unc*	Cloud albedo at 0.6µm/0.8µm - mean of individual pixel uncertainties
Level-3C	*cla_vis006/008_std*	Cloud albedo at 0.6µm/0.8µm – standard deviation of individual pixel retrievals
Level-3C	*cla_vis006/008_liq/ice*	Liquid/ice cloud albedo at 0.6µm/0.8µm - mean of individual pixel retrievals
Level-3C	*cla_vis006/008_liq/ice_unc*	Liquid/ice cloud albedo at 0.6µm/0.8µm - mean of individual pixel uncertainties
Level-3C	*cla_vis006/008_liq/ice_std*	Liquid/ice cloud albedo at 0.6µm/0.8µm - standard deviation of individual pixel retrievals
Level-3C	*cla_vis006/008_prop_unc*	Cloud albedo at 0.6µm/0.8µm - propagated uncertainty: total uncertainty from individual pixel uncertainty added in quadrature
Level-3C	*cla_vis006/008_corr_unc*	Cloud albedo at 0.6µm/0.8µm - correlated uncertainty assuming correlation of 0.1
Level-3C	*hist1d_cla_vis006/008*	Cloud albedo at 0.6µm/0.8µm - histogram

* Complete list of data fields is given in Annex B

2.9 Joint cloud property histogram

The joint cloud property histogram product (JCH) is a two-dimensional histogram per grid cell and is composed of occurrences of COT-CTP combinations. The frequency is represented by absolute counts in each histogram bin. The bin definitions are given below. This product is daytime only. Figure 2-9 shows an example of JCH when aggregated globally and when shown as map of relative occurrence of a specific cloud type.

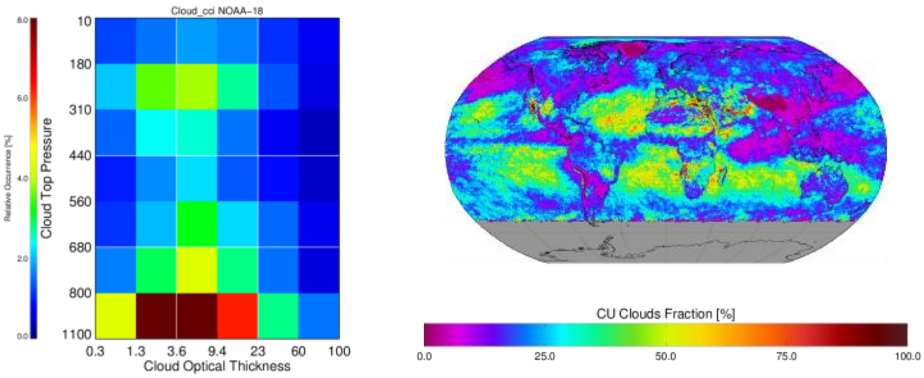

Figure 2-9 *Left: JCH histogram after globally aggregated over all grid cells, and normalized by the total number. Right: Global map of relative occurrence of cumulus clouds (according to ISCCP (Rossow and Schiffer, 1999) definition: CTP>680hPa and COT<3.6) with respect to all occurring clouds. Data is for 2008/06. (Both examples are taken from the AVHRR-PM dataset. Examples of all datasets are shown in Annex A)*

Short algorithm approach description:

For each daytime Level-2 pixel for which a cloud was detected and valid cloud optical thickness and cloud top pressures were retrieved, the counts of the specific COT-CTP bins is incremented.

Uncertainty information:

All datasets:

- No uncertainty information available for this product.

Known limitations:

- JCH is a daytime only product
- Limitation as for CTP and COT also apply to this product.

Data fields* and descriptions:

Product level	Data field name	Description
Level-2	N/A	N/A
Level-3U	N/A	N/A
Level-3C	*hist2d_cot_ctp*	Two-dimensional, COT-CTP histogram containing absolute counts

* Complete list of data fields is given in Annex B

3. Data format description

3.1 File names and vocabulary

According to Data Standards Requirements for CCI Data Producers (DSRDPv2.1) following filename convention is applied. Example filename:

<Indicative Date>[<Indicative Time>]-ESACCI-<Processing Level>_<CCI Project>-<Data Type>-<Product String>[-<Additional Segregator>][-v<GDS version>]-fv<File version>.nc

Table 3-1 *Components of Cloud_cci file names and possible assignments.*

Field name field	Description
<Indicative Date>	The identifying date for this data set. Format is YYYY[MM[DD]], where YYYY is the four digit year, MM is the two digit month from 01 to 12 and DD is the two digit day of the month from 01 to 31. The date used should best represent the observation date for the data set. It can be a year, a year and a month or a year and a month and a day.
<Indicative Time>	The identifying time for this data set in UTC. Format is [HH[MM[SS]]] where HH is the two digit hour from 00 to 23, MM is the two digit minute from 00 to 59 and SS is the two digit second from 00 to 59.
<Processing Level>	Possible assignments: **L2, L3U, L3C, L3S**. See **Table 1-3** for description.
<CCI Project>	**CLOUD**
<Data Type>	**CLD_PRODUCTS** (standard, all cloud properties are included in this file. For file with only one or a subset of the cloud properties, the Data Type is e.g. COT, CTP, CFC etc.)
<Product String>	The Product String gives information about the sensor(s) and platform(s) used. It therefore depends on the processing levels: L2P, L3U and L3C: Product string is **SENSOR_PLATFORM** Examples: **AVHRR_NOAA18, MODIS_AQUA, AATSR_ENVISAT, MERISAATSR_ENVISAT** L3S: Product string is **SENSOR_MERGED** Examples: **AVHRR_MERGED, MODIS_MERGED**
v<GDS version>	not used in Cloud_cci
fv<File Version>	File version number in the form n{1,}[.n{1,}] (That is 1 or more digits followed by optional . and another 1 or more digits.)

3.2 Data format

Cloud_cci 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 1.6 (http://cf-pcmdi.llnl.gov/) and NetCDF Attribute Convention for Dataset Discovery (ACDD) version 1.3.

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 Cloud_cci products files are built following the same design principles. All files contain general variables, which are common for all files, and product specific variables. Dimension of all two-dimensional fields are named *lon*, *lat*. For the Histograms, additional three dimensions for COT and CTP and Phase bins are included. General variables of each file are *time, latitude*, and *longitude* (see below).

Each variable and data fields have associated attributes which are listed in Table 3-2. Global attributes contain in each of the data files are given in Table 3-3.

Table 3-2 *Attributes assigned to variables in NetCDF*.

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.
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 represents missing or undefined data. Missing values are to be filtered before scaling.
missing	same as _FillValue

General variables

Name	Description
time	start of averaging/composite time period [Julian Date, days elapsed since 1970-01-01 00:00:00]
lat	geographical latitude of grid-box centre [degree_north]
lon	geographical longitude of grid-box centre [degree_east]

Note, the L2 files contain two-dimensional latitude and longitude fields.

Table 3-3 *Overview of global attributes of NetCDF files of Cloud_cci cloud products and possible corresponding values.*

Name	Description
title	Title of the product. (e.g. **ESA Cloud_cci L2 product**)
institution	Institution on which the data and file was processed. E.g. **Deutscher Wetterdienst (DWD), Rutherford Appleton Laboratory (RAL), Freie Universität Berlin (FUB)**
source	Satellite sensor(s) of which the measurements were used to create the presented data. E.g. **AVHRR-GAC, MODIS-C6 (collection 6), AATSR, MERIS RR L1B version 4.02**
history	Date and time the file was generated and optional information on product generation. E.g. **2011-02-14 12:22:43 - Product generated from CC4CL single view v2.0**
references	Web link to reference information (e.g. http://www.esa-cloud-cci.org/)
tracking_id	Universally Unique Identifier (UUID) generated using OSSP (http://www.ossp.org/pkg/lib/uuid/)(format example: **0c9e9570---cd44---102f---8001---0050c28e1010**)
conventions	NetCDF Climate and Forecast (CF) Metadata Convention 1.6
product_version	Version of product. E.g. **1.0**
summary	Summary of the products contained. E.g. **This dataset contains Level-3 (monthly) global cloud property products from satellite observations. Level 3 data are raw observations processed to geophysical quantities, and averaged onto a regular grid.**
keywords	Specific Cloud_cci keywords. E.g. **satellite, observations, cloud properties.**
id	filename.nc
naming authority	optional
keywords_vocabolary	optional
cdm_data_type	optional
comment	"These data were produced at ESACCI as part of the ESA CLOUD_CCI project."
date_created	Data and time the file was created. E.g. **yyyymmddThhmmssZ**
creator_name	Name of the creator (members of the Cloud_cci consortium) of the file/product. E.g. **Deutscher Wetterdienst (DWD), Rutherford Appleton Laboratory (RAL), Freie Universität Berlin (FUB)**
creator_url	Url of creator. E.g. http://www.esa-cloud-cci.org
creator_email	contact.cloudcci@dwd.de
project	Climate Change Initiative --- European Space Agency

Name	Description
geospatial_lat_min	Minimum latitude of data fields
geospatial_lat_max	Maximum latitude of data fields
geospatial_lon_min	Minimum longitude of data fields
geospatial_lon_max	Maximum longitude of data fields
geospatial_lat_units	Unit of latitude data. E.g. **degrees_north**
geospatial_lon_units	Unit of longitude data. E.g. **degrees_east**
geospatial_vertical_min	N/A
geospatial_vertical_max	N/A
spatial_resolution	Spatial resolution of products (See Section 1.3, **Table 1-3** of PUG for more details)
time_coverage_start	Start time of temporal coverage of data. E.g.: **yyyymmddThhmmssZ**
time_coverage_end	End time of temporal coverage of data. E.g.: **yyyymmddThhmmssZ**
time_coverage_duration	Total temporal coverage of data. E.g. **P1M** for monthly files
time_coverage_resolution	Temporal resolution of data. E.g. **P1D** for daily files
standard_name_vocabulary	e.g. NetCDF Climate and Forecast (CF) Metadata Convention version 1.6
license	ESA CCI Data Policy: free and open access
platform	Platform(s) of sensors used. E.g. **Envisat, NOAA-18, AQUA, TERRA**
sensor	Sensors used to generate contained data. E.g. **AATSR, MERIS, AVHRR, MODIS**

4. Data access, citation, acknowledgement, user support

4.1 Data access

Cloud_cci datasets can be access via the Cloud_cci website:

http://www.esa-cloud-cci.org/?q=data_download

or via the CCI Open Data Portal:

http://cci.esa.int or via the CCI Toolbox (being released in the near future).

Special data requests can be sent to:

contact.cloudcci@dwd.de

4.1 User support

Basic user services are provided through the Cloud_cci homepage www.esa-cloud-cci.org. The user service includes information and documentation about the Cloud_cci project and the Cloud_cci products, information on how to contact the user help desk and allows searching the product catalogue. A specific support section can be found under:

http://www.esa-cloud-cci.org/?q=support

4.2 Terms and conditions for use of Cloud_cci data

The Cloud_cci datasets may be used by any user for any purpose, with the following terms and conditions:

1) Users of the CCI data are required to acknowledge the ESA Climate Change Initiative and Cloud_cci together with the individual data providers if the data are used in a presentation or publication. Please also cite any relevant dataset DOIs (see example citation text below).
2) Users of the CCI data are encouraged to interact with the CCI programme on use of the products, and to provide a copy of all reports and publications using the dataset. An offer of co-authorship should be considered, if the CCI data constitute a major component of a scientific publication.
3) Intellectual property rights (IPR) in the CCI data lie with the researchers and organisations producing the data.
4) Liability: No warranty is given as to the quality or the accuracy of the CCI data or its suitability for any use. All implied conditions relating to the quality or suitability of the information, and all liabilities arising from the supply of the information (including any liability arising in negligence) are excluded to the fullest extent permitted by law.

4.3 Citation

Citing the scientific content of the datasets:

Stengel et al. (2017): Cloud property datasets retrieved from AVHRR, MODIS, AATSR and MERIS in the framework of the Cloud_cci project. Manuscript in preparation, to be submitted to ESSD.

Citing the datasets:

Cloud_cci **AVHRR-PM, AVHRR-AM, MODIS-Aqua, MODIS-Terra** datasets:

Stengel M., Sus O., Stapelberg S., Schlundt C., Poulsen C., Hollmann R. (2017): ESA Cloud Climate Change Initiative (ESA Cloud_cci) data: Cloud_cci [*AVHRR-PM, AVHRR-AM, MODIS-Aqua, MODIS-Terra*] L3C/L3U CLD_PRODUCTS v2.0, Deutscher Wetterdienst (DWD), DOI:10.5676/DWD/ESA_Cloud_cci/[*AVHRR-PM, AVHRR-AM, MODIS-Aqua, MODIS-Terra*]/V002

Cloud_cci **ATSR2-AATSR** dataset:

Poulsen C., McGarragh G., Thomas G., Christensen M., Povey A., Grainger D., Proud S., Hollmann R. (2017): ESA Cloud Climate Change Initiative (ESA Cloud_cci) data: Cloud_cci ATSR2-AATSR L3C/L3U/L2 CLD_PRODUCTS v2.0, Deutscher Wetterdienst (DWD) and Rutherford Appleton Laboratory (Dataset Producer), DOI:10.5676/DWD/ESA_Cloud_cci/ATSR2-AATSR/V002

Cloud_cci **MERIS+AATSR** datasets:

Carbajal Henken C.K., Preusker R., Fischer F., Hollmann R. (2017): ESA Cloud Climate Change Initiative (ESA Cloud_cci) data: Cloud_cci MERIS+AATSR L3C/L3U CLD_PRODUCTS v2.0, Deutscher Wetterdienst (DWD) and Freie Universität Berlin (Dataset Producer), DOI:10.5676/DWD/ESA_Cloud_cci/MERIS+AATSR/V002

4.4 Feedback

Users of Cloud_cci products and services are encouraged to provide feedback on the Cloud_cci product and services to the Cloud_cci team. For this, users should contact the User Help Desk.

http://www.esa-cloud-cci.org/?q=contact_points

4.5 Re-distribution of Cloud_cci data

Please do not re-distribute Cloud_cci data to 3rd parties. The use of the Cloud_cci products is granted free of charge to every interested user, but there is an essential interest to know how many and what users Cloud_cci has.

5. Glossary

ACDD	Attribute Convention for Dataset Discovery
AATSR	Advanced Along Track Scanning Radiometer
ATBD	Algorithm Theoretical Baseline Document
ATSR2	Along-Track Scanning Radiometer 2
AVHRR	Advanced Very High Resolution Radiometer
BRDF	Bidirectional Reflectance Distribution Function
CALIOP	Cloud-Aerosol Lidar with Orthogonal Polarization
CC4CL	Community Cloud retrieval for Climate
CCI	Climate Change Initiative
CER	Cloud Effective Radius
CF	Climate and Forecast
CFC	Cloud Fractional Coverage
CFMIP	Cloud Feedback Model Intercomparison Project
CLA	Spectral Cloud Albedo
CMA	Cloud Mask
COSP	CFMIP Observation Simulator Package
CPH	Cloud Phase
COT	Cloud Optical Thickness
CTH	Cloud Top Height
CTP	Cloud Top Pressure
CTT	Cloud Top Temperature
CWP	Cloud Water Path
DCHP-A	Daytime Cloud Height Property AATSR

DCHP-M	Daytime Cloud Height Property MERIS
DOI	Digital Object Identifier
DSRDP	Data Standards Requirements for CCI Data
DWD	Deutscher Wetterdiest
ECV	Essential Climate Variable
ENVISAT	Environmental Satellite
ESA	European Space Agency
FAME-C	FUB AATSR MERIS Cloud retrieval algorithm
FUB	Freie Universität Berlin
FCDR	Fundamental Climate Data Record
GAC	Global Area Coverage - globally available AVHRR dataset with reduced resolution (4 km).
JCH	Joint Cloud property Histogram
ISCCP	International Satellite Cloud Climatology Project
IWP	Ice Water Path
LUT	Look-up Table
LWP	Liquid Water Path
MERIS	Medium Resolution Imaging Spectrometer
Metop	Meteorological Operational Satellite
MODIS	Moderate Resolution Imaging Spectroradiometer
NOAA	National Oceanic & Atmospheric Administration
OE	Optimal Estimation
PUG	Product User Guide
PVIR	Product Validation and Intercomparison Report
RAL	Rutherford Appleton Laboratory

6. References

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Annex A – More examples of Cloud_cci data

A.1 Cloud mask for 2008/06/22 – Level-3U (global composite, Level-2 sampled onto a Latitude-Longitude grid of 0.05°)

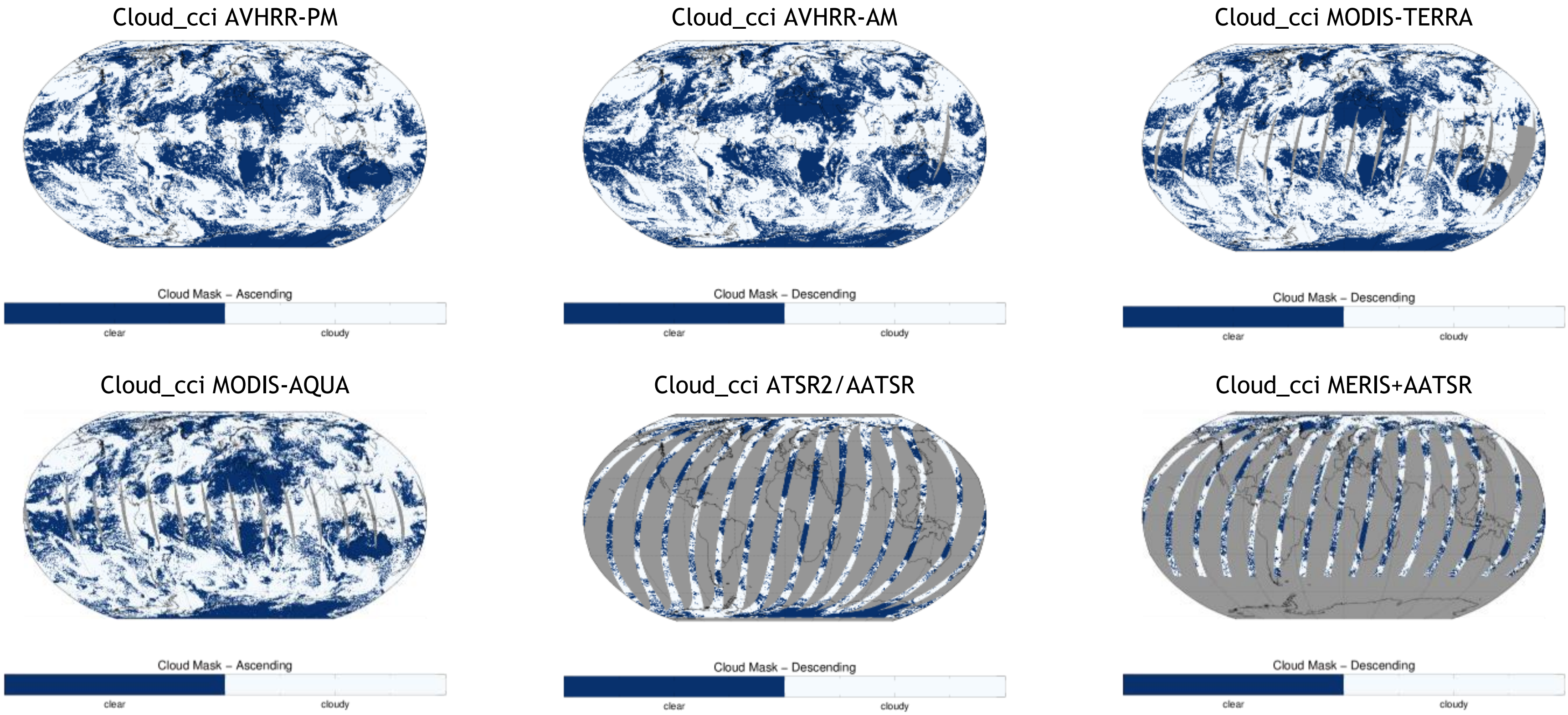

Figure A-1 *Cloud_cci L3U cloud mask for 2008/06/22. Shown are the ascending parts of the orbits for AVHRR-PM and MODIS-Aqua and the descending parts for AVHRR-AM, MODIS-Terra, ATSR2-AATSR and MERIS+AATSR, which roughly correspond to the daytime parts of the orbits. Figures are taken from Stengel et al. (2017).*

A.2 Cloud fraction for 2008/06 – Level-3C (Monthly average on a Latitude-Longitude grid of 0.5°)

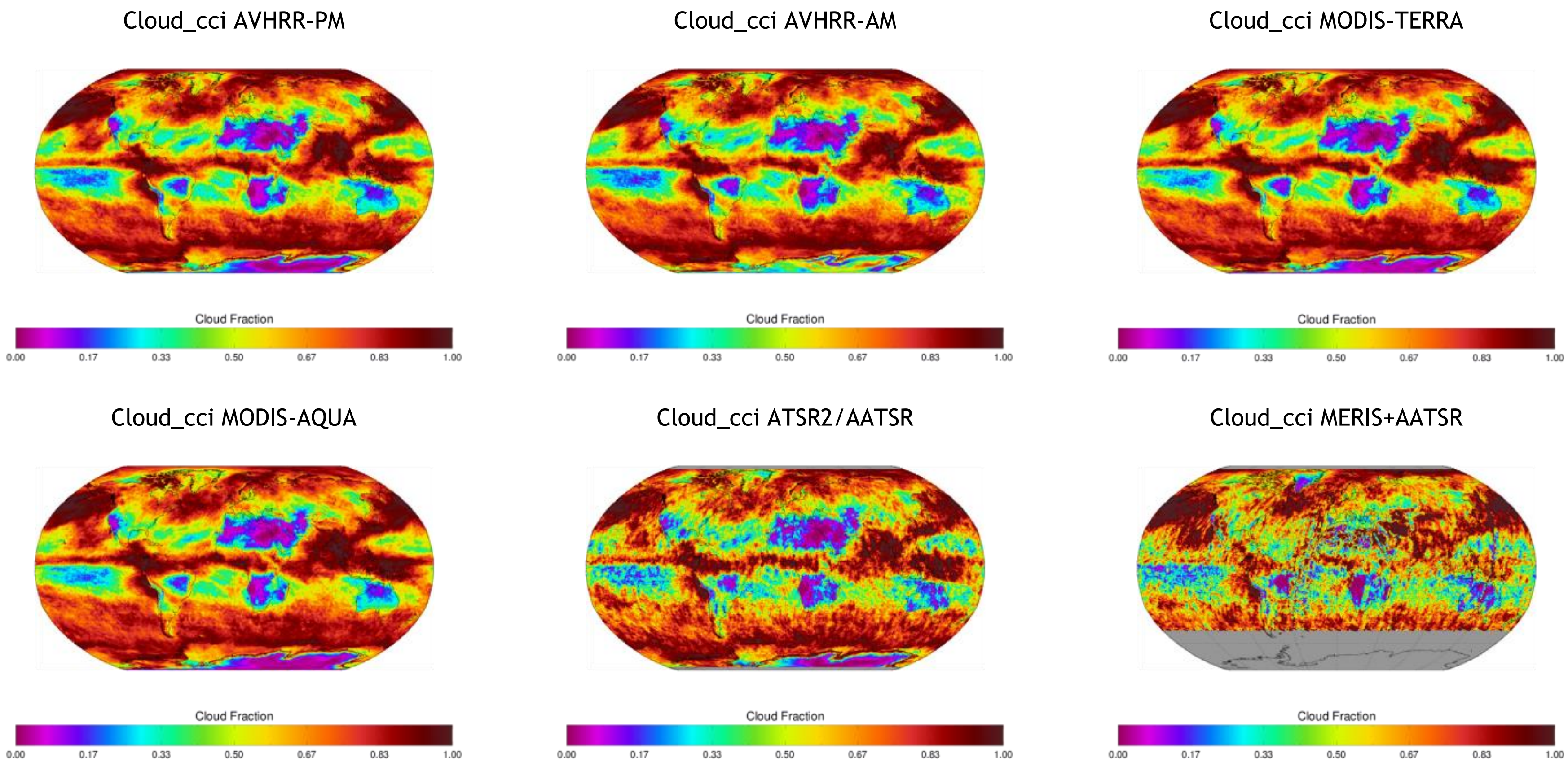

Figure A-2 *Cloud_cci monthly mean cloud fraction for 2008/06.*

A.3 Cloud phase for 2008/06/22 – Level-3U (global composite, Level-2 sampled onto a Latitude-Longitude grid of 0.05°)

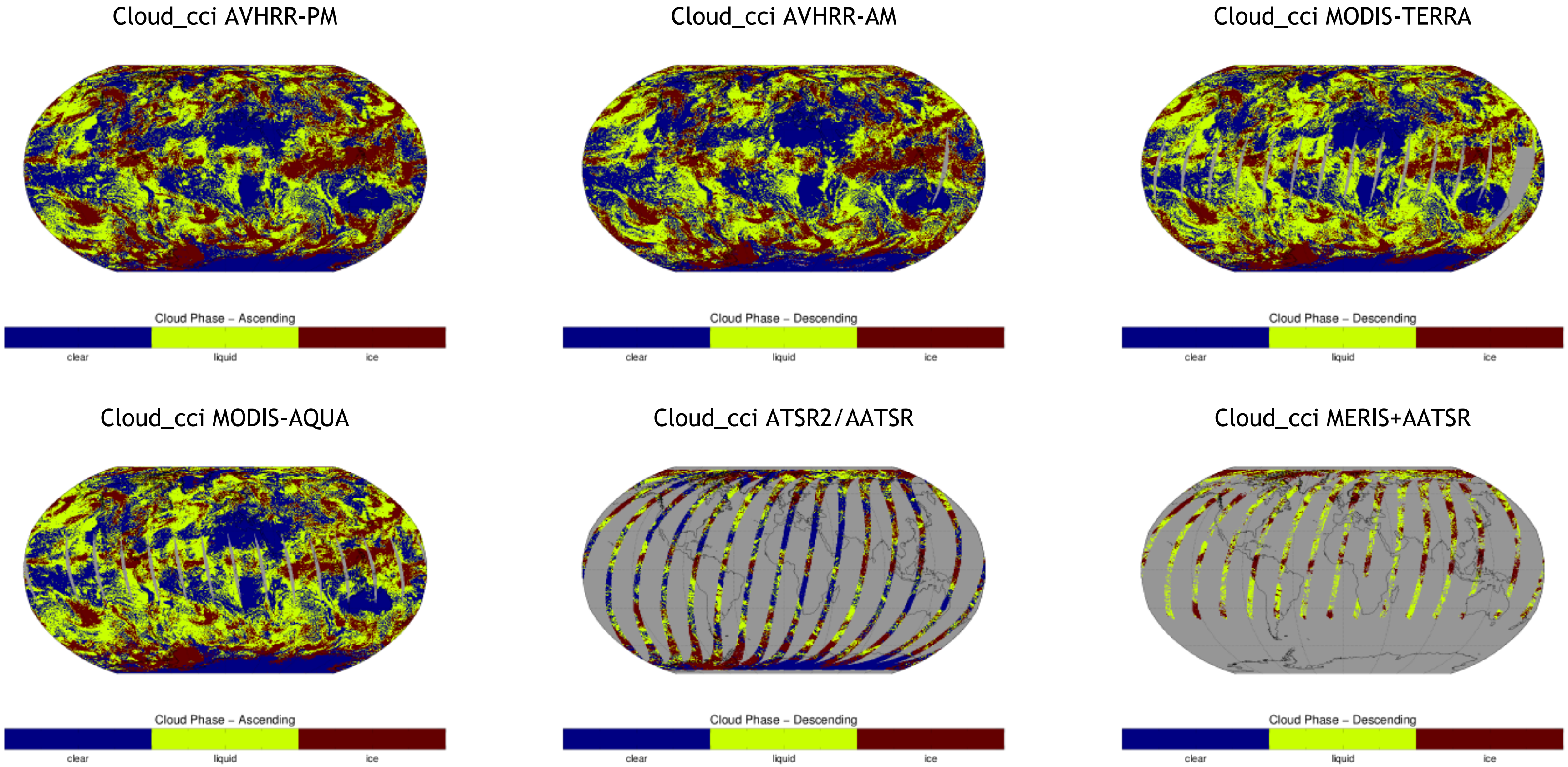

Figure A-3 *As Figure A-1 but for cloud phase.*

A.4 Liquid cloud fraction for 2008/06 – Level-3C (Monthly average on a Latitude-Longitude grid of 0.5°)

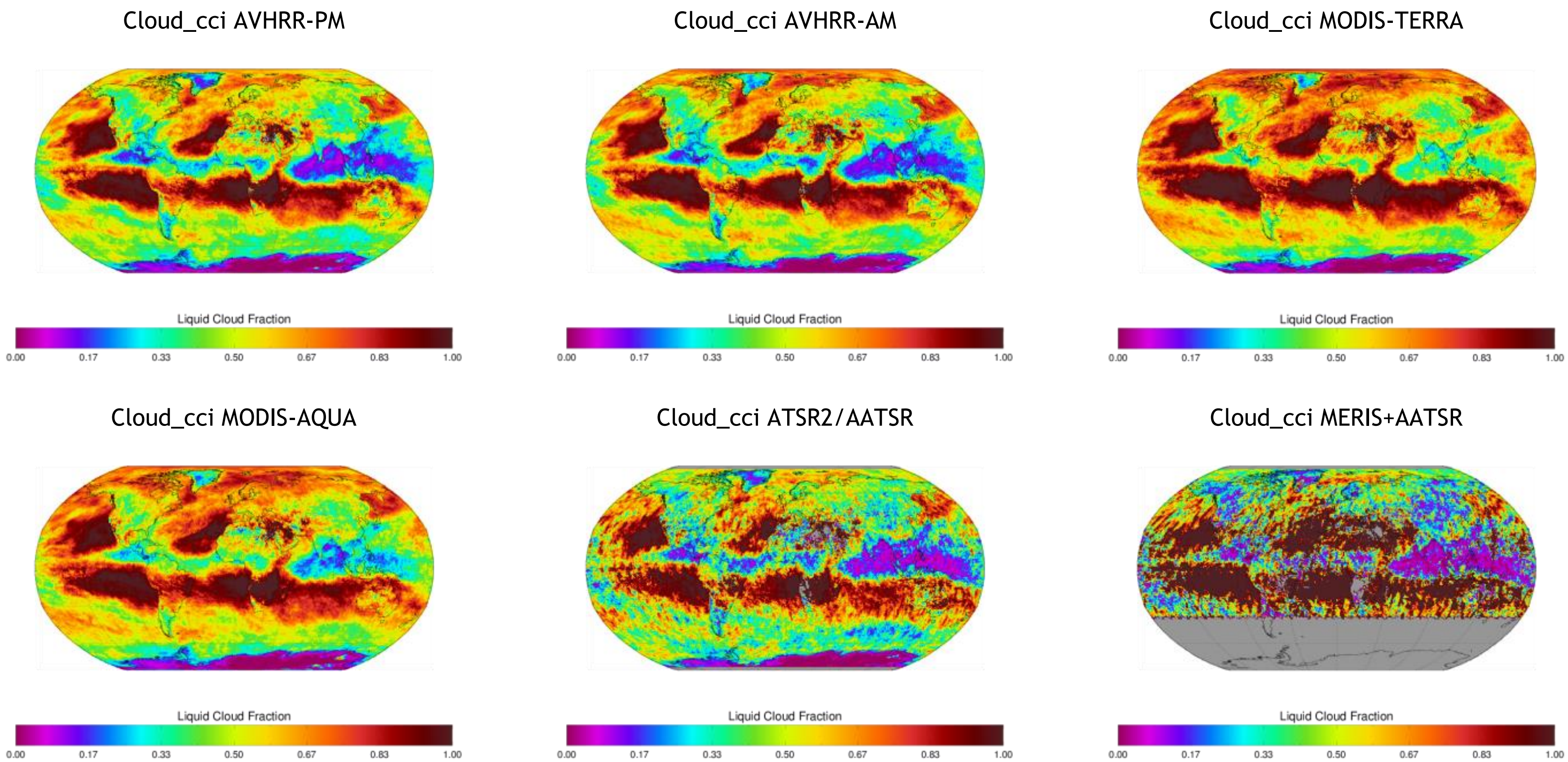

Figure A-4 *Monthly mean liquid cloud fraction for 2008/06.*

A.5 Cloud optical thickness for 2008/06/22 – Level-3U (global composite, Level-2 sampled onto a Latitude-Longitude grid of 0.05°)

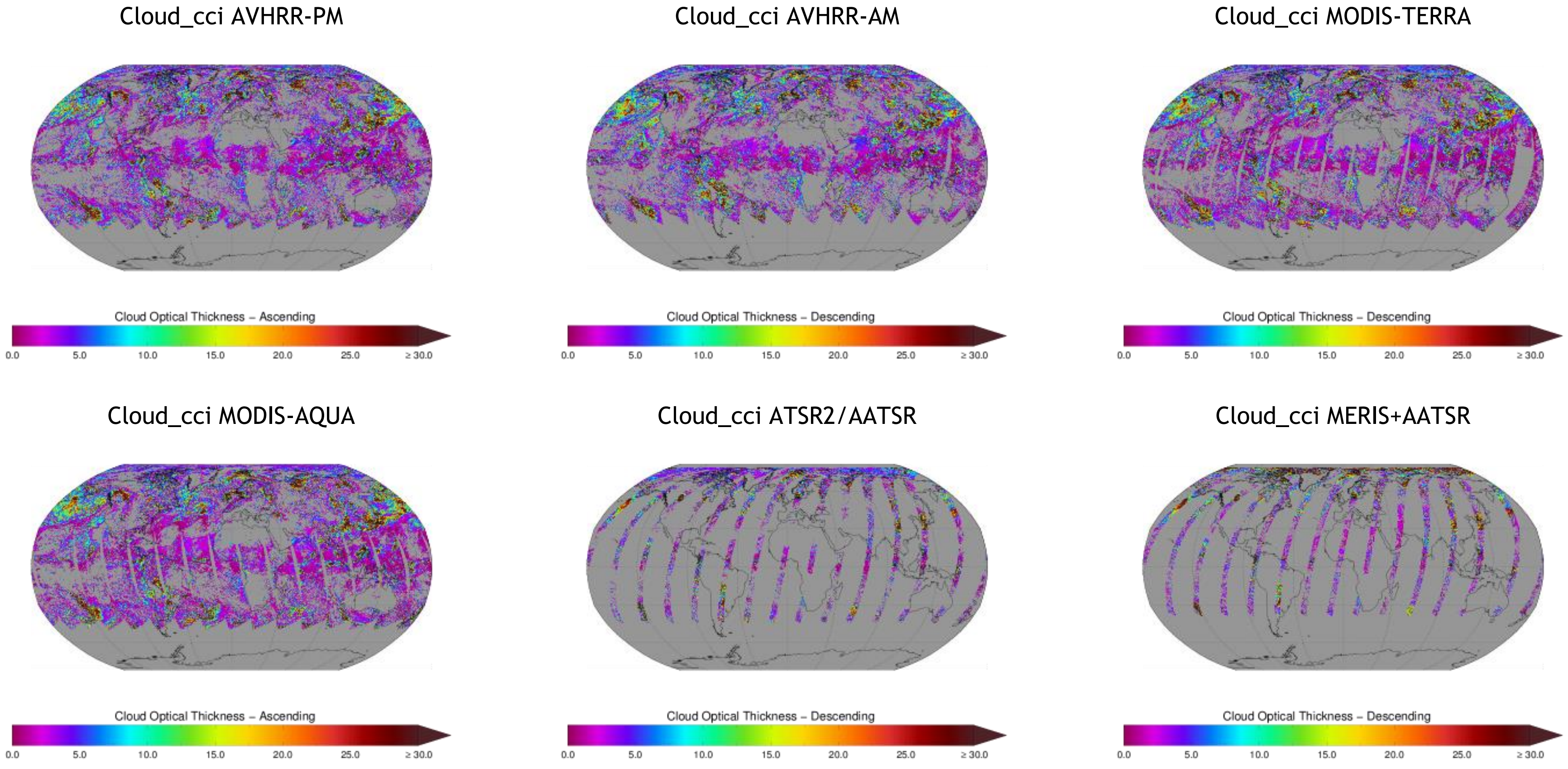

Figure A-5 *As Figure A-1 but for cloud optical thickness.*

A.6 Cloud optical thickness for 2008/06 – Level-3C (Monthly average on a Latitude-Longitude grid of 0.5°)

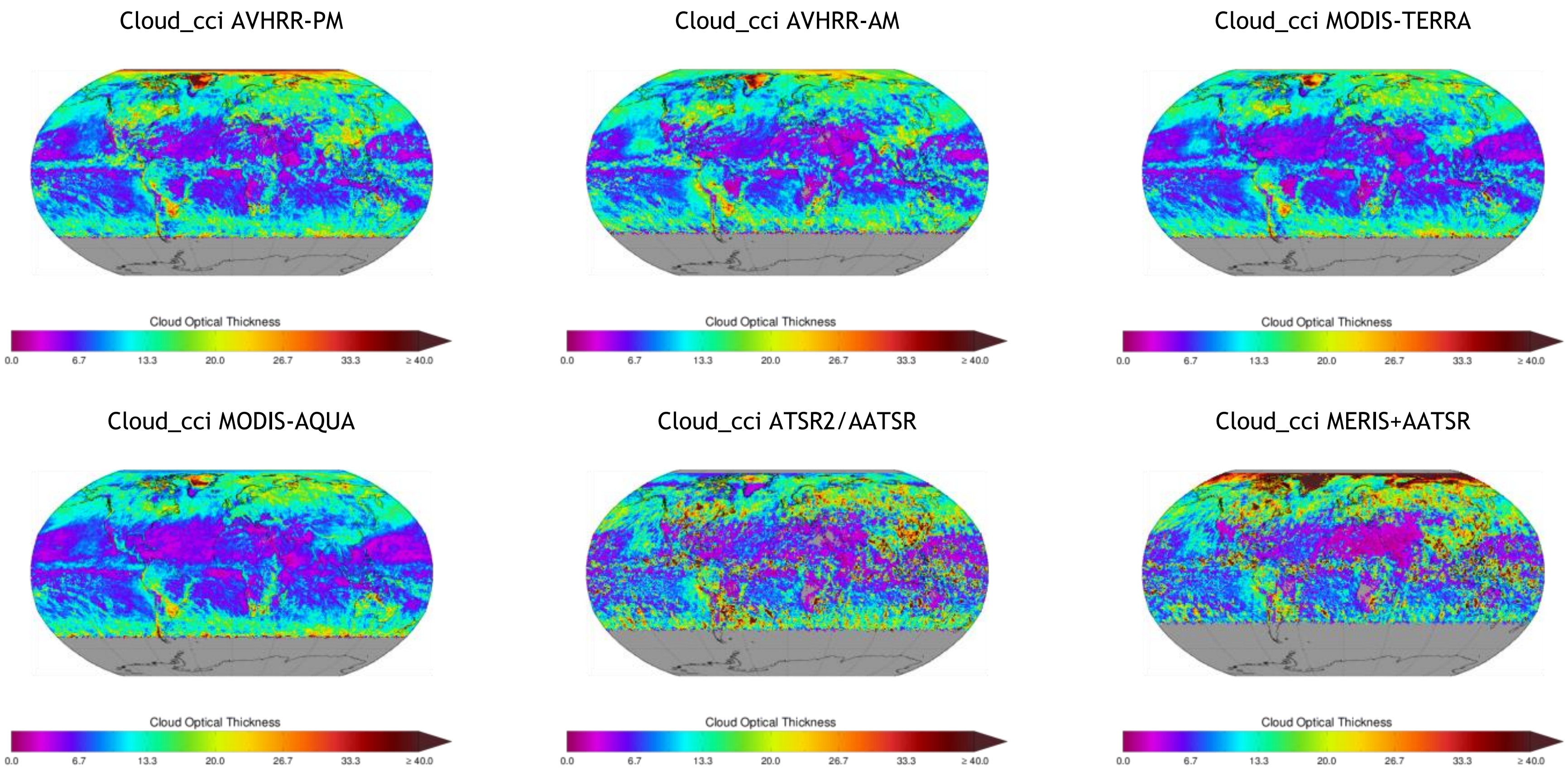

Figure A-6 *Monthly mean cloud optical thickness for 2008/06.*

A.7 Cloud effective radius for 2008/06/22 – Level-3U (global composite, Level-2 sampled onto a Latitude-Longitude grid of 0.05°)

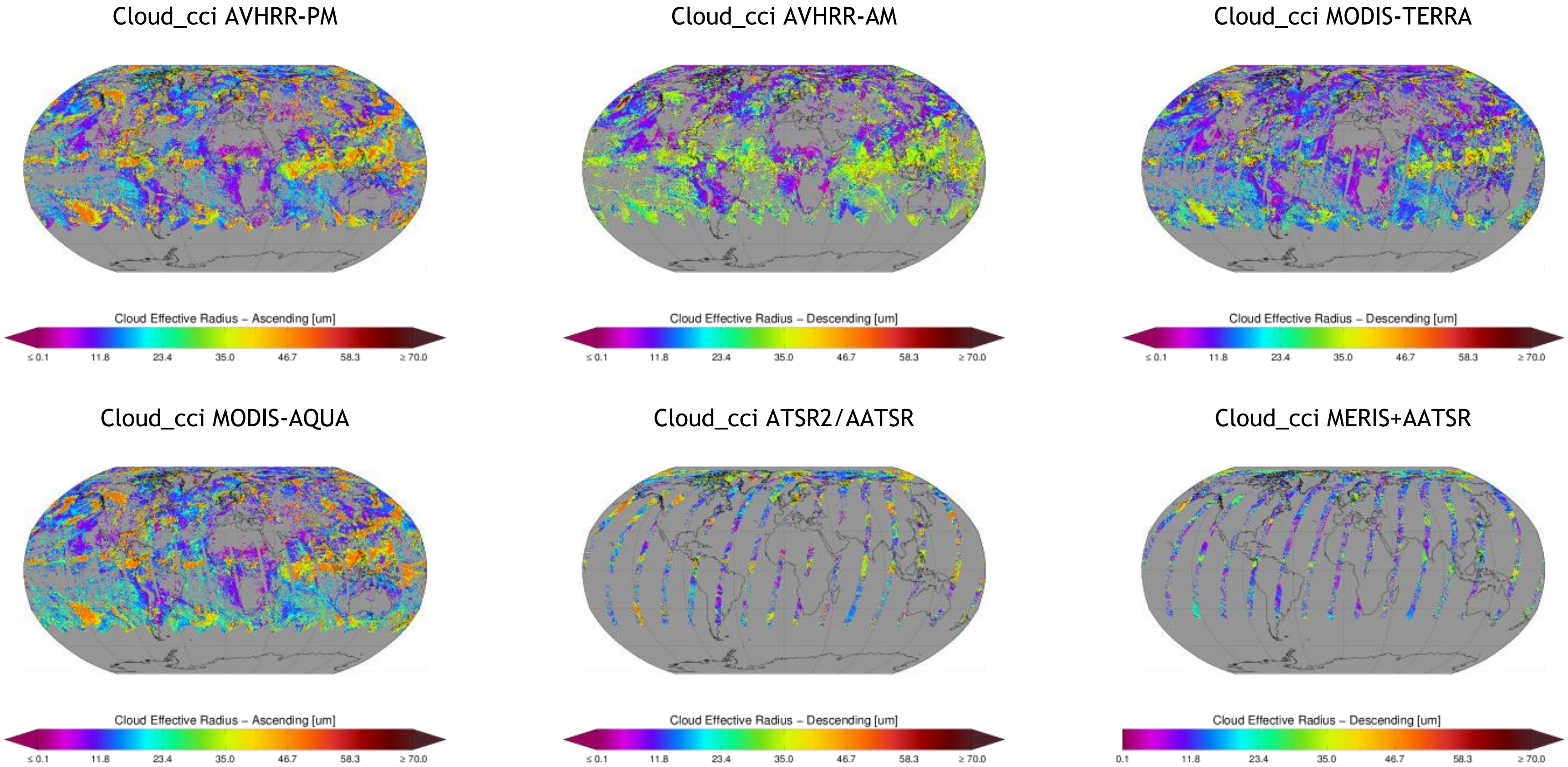

Figure A-7 *As Figure A-1 but for cloud effective radius.*

A.8 Cloud effective radius for 2008/06 – Level-3C (Monthly average on a Latitude-Longitude grid of 0.5°)

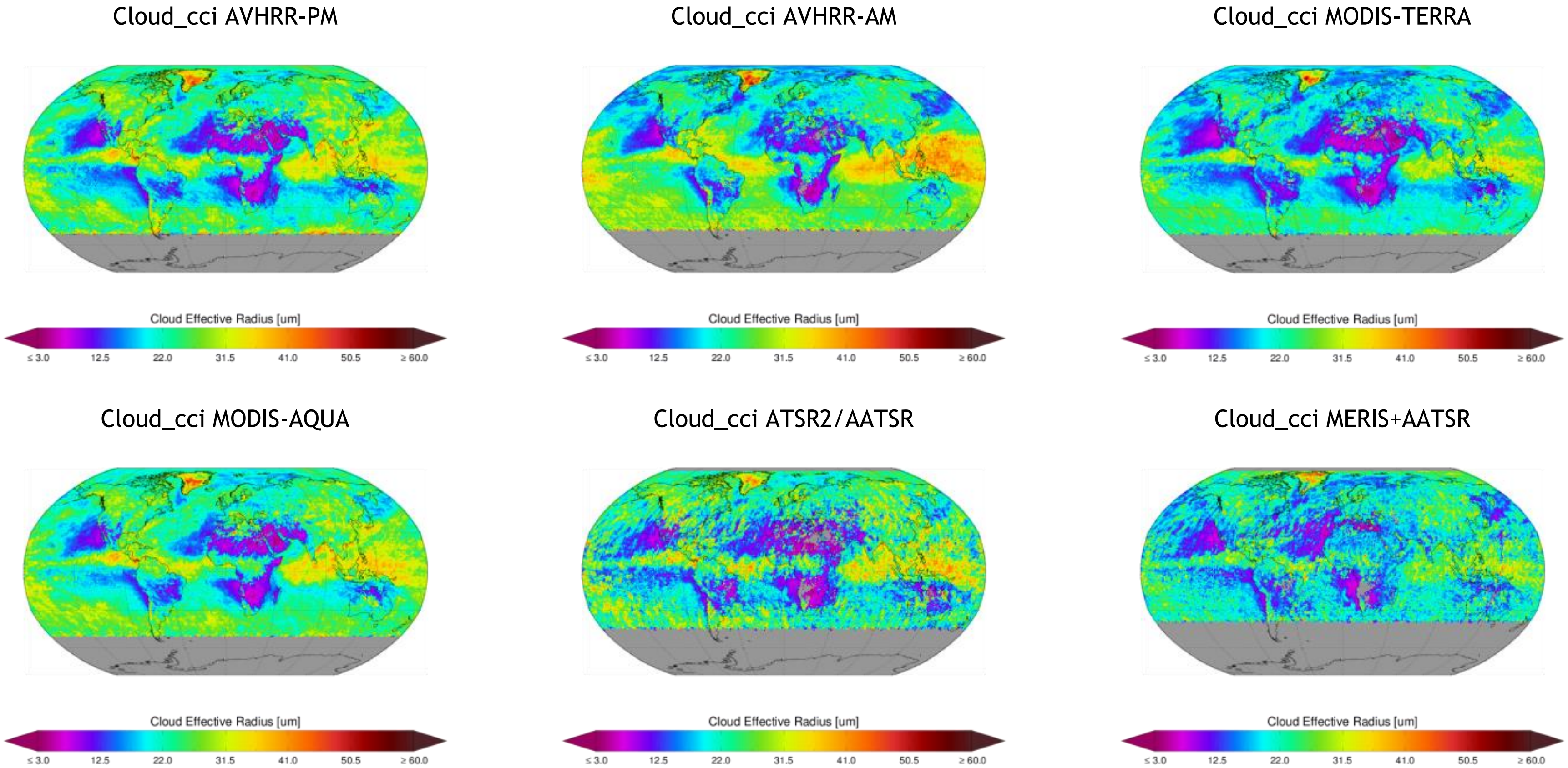

Figure A-8 *Monthly mean cloud effective radius for 2008/06.*

A.9 Cloud top pressure for 2008/06/22 – Level-3U (global composite, Level-2 sampled onto a Latitude-Longitude grid of 0.05°)

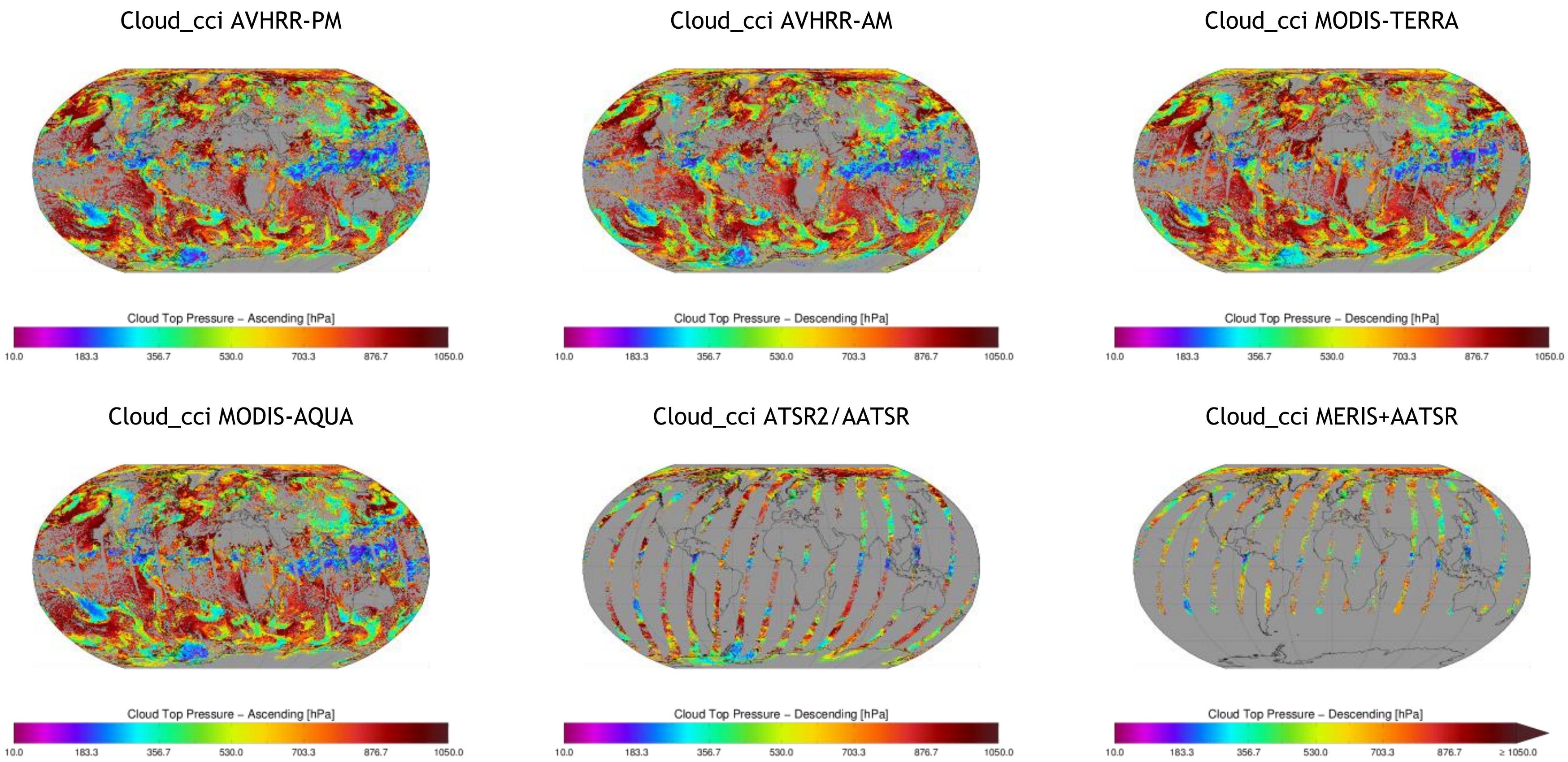

Figure A-9 *As Figure A-1 but for cloud top pressure.*

A.10 Cloud top pressure/height/temperature for 2008/06 – Level-3C (Monthly average on a Latitude-Longitude grid of 0.5°)

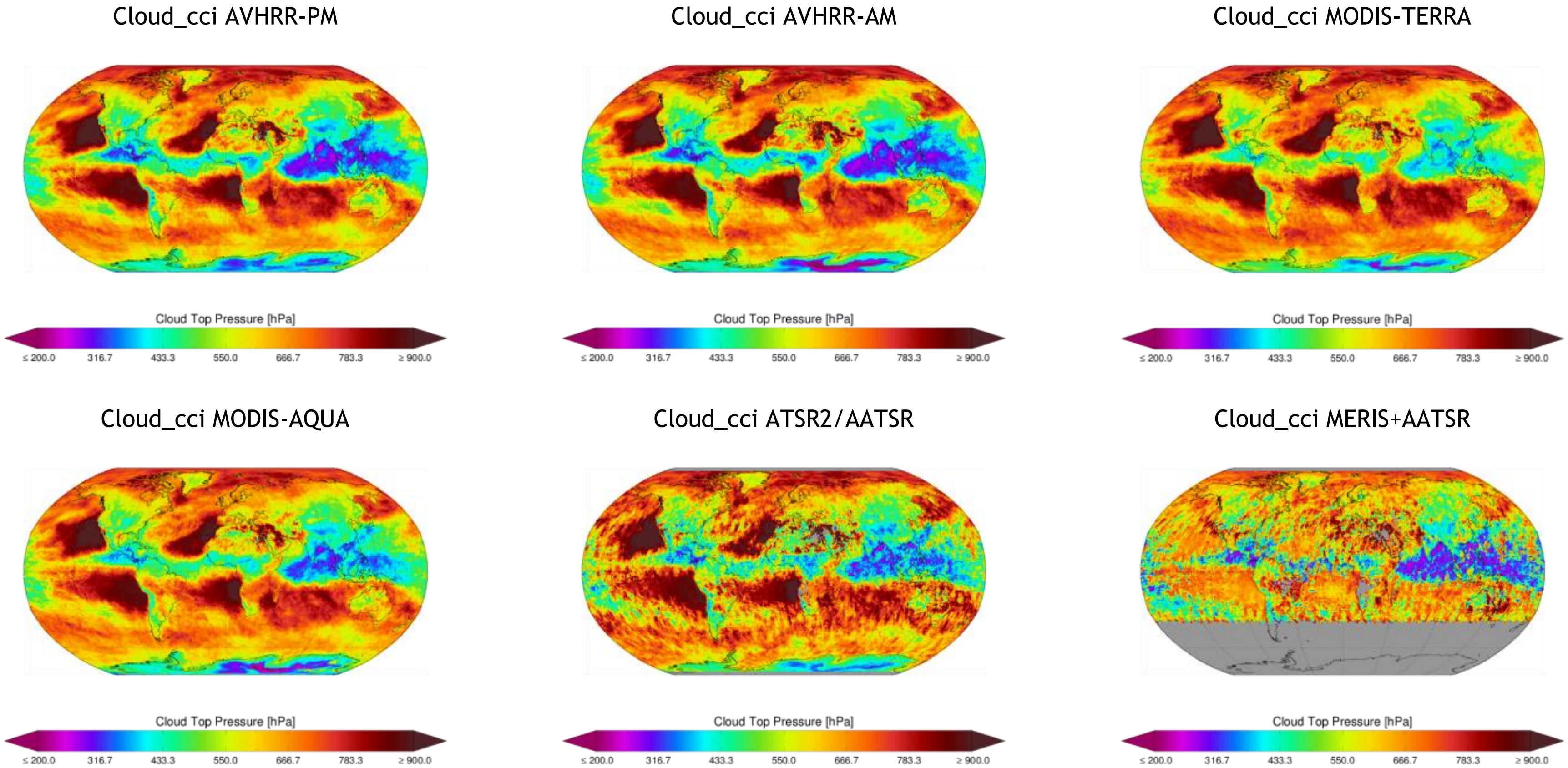

Figure A-10 *Monthly mean cloud top pressure for 2008/06.*

A.11 Cloud water path for 2008/06/22 – Level-3U (global composite, Level-2 sampled onto a Latitude-Longitude grid of 0.05°)

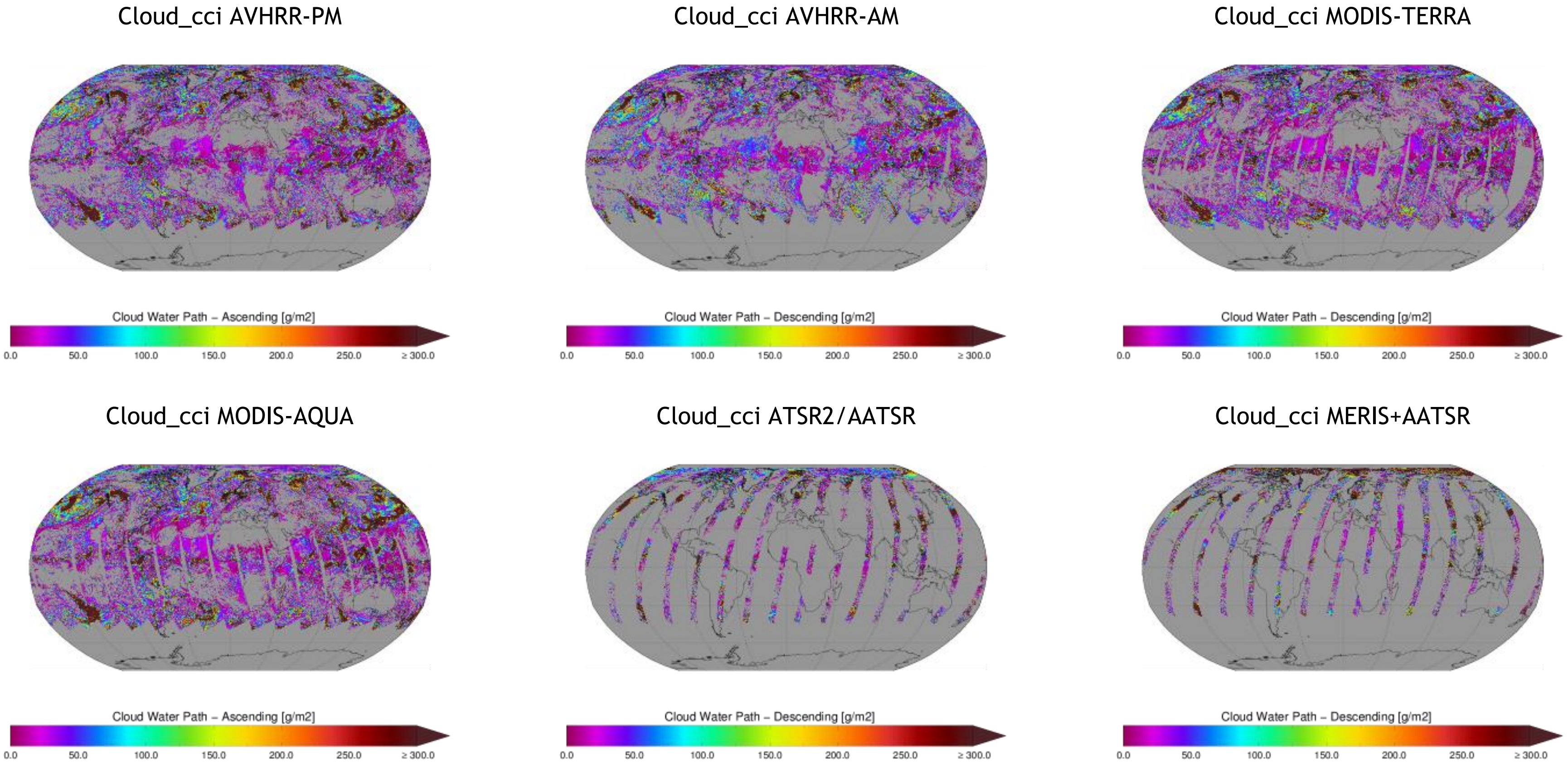

Figure A-11 *As Figure A-1 but for cloud water path.*

A.12 Cloud liquid water path for 2008/06 – Level-3C (Monthly average on a Latitude-Longitude grid of 0.5°)

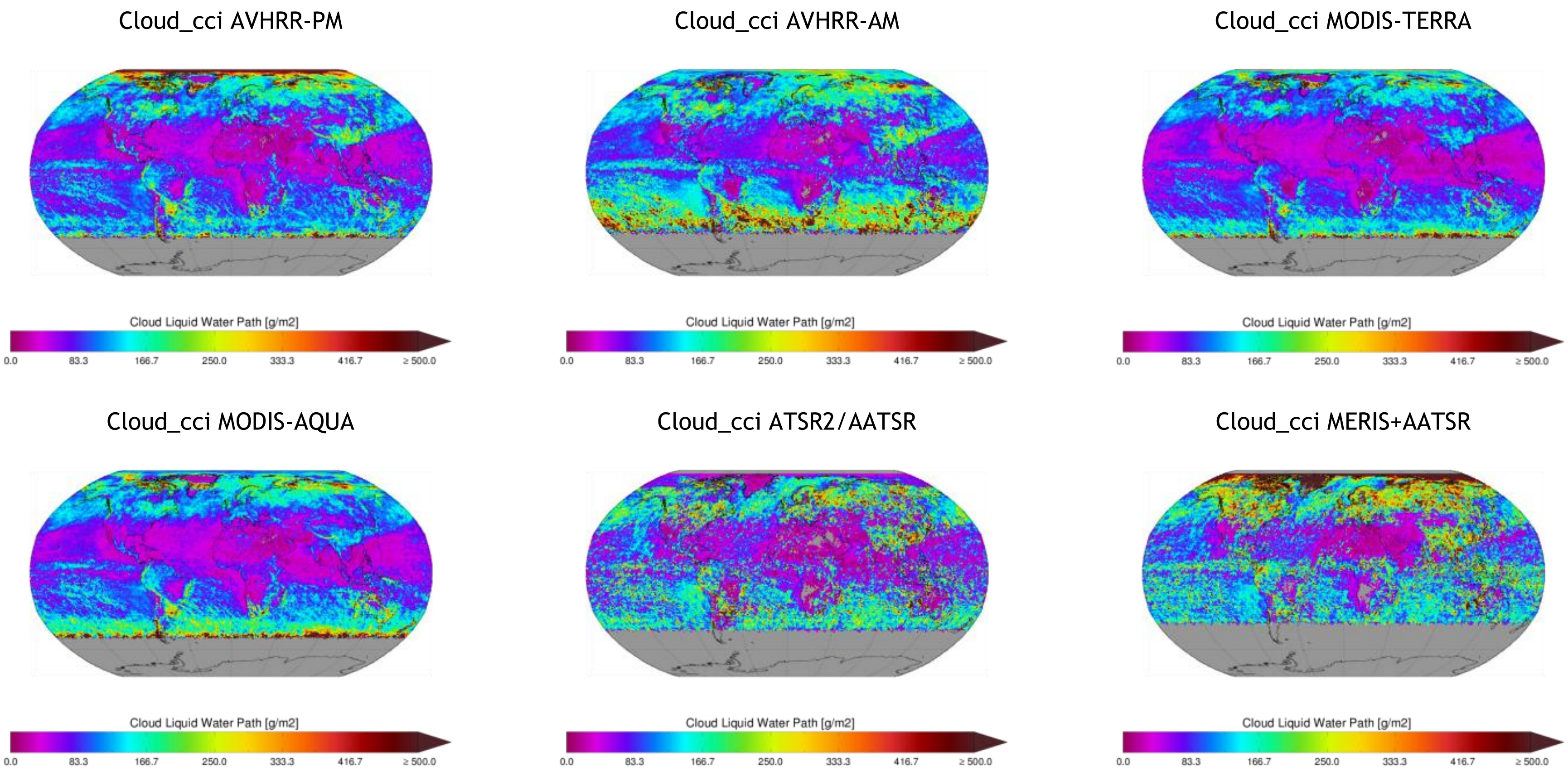

Figure A-12 *Monthly mean cloud liquid water path for 2008/06.*

A.13 Cloud ice water path for 2008/06 – Level-3C (Monthly average on a Latitude-Longitude grid of 0.5°)

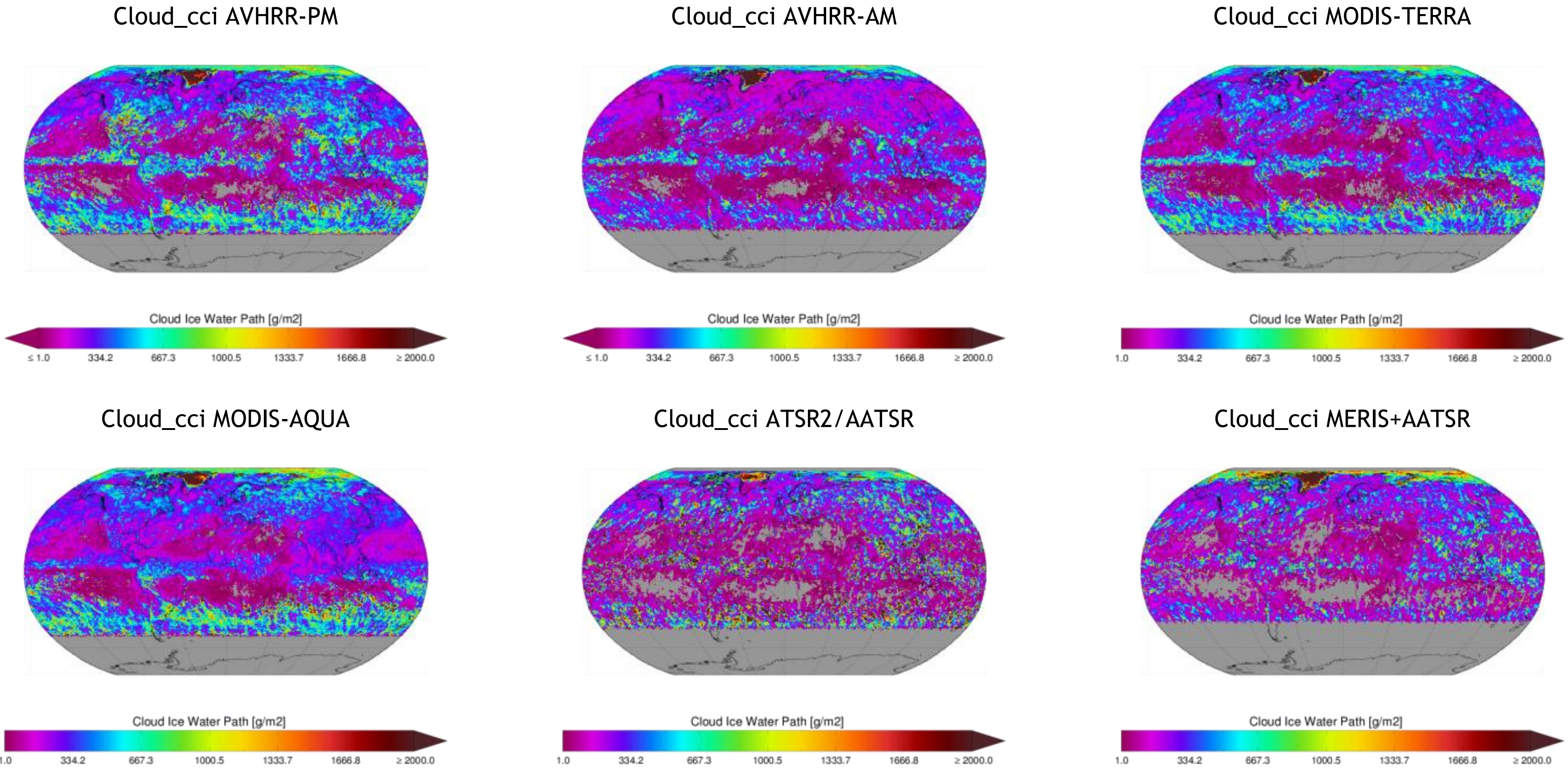

Figure A-13 *Monthly mean cloud ice water path for 2008/06.*

A.14 Spectral cloud albedo for 2008/06/22 – Level-3U (global composite, Level-2 sampled onto a Latitude-Longitude grid of 0.05°)

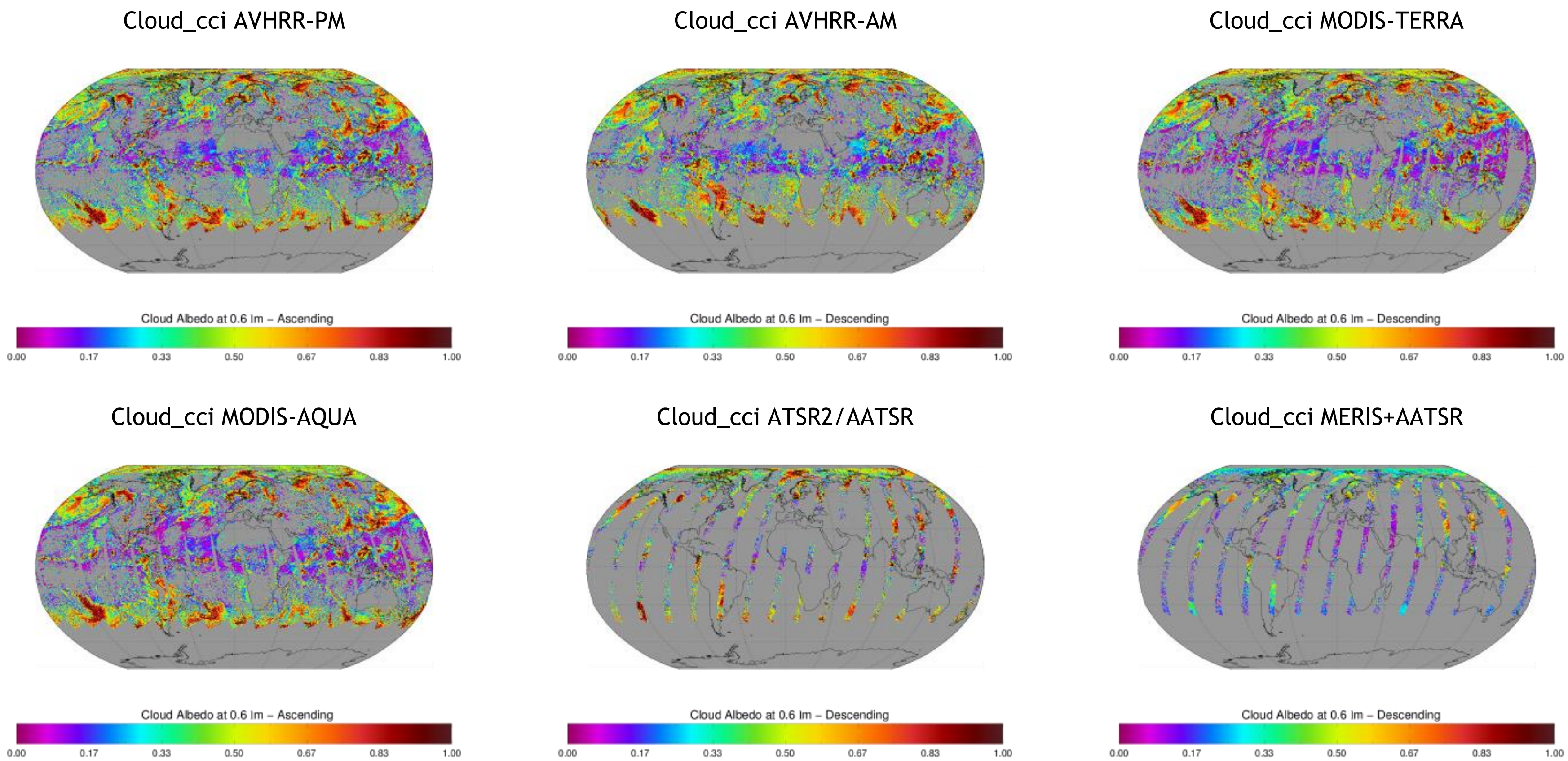

Figure A-14 *As Figure A-1 but for spectral cloud albedo at 0.6μm.*

A.15 Spectral cloud albedo for 2008/06 – Level-3C (Monthly average on a Latitude-Longitude grid of 0.5°)

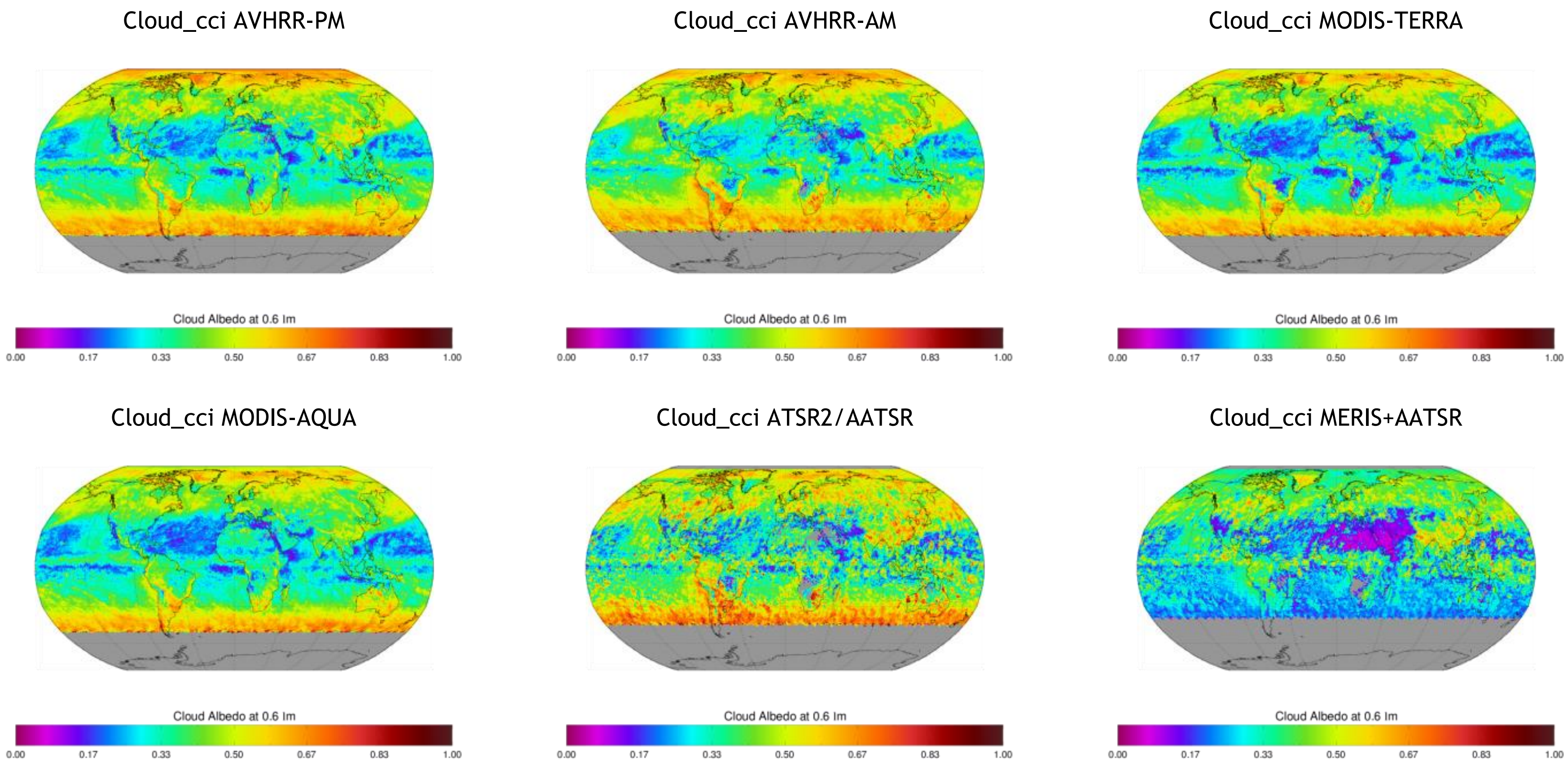

Figure A-15 *Monthly mean spectral cloud albedo at 0.6µm for 2008/06.*

A.16 Joint cloud property histogram for 2008/06 – Level-3C (Monthly histogram on a Latitude-Longitude grid of 0.5°)

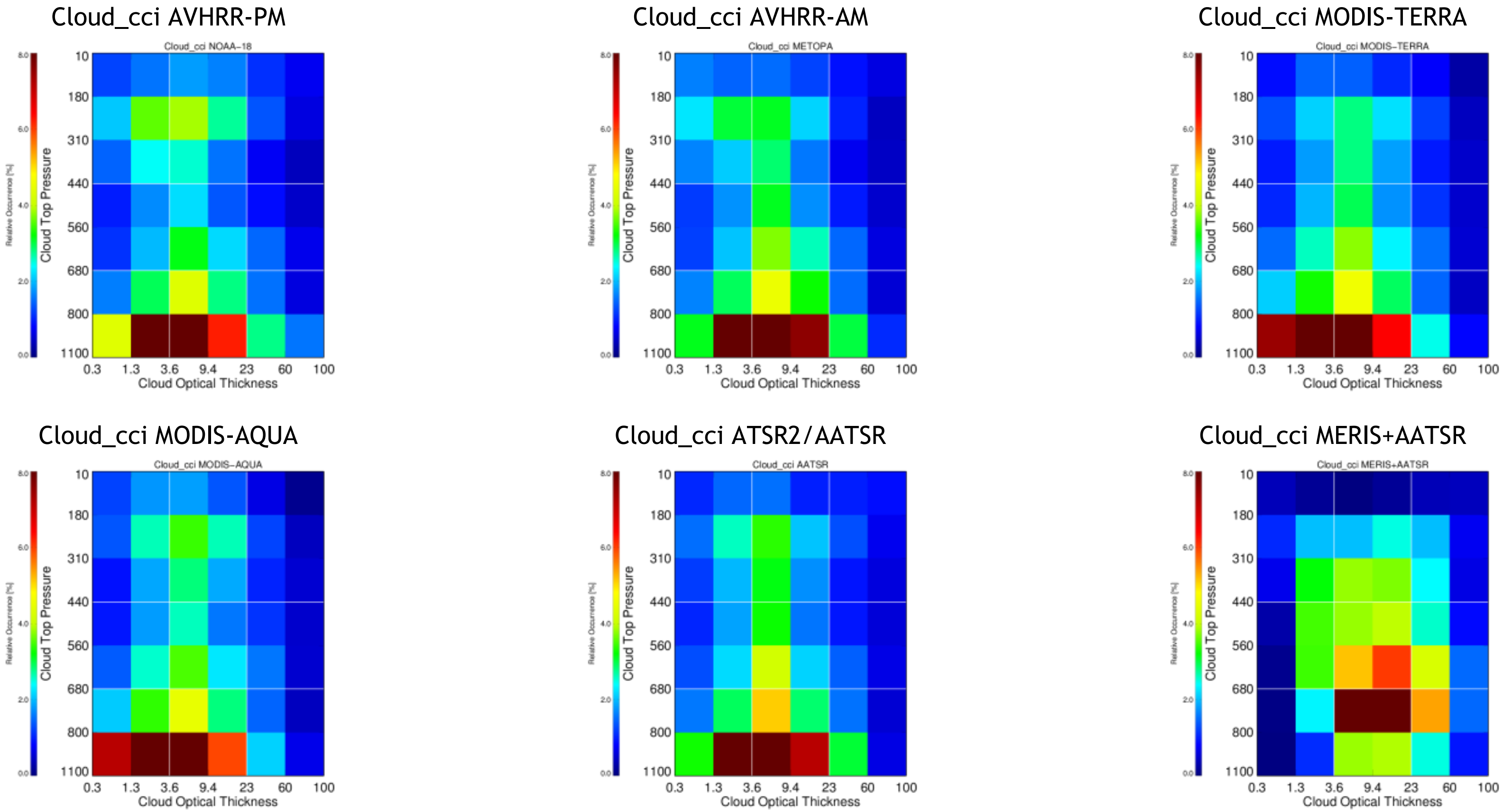

Figure A-16 *Monthly joint cloud property histogram for 2008/06, globally aggregated over all grid cells.*

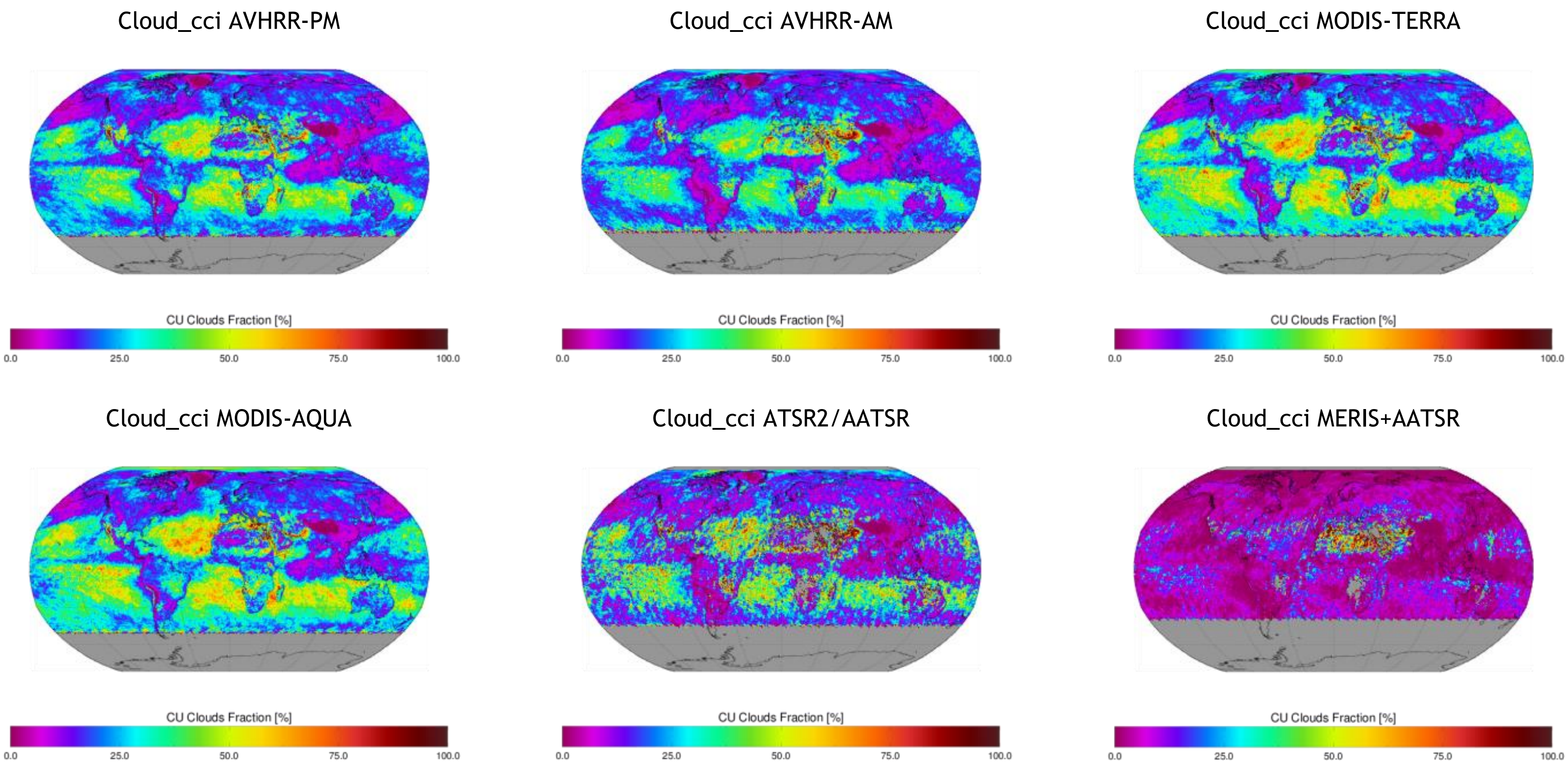

Figure A-17 Relative frequency of *Cumulus clouds (according to ISCCP definition of* Rossow and Schiffer (1999)*: CTP > 680hPa and COT < 3.6) wrt. all occurring clouds.*

A.17 Number of daytime observations for 2008/06 – Level-3C

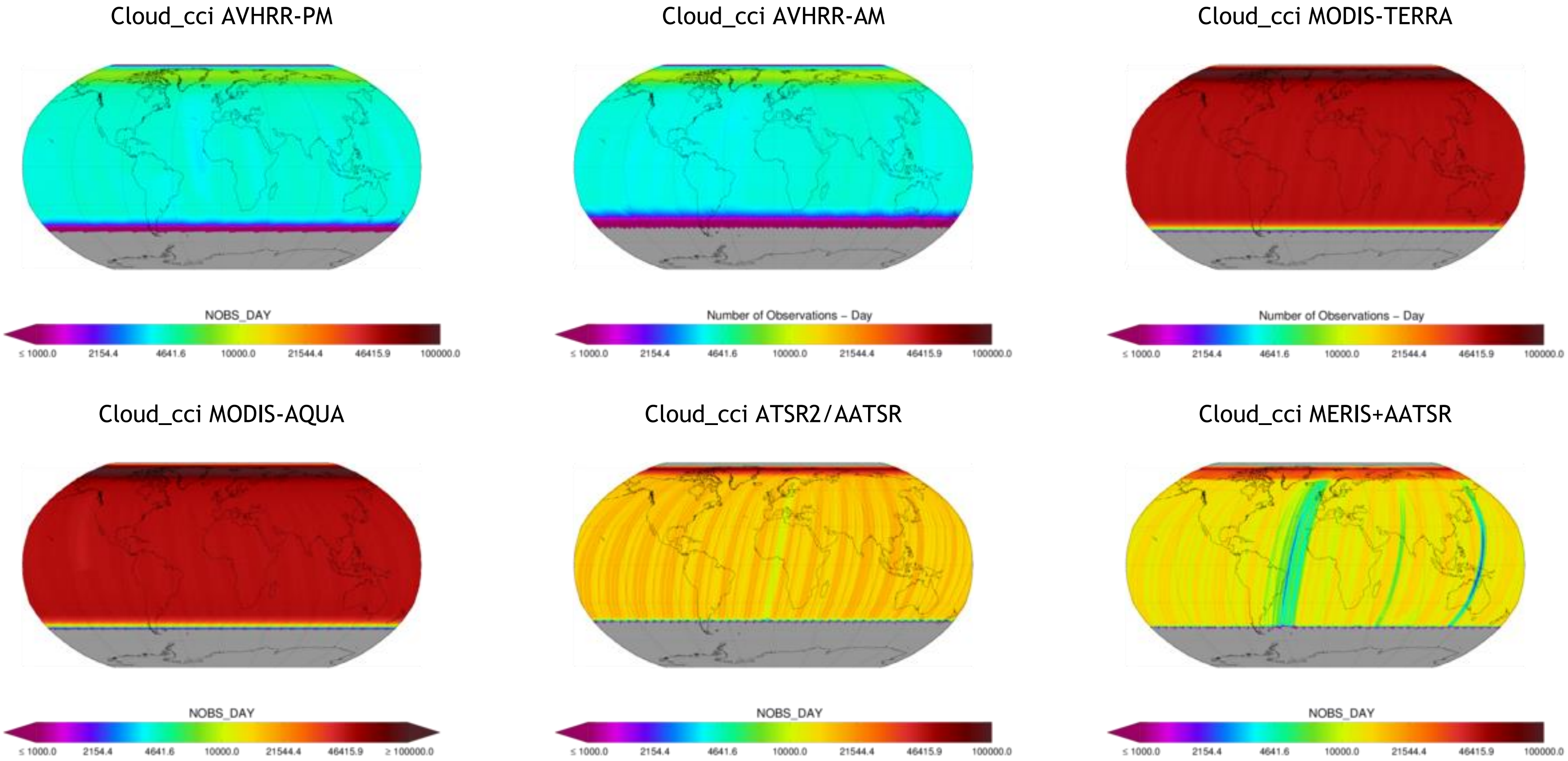

Figure A-18 *Monthly aggregated number of daytime observations for 2008/06.*

Annex B - Complete description of data fields

B.1 Level 2 and Level 3U data

Level 2 variable *Dimensions: along_track, across_track*	Level 3U variable	Description
Auxiliary data fields		
satellite_zenith_view_no1	*satzen_asc/desc(time, lat, lon)*	Satellite zenith angle [deg]
solar_zenith_view_no1	*solzen_asc/desc(time, lat, lon)*	Solar zenith angle [deg]
rel_azimuth_view_no1	*relazi_asc/desc(time, lat, lon)*	Relative azimuth angle [deg]
illum	*illum_asc/desc(time, lat, lon)*	Illumination flag (1: day, 2: twilight, 3: night)
lsflag(time, lat, lon)	-	Land/sea mask (0: sea , 1: land)
lusflag	-	Land use flag
dem	-	Digital elevation model
nicemask	-	Snow/ice mask
Optimal Estimation related data fields		
costja	-	field containing the a priori cost
costjm	-	field containing the measurement cost
convergence	-	field containing the retrieval convergence flag with value 0 : converged , 1 : no convergence
niter	-	field containing the number of the retrieval iterations
qcflag	*qcflag_asc/desc(time, lat, lon)*	field containing a quality-check bit mask. With Bit 0 unused, Bits 1-5 set to 1 if state variable error out of bounds, Bit 6 set to 1 if no convergence achieved, Bit 7 set to 1 if cost too large. Bit 1=COT Bit 2=REF Bit 3=CTP Bit 4=CCT Bit 5=STEMP

Level 2 variable *Dimensions: along_track, across_track*	Level 3U variable	Description
Cloud mask		
cc_total	*cmask_asc/desc(time, lat, lon)*	Cloud mask (0: cloud free, 1: cloudy)
cc_total	*cmask_asc/desc_unc(time, lat, lon)*	Cloud mask uncertainty
cccot_pre	*cccot_asc/desc(time, lat, lon) ;*	Native output of cloud detection (represents a pseudo CALIPSO COT)
Cloud phase & type		
phase	*cph_asc/desc(time, lat, lon)*	Cloud top thermodynamic phase (1: water cloud, 2: ice cloud)
phase_pavolonis	*cty_asc/desc(time, lat, lon)*	Cloud type (0: clear,1: switched to liquid, 2: fog, 3: liquid, 4: supercooled, 5: switched to ice, 6: opaque ice, 7: cirrus, 8: overlapping, 9: probably opaque ice)
Cloud top pressure/height/temperature		
ctt	*ctt_asc/desc(time, lat, lon) ;*	Cloud top temperature [K]
ctt_uncertainty	*ctt_asc/desc_unc(time, lat, lon) ;*	Cloud top temperature uncertainty [K]
ctt_corrected	*ctt_corrected_asc/desc(time, lat, lon) ;*	Cloud top temperature corrected [K]
ctt_corrected_uncertainty	*ctt_corrected_asc/desc_unc(time, lat, lon) ;*	Cloud top temperature corrected uncertainty [K]
cth	*cth_asc/desc(time, lat, lon) ;*	Cloud top height [km]
cth_uncertainty	*cth_asc/desc_unc(time, lat, lon) ;*	Cloud top height uncertainty [km]
cth_corrected	*cth_corrected_asc/desc(time, lat, lon) ;*	Cloud top height corrected [K km
cth_corrected_uncertainty	*cth_corrected_asc/desc_unc(time, lat, lon) ;*	Cloud top height corrected uncertainty [km]
ctp	*ctp_asc/desc(time, lat, lon) ;*	Cloud top pressure [hPa]

Level 2 variable *Dimensions: along_track, across_track*	Level 3U variable	Description
ctp_uncertainty	*ctp_asc/desc_unc(time, lat, lon) ;*	Cloud top pressure uncertainty [hPa]
ctp_corrected	*ctp_corrected_asc/desc(time, lat, lon) ;*	Cloud top pressure corrected [hPa]
ctp_corrected_uncertainty	*ctp_corrected_asc/desc_unc(time, lat, lon) ;*	Cloud top pressure corrected uncertainty [hPa]
Cloud optical thickness		
cot	*cot_asc/desc(time, lat, lon)*	Cloud optical thickness
cot_uncertainty	*cot_asc/desc_unc(time, lat, lon)*	Cloud optical thickness uncertainty
Effective Radius		
cer	*cer_asc/desc(time, lat, lon)*	Cloud effective radius [µm]
cer_uncertainty	*cer_asc/desc_unc(time, lat, lon)*	Cloud effective radius uncertainty [µm]
Cloud water path		
cwp	*cwp_asc/desc(time, lat, lon)*	Cloud water path [g/m2]
cwp_uncertainty	*cwp_asc/desc_unc(time, lat, lon)*	Cloud water path uncertainty [g/m2]
Spectral cloud albedo		
cloud_albedo_in_channel_no_1	*cla_vis006_asc/desc(time, lat, lon)*	Cloud albedo at 0.6µm
cloud_albedo_uncertainty_in_ channel_no_1	*cla_vis006_asc/desc_unc(time, lat, lon)*	Cloud albedo at 0.6µm uncertainty
cloud_albedo_in_channel_no_2	*cla_vis008_asc/desc(time, lat, lon)*	Cloud albedo at 0.8µm
cloud_albedo_uncertainty_in_ channel_no_2	*cla_vis008_asc/desc_unc(time, lat, lon)*	Cloud albedo at 0.8µm uncertainty
cloud_albedo_in_channel_no_3	-	
cloud_albedo_uncertainty_in _channel_no_3	-	

Level 2 variable *Dimensions: along_track, across_track*	Level 3U variable	Description
cloud_albedo_in_channel_no_3	-	
cloud_albedo_uncertainty_in_channel_no_4	-	
Cloud effective emissivity		
cee_in_channel_no_4	-	Cloud effective emissivity at 3.7 µm
cee_uncertainty_in_channel_no_4	-	Cloud effective emissivity at 3.7 µm
cee_in_channel_no_5	*cee_asc/desc(time, lat, lon)*	Cloud effective emissivity at 10.8 µm
cee_uncertainty_in_channel_no_5	*cee_asc/desc_unc(time, lat, lon)*	Cloud effective emissivity at 10.8 µm
cee_in_channel_no_6	-	Cloud effective emissivity at 12.0 µm
cee_uncertainty_in_channel_no_6	-	Cloud effective emissivity at 12.0 µm
Surface Temperature		
stemp	stemp*_asc/desc(time, lat, lon)*	field containing the surface temperature in Kelvin
stemp_uncertainty	stemp*_asc/desc_unc(time, lat, lon)*	field containing the uncertainty of *stemp* in Kelvin

B.2 Level 3C and Level 3S

Level-3C/3S variable	Description
Numbers/counters used for averaging	
nobs(time, lat, lon)	Total number of observations
nobs_day(time, lat, lon)	Total number of daytime observations
nobs_clear_day(time, lat, lon)	Number of clear-sky, daytime observations
nobs_cloudy_day(time, lat, lon)	Number of cloudy, daytime observations
nobs_clear_night(time, lat, lon)	Number of clear-sky, nighttime observations
nobs_cloudy_night(time, lat, lon)	Number of cloudy, nighttime observations
nobs_clear_twl(time, lat, lon)	Number of clear-sky, twilight observations
nobs_cloudy_twl(time, lat, lon)	Number of cloudy, twilight observations
nobs_cloudy(time, lat, lon)	Total number of cloudy observations
nretr_cloudy(time, lat, lon)	Number of cloud property retrievals
nretr_cloudy_liq(time, lat, lon)	Number of cloud property retrievals for liquid clouds
nretr_cloudy_ice(time, lat, lon)	Number of cloud property retrievals for ice clouds
nretr_cloudy_day(time, lat, lon)	Number of daytime cloud property retrievals
nretr_cloudy_day_liq(time, lat, lon)	Number of daytime cloud property retrievals for liquid clouds
nretr_cloudy_day_ice(time, lat, lon)	Number of daytime cloud property retrievals for ice clouds
nretr_cloudy_low(time, lat, lon)	Number of cloud property retrievals for low clouds
nretr_cloudy_mid(time, lat, lon)	Number of cloud property retrievals for mid-level clouds
nretr_cloudy_high(time, lat, lon)	Number of cloud property retrievals for high clouds
Cloud fraction	
cfc(time, lat, lon)	Total cloud fraction - mean of individual pixel retrievals
cfc_std(time, lat, lon)	Total cloud fraction - standard deviation of individual pixel retrievals
cfc_prop_unc(time, lat, lon)	Total cloud fraction - propagated uncertainty: total uncertainty from individual pixel uncertainty added in quadrature
cfc_corr_unc(time, lat, lon)	Total cloud fraction - correlated uncertainty assuming correlation of 0.1

Level-3C/3S variable	Description
cfc_unc(time, lat, lon)	Total cloud fraction - mean of individual pixel uncertainties
cfc_low(time, lat, lon)	Portion of total cloud fraction due to low clouds
cfc_mid(time, lat, lon)	Portion of total cloud fraction due to mid-level clouds
cfc_high(time, lat, lon)	Portion of total cloud fraction due to high clouds
cfc_day(time, lat, lon)	Total cloud fraction daytime - mean of individual pixel retrievals
cfc_night(time, lat, lon)	Total cloud fraction night time - mean of individual pixel retrievals
cfc_twl(time, lat, lon)	Total cloud fraction twilight - mean of individual pixel retrievals
Cloud phase	
cph(time, lat, lon)	Liquid cloud fraction - mean of individual pixel phase retrievals
cph_std(time, lat, lon)	Liquid cloud fraction— standard deviation of individual pixel phase retrievals
cph_day(time, lat, lon)	Liquid cloud fraction daytime - mean of individual pixel phase retrievals
cph_day_std(time, lat, lon)	Liquid cloud fraction daytime - standard deviation of individual pixel phase retrievals
Cloud top pressure/height/temperature	
ctt(time, lat, lon)	Cloud top temperature - mean of individual pixel retrievals
ctt_std(time, lat, lon)	Cloud top temperature - standard deviation of individual pixel retrievals
ctt_prop_unc(time, lat, lon)	Cloud top temperature - propagated uncertainty: total uncertainty from individual pixel uncertainty added in quadrature
ctt_corr_unc(time, lat, lon)	Cloud top temperature - correlated uncertainty assuming correlation of 0.1
ctt_unc(time, lat, lon)	Cloud top temperature - mean of individual pixel uncertainties
ctt_corrected(time, lat, lon)	Corrected cloud top temperature - mean of corrected individual pixel retrievals
ctt_corrected_std(time, lat, lon)	Corrected cloud top temperature - standard deviation of corrected individual pixel retrievals
ctt_corrected_prop_unc(time, lat, lon)	Corrected cloud top temperature - propagated uncertainty: total uncertainty from corrected individual pixel uncertainty added in

Level-3C/3S variable	Description
	quadrature
ctt_corrected_corr_unc(time, lat, lon)	Corrected cloud top temperature - correlated uncertainty assuming correlation of 0.1
ctt_corrected_unc(time, lat, lon)	Corrected cloud top temperature - mean of corrected individual pixel uncertainties
cth(time, lat, lon)	Cloud top height - mean of individual pixel retrievals
cth_std(time, lat, lon)	Cloud top height - standard deviation of individual pixel retrievals
cth_prop_unc(time, lat, lon)	Cloud top height - propagated uncertainty: total uncertainty from individual pixel uncertainty added in quadrature
cth_corr_unc(time, lat, lon)	Cloud top height - correlated uncertainty assuming correlation of 0.1
cth_unc(time, lat, lon)	Cloud top height - mean of individual pixel uncertainties
cth_corrected(time, lat, lon)	Corrected cloud top height - mean of corrected individual pixel retrievals
cth_corrected_std(time, lat, lon)	Corrected cloud top height - standard deviation of corrected individual pixel retrievals
cth_corrected_prop_unc(time, lat, lon)	Corrected cloud top height - propagated uncertainty: total uncertainty from corrected individual pixel uncertainty added in quadrature
cth_corrected_corr_unc(time, lat, lon)	Corrected cloud top height - correlated uncertainty assuming correlation of 0.1
cth_corrected_unc(time, lat, lon)	Corrected cloud top height - mean of corrected individual pixel uncertainties
ctp(time, lat, lon)	Cloud top pressure - mean of individual pixel retrievals
ctp_std(time, lat, lon)	Cloud top pressure - standard deviation of individual pixel retrievals
ctp_prop_unc(time, lat, lon)	Cloud top pressure - propagated uncertainty: total uncertainty from individual pixel uncertainty added in quadrature
ctp_corr_unc(time, lat, lon)	Cloud top pressure - correlated uncertainty assuming correlation of 0.1
ctp_unc(time, lat, lon)	Cloud top pressure - mean of individual pixel uncertainties
ctp_log(time, lat, lon)	Cloud top pressure - logarithmic mean of individual pixel retrievals
ctp_corrected(time, lat, lon)	Corrected cloud top pressure - mean of corrected individual pixel retrievals
ctp_corrected_std(time, lat, lon)	Corrected cloud top pressure - standard deviation of corrected

Level-3C/3S variable	Description
	individual pixel retrievals
ctp_corrected_prop_unc(time, lat, lon)	Corrected cloud top pressure - propagated uncertainty: total uncertainty from corrected individual pixel uncertainty added in quadrature
ctp_corrected_corr_unc(time, lat, lon)	Corrected cloud top pressure - correlated uncertainty assuming correlation of 0.1
ctp_corrected_unc(time, lat, lon)	Corrected cloud top pressure - mean of corrected individual pixel uncertainties
Surface temperature	
stemp(time, lat, lon)	Surface temperature - mean of individual pixel retrievals
stemp_std(time, lat, lon)	Surface temperature - standard deviation of individual pixel retrievals
stemp_prop_unc(time, lat, lon)	Surface temperature - propagated uncertainty: total uncertainty from individual pixel uncertainty added in quadrature
stemp_corr_unc(time, lat, lon)	Surface temperature - correlated uncertainty assuming correlation of 0.1
stemp_unc(time, lat, lon)	Surface temperature - mean of individual pixel uncertainties
Cloud effective radius	
cer(time, lat, lon)	Cloud effective radius - mean of individual pixel retrievals
cer_std(time, lat, lon)	Cloud effective radius - standard deviation of individual pixel retrievals
cer_prop_unc(time, lat, lon)	Cloud effective radius - propagated uncertainty: total uncertainty from individual pixel uncertainty added in quadrature
cer_corr_unc(time, lat, lon)	Cloud effective radius - correlated uncertainty assuming correlation of 0.1
cer_unc(time, lat, lon)	Cloud effective radius - mean of individual pixel uncertainties
cer_liq(time, lat, lon)	Liquid cloud effective radius - mean of individual pixel retrievals
cer_liq_std(time, lat, lon)	Liquid cloud effective radius - standard deviation of individual pixel retrievals
cer_liq_prop_unc(time, lat, lon)	Liquid cloud effective radius - propagated uncertainty: total uncertainty from individual pixel uncertainty added in quadrature
cer_liq_corr_unc(time, lat, lon)	Liquid cloud effective radius - correlated uncertainty assuming correlation of 0.1

Level-3C/3S variable	Description
cer_liq_unc(time, lat, lon)	Liquid cloud effective radius - mean of individual pixel uncertainties
cer_ice(time, lat, lon)	Ice cloud effective radius - mean of individual pixel retrievals
cer_ice_std(time, lat, lon)	Ice cloud effective radius - standard deviation of individual pixel retrievals
cer_ice_prop_unc(time, lat, lon)	Ice cloud effective radius - propagated uncertainty: total uncertainty from individual pixel uncertainty added in quadrature
cer_ice_corr_unc(time, lat, lon)	Ice cloud effective radius - correlated uncertainty assuming correlation of 0.1
cer_ice_unc(time, lat, lon)	Ice cloud effective radius - mean of individual pixel uncertainties
Cloud optical thickness	
cot(time, lat, lon)	Cloud optical thickness - mean of individual pixel retrievals
cot_log(time, lat, lon)	Cloud optical thickness - logarithmic mean of individual pixel retrievals
cot_std(time, lat, lon)	Cloud optical thickness - standard deviation of individual pixel retrievals
cot_prop_unc(time, lat, lon)	Cloud optical thickness - propagated uncertainty: total uncertainty from individual pixel uncertainty added in quadrature
cot_corr_unc(time, lat, lon)	Cloud optical thickness - correlated uncertainty assuming correlation of 0.1
cot_unc(time, lat, lon)	Cloud optical thickness - mean of individual pixel uncertainties
cot_liq(time, lat, lon)	Liquid cloud optical thickness- mean of individual pixel retrievals
cot_liq_std(time, lat, lon)	Liquid cloud optical thickness - standard deviation of individual pixel retrievals
cot_liq_prop_unc(time, lat, lon)	Liquid cloud optical thickness - propagated uncertainty: total uncertainty from individual pixel uncertainty added in quadrature
cot_liq_corr_unc(time, lat, lon)	Liquid cloud optical thickness - correlated uncertainty assuming correlation of 0.1
cot_liq_unc(time, lat, lon)	Liquid cloud optical thickness - mean of individual pixel uncertainties
cot_ice(time, lat, lon)	Ice cloud optical thickness - mean of individual pixel retrievals
cot_ice_std(time, lat, lon)	Ice cloud optical thickness - standard deviation of individual pixel retrievals

Level-3C/3S variable	Description
cot_ice_prop_unc(time, lat, lon)	Ice cloud optical thickness - propagated uncertainty: total uncertainty from individual pixel uncertainty added in quadrature
cot_ice_corr_unc(time, lat, lon)	Ice cloud optical thickness - correlated uncertainty assuming correlation of 0.1
cot_ice_unc(time, lat, lon)	Ice cloud optical thickness - mean of individual pixel uncertainties
Cloud effective emissivity	
cee(time, lat, lon)	Cloud effective emissivity at 10.8 µm - mean of individual pixel retrievals
cee_std(time, lat, lon)	Cloud effective emissivity at 10.8 µm - standard deviation of individual pixel retrievals
cee_prop_unc(time, lat, lon)	Cloud effective emissivity at 10.8 µm - propagated uncertainty: total uncertainty from individual pixel uncertainty added in quadrature
cee_corr_unc(time, lat, lon)	Cloud effective emissivity at 10.8 µm - correlated uncertainty assuming correlation of 0.1
cee_unc(time, lat, lon)	Cloud effective emissivity at 10.8 µm - mean of individual pixel uncertainties
Spectral cloud albedo	
cla_vis006(time, lat, lon)	Cloud albedo at 0.6 µm - mean of individual pixel retrievals
cla_vis006_std(time, lat, lon)	Cloud albedo at 0.6 µm - standard deviation of individual pixel retrievals
cla_vis006_prop_unc(time, lat, lon)	Cloud albedo at 0.6 µm - propagated uncertainty: total uncertainty from individual pixel uncertainty added in quadrature
cla_vis006_corr_unc(time, lat, lon)	Cloud albedo at 0.6 µm - correlated uncertainty assuming correlation of 0.1
cla_vis006_unc(time, lat, lon)	Cloud albedo at 0.6 µm - mean of individual pixel uncertainties
cla_vis006_liq(time, lat, lon)	Liquid cloud albedo at 0.6 µm - mean of individual pixel retrievals
cla_vis006_liq_std(time, lat, lon)	Liquid cloud albedo at 0.6 µm - standard deviation of individual pixel retrievals
cla_vis006_liq_unc(time, lat, lon)	Liquid cloud albedo at 0.6 µm - mean of individual pixel uncertainties
cla_vis006_ice(time, lat, lon)	Ice cloud albedo at 0.6 µm - mean of individual pixel retrievals
cla_vis006_ice_std(time, lat, lon)	Ice cloud albedo at 0.6 µm - standard deviation of individual pixel retrievals

Level-3C/3S variable	Description
cla_vis006_ice_unc(time, lat, lon)	Ice cloud albedo at 0.6 µm - mean of individual pixel uncertainties
cla_vis008(time, lat, lon)	Cloud albedo at 0.8 µm - mean of individual pixel retrievals
cla_vis008_std(time, lat, lon)	Cloud albedo at 0.8 µm - standard deviation of individual pixel retrievals
cla_vis008_prop_unc(time, lat, lon)	Cloud albedo at 0.8 µm - propagated uncertainty: total uncertainty from individual pixel uncertainty added in quadrature
cla_vis008_corr_unc(time, lat, lon)	Cloud albedo at 0.8 µm - correlated uncertainty assuming correlation of 0.1
cla_vis008_unc(time, lat, lon)	Cloud albedo at 0.8 µm - mean of individual pixel uncertainties
cla_vis008_liq(time, lat, lon)	Liquid cloud albedo at 0.8 µm - mean of individual pixel retrievals
cla_vis008_liq_std(time, lat, lon)	Liquid cloud albedo at 0.8 µm - standard deviation of individual pixel retrievals
cla_vis008_liq_unc(time, lat, lon)	Liquid cloud albedo at 0.8 µm - mean of individual pixel uncertainties
cla_vis008_ice(time, lat, lon)	Ice cloud albedo at 0.8 µm - mean of individual pixel retrievals
cla_vis008_ice_std(time, lat, lon)	Ice cloud albedo at 0.8 µm - standard deviation of individual pixel retrievals
cla_vis008_ice_unc(time, lat, lon)	Ice cloud albedo at 0.8 µm - mean of individual pixel uncertainties
Cloud water path	
lwp(time, lat, lon)	Cloud liquid water path - mean of individual pixel retrievals
lwp_std(time, lat, lon)	Cloud liquid water path - standard deviation of individual pixel retrievals
lwp_prop_unc(time, lat, lon)	Cloud liquid water path - propagated uncertainty: total uncertainty from individual pixel uncertainty added in quadrature
lwp_corr_unc(time, lat, lon)	Cloud liquid water path - correlated uncertainty assuming correlation of 0.1
lwp_unc(time, lat, lon)	Cloud liquid water path - mean of individual pixel uncertainties
lwp_allsky(time, lat, lon)	Cloud liquid water path all-sky - grid box mean of individual pixel retrievals, including clear-sky pixels
iwp(time, lat, lon)	Cloud ice water path - mean of individual pixel retrievals
iwp_std(time, lat, lon)	Cloud ice water path - standard deviation of individual pixel retrievals

Level-3C/3S variable	Description
iwp_prop_unc(time, lat, lon)	Cloud ice water path - propagated uncertainty: total uncertainty from individual pixel uncertainty added in quadrature
iwp_corr_unc(time, lat, lon)	Cloud ice water path - correlated uncertainty assuming correlation of 0.1
iwp_unc(time, lat, lon)	Cloud ice water path - mean of individual pixel uncertainties
iwp_allsky(time, lat, lon)	Cloud ice water path all-sky - grid box mean of individual pixel retrievals, including clear-sky pixels
Histograms	
hist2d_cot_ctp(time, hist_phase, hist2d_ctp_bin_centre, hist2d_cot_bin_centre, lat, lon)	Two-dimensional, COT-CTP histogram containing absolute counts
hist2d_ctp_bin_centre	Center of CTP bins in 2-dim COT-CTP histogram
hist2d_cot_bin_centre	Center of COT bins in 2-dim COT-CTP histogram
hist2d_ctp_bin_border	Borders of CTP bins in 2-dim COT-CTP histogram
hist2d_cot_bin_border	Borders of COT bins in 2-dim COT-CTP histogram
hist1d_cot(time, hist_phase, hist1d_cot_bin_centre, lat, lon)	1-dimensional histogram of cloud optical thickness per grid cell
hist1d_cot_bin_centre	Center of COT bins in 1-dim COT histogram
hist1d_cot_bin_border	Borders of COT bins in 1-dim COT histogram
hist1d_ctp(time, hist_phase, hist1d_ctp_bin_centre, lat, lon)	1-dimensional histogram of cloud top pressure per grid cell
hist1d_ctp_bin_centre	Center of CTP bins in 1-dim CTP histogram
hist1d_ctp_bin_border	Borders of CTP bins in 1-dim CTP histogram
hist1d_ctt(time, hist_phase, hist1d_ctt_bin_centre, lat, lon)	1-dimensional histogram of cloud top temperature per grid cell
hist1d_ctt_bin_centre	Center of CTT bins in 1-dim CTT histogram
hist1d_ctt_bin_border	Borders of CTT bins in 1-dim CTT histogram
hist1d_cer(time, hist_phase, hist1d_cer_bin_centre, lat, lon)	1-dimensional histogram of cloud effective radius per grid cell
hist1d_cer_bin_centre	Center of CER bins in 1-dim CER histogram

Level-3C/3S variable	Description
hist1d_cer_bin_border	Borders of CER bins in 1-dim CER histogram
hist1d_cwp(time, hist_phase, hist1d_cwp_bin_centre, lat, lon)	1-dimensional histogram of cloud water path per grid cell
hist1d_cwp_bin_centre	Center of CWP bins in 1-dim CWP histogram
hist1d_cwp_bin_border	Borders of CWP bins in 1-dim CWP histogram
hist1d_cla_vis006(time, hist_phase, hist1d_cla_vis006_bin_centre, lat, lon)	1-dimensional histogram of cloud albedo at 0.6µm per grid cell
hist1d_cla_vis006_bin_centre	Center of CLA_vis006 bins in 1-dim CLA_vis006 histogram
hist1d_cla_vis006_bin_border	Borders of CLA_vis006 bins in 1-dim CLA_vis006 histogram
hist1d_cla_vis008(time, hist_phase, hist1d_cla_vis008_bin_centre, lat, lon)	1-dimensional histogram of cloud albedo at 0.8µm per grid cell
hist1d_cla_vis008_bin_centre	Center of CLA_vis008 bins in 1-dim CLA_vis008 histogram
hist1d_cla_vis008_bin_border	Borders of CLA_vis008 bins in 1-dim CLA_vis008 histogram

Annex C – Propagation of Level-3 uncertainties into higher level products

This section is provides basic information on the propagation of uncertainties provided in Cloud_cci Level-3 products to higher level products such as zonal or global means.

To recall, the reported pixel-based uncertainties X_{unc} for a given variable X (both being a result of the optimal estimation technique) represent the 68% confidence interval that the true value is within $X \pm X_{unc}$. Given this, it can be assumed that for 68% of all pixels the truth is within $X \pm X_{unc}$. This confidence interval can be propagated into Level-3 product, i.e. monthly mean values, following the rationale given in equation 1 to 5 in Stengel et al. (2017) which are repeated in the following:

$$\sigma_{\mathrm{std}}^2 = \frac{1}{\mathrm{N}} \sum_{i=1}^{\mathrm{N}} (x_i - \langle x \rangle)^2$$ Equation (1)

$$\langle \sigma_i \rangle = \frac{1}{\mathrm{N}} \sum_{i=1}^{\mathrm{N}} (\sigma_i)$$ Equation (2)

$$\langle \sigma_i^2 \rangle = \frac{1}{\mathrm{N}} \sum_{i=1}^{\mathrm{N}} (\sigma_i^2)$$ Equation (3)

$$\sigma_{natural}^2 = \sigma_{std}^2 - (1-c)\langle \sigma_i^2 \rangle$$ Equation (4)

$$\sigma_{\langle x \rangle}^2 = \frac{1}{N}\sigma_{natural}^2 + c\langle \sigma_i \rangle^2 + (1-c)\frac{1}{N}\langle \sigma_i^2 \rangle$$ Equation (5)

Equation (5) reports the uncertainty of the a monthly mean value which is calculated from OE output variables and their uncertainties (σ_i). This uncertainty of the mean ($\sigma_{\langle x \rangle}$) also represents a 68% confidence interval around the calculated mean ($\langle x \rangle$), meaning a likelihood of 68% that the truth is within $\langle x \rangle \pm \sigma_{\langle x \rangle}$.

Based on these Level-3 uncertainty rationale above, the uncertainties for higher level products, such as zonal, global, annual or multi-annual means (Level-4 hereafter), can be formulated in a similar fashion. For this we replace σ_i, which is the pixel-based (Level-2) uncertainty, by $\sigma_{\langle x \rangle}$ which is the uncertainty of a averaged value (Level-3) in equation (5) to express the uncertainty of the Level-4 mean of means ($\sigma_{\langle \langle x \rangle_j \rangle}^2$); see equation (6).

$$\sigma_{\langle \langle x \rangle_j \rangle}^2 = \frac{1}{M}(\sigma_{\langle x \rangle})_{std}^2 + c\langle (\sigma_{\langle x \rangle})_j \rangle^2 + (1-c)\frac{1}{M}\langle (\sigma_{\langle x \rangle})_j^2 \rangle$$ Equation (6)

$$\sigma_{\langle \langle x \rangle_j \rangle} = \frac{1}{\mathrm{M}} \sqrt{\sum_{j=1}^{\mathrm{M}} ((\sigma_{\langle x \rangle})_j^2)}$$ Equation (7)

Assuming all Level-3 uncertainties being random and uncorrelated the Level-4 uncertainty reduces to the third term of the right hand side of equation (6), which is basically just adding the Level-3 uncertainties in quadrature (as done for uncertainty propagation for sums) devided by the number M (equation (7)). It needs to be noted that in this scenario also a large set of Level-3 input data is assumed which allows the omission of the first term on the right hand side of equation (6), which represents the sampling uncertainty for a Gaussian distributed sample. In the following the impact of incorporating different uncertainty propagation terms is discussed.

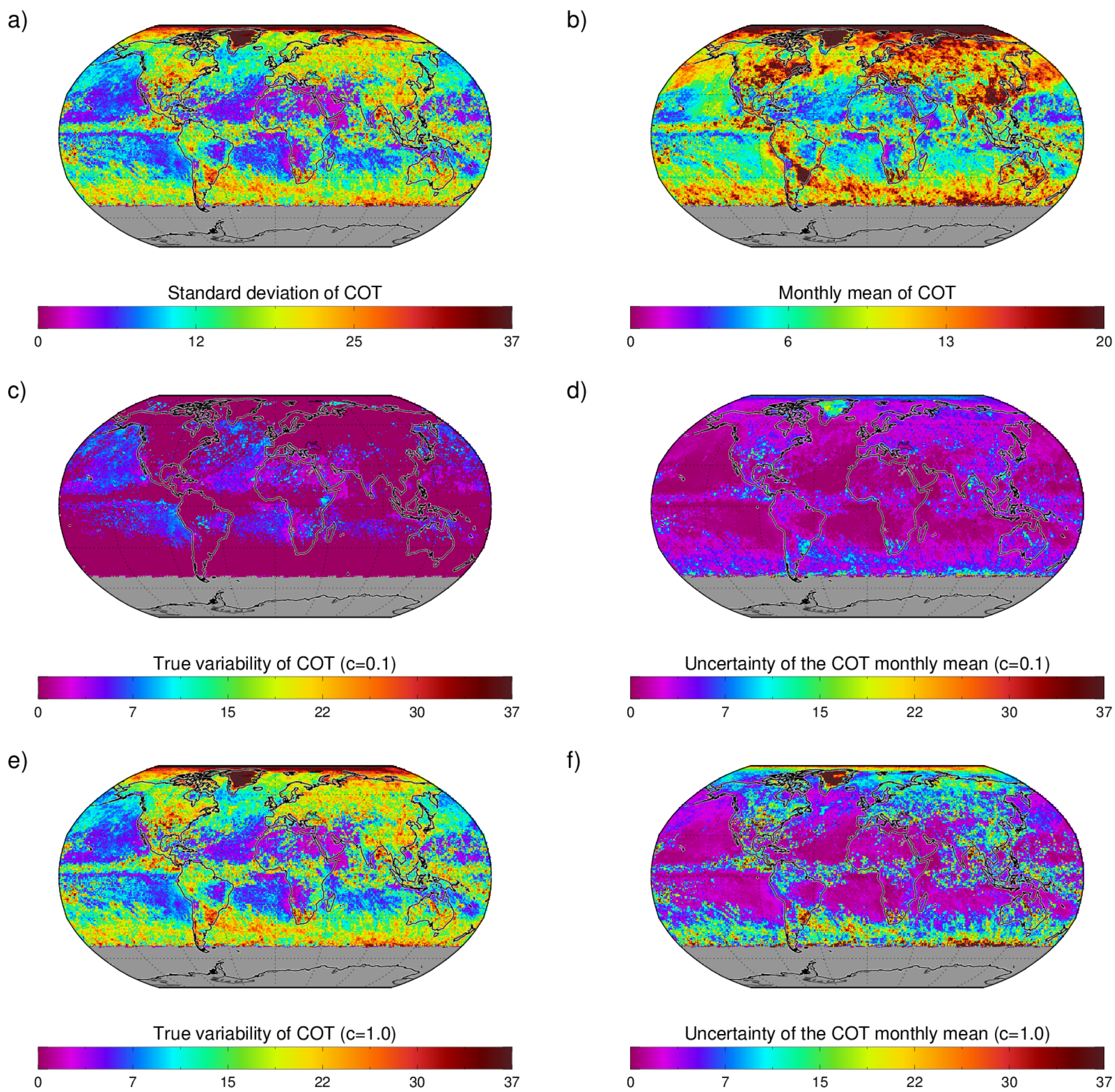

Figure C-1 *Monthly standard deviation (a) and monthly mean (b) for cloud optical thickness (COT). Panels (c) and (d) show the estimated natural variability and uncertainty of the mean (d) for a correlation of 0.1. Panel (e) and (f) are as panels (c) and (d) but for an uncertainty correlation of 1.0. All data is from AVHRR-PM in 2008/06. Figure taken from Stengel et al. (2017).*

Panels (d) and (f) of Figure C-1 show global maps of the Level-3 uncertainties of COT for Level-2 uncertainty correlations of 0.1 and 1.0. These two scenarios are used in the following to demonstrate the uncertainty propagation from Level-3 monthly means to Level-4 zonal means. 5 cases are defined as given in Table C-1 with different terms being incorporated in the uncertainty propagation.

Table C-1 *Definition of test cases with differnet uncertainty terms taken into account when propagating the uncertainties from monthly means to zonal means.*

Case	Description
Case 1	Arithmetrically averaging the Level 3 uncertainties
Case 2	Using all terms of equation (6) and assuming an Level-3 uncertainty correlation of 1.0
Case 3	Using all terms of equation (6) and assuming an Level-3 uncertainty correlation of 0.1
Case 4	Using all terms of equation (6) and assuming an Level-3 uncertainty correlation of 0.0 (term 2 is vanishing).
Case 5	Using all terms of equation (6) and assuming an Level-3 uncertainty correlation of 0.0 and assuming a sampling uncertainty of 0 (only term 3 remains)

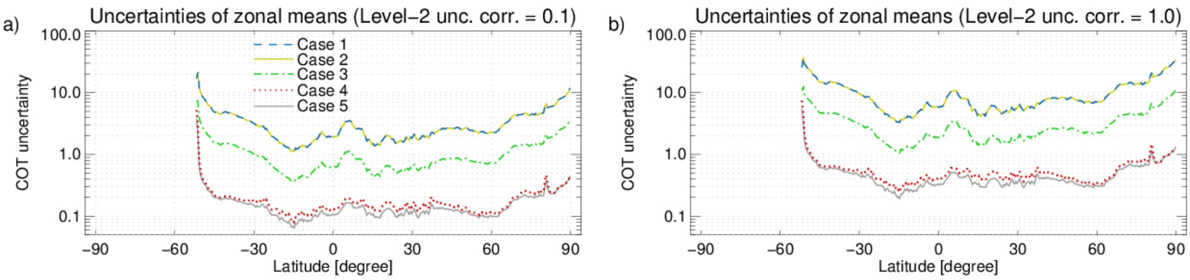

Figure C-2 *Uncertainties for zonal mean COT values shown for the 5 cases defined in Table C-1. Panel (a) shows the results when using the Level-3 uncertainties shown Figure C-1 panel (d), which are based on Level-2 uncertainty correlations of 0.1, and panel (b) shows the results when using Level-3 uncertainties shown in Figure C-1 panel (f), which are based on Level-2 uncertainty correlations of 1.0.*

For all 5 cases the uncertainties of the zonal mean (calculated from the 2d fields of monthly means) were determined and are shown in Figure C-2. Case 1 and Case 2 uncertainties are identical, which is clear when considering that equation (6) reduces to the seconded term for uncertainty correlations of 1.0, which is the artimetrical average of the Level-3 uncertainties. When reducing the Level-3 uncertainty correlation, Level-4 uncertainties reduce as well (Case 3). Level-4 uncertainties are partly more than 10 times lower when assuming no Level-3 uncertainty correlations compared to assuming a correlation of 1.0. The sampling uncertainty, visible as difference between Case 1 and Case 2 is only of minor importance in the given scenarios.

As demonstrated in the discussion above, the uncertainty correlations drive the amplitude of the higher level uncertainties, although they remain to be not exacty known at the moment.