The EUMETSAT Network of Satellite Application Facilities

NWC SAF

Support to Nowcasting and Very Short Range Forecasting

Algorithm Theoretical Basis Document for “Precipitation products from Cloud Physical Properties” (PPh-PGE14: PCPh v1.0 & CRPh v1.0)

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REPORT SIGNATURE TABLE

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DOCUMENT CHANGE RECORD

Version	Date	Pages	CHANGE(S)
1.0	15 July 2013	40	Initial version Indications and recommendations given by the NWC SAF SW Package MSG 2013 PCR and DRR have been included.

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Tables and Figures

1. INTRODUCTION

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

1.1 SCOPE OF THE DOCUMENT

This document is the Algorithm Theoretical Basis Document (ATBD) for the PPh-PGE14 (Precipitation products from Cloud Physical Properties) belonging to the SAFNWC/MSG software. PGE14 generates two different products: Precipitating Clouds from Cloud Physical Properties (PCPh) and Convective Rainfall rate from Cloud Physical Properties (CRPh).

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 SCOPE OF OTHER DOCUMENTS

The Product User Manual contains practical information on the characteristics of the product, including the input data and the output product. It also gives information about the algorithm's implementation.

The Validation Report document, showing the validation results that give information about the extended validation performed over Spain for a complete year period.

The Interface Control Document ICD/1 describes the External and Internal Interfaces of the SAFNWC/MSG software.

1.3 SOFTWARE VERSION IDENTIFICATION

This document describes the PPh algorithm implemented in the delivery 2013 of the SAFNWC/MSG package. This delivery corresponds to PPh-PGE14: version 1.0 of PCPh and version 1.0 of CRPh.

1.4 IMPROVEMENTS FROM PREVIOUS VERSION

This is the first version of this product using this approach.

1.5 DEFINITIONS, ACRONYMS AND ABBREVIATIONS

AEMET	Agencia Estatal de Meteorología
ATBD	Algorithm Theoretical Basis Document
BALTRAD	Baltic Radar Network
COT	Cloud Optical Thickness

CRPh	Convective Rainfall Rate from Cloud Physical Properties
CSI	Critical Success Index
CT	Cloud Type
CWP	Cloud Water Path
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FAR	False Alarm Ratio
ICD	Interface Control Document
ICP	Illumination Conditions Parameter
IQF	Illumination Quality Flag
IR	Infrared
MAE	Mean Absolute Error
CTMP	Cloud Top Microphysical Properties
ME	Mean Error
MSG	Meteosat Second Generation
NIR	Near Infrared
NWC SAF	Satellite Application Facility for Nowcasting
PC	Percentage of Corrects
PCPh	Precipitating Clouds from Cloud Physical Properties
PGE	Product Generation Element
POD	Probability of Detection
PoP	Probability of Precipitation
PPh	Precipitation from Cloud Physical Properties
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
VIS	Visible

1.6 REFERENCES

1.6.1 Applicable Documents

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.

Reference	Title	Code	Vers	Date
[AD. 1]	Algorithm Theoretical Basis Document for Cloud Products" (CMa-PGE01 v3.2, CT-PGE02 v2.2 & CTTH-PGE03 v2.2)	SAF/NWC/CDOP2/MFL/SCI/ATBD/01	2.1	15/07/13
[AD 2]	Validation Report for "Precipitation products from Cloud Physical Properties" (PPh-PGE14: PCPh v1.0 & CRPh v1.0)	SAF/NWC/CDOP2/INM/SCI/VR/15	1.0	15/07/13
[AD 3]	Product User Manual for "Precipitation products from Cloud Physical Properties" (PPh-PGE14: PCPh v1.0 & CRPh v1.0)	SAF/NWC/CDOP2/INM/PUM/14	1.0	15/07/13
[AD 4]	Interface Control Document for the External and Internal Interfaces of the SAFNWC/MSG	SAF/NWC/CDOP2/INM/SW/ICD/1	7.0	15/07/13
[AD 5]	NWC SAF Product Requirements Document	NWC/CDOP2/SAF/AEMET/MGT/PRD	1.2	15/07/13
[AD 6]	User Manual for the SAFNWC/MSG Parallax Correction Tool	GMV/SAFCDOP/VSAREP/02	1.0	02/06/08

Table 1: List of Applicable Documents

1.6.2 Reference Documents

Reference	Title
[RD.1]	Pilewskie, P. and Twomey, S., 1987. Discrimination of ice from water in clouds by optical remote sensing. Atmos. Res., 21:113-122
[RD.2]	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.
[RD 3]	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.
[RD 4]	Roebeling, R.A. and I. Holleman, 2009. SEVIRI rainfall retrieval and validation using weather radar observations. J. Geophys. Res., D2120, 114.
[RD 5]	Tapia, A., Smith, J. A., Dixon, M., 1998: Estimation of Convective Rainfall from Lightning Observations, Bull. American Meteorological Society, Vol. 37, pp. 1497-1509.
[RD 6]	Daniel Rosenfeld, 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.
[RD 7]	Gutierrez, J. M. and Aguado, F.: Quality image for the Spanish Radar National Composite, Proceedings of ERAD 2006, 318-320.

Table 2: List of Referenced Documents

2. ALGORITHM DESCRIPTION OF THE PRECIPITATING CLOUDS FROM CLOUD PHYSICAL PROPERTIES (PCPH) PRODUCT

2.1 PRECIPITATING CLOUDS FROM CLOUD PHYSICAL PROPERTIES (PCPH) PRODUCT OVERVIEW

Precipitating Clouds from Cloud Physical Properties (PCPh) 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 SEVIRI pixel.

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

2.2 PRECIPITATING CLOUDS FROM CLOUD PHYSICAL PROPERTIES THEORETICAL DESCRIPTION

2.2.1 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 [RD.1]. 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 [RD.2]. 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 SEVIRI [RD 3].

Two SEVIRI 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 IR3.9. Due to the number of disadvantages that IR3.9 channel presents [RD 3], 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 [RD 4].

The Effective Radius and the Cloud Optical Thickness used by this algorithm are retrieved within the PGE02 algorithm [AD. 1].

2.2.2 Mathematical description of the 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 [RD 4]:

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

The tuning of this PCPh 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 (Figure 1).

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 578 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 = 578 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 = 372 gm^{-2}, PoP_2 = 60%).

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

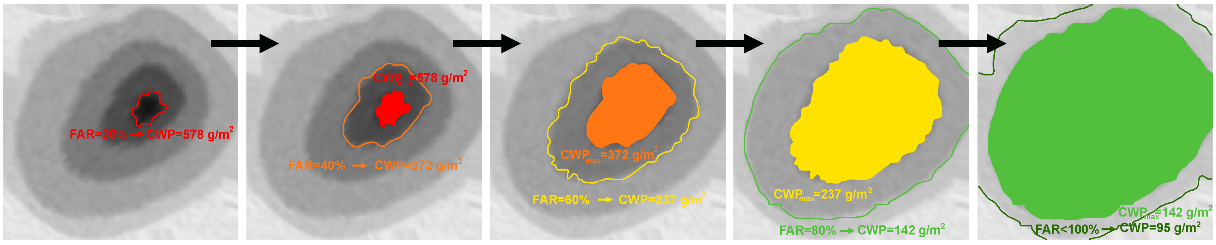


Figure 1: Schematic illustration of the procedure followed to tune PCPh product representing the CWP isolines connected with the different FAR values (no real data).

The pairs CWP-PoP obtained for this PCPh tuning can be seen in Figure 2:

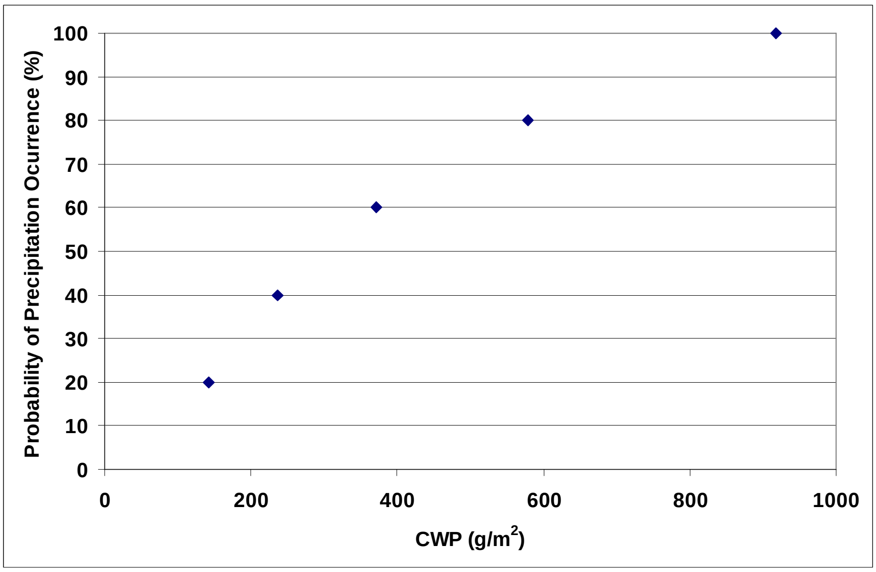


Figure 2: Data pairs obtained for PCPh tuning.

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

$$PoP = 43.7 * Ln(CWP) - 198.1$$

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 3.

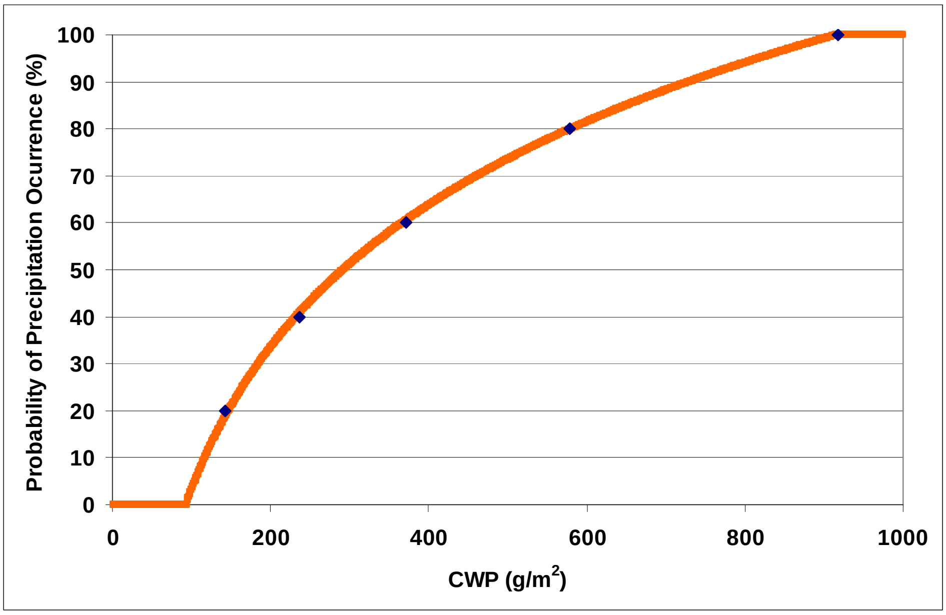


Figure 3: Function that connects probability of precipitation with CWP

As the cloud top microphysical properties used by this algorithm depend directly on SEVIRI 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 SEVIRI 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 SEVIRI 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 MSG 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 $\leq$ 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:	**0.1**	**900985**	**90,4**
80% < FAR ≤ 100%	**0.2**	**900985**	**90,4**
	0.3	**867533**	**90,5**
	0.4	**641036**	**90,9**
	0.5	**409843**	**90,9**
	0.6	**150706**	**90,3**
	0.7	**4775**	**94,8**

Table 3: Categorical scores for 0% < PoP ≤ 20% depending on ICP

20% < PoP ≤ 40%	**ICP interval lower limit**	**N**	**FAR (%)**
Expected FAR:	**0.1**	**470407**	**76,6**
60% < FAR ≤ 80%	**0.2**	**470407**	**76,6**
	0.3	**452640**	**76,5**
	0.4	**336139**	**76,7**
	0.5	**209570**	**76,3**
	0.6	**76434**	**74,6**
	0.7	**2450**	**84,8**

Table 4: Categorical scores for 20% < PoP ≤ 40% depending on ICP

40% < PoP ≤ 60%	**ICP interval lower limit**	**N**	**FAR (%)**
Expected FAR:	**0.1**	**352631**	**57,5**
40% < FAR ≤ 60%	**0.2**	**352631**	**57,5**
	0.3	**340631**	**57,3**
	0.4	**257066**	**57,0**
	0.5	**162388**	**56,0**
	0.6	**61983**	**52,5**
	0.7	**2539**	**70,0**

Table 5: Categorical scores for 40% < PoP ≤ 60% depending on ICP

60% < PoP ≤ 80%	ICP interval lower limit	N	FAR (%)
Expected FAR: 20% < FAR ≤ 80%	0.1	226405	34,9
	0.2	226405	34,9
	0.3	219928	34,5
	0.4	170584	33,5
	0.5	112124	32,0
	0.6	46117	29,1
	0.7	2140	46,9

Table 6: Categorical scores for 60% < PoP ≤ 80% depending on ICP

80% < PoP ≤ 100%	ICP interval lower limit	N	FAR (%)
Expected FAR: 0% < FAR ≤ 20%	0.1	117761	18,1
	0.2	117761	18,1
	0.3	113690	17,5
	0.4	82177	15,4
	0.5	50286	13,8
	0.6	18702	12,1
	0.7	615	16,1

Table 7: Categorical scores for 80% < PoP ≤ 100% depending on ICP

Comparisons with wider ICP ranges contain values estimated under worse illumination conditions. If illumination conditions would affect PCPh 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 0.7, 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 PCPh 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 PCPh 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.

2.3 LIST OF INPUTS

PGE02 Cloud type (CT) microphysical parameters:

CT-PGE02 Phase, COT and R_{eff} parameters are mandatory inputs to PCPh.

Satellite imagery:

IR10.8 SEVIRI 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 back up 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 directoryModel configuration file for PGE14:

PGE14 model configuration file contains configurable system parameters in the generation process of both PCPh and CRPh products. The PCPh 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 are available in the Product User Manual [AD 3] and in the Interface Control Document [AD 4].

2.4 DESCRIPTION OF THE OUTPUTS

PCPh product is coded in HDF5 format. The available outputs are the following:

- PCPh_PC output provides an estimation of the probability of precipitation.
- PCPh_QUALITY that provides information on whether parallax correction has been applied
- PCPh_DATAFLAG that contains information on the computing conditions of the PCPh product.

2.4.1 PCPh PC.

The PCPh output provides an estimation of the probability of precipitation from 0% to 100% of probability.

The colour scale delivered with the product is divided into five PoP intervals as can be observed in Figure 4.

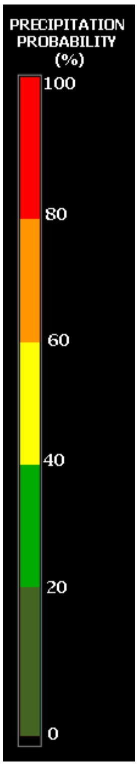


Figure 4: PCPh_PC palette

2.4.2 PCPh_QUALITY

2 bits mask indicating if parallax correction has been applied for each pixel:

- 1 bit for parallax correction:
  - 0: No correction
  - 1: Corrected by parallax
- 1 bit for the filled holes after parallax correction
  - 0: No hole due to the parallax correction
  - 1: Hole due to the parallax correction filled by a median filter

2.4.3 PCPh_DATAFLAG

5 bits mask indicating the processing status of each pixel:

- 1 bit for cloud optical thickness, effective radius or phase data missing
  - 0: Cloud optical thickness, effective radius and phase data are available
  - 1: Cloud optical thickness, effective radius or phase data are missing
- 1 bit for cloud optical thickness or effective radius no computed (out of the cloud, night time or undefined phase)
  - 0: cloud optical thickness and effective radius computed
  - 1: cloud optical thickness or effective radius no computed
- 1 bit to indicate if phase data have been computed
  - 0: Phase is water or ice

1: Phase not computed or undefined

1 bit for IR10.8 data missing:

0: IR10.8 data available

1: IR10.8 data missing

1 bit to identify mathematical errors

0: No mathematical error

1: A mathematical error has occurred

2.5 PRACTICAL CONSIDERATIONS

2.5.1 Validation

The following tables summarize the validation results of PCPh algorithm. More details can be obtained from the Validation Report for "Precipitation products from Cloud Physical Properties" (PPh-PGE14: PCPh v1.0 & CRPh v1.0) [AD 2].

Green colour values in tables mean that FAR or POD values obtained in this validation fulfill the FAR and POD target values defined in the NWC SAF Product Requirements document [AD 5].

Probability of precipitation intervals validation:

It should bear in mind that a region with the probability of precipitation interval A-B% should have 100-B ≤ FAR < 100-A.

Probability interval (%)	N	FAR (%)
0-20	900985	90,4
20-40	470407	76,6
40-60	352631	57,5
60-80	226405	34,9
80-100	117761	18,1

Table 8: False alarm ratio obtained for each PCPh probability of precipitation interval.

Probability of precipitation thresholds validation:

PoP threshold	N	FAR (%)	POD (%)	CSI (%)	PC (%)
20%	3072175	56,8	82,8	39,6	75,0
30%	3072175	50,5	74,6	42,3	79,7
40%	3072175	43,5	64,7	43,2	83,1
60%	3072175	29,2	40,1	34,4	84,9
80%	3072175	18,1	15,8	15,3	82,6

Table 9: Categorical scores for PCPh algorithm taking as rainy pixels those with probability of precipitation higher than a threshold

2.5.2 Example of visualisation

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

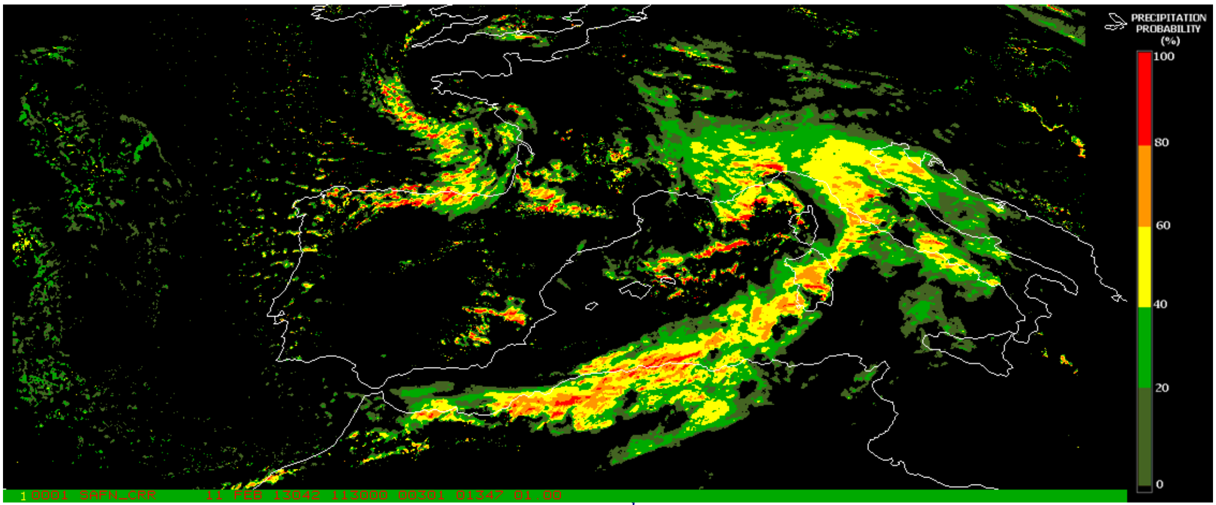


Figure 5: PCPh probability of precipitation for 11th February 2013 at 11:30 UTC over Europe.

2.5.3 Implementation

The execution step is the real-time process of the PPh information over the region. This process consists of the launch of the command PGE14 along with the required parameters: slot, region file name and model configuration file.

PCPh requires mainly five steps:

- First step consists of an initialisation, which performs the environment settings for a given region. Check the existence of the required PGE02 generated files.
- Second step is intended to read the external PGE02 files.
- Third step is the computation of CWP.
- Fourth step computes PoP from CWP as well as PCPh_QUALITY and PCPh_DATAFLAG.
- Fifth step computes Parallax correction if chosen and PCPh_QUALITY is updated.
- Last step writes the product outputs in NWC SAF format.

2.6 ASSUMPTIONS AND LIMITATIONS

This algorithm can be run only over daytime.

For undefined phase pixels, R_{eff} and COT values are not computed by PGE02, so a 0% probability of precipitation is assigned in these cases by the algorithm.

As the main inputs of the product are computed by PGE02, there exists the need to run PGE02 previous to run PGE14.

It has been observed that pixels located in the surroundings of snow according to PGE02 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.

3. ALGORITHM DESCRIPTION OF THE CONVECTIVE RAINFALL RATE FROM CLOUD PHYSICAL PROPERTIES PRODUCT

3.1 CONVECTIVE RAINFALL RATE FROM CLOUD PHYSICAL PROPERTIES OVERVIEW

Convective Rainfall Rate from Cloud Physical Properties (CRPh) 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 PGE02, 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 CRPh precipitation pattern computed in the previous step is combined with a precipitation pattern derived through a lightning algorithm. This step is optional.

Parameters used by this product are highly dependant on SEVIRI 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.

3.2 CONVECTIVE RAINFALL RATE FROM CLOUD PHYSICAL PROPERTIES THEORETICAL DESCRIPTION

3.2.1 Physics of the problem

Since both PCPh and CRPh algorithms are based on the same foundation, information provided in section 2.2.1 applies in this section.

3.2.2 Mathematical description of the algorithm

The cloud top microphysical properties used to retrieve the CRPh rain rates are the ones described in section 2.2.

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 datasets used for the calibration of both, the precipitation area and the rain rates assignment, are described in the following table:

Radar network	Type of radar	Frequency Scanning Radar	Dataset used	Type of product used	MSG scans over the radar area	Matching time
Hungarian radar network	C- Band	15 minutes	18 storms from May to September 2009 at 10:00-12:00 UTC every 30 minutes	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	40 storms over Spain from May to September 2009 at 12:00 UTC	PPI and Echotop	About 10 min later than the MSG time slot	0 and 20 min MSG slots have been matched to 10 and 40 min radar images respectively.

Table 10: Description of the radar calibration data

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.

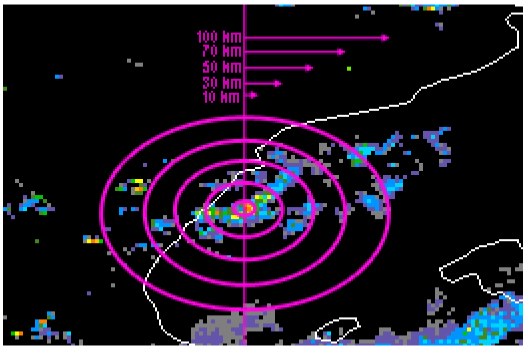
A quality control has been used for the Spanish radar dataset taking advantage of the quality image generated for the radar national composite products [RD 7]. No quality control methods have been used for Hungarian radar dataset.

Calibration of the rainy area:

According to the literature, clouds need, at least, cloud top effective radius higher than 14 µm to produce rain [RD.2] 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 has been summed up in annular bins with different radius. The centre of the annuli matches with the centre of the storm, see Figure 6. The centre of the storm was taken as the pixel with highest radar rain rate. The number of rainy pixels included in each annulus in radar images has been compared with the one obtained in satellite images from algorithms using different CWP thresholds. The threshold to consider a radar pixel as rainy was fixed in 0.2 mm/h. Accuracy measurements have been obtained for each CWP threshold. Figure 7 and Figure 8 show the results obtained for Spain and Hungary respectively. Both graphs point at $CWP_0 = 200$ g/m^2 as the most suitable threshold.



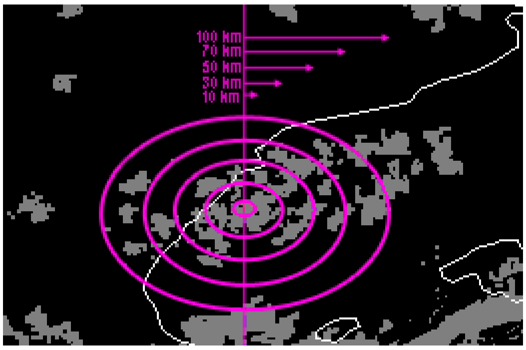


Figure 6: Annular bins used for calibration over a Radar image on the left and over a rain/no rain CWP map on the right.

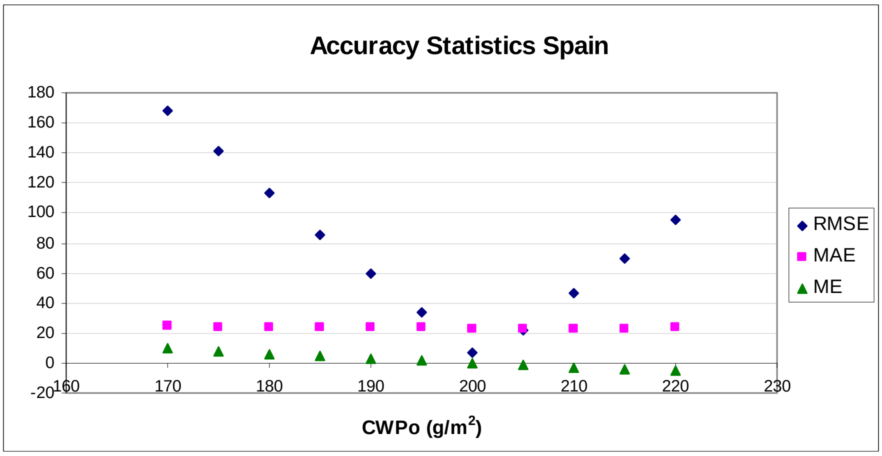


Figure 7: Accuracy statistics obtained in the comparison of number of rainy pixels in annular bins for Spanish storms

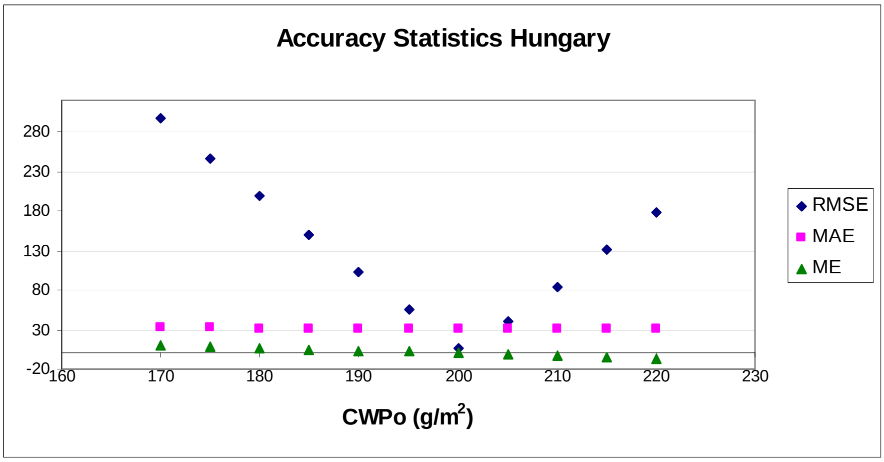


Figure 8: Accuracy statistics obtained in the comparison of number of rainy pixels in annular bins for Hungarian storms

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 9 for both Spanish (orange dots) and Hungarian (green dots) storms.

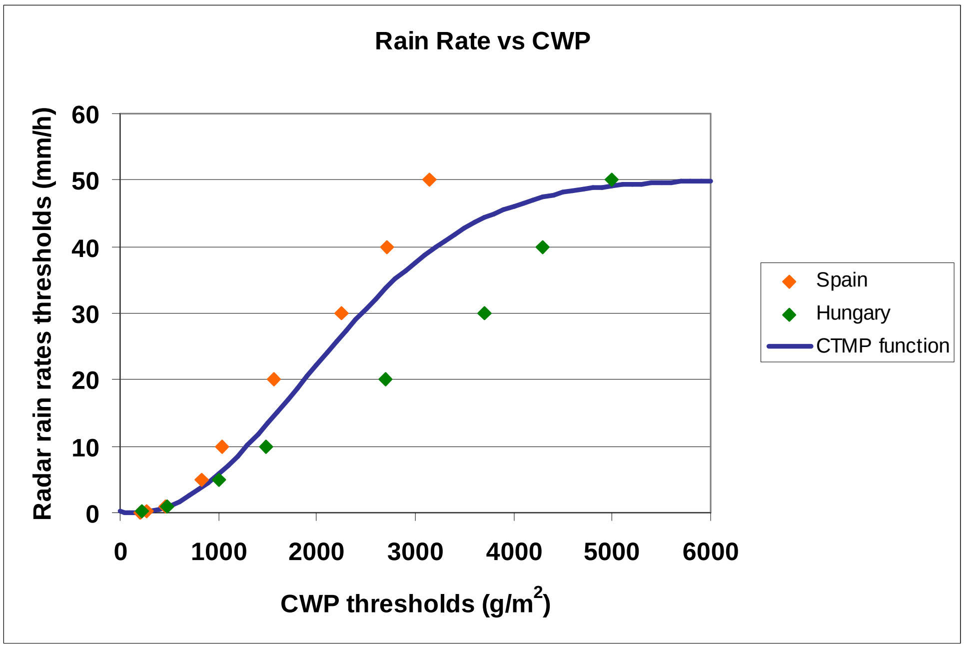


Figure 9: Results of rain rates calibration. Radar rain rates vs CWP, thresholds.

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 9. The mathematical expression of it is the following:

$$RR = 50 * \left\{ 1 - \exp\left[-0.5 * \left(\frac{CWP - 155}{1700} \right)^2 \right] \right\}$$

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 (CRPh_IQF) has been developed. For this purpose the ICP 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 CRPh 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:

- $N\text{-}CRPh_{max}$: the number of CRPh pixels with estimated rain rates higher than or equal to the highest radar rain rate
- $N\text{-}Radar_{max}$: 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 ($N\text{-}CRPh_{max}$, $N\text{-}Radar_{max}$) 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 10 shows the average of ($N\text{-}CRPh_{max}$/ $N\text{-}Radar_{max}$) for different ICP ranges.

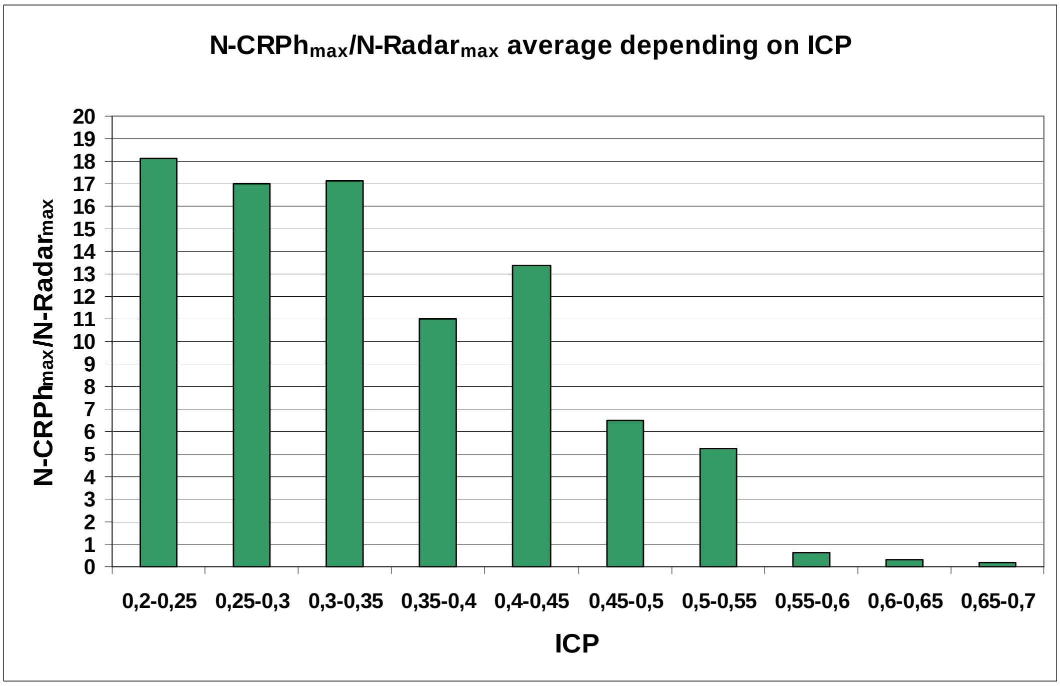


Figure 10: Average of ($N\text{-}CRPh_{max}$/ $N\text{-}Radar_{max}$) for different ICP ranges.

Figure 10 shows that the lower value takes ICP, the higher is the number of too high rain rates estimated by CRPh. In other words, the poorer are the illumination conditions, the higher is the overestimation of CRPh rain rates. Other conclusion that can be obtained from Figure 10 is that, for ICP values higher than 0.55, CRPh rain rates estimations are not overestimated.

Looking at the triads ($N\text{-}CRPh_{max}$, $N\text{-}Radar_{max}$, ICP) it can be observed that even for ICP < 0.55 it happens that $N\text{-}CRPh_{max}$ is lower or equal than $N\text{-}Radar_{max}$ in some cases. So the percentage of the cases when $N\text{-}CRPh_{max}$ is lower or equal $N\text{-}Radar_{max}$, has been computed for some ICP intervals taking into account the ICP ≥ 0.55 threshold. Figure 11 shows the percentage of the cases when $N\text{-}CRPh_{max}$ is lower or equal $N\text{-}Radar_{max}$. To test whether the previous relationship is too restrictive, the percentage of cases when N-$CRPh_{max}$ is lower or equal two times, and three times, N-$Radar_{max}$ have been computed and can be seen in Figure 12 and Figure 13, respectively.

The best results are obtained for ICP > 0,55 when 90% 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 CRPh results.

ICP > 0,5 accomplishes the condition in more than 70% of the cases, and ICP > 0,4 in more than 50% of the cases.

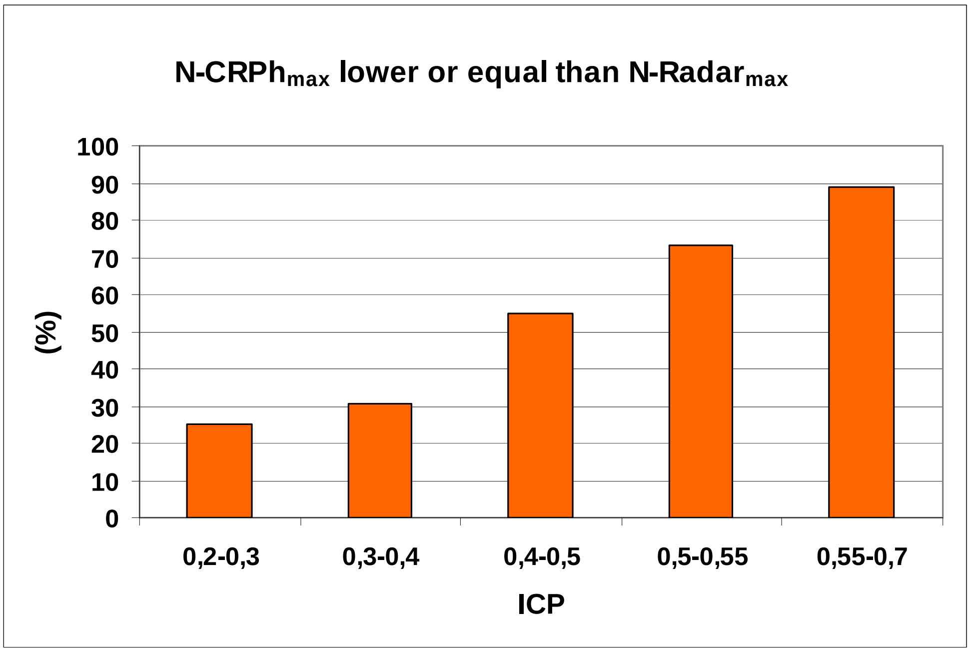


Figure 11: percentage of the cases when N-$CRPh_{max}$ is lower or equal N-$Radar_{max}$.

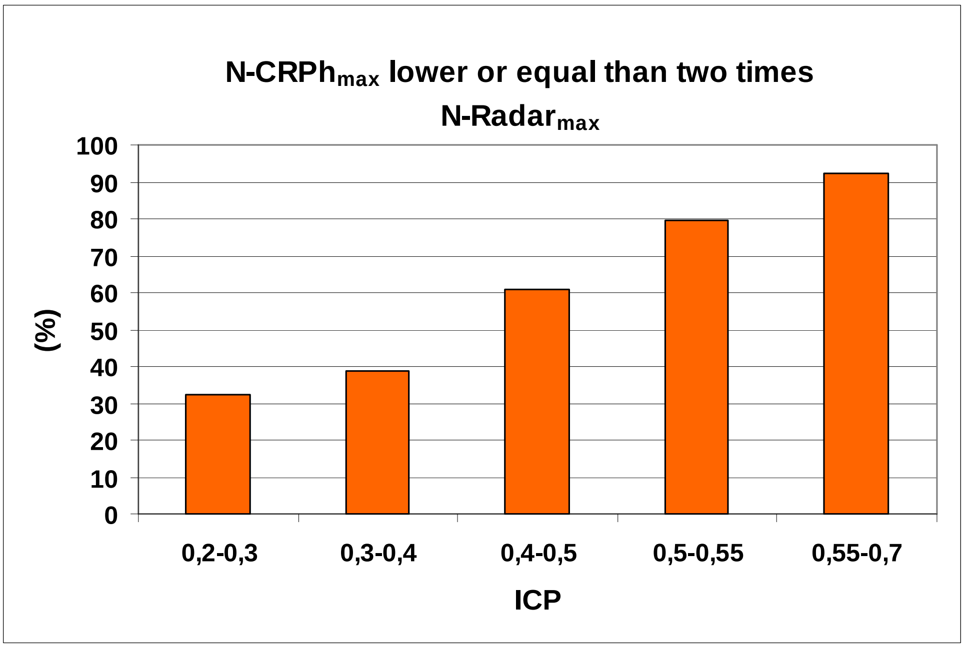


Figure 12: percentage of the cases when N-$CRPh_{max}$ is lower or equal than two times N-$Radar_{max}$.

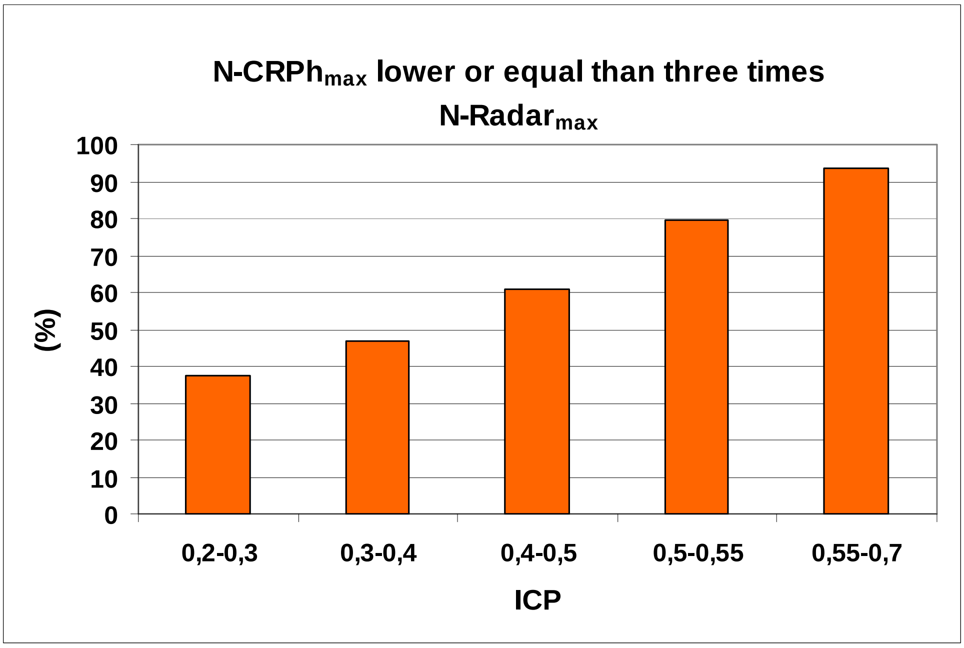


Figure 13: percentage of the cases when N-CRPh$_{max}$ is lower or equal than three times N-Radar$_{max}$

It can be complicated for the forecaster to directly use ICP value so, using an average of the results obtained in Figure 11, Figure 12 and Figure 13, 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 CRPh rain rates is included in the variable CRPh_IQF and depends on ICP on the following way:

CRPh_IQF = 160.0 * ICP - 8.32
If CRPh_IQF < 0 then CRPh_IQF = 0
If CRPh_IQF > 100 then CRPh_IQF = 100

Figure 14: Relation between ICP and CRPh_IQF

CRPh_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 algorithm:

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 CRPh one computed in the previous step in order to complement it.

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 ($\Delta\tau$) 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. [RD 5] 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 [RD 5]. 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 15: 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 (CRPh 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 CRPh time:

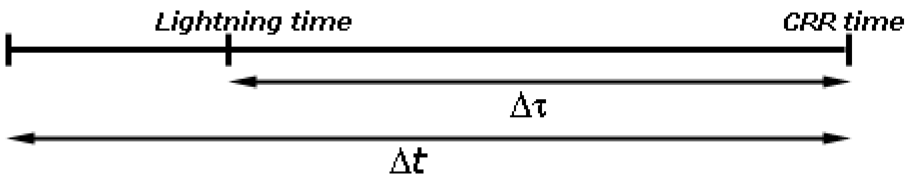


Figure 16: Diagram that shows the relationship between $\Delta\tau$ and Δt

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:

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

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 CRPh precipitation pattern in order to obtain the final product. This final product contains the highest rain rate of the two.

Hourly accumulations:

At the end of the process the final values of the CRPh rainfall rates in mm/h are used in order to obtain 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 CRPh rate in mm/h output is the one used to make the computing.

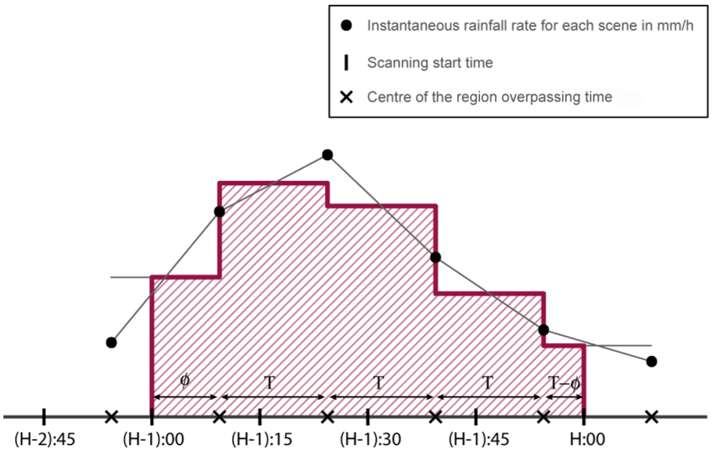


Figure 17. Trapezoidal integration

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:

$$A_6 = \frac{I_1 + I_2}{2}\phi + \frac{I_2}{2}T + I_3T + I_4T + \frac{I_5}{2}T + \frac{I_5 + I_6}{2}(T-\phi)$$

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.

<u>Rapid Scan mode:</u>

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.

3.3 LIST OF INPUTS

PGE02 Cloud type (CT) microphysical parameters:

CT-PGE02 Phase, COT and R_{eff} parameters are mandatory inputs to PCPh.

Satellite imagery:

IR10.8 SEVIRI 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 back up 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 CRPh product:

A file with information on every lightning occurred in a time interval is mandatory to choose the option of adjusting the CRPh precipitation pattern with the lightning information. Information about the "Lightning information file for CRPh product" structure can be found in the Interface Control Document [AD 4].

Model configuration file for PGE14:

PGE14 model configuration file contains configurable system parameters in the generation process of both PCPh and CRPh products. The CRPh 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 are available in the Product User Manual [AD 3] and in the Interface Control Document [AD 4].

3.4 DESCRIPTION OF THE OUTPUTS

CRPh product is coded in HDF5 format. The available outputs are the following:

- CRPh_CRR provides information about the rain rates
- CRPh_ACCUM provides information about the hourly accumulations
- CRPh_IQF contains information on the Illumination Quality flag
- CRPh_QUALITY that provides information on whether parallax correction and lightning algorithm have been applied
- CRPh_DATAFLAG that contains information on the computing conditions of the CRPh product

3.4.1 CRPh_CRR

CRPh_CRR output contains the rainfall rates associated to convective clouds. The rain rates can take values from 0.0 to 51.0 mm/h with a step of 0.2 mm/h.

The colour scale delivered with the product is divided into twelve precipitation intensity intervals as can be observed in Figure 18.

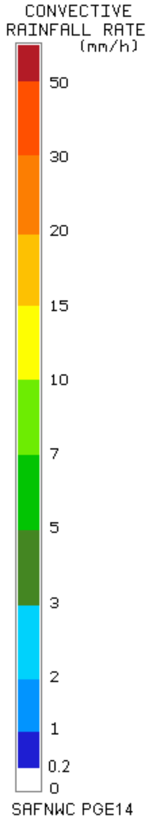


Figure 18: CRPh_CRR palette

3.4.2 CRPh _ACCUM

CRPh_ACCUM output provides hourly accumulations associated to convective clouds and computed using the rainfall rates from the images in the last hour. This output provides precipitation accumulations from 0.0 to 51.0 mm with a step of 0.2 mm and includes a palette that uses the same colours as the intensities output palette.

3.4.3 CRPh_IQF

CRPh_IQF is a flag that provides information on the confidence that a user can have on the estimated rain rates according to the illumination conditions and viewing angles.

The color scale provided with the product is divided into five intervals as can be observed in Figure 19.

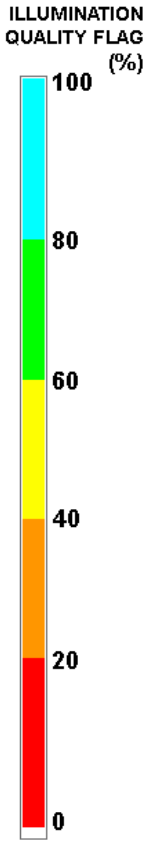


Figure 19: CRPh_IQF palette

3.4.4 CRPh_QUALITY

3 bits mask indicating whether parallax correction and lightning algorithm have been applied

- 1 bit for parallax correction:
  - 0: No correction
  - 1: Corrected by parallax
- 1 bit for the filled holes after parallax correction
  - 0: No hole due to the parallax correction
  - 1: Hole due to the parallax correction filled by a median filter
- 1 bit for lightning information used:
  - 0: No lightning information used
  - 1: Lightning information used

3.4.5 CRPh_DATAFLAG

8 bits mask indicating the processing status of each pixel:

- 1 bit for cloud optical thickness, effective radius or phase data missing
  - 0: Cloud optical thickness, effective radius and phase data are available

1: Cloud optical thickness, effective radius or phase data are missing

1 bit for cloud optical thickness or effective radius no computed (out of the cloud, night time or undefined phase)

0: cloud optical thickness and effective radius computed

1: cloud optical thickness or effective radius no computed

1 bit to indicate if phase data have been computed

0: Phase is water or ice

1: Phase not computed or undefined

1 bit for IR10.8 data missing

0: IR10.8 data available

1: IR10.8 data missing

1 bit to identify mathematical errors

0: No mathematical error

1: A mathematical error has occurred

2 bits for the hourly accumulation CRPh output status

0: All required scenes were available

1: One previous CRPh scene is missing

2: At least two previous CRPh scenes are missing (no consecutive)

3: At least two previous CRPh scenes are missing (some are consecutive)

1 bit for the status of the CRPhR pixels used to compute the hourly accumulation

0: All the pixels used in the computing of the hourly accumulation have their CRPh_DATAFLAG bits set to 0

1: At least one of the pixels used in the computing of the hourly accumulation has at least one of its CRPh_DATAFLAG bits set to 1

3.5 Practical considerations

3.5.1 Validation

The following tables summarize the validation results of CRPh algorithm. More details can be obtained from the Validation Report for "Precipitation products from Cloud Physical Properties" (PPh-PGE14: PCPh v1.0 & CRPh v1.0) [AD 2].

Green colour values in tables mean that FAR or POD values obtained in this validation fulfill the FAR and POD target values defined in the NWCSAF Product Requirement document [AD 5].

3.5.1.1 Instantaneous rain rates:

Accuracy statistics:

CRPh_IQF threshold	N	MEAN (mm/h)	ME (mm/h)	MAE (mm/h)	RMSE (mm/h)
0, 0	579705	0,62	0,85	1,38	4,10
0,18	579670	0,62	0,85	1,38	4,10
0,30	563371	0,62	0,81	1,33	3,97
0,43	367610	0,61	0,40	0,94	2,76
0,55	170182	0,58	0,16	0,70	1,89

Table 11: CRPh Instantaneous rates accuracy statistics

Categorical scores:

CRPh_IQF threshold	FAR (%)	POD (%)	CSI (%)	PC (%)
0, 0	27,4	84,2	63,9	73,9
0,18	27,4	84,2	63,9	73,9
0,30	27,2	84,2	64,1	74,1
0,43	26,4	84,5	64,8	74,9
0,55	25,4	84,9	65,9	76,0

Table 12: CRPh Instantaneous rates categorical scores

3.5.1.2 Hourly accumulations:

Accuracy statistics:

CRPh_IQF threshold	N	MEAN (mm/h)	ME (mm/h)	MAE (mm/h)	RMSE (mm/h)
0, 0	297809	0,43	0,68	0,94	2,55
0,18	297794	0,43	0,68	0,94	2,55
0,30	270484	0,42	0,59	0,85	2,35
0,43	180351	0,40	0,40	0,67	1,84
0,55	83630	0,39	0,24	0,51	1,35

Table 13: CRPh Hourly accumulations accuracy statistics

Categorical scores:

CRPh_IQF threshold	FAR (%)	POD (%)	CSI (%)	PC (%)
0, 0	47,2	91,0	50,2	65,6
0,18	47,2	91,0	50,2	65,6
0,30	47,4	90,8	50,0	65,6
0,43	47,3	90,9	50,1	66,3
0,55	47,0	91,8	50,6	66,8

Table 14: CRPh Hourly accumulations categorical scores

3.5.2 Example of visualisation

3.5.2.1 CRPh Instantaneous rain rates

Below is shown an image of the instantaneous rain rates CRPh product. It has been obtained at full resolution

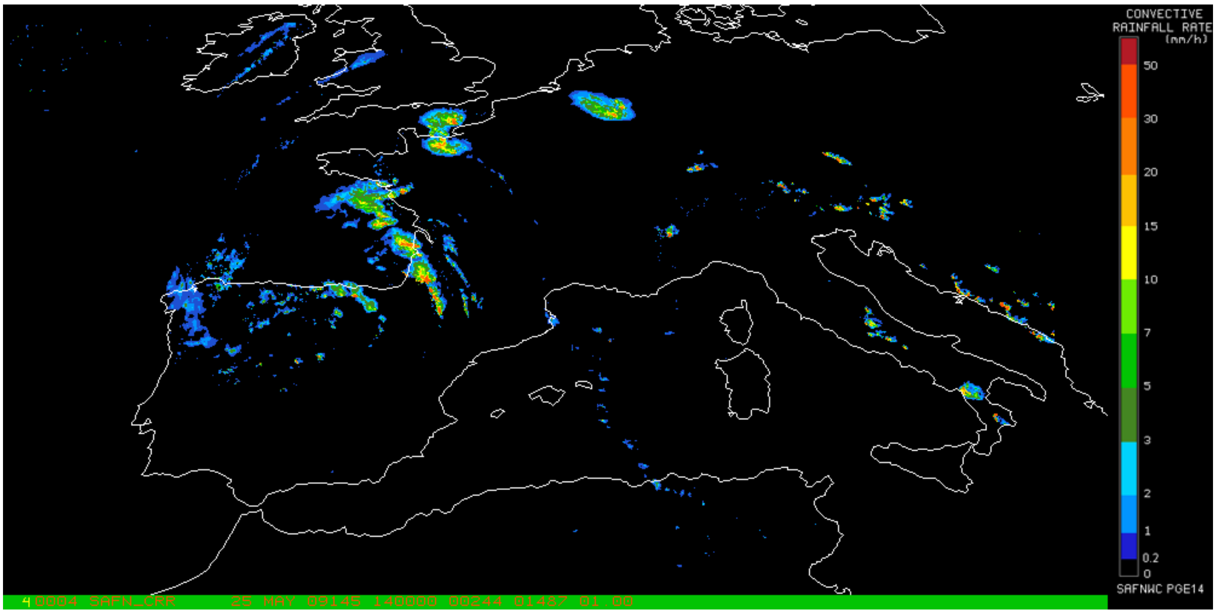


Figure 20: CRPh instantaneous rain rates for 25th May 2009 at 14:00 UTC over Europe

3.5.2.2 CRPh Hourly accumulations

Below is shown an image of the hourly accumulation CRPh product. It has been obtained at full resolution.

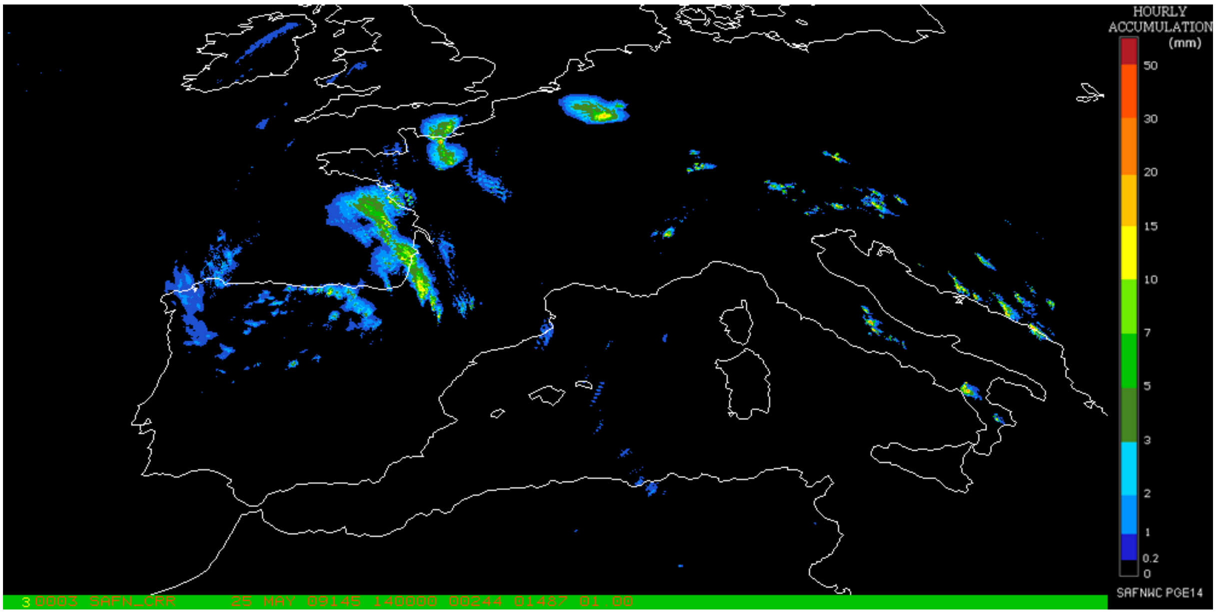


Figure 21: CRPh hourly accumulations for 25th May 2009 at 14:00 UTC over Europe

3.5.2.3 CRPh_IQF

Figure 22 shows an example of CRPh_IQF over Europe.

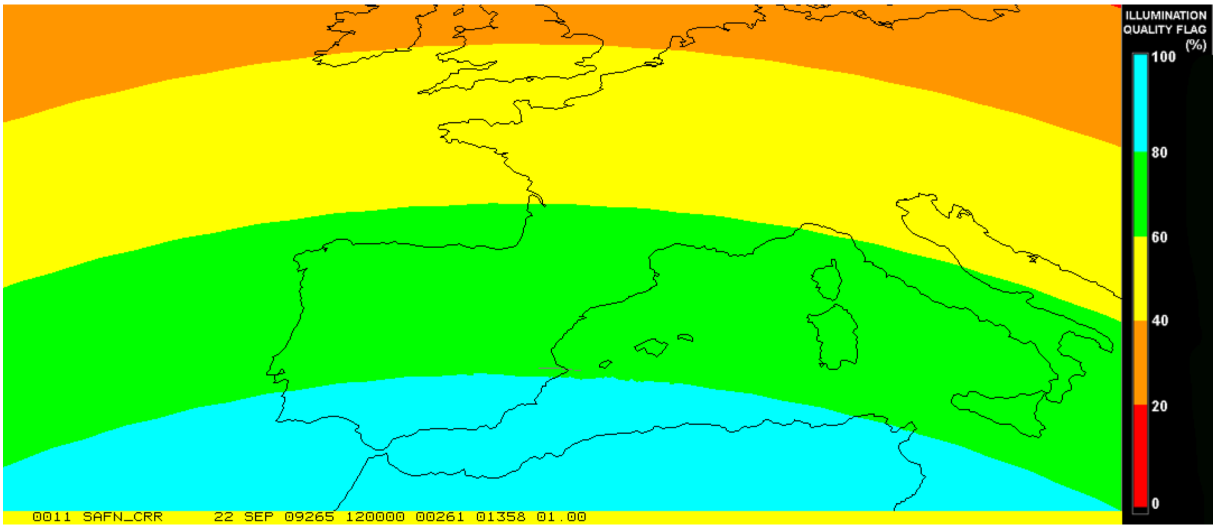


Figure 22: CRPh_IQF for 22nd September 2009 at 12:00 UTC over Europe

3.5.3 Implementation

The execution step is the real-time process of the PPh images over the region. This process consists of the launch of the command PGE14 along with the required parameters: slot, region file name and model configuration file.

CRPh requires mainly five steps:

- First step consists of an initialisation, which performs the environment settings for a given region. Check the existence of the required PGE02 files.

- Second step is intended to read the external PGE02 files.
- Third step is to computation of CWP.
- Fourth step computes the precipitation area and the rain rates within the computed precipitation area as well as CRPh_QUALITY, CRPh_DATAFLAG and CRPh_IQF.
- Fifth step applies Parallax correction if chosen. CRPh_QUALITY is updated.
- Sixth step computes rain rates from lightning information if this option has been chosen. This data are combined with the output data from the previous step. CRPh mm/h values, CRPh_QUALITY and CRPh_DATAFLAG are updated.
- Last step computes the hourly accumulation, updates CRPhR_DATAFLAG and writes the product outputs in NWC SAF format.

3.6 ASSUMPTIONS AND LIMITATIONS

This algorithm can be run only over daytime.

For undefined phase pixels, R_{eff} and COT values are not computed by PGE02, 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 PGE02, there exists the need to run PGE02 previous to run PGE14.

It has been observed that pixels located in the surroundings of snow according to PGE02 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 *[RD 6]*. This could cause erroneous rain rate estimations.

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 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.

4. 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 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.

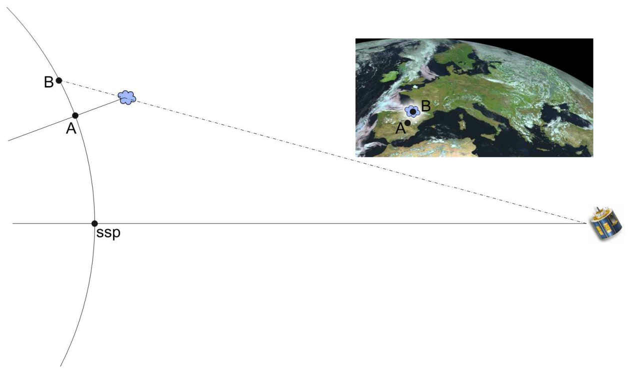


Figure 23: Parallax geometry

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 IR10.8 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 IR10.8 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 value of PCPh or CRPh product. 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 PCPh or CRPh
- 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 PoP or rainfall rate value (to compute the median, the pixels within the 3x3 pixels box identified as holes are excluded)

The theoretical basis used in the computing of the Parallax correction in both the PGE14 and the SAFNWC/MSG Parallax Correction Tool [AD 6] is the same.