Review of manuscript egusphere-2025-3455 submitted to Natural Hazards and Earth System Sciences (NHESS)

Anonymous Referee #2, 1 Sep 2025

[answers in blue]

General comments: This manuscript presents an analysis of precipitation event properties (frequency, intensity, duration, and size) using a convection-permitting reanalysis dataset for Italy. The paper is well written, scientifically rigorous, and of clear interest to the NHESS community. That said, the manuscript would benefit from more cautious phrasing regarding the ability of the reanalysis to represent meso-beta scale processes, a more concise and focused introduction, and more consistent use of acronyms. These revisions would improve readability and balance some of the claims. I therefore recommend major revisions before the paper can be considered for publication.

Specific comment: I find the manuscript highly relevant, as it combines two approaches that are still not very common in the community: the high-resolution reanalysis from ERA5 and WRF, and the event-based approach. This framework could be extended to other regions, which increases the value of the study. But the paper would benefit from addressing the following points:

- Introduction: The introduction is overly long. Please consider streamlining it to improve readability and focus on the main motivation and novelty of the study.

Thank you for your constructive and insightful comments. We appreciate your recognition of the relevance and potential of our study, as well as your detailed suggestions for improvement. We will carefully revise the manuscript to implement your recommendations, in particular by streamlining and focusing the introduction.

- Section 2.1: Here you present the MERIDA HRES reanalysis, but you do not describe the quality or limitations of the dataset. While some of this is discussed later, it would be more appropriate to include a clear description of dataset strengths and limitations already in this section.

We agree that Section 2.1 would benefit from a clearer description of the strengths and limitations of the MERIDA HRES reanalysis. While these aspects have already been extensively discussed in our previous works (Cavalleri et al., 2024; Viterbo et al., 2024), in the revised version of the manuscript we will expand this section to include a concise overview of the dataset's quality—highlighting both its ability to capture precipitation processes at convection-permitting scales and its known limitations. We believe that relocating part of this information (currently presented in the Discussion) to an earlier section will improve clarity and allow readers to better evaluate the results.

Cavalleri, F., C. Lussana, F. Viterbo, M. Brunetti, R. Bonanno, V. Manara, M. Lacavalla, S. Sperati, and M. Raffa (2024). Multi-scale assessment of high-resolution reanalysis precipitation fields over Italy. Atmospheric Research, 312, 107734. https://doi.org/10.1016/j.atmosres.2024.107734

Viterbo, F., S. Sperati, B. Vitali, F. D'Amico, F. Cavalleri, R. Bonanno, and M. Lacavalla (2024). MERIDA HRES: A New High-Resolution Reanalysis Dataset for Italy. Meteorological Applications, 31(6), e70011. https://doi.org/10.1002/met.70011

- Resolution: The reanalysis resolution is reported as 4 km, presumably referring to the horizontal grid spacing. What about the vertical resolution? A more careful discussion of its role would be valuable. In addition, in the results you claim that the model can resolve meso-beta processes (2–20 km). In my view, a 4 km horizontal resolution may not be sufficient to adequately resolve the full

meso-beta range, perhaps only processes above ~10 km. For example, at 4 km resolution, a 10 km feature would be represented by only a handful of grid points. I recommend revising this claim to reflect these limitations.

Thank you for this important observation. We agree that additional detail on the resolution of MERIDA HRES is needed. In the revised manuscript, we will explicitly state that MERIDA HRES has 56 vertical levels, with increased vertical resolution in the lower atmosphere (e.g., levels located at 10, 35, 70, 100, 130, 180, 250, 325, 415, and 500 m; Viterbo et al., 2024). The effective horizontal spatial resolution of MERIDA HRES has been thoroughly evaluated in one of our previous work using a wavelet spectral decomposition approach (Cavalleri et al., 2024b), which demonstrated the dataset's ability to represent convective precipitation events. At the same time, we will revise our discussion of meso-beta processes, expanding this discussion in the revised version of the manuscript to provide a more complete and balanced assessment of the dataset's capabilities and limitations.

> Viterbo, F., S. Sperati, B. Vitali, F. D'Amico, F. Cavalleri, R. Bonanno, and M. Lacavalla (2024). *MERIDA HRES: A New High-Resolution Reanalysis Dataset for Italy*. Meteorological Applications, 31(6), e70011. https://doi.org/10.1002/met.70011

- Acronyms: The manuscript contains many acronyms, which makes it easy to lose track. I recommend reducing their use where possible and writing terms explicitly. I will provide examples in the technical corrections.

Thank you for this helpful suggestion. Reducing the number of acronyms and writing terms explicitly where possible will improve the readability of the manuscript. In the revised version, we will carefully review the text and limit the use of acronyms, while ensuring that the key terms remain clear and consistent throughout the paper.

Technical corrections:

-Line 4: Please specify explicitly how many years of data are available.

Thank you for pointing this out. In the revised manuscript, we will explicitly indicate that the dataset spans 37 years, from 1986 to 2022.

-Line 25: Here you state that extreme precipitation changes are due to thermodynamics (CC scaling). What about the role of dynamics? For instance, see Pfahl et al. (2017):

Pfahl, S., O'Gorman, P. A., & Fischer, E. M. (2017). Understanding the regional pattern of projected future changes in extreme precipitation. Nature Climate Change, 7(6), 423-427.

Thank you for this important comment and for suggesting a valuable reference. We agree that extreme precipitation changes are influenced not only by thermodynamic effects, such as Clausius–Clapeyron scaling, but also by dynamic processes. While thermodynamic effects tend to produce a relatively uniform fractional increase in extremes, dynamic contributions can modify these changes regionally, leading to variations in the intensity and frequency of extreme events. In the revised manuscript, we will clarify this point and discuss both thermodynamic and dynamic influences on extreme precipitation.

- Line 51: Please, define ARCIS.

Thank you for pointing this out. In the revised manuscript, we will explicitly define ARCIS as the "*Archivio Climatologico per l'Italia Centro Settentrionale*", a high-resolution climate precipitation dataset for north-central Italy (Pavan et al., 2019)

Pavan, V., Antolini, G., Barbiero, R., Berni, N., Brunier, F., C., A. Cagnati, O. Cazzuli, A. Cicogna, C. De Luigi, E. Di Carlo, M. Francioni, L. Maraldo, G. Marigo, S. Micheletti, L. Onorato, E. Panettieri, U. Pellegrini, R. Pelosini, D. Piccinini, S. Ratto, C. Ronchi, L. Rusca, S. Sofia, M. Stelluti, R. Tomozeiu, T. Torrigiani Malaspina, 2019: *High resolution climate precipitation analysis for north-central Italy, 1961–2015.* Clim. Dyn. 52, 3435–3453. https://doi.org/10.1007/s00382-018-4337-6

- Line 65: Please, define GRIPHO

In the revised manuscript, we will explicitly define GRIPHO as "GRidded Italian Precipitation Hourly Observations", a high-resolution precipitation dataset for Italy (Fantini, 2019).

Fantini, A. *Climate change impact on flood hazard over Italy*, PhD Thesis, (2019).

-Lines 77-79: Please add supporting references.

Thank you for this suggestion. We agree that providing supporting references will strengthen these statements. In the revised manuscript, we explain that operative rain gauge networks tend to underestimate extreme convective precipitation over small areas, and point-scale extremes can be underestimated by about 20% (Schroeer et al., 2018). Conversely, radar and satellite-based precipitation estimates may exhibit large positive or negative biases (Wang et al., 2021).

Schroeer, K., Kirchengast, G., & O, S. (2018). *Strong Dependence of Extreme Convective Precipitation Intensities on Gauge Network Density.* Geophysical Research Letters, 45, 8253–8263. https://doi.org/10.1029/2018GL077994

Wang, S., Li, C., Li, D., Tian, X., Bao, H., Chen, G., & Xia, Y. (2021). *Exploring the utility of radar and satellite-sensed precipitation and their dynamic bias correction for integrated prediction of flood and landslide hazards.* Journal of Hydrology. https://doi.org/10.1016/j.jhydrol.2021.126964

-Line 147: How sensitive are your results to the choice of the 50th percentile threshold?

Thank you for this comment. We have tested the sensitivity of our results building alternative event-based datasets constructed with different thresholds, both percentile-based and fixed. In particular, as noted in lines 286–290 of the manuscript, using a fixed 1 mm threshold (figures provided in the Supplementary Material), our analyses show small variations, indicating that the observed seasonal differences primarily reflect genuine variability rather than artifacts introduced by the clustering method. Importantly, this also holds for extreme precipitation trends, suggesting that our results are robust to the choice of the 50th percentile threshold.

-Figure 2: Consider using a single colorbar and enlarging it for clarity.

Thank you for this suggestion. In the revised manuscript, we will adjust Figure 2 accordingly to enhance readability.

-Table 1: Consider alternative acronyms instead of axis_maj or lon_wavg, lat_wavg, which are not very intuitive.

Thank you for the suggestion. The acronyms `axis_maj`, `lon_wavg`, and `lat_wavg` are those used in the HOPE-X dataset, and we need to retain them to maintain consistency and facilitate reference to the original data. In the rest of the text, we will strive to use more descriptive terms to ensure clarity.

-Line 178: Have you considered that grid cell size decreases with latitude? This could affect your area-based results.

Thank you for the comment. We have considered the variation of grid cell size with latitude. Across our study area (36°N–47°N), the relative difference in grid cell area due to meridian convergence is limited, with cells at higher latitudes being slightly smaller. To quantify this effect, we used the NOAA distance calculator (https://www.nhc.noaa.gov/gccalc.shtml) and verified that the distance represented by 0.1° in longitude decreases only modestly with latitude: for example, from approximately 9 km at 36°N to about 8 km at 47°N.

For many large-scale analyses, this difference (on the order of ~10–15%) is considered negligible, particularly when results are aggregated or averaged across the domain. Our objective is to provide a consistent view of the relationship between spatial scales and the characteristics of the identified events. In this context, the modest variations in grid cell shape and size do not significantly affect our conclusions.

-Line 181-182: The acronyms here are difficult to follow, please consider spelling them out.

Thank you for the comment. We will follow your suggestion and avoid using acronyms here, spelling them out instead to improve clarity, as also suggested by reviewer #1.

-Line 230: Please clarify whether this refers to a large quasi-stationary cyclone.

Thank you for this comment. You are correct: it refers to a large quasi-stationary cyclone. We will clarify this point in the revised manuscript to make it explicit.

-Line 240: Be cautious with the claim that 4 km simulations can fully resolve these processes; please consider rephrasing.

Thank you for the comment. We agree that the original statement may sound too strong. In the revised manuscript, we will rephrase it more cautiously to reflect that 4 km simulations are able to *explicitly represent* convection and related processes, but *may not fully resolve* them. This wording better captures the current understanding of the capabilities and limitations of convection-permitting simulations.

-Line 374-377: It would be useful to mention dataset biases earlier (e.g. in the data section), and to quantify them explicitly as percentages relative to observations.

Thank you for the comment. We agree that discussing dataset biases earlier in the manuscript would improve clarity. In the revised version, we will introduce this information already in the Data section and provide a quantification of the biases as percentages relative to observations.

-Line 378: Please elaborate on the role of skin temperature in WRF biases.

Thank you for the comment. In the revised manuscript, we will elaborate on the role of skin temperature in WRF biases, highlighting how deviations in surface temperature can propagate to near-surface variables and influence model performance.