The EUMETSAT Network of Satellite Application Facilities

NWC SAF

Support to Nowcasting and Very Short Range Forecasting

Algorithm Theoretical Basis Document for the Cloud Product Processors of the NWC/GEO

NWC/CDOP2/GEO/MFL/SCI/ATBD/Cloud, Issue 1, Rev. 1

15 October 2016

Applicable to

GEO-CMA-v4.0	*(NWC-002)*
GEO-CT-v3.0	*(NWC-006)*
GEO-CTTH-v3.0	*(NWC-010)*
GEO-CMIC-v1.0	*(NWC-013)*

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REPORT SIGNATURE TABLE

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DOCUMENT CHANGE RECORD

Version	Date	Pages	Changes
1.0d	11 June 2013	113	Draft version for PDCR (content derived from "Algorithm Theoretical Basis Document for "Cloud Products" (CMa-PGE01 v3.2, CT-PGE02 v2.2 & CTTH-PGE03 v2.2)"
1.0	29 November 2013	113	Inclusion of PDCR outcome.
1.1	15 October 2016	118	Update of CMa description (monitoring biais for RTTOV use, correction of some insconsistencies) Update of CMIC algorithm description (number of cloud mode) Update of product illustration Update of the list of configurable parameters Update of validation results

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1 INTRODUCTION

The Eumetsat "Satellite Application Facilities" (SAF) are dedicated centres of excellence for processing satellite data, and form an integral part of the distributed EUMETSAT Application Ground Segment (http://www.eumetsat.int). This documentation is provided by the SAF on Support to Nowcasting and Very Short Range Forecasting, NWC SAF. The main objective of NWC SAF 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 NWC SAF webpage, http://www.nwcsaf.org. This document is applicable to the NWC SAF processing package for geostationary meteorological satellites, NWC/GEO.

1.1 SCOPE OF THE DOCUMENT

This document is the Algorithm Theoretical Basis Document for the Cloud Products components PGE01 (GEO-CMA, Cloud Mask), PGE02 (GEO-CT, Cloud Type), PGE03 (GEO-CTTH, Cloud Top Temperature and Height) and PGE15 (GEO-CMIC, Cloud Microphysics) of the NWC/GEO software package.

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

1.2 SOFTWARE VERSION IDENTIFICATION

This document describes the algorithms implemented in the release 2016 of the NWC/GEO software package (GEO-CMA-v4.0 (Product Id NWC-002), GEO-CT-v3.0 (Product Id NWC-006), GEO-CTTH-v3.0 (Product Id NWC-010) and GEO-CMIC-v1.0 (Product Id NWC-013)).

1.3 IMPROVEMENT FROM PREVIOUS VERSION

Since 2013 release, the following improvements have been implemented:

- Technical improvements: interface to updated NWCLIB, new output format, technical adaptation to process other meteorological geostationary satellites than MSG
- Scientific improvements (see details in [RD.4.]):
    - GEO-CMA: use of RTTOV on line to improve some thresholds, reduction of fire/cloud confusion
    - GEO-CT: none
    - GEO-CTTH: none
    - GEO-CMIC: new product based on cloud phase and cloud optical thickness and effective particle size respectively output and internally computed in CT from 2013 release. The main improvement since 2013 release is the availability of new outputs (cloud optical thickness, effective particle size, liquid and ice water path) and the use by the retrieval algorithm of cloud reflectance simulations based on DISORT instead RTMOM.

1.4 DEFINITIONS, ACRONYMS AND ABBREVIATIONS

6S	Second Simulation of Satellite Signal in the Solar Spectrum
BRDF	Bi-directional Reflectance Functions
CMA	Cloud Mask
CMIC	Cloud Microphysics
CMS	Centre de Meteorologie Spatiales (Météo-France, satellite reception centre in Lannion)
CTTH	Cloud Top Temperature and Height
CT	Cloud Type
DISORT	Discrete Ordinates Radiative Transfer Program
ECMWF	European Centre for Medium range Weather Forecast
EUMETSAT	European Meteorological Satellite Agency
FOV	Field Of View
GEO	Meteorological Geostationary Satellite
HDF	Hierarchical data Format
HRIT	High Rate Information Transmission
IR	Infrared
K	Kelvin
LUT	Look-Up Table
MODIS	Moderate-Resolution Imaging Spectroradiometer
MSG	Meteosat Second Generation
NIR	Near Infra-Red
NOAA	National Oceanic and Atmospheric Administration
NWC SAF	SAF to support NoWCasting and VSRF
NWCLIB	NWC/GEO common library
NWP	Numerical Weather Prediction
OSI SAF	Ocean and Sea Ice SAF
OSTIA	Operational Sea Surface Temperature and Sea Ice Analysis
PGE	Product Generation Element
$R0.6_{\mu m}$	0.6 visible reflectance
RTMOM	Radiative Transfer based on Matrix Operator Method
RTTOV	Rapid Transmissions for TOVs
SAF	Satellite Application Facility
SEVIRI	Spinning Enhanced Visible & Infrared Imager
SST	Sea Surface Temperature
SUM	Software User Manual

SW Software

T11µm 11 micrometer infrared brightness temperature

TIGR Tovs Initial Guess Retrieval

TOA Top Of Atmosphere

VIS Visible

1.5 REFERENCES

1.5.1 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 the NWC SAF Helpdesk web: http://www.nwcsaf.org

Ref	Title	Code	Vers	Date
[AD.1.]	Proposal for the Second Continuous Development and operation Phase (CDOP) march 2012 – February 2017	NWC/CDOP2/MGT/AEMET/PRO	1.0	15/03/2011
[AD.2.]	NWCSAF Project Plan	NWC/CDOP2/SAF/AEMET/MGT/PP	1.9	15/10/2016
[AD.3.]	Configuration Management Plan for the NWCSAF	NWC/CDOP2/SAF/AEMET/MGT/CMP	1.4	15/10/2016
[AD.4.]	NWCSAF Product Requirement Document	NWC/CDOP2/SAF/AEMET/MGT/PRD	1.9	31/08/2016
[AD.5.]	System and Components Requirements Document for the NWC/GEO	SAF/NWC/CDOP2/AEMET/SW/SCRD	1.2	15/10/2016
[AD.6.]	The Nowcasting SAF glossary	NWC/CDOP2/SAF/AEMET/MGT/GLO	2.0	18/02/2014

Table 1: List of Applicable Documents

1.5.2 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 the NWC SAF Helpdesk web: http://www.nwcsaf.org.

Ref	Title	Code	Vers	Date
[RD.1.]	Scientific and Validation report for the cloud products processors of the NWC/GEO	/NWC/CDOP2/GEO/MFL/SCI/VR/Cloud	1.0	15/10/2016
[RD.2.]	Data Output Format for the NWC/GEO	NWC/CDOP2/GEO/AEMET/SW/DOF	1.1	15/10/2016
[RD.3.]	User Manual for the NWC/GEO application: software part	NWC/CDOP2/GEO/AEMET/SW/UM	1.0d	15/10/2016
[RD.4.]	Scientific report on improving the cloud product processors of the NWC/GEO	NWC/CDOP2/GEO/MFL/SCI/RP/03	1.0	15/10/2016

Table 2: List of Referenced Documents

2 DESCRIPTION OF CLOUD MASK (GEO-CMA) PRODUCT

2.1 CLOUD MASK (CMA) OVERVIEW

The cloud mask (CMA), developed within the NWC SAF context, aims to support nowcasting applications, and additionally the remote-sensing of continental and oceanic surfaces. The CMA allows identifying cloud free areas where other products (total or layer precipitable water, instability indices, land or sea surface temperatures, snow/ice cover delineation) may be computed. It also allows identifying cloudy areas where other products (cloud types, cloud top temperature/height, cloud microphysic, precipitation) may be derived.

The central aim of the CMA is therefore to delineate all cloud-free pixels in a satellite scene with a high confidence. In addition, the product provides information on the presence of snow/sea ice, dust clouds, volcanic plumes.

CMA cloud detection is performed by a multi-spectral threshold method: the image is compared with thresholds which delimit brightness temperatures/reflectance of cloud free pixels from those of pixels containing clouds or snow/sea ice. The critical point is the thresholds tuning which are computed from Look-Up Table and (optionally) from RTTOV applied on-line to NWP vertical profiles. This process is complemented by an analysis of the temporal variation (on a short period of time (around 15 minutes)) of some spectral combination of channels (to detect rapidly moving clouds), a specific treatment combining temporal coherency analysis and region growing technique (to improve the detection of low clouds) and a temporal analysis of visible channels at high horizontal resolution (HRV for MSG) to detect sub-pixel low clouds.

2.2 CLOUD MASK (CMA) ALGORITHM DESCRIPTION

2.2.1 Theoretical description

2.2.1.1 Physics of the problem

Brightness temperatures and reflectances of a cloud free area depend on its type, on the atmospheric conditions, on the sun and satellite respective positions. Moreover, they remain rather constant in time (at least on short periods of time). They are more or less modified by clouds, aerosols or snow/sea ice. Indeed, cloudy pixels can be often identified, because they appear colder (at 10.8 micron) and/or brighter (at 0.6 or 0.8 micron) than cloud free areas. A fine analysis of their respective spectral behaviour is nevertheless needed to perform full cloud detection. For example, low clouds identification at nighttime relies on their low emissivities at 3.8 micron, whereas thin cirrus clouds can be identified, due to their different emissivities at 10.8 micron and 12.0 micron. Cloud free areas covered by snow or ice are identified at daytime with their very low reflectivity at 1.6 or 3.8 micron and high reflectivity at 0.6 micron, whereas oceanic cloud free areas affected by sun glint are identified with their very high reflectivity at 3.8 micron...

The CMA identifies pixels that are contaminated by either clouds, dust, volcanic ash clouds, snow/sea ice. The problem to be solved is to automatically predict, with sufficient accuracy, brightness temperatures and reflectance of cloud free areas, so that any discrepancy between the measured and predicted values can be used to detect contaminated pixels. An additional process is to analyse the variation in time of channel features in order to identify moving clouds.

2.2.1.2 Mathematical Description of the algorithm

2.2.1.2.1 Algorithm outline

The algorithm has been designed to be applicable to imagers on board meteorological geostationary satellites. The imagers may have different set of channels possibly at different horizontal resolutions. The lowest native resolution of the radiometer (3km at nadir for MSG/SEVIRI), which is for most imagers on board present and future meteorological geostationary satellites the horizontal resolution of all IR channels and some solar channels, will be chosen as the default horizontal resolution. Solar channels may be available at higher horizontal resolution (1km at nadir for HRV). In this release, the process is applied to all useful channels at the default horizontal resolution (high resolution channels being averaged at this resolution), the high resolution channels being additionally used at their native resolution to detect sub-pixels clouds inside pixels at default horizontal resolution. We use generic labels in this document (for example, T3.8µm, T8.7µm, T10.8µm, T12.0µm, R0.6µm, R0.8µm and R1.6µm), the exact central wavelengths of the corresponding channels depending on the satellite. The list of available labels depends on the satellite; the list of mandatory channels is listed in 2.2.2.3 .

A first process allows the identification of clouds or snow/ice. It consists in the following steps which are applied to all pixels at default horizontal resolution:

- a first set of multispectral tests with thresholds computed from Look-Up Tables (LUT) (detailed in 2.2.1.2.2) allows detecting most of the pixels containing cloud or snow,
- (optional step) a second limited set of multispectral tests with thresholds computed from RTTOV applied on-line to NWP vertical profiles (detailed in 2.2.1.2.3) allows by a more accurate threshold computation a detection of low or thin high clouds that remained undetected when using LUTs
- an analysis of the temporal variation (on a short period of time around 15 minutes) of some spectral combination of channels allows detecting rapidly moving clouds (see 2.2.1.2.4),
- a specific treatment combining temporal coherency analysis and region growing technique allows the improvement of low clouds detection in twilight conditions (see 2.2.1.2.5),
- (optional step) an analysis of solar channels at high spatial resolution (HRV for MSG) allows detecting sub-pixel clouds inside pixel at default horizontal resolution (see 2.2.1.2.6),
- a spatial filtering is finally applied to cold areas, cloud edges (over ocean), isolated cloud pixel (land) and snow-area edges (see 2.2.1.2.7)

Additional processes (detailed in 2.2.1.2.8 and 2.2.1.2.9) allowing the identification of dust clouds or volcanic ash clouds, are applied to all pixels (even already classified as cloud-free or contaminated by clouds). The result is stored in separate flags (dust cloud or volcanic ash cloud flags).

2.2.1.2.2 Description of cloud detection tests using Look-Up Table

The first series of tests allows the identification of pixels contaminated by clouds or snow/ice; this process is stopped if one test is really successful (i.e., if the threshold is not too close to the measured value). The characteristics of this set of tests are summed up below:

- The tests, applied to land or sea pixels, depend on the solar illumination and on the viewing angles (daytime, night-time, twilight, sunglint, as defined in Table 3) and are presented in Table 4 and Table 5.
- Most thresholds are determined from satellite-dependent look-up tables (available in coefficients' files) using as input the viewing geometry (sun and satellite viewing angles), NWP forecast fields (surface temperature and total atmospheric water vapour content) and ancillary data (elevation and climatological data). The thresholds are computed at a spatial resolution (called "segment size") defined by the user as a number of pixels at default horizontal resolution. Some thresholds are empirical constant or satellite-dependent values (available in coefficients' files).
- The quality of the cloud detection process is assessed.

This first series of tests allows to determine the cloud cover category of each pixel (cloud-free, cloud contaminated, cloud filled, snow/ice contaminated or undefined/non processed) and compute a quality flag on the processing itself. Moreover, the tests that have allowed the cloud detection (more that one test are possible, if some tests were not really successful) are stored.

Nighttime	**Twilight**	**Daytime**	**Sunglint**
Solar elevation < -3	-3<Solar elevation<10	10 < Solar elevation	Cox & Munck > 10% Solar elevation > 15

Table 3: Definition of illumination conditions

Cox & Munck stands for the reflectance computed using Cox & Munck theory (see Cox and Munck, 1954) ; the solar elevation is expressed in degrees.

Daytime	Twilight	Nighttime
Snow detection	Snow detection	T10.8µm -T3.8µm
R0.6µm	R0.6µm	T10.8µm
T10.8µm	T10.8µm	T10.8µm -T12.0µm
T10.8µm-T12.0µm	T10.8µm-T12.0µm	T8.7µm-T10.8µm
T8.7µm-T10.8µm	T10.8µm-T3.8µm	T3.8µm-T10.8µm
T10.8µm-T3.8µm	T8.7µm-T10.8µm	Local Spatial Texture
T3.8µm-T10.8µm	T3.8µm-T10.8µm	T8.7µm-T3.8µm
Local Spatial Texture	Local Spatial Texture	
	T8.7µm-T3.8µm	

Table 4: Test sequence over land

Daytime	**Sunglint**	**Twilight**	**Nighttime**
Ice detection	Ice detection	Ice detection	T10.8µm-T3.8µm

R0.8µm (R0.6µm)	SST	R0.8µm (R0.6µm)	SST
SST	T10.8µm-T12.0µm	T10.8µm-T3.8µm	T8.7µm-T10.8µm
R1.6µm	T8.7µm-T10.8µm	SST	T10.8µm-T12.0µm
T10.8µm-T12.0µm	Local Spatial Texture	R1.6µm	T12.0µm-T3.8µm
T8.7µm-T10.8µm	R0.8µm (R0.6µm)	T8.7µm-T10.8µm	T3.8µm-T10.8µm
T10.8µm-T3.8µm	T10.8µm-T3.8µm	T10.8µm-T12.0µm	Local Spatial Texture
T3.8µm-T10.8µm	Low Clouds in Sunglint	T12.0µm-T3.8µm	
Local Spatial Texture		T3.8µm-T10.8µm	
		Local Spatial Texture	

Table 5: Test sequence over sea

[T3.8µm, T8.7µm, T10.8µm and T12.0µm are labels that stand for brightness temperatures at around 3.8, 8.7, 10.8 and 12.0 micrometer; R0.6µm, R0.8µm and R1.6µm stand for VIS/NIR bi-directional top of atmosphere reflectances at around 0.6, 0.8 and 1.6 micrometer normalised for solar illumination ; SST is the split-window (used for SST calculation) computed from T10.8µm and T12.0µm measurements. Low Clouds in Sunglint is a specific module for low clouds identification in sunglint areas. It must be noted that labels (T3.8µm, T8.7µm, T10.8µm, T12.0µm, R0.6µm, R0.8µm and R1.6µm) are generic, the exact central wavelength of the corresponding channel depending on the satellite]

2.2.1.2.2.1 Test on SST

The test is the following :

Over sea, a pixel is classified as cloud contaminated if :

- SST(T10.8µm, T12.0µm) < SSTthreshold and
- sstclim > 270.15 K

where (for MSG1/SEVIRI)

SST(T10.8µm, T12.0µm)=0.977*(T10.8-273.15)
+ (0.075*(sstclim-273.15)+1.127*(sec-1))*(T10.8-T12.0)
+ 1.156 +273.15 (in K)

sec is the secant of the satellite zenith angle,
sstclim is the climatological SST (in K)

This test allows detecting most of the clouds over the ocean for any solar illumination. This test is not applied if the climatological SST is too low, which indicates that the ocean could be frozen.

A split window algorithm, using T10.8µm and T12.0µm brightness temperatures to compute Sea Surface Temperature, is applied to all pixels over the ocean. A pixel is then classified as cloudy if its split window value is lower that the estimated Sea Surface Temperature.

The threshold is computed from a monthly climatological minimum SST by substracting an offset (linear function of the secant of the satellite zenith angle ranging from 1.5K (for satellite zenith angle lower than 60 degrees) up to 2.5K (satellite zenith angles larger than 78.5), an additional 0.5K being added in coastal areas). This offset is needed to account for the imperfections of the climatology, especially in areas with persistent cloudiness, and in areas where the oceanic SST varies rapidly in space and time.

If T12.0µm is missing, the test is replaced by T10.8µm < sstclim – 9K.

2.2.1.2.2.2 Test on T10.8µm

The test is the following :

A pixel is classified as cloud contaminated if :

- T10.8µm < T10.8threshold.

This test is applied over land and sea (only if the climatological SST is lower than 270.15 K which indicates that the ocean may be frozen). It allows the detection of the clouds having a 10.8µm brightness temperature lower than the surface brightness temperature.

The T10.8µm threshold is computed from surface temperatures forecast by NWP model, by accounting for atmospheric absorption and small scale height effects (over land only) as described below [the different physical meaning of brightness temperature and NWP surface temperature (dependent on the NWP model) is not accounted for] :

- The surface temperature for a given slot is then interpolated from the two nearest NWP fields (spatially interpolated at the segment's spatial resolution) according to rules related to the relative position of the scene and the two NWP terms in a diurnal cycle assumed to be driven by sun rise and sun set local times.
- The atmospheric absorption is accounted for through an offset computed as a function of satellite zenith angle, integrated atmospheric water vapour content and solar zenith angle. Two tables (for night-time and daytime conditions) have been pre-computed by applying RTTOV to radio-soundings from a data set provided by ECMWF (F.Chevalier, 1999). The satellite zenith angle and the water vapour content are used to interpolate in these tables, whereas the solar zenith angle is used to interpolate between the night-time and the daytime values.
- A dry adiabatic law is used to account for the height difference between the elevation of the NWP grid and of the pixel; this simple process, only applied over land, allows roughly simulating small scale height effects in mountainous regions.

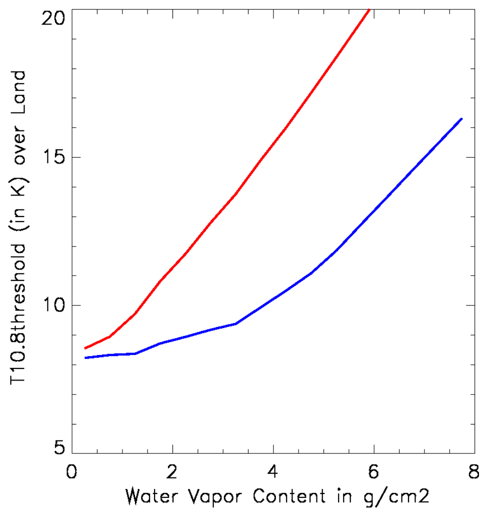


Figure 1: Illustration of the offset accounting for atmospheric absorption over vegetated surface for a satellite zenith angle of 48 degrees. Blue and red curves correspond to nighttime and daytime conditions

An offset of -3K is added in nighttime conditions over Africa to limit the confusion of cloud free areas with clouds.

A pixel is diagnosed favourable to extreme cooling over land in nighttime and twilight conditions when:

- altitude < 1500m and (FSKT < 263K or FSKT < 268K and SNOC > 5 pixels (out of 16))

Where FSKT is the forecasted skin temperature and SNOC is the snow occurrence in any pixel of the segment box surrounding the considered pixel (counted during any of the four previous or the current day for any daytime duration). A box size of 16 pixels has been used when prototyping.

When these conditions are met, T10.8threshold is modified as follows:

- If T108threshold > = 255K
  - T108threshold=T108threshold – 5.0K
- If T108threshold <255K
  - T108threshold=T108threshold – 5.0K -0.4*(255K-T108threshold)

2.2.1.2.2.3 Test on T10.8µm-T12.0µm

The test is the following:

A pixel is classified as cloud contaminated if :

- T10.8µm -T12.0µm > T10.8T12.0threshold and
- (over land only) T10.8µm < 303.15 K

This test, which can be applied over all surfaces in any solar illumination, allows the detection of thin cirrus clouds and cloud edges characterised by a higher T10.8µm-T12.0µm than cloud-free surfaces.

The difficulty is to estimate the cloud free surfaces T10.8µm-T12.0µm difference which depends on the difference of atmospheric absorption (mainly due to water vapour) and surface emissivity in the two infrared wavelengths. This test will be useless if the estimated clear-sky T10.8µm-T12.0µm difference is too high, which may be the case at daytime. The rough check applied over land to T10.8µm allows minimizing the confusion of very warm moist areas with clouds.

Over sea, two look-up tables (for cold and warm seas) have been elaborated by applying RTTOV to radio-soundings from an ECMWF dataset (F.Chevalier, 1999), using Masuda emissivities (Masuda et al., 1988). The threshold is interpolated into these two tables using satellite zenith angle and water vapour content, and between these tables using the climatological SST.

Over land, two look-up tables (for night-time and daytime conditions) have been calculated by applying RTTOV to radio-soundings from an ECMWF dataset, using a constant emissivity of 0.98 in both channels (Salisbury et al., 1992). The threshold is interpolated into these two tables using satellite zenith angle and water vapour content, and between these two tables using the solar zenith angle.

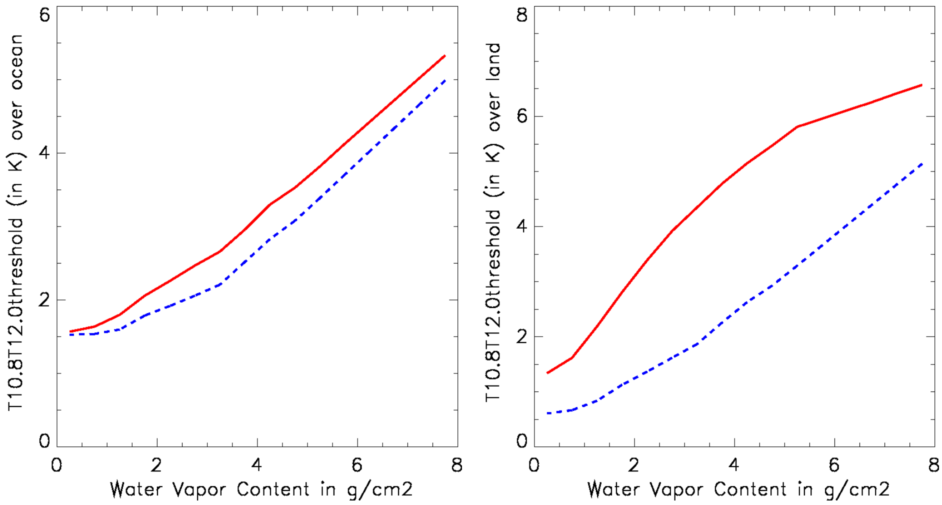


Figure 2: Illustration of T10.8T12.0threshold for a satellite zenith angle of 48 degrees. Over Ocean, blue and red curve correspond to cold and warm seas. Over Land, blue and red curves correspond to nighttime and daytime conditions

An offset of 1K has been added over Africa to limit the confusion of very moist cloud free areas with clouds.

2.2.1.2.2.4 Test on T8.7µm-T10.8µm

The test is the following:

A pixel is classified as cloud contaminated if :

- T8.7µm -T10.8µm > T8.7T10.8threshold.

This test aims to detect thin cirrus clouds over all surfaces in any solar illumination.

It is based on the fact that high semi-transparent clouds are characterised by relatively high T8.7µm-T10.8µm difference as compared to surface values. The difficulty is to estimate the cloud free surfaces T8.7µm-T10.8µm difference which depends on the difference of atmospheric absorption (mainly due to water vapour) and surface emissivity in the two infrared wavelengths.

Over sea, one look-up table has been elaborated by applying RTTOV to radio-soundings from an ECMWF dataset (F.Chevalier, 1999), using Masuda emissivities (Masuda et al., 1988). The threshold is interpolated into this table using satellite zenith angle and water vapour content.

Over land, two look-up tables (in daytime and nighttime conditions) have been established by applying RTTOV to radio-soundings from an ECMWF dataset. Only one set of emissivities (Salisbury et al., 1992) has been used, corresponding to vegetated areas (0.98 in both channel). The threshold is interpolated into these two tables using satellite zenith angle and water vapour content, and between these two tables using the solar zenith angle.

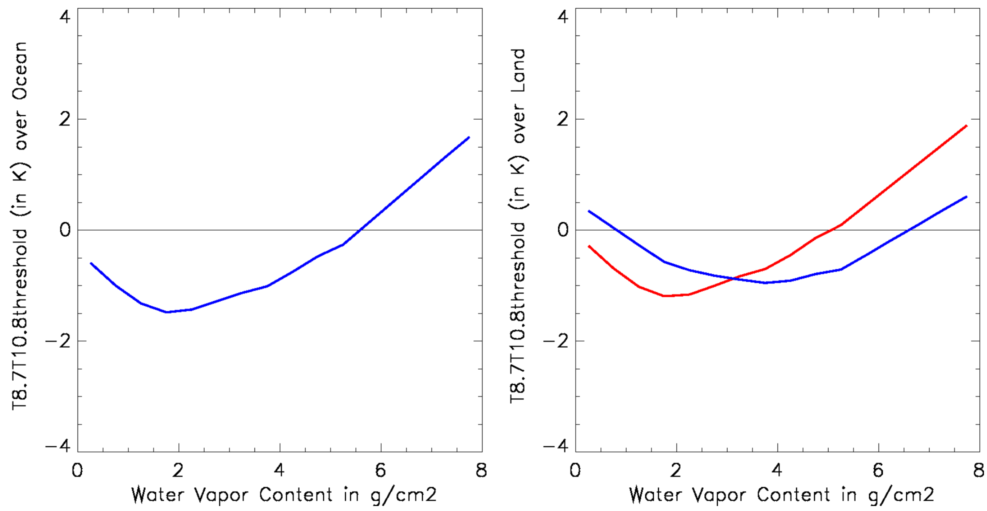


Figure 3: Illustration of T8.7T10.8threshold for a satellite zenith angle of 48 degrees. Over Land, blue and red curve correspond to night and daytime conditions.

A pixel is diagnosed favourable to extreme cooling over land in nighttime and twilight conditions when:

- altitude < 1500m and (FSKT < 263K or FSKT < 268K and SNOC > 5)

Where FSKT is the forecasted skin temperature and SNOC is the snow occurrence in any pixel of the segment box surrounding the considered pixel (counted during any of the four previous or the current day for any daytime duration). A box size of 16 pixels has been used when prototyping.

When these conditions are met T8.7T10.8threshold is modified as follows:

- if T108threshold <250K T8.7T10.8threshold = T8.7T10.8threshold + 0.4K

2.2.1.2.2.5 Test on T3.8µm-T10.8µm in night-time conditions

The test is the following:

A pixel is classified as cloud contaminated if :

- T3.8µm - T10.8µm > T3.8T10.8threshold_night and
- T3.8µm > 240 K and
- T3.8µm < Min(320 K,FSKT+10K)

A pixel is diagnosed favourable to extreme cooling over land in nighttime condition when:

- altitude < 1500m and (FSKT < 263K or FSKT < 268K and SNOC > 5)

Where FSKT is the forecasted skin temperature and SNOC is the snow occurrence in any pixel of the segment box surrounding the considered pixel (counted during any of the four previous or the current day for any daytime duration). A box size of 16 pixels has been used when prototyping.

When these conditions are met T3.8T10.8threshold_night is modified as follows:

- If 250K <= T108threshold <= 255K
  - o T3.8T10.8threshold = MAX(T3.8T10.8threshold, -0.5x T108threshold +129.0)
- If T108threshold <250K
  - o T3.8T10.8threshold = -0.15x T108threshold +41.5

Where T108threshold is the primary threshold on T10.8 as computed for the considered vegetated surface.

This test allows the detection of high semi-transparent clouds only in night-time conditions.

It is based on the fact that the contribution of the relatively warm grounds to the brightness temperature is higher at 3.8µm than at 10.8µm, due to a lower ice cloud transmittance (Hunt, 1973), and to the high non-linearity of the Planck function at 3.8µm. This test is usable only at night-time, when solar irradiance does not act upon the 3.8µm channel radiance. The cloud free surfaces T10.8µm-T3.8µm difference (depending on the difference of atmospheric absorption (mainly due to water vapour) and surface emissivity in the two infrared wavelengths) has to be accurately estimated to allow this test to detect most semi-transparent clouds. An additional difficulty is the high radiometric noise (enhanced for low temperatures) that affects the 3.8µm channel: this is the reason why the use of this test is limited to pixels warmer than 240K. The non linearity effect makes this test much more efficient than the T10.8µm-T12.0µm test to detect high semi-transparent clouds over rather warm grounds at night-time. The testing of T3.8µm is to limit the confusion of fires (characterized by high T3.8µm value as compared to T10.8µm) with clouds.

Two look-up tables (for cold and warm seas) and four look-up tables (for cold and warm vegetated or arid surfaces) have been elaborated by applying RTTOV to radio-soundings from an ECMWF dataset (F.Chevalier, 1999), using Masuda emissivities (Masuda et al., 1988) for oceanic conditions and using a constant emissivity of 0.98 in both channels (Salisbury et al., 1992) for vegetation (an offset of 1 Kelvin is added to simulate arid conditions). The threshold is interpolated into these tables using satellite zenith angle and water vapour content, together with the climatological SST (sea) or forecast surface temperature and climatological visible reflectance (land).

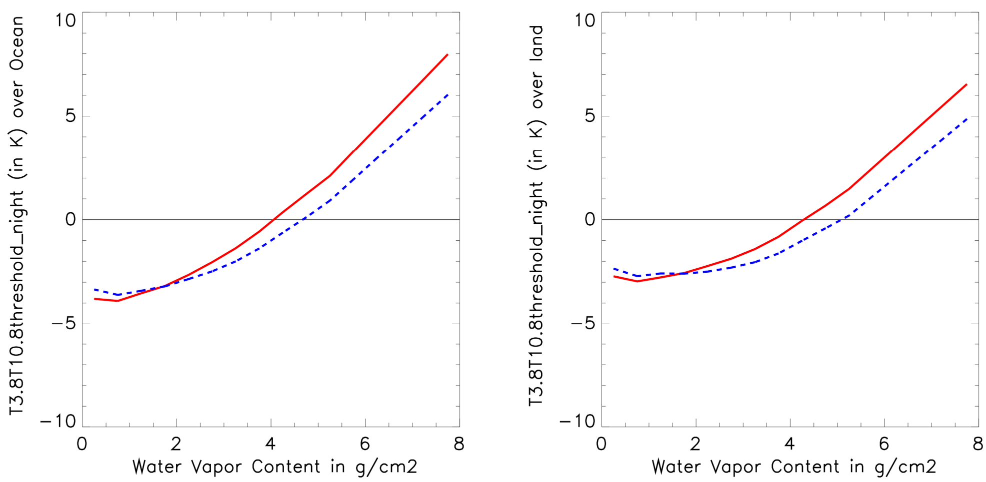


Figure 4: Illustration of T3.8T10.8threshold_night for a satellite zenith angle of 48 degrees. Blue and red curve correspond to cold and warm vegetated surfaces.

2.2.1.2.2.6 Test on T10.8µm-T3.8µm

The test is the following:

A pixel is classified as cloud contaminated if :
- T10.8µm - T3.8µm > T10.8T3.8threshold and
- T3.8µm > 240 K and
- (over land only) T8.7µm – T10.8µm > $(-4.5-1.5*(1./\cos(\theta_{sat})-1))$ (in K)

where θ_{sat} is the satellite zenith angle

This test allows the detection of low water clouds at night-time, but also low clouds shadowed by higher clouds.

It is based on the fact that the water cloud emissivity is lower at 3.8µm than at 10.8µm (Hunt, 1973), which is not the case for cloud free surfaces (except sandy desertic areas). A basic assumption is that the 3.8µm channel is not affected by the solar irradiance, which is the case at night-time and in shadows. The cloud free surfaces T10.8µm-T3.8µm difference (depending on the difference of atmospheric absorption (mainly due to water vapour) and surface emissivity in the two infrared wavelengths) has to be accurately estimated to allow this test to detect most low water clouds. An additional difficulty is the high radiometric noise (enhanced for low temperatures) that affects the 3.8µm channel: this is the reason why the use of this test is limited to pixels warmer than 240K. The rough check applied to T8.7µm-T10.8µm allows minimizing the confusion of sandy arid areas with low clouds.

Over sea, one look-up table has been elaborated by applying RTTOV to radio-soundings from an ECMWF dataset (F.Chevalier, 1999), using Masuda emissivities (Masuda et al., 1988). The satellite zenith angle and the water vapour content are used to interpolate in this table.

Over land, two look-up tables (for vegetated and arid surfaces) have been established by applying RTTOV to radio-soundings from an ECMWF dataset. A set of emissivities (Salisbury et al., 1992 and 1994) corresponding to vegetated areas (0.98 in both channels) has been used, the table corresponding to arid areas being obtained from the one for vegetated areas by adding an offset of 4K. The threshold is interpolated into these two tables using satellite zenith angle and water vapour content, and between these two tables using the climatological visible reflectance.

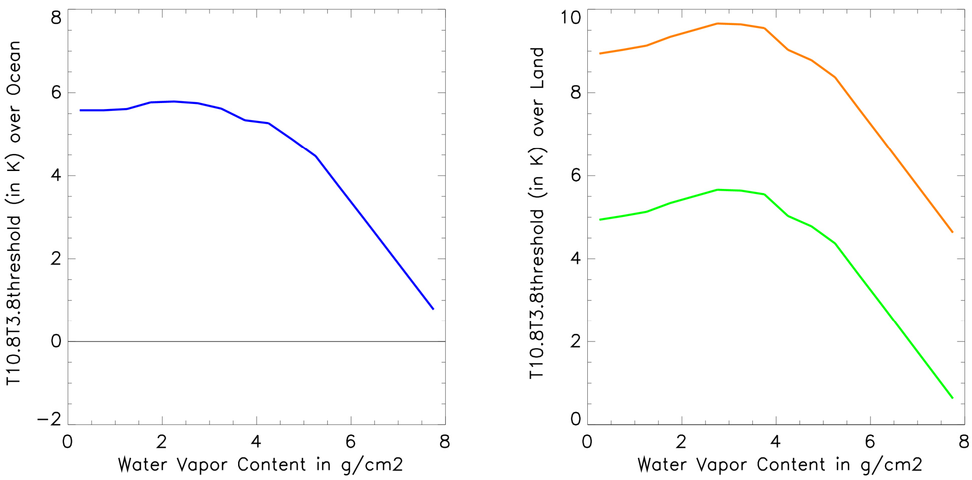


Figure 5: Illustration of T10.8T3.8threshold for a satellite zenith angle of 48 degrees. Over Land, green and brown curves correspond to vegetation and desert.

To increase the T10.8µm-T3.8µm test efficiency over Europe, two correction factors, empirically developed from measurements to better account for satellite zenith angle effect and CO_2 absorption, are added to the threshold computed from RTTOV simulations only over European regions (defined by their latitude between 36 and 90 degrees north, and their longitude between 30 degrees west and 60 degrees east):

-The correction factor to account for satellite zenith angle effect is tabulated below (for MSG/SEVIRI) as a function of satellite secant $1/\cos(\theta_{sat})$):

$1/\cos(\theta_{sat})$	1	1.5	2.0	3.0	3.8	4.25	8

T10.8T3.8threshold correction factor (in K)	0.0	0.0	-0.6	-1.1	-1.1	0.5	0.5

-The correction factor to better account for CO_2 absorption is tabulated below (for MSG/SEVIRI) as a function of (T10.8µm-T13.4µm) brightness temperatures difference:

T10.8µm-T13.4µm (in Kelvin)	0.0	11	13.0	15.0	17.0	20.0
T10.8T3.8threshold correction factor (in K)	-1.5	-1.5	-1.0	-0.5	0.0	0.0

Finally, an offset of 1K has been added to the threshold over Africa to decrease the confusion of arid areas with low clouds.

2.2.1.2.2.7 Test on T12.0µm-T3.8µm over ocean

The test is the following:

A pixel is classified as cloud contaminated if :

- T12.0µm - T3.8µm > T12.0T3.8threshold and
- T3.8µm > 240 K

This test intends to detect low water clouds over the ocean in night-time conditions.

This test is very similar to the one applied to the T10.8µm - T3.8µm (see 2.2.1.2.2.6), but is usually more efficient over ocean due to a higher contrast between cloud free and low clouds T10.8µm-T3.8µm values. An example of the threshold used is displayed in Figure 6

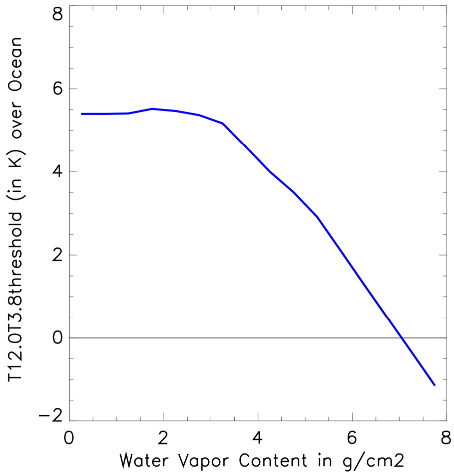


Figure 6: Illustration of T12.0T3.8threshold over the Ocean for a satellite zenith angle of 48 degrees.

2.2.1.2.2.8 Test on T8.7µm-T3.8µm over desert

The test is the following:

A pixel is classified as cloud contaminated if :

- T8.7µm - T3.8µm > T8.7T3.8threshold and
- T10.8µm - T3.8µm > T10.8T3.8veget_threshold and
- T3.8µm > 240 K

where T10.8T3.8veget_threshold is computed assuming vegetated surface

This test allows the detection over the desert of low water clouds at night-time. It is only applied over Africa.

Low clouds are usually detected at night-time thanks to their T10.8µm-T3.8µm brightness temperatures differences as explained in 2.2.1.2.2.6. This is practically never the case over desert because there is no contrast in this feature between low clouds and desert.

The T8.7µm-T3.8µm test is based on the fact that desertic areas have low emissivities at 3.8µm and 8.7µm, whereas low water clouds have low emissivities at 3.8µm, but not at 8.7µm. A consequence is that low clouds are characterized by higher T8.7µm-T3.8µm differences as compared to values over desert. This test is limited to pixels warmer than 240K to insure that the 3.8µm channel is not too much affected by radiometric noise (enhanced for low temperatures) and to pixels having not too low T10.8µm-T3.8µm brightness temperature differences to limit confusion of savannah with low clouds.

One look-up table has been established by applying RTTOV to radio-soundings from an ECMWF dataset. A set of emissivities (0.98 in both channels) has been used. The threshold is interpolated into this tables using satellite zenith angle and water vapour content.

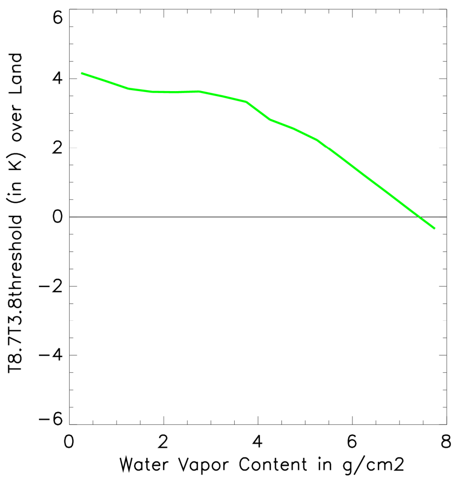


Figure 7: Illustration of T8.7T3.8 threshold over desertic area for a satellite zenith angle of 48 degrees.

2.2.1.2.2.9 Test on T10.8µm-T8.7µm over land

The test is the following :

A pixel is classified as cloud contaminated if :

- T10.8µm – T8.7µm > T10.8T8.7threshold and
- Climatological albedo < 20 % and
- $1/\cos(\theta_{sat}) > 1.5$

where θ_{sat} is the satellite zenith angle

This test intends to detect low clouds over vegetated areas at high satellite zenith angle at night-time or at low solar elevation. It is only applied over European areas (defined by their latitude between 36 and 90 degrees north, and their longitude between 30 degrees west and 60 degrees east).

Usually, low clouds are characterized at night-time by high T10.8µm-T3.8µm brightness temperatures differences, which allow their identification over land (see 2.2.1.2.2.6). This detection may be less efficient at large viewing angles as cloud free T10.8µm-T3.8µm values may become rather high. To increase low clouds detection efficiency in night-time conditions at high satellite zenith angle, an empirical test has been developed, based on the observation that the decrease of T8.7µm–T10.8µm with satellite zenith angle is much stronger for low clouds than for vegetated areas. This empirical test is also very useful in case low solar elevation to detect low clouds (at large viewing angles only).

The T10.8T8.7threshold has been empirically derived from measurements as a function of the satellite secant: T10.8T8.7threshold (in K) =3.7+0.3*(1/cos(θ_{sat})) (for MSG1/SEVIRI).

2.2.1.2.2.10 Test on R0.6µm, R0.8µm or R1.6□µm

These tests are the following :

Over land and over sea (only if R0.8µm unavailable), a pixel is classified as cloud contaminated if :

- R0.6µm > R0.6threshold

Over sea, a pixel is classified as cloud contaminated if :

- R0.8µm > R0.8threshold

Over sea, a pixel is classified as cloud contaminated if :

- R1.6µm > R1.6threshold

These tests, applied to the visible (0.6µm) or near-infrared (0.8µm and 1.6µm) TOA reflectances, aim to detect at daytime clouds having a reflectance higher than the underlying surfaces.

The visible or near-infrared reflectance measured over the cloud-free oceans mainly corresponds to Rayleigh and aerosol scattering (weaker in the near-infrared band) and to the solar reflection over the ocean, which is very low apart from sunglint conditions, and in turbid areas (for the visible channel only). Therefore near-infrared bands (0.8µm and 1.6µm) are used over the ocean, the visible band (0.6µm) being used only in case 0.8µm is not available.

As the cloud-free land reflectance is usually much higher in the near-infrared wavelengths than in the visible (due to the vegetation spectral radiative behaviour at these wavelengths), the test is therefore only applied to the visible channel.

The threshold is computed from the simulation of the surface (ocean or land) TOA reflectance by adding an offset:

- The TOA reflectance is simulated as: TOA Reflectance = (a0 + a1*surface/(1-a2*max(surface,200%))) + offset + corrective_factor where :
    - o a0, a1 and a2 are coefficients computed from satellite and solar angles, water vapour and ozone content using look-up tables. These look-up tables have been pre-computed for a great variety of angles and water vapour and ozone content using a very fast model based on 6S (Tanre et al., 1990), using a maritime or continental aerosol of 30km or 70km horizontal visibility for sea and land respectively.
    - o surface is the land or ocean surface reflectance. The Ocean surface reflectance is given by the maximum reflectance computed by the Cox & Munck model (Cox & Munck, 1954), for the satellite and solar angles and for wind speed between 0 and 20 m/s: this approach overestimates the reflectance in sunglint conditions. The Land surface reflectance is computed from a monthly climatological visible reflectance

atlas, bi-directional effects being simulated using a model developed by Roujean (Roujean et al., 1992) with 2 sets of coefficients empirically derived [(k0=1.4, k1=0.15*k0, k2=1.0*k0) for low reflectance and (k0=1.3, k1=0.05*k0, k2=0.5*k0) for highly reflective areas].

- Offsets (7% over sea (9% for R0.6µm), 8% over land) are added; an additional offset (3%) is added over sea in coastal areas to account for possible misregistration.
- The following corrective factor is added over land to allow high reflectance in the forward scattering direction: corrective_factor (in %) = 4.0 +29*(cos(scattering angle)-0.68)^2 where scattering_angle is the scattering angle ([0.,π] from backward to forward direction).

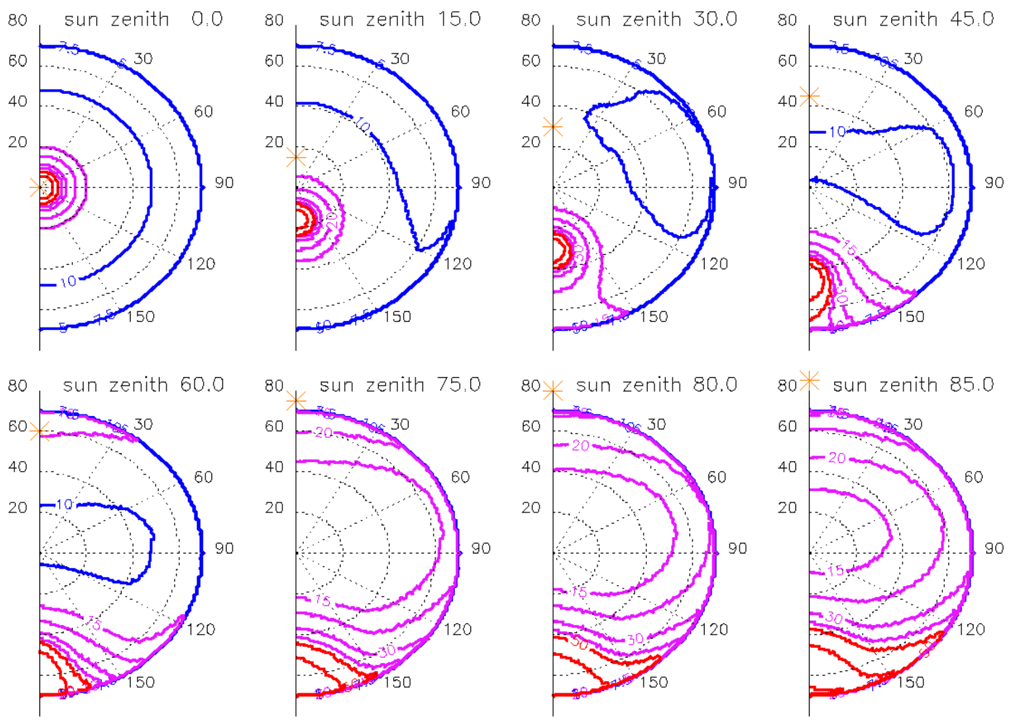


Figure 8: Polar representation of R0.8threshold over Ocean for eight sun zenith angles.

The polar angle corresponds to the satellite azimuth angle (sun azimuth is taken equal to 0); the radius represents the satellite zenith angle; iso-reflectance curves are displayed in different colours according to their reflectance value (blue if lower than 10%, purple if lower than 40%, red if higher than 40%)

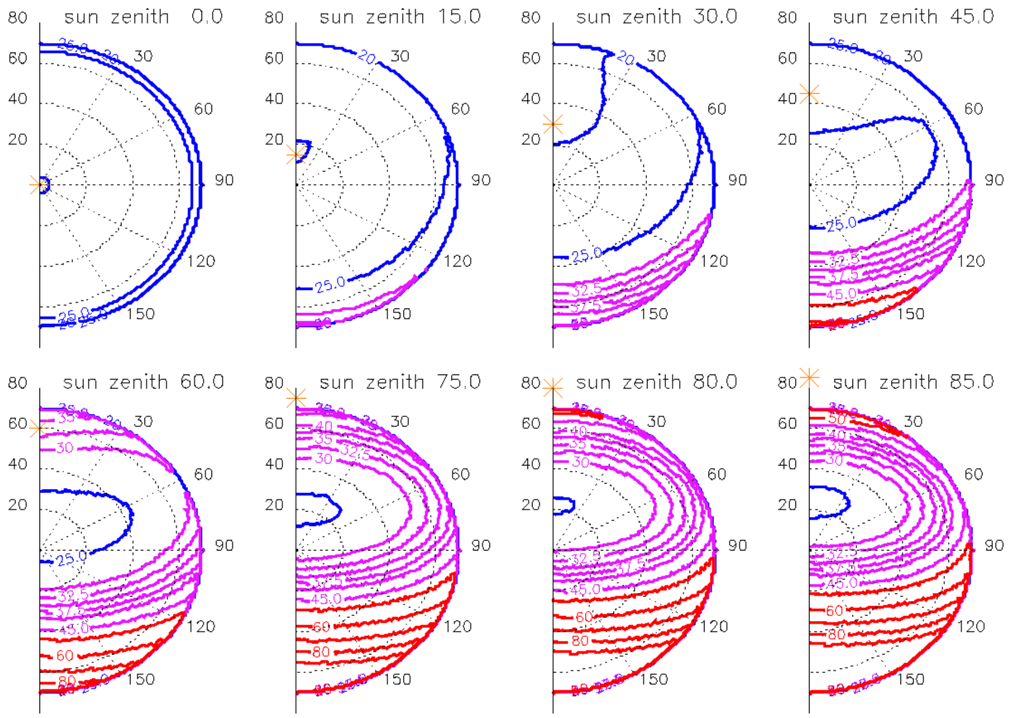


Figure 9: Polar representation of R0.6threshold over Land (surface reflectance of 10%) for eight sun zenith angles.

The polar angle corresponds to the satellite azimuth angle (sun azimuth is taken equal to 0); the radius represents the satellite zenith angle; iso-reflectance curves are displayed in different colours according to their reflectance value (blue if lower than 25%, purple if lower than 45%, red if higher than 45%)

2.2.1.2.2.11 Low Cloud Test in Sunglint

The following test is applied if the sun elevation is higher than 15 degrees:

A pixel is classified as cloud contaminated if :

- T3.8µm < 320 K (to make sure 3.8µm is not saturated) and
- R0.6µm > 60% and
- (T3.8µm-T10.8µm)/cos(θ_{sol}) > 0 K and
- R0.6µm > (1./0.15)*(T3.8µm-T10.8µm)/cos(θ_{sol}) (θ_{sol} is the solar zenith angle)

This test aims to detect low clouds in sunglint conditions.

Low clouds can easily be detected at daytime over the ocean by their high visible or near-infrared reflectances. This is not possible in case of sunglint, because the sea reflectance at these wavelengths may then be higher than that of clouds. The use of both 0.6µm and 3.8µm channels allows detecting low clouds even in areas affected by sunglint. Indeed, oceanic areas with high 0.6µm reflectances have also very high 3.8µm reflectances, which is usually not the case for low clouds. The solar contribution in the 3.8µm channel in case of sunglint is approximated by (T3.8µm-T10.8µm)/cos(θ_{sol}). The rapid saturation of the 3.8µm radiance limits the use of this test in case of strong sunglint.

2.2.1.2.2.12 Test on T3.8µm-T10.8µm in daytime or twilight conditions

The following test is applied in daytime or twilight conditions (except in sunglint areas):

A pixel is classified as cloud contaminated if :

- T3.8µm - T10.8µm > T3.8T10.8threshold_day and
- T3.8µm > 240 K and
- (over Africa only) T8.7µm – T10.8µm > (-4.5-1.5*(1./cos(θ_{sat})-1)) (in K)

where θ_{sat} is the satellite zenith angle and FSKT is the forecast skin surface temperature

This test allows the detection of low clouds at day-time (except sunglint areas over the ocean) and twilight conditions.

It is based on the fact that solar reflection at 3.8µm may be high for clouds (especially low clouds), which is not the case for cloud free areas (except sunglint). The rough check applied to T8.7µm-T10.8µm allows minimizing the confusion of sandy arid areas with low clouds.

The threshold T3.8T10.8threshold_day is computed from T3.8T10.8threshold_night (see section 2.2.1.2.2.5) by adding the solar contribution:

Over ocean: T3.8T10.8threshold_day (in K)=T3.8T10.8threshold_night + 0.7*Cox_munck*cos(θ_{sol}) +7

Over land: T3.8T10.8threshold_day (in K)= T3.8T10.8threshold_night + 0.4*Clim_alb*cos(θ_{sol}) +2.0 + corrective_factor

T3.8T10.8threshold_night is computed as explained in section 2.2.1.2.2.5, Cox_munck is the maximum ocean surface reflectance computed using Cox&Munck theory, Clim_alb is the continental climatological visible reflectance, corrective_factor, added to account for contribution of the solar illumination in backward and forward scattering direction, is defined as:

Corrective_factor=36*cos(θ_{sol})*(cos(scattering angle)-0.41)^2

θ_{sol} is the solar zenith angle and scattering_angle is the scattering angle ([0.,π] from backward to forward direction).

2.2.1.2.2.13 Snow or Ice detection Test

The following snow and ice detection test is applied if the sun elevation is larger than 5 degrees:

A pixel is classified as contaminated by snow if :

- (R1.6µm) < R1.6threshold and
- (R0.6µm -R1.6µm)/ (R0.6µm +R1.6µm) > (0.30+0.15*(cos(scattering angle)-1)^2) and
- (T3.8µm-T10.8µm)/cos(θsol) < 10K and
- (T10.8threshold – 5.0) < T10.8µm < 286.15 (in K) and
- T10.8µm-T12.0µm < 2K and
- Min(R0.6threshold, (20+45*(cos(scattering angle)-0.55)^2)%) < R0.6µm and
- 20% < R0.8µm

-where R1.6thrshold is the threshold displayed on Figure 10, T10.8threshold and R0.6threshold are thresholds used in cloud masking with infrared and visible channels, θsol is the solar zenith angle, and scattering angle is the scattering angle ([0,π] from backward to forward direction).

A pixel is classified as contaminated by ice if :

- Climatological SST < 277.15 K and
- (R1.6µm) < R1.6threshold and
- R0.6µm -R1.6µm)/ (R0.6µm +R1.6µm) > (0.30+0.15*(cos(scattering angle)-1)^2) and
- (T3.8µm-T10.8µm)/cos(θsol) < 10K and
- (T10.8threshold – 5.0) < T10.8µm < 277.15 (in K) and
- T10.8µm-T12.0µm < 2K and

- R0.6threshold < R0.6µm and
- 20% < R0.8µm

-where R1.6thrshold is the threshold displayed on Figure 10, T10.8threshold and R0.6threshold are thresholds used in cloud masking with infrared and visible channels, θsol is the solar zenith angle, and scattering angle is the scattering angle ([0,π] from backward to forward direction).

Ice and snow appear rather cold and bright, and may therefore be confused with clouds (especially with low clouds) during the cloud detection process. Ice and snow must therefore be identified first, prior to the application of any cloud detection test. This test aims to detect pixels contaminated by snow or ice: if this test is satisfied, the pixel is classified as snow or ice and no further cloud detection is attempted.

The basis of this test, restricted to daytime conditions, is the following:

- Snow & ice are separated from water clouds by their low reflectance at 1.6 µm or at 3.8 µm.
- Snow & ice are separated from cloud free oceanic or continental surfaces by their higher R0.6µm visible reflectance and slightly colder T10.8µm brightness temperature.
- T10.8µm-T12.0µm brightness temperature difference helps to discern cirrus from snow & ice.
- R0.8µm is useful to separate shadows from snow & ice.

Surface snow reflectances have been tabulated for various viewing geometries and for hexagonal particle shape (3 different sizes) with the radiative transfer model developed by C.Le Roux (see Le Roux et al, 1996). Top of Atmosphere snow reflectance at 1.6µm are then computed using these look-up tables (both 250µm and 70µm hexagonal particles have been retained) together with a module (based on 6S (Tanre et al., 1990)) to simulate the atmospheric effects. The R1.6threshold threshold applied to the 1.6µm channel is derived from these simulated snow reflectances by adding an offset (10%).

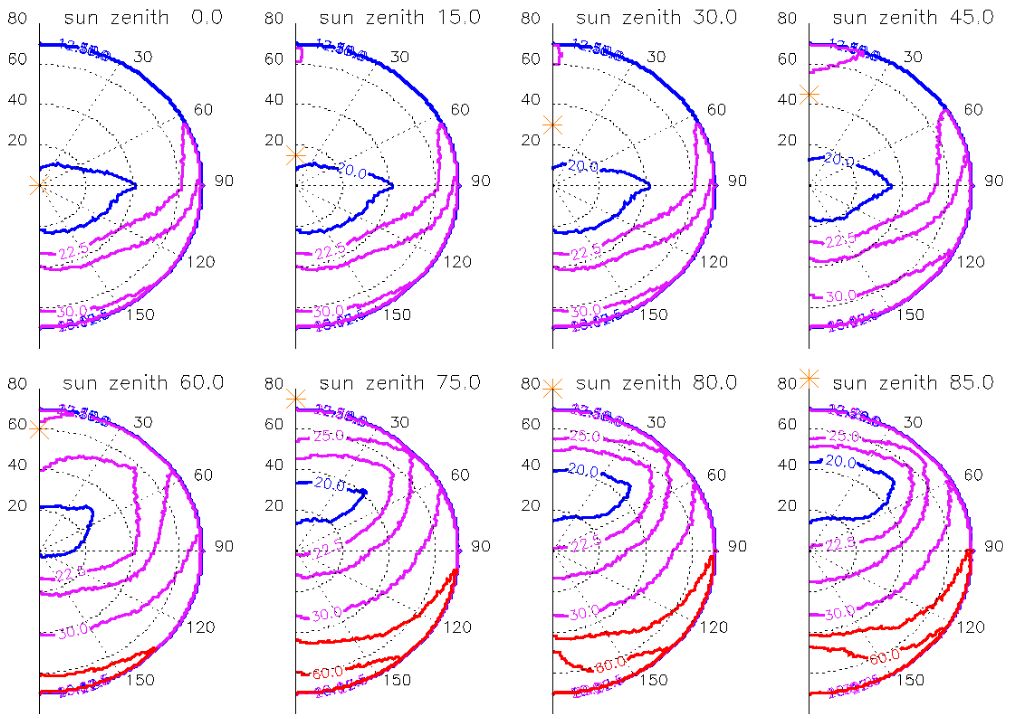


Figure 10: Polar representation of R1.6threshold over snow for eight sun zenith angles.

The polar angle corresponds to the satellite azimuth angle (sun azimuth is taken equal to 0); the radius represents the satellite zenith angle; iso-reflectance curves are displayed in different colours according to their reflectance value (blue if lower than 20%, purple if lower than 30%, red if higher than 30%)

2.2.1.2.2.14 Local Spatial Texture Tests

The following tests are applied:

Over Sea, a pixel is classified as cloudy if :

- [SD(T10.8µm) > 0.6K and SD(T10.8µm-T3.8µm) > 0.2K (0.4K at daytime) and T10.8µm < MAX(T10.8µm) – 2*noise(T10.8µm)]

or

- [SD(R0.8µm) > (0.8%+0.03* R0.8threshold) and R0.8µm > MIN(R0.8µm) + 2./SNR(R0.8µm) at daytime only]

T10.8µm-T3.8µm is not used in too cold areas (due to noise effects).

Over Land, a pixel is classified as cloudy if :

- [SD(T10.8µm) > 1.0K (2.0K at daytime) and SD(T10.8µm-T3.8µm) > 1.0K (2.0K at daytime] or
- [DR0.6µm > f(DT10.8µm) / (DR0.6µm)) at daytime only]

This process is not applied in very mountainous regions ; moreover T10.8µm-T3.8µm is not used in too cold areas (due to noise effects).

-SD, MIN, MAX, stand for local standard deviation, minimum, maximum, computed using the 8 surrounding pixels, provided they correspond to the same surface type (i.e., sea or land)
-R0.8threshold is the visible threshold (in %) defined previously
-DR0.6µm stands for the maximum difference between the visible reflectance of a pixel and its eight neighbours; DT10.8µm is the corresponding brightness temperature difference and R= DT10.8µm/ DR0.6µm is the ratio.
Noise stands for the instrumental noise in Kelvin of the feature at the given brightness temperature
SNR stands for the signal to noise ratio of the feature for the given visible band

-The f(R) function is tabulated below:

R=(DT10.8µm) / (DR0.6µm)	-5	-3	0	0.25	0.5	1
Threshold applied to (DR0.6µm)	2%	2%	5%	10%	15%	15%

These tests detect small broken clouds, thin cirrus or cloud edges, by using their high spatial variations in the visible, near infrared or infrared channels. The difficulty comes from the natural heterogeneity of the surface background: Oceanic areas are rather homogeneous, with the exception of strong thermal fronts (large T10.8µm variation), turbid coastal areas (large R0.6µm variation), sunglint areas (large R0.6µm and R0.8µm variation) ; Land surfaces are generally much more inhomogeneous, especially in mountainous or desertic regions. The simultaneous analysis of spatial coherency in two spectral bands allows overcoming the difficulty:

- Over Ocean, the combined use of T10.8µm & T10.8µm-T3.8µm for all illumination conditions is efficient for detecting clouds, and avoids misclassification of thermal front.
- Over land, the combined use of T10.8µm & T10.8µm-T3.8µm for all illumination conditions allows minimising misclassification, except in very mountainous or in arid areas.
- Continental areas at daytime may present as large R0.6µm, R0.8µm and T10.8µm horizontal differences as clouds do. But, a cloud-free surface having higher R0.6µm than the neighbourhood is less vegetated and therefore warmer, whereas a pixel contaminated by

clouds and having higher R0.6µm than its neighbours should be more cloud contaminated, and therefore colder. This property, not observed in arid areas, is used at daytime over land in the Local Spatial Texture Test.

2.2.1.2.2.15 Quality assessment

A quality flag is appended to the CMA (see 2.2.2.4). It allows the identification of cloud-free, cloudy and snowy pixels that may have been misclassified:

- a pixel classified as cloudy is flagged as of "bad quality" if no cloud detection test has been really successful. A threshold test is said really successful if the difference between the threshold and the measurement is larger than a security margin depending on the test itself:

Cloud Tests	**SST**	**T10.8µm**	**T10.8µm-T12.0µm**	**T10.8µm-T3.8µm** **T12.0µm-T3.8µm** **T8.7µm-T3.8µm**	**T3.8µm-T10.8µm**
Security margin for quality assessment	2 K	3 K	0.5 K	0.5 K	0.5 K
Cloud Tests	**R0.6µm**	**R0.6µm**	**R0.6µm**	**Local Spatial Texture**	
Security margin for quality assessment	0.2*threshold	0.2*threshold	0.2*threshold	0.2*threshold	

- a pixel classified as cloud free is flagged as of "bad quality" if the difference between the threshold and the measurement is lower than an security margin (see above table) for at least one cloud detection test.
- a pixel classified as snow/ice is flagged as of "bad quality" if the difference between its observed R1.6µm and the corresponding threshold of this feature used in the snow/ice detection test is lower than 0.2*threshold.

Such a quality flag should allow identifying good quality cloud free areas for surface parameters computation. On the other hand, the identification of extended cloudy or cloud free area flagged as "bad quality" should help in identifying areas where the algorithm may be not accurate enough [note that it is understandable that cloud edges or cloud free areas bordering clouds are flagged as of "bad quality"].

2.2.1.2.3 Cloud detection test using RTTOV on-line

The use of RTTOV clear-sky simulations, computed on-line from NWP information and surface conditions, has been studied and developed during a prototyping activity to improve the detection of some clouds which remained not detected by the previous tests (generally at night-time and in presence of low-contrast clouds, i.e. warm low clouds, semitransparent clouds or subpixel clouds). The RTTOV on-line tests have been formulated to be efficient in presence of low-contrast cloudiness while minimizing false cloud detections. When the clear-sky simulations are used to threshold observed brightness temperatures, it is rather difficult to design a universal threshold performing as well as the previous ones (false alarms being the matter). We have decided to use them only as a complement to the previous scheme and targeting the test for a very specific use (low clouds at night over sea, cirrus clouds at night over sea, low clouds over Europe with high viewing angles, etc). Therefore the RTTOV-based tests are applied only to pixels flagged as clear by the first set of tests, so that some false alarms of the previous tests can be avoided if not detected by RTTOV on-line tests. This technique allows new cloud detections but also clear restoration of few false alarms among the cloudy pixels with bad quality indicators as when an existing threshold is doubled by an equivalent RTTOV-based technique it can be relaxed when not confirmed by the last.

But the use of thresholds based on clear-sky simulations is not without drawbacks. The RTTOV-based technique is sensitive to biases between simulations and observations. The biases (slope and offset) depend on the NWP model used, the number and the way the atmospheric layers are described, the RTTOV version and its coefficient file. They may fluctuate substantially in time. Two options are available to get these biases:

- **Biases obtained from NWC/GEO specific interface:** The biases (slope and offset) will be read through a specific NWC/GEO interface. The biases are provided by NWCSAF as ascii file only for one model (the ECMWF model) and the RTTOV release used. Users may use this interface either if they use ECMWF model or if they provide their own bias in the same ascii file format.

- **Biases monitored by NWC/GEO Cma:** Moreover, some biases could fluctuate sometimes substantially (that is the case of channel IR039). So, it is possible to monitor the biases in line through the CMa-PGE01. This option is described below. The flag RTTOV_USE_COMPUTED_BIAS, when it is TRUE, allows to monitor biases in line. Biases between simulations and observations (Tobs – Tsim) are calculated for clear pixels flagged “QUALITY_GOOD”, over sea, in night conditions for each slot. Mean and standard deviation are calculated only if there are more than 50 000 clear pixels on night over sea and where the satellite zenith angle is lower than 70°. Then a daily file is written on the SAFNWC/tmp directory. The Cloud Mask generator needs 2 daily files (from the 7 previous days) to compute the biases of each channel used for RTTOV simulations. In this case, slope is set to 1 and offset is equal to the bias. If the files are not available, the Generator will read biases through the NWC/GEO specific interface (if available), or will not use the RTTOV-based technique.

Moreover we can also note that over land, the thresholds tuning is also dependent on the emissivity atlas used to compute the clear-sky simulations. Those emissivity atlases come with RTTOV release, one must care that RTTOV version that will be implemented in NWCSAF/GEO keeps the same atlas version as the one used in the prototype.

2.2.1.2.3.1 Direct thresholding of T3.8 over sea

This test is the main impact of RTTOV-based threshold method. It is efficient to improve the detection of low clouds over sea. The surface temperature used in the RTTOV simulation comes from last available OSTIA analysis (generally of the previous day). To minimize false alarms it is necessary to make the threshold looser where the surface temperature analysis is more uncertain or more variable with time. Therefore an offset depending on T3.8 simulations, accounts also for local error of the OSTIA analysis and the standard deviation of the monthly climatology of SST, and the distance to coast (TBC, as some false alarms have been recently observed on a thin band of pixels stuck to the Italian coast in the Adriatic Sea). Moreover the test is not applied where terrain type is inland water because numerous false alarms are observed in such places.

$$Thr=T_{SIM}-\varepsilon*\tau_s*[(T_{SFC}-T_{Ostia,}) + local\_ostia\_error(x,y)*ostia\_margin\_factor\_sea$$
$$+maxstdev\_climostia*clim\_margin\_factor] - margin\_offset - Bias_{TSIM}$$

On 3 March 2013 air masses sweep from North-East to South-West across the Cape Verde islands area. They contain thin layers of marine Sc and St blocked inside the moist low atmospheric layers capped with dry air above. When observing such clouds at an early stage of their formation during night-time cooling, their detection is a challenging task as illustrated in figure below.

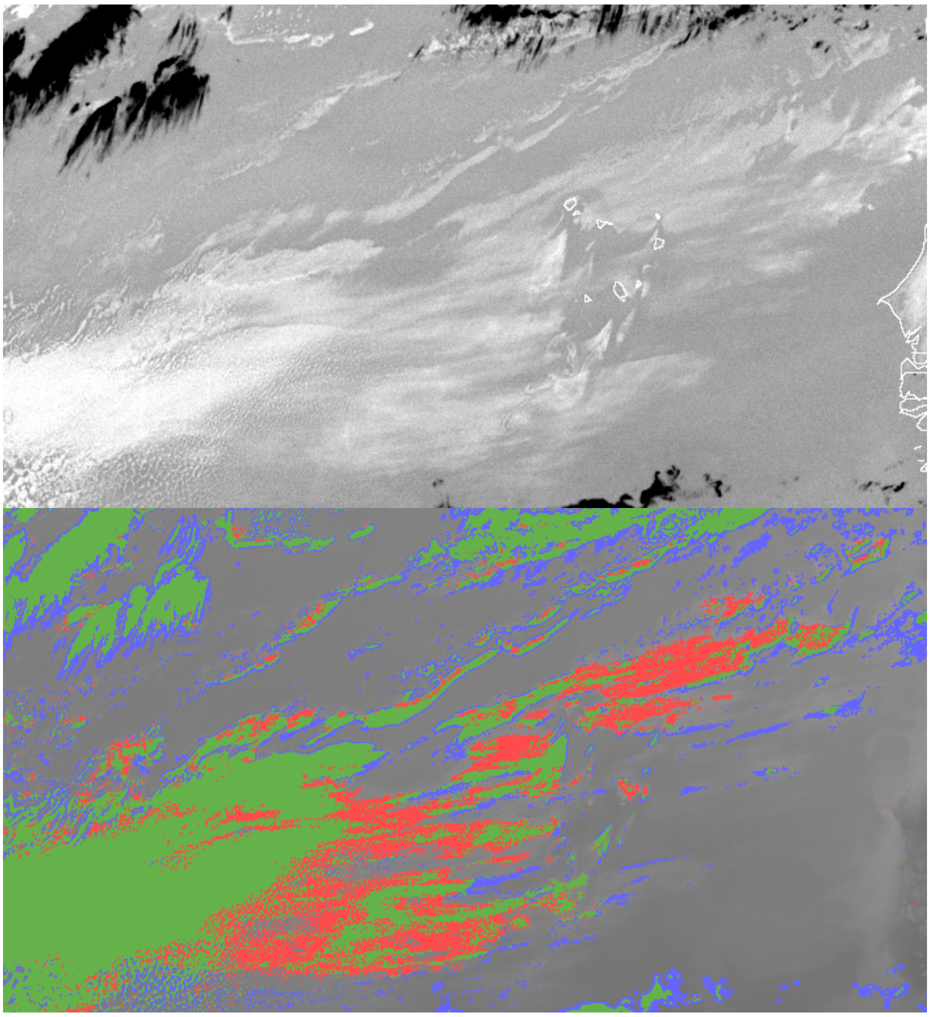


Figure 11 Meteosat-10, 3 March 2013 21h00 UTC ; (top) enhanced T10.8-T3.8 with low clouds appearing clear gray, sea in intermediate gray and high clouds dark; (bottom) red pixels correspond to those flagged as cloud by the prototyped RTTOV-based test of T3.8, green corresponds to pixels detected both by prototype and operational SAFNWC, and blue are detections by other operational SAFNWC test, grey pixels are T39 (warm is dark)

2.2.1.2.3.2 Direct thresholding of T10.8 over sea

If tuned to perform an efficient detection of low clouds the RTTOV-based test of T10.8 at night over sea leads to increase false alarms (more frequent than when thresholding T3.8). When relaxed it becomes less efficient to detect low clouds (not as efficient as test of T3.8) but remains still useful to improve the detection of semitransparent clouds over sea (these types of clouds are rarely caught by the thresholding of T3.8).

The surface temperature used in the RTTOV simulation comes from last available OSTIA analysis (generally of the previous day). To minimize false alarms it is necessary to make the threshold looser where the surface temperature analysis is more uncertain. An offset depending on T108 simulations (surface emissivity and total atmospheric transmission), accounts also for local error of the OSTIA analysis and the maximum standard deviation of the monthly climatology of SST. The test is not applied where terrain type is inland water.

$$Thr=T_{SIM}- \varepsilon*\tau_s*[(T_{SFC}-T_{Ostia,}) + local\_ostia\_error(x,y)*ostia\_margin\_factor\_sea$$

$$+maxstdev\_climostia*clim\_margin\_factor] -margin\_offset - Bias_{TSIM}$$

An effect of this test is illustrated with Meteosat-10 data on 20 March 2013,15h00 UTC over central Atlantic.

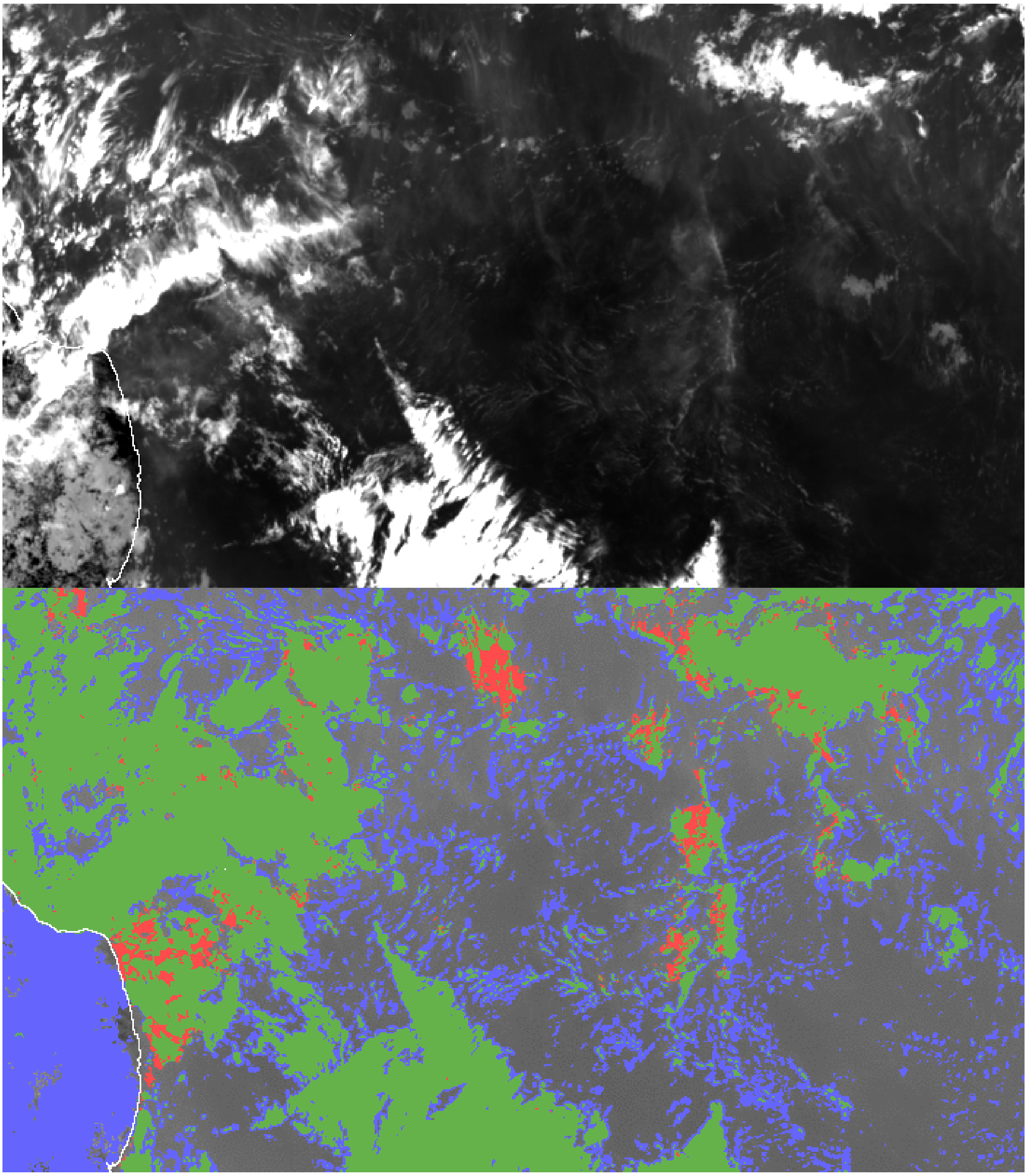


Figure 12 Meteosat-10, 20 March 2013 15h00 UTC ; (top) enhanced T10.8 (top) ; (bottom) red pixels correspond to those flagged as cloud by the prototyped RTTOV-based test of T108, green corresponds to pixels detected both by prototype and operational SAFNWC, and blue are detections by other operational SAFNWC test

2.2.1.2.3.3 Direct thresholding of T10.8-T12.0

This test may be useful to improve the detection of semitransparent clouds. It happens that it complements the direct T10.8 thresholding. It is applied over land only at night.

2.2.1.2.3.4 Direct thresholding of T8.7-T3.8 at night over barren surfaces

The difference T8.7 – T3.8 at night is useful to detect low clouds over barren grounds. Such surfaces have low T8.7 – T3.8 signatures whereas the low clouds exhibit higher values. Therefore the contrast between the cloud and such a background is higher with (T8.7 – T3.8) than with (T10.8 – T3.8) as this feature is high for barren surfaces and low clouds.

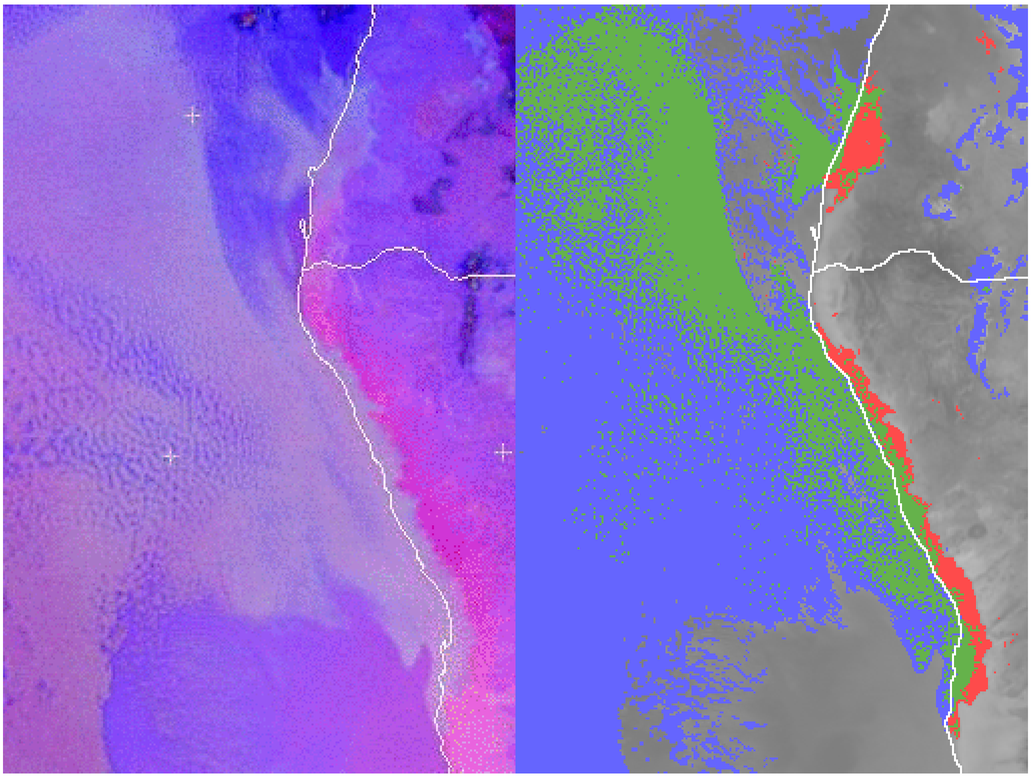


Figure 13 Meteosat-10, 2 March 03h00UTC ; EUMETSAT Fog RGB depicting low cloud spreading over Namib desert (left), Prototype T8.7-T3.8 direct thresholding (right), red pixels correspond to those flagged as cloud by the prototyped RTTOV-based test of T8.7-T3.8, green corresponds to pixels detected both by prototype and operational SAFNWC, and blue are detections by other operational SAFNWC test, grey pixels are T3.8 (warm is dark)

As observed when analysing the prototype behaviour, this test detects also dust clouds over barren surfaces. The following case observed on 22 February 2013 with Meteosat-10 data illustrates that this test performs also detection of dust clouds over barren surfaces at night. Frontal dust clouds are lifted up in areas where strong winds associated to a wide mature storm are observed. The dust clouds were also partially detected by the previous Cloud Mask algorithm, but the prototype of the direct thresholding of T8.7 –T3.8 improves particularly the detection of the prefrontal dust cloud growing on the warm side of the cold front (South East Libya), and adds also the detection of the a part of the postfrontal dust cloud present above the Great Sand Sea, which appears much thinner than the first one. One can also note that clear barren surfaces displaying similar colours as dust clouds are correctly classified as clear by the prototype.

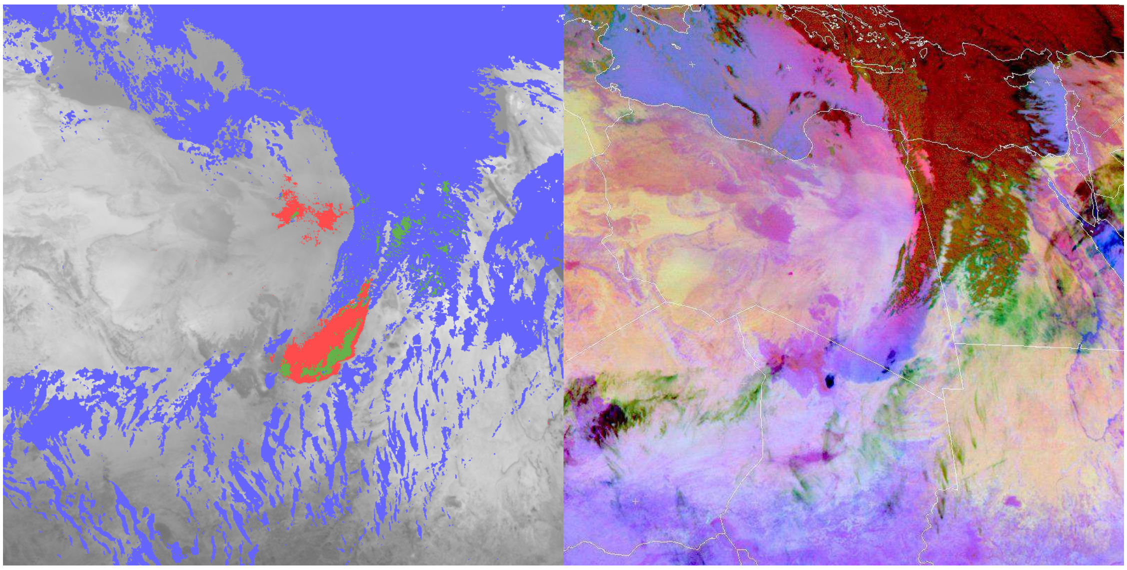


Figure 14 Meteosat-10, 22 February 2013 00h00 UTC ; Prototype T8.7-T3.8 direct thresholding (left), red pixels correspond to those flagged as cloud by the prototyped RTTOV-based test of T8.7-T3.8, green corresponds to pixels detected both by prototype and operational SAFNWC, and blue are detections by other operational SAFNWC test, grey pixels are T8.7 (warm is dark); EUMETSAT dust RGB (right)

2.2.1.2.3.5 Direct thresholding of T10.8 – T8.7 at high satellite angles

SAFNWC cloud mask makes use of T10.8 – T8.7 at high satellite angles to improve the detection of low clouds (T10.8-T3.8 becomes less efficient when viewing angle is high). We have prototyped a direct thresholding of T10.8 – T8.7 and observed its behaviour. Its impact on a poor detection by operational SAFNWC cloud mask is illustrated below. The red pixels added by the prototype are more numerous when viewing angle increases. Only very few false alarms appear over Caucasu mountains between Black Sea and Caspian Sea, at the border between Georgia and Russian federation. To avoid these false alarms the final test is not applied over mountains.

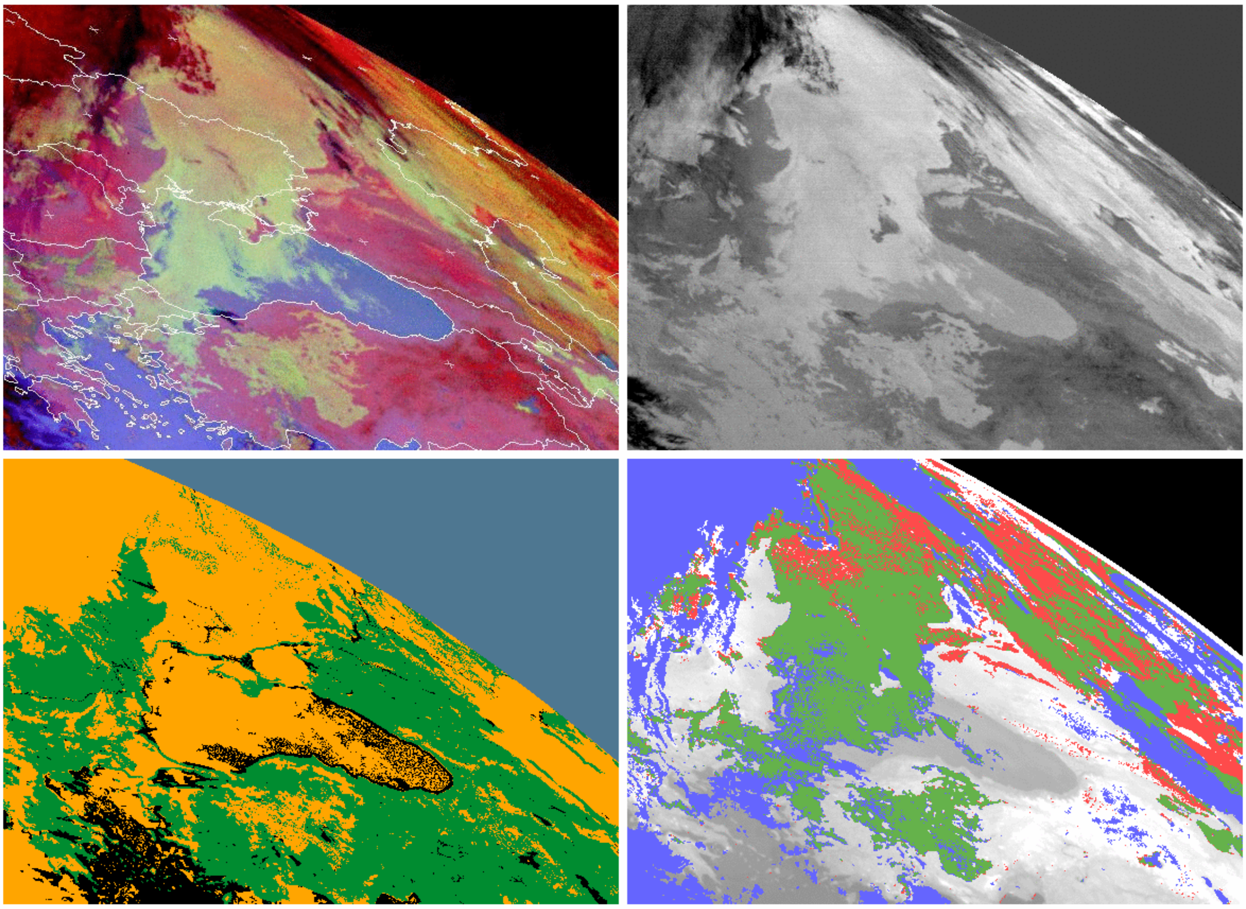


Figure 15 Meteosat-9 3 January 2013 00h00 UTC; Fog RGB (top left); T10.8-T8.7 clear gray pixels are low clouds (top right);MPEF Cloud mask (bottom left); Prototype T10.8-T8.7 direct thresholding (bottom right), red pixels correspond to correction of SAFNWC cloud mask with prototype, green corresponds to pixels detected both by prototype and operational SAFNWC, and blue are detections by other operational SAFNWC test, grey pixels are T8.7 (warm is dark)

2.2.1.2.4 Temporal test to detect rapidly moving or developing clouds

This time-differencing test is applied over the whole image to pixels still classified as cloud-free after the set of tests using LUT or RTTOV on line (2.2.1.2.2 and 2.2.1.2.3). It is designed to catch high thin clouds moving rapidly and appearing colder than their underlying surface that are not detected by spectral or textural tests. It is similar to the technique described by d'Entremont and Gustafson, 2003. A time-interval around 15 minutes (depending on satellite) is used.

- Over sea a pixel whose Δ_{15mn}(T10.8) is lower than -0.6K is declared as cloudy.
- Over land a pixel whose Δ_{15mn}(T10.8) is lower than DT10.8 is declared as cloudy.

where DT10.8 varies from –3.0K to -0.6K according to time related to local sunset and sunrise. For deserts near sunset DT10.8 has been set to –4K. This temporal test is also applied to snow contaminated pixels.

The threshold DT10.8 used over land is computed so that a maximum cooling in the diurnal cycle near the sunset does not generate a false alarm. Therefore the test may be more efficient over arid surfaces around sunset than at noon during the warming period before the observed maximum temperature. Its computation is illustrated in Figure 16 below.

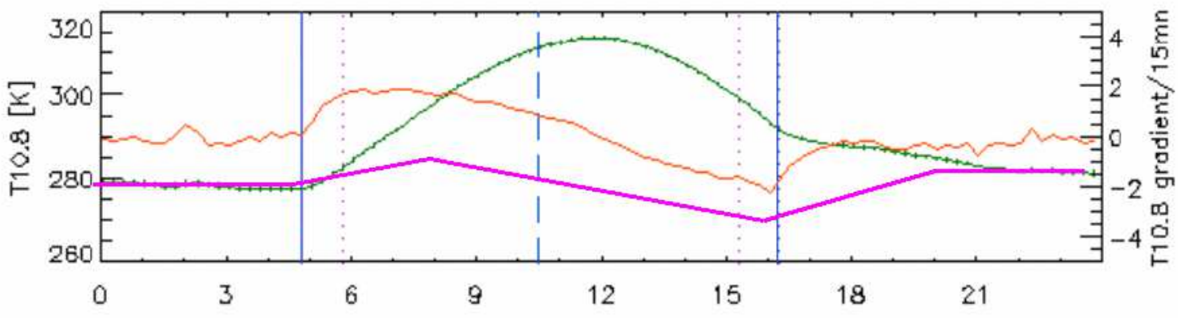


Figure 16 graphical illustration of DT10.8 threshold over land (pink) for a 24h period labelled in UTC time, sunrise and sunset are vertical solid blue line, compared with a real T10.8 cycle(green) and its gradient (orange) for a 15 minute interval

The pixels caught by this test are flagged as of “questionable quality” (see 2.2.2.4).

2.2.1.2.5 Detection of low clouds in twilight conditions

The detection of low clouds in twilight conditions is performed in two steps. It is applied to pixels still classified as cloud-free after the set of tests using LUT or RTTOV on line (2.2.1.2.2 and 2.2.1.2.3) and the temporal test (2.2.1.2.4). The pixels detected by this test are flagged as of “questionable quality” (2.2.2.4).

2.2.1.2.5.1 Temporal test to restore stationary low or mid-level clouds in twilight conditions

The day-night terminator separates sunlit from dark regions and its line is apparent near local sunrise and sunset. It crosses the earth's disk with a speed about 1600 km/h in equatorial regions. Its orientation varies with the season, showing a larger sunlit area in the higher latitudes during summer. If defining the day-night transition as the area where sun zenith angle θ is between 80° and 93°, about one hour is necessary to get separated zones near the equator, for high latitude regions it may be longer. Therefore a one-hour time interval between images is a minimum if one wants to get a given “twilight” pixel previously analysed by the day or night algorithm.

In the current image the day-night transition portion is delimited according to sun zenith angle, and temporal differences of features that are known to be nearly insensitive to solar illumination change for a low cloud target are computed: $|\Delta_{1h}(T10.8)|$, $|\Delta_{1h}(T10.8-T12.0)|$, $|\Delta_{1h}(T10.8-T8.7)|$ where $|\Delta_{1h}|$ is the absolute value of temporal difference with a time interval of one hour. The CMA_{1h} and CT_{1h} of the previous image are used to identify pixels of the current image that were previously classified as low or mid-level clouds one hour earlier and detected by a high confidence test. Those pixels are restored as cloudy in the current transition area if the absolute values of temporal features, noted Δ_{1h},satisfy the following conditions:

- over land $|\Delta_{1h}(T10.8)| <1.0K$ and $|\Delta_{1h}(T10.8-T8.7)|<0.5K$
- over water $|\Delta_{1h}(T10.8)| <1.0K$ and $|\Delta_{1h}(T10.8-T12.0)|<0.6K$

When analysing the results obtained by this first step during testing, we were not fully satisfied because cloud parts remained undetected, but still discernible in enhanced VIS image. In general the inner part of low cloud decks were caught while their optically thinner part or new portions appearing with the cloud development or its forward motion may have passed through the temporal differencing procedure and kept as clear. Moreover pixels that are not detected one hour earlier can’t be restored by this technique. An example of the efficiency of this technique is illustrated in Figure

17, where one can see that it is efficient for a part of the image, where clouds were previously detected, and that it does not work over a wide area over Spain where clouds were not detected one hour eralier.

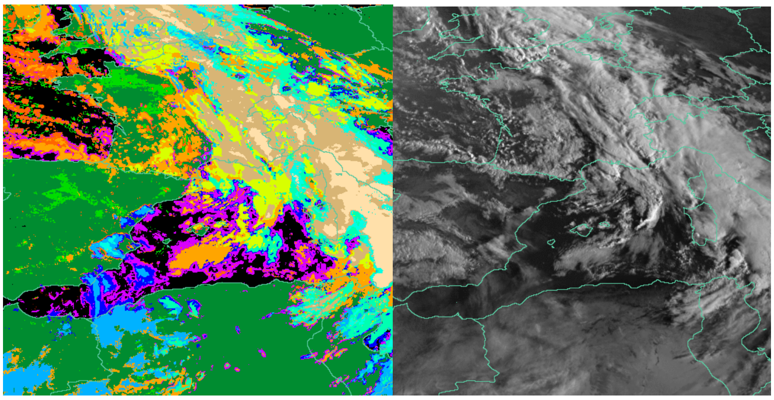


Figure 17 Illustration of stationary clouds restoration displayed in light green in CT picture (right) compared with BRF 0.6 (left) MSG2 on 25 September 2006, 06h30 UTC

2.2.1.2.5.2 Spatial expansion of stationary clouds in twilight conditions

To improve the detection of the outer part of the cloud we decided to use the radiometric statistical attributes of the newly detected pixels as constraints of a region-growing technique applied to the initial stationary cloudy pixels identified by the first step. The goal of this second step is to spatially extend the initial cloud “seeds” to their connected pixels presenting similar characteristics.

The normalization used when handling VIS values is an inverse cosine function of satellite zenith angle θ. This purely geometric normalization is an air-mass correction of the solar beam pathlength assuming a plane-parallel atmosphere. In the day-night terminator area this assumption is no longer correct, and two effects become important: curvature of atmosphere and refraction. When sun zenith angle approaches 90°, because of curvature of atmosphere the solar beam pathlength is significantly shorter than the plane parallel one. This explains why for VIS pictures normalized using this inverse cosine function, values displayed near day-night terminator appear too high.

Twilight whose exact definition is the diffused light in the sky when the sun is just below the horizon, just after sunset or just before sunrise, is an effect of atmospheric refraction. The refractive index of air decreases when wavelength increases, in other words, blue light, which comprises the shortest wavelength region in visible light, is refracted at significantly greater angles than is red light. Refraction may be neglected even for θ near 85°, but not when caring about features in rather low atmosphere for higher sun zenith angle.

For these two reasons we have replaced the inverse cosine BRF normalization function by an analytical formulation valid for a standard atmosphere proposed by Li and Shibata, 2006. Their parameterization accounts for spherical atmosphere and refraction. Aware that this parameterization should be adapted to the narrowband spectral characteristics of each VIS band and to the current state of atmosphere, we keep it as a first order correction for a better handling of VIS BRF in twilight area. Figure 18 compares it with inverse cosine normalization.

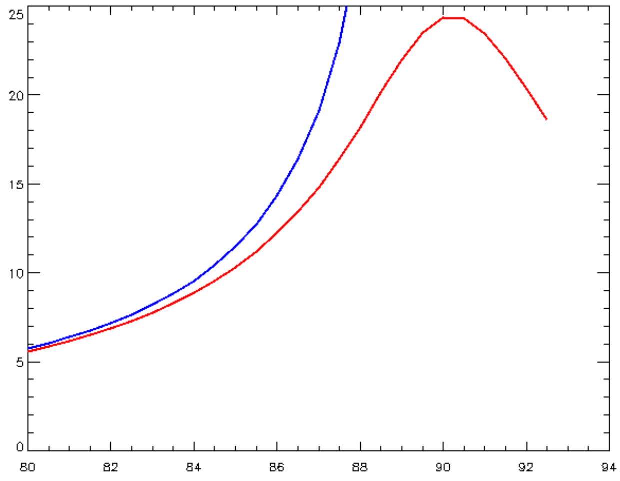


Figure 18 VIS normalization factor variation with sun zenith angle, inverse cosine (blue) and parameterization given by Li et al 2006 (red)

Because BRF of pixels in day-night terminator portion becomes very sensitive to noise when approaching the terminator line, we allow region-growing for 75°<θ<89°. Groups of connected pixels restored by the first temporal-differencing method form initial seeds for the region-growing are identified. Any group comprising more than eight elements is taken into account. For each significant group two mean values are computed: normalized BRF0.6 (AVG0.6) and T108 (AVG10.8). A group is expanded while a 8-connectivity neighbour pixel x belonging to the day-night transition area satisfies simultaneously the following conditions:

- $SCAT_x$<150° and
- $BRF0.6_x$ > MAX(1.05*AVG0.6,THR_{exp}) and
- AVG10.8 + 0.5K <$T10.8_x$< AVG10.8 - 5.0K

Where THR_{exp} is 40% over Africa to avoid false alarms over arid areas and 30% elsewhere
$SCAT_x$ is the scattering angle [0°,180°], 0° for backward scattering
$BRF0.6_x$ is the normalized BRF in VIS06 at location x
$T10.8_x$ is the brightness temperature of 10.8 µm at location x

The main risk of the method is to add cloud false alarms and it is maximal when the radiometer is looking in the sun direction because measured clear-sky BRF0.6 increase dramatically. That is why we forbid region growing at locations where scattering angle is greater than 150°. Moreover we reject region-growing restoring more than 10000 elements for the same seed assuming that a too wide region-growing is suspect. The strategy employed in the region-growing technique may produce small differences in presence of blurry low cloud edges resulting in small jumps in cloud features animations.

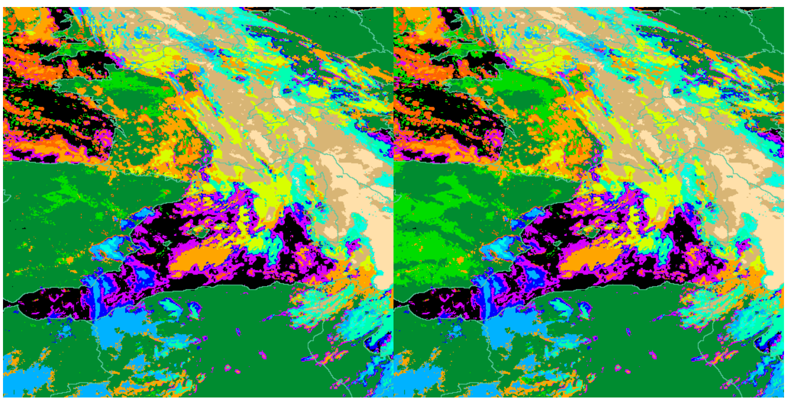


Figure 19 Illustration of spatial expansion restoration and stationary cloud restoration displayed in light green in CT picture (right) compared with stationary clouds restoration only (left), MSG2 on 25 September 2006, 06h30 UTC

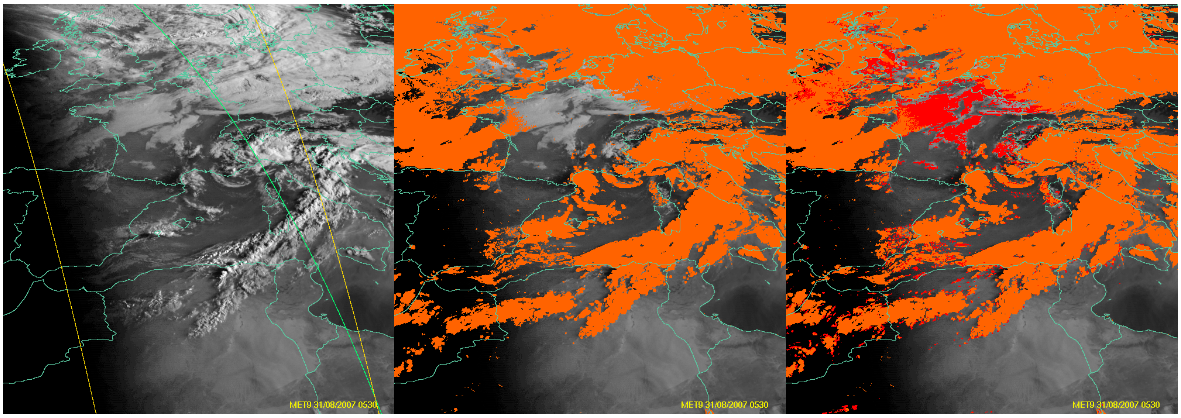


Figure 20 31 August 2007, 05h30 UTC METEOSAT 9 left: Normalized SEVIRI 0.6 with limits of transition area (yellow) and 1h earlier (green) centre: SAFNWC/MSG v2.0 cloud mask (orange) superimposed with SEVIRI 0.6 right: same as centre with new twilight detection (red)

2.2.1.2.6 Analysis of high resolution solar channels to detect sub-pixel clouds

A better detection of small scale low clouds at daytime was requested by users during the NWC SAF users workshop held at Madrid in 2005. Therefore the use of HRV for its better spatial resolution (1km x 1km at satellite sub-point) was one of the improvement tasks planned during CDOP. The algorithm described in this section is the generalisation of the algorithm implemented during CDOP for HRV: high resolution visible channel (HRV for MSG) is used to detect sub-pixel clouds inside pixels at default horizontal resolution.

We designed this improvement as an add-on option of the cloud mask, as some users may be restricted by hardware considerations or would like to avoid changes in cloud detection efficiency that is the main drawback of using HRV as it does not always cover the same regions of the earth disk all the day long. The optional HRV-based algorithm is applied only to pixels remained as clear after previous steps of the cloud mask algorithm (spectral and textural thresholding, temporal-differencing and region-growing. It requires not only the high spatial resolution solar channels data of the current scene, but also the scene observed and analysed around 15 minutes earlier.

This process is applied to default horizontal resolution pixels still classified as cloud-free after the set of tests using LUT or RTTOV on line (2.2.1.2.2 and 2.2.1.2.3), the temporal test (2.2.1.2.4) and the test in twilight conditions (2.2.1.2.5). The pixels at default horizontal resolution detected by this process are flagged as of "questionable quality" (2.2.2.4).

2.2.1.2.6.1 High spatial resolution visible reflectance test over land

The high horizontal resolution visible channel is denominated hrvis (for MSG: HRV) and each pixel at default horizontal resolution contains nxn hrvis pixels (3x3 for HRV).

The assumption is that any low cloud exhibits higher hrvis reflectance than underlying clear-sky surface. This test is designed to catch static small scale low clouds that are not detected by change detection technique.

A pixel is classified as cloud contaminated if not already classified as cloud by previous tests and if:

- solar elevation > 5° and Max(R_{hrvis} nxn) > R_{hrvis}threshold
  Where Max(R_{hrvis} nxn) is the maximum hrvis normalized reflectance in the nxn hrvis array covered by the corresponding pixel at default horizontal resolution.

The threshold is estimated of clear-sky broadband reflectances derived from maps of monthly values and an angular empirical correction. The monthly maps are obtained from a combination of black sky albedo for 3 MODIS narrow bands (0.55µm, 0. 67µm and 0.86µm) available from a NASA website dedicated to MODIS atmosphere (http://modis-atmos.gsfc.nasa.gov/ALBEDO/index.html). Black-sky albedo is the directional hemispherical reflectance computed at local solar noon estimated from MODIS Terra and Aqua measurements.

The following black-sky albedo combination is used for HRV:

- $Rmap=0.265xBSA_{0.55}+0.222xBSA_{0.67}+0.513xBSA_{0.86}$

And the threshold is derived from this combination according to

- $R_{hrvis}threshold = 1.0xRmap + 60.0 + 29*(\cos(scattering\_angle)-0.68)^2$

where scattering_angle is the scattering angle ([0.,π] from backward to forward direction).

The parameterization of this test has been designed using a period of collocations of SYNOP and satellite data including HRV. When applied to full disk data during summer 2009 false alarms that were too difficult to remove (not clearly depending on Rmap or scattering angle) appeared in some places. To avoid them, the threshold has been increased lately before the software delivery to the integrator. The consequence is that some rather static topographically induced clouds such as for instance valley fog not directly detected from visible channels at lower horizontal resolution still remain not detected by this test.

2.2.1.2.6.2 Test of high spatial resolution visible channel local spatial texture over sea

The high spatial resolution visible channel is denominated hrvis (for MSG: HRV) and each pixel at default horizontal resolution contains nxn hrvis pixels (3x3 for HRV).

A pixel is classified as cloud contaminated if:

- solar elevation > 10° and SD(R_{hrvis} nxn)/Mean(R_{hrvis} nxn) > .08 or SD(R_{hrvis} nxn) > 0.8%
- solar elevation < 10° and solar elevation > 5° and SD(R_{hrvis} nxn)/Mean(R_{hrvis} nxn) > .16 or SD(R_{hrvis} nxn) > 0.4%

- Mean(R_{hrvis} nxn) and SD(R_{hrvis} nxn) stand respectively for the mean and standard deviation computed using the nxn reflectances of hrvis pixels covered by the pixel at default horizontal resolution

This test based only on hrvis local texture inside pixel at default horizontal resolution detects heterogeneities over sea, one feature detects small clouds when background is rather dark whereas the other one is more efficient for heterogeneities inside clouds or sunglint, that were not detected by previous test based on other visible channels.

2.2.1.2.6.3 Temporal test of high spatial resolution visible channel local spatial texture over land

The high spatial resolution visible channel is denominated hrvis (for MSG: HRV) and each pixel at default horizontal resolution contains nxn hrvis pixels (3x3 for HRV).

This test is a mixture of texture tests, change detection tests and image processing technique.

2.2.1.2.6.3.1 Change detection test over land

A pixel is classified as cloud contaminated if:

- clear (and not snowy)

and

- [SD(R_{hrvis} nxn) > 5% and MIN(RN_{hrvis} nxn)$_{cur}$ > 10%
  and abs(1.0- MAX_{cur}(RN_{hrvis}nxn)/ MAX_{prev}(RN_{hrvis}nxn) > 0.03
  and abs(1.0- MIN_{cur}(RN_{hrvis}nxn)/ MIN_{prev}(RN_{hrvis}nxn) > 0.03]
  or
- [SD(R_{hrvis} nxn) > 1.5% and MIN(RN_{hrvis} nxn)$_{cur}$ > 10%
  and SD_{cur}(R_{hrvis} nxn)/$MEAN_{cur}$(R_{hrvis} nxn) – SD_{prev}(R_{hrvis} nxn)/$MEAN_{prev}$(R_{hrvis} nxn) > 0.03
  and MAX_{cur}(RN_{hrvis} nxn)) > 1.03* MAX_{prev}(RN_{hrvis} nxn))]

-SD MIN MAX MEAN stand respectively for the spatial standard deviation, minimum value, maximum value and mean of the feature.
-R_{hrvis} is the hrvis reflectance
-RN_{hrvis} is the hrvis reflectance normalized by the analytical formulation of solar path length valid for a standard atmosphere proposed by Li and Shibata, 2006. (in place of classical inverse cosine function).
-indices $_{cur}$ and $_{prev}$ stands for pixels from the current image or the one around 15 minutes (depending on satellite) eralier.

The assumption behind this test is that a mobile or evolving bright target inside a nxn hrvis array is a cloud. False alarms that have been problematic are clear sides of cloud shadow limits moving over bright grounds. This is why the pixels detected by this test are further processed by a neighbourhood analysis described below.

2.2.1.2.6.3.2 Clear restoral test over land

This test is designed to remove some false alarms passing through the previous test, and is applied only to pixels detected by the previous test

A pixel at default horizontal resolution scale is restored as clear

- Its MEAN(R_{hrvis}nxn) is minimum among other land pixels in its default horizontal resolution direct neighbourhood (3x3)

2.2.1.2.6.3.3 Cloud restoral test over land

Obviously during visual inspection of the results some clouds remained missed after the change detection test. Brighter pixels in the neighbourhood of pixels detected as clouds by the hrvis change detection algorithm described in the previous sections should also be detected as cloudy. This test is designed to this purpose.

A pixel on land at default horizontal resolution scale in the 11x11 neighbourhood of high resolution visible change detection is restored as cloud if at least 5 pixels inside 11x11 neighbourhood are detected by high resolution visible change detection tests

- MIN(RN_{hrvis} nxn)$_{cur}$ > 10%

and

- MAX(R_{hrvis} nxn) > $MEAN_{11x11}$(Max(R_{hrvis} nxn) of the pixels detected by hrvis if nb > (nxn/2+1))

and

- [SD(R_{hrvis} nxn) > 1.5%]
  or
  [MAX(R_{hrvis} nxn)-MIN(R_{hrvis} nxn) >
  $MEAN_{11x11}$(MAX(R_{hrvis} nxn)- MIN(R_{hrvis} nxn)) of the pixels detected by hrvis if nb > (nxn/2+1))]

2.2.1.2.6.4 Examples of impact using high spatial resolution visible channel

Illustration is done using MSG2/HRV imagery.

2.2.1.2.6.4.1 Maritime cloud patterns

As the algorithms are different over water, 2 cases illustrate typical difficult cloud patterns. The figures show how HRV resolves the cloud field when compared with the low resolution SEVIRI visible band and how the HRV-based detections are transposed at the SEVIRI low spatial resolution. One can also note that generally these detections correspond to either fractional or low clouds in the CT cloud type product.

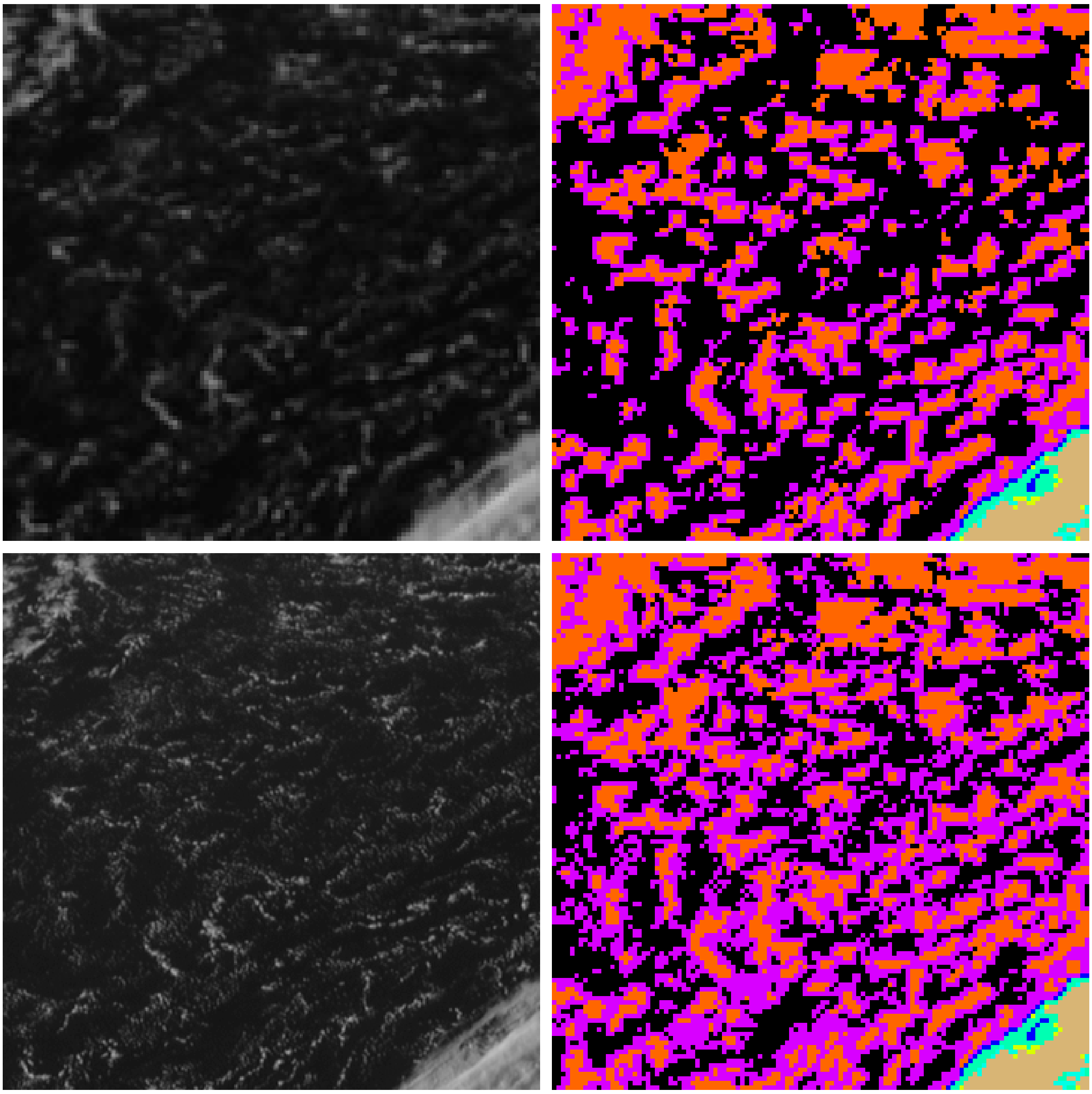


Figure 21 Shallow convection maritime clouds over Northern Atlantic, 8 September 2009. 17h00UTC, (120x120 at low resolution SEVIRI scale). Top left: 0.8 µm visible reflectance; top right: v2009 cloud type; bottom left: HRV reflectance; bottom right: v2010 cloud mask

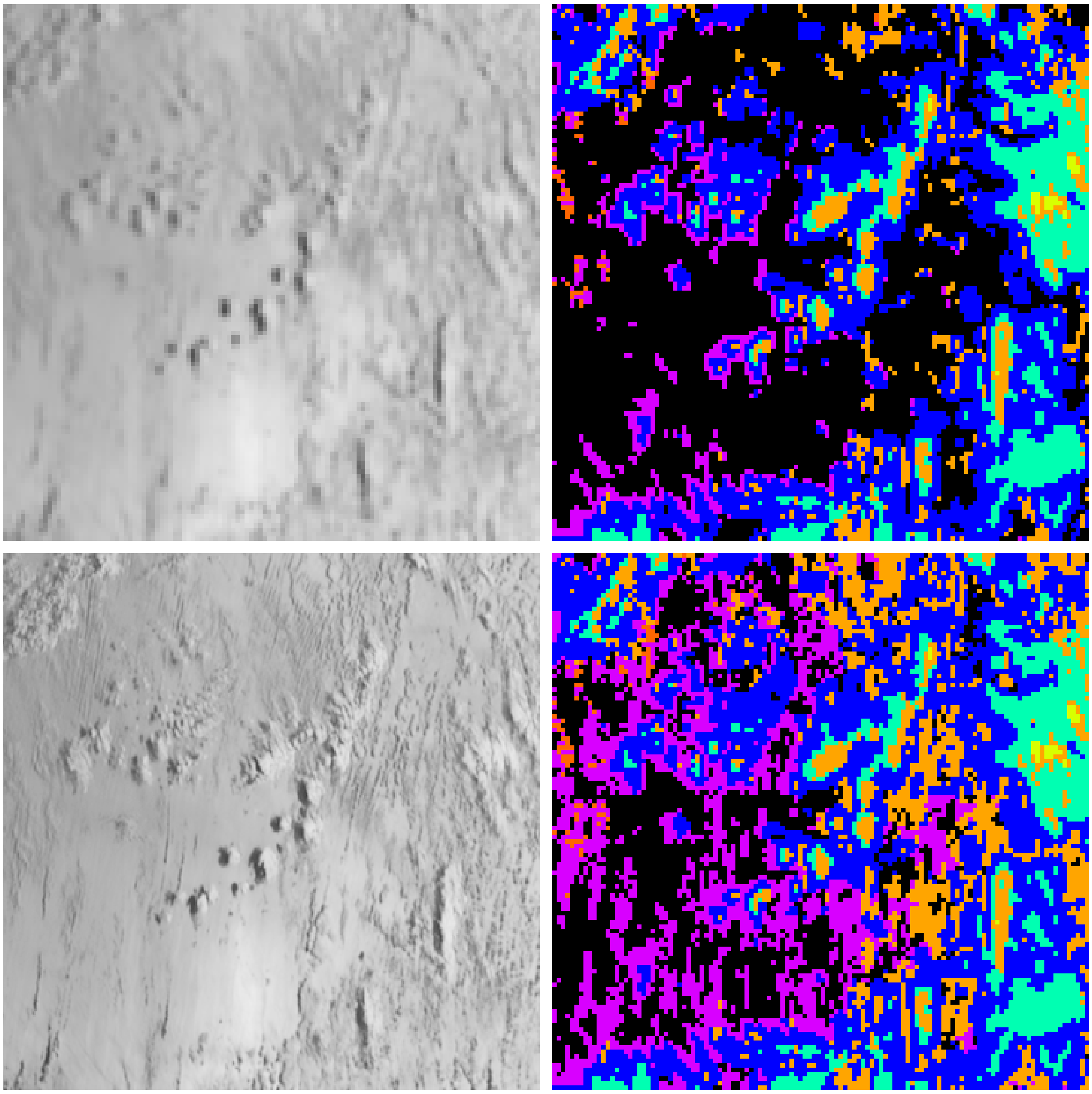


Figure 22 Sunglint with trade-wind convective low clouds over Indian Ocean, 8 September 2009, 04h00UTC, (120x120 at low resolution SEVIRI scale). Top left: 0.8 µm visible reflectance; top right: v2009 cloud type; bottom left: HRV reflectance; bottom right: v2010 cloud type

2.2.1.2.6.4.2 Continental cloud patterns

Four cases are displayed to illustrate situations with various backgrounds where the algorithm applied to HRV data improves the cloud detection, one over Europe, two over Africa, and one over South America.

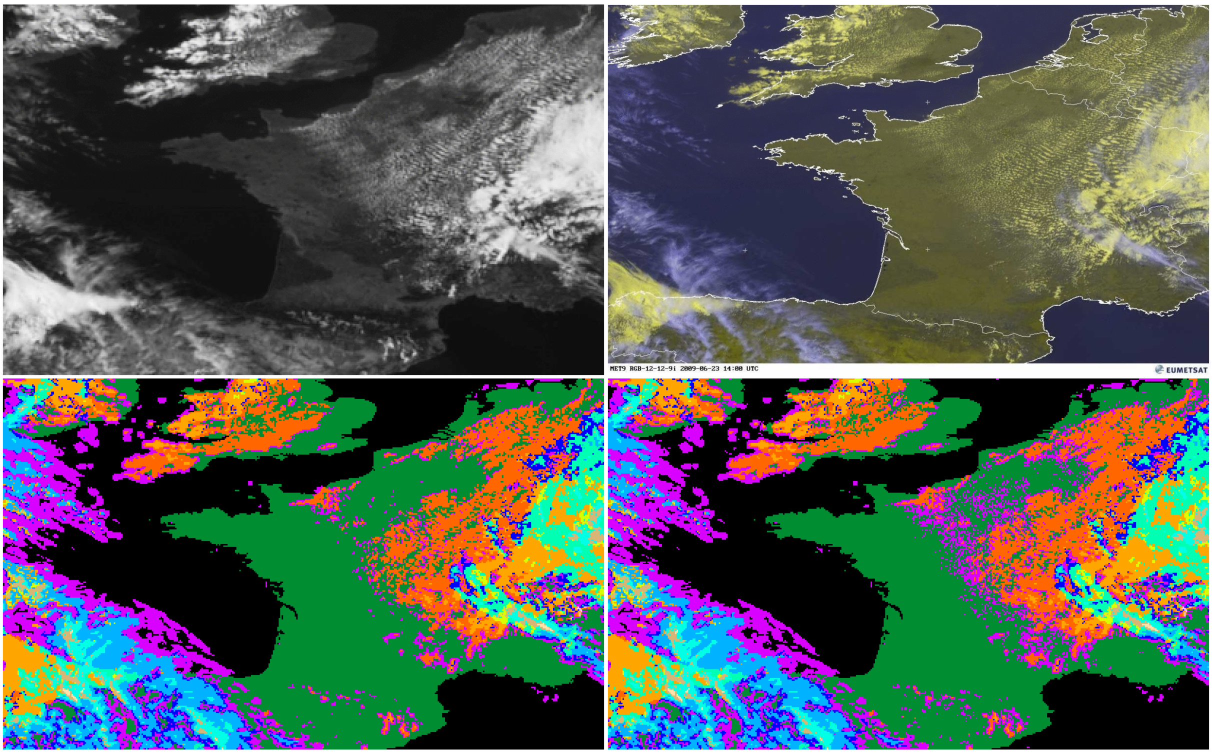


Figure 23 Fair-weather cumulus in subsident air over western Europe, 23 June 2009, 14h00UTC, (1270x770 at SEVIRI low resolution scale). Top left: enhanced 0.6 µm visible reflectance; top right: EUMETSAT RGB (12-12-9); bottom left: v2009 cloud type; bottom right: v2010 cloud type

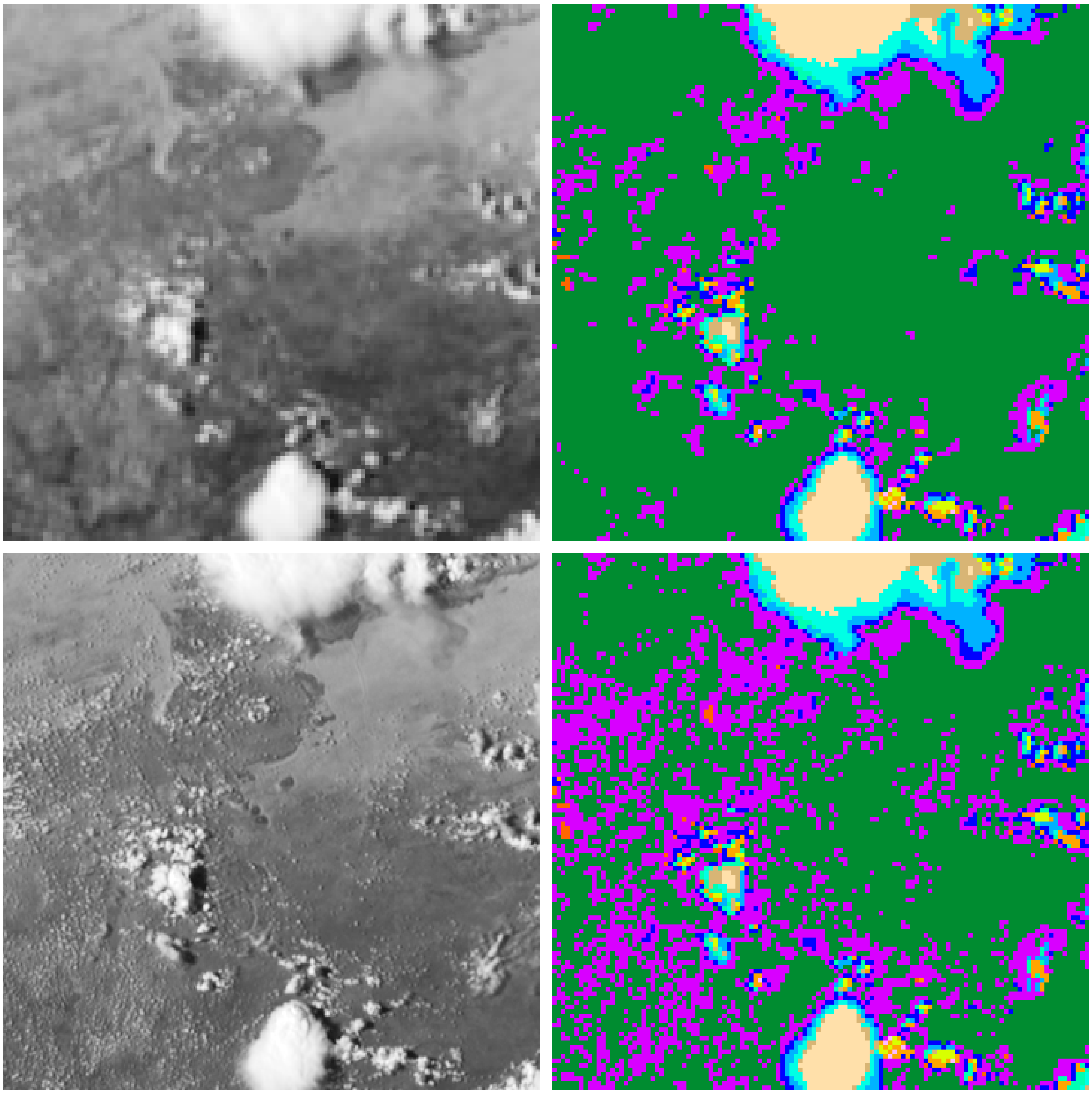


Figure 24 Heterogeneous convection over complex terrain in Mauritania, 8 September 2009, 15h00UTC, (120x120 at low resolution SEVIRI scale). Top left: 0.6 µm visible reflectance; top right: v2009 cloud type; bottom left: HRV reflectance; bottom right: v2010 cloud type

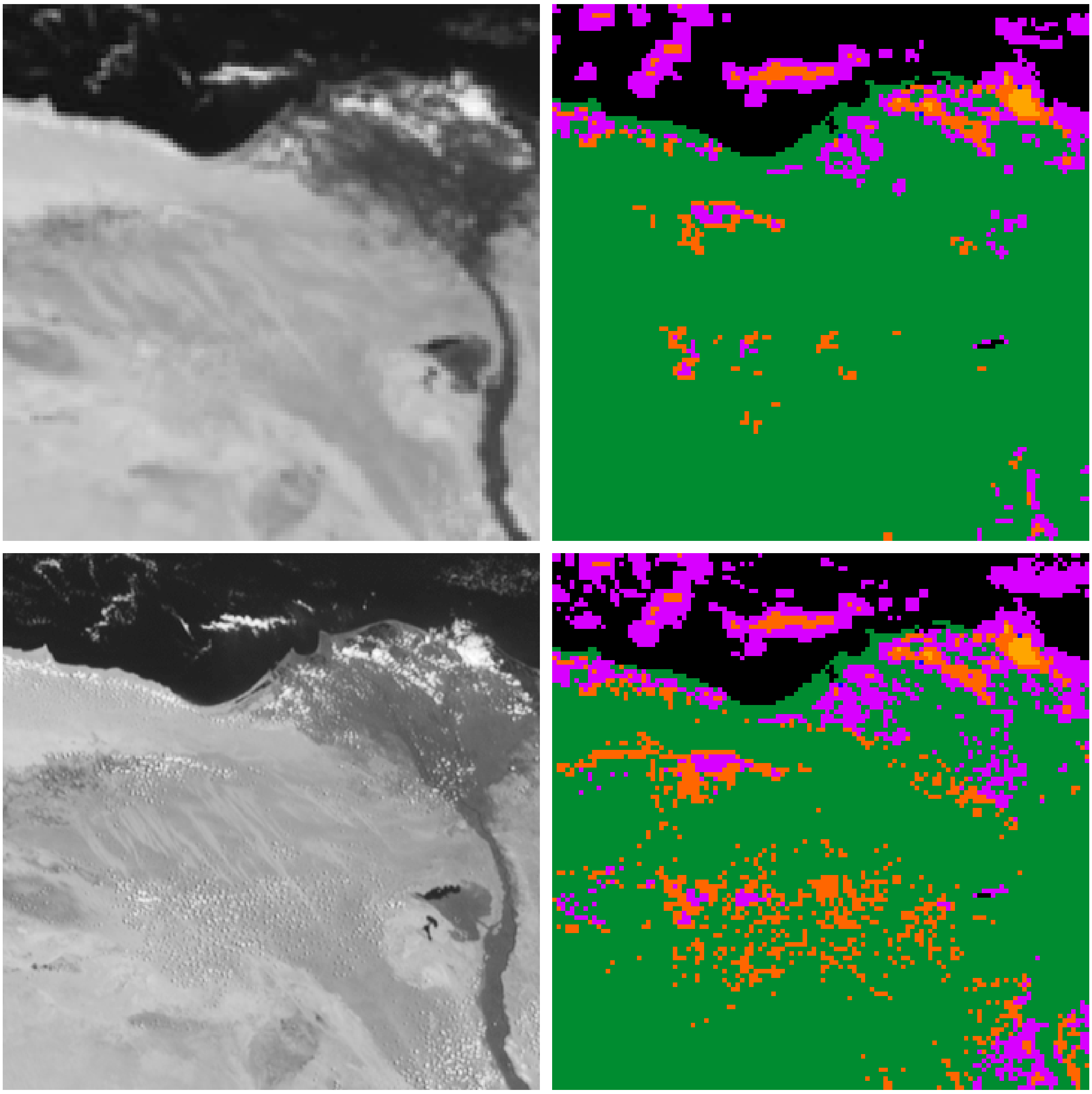


Figure 25 Fair-weather cumulus over Egypt near Nile delta, 9 September 2009, 10h00UTC, (120x120 at low resolution SEVIRI scale). Top left: 0.6 µm visible reflectance; top right: v2009 cloud type; bottom left: HRV reflectance; bottom right: v2010 cloud type

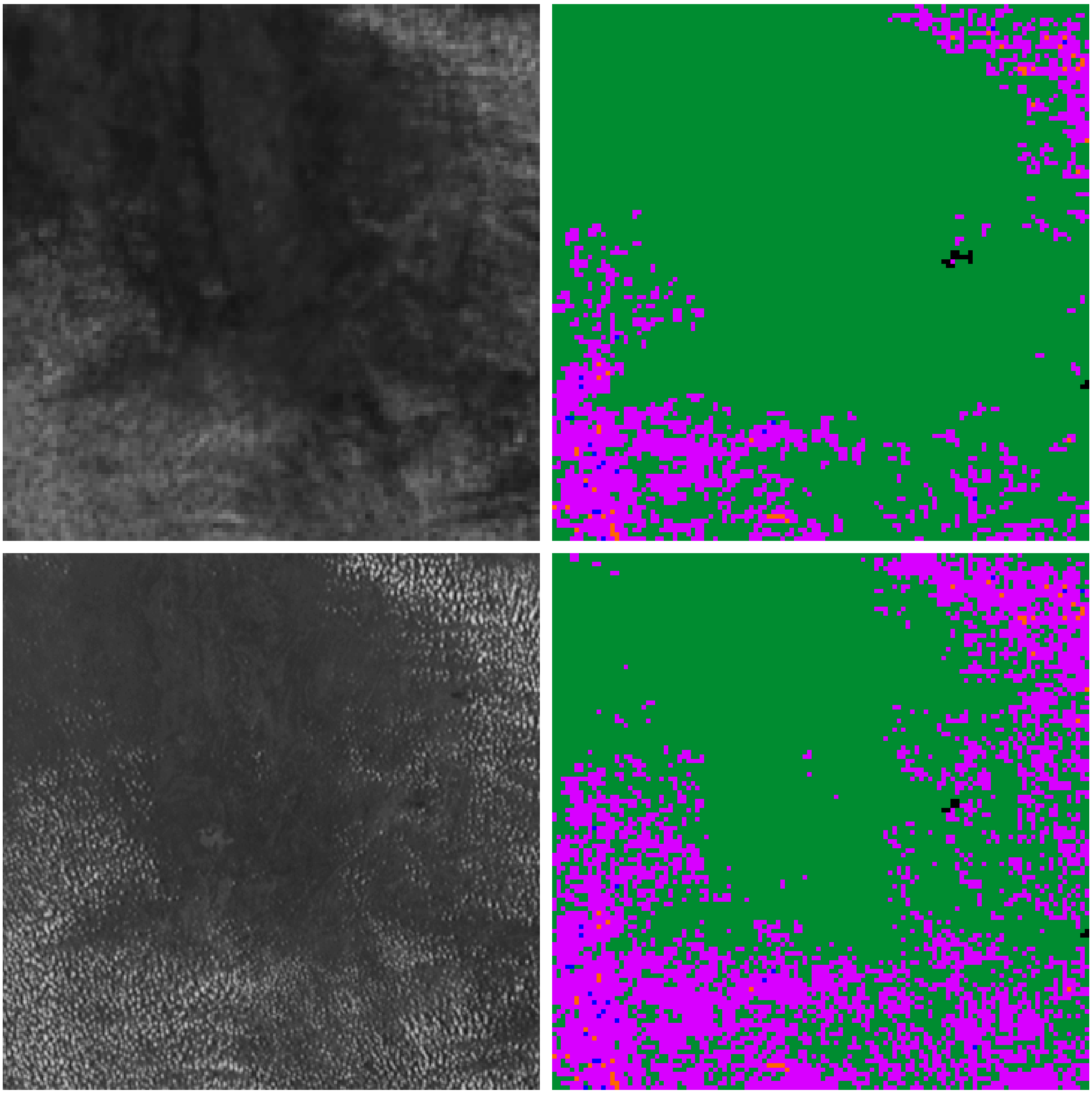


Figure 26 Shallow convection over Brazil, 7 September 2009, 17h00UTC, (120x120 at low resolution SEVIRI scale). Top left: 0.6 µm visible reflectance; top right: v2009 cloud type; bottom left: HRV reflectance; bottom right: v2010 cloud type

2.2.1.2.7 Spatial filtering

The following spatial filtering is applied at the final stage of cloud detection after the sequence of all tests.

One part of this filtering is designed to remove some remaining false alarms in the coldest scenes. It exploits the fact that for some extremely cold ground surfaces, in presence of strong nocturnal clear-sky inversion, the T7.3 brightness temperature, sensitive to atmosphere temperature is warmer than the one observed in the 10.8µm atmospheric window.

A pixel is restored as clear when detected by T108thr test at any illumination, or Visible test or T38T108thr test at daytime or twilight under the following conditions:

- If t108thr < 250K and T7.3-T10.8> 0.5K

The reclassified cloud free pixels are flagged as of "questionable" quality.

The second spatial filtering is designed to remove false alarms in the sea side of the coastal zone due to the use of local spatial texture test, even relaxed, in the vicinity of coast line. This spatial filtering dedicated only to coastal pixels is designed to reduce this default. It is not applied around a water group smaller than 50 elements

The coastal seaside pixels are identified by subtracting the result of 2 morphological dilatations of land pixels eroded twice by a 3x3 structuring element.

The following filtering is applied to coastal pixels:

- Over sea a pixel detected cloudy by a local spatial texture test is restored clear when belonging to a 3x3 box clear at 10% and to a 7x7 box clear at 50%.
- Over land a pixel detected as cloudy is restored clear when belonging to a 3x3 box clear at 10% and to a 7x7 box clear at 50%.

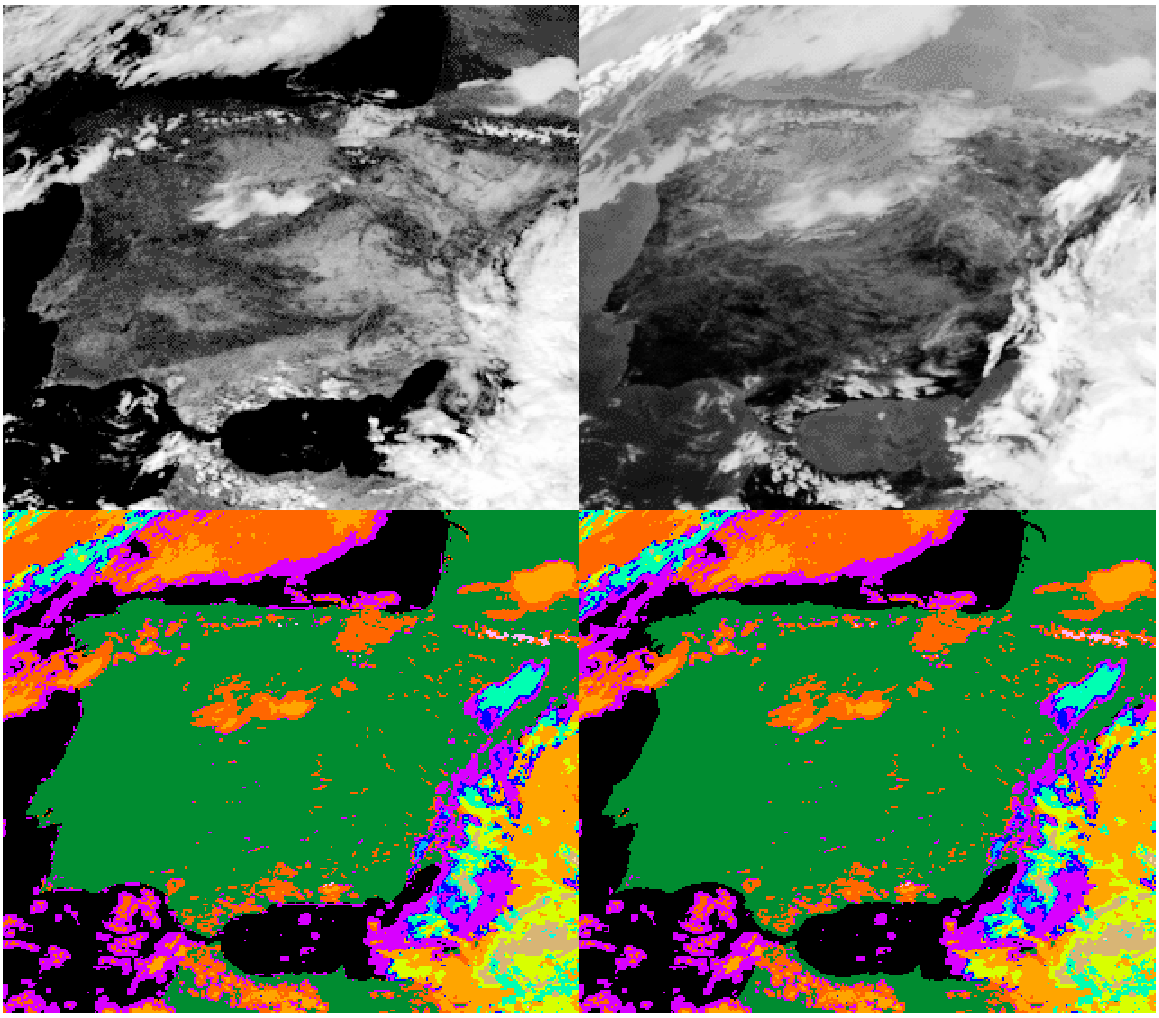


Figure 27 Illustration of spatial filtering effect in coastal area, 28 November 2007 12h00UTC top left VIS 0.6, top right IR T10.8; bottom left, CT without coastal filtering; bottom right CT with coastal filtering

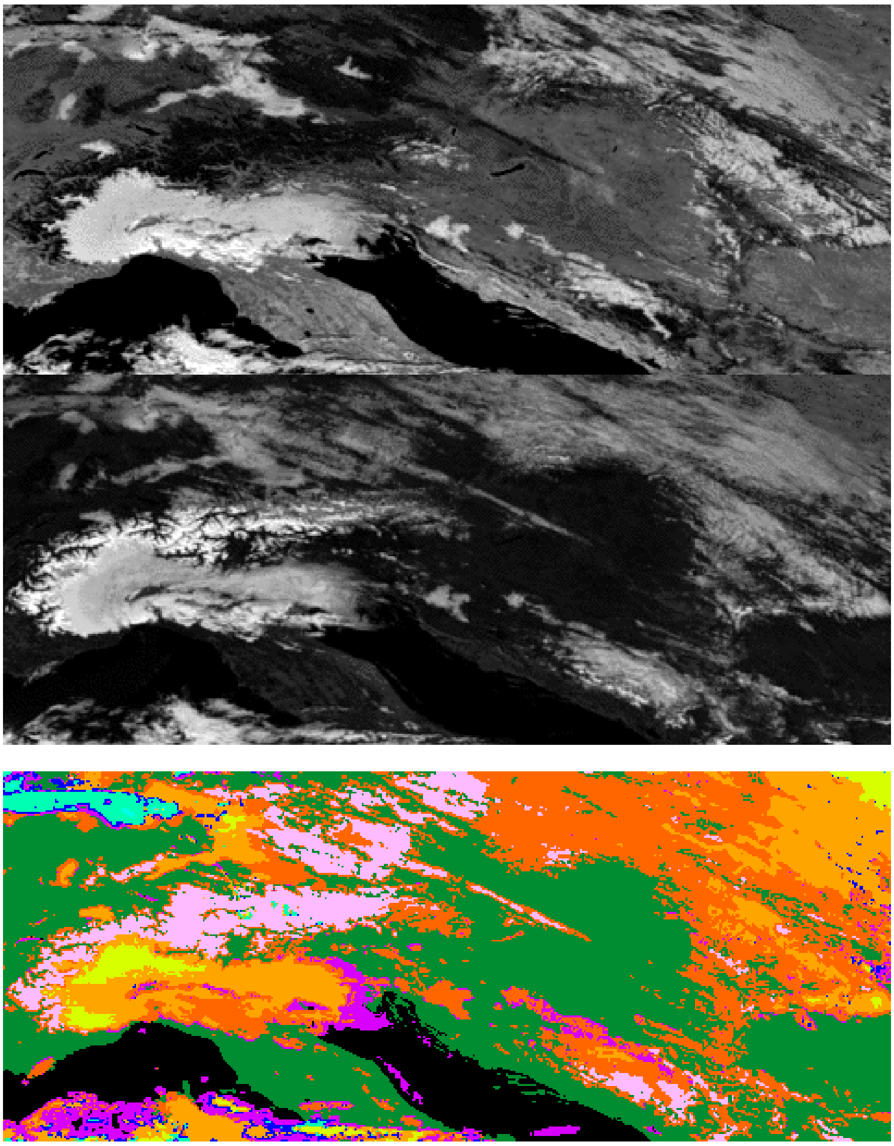
The reclassified pixel are flagged as of "interpolated" quality.

The last spatial filtering is designed to reclassify the narrow bands of low clouds often observed in the surrounding of snowy areas. In general such pixels are in fact partially covered by snow and wrongly detected as cloud because insufficiently covered by snow. When examining in details this default we have found that in general such pixels are detected cloudy by a local spatial texture test.

The outer limits of snowy areas are identified by subtracting the result of 2 morphological dilatations of snowy pixels by a 3x3 structuring element eroded twice by the same structuring element.

The following filtering is applied to outer edge band of a snowy area:

- A pixel detected cloudy by local spatial texture test is restored clear if belonging to a 3x3 box with at least a clear pixel and without cloudy pixels detected by another test



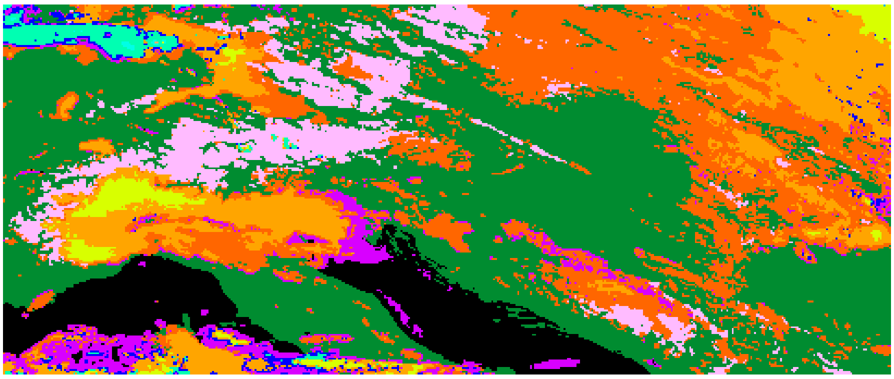


Figure 28 Illustration of spatial filtering effect in snowy area edges, 28 November 2007 12h00UTC, from top to bottom; NIR 1.6,VIS 0.6; CT without snow edge filtering; CT with snow edge filtering

The following spatial filtering process is finally applied:

- all the isolated cloudy pixels that have been detected by a test using the 3.8µm are reclassified as cloud-free.
- all the isolated cloud free pixels are reclassified as cloudy.

The reclassified pixel are flagged as of "interpolated" quality.

2.2.1.2.8 Dust cloud identification

The following algorithm has been empirically derived to detect and classify dust clouds at daytime and also at night-time over sea:

Over the ocean at daytime, a pixel is classified as contaminated by dust cloud if :

- Separation from cloud free surfaces:
- {
  - [(R1.6µm / R0.6µm) > 0.4 and
    (R1.6µm > R1.6threshold - 5%) and
    (T12.0µm-T10.8µm) > T120T108threshold)] or
  - [(R1.6µm / R0.6µm) > 0.6 and
    (R1.6µm > R1.6threshold - 5%)] or
  - [(R1.6µm / R0.6µm) > 0.4 and
    (R1.6µm > R1.6threshold - 7%) and
    SD(T10.8µm-T3.8µm) <0.3°C and
    (T12.0µm-T10.8µm) > -1K)] or
  - [R0.6µm > R0.6threshold - 5% and
    (T12.0µm-T10.8µm) > T120T108threshold] } and

- Separation from clouds:
- {
  - -5°C - 5*(1/cos(θsat) -1) < T10.8µm – SSTclim and
  - (T8.7µm-T10.8µm) >-(2.5-0.17*(1-1/cos(θsat))) and
  - SD(T10.8µm)<0.4°C and
  - { [R0.6µm < R0.6threshold +20% and
    SD(R0.6µm)<0.6 % and SD(R0.8µm)<0.6 % and
    SD(R1.6µm) <0.3%+0.01*R0.6µm or SD(R0.6µm)<0.1% and
    SD(T10.8µm-T3.8µm) <0.4°C] or
    [R0.6threshold+10%<R0.6µm and
    (T8.7µm-T10.8µm) > -1.0 and
    SD(R0.6µm)<1.0 %] or

[R0.6threshold+20%<R0.6µm<R0.6threshold +40% and
(T8.7µm-T10.8µm) > -1.5 and
SD(R0.6µm)<0.6 % and SD(R0.8µm)<0.6 % and
SD(T10.8µm-T3.8µm) <0.4°C] }

- Sun elevation larger than 20 degrees, including sunglint areas):

[where R0.6threshold and R1.6threshold are used in the cloud masking scheme, θsat is the satellite zenith angle, T120T108threshold defined in text, SD is the standard deviation,]

Over the ocean at nightime, a pixel is classified as contaminated by dust cloud if :

- {[(Saharan_dust_index > 0.6 and -5°C - 5*(1/cos(θsat) -1) < T10.8µm – SSTclim) or
  (Saharan_dust_index > 1.0 and -10°C - 5*(1/cos(θsat) -1) < T10.8µm – SSTclim)] and
- SD(T10.8µm) < 0.4°C and SD(T10.8µm-T3.8µm) <0.4°C and
- (T108µm-T120µm)<1.2 and
- (T87µm-T108µm)>-(2.5-0.17*(1-1/cos(θsat)) }
- Sun elevation lower than –3 degrees:

[where θsat is the satellite zenith angle and SD is the standard deviation and
Saharan Dust Index (SDI)= 0.53476*(T3.8µm-T8.7µm)-0.838710*(T10.8µm-T12.0µm)+1.28362 (for MSG1)]

Over continental surfaces at daytime, a pixel is classified as contaminated by dust cloud if :

- Sun elevation larger than 20 degrees and
- 273.15K < T10.8µm < 315.15K and
- R0.6µm < R0.6threshold +15% and
- SD(T10.8µm) < 3.0 K and SD(R0.6µm) < 3.0 % and
- [[((T3.8µm - T10.8µm) > -10 K and (T12.0µm-T10.8µm) > 2.5 K or
  ((T3.8µm - T10.8µm) > 12 K and (T12.0µm-T10.8µm) > 0.6 K] or
  [(T12.0µm-T10.8µm) > -1 K and
  { (T8.7µm-T10.8µm) > -1.0 K and R0.6µm /R1.6µm <0.8 } or
  (T8.7µm-T10.8µm) > min(-1.0,2.5-0.18* R0.6µm) K and R0.6µm /R1.6µm <0.7}]]

[where R0.6threshold used in cloud masking, R0.6threshold used in cloud masking]

The aim is to identify dust that is transported out of deserts over both continental and oceanic surfaces. These events are rather frequent over North Africa and adjacent seas (Atlantic Ocean and Mediterranean sea). The difficulty is to separate dust clouds from cloud free areas without confusing them with water clouds. Techniques proposed in literature are based on brightness temperature differences [10.8 and 3.8µm (Ackerman, 1989), or 10.8 and 12.0µm (used by NOAA to map dust clouds); a thermal contrast between the ground and the dust cloud is needed to make these techniques efficient], or on visible reflectances spatial homogeneity (Jankowiak and Tanre, 1992). The result of this detection process is stored in a separate flag.

The threshold applied over the ocean to the T12.0µm-T10.8µm brightness temperature difference is, as most IR thresholds, calculated from pre-computed tables defined by applying RTTOV to an atmospheric profiles database provided by ECMWF (F.Chevalier, 1999). It is illustrated on Figure 29.

The nightime detection of dust over sea is based on the thresholding of the Saharan Dust Index (SDI, see Merchant et al., 2006) computed from T3.8µm, T8.7µm, T10.8µm and T12.0µm.

2.2.1.2.9 Volcanic ash cloud identification

The following algorithm has been empirically derived to detect and classify volcanic ash clouds:

At nightime or twilight, a pixel is classified as contaminated by volcanic ash if:

- T12.0µm -T10.8µm > T12.0T10.8threshold_volcan_night and
- T3.8µm -T10.8µm > T3.8T10.8threshold

[T12.0T10.8threshold_volcan_night is a finely tuned threshold explained below in the text, T3.8T10.8threshold is a threshold used in the cloud detection process].

At daytime over sea, a pixel is classified as contaminated by volcanic ash if:

- T12.0µm -T10.8µm > T12.0T10.8threshold_volcan_day and
- |R0.6µm - R1.6µm| < 10%

At daytime over land, a pixel is classified as contaminated by volcanic ash if:

- T12.0µm -T10.8µm > T12.0T10.8threshold_volcan_day and
- T10.8µm < (T10.8threshold + 20K) and
- |R0.6µm -R1.6µm| < 10% and T3.8µm -T10.8µm > 5K or
  |R0.6µm -R1.6µm| < 20% and T3.8µm -T10.8µm > 13K

[T12.0T10.8threshold_volcan_day is a finely tuned threshold explained below in the text, T10.8threshold is the threshold used in the T10.8µm infrared test during the cloud detection process].

Most volcanic ash clouds events (but not all!) are characterized by highly positive T12.0µm-T10.8µm brightness temperature difference. The aim of this test is to detect these volcanic events, and minimize false alerts. The result of this detection process is stored in a separate flag.

The threshold applied to the T12.0µm -T10.8µm is finely tuned to limit at the maximum the false alert rate:

- at daytime, T12.0T10.8threshold_volcan_day varies linearly with R0.6µm from 0.7K (at R0.6µm equal 0%) up to 1.7K (at R0.6µm larger than 60%); an additional offset, which is a linear function of the satellite secant (from 0K up to 1K for a satellite secant of 5) is finally added to T12.0T10.8threshold_volcan_day to account for the higher T12.0µm-T10.8µm of clouds at large satellite zenith angle.
- at nighttime, T12.0T10.8threshold_volcan_night decreases with T10.8µm from 1.2K (at T10.8µm lower than 223.15K) down to T12.0T10.8threshold (at T10.8µm larger than T10.8threshold+20K); an additional offset, which is a linear function of the satellite secant (from 0K up to 1K for a satellite secant of 5) is finally added to T12.0T10.8threshold_volcan_day to account for the higher T12.0µm -T10.8µm of clouds at large satellite zenith angle. T10.8threshold is the threshold used in the T10.8µm infrared test during the cloud detection process, whereas T12.0T10.8threshold, illustrated on Figure 29, is calculated as explained in 2.2.1.2.8.

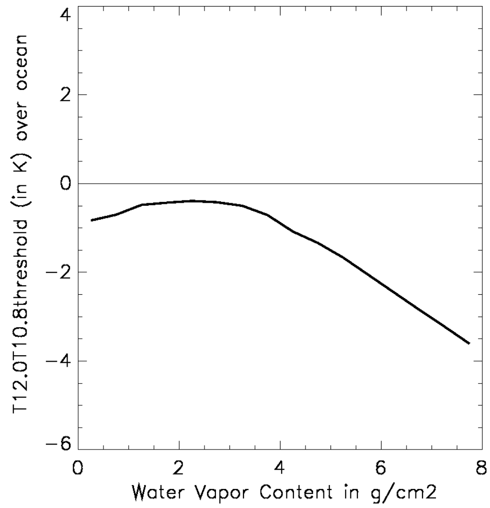


Figure 29: Illustration of T12.0T10.8threshold used in the dust and volcanic cloud detection over the ocean for a satellite zenith angle of 48 degrees

2.2.2 Practical considerations

2.2.2.1 Validation

Table 6 summarises the validation results of the current version. More details can be obtained from the validation report for cloud products ([RD.1.]).

GEO-CMA flags	Validated accuracy
GEO-CMA cloud detection If validated over European areas using SYNOP observations If validated over full disk using SYNOP and SHIP observations	POD: 97.1% POD: 94.5%
GEO-CMA dust flag If validated over sea and Africa for solar elevation larger than 20 degrees using interactive targets	POD: 55.5% over sea 58.5% over land

Table 6: Summary of validation results of the current CMA version (POD stands for Probability Of Detection)

2.2.2.2 Quality control and diagnostics

A quality assessment is performed by the CMA itself, especially through a comparison between thresholds and measurements, “bad quality” corresponding to thresholds and measurements close to each other (detailed in 2.2.1.2.2.15). When method not based on test sequence are used, the quality is set as “questionable” or “interpolated” (see details in each sub-section of 2.2.1.2).

Two CMA output fields are used to describe the quality and processing conditions (see in 2.2.2.4 and [RD.2.]). They include the quality assessment performed by the CMA, but also information on the lack of NWP fields or satellite non mandatory channels which leads to a decrease of CMA quality.

2.2.2.3 List of inputs for Cloud Mask (CMA)

The input data to the CMA algorithm are described in this section. Mandatory inputs are flagged, whereas the impact of missing non-mandatory data on the processing are indicated.

- **Satellite imagery:**

For the current slot (H+00):

The following bi-directional reflectances or brightness temperatures are needed at default horizontal resolution (3km at nadir for MSG/SEVIRI):

R0.6µm	R0.8µm	R1.6µm	T3.8µm	T7.3µm	T8.7µm	T10.8µm	T12.0µm	T13.4µm
Mandatory	Optional	Optional	Mandatory	Optional	Optional	Mandatory	Mandatory	Optional

and at high spatial resolution (1km at nadir for MSG) :

hrvis
Optional

(hrvis is one visible channel at around 0.6µm (HRV for MSG))

The CMA software checks the availability of channels for each pixel. If non mandatory channels are missing for one pixel, the tests using these channels are not applied, or applied differently (for example, snow detection uses either R1.6µm or T3.8µm; visible channel test over the ocean uses either R0.8µm or R0.6µm) and a result is available for this pixel. No results are provided for pixels where at least one mandatory channel is missing.

For the slot one hour earlier (H-60min):

The following bi-directional reflectances or brightness temperatures or CMA or CT of the scene analysed one hour earlier are optionally needed (at default horizontal resolution) to improve the cloud detection in day-night transition. If one of them misses this improvement is not performed.

$R0.6\mu m_{1h}$	$T8.7\mu m_{1h}$	$T10.8\mu m_{1h}$	$T12.0\mu m_{1h}$	CMA_{1h}	CT_{1h}
Optional	Optional	Optional	Optional	Optional	Optional

For the slot around 15 minutes earlier (H-15min, exact delay depending on the satellite):

The following brightness temperatures or CMA or CT of the scene analysed around 15 minutes earlier (exact delay depending satellite) are optionally needed (at default horizontal resolution) to improve the cloud detection of fast moving clouds. If one of them misses this improvement is not performed.

$T8.7\mu m_{15mn}$	$T10.8\mu m_{15mn}$	$T12.0\mu m_{15mn}$	CMA_{15mn}	CT_{15mn}
Optional	Optional	Optional	Optional	Optional

The hrvis bi-directional reflectance of the scene analysed around 15 minutes earlier (exact delay depending satellite) is optionally needed to improve the sub-pixel cumulus cloud detection. If not available this improvement is not performed.

$\mathbf{hrvis_{15mn}}$
Optional

(hrvis is one visible channel at around 0.6µm (HRV for MSG))

The channels are input by the user in specified format (HRIT for MSG), and extracted on the processed region by NWC/GEO software package.

- **Sun and satellite angles associated to satellite imagery**

This information is mandatory. It is computed by the CMA software itself, using the definition of the region and the satellite characteristics.

- **NWP parameters:**

The forecast fields of the following parameters, remapped onto satellite images, are used as input:

  - surface temperatures (required to get good quality results over land ; but not mandatory)
  - air temperature at 950hPa (alternatively 925hPa). Used to check low level inversion.
  - total water vapour content of the atmosphere,
  - altitude of the NWP model grid (alternatively surface geopotential on the NWP model grid). Required if NWP fields are used as input.

These remapped fields are elaborated by the NWC/GEO software package from the NWP fields input by the user in GRIB format.

The NWP fields are not mandatory: the CMA software replaces missing NWP surface temperatures or total water vapour content of the atmosphere by climatological values extracted from ancillary dataset, but the quality of CMA is then lower.

- **RTTOV simulations:**

The following parameters simulated by RTTOV are used as input:

- Clear sky top of atmosphere radiance
- Transmittance from surface to TOA
- Clear sky downwelling radiance

These remapped fields are elaborated by the NWC/GEO software package by applying RTTOV to the NWP fields input by the user in GRIB format.

The RTTOV simulations are not mandatory: if not available, the CMA software does not apply corresponding tests (2.2.1.2.3), the CMA quality being then slightly lower (especially in nightime conditions).

- **OSTIA fields:**

The following parameters are used as input:

- OSTIA SST and local estimated error

High resolution global daily bulk SST fields (OSTIA) are input by the user who can obtain them from MyOcean service desk (see http://www.myocean.eu.org). They are used in conjunction with RTTOV simulations.

These OSTIA fields are not mandatory: if not available the RTTOV simulations are not used over ocean and the CMA software does not apply corresponding tests (2.2.1.2.3), the CMA quality being then slightly lower (especially in nightime conditions).

- **RTTOV bias files:**

Rttov bias files are used as input. They can be downloaded from AEMET ftp server. They are valid only for ECMWF model.

These files are not mandatory. If not available, the bias can be computed by GEO-CMA (the processed region needs to contain large enough area covered by oceanic surfaces (see 2.2.1.2.3). If this computation is not possible, the GEO-CMA does not apply test using RTTOV simulation and the GEO-CMA quality being then slightly lower (especially in nightime conditions).

- **Ancillary data sets:**

The following ancillary data, remapped onto satellite images, are mandatory:

  - Land/sea atlas
  - Land/sea/coast atlas
  - Elevation atlas
  - Monthly SST minimum and standard deviation values climatology
  - Monthly mean 0.6µm atmospheric-corrected reflectance climatology (land)
  - Monthly mean visible surface reflectance climatology for hrvis processing (land, (for MSG: HRV large band surface reflectance)) (derived from monthly MODIS black-sky albedos at 0.55 µm, 0.67 µm and 0.86µm)
  - Land cover database (BATS)
  - Monthly integrated atmospheric water vapor content climatology
  - Monthly climatology of mean air temperature at 1000 hPa
  - Monthly thermal emissivity at IR wavelength

These ancillary data are available in the NWC/GEO software package on a global scale; a SAFNWC tool allows their remapping on full disk for each new satellite; they are finally extracted on the processed region by the CMA software itself.

Coefficients's file (also called threshold tables), containing satellite-dependent values and look-up tables for IR thresholds and for solar channels' thresholds, are available in the NWC/GEO software package, and are needed by the CMA software.

- **Configurable parameters:**

The following configurable parameters are available in the default CMA model configuration file:

- CMA_SZSEG: the size of the segment is configurable (see its definition in section 2.2.2.6). Its default value is 4. Information on how to change the size of the segment can be found in section 2.2.2.6 and in the software user manual ([RD.3.]).
- NWP_FREQUENCY_PER_DAY: the number of NWP forecast term per day is configurable (see its definition in section 2.2.2.6). Its default value is 4. Information on how to change this number of NWP can be found in section 2.2.2.6 and in the software user manual ([RD.3.]).
- IS_ALREADY_RECALIBRATED: the flag, defining whether satellite data input by user are already recalibrated with post-launch calibration coefficients (solar channels) and GSICS IR calibration coefficients, is configurable (see its definition in section 2.2.2.6). Its default

value is FALSE. Information on how to change this value can be found in section 2.2.2.6 and in the software user manual ([RD.3.]).

- RTTOV_USE: the flag defining if RTTOV is to be used on line (to allow a better detection of low or thin clouds) is configurable (see its definition in section 2.2.2.6). Its default value is FALSE. Information on how to change this value can be found in section 2.2.2.6 and in the software user manual ([RD.3.]).
- RTTOV_USE_COMPUTED_BIAS: the flag defining if biases are to be monitored on line, is configurable (see its definition in section 2.2.2.6). Its default value is FALSE. Information on how to change this value can be found in section 2.2.2.6 and in the software user manual ([RD.3.]).
- HRVIS_NEED: the flag indicating if hrvis data have to be used (to allow enhanced sub-pixel cumulus detection) is configurable (see its definition in section 2.2.2.6). Its default value is TRUE. Information on how to change this value can be found in section 2.2.2.6 and in the software user manual ([RD.3.]).

2.2.2.4 Description of Cloud Mask (CMA) output

The content of the CMA is described in the Data Output Format document ([RD.2.]), a summary is given below:

<table>
<tr><th>Container</th><th>Content</th></tr>
<tr><td>GEO-CMA</td><td>SAFNWC GEO CMA Cloud Mask
<table>
<tr><th>Class</th><th>Cloud Mask category</th></tr>
<tr><td>0</td><td>Cloud-free</td></tr>
<tr><td>1</td><td>Cloudy</td></tr>
<tr><td>FillValue</td><td>No data or corrupted data</td></tr>
</table></td></tr>
<tr><td>GEO-CMA
_CLOUDSNOW</td><td>SAFNWC GEO CMA Cloud and Snow Mask
<table>
<tr><th>Class</th><th>Cloud and Snow Mask category</th></tr>
<tr><td>0</td><td>Cloud-free</td></tr>
<tr><td>1</td><td>Cloud (except thin ice cloud over snow)</td></tr>
<tr><td>2</td><td>Thin ice cloud over snow/ice</td></tr>
<tr><td>3</td><td>Snow/Ice</td></tr>
<tr><td>FillValue</td><td>No data or corrupted data</td></tr>
</table></td></tr>
<tr><td>GEO-CMA
_DUST</td><td>SAFNWC GEO CMA Dust Detection
<table>
<tr><th>Class</th><th>Dust Detection category</th></tr>
<tr><td>0</td><td>No dust</td></tr>
<tr><td>1</td><td>Dust</td></tr>
<tr><td>2</td><td>Undefined (separability problem)</td></tr>
<tr><td>FillValue</td><td>No data or corrupted data</td></tr>
</table></td></tr>
<tr><td>GEO-CMA
_VOLCANIC</td><td>SAFNWC GEO CMA Volcanic Plume Detection
<table>
<tr><th>Class</th><th>Volcanic Plume Detection category</th></tr>
<tr><td>0</td><td>No volcanic plume</td></tr>
<tr><td>1</td><td>Volcanic plume</td></tr>
<tr><td>2</td><td>Undefined (separability problem)</td></tr>
<tr><td>FillValue</td><td>No data or corrupted data</td></tr>
</table></td></tr>
</table>

Container	Content
GEO-CMA _TESTLIST	28 bits indicating (if set to 1) Bit 0: R0.6µm (land) or R0.8µm (sea) Bit 1: R1.6µm (sea) Bit 2: Sunglint test using 3.8µm Bit 3: R1.38µm Bit 4: T10.8µm or SST Bit 5: T10.8µm – T12.0µm Bit 6: T10.8µm – T3.8µm Bit 7: T12.0µm – T3.8µm Bit 8: T3.8µm – T10.8µm Bit 9: T10.8µm – T8.7µm Bit 10: T8.7µm – T10.8µm Bit 11: T8.7µm – T3.8µm Bit 12: Snow with only T3.8µm Bit 13: Snow with R1.6µm Bit 14: Snow with combined use of R1.6 µm and R2.2µm Bit 15: Local Spatial Texture Bit 16: T10.8µm with RTTOV Bit 17: T3.8µm with RTTOV Bit 18: T8.7µm – T3.8µm with RTTOV Bit 19: T10.8µm – T12.0µm with RTTOV Bit 20: T10.8µm – T8.7µm with RTTOV Bit 21: T10.8µm – T3.8µm with RTTOV Bit 22: Temporal-differencing Bit 23: Stationary cloud in twilight Bit 24: Spatial extension of stationary clouds in twilight Bit 25: Use of high resolution visible Bit 26: Spatial filtering: cloud reclassified as cloud-free Bit 27: Spatial filtering: cloud-free reclassified as cloud
GEO-CMA _status_flag	10 bits indicating (if set to 1) Bit 0: Low level thermal inversion in NWP field Bit 1: Cold snowy ground suspected Bit 2: Temporal algorithm passed Bit 3: High resolution satellite data used Bit 4: RTTOV on line-used Bit 5: SST analysis available Bit 6: Snow map available (not yet used) Bit 7: Sea ice map is available (not yet used) Bit 8: No method for dust Bit 9: No method for volcanic plume

Geophysical Conditions

Field	Type	Description
Space	Flag	Set to 1 for space pixels
Illumination	Parameter	Defines the illumination condition 0: N/A (space pixel) 1: Night 2: Day 3: Twilight
Sunglint	Flag	Set to 1 if Sunglint
Land_Sea	Parameter	0: N/A (space pixel) 1: Land 2: Sea 3: Coast
Rough_terrain	Flag	Set to 1 if rough terrain
High_terrain	Flag	Set to 1 if high terrain

Processing Conditions

Field	Type	Description
Satellite_input_data	Parameter	Describes the Satellite input data status 0: N/A (space pixel) 1: All satellite data are available 2: At least one useful satellite channel is missing 3: At least one mandatory satellite channel is missing
NWP_input_data	Parameter	Describes the NWP input data status 0: N/A (space 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
Product_input_data	Parameter	Describes the Product input data status 0: N/A (space pixel or Auxiliary data not used) 1: All input Product data are available 2: At least one useful input Product is missing 3: At least one mandatory input Product is missing
Auxiliary_input_data	Parameter	Describes the Auxiliary input data status (includes products used as input to PGE) 0: N/A (space 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 field is missing

Quality

Field	Type	Description
Nodata	Flag	Set to 1 if pixel is NODATA
Internal_consistency	Flag	Set to 1 if an internal consistency check has been performed. Internal consistency checks will be based in the comparison of the retrieved meteorological parameter with physical limits, climatological limits, neighbouring data, NWP data, etc.
Temporal_consistency	Flag	Set to 1 if a temporal consistency check has been performed Temporal consistency checks will be based in the comparison of the

		retrieved meteorological parameters with data obtained in previous slots.
Quality	Parameter	Retrieval Quality 0: N/A (no data) 1: Good 2: Questionable 3: Bad 4: Interpolated

2.2.2.5 Example of Cloud Mask (CMA) visualisation

It is important to note that the CMA product is not just images, but numerical data. At first hand, the CMA is rather thought to be used digitally (together with the appended flags (quality, dust detection, volcanic ash detection)) as input to mesoscale analysis models, objective Nowcasting schemes, but also during the extraction of other NWC SAF products (CT for example).

Colour palettes are included in CMA NetCdF files, allowing an easy visualisation of CMA main categories, dust and volcanic ash flags.

No example of CMA main categories's visualisation are given, as it is thought that the user will be more interested to visualize the CT product which can be seen as a refinement.

Example of visualisation of the dust cloud and the volcanic ash cloud flags superimposed on infrared images are given in Figure 30 and Figure 31 , using SEVIRI and MODIS imagery.

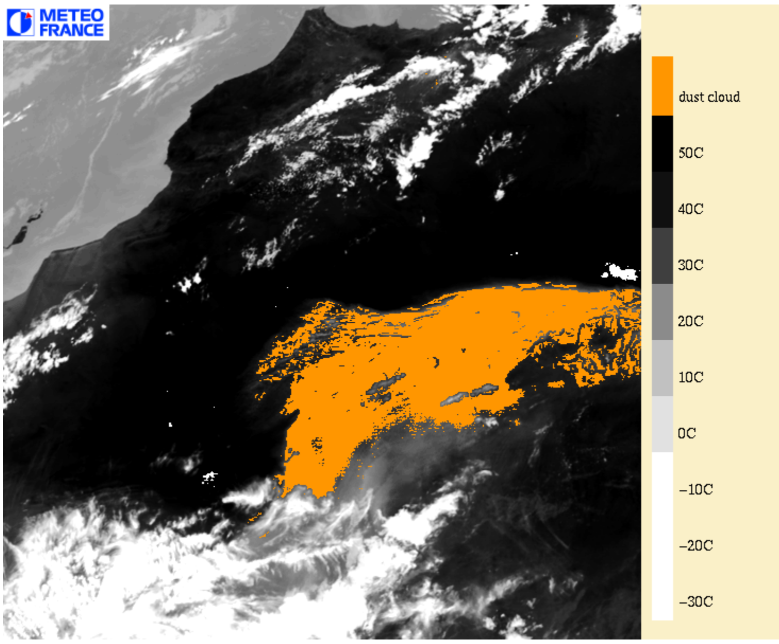


Figure 30: Example of SEVIRI dust cloud flag superimposed on a 10.8µm infrared image: dust cloud over North Africa on 14th July 2003 at 13h00 UTC.

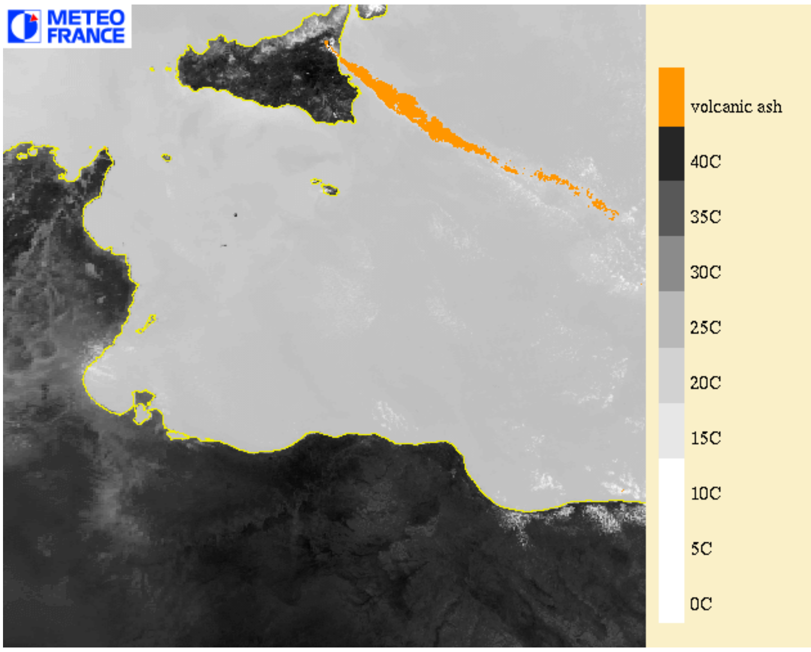


Figure 31: Example of MODIS volcanic ash cloud superimposed on a 10.8μm infrared image: Etna eruption on 22th July 2001 at 9h55 UTC.

2.2.2.6 Implementation of Cloud Mask (CMA)

CMA is extracted by PGE01 (GEO-CMA) component of the NWC/GEO software package. Detailed information on how to run this software package is available in the software user manual ([RD.3.]).

When a new region is defined the user has to manually prepare the CMA model configuration files for this new region using a default CMA model configuration file provided in the NWC/GEO software package. The following parameters are configurable in the default CMA model configuration file:

- CMA_SZSEG (default value: 4): the size of the segment for CMA. [Segments are square boxes in the satellite projection, whose size is expressed as the number of default horizontal resolution pixels (3km at nadir for MSG) of one edge of the square box. The size of the processed regions must be a multiple of the segment size. All the solar and satellite angles, the NWP model forecast values, the RTTOV simulations, the atlas values and the thresholds will be derived over all the processed regions at the horizontal resolution of the segment. Note also that the land/sea atlas will be available at the full default horizontal resolution, allowing the identification of the surface type (land or sea) of all pixels, whatever the segment size. The quality is not very much dependent of the segment size (if lower than 4). Decreasing the segment size will increase the execution time]
- NWP_FREQUENCY_PER_DAY (default value: 4): the number of NWP forecast term per day input by the user. [By default, it is set to 4 (corresponds to NWP fields every 6 hours which is the minimum number authorized by the NWCSAF software). If the user inputs more frequent NWP fields, the NWP_FREQUENCY_PER_DAY key should be changed (for example 8 per day in case NWP fields every 3hours). This key allows to use the NWP fields input by the user avoiding hidden temporal interpolation. In fact, the computation of some IR threshold may need to analyse how NWP parameters has change before and after current slot. This require that the NWP parameters (before and after current slot) should be those input by the user without temporal linear interpolation (which is automatically performed by NWCSAF NWP handling routines).]

- IS_ALREADY_RECALIBRATED (default value: FALSE): a flag defining whether satellite data input by the user are already recalibrated using post-launch calibration coefficients (solar channels) and GSICS IR calibration coefficients. [For nearly all users, it shall remain set to FALSE (defaut value). If set to TRUE (for example, CM-SAF may use this option), the RTTOV on line option is desactivated because RTTOV infrared bias files may not be adequate].
- RTTOV_USE (default value: FALSE): a flag defining if the set of tests using thresholds computed on-line with RTTOV (see 2.2.1.2.3) should be applied. [RTTOV_USE flag is checked at the execution step. GEO-CMA applies the set of tests using thresholds computed on-line with RTTOV if its value is TRUE. This flag has been made configurable to allow users being blocked by hardware resources to still run GEO-CMA by assigning it to FALSE in the configuration file.]
- RTTOV_USE_COMPUTED_BIAS (default value:FALSE): a flag defining if biases are to be monitored on line (see 2.2.1.2.3) when RTTOV-based tests are used. [This key should be set to TRUE in case RTTOV_USE is set to TRUE and RTTOV bias files are not available for the NWP model used by the user (AEMET provides bias files for ECMWF only). But there are some constraints to create thoses bias files (see 2.2.1.2.3).]
- HRVIS_NEED (default value: TRUE): a flag indicating whether the hrvis analysis (see 2.2.1.2.6) should be done. [HRVIS_NEED flag is checked at the execution step. GEO-CMA applies the hrvis analysis if its value is TRUE. This flag has been made configurable to allow users being blocked by hardware resources to still run GEO-CMA by assigning it to FALSE in the configuration file.]

The CMA execution step is the real-time processing of the satellite images over the region. This process consists in the launch of the command: GEO-CMA by the Task manager.

2.3 ASSUMPTIONS AND LIMITATIONS

The following problems may be encountered:

- Low clouds may be not detected in case low solar elevation, over both sea and land.
- It may happen that large areas of low clouds are not detected in night-time conditions over land. This can be the case in "warm sectors", but also in areas viewed with high satellite zenith angles or if the low clouds are surmounted by very thin cirrus.
- Snowy grounds are not detected at night-time and are therefore confused either with low clouds or cloud free surface.
- False detection of volcanic ash clouds happens especially in daytime conditions (over low clouds and desertic surfaces), but also in night-time (over cold clouds). The volcanic ash clouds detection is not performed in case low solar elevation.
- Over land, dust cloud detection is performed only at daytime. Over land, dust clouds are not well detected when the sun is low or if they are too thin. Over sea, some dust areas may not be detected(especially the thinnest parts). Moreover, some wrong detection may be observed in oceanic regions, especially at nighttime near Namibie coast and occasionally over the South Atlantic (at latitude larger than 50 degrees).

The CMA product may be used to identify cloud-free surfaces for oceanic or continental surface parameters retrieval. Nevertheless, as some clouds remains undetected and to account for artefacts such as shadows or aerosols, the user should apply a post-processing which could include:

- the spreading of the cloud mask that should allow detecting cloud edges and mask shadows or moist areas near cloud edges

- the use of the cloud mask quality flag not to compute surface parameters in bad quality cloud free areas
- the implementation of an additional filtering based on the temporal variation around the current slot

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3 DESCRIPTION OF CLOUD TYPE (GEO-CT) PRODUCT

3.1 CLOUD TYPE (GEO-CT) OVERVIEW

The cloud type (CT), developed within the NWC SAF context, mainly aims to support nowcasting applications. The main objective of this product is to provide a detailed cloud analysis. It may be used as input to an objective meso-scale analysis (which in turn may feed a simple nowcasting scheme), as an intermediate product input to other products, or as a final image product for display at a forecaster's desk. The CT product is essential for the generation of the cloud top temperature and height product, cloud microphysics and for the identification of precipitation clouds. Finally, it is also essential for the computation of radiative fluxes over sea or land, which are SAF Ocean & Sea Ice products.

The CT product therefore contains information on the major cloud classes: fractional clouds, semitransparent clouds, high, medium and low clouds (including fog) for all the pixels identified as cloudy in a scene. A second priority is the distinction between convective and stratiform clouds (implementation not planned before 2017).

CT is performed by a multi-spectral threshold method: pixels previously detected as cloudy by CMA are classified by a threshold procedure which is applied to the channels combinations that allow the discrimination of all cloud types. The critical points are the choice of the channels combinations and the threshold tuning.

3.2 CLOUD TYPE (GEO-CT) ALGORITHM DESCRIPTION

3.2.1 Theoretical description

3.2.1.1 Physics of the problem

Brightness temperatures and reflectance of clouds very much depend on their characteristics: - height (low, medium or high level clouds); - amount (semi-transparent or opaque; sub-pixel or filling the pixel) and texture; - phase (water or ice clouds). They are also affected by the atmospheric conditions and by the sun and satellite respective positions.

The pixels contaminated by clouds are supposed to have been identified by the CMA product. The problem to be solved is then, to determine the adequate combinations of satellite imagery channels that will allow the separation of clouds presenting different characteristics, and how these combinations of channels will be affected by atmospheric conditions and sun/satellite geometry.

3.2.1.2 Mathematical Description of the algorithm

3.2.1.2.1 Algorithm outline:

The algorithm has been designed to be applicable to imagers on board meteorological geostationary satellites. The imagers may have different set of channels possibly at different horizontal resolutions. The lowest native resolution of the radiometer (3km at nadir for MSG/SEVIRI), which is for most imagers on board present and future meteorological geostationary satellites the horizontal resolution of all IR channels and some solar channels, will be chosen as the default horizontal resolution. Solar channels may be available at higher horizontal resolution (1km at nadir for HRV). In this release, the process is applied to all useful channels at the default horizontal resolution (high resolution channels being averaged at this resolution). We use generic labels in this document (for example, T3.8µm, T8.7µm, T10.8µm, T12.0µm, R0.6µm, R0.8µm and R1.6µm), the exact central wavelengths of the corresponding channels depending on the satellite. The list of available labels depends on the satellite; the list of mandatory channels is listed in 3.2.2.3.

The CT algorithm is a threshold algorithm applied at the pixel scale, based on the use of CMA and spectral & textural features computed from the multispectral satellite images and compared with a set of thresholds.

The set of thresholds to be applied depends mainly on the illumination conditions (defined in Table 3), whereas the values of the thresholds themselves may depend on the illumination, the viewing geometry, the geographical location and NWP data describing the water vapour content and a coarse vertical structure of the atmosphere.

The CT classification algorithm is based on a sequence of thresholds tests which are detailed in the following sections. In addition, it should be noted that in the current version of CT, no separation between cumuliform and stratiform clouds is performed.

3.2.1.2.2 Main cloud type identification

3.2.1.2.2.1 Fractional and high semitransparent clouds identification at nighttime

The high semitransparent clouds are distinguished from opaque clouds using the T10.8µm-T12.0µm, T8.7µm-T10.8µm or T3.8µm-T10.8µm features.

- T10.8µm-T12.0µm is usually higher for cirrus clouds than for thick clouds, especially in case of large thermal contrast between the cloud top and the surface. This brightness temperature difference decreases if the semitransparent cloud is too thick or too thin.
- T8.7µm-T10.8µm is usually higher for cirrus clouds than for thick clouds, especially in case of large thermal contrast between the cloud top and the surface.
- The T3.8µm-T10.8µm feature is also very efficient to distinguish high semitransparent clouds from the opaque clouds. It is based on the fact that the contribution of the relatively warm grounds to the brightness temperature of semitransparent cloud is higher at 3.8µm than at 10.8µm, due to a lower ice cloud transmittance, and to the high non-linearity of the Planck function at 3.8µm. This feature is more efficient if the thermal contrast between cloud top and surface is large. Due to noise problem, this feature cannot be used in case of too cold T3.8µm.

The fractional low clouds have also T10.8µm-T12.0µm and T3.8µm-T10.8µm higher than opaque clouds, which therefore may lead to confusion with very thin cirrus. But usually cirrus clouds have larger T8.7µm-T10.8µm than fractional low clouds.

The presence of a lower level under the cirrus cloud leads to reduce T10.8µm-T10.2µm and T3.8µm-T10.8µm when compared to those of single level cirrus. T10.8µm-T12.0µm is more reduced than T3.8µm-T10.8µm, making this last feature more efficient to detect cirrus overlaying low water clouds. But it seems impossible to detect overlapping clouds with only spectral features such as T10.8µm-T12.0µm or T3.8µm-T10.8µm at the pixel resolution, neither with local textural features; the CT algorithm therefore does not separate cirrus overlaying low clouds from fractional cover or mid-level clouds at nighttime.

The scheme used at nighttime is the following:

High semitransparent clouds		
high semitransparent thick clouds:	T10.8µm < maxT108hi	T10.8µm -T12.0µm > T108T120thick
high semitransparent meanly thick clouds:	maxT108hi < T10.8µm < T108interthr	[T3.8µm –T10.8µm > T38T108thin_high or T10.8µm -T12.0µm > T108T120thick]
	T108interthr < T10.8µm < maxT108med	[T3.8µm –T10.8µm > T38T108thin_low or T10.8µm -T12.0µm > T108T120thick]
high semitransparent thin clouds:	maxT108med < T10.8µm < maxT108low	[T3.8µm –T10.8µm > T38T108t_low or T10.8µm -T12.0µm > T108T120thick] and [T8.7µm -T10.8µm > T87T108opaque or T3.8µm –T10.8µm > T38T108thin_low]
	maxT108low < T10.8µm<maxT108low+delta	[T3.8µm –T10.8µm > T38T108_vlow or T10.8µm -T12.0µm > T108T120thick] and [T8.7µm -T10.8µm > T87T108opaque or T3.8µm –T10.8µm > T38T108thin _low]

Fractional low clouds		
Fractional clouds:	maxT108med < T10.8µm < maxT108low	[T3.8µm –T10.8µm > T38T108_low or T10.8µm -T12.0µm > T108T120thick] and [T8.7µm -T10.8µm < T87T108opaque] and [T3.8µm –T10.8µm < T38T108thin _low]
	maxt108low<T10.8µm<maxT108low+delta	[T10.8µm -T12.0µm > T108T120thick or T3.8µm -T10.8µm > T38T108_vlow] and [T8.7µm -T10.8µm < T87T108opaque] and [T3.8µm -T10.8µm < T38T108thin _low]
	maxT108low+delta < T10.8µm	[T10.8µm -T12.0µm > T108T120thick or T3.8µm -T10.8µm > T38T108_vlow]

The thresholds used in this scheme are the following:

- MaxT11low, maxT11med, maxT11hi and maxT11vh thresholds are explained in section 3.2.1.2.2.4.
- An intermediate T10.8µm threshold has been defined:
  T108interthr = maxT108low+(maxT108hi- maxT108low)/2
  If T108interthr > maxT108med T108interthr= maxT108med+(maxT108hi- maxT108med)/2.
- T108T120opaque, T38T108opaque, T87T108opaque and Delta are computed by interpolating in look-up tables using satellite zenith angle and total integrated atmospheric

water vapour content. These look-up tables have been elaborated by applying RTTOV to radiosoundings from an ECMWF dataset (F.Chevalier, 1999) for surface having an emissivity of one.

- New T38T108 thresholds according to observed T10.8µm have been defined as:
  T38T108thin_high = T38T108opaque +5.*(maxT108low-T108)/(maxT108low- maxT108hi)
  T38T108thin_low = T38T108opaque+2.*(maxT108low-T108)/(maxT108low- maxT108hi)
  T38T108_low = T38T108opaque+1 (in K)
  T38T108_vlow = T38T108opaque-1 (in K)
- T108T120thick has been defined as : MAX (T108T120opaque-0.2 , 1.5) (in K)

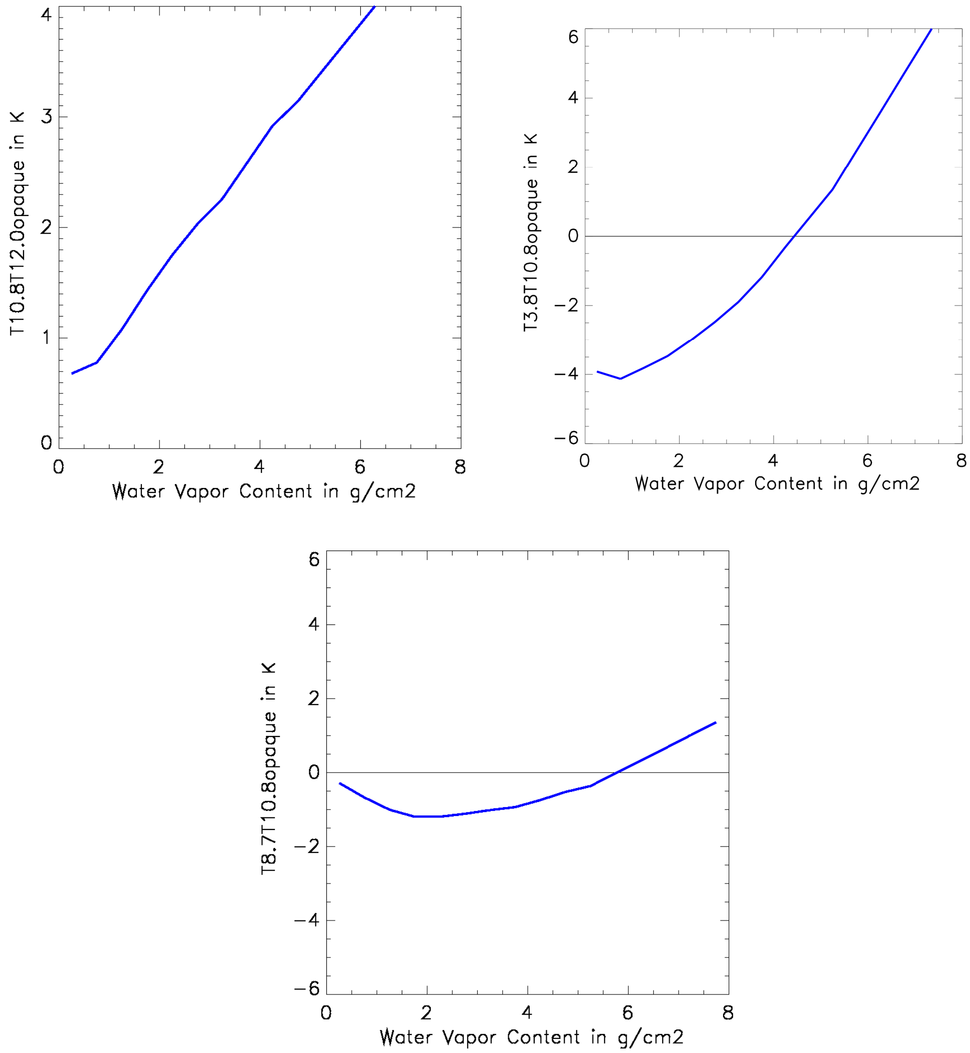

Figure 32: Illustration of T108T120opaque,T38T108opaque and T87T108opaque for a satellite zenith angle of 48 degrees

3.2.1.2.2.2 Fractional and semitransparent clouds identification in twilight conditions

T3.8µm cannot be used in twilight conditions as in nighttime conditions, due to solar contamination. High semitransparent or fractional low clouds can still be separated from opaque clouds by their relatively high T10.8µm-T12.0µm value. As in nightime conditions, cirrus clouds have much higher T8.7µm-T10.8µm values than fractional low clouds.

The scheme used in twilight conditions is the following:

High semitransparent clouds		
high semitransparent thick clouds:	T10.8µm < maxT108hi	T10.8µm -T12.0µm > T108T120opaque
high semitransparent meanly thick clouds:	maxT108hi < T10.8µm < maxT108med	T10.8µm -T12.0µm > T108T120opaque
high semitransparent thin clouds:	maxT108med<T10.8µm<maxT108low+delta	T10.8µm -T12.0µm > T108T120opaque and T8.7µm -T10.8µm > T87T108opaque

Fractional low clouds		
Fractional clouds:	maxt108med<T10.8µm<maxT108low+delta	T10.8µm -T12.0µm > T108T120opaque and T8.7µm -T10.8µm < T87T108opaque
	maxT108low+delta < T10.8µm	T10.8µm -T12.0µm > T108T120opaque

The meaning of the thresholds is the same as in the nighttime scheme.

3.2.1.2.2.3 Fractional and high semitransparent clouds identification at daytime

The high semitransparent clouds are distinguished from opaque clouds using spectral features (T10.8µm-T12.0µm, T8.7µm-T10.8µm, R0.6µm) and textural features (variance T10.8µm coupled to variance R0.6µm in daytime conditions):

- T10.8µm-T12.0µm is usually higher for cirrus clouds than for thick clouds, especially in case of large thermal contrast between the cloud top and the surface. This brightness temperature difference decreases if the cloud is too thick or too thin.
- T8.7µm-T10.8µm is usually higher for cirrus clouds than for thick clouds, especially in case of large thermal contrast between the cloud top and the surface.
- Cirrus clouds present lower R0.6µm reflectances than opaque clouds having the same radiative temperature.
- Cirrus clouds are much more spatially variable in temperature than in visible reflectance.

The fractional low clouds have also T10.8µm-T12.0µm higher than opaque clouds, but usually lower than thin cirrus. Fractional low clouds usually appears warmer and brighter than thin cirrus clouds; moreover cirrus clouds have larger T8.7µm-T10.8µm than fractional low clouds

High semitransparent over low or medium clouds appear rather bright and cold, but are characterised by rather high T10.8µm-T12.0µm and T8.7µm-T10.8µm (if the thermal contrast between cirrus and lower cloud layer top temperature is large enough).

The scheme used at daytime is the following:

<table>
<tr><th colspan="3">High semitransparent clouds</th></tr>
<tr><td>high semitransparent thick clouds:</td><td>T10.8µm < maxT108hi</td><td>T10.8µm -T12.0µm > T108T120opaque</td></tr>
<tr><td>high semitransparent meanly thick clouds:</td><td rowspan="2">maxT108hi < T10.8µm < maxT108med</td><td>R0.6µm < maxCiR06
and
T10.8µm -T12.0µm > T108T120opaque</td></tr>
<tr><td>high semitransparent above low or medium clouds:</td><td>R0.6µm > maxCiR06
and
T10.8µm -T12.0µm > T108T120opaque</td></tr>
<tr><td rowspan="2">high semitransparent thin clouds:</td><td>maxT108med < T10.8µm < maxT108low</td><td>[R0.6µm > maxCiR06
and
T10.8µm-T12.0µm > T108T120opaque
and
varilogT10.8/varilogR06 > varilogthr]
or
[R0.6µm < maxCiR06
and
T8.7µm -T10.8µm > T87T108opaque]</td></tr>
<tr><td>maxt108low< T10.8µm < maxT108low+delta</td><td>[R0.6µm < maxCiR06
and
T8.7µm -T10.8µm > T87T108opaque]
or
[R0.6µm > maxCiR06
and
T10.8µm-T12.0µm >
(T108T120Threshold+ T108T120opaque)/2
and
T8.7µm -T10.8µm > T87T108opaque]</td></tr>
</table>

<table>
<tr><th colspan="3">Fractional low clouds</th></tr>
<tr><td rowspan="3">Fractional clouds:</td><td>maxT108med < T10.8µm < maxT108low</td><td>R0.6µm < maxCiR06
and
T8.7µm -T10.8µm < T87T108opaque</td></tr>
<tr><td>maxt108low<T10.8µm<maxT108low+delta</td><td>[R0.6µm > maxCiR06
and
T10.8µm -T12.0µm >
(T108T120threshold+ T108T120opaque)/2
and
T8.7µm -T10.8µm < T87T108opaque]
or
[R0.6µm < maxCiR06
and
T8.7µm -T10.8µm < T87T108opaque]</td></tr>
<tr><td>maxT108low+delta < T10.8µm</td><td>[R0.6µm > minLowR06
and
T10.8µm -T12.0µm >
(T108T120threshold+ T108T120opaque)/2]
or
[R0.6µm < minLowR06]</td></tr>
</table>

The IR thresholds used in this scheme are the following:

- MaxT11low, maxT11med, maxT11hi and maxT11vh thresholds are explained in section3.2.1.2.2.4.

- T108T120Threshold is the threshold used to separate cloudy from cloud-free pixels (see section 2.2.1.2.2.3).
- T87T120opaque, T108T120opaque and Delta have already been defined in the night-time scheme.

The textural features used are defined as:

- VarilogT10.8=log(1+ var(T10.8µm)) and
- VarilogR0.6=log(1+var(R0.6µm)/13.)

where var stands for the standard deviation in a bin of 9 pixels centred on the pixel to classify. The threshold applied to the ratio varilogT10.8/varilogR0.6 (varilogthr) is a constant value: 2.2

MaxCiR06 mainly aims to separate opaque from semi-transparent clouds. Its computation is based on the assumption that semitransparent and opaque clouds can be roughly separated in the R0.6µm/T10.8µm space by a straight line defined by two reference points:

- The coldest and brighter one is determined by: (T10.8µm=223.15K, R0.6µm=35%).
- The warmest and darker one is depending surface effects and atmospheric effects :
  - Its reflectance depends on the surface reflectance, for which we have an indication from a sea reflectance when over sea or the monthly mean 0.6µm value from climatology when over ground.
  - Its temperature is estimated from the SST climatology file over sea or from NWP surface forecast temperature over land.

Two sets (sea and land) of thresholds (slope and intercept of the straight line) are then computed by accounting for cloud bidirectional effects (using coefficients proposed by Manalo & Smith, 1996, overcast model, and with a weighting factor of 0.4 for Rayleigh part), for the visible calibration variation with time, and for the variation of earth-sun distance.

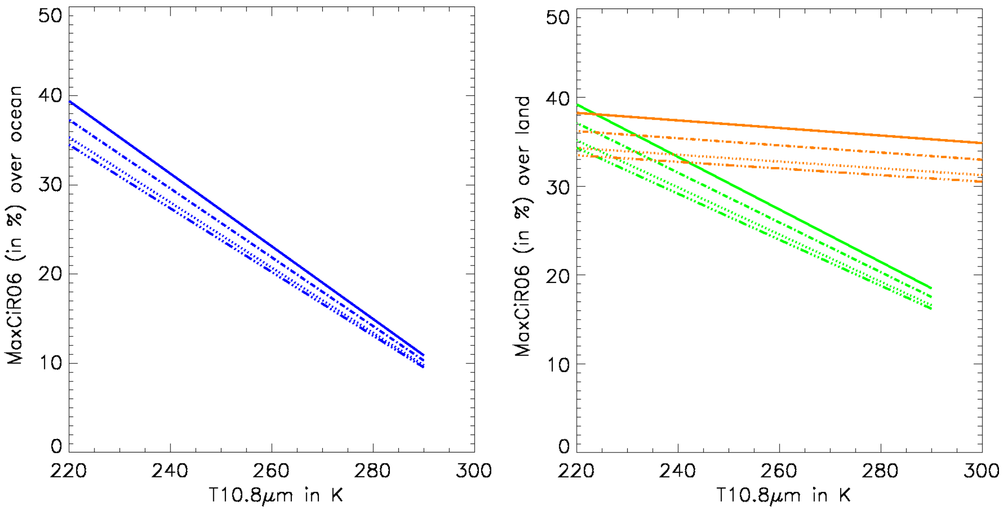

Figure 33: Illustration of MaxCiR06 over Ocean and over Land. Solar zenith angles (30 and 70 degrees), azimuth difference (0 and 90 degrees). In green over vegetated areas, in brown over desert

MinLowR06 is aimed to put a minimum value to an acceptable reflectance of a low cloud, mainly to separate fractional and low clouds. It is derived from a constant value (13% over sea and 20% over land) accounted for bidirectional effects (using coefficients proposed by Manalo & Smith, 1996, overcast model, and with a weighting factor of 0.4 for Rayleigh part).

3.2.1.2.2.4 Low/medium/high clouds separation

Once the semitransparent or fractional clouds have been identified, the classification of the remaining cloudy pixels between low, mid-level and high clouds is performed through a simple thresholding on the T10.8µm brightness temperature which is related to their height. In order to account for atmospheric variability, NWP forecast temperatures at several pressure levels are used to compute the thresholds that allows separating very low from low clouds (maxT11low), low from medium clouds (maxT11med), medium from high clouds (maxT11hi), and high from very high clouds (maxT11vh).

To decrease the wrong classification of low clouds as medium clouds (in case strong atmospheric thermal inversion), medium clouds are not allowed to present too large T10.8µm-T7.3µm brightness temperature differences. In fact, for a field of view obstructed by a low or mean opaque cloud, T7.3µm is sensitive to water vapour content above the cloud and to cloud top temperature. Therefore for a same atmospheric profile and identical microphysical properties of opaque clouds, T10.8µm-T7.3µm decreases with cloud top pressure.

The separation between cumuliform and stratiform clouds is not performed in the current version of CT. Hence, the clouds are labelled as stratiform and a flag indicates that the separation between stratiform and cumuliform clouds has not been attempted.

Opaque clouds		
Very high opaque and stratiform clouds:	T10.8µm < maxT108vh	Not semitransparent or fractional
high opaque and stratiform clouds:	maxT108vh < T10.8µm < maxT108hi	Not semitransparent or fractional
Medium and stratiform clouds:	maxT108hi < T10.8µm < maxT108me and T10.8µm – T7.3µm < T108T73thrlow	Not semitransparent or fractional
Low and stratiform clouds:	maxt108me < T10.8µm < maxT108low or [maxT108hi < T10.8µm < maxT108me and T10.8µm – T7.3µm > T108T73thrlow]	Not semitransparent or fractional
Very low and stratiform clouds:	maxT108low < T10.8µm	Not semitransparent or fractional

These five thresholds are the following :

- maxT10.8vh = 0.4 * T_{500hPa} +0.6 * T_{tropo} - 5 K
- maxT10.8h = 0.5 * T_{500hPa} -0.2 * T_{700hPa} + 178 K
- maxT10.8me = 0.8 * T_{850hPa} +0.2 * T_{700hPa} - 8 K
- maxT10.8low = 1.2 * T_{850hPa} -0.2 * T_{700hPa} - 5 K
- T108T73thrlow = 4.0*sec + 8.5 K (sec is the secante of the satellite zenith angle)

If the air temperature at tropopause level is not available, maxT10.8vh = maxT10.8h – 25K.

In case a thermal inversion has been detected in the NWP fields input by the user, an additional process is applied that allows reclassifying medium clouds as low clouds if their T8.7µm-T10.8µm is lower than a specific thresholds depending of the satellite viewing secant and if their T10.8µm is warmer than maxT11med minus an offset (up to 10K depending on the T8.7µm-T10.8µm value). The basis of this test is that low T8.7µm-T10.8µm values characterizes low clouds rather than medium clouds. The test on T10.8µm is a security to avoid too cold clouds to be classified as low clouds. This "reclassification test" is applied only in case of the presence of a thermal inversion which is characterized by NWP air temperature differences between two vertical levels (950/925hPa and surface, 850hPa and surface, 850hPa and 950/925hPa) larger than 3°K. This test is not applied over arid areas. To summarize, a mid-level clouds is therefore reclassified as low level clouds if:

- A thermal inversion is present in the NWP fields input by the user
- Visclim < 30% (to exclude arid areas)
- T8.7µm-T10.8µm < -1.2-(1./cos(θ_{sat})-1) (in K) and T10.8µm > maxT108me –5.0 (K) or
  T8.7µm-T10.8µm < -1.7-(1./cos(θ_{sat})-1) (in K) and T10.8µm > maxT108me –8.0 (K) or
  T8.7µm-T10.8µm < -2.2-(1./cos(θ_{sat})-1) (in K) and T10.8µm > maxT108me –10.0 (K)

Where visclim is the climatological 0.6µm reflectance value, maxT108me is the threshold normally applied to T10.8µm to distinguish low from mid-level clouds, θ_{sat} is the satellite zenith angle

A rough insight of the range of low/medium/high clouds top pressures has been obtained by analysing statistics of retrieved (using GEO-CTTH) cloud top pressure for each of these cloud types. The following rough top pressure ranges have been obtained (no dependency with latitude or season was observed):

Very low opaque clouds	pressure larger than 800hPa
Low opaque clouds	pressure between 650hPa and 800hPa
Medium opaque clouds	pressure between 450hPa and 650hPa
High opaque clouds	pressure between 300hPa and 450hpa
Very high opaque clouds	pressure lower than 300hPa

3.2.1.2.3 Stratiform/cumuliform separation

The separation between cumuliform and stratiform clouds is not performed in the current version of CT. The "stratiform:cumuliform category" (see 3.2.2.4) is set to "undefined".

3.2.1.2.4 Multilayer cloud identification

The "multilayer cloud" (see 3.2.2.4) corresponds to the "high semi-transparent above low or medium clouds" class (only in daytime conditions).

3.2.1.2.5 Quality assessment

A quality flag is appended to the CT (see 3.2.2.4). It allows the identification of pixels that may have been misclassified:

- The quality flag of a cloudless pixel is the same as that of CMA
- A pixel classified as cloudy is flagged as of "bad quality":
  - if is flagged as of "bad quality" in CMA
  - or if, either for spectral (T10.8µm-T12.0µm, T3.8µm-T10.8µm, R0.6µm) or for textural features (variance T10.8µm coupled to variance R0.6µm), the difference between the threshold and the measurement is lower that a security margin listed in next table:

Cloud Test	**T10.8µm-T12.0µm**	**T3.8µm-T10.8µm**	**T8.7µm-T10.8µm**	**R0.6**	**varilogT10.8/varilogR06**

Security margin for quality assessment	0.2 K	0.2 K	0.2 K	0.2*threshold	0.2*threshold

3.2.2 Practical considerations

3.2.2.1 *Validation*

Table 7 summarises the validation results of the current version for the CT cloud type. More details can be obtained from the validation report for cloud products ([RD.1.]).

GEO-CT	**Validated accuracy**
GEO-CT cloud type If validated over full disk (the user accuracy is defined as the probability of a pixel being classified into a category to really belong to this category)	User accuracy for low opaque, high opaque, semi-transparent high clouds : between 79% and 96% depending on illumination

Table 7: Summary of validation results of the current CT version

3.2.2.2 *Quality control and diagnostics*

A quality assessment, detailed in 3.2.1.2.5, is performed by the CT itself through a comparison between thresholds and measurements, “bad quality” corresponding to thresholds and measurements close to each other.

Two CT output fields are used to describe the quality and processing conditions (see in 3.2.2.4 and [RD.2.]). They include the quality assessment performed by the CT, but also information on the lack of NWP fields or satellite non mandatory channels which leads to a decrease of CT quality.

3.2.2.3 *List of inputs for Cloud Type (CT)*

The input data to the CT algorithm are described in this section. Mandatory inputs are flagged, whereas the impact of missing non-mandatory data on the processing are indicated.

- **Satellite imagery:**

The following bi-directional reflectances or brightness temperatures are needed at default horizontal resolution (3km at nadir for MSG):

R0.6µm	**T3.8µm**	**T7.3µm**	**T8.7µm**	**T10.8µm**	**T12.0µm**
Mandatory	Mandatory	Optional	Optional	Mandatory	Mandatory

The CT software checks the availability of these channels for each pixel; no results are available for pixels where at least one mandatory channel is missing.

The channels are input by the user in specified format (HRIT for MSG), and extracted on the processed region by NWC/GEO software package.

- **CMA cloud categories**

The CMA cloud categories are mandatory. They are computed by the CMA software.

- **Sun and satellite angles associated to satellite imagery**

This information is mandatory. It is computed by the CT software itself, using the definition of the region and the satellite characteristics.

- **NWP parameters:**

The forecast fields of the following parameters, remapped onto satellite images, are used as input :

  - surface temperatures
  - air temperature at 950hPa (alternatively 925hPa) (to check low level inversion), 850hPa, 700hPa, 500hPa and at tropopause level
  - total water vapour content of the atmosphere,
  - altitude of the NWP model grid (alternatively surface geopotential of the NWP model grid). Required if NWP fields are used as input.

These remapped fields are elaborated by the NWC/GEO software package from the NWP fields input by the user in GRIB format.

The NWP fields are not mandatory. The CT software replaces missing NWP surface temperatures, air temperature at 850hPa, 700hPa, 500hPa or total water vapour content of the atmosphere by climatological values extracted from ancillary dataset. An alternative method is used in case of missing NWP air temperature at tropopause level (see section 3.2.1.2.2.4). The quality of CT is lower if some NWP fields are missing.

- **Ancillary data sets:**

The following ancillary data, remapped onto satellite images, are mandatory :

  - Land/sea atlas
  - Elevation atlas
  - Monthly minimum SST climatology
  - Monthly mean 0.6µm atmospheric-corrected reflectance climatology (land)
  - Monthly integrated atmospheric water vapor content climatology
  - Monthly climatology of mean air temperature at 1000hPa, 850hPa, 700hPa, 500hPa.

These ancillary data are available in the NWC software package on a global scale; a SAFNWC tool allows their remapping on full disk for each new satellite; they are finally extracted on the processed region by the CT software itself.

One coefficients's file (also called threshold table), containing satellite-dependent values and look-up tables for thresholds, is available in the NWC software package, and is needed by the CT software.

- **Configurable parameters:**

The following configurable parameter is available in the default CT model configuration file:

  - CT_SZSEG: the size of the segment is configurable (see its definition in section 3.2.2.6). Its default value is 4. Information on how to change the size of the segment can be found in section 3.2.2.6 and in the software user manual ([RD.3.]).

3.2.2.4 Description of Cloud Type (CT) output

The content of the CT is described in the Data Output Format document ([RD.2.]), a summary is given below:

<table>
<tr><th>Container</th><th>Content</th></tr>
<tr><td>GEO-CT</td><td>SAFNWC GEO CT Cloud Type

<table>
<tr><th>Class</th><th>Cloud Type category</th></tr>
<tr><td>1</td><td>Cloud-free land</td></tr>
<tr><td>2</td><td>Cloud-free sea</td></tr>
<tr><td>3</td><td>Snow over land</td></tr>
<tr><td>4</td><td>Sea ice</td></tr>
<tr><td>5</td><td>Very low clouds</td></tr>
<tr><td>6</td><td>Low clouds</td></tr>
<tr><td>7</td><td>Mid-level clouds</td></tr>
<tr><td>8</td><td>High opaque clouds</td></tr>
<tr><td>9</td><td>Very high opaque clouds</td></tr>
<tr><td>10</td><td>Fractional clouds</td></tr>
<tr><td>11</td><td>High semitransparent thin clouds</td></tr>
<tr><td>12</td><td>High semitransparent meanly thick clouds</td></tr>
<tr><td>13</td><td>High semitransparent thick clouds</td></tr>
<tr><td>14</td><td>High semitransparent above low or medium clouds</td></tr>
<tr><td>15</td><td>High semitransparent above snow/ice</td></tr>
<tr><td>FillValue</td><td>No data or corrupted data</td></tr>
</table></td></tr>
<tr><td>GEO-CT
_CUMULIFORM</td><td>SAFNWC GEO CT Stratiform/Cumuliform Cloud Detection

<table>
<tr><th>Class</th><th>Stratiform/Cumuliform Cloud category</th></tr>
<tr><td>1</td><td>Stratiform status</td></tr>
<tr><td>2</td><td>Cumuliform status</td></tr>
<tr><td>3</td><td>Mixed status</td></tr>
<tr><td>4</td><td>Cloud-free</td></tr>
<tr><td>5</td><td>Undefined (separability problem)</td></tr>
<tr><td>FillValue</td><td>No data or corrupted data</td></tr>
</table></td></tr>
<tr><td>GEO-CT
_MULTILAYER</td><td>SAFNWC GEO CT Multilayer Cloud Detection

<table>
<tr><th>Class</th><th>Multilayer Cloud category</th></tr>
<tr><td>0</td><td>No multilayer detected</td></tr>
<tr><td>1</td><td>Multilayer detected</td></tr>
<tr><td>2</td><td>Cloud free</td></tr>
<tr><td>3</td><td>Undefined (separability problem)</td></tr>
<tr><td>FillValue</td><td>No data or corrupted data</td></tr>
</table></td></tr>
<tr><td>GEO-CT
_status_flag</td><td>6 bits indicating (if set to 1)

Bit 0: Low level thermal inversion in NWP field
Bit 1: Tropopause temperature available from NWP field
Bit 2: R1.38µm used for cirrus identification
Bit 3: High resolution satellite data used
Bit 4: No method for stratiform/cumuliform separation
Bit 5: No method for multi-layer</td></tr>
</table>

Geophysical Conditions

Field	Type	Description
Space	Flag	Set to 1 for space pixels
Illumination	Parameter	Defines the illumination condition 0: N/A (space pixel) 1: Night 2: Day 3: Twilight
Sunglint	Flag	Set to 1 if Sunglint
Land_Sea	Parameter	0: N/A (space pixel) 1: Land 2: Sea 3: Coast
Rough_terrain	Flag	Set to 1 if rough terrain
High_terrain	Flag	Set to 1 if high terrain

Processing Conditions

Field	Type	Description
Satellite_input_data	Parameter	Describes the Satellite input data status 0: N/A (space pixel) 1: All satellite data are available 2: At least one useful satellite channel is missing 3: At least one mandatory satellite channel is missing
NWP_input_data	Parameter	Describes the NWP input data status 0: N/A (space 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
Product_input_data	Parameter	Describes the Product input data status 0: N/A (space pixel or Auxiliary data not used) 1: All input Product data are available 2: At least one useful input Product is missing 3: At least one mandatory input Product is missing
Auxiliary_input_data	Parameter	Describes the Auxiliary input data status (includes products used as input to PGE) 0: N/A (space 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 field is missing

Quality

Field	Type	Description
Nodata	Flag	Set to 1 if pixel is NODATA
Internal_consistency	Flag	Set to 1 if an internal consistency check has been performed. Internal consistency checks will be based in the comparison of the retrieved meteorological parameter with physical limits, climatological limits, neighbouring data, NWP data, etc.
Temporal_consistency	Flag	Set to 1 if a temporal consistency check has been performed Temporal consistency checks will be based in the comparison of the retrieved meteorological parameters with data obtained in previous slots.

Quality	Parameter	Retrieval Quality 0: N/A (no data) 1: Good 2: Questionable 3: Bad 4: Interpolated

3.2.2.5 Example of Cloud Type (CT) visualisation

It is important to note that the CT product is not just an image, but numerical data. At first hand, the CT is rather thought to be used digitally (together with the appended flags (quality, multilayer, stratiform/cumuliform (not yet available))) as input to mesoscale analysis models, objective Nowcasting schemes, but also in the extraction of other NWC SAF products (CTTH or CMIC for example).

Colour palettes are included in CT NetCdF files, thus allowing an easy visualisation of CT cloud type categories as illustrated on Figure 34.

The user may be interested in visualising all the available classes as displayed on a SEVIRI example in Figure 34, or highlight one or a few categories suitable for the application of interest. Product's animation will be a help for the user to interpret the visualized CT, and to identify artefacts (for example, the replacement of a snowy area by a low cloud between two successive pictures may be due only to the transition from day to night, as the snow detection is not possible at nighttime).

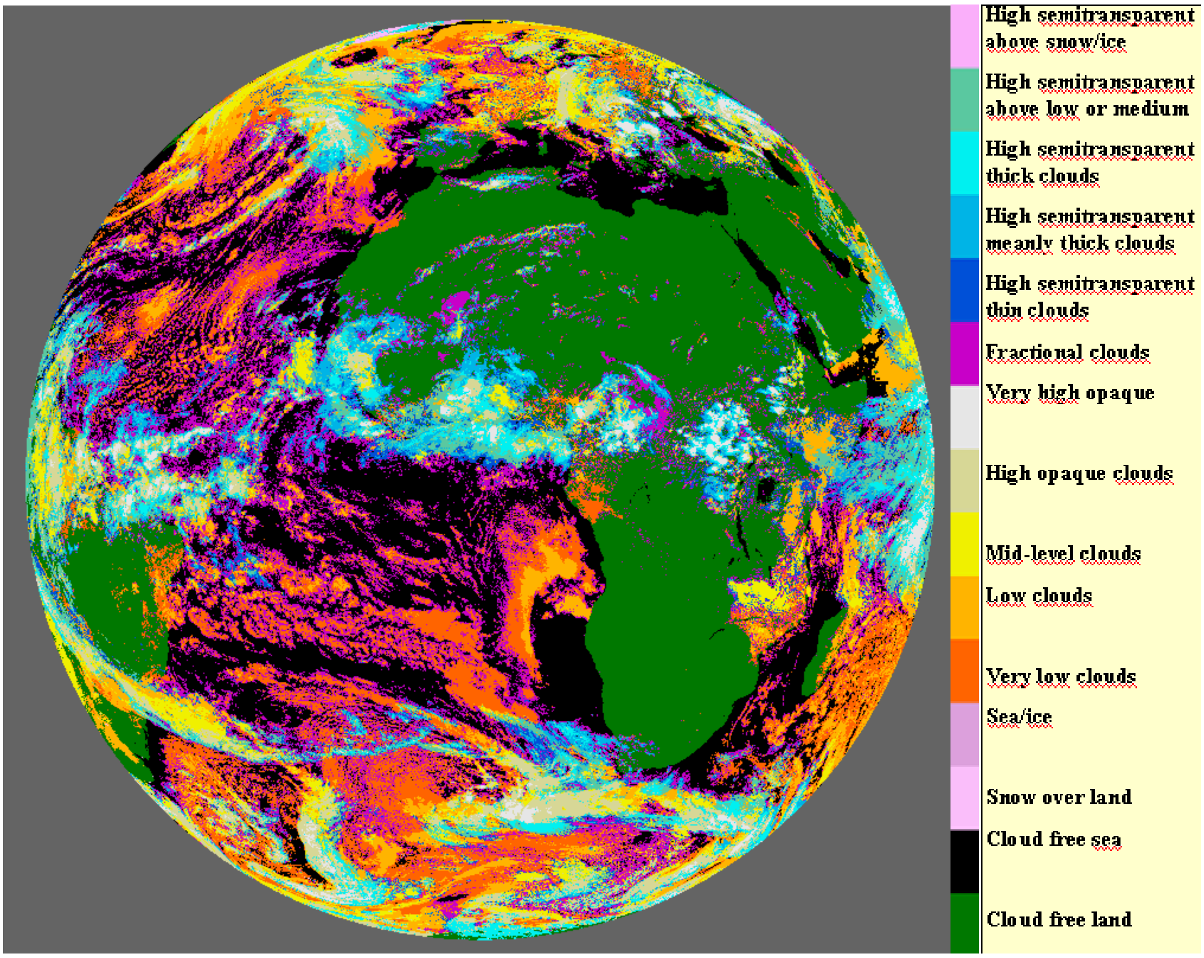

Figure 34: Example of SEVIRI CT cloud type using the colour palette included in CT NetCdF files.

3.2.2.6 Implementation of Cloud Type (CT)

CT is extracted by PGE02 (GEO-CT) component of the NWC/GEO software package. Detailed information on how to run this software package is available in the software user manual ([RD.3.]).

When a new region is defined the user has now to manually prepare the CT model configuration files for this new region using a default CT model configuration file provided in the NWC/GEO software package. The following parameter is configurable in the default CT model configuration file:

- CT_SZSEG (default value: 4): the size of the segment. This default value may be manually changed. [Segments are square boxes in the satellite projection, whose size is expressed as the number of default horizontal resolution pixels (3km for MSG) of one edge of the square box. The size of the processed regions must be a multiple of the segment size. All the solar and satellite angles, the NWP model forecast values, the atlas values and the thresholds will be derived over all the processed regions at the horizontal resolution of the segment. Note also that the land/sea atlas will be available at the full default horizontal resolution, allowing the identification of the surface type (land or sea) of all pixels, whatever the segment size. The quality is not very much dependent on the segment size (if lower than 4). Decreasing the segment size will increase the execution time]

The CT execution step is automatically launched by the Task Manager (if real-time environment is selected).

3.3 ASSUMPTIONS AND LIMITATIONS

The following problems may be encountered (for wrong cloud detection, please refer to paragraph 2.3):

- Very thin cirrus are often classified as fractional clouds.
- Very low clouds may be classified as medium clouds in case strong thermal inversion.
- Low clouds surmounted by thin cirrus may be classified as medium clouds.

3.4 REFERENCES

Chevalier F., 1999, TIGR-like sampled databases of atmospheric profiles from the ECMWF 50-level forecast model. NWPSAF Research report n°1

Eyre J., 1991, A Fast radiative transfer model for satellite sounding systems. *ECMWF Res.Dep.Tech.Mem 176. ECMWF*, *Reading, United Kinkdom*.

Manalo-Smith N., Smith G.L., Tiwari S.N., and Staylor W.F., 1998, Analytical forms of bidirectional reflectance functions for application to Earth radiation budget studies, *Journal of Geophysical Research*, **103 (D16)** 19733-19751.

4 DESCRIPTION OF CLOUD TOP TEMPERATURE AND HEIGHT (GEO-CTTH) PRODUCT

4.1 CLOUD TOP TEMPERATURE AND HEIGHT (CTTH) OVERVIEW

The cloud top temperature and height (CTTH), developed within the NWC SAF context, aims to support nowcasting applications. This product contributes to the analysis and early warning of thunderstorm development. Other applications include the cloud top height assignment for aviation forecast activities. The product may also serve as input to mesoscale models or to other NWC SAF product generation elements.

The CTTH product contains information on the cloud top temperature and height for all pixels identified as cloudy in the satellite scene.

Cloud top pressure or height are derived from their IR brightness temperatures by comparison to simulated IR brightness temperatures computed from temperature and humidity vertical profiles forecast by NWP using a IR radiative transfer model (RTTOV). Exact retrieval method depends on cloud type as semi-transparency correction using window and sounding IR channels may be needed.

4.2 CLOUD TOP TEMPERATURE AND HEIGHT (CTTH) ALGORITHM DESCRIPTION

4.2.1 Theoretical description

4.2.1.1 Physics of the problem

Temperatures of the top of opaque clouds may be deduced from the IR brightness temperatures measured in window channels, by accounting for the atmosphere effect above the cloud. Their height can then be retrieved from temperature profiles forecast by NWP.

This does not apply to semi-transparent clouds or sub-pixel (fractional) clouds for two reasons: -the IR brightness temperatures in window channels are contaminated by the underlying surface. -at least two parameters (the effective cloudiness (cloudiness x emissivity) and the top temperature) contribute to the measured brightness temperatures, and must be retrieved simultaneously. A multi-spectral approach with relevant assumptions (such as cloud emissivities' dependence on wavelength) is therefore needed.

4.2.1.2 Mathematical Description of the algorithm

The general scheme used to retrieve the CTTH from satellite imagery is first outlined; individual retrieval techniques and general modules used in this scheme are then detailed in the following sections.

4.2.1.2.1 Algorithm outline

The algorithm has been designed to be applicable to imagers on board meteorological geostationary satellites. The imagers may have different set of channels possibly at different horizontal resolutions. The lowest native resolution of the radiometer (3km at nadir for MSG/SEVIRI), which is for most imagers on board present and future meteorological geostationary satellites the horizontal resolution of all IR channels and some solar channels, will be chosen as the default horizontal resolution. Solar channels may be available at higher horizontal resolution (1km at nadir for HRV). In this release, the process is applied to all useful channels at the default horizontal resolution (high resolution channels being averaged at this resolution). We use generic labels in this document (for example, Rad6.2µm, Rad7.3µm, Rad13.4µm, T10.8µm, T12.0µm (Rad and T stand for radiance and brightness temperatures)), the exact central wavelengths of the corresponding channels depending on the satellite. The list of available labels depends on the satellite; the used and mandatory channels are listed in 4.2.2.3.

The different steps of the processing, applied to cloud-classified image at default horizontal resolution (3km at nadir for MSG), are summarized below. The exact process applied to each pixel depends on the availability of NWP and satellite imagery data.

<u>If all mandatory NWP and satellite data are available (see list of input for CTTH):</u>

The following process is then applied:

- RTTOV radiative transfer model (Eyre, 1991) is applied using NWP temperature and humidity vertical profile to simulate cloud free and overcast (clouds successively on each vertical pressure levels) radiances and brightness temperatures for window channels (10.8µm, and 12.0µm) and sounding channels (full list in 4.2.2.3, 6.2µm, 7.3µm, 13.4µm for MSG/SEVIRI). This process is performed in each segment of the image (the size of the segment is defined by the user, the default value being 4*4 pixels). The vertical profiles used are temporally interpolated to the exact slot time using the two nearest in time NWP fields input by the user.
- The techniques used to retrieve the cloud top pressure depend on the cloud's type (as available in CT product):
  - For very low, low or medium thick clouds: The cloud top pressure is retrieved on a pixel basis and corresponds to the best fit between the simulated and the measured 10.8µm brightness temperatures. The simulated brightness temperatures are available at the segment resolution. In case of the presence of a low level thermal inversion in the forecast NWP fields, the very low, low or medium clouds are assumed to be above the thermal inversion only if their brightness temperatures are colder than the air temperature below the thermal inversion minus an offset whose value depends on the nature of thermal inversion (dry air above the inversion level or not).
  - For high thick clouds: a method called the radiance ratioing method (see the next bullet for further explanation of this method) is first applied to remove any remaining semi-transparency that could have been undetected by the cloud type scheme. In case of failure, the method defined for medium opaque clouds is then applied.
  - For high semi-transparent clouds: The 10.8µm infrared brightness temperatures are contaminated by the underlying surfaces and cannot be used as for opaque clouds. A correction of semi-transparency is applied, which requires the use of two infrared channels: the 10.8µm window channel and a sounding (6.2µm, 7.3µm, 13.4µm for MSG) channel. The basis is that clouds have a stronger impact in a window channel than in a sounding channel. The following process is implemented:
    - The H_2O/IRW intercept method (as described in Schmetz et al., 1993), based on a window (10.8µm) and sounding (13.4µm, 7.3µm or 6.2µm for MSG) radiance bi-dimensional histogram analysis, is first applied. The histograms are built in boxes

of 32*32 pixels centred on each segment of the image (whose size is defined by the user, the default value being 4*4 pixels). It therefore allows the retrieval of cloud top pressure at the segment horizontal resolution (i.e., by default 4*4 pixels). This method is successively applied using the radiances of sounding channels (7.3µm, 6.2µm and 13.4µm for MSG), the final retrieved cloud pressure being the minimum cloud top pressures obtained using single sounding channel.

    - If no result can be obtained with the H_2O/IRW intercept method, the radiance ratioing method, as described in Menzel et al. 1982, is then applied at a pixel basis to retrieve the cloud top pressure from the radiances of two channels: a window channel (10.8µm) and a sounding channel (for MSG, successively 7.3µm, 6.2µm and 13.4µm).
    - If the radiance ratioing technique leads to cloud top temperatures warmer than the corresponding 10.8µm brightness temperatures, the method for thick clouds is used instead.
  - For fractional clouds : No technique is proposed in the current version for low broken clouds. The sounding channels are nearly unaffected by broken low clouds and are therefore useless; the infrared channels at 10.8µm and 12.0µm are contaminated by the surface and cannot therefore be used as for opaque clouds.
- A gap-filling procedure is applied in semi-transparent cloud top pressure field: in each box of 32x32 pixels, a cloud top pressure is computed as the average pressure of all pixels containing semi-transparent clouds inside the current and the eight surrounding boxes. This average cloud top pressure is then assigned to all pixels of the current box containing semi-transparent clouds and having no retrieved cloud top pressure.
- Cloud top temperature and altitude (above sea level) are then computed from their pressure using general modules. During these processes, the atmospheric vertical profiles are temporally interpolated to the exact slot time using the two nearest in time NWP outputs fields.
- Effective cloudiness (defined as the fraction of the field of view covered by cloud (the cloud amount) multiplied by the cloud emissivity in the 10.8µm window channel) is also computed during the processing. It is equal to 1.0 for thick clouds and takes a value between 0. and 1. for semi-transparent clouds.

<u>In case some mandatory NWP or satellite data are missing (see list of inputs for CTTH):</u>

Cloud top temperatures of very low, low, medium and high clouds are then computed by applying a climatological atmospheric absorption correction to the 10.8µm brightness temperature using look-up tables. The cloud top pressure and height are not retrieved.

4.2.1.2.2 Cloud top retrieval techniques

4.2.1.2.2.1 Opaque Cloud Top Temperature retrieved from climatological atmospheric absorption correction

This empirical technique allows retrieving the cloud top temperature of opaque clouds on a pixel basis, only using T10.8µm brightness temperature. This technique is used if NWP temperature and humidity vertical profile or if mandatory satellite channels are missing.

The cloud top temperature is calculated from the 10.8µm brightness temperature by adding an offset that accounts for the atmospheric absorption. This offset, which should be higher for low clouds and high viewing angles, is estimated from a pre-computed table with the 10.8µm brightness temperature of the pixel (indicating the cloud height) and the viewing angle as input.

This pre-computed table has been elaborated off-line using RTTOV simulations: T10.8µm brightness temperatures have been simulated from radio-soundings from a ECMWF dataset (Chevalier F., 1999) by assuming opaque clouds at various pressure levels in the troposphere. The values of the pre-computed table have been regressed from these simulations and are displayed in Figure 35.

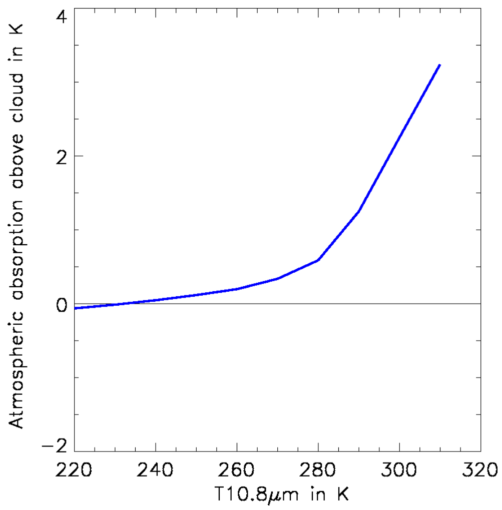

Figure 35: Climatological atmospheric absorption used to compute cloud top temperature from 10.8µm brightness temperature

Pixels processed by this method are flagged as of “bad quality”.

4.2.1.2.2.2 Opaque Cloud top pressure retrieved from window channel brightness temperature

This technique allows retrieving the cloud top pressure of opaque clouds on a pixel basis. It is not applied to low or medium clouds if a thermal inversion is detected in forecast NWP fields (see 4.2.1.2.2.3). It relies on the support of on-line RTTOV simulations and therefore requires the availability of the atmospheric vertical profile. These atmospheric profiles are forecast by a NWP model and temporally interpolated to the exact slot. The RTTOV simulations are computed on segments whose size is defined by the user (by default, 4*4 pixels).

Top of Atmosphere T10.8µm brightness temperatures are simulated assuming opaque clouds at the different pressure levels of the atmospheric vertical profile. These simulated T10.8µm brightness temperature vertical profiles are then inspected from surface level up to the tropopause level : two consecutive pressure levels having simulated temperatures respectively higher and lower than the T10.8µm brightness temperature are looked for; the cloud top pressure is finally obtained by a linear interpolation (logarithm of pressure used) between these two simulated temperatures.

The consistency of the technique is estimated on-line by retrieving the cloud top pressure from both the T10.8µm and T12.0µm brightness temperatures, the result being ideally equal. The pixel will be flagged as of "bad quality" if the difference between the results obtained from these two wavelengths is larger than 0.5°C.

4.2.1.2.2.3 Low or medium opaque Cloud top pressure retrieved from window channel brightness temperature in case thermal inversion

This technique allows retrieving the cloud top pressure of low or medium opaque clouds on a pixel basis, in case a thermal inversion has been detected in forecast NWP fields. It relies on the support of on-line RTTOV simulations and therefore requires the availability of the atmospheric vertical profile. These atmospheric profiles are forecast by a NWP model, temporally and spatially interpolated to the exact slot and to the processed pixel. The RTTOV simulations are computed on segments whose size is defined by the user (by default, 4*4 pixels).

The cloud is set below the thermal inversion only if its T10.8µm brightness temperature is larger than the air temperature below the inversion minus 10K (in case of subsident thermal inversion (see the definition in 4.2.1.2.3.1)) or larger than the simulated T10.8µm brightness temperature below the inversion minus 5K (in case of non subsident thermal inversion). In that case, the cloud is set below the inversion at a level between the top of the inversion and the colder part below the inversion depending on the strength of the inversion.

Otherwise, the cloud is set above the thermal inversion. The method to retrieve its top pressure is then similar to the one described in 4.2.1.2.2.2 if the difference between the T10.8µm brightness temperature and the air temperature is larger than 10K. Otherwise, the cloud top is set at a level between the level where simulated and observed brightness temperature fits best and a level between the top of the inversion and the colder level between the inversion.

Pixels processed by this method are flagged as of "bad quality". Moreover the presence of a thermal inversion in the forecast vertical temperature profile is also flagged.

4.2.1.2.2.4 Semi-transparent Cloud Top Pressure retrieved using radiance ratioing technique

The radiance ratioing technique allows retrieving semitransparent cloud top pressure at a pixel scale from radiances in two infrared channels, one of these channels being a sounding channel. It relies on on-line RTTOV simulations and therefore requires the availability of the atmospheric vertical profile.

This technique is detailed in Menzel et al., 1983. The basic equation of the method is the following:

$$\frac{R_{m1} - R_{clear1}}{R_{m2} - R_{clear2}} = \frac{N\varepsilon_1 (R_{op1} - R_{clear1})}{N\varepsilon_2 (R_{op2} - R_{clear2})} \qquad \textit{Eq. 1}$$

where R_m is the measured radiance, R_{clear} is the clear radiance, R_{op} is the opaque cloud radiance, N is the cloud amount and ε is the cloud emissivity. The terms of denominators on both side come from the same channel (index 2) and the nominators from the other one of the pair (index 1).

Assuming that the ratio of the emissivities is close to one the equation becomes simpler:

$$\frac{R_{m1} - R_{clear1}}{R_{m2} - R_{clear2}} = \frac{R_{op1} - R_{clear1}}{R_{op2} - R_{clear2}} \qquad \textit{Eq. 2}$$

Both side of this equation depends on the chosen channels, surface temperature, vertical temperature and absorbing material profiles. The right side of the equation also depends on the cloud pressure due to R_{op}. Consequently if we use a fixed surface temperature and vertical profiles, the right side becomes a function depending on the pressure, the left side being a constant. The retrieved cloud top pressure corresponds to the pressure that satisfies Eq.2. In practice the clear sky radiances R_{clear} are either measured or simulated, the opaque cloud radiances R_{op} are simulated values, while the R_m is the measured data.

It has been implemented using the 10.8µm window channel together with all the sounding channels (for MSG: 13.4µm CO_2 channels, 7.3µm and 6.2µm water vapour channels). It allows retrieving cloud top pressure for semitransparent ice clouds and high thick clouds on a pixel basis. The process is performed in several steps described below.

Simulation of the radiances

TOA infrared radiances of 10.8µm window channel and all sounding channels (for MSG: 13.4µm, 7.3µm and 6.2µm) for clear atmosphere and for opaque clouds at various pressure levels have been previously simulated with RTTOV.

Modification of simulated radiances

The method very much depends on the cloud free and opaque clouds values. As the simulated radiances for the water vapour channels are not reliable enough (mainly due to the inaccuracy of the atmosphere water vapour description by NWP models, as pointed out in Nieman et al., 1993), the following process is applied to modify them:

- modification of cloud free simulated radiances of water vapour sounding channels (for MSG: 7.3µm and 6.2µm) : the cloud free radiances for these channels are computed over the whole image at the segment spatial resolution from cloud free individual pixels and pixels containing opaque clouds too low to affect these measurements. They are used instead the simulated ones.
- modification of opaque simulated radiances of water vapour sounding channels (for MSG: 7.3µm and 6.2µm): the cloudy radiances for these channels are modified to account for the discrepancy between the simulated and observed cloud free radiances: the radiances for clouds at the tropopause remain unchanged, the radiances for the lowest clouds are replaced by the cloud free observed radiance, whereas the modification for the other clouds is linearly linked to its 10.8µm radiance. This modification is performed only if it leads to an increase of the simulated radiances.
- modification of cloud free simulated radiances of the 10.8µm window channel and the CO2 sounding channel (for MSG: 13.4µm): cloud free radiances for these channels are computed over the whole image at the segment spatial resolution from cloud free individual pixels. When available, these observed cloud free values replace the simulated ones.

Calculation of the cloud top pressure

Using the simulated and the measured radiances, we calculate the simulated ratio as a function of the cloud top pressure (right side of Eq.2), and the measured ratios (left side of Eq.2). The retrieved pressure level corresponds to this difference equal to zero. This is illustrated on Figure 36 with SEVIRI measurements.

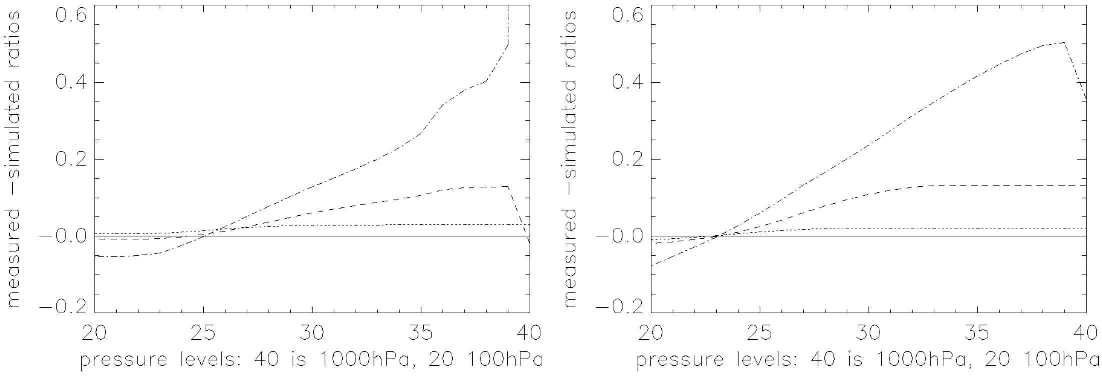

Figure 36: Illustration of the Radiance Ratioing technique applied to SEVIRI radiances.

Examples of measured minus simulated ratios as a function of the pressure level. The cloud top pressure level corresponds to the crossing of the curves with the X-axis. The three curves corresponds to different channel pairs : 10.8µm/13.4µm (dash-dot), 10.8µm/7.3µm (long dash), 10.8µm/6.2µm (dot)

Calculation of the cloud effective cloudiness

The cloud effective cloudiness (Nε) is calculated from the 10.8µm window radiance, using the retrieved cloud pressure.

Rejection

The retrieved cloud pressure is assumed to be unreliable in the following cases :

- the difference between the measured and the simulated clear sky radiances (R_m - R_{clear}) is within three times the instrument noise level.
- the difference between the retrieved and measured radiances is larger than 30% of the difference between the simulated and measured radiances

Quality flag

The pressure retrieval is flagged as of "bad quality" if :

- the cloud free cluster is derived from simulation.
- the retrieved radiances are higher than measured ones.

This technique is very much sensitive to the noise (especially for very thin clouds), and to the inaccuracy of the water vapour channel simulated radiances (if 7.3µm or 6.2µm channels are used), due to bad water vapour forecast.

4.2.1.2.2.5 Semi-transparent Cloud Top Pressure retrieved using H2O/IRW Intercept method

The H_2O/IRW intercept method is described Schmetz et al., 1993. It is successively applied to the 10.8µm window channel and one sounding channel (for MSG: either 6.2µm, 7.3µm or 13.4µm), the final retrieved cloud pressure being the averaged cloud top pressures obtained using a single sounding channel. This method is based on a radiance histogram analysis (see Figure 37). The histograms are built in boxes of 32*32 pixels centred on each segment of the image (whose size is defined by the user, the default value being 4*4 pixels). It therefore allows the retrieval of semitransparent ice cloud top pressure at the segment horizontal resolution (i.e., by default 4*4 pixels). It makes use of on-line RTTOV simulations and therefore requires the availability of the atmospheric vertical profile.

The fundamental assumption of the method is that there is a linear relationship between radiances in the two spectral bands observing a single cloud layer. In particular, all pairs of radiances in the sounding (for MSG: 6.2µm, 7.3µm or 13.4µm) and 10.8µm window channels viewing a cloud layer at pressure p_c will lay along a straight line, the spreading along the line corresponding to changes in cloud amounts. On the other hand, the pairs of radiances in the 10.8µm window channel and sounding channel (for MSG: 6.2µm, 7.3µm or 13.4µm) for opaque clouds at different pressure levels will lay along a curve that can be calculated from the atmospheric vertical structure using RTTOV radiative transfer model. Therefore, the cloud top pressure for semitransparent ice clouds is retrieved as the intersection between the linear fit to the observations and the simulated opaque cloud curve. This is illustrated with SEVIRI radiances on Figure 37.

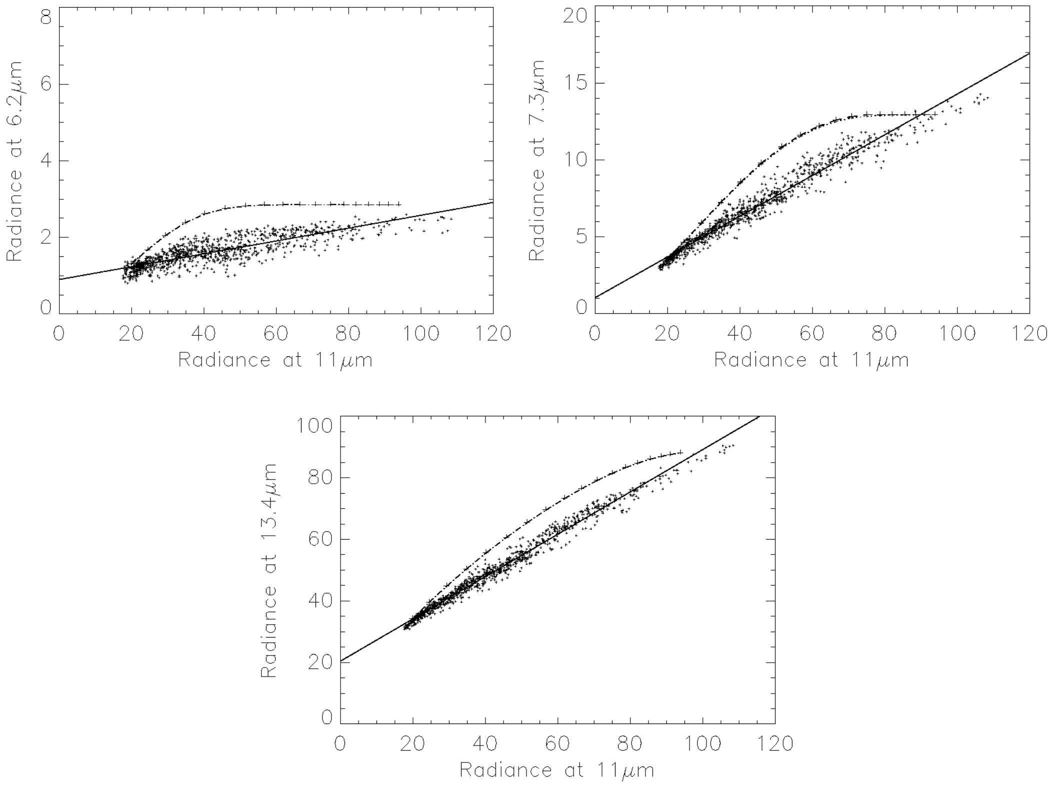

Figure 37: Illustration of the H_2O/IRW intercept method with SEVIRI radiances (expressed in $mWm^{-2}sr^{-1}cm$).

The dashed curve simulates the 10.8µm and 6.2µm (respectively 7.3 and 13.4µm) radiances of opaque clouds at various pressure levels.

The small crosses represent radiance of clouds at the same height, but with varying thickness, and the radiance of cloud free pixels.

The top pressure of the semitransparent cloud layer is retrieved from the intersection between the simulated curve (dashed curve) and the regression line.

The process is performed in several steps detailed below :

Simulation of window and sounding channels radiances

TOA infrared radiances of the 10.8µm window channel and all sounding channels (for MSG: 13.4µm, 7.3µm and 6.2µm) for clear atmosphere and for opaque clouds at various pressure levels have been previously simulated with RTTOV.

Modification of simulated radiances

As the method very much depends on the opaque clouds values, and as these simulations for the water vapour channels are not very reliable (mainly due to the inaccuracy of the atmosphere water vapour description by NWP models, as pointed out in Nieman et al., 1993), the following process is applied to modify the simulated values :

- modification of cloud free simulated radiances for water vapour channels (for MSG: 7.3µm and 6.2µm): cloud free radiances for these channels are computed over the whole image at the segment spatial resolution from cloud free individual pixels and pixels containing opaque clouds too low to affect these measurements. They are used instead the simulated ones.
- modification of opaque simulated radiances for water vapour sounding channels (for MSG: 7.3µm and 6.2µm): the cloudy radiances for these channels are modified to account for the discrepancy between the simulated and observed cloud free radiances : the radiance for clouds at the tropopause remain unchanged, the radiance for the lowest clouds are replaced by the cloud free observed radiance, whereas the modification for the other clouds is linearly linked to its 10.8µm radiance. This modification is performed only if it leads to an increase of the simulated radiances.

Calculation of the cloud top pressure

A straight line is adjusted, using the radiances of one sounding channel (for MSG: 13.4µm, 7.3µm or 6.2µm) and the 10.8µm window channel of all pixels previously classified as semitransparent, high thick clouds or cloud-free. The intersection of this straight line with the opaque cloud curve will give the cloud top pressure. This process, illustrated on Figure 37, is successively applied to all the sounding channels (for MSG: 7.3µm, 6.2µm and 13.4µm). When cloud top pressure can be obtained from more than one sounding channel, the final retrieved cloud top pressure corresponds to the minimum value obtained with the individual sounding channels.

Calculation of the effective cloudiness

The effective cloudiness (Nε) of each pixel is calculated from the radiance in the 10.8µm window channel, using the retrieved cloud pressure.

Rejection

The retrieved cloud pressure is assumed to be unreliable in the following cases :

- unreliable regression :
    - too few pixels (less than 50)
    - too low spread of the pixels in the 10.8µm channel is observed (less than 15 $mWm^{-2} sr^{-1} cm$ between the 10.8µm radiance of the coldest and the warmest pixels)
    - too low correlation coefficient (lower than 0.7)
- not adequate regression line :
    - slope of the regression line too small
    - regression line too close to opaque cloud curve

If no intersection has been found, but if the regression seems reliable (large number of pixels (more than 100), large spread of the pixels in the 10.8µm channel (more than 23 $mWm^{-2} sr^{-1} cm$ between the radiance of the 10.8µm window channel of the coldest and the warmest pixels), large correlation coefficient (larger than 0.9), large regression's slope), then the cloud top pressure is assumed to be the tropopause's pressure minus 50hPa, but the retrieval is flagged as bad quality.

Quality flag

The pressure retrieval is flagged as "good quality" if :

- The final cloud top pressure is a minimum value obtained from at least two sounding channels, the maximum difference between each individual cloud top pressure being less than 75hPa.
- The final cloud top pressure is obtained using a single sounding channel, but:
  - a high number of pixel is used in the regression (more than 100 pixels),
  - a large spread of the pixels in the 10.8µm channel is observed (more than 23 mWm^{-2} sr^{-1} cm between the 10.8µm radiance of the coldest and the warmest pixels),
  - a high correlation coefficient is observed (larger than 0.8)

4.2.1.2.3 General modules

4.2.1.2.3.1 Identification and characterisation of thermal inversions from forecast NWP fields

The NWP forecast air temperature and relative humidity on user-defined pressure levels are analysed as follows to identify and characterize thermal inversions:

- a thermal inversion is detected if layers exist between the surface and 700hPa where the air temperature increases with decreasing pressure.
- this thermal inversion is said "subsident" if the relative humidity between 850 and 600hPa is lower than 30%.

4.2.1.2.3.2 Tropopause height estimation

The pressure and height of the tropopause is extracted from a vertical profile (temperature, height and pressure), the ground height and the latitude. The tropopause estimation is mainly based on the WMO definition of the tropopause : the lowest level (above 5000m) corresponding to a temperature decrease of less than 2°C/km during 2km. A maximum height of the tropopause level is assumed (20km at the equator, 12-13km at the poles) to check the result's coherency.

4.2.1.2.3.3 Application of RTTOV to vertical atmospheric profiles

The RTTOV simulations are performed by NWC/GEO common software modules and are used to compute brightness temperatures and radiances of the simulated channels for cloud-free atmosphere and assuming opaque clouds on user-defined pressure levels. OSTIA SST analysis is used over ocean instead the NWP skin surface temperature.

4.2.1.2.3.4 Cloud Top altitude (above sea level) retrieved from its pressure

A module is used to compute the altitude vertical profile from the corresponding vertical profile of pressure, temperature & water vapour mixing ratio, the surface height and the latitude. The cloud altitude (above sea level) is then interpolated using the height of the two nearest pressure levels in the vertical profile. The interpolation used is linear in logarithm of the pressure.

4.2.1.2.3.5 Cloud Top Temperature retrieved from its pressure

A vertical temperature profile in pressure levels is needed in this process. The cloud temperature is interpolated using the temperature of the two nearest pressure levels in the vertical profile. The interpolation used is linear in logarithm of the pressure.

4.2.2 Practical considerations

4.2.2.1 Validation

Table 8 summarises the validation results of the current version for CTTH. More details can be obtained from the validation report for cloud products ([RD.1.]).

GEO-CTTH products	**Validated accuracy: bias(std)**
Top height of opaque low, mid-level and high cloud If validated over full disk using satellite-based lidar If validated over full disk using satellite-based radar	 -0.49km(0.99km) -0.35km(0.82km)
Top height of semi-transparent cloud If validated over full disk using satellite-based lidar If validated over full disk using satellite-based radar	 -1.44km(1.97km) 0.21km(1.88km)

Table 8: Summary of validation results of the current CTTH version (std stands for standard deviation)

4.2.2.2 Quality control and diagnostics

A quality assessment, detailed in 4.2.1.2.2, is performed by the CTTH itself through methods depending on the cloud type and the used retrieval techniques.

Two CTTH output fields are used to describe the quality and processing conditions (see in 4.2.2.4 and [RD.2.]). They include the quality assessment performed by the CTTH, but also information on the lack of NWP fields, RTTOV simulations or satellite non mandatory channels which leads to a decrease of CTTH quality. Information is also available on the method used (especially for semi-transparent clouds) which can be associated with validation results (see the validation results for cloud products ([RD.1.])).

4.2.2.3 List of inputs for Cloud Top Temperature and Height (CTTH)

The input data to the CTTH algorithm are described in this section. Mandatory inputs are flagged, whereas the impact of missing non-mandatory data on the processing are indicated.

- **Satellite imagery:**

The following satellite brightness temperatures and radiances are needed at default horizontal resolution (3km at nadir for MSG):

Rad6.2µm	Rad7.3µm	Rad13.4µm	Rad10.8µm	T10.8µm	T12.0µm
At least one of these channels is mandatory, the two others are then optional			Mandatory	Mandatory	Optional

The CTTH software checks the availability of satellite brightness temperatures and radiances for each pixel. Full CTTH product is computed only if all mandatory satellite radiances and brightness temperatures are available. If T10.8µm brightness temperature is missing, no result is available. If T10.8µm brightness temperature is available, but mandatory channels are missing, only the cloud top temperature is computed using the method based on climatological atmospheric absorption correction.

The satellite channels are input by the user in requested format (HRIT for MSG), and extracted on the processed region by NWC/GEO software package.

- **CMA and CT cloud categories**

The CMA and CT cloud categories are mandatory. They are computed by the CMA and CT software.

- **Satellite angles associated to satellite imagery**

This information is mandatory. It is computed by the CTTH software itself, using the definition of the region and the satellite characteristics.

- **NWP parameters:**

The forecast fields of the following parameters, remapped onto satellite images, are used as input :

  - surface temperature
  - surface pressure
  - air temperature and relative humidity (alternatively dew point temperature) at 2m
  - air temperature, relative humidity and geopotential on vertical pressure levels
  - tropopause temperature, pressure and geopotential
  - altitude of the NWP model grid (alternatively surface geopotential on the NWP model grid). Required if NWP fields are used as input.

Vertical pressure levels on which air temperature and humidity are defined by the user. All the surface and near-surface NWP informations and at least NWP informations every 210hPa on the vertical are mandatory to get full CTTH product. Otherwise only the cloud top temperature is retrieved using the method based on climatological atmospheric absorption correction. Furthermore, it is recommended to provide NWP information on levels at least up to 100hPa to ensure a good height retrieval quality for very high clouds.

These remapped fields are elaborated by the NWC software package from the NWP fields input by the user in GRIB format.

- **RTTOV simulations:**

The following parameters simulated by RTTOV are used as input for 10.8µm and 12.0µm window channels and all sounding channels (for MSG: 6.2 µm, 7.3 µm and 13.4 µm)

- Clear sky top of atmosphere radiance
- Transmittance from surface to TOA
- Clear sky downwelling radiance
- Clear+cloudy TOA radiance for given cloud top pressure and fraction (run RTTOV with black cloud at surface level)
- Level to space overcast radiance given black cloud for each vertical level defined by the user

These remapped fields are elaborated by the NWC/GEO software package by applying RTTOV to the NWP fields input by the user in GRIB format.

The RTTOV simulations are mandatory to get full CTTH product. Otherwise only the cloud top temperature is retrieved using the method based on climatological atmospheric absorption correction.

- **OSTIA fields:**

The following parameters are used as input:

- OSTIA SST

High resolution global daily bulk SST fields (OSTIA) are input by the user who can obtain them from MyOcean service desk (see http://www.myocean.eu.org). They are used in conjunction with RTTOV simulations.

These OSTIA fields are not mandatory: if not available the RTTOV simulations will be performed using NWP skin surface temperature.

- **Ancillary data sets:**

The following ancillary data, remapped onto satellite images, are mandatory :

  - Land/sea atlas
  - Elevation atlas
  - Monthly minimum SST climatology
  - Monthly mean 0.6µm atmospheric-corrected reflectance climatology (land)
  - Monthly thermal emissivity at IR wavelength

These ancillary data are available in the NWC software package on a global scale; a SAFNWC tool allows their remapping on full disk for each new satellite; they are finally extracted on the processed region by the CTTH software itself.

One coefficients's file, containing satellite-dependent values and one look-up table for climatological atmospheric absorption correction, is available in the NWC software package, and is needed by the CTTH software.

- **Configurable parameters:**

The following parameter is configurable in the default CTTH model configuration file:

- CTTH_SZSEG: the size of the segment is configurable (see its definition in 4.2.2.6). Its default value is 4. Information on how to change the size of the segment can be found in section 4.2.2.6 and in the software user manual ([RD.3.]).

4.2.2.4 Description of Cloud Top Temperature and Height (CTTH) output

The content of the CTTH is described in the Data Output Format document ([RD.2.]), a summary is given below:

Container	Content
GEO-CTTH _PRES	SAFNWC GEO CTTH Cloud Top Pressure GEO-CTTH_PRES(Pa) = scale_factor * Counts + add_offset where: *scale_factor = 10.0* *add_offset = 0.0*
GEO-CTTH _ALTI	SAFNWC GEO CTTH Cloud Top Altitude GEO-CTTH_ALTI(m) = scale_factor * Counts + add_offset where: *scale_factor = 1.0* *add_offset = -2000.0*
GEO-CTTH _TEMPE	SAFNWC GEO CTTH Cloud Top Temperature GEO-CTTH_TEMPE(K) = scale_factor * Counts + add_offset where: *scale_factor = 0.01* *add_offset = 130.0*
GEO-CTTH _EFFECTIV	SAFNWC GEO CTTH Cloud Effective Cloudiness GEO-CTTH_EFFECTIV = scale_factor * Counts + add_offset where: *scale_factor = 0.01* *add_offset = 0.0*
GEO-CTTH _METHOD	14 bits indicating (if set to 1) Bit 0: Cloud-free Bit 1: No relieable method Bit 2: Opaque cloud, RTTOV not available Bit 3: Opaque cloud, using RTTOV Bit 4: Opaque cloud, using RTTOV, in case thermal inversion Bit 5: Intercept method 10.8µm/13.4µm Bit 6: Intercept method 10.8µm/6.2µm Bit 7: Intercept method 10.8µm/7.0µm Bit 8: Intercept method 10.8µm/7.3µm Bit 9: Radiance ratioing method 10.8µm/13.4µm Bit 10: Radiance ratioing method 10.8µm/6.2µm Bit 11: Radiance ratioing method 10.8µ7.0µm Bit 12: Radiance ratioing method 10.8µm/7.3µm Bit 13: Spatial smoothing (gap filling in semi-transparent cloud field)
GEO-CTTH _status_flag	6 bits indicating (if set to 1) Bit 0: Cloud-free Bit 1: Low level thermal inversion in NWP field Bit 2: Opaque clouds Bit 3: Fractional clouds : no retrieval method Bit 4: Too thin clouds : no retrieval method Bit 5: Multilayer suspected

Geophysical Conditions

Field	Type	Description
Space	Flag	Set to 1 for space pixels
Illumination	Parameter	Defines the illumination condition 0: N/A (space pixel) 1: Night 2: Day 3: Twilight
Sunglint	Flag	Set to 1 if Sunglint
Land_Sea	Parameter	0: N/A (space pixel) 1: Land 2: Sea 3: Coast
Rough_terrain	Flag	Set to 1 if rough terrain
High_terrain	Flag	Set to 1 if high terrain

Processing Conditions

Field	Type	Description
Satellite_input_data	Parameter	Describes the Satellite input data status 0: N/A (space pixel) 1: All satellite data are available 2: At least one useful satellite channel is missing 3: At least one mandatory satellite channel is missing
NWP_input_data	Parameter	Describes the NWP input data status 0: N/A (space 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
Product_input_data	Parameter	Describes the Product input data status 0: N/A (space pixel or Auxiliary data not used) 1: All input Product data are available 2: At least one useful input Product is missing 3: At least one mandatory input Product is missing
Auxiliary_input_data	Parameter	Describes the Auxiliary input data status (includes products used as input to PGE) 0: N/A (space 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 field is missing

Quality

Field	Type	Description
Nodata	Flag	Set to 1 if pixel is NODATA
Internal_consistency	Flag	Set to 1 if an internal consistency check has been performed. Internal consistency checks will be based in the comparison of the retrieved meteorological parameter with physical limits, climatological limits, neighbouring data, NWP data, etc.
Temporal_consistency	Flag	Set to 1 if a temporal consistency check has been performed Temporal consistency checks will be based in the comparison of the retrieved meteorological parameters with data obtained in previous slots.

Quality	Parameter	Retrieval Quality 0: N/A (no data) 1: Good 2: Questionable 3: Bad 4: Interpolated

4.2.2.5 Example of Cloud Top Temperature and Height (CTTH) visualisation

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

Colour palettes are included in CTTH NetCdF files, thus allowing an easy visualisation of cloud top pressure (as illustrated with the SEVIRI example on Figure 38), height, temperature and effective cloudiness.

The product, if used as an image on the forecaster desk, may be visualized (together with CT) in an interactive visualisation system, where individual pixel values (top temperature, height and pressure, cloudiness) may be displayed while moving the mouse over the image.

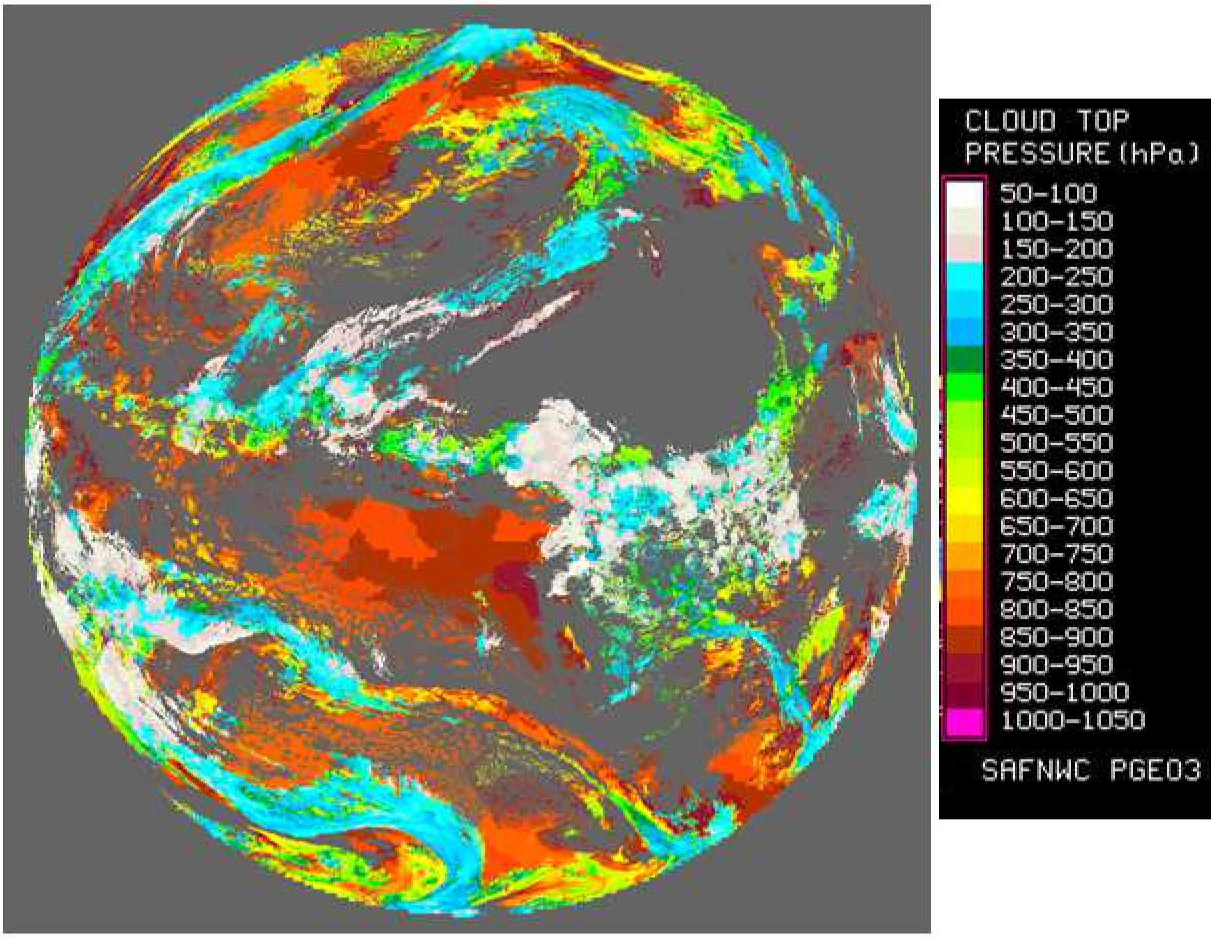

Figure 38: Example of SEVIRI CTTH cloud top pressure

4.2.2.6 Implementation of Cloud Top Temperature and Height (CTTH)

CTTH is extracted by PGE03 (GEO-CTTH) component of the NWC/GEO software package. Detailed information on how to run this software package is available in the software user manual ([RD.3.]).

When a new region is defined the user has now to manually prepare the CTTH model configuration files for this new region using a default CTTH model configuration file provided in the NWC/GEO software package. The following parameter is configurable in the default CTTH model configuration file:

- CTTH_SZSEG (default value: 4): the size of the segment. [Segments are square boxes in the satellite projection, whose size is expressed as the number of default horizontal resolution pixels (3km at nadir for MSG) of one edge of the square box. The size of the processed regions must be a multiple of the segment size. The NWP model forecast values and RTTOV simulations will be derived over all the processed regions at the horizontal resolution of the segment. A small ctth_szseg will decrease the box aspect in the retrieved cloud top pressure and will be especially useful if the NWP fields have a high horizontal resolution. But it may become very time consuming as RTTOV is launched every segment.]

The CTTH execution step is automatically launched by the Task Manager (if real-time environment is selected).

4.3 Assumptions and Limitations

The following problems may be encountered:

- CTTH will be wrong if the cloud is wrongly classified:
  - Underestimation of cloud top height/pressure for semi-transparent clouds classified as low/medium
  - Over estimation of cloud top height/pressure for low/medium clouds classified as semi-transparent
- No CTTH is available for clouds classified as fractional.
- CTTH may be not computed for thin cirrus clouds.
- Retrieved low cloud top height may be overestimated.

4.4 References

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5 DESCRIPTION OF CLOUD MICROPHYSICS (GEO-CMIC) PRODUCT

5.1 CLOUD MICROPHYSICS (CMIC) OVERVIEW

The cloud mycrophysics (CMIC), developed within the NWC SAF context, mainly aims to support nowcasting applications. The main objective of this product is to provide detailed information on the cloud microphysics. It may be used as input to an objective meso-scale analysis (which in turn may feed a simple nowcasting scheme), as an intermediate product input to other products (such as precipitation), or as a final image product for display at a forecaster's desk. The CMIC product is useful for the identification of precipitation clouds and useful for characterisation of rapidly developing thunderstorm.

The CMIC product contains information relevant to the cloud top (thermodynamical phase, cloud particle size) or integrated on the full vertical extent (optical depth, liquid and ice water path).

The CMIC retrieval algorithm first retrieves the thermodynamical phase through an empirical use of T8.7µm-T10.8µm, T10.8µm and the CT cloud type itself complemented (only during daytime) by an combined analysis of the measured and simulated 0.6µm and 1.6µm reflectances. The additional microphysics parameters are obtained only in daytime conditions through the comparison of measured and simulated 0.6µm and 1.6µm reflectances.

5.2 CLOUD MICROPHYSIC (CMIC) ALGORITHM DESCRIPTION

5.2.1 Theoretical description

5.2.1.1 Physics of the problem

The cloud microphysics retrieval is based on the following features:

- The T8.7µm –T10.8µm brightness temperature differences are sensitive to thermodynamical phase, being larger for ice clouds than for water clouds; the reason is the respective water and ice absorption at 8.7µm and 10.8µm nearly equal at 8.7µm but larger for ice at 10.8µm.
- The reflectance of clouds at a non-absorbing wavelength in the visible region (0.6µm) is strongly related to the optical thickness and has little dependence on particle size, whereas the reflectance of clouds at an absorbing wavelength in the near-infrared region (1.6µm) is primarily related to particle effective radius (larger for ice clouds than for water clouds).

The algorithm is applied to cloudy pixels which type and height are obtained from CT and CTTH. The algorithm requires simulated cloud 0.6µm and 1.6µm reflectances obtained from tabulated DISORT cloud radiative properties.

5.2.1.2 Mathematical Description of the algorithm

5.2.1.2.1 Algorithm outline :

The algorithm has been designed to be applicable to imagers on board meteorological geostationary satellites. The imagers may have different set of channels possibly at different horizontal resolutions. The lowest native resolution of the radiometer (3km at nadir for MSG/SEVIRI), which is for most imagers on board present and future meteorological geostationary satellites the horizontal resolution of all IR channels and some solar channels, will be chosen as the default horizontal resolution. Solar channels may be available at higher horizontal resolution (1km at nadir for HRV). In this release, the process is applied to all useful channels at the default horizontal resolution (high resolution channels being averaged at this resolution). We use generic labels in this document (for example, T8.7µm, T10.8µm, R0.6µm, and R1.6µm), the exact central wavelengths of the corresponding channels depending on the satellite. The list of available labels depends on the satellite; the list of mandatory channels is listed in 5.2.2.3.

The cloud top phase is first retrieved by an empirical use of T8.7µm-T10.8µm, T10.8µm and the CT cloud type itself complemented by an combined analysis of 0.6µm and 1.6µm measured and simulated reflectances, as summarized below:

- Warm (respectively cold) opaque clouds are supposed to be constituted of water (respectively ice) particles, whereas the temperature range between 0°C and –40°C may correspond to both (or a mixture) of water or ice clouds.
- Cloud classified as semi-transparent in CT cloud type are supposed be constituted of ice particles. Cloud classified as fractional may correspond to thin cirrus or sub-pixel low clouds; their retrieved cloud phase is therefore set "undefined".
- Water clouds usually have low T8.7µm-T10.8µm and ice clouds rather high values. Simple viewing angle-dependant thresholds subjectively defined from SEVIRI observations are applied to identify obviously water or ice clouds.
- If the cloud top phase is still not determined, the comparison of observed and simulated 0.6µm and 1.6µm reflectances for cloudy pixels may allow retrieving the cloud top phase (but ambiguous situations may still exists).

Once the cloud phase has been determined, the optical depth and the particle size are obtained using the measured and the simulated 0.6µm and 1.6µm reflectances. Finally liquid and ice water path are obtained by empirical formula.

The different steps are described in following sections.

5.2.1.2.2 Cloud 0.6µm and 1.6µm reflectances simulations

Cloud 0.6µm and 1.6µm reflectances are simulated by assuming a set of plane parallel ice and water clouds (radiative properties obtained from LUT computed from DISORT) at an given altitude (obtained from CTTH) embedded in an atmosphere (described from NWP fields: water vapour content (above and below the cloud layer), integrated ozone content) and above a surface (characteristics obtained from monthly climatology over land or constant value over sea).

The simulation is performed through the following equation:

$\rho = T_{2ac} * \rho_{bd} + \rho_s * (T_b + T_{fbd}) * T_d * (T_{2bc} * T_{2ac}) / (1.0 - \rho_s * \rho_{fd} * T_{2bc})$ where

$-\rho$	is the simulated reflectance
$-T_{2bc}$ and T_{2ac}	are two-path atmospheric transmission above or below the cloud
$-\rho_s$	is the surface reflectance
$-\rho_{bd}$, T_b, T_{fbd}, T_d, ρ_{fd}	are cloud radiative properties (including Rayleigh scattering) available in LUT

The different steps are described in the following subsections:

5.2.1.2.2.1 Computation of cloud radiative properties from DISORT

Cloud radiative properties are computed at 0.6µm and 1.6µm for a set of ten water clouds and eight ice clouds for a wide range of geometries and cloud optical thickness (see Table 9). These computations performed off-line are stored in Look-Up Table (LUTs) available in the NWC/GEO software.

Water cloud scattering properties are computed as follows:

- the refractive index database are described in Hale and Query, 1972, Palmer and Williams, 1974 and Downing and Williams, 1976 depending on the wavelength.
- the water clouds scattering properties are computed using a program (Make_mie_table by Franck Evans 2003) from SHDOM software package.
- the droplet size distribution is a Gamma distribution with veff=0.1111, maximum size from 30 to 75 micron (depending on effective radius), discretization depending on radius.
- single scattering albedo and extinction coefficients (normalized by extinction coefficient at 0.55µm) are computed together with the phase function expressed in Legendre moments (number of moments depending on wavelength and particle size, up to 1560 moments for 0.6µm channel for 30 microns effective radius).
- the computation is performed for a given wavelength discretization (ex: every 0.01µm for visible channels) and then averaged over the band filter.

Ice cloud scattering properties are computed as follows:

- the 2012 Baum dataset from CIMSS (Baum et all, 2012) is used. This dataset contains ice scattering properties (single scattering albedo, extinction coefficient, phase function) at a high spectral resolution (every 0.01µm between 0.2 and 15.2µm) for particle effective diameters ranging from 10 up to 120 micrometer (step: 5micrometer). Three ice cloud datasets are available: "smooth", "moderately_rough", "severely_rough", the latter has been chosen.
- the computation of ice cloud scattering properties for a spectral band is performed by averaging the scattering properties from the Baum dataset over the band filter.
- the moments of the averaged phase function are then obtained using an idl program (pmom.pro). 8192 moments are retained.

The cloud radiative properties are computed using DISORT2.0:

- the cloud radiative properties are computed by assuming a single plane-parallel cloud layer embedded in a two-layer Rayleigh scattering atmosphere using DISORT2.0 (32 streams (48 for diffuse quantities)) with water or ice cloud scattering properties obtained as explained above. The rayleigh scattering effect from the two layer above and below clouds (set at 700hPa) is included. The settings for the DISORT simulations are described in Table 9.
- The cloud radiative properties computed and stored in Look-Up Table (LUTs) are:
  - ρ_{bd} beam directional reflection
  - T_b beam direct transmission
  - T_{fbd} beam diffuse transmission
  - T_d diffuse transmission
  - ρ_{fd} diffuse reflexion flux

Wavelengths	VIS0.6 and NIR1.6

Illumination and Viewing Angles	
Solar Zenith Angle (μ_0):	31 values from 0.0 to 90.0 (regular step: 3.0)
Viewing Zenith Angle (μ):	31 values from 0.0 to 90.0 (regular step: 3.0)
Relative Azimuth Angle (ψ):	31 values from 0.0 to 90.0 (regular step: 3.0)
Cloud Properties	
Water Droplets:	Mie theory
	r_e = 3.0, 6.0, 9.0, 12.0, 15.0, 18.0, 21.0, 24.0, 27.0, 30.0 µm
Ice Particles:	Obtained from Baum.
	D_e = 10.0, 20.0, 30.0, 40.0, 50.0, 60.0, 70.0, 80.0 µm
Optical Depths:	0.0625,0,125,0.25,0.50,1,2,3,4,8,16,32,64,96,128,256

Table 9 Settings used for the radiative transfer calculations by DISORT to generate the LUTs.

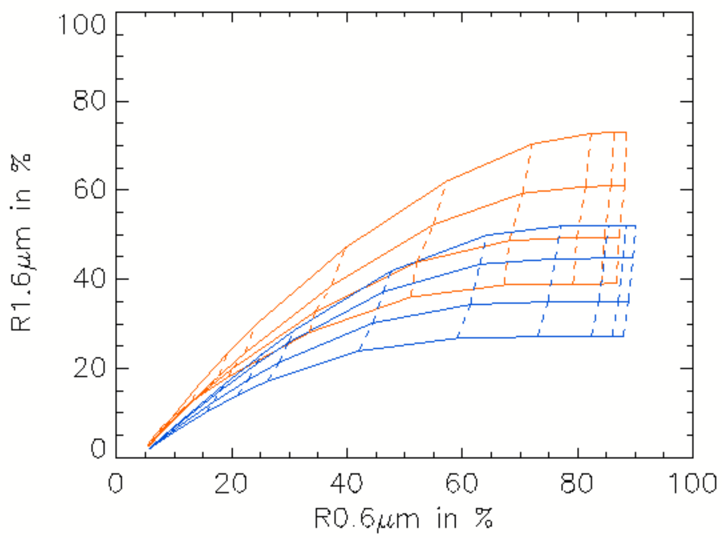

Figure 39 Illustration of the simulation of 0.6µm and 1.6µm cloud reflectances for a selection of water (in orange) and ice (in blue) cloud models for a given oceanic location (fixed viewing angles and surface cloud-free reflectances).

5.2.1.2.2.2 Atmospheric contribution

Two-path atmospheric gaz transmissions above or below the cloud are computed separately for ozone, water vapour and constant gazes. The method is to compute the transmittance for these gazes from regression (fitted with 6S). The final formulae for the transmission are the following:

$T2ac(O_3)$ = exp[a1+a2*(AMF*uO_3)+a3*(AMF*uO_3)^2] (above cloud)
$T2bc(O_3)$ = 1.0 (below cloud)
T2ac(H_2O)= exp[b1+b2*(AMF*u_aH_2O)+b3*(AMF*u_aH_2O)^2] (above cloud)
T2bc(H_2O)= exp[b1+b2*(AMF*u_bH_2O)+b3*(AMF*u_bH_2O)^2] (below cloud)
T2ac(constant_gaz) = exp[(c1+c2*(AMF)+c3*(AMF)^2) * Pc/1013] (above cloud)

T2bc(constant_gaz) = exp[(c1+c2*(AMF)+c3*(AMF)^2) * (1.0 - Pc/1013] (below cloud)

Where AMF=(1/cos(tetasat)+1/cos(tetasol)) is the air mass factor (tetasat and tetasol are satellite and solar zenith angles)

u_aH_2O (u_bH2O) is the water vapour content above (resp below) cloud (in kg/m2)
u_O_3 is the ozone content (assumed above cloud) (in Dobson)
Pc is the cloud top pressure (in hPa)
a1, a2, a3, b1, b2, b3, c21, c2, c3 are the regression coefficients (see value for MSG2)

Ozone	**a1**	**a2**	**a3**
0.6µm	$6.00476*10^{-6}$	$-8.13008*10^{-5}$	$4.1343*10^{-10}$
1.6µm	0.0	0.0	0.0
Water vapour	**b1**	**b2**	**b3**
0.6µm	-0.00144223	-0.000141195	$1.11101*10^{-7}$
1.6µm	-0.00273443	-0.000161682	$1.24263*10^{-7}$
Constant gazes	**c1**	**c2**	**c3**
0.6µm	-0.000662925	-0.000415767	$1.49941*10^{-5}$
1.6µm	-0.00662784	-0.0110764	0.000261246

Table 10 The regression coefficients for MSG2

The Rayleigh scattering is included in the computation of the cloud radiative properties LUT (see 5.2.1.2.2.1).

5.2.1.2.2.3 Surface characteristics

Surface reflectances are needed for the simulation of 0.6µm/1.6µm cloudy reflectances. Over continental areas, they are derived from MODIS white-sky surface albedo monthly climatologies available from NASA (http://modis-atmos.gsfc.nasa.gov/ALBEDO/index.html). These white sky albedos represent bi-hemispheric reflectances without the direct component which is a good approximation of the surface albedo below a cloud. Over sea, constant values are used: 3% (at 0.6µm) and 1% (at 1.6µm).

5.2.1.2.3 Retrieval scheme in night-time of twilight conditions

The cloud phase retrieval is only based on the use of CT cloud type and on the T8.7µm and T10.8µm brightness temperatures. The algorithm logic is the following:

- If CT cloud type is fractional : cloud phase is set to undefined
- If CT cloud type is semi-transparent (thin, medium, thick or above) : cloud phase is set to ice
- If CT cloud type is opaque cloud:
  - If T10.8µm>273.15K : cloud phase is set to liquid
  - If T10.8µm<233.15K : cloud phase is set ice
  - If 233.15K<T10.8mm<273.15K:
    - If T8.7µm-T10.8µm<-1.5-(1./cos(θ_{sat})-1) (in K) : cloud phase is set to liquid
    - If T8.7µm-T10.8µm>-0.8(1./cos(θ_{sat})-1) (in K) : cloud phase is set to ice
    - If -1.5-(1./cos(θ_{sat})-1) < T8.7µm-T10.8µm < -0.8(1./cos(θ_{sat})-1) : cloud phase is set to mixed

The other microphysical parameters are not computed in nighttime or twilight conditions.

5.2.1.2.4 Retrieval scheme in daytime conditions

The cloud phase retrieval is based on the use of the CT cloud type, the T8.7µm and T10.8µm brightness temperatures, complemented if needed by a combined analysis of the measured and simulated 0.6µm and 1.6µm reflectances. It is essential to use well calibrated 0.6µm and 1.6µm reflectances: calibration coefficients provided by KNMI (see Meirink et al., 2013) are used.

Cloud phase retrieval using CT cloud type, the T8.7µm and T10.8µm brightness temperatures:

- If CT cloud type is fractional : cloud phase is set to undefined
- If CT cloud type is semi-transparent (thin, medium, thick or above) : cloud phase is set to ice
- If CT cloud type is opaque cloud:
  - If T10.8µm>273.15K : cloud phase is set to liquid
  - If T10.8µm<233.15K : cloud phase is set to ice
  - If 233.15K<T10.8µm<273.15K:
    - If T8.7µm-T10.8µm<-1.5-(1./cos(θ_{sat})-1) (in K) : cloud phase is set to liquid
    - If T8.7µm-T10.8µm>-0.8(1./cos(θ_{sat})-1) (in K) : cloud phase is set to ice
    - If -1.5-(1./cos(θ_{sat})-1) < T8.7µm-T10.8µm < -0.8(1./cos(θ_{sat})-1) : cloud phase is the cloud phase retrieved from 0.6µm and 1.6µm reflectances (see below)

Cloud phase retrieval using measured and simulated 0.6µm and 1.6µm reflectances (illustrated in Figure 40):

- As a first step, the particle size and optical thickness are estimated by a comparison of measured and simulated 0.6µm and 1.6µm reflectances (assuming a water cloud). Simulated reflectances are obtained as explained in 5.2.1.2.2 and depends on viewing angles, surface reflectances (known values only dependant on the location and time of the day), atmospheric state (from forecast NWP), cloud top height (provided by CTTH), and particle size and optical thickness (quantities to be retrieved). This step is straightforward except if the 1.6µm reflectances does not regularly decrease with the increasing particle size which may be the case for low cloud optical thickness.
- The ideal case is that for a given 0.6µm reflectances the simulated 1.6µm reflectances for water clouds are larger than those for ice clouds. The simple comparison of the measured 1.6µm reflectance to the simulated one should then give the cloud phase. In practice the cloud phase only using 0.6µm and 1.6µm is retrieved as follows:
  - The cloud phase is set to liquid if the retrieved particle size is lower than 32 micron and if the measured 1.6µm reflectance is higher than the 1.6µm reflectance simulated for all ice cloud model (for the current measured 0.6 reflectance)
  - The cloud phase is set to ice:
    - If the retrieved particle size is larger than 32 micron,
    - or if the retrieved particle size is between 16 and 32 micron and if the measured 1.6µm reflectance is lower than the 1.6µm reflectance simulated for at least 7 ice cloud models (for the current measured 0.6 reflectance)
    - or if the retrieved particle size is between 2 and 16 micron and if the measured 1.6µm reflectance is lower than the 1.6µm reflectance simulated for all ice cloud model (for the current measured 0.6 reflectance)
  - Eitherwise the cloud phase is set "mixed"

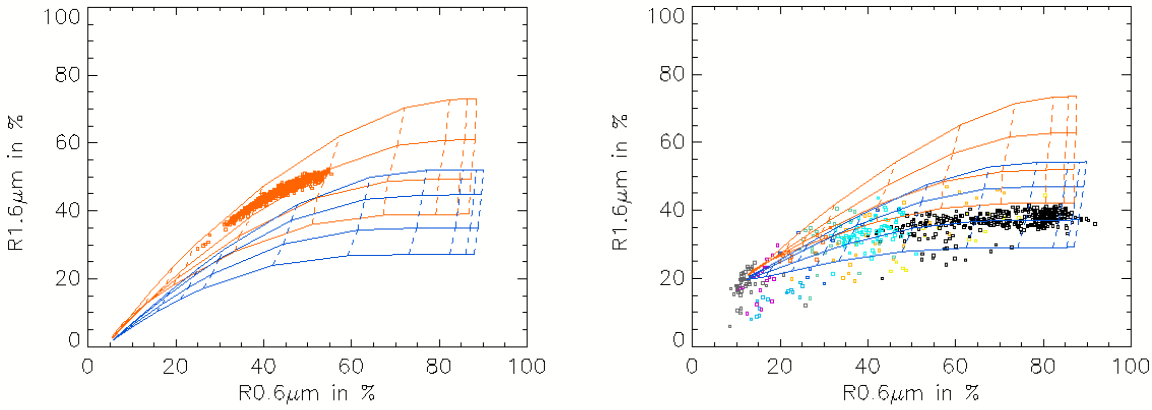

Figure 40 Illustration of the cloud phase retrieval using 0.6μm and 1.6μm reflectances. Cloud measurements (coloured using CT cloud type colors, except white color replaced by black) are superimposed to simulated curves. Left: for a maritime stratocumus cloud; right: for a convective system over the Pyrenees.

Once the cloud phase has been determined, the optical depth and the particle size are obtained (except for mixed phase and undetermined) using the measured and the simulated 0.6μm and 1.6μm reflectances in a similar way as what has been performed for the cloud phase retrieval by using the adequate cloud models (ice or water).

Finally liquid and ice water path are obtained by empirical formulae:

$LWP = (2/3)*\tau*r_e*\rho_l$ where τ is the optical thickness, r_e the effective radius and ρ_l the density of water (Stephens et al., 1978)

$IWP = (\tau/0.065)^{(1/0.84)}$ where τ is the optical thicknes (proposed by Heymsfield, see CREW2 report)

5.2.2 Practical considerations

5.2.2.1 Validation

Table 7 summarises the validation results of the current version. More details can be obtained from the validation report for cloud products ([RD.1.]).

	Validated accuracy
GEO-CMIC cloud phase If validated over full disk using space-based lidar	For water phase: POD: 93.78% FAR: 5.40% For ice phase: POD: 96.59% FAR: 3.94%
GEO-CMIC cloud liquid water path If validated over full disk over ocean using AMSR mirco-wave imagery	Bias: -0.96g/m^2 ; rms: 38.46g/m^2

Table 11: Summary of validation results for the current CMIC cloud phase and cloud liquid water path (POD stands for Probability Of Detection)

5.2.2.2 Quality control and diagnostics

Two CMIC output fields are used to describe the quality and processing conditions (see in 5.2.2.4 and [RD.2.]). They include information on the lack of NWP fields or satellite non mandatory channels which leads to a decrease of CMIC quality.

5.2.2.3 List of inputs for Cloud Microphysic (CMIC)

The input data to the CMIC algorithm are described in this section. Mandatory inputs are flagged, whereas the impact of missing non-mandatory data on the processing are indicated.

- **Satellite imagery:**

The following bi-directional reflectances or brightness temperatures are needed at default horizontal resolution (3km at nadir for MSG):

R0.6µm	R1.6µm	T8.7µm	T10.8µm
Mandatory	Mandatory	Mandatory	Mandatory

The CMIC software checks the availability of channels for each pixel; no results are available for pixels where at least one mandatory channel is missing.

The channels are input by the user in requested format (HRIT for MSG), and extracted on the processed region by NWC/GEO software package.

It is essential to use well calibrated 0.6µm and 1.6µm reflectances: calibration coefficients provided by KNMI (see Meirink et al., 2013) are used by CMIC to recalibrate these channels during CMIC computation..

- **CT cloud categories**

The CT cloud categories are mandatory. They are computed by the CT software.

- **CTTH cloud categories**

The CTTH cloud top pressure are optional. They are computed by the CTTH software. If they are bnot available, default value are used for water (800hPa) or ice clouds (300hPa).

- **Sun and satellite angles associated to satellite imagery**

This information is mandatory. It is computed by the CMIC software itself, using the definition of the region and the satellite characteristics.

- **NWP parameters:**

The forecast fields of the following parameters, remapped onto satellite images, are used as input :

  - Total ozone content
  - Integrated water vapour content above and below pressure levels defined by user

These remapped fields are elaborated by the NWC/GEO software package from the NWP fields input by the user in GRIB format.

The NWP fields are not mandatory. The CMIC software replaces missing NWP fields by climatological values extracted from ancillary dataset. The quality of CMIC is lower if NWP fields are missing.

- **Ancillary data sets:**

The following ancillary data, remapped onto satellite images, are mandatory :

  - Land/sea atlas
  - Elevation atlas
  - Monthly 0.6µm and 1.6µm white-sky surface albedo climatology (land)
  - Monthly integrated atmospheric water vapor content climatology
  - Monthly ozone content climatology

These ancillary data are available in the NWC/GEO software package on a global scale; a SAFNWC tool allows their remapping on full disk for each new satellite; they are finally extracted on the processed region by the CMIC software itself.

One coefficients's file (also called threshold table), containing satellite-dependent values and look-up tables for thresholds, is available in the NWC/GEO software package, and is needed by the CMIC software.

One file containing offline DISORT simulations of 0.6µm and 1.6µm cloud radiative properties (beam bi-directional reflection, beam direct transmission, beam diffuse transmission, diffuse transmission, diffuse reflection flux) performed for a set of water and ice clouds, is available in the NWC/GEO software package, and is needed by the CMIC software.

- **Configurable parameters:**

The following configurable parameter are available in the default CMIC model configuration file:

- CMIC_SZSEG: The size of the segment is configurable (see its definition in section 5.2.2.6). Its default value is 4. Information on how to change the size of the segment can be found in section 5.2.2.6 and in the software user manual ([RD.3.]).
- IS_ALREADY_RECALIBRATED: this flag, defining whether satellite data input by the user are already recalibrated with post-launch calibration coefficients (solar channels) and GSICS IR calibration coefficients, is configurable (see its definition in section 5.2.2.6). Its default value is FALSE. Information on how to change this value can be found in section 5.2.2.6 and in the software user manual ([RD.3.]).

5.2.2.4 Description of Cloud Microphysic (CMIC) output

The content of the CMIC is described in the Data Output Format document ([RD.2.]), a summary is given below:

Container	**Content**
GEO-CMIC _PHASE	SAFNWC GEO CMIC Cloud Top Phase **Class** / **Cloud Top Phase category**: 1: Liquid 2: Ice 3: Mixed 4: Cloud-free 5: Undefined (separability problem) FillValue: No data or corrupted data
GEO-CMIC _REFF	SAFNWC GEO CMIC Cloud Drop Effective Radius GEO-CMIC_REFF(m) = scale_factor * Counts + add_offset where: *scale_factor* = 10^{-8} *add_offset* = *0.0*
GEO-CMIC _COT	SAFNWC GEO CMIC Cloud Optical Thickness GEO-CMIC_COT = scale_factor * Counts + add_offset where: *scale_factor* = *0.01* *add_offset* = *0.0*
GEO-CMIC _LWP	SAFNWC GEO CMIC Cloud Liquid Water Path GEO-CMIC_LWP(kg.m^{-2}) = scale_factor * Counts + add_offset where: *scale_factor* = *0.001* *add_offset* = *0.0*
GEO-CMIC _IWP	SAFNWC GEO CMIC Cloud Ice Water Path GEO-CMIC_IWP(kg.m^{-2}) = scale_factor * Counts + add_offset where: *scale_factor* = *0.001* *add_offset* = *0.0*
GEO-CMIC _status_flag	11 bits indicating (if set to 1) Bit 0: Cloud-free Bit 1: High resolution satellite data used Bit 2: Combined use of 1.6µm & 2.2µm for phase retrieval Bit 3: No retrieved phase: no reliable Reff/Cot retrieval Bit 4: Mixed phase : no reliable Reff/Cot retrieval Bit 5: Measurement incoherent with simulation: no reliable Reff/Cot retrieval Bit 6: Too much overlap in simulation : no reliable Reff/Cot retrieval Bit 7: 1.6µm used for reff/cot retrieval Bit 8: 2.2µm used for reff/cot retrieval Bit 9: 3.8µm used for reff/cot retrieval Bit 10: Multilayer cloud suspected

Geophysical Conditions

Field	Type	Description
Space	Flag	Set to 1 for space pixels
Illumination	Parameter	Defines the illumination condition 0: N/A (space pixel) 1: Night 2: Day 3: Twilight
Sunglint	Flag	Set to 1 if Sunglint
Land_Sea	Parameter	0: N/A (space pixel) 1: Land 2: Sea 3: Coast
Rough_terrain	Flag	Set to 1 if rough terrain
High_terrain	Flag	Set to 1 if high terrain

Processing Conditions

Field	Type	Description
Satellite_input_data	Parameter	Describes the Satellite input data status 0: N/A (space pixel) 1: All satellite data are available 2: At least one useful satellite channel is missing 3: At least one mandatory satellite channel is missing
NWP_input_data	Parameter	Describes the NWP input data status 0: N/A (space 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
Product_input_data	Parameter	Describes the Product input data status 0: N/A (space pixel or Auxiliary data not used) 1: All input Product data are available 2: At least one useful input Product is missing 3: At least one mandatory input Product is missing
Auxiliary_input_data	Parameter	Describes the Auxiliary input data status (includes products used as input to PGE) 0: N/A (space 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 field is missing

Quality

Field	Type	Description
Nodata	Flag	Set to 1 if pixel is NODATA
Internal_consistency	Flag	Set to 1 if an internal consistency check has been performed. Internal consistency checks will be based in the comparison of the retrieved meteorological parameter with physical limits, climatological limits, neighbouring data, NWP data, etc.
Temporal_consistency	Flag	Set to 1 if a temporal consistency check has been performed Temporal consistency checks will be based in the comparison of the retrieved meteorological parameters with data obtained in previous slots.

Quality	Parameter	Retrieval Quality 0: N/A (no data) 1: Good 2: Questionable 3: Bad 4: Interpolated

5.2.2.5 Example of Cloud Microphysics (CMIC) visualisation

It is important to note that the CMIC product is not just an image, but numerical data. At first hand, the CMIC is rather thought to be used digitally (together with the appended flags (quality) as input to mesoscale analysis models, objective Nowcasting schemes, but also in the extraction of other NWC SAF products (precipitation products for example).

Colour palettes are included in CMIC NetCdF files, thus allowing an easy visualisation of CMIC different parameters such as the cloud phase, cloud optical thickness (as illustrated in Figure 41), cloud effective radius (as illustrated in Figure 42), cloud liquid or ice water path.

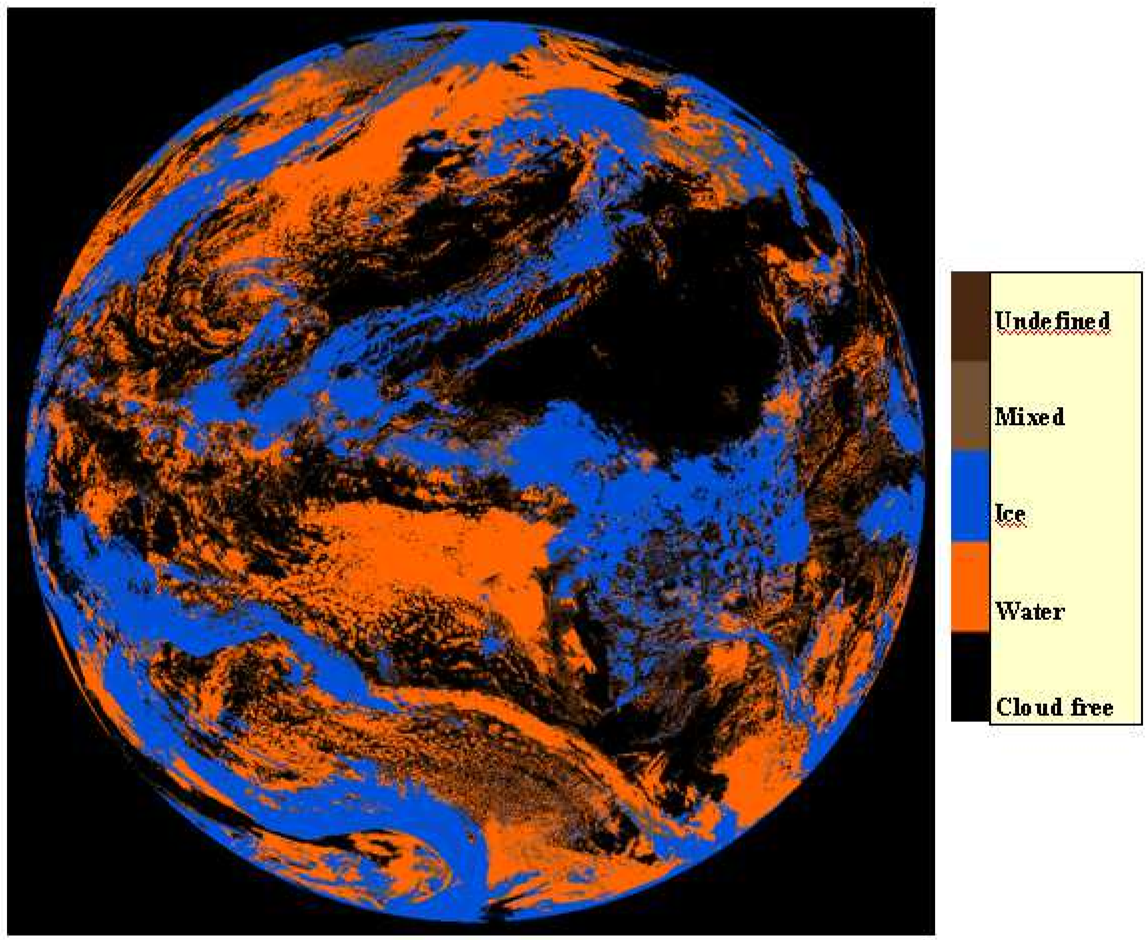

Figure 41 Example of SEVIRI cloud phase flag illustrated with the colour palette included in the CMIC NetCdF files.

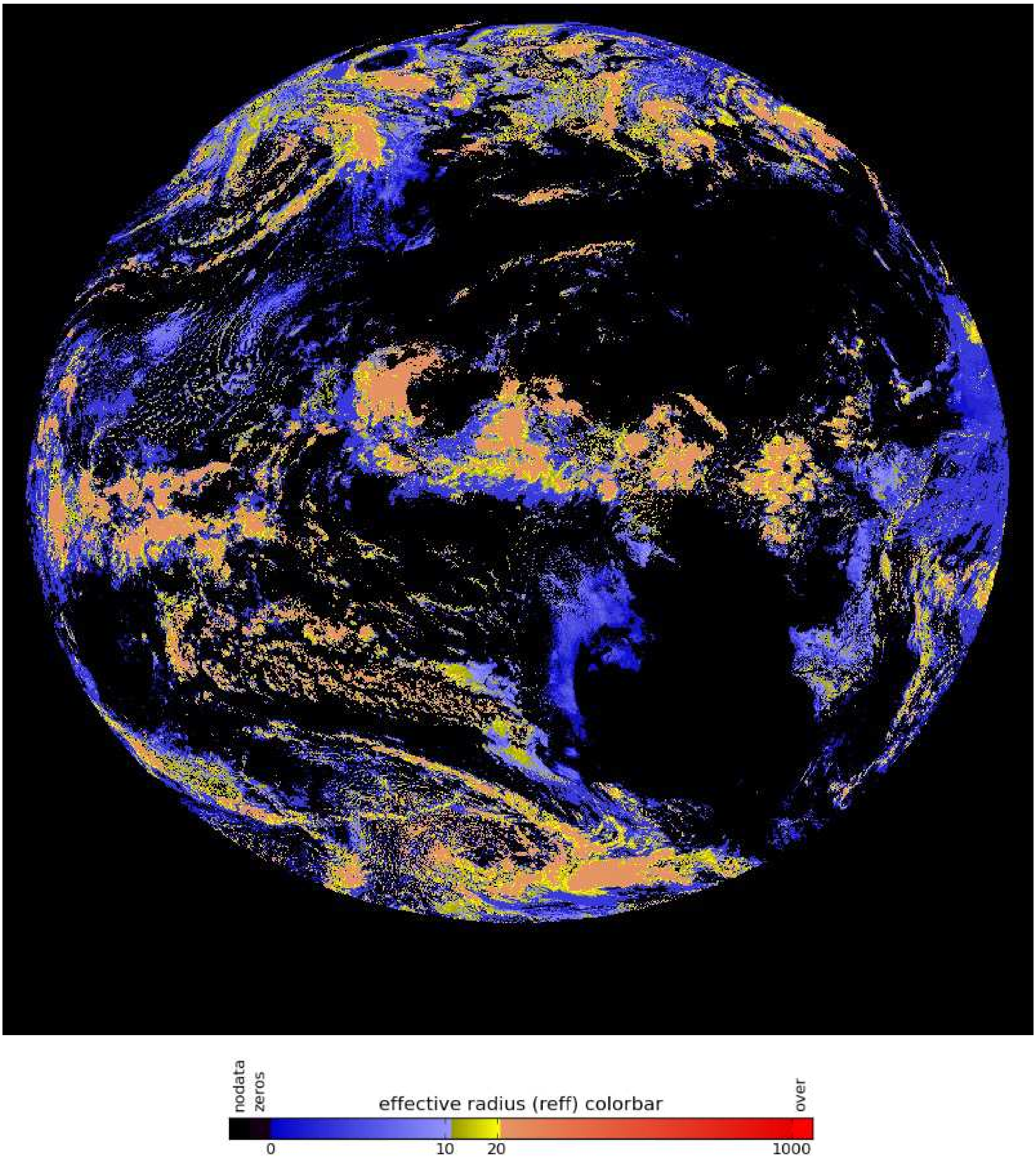

Figure 42 Example of SEVIRI cloud effective radius illustrated with the colour palette included in the CMIC NetCdF files.

5.2.2.6 Implementation of Cloud Microphysic (CMIC)

CMIC is extracted by PGE15 (GEO-CMIC) component of the NWC/GEO software package. Detailed information on how to run this software package is available in the software user manual ([RD.3.]).

When a new region is defined the user has now to manually prepare the CMIC model configuration files for this new region using a default CMIC model configuration file provided in the NWC/GEO software package. The following parameters are configurable in the default CMIC model configuration file:

- CMIC_SZSEG (default value: 4): the size of the segment. This default value may be manually changed. [Segments are square boxes in the satellite projection, whose size is expressed as the number of default horizontal resolution pixels (3km at nadir for MSG) of one edge of the square box. The size of the processed regions must be a multiple of the segment size. All the solar and satellite angles, the NWP model forecast values, the cloud simulations, the atlas values will be derived over all the processed regions at the horizontal resolution of the segment. Note also that the land/sea atlas will be available at the full default horizontal resolution, allowing the identification of the surface type (land or sea) of all default horizontal resolution pixels, whatever the segment size. The quality is not very much dependent on the segment size (if lower than 16)]
- IS_ALREADY_RECALIBRATED (default value: FALSE): this flag defines whether satellite data input by the user are already recalibrated with post-launch calibration coefficients (solar channels) and GSICS IR calibration coefficients. [For nearly all users, it should remain set to FALSE (defaut value). If set to TRUE (for example, CM-SAF may use this option), the CMIC does not perform its own recalibration of solar channels].

The CMIC execution step is automatically launched by the Task Manager (if real-time environment is selected).

5.3 ASSUMPTIONS AND LIMITATIONS

The following problems may be encountered:

- No CMIC is available for cloud classified as fractional
- No optical thickness, drop effective radius and liquid/ice water path are retrieved at nightime or twilight, or at daytime for “mixed phase” or “undefined phase”

5.4 REFERENCES

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ANNEX 1. ATLAS AND CLIMATOLOGICAL DATASET

Atlas and climatological datasets at a global scale are available within the NWC software package and are used in the elaboration of CMA, CT, CTTH and CMIC products. The following sections give a short description of the source of these ancillary data.

A1.1 LAND/SEA ATLAS

Common atlas.

A1.2 LAND/SEA/COAST ATLAS

Common atlas.

A 1.3 ELEVATION ATLAS

Common atlas.

A 1.4 MONTHLY LAND SURFACE EMISSIVITY CLIMATOLOGY

Thermal emissivities are computed from RTTOV (version higher than 10) using the subroutines giving access to the emissivity; these subroutines would be applied (only once) to all pixels of the region and the emissivity stored. These are common atlas.

A 1.5 MONTHLY MINIMUM SEA SURFACE TEMPERATURE MINIMUM AND STANDARD DEVIATION CLIMATOLOGY

The original dataset is the OSTIA SST analysis archive (http://ghrsst-pp.metoffice.com/pages/latest_analysis/ostia.html):

- OSTIA SST fields cover the entire world on a latitude/longitude grid (spatial resolution: 1/20 degrees).
- The archive consists in daily fields (average value and standard deviation) over the period from 07/1985 up to 07/2007 .
- The fields are coded in NetCdF format.

A monthly climatology of SST minimum and standard deviation has been prepared by retaining the minimum SST value and the maximum SST standard deviation over the 22 years.

A 1.6 MONTHLY VISIBLE ATMOSPHERIC-CORRECTED REFLECTANCES CLIMATOLOGY

The initial source is a 10 minutes horizontal resolution global climatology of Top Of Atmosphere monthly visible reflectances derived by NOAA from AVHRR GAC measurements (see Gutman et al., 1995).

These TOA reflectances have been roughly corrected from atmospheric effects. The values corresponding to snowy targets have been replaced, either with the nearest in time value, either by a constant value (20%). The data have been finally spread spatially in the coastal areas. Monthly visible atmospheric-corrected reflectance over land is obtained from the nearest value of these TOA reflectances. Sea pixels are given a default value.

A 1.7 MONTHLY 0.6µM/1.6µM WHITESKY SURFACE ALBEDOE CLIMATOLOGY

Cloud free surface reflectances are needed during the comparison of the simulated and measured 0.6µm/1.6µm cloudy reflectances performed during the CT cloud phase retrieval. Over continental areas, they are derived from MODIS monthly 0.6µm and 1.6µm white-sky surface albedo climatologies available from NASA (http://modis-atmos.gsfc.nasa.gov/ALBEDO/index.html). These white sky albedos represents bi-hemispheric reflectances without the direct component which is a good approximation of the surface albedo below a cloud. Over sea, constant values are used: 3% (at 0.6µm) and 1% (at 1.6µm).

A 1.8 MONTHLY CLOUD FREE LARGE BAND VISIBLE SURFACE REFLECTANCES CLIMATOLOGY

Cloud free large band visible surface reflectances are used to process HRV during the CMA cloud detection process. Over continental areas, they are derived from MODIS monthly 0.5µm, 0.6µm and 0.8µm black-sky surface albedo climatologies available from NASA (http://modis-atmos.gsfc.nasa.gov/ALBEDO/index.html). These black sky albedos represents bi-hemispheric reflectances with the direct component. These three monthly climatologies are averaged, the weight of each band (0.5µm, 0.6µm and 0.8µm) being dependant on the HRV spectral filter.

A 1.9 LAND COVER DATABASE

Land cover database is obtained from the Global Land Cover database provided by USGS (http://edc2.usgs.gov/glcc/glcc.php . Preferably version 2.0). The Biosphere Atmosphere Transfer Scheme (BATS) is used which provide 20 surface types on a iso latitude/longitude grid (30 arc second):

```
1      Crops, Mixed Farming
2      Short Grass
3      Evergreen Needleleaf Trees
4      Deciduous Needleleaf Tree
5      Deciduous Broadleaf Trees
6      Evergreen Broadleaf Trees
7      Tall Grass
8      Desert
9      Tundra
10     Irrigated Crops
11     Semidesert
12     Ice Caps and Glaciers
13     Bogs and Marshes
14     Inland Water
15     Ocean
16     Evergreen Shrubs
17     Deciduous Shrubs
18     Mixed Forest
19     Forest/Field Mosaic
20     Water and Land Mixtures
```

A 1.10 MONTHLY AIR TEMPERATURE (AT 1000, 850, 700, 500 HPA) CLIMATOLOGY

The initial source is a 1.5 degrees horizontal resolution global monthly climatology of air temperatures at 1000hPa, 850hPa, 700hPa and 500hpa derived from the ECMWF model.

A 1.11 MONTHLY ATMOSPHERIC INTEGRATED WATER VAPOUR CONTENT CLIMATOLOGY

The initial source is a 2.5 degrees horizontal resolution global monthly climatology of specific humidity on 11 vertical pressure levels (1000, 950, 900, 850, 700, 500, 400, 300, 200, 100, and 50 hPa), elaborated by Oort from a collection of 15 years of global rawinsonde data (Oort, 1983).

The integrated water vapor content is computed from the specific humidity of pressure levels above the surface level (whose pressure is derived from the height map using a standard OACI standard atmosphere for the height/pressure conversion).

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A 1.12 MONTHLY INTEGRATED OZONE CLIMATOLOGY

The initial source is an ozone climatology (1978-2008) available from www.temis.nl/protocols/O3global.html (monthly field over 30 years on a iso latitude/longitude grid (spatial resolution: 1.5 in longitude and 1.0 in latitude). A monthly climatology has been created by averaging over the 30 years.