The EUMETSAT Network of Satellite Application Facilities

NWC SAF

Support to Nowcasting and Very Short Range Forecasting

Algorithm Theoretical Basis Document for Cloud Type of the NWC/PPS

NWC/CDOP2/PPS/SMHI/SCI/ATBD/2, Issue 1, Rev. 0

15 September 2014

Applicable to SAFNWC/PPS version 2014

Applicable to the following PGE:s:

PGE	Acronym	Product ID	Product name	Version number
PGE02	CT	NWC-065	Cloud Type	2.0

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REPORT SIGNATURE TABLE

Function	Name	Signature	Date
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DOCUMENT CHANGE RECORD

Version	Date	Pages	Changes
1.0d	22 January 2014	39	Replacing CDOP-document: SAF/NWC/CDOP/SMHI-PPS/SCI/ATBD/2 First version for SAFNWC/PPS v2014 Changes since v2012: Updated the output description, and some smaller general improvements.
1.0	15 September 2014	40	Implemented RIDs from PCR-v2014: -LSc1 (formal issues) -LSc2 (summary of requirements) -LSc3, PW21-PW22 (editorials and clarifications) -PW23 (removing unnecessary status flags) General changes: -Added a description of the new dataset: multi-layer. -Replaced validation with results from v2014.

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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://www.nwcsaf.org . 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 the Algorithm theoretical Basis Document for the PGE02 (CT, Cloud Type) of the SAFNWC/PPS software package.

This document contains a description of the algorithm, including scientific aspects and practical considerations.

1.2 Scope

This document describes the algorithms implemented in the PGE02 version 2.0 of the 2014 SAFNWC/PPS software package delivery.

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 PGE:s.)
AEMET	Agencia Estatal de Meteorología (Spain)
AHAMAP	AMSU-HIRS-AVHRR Mapping Library (A part of the SAFNWC/PPS s.w.)
AMSU	Advance Microwave Sounding Unit
AVHRR	Advanced Very High Resolution Radiometer
CDOP	Continuous Development and Operational Phase
CDOP-2	Second Continuous Development and Operational Phase
CMA	Cloud Mask (also PGE01)
CM-SAF	Climate Monitoring SAF
CPP	Cloud Physical Products
CT	Cloud Type (also PGE02)
CTTH	Cloud Top Temperature, Height and Pressure (also PGE03)
EPS	EUMETSAT Polar System
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
GEO	Geosynchronous equatorial orbit

Acronym	Explanation
IR	Infrared
ISCCP	International Satellite Cloud Climatology Project
LEO	Low earth orbit
MHS	Microwave Humidity Sounding Unit
NIR	Near Infrared
NOAA	National Oceanic and Atmospheric Administration
NWP	Numerical Weather Prediction
OSISAF	Ocean and Sea Ice SAF
PC	Precipitating Cloud (also PGE04)
PGE	Process Generating Element
PPS	Polar Platform System
RGB	Red Green Blue
SAF	Satellite Application Facility
SAFNWC	Satellite Application Facility for support to NoWcasting
SMHI	Swedish Meteorological and Hydrological Institute
TBC	To Be Confirmed
TBD	To Be Defined
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/CDOP2/SAF/AEMET/MGT/PP	1.2	28/06/13
[AD.2.]	NWCSAF Product Requirements Document	NWC/CDOP2/SAF/AEMET/MGT/PRD	1.5	05/06/14
[AD.3.]	System and Components Requirements Document for the SAFNWC/PPS	NWC/CDOP2/PPS/SMHI/SW/SCRD	1.0	15/09/14

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/CDOP2/SAF/AEMET/MGT/GLO	2.0	18/02/14
[RD.2]	Validation of CM-SAF cloud products derived from AVHRR data in the Arctic region”	SAF/CM/SMHI/SR/CLOUDS-ORR/B	1.0	19/01/09
[RD.3]	Output Data Format of the SAFNWC/PPS	NWC/CDOP2/PPS/SMHI/SW/DOF	1.1	15/09/14
[RD.4]	Algorithm Theoretical Basis Document for the Cloud Mask of the NWC/PPS	NWC/CDOP2/PPS/SMHI/SCI/ATBD/1	1.0	15/09/14
[RD.5]	Algorithm Theoretical Basis Document for Cloud Top Temperature, Pressure and Height of the NWC/PPS	NWC/CDOP2/PPS/SMHI/SCI/ATBD/3	1.0	15/09/14
[RD.6]	Algorithm Theoretical Basis Document for Precipitating Clouds of the NWC/PPS	NWC/CDOP2/PPS/SMHI/SCI/ATBD/4	1.0	15/09/14
[RD.7.]	User manual for the SAFNWC/PPS Application: Software Part, 2.Operation	NWC/CDOP2/PPS/SMHI/SW/UM/2	1.0	15/09/14
[RD.8]	Scientific and Validation Report for the Cloud Product Processors of the NWC/PPS	NWC/CDOP2/PPS/SMHI/SCI/VR/Cloud	1.0	15/09/14

Table 2: List of Referenced Documents

1.4.3 Scientific References

Since the algorithm design for cloud type follows same physical principles and to large extend the same logic as for cloud mask, the references for cloud mask also apply to cloud type classification:

Allen, R. C., Durkee, P. A., and Wash, C. H., 1990. Snow/cloud discrimination with multispectral satellite measurements. *Journal of Applied Meteorology* ***29***, 994-1004.

Anderson, J., Hardy, E., Roach, J., and Witmer, R., 1976. A land use and land cover classification system for use with remote sensor data. Technical report, U.S. Geological Survey.

Berendes, T., Kuo, K., Logar, A., Corwin, E., Welch, R., Baum, B., Petre, A., and Weger, R., 1999. A comparison of paired histogram, maximum likelihood, class elimination, and neural network approaches for daylight global cloud classi_cation using AVHRR imagery. *Journal of Geophysical Research* ***104*****(D6)**, 6199-6213.

Cox, C. and Munk, W., 1954. Measurement of the Roughness of the Sea Surface from Photographs of the Sun's Glitter. *Journal of the Optical Society of America* ***44*****(11)**, 838-850.

Derrien, M., Farki, B., Harang, L., Gléau, H. L., Noyalet, A., Pochic, D., and Sairouni, A., 1993. Automatic cloud detection applied to NOAA-11/AVHRR imagery. *Remote Sensing of Environment* ***46***, 246-267.

Dybbroe, A., Karlsson, K.-G., and Thoss, A., 2005a. AVHRR cloud detection and analysis using dynamic thresholds and radiative transfer modelling - part one: Algorithm description. *Journal of Applied Meteorology* ***41*****(1)**, 39-54.

Dybbroe, A., Karlsson, K.-G., and Thoss, A., 2005b. AVHRR cloud detection and analysis using dynamic thresholds and radiative transfer modelling - part two: Tuning and Validation. *Journal of Applied Meteorology* ***41*****(1)**, 55-71.

Eidenshink, J. and Faundeen, J., 1994. The 1 km AVHRR global land data set-first stages in implementation. International Journal of Remote Sensing **15(17)**, 3443-3462.

Eyre, J. R., Brownscombe, J. L., and Allam, R. J., 1984. Detection of fog at night using Advanced Very High Resolution Radiometer (AVHRR) imagery. *Meteorological Magazine* ***113***, 266-271.

Hunt, G. E., 1973. Radiative properties of terrestrial clouds at visible and infra-red thermal wavelengths. *Quarterly Journal of the Royal Meteorological Society* ***99***, 346-369.

Inoue, T., 1985. On the temperature and effective emissivity determination of semi-transparent cirrus clouds by bi-spectral measurements in the 10 µm window region. Journal of the Meteorological Society of Japan **63(1)**, 88-98.

Karlsson, K.-G., 1989. Development of an operational cloud classification model. *Int. J. Remote Sens*., **10**, 687-693.

Karlsson, K.-G., 1996. Cloud Classification with the SCANDIA model. Reports Meteorology and Climatology **67**, SMHI.

Karlsson, K.-G. and Dybbroe, A., 2009. Evaluation of Arctic cloud products from the EUMETSAT Climate Monitoring Satellite Application Facility based on CALIPSO-CALIOP observations. *Atmos. Chem. Phys. Discuss.*, ***9***, *16755-16810, 2009.*

Karlsson, K.-G. and Liljas, E., 1990. The SMHI model for cloud and precipitation analysis from multispectral AVHRR data. PROMIS reports **10**, SMHI. 74pp.

Kriebel, K. T., G. Gesell, M. Kästner, and H. Mannstein, 2003. The cloud analysis tool APOLLO: Improvements and validations. *Int., J. Remote Sens*., **24**, 313-329.

Salisbury, J. W. and d'Aria, D., 1994. Emissivity of terrestrial materials in the 3 - 5µm atmospheric window. *Remote Sensing of Environment* ***47***, 345-361.

Saunders, R. and Kriebel, T., 1988. An improved method for detecting clear sky and cloudy radiances from AVHRR data. *Int. J. Rem. Sens.* ***9***, 123-150.

Stowe, L., McClain, E. P., Carey, R., Pellegrino, P., and Gutman, G. G., 1991. Global distribution of cloud cover derived from NOAA/AVHRR operational satellite data. *Adv. Space Res.* ***11***, 51-54.

Stowe, L. L., Davis, P. A., and McClain, E. P., 1999. Scientific Basis and Initial Evaluation of the CLAVR-1 Global Clear/Cloud Classification Algorithm for the Advanced Very High Resolution Radiometer. *Journal of Atmospheric and Oceanic Technology* ***16***, 656-681.

Warren, D., 1989. AVHRR channel-3 noise and methods for its removal. *Int. J. Remote Sens*., **10**, 645-651.

1.5 DOCUMENT OVERVIEW

This document contains a theoretical description of the algorithms for cloud type derivations. The 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 A short introduction to the cloud type product
- Section 3 A short overview of the cloud type algorithm
- Section 4 Algorithm description in more detail

1.6 SCIENTIFIC UPDATES SINCE PPS VERSION 2012

For v2014 PGE02 has not undergone a certain scientific update in terms of changing the algorithm. However, it is noteworthy that the cloud-classes have been cleaned from unused categories and the output has been harmonized in general with the respectively output from GEO algorithms.

It is also worth to notice that the Cloud Mask has undergone major changes since v2012, thus indirectly influencing the Cloud Type product.

2. INTRODUCTION TO THE SAFNWC/PPS CLOUD TYPE

The Cloud Type is first of all aimed at nowcasting applications, but will also be used to build up cloud climatologies in the framework of the Climate Monitoring SAF (CMSAF). It also provides an essential first step in the derivation of radiative fluxes over sea within the Ocean & Sea Ice SAF OSISAF). The main objective is to provide a detailed cloud scene analysis, which for all cloudy pixels in the scene distinguishes between the following generic cloud classes: fractional clouds, semi-transparent clouds, high, medium, and low clouds (including fog). A second priority is the identification of clouds for which the top mainly consists of water droplets. Here only a rather crude *poor man's* cloud phase flag is implemented, identical to the one used in the ISCCP (International Satellite Cloud Climatology Project) cloud scheme. The CT product is input to the SAFNWC polar satellite based retrievals for the CTTH and Precipitating Clouds, PC, described in **[RD.5]** and **[RD.6]**.

The SAFNWC/PPS have been developed for the Advanced Very High Resolution Radiometer (AVHRR) onboard the polar-orbiting weather satellites NOAA and Metop. It has been implemented so that it automatically handles both AVHRR/2 data, with channel 3B during both day and night, and AVHRR/3 data, which has the possibility to activate channel 3B during night and switch to channel 3A during day. The instrument measures outgoing reflected solar energy and radiated thermal energy from land, sea, clouds and the atmosphere in 6 channels.

By now the algorithm has been generalized. It is able to process data from the MODIS and VIIRS instruments. As all these channels have different sensitivity from those different features, the SAFNWC/PPS algorithm uses this for its product derivation.

2.1 Satellite channels

Satellite channels used by the SAFNWC/PPS are from the Metop and NOAA imager instrument AVHRR/3 as well as from MODIS and VIIRS. See Table 3, Table 4 and

Table 5 for more details about the different channels.

Table 3 The AVHRR/3 channels and their approximate spectral positions on NOAA 15, 16 and 17 (small deviations in the spectral response do occur between different NOAA satellites).

	Ch 1	**Ch 2**	**Ch 3A**	**Ch 3B**	**Ch 4**	**Ch 5**
λ (µm)	**0.58-0.68**	**0.725-1.0**	**1.58-1.64**	**3.55-3.93**	**10.3-11.3**	**11.5-12.5**

Table 4: Names and spectral specifications of MODIS channels, used so far. A new spectral range (compared to the previously used AVHRR channels) is introduced by the use of channel 29.

	Ch 1	**Ch 2**	**Ch 6**	**Ch 20**	**Ch 29**	**Ch 31**	**Ch 32**
λ (µm)	**0.62-0.67**	**0.841-0.876**	**1.628-1.652**	**3.66-3.84**	**8.4-8.7**	**10.78-11.28**	**11.77-12.27**

Table 5: Names and spectral specifications of VIIRS channels, used so far. A new spectral range (compared to the previously used AVHRR channels) is introduced by the use of channel M14, but the VIIRS channels are similar to those used for MODIS..

	Ch M5	**Ch M7**	**Ch M10**	**Ch M12**	**Ch M14**	**Ch M15**	**Ch M16**
λ (µm)	**0.672**	**0.865**	**1.61**	**3.7**	**8.55**	**10.763**	**12.013**

2.1.1 Solar channels

Because of their different names that come with different instruments, channels are determined by their spectral position rather than by their name. Exceptions are made in case of referencing to instrument specific issues.

In the 0.6µm channel, clouds appear bright because of the high reflectance while the signal from land and sea is generally poor (exception: sunglint areas over sea). Snow and ice on ground also appear bright. For the 0.8µm channel, the contrast between clouds and land is high and reflectance from sea surface is low, too (except for sunglint areas). However the signal from vegetated land is more intense compared to the 0.6µm channel.

The 1.6µm channel is a so called near IR-channel. It allows to distinguish between snow/ice covered land and signal from other sources. The reflectance from snow and ice decreases with increasing wavelength in the Visible to NIR spectral range, and the reflectance over snow/ice is thus much smaller than in the 0.6µm or 0.8µm channels, providing a means to detect snow cover on the ground during daytime. Similarly this channel is also sensitive to the cloud phase; water clouds reflect more energy in this spectral range than ice clouds.

2.1.2 Thermal channels

The 3.7µm channel lies in the spectrum where the outgoing energy comes from two sources: solar reflectance and thermally emitted radiation. This channel is sensitive to cloud phase and is particularly useful for the detection of night-time water clouds. The detection of thin cirrus can be done by analysing differences of the 3.7µm channel to the 11µm or the 12µm channel. Snow-covered ground has almost no contribution to the signal, received within this spectral range.

In the region around 8.5µm, there is a channel (unfortunately not on AVHRR instruments) close to one ozone-line but still in the window region. This channel in combination with the 11µm channel might enhance the contrast in the night cirrus test if used instead of one of the 11 or 12 micron channels. This channel is not active in the CT product yet.

The channel, located round 11 µm, is what is often referred to as the “IR window channel”, i.e. radiation from the Earth’s surface or cloud tops is little effected by extinction in the atmosphere. This channel responds to the temperature of clouds and surfaces and returns a signal close to what is called the thermodynamic temperature. The characteristic of the 12µm channel is very similar to its neighbour at 11µm. However, there are some differences, for example the detection of cirrus (the atmosphere seems denser with increasing wavelength).

2.2 REQUIREMENTS

The requirements for the SAFNWC/PPS products are described in the Product Requirements Document [AD.2.]. In Table 6 is given a summary of the requirement specific for the cloud type product. These requirements are valid for central Europe

Table 6 Accuracy requirements for Cloud Type

	POD	**FAR**
Threshold accuracy	50%	60%
Target accuracy	70%	40%
Optimal accuracy	80%	20%

3. ALGORITHM OVERVIEW

The main objective for the CT is to give a detailed cloud analysis after the CMA is done. For every cloud filled or cloud contaminated pixel in the CMA, the CT algorithm sub-divide each cloudy pixel into different cloud categories. The CT algorithm uses a threshold technique which works using one or several tests. Spectral information from the satellite channels, brightness temperature and reflectance depending on light condition, are compared with thresholds which mark the border between the different cloud categories. Together with the threshold test there are also so called threshold offsets. The threshold offsets are empirically derived, using the database of interactive training targets and from visual inspection. When deriving the offsets, they may vary with the underlying surface (land, sea or coast), the sun-satellite viewing geometry and illumination (night, twilight, day) or sunglint, and presence of low-level inversion or topography (low or high terrain). Those offsets work as a tuning parameter to adapt the algorithm to the training targets (compare Dybbroe et al., 2005a; Dybbroe et al., 2005b).

The CT algorithm is a multi-spectral threshold retrieval applied to each pixel of the satellite scene. The multi-spectral retrieval technique is widely used in operational cloud typing using AVHRR data. The SCANDIA, APOLLO, and the LUX schemes on which the PPS system inherits are good examples. See Karlsson (1989), Derrien et al. (1993) and Kriebel et al. (2003). The retrieval utilise that different cloud types leave varying marks in the visible and thermal spectrum. Carefully derived thresholds help to discriminate single features. In the best case the sum of spectral signs, the fingerprint leads univocally to a certain cloud type.

The cloud type classification employs a sequence of threshold tests in an `if-else-if`-structure. Contrary to the CMA algorithm, where testing is continued if one of the features tested is close in value to its corresponding threshold, the CT algorithm stops if a threshold test is successful. Also where almost all of the threshold tests of the CMA algorithm are grouped (using several threshold tests concurrently), the threshold tests in the CT algorithm often use a few or even a single feature (e.g. the T11T12). The sequence of testing depends slightly on the time of day. During day, where the 0.6µm reflectance is used in the separation of fractional water clouds (sub pixel clouds) and thin cirrus, the sequence produces cloud categories in the following order: 1.) fractional water clouds; 2.) thin cirrus; 3.) fractional water clouds; 4.) opaque clouds. During night and twilight conditions the 0.6µm reflectance is not used and the order is as above but with category 1 removed (definition of twilight; see chapter 4.2.4.3).

In short the first category above corresponds to pixels with an increased T11-T12 as compared to the cloud free case, a high local texture in the 11µm brightness temperature, and a sufficiently increased 0.6µm reflectance. Texture is defined as spatial variability where the standard deviation is calculated over 5 by 5 pixels; and over 3 by 3 pixels when using GAC-settings. High local texture means large variance. The category of thin cirrus clouds are all pixels with an increased T11-T12 as compared to the cloud free case, not already caught by the previous test, if available. The thin cirrus cloud category is then divided in the four classes: *very thin cirrus*, *thin cirrus*, *thick cirrus* and *cirrus above low or mid level clouds*, according to the 11µm brightness temperature and to the distance of T11-T12 from the cloud free case. The third category above catches pixels with a T11-T12 value lower or equal to, and a 11µm brightness temperature close to, the cloud free case, and a high local texture in the 11µm brightness temperature.

The activities carried out in the main processing stage are described in Figure 1. Prior to performing CT classification, necessary satellite input imageries must be prepared.

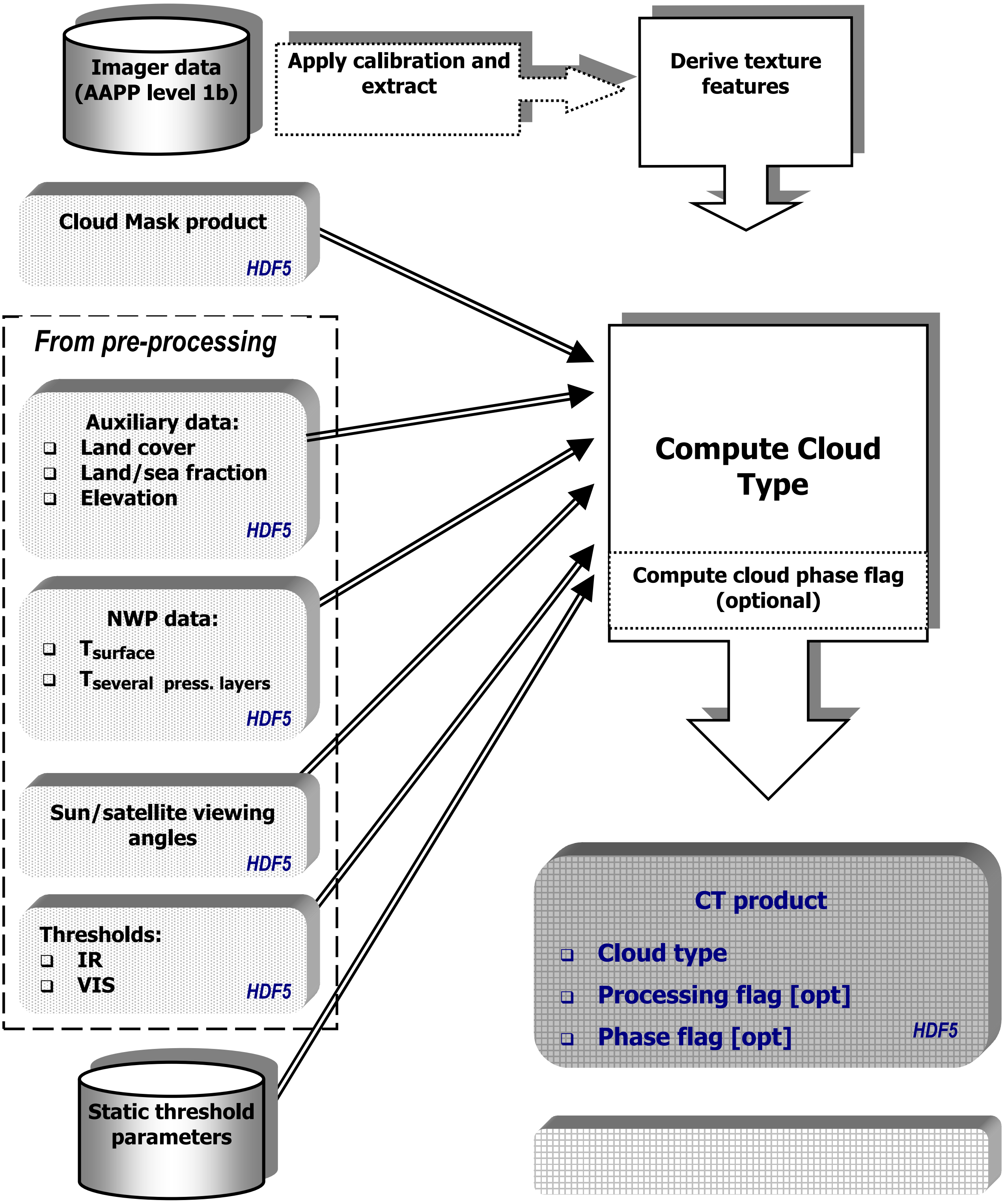

Figure 1 Cloud type processing as performed within the PPS.

The output file comes, configurably, either in hdf5 and/or in netcdf.

4. ALGORITHM DESCRIPTION

4.1 THEORETICAL DESCRIPTION

4.1.1 Physics of the Problem

As described already in [RD.4], the light emitted or reflected by the earths surface or atmospheric constituents carries information on the matter within its path. The spectral composition of the instruments observations allows (under good conditions, explained later in this document) to distinguish not only between cloud-free and cloudy but also between certain cloud types.

Similar to the cloud-mask algorithm a threshold technique is applied to tackle this task. In case of having adequate temperature differences between surface and the cloud itself, it is possible to categorise a cloudy pixel in semi-transparent, fractional and opaque. Semi-transparent clouds means clouds optically thin enough for the signal to be influenced by underlying clouds or surface. In principle semi-transparent clouds have an optical thickness of 1 to 2, for example thin cirrus.

Another valuable hint regarding the cloud type is gathered from the combination of temperature difference between surface and cloud as well as the atmospheric temperature profile. This approach allows for a rough assignment of the clouds vertical position in the atmosphere, which again gives valuable information on the cloud type.

4.1.2 Mathematical Description of the Problem

In the following we present a detailed description of the numerical cloud type identification during night, twilight, and daytime. The separation of the five opaque cloud categories is independent of illumination and is treated after the identification of semi-transparent cirrus and fractional water clouds.

The cloud type algorithm use threshold tests which are made by some different features. The features are single channel or a combination of two channels, i.e. brightness temperature difference. Only the two features created between T11 and T_{sur} make use of non-satellite data. However, before the threshold test start, every pixel go through a preparation step where time of day and location has to be identified. The pixel is classified if it is day, twilight or night using the sun zenith angle. The land-use and elevation data are needed for identifying if the pixel has its location over land, coast or sea. After this preparation step the identification of cloud type can start using the different categories described below.

Table 7 Description of the features used for threshold tests.

Feature	Description
R06	**Reflectance at 0.6 µm**
T37	**Brightness temperature at 3.7 µm**
T11	**Brightness temperature at 11 µm**
T12	**Brightness temperature at 12 µm**
T11T12	**Brightness temperature difference T11 – T12**

T11Tsur	**Brightness temperature difference T11 and surface skin temperature (from NWP)**
T37T12	**Brightness temperature difference T37 – T12**
T11T37	**Brightness temperature difference T11 – T37**
$T11\text{-}T_{sur}$	**Difference between T11 and surface skin temperature (from NWP)**
$T11_{text}$	**Local (5 x 5, or 3 x 3 for GAC-settings) T11 standard deviation**

4.1.2.1 Identification of fractional water clouds and thin cirrus over land at night time and in twilight

4.1.2.1.1 Introduction

High semi-transparent (cirrus) clouds can be distinguished from opaque clouds using the T11T12 or T3.7T12 features. The method builds on the facts that the transmissivity decreases with increasing wavelength in the IR for ice clouds, that the atmospheric temperature decrease with height, and that the surface temperature is usually much higher than the cloud temperature. Those facts often work well but one should be aware of the following which can lead to misinterpretation; The colder the surface the more ambiguous the separation of opaque and semi-transparent high clouds gets.

Due to the larger difference in transmissivity and the higher non-linearity of the Planck function at 3.7µm the T3.7T12 feature is most efficient provided the ground is relatively warm. It can, however, only be used during night as the solar reflection contaminates the feature in daylight. At lower surface skin temperatures this feature gets less useful due to the increased noise stemming from a high digitisation error. At around and below 230-240 K the signal to noise level is so low that the benefit of this feature in cloud discrimination gets insignificant. For other instruments than the AVHRR, the use of the 8.5µm channel is pronounced to provide valuable benefit in the future.

Unfortunately fractional low clouds may also give rise to the same increase in the T11T12 and T3.7T12 features as observed for thin cirrus clouds. This is due to the non-linearity of these features with temperature and an often observed difference in temperature between the surface and the cloud. This leads to an inherent ambiguity in the attempt to distinguish between fractional water clouds and thin cirrus clouds. However, at least a partial separability seems possible as thin cirrus clouds may appear colder (as observed by T11 for instance) than fractional water clouds. But the variabilities in cirrus and fractional water cloud temperatures are very large, and often the overlap is considerable if at all separable.

The presence of low or medium level cloud cover beneath the semi-transparent cirrus has the effect of reducing the T11T12 and T3.7T12 due to a lowered background temperature, further complicating the cloud separation.

4.1.2.1.2 Implementation

For the thin cirrus and fractional water cloud separation we have chosen an approach where we require the T11T12 to be low for fractional clouds and high for cirrus. We then separate the different cirrus categories using the T11T12 and the T11 compared to the surface temperature. We are well aware that we do miss a substantial amount of the fractional clouds, but the risk of misclassifying cirrus clouds into fractional water clouds is small. Table 8 shows the tests applied during night over land. All cloudy pixels which do not fall into the categories listed are assumed to belong to the opaque categories. The corresponding tests and offsets applied in twilight are identical, except that the extra test for *very thin cirrus* using T37T12 is omitted.

Table 8 The nighttime thresholding of semi-transparent cirrus and fractional clouds over land. "O" stands for offset, and is either a true constant offset or linearly varying in the secant of the satellite zenith angle.Each table row corresponds to an `if-else` clause, so that in addition to the test requirements listed in one row for one cloud category the previous tests should have failed if the classification should result in the given category.

Cloud Type Class	First Test	Second Test
Very thin cirrus	$T11 - T12 > T11T12_{threshold} + O_{t11t12(opaque)}$	$\|(T11 - T_{sur}) - T11Tsur_{threshold}\| < O_{t11tsur(thin-cirrus)}$
Cirrus on lower clouds	$T11 - T12 > T11T12_{threshold} + O_{t11t12(verythin)}$	$\|(T11 - T_{sur}) - T11Tsur_{threshold}\| > O_{t11tsur(thin-cirrus)}$ **AND** $T11 < T_{500hPa}$
Cirrus on lower clouds	$T11 - T12 > T11T12_{threshold} + O_{t11t12(thin)}$	$T11 < 0.5T_{500hPa} + 0.5T_{tropopause}$
Thin cirrus	$T11 - T12 > T11T12_{threshold} + O_{t11t12(thin)}$	
Thick cirrus	$T11 - T12 > T11T12_{threshold} + O_{t11t12(opaque)}$	
Very thin cirrus	$T11 - T12 < T11T12_{threshold} + O_{t11t12(opaque)}$ AND $T37 - T12 > T37T12_{threshold} + O_{t37t12(opaque)}$	$\|(T11 - T_{sur}) - T11Tsur_{threshold}\| < O_{t11tsur(thin-cirrus)}$ **AND** $T11 > T_{500hPa}$
Fractional clouds	$T11 - T12 < T11T12_{threshold} + O_{t11t12(opaque)}$ **AND** $T11 - T37 > T11T37_{threshold}$ **AND** $T11_{text} > O_{t11text(subpixel)}$	$\|(T11 - T_{sur}) - T11Tsur_{threshold}\| < O_{t11tsur(subpixel)}$

4.1.2.1.3 Possible future improvements

In the future we will consider the additional check for fractional clouds also with high T11T12 values, so that the first *very thin cirrus* category listed in Table 8 will be split into fractional water clouds and very thin cirrus. This category will inevitably consist partly of fractional clouds in the current implementation.

The threshold offsets used in the testing shown in Table 8 are listed in Table 9 and illustrated graphically in Figure 2 as a function of satellite zenith angle for two different value couples of total water vapour content and surface temperature.[1]

Additionally, the use of complement information from different channels (provided by new instruments) will certainly help to improve the CT product.

Table 9 The threshold offsets used in the night time and twilight detection of semi-transparent cirrus and fractional water clouds over land. sec stands for the secant of the satellite zenith angle: 1/cos(θ_{sat})

Threshold Offsets	
T11T12	
$O_{t11t12(opaque)}$	$0.5K$
$O_{t11t12(verythin)}$	$O_{t11t12(opaque)} + 1.6K - 0.2\times(\sec - 1)$
$O_{t11t12(thin)}$	$O_{t11t12(opaque)} + 0.8K - 0.2\times(\sec - 1)$
$O_{t11t12(thick)}$	$O_{t11t12(opaque)} + 0.0K + 0.0\times(\sec - 1)$
T37T12	
$O_{t37t12(opaque)}$	$2.0K$
T11-T$_{sur}$	
$O_{t11tsur(thin-cirrus)}$	$20K$
$O_{t11tsur(subpixel)}$	$14K$
T11$_{text}$	
$O_{t11text(subpixel)}$	$1.0K$

[1] We here show only examples corresponding to mid and high latitude conditions, for which the NWCSAF/PPS system was originally developed for. However, the threshold tables span a humidity interval of 0 to 45 kg/m2 and surface skin temperatures from 220 to 330 K. It is possible to show similar figures also for tropical like conditions with high water vapour contents. The Tb11-Tb12 thresholds will increase further (than the values displayed in the left panel of Figure 2) and the sensitivity to the viewing angle will increase.

Some offsets differ between GAC settings and not-GAC settings, but the values in Table 9 are valid for both cases.

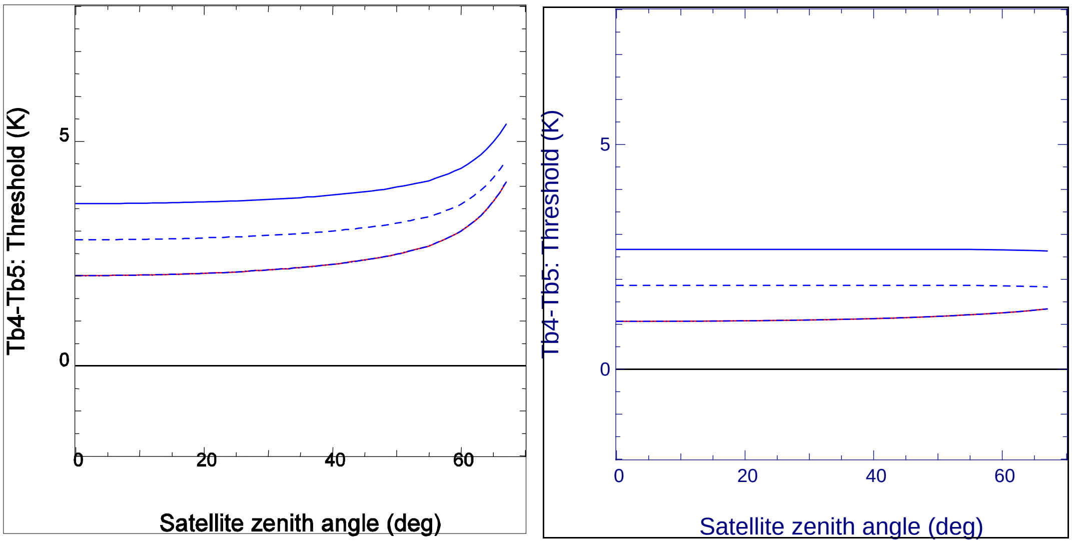

Figure 2 Examples of the T11T12 thresholds used for semi-transparent clouds distinction. The thresholds are displayed as a function of satellite zenith angle. The panel to the left shows the thresholds used for an integrated water vapour content of 25 kg/m² and surface temperature of 290K, and the thresholds to the right are valid for 10 kg/m² and 270K. The red curves (difficult to see as they are almost exactly coinciding with the blue ones for this example) are the cloud free thresholds ($O_{t11t12(opaque)}$), and the blue ones are for the thin cirrus separation. The dash-dotted is for the thick cirrus ($O_{t11t12(thick)}$) and is equal to the cloud free threshold. The dashed curves are for the thin cirrus ($O_{t11t12(thin)}$), and the full blue curves are for the very thin cirrus clouds ($O_{t11t12(verythin)}$).

4.1.2.2 Identification of fractional water clouds and thin cirrus over elevated terrain at night time and in twilight

The attempt to separate the thin cirrus cloud categories and the fractional cloud category over elevated terrain during night and in twilight conditions is fairly similar to that applied over low land. Elevated or high terrain is on default over 500 m. But as the forecasted surface temperature is less reliable and highly variable in space over high and rough terrain the use of T11 and T11Tsur is minimised, and the separation depends more on the T11T12 feature.

Table 10 lists the applied tests. The thresholds and offsets are much the same as over low land. Table 11 lists those that differ.

Table 10 Thresholding; similar to Table 8, but here for high terrain. The offsets are equal to those used over low terrain

Cloud Type Class	First Test	Second Test
Cirrus on lower clouds	$T11 - T12 > T11T12_{threshold} + O_{t11t12(verythin)}$	$T11 < T_{500hPa}$
Very thin cirrus	$T11 - T12 > T11T12_{threshold} + O_{t11t12(verythin)}$	
Cirrus on lower clouds	$T11 - T12 > T11T12_{threshold} + O_{t11t12(thin)}$	$T11 < 0.5T_{500hPa} + 0.5T_{tropopause}$
Thin cirrus	$T11 - T12 > T11T12_{threshold} + O_{t11t12(thin)}$	
Thick cirrus	$T11 - T12 > T11T12_{threshold} + O_{t11t12(opaque)}$	
Fractional clouds	$T11 - T12 < T11T12_{threshold} + O_{t11t12(opaque)}$ **AND** $T11 - T37 > T11T37_{threshold}$ **AND** $T11_{text} > O_{t11text(subpixel)}$	$\|(T11 - T_{sur}) - T11Tsur_{threshold}\| < O_{t11tsur(subpixel)}$

Table 11 The threshold offset which differs from the one listed in Table 9, and used in the detection of semitransparent cirrus and fractional water clouds during night and twilight over elevated terrain.

Threshold Offsets	
T11$_{text}$	
$O_{t11text(subpixel)}$	$1.5K$
GAC-settings $O_{t11text(subpixel)}$	$6.0K$

4.1.2.3 Identification of fractional water clouds and thin cirrus over sea at night and in twilight

The separation of the thin cirrus cloud categories and the fractional cloud category over sea at night and in twilight is conceptually identical to the night/twilight algorithm over elevated and low terrain. The difference lies in slightly changed values for a few of the applied offsets as shown in Table 12.

Table 12 The threshold offset which differs from the one listed in Table 9, and used in the detection of semi-transparent cirrus and fractional water clouds during night and twilight over sea.

Threshold Offsets	
T11T12	
$O_{t11t12(opaque)}$	$0.0K$
T11-T$_{sur}$	
$O_{t11tsur(subpixel)}$	$12K$
T11$_{text}$	
$O_{t11text(subpixel)}$	$0.5K$
GAC-settings $O_{t11text(subpixel)}$	$2.0K$

4.1.2.4 Identification of fractional water clouds and thin cirrus over land at daytime

The separation of thin cirrus and fractional water clouds over land at daytime makes use of R0.6 in addition to the IR features used in the night and twilight algorithms. First a fractional cloud identification is attempted, requiring the pixel to be warm as given by T11, having a cloud signal in T11T12 (T11T12 higher than cloud free threshold), a high texture (spatial variability) in T11 and a high visible reflectance (R0.6).

Then follows a similar division of the semi-transparent cirrus classes, as is applied at night and twilight. At the end an additional check for fractional clouds in cases of a low level inversion is applied. The details are provided in Table 13.

The values of the applied offsets as presented in Table 13 are listed in Table 14. Note that the offsets for texture features may be different for LAC and GAC data. This is because of the general difference in the size of individual pixels and the size dependent differences in radiance-difference.

Table 13 Thresholding; similar to Table 8, but here for daytime

Cloud Type Class	**First Test**	**Second Test**

Cloud Type Class	First Test	Second Test
Fractional clouds	$T11-T12 > T11T12_{threshold} + O_{t11t12(opaque)}$ AND $T11_{text} > O_{t11text(subpixel)}$	$\lVert(T11-T_{sur})-T11Tsur_{threshold}\rVert < O_{t11tsur(thin-cirrus)}$ **AND** $R0.6 > O_{r06(cirrus)}$
Cirrus on lower clouds	$T11-T12 > T11T12_{threshold} + O_{t11t12(verythin)}$	$T11 < T_{500hPa}$
Very thin cirrus	$T11-T12 > T11T12_{threshold} + O_{t11t12(verythin)}$	
Cirrus on lower clouds	$T11-T12 > T11T12_{threshold} + O_{t11t12(thin)}$	$T11 < 0.5T_{500hPa} + 0.5T_{tropopause}$
Thin cirrus	$T11-T12 > T11T12_{threshold} + O_{t11t12(thin)}$	
Thick cirrus	$T11-T12 > T11T12_{threshold} + O_{t11t12(opaque)}$	
Fractional clouds	$T11-T12 < T11T12_{threshold} + O_{t11t12(opaque)}$ AND $T11_{text} > O_{t11text(subpixel)}$	$\lVert(T11-T_{sur})-T11Tsur_{threshold}\rVert < O_{t11tsur(subpixel)}$
Fractional clouds	$T11-T12 < T11T12_{threshold} + O_{t11t12(opaque)}$ **and** $T11_{text} > 1.0$	**Low level inversion present AND (** $T11 > T_{700hPa}$ **or** $T11 > T_{sur}$ **or** $T11 > T_{500hPa}$ **)**

Table 14 The threshold offsets which differ from the ones listed in Table 9, and used in the daytime detection of semi-transparent cirrus and fractional water clouds over land.

Threshold Offsets	
T11T12	
$O_{t11t12(opaque)}$	$0.5K$
T11-T$_{sur}$	
$O_{t11tsur(subpixel)}$	$12K$
T11$_{text}$	
$O_{t11text(subpixel)}$	$1.0K$
GAC-settings $O_{t11text(subpixel)}$	$4.0K$
R06	
$O_{r06(cirrus)}$	$0.25+0.12\times(\sec-1)\times100\%$

4.1.2.5 Identification of fractional water clouds and thin cirrus over sea at daytime

The separation of thin cirrus and fractional water clouds over sea and land at daytime is done in a very similar way. The difference is that over sea no check for temperature inversions is applied. Table 15 describes the last test for fractional clouds which is different from the one applied over land. Otherwise the testing is the same. The offsets differ, however, slightly and are displayed in Table 16.

Table 15 Last test for fractional clouds applied during daytime over sea. Replaces the similar test listed at the bottom of Table 13. The other tests are equal over both land and sea.

Cloud Type Class	First Test	Second Test
Fractional clouds	$T11-T12 < T11T12_{threshold} + O_{t11t12(opaque)}$ **AND** $T11_{text} > 1.0$	$T11 > T_{850hPa}$

Table 16 The threshold offsets which differ from the ones listed in Table 9, and used in the daytime detection of semi-transparent cirrus and fractional water clouds over sea.

Threshold Offsets	
T11T12	
$O_{t11t12(opaque)}$	$0.0K$
T11-T$_{sur}$	
$O_{t11tsur(subpixel)}$	$10K$
T11$_{text}$	
$O_{t11text(subpixel)}$	$0.5K$
GAC-settings $O_{t11text(subpixel)}$	$2.0K$
R06	
$O_{r06(cirrus)}$	$0.25 + 0.08 \times (\sec - 1) \times 100\%$

4.1.2.6 Opaque clouds separation

All cloudy pixels which have not been classified as fractional water clouds or semi-transparent cirrus according to the tests outlined in the sections above, are classified as opaque clouds. The separation of the opaque clouds is then performed using the T11 and the thermodynamic temperature at various levels of the atmosphere and provided by NWP.

The way the opaque clouds are separated depends slightly on the background (sea, low terrain land, and mountainous or elevated terrain) and the illumination. The main cause for the background dependency is the high likelihood of lower level temperature inversions over land, especially at night time, and the problems of relying on the temperature profile at the lowest levels over elevated terrain.

The separation is the same everywhere for the two highest cloud categories *very high clouds* and *high clouds* and is as presented in Table 17.

Two parameters have been defined to monitor temperature inversions in the lower troposphere as seen by the NWP model. The *lifted inversion* and the *low level inversion* parameters are defined as follows:

Lifted inversion =	Present	$if\ (T_{950hPa} < T_{700hPa})$
	Not Present	$if\ (T_{950hPa} \geq T_{700hPa})$
Low level inversion =	Present	$if\ (T_{surface} < T_{950hPa})$

Not Present $if\ (T_{surface} \geq T_{750hPa})$

Table 18 presents the separation of the low and medium level categories during night and twilight. The separation is the same during daytime except for the last test giving *very low clouds*. During daytime this last step may also result in fractional clouds (see Table 13). The *very low clouds* then requires a low texture ($T11_{text}$<1.0K)

Table 17 The separation of high opaque clouds applied everywhere during day, twilight and night. The categories listed in the left column are uniquely defined by the tests detailed in the right column

Cloud Type Class	Test
Very high clouds	$T11 < 0.5 \times T_{500hPa} + 0.5 \times T_{tropopause}$
High clouds	$0.5 \times T_{500hPa} + 0.5 \times T_{tropopause} < T11 < T_{500hPa}$

Table 18 Low and medium level opaque clouds separation at night time and at twilight over low terrain. Each cloud category listed in the left column is uniquely defined by the tests detailed in the right column.

Cloud Type Class	Test
Night & twilight – Low terrain	
Medium level clouds	**No temperature inversions present AND** $T11 > T_{500hPa}$ **AND** $T11 < T_{700hPa}$
Low clouds	**No temperature inversions present AND** $T11 > T_{700hPa}$ **AND** $T11 < T_{850hPa}$
Very low clouds	**No temperature inversions present AND** $T11 > T_{850hPa}$
Medium level clouds	**Lifted but no low level inversion present AND** $T11 < Minimum\{T_{700hPa}, T_{850hPa}, T_{950hPa}, T_{surface}\}$ **AND** $T11 > T_{500hPa}$
Low clouds	**Lifted but no low level inversion present AND (**$T11 > T_{700hPa}$ **OR** $T11 > T_{850hPa}$ **OR** $T11 > T_{950hPa}$ **OR** $T11 > T_{surface}$**) AND** $T11 > T_{500hPa}$
Medium level clouds	**Low level inversion present AND** $T11 < T_{700hPa}$ **AND** $T11 < T_{surface}$
Very low clouds	**Low level inversion present AND (**$T11 > T_{700hPa}$ **OR** $T11 > T_{surface}$**)**

The opaque clouds separation over high terrain, elevation above 500 m, is presented in Table 19. This differs from the algorithm applied over low terrain in the way that no checks for temperature inversions are performed, and that the actual surface elevation is taken into account in the separation of the lowest cloud categories.

Table 19 Opaque clouds separation over high terrain. Each cloud category listed in the left column is uniquely defined by the tests detailed in the right column.

Cloud Type Class	Test
High terrain	
Medium level clouds	$Elevation < 2000m$ AND

Cloud Type Class	Test
	$T11 > T_{500hPa}$ AND $T11 < T_{700hPa}$
Low clouds	$Elevation > 2000m$ AND $T11 > T_{500hPa}$ AND $T11 < T_{700hPa}$
Low clouds	$Elevation < 1000m$ AND $T11 > T_{700hPa}$ AND $T11 < T_{850hPa}$
Very low clouds	$Elevation > 1000m$ AND $T11 > T_{700hPa}$ AND $T11 < T_{850hPa}$
Very low clouds	$T11 > T_{850hPa}$

The separation over sea is the most straightforward one as the surface is smooth and at constant level and no checks for inversions are performed. The separation of the lowest categories during night time and in twilight is presented in Table 20.

The separation is the same during daytime except for the last test giving *very low clouds*. During daytime this last step may also result in fractional clouds (see Table 13) just as is the case over land discussed earlier. The *very low clouds* during daytime also requires a low texture ($T11_{text}$<1.0K)

Table 20 Opaque clouds separation over sea at night time and in twilight. Each cloud category listed in the left column is uniquely defined by the tests detailed in the right column.

Cloud Type Class	Test
Night & Twilight – Sea	
Medium level clouds	$T11 > T_{500hPa}$ AND $T11 < T_{700hPa}$
Low clouds	$T11 > T_{700hPa}$ AND $T11 < T_{850hPa}$
Very low clouds	$T11 > T_{850hPa}$

4.2 PRACTICAL CONSIDERATION

4.2.1 Validation

Validation of the PPS cloud type product can be carried out against CALIOP data, making use of the vertical feature mask classification. Caliop cloud layers are subdivided according to height using the ISCCP method and according to transparency (low level clouds > 680hPa, medium level 680-440hPa, high level <440hPa). PPS cloud categories “thin cirrus” and “fractional” can however not be validated using this method, since the existing CALIOP “thin” category selects much thinner clouds than imager used for this CT and Caliop generally is sensitive to clouds too thin to detect with instruments, used here In Table 21 is presented the results from such a study, of PPS v2014. In this study thin cirrus is treated as high level clouds while fractional clouds is left out.

Table 21 POD and FAR scores for the three different cloud categories, from validation in Europe and arctic areas.

Time of day	POD Low (%)	POD Medium (%)	POD High (%)	FAR Low (%)	FAR Medium (%)	FAR High (%)
All	53.5	38.1	69.4	26.6	61.5	39.1
Day	51.1	41.1	68.0	22.7	54.0	45.0
Night	58.4	35.8	71.2	31.3	70.8	32.2
Twilight	50.4	34.9	66.8	25.0	58.7	45.4

.

Another PPS cloud type validation has been performed in CMSAF for arctic areas ([RD.2]). For details of that study see also Karlsson et al., 2009.

4.2.2 Quality control

The processing/quality flags appended to the CMA are copied to the CT output. Thus e.g. a pixel having low confidence according to the CMA processing flags will be assigned a low confidence also in the CT. See section *Quality control and validation* in ATBD-01 [RD.4] for details.

4.2.3 Assumptions and limitations

The quality and performance of this algorithm has not been tested yet globally (efforts in this direction are ongoing), even though it is designed in a way that it should produce valuable results globally. However, there are limitations. A known problem is the misclassification of semitransparent cirrus as fractional water clouds. Cloud edges on the other hand are frequently interpreted as high semitransparent clouds. These mentioned situations provide an ambivalent spectral signature and are probably not solvable with the information given by the channels.

4.2.4 List of inputs

4.2.4.1 Satellite data

The same spectral information as needed by the CMA is input to the CT and as the CMA is mandatory input to the CT, all channels except the 0.9µm channel are mandatory also for the CT.

The algorithm has been developed specifically for the AVHRR instrument on board the current and future polar orbiting NOAA and EUMETSAT Metop satellites. It has been implemented so that it automatically handles both AVHRR/2 data, with channel 3B during both day and night, and AVHRR/3 data, with channel 3B during night and 3A during day.

Recent efforts have been made to widen the applicability of the PPS to other instruments on polar platforms. Up to now it is possible to process data from MODIS and from VIIRS on the Suomi-NPP platform and future JPSS satellites. See Table 22 for a complete list of channels and requirements.

Table 22 The channels and their approximate spectral positions. Mandatory channels and those which are not yet used are specified. Either 1.6µm channel or 3.7µm channel has to be provided. The 3.7µm channel is, however, mandatory for the aerosol flag output (see section 4.2.5).

λ (µm)	**0.6**	**0.9**	**1.6**	**3.7**	**8.5**	**11**	**12**
	Mandatory	**mandatory**	**At least one of them is mandatory**		**Optional (not used yet)**	**mandatory**	**Mandatory**

4.2.4.2 Cloud Mask

The cloud mask product as provided by the CMA is mandatory input for the CT. The CT is not processed for pixels that are classified as cloud free in the CMA, but the cloud free class already assigned in the CMA is filled in. Also the CMA processing flags are used within the CT algorithm, and some flags are even copied without modification from CMA to CT.

4.2.4.3 Sun and satellite angles

Similar to the CMA the CT needs information on the sun- satellite viewing geometry in pixel resolution.

The instantaneous sun-satellite viewing geometry is stored for every satellite FOV. The angles are the sun zenith angle (θsun), the satellite zenith angle (θsat) and the sun-satellite azimuth difference angle. The satellite zenith angle is always positive and increases from 0° at the sub-satellite point to about 68° at the edges of the swath. The azimuth difference is defined as

$$\delta\phi = \begin{cases} 360° - \delta\phi' : \delta\phi' > 180° \\ \delta\phi' \quad : \delta\phi' \leq 180° \end{cases}$$

Where $\delta\Phi' = |\Phi_{sun} - \Phi_{sat}|$. Here Φ_{sun} is the sun azimuth (counted clockwise from the local north) and Φ_{sat} is the satellite azimuth. Surface specular reflection on a perfect mirror will be observed by the satellite when $\delta\Phi = 180°$ provided the sun zenith angle equals the satellite zenith angle.

The sun zenith angle is used to define what we refer to as day, night and twilight, used when structuring the algorithm in different test sequences using different grouped threshold tests and different threshold offsets. According to the definition used here it is day when $\theta_{sun} \leq 80°$, night when $\theta_{sun} \geq 95°$, and twilight for values of θ_{sun} in between.

The sun-satellite angles are mandatory for the CMA and CT. The angles are be derived from the AAPP level 1b file (or the corresponding NOAA LAC data) by using interpolation and extrapolation (see [RD.7.]).

4.2.4.4 Land cover characterisation and elevation

The same land-use and elevation data needed by the CMA is required by the CT.

We use the 1km global land cover characterisation database available from the Unites States Geological Survey (USGS) (see Anderson et al., 1976 and Eidenshink and Faundeen, 1994), mainly for separating land and water surfaces, but also to identify barren and desert areas where shortwave IR emissivities are significantly below 1 (Salisbury and d'Aria, 1994). Digital elevation model (DEM) data is derived from the *Global 30 arc seconds topography database*, GTOPO30, (http://edcdaac.usgs.gov/gtopo30/) and used to separate low and gentle terrain from high and rough mountaneous terrain.

The native elevation and land-use data are being processed and mapped onto the swath by the PPS software to produce land-use, elevation, and fraction of land maps valid for the current scene. See [RD.7.] for a description of how to generate physiography data for a swath. The physiography data are mandatory for the CMA and CT.

4.2.4.5 NWP data

Like the CMA, the CT uses NWP parameters as either provided by a short range forecast (lead times between 6 and 24 hours) in case of nowcasting, or as provided by a valid analysis in case of off line processing (as e.g. in re-processing for climate applications).

In addition to the column integrated water vapour, the surface (skin) temperature, and the temperature at the 950hPa level, as needed by the CMA, the CT additionally requires the temperature at the 850hPa, 700hPa, 500hPa, and tropopause levels. Like for the CMA these parameters are needed in full (map-projected) pixel resolution.

4.2.4.6 Parameter files and algorithm configuration files

The CT only has a few configuration parameters related to how much is wanted in the final output. These can be found in the file `pps_config_common.cfg` and are listed here:

- `GENERATE_CLOUDTYPE` (default yes): Whether the cloud type main output is wanted.
- `GENERATE_PROCESSING_FLAG` (default yes): Whether the processing flags are wanted.
- `GENERATE_PHASE_FLAG` (default no): Whether the cloud phase flags are wanted.

At least GENERATE_CLOUDTYPE must be yes for being able to use CT as an input to CTTH and PC. It is also a benefit for CTTH and PC if GENERATE_PROCESSING_FLAG is yes.

The CT uses a number of static thresholds and threshold offsets, defined in the file threshold_offsets.cfg, and threshold_offsets_gac.cfg when GAC-settings are used. Altering these parameters, which have been determined during algorithm tuning and validation, will strongly affect the quality of the CT output. It is **not** recommended to modify those.

4.2.5 Description of output

The content of the CT consist of six datasets, as described below.

Main Output

Table 23 Main output key

Number of the Class	Name of the Class	Description/ Comments
1	Cloudfree land	No contamination by clouds or snow covered surface.
2	Cloud free sea	No contamination by clouds or snow/ice covered surface.
3	Land contaminated by snow	
4	Sea contaminated by snow/ice	
5	Very low clouds	Include fog, used for all very low clouds
6	Low clouds	used for all low clouds
7	Medium level clouds	used for all very medium level clouds
8	High opaque clouds	used for all high opaque clouds
9	Very high opaque clouds	Used for all very high opaque clouds
10	Fractional	Sub-pixel water clouds (including cloud edges)
11	High semi-transparent very thin cirrus	
12	High semi-transparent thin cirrus	
13	High semi-transparent thick cirrus	

Number of the Class	Name of the Class	Description/ Comments
14	High semi-transparent cirrus above low or medium level clouds	
15	Not used value	For GEO: High semi-transparent above snow/ice
Fill Value	No/corrupted data	

Status flags

Table 24 Statusflags

Meaning of individual status flags (i.e. if according bit is set to 1).

Bit Number	Description
0	Low level thermal inversion in NWP field
1	NWP data suspected low quality
2	Sea ice map is available
3	Sea ice, according to external map

Conditions flags

Bit Number	Description
0	Pixel is out of swath or points to space
1 and 2	Defines the illumination condition: 0: N/A 1: Night 2: Day 3: Twilight
3	Sunglint

Bit Number	**Description**
4 and 5	Defines whether it is land or sea: 0: N/A 1: Land 2: Sea 3: Coast
6	High terrain
7	Rough terrain
8 and 9	Satellite input data status: 0: N/A 1: All satellite data are available 2: At least one useful channel is missing 3: At least one mandatory channel is missing
10 and 11	NWP input data status: 0: N/A (not classified pixel or NWP data not used) 1: All NWP data are available 2: At least one useful NWP field is missing 3: At least one mandatory NWP field is missing
12 and 13	Product input data status: 0: N/A (not classified pixel or input product data not used) 1: All product input data are available 2: At least one useful input product is missing 3: At least one mandatory input product is missing
14 and 15	Auxiliary data status: 0: N/A (not classified pixel or auxiliary data not used) 1: All auxiliary data are available 2: At least one useful auxiliary field is missing

Bit Number	Description
	3: At least one mandatory auxiliary is missing

Quality flags

Bit Number	Description
0	Pixel is NODATA
1	This bit is not used in PPS. It is a left over to keep the same bit numbers as GEO.
2	This bit is not used in PPS. It is a left over to keep the same bit numbers as GEO.
3 to 5	Retrieval quality: 0: N/A (no data) 1: Good 2: Questionable 3: Bad 4: Interpolated/Reclassified

Multi-layer flag

Table 25 Multi-layer flag

Bit Number	Flag Name	Description
0	Not multi-layer	Cloudy, but not multi-layer. (i.e. single layer)
1	Multi-layer	
_FillValue	nodata	Either cloud free, or missing information.

Cloud Phase flags

It is still possible to configure pge02 for producing the cloud phase flag (see 4.2.4.6), but the recommendation is to *not* produce this cloud phase flag, but instead use the Cloud Phase product of pge05, containing the same type of information but in a better quality.

The cloud phase flag is thought to inform about the dominating phase of the cloud particles at the top of the cloud. The current implementation is fairly crude and is inspired by the ISCCP cloud algorithms. The cloud top is said to consist of ice particles if the T11 is lower than 233K and by water particles if the T11 is higher than 273K. In between both cloud phases co-exist. A special flag (the ISCCP method) identifies if the T11 is below or above 260K, thought to indicate which particle phase is dominant.

Table 26 Cloud phase flags

Bit Number	**Flag Name**	**Description**
0	Undefined	Outside satellite swath, or identification not attempted
1	Water	
2	Ice	

4.2.6 Visualisation

It is important to note that the PPS CT product first of all provide a digital analysis of the cloud field, and the cloud classification should be used together with the appended flags (quality and cloud phase, or PPS CPP Cloud Phase as a better alternative to the latter) as input to automatic mesoscale analysis or nowcasting schemes.

Images may be derived and displayed to the forecaster but the products are not just images. Even when used for image display the additional flags should be presented or made easily available to the forecaster as is the case using the SMHI PPS viewer (see Figure 4). The user may also with advantage choose to highlight certain cloud categories as is done on the SMHI web site (http://www.smhi.se/saf).

Figure 3 shows the cloud type classification using hdfview for the same case as presented in Figure 4 which shows the same data but using the PPS viewer.

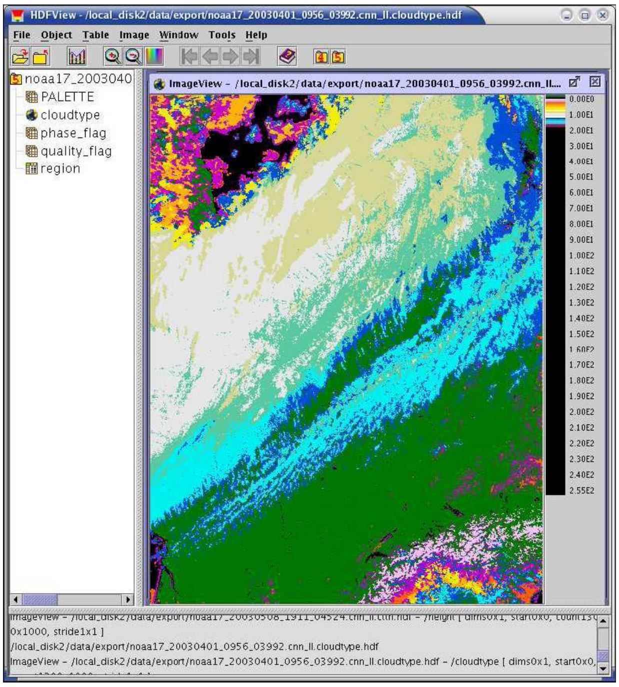

Figure 3 An example of CT image display using hdfview: A NOAA 17 scene over West Europe April 1, 2003, 09:56 UTC (orbit 3992).

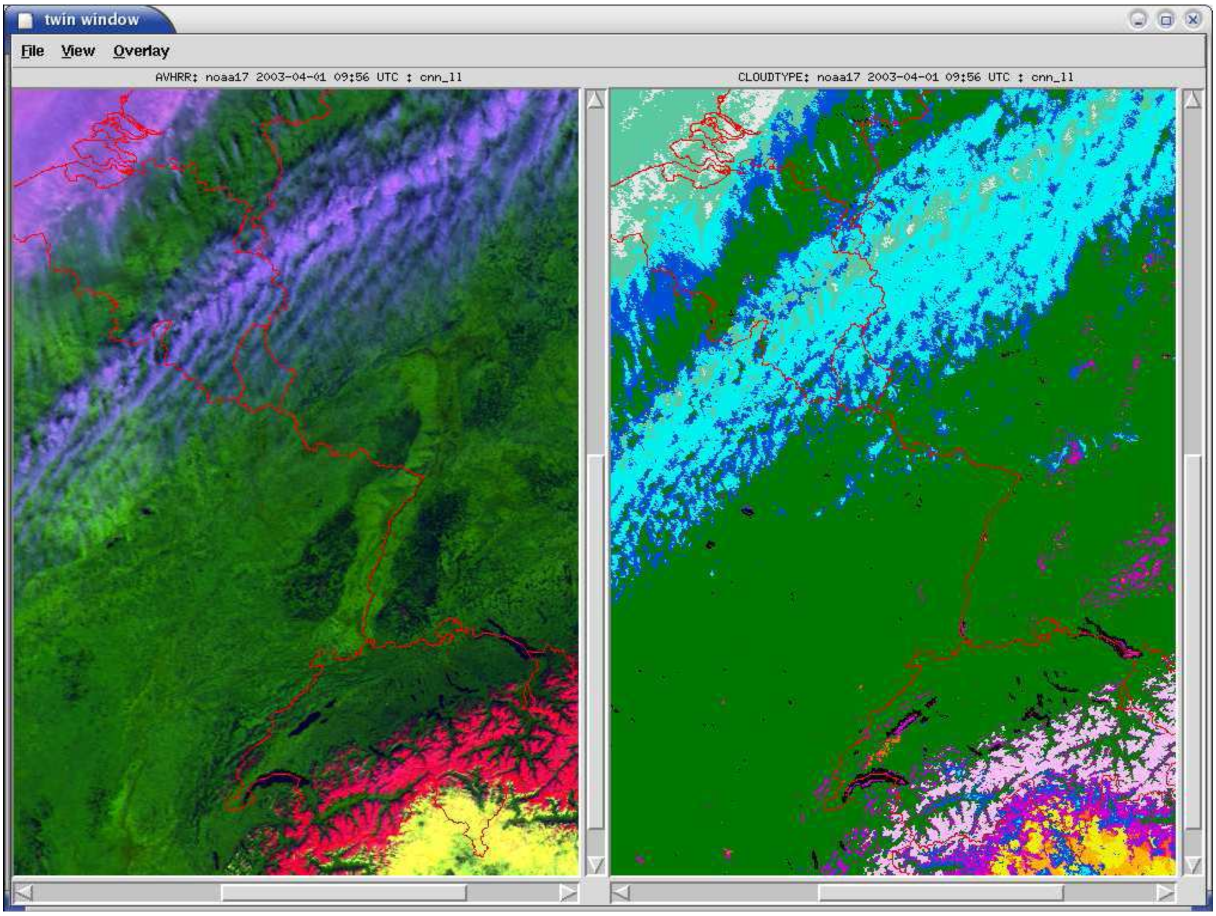

Figure 4 Example of cloud type image display using a dedicated PPS image viewer developed at SMHI. Same scene as shown in figure 2. To the left a close up RGB image using channels 1, 3A and 4 is displayed and to the right the corresponding cloud type.

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

TBD/TBC	Section	Resp.	Comment