The EUMETSAT Network of Satellite Application Facilities

NWC SAF

Support to Nowcasting and Very Short Range Forecasting

Scientific and Validation Report for the Precipitation Product Processors of the NWC/GEO

NWC/CDOP2/GEO/AEMET/SCI/VR/Precipitation, Issue 1, Rev. 0
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GEO-CRR-v401 (NWC-023)
GEO-PC-Ph-v1.1 (NWC-076a)
GEO-CRR-Ph-v1.1 (NWC-080a)

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DOCUMENT CHANGE RECORD

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1.0d	2 December 2015	28	Draft version for STRR
1.0	15 October 2016	44	Update of precipitation products validation for NWC SAF SW Package GEO V2016 DRR Indications and recommendations given by the NWC SAF SW Package GEO V2016 DRR have been included.

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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 geostationary meteorological satellites, NWC/GEO.

1.1 SCOPE OF THE DOCUMENT

This document is the Validation Report (VR) for the precipitation GEO products Precipitating Clouds (PC), Convective Rainfall Rate (CRR) and Precipitation products from Cloud Physical Properties (PPh) of the NWC/GEO 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).
This document compares the accuracies of the GEO precipitation products to the threshold accuracies for CDOP2 listed in the NCWSAF product requirements document *[AD 4]*.

1.2 SOFTWARE VERSION IDENTIFICATION

This document applies to the algorithms implemented in the release 2016 of the NWC/GEO software package (GEO-PC-v1.5.3, GEO-CRR-v4.0.1, GEO-PC-Ph-v1.0 and GEO-CRR-Ph-v1.0).

1.3 IMPROVEMENT FROM PREVIOUS VERSION

Since 2013 release, these technical improvements have been implemented:

- Interface to updated NWCLIB
- New output format
- New calibration of PPh products

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
CWP	Cloud Water Path
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FAR	False Alarm Ratio

HRIT	High Rate Information Transmission
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
MRV	Maximum Reflectivity in the Vertical
MSG	Meteosat Second 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	1.9	15/10/16
[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	1.9	31/08/16

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]	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 2]	Data Output Format for the NWC/GEO	NWC/CDOP2/GEO/AEMET/SW/DOF	1.1	15/01/15
[RD 3]	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 4]	Algorithm Theoretical Basis Document for the Precipitation Product Processors of the NWC/GEO	NWC/CDOP2/GEO/AEMET/SCI/ATBD/Precipitation	1.1	15/10/16
[RD 5]	User Manual for the SAFNWC/MSG Parallax Correction Tool	GMV/SAFCDOP/VSAREP/02	1.0	02/06/08

Table 2. List of Referenced Documents

2. VALIDATION FOR PRECIPITATING CLOUDS PRODUCT

This section contains the results obtained from the validation of the PC product which is described in the Algorithm Theoretical Basis Document for SAFNWC/MSG "Precipitating Cloud" (PC-PGE04 v1.5) [RD 3].

2.1 SUBJECTIVE VALIDATION FOR PRECIPITATING CLOUDS (PC)

Many cases have been visually studied by comparing the probability of precipitation (PoP) obtained from the PC algorithm against the radar data. Since PC product estimates probability of precipitation occurrence, the most suitable product to compare with would be the one that assigns 100% PoP where it is raining and 0% otherwise. So PC 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. Since satellite scanning over the Iberian Peninsula takes place about 10 minutes later than the satellite imagery nominal time, PC images have been compared to radar ones taken 10 minutes later for a better time matching.

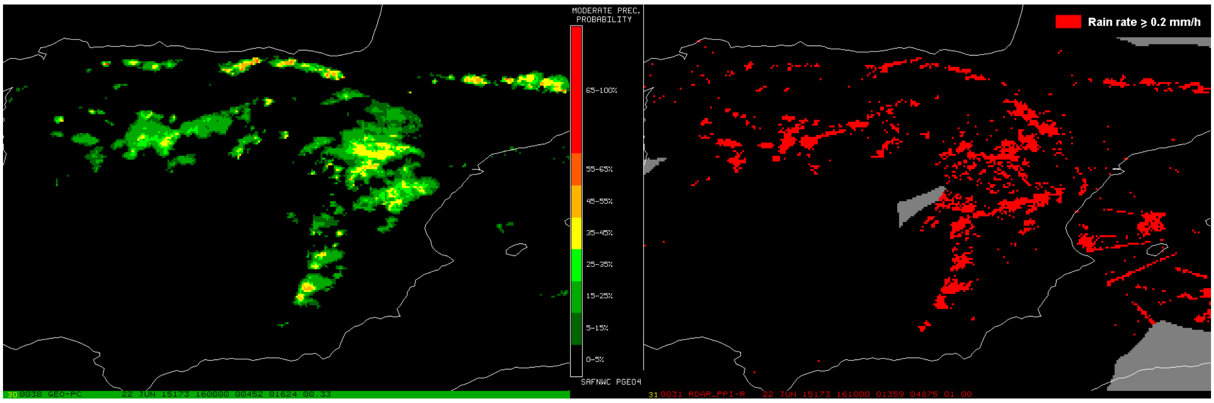

Figure 1. Comparison of PC product and radar (PPI) on 22nd June 2015 at 16:00UTC.

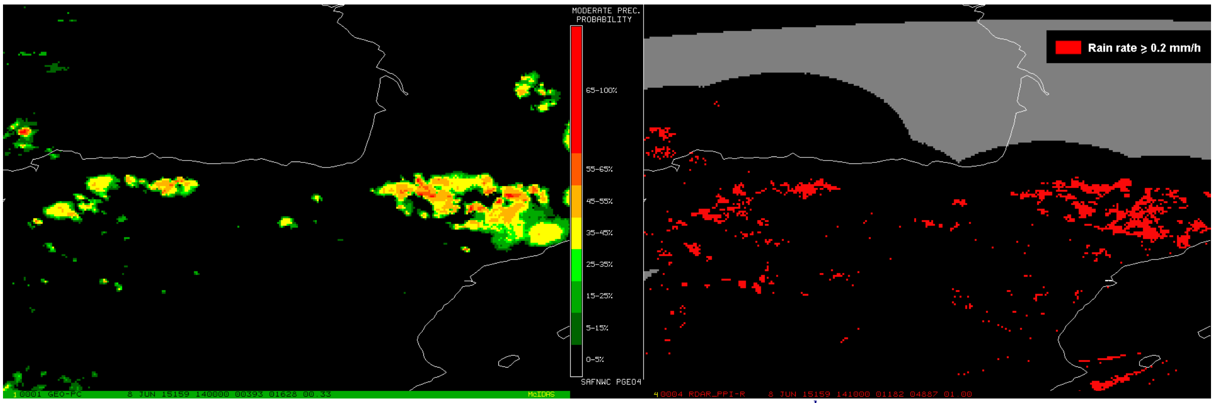

Figure 2. Comparison of PC product and radar (PPI) on 8th June 2015 at 14:00UTC.

Both Figure 1 and Figure 2 show day-time PC algorithm estimations where the overall precipitation areas are well depicted. However, PoP assigned are not so high, above all in the case of Figure 1, where few pixels take values of PoP higher than 50%. This fact could be explained by the time of the scanning of the satellite imagery used to compute the product. The set of satellite channels used by day-time PC algorithm includes some solar channels with valuable information for precipitation detection. The poorer are the illumination conditions, the lower is the confidence of the algorithm to assign higher PoPs.

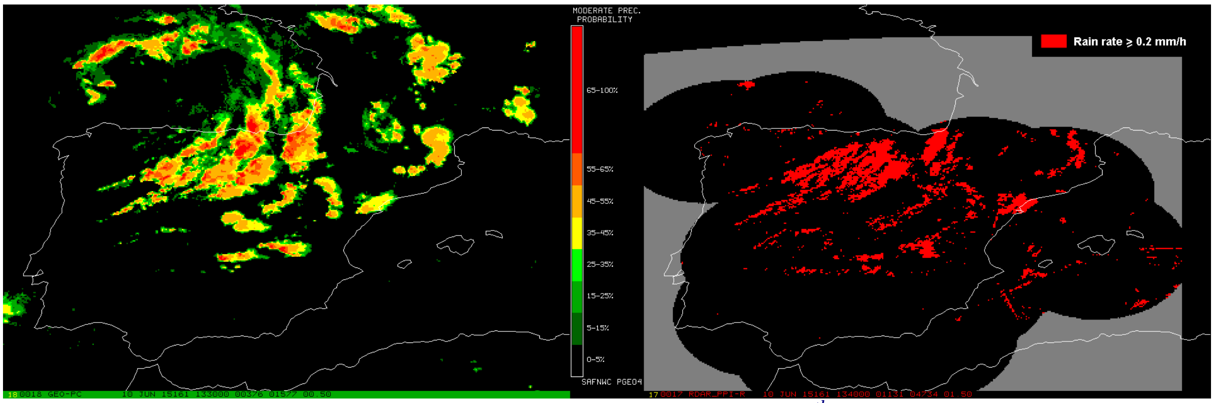

Figure 3. Comparison of PC product and radar (PPI) on 10th June 2015 at 13:30UTC.

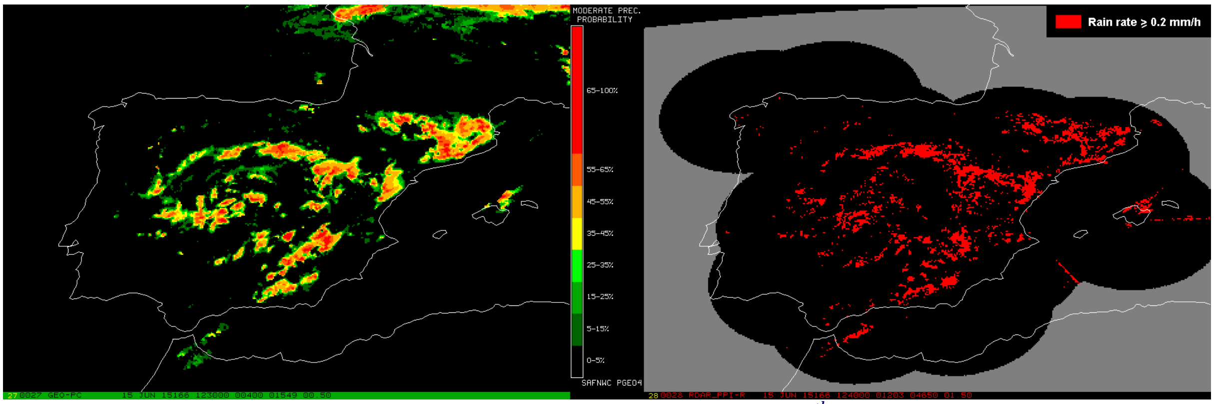

Figure 4. Comparison of PC product and radar (PPI) on 15th June 2015 at 12:30UTC.

Figure 3 and Figure 4 show day-time PC algorithm estimations with better illumination conditions than Figure 1 and Figure 2. In these cases it can be observed that the estimated precipitation areas are in good agreement with the radar ones and also that higher PoPs have been assigned.

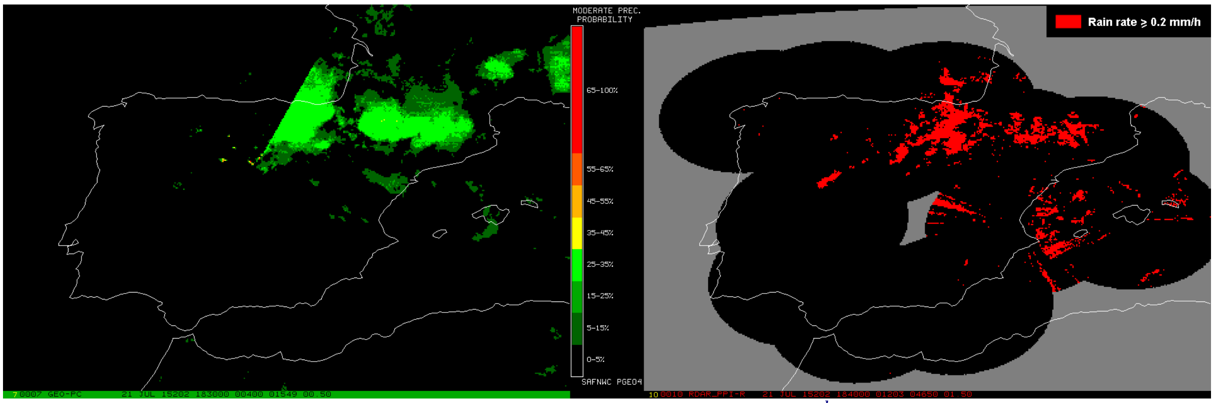

Figure 5. Comparison of PC product and radar (PPI) on 21th June 2015 at 18:30UTC

Figure 5 shows a scene with a day-night transition of PC algorithms. The day-time algorithm is displayed on the right side of the abrupt precipitation product transition. The night-time algorithm is displayed on the left side of this feature. At this time PC day-time algorithm is computed under poor illumination conditions, and so, there is a low confidence in the assignment of PoP. On the other hand night-time algorithm, which also shows a low confidence in the assignment of PoP, estimates bigger precipitation areas with more false alarms.

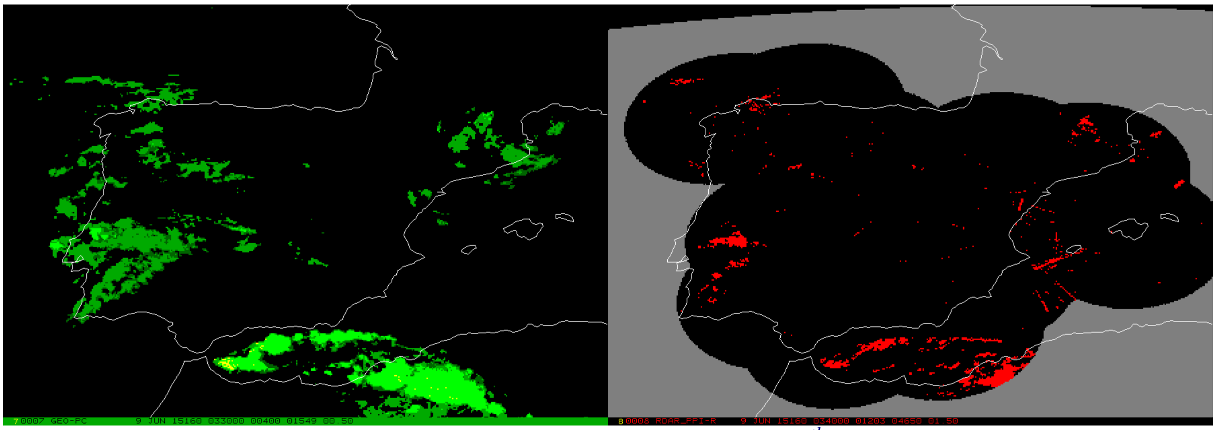

Figure 6. Comparison of PC product and radar (PPI) on 9th June 2015 at 03:30UTC

Figure 6 shows a night time scene where almost all precipitation areas depicted in the radar image are detected by PC product. However, since less information is contained in the night-time algorithm than in the day-time one, the confidence of PoP is lower. Also, the precipitation areas are overestimated providing a higher number of false alarms.

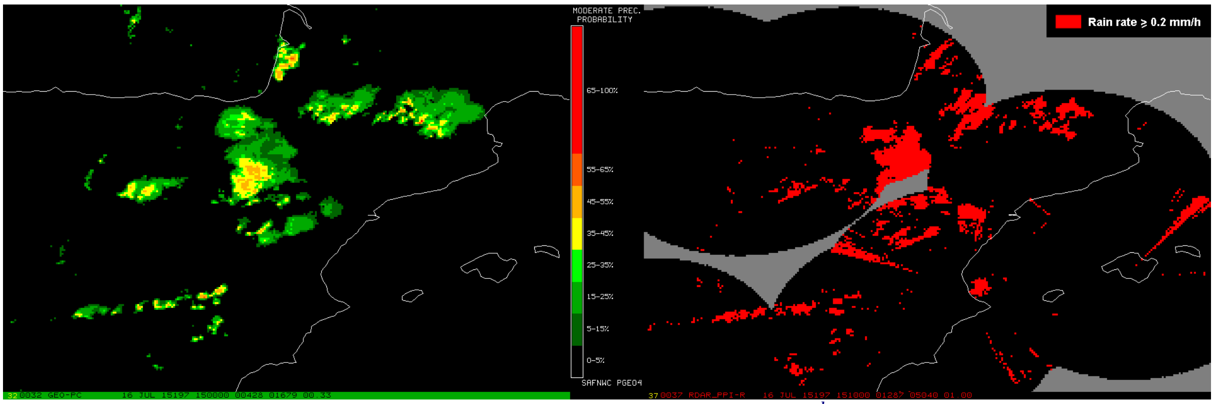

Figure 7. Comparison of PC product and radar (PPI) on 16th June 2015 at 15:00UTC.

Figure 7 shows a scene where there is a lack of several radars to compute a radar mosaic, and so there is no information over some areas. Here the usefulness of the PC product is shown. It is in agreement with the radar covered areas and complements its information over the rest of the image.

2.2 OBJECTIVE VALIDATION FOR PRECIPITATING CLOUDS (PC)

2.2.1 Validation Procedure

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

Both day-time and night-time algorithms have been validated. Day-time algorithm has been used for those cases with sun zenith angles lower than 80º and night-time algorithm has been used for the rest of the cases.

The original radar data is in Lambert projection, for a better matching, it has been customary reprojected to the MSG projection using a bi-linear interpolation scheme. The NWCSAF parallax tool *[RD 5]* has been applied to the PC 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 (Vicente et al., 1998). 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.

Although satellite data have been used for decluttering the radar data, since this information has been used in a non-aggressive way, datasets are still independent enough for statistical comparison in the validation.

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 PC 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 PC 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 PC and radar scenes is choosing 0 and 30 minutes PC images corresponding to 10 and 40 minutes radar images respectively. As 15 and 45 minutes PC 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:

Eight PoP intervals have been validated. This intervals have been chosen in line with the colour scale delivered with the product:

- 0-5%: $0\% < \text{PoP} \leq 5\%$
- 5-15%: $5\% < \text{PoP} \leq 15\%$
- 15-25%: $15\% < \text{PoP} \leq 25\%$
- 25-35%: $25\% < \text{PoP} \leq 35\%$
- 35-45%: $35\% < \text{PoP} \leq 45\%$
- 45-55%: $45\% < \text{PoP} \leq 55\%$
- 55-65%: $55\% < \text{PoP} \leq 65\%$
- 65-100%: $65\% < \text{PoP} \leq 100\%$

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 $100\text{-}B \leq FAR < 100\text{-}A$. For a better understanding of this, see Figure 8. Lets imagine a precipitation probability pattern estimated like the one in the left part of the image. And imagine that the 25-35% probability interval is going to be validated. In this case only the green area in the center part of the image would be taken into account for validation, for both observation and estimation. In this case, the entire green area would be a rainy area according to the estimation, and so, a probability of detection of 100% would be assigned to this area. This assumption is represented at the right part of the image. To check whether this area has in effect a 25-35% precipitation probability, attention should be focused on false alarms. So, if the precipitation probability is 25-35%, then, false alarm ratio should be 65-75%.

Figure 8. Drawing example of probability of precipitation intervals validation

The categorical scores obtained are showed in Table 3.

Probability interval (%)	N (Day algorithm)	FAR (%) (Day algorithm)	N (Night algorithm)	FAR (%) (Night algorithm)
0-5	580028	87,28	487349	88,17
5-15	874949	79,97	1238899	85,49
15-25	573867	67,38	1286422	73,09
25-35	331008	54,53	1100344	60,86
35-45	327523	47,64	191587	50,72
45-55	281118	37,56	1719	41,42
55-65	114062	27,21	527	9,11
65-100	24139	19,50	91	5,49

Table 3. Categorical scores for PC algorithm probability of precipitation intervals

It can be observed that PC algorithm provides FAR scores lower than expected, most of all for the highest probability intervals. It should be noted that the highest probability intervals include lower number of cases, most of all in the case of the night-time algorithm that assigns PoP with lower confidences, which is in agreement with the results observed during the subjective validation. The FAR for PoPs higher than 50% are even lower with respect to the FARs from the PoPs lower than 50%.

It can be also observed that the higher quality of the day-time algorithm obtained due to the valuable information provided by the solar channels, leads into lower FAR values for each probability interval.

2.2.3 Probability of precipitation thresholds validation:

Seven probability of precipitation thresholds have been validated. These thresholds are: 5%, 15%, 25% , 35% , 45% , 55% and 65% probability of precipitation.
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, all the other pixels are taken as non-rainy.

Probability of precipitation threshold (%)	N	FAR (%)	POD (%)	CSI (%)	PC (%)
5	5254532	61,91	87,09	36,06	67,52
15	5254532	52,34	71,23	39,97	77,50
25	5254532	44,34	54,29	37,90	81,29
35	5254532	39,82	40,67	32,05	81,86
45	5254532	33,71	25,15	22,30	81,57
55	5254532	25,86	9,27	8,98	80,24
65	5254532	19,50	1,76	0,02	0,79

Table 4. Categorical scores for PC day-time algorithm taking as rainy pixels those with probability of precipitation higher than the threshold

Probability of precipitation threshold (%)	N	FAR (%)	POD (%)	CSI (%)	PC (%)
5	6179225	72,44	89,55	26,70	53,23
15	6179225	66,18	74,26	30,27	67,47
25	6179225	59,31	44,81	27,11	77,08
35	6179225	50,50	8,17	7,54	80,95
45	6179225	32,73	0,13	0,13	80,99
55	6179225	8,58	0,05	0,05	80,99
65	6179225	5,49	0,01	0,01	80,98

Table 5. Categorical scores for PC night-time algorithm taking as rainy pixels those with probability of precipitation higher than the threshold

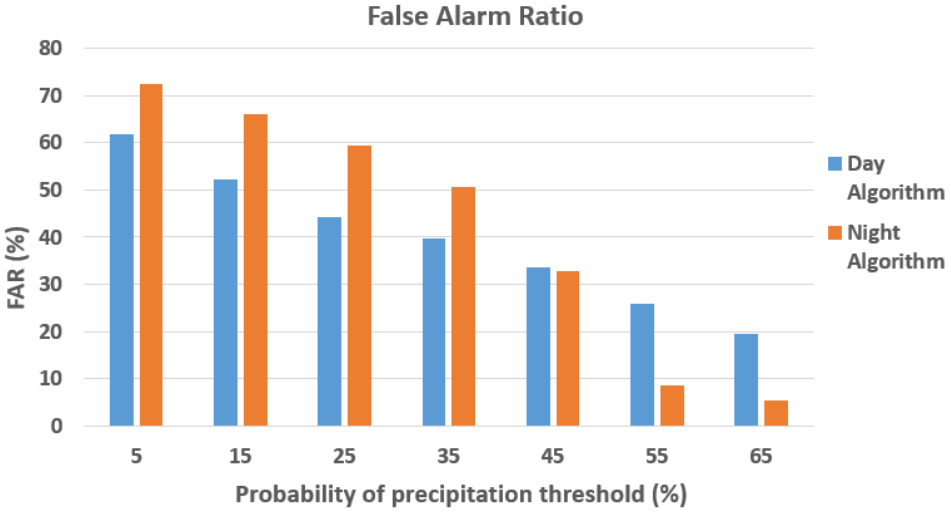

Figure 9. Comparison of day-time and night-time algorithms false alarm ratio

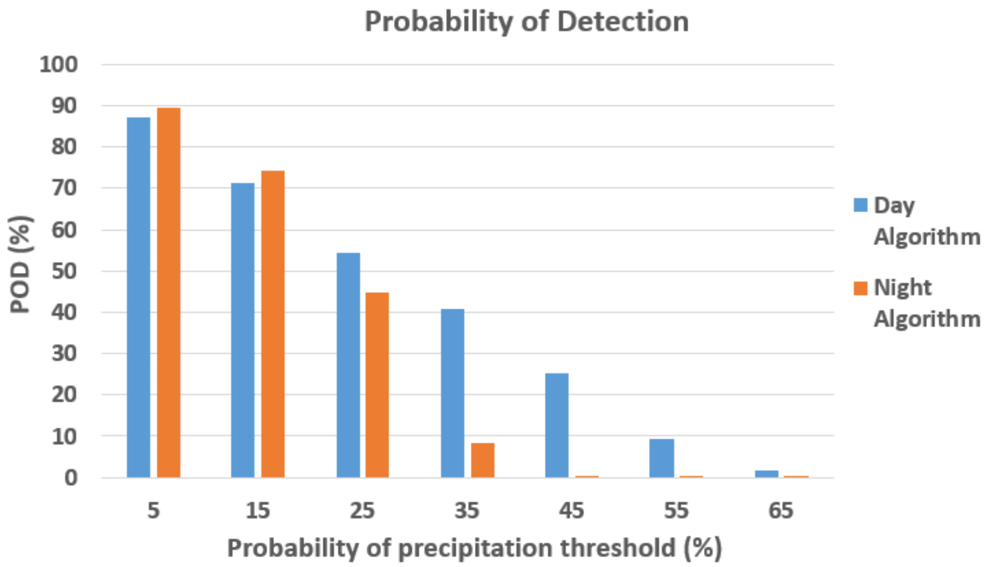

Figure 10. Comparison of day-time and night-time algorithms probability of detection

A clear better performance of the day-time algorithm over the night-time one can be observed in the graphs. Both lower FAR and higher POD have been obtained for the day-time algorithm for all the PoP thresholds. For 35% PoP and lower thresholds, POD is higher than FAR for the day-time algorithm. In the case of the night-time algorithm, this happens for 15% PoP threshold and the lower ones. For the higher PoP thresholds, scores get worse due to the low number of cases that reach these thresholds.

2.2.4 Conclusion

PC product catches most of the precipitation areas; however, probability of precipitation assigned, in a high number of cases, is underestimated. For this reason, although precipitation is detected, most of the time, is located in areas with PoPs lower than 55% for the day-time algorithm and lower than 45% in the case of the night-time one. PoPs higher than 65% are assigned few times in the case of the day-time algorithm and almost never in the case of the night-time one. So it is clear that the day-time algorithm provides better results than the night-time one due to the influence of the solar channels.

3. VALIDATION FOR CONVECTIVE RAINFALL RATE PRODUCT

This section contains the results obtained from the validation of the CRR product which is described in the Algorithm Theoretical Basis Document for the Precipitation Product Processors of the NWC/GEO *[RD 4]*.

3.1 SUBJECTIVE VALIDATION FOR CONVECTIVE RAINFALL RATE (CRR)

The monitoring of the precipitation pattern as well as its evolution is valuable information for the forecaster. In order to show the valuable information that CRR product can provide, a set of examples of CRR have been selected and compared to the radar estimations.

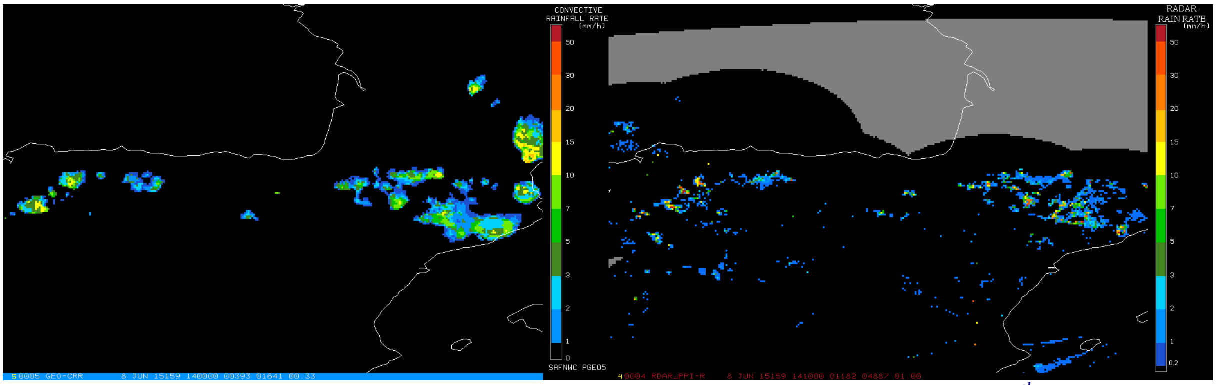

Figure 11. Comparison of CRR instantaneous rates product and radar (PPI) on 8th June 2015 at 10:00UTC

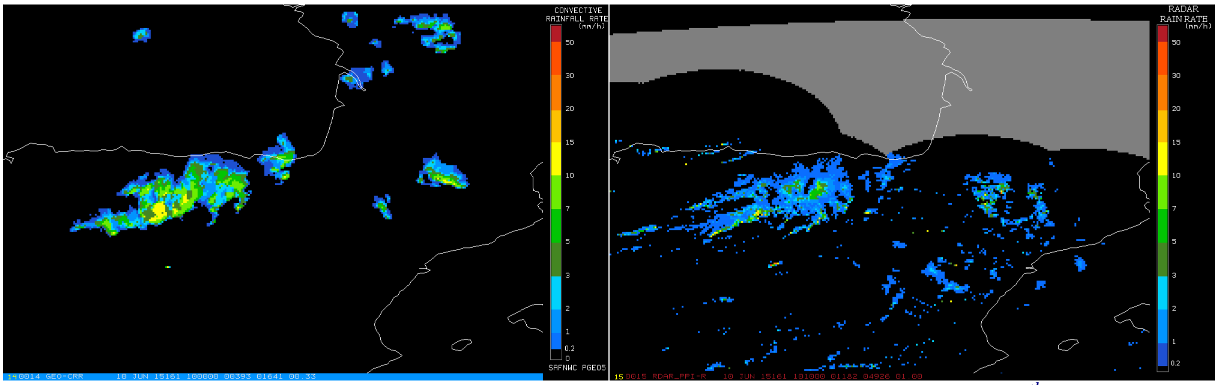

Figure 12. Comparison of CRR instantaneous rates product and radar (PPI) on 10th June 2015 at 10:00UTC

Figure 11 and Figure 12 show a couple of comparisons of CRR instantaneous rain rates with radar PPI product where most of the precipitation areas have been detected by CRR. Although the CRR precipitation pattern is quite similar to the radar one and the maxima of precipitation match well in location, maximum CRR rain rates are in general lower than the radar ones.

It is well known that for this kind of product directly based on cloud top radiances it is very difficult to detect the smallest precipitation nuclei. And it is also difficult to detect the lowest rain rates. It can be observed in the images that the rainy area is well depicted but sometimes is overestimated, being very similar to the cloud top structure. And it can also be observed a general underestimation of the highest rain rates.

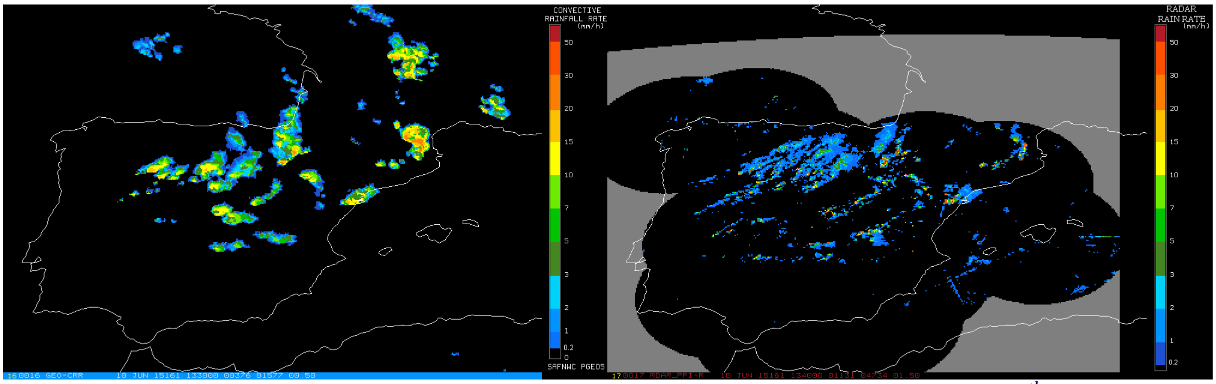

Figure 13. Comparison of CRR instantaneous rates product and radar (PPI) on 10th June 2015 at 13:30UTC

Figure 13 shows an example of a good performance of CRR product day-time algorithm. Although the smallest rain nuclei are missed by CRR, the precipitation pattern is very similar to the radar one and the maximum rain rates are also very similar.

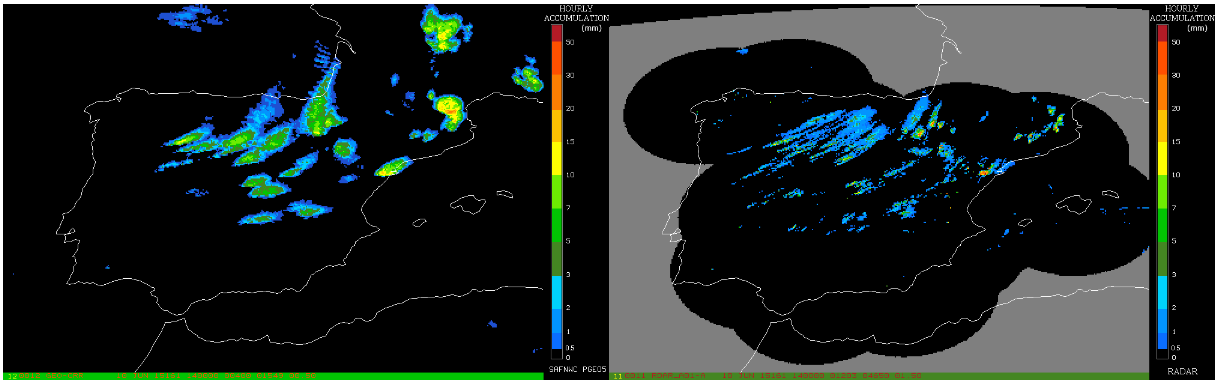

Figure 14. Comparison of CRR hourly accumulation product and radar hourly accumulation on 10th June 2015 at 14:00UTC

Figure 14 shows a comparison of hourly accumulation estimated by CRR and radar. Similar conclusions as in the case of instantaneous rain rates can be reached for hourly accumulations since hourly accumulations are obtained by using the instantaneous rain rates.

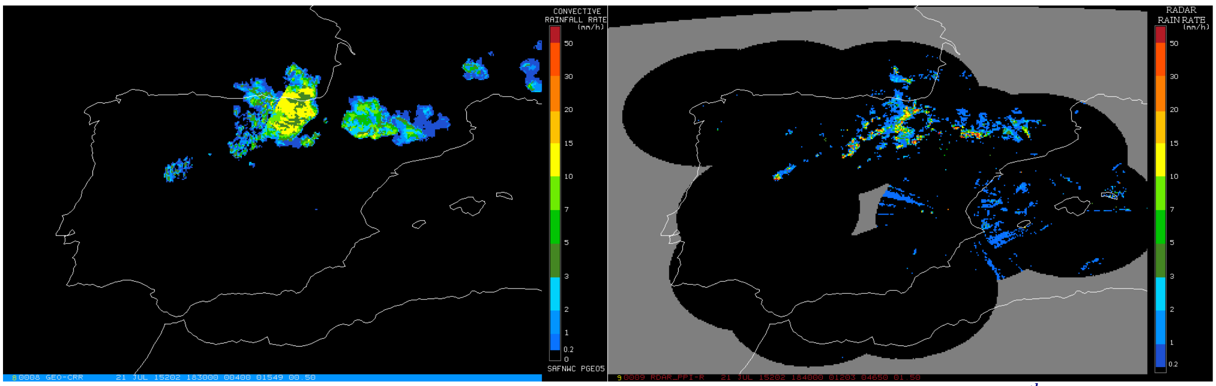

Figure 15. Comparison of CRR instantaneous rates product and radar (PPI) on 21th June 2015 at 18:30UTC

Figure 15 shows a CRR day-night algorithm transition. The day-time algorithm is displayed on the right side of the abrupt precipitation product transition. The night-time algorithm is displayed on the left side of this feature. It is quite clear through this example the main differences between both algorithms. Day-time algorithm provides a rain pattern more adjusted to the radar one while night-time one is more similar to the cloud top, overestimating rainy areas. Day-time algorithm provides better results due to the important information included in the visible channel related to the cloud optical thickness.

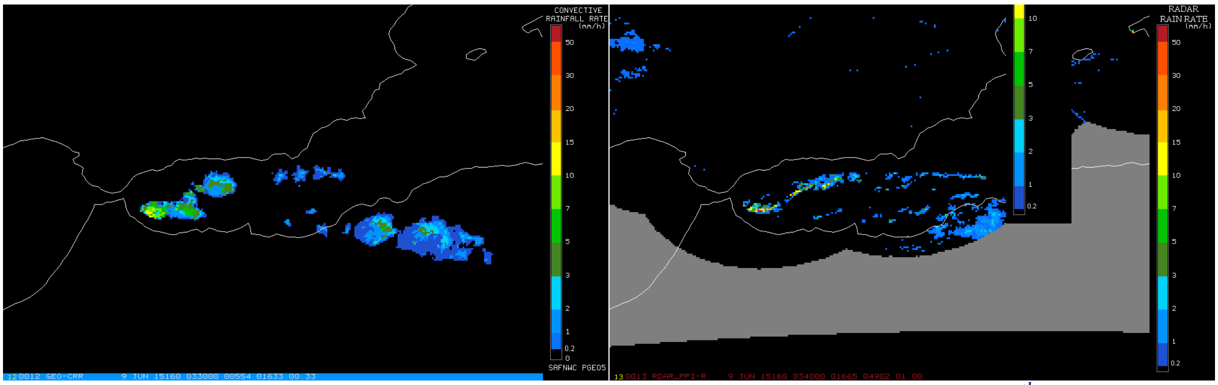

Figure 16. Comparison of CRR instantaneous rates product and radar (PPI) on 9th June 2015 at 03:30UTC

Figure 16 shows an example of the night-time algorithm. Although quality is not as good as in the case of the day-time one, precipitation areas are very similar to the radar one, and maximum rain rates are well located.

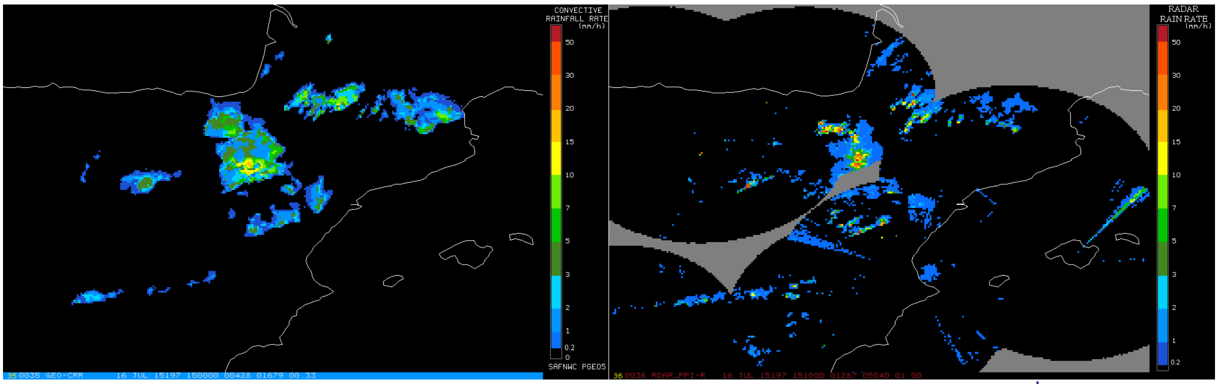

Figure 17. Comparison of CRR instantaneous rates product and radar (PPI) on 16th June 2015 at 15:00UTC

Figure 17 shows an example of the usefulness of CRR information when radar does not totally cover the studied area. Precipitation areas in those places covered by radar are similar and complementary information can be obtained through CRR out of those areas.

3.2 OBJECTIVE VALIDATION FOR CONVECTIVE RAINFALL RATE (CRR)

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. The original data in Lambert projection has been customary reprojected on the 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 (Vicente et al., 1998). 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.

Although satellite data have been used for decluttering the radar data, since this information has been used in a non-aggressive way, datasets are still independent enough for statistical comparison.

In the instantaneous cases, since CRR product addresses convective situations, only images with convective echoes should be validated. In order to select those images, when in the ECHOTOP image the ratio between the number of pixels with ECHOTOP higher than 6 Km and the number of pixels with ECHOTOP higher than 0 Km is lower than 15%, the radar images have been rejected. This procedure tends to discard non-convective precipitation.

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 pixels that reach 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 CRR 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 CRR values have been obtained applying all the corrections with the default values *[RD 4]*. The fields for the moisture, parallax and orographic corrections have been extracted from ECMWF at 0.5 x 0.5 degree spatial resolution, every 3h.

The dataset used for the validation of both algorithms contains 78 days with convective events along 2008. Accuracy and categorical statistics described in ANNEX 1: STATISTICAL PARAMETERS have been computed for instantaneous rain rates and for hourly accumulations.

3.2.2 Instantaneous Rain Rates

According to the procedure described above, the statistical accuracy measurements are shown in the following table:

Algorithm	N	Mean (mm/h)	ME (mm/h)	MAE (mm/h)	RMSE (mm/h)
3 - Variables	832614	0,58	0,54	1,19	2,97
2 - Variables	877299	0,62	0,82	1,55	3,18

Table 6. Accuracy measurements for instantaneous rates

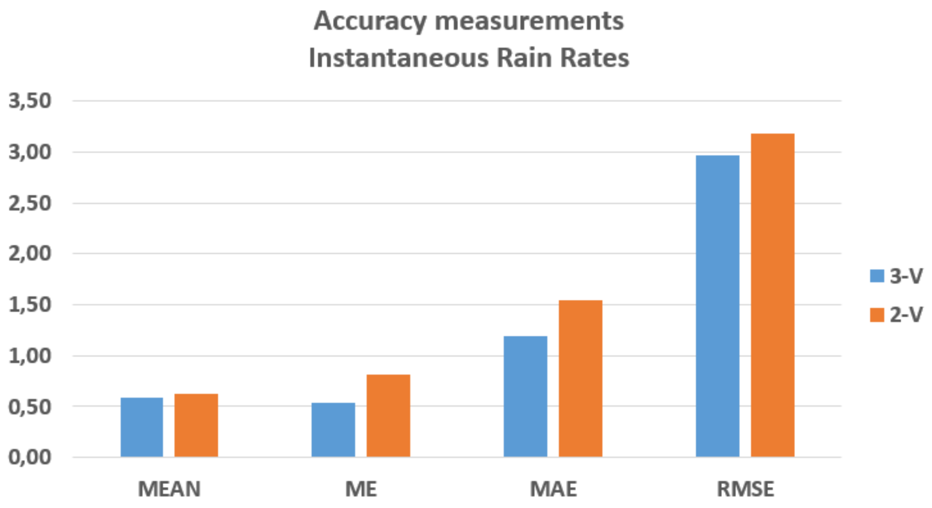

Figure 18. Accuracy measurements for CRR instantaneous rates

Although both day-time and night-time algorithms provide similar results, it can be observed a slight better performance in the day-time algorithm according to the results showed in Figure 18. This can be explained, as seen during the subjective validation, because day-time algorithm adjust better precipitation areas reducing error with respect to the night-time ones.

Categorical scores for CRR can be obtained assuming that values higher than or equal to 0.2 mm/h for instantaneous rates are considered rainy. Results are shown in Table 7.

Algorithm	FAR (%)	POD (%)	CSI (%)	PC (%)
3 - Variables	34,13	63,26	47,64	64,55
2 - Variables	45,53	53,74	37,08	54,57

Table 7. Categorical scores for CRR instantaneous rates

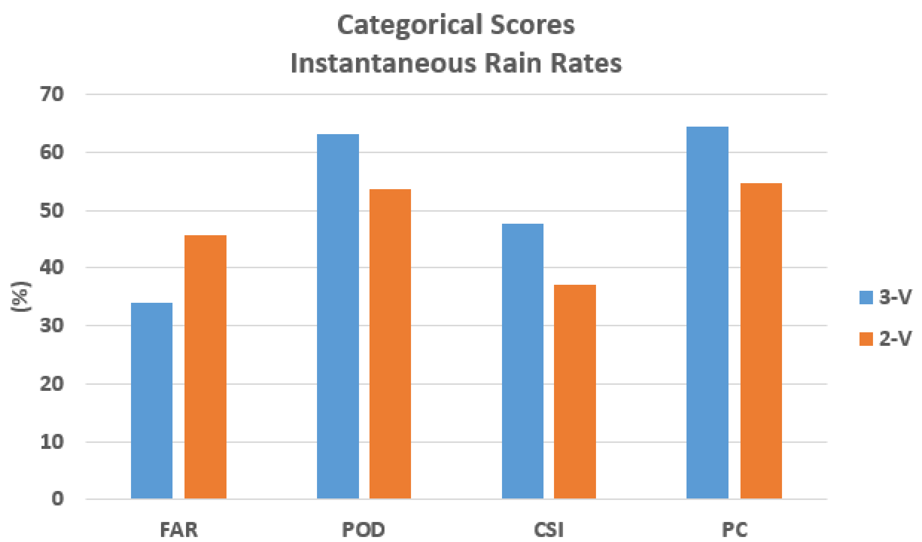

Figure 19. Categorical scores for CRR instantaneous rates

Figure 19 also brings to light the better estimations of the day-time algorithm that provides lower FAR and higher POD than the night-time one. These results, showed also in Table 7, fulfil the FAR and POD target values defined in the NWCSAF Product Requirements document *[AD 4]*.

3.2.3 Hourly accumulations

Accuracy measurements, obtained statistically as explained above, for hourly precipitation accumulations are shown in Table 8.

Algorithm	N	Mean (mm/h)	ME (mm/h)	MAE (mm/h)	RMSE (mm/h)
3 - Variables	465555	0,37	0,43	0,80	1,96
2 - Variables	598562	0,40	0,57	0,99	2,19

Table 8. Accuracy measurements for CRR hourly accumulations

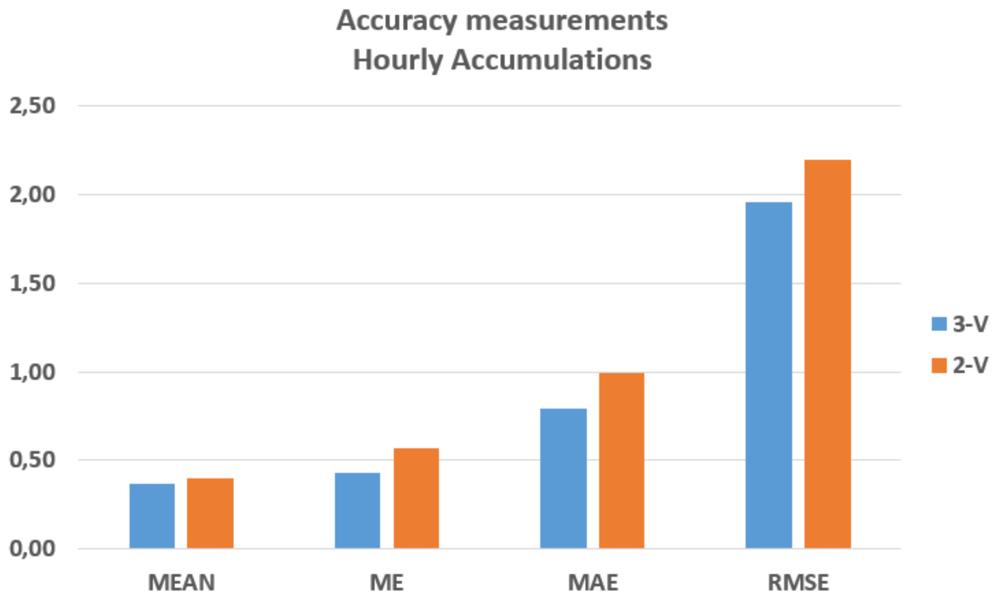

Figure 20. Accuracy measurements for CRR hourly accumulations

Since hourly accumulations have as a base the instantaneous rain rates, similar results are expected. Figure 20 show that accuracy measurements take lower values for hourly accumulations than for instantaneous rain rates. This happens because hourly accumulations fields are smoother than instantaneous rain rates ones. It can also observed the better performance of the day-time algorithm with respect to the night-time one.

Categorical scores can be obtained assuming that values higher than or equal to 0.2 mm/h for hourly precipitation accumulations are considered rainy. Results are shown in Table 9.

Algorithm	FAR (%)	POD (%)	CSI (%)	PC (%)
3 - Variables	51,07	65,33	38,84	63,17
2 - Variables	58,19	56,43	31,61	56,29

Table 9. Categorical scores for CRR hourly accumulations

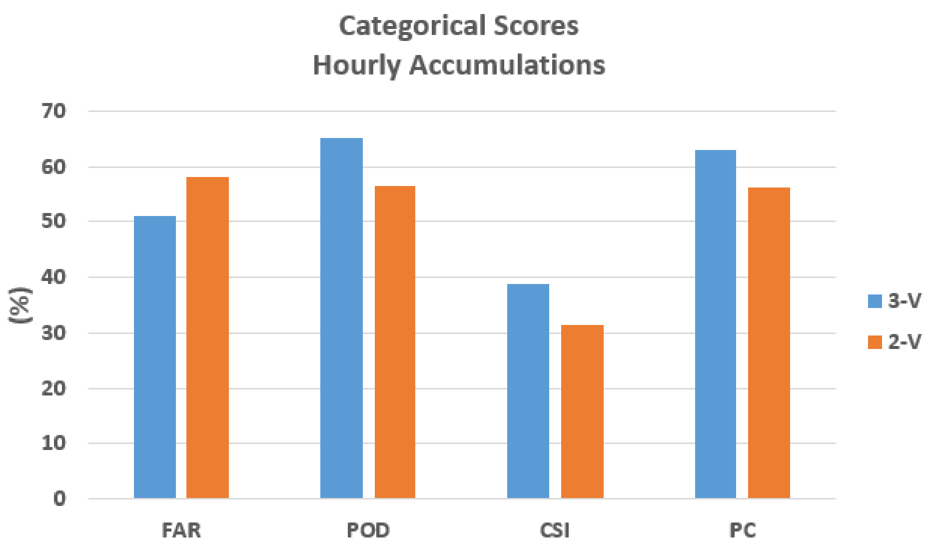

Figure 21. Categorical scores for CRR hourly accumulations

As for categorical scores, Figure 21 shows also the better estimations provided by the day-time algorithm and results from Table 9 fulfil the FAR and POD target values defined in the NWCSAF Product Requirements document *[AD 4]*.

3.2.4 Conclusion

Algorithm	Threshold Accuracy FAR (%)	Target Accuracy FAR (%)	Optimal Accuracy FAR (%)	FAR (%)
3 - Variables	<60	<40	<38	34.13
2 - Variables	<65	<50	<44	45.53

Table 10. Comparison of CRR instantaneous rates FAR scores and FAR accuracy values defined in the NWCSAF Product Requirement table

Algorithm	Threshold Accuracy POD (%)	Target Accuracy POD (%)	Optimal Accuracy POD (%)	POD (%)
3 - Variables	>40	>53	>87	63.26
2 - Variables	>35	>47	>85	53.74

Table 11. Comparison of CRR instantaneous rates POD scores and POD accuracy values defined in the NWCSAF Product Requirement table

Algorithm	Threshold Accuracy FAR (%)	Target Accuracy FAR (%)	Optimal Accuracy FAR (%)	FAR (%)
3 - Variables	<65	<55	<45	51.07
2 - Variables	<70	<60	<50	58.19

Table 12. Comparison of CRR hourly accumulations FAR scores and FAR accuracy values defined in the NWCSAF Product Requirement table

Algorithm	Threshold Accuracy POD (%)	Target Accuracy POD (%)	Optimal Accuracy POD (%)	POD (%)
3 - Variables	>45	>58	>95	65.33
2 - Variables	>37	>50	>90	56.43

Table 13. Comparison of CRR hourly accumulations POD scores and POD accuracy values defined in the NWCSAF Product Requirement table

4. VALIDATION FOR PRECIPITATING CLOUDS FROM CLOUD PHYSICAL PROPERTIES PRODUCT

This section contains the results obtained from the validation of the PC-Ph product which is described in the Algorithm Theoretical Basis Document for the Precipitation Product Processors of the NWC/GEO *[RD 4]*.

4.1 SUBJECTIVE VALIDATION FOR PRECIPITATING CLOUDS FROM CLOUD PHYSICAL PROPERTIES (PC-PH)

Many cases have been visually studied by comparing the probability of precipitation (PoP) obtained from the PC-Ph 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 PC-Ph 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:

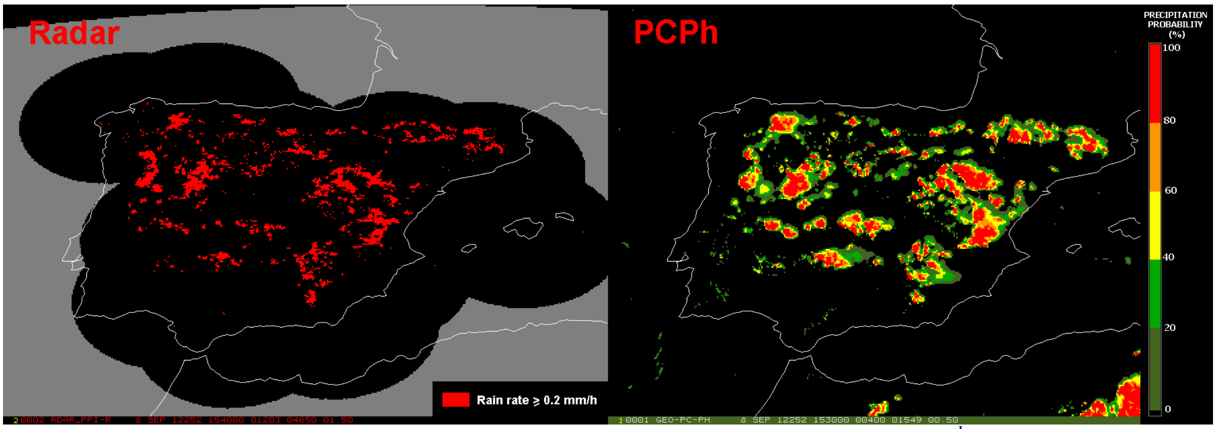

Figure 22. Visual comparison between radar (PPI) and PC-Ph product on 8th September 2012 at 15:30UTC over Spain

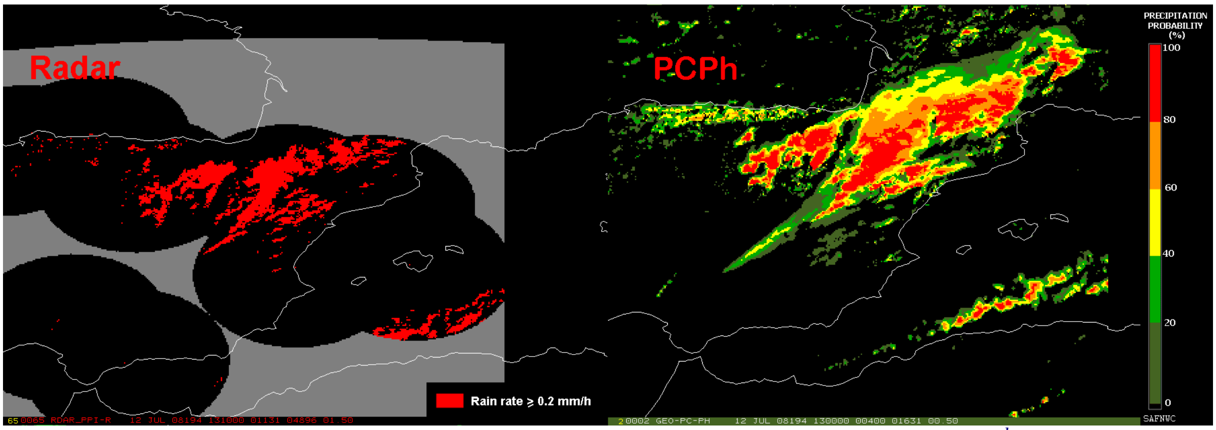

Figure 23. Visual comparison between radar (PPI) and PC-Ph product on 12th July 2008 at 13:00UTC over Spain

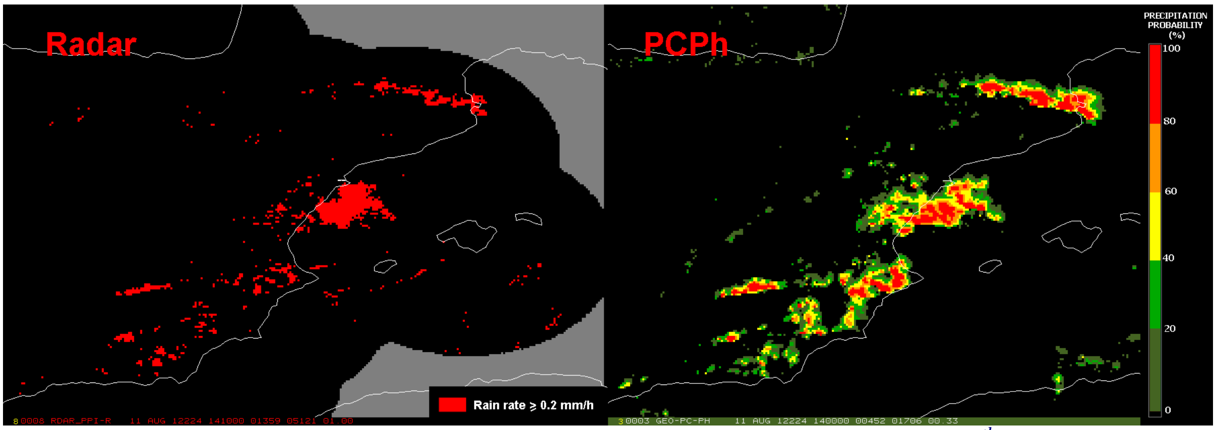

Figure 24. Visual comparison between radar (PPI) and PC-Ph product on 11th August 2012 at 14:00UTC over Spain

Figure 22, Figure 23 and Figure 24 show a visual comparison between radar and PC-Ph product over Spain. It can be seen that the area with a PoP higher than 80% (red pixels) assigned by the PC-Ph 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.
Analysing images in depth it can be observed that sometimes the red area computed by PC-Ph is a bit greater than the one detected by radar (indicated by blue arrows). This can be observed in Figure 25, which is a zoom of Figure 22. In this case PC-Ph product provides false alarms.

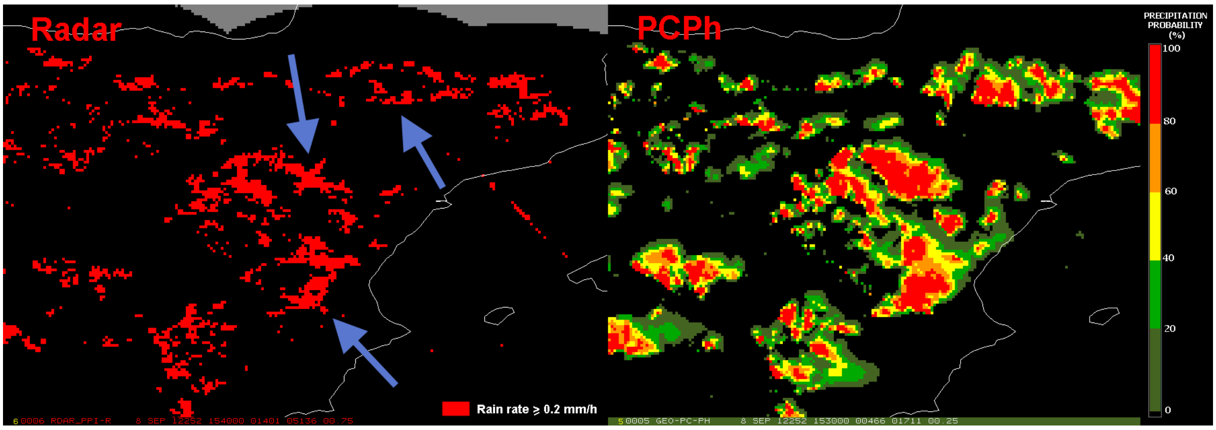

Figure 25. Zoom of Figure1 over a specific area where PC-Ph product provides false alarms

Other times the red area computed by PC-Ph is not as extensive as the radar rainy area. This can be observed in Figure 26, which is also a zoom of Figure 22 (indicated by blue arrows in radar image). This time, although the red area computed by PC-Ph does not cover the total rainy area, PC-Ph assigns pixels with probabilities of precipitation higher than 0 % that cover the total rainy areas in agreement with the radar.

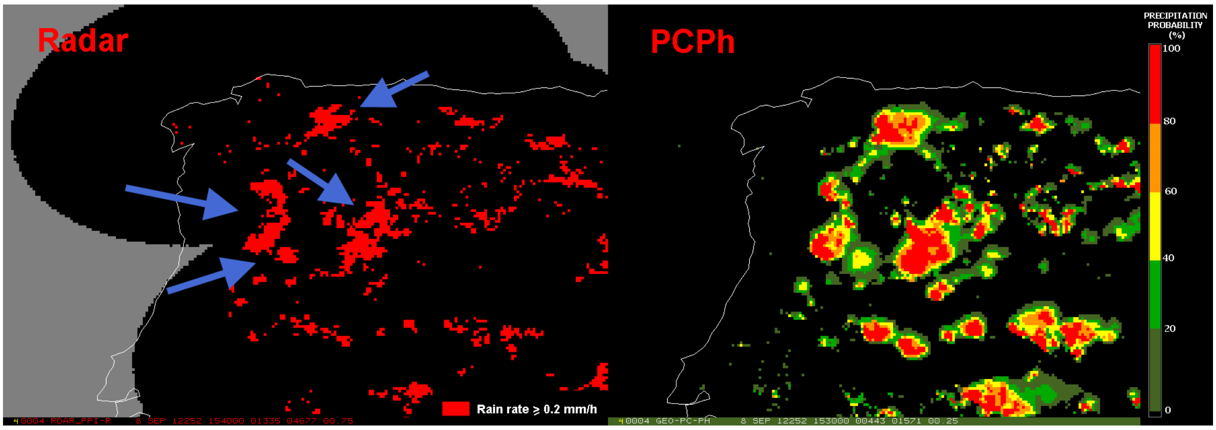

Figure 26. Zoom of Figure1 over a specific area where the PoP greater or equal 80% provided by PC-Ph in not extensive enough

4.2 OBJECTIVE VALIDATION FOR PRECIPITATING CLOUDS FROM CLOUD PHYSICAL PROPERTIES (PC-PH)

4.2.1 Validation Procedure

An objective validation for PC-Ph 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 PC-Ph algorithm have been computed only for sun zenith angles lower than 70º, this validation has been done under this condition.

The PC-Ph product assigns NO DATA value to those pixels with undefined phase according to the phase output of the CMIC product, which means that no information on whether the cloud consists of water or ice is available. Those pixels have been excluded in the 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. Parallax correction has been applied to the PC-Ph 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 (Vicente et al., 1998). 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 (see Table 29 in ANNEX 1: STATISTICAL PARAMETERS section) 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 PC-Ph 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 PC-Ph 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 PC-Ph and radar scenes is choosing 0 and 30 minutes PC-

Ph images corresponding to 10 and 40 minutes radar images respectively. As 15 and 45 minutes PC-Ph 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.

4.2.2 Probability of precipitation intervals validation:

Five probability of precipitation intervals have been validated:

- 0-20%: 0% < PoP ≤ 20%
- 20-40%: 20% < PoP ≤ 40%
- 40-60%: 40% < PoP ≤ 60%
- 60-80%: 60% < PoP ≤ 80%
- 80-100%: 80% < PoP ≤ 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-B ≤ FAR < 100-A. For a better understanding of this, see Figure 27. Lets imagine a precipitation probability pattern estimated like the one in the left part of the image. And imagine that the 25-35% probability interval is going to be validated. In this case only the green area in the center part of the image would be taken into account for validation, for both observation and estimation. In this case, the entire green area would be a rainy area according to the estimation, and so, a probability of detection of 100% would be assigned to this area. This assumption is represented at the right part of the image. To check whether this area has in effect a 25-35% precipitation probability, attention should be focused on false alarms. So, if the precipitation probability is 25-35%, then, false alarm ratio should be 65-75%.

Figure 27. Drawing example of probability of precipitation intervals validation

The categorical scores obtained are showed in Table 14.

Probability interval (%)	N	FAR (%)
0-20	1613571	93,05
20-40	702028	81,05
40-60	453418	62,70
60-80	255794	39,53

80-100	**144543**	**23,05**

Table 14. Categorical scores for PC-Ph algorithm probability of precipitation intervals

It can be observed that PC-Ph algorithm provide a FAR score within the expected interval at every interval except for the 80-100 PoP one, which gets a FAR value a bit higher than expected.

4.2.3 Probability of precipitation thresholds validation:

Five probability of precipitation thresholds have been validated. These thresholds are: 20%, 40%, 60% and 80% probability of precipitation. 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 4]*, 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 (%)
4319189	**63,49**	**81,61**	**33,74**	**74,17**

Table 15. Categorical scores for PC-Ph algorithm taking as rainy pixels those with probability of precipitation higher than 20%

- 30% probability of precipitation threshold:

N	FAR (%)	POD (%)	CSI (%)	PC (%)
4319189	**56,55**	**72,68**	**37,35**	**80,36**

Table 16. Categorical scores for PC-Ph algorithm taking as rainy pixels those with probability of precipitation higher than 30%

Green colour values in Table 16 mean that FAR or POD values obtained in that validation fulfil the FAR and POD target values defined in the NWCSAF Product Requirement document *[AD 4]*.

- 40% probability of precipitation threshold:

N	FAR (%)	POD (%)	CSI (%)	PC (%)
4319189	**49,05**	**62,5**	**39,02**	**84,26**

Table 17. Categorical scores for PC-Ph algorithm taking as rainy pixels those with probability of precipitation higher than 40%

- 60% probability of precipitation threshold:

N	FAR (%)	POD (%)	CSI (%)	PC (%)
4319189	**33,58**	**38,2**	**32,02**	**86,93**

Table 18. Categorical scores for PC-Ph algorithm taking as rainy pixels those with probability of precipitation higher than 60%

- 80% probability of precipitation threshold:

N	FAR (%)	POD (%)	CSI (%)	PC (%)
4319189	23,05	15,98	15,25	85,69

Table 19. Categorical scores for PC-Ph algorithm taking as rainy pixels those with probability of precipitation higher than 80%

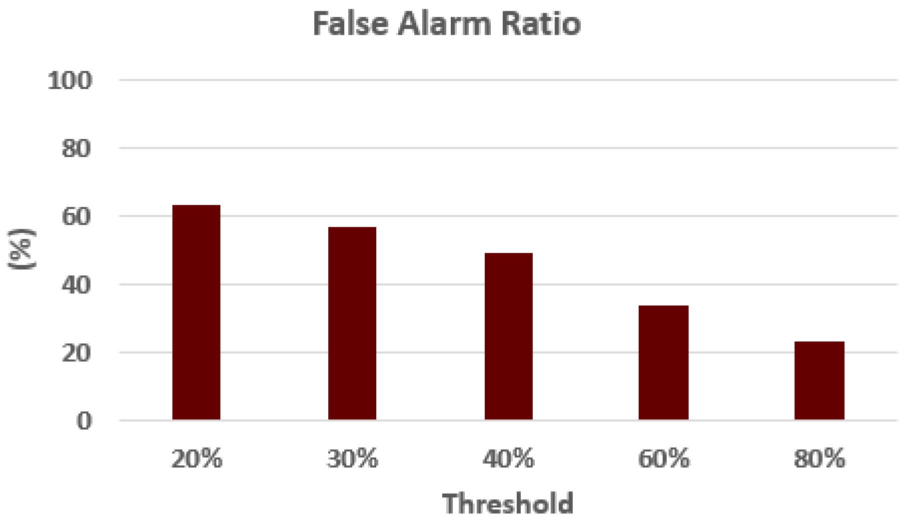

Figure 28. FAR for PC-Ph thresholds

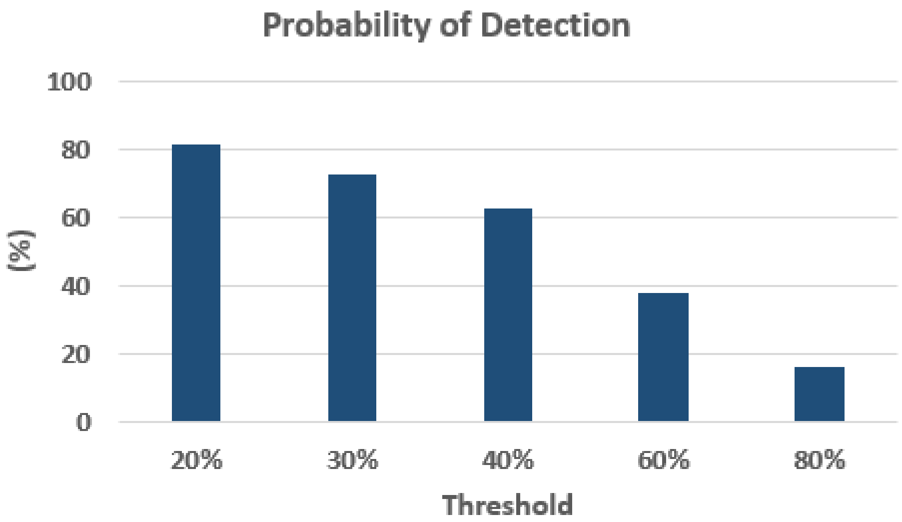

Figure 29. POD for PC-Ph thresholds

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 reliable way. On the other hand PoP higher than 20% obtained a probability of detection of almost 82% in this validation. This means that precipitation is well detected by the algorithm. False alarm ratio provided by 20% PoP threshold is about 63%, which is not too high. This shows that, overall, PC-Ph 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 4]* are referred to a probability threshold of 30%. Table 16 shows that both POD and FAR values for PC-Ph product fulfil the target requirements.

4.2.4 Conclusion

PC-Ph product provides a good depiction of the precipitation areas. The probability of precipitation intervals validation showed that the algorithm provide a FAR score within the expected interval at every interval except for the 80-100 PoP one, which gets a FAR value a bit higher than expected. This means that PC-Ph assigns well the PoPs most of the times. On the other hand probability of precipitation thresholds validation showed that 20% PoP threshold obtain a POD score higher than 80% while a FAR lower than 65%. This means that all PoP intervals should be taken into account for the Nowcasting tasks. Also, both POD and FAR scores at 30% PoP threshold fulfil the FAR and POD target values defined in the NWCSAF Product Requirement document *[AD 4]* as shown in Table 20.

Algorithm	Threshold Accuracy	Target Accuracy	Optimal Accuracy	PC-Ph
POD (%)	>55	>65	>80	72.68
FAR (%)	<70	<65	<50	56.55

Table 20. Comparison of scores provided by PC-Ph for 30% PoP threshold and accuracy values defined in the NWCSAF Product Requirement table

5. VALIDATION FOR CONVECTIVE RAINFALL RATE FROM CLOUD PHYSICAL PROPERTIES PRODUCT

This section contains the results obtained from the validation of the CRR-Ph product which is described in the Algorithm Theoretical Basis Document for the Precipitation Product Processors of the NWC/GEO *[RD 4]*.

5.1 SUBJECTIVE VALIDATION FOR CONVECTIVE RAINFALL RATE FROM CLOUD PHYSICAL PROPERTIES (CRR-PH)

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 CRR-Ph 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.

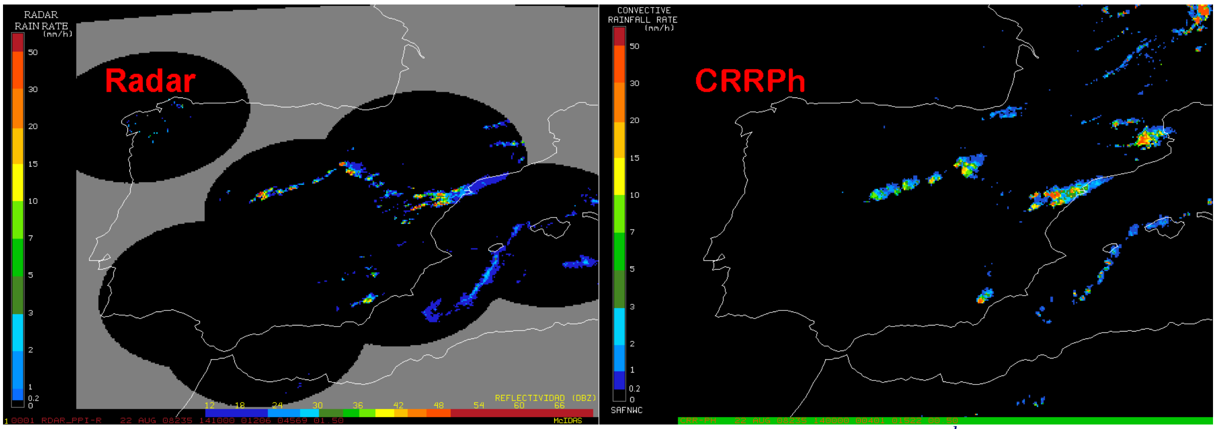

Figure 30. Visual comparison between radar (PPI) and CRR-Ph on 22nd August 2008 at 14:00UTC

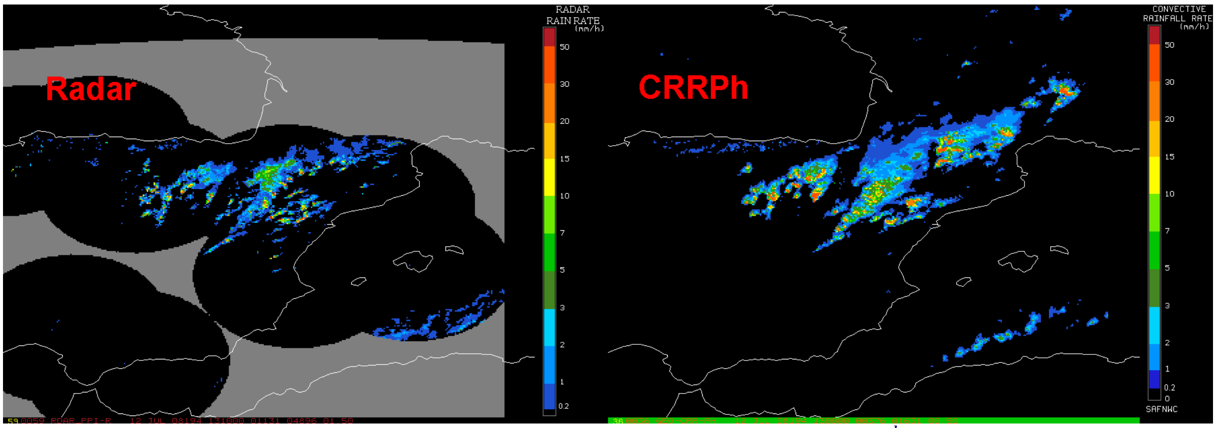

Figure 31. Visual comparison between radar (PPI) and CRR-Ph on 12th July 2008 at 13:00UTC

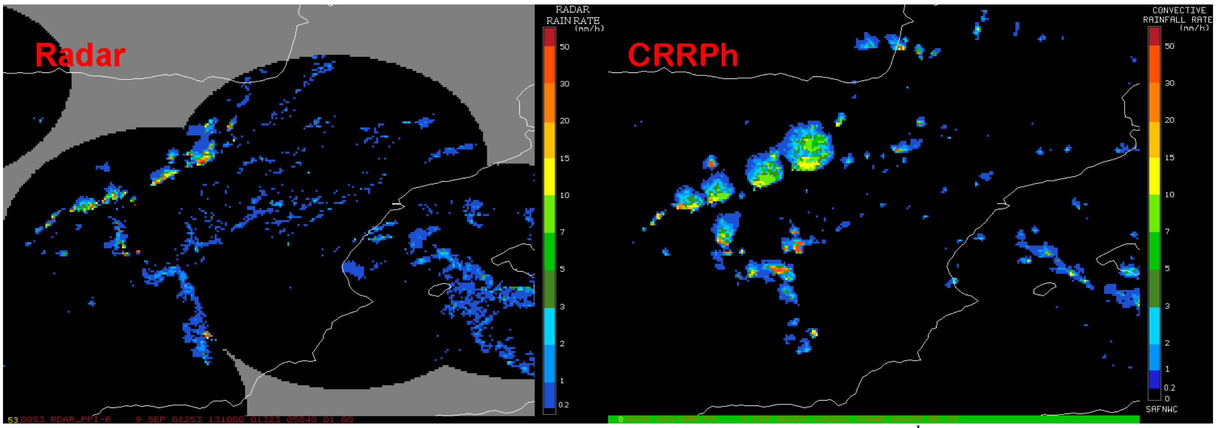

Figure 32. Visual comparison between radar (PPI) and CRR-Ph on 9th September 2008 at 13:00UTC

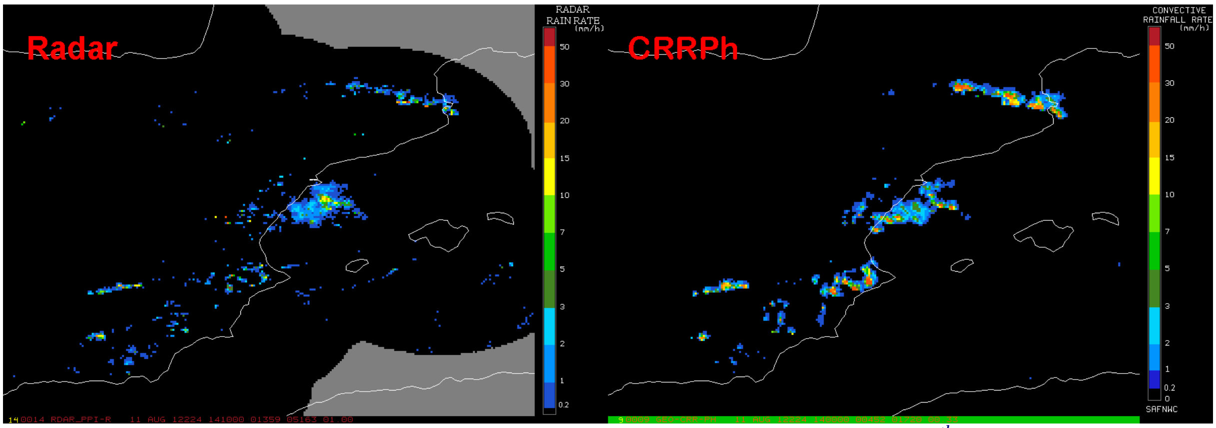

Figure 33. Visual comparison between radar (PPI) and CRR-Ph on 11th August 2012 at 14:00UTC

Figure 30 and Figure 31 show that PC-Ph product provides precipitation areas as well as precipitation intensities close to the radar ones. Figure 32 and Figure 33 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 CRR-Ph can be overestimated. Figure 34 shows a sequence of radar, CRR-Ph and CRRPh_IQF images that correspond to the same day with one-hour time interval to illustrate this fact. CRRPh_IQF is an illumination quality flag that provides information on how reliable the estimated CRRPh rain intensities can be due to good or poor illumination conditions. The higher values takes CRRPh_IQF, the better are the illumination conditions and so, the more reliable are the estimated rain rates. It can be observed that under good illumination conditions both precipitation area and rain rates assigned by CRR-Ph are similar to the radar ones, but when illumination conditions get worse, CRR-Ph overestimates rain rates while precipitation area remains well detected in agreement with the radar.

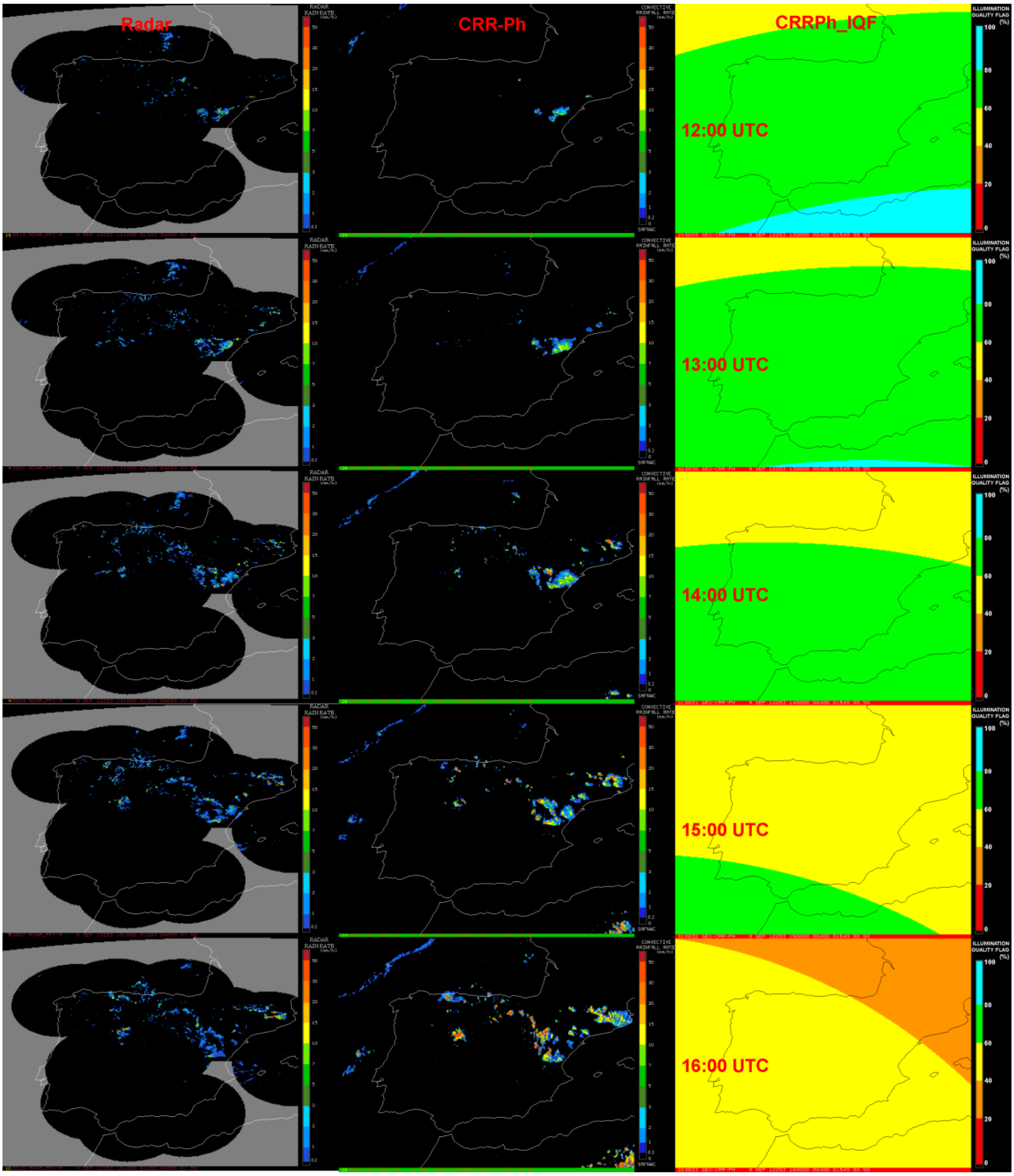

Figure 34. Sequence of radar, CRR-Ph and CRRPh_IQF images with one-hour time interval that shows the quality degradation of CRR-Ph with poor illumination conditions

5.2 OBJECTIVE VALIDATION FOR CONVECTIVE RAINFALL RATE FROM CLOUD PHYSICAL PROPERTIES (CRR-PH)

5.2.1 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 (Vicente et al., 1998). 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 CRR-Ph 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 CRR-Ph 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 CRR-Ph values have been obtained applying parallax correction *[RD 4]*. 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 CMIC for undefined Phase pixels, those cases have been excluded from validation.

CRR-Ph product includes the CRRPh_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 *[RD 4]*.

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

5.2.2 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)
CRRPh_IQF ≥ 0 %	1040899	0,63	0,68	1,42	4,07
CRRPh_IQF ≥ 20 %	907870	0,60	0,90	1,52	4,29
CRRPh_IQF ≥ 40 %	712360	0,58	1,11	1,57	4,40
CRRPh_IQF ≥ 60 %	378767	0,56	0,57	1,04	3,18
CRRPh_IQF ≥ 80 %	43791	0,63	0,16	0,73	2,09

Table 21. Accuracy measurements for instantaneous rates. Comparison among CRR-Ph product using different CRRPh_IQF thresholds.

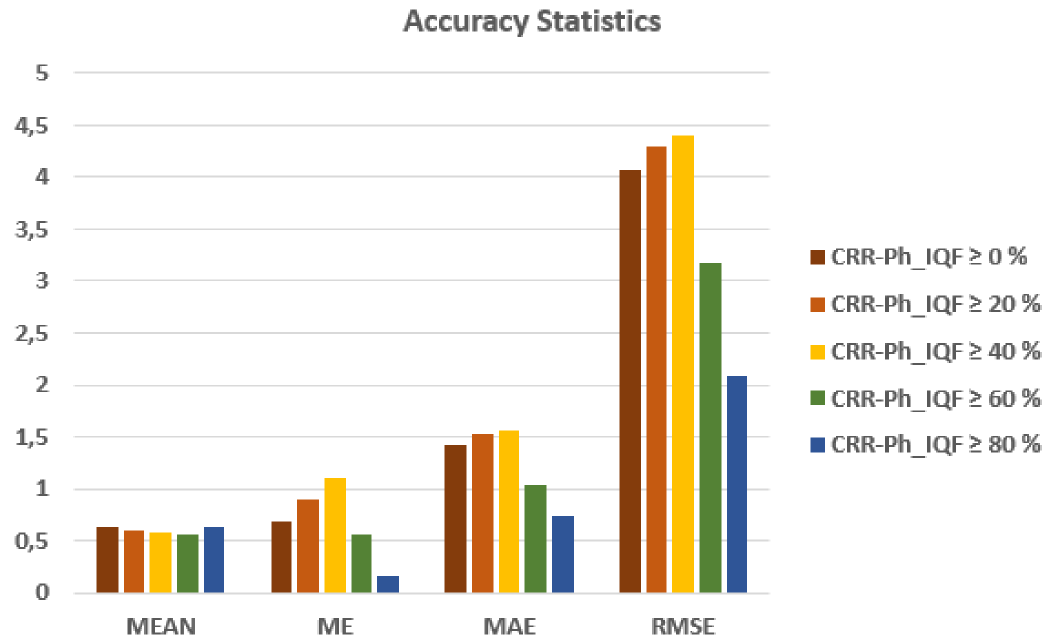

Figure 35. Accuracy measurements for instantaneous rates. Comparison among CRR-Ph product using different CRRPh_IQF thresholds.

Higher MAE and RMSE values are obtained when illumination conditions are poor. This confirms the overestimation of rain rates in these cases.

The following table summarizes the results obtained for categorical scores:

Algorithm	FAR (%)	POD (%)	CSI (%)	PC (%)
CRRPh_IQF ≥ 0 %	43,09	54,89	38,78	67,58
CRRPh_IQF ≥ 20 %	43,09	64,03	43,12	68,95
CRRPh_IQF ≥ 40 %	42,14	77,44	49,52	71,27
CRRPh_IQF ≥ 60 %	39,30	76,55	51,18	73,58
CRRPh_IQF ≥ 80 %	32,55	78,29	56,82	76,57

Table 22: Categorical scores for instantaneous rates. Comparison among CRR-Ph product using different CRRPh_IQF thresholds.

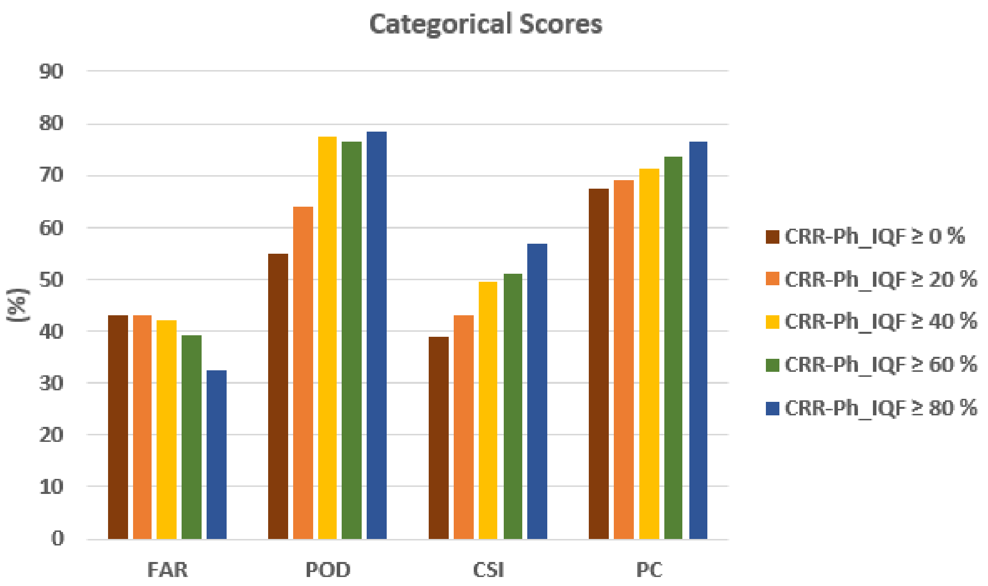

Figure 36. Categorical scores for instantaneous rates. Comparison among CRR-Ph product using different CRRPh_IQF thresholds.

The better are the illumination conditions the better are the scores obtained reaching high differences between FAR and POD for the best illumination conditions.

5.2.3 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)
CRRPh_IQF ≥ 0 %	590338	0,39	0,5	0,9	2,43
CRRPh_IQF ≥ 20 %	495037	0,37	0,69	0,97	2,58
CRRPh_IQF ≥ 40 %	363079	0,35	0,65	0,87	2,4
CRRPh_IQF ≥ 60 %	193933	0,34	0,38	0,61	1,77
CRRPh_IQF ≥ 80 %	23176	0,38	0,26	0,52	1,36

Table 23. Accuracy measurements for hourly accumulations. Comparison among CRR-Ph product using different CRRPh_IQF thresholds.

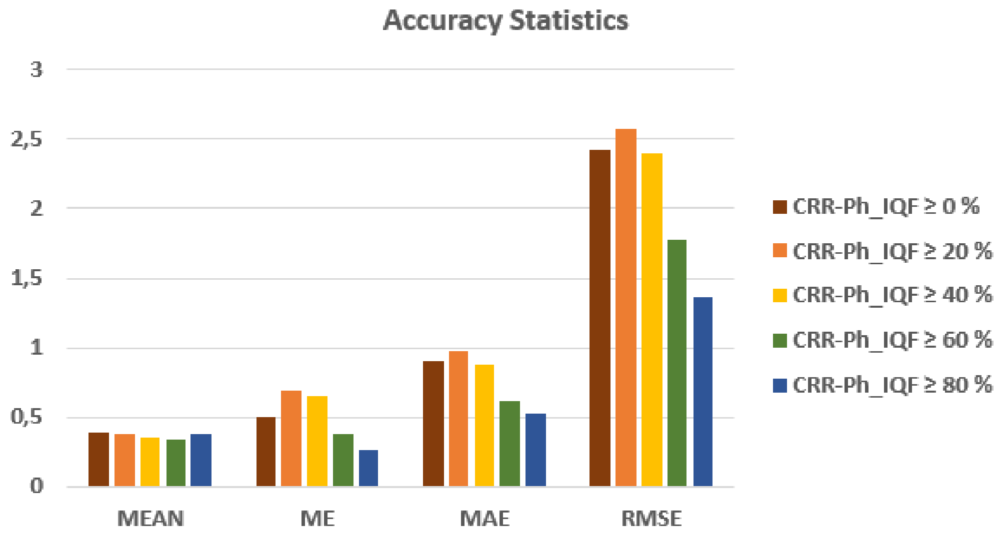

Figure 37. Accuracy measurements for hourly accumulations. Comparison among CRR-Ph product using different CRRPh_IQF thresholds.

The following table summarizes the results obtained for categorical scores:

Algorithm	FAR (%)	POD (%)	CSI (%)	PC (%)
CRRPh_IQF ≥ 0 %	50,20	58,26	36,70	71,90
CRRPh_IQF ≥ 20 %	50,24	72,25	41,78	72,99
CRRPh_IQF ≥ 40 %	49,09	77,25	44,28	74,51
CRRPh_IQF ≥ 60 %	47,03	76,08	45,41	76,34
CRRPh_IQF ≥ 80 %	43,84	79,66	49,11	76,83

Table 24: Categorical scores for hourly accumulations. Comparison among CRR-Ph product using different CRRPh_IQF thresholds.

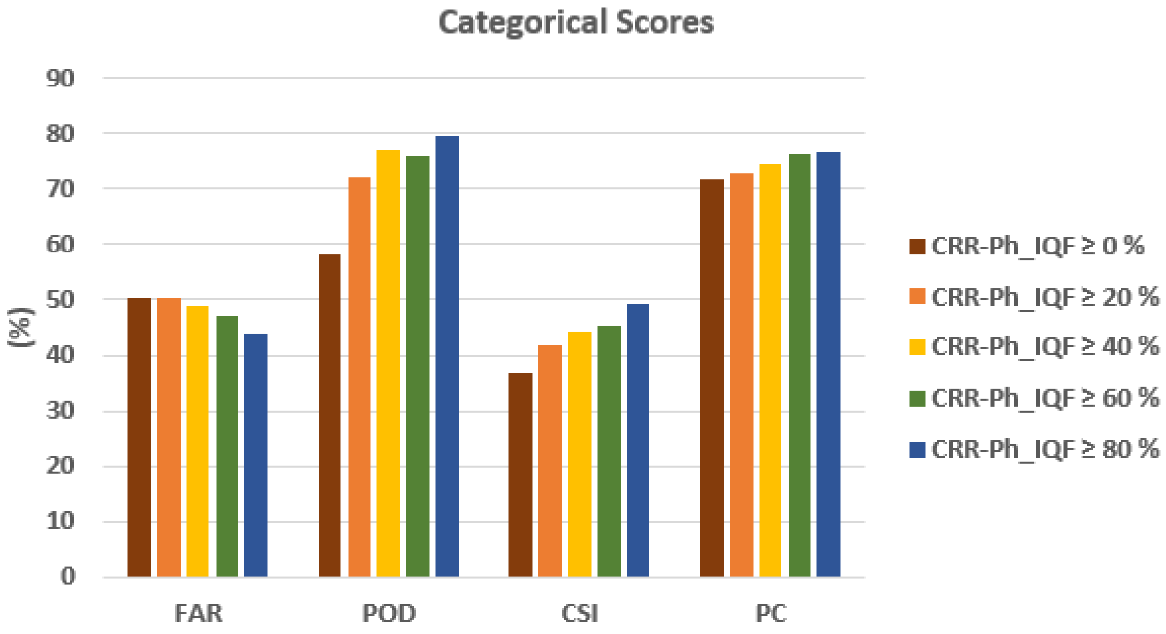

Figure 38. Categorical scores for hourly accumulations. Comparison among CRR-Ph product using different CRRPh_IQF thresholds.

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

5.2.4 Conclusion

A comparison of results obtained for CRR-Ph instantaneous rain rates validation and accuracy values defined in the NWCSAF Product Requirement document *[AD 4]* is shown in Table 25 and Table 26.

Algorithm	Threshold Accuracy FAR (%)	Target Accuracy FAR (%)	Optimal Accuracy FAR (%)	FAR (%)
CRRPh_IQF ≥ 0 %	<50,0	<35,0	<30,0	43,09
CRRPh_IQF ≥ 20 %	<50,0	<35,0	<30,0	43,09
CRRPh_IQF ≥ 40 %	<50,0	<35,0	<30,0	42,14
CRRPh_IQF ≥ 60 %	<50,0	<35,0	<30,0	39,30
CRRPh_IQF ≥ 80 %	<50,0	<35,0	<30,0	32,55

Table 25. Comparison of CRR-Ph instantaneous rain rates FAR scores and FAR accuracy values defined in the NWCSAF Product Requirement table

Algorithm	Threshold Accuracy POD (%)	Target Accuracy POD (%)	Optimal Accuracy POD (%)	POD (%)
CRRPh_IQF ≥ 0 %	>50,0	>75,0	>90,0	54,89
CRRPh_IQF ≥ 20 %	>50,0	>75,0	>90,0	64,03
CRRPh_IQF ≥ 40 %	>50,0	>75,0	>90,0	77,44
CRRPh_IQF ≥ 60 %	>50,0	>75,0	>90,0	76,55
CRRPh_IQF ≥ 80 %	>50,0	>75,0	>90,0	78,29

Table 26. Comparison of CRR-Ph instantaneous rain rates POD scores and POD accuracy values defined in the NWCSAF Product Requirement table

Green colour values in Table 25 and Table 26 mean that FAR or POD values obtained in this validation fulfil the FAR and POD target values defined in the NWCSAF Product Requirement document *[AD 4]*, while red colour values mean that target values are not accomplished.

Both for FAR and POD, threshold accuracy is always reached. Target accuracy is fulfilled only when the illumination conditions are good enough. FAR target accuracy is reached only for CRRPh_IQF thresholds higher than 80% while POD target accuracy is reached for CRRPh_IQF thresholds higher than 40%.

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 CRRPh_IQF), CRR-Ph rain rates are overestimated leading in to a rise of the accuracy measurements. However, differences between categorical scores for different CRRPh_IQF thresholds, are smaller. This means that although illumination conditions affect the rain rates assigned, the rainy areas detected are less affected by this fact. These results are in agreement with conclusions drawn from the subjective validation (section 5.1).

A comparison of results obtained for CRR-Ph hourly accumulations validation and accuracy values defined in the NWCSAF Product Requirement document *[AD 4]* is shown in Table 27 and Table 28.

Algorithm	Threshold Accuracy FAR (%)	Target Accuracy FAR (%)	Optimal Accuracy FAR (%)	FAR (%)
CRRPh_IQF ≥ 0 %	<60,0	<55,0	<45,0	50,20
CRRPh_IQF ≥ 20 %	<60,0	<55,0	<45,0	50,24
CRRPh_IQF ≥ 40 %	<60,0	<55,0	<45,0	49,09
CRRPh_IQF ≥ 60 %	<60,0	<55,0	<45,0	47,03
CRRPh_IQF ≥ 80 %	<60,0	<55,0	<45,0	43,84

Table 27. Comparison of CRR-Ph hourly accumulations FAR scores and FAR accuracy values defined in the NWCSAF Product Requirement table

Algorithm	Threshold Accuracy POD (%)	Target Accuracy POD (%)	Optimal Accuracy POD (%)	POD (%)
CRRPh_IQF ≥ 0 %	>60,0	>80,0	>95,0	58,26
CRRPh_IQF ≥ 20 %	>60,0	>80,0	>95,0	72,25
CRRPh_IQF ≥ 40 %	>60,0	>80,0	>95,0	77,25
CRRPh_IQF ≥ 60 %	>60,0	>80,0	>95,0	76,08
CRRPh_IQF ≥ 80 %	>60,0	>80,0	>95,0	79,66

Table 28. Comparison of CRR-Ph hourly accumulations POD scores and POD accuracy values defined in the NWCSAF Product Requirement table

Green colour values in Table 27 and Table 28 mean that FAR or POD values obtained in this validation fulfil the FAR and POD target values defined in the NWCSAF Product Requirement document *[AD 4]*, while red colour values mean that target values are not accomplished.

Both for FAR and POD, threshold accuracy is always reached. FAR target accuracy is always reached while POD target accuracy is almost fulfilled.

While target values defined in the NWCSAF Product Requirement document *[AD 4]* are accomplished for CRR-Ph instantaneous intensities when illumination conditions are good enough, in the case of CRR-Ph hourly accumulations this is not the case. FAR values computed for hourly accumulations fulfil the target values but POD do not, although for the best illumination conditions the POD value almost reaches the target value. According to the numerical results obtained in the objective validation, CRR-Ph almost always fulfil target accuracy thresholds. And according to the results obtained from the subjective validation, CRR-Ph provides useful information to the forecasters, very similar to the one provided by the radar, when illumination conditions are good enough.

6. ANNEX 1: STATISTICAL PARAMETERS

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.

Categorical Statistics

The following scores derived from Table 29, 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 (CRR)	
		occurred[1]	no occurred
Observed (Radar)	occurred*	hits	misses
	no occurred	false alarms	correct negatives

Table 29. 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.*

7. REFERENCES

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.