**EUMETSAT Satellite Application Facility on Climate Monitoring**

# Algorithm Theoretical Basis Document

# CM-SAF Product CM-02, CM-08 and CM-14

# Cloud Fraction, Cloud Type and Cloud Top Parameter Retrieval from SEVIRI

| | |
|---|---|
| Reference Number: | SAF/CM/DWD/ATBD/CFC_CTH_CTO_SEVIRI |
| Version: | 1.0 |
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# Preface

This Algorithm Theoretical Basis Document was produced by the EUMETSAT Satellite Application Facility on Nowcasting (NWC-SAF). The EUMETSAT Satellite Application Facility on Climate Monitoring (CM-SAF) has implemented the herein described algorithms and software to derive cloud fraction, cloud type and cloud top temperature, pressure and height from SEVIRI observations. The document has a CM-SAF version number that will be updated whenever a new version of the SEVIRI software is introduced into the CM-SAF processing system. The version number assigned by NWC-SAF is kept in the appended document. Please note that the appended NWC-SAF document not necessarily describes the latest version of algorithms and software.

# Algorithm Theoretical Basis Document for "Cloud Products" (CMa-PGE01, CT-PGE02 & CTTH-PGE03 v1.4)

SAF/NWC/CDOP/MFL/SCI/ATBD/01, Issue 1, Rev. 4

*7 November 2007*

*Applicable to SAFNWC/MSG version 2008*

**Prepared by Météo-France / Centre de Météorologie Spatiale**

## REPORT SIGNATURE TABLE

| Function | Name | Signature | Date |
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# DOCUMENT CHANGE RECORD

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| 1.4 | 7 November 2007 | 69 | Initial version (content derived from "User Manual for PGE01-02-03 v1.3 (Cloud Products) of the SAFNWC/MSG: scientific part") |
| | | | |

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# 1. INTRODUCTION

## 1.1 SCOPE OF THE DOCUMENT

This document is the Algorithm theoretical Basis Document for the cloud products PGE01 (CMa, Cloud Mask), PGE02 (CT, Cloud Type) and PGE03 (CTTH, Cloud Top Temperature and Height) of the SAFNWC/MSG software package.

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

## 1.2 SOFTWARE VERSION IDENTIFICATION

This documents describes the algorithms implemented in the PGE01-02-03 version v1.4 of the 2008 SAFNWC/MSG software package delivery.

## 1.3 IMPROVEMENT FROM PREVIOUS VERSION

No algorithm improvement has been implemented since previous version (v1.3 implemented in the 2007 SAFNWC/MSG software package delivery), only a slight tuning to account for Eumetsat plans to change in 2008 the currently disseminated SEVIRI IR "spectral radiances" into "effective radiance" (see [AD. 2]).

## 1.4 DEFINITIONS, ACRONYMS AND ABBREVIATIONS

| | |
| --- | --- |
| **6S** | Second Simulation of Satellite Signal in the Solar Spectrum |
| **BRDF** | Bi-directional Reflectance Functions |
| **CMa** | Cloud Mask (also PGE01) |
| **CMS** | Centre de Meteorologie Spatiales (Météo-France, satellite reception centre in Lannion) |
| **CTTH** | Cloud Top Temperature and Height |
| **CT** | Cloud Type |
| **ECMWF** | European Centre for Medium range Weather Forecast |
| **EUMETSAT** | European Meteorological Satellite Agency |
| **FOV** | Field Of View |
| **HDF** | Hierarchical data Format |
| **HRIT** | High Rate Information Transmission |
| **IR** | Infrared |
| **K** | Kelvin |
| **MODIS** | Moderate-Resolution Imaging Spectroradiometer |
| **MSG** | Meteosat Second Generation |
| **NIR** | Near Infra-Red |
| **NOAA** | National Oceanic and Atmospheric Administration |
| **NWP** | Numerical Weather Prediction |
| **PGE** | Product Generation Element |
| **R0.6μm** | 0.6 visible reflectance |
| **RTTOV** | Rapid Transmissions for TOVs |
| **SAF** | Satellite Application Facility |
| **SAF NWC** | SAF to support NoWCasting and VSRF |

**SAF O&SI** Ocean and Sea Ice SAF
**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

| Reference | Title | Code | Vers | Date |
|---|---|---|---|---|
| [AD. 1] | Validation Report for "Cloud Products" (CMa-PGE01, CT-PGE02 & CTTH-PGE03 v1.4) | SAF/NWC/CDOP/MFL/VR/02 | 1.4 | 07/11/07 |
| [AD. 2] | Change to the MSG Level1.5 Image product Radiance Definition | EUM/STG-OPS/21/07/DOC/04 | | 20/02/07 |
| [AD. 3] | Software User Manual for the SAFNWC/MSG application | SAF/NWC/CDOP/INM/SW/SUM/2 | | |
| | | | | |

*Table 1: List of Applicable Documents*

### 1.5.2 Reference Documents

| Reference | Title | Code | Vers | Date |
|---|---|---|---|---|
| [RD.1] | | | | |
| [RD.2] | | | | |

*Table 2: List of Referenced Documents*

# 2. DESCRIPTION OF CMA PRODUCT

## 2.1 CMA OVERVIEW

The cloud mask (CMa), developed within the SAF NWC 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, land or sea surface temperatures, snow/ice cover delineation) may be computed. It also allows identifying cloudy areas where other products (cloud types and cloud top temperature/height) 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 and volcanic plumes.

CMa 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, dust or snow/sea ice. The critical point is the thresholds tuning.

## 2.2 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. 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 a full cloud detection. For example, low clouds identification at nighttime relies on their low emissivities at 3.7 micron, whereas thin cirrus clouds can be identified, due to their different emissivities at 10.8 micron and 12 micron. Cloud free areas covered by snow or ice are identified at daytime with their very low reflectivity at 3.7 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 3.7 micron...

The CMa identifies pixels that are contaminated by either clouds, dust or 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.

#### 2.2.1.2 Mathematical Description of the algorithm

##### 2.2.1.2.1 Algorithm outline

The algorithm is based on multispectral threshold technique applied to each pixel of the image.

A 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 SEVIRI infra-red pixels. Some thresholds are empirical constant or satellite-dependent values (available in coefficients' files).
- The quality of the cloud detection process is assessed.
- A spatial filtering is applied, allowing to reclassify pixels having a class type different from their neighbours.
- A test is applied to cloud contaminated pixels to check whether the cloud cover is opaque and completely fills the FOV.

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.

A second process, allowing the identification of dust clouds and volcanic ash clouds, is applied to all pixels (even already classified as cloud-free or contaminated by clouds). The result is stored in the dust cloud and volcanic ash cloud flags.

Details on the tests are given in section 2.2.1.2.2.

| Nighttime | Twilight | Daytime | Sunglint |
|---|---|---|---|
| Solar elevation < -3 | -3<Solar elevation<10 | 10 < Solar elevation | Cox & Munck > 10%<br>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 |
| T10.8µm | T10.8µm | T10.8µm-T12.0µm |
| R0.6µm | R0.6µm | T8.7µm-T10.8µm |
| T10.8µm-T12.0µm | T10.8µm-T12.0µm | T10.8µm-T8.7µm |
| T8.7µm-T10.8µm | T8.7µm-T10.8µm | T10.8µm-T3.9µm |
| T10.8µm-T3.9µm | T10.8µm-T8.7µm | T3.9µm-T10.8µm |
| T3.9µm-T10.8µm | T10.8µm-T3.9µm | Local Spatial Texture |
| Local Spatial Texture | T3.9µm-T10.8µm | T8.7µm-T3.9µm |
| | Local Spatial Texture | |

| | | |
|---|---|---|
| | T8.7µm-T3.9µm | |

*Table 4: Test sequence over land*

| Daytime | Sunglint | Twilight | Nighttime |
|---|---|---|---|
| Ice detection | Ice detection | Ice detection | SST |
| SST | SST | SST | T10.8µm-T12.0µm |
| R0.8µm (R0.6µm) | T10.8µm-T12.0µm | R0.8µm (R0.6µm) | T8.7µm-T10.8µm |
| R1.6µm | T8.7µm-T10.8µm | R1.6µm | T10.8µm-T3.9µm |
| T10.8µm-T12.0µm | Local Spatial Texture | T10.8µm-T12.0µm | T12.0µm-T3.9µm |
| T8.7µm-T10.8µm | R0.8µm (R0.6µm) | T8.7µm-T10.8µm | T3.9µm-T10.8µm |
| T10.8µm-T3.9µm | T10.8µm-T3.9µm | T10.8µm-T3.9µm | Local Spatial Texture |
| T3.9µm-T10.8µm | Low Clouds in Sunglint | T12.0µm-T3.9µm | |
| Local Spatial Texture | | T3.9µm-T10.8µm | |
| | | Local Spatial Texture | |

*Table 5: Test sequence over sea*

[T3.9µm, T8.7µm , T10.8µm and T12.0µm stand for brightness temperatures at 3.9, 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 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.]

#### 2.2.1.2.2 Individual cloud detection tests description

##### 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 to detect 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 (4K). 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 over 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 to roughly simulate small scale height effects in mountainous regions.

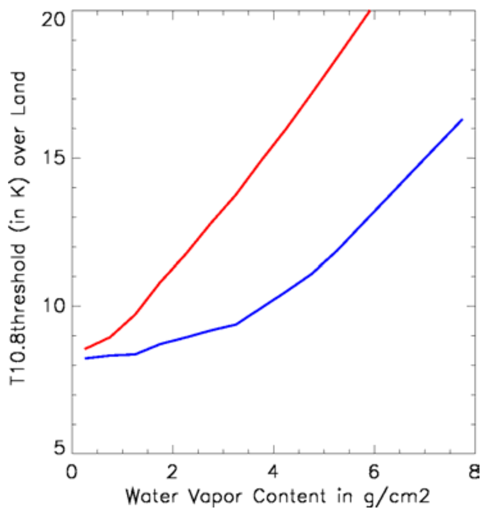


*Figure 1: Illustration of the offset accounting for atmospheric absorption over vegetated surface for a satellite zenith angle of 48 degrees. Blue and red curves correspond to nighttime and daytime conditions*

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

2.2.1.2.2.3 <u>Test on T10.8µm-T12.0µm</u>

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 to minimize 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.

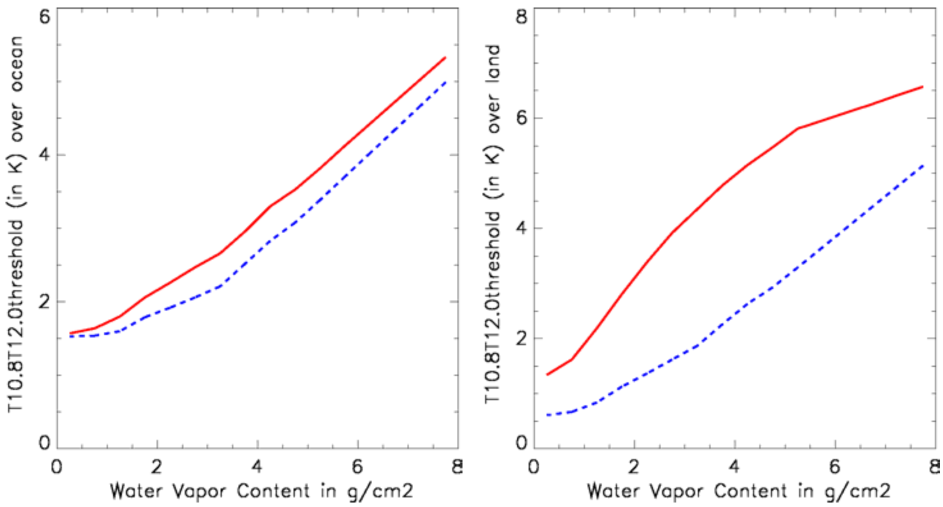


*Figure 2: Illustration of T10.8T12.0threshold for a satellite zenith angle of 48 degrees. Over Ocean, blue and red curve correspond to cold and warm seas. Over Land, blue and red curves correspond to nighttime and daytime conditions*

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.

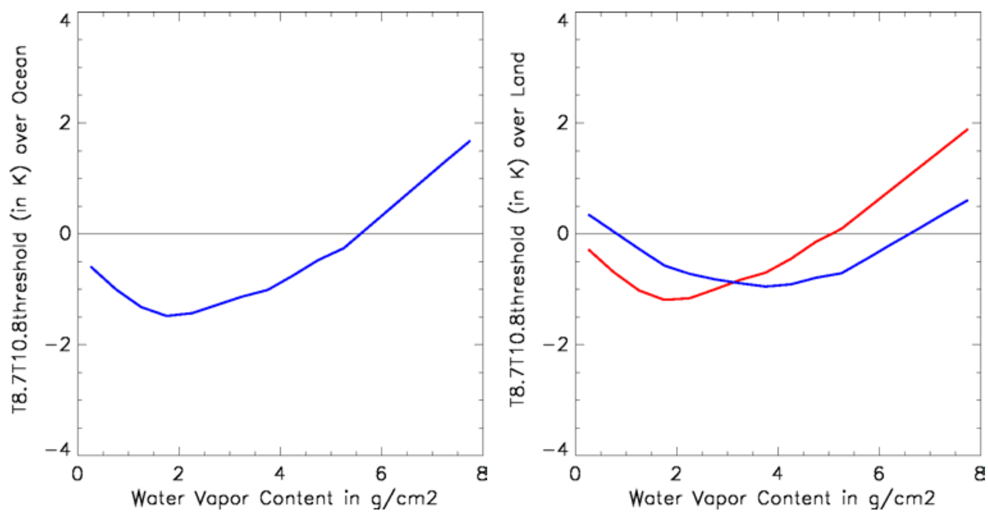


*Figure 3: Illustration of T8.7T10.8threshold for a satellite zenith angle of 48 degrees. Over Land, blue and red curve correspond to night and daytime conditions.*

#### 2.2.1.2.2.5 Test on T3.9µm-T10.8µm in nighttime conditions

The test is the following :

A pixel is classified as cloud contaminated if :

- T3.9µm - T10.8µm > T39T10.8threshold_night and
- T10.8µm > 240 K

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 3.9µm than at 10.8µm, due to a lower ice cloud transmittance (Hunt, 1973), and to the high non-linearity of the Planck function at 3.9µm. This test is usable only at night-time, when solar irradiance does not act upon the 3.9µm channel radiance. The cloud free surfaces T10.8µm-T3.9µm 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 3.9µm 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.

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).

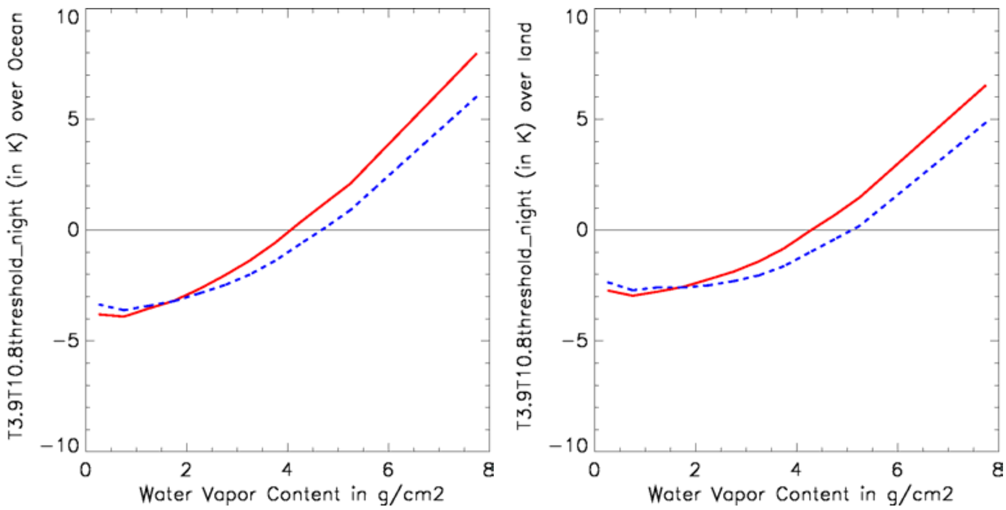


*Figure 4: Illustration of T3.9T10.8threshold_night for a satellite zenith angle of 48 degrees. Blue and red curve correspond to cold and warm vegetated surfaces.*

#### 2.2.1.2.2.6 Test on T10.8µm-T3.9µm

The test is the following :

A pixel is classified as cloud contaminated if :

- T10.8µm - T3.9µm > T10.8T3.9threshold and
- T10.8µm > 240 K and
- (over land only ) T8.7µm – T10.8µm > (-4.5-1.5*(1./cos($\theta_{sat}$)-1)) (in K)

where $\theta_{sat}$ 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 3.9µm 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 3.9µm channel is not affected by the solar irradiance, which is the case at night-time and in shadows. The cloud free surfaces T10.8µm-T3.9µm 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 3.9µm 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 to minimize 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.

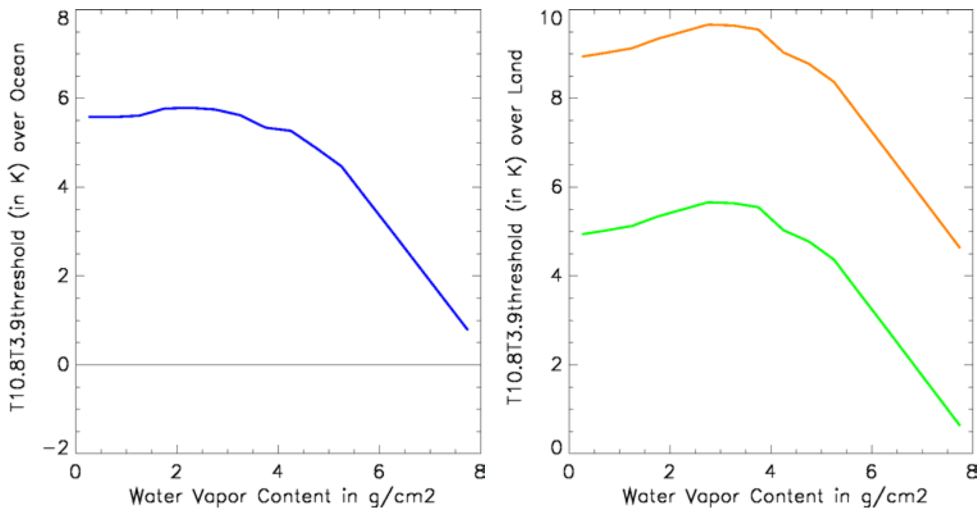


*Figure 5: Illustration of T10.8T3.9threshold for a satellite zenith angle of 48 degrees. Over Land, green and brown curves correspond to vegetation and desert.*

To increase the T10.8µm-T3.9µm test efficiency over Europe, two correction factors, empirically developed from SEVIRI 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 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 |
|---|---|---|---|---|---|---|---|
| T10.8T3.9threshold 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 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 |
|---|---|---|---|---|---|---|
| T10.8T3.9threshold 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-T3.9µm over ocean

The test is the following :

A pixel is classified as cloud contaminated if :

- T12.0µm - T3.9µm > T12.0T3.9thresholdand
- T10.8µm > 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 - T3.9µm (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-T3.9µm values. An example of the threshold used is displayed in Figure 6

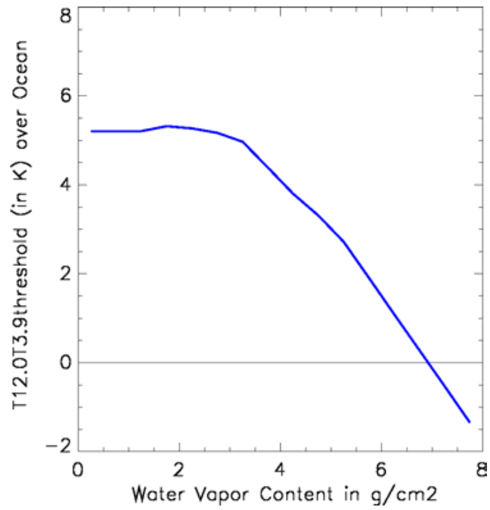


*Figure 6: Illustration of T12.0T3.9threshold over the Ocean for a satellite zenith angle of 48 degrees.*

### 2.2.1.2.2.8 Test on T8.7µm-T3.9µm over desert

The test is the following :

A pixel is classified as cloud contaminated if :

- T8.7µm - T3.9µm > T8.7T3.9threshold and
- T10.8µm - T3.9µm > T10.8T3.9veget_threshold and
- T10.8µm > 240 K

where T10.8T3.9veget_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-T3.9µm 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-T3.9µm test is based on the fact that desertic areas have low emissivities at 3.9µm and 8.7µm, whereas low water clouds have low emissivities at 3.9µm, but not at 8.7µm. A consequence is that low clouds are characterized by higher T8.7µm-T3.9µm differences as compared to values over desert. This test is limited to pixels warmer than 240K to insure that the 3.9µm channel is not too much affected by radiometric noise (enhanced for low temperatures) and to pixels having not too low T10.8µm-T3.9µm 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.

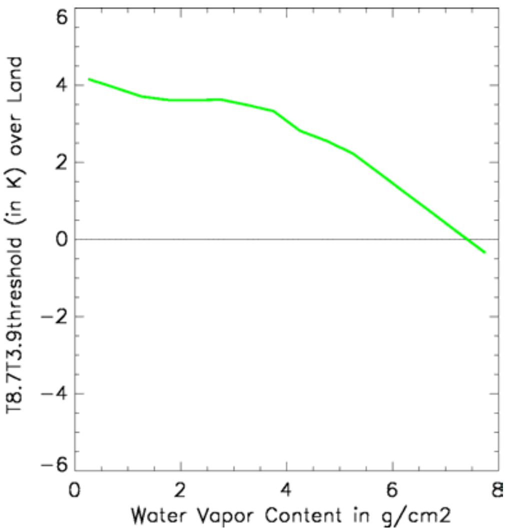


*Figure 7: Illustration of T8.7T3.9 threshold over desertic area for a satellite zenith angle of 48 degrees.*

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 $\theta_{sat}$ 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-T3.9µm 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-T3.9µm 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 SEVIRI measurements as a function of the satellite secant: T10.8T8.7threshold (in K) $=3.7+0.3*(1/\cos(\theta_{sat}))$

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 :
  - 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.
  - 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.,$\pi$] from backward to forward direction).

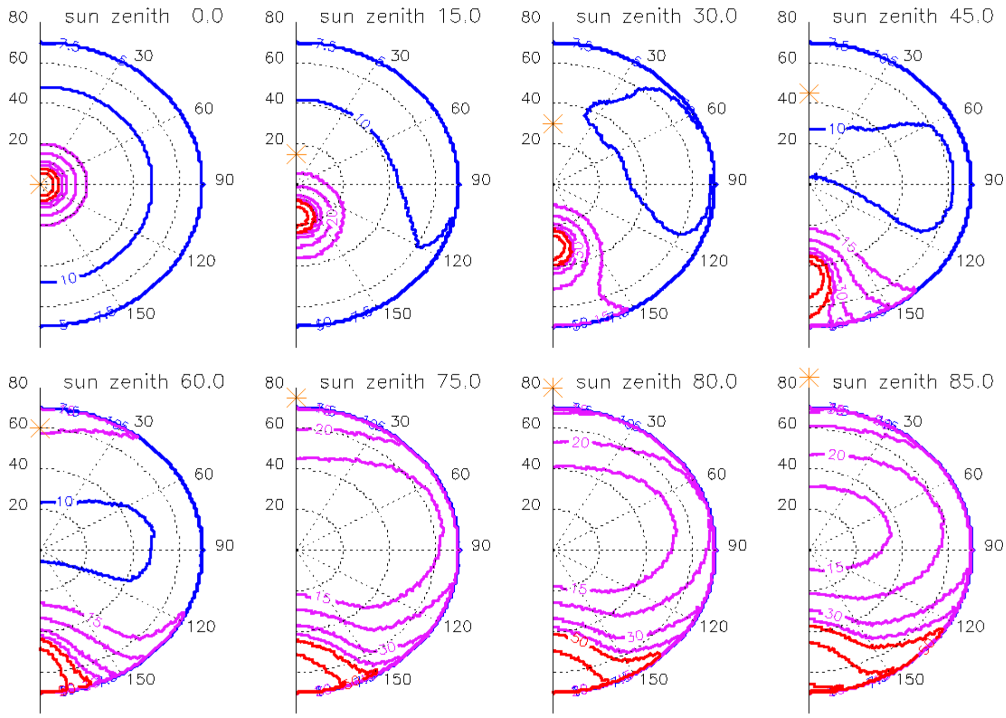


*Figure 8: Polar representation of R0.8threshold over Ocean for eight sun zenith angles.*

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%)

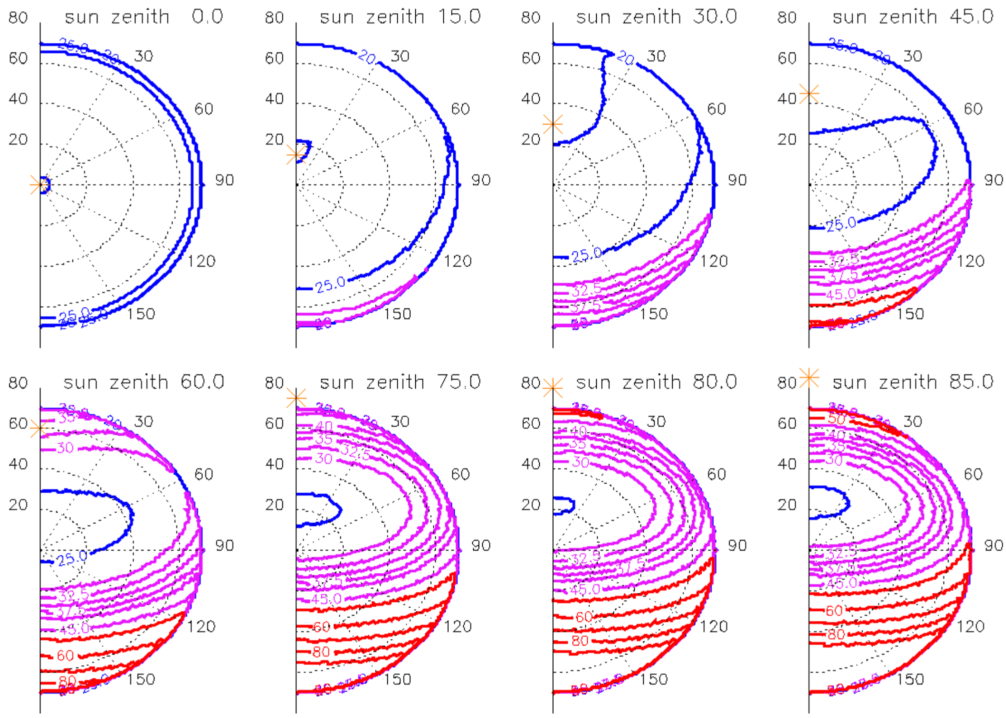


*Figure 9: Polar representation of R0.6threshold over Land (surface reflectance of 10%) for eight sun zenith angles.*

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 :

- T3.9µm < 320 K (to make sure 3.9µm is not saturated) and
- R0.6µm > 60% and
- (T3.9µm-T10.8µm)/cos($\theta_{sol}$) > 0 K and
- R0.6µm > (1./0.15)*(T3.9µm-T10.8µm)/cos($\theta_{sol}$) ($\theta_{sol}$ 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 3.9µm channels allows to detect low clouds even in areas affected by sunglint. Indeed, oceanic areas with high 0.6µm reflectances have also very high 3.9µm reflectances, which is usually not the case for low clouds. The solar contribution in the 3.9µm channel in case of sunglint is approximated by (T3.9µm-T10.8µm)/cos($\theta_{sol}$). The rapid saturation of the 3.9µm radiance limits the use of this test in case of strong sunglint.

###### 2.2.1.2.2.12 Test on T3.9µm-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 :

- T3.9µm - T10.8µm > T3.9T10.8threshold_day and
- T10.8µm > 240 K and
- (over Africa only) T8.7µm – T10.8µm > (-4.5-1.5*(1./cos($\theta_{sat}$)-1)) (in K)

where $\theta_{sat}$ is the satellite zenith angle

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 3.9µm 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 to minimize the confusion of sandy arid areas with low clouds.

The threshold T3.9T10.8threshold_day is computed from T3.9T10.8threshold_night (see section 2.2.1.2.2.3) by adding the solar contribution:

Over ocean: T39.T10.8threshold_day (in K)=T3.9T10.8threshold_night + 0.7*Cox_munck*cos($\theta_{sol}$) +7

Over land: T3.9T10.8threshold_day (in K)= T3.9T10.8threshold_night + 0.4*Clim_alb*cos($\theta_{sol}$) +2.0 + corrective_factor

T3.9T10.8threshold_night is computed as explained in section 2.2.1.2.2.3, 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($\theta_{sol}$)*(cos(scattering angle)-0.41)$^2$

$\theta_{sol}$ is the solar zenith angle and scattering_angle is the scattering angle ([0.,$\pi$] 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
- (T3.9µm-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
- (T3.9µm-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 detects 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 3.9 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%).

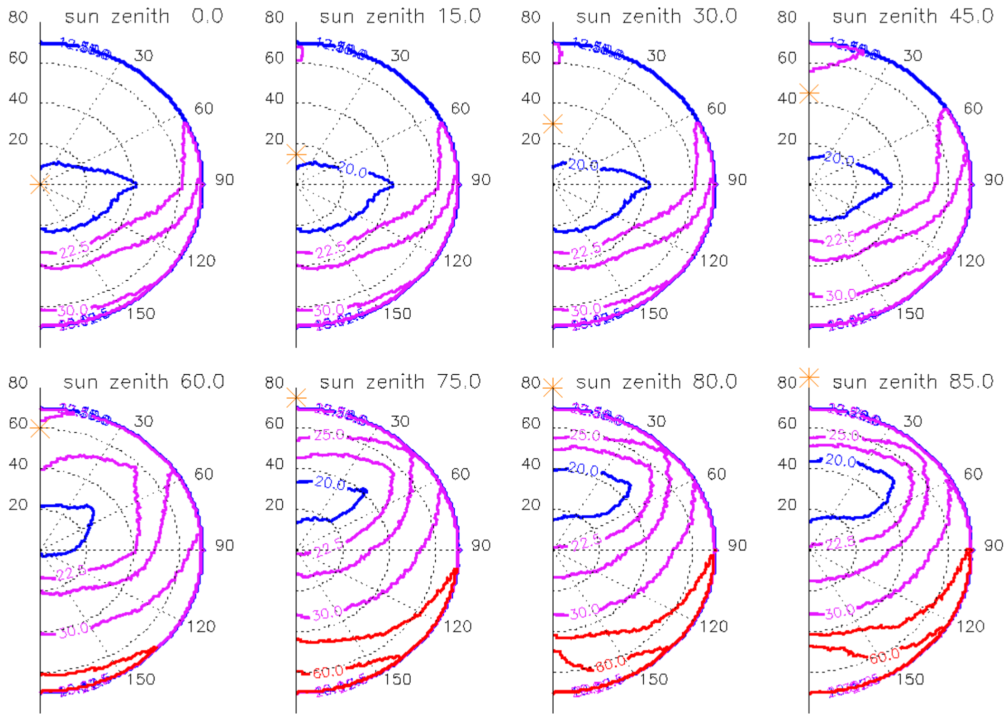


*Figure 10: Polar representation of R1.6threshold over snow for eight sun zenith angles.*

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-T3.9µm) > 0.1K (0.4K at daytime) ] or
- [SD(R0.8µm) > (0.8%+0.03* R0.8threshold) at daytime only ]

T10.8µm-T3.9µm 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-T3.9µm) > 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-T3.9µm is not used in too cold areas (due to noise effects).

-SD stands for local standard deviation 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.
-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 to overcome the difficulty:

- Over Ocean, the combined use of T10.8µm & T10.8µm-T3.9µm 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-T3.9µm for all illumination conditions allows to minimise 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 Spatial filtering

The following spatial filtering process is applied after the sequence of thresholding tests:

- all the isolated cloudy pixels that have been detected by a test using the 3.9µm are reclassified as cloud-free.
- all the isolated cloud free pixels are reclassified as cloudy.

These reclassified pixel are flagged as of very low confidence.

2.2.1.2.2.16 Opaque clouds detection Test

This test has been implemented to identify opaque clouds :

A cloud contaminated pixel is classified as opaque cloud if :

- T10.8µm -T12.0µm < 2K

The aim is to identify pixels fully covered by a single cloud layer whose infrared emissivity is close to unity, and are therefore not contaminated in the infrared wavelength by the surface. The calculation of the cloud top temperature and height of these pixels would then have only required a correction for atmospheric attenuation above the cloud.

The opaque cloud identification is applied to pixels previously detected as cloud contaminated. It relies on the analysis of the T10.8µm -T12.0µm brightness temperature difference : this difference is higher for semi-transparent ice clouds (due to their higher transmitivity at 10.8µm) and broken clouds, than for opaque clouds.

Nota Bene: if the user is interested in getting information on whether the pixel is partly or fully covered by clouds, it is thought that the CT product should be used instead the CMa product, because the CT algorithm is much more sophisticated. Nevertheless, the opaque cloud identification remains implemented in CMa not to force the user to change their applications.

**2.2.1.2.3 Quality assessment**

A quality flag is appended to the CMa. 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 low confidence 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-T3.9µm<br>T12.0µm-T3.9µm<br>T8.7µm-T3.9µm | T3.9µm-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 low confidence 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 low confidence 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 to identify high confidence cloud free areas for surface parameters computation. On the other hand, the identification of extended cloudy or cloud free area flagged as low confidence 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 low confidence].

#### 2.2.1.2.4 Dust cloud identification

The following algorithm has been empirically derived to detect and classify dust clouds at daytime:

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

- R0.6threshold –5% < R0.6µm < R0.6threshold +20% and
- -5°C - 5*(1/cos(θsat) -1) < T10.8µm - SSTclim and
- T12.0µm-T10.8µm > T120T108threshold and
- SD(T10.8µm) < 0.4°C and SD(R0.6µm) < 0.6 % and
- Sun elevation larger than 20 degrees

[where R0.6threshold used in cloud masking, θsat is the satellite zenith angle, T120T108threshold defined in text and illustrated in Figure 11, SD is the standard deviation]

Over continental surfaces, 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
- [ [ ( (T3.9µm - T10.8µm) > -10 K and (T12.0µm-T10.8µm) > 2.5 K or
  ( (T3.9µm - 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 3.9µm (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 11.

#### 2.2.1.2.5 Volcanic ash cloud identification

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

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

- T12.0µm -T10.8µm > T12.0T10.8threshold_volcan_night and
- T3.9µm -T10.8µm > T3.9T10.8threshold

[T12.0T10.8threshold_volcan_night is a finely tuned threshold explained below in the text, T3.9T10.8threshold 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 T3.9µm -T10.8µm > 5K or
  |R0.6µm -R1.6µm| < 20% and T3.9µm -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 11, is calculated as explained in 2.2.1.2.4.

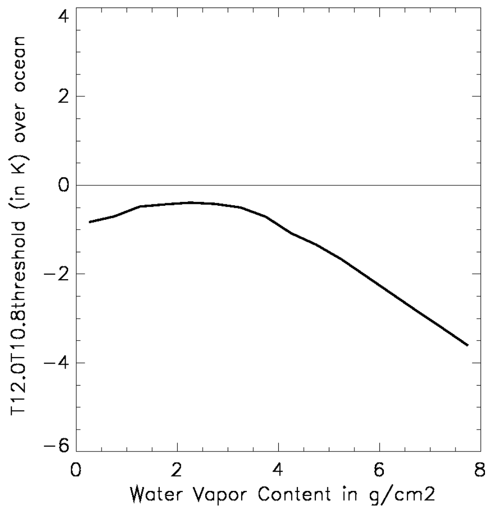


*Figure 11: Illustration of T12.0T10.8threshold used in the dust and volcanic cloud detection over the ocean for a satellite zenith angle of 48 degrees*

### 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 [AD. 1].

| PGE01 flags | Validated accuracy |
|---|---|
| **PGE01 cloud detection**<br>If validated over European areas using SYNOP observations | POD: 95.90% |
| **PGE01 dust flag**<br>If validated over sea and Africa for solar elevation larger than 20 degrees using interactive targets | POD:<br>38.5% over sea<br>58.5% over land |

*Table 6: Summary of validation results of the current PGE01 version (POD stands for Probability Of Detection)*

#### 2.2.2.2 Quality control and diagnostics

A quality assessment, detailed in 2.2.1.2.3, is performed by the CMa itself through a comparison between thresholds and measurements, low confidence corresponding to thresholds and measurements close to each other.

Nine bits in the CMa output are dedicated to quality description (see in 2.2.2.4). They include a quality flag based on the quality assessment performed by the CMa (see above paragraph), but also information on the lack of NWP fields or SEVIRI non mandatory channels which leads to a decrease of CMa quality.

#### 2.2.2.3 List of inputs for 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:**

The following SEVIRI bi-directional reflectances or brightness temperatures are needed at full IR spatial resolution:

| R0.6µm | R0.8µm | R1.6µm | T3.9µm | T8.7µm | T10.8µm | T12.0µm | T13.4µm |
|---|---|---|---|---|---|---|---|
| Mandatory | Optional | Optional | Mandatory | Optional | Mandatory | Mandatory | Optional |

The CMa software checks the availability of SEVIRI 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 T3.9µm; 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.

The SEVIRI channels are input by the user in HRIT format, and extracted on the processed region by SAFNWC software package.

- **Sun and satellite angles associated to SEVIRI 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 SAFNWC 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.

- **Ancillary data sets:**

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

  - Land/sea atlas
  - Land/sea/coast 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 1000 hPa

These ancillary data are available in the SAFNWC software package on MSG full disk in the default satellite projection at full IR resolution; They are 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 SAFNWC software package, and are needed by the CMa software.

- **Configurable parameters:**

The only configurable parameter is the size of the segment (see its definition in 2.2.2.6.1). Its default value is 4. Information on how to change the size of the segment can be found in the PGE01 pre-operation section of [AD. 3].

#### 2.2.2.4 Description of CMa output

The content of the CMa is the following:

- **The main product output consists in the following six categories coded on 3 bits**

| | | |
|---|---|---|
| 0 | Non-processed | containing no data or corrupted data |
| 1 | cloud-free | no contamination by snow/ice covered surface,<br>no contamination by clouds ;<br>but contamination by thin dust/volcanic clouds not checked |
| 2 | Cloud contaminated | partly cloudy or semitransparent. May also include dust clouds or volcanic plumes. |
| 3 | Cloud filled | opaque clouds completely filling the FOV. May also include thick dust clouds or volcanic plumes. |
| 4 | Snow/Ice contaminated | |
| 5 | Undefined | has been processed but not classified due to known separability problems |

- **16 bits to describe which test was successful**

For each cloudy pixel, the bits corresponding to the successful tests are activated. More than one bit may be activated, if tests were not really successful (measurement too close to thresholds)).

| | |
|---|---|
| 0 | T10.8µm or SST |
| 1 | R0.6µm (land) or R0.8µm (sea) |
| 2 | Sunglint test using 3.9µm |
| 3 | Local Spatial Texture |
| 4 | T10.8µm - T12.0µm |
| 5 | T10.8µm - T3.9µm or T12.0µm - T3.9µm |
| 6 | T3.9µm - T10.8µm |
| 7 | Spatial smoothing (reclassify isolated cloud-free pixels) |
| 8 | T8.7µm - T3.9µm |
| 9 | R1.6µm (sea) |
| 10 | T8.7µm –T10.8µm or T10.8µm –T8.7µm |
| 11 | Snow using R1.6µm |
| 12 | Snow using T3.9µm |
| 13-15 | spare |

- **9 bits for quality**

3 bits to define illumination and viewing conditions:

0 Undefined (space)

1 Night
2 Twilight
3 Day
4 Sunglint

2 bits to describe NWP input data
0 Undefined (space)
1 All NWP parameters available (no low level inversion)
2 All NWP parameters available (low level inversion)
3 At least one NWP parameter missing

2 bits to describe SEVIRI input data
0 Undefined (space)
1 All useful SEVIRI channels available ;
2 At least one useful SEVIRI channel missing
3 A least one mandatory SEVIRI channel missing

2 bits to describe the quality of the processing itself:
0 Non processed (containing no data or corrupted data)
1 Good quality (high confidence)
2 Poor quality (low confidence)
3 Reclassified after spatial smoothing (very low confidence)

- **2 bits for dust detection**

0 Non processed (containing no data or corrupted data)
1 dust
2 non dust
3 undefined (due to known separability problems)

- **2 bits for volcanic plume detection**

0 Non processed (containing no data or corrupted data)
1 volcanic plume
2 non volcanic plume
3 undefined (due to known separability problems)

#### 2.2.2.5 Example of 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 SAFNWC products (CT for example).

Colour palettes are included in CMa HDF files, allowing an easy visualisation of CMa main categories, dust and volcanic ash clouds 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 12 and Figure 13 , using SEVIRI and MODIS imagery.

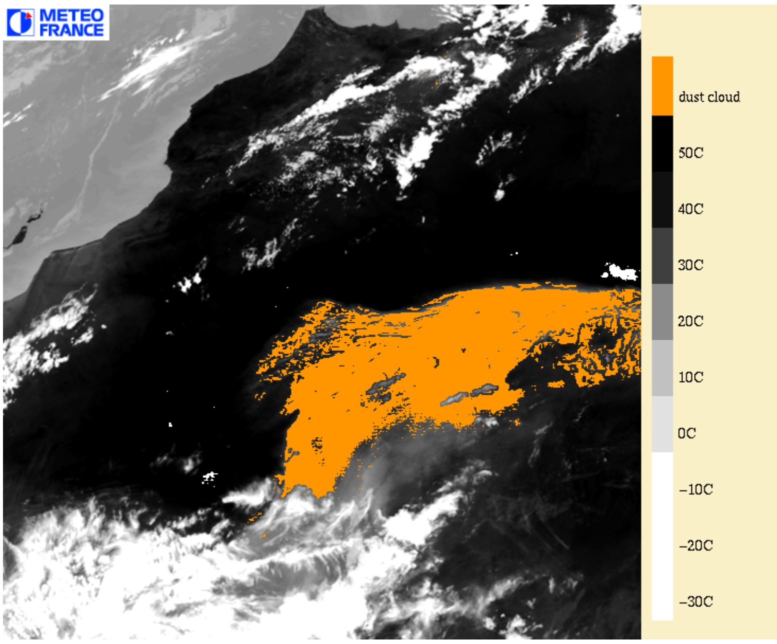


*Figure 12: Example of SEVIRI dust cloud flag superimposed on a 10.8µm infrared image: dust cloud over North Africa on 14th July 2003 at 13h00 UTC.*

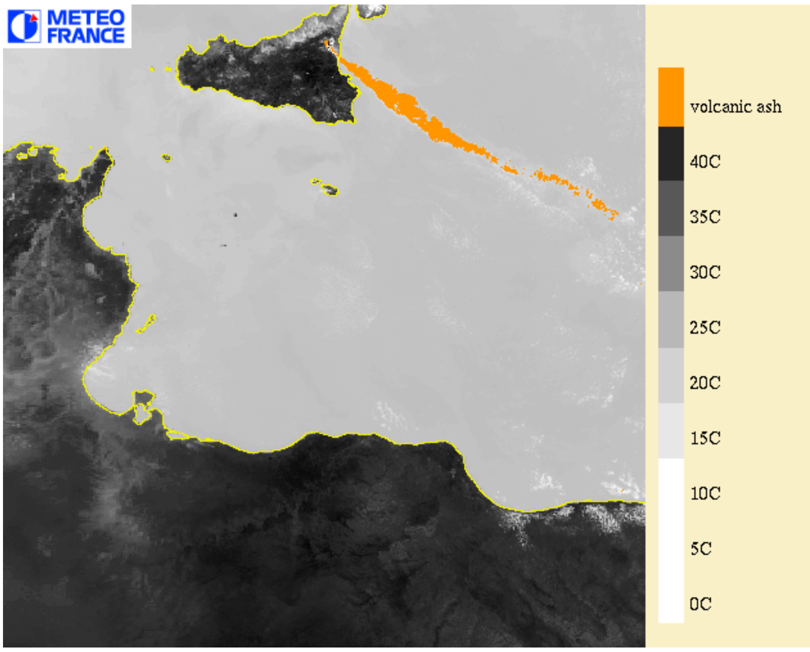


*Figure 13: Example of MODIS volcanic ash cloud superimposed on a 10.8µm infrared image: Etna eruption on 22th July 2001 at 9h55 UTC.*

### 2.2.2.6 Implementation of CMa

The installation procedures, fully described in the Software User Manual (see [AD. 3]), are summarized below. Three main steps are identified. The user manually interacts with the CMa software during the installation step, the CMa preparation and execution steps being automatically monitored by the Task Manager (if real-time environment is selected).

#### 2.2.2.6.1 The CMa installation step:

When a new region is defined and added in system and run configuration files, the user launches (only once) the command mfcms_inst_pge01. This command allows:

- The automatic elaboration of monthly climatological and atlas maps, as well as latitude/longitude and satellite angles information on the new region at the full IR horizontal resolution. These regional atlas and maps are extracted from maps available on the whole MSG disk.
- The automatic elaboration of the model configuration file. In this file, a default value of 4 is given to the size of segments (Cma_szseg). This default value may be manually changed. [Segments are square boxes in the satellite projection, whose size is expressed as the number of IR pixels 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 IR resolution, allowing the identification of the surface type (land or sea) of all IR pixels, whatever the segment size. The quality is not very much dependent of the segment size (if lower than 4). A segment size of 4 allows the preparation step to be 9 times faster than if a segment size of 1 was used]
- The automatic set of pre-defined time scheduling (of the preparation step) in Programmed Task Definition Files.

#### 2.2.2.6.2 The CMa preparation step:

The preparation step is performed by the command mfcms_next_pge01 which is launched in advance of satellite data reception according to a pre-defined time scheduling set during the installation step.

This preparation step includes the computation on the region at the segment spatial resolution of:

- the solar & satellite angles,
- the monthly climatological & atlas maps,
- the thresholds for the CMa algorithm

#### 2.2.2.6.3 The CMa execution step:

The execution step is the real-time processing of the SEVIRI images itself over the region. This process consists in the launch of the command: PGE01 by the Task manager. The cloud masking is then performed, using the thresholds prepared during the preparation step.

## 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 or even seas. 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.
- 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, large areas of dust may not be detected if their thermal signature is not strong enough. Moreover, wrong detection may be observed in oceanic regions.

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 to detect 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

## 2.4 REFERENCES

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# 3. DESCRIPTION OF CT PRODUCT

## 3.1 CT OVERVIEW

The cloud type (CT), developed within the SAF NWC 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 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 2012), and the identification of clouds for which the top mainly consists of water droplets.

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 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 SEVIRI 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 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. Some details on the tests are given 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, and no cloud phase flag is available.

#### 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 T3.9µm-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 T3.9µm-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 3.9µm than at 10.8µm, due to a lower ice cloud transmittance, and to the high non-linearity of the Planck function at 3.9µm. 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 T3.9µm.

The fractional low clouds have also T10.8µm-T12.0µm and T3.9µm-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 T3.9µm-T10.8µm when compared to those of single level cirrus. T10.8µm-T12.0µm is more reduced than T3.9µm-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 T3.9µm-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 | [ T3.9µm –T10.8µm > T39T108thin_high or T10.8µm -T12.0µm > T108T120thick] |
| | T108interthr < T10.8µm < maxT108med | [ T3.9µm –T10.8µm > T39T108thin_low or T10.8µm -T12.0µm > T108T120thick] |

| | | |
|---|---|---|
| high semitransparent thin clouds: | maxT108med < T10.8µm < maxT108low | [T3.9µm –T10.8µm > T39T108t_low or T10.8µm -T12.0µm > T108T120thick] and [ T8.7µm -T10.8µm > T87T108opaque or T3.9µm –T10.8µm > T39T108thin_low ] |
| | maxT108low < T10.8µm<maxT108low+delta | [ T3.9µm –T10.8µm > T39T108_vlow or T10.8µm -T12.0µm > T108T120thick] and [ T8.7µm -T10.8µm > T87T108opaque or T3.9µm –T10.8µm > T39T108thin _low] |

| Fractional low clouds | | |
|---|---|---|
| Fractional clouds: | maxT108med < T10.8µm < maxT108low | [ T3.9µm –T10.8µm > T39T108_low or T10.8µm -T12.0µm > T108T120thick] and [ T8.7µm -T10.8µm < T87T108opaque ] and [T3.9µm –T10.8µm < T39T108thin _low] |
| | maxt108low<T10.8µm<maxT108low+delta | [ T10.8µm -T12.0µm > T108T120thick or T3.9µm -T10.8µm > T39T108_vlow ] and [ T8.7µm -T10.8µm < T87T108opaque ] and [T3.9µm -T10.8µm < T39T108thin _low] |
| | maxT108low+delta < T10.8µm | [ T10.8µm -T12.0µm > T108T120thick or T3.9µm -T10.8µm > T39T108_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, T39T108opaque, 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 T39T108 thresholds according to observed T10.8µm have been defined as:
  T39T108thin_high = T39T108opaque +5.*(maxT108low-T108)/(maxT108low- maxT108hi)
  T39T108thin_low = T39T108opaque+2.*(maxT108low-T108)/(maxT108low- maxT108hi)
  T39T108_low = T39T108opaque+1 (in K)
  T39T108_vlow = T39T108opaque-1 (in K)
- T108T120thick has been defined as : MAX (T108T120opaque-0.2 , 1.5) (in K)

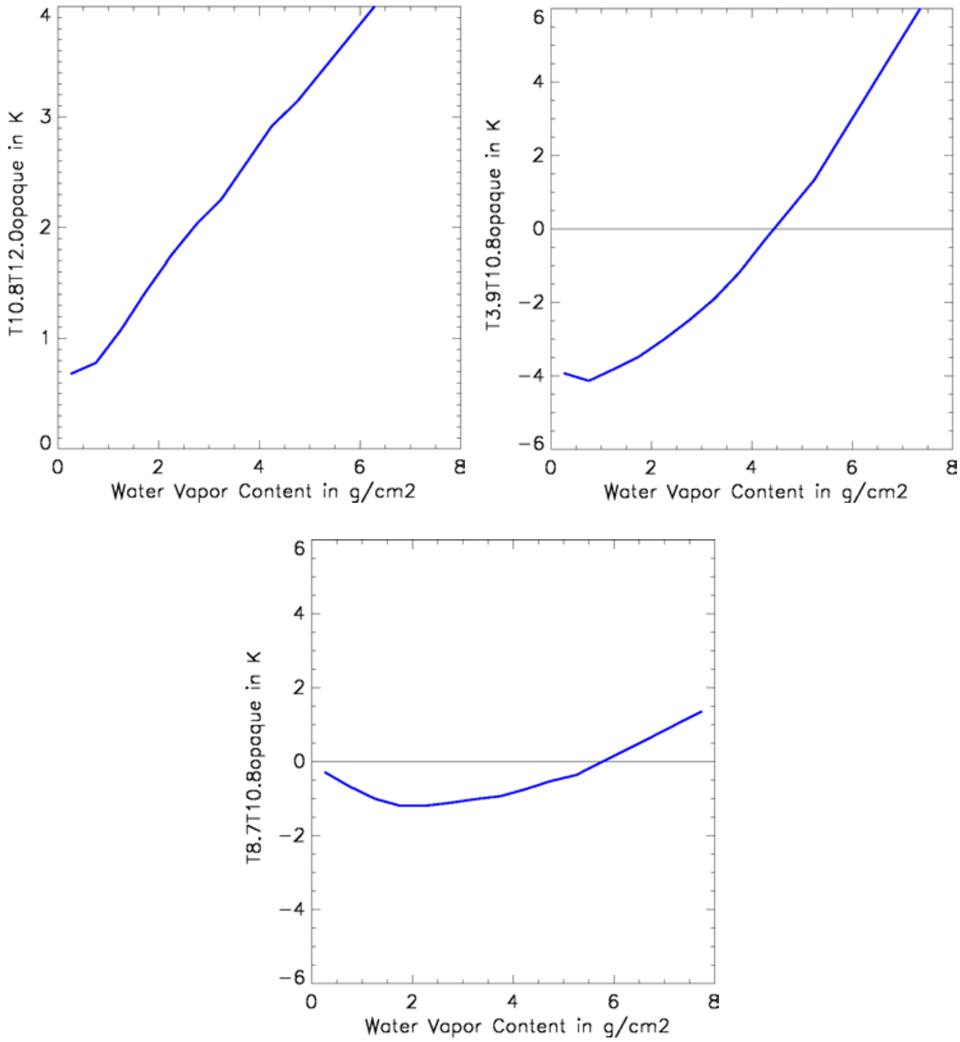


*Figure 14: Illustration of T108T120opaque,T39T108opaque and T87T108opaque for a satellite zenith angle of 48 degrees*

### 3.2.1.2.2.2 Fractional and semitransparent clouds identification in twilight conditions

T3.9µm 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<br>and<br>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:

| High semitransparent clouds | | |
|---|---|---|
| high semitransparent thick clouds: | T10.8µm < maxT108hi | T10.8µm -T12.0µm > T108T120opaque |
| high semitransparent meanly thick clouds: | maxT108hi < T10.8µm < maxT108med | R0.6µm < maxCiR06<br>and<br>T10.8µm -T12.0µm > T108T120opaque |
| high semitransparent above low or medium clouds: | | R0.6µm > maxCiR06<br>and<br>T10.8µm -T12.0µm > T108T120opaque |
| | maxT108med < T10.8µm < maxT108low | [ R0.6µm > maxCiR06<br>and<br>T10.8µm-T12.0µm > T108T120opaque<br>and<br>varilogT10.8/varilogR06 > varilogthr ]<br>or<br>[ R0.6µm < maxCiR06<br>and<br>T8.7µm -T10.8µm > T87T108opaque ] |

| | | |
|---|---|---|
| high semitransparent thin clouds: | maxt108low< T10.8µm < maxT108low+delta | [ R0.6µm < maxCiR06<br>and<br>T8.7µm -T10.8µm > T87T108opaque ]<br>or<br>[ R0.6µm > maxCiR06<br>and<br>T10.8µm-T12.0µm ><br>(T108T120Threshold+ T108T120opaque)/2<br>and<br>T8.7µm -T10.8µm > T87T108opaque ] |

| Fractional low clouds | | |
|---|---|---|
| Fractional clouds: | maxT108med < T10.8µm < maxT108low | R0.6µm < maxCiR06<br>and<br>T8.7µm -T10.8µm < T87T108opaque |
| | maxt108low<T10.8µm<maxT108low+delta | [ R0.6µm > maxCiR06<br>and<br>T10.8µm -T12.0µm ><br>(T108T120threshold+ T108T120opaque)/2<br>and<br>T8.7µm -T10.8µm < T87T108opaque ]<br>or<br>[ R0.6µm < maxCiR06<br>and<br>T8.7µm -T10.8µm < T87T108opaque ] |
| | maxT108low+delta < T10.8µm | [ R0.6µm > minLowR06<br>and<br>T10.8µm -T12.0µm ><br>(T108T120threshold+ T108T120opaque)/2 ]<br>or<br>[ R0.6µm < minLowR06 ] |

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.

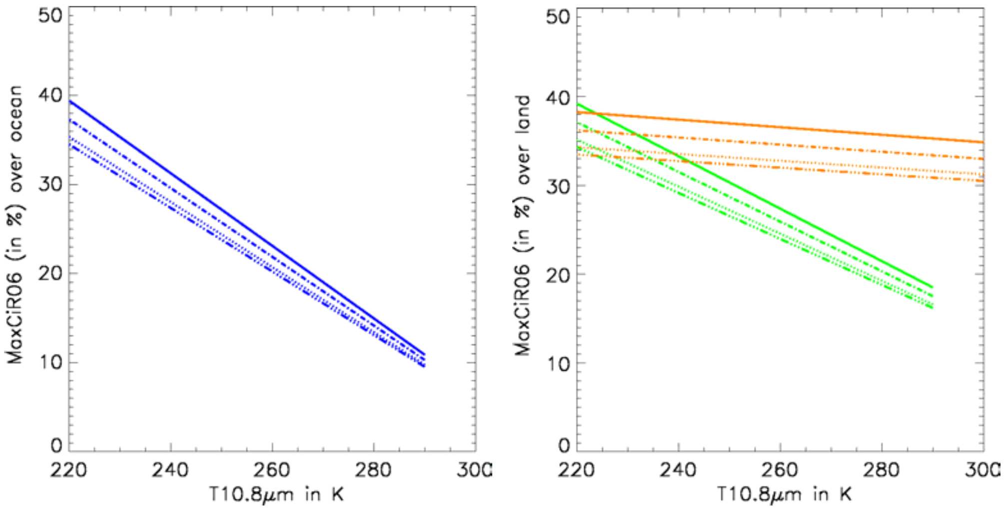


*Figure 15: Illustration of MaxCiR06 over Ocean and over Land. Solar zenith angles (30 and 70 degrees), azimuth difference (0 and 90 degrees). In green over vegetated areas, in brown over desert*

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 to separate 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.

A rough insight of the range of low/medium/high clouds top pressures has been obtained by analysing statistics of retrieved (using PGE03) 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 cloud | pressure larger than 800hPa |
| Low opaque cloud | 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 Quality assessment

A quality flag is appended to the CT. 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 low confidence:
  - if is flagged as of low confidence in CMa
  - or if, either for spectral (T10.8µm-T12.0µm, T3.9µm-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 | T3.9µm-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. More details can be obtained from [AD. 1].

| PGE02 | Validated accuracy |
|---|---|
| **PGE02 cloud type**<br>If validated over European areas and adjacent seas using interactive targets<br>(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 78% and 96% depending on illumination |

*Table 7: Summary of validation results of the current PGE02 version*

### 3.2.2.2 Quality control and diagnostics

A quality assessment, detailed in 3.2.1.2.3, is performed by the CT itself through a comparison between thresholds and measurements, low confidence corresponding to thresholds and measurements close to each other.

Nine bits in the CT output are dedicated to quality description (see in 3.2.2.4). They include a quality flag based on the quality assessment performed by the CT (see above paragraph), but also information on the lack of NWP fields or SEVIRI non mandatory channels which leads to a decrease of CT quality.

### 3.2.2.3 List of inputs for 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 SEVIRI bi-directional reflectances or brightness temperatures are needed at full IR spatial resolution:

| R0.6µm | R1.6µm | T3.9µm | T7.3µm | T8.7µm | T10.8µm | T12.0µm |
|---|---|---|---|---|---|---|
| Mandatory | Optional | Mandatory | Optional | Optional | Mandatory | Mandatory |

The current version of CT software does not use the 1.6 µ channel.

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

The SEVIRI channels are input by the user in HRIT format, and extracted on the processed region by SAFNWC software package.

- **CMa cloud categories**

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

- **Sun and satellite angles associated to SEVIRI 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 SAFNWC 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 SAFNWC software package on MSG full disk in the default satellite projection at full IR resolution; They are 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 SAFNWC software package, and is needed by the CT software.

- **Configurable parameters:**

The only configurable parameter is the size of the segment (see its definition in 3.2.2.6.1). Its default value is 4. Information on how to change the size of the segment can be found in the PGE02 pre-operation section of [AD. 3].

#### 3.2.2.4 Description of CT output

The content of the CT is the following :

- **The main product output consists in the following twenty-one categories coded on 5 bits**

0 non-processed containing no data or corrupted data
1 cloud free land no contamination by snow/ice covered surface,

| | | |
|---|---|---|
| | | no contamination by clouds ; but contamination by thin dust/volcanic clouds not checked |
| 2 | cloud free sea | no contamination by snow/ice covered surface, no contamination by clouds ; but contamination by thin dust/volcanic clouds not checked |
| 3 | land contaminated by snow | |
| 4 | sea contaminated by snow/ice | |
| 5 | very low and cumuliform clouds | |
| 6 | very low and stratiform clouds | |
| 7 | low and cumuliform clouds | |
| 8 | low and stratiform clouds | |
| 9 | medium and cumuliform clouds | |
| 10 | medium and stratiform clouds | |
| 11 | high opaque and cumuliform clouds | |
| 12 | high opaque and stratiform clouds | |
| 13 | very high opaque and cumuliform clouds | |
| 14 | very high opaque and stratiform clouds | |
| 15 | high semitransparent thin clouds | |
| 16 | high semitransparent meanly thick clouds | |
| 17 | high semitransparent thick clouds | |
| 18 | high semitransparent above low or medium clouds | |
| 19 | fractional clouds (sub-pixel water clouds) | |
| 20 | undefined (undefined by CMa) | |

In the current version of CT, the separation between cumuliform and stratiform is not performed: low, medium or high clouds will be classified as stratiform, and a specific bit indicating whether the separation between stratiform and cumuliform clouds has been attempted, will be set to zero (see below quality flag).

- **10 bits for quality**

3 bits to define illumination and viewing conditions:

0 Undefined (space)
1 Night
2 Twilight
3 Day
4 Sunglint

2 bits to describe NWP input data

0 Undefined (space)
1 All NWP parameters available (no low level inversion)
2 All NWP parameters available (low level inversion)
3 At least one NWP parameter missing

2 bits to describe SEVIRI input data

0 Undefined (space)
1 All useful SEVIRI channels available ;
2 At least one useful SEVIRI channel missing
3 At least one mandatory SEVIRI channel missing

2 bits to describe the quality of the processing itself:

0 Non processed (containing no data or corrupted data)
1 Good quality (high confidence)
2 Poor quality (low confidence)

3 Reclassified after spatial smoothing (very low confidence)

1 bit set to 1 to indicate that the separation between cumuliform and stratiform clouds has been performed.

In the current version of CT, the separation between cumuliform and stratiform is not performed: this bit will be set to zero and the low, medium or high clouds will be classified as stratiform.

- **2 bits for cloud phase**

0 Non processed (containing no data or corrupted data)
1 water cloud
2 ice cloud
3 undefined (due to known separability problems)

In the current version, the cloud phase is set to Non processed

#### 3.2.2.5 Example of 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, cloud phase)) as input to mesoscale analysis models, objective Nowcasting schemes, but also in the extraction of other SAFNWC products (CTTH for example).

Colour palettes are included in CT HDF files, thus allowing an easy visualisation of CT categories as illustrated on Figure 16.

The user may be interested in visualising all the available classes (please keep in mind that the separation between stratiform and cumuliform clouds is not performed in the current CT version) as displayed on a SEVIRI example in Figure 16, 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).

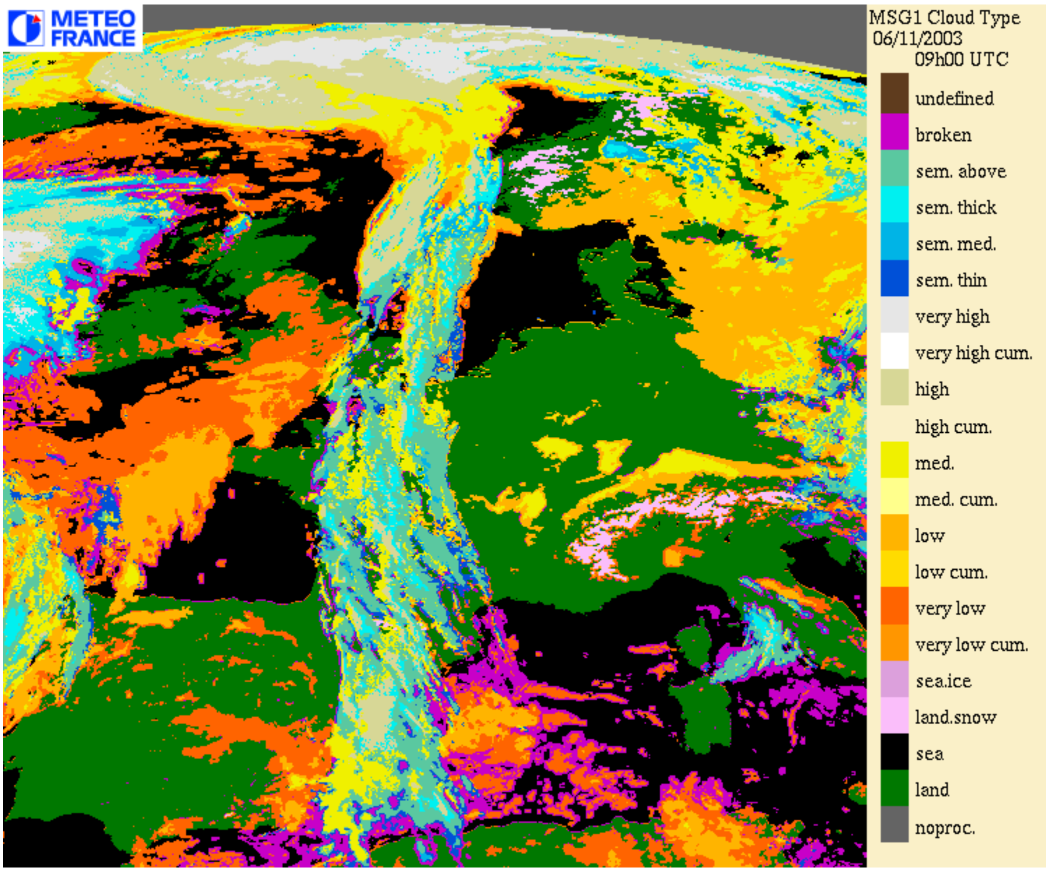


*Figure 16: Example of SEVIRI CT using the colour palette included in CT HDF files.*

### 3.2.2.6 Implementation of CT

The installation procedures, fully described in the Software User Manual (see [AD. 3]), are summarized below. Three main steps are identified. The user manually interacts with the CT software during the installation step, the CT preparation and execution steps being automatically monitored by the Task Manager (if real-time environment is selected).

#### 3.2.2.6.1 The CT installation step:

When a new region is defined and added in system and run configuration files, the user launches (only once) the command mfcms_inst_pge02. This command allows:

- The automatic elaboration of monthly climatological and atlas maps, as well as latitude/longitude and satellite angles information on the new region at the full IR horizontal resolution. These regional atlas and maps are extracted from maps available on the whole MSG disk.

- The automatic elaboration of the model configuration file. In this file, a default value of 4 is given to the size of segments (Cma_szseg). This default value may be manually changed, but must be the same as for CMa. [Segments are square boxes in the satellite projection, whose size is expressed as the number of IR pixels 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

IR resolution, allowing the identification of the surface type (land or sea) of all IR pixels, whatever the segment size. The quality is not very much dependent on the segment size (if lower than 4). A segment size of 4 allows the preparation step to be 9 times faster than if a segment size of 1 was used]

- The automatic set of pre-defined time scheduling (of the preparation step) in Programmed Task Definition Files.

#### 3.2.2.6.2 The CT preparation step:

The preparation step is performed by the command mfcms_next_pge02. which is launched in advance of satellite data reception according to a pre-defined time scheduling set during the installation step.

This preparation step includes the computation on the region at the segment spatial resolution of:

- the solar & satellite angles,
- the monthly climatological & atlas maps,
- the thresholds for the CT algorithm

#### 3.2.2.6.3 The CT execution step:

The execution step is the real-time processing of the SEVIRI images itself over the region. This process consists in the launch of the command: PGE02 by the Task manager. The CT is then performed, using the thresholds prepared during the preparation step.

## 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 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 CTTH PRODUCT

## 4.1 CTTH OVERVIEW

The cloud top temperature and height (CTTH), developed within the SAF NWC 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 SAF NWC 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 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 SEVIRI 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 different steps of the processing, applied to cloud-classified image, are listed below. The exact process applied to each pixel depend on the availability of NWP and SEVIRI data.

If all mandatory NWP and SEVIRI data are available (see list of input for CTTH):

The following process is then applied:

- RTTOV radiative transfer model (Eyre, 1991) is applied using NWP temperature and humidity vertical profile to simulate 6.2µm, 7.3µm, 13.4µm, 10.8µm, and 12.0µm cloud free and overcast (clouds successively on each RTTOV vertical pressure levels) radiances and brightness temperatures. This process is performed in each segment of the image (for the CTTH product, the segment is a box of 32*32 SEVIRI IR 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, medium of high 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 temperature, initially computed at the segment resolution, are spatially interpolated to individual pixels during this process. 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 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: a window (10.8µm) and a sounder (13.4µm, 7.3µm or 6.2µm) channels. 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) radiance bi-dimensional histogram analysis, is first applied. It allows the retrieval of cloud top pressure at the segment horizontal resolution (i.e., 32*32 SEVIRI IR pixels). This method is successively applied using the 13.4µm, 7.3µm and 6.2µm radiances, the final retrieved cloud pressure being the averaged cloud top pressures obtained using single sounding channels.
    - 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 to the 10.8µm and 7.3µm radiances to retrieve the cloud top pressure at a pixel basis. If no result can be obtained, the method is applied to 6.2µm and finally to 13.4µm radiances.
    - 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.
- Cloud top temperature and height (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, and spatially interpolated to individual pixels.

- 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.

In case some mandatory NWP or SEVIRI data are missing (see list of inputs for CTTH):

Cloud top temperature 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 to retrieve 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 SEVIRI 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 available in TIGR dataset 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 17.

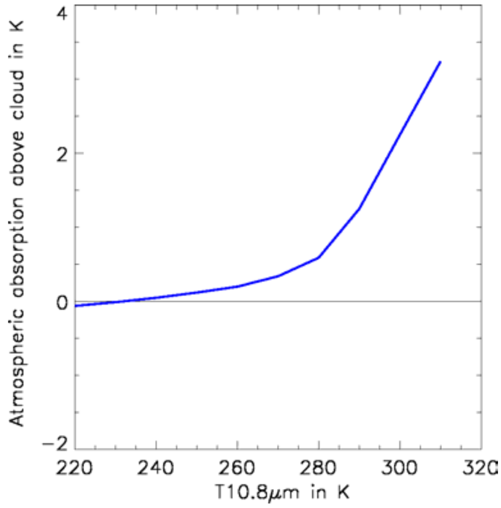


*Figure 17: Climatological atmospheric absorption used to compute cloud top temperature from 10.8µm brightness temperature*

Pixels processed by this method are flagged as of low confidence.

4.2.1.2.2.2 Opaque Cloud top pressure retrieved from window channel brightness temperature

This technique allows to retrieve 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, initially computed on segments of 32*32 IR pixels, are then spatially interpolated to the processed pixel.

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 low confidence 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 to retrieve 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, initially computed on segments of 32*32 IR pixels, are then spatially interpolated to the processed pixel.

The cloud is set above the thermal inversion only if its T10.8µm brightness temperature is lower 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 lower than the simulated T10.8µm brightness temperature below the inversion minus 5K (in case of non subsident thermal inversion). In that case, the method to retrieve its top pressure is then similar to the one described in 4.2.1.2.2.2. Otherwise, the cloud is set below the inversion, and its top pressure is computed using the following rules:

- In case a subsident thermal inversion, the cloud top is set to the level where the minimum air temperature below the inversion is observed
- In case a non-subsident thermal inversion, the cloud top is set to the level where the minimum air temperature below the inversion is observed (if its T10.8µm brightness temperature is lower than the simulated T10.8µm brightness temperatures below the inversion) or corresponds to the best fits between its T10.8µm brightness temperature and the simulated T10.8µm brightness temperature below the inversion.

Pixels processed by this method are flagged as of low confidence. 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 to retrieve 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 the 13.4µm $CO_2$ channels, the 7.3µm and 6.2µm water vapour channel. It allows to retrieve cloud top pressure for semitransparent ice clouds and some high thick clouds (for which the method used for opaque clouds leads to poor quality) on a pixel basis. The process is performed in several steps described below.

<u>Simulation of the radiances</u>

TOA infrared 10.8µm, 13.4µm, 7.3µm and 6.2µm SEVIRI radiances for clear atmosphere and for opaque clouds at various pressure levels have been previously simulated with RTTOV.

<u>Modification of simulated radiances</u>

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 7.3µm and 6.2µm simulated radiances : cloud free 7.3µm and 6.2µm radiances are computed over the whole image at the segment spatial resolution (i.e., 32*32 pixels) 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 7.3µm and 6.2µm simulated radiances : the cloudy 7.3µm and 6.2µm radiances 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.

- modification of cloud free 10.8µm and 13.4µm simulated radiances : cloud free 10.8µm and 13.4µm radiances are computed over the whole image at the segment spatial resolution (i.e., 32*32 pixels) 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 18 with SEVIRI measurements.

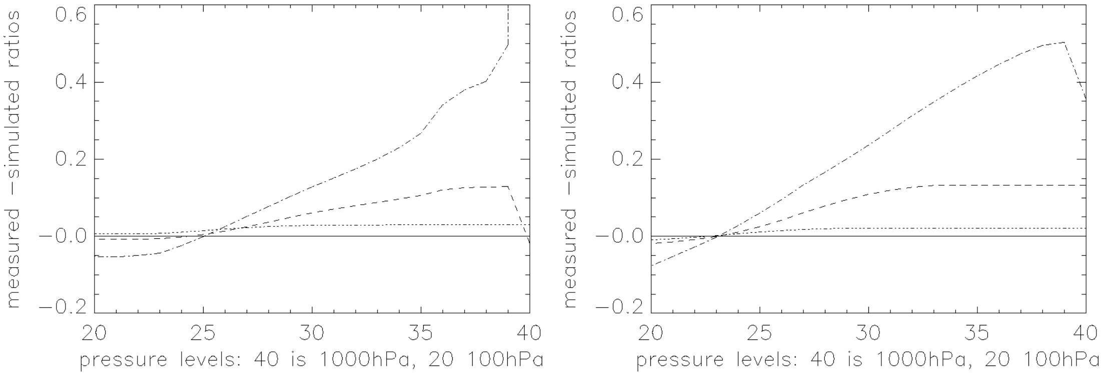


*Figure 18: Illustration of the Radiance Ratioing technique applied to SEVIRI radiances.*

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/13.7µm (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 20% of the difference between the simulated and measured radiances

Quality flag

The pressure retrieval is flagged as of low confidence 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 window 10.8µm channel and one sounding channel (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 19) that allows the top pressure retrieval at the segment spatial resolution (i.e., 32*32 SEVIRI IR pixels) for semitransparent ice cloud and some high thick clouds (for which the method used for opaque clouds leads to poor quality). 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 (6.2µm, 7.3µm or 13.4µm) and window (10.8µm) 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 window (10.8µm) and sounding channel (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 19.

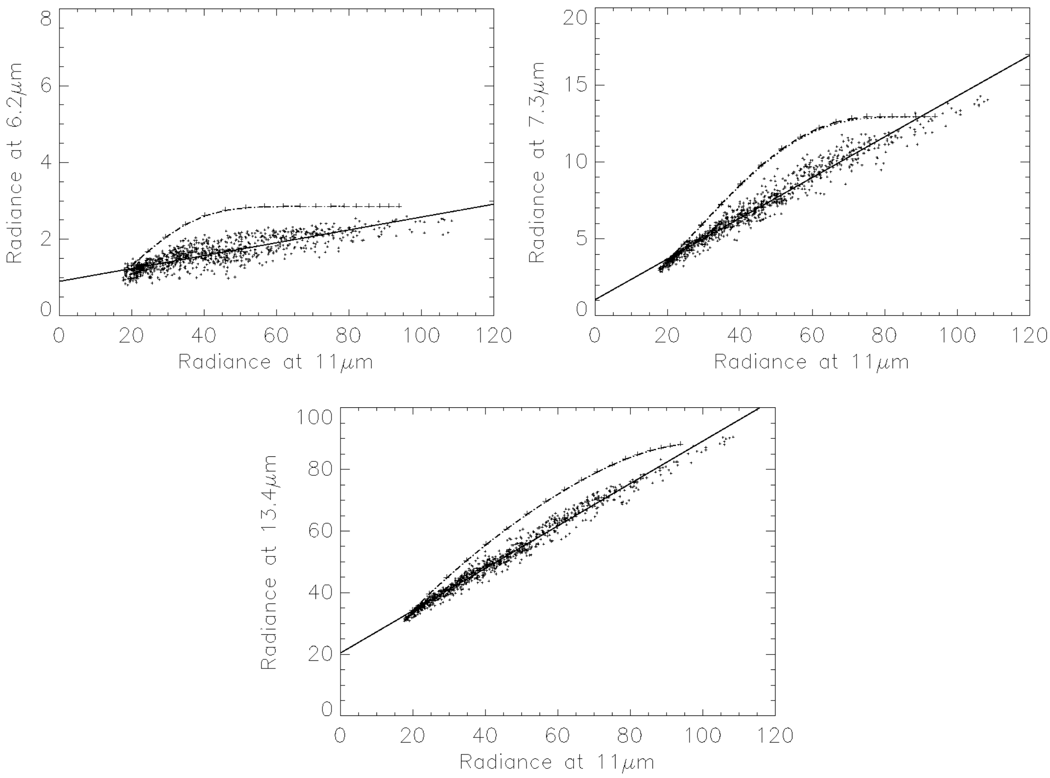


*Figure 19: Illustration of the $H_2O$/IRW intercept method with SEVIRI radiances (expressed in $mWm^{-2}sr^{-1}cm$).*

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 :

<u>Simulation of the SEVIRI radiances</u>

TOA infrared 10.8µm, 13.4µm, 7.3µm and 6.2µm SEVIRI radiances for clear atmosphere and for opaque clouds at various pressure levels have been previously simulated with RTTOV.

<u>Modification of simulated radiances</u>

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 7.3µm and 6.2µm simulated radiances : cloud free 7.3µm and 6.2µm radiances are computed over the whole image at the segment spatial resolution (i.e., 32*32 pixels) 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 7.3µm and 6.2µm simulated radiances : the cloudy 7.3µm and 6.2µm radiances 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 13.4µm (or 7.3µm or 6.2µm) and 10.8µm radiances 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 19, is successively applied to the three sounding channels (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 averaged value obtained with the individual sounding channels.

Calculation of the effective cloudiness

The effective cloudiness (Nε) of each pixel 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 :

- 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 10.8µm radiance 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, but the retrieval is flagged as bad quality.

Quality flag

The pressure retrieval is flagged as good confidence if :

- The final cloud top pressure is an averaged 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 module used has been developed by the aeronautic forecast service in Toulouse. 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

RTTOV radiative transfer model simulates radiances through a cloud-free atmosphere described in 43 standard pressure levels. The NWP forecast temperature and humidity fields available on user-defined vertical pressure levels are interpolated (linearly in logarithm of the pressure) to the RTTOV pressure levels. The surface emissivity is assumed to be 0.98 for continental surface, and is computed from Masuda tables (Masuda et al., 1988) over the sea.

The outputs of RTTOV that have been used are the brightness temperatures and radiances of the simulated channels for cloud-free atmosphere and assuming opaque clouds at the 43 standard pressure levels of RTTOV-7.

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

A module is used to compute the height vertical profile from the corresponding vertical profile of pressure, temperature & water vapour mixing ratio, the surface height and the latitude. The cloud height (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. More details can be obtained from [AD. 1].

| PGE03 products | Validated accuracy: bias(std) |
|---|---|
| **Top height of opaque low, mid-level and high cloud**<br>If validated over European areas using ground-based radar/lidar | 50m (1170m) |
| **Top height of semi-transparent cloud**<br>If validated over European areas using ground-based radar/lidar | 1090m (1090m) |

*Table 8: Summary of validation results of the current PGE03 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.

Fourteen bits in the CTTH output are dedicated to quality description (see in 4.2.2.4). It includes a quality flag based on the quality assessment performed by the CTTH (see above paragraph), but also information on the lack of NWP fields, RTTOV simulation, SEVIRI 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 [AD. 1]).

#### 4.2.2.3 List of inputs for 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 SEVIRI brightness temperatures and radiances are needed at full IR spatial resolution:

| 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 SEVIRI brightness temperatures and radiances for each pixel. Full CTTH product is computed only if all mandatory SEVIRI 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 SEVIRI channels are input by the user in HRIT format, and extracted on the processed region by SAFNWC 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 SEVIRI 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 and relative humidity on vertical pressure levels
  - 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 SAFNWC software package from the NWP fields input by the user in GRIB format.

- **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)

These ancillary data are available in the SAFNWC software package on MSG full disk in the default satellite projection at full IR resolution; They are extracted on the processed region by the CTTH software itself.

RTTOV coefficients's file, mandatory for RTTOV radiative transfer calculation, is available in the SAFNWC software package. If RTTOV model cannot be launched, only the cloud top temperature is computed using the method based on climatological atmospheric absorption correction.

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

- **Configurable parameters:**

PGE03 has no configurable parameter.

#### 4.2.2.4 Description of CTTH output

The content of the CTTH is the following :

- **6 bits for the cloud top pressure**

Linear conversion from count to pressure : Cloud_Pressure = gain * $Count_{6bits}$ + intercept
(correspond to pressures ranging between Cloud_Pressure and Cloud_Pressure+25hPa)

| Gain | Intercept | Special count |
|---|---|---|
| 25 hPa/count | -250hPa | 0 (no pressure available) |

- **7 bits for the cloud top height**

Linear conversion from count to height : Cloud_Height = gain * $Count_{7bits}$ + intercept
(correspond to heights ranging between Cloud_Height and Cloud_Height+200m)

| Gain | Intercept | Special count |
|---|---|---|
| 200 m/count | -2000 m | 0 (no height available) |

- **8 bits for the cloud top temperature**

Linear conversion from count to temperature : Cloud_Temperature = gain * $Count_{8bits}$ + intercept
(correspond to temperatures ranging between Cloud_Temperature and Cloud_Temperature+1K)

| Gain | Intercept | Special count |
|---|---|---|
| 1 K/count | 150 K | 0 (no temperature available) |

- **5 bits for effective cloudiness**

Linear conversion from count to effective cloudiness : Cloudiness = gain * $Count_{5bits}$ + intercept
(correspond to cloudiness ranging between Cloudiness and Cloudiness+5%)

| Gain | Intercept | Special count |
|---|---|---|
| 5 %/count | -50 % | 0 (no cloudiness available) |

- **14 bits for quality**

2 bits to define processing status:

0 non-processed. encompasses :
-CMa and/or CT Non-processed or undefined,
-Image areas that may not be processed [when the images'size is not a multiple of the PGE03 segment size]

1 non-processed because FOV is cloud free

2 processed because cloudy, but without result

3 processed because cloudy, with result

1 bit set to 1 when RTTOV IR simulations are available

3 bits to describe NWP input data

0 undefined (space)
1 All NWP parameters available, no thermal inversion
2 All NWP parameters available, thermal inversion present
3 Some NWP pressure levels missing, no thermal inversion
4 Some NWP pressure levels missing, thermal inversion present
5 At least one mandatory NWP information is missing

2 bits to describe SEVIRI input data
0 undefined (space)
1 all SEVIRI useful channels available
2 at least one SEVIRI useful channel missing
3 at least one SEVIRI mandatory channel is missing

4 bits to describe which method has been used
0 Non-processed
1 Opaque cloud, using rttov
2 Opaque clouds, not using rttov
3 Intercept method 10.8µm/13.4µm
4 Intercept method 10.8µm/6.2µm
5 Intercept method 10.8µm/7.3µm
6 Radiance Ratioing method 10.8µm/13.4µm
7 Radiance Ratioing method 10.8µm/6.2µm
8 Radiance Ratioing method 10.8µm/7.3µm
9 Intercept method averaged value:10.8µm/6.2µm and 10.8µm/7.3µm
10 Intercept method averaged value: 10.8µm/6.2µm and 10.8µm/13.4µm
11 Intercept method averaged value: 10.8µm/7.3µm and 10.8µm/13.4µm
12 Intercept method averaged value: 10.8µm/13.4µm, 10.8µm/6.2µm and 10.8µm/7.3µm
13 Opaque cloud, using rttov, in case thermal inversion
14-15 Spare for not yet defined methods

2 bits to describe quality of the processing itself
0 No result (Non-processed, cloud free, no reliable method)
1 Good quality (high confidence)
2 Poor quality (low confidence)

#### 4.2.2.5 Example of 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 SAFNWC products.

Color palettes are included in CTTH HDF files, thus allowing an easy visualisation of cloud top pressure (as illustrated with the SEVIRI example on Figure 20), 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.

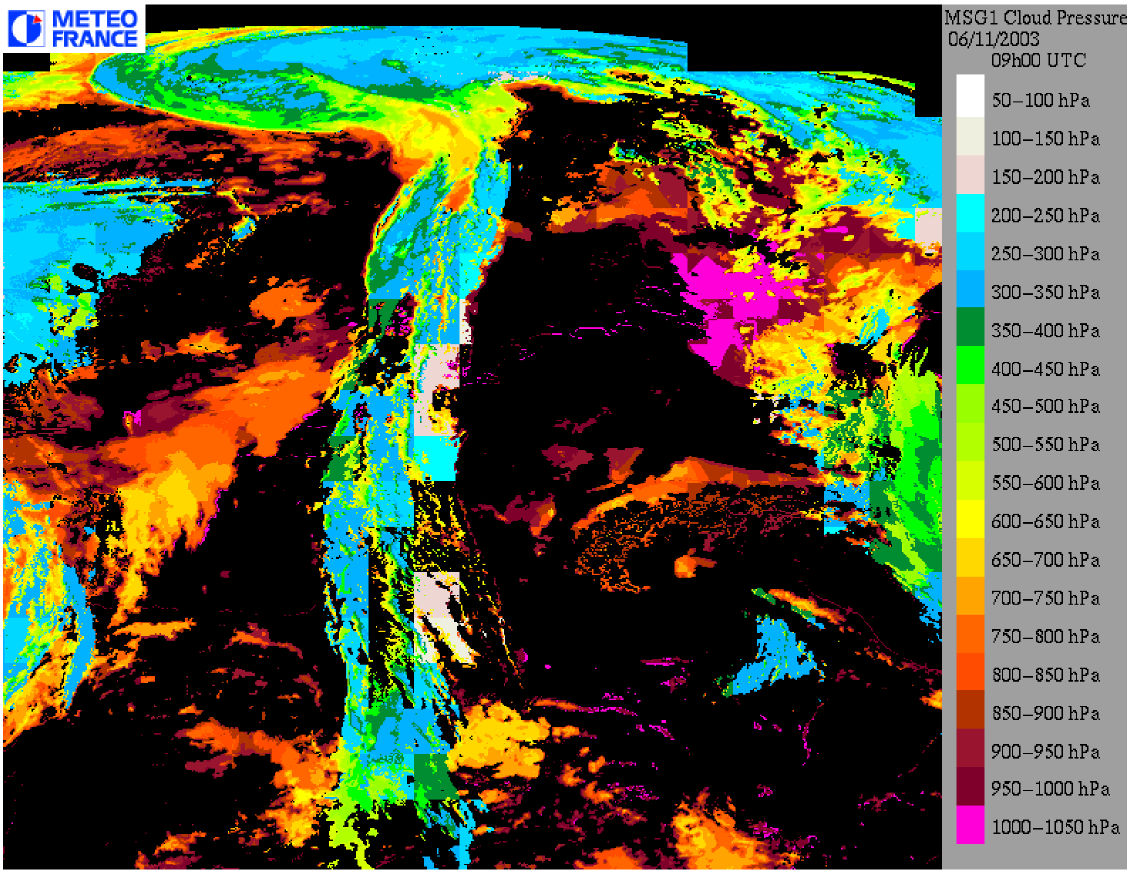


*Figure 20: Example of SEVIRI CTTH cloud top pressure*

#### 4.2.2.6 Implementation of CTTH

In order to prepare the remapping of NWP fields by the SAFNWC software, the user has to manually prepare (once for ever) the NWP configuration file:

- he defines the NWP vertical pressure levels on which he will input air temperature and relative humidity. For CTTH purposes, vertical levels must be at least be available every 210hPa.
- he defines the codes (depending on local EMOS table) of needed parameters.

The installation procedures, fully described in the Software User Manual (see [AD. 3]), are summarized below. Three main steps related to the CTTH software are identified. The user manually interacts with the CTTH software during the installation step, the CTTH preparation and execution steps being automatically monitored by the Task Manager (if real-time environment is selected).

##### 4.2.2.6.1 The CTTH installation step:

When a new region is defined and added in system and run configuration files, the user launches (only once) the command mfcms_inst_pge03. This command allows:

- The automatic elaboration of monthly climatological and atlas maps, as well as latitude/longitude and satellite angles information on the new region at the full IR horizontal resolution. These regional atlas and maps are extracted from maps available on the whole MSG disk.

- The automatic elaboration of the model configuration file. In this file, the value of 32 is given to the size of segments. It cannot be changed by the user.
- The automatic set of pre-defined time scheduling (of the preparation step) in Programmed Task Definition Files.

#### 4.2.2.6.2 The CTTH preparation step:

The preparation step is performed by the command mfcms_next_pge03 which is launched in advance of satellite data reception according to a pre-defined time scheduling set during the installation step.

This preparation step includes the computation on the region at the segment spatial resolution of:

- the solar & satellite angles,
- the monthly climatological & atlas maps,
- the simulated cloud free & opaque cloud radiances with RTTOV

#### 4.2.2.6.3 The CTTH execution step:

The execution step is the real-time processing of the SEVIRI images itself over the region. This process consists in the launch of the command: PGE03 by the Task manager. The CTTH is then performed, using the simulated radiances prepared during the preparation step.

## 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.
- CTTH for cirrus clouds may have a square-like appearance due to the use of histogram analysis in the retrieval process.
- Retrieved low cloud top height may be overestimated (to be confirmed during validation).

## 4.4 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*.

Masuda K., Takashima T., Takayama Y., 1988, Emissivity of pure and sea waters for the model sea surface in the infrared window regions, *Remote Sensing of Environment* 24 :313-329.

Menzel W.P., Smith W.L., and Stewart T.R., 1983, Improved Cloud Motion Wind Vector and Altitude Assignment using VAS, *Journal of Climate and Applied meteorology*, **22**, 377-384.

Nieman S.J., Schmetz J., Menzel W.P., 1993, A comparison of several techniques to assign heights to cloud tracers. *Journal of Applied Meteorology*, **32**, 1559-1568.

Putsay M, Derrien M., LeGleau H. and Monnier G., 1999,Comparison of two methods to estimate the cloud top temperature and pressure for NOAA-AVHRR and HIRS data, *Proceeding of the 1999 Eumetsat Meteorological Satellite Data user' conference, Copenhague 6-10 September 1999.*

Schmetz J., Hollmund K., Hoffman J. and B.Strauss, 1993, Operational cloud motion winds from Meteosat infrared images. *J.Appl.Meteor*, 32, 1207-1225.

# ANNEX 1. ATLAS AND CLIMATOLOGICAL DATASET

Atlas and climatological datasets covering the whole MSG disk in the default satellite projection at full SEVIRI IR horizontal resolution are available within the SAFNWC software package and are used in the elaboration of CMa, CT and CTTH products. The following sections give a short description of the source of these ancillary data.

## A1.1 LAND/SEA ATLAS

The initial source is the full resolution coast line available in GMT 3.1 tool (see Wessel et al., 1995, code available on internet (http ://www.soest.hawaii.edu /gmt)).

Each SEVIRI IR pixel is classified as sea (more than 50 % water surface (sea or lake)), land (more than 50% land surface) or space.

Wessel P., Smith W.H.F., 1995, New version of the Generic Mapping Tools released, *EOS Trans. Amer. Geophys. U. Electronic.* Vol 76 (33), 329

## A1.2 LAND/SEA/COAST ATLAS

The land/sea/coast atlas is derived from the land/sea atlas by identifying coastal areas defined as pixels for which a transition land/sea is observed within 2 SEVIRI IR pixels.

## A 1.3 ELEVATION ATLAS

The initial source is GTOPO30 (available on internet http://edcwww.cr.usgs.gov/landaac/gtopo30/gtopo30.html) which is a Digital Elevation Model having an horizontal resolution of 30 arc-seconds.

The altitude of each SEVIRI IR pixel over land (and lakes) is obtained by averaging GTOPO30 values located inside this pixel, whereas oceanic pixel are given a zero value.

## A 1.4 MONTHLY MINIMUM SEA SURFACE TEMPERATURE CLIMATOLOGY

The initial source is a global Pathfinder climatology covering a 10 years period (1985-1995) and available at $1/9^{th}$ degree horizontal resolution. This climatology contains mean and minimum SST values for every decade, and identifies areas covered by ice.

Monthly minimum SST values are obtained for each SEVIRI IR pixel over sea (including lakes) by retaining the minimum values of all the corresponding decades. Pixels covered by ice are given a constant value (269.15K) whereas land pixels are given a default value.

## A 1.5 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 for each SEVIRI IR pixel over land is obtained from the nearest value of these TOA reflectances. Sea pixels are given a default value.

## A 1.6 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 of each SEVIRI IR pixel 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).

Oort A.H., 1983, Global atmospheric circulation statistics, 1958-1973. NOAA professional Paper No. 14.

## A 1.7 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.