Reviewer #2

General

The authors analyse different precipitation data based on measurements from different sources as well as numerical weather prediction (NWP) model data. The measurement data include rain gauges, weather radar, satellite data and commercial microwave link (CML) data or products based on these data. The precipitation data are analysed for an extreme precipitation event on the Odra river catchment which occurred during four days in September 2024.

The paper is presenting the different results in a clear manner and discusses the advantages and disadvantages of the different measurement / modelling principles in detail.

In particular, limitations for satellite and NWP products can be demonstrated, while rain gauge and radar based products perform the best.

Detailed discussion items

Line 124 ff: Reference for the analysis:

The authors discuss the relevance for a reference data set which is independent from the other data sets. Unfortunately, they later include precipitation products that are not independent from the reference data set.

- While for daily values, the manual gauges are selected as reference - a choice which is the best possible from the available data -, the post processed GRS Clim product which is adjusted based on these reference station data enters into the investigated methods. This should be avoided because it deviates the attention of the reader from the relevant data to be compared.

> We have agreed with the Reviewer's arguments and removed the GRS Clim estimates from all analyses. In particular, we have revised the paragraph 191-198 in section 2.2:
>
>> "At many locations, the daily precipitation accumulation in this period exceeded 200 mm, and its territorial range covered mainly the Eastern Sudetes. Four-day precipitation accumulation reached values above 400 mm, with the highest in the Jeseníky and Śnieżnik Mountains. They might have exceeded even 550 mm, as indicated by reanalyses RainGRS Clim (Jurczyk et al., 2023) based on estimates from the Rain GRS system adjusted to observations from manual rain gauges (Fig. 2). Apart from intense, widespread precipitation, numerous thunderstorms and several associated tornadoes were recorded during these days. On 16 September, rainfall began to diminish; mainly light to moderate precipitation was observed, and in the following days, the weather in Poland was influenced by a high-pressure system, with the advection of warm and dry air of continental origin."

- Concerning hourly values, the choice of an independent reference of high quality is not solvable with the existing precipitation products. Therefore, the choice made by the authors is understandable, in particular since they are pinpointing this methodological weakness.

> OK.

Line 379ff: Selected metrics

When comparing gridded data to point data at the ground, location uncertainties may arise because rainfall observed at a certain height (or from space) does not necessarily fall down at the point which is considered by overlaying grids and points. Furthermore, uncertainties of comparing a grid area average to a point value occur in particular in heavy rain - in the order of 20% have been observed (Schellart et al., 2017). Can you please add a short section on how you take into account such uncertainties or, alternatively, which range of values has to be considered reliable?

We agree with the Reviewer that the problems associated with uncertainty in comparing point and grid data are important, although in our view it is challenging, especially when analysing such short accumulations. So we have added the relevant sentences to line 136 (in sect. 1.2.4):

> "Furthermore, comparing the average precipitation over a grid area to a specific point value introduces some uncertainty, particularly during heavy rain (Ensor and Robeson, 2008). An analysis of findings by Sun et al. (2018), Herrera et al. (2019), and others shows that, due to the high spatial variability of precipitation, it is not possible to establish a single universal error value when comparing point and grid data. The level of the uncertainty varies depending on the nature of the precipitation. For widespread (large-scale) precipitation, the uncertainty typically ranges from about 10% to 15%. However, for intense, convective extreme precipitation, this uncertainty can rise to approximately 15% to 25% (Schellart et al., 2017; Henn et al., 2018; Tarek et al., 2021). Special care should be taken when analysing local precipitation maxima using gridded data, as noted by Sun et al. (2018) and others, who point out that these data may smooth out extreme values compared to point measurements."

New references:

Ensor, L. A. and Robeson, S. M.: Statistical Characteristics of Daily Precipitation: Comparisons of Gridded and Point Datasets. Journal of Applied Meteorology and Climatology, 47, 2468–2476, https://doi.org/10.1175/2008JAMC1757.1, 2008.

Henn, B., Newman, A. J., Livneh, B., Daly, C., and Lundquist, J. D.: An assessment of differences in gridded precipitation datasets in complex terrain. Journal of Hydrology, 556, 1205-1219, https://doi.org/10.1016/j.jhydrol.2017.03.008, 2018.

Sun, Q., Miao, C., Duan, Q., Ashouri, H., Sorooshian, S., and Hsu, K.-L.: A review of global precipitation data sets: Data sources, estimation, and intercomparisons. Reviews of Geophysics, 56, 79-107, https://doi.org/10.1002/2017RG000574, 2018.

Tarek, M., Brissette, F., and Arsenault, R.: Uncertainty of gridded precipitation and temperature reference datasets in climate change impact studies, Hydrology and Earth System Sciences, 25, 3331–3350, https://doi.org/10.5194/hess-25-3331-2021, 2021.

Herrera, S., Kotlarski, S., Soares, P. M. M., Cardoso, R. M., Jaczewski, A., Gutiérrez, J. M., and Maraun, D.: Uncertainty in gridded precipitation products: Influence of station density, interpolation method and grid resolution. International Journal of Climatology, 39, 3717–3729, https://doi.org/10.1002/joc.5878, 2019.

Do the selected metrics show well the effects that you are most interested in, i.e. the best estimate for extreme intensities and also for the cumulated sums? Squared error indices tend to heavily penalize individual outliers which may be one effect that you are after, but please discuss this aspect.

In line 390 we have added:

> „The RMSE is particularly sensitive to outliers as squaring the errors emphasizes larger deviations."

In line 391 we have added:

> "as it relates the deviations to the spread of the reference values around their mean"

Line 553: Do you want to say that interpolated gauges are more reliable than adjusted radar data? Then you contradict yourself because earlier you said that interpolated station data are underestimating the true values.

The sentence in lines 552-555 is incorrect. We have corrected it to:

> "The conclusion from this analysis is that the estimation of extremely high precipitation fields with very high spatial (1 km) and temporal (1 hour) resolution is mainly based on weather radar observations, but these must first be adjusted to the rain gauge data. Rain gauges can also produce reliable estimates, but under the condition that a sufficiently dense network of such gauges is available."

Formal aspects

Line 14: please replace "... 200 mm daily" by "... 200 mm on one day at one rain gauge location"

We have significantly rebuilt the abstract, and as a consequence this fragment is no longer included.

Line 71ff: please give the explanation for each abbreviation before using it (RLAN, GPM, NOAA, MetOp, GAU, etc.)!

We have added abbreviation expansions:
- RLAN in line 71 (Radio Local Area Network)
- GPM in line 80 (Global Precipitation Measurement)
- NOAA in line 80 (National Oceanic and Atmospheric Administration)

Line 191: please start the sentence with "In many locations, the daily precipitation ..." - the values in the tables given later suggest that this formulation is more precise.

Changed.

Line 366: please rephrase to something like "... which we consider to be the most reliable values."

Changed.

Line 479: according to Table 2, the Bias is -3.8 mm (not -3.6 mm) - one of the two should be corrected...

Corrected to "-3.8" in the text.

Technical points

Lines 274-278: This explanation should be clarified - which other approaches were tested before selecting the final method and by which means is it different to the others? Please also refer to the results from the COST OpenSense Action!

We have removed the sentence in lines 276-278, because it does not explain anything, and the methods are described in the in the paper by Pasierb et al.

We have added a reference to the paper here: Olsson et al. (2025) in line 274.

Line 309: You are writing "closest to reality" - however, this is correct for one point and is of limited value for areas. Please emphasize it here again, although you mentioned this earlier already.

Corrected to:

> "The data from the manual rain gauges are the closest to reality at their locations, and therefore were selected as the point reference for the 2024 flood."

Lines 329 - 331:

- "...satellite data as a base line and intercalibrates." What is intercalibrated here?
- "... other observations with international satellite constellation ..." Please note that GPM as the Global Precipitation Measurement mission is heavily based on satellite-based weather radars. The chosen formulation suggests that GPM does not include radar and these data need to be retrieved from other sources

We have corrected the sentences to (lines 329-332):

> "This product is calibrated with Global Precipitation Measurement (GPM Core Observatory) satellite data, which is based on microwave imager and the dual-frequency precipitation radar, and uses it as a baseline. It is combined with other observations from national or international satellite constellations equipped with weather radars and passive microwave and infrared sensors, as well as with rain gauge data (Huffman et al., 2020; Bogerd et al., 2021)."

Lines 347-348: How can you analyse short lived phenomena if your resolution is not sufficient for convective cells? Please explain!

We have changes the sentences to:

> Such data allows for an overall analysis of rainfall offline. However, it is impossible to use these reanalyses when knowledge of the course of convective phenomena at the microscale is needed, i.e. with a spatial resolution of 1 km or less.

Lines 365 to 378: I understand it correctly that the daily analysis relies on 112 data points (= all manual stations in the area) and the hourly analysis on statistics calculated from 44218 pixels? If so, please add the numbers here for a better understanding!

We have completed the sentence in lines 366-367:

> "These measurements are point wise, so verification of individual precipitation fields was performed only at the locations of these stations (112 ones)."

…and in lines 374-375:

> "As measurements from manual rain gauges are not available at such a short time step, the RainGRS (GRS) fields (44,218 pixels within the basin) were used as a benchmark for the verification."

Line 411-412: What is the influence of data from the Czech territory? I do not understand.

The GRS multi-source precipitation field (generated by the RainRGS system) is created from, among others, the precipitation field resulting from spatial interpolation of rain gauge measurements. The amount of precipitation in each pixel is influenced by the nearest rain gauges. Near the border with the Czech Republic, rain gauges located on the other side of the border also contribute to this interpolation. Hence this influence, which is only visible close to this border.

Lines 413: RAD data product: please eliminate the discussion of unadjusted radar data - else readers may think that they can work with such data. Merely, a warning would be adequate to never use unadjusted radar data for any quantitative purpose, maybe with a reference to the WMO Operational Weather Radar Best Practice Guidance (WMO document no. 1257 - https://library.wmo.int/records/item/68834-guide-to-operational-weather-radar-best-practices?offset=5).

The Reviewer is right - thank you for this comment. Indeed, the paragraph as it is now may lead to confusing conclusions. We have changed it as follows:

> "In the case of radar-derived fields (RAD and RAD Adj), the precipitation pattern is also well represented, but the estimate based solely on radar observations (RAD) underestimates values. Therefore, unadjusted radar data should not be used, especially for quantitative precipitation estimates (WMO-No. 1257, 2025). Radar data after adjustment with rain gauge measurements (RAD Adj) demonstrates good agreement concerning precipitation values."

We have added this item in References:

> WMO-No. 1257: Guide to Operational Weather Radar Best Practices. Volume VI: Weather Radar Data Processing, World Meteorological Organization, Geneva, 156 pp., https://library.wmo.int/records/item/69563-guide-to-operational-weather-radar-best-practices (last access: 16 July 2025), 2025.

References:

- Schellart ANA, Wang L & Onof C (2017) High resolution rainfall measurement and analysis in a small urban catchment. 9th International Workshop on Precipitation in Urban Areas: Urban Challenges in Rainfall Analysis, UrbanRain 2012 (pp 115-120)

We have added this paper - we were not aware of it before. Thank you for pointing it out!

> Schellart, A.N.A., Wang, L, and Onof, C.: High resolution rainfall measurement and analysis in a small urban catchment. 9th International Workshop on Precipitation in Urban Areas: Urban Challenges in Rainfall Analysis, UrbanRain 2012, ETH Zurich, 115-120, ISBN 978-390603121-7, 2017.