The EUMETSAT Network of Satellite Application Facilities

NWC SAF

Support to Nowcasting and Very Short Range Forecasting

Scientific and Validation report for the Cloud Product Processors of the NWC/GEO

NWC/CDOP2/GEO/MFL/SCI/VR/Cloud, Issue 1, Rev. 0

15 October 2016

Applicable to

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

Prepared by Météo-France / Centre de Météorologie Spatiale

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DOCUMENT CHANGE RECORD

Version	Date	Pages	Changes
1.0d	15 June 2015	30	Draft version for STRR
1.0	15 October 2016	33	Inclusion of STRR outcome

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1 INTRODUCTION

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

1.1 Scope of the document

This document is the cloud product validation report applicable to NWC/GEO software package v2016. The accuracies of 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) are compared to the threshold accuracies for CDOP2 listed in the NCWSAF product requirements document [AD.4.]. They are also compared to the accuracies reached in the previous version (V2013, reported in [RD.1.]).

1.2 Software Version Identification

The validation results presented in this document apply to the algorithms implemented in the release 2016 of the NWC/GEO software package (GEO-CMA-v4.0 (Product Id NWC-002), GEO-CT-v3.0 (Product Id NWC-006), GEO-CTTH-v3.0 (Product Id NWC-010) and GEO-CMIC-v1.0 (Product Id NWC-013)).

1.3 Definitions, Acronyms and Abbreviations

AMSR	Advanced Microwave Scanning radiometer
BUFR	Binary Universal Form for Representation of meteorological data
CALIOP	Cloud Aerosol Lidar with Orthogonal Polarization
CALIPSO	Cloud Aerosol Lidar and Infraed Pathfinder Satellite Observation
CLOUDSAT	Cloud satellite
CMA	Cloud Mask
CMIC	Cloud Microphysics
CMS	Centre de Meteorologie Spatiale (Météo-France, satellite reception centre in Lannion)
CPR	Cloud Profiling Radar
CTTH	Cloud Top Temperature and Height
CT	Cloud Type
ECMWF	European Centre for Medium range Weather Forecast
EUMETSAT	European Meteorological Satellite Agency

FAR	False Alarm Rate
FOV	Field Of View
GEO	Meteorological Geostationary Satellite
IR	Infrared
K	Kelvin
LWP	Liquid Water Path
MSG	Meteosat Second Generation
NWC SAF	SAF to support NoWCasting and VSRF
NWP	Numerical Weather Prediction
PGE	Product Generation Element
POD	Percentage Of Detection
SAF	Satellite Application Facility
SEVIRI	Spinning Enhanced Visible & Infrared Imager
SHIP	Ship observation
SYNOP	Surface synoptic observations

1.4 REFERENCES

1.4.1 Applicable documents

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

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

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

Ref	Title	Code	Vers	Date
[AD.1.]	Proposal for the Second Continuous Development and operation Phase (CDOP) march 2012 – February 2017	NWC/CDOP2/MGT/AEMET/PRO	1.0	15/03/2011
[AD.2.]	NWCSAF Project Plan	NWC/CDOP2/SAF/AEMET/MGT/PP	1.9	15/10/2016
[AD.3.]	Configuration Management Plan for the NWCSAF	NWC/CDOP2/SAF/AEMET/MGT/CMP	1.4	15/10/2016
[AD.4.]	NWCSAF Product Requirement Document	NWC/CDOP2/SAF/AEMET/MGT/PRD	1.9	31/08/2016
[AD.5.]	System and Components Requirements Document for the NWC/GEO	SAF/NWC/CDOP2/AEMET/SW/SCRD	1.2	15/10/2016
[AD.6.]	Interface Control Document for Internal and External Interfaces of the NWC/GEO	NWC/CDOP2/GEO/AEMET/SW/ICD/1	1.1	15/10/2016
[AD.7.]	Interface Control Document for the NWCLIB of the NWC/GEO	NWC/CDOP2/GEO/AEMET/SW/ICD/2	1.1	15/10/2016
[AD.8.]	Data Output Format for the NWC/GEO	NWC/CDOP2/GEO/AEMET/SW/DOF	1.1	15/10/2016
[AD.9.]	Architectural Design Document for the NWC/GEO	NWC/CDOP2/GEO/AEMET/SW/ACDD	1.1	15/10/2016
[AD.10.]	Component Design Document for the Cloud Product Processors of the NWC/GEO	NWC/CDOP2/GEO/MFL/SW/ACDD/Cloud	1.1	15/10/2016
[AD.11.]	Algorithm Theoretical Basis Document for the Cloud Product Processors of the NWC/GEO	NWC/CDOP2/GEO/MFL/SCI/ATBD/Cloud	1.1	15/10/2016
[AD.12.]	The Nowcasting SAF glossary	NWC/CDOP2/SAF/AEMET/MGT/GLO	2.0	18/2/2014

Table 1: List of Applicable Documents

1.4.2 Reference documents

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

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

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

Ref	Title	Code	Vers	Date
[RD.1.]	Validation report for "cloudproducts" (CMa-PGE01 v3.2, CT-PGE02 v2.2 & CTTH-PGE03 v2.2)	SAF/NWC/CDOP/MFL/SCI/VR/06	1.0.1	25/11/2013
[RD.2.]	Validation report for the PGE01-02-03 (v1.2) (Cloud Products) of the SAFNWC/MSG	SAF/NWC/IOP/MFL/SCI/VAL/01	1.2	17/01/07

Table 2: List of Referenced Documents

2 CLOUD MASK (GEO-CMA) VALIDATION

2.1 OVERVIEW

2.1.1 General objectives of the validation

The main objective of this section is to document CMa accuracies and compare them to the threshold accuracies listed in the NWCSAF product requirements document [AD. 4]. Additionally, CMa accuracies are compared to those obtained with the previous version.

2.1.2 Methodology outline

The following validation of the CMa product is performed:

- ✓ The CMa cloud detection is validated using SYNOP and SHIP data gathered over full disk during the year 2010 (one day every three days), collocated with the CMa produced at the Centre de Meteorologie Spatiale. The POD (Probability Of Detection) and FAR (False Alarm Rate) are computed and compared to the threshold accuracy applicable to the current software version (see NWCSAF product requirements document [AD. 4]). The statistics are computed over Europe and over full MSG disk. For this validation, CMa is retrieved using NWP fields forecast by ECMWF four times per day (0h, 6h, 12h and 18h) at a 1.5 degree horizontal resolution.

- ✓ The CMa dust detection is validated from interactively selected targets over seas and Africa for solar elevation larger than 20 degrees. The POD (Probability Of Detection) and FAR (False Alarm Rate) are computed and compared to the threshold accuracy applicable to the current software version (see NWCSAF product requirements document [AD. 4]). The CMa dust detection has remained unchanged since last version (v2013).

2.2 CMA CLOUD MASK: COMPARISON WITH SURFACE OBSERVATION (SYNOP,SHIP)

From the SYNOP or SHIP data set, ground-based total cloud cover (N) and partial cloud cover from low, medium and high clouds are available. Satellite cloud coverage is estimated from CMa applied to the pixels of the satellite targets. To simulate the surface observations from the satellite pixels, no attempt is made to take into account the complexity of the observation, and the 25 pixels inside the satellite data target are used for the evaluation. The total cloudiness over SYNOP station or SHIP is simply simulated from CMa results over the 5x5 target centred on the station or the ship by counting each pixel detected as cloud contaminated as 100% covered.

The CMa cloud mask validation examines only cases that show disagreement with SYNOP/SHIP cloud cover, i.e. when CMa misses clouds reported almost overcast by the ground observer and when CMa detects clouds where SYNOP/SHIP report no or insignificant cloud cover. For this purpose we build up two-by-two contingency tables counting “cloudy” and “clear” events. An observation is cloudy if N from SYNOP/SHIP is strictly more than 5 octas, clear if N is strictly less than 3 octas. A detection is cloudy if more than 16/25 pixels are flagged cloud contaminated, clear if less than 8/25 are cloudy. Consequently all events with N=3,4,5 and equivalent CMa cloud covers expressed in octas are not taken into account in these statistics. This study relies on analysis of contingency tables and comparison of statistical scores.

	Cloud detected	Clear detected
Cloud observed	H	M
Clear observed	Fa	cr

Table 3 Contingency table conventions

Two following statistical indicators stratified by observation are computed (the POD (Probability Of Detection) should be as high as possible and the FAR (False Alarm Rate) as low as possible:

- POD=[h/(h+m)], is the rate of correctly detected cloud observations, i.e. targets classified as cloudy and observed cloudy.
- FAR=[fa/(fa+cr)], is the rate of missed clear observations or false flagging of clouds, i.e. the targets classified as cloudy but observed clear (it expresses cloud over-detection errors)

2.2.1 Over European SYNOP stations

Contingency tables and statistical scores have been computed for different illumination conditions (day, night, twilight) for all European selected SYNOP stations for the year 2010 (one day every three). The results are displayed in the following tables for v2013 and v2016.

CMa v2013	POD(%)	FAR(%)
All illumination :	97.1	4.1
Daytime :	98.5	2.3
Night-time :	95.8	7.3
Twilight :	95.7	1.8

Table 4 CMa v2013 performance in the detection of fully cloudy and cloud-free events estimated from collocated SYNOP and MSG-2/SEVIRI observations over land on Europe for 2010. Stratified by illumination

CMa v2016	POD(%)	FAR(%)
All illumination :	97.1	4.0
Daytime :	98.4	2.1
Night-time :	96.0	7.3
Twilight :	95.6	1.8

Table 5 CMa v2016 performance in the detection of fully cloudy and cloud-free events estimated from collocated SYNOP and MSG-2/SEVIRI observations over land on Europe for 2010. Stratified by illumination

The CMa v2016 cloud detection reaches over Europe the threshold accuracy (POD: 85.0% and FAR: 20.0%) and even the target accuracy (POD: 95.0% and FAR: 10.0%) (see NWCSAF product requirements document [AD. 4]).

The impact of missing NWP data has been analyzed in details and reported in [RD.2.].

2.2.2 Over SYNOP and SHIP on MSG full disk

Contingency tables and statistical scores have been computed for different illumination conditions (day, night, twilight) for SYNOP stations and SHIP all over the MSG full disk for the year 2010 (one day every three). The results are displayed in the following table v2016.

CMa v2013	POD(%)	FAR(%)
All illumination :	94.4	6.8
Daytime :	96.0	4.3
Night-time :	92.8	11.5
Twilight :	93.2	3.0

Table 6 CMa v2013 performance in the detection of fully cloudy and cloud-free events estimated from collocated SHIP and SYNOP and MSG-2/SEVIRI observations over MSG full disk for 2010. Stratified by illumination

CMa v2016	POD(%)	FAR(%)
All illumination :	94.5	6.8
Daytime :	95.9	4.1
Night-time :	93.1	11.6
Twilight :	93.1	3.0

Table 7 CMa v2016 performance in the detection of fully cloudy and cloud-free events estimated from collocated SHIP and SYNOP and MSG-2/SEVIRI observations over MSG full disk for 2010. Stratified by illumination

The CMa v2016 cloud detection reaches over MSG full disk the threshold accuracy (POD: 85.0% and FAR: 20.0%) and even the target accuracy (POD: 90.0% and FAR: 15%) to be reached with SHIP/SYNOP over full disk (see NWCSAF product requirements document [AD. 4]).

2.3 CMA DUST FLAG VALIDATION

As CMa dust detection algorithm has remained unchanged between v2016 and v2013, and as CMa dust detection v2013 already reached the threshold and even the target accuracy values for the CDOP2 period, this section is just a reminder of CMa dust detection algorithm accuracies that we obtained for v2013.

The database available at CMS to quantify the CMa dust flag is the Interactive Target Database (see Annex 1) which gathers about 3800 targets corresponding to dust events located over Africa and adjacent seas (Figure 1 shows their location) in 2003, 2004 and 2005.

It must be noted that the validation is not fully independent as part of the database has been used to develop the algorithm's improvement.

The satellite part of the dataset (described in Annex 2) allows the reprocessing of different version of CMa and also allows the simulation of "effective radiances" from the stored "spectral radiances".

Statistical scores are indicators of how much the automated CMa dust flag agrees with the interactively manned targets types. Note that no attempt to quantify the thin dust clouds detection over Europe has been performed as all the targets corresponds to dust storms over Africa or adjacent seas.

The following statistical scores stratified by observation are computed from contingency tables built from this database (see Table 8 for conventions; "dust detected" corresponds to more than half the pixels of the target flagged as dust by CMa; "no dust detected" corresponds to less than half the pixels of the target flagged as dust by CMa) :

- POD=[h/(h+m)], is the rate of correctly detected dust observations, i.e. targets classified as dust and observed dust (it expresses the dust correct detection).
- FAR=[fa/(fa+h)], is the rate of false flagging of dust, i.e. the targets classified as dust but observed without dust (it expresses dust overdetection errors)

	Dust detected	No dust Detected
Dust observed	h	m
No dust observed	fa	Cr

Table 8 Contingency table conventions (h for hits, m for misses, fa for false alarm and cr for correct rejection)

The POD (Probability Of Detection) should be as high as possible and the FAR (False Alarm Rate) as low as possible.

Database is stratified according to land and sea and is limited to solar elevation larger than 20 degrees. Results are sum up in Table 9 and Table 10.

	Contingency table (over sea)	FAR (%)	POD (%)

CMa v2016	728	583	4.5	55.5
	34	2643		

Table 9 Dust flag performance over sea estimated from the Interactive Target Database

	Contingency table (over land)		FAR (%)	POD (%)
CMa v2016	1294	918	1.5	58.5
	20	3131		

Table 10 Dust flag performance over land estimated from the Interactive Target Database

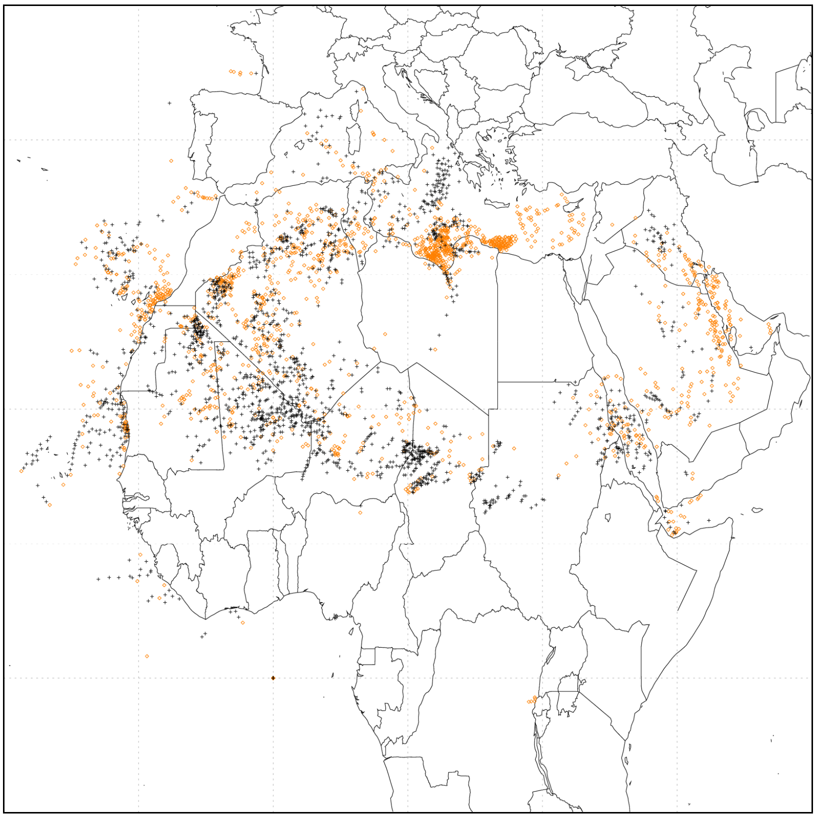


Figure 1 Localisation of the interactive targets corresponding to dust events. Black symbol and orange diamond correspond respectively to detected and non detected by the CMa dust flag.

Over land, the dust detection algorithm has remained unchanged and the POD and FAR reached by the CMa v2016 dust detection over land (respectively 58.5% and 1.5%) are within the threshold accuracy (POD: 20% and FAR: 15%) and even the target accuracy (POD: 50% and FAR: 10%) (see NWCSAF product requirements document [AD.4.]).

Over sea, the dust detection algorithm has remained unchanged and the POD and FAR reached by the CMa v2016 dust detection over sea (55.5% and 4.5%) are within the threshold accuracy (POD:

20% and FAR: 15%) and even the target accuracy (POD: 50% and FAR: 10%) (see NWCSAF product requirements document [AD.4.]).

2.4 ASSESSMENT OF ALGORITHM QUALITY

The CMa v2016 cloud detection reaches the threshold accuracies applicable to the current software version. In fact the POD and FAR reached respectively over the European area and over full disk by CMa v2016 are 97.1%/94.5% and 4.0%/6.8% which are within the threshold accuracy (POD: 85% and FAR: 20.%) to be reached over European area and full disk (see Table 11)..

	CMA over Europe (POD and FAR in %)	CMA over full disk (POD and FAR in %)
v2013	97.1% / 4.1%	94.4% / 6.8%
v2016	97.1% / 4.0%	94.5% / 6.8%
Optimal accuracy	98.0% / 5.0%	95.0% / 10.0%
Target accuracy	95.0% / 10.0%	90.0% / 15.0%
Threshold accuracy	85.0% / 20.0%	85.0% / 20.0%

Table 11 Comparison of cloud CMA accuracies obtained with v2013 and v2016 to those listed in Product Requirement Table.

The CMa v2016 dust detection, which remained unchanged since last version (v2013), reaches the threshold accuracy applicable to the current software version over both Africa and the ocean: the v2016 POD (55.5 over the ocean and 58.5% over Africa) and FAR (4.5% over ocean, 1.5% over Africa) are within the threshold accuracy (POD: 20% and FAR: 15%) (see Table 12)..

	Dust flag over ocean (POD and FAR in %)	Dust flag over land (POD and FAR in %)
v2013	55.5% / 4.5%	58.5% / 1.5%
v2016	55.5% / 4.5%	58.5% / 1.5%
Optimal accuracy	80.0% / 5.0%	80.0% / 5.0%
Target accuracy	50.0% / 10.0%	50.0% / 10.0%
Threshold accuracy	20.0% / 15.0%	20.0% / 15.0%

Table 12 Comparison of dust flag accuracies obtained with v2013 and v2016 to those listed in Product Requirement Table.

3 CLOUD TYPE (GEO-CT) VALIDATION

3.1 OVERVIEW

3.1.1 General objectives of the validation

The main objective of this section is to document CT cloud type accuracies and compare them to the threshold accuracies listed in the NWCSAF product requirements document [AD.4.]. As the CT cloud type algorithm has remained unchanged between v2013 and v2016, we only extend the existing validation (already available over European areas) to the full disk.

3.1.2 Methodology outline

The following validation of the CT product is performed:

- ✓ The CT cloud type (v2016) is validated for all seasons over full disk using the Interactive Target database. The "User Accuracy" is computed and is compared to the threshold accuracy applicable to the current software version (see the NWCSAF product requirements document [AD.4.]).

In all these validation studies, CT is retrieved using NWP fields forecast by the French model ARPEGE four times per day (0h, 6h, 12h and 18h) at a 1.5 degree horizontal resolution.

3.2 COMPARISON WITH INTERACTIVE TARGET DATABASE

The Interactive Target Database (see Annex 1) allows the comparison of the CT cloud types and the cloud class manually labelled from SEVIRI imagery. This comparison is an indicator of the CT algorithm's quality but also of the separability of the cloud classes, and a way to understand how the CT algorithm manages classes. Although the interactive targets have been gathered over the MSG full disk, the validation is performed both over European and adjacent seas and over full disk.

The satellite part of the dataset (described in Annex 2) allows the reprocessing of different version of CT.

The CT and the manually labelled cloud classes are first gathered into the main classes described in Table 13 before being compared. There is an agreement if the most probable CT main class (i.e. the most frequent main class among the 9 central pixels) is identical to the observer main class. As clear and cloud confusions have been analysed in CMa validation section, the database is limited to cases identified as cloudy by the observer and CT.

Contingency tables and statistical scores (user's accuracy (probability of a pixel classified into a category on a picture to really belong to that category)) are then computed. They are associated with changes illumination (day, night, twilight, sunglint).

Main Classes name	**Target type**	**CT type**

Sea	Open sea, Sea with haze, Sea with shadow, Sea with sunglint	Sea not contaminated by clouds, aerosol or ice/snow
Land	Land, land with haze, land with shadow,	Land not contaminated by clouds, aerosol or snow
Ice	Ice, ice with shadow	Sea contaminated by ice/snow
Snow	Snow, snow with shadow	Land contaminated by snow
Low	Fog, stratus, small cumulus over land, small cumulus over sea Stratocumulus, stratocumulus with shadow	Very low clouds Low clouds
Mid-level cloud	Altocumulus, Altostratus, cumulus congestus over land and sea	Medium clouds
Semitransparent	Thin cirrus above stratus or stratocumulus or cumulus Thin cirrus over sea, thin cirrus over land, thin cirrus over snow, thin cirrus over ice Cirrostratus	Cirrus above lower clouds Thin cirrus Mean and thick cirrus
High clouds	Cirrostratus over Altocumulus or Altostratus. Thin cirrus over Ac As Isolated or merged Cb	High opaque clouds Very high opaque clouds

Table 13 Equivalence between manually labelled targets and CT types

CT v2016	Low clouds	Mid-level clouds	Semitransparent	High clouds
All illumination	91.30 %	60.57%	87.75 %	86.60 %
Daytime	86.71 %	61.29 %	92.52 %	85.61 %
Nightime	94.15 %	63.54 %	80.59 %	88.79 %
Twilight	95.68 %	42.50 %	79.31 %	83.33 %

Table 14 Users accuracy for each main cloud classes estimated from the Interactive Target database stratified by illumination. Over full disk.

Table 14 shows that the users accuracies obtained by CT v2016 over full disk for low clouds (91.30%), high clouds (86.60%) and semi-transparent clouds (87.75%) are above the threshold accuracy (50%) and even the target accuracy (70%) (see NWCSAF product requirements document [AD.4.]).

3.3 ASSESSMENT OF ALGORITHM QUALITY

The CT v2016 cloud type reaches the threshold accuracy applicable to the current software version: the user accuracies obtained by CT v2016 for low clouds (91.30%), high clouds (86.60%) and semi-transparent clouds (87.75%) are far above the threshold accuracy (50%) (see Table15).

	Low clouds (POD in %)	Semitransparent (POD in %)	High clouds (POD in %)
v2013	91.30%	87.75%	86.60%
v2016	91.30%	87.75%	86.60%
Optimal accuracy	90.0%	90.0%	90.0%
Target accuracy	70.0%	70.0%	70.0%
Threshold accuracy	50.0%	50.0%	50.0%

Table 15 Comparison of CT accuracies obtained with v2013 and v2016 to those listed in Product Requirement Table.

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

4.1 OVERVIEW

4.1.1 General objectives of the validation

The main objective of this section is to document CTTH accuracies and compare them to the threshold accuracies listed in the NWCSAF product requirements document [AD. 4]. Additionally, CTTH accuracies are compared to those obtained with the previous version.

4.1.2 Methodology outline

The following validation of the CTTH product is performed:

- ✓ The CTTH cloud cloud top altitude is validated against cloud top height obtained from space-born lidar (CALIOP) and radar (CPR) measurements gathered over full disk during the year 2010 (one day every three days). Bias and standard deviation are computed and compared to the threshold accuracy applicable to the current software version (see NWCSAF product requirements document [AD. 4]). The statistics are computed over full MSG disk. For this validation, CTTH is retrieved using NWP fields forecast by ECMWF four times per day (0h, 6h, 12h and 18h) at a 1.5 degree horizontal resolution. Temperatures and humidity are available on thirty-two pressure levels ranging from 1000hPa to 10hPa.

4.2 VALIDATION OF CTTH ALTITUDE WITH SPACE-BORN LIDAR MEASUREMENTS

A collocated dataset has been prepared covering 2010 (one day every three):

- Both the CT (Cloud Type) and the CTH (Cloud Top altitude) computed from the SEVIRI slot closest in time to the CALIOP lidar measurements are stored. The SEVIRI data are kept not only below the CALIOP track but on a certain width so that it is possible to analyse the cloud spatial homogeneity. No parallax correction is applied. All the day passes (respectively the night passes) are stored on a single image.

- All the cloud layers detected by CALIOP and having an optical thickness larger than 0.2 are retained. The altitude of their base and top are stored.

Furthermore, additional tests are performed before statistical scores are computed from this collocated dataset:

- A selection of homogeneous areas (area of 9*9 IR SEVIRI pixels) is performed: homogeneous cloud type in CT and CALIOP cloud top pressure variation less than 200hPa. The SEVIRI and CALIOP cloud top altitude are spatially averaged in these homogeneous areas before being used to compute statistical scores. The CALIOP cloud top altitude correspond to the altitude of the top of the upper not too thin (optical thickness is larger than 0.2) layer.

- To limit the parallax effect, the viewing angles are limited to a maximum of 65 degrees, thus excluding the MSG disk edge.

Statistics are separately computed for opaque and semi-transparent clouds.

4.2.1 Opaque clouds

In this section, we analyse SEVIRI CTH retrieval for opaque clouds using lidar measurements.

Opaque clouds	Bias (km)	Standard deviation (km)	Number of cases
CTTH v2013	-0.48	0.99	286999
CTTH v2016	-0.49	0.99	295140

Table 16 Opaque clouds statistical scores for (CTH_SEVIRI-CTH_CALIOP).Over full disk.

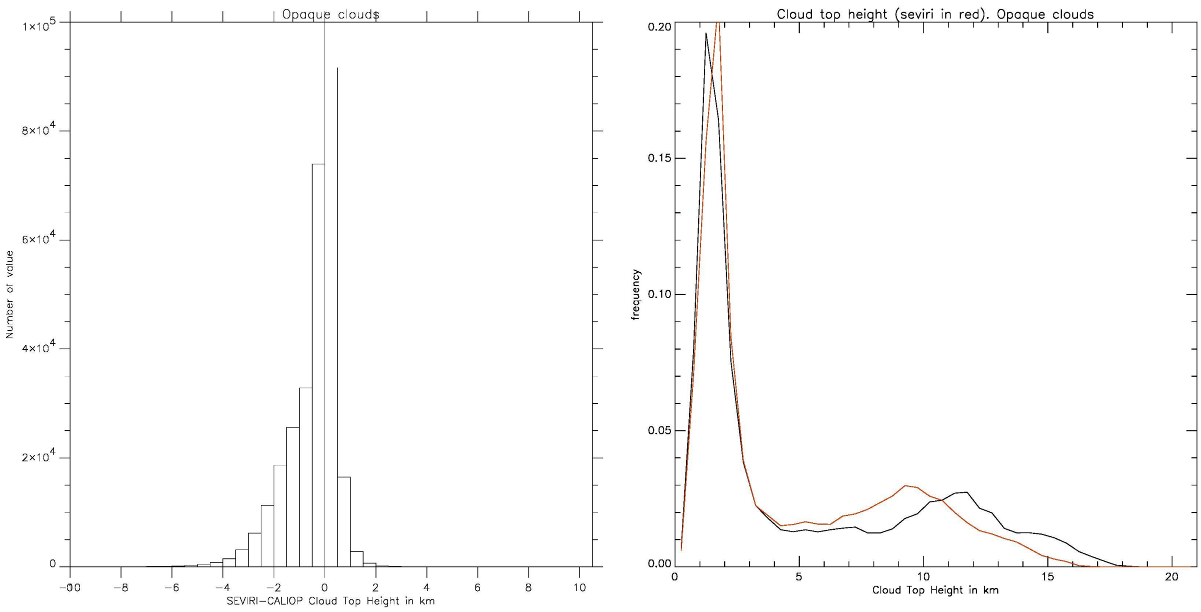


Figure 2 Left: probability Density of CTH(SEVIRI) – CTH(CALIOP). Right: Seviri (red) and CALIOP (black) cloud top height distribution. For opaque clouds over full disk.

Bias and standard deviation for the previous and current versions are given for opaque clouds in Table 16. The scatter between SEVIRI and CALIOP cloud top height is illustrated in Figure 2.

CTTH v2016 bias are slightly worse than those obtained with v2013 although the algorithm in both version are the same, the reason is the larger number of cases for v2016 due to more clouds detected by CMA (cloud detection using online RTTOV has been added).

The CTTH v2016 reaches for opaque clouds the threshold accuracy (bias: 1000m; std: 2000m) and even the threshold accuracy (bias: 750m; std: 1500m).

4.2.2 Semi-transparent clouds

In this section, we analyse SEVIRI CTH retrieval for semi-transparent clouds using lidar measurements.

Semi-transparent clouds	Bias (km)	Standard deviation (km)	Number of cases
CTTH v2013	-1.32	1.98	140252
CTTH v2016	-1.44	1.97	142509

Table 17 Semi-transparent clouds statistical scores for (CTH_SEVIRI-CTH_CALIOP).Over full disk.

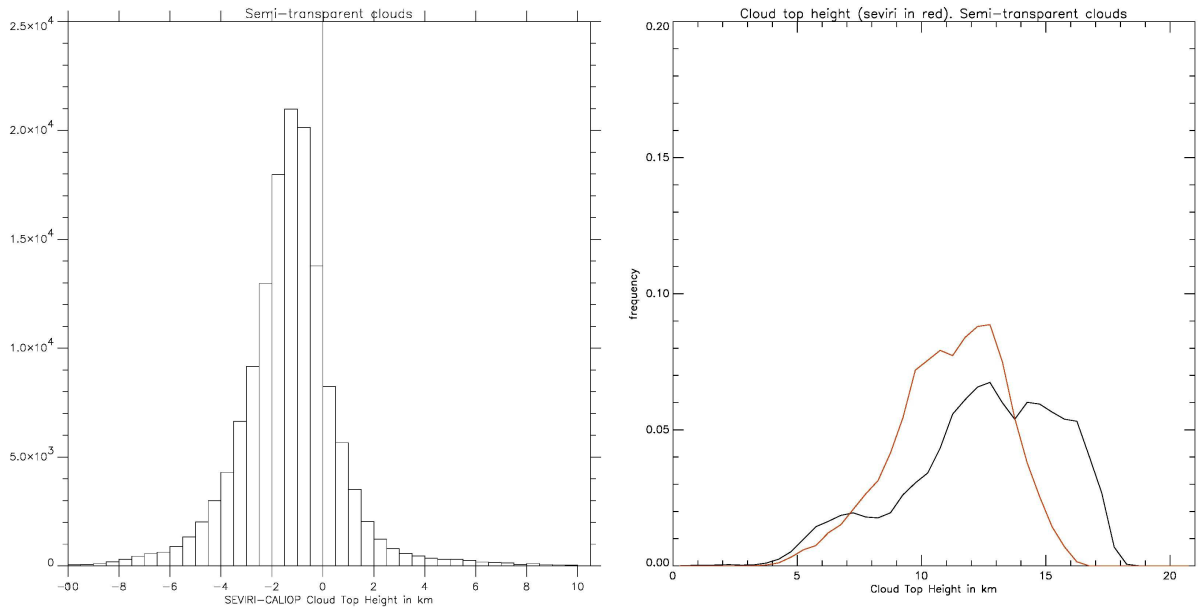


Figure 3 Left: probability Density Function of CTH(SEVIRI) – CTH(CALIOP). Right: Seviri (red) and CALIOP (black) cloud top height distribution. For semi-transparent clouds over full disk.

Bias and standard deviation for the previous and current versions are given in Table 17. The scatter between SEVIRI and CALIOP cloud top height is illustrated in Figure 3.

CTTH v2016 bias are slightly worse than those obtained with v2013 although the algorithm in both version are the same, the reason is the larger number of cases for v2016 due to more clouds detected by CMA (cloud detection using online RTTOV has been added).

The CTTH v2016 reaches for semi-transparent clouds the threshold accuracy (bias: 2000m; std: 2000m). The target accuracy (bias: 1500m; std: 1500m) is reached for the bias but not for the standard deviation.

4.3 VALIDATION OF CTTH ALTITUDE WITH SPACE-BORN RADAR MEASUREMENTS

A collocated dataset has been prepared covering 2010 (one day every three):

- Both the CT (Cloud Type) and the CTH (Cloud Top altitude) computed from the SEVIRI slot closest in time to the CPR radar measurements are stored. The SEVIRI data are kept not only below the CPR track but on a certain width so that it is possible to analyse the cloud spatial homogeneity. No parallax correction is applied. All the day passes (respectively the night passes) are stored on a single image.

- The top altitude of the highest cloud layer derived from CPR is stored (radar echos classified as good or strong echo (ie, corresponding to CPR mask value 30 or 40) are retained).

Furthermore, additional tests are performed before statistical scores are computed from this collocated dataset:

- A selection of homogeneous areas (area of 9*9 IR SEVIRI pixels) is performed: homogeneous cloud type in CT and CPR altitude variation less than 3km. The SEVIRI and CPR cloud top altitude are spatially averaged in these homogeneous areas before being used to compute statistical scores (bias and standard deviation).
- To limit the parallax effect, the viewing angles are limited to a maximum of 65 degrees, thus excluding the MSG disk edge.

Statistics are separately computed for opaque and semi-transparent clouds.

4.3.1 Opaque clouds

In this section, we analyse SEVIRI CTH retrieval for opaque clouds using radar measurements.

Opaque clouds	Bias (km)	Standard deviation (km)	Number of cases
CTTH v2013	-0.34	0.82	313901
CTTH v2016	-0.35	0.82	320132

Table 18 Opaque clouds statistical scores for (CTH_SEVIRI-CTH_CPR).Over full disk.

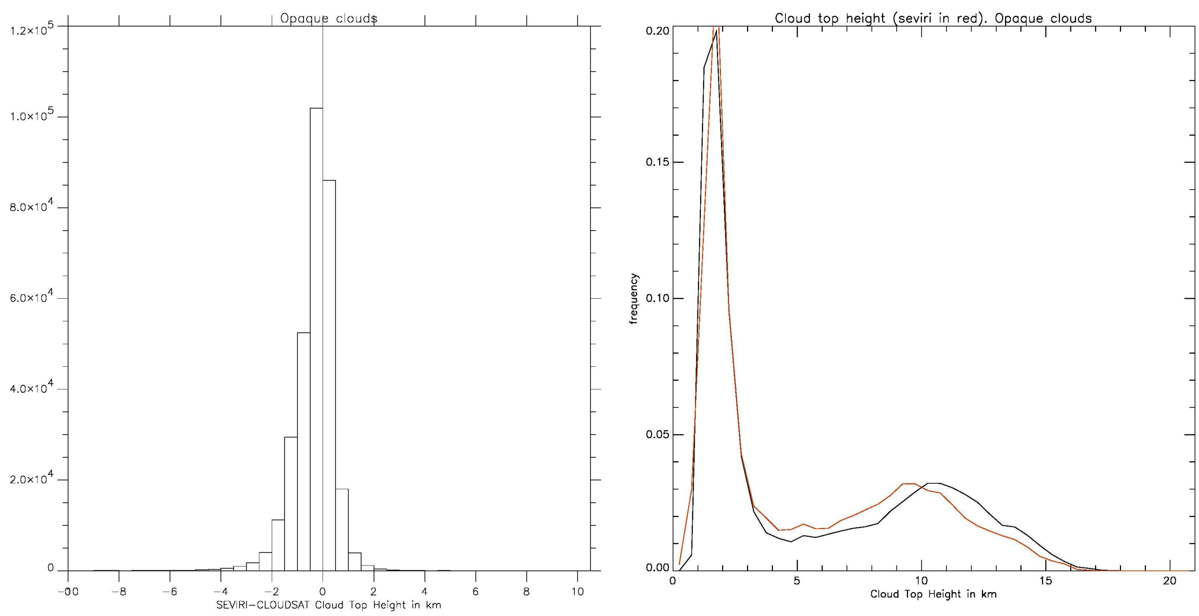


Figure 4 Left: probability Density Function of CTH(SEVIRI) – CTH(CPR). Right: Seviri (red) and CPR (black) cloud top height distribution. For opaque clouds over full disk.

Bias and standard deviation for the previous and current versions are given in Table 18. The scatter between SEVIRI and CPR cloud top height is illustrated in Figure 4.

CTTH v2016 bias are slightly worse than those obtained with v2013 although the algorithm in both version are the same, the reason is the larger number of cases for v2016 due to more clouds detected by CMA (cloud detection using online RTTOV has been added).

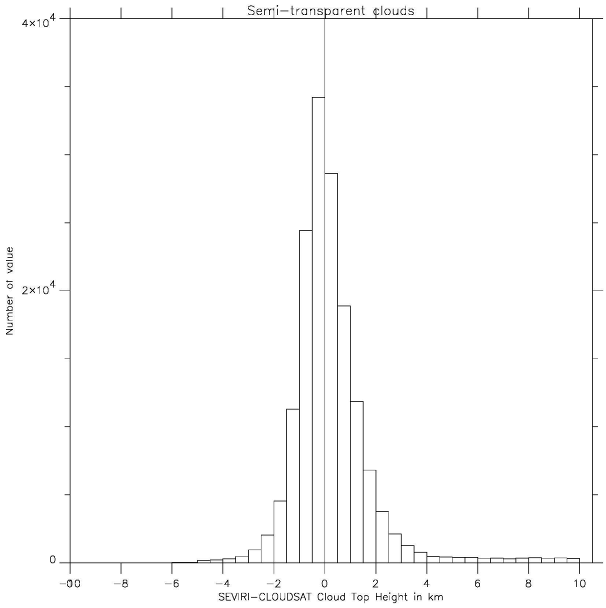
The CTTH reaches for opaque clouds the threshold accuracy (bias: 1000m; std: 2000m) and even the threshold accuracy (bias: 750m; std: 1500m).

4.3.2 Semi-transparent clouds

In this section, we analyse SEVIRI CTH retrieval for semi-transparent clouds using radar measurements.

Semi-transparent clouds	Bias (km)	Standard deviation (km)	Number of cases
CTTH v2013	0.32	1.85	158327
CTTH v2016	0.21	1.88	159924

Table 19 Semi-transparent clouds statistical scores for (CTH_SEVIRI-CTH_CPR).Over full disk.



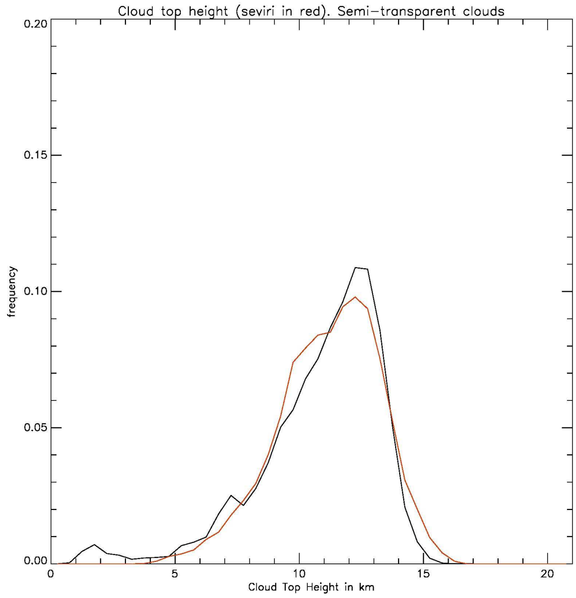


Figure 5 Left: probability Density Function of CTH(SEVIRI) – CTH(CPR). Right: Seviri (red) and CPR (black) cloud top height distribution. For semi-transparent clouds over full disk.

Bias and standard deviation for the previous and current versions are given in Table 19. The scatter between SEVIRI and CPR cloud top height is illustrated in Figure 5.

CTTH v2016 standard deviation are slightly worse than those obtained with v2013 although the algorithm in both version are the same, the reason is the larger number of cases for v2016 due to more clouds detected by CMA (cloud detection using online RTTOV has been added).

The CTTH v2016 reaches for semi-transparent clouds the threshold accuracy (bias: 2000m; std: 2000m). The target accuracy (bias: 1500m; std: 1500m) is reached for the bias but not for the standard deviation.

4.4 Assessment of Algorithm Quality

The CTTH v2016 reaches the threshold accuracy for both opaque clouds and semi-transparent clouds.

For opaque clouds, bias/standard deviation values obtained with CTTH v2016 (-490m/990m with lidar, -350m/820m with radar)) are lower than the threshold values (1000m/2000m) applicable to the current software version (see Table 20).

For semi-transparent clouds, bias/standard deviation values obtained with CTTH v2016 (-1440m/1970m with lidar, 210m/1880m with radar) are lower than the threshold values (2000m/2000m) applicable to the current software version (see Table 20).

	Opaque clouds with lidar (bias/std in km)	Opaque clouds with radar (bias/std in km)	Semitransparent Cloud with lidar (bias/std in km)	Semitransparent clouds with radar (bias/std in km)
v2013	-0.48km/0.99km	-0.34km/0.82km	-1.32km/1.98km	0.32km/1.85km
v2016	-0.49km/0.99km	-0.35km/0.82km	-1.44km/1.97km	0.21km/1.88km
Optimal accuracy	0.20km/0.50km	0.20km/0.50km	0.20km/0.50km	0.20km/0.50km
Target accuracy	0.50km/1.50km	0.50km/1.50km	1.50km/1.50km	1.50km/1.50km
Threshold accuracy	1.00km/2.00km	1.00km/2.00km	2.00km/2.00km	2.00km/2.00km

Table 20 Comparison of CTTH accuracies obtained with v2013 and v2016 to those listed in Product Requirement Table.

5 CLOUD MICROPHYSICS (GEO-CMIC) VALIDATION

5.1 OVERVIEW

5.1.1 General objectives of the validation

The main objective of this section is to document CMIC accuracies and compare them to the threshold accuracies listed in the NWCSAF product requirements document [AD. 4]. Additionally, CMIC cloud phase accuracy is compared to the one obtained with the previous version.

5.1.2 Methodology outline

The following validation of the CMIC product is performed:

- ✓ The CMIC cloud phase is validated against cloud phase obtained from space-born lidar (CALIOP) measurements gathered over full disk during the year 2010 (one day every three days). The POD (Percentage Of Detection) and FAR (False Alarm Ratio) for water phase and for ice phase are computed and compared to the threshold accuracy applicable to the current software version (see NWCSAF product requirements document [AD. 4]). The statistics are computed over full MSG disk.

- ✓ The CMIC cloud liquid water path is validated against passive microwave imagery (AMSR) gathered over full disk during the year 2010 (one day every three). This comparison is only valid over ocean in case rain is not observed. Bias and rms are computed and compared to the threshold accuracy applicable to the current software version (see NWCSAF product requirements document [AD. 4]). The statistics are computed over full MSG disk.

5.2 VALIDATION OF CMIC CLOUD PHASE WITH SPACE-BORN LIDAR MEASUREMENTS

A collocated dataset has been prepared covering 2010 (one day every three):

- Both the CT (Cloud Type) and the CMIC cloud phase computed from the SEVIRI slot closest in time to the CALIOP lidar measurements are stored. The SEVIRI data are kept not only below the CALIOP track but on a certain width so that it is possible to analyse the cloud spatial homogeneity. No parallax correction is applied. All the day passes (respectively the night passes) are stored on a single image.

- All the cloud layers detected by CALIOP and having an optical thickness larger than 0.2 are retained. The phase of their top is stored.

Furthermore, additional tests are performed before statistical scores are computed from this collocated dataset:

- A selection of homogeneous areas (area of 9*9 IR SEVIRI pixels) is performed: homogeneous cloud type in CT and CALIOP cloud top pressure variation less than 200hPa. The SEVIRI and CALIOP cloud phase are counted in these homogeneous areas before being used to compute statistical scores. Mixed phase cases are not retained.

- To limit the parallax effect, the viewing angles are limited to a maximum of 65 degrees, thus excluding the MSG disk edge.

Contingency table for water phase and for ice phase are built from which POD and FAR for respectively water and ice phase are computed (see section 2.2 for the definition of these statistical scores).

Water phase	Contingency table		FAR (%)	POD (%)
CMIC v2013	129976	8505	5.25	93.77
	7089	204373		
CMIC v2016	128922	8547	5.40	93.78
	7359	208536		

Table 21 Contingency, POD and FAR for water phase. Over full disk.

Ice phase	Contingency table		FAR (%)	POD (%)
CMIC v2013	204373	7089	4.00	96.65
	8505	127976		
CMIC v2016	208536	7359	3.94	96.59
	8547	128922		

Table 22 Contingency, POD and FAR for ice phase. Over full disk.

The CMIC v2016 cloud phase reaches over MSG full disk the threshold accuracy (POD (60.0%/70.0%) and FAR (35%)) and even the target accuracy (POD (80.0%) and FAR (20%)).

5.3 VALIDATION OVER OCEAN OF CMIC CLOUD LIQUID WATER PATH WITH PASSIVE MICROWAVE IMAGERY (AMSR)

SEVIRI cloud liquid water path are averaged inside each AMSR 0.25 degree grid box. The closest in time SEVIRI slot is used. The comparison is only valid over ocean. Some restrictions are applied: SEVIRI viewing angles are restricted to 65 degrees; only low clouds are retained and AMSR flagged as containing rain in the AMSR rain product are rejected.

Liquid Cloud Water Path	Bias (g/m^2)	rms (g/m^2)	Number of cases
CMIC v2016	-0.96	38.46	721830

Table 23 Liquid Cloud Water Path statistical scores for (LWP_SEVIRI-LWP_AMSR).Over full disk.

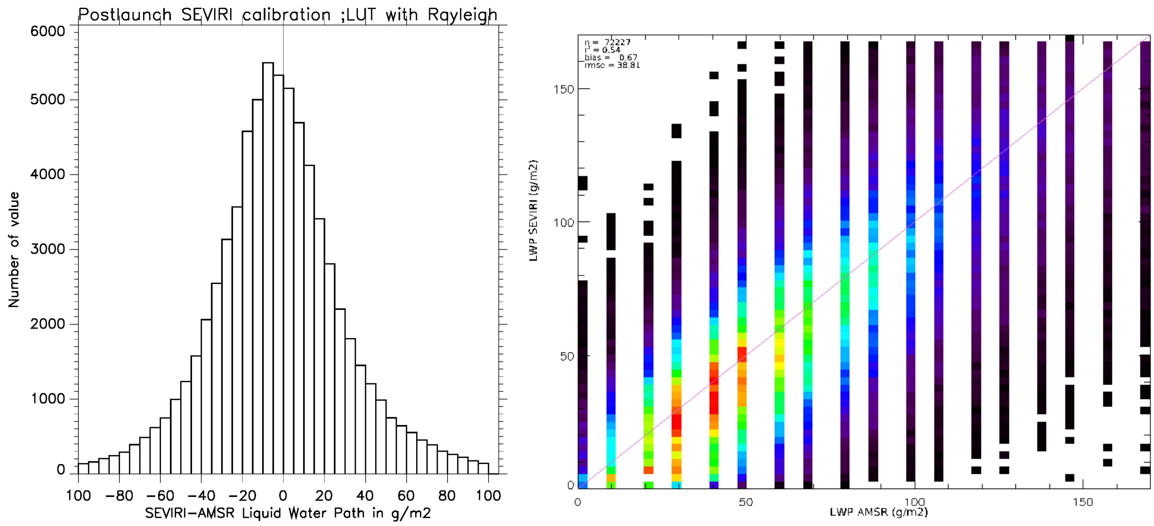


Figure 6 Probability Density Function of LWP(SEVIRI) – LWP(AMSR). Over full disk.

Bias and standard deviation for the current versions are given in Table 23. The scatter between SEVIRI and AMSR Liquid cloud Water Path is illustrated in Figure 6.

The CMIC v2016 Liquid Water Path reaches the threshold accuracy (bias: 20g/m^2; rms: 100g/m^2) and even the threshold accuracy ((bias: 10g/m^2; rms: 50g/m^2).

5.4 ASSESSMENT OF ALGORITHM QUALITY

The CMIC v2016 cloud phase reaches over MSG full disk the threshold accuracy applicable to the current software version. In fact the water and ice POD and FAR reached over MSG full disk by CMIC v2016 are 93.78%/96.59% and 5.40%/3.94% which is within the threshold values (POD: 60%/70% and FAR: 35%) (see Table 24).

The CMIC v2016 Liquid Water Path reaches the threshold accuracy applicable to the current software version. In fact the bias and rms reached over MSG full disk by CMIC v2016 Liquid Water Path (respectively -0.96 and 38.46 g/m^2) are lower than the threshold values (20g/m^2 and 100g/m^2) (see Table 24).

	Water clouds phase (POD/FAR in %)	Ice clouds phase (POD/FAR in %)	Cloud liquid water path (bias/rms in g/m^2)
v2013	93.77% / 5.25%	96.65% / 4.00%	
v2016	93.78% / 5.40%	96.59% / 3.94%	0.96 / 38.46
Optimal accuracy	90.0% / 10.0%	90.0% / 10.0%	5.0 / 20.0
Target accuracy	80.0% / 20.0%	80.0% / 20.0%	10.0 / 50.0
Threshold accuracy	70.0% / 35.0%	60.0% / 35.0%	20.0 / 100.0

Table 24 Comparison of CMIC accuracies obtained with v2013 and v2016 to those listed in Product Requirement Table.

ANNEX: TEST AND VALIDATION DATASET

ANNEX 1 INTERACTIVE TARGET DATABASE

An interactive tool, based on the use of the commercial image processing software WAVE, has been used by experienced operators for the extraction of visually identified satellite targets in SEVIRI images (area: full disk). The result of this work is a dedicated database for spectral signature studies that we call the Interactive Target Database. Such a database has already been gathered from GOES during prototyping activities. The interactive procedure allows:

- the display of various channels combination full resolution in satellite projection,
- the zoom of an area
- the choice of small square targets (configurable size, by default: 5*5 SEVIRI IR pixels)
- the labelling of the targets through a menu

The Interactive Target Database gathers the following information (detailed below) for each satellite target:

- the label given by the operator to the target (list displayed in Table 25 below),
- the full satellite information in the square targets together with satellite & solar angles and time information,
- the collocated and nearest in time meteorological information extracted from ARPEGE forecast fields,
- collocated atlas values.

Open sea	Sea with shadow	Sea with sand aerosols	Sea with ash
Sea with haze	Sea with sunglint	Sea with volcanic plume	
Land	Land with shadow	Land with sand aerosol	Land with ash
Land with Haze	Land with volcanic plume	Ice	Ice with shadow
Snow	Snow with shadow	Unclassified (cloudy or cloudfree)	Cloudy (unknown)
fog	stratus	Stratocumulus	shadow over low clouds
small cumulus over sea	Cumulus congestus over sea	small cumulus over land	Cumulus congestus over land
Cumulonimbus	Extensive cumulonimbus	Thin cirrus over sea	Thin Cirrus over ice
Thin cirrus over land	Thin cirrus over snow	Thin cirrus over St/Sc	Thin cirrus over Cu
Thin cirrus over Ac/As	Altocumulus/Altrostratus	Altocumulus	Cirrostratus
Cirrostratus over Ac/As			

Table 25 List of cloud & earth types available in the Interactive Target Database

At present time, interactive target have been extracted from MSG1/SEVIRI imagery from 2003 until 2005.

ANNEX 2 FORMAT FOR SEVIRI SATELLITE TARGET

Satellite targets are gathered, either manually with the Interactive Target Database, either automatically around synoptic meteorological stations.

Each satellite target window will be have a configurable size, the default size being 5 columns by 5 rows (3km IR pixel).

The satellite targets contain the following information that allows the reprocessing of PGE01-02-03 (for example to validate different versions) including the version using a temporal analysis as satellite data from previous slots are stored:

<u>Full satellite information in the square targets, together with satellite & solar angles and time information :</u>

type a*2 target type (in for interactive)
observer a*10 user name of the person who has analysed the target
lat i*4 latitude of the centre of the target (1000th of degrees)
lon i*4 longitude of the centre of the target (1000th of degrees)
date i*4 julian day (count from 00h, 1 Jan 1950)
hour i*4 UTC time of day in milliseconds
idsat i*4 satellite identification (1=MSG1, 2=MSG2, 3=MSG3)
nbp i*2 number of columns expressed in 3km IR coordinates
nbl i*2 number of rows expressed in 3km IR coordinates
nbc i*2 number of channels (7,10 or 11, according to day/night consideration and HRV availability)
valcan_VIS06 I*2 indicator of VIS0.6 availability
valcan_VIS08 I*2 indicator of VIS0.8 availability
valcan_IR16 I*2 indicator of IR1.6 availability
valcan_IR38 i*2 indicator of IR3.8 availability [-1 =not in the file
valcan_WV62 i*2 indicator of WV62 availability [0 =is missing
valcan_WV73 i*2 indicator of WV73 availability [>0 =mean value in the
valcan_IR87 i*2 indicator of IR87 availability [target(unit: 1/100 % or 1/100 K)]
valcan_IR97 i*2 indicator of IR97 availability
valcan_IR108 i*2 indicator of IR108 channel availability
valcan_IR120 i*2 indicator of IR120 channel availability
valcan_IR134 i*2 indicator of IR134 channel availability
valcan_HRV I*2 indicator of HRV availability
canal VIS06 x i*2 window from VIS06 (x = nbp*nbl) in 1/100 %
canal VIS08 x i*2 window from VIS08 (x = nbp*nbl) in 1/100 %
canal IR6 x i*2 window from IR16 (x = nbp*nbl) in 1/100 %
canal IR38 x i*2 window from IR38 (x = nbp*nbl) in 1/100 K
canal WV62 x i*2 window from WV62 (x = nbp*nbl) in 1/100 K
canal WV73 x i*2 window from WV73 (x = nbp*nbl) in 1/100 K
canal IR87 x i*2 window from IR87 (x = nbp*nbl) in 1/100 K
canal IR97 x i*2 window from IR97 (x = nbp*nbl) in 1/100 K
canal IR108 x i*2 window from IR108 (x = nbp*nbl) in 1/100 K
canal IR120 x i*2 window from IR120 (x = nbp*nbl) in 1/100 K
canal IR134 x i*2 window from IR134 (x = nbp*nbl) in 1/100 K
canal HRV x i*2 window from HRV (x = 3*nbp*3*nbl) in 1/100 %

solzen i*2 solar zenith angle (100th of degrees)
satzen i*2 satellite zenith angle (100th of degrees)
daz i*2 local azimuth angle (100th of degrees)s
typ_cloud i*2 target code (given by the observer , or –9999 if automatically fed)

Full CMa/CT/CTTH results in the square targets:

CMa main categories x i*1 window from CMa main categories (x = nbp*nbl)
CMa tests x i*2 window from CMa tests (x = nbp*nbl)
CMa quality flag x i*2 window from CMa quality flag (x = nbp*nbl
CT main categories x i*1 window from CT main categories (x = nbp*nbl)
CT quality flag x i*2 window from CT quality flag (x = nbp*nbl
CTTH top pressure x i*1 window from CTTH top pressure (x = nbp*nbl)
CTTH top temperature x i*1 window from CTTH top temperature (x = nbp*nbl)
CTTH top height x i*1 window from CTTH top height (x = nbp*nbl)
CTTH cloudiness x i*1 window from CTTH cloudiness (x = nbp*nbl)
CTTH quality flag x i*1 window from CTTH quality flag (x = nbp*nbl)

Collocated atlas values and climatological values :

land/sea x i*1 land/sea atlas (space=0, sea=2, land=3), (x = nbp*nbl)
land/sea/coast x i*1 land/sea/coast atlas (space=0, coast=1,sea=2, land=3), (x = nbp*nbl)
height x i*2 height atlas value (in meters), (x = nbp*nbl)
stt x i*2 sst climatological value (in 1/100 K), (x = nbp*nbl)
albedo x i*2 visible reflectance climatological value (in 1/100 %), (x = nbp*nbl)
h2o i*2 climatological integrated water vapor content (in 1/100 kg/m2)
T1000 i*2 climatological air temperature at 1000hPa (in 1/100 K)
T850 i*2 climatological air temperature at 850hPa (in 1/100 K)
T700 i*2 climatological air temperature at 700hPa (in 1/100 K)
T500 i*2 climatological air temperature at 500hPa (in 1/100 K)

Collocated and nearest in time meteorological information extracted from ARPEGE forecast fields (temperature & humidity vertical profile) [missing values : -9999] :

Modele a*7 name of modele (ARPEGE or ECMWF…)
Two set of forecast NWP fields are available (nearest in time before and after SEVIRI image):
date i*4 julian day of forecast day (count from 00h, 1 Jan 1950)
res i*4 hour of forecast
ech i*4 forecast term (in hour)
HeightNWP I*4 height of NWP grid (in meters)
psol i*4 ground pressure (1/100 hPa)
tsol i*4 ground temperature (1/100 K)
t2m i*4 2m air temperature (1/100 K)
hu2m i*4 2m air relative humidity (1/100 %)
nbniv I*4 number of pressure levels on the vertical
pniv 20 i*4 nbniv pressure level (in hPa)
tniv 20 i*4 temperature at nbniv pressure levels (1/100 K)
huniv 20 i*4 relative humidity at nbniv pressure levels (1/100 %)
ptropo i*4 pressure at tropopause level (1/100 hPa)
ttropo i*4 temperature at tropopause level (1/100 K)

W i*4 integrated water vapor content (in 1/100 kg/m2)

Spare values :

spare 30 i*4 spare data (not used)

ANNEX 3 SURFACE OBSERVATIONS (SYNOP AND SHIP) FOR CMA VALIDATION

The data used are the routine weather observations, coded by the observers into the WMO synoptic code (SYNOP or SHIP), gathered at Toulouse and made available to users through a METEO-FRANCE data base. From this data base we extract all the synoptic reports (coded in BUFR) from a list of land stations and for all ships inside the full MSG disk. The SYNOP network status is permanently evolving because several nations are replacing human cloud cover observations by automatic systems delivering cloud covers. For this reason we decided to keep from the initial database only the SYNOP whose $i_x < 4$ (in $i_R i_x$hVV group of section 1 of SYNOP, coded according to table code 1860 of the WMO manual on codes) because they are assumed to be manned station. Their spatial distribution over Europe is displayed on Figure 7. This set is the basis retained for our statistics

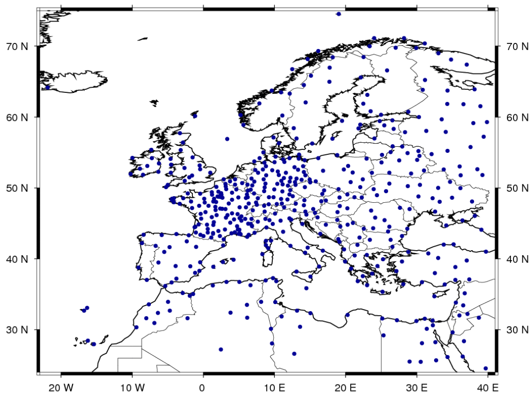


Figure 7 Geographical distribution of European SYNOP stations used in the statistics

To avoid cases where solar intrusion in IR 3.9 µm at night-time is significant, we also rejected from the selection all the matchups presenting a mean reflectance in SEVIRI VIS 0.6 µm greater than .9% with a sun zenithal angle greater than 93 degrees.

ANNEX 4 RADAR AND LIDARS SPACE-BORN MEASUREMENTS FOR CLOUD PHASE AND CLOUD HEIGHT VALIDATION

CALIOP is a lidar on board the CALIPSO polar orbiting satellite which is flying in a formation called A-train. In this study, the CALIOP operational level2 cloud layer boundary products (version V3.01) are used with 5km and 333m along-track resolution (70m across-track resolution). The altitude of every cloud layers (expressed in kilometres) is available in this dataset. The vertical resolution is 30m. Both day and night passes (at around 13h30 and 1h30 local time) are used in the study. These data are collocated and compared to SEVIRI from the closest in time slot (less than 7.5 minutes time difference). CALIOP lidar geophysical products are retrieved from the ICARE data centre at Lille/France.

CPR is a radar on board the CLOUDSAT polar orbiting satellite which is flying in a formation called A-train. In this study, the CPR operational GEOPROF level2 products (version R04) are used with 1.7km along-track resolution (1.3km across-track resolution). The altitude of every cloud layers (expressed in kilometres) is available in this dataset. The vertical resolution is 240m. Both day and night passes (at around 13h30 and 1h30 local time) are used in the study. These data are collocated and compared to SEVIRI from the closest in time slot (less than 7.5 minutes time difference). CPR radar geophysical products are retrieved from the ICARE data centre at Lille/France.

ANNEX 5 AMSR SPACE BORN MICROWAVE IMAGERY FOR CLOUD LIQUID WATER PATH VALIDATION OVER OCEAN

AMSR-E is a passive microwave radiometer on board aqua polar orbiting satellite. In this study, level3 ocean geophysical products (version 7) are used; they are daily available on a 0.25 degree grid for both ascending and descending orbits. We have used cloud liquid water and rain rate. Only day passes (at around 13h30 local time) are used in the study. These data are collocated and compared to SEVIRI from the closest in time slot (less than 7.5 minutes time difference). AMSR-E microwave daily geophysical products are retrieved from www.remss.com.