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

# Product Validation Report (PVR) for products P-AC-FCI (H42B)

## Accumulated precipitation at ground by blended MW+MTG FCI-IR

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| Reference Number: | SAF/HSAF/PVR-42B |
| Issue/Revision Index: | 1.1 |
| Last Change: | 20 May 2025 |
| About this document: | This Document has been prepared by the H SAF Quality Assessment Cluster under supervision of Product Validation Cluster Leader (Alexander Toniazzo, DPC) |
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## DOCUMENT CHANGE RECORD

| Issue / Revision | Date | Description |
| --- | --- | --- |
| 0.1 | 19/03/2025 | First draft |
| 0.2 | 20/03/2025 | Draft |
| 1.0 | 20/03/2025 | Version 1, submitted to ORR-2. |
| 1.1 | 20/05/2025 | Document updated following RIDs from ORR-2:<br>– Addition of the reference to PVR H61B in Section 3.2;<br>– Correction of the FSE unit (Figure 2) and the MB formula (Table 6);<br>– Inclusion of the FSE score in Table 1 and in Figures 3 and 4. |

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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 H42B (P-AC-FCI) product

H42B (P-AC-FCI, Accumulated precipitation at ground by blended MW+MTG FCI-IR) 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 input data are P-IN-FCI (H40B) product.

The spatial coverage of H42B product corresponds to the Meteosat full disk (FD) coverage (Figure 1). The product is provided on the MTG FCI grid, with an hourly frequency for the 1 hour accumulated precipitation product, and a six-hour frequency for the 24 hours accumulated precipitation, and the spatial resolution is consistent with the FCI pixel (2 km at nadir).

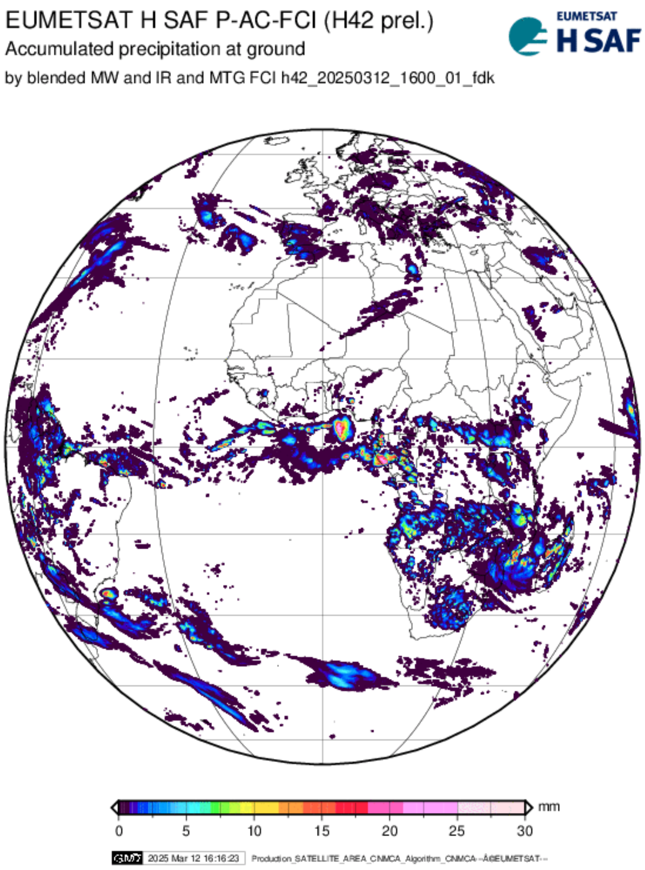


**Figure 1: P-AC-FCI product for the 1h accumulated estimates on 12 Mar 2025 at 16:00 UTC.**

H42B product is provided in NetCDF format. It contains *x* and *y* dimension and 2 main output variables: acc_*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) | H42B (P-AC-FCI) | |
|---|---|---|
| Product name | Accumulated precipitation at ground by blended MW+MTG FCI-IR | |
| Algorithm version number | Latest version: | 1.0 |
| | Version considered for Q.A.: | 1.0 |
| Covered period | 01/01/2025 – 18/03/2025 (2.5 months; 76 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 (FD) using the intercomparison methodology as described in detail in Appendix A1.3

## 3.2 Intercomparison results

The MTG-based accumulated product (H42B) was compared with the corresponding instantaneous product from MSG (H61B) which had previously undergone evaluation and was declared pre-operational product. For detailed results and quality assessment of H61B, please refer to the PVR (Ref. SAF/HSAF/PVR-61-90, https://hsaf.meteoam.it/Products/Detail?prod=H61B).

The temporal resolution between the two is the same, so the same hourly and daily outputs are compared.

For this analysis, no quality threshold was defined (quality index = 0.0), and no changes were made to the precipitation data in order to preserve the original values of the products. H42B is thus evaluated as distributed, to highlight any inconsistencies and potential improvements.

The results obtained from the comparison between H42B and H61B are presented in this section. The results are presented in an increasing level of detail: first, a summary of the overall results over the long term is shown, followed by a more detailed comparison, moving from monthly to daily and then to hourly analyses.

### 3.2.1 Final scores

The overall results of the instantaneous comparison between H42B and H61B are very good and highlight the strong agreement between the new MTG-based product and its operational predecessor MSG-based. The Table 1 shows all the key scores obtained from the comparisons during the whole analyzed period.

| H42B vs H61B | Statistical score | Perfect score | Value |
|---|---|---|---|
| ≥ 0 mm/1h | **ME** | 0.00 mm/1h | +0.07 mm/1h |
| | **MAE** | 0.00 mm1/h | 0.09 mm/1h |
| | **MB** | 1.00 | 1.60 |
| | **CC** | 1.00 | 0.56 |
| ≥ 0.25 mm/1h | **POD** | 1.00 | 0.95 |
| | **FAR** | 0.00 | 0.20 |

| | | | |
|---|---|---|---|
| | **MIS** | 0.00 | 0.05 |
| | **CSI** | 1.00 | 0.77 |
| | **ETS** | 1.00 | 0.77 |
| | **HSS** | 1.00 | 0.82 |
| **≥ 1 mm/1h** | **FSE** | 0% | 45% |

**Table 1: Statistical scores obtained by H42B vs H61B in the long period analyzed.**

Looking at the ME and MB, there is a slight tendency for the new product to overestimate the total precipitation, although the bias is very limited and close to the perfect value. The multi-categorical statistics (with a threshold above 0.25mm/1h) also show good agreement between the two products, with particularly good POD, MIS and HSS scores, and satisfactory FAR, CSI and ETS scores. The FSE is 45% - 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 hourly comparison between H42B and H61B in terms of continuous scores (ME, MAE, FSE, and MB) and categorical scores (CC, POD, FAR, MIS, CSI, ETS, and HSS). The analyzed period spans from the beginning of January to mid-March 2025 (current date). The graphs, presented as boxplots, include all the results from the daily comparisons: the blue rectangle highlights the range of values falling within the $2^{nd}$ and $3^{rd}$ quartiles of the distribution. The red line indicates the median value of the entire distribution. The farther the blue box is from the median, the wider the distribution, indicating a greater spread. Similarly, very narrow blue boxes close to the median indicate a concentrated distribution with a very small spread.

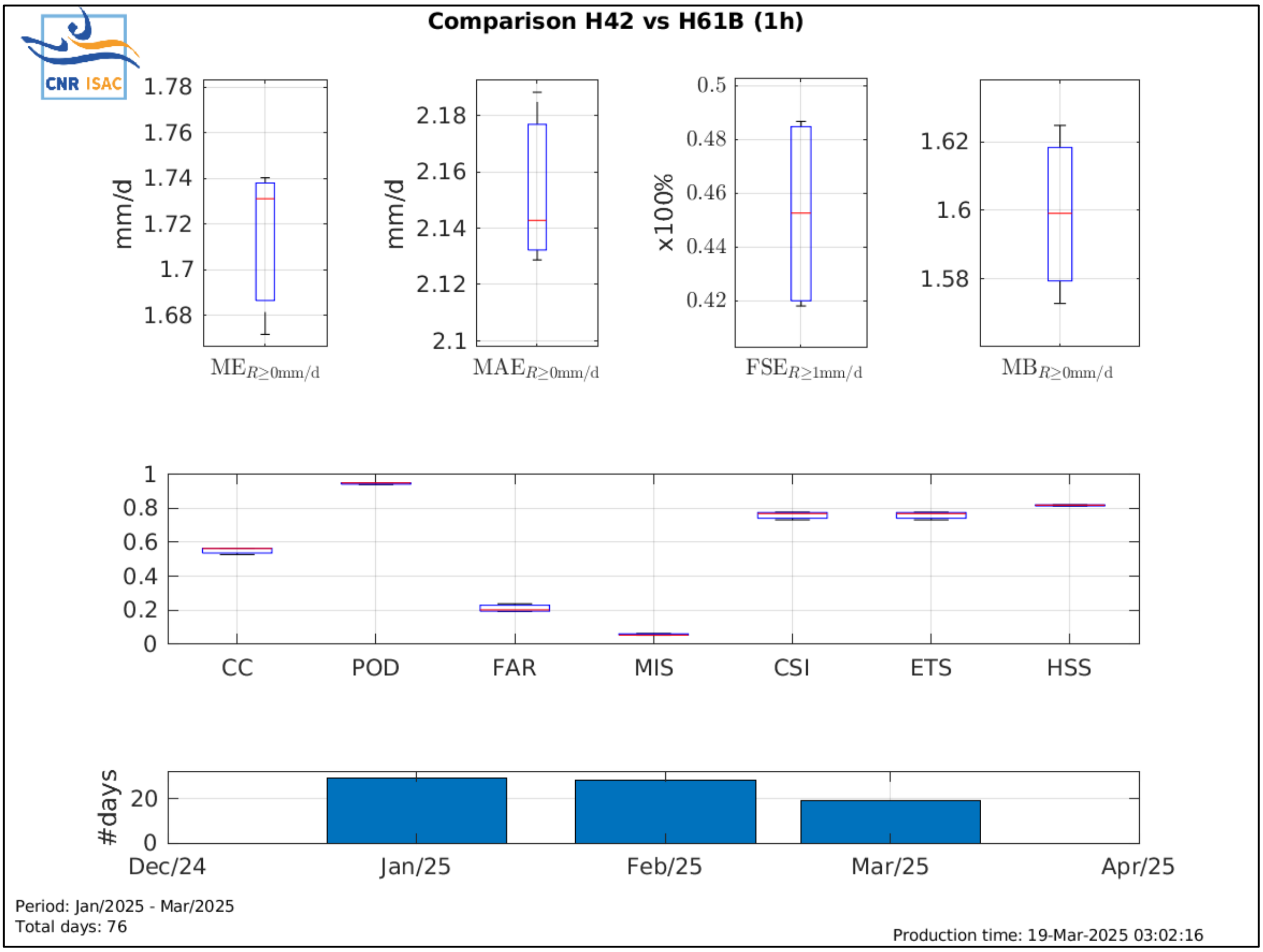


**Figure 2: Overall results between H42B and H61B.**

The analysis of the overall daily results indicates that the performance of H42B compared to H61B shows excellent agreement, with high stability over the entire period and a distribution of daily results that is consistently narrow. POD and MIS values are excellent, and HSS is particularly high.

### 3.2.3 Monthly analysis

All the daily results obtained from individual comparisons contribute to evaluating the performance of H42B on a monthly basis. The Figure 3 shows the scores obtained for the entire month of February 2025. At the top, the overall monthly distributions of precipitation estimated by the two products being compared are presented. In the center, the overall PDF of the monthly precipitation values for H42B (in blue) and H61B (in red) is displayed. To the left of the PDF are the daily average numerical results for the continuous statistical scores. These values refer to the number of days indicated in the figure (#28 for February) 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 the categorical scores are shown for three different precipitation thresholds: ≥0.25, ≥1, and ≥10 mm/d. Finally, at the bottom, the temporal trends of two continuous scores are shown for all days analyzed in the month: CC in blue (with the vertical scale on the left) and ME in orange (expressed in mm/d, with the scale on the right). As in all the figures here shown, useful information (e.g., number of days, number of hours, or the output generation date) is provided at the bottom left and bottom right to help with the interpretation and understanding of the results presented in the output.

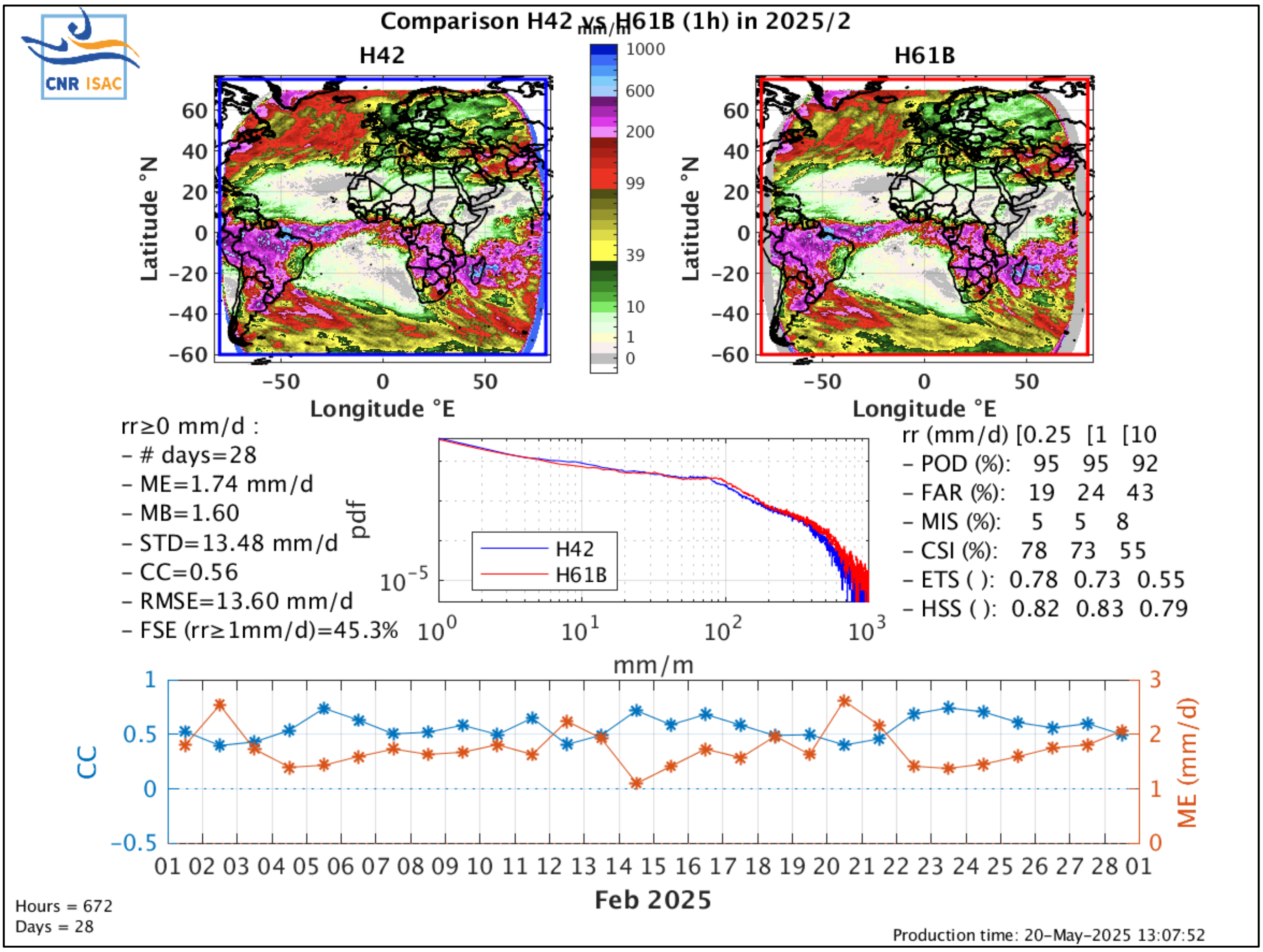


**Figure 3: Monthly results between H42B and H61B for February 2025.**

The monthly results for February are consistent with the previously described findings (as they represent more than one-third of the entire period under analysis). The correlation remains at good levels, with small daily variations, and values close to or above 0.5. The Bias is positive, ranging between 1 and 3 mm/24h. Looking at the multi-categorical scores, the rain detection capability is in excellent agreement with that of H61B. Only for accumulations greater than 10mm/d there is a slight deterioration in some scores (due to the edge of the FD, as shown in the figure).

### 3.2.4 Daily comparison

The set of hourly comparisons contributes to the overall daily analysis between H42B and H61B. The Figure 4 shows a typical daily output: at the top, the precipitation maps estimated by the two products are displayed, expressed in mm/d based on all the comparisons performed during that day. In the center-left, there is a scatterplot in green showing the estimated accumulated rates: the bisector is represented by the black dashed line, and the continuous numerical statistical values for all the precipitation values (≥0mm/1h) acquired throughout the day are overlaid.
On the center-right, the PDFs of the two products are shown, expressed in mm/1h. The product under analysis (H42B) is indicated in blue, while the reference product (H61B) is shown in red.
At the bottom, the temporal trends of two continuous scores (CC and ME) are displayed, calculated from the various instantaneous comparisons throughout the day.
Finally, at the bottom left, the number of comparisons analyzed during the day is provided, and at the bottom right, the time of the graphic output generation is indicated.

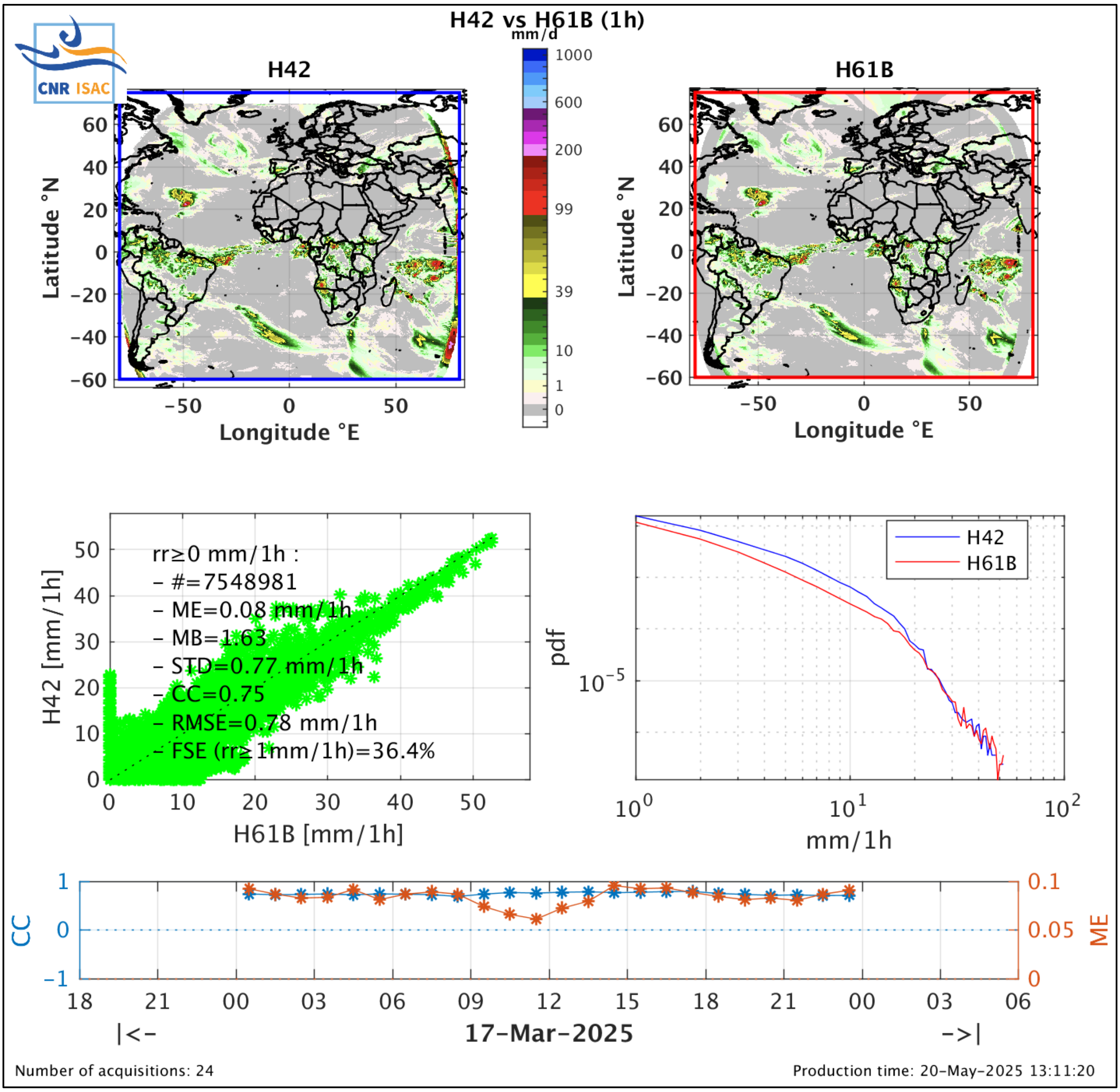


**Figure 4: Typical daily output showing the comparison results between H42B and H61B for March 17, 2025.**

The Figure 4 shows, as an example, the output of a daily comparison between H42B and H61B. The set of all comparisons acquired throughout March 17, 2025, contributes to the calculation of the daily scores. The temporal trend highlights how the correlation remains stable throughout the entire day, with very good values exceeding 0.75, without significant variations. The ME is also stable, with values below +0.1 mm/1h. All values acquired during the day are shown in the scatterplot: over 7.5 million data pairs contribute to the calculation for this day, with a positive bias of only +0.08 mm/1h, an MB of 1.63, a standard deviation (STD) of 0.77 mm/1h, a RMSE of 0.78 mm/1h, a FSE of only 36.4% and an overall correlation of particularly good value equal to 0.75.
As also highlighted in the PVR of the respective instantaneous product (H40B), the visual comparison between the daily maps of H42B and H61B shows differences near the edges of the FD, also influenced by the higher spatial resolution of MTG. The application of a mask to limit

precipitation estimation near the edges could further improve the product and its performance in comparison to H61B and not only.

#### 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 accumulated rain class with PC<1 mm/1h, the second class identifies the rain between 1≤PC<10 mm/1h, while the last one classifies the higher accumulated rain (PC≥10 mm/1h).

| Overall | | | |
|---|---|---|---|
| Multi-Categorical Statistics | | | |
| P-AC-FCI vs P-AC-SEVIRI-PMW | < 1 mm/1h | [1 - 10[ mm/1h | ≥10 mm/1h |
| < 1 mm/1h | 98% | 11% | 0% |
| [1 - 10[ mm/1h | 2% | 85% | 21% |
| ≥10 mm/1h | 0% | 4% | 79% |

**Table 2: Multi-categorical table for product P-AC-FCI (H42B) versus P-AC-SEVIRI-PMW (H61B). The precipitation classes along the columns (rows) are relative to H61B (H42B) precipitation.**

It is possible to note the excellent agreement between the two products, for all precipitation classes, and particularly for low and medium ones: 98% and 85% respectively. Even for higher accumulated rains, there is good agreement between the two products.

# 4 Conclusions

The H42B (P-AC-FCI) product provides hourly and daily accumulated precipitation estimates from the FCI instrument onboard Meteosat Third Generation (MTG) satellites. The key features of the H42B product are aligned with those of MTG: FD coverage 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 H61B product based on MSG.

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

The only noticeable differences occur near the edges of the FD, 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 H61B.

# 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 3). Hydrologists, meteorologists, and precipitation ground data experts, coming from these countries are involved in the product validation activities (Table 4).

| Precipitation Products Validation Group (PPVG): Leadership CNR-ISAC, Italy | | | | | | | |
|---|---|---|---|---|---|---|---|
| Belgium IRM | Bulgaria NIMH, BAS | Germany BfG | Hungary OMSZ | Italy DPC, ISAC | Poland IMWM | Slovakia SHMU | Turkey ITU, TSMS |

**Table 3: 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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| | | | |
|---|---|---|---|
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| Mariàn Jurasek | Slovenský Hydrometeorologický Ústav (SHMÚ) | Slovakia | marian.jurasek@shmu.sk |
| Ladislav Méri | Slovenský Hydrometeorologický Ústav (SHMÚ) | Slovakia | ladislav.meri@shmu.sk |
| Ahmet Öztopal | Istanbul Technical University (ITU) | Turkey | oztopal@itu.edu.tr |

**Table 4: 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**, and mainly for long period analysis (such as Data Records products), 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.

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.

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 descripted in Table 5: 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 5: 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*** | ***Calculation*** |
|---|---|---|---|---|
| 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 | - ∞ to ∞ | 0 | $ME = \frac{1}{N}\sum_{k=1}^{N}(sat_k - obs_k)$ |
| Mean Absolute Error | MAE | 0 to ∞ | 0 | $MAE = \frac{1}{N}\sum_{k=1}^{N}\lvert sat_k - obs_k \rvert$ |
| 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* | *Calculation* |
|---|---|---|---|---|
| Multiplicative Bias | MB | - ∞ to ∞ | 1 | $MB = \frac{\frac{1}{N}\sum_{1}^{N} sat_K}{\frac{1}{N}\sum_{1}^{N} obs_K}$ |
| 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 6: Continuous statistical scores**

In the Table 6:
- N represents the total number of observation samples and equivales 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 7: 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 $Obs_k < R_{th}$

$\mathbf{R_{th}}$ is the threshold between the "rain" and "no rain" conditions. The scores evaluated from the contingency table are:

| Score | Acronym | Range | Perfect score | Calculation |
|---|---|---|---|---|
| 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 8: 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 |