The EUMETSAT Network of Satellite Application Facilities

NWC SAF

Support to Nowcasting and Very Short Range Forecasting

Algorithm Theoretical Basis Document for the Precipitation Product Processors of the NWC/GEO MTG-I day-1

NWC/CDOP2/MTG/AEMET/SCI/ATBD/Precipitation, Issue 1, Rev. 0d

17 January 2017

Applicable to

GEO-PC-MTG (NWC-020)
GEO-CRR-MTG (NWC-025)
GEO-PC-Ph-MTG (NWC-079)
GEO-CRR-Ph-MTG (NWC-083)

Prepared by AEMET

REPORT SIGNATURE TABLE

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DOCUMENT CHANGE RECORD

This is the first version of the document, which is based on the Algorithm Theoretical Basis Document for the Precipitation Product Processors of the NWC/GEO.

Changes describe bellow refer to this document.

Version	**Date**	Pages	CHANGE(S)
1.0d	*17 January 2017*	69	Adaptation to MTG FCI and LI of the MSG Precipitation Products

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1. INTRODUCTION

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

1.1 SCOPE OF THE DOCUMENT

This document is the Algorithm Theoretical Basis Document for the precipitation products Precipitating Clouds (PC), Convective Rainfall Rate (CRR) and Precipitation products from Cloud Physical Properties (PPh) of the NWC/MTG software package. PPh generates two different products: Precipitating Clouds from Cloud Physical Properties (PC-Ph) and Convective Rainfall rate from Cloud Physical Properties (CRR-Ph).

The Algorithm Theoretical Basis Document describes the physics of the problem together with the mathematical description of the algorithm. It also provides information on the objectives, the needed input data and the outputs of the products.

1.2 SOFTWARE VERSION IDENTIFICATION

This document describes the algorithms implemented in the release MTG-I day-1 of the NWC-GEO software package (GEO-PC-MTG, GEO-CRR-MTG, GEO-PC-Ph-MTG and GEO-CRR-Ph-MTG).

1.3 IMPROVEMENT FROM PREVIOUS VERSION

NWCSAF/MTG software package will be an evolution of NWCSAF/GEO software packages. These technical improvements have been implemented:

- Better spatial and temporal resolution.
- Technical adaptation to use lightning data from MTG Lightning Imager (LI).
- Adaptation to Himawari8. This adaptation is purely technical in order to use Himawari8 channels, but no validation has been performed for this satellite.

The MTG-I day1 release of NWC/GEO is planned 3 years after NWC/GEO v2018, but the ATBD have been reviewed at the same time.

1.4 DEFINITIONS, ACRONYMS AND ABBREVIATIONS

AEMET	Agencia Estatal de Meteorología
ATBD	Algorithm Theoretical Basis Document
BALTRAD	Baltic Radar Network
CAPPI	Constant Altitude Plan Position Indicator
COT	Cloud Optical Thickness
CRR-Ph	Convective Rainfall Rate from Cloud Physical Properties
CRR	Convective Rainfall Rate
CSI	Critical Success Index
CT	Cloud Type
CTMP	Cloud Top Microphysical Properties
CWP	Cloud Water Path
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FAR	False Alarm Ratio
FCI	Flexible Combined Imager
HRIT	High Rate Information Transmission
ICD	Interface Control Document
ICP	Illumination Conditions Parameter
IQF	Illumination Quality Flag
IR	Infrared
LI	Lightning Imager
MAE	Mean Absolute Error
ME	Mean Error
MRV	Maximum Reflectivity in the Vertical
MSG	Meteosat Second Generation
MTG	Meteosat Third Generation
NIR	Near Infrared
NWCLIB	Nowcasting SAF Library
NWC SAF	Satellite Application Facility for Nowcasting
PC	Precipitating Clouds
PC	Percentage of Corrects
PC-Ph	Precipitating Clouds from Cloud Physical Properties
PGE	Product Generation Element
POD	Probability of Detection
PoP	Probability of Precipitation
PPh	Precipitation from Cloud Physical Properties
PWRH	Moisture Correction Factor

R_{eff}	Effective Radius
RLR	Rainfall-Lightning Ratio
RMSE	Root Mean Square Error
RR	Rain Rate
SAF	Satellite Application Facility
SEVIRI	Spinning Enhanced Visible and Infrared Imager
SW	Software
2-V	2-Variable
3-V	3-Variable
VIS	Visible
VIS-N	Normalized Visible
WV	Water Vapour

1.5 REFERENCES

1.5.1 Applicable Documents

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

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

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

Reference	Title	Code	Vers	Date
[AD. 1]	Proposal for the Second Continuous Development and Operations Phase (CDOP) March 2012 – February 2017	NWC/CDOP2/MGT/AEMET/PRO	1.0	15/03/11
[AD. 2]	NWCSAF Project Plan	NWC/CDOP2/SAF/AEMET/MGT/PP	1.10	25/11/16
[AD 3]	Configuration Management Plan for the NWC SAF	NWC/CDOP2/SAF/AEMET/MGT/CMP	1.4	15/10/16
[AD 4]	NWCSAF Product Requirements Document	NWC/CDOP2/SAF/AEMET/MGT/PRD	1.10d	

Table 1: List of Applicable Documents

1.5.2 Reference Documents

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

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

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

Reference	Title	Code	Vers	Date
[RD 1]	Algorithm Theoretical Basis Document for SAFNWC/MSG “Precipitating Cloud” (PC-PGE04 v1.5)	SAF/NWC/CDOP2/SMHI/SCI/ATBD/4	1.5.4	15/07/13
[RD 2]	Scientific and Validation Report for the Precipitation Product Processors of the NWC/GEO	NWC/CDOP2/GEO/AEMET/SCI/VR/Precipitation	1.0	15/10/16
[RD 3]	Data Output Format for the NWC/GEO	NWC/CDOP2/GEO/AEMET/SW/DOF	1.1	15/01/15
[RD 4]	Interface Control Document for Internal and External Interfaces of the NWC/GEO	NWC/CDOP2/GEO/AEMET/SW/ICD/1	1.1	15/01/15
[RD 5]	User Manual for the Precipitation Product Processors of the NWC/GEO	NWC/CDOP2/GEO/AEMET/SCI/UM/Precipitation	1.0	15/10/16
[RD 6]	Algorithm Theoretical Basis Document for the Cloud Product Processors of the NWC/GEO	NWC/CDOP2/GEO/MFL/SCI/ATBD/Cloud	1.1	15/10/16
[RD 7]	Software User Manual of the Parallax Correction Processor of the NWC/GEO	NWC/CDOP2/GEO/AEMET/SW/SUM/PLAX	1.0d	18/05/15
Reference	Title	Code	Vers	Date
[RD 8]	Algorithm Theoretical Basis Document for SAFNWC/MSG “Precipitating Cloud” (PC-PGE04 v1.5)	SAF/NWC/CDOP2/SMHI/SCI/ATBD/4	1.5.4	15/07/13
[RD 9]	Scientific and Validation Report for the Precipitation Product Processors of the NWC/GEO	NWC/CDOP2/GEO/AEMET/SCI/VR/Precipitation	1.0	15/10/16
[RD 10]	Data Output Format for the NWC/GEO	NWC/CDOP2/GEO/AEMET/SW/DOF	1.1	15/01/15
[RD 11]	Interface Control Document for Internal and External Interfaces of the NWC/GEO	NWC/CDOP2/GEO/AEMET/SW/ICD/1	1.1	15/01/15
[RD 12]	User User Manual for the Precipitation Product Processors of the NWC/GEO	NWC/CDOP2/GEO/AEMET/SCI/UM/Precipitation	1.0	15/10/16
[RD 13]	Algorithm Theoretical Basis Document for the Cloud Product Processors of the NWC/GEO	NWC/CDOP2/GEO/MFL/SCI/ATBD/Cloud	1.1	15/10/16
[RD 14]	Software User Manual of the Parallax Correction Processor of the NWC/GEO	NWC/CDOP2/GEO/AEMET/SW/SUM/PLAX	1.0d	18/05/15

Reference	Title	Code	Vers	Date
[RD 15]	Algorithm Theoretical Basis Document for SAFNWC/MSG “Precipitating Cloud” (PC-PGE04 v1.5)	SAF/NWC/CDOP2/SMHI/SCI/ATBD/4	1.5.4	15/07/13

Reference	Title	Code	Vers	Date
[RD 16]	Scientific and Validation Report for the Precipitation Product Processors of the NWC/GEO	NWC/CDOP2/GEO/AEMET/SCI/VR/Precipitation	1.0	15/10/16
[RD 17]	Data Output Format for the NWC/GEO	NWC/CDOP2/GEO/AEMET/SW/DOF	1.1	15/01/15
[RD 18]	Interface Control Document for Internal and External Interfaces of the NWC/GEO	NWC/CDOP2/GEO/AEMET/SW/ICD/1	1.1	15/01/15
[RD 19]	User Manual for the Precipitation Product Processors of the NWC/GEO	NWC/CDOP2/GEO/AEMET/SCI/UM/Precipitation	1.0	15/10/16
[RD 20]	Algorithm Theoretical Basis Document for the Cloud Product Processors of the NWC/GEO	NWC/CDOP2/GEO/MFL/SCI/ATBD/Cloud	1.1	15/10/16
[RD 21]	Software User Manual of the Parallax Correction Processor of the NWC/GEO	NWC/CDOP2/GEO/AEMET/SW/SUM/PLAX	1.0d	18/05/15

Table 2: List of Referenced Documents

2. DESCRIPTION OF PRECIPITATING CLOUDS (PC) PRODUCT

Refer to Algorithm Theoretical Basis Document for SAFNWC/MSG “PrecipitatingCloud” (PC-PGE04 v1.5) **¡Error! No se encuentra el origen de la referencia.**].

2.1 PRECIPITATING CLOUDS (PC) OVERVIEW

This product is an adaptation of PC for MSG to MTG. The adaptation is purely technical in order to use the MTG FCI channels, but no improvement in the algorithm, tuning or validation has been performed.

The relatively weak coupling between spectral features in the visible and infrared channels with precipitation rate for all situations except for strong convection makes it in most cases doubtful to try to assign precipitation rates from FCI data alone. However it is possible to statistically determine the likelihood of from visible and infrared spectral signatures in a FCI scene. The PC product for MTG is thus to be seen as a complement of the convective rain rate product, which specifically addresses convective situations, and the rapidly developing thunderstorm product, which also takes into account the time evolution of systems. The precipitating cloud product can serve as a general tool for Nowcasting of precipitation, especially for areas where no surface radar data is available. It should however be noted, that the nature of the input data usually leads to an overestimation of the precipitating area.

2.2 PRECIPITATING CLOUDS (PC) ALGORITHM DESCRIPTION

2.2.1 General algorithm design

The precipitating clouds product gives the likelihood of precipitation. Validation and prototyping for earlier software versions have shown that there is no skill in trying to stratify Total precipitation likelihood into light to moderate precipitation and strong precipitation. As a consequence only the total precipitation likelihood is now reported as class 1:

- Class 1: precipitation >0.1 mm/h
- Class2: obsolete, set to zero

A linear combination of those spectral features, which have the highest correlation with precipitation, is used to construct a Precipitation index PI. For each value of the PI, the probability of precipitation in the respective classes is then determined from a comprehensive dataset of co-located satellite data, precipitation rates from rain gauge measurements and surface temperatures from NWP.

In the calculation of the PI special attention has been given to spectral features in the visible, which implicitly contain information on cloud microphysical properties at the cloud top, such as effective radius and cloud phase. The algorithm employed is cloud type dependent in the sense that mapping from PI to precipitation likelihood makes use of cloud type dependent lookup tables. For the PI calculation a day and a night version exists, where the night version only makes use of IR channels not influenced by sunlight.

2.2.2 Data used for algorithm development and tuning

Tuning had to be performed over the central Europe. Since not enough systematic radar data sets were available for tuning of the SEVIRI algorithm to radar, SYNOP current weather reports (October2003 – August 2004) and French rain gauge data (January 2004 – December 2004) were used for tuning. The current default configuration for algorithm version 1.5 has been unchanged since version 1.3 (released spring 2007) and uses a cloud type dependent tuning based on French Gauge data. There is also the option to configure the algorithm for a previous version of tuning released with v1.2. This older tuning is independent of cloud type, and based on European SYNOP reports for current weather. It is however not recommended to change to this option because of inferior algorithm performance. Validation results for version 1.2 and the versions identical to the current default algorithm version are reported in the validation report Scientific and Validation Report for the Precipitation Product Processors of the NWC/GEO **¡Error! No se encuentra el origen de la referencia.**.

A precipitation index PI is calculated using the same formula for all cloud types, but mapping to likelihood is performed cloud type dependent. Validation results are reported in Scientific and Validation Report for the Precipitation Product Processors of the NWC/GEO **¡Error! No se encuentra el origen de la referencia.**.

	Precipitation Frequency [%]	Precipitation Frequency [%]	Algorithm number used for potentially raining cloud types (
Cloud type	French gauges	Hungarian gauges	
1 –cloud free land	**0,6**	**0,1**	
2 –cloud free sea	**0,1**	**-**	
3 –snow/ice land	**4,0**	**3,9**	
4 –snow/ice sea	**-**	**-**	
5 –very low Cu	**-**	**-**	
6 –very low St	**1,9**	**0,5**	
7 –low Cu	**-**	**-**	
8 –low St	**7,7**	**4,3**	**Not considered raining, might need adjustment**
9 -medium Cu	**-**	**-**	**Algorithm 1**
10 -medium St	**21,5**	**13,3**	**Algorithm 1**
11 -high&opaque Cu	**-**	**-**	**Algorithm 2**
12 - high&opaque St	**30,3**	**31,4**	**Algorithm 2**
13 -v. high&op Cu	**-**	**-**	**Algorithm 2**
14 -v. high&op St	**43,6**	**35,4**	**Algorithm 2**
15 – thin Ci	**1,4**	**0,9**	
16 - mod. Thick Ci	**3,6**	**2,4**	
17 – thick Ci	**13,1**	**11,0**	**Algorithm 3**

18 –Ci above lower cloud	**5,1**	**3,9**	**Algorithm 4**
19[2)] Fractional cloud	**1,2**	**0,5**	

Table 3: Total likelihood of precipitation for different cloud types as compared to collocated French rain gauge data and Hungarian gauge data for Jan-Dec 2004. Rain gauge data averaged over 30 minutes

2.2.3 Algorithm details

It was investigated which spectral features of SEVIRI were most correlated with precipitation. The Precipitation Index PI is constructed as a linear combination of those spectral features which are most correlated with precipitation as to maximise the correlation of PI and precipitation.

We have chosen a Precipitation Index of the form:

PI=a0 +a1*Tsurf +a2*T108+a3*(T108-T120) +a4*abs(a5-R06/R16)

+a6*R06+ a7*R16+a8*T062+a9*T073+a10*T039) *Eq.1*

This formulation will allow to specify different day and night algorithms and to easily tune the algorithm by just providing different coefficient files, for example for different cloud types. In the current implementation however, algorithms for different cloud type groups are using the same set of coefficients, but a cloud type specific mapping of PI to precipitation likelihood.

Cloud type groups are defined as follows:

Algorithm 0: all cloudtypes. In version 1.2 PI coefficients from tuning to synop current weather observations are supplied, together with tables for matching PI to precipitation likelihood. Use of this algorithm is not recommended. Instead the cloud type dependent algorithms tuned on French gauge data and outlined below should be used, as supplied in the standard configuration since version 1.3.

Algorithms 1 to 4 are tuned on French gauge data (average over 30 minutes). Coefficient sets for these algorithms are identical since version 1.3, but mapping of the resulting PI to precipitation likelihood is cloud type dependent:

Algorithm 1: cloud type 9,10 = medium level opaque cloud

Algorithm 2: cloud types 11 – 14 = high and very high opaque cloud

Algorithm 3: cloud type 17 = thick cirrus

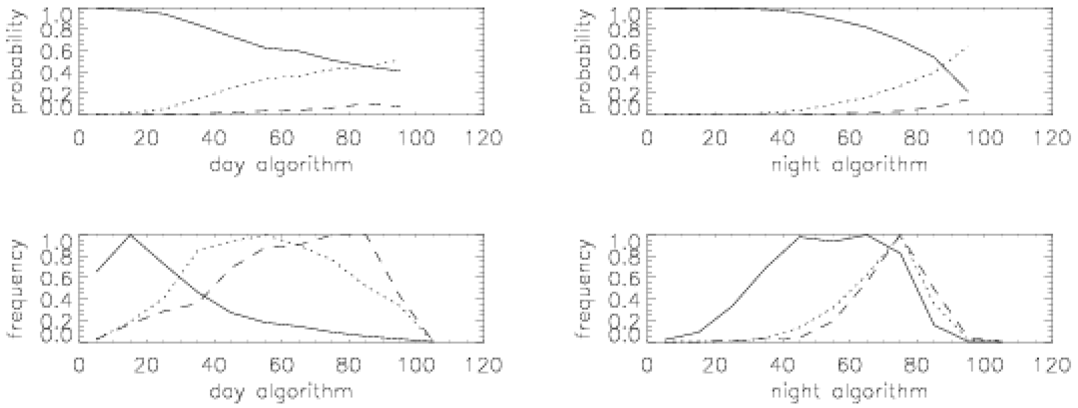
Algorithm 4: cloud type 18 = cirrus above lower clouds

Table 4 shows PC algorithm coefficients for day and night for all clouds, both for synop based tuning (Alg0), and for tuning to French gauge data which is currently identical to Algorithms 1 to 4.

Alg0-day Tuned on SYNOP (use not recommended)	130.0	-1.17841	0.193517	1.34862	-0.403661	3.2	1.21913	-1.14646	1.0137	-0.729214	0.482047
Alg0-night Tuned on synop (use not recommended)	130. 0	-0.808931	-0.660192	-1.3209	0.0	0.0	0.0	0.0	1.56148	-1.46149	0.
Alg1,2,3,4-day Tuned on rain gauges (default)	**230.0**	**-1.35**	**-0.63**	**-2.59**	**63.79**	**0.0**	**-0.40**	**0.0**	**-0.92**	**0.32**	**1.52**
Alg1,2,3,4-night Tuned on rain gauges(default)	**460.0**	**-0.90**	**-0.91**	**-5.34**	**0.0**	**0.0**	**0.0**	**0.0**	**-0.27**	**0.65**	**0.0**

Table 4: Coefficients a0 to a10 for current day and night algorithm according to tuning with current weather observations from synop (algorithm 0) and tuned on French gauge data (algorithms1 to 4)

How the PI maps to probability for different intensity classes is illustrated in Figure 1. The normalised frequency distribution for different intensity classes as observed by gauge data is given in the lower panel. The total likelihood of precipitation is split into two intensity classes in these plots and would be represented by the sum of likelihood for light and heavy precipitation for each value of PI respectively. The likelihood that a certain value of the PI falls into a certain precipitation class is determined from the (not normalised) frequency distribution under the constraint that the total likelihood has to be 100% (upper panel). There seems to be no potential to differentiate intensity classes for the large majority of cases. A substantial overlap of all precipitating classes with the no-precipitation class is apparent in the normalized frequency distribution. This is especially true for the night algorithm. Generally better precipitation discrimination can be performed at day time since the daytime algorithm is strongly dependent on the R6/R16 feature, discontinuities between day and night algorithms could not be avoided. When deriving the probabilities that a given PI belongs to a certain precipitation class, the resulting distribution suffers from the fact that there is a wide overlap between the precipitating and non-precipitating classes, as well as from the generally much larger number of non-precipitating cases.



DAY **NIGHT**

Figure 1: algorithm1-4 for all potentially precipitating cloud types tuned on French gauge data. Left: day algorithm, right: night algorithm. Lower panels: normalised histogram for different precipitation classes (solid line: no precipitation, dotted: light to moderate precipitation, dashed: heavy precipitation). Upper panels: same as lower, but for probability, total precipitation likelihood would be the sum of the dotted and dashed lines in the upper panel X-axis: Precipitation Index PI

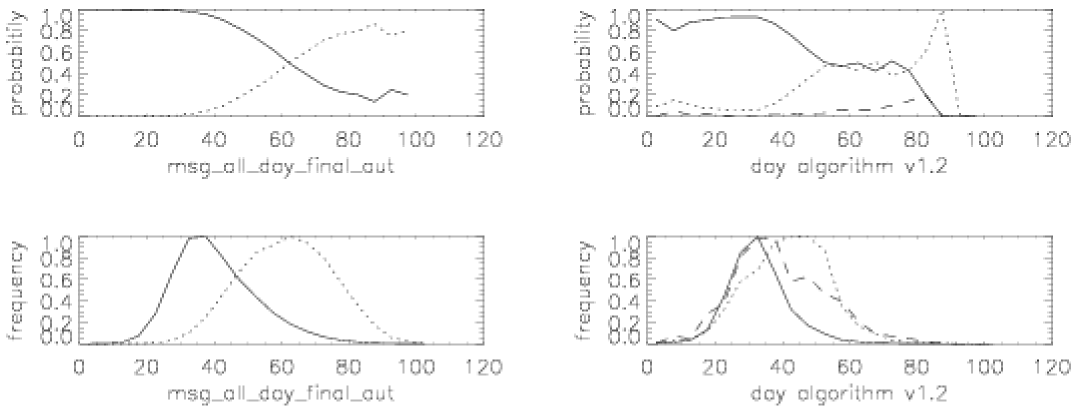


Figure 2 : left: day algorithm tuned on synop collocation data set (dotted: all precipitation). Right: same algorithm, but applied on rain gauge collocation data set (dotted light to moderate precipitation, dashed heavy precipitation). X-axis: Precipitation Index PI

An example of the precipitating clouds product is given in Figure 3.

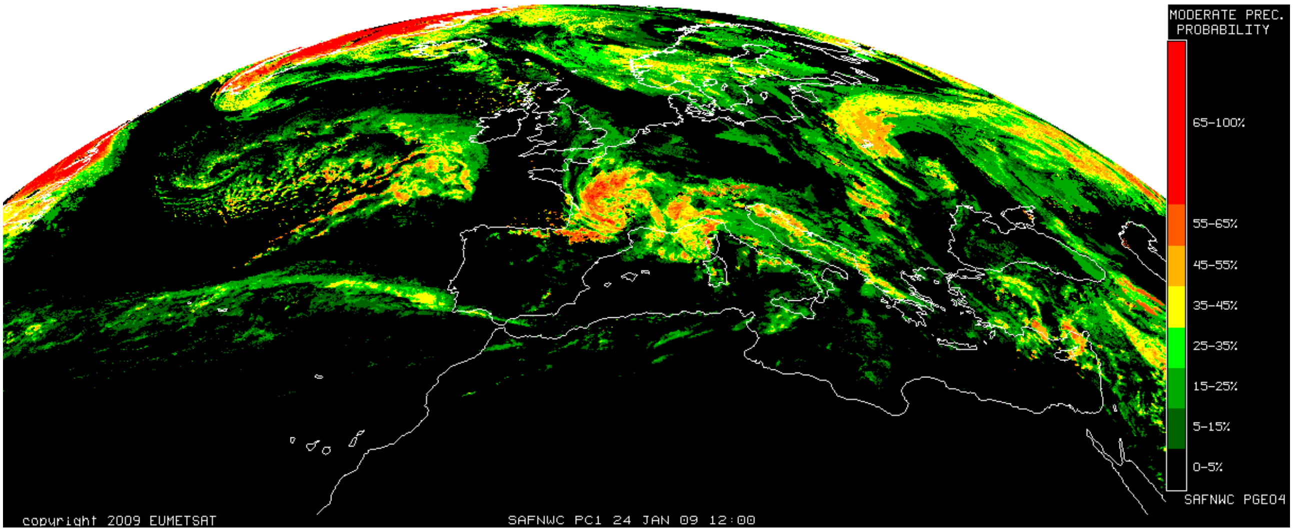


Figure 3: 200901241200 precipitating clouds product over MSG-N, configured for day algorithm. Dark green hues present precipitation likelihood 5%-25%,light green 25%-35%, yellow hues 35%-45% and orange/red red 45% and higher

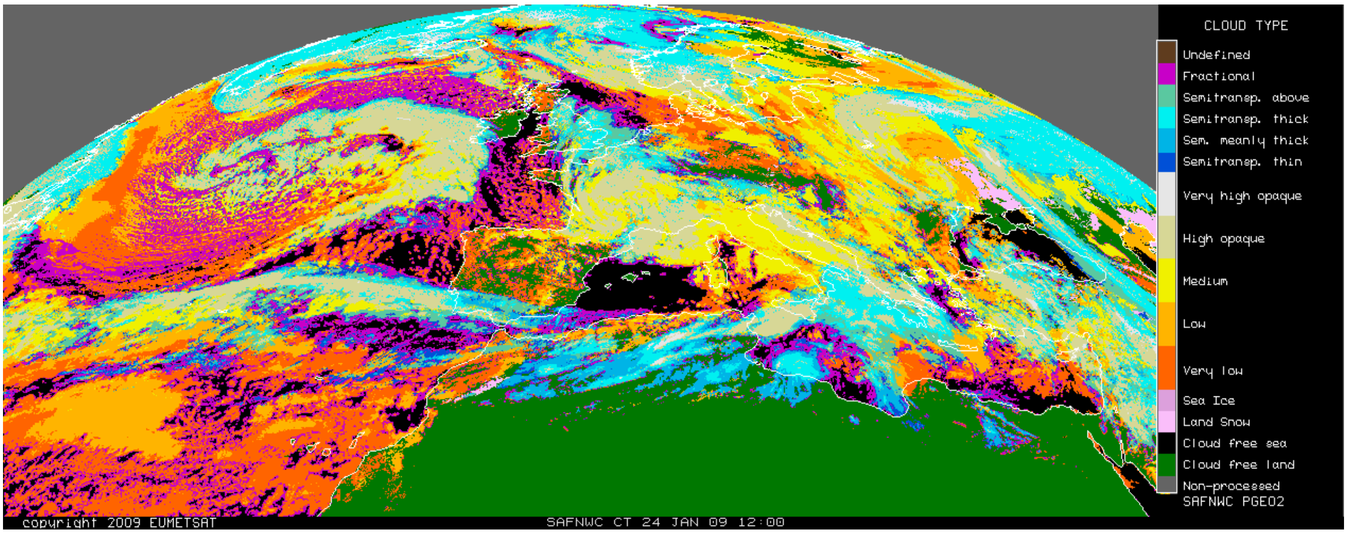


Figure 4: Cloud type input 200901241200 over MSG-N.

2.2.4 Practical considerations

2.2.4.1 List of Precipitating Clouds (PC) inputs

Satellite imagery:

The following FCI brightness temperatures and visible reflectances are needed at full IR spatial resolution:

VIS0.6	*NIR1.6*	*IR3.8*	*IR6.2*	*IR7.3*	*IR10.8*	*IR12.0*

Day-time	Day-time	Day-time	Day-time and Night-time	Day-time and Night-time	Day-time and Night-time	Day-time and Night-time

Table 5. PC FCI inputs

The FCI channels are input by the user in HRIT format and extracted on the desired region by NWC-MTG software package.

Cloud type (CT) product output:

CT output, in NetCDF format, is mandatory input to PC.

NWP parameters:

NWP surface temperature is a mandatory input for PC.

Sun and satellite angles associated to satellite imagery

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

2.2.4.2 Description of the Precipitating Clouds (PC) output

The content of the PC output is described in the Data Output Format Document **¡Error! No se encuentra el origen de la referencia.**. A summary is given below:

<table>
<tr><th>Container</th><th>Content</th></tr>
<tr><td>PC</td><td>NWC GEO PC Total Precipitation Likelihood:
<table>
<tr><th>Class</th><th>Total Precipitation Likelihood (%)</th></tr>
<tr><td>0</td><td>0</td></tr>
<tr><td>1</td><td>10</td></tr>
<tr><td>2</td><td>20</td></tr>
<tr><td>3</td><td>30</td></tr>
<tr><td>4</td><td>40</td></tr>
<tr><td>5</td><td>50</td></tr>
<tr><td>6</td><td>60</td></tr>
<tr><td>7</td><td>70</td></tr>
<tr><td>8</td><td>80</td></tr>
<tr><td>9</td><td>90</td></tr>
<tr><td>10</td><td>100</td></tr>
<tr><td>FillValue</td><td>No data or corrupted data</td></tr>
</table></td></tr>
</table>

Geophysical Conditions

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

Processing Conditions

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

Quality

Field	Type	Description
Nodata	Flag	Set to 1 if pixel is NODATA
Internal_consistency	Flag	Set to 1 if an internal consistency check has been performed. Internal consistency checks will be based in the comparison of the retrieved meteorological parameter with physical limits, climatological limits, neighbouring data, NWP data, etc.
Temporal_consistency	Flag	Set to 1 if a temporal consistency check has been performed Temporal consistency checks will be based in the comparison of the retrieved meteorological parameters with data obtained in previous slots.
Quality	Parameter	Retrieval Quality 0: N/A (no data) 1: Good 2: Questionable 3: Bad 4: Interpolated

Another file is generated including statistical information related to the product generation. It contains histograms of precipitation probability and processing flags, and it is generated in ascii format. This file may be useful to get statistics on general algorithm performance.

2.2.4.3 Example of Precipitating Clouds (PC) visualisation

Examples of both day-time and night-time PC product can be found below:

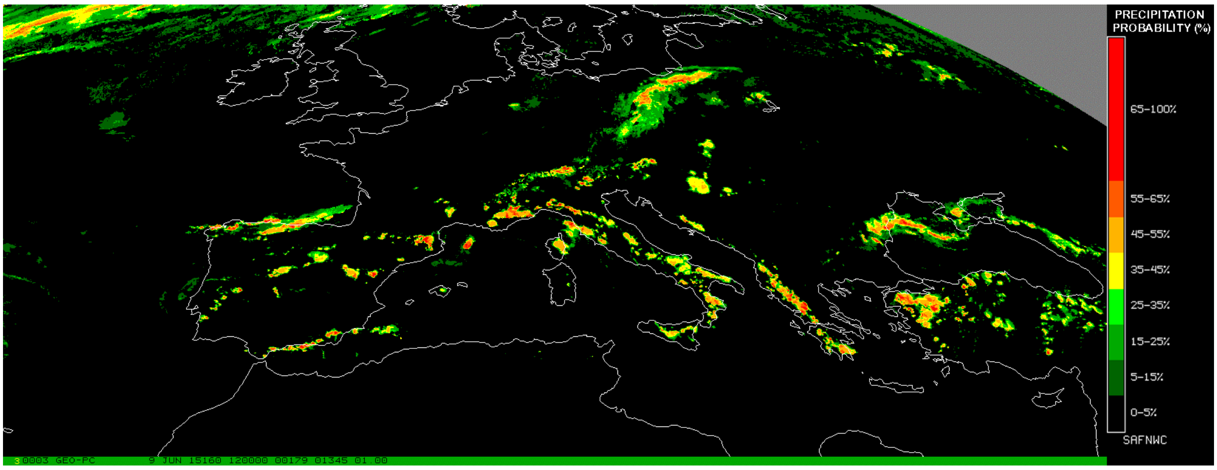


Figure 5. Example of the precipitating clouds product over a day-time scene on 9th June 2015 at 12:00 UTC

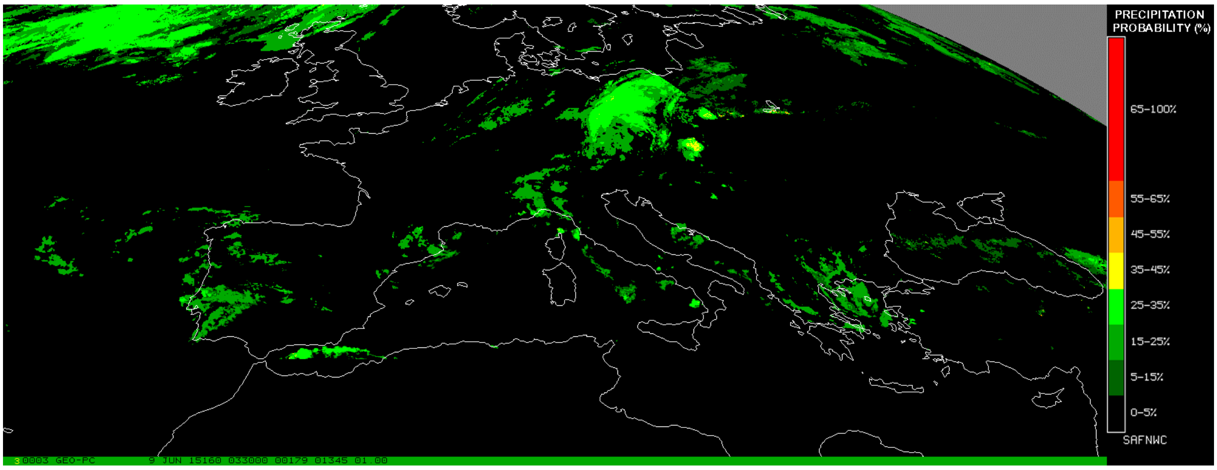


Figure 6. Example of the precipitating clouds product over a night-time scene on 9th June 2015 at 03:30 UTC

2.3 ASSUMPTIONS AND LIMITATIONS

- The current version of the product contains a certain dependence on sun zenith angle.
- There is also a clear jump in algorithm performance between day and night algorithm, which cannot be totally avoided.
- The product degrades considerably at high viewing angles and use for viewing angles greater than 60 degrees is not recommended.
- The algorithm does currently not detect any precipitation from low clouds

3. DESCRIPTION OF CONVECTIVE RAINFALL RATE (CRR) PRODUCT

3.1 CONVECTIVE RAINFALL RATE (CRR) OVERVIEW

Convective Rainfall Rate (CRR) product is a Nowcasting tool that provides information on convective, and stratiform associated to convection, instantaneous rain rates and hourly accumulations.

In the processing of the product, CRR uses some calibration analytical functions that have been calibrated taking as "truth" the radar data. There are two types of functions:

- 2-Variable (2-V) function that depends on 10.8IR and (10.8IR - 6.2WV) FCI data
- 3-Variable (3-V) function that depends on 10.8IR, (10.8IR - 6.2WV) and 0.6VIS-N FCI data

The 3-V calibration analytical function gives better results but there are some situations in which it can't be used, for instance, during the night time. The type of calibration to be used can be chosen by the user through the CRR model configuration file.

The analytical functions have been calibrated using radar data from:

- Baltic radar network
- Hungarian radar network
- Spanish radar network

To take into account the influence of environmental and orographic effects on the precipitation distribution, some corrections can be applied to the basic CRR value. The possible corrections are the moisture correction, the cloud top growth/decaying rates or evolution correction, the cloud top temperature gradient correction and the orographic correction.

At this stage, the CRR precipitation pattern computed in the previous step is combined with a precipitation pattern derived through a lightning algorithm.

At the end of the process CRR product produces five different outputs.

In one of them, the CRR value in mm/h is converted into classes. There are 12 classes that divide the rain rates in some different ranges and each pixel of the output image has a rain class assigned.

There exists an output that contains the information on the instantaneous rain rate in mm/h in each pixel of the image. The hourly accumulation output gives information about the precipitation occurred during the last hour.
The classes, the instantaneous rain rate in mm/h and the hourly accumulation outputs have the same colour palette.
Information on the corrections applied and the processing status is available on the CRR_QUALITY and CRR_DATAFLAG outputs respectively.

3.2 CONVECTIVE RAINFALL RATE (CRR) ALGORITHM DESCRIPTION

3.2.1 Theoretical description

In this section the theoretical basis and practical implementation of the algorithm are described.

3.2.1.1 Physics of the problem

All visible and infrared precipitation estimation schemes are necessary indirect because the radiation does not penetrate through the cloud. The cloud's brightness temperature and visible reflectance may be related to the rain falling from it, but the raindrops themselves are not directly sensed (Kidder and Vonder Haar, 1995).

The empirical relationship that the higher and thicker are the clouds the higher is the probability of occurrence and the intensity of precipitation is used in the CRR algorithm. Information about cloud top height and about cloud thickness can be obtained, respectively, from the infrared brightness temperature (IR) and from the visible reflectances (VIS) (Scofield, 1987) (Vicente and Scofield, 1996).

IR-WV brightness temperature difference is a useful parameter for extracting deep convective cloud with heavy rainfall (Kurino, 1996). Negatives values of the IR-WV brightness temperature difference have been shown to correspond with convective cloud tops that are at or above the tropopause (Schmetz et al., 1997).

Some observable features (like environmental moisture, cloud growth, cloud top structure, topography underneath, etc.) affect to convective precipitation rates more than the stratiform rain cases (Vicente, 1998) (Vicente, 1999).

It is stated that convective phenomena are related to the electrical activity in the clouds. The lightning algorithm is based on the assumption that the higher is the spatial and temporal density of lightning occurrence, the stronger is the convective phenomenon and the higher is the probability of occurrence and the intensity of convective precipitation.

3.2.1.2 Mathematical Description of the Convective Rainfall Rate (CRR) algorithm

3.2.1.2.1 Convective Rainfall Rate (CRR) algorithm outline

The CRR algorithm developed within the NWC SAF context estimates rainfall rates from convective systems, using IR, WV and VIS-N MTG FCI imagery and calibration analytical functions generated by combining satellite and Radar data.

The calibration functions, which have been calibrated through a statistical process, try to connect satellite multi-band imagery with rain rates. In the calibration process composite radar data are compared pixel by pixel with geographically matched satellite data with the same resolution. Rainfall rate RR is obtained, as a function of two or three variables (IR brightness temperature, IR-WV brightness temperature differences and normalised VIS reflectances):

RR = f (IR, IR-WV, VIS-N), for 3-V calibration

RR = f (IR, IR-WV), for 2-V calibration

The basic CRR mm/h value for each pixel is obtained from the calibration functions. If in a pixel the sun zenith angle is lower than a threshold and the solar channel is used, the basic CRR data is obtained from a 3-V analytical function which uses 10.8IR, 6.2WV and 0.6VIS-N imagery. If in a pixel the sun zenith angle is higher than the threshold or lower, but the solar channel is not going to be used, the basic rain rate values are obtained from 2-V analytical function which only uses 10.8IR and 6.2WV imagery. The threshold that decides, depending on the sun zenith angle, whether the solar channel can be used or not, is chosen by the user through the CRR model configuration file. The name of this threshold in the configuration file is DAY_NIGHT_ZEN_THRESHOLD and its default value is 80º.

When the solar channel is used, the normalised visible reflectances are obtained dividing by the cosine of the solar zenith angle. The option of using the solar channel in the computation of the CRR values can be chosen by the user through the CRR model configuration file.

In the retrieval of basic CRR values from 3-V calibration function, some pixels could occasionally present normalised visible reflectances greater than 100. In those cases the CRR values will be retrieved using the 2-V calibration function. This occurs in few instances and has been observed mainly under very low sun illumination conditions. Those pixels can be easily identified as they will have assigned a value as a missing data in some channel in the CRR_DATAFLAG output.

A filtering process is performed in order to eliminate stratiform rain data which are not associated to convective clouds: the obtained basic CRR data are set to zero if all the pixels in a grid of a selected semisize (def. value: 3pix) centred on the pixel have a value lower than a selected threshold (def. value: 3mm/h). The threshold and the size of the grid can be modified by the user by means of the model configuration file.

To take into account the temporal and spatial variability of cloud tops, the amount of moisture available to produce rain and the influence of orographic effects on the precipitation distribution, several correction factors can be applied to the basic CRR value. Therefore, the possible correction factors are the moisture correction, the cloud top growth/decaying rates or evolution correction, the cloud top temperature gradient correction and the orographic correction.

Lightning activity can provide valuable information about convection. A lightning algorithm can be applied to derive a precipitation pattern that will be combined with the CRR one computed in the previous step in order to complement it.

At the end of the process the final values of the CRR rainfall rates in mm/h are used in order to obtain three different outputs:

- CRR rainfall rates in mm/h
- CRR classes: rainfall rate in mm/h is divided into twelve classes.
- CRR hourly accumulations: A trapezoidal integration is performed in order to compute the hourly accumulations. The description of this process can be found in ANNEX C: Hourly accumulations.

3.2.1.2.2 Convective Rainfall Rate (CRR) calibration analytical functions procedure

The analytical functions have been built taking the previous calibration matrices as starting point. The calibration matrices obtaining method can be read in ATBD for CRRv3.1.1.

The calibration matrices were modelled and described by the analytical functions that best fitted them. An example of this modelling can be seen in Figure3.

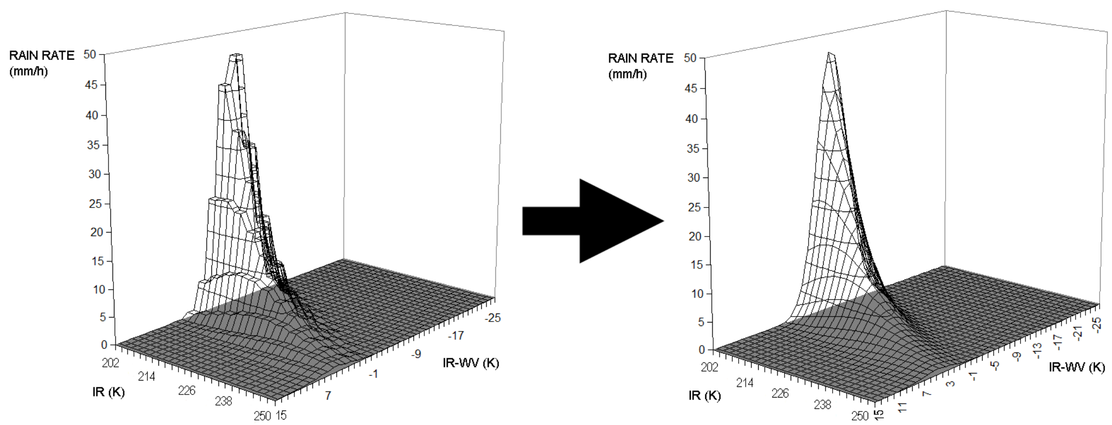


Figure 7. From calibration matrices to analytical functions

The perfect matching between matrices and functions is impossible to reach; also, the calibration process over a function is easier than over a matrix. For these reasons a new calibration process was done over the functions.

3.2.1.2.2.1 Analytical functions calibration process

This product is an adaptation of CRR for MSG to MTG and its calibration was performed for MSG. The calibration process was done using the following radar data:

Radar network	Type of radar	Frequency Scanning Radar	Dataset used	Type of product used	MSG scans over the radar area	Matching time
Baltrad network	C- Band	15 minutes	21 rainy days June-August 2004	Pseudo-CAPPI at 2Km	About 11 min later than the MSG time slot	MSG time slot 15 min later than the radar one.
Hungarian radar network	C- Band	15 minutes	18 rainy days May-September 2009	Maximum reflectivity in the vertical (MRV) and Echotop	About 11 min later than the MSG time slot	MSG time slot 15 min later than the radar one.
Spanish radar network	C- Band	10 minutes	111 rainy days throughout 2009	PPI and Echotop	About 10 min later than the MSG time slot	0 and 30 min MSG slots have been matched to 10 and 40 min radar images respectively.

Table 6. Description of the radar calibration data

For a better matching of radar – satellite images, the radar products were converted into MSG projection using a bi-linear interpolation scheme.

A quality control has been used for the Spanish radar dataset taking advantage of the quality image generated for the radar national composite products (Gutierrez and Aguado, 2006). No quality control methods have been used for Baltrad and Hungarian radar datasets.

Ground echoes, like anomalous propagation echoes, were removed in Pseudo-CAPPI, MRV and PPI scenes. To that end 10.8IR SEVIRI imagery were used together with the basic AUTOESTIMATOR algorithm (Vicente et al., 1998).

Considering that CRR is a specific product for convective situations, only images with convective echoes, as far as possible, were used during the calibration process. To that end, Echotop product was used when available. Only scenes where the ratio between the number of echoes greater than 6 Km and the ones greater than 0 Km was lower than 15% in the Echotop image were selected.

Since images with convective situations can also include non convective echoes, a calibration area was selected. This selection included the area corresponding to 15x15 pixels boxes centred on that ones that reached a top of 6 km and a rain rate of 3 mm/h simultaneously.

Since the perfect matching is not possible a smoothing process in 3x3 pixels boxes was done for a better radar-satellite matching.

Once the radar calibration dataset was prepared, CRR was run using the analytical functions applying small shifts to the coefficients. Also a smoothing process in 3x3 pixels boxes was done over CRR imagery. Then several comparisons between CRR rain rates and radar rain rates were done computing accuracy and categorical scores. Special attention was paid to RMSE, POD and FAR. The coefficients of the functions were adjusted and the ones which got the best scores were chosen.

3.2.1.2.2.2 Analytical functions description

An analytical function is easier to handle and to analyze than a big matrix. Two calibration functions were obtained:

2-V calibration function: RR (IR, IR-WV)

The function independent variable is (10.8IR-6.2WV) FCI data and its coefficients have a dependence on 10.8IR FCI data. The mathematical formulation of this function is the following:

$$RR(mm/h) = H(IR) * \exp\left[-0.5 * \left(\frac{(IR-WV)-C(IR)}{W(IR)}\right)^2\right]$$

Where RR is the rain rate in mm/h, and H(IR), C(IR) and W(IR) are coefficient functions depending on 10.8IR FCI data.

Looking at the formula of this function it can be observed that it is a symmetric bell-shaped curve where H(IR) is the height, C(IR) is the position of the symmetry axis and W(IR) is related to the width of the curve. All these parameters, depending on 10.8IR data, have a meaning.

The mathematical formula of the coefficient function related to the height of the 2-V calibration function, H(IR), is the following:

$$H(IR) = a * \exp[b * IR]$$

Where the coefficients are: $a = 8*10^8$ and b = - 0.082

According to these coefficients the graph of this curve is shown in Figure 8.

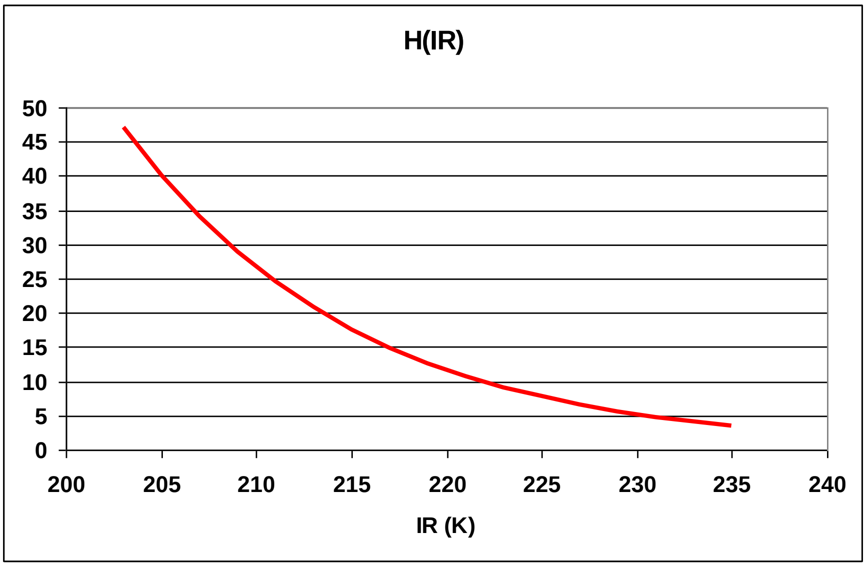


Figure 8. Height of the 2-V function plotted between 205K and 235K

It is clear from the curve that the lower the IR brightness temperature the higher H(IR), so the higher are the estimated rain rates.

Regarding the position of the symmetry axis C(IR), the formula is:

$$C(IR) = c * IR + d$$

Where the coefficients are: c = 0.2 and d = - 45.0

This function is plotted in Figure 9.

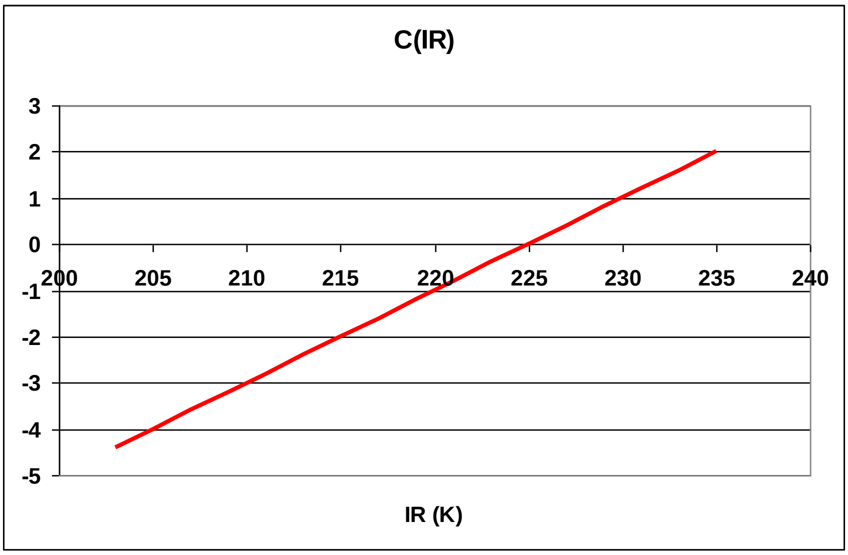


Figure 9. Coefficient related to the position of the symmetry axis of the 2-V function

As it has been seen, the 2-V calibration function is a symmetric bell-shaped curve whose independent variable is (IR-WV) and whose coefficients depend on IR. The symmetry axis of the "bell curve" is given by C(IR). Looking at Figure 9 it can be deduced that the highest rain rates are estimated for IR-WV values close to zero; and the lower are the IR brightness temperatures, the lower the value of IR-WV that provides the highest rain rates estimations.

Finally, the equation that provides information on the width of the bell-shaped curve is:

$$W(IR) = f * \exp\left[-0.5\left(\frac{IR + g}{h}\right)^2\right] + j$$

Where f = 1.5; g = - 215.0; h = 3.0 and j = 2.0

The graph of the W(IR) is plotted in Figure 10.

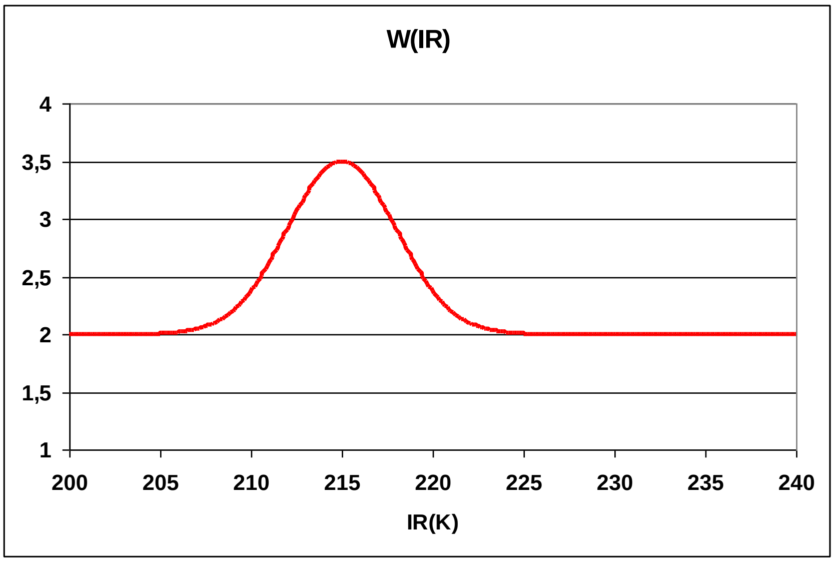


Figure 10. Coefficient that provides information on the width of the 2-V function

W(IR) is also a symmetric bell-shaped curve whose symmetry axis is centred in 215K. This means that for this brightness temperature the curve gets wider so it could be deduced that for IR=215K, there is a higher likelihood of precipitation occurrence although the rain rates are not the highest.

3-V calibration function: RR(IR, IR-WV, VIS)

The 3-V function independent variables are 10.8IR-6.2WV and 0.6VIS-N FCI data and its coefficients have dependence on 10.8IR FCI data and on latitude. Its mathematical formulation is the following:

$$RR(mm/h) = \exp\left[-0.5*\left(\frac{VIS\_N - C\_Vis(Lat)}{8.5}\right)^2\right] * H(IR) * \exp\left[-0.5*\left(\frac{(IR-WV)-C(IR)}{W(IR)}\right)^2\right]$$

$$\underbrace{\qquad\qquad}_{(Factor\_VIS-N)} \qquad \underbrace{\qquad\qquad}_{(Factor\_IRWV)}$$

The 3-V calibration function is the product of two symmetric bell-shaped curves, Factor_VIS-N and Factor_IRWV. The Factor_IRWV one is similar to the 2-V function and Factor_VIS-N depends on the VIS-N imagery.

The interpretation of the bell-shaped curve Factor_IRWV is the same as in the case of the 2-V function. For the 3-V function the H(IR), C(IR) and W(IR) coefficients are the following:

$$H(IR) = a * \exp[b * IR]$$

Where: a = $1.25*10^8$ and b = - 0.073

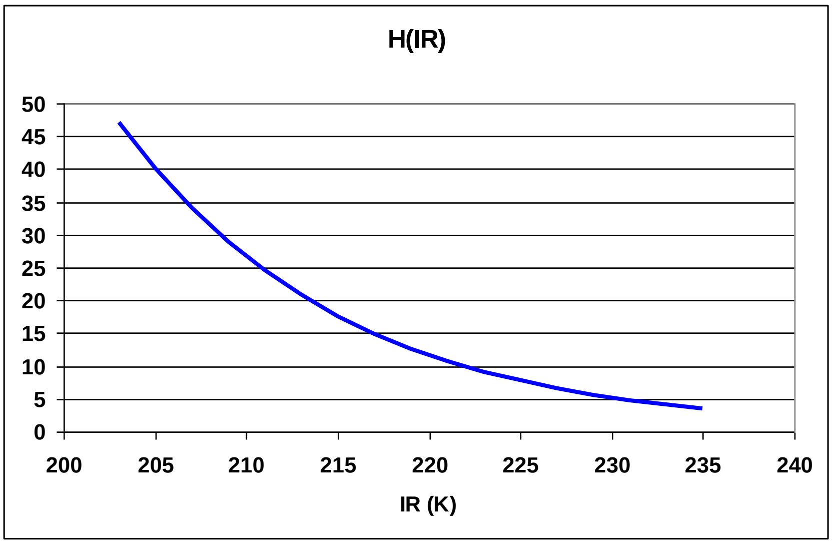


Figure 11. Height of the 3-V function plotted between 205K and 235K .

$$C(IR) = c * IR + d$$

Where: c = 0.25 and d = - 53.75

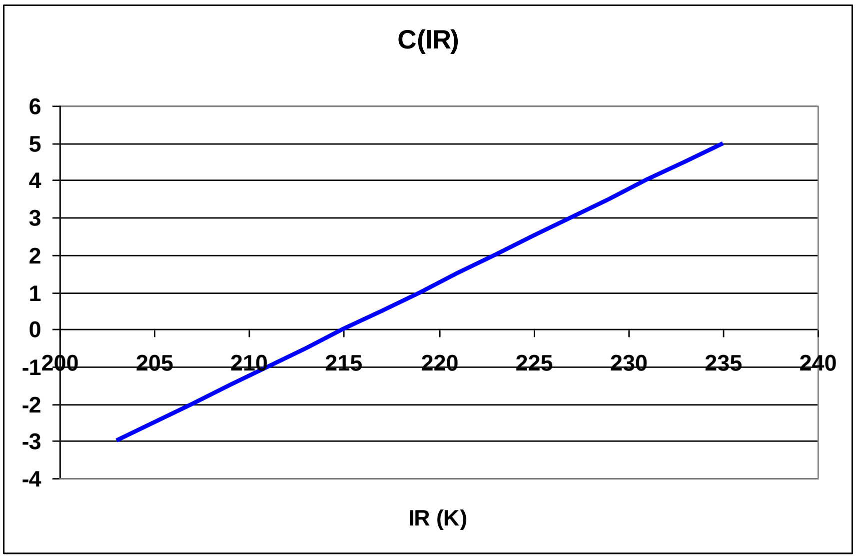


Figure 12. Coefficient related to the position of the symmetry axis of the 3-V function .

$$W(IR) = f * \exp\left[-0.5\left(\frac{IR+g}{h}\right)^2\right] + j$$

Where: f = 1.5; g = - 227.0; h = 14.0 and j = 4.0

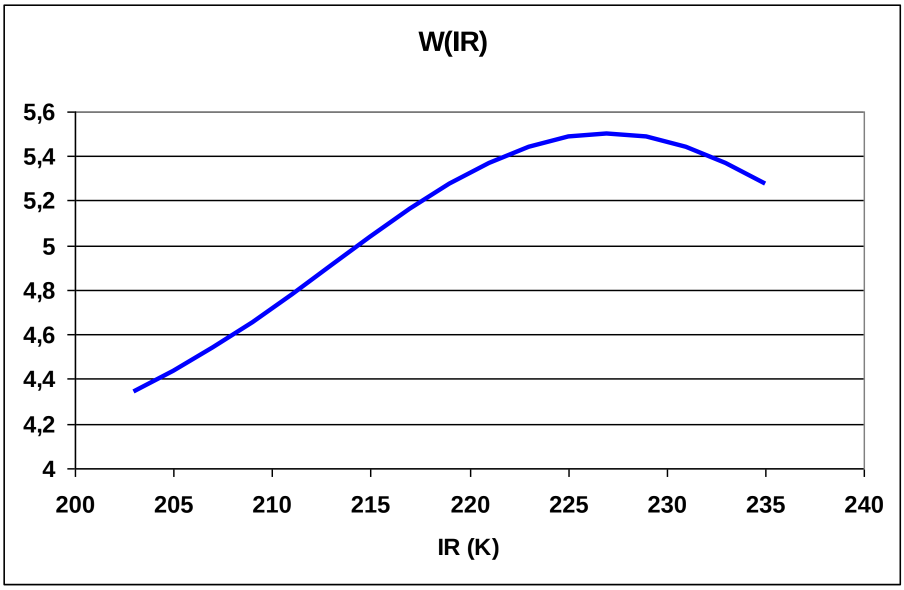


Figure 13. Coefficient that provides information on the width of the 3-V function

Regarding the H(IR) coefficients for 2-V and 3-V functions, both the shape and the maximum rain rates estimated are very similar.

As for the position of the symmetry axis, the lower the IR brightness temperatures, the lower the value of IR-WV that provides the highest rain rates estimations for both 2-V and 3-V functions. The difference is that in 3-V case, the (IR-WV) values that provide the highest rain rates are a bit higher than in the case of 2-V function.

In the case of the coefficient that provides information on the width of the 2-V and 3-V functions, the difference is higher. It can be observed that the 3-V function is always much wider and the IR brightness temperature for which there is a higher likelihood of precipitation occurrence is warmer (227K) than in the case of the 2-V function. This means that 3-V function rain rates estimations are higher for the same range of IR brightness temperatures and (IR-WV) differences than 2-V function rain rates estimations. 2-V function limits the rain rate estimations to lower IR brightness temperatures.

It must be taken into account that 3-V function is also composed of other symmetric bell-shaped curve Factor_VIS-N that depends on the VIS-N imagery. It can be interpreted that Factor_IRWV is the height of Factor_VIS-N, so the highest estimations given by 3-V function will be given by Factor_IRWV, and Factor_VIS-N filters these estimations depending on the normalized visible reflectances.

The higher is the VIS-N reflectance, the higher is the optical thickness of the cloud so the higher should be the rain rate assigned. This can be seen in Figure 14.

It has been seen that for Spanish latitudes the highest rain rates are obtained for VIS reflectances of about 82%, for different years. According to the other radar-satellite datasets (Hungary and Baltrad) reflectances that provide the highest rain rates decrease with latitude. The quantity of solar energy that reaches higher latitudes is lower than the ones that reach latitudes closer to the equator and normalization process is not good enough to fix this problem. This dependence on the latitude could be a corrective effect additional to the normalization.

To take account of this fact a latitude dependency has been included in the 3-V function. As can be observed in Figure 14, the lower is the latitude the higher is the reflectance for which 3-V function assigns higher rain rates. This latitude dependence can be observed in Figure 15.

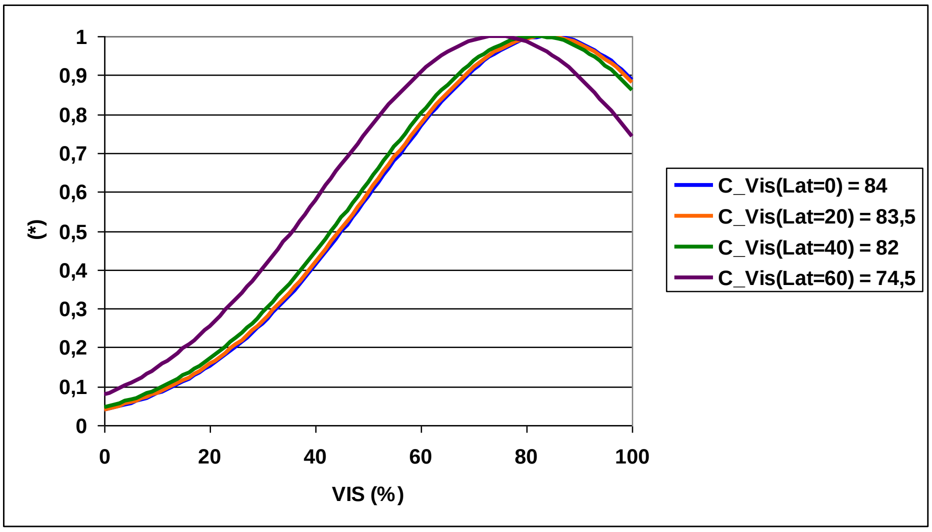


Figure 14. Dependence of the 3-V function on the Normalized Visible Reflectances.

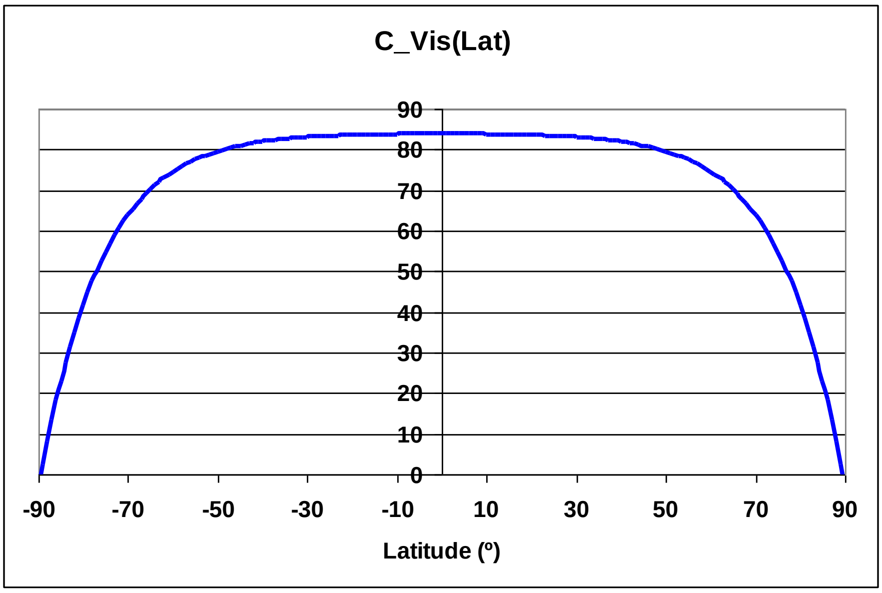


Figure 15. Dependence of the Normalized Visible reflectances on Latitude

3.2.1.2.3 Convective Rainfall Rate (CRR) correction factors description

3.2.1.2.3.1 Moisture Correction Factor

When thunderstorms take place in quite moist environments the computed rainfall rate should be greater than when they occur in dry air masses. To take into account this effect a moisture correction factor has been developed. It adjusts the estimates when the air is dry or quite moist. This factor has been defined as the product of the total precipitable water, PW, in the layer from surface to 500 hPa. by the relative humidity, RH, (mean value between surface and 500 hPa. level), obtained from a numerical model.

In order to compute the PWRH factor, the precipitable water is expressed in inches of water and the relative humidity in percentage. This factor takes values between 0.0 and 2.0. An environment is considered to be dry if PWRH is significantly below 1.0 and quite moist if PWRH is greater than 1.0.

The PWRH factor decreases rainfall rates in very dry environments and increases them in very moist ones. However, for high latitudes where convective systems can contain hail (so that radar rainfall is unrealistically high), if IR cloud top temperature is lower than 215K , there is no need to increase the rainfall rates, but instead, it is necessary to decrease them whenever the environment is dry (PWRH<1.0). Based on this justification, the following criterion is applied:

If latitude >55°N, T10.8 < 215 K and PWRH >1.0 the computed rainfall rate should not be multiplied by the PWRH correction factor.

Otherwise, the computed rainfall rate is multiplied by the PWRH correction factor.

3.2.1.2.3.2 Cloud Growth Rate Correction Factor

Convective rain is assumed to be associated with growing clouds exhibiting overshooting tops. Consecutive satellite IR images are used to indicate vertically growing and decaying cloud systems.

A convective system is more active and produces greater rainfall rates when the tops are becoming colder and expanding. Based on the conclusion that decaying clouds with cold tops that are becoming warmer produce little or no rainfall, the output is modified according to the following:

· If a IR pixel in the second scene is colder than in the first one, convection is intensifying, so rainfall rate computed in that pixel with the information from the second scene remains the same.

· If a IR pixel in the second scene is warmer than in the first one, convection is weakening. In this case, rainfall rate computed with the information from the second scene is multiplied by a coefficient. The coefficient value can be modified by the user through the Keyword COEFF_EVOL_GRAD_CORR_00 in the model configuration file (Default value for Normal Mode (0.35) is set in the configuration file. Recommended value for Rapid Scan mode is 0.55).

· If there is no change in the cloud-top temperature in the two consecutive scenes (no growth or decay), rainfall rate computed from the second scene stays the same.

Therefore, the cloud growth correction factor, also designated as evolution correction factor, is only applied if the analysed pixel becomes warmer in the second image.

3.2.1.2.3.3 Cloud-top Temperature Gradient Correction Factor

When consecutive IR scenes are not available, cloud growth rate correction factor can not be applied. Then cloud-top temperature gradient correction is used instead.

This alternative correction method is based on the fact that much information can be extracted from cloud-top structure on a single IR image.

Cloud-top temperature gradient correction factor, also designated as gradient correction factor, is based on a search of the highest (coldest) and lowest (less cold) cloud tops. The concept of finite difference is used to locate the maximum and minimum local temperature within grids of 3x3 or 5x5 pixels centred on the point $P_0=(x_0,y_0)$. The idea is to search for the pixels that are below the average cloud top surface temperature (local temperature minima) and assume that these pixels indicate active convection connected to precipitation beneath.

Cloud-top temperature can be named as $T=T(x,y)$, where T is the cloud-top temperature as a function of the x and y co-ordinates. For those pixels whose T is lower than 250K, the following analysis is done:

Maxima and minima can be found studying the first and second derivative of T. The process is the following:

Second derivative of T in the point $P_0=(x_0, y_0)$:

$$T''_x(x = x_0) = \left.\frac{\partial^2 T}{\partial x^2}\right|_{x=x_0}$$

$$T''_y(y = y_0) = \left.\frac{\partial^2 T}{\partial y^2}\right|_{y=y_0}$$

$$T''_{xy}(x = x_0, y = y_0) = \left.\frac{\partial^2 T}{\partial x \partial y}\right|_{x=x_0, y=y_0}$$

Hessian in $P_0=(x_0, y_0)$:

$$H = (T''_x(x = x_0)) \cdot (T''_y(y = y_0)) - (T''_{xy}(x = x_0, y = y_0))^2$$

P_0 is characterized in the following way:

- $H > 0$ *and* $T''_x(x=x_0) < 0 \Rightarrow$ *maximum*
- $H > 0$ *and* $T''_x(x=x_0) > 0 \Rightarrow$ *minimum*
- $H < 0 \Rightarrow$ *no maximum, no minimum*
- $H = 0 \Rightarrow$ *not known*

Once this analysis has been done in a grid of 3x3 pixels, the previous derived rainfall rate is adjusted in the following way:

- If the pixel P_0 has a temperature maximum, indicating a relatively low cloud top with P_0 warmer than its surrounding, the previous rainfall rate is multiplied by a coefficient whose value can be modified by the user through the keyword COEFF_EVOL_GRAD_CORR_01 in the model configuration file (Default value: 0.25).
- If the pixel P_0 has a temperature minimum, which means that P_0 is colder than the surrounding indicating a high cloud top, the previous rainfall rate stays the same.
- If P_0 has not a temperature maximum or minimum, which means that P_0 is at the same height and temperature as the surrounding pixels, the previous rainfall rate is multiplied by a coefficient whose value can be modified by the user through the keyword COEFF_EVOL_GRAD_CORR_02 in the model configuration file (Default value: 0.50).
- If P_0 temperature can not be defined as a maximum or a minimum, the whole process is repeated using pixels within a 5x5 pixel's grid.
- Finally, if P_0 temperature remains undefined as a maximum or a minimum within the 5x5 pixel's grid, the original rainfall rate value is not modified.

3.2.1.2.3.4 Orographic Correction Factor

Local topography has long been recognised to have an effect on the distribution and intensity of precipitation. However, the rain induced by orographic forcing is a complex process associated with complicated flows. Rainfall amounts are dependent on the atmospheric flow over the mountains and on the characteristics of the flow disturbances created by the mountains themselves.

This correction factor uses the interaction between the wind vector (corresponding to 850 hPa level from the NWP) and the local terrain height gradient in the wind direction to create a multiplier that enhances or diminishes the previous rainfall estimate, as appropriate.

The wind direction for the 48-km grid cell containing the location being tested is assumed to be constant in magnitude and direction. A one-dimensional cross-section of the terrain, determined by the wind direction, is extracted from the elevation map. The wind path length, D pixels, is variable from 3 km (pixel resolution) to 24 km (8 pixels), depending upon wind speed. Accordingly, D is determined by a 15-minute fetch (converted into units of pixels) of the wind speed U:

$$D = U * \frac{900s}{3000m / pixel}$$

The extracted terrain cross-section extends D pixels upwind and downwind from the reference site, giving a total length of 2D+ 1 pixel. The height of the test location can be denoted as Z_{D+1}; the location farthest upwind is Z_1, the location farthest downwind is Z_{2D+1}. The slope between a point A and a downwind point B can be defined as

$$S_{AB} = \frac{(Z_B - Z_A)}{(B - A)}$$

For each pixel, A, upwind of the site and the site itself (i.e., from 1 to D+1), the slope between it and each point B within D pixels downwind is calculated (i.e., from A+1 to A+D). The maximum slope found for each point A is retained as the slope S_A. The net slope S, used for the correction, is equal to the mean of the S_A values.

Finally, we can define a rainfall rate enhancement parameter, M, as the result of the vertical velocity induced by a wind with horizontal speed U blowing over a surface with slope of S. Since M should not have effect on the rainfall amounts on a flat terrain, it can be written as:

$$M = 1 + S * U$$

M is limited to be between 0.2 and 3.5. Every CRR rain point is multiplied by the co-located M values. The eight pixels all around the image edge can not be corrected.

3.2.1.2.3.5 Parallax Correction Factor

For a better convective precipitation area location a parallax correction [ANNEX A: Parallax Correction] can be applied to this product. This option is chosen by the user through the product model configuration file and it is applied by default.

3.2.1.2.4 Lightning algorithm

As lightning activity is related with convection, an option to use this information to improve precipitation estimates has been added to the product.

An algorithm for rainfall estimation using lightning information has been developed. Its description can be found in ANNEX B: Lightning algorithm.

3.2.2 Practical considerations

3.2.2.1 List of Convective Rainfall Rate (CRR) inputs

Satellite imagery:

The following FCI brightness temperatures and normalized visible reflectances are needed at full IR spatial resolution:

T10.8µm	TPrev10.8µm	T6.2µm	VIS0.6µm
Mandatory	Optional*	Mandatory	Optional

Table 7. CRR SEVIRI inputs

The FCI channels are input by the user in HRIT format and extracted on the desired region by NWC-MTG software package.

* If TPrev10.8µm is not available, the Cloud Growth Rate Correction Factor cannot be computed but the Cloud-top Temperature Gradient Correction Factor is computed instead as an alternative.

Numerical model:

This information is mandatory for moisture and orographic corrections. When this information is not available, CRR is computed without applying these two corrections.

Parallax correction can run without the NWP parameters using the climatological profile.

For moisture correction:

Relative Humidity at 1000, 925, 850, 700 and 500 hPa

Dew Point temperature at 2 m

Temperature at 2 m

Temperature at 1000, 925, 850, 700, 500 hPa

Surface Pressure

For parallax correction:

Temperature at 1000, 925, 850, 700, 500, 400, 300, 250 and 200 hPa

Geopotential at 1000, 925, 850, 700, 500, 400, 300, 250 and 200 hPa

For orographic correction:

U and V wind components in 850 hPa

Lightning information file for CRR:

A file with information on every lightning strike occurred in a time interval is mandatory to choose the option of adjusting the CRR precipitation pattern with the lightning information provided by ground based lightning detection networks. Information about this lightning information file structure can be found in the Interface Control Document for Internal and External Interfaces of the NWC/GEO **¡Error! No se encuentra el origen de la referencia.**.

Sun angles associated to satellite imagery

This information is mandatory for normalising the VIS image when the solar channel is used. It is also used to choose whether to run day-time or night-time algorithm.

Ancillary data sets:

All this information is included in the software package:

- Saturation Vapour table is mandatory for Humidity correction and is located in the $SAFNWC/import/Aux_data/ CRR directory.
- Saturation Vapour Polynomial Coefficients table is mandatory for Humidity correction and is located in the $SAFNWC/import/Aux_data/CRR directory.
- Elevation mask is mandatory for orographic correction and is located in the $SAFNWC/import/Aux_data/ Common directory.
- Climatological profile is necessary as a backup for Parallax correction in case NWP is not available. This information is located in the $SAFNWC/import/Aux_data/CRR directory

Model configuration file for CRR:

The CRR model configuration file contains configurable system parameters in the product generation process related to algorithm thresholds, ancillary datasets, numerical model data, corrections to be applied, etc. The complete list of these parameters and the explanation of the most useful ones is available in the User Manual for the Precipitation Product Processors of the NWC/GEO **¡Error! No se encuentra el origen de la referencia.**.

3.2.2.2 Description of the Convective Rainfall Rate (CRR) output

The content of the CRR output is described in the Data Output Format Document [*RD 3*]. A summary is given below:

<table>
<tr><th>Container</th><th>Content</th></tr>
<tr><td>crr</td><td>NWC GEO CRR Convective Rainfall Rate Class:
<table>
<tr><th>Class</th><th>Rainfall Intensity (mm/h)</th></tr>
<tr><td>0</td><td>[0.0, 0.2)</td></tr>
<tr><td>1</td><td>[0.2, 1.0)</td></tr>
<tr><td>2</td><td>[1.0, 2.0)</td></tr>
<tr><td>3</td><td>[2.0, 3.0)</td></tr>
<tr><td>4</td><td>[3.0, 5.0)</td></tr>
<tr><td>5</td><td>[5.0, 7.0)</td></tr>
<tr><td>6</td><td>[7.0, 10.0)</td></tr>
<tr><td>7</td><td>[10.0, 15.0)</td></tr>
<tr><td>8</td><td>[15.0, 20.0)</td></tr>
<tr><td>9</td><td>[20.0, 30.0)</td></tr>
<tr><td>10</td><td>[30.0, 50.0)</td></tr>
<tr><td>11</td><td>[50.0,)</td></tr>
<tr><td>FillValue</td><td>No data or corrupted data</td></tr>
</table>
</td></tr>
<tr><td>crr_intensity</td><td>NWC GEO CRR Convective Rainfall Intensity:

crr_intensity(mm/h) = scale_factor * counts + add_offset

where:
scale_factor = 0.1
add_offset = 0.0</td></tr>
</table>

Container	Content
crr_accum	NWC GEO CRR Convective Hourly Rainfall Accumulation: crr_accum(mm) = scale_factor * counts + add_offset where: *scale_factor* = *0.1* *add_offset* = *0.0*
crr_status_flag	13 bits indicating Applied Corrections: Bit 0: Humidity correction applied Bit 1: Evolution correction applied Bit 2: Gradient correction applied Bit 3: Parallax correction applied Bit 4: Orographic correction applied Use of optional data: Bit 5: Solar channel used Bit 6: Lightning data used Processing information Bit 7: crr_intensity set to 0 due to filtering process Bit 8: crr_intensity was a hole because of the parallax correction, and then was filled by the median filter Bit 9,10, 11: Use of bands for accumulation 1: All required bands were available 2: One previous CRR band is missing 3: At least two previous CRR bands are missing (no consecutive) 4: At least two previous CRR bands are missing (some are consecutive) Bit 12: Accumulation quality flag. Set to 1 if: not all crr values are available to perform the accumulation, OR any of the crr_intensity values was set to 0 due to filtering process OR Any of the crr_intensity values was a hole because parallax correction

Geophysical Conditions

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

Processing Conditions

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

Quality

Field	Type	Description
Nodata	Flag	Set to 1 if pixel is NODATA
Internal_consistency	Flag	Set to 1 if an internal consistency check has been performed. Internal consistency checks will be based in the comparison of the retrieved meteorological parameter with physical limits, climatological limits, neighbouring data, NWP data, etc.
Temporal_consistency	Flag	Set to 1 if a temporal consistency check has been performed Temporal consistency checks will be based in the comparison of the retrieved meteorological parameters with data obtained in previous slots.
Quality	Parameter	Retrieval Quality 0: N/A (no data) 1: Good 2: Questionable 3: Bad 4: Interpolated

3.2.2.3 Example of Convective Rainfall Rate (CRR) visualisation

3.2.2.3.1 Instantaneous Rates

Below is shown an image corresponding to CRR classes output. It has been obtained at full resolution and all corrections have been applied.

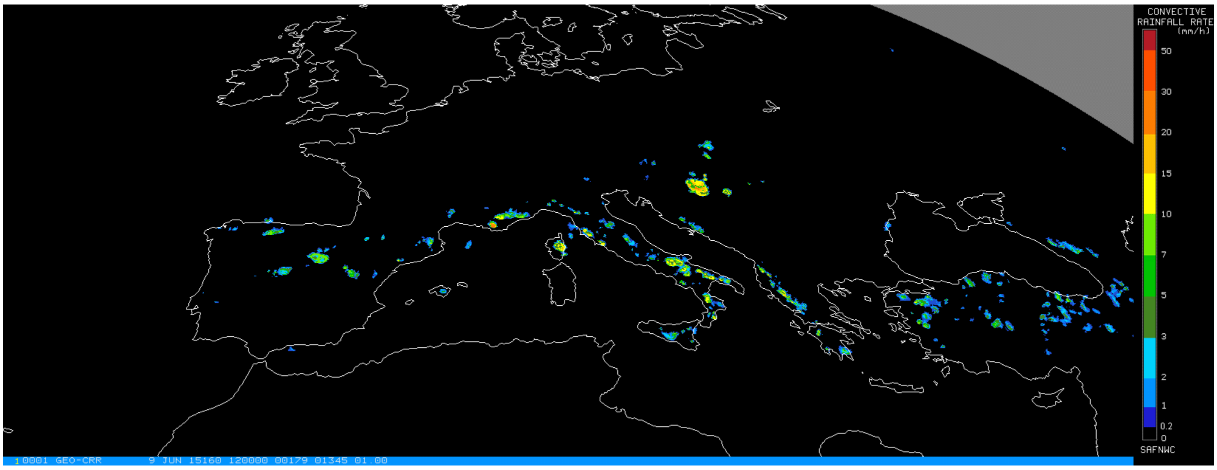


Figure 16. CRR instantaneous intensities output corresponding to 9th June 2015 at 12:00Z

3.2.2.3.2 Hourly Accumulations

Below is shown an image corresponding to CRR hourly accumulations output. It has been obtained at full resolution and all corrections have been applied.

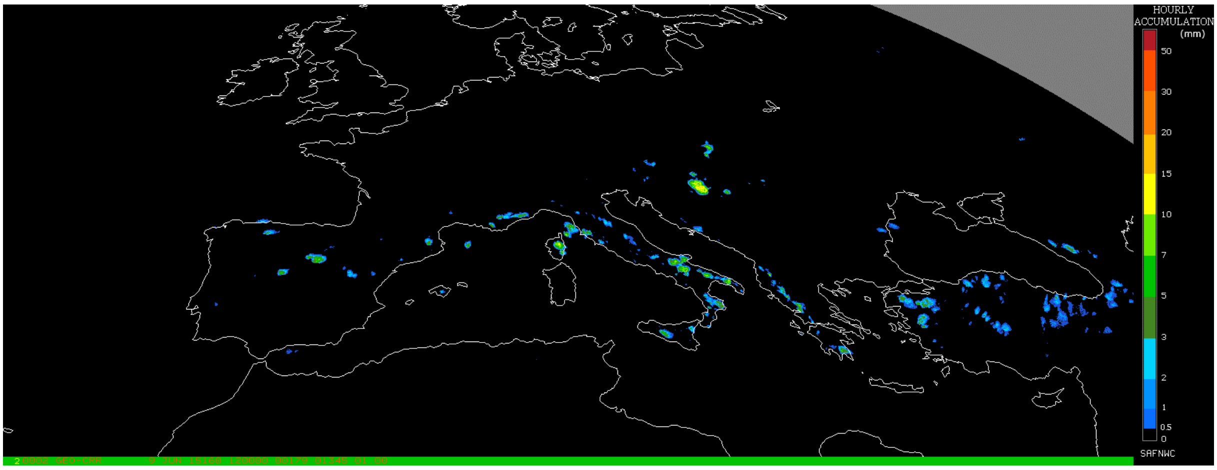


Figure 17. CRR hourly accumulations output corresponding to 9th June 2015 at 12:00Z

3.3 Assumptions and Limitations

The CRR product is based on a calibration method which requires the availability of a training set of precipitation data derived from radar information, to be used as ground truth to derive the relationship between satellite information and rainfall rate.

Regarding the radar data:

- The drop size distribution, used to obtain the radar rainfall rates (mm/h) from the radar reflectivity (dBZ), has been assumed to be the Marshall Palmer type throughout the calibration and validation procedures.

- No online operational method has been applied in order to adjust the radar rainfall intensities using rain gauge measurements.

- The limited availability of radar data at the time of carrying out the CRR calibration caused that three different radar datasets, with different radar products, had to be used. In the case of the Spanish radar data, PPI product were used and a quality control, taking advantage of a quality image generated for the radar national composite products (Gutierrez and Aguado, 2006), was used. In the case of the Hungarian radar data, rain rates based on Maximum reflectivity in the vertical were used, while in the case of Baltrad network, Pseudo-CAPPI at 2Km were used to derive rain rates. Is should be borne in mind that no quality control methods were used for Baltrad and Hungarian radar datasets.

- Data from the radar networks in different areas were not compared to an independent reference.

Regarding the lightning algorithm:

- The CRR lightning algorithm and the coefficients applied have been derived for Spain using the lightning information from the AEMET lightning detection network. Concerning this particular, it is important to highlight that ground based lightning detection networks provide information with different performances in detection efficiency and location accuracy. For this reason, in the model configuration file the keyword APPLY_LIGHTNING is set to 0 and by default the lightning information is not used.

- Before to use the lightning algorithm it is highly recommended to the user to adapt the coefficients to the specific performances of the lightning detection network serving that information.

- This issue can be solved in a satisfactory manner with the use of lightning information provided by MTG Lightning Imager which still requires of a technical adaptation and calibration.

3.4 References

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4. DESCRIPTION OF PRECIPITATING CLOUDS FROM CLOUD PHYSICAL PROPERTIES (PC-PH) PRODUCT FOR DAYTIME

4.1 PRECIPITATING CLOUDS FROM CLOUD PHYSICAL PROPERTIES (PC-PH) OVERVIEW

Precipitating Clouds from Cloud Physical Properties (PC-Ph) product, developed within the NWC SAF context, is a Nowcasting tool that provides estimation on the probability of precipitation (PoP) occurrence.

In our context, PoP is defined as the instantaneous probability that a rain rate greater than or equal to 0.2 mm/h occurs at the pixel level.

The PoP estimation is done using information on the cloud top microphysical properties (CTMP), Effective Radius (R_{eff}) and Cloud Optical Thickness (COT). Using these two parameters the Cloud Water Path (CWP) is computed. A relation between CWP and PoP has been obtained in order to assign a PoP to each FCI pixel.

The microphysical properties are computed within the NWC SAF Cloud Microphysics (CMIC) product for daytime, so it is necessary to run CMIC product previous to run PC-Ph. The main limitation of this product is that only provides results during daytime.

4.2 PRECIPITATING CLOUDS FROM CLOUD PHYSICAL PROPERTIES (PC-PH) DAYTIME ALGORITHM DESCRIPTION

4.2.1 Theoretical description

In this section the theoretical basis and practical implementation of the algorithm are described.

4.2.1.1 Physics of the problem

Reflected IR solar radiation by the cloud tops can be useful to obtain information on microphysics and rain processes near cloud tops (Pilewskie and Twomey, 1987). The radiative properties of a cloud can be characterized through the Effective Radius (R_{eff}) and Cloud Optical Thickness (COT).

The most relevant measure that indicates the possibility of occurrence of rain formation processes in observed clouds is the effective radius (Rosenfeld and Gutman, 1994). The effective radius is defined as the ratio of the third to second moments of the droplet size distribution.

$$R_{eff} = \frac{\int_0^\infty N(r) r^3 dr}{\int_0^\infty N(r) r^2 dr}$$

Where N(r) is the concentration of particles having radius r.

Cloud optical thickness depends on the moisture density as well as the vertical thickness of the cloud. The higher is the COT, the higher is the possibility of occurrence of rain formation processes. It is possible to retrieve COT values from satellite data (Roebeling et al., 2006).

Two FCI channels are used, together with a radiative transfer model, in order to retrieve R_{eff} and COT. The cloud reflectance at VIS0.6 channel is directly related with COT while R_{eff} is connected with the reflectance variations measured in near infrared channels like NIR1.6 and IR3.8. Due to the number of disadvantages that IR3.8 channel presents (Roebeling et al., 2006), NIR1.6 has been used.

Under certain assumptions, these two cloud top microphysical properties can be used to estimate the amount of water available to produce rain within a cloud (Roebeling and Holleman, 2009).

The Effective Radius and the Cloud Optical Thickness used by this algorithm are retrieved within the CMIC algorithm **¡Error! No se encuentra el origen de la referencia.**.

4.2.1.2 Mathematical Description of the Precipitating Clouds from Cloud Physical Properties (PC-Ph) daytime algorithm

This section contains the description of the algorithm used to obtain the probability of precipitation from cloud top microphysical properties as well as it has been calibrated. Although the calibration methodology it is not completely rigorous mathematically it has been proved that it provides good results.

For the retrieval of the probability of precipitation, the Cloud Water Path (CWP) is used. CWP means Liquid Water Path for water clouds and Ice Water Path of ice clouds. This parameter is computed using the following equation (Roebeling and Holleman, 2009):

$$CWP = \frac{2}{3} * R_{eff} * COT$$

The tuning of this PC-Ph algorithm has been done comparing Spanish composite radar data (rainy/no rainy pixel) with CWP maps. Radar pixels with rain rates greater than or equal to 0.2 mm/h have been considered as rainy. The dataset used to that end contains 111 rainy days all over 2009.

The calibration area has been restricted to 15x15 pixel boxes around radar rainy pixels. CWP values have only been computed for those pixels identified by CT product with water or ice phase. Pixels with no computed CWP value have been excluded from the calibration process.

A database of pairs CWP - Radar rainy/no rainy pixel has been built. SAFNWC/MSG Parallax Correction tool has been applied to CWP maps. As the perfect matching between Radar and MSG images is not possible, a smoothing process in 3x3 pixels boxes has been applied to both types of data (CWP and Radar rain rates) previous to build the database.

The probability of precipitation occurrence has been connected with the CWP values taking into account that the higher CWP the higher the probability of precipitation.

Five iterative computations have been done to connect CWP with FAR.

A satellite pixel has been considered as rainy when its CWP is higher than a CWP specific threshold that connects to a specific FAR. The first CWP specific threshold computed (CWP_1) is the one that provides FAR=20%. To find this CWP_1 threshold, several iterations have been computed using the database data pairs, assuming that a satellite pixel with $CWP \geq CWP_1$ is a rainy pixel. This way CWP_1 with FAR=20% has been obtained. This CWP_1 threshold takes a value of 970 gm^{-2}.

According to this method, those data pairs with $CWP \geq CWP_1$ have a PoP greater than or equal to 80%. This way has been obtained the data pair (CWP_1 = 970 gm^{-2}, PoP_1 = 80%).

At next step the CWP_2 threshold is computed. CPW_2 is the one that provides a FAR = 40% using those data pairs with $CWP_2 \leq CWP < CWP_1$. In line with the previous step, a second data pair have been obtained (CWP_2 = 591 gm^{-2}, PoP_2 = 60%).

The same procedure has been followed in order to match CWP thresholds with different PoPs.

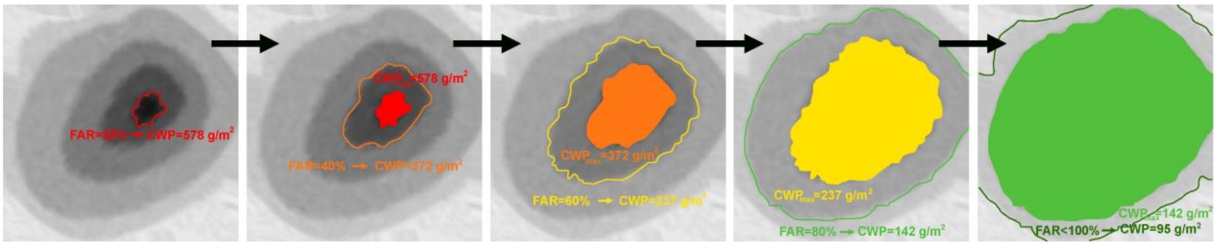

Figure 18. Schematic illustration of the procedure followed to tune PC-Ph product representing the CWP isolines connected with the different FAR values (no real data).

The pairs CWP-PoP obtained for this PC-Ph tuning can be seen in Figure 19:

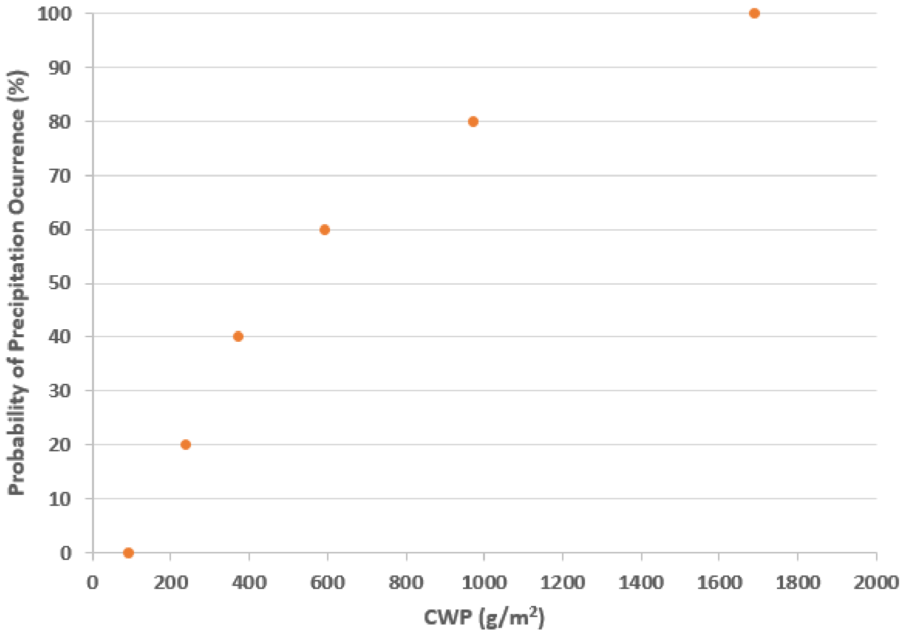

Figure 19. Data pairs obtained for PC-Ph tuning .

The function that best adjusted to these CWP-PoP data pairs is:

$$PoP = 33.0 * Ln(CWP) - 149.6$$

Where PoP is the Probability of Precipitation occurrence (%) and CWP is the Cloud Water Path (gm^{-2}).

The graph of this function can be observed in Figure 20.

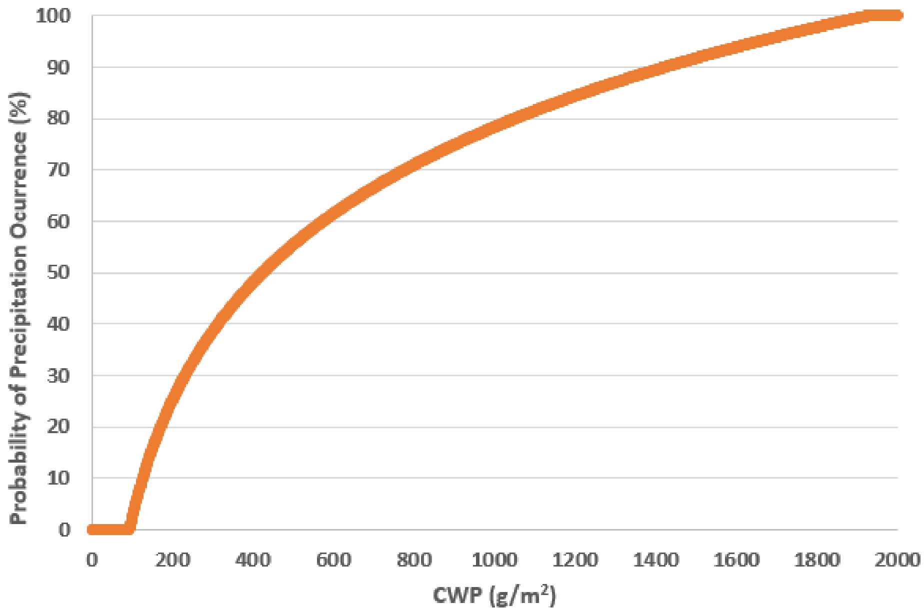

Figure 20. Function that connects probability of precipitation with CWP

As the cloud top microphysical properties used by this algorithm depend directly on FCI solar channel reflectances, there could be a degradation of the results given by this algorithm under poor illumination conditions.

An independent study has been done in order to check this possible degradation with illumination conditions. Data belonging to 103 rainy days throughout 2008 have been used for this purpose.

The illumination conditions parameter (ICP), which takes into account the illumination conditions and the view angle, has been computed for each pixel used for this study. This ICP has been defined as:

$$ICP = \cos[SatZen] * \cos[SunZen]$$

Where SatZen is the satellite zenith angle and SunZen is the sun zenith angle. This parameter takes account of solar illumination conditions as well as FCI pixel position that influence the quantity of radiance that reaches the satellite sensor reflected from surface or cloud tops.

As deduced from its definition, ICP takes values from 0 to 1. It is clear that the higher ICP the better illumination conditions.

A database of triads PoP - Radar rainy/no rainy pixel - ICP has been built. SAFNWC/MSG Parallax Correction tool has been applied to the satellite derived products. As the perfect matching between Radar and satellite images is not possible, a smoothing process in 3x3 pixels boxes has been applied to all types of data (PoP, Radar rain rates and ICP) previous to build the database. Then, a comparison between PoP and Radar have done and categorical scores have been computed. This comparison has been done for different PoP intervals as well as for different ICP intervals. Regarding the satellite estimations, for comparisons, only pixels belonging to the PoP category that is being compared in each moment are taken into account, and all of them are considered as satellite rainy pixels, so POD will always be 100%. Special attention has to be paid to FAR values and it should bear in mind that a region with the probability of precipitation interval A-B% should have 100-B ≤ FAR < 100-A.

PoP has been divided into five intervals: 0-20%, 20-40%, 40-60%, 60-80% and 80-100%. In each PoP interval, different ICP intervals have been compared taking always 1.0 as upper limit. Since this study have been done over Spain, few values of ICP > 0.7 have been found, so this has been taken as the last lower limit of the ICP intervals. Results can be seen in the following tables:

0% < PoP ≤ 20%	ICP interval lower limit	N	FAR (%)
Expected FAR: 80% < FAR ≤ 100%	0.1	1613571	93,05
	0.2	1613571	93,05
	0.3	1611726	93,05
	0.4	1216130	92,95
	0.5	59112	96,15
	0.6	1	100,00

Table 8. False alarm ratio obtained for 0% < PoP ≤ 20% depending on ICP

20% < PoP ≤ 40%	ICP interval lower limit	N	FAR (%)
Expected FAR: 60% < FAR ≤ 80%	0.1	702028	81,05
	0.2	702028	81,05
	0.3	700955	81,04
	0.4	531071	80,65
	0.5	28444	89,65
	0.6	1	100,00

Table 9. False alarm ratio obtained for 20% < PoP ≤ 40% depending on ICP

40% < PoP ≤ 60%	ICP interval lower limit	N	FAR (%)
Expected FAR: 40% < FAR ≤ 60%	0.1	453418	62,7
	0.2	453418	62,7
	0.3	452266	62,67
	0.4	345179	61,98
	0.5	17380	76,73
	0.6	4	75,00

Table 10. False alarm ratio obtained for 40% < PoP ≤ 60% depending on ICP

60% < PoP ≤ 80%	ICP interval lower limit	N	FAR (%)

	0.1	255794	39,53
Expected FAR:	0.2	255794	39,53
20% < FAR ≤ 80%	0.3	254958	39,46
	0.4	190320	38,02
	0.5	7784	52,48
	0.6	11	9,09

Table 11. False alarm ratio obtained for 60% < PoP ≤ 80% depending on ICP

80% < PoP ≤ 100%	ICP interval lower limit	N	FAR (%)
Expected FAR:	0.1	144543	23,05
0% < FAR ≤ 20%	0.2	144543	23,05
	0.3	144346	23,05
	0.4	100557	20,19
	0.5	2914	20,93
	0.6	24	12,50

Table 12. False alarm ratio obtained for 80% < PoP ≤ 100% depending on ICP

Comparisons with wider ICP ranges contain values estimated under worse illumination conditions. If illumination conditions would affect PC-Ph estimations, higher fluctuations of the categorical scores should have been obtained among the different ICP ranges considered. According to the tables, the highest fluctuation obtained for all PoP intervals that gets the worse categorical scores, is the one that uses ICP values higher than 0.6, but, this specific range is the one computed under the best illumination conditions. The reason could be that few data pairs are included in this interval. Also can be observed that few data with ICP < 0.3 was obtained in this study. In relation to this, it should be bear in mind that PC-Ph are computed only for sun zenith angles lower than 70º.

From these results it can be concluded that illumination conditions don't affect the quality of this PC-Ph product.

For a better precipitation area location a parallax correction [ANNEX A: Parallax Correction] can be applied to this product. This option is chosen by the user through the product model configuration file and it is applied by default.

4.2.2 Practical considerations

4.2.2.1 List of Precipitating Clouds from Cloud Physical Properties (PC-Ph) inputs

<u>CMIC product physical properties</u>:

CMIC Phase, COT and R_{eff} parameters are mandatory inputs to PC-Ph.

Satellite imagery:

IR10.8 FCI brightness temperature at full IR spatial resolution is a mandatory input to compute Parallax Correction.

Numerical model:

Temperature at 1000, 925, 850, 700, 500, 400, 300, 250 and 200 hPa

Geopotential at 1000, 925, 850, 700, 500, 400, 300, 250 and 200 hPa

This information is used by default for parallax correction. In case of lack of NWP parameters parallax correction will be run using a climatological profile.

Ancillary data sets:

Climatological profile is necessary as a backup for Parallax correction in case NWP is not available. This information is included in the software package and is located in the $SAFNWC/import/Aux_data directory.

Model configuration file for PPh:

PPh model configuration file contains configurable system parameters in the generation process of both PC-Ph and CRR-Ph products. The PC-Ph product related parameters refers to ancillary datasets, numerical model data and parallax correction. The complete list of these parameters and the explanation of the most useful ones is available in the User Manual for the Precipitation Product Processors of the NWC/GEO [RD5]

4.2.2.2 Description of the Precipitating Clouds from Cloud Physical Properties (PC-Ph) output

The content of the PC-Ph output is described in the Data Output Format Document **¡Error! No se encuentra el origen de la referencia.**. A summary is given below:

Container	Content
pcph	NWC GEO PC-Ph Precipitating Clouds from cloud Physical Properties pcph(%) = scale_factor * counts + add_offset where: *scale_factor* = *1.0* *add_offset* = *0.0*
pcph_status_flag	5 bits indicating Data Availability: Bit 0: R_{eff} or COT not computed (out of cloud, night time or undefined phase) Bit 1: Phase not computed or undefined Bit 2: IR band missing (used in parallax correction) Applied Correction: Bit 3: Parallax correction applied Other information Bit 8: pc_intensity was a hole because of the parallax correction, and then was filled by the median filter

Geophysical Conditions

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

Processing Conditions

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

Quality

Field	Type	Description
Nodata	Flag	Set to 1 if pixel is NODATA
Internal_consistency	Flag	Set to 1 if an internal consistency check has been performed. Internal consistency checks will be based in the comparison of the retrieved meteorological parameter with physical limits, climatological limits, neighbouring data, NWP data, etc.
Temporal_consistency	Flag	Set to 1 if a temporal consistency check has been performed Temporal consistency checks will be based in the comparison of the retrieved meteorological parameters with data obtained in previous slots.
Quality	Parameter	Retrieval Quality 0: N/A (no data) 1: Good 2: Questionable 3: Bad 4: Interpolated

4.2.2.3 Example of Precipitating Clouds from Cloud Physical Properties (PC-Ph) visualisation

Below is shown an example of the PCPh product. It has been obtained at full resolution.

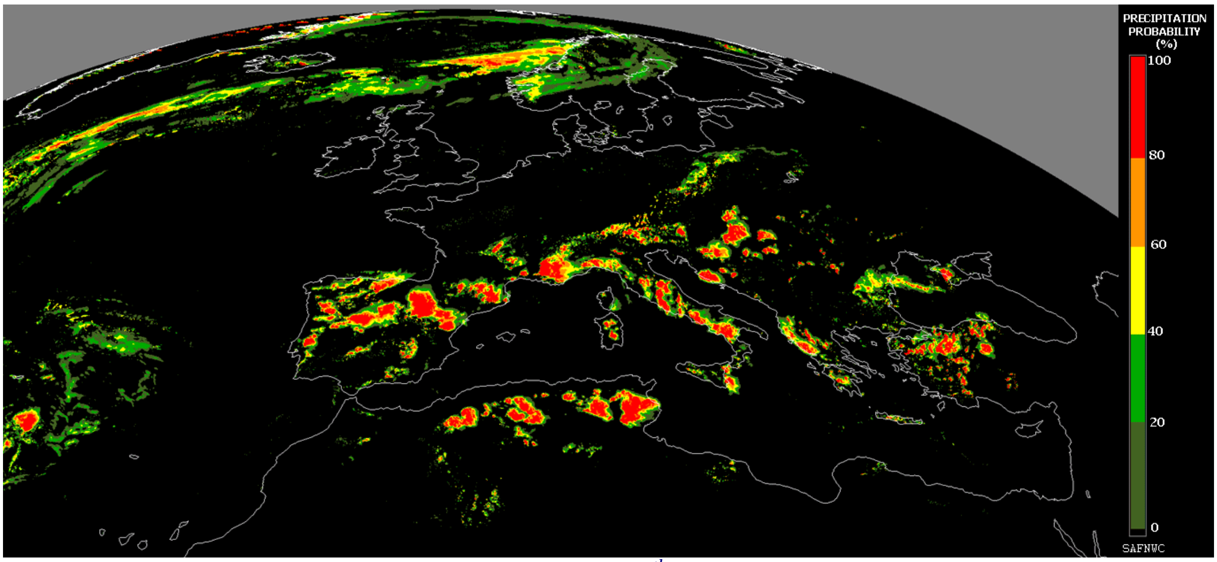

Figure 21. PC-Ph probability of precipitation for 9th June 2015 at 15:00 UTC over Europe and North Africa

4.3 ASSUMPTIONS AND LIMITATIONS

The PCPh product is based on a calibration method which requires the availability of a training set of precipitation data derived from radar information, to be used as ground truth to derive the relationship between satellite information and rainfall rate. As for this radar training dataset, the drop size distribution, used to obtain the radar rainfall rates (mm/h) from the radar reflectivity (dBZ), has been assumed to be the Marshall Palmer type throughout the calibration and validation procedures. No online operational method has been applied in order to adjust the radar rainfall intensities using rain gauge measurements.

This algorithm can be run only over daytime.

For undefined phase pixels, R_{eff} and COT values are not computed by CMIC, so a 0% probability of precipitation is assigned in these cases by the algorithm.

As the main inputs of the product are computed by CMIC, there exists the need to run CMIC previous to run PPh.

It has been observed that pixels located in the surroundings of snow according to CMIC take sometimes high values of CWP, so a probability of precipitation higher than 0% is assigned erroneously.

It is highly recommended to apply parallax correction for a better location of precipitation areas with respect to the ground below.

This product obtains the best results for convective events.

4.4 REFERENCES

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Roebeling, R.A., A.J. Feijt and P. Stammes, Cloud property retrievals for climate monitoring: implications of differences between SEVIRI on METEOSAT-8 and AVHRR on NOAA-17 J. Geophys. Res., 2006, 111, 20210, doi:10.1029/2005JD006990.

Rosenfeld, D., and G. Gutman, 1994. Retrieving microphysical properties near the tops of potential rain clouds by multispectral analysis of AVHRR data, Atmos. Res., 34, 259–283, doi:10.1016/0169-8095(94)90096-5.

5. DESCRIPTION OF CONVECTIVE RAINFALL RATE FROM CLOUD PHYSICAL PROPERTIES (CRR-PH) PRODUCT FOR DAYTIME

5.1 CONVECTIVE RAINFALL RATE FROM CLOUD PHYSICAL PROPERTIES (CRR-PH) OVERVIEW

Convective Rainfall Rate from Cloud Physical Properties (CRR-Ph) product, developed within the NWC SAF context, is a Nowcasting tool that provides information on convective, and stratiform associated to convection, instantaneous rain rates and hourly accumulations.

The main inputs of this product are the cloud top microphysical properties generated by CMIC, Cloud Top Phase, Effective Radius and Cloud Optical Thickness.

The first step of the processing of the product is the computation of Cloud Water Path (CWP). Then, depending on some R_{eff} and CWP thresholds, the precipitation area is enclosed. Only in those pixels belonging to the precipitation area, the rain rate is computed.

To assign an instantaneous rain rate to each pixel, a relationship between CWP and precipitation intensity is applied. In the following step, taking into account the instantaneous rain rates computed in the last hour time interval, hourly accumulations are computed through a trapezoidal integration.

At this stage, the CRR-Ph precipitation pattern computed in the previous step is combined with a precipitation pattern derived through a lightning algorithm (ANNEX B: Lightning algorithm). This step is optional.

Parameters used by this product are highly dependent on satellite solar channels. For this reason this product can only be generated during daytime.

It has been seen that this product provides erroneous rain rates for poor illumination conditions. For this reason an Illumination Conditions Quality flag, that provides information on the confidence of the estimated rain rates, is computed and delivered with the product.

5.2 CONVECTIVE RAINFALL RATE FROM CLOUD PHYSICAL PROPERTIES (CRR-PH) DAYTIME ALGORITHM DESCRIPTION

5.2.1 Theoretical description

In this section the theoretical basis and practical implementation of the algorithm are described.

5.2.1.1 Physics of the problem

Since both PC-Ph and CRR-Ph daytime algorithms are based on the same foundation, information provided in section 4.2.1.1 applies in this section.

5.2.1.2 Mathematical Description of the Convective Rainfall rate from Cloud Physical Properties (CRR-Ph) algorithm

The cloud top microphysical properties used to retrieve the CRR-Ph rain rates are the ones described in section 4.2.1.1.

As this product is an adaptation from MSG to MTG, the calibration and validation were performed only for MSG. The calibration of this algorithm has been done in two steps. Firstly the precipitation area has been enclosed, and then, rain rates have been assigned to the enclosed precipitation area.

The dataset used for the calibration of both, the precipitation area and the rain rates assignment, includes 40 storms over Spain occurred from May to September 2009. PPI composites of the C-Band Spanish Radar network have been used. Since these radar products are available every 10 minutes and the MSG scanning over Spain takes place about 10 minutes later than the MSG slot time, 0 and 20 minutes MSG slots have been matched to the 10 and 40 minutes radar images respectively.

Since illumination conditions are very important for this kind of algorithm, only SEVIRI imagery measured close to the hours of highest sun elevation have been included in this calibration dataset in order to avoid errors due to poor illumination conditions.

For a better matching of radar – satellite images, the radar products were converted into MSG projection using a bi-linear interpolation scheme.

A quality control has been used for the Spanish radar dataset taking advantage of the quality image generated for the radar national composite products (Gutierrez and Aguado, 2006).

Calibration of the rainy area:

According to the literature, clouds need, at least, cloud top effective radius higher than 14 µm to produce rain (Rosenfeld and Gutman, 1994) so this threshold have been accepted to detect rainy clouds.

SAFNWC/MSG Parallax tool has been applied to CWP maps.

To establish a CWP threshold, the number of rainy pixels in radar and CWP images have been compared. The threshold to consider a radar pixel as rainy was fixed to 0.2 mm/h. In the case of CWP images, a pixel has been considered as rainy when CWP in that pixel was higher than a certain threshold. The determination of this threshold has been done by comparing the number of rainy pixels summed up in annular bins with different radius. The centre of the annuli matches with the centre of the storm, see Figure 22. The centre of the storm was taken as the pixel with the highest radar rain rate. The number of rainy pixels included in each annulus in radar images has been compared with the ones obtained in satellite images using different CWP thresholds. Accuracy measurements (RMSE, MAE, ME) in the comparison between the number of radar rainy pixels obtained and the satellite ones using a certain CWP threshold have been obtained. Figure 23 shows the results obtained, indicating that the most appropriate CWP threshold that indicates a rainy area is 356 g/m^2.

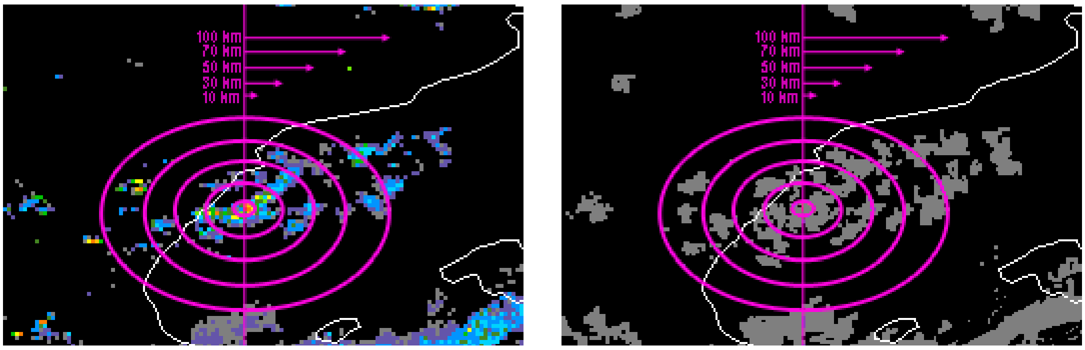

Figure 22. Annular bins used for calibration over a Radar image on the left and over a rain/no rain CWP map on the right.

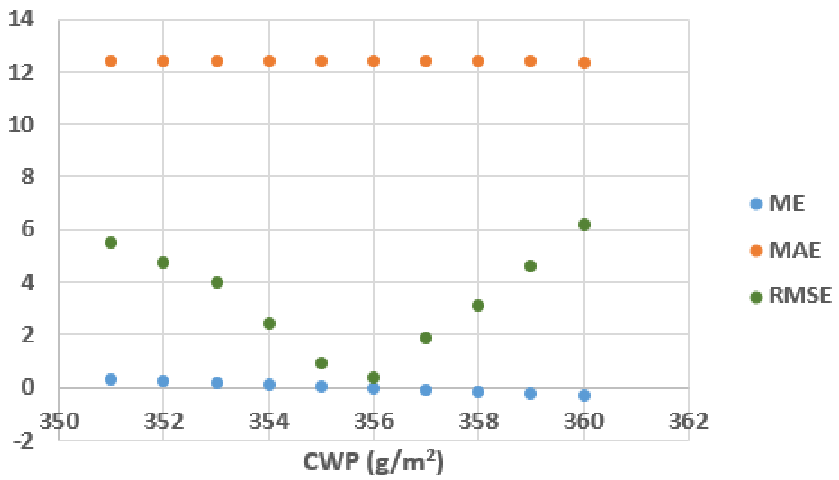

Figure 23. Accuracy statistics obtained in the comparison of number of rainy pixels in annular bins for Spanish storms

Calibration of the rain rates:

A similar calculation has been done for the rain rates calibration. This time the number of radar rainy pixels has been summed up for different rain rate thresholds, and for each threshold it has been compared with the number of satellite estimated rainy pixels from algorithms using different CWP thresholds. The CWP threshold algorithm with lower RMSE has been selected for each radar rain rate threshold.

Results of this comparison are shown in Figure 24.

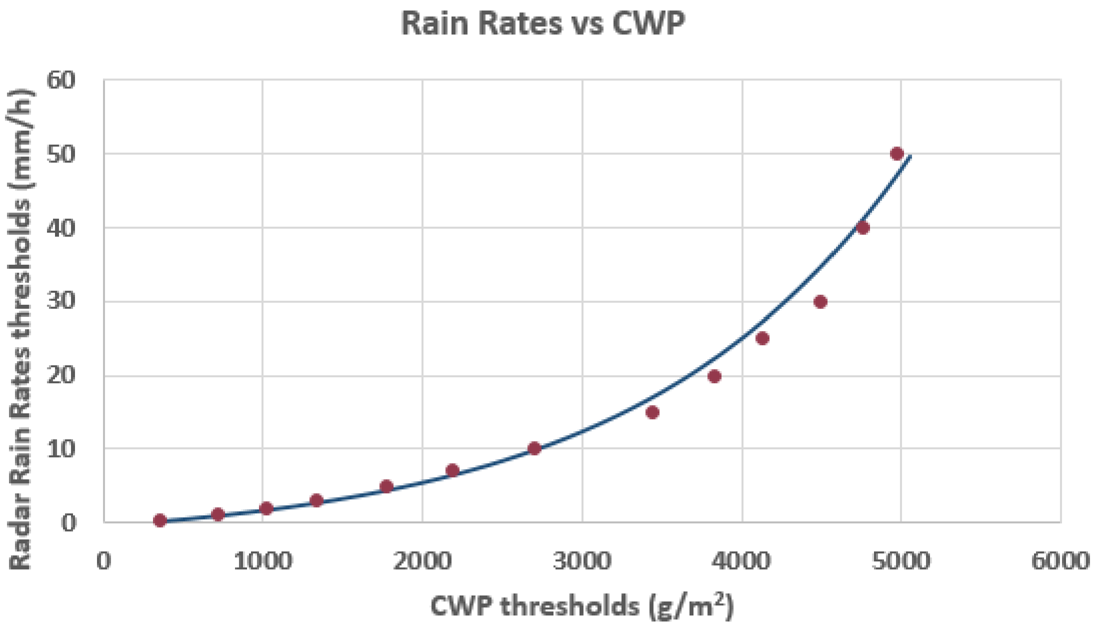

Figure 24. Results of rain rates calibration. Radar rain rates vs CWP, thresholds .

Rain rates estimation from geostationary satellite data can not be very accurate so trying to estimate rain rates higher than 50 mm/h using this type of data is not realistic. For this reason a maximum limit of 50 mm/h has been established. Then an adjustment with the obtained dots has been done in order to obtain the best fit function. This analytical function (MCTP function - blue line) is shown in Figure 24. The mathematical expression of it is the following:

$$RR = 2.0 * \exp\left(6 * 10^{-4}\left(CWP + 400.0\right)\right) - 3.02$$

where:

RR – Rain rates (mmh^{-1})

CWP – Cloud Water Path (gm^{-2})

It has been seen that, under some conditions, rain rates assigned by this product are erroneously high. In order to provide the user with information about the reliability of the estimated rain rates, an illumination quality flag (CRR-Ph_IQF) has been developed. For this purpose the illumination conditions parameter (ICP), which takes into account the illumination conditions and the view angle, as described in section 4.2.1.2, has been used:

$$ICP = \cos[SatZen] * \cos[SunZen]$$

Where SatZen is the satellite zenith angle and SunZen is the sun zenith angle.

In order to define the influence of the illumination conditions in the degradation of the product a comparison between radar and CRR-Ph has been done. 40 storms over Spain from May to September 2009 and from 6:30 to 17:30 UTC (except for 12:00 UTC because this time was used for calibration of the product) every 30 minutes, were used for this purpose. Rain rates of radar higher than 50 mm/h were set to 50 mm/h.

Assuming that the centre of the storm is placed in the pixel with highest radar rain rate, two parameters have been computed in circular areas of 50 km radius centred in that pixel:

- N-CRR-Ph$_{max}$: the number of CRR-Ph pixels with estimated rain rates higher than or equal to the highest radar rain rate
- N-Radar$_{max}$: the number of radar pixels with rain rates equal to the highest radar rain rate

A study of the data pairs obtained for each storm (N-CRR-Ph$_{max}$, N-Radar$_{max}$) has been done taking into account the ICP registered at the centre of the storm.

The usual behaviour of this kind of satellite derived precipitation products is to provide lower rain rates and wider precipitation areas than the ones detected by the radar. The degradation of the product estimations under poor illumination conditions leads to an overestimation of the estimated rain rates remaining the precipitation area well detected.

It can be assumed that under good illumination conditions, the following relationship should apply most of the times:

$$\frac{N - CRPh_{max}}{N - Radar_{max}} \leq 1$$

Figure 25 shows the average of (N-CRR-Ph$_{max}$/ N-Radar$_{max}$) for different ICP ranges.

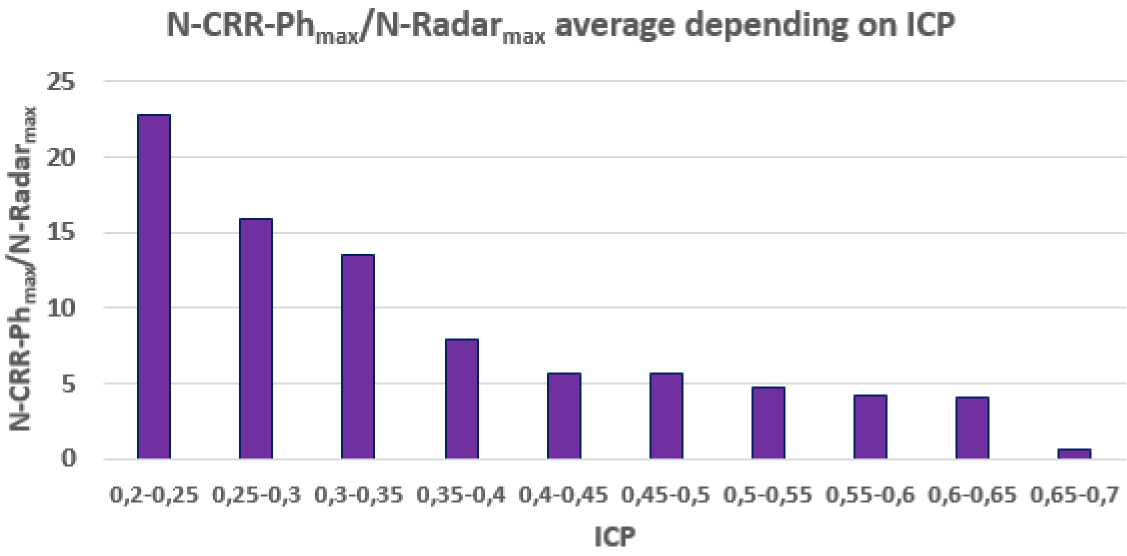

Figure 25. Average of (N-CRR-Phmax/ N-Radarmax) for different ICP ranges

Figure 25 shows that the lower value takes ICP, the higher is the number of too high rain rates estimated by CRR-Ph. In other words, the poorer are the illumination conditions, the higher is the overestimation of CRR-Ph rain rates. Other conclusion that can be obtained from Figure 25 is that, for ICP values higher than 0.65, CRR-Ph rain rates estimations are not overestimated.

Looking at the triads (N-CRR-Ph_{max}, N-$Radar_{max}$, ICP) it can be observed that even for ICP < 0.65 it happens that N-CRR-Ph_{max} is lower or equal than N-$Radar_{max}$ in some cases. So the percentage of the cases when N-CRR-Ph_{max} is lower or equal N-$Radar_{max}$, has been computed for some ICP intervals taking into account the ICP ≥ 0.65 threshold. Figure 26 shows the percentage of the cases when N-CRR-Ph_{max} is lower or equal N-$Radar_{max}$. To test whether the previous relationship is too restrictive, the percentage of cases when N-CRR-Ph_{max} is lower or equal two times, and three times, N-$Radar_{max}$ have been computed and can be seen in Figure 27 and Figure 28, respectively.

The best results are obtained for ICP > 0,6 when 76% of cases accomplishes the condition. It must be taken into account that, even for good illumination conditions, the condition could not be accomplished in some cases and it doesn't mean bad CRR-Ph results.

ICP > 0,5 accomplishes the condition in more than 67% of the cases, and ICP > 0,4 in more than 66% of the cases.

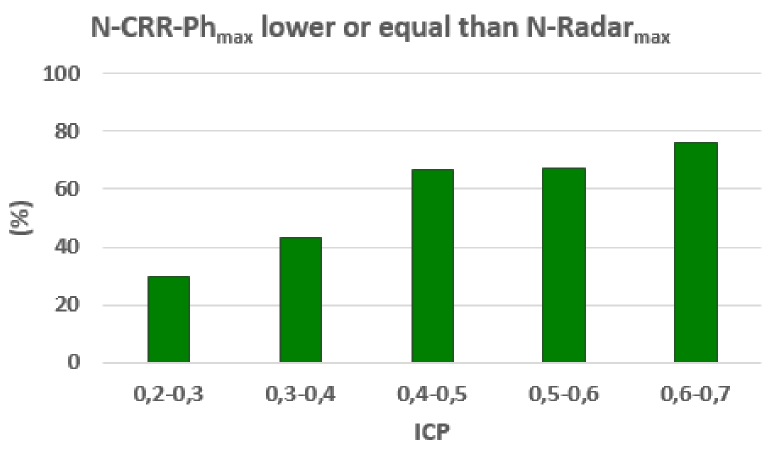

Figure 26. Percentage of the cases when N-CRR-Ph_{max} is lower or equal N-$Radar_{max}$.

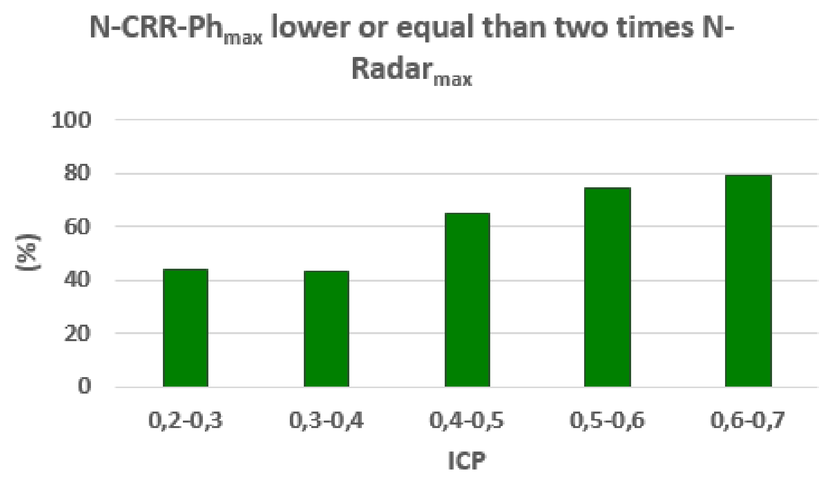

Figure 27. Percentage of the cases when N-CRR-Ph$_{max}$ is lower or equal than two times N-Radar$_{max}$.

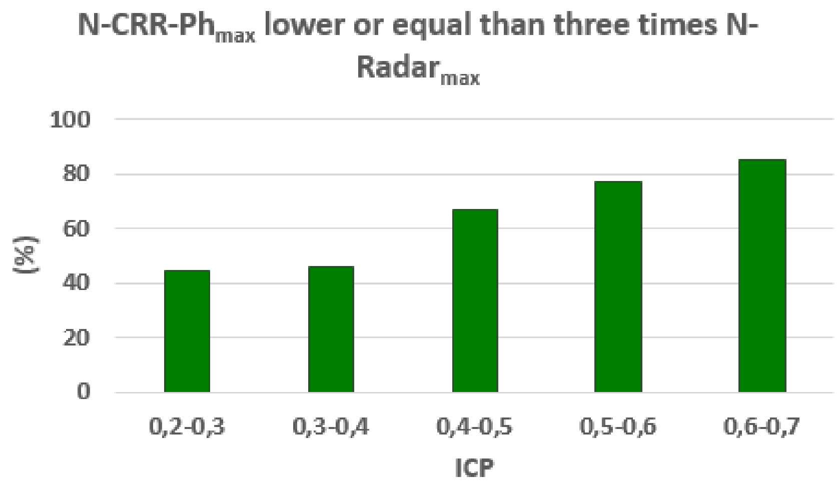

Figure 28. Percentage of the cases when N-CRR-Ph$_{max}$ is lower or equal than three times N-Radar$_{max}$

It can be complicated for the forecaster to directly use ICP value so, using an average of the results obtained in Figure 26, Figure 27 and Figure 28, the percentage of cases, depending on ICP, when the algorithm provides good results, as far as illuminations conditions and viewing angles are concerned, have been computed. This percentage of confidence on the CRR-Ph rain rates is included in the variable CRR-Ph_IQF and depends on ICP on the following way:

CRR-Ph_IQF = 109.95 * ICP + 11.09
If CRR-Ph_IQF < 0 then CRR-Ph_IQF = 0
If CRR-Ph_IQF > 100 then CRR-Ph_IQF = 100
CRR-Ph_IQF = 109.95 * ICP + 11.09

If CRR-Ph_IQF < 0 then CRR-Ph_IQF = 0
If CRR-Ph_IQF > 100 then CRR-Ph_IQF = 100

Figure 29. Relation between ICP and CRR-Ph_IQF

CRR-Ph_IQF (%) is included as an output of the product and it must be understood as an indicator of the confidence that a forecaster can have on the rain rates estimated by the product.

For a better convective precipitation area location a parallax correction [ANNEX A: Parallax Correction] can be applied to this product. This option is chosen by the user through the product model configuration file and it is applied by default.

Lightning activity can provide valuable information about convection. A lightning algorithm can be applied to derive a precipitation pattern that will be combined with the CRR-Ph one computed in the previous step in order to complement it. Description of the lightning algorithm can be found in ANNEX B: Lightning algorithm.

Using the computed rain rates, hourly accumulations are computed. The description of this process can be found in ANNEX C: Hourly accumulations.

5.2.2 Practical considerations

5.2.2.1 List of Convective Rainfall rate from Cloud Physical Properties (CRR-Ph) inputs

CMIC product physical properties:

CMIC Phase, COT and R_{eff} parameters are mandatory inputs to CRR-Ph.

Satellite imagery:

IR10.8 FCI brightness temperature at full IR spatial resolution is a mandatory input to compute Parallax Correction.

Numerical model:

Temperature at 1000, 925, 850, 700, 500, 400, 300, 250 and 200 hPa

Geopotential at 1000, 925, 850, 700, 500, 400, 300, 250 and 200 hPa

This information is used by default for parallax correction. In case of lack of NWP parameters parallax correction will be run using a climatological profile.

Ancillary data sets:

Climatological profile is necessary as a backup for Parallax correction in case NWP is not available. This information is included in the software package and is located in the $SAFNWC/import/Aux_data directory

Lightning information file for CRR-Ph product:

A file with information on every lightning occurred in a time interval is mandatory to choose the option of adjusting the CRR-Ph precipitation pattern with the lightning information. Information about this lightning information file structure can be found in the Interface Control Document for Internal and External Interfaces of the NWC/GEO **¡Error! No se encuentra el origen de la referencia.**.

Model configuration file for PPh:

PPh model configuration file contains configurable system parameters in the generation process of both PC-Ph and CRR-Ph products. The CRR-Ph product related parameters refers to ancillary datasets, numerical model data, lightning algorithm and parallax correction. . The complete list of these parameters and the explanation of the most useful ones is available in the User Manual for the Precipitation Product Processors of the NWC/GEO **¡Error! No se encuentra el origen de la referencia.**.

5.2.2.2 Description of the Convective Rainfall rate from Cloud Physical Properties (CRR-Ph) output

The content of the CRR-Ph output is described in the Data Output Format Document **¡Error! No se encuentra el origen de la referencia.**. A summary is given below:

Container	Content
crrph_intensity	NWC GEO CTMP-CRR Convective Rainfall Intensity crrph_intensity(mm/h) = scale_factor * counts + add_offset where: *scale_factor* = *0.1* *add_offset* = *0.0*
crrph_accum	NWC GEO CTMP-CRR Convective Hourly Rainfall Accumulation crrph_accum(mm) = scale_factor * counts + add_offset where: *scale_factor* = *0.1* *add_offset* = *0.0*
crrph_iqf	NWC GEO CTMP-CRR Confidence based on illumination conditions crrph_iqf(%) = scale_factor * counts + add_offset where: *scale_factor* = *1.0* *add_offset* = *0.0*
crrph_status_flag	10 bits indicating Data Availability: Bit 0: R_{eff} or COT not computed (out of cloud, night time, phase not defined) Bit 1: Phase not computed or undefined Bit 2: IR band missing (used in parallax correction) Applied Correction: Bit 3: Parallax correction applied Use of optional data: Bit 6: Lightning data used Other information Bit 8: crr_intensity was a hole because of the parallax correction, and then was filled by the median filter Bit 9, 10, 11: Use of bands for accumulation 1: All required bands were available 2: One previous CRR band is missing 3: At least two previous CRR bands are missing (no consecutive) 4: At least two previous CRR bands are missing (some are consecutive) Bit 12: Accumulation quality flag. Set to 1 if: not all crr values are available to perform the accumulation, OR any of the crr_intensity values was set to 0 due to filtering process OR Any of the crr_intensity values was a hole because parallax correction

Geophysical Conditions

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

Processing Conditions

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

Quality

Field	Type	Description
Nodata	Flag	Set to 1 if pixel is NODATA
Internal_consistency	Flag	Set to 1 if an internal consistency check has been performed. Internal consistency checks will be based in the comparison of the retrieved meteorological parameter with physical limits, climatological limits, neighbouring data, NWP data, etc.
Temporal_consistency	Flag	Set to 1 if a temporal consistency check has been performed Temporal consistency checks will be based in the comparison of the retrieved meteorological parameters with data obtained in previous slots.
Quality	Parameter	Retrieval Quality 0: N/A (no data) 1: Good 2: Questionable 3: Bad 4: Interpolated

5.2.2.3 Example of Precipitating Clouds from Convective Rainfall rate from Cloud Physical Properties (CRR-Ph) visualisation

Below is shown an example of the CRR-Ph instantaneous rain rates. It has been obtained at full resolution.

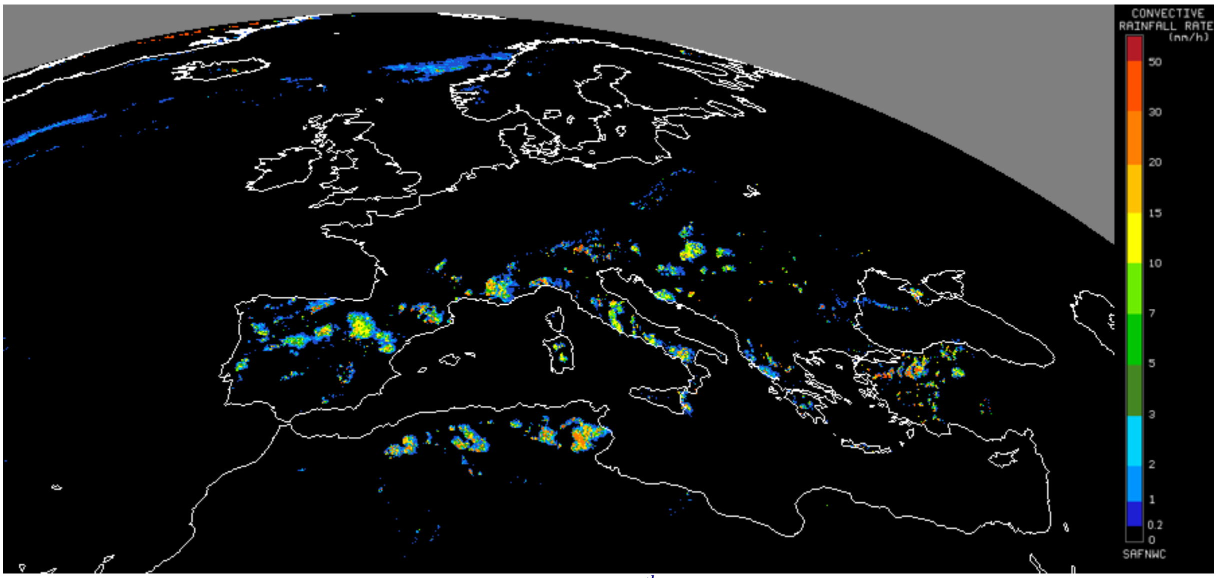

Figure 30. CRR-Ph instantaneous rain rates for 9th June 2015 at 15:00 UTC over Europe and North Africa

Below is shown an example of the CRR-Ph hourly accumulations. It has been obtained at full resolution.

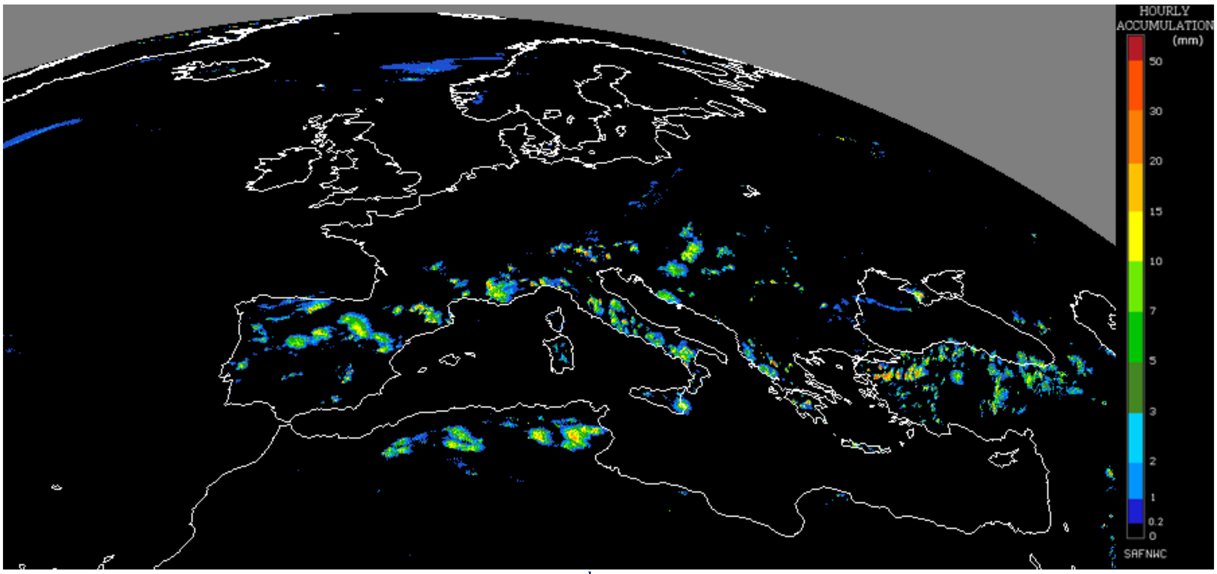

Figure 31. CRR-Ph hourly accumultions for 9th June 2015 at 15:00 UTC over Europe and North Africa

Below is shown an example of the CRR-Ph illumination quality flag.

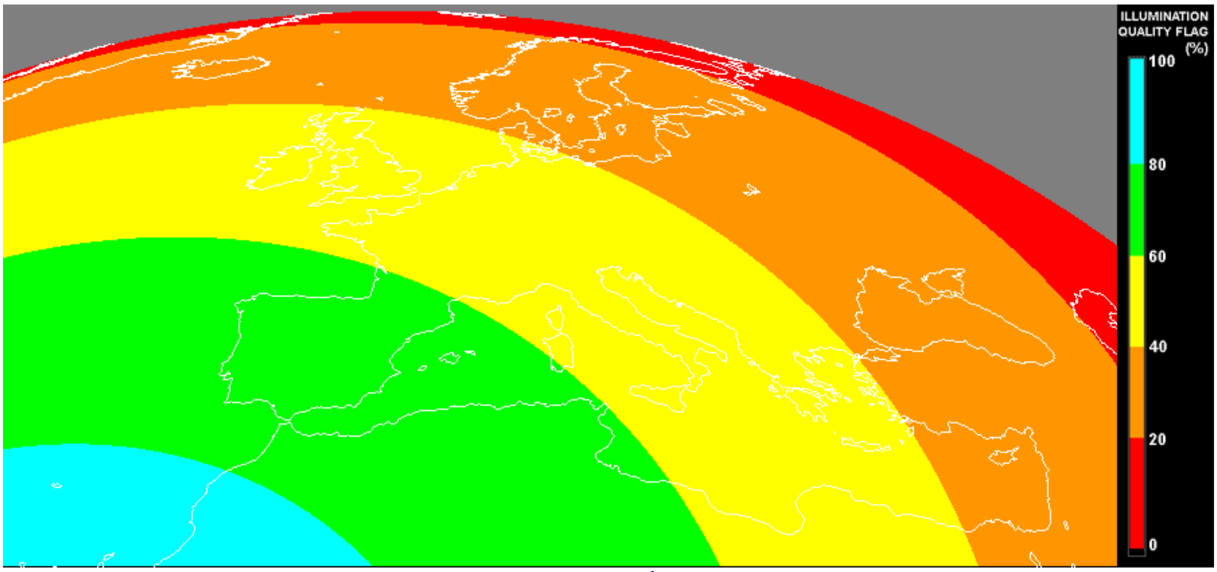

Figure 32. CRR-Ph illumination quality flag for 9th June 2015 at 15:00 UTC over Europe and North Africa

5.3 ASSUMPTIONS AND LIMITATIONS

The CRR-Ph product is based on a calibration method which requires the availability of a training set of precipitation data derived from radar information, to be used as ground truth to derive the relationship between satellite information and rainfall rate. As for this radar training dataset, the drop size distribution, used to obtain the radar rainfall rates (mm/h) from the radar reflectivity (dBZ), has been assumed to be the Marshall Palmer type throughout the calibration and validation procedures. No online operational method has been applied in order to adjust the radar rainfall intensities using rain gauge measurements.

This algorithm can be run only over daytime.

For undefined phase pixels, R_{eff} and COT values are not computed by CMIC, so a 0 mm/h rain rate is assigned in these cases by the algorithm.

As the main inputs of the product are computed by CMIC, there exists the need to run CMIC previous to run PPh.

It has been observed that pixels located in the surroundings of snow according to CMIC take high values of CWP, so a rain rate higher than 0 mm/h is assigned erroneously.

It is highly recommended to apply parallax correction for a better location of precipitation areas with respect to the ground below.

There exists a high dependence on illumination conditions for this product.

It must be borne in mind that these kind of cloud top based precipitation indirect methods necessarily have uncertainties. Although not found during the calibration and validation processes, according to the literature it is possible to find small ice particles in high-level strong updrafts of deep convective clouds (Rosenfeld et al., 2008). This could cause erroneous rain rate estimations.

As for the lightning data, the lightning algorithm and the coefficients applied have been derived for Spain using the lightning information from the AEMET lightning detection network. Concerning this particular, it is important to highlight that ground based lightning detection networks provide information with different performances in detection efficiency and location accuracy. For this reason, in the model configuration file the keyword APPLY_LIGHTNING is set to 0 and by default the lightning information is not used. Therefore, before to use the lightning algorithm, it is highly recommended to the user to adapt the coefficients to the specific performances of the lightning detection network serving that information.

5.4 REFERENCES

Gutierrez, J. M. and Aguado, F.: Quality image for the Spanish Radar National Composite, Proceedings of ERAD 2006, 318-320.

Rosenfeld, D. and G. Gutman, 1994. Retrieving microphysical properties near the tops of potential rain clouds by multispectral analysis of AVHRR data, Atmos. Res., 34, 259–283, doi:10.1016/0169-8095(94)90096-5.

Rosenfeld, D., William L. Woodley, Amit Lerner, Guy Kelman, Daniel T. Lindsey, 2008. Satellite detection of severe convective storms by their retrieved vertical profiles of cloud particle effective radius and thermodynamic phase. J. Geophys. Res. D4, 113.

Tapia, A., Smith, J. A., Dixon, M., 1998: Estimation of Convective Rainfall from Lightning Observations, Bull. American Meteorological Society, Vol. 37, pp. 1497-1509.

6. ANNEX A: PARALLAX CORRECTION

Two important factors for accurate precipitation estimations from satellite imagery are the position of the cloud tops and the influence of orographic effects on the distribution of precipitation.

The exact cloud position with respect to the ground below is needed to apply the CRR orographic correction. This is not a problem when a cloud is located directly below the satellite; however, as one looks away from the sub-satellite point, the cloud top appears to be farther away from the satellite than the cloud base. This effect increases as you get closer to the limb and as clouds get higher. Since parallax correction rectifies this effect, it is needed to be applied before orographic correction in the case of the CRR product.

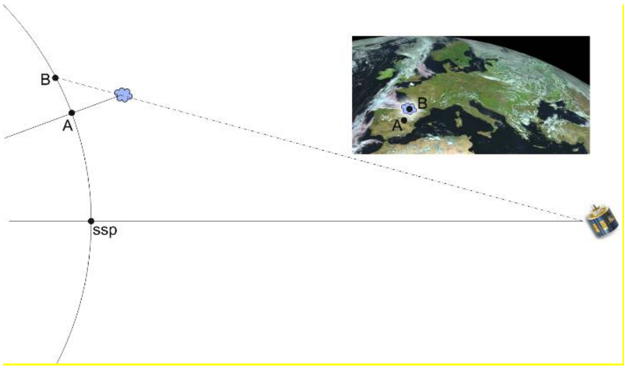

Figure 33. Parallax geometry

The parallax correction depends on three factors: a) the cloud height, b) the apparent position on the earth of that cloud and c) the position of the satellite.

The last two factors are known, but the first one has to be estimated. Two height estimation methods have been studied: numerical model and climatological profile obtained from the 1962 standard atmosphere model. Both of them are based on the conversion of each 10.8IR brightness temperature to height.

By default, height is estimated using NWP data. Parallax correction needs the NWP geopotential and temperature data at some levels (1000, 925, 850, 700, 500, 400, 300, 250 and 200). If NWP previous and next (according to the forecast time) models are available for the current slot time, a linear interpolation between these two models is performed.

Using 10.8IR brightness temperature, a linear interpolation is done among NWP temperatures and geopotential giving as a result the cloud height for each pixel. This height is then converted to meters.

In case of lack of NWP data or different number of pressure levels found (between temperature and geopotential) the NWP method for height calculation won't be used, and the climatological profile will be applied instead.

The used climatological data contain geopotential and temperature information related to five zones: 0º-15º, 15º-30º, 30º-45º, 45º-60º and 60º-75º. Two seasons are considered, summer and winter. A linear interpolation is used for latitude position and a cosine interpolation is used for Julian date.

Cloud height (in meters) is obtained using a bi-lineal interpolation according to the pixel temperature and considering the nearest four climatological temperature and geopotential measurements.

Parallax correction begins by converting the point and satellite locations into cartesian coordinates using the Earth centre as the origin. The Earth's surface is considered as an ellipsoid with an equatorial radius of 6378.077 Km. and a polar radius of 6356.577 Km. A virtual ellipsoid (as the earth's one) is performed using the distance from the cloud top to the earth centre. The cross point between the line joining the satellite and the apparent cloud surface position and this ellipsoid is found. The surface point connecting it with the Earth centre is then obtained, providing as result the new co-ordinate of the pixel. Finally, cartesian coordinates are converted into geographical ones.

When Parallax Correction is working, a spatial shift is applied to every pixel with precipitation according to the basic CRR value. In this re-mapping process, and only for a very small percentage of pixels, it could happen that (1) two pixels of the original image are assigned to the same pixel of the final image or (2) a pixel of the final image is not associated to any pixel of the original image (a “hole” appears in the final image). To solve these special cases, the next solutions have been implemented in the software:

- Case (1): the algorithm takes the maximum value of the rainfall rate
- Case (2): the software identifies the pixels with “hole”. A 3x3 median filter centred on that hole pixel is applied in order to assign a rainfall rate value (to compute the median, the pixels within the 3x3 box identified as holes are excluded)

The theoretical basis used in the computing of the Parallax correction in the CRR and CRR-Ph products and the Parallax Correction Processor of the NWC/GEO **¡Error! No se encuentra el origen de la referencia. ¡Error! No se encuentra el origen de la referencia.** is the same.

7. ANNEX B: LIGHTNING ALGORITHM

The lightning algorithm is based on the assumption than the higher is the spatial and temporal density of lightning occurrence, the stronger is the convective phenomenon and the higher is the probability of occurrence and the intensity of convective precipitation.

Only Cloud-to-Ground lightning flashes are used by this algorithm. To incorporate this information into the product a rain rate has been assigned to every lightning depending on:

- the time distance (Δτ) between the lightning event and scanning time of the processing region centre.
- the location of the lightning
- the spatial density of lightning in a time interval.

In order to know the rain rate to be assigned to each lightning the process proposed in Tapia et all. (Tapia et al., 1998) has been followed in this way:

A representative set of convective storms occurred over Spain have been selected. For each of them a Rainfall-Lightning Ratio (RLR) has been computed. This RLR takes into account the quantity of precipitation measured as well as the number of lightning occurred during each event. The mean of the RLR obtained for the selected storms is 10.08 mm/lightning.

The procedure followed is the following:

First of all, the number of lightning occurred within an interval Δt before the scanning time of the processing region centre, are assigned to each pixel according to its latitude and longitude. The interval Δt is selected by the user (default value: 15 minutes).

Afterwards a rain amount is assigned to every pixel according to the number of lightning allocated to it. The variability of the spatial correlation between lightning and rainfall within the storm area suggest the use of a uniform distribution of rainfall about lightning flashes (Tapia et al., 1998). For this reason, instead of assigning the RLR just to one pixel, this quantity of precipitation is spread around the pixel in order to obtain a more homogeneous pattern of precipitation in this way:

Z4	$\frac{Z3+Z4}{2}$	Z3	$\frac{Z3+Z4}{2}$	Z4
$\frac{Z3+Z4}{2}$	$\frac{Z2+Z3}{2}$	Z2	$\frac{Z2+Z3}{2}$	$\frac{Z3+Z4}{2}$
Z3	Z2	Z1	Z2	Z3
$\frac{Z3+Z4}{2}$	$\frac{Z2+Z3}{2}$	Z2	$\frac{Z2+Z3}{2}$	$\frac{Z3+Z4}{2}$
Z4	$\frac{Z3+Z4}{2}$	Z3	$\frac{Z3+Z4}{2}$	Z4

Figure 34. Spreading of the RLR value in a 5 by 5 pixels box

Being Z1, Z2, Z3 and Z4 the rain rate assignments according to the RLR obtained in the calibration process. The spreading of the RLR value has been done in the following way:

Z1= 0.228 * RLR (default value: 2.30 mm)

Z2= 0.074 * RLR (default value: 0.75 mm)

Z3= 0.025 * RLR (default value: 0.25 mm)

Z4= 0.010 * RLR (default value: 0.10 mm)

Simultaneously, the time of occurrence of each lightning event is taken into account. Since the point of view of instantaneous precipitation rates, lightning closer in time to the instant of rainfall measurement are better spatially correlated to the convective nuclei at that moment. So a higher weight is given to those lightning that occurred closer in time to the scanning time of the processing region centre (CRR-Ph time). To do that, all rain rates already assigned are multiplied by the factor COEFF_τ being:

$$COEF\_\tau = -1*10^{-7}(\Delta\tau)^4 - 3*10^{-3}(\Delta\tau)^2 + 1$$

Where Δτ is the interval of time between the time of occurrence of the lightning and the CRR-Ph time:

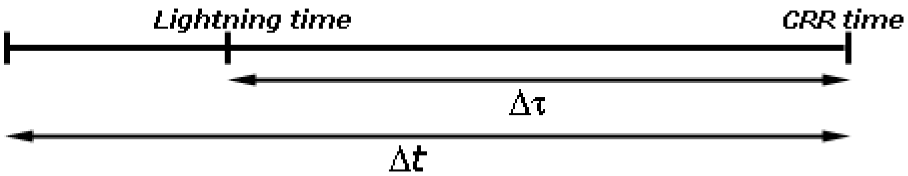

Figure 35. Diagram that shows the relationship between Δτ and Δt

Based on the fact than the higher is the spatial density of lightning occurrence the higher is the probability of the occurrence of greater intensities of precipitations, the density of lightning around each pixel is taken into account in the last step. To do that, rain rate corresponding to each pixel is multiplied by COEFF_N with:

$$COEFF\_N = a * \left(1 - b^N\right)$$

Where N is the number of lightning occurred in a 11x11 pixels box centred on every pixel within the Δt interval. a and b are the parameters of the equation (default values: a=0,45; b=0,7).

Once the precipitation pattern has been computed, it is compared to the CRR-Ph precipitation pattern in order to obtain the final product. This final product contains the highest rain rate of the two.

Instructions on how to tune lightning algorithm can be found in the User Manual for the Precipitation Product Processors of the NWC/GEO **¡Error! No se encuentra el origen de la referencia.**.

8. ANNEX C: HOURLY ACCUMULATIONS

At the end of the process the final values of the rainfall rates in mm/h are used in order to obtain hourly accumulations. A trapezoidal integration (Sánchez-Sesma and Sosa, 2004) is performed in order to compute the hourly accumulations.

Normal mode:

Six scenes are used in this process: the instantaneous scene corresponding to the time of the hourly accumulation and the five previous instantaneous scenes. The rain rate in mm/h output is the one used to make the computing.

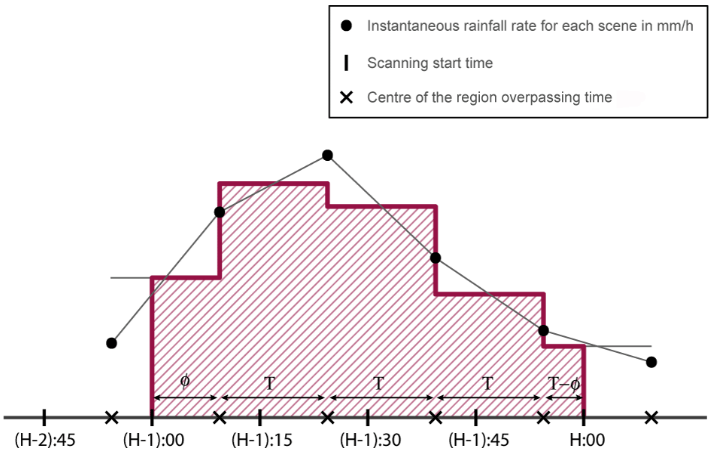

Figure 36. Trapezoidal integration

The nominal time of a scene corresponds to the moment when the satellite starts the scanning. Some minutes are needed to overpass the centre of the region where the product is being running. In order to avoid the time window effect, the following equation has been used to compute the hourly accumulations:

$$A_6 = \frac{I_1 + I_2}{2}\phi + \frac{I_2}{2}T + I_3 T + I_4 T + \frac{I_5}{2}T + \frac{I_5 + I_6}{2}(T - \phi)$$

Where:

- A_i: hourly accumulation, in mm, corresponding to the time i.
- T: time interval between scenes in hours (T= 0.25)
- Φ: part of T that corresponds to the time that takes the satellite to reach the centre of the region.
- I_i: Instantaneous rainfall rate for each scene in mm/h

The hourly accumulation won't be computed when there is a lack of more than two scenes or two consecutive ones in the complete interval.

Rapid Scan mode:

Fourteen scenes are used in this case: the instantaneous scene corresponding to the time of the hourly accumulation and the thirteen previous instantaneous scenes.

The equation that is used in the trapezoidal integration for the Rapid Scan mode is:

$$A_{14} = \frac{I_1 + I_2}{2}\phi + \frac{I_2}{2}T + \left(\sum_{i=3}^{12} I_i\right)T + \frac{I_{13}}{2}T + \frac{I_{13} + I_{14}}{2}(T - \phi)$$

Where:

- A_i: hourly accumulation, in mm, corresponding to the time i.
- T: time interval between scenes in hours (T= 1/12)
- Φ: part of T that corresponds to the time that takes the satellite to reach the centre of the region.
- I_i: Instantaneous rainfall rate for each scene in mm/h

The hourly accumulation won't be computed when there is a lack of more than six scenes or four consecutive ones in the complete interval.