22B.5 LONG-TERM ASSESSMENT OF THE DPR RAINFALL PRODUCTS IN THE MEDITERRANEAN AREA ACCORDING TO THE H-SAF VALIDATION PROTOCOL

Marco Petracca*, Silvia Puca, Stefano Sebastianelli, Gianfranco Vulpiani
Department of Civil Protection, Presidency of the Council of Ministers, Rome, Italy

1.INTRODUCTION

Global Precipitation Measurement (GPM) mission provides numerous precipitation products using different sensors' combination. The Dual-frequency Precipitation Radar (DPR) plays a key role in the mission, serving as main calibration instrument and space reference for different precipitation algorithms (Neeck et al. 2014). DPR provides three algorithms (KuPR, KaPR and dual-frequency algorithm) to estimate precipitation rates. Within the scientific collaboration between EUMETSAT Satellite Application Facility on Support to Operational Hydrology and Water Management (H-SAF) and GPM established from 2014, DPR rainfall products are compared with ground radars in a complex terrain such as Italy, over an 18 months' time interval. The results are analyzed to define potentialities and restrictions in the use of DPR products as reference for the comparison of the H-SAF precipitation products over the MSG full disk area. The main goal of this study is to assess the overall performances of the DPR products applying the H-SAF validation methodology (Puca et al. 2014). The description of ground radar data and satellite products used are presented in Section 2. The overall results are shown in Section 3. A deep study of possible error sources is reported in Section 4. Results are shown in Section 5, while the conclusions are summarized in Section 6.

2. DATA USED

The GPM Level-2A precipitation products over the Italian peninsula collected during a period of 18 months (from 1st July 2015 to 31st December 2016) have been analyzed in comparison with ground estimates from radar network, as delivered by the Italian Department of Civil Protection (DPC). Only the liquid precipitation phase over land areas have been considered, applying the flags provided in the GPM precipitation products.

2.1 DPR PRODUCTS

The version V04A of 2A-DPR and Ka/Ku Level-2A products have been used in this analysis. In particular, we considered the precipRateNearSurface (prNs) and precipRateESurface (prEs) variables: the first one refers to the rain estimation at the first DPR bin free from ground clutter, the second one estimates the precipitation rate at surface.

2.2 RADAR DATA

The operational mosaic, with a time resolution of 10 minutes over a regular spatial grid 1 km x 1km as well delivered by the DPC has been used as ground reference in this study. The network, managed by 11 administrations, is composed by 20 C-band and 2 X-band radars, as depicted on Figure 1.

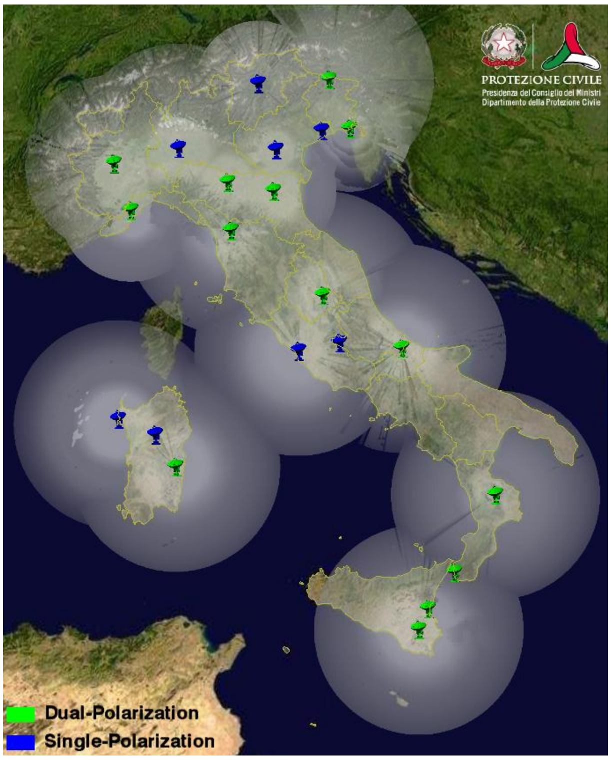

Figure 1: Map showing the distribution over the Italian territory of single- and dual-polarization operational radar systems.

The operational radar processing chain (Vulpiani et al. 2014) aims at identifying most of the uncertainty sources affecting the rainfall estimation process (Friedrich et al. 2006). The following error sources are considered: contamination by non-weather returns (clutter), Partial Beam Blocking (PBB), beam broadening at increasing distances, vertical variability of precipitation (Joss and Lee 1995; Germann and Joss 2002; Marzano et al. 2004); and rain path attenuation (Carey et al. 2000; Testud et al. 2000; Bringi and Chandrasekar 2001; Vulpiani et al. 2008). Every error source is quantified to obtain the overall data quality index (RQI) as described in Rinollo et al. (2013).
Only radar data with high RQI (over 0.60) were considered in this study.

3. COMPARISON RESULTS

The performance of satellite products is evaluated by considering two groups of statistical scores: continuous and multi-categorical ones. Belong to the first group: Mean

* *Corresponding author address:* Marco Petracca,
Department of Civil Protection, Presidency of the Council of Ministers, Rome, Italy; e-mail: Marco.Petracca@protezionecivile.it

Error (ME), Root Mean Square Error (RMSE), Fractional Standard Error (FSE, defined as the ratio between the RMSE and the average of the ground observation rate) and the Pearson Correlation Coefficient (CC). Probability of Detection (POD), False Alarm Rate (FAR) and Missing rate (MISS) belong to the second group.
The satellite product and ground reference data have been spatially and temporally matched to perform the comparison. Since the higher spatial resolution of radar product with respect to the DPR IFOV, the ground data within the DPR IFOV have been averaged (up-scaled). The spatial closest radar (averaged) pixel to the DPR IFOV, as well as the time closest ground acquisition to the GPM passage has been considered.
A first comparison between the prEs and prNs DPR output variables has been carried out. As shown in Figure 2, the differences are minimal for all the scan types considered, with prEs reporting lower rainrates with respect to prNs. Given the negligible difference, we decided to carry on the analysis on the prEs values for all scan types and products considered, with a total of six products (three from DPR and three from Ka/Ku-only band algorithm).

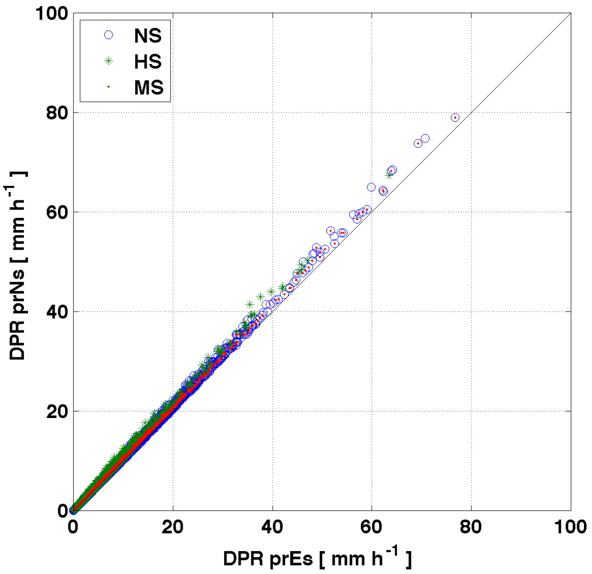

Figure 2: Scatterplot between DPR prNs and prEs output variables for all three scans (NS, MS and HS).

Comparison results for the six satellite products selected respect to the up-scaled radar data are reported in Table 1. The best (worst) score for each indicator is bolded in green (red). Combined products (on top for each cell) generally show better performance with respect to single-band products (on bottom for each cell), indicating that the synergy between the two frequencies increases the overall quality.

Product	DPR Ku	DPR Ka	DPR Ka
Scan	NS	MS	HS
N of points	19,597 19,305	11,096 11,115	9,271 10,088
ME (mm h^{-1})	0.32 **1.07**	**0.13** -0.39	-0.69 -0.50
RMSE (mm h^{-1})	**4.50** **6.44**	4.80 5.57	5.02 5.23
CC	**0.41** 0.35	0.40 **0.21**	0.27 0.23
FSE (%)	**159** **228**	166 186	165 173
POD (%)	**93** **93**	**92** **93**	**92** **93**
FAR (%)	6 6	6 **8**	**3** 4
MISS (%)	**7** **7**	**8** **7**	**8** **7**

Table 1: Statistical indicators for the whole dataset. For each cell, the top and bottom values are refered to DPR and Ka/Ku-only band product, respectively. Bold numbers indicate the best score (in green) and the worst (in red) for each indicator.

Considering the best GPM radar products, as derived above, we investigate the impact of rainrate intensity (RR) considering four precipitation classes defined as:

- "all" for RR ≥ 0.5 mm h^{-1};
- "light" for 0.5 mm h^{-1} ≤ RR < 1.0 mm h^{-1};
- "moderate" for 1.0 mm h^{-1} ≤ RR < 10.0 mm h^{-1}
- and "heavy" for RR ≥ 10.0 mm h^{-1}.

In table 2 are reported the values obtained according to the rainfall intensity classes. In each cell we reported three lines referring from top to bottom to NS, MS and HS DPR performances, respectively. Best score for each cell is bolded in green. For light precipitation, the HS product outperforms the NS and MS products in terms of ME, RMSE and FSE. For the moderate and the heavy class, HS underestimates the precipitation indicating its high sensitivity to lower rainrates but it is less able to detect higher rainrates. In these classes, the DPR-NS outperforms the other products for all indicators considered.

Product	DPR NS/MS/HS		
Rainrate class	light	moderate	heavy
N of points	5,543 3,118 2,368	13,320 7,585 6,549	734 393 354
ME (mm h^{-1})	0.89 0.90 **0.51**	0.54 **0.30** -0.41	**-7.96** -9.15 -13.88
RMSE (mm h^{-1})	2.36 2.37 **1.88**	3.86 3.84 **3.43**	**15.13** 17.88 20.49

CC	**0.08** 0.09 0.08	**0.35** 0.33 0.27	**0.18** 0.15 0.08
FSE (%)	320 323 **255**	133 132 **114**	**86** 92 106
POD (%)	**93** 92 92	**80** 79 74	**31** **31** 9
FAR (%)	6 6 **3**	22 22 **18**	78 **75** 85
MISS (%)	**7** 8 8	**20** 21 26	**69** **69** 91

Table 2: Statistical indicators for the three classes of rainfall intensity (light, moderate and heavy) computed with respect to ground radar dataset. For each cell, three values are reported for DPR NS, MS and HS from top down. Bold numbers indicate the best value for each cell.

4. OUTLIERS' ANALYSIS

A deeper analysis was carried out to investigate the main causes of the largest discrepancies between DPR products and ground radar reference, focusing the attention on marked over and under-estimation of the satellite products. We defined as outliers the samples with largest errors, namely where the DPR (radar) RR≥ 10 mm h-1 and the ratio between DPR RR and radar RR is at least 4 (1/4). We labeled as DPRout the outliers with a DPR overestimate, while those whit DPR underestimate as RADARout. We also considered a benchmark set (BS) composed by couples where the estimation is very close to the reference value and their normalized absolute differences does not exceed the 5%. We considered three features of the matched DPR-radar pair that are expected to impact on the discrepancies, that are: time difference between the radar and DPR observations (TD), rainfall pattern variability of radar (RV) (computed as the standard deviation of all radar data) within the IFOV and radar quality index (RQI). In table 3 are reported the number of samples (and the percentage of total outliers with respect to the total number of samples) for the three categories (BS, RADARout and DPRout) for the three DPR products. The prevalence of RADARout respect to DPRout only for the HS product provides a signal of attenuation for higher rainrates, resulting in a marked underestimation.

	DPR-NS	DPR-MS	DPR-HS
BS	954	521	425
RADARout	144	90	167
DPRout	393	186	99
OUTs %	36%	35%	38%

Table 3: Number BS, RADARout and DPRout samples for the different DPR scans in comparison with radar data. Percentage of total outlier samples for each product is also reported.

Figures 3-5 show the distribution of the three categories with respect to the individuated features. The number of samples for each category is reported on the left-axis. The percentage of total outliers for each class is also shown in transparent color bars with relative values on the right-axis.

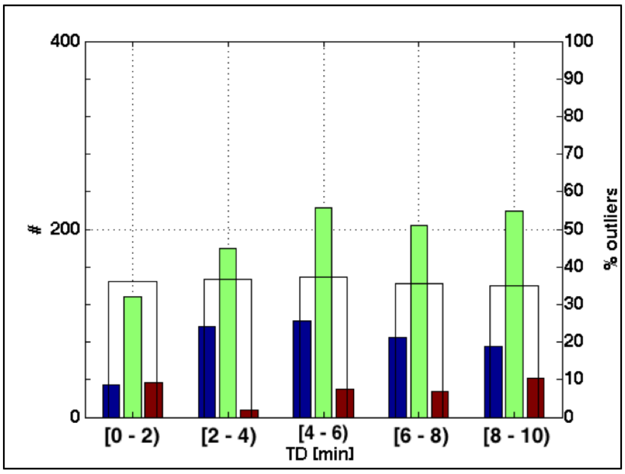

Figure 3: Distribution of DPRout (blu bars), BS (green bars) and RADARout (red bars) samples with respect to Time Difference (TD). The total occurrence of samples for each interval considered is reported on the left y-axis, while the relative percentage of outliers for each interval (transparent bars) is reported on the right y-axis.

Figure 3 shows the category distribution respect to the TD. The percentage of total outliers is equally distributed indicating the absence by varying the TD of any significative impact on the validation results.

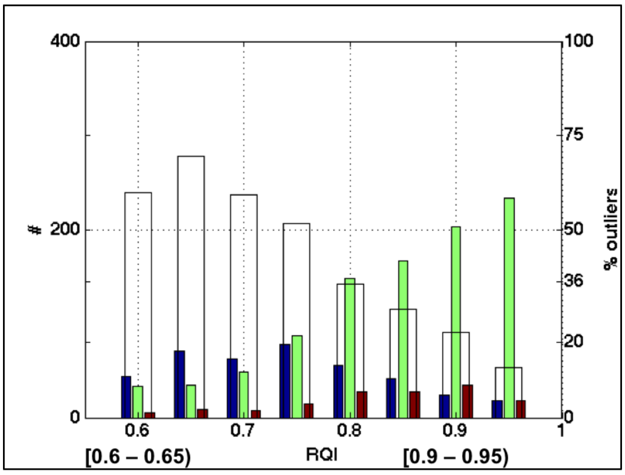

Figure 4: Distribution as in Figure 3, respect to Radar Quality Index (RQI).

The distribution with respect the RQI threshold is presented in Figure 4. The BS number increases steadily improving the RQI values. The percentage of total outliers decreases for higher RQI thresholds up to only 10% for RQI greater than 0.95.

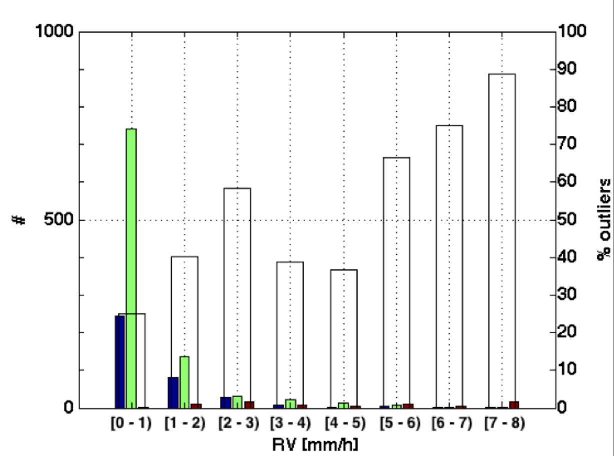

Figure 5: Distribution as in Figure 3, respect to Rainfall Variability (RV).

Low rainfall rate spatial variability favors the occurrence of BS as shown in Figure 5. For RV lesser than 5 mm h^{-1} the BS number prevails.

5. RESULTS

The outliers'analysis proved a clear signal in terms of RQI and RV. In order to evaluate at best the performance of the DPR product and, at the same time, maintain a statistically significant reference dataset, we considered the ground radar estimates with up-scaled RQI above 0.8 and RV less than 5 mm h^{-1}. In table 4 we reported the number of BS, RADARout and DPRout samples before and after the RQI and RV filter processing, and the relative percentage variation. The filter processing reduced the dataset of about 31%. It is interesting to note the low percentage of BS samples filtered-out of only 22%.

	DPR-NS	***High-quality dataset***	***Percentage variation***
BS	954	*739*	*-22%*
RADARout	144	*26*	*-82%*
DPRout	393	*134*	*-66%*

Table 4: BS, RADARout and DPRout samples obtained for radar comparison with DPR NS product before and after the high-quality filter processing and the relative percentage variation.

The new statistical scores are shown in Table 5 for the DPR-NS product in comparison with the high-quality radar dataset.

Product	**DPR – NS prEs**	
scan	**Whole-dataset**	**High-quality dataset**
N of points	19,597	13,880
ME (mm h^{-1})	0.32	**0.16**
RMSE (mm h^{-1})	4.50	**2.89**
CC	0.41	**0.52**
FSE (%)	159	**111**
POD (%)	93	93
FAR (%)	6	**1**
MISS (%)	7	7

Table 5: Statistical indicators computed for the whole radar dataset and the high-quality filtered radar dataset in comparison with the DPR NS product. Bold numbers in green color indicate the best score for each indicator.

6. CONCLUSIONS

The GPM Level 2A (Ka/Ku and DPR) estimated surface products are compared with respect to ground radar estimates for an 18 months'period over Italian land for only liquid phase precipitation. The methodology applied is based on the H-SAF protocol that consists to evaluate the satellite product on the itself product grid (pixel-based approach) respect to a ground reference data.

As first comparison, DPR (combined) products generally show better performance with respect to single-band products, confirming the synergy between the two frequencies. Differences between prEs and prNs output variables are negligible. On this basis, the study was carried out on the DPR prEs product for all three scans (NS, MS and HS).

For light precipitation, the HS outperforms NS and MS products, but it tends to underestimate for moderate and heavy intensities. The DPR-NS product evidences similar performances for all different rainfall regimes.

A deeper analysis was carried out to investigate the main causes of the largest discrepancies between DPR-NS product and radar data. BS and outlier samples highlight a marked dependence by RQI and RV values. The high-quality radar dataset, filtered by high RQI and low RV values, show a significant improvement for all statistical scores considered. Comparing DPR-NS with radar data we obtain this score values: ME=0.16 mm h^{-1}, RMSE=2.89 mm h^{-1}, CC=0.52, FSE=111%, POD=93%, MISS=7% and FAR=1%.

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