

ESA Cloud_cci Product User Guide (PUG)

Cloud_cci+ Phase 1 SEVIRI and SLSTR
demonstrator data products version 3



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Document Change Record

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PUGv1.0	30/06/2023	Initial version	M. Stengel
PUGv1.1	22/01/2024	Added warnings for COT and CER retrievals which might be erroneous due to a bug in the Earth Sun correction calculation and the treatment of NIR channels that have contributions from VIS and IR.	M. Stengel

Purpose

The purpose of this document is to provide user guidance for Cloud_cci+ Phase 1 SEVIRI and SLSTR demonstrator data products version 3 which include cloud and radiation property data.

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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.

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1. Introduction

1.1 The ESA Cloud_cci+ project

The Cloud_cci+ project contributes to and improves on the successful efforts of Cloud_cci: the development, validation and application of novel cloud property data sets maximising the use of ESA and other European EO mission data and targeting the GCOS requirements for the Cloud ECV. The current Cloud_cci+ project phase I was kicked off in March 2020.

Cloud_cci+ Phase I

The goal of the ESA Cloud_cci+ has been the improvement of retrieval algorithms and processing concepts and implementations, and the development of two demonstrator data sets based on measurements from the Spinning Enhanced Visible and Infrared Imager (SEVIRI) and from the Sea and Land Surface Temperature Radiometer (SLSTR). The processing systems have the potential to be used for a sustained data production in operational entities, for instance the EUMETSAT SAF network and the Copernicus Climate Change Service, after the current R&D under the ESA CCI programme has been completed.

A full list of planned and carried out CC4CL developments in Cloud_cci+ Phase I is given in the Algorithm Development Plan ([ADPv3.0](#)). The cloud products retrieved from SEVIRI and SLSTR remain the same compared to previous datasets and are outlined in the next subsection. The SEVIRI and SLSTR data cover the year 2019 and include the cloud products presented in the next subsection. Examples are shown in **Figure 1-1**.

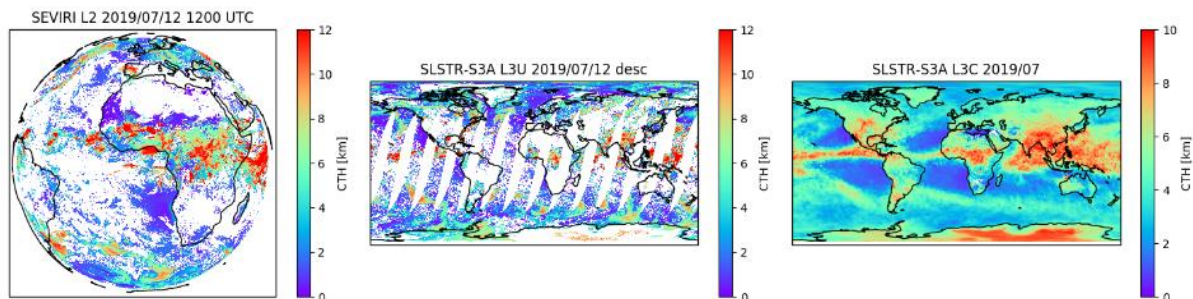


Figure 1-1 Examples of Level-2 cloud top height fields from SEVIRI (left) and SLSTR-S3a (middle). Right panel depicts an example monthly mean cloud top height field from SLSTR-S3a.

1.2 Cloud_cci cloud and radiative flux products

The cloud properties derived on satellite pixel level of each utilized sensor are listed in Table 1-1. Primarily retrieved cloud properties are CMA/CFC, CPH, CTP, COT and CER. The properties CLA, LWP, IWP are 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. Radiative fluxes properties are calculated using radiative transfer calculation (requiring ERA5 data) ingesting the retrieved cloud properties.

Based on the pixel level retrievals the data is further processed into different processing levels as summarized in Table 1-2. Level-3U denotes a global composite on a global Latitude-Longitude grid (of 0.05° resolution) onto which the Level-2 data is sampled. Level-3C products are also defined on Latitude-Longitude grid (0.5° resolution) onto which the properties are averaged and 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 1-3). The reader is referred to [ATBDv9.0](#) for more details on Level-3U and Level-3C generation)

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Table 1-1 List of generated cloud properties. CMA/CFC and CPH are derived in a pre-processing step using Artificial Neural Networks. 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. In a post-processing step, derived cloud properties and ERA-Interim information are used to determine radiative broadband fluxes.

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) 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).
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 liquid 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)
Cloud effective emissivity	CEE	cloud radiative thickness in the infrared typically referred to as the “effective emissivity”
Top of atmosphere upwards/downwards flux	TOA	Shortwave (SW) and longwave (LW) fluxes at the Top of the atmosphere, upwelling and downwelling
Top of atmosphere upwards/downwards flux - clear-sky	TOA _{clear}	Shortwave (SW) and longwave (LW) fluxes at the Top of the atmosphere, upwelling and downwelling - for clear sky conditions
Bottom of atmosphere (surface) upwards/downwards flux	BOA	Shortwave (SW) and longwave (LW) fluxes at the Bottom of the atmosphere, upwelling and downwelling
Bottom of atmosphere (surface) upwards/downwards flux - clear-sky	BOA _{clear}	Shortwave (SW) and longwave (LW) fluxes at the Bottom of the atmosphere, upwelling and downwelling - for clear sky conditions

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

Processing level	Spatial resolution	Description
Level-2 (L2)	SLSTR: 1km SEVIRI: 3-5 km	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.	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-3U data are only provided for SLSTR and not for SEVIRI products

Table 1-3 Cloud_cci product features incl. day and night separation, liquid water and ice as well as histogram representation. Level-3U refers to the un-averaged, pixel-based cloud retrievals sampled onto a global Latitude-Longitude (lat/lon) grid. ¹CMA 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
TOA_{up,dn,sw,lw}	✓	✓	✓	-
BOA_{up,dn,sw,lw}	✓	✓	✓	-

* Level-3U data are only provided for SLSTR and not for SEVIRI products

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2. Product description and guidance

This section summarizes the core cloud properties derived in Cloud_cci+ for SEVIRI and SLSTR.

2.1 Cloud mask & fraction

The used cloud detection schemes output 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 SEVIRI Level-2, SLSTR Level-3U and Level-3C are shown in Figure 2-1.

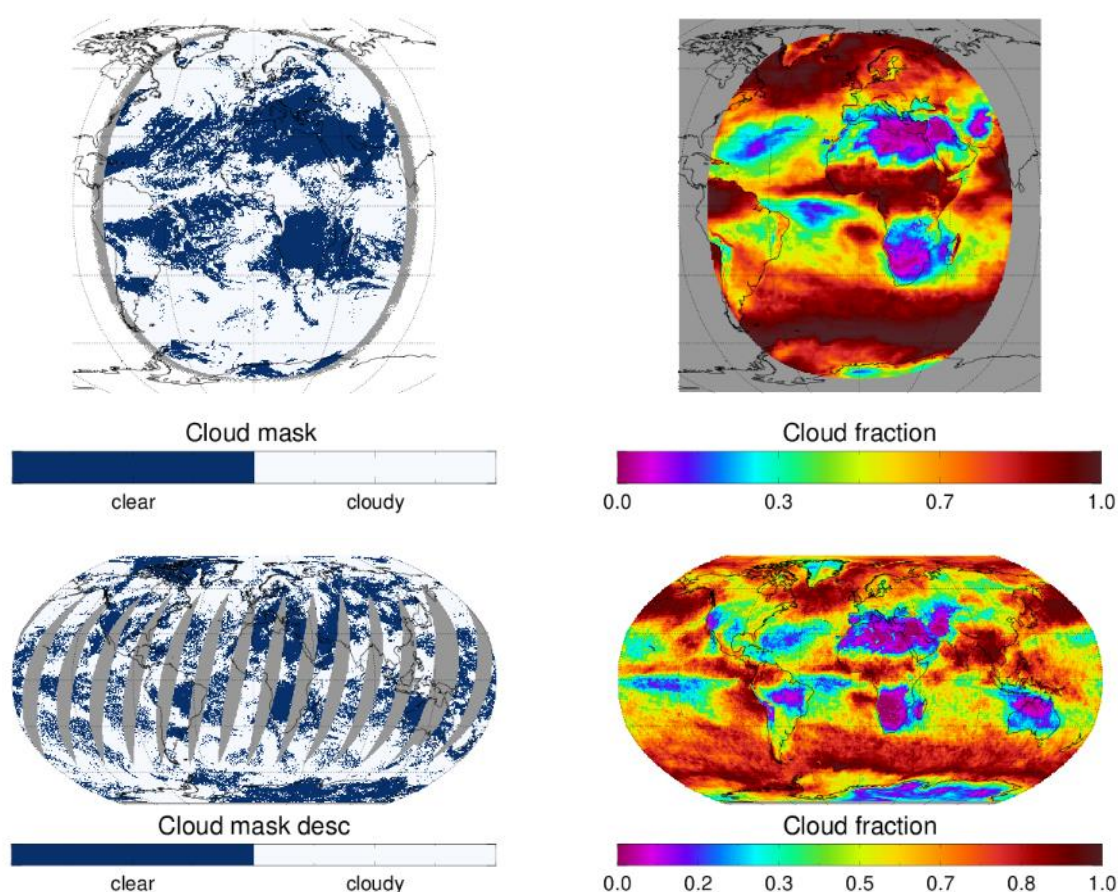


Figure 2-1 Top row: Map of Cloud_cci SEVIRI L2 cloud mask for 2019/07/01 12 UTC (left) and map of Cloud_cci SEVIRI L3C monthly mean total cloud fraction for 2019/07 (right). Bottom row: Map of Cloud_cci SLSTR S3a L3U cloud mask for 2019/07/01 (left) and map of Cloud_cci SLSTR S3a L3C monthly mean total cloud fraction for 2019/07 (right).

Short algorithm description:

SEVIRI and SLSTR cloud detection in CC4CL is based on a neural network with which CALIOP optical thickness is approximated followed by an application of thresholds. Please see [ATBDv9.0](#) and [ATBD-CC4CLv9.0](#) for more information.

Uncertainty information:

- 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

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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-3C 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.

Known limitations:

- 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 bright surfaces (also applies to all other cloud properties)
- Due to a limitation of passive imagers, the mean cloud fraction is usually biased toward lower values, compared to example CALIOP.

Cloud mask/fraction - data fields* and descriptions:

Product level	Data field name	Description
Level-2	<i>cc_total</i>	Cloud mask (0: cloud free; 1: cloudy)
Level-3U	<i>cmask_asc</i> <i>cmask_desc</i>	Cloud mask, ascending node of orbit Cloud mask, descending node of orbit
Level-3U	<i>cmask_asc_unc</i> <i>cmask_desc_unc</i>	Cloud mask uncertainty, ascending node Cloud mask uncertainty, descending node
Level-3C	<i>cfc</i>	Total cloud fraction using all available observations
Level-3C	<i>cfc_unc</i>	Uncertainty of total cloud fraction using all available observations
Level-3C	<i>cfc_day</i> <i>cfc_night</i> <i>cfc_twi</i>	Daytime cloud fraction Nighttime cloud fraction Twilight cloud fraction
Level-3C	<i>cfc_low</i> <i>cfc_mid</i> <i>cfc_high</i>	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

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2.2 Cloud phase & liquid cloud fraction

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

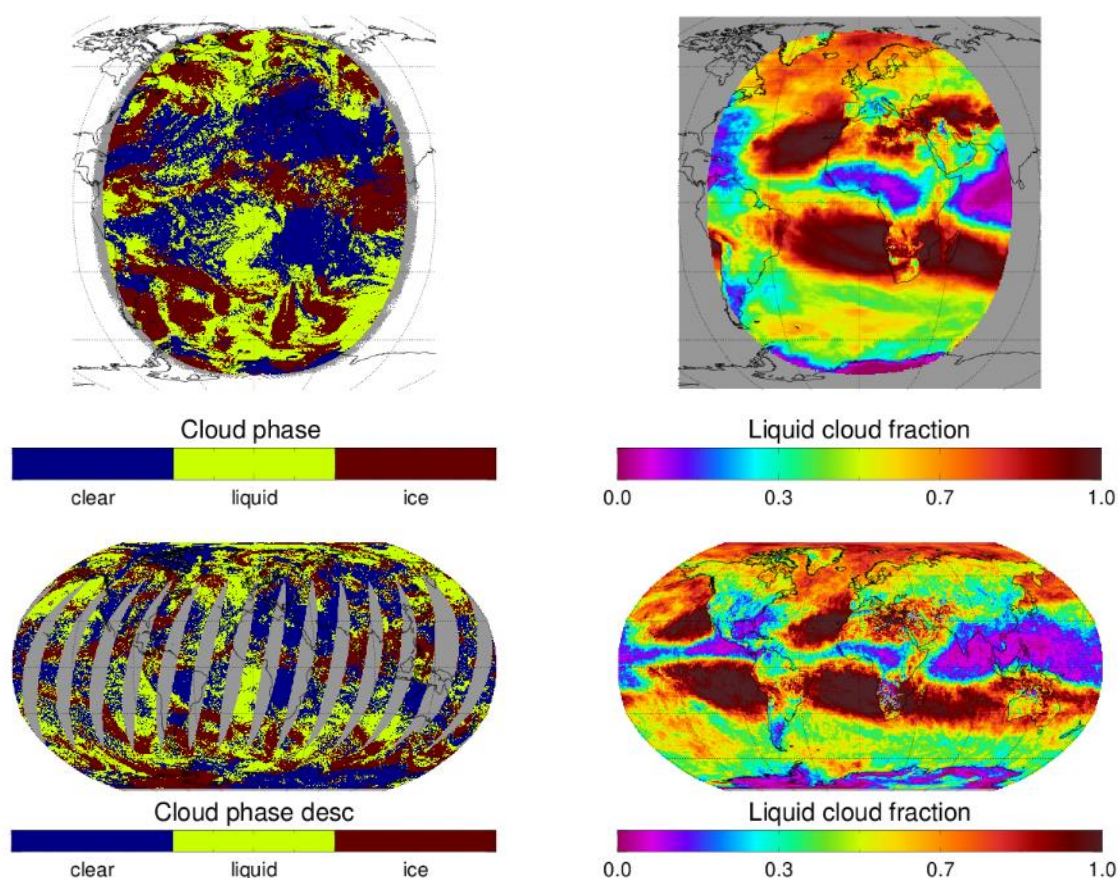


Figure 2-2 Top row: Map of Cloud_cci SEVIRI L2 cloud phase for 2019/07/01 12 UTC (left) and map of Cloud_cci SEVIRI L3C monthly mean liquid cloud fraction for 2019/07 (right). Bottom row: Map of Cloud_cci SLSTR S3a L3U cloud phase for 2019/07/01 (left) and map of Cloud_cci SLSTR S3a L3C monthly mean liquid cloud fraction for 2019/07 (right).

Short algorithm approach description:

SEVIRI and SLSTR cloud phase determination in v3 datasets is based on a neural network with which CALIOP optical thickness is approximated, followed by an application of thresholds. Please see [ATBDv9.0](#) and [ATBD-CC4CLv9.0](#) for more information.

Uncertainty information:

- Cloud phase uncertainty on pixel level (Level-2, Level-3U) originates from quantifying the agreement to CALIOP cloud phase as a function of used threshold. The uncertainty values provided

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on Level-2 are to be interpreted as probability (in %) that the given cloud phase 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 liquid cloud fraction.

Known limitations:

- Uncertainties in cloud detections (misclassified cloudy pixels) directly lead to errors in cloud phase.
- Retrieving the correct phase for uppermost, thin cloud layers is challenging.

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

Product level	Data field name	Description
Level-2	<i>phase</i>	Cloud thermodynamic phase (1: water cloud, 2: ice cloud)
Level-2	<i>phase_pavolonis</i>	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	<i>cph_asc</i> <i>cph_desc</i>	Cloud thermodynamic phase, ascending node of orbit Cloud thermodynamic phase, descending node of orbit
Level-3U	<i>cty_asc</i> <i>cty_desc</i>	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	<i>cph</i>	Liquid cloud fraction using all available observations
Level-3C	<i>cph_std</i>	Standard deviation over all Level 2 phase retrievals
Level-3C	<i>cph_day</i>	Liquid cloud fraction using daytime observations only
Level-3C	<i>cph_day_std</i>	Standard deviation over all daytime Level 2 phase retrievals

* Complete list of data fields is given in Annex B

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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 SEVIRI Level-2, SLSTR Level-3U and Level-3C are shown in Figure 2-3.

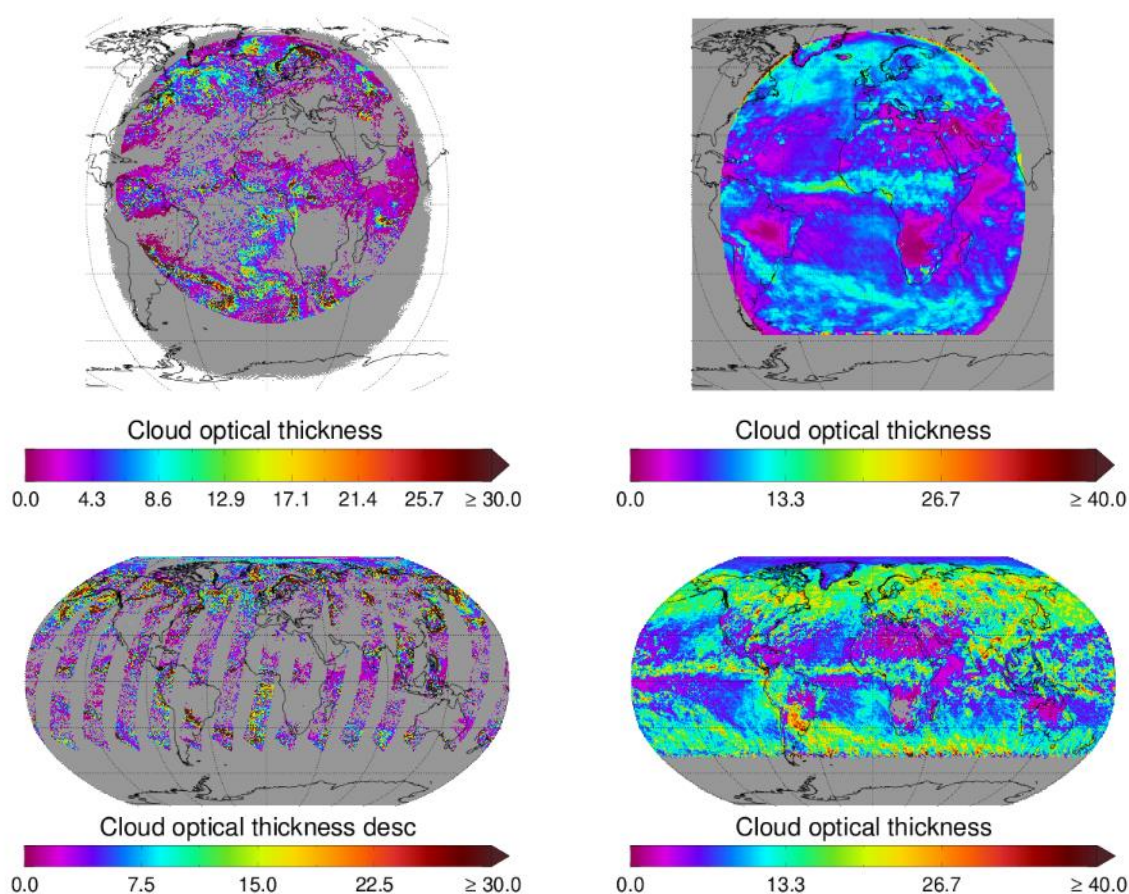


Figure 2-3 Top row: Map of Cloud_cci SEVIRI L2 cloud optical thickness for 2019/07/01 12 UTC (left) and map of Cloud_cci SEVIRI L3C monthly mean cloud optical thickness for 2019/07 (right). Bottom row: Map of Cloud_cci SLSTR S3a L3U cloud optical thickness for 2019/07/01 (left) and map of Cloud_cci SLSTR S3a L3C monthly mean cloud optical thickness for 2019/07 (right).

Short algorithm approach description:

Cloud optical thickness is direct output of the optimal estimation retrieval CC4CL ([McGarragh et al., 2018](#); [Sus et al., 2018](#), ATBD-CC4CLv9.0) 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.

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Uncertainty information:

- 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:

- 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.
- A problem in the calculation of the Earth Sun correction may impact the COT retrievals

Cloud optical thickness - data fields* and descriptions:

Product level	Data field name	Description
Level-2	<i>cot</i>	Cloud optical thickness
Level-2	<i>cot_unc</i>	Cloud optical thickness uncertainty
Level-3U	<i>cot_asc</i> <i>cot_desc</i>	Cloud optical thickness, ascending node of orbit Cloud optical thickness, descending node of orbit
Level-3U	<i>cot_asc_unc</i> <i>cot_desc_unc</i>	Cloud optical thickness uncertainty, ascending Cloud optical thickness uncertainty, descending
Level-3C	<i>cot</i>	Cloud optical thickness, mean of individual pixel retrievals
Level-3C	<i>cot_log</i>	Cloud optical thickness, logarithmic mean of individual pixel retrievals
Level-3C	<i>cot_unc</i>	Cloud optical thickness - mean of individual pixel uncertainties
Level-3C	<i>cot_std</i>	Cloud optical thickness - standard deviation of individual pixel retrievals
Level-3C	<i>cot_prop_unc</i>	Cloud optical thickness - propagated uncertainty: total uncertainty from individual pixel uncertainty added in quadrature

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

* Complete list of data fields is given in Annex B

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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 SEVIRI Level-2, SLSTR Level-3U and Level-3C are shown in Figure 2-4.

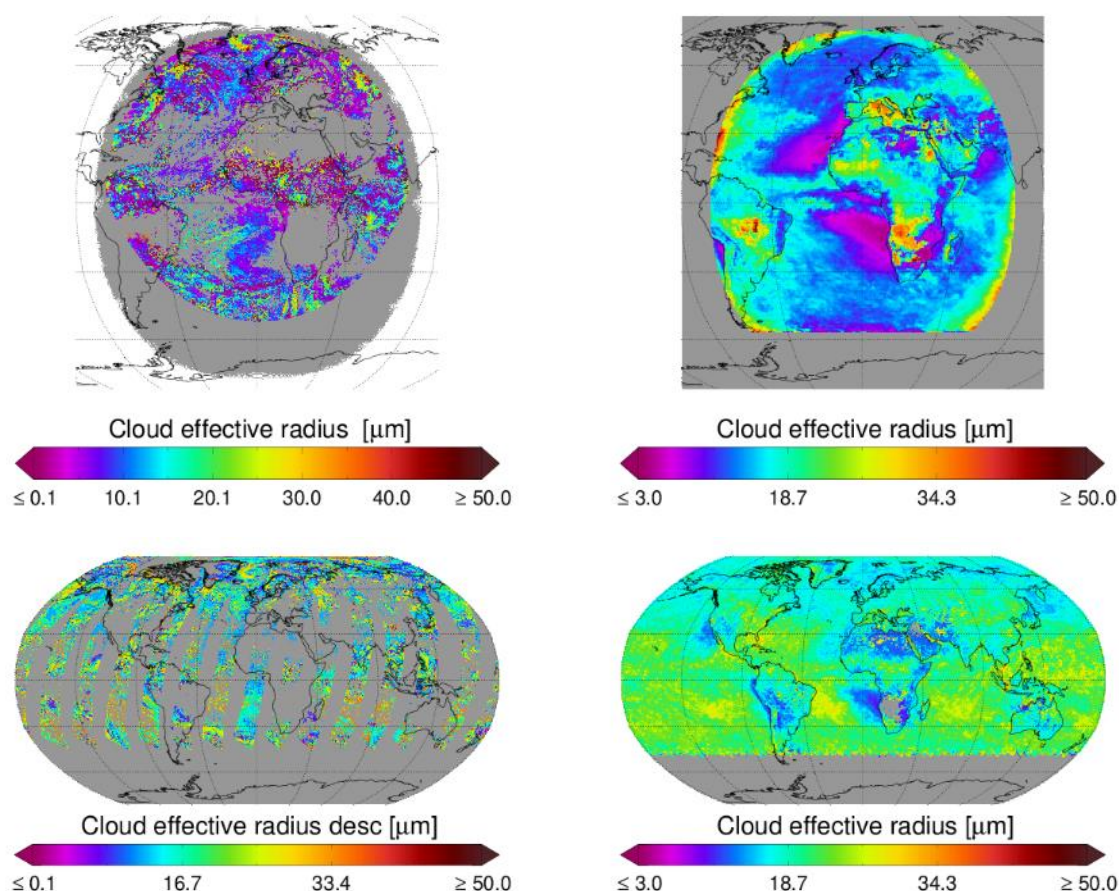


Figure 2-4 Top row: Map of Cloud_cci SEVIRI L2 cloud effective radius for 2019/07/01 12 UTC (left) and map of Cloud_cci SEVIRI L3C monthly mean cloud effective radius for 2019/07 (right). Bottom row: Map of Cloud_cci SLSTR S3a L3U cloud effective radius for 2019/07/01 (left) and map of Cloud_cci SLSTR S3a L3C monthly mean cloud effective radius for 2019/07 (right).

Short algorithm approach description:

Cloud effective radius is direct output of the optimal estimation retrieval CC4CL (McGarragh et al., 2018; Sus et al., 2018, ATBD-CC4CLv9.0) 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.

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Uncertainty information:

- 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.
- A discovered unit error in the treatment of channels which have a VIS and IR contribution (e.g. channels located around 3.8 μ m) might affect the accuracy of the CER retrievals.

Known limitations:

- 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 borders, the effective radius is likely to have significant errors.

Cloud effective radius - data fields* and descriptions:

Product level	Data field name	Description
Level-2	<i>cer</i>	Cloud effective radius
Level-2	<i>cer_unc</i>	Cloud effective radius uncertainty
Level-3U	<i>cer_asc</i> <i>cer_desc</i>	Cloud effective radius, ascending node of orbit Cloud effective radius descending node of orbit
Level-3U	<i>cer_asc_unc</i> <i>cer_desc_unc</i>	Cloud effective radius uncertainty, ascending Cloud effective radius uncertainty, descending
Level-3C	<i>cer</i>	Cloud effective radius, mean of individual pixel retrievals
Level-3C	<i>cer_unc</i>	Cloud effective radius - mean of individual pixel uncertainties
Level-3C	<i>cer_std</i>	Cloud effective radius - standard deviation of individual pixel retrievals
Level-3C	<i>cer_prop_unc</i>	Cloud effective radius - propagated uncertainty: total uncertainty from individual pixel uncertainty added in quadrature

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

* Complete list of data fields is given in Annex B

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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 SEVIRI Level-2, SLSTR Level-3U and Level-3C are shown in Figure 2-5.

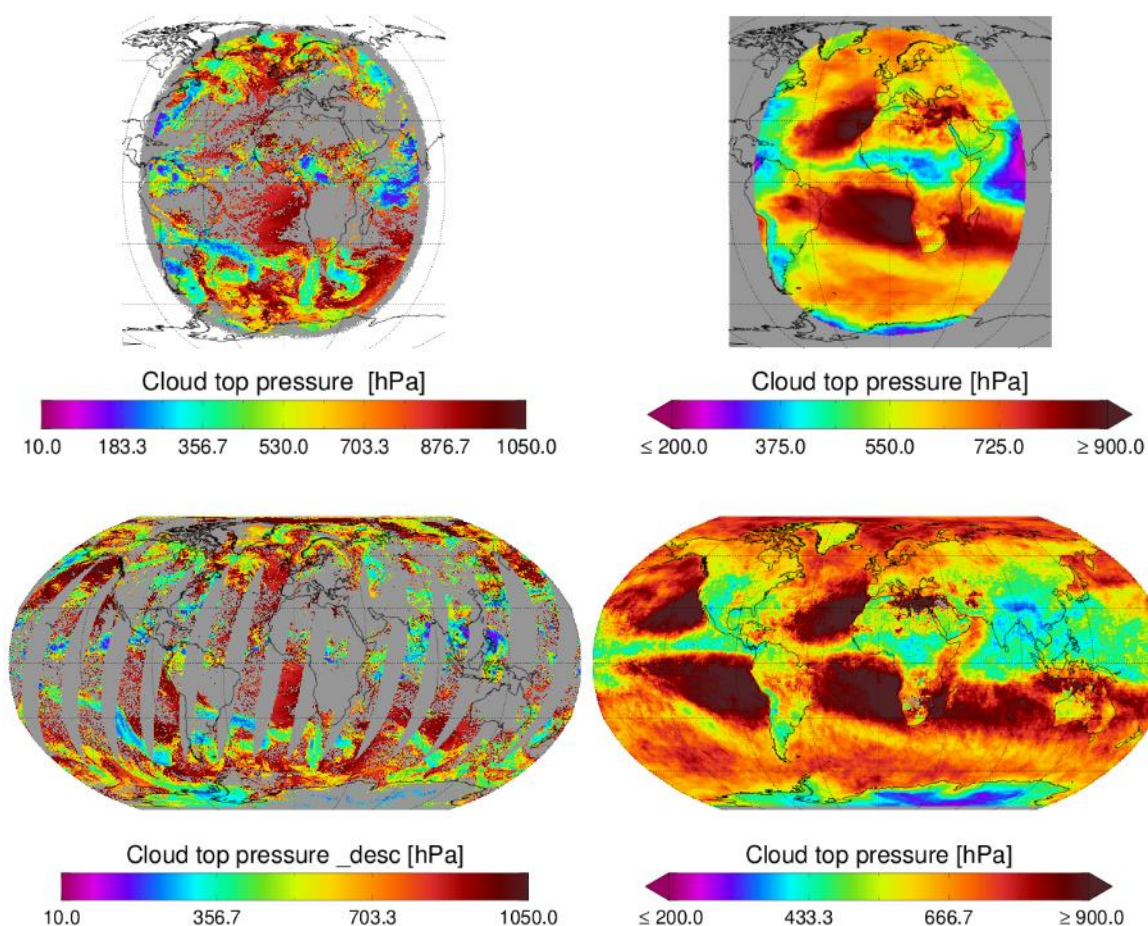


Figure 2-5 Top row: Map of Cloud_cci SEVIRI L2 cloud top pressure for 2019/07/01 12 UTC (left) and map of Cloud_cci SEVIRI L3C monthly mean cloud top pressure for 2019/07 (right). Bottom row: Map of Cloud_cci SLSTR S3a L3U cloud top pressure for 2019/07/01 (left) and map of Cloud_cci SLSTR S3a L3C monthly mean cloud top pressure for 2019/07 (right).

Short algorithm approach description:

Cloud top pressure is direct output of the optimal estimation retrieval CC4CL (McGarragh et al., 2018; Sus et al., 2018, ATBD-CC4CLv9.0) 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

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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.

Uncertainty information:

- 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 CTP uncertainty has been validated using Calipso/Cloudsat data as reference and found to not represent the actual uncertainty well

Known limitations:

- 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 infrared radiation, which is primarily used to determine the vertical placement of clouds. In such cases the measured radiance is a mixture 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).
- 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.
- The uncertainty has been validated using Calipso/Cloudsat data as reference and found to not represent the actual uncertainty well.

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

Product level	Data field name	Description
Level-2	<i>ctp/cth/ctt</i>	Cloud top pressure/height/temperature
Level-2	<i>ctp/cth/ctt_uncertainty</i>	Cloud top pressure/height/temperature uncertainty
Level-2	<i>ctp/cth/ctt_corrected</i>	Corrected Cloud top pressure/height/temperature uncertainty
Level-2	<i>ctp/cth/ctt_corrected_unc</i>	Corrected cloud top pressure/height/temperature uncertainty

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Product level	Data field name	Description
Level-3U	<i>ctp/cth/ctt_asc</i> <i>ctp/cth/ctt_desc</i>	Cloud top pressure/height/temperature, ascending node of orbit Cloud top pressure/height/temperature, descending node of orbit
Level-3U	<i>ctp/cth/ctt_asc_unc</i> <i>ctp/cth/ctt_desc_unc</i>	Cloud top pressure/height/temperature uncertainty, ascending node of orbit Cloud top pressure/height/temperature uncertainty, descending node of orbit
Level-3U	<i>ctp/cth/ctt_corrected_asc</i> <i>ctp/cth/ctt_corrected_desc</i>	Corrected cloud top pressure/height/temperature, ascending node of orbit Corrected cloud top pressure/height/temperature, descending node of orbit
Level-3U	<i>ctp/cth/ctt_corrected_asc_unc</i> <i>ctp/cth/ctt_corrected_desc_unc</i>	Corrected cloud top pressure/height/temp. uncertainty, ascending node of orbit Corrected cloud top pressure/height/temp. uncertainty, descending node of orbit
Level-3C	<i>ctp/cth/ctt</i>	Cloud top pressure/height/temperature, mean of individual pixel retrievals
Level-3C	<i>ctp/cth/ctt_std</i>	Cloud top pressure/height/temp. - standard deviation of individual pixel retrievals
Level-3C	<i>ctp/cth/ctt_unc</i>	Cloud top pressure/height/temperature - mean of individual pixel uncertainties
Level-3C	<i>ctp/cth/ctt_corrected</i>	Corrected cloud top pressure/height/temperature, mean of individual pixel retrievals
Level-3C	<i>ctp/cth/ctt_corrected_std</i>	Corrected cloud top pressure/height/temperature, standard deviation of individual pixel retrievals
Level-3C	<i>ctp/cth/ctt_prop_unc</i>	Cloud top pressure/height/temperature - propagated uncertainty: total uncertainty from individual pixel uncertainty added in quadrature
Level-3C	<i>ctp/cth/ctt_corr_unc</i>	Cloud top pressure/height/temperature - correlated uncertainty assuming correlation of 0.1
Level-3C	<i>ctp/cth/ctt_corrected_prop_unc</i>	Corrected cloud top pressure/height/temperature - propagated uncertainty: total uncertainty from individual pixel uncertainty added in quadrature

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Product level	Data field name	Description
Level-3C	<i>ctp/cth/ctt_corrected_corr_unc</i>	Corrected cloud top pressure/height/temperature - correlated uncertainty assuming correlation of 0.1
Level-3C	<i>hist1d_ctp/hist1d_ctt</i>	Cloud top pressure/temperature - histogram

* Complete list of data fields is given in Annex B

 cloud cci	Doc:		Cloud_cci+_D4.2_PUG_v1.1.docx		
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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 SEVIRI L2, SLSTR Level-3U (cloud water path is shown) and Level-3C are shown in Figure 2-6.

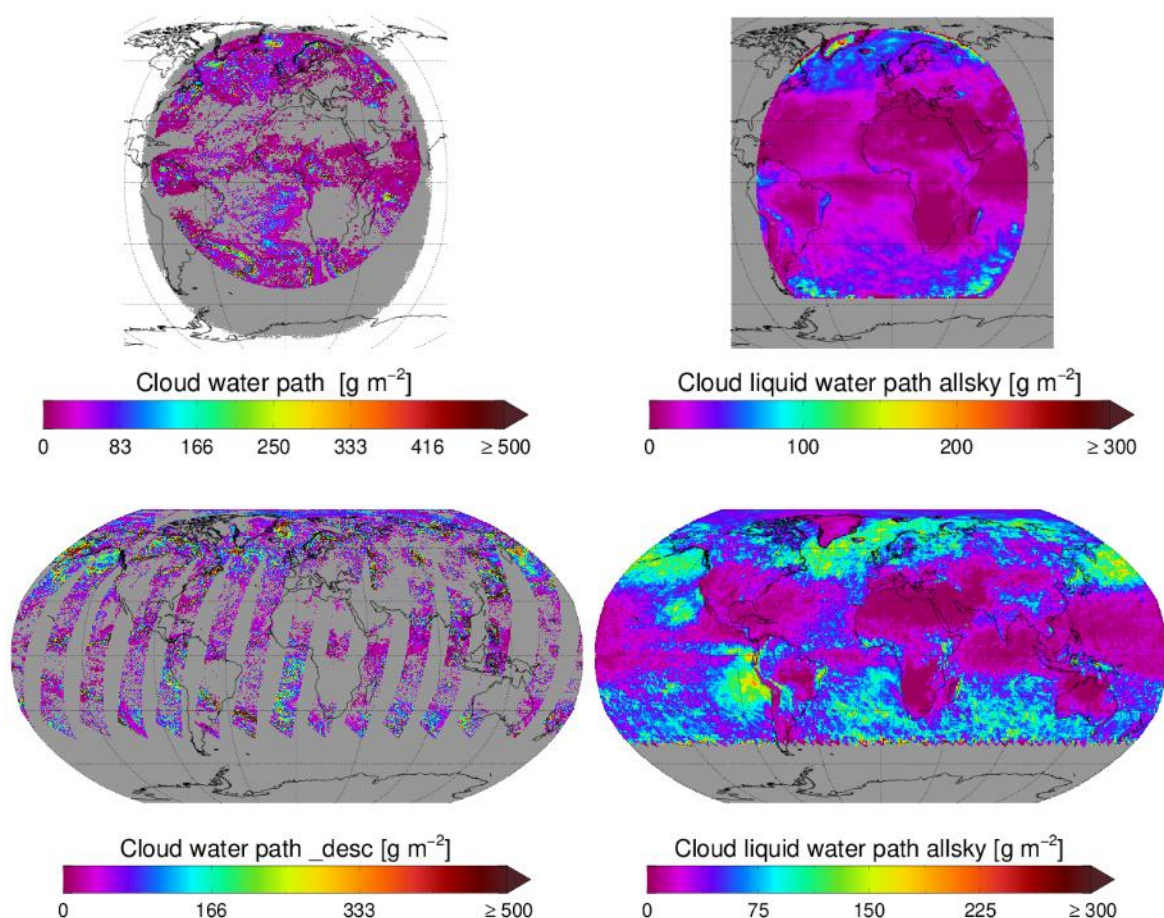


Figure 2-6 Top row: Map of Cloud_cci SEVIRI L2 cloud water path for 2019/07/01 12 UTC (left) and map of Cloud_cci SEVIRI L3C monthly mean cloud liquid water path for 2019/07 (right). Bottom row: Map of Cloud_cci SLSTR S3a L3U cloud water path for 2019/07/01 (left) and map of Cloud_cci SLSTR S3a L3C monthly mean cloud liquid water path for 2019/07 (right).

Short algorithm approach description:

Cloud water path (LWP) is diagnosed from retrieved COT and CER using the [Stephens \(1978\)](#) relation (More details in [ATBD-CC4CLv9.0](#)). Vertically homogeneous clouds are assumed, thus a factor of 2/3 is used in the Stephens formula.

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Uncertainty information:

- 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.

Known limitations:

- 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.

Cloud liquid water path - data fields* and descriptions:

Product level	Data field name	Description
Level-2	<i>cwp</i>	Cloud water path
Level-2	<i>cwp_uncertainty</i>	Cloud water path uncertainty
Level-3U	<i>cwp_asc</i> <i>cwp_desc</i>	Cloud water path, ascending node of orbit Cloud water path, descending node of orbit
Level-3U	<i>cwp_asc_unc</i> <i>cwp_desc_unc</i>	Cloud water path uncertainty, ascending Cloud water path uncertainty, descending
Level-3C	<i>lwp</i>	Cloud liquid water path, mean of individual pixel retrievals
Level-3C	<i>lwp_unc</i>	Cloud liquid water path - mean of individual pixel uncertainties
Level-3C	<i>lwp_std</i>	Cloud liquid water path - standard deviation of individual pixel retrievals
Level-3C	<i>lwp_prop_unc</i>	Cloud liquid water path - propagated uncertainty: total uncertainty from individual pixel uncertainty added in quadrature
Level-3C	<i>lwp_corr_unc</i>	Cloud liquid water path - correlated uncertainty assuming correlation of 0.1

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Level-3C	<i>lwp_allsky</i>	Cloud liquid water path all-sky - grid box mean of individual pixel retrievals, including clear-sky pixels
Level-3C	<i>hist1d_cwp</i>	Cloud water path - histogram

* Complete list of data fields is given in Annex B

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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 SEVIRI Level-2, SLSTR Level-3U (cloud water path is shown) and Level-3C are shown in Figure 2-7.

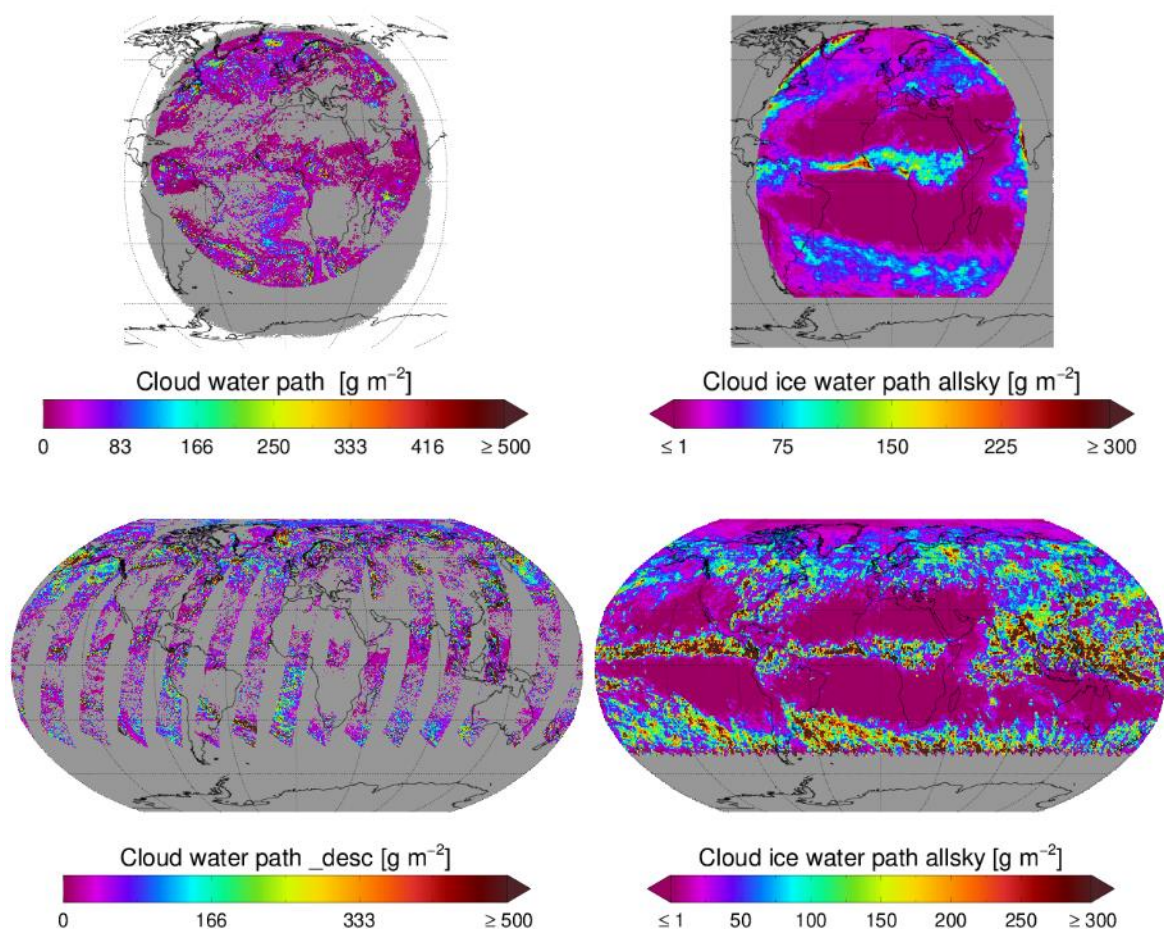


Figure 2-7 Top row: Map of Cloud_cci SEVIRI L2 cloud water path for 2019/07/01 12 UTC (left) and map of Cloud_cci SEVIRI L3C monthly mean cloud ice water path for 2019/07 (right). Bottom row: Map of Cloud_cci SLSTR S3a L3U cloud water path for 2019/07/01 (left) and map of Cloud_cci SLSTR S3a L3C monthly mean cloud ice water path for 2019/07 (right).

Short algorithm approach description:

Cloud ice path (IWP) is diagnosed from retrieved COT and CER using the [Stephens \(1978\)](#) relation (More details in [ATBD-CC4CLv9.0](#)).

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Uncertainty information:

- 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.

Known limitations:

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

Cloud ice water path - data fields and descriptions:

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

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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 ($0.67\ \mu\text{m}$) and channel 2 ($0.87\ \mu\text{m}$), 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 SEVIRI Level-2, SLSTR Level-3U and Level-3C are shown in Figure 2-8.

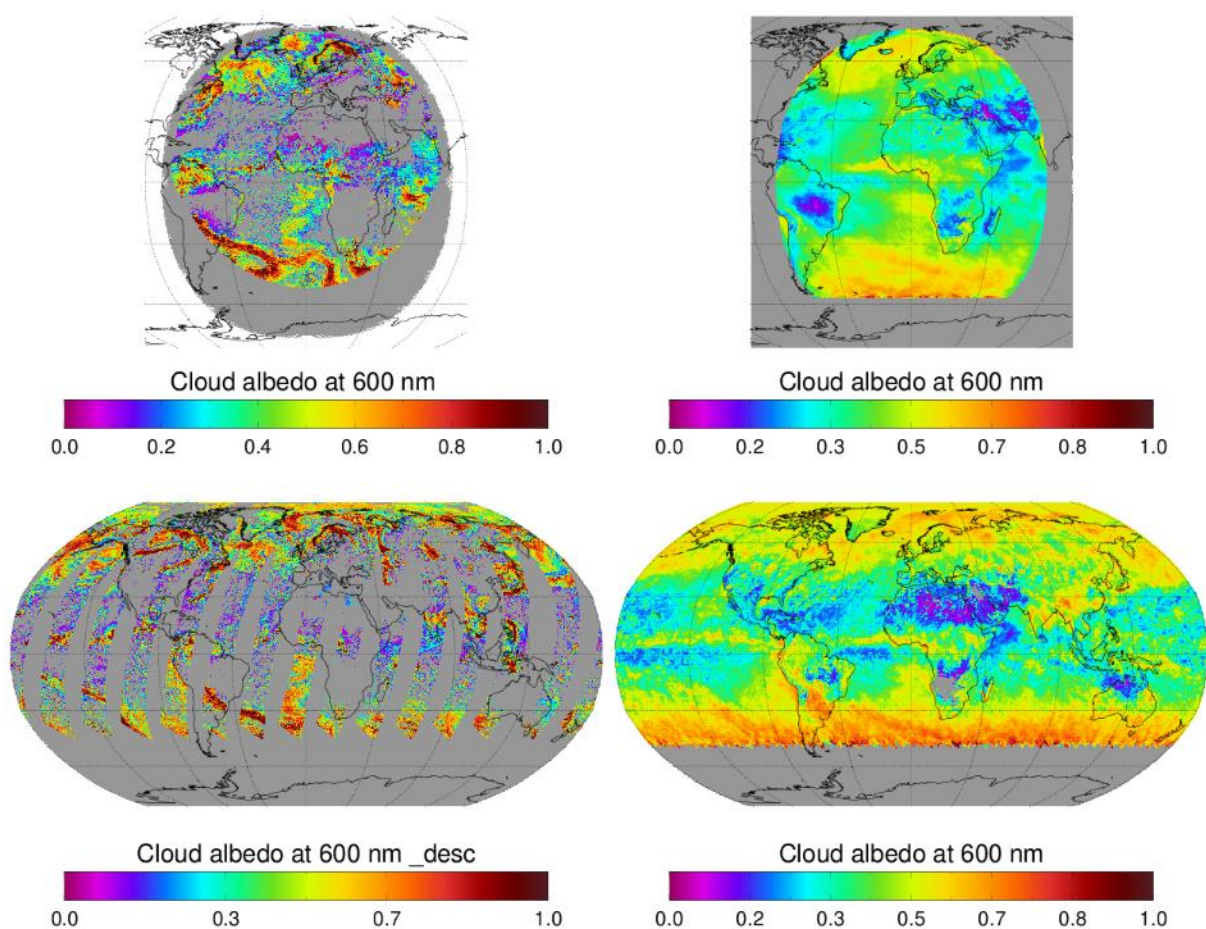


Figure 2-8 Top row: Map of Cloud_cci SEVIRI L2 spectral cloud albedo for 2019/07/01 12 UTC (left) and map of Cloud_cci SEVIRI L3C monthly mean spectral cloud albedo for 2019/07 (right). Bottom row: Map of Cloud_cci SLSTR S3a L3U spectral cloud albedo for 2019/07/01 (left) and map of Cloud_cci SLSTR S3a L3C monthly mean spectral cloud albedo for 2019/07 (right).

Short algorithm approach description:

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 (More details in [ATBD-CC4CLv9.0](#)).

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Uncertainty information:

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

Known Limitations:

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

Spectral cloud albedo - data fields* and descriptions:

Product level	Data field name	Description
Level-2	<i>cloud_albedo_in_channel_no_1/2</i>	Cloud albedo at 0.6µm/0.8µm
Level-2	<i>cloud_albedo_uncertainty_in_channel_no_1/2</i>	Cloud albedo at 0.6µm/0.8µm uncertainty
Level-3U	<i>cla_vis006/008_asc</i> <i>cla_vis006/008_desc</i>	Cloud albedo at 0.6µm/0.8µm, ascending node of orbit Cloud albedo at 0.6µm/0.8µm, descending node of orbit
Level-3U	<i>cla_vis006/008_asc_unc</i> <i>cla_vis006/008_desc_unc</i>	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	<i>cla_vis006/008</i>	Cloud albedo at 0.6µm/0.8µm - mean of individual pixel retrievals
Level-3C	<i>cla_vis006/008_unc</i>	Cloud albedo at 0.6µm/0.8µm - mean of individual pixel uncertainties
Level-3C	<i>cla_vis006/008_std</i>	Cloud albedo at 0.6µm/0.8µm - standard deviation of individual pixel retrievals
Level-3C	<i>cla_vis006/008_liq/ice</i>	Liquid/ice cloud albedo at 0.6µm/0.8µm - mean of individual pixel retrievals
Level-3C	<i>cla_vis006/008_liq/ice_unc</i>	Liquid/ice cloud albedo at 0.6µm/0.8µm - mean of individual pixel uncertainties
Level-3C	<i>cla_vis006/008_liq/ice_std</i>	Liquid/ice cloud albedo at 0.6µm/0.8µm - standard deviation of individual pixel retrievals
Level-3C	<i>cla_vis006/008_prop_unc</i>	Cloud albedo at 0.6µm/0.8µm - propagated uncertainty: total uncertainty from

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		individual pixel uncertainty added in quadrature
Level-3C	<i>cla_vis006/008_corr_unc</i>	Cloud albedo at 0.6µm/0.8µm - correlated uncertainty assuming correlation of 0.1
Level-3C	<i>hist1d_cla_vis006/008</i>	Cloud albedo at 0.6µm/0.8µm - histogram

* Complete list of data fields is given in Annex B

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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 (SLSTR) or over the disk (SEVIRI) and when presented as map of relative occurrence of a specific cloud type.

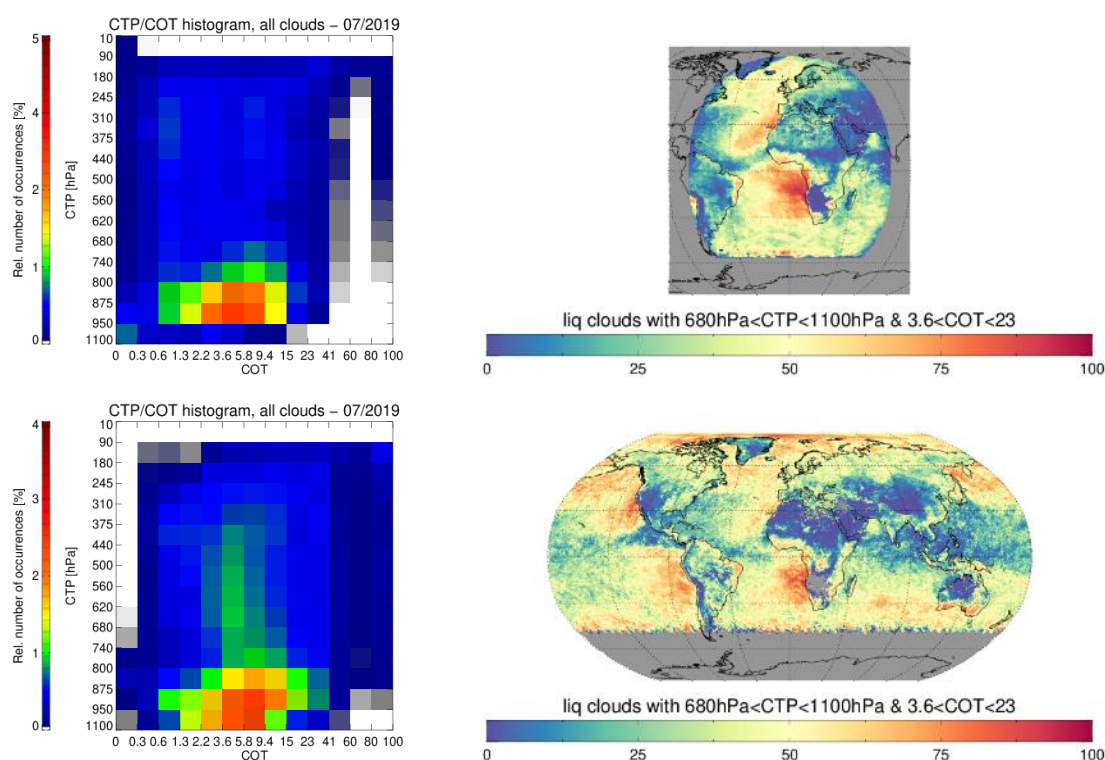


Figure 2-9 Top row: Left: Cloud_cci SEVIRI JCH histogram after aggregated over all grid cells, and normalized by the total number. Right: Map of relative occurrence of stratocumulus clouds with CTP larger than 680hPa and COT between 3.6 and 23 (according to Rossow and Schiffer, 1999) with respect to all occurring clouds. Bottom row: Left: Cloud_cci SLSTR JCH histogram after aggregated over all grid cells, and normalized by the total number. Right: Map of relative occurrence of stratocumulus clouds in SLSTR data. All data is for 2019/07.

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 (More details in ATBDv9.0).

Uncertainty information:

- 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.

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Data fields* and descriptions:

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

* Complete list of data fields is given in Annex B

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2.10 Top of atmosphere broadband radiative flux

This product group contains following radiative fluxes at top of atmosphere (TOA):

- Downwelling shortwave (solar) broadband radiative flux at TOA (SWF_{TOA}^{down})
- Upwelling shortwave (solar) broadband radiative flux at TOA (SWF_{TOA}^{up})
- Upwelling longwave (thermal) broadband radiative flux at TOA (LWF_{TOA}^{up})

For the upwelling components, all-sky and clear-sky fluxes are available. All products exists on pixel level in Level-2, globally gridded but unaveraged (Level-3U) composites and as monthly mean fluxes (Level-3C) which includes already a diurnal cycle correction. Examples of SEVIRI Level-2, SLSTR Level-3U and Level-3C are shown in Figure 2-11 and Figure 2-11.

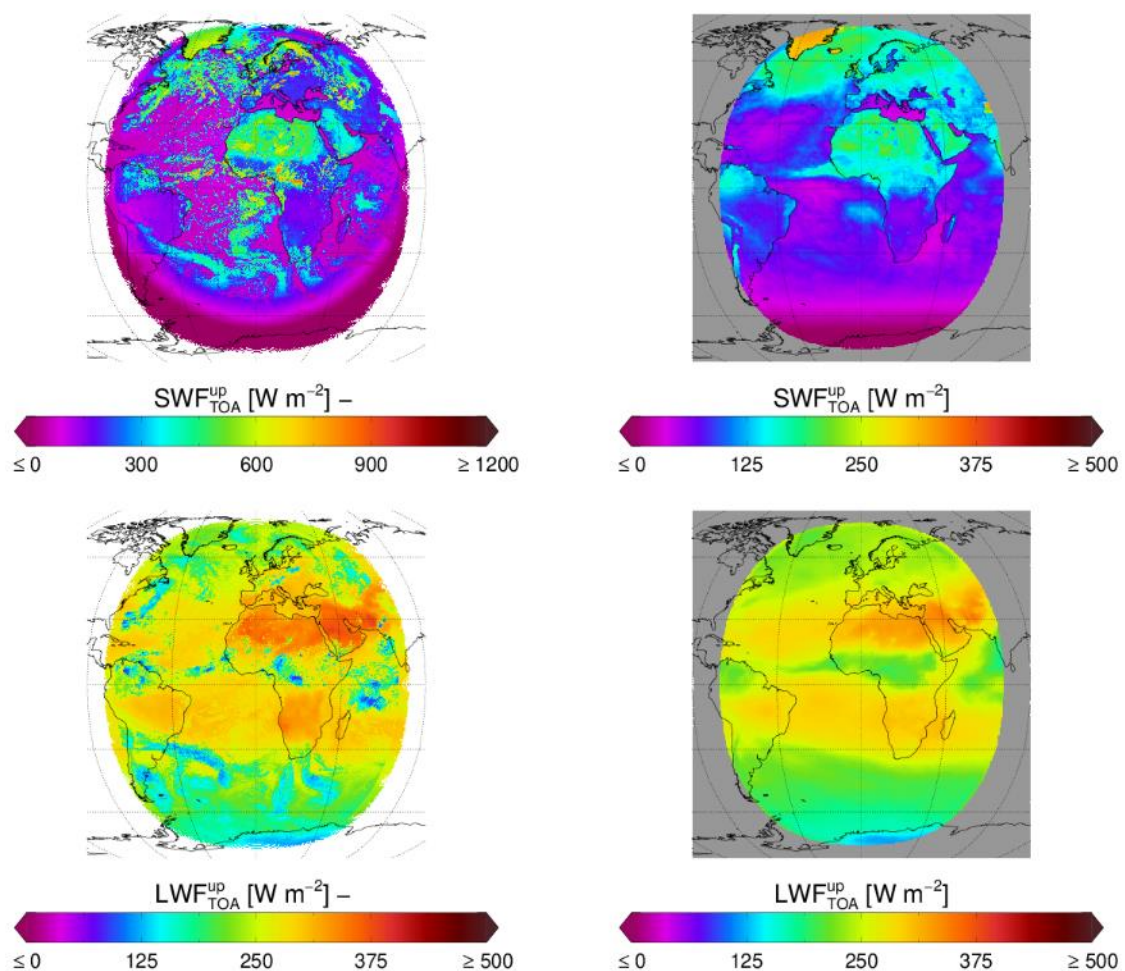


Figure 2-10 Left column: Maps of Cloud_cci SEVIRI L2 upwelling shortwave (top) and longwave (bottom) broadband flux at top of the atmosphere (SWF_{TOA}^{up} , LWF_{TOA}^{up}) for 2019/07/01 12 UTC. Right column: Maps of Cloud_cci SEVIRI L3C monthly mean upwelling shortwave (top) and longwave (bottom) broadband flux at top of the atmosphere for 2019/07.

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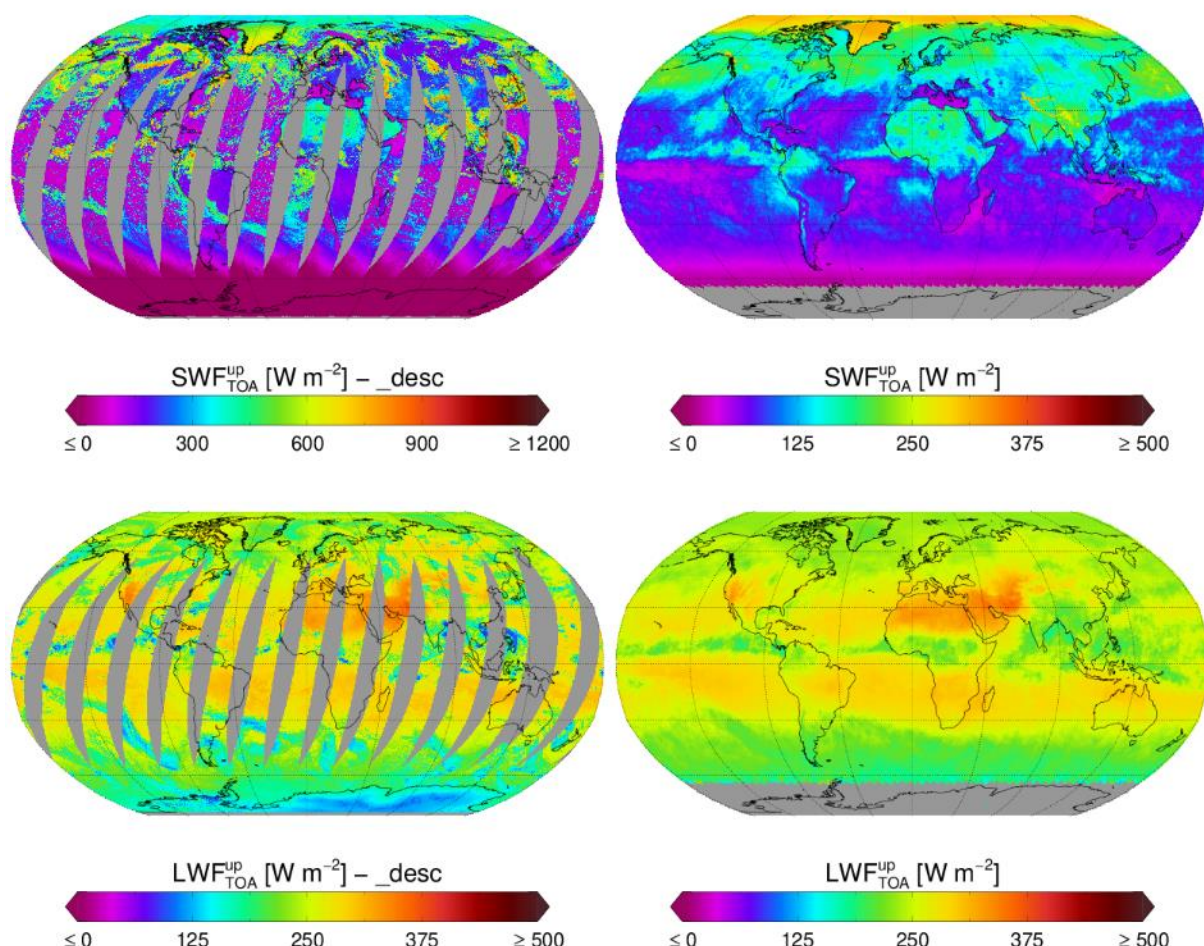


Figure 2-11 Left column: Maps of Cloud_cci SLSTR S3a L3U upwelling shortwave (top) and longwave (bottom) broadband flux at top of the atmosphere (SWF_{TOA}^{up}, LWF_{TOA}^{up}) for 2019/07/01 12 UTC. Right column: Maps of Cloud_cci SLSTR S3a L3C monthly mean upwelling shortwave (top) and longwave (bottom) broadband flux at top of the atmosphere for 2019/07.

Short algorithm approach description:

Broadband radiative fluxes are computed in a post-processing step of the CC4CL using BUGSrad (Stephens et al., 2001). BUGSrad is based on the two-stream approximation and correlated-k distribution methods of atmospheric radiative transfer. The basis of the algorithm is the same as that described by Fu and Liou (1992). It is applied to a single-column atmosphere for which the cloud and aerosol layers are assumed to be plane-parallel. Cloud properties retrieved using CC4CL are ingested into BUGSrad to compute both shortwave and longwave radiative fluxes for the top and bottom of atmosphere. The algorithm uses 18 bands that span the entire electromagnetic spectrum to compute the broadband flux. In total, 6 bands are used for shortwave and 12 bands are used for longwave radiative flux calculations. In depth information about BUGSrad and its application can be found in [ATBD-CC4CL-TOA_FLUXv1.1](#). Important to note that in twilight conditions the shortwave fluxes are based on a linear fit to measured 0.6 μm reflectances.

Uncertainty information:

- No direct uncertainty information available. However, the TOA fluxes have been evaluated by comparisons to CERES data (see PVIRv6).

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Known Limitations:

- Often the monthly mean flux calculations are based on one or two observations a day, thus based on coarse temporal sampling. However, a diurnal cycle correction is implemented to limit corresponding uncertainty when generating monthly means.
- In particular for the long-wave fluxes, a fair amount of ERA-Interim data is incorporated in the flux calculation.
- Shortwave fluxes in twilight conditions are characterized by higher uncertainties.

TOA broadband radiative fluxes - data fields* and descriptions:

Product level	Data field name	Description
Level-2	<i>toa_lwup</i>	top of atmosphere upwelling longwave radiation, all-sky
	<i>toa_lwup_clr</i>	top of atmosphere upwelling longwave radiation, clear-sky
	<i>toa_swup</i>	top of atmosphere upwelling shortwave radiation, all-sky
	<i>toa_swup_clr</i>	top of atmosphere upwelling shortwave radiation, clear-sky
	<i>toa_swdn</i>	top of atmosphere downwelling shortwave radiation
Level-3U	<i>toa_lwup_asc/desc</i>	top of atmosphere upwelling longwave radiation ascending/descending, all-sky
	<i>toa_lwup_clr_asc/desc</i>	top of atmosphere upwelling longwave radiation ascending/descending, clear-sky
	<i>toa_swup_asc/desc</i>	top of atmosphere upwelling shortwave radiation ascending/descending, all-sky
	<i>toa_swup_clr_asc/desc</i>	top of atmosphere upwelling shortwave radiation ascending/descending, clear-sky
	<i>toa_swdn_asc/desc</i>	top of atmosphere downwelling shortwave radiation ascending/descending
Level-3C	<i>toa_lwup</i>	top of atmosphere upwelling longwave radiation, all-sky
	<i>toa_lwup_clr</i>	top of atmosphere upwelling longwave radiation, clear-sky
	<i>toa_swup</i>	top of atmosphere upwelling shortwave radiation, all-sky
	<i>toa_swup_clr</i>	top of atmosphere upwelling shortwave radiation, clear-sky
	<i>toa_swdn</i>	top of atmosphere downwelling shortwave radiation, clear-sky

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<i>toa_lwup_low</i>	top of atmosphere downwelling shortwave radiation
<i>toa_lwup_mid</i>	top of atmosphere upwelling longwave radiation, all-sky + low clouds
<i>toa_lwup_hig</i>	top of atmosphere upwelling longwave radiation, all-sky + mid-level clouds
<i>toa_swup_low</i>	top of atmosphere upwelling longwave radiation, all-sky + high clouds
<i>toa_swup_mid</i>	top of atmosphere upwelling shortwave radiation, all-sky + low clouds
<i>toa_swup_hig</i>	top of atmosphere upwelling shortwave radiation, all-sky + mid-level clouds
	top of atmosphere upwelling shortwave radiation, all-sky + high clouds

* Complete list of data fields is given in Annex B

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2.11 Bottom of atmosphere broadband radiative flux

This product group contains following radiative fluxes at the surface (bottom of atmosphere, BOA):

- Downwelling shortwave (solar) broadband radiative flux at BOA (SWF_{BOA}^{down})
- Downwelling longwave (thermal) broadband radiative flux at BOA (LWF_{BOA}^{down})
- Upwelling shortwave (solar) broadband radiative flux at BOA (SWF_{BOA}^{up})
- Upwelling longwave (thermal) broadband radiative flux at BOA (LWF_{BOA}^{up})

For all components, all-sky and clear-sky fluxes are available. All products exists on pixel level in Level-2, globally gridded but unaveraged (Level-3U) composites and as monthly mean fluxes (Level-3C) which includes already a diurnal cycle correction. Examples of SEVIRI Level-2, SLSTR Level-3U and Level-3C are shown in Figure 2-12 and Figure 2-13

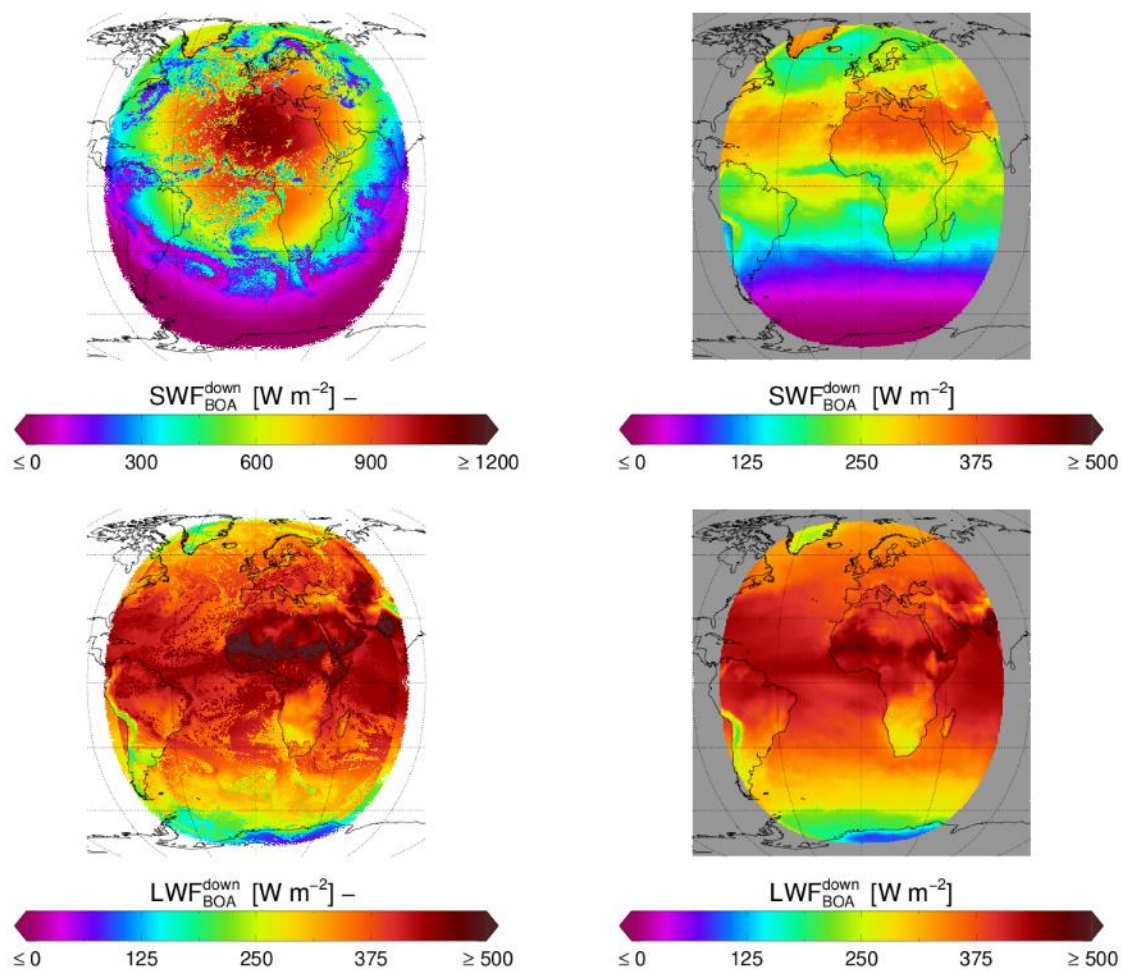


Figure 2-12 Left column: Maps of Cloud_cci SEVIRI L2 downwelling shortwave (top) and longwave (bottom) broadband flux at bottom of the atmosphere (SWF_{BOA}^{down} , LWF_{BOA}^{down}) for 2019/07/01 12 UTC. Right column: Maps of Cloud_cci SEVIRI L3C monthly mean downwelling shortwave (top) and longwave (bottom) broadband flux at bottom of the atmosphere for 2019/07.

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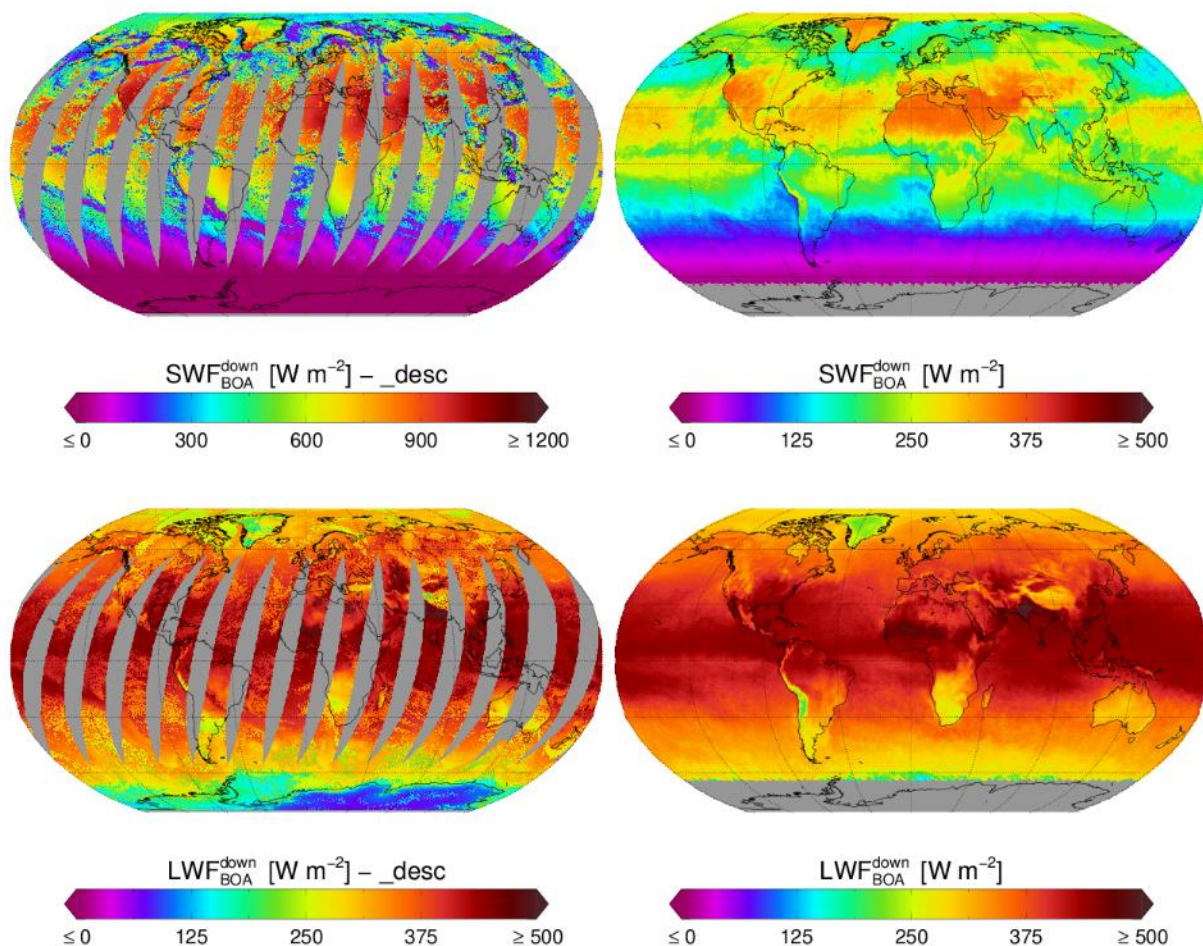


Figure 2-13 Left column: Maps of Cloud_cci SLSTR S3a L3U downwelling shortwave (top) and longwave (bottom) broadband flux at bottom of the atmosphere (SWF_{BOA}^{down} , LWF_{BOA}^{down}) for 2019/07/01 12 UTC. Right column: Maps of Cloud_cci SLSTR S3a L3C monthly mean downwelling shortwave (top) and longwave (bottom) broadband flux at bottom of the atmosphere for 2019/07.

Short algorithm approach description:

Broadband radiative fluxes are computed in a post-processing step of the CC4CL using BUGSrad (Stephens et al., 2001). BUGSrad is based on the two-stream approximation and correlated-k distribution methods of atmospheric radiative transfer. The basis of the algorithm is the same as that described by Fu and Liou (1992). It is applied to a single-column atmosphere for which the cloud and aerosol layers are assumed to be plane-parallel. Cloud properties retrieved using CC4CL are ingested into BUGSrad to compute both shortwave and longwave radiative fluxes for the top and bottom of atmosphere. The algorithm uses 18 bands that span the entire electromagnetic spectrum to compute the broadband flux. In total, 6 bands are used for shortwave and 12 bands are used for longwave radiative flux calculations. In depth information about BUGSrad and its application can be found in [ATBD-CC4CL-TOA_FLUXv1.1](#). Important to note that in twilight conditions the shortwave fluxes are based on a linear fit to measured 0.6 μ m reflectances.

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Uncertainty information:

- No direct uncertainty information available. However, the BOA fluxes have been evaluated by comparisons to BSRN and SURFRAD data (see PVIRv6 and ATBD-CC4CL_TOA_FLUXv1.1).

Known Limitations:

- Often the monthly mean flux calculations are based on one or two observations a day, thus based on coarse temporal sampling. However, a diurnal cycle correction is implemented to limit corresponding uncertainty when generating monthly means.
- In particular for the long-wave fluxes, a fair amount of ERA-Interim data is incorporated in the flux calculation.
- Shortwave fluxes in twilight conditions are characterized by higher uncertainties.

TOA broadband radiative fluxes - data fields* and descriptions:

Product level	Data field name	Description
Level-2	<i>boa_lwdn</i>	bottom of atmosphere downwelling longwave radiation, all-sky
	<i>boa_lwdn_clr</i>	bottom of atmosphere downwelling longwave radiation, clear-sky
	<i>boa_swdn</i>	bottom of atmosphere downwelling shortwave radiation, all-sky
	<i>boa_swdn_clr</i>	bottom of atmosphere downwelling shortwave radiation, clear-sky
	<i>boa_lwup</i>	bottom of atmosphere upwelling longwave radiation, all-sky
	<i>boa_lwup_clr</i>	bottom of atmosphere upwelling longwave radiation, clear-sky
	<i>boa_swup</i>	bottom of atmosphere upwelling shortwave radiation, all-sky
	<i>boa_swup_clr</i>	bottom of atmosphere upwelling shortwave radiation, clear-sky
Level-3U	<i>boa_lwdn_asc/desc</i>	bottom of atmosphere downwelling longwave radiation asc./desc., all-sky
	<i>boa_lwdn_clr_asc/desc</i>	bottom of atmosphere downwelling longwave radiation asc./desc., clear-sky
	<i>boa_swdn_asc/desc</i>	bottom of atmosphere downwelling shortwave radiation asc./desc., all-sky
	<i>boa_swdn_clr_asc/desc</i>	bottom of atmosphere downwelling shortwave radiation asc./desc., clear-sky
	<i>boa_lwup_asc/desc</i>	bottom of atmosphere upwelling longwave radiation asc./desc., all-sky
	<i>boa_lwup_clr_asc/desc</i>	bottom of atmosphere upwelling longwave radiation asc./desc., clear-sky

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Level-3C	<i>boa_swup_asc/desc</i>	bottom of atmosphere upwelling shortwave radiation asc./desc., all-sky
	<i>boa_swup_clr_asc/desc</i>	bottom of atmosphere upwelling shortwave radiation asc./desc., clear-sky
	<i>boa_lwdn</i>	bottom of atmosphere downwelling longwave radiation, all-sky
	<i>boa_lwdn_clr</i>	bottom of atmosphere downwelling longwave radiation, clear-sky
	<i>boa_swdn</i>	bottom of atmosphere downwelling shortwave radiation, all-sky
	<i>boa_swdn_clr</i>	bottom of atmosphere downwelling shortwave radiation, clear-sky
	<i>boa_lwup</i>	bottom of atmosphere upwelling longwave radiation, all-sky
	<i>boa_lwup_clr</i>	bottom of atmosphere upwelling longwave radiation, clear-sky
	<i>boa_swup</i>	bottom of atmosphere upwelling shortwave radiation, all-sky
	<i>boa_swup_clr</i>	bottom of atmosphere upwelling shortwave radiation, clear-sky

* Complete list of data fields is given in Annex B

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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 1-2 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 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.)

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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]

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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, AATSR
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.ossf.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_vocabulary	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)

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Name	Description
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
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 1.2, Table 1-2 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, AVHRR

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4. Data access, citation, acknowledgement, user support

4.1 Data access

Data requests can be sent to: contact.cloudcci@dwd.de

4.2 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:

<https://climate.esa.int/en/projects/cloud/contacts/>

4.3 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.

4.4 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>

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 Wetterdienst
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

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Annex B - Complete description of data fields

B.1 Level 2 and Level 3U data

Level 2 variable <i>Dimensions: along_track, across_track</i>	Level 3U variable	Description
<u>Auxiliary data fields</u>		
<i>satellite_zenith_view_no1</i>	<i>satzen_asc/desc(time, lat, lon)</i>	Satellite zenith angle [deg]
<i>solar_zenith_view_no1</i>	<i>solzen_asc/desc(time, lat, lon)</i>	Solar zenith angle [deg]
<i>rel_azimuth_view_no1</i>	<i>relazi_asc/desc(time, lat, lon)</i>	Relative azimuth angle [deg]
<i>illum</i>	<i>illum_asc/desc(time, lat, lon)</i>	Illumination flag (1: day, 2: twilight, 3: night)
<i>lsflag(time, lat, lon)</i>	-	Land/sea mask (0: sea , 1: land)
<i>lusflag</i>	-	Land use flag
<i>dem</i>	-	Digital elevation model
<i>nicemask</i>	-	Snow/ice mask
<u>Optimal Estimation related data fields</u>		
<i>costja</i>	-	field containing the a priori cost
<i>costjm</i>	-	field containing the measurement cost
<i>convergence</i>	-	field containing the retrieval convergence flag with value 0 : converged , 1 : no convergence
<i>niter</i>	-	field containing the number of the retrieval iterations
<i>qcflag</i>	<i>qcflag_asc/desc(time, lat, lon)</i>	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

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Level 2 variable <i>Dimensions: along_track, across_track</i>	Level 3U variable	Description
<u>Cloud mask</u>		
<i>cc_total</i>	<i>cmask_asc/desc(time, lat, lon)</i>	Cloud mask (0: cloud free, 1: cloudy)
<i>cc_total_uncertainty</i>	<i>cmask_asc/desc_unc(time, lat, lon)</i>	Cloud mask uncertainty
<i>cccot_pre</i>	<i>cccot_asc/desc(time, lat, lon) ;</i>	Native output of cloud detection (represents a pseudo CALIPSO COT)
<u>Cloud phase & type</u>		
<i>phase</i>	<i>cph_asc/desc(time, lat, lon)</i>	Cloud top thermodynamic phase (1: water cloud, 2: ice cloud)
<i>phase_pavolonis</i>	<i>cty_asc/desc(time, lat, lon)</i>	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)
<u>Cloud top pressure/height/temperature</u>		
<i>ctt</i>	<i>ctt_asc/desc(time, lat, lon) ;</i>	Cloud top temperature [K]
<i>ctt_uncertainty</i>	<i>ctt_asc/desc_unc(time, lat, lon) ;</i>	Cloud top temperature uncertainty [K]
<i>ctt_corrected</i>	<i>ctt_corrected_asc/desc(time, lat, lon) ;</i>	Cloud top temperature corrected [K]
<i>ctt_corrected_uncertainty</i>	<i>ctt_corrected_asc/desc_unc(time, lat, lon) ;</i>	Cloud top temperature corrected uncertainty [K]
<i>cth</i>	<i>cth_asc/desc(time, lat, lon) ;</i>	Cloud top height [km]
<i>cth_uncertainty</i>	<i>cth_asc/desc_unc(time, lat, lon) ;</i>	Cloud top height uncertainty [km]
<i>cth_corrected</i>	<i>cth_corrected_asc/desc(time, lat, lon) ;</i>	Cloud top height corrected [K km]
<i>cth_corrected_uncertainty</i>	<i>cth_corrected_asc/desc_unc(time, lat, lon) ;</i>	Cloud top height corrected uncertainty [km]
<i>ctp</i>	<i>ctp_asc/desc(time, lat, lon) ;</i>	Cloud top pressure [hPa]

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Level 2 variable <i>Dimensions: along_track, across_track</i>	Level 3U variable	Description
<i>ctp_uncertainty</i>	<i>ctp_asc/desc_unc(time, lat, lon) ;</i>	Cloud top pressure uncertainty [hPa]
<i>ctp_corrected</i>	<i>ctp_corrected_asc/desc(time, lat, lon) ;</i>	Cloud top pressure corrected [hPa]
<i>ctp_corrected_uncertainty</i>	<i>ctp_corrected_asc/desc_unc(time, lat, lon) ;</i>	Cloud top pressure corrected uncertainty [hPa]
<u>Cloud optical thickness</u>		
<i>cot</i>	<i>cot_asc/desc(time, lat, lon)</i>	Cloud optical thickness
<i>cot_uncertainty</i>	<i>cot_asc/desc_unc(time, lat, lon)</i>	Cloud optical thickness uncertainty
<u>Effective Radius</u>		
<i>cer</i>	<i>cer_asc/desc(time, lat, lon)</i>	Cloud effective radius [μm]
<i>cer_uncertainty</i>	<i>cer_asc/desc_unc(time, lat, lon)</i>	Cloud effective radius uncertainty [μm]
<u>Cloud water path</u>		
<i>cwp</i>	<i>cwp_asc/desc(time, lat, lon)</i>	Cloud water path [g/m2]
<i>cwp_uncertainty</i>	<i>cwp_asc/desc_unc(time, lat, lon)</i>	Cloud water path uncertainty [g/m2]
<u>Spectral cloud albedo</u>		
<i>cloud_albedo_in_channel_no_1</i>	<i>cla_vis006_asc/desc(time, lat, lon)</i>	Cloud albedo at 0.6μm
<i>cloud_albedo_uncertainty_in_channel_no_1</i>	<i>cla_vis006_asc/desc_unc(time, lat, lon)</i>	Cloud albedo at 0.6μm uncertainty
<i>cloud_albedo_in_channel_no_2</i>	<i>cla_vis008_asc/desc(time, lat, lon)</i>	Cloud albedo at 0.8μm
<i>cloud_albedo_uncertainty_in_channel_no_2</i>	<i>cla_vis008_asc/desc_unc(time, lat, lon)</i>	Cloud albedo at 0.8μm uncertainty
<i>cloud_albedo_in_channel_no_3</i>	-	
<i>cloud_albedo_uncertainty_in_channel_no_3</i>	-	

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Level 2 variable <i>Dimensions: along_track, across_track</i>	Level 3U variable	Description
<i>cloud_albedo_in_channel_no_3</i>	-	
<i>cloud_albedo_uncertainty_in_channel_no_4</i>	-	
<u>Cloud effective emissivity</u>		
<i>cee_in_channel_no_4</i>	-	Cloud effective emissivity at 3.7 μm
<i>cee_uncertainty_in_channel_no_4</i>	-	Cloud effective emissivity at 3.7 μm
<i>cee_in_channel_no_5</i>	<i>cee_asc/desc(time, lat, lon)</i>	Cloud effective emissivity at 10.8 μm
<i>cee_uncertainty_in_channel_no_5</i>	<i>cee_asc/desc_unc(time, lat, lon)</i>	Cloud effective emissivity at 10.8 μm
<i>cee_in_channel_no_6</i>	-	Cloud effective emissivity at 12.0 μm
<i>cee_uncertainty_in_channel_no_6</i>	-	Cloud effective emissivity at 12.0 μm
<u>Surface Temperature</u>		
<i>stemp</i>	<i>stemp_asc/desc(time, lat, lon)</i>	field containing the surface temperature in Kelvin
<i>stemp_uncertainty</i>	<i>stemp_asc/desc_unc(time, lat, lon)</i>	field containing the uncertainty of <i>stemp</i> in Kelvin
<u>TOA broadband radiative fluxes</u>		
<i>toa_lwup</i>	<i>toa_lwup_asc/desc(time, lat, lon)</i>	top of atmosphere upwelling longwave radiation, all-sky
<i>toa_lwup_clr</i>	<i>toa_lwup_clr_asc/desc (time, lat, lon)</i>	top of atmosphere upwelling longwave radiation, clear-sky
<i>toa_swup</i>	<i>toa_swup_asc/desc (time, lat, lon)</i>	top of atmosphere upwelling shortwave radiation, all-sky
<i>toa_swup_clr</i>	<i>toa_swup_clr_asc/desc (time, lat, lon)</i>	top of atmosphere upwelling shortwave radiation, clear-sky

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Level 2 variable <i>Dimensions: along_track, across_track</i>	Level 3U variable	Description
<i>toa_swdn</i>	<i>toa_swdn_asc/desc (time, lat, lon)</i>	top of atmosphere downwelling shortwave radiation
<u>BOA broadband radiative fluxes</u>		
<i>boa_lwdn</i>	<i>boa_lwdn_asc/desc(time, lat, lon)</i>	bottom of atmosphere downwelling longwave radiation, all-sky
<i>boa_lwdn_clr</i>	<i>boa_lwdn_clr_asc/desc (time, lat, lon)</i>	bottom of atmosphere downwelling longwave radiation, clear-sky
<i>boa_swdn</i>	<i>boa_swdn_asc/desc (time, lat, lon)</i>	bottom of atmosphere downwelling shortwave radiation, all-sky
<i>boa_swdn_clr</i>	<i>boa_swdn_clr_asc/desc (time, lat, lon)</i>	bottom of atmosphere downwelling shortwave radiation, clear-sky
<i>boa_lwup</i>	<i>boa_lwup_asc/desc (time, lat, lon)</i>	bottom of atmosphere upwelling longwave radiation, all-sky
<i>boa_lwup_clr</i>	<i>boa_lwup_clr_asc/desc (time, lat, lon)</i>	bottom of atmosphere upwelling longwave radiation, clear-sky
<i>boa_swup</i>	<i>boa_swup_asc/desc (time, lat, lon)</i>	bottom of atmosphere upwelling shortwave radiation, all-sky
<i>boa_swup_clr</i>	<i>boa_swup_clr_asc/desc (time, lat, lon)</i>	bottom of atmosphere upwelling shortwave radiation, clear-sky
<i>boa_par_dif</i>	<i>boa_par_dif_asc/desc (time, lat, lon)</i>	bottom of atmosphere diffuse downwelling photosynthetic radiative flux
<i>boa_par_tot</i>	<i>boa_par_tot_asc/desc (time, lat, lon)</i>	bottom of atmosphere total downwelling photosynthetic radiative flux

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B.2 Level 3C

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

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

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

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

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

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

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Level-3C variable	Description
<i>cla_vis006_ice_std(time, lat, lon)</i>	Ice cloud albedo at 0.6 μm - standard deviation of individual pixel retrievals
<i>cla_vis006_ice_unc(time, lat, lon)</i>	Ice cloud albedo at 0.6 μm - mean of individual pixel uncertainties
<i>cla_vis008(time, lat, lon)</i>	Cloud albedo at 0.8 μm - mean of individual pixel retrievals
<i>cla_vis008_std(time, lat, lon)</i>	Cloud albedo at 0.8 μm - standard deviation of individual pixel retrievals
<i>cla_vis008_prop_unc(time, lat, lon)</i>	Cloud albedo at 0.8 μm - propagated uncertainty: total uncertainty from individual pixel uncertainty added in quadrature
<i>cla_vis008_corr_unc(time, lat, lon)</i>	Cloud albedo at 0.8 μm - correlated uncertainty assuming correlation of 0.1
<i>cla_vis008_unc(time, lat, lon)</i>	Cloud albedo at 0.8 μm - mean of individual pixel uncertainties
<i>cla_vis008_liq(time, lat, lon)</i>	Liquid cloud albedo at 0.8 μm - mean of individual pixel retrievals
<i>cla_vis008_liq_std(time, lat, lon)</i>	Liquid cloud albedo at 0.8 μm - standard deviation of individual pixel retrievals
<i>cla_vis008_liq_unc(time, lat, lon)</i>	Liquid cloud albedo at 0.8 μm - mean of individual pixel uncertainties
<i>cla_vis008_ice(time, lat, lon)</i>	Ice cloud albedo at 0.8 μm - mean of individual pixel retrievals
<i>cla_vis008_ice_std(time, lat, lon)</i>	Ice cloud albedo at 0.8 μm - standard deviation of individual pixel retrievals
<i>cla_vis008_ice_unc(time, lat, lon)</i>	Ice cloud albedo at 0.8 μm - mean of individual pixel uncertainties
<u>Cloud water path</u>	
<i>lwp(time, lat, lon)</i>	Cloud liquid water path - mean of individual pixel retrievals
<i>lwp_std(time, lat, lon)</i>	Cloud liquid water path - standard deviation of individual pixel retrievals
<i>lwp_prop_unc(time, lat, lon)</i>	Cloud liquid water path - propagated uncertainty: total uncertainty from individual pixel uncertainty added in quadrature
<i>lwp_corr_unc(time, lat, lon)</i>	Cloud liquid water path - correlated uncertainty assuming correlation of 0.1
<i>lwp_unc(time, lat, lon)</i>	Cloud liquid water path - mean of individual pixel uncertainties
<i>lwp_allsky(time, lat, lon)</i>	Cloud liquid water path all-sky - grid box mean of individual pixel retrievals, including clear-sky pixels
<i>iwp(time, lat, lon)</i>	Cloud ice water path - mean of individual pixel retrievals

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Level-3C variable	Description
<i>iwp_std(time, lat, lon)</i>	Cloud ice water path - standard deviation of individual pixel retrievals
<i>iwp_prop_unc(time, lat, lon)</i>	Cloud ice water path - propagated uncertainty: total uncertainty from individual pixel uncertainty added in quadrature
<i>iwp_corr_unc(time, lat, lon)</i>	Cloud ice water path - correlated uncertainty assuming correlation of 0.1
<i>iwp_unc(time, lat, lon)</i>	Cloud ice water path - mean of individual pixel uncertainties
<i>iwp_allsky(time, lat, lon)</i>	Cloud ice water path all-sky - grid box mean of individual pixel retrievals, including clear-sky pixels
<u>TOA broadband radiative fluxes</u>	
<i>toa_lwup(time, lat, lon)</i>	top of atmosphere upwelling longwave radiation, all-sky
<i>toa_lwup_clr(time, lat, lon)</i>	top of atmosphere upwelling longwave radiation, clear-sky
<i>toa_swup(time, lat, lon)</i>	top of atmosphere upwelling shortwave radiation, all-sky
<i>toa_swup_clr(time, lat, lon)</i>	top of atmosphere upwelling shortwave radiation, clear-sky
<i>toa_swdn(time, lat, lon)</i>	top of atmosphere downwelling shortwave radiation
<i>toa_lwup_low(time, lat, lon)</i>	top of atmosphere upwelling longwave radiation, all-sky + low clouds
<i>toa_lwup_mid(time, lat, lon)</i>	top of atmosphere upwelling longwave radiation, all-sky + mid-level clouds
<i>toa_lwup_hig(time, lat, lon)</i>	top of atmosphere upwelling longwave radiation, all-sky + high clouds
<i>toa_swup_low(time, lat, lon)</i>	top of atmosphere upwelling shortwave radiation, all-sky + low clouds
<i>toa_swup_mid(time, lat, lon)</i>	top of atmosphere upwelling shortwave radiation, all-sky + mid-level clouds
<i>toa_swup_hig(time, lat, lon)</i>	top of atmosphere upwelling shortwave radiation, all-sky + high clouds
<u>BOA broadband radiative fluxes</u>	
<i>boa_lwdn(time, lat, lon)</i>	bottom of atmosphere downwelling longwave radiation, all-sky
<i>boa_lwdn_clr(time, lat, lon)</i>	bottom of atmosphere downwelling longwave radiation, clear-sky
<i>boa_swdn(time, lat, lon)</i>	bottom of atmosphere downwelling shortwave radiation, all-sky
<i>boa_swdn_clr(time, lat, lon)</i>	bottom of atmosphere downwelling shortwave radiation, clear-sky
<i>boa_lwup(time, lat, lon)</i>	bottom of atmosphere upwelling longwave radiation, all-sky
<i>boa_lwup_clr(time, lat, lon)</i>	bottom of atmosphere upwelling longwave radiation, clear-sky
<i>boa_swup(time, lat, lon)</i>	bottom of atmosphere upwelling shortwave radiation, all-sky
<i>boa_swup_clr(time, lat, lon)</i>	bottom of atmosphere upwelling shortwave radiation, clear-sky
<i>boa_par_dif(time, lat, lon)</i>	bottom of atmosphere diffuse downwelling photosynthetic radiative flux

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Level-3C variable	Description
<i>boa_par_tot(time, lat, lon)</i>	bottom of atmosphere total downwelling photosynthetic radiative flux
<u>Histograms</u>	
<i>hist2d_cot_ctp(time, hist_phase, hist2d_ctp_bin_centre, hist2d_cot_bin_centre, lat, lon)</i>	Two-dimensional, COT-CTP histogram containing absolute counts
<i>hist2d_ctp_bin_centre</i>	Center of CTP bins in 2-dim COT-CTP histogram
<i>hist2d_cot_bin_centre</i>	Center of COT bins in 2-dim COT-CTP histogram
<i>hist2d_ctp_bin_border</i>	Borders of CTP bins in 2-dim COT-CTP histogram
<i>hist2d_cot_bin_border</i>	Borders of COT bins in 2-dim COT-CTP histogram
<i>hist1d_cot(time, hist_phase, hist1d_cot_bin_centre, lat, lon)</i>	1-dimensional histogram of cloud optical thickness per grid cell
<i>hist1d_cot_bin_centre</i>	Center of COT bins in 1-dim COT histogram
<i>hist1d_cot_bin_border</i>	Borders of COT bins in 1-dim COT histogram
<i>hist1d_ctp(time, hist_phase, hist1d_ctp_bin_centre, lat, lon)</i>	1-dimensional histogram of cloud top pressure per grid cell
<i>hist1d_ctp_bin_centre</i>	Center of CTP bins in 1-dim CTP histogram
<i>hist1d_ctp_bin_border</i>	Borders of CTP bins in 1-dim CTP histogram
<i>hist1d_ctt(time, hist_phase, hist1d_ctt_bin_centre, lat, lon)</i>	1-dimensional histogram of cloud top temperature per grid cell
<i>hist1d_ctt_bin_centre</i>	Center of CTT bins in 1-dim CTT histogram
<i>hist1d_ctt_bin_border</i>	Borders of CTT bins in 1-dim CTT histogram
<i>hist1d_cer(time, hist_phase, hist1d_cer_bin_centre, lat, lon)</i>	1-dimensional histogram of cloud effective radius per grid cell
<i>hist1d_cer_bin_centre</i>	Center of CER bins in 1-dim CER histogram
<i>hist1d_cer_bin_border</i>	Borders of CER bins in 1-dim CER histogram
<i>hist1d_cwp(time, hist_phase, hist1d_cwp_bin_centre, lat, lon)</i>	1-dimensional histogram of cloud water path per grid cell
<i>hist1d_cwp_bin_centre</i>	Center of CWP bins in 1-dim CWP histogram
<i>hist1d_cwp_bin_border</i>	Borders of CWP bins in 1-dim CWP histogram

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Level-3C variable	Description
<i>hist1d_cla_vis006(time, hist_phase, hist1d_cla_vis006_bin_centre, lat, lon)</i>	1-dimensional histogram of cloud albedo at 0.6μm per grid cell
<i>hist1d_cla_vis006_bin_centre</i>	Center of CLA_vis006 bins in 1-dim CLA_vis006 histogram
<i>hist1d_cla_vis006_bin_border</i>	Borders of CLA_vis006 bins in 1-dim CLA_vis006 histogram
<i>hist1d_cla_vis008(time, hist_phase, hist1d_cla_vis008_bin_centre, lat, lon)</i>	1-dimensional histogram of cloud albedo at 0.8μm per grid cell
<i>hist1d_cla_vis008_bin_centre</i>	Center of CLA_vis008 bins in 1-dim CLA_vis008 histogram
<i>hist1d_cla_vis008_bin_border</i>	Borders of CLA_vis008 bins in 1-dim CLA_vis008 histogram

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

This section 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:

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

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

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

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

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

Equation (5) reports the uncertainty of the 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 an 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).

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

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

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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) divided 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.

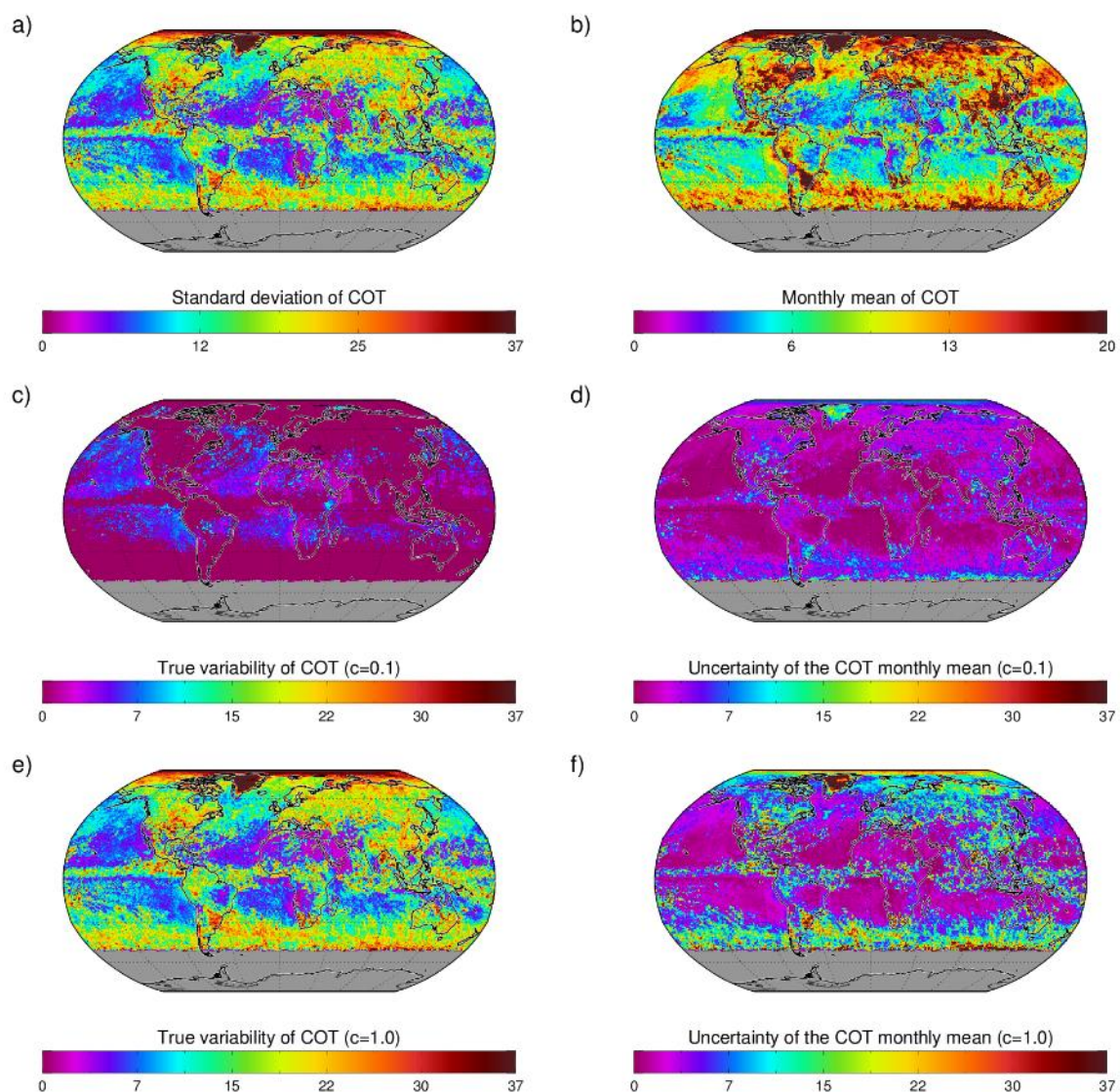


Figure C-0-1 Monthly standard deviation (a) and monthly mean (b) for cloud optical thickness (COT). Panels (c) and (d) show the estimated natural variability and uncertainty of the mean (d) for a correlation of 0.1. Panel (e) and (f) are as panels (c) and (d) but for an uncertainty correlation of 1.0. All data is from AVHRR-PM in 2008/06. Figure taken from Stengel et al. (2017).

Panels (d) and (f) of Figure C-0-1 show 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 different uncertainty terms taken into account when propagating the uncertainties from monthly means to zonal means.

Case	Description
Case 1	Arithmetically 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)

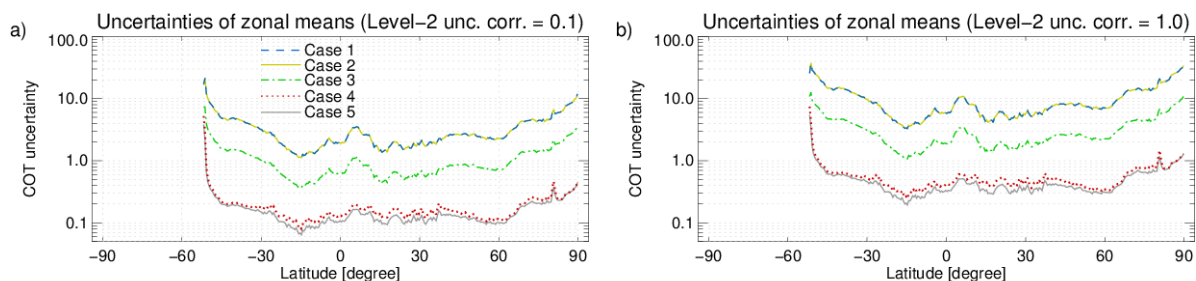


Figure C-0-2 Uncertainties for zonal mean COT values shown for the 5 cases defined in Table C-1. Panel (a) shows the results when using the Level-3 uncertainties shown Figure C-1 panel (d), which are based on Level-2 uncertainty correlations of 0.1, and panel (b) shows the results when using Level-3 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-0-2. Case 1 and Case 2 uncertainties are identical, which is clear when considering that equation (6) reduces to the second term for uncertainty correlations of 1.0, which is the arithmetical 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 exactly known at the moment.