User Manual for the Cloud Product Processors of the NWC/PPS: Science Part

NWC/CDOP3/PPS/SMHI/SCI/UM/Cloud, Issue 3, Rev. 1.0

01 September 2022

Applicable to SAFNWC/PPS version v2021

Applicable to the following PGEs:

Acronym	Product ID	Product name	Version number
CMa	NWC-064	Cloud Mask	5.1
CMa-Prob	NWC-154	Cloud Probability	1.1
CT	NWC-067	Cloud Type	3.1
CTTH	NWC-070	Cloud Top Temperature and Height	5.1
CMIC	NWC-082	Cloud Micro Physics	2.1

Prepared by Swedish Meteorological and Hydrological Institute (SMHI)

REPORT SIGNATURE TABLE

Function	Name	Signature	Date
Prepared by	SMHI		01 September 2022
Reviewed by	SAFNWC Project Team EUMETSAT		for v2021: 28 September 2021
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DOCUMENT CHANGE RECORD

Version	Date	Pages	Changes
1.0d	27 June 2014	53	Replacing CDOP-document: SAF/NWC/CDOP/SMHI-PPS/SCI/PUM/1 First version for SAFNWC/PPS v2014. Implemented RIDs from PCR-v2014: -Action8 (note on new output format) General changes: -updates for PPS v2014, eg.: updated validation, more input to CPP, removed Task Manager, no special descriptions for VIIRS (as VIIRS is an integrated part now). -New datasets: CMa binary cloudmask, CT multi-layer, CPP cwp and cph_extended.
1.0	15 September 2014	53	Implemented RIDs from DRR-v2014: -LSc04, TH: Typos -LSc05: Added a limitation: LWP not validated over sea.
1.1	13 March 2015	57	Added a figure to give a help to interpret COT and REFF colours.
2.0d	17 October 2018	61	Updates for PPS v2018: -Added new product: Cloud Probability. -Updates in the CTTH algorithm. -Updated PGE inter-dependencies. -Added usage of MODIS and high resolution VIIRS. -Removed Cloud Type dataset cloud particle phase flag. -For PC, always use MW + IR algorithm. (not eg. VIS/IR) -Updated validation results.
2.0	13 December 2018	61	Updates after v2018 ORR: OBJ2_UM_SCI_Heinemann_039: Removed most PGE-<*number*> notations in this document OBJ2_UM_SCI_Heinemann_040: editorial OBJ2_UM_SCI_Heinemann_041: editorial OBJ2_UM_SCI_Vicente_062: added MODIS among the news. OBJ2_VR_C_Heinemann_035: Explain the small changes done in PC. OBJ2_VR_C_Peregrin_064: Clarifying that the class fractional is only used for low clouds. Other changes: Clarified the dependencies between PGEs.
3.0d	1 September 2021	51	Changed document code from NWC/CDOP3/PPS/SMHI/SCI/UM/SCIE to NWC/CDOP3/PPS/SMHI/SCI/UM/Cloud. Updates for PPS v2021: -Removed the product Precipitating Clouds. -Renamed the product CPP to CMIC. -Added a few references to the new product HRW (otherwise described in a separate documents) -Action 002 RR (RID-013) Included instructions how to use cloud probability product new section 2.2.1.3 -Updated validation section. -Made smaller clarification for the products. -Updated product visualisation examples. (Not with full changelog, as the document size grew too much.)
NWC/CDOP3/PPS/SMHI/SCI/UM/Cloud 3.0	12 October 2021	51	Changes related to DRR v2021: -RID-40 Added limitation that lower quality is expected for thin clouds in 5.2. -RID-041: editorial

NWC/CODP4/EPSSG/SMHI/SCI/UM/Cloud 1.0.0	29 March 2022	53	Changes for vEPSSG-SAFbeta3: -Added more information about METimage processing. -For CTTH added one dataset: cloud top in hecto feet.
NWC/CODP3/PPS/SMHI/SCI/UM/Cloud 3.1.0	01 September 2022	51	The version for v2021-patch2 is identical as for vEPSSG-SAF-beta3 release, except for document code and version. References are updated.

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List of Tables and Figures

1. INTRODUCTION

The EUMETSAT "Satellite Application Facilities" (SAF) are dedicated centres of excellence for processing satellite data, and form an integral part of the distributed EUMETSAT Application Ground Segment (http://www.eumetsat.int). This documentation is provided by the SAF on Support to Nowcasting and Very Short Range Forecasting, SAFNWC. The main objective of SAFNWC is to provide, further develop and maintain software packages to be used for Nowcasting applications of operational meteorological satellite data by National Meteorological Services. More information can be found at the SAFNWC webpage, http://nwc-saf.eumetsat.int . This document is applicable to the SAFNWC processing package for polar orbiting meteorological satellites, SAFNWC/PPS, developed and maintained by SMHI (http://nwcsaf.smhi.se).

1.1 PURPOSE

This document is intended for the end-user, i e the forecaster.

For the person in charge of building and installing the PPS software package, thus the sys-admin we refer to the Software User Manual ([RD.9]), which will of course also be relevant for the science-admin.

For the person interested in the algorithms in detail we refer to the ATBD documents ([RD.2], [RD.2b], [RD.3], [RD.4]and [RD.5]).

1.2 SCOPE

This document is the Scientific User Manual for the NWCSAF Polar Platform System (PPS) based cloud products. The document describes how to use the products after installation. It is meant to support the interpretation as well as describe the possibilities and limitations.

Please observe that there is a separate Scientific User Manual for the NWCSAF/PPS wind product, see [RD.13].

1.3 DEFINITIONS AND ACRONYMS

Acronym	Explanation
ACPG	AVHRR/AMSU Cloud Product Generation software (A major part of the SAFNWC/PPS s.w., including the PGEs.)
AHAMAP	AMSU-HIRS-AVHRR Mapping Library (Previously a part of the SAFNWC/PPS s.w.)
AMSU	Advance Microwave Sounding Unit
AVHRR	Advanced Very High Resolution Radiometer
CALIOP	Cloud-Aerosol Lidar with Orthogonal Polarization
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite
CDOP	Continuous Development and Operational Phase
CLIWA-NET	Cloud Liquid Water Network
CMa	Cloud Mask (also PGE01)
CMa-Prob	Cloud Probability (also PGE01c)
CMIC	Cloud Micro Physics (CPP s.w. produces CMIC product)
CM-SAF	Climate Monitoring SAF
COT	Cloud Optical Thickness
CPH	Cloud Phase
CPP	Cloud Physical Properties (also PGE05) (CPP s.w. produces CMIC product)
CT	Cloud Type (also PGE02)
CTTH	Cloud Top Temperature and Height (also PGE03)
CWP	Cloud Water Path
ECMWF	European Centre for Medium-range Weather Forecasts
EPS	EUMETSAT Polar System

Acronym	Explanation
EPS-SG	EUMETSAT Polar System Second Generation
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FAR	False Alarm Rate
FOV	Field of View
GIS	Geographic Information System
GOES	Geostationary Operational Environmental Satellite
HDF5	Hierarchical Data format version 5
HIRLAM	High Resolution Area Model
HRW	High Resolution Winds
IR	Infrared
IWP	Ice Water Path
LUT	Look-Up-Table
LWP	Liquid Water Path
MERSI	Medium Resolution Spectral Imager
METimage	Meteorological Imager
MODIS	Moderate Resolution Imaging Spectrometer
NIR	Near Infrared
NOAA	National Oceanic and Atmospheric Administration
NORDRAD	Nordic Weather Radar Network
NWP	Numerical Weather Prediction
OSISAF	Ocean and Sea Ice SAF
PC	Precipitating Cloud (also PGE04) (discontinued product)
PGE	Process Generating Element
POD	Probability Of Detection
POFD	Probability Of False Detection

Acronym	Explanation
PPS	Polar Platform System
RGB	Red Green Blue
REFF (reff)	Effective Radius
RMS	Root Mean Square Deviation
RTTOV	Radiative Transfer for TOVs
SAF	Satellite Application Facility
SAFNWC	Satellite Application Facility for support to NoWcasting
SEVIRI	Spinning Enhanced Visible InfraRed Imager
SI	scattering index
SLSTR	Sea and Land Surface Temperature Radiometer
SMHI	Swedish Meteorological and Hydrological Institute
SW	SoftWare
UTC	Universal Time Co-ordinated
VIIRS	Visible Infrared Imaging Radiometer Suite
VIS	Visible

See [RD.1.] for a complete list of acronyms for the SAFNWC project.

1.4 References

1.4.1 Applicable documents

The following documents, of the exact issue shown, form part of this document to the extent specified herein. Applicable documents are those referenced in the Contract or approved by the Approval Authority. They are referenced in this document in the form [AD.X]

For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. For undated references, the current edition of the document referred applies.

Current documentation can be found at SAFNWC Helpdesk web: http://www.nwcsaf.org

Ref	Title	Code	Vers	Date
[AD.1.]	NWCSAF Project Plan	NWC/CDOP3/SAF/AEMET/MGT/PP	1.6	01/12/21
[AD.2.]	NWCSAF Product Requirements Document	NWC/CDOP3/SAF/AEMET/MGT/PRD	1.5	01/12/21
[AD.3.]	System and Components Requirements Document for the SAFNWC/PPS	NWC/CDOP3/PPS/SMHI/SW/SCRD	2.3	12/10/21

Table 1: List of Applicable Documents

1.4.2 Reference documents

The reference documents contain useful information related to the subject of the project. These reference documents complement the applicable ones, and can be looked up to enhance the information included in this document if it is desired. They are referenced in this document in the form [RD.X]

For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. For undated references, the current edition of the document referred applies

Current documentation can be found at SAFNWC Helpdesk web: http://www.nwcsaf.org

Ref	Title	Code	Vers	Date
[RD.1.]	The Nowcasting SAF Glossary	NWC/CDOP3/SAF/AEMET/MGT/GLO	1.0	20/12/20
[RD.2]	Algorithm Theoretical Basis Document for the Cloud Mask of the NWC/PPS	NWC/CDOP3/PPS/SMHI/SCI/ATBD/CloudMask	3.1.0	01/09/22
[RD.2b]	Algorithm Theoretical Basis Document for the Cloud Probability of the NWC/PPS	NWC/CDOP3/PPS/SMHI/SCI/ATBD/CloudProbability	2.0	26/04/22
[RD.3]	Algorithm Theoretical Basis Document for the Cloud Type of the NWC/PPS	NWC/CDOP3/PPS/SMHI/SCI/ATBD/CloudType	3.1.0	01/09/22
[RD.4]	Algorithm Theoretical Basis Document for the Cloud Top Temperature, Pressure and Height of the NWC/PPS	NWC/CDOP3/PPS/SMHI/SCI/ATBD/CTTH	3.1.0	01/09/22
[RD.5]	Algorithm Theoretical Basis Document for the Cloud Micro Physics of the NWC/PPS	NWC/CDOP3/PPS/SMHI/SCI/ATBD/CMIC	3.1.0	01/09/22
[RD.6]	Algorithm Theoretical Basis Document for the Wind product processor of the NWC/PPS	NWC/CDOP3/PPS/AEMET/SCI/ATBD/Wind	0.1	12/10/21
[RD.7]	Interface Control Document for Internal and External Interfaces NWC/PPS	NWC/CDOP3/PPS/SMHI/SW/ICD/1	3.1.0	01/09/22
[RD.8]	Datat Output Format of the NWC/PPS	NWC/CDOP3/PPS/SMHI/SW/DOF	3.1.0	01/09/22
[RD.9]	User Manual for the NWC/PPS Application: Software Part, 1. Installation	NWC/CDOP3/PPS/SMHI/SW/UM/INST	3.1.0	01/09/22
[RD.10]	User Manual for the NWC/PPS Application: Software Part, 2. Operations	NWC/CDOP3/PPS/SMHI/SW/UM/OPER	3.2.0	01/09/22
[RD.11]	Scientific and Validation Report for the Cloud Product Processors of the NWC/PPS	NWC/CDOP3/PPS/SMHI/SCI/VR/Cloud	3.0	12/10/21
[RD.12]	Scientific and Validation Report for the Wind Product Processors of the NWC/PPS	NWC/CDOP3/PPS/AEMET/SCI/VR/Wind	0.1	12/10/21
[RD.13]	User Manual for the Wind product processor of the NWC/PPS: Science Part	NWC/CDOP3/PPS/AEMET/SCI/UM/Wind	0.1	12/10/21

Table 2: List of Referenced Documents

1.5 Document Overview

This document contains the description of usage of the SAF NWC PPS-based application and its products. To cover these objectives the present document has been structured in the following sections:

- Section 1 contains the current introduction along with the list of used acronyms and applicable and reference documents.
- Section 2 describes which products there are, their algorithms and their outputs.
- Section 3 describes shortly how to run the products.
- Section 4 describes which input is needed, and that the s.w. can be configured.
- Section 5 gives a summary of the validation

- Section 6 gives some examples of visualization of the products.

1.6 Scope of other documents

The algorithms used to extract the PPS Cloud Products CMa, CMa-Prob, CT, CTTH and CMIC are detailed in Algorithm Theoretical Basis Documents ([RD.2], [RD.2b] [RD.3], [RD.4], and [RD.5]).

The validation of the algorithms used to extract the PPS Cloud Products CMa, CMa-Prob, CT, CTTH and CMIC is reported in a validation report ([RD.11]).

Instructions for install, configure and execute the SAFNWC/PPS software, in order to extract the PPS Cloud Products, are detailed in a Software User Manuals ([RD.9] and [RD.10]).

The Interface Control Documents ([RD.7]) (for the External and Internal Interfaces of the NWC/PPS) and ([RD.8]) (Data Output Format) details the input and output data format for the NWC/PPS software.

For the wind products of PPS there are some separate documents: User Manual Scientific Part: [RD.13] (i.e. a counterpart to this document), Algorithm Theoretical Basis Document [RD.6] and Validation Report [RD.12].

1.7 License and conditions of use

The software accompanying this Users Manual is provided under license. Rights to use, copy, or modify, this software follows EUMETSAT policy of the SAFNWC/PPS software, and is specified in the dedicated license agreement.

A Help Desk facility is available for the registered user. The exact coordinates of this Help Desk web-site is http://www.nwcsaf.org .

2. DESCRIPTION OF THE PRODUCT

These are the five cloud and one wind product generation elements (PGEs), that are derived from METimage/AVHRR/VIIRS/MODIS/MERSI-2/SLSTR data:

Cloud Mask (CMa)

Cloud Probability (CMa-Prob)

Cloud Type (CT)

Cloud Top Temperature and Height (CTTH)

Cloud Micro Physics (CMIC)

High Resolution Winds (HRW)

From here the product generation element will be referred to by their names.

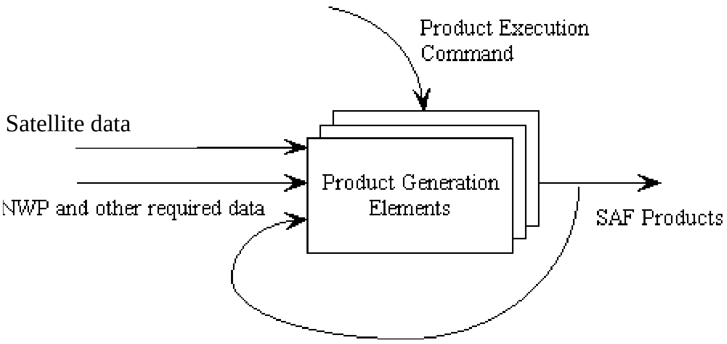


Figure 1: Simplified SAFNWC/PPS design

The CT product requires the output of both CMa and CTTH as input. The CTTH product requires input from CMa. CMIC uses input from CMa and CTTH, though the input from CTTH is optional. Alternatively: CTTH and CMIC (but not CT) can use CMa-Prob as input instead of using CMa.

The HRW product (described in [RD.13]) requires CTTH and CT as input.

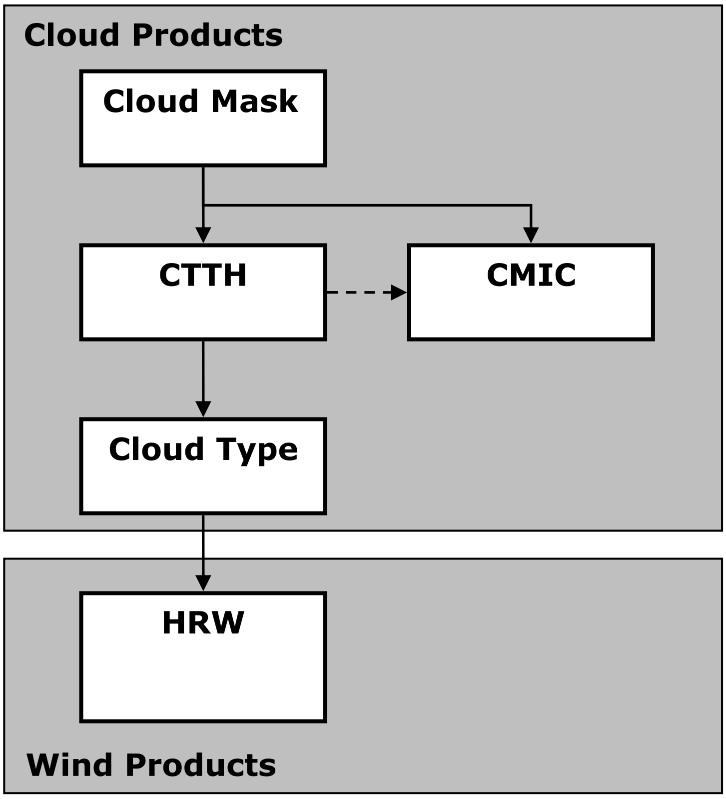


Figure 2 Internal dependence of the products

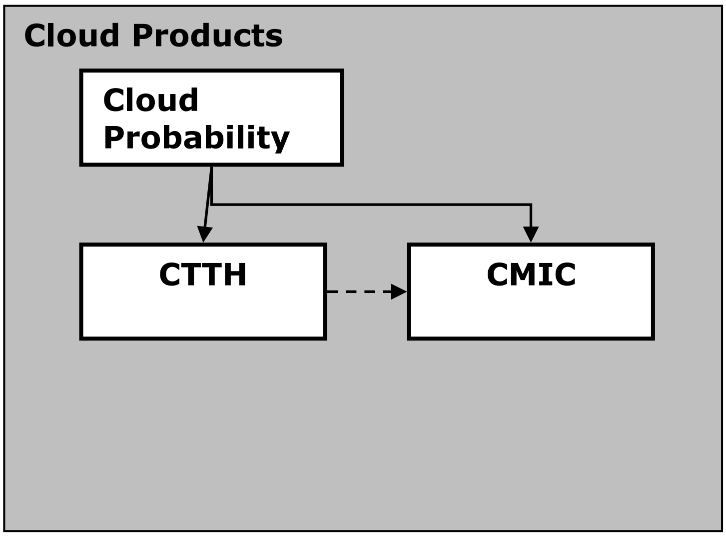


Figure 3 Internal dependence of the products, alternative set-up using cloud probability instead of cloud mask

The different products have been designed in such a way as to allow individual execution as stand-alone applications.

2.1 Summary of Changes since SAFNWC/PPS version 2018

Major changes in version 2021 are:

- High resolution winds (HRW) processing is a new demonstrational product. (See separate SCI/UM.)
- Precipitating clouds product has been discontinued.
- MERSI-2 processing (new instrument)
- SLSTR processing (new instrument, demonstrational functionality)
- METimage processing as demonstrational functionality (CMa, CMa-prob, CT, CTTH)
- Cloud Probability and Cloud Micro Physics has got improved algorithms.

Major changes after version 2021 (i.e. for vEPSSG-SAFbeta3) are:

- Also Cloud Micro Physics can be processed on METimage data.
- For Cloud Mask thresholds, a possibility to set noise offsets has been implemented, which can be used for noisy channels.
- For CTTH the new dataset Cloud Top in hecto-feet has been added.

2.2 Goal of the Products

2.2.1 Cloud Mask

2.2.1.1 Threshold based (the classic cloud mask)

This product attempts to delineate all absolutely cloud-free pixels in a satellite scene with a high confidence. In addition, it will identify cloud free snow or ice contaminated pixels when illumination allows.

Coverage and resolution:

- Coverage is depending on the coverage of the polar satellites.
- The algorithm will work everywhere, but the product quality depends on the surface type and time of day. The quality is at its best during day time and especially over ice-covered sea. The algorithm has a bit lower scores during twilight and night, especially over snow-covered land (night and twilight) and ice-covered sea (night).
- Resolution is either of: : Full METimage (500m) resolution; full AVHRR (1 km) resolution; AVHRR GAC (5 km); full VIIRS (750 m) resolution; VIIRS high resolution (375m); MODIS data (1km), MERSI-2 data (1 km), SLSTR data in 1 km resolution.

2.2.1.2 Probabilistic cloud mask (Cloud Probability)

The Cloud Probability product has been introduced to allow a shift of focus from clear-conservative to cloud-conservative or anything in between. This is realized by providing cloud probabilities instead of conditions like cloudy or cloud-free.

Coverage and resolution:

- Coverage is depending on the coverage of the polar satellites.
- CMa-Prob provides best results over ice-free ocean where clouds with optical thicknesses below 0.1 generally can be detected. Results are also good over land surfaces except over deserts during night when some thin clouds will be missed. Problems are also found over snow- and ice-covered surfaces during the polar winter when a large fraction of thin clouds remains undetected.
- Resolution is either of: Full METimage (500m) resolution; full AVHRR (1 km) resolution; AVHRR GAC (5 km); full VIIRS (750 m) resolution; VIIRS high resolution (375m); MODIS data (1km), MERSI-2 data (1 km), SLSTR data in 1 km resolution.

2.2.1.3 Recommended usage of cloud probability and cloud mask

The cloud probability and the cloud mask are two different products that can both be used as binary cloud masks and they complement each other.

For nowcasting with extreme timeliness requirements or limited computational resources the binary cloud mask should be used and the cloud probability does not need to be produced.

For climate data records generation, where algorithm consistency (similar channels) and detailed error estimates are important, the cloud probability product should be used as cloud mask. For the general decision cloudy/clear a cloud probability of 50% should be used as a threshold, being aware that values around 50% cloud probability also present the maximum possible uncertainty.

For retrieving high confidence cloudy or high confidence clear pixels the two products should be combined. For example, for SST retrievals we recommend using only high-quality cloud mask clear pixels that have cloud probability lower than 5% as this reduces the false alarm rate for clear. For validation result of the combined use CMa/CMs-Prob see the Validation report (RD.12) Annex B.

2.2.2 Cloud Type

The main objective of the Cloud Type product is to distinguish between thin and opaque clouds and provide a rough estimate of the cloud top height, and try to distinguish between water particle clouds and ice particle clouds. The highest priority is given to the reliable identification of the major cloud categories: low, medium, high, and semi-transparent cirrus.

Coverage and resolution:

- Coverage is depending on the coverage of the polar satellites.
- The algorithm will work everywhere, but the product quality depends on the surface type and illumination condition. The quality is best at night time followed by day. It is better over sea than over land and better over open water than over ice.
- Resolution is either of: : Full METimage (500m) resolution; full AVHRR (1 km) resolution; AVHRR GAC (5 km); full VIIRS (750 m) resolution; VIIRS high resolution (375m); MODIS data (1km), MERSI-2 data (1 km), SLSTR data in 1 km resolution.

2.2.3 Cloud Top Temperature and Height

The output provides information on the temperature, pressure and height of clouds. The primary product is the pressure. Temperature and height are derived from the pressure, using NWP-data.

Coverage and resolution:

- Coverage is depending on the coverage of the polar satellites.
- The algorithm will work everywhere, but the product quality depends on the type of clouds. Performance (mean absolute error) is bit worse in the tropic zone where high thin cirrus is more common.
- Resolution is either of: : Full METimage (500m) resolution; full AVHRR (1 km) resolution; AVHRR GAC (5 km); full VIIRS (750 m) resolution; VIIRS high resolution (375m); MODIS data (1km), MERSI-2 data (1 km), SLSTR data in 1km resolution.

2.2.4 Cloud Micro Physics

The official products are liquid water path and cloud phase. The additional products are ice water path, cloud optical thickness, cloud geometrical thickness, cloud droplet number concentration and cloud particle effective radius.

Images of the liquid and ice water path are useful to analyse the structure of the atmosphere. These products show the pattern of, and help to distinguish between, different air-masses (e.g. in large low pressure systems). Effective radius together with cloud phase helps to complete information about the character of a cloud. They provide valuable support in the identification of fog and areas of potential precipitation. The optical thickness on the other hand is most important for energetic considerations since it is the most important atmospheric measure for variations in the earth’s energy budget.

Coverage and resolution:

- Coverage is depending on the coverage of the polar satellites.
- The algorithm will work everywhere, but the product quality depends on the geographical area. While night or twilight, only the cloud phase product will have values.
- Resolution is either of: : Full METimage (500m) resolution; full AVHRR (1 km) resolution; AVHRR GAC (5 km); full VIIRS (750 m) resolution; VIIRS high resolution (375m); MODIS data in 1km resolution, MERSI-2 data (1 km).

2.3 OUTLINE OF THE ALGORITHM

2.3.1 Cloud Mask

2.3.1.1 Threshold-based

This Cloud Mask scheme is utilising all 5/6 spectral channels of the AVHRR/2 or AVHRR/3 sensor, or up to 8 spectral channels from the other applicable sensors, NWP short range forecast data, emissivity maps and 1 km GIS (digital elevation model and landuse) data. The scheme makes use of off-line (i.e. preparing pre-calculated tables) radiative transfer simulations (6S and RTTOV) of cloud free atmospheres, to estimate the optimal thresholds valid for the given satellite scene.

2.3.1.2 Probabilistic

This algorithm uses the naïve Bayes approach to estimate the cloud probability of individual pixels. All AVHRR or AVHRR-like channels on other instruments are used. The dynamic threshold tables from the classic approach are used to simplify the problem. As input is also required NWP short range forecast data, emissivity maps and 1 km GIS (digital elevation model and landuse) data. The NWP data must include snow depth, which is not mandatory for any other of the PPS products.

2.3.2 Cloud Type

The Cloud Type algorithm takes as input the Cloud Mask and Cloud Top Temperature and Height output, and utilise all 5/6 spectral channels of the AVHRR/2 or AVHRR/3 sensor, or corresponding channels from the other applicable sensors, NWP short range forecast data, and 1 km GIS (digital elevation model and landuse) data. The algorithm distinguishes different cloud types using thresholds defined by off-line radiative transfer calculations and a database of interactively collected training targets.

2.3.3 Cloud Top Temperature and Height

The Cloud Top Temperature and Height will take as input the Cloud Mask. Mandatory for spectral information is an 11 micron channel and additionally a 3.7 or 12 micron channel. The CTTH further requires NWP short range forecast data in high vertical resolution. The cloud top pressure is derived using neural network. This means that an artificial neural network has been trained (i.e. the cost-function has been minimized for a dataset of given input and output data) carefully offline. The derived system of weights and functions is then applied to actual input data which give direct output on the same spatial resolution. For a more detailed overview about the training and application processes, please refer to the according ATBD.

2.3.4 Cloud Micro Physics

The Cloud Micro Physics algorithm takes as input the Cloud Mask and CTTH outputs, and utilises all 5/6 spectral channels of the AVHRR/2 or AVHRR/3 sensor, or corresponding channels from the other applicable sensors, NWP short range forecast data, OSISAF ice maps, and 1 km GIS (digital elevation model and landuse) data. Also the 2.2 micron channel is used (configurable) if available. The algorithm uses lookup-tables, pre-calculated with a plane-parallel radiative transfer model. Visible and near-infrared channels are used to derive the basic quantities optical thickness and effective radius. Cloud phase and liquid water path are then calculated from those quantities.

2.4 Description of the Output

All output is given as netCDF-files.

2.4.1 Cloud Mask

2.4.1.1 Threshold based Cloud Mask

The threshold based Cloud Mask output consist of

- a five category cloud mask
- a binary cloud mask
- three quality/conditions flags
- aerosol mask (optional)
- dust mask (optional)

2.4.1.1.1 Main output

The main output is the cloud mask, which is presented in two ways: either a binary cloud mask (cloud free/cloudy) or an extended cloud mask with more categories described.

The extended cloud mask values are given by the five categories listed below. Cloud free land and cloud free sea are originally only one cloud free category, so in order to make an output image like Figure 4 the user will have to apply a land/sea mask herself, or use the information available in the conditions flag (bit number 4 and 5 – see 2.4.1.1.2.1).

The binary cloud mask (Figure 5) has only got the values: cloud free and cloudy. Which means that cloud contaminated is classified as cloudy, and snow/ice is classified as cloud free. The separation in cloud free land and cloud free sea is applied afterwards, as for the extended cloud mask image.

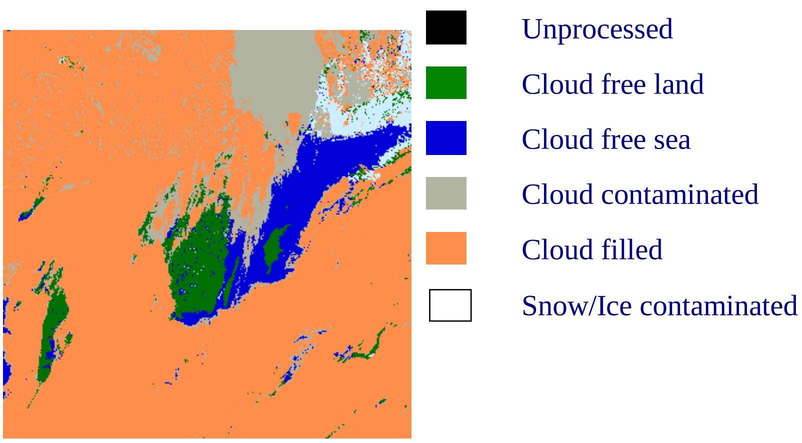


Figure 4: Extended Cloud Mask Classification

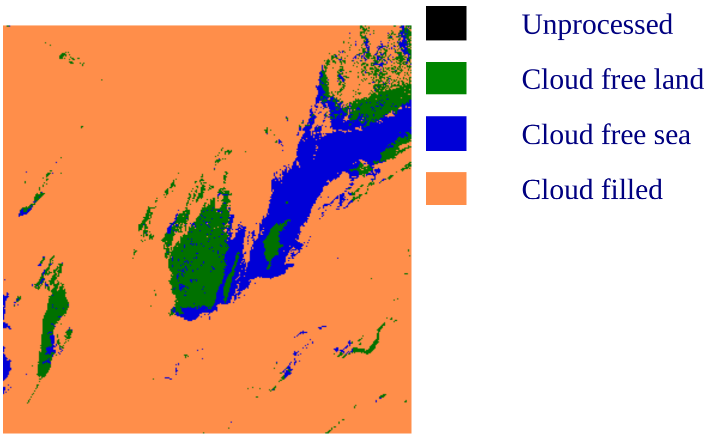


Figure 5: Binary Cloud Mask Classification

Table 3: Cloud Mask, extended

value	**class**
0	Cloud free
1	Cloud filled
2	Cloud contaminated
3	Snow/Ice contaminated
255	No data

Table 4: Cloud Mask, binary

value	**class**
0	Cloud free
1	Cloud filled
255	No data

2.4.1.1.2 Quality and condition flags

There are three flags available in the product files: the condition flag and the quality flag, which are common for all the PGEs, and a statusflag, which is specific for each PGE. Each flag occupies 16 bits, and provide the user with valuable information on the conditions under which the processing was performed, and on the quality of the product. For cloud mask there might also be a set of flags describing which threshold tests that have been performed. The exact outline of the flags are given below, except to the cloud mask test flags which are not described here.

2.4.1.1.2.1 Common flags: condition flag and quality flag

The condition flag describes environmental and illumination conditions, as well as the availability of input data. The first part of the flag describes the conditions:

Table 5: Condition flag, environmental conditions

Illumination & environmental conditions	
bit number	**meaning of the bit**
0	Outside swath/In swath
1-2	Illumination: 0 N/A, 1 night, 2 day, 3 twilight
3	Sunglint/No sunglint
4-5	Land/sea: 0 N/A, 1 land, 2 sea, 3 coast
6	High terrain/Low terrain
7	Rough terrain/Not rough terrain

A number of bits describe the use/availability of various kinds of input data, eg. NWP fields and the availability of the imager channels (mostly for AVHRR/VIIRS heritage channels):

Table 6: Condition flag, input data

Missing data	
bit number	**meaning of the bit**
8-9	Satellite data: 0 N/A, 1 Data available, 2 Useful data missing, 3 Mandatory data missing
10-11	NWP-data: 0 N/A, 1 Data available, 2 Useful data missing, 3 Mandatory data missing
12-13	PGE-data: 0 N/A, 1 Data available, 2 Useful data missing, 3 Mandatory data missing (This flag is not relevant for Cloud Mask, which has no other PGE as input)
14-15	Auxiliary data: 0 N/A, 1 Data available, 2 Useful data missing, 3 Mandatory data missing

The quality flag describes information related to the product quality.

Table 7: Quality flag

Thresholding quality and smoothing	
bit number	**meaning of the bit**
0	This pixel has been assigned to no data
1-2	*These bits are not used*
3-5	Quality: 0 N/A 1 Good 2 Questionable 3 Bad 4 Reclassified or interpolated

For cloud mask the quality (bit number 3-5) is set to bad (=3) for pixels with low quality results. This happens when the value of a pixel in some feature is close to the threshold determining the output. Bit number 3-5 is set to reclassified/interpolated (=4) when an isolated pixel has been changed from cloudy to cloud free (or vice-versa) after applying spatial smoothing. This spatial smoothing will only be applied when the T11-T37 test was the one determining the output value.

2.4.1.1.2.2 Status flag for Cloud Mask

The status flag has got different meanings for different PGEs. Here is described the meaning of the status flag for the cloud mask. Two bits are used to describe the usage of sea-ice input information. The ice concentration maps that can be used are produced by OSISAF.

Table 8: Cloud Mask, status flag

Status flag	
bit number	**meaning of the bit**
0	Low level inversion present
1	Suspected low quality of the NWP data.
2	External sea-ice information used.
3	Sea-ice cover, according to external sea ice maps.
4	There is no method applied for a separate aerosol data set.
5	There is suspected heavy aerosol. (Can be set un-according to flag 4).

A flag is set to 1 if the condition described (e.g. Low level inversion) applies; otherwise it is set to 0.

2.4.1.2 Probabilistic Cloud Mask (Cloud Probability)

2.4.1.2.1 Main output

The cloud probability main output consists of cloud probabilities, i.e., each value on pixel level gives the likelihood in percent, that this pixel is cloudy. See example in Figure 6.

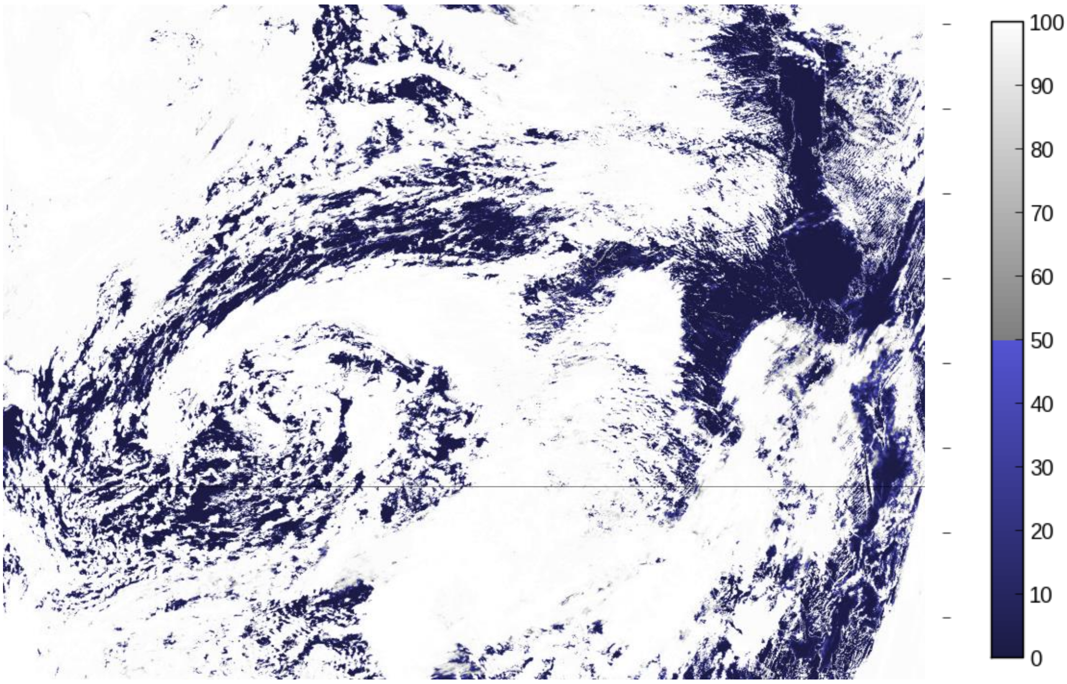


Figure 6 Example of the cloud probability output and its values (see color bar to the right).

2.4.1.2.1.1 Status flag for the Cloud Probability

Five bits (values 1-28) are used to describe the surface category, one to identify low level thermal inversions, one to mark presence of sea-ice and one to point out other snow or ice conditions. For surface categories, some of them have seven similar categories but for different latitude: vhi=very high latitude, hi=high latitude, mid=mid-latitude, and tropical –all of them except the tropical, have one northern and one southern category.

Table 9: Cloud Probability, status flag

Status flag	
bit number	**meaning of the bit**
0 - 4	Describes the surface category used for CMa-Prob calculation: 0: N/A 1: ocean_marginal_seaice 2: ocean_seaice 3: ocean_icefree_north_vhi_lat_nosunglint 4: ocean_icefree_north_hi_lat_nosunglint 5: ocean_icefree_north_mid_lat_nosunglint

	6: ocean_icefree_tropical_nosunglint 7: ocean_icefree_south_mid_lat_nosunglint 8: ocean_icefree_south_hi_lat_nosunglint 9: ocean_icefree_south_vhi_lat_nosunglint 10: homogeneous_land_dry_snowfree 11: homogeneous_land_extratropical_snowfree 12: homogeneous_land_extratropical_snowcovered_seasonal 13: homogeneous_land_extratropical_snowcovered_permanent 14: rough_land_dry_snowfree 15: rough_land_extratropical_snowfree 16: rough_land_extratropical_snowcovered_seasonal 17: rough_land_extratropical_snowcovered_permanent 18: homogeneous_land_tropical_nondry 19: rough_land_tropical_nondry 20: ocean_icefree_north_vhi_sunglint 21: ocean_icefree_north_hi_lat_sunglint 22: ocean_icefree_north_mid_lat_sunglint 23: ocean_icefree_tropical_sunglint 24: ocean_icefree_south_mid_sunglint 25: ocean_icefree_south_hi_lat_sunglint 26: ocean_icefree_south_vhi_lat_sunglint 27: coast_extratropical 28: coast_tropical
5	Low level thermal inversion in NWP field
6	Sea ice according to auxiliary data
7	Snow or sea ice according to NWC SAF / PPS cloud mask

2.4.2 Cloud Type

The Cloud Type output consist of

- a 15-category main output (Cloud classification)
- a multi-layer cloud dataset
- three quality/condition flags

2.4.2.1 Main output

Except when outside the swath, or when processing is stopped due to erroneous input data, a pixel may take one of 4 cloud free values (depending on the underlying surface being land or sea and snow/ice covered or not) or one of 10 cloudy values in the current implementation. The cloudy values can be sub-divided into 5 opaque categories depending on the height of the cloud top, 4 semi-transparent cloud categories (*very thin*, *thin* and *thick cirrus*, and *cirrus over medium and low clouds*) and a *fractional clouds* category (only for low fractional clouds). There is no separation between cumiliform and stratiform clouds.

The colour legend applied for the Cloud Type presentations has been agreed upon between SMHI and Meteo-France, CMS-Lannion, who are developing the SEVIRI Cloud Type product. At the Meteo-France server you may access the latest images from their prototype Cloud Type based on GOES data.

The choice of colours is based first of all on the idea that the meteorological interesting features (clouds and snow) should be easily detected against the background (clear). Secondly it shall be possible to identify the individual cloud classes (in terms of height, opaqueness, and dominating particle phase) from each other, and from cloud free snow or ice on the ground or sea.

Therefore, dark colours (black and green) have been chosen for the (clear) background. The semi-transparent cirrus clouds are kept in blue-cyan. Opaque clouds go from orange over yellow, to white for increasing height (and increasing amount of ice-particles in the cloud). Where can be identified cirrus clouds above other clouds, they are represented by grey-greenish. Fractional cloud is dark purple, whereas ice/snow is light violet and pink.

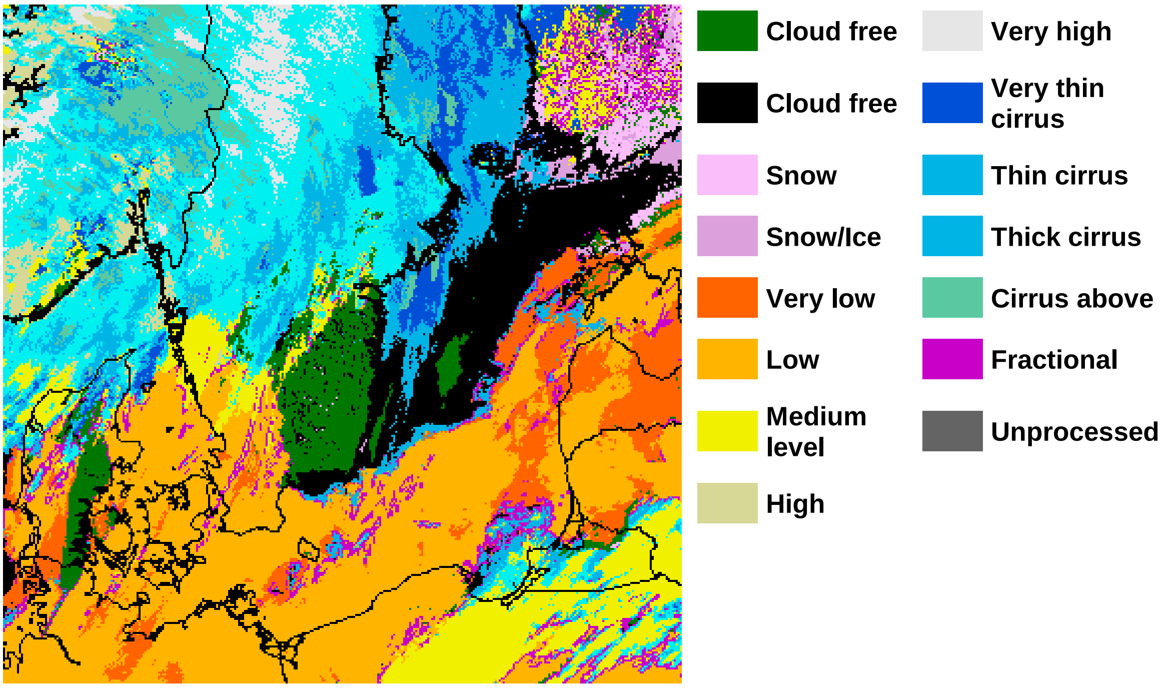


Figure 7: Cloud Type Classification

Table 10: Cloud Type, main output

value	class	value	Class
1	Cloud free land	9	Very High
2	Cloud free sea	10	Fractional (For PPS, this class is only used for low fractional clouds.)
3	Snow/Ice land	11	High semi-transparent very thin cirrus

4	Snow/Ice sea	12	High semi-transparent thin cirrus
5	Very low	13	High semi-transparent thick cirrus
6	Low	14	High semi-transparent above low clouds
7	Medium	15	Not used for PPS. (For GEO: High semi-transparent above snow/ice)
8	High opaque clouds	Fill Value	No data or corrupted data

Table 11: Cloud Type, multi-layer clouds

value	**Class**
0	Single layer cloud
1	Multi-layer cloud
255	No data (including cloud free)

2.4.2.2 Quality and condition flag

The quality flag and the conditions flag are the same for all products, see description as for the Cloud Mask (2.4.1.1.2.1). For the Cloud Type product, the flag for bad quality is set when cloud mask flags for bad quality, while the reclassified/interpolated value is not used for the cloud type product.

The status flag has got different meanings for different products. Here is described the meaning of the status flag for the cloud type. Two of its bits are used to describe the usage of sea-ice input information. The ice concentration maps that can be used are produced by OSISAF.

Table 12: Cloud Type, status flag

Status flag	
bit number	**meaning of the bit**
0	Low level inversion present
1	Suspected low quality of the NWP data.
2	External sea-ice information used.
3	Sea-ice cover, according to external sea ice maps.
4	(not used for CT)
5	Suspected heavy aerosol

A flag is set to 1 if the condition described (e.g. Low level inversion) applies; otherwise it is set to 0.

2.4.3 Cloud Top Temperature and Height

2.4.3.1 Main output

The output provides information on the temperature, pressure and height of the cloud top.

- Temperature is given in Kelvin
- Pressure is given in Pa
- Height is given in meter
- Cloud top in hecto feet (flight level)

Please note that a product value of no-data can represent either a clear pixel -where cloud top properties are not relevant- or it can represent a problem (eg. missing input data). The condition and status flags can be used, to find out which is the case for each pixel.

Following example shows the cloud top height output.

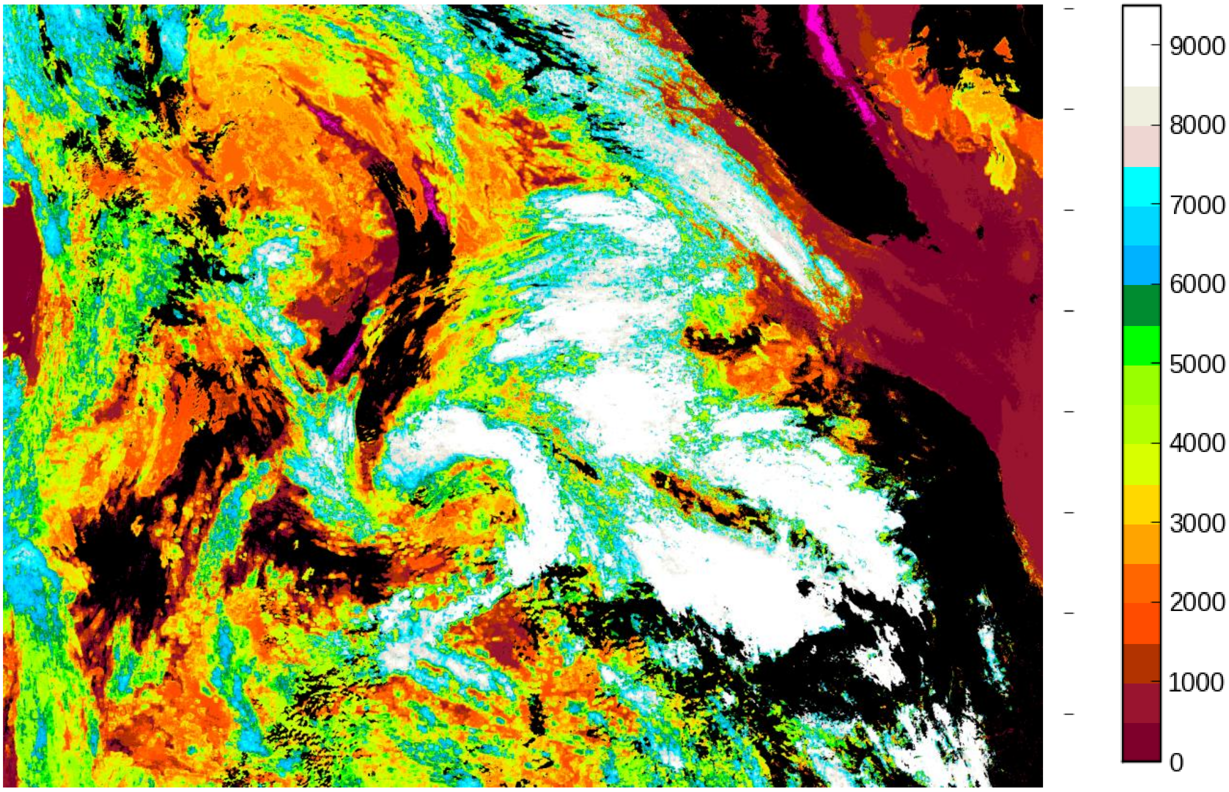


Figure 8: CTTH product, example from cloud top height output

2.4.3.2 Flags

The quality flag and the conditions flag are the same for all products, see description as for the Cloud Mask (2.4.1.1.2.1). For the CTTH product, the flag for quality is set to questionable when the cloud top pressure has got a value higher than the surface pressure from NWP. The surface pressure has been limited to stay between 70hPa and 140hPa -values outside that is considered so bad that they are set to no-data (see status flag).

The status flag has got different meanings for different products. Here is described the meaning of the status flag for the cloud top temperature and height. The exact outline of the flag is given below.

Table 13: CTTH, status flag

Status flag	
bit number	**meaning of the bit**
0	Cloud free
1	Cloud top pressure below the lower bound (i.e. < 70hPa)
2	Cloud top pressure above the upper bound (i.e. > 140hPa)

3	Cloud top pressure above the surface pressure
4	Low level inversion present
5	Suspected low quality of the NWP data.

2.4.4 Cloud Micro Physics

The Cloud Micro Physics output consist of

- Two main output products:
    - Liquid water path, given in kg/m^2
    - Cloud Phase, in 3 categories
- Seven additional output products: (not committed)
    - Ice water path, given in kg/m^2
    - Cloud water path (i.e. both liquid and ice water path)
    - Cloud Optical Thickness –a dimensionless quantity from 0 and up
    - Cloud Geometrical Thickness, given in m
    - Cloud Droplet Number Concentration, given in m^{-3}
    - Cloud Particle Effective radius, given in m
    - Extended cloud phase, in 8 categories
- Eight data sets for quality and processing information:
    - Error estimates for: cloud water path, cloud optical thickness, cloud geometrical thickness, cloud droplet number concentration and cloud particle effective radius.
    - Three quality/condition flags

2.4.4.1 Main output

The liquid water path is given in kg/m^2, displayed in the figure below. The cloud phase is given in 3 categories: nodata (including cloud free), water and ice –as is also displayed in the figure below.

It is also worth to notice that while the cloud phase product works at any time of the day, the liquid water path only works at daylight. Processing a scene at night time will give a liquid water path product of only no-data. Processing a scene, which is partly in bad lighting conditions, will give part of the scene as no-data.

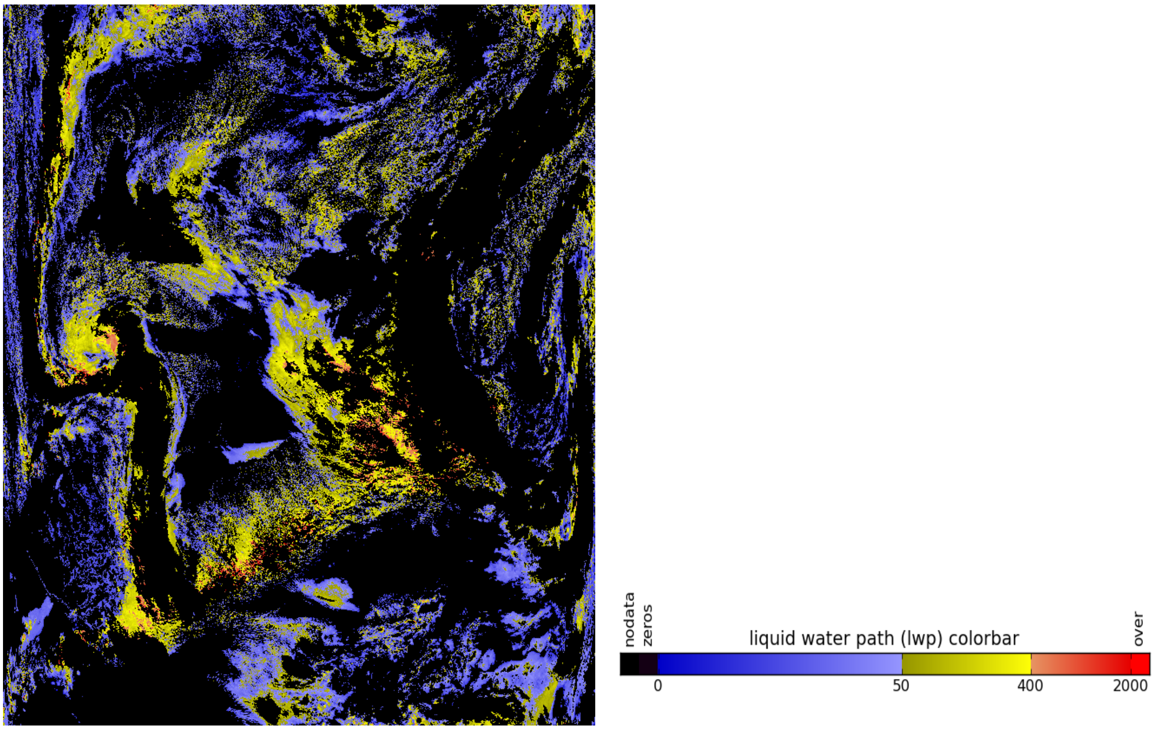
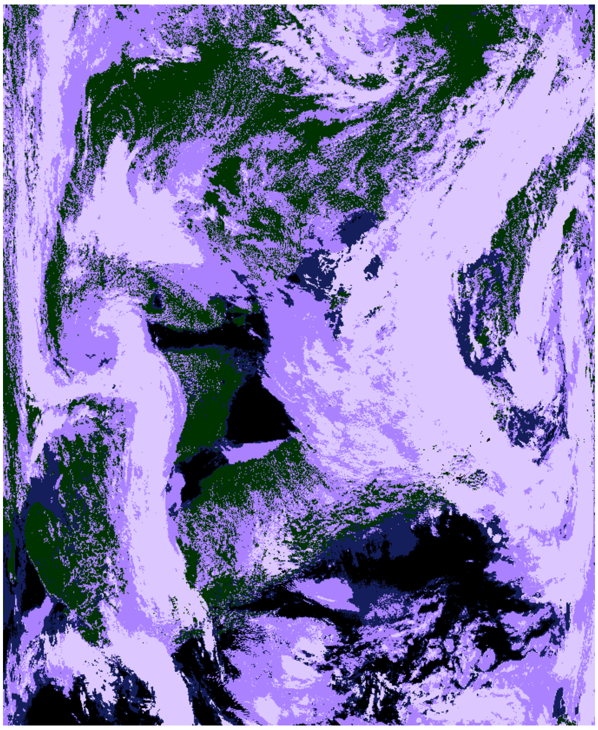


Figure 9 Cloud Micro Physics products: Liquid Water Path (colour scale in g/m^2)



	No data
	Cloud free, sea
	Cloud free, land
	Liquid
	Ice

Figure 10 Cloud Micro Physics product: Cloud Phase

Table 14: Cloud Micro Physics, cloud phase classes

Value	class
1	Cloud phase: liquid
2	Cloud phase: ice
255	No data (incl. cloud free)

2.4.4.2 Additional output

The liquid water path and the ice water path (additional product) are kind of complementary. Liquid water path only has values in locations where cloud phase is 'water', while ice water path only has values in location where cloud phase is 'ice'. While the product cloud water path displays both liquid water path and ice water path.

The cloud particle effective radius is given in m. But please note that the typical values are in the scale of µm. The cloud optical thickness is a dimensionless quantity with values from 0 and up.

It is also worth to notice that ice water path, cloud optical thickness, cloud geometrical thickness, cloud droplet number concentration and cloud particle effective radius only works at daylight. –Just as for the liquid water path, described above.

The extended cloud phase, with more classes than the normal cloud phase, is described in Table 15.

Table 15: Cloud Micro Physics, extended cloud phase classes

Value	class
2	Fog
3	Cloud phase: liquid
4	Super cooled
5	Mixed cloud phases
6	Opaque
7	Cirrus
8	Overlap
255	No data (incl. cloud free)

2.4.4.3 Quality and condition flag

The quality flag and the conditions flag are the same for all PGEs, see description as for the Cloud Mask (2.4.1.1.2.1). For the CMIC product, the flag for bad quality is set when the retrieval quality of cloud optical thickness and cloud particle effective radius is bad. The flag for questionable quality is set when there is snow or ice on the ground, or when the cloud phase value was changed during processing. The reclassified/interpolated flag is set when cloud phase value is changed to clear during processing.

The status flag has got different meanings for different products. Here is described the meaning of the status flag for the cloud micro physics product.

Table 16: CMIC, status flag

Status flag	
bit number	**meaning of the bit**
0	Cloud free
1	Bad optical conditions (e.g. night)
2	Suspected snow or ice
3	1.6 µm channel used
4	3.8 µm channel used
5	2.1 µm channel used (not actually used yet, in PPS vEPSSG)
6	2.2 µm channel used

A flag is set to 1 if the condition described (e.g. cloud free) applies; otherwise it is set to 0.

3. IMPLEMENTATION OF THE PRODUCTS

Three main steps are identified. The preparation and execution steps are always needed. If wanted, the products can afterwards be remapped to regions.

More about the implementation can be found in Software User Manual ([RD.9]) and [RD.10]).

3.1.1 The preparation step:

Good to know is that before the execution of the cloud products a preparation step must be run. This preparation step includes the computation for the specific scene of:

Separate from PPS s.w. package (recommended to use s.w. level1c4pps):

- Imager observation data
- the solar & satellite angles

By PPS s.w. package:

- the monthly climatological & atlas maps
- NWP data
- the thresholds for the algorithm
- texture data
- emissivity data
- OSISAF ice maps (configurable)

Most of the preparations are required for all products. The HRW product has its own additional preparation step.

3.1.2 The execution step:

The execution step is the processing of the algorithms for each product. It is using the data and thresholds prepared during the preparation step. Some of the PPS products depend on other PPS products, e.g. CTTH requires Cloud Mask as input.

3.1.3 Products on region

The product processing is performed in satellite projection. If the products are wanted on a certain region, a script has to be run after the execution step, to remap the products on the region. The user can define the region(s) he wants to have; instructions can be found in Software User Manual ([RD.10]).

The HRW product is an exception, it takes remapped data as input, and make the processing directly on regions.

4. INPUTS AND CONFIGURABLE PARAMETERS

4.1 LIST OF INPUTS

The package was first built for real-time processing on AVHRR (1 km full resolution) data from NOAA- and Metop-scenes. It is also possible to process 750m or 375m resolution data from the VIIRS instrument on-board the NPP and NOAA-20 satellite, and planned for the coming JPSS satellites. Processing on MODIS, MERSI-2 and SLSTR data is also possible. PPS v2021 can also process on the METimage testdata, and PPS vEPSSG will be processing METimage data when available.

Additional input data needed is NWP-data (from ECMWF or GFS) and ice maps from OSISAF. The package can also be run without ice cover data.

Read more about the input in Software User Manual ([RD.10]) and in the ATBD documents ([RD.2], [RD.2b], [RD.3], [RD.4]and [RD.5]).

4.1.1 Cloud Mask

4.1.1.1 Threshold based Cloud Mask

Following input is used for the generation of Cloud Mask:

- NWP surface temperature
- NWP 500 hPa, 700 hPa, 850 hPa and 950 hPa temperature
- NWP tropause temperature
- NWP Total precipitable water
- Sun zenith, satellite view zenith, and sun-satellite view relative azimuth difference angle
- 1km Landuse data (including land/sea mask)
- 1km Digital elevation map
- OSISAF ice maps (optional)
- Imager observation data
- Emissivity maps

4.1.1.2 Probabilistic Cloud Mask (Cloud Probability)

Following input is used for the generation of Cloud Probability:

- NWP surface temperature
- NWP 950 hPa temperature
- NWP snow depth
- Sun zenith, satellite view zenith, and sun-satellite view relative azimuth difference angle

- 1km Landuse data (including land/sea mask)
- 1km Digital elevation map
- OSISAF ice maps (optional)
- Imager observation data
- Emissivity maps
- Threshold and texture tables (from Cloud Mask/Cloud Type prepare)
- Output from Cloud Mask flags (if complete processing flags is wanted)

4.1.2 Cloud Type

Following input is used for the generation of Cloud Type:

- NWP surface temperature
- NWP temperature at several vertical levels (e.g. 950,850,700,500, and tropopause)
- Sun zenith, satellite view zenith, and sun-satellite view relative azimuth difference angle
- 1km Landuse data (including land/sea mask)
- 1km Digital elevation map
- Output from Cloud Mask
- Output from CTTH
- Imager observation data

4.1.3 Cloud Top Temperature and Height

Following input is used for the generation of Cloud Top Temperature and Height:

- NWP temperature at several vertical pressure levels
- NWP geopotential height at several vertical pressure levels
- NWP temperature and pressure at the surface
- NWP column integrated water vapour
- Latitude and longitude1km
- Threshold and texture tables (from Cloud Mask/Cloud Type prepare)
- Output from Cloud Mask
- Imager observation data

4.1.4 Cloud Micro Physics

Following input is used for the generation of Cloud Micro Physics:

- NWP surface temperature
- NWP total integrated water vapour
- NWP snow depth and snow albedo (both are optional)
- OSISAF ice maps (optional)
- Sun zenith, satellite view zenith, and sun-satellite view relative azimuth difference angle
- 1km Landuse data (including land/sea mask)
- Imager observation data
- Output from PPS Cloud Mask
- Output from PPS CTTH (optional)

4.2 Configurable parameters

SAFNWC/PPS has been designed to allow a full configuration. That means that the implementation of the application includes minimum information about processing of the PGEs and secondary actions. All this data is submitted in several configuration files, and therefore it can be configured according to the user's preferences.

Possible configuration is for example:

- Processing methods configuration. Examples: Which dataset should be generated in each product, generation of flags, level of logging etc.
- Input and output: Examples: Where to find/put it, what kind of input should be used for the generation.

The possible configurable parameters are described in the Software User Manual ([RD.10]).

5. VALIDATION

5.1 SUMMARY OF VALIDATION RESULTS

The latest validation of CMa, CT and CTTH is made for SAFNWC/PPS v2021 with matchup data between VIIRS, MODIS, MERSI-2 and AVHRR (GAC and hrpt) co-located with CPR (CloudSat), SYNOP, AMSR-E and CALIPSO data. The validation result shows that all threshold-, and many target-, and some optimal accuracies are reached.

5.1.1 Cloud Mask and Cloud Probability

In Table 17 we see the results (HR) of the PPS Cloud Mask version 2021, validated with CALIPSO data. Data are shown for different instruments (VIIRS/MODIS/AVHRR/MERSI-2) and resolutions (high resolution VIIRS/MODIS/MERSI-2/AVHRR (Metop-B), low resolution GAC). Data are presented for high-quality and high-quality pixels respectively. For cloud probability high-quality is defined as those with values below 20% or above 80% and low-quality are those with cloud probability between 20% and 80%. For cloud mask the quality flag is used. More detailed validation can be found in the validation report.

Table 17: Cloud Mask global validation for PPS-v2021. Scores for PPS-CMA for MODIS is identical for the cases without and with OSISAF ice data as input. Green: within target accuracy, red: outside threshold accuracy. Yellow marks measures with requirements

SENSOR	Hit rate (low-quality)	Hit rate (high-quality)	Part of data that is high-quality.	N
CMa VIIRS	63.9	88.1	92.4	643025
CMa-Prob VIIRS	55.4	88.9	87.8	606931
CMa MODIS	70.4	88.7	89.2	3453079
CMa-Prob MODIS	58.4	90.5	85.0	3363627
CMa AVHRR GAC	63.7	84.6	90.1	293513
CMa-Prob ACHRR GAC	54.8	87.1	83.1	291279
CMa MERIS-2	57.3	84.1	91.8	1358616
CMa-Prob- MERSI-2	53.1	88.2	77.8	1347004
CMa AVHRR Metop-B	62.7	79.9	87.5	21821
CMa-Prob AVHRR Metop-B	51.3	80.6	64.6	21817

5.1.2 Cloud Type

For a validation of the cloud type, we use the classification provided with the CALIPSO data. The CALIPSO cloud types can be condensed into three height classes, which are low level, medium level and high-level clouds (low level clouds > 680hPa, medium level 680-440hPa, high level <440hPa). In Table 18 we can see that most clouds are classified correctly except for some medium level altostratus and deep convective clouds being classified as cirrus clouds.

Table 18: Comparison of PPS version 2021 VIIRS with CALIOP. Fields marked green are considered successfully matched. The largest error consists of alto stratus and deep convective clouds that can be classified as cirrus. For other sensors results are similar except for MERSI-2 where a quarter of CALIOP low clouds are classified as PPS-medium. And around 10 percentage point more CALIOP clouds are classed as PPS-High for all CALIOP medium and high cloud classes. Note that MERSI-2 as default uses the 11 and 3.7 for CTTH and not the 12 micron channel as the other sensors does.

		PPS type						
		N	Low	Frac	Medium	High	Cirrus	
	CALIOP type:							
	low overcast (tp)	18311	**70.9**	**23.4**	3.0	0.1	2.5	
	low overcast (oq)	37562	**86.3**	**7.5**	3.4	0.2	2.6	
	transition stratocumulus	66864	**47.3**	**43.6**	5.7	0.3	3.1	
	low broken cumulus	16355	**33.6**	**45.3**	10.3	0.9	9.9	
	altocumulus (tp)	31320	8.8	6.2	**34.7**	5.3	**45.0**	
	altostratus (oq)	33629	3.5	0.5	**54.0**	7.9	34.1	
	cirrus (tp)	110016	3.7	3.1	9.0	**15.2**	**69.1**	
	deep convective (op)	57603	0.0	0.0	1.8	**61.1**	37.1	

5.1.3 Cloud Top Height

The performance of the CTTH product is shown in Table 19. It can be seen that all requirements are met.

Table 19: Validation results separated by opaque semi-transparent filtered to get the cases where CALIOP and the imager really should agree. Filtering is done as similar as possible to GEO validation, considering different validation software. Only pixels where 9 neighbouring measurements have the same cloud type and the variation in CALIOP pressure are less than 200hPa are included. Pixels where the 5km CALIOP top-layer are thinner than 0.2 are excluded. This leaves 1/4 of the data. Results within target accuracy marked green. Yellow: measures with requirement.

Comparison to filtered CALIOP.	Bias (m)	Median (m)	IQR (m)	PE0.5 (%)	PE>1.0 (%)	MAE (m)	std (m)	N
S-NPP VIIRS 15 orbits								
Opaque	115	52	449	24	8	381	618	69067
Semi	-247	20	1037	51	32	1070	1893	27563
NOAA-18 GAC 28 orbits (2009)								
Opaque	30	1	313	18	6	309	531	21461
Semi	-183	-11	731	42	24	843	1658	8029
MODIS data 6 days								
Opaque	-36	-6	424	23	8	368	590	426509
Semi	-568	-163	1223	52	32	1043	1741	172517
MERSI-2 (uses channel 3.7 and 11)								
Opaque	682	463	751	53	25	889	1420	162225
Semi	223	234	1668	68	44	1289	1945	64233
Metop-B AVHRR (mostly polar night and twilight)								
Opaque	367	211	652	31	17	537	707	1709
Semi	-140	212	1083	56	34	1061	1632	1649
Threshold	2000/ 1000	2000/ 1000	2700	80	60	2350/ 1800	2000	
Target	1500/ 500	1500/ 500	2200	75	50	1750/ 1250	1500	
Optimal	200	200	670	30	5	430	500	

5.1.4 Cloud Micro Physics

The validation of the CMIC cloud phase and liquid water path show that both algorithms met the specified requirements. While the cloud phase product has been validated over both land and sea, the LWP product has only been properly validated over sea.

The CMIC cloud phase is validated against the CALIOP instrument on board the CALIPSO platform. The threshold or target accuracy, POD and FAR, is met for all scores under investigation, see Table 20.

The validation of the CMIC liquid water path is made against the Advanced Microwave Scanning Radiometer for EOS (AMSR-E) instrument on board the Aqua satellite or against CloudSat RVOD for VIIRS. The AMSR-E validation is only made over sea. The root mean square deviation (RMS) and the bias are all within threshold or target accuracy. See Table 21.

For all details, we refer to the Product Validation Report ([RD.11]).

Table 20: Validation results, and required accuracies, for CMIC Cloud Phase. Verified against CALIOP data

		POD liquid	FAR liquid	POD solid	FAR solid
Achieved performance		0.75-0.87	0.12-0.25	0.82-0.89	0.09 – 0.25
Threshold accuracy		≥ 0.70	≤ 0.35	≥ 0.60	≤ 0.35
Target accuracy		≥ 0.80	≤ 0.20	≥ 0.80	≤ 0.20
Optimal accuracy		≥ 0.90	≤ 0.10	≥ 0.90	≤ 0.10

Table 21: Validation results, and required accuracies, for CMIC Liquid Water Path. Verified against AMSR-E data. Validation only over sea.

	RMS [g/m²]	Bias [g/m²]
Achieved accuracy AVHRR GAC compared to AMSER-E	43.4	-4.1
Achieved accuracy MODIS compared to AMSR-E	59.0	-6.2
Achieved accuracy VIIRS compared to RVOD (CloudSat)	78.4	1.9
Threshold accuracy	≤ 100.	≤ 20.
Target accuracy	≤ 50.	≤ 10.
Optimal accuracy	≤ 20.	≤ 5.

5.2 KNOWN PROBLEMS AND LIMITATIONS

The Cloud Micro Physics product only give a product while day light (sun zenith angle below 72 degrees), except for the cloud phase which works at all time of the day.

The Liquid Water Path (part of Cloud Micro Physics product) is not validated over land, only over sea.

Processing with METimage data has so far (PPS v2021 and beta-releases of vEPSSG) only been tried out with test data.

Quality (for all products) are generally lower in situations with very thin clouds. Some clouds are too thin for the imager to even detect.

6. EXAMPLE OF PRODUCT VISUALISATION

It is important to note that the products are not just images, but numerical data. At first hand, for example the CT is rather thought to be used digitally (together with the appended flags) as input to mesoscale analysis models, objective Nowcasting schemes, but also in the extraction of other SAFNWC products (CMa as input to CTTH for example).

Colour palettes are included in netCDF files, allowing an easy visualisation. And while processing the product, png/jpg files can be produced at the same time, for an even easier visualisation.

6.1 CLOUD MASK

6.1.1 Threshold based Cloud Mask

The threshold based cloud mask algorithm produces two types of cloud masks, an extended (the classic one) and a binary cloud mask. The binary cloud mask has only two classes: cloudy and cloud free (and also no data, e.g. if missing input data). For an example of both products see Figure 11. Please note that cloud free land and cloud free sea both are the class ‘cloud free’; it is split into land and sea in the png, for easier localization.

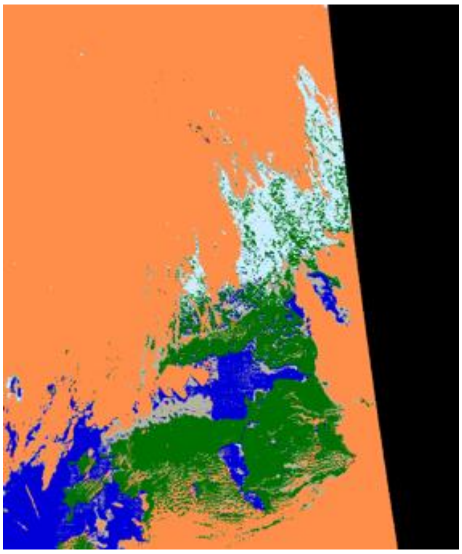
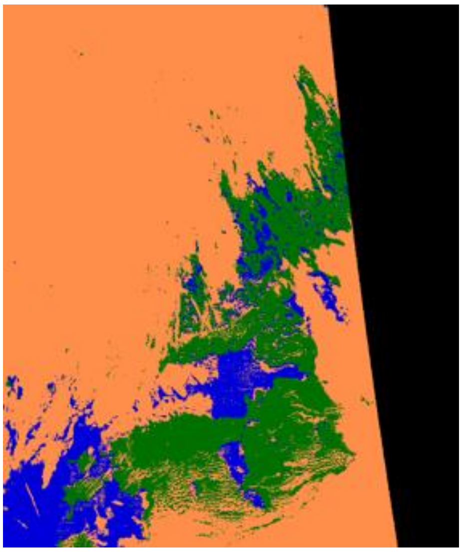
		**Cloud free land** **Cloud free sea** **Cloud contaminated** **Cloud filled** **Snow/Ice contaminated**
extended cloud mask	binary cloud mask	

Figure 11 Cloud Mask and Binary Cloud Mask

The output and the quality flag could be visualised together. This example is from 1157UTC. In the north-western part is the snow covered area well presented.

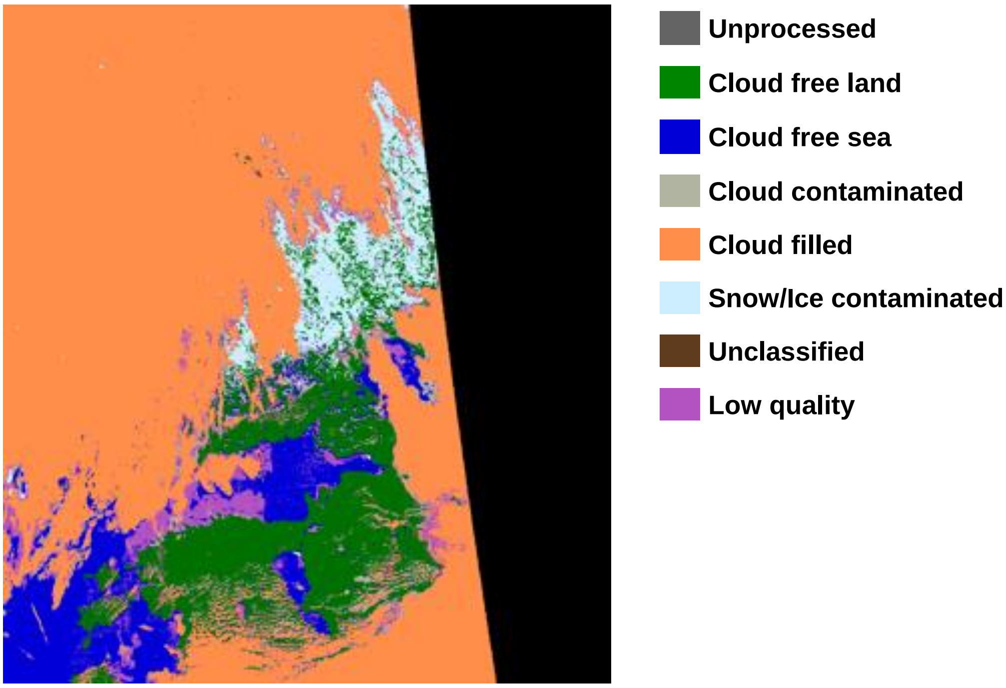
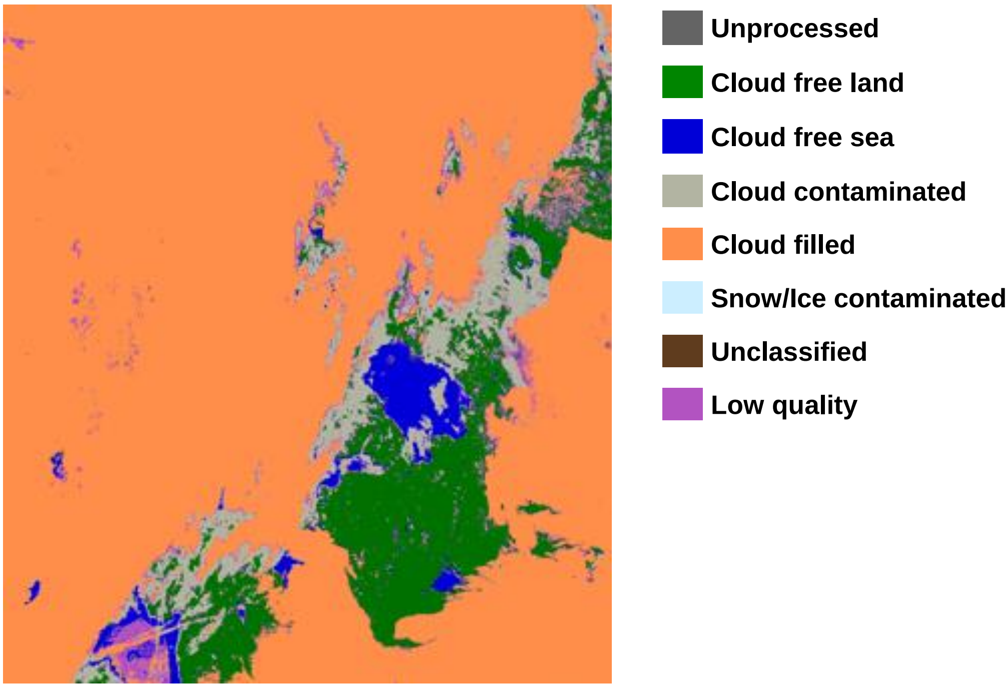
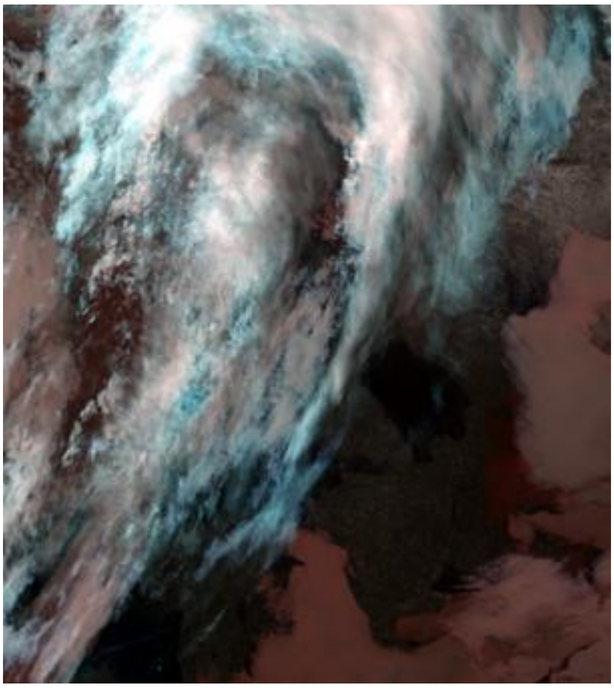


Figure 12: Cloud Mask UTC1157, main output and quality flag

Later, at night, the Cloud Mask product has some problem to identify the snow:





Reference image

RGB Ch 3.7, 11, 12 µm

Figure 13: Cloud Mask,UTC 2314-night

6.1.2 Probabilistic Cloud Mask (Cloud Probability)

An example of the cloud probability is given below. This is a detail of the central part of the VIIRS swath. The presented quantity is the likelihood that individual pixels are cloudy. The values are in ‘per cent’ (see colour bar). The corresponding RGB image is shown further below.

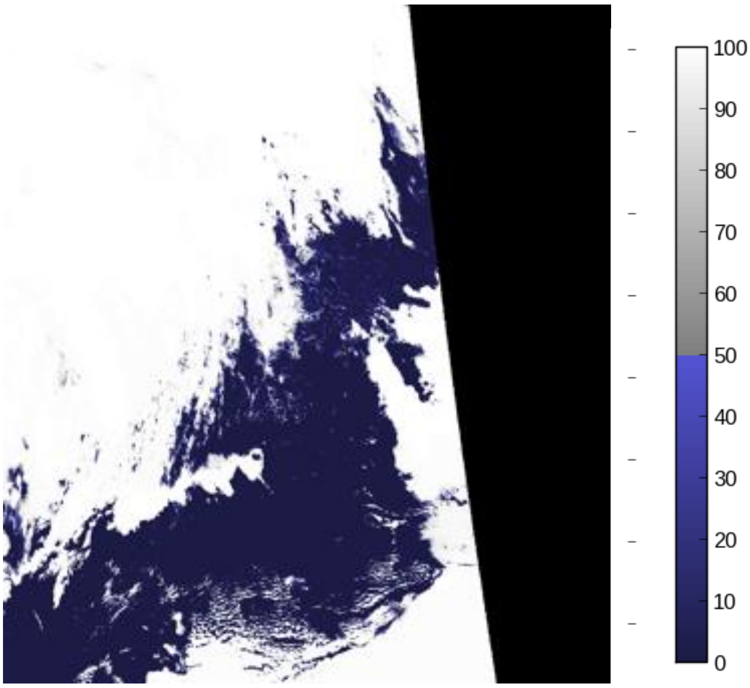


Figure 14: Example to demonstrate the Cloud Probability product. Same scene as for Cloud Mask at day time, shown above, but a bit broader.

Figure 15 Reference image for Cloud Probability. Ch 0.6, 0.9 and 11 µm

6.2 Cloud type

The Cloud Top Temperature and Height is generated based on the output from the Cloud Mask and CTTH. The results are shown below. The cloud type classification works well, except for in certain situations: at twilight and in winter conditions with very cold surface temperatures.

First is the Cloud Type product output for UTC 1157:

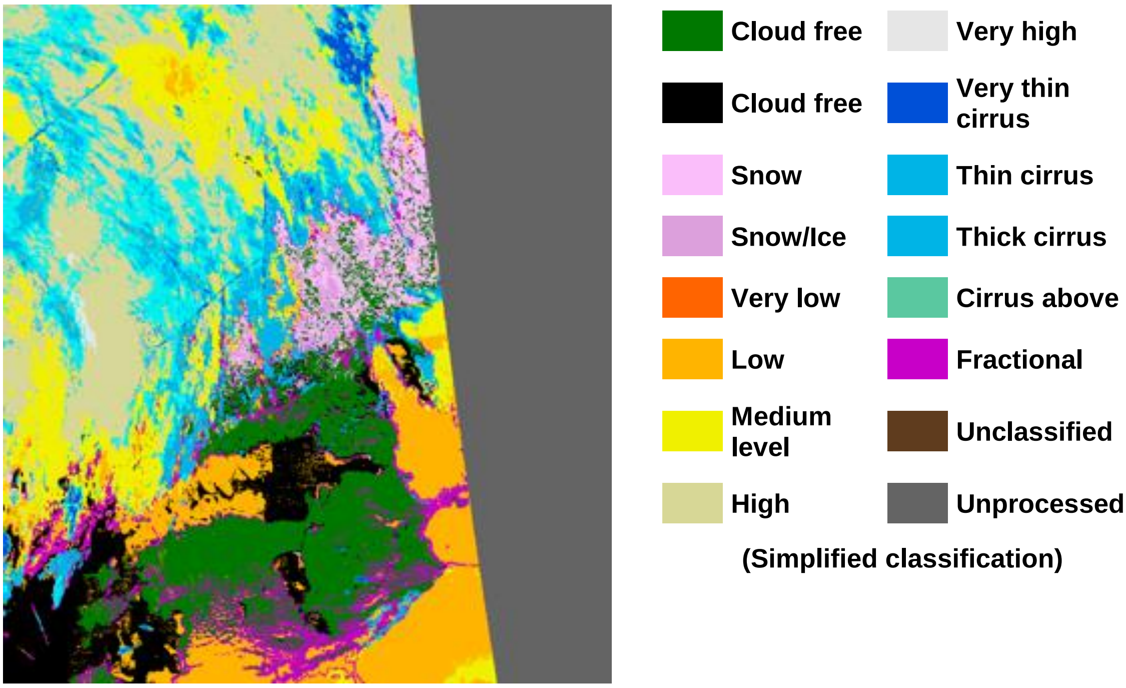


Figure 16: Cloud Type UTC1157

But, also for Cloud Type, snow is missing for low sun zenith angle and night situations (UTC2314). To be compared to the example for Cloud Mask.

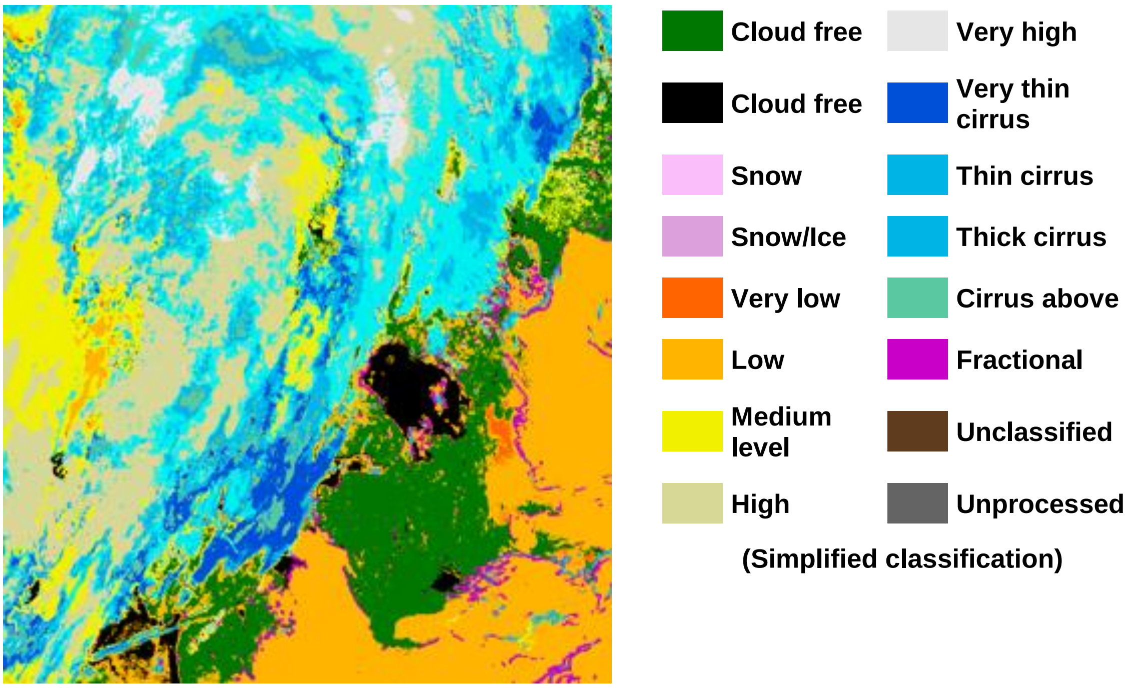


Figure 17: Cloud Type UTC2357 - night

6.3 Cloud top temperature and height

The Cloud Top Temperature and Height is generated based on the output from the Cloud Mask. The results are shown below.

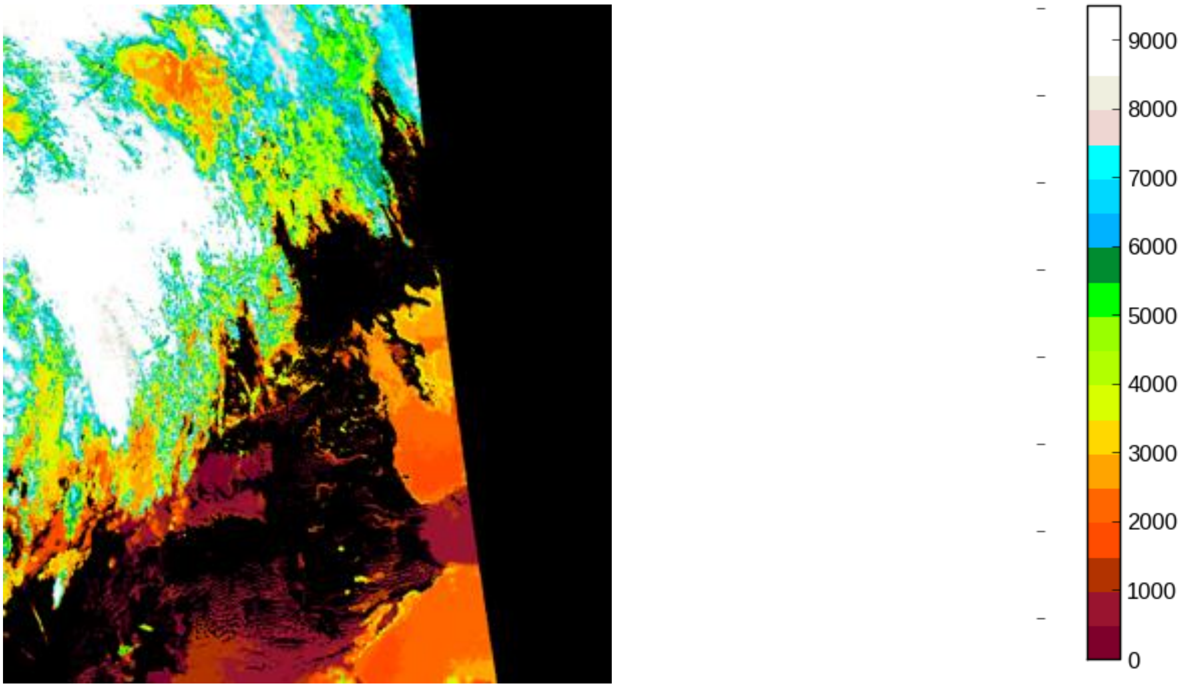


Figure 18: Cloud Top Temperature and Height product (example shows the cloud top height). A detail of a VIIRS scene. For reference RGB image see Figure 15.

6.4 Cloud Micro Physics

There are two official products within the Cloud Micro Physics product and five additional products. An example of visualisation for a couple of them is shown here.

This example is in early March at 11:57 (local time 13:57). We can see it as an example of the need for daylight. Upper/central right part is over Finland while the lower part is over Estonia. Over northern Finland the daylight is in this case not enough for the Cloud Micro Physics product, thus being no-data there.

The same colour bar is used for liquid water path and ice water path:

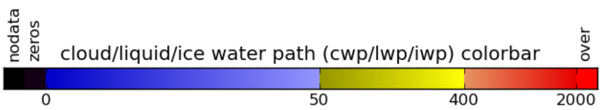


Figure 19: Colour scale used for liquid water path, as well as ice water path (in g/m^2)

	No data

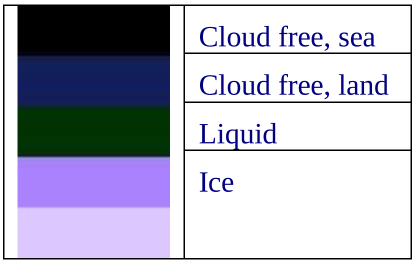
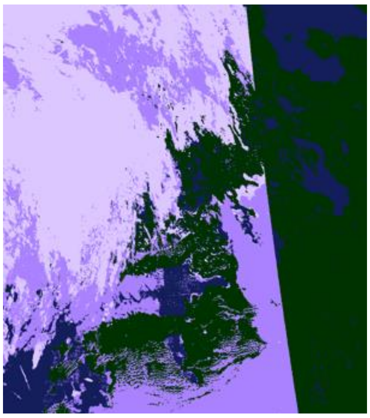
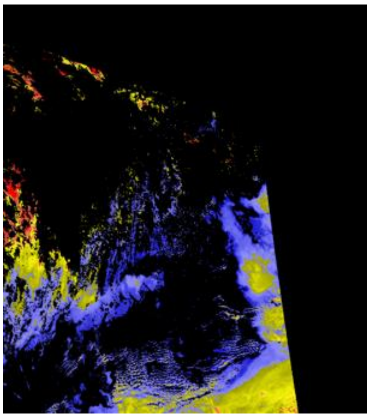
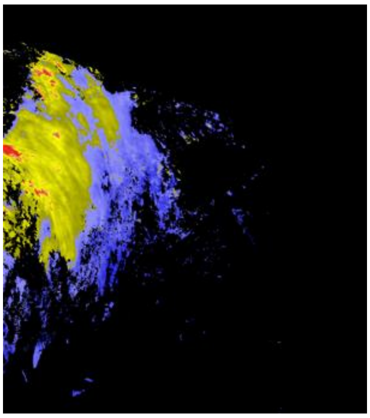
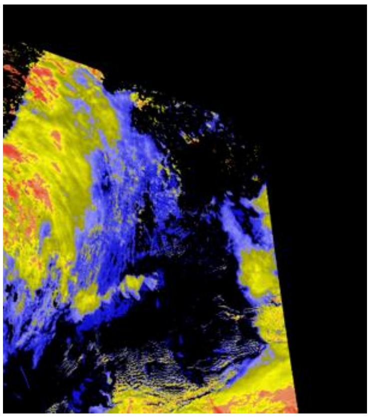
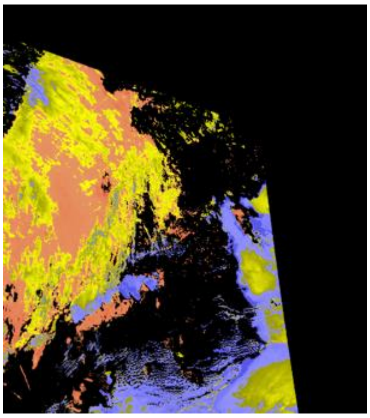


Figure 20: Colour scale used for cloud phase

Below, in Figure 21, all outputs Cloud Micro Physics products are displayed. Also, a Cloud Type and an RGB (0.6µm, 0.9µm, 11µm) are displayed, for comparison.

cloud phase	liquid water path	ice water path
		
cloud optical thickness	effective radius	
		
cloud type	rgb	

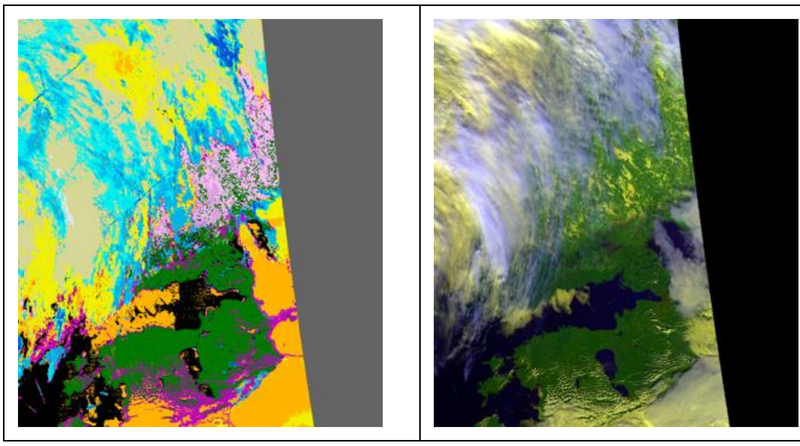


Figure 21: Cloud Micro Physics UTC 11:57. For colour bars for the CMIC products, see Figure 19 and Figure 20.

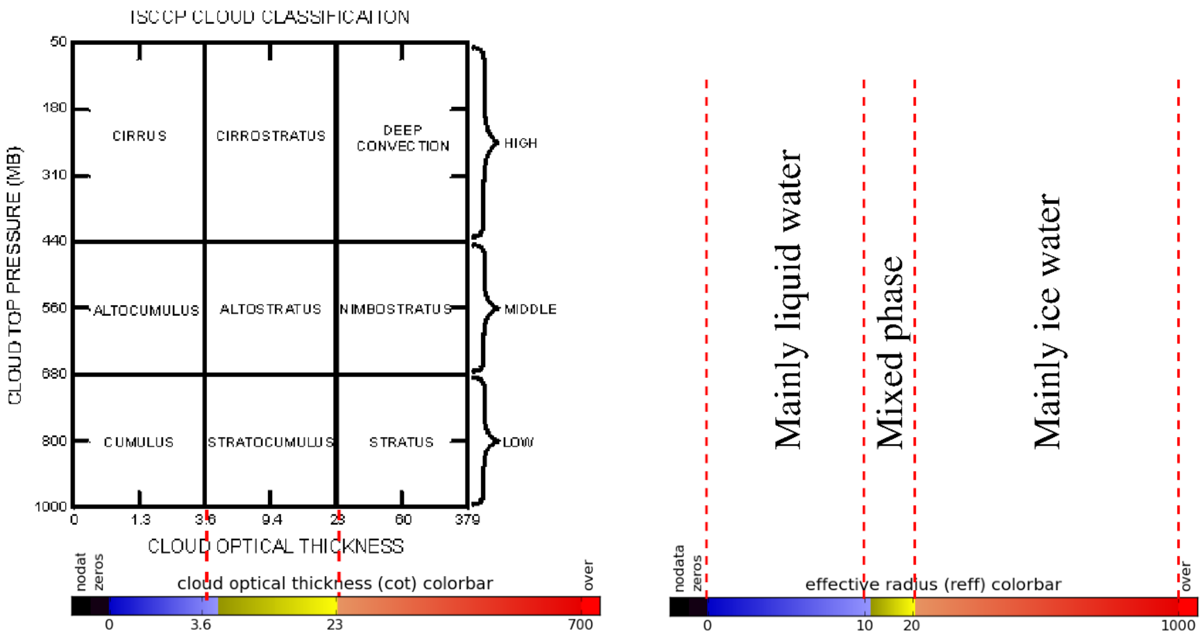


Figure 22: Colour scales of Cloud Optical Thickness and Effective Radius, and some help to interpret them.

ANNEX A. List of TBC, TBD, Open Points and Comments

TBD/TBC	Section	Resp.	Comment