

EUMETSAT Satellite Application Facility on
Support to Operational Hydrology and Water Management



**Product Validation Report (PVR)
for products P-IN-FCI (H40B)**

**Precipitation rate at ground by MTG FCI IR channel
supported by LEO/MW**

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1 Introduction to the Product Validation Report

The Product Validation Report (PVR) contains all the useful information for users to know about limits and capabilities of the precipitation product. The document collects all the information and results obtained from the Quality and Monitoring Assessment Cluster.

The precipitation product under review, during the analyzes carried out by the cluster, is on “in-development” phase. The objective of this report is to assess the overall quality of the product and if suitable, make it available to end users.

The report is structured as follows:

In **Chapter 2** there is a brief description of the product and the precipitation algorithm retrieval. More details about this can be found on the PUM (Product User Manual) and on the ATBD (Algorithm Theoretical Baseline Document) of the products themselves.

The main part of this document is contained in **Chapter 3** dedicated to the description of the validation results obtained analyses over a long period.

Conclusions are written in **Chapter 4**.

For more information about the analysis, validation, and quality assessment methodology, refer to **Appendix 1**.

Finally, the last **Appendix 2** is dedicated to the list of acronyms used in this document.

For any errors, oversights, or requests for updates or changes, please contact us via H SAF project website: <http://h-saf.eumetsat.int>

2 H40B (P-IN-FCI) product

H40B (P-IN-FCI, precipitation rate at ground by GEO/IR supported by LEO/MW) is based on the IR images from the FCI instrument on-board Meteosat Third Generation (MTG) satellites blended with all the available precipitation MW estimates (PMW).

The spatial coverage of H40B product corresponds to the Meteosat full disk coverage (Figure 1). The product is provided on the MTG FCI grid, at the 10-min imaging rate of FCI, and the spatial resolution is consistent with the FCI pixel (2 km at nadir).

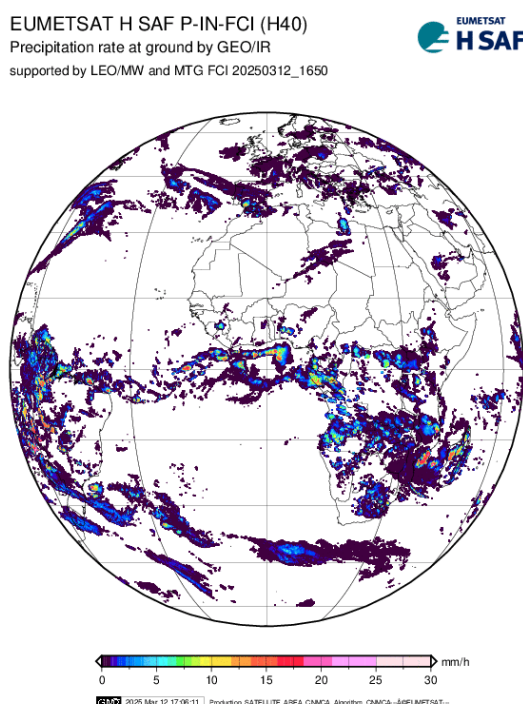


Figure 1: P-IN-FCI product example for the 12 Mar 2025 at 16:30 UTC.

H40B product is provided in NetCDF format (one file per single 10-minute acquisition). It contains x and y dimension and 2 main output variables: rr and $quality$. Geographic latitude and longitude coordinates are not present within the files, but the metadata contain all parameters (projection) to calculate them.

Validation scores have been evaluated, and results are shown in this PVR (Product Validation Report) document.

For more detailed description of the scientific background and theoretical justification for the algorithm used please refer to the Algorithm Theoretical Baseline Document (ATBD).

3 Validation results

3.1 Overview

| | | |
|--------------------------|--|-----|
| Product ID (Acronym) | H40B (P-IN-FCI) | |
| Product name | Precipitation rate at ground by MTG FCI IR channel supported by LEO/MW | |
| Algorithm version number | Latest version: | 1.0 |
| | Version considered for Q.A.: | 1.0 |
| Covered period | 01/01/2025 – 17/03/2025 (2.5 months; 75 days) | |
| Q.A. methods applied | Intercomparison methodology | |

The validation has been performed over the period between January and March 2025. The product release currently in force at the time of writing has been evaluated. The results are showed over the whole domain area (Full Disk) using the intercomparison methodology as described in detail in Appendix A1.3

3.2 Intercomparison results

The instantaneous product based on MTG (H40B) has been compared with its analogous instantaneous product from MSG (H60B) which had previously undergone evaluation and was declared operational product. For detailed results and quality assessment of H60B, please refer to the PVR (Ref. SAF/HSAF/PVR-60-63, <https://hsaf.meteoam.it/Products/Detail?prod=H60B>).

The intercomparison methodology used involves several steps (described in the Appendix), ranging from temporal matching to quality control and upscaling onto a fixed grid.

Regarding temporal matching, the two products have different temporal resolutions and, consequently, different scanning frequencies: MSG acquires the full disk every 15 minutes, while MTG acquires it every 10 minutes. These different observation frequencies require selecting a temporal threshold wide enough to ensure complete full-disk coverage for each MTG acquisition. After several tests, a threshold of 5 minutes was chosen. The Table 1 indicates, for each MTG acquisition within an hour, the MSG references used for comparison within the same hour.

| MTG start acquisition time [time coverage] (in minutes) | Corresponding MSG start acquisition time [time coverage] (in minutes) | MTG-MSG Temporal matching coverage (in minutes) | Number of MSG acquisitions for comparing a single MTG acquisition |
|---|---|---|---|
| 00 [00-09] | 00 [00-14] | [00-14] | 1 |
| 10 [10-19] | 00 and 15 | [07-14] + [15-19] | 2 |
| 20 [20-29] | 15 [15-29] | [15-26] | 1 |
| 30 [30-39] | 30 [30-44] | [30-41] | 1 |
| 40 [40-49] | 30 and 45 | [37-44] + [45- 49] | 2 |
| 50 [50-59] | 45 [45-59] | [45-56] | 1 |

Table 1: Temporal matching within 5 minutes for each MTG acquisition respect to MSG acquisitions.

It should be noted that for the MTG acquisitions at minutes 10 and 40, it is necessary to concatenate two consecutive MSG acquisitions (00 and 15; 30 and 45, respectively) in order to cover the entire full disk (FD). Specifically, the preceding MSG acquisition (at minutes 00 and 30) will contribute to the comparison with the second half of the acquisition, covering the Northern Hemisphere, while

the subsequent acquisition (at minutes 15 and 45) will complete the FD coverage by covering the first part of the scan, corresponding to the southernmost portion of the hemisphere. This approach ensures that each MTG-MSG data pair spans the entire FD while maintaining a temporal observation difference within ± 5 minutes.

Regarding the quality control, no threshold has been defined for either the quality index (quality index = 0.0) or precipitation in this analysis, in order to preserve the original data of the products. This approach allows H40B to be evaluated exactly as it is distributed, highlighting any inconsistencies and potential areas for improvement.

Finally, the last step is upscaling to a fixed grid: both products are rescaled to the same regular 0.25° grid and subjected to statistical analysis. The results obtained from the comparison between H40B and H60B are presented in this section. They are organized in increasing levels of detail: first, an overall summary of the long-term results is shown, followed by a more detailed comparison, progressing from monthly analyses to daily ones, and finally to instantaneous analyses.

3.2.1 Overall results

The overall results of the instantaneous comparison between H40B and H60B are very good and highlight the satisfactory agreement between the new MTG-based product and its currently operational MSG-based predecessor. The Table 2 presents all the main scores obtained from the comparisons conducted during the analyzed period.

| H40B vs H60B | Statistical score | Perfect score | Value |
|------------------|-------------------|---------------|------------|
| ≥ 0 mm/h | ME | 0.00 mm/h | +0.07 mm/h |
| | MAE | 0.00 mm/h | 0.09 mm/h |
| | MB | 1.00 | 1.61 |
| | CC | 1.00 | 0.60 |
| ≥ 0.25 mm/h | POD | 1.00 | 0.92 |
| | FAR | 0.00 | 0.24 |
| | MIS | 0.00 | 0.07 |
| | CSI | 1.00 | 0.72 |
| | ETS | 1.00 | 0.72 |
| | HSS | 1.00 | 0.78 |
| ≥ 1 mm/h | FSE | 0% | 47% |

Table 2: Statistical scores obtained by H40B vs H60B in the long period analyzed.

Looking at the ME and MB, a very slight tendency of the new product to overestimate the total precipitation can be observed. However, the bias is very limited and close to the perfect value. The multi-category statistics (with a threshold above 0.25 mm/h) also show a good agreement between the two products, with high values of POD, HSS, ETS, and CSI, and low values of FAR and MIS. The FSE, which represents the reference score for the validation of this instantaneous product, is 47%—well below the required threshold of 200%—confirming the quality of the product under analysis.

3.2.2 Full period evaluation

The Figure 2 summarizes the overall results obtained from the instantaneous comparison between H40B and H60B in terms of continuous scores (ME, MAE, FSE, and MB) and categorical scores

(CC, POD, FAR, MIS, CSI, ETS, and HSS). The analyzed period covers 24 days, spanning from late February 2025 to mid-March 2025.

The graphs, presented as boxplots, include all the results from the daily comparisons: the blue rectangle highlights the range of values falling within the 2nd and 3rd quartiles of the distribution. The red line indicates the median value of the entire distribution. The further the blue box is from the median value, the wider the distribution, implying a greater spread. Conversely, very narrow blue boxes close to the median value indicate a concentrated distribution with a significantly reduced spread.

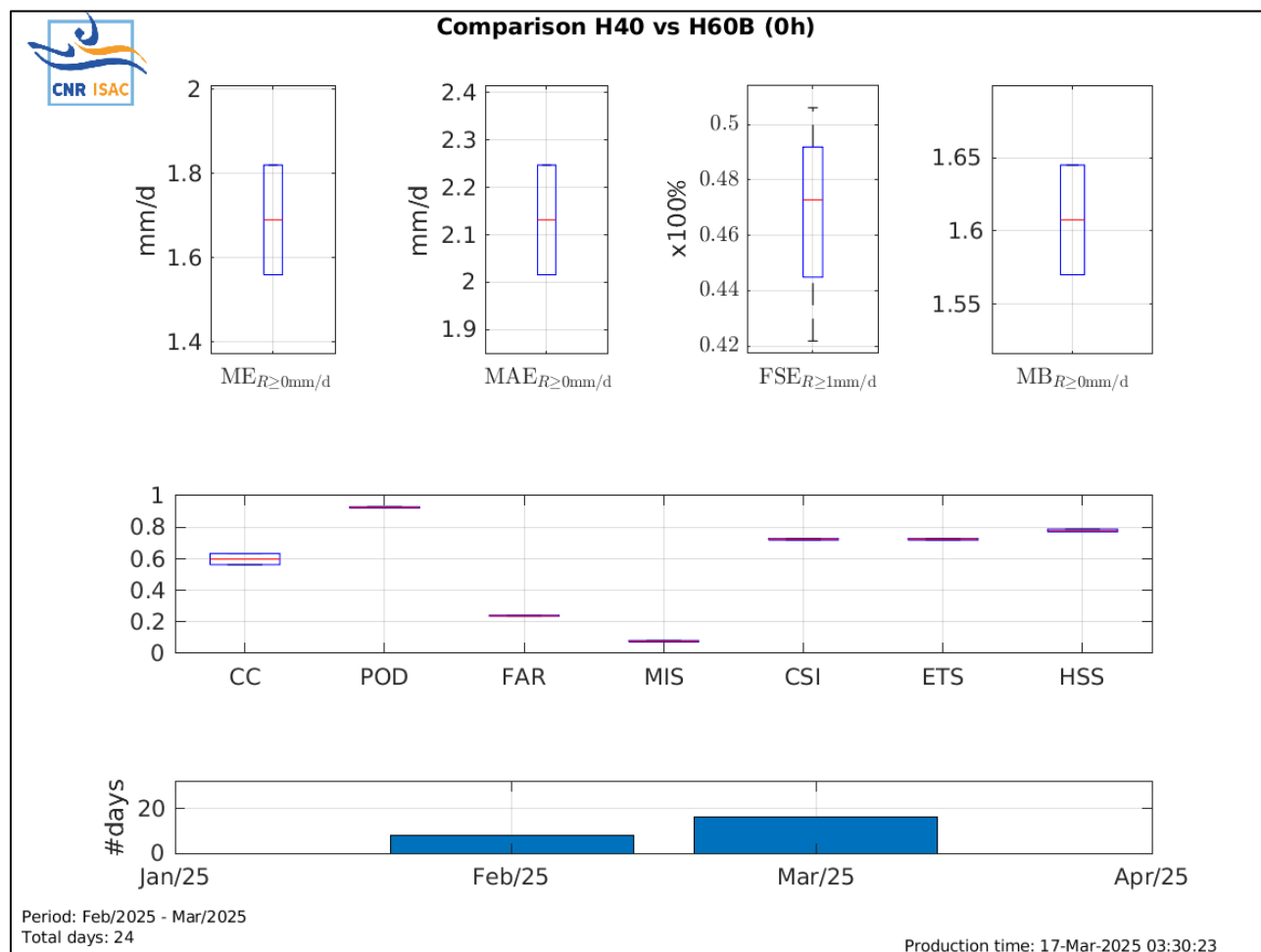


Figure 2: Overall results between H40B and H60B.

The analysis of the overall results on a daily basis indicates that the performance of H40B compared to H60B is in excellent agreement, very stable throughout the evaluated period, and characterized by a notably consistent distribution of daily results.

3.2.3 Monthly analysis

All the daily results obtained from individual comparisons contribute to evaluating the performance of H40B on a monthly basis. The Figure 3 and Figure 4 below show the scores obtained for February 2025 and March 2025, respectively.

In each figure, the overall probability density function (pdf) of the monthly precipitation values derived from the daily estimates of H40B (in blue) and H60B (in red) is displayed at the top center.

To the left of the pdf, the average daily numerical results for continuous statistical scores are reported. These values correspond to the number of days indicated in the figure (#8 for February, #17 for March) and are expressed in daily millimeters (i.e., mm/d or mm/24h).

To the right of the pdf, the average daily numerical scores for categorical metrics are provided for three different precipitation thresholds: ≥ 0.25 , ≥ 1 , and ≥ 10 mm/d.

Finally, at the bottom, the temporal trend of two specific continuous scores over the analyzed days of each month is represented: CC is shown in blue with its vertical scale on the left, while ME is shown in orange, expressed in mm/d, with its vertical scale on the right.

As in all the displayed graphs, additional useful information (e.g., number of days, number of hours, or the date of output generation) is provided at the bottom left and bottom right to facilitate the interpretation and understanding of the results presented in the figure.

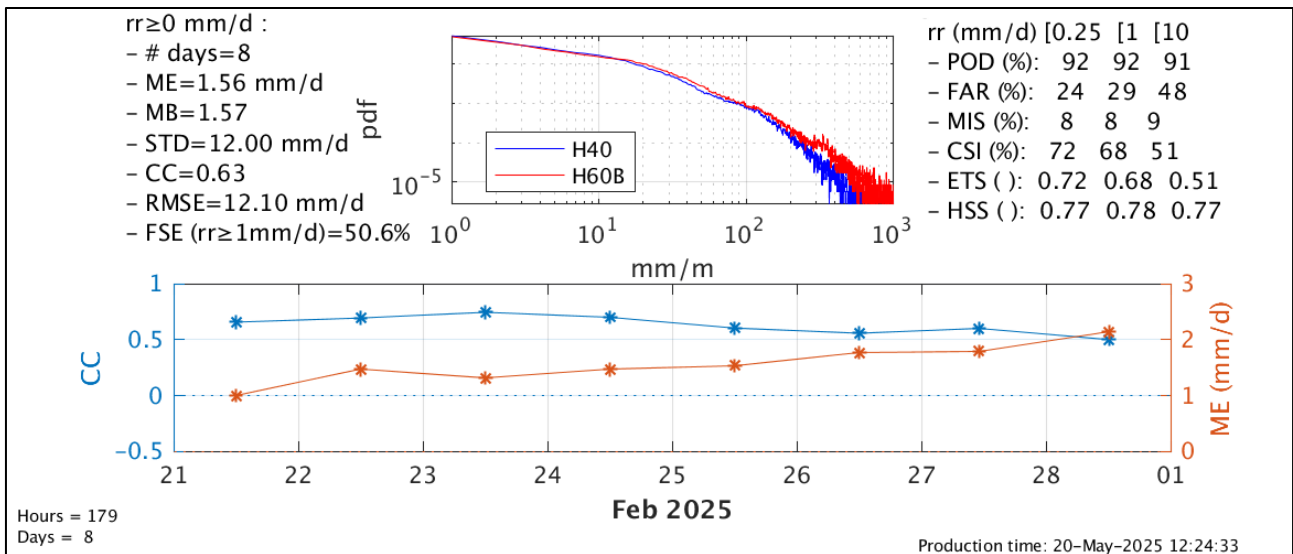


Figure 3: Monthly results between H40B and H60B for February 2025.

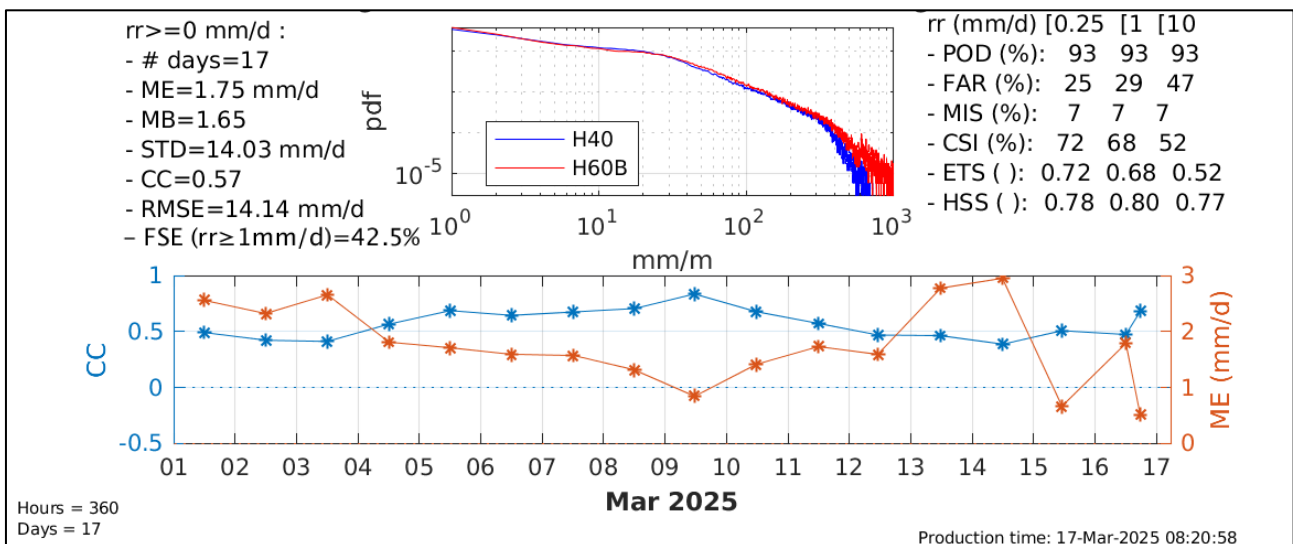



Figure 4: As Figure 3 for March 2025.

The monthly results for February and March are fairly consistent with each other and confirm the findings described earlier. The correlation remains at good levels, close to or above 0.60. The bias is

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slightly positive. The rain detection capability is in excellent agreement with that of H60B and maintains its performance even as the precipitation threshold increases.

3.2.4 Daily comparison

The set of instantaneous comparisons contributes to the overall daily analysis between H40B and H60B. The Figure 5 shows a typical daily output: at the top, precipitation maps estimated by both products are displayed in mm/d (product under analysis on the left while the reference on the right) based on all the instantaneous comparisons performed during the day.

In the center-left, there is a scatterplot in green of the rain rates: the bisector is represented by the dashed black line, and the continuous numerical statistical values are overlaid for all the rain rate values (≥ 0 mm/h) estimated throughout the day.

On the center-right, the PDFs of the two products are displayed in mm/h. The product being analyzed (H40B) is shown in blue, while the reference product (H60B) is shown in red.

At the bottom, the time series of two continuous scores (CC and ME) calculated from the various instantaneous comparisons throughout the day is presented.

Finally, at the bottom-left, the number of comparisons analyzed during the day is provided, and at the bottom-right, the time of output generation is displayed.

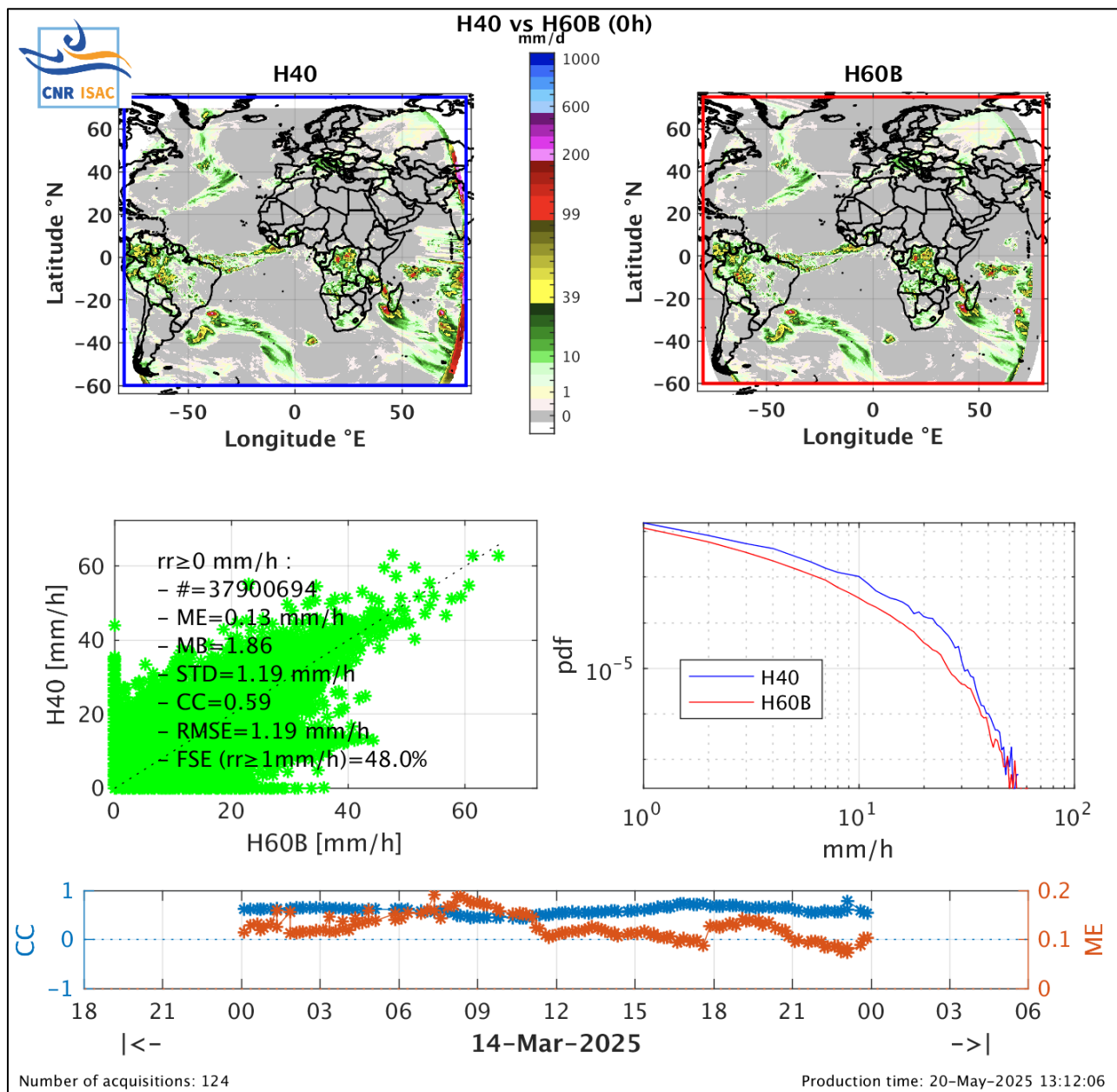


Figure 5: Typical daily output showing the comparison results between H40B and H60B for March 14, 2025.

The figure shows an example of the daily comparison output between H40B and H60B. The set of all instantaneous comparisons acquired on March 14, 2025, contributes to the calculation of the daily scores. The temporal trend highlights how the correlation remains stable throughout the day at values above 0.50, with no significant variations. The ME shows slight variations but always remains around values close to +0.1 mm/h, specifically between +0.08 and +0.20 mm/h. All the instantaneous values acquired during the day are represented in the scatterplot: a total of 37.9 million data pairs contribute to the calculation for this day, with a positive bias of +0.13 mm/h, an MB of 1.86, a STD, a RMSE of 1.19 mm/h, a FSE of 48% and an overall correlation of 0.59. It is important to note that scores calculated using all the values acquired during the day (e.g., CC = 0.59 and ME = 0.13 mm/h) may sometimes differ from those calculated as the average of the results from individual comparisons (e.g., CC = 0.49 and ME = 3 mm/d, which corresponds to 0.13 mm/h), which are reported as daily results in the monthly results (as in the figure above) and subsequent temporal aggregations.

The visual comparison between the daily maps of H40B and H60B shows differences only near the edges of the full disk, also due to the higher spatial resolution of H40B (MTG) compared to H60B (MSG). The application of a mask to limit precipitation estimation near the edges could further improve the product and performance, especially in comparison with H60B.


3.2.5 Multi-categorical statistics

In the following table, the percentages of corrected estimates in three different precipitation classes are indicated. The percentages are normalized along each column that represent the reference for the precipitation. The first class detects the very low rain rate class with $PR < 1$ mm/h, the second class identifies the rain between $1 \leq PR < 10$ mm/h, while the last one classifies the higher rain rates ($PR \geq 10$ mm/h).

| Overall | | | |
|--------------------------------|----------|---------------|----------------|
| Multi-Categorical Statistics | | | |
| P-IN-FCI vs P-IN-SEVIRI-PMW | < 1 mm/h | [1 - 10[mm/h | ≥ 10 mm/h |
| < 1 mm/h | 98% | 20% | 20% |
| [1 - 10[mm/h | 2% | 79% | 12% |
| ≥ 10 mm/h | 0% | 1% | 68% |

**Table 3: Multi-categorical table for product P-IN-FCI (H40B) versus P-IN-SEVIRI-PMW (H60B).
The precipitation classes along the columns (rows) are relative to H60B (H40B) precipitation.**

It is possible to note the excellent agreement between the two products, particularly for low and medium classes: 98% and 79%. Also for higher intensities, even if the agreement is not particularly good, there is a discrete understanding between the two instantaneous precipitation products.

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4 Conclusions

The H40B (P-IN-FCI) product provides instantaneous precipitation estimates from the FCI instrument onboard Meteosat Third Generation (MTG) satellites. The key features of the H40B product are aligned with those of MTG: full disk coverage at a 10-minute observation frequency with a 2 km resolution over nadir.

It was evaluated from January 2025 to March 2025 through an intercomparison on a regular grid, compared to the H60B product based on MSG.

The performance of the two Meteosat-based products, in terms of bias, correlation, and multi-categorical scores, shows good agreement. The results are stable over the long period and consistent across different precipitation intensities.

The only noticeable differences occur near the edges of the full disk, likely due to the higher spatial resolution of MTG compared to MSG. Applying a mask to limit these areas could further enhance the product's performance in comparison to H60B.

Appendix 1 Validation strategy, methods and tools

The quality assessment procedure, methodologies and instruments used to assess the performances of precipitation products are described in this chapter.

A1.1 Validation team and work plan

To evaluate the satellite precipitation product accuracy, a Validation Group has been established by the beginning of the Validation Phase in the H SAF project. The Precipitation Product Validation team is composed of experts from the National Meteorological and Hydrological Institutes of Belgium, Bulgaria, Germany, Hungary, Italy, Poland, Slovakia, and Turkey (Table 4). Hydrologists, meteorologists, and precipitation ground data experts, coming from these countries are involved in the product validation activities (Table 5).

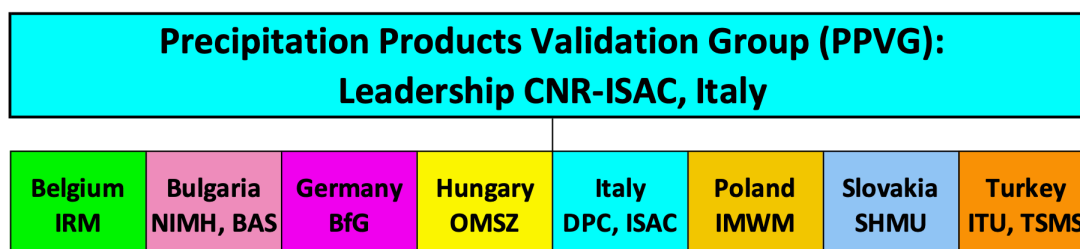


Table 4: Structure of the Precipitation products validation team.

| Validation team for precipitation products | | | |
|--|--|----------|--|
| Name | Institute | Country | e-mail |
| Marco Petracca (Leader) | National Research Council (CNR - ISAC) | Italy | M.Petracca@isac.cnr.it |
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| Giovanni Valgimigli | Civil Protection Department (DPC) | Italy | Giovanni.valgimigli@protezionecivile.it |
| Pierre Baguis | Royal Meteorological Institute of Belgium (RMI) | Belgium | Pierre.Baguis@meteo.be |
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| Petko Tsarev | National Institute of Meteorology and Hydrology (NIMH) | Bulgaria | petko.tsarev@meteo.bg |

| | | | |
|---------------------|--|----------|--|
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| Peter Krahe | Bundesanstalt für Gewässerkunde (BfG) | Germany | krahe@bafg.de |
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| Ladislav Méri | Slovenský Hydrometeorologický Ústav (SHMÚ) | Slovakia | ladislav.meri@shmu.sk |
| Ahmet Öztopal | Istanbul Technical University (ITU) | Turkey | oztopal@itu.edu.tr |

Table 5: List of the people involved in the H SAF precipitation products validation group (PPVG)

The Precipitation products validation programme started with a first workshop in Rome, 20-21 June 2006, soon after the H SAF Requirements Review (26-27 April 2006). The first activity was to lay down the Validation plan, that was finalised as first draft early as 30 September 2006. After the first Workshop, other ones followed, at least one per year to exchange experiences, problem solutions and to discuss possible improvement of the validation methodologies. Often the Precipitation Product Validation workshop are joined with the Hydrological validation group. The results of the Product Validation Programme are reported in this Product Validation Report (PVR) and are published in the validation section of the H SAF web page, that section is continuously updated with the last validation results and studies coming from the Precipitation Product Validation Group (PPVG).

A1.2 Validation objects and issues

The products validation activity has to serve multiple purposes:

- to provide input to the product developers for improving calibration for better quality of baseline products, and for guidance in the development of more advanced products;
- to characterise the product error structure in order to enable the Hydrological validation programme to appropriately use the data;
- to provide information on product error to accompany the product distribution in an open environment, after the initial phase of distribution limited to the so-called “beta users”.

Validation is a challenging task in the case of precipitation, both because the sensing principle from space is very much indirect, and because of the natural space-time variability of the precipitation field (sharing certain aspects with fractal fields), that poses severe sampling problems.

It is known that an absolute ‘ground reference’ does not exist. In the H SAF project the validation is based on comparisons of satellite products with European ground data: radar, rain gauge and radar integrated with rain gauge. During the Development phase some main problems have been pointed out. First of all, the importance to characterize the error associated to the ground data used by PPVG. Secondly to develop software for all steps of the Validation Procedure, a software available to all the members of the PPVG. The radar and rain gauge Working Group (WG) have been composed to solve these problems.


In CDOP-3, with the release of more than 30 products over the MSG full disk area, the Validation Cluster had to develop new methodologies to compare precipitation estimates on almost global area coverage. The Associated Scientist analysis (H_AS16_03 DPC/CNR-ISAC 2016) has been identified the DPR (Dual-frequency Precipitation Radar) onboard of GPM-CO (Global Precipitation Measurement – Core Observatory) satellite as worthy instrument reference for the estimation of instantaneous precipitation on a global scale. In particular, the 2A-DPR NS V05 (DPR) was considered as most suitable product for potential use within the H SAF Precipitation Product Validation activity for instantaneous precipitation estimates. For more details, refer to Sebastianelli, 2017.

For accumulated precipitation products, instead, the Triple Collocation (TC) methodology (Brocca et al., 2014) was used to perform the validation activity. TC requires the simultaneous availability of three products with mutually uncorrelated errors with similar spatial coverage, resolution and accumulation time.

In the following sections, the validation methodology and data used as reference to perform the comparison described in this PVR are shown.

A1.3 Intercomparison Methodology

The validation of precipitation products available in the H SAF portfolio is a crucial step in ensuring their reliability and operational utility. For this reason, an advanced validation platform has been developed to compare a wide range of precipitation products, both operational and under development, against various reference datasets, including ground-based radar estimates, measurements from rain gauge networks, and other satellite and non-satellite precipitation products.

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This platform, developed by CNR-ISAC in collaboration with DPC, benefits from years of experience gained through H SAF validation activities. It leverages the **Unique Common Code (UCC)** developed by the PPVG, which has been extensively used for the validation of instantaneous full-disk Meteosat precipitation products against the Dual-frequency Precipitation Radar (DPR) onboard the GPM-CO satellite. This methodology allows for a systematic approach to product analysis, ensuring consistent and reproducible evaluations over time.

Below, are described the key steps of the applied methodology, including **temporal matching**, **quality checks**, **spatial upscaling**, and the use of **statistical techniques** for calculating comparison results.

Temporal Matching

The comparison process follows the same approach used for validating full-disk instantaneous products against DPR. For each product under validation, an appropriate reference is identified, which may be instantaneous, hourly, or daily, depending on the product being analyzed. A fundamental rule is that the product to be validated must maintain its native temporal characteristics, while the reference dataset must be adjusted accordingly, even through temporal aggregation.

- An instantaneous product is compared exclusively with other instantaneous reference data (not accumulated).
- An hourly product can be compared with both hourly and instantaneous reference data, provided the latter are converted into hourly values.
- A daily accumulated product can be compared with daily reference data, as well as hourly or instantaneous data, provided they are converted into daily accumulations.


Temporal consistency is maintained at each step to ensure the highest possible coherence between the datasets being compared. Temporal matching is then performed between the product and the reference data to identify common precipitation areas, i.e., regions where precipitation occurs simultaneously within a predefined time threshold. This step is crucial to ensure that comparisons are conducted correctly, excluding data acquisitions that are not temporally aligned.

Quality Checks

Temporally matched data undergo a **quality control process** based on the quality indices provided by the product itself and the precipitation values. A quality threshold may be defined (either predetermined or suggested by product developers), below which data are discarded. Additionally, precipitation values that are physically unrealistic (e.g., negative values or extreme outliers) are also removed.

Spatial Upscaling

Once the temporally coincident precipitation areas have been identified, the data that pass the quality control checks are mapped onto a **common grid**. In accordance with the methodology used for DPR validation, a regular **0.25° latitude-longitude grid** has been selected. This resolution represents the best possible trade-off between system performance and the quality of the results.

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The chosen resolution serves as an intermediate reference between different satellite spatial resolutions, balancing the high resolution of geostationary infrared (IR) channels and the coarser resolution of microwave (MW) channels from polar-orbiting satellites. Additionally, many distributed satellite products have a native resolution that does not exceed this grid step, meaning that choosing a higher spatial resolution would lead to unrealistic comparisons.

The upscaling process is necessary to harmonize the datasets, making them comparable and avoiding discrepancies due to differences in native resolutions, data acquisition geometries, and potential errors such as parallax displacement.

Statistical Analysis

Each data pair that successfully passes all previous checks is analyzed and contributes to the final results. Each comparison is processed using a set of statistical analyses (detailed in the Appendix section A1.4).

The results of individual comparisons are stored in a database, allowing for deeper statistical analyses and subsequent evaluations.

Result Aggregation: Daily, Monthly, and Full-Period Analyses

Comparisons are analyzed at multiple temporal levels:

- **Daily results:** All instantaneous or hourly comparisons conducted within the same day are aggregated to provide a summary of the product's performance for that specific day. Data are stored in a structured database for easy access and consultation.
- **Monthly results:** Daily results are further processed to generate monthly statistics, providing a broader view of the product's performance over extended periods. This aggregation helps identify **seasonal trends** or systematic variations.
- **Full-period results:** Finally, monthly results are consolidated to produce an **overall performance assessment** for the entire study period. This allows for a robust and statistically significant comparison of the precipitation products.

Cross-Comparative Analyses

Beyond individual evaluations, the platform enables cross-comparison analyses among different validation cases. This allows for a more comprehensive overview, comparing:

- The **performance of a single product** against multiple reference datasets.
- The **results of multiple products** against the same reference dataset.

These analyses help identify systematic biases, performance differences among products, and geographical or temporal variations in product reliability. Such insights are essential for precipitation product developers and operational users, enabling them to select the most suitable datasets for their specific needs.

A1.4 Large statistic

The large statistical analysis allows to point out the existence of pathological behavior in the satellite product performance. The application of the same validation technique step by step is guaranteed in all institutes take part of the PPVG and in both validation methodologies above described.

The large statistical analysis in PPVG is based on the evaluation of monthly and seasonal **Continuous verification** and **Multi-Categorical** statistical scores on the full period (typically one year) of data. It was decided to evaluate both continuous and multi-categorical statistics to give a complete view of the error structure associated to the H SAF product. Since the accuracy of precipitation measurements depends on the type of precipitation or, to simplify matters, on the intensity or accumulated precipitation, the verification is carried out on three precipitation classes as described in Table 6: Classes for evaluating precipitation products.

| Classes | 1 | 2 | 3 |
|--|-------------|-----------|-------------|
| Accumulated Precipitation Classes (CR) | ≥ 1 mm/24h | ≥5 mm/24h | ≥ 10 mm/24h |
| Precipitation Rate Classes (PR) | ≥ 0.25 mm/h | ≥ 1 mm/h | ≥ 10 mm/h |

Table 6: Classes for evaluating precipitation products

The impact of different background is also considered in the product performances. Statistical scores are separately computed for land, sea and coast areas. The Precipitation Product Validation Leader collects all validation results as computed by European institutes, verifies the consistency of these results and evaluates the monthly and seasonal common statistical results as reported in Chapter 3.

Continuous statistics

Continuous statistics are provided for each month and season of assessment. The main statistical scores are here listed:

| Score | Acronym | Range | Perfect score | Formula |
|--|-----------|-----------------------|---------------|---|
| Number of Satellite samples | NS | N.A. | N.A. | N.A. |
| Number of Reference (radar/rain gauge/etc..) samples | N | N.A. | N.A. | N.A. |
| Mean Error or Bias | ME | $-\infty$ to ∞ | 0 | $ME = \frac{1}{N} \sum_{k=1}^N (sat_k - obs_k)$ |
| Mean Absolute Error | MAE | 0 to ∞ | 0 | $MAE = \frac{1}{N} \sum_{k=1}^N sat_k - obs_k $ |
| Standard Deviation | SD or STD | 0 to ∞ | 0 | $SD = \sqrt{\frac{1}{N} \sum_{k=1}^N (sat_k - obs_k - ME)^2}$ |

| Score | Acronym | Range | Perfect score | Formula |
|--|---------|-----------------------|---------------|---|
| Multiplicative Bias | MB | $-\infty$ to ∞ | 1 | $MB = \frac{\frac{1}{N} \sum_{k=1}^N sat_k}{\frac{1}{N} \sum_{k=1}^N obs_k}$ |
| Correlation Coefficient | CC | - 1 to 1 | 1 | $CC = \frac{\sum_{k=1}^N (sat_k - \overline{sat})(obs_k - \overline{obs})}{\sqrt{\sum_{k=1}^N (sat_k - \overline{sat})^2 \sum_{k=1}^N (obs_k - \overline{obs})^2}}$ |
| Root Mean Square Error (or Root Mean Square Difference) | RMSE | 0 to ∞ | 0 | $RMSE = \sqrt{\frac{1}{N} \sum_{k=1}^N (sat_k - obs_k)^2}$ |
| Fractional Standard Error (%) | FSE | 0 to ∞ | 0 | $FSE = [RMSE / \overline{obs}] * 100\%$ |

Table 7: Continuous statistical scores

In the Table 7:

- N represents the total number of observation samples and equivaless to all satellite/observation pairs for computing all the statistical scores;
- NS indicates the number of product satellite estimates with given characteristics (e.g.; with estimated rain rate > 1 mm/h);
- the index “k” represents the spatial and temporal grid point at the scale of the common reference grid;
- *obs* and *sat* stand for rainfall value acquired by reference observations and satellite estimations, respectively.

Multi Categorical statistics

Multi categorical statistics are derived by the following contingency table:

| | | Observation | | |
|-----------|-------|--------------|-------------------|--------------|
| | | yes | no | total |
| Satellite | yes | hits | false alarms | forecast yes |
| | no | misses | correct negatives | forecast no |
| | total | observed yes | observed no | total |

Table 8: Multi-categorical statistical contingency table

where:

hits: $Sat_k \geq R_{th}$ and $Obs_k \geq R_{th}$

misses: $Sat_k < R_{th}$ and $Obs_k \geq R_{th}$

false alarms: $Sat_k \geq R_{th}$ and $Obs_k < R_{th}$

correct negatives: $Sat_k < R_{th}$ and $Obs_k < R_{th}$

R_{th} is the threshold between the “rain” and “no rain” conditions. The scores evaluated from the contingency table are:

| Score | Acronym | Range | Perfect score | Formula |
|--------------------------|---------|---------|---------------|--|
| Probability Of Detection | POD | 0 to 1 | 1 | $POD = \frac{hits}{hits + misses} = \frac{hits}{observed\ yes}$ |
| False Alarm Rate | FAR | 0 to 1 | 0 | $FAR = \frac{false\ alarms}{hits + false\ alarms} = \frac{false\ alarms}{forecast\ yes}$ |
| Misses | MIS | 0 to 1 | 0 | $MIS = \frac{misses}{hits + misses} = \frac{misses}{observed\ yes}$ |
| Critical Success Index | CSI | 0 to 1 | 1 | $CSI = \frac{hits}{hits + misses + false\ alarm}$ |
| Heidke Skill Score | HSS | -1 to 1 | 1 | $HSS = \frac{2 \times (hits \times forecast\ no - f.al. \times mis)}{(hits + f.al.) \times (hits + mis) + (for.no + f.al.) \times (for.no + mis)}$ |
| Equitable Threat Score | ETS | -1 to 1 | 1 | $ETS = \frac{hits - [(hits + f.al.) \times (hits + mis)] / obs\ yes}{hits + f.al. + mis - [(hits + f.al.) \times (hits + mis)] / obs\ yes}$ |

Table 9: Multi-categorical statistical scores

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Appendix 2 Acronyms

| | |
|-------|--|
| BE | Belgium |
| BfG | German Federal Institute of Hydrology |
| CNR | National Research Council - Italy |
| CSI | Critical Success Index |
| DE | Germany |
| DPC | Italian Department of Civil Protection |
| EU | European |
| FAR | False Alarm Ratio |
| FD | Full Disk |
| GRISO | Rainfall Generator of Spatial Interpolation from Observation |
| HU | Hungary |
| IMWM | Institute of Meteorology and Water Management - Poland |
| ISAC | Institute of Atmospheric Sciences and Climate - Italy |
| IT | Italy |
| MAE | Multiplicative Absolute Error |
| MB | Multiplicative Bias |
| ME | Mean Error |
| OMSZ | Hungarian Meteorological Service |
| PL | Poland |
| POD | Probability Of Detection |
| PPVG | Precipitation Product Validation Group |
| PR | Product Requirement |
| PUM | Product User Manual |
| PVR | Product Validation Report |
| RMSE | Root Mean Square Error |
| SAF | Satellite Application Facility |
| SHMU | Slovak hydrometeorological institute |
| SK | Slovakia |
| STD | Standard Deviation |
| TC | Triple Collocation |
| UCC | Unique Common Code |
| WG | Working Group |