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Design of the QPE evaluation scheme for the new OPERA NIMBUS composites

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1 Introduction and scope

INLINE WP2 aims to evaluate the precipitation European-wide radar rainfall composites produced by the EUMETNET project OPERA¹ (Operational Program for the Exchange of weather Radar information), and develop an alternative scheme to generate improved European-wide Quantitative Precipitation Estimates (QPE) over the EFAS grid to better initialize the EFAS LISFLOOD river discharge forecasts.

This short report presents the strategy for systematically evaluating the rainfall inputs by comparing them with the rain gauge networks currently used in EFAS (Copernicus EMS for floods), as well as with other available observations in Finland, Spain and Portugal.

2 Data

2.1 OPERA NIMBUS rainfall composites

The EUMETNET project OPERA provides high-resolution precipitation observations at European scale (on a 2200 x 1900 2-km Lambert Equal Area grid with a time resolution 15 minutes) since mid 2012. The OPERA surface rainfall rate composites have been an essential input to hydrometeorological applications (e.g., pan-European flood hazard estimates and forecasts induced by heavy rainfall; Park et al. 2019; 2024).

On 30 October 2024, the OPERA operational composite production line was replaced from ODYSSEY to NIMBUS (Bouilloud et al., 2024). The real-time data feed from GeoSphere Austria is set up in the UPC CRAHI's servers, under a licence agreement with EUMETNET OPERA for research uses.

2.2 EFAS point precipitation data

To evaluate OPERA EUMETNET products and to develop the improved precipitation inputs to the EFAS LISFLOOD hydrological model, the EFAS point precipitation data used to produce EMO-1arcmin (Gomes et al. 2020; Joint Research Centre et al. 2023) has been obtained from the EC Joint Research Centre (JRC), which participates in INLINE as stakeholder. As of June 2025, the following data is available at UPC-CRAHI's servers:

- Historical data: precipitation for accumulation windows of 6h (from 2013 to 15 May 2025, except January 2024) and 24h (06UTC-06UTC+1day from 2013 to 31 December 2023).
- Near Real Time (NRT) data since 15 May 2025: precipitation for accumulation windows of 6h and 24h (06UTC-06UTC+1day), which arrive with delays between 18 and 36 hours.

¹ <https://www.eumetnet.eu/observations/weather-radar-network/>

2.3 Specific datasets from the National HydroMeteorological Services participating in INLINE

The three National HydroMeteorological Services participating in INLINE (AEMET, IPMA and FMI) have specific datasets that will be used to evaluate the OPERA precipitation estimates in Spain, Portugal and Finland, respectively.

2.3.1 AEMET datasets

Rain gauge observations

The Spanish Meteorological Agency (AEMET) utilizes multiple pluviometric networks for precipitation monitoring. The primary network comprises 873 Automatic Weather Stations (AWS) that transmit data in real time; 323 stations provide data at 10-minute intervals, while the remaining 550 transmit at frequencies ranging from once every hour to once every four hours.

Complementing this, a secondary climatic network -managed by volunteer observers- consists of approximately 2000 stations that measure accumulated precipitation over a 24-hour period (from 07 UTC to 07 UTC+1 day). Data from this network are typically available with a latency of two to three months.

Interpolated gauge map

In addition to the AWS precipitation observations, AEMET produces a 24-hour accumulated precipitation map interpolated with a spatial resolution of 5 km × 5 km. This product is generated daily using observations exclusively from the primary meteorological network (Fig. 1).

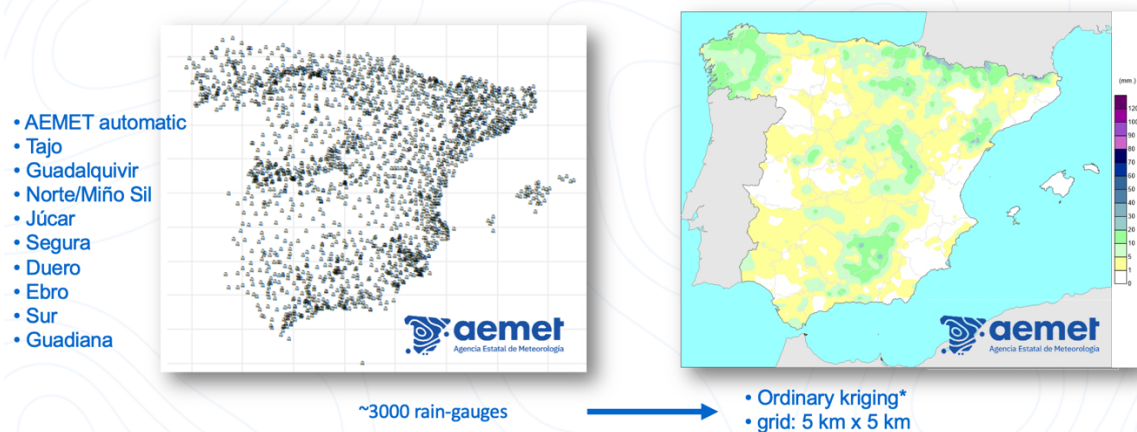


Figure 1. An example of the interpolated gauge map over Spain.

2.3.2 IPMA datasets

Rain gauge observations

Precipitation from up to 135 Automatic Weather Stations (AWS) of IPMA's network over mainland Portugal will be used. In addition, AWS data from external networks with which IPMA has formal agreements will also be considered to assess the impact of stations' density in the analysis of the results.

2.3.3 FMI datasets

National precipitation composites including dual-pol radars

The FMI radar network consists of 12 C-band radars with dual-polarization capability. Several radar-based precipitation products are available with features not currently available in the OPERA products. Composites of reflectivity and rain rate covering Finland are available at 1 km spatial and 5-minute temporal resolutions. Radar scans and the corresponding products have been stored to FMI archives starting from 1998.

The official FMI composites are generated by interpolating radar measurements from two lowest elevation angles into a Cartesian grid. Calibration has been done by sun-based methods (Holleman et al. 2009) and pair-wise comparison between radars observing the same locations. Basic clutter filter has been applied to remove echoes originating from ground and sea clutter and biological targets. This is done by using the rack software package (<https://github.com/fmidev/rack>). Vertical profile effects due to increasing beam altitude become significant for distances beyond 80 km to the nearest radar, and a statistical correction is applied to these to extrapolate radar-based rainfall estimates to ground level.

An experimental radar composite is being implemented in FMI. This composite uses the same radar measurements as the official one, but they are processed by using advanced techniques not yet available in the official FMI products. The conversion from radar-measured reflectivity (Z) to rain rate (R) has been optimized to the Finnish climatology by using disdrometer observations. Polarimetric attenuation correction and rain rate estimates based on specific differential phase (KDP) improve reliability of rain rate estimates in heavy rainfall. Classification of radar echoes is done by using polarimetric techniques. Discrimination between liquid rainfall and other sources of radar echoes is primarily based on the co-polar correlation coefficient (RHOHV). Hydrometeor classes identified by the Vaisala HydroClass algorithm include liquid rain, dry snow, wet snow, graupel and hail. A separate algorithm has been implemented to identify the "bright band" containing anomalously high reflectivity values. This phenomenon is commonly observed near the freezing level height, where ice particles or snowflakes melt into liquid precipitation. Kriging-based correction by using rain gauges has also been implemented.

Precipitation gauges

As of 2025, FMI has rain gauges at 216 locations in Finland. Of those, 117 are automatically weighing OTT Pluvio gauges that are the primary instrument used for rainfall measurements in Finland. They measure hourly rainfall accumulations. 24-hour rainfall accumulations are measured at 60 locations by using manual tipping bucket gauges. Instantaneous rain rate averaged over the previous 10 minutes is measured at 118 locations. The above are complemented by optical Vaisala FD12P sensors measuring hourly accumulations and 10-minute average rain rates at 104 locations. In addition, they provide information about the prevailing precipitation and visibility conditions.

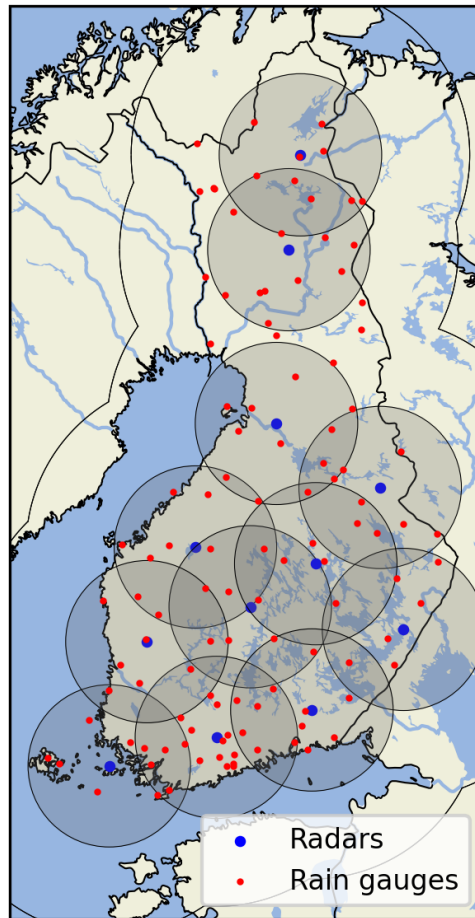


Figure 2. Radar and rain gauge networks operated by FMI. The stations shown here are those equipped with the OTT Pluvio rain gauge. The inner and outer rings represent 120 km and 250 km distances to the nearest radar, respectively.

3 QPE evaluation scheme

The evaluation of the new OPERA NIMBUS composites will be done in three folds (Fig. 3): i) Systematic daily evaluation over Europe in real time, ii) event-based comparisons with additional gauges available in Spain and Portugal, and iii) event-based comparisons with dual-pol radar composites available in Finland. The following subsections outline initial plans, which will be updated throughout the project. The results of the systematic monitoring of OPERA NIMBUS precipitation composites will be compiled in the INLINE Deliverable 2.1 at Month 24.

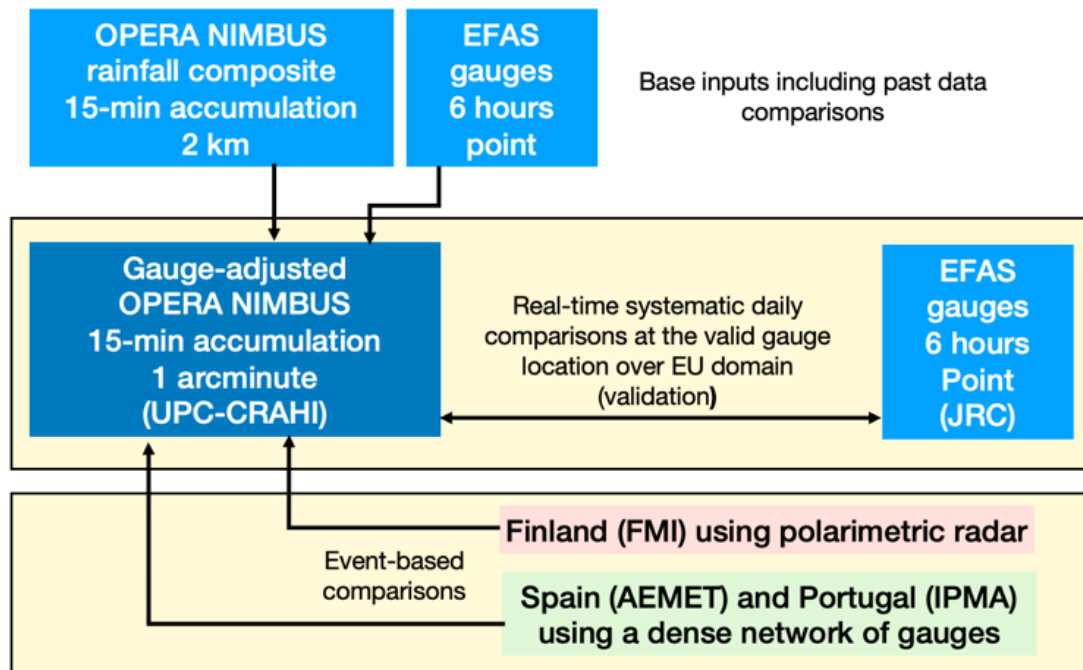


Figure 3. QPE evaluation scheme for the new OPERA NIMBUS composites.

3.1 Real-time systematic daily evaluation over Europe

Due to various sources of error affecting radar estimates at ground level, where comparisons are made with gauge measurements, a quality check of the radar estimates is necessary. INLINE will apply a similar method of monitoring radar artifacts (due to ground and sea clutter, LAN interferences...), and adjusting radar biases (Park et al. 2019) by comparison of past rainfall accumulations from both OPERA NIMBUS QPE and EFAS gauge observations.

The quality assessment of both radar and gauge estimates will involve first identifying radar artifacts and applying a new spatial interpolation to fill areas with low data quality, including the use of NWP. From the comparison of radar and rain gauge accumulations, a daily map of the correction factor over the radar coverage will be generated to adjust the OPERA NIMBUS rainfall estimates. The resulting gauge-adjusted radar rainfall estimates will have 1 arcminute spatial resolution and 15 minutes temporal resolution. Because these are not influenced by real-time gauge observations, their real-time validation using the EFAS gauges or other national QPE and radar composites is straightforward.

INLINE plans to update the production of the gauge-adjusted OPERA rain accumulation since 2013 using the EFAS rain gauges, which will serve as the new inputs

- for testing the initial conditions to LISFLOOD model outputs (Task 2.3); i.e., by comparisons of EMO1 (current input to EFAS), interpolated gauge-adjusted radar rain estimates at the gauge locations (Fig. 4) and gauge-adjusted radar rain estimates at 1 arcminute grid (the INLINE output). The first dataset from November 2024 to September 2025 will be generated for ECMWF to set-up running the LISFLOOD model in mid-October 2025.

- for updating the radar-based rain accumulation threshold to assess the flash/urban flood hazard.
- for cross-validating with other products available from Sections 3.2 and 3.3.

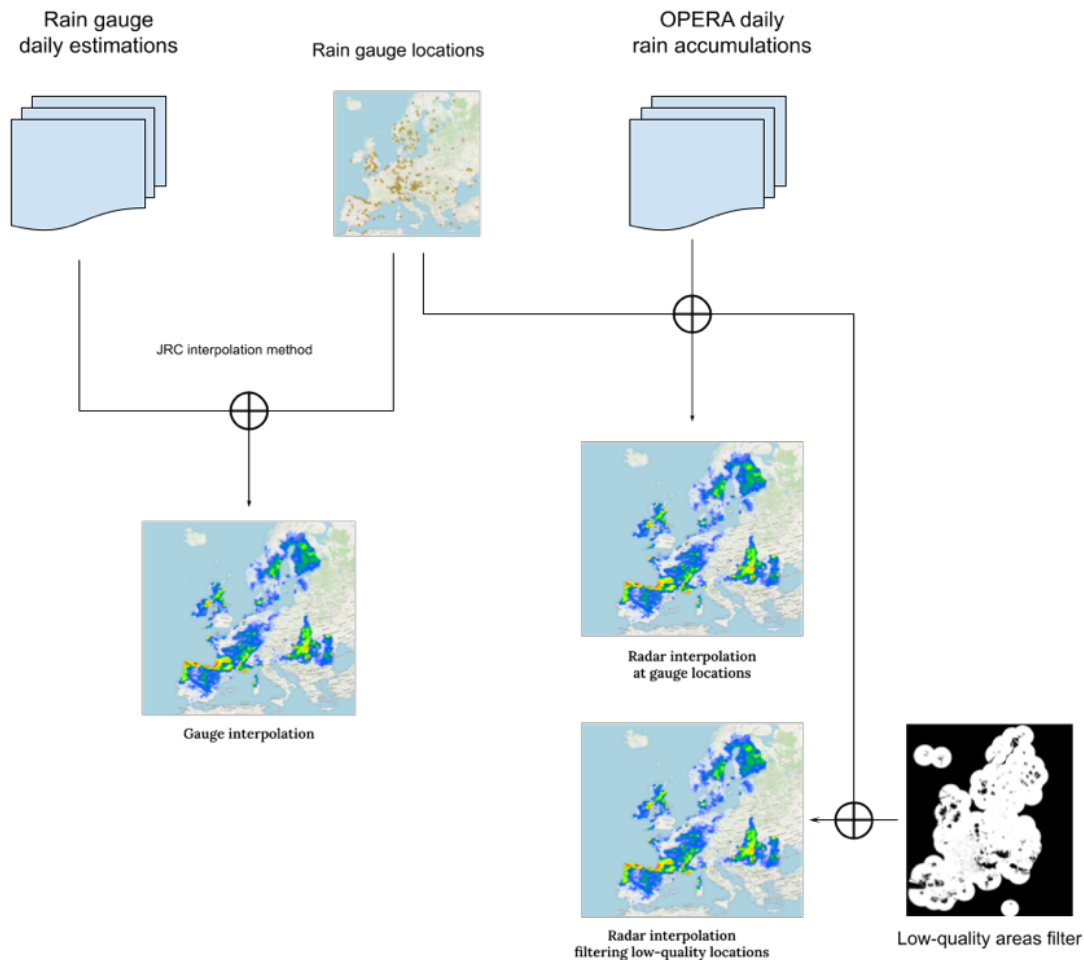


Figure 4. INLINE interpolated gauge-adjusted radar rain estimates at the gauge locations using the same interpolation method used in JRC's EMO1.

3.2 Comparisons using dense-network of gauges

3.2.1 Over Spain

Two enhanced accumulated precipitation grids will be developed based on multi-source pluviometric observations. The first dataset will integrate measurements from the primary AEMET network with data from the Automatic Hydrological Information System (SAIH) and the Irrigation Agroclimatic Information System (SiAR).

The second grid, with a higher spatial resolution of 1 km × 1 km, will incorporate data from the three networks (primary, SAIH, and SiAR), in addition to observations from regional meteorological services and citizen-based weather observation networks.

Concerning the evaluation of precipitation events occurring between October 2024 and the present, priority may be given to episodes in which official orange or red warnings were issued for hourly or 12-hourly accumulated precipitation, as defined within the Meteoalerta Plan².

3.2.2 Over Portugal

QPE will be assessed in an event-based approach over two main urban areas – Algarve coastal cities and the region of Lisbon and surroundings. Generally, heavy precipitation events in 2025 will be used, leading or not to flash floods. For Lisbon, the additional extreme flood events of 7 and 13 December 2022 will also be used.

3.3 Comparisons using polarimetric radars and rain gauges in Finland

Three radar composite products will be evaluated by using the Finnish rain gauge network as ground truth. These are OPERA NIMBUS, the Finnish national radar composite provided by FMI and an experimental composite generated from FMI radar data. Instantaneous rain rates will be converted into accumulated rainfall and compared with 10-minute average rain rate and hourly and 24-hour rainfall accumulations measured by rain gauges. The mean absolute error (MAE) and root-mean square error (RMSE) will be used as verification metrics. The evaluation will be based on weather events that occurred in Finland between 2020-2025 with focus on the following categories:

- summertime rainfall events that caused significant damages
- winter events, where heavy snowfall could be misinterpreted as rainfall
- examples of ground clutter (e.g. wind turbines), biological clutter (e.g. insects) or hail that could be misinterpreted as rainfall

The main error sources in radar-based rain rate estimation in Finland and applicable solution methods are listed in Table 1. The current state of the radar composite products is:

- OPERA NIMBUS: none of the corrections applied
- Official FMI composites: corrections 1, 3, 4, and 7 applied
- Experimental composites: all corrections applied and option to disable different corrections for testing purposes

In addition, the OPERA and FMI composites differ by the method used for compositing (i.e. interpolating the radar measurements from multiple elevation angles into Cartesian grid).

The impact of the corrections on rain gauge-based verification metrics will be analyzed by comparing different composites and also different versions of the experimental composite with selected features enabled or disabled.

² https://www.aemet.es/es/lineas_de_interes/meteoalerta

Table 1: Main error sources in radar-based rainfall estimation in Finland.

No.	Error source	Type	Solution
1	inaccurate R(Z) relationship	systematic	optimize to local climatology
2	attenuation	transient	polarimetric correction
3	ground clutter	systematic	apply mask derived from polarimetric parameters
4	biological clutter	transient	apply mask derived from polarimetric parameters
5	hail	transient	apply mask derived from polarimetric parameters
6	erroneous rain rate estimates in snowfall	in winter	polarimetric identification of hydrometeor phase
7	vertical profile	systematic	statistical correction based on a large sample of radar-measured vertical profiles of precipitation
8	bright band	transient	apply mask derived from polarimetric parameters
9	beam overshooting (i.e. altitude of radar beam too high to observe precipitation)	systematic	restrict distance to nearest radar
10	differences between radar-based and ground-level rainfall measurements	systematic / transient	statistical correction based on comparison with rain gauges

While radar-based rain rate estimates can be corrected by using rain gauges, the applicability of this method depends on the density of the gauge network. The impact of the network density will be studied by comparing verification metrics of gauge-adjusted FMI radar composites in southern and central part of Finland. The FMI gauge network has higher density in the densely populated south and decreases towards the north (see Fig. 2).

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