The EUMETSAT Network of Satellite Application Facilities

NWC SAF

Support to Nowcasting and Very Short Range Forecasting

Validation Report for "Precipitation products from Cloud Physical Properties" (PPh-PGE14: PCPh v1.0 & CRPh v1.0)

SAF/NWC/CDOP2/INM/SCI/VR/15, Issue 1, Rev. 0

15 July 2013

Applicable to SAFNWC/MSG version 2013

Prepared by AEMET

REPORT SIGNATURE TABLE

Function	Name	Signature	Date
Prepared by	Cecilia Marcos (AEMET) Antonio Rodríguez (AEMET)		*15 July 2013*
Reviewed by	Marcelino Manso (AEMET)		*15 July 2013*
Authorised by	Pilar Fernández SAFNWC Project Manager		*15 July 2013*

DOCUMENT CHANGE RECORD

Version	Date	Pages	CHANGE(S)
1.0	15 July 2013	26	Initial version. Indications and recommendations given by the NWC SAF SW Package MSG 2013 DRR have been included.

Table of contents

List of Tables and Figures

1. INTRODUCTION

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

1.1 PURPOSE

The purpose of this document is to present the Scientific Validation Results of the 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). Validation results presented in this document correspond to version 1.0 of PCPh and version 1.0 of CRPh.

1.2 SCOPE OF THE DOCUMENT

This document describes the validation methodology and the results obtained in order to test the CRR product value.

Two different validation processes have been carried out.

- Precipitation products from Cloud Physical Properties are thought to be used by forecasters. Besides the probability and intensity of precipitation it is also important monitoring the precipitation pattern as well as its evolution. In order to check this kind of information, a subjective validation has been carried out. Several cases have been checked in this process. A selection of the most representative ones that summarizes the general observed results is presented in this document.
- Results of an objective extended validation using 78 days with convective events occurred along the year 2008 over Spain are presented here. The rainfall rate from PPI and the Hourly accumulations products from the Spanish Radar Network have been taken as truth data in this validation process. Probabilities of precipitation, instantaneous rates and hourly accumulations have been validated.

1.3 SOFTWARE VERSION IDENTIFICATION

The validation results presented in this document apply to 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 DEFINITIONS, ACRONYMS AND ABBREVIATIONS

AEMET	Agencia Estatal de Meteorología
ATBD	Algorithm Theoretical Basis Document
COT	Cloud Optical Thickness

CRPh	Convective Rainfall Rate from Cloud Physical Properties
CSI	Critical Success Index
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FAR	False Alarm Ratio
IQF	Illumination Quality Flag
IR	Infrared
MAE	Mean Absolute Error
CTMP	Cloud Top Microphysical Properties
ME	Mean Error
MSG	Meteosat Second Generation
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
RMSE	Root Mean Square Error
SAF	Satellite Application Facility
SEVIRI	Spinning Enhanced Visible and Infrared Imager
SW	Software

1.5 REFERENCES

1.5.1 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 "Precipitation products from Cloud Physical Properties" (PPh-PGE14: PCPh v1.0 & CRPh v1.0)	SAF/NWC/CDOP2/INM/SCI/ATBD/14	1.0	15/07/13
[AD. 2]	Product User Manual for "Precipitation products from Cloud Physical Properties" (PPh-PGE14: PCPh v1.0 & CRPh v1.0)	SAF/NWC/CDOP2/INM/SCI/PUM/14	1.0	15/07/13
[AD 3]	NWC SAF Product Requirements Document	NWC/CDOP2/SAF/AEMET//MGT/PRD	1.2	15/07/13

Table 1: List of Applicable Documents

1.5.2 Reference Documents

Reference	Title
[RD.1]	Vicente, G.A., Scofield, R.A. and Menzel W.P. 1998: The Operational GOES Infrared Rainfall Estimation Technique, Bull. American Meteorological Society, Vol. 79, No. 9, pp. 1883-1898.
[RD.2]	

Table 2: List of Referenced Documents

2. VALIDATION FOR PRECIPITATING CLOUDS FROM CLOUD PHYSICAL PROPERTIES (PCPH)

This section contains the results obtained from the validation of the PCPh product which is described in the Algorithm Theoretical Basis Document for "Precipitation products from Cloud Physical Properties" [AD. 1].

2.1 SUBJECTIVE VALIDATION FOR PRECIPITATING CLOUDS FROM CLOUD PHYSICAL PROPERTIES (PCPH)

Many cases have been visually studied by comparing the probability of precipitation (PoP) obtained from the PCPh algorithm against the radar data. This study has focused on convective episodes. The most suitable product to compare with would be the one that assigns 100% PoP where it is raining and 0% otherwise. So PCPh product has been compared with modified PPI product radar images where pixels with rain rates higher than or equal to 0.2 mm/h are set as rainy pixels (red colour) and the others as no rainy pixels (black colour).

A selection of cases that show the general behaviour of this product can be seen below:

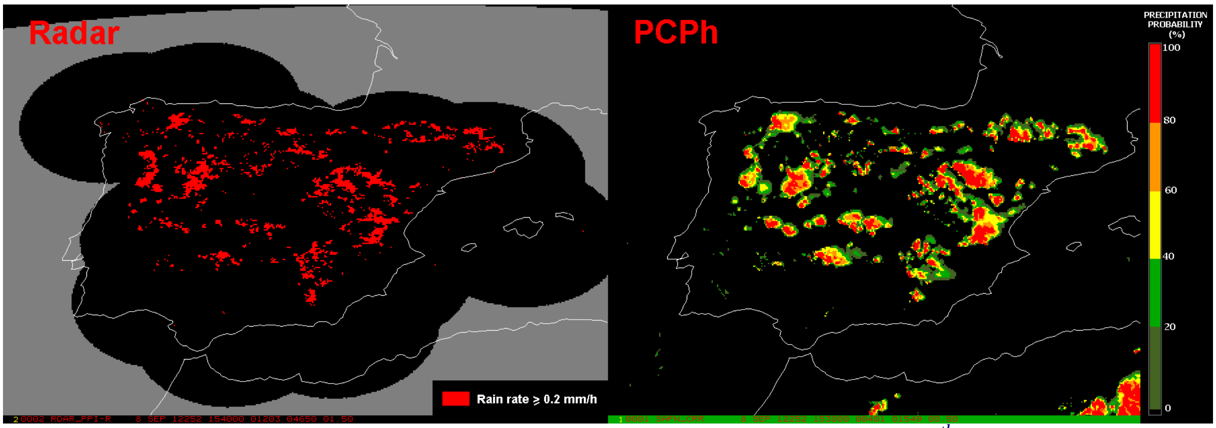

Figure 1: Visual comparison between radar (PPI) and PCPh product on 8th September 2012 at 15:30UTC over Spain.

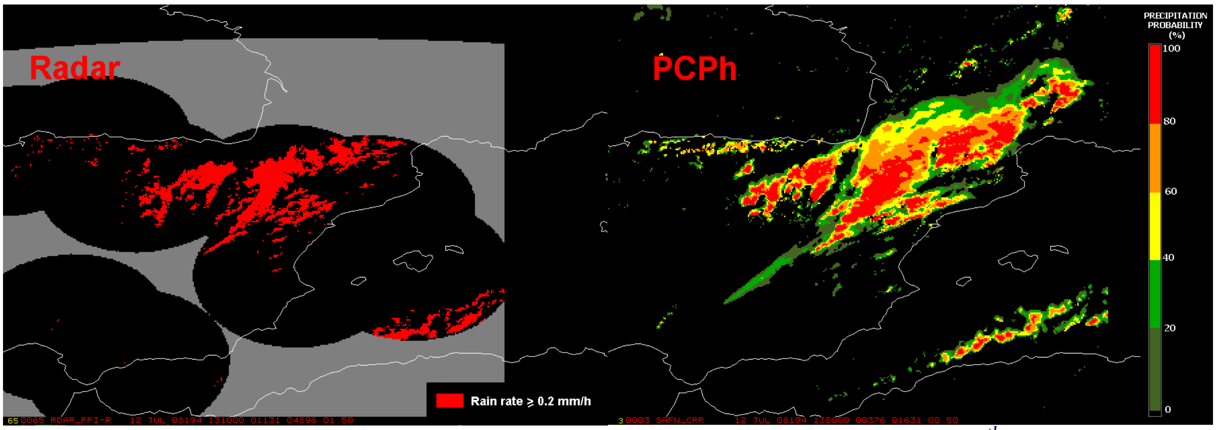

Figure 2: Visual comparison between radar (PPI) and PCPh product on 12th July 2008 at 13:00UTC over Spain.

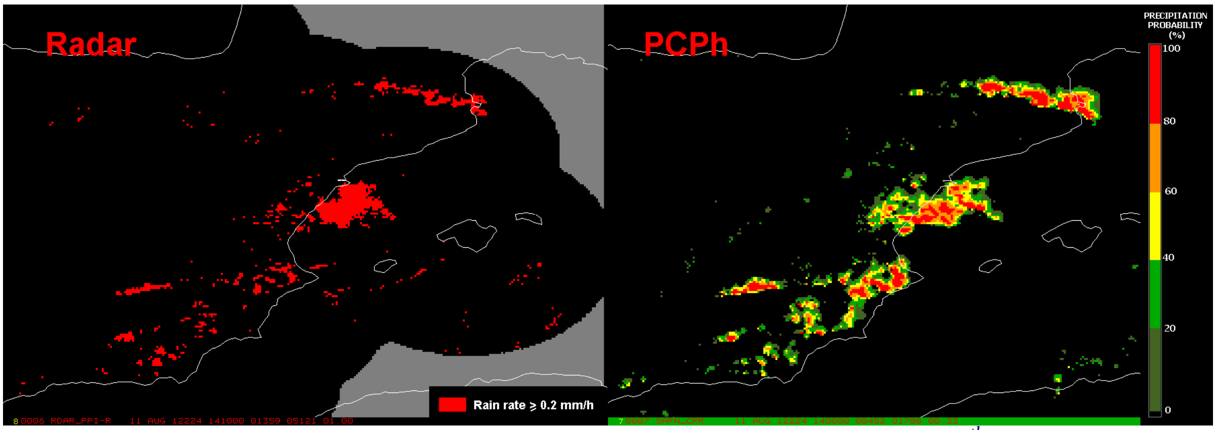

Figure 3: Visual comparison between radar (PPI) and CPPh product on 11th August 2012 at 14:00UTC over Spain

Figure 1, Figure 2 and Figure 3 show a visual comparison between radar and PCPh product over Spain. It can be seen that the area with a PoP higher than 80% (red pixels) assigned by the PCPh product is very similar to the radar rainy area, although there are areas where PoP higher that 80% is not enough to detect the whole precipitation area according to the radar.

Analyzing images in depth it can be observed that sometimes the red area computed by PCPh is a bit greater than the one detected by radar (indicated by blue arrows). This can be observed in Figure 4 which is a zoom of Figure 1. In this case PCPh product provides false alarms.

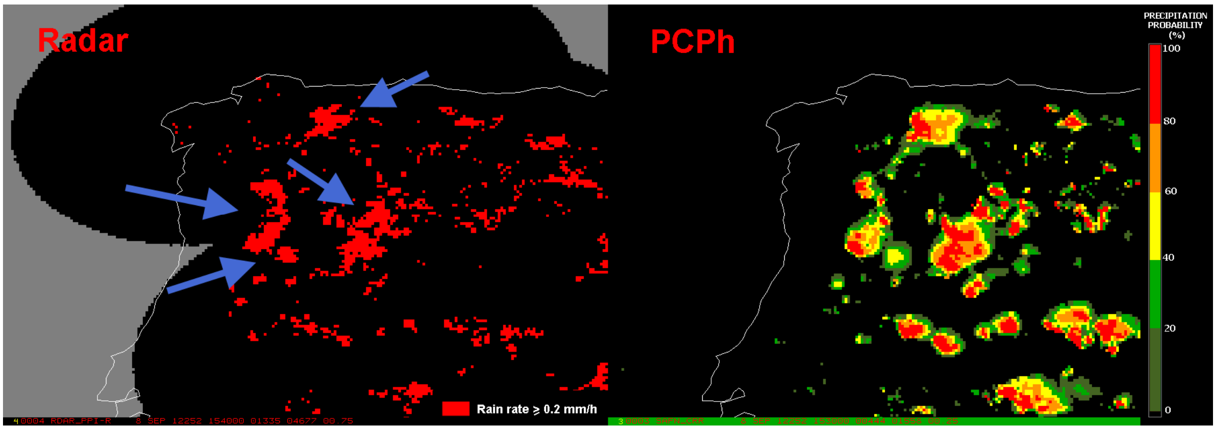

Figure 4: Zoom of Figure1 over a specific area where PCPh product provides false alarms.

Other times the red area computed by PCPh is not as extensive as the radar rainy area. This can be observed in Figure 5 which is also a zoom of Figure 1 (indicated by blue arrows in radar image). This time, although the red area computed by PCPh does not cover the total rainy area, PCPh assigns pixels with probabilities of precipitation higher than 0 % that cover the total rainy areas in agreement with the radar.

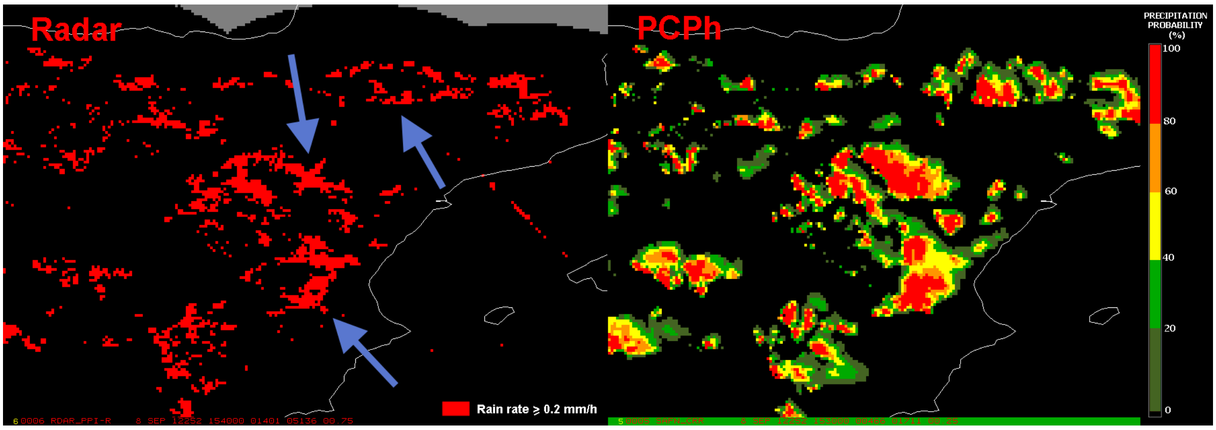

Figure 5: Zoom of Figure1 over a specific area where the PoP greater or equal 80% provided by PCPh in not extensive enough.

It is reasonable that results given by algorithms based mainly on solar channel information depend on the illumination conditions. Illumination conditions in high latitude regions are worse than illumination conditions in areas closer to the equator. In order to see if this dependence on illumination conditions degrades the results given in high latitude regions, an example over the Baltic countries is shown in Figure 6.

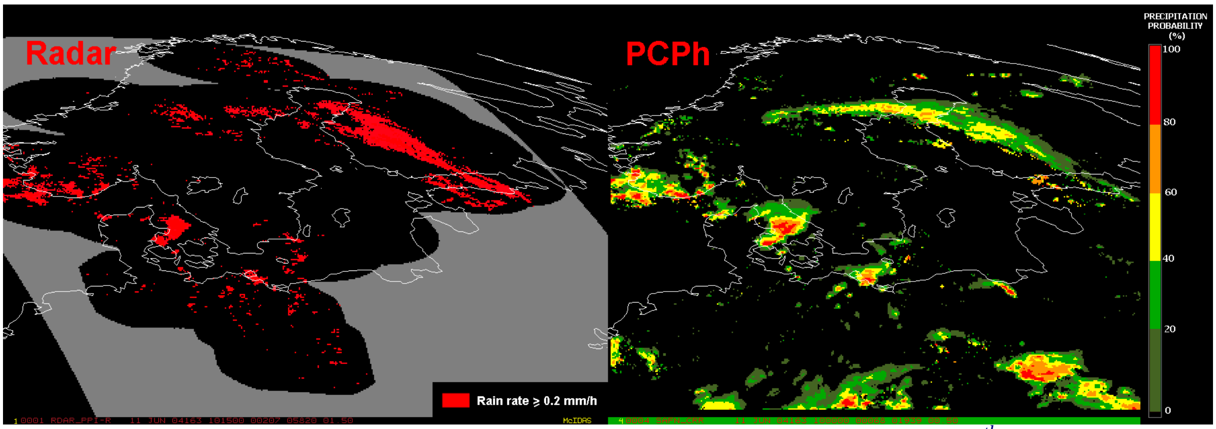

Figure 6: Visual comparison between radar (PPI) and PCPh product on 11th June 2004 at 10:00UTC over the Baltic Region.

Example displayed in Figure 6 shows that in those regions with poorer illumination conditions, PCPh algorithm is able to detect the rainy areas properly although PoP values are less accurate in the northern part.

2.2 OBJECTIVE VALIDATION FOR PRECIPITATING CLOUDS FROM CLOUD PHYSICAL PROPERTIES (PCPH)

2.2.1 Validation Procedure

An objective validation for PCPh algorithm against Spanish composite radar data has been done. The dataset used for this validation contains 103 rainy days throughout 2008.

Since Microphysical Cloud Top parameters used by the PCPh algorithm have been computed only for sun zenith angles lower than 70º, this validation has been done under this condition.

The PCPh product assigns 0% probability of precipitation to those pixels with undefined phase according to the phase output of the PGE02 product. Those pixels have been excluded in the new algorithm validation.

The radar data, which are in Lambert projection, have been converted into MSG projection, using a bi-linear interpolation scheme, for a better matching. The NWCSAF parallax tool has been applied to the PCPh product. A comparison against radar data in 3x3 MSG pixels boxes in a yes/no way has been done. As detection of very light rain rates using GEO satellite data is not possible, the threshold to consider a radar pixel as rainy has been fixed at 0.2 mm/h.

Ground echoes in PPI scenes have been removed. To do that, a filter image, available as a radar product, has been used in order to remove ground echoes (wind mills,…). Ground echoes, like anomalous propagation echoes, have been removed through the 10.8IR scene. To do that, a rain image has been obtained from the 10.8IR data using the basic AUTOESTIMATOR algorithm [RD.1]. A pixel with significant radar echo is considered to be a ground echo and set to zero if no significant value is found in a 15x15 centred box in the AUTOESTIMATOR image.

In order to avoid a high number of correct negative comparisons that can contaminate the computation of validation scores, the validation area has been restricted to 15x15 pixel boxes around radar pixels with at least 0.2 mm/h. As some PCPh rainy pixels can appear out of the previous validation area, those pixels have been added to the final validation area in order to include all the possible false alarms.

Due to the temporal resolution of the SEVIRI data in the normal mode, there are four PCPh outputs available every hour. The Spanish radar network generates a set of instantaneous products every 10 minutes. The MSG scanning over Spain is done over 10 minutes after the time of the slot. The only way to match temporally PCPh and radar scenes is choosing 0 and 30 minutes PCPh images corresponding to 10 and 40 minutes radar images respectively. As 15 and 45 minutes PCPh images don't match temporally with the radar ones, those images haven't been used in the validation process.

A smoothing in 3x3 MSG pixels boxes has been applied in order to reduce the radar and satellite estimations spatial mismatching. One every three ordered pixels of the smoothed fields have been taken into account.

The statistical parameters computed for this validation are described in ANNEX 1: STATISTICAL PARAMETERS.

Since this is a yes/no validation only categorical scores have been computed.

2.2.2 Probability of precipitation intervals validation:

Five probability of precipitation intervals have been validated:

- 0-20%: $0\% < \text{PoP} \leq 20\%$
- 20-40%: $20\% < \text{PoP} \leq 40\%$
- 40-60%: $40\% < \text{PoP} \leq 60\%$
- 60-80%: $60\% < \text{PoP} \leq 80\%$
- 80-100%: $80\% < \text{PoP} \leq 100\%$

For each probability interval only the rainy area with the selected probability has been taken into account. According to this, POD will always be 100%. Attention should be focused on FAR. A region with the probability of precipitation interval (A-B] should have $100\text{-B} \leq \text{FAR} < 100\text{-A}$.

The categorical scores obtained are showed in Table 3.

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 3: Categorical scores for PCPh algorithm probability of precipitation intervals

It can be observed that PCPh algorithm provide a FAR score within the expected interval at every interval.

2.2.3 Probability of precipitation thresholds validation:

Five probability of precipitation thresholds have been validated. The choice of these thresholds have been done taking into account the PCPh colour scale so 20%, 40%, 60% and 80% probability of precipitation thresholds have been used. To maintain coherence between precipitation products, a threshold of 30% probability of precipitation have been fixed for the validation of this product in the NWCSAF Product Requirements document [AD 3], which is the same threshold used for the PPS precipitation product. This 30% probability of precipitation threshold has also been validated.

For this kind of validation, the whole validation area has been taken into account and only pixels with a probability of precipitation higher than the specified threshold have been taken as satellite rainy pixels.

- 20% probability of precipitation threshold:

N	FAR (%)	POD (%)	CSI (%)	PC (%)
3072175	56,8	82,8	39,6	75,0

Table 4: Categorical scores for PCPh algorithm taking as rainy pixels those with probability of precipitation higher than 20%

- 30% probability of precipitation threshold:

N	FAR (%)	POD (%)	CSI (%)	PC (%)
3072175	50,5	74,6	42,3	79,7

Table 5: Categorical scores for PCPh algorithm taking as rainy pixels those with probability of precipitation higher than 30%

Green colour values in Table 5 mean that FAR or POD values obtained in that validation fulfill the FAR and POD target values defined in the NWCSAF Product Requirement document [AD 3].

- 40% probability of precipitation threshold:

N	FAR (%)	POD (%)	CSI (%)	PC (%)
3072175	43,5	64,7	43,2	83,1

Table 6: Categorical scores for PCPh algorithm taking as rainy pixels those with probability of precipitation higher than 40%

- 60% probability of precipitation threshold:

N	FAR (%)	POD (%)	CSI (%)	PC (%)
3072175	29,2	40,1	34,4	84,9

Table 7: Categorical scores for PCPh algorithm taking as rainy pixels those with probability of precipitation higher than 60%

- 80% probability of precipitation threshold:

N	FAR (%)	POD (%)	CSI (%)	PC (%)
3072175	18,1	15,8	15,3	82,6

Table 8: Categorical scores for PCPh algorithm taking as rainy pixels those with probability of precipitation higher than 80%

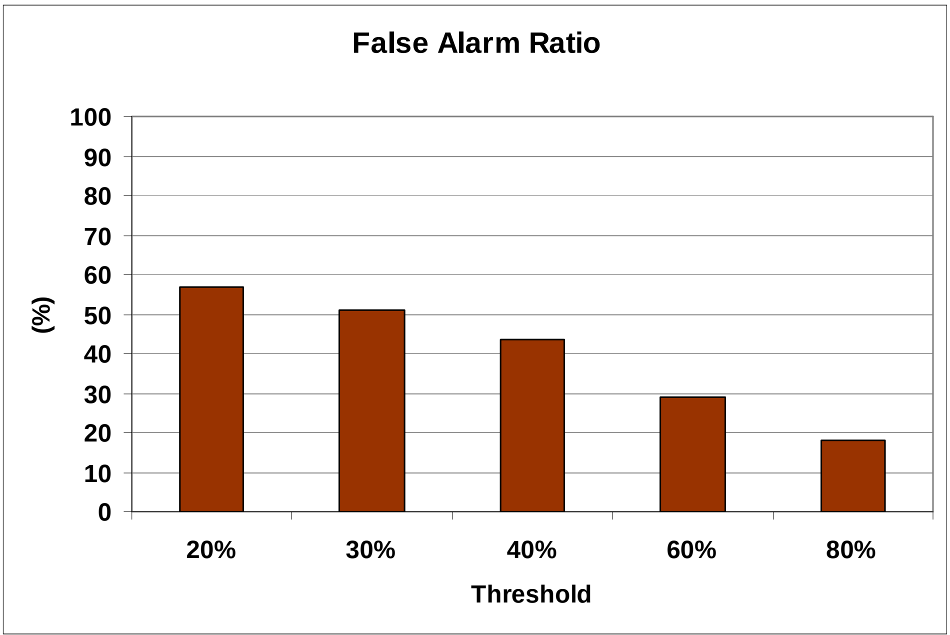

Figure 7: FAR for PCPh thresholds

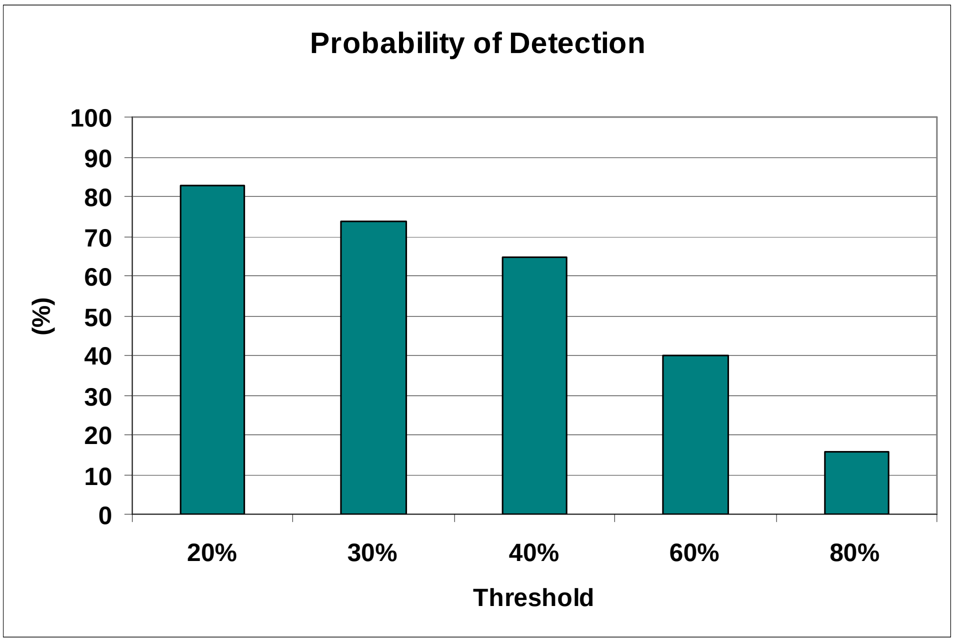

Figure 8: POD for PCPh thresholds

PoP greater than 80% provides a very low false alarm ratio but also a low probability of detection. This means that these range of PoP detect precipitation in a realiable way. On the other hand PoP higher than 20% obtained a probability of detection of almost 83% in this validation. This means that precipitation is well detected by the algorithm. False alarm ratio provided by 20% PoP threshold is about 53%, which is not too high. This shows that, overall, PCPh product is able to detect most of precipitation without providing too many false alarms.

FAR and POD target values defined in the NWCSAF Product Requirement document [AD 3] are referred to a probability threshold of 30%. Table 5 shows that both POD and FAR values for PCPh product fulfill the target requirements.

3. VALIDATION FOR CONVECTIVE RAINFALL RATE FROM CLOUD PHYSICAL PROPERTIES (CRPH)

This section contains the results obtained from the validation of the CRPh product which is described in Algorithm Theoretical Basis Document for "Precipitation products from Cloud Physical Properties" [AD. 1].

3.1 SUBJECTIVE VALIDATION FOR CONVECTIVE RAINFALL RATE FROM CLOUD PHYSICAL PROPERTIES (CRPH)

The monitoring of the precipitation pattern as well as its evolution is valuable information for the forecaster. In order to check this information, visual comparisons between CRPh and radar images have been done. A summary of these comparisons containing four cases that represent the general behaviour of these algorithms have been selected for this purpose.

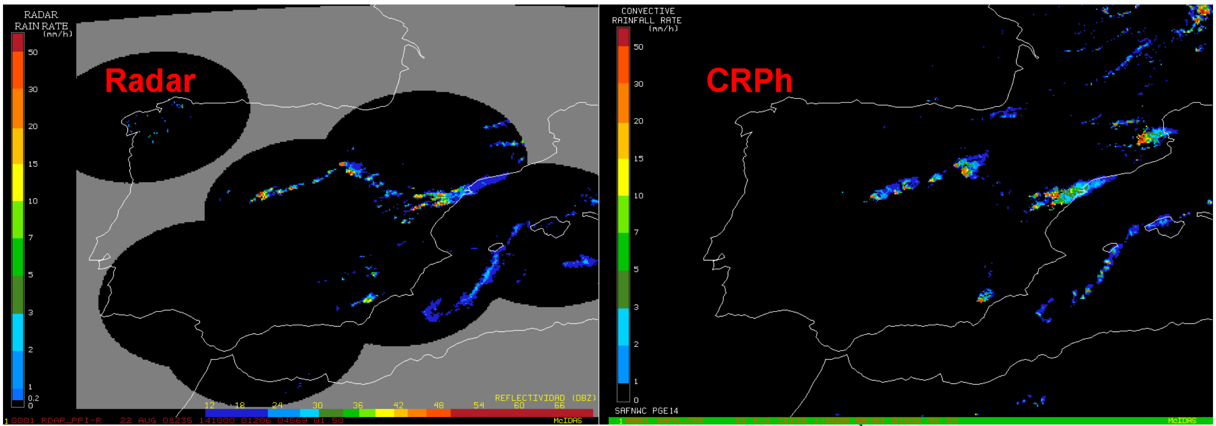

Figure 9: Visual comparison between radar (PPI) and CRPh on 22nd August 2008 at 14:00UTC.

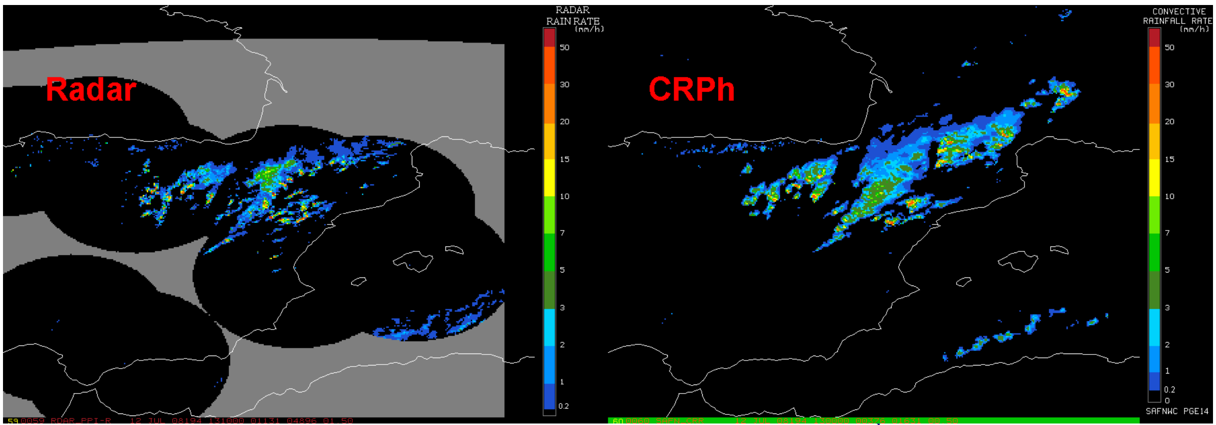

Figure 10: Visual comparison between radar (PPI) and CRPh on 12th July 2008 at 13:30UTC.

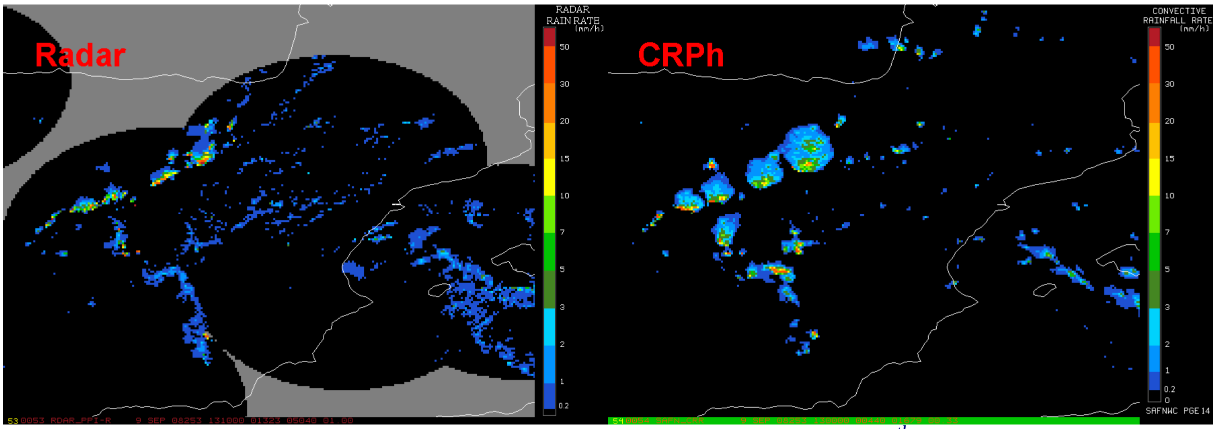

Figure 11: Visual comparison between radar (PPI) and CRPh on 9th September 2008 at 13:00UTC.

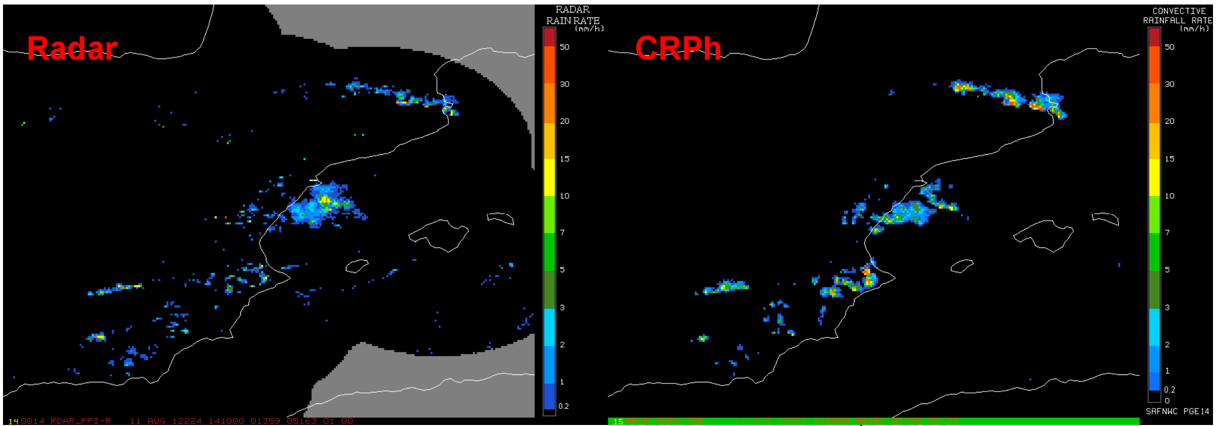

Figure 12: Visual comparison between radar (PPI) and CRPh on 11th August 2012 at 14:00UTC.

Figure 9 and Figure 10 show that PCPh product provides precipitation areas as well as precipitation intensities close to the radar ones. Figure 11 and Figure 12 show that small convective nuclei and low precipitation intensities are detected by this product. These last two figures also show that sometimes precipitation areas can be overestimated and that intense precipitation nuclei can have a small displacement with respect to the radar ones.

It has also been observed that under poor illumination conditions rain rates estimated by CRPh can be overestimated. Figure 13 show a sequence of radar, CRPh and CRPh_IQF images that correspond to the same day with one-hour time interval to illustrate this fact. It can be observed that under good illumination conditions both precipitation area and rain rates assigned by CRPh are similar to the radar ones, but when illumination conditions get worse, CRPh overestimates rain rates while precipitation area remains well detected in agreement with the radar.

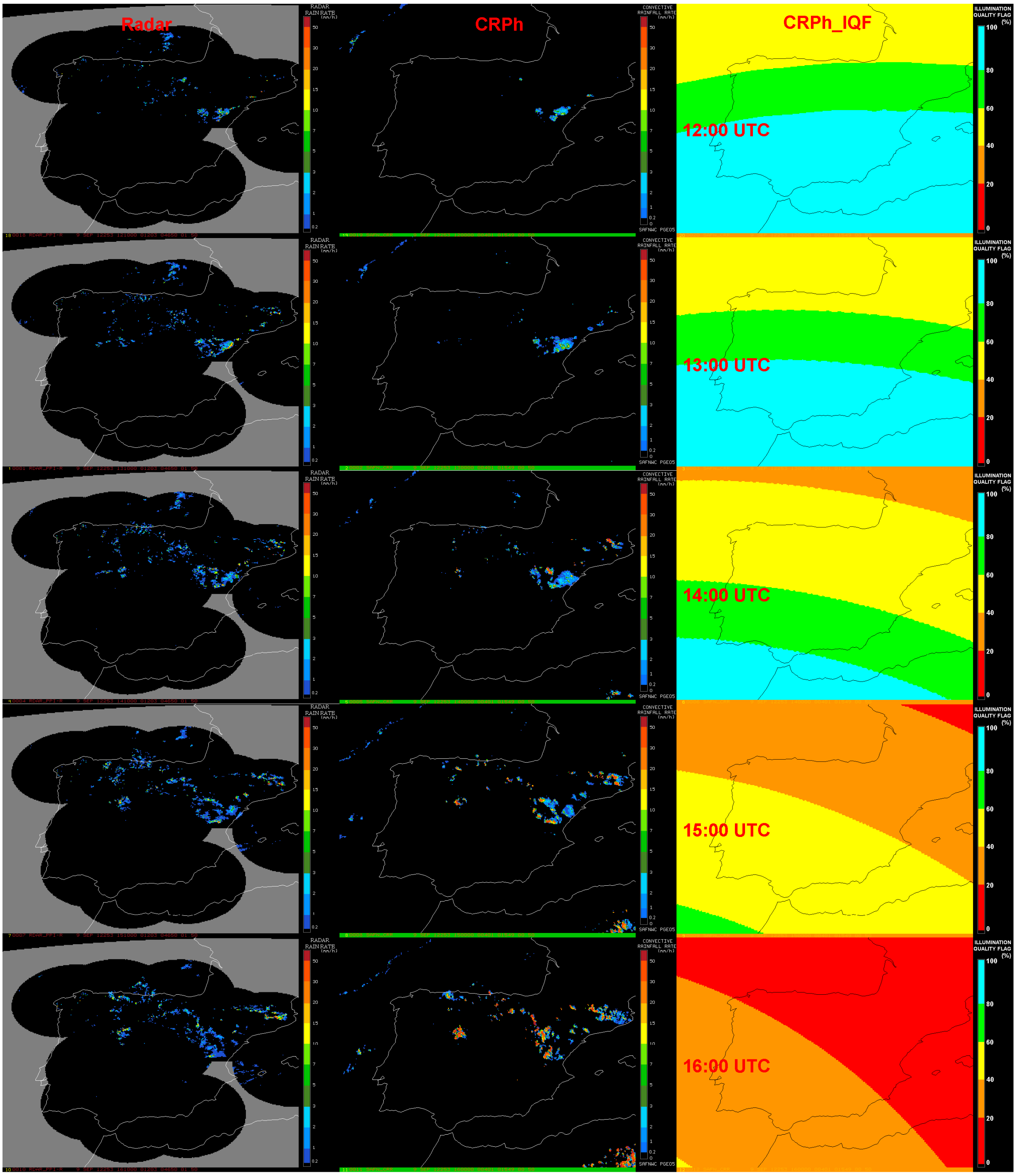

Figure 13: Sequence of radar, CRPh and CRPh_IQF images with one-hour time interval that shows the quality degradation of CRPh with poor illumination conditions

3.2 OBJECTIVE VALIDATION FOR CONVECTIVE RAINFALL RATE FROM CLOUD PHYSICAL PROPERTIES (CRPH)

3.2.1 Validation Procedure

The objective instantaneous rain rates validation has been done against instantaneous rates taken from Spanish radar PPI data and the hourly accumulations have been done against radar hourly accumulations obtained from the 500m Pseudo-CAPPI. For a better matching of the radar – satellite images, the radar, which is in Lambert projection, has been converted to MSG projection using a bi-linear interpolation scheme.

Ground echoes in PPI scenes have been removed. To do that, a filter image, available as a radar product, has been used in order to remove ground echoes (windmills, …). For instantaneous products there exists the possibility to remove ground echoes, like anomalous propagation echoes, through the 10.8IR scene. A rain image has been obtained from the 10.8IR data using the basic AUTOESTIMATOR algorithm [RD.1]. A pixel with significant radar echo is considered to be a ground echo and set to zero if no significant value is found in a 15x15 centred box in the AUTOESTIMATOR image.

In the instantaneous cases, since CRPh product addresses convective situations, only images with convective echoes should be validated. In order to select that images, when in the ECHOTOP image the ratio between the number of echoes greater than 6 Km and the ones greater than 0 Km is lower than 15%, the radar images have been rejected.

Images with convective situations can also include non convective echoes. In order to validate only the convective ones, a validation area has been selected taking into account the convective area that has been calculated in each image. To do that, PPI and ECHOTOP images have been used. The convective area in the instantaneous images has been made up of 15x15 pixels boxes centred on that ones that reaches a top of 6 km and a rainfall rate of 3 mm/h simultaneously. In the hourly accumulations, the validation area has been chosen adding the validation areas in the corresponding instantaneous images. As some CRPh rainy pixels can appear out of the convective area, these pixels have been added to the validation area in order to include all the possible false alarms.

The perfect matching between images will never be reached so a smoothing process in a 3x3 pixels base has been done. Then a pixel by pixel (every three pixels) comparison has been carried out. The definition of the statistics computed can be checked at ANNEX 1: STATISTICAL PARAMETERS.

The CRPh values have been obtained applying parallax correction [AD. 1]. The fields for the parallax correction have been extracted from ECMWF at 0.5 x 0.5 degree spatial resolution, every 6h.

The dataset used for the validation of both algorithms contains 78 days with convective events along 2008. Accuracy and categorical statistics have been computed for instantaneous rain rates and for hourly accumulations.

Since R_{eff} and COT parameters are not computed by PGE02 for undefined Phase pixels, those cases have been excluded from validation.

CRPh product includes the CRPh_IQF output which is a flag that provides information on the confidence that a user can have on the estimated rain rates according to the illumination conditions [AD. 1].

Different validations have been done for each CRPh_IQF threshold. This way it can be checked the influence of the illumination conditions on the validation results.

3.2.2 Instantaneous Rain Rates

The following table summarizes the results obtained for accuracy measurements:

Algorithm	N	Mean (mm/h)	ME (mm/h)	MAE (mm/h)	RMSE (mm/h)
CRPh_IQF ≥ 0 %	579705	0,62	0,85	1,38	4,10
CRPh_IQF ≥ 20 %	579670	0,62	0,85	1,38	4,10
CRPh_IQF ≥ 40 %	563371	0,62	0,81	1,33	3,97
CRPh_IQF ≥ 60 %	367610	0,61	0,40	0,94	2,76
CRPh_IQF ≥ 80 %	170182	0,58	0,16	0,70	1,89

Table 9: Accuracy measurements for instantaneous rates. Comparison among CRPh product using different CRPh_IQF thresholds.

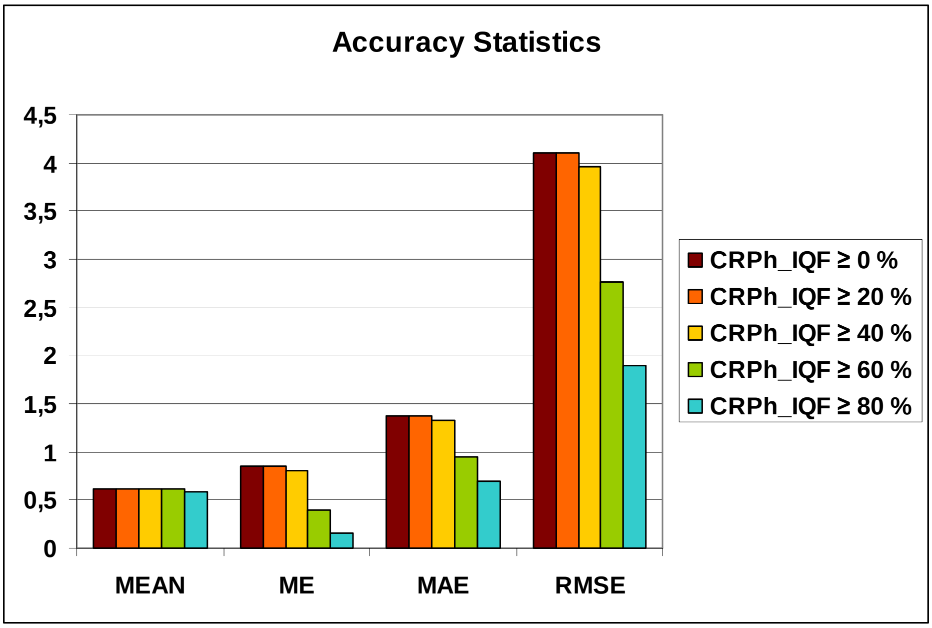

Figure 14: Accuracy measurements for instantaneous rates. Comparison among CRPh product using different CRPh_IQF thresholds.

The following table summarizes the results obtained for categorical scores:

Algorithm	FAR (%)	POD (%)	CSI (%)	PC (%)
CRPh_IQF ≥ 0 %	27,4	84,2	63,9	73,9
CRPh_IQF ≥ 20 %	27,4	84,2	63,9	73,9
CRPh_IQF ≥ 40 %	27,2	84,2	64,1	74,1
CRPh_IQF ≥ 60 %	26,4	84,5	64,8	74,9
CRPh_IQF ≥ 80 %	25,4	84,9	65,9	76,0

Table 10: Categorical scores for instantaneous rates. Comparison among CRPh product using different CRPh_IQF thresholds.

Green colour values in Table 10 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 3].

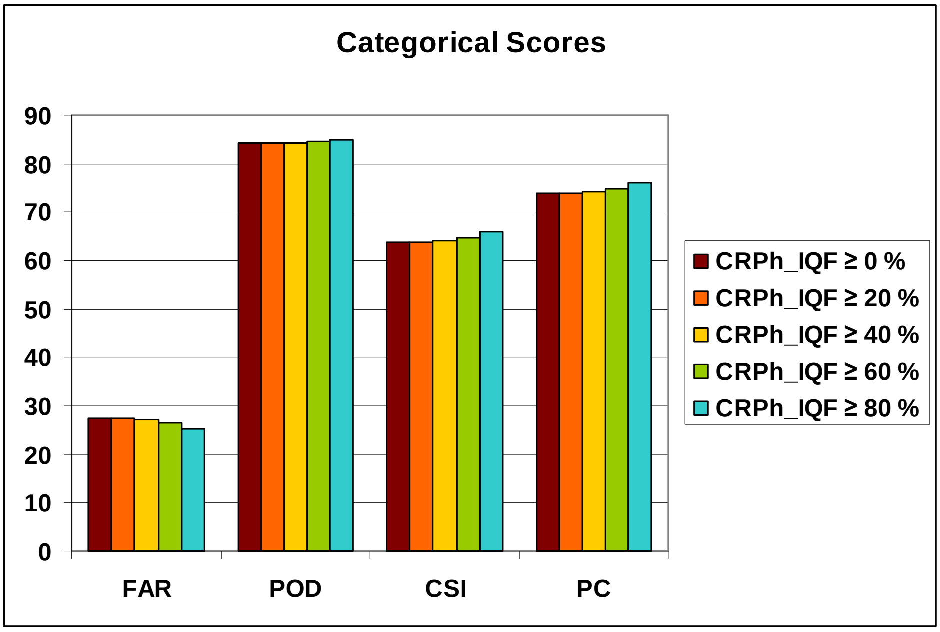

Figure 15: Categorical scores for instantaneous rates. Comparison among CRPh product using different CRPh_IQF thresholds.

It is obvious that the better are illumination conditions, the more accurate are the rainfall estimations. It has been seen that for bad illumination conditions and regions positioned far from the subsatellite point (that is, low values of CRPh_IQF), CRPh rain rates are overestimated leading in to a rise of the accuracy measurements. However, no big changes are detected in categorical scores when CRPh_IQF take different values. This means that although illumination conditions affect the rain rates assigned, the rainy areas are not affected by this fact. These results are in agreement with conclusions drawn from the subjective validation (section 3.1).

3.2.3 Hourly Accumulations

The following table summarizes the results obtained for accuracy measurements:

Algorithm	N	Mean (mm/h)	ME (mm/h)	MAE (mm/h)	RMSE (mm/h)
CRPh_IQF ≥ 0 %	297809	0,43	0,68	0,94	2,55
CRPh_IQF ≥ 20 %	297794	0,43	0,68	0,94	2,55
CRPh_IQF ≥ 40 %	270484	0,42	0,59	0,85	2,35
CRPh_IQF ≥ 60 %	180351	0,40	0,40	0,67	1,84
CRPh_IQF ≥ 80 %	83630	0,39	0,24	0,51	1,35

Table 11: Accuracy measurements for hourly accumulations. Comparison among CRPh product using different CRPh_IQF thresholds.

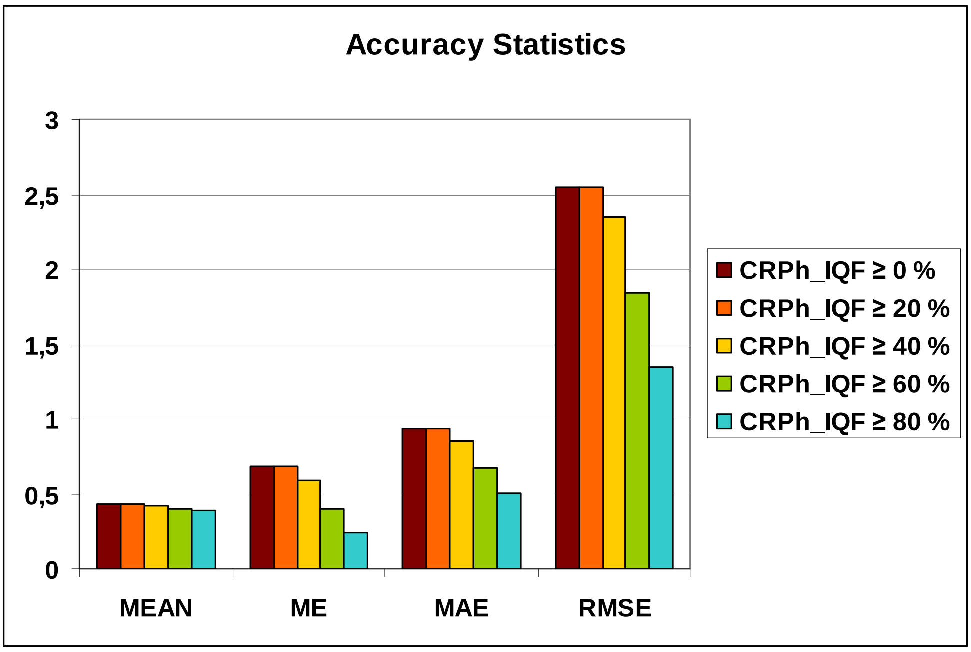

Figure 16: Accuracy measurements for hourly accumulations. Comparison among CRPh product using different CRPh_IQF thresholds.

The following table summarizes the results obtained for categorical scores:

Algorithm	FAR (%)	POD (%)	CSI (%)	PC (%)
CRPh_IQF ≥ 0 %	47,2	91,0	50,2	65,6
CRPh_IQF ≥ 20 %	47,2	91,0	50,2	65,6
CRPh_IQF ≥ 40 %	47,4	90,8	50,0	65,6
CRPh_IQF ≥ 60 %	47,3	90,9	50,1	66,3
CRPh_IQF ≥ 80 %	47,0	91,8	50,6	66,8

Table 12: Categorical scores for hourly accumulations. Comparison among CRPh product using different CRPh_IQF thresholds.

Green colour values in Table 12 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 3].

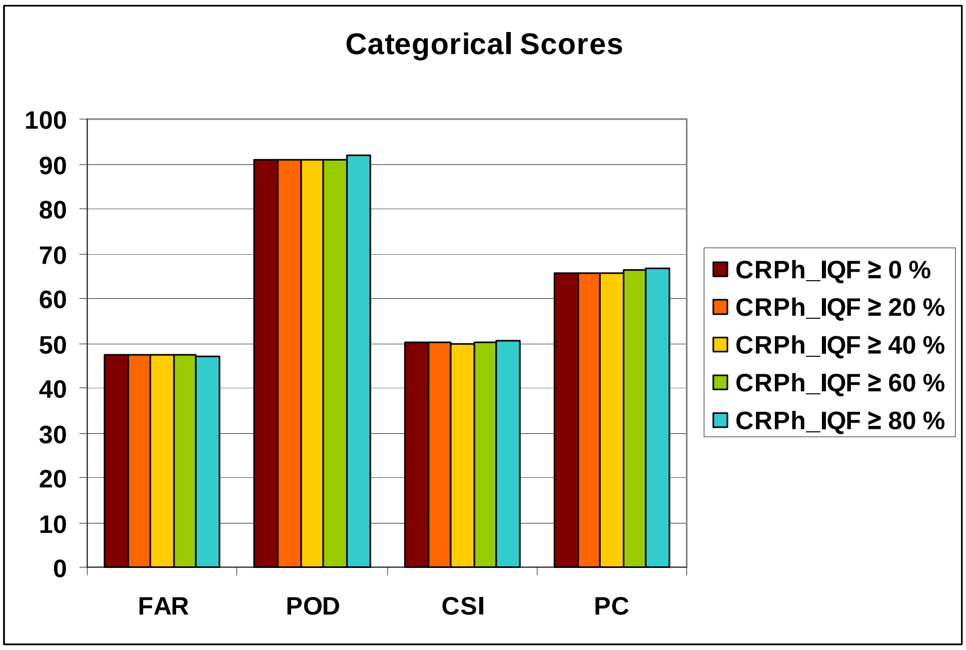

Figure 17: Categorical scores for hourly accumulations. Comparison among CRPh product using different CRPh_IQF thresholds.

Since hourly accumulations are computed using instantaneous rates, results obtained in both cases are similar.

4. ANNEX 1: STATISTICAL PARAMETERS

4.1 Accuracy Statistics

For each data pair the difference between the satellite estimation (E_i) and the radar observation measurements (O_i) has been calculated in order to obtain the following accuracy statistics:

- **N**: Number of data pairs used in the validation
- Mean Error:

$$ME = \frac{1}{N}\sum_{i=1}^{N}(E_i - O_i)$$

- Mean Absolute Error:

$$MAE = \frac{1}{N}\sum_{i=1}^{N}\left|E_i - O_i\right|$$

- Root Mean Square error:

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(E_i - O_i)^2}$$

The average of the radar observed rates has also been calculated:

$$MEAN = \frac{1}{N}\sum_{i=1}^{N}O_i$$

Where N is number of data pairs used in the computing.

4.2 Categorical Statistics

The following scores derived from Table 13, have been calculated:

- False Alarm Ratio:

$$FAR = \frac{false\_alarms}{hits + false\_alarms}$$

Measures the fraction of estimated events that were actually not events.

- Probability of Detection:

$$POD = \frac{hits}{hits + misses}$$

Measures the fraction of observed events that were correctly estimated.

- Critical Success Index:

$$CSI = \frac{hits}{hits + misses + false\_alarms}$$

Measures the fraction of observed and/or estimated events that were correctly diagnosed.

- Percentage of Corrects:

$$PC = \frac{hits + correct\_negatives}{hits + misses + false\_alarms + correct\_negatives}$$

Is the percentage of correct estimations.

		Estimated (CRPh)	
		occurred[1]	no occurred
Observed (Radar)	occurred*	hits	misses
	no occurred	false alarms	correct negatives

Table 13. Contingency table convention

[1] *Occurred means values higher than or equal to 0.2 mm/h for instantaneous rates and higher than or equal to 0.2 mm for hourly and daily accumulations.*