EUMETSAT NWC SAF

SUPPORT TO NOWCASTING AND VERY SHORT RANGE FORECASTING

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

NWC/CDOP3/PPS/SMHI/SCI/ATBD/CloudMask, Issue 2, Rev. 1

13 December 2018

Applicable to SAFNWC/PPS version 2018

Applicable to the following PGEs:

Acronym	**Product ID**	**Product name**	**Version number**
CMa	NWC-063	Cloud Mask	5.0

Prepared by Swedish Meteorological and Hydrological Institute (SMHI)

REPORT SIGNATURE TABLE

Function	Name	Signature	Date
Prepared by	SMHI		13 December 2018
Reviewed by	SAFNWC Project Team EUMETSAT		3 February 2017
Authorised by	Anke Thoss, SMHI *SAFNWC PPS Manager*		13 December 2018

DOCUMENT CHANGE RECORD

Version	Date	Pages	Changes
1.0d	22 January 2014	64	Replacing CDOP-document: SAF/NWC/CDOP/SMHI-PPS/SCI/ATBD/1 First version for SAFNWC/PPS v2014 Changes since v2012: -Updated according to scientific changes since v2012, se section 1.6 -Updated the output format. -Some general update.
1.0	15 September 2014	65	Implemented RIDs from PCR-v2014: -Act.4: Given a rational for using 6s and RTTOV. -Act.7 Both operational and re-processed OSISAF ice maps can be used. -DF1 (rewriting section 1.6) -LSc1 (formal issues) -LSc2 (summary of requirements) -LSc3, PW1-PW7, PW10, PW12-PW19 (editorials and clarifications) -PW8 (restructuring section 4.1.2) Other changes: -Updated the validation results, after v2014 final validation.
1.1	13 March 2015	77	Change for PPS v2014-patch20150327: -Added a section describing scientific updates in the patch -Updated according to the patch changes: -the descriptions of the tests. -which tests are included in which test scheme. -threshold calculations -list of input -reference emissivity -Added validation results for the patch.
1.2	01 December 2015	81	Change for PPS v2014-patch20151201: -Added an appendix describing AVHRR/2 filtering.
2.0d	23 December 2016	76	Changes for PPS v2018: - Added new features and threshold tests. - Updated description on test sequence. (The same order for all illumination conditions in v2018) - Added description on the aerosol flags cma_aerosol and cma_dust. - Replaced old testlist (21-bits) with a new more accurate testlist. (92 bits) - Describe channels needed for using VIIRS I-bands. - Describe channels needed for MERSI-2. - Corrected the threshold for roughness. (No changes in calculations.) - Updated validation and visualisation section with preliminary v2018 results and images.
2.0	20 February 2017	73	Implemented RIDs from PCR-v2018: -Heinemann-001: (H-001) Describe POD and FAR. -H-002: Modernized the introduction section. -H-004: For each threshold describe whether static or dynamic. -H-005: Give a description of the 1.3 µm channel. -H-006, -007: Clarified description of features T11 and T3.7T12_text. -H-008,-009,-012: Re-ordered the tables with 'threshold tests, per function', and updated (and added more) cross references to them. -H-010: Clarified text about test safety margins. -H-003, H-011, H-15: Typos -H-013: Clarification for 'Thresholds with 3.7 µm over land during light condition.' -H-014: Removed some old text about validation result.
2.1beta	9 May 2018	76	Document code changed from NWC/CDOP2/PPS/SW/ICD/1 to NWC/CDOP3/PPS/SMHI/SW/ICD/1 More changes for PPS v2018:-Added a few new tests, and reassessed when to do which test.

			-Added description of the sun zenith angle correction used -New threshold table have been calculated. -Describe the visualization of aerosol and dust flags. -Added a note about aerosols and the status flag. -Changed configuration from yes/no to True/False. -Added description of threshold tables construction
2.1d	17 October 2018	74	Changes for v2018 ORR: -Updated the threshold test flag. -Added TBD02 about MERSI-2 usage. -Closed TBD01 and updated section 4.1.2.6 -Removed Table with version 2014 results from section 4.2.1 -Added reference to the validation report for version 2018
2.1	13 December 2018	74	Updates after v2018 ORR: OBJ2_UM_SCI_Heinemann_039: Removed most PGE-<*number*> notations in this document. OBJ2_UM_SCI_Heinemann_041: editorial

Table of Contents

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 the Algorithm Theoretical Basis Document for the Cloud Mask (CMa) 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 CMa version v5.0 of the 2018 SAFNWC/PPS software package delivery.

1.3 DEFINITIONS AND ACRONYMS

Acronym	Explanation
AAPP	AVHRR and ATOVS Processing Package
ACPG	AVHRR/AMSU Cloud Product Generation software (A major part of the SAFNWC/PPS s.w., including the PGEs.)
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
CLAVR	Clouds from AVHRR
CMa	Cloud Mask (also PGE01)
CMa-prob	Cloud Probability (also PGE01c)
CPP	Cloud Physical Products (also PGE05)
CT	Cloud Type (also PGE02)
CTTH	Cloud Top Temperature, Height and Pressure (also PGE03)
DEM	Digital Elevation Model
EPS	EUMETSAT Polar System
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FAR	False Alarm Rate
FOV	Field Of View
GEO	Geosynchronus equatorial Orbit
IR	Infrared
LEO	Low Earth Orbit
MAIA	Mask Avhrr for Inversion Atovs (an AVHRR Cloud Mask)
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
POD	Probability Of Detection
PPS	Polar Platform System
RGB	Red Green Blue
RTM	Radiative Transfer Model
SAF	Satellite Application Facility
SAFNWC	Satellite Application Facility for support to NoWcasting
SCANDIA	Cloud Analysis model using digital AVHRR data
SMHI	Swedish Meteorological and Hydrological Institute
SST	Sea Surface Temperature
TBC	To Be Confirmed
TBD	To Be Defined
TOA	Top Of Atmosphere
USGS	U.S. Geological Survey
VIIRS	Visible Infrared Imaging Radiometer Suite
VIS	Visible

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

For validation of the cloud mask product is used probability of detection (POD) and false alarm rate (FAR). For definition of the validation measures, see [RD.3].

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	1.2	10/10/18
[AD.2.]	NWCSAF Product Requirements Document	NWC/CDOP3/SAF/AEMET/MGT/PRD	1.1	17/12/18
[AD.3.]	System and Components Requirements Document for the SAFNWC/PPS	NWC/CDOP3/PPS/SMHI/SW/SCRD	2.1	13/12/18

Table 1-1: 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	2.1	03/02/17
[RD.2.]	User manual for the SAFNWC/PPS Application: Software Part, 2.Operation	NWC/CDOP3/PPS/SMHI/SW/UM/OPER	2.0	13/12/18
[RD.3]	Scientific and Validation Report for the Cloud Product Processors of the NWC/PPS	NWC/CDOP3/PPS/SMHI/SCI/VR/Cloud	2.0	13/12/18
[RD.4]	-			
[RD.5]	Output Data Format of the SAFNWC/PPS	NWC/CDOP3/PPS/SMHI/SW/DOF	2.0	13/12/18

Table 1-2: List of Referenced Documents

1.4.3 Scientific References

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.

Chevallier, F., Michele, S.D., and McNally, A.P., 2006. Diverse profile datasets from the ECMWF 91-level short-range forecast. *NWPSAF Research Report No. NWPSAF-EC-TR-010, 14p.*

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.

Hocking, J., Rayer, P., Rundle, D., Saunders, R., Matricardi, M., GNWPSAF-MO-UD-037eer, A., Brunel, P., and Vidot, J. 2018, RTTOV v12 users guide, UK Met office publication, NWPSAF-MO-UD-037, 142p.

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., 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., Rühelä A., Müller R., Meirink J.F., Sedlar J., Stengel M., Lockhoff M., Trentmann J., Kasper F., Hollmann R. and Wolters E., 2013. CLARA-A1: a cloud, albedo and radiation dataset from 28yr of global AVHRR data.. *Atmos. Chem. Phys.* ***13****,5351-5367, 2013 doi:10.5194/acp-13-5351-2013*

Karlsson, K.-G. and Johansson E, 2013, On the optimal method for evaluating cloud products from passive satellite imagery using CALIPSO-CALIOP data: example investigating the CM SAF CLARA-A1 dataset. *Atmos Meas. Thech.* ***6****, 1271-1286, 2013 doi:105194/amt-6-1271-2013*

Karlsson, K.-G., Anttila, K., Trentmann, J., Stengel, M., Meirink, J. F., Devasthale, A., Hanschmann, T., Kothe, S., Jääskeläinen, E., Sedlar, J., Benas, N., van Zadelhoff, G.-J., Schlundt, C., Stein, D., Finkensieper, S., Håkansson, N., and Hollmann, R.: CLARA-A2: The second edition of the CM SAF cloud and radiation data record from 34 years of global AVHRR data, Atmos. Chem. Phys. Discuss., doi:10.5194/acp-2016-935, in review, 2016.

Karlsson, K. and Dybbroe, A, 2010.: Evaluation of Arctic cloud products from the EUMETSAT Climate Monitoring Satellite Application Facility based on CALIPSO-CALIOP observations, Atmos. Chem. Phys, 10, 1789–1807..

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

Li, J. and Shibata, K. 2006. On the Effective Solar Pathlength *Journal of the Atmospheric Sciences* Vol. **64** (4) 1365-1371.

Seemann, S.W., E. E. Borbas, R. O. Knuteson, G. R. Stephenson, H.-L. Huang, 2007: Development of a Global Infrared Land Surface Emissivity Database for Application to Clear Sky Sounding Retrievals from Multi-spectral Satellite Radiance Measurements. *J. of Appl. Meteor. and Climatol.*, Vol. **47**, 108-123.

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.

Saunders, R., Matricardi, M., and Geer, A., 2008, RTTOV9.1 user guide, *UK Met office publication, NWPSAF-MO-UD-016*, 57p.

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.

Vermote, E., Tanre, D., Deuze, J. L., Herman, M., and Morcrette, J. J., 1997. Second Simulation of the Satellite Signal in the Solar Spectrum: An overview, IEEE Trans. Geosci. Remote Sens., 35(3), 675-686.

Vermote, E., Tanre, D., Deuze, J. L., Herman, M., Morcrette, J. J., and Kotchenova, S. Y., 2006. Second Simulation of the Satellite Signal in the Solar Spectrum - Vector, 6S User Guide Version 3, http://www.6s.ltdri.org.

Warren, D., 1989. AVHRR channel-3 noise and methods for its removal. *International Journal of Remote Sensing* ***10***, 645-651.

1.5 DOCUMENT OVERVIEW

This document contains a theoretical description of the Cloud Mask algorithms. 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 mask product

- Section 3 A short overview of the cloud mask algorithm
- Section 4 Algorithm description in more detail

1.6 Scientific Updates since PPS Version 2014

In PPS version 2018 the inner part of the CMa code are rewritten. This is mostly a technical change. Around 15000 lines of codes where deleted. Things that make sense to have in the same place were made into functions and structures. The use of Cloud filled and Cloud contaminated between different illumination and land use conditions were harmonized as all pixels now use the same function. This means much less duplicated code and the order of tests is also the same for all illumination and land use conditions. In an attempt to increase POD-cloudy all tests where first turned on for all illumination and land use conditions, then tests where turned off in areas where they detect too few cloudy pixels compared with the clear misclassified by that test. After the rewrite the CMa has been tuned. The actual tests are kept from version 2014 and some new tests are introduced.

A set of testflags have been added to the cloudmask, cma_testlist0-5. These contain information on which test where successful or nearly successful.

A new test using reflectance in channel 1.3µm is included in the CMa (channel 1.3µm is not present on AVHRR, but on MODIS, VIIRS and MERSI-2). New tests using the variation in channel brightness temperature 11 -12µm and channel 3.7µm minus surface temperature are added.

Two new datasets where added to the CMa product. The flags cma_aerosol and cma_dust.

PPS-v2018 can process CMa on VIIRS I-band resolution. It requires imager data in a level 1c file as input. In the level 1c file the M15 and M16 should be resampled to the I-band resolution. This is done to not lose the M15-M16 information from the M-band resolution.

New thresholds has been calculated using RTTOV version 12 to ensure future compatibility with RTTOV also including new satellites. We will use this oportunity to enlarge the profile database with more profiles with higher surface temperatures above 300K. Also we will simulate the 3.7 channel for VIIRS I-band.

The sun zenith angle correction formula used for the rflectances is update to be more accurate in twilight.

2. INTRODUCTION TO THE SAFNWC/PPS CLOUD MASK

The Cloud Mask is the most basic product of the Polar Platform System (PPS) based cloud and precipitation products and necessary for the production of the other cloud and precipitation products. The aim of the Cloud Mask product is to delineate all absolutely cloud-free pixels in a satellite scene with high confidence. In addition, it will identify cloud free snow or ice contaminated pixels when illumination allows and provides processing flags indicating processing conditions and estimated quality for each pixel. The Cloud mask can thus be used both as input to products which will require information on cloud free pixels for further processing, and as input to a more detailed cloud analysis.

Instruments

The SAFNWC/PPS have been developed for a number of imager instruments on-board polar-orbiting weather satellites. The imager instruments measures outgoing reflected solar energy and radiated thermal energy from land, sea, clouds and the atmosphere in at least five channels. As the channels have different sensitivity from those different features, the SAFNWC/PPS algorithm uses this for its product derivation.

The Cloud Mask now runs for the following instruments:

- Very High Resolution Radiometer (AVHRR) on-board the polar-orbiting weather satellites NOAA and Metop (Both AVHRR/2 and AVHRR/3 can be handled, and to some degree AVHRR/1)
- Visible Infrared Imaging Radiometer Suite (VIIRS) on-board the polar-orbiting weather satellite Suomi-NPP, and the coming JPSS satellites
- Moderate-resolution Imaging Spectro-radiometer (MODIS) on-board the polar-orbiting satellites Terra and Aqua.
- Medium Resolution Spectral Imager-2 (MERSI-2) on-bord the coming polar-orbiting weather satellite FY-3D, and its successors.

History and algorithm priorities

The actual PPS software has its roots in the older SCANDIA algorithm (Karlsson and Liljas, 1990 and Karlsson, 1996). This scheme has several similarities to other approaches of that era (e.g. APOLLO [Saunders and Kriebel, 1988], LUX [Derrien et al., 1993] and CLAVR [Stowe et al., 1991 and Stowe et al., 1999]). Common is the use of the typical differences in cloud appearances in all five spectral channels of the AVHRR instrument by applying sequences of threshold tests. However, a common weakness is that these earlier schemes employ static or partially static thresholds which are regionally specific. In some cases thresholds depend on season or the sun elevation according to a few classes, but no dynamic adaptation is made to the actual state of the atmosphere and surface at each individual field of view (FOV), and no consistent correction for the sun satellite viewing geometry is made.

In the development and design of the new SAF retrievals for cloud mask analysis and cloud type classification three things have been of particular importance. First we wanted to improve corrections for bi-directional and atmospheric effects. Second, wherever possible, dynamic thresholds depending on the current atmospheric state, the actual illumination, viewing conditions and the state of the surface at the satellite footprint, should be used, rather than static climatologically determined thresholds. Third, the approach should be such that the algorithms could be adapted in a consistent way to coming AVHRR and other sensors with AVHRR heritage channels.

The way in which we have chosen to meet these requirements is to use radiative transfer models (RTMs) to simulate the satellite signal as it would have been observed in cloud free but otherwise similar conditions.

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, and planned for MERSI-2. See Table 2-1 - Table 2-5 for more details about the different channels.

Table 2-1: The AVHRR/3 channels and their approximate spectral positions on NOAA 15, 16 and 17 (small deviations in the spectral response do occur between individual instruments on 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 2-2: Names and spectral specifications of MODIS channels, used so far. Channel 29 has no complement on any AVHRR instrument and is introduced here as an extension.

	Ch 1	Ch 2	Ch 26	Ch 6	Ch 20	Ch 29	Ch 31	Ch 32
λ (µm)	0.62-0.67	0.841-0.876	1.360 - 1.390	1.628-1.652	3.66-3.84	8.4-8.7	10.78-11.28	11.77-12.27

Table 2-3 Names and spectral specifications of MERSI-2 channels, as planned to use (TBD02)

λ (µm)	0.650	0.865	1.380	1.640	3.80	8.55	10.8	12.0

Table 2-4: Names and spectral specifications of VIIRS channels, used so far. With the exception minor differences in spectral response functions, the VIIRS channels are similar to those used for MODIS.

	Ch M5	Ch M7	Ch M9	Ch M10	Ch M12	Ch M14	Ch M15	Ch M16
λ (µm)	0.672	0.865	1.378	1.61	3.7	8.55	10.763	12.013

Table 2-5: Names and spectral specifications of VIIRS channels, when using a combination of I-band and M-band channels.

	Ch I1	Ch I2	Ch M9	Ch I3	Ch I4	Ch M14	Ch M15	Ch M16
λ (µm)	0.64	0.865	1.378	1.61	3.74	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.

In contrast to most other channels, the 1.3 µm channel is placed in a very strong water vapour absorption band and not in a window region. This implies that under cloud-free conditions and with a certain amount of atmospheric water vapour (at least about 1 g/cm²), reflection is close to 0 %. A reflector high up in the atmosphere (like a cloud) increases the observed reflection remarkably.

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.

2.1.1.1 Sun zenith angle correction

Normally the solar channels are corrected for sun zenith angle dependence in the preparation step and the corrected reflectances are stored in the level 1 c file. However if the correction is not applied it is done from within the cloud mask. For PPS-v2018 the formula is updated to give more accurate values in twilight. Instead of dividing with cosine of the sun zenith angle (μ_0) we divide with the formula described in Li and Shibata (2006):

$$\mu_0 = \frac{2\mu_0 + \sqrt{498.5225\mu_0^2 + 1}}{24.35}$$

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 has a pronounced strength in detecting low clouds over certain surfaces (e.g. woodlands) under large observation angles. Additionally it might enhance the contrast in the night cirrus test if used instead of one of the 11 or 12 micron channels.

The channel, located round11 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 2-6 is given a summary of the requirement specific for the cloud mask product. POD = Probability Of Detection. FAR = False Alarm Rate.

Table 2-6 Accuracy requirements for Cloud Mask

	POD (Europe)	**FAR (Europe)**	**POD (global)**	**FAR (global)**
Threshold accuracy	85%	20%	85%	20%
Target accuracy	95%	10%	90%	15%
Optimal accuracy	98%	5%	95%	10%

Table 2-7 Accuracy requirements for Dust flag

	POD (global)	**FAR (global)**
Threshold accuracy	20%	15%
Target accuracy	50%	10%
Optimal accuracy	80%	5%

3. ALGORITHM OVERVIEW

The CMa algorithm is based on a multi-spectral threshold technique applied to each pixel of the satellite scene. As in the SCANDIA model the threshold tests of the SAF CMa algorithm are coupled or grouped together, so that the identification of a cloud-filled or cloud-contaminated pixel requires that several threshold tests (one for each applicable image feature) all must be passed.

For every satellite scene a unique set of feature thresholds is extracted in full image resolution and applicable only for that particular composition of instrument, surface conditions and atmospheric conditions. The features employed are listed in Table 4-1. For the spectral features *R1.6*, *R1.3*, *T11* static offsets or offsets varying with satellite zenith angle are used, these are always used together with other features. The thresholds applied to the spectral features *T11T3.7*, *T11T12*, *T3.7T12*, T85T11, and *T11Tsur* are what we call dynamic and have all been derived by calculating the cloud free satellite signal using RTM simulations. For the simulations of thermal radiation and brightness temperature, the model RTTOV12 (Hocking et al., 2018) is used. For a detailed description of the derivation of the dynamic thresholds please see ANNEX C.

Resulting radiances (for the 3.7µm channel a combination of solar and thermal contribution) are a function of the actual atmospheric state, the surface characteristics, and the sun-satellite (for pure IR channels just the satellite) viewing geometry. The lack of both a sufficiently reliable global land-use database and accurate surface BRDF's (Bidirectional Reflectance Distribution Functions), together with uncertainties in geo-location (this problem appears mainly for the AVHRR instrument), the high anisotropic behaviour of earth surfaces and the high pixel to pixel variability of the reflectance at 1.6 and 3.7µm, prevented us so far from trying to simulate the TOA signals at these wavelengths. For more information on the how the t37t12 threshold, during light conditions over land, is handled see 4.1.2.6.

The dynamic thresholds are determined from satellite dependent look-up tables (stored in ASCII or HDF5 format). The pure IR tables are multidimensional, depending on viewing geometry (satellite viewing angles), NWP parameters (surface temperature and total water vapour column) and surface emissivity. IR-threshold-tables over land are calculated for an emissivity of 0.98 (= ε ref) on the base of 10755 atmospheric profiles. These thresholds are corrected according to actual or climatological emissivity-maps afterwards. Therefore gain and intercept matrices (with the same rank as referring thresholds) are calculated, determine the change of threshold value with change of emissivity for all atmospheric and surface conditions:

The slope for the *i*:th profile is given by

$$a_i = \frac{TB_i(\varepsilon \equiv 1.0) - TB_i(\varepsilon \equiv 0.6)}{0.4}$$

This leads to a mean slope

$$\bar{a} = \frac{1}{N}\sum_{i=1}^{N} a_i$$

And to a mean intercept as

$$\bar{b} = -\bar{a}\,\varepsilon_{ref}$$

Since the relationship between emissivity and brightness temperature for cloudfree atmospheres is sufficient linear on small scales, the threshold values are corrected by shifting them along the calculated functions. As mentioned above an exception is made during daytime and in case the 3.7µm channel is involved in calculating the feature.

The thresholds are computed in full resolution as dictated by the defined processing region (see [RD.2.]). Constant offsets to the dynamic thresholds, determined during algorithm tuning, are also often applied. See (Dybbroe et al., 2005b) for details on algorithm tuning. Different offsets may be applied over sea, sea ice and land, and dependent on the illumination (day, night or twilight). In addition to these dynamic thresholds also constant, or linearly (e.g. in the sun zenith angle) varying thresholds determined empirically, are applied. Coefficients determining these are available in a static ASCII file (threshold_offsets.cfg, and threshold_offsets_gac.cfg for GAC-settings), which is not normally to be altered by the user.

The thresholding is fuzzy in the sense that the distances in feature space to the thresholds are stored and used to determine whether to stop or continue testing, this is also used as a quality indicator of the final output. More details are provided in section 4.1.2.2 .

4. ALGORITHM DESCRIPTION

4.1 THEORETICAL DESCRIPTION

4.1.1 Physics of the Problem

Light entering the detector onboard a satellite platform carries somehow information on interactions with matter on its path with it. The task addressed to an inverse algorithm, is to use this information to retrieve the nature of the matter that caused it.

In order to derive a cloudmask, the complexity reduces to the question whether a pixel is cloudy or not. The approach chosen here to solve this problem is a threshold technique. A pixel is considered cloudy if the measured reflectance or brightness-temperature deviates in a certain way from pre-calculated clear-sky values.

Since there is more matter around than just clouds that may affect a pencil of rays, it is necessary to reduce these perturbances as far as possible. The moving positions of sun and satellite are also sources of perturbing variations within the received signal. To account for this uncertainty, dynamical thresholds are used (i.e. thresholds are not fixed but adapted to atmospheric, surface, and geometrical conditions).

Generally, most of cloudy pixels can be detected because of a lower temperature (observed at 10.8 µm) or a higher reflectivity (in the solar wavelengths at 0.6 and 0.8 µm) compared to their cloud-free counterparts. Obviously this doesn't hold for all cases (e.g. over cold surfaces, for low clouds, over desert areas, etc.) therefore several independent pieces of information have to be taken into account to determine the cloud-status and to address the quality of the product. This is done by combining observations at different wavelengths with information on the spatial structure.

4.1.2 Mathematical Description of the Problem

4.1.2.1 Features

Table 4-1 shows the utilised image features for all channels. Note that not all channels are provided by all instruments (e.g. no 8.5um channel on AVHRR instruments). As seen from the table we use both spectral features and local texture (spatial variability) features. The spectral features are both simple linear combinations (differences) of channel reflectances or brightness temperatures and non-linear features such as the ratios of the 1.6µm and 3.7µm over the 0.6µm reflectance. One spectral feature is the difference between the T11 and the forecasted thermodynamic skin temperature. This is the only feature making direct use of non-satellite data (but other features are indirect dependent on NWP data). The texture features are all derived by taking the standard deviation of a spectral feature over a 5 by 5 (or 3 by 3) pixel size box centred on the given pixel. For GAC settings a 3 by 3 pixel size box is used, for not-GAC settings a 5 by 5 pixel size box is used. This distinction is because the original GAC-pixels are bigger, and a 5 by 5 pixel box is getting too big then.

The feature creation and selection has been done to a large extent following past experience with thresholding AVHRR data for cloud classification, as in e.g SCANDIA, APOLLO, LUX, and CLAVR. But, there are a number of new features as compared to these known cloud schemes. One example is the texture feature derived from the local standard deviation of the brightness temperature difference between 3.7µm and 12 µm motivated later.

There is of course a significant amount of redundant information in this large set of features used. The dimension of the feature space described by the 21 selected features is not 21, but rather somewhat smaller, and many of the features are strongly dependent on each other. A principal component analysis using a hypothetical large amount of training data might show that the features chosen are not optimal for the description of the feature space. However, for our purpose it has been important to select features for which it is possible to reason in a consistent physical manner on how they may be affected when clouds with different physical characteristics (in terms of particle size, shape, and phase distribution) fill the FOV.

In the subsections below we give a short summary explanation and motivation for the chosen image features listed in Table 4-1. More physical explanations and how the features are applied can be found in *Table* 4-2, *Table* 4-3, Table 4-4, Table 4-5 and Table 4-6.

Table 4-1: List of utilised image features (Note: Not all listed features are provided by all instruments).

Image feature	**Composition**	**Threshold type**
R0.6	**Reflectance for 0.6µm channel**	**Static**
PseudoR0.6	**Reflectance assuming sun in zenith for 0.6µm channel**	**Static**
R0.9	**Reflectance for 0.9µm channel**	**Static**
PseudoR0.9	**Reflectance assuming sun in zenith for 0.9µm channel**	**Static**
R1.3	**Reflectance for 1.3µm channel**	**Static**
R0.6_text	**Local (5 by 5 pixels, 3 by 3 for gac) R0.6 standard deviation**	**Static (but dependent on pixel size)**
R1.6	**Reflectance for 1.6µm channel**	**Static**
R3.7	**Reflectance for 3.7µm channel** **(derived from T3.7 subtracting the thermal part using T11)**	**Dynamic**
QR0.9R0.6	**Reflectance ratio of R0.9 and R0.6**	**Static**
QR1.6R0.6	**Reflectance ratio of R1.6 and R0.6**	**Static**
QR3.7R0.6	**Reflectance ratio of R3.7 and R0.6**	**Static**
T11	**Brightness temperature for 11µm channel**	**Dynamic**
T11T3.7	**Brightness temperature difference of 11 and 3.7µm channels**	**Dynamic**
T11_text	**Local (5 by 5 pixels, 3 by 3 for gac) T11 standard deviation**	**Static (but dependent on pixel size)**
T11T12	**Brightness temperature difference of 11 and 12µm channels**	**Dynamic**

Image feature	Composition	Threshold type
T11T12_text	**Local (5 by 5 pixels, 3 by 3 for gac) T11T12 standard deviation**	**Static (but dependent on pixel size)**
T3.7T12	**Brightness temperature difference of 3.7 and 12µm channels**	**Dynamic**
T3.7T12_text	**Local (5 by 5 pixels, 3 by 3 for gac) T3.7T12 standard deviation**	**Static (but dependent on pixel size)**
T3.7_text	**Local (5 by 5 pixels, 3 by 3 for gac) T3.7 standard deviation**	**Static (but dependent on pixel size)**
T11Tsur	**Difference between T11 and forecasted surface temperature**	**Dynamic**
T8.5T11	**Brightness temperature difference between 8.5 and 11µm channel**	**Dynamic**

4.1.2.1.1 Feature R0.6

The reflectance at 0.6µm is used to distinguish clouds and snow from a dark background (snow-free and cloud-free land or ocean surface, see *Table* 4-2 and *Table* 4-3) when the sun is significantly above the horizon. The sun elevation limit is set to 4°. For the separation of cloudy and cloudfree snow covered surfaces features using the near infrared or thermal infrared channels at 1.6 and 3.7µm must be used (see later). This feature is tested using a dynamic threshold. However, knowing the difficulties in simulating realistically the top of atmosphere (TOA) reflectance, due to BRDF deficiencies and lack of knowledge about the actual state of the surface, we use this feature both over land and over sea only with rather conservative threshold settings, that is with threshold values far from the average (or normal) cloudfree values.

Thus, away from snow covered areas this feature, if applied alone, would most often fail to detect both water clouds only filling the FOV partially and thin cirrus clouds. But being a grouped thresholding algorithm this feature is always applied together with other tests as seen from Table 4-5.

4.1.2.1.2 Feature PseudoR0.6

The reflectance at 0.6µm assuming sun in zenith (i.e. not applying the correction factor 1/cos(ϴsun)) is used to distinguish clouds and snow from a dark background at low sun elevations (< 4°). (See Table 4-4). This feature is tested against an empirically derived threshold linearly dependent on the sun elevation.

This feature is introduced in order to attempt utilising fundamental reflection differences (e.g. between snow/clouds and snow-free/cloudfree surfaces) even at very low sun elevations. The feature is especially important in cases when a pixel exhibits illumination and the 1.6µm channel is still not switched on, as the 3.7µm channel signal gets highly ambiguous at very low sun elevations.

4.1.2.1.3 Feature R0.9 and Pseudo R0.9

Works similarly to R0.6 and Pseudo R0.6. R09 is extra useful over water, which has very low reflection in R09. High reflectivity in R0.9 over water means presence of either cloud, aerosol, snow or sunglint. R0.9 is less useful over land, as forests have also very high reflectivity in this channel.

4.1.2.1.4 Feature R1.3

If there is water vapour in the atmosphere the signal from channel 1.3 will be absorbed. Moderate to high reflectivity in the 1.3 µm channel thus means there is either a cloud or that the water vapour content of the atmosphere is extremely low.

4.1.2.1.5 Feature R0.6_text

The local texture in the 0.6 µm channel is used to detect sub-pixel clouds and cloud edges over sea.

4.1.2.1.6 Feature R1.6

The reflectance at 1.6µm is particularily useful in the detection of low water clouds over snow covered surfaces (over land and sea-ice) and in sunglint areas over water bodies.

4.1.2.1.7 Feature R3.7

The reflectance at 3.7µm is derived by subtracting the emission part from the 3.7µm radiance using 11µm channel under the assumption of unit emissivity (see Allen et al. (1990) for a derivation). As above, this feature is particular important when attempting to detect low water clouds over either snow covered surfaces (over land and sea-ice) or water bodies in sunglint.

4.1.2.1.8 Feature QR0.9R0.6

The reflectance ratio between R09 and R06 was introduced in beginning of 2006 as a result of an inter-comparison study between the MAIA and the PPS cloud mask schemes, in particular over the arctic. There it was found that in particular when having no 3.7µm channel (but 1.6µm channel) the low cloud detection in sunglint with the feature QR1.6R0.6 was not as efficient as expected, and that this additional feature might help. Also, in more recent updates to PPS, this feature is used more frequently, for instance in the new clear tests which try to account for the, mainly man-made impacted, varying land use with time. See 4.1.2.9.

4.1.2.1.9 Feature QR1.6R0.6

The reflectance ratio between R1.6 and R0.6 is used in particular in the separation of water clouds from snow cover (over land and sea-ice) and sunglint.

4.1.2.1.10 Feature QR3.7R0.6

The reflectance ratio between R3.7 and R0.6 is used in particular in the separation of water clouds from snow cover (over land and sea-ice) and sunglint. Feature T11

The 11µm brightness temperature is used to detect cold clouds. It is normally used with a rather high offset to avoid miss-classifying cold land surfaces as clouds, and it is only used alone when all other usual low cloud features fail (during twilight and in cases of super-cooled water particles during night).

4.1.2.1.11 Feature T11

The brightness temperature T11 is, for thick opaque clouds, a good approximation for the cloud temperature. Cloud temperatures above 303.15 are unlikely to occur. If the T11 temperature is above 303.15K it indicates that the pixel does not contain much thick opaque cloud, though the pixel could still contain thin semi-transparent cloud or just a very small cloud fraction.

4.1.2.1.12 Feature T11T3.7

The brightness temperature difference between the 11µm and 3.7µm channels is used to detect water clouds at night. This is a well known technique to detect stratus and fog at night as e.g. used by Eyre et al. (1984) using the findings of Hunt (1973).

4.1.2.1.13 T11_text

The local texture in the 11µm brightness temperature is used to detect sub-pixel clouds and cloud edges over sea, and requires a cloud top temperature different (warmer or colder) from the surface in order to be effective. This feature is always applied together with other texture features, in order to avoid miss-classifying pixels in sea surface temperature gradient zones as being cloud contaminated.

4.1.2.1.14 Feature T11T12

The brightness temperature difference between 11 and 12µm channel is used for thin cirrus detection due to the decrease of transmissivity of these clouds with increasing wavelength (Inoue, 1985). Its main use is during daytime, as it can be replaced by the T3.7T12 (see below) during night. If the 8.5µm channel is available, a combination with the 11 or 12µm channel will merge advantages of both mentioned tests: It will provide a better contrast than the T11T12 feature and is not affected by solar radiation during daytime like the T3.7T12 feature.

Over sea ice we use this feature during night-time to detect transparent clouds that are warmer then the underlying surface. Here the 11µm 12µm channel difference is often negative.

4.1.2.1.15 Feature T11T12_text

The local texture in the 11µm and 12µm channel brightness temperature difference is used together with other features to detect cirrus clouds. The idea is that cirrus clouds have more variability compared to water vapour. It can also be more trusted in colder temperatures compared to T3.7T12_text.

4.1.2.1.16 Feature T3.7T12

The brightness temperature difference between 3.7µm and 12µm channel, is similar to the T11T12 feature, and is used to detect thin cirrus. The feature is more sensitive to thin cirrus and has proven useful on the later NOAA (15 and later) satellites where the earlier observed periodic noise (Warren, 1989) seems to have disappeared.

4.1.2.1.17 Feature T3.7T12_text

The local texture in the 3.7µm and 12µm channel brightness temperature difference is used together with T11_text to detect sub-pixel clouds and cloud edges. Due to the strong non linearity of the Planck function at 3.7µm the brightness temperature difference has a significant non-linear response to the fractional cloud cover over the satellite FOV. Assuming a cloud top temperature different from the surface, a partially covered pixel will have a large brightness temperature difference, compared to its cloud free or completely cloud covered neighbour (over the sea). This assumes that any co-located sea surface temperature gradient is smoother than the cloud/no cloud boundary which is under detection.

In addition, this feature has been proven to be powerful to filter channel 3.7 um noise. For AVHRR2 there is much noise, while for the AVHRR3 sensor channel 3.7um noise is only a problem at very low temperatures. The T.37T12_text feature is used in several tests intended for arctic night conditions to avoid classifying noise as clouds.

4.1.2.1.18 Feature T3.7_text

The T3.7_text feature is only used over sea ice during night-time. Sea ice surfaces often contain leads (= cracks filled with water) which are of sub-pixel size. The T3.7_text feature can filter these leads.

4.1.2.1.19 Feature T11Tsur

This feature describes the difference between the measured brightness temperature at 11µm and an assumed surface skin temperature (in our case described by a short range NWP model forecast). In the Arctic we apply this feature to detect clouds that are significant warmer then the underlying surface.

4.1.2.1.20 Feature T8.5T11

Similarly to the T11T12 and the T37T12 features this feature is meant to detect thin cirrus. Even if it is less sensitive than the T37T12 feature it has the advantage that it can be used during daytime without introducing any uncertainty due to daylight. On the other hand it is expected to be more sensitive than the T11T12 feature which also works fine during daytime.

4.1.2.2 Test sequence and the Threshold Tests

The algorithm consists of a sequence of grouped threshold tests. In a grouped threshold test, several of the features listed in Table 4-1 are tested together. In order for a grouped threshold test to be successful (decisive), all feature tests constituting the particular grouped test have to be successful for the given pixel.

As the dynamic thresholds have been derived from RTM simulations of cloud free land and ocean surfaces in absence of snow cover (or sea ice), an identification and screening of snow covered cloud free surface are attempted prior to any cloud or clear screening tests. All clear screening tests are done before the cloud screening tests. The set of grouped threshold tests used in the snow screening clear screening, and in the cloud screening are listed in *Table* 4-2, *Table* 4-3, Table 4-4, Table 4-5, and Table 4-6.

Some degree of fuzziness is introduced in the thresholding, by keeping track of the feature distances to the thresholds. The test sequence is continued until a grouped threshold test is successful and all of its feature tests are passed with a safety margin. When this happens the pixel is with high confidence cloudy. The pixel will have high quality and further processing will be stopped. When a test is passed without the safety margin processing will continue.

First of all the pixel is set to 1 (*clear*). If the test is passed and all of the features have values far away from their corresponding thresholds the output is set to *1 (clear, only for clear tests)* 2 (*snow/ice contaminated*), 3 (*cloud contaminated*), or 4 (*cloud filled*) depending on the purpose of the test, and the test sequence is stopped; the low quality flag is unset if set. If the test is passed but one or more of the features have values close to their corresponding threshold the output is set to 2, 3, or 4 depending on the purpose of the test, a dedicated *low quality flag* is set, and the test sequence is continued. The thresholding algorithm consists of only one algorithm in PPS-version 2018. And for each test an extra logical condition on illumination, sunglint, geography or topography can be present to turn off the test for some conditions. In Table 4-7 these extra logical conditions are shown, for example the brightCloudTestR13 is not used over rough terrain. All the above variables put special requirements on the algorithm. Different environments and illumination conditions require different feature tests and sometimes also different thresholds or threshold offsets.

Sunglint is the specular reflection of sunlight over water surfaces, and is thus only considered over *coast* and open *sea surfaces*. Furthermore we only consider low level temperature inversions during night and twilight over land and coast, and only in low terrain. The presence or not of temperature inversions are relevant only when testing the observed T11 (T11) against the forecasted surface temperature. During day other more effective features are always available and furthermore temperature inversions are far less frequent. See section 4.1.2.2.2 for the motivation of the inclusion of the inversion variable.

Observe that it is possible to have high terrain in a coastal area, as is the case e.g. along large parts of the Norwegian coast (at many places fjords cut into rather rough terrain where the topography within the instruments FOV may vary as much as from sea level to around 2000 meters above sea level). Furthermore since the FOV may be over both water and low land at the same time one may encounter problems of both sunglint and the presence of low level inversions.

4.1.2.2.1 Threshold tests, per function

Table 4-2: The components (generic tests) of the grouped threshold tests applied in the snow screening

Component name (and result)	**Used image features**	**Function**
Snow v2018 **(snow/ice)**	T11Tsur T11 T11T12 R0.6 R0.9 *One of 1.6 and 3.7, or both:* R1.6 Pseudo1.6 QR1.6R0.6 R3.7 QR3.7R0.6 T3.7T11 T3.7T12	**Detects snow, snow covered sea ice, old sea ice during day and twilight. The T11 has to be close to the forecasted surface temperature but colder than 278Kand colder than the snow max limit. To avoid thin cirrus (over open sea) to be erroneously detected as snow the R0.6 and R0.9 shall be sufficiently large.** **Reflection in R1.6 and the QR1.6R06 should be small if channel 1.6 is available.** **Reflection in R3.7 and the QR3.7R06 should be small if channel T3.7 is available.** **To avoid miss classifying cirrus T11T12 needs to be close to the simulated cloudfree values.** **To avoid water clouds in twilight T11T12 is not allowed to deviate to much from cloudfree simulations, or T37T12 should be small positive.**

Component name (and result)	Used image features	Function
Ice v2018 **(snow/ice)**	(T11Tsur) T11 T11T12 R0.9 QR0.6R0.9 *One of 1.6 and 3.7, or both:* R1.6 Pseudo1.6 QR1.6R0.6 T3.7refl QR3.7R0.6 T3.7T11 T3.7T12	**The idea is that if there is a water signal 09/06<0.75 and t11 is too cold for it to be water, it must be ice or cloud.** **It the reflection in R3.7 and R1.6 and the quotas with R0.6 are low. And the T11T12 is close to simulated cloud free threshold, it should not be a cloud, thus it should be ice.**
Snow For Clear Pixels **(Snow/Ice contaminated)**	R06, R09 T11 R3.7 QR37R06 R37	**This test is done after all cloud tests, for the pixels still classified as clear. If the reflection in r06 and r09 is high enough. And reflectance in R3.7 is low enough. And the Quota of reflectance in R3.7 and R06 is low enough the pixel will be classified as snow/ice. For this test no t11-Tsur check is used. The t11 should be below the t11_snow_max_limit.**
Snow For Clear Pixels R1.6	**R09 R06 R1.6** **QR16R06** **T11**	**The same as "Snow For Clear Pixels" but using channel 1.6 instead of 3.7.**

Table 4-3: Clear tests used to screen out obvious clear pixels before the cloud tests.

Component name (and result)	Used image features	Function
New Water Body **(Cloudfree)**	QR0.9R0.6 R0.6 T3.7T12 T3.7T11	**Test for clear water bodies not included in PPS landuse. Used during daytime over land (coast).**

Component name (and result)	Used image features	Function
coldClearArcticAreaTest **(Cloudfree)**	T11Ts Tsur T11T12 (T11T3.7)	**Test for cold clear arctic (very cold) areas. Test will pass if: T11 –T12 is reasonable for clear conditions, T11 is close to forecasted surface temperature, temperature is below 230K and T11-T37 need to be within reasonable clear conditions if ch 3.7 is available. In very cold regions channel 3.7 is often nodata. Test is used during night and twilight over land (coast). T11 also should be warmer than at least one of the temperatures above it in the profile t950, t850, t700, t500.** **Part II: if there are no cirrus signal. And inversion. And tsur is close to ttro temperature. And t11 is colder than ttro. Then it is most likely clear.**
SaltLakeTest **(Cloudfree)**	QR0.9R0.6 R0.6 T11 T11Tsur T3.7T12 T11T12	**Test is used during day over sea (coast). The aim is to catch obvious cloudfree pixels over areas that are open water according to the USGS land use database, but where a high reflectivity indicates a dried out lake or salt lake. If not catched early such a dry or semi-dry salt lake will always be classified cloudy in daytime.** **This test requires the 3.7 micron channel.**
DriedOutLakesAndRiversTest **(Cloudfree)**	QR0.9R0.6 T11 T11Tsur T11T12 (T3.7T12)	**Test is used during day over sea (coast). Similar to the above test, but 3.7 micron channel is not mandatory. Thus this test is active on Metop/AVHRR data (where only the 1.6 micron channels is available).**
aerosolTestsLandDay **(Cloudfree)**	R0.6 T11Tsur T11T12 T3.7T12	**Test for heavy aerosols which is not clouds.** **This test will pass for pixels that have low reflectivity in channel 0.6, T11 –T12 is within reasonable margins for clear and we have a very large channel T37-T12 difference. Test is used during day over land.**

Component name (and result)	Used image features	Function
aerosolTests **(Cloudfree)**	R0.6 T11Tsur T11T12 T3.7T12	**Test for heavy aerosols which is not clouds.** **This test will pass for pixels that have low reflectivity in channel 0.6, T11 –T12 is within reasonable margins for clear and we have a very large channel T37-T12 difference. Test is used during day over land.**
dustTest **(Cloudfree)**	T11T12, T11, R0.6, T11T12_text, Used if available: T37T12_text, QR3.7R06, QR1.6T06, T8.5T11	**Test for heavy aerosol which is not cloud. This test will pass for pixels that have low reflectivity in channel 0.6, T11 –T12 is low compared to simulated threshold. The textures in T11T12 and T3.7T12 should be low to avoid cirrus. The QR1.6R06 should be either low, or higher than highest limit for clouds. There should be only low reflection in R1.3. And T8.5T11 should be above 0.5. Also the temperature in T11 should be warm, above 283K.** **Test is done only for day-time pixels.**
clearDesertTest (Cloudfree)	R0.6 R0.9 T11 Tsur T11T12 T3.7T12 QR09R06	**Test for cloudfree desert.** **PartI: If is is very warm t11>30C. And not a high cirrus signal. And T37-T12 are above threshold, but below threshold + offset. And R06 is high. If it was indeed a cloud the t11 temperature should be below 30C!** **Part II: QR09R06 is higher than 1. And R06 and R09 is high. And it is warm Tsur is above 20C and T11 is above 10C. And T11-T12<-0.2. A negative T11T12 signal is expected only for warm cirrus (or wvp) over cold ground. And for some aereosols. Not for clouds.**

Table 4-4: The pure IR components of the grouped threshold tests applied in the cloud screening (these are the only tests being used during night time).

Component name (and result)	Used image features	Function
Cold Cloud	T11Tsur	**Screens all clouds sufficiently colder than the surface but only if the**

Component name (and result)	**Used image features**	**Function**
(cloud filled) or **(cloud contaminated)**	Tsur	**surface is not too cold.**
Cold Cloud v2014 **(cloud filled) or** **(cloud contaminated)**	T11T3.7 T3.7T12 T11T12 T11Tsur Tsur T950 T11	**This test measure the departure/deviation of the observed T11t3.7 and T3.7t12 and T11t12 differences from the cloudfree simulations. If they are close to the cloudfree simulations then we have a high confidence that the FOV is actually cloudfree and therefore require a larger departure in the t11-tsur in order to classify cloudy. For security T11 should also be below T950. And T11<20C.** **Instead of applying a definite threshold in the water cloud features T11T3.7 and T3.7T12 as e.g. in the original cold cloud tests (see above) pixels can still be classified cloudy in this test even if the water cloud features have values below such thresholds, provided the cloud top is "cold enough".**
Cold high cloud850	T11T3.7 T3.7T12 T11T12 T11T37 T11Tsur Tsur T850 T11	As cold cloud test v2014. But a smaller threshold is used if t11 is smaller than t850 and t850 is colder than surface temperature. Only used for t11 below 20C.
Cold cloud test 850 night	T11T950 T11T850 T11TS T11	Only used for t11 below 30C. Test that T11Ts is less than the dynamic threshold + some extra margin that are linearly increased if T850 is close to T950 or Tsur. T11T850 should be less than a threshold that is linearly decreased if T850 is close to Tsur and T950.

Component name (and result)	Used image features	Function
Cold very high cloud 700	T11T700 (T850) (T950) T11Tsur T11	As cold cloud test v2014. But a smaller threshold is used if t11 is smaller than t700 and t700 is colder than surface temperature. Only used for t11 below 20C.
Warm Cloud Test Tropopause	Tsur T11Tsur T850 T700 T500 T950 T11_text T11	**Used over cold surfaces during night and twilight: tsur <240K. Intended for conditions when t37 can not be trusted.** **There should be an inversion. And t11 should be at least 5K warmer than warmest simulated t11.** **Also t11 should be warmer than t500. And warmer than t700 or t850. T11 texture should not be to high.** **T11 should be colder than 293K.**
Arctic Warm Cloud Salomon (cloud filled)	T11Tsur T11T3.7 T3.7T12 T3.7_TEXT T3.7T12_TEXT	**Screens all clouds sufficiently warmer than the surface. This test is only applied over cold ground with rather conservative threshold settings. Texture included to avoid classifying ice cracks as clouds.**
Cold Water Cloud (cloud filled)	T11T3.7 T11Tsur	**Screens sufficiently cold water clouds at night due to their colder appearance in 3.7µm channel.**
Water Cloud (cloud filled) or (cloud contaminated)	T11T3.7	**Same as above but without temperature restriction.**
Water Cloud Desert Night	T11T37 T11T12 T11 T11_text T37_text Emiss37	**If there is a water cloud signal in T11T37 and T11T12 is close to zero and texture in both T37_text and T11_text there is likely a water cloud present. The test is only made if emissivity in 3.7 is below 0.95. And only for pixels with temperature in t11 between 250 and 293K.**

Component name (and result)	Used image features	Function
Arctic Water Cloud (cloud filled)	T11T37 T37T12_TEXT	Aims to detect water or mixed phase clouds over sea ice. The T37T12_TEXT is included to exclude 3.7µm noise that is significant at very cold temperatures.
Arctic Cold Water Cloud (cloud filled)	T11T37 T37T12_TEXT Tsur T950	Same as above and also. T11 should be colder than min(T11,T950)
Thin Cirrus primary (cloud contaminated)	T3.7T12	Screens thin cirrus clouds at night through their warmer appearance at shorter infrared wavelengths (semi-transparency sign).
Thin Cirrus Primary T3.7Ts Night	T11 T11T12 T11T12_text T3.7T12 T3.7Tsur	Not for extremely cold or warm T11. 220K < T11 < 298K. T37T12 should be above simulated threshold. It is used only for dark conditions. The T11T12_texture should be above 0.1K. And T3.7Tsur < 5.0K. The Idea is that Ice-cracks will make T3.7 warmer than the surface temperature.
Thin Cirrus Primary T11T12Text	T3.7T12 T3.7Tsur T11T12_text	T37T12 should be above simulated threshold. The T11T12_texture should be above 0.25K. And T3.7Tsur < 0.0K. The Idea is that Ice-cracks and most cloudfree pixels will result in T3.7 warmer than the surface temperature. Or T11T12_texture lower than the threshold.
Arctic thin Cirrus primary (cloud contaminated)	T37T12 T37_TEXT	Same as thin Cirrus primary, but we include the T37_TEXT feature over sea ice to avoid misclassifications of leads.
Arctic thin Water cloud (cloud contaminated)	T37T12 T37T12_TEXT	We use the T37T12 feature with opposite signed thresholds over sea ice to detect transparent clouds that are significant warmer then the underlying surface. The T37T12_TEXT feature is included here to avoid a misclassification of

Component name **(and result)**	**Used image features**	**Function**
		3.7µm noise.
Thin Cirrus secondary **(cloud contaminated)**	T11T12	**Same as Thin Cirrus Primary Test but using a smaller spectral interval and applied at daytime/twilight.**
Thin Cirrus secondary T11T12_texture	T11T12 T11 T11T12_text	**Same as Thin Cirrus Secondary Test but using a smaller spectral interval and applied at daytime/twilight. Using T11T12text above 0.25 to avoid detecting water vapour. Not used for very warm pixels, T11<298.**
Arctic warm Cirrus secondary Test **(cloud contaminated)**	T11T12	**Same as above, but with opposite signed thresholds over sea ice to detect transparent clouds that are significant warmer then the underlying surface.**
Arctic thin Cirrus secondary **(cloud contaminated)**	T11T12 T37_TEXT	**We use the T11T12 feature over sea ice with +/- similar threshold settings as the Thin Cirrus Secondary Test to detect cold transparent clouds. To avoid a false detection of leads the T37_TEXT feature is included here.**
Thin Cold Cirrus **(cloud contaminated)**	T11T12 T11Tsur	**Same as above but requiring clouds to be sufficiently cold.**
coldThinCirrusPrimaryTest	T37T12 T11Tsur	**As the thin cirrus primary test but t11 should be colder than tsur.**
Highcloud T8.5T11 (cloud contaminated)	T85T11	**This feature detects high clouds. The idea is that the contrast is better than for the T11T12 case and more robust against sunlight than the T37T12 test.**
watercloudTestOver ColdGround_2014	T11T37 Quota: T11T37 and T37T12 T11	**For watercloud without cirrus above. Watercloud signal. And** Quota: T11T37 and T37T12 near -1.0.
cirrusOverWatercloudTestOver ColdGround_v2014	T11T37 T11T12 T11	**T11T12 show cirrus singal. And there is also weak watercloud singnal T11T37>0.2.** **Test is only used over cold ground.**
Cirrus over snow/ice night	T11T12	**If T11 is cold, below 260K. And there**

Component name **(and result)**	**Used image features**	**Function**
	T11	**is a strong T11T12 signal for warm or cold cirrus.**
sstNighttime	T11 T3.7 Tsur T11T12 Satsec:Cos(Θ_{sat}) T11texture	**This test aims at detecting any cloud contaminated pixel over sea, in particular thin cirrus clouds which can have T11 values very close to the predicted surface skin temperature, and may go undetected by the other tests over sea.** **The Sea Surface Temperature (SST) is derived for the pixel using the satellite secant (Cos(Θ_{sat})) and the OSAISAF platform dependent algorithm (see ANNEX A), and the NWP predicted surface skin temperature as the background climatological SST.** **Both the departure between the observed SST and the predicted surface skin temperature (Tsur) and the departure of the observed T11T12 to the predicted cloudfree value is stored.** **The T11T12 departure is the tested against a threshold which depends linearly on the sst-departure. The larger the sst-departure, the larger the T11T12 threshold.** **This means that pixel with a large SST departure needs only a small departure in T11T12 to classify cloudy, but a pixel with a small SST departure requires a large T11T12 departure (a very obvious thin cirrus feature).** **In addition to this the pixel needs to have a slightly raised local texture in T11 compared to the expected cloudfree texture.**

Table 4-5: Components of the grouped threshold tests applied in the cloud screening during day and twilight conditions.

Component name **(and result)**	**Used image features**	**Function**
bright Cloud Medium Temperature R1.6 T3.7	R0.6 R0.9 T11Tsurf QR0.9R0.6 T11T12 T11 T3.7T12 R1.6 QR1.6R0.6	**This test aims at capturing low clouds in daytime with top temperatures close to the predicted cloudfree surface temperature and with only a medium cloud signal in the T3.7-T12 feature.** **For channel 3A the test R1.6 should be higher than the threshold (dependent on satsec) and the quota QR1.6/R0.6 should be above 0.6.** **For channel 3B T3.7-T12 should be above simulated threshold plus a smaller offset.** **T11T12 should not be too negative. To avoid detecting aerosols and sand-storms.** **The reflectance in R06 and R09 should be high.** **T11 should be warmer than 260K and colder than 298K** **T11 should be colder than surface.**
Bright Cloud v2014 **(cloud filled)**	R0.6 T11Tsurf QR0.9R0.6 T11T12 T11	**This test aims at capturing low clouds in daytime with top temperatures close to the predicted cloudfree surface temperature and with only a weak cloud signal in the T3.7-T12 feature. These clouds usually have a high reflectance in in the 0.6 band (R06) but as the cloudfree 0.6 reflectance is not adequately simulated for the actual surface relflectance conditions (the simulations are done assuming a static mixture and forrest and open land with no coupling to the actual surface conditions) the threshold offset in this feature has to be set rather high to avoid misclassifying e.g. barren and semi-arid cloudfree areas as cloudy.** **The test use the fact that** **1. the 11 and 12 micron emissivities of a stratus cloud are nearly equal and that the**

Component name (and result)	Used image features	Function
		abundance of water vapour is concentrated beneath and in the cloud deck. Thus the t11 - t12 difference is close to zero and much smaller than the calculated cloudfree threshold. 2. stratus clouds have very high reflectance values in the 0.6 channel 3. daytime stratus clouds seldom have top temperatures above 20 C (measured in the 11 micron channel) 4. clouds have 0.6/0.9 reflectance quotas around and a little below 1.0 5. stratus clouds have daytime top temperatures colder than the cloudfree condition (not warmer!) Point 3, 4 and 5 above are all safety checks to try to avoid misclassifying cloudfree scenes as cloudy. Of particular concern here are desert or barren land surfaces. Those areas may have dry atmospheres (having low total integrated water content) making the cloudfree t11-t12 low, and may have small scale variations in the 11 and 12 micron emissivity further enhancing a low cloudfree t11-t12. Also desert/barren areas have high cloudfree 0.6 micron reflectivities. But with an upper limit of 293.15K in the t11 many such daytime cases should be avoided. Concerning 1) the information content (or the detection capability) in this feature degrades as the cloudfree atmosphere get's dryer. This means that in general this test will not work as efficient in elevated terrain and at high latitudes. We have made a threshold test dependency trying to account for this, so that it will be harder for a pixel to be classified as cloudy as the t11-t12 threshold gets

Component name (and result)	Used image features	Function
		lower.
Bright Cloud (cloud filled)	R0.6 T3.7T12	Screens all sufficiently bright clouds, requiring high reflectance in 0.6µm channel and minimum difference in 3.7µm – 12µm channel.
Bright Cloud Sea (cloud filled)	R0.6 T11	Screens all sufficiently bright clouds, requiring high reflectance in 0.6µm channel and cold cloud tops according to T11. This test has marginal effect, if any, since the introduction of more effective daytime tests over sea in v2014. See above. For the same reason the test utilise rather conservative threshold offsets in T11 to avoid misclassifying clear pixels as cloudy.
Bright Cloud R1.3	R1.3 ciwv	If there is at least some water vapour. And there is some reflection in R1.3 it should be a cloud.
Bright Cloud R1.6 (cloud filled)	R0.6 QR1.6 T11Ts	Screens all sufficiently bright clouds, requiring high reflectance in both channels, 0.6µm and 1.6µm. The R1.6 threshold is linear in the secant of the satellite zenith angle and is higher in the forward scattering regime.
Bright Cloud R1.6 (cloud filled)	R0.6 QR1.6 T11Ts	Screens all sufficiently bright clouds, requiring high reflectance in both channels, 0.6µm and 1.6µm. The R1.6 threshold is linear in the secant of the satellite zenith angle and is higher in the forward scattering regime.
Bright Cloud R1.6 No Sunglint Sea (cloud filled)	R0.6 R0.9 QR1.6R0.6 T11	Screens all sufficiently bright clouds, requiring high reflectance in both channels, 0.6µm and 1.6µm . Applied outside potential sunglint areas. The R1.6/R0.6 threshold is static and set to 0.32.
Bright Cloud R1.6 T11Tsur No Sunglint (cloud filled)	R0.6 QR1.6R0.6 T11Ts	Screens all sufficiently bright clouds, requiring high reflectance in both channels, 0.6µm and 1.6µm . Applied outside potential sunglint areas. The R1.6/R0.6 threshold is static and set to

Component name **(and result)**	**Used image features**	**Function**
	T11	**0.32. Also clouds should be sufficiently colder than surface (T11Ts)**
Cold Bright Cloud **(cloud filled)**	T11Tsur Tsur R0.6 R0.9	**Same as the cold cloud test but also requires the VIS and NIR reflectance to exceed a threshold.**
Cold Bright Cloud 3.7 **(cloud filled)**	T11Tsur Tsur R0.6 R.09 T3.7T12	**This test is used under daytime conditions over land and coast areas. Complementing and to some extent replacing the old "Cold Bright Cloud" test. In addition to the "Cold Bright Cloud" test it also test the T3.7T12 feature.** **The additional use of T3.7-T12 is possible through a more accurate description in v2014 of this feature under cloudfree conditions over land.**
Cold Cloud Day v2014 **(cloud filled) or** **(cloud contaminated)**	R06 R09 QR0.9R0.6 T11 T3.7T12 T11T12 T11Tsur Tsur T850 T950	**Same as cold cloud v2014. But there are also both minimum and maximum limits for QR0.9R0.6. And the reflection in R0.9 ad R0.6 should be above the thresholds.**
Cold Water Cloud Day	QR0.9R0.6 T11 T11T3.7 T11Tsur	**Similar to the Cold Cloud v2014 test described above. But in daytime we additionally constrain the test by use of the R0.9/R0.6 quota.**
Reflecting Cloud **(cloud filled)**	PseudoR0.6 T3.7T12	**Identifies any reflecting cloud near the night/day terminator. Requires reflection also in 3.7µm channel (separation from snow/ice)**
Reflecting Cloud Sea	T11	**Similar test and purpose as the "Reflecting Cloud" test described**

Component name **(and result)**	**Used image features**	**Function**
(cloud filled)	PseudoR0.6	**above. This test is, however, only applied over sea and coast and doesn't use the T3.7T12 feature.**
Cloud pseudo0.6 R1.6 **(cloud filled)**	PseudoR0.6 QR1.6R0.6 T11	**Identifies any reflecting cloud near the night/day terminator. Requires a R1.6/R0.6 feature higher than 0.45. The threshold in PseudoR0.6 is linear in the sun elevation with the expression: 0.5%Θ + 1.5%, where Θ denotes the sun elevation here).**
Clouds in Sunglint **(cloud contaminated)**	R0.6 QR3.7R0.6 T11T12	**Low (opaque) clouds are separated from cloud free sea in potential sunglint areas when the R3.7/R0.6 ratio is lower than 0.7 and R0.6 exceeds 15%. As an extra precaution the T11T12 difference shall be lower than the threshold for detection of thin cirrus.**
Sunglint R1.6 **(cloud contaminated)**	R0.6 QR1.6R0.6	**Low (opaque) clouds are separated from cloud free sea in potential sunglint areas when the R1.6/R0.6 ratio is lower than 0.6 and R0.6 exceeds 15%.**
Clouds in Sunglint R1.6 **(cloud contaminated)**	R0.6 QR1.6R0.6 QR0.9R0.6 T11Tsur T11T12	**This test is applied over coastal regions (no mountains) under both twilight and day conditions, and in open water where sunlint prevails. It relies on the 1.6 micron channel, and the 3.7 micron band is not needed.** **It uses QR1.6R06 to avoid snow and sea ice. It detects mainly low clouds by requiring the T11T12 feature to be lower than the cloudfree threshold (a low opaque cloud deck will screen the lower part of the atmosphere where the abundance of water vapour is found and which give rise to the main part of the cloudfree T11-T12 difference through a lower transmissivity in at high IR wavelengths and a decreasing temperature with height).** **The QR0.9R0.6 feature is used to further constrain the test, as cloudy**

Component name **(and result)**	**Used image features**	**Function**
		pixels have quota values close to one.
Cold Clouds in Sunglint **(cloud filled)**	R0.6 QR3.7R0.6 T11Tsur	**Clouds are separated from cloud free sea in potential sunglint areas when the R3.7/R0.6 ratio is lower than 0.7 and R0.6 exceeds 15%. As an extra precaution the cloud shall be sufficiently cold in T11 as compared to the surface temperature.**
Cold Clouds in Sunglint R1.6 **(cloud filled)**	R0.6 QR1.6R0.6 T11Tsur	**Clouds are separated from cloud free sea in potential sunglint areas when the R1.6/R0.6 ratio is lower than 0.6 and R0.6 exceeds 15%. As an extra precaution the cloud shall be sufficiently cold in T11 as compared to the surface temperature.**
Visland Cloud Test	pseudoR0.6 T3.7T12	**This test is used at twilight and over coastal regions only.** **It seeks to catch mainly low water clouds or sub-pixel clouds without using the temperature information, but only using the reflective signal in the 0.6 and 3.7 micron bands.**
Cirrus over snow/ice R1.6	R.06, R.09, QR0906, T11T12, T11 R1.6, PseudoR1.6, QR1.6R06	**If R06, R09 and reflectance in cannel 3Afulfill snow test. And T11T12 have strong cirrus signal. Test is only used over cold ground.**
Cirrus over snow/ice	R.06, R.09, QR0906, T11T12, T11 T3.7refl, QR3.7R0.6	**Same as cirrus over snow ice R1.6 but using R3.7 instead.**
Bright Clouds In Sunglint 2014	QR09R06 QR3BR06 R3.7 R06	**Replaces bright cloud test in sunglint scheme.** **R3.7 should be large. But also QR3BR06 should be small enough for it to be cloud not sunglint. And QR09R06 should be within cloudy**

Component name (and result)	Used image features	Function
	T37T12	**limits.** **Other conditions from bright cloud test.**
Reflecting Cloud Sea v 2014	R09 QR09R06 Tsur T11ts CH3brefl	**Cloud have higher r09 reflectance than threshold.** **Also cloud is colder than tsur OR have high ch3b reflectance.** **Qr09r06 is abouve 0.5.** **Only used over ocean with tsur > 273.15K.**
brightCloudTest R1.6 No T11Ts	QR16R06 QR09R06 T11 R06 R09 R16	**If QR16R06 and QR09R06 are with in cloudy thresholds. And t11 is below 300K. And reflection in R16 is sufficiently high. This test uses no Tsur information. It is a combination of the old BrightCloudTestR16 and BrightCloudTestNoSunglintR16. For safety also reflection in r06 and r09 should be over thresholds**

Table 4-6: The components of the grouped threshold tests using texture and spatial information are applied in the cloud screening .

Component name (and result)	Used image features	Function
Texture Night **(cloud contaminated)**	T11_text T3.7T12_text R0.9R0.9warmest	**Pixel with high spatial variations in IR identified as clouds. Difference of infrared channels are used in addition to reduce influence from thermal fronts at sea. The 0.9 micron reflectivity is larger than for the warmest pixel if day conditions.**
Texture VIS **(cloud contaminated)**	R0.6_text R0.9R0.9warmest	**Pixel with high spatial variations in VIS identified as clouds. The 0.9 micron reflectivity is larger than the for the warmest pixel.**
Texture IR/VIS **(cloud contaminated)**	T11_text R0.6_text	**Pixel with high spatial variations in both VIS and IR identified as clouds. High texture in both VIS and IR required in**

Component name (and result)	Used image features	Function
	R0.9R0.9warmest	**order to avoid mis-classifying thermal fronts. The 0.9 micron reflectivity is larger than the for the warmest pixel.**
Texture Vis R16 Sea	R06_text R0.9R0.9warmest R09 R06 R16 QR0.9R0.6 QR1.6R0.6 T11	**QR1.6R0.6 and QR.09R0.6 should be with in limits for cloud pixels. The reflectance in R0.6, R0.9 and R1.6 should be above the threshold. The reflectance in R.09 should be higher than for the warmest pixel.**
Texture T11	T11 T11_text	
Water Cloud Over Water	T11T3.7-T11T3.7warmest T11-T11warmest Tsur	**The test aim to detect water clouds at night over open sea with cloud tops colder than the sea surface. It tests if the pixel is "more cloudy" in terms of t11 and t37 compared to the warmest (in terms of t11) pixel in a 5 by 5 pixel neighbourhood. To avoid applying the test over sea ice, the NWP predicted surface temperature has to be above a threshold (set to 275 K).**
Bright Cloud Over Water	Tsur R0.9 T11T11warmest R0.9R0.9warmest	**The test aims at detecting thin and broken clouds over sea at day (including sunglint). It finds the warmest pixel in t11 in a 5 by 5 pixel neighbourhood, and if the following points are fulfilled the pixel is cloud contaminated:** • **If the 0.9 micron reflectivity is larger than the for the warmest pixel. And the r09 reflectivity should also be warmer than the r09 threshold.** • **If the 11 micron tb is lower (pixel is colder) than for the warmest pixel minus a threshold dependent on tsur. Higher threshold over warmer water.** • **If the nwp forecasted/analysed skin temperature is higher than a**

Component name (and result)	**Used image features**	**Function**
		static offset (this is to avoid testing over potentially sea-ice covered areas)
SST Daytime Test	T11 Tsur Satsec:Cos(Θ_{sat}) T11T12 (R1.6 if available) T11_text QR0.9R0.6 R0.6_text (R3.7 if available)	**Similar to the SST Nighttime Test. But utilising also the local texture in R0.6 and additional short wave features (R1.6 or R3.7 and QR0.9R0.6)** **The daytime OSISAF algorithm is also different and only utilise the T11 and T12 bands, and not the 3.7 micron band which is used in the nighttime algorithm. See ANNEX A.**
SST Twilight test	R0.9 T11 Tsur	**Similar to the SST Dayttime Test. But using R09. The higher above the threshold R09 is the lower threshold for SST-TSUR deviation is used.** **The twilight SST test uses the same algorithm as the daytime test.**
SpatialCloudTestLand	R06, R06warmest T11, T11warmest Tsur	**The test aim at detecting sub-pixel and broken cumulus clouds and thin cirrus clouds over land at day.** **The assumption is that the warmest pixel in a 5x5 neighbourhood is cloudfree or closest to the cloudfree conditions in the features tested, and that if the pixel in question is both significantly colder and brighter, and also have a greater t11t12 difference, then it is most likely contaminated by a cloud.** **The test is bounded by the t11 and predicted surface skin temperature, so that a pixel cannot be cloudy if the t11 is above 34°C or if the Tsur is warmer than 40°C**
Spatial bright cloud test 2014	R06, R06warmest R09, R09warmest R16, R16warmest	**A pixel that is colder than the warmest neighbour and are more reflective in all channels R06, R09, R1.6 if available, T37T12 (if available). It should be a**

Component name (and result)	**Used image features**	**Function**
	T37T12, T37T12warmest T11, T11warmest T11	**cloud.** **To avoid false clouds T11 must be below 34C and there should be some reflectance in R09, R06 and R1.6 (if available).**

4.1.2.2.2 Threshold tests, order and conditions

In Table 4-7 is described the test order, and for each test: the conditions for when the test is applied or not. The tests are always performed in the same order. (In versions before PPS v2018 the order of the tests differed between different light and surface conditions.)

Table 4-7 Test order and conditions when test is applied or not applied. The test are applied in the order they come in this table

Test (in order)	**Conditions when applied**
brightCloudTestR13	not over rough terrain during light conditions
snowTest_v2018	during light conditions
iceTest_v2018	only used over sea, during light conditions
dustTests	during day
aerosolTests	always applied
aerosolTestsLandDay	only for day, not over sea, not over rough terrain
coldClearArcticAreaTest	always applied
SaltLakeTest	only used for day, only for elevation above 0
ClearDesertTest	during light conditions
DriedOutLakesAndRiversTest	not over land, not over ice, only for elevation above 0
coldCloudTest	always applied

Test (in order)	Conditions when applied
coldCloudTest850Night	during light conditions
coldCloudTestDay_v2014	during light conditions
coldCloudTest_v2014	always applied
coldHighCloudTest850	always applied
coldVeryHighCloudTest700	always applied
sstDaytimeTest	only used over ocean, during light conditions
sstNighttimeTest	only used over ocean, during dark conditions
sstTwilighttimeTest	only used over ocean, during light conditions
warmCloudTestTrop	always applied
coldBrightCloudTest	during light conditions
coldCloudsInSunglint	during light conditions not over land
coldCloudsInSunglintR16	during light conditions
arcticcoldwatercloudTest	always applied
arcticwarmCloudTestSalomon	not applied over arctic_cold_dark_too_cold_t37
arcticwatercloudTest	not for day
cirrusOverSnowiceNight	not for day, over ice or arctic cold dark areas
cirrusOverWatercloudTestOverColdGround_v2014	always applied
watercloudTest	not applied over arctic cold dark areas
watercloudTestDesertNight	not for day, only for land and coast
watercloudTestOverColdGround_v2014	always applied
coldWatercloudTest	always applied
coldWatercloudTestDay	during light conditions
pseudo06CloudTestR16	for twilight light conditions
reflectingCloudTestSea	only used over sea, during light conditions
reflectingCloudTestSea_v2014	only used over sea, during light conditions
brightCloudTestMediumTemperatureR16T37	always applied, during light conditions
brightCloudTestNoSunglintR16Sea	not applied over sunglint, only used over sea

Test (in order)	Conditions when applied
brightCloudTestNoSunglintR16T11Ts	not applied over sunglint
brightCloudTestR16	during light conditions
brightCloudTestR16_NoT11Ts	not applied over sunglint
brightCloudTestSea	only used over sea, during light conditions
coldBrightCloudTest37	during light conditions
reflectingCloudTest	only used over twilight, not applied over rough terrain
brightCloudTest	not applied over sunglint, during light conditions
brightCloudsInSunglint_2014	during light conditions
cloudsInSunglint	only used over sunglint
cloudsInSunglintR16	during light conditions
sunglintTestR16	only used over sunglint
arcticthinCirrusPrimaryTest	not applied over arctic_cold_dark_too_cold_t37
arcticthinCirrusSecondaryTest	not applied over arctic_cold_dark_too_cold_t37
arcticwarmCirrusSecondaryTest	over ice or arctic cold dark areas, not for day
thinCirrusPrimaryTest	not applied over day, not applied over sunglint
thinCirrusPrimaryTestT11T12Text	always applied
thinCirrusSecondaryTest	Day: only used over sea and not over ice and not for sunglint. Twilight and night: always applied.
thinCirrusSecondaryTestT11T12Text	always applied
thinColdCirrusTest	always applied
coldThinCirrusPrimaryTest	during dark conditions
thinCirrusPrimaryT37TSNightTest	during dark conditions
cirrusOverSnowice	during light conditions
cirrusOverSnowiceR16	during light conditions

Test (in order)	**Conditions when applied**
HighcloudTestt85t11	always applied
watercloudOverWaterTest	only used over sea, not applied over ice, not applied during day
brightCloudOverWaterTest	during light conditions
textureVisR16_Sea	only used over sea, during light conditions
textureIrvisTest	only used over sea, during light conditions
textureNightTest	only used over sea, not applied over ice
SpatialCloudTestLand	during light conditions, not for cost
snowTestForClearPixels	applied for clear pixels, during light conditions
snowTestForClearPixelsR16	applied for clear pixels, during light conditions

4.1.2.3 Low level temperature inversions

Separation of low clouds and cloud free land or water surfaces during night and in twilight sometimes becomes a particular challenging, if not impossible, task using satellite data alone.

In the absence of sunlight the brightness temperature difference between the 11 and 3.7µm channels is normally large enough to allow detection of low water clouds. However, exceptions do occur where this difference is so small that separation from the cloudfree case becomes ambiguous. Over the open ocean low clouds may contain rather large water droplets and during the mid to high latitude winter season low clouds may sometimes consist of a sufficiently high amount of ice particles. In both cases the shortwave IR emissivity at the cloud top is high enough so as to erase the normally existing 11 minus 3.7µm brightness temperature difference.

When the sun is just above the horizon the 3.7µm brightness temperature is raised due to the additional radiance from reflected sunlight, and water cloud detection using the 11 and 3.7µm brightness temperature difference is impossible. The configuration employed the AVHRR/3 on some of the polar orbiters (see section 4.2.2.1.1) where the channel 3A and channel 3B are switched passing between day and night does not eliminate this problem. First as the switching is done from one line to another there will inevitably be regions without sunlight and without channel 3B data. Secondly even with the sun above the horizon the 1.6µm reflectance signal might not be sufficiently strong in order to be used unambiguously to separate water clouds from cloud free land surfaces.

In the above described situations the only possibly useful feature is the difference in the surface temperature and the 11µm brightness temperature. However, it requires that the cloud top is sufficiently colder than the surface, and this is not always the case. Especially over land and during the winter season low level temperature inversions are normally quite frequent, and the cloud top is often as warm as or even warmer than the surface (the latter phenomena is often referred to as black stratus in satellite remote sensing).

Comparing radiosonde and Hirlam profiles, we found using the temperature difference between 950hPa and the surface that Hirlam is generally capable of correctly detecting the presence of low level inversions in wintertime situations over northern Europe, even though the strength is often not correct. The 950hPa level may seem rather low, but the situations we are after are those occurring in stationary situations with usually a rather high surface pressure. No attempt is made to detect inversions in high terrain and over sea ice, as NWP profiles are less reliable in lower levels here. For the same reason the threshold offset in T11 is generally set rather high in mountainous terrain and over sea ice.

The presence of a low level inversion as detected with this method is a direct indication of high risk for significant errors in the estimated surface temperature (frequently the skin temperature is much lower in reality). If an algorithm were to ignore such expected errors and rely on the T11 only and its threshold (derived assuming a correct skin temperature) cloudfree areas at night or in twilight would frequently be misclassified as cloudy.

When a low level inversion is detected a particular bit in the processing flags dataset is set implicitly indicating low quality (see sections 4.2.1 and 4.2.3).

In case of a weak inversion the observed brightness temperature at 11µm has to be 17K lower than the cloudfree simulation using the forecasted, and often erroneously too warm, surface temperature, whereas in areas of no risk of low level inversions the corresponding offset is 8K (12K in mountainous terrain). With the introduction of the new cold cloud tests in version 2014, this offset (for t11-surface temperature) is instead mainly dependent on the cloudy signal in the other features (t37t12 and t11t12). See Table 4-4: *Cold cloud v2014* for more information about the test. The original cold cloud test that was not used in version 2014 is now in version 2018 only used with a very high offset (30K).

4.1.2.4 Probability for sunglint

The probability for sunglint is calculated using the formula derived by Berendes et al. (1999) which depends purely on the sun-satellite viewing geometry. Berendes et al. derived their formula from the distribution found by Cox and Munk (1954) assuming an isotropic average wind field with wind speeds in the range of 0 to 14m/s. We use this probability of sunglint measure only as an indicator of risk for sunglint. If the probability is larger than a threshold, currently set to 1.0%, we activate the processing flag for presence of sunglint and some tests are no longer performed.

4.1.2.5 Desert and barren areas

The PPS cloud algorithms were foremost developed for applications at high and mid latitudes, such as encountered in central and northern Europe and adjacent seas. However, the PPS cloudmask has been tested and improved for the purpose of cloudmasking over the whole world. The surface conditions, concerning the spectral emissivities and reflectivities over desert and semi arid areas are considerably different from the surfaces (mixed open land and forest) for which the PPS was developed and tuned. This is most pronounced for the 3.7µm channel whose emissivity is substantially less than 1. Additionally, the short wave reflectivities are high over desert sands. Therefore these extreme conditions have been tackled by a special treatment in earlier versions, they are now mostly handled by thresholds (t37t12) dependent on the emissivity of channel 3.7 (see 4.1.2.6).

4.1.2.6 Thresholds with 3.7 µm over land during light condition.

Different methods to derive 3.7µm thresholds over land has been used. Here is described how it was done in v2014 and in v2014-patch20150327, which si what is used in verison 2018.

For version 2014 efforts were made to include the solar component of the 3.7µm channel in the threshold-tables for daytime use over land, using simulations from 6S for the solar part. However these thresholds were discovered to not perform as expected in PPS v2014. The dynamic thresholds was therefore replaced (in PPS v2014-patch20150327) with thresholds dependent only on emissivity of channel 3.7 µm and the satellite zenith and absolute azimuth difference angle. For the brightness temperature difference $T_\alpha - T_\beta$ where α or β is 3.7µm and the other is 11 µm or 12 µm, the thresholds will be calculated by:

Upper threshold azimuth difference angle >50:

$T_\alpha - T_\beta$ upper threshold = 5.0 + 65· (1.0-emissivity$_\alpha$) + (2 + 5·(1.0- emissivity$_\alpha$))(satsec-1.0)

Upper threshold azimuth difference angle <=50:

$T_\alpha - T_\beta$upper threshold=5.0 + 65· (1.0 - emissivity$_\alpha$)

where satsec = 1.0/cos(satellite zenith angle).

This threshold is independent of water vapour and surface temperature. As this formula does not consider the spectral response functions of channel 3.7 µm at all there is a risk for varying performance between satellites.

For version 2018 an attempt to add the solar contribution in a simple way, at least partly using the spectral response function was tested. The solar contribution was calculated considering only the solar flux, central wavelength, channel width and the sun zenith angle. The solar contribution will be independent of water vapour and satellite zenith angle. As this threshold showed similar but slightly decreased perfromance the threshold used in PPS v2014-patch20150327 was kept for version 2018.

4.1.2.7 Definition of mountainous terrain

Mountainous terrain pose problems for the PPS cloud mask for several reasons, the most important ones are listed here below:

1. Sloping terrain within the AVHRR/VIIRS FOV resulting in locally changing sun-satellite viewing conditions and shadows, altering the surface reflectance.
2. Locally varying terrain height on a scale not resolved by the NWP model topography. This may result in an actual average elevation over the AVHRR/VIIRS FOV which is far from the elevation given by the model topography, and consequently the NWP parameters, and in particular the forecasted/analysed surface skin temperature, may deviate substantially from the truth.
3. A highly varying topography (on the scale of a few hundred meters to a few kilometers) enhance small scale climate variability usually not well captured by an NWP model with a resolution of several km (say 10 or more). This is related to point 2 above.
4. Highly elevated terrain (including plateus, not necessarily with a high local variation in topography) in general give rise to colder temperatures. Very cold surface conditions reduce the signal to noise especially in the longwave IR region around 3.7 microns, which is a crucial spectral band for nighttime cloud detection.

As shadows are not explicitly handled in the algorithm, and since surface reflectance is modelled after a completely flat earth surface over the FOV, the issue raised in point 1 degrades the daytime cloud detection features based on the short wave spectral bands (0.6, 0.8, 1.6 and 3.7 microns). Under point 1 conditions the algorithm needs to be careful not to go as close to cloudfree

thresholds as it is possible over more gentle terrain. Point 2 and 3 requires the cloud mask algorithm to be more cautious especially in the use of the surface skin temperature in terrain with high local variability in elevation, as it is more prone to be wrong here.

Point 4 is actually implicitly treated by the NWP model as long as the terrain is only varying slowly in elevation over horizontal scale comparable to the NWP grid resolution. If the terrain is highly variable, the problem is already described by point 2 and 3.

Due to these potential problems PPS is using a static map that distinguish gentle terrain, with variations in elevation which are small over a scale comparable to the NWP grid resolution, from rough terrain with variations in elevation which are large over the NWP grid cell. Before PPS-v2014 the distinction between gentle and rough terrain was done purely on the 1km resolution digital elevation map (USGS GTOPO 30, see further on). From version 2014 we derive a roughness map from the 1km elevation data, by deriving the standard deviation of the elevation in meters over a local 11 by 11 pixel kernel. The threshold delineating gentle from rough terrain is set to 100m. In version 2012 end earlier the threshold was 500m on elevation.

There is a rather good correlation between roughness (as defined above) and elevation over the European area and thus the general impact of this change is modest on average over Europe. However, on a global scale there are substantial differences between the two means of identifying rough terrain as can be seen from Figure 1, Figure 2, and Figure 3. Especially over the East Asian areas and over large parts of Africa and Antarctica the differences are significant.

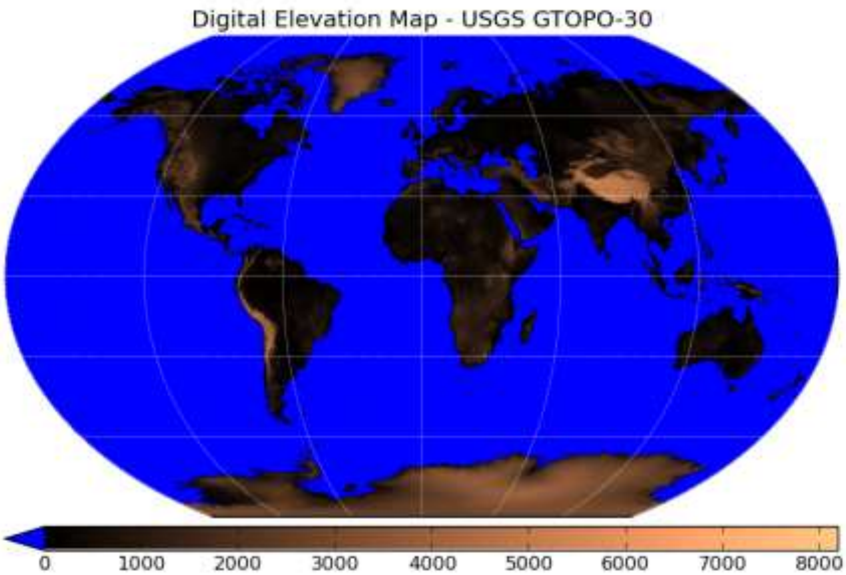

Figure 1: The digital elevation map used in PPS

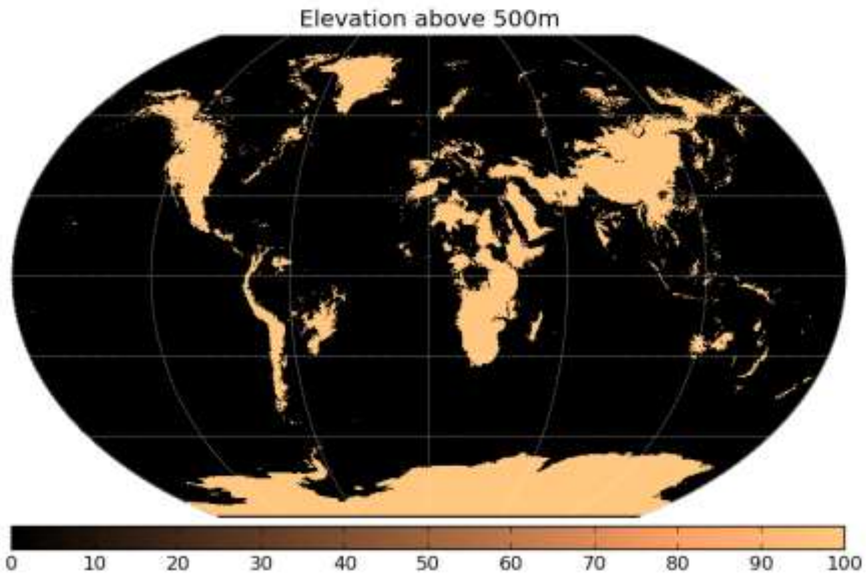

Figure 2: Global map highlighting areas on the earth with an elevation above 500 meters.The 500 meter limit was used previously in PPS to delineate low-land from mountainous terrain.

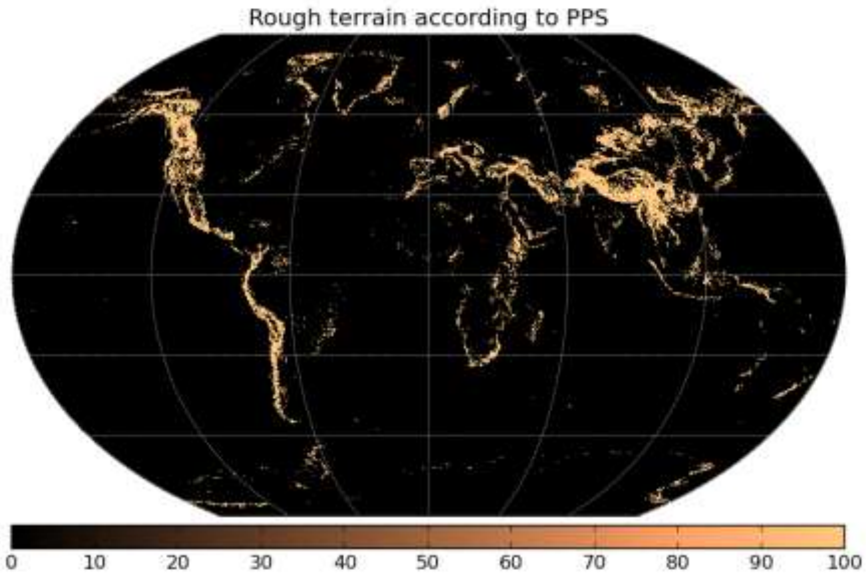

Figure 3 Global map showing where on earth the terrain is rough according to PPS. This is the dataset used in PPS from version 2014 to deliniate rough/mountanous terrain from low-land/gentle terrain.

4.1.2.8 Definition of sea ice surface

We have adapted the PPS software for cloud product generation over sea ice. The cloud detection is very problematic over sea ice during night-time because of 1) the unreliability of the NWP surface temperature prediction over ice, 2) the frequent occurrence of temperature inversion, i.e. clouds have often similar temperatures as the ice surface and, 3) the extreme low temperatures leading to a very high noise to signal ratio in the 3.7µm channel (most pronounced for the AVHRR instrument). During daytime misclassifications of thin fog layers, occurring frequently over sea ice during spring and fall, were observed and the software was adapted accordingly.

The surface conditions over sea ice are rather different then surface conditions over open ocean or land surfaces and we have thus decided to use the OSISAF sea ice product to define a different environmental regime. We define the open ocean as 'ice covered' if the sea ice concentration is higher then 30 % or in case an ice map is not available, if the NWP ice surface temperature definition is significant below 273 K over open ocean. The OSISAF product does not contain data around the pole, but we consider this area as being constantly ice covered.

4.1.2.9 Accounting for a changing land cover with time

Due to the ongoing global climate change and increasing man-made impact (e.g. dams for water power or heavy and sustained irrigation) on the earths resources, or simply because of natural seasonal variations, it happens that the USGS land use dataset show water in some locations where it actually is land at the time of the satellite data retrieval. Or vice versa, the land use dataset might show land where there actually is water. Figure 4 illustrate a case where the land use shows a lake of a certain size, while one can see in the satellite image that the actual size of the lake is significantly smaller.

To cover up for some of such situations we have introduced a number of clear tests (*Clear New Water Bodies*, *Salt Lake Test* and *Dried Out Lakes And Rivers Test*) as outlined in *Table* 4-3.

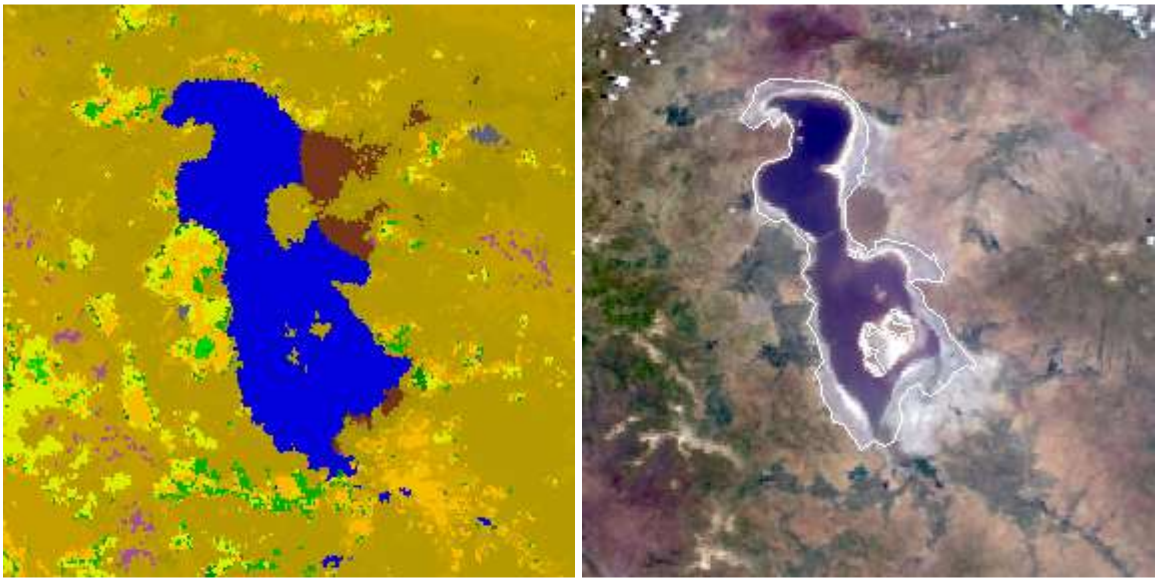

Figure 4: Usgs Landuse map (left) and S-NPP VIIRS True Color image taken June 5th, 2013, 10:41 UTC received and processed at SMHI. The area in focus is the Lake Urmia in Northeastern Iran.

4.1.2.10 Other clear screening test

In version 2014 CMa several clear screening tests have been included. These are performed before the cloud tests. A part from the test accounting for changing land cover there are one test that checks for very cold (below 230K) clear areas during night. In these conditions the temperatures are so low that cannel 3.7 often have nodata and can not be used for any tests, at least not for the AVHRR sensor. The other new clear test screens for very heavy aerosols to not misclassify these as clouds. See *Table* 4-3 for all clear tests and descriptions.

4.1.2.11 Aerosol and dust detection

In addition to the cloudmask, there are also an aerosol and a dust flag. Pixels that passed the aerosol tests in the cloudmask (see *Table* 4-3for the tests) will be flagged as aerosols in the aerosol flag.

In addition to this some dust tests are done in a separate function for all cloud-free pixels, after the cloudmask is calculated (see the tests in *Table* 4-8). These dusty pixels will be flagged both as aerosol in the aerosol flag and as dust in the dust flag. Please notice that these pixels will not be flagged as heavy aerosols in the CMa status flag.

Table 4-8: Clear tests used to detect dust.

Component name (and result)	Used image features	Function
Cold dust test **(Dust or Aerosol)**	T11T12 R0.6 T11Ts	**If the T11 indicates cold air T11TS<0, but the T11T12 has a warm signal it should be dust. T11-T12 are lower than the simulated mean minus one standard deviation. Also T11T12<0.5. During night must be T11T12<0 and during day R06<35% to avoid classifying water clouds as dust.**
Warm dust test **(Dust or Aersol)**	T11T12 R0.6 T11Ts	**If the T11 indicates warm air T11TS>0, but the T11T12 has a cold signal it should be dust. T11-T12 are higher than the simulated mean plus one standard deviation. During day R06<35% to avoid classifying water clouds as dust.**

4.2 PRACTICAL CONSIDERATION

4.2.1 Quality control and validation

Table 4-9: Offsets (safety margins) for quality assessment applied to the CMa thresholding. Values for arctic tests in parenthesis when different.

Cloud test	R0.6	PseudoR0.6	R1.6	R3.7	QR1.6R0.6	QR0.9R0.6
Offset margin	2.0%	0.5%	2.0%	1.0%	0.06	0.10

Cloud test	**QR3.7R0.6**	**T11**	**T11T3.7**	**T11T12**	**T3.7T12**	**T11Tsur**
Offset margin	0.06	1.0K	0.30K (0.5K)	0.30K	0.30K (0.5K)	1.0K (0.5K)
Cloud test	**R0.6_text**	**T11_text**	**T3.7T12_ text**	**T37_text**	**SST**	**PSEUDO R0.6**
Offset margin	0.15	0.15	0.15	0.4	0.2	1.0

Some offsets differ between GAC settings and non-GAC settings, but the values in Table 4-9 are valid for both cases.

As outlined in detail in section 4.2.3 a set of processing flags are included in the CMa product. One of these flags may be used directly as a quality indicator of the pixel classification. The procedure on how this *low quality* flag is being set has been outlined in section 4.1.2.2:

- a pixel classified as cloudy is flagged *low quality* (cloud mask result is associated with low confidence) if no cloud detection test was really successful. A threshold test is considered really successful only if the difference between the threshold and the measurement is larger than a test dependent offset or safety margin. Table 4-9 lists the offsets applied.
- a pixel classified as cloud free is flagged *low quality* if the difference between a feature threshold and its observed (measured) value is lower than the offset associated with that feature (see Table 4-9) for at least one grouped cloud test.
- a pixel classified as snow/ice contaminated is flagged *low quality* if the difference between a feature threshold and its observed (measured) value is lower than the offset associated with that feature (Table 4-9) for the grouped snow/ice detection test or at least one grouped cloud test.

Table 4-10 Accuracy measures and verification scores for the CMa (version 2018) for 28 orbits of AVHRR-GAC data 2009 compared to CALIPSO version 4. Pixels with cloud free in 5km data and 1 to 4 cloudfree pixels in 1km data are not included.

Observed Accuracy --- AVHRR GAC Global data						
	Hitrate	POD-cloudy%	FAR-cloudy %	POD-clear %	FAR-clear %	N
PPS GAC (all) v2014 + patch	0.81	77.2	2.8	93.0	43.4	194671
PPS GAC (all) v2018	0.83	81.5	3.7	90.3	39.5	194671

Table 4-11 Accuracy measures and verification scores for the CMa dust flag (version 2018) for 2 days of MODIS data 14th May and 14th November 201. The PPS products were matched with CALIPSO aerosol

and cloud products. There where 29674 CALIPSO cloud free dust pixels. For the validation the same amount (29674) clear and cloudy pixels each where randomly selected.

Contingency table	PPS dust	PPS no dust	FAR (%)	POD (%)
Calipso Clear	3537	26137	29	33
Calipso Cloud	456	29218		
Calipso Dust	9690	19984		

In addition to the *low quality* flag there are further processing flags which indirectly provide information on the reliability or quality of the CMa output. For instance, it is well known that cloud detection is more difficult during night and twilight as compared to day, and this is also reflected in the cloudmask validation results (see validation report of pps v2018, Dybbroe et al. (2005b)). Likewise, the presence of low level temperature inversions over land and sunglint over sea, should raise a warning indicating lower reliability. The CMa processing flags include a flag for high risk of sunglint and a flag for presence of low level inversions, which may be used to sort out these pixels.

Despite a much improved cloud detection in sunglint as compared to SCANDIA for instance as reported in Dybbroe et al. (2005b) it still happens quite frequently that the CMa mistakes cloud free sea in sunglint for clouds. Results for CMa v2014 compared with CALIPSO data show that POD-cloudy is lower (-15%) when there are inversions present. However, POD-clear is better (2.5%) for inversion conditions. Data compared was 150 thousands matched locally received avhrr/viirs pixels over land during night/twilight and inversion/not inversion conditions.

Preliminary comparison between CMa v2018 and v2014 show that POD-cloudy is improved, while POD-clear is lower, see Table 4-10. See the validation report of PPS v2018 for more detailed results [RD.3]..

The CM SAF cloud dataset CLARA-A2, used PPS version 2014+patch to retrieve cloud products, for more information on the performance of the PPS CMa see Karlsson et al. (2016). The CM SAF cloud dataset CLARA-A1, used PPS version 2010 to retrieve cloud mask. CLARA-A1 has been validated against CLOUDSAT/CALIPSO (see Karlsson and Johansson 2013 and Karlsson et al. 2013). For the Metop validation against CLOUDAT/CALIPSO it is unfortunately only possible for arctic regions due to overlap constrains of orbits. See also Karlsson and Dybbroe, 2010 for validation of earlier version of PPS in the Arctic.

4.2.2 List of inputs

4.2.2.1 Satellite data

The algorithm has been developed specifically for the Advanced Very High Resolution Radiometer (AVHRR) 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.

Table 2-1 lists the set of channels of the AVHRR/3. All channels are mandatory for the CMa. 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 MODIS data, data from VIIRS on the Suomi-NPP and preparations have been done (as far as possible) for future JPSS satellites. See Table 4-12 for a complete set of channels. See section 2.1 for a description of channels for each of those instruments.

Table 4-12: The channels, which are used for the cloudmask classification. Mandatory and optional channels are specified. Either the 1.6µm channel or the 3.7µm channel has to be available. The 3.7µm channel is, however, mandatory for the aerosol flag output (see section 4.2.3).

λ(µm)	**0.6**	**0.9**	**1.3**	**1.6**	**3.7**	**8.5**	**11**	**12**
	mandatory	**mandatory**	**optional**	**At least one of them is mandatory**		**optional**	**mandatory**	**mandatory**

The instrument data being input to the CMa are calibrated, geo-located (navigated) and mapped to the specific geographical projection and area of interest or processed on the whole satellite swath. For AVHRR, the calibration, geo-location and remapping is done outside the CMa by the PPS common functions (AHAMAP) taking either AVHRR level 1b (AAPP definition) data as generated by AAPP, or archived level 1b NOAA LAC data. The latter is not a SAF requirement.

4.2.2.1.1 AVHRR channel 3A/3B commutation scheme

The AVHRR/3 instrument has 6 spectral channels available. However, due to a fundamental constraint in the AVHRR only data from five channels can be transmitted to ground at the same time. As a consequence a switching or selection of the channel 3A (1.6µm) and 3B (3.7µm) data stream has to be made. The commutation scheme currently in effect is so that all current NOAA satellites except NOAA-17, transmit only data from channel 3B. Only on NOAA-17 an automatic switching is performed so that in daytime channel 3A is provided and during night-time the channel 3B is the active. The switching is performed when the satellite passes a day-night terminator.

NB! It is worth mentioning that the switching will sometimes result in situations with only two useful channels (the IR channels 4 (11µm) and 5(12µm)) available, in contrast to three (channels 3B, 4, and 5) when no switching is performed. This is when channel 3A is active and part of the scan the sun is below the horizon.

For the VIIRS instrument channel M10 and M12 (respectively channel I3 and I4 in the higher spatial resolution), corresponding to the AVHRR channels 3A and 3B, are usually both available at the same time.

4.2.2.1.2 Filtered AVHRR/2 data

For historical satellites (noaa7 - noaa14), using the AVHRR/2 sensor, the data in the 3.7 µm channel might be very noisy. Therefor there is a configurable option of filtering those data before using them in PPS CloudMask, CloudType and CPP. The filtering is only available for AVHRR/2 data in GAC-format.

How to technical apply it, see [RD.2.]. The filtering algorithm is described in ANNEX B.

4.2.2.2 Sun and satellite angles

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 as well as the sun and satellite azimuth angles. 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

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

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 $\theta_{sun} \le 80°$, night when $\theta_{sun} \ge 95°$, and twilight for values of θ_{sun} in between.

The sun-satellite angles are mandatory for the CMa. They are derived from the AAPP level 1b file (or the corresponding NOAA LAC data) by using (rather extensive and expensive) interpolation and extrapolation (see [RD.2.]). For VIIRS angles are derived from the str data file, prepared by CSPP. For MODIS the angles are derived from the level 1b data file.

4.2.2.3 Land cover characterisation and elevation

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 of each scene by the PPS software to produce land-use, elevation, roughness, and fraction of land maps. See [RD.2.] for a description of how to generate physiography data for a scene. The physiography data are mandatory for the CMa.

4.2.2.4 Surface Infrared emissivity data

For calculating the threshold tables varying land surface infrared emissivity data has been taken into account. The global land surface emissivity data used is the standard MODIS product, MYD11C3 (Version 005)..

In the PPS software package is included a number of emissivity files, which contains a climatology of the described emissivity data from ten years of data (2003-2012), and mapped to tiles.

4.2.2.5 Sea ice data

Sea ice data can be provided optional to the PPS cloud masking algorithm to define the presence of sea ice. We use the ice concentration map from the OSISAF to define the environmental regime 'sea ice'. The sea ice schemes are used in case the ice concentration is higher then 70 %. If no ice data are provided, the NWP surface temperature is checked over open ocean. If this temperature is significant below 273 K , the sea ice cloud masking schemes are switched on.

Either operational or re-processed ice concentration map from OSISAF can be used.

4.2.2.6 NWP data

The CMa algorithm needs a reliable estimate of the column integrated water vapour content, the surface (skin) temperature, and the temperature at the 950 hPa level, in full (map-projected) pixel resolution. The total water vapour column and surface temperature are input to the derivation of the dynamic thresholds, and the temperatures at the surface and 950 hPa are used to identify low level temperature inversions. The CMa can also use the temperatures as 850hPa, 700hPa, 500hPa and Tropopause temperature if available.

These data are extracted from NWP model output. For Nowcasting purposes time is critical and therefore the PPS system will attempt to derive the thresholds and mapped NWP parameters prior to the satellite overpass. The system is configured by default to look for both analysis fields and short range forecasts with lead times between 6 and 24 hours from the configured NWP model. The lower limit of 6 hours is in order to avoid possible problems related to model spin-up. When possible (eg. for re-processing) PPS can be configured to use a valid (close in time to the satellite overpass) NWP analysis.

The PPS will extract raw NWP data in Grib format and generate the required parameters to the swath. There is, however, a minimum requirement for the content of the NWP Grib file in order for PPS to generate the parameters mentioned above. See [RD.2.] for these minimum requirements.

4.2.2.7 Parameter files and algorithm configuration files

The CMa 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_CLOUDMASK (default True): Whether the cloud mask main output is wanted.
- GENERATE_PROCESSING_FLAG (default True): Whether the processing flags are wanted.
- GENERATE_TEST_FLAG (default False): Whether the threshold test flags are wanted.
- GENERATE_AEROSOL_FLAG (default True): Whether the aerosol flags are wanted.
- GENERATE_DUST_FLAG (default False): Whether the aerosol flags are wanted.

The CMa uses a number of static thresholds and threshold offsets, defined in the file threshold_offsets.cfg, with threshold_offsets_gac.cfg as an alternative. Altering these parameters which have been determined during algorithm tuning and validation, will strongly affect the quality of the CMa output. It is **not** recommended to modify these values. The file threshold_offsets.cfg should be used for running not-GAC data, and the file threshold_offsets_gac.cfg should be used for running GAC data.

4.2.3 Description of output

The content of the CMa consist of up to thirteen datasets, as described below.

Main Output

Table 4-13: Cloud Mask

Number of the Class	Description/ Comments
0	Cloud-Free
1	Cloudy
Fill Value	No data/Undefined (separability problem)

Table 4-14: Cloud Mask extended

Number of the Class	Description/ Comments
0	Cloud-Free
1	Cloudy
2	Cloud contaminated
3	Snow/Ice
Fill Value	No data/Undefined (separability problem)

Threshold test flags

Six 16 bit-lists to describe which test was successful: If a test is successful the test flags identifying the actual tests are set (the corresponding bit is activated). Thus all cloudy pixels will contain information on which test, or tests were successful, both the decisive ones and any possible earlier tests where one or more of the features tested were close to its corresponding thresholds. Also a few of the cloudfree pixels will have information of which tests were successful.

Table 4-15 Threshold test bits

Bit	Testlist 0	Testlist 1	Testlist 2	Testlist 3	Testlist 4	Testlist 5
0	coldCloudTest	coldCloudsInSunglint	cirrusCloudOverWaterTest	reflectingCloudTestSea	SpatialBrightCloudTest_2014	snowSunglintTest
1	coldCloudTestDay_v2014	coldCloudsInSunglintR16	cirrusOverSnowice	reflectingCloudTestSea_v2014	SpatialCloudTestLand	snowSunglintTestR16
2	coldCloudTest_v2014	sunglintTestR16	cirrusOverSnowiceNight	vislandCloudTest	arcticIceCrackTest	snowTestForClearPixels
3	coldHighCloudTest850	arcticcoldwatercloudTest	cirrusOverSnowiceR16	brightCloudOverWaterTest	coldClearArcticAreaTest	snowTestForClearPixelsR16
4	coldVeryHighCloudTest700	arcticthinCirrusPrimaryTest	cirrusOverWatercloudTestOverColdGround_v2014	brightCloudTest	aerosolTests	snowTwilightTest
5	coldCloudTest850Nigh	arcticthinCirrusSecondaryTest	HighcloudTestt85t11	brightCloudTestMediumTemperatureR16T37	aerosolTestsLandDay	snowTwilightTestR16
6	sstDaytimeTest	arcticthinwaterCloudTest	brightCloudTestT13	brightCloudTestNoSunglintR16Sea	SaltLakeTest	newWaterBodyTest
7	sstNighttimeTest	arcticwarmCirrusSecondaryTest	watercloudOverWaterTest	brightCloudTestNoSunglintR16T11Ts	ClearDesertTest	snowTest_v2018
8	sstTwilighttimeTest	arcticwarmCloudTest	watercloudTest	brightCloudTestR16	DriedOutLakesAndRiversTest	iceTest_v2018
9	warmCloudTestTrop	arcticwarmCloudTestSalomon	watercloudTestOverColdGround_v2014	brightCloudTestR16_NoT11Ts	snowLandTest	thinCirrusPrimaryT37TSNightTest
10	coldBrightCloudTest	arcticwarmCloudTest_v2014	coldWatercloudTest	brightCloudTestSea	snowLandTestR16	thinCirrusPrimaryTestT11T12Text

Bit	Testlist 0	Testlist 1	Testlist 2	Testlist 3	Testlist 4	Testlist 5
11	coldBrightCloudTest37	arcticwatercloudTest	coldWatercloudTestDay	brightCloudTest_v2014	snowMountainTest	thinCirrusSecondaryTestT11T12Text
12	coldBrightCloudTestDay_v2014	thinCirrusPrimaryTest	WatercloudTestt85t11land	textureIrvisTest	snowMountainTestR16	dustTests
13	brightCloudsInSunglint_2014	thinCirrusSecondaryTest	WatercloudTestt85t11sea	textureNightTest	snowSeaTest	brightSnowTest37_v2018
14	cloudsInSunglint	thinColdCirrusTest	pseudo06CloudTestR16	textureT11Test	snowSeaTestR16	textureVisR16_Sea
15	cloudsInSunglintR16	coldThinCirrusPrimaryTest	reflectingCloudTest	textureVisTest	snowSeaTestR16_v2014	watercloudTestDesertNigh

Status flags

Table 4-16: Status flag

Bit number	Description/Comment
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
4	No method for aerosol
5	Suspected heavy aerosol

Note: Bit flag 'No method for aerosols' is set either if the dataset aerosols is not created at all, or if the dataset is created: the bit is set if no aerosol retrieval could be done in the individual pixel (eg. missing input data, or a cloudy pixel). While bit flag 'Suspected heavy aerosol' is set independently of the dataset aerosols; this bit is set if the aerosols are suspected to be so heavy that they disturb the cloud mask retrieval.

Condition flags

Table 4-17 Conditions flag

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
4 and 5	Defines whether it is land or sea: 0: N/A 1: Land 2: Sea 3: Coast This division in land/sea/coast is defined by the environmental variables SM_COASTALZONE_LIMIT (0 on default) and SM_LANDSEA_FRACTION_MAX (255 on default). See [RD.2.] for details.
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

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

Quality flags

Table 4-18 Quality flag

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

Aerosol flags

There are two aerosol flags: One for all kinds of aerosol: dust, smoke, volcanic ash and other heavy aerosols. The other one for dust. Thus, pixels that are flagged as dust in the dust flag, will also be flagged as aerosol in the aerosol flag.

Table 4-19: Aerosol flag cma_aerosol

Value	Flag name	Description/Comment
0	No aerosol	No detected contamination by aerosols.

Value	Flag name	Description/Comment
1	Aerosol	Aerosol detected. Can be of type dust, smoke, other heavy aerosol or volcanic ash.
255	Nodata	

Table 4-20: Dust flag cma_dust

Value	Flag name	Description/Comment
0	No dust	No detected contamination by dust.
1	Dust	Contamination by dust.
255	Nodata	

4.2.4 Visualisation

It is important to note that the PPS cloud and precipitation products first of all provide a digital analysis of the cloud and precipitation field, to be input to automatic mesoscale analysis or nowcasting schemes. Images may be derived and displayed to the forecaster but the products are not just images.

The CMa in particular is not the most obvious choice for image display at the forecaster's desk. The CMa rather is a base product being input to other SAF products like the CT, which is more suitable for image display. But if desired the CMa may be visualised, either directly using a hdf-viewer (works fine for netCDF-files as well), or by using some dedicated image tool. Or looking at the png-images created by PPS; it comes in three versions: binary cloud mask, extended cloud mask and extended cloud mask with low-quality pixels marked.

Figure 5 shows an example using a PPS products viewer (Image Viewer) developed at SMHI for algorithm development purposes. The SMHI viewer allows the synchronous display of both an instrument RGB and the cloud product. Pixel values (brightness temperature, reflectance, product value, flags etc.) may be shown under the mouse pointer.

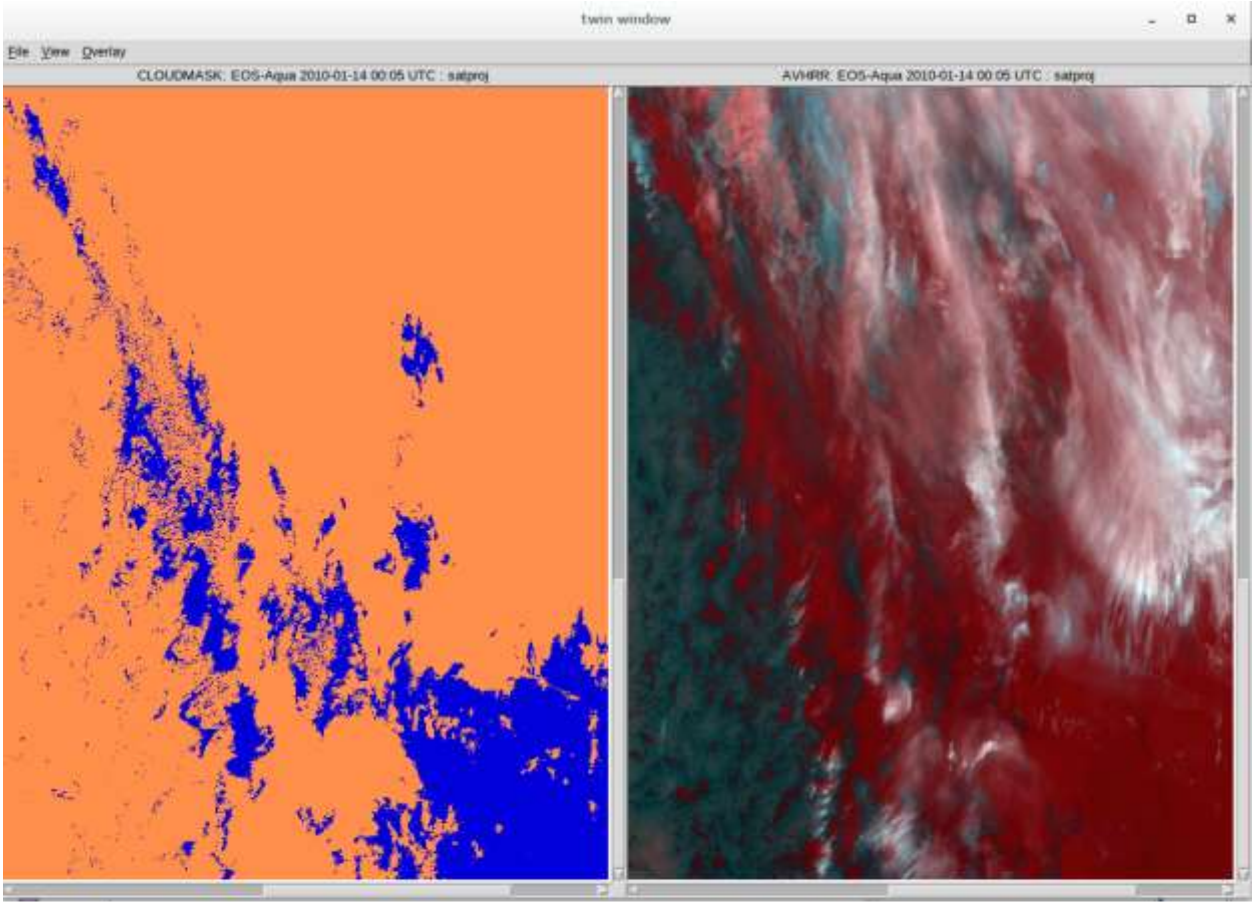

Figure 5: Example of cloud mask image display using the dedicated PPS image viewer developed at SMHI. To the right a close up RGB image using 11µm, 12µm and 3.7µm channels is displayed and to the left the corresponding cloud mask. Instrument MODIS on sattelite EOS-Aqua 2010-01-14 00:05UTC.

The aerosol and dust flag products can be visualized either via a tool like hdf-viewer, or PPS can create png-images. There will be up to three png-images (depending on data available): the aerosol flag and the dust flag separately, and also an image with the aerosol displayed together with the binary cloud mask. By default the aerosols are shown in brownish colours, but it can be configured to show them in an intensive green colour instead.

PPS image viewer does not show any aerosol images, it just shows it as pixel information.

ANNEX A. Summary SST algorithm descriptions and formalism

The algorithms below origins from the OSISAF team at Lannion, Pierre LeBorgne, et al., and is collected from various OSISAF documents including the official manual, and put together here for all satellites and using one and the same notation:

A.1.1 Formalism:

NLC = Non-Linear Complete algorithm

NL = Non-Linear algorithm

T_{CLI} = climatologic SST, NWP t-skin for the climate

$S_\theta = 1/\cos(\theta) - 1$

Daytime: NLC

$$SST = (a + b\,S_\theta)\ T_{11} + (c + d\,S_\theta + eT_{CLI})\ (T_{11} - T_{12}) + f + g\,S_\theta$$

Daytime: NL

$$SST = a\,T_{11} + (b\,S_\theta + cT_{CLI})\ (T_{11} - T_{12}) + d + e\,S_\theta + corr$$

Nighttime: T37_1

$$SST = (a + b\,S_\theta)\ T_{37} + (c + d\,S_\theta)\ (T_{11} - T_{12}) + e + f\,S_\theta + corr$$

The daytime NLC algorithm is slightly more accurate compared to the NL (personal communication Pierre LeBorgne, October 2013).

NB! **All temperatures expressed in Celcius**

A.1.2 Coefficients:

A.1.2.1 Metop-B

Table 4-21 Metop-B SST algorithm coefficients

	a	b	c	d	e	f	g	corr
NLC	1.00400	0.00495	0.37766	0.59561	0.05609	0.61760	0.96388	-
NL	1.00244	0.68606	0.06692	0.85319	0.89201	-	-	0.0
T37_1	1.01432	0.02511	0.698846	0.35973	1.05387	0.99483	-	0.0

A.1.2.2 S-NPP

In Table 4-22 is described the coefficients of the non linear split window (NLC) and triple window (T37_1) algorithms for NPP/VIIRS, with all temperatures expressed in Celsius.

Table 4-22 S-NPP SST algorithm coefficients

	a	b	c	d	e	f	g	corr
NLC	1.00055	0.00852	1.29073	0.0401	0.77930	1.05141	0.81520	-
T37_1	1.01612	0.01709	0.85154	0.36969	1.13960	0.82285	-	0.0

A.1.2.3 Metop-A

Table 4-23 Metop-A SST algorithm coefficients

	a	b	c	d	e	f	corr
NL	0.99052	0.06641	1.16321	1.26512	0.16400	-	0.23
T37_1	1.01867	0.02109	0.68858	0.33056	1.02351	1.27303	0.13

A.1.2.4 NOAA-18

Table 4-24 NOAA-18 SST algorithm coefficients

	a	b	c	d	e	f	corr
NL	0.97588	0.05905	0.95641	1.49882	0.28288	-	0.0
T37_1	1.01477	0.01467	0.59010	0.30312	1.24160	1.2451 0	0.0

A.1.2.5 NOAA-19

Table 4-25 NOAA-19 SST algorithm coefficients

	a	b	c	d	e	f	corr
NL	0.96832	0.05513	0.81105	1.5673	0.302	-	0.0
T37_1	1.01665	0.00851	0.54315	0.32588	1.01787	1.42468	0.0

A.1.2.6 NOAA-17 and older NOAA satellites

For NOAA-17 and older NOAA satellite we have no OSISAF algorithm coefficients. Therefore we use the coefficients for NOAA-18 and apply the SST based tests with larger and more cautious threshold offsets.

ANNEX B. AVHRR/2 Filtering

The AVHRR/2 filtering is not applied automatically for AVHRR/2 (noaa7-noaa14) data, but has to be configured for and an extra script has to be run as well.

Goal: The goal is to filter noisy channel 3.7 AVHRR data with a low pass filter to improve the PPS products for these scenes. It is important to not destroy the high channel 3.7 variations in scenes that are OK. Also in noisy scenes: areas without noise should preferably preserve cloud edges, small clouds and small clear objects as good as possible.

B.1 Noise Level

PPS use noise levels from Jon Mittaz to estimate the need for filtering and how to filter. In the configure file for filtering (pps_configure_37_filtering.py), for each satellite the maximum error for each day is available. What is actually found in the file is std_error_of_bb_std_cnts/10, where std_error_of_bb_std_cnts is the standard deviation of an orbits worth of blackbody views, where the mean has been subtracted for each scan line (average of 10 values).

These values vary between 0.05 and 1.5. Very few days (around 200 out of 8000) have higher values -up to 5.0. Most of these are at the end of life for noaa14. Some days were missing in the data. If the day is missing closest day within 30 days is used. If still no value is found, default value 0.0 will be used (no filtering).

There is a configurable limit (**NOISE_LIMIT**=0.1) which sets the lowest noise level that will still be filtered.

B.2 More filtering for nosier data, filter size:

The radius of the filter used is a function of the noise level. At noise level=0.1 the radius of the filter will be **MIN_RADIUS**. At high noise levels, above>1.25, the radius **MAX_RADIUS** will be used. Default values are **MIN_RADIUS = 2** and **MAX_RADIUS =7**. For intermediate noise levels the radius is interpolated linearly between the two. Parameters **MIN_RADIUS** and **MAX_RADIUS** are set in pps_configure_37_filtering.py.

B.3 Different filter types

During prototyping we have tested: mean, median and wiener filters. Wiener filters for brightness temperatures or for radiances. I recommend median filter as it process fast: about 10s per scene compared to wiener filter 30s. Also it handles no-data in a nice way; it never produces values between the real data and the no-data value. And also it preserves edges of clouds quite well, compared to for example mean filters.

B.4 Rescue some filtered values

In all scenes also the areas without noise will be affected by the filtering. In the bad scenes this is OK but in low level noise scenes this is really a problem. In these scenes the filtering destroys more than it fixes. The problem is largest during day-time. Example of problems: small clouds with brightness temperatures around 310K will be set to sea-surface temperature of around 290K. Or the other way around, sea-surface near clouds with temperature around 293K can be set to 310K (the temperature of the cloud). To improve the filtering these types of pixels are reset to original data. In large cloud-free or large cloudy areas there is no problem of course.

To find the pixels to restore we use the noise-level from Jon Mittaz to calculate an individual maximum temperature difference ΔT for each pixel. The first step is to multiply the noise level with a factor (**NOISE_MAX_AT_270K_FACTOR**=15 set in pps_configure_37_filtering.py). The value received will be used as maximum temperature difference ΔT at temperature 270K + ΔT. This ΔT is then transformed to maximum radiation difference. The delta radiation is used to calculate a vector of maximum ΔT for all temperatures. Pixels where the filtering has changed the brightness temperature more than this limit will get back their original value.

B.4.1.1 Example ΔT limits for noise level 0.11:

Limit = 31.7 K, for temperature = 200 K.
Limit = 15.8 K, for temperature = 220 K.
Limit = 6.4 K, for temperature = 240 K.
Limit = 2.5 K, for temperature = 260 K.
Limit = 1.0 K, for temperature = 280 K.
Limit = 0.5 K, for temperature = 300 K.
Limit = 0.2 K, for temperature = 320 K.
Limit = 0.1 K, for temperature = 340 K.

B.4.1.2 Example ΔT limits for noise level 0.23:

Limit = 45.2 K, for temperature = 200 K.
Limit = 27.2 K, for temperature = 220 K.
Limit = 13.6 K, for temperature = 240 K.
Limit = 6.0 K, for temperature = 260 K.
Limit = 2.6 K, for temperature = 280 K.
Limit = 1.3 K, for temperature = 300 K.
Limit = 0.6 K, for temperature = 320 K.
Limit = 0.4 K, for temperature = 340 K.

B.4.1.3 Example ΔT limits for noise level 1.25:

Limit = 93.6 K, for temperature = 200 K.
Limit = 73.9 K, for temperature = 220 K.
Limit = 54.8 K, for temperature = 240 K.
Limit = 37.5 K, for temperature = 260 K.
Limit = 23.5 K, for temperature = 280 K.
Limit = 13.8 K, for temperature = 300 K.
Limit = 8.0 K, for temperature = 320 K.
Limit = 4.7 K, for temperature = 340 K.

B.4.2 What temperature to use?

What temperature for the pixel should be used to get the ΔT limit for that pixel? What we need is the actual 3.7 micron brightness temperature. But if we had that we would not be doing this at all! Several possibilities can be suggested: for example brightness temperature of the 11, original 3.7 or new 3.7 micron channels. Brightness temperature of 11micron is an okay approximation for night, so for night/twilight (reflectance in channel 0.6 micron less than1%) this is used. For day, channel 3.7 can have much higher values especially for cloudy pixels. For day the approximation with the 11 micron brightness temperature is not so good. For day the max(original 3.7, new 3.7) is used as the temperature. It looks promising in tested scenes.

B.4.2.1 Examples of filtering

One pixel, day, noise level = 0.1, original temperature = 320K, new temperature 293K. The difference 27K is more then the allowed change of 0.2K. And the original temperature of 320K will be used.

One pixel, day, noise level = 1.25, original temperature = 320K, new temperature 293K. The difference 27K is more then the allowed change of 8K. And the original temperature of 320K will be used.

One pixel, day, noise level = 1.25, original temperature = 300K, new temperature 293K. The difference 7K is less then the allowed change of 13.8K. And the new temperature of 300K will be used.

One pixel, day, noise level = 1.25, original temperature = 260K, new temperature 240K. The difference 20K is less then the allowed change of 37.5K. And the new temperature of 240K will be used.

B.4.3 Extra condition for cold pixels

In order for pixels to get back their original values, we also demand that both the original and the new values are not no-data.

No pixels are rescued if both the new and the original data are below **COLDEST_PIXELS_TO_RESCUE**=263K (set in pps_configure_37_filtering.py). This is because the noise is large in very cold areas, but our estimate of how large might be wrong. So it is best to keep the filtering in cold areas.

ANNEX C. Calculation of cloud free thresholds

For deriving the cloud free thresholds we use a dataset with 10755 profiles of numerical weather prediction data. For PPS 2018 755 extra profiles were added with warmer surface temperatures. For each profile we used RTTOV12 to simulate the brightness temperatures for different surface emissivities and satellite zenith angles. Threshold tables are produced for land and sea separately.

Over land the surface emissivity of 0.98 is used for preparation of tables. For each satellite zenith angle in Table 26 thresholds are calculated for surface temperatures in step of 5K and ciwv in steps of 0.25 unit. To avoid discontinuities some extra profiles are included in the calculations, i.e when calculating the threshold to be valid for surface temperature at 275K and 2.0 in water vapour all profiles with surface temperature between $275 \pm 1.5 \cdot 5$K and water vapour between $2.0 \pm 1.5 \cdot 0.25$ unit is used. When surface temperature is warmer than 315K all profiles with temperatures down to 315K are always included. The temperature differences are calculated for the selected profiles and the 90 percentile is stored as the upper threshold and the 10% percentile is stored as the lower threshold.

The thresholds over sea are calculated as for land except that the emissivity of 0.98 not used. Over sea water emissivites for the considered satellite zenith angle is used for water (surface temperatures warmer than 275K). For surface temperatures below 265K snow emissivities are used. For surface temperatures between 265 and 275K temperature profiles are included using both water and snow emissivities.

For threshold table entries far from all profile data default values are used (1.0K for upper thresholds and -1.0 K for lower thresholds and -5.0 for lower threshold for the T11Ts feature). These will only be used if the NWP-data for a pixel is far from all the profiles in the database. This is not likely to ever happen. For the upper threshold for the feature T11T37 a minimum value of 0.2 is used.

Thresholds overland are linearly adjusted using the emissivity from the climatological emissivity database included in with PPS. The linear coefficients are calculated using the same simulation data with the surface emissivities of 1.0 and 0.8. Where emissivity data is lacking the default value 1.0 is used if it is not colder than 273.15. It it is colder than 273.15K the value 0.985 is used for channel T11, 0.975 for channel T12 and 0.96 for channel T3.7 and 1.0 is used for other channels. For the T11T37 threshold the adjustment coefficient are added to the upper threshold and removed from the lower threshold to create a wider threshold over desert, reflecting the uncertainties present under those conditions.

Table 26 Satellite zenith angles used for threshold preparation

Satellite Zenith angles	0.00	36.87	48.19	55.15	60.00	63.61	66.42	68.68	70.53

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

TBD/TBC	Section	Resp.	Comment
TBD01	4.1.2.6	SMHI	Decide what kind of thresholds for t37t12 to use. Thresholds from v2014 patch are kept. Closed for v2018!
TBD02	2.1	SMHI	MERSI-2 capabilities will be provided later as a patch to v2018, if and when, necessary info and data are available.