EUMETSAT NWC SAF

SUPPORT TO NOWCASTING AND VERY SHORT RANGE FORECASTING

User Manual for the Cloud Product Processors of the NWC/GEO: MTG-I Day-1

NWC/CDOP3/MTG/MFL/SCI/UM/Cloud, Issue 1, Rev. 1.1

30 May 2025

Applicable to

GEO-CMA-v6.0 (NWC-004)
GEO-CT-v5.0 (NWC-008)
GEO-CTTH-v5.0 (NWC-012)
GEO-CMIC-v3.0 (NWC-015)

Prepared by Météo-France / Centre d'études en Météorologie Satellitaire

REPORT SIGNATURE TABLE

Function	Name	Signature	Date
Prepared by	Gaëlle Kerdraon MF/DESR/CNRM/CEMS		30 May 2025
Reviewed by	Emmanuel Fontaine MF/DESR/CNRM/CEMS		30 May 2025
Authorised by	NWC SAF Project Manager		30May 2025

DOCUMENT CHANGE RECORD

Version	Date	Pages	Changes
1.0	13 November 2020	61	Prepared for STRR
1.1.0	3 February 2023	64	Version for MTG-I Day-1 ORR1 Changes concerning all versions that have been delivered since STRR. Track of changes from 2021, except date, code, version Inclusion of reference tables of satellites bands New variable Cloud Top in hectofeet for the CTTH product
1.1.1	30 May 2025		Version of MTG-I day-1 ORR2 Changes lot of references to MSG/SEVIRI by references to MTG/FCI Corrections of fonts size and styles.

Table of Contents

List of Tables and Figures

1 INTRODUCTION

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

1.1 SCOPE OF THE DOCUMENT

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

This document contains practical information of the above-mentioned products, on their applicability and limitations.

1.2 SCOPE OF OTHER DOCUMENTS

The algorithms used to extract the GEO Cloud Products are detailed in the algorithm theoretical basis document for cloud products ([RD.3.])

Instructions to install, configure and execute the SAFNWC/GEO software in order to extract the GEO Cloud Products are detailed in the software user manual ([AD.11])

The interface control documents ([AD.5.]) (for the External and Internal Interfaces of the SAFNWC/GEO) and ([AD.6.]) (GEO Output Product Format Definition) detail the input and output data format for the SAFNWC/GEO software.

1.3 SOFTWARE VERSION IDENTIFICATION

This document describes the products obtained from the GEO-CMA-v6.0 (Product Id NWC-004), GEO-CT-v5.0 (Product Id NWC-008), GEO-CTTH-v5.0 (Product Id NWC-012) and GEO-CMIC-v3.0 (Product Id NWC-015) implemented in the release vMTG-I Day-1 of the NWC/GEO software package.

1.4 IMPROVEMENT FROM PREVIOUS VERSION

Since 2021 release, the following improvements have been implemented:

- Technical improvements:
- Geo-CTTH: Provides the Cloud Top in hectofeet

1.5 DEFINITIONS, ACRONYMS AND ABBREVIATIONS

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

SW	Software
T11μm	11 micrometer infrared brightness temperature
TIGR	Tovs Initial Guess Retrieval
TM	Task Manager
TOA	Top Of Atmosphere
VIS	Visible

1.6 REFERENCES

1.6.1 Applicable documents

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

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

Current documentation can be found at the NWC SAF Helpdesk web: http://www.nwcsaf.org

Ref	Title	Code	Vers	Date
[AD.1.]	Proposal for the Fouth Continuous Development and operation Phase (CDOP) March 2022 – February 2027	NWC/SAF/AEMET/MGT/CDOP4Proposal	1.0	12/03/2021
[AD.2.]	Project Plan for the NWCSAF CDOP3 phase	NWC/CDOP4/SAF/AEMET/MGT/PP	1.0.0	31/10/2022
[AD.3.]	Configuration Management Plan for the NWCSAF	NWC/CDOP4/SAF/AEMET/MGT/CMP	1.0.1	23/01/2023
[AD.4.]	NWCSAF Product Requirement Document	NWC/CDOP4/SAF/AEMET/MGT/PRD	1.0.0	31/10/2022
[AD.5.]	Interface Control Document for Internal and External Interfaces of the NWC/GEO MTG-I Day-1	NWC/CDOP2/GEO/AEMET/SW/ICD/1	1.3	03/02/2023
[AD.6.]	Data Output Format for the NWC/GEO MTG-I Day-1	NWC/CDOP2/GEO/AEMET/SW/DOF	1.3	03/02/2023
[AD.7.]	Interface Control Document for the NWCLIB of the NWC/GEO MTG-I Day-1	NWC/CDOP2/MTG/AEMET/SW/ICD/2	1.3	03/02/2023
[AD.8.]	NWCSAF CDOP4 Service Specifications	NWC/CDOP4/SAF/AEMET/MGT/SSD	1.0.0	31/10/2022
[AD.9.]	System and Components Requirements Document for the NWC/GEO MTG-I Day-1	NWC/CDOP2/MTG/AEMET/SW/SCRD	1.3	13/11/2020
[AD.10.]	Architecture Design Document for the NWC/GEO MTG-I Day-1	NWC/CDOP2/MTG/AEMET/SW/ACDD	1.2	13/11/2020
[AD.11.]	User Manual for the NWC/GEO: Software part	NWC/CDOP3/MTG/AEMET/SW/UM	1.1	03/02/2023

Table 1: List of Applicable Documents

1.6.2 Reference documents

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

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

Current documentation can be found at the NWC SAF Helpdesk web: http://www.nwcsaf.org.

Ref	Title	Code	Vers	Date
[RD.1.]	The Nowcasting SAF Glossary	NWC/CDOP3/SAF/AEMET/MGT/GLO	1.0	20/10/2020
[RD.2.]	Component Verification File for the Cloud Product Processors of the NWC/GEO MTG-I Day-1	NWC/CDOP2/MTG/MFL/SW/SCVERF/Cloud	1.3	31/01/2021
[RD.3.]	Algorithm Theoretical Basis Document for the Cloud Product Processors of the NWC/GEO MTG-I Day-1	NWC/CDOP2/MTG/MFL/ATBD/Cloud	1.1	31/01/2021
[RD.4.]	Validation Report Document for Processors of the NWC/GEO MTG-I DAY-1	NWC/CDOP4/MTG/MFL/SCI/VR/Cloud	1.0	30/05/2025

Table 2: List of Referenced Documents

1.6.3 Reference table of channels

Each geostationary satellite has its own labels for its channels. However, the software SAFNWC/GEO does not change the labels it uses to call a given band for its processing. The Table 3 gives the labels that are used by the software and the corresponding channels as function of the GEO satellites.

SAFNWC/GEO labels	MSG labels (res)	MTG labels (res)	GOES-16/17 labels (res)	Himawari-8/9 labels (res)
VIS04/R0.4µm		vis_04 (1km)	01 or VIS_004 (1km)	VIS004 (1km)
VIS05/R0.5µm		vis_05 (1km)		VIS005 (1km)
VIS06/R0.6µm	VIS006 (3km)	vis_06 (0.5km)	02 or VIS_006 (0.5km)	VIS006 (0.5km)
VIS08/R0.8µm	VIS008 (3km)	vis_08 (1km)	03 or VIS_008 (1km)	VIS008 (1km)
VIS09/R0.9µm		vis_09 (1km)		
HRV/hrvis	HRV (1km)			
NIR13/R1.3µm		nir_13 (1km)	04 or VIS_014 (2km)	
NIR16/R1.6µm	IR_016 (3km)	nir_16 (1km)	05 or VIS_016 (1km)	IR_016 (2km)
NIR22/R2.2µm		nir_22 (0.5km)	06 or VIS_022 (2km)	IR_022 (2km)
IR38/T3.8µm	IR_039 (3km)	ir_38 (1km)	07 or IR_039 (2km)	IR_038 (2km)
WV62/T6.2µm	WV_062 (3km)	wv_63 (2km)	08 or IR_062 (2km)	WV_062 (2km)
WV70/T7.0µm			09 or IR_069 (2km)	WV_069 (2km)
WV73/T7.3µm	WV_073 (3km)	wv_73 (2km)	10 or IR_073 (2km)	WV_073 (2km)
IR87/T8.7µm	IR_087 (3km)	ir_87 (2km)	11 or IR_085 (2km)	IR_085 (2km)
IR97/T9.7µm	IR_097 (3km)	ir_97 (2km)	12 or IR_096 (2km)	IR_096 (2km)
IR103/T10.3µm			13 or IR_103 (2km)	IR_104 (2km)

IR108/T10.8µm	IR_108 (3km)	ir_105 (1km)	14 or IR_112 (2km)	IR_112 (2km)
IR120/T12.0µm	IR_120 (3km)	ir_123 (2km)	15 or IR_123 (2km)	IR_123 (2km)
IR134/T13.4µm	IR_134 (3km)	ir_133 (2km)	16 or IR_133 (2km)	IR_132 (2km)

Table 3: Channels labels used by the SAFNWC/GEO software with the corresponding labels given in each GEO satellites.

2 CLOUD MASK (GEO-CMA) PRODUCT

2.1 DESCRIPTION OF CLOUD MASK (GEO-CMA) PRODUCT

2.1.1 Goal of Cloud Mask (GEO-CMA) product

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

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

2.1.2 Description of Cloud Mask (GEO-CMA) algorithm

The algorithm has been designed to be applicable to imagers on board meteorological geostationary satellites. The imagers may have different set of channels possibly at different horizontal resolutions. The lowest native resolution of the radiometer is chosen as the default resolution, which is for most imagers on board present and future meteorological geostationary satellites the horizontal resolution of all IR channels and some solar channels: 2km for MTG, Himawari-8/9 and GOES-16/17/18/19 satellites and 3km for MSG. Solar channels may be available at higher horizontal resolution such 1km for MTG, Himawari-8/9, GOES-16/17 and MSG (HRVIS only). The visible at 0.6µm is available at very high resolution such 0.5km for MTG, GOES-16/17/18/19 and Himawari-8/9. In this release, the process is applied to all useful channels at the default horizontal resolution (high resolution channels being averaged at this resolution). The high resolution channels are additionally used at their native resolution to detect sub-pixels clouds inside pixels at default horizontal resolution. We use generic labels in this document (for example, T3.8µm, T8.7µm, T10.8µm, T12.0µm, R0.6µm, R0.8µm and R1.6µm), the exact central wavelengths of the corresponding channels depending on the satellite. The list of available labels depends on the satellite (see Table 3); the list of mandatory channels is listed in 2.3.1.

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

- a first set of multispectral tests with thresholds computed from Look-Up Tables (LUT) allows detecting most of the pixels containing cloud or snow,
- (optional step) a second limited set of multispectral tests with thresholds computed from RTTOV applied on-line to NWP vertical profiles allows by a more accurate threshold computation a detection of low or thin high clouds that remained undetected when using LUTs,
- an analysis of the temporal variation (on a short period of time around 20 minutes) of some spectral combination of channels allows detecting rapidly moving clouds,

- a specific treatment combining temporal coherency analysis and region growing technique allows the improvement of low clouds detection in twilight conditions,
- (optional step) an analysis of solar channels at high spatial resolution allows detecting sub-pixel clouds inside pixel at default horizontal resolution,
- a spatial filtering is finally applied to cold areas, cloud edges (over ocean), isolated cloud pixel (land) and snow-area edges

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

Details on the tests are given in the algorithm theoretical basis document for cloud products ([RD.3.]).

Daytime	Twilight	Nighttime
Snow detection	Snow detection	T10.8µm -T3.8µm
R0.6µm	R0.6µm	T10.8µm
T10.8µm	T10.8µm	T10.8µm -T12.0µm
T10.8µm-T12.0µm	T10.8µm-T12.0µm	T8.7µm-T10.8µm
T8.7µm-T10.8µm	T10.8µm-T3.8µm	T3.8µm-T10.8µm
T10.8µm-T3.8µm	T8.7µm-T10.8µm	Local Spatial Texture
T3.8µm-T10.8µm	T3.8µm-T10.8µm	T8.7µm-T3.8µm
R1.38µm	Local Spatial Texture	
Local Spatial Texture	T8.7µm-T3.8µm	

Table 4: Test sequence over land

Daytime	Sunglint	Twilight	Nighttime
Ice detection	Ice detection	Ice detection	T10.8µm-T3.8µm
R0.8µm (R0.6µm)	SST	R0.8µm (R0.6µm)	SST
SST	T10.8µm-T12.0µm	T10.8µm-T3.8µm	T8.7µm-T10.8µm
R1.6µm	T8.7µm-T10.8µm	SST	T10.8µm-T12.0µm
T10.8µm-T12.0µm	Local Spatial Texture	R1.6µm	T12.0µm-T3.8µm
T8.7µm-T10.8µm	R0.8µm (R0.6µm)	T8.7µm-T10.8µm	T3.8µm-T10.8µm
T10.8µm-T3.8µm	T10.8µm-T3.8µm	T10.8µm-T12.0µm	Local Spatial Texture
T3.8µm-T10.8µm	Low Clouds in Sunglint	T12.0µm-T3.8µm	
R1.38µm		T3.8µm-T10.8µm	
Local Spatial Texture		Local Spatial Texture	

Table 5: Test sequence over sea

2.1.3 Description of Cloud Mask (GEO-CMA) output

The content of the GEO-CMA output (in NetCdF format) is described in the Data Output Format document ([AD.6.]), a summary is given below:

<table>
<tr><th>Container</th><th>Content</th></tr>
<tr><td>GEO-CMA</td><td>SAFNWC GEO CMA Cloud Mask
<table><tr><th>Class</th><th>Cloud Mask category</th></tr><tr><td>0</td><td>Cloud-free</td></tr><tr><td>1</td><td>Cloudy</td></tr><tr><td>FillValue</td><td>No data or corrupted data</td></tr></table></td></tr>
<tr><td>GEO-CMA
_CLOUDSNOW</td><td>SAFNWC GEO CMA Cloud and Snow Mask
<table><tr><th>Class</th><th>Cloud and Snow Mask category</th></tr><tr><td>0</td><td>Cloud-free</td></tr><tr><td>1</td><td>Cloud (except thin ice cloud over snow)</td></tr><tr><td>2</td><td>Thin ice cloud over snow/ice</td></tr><tr><td>3</td><td>Snow/Ice</td></tr><tr><td>FillValue</td><td>No data or corrupted data</td></tr></table></td></tr>
<tr><td>GEO-CMA
_DUST</td><td>SAFNWC GEO CMA Dust Detection
<table><tr><th>Class</th><th>Dust Detection category</th></tr><tr><td>0</td><td>No dust</td></tr><tr><td>1</td><td>Dust</td></tr><tr><td>2</td><td>Undefined (separability problem)</td></tr><tr><td>FillValue</td><td>No data or corrupted data</td></tr></table></td></tr>
<tr><td>GEO-CMA
_VOLCANIC</td><td>SAFNWC GEO CMA Volcanic Plume Detection
<table><tr><th>Class</th><th>Volcanic Plume Detection category</th></tr><tr><td>0</td><td>No volcanic plume</td></tr><tr><td>1</td><td>Volcanic plume</td></tr><tr><td>2</td><td>Undefined (separability problem)</td></tr><tr><td>FillValue</td><td>No data or corrupted data</td></tr></table></td></tr>
<tr><td>GEO-CMA
_SMOKE</td><td>SAFNWC GEO CMA Smoke Detection (not yet performed -> set to undefined)
<table><tr><th>Class</th><th>Smoke Detection category</th></tr><tr><td>0</td><td>No smoke</td></tr><tr><td>1</td><td>Smoke</td></tr><tr><td>2</td><td>Undefined (separability problem)</td></tr><tr><td>FillValue</td><td>No data or corrupted data</td></tr></table></td></tr>
</table>

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

Geophysical Conditions

Field	Type	Description
Space	Flag	Set to 1 for space pixels
Illumination	Parameter	Defines the illumination condition 0: N/A (space pixel) 1: Night 2: Day 3: Twilight
Sunglint	Flag	Set to 1 if Sunglint
Land_Sea	Parameter	0: N/A (space pixel) 1: Land 2: Sea 3: Coast
Rough_terrain	Flag	Set to 1 if rough (hilly) terrain (differences in surface elevation greater than 300m in boxes of 3x3 pixels)
High_terrain	Flag	Set to 1 if surface elevation>1500m

Processing Conditions

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

Quality

Field	Type	Description
Nodata	Flag	Set to 1 if pixel is NODATA
Internal_consistency	Flag	Set to 1 if an internal consistency check has been performed. Internal consistency checks will be based in the comparison of the retrieved meteorological parameter with physical limits, climatological limits, neighbouring data, NWP data, etc. (not performed)
Temporal_consistency	Flag	Set to 1 if a temporal consistency check has been performed Temporal consistency checks will be based in the comparison of the retrieved meteorological parameters with data obtained in previous slots. (not performed)
Quality	Parameter	Retrieval Quality 0: N/A (no data) 1: Good 2: Questionable 3: Bad 4: Interpolated (not used)

Additionally, the two following scores are available in the header of the NetCdF files:

- The product completeness is the ratio (in %) between the number of processed pixels and the number of "non space" pixels (i.e., the pixels that should be processed).
- The product quality is the ratio (in %) between the number of good quality pixels and the number of "non space pixels" (i.e., the pixels that should be processed). The definition of good quality pixel is given in the ATBD.

2.2 IMPLEMENTATION OF CLOUD MASK (GEO-CMA)

CMA is extracted by PGE01 (GEO-CMA) component of the NWC/GEO software package. Detailed information on how to run this software package is available in the software user manual ([AD.11).

When a new region is defined the user has to manually prepare the CMA model configuration files for this new region using a default CMA model configuration file provided in the NWC/GEO software package (see its content in section 2.3.2).

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

2.2.1 Manual preparation of Cloud Mask (GEO-CMA) model configuration file for each region

When a new region is defined and added in system and run configuration files, the user must manually prepare the GEO-CMA model configuration file by adapting the GEO-CMA default model configuration file available in the SAFNWC/GEO software package (see its content in section 2.3.2).

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

- CMA_SZSEG (default value: 6): the size of the segment for CMA. [Segments are square boxes in the satellite projection, whose size is expressed as the number of default horizontal resolution pixels (2km at nadir for MTG) of one edge of the square box. The size of the processed regions must be a multiple of the segment size. All the solar and satellite angles, the NWP model forecast values, the RTTOV simulations, the atlas values and the thresholds will be derived over all the processed regions at the horizontal resolution of the segment. Note also that the land/sea atlas will be available at the full default horizontal resolution, allowing the identification of the surface type (land or sea) of all pixels, whatever the segment size. The quality is not very much dependent of the segment size (if lower than 6). Decreasing the segment size will increase the execution time]. Note that sampling rate of NWP_PARAM and RTS_PARAM (see 2.3.2) should be modified accordingly.
- NWP_FREQUENCY_PER_DAY (default value: 4): the number of NWP forecast term per day input by the user. [By default, it is set to 4 (corresponds to NWP fields every 6 hours which is the minimum number authorized by the NWCSAF software). If the user inputs more frequent NWP fields, the NWP_FREQUENCY_PER_DAY key should be changed (for example 8 per day in case NWP fields every 3hours). This key allows to use the NWP fields input by the user avoiding hidden temporal interpolation. In fact, the computation of some IR threshold may need to analyse how NWP parameters have changed before and after current slot. This require that the NWP parameters (before and after current slot) should be those input by the user without temporal linear interpolation (which is automatically performed by NWCSAF NWP handling routines).]
- NWP_ANALYSIS: the flag indicating if NWP analysis fields can be used. Its default value is FALSE. This flag has been made configurable to allow users to provide NWP analysis, in case of reprocessing activities. When it is set to TRUE, NWP fields with forecast time 00 are used by the PGE if they are available.
- IS_ALREADY_RECALIBRATED (default value: FALSE): a flag defining whether satellite data input by the user are already recalibrated using post-launch calibration coefficients (solar channels) and GSICS IR calibration coefficients. [For nearly all users, it shall remain set to FALSE (default value). If set to TRUE (for example, CM-SAF may use this option), the RTTOV on-line option is deactivated because RTTOV infrared bias files may not be adequate].
- RTTOV_USE (default value: FALSE): a flag defining if the set of tests using thresholds computed on-line with RTTOV should be applied. [RTTOV_USE flag is checked at the execution step. GEO-CMA applies the set of tests using thresholds computed on-line with RTTOV if its value is TRUE. This flag has been made configurable to allow users being blocked by hardware resources to still run GEO-CMA by assigning it to FALSE in the configuration file.]
- RTTOV_USE_COMPUTED_BIAS (default value: FALSE): a flag defining if biases are to be monitored on-line when RTTOV-based tests are used. [This key should be set to TRUE in case RTTOV_USE is set to TRUE and RTTOV bias files are not available for the NWP

model used by the user (AEMET provides bias files for ECMWF only). But there are some constraints to create those bias files (see [RD.3.])

- HRVIS_NEED (default value: TRUE): a flag indicating whether the hrvis analysis should be done. [HRVIS_NEED flag is checked at the execution step. GEO-CMA applies the hrvis analysis if its value is TRUE. This flag has been made configurable to allow users being blocked by hardware resources to still run GEO-CMA by assigning it to FALSE in the configuration file.]
- NP_OMP_CMA_THREAD (default value: -1): The CMA is parallelized using openMP standard. If set to a strictly positive integer value, NB_OMP_CMA_THREAD corresponds to the number of threads used by CMA. If NB_OMP_CMA_THREAD is set to a negative value, the number of threads used by CMA will be monitored by the OMP_NUM_THREADS environment variable set at NWCSAF SW level.

2.2.2 Cloud Mask (GEO-CMA) execution step

The GEO-CMA execution step consists in the launch of the command: GEO-CMA by the Task Manager with the required parameters: time of slot, region and configuration file name.

The following command is used to process GEO-CMA manually, without the presence of the TM:

```
% GEO-CMA-v<vers> <time_of_slot> <region_configuration_file>
                   <CMA model_configuration_file>
   2.2.2.1 Example
```

```
%GEO-CMA-v60 20211029T120000Z global.cfg safnwc_CMA.cfm
```

This command executes GEO-CMA version 6.0 over the region `global.cfg` manually, without the presence of the TM

2.3 INPUTS AND CONFIGURABLE PARAMETERS FOR CLOUD MASK (GEO-CMA)

2.3.1 List of inputs for Cloud Mask (GEO-CMA)

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

- **Satellite imagery:**

For the current slot (H+00):

The following bi-directional reflectances or brightness temperatures are needed at default horizontal resolution (2km at nadir for MTG/FCI):

R0.6µm	R0.8µm	R1.38µm	R1.6µm	R2.25µm	T3.8µm	T7.3µm	T8.7µm	T10.4µm	T10.8µm	T12.0µm	T13.4µm
Mandatory	Optional	Optional	Optional	Optional	Mandatory	Optional	Optional	Optional	Mandatory	Mandatory	Optional

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

hrvis
Optional

(hrvis is one visible channel at around 0.6µm)

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

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

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

R0.6µm$_{1h}$	**T8.7µm$_{1h}$**	**T10.8µm$_{1h}$**	**T12.0µm$_{1h}$**	**CMA$_{1h}$**	**CT$_{1h}$**
Optional	Optional	Optional	Optional	Optional	Optional

For the slot around 20 minutes earlier (H-15min for MSG)):

The following brightness temperatures or CMA or CT of the scene analysed around 20 minutes earlier are optionally needed (at default horizontal resolution) to improve the cloud detection of fast-moving clouds. If one of them is missing this improvement is not performed.

T8.7µm20$_{mn}$	**T10.8µm20$_{mn}$**	**T12.0µm20$_{mn}$**	**CMA20$_{mn}$**	**CT20$_{mn}$**
Optional	Optional	Optional	Optional	Optional

The hrvis bi-directional reflectance of the scene analysed around 20 minutes earlier is optionally needed to improve the sub-pixel cumulus cloud detection. If not available, this improvement is not performed.

hrvis20$_{mn}$
Optional

(hrvis is one visible channel at around 0.6µm)

The channels are input by the user in specified format and extracted on the processed region by NWC/GEO software package.

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

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

- **NWP parameters:**

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

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

These remapped fields are elaborated by the NWC/GEO software package from the NWP fields input by the user in GRIB format. The CMA needs NWP data before and after the date of the slot to process temporal interpolation.

In case of reprocessing activities, NWP analysis can be used. To be remapped the NWP_ANALYSIS flag must be set to YES in the nwp_conf_file.

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

- **RTTOV simulations:**

The following parameters simulated by RTTOV are used as input:

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

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

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

- **OSTIA fields:**

The following parameters are used as input:

- OSTIA SST and local estimated error

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

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

- **RTTOV bias files:**

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

These files are not mandatory. If not available, the bias can be computed by GEO-CMA (the processed region needs to contain a large enough area covered by oceanic surfaces (see [RD.3.]). If this computation is not possible, the GEO-CMA does not apply test using RTTOV simulation and the GEO-CMA quality being then slightly lower (especially in nighttime conditions).

- **Ancillary data sets:**

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

  - Land/sea atlas
  -
  - Elevation atlas
  - Monthly SST minimum and standard deviation climatology values

- Monthly mean 0.6μm atmospheric-corrected reflectance climatology (land)
- Monthly mean visible surface reflectance climatology for hrvis processing (land,) (derived from monthly MODIS black-sky albedos at 0.55 μm, 0.67 μm and 0.86μm)
- Land cover database (BATS)
- Monthly integrated atmospheric water vapor content climatology
- Monthly climatology of mean air temperature at 1000 hPa
- Monthly land surface thermal emissivity climatology at IR wavelength

These ancillary data are available in the NWC/GEO software package on full disk for each satellite; they are extracted on the processed region by the CMA software itself.

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

2.3.2 CMa Model Configuration File

The CMA model configuration file contains all the coefficients and constants required for the derivation of the GEO-CMA product. The model configuration file must be placed in the $SAFNWC/config directory. The file contains the following information:

Keyword	Description	Type	Default Value(s)
PGE_ID	Identifier of the PGE	Chain of characters	GEO-CMA
SEV_BANDS	Channels to be used by CMA	Chain of characters	HRV,VIS06,VIS08,NIR13,NIR16,NIR22,R38,WV73,IR87,IR103,IR108,IR120, IR134
INT_PRODUCT	Enables/disables the generation of intermediate products	Chain of characters	NO
CMA_SZSEG	Size of CMA segments (same value for lines and columns)	Integer	6
HRV_NEED	Flag to indicate if HRVIS band is to be used	Chain of characters	TRUE
RTTOV_USE	Flag to indicate if temporal information from previous scenes and products are to be used	Chain of characters	FALSE
RTTOV_USE_COMPUTED_BIAS	Flag defining if biases are to be monitored on line when RTTOV-based tests are used	Chain of characters	FALSE
IS_ALREADY_RECALIBRATED	Flag defining whether satellite data input by the user are already recalibrated using post-launch and GSICS calibration coefficients	Chain of characters	FALSE
NWP_FREQUENCY_PER_DAY	Number of NWP forecast term per day input by user	Integer	4
NWP_ANLYSIS	Flag to allow the use of NWP analysis	Chain of characters	FALSE
NB_OMP_CMA_THREAD	Number of threads used by CMA (if set to negative value, number of threads monitored by environment variable OMP_NUM_THREADS	Integer	-1
NWP_PARAM	Parameter :Temperature at surface level sampling rate : (=segment size CMA_SZSEG) interpolation method.	Chain of characters	NWP_ST 6 BLM
NWP_PARAM	Parameter :Temperature at pressure levels sampling rate : (=segment size CMA_SZSEG) interpolation method.	Chain of characters	NWP_T 6 BLI
NWP_PARAM	Parameter :Total column water vapour sampling rate : (=segment size CMA_SZSEG) interpolation method.	Chain of characters	NWP_TCWV 6 MAX
NWP_PARAM	Parameter :Altitude of the model at surface sampling rate : (=segment size CMA_SZSEG) interpolation method.	Chain of characters	NWP_ALTM 6 BLI
NWP_PARAM	Parameter : Geopotential at surface sampling rate : (=segment size CMA_SZSEG) interpolation method	Chain of characters	NWP_SGEOP 6 BLI

Keyword	Description	Type	Default Value(s)
RTS_PARAM	Parameter : Clear sky TOA radiance sampling rate : (=segment size `CMA_SZSEG`) interpolation method	Chain of characters	RTS_CLEAR 6 BLI
RTS_PARAM	Parameter : Transmittance from surface to TOA sampling rate : (=segment size `CMA_SZSEG`) interpolation method	Chain of characters	RTS_TAUTOTAL 6 BLI
RTS_PARAM	Parameter : Clear sky down-welling radiance sampling rate : (=segment size `CMA_SZSEG`) interpolation method	Chain of characters	RTS_DNCLEAR 6 BLI

Table 6: CMA default Model Configuration File description

2.3.3 Configurable parameters for Cloud Mask (GEO-CMA)

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

- CMA_SZSEG: the size of the segment is configurable (see its definition in section 2.2.1). Its default value is 6. Information on how to change the size of the segment can be found in section 2.2.1.
- NWP_FREQUENCY_PER_DAY: the number of NWP forecast term per day is configurable (see its definition in section 2.2.1). Its default value is 4. Information on how to change this number of NWP can be found in section 2.2.1.
- NWP_ANALYSIS: the flag indicating if NWP analysis fields can be used. Its default value is FALSE. Information on how to change this flag can be found in section 2.2.1.
- IS_ALREADY_RECALIBRATED: the flag, defining whether satellite data input by user are already recalibrated with post-launch calibration coefficients (solar channels) and GSICS IR calibration coefficients, is configurable (see its definition in section 2.2.1). Its default value is FALSE. Information on how to change this value can be found in section 2.2.1.
- RTTOV_USE: the flag defining if RTTOV is to be used on line (to allow a better detection of low or thin clouds) is configurable (see its definition in section 2.2.1). Its default value is FALSE. Information on how to change this value can be found in section 2.2.1.
- RTTOV_USE_COMPUTED_BIAS: the flag defining if biases are to be monitored on line, is configurable (see its definition in section 2.2.1). Its default value is FALSE. Information on how to change this value can be found in section 2.2.1.
- HRVIS_NEED: the flag indicating if hrvis data must be used (to allow enhanced sub-pixel cumulus detection) is configurable (see its definition in section 2.2.1). Its default value is TRUE. Information on how to change this value can be found in section 2.2.1.
- NP_OMP_CMA_THREAD (default value: -1): The CMA is parallelized using openMP standard. If set to a strictly positive integer value, NB_OMP_CMA_THREAD corresponds to the number of threads used by CMA. If NB_OMP_CMA_THREAD is set to a negative value, the number if threads used by CMA will be monitored by the OMP_NUM_THREADS environment variable set at NWCSAF SW level.

2.4 CLOUD MASK (GEO-CMA) VALIDATION

2.4.1 Summary of Cloud Mask (GEO-CMA) validation results

The following table summarises the validation results of the current version for MTG. (see [RD4])

GEO-CMA flags	**Validated accuracy**
GEO-CMA cloud detection If validated over full disk using SYNOP and SHIP observations	POD: 85.9%

Table 7: Summary of validation results of the current CMA version for MTG (POD stands for Probability Of Detection)

2.4.2 Typical known problems and recommendation for use

The following problems may be encountered:

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

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

- the use of the cloud mask quality flag not to compute surface parameters in bad quality cloud free areas
-

The only aim of snow detection by CMA is to limit the confusion with clouds. The users interested in snow cover should rather use H-SAF daily snow products and not the CMA snow category which should be considered as an additional information to help the image interpretation.

2.5 Example of Cloud Mask (GEO-CMA) visualisation

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

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

No example of CMA main categories' 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.

12

1

2

3 CLOUD TYPE (GEO-CT) PRODUCT

3.1 DESCRIPTION OF CLOUD TYPE (GEO-CT) PRODUCT

3.1.1 Goal of Cloud Type (GEO-CT) product

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

The CT product therefore contains information on the major cloud classes: fractional clouds, semi-transparent 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 (the implementation is planned for the next release).

3.1.2 Outline of Cloud Type (GEO-CT) product

The algorithm has been designed to be applicable to imagers on board meteorological geostationary satellites. The imagers may have different set of channels possibly at different horizontal resolutions. The lowest native resolution of the radiometer is chosen as the default resolution, which is for most imagers on board present and future meteorological geostationary satellites the horizontal resolution of all IR channels and some solar channels: 2km for MTG, Himawari-8/9 and GOES-16/17/18/19 satellites and 3km for MSG. Solar channels may be available at higher horizontal resolution such 1km for MTG, Himawari-8/9, GOES-16/17/18/19 and MSG (hrvis only). The visible at 0.6µm is available at very high resolution such 0.5km for MTG, GOES-16/17/18/19 and Himawari-8/9. In this release, the process is applied to all useful channels at the default horizontal resolution (high resolution channels being averaged at this resolution)., We use generic labels in this document (for example, T3.8µm, T8.7µm, T10.8µm, T12.0µm, R0.6µm, R0.8µm and R1.6µm), the exact central wavelengths of the corresponding channels depending on the satellite. The list of available labels depends on the satellite (see Table 3); the list of mandatory channels is listed in 3.3.1

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, 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.

Opaque clouds are first separated from semi-transparent and from fractional (sub-pixel) clouds using brightness temperature differences (T10.8µm-T12.0µm, T8.7µm-T10.8µm or T3.9µm-T10.8µm) together with R0.6µm and R1.38µm (at daytime). Opaque clouds are then separated in very low, low, mid-level, high or very high clouds using their T10.8mm brightness temperatures which are

compared to NWP forecast air temperatures at various pressure levels. Details are available in the algorithm theoretical basis document for cloud products ([RD.3.])

3.1.3 Description of Cloud Type (GEO-CT) output

The content of the CT output (in NetCdF format) is described in the Data Output Format document ([AD.6.]), a summary is given below:

<table>
<tr><th>Container</th><th>Content</th></tr>
<tr><td>GEO-CT</td><td>SAFNWC GEO CT Cloud Type
<table>
<tr><th>Class</th><th>Cloud Type category</th></tr>
<tr><td>1</td><td>Cloud-free land</td></tr>
<tr><td>2</td><td>Cloud-free sea</td></tr>
<tr><td>3</td><td>Snow over land</td></tr>
<tr><td>4</td><td>Sea ice</td></tr>
<tr><td>5</td><td>Very low clouds</td></tr>
<tr><td>6</td><td>Low clouds</td></tr>
<tr><td>7</td><td>Mid-level clouds</td></tr>
<tr><td>8</td><td>High opaque clouds</td></tr>
<tr><td>9</td><td>Very high opaque clouds</td></tr>
<tr><td>10</td><td>Fractional clouds</td></tr>
<tr><td>11</td><td>High semitransparent thin clouds</td></tr>
<tr><td>12</td><td>High semitransparent moderately thick clouds</td></tr>
<tr><td>13</td><td>High semitransparent thick clouds</td></tr>
<tr><td>14</td><td>High semitransparent above low or medium clouds</td></tr>
<tr><td>15</td><td>High semitransparent above snow/ice</td></tr>
<tr><td>FillValue</td><td>No data or corrupted data</td></tr>
</table></td></tr>
<tr><td>GEO-CT
_CUMULIFORM</td><td>SAFNWC GEO CT Stratiform/Cumuliform Cloud Detection
<table>
<tr><th>Class</th><th>Stratiform/Cumuliform Cloud category</th></tr>
<tr><td>1</td><td>Stratiform status</td></tr>
<tr><td>2</td><td>Cumuliform status</td></tr>
<tr><td>3</td><td>Mixed status</td></tr>
<tr><td>4</td><td>Cloud-free</td></tr>
<tr><td>5</td><td>Undefined (separability problem)</td></tr>
<tr><td>FillValue</td><td>No data or corrupted data</td></tr>
</table></td></tr>
<tr><td>GEO-CT
_MULTILAYER</td><td>SAFNWC GEO CT Multilayer Cloud Detection
<table>
<tr><th>Class</th><th>Multilayer Cloud category</th></tr>
<tr><td>0</td><td>No multilayer detected</td></tr>
<tr><td>1</td><td>Multilayer detected</td></tr>
<tr><td>2</td><td>Cloud free</td></tr>
<tr><td>3</td><td>Undefined (separability problem)</td></tr>
<tr><td>FillValue</td><td>No data or corrupted data</td></tr>
</table></td></tr>
<tr><td>GEO-CT
_status_flag</td><td>6 bits indicating (if set to 1)

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

Geophysical Conditions

Field	Type	Description
Space	Flag	Set to 1 for space pixels
Illumination	Parameter	Defines the illumination condition 0: N/A (space pixel) 1: Night

		2: Day 3: Twilight
Sunglint	Flag	Set to 1 if Sunglint
Land_Sea	Parameter	0: N/A (space pixel) 1: Land 2: Sea 3: Coast
Rough_terrain	Flag	Set to 1 if rough (hilly) terrain (differences in surface elevation greater than 300m in boxes of 3x3 pixels)
High_terrain	Flag	Set to 1 if surface elevation >1500m

Processing Conditions

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

Quality

Field	Type	Description
Nodata	Flag	Set to 1 if pixel is NODATA
Internal_consistency	Flag	Set to 1 if an internal consistency check has been performed. Internal consistency checks will be based in the comparison of the retrieved meteorological parameter with physical limits, climatological limits, neighbouring data, NWP data, etc. (not performed)
Temporal_consistency	Flag	Set to 1 if a temporal consistency check has been performed Temporal consistency checks will be based in the comparison of the retrieved meteorological parameters with data obtained in previous slots. (not performed)
Quality	Parameter	Retrieval Quality 0: N/A (no data) 1: Good 2: Questionable 3: Bad 4: Interpolated (not used)

Additionally, the two following scores are available in the header of the NetCdF files:

- The product completeness is the ratio (in %) between the number of processed pixels and the number of "non space" pixels (i.e., the pixels that should be processed).
- The product quality is the ratio (in %) between the number of good quality pixels and the number of "non space pixels (i.e., the pixels that should be processed). The definition of good quality pixel is given in the ATBD.

3.2 IMPLEMENTATION OF CLOUD TYPE (GEO-CT)

CT is extracted by PGE02 (GEO-CT) component of the NWC/GEO software package. Detailed information on how to run this software package is available in the software user manual ([AD.11).

When a new region is defined the user must manually prepare the CT model configuration files for this new region using a default CT model configuration file provided in the NWC/GEO software package (see its content in section 3.3.2).

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

3.2.1 Manual preparation of Cloud Type (GEO-CT) model configuration file for each region

When a new region is defined and added in system and run configuration files, the user must manually prepare the GEO-CT model configuration files by adapting the GEO-CT default model configuration file available in the SAFNWC/GEO software package (see its content in section 3.3.2).

The following parameters are configurable in the default GEO-CT model configuration file:

- CT_SZSEG (default value: 6): the size of the segment. This default value may be manually changed. [Segments are square boxes in the satellite projection, whose size is expressed as the number of default horizontal resolution pixels (2km for MTG) of one edge of the square box. The size of the processed regions must be a multiple of the segment size. All the solar and satellite angles, the NWP model forecast values, the atlas values and the thresholds will be derived over all the processed regions at the horizontal resolution of the segment. Note also that the land/sea atlas will be available at the full default horizontal resolution, allowing the identification of the surface type (land or sea) of all pixels, whatever the segment size. The quality is not very much dependent on the segment size (if lower than 6). Decreasing the segment size will increase the execution time]. Note that sampling rate of NWP_PARAM and RTS_PARAM (see 2.3.2) should be modified accordingly.
- NWP_ANALYSIS: the flag indicating if NWP analysis fields can be used. Its default value is FALSE. This flag has been made configurable to allow users to provide NWP analysis, in case of reprocessing activities. When it is set to TRUE, NWP fields with forecast time 00 are used by the PGE if they are available

- NP_OMP_CT_THREAD (default value: -1): The CT is parallelized using openMP standard. If set to a strictly positive integer value, NB_OMP_CT_THREAD corresponds to the number of threads used by CT. If NB_OMP_CT_THREAD is set to a negative value, the number if

threads used by CT will be monitored by the OMP_NUM_THREADS environment variable set at NWCSAF SW level.

3.2.2 The Cloud Type (GEO-CT) execution step

The GEO-CT execution step consists in the launch of the command: GEO-CT by the Task Manager with the required parameters: time of slot, region and configuration file name.

The following command is used to process GEO-CT manually, without the presence of the TM:

```
% GEO-CT-v<vers> <time_of_slot> <region_configuration_file>
                  <CT model_configuration_file>
   3.2.2.1 Example
```

```
%GEO-CT-v50 20211029T120000Z global.cfg safnwc_CT.cfm
```

This command executes GEO-CT version 5.0 over the region `global.cfg` manually, without the presence of the TM

3.3 INPUT AND CONFIGURABLE PARAMETERS FOR CLOUD TYPE (GEO-CT)

3.3.1 List of inputs for Cloud Type (GEO-CT)

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

- **Satellite imagery:**

The following bi-directional reflectances or brightness temperatures are needed at default horizontal resolution (2km at nadir for MTG):

R0.6µm	R1.38µm	T3.8µm	T7.3µm	T8.7µm	T10.4µm	T10.8µm	T12.0µm
Mandatory	Optional	Mandatory	Optional	Optional	Optional	Mandatory	Mandatory

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

The channels are input by the user,and extracted on the processed region by NWC/GEO software package.

- **CMA cloud categories**

The CMA cloud categories are mandatory. They are computed by the CMA software. (see section 2.)

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

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

- **NWP parameters:**

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

  - surface temperature

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

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

In case of reprocessing activities, NWP analysis can be used. To be remapped the NWP_ANALYSIS flag has to be set to YES in the nwp_conf_file.

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. The pressure, height and temperature of the tropopause is extracted from a vertical NWP profile, the ground height and the latitude. This tropopause estimation is based on the WMO definition of the tropopause. The quality of CT is lower if some NWP fields are missing.

- **Ancillary data sets:**

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

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

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

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

3.3.2 CT Model Configuration File

The CT model configuration file contains all the coefficients and constants required for the derivation of the GEO-CT product. The model configuration file must be placed in the $SAFNWC/config directory. The file contains the following information:

Keyword	Description	Type	Default Value(s)
PGE_ID	Identifier of the PGE	Chain of characters	GEO-CT
SEV_BANDS	Channels to be used by CT	Chain of characters	VIS06,NIR13,IR38,WV73,IR87,IR103 ,IR108,IR120
INT_PRODUCT	Enables/disables the generation of intermediate products	Chain of characters	NO
CT_SZSEG	Size of CT segments expressed in SEVIRI coordinates (same value for lines and columns)	Integer	6

Keyword	Description	Type	Default Value(s)
NB_OMP_CT_THREAD	Number of threads used by CT (if set to negative value, number of threads monitored by environment variable OMP_NUM_THREADS	Integer	-1
NWP_ANLYSIS	Flag to allow the use of NWP analysis	Chain of characters	FALSE
STSC_APPLIED	Enables the separation stratiform/cumuliform. Not available in this SW version..	Chain of characters	FALSE
NWP_PARAM	Parameter :Temperature at surface level sampling rate : (=segment size CT_SZSEG) interpolation method.	Chain of characters	NWP_ST 6 BLM
NWP_PARAM	Parameter :Temperature at pressure levels sampling rate : (=segment size CT_SZSEG) interpolation method.	Chain of characters	NWP_T 46 BLI
NWP_PARAM	Parameter :Temperature at tropopause level sampling rate : (=segment size CT_SZSEG) interpolation method.	Chain of characters	NWP_TT 6 BLI
NWP_PARAM	Parameter :Total column water vapour sampling rate : (=segment size CT_SZSEG) interpolation method.	Chain of characters	NWP_TCWV 6 MAX
NWP_PARAM	Parameter :Altitude of the model at surface sampling rate : (=segment size CT_SZSEG) interpolation method.	Chain of characters	NWP_ALTM 6 BLI
NWP_PARAM	Parameter : Geopotential at surface sampling rate : (=segment size CT_SZSEG) interpolation method	Chain of characters	NWP_SGEOP 6 BLI

Table 8: CT default Model Configuration File description

3.3.3 Configurable parameters for Cloud Type (GEO-CT)

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

- CT_SZSEG: the size of the segment is configurable (see its definition in section 3.2.1). Its default value is 6. Information on how to change the size of the segment can be found in section 3.2.1).
- NWP_ANALYSIS: the flag indicating if NWP analysis fields can be used. Its default value is FALSE. Information on how to change this flag can be found in section 2.2.1.

- NP_OMP_CT_THREAD (default value: -1): The CT is parallelized using openMP standard. If set to a strictly positive integer value, NB_OMP_CT_THREAD corresponds to the number of threads used by CT. If NB_OMP_CT_THREAD is set to a negative value, the number if threads used by CT will be monitored by the OMP_NUM_THREADS environment variable set at NWCSAF SW level.

3.4 CLOUD TYPE (GEO-CT) VALIDATION

3.4.1 Summary of Cloud Type (GEO-CT) validation

The following table summarises the validation results of the current version for the CT cloud type for MSG.

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

Table 9

Cloud classifications processed with MTG-I1 data and cloud classifications processed with MSG3 data were compared. In all conditions, and taking as references Cloud Type from MSG3, the Cloud Type from MTG-I1 reaches the Optimal accuracy (90%) for the opaque high clouds and for the low clouds. It reaches the threshold accuracy (50%) and sometime the target accuracy (70%) for the semi-transparent clouds. For more details, see the validation report ([RD 4])

3.4.2 Typical known problems and recommendation for use

The following problems may be encountered (for wrong cloud detection, please refer to paragraph 2.4.2):

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

As already stated in 2.4.2, the users interested in snow cover should rather use H-SAF daily snow products and not the CT snow category which should be considered as an additional information to help the image interpretation.

3.5 Example of Cloud Type (GEO-CT) visualisation

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

Colour palettes are included in CT NetCdF files, thus allowing an easy visualisation of CT cloud type categories as illustrated on Figure 3.

The user may be interested in visualising all the available classes as displayed on a SEVIRI example in Figure 3, 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).

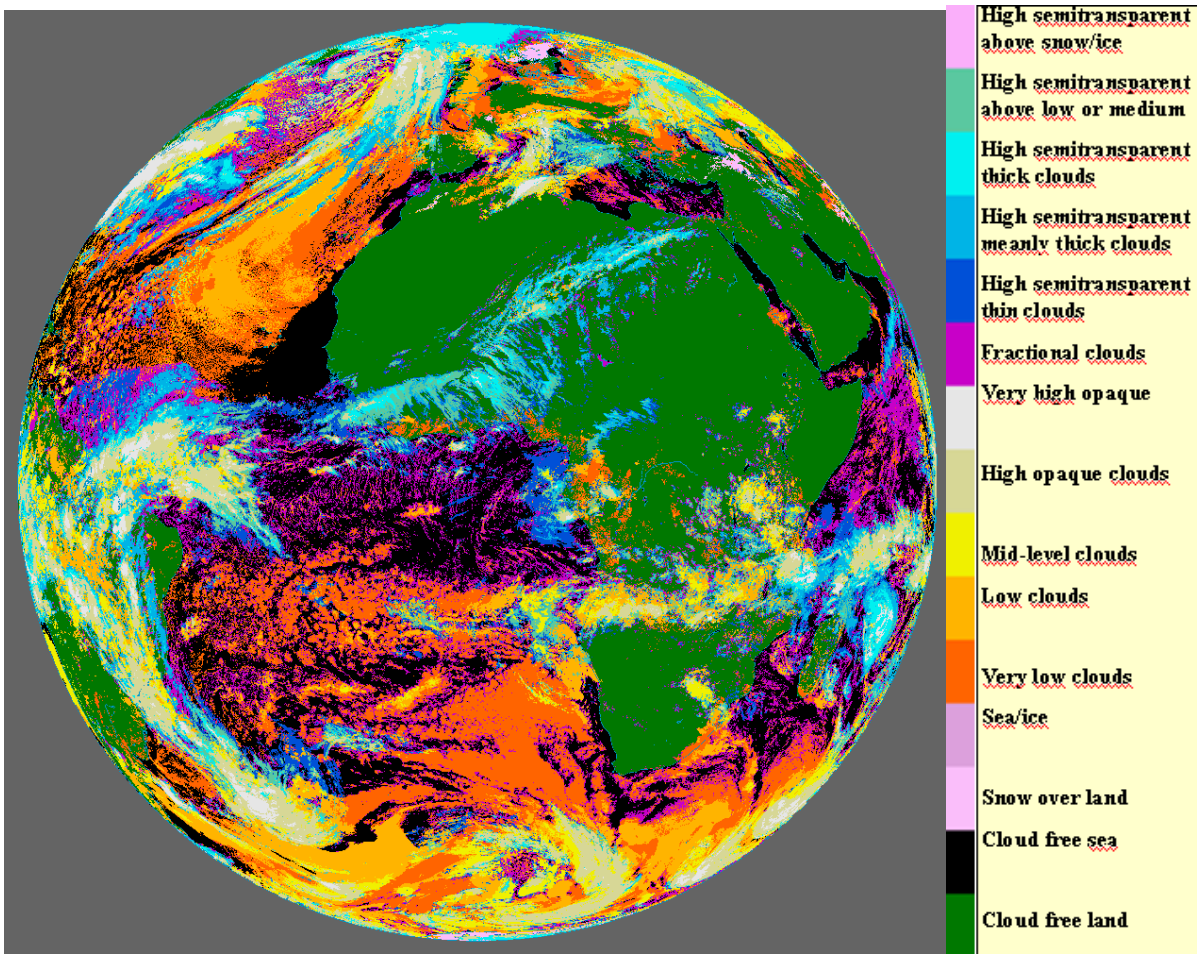

Figure 3: Example of MTG CT cloud type using the colour palette included in CT NetCdF files.

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

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

4.1.1 Goal of Cloud Top Temperature and Height (GEO-CTTH) product

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

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

4.1.2 Outline of Cloud Top Temperature and Height (GEO-CTTH) algorithm

The algorithm has been designed to be applicable to imagers on board meteorological geostationary satellites. The imagers may have different set of channels possibly at different horizontal resolutions. The lowest native resolution of the radiometer is chosen as default resolution, which is for most imagers on board present and future meteorological geostationary satellites the horizontal resolution of all IR channels and some solar channels: 2km for MTG, Himawari-8/9 and GOES-16/17 satellites and 3km for MSG. Solar channels may be available at higher horizontal resolution such 1km for MTG, Himawari-8/9, GOES-16/17 and MSG (HRVIS only). And the visible at 0.6µm is available at very high resolution such 0.5km for MTG, GOES-16/17 and Himawari-8/9. In this release, the process is applied to all useful channels at the default horizontal resolution (high resolution channels being averaged at this resolution), the high resolution channels being additionally used at their native resolution to detect sub-pixels clouds inside pixels at default horizontal resolution We use generic labels in this document (for example, Rad6.2µm, Rad7.3µm, Rad13.4µm, T10.8µm, T12.0µm (Rad and T stand for radiance and brightness temperatures)), the exact central wavelengths of the corresponding channels depending on the satellite (see table 3). The list of available labels depends on the satellite; the used and mandatory channels are listed in 4.3.1.

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.

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

If all mandatory NWP and satellite 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 cloud free and overcast (clouds successively on each vertical pressure

levels) radiances and brightness temperatures for window channels (10.8µm, and 12.0µm) and sounding channels (6.2µm, 7.3µm, 13.4µm for MSG/SEVIRI). This process is performed in each segment of the image (the size of the segment is defined by the user, the default value being 4*4 pixels). The vertical profiles used are temporally interpolated to the exact slot time using the two nearest in time NWP fields input by the user.

- The techniques used to retrieve the cloud top pressure depend on the cloud's type (as available in CT product):
    - For very low, low or medium thick clouds: The cloud top pressure is retrieved on a pixel basis and corresponds to the best fit between the simulated and the measured 10.8µm brightness temperatures. The simulated brightness temperatures are available at the segment resolution. In case of the presence of a low level thermal inversion in the forecast NWP fields, the very low, low or medium clouds are assumed to be above the thermal inversion only if their brightness temperatures are colder than the air temperature below the thermal inversion minus an offset whose value depends on the nature of thermal inversion (dry air above the inversion level or not).
    - For high thick clouds: a method called the radiance ratioing method (see the next bullet for further explanation of this method) is first applied to remove any remaining semi-transparency that could have been undetected by the cloud type scheme. In case of failure, the method defined for medium opaque clouds is then applied.
    - For high semi-transparent clouds: The 10.8µm infrared brightness temperatures are contaminated by the underlying surfaces and cannot be used as for opaque clouds. A correction of semi-transparency is applied, which requires the use of two infrared channels: the 10.8µm window channel and a sounding (6.2µm, 7.3µm, 13.4µm for MSG) channel. The basis is that clouds have a stronger impact in a window channel than in a sounding channel. The following process is implemented:
        - The H_2O/IRW intercept method, based on a window (10.8µm) and sounding (13.4µm, 7.3µm or 6.2µm for MSG) radiance bi-dimensional histogram analysis, is first applied. The histograms are built in boxes of 32*32 pixels centred on each segment of the image (whose size is defined by the user, the default value being 4*4 pixels). It therefore allows the retrieval of cloud top pressure at the segment horizontal resolution (i.e., by default 4*4 pixels). This method is successively applied using the radiances of sounding channels (7.3µm, 6.2µm and 13.4µm for MSG), the final retrieved cloud pressure being the minimum cloud top pressures obtained using single sounding channel.
        - If no result can be obtained with the H_2O/IRW intercept method, the radiance ratioing method is then applied at a pixel basis to retrieve the cloud top pressure from the radiances of two channels: a window channel (10.8µm) and a sounding channel (for MSG, successively 7.3µm, 6.2µm and 13.4µm).
        - If the radiance ratioing technique leads to cloud top temperatures warmer than the corresponding 10.8µm brightness temperatures, the method for thick clouds is used instead.
    - For fractional clouds: No technique is proposed in the current version for low broken clouds. The sounding channels are nearly unaffected by broken low clouds and are therefore useless; the infrared channels at 10.8µm and 12.0µm are contaminated by the surface and cannot therefore be used as for opaque clouds.

- A gap-filling procedure is applied in semi-transparent cloud top pressure field: in each box of 32x32 pixels, a cloud top pressure is computed as the average pressure of all pixels containing semi-transparent clouds inside the current and the eight surrounding boxes. This average cloud top pressure is then assigned to all pixels of the current box containing semi-transparent clouds and having no retrieved cloud top pressure.
- Cloud top temperature and altitude (above sea level) are then computed from their pressure using general modules. During these processes, the atmospheric vertical profiles are temporally interpolated to the exact slot time using the two nearest in time NWP outputs fields.
- Effective cloudiness (defined as the fraction of the field of view covered by cloud (the cloud amount) multiplied by the cloud emissivity in the 10.8µm window channel) is also computed during the processing. It is equal to 1.0 for thick clouds and takes a value between 0. and 1. for semi-transparent clouds.

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

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

Details are available in the algorithm theoretical basis document for cloud products ([RD.3.])

4.1.3 Description of Cloud Top Temperature and Height (GEO-CTTH) output

The content of the CTTH output (in NetCdF format) is described in the Data Output Format document ([AD.6.]), a summary is given below:

Container	Content
GEO-CTTH _PRES	SAFNWC GEO CTTH Cloud Top Pressure GEO-CTTH_PRES(Pa) = scale_factor * Counts + add_offset where: scale_factor = 10.0 add_offset = 0.0
GEO-CTTH _ALTI	SAFNWC GEO CTTH Cloud Top Altitude GEO-CTTH_ALTI(m) = scale_factor * Counts + add_offset where: scale_factor = 1.0 add_offset = -2000.0
GEO-CTTH _TEMPE	SAFNWC GEO CTTH Cloud Top Temperature GEO-CTTH_TEMPE(K) = scale_factor * Counts + add_offset where: scale_factor = 0.01 add_offset = 130.0
GEO-CTTH_HFEET	SAFNWC GEO CTTH Cloud Top in hecto feet GEO-CTTH_EFFECTIV = scale_factor * Counts + add_offset where: scale_factor = 1.0 add_offset = -40.0
GEO-CTTH _EFFECTIV	SAFNWC GEO CTTH Cloud Effective Cloudiness GEO-CTTH_EFFECTIV = scale_factor * Counts + add_offset where: scale_factor = 0.01 add_offset = 0.0

Container	Content
GEO-CTTH _METHOD	14 bits indicating (if set to 1) Bit 0: Cloud-free Bit 1: No relieable method Bit 2: Opaque cloud, RTTOV not available Bit 3: Opaque cloud, using RTTOV Bit 4: Opaque cloud, using RTTOV, in case thermal inversion Bit 5: Intercept method 10.8µm/13.4µm Bit 6: Intercept method 10.8µm/6.2µm Bit 7: Intercept method 10.8µm/7.0µm Bit 8: Intercept method 10.8µm/7.3µm Bit 9: Radiance ratioing method 10.8µm/13.4µm Bit 10: Radiance ratioing method 10.8µm/6.2µm Bit 11: Radiance ratioing method 10.8µ7.0µm Bit 12: Radiance ratioing method 10.8µm/7.3µm Bit 13: Spatial smoothing (gap filling in semi-transparent cloud field)
GEO-CTTH _status_flag	6 bits indicating (if set to 1) Bit 0: Cloud-free Bit 1: Low level thermal inversion in NWP field Bit 2: Opaque clouds Bit 3: Fractional clouds : no retrieval method Bit 4: Too thin clouds : no retrieval method Bit 5: Multilayer suspected

Geophysical Conditions

Field	Type	Description
Space	Flag	Set to 1 for space pixels
Illumination	Parameter	Defines the illumination condition 0: N/A (space pixel) 1: Night 2: Day 3: Twilight
Sunglint	Flag	Set to 1 if Sunglint
Land_Sea	Parameter	0: N/A (space pixel) 1: Land 2: Sea 3: Coast
Rough_terrain	Flag	Set to 1 if rough (hilly) terrain (differences in surface elevation greater than 300m in boxes of 3x3 pixels)
High_terrain	Flag	Set to 1 if surface elevation > 1500m

Processing Conditions

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

		3: At least one mandatory Auxiliary field is missing

Quality

Field	Type	Description
Nodata	Flag	Set to 1 if pixel is NODATA
Internal_consistency	Flag	Set to 1 if an internal consistency check has been performed. Internal consistency checks will be based in the comparison of the retrieved meteorological parameter with physical limits, climatological limits, neighbouring data, NWP data, etc. (Not performed)
Temporal_consistency	Flag	Set to 1 if a temporal consistency check has been performed Temporal consistency checks will be based in the comparison of the retrieved meteorological parameters with data obtained in previous slots. (Not performed)
Quality	Parameter	Retrieval Quality 0: N/A (no data) 1: Good 2: Questionable 3: Bad 4: Interpolated (not used)

Additionally, the two following scores are available in the header of the NetCdF files:

- The product completeness is the ratio (in %) between the number of processed pixels and the number of "non space" pixels (i.e., the pixels that should be processed).
- The product quality is the ratio (in %) between the number of good quality pixels and the number of "non space pixels (i.e., the pixels that should be processed). The definition of good quality pixel is given in the ATBD.

4.2 IMPLEMENTATION OF CLOUD TOP TEMPERATURE AND HEIGHT (GEO-CTTH)

CTTH is extracted by PGE03 (GEO-CTTH) component of the NWC/GEO software package. Detailed information on how to run this software package is available in the software user manual (AD.11).

When a new region is defined the user must manually prepare the CTTH model configuration files for this new region using a default CTTH model configuration file provided in the NWC/GEO software package (see its content in section 4.3.2).

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

4.2.1 Manual preparation of Cloud Top Temperature and Height (CTTH) model configuration file for each region

When a new region is defined and added in system and run configuration files, the user must manually prepares the GEO-CTTH model configuration files by adapting the GEO-CTTH default model configuration file available in the SAFNWC/GEO software package (see its content in section 4.3.2).

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

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

become very time consuming as RTTOV is launched every segment.]. Note that sampling rate of NWP_PARAM and RTS_PARAM (see 2.3.2) should be modified accordingly.

- RTTOV_USE_COMPUTED_BIAS (default value: FALSE): a flag defining if biases are to be monitored online [This key should be set to TRUE in case RTTOV bias files are not available for the NWP model used by the user (AEMET provides bias files for ECMWF only). But there are some constraints to create those bias files (see [RD.3]).
- OUTPUT_FLIGHT_LEVEL (default value: FALSE) : If the user chooses TRUE, in addition the variable ctth_hfeet which gives cloud top height in hecto feet, will be included in the CTTH cloud products output file. It uses a function from the NWCLIB to convert cloud top height in pressure in feet. In order to retrieve the cloud top in flight level, one must take the round of the ctth_hfeet divided by 5.
- NWP_ANALYSIS: the flag indicating if NWP analysis fields can be used. Its default value is FALSE. This flag has been made configurable to allow users to provide NWP analysis, in case of reprocessing activities. When it is set to TRUE, NWP fields with forecast time 00 are used by the PGE if they are available
- NP_OMP_CTTH_THREAD (default value: -1): The CTTH is parallelized using openMP standard. If set to a strictly positive integer value, NB_OMP_CTTH_THREAD corresponds to the number of threads used by CTTH. If NB_OMP_CTTH_THREAD is set to a negative value, the number if threads used by CTTH will be monitored by the OMP_NUM_THREADS environment variable set at NWCSAF SW level.

4.2.2 The Cloud Top Temperature and Height (GEO-CTTH) execution step

The GEO-CTTH execution step consists in the launch of the command: GEO-CTTH by the Task manager with the required parameters: time of slot, region and configuration file name.

The following command is used to process GEO-CTTH manually, without the presence of the TM:

```
% GEO-CTTH-v<vers> <time_of_slot> <region_configuration_file>
                   <CTTH model_configuration_file>
```

4.2.2.1 Example

```
%GEO-CTTH-v41 20211029T120000Z global.cfg safnwc_CTTH.cfm
```

This command executes GEO-CTTH version 4.1 over the region `global.cfg` manually, without the presence of the TM

4.3 Inputs and configurable parameters for Cloud Top Temperature and Height (GEO-CTTH)

4.3.1 List of inputs for Cloud Top Temperature and Height (GEO-CTTH)

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

- **Satellite imagery:**

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

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

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

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

- **CMA and CT cloud categories**

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

- **Satellite angles associated to satellite imagery**

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

- **NWP parameters:**

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

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

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

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

In case of reprocessing activities, NWP analysis can be used. To be remapped the NWP_ANALYSIS flag must be set to YES in the nwp_conf_file.

- **RTTOV simulations:**

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

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

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

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

- **OSTIA fields:**

The following parameters are used as input:

- OSTIA SST

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

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

- **RTTOV bias files:**

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

These files are not mandatory. If not available, the bias can be computed by GEO-CTTH (the processed region needs to contain large enough area covered by oceanic surfaces (see [RD.3]). If this computation is not possible, the GEO-CTTH uses IR RTTOV simulation without bias correction).

- **Ancillary data sets:**

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

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

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

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

4.3.2 CTTH Model Configuration File

The CTTH model configuration file contains all the coefficients and constants required for the derivation of the GEO-CTTH product. The model configuration file must be placed in the $SAFNWC/config directory. The file contains the following information:

Keyword	Description	Type	Default Value(s)
PGE_ID	Identifier of the PGE	Chain of characters	GEO-CTTH
SEV_BANDS	SEVIRI channels to be used by CTTH	Chain of characters	WV62,WV70,WV73,IR108,IR120, IR134
INT_PRODUCT	Enables/disables the generation of intermediate products	Chain of characters	NO
CTTH_SZSEG	Size of CTTH segments expressed in SEVIRI coordinates (same value for lines and columns)	Integer	4
RTTOV_USE_COMPUTED_BIAS	Flag defining if biases are to be monitored on line	Chain of characters	FALSE
IS_ALREADY_RECALIBRATED	Flag defining whether satellite data input by the user are already recalibrated using post-launch and GSICS calibration coefficients (not configurable in current version)	Chain of characters	FALSE
NB_OMP_CTTH_THREAD	Number of threads used by CTTH (if set to negative value, number of threads monitored by environment variable OMP_NUM_THREADS	Integer	-1
OUTPUT_FLIGHT_LEVEL	Flag to compute the Cloud Top Height in hectofeet	Chain of characters	FALSE
NWP_ANLYSIS	Flag to allow the use of NWP analysis	Chain of characters	FALSE
NWP_PARAM	Parameter :Temperature at surface level sampling rate : (=segment size CTTH_SZSEG) interpolation method.	Chain of characters	NWP_ST 4 BLM
NWP_PARAM	Parameter :Temperature at surface level sampling rate : (=segment size CTTH_SZSEG) interpolation method.	Chain of characters	NWP_ST 4 BLI
NWP_PARAM	Parameter :Pressure at surface level sampling rate : (=segment size CTTH_SZSEG) interpolation method.	Chain of characters	NWP_SP 4 BLI
NWP_PARAM	Parameter :temperature at 2m sampling rate : (=segment size CTTH_SZSEG) interpolation method.	Chain of characters	NWP_2T 4 BLI
NWP_PARAM	Parameter :relative humidity at 2m sampling rate : (=segment size CTTH_SZSEG) interpolation method.	Chain of characters	NWP_2RH 4 BLI
NWP_PARAM	Parameter :Temperature at pressure levels sampling rate : (=segment size CTTH_SZSEG) interpolation method.	Chain of characters	NWP_T 4 BLI
NWP_PARAM	Parameter :relative humidity at pressure levels sampling rate : (=segment size CTTH_SZSEG) interpolation method.	Chain of characters	NWP_RH 4 BLI
NWP_PARAM	Parameter :geopotential at pressure levels sampling rate : (=segment size CTTH_SZSEG) interpolation method.	Chain of characters	NWP_GEOP 4 BLI
NWP_PARAM	Parameter :Temperature at tropopause level sampling rate : (=segment size CTTH_SZSEG) interpolation method.	Chain of characters	NWP_TT 4 BLI
NWP_PARAM	Parameter :Pressure at tropopause level sampling rate : (=segment size CTTH_SZSEG) interpolation method.	Chain of characters	NWP_TP 4 BLI
NWP_PARAM	Parameter :Height at tropopause level sampling rate : (=segment size CTTH_SZSEG) interpolation method.	Chain of characters	NWP_TH 4 BLI
NWP_PARAM	Parameter :Altitude of the model at surface sampling rate : (=segment size CTTH_SZSEG) interpolation method.	Chain of characters	NWP_ALTM 4 BLI
NWP_PARAM	Parameter : Geopotential at surface sampling rate : (=segment size CTTH_SZSEG) interpolation method	Chain of characters	NWP_SGEOP 4 BLI
RTS_PARAM	Parameter : Clear sky TOA radiance sampling rate : (=segment size CTTH_SZSEG) interpolation method	Chain of characters	RTS_CLEAR 4 BLI

Keyword	Description	Type	Default Value(s)
RTS_PARAM	Parameter : Transmittance from surface to TOA sampling rate : (=segment size CTTH_SZSEG) interpolation method	Chain of characters	RTS_TAUTOTAL 4 BLI
RTS_PARAM	Parameter : Clear sky down-welling radiance sampling rate : (=segment size CTTH_SZSEG) interpolation method	Chain of characters	RTS_DNCLEAR 4 BLI
RTS_PARAM	Parameter : TOA radiance for given cloud top pressure and fraction sampling rate : (=segment size CTTH_SZSEG) interpolation method	Chain of characters	RTS_TOTAL 4 BLI
RTS_PARAM	Parameter : Level to space overcast radiance given black cloud for each layer sampling rate : (=segment size CTTH_SZSEG) interpolation method	Chain of characters	RTS_OVERCAST 4 BLI

Table 10: CTTH default Model Configuration File description

4.3.3 Configurable parameters for Cloud Top Temperature and Height (GEO-CTTH)

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

- CTTH_SZSEG: the size of the segment is configurable (see its definition in 4.3.1). Its default value is 4. Information on how to change the size of the segment can be found in section 4.2.1.
- RTTOV_USE_COMPUTED_BIAS: the flag defining if biases are to be monitored on line, is configurable (see its definition in section 4.2.1). Its default value is FALSE. Information on how to change this value can be found in section 4.2.1.
- NWP_ANALYSIS: the flag indicating if NWP analysis fields can be used. Its default value is FALSE. . Information on how to change this flag can be found in section 2.2.1
- NP_OMP_CTTH_THREAD (default value: -1): The CTTH is parallelized using openMP standard. If set to a strictly positive integer value, NB_OMP_CTTH_THREAD corresponds to the number of threads used by CTTH. If NB_OMP_CTTH_THREAD is set to a negative value, the number if threads used by CTTH will be monitored by the OMP_NUM_THREADS environment variable set at NWCSAF SW level.
- OUTPUT_FLIGHT_LEVEL (default value: FALSE) : If the user chooses TRUE, in addition the variable ctth_hfeet which give cloud top height in hecto feet, will be included in the CTTH cloud products output file. It uses a function from the NWCLIB to convert cloud top height in pressure in feet. In order to retrieve the cloud top in flight level, one must take the round of the ctth_hfeet divided by 5.

4.4 CLOUD TOP TEMPERATURE AND HEIGHT (GEO-CTTH) VALIDATION

4.4.1 Summary of Cloud Top Temperature and Height (GEO-CTTH) validation results

The following table summarises the validation results of the current version for CTTH for MSG.

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

Table 11: Summary of validation results of the current CTTH version for MSG (std stands for standard deviation)

4.4.2 Typical known problems and recommendation for use

The following main problems may be encountered:

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

4.5 EXAMPLE OF CLOUD TOP TEMPERATURE AND HEIGHT (CTTH) VISUALISATION

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

Colour palettes are included in CTTH NetCdF files, thus allowing an easy visualisation of cloud top pressure (as illustrated with the SEVIRI example on Figure 4), 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.

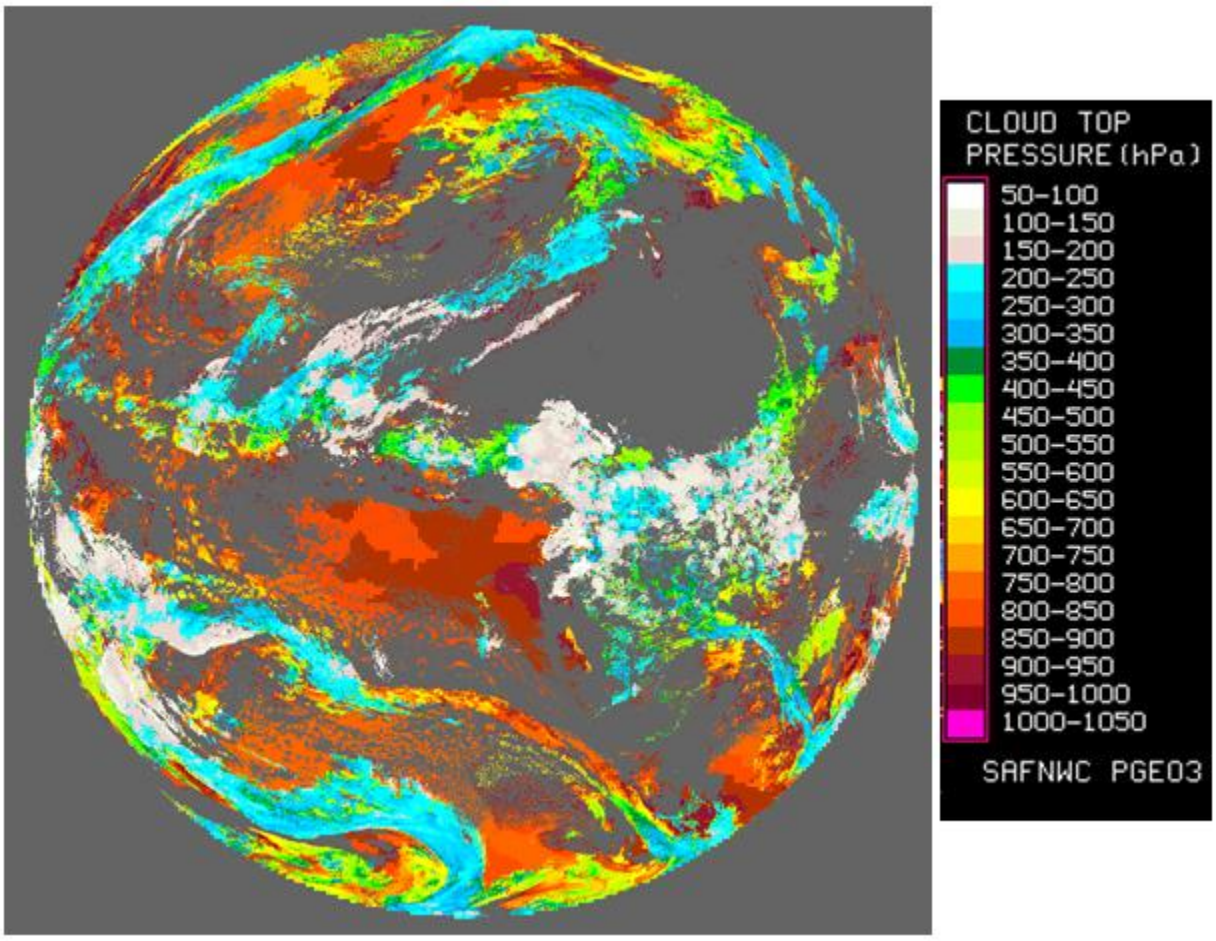

Figure 4: Example of SEVIRI CTTH cloud top pressure

5 CLOUD MICROPHYSICS (GEO-CMIC) PRODUCT

5.1 DESCRIPTION OF CLOUD MICROPHYSICS (GEO-CMIC) PRODUCT

5.1.1 Goal of Cloud Microphysics product

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

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

5.1.2 Outline of Cloud Microphysics (GEO-CMIC) algorithm

The CMIC retrieval algorithm first retrieves the thermodynamical phase through an empirical use of T8.7µm-T10.8µm, T10.8µm and the CT cloud type itself complemented (only during daytime) by a combined analysis of the measured and simulated 0.6µm, 1.6µm and 2.25µm reflectances. The additional microphysics parameters are obtained only in daytime conditions through the comparison of measured and simulated 0.6µm and 1.6µm reflectances.

The algorithm has been designed to be applicable to imagers on board meteorological geostationary satellites. The imagers may have different set of channels possibly at different horizontal resolutions. The lowest native resolution of the radiometer is chosen as the default resolution, which is for most imagers on board present and future meteorological geostationary satellites the horizontal resolution of all IR channels and some solar channels: 2km for MTG, Himawari-8/9 and GOES-16/17 satellites and 3km for MSG. Solar channels may be available at higher horizontal resolution such 1km for MTG, Himawari-8/9, GOES-16/17 and MSG (HRVIS only). And the visible at 0.6µm is available at very high resolution such 0.5km for MTG, GOES-16/17 and Himawari-8/9. In this release, the process is applied to all useful channels at the default horizontal resolution (high resolution channels being averaged at this resolution), the high-resolution channels being additionally used at their native resolution to detect sub-pixels clouds inside pixels at default horizontal resolution. We use generic labels in this document (for example, T3.8µm, T8.7µm, T10.8µm, T12.0µm, R0.6µm, R0.8µm and R1.6µm), the exact central wavelengths of the corresponding channels depending on the satellite. The list of available labels depends on the satellite (see Table 3); the list of mandatory channels is listed in 5.3.1.

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

- Warm (respectively cold) opaque clouds are supposed to be constituted of water (respectively ice) particles, whereas the temperature range between 0°C and –40°C may correspond to both (or a mixture) of water or ice clouds.

- Cloud classified as semi-transparent in CT cloud type are supposed be constituted of ice particles. Cloud classified as fractional may correspond to thin cirrus or sub-pixel low clouds; their retrieved cloud phase is therefore set “undefined”.
- Water clouds usually have low T8.7µm-T10.8µm and ice clouds rather high values. Simple viewing angle-dependant thresholds subjectively defined from MTG/FCI observations are applied to identify obviously water or ice clouds.
- If the cloud top phase is still not determined, the comparison of observed and simulated 0.6µm ,1.6µm and 2.25 µm reflectances for cloudy pixels may allow retrieving the cloud top phase (but ambiguous situations may still exist).

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

Details are available in the algorithm theoretical basis document for cloud products ([RD.3])

5.1.3 Description of Cloud Microphysics (GEO-CMIC) output

The content of the CMIC output (in NetCdF format) is described in the Data Output Format document ([AD.6.]), a summary is given below:

<table>
<tr><th>Container</th><th>Content</th></tr>
<tr><td>GEO-CMIC
_PHASE</td><td>SAFNWC GEO CMIC Cloud Top Phase
<table><tr><th>Class</th><th>Cloud Top Phase category</th></tr><tr><td>1</td><td>Liquid</td></tr><tr><td>2</td><td>Ice</td></tr><tr><td>3</td><td>Mixed</td></tr><tr><td>4</td><td>Cloud-free</td></tr><tr><td>5</td><td>Undefined (separability problem)</td></tr><tr><td>FillValue</td><td>No data or corrupted data</td></tr></table></td></tr>
<tr><td>GEO-CMIC
_REFF</td><td>SAFNWC GEO CMIC Cloud Drop Effective Radius

GEO-CMIC_REFF(m) = scale_factor * Counts + add_offset
where:
scale_factor = 10^{-8}
add_offset = 0.0</td></tr>
<tr><td>GEO-CMIC
_COT</td><td>SAFNWC GEO CMIC Cloud Optical Thickness

GEO-CMIC_COT = scale_factor * Counts + add_offset
where:
scale_factor = 0.01
add_offset = 0.0</td></tr>
<tr><td>GEO-CMIC
_LWP</td><td>SAFNWC GEO CMIC Cloud Liquid Water Path

GEO-CMIC_LWP($kg.m^{-2}$) = scale_factor * Counts + add_offset
where:
scale_factor = 0.001
add_offset = 0.0</td></tr>
<tr><td>GEO-CMIC
_IWP</td><td>SAFNWC GEO CMIC Cloud Ice Water Path

GEO-CMIC_IWP($kg.m^{-2}$) = scale_factor * Counts + add_offset
where:
scale_factor = 0.001
add_offset = 0.0</td></tr>
</table>

Container	Content
GEO-CMIC _status_flag	11 bits indicating (if set to 1) Bit 0: Cloud-free Bit 1: High resolution satellite data used Bit 2: Combined use of 1.6µm & 2.2µm for phase retrieval Bit 3: No retrieved phase: no reliable Reff/Cot retrieval Bit 4: Mixed phase: no reliable Reff/Cot retrieval Bit 5: Measurement incoherent with simulation: no reliable Reff/Cot retrieval Bit 6: Too much overlap in simulation: no reliable Reff/Cot retrieval Bit 7: 1.6µm used for reff/cot retrieval Bit 8: 2.2µm used for reff/cot retrieval Bit 9: 3.8µm used for reff/cot retrieval Bit 10: Multilayer cloud suspected

Geophysical Conditions

Field	Type	Description
Space	Flag	Set to 1 for space pixels
Illumination	Parameter	Defines the illumination condition 0: N/A (space pixel) 1: Night 2: Day 3: Twilight
Sunglint	Flag	Set to 1 if Sunglint
Land_Sea	Parameter	0: N/A (space pixel) 1: Land 2: Sea 3: Coast
Rough_terrain	Flag	Set to 1 if rough (hilly) terrain (differences in surface elevation greater than 300m in boxes of 3x3 pixels)
High_terrain	Flag	Set to 1 if surface elevation > 1500m

Processing Conditions

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

Quality

Field	Type	Description
Nodata	Flag	Set to 1 if pixel is NODATA
Internal_consistency	Flag	Set to 1 if an internal consistency check has been performed. Internal consistency checks will be based in the comparison of the retrieved meteorological parameter with physical limits, climatological limits, neighbouring data, NWP data, etc. (Not performed)
Temporal_consistency	Flag	Set to 1 if a temporal consistency check has been performed Temporal consistency checks will be based in the comparison of the retrieved meteorological parameters with data obtained in previous slots. (Not performed)

Quality	Parameter	Retrieval Quality 0: N/A (no data) 1: Good 2: Questionable 3: Bad 4: Interpolated (not used)

Additionally, the two following scores are available in the header of the NetCdF files:

- The product completeness is the ratio (in %) between the number of processed pixels and the number of "non space" pixels (i.e., the pixels that should be processed).
- The product quality is the ratio (in %) between the number of good quality pixels and the number of "non space pixels (i.e., the pixels that should be processed). The definition of good quality pixel is given in the ATBD.

5.2 IMPLEMENTATION OF CLOUD MICROPHYSICS (GEO-CMIC)

CMIC is extracted by PGE15 (GEO-CMIC) component of the NWC/GEO software package. Detailed information on how to run this software package is available in the software user manual ([AD.11).

When a new region is defined the user must manually prepare the CMIC model configuration files for this new region using a default CMIC model configuration file provided in the NWC/GEO software package (see its content in section 5.3.2).

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

5.2.1 Manual preparation of Cloud Microphysics (GEO-CMIC) model configuration file for each region

When a new region is defined and added in system and run configuration files, the user must manually prepare the GEO-CMIC model configuration files by adapting the GEO-CMIC default model configuration file available in the SAFNWC/GEO software package (see its content in section 5.3.2).

The following parameters are configurable in the default GEO-CMIC model configuration file:

- CMIC_SZSEG (default value: 4): the size of the segment. This default value may be manually changed. [Segments are square boxes in the satellite projection, whose size is expressed as the number of default horizontal resolution pixels (3km at nadir for MSG) of one edge of the square box. The size of the processed regions must be a multiple of the segment size. All the solar and satellite angles, the NWP model forecast values, the cloud simulations, the atlas values will be derived over all the processed regions at the horizontal resolution of the segment. Note also that the land/sea atlas will be available at the full default horizontal resolution, allowing the identification of the surface type (land or sea) of all default horizontal resolution pixels, whatever the segment size. The quality is not very much dependent on the segment size (if lower than 16)]. Note that sampling rate of NWP_PARAM and RTS_PARAM (see 2.3.2) should be modified accordingly.
- IS_ALREADY_RECALIBRATED (default value: FALSE): this flag defines whether satellite data input by the user are already recalibrated with post-launch calibration coefficients (solar channels) and GSICS IR calibration coefficients. [For nearly all users, it

should remain set to FALSE (default value). If set to TRUE (for example, CM-SAF may use this option), the CMIC does not perform its own recalibration of solar channels].

- NP_OMP_CMIC_THREAD (default value: -1): The CMIC is parallelized using openMP standard. If set to a strictly positive integer value, NB_OMP_CMIC_THREAD corresponds to the number of threads used by CMIC. If NB_OMP_CMIC_THREAD is set to a negative value, the number if threads used by CMIC will be monitored by the OMP_NUM_THREADS environment variable set at NWCSAF SW level.
- NWP_ANALYSIS: the flag indicating if NWP analysis fields can be used. Its default value is FALSE. This flag has been made configurable to allow users to provide NWP analysis, in case of reprocessing activities. When it is set to TRUE, NWP fields with forecast time 00 are used by the PGE if they are available

5.2.2 The Cloud Microphysics (GEOCMIC) execution step

The GEO-CMIC execution step consists in the launch of the command: GEO-CMIC by the Task manager with the required parameters: time of slot, region and configuration file name.

The following command is used to process GEO-CMIC manually, without the presence of the TM:

```
% GEO-CMIC-v<vers> <time_of_slot> <region_configuration_file>
                    <CMIC model_configuration_file>
```

5.2.2.1 Example

```
%GEO-CMIC-v30 20211029T120000Z global.cfg safnwc_CMIC.cfm
```

This command executes GEO-CMIC version 3.0 over the region `global.cfg` manually, without the presence of the TM

5.3 INPUTS AND CONFIGURATION PARAMETERS FOR CLOUD MICROPHYSICS (GEO-CMIC)

5.3.1 List of inputs for Cloud Microphysics (GEO-CMIC)

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

- **Satellite imagery:**

The following bi-directional reflectances or brightness temperatures are needed at default horizontal resolution (2km at nadir for MTG/FCI):

R0.6µm	R1.6µm	R2.25µm	T8.7µm	T10.8µm
Mandatory	Mandatory	Optional	Mandatory	Mandatory

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

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

It is essential to use well calibrated 0.6µm and 1.6µm reflectances: calibration coefficients provided by KNMI are used by CMIC to recalibrate these channels during CMIC computation.

- **CT cloud categories**

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

- **CTTH cloud categories**

The CTTH cloud top pressure are optional. They are computed by the CTTH software. If they are not available, default values are used for water (800hPa) or ice clouds (300hPa)

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

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

- **NWP parameters:**

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

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

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

In case of reprocessing activities, NWP analysis can be used. To be remapped the NWP_ANALYSIS flag must be set to YES in the nwp_conf_file

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

- **Ancillary data sets:**

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

  - Land/sea atlas
  - Elevation atlas
  - Monthly 0.6µm, 1.6µm and 2.25µm white-sky surface albedo climatology (land)
  - Monthly integrated atmospheric water vapor content climatology
  - Monthly ozone content climatology

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

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

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

5.3.2 CMIC Model Configuration File

The CMIC model configuration file contains all the coefficients and constants required for the derivation of the GEO-CMIC product. The model configuration file must be placed in the $SAFNWC/config directory. The file contains the following information:

Keyword	Description	Type	Default Value(s)
PGE_ID	Identifier of the PGE	Chain of characters	GEO-CMIC
SEV_BANDS	MTG/FCI channels to be used by CMIC	Chain of characters	VIS06,NIR16,NIR22,IR87,IR108
INT_PRODUCT	Enables/disables the generation of intermediate products (not configurable in current version)	Chain of characters	NO
CMIC_SZSEG	Size of CMIC segments expressed in MTG/FCI coordinates (same value for lines and columns)	Integer	4
IS_ALREADY_RECALIBRATED	Flag defining whether satellite data input by the user are already recalibrated using post-launch and GSICS calibration coefficients	Chain of characters	FALSE
NB_OMP_CMIC_THREAD	Number of threads used by CMIC (if set to negative value, number of threads monitored by environment variable OMP_NUM_THREADS	Integer	-1
NWP_ANLYSIS	Flag to allow the use of NWP analysis	Chain of characters	FALSE
NWP_PARAM	Parameter :Total ozone content sampling rate : (=segment size CMIC_SZSEG) interpolation method.	Chain of characters	NWP_TOZ 4 BLI
NWP_PARAM	Parameter :Integrated water vapour above pressure level sampling rate : (=segment size CMIC_SZSEG) interpolation method.	Chain of characters	NWP_AWV 4 BLI
NWP_PARAM	Parameter :Integrated water vapour below pressure level sampling rate : (=segment size CMIC_SZSEG) interpolation method.	Chain of characters	NWP_BWV 4 BLI

Table 12: CMIC default Model Configuration File description

5.3.3 Configurable parameters for Cloud Microphysics (GEO-CMIC)

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

- CMIC_SZSEG: The size of the segment is configurable (see its definition in section 5.3.1). Its default value is 8. Information on how to change the size of the segment can be found in section 5.2.1.
- IS_ALREADY_RECALIBRATED: this flag, defining whether satellite data input by the user are already recalibrated with post-launch calibration coefficients (solar channels) and GSICS IR calibration coefficients, is configurable (see its definition in section 5.3.1). Its default value is FALSE. Information on how to change this value can be found in section 5.3.1 and in the software user manual (AD.11).

- NWP_ANALYSIS: the flag indicating if NWP analysis fields can be used. Its default value is FALSE. . Information on how to change this flag can be found in section 2.2.1
- NP_OMP_CMIC_THREAD (default value: -1): The CMIC is parallelized using OpenMP standard. If set to a strictly positive integer value, NB_OMP_CMIC_THREAD corresponds to the number of threads used by CMIC. If NB_OMP_CMIC_THREAD is set to a negative value, the number if threads used by CMIC will be monitored by the OMP_NUM_THREADS environment variable set at NWCSAF SW level.

5.4 CLOUD MICROPHYSICS (GEO-CMIC) VALIDATION

5.4.1 Summary of Cloud Microphysics (GEO-CMIC) validation results

The following table summarises the validation results of the current version for MSG.

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

Table 13: Summary of validation results of the current CMIC cloud phase and cloud liquid water path for MSG (POD stands for Probability Of Detection)

5.4.2 Typical known problems and recommendation for use

The following problems may be encountered:

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

5.5 EXAMPLE OF CLOUD MICROPHYSICS (CMIC) VISUALISATION

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

Colour palettes are included in CMIC NetCdF files, thus allowing an easy visualisation of CMIC different parameters such as the cloud phase, cloud optical thickness (as illustrated in Figure 5), cloud effective radius (as illustrated in Figure 6), cloud liquid or ice water path.

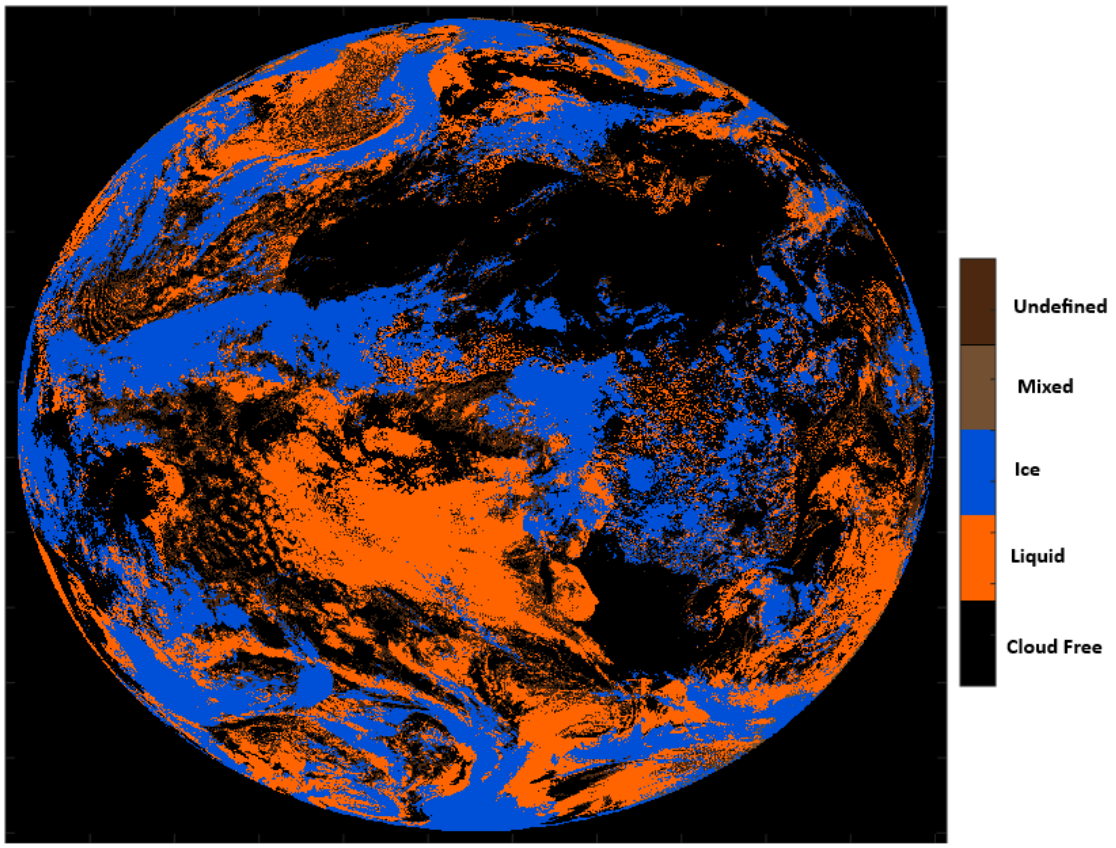

Figure 5: Example of MTG-I1/FCI cloud phase flag illustrated with the colour palette included in the CMIC NetCdF files.

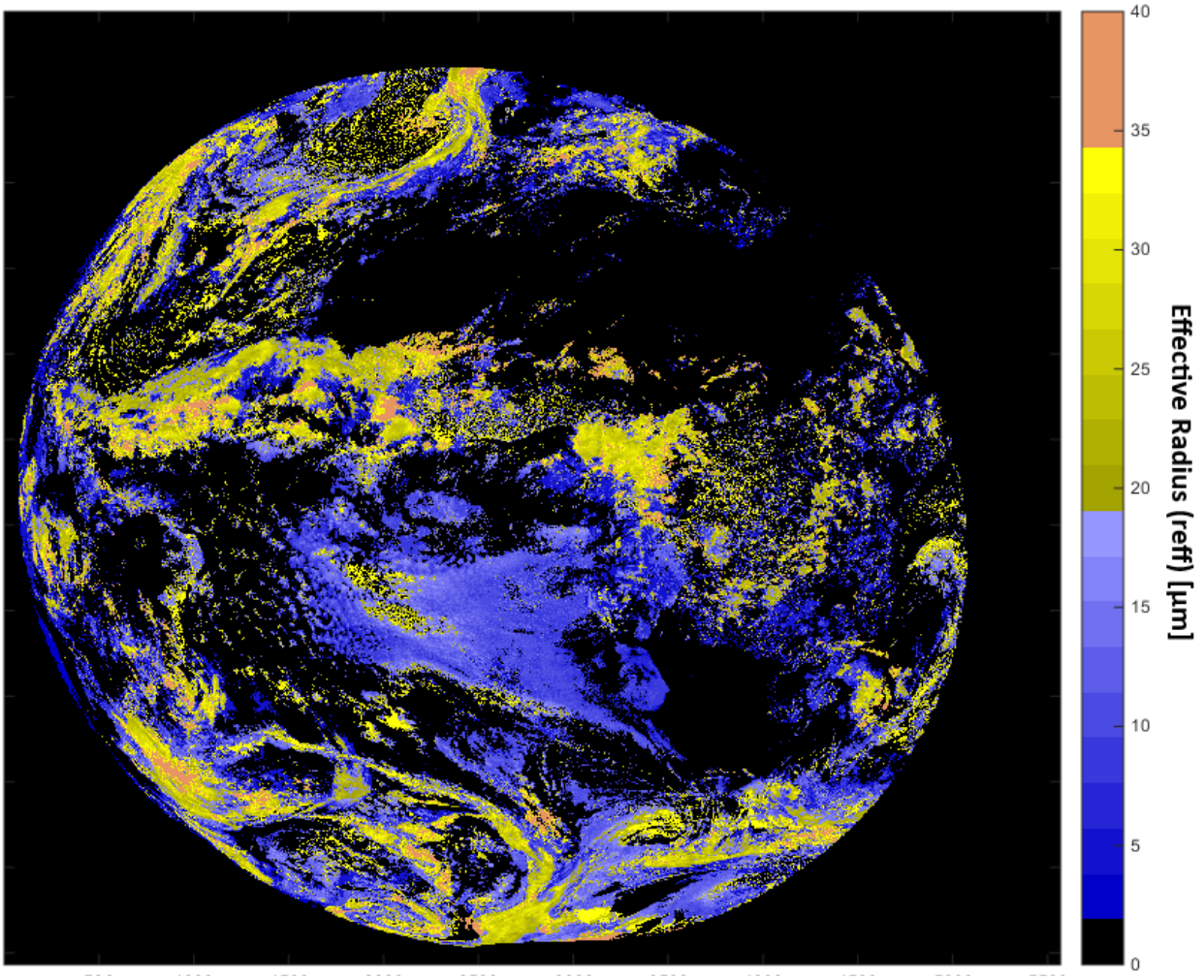

Figure 6: Example of MTG-I1/FCI cloud effective radius illustrated with the colour palette included in the CMIC NetCdF files.

6 WARNING AND ERROR MESSAGES

Code (E/W)	Message	Comment	Recovery action
E	"Usage:%sYYYYMMDDThhmmssZ region_conf_file model_conf_file"	Error when launching one cloud product	Check instruction for launching Cloud products
E	"NWC/GEO environment variable is not set"	`$SAFNWC` is not set	Set $SAFNWC
E	All messages related to NWCLIB time handling functions: NwcTimeSetStr, NwcTimeSetJR, NwcTimeAdd	Time input when launching PGE may be wrong. Time string read in Gen_Info_MSG.asc file may be corrupted.	Check the slot time input when launching PGE. Check Gen_Info_*sat*.asc on `$SAFNWC/import/Aux_data/Cloud`. If necessary, copy it form delivered SW.
E	All messages including following string: "memory allocation" "allocation error" "Unable to allocate" "Error allocating" "not allocated" "cannot be allocated" "ERR NwcMemMalloc"	Problem of memory allocation	Check memory
E	All messages containing following string: "Unable to open" "unable to create"	Problem to open an existing file or to create a new file.	Check permission and disk space on the directory. Check presence of the requested file. The recovery actions depends on the type of file: for missing configuration files, copy them from delivered SW; for missing file to be input by user: check why they are missing; for new file, check permission/disk space on the directory.
E	All messages containing the string: "NwcCFGetStr"	Problem when reading key in configuration file.	Check corresponding configuration file. If needed, copy them from delivered SW.
E	Messages containing following string: "bad sat_ids" "bad key" "Tab name read … expected" "pb key TAB_TYPE" "chn number pb read" "pb RANG_VIS"	Problem when reading ascii file on : `$SAFNWC/import/Aux_data/Cloud` May be either requested key or table missing or unexpected, or incoherency with current satellite	Check the ascii file on $SAFNWC/import/Aux_data/Cloud If necessary copy it from delivered SW.
E	Messages containing the following string: "ERR Sat_band" "ERR nc_inq_varid varname" "ERR name ….nc_inq_dimid status" "ERR name … nc_inq_dim status" "ERR size … length" "ERR nc_get_vara_short status"	Problem when reading CMIC LUT in netcdf format	Ckeck the CMIC LUT netcdf file on `$SAFNWC/import/Aux_data/Cloud` If necessary copy it from delivered SW.
E	Messages containing the following string: "CldLibSegReadLSC: Error Reading landseacoast databuf file" "CldLibSegWriteLSC: Error Writing landseacoast databuf file"	Problem related to management of Land/Sea/Coast databuf file on `$SAFNWC/tmp`.	Check permission and disk space on `$SAFNWC/tmp`. If file CLD_LANDSEACOAST_*sat_region*-n_m.raw exists on `$SAFNWC/tmp`, it may be corrupted: delete this file (it will be created when sw is relaunched).
E	Messages containing following string: "Pb reading Ostia file" "No appropriate OSTIA file available on"	Problem when reading OSTIA netcdf file input by the user.	Check permission on $SAFNWC/import/Aux_data/OSTIA. Check existence of OSTIA netcdf file input by the user on `$SAFNWC/import/Aux_data/OSTIA`. If missing or corrupted file, download OSTIA file from ftp server as explained in Software User Manual.

Code (E/W)	Message	Comment	Recovery action
E	Messages containing following string: "CldLibSegOstia : ERROR when reading OSTIA in databuf" "CldLibSegReadOstiaDB: Error Reading OSTIA databuf file" "CldLibSegOstia : ERROR when writing OSTIA in databuf" "CldLibSegWriteOstiaDB: Error writing OSTIA databuf file" "CldLibSegWriteOstiaDB: Error when removing OSTIA databuf file"	Problem related to management of OSTIA databuf	Check permission and space disk on `$SAFNWC/tmp`. Remove OSTIA databuf from `$SAFNWC/tmp` (if available).
E	Messages containing following strings: "Error fgetpos when reading bias file" "Error when reading bias file" "PB reading bias file" "PB reading channel in bias file"	Problem related to reading rttov bias file monitored by cloud PGE.	Check permission and space disk on `$SAFNWC/tmp`. Edit bias files to check their content If corrupted, remove rttov bias file
E	CldLibReadRttovBias: the RTTOV Bias file is too old (%d days). Please load a valid file	The RTTOV bias file is too old to be used (maximum 35 day off from the validity range).	Download more recent rttov bias from AEMET ftp server
E	Messages containing following strings: "CldCmaFinWriteSnowMap read error snow_hits on current_snow_file" "CldCmaFinWriteSnowMap read error list_images on current_snow_file" "CldCmaFinWriteSnowMap write error on" "CldCmaFinWriteSnowMap write error on"	Problem related to management of snowmap databuf file (name in error message) on `$SAFNWC/tmp`.	Check permission and space disk on `$SAFNWC/tmp`. Remove snow map databuf (name in error message) from `$SAFNWC/tmp` (if available).
E	"in CldLibHandleResolution: incoherency in region order"	The spatial resolutions of the region initialised with NWCLIB functions are not ordered correctly: this is unexpected.	Should not happen. Contact developers on the helpdesk.
E	"problem in decoding time string in CldLibInitCorDailyVis"	Time string read in Gen_Info_MSG.asc file may be corrupted.	Check Gen_Info_MSG.asc on `$SAFNWC/import/Aux_data/Cloud`. If necessary, copy it from delivered SW.
E	"Error due to incoherency in horizontal resolution" "incoherency of size"	Incoherency in spatial resolution or image size.	Should not happen. Contact developers on the helpdesk.
E	"CldLibSegCompAtlasClimSeg atlascode: ….. unknown atlascode"	Unexpected atlas map code	Should not happen. Contact developers on the helpdesk.
W	"Not enough pixels to compute RTTOV bias"	Not enough cloud free oceanic pixel to compute RTTOV bias for current slot.	Check that your region allows the computation of the RTTOV bias (minimum number of oceanic pixels as explained in ATBD). Do nothing if your region contains enough oceanic pixels. The RTTOV bias will be computed on other slots that are less cloudy.
E	"Mandatory NWP fields are missing: height/pressure will not be computed"	Mandatory NWP field are missing; product cannot be computed	Check why NWP remapped field are not available
E	"Not enough pixel with mandatory input data available for CMA (or CT, CTTH,CMIC)"	Not enough pixel with mandatory data for CMA (or CT, CTTH,CMIC) –> no output is computed	Check input data for CMA (or CT, CTTH,CMIC), especially NWP data.