EUMETSAT

NWC SAF

SUPPORT TO NOWCASTING AND VERY SHORT RANGE FORECASTING

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

NWC/CDOP3/GEO/MF-CMS/SCI/VR/Cloud, Issue 1, Rev. 1

10 April 2019

Applicable to

GEO-CMA-v5.0	*(NWC-003)*
GEO-CT-v4.0	*(NWC-007)*
GEO-CTTH-v4.0	*(NWC-011)*
GEO-CMIC-v2.0	*(NWC-014)*

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DOCUMENT CHANGE RECORD

Version	Date	Pages	Changes
1.0d	15 June 2015	30	Draft version for STRR
1.0	15 Octobre 2016	33	Inclusion of STRR outcome
1.0	21 January 2019	45	Applicable to v2018
1.1	10 April 2019	50	Applicable to v2018. Update with GOES16 validation results

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1 INTRODUCTION

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

1.1 Scope of the document

This document is the cloud product validation report applicable to NWC/GEO software package v2018. 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 (V2016, reported in [RD.1.]).

1.2 Software Version Identification

The validation results presented in this document apply to the algorithms implemented in the release 2018 of the NWC/GEO software package (GEO-CMA-v5.0 (Product Id NWC-003), GEO-CT-v4.0 (Product Id NWC-007), GEO-CTTH-v4.0 (Product Id NWC-011) and GEO-CMIC-v2.0 (Product Id NWC-014)).

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.]	Project Plan for the NWCSAF CDOP3 phase	NWC/CDOP3/SAF/AEMET/MGT/PP	1.0	06/03/2018
[AD.3.]	Configuration Management Plan for the NWCSAF	NWC/CDOP3/SAF/AEMET/MGT/CMP	1.0	21/02/2018
[AD.4.]	NWCSAF Product Requirement Document	NWC/CDOP3/SAF/AEMET/MGT/PRD	1.0	January 2018
[AD.5.]	Data Output Format for the NWC/GEO	NWC/CDOP3/GEO/AEMET/SW/DOF	1.0	21/01/2019
[AD.6.]	Algorithm Theoretical Basis Document for the Cloud Product Processors of the NWC/GEO	NWC/CDOP2/GEO/MFL/SCI/ATBD/ Cloud	2.1	21/01/2019
[AD.7.]	The Nowcasting SAF glossary	NWC/CDOP2/SAF/AEMET/MGT/GLO	2.0	18/2/2014

Table1: 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.]	Scientific and validation report for Cloud Products Processors of the NWC/GEO	NWC/ CDOP2/GEO/MFL/SCI/VR/Cloud	1.0.	15/10/2016
[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
[RD.3.]	Scientific report on improving the cloud product processors of the NWC/GEO	NWC/CDOP2/GEO/MFL/SCI/RP/05	1.0.	27/02/2017
[RD.4.]	Scientific report on additional tuning of the cloud product processors of the NWC/GEO	NWC/CDOP3/GEO/MF-CMS/SCI/RP/01	1.0	21/01/2019

Table2: 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, 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 (only MSG) and over full 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 only for MSG
  - o The MSG CMA dust detection has been for long 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 MSG CMA dust detection has remained unchanged since last version (v2016).

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+h)], 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 MSG over Europe

The only change of MSG CMA cloud detection algorithm over Europe is the improvement over Aral Sea (see [RD.4.]) which is not noticeable in the validation results with SYNOP and SHIP.

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 for v2018 are displayed in the following table.

CMA v2018 MSG Europe	**POD (%)**	**FAR (%)**
All illumination :	97.1	4.0
Daytime :	98.4	2.1
Night-time :	96.0	7.3
Twilight :	95.6	1.8

Table4 CMA v2018 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 v2018 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 MSG over full disk

The only changes of MSG CMA cloud detection are the improvements over Aral Sea and over the desert in Africa (only twilight) (see [RD.4.]) which is not noticeable in the validation results with SYNOP and SHIP observations.

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 for v2018 are displayed in the following table.

CMA v2018 MSG full disk	POD (%)	FAR (%)
All illumination :	94.5	6.8
Daytime :	95.9	4.1
Night-time :	93.1	11.6
Twilight :	93.1	3.0

Table5 CMA v2018 performance in the detection of fully cloudy and cloud-free events estimated from collocated SHIP and SYNOP and MSG-2/SEVIRI observations over full disk for 2010. Stratified by illumination

The CMA v2018 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]).

2.2.3 Himawari over full disk

The dataset covers one full year (August 2015-July2016) two days per month..

Contingency tables and statistical scores have been computed for different illumination conditions (day, night, twilight) for SYNOP stations and SHIP all over the Himawari full disk on the time period August 2015-July2016 (two days per month). The results are displayed in the following table.

CMA v2018 Himawari full disk	POD (%)	FAR (%)
All illumination :	87,66	5.76
Daytime :	92,27	3,73
Night-time :	82,59	9,75
Twilight :	80,03	3,69

Table6 CMA v2018 performance in the detection of fully cloudy and cloud-free events estimated from collocated SHIP and SYNOP and Himawari8/AHI observations over full disk over time period August 2015-July 2016. Stratified by illumination

The CMA v2018 cloud detection reaches over Himawari full disk the threshold accuracy (POD: 80.0% and FAR: 20.0%)to be reached with SHIP/SYNOP over full disk (see NWCSAF product requirements document [AD. 4]).

2.2.4 GOES16 over full disk

The dataset covers one year (January-december2018) two days per month.

Contingency tables and statistical scores have been computed for different illumination conditions (day, night, twilight) for SYNOP stations and SHIP all over the GOES16 full disk on the time period January-december2018 (two days per month). The results are displayed in the following table.

CMA v2018 GOES16 full disk	POD (%)	FAR (%)
All illumination :	90,56	10.3
Daytime :	92.35	6.7
Night-time :	88,81	16.10
Twilight :	86.28	7.47

Table7 CMA v2018 performance in the detection of fully cloudy and cloud-free events estimated from collocated SHIP and SYNOP and GOES16/ABI observations over full disk over time period January-December 2018. Stratified by illumination

The CMA v2018 cloud detection reaches over GOES16 full disk the threshold accuracy (POD: 80.0% and FAR: 20.0%)to be reached with SHIP/SYNOP over full disk (see NWCSAF product requirements document [AD. 4]).

2.3 MSG CMA DUST FLAG VALIDATION USING INTERACTIVE TARGETS

As CMA dust detection algorithm has remained unchanged between v2016 and v2018, and as CMA dust detection v2016 already reached the threshold and even the target accuracy values for the CDOP2 period, this section is just a reminder of accuracies obtained for v2016.

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 Table9 and Table10.

	Contingency table (over sea)		FAR (%)	POD (%)
CMA v2018	728	583	4.5	55.5
	34	2643		

Table9 Dust flag performance over sea estimated from the Interactive Target Database

	Contingency table (over land)		FAR (%)	POD (%)
CMaAv2018	1294	918	1.5	58.5
	20	3131		

Table10 Dust flag performance over land estimated from the Interactive Target Database

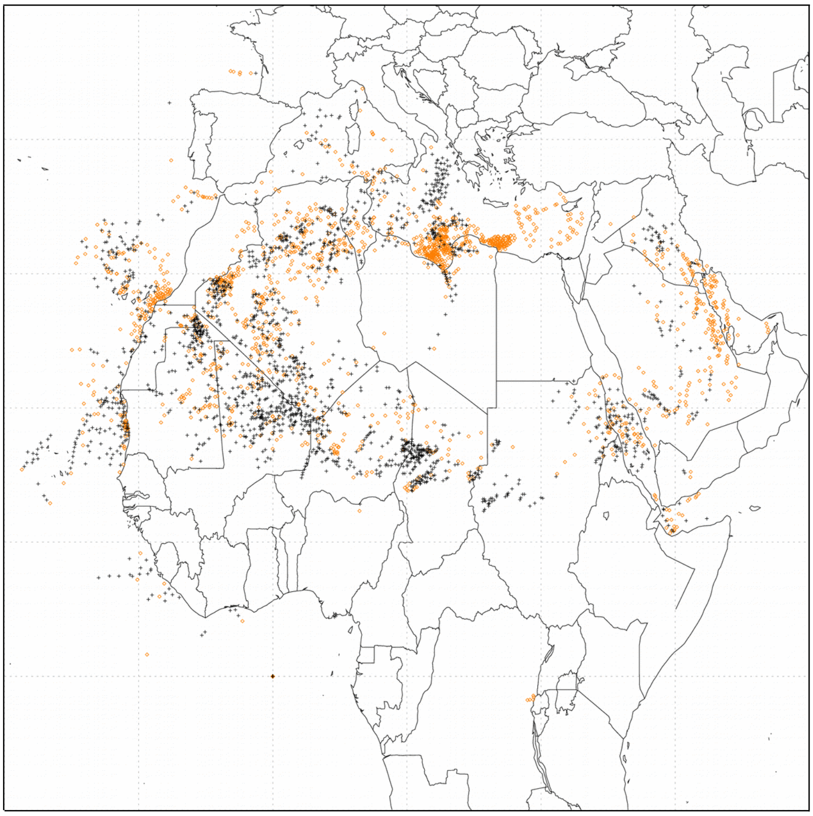

Figure 1 Localisation of the interactive targets corresponding to dust events. Black symbol and orange diamond correspond respectively to detected and non detected by the CMA dust flag.

Over land, the dust detection algorithm has remained unchanged and the POD and FAR reached by the CMA v2018 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 v2018 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

2.4.1 CMA algorithm quality for MSG

The MSG CMA v2018 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 v2018 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 Table11)..

For MSG	CMA over Europe (POD and FAR in %)	CMA over full disk (POD and FAR in %)

v2016	97.1% / 4.0%	94.5% / 6.8%
v2018	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%

Table11 Comparison of cloud MSG CMA accuracies obtained with v2016 and v2018 to those listed in Product Requirement Table.

The MSG CMA v2018 dust detection, which remained unchanged since last version (v2016), 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 Table12)..

For MSG	Dust flag over ocean (POD and FAR in %)	Dust flag over land ((POD and FAR in %)
v2016	55.5% / 4.5%	58.5% / 1.5%
v2018	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%

Table12 Comparison of MSG dust flag accuracies obtained with v2016 and v2018 to those listed in Product Requirement Table.

2.4.2 CMA algorithm quality for Himawari

The Himawari CMA v2018 cloud detection reaches the threshold accuracies applicable to the current software version. In fact the POD and FAR reached over full disk by CMA v2018 are 87,66% and 5,76% which are within the threshold accuracy (POD: 80% and FAR: 20.%) to be reached over Himawari full disk (see Table13)..

For Himawari	CMA over full disk (POD and FAR in %)
v2018	87,66% / 5,76%
Optimal accuracy	95.0% / 10.0%

Target accuracy	90.0% / 15.0%
Threshold accuracy	80.0% / 20.0%

Table13 Comparison of cloud Himawari CMA accuracies obtained with v2018 to those listed in Product Requirement Table.

2.4.3 CMA algorithm quality for GOES16

There is no commitment for GOES16 processing. We have nevertheless checked the compliance of GOES16 products with Himawari requirements.

The GOES16 CMA v2018 cloud detection reaches the threshold accuracies applicable to the current software version. In fact the POD and FAR reached over full disk by CMA v2018 are 90,56% and 10.3% which are within the threshold accuracy (POD: 80% and FAR: 20.%) to be reached over GOES16 full disk (see table belowTable13).

For GOES16	CMA over full disk (POD and FAR in %)
v2018	90,56% / 10.3%
Optimal accuracy	95.0% / 10.0%
Target accuracy	90.0% / 15.0%
Threshold accuracy	80.0% / 20.0%

Table14 Comparison of cloud GOES16 CMA accuracies obtained with v2018 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.].

3.1.2 Methodology outline

The following validation of the CT product is performed:

- ✓ The MSG CT cloud type has been for long 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.]). The MSG CT has remained unchanged since last version (v2016).
- ✓ A new method to validate the CT cloud type has been developed, based on the use of space born lidar measurements (CALIOP). This method which does not need an interactively gathered database, will be used in the future for all satellites. Similarly, a "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 either ARPEGE (for the interactive target database) or ECMWF (four times per day (0h, 6h, 12h and 18h) at a 1.5 degree horizontal resolution.

3.2 MSG CT COMPARISON WITH INTERACTIVE TARGET DATABASE

As CT algorithm has remained unchanged between v2016 and v2018, and as CT v2016 already reached the threshold and even the target accuracy values for the CDOP2 period, this section is just a reminder of accuracies obtained for v2016.

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 Table15 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

Table15 Equivalence between manually labelled targets and CT types

CT v2016 and v2018 (MSG full disk)	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 %
Night-time	94.15 %	63.54 %	80.59 %	88.79 %
Twilight	95.68 %	42.50 %	79.31 %	83.33 %

Table16 Users accuracy for each main cloud classes estimated from the Interactive Target database stratified by illumination. Over MSG full disk.

Table16 shows that the users accuracies obtained by CT v2018 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 Validation of CT with space born lidar measurements

A collocated dataset has been prepared over a time period and location depending on the processed satellite:

- The CT computed from the satellite slot closest in time to the CALIOP lidar measurements is stored. The satellite 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 are retained. Their type (available in the Feature Classification flag), top and bottom altitude and optical depth 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 pixels) is performed both in CALIOP and CT. An area is homogeneous when more than 70 pixels from the box belong to the same class (low, mid-level, semitransparent or high). The higher cloud layer detected by CALIOP and having an optical thickness larger than 0.2 is retained to be compared with the CT.
- To limit the parallax effect, the viewing angles are limited to a maximum of 65 degrees, thus excluding the disk edge.

The CT and the CALIOP parameters are first analysed and gathered into the main classes described in Table17 before being compared. As clear and cloud confusions have been analysed in CMA validation section, the analysis is limited to cases identified as cloudy by the CALIOP and CT.

Main Classes name	CALIOP parameters	CT type
Low	Low, overcast, transparent Low, overcast, opaque Transition stratocumulus Low, broken cumulus	Very low clouds Low clouds
Mid-level cloud	Altocumulus (transparent) with optical depth > 1.3 Altostratus (opaque)	Medium clouds
Semitransparent	Altocumulus (transparent) with optical depth <= 1.3 Cirrus (transparent)	Cirrus above lower clouds Thin cirrus Mean and thick cirrus
High clouds	Deep convective (opaque)	High opaque clouds Very high opaque clouds

Table17 Equivalence between CALIOP cloud parameters and CT types

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).

3.3.1 Himawari over full disk

CT v2018 Himawari	Low clouds	Mid-level clouds	Semitransparent	High clouds
All illumination	87.94%	54.39 %	75.89 %	88.34 %
Daytime	86.82 %	58.07 %	69.96 %	87.73 %
Night-time	88.83 %	51.64 %	80.60 %	89.02 %

Table18 CT v2018 users accuracy for each main cloud classes computed from collocated CALIOP and Himawari8/AHI observations over full disk over time period August 2015-July 2016. Stratified by illumination

More than 20% of the clouds classified as semitransparent clouds by the CT are classified as Deep convective in the lidar dataset. In the same way, 29% of the clouds classified as mid-level clouds by the CT are classified as Deep convective in the lidar dataset.

There are not enough twilight pixels in the CALIOP dataset to compute statistical scores exclusively for twilight.

3.3.2 MSG over full disk

CT v2018 MSG	Low clouds	Mid-level clouds	Semitransparent	High clouds
All illumination	94.35%	67.98%	75.33%	92.42%
Daytime	93.78%	72.40%	68.71%	91.77%
Night-time	94.86%	64.75%	79.50%	93.29%

Table19 v2018 users accuracy for each main cloud classes computed from collocated CALIOP and MSG/SEVIRI observations over full disk for 2010. Stratified by illumination

There are not enough twilight pixels in the CALIOP dataset to compute statistical scores exclusively for twilight.

Results of the validation of the cloud type with space born lidar measurements are consistent with those of the validation with the interactive target database. Scores are even higher, except for the classification of semitransparent clouds.

More than 19% of the clouds classified as semitransparent clouds by the CT are classified as Deep convective in the lidar dataset. In the same way, 22% of the clouds classified as mid-level clouds by the CT are classified as Deep convective in the lidar dataset.

3.3.3 GOES16 over full disk

The dataset covers one year (January-December2018) two days per month.

CT v2018 GOES16	Low clouds	Mid-level clouds	Semitransparent	High clouds
All illumination	91.13%	60.10 %	75.18 %	82.90 %
Daytime	88.68 %	59.93 %	69.55 %	81.30 %
Night-time	92.51 %	60.27 %	80.18 %	84.49 %

Table20 CT v2018 users accuracy for each main cloud classes computed from collocated CALIOP and GOES16/ABI observations over full disk over time period January-December 2018. Stratified by illumination

There are not enough twilight pixels in the CALIOP dataset to compute statistical scores exclusively for twilight.

3.4 Assessment of algorithm quality

3.4.1 CT algorithm quality for MSG

The MSG CT v2018 cloud type, which remains unchanged since v2016, reaches the threshold accuracy applicable to the current software version.

When using interactive target database (see 3.2 and Table 21), the user accuracies obtained by CT v2018 for low clouds (91.30%), high clouds (86.60%) and semi-transparent clouds (87.75%) are far above the threshold accuracy (50%).

MSG	Low clouds (POD in %)	Semitransparent (POD in %)	High clouds (POD in %)
v2016	91.30%	87.75%	86.60%
v2018	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 21 Comparison of MSG CT accuracies obtained with v2016 and v2018 to those listed in Product Requirement Table (when Interactive target database used see 3.2) .

This is also the case when using CALIOP lidar measurements (see 3.3.2 and Table22): the user accuracies obtained by CT v2018 for low clouds (94.35%), high clouds (92.42%) and semi-transparent clouds (75.33%) are far above the threshold accuracy (50%) , and even the target accuracy.

MSG	Low clouds (POD in %)	Semitransparent (POD in %)	High clouds (POD in %)
v2018	94.35%	75.33%	92.42%
Optimal accuracy	90.0%	90.0%	90.0%
Target accuracy	70.0%	70.0%	70.0%
Threshold accuracy	50.0%	50.0%	50.0%

Table22 Comparison of MSG CT accuracies obtained with v2018 to those listed in Product Requirement Table (when CALIOP lidar measurements are used see 3.3.2) .

3.4.2 CT algorithm quality for Himawari

The Himawari CT v2018 cloud type reaches the threshold accuracy applicable to the current software version: the user accuracies obtained by CT v2018 for low clouds (87.94%), high clouds (88.34%) and semi-transparent clouds (75.89%) are above the threshold accuracy (50%) , and even above the target accuracy (70%) (see 3.3.1 and Table 23).

Himawari	Low clouds (POD in %)	Semitransparent (POD in %)	High clouds (POD in %)
v2018	87.94%	75.89%	88.34%
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 23 Comparison of Himawari CT accuracies obtained with v2018 to those listed in Product Requirement Table.

3.4.3 CT algorithm quality for GOES16

There is no commitment for GOES16 processing. We have nevertheless checked the compliance of GOES16 products with Himawari requirements.

The GOES16 CT v2018 cloud type reaches the threshold accuracy applicable to the current software version: the user accuracies obtained by CT v2018 for low clouds (91.13%), high clouds (82.90%) and semi-transparent clouds (75.18%) are above the threshold accuracy (50%), and even above the target accuracy (70%) (see 3.3.3 and table below).

GOES16	Low clouds (POD in %)	Semitransparent (POD in %)	High clouds (POD in %)
v2018	91.13%	75.18%	82.90%

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 24 Comparison of GOES16 CT accuracies obtained with v2018 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 top altitude is validated against cloud top height obtained from space-born lidar (CALIOP) and radar (CPR) measurements gathered over full disk. 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 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 over a time period and location depending on the processed satellite:

- Both the CT (Cloud Type) and the CTH (Cloud Top altitude) computed from the satellite slot closest in time to the CALIOP lidar measurements are stored. The satellite 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 pixels) is performed: homogeneous cloud type in CT and CALIOP cloud top pressure variation less than 200hPa. The satellite 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 disk edge.

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

4.2.1 MSG over full disk

The dataset covers the year 2010 (one day every 3).

4.2.1.1 Opaque clouds

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

Opaque clouds MSG full disk	Bias (km)	Standard deviation (km)	Number of cases
CTTH v2016	-0.49	0.99	295140
CTTH v2018	-0.46	0.93	304152

Table25 Opaque clouds statistical scores for (CTH(SEVIRI)-CTH(CALIOP)).Over full disk.

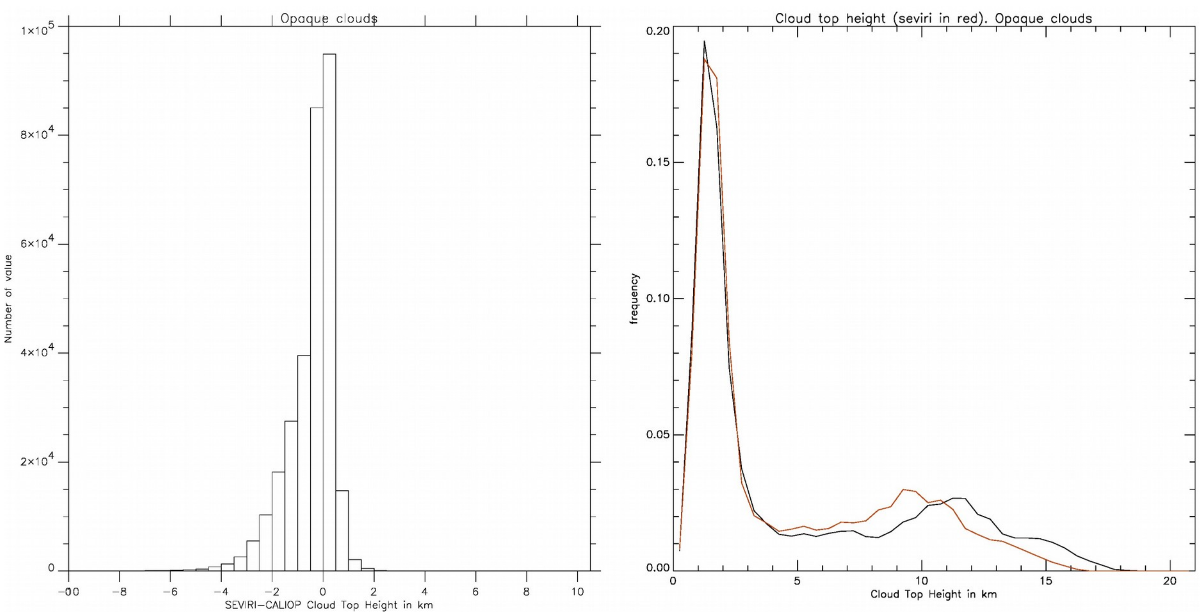

Figure 2 Left: probability Density of CTH(SEVIRI) – CTH(CALIOP). Right: Seviri (red) and CALIOP (black) cloud top height distribution. For opaque clouds over full disk.v2018.

Bias and standard deviation for the previous and current versions are given for opaque clouds in Table25. The scatter between MSG/SEVIRI and CALIOP cloud top height is illustrated in Figure 2.

Both CTTH v2018 bias and standard deviation are slightly lower than those obtained with v2016.

The CTTH v2018 reaches for opaque clouds the threshold accuracy (bias: 1000m; std: 2000m) and even the threshold accuracy (bias: 750m; std: 1500m).

4.2.1.2 Semi-transparent clouds

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

Semi-transparent clouds MSG full disk	Bias (km)	Standard deviation (km)	Number of cases
CTTH v2016	-1.44	1.97	142509
CTTH v2018	-1.26	2.02	145702

Table26 Semi-transparent clouds statistical scores for (CTH(SEVIRI) -CTH(CALIOP)).Over full disk

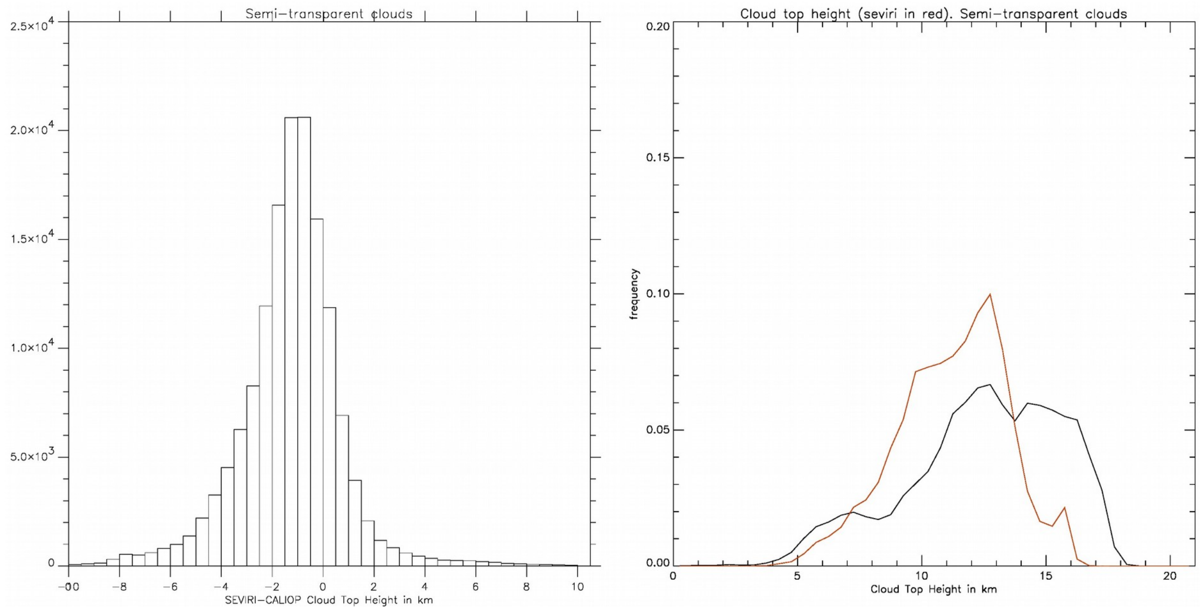

Figure 3 Left: probability Density Function of CTH(SEVIRI) – CTH(CALIOP). Right: Seviri (red) and CALIOP (black) cloud top height distribution. For semi-transparent clouds over full disk.v2018.

Bias and standard deviation for the previous and current versions are given in Table26. The scatter between MSG/SEVIRI and CALIOP cloud top height is illustrated in Figure 3.

When compared to CTTH v2016, bias is slightly lower (-120m) whereas standard deviation is slightly higher (+50m).

The CTTH v2018 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.

4.2.2 Himawari over full disk

The dataset covers one full year (August 2015-July2016) two days per month..

4.2.2.1 Opaque clouds

In this section, we analyse Himawari/AHI CTH retrieval for opaque clouds using lidar measurements.

Opaque clouds Himawari full disk	Bias (km)	Standard deviation (km)	Number of cases
CTTH v2018	-0.82	1.21	82684

Table 27 Opaque clouds statistical scores for (CTH(AHI) – CTH(CALIOP)).Over full disk.

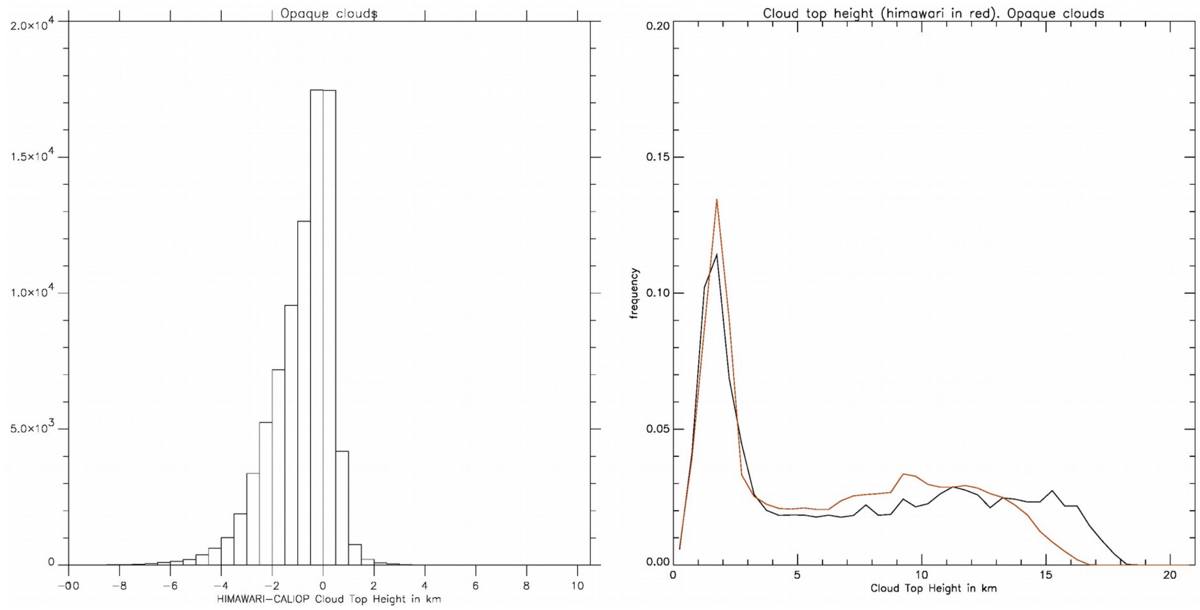

Figure 4 Left: probability Density of CTH(AHI) – CTH(CALIOP). Right: AHIi (red) and CALIOP (black) cloud top height distribution. For opaque clouds over full disk.v2018.

Bias and standard deviation for the previous and current versions are given for opaque clouds in Table 27. The scatter between Himawari/AHI and CALIOP cloud top height is illustrated in Figure 6.

The CTTH v2018 reaches for opaque clouds the threshold accuracy (bias: 1000m; std: 2000m).

4.2.2.2 Semi-transparent clouds

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

Semi-transparent clouds Himawari full disk	Bias (km)	Standard deviation (km)	Number of cases
CTTH v2018	-1.41	2.19	42327

Table 28 Semi-transparent clouds statistical scores for (CTH(AHI) -CTH(CALIOP)).Over full disk

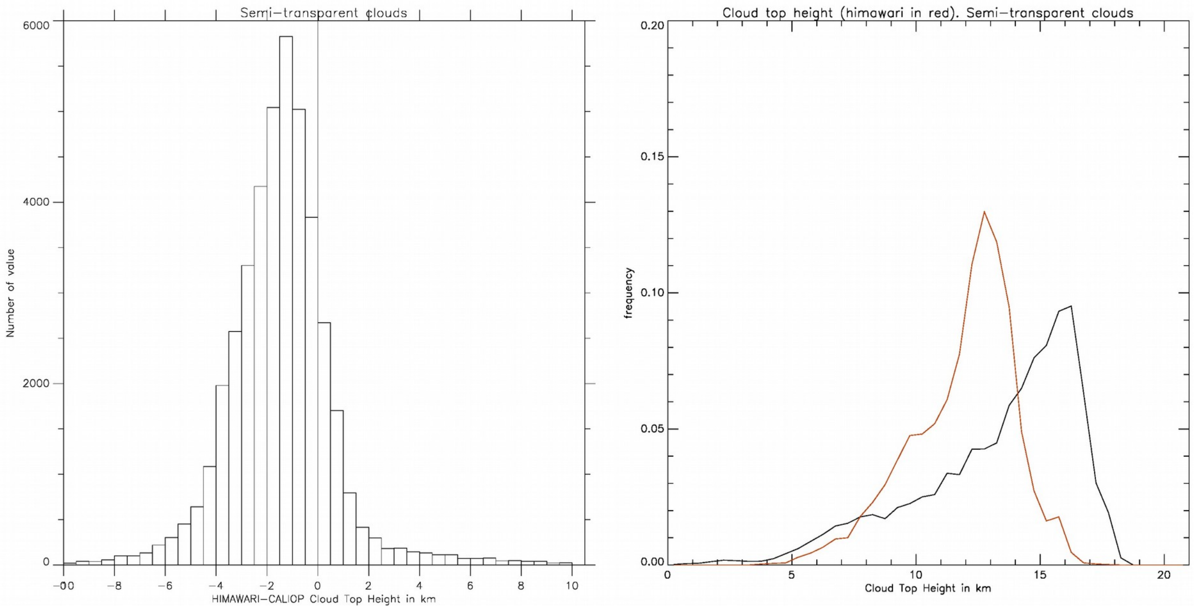

Figure 5 Left: probability Density Function of CTH(AHI) – CTH(CALIOP). Right: AHI (red) and CALIOP (black) cloud top height distribution. For semi-transparent clouds over full disk.v2018.

Bias and standard deviation for the previous and current versions are given in Table 28. The scatter between Himawari/AHI and CALIOP cloud top height is illustrated in Figure 7.

The CTTH v2018 reaches for semi-transparent clouds the threshold accuracy (bias: 2000m; std: 2500m).

4.2.3 GOES16 over full disk

The dataset covers one year (January-December2018) two days per month.

4.2.3.1 Opaque clouds

In this section, we analyse GOES16/ABI CTH retrieval for opaque clouds using lidar measurements.

Opaque clouds GOES16 full disk	Bias (km)	Standard deviation (km)	Number of cases
CTTH v2018	-0.62	1.12	50498

Table 29 Opaque clouds statistical scores for (CTH(ABI) – CTH(CALIOP)).Over full disk.

The CTTH v2018 reaches for opaque clouds the threshold accuracy (bias: 1000m; std: 2000m).

4.2.3.2 Semi-transparent clouds

In this section, we analyse GOES16/ABI CTH retrieval for semi-transparent clouds using lidar measurements.

Semi-transparent clouds GOES16 full disk	Bias (km)	Standard deviation	Number of cases

		(km)	
CTTH v2018	-1.00	2.01	20086

Table 30 Semi-transparent clouds statistical scores for (CTH(ABI) -CTH(CALIOP)).Over full disk

The CTTH v2018 reaches for semi-transparent clouds the threshold accuracy (bias: 2000m; std: 2500m).

4.3 VALIDATION OF CTTH ALTITUDE WITH SPACE-BORN RADAR MEASUREMENTS

A collocated dataset has been prepared over a time period and location depending on the processed satellite:

- Both the CT (Cloud Type) and the CTH (Cloud Top altitude) computed from the satellite slot closest in time to the CPR radar measurements are stored. The satellite 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 pixels) is performed: homogeneous cloud type in CT and CPR altitude variation less than 3km. The satellite 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 disk edge.

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

4.3.1 MSG over full disk

The dataset covers the year 2010 (one day every 3).

4.3.1.1 Opaque clouds

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

Opaque clouds MSG full disk	Bias (km)	Standard deviation (km)	Number of cases
CTTH v2016	-0.35	0.82	320132

CTTH v2018	-0.31	0.73	333877

Table31 Opaque clouds statistical scores for (CTH_SEVIRI-CTH_CPR).Over full disk

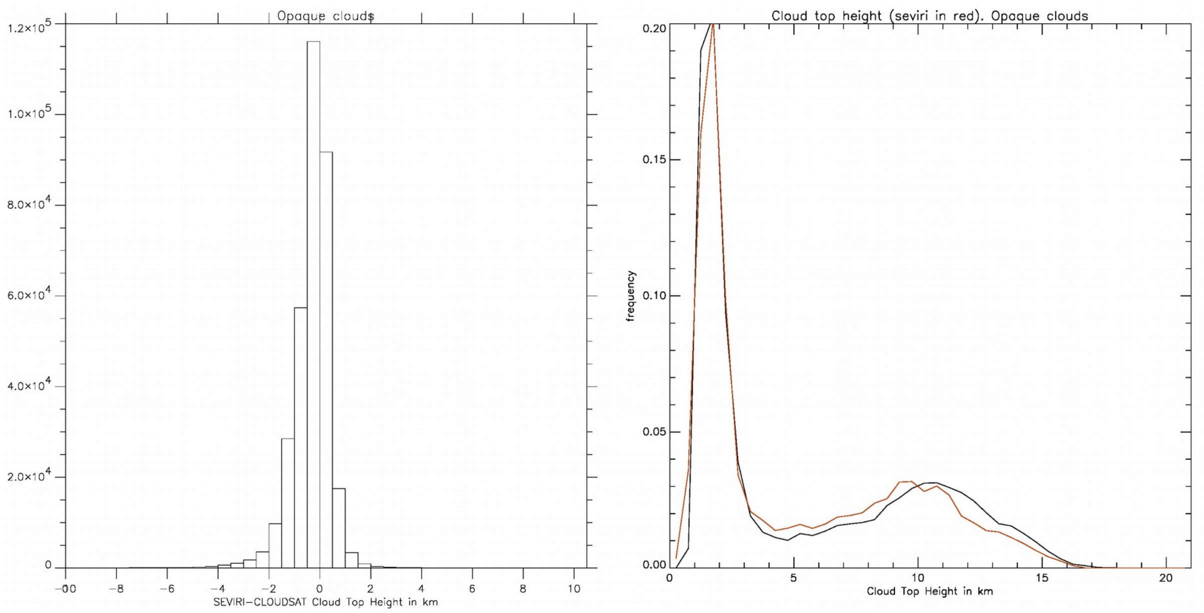

Figure 6 Left: probability Density Function of CTH(SEVIRI) – CTH(CPR). Right: Seviri (red) and CPR (black) cloud top height distribution. For opaque clouds over full disk. v2018.

Bias and standard deviation for the previous and current versions are given in Table31. The scatter between MSG/SEVIRI and CPR cloud top height is illustrated in Figure 6.

Both CTTH v2018 bias and standard deviation are slightly lower than those obtained with v2016.

The CTTH v2018 reaches for opaque clouds the threshold accuracy (bias: 1000m; std: 2000m) and even the target accuracy (bias: 750m; std: 1500m).

4.3.1.2 Semi-transparent clouds

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

Semi-transparent clouds MSG full disk	Bias (km)	Standard deviation (km)	Number of cases
CTTH v2016	0.21	1.88	145924
CTTH v2018	0.44	1.90	146027

Table32 Semi-transparent clouds statistical scores for (CTH(SEVIRI)-CTH(CPR)).Over full disk.

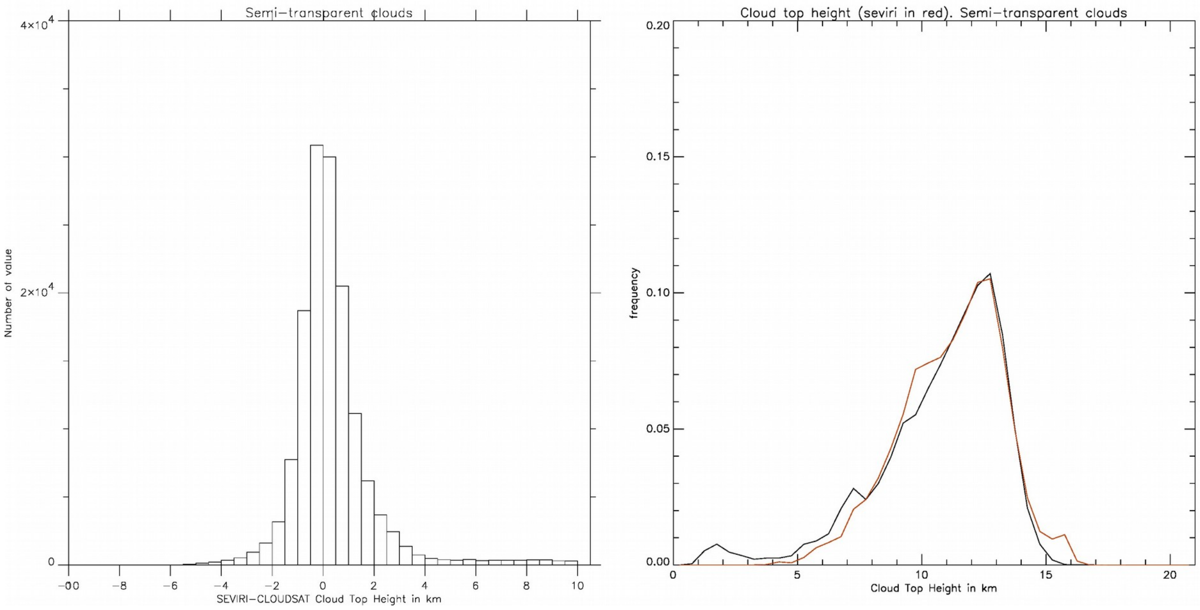

Figure 7 Left: probability Density Function of CTH(SEVIRI) – CTH(CPR). Right: Seviri (red) and CPR (black) cloud top height distribution. For semi-transparent clouds over full disk. v2018.

Bias and standard deviation for the previous and current versions are given in Table32. The scatter between MSG/SEVIRI and CPR cloud top height is illustrated in Figure 7.

When compared to CTTH v2016, bias and standard deviation are both higher (+230m and +20m). But it must be kept in mind that radar data tends to underestimate semi-transparent cloud top height. So an increase of the bias between seviri and the radar does not automatically in a decrease of the quality, as long as the bias remains rather small which is the case. When CALIOP are used, a decrease of the bias has been observed (see 4.2.1.2).

The CTTH v2018 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.

4.3.2 Himawari over full disk

The dataset covers one full year (August 2015-July2016) two days per month.

4.3.2.1 Opaque clouds

In this section, we analyse Himawari/AHI CTH retrieval for opaque clouds using radar measurements.

Opaque clouds Himawari full disk	Bias (km)	Standard deviation (km)	Number of cases
CTTH v2018	-0.56	0.96	57973

Table33 Opaque clouds statistical scores for (CTH(AHI) –CTH(CPR)).Over full disk

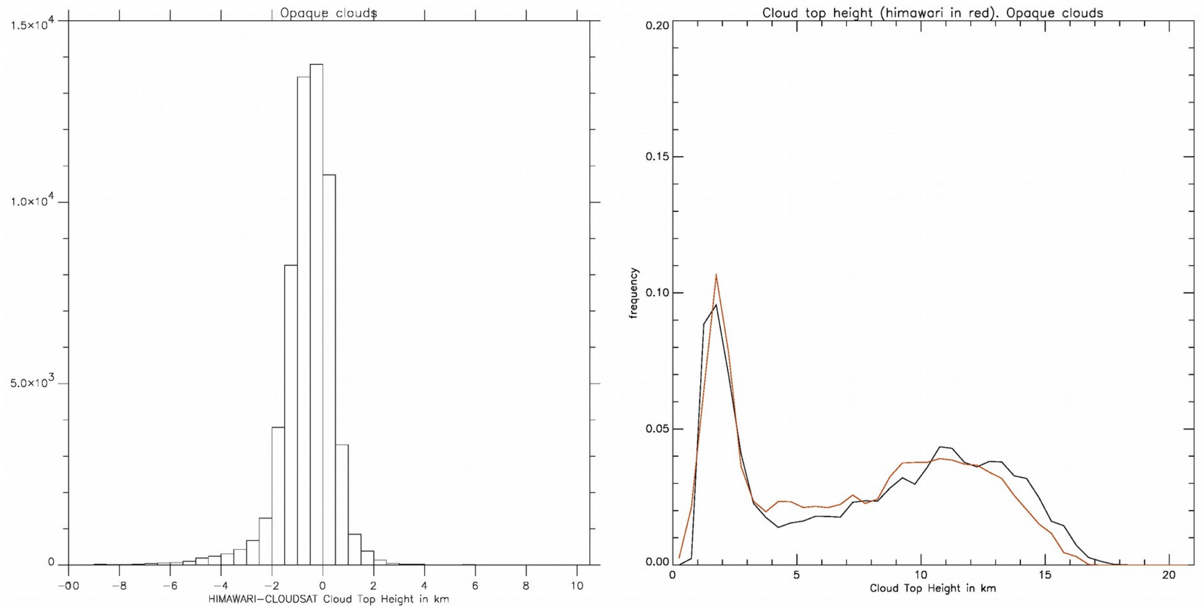

Figure 8 Left: probability Density Function of CTH(AHI) – CTH(CPR). Right: AHI (red) and CPR (black) cloud top height distribution. For opaque clouds over full disk. v2018.

Bias and standard deviation for the previous and current versions are given in Table33. The scatter between Himawari/AHI and CPR cloud top height is illustrated in Figure 8.

The CTTH v2018 reaches for opaque clouds the threshold accuracy (bias: 1000m; std: 2000m) and even the target accuracy (bias: 750m; std: 1500m).

4.3.2.2 Semi-transparent clouds

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

Semi-transparent clouds Himawari full disk	Bias (km)	Standard deviation (km)	Number of cases
CTTH v2018	0.50	2.06	23600

Table34 Semi-transparent clouds statistical scores for (CTH(AHI)-CTH(CPR)).Over full disk.

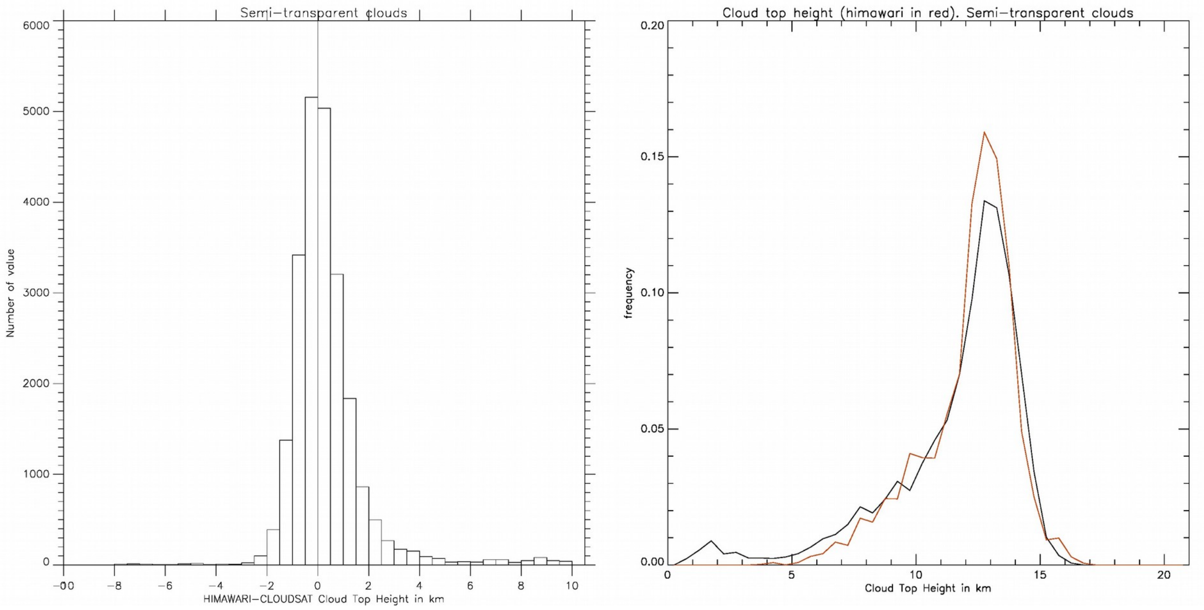

Figure 9 Left: probability Density Function of CTH(AHI) – CTH(CPR). Right: AHI (red) and CPR (black) cloud top height distribution. For semi-transparent clouds over full disk. v2018.

Bias and standard deviation for the previous and current versions are given in Table34. The scatter between Himawari/AHI and CPR cloud top height is illustrated in Figure 9.

The CTTH v2018 reaches for semi-transparent clouds the threshold accuracy (bias: 2000m; std: 2500m).

4.3.3 GOES16 over full disk

No Cloudsat/CPR radar data were available for the period (January-December2018).

4.4 Assessment of algorithm quality

4.4.1 CTTH algorithm quality for MSG

The MSG CTTH v2018 reaches the threshold accuracy for both opaque clouds and semi-transparent clouds.

For opaque clouds, bias/standard deviation values obtained with CTTH v2018 (-460m/930m with lidar, -310m/730m with radar)) are lower than the threshold values (1000m/2000m) applicable to the current software version (see Table 35).

For semi-transparent clouds, bias/standard deviation values obtained with CTTH v2018 (-1260m/2020m with lidar, 440m/1900m with radar) are lower than the threshold values (2000m/2000m) applicable to the current software version (see Table 35), except for the standard deviation using lidar which exceeds the threshold values by 20m.

MSG full disk	Opaque clouds with lidar	Opaque clouds with radar	Semitransparent Cloud with lidar	Semitransparent clouds with radar

	(bias/std in km)	(bias/std in km)	(bias/std in km)	(bias/std in km)
v2016	-0.49km/0.99km	-0.35km/0.82km	-1.44km/1.97km	0.21km/1.88km
v2018	-0.46km/0.93km	-0.31km/0.73km	-1.26km/2.02km	0.44km/1.90km
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 35 *Comparison of MSG CTTH accuracies obtained with v2016 and v2018 to those listed in Product Requirement Table*.

4.4.2 CTTH algorithm quality for Himawari

The Himawari CTTH v2018 reaches the threshold accuracy for both opaque clouds and semi-transparent clouds.

For opaque clouds, bias/standard deviation values obtained with CTTH v2018 (-825m/1215m with lidar, -560m/960m with radar)) are lower than the threshold values (1000m/2000m) applicable to the current software version (see Table 36).

For semi-transparent clouds, bias/standard deviation values obtained with CTTH v2018 (-1409m/2190m with lidar, 496m/2057m with radar) are lower than the threshold values (2000m/2500m) applicable to the current software version (see Table 36).

Himawari full disk	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)
v2018	-0.82km/1.21km	-0.56km/0.96km	-1.41km/2.19km	0.50km/2.06km
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/2.50km	2.00km/2.50km

Table 36 Comparison of Himawari CTTH accuracies obtained with v2018 to those listed in Product Requirement Table.

4.4.3 CTTH algorithm quality for GOES16

There is no commitment for GOES16 processing. We have nevertheless checked the compliance of GOES16 products with Himawari requirements.

The GOES16 CTTH v2018 reaches the threshold accuracy for both opaque clouds and semi-transparent clouds.

For opaque clouds, bias/standard deviation values obtained with CTTH v2018 (-616m/1125m with lidar)) are lower than the threshold values (1000m/2000m) applicable to the current software version (see table below).

For semi-transparent clouds, bias/standard deviation values obtained with CTTH v2018 (-1000m/2014m with lidar) are lower than the threshold values (2000m/2500m) applicable to the current software version (see table below).

GOES16 full disk	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)
v2018	-0.62km/1.12km	No data	-1.00km/2.01km	No data
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/2.50km	2.00km/2.50km

Table 37 Comparison of GOES16 CTTH accuracies obtained with v2018 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. 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 disk.
- ✓ The CMIC cloud liquid water path is validated against passive microwave imagery (AMSR) gathered over full disk. 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 disk.

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

A collocated dataset has been prepared over a time period and location depending on the processed satellite:

- Both the CT (Cloud Type) and the CMIC cloud phase computed from the satellite slot closest in time to the CALIOP lidar measurements are stored. The satellite 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 pixels) is performed: homogeneous cloud type in CT and CALIOP cloud top pressure variation less than 200hPa. The satellite 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 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).

5.2.1 MSG over full disk

The dataset covers the year 2010 (one day every 3).

Water phase MSG	Contingency table		FAR (%)	POD (%)
CMIC v2016	128922	8547	5.40	93.78
	7359	208536		
CMIC v2018	132701	8755	5.43	93.81
	7628	213213		

Table38 Contingency, POD and FAR for water phase. Over MSG full disk.

Ice phase MSG	Contingency table		FAR (%)	POD (%)
CMIC v2016	208536	7359	3.94	96.59
	8547	128922		
CMIC v2018	213213	7628	3.94	96.54
	8755	132701		

Table39 Contingency, POD and FAR for ice phase. Over MSG full disk.

The v2016 and v2018 POD and FAR values are very similar. It must be noted that the better account of the rayleight scattering in CMIC (see [RD.4.]) allows a better coherency between simulation and measurements and consequently a larger number of pixels can be correctly classified as water or ice (ie without degrading the FAR).

The MSG CMIC v2018 cloud phase reaches over full disk the threshold accuracy (POD (60.0%/70.0%) and FAR (35%)) and even the target accuracy (POD (80.0%) and FAR (20%)).

5.2.2 Himawari over full disk

The dataset covers one full year (August 2015-July2016) two days per month.

Water phase Himawari	Contingency table	FAR (%)	POD (%)

CMIC v2018	26445	2313	6.69	91.96
	1896	68262		

Table40 Contingency, POD and FAR for water phase. Over Himawari full disk.

Ice phase Himawari	Contingency table		FAR (%)	POD (%)
CMIC v2018	68262	1896	3.28	97.30
	2313	26445		

Table41 Contingency, POD and FAR for ice phase. Over Himawari full disk.

The Himawari CMIC v2018 cloud phase reaches over full disk the threshold accuracy (POD (60.0%/ 70.0%) and FAR (35%)) and even the target accuracy (POD (80.0%) and FAR (20%)).

5.2.3 GOES16 over full disk

The dataset covers one year (January-December2018) two days per month.

Water phase GOES16	Contingency table		FAR (%)	POD (%)
CMIC v2018	19404	2219	5.63	89.74
	1157	32955		

Table42 Contingency, POD and FAR for water phase. Over GOES16 full disk.

Ice phase GOES16	Contingency table		FAR (%)	POD (%)
CMIC v2018	32955	1157	6.31	96.61
	2219	19404		

Table43 Contingency, POD and FAR for ice phase. Over GOES16 full disk.

The GOES16 CMIC v2018 cloud phase reaches over 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)

Satellite cloud liquid water path are averaged inside each AMSR 0.25 degree grid box. The closest in time satellite slot is used. The comparison is only valid over ocean. Some restrictions are applied: satellite 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.

5.3.1 MSG over full disk

The dataset covers the year 2010 (one day every 3).

Liquid Cloud Water Path MSG full disk	Bias (g/m^2)	rms (g/m^2)	Number of cases
CMIC v2016	-0.96	38.46	721830
CMIC v2018	5.45	32.75	724365

Table44 Liquid Cloud Water Path statistical scores for (LWP(SEVIRI)-LWP(AMSR)).Over full disk.

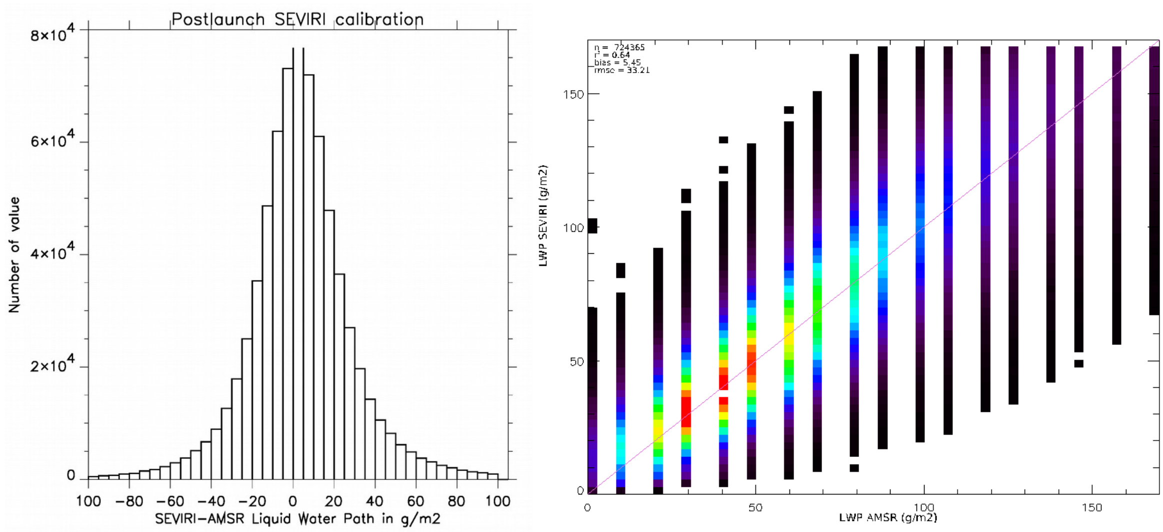

Figure 10 Probability Density Function of LWP(SEVIRI) – LWP(AMSR). Over full disk.

Bias and standard deviation for the current versions are given in Table44. The scatter between MSG/SEVIRI and AMSR Liquid cloud Water Path is illustrated in Figure 10.

When compared to CMIC v2016, an increase of the bias and a decrease of rms have been observed (see Table44). In fact, the decrease of the rms indicates a better account of the illumination as shown in [RD.4.] through a comparison using microwave imagery (ssmi,tmi,windsat) with different local time and therefore different illumination conditions.

The MSG CMIC v2018 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).

5.3.2 Himawari over full disk

The dataset covers one full year (August 2015-July2016) two days per month.

Liquid Cloud Water Path Himawari full disk	Bias (g/m^2)	rms (g/m^2)	Number of cases

CMIC v2018	6.28	36.39	120819

Table45 Liquid Cloud Water Path statistical scores for (LWP(AHI)-LWP(AMSR)).Over full disk.

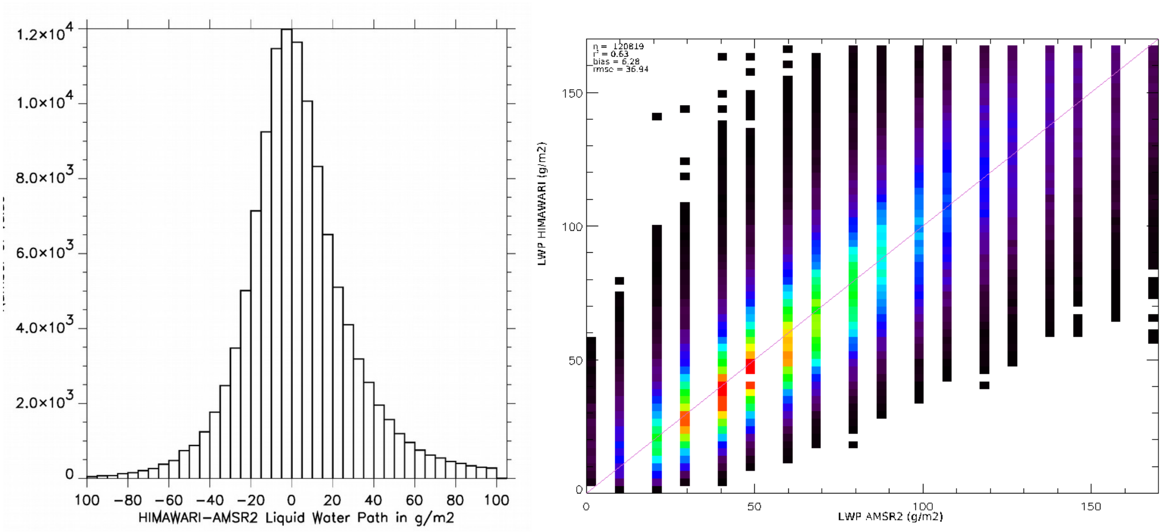

Figure 11 Probability Density Function of LWP(AHI) – LWP(AMSR). Over full disk.

Bias and standard deviation for the current versions are given in Table45. The scatter between Himawari/AHI and AMSR Liquid cloud Water Path is illustrated in Figure 11.

The Himawari CMIC v2018 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).

5.3.3 GOES16 over full disk

The dataset covers one year (January-December2018) two days per month.

Liquid Cloud Water Path GOES16 full disk	Bias (g/m^2)	rms (g/m^2)	Number of cases
CMIC v2018	0.17	44.66	90965

Table46 Liquid Cloud Water Path statistical scores for (LWP(ABI)-LWP(AMSR)).Over full disk.

Bias and standard deviation for the current versions are given in above table.

The GOES16 CMIC v2018 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

5.4.1 CMIC algorithm quality for MSG

The MSG CMIC v2018 cloud phase reaches over full disk the threshold accuracy applicable to the current software version. In fact the water and ice POD and FAR reached over full disk by CMIC v2018 are 93.81%/96.54% and 5.43%/3.94% which is within the threshold values (POD: 60%/70% and FAR: 35%) (see Table 47).

The MSG CMIC v2018 Liquid Water Path reaches the threshold accuracy applicable to the current software version. In fact the bias and rms reached over full disk by CMIC v2018 Liquid Water Path (respectively 5.45 and 32.75 g/m^2) are lower than the threshold values (20g/m^2 and 100g/m^2) (see Table 47).

MSG full disk	Water clouds phase (POD/FAR in %)	Ice clouds phase (POD/FAR in %)	Cloud liquid water path (bias/rms in g/m^2)
v2016	93.78% / 5.40%	96.59% / 3.94%	0.96 / 38.46
v2018	93.81% / 5.43%	96.54% / 3.94%	5.45 / 32.75
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 47 Comparison of MSG CMIC accuracies obtained with v2016 and v2018 to those listed in Product Requirement Table.

5.4.2 CMIC algorithm quality for Himawari

The Himawari CMIC v2018 cloud phase reaches over full disk the threshold accuracy applicable to the current software version. In fact the water and ice POD and FAR reached over full disk by CMIC v2018 are 91.96%/97.30% and 6.69%/3.28% which is within the threshold values (POD: 60%/70% and FAR: 35%) (see Table48).

The Himawari CMIC v2018 Liquid Water Path reaches the threshold accuracy applicable to the current software version. In fact the bias and rms reached over full disk by CMIC v2018 Liquid Water Path (respectively 6.28 and 36.39 g/m^2) are lower than the threshold values (20g/m^2 and 100g/m^2) (see Table48).

Himawari full disk	Water clouds phase (POD/FAR in %)	Ice clouds phase (POD/FAR in %)	Cloud liquid water path (bias/rms in g/m^2)
v2018	91.96% / 6.69%	97.30% / 3.28%	6.28 / 36.39

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

Table48 Comparison of Himawari CMIC accuracies obtained with v2016 and v2018 to those listed in Product Requirement Table.

5.4.3 CMIC algorithm quality for GOES16

There is no commitment for GOES16 processing. We have nevertheless checked the compliance of GOES16 products with Himawari requirements.

The GOES16 CMIC v2018 cloud phase reaches over full disk the threshold accuracy applicable to the current software version. In fact the water and ice POD and FAR reached over full disk by CMIC v2018 are 89.74%/96.61% and 5.63%/6.31% which is within the threshold values (POD: 60%/70% and FAR: 35%) (see table below).

The GOES16 CMIC v2018 Liquid Water Path reaches the threshold accuracy applicable to the current software version. In fact the bias and rms reached over full disk by CMIC v2018 Liquid Water Path (respectively 0.17 and 44.86 g/m^2) are lower than the threshold values (20g/m^2 and 100g/m^2) (see table below).

GOES16 full disk	Water clouds phase (POD/FAR in %)	Ice clouds phase (POD/FAR in %)	Cloud liquid water path (bias/rms in g/m^2)
v2018	89.74% / 5.63%	96.61% / 6.31%	0.17 / 44.86
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

Table49 Comparison of GOES16 CMIC accuracies obtained with v2018 to those listed in Product Requirement Table.

ANNEX: TEST AND VALIDATION DATASET

ANNEX 1 SEVIRI 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 Table50 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			

Table50 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:

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

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 12. This set is the basis retained for our statistics

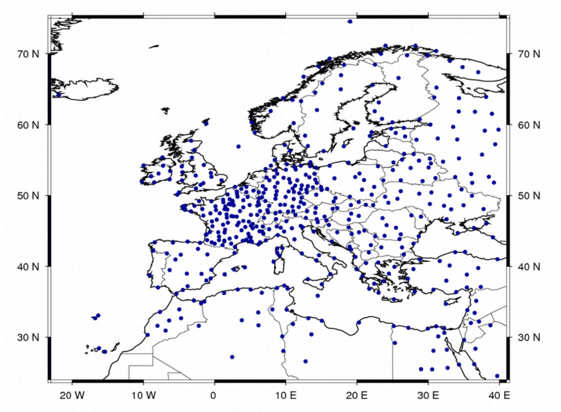

Figure 12 Geographical distribution of European SYNOP stations used in the statistics

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 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 DUST FLAG, CLOUD TYPE, 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, type and optical depth of every cloud/aerosol layers (expressed in kilometres) are 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 meteorological geostationary satellite data from the closest in time slot (less than 7.5 minutes time difference for SEVIRI). 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 (expressed in kilometres) and type of every cloud layers are 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 meteorological geostationary satellite data from the closest in time slot (less than 7.5 minutes time difference for SEVIRI). 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/AMSR-2 are passive microwave radiometers on board 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 meteorological geostationary satellite data from the closest in time slot (less than 7.5 minutes time difference for SEVIRI). AMSR-E/AMSR-2 microwave daily geophysical products are retrieved from www.remss.com.