We would like to thank the reviewer for careful assessment of our manuscript . In the supplement, we outline how we propose each point and describe the corresponding revisions. Overall, we feel that this exchange has led to a clearer and more robust version of the manuscript.

Introduction

The Introduction provides a strong motivation, but it would be helpful to explicitly state the research gap early on-what is unknown about the spatio-temporal structure of extreme precipitation in Germany that this study addresses?

> → We agree with this comment and would like to add the following paragraphs in our introduction to address this:
> Line 30: "This article presents a method for the quantitative assessment of changes in the spectral properties of an event simultaneously in space and time. This provides information about the processes involved, as the spatial and temporal scales are characteristic of certain processes. It is therefore to be expected that the proportion of convective precipitation will be greater in phases with increased small-scale variability. This can be observed when comparing typical scales in summer and winter. This can be observed when comparing typical scales in summer and winter. Over Germany, the average spatial scale of precipitation events in summer is significantly reduced compared to the winter months, reflecting the increased number of convective precipitation events in summer. (Lengfeld et al., 2020)."
> Line 37: "The CatRaRe catalog (Lengfeld et al., 2025), provided by the German Weather Service (DWD) e.g., uses the duration and affected area of the respective event to characterise precipitation events by their space-time characteristics. "

Lines 61-70- Including a brief note on uncertainties associated with radar data or the wavelet decomposition approach would be helpful.

> → We would like to add a more detailed discussion of uncertainties in the "Summary and Conclusion" section. Particularly given that the reviewer requested a detailed discussion here as well. We thus propose adding the following:
> Line 332: "The potentially large uncertainties in precipitation data should always be taken into account, particularly when comparing the spectral properties of precipitation from different data sources or even non-homogeneous observation systems. An impression of how large the differences are in the precipitation amounts of a single event can be seen in Kracheletz et al. (2025), who compared different observations and reanalyses. In addition, the spatial error structure of radar data is very inhomogeneous due to the radial observation method, although radar data is probably the best data we have to assess spatial properties. Different spatial interpolation methods also influence the spatial structure of the data and contain little information about the actual spatial dependency structure. Therefore, gridded data based on station data are unsuitable for such an analysis. In reanalyses and models, the spatial structure is determined by the effective resolution of the models, which is usually much coarser than the grid spacing (Bierdel et al., 2012).
>
> The uncertainties in the spectral characteristics of the data is similarly large as in the respective gridded version, since wavelet transformation represents a linear transformation, and the calculation of the spectral characteristics only provide some averaging over space. One should therefore treat these spectral characteristics similar to other measures in data analysis, with a thorough assessment of statistical significance (Torrence and Compo, 1998)."

Lines 65-69- a short remark on how the metrics (e.g., characteristic scale and characteristic speed) could be useful beyond this study (e.g., for model evaluation or future climate projections) would broaden the perceived relevance.

> → Thanks for raising this. We agreee and would like to include the following statement:
> Line 70: "The proposed metrics have a wide range of uses beyond the scope of this study. These include quality assessment and intercomparison of datasets, as well as evaluation of climate projections (e.g. CMIP)."

Theory

Line 85- A short clarification of how alternative wavelet families were evaluated would improve transparency.

> → Something similar was also noted in the second review. Considering this comment, we would like to expand on our explanation: In principle, every wavelet family has its advantages and disadvantages. The DT-CWT is complex, but provides better shift invariance compared to e.g Daubechies wavelets, which means that DT-CWT is more robust to small shifts of the signal in space and time. We would rewrite the paragraph as follows:
> "Compared to more traditional, real wavelet families, such as Haar or Daubechies wavelets, the DT-CWT exhibits improved shift invariance, meaning that its coefficients are more robust to small spatial and temporal displacements of the signal. In principle, the proposed method can be implemented with any wavelet family. We tested several alternatives, including Haar and Daubechies wavelets, but did not observe any substantial performance advantage over the DT-CWT in terms of computational efficiency"

Lines 120-127- It would be beneficial to highlight the advantage of combining 1D temporal and 2D spatial WTs over a fully 3D WT.

→ We can add this in the manuscript. Specifically, we would like to add the following paragraph:
Line 125: "A rather intuitive approach is to extend the DT ℂWT to three dimensions (Selesnick, 2003), in which case the complex wavelet coefficients can be expressed as:

$$d_q^{j_{X,Y,T}}(k_X, k_Y, k_T) = \langle f(x,y,t), \psi^{(k_X,k_Y,k_T),j_{X,Y,T}}(x,y,t)\rangle_{x,y,t}. \tag{1}$$

The scaling parameter $j_{x,y,t}$ of the 3D wavelet determines the resolution in all three dimensions simultaneously. As a result, it is very difficult to determine the scale changes in space and time separately. This limitation is analogous to the two-dimensional transform, where a single scaling parameter controls both the x and y dimensions (see Sect. 2.1). To address this limitation, we adopt a hybrid approach that separates spatial and temporal scales. Specifically, a one-dimensional WT along the temporal dimension t and a two-dimensional WT for the spatial fields (x, y) and calculate the wavelet coefficients as follows: ..."

0.1 Data & Preprocessing

Line 155- A short statement clarifying why these specific pressure levels were chosen in ERA5 would strengthen the physical interpretation.

→ Thanks for this comment. We would like to add the following statement:
Line 155: "The selected pressure levels cover all relevant atmospheric layers, ranging from near-surface conditions (1000 hPa) through the lower and mid-troposphere (850–500 hPa) up to the upper troposphere (300 hPa), thereby providing a vertically comprehensive representation of the atmospheric state."

Line 166- It may be useful to briefly discuss how the 72-hour separation criterion affects the number and independence of events.

→ Thanks for noticing. We would like to include the following explanation:
Line 167: "The choice of 72 hours has no impact on the number of events and we consider this interval long enough to ensure the independence as typical precipitation events in Germany tend to not exceed this time interval."

Line 181- Acknowledging potential implications for events extending beyond the RadKlim spatial domain could strengthen the discussion.

→ We agree with this comment and would like to include the following explanation:
Line 181: "This limitation may lead to an underestimation of the characteristic length compared to an analysis that accounts for the full spatial extent of the event."

Analysis

Section 4.1

Lines 191-193- While the 2002 and 2021 events are noted among the top five, briefly clarifying if they represent different precipitation regimes (multi-day vs. short, intense convective events) would strengthen the case study motivation.

→ We agree and would like to move the following sentence (Lines 213-215) to
Line 195: "Previous studies highlight the August 2002 event as a multi-day rainfall episode (e.g. Ulbrich et al., 2003). By contrast, the July 2021 event was dominated by a series of very intense, short-duration convective rainfall events (e.g. Ludwig et al., 2023; Tradowsky et al., 2023). These contrasting characteristics make both events particularly suitable for a comparative case study."

Lines 200-203 note that 1D and 2D WTs treat space and time separately. A brief remark on how this limitation might affect interpretation or potential biases in estimating characteristic scales could benefit the readers.

→ Thanks to pointing this out. We can provide more detail on this as follows:
Line 198: "The characteristic times and lengths that emerge as dominant in this representation are also found in the wavelet spectrum in Fig. 4. However, this representation additionally provides insight into when and where particular scale contributions occur."

The comparison across the top six events is informative. Commenting on how representative these events are of the full sample would help contextualise the results.

→ Good point! We can include such a statement:
Line 207: "Each event shows different characteristics in terms of their space-time characteristics, reflecting how different individual precipitation events can be."

Line 231: "In comparison to the top 100 precipitation events analyzed in the following section, the top six events are characterized by comparatively large characteristic scales and low characteristic speeds (see Fig. 9). This tendency toward larger-scale, slower-moving systems among the most extreme events is discussed in more detail below."

Minor- there is a misalignment in the Table reference (mentioned Tab. 2) on Line 226 and the Table caption on Line 233 (mentioned Table 1).

→ Thanks! we would be happy to correct that.

Section 4.2

It would be helpful to briefly justify the choice of K-means clustering over other clustering methods.

→ That is a good point. In fact we did try other clustering techniques, which did not change our results. We would like to ad this as follows:
Line 246: "We apply K-means clustering because it is widely used and provides interpretable results. Tests with alternative clustering techniques yielded consistent results and did not modify the findings presented below."

A short physical interpretation of each cluster (in the three-cluster solution) in terms of precipitation-generating processes would be helpful.

→ We would like to modify the interpretation of the cluster solutions in Line 253 as follows: "(A) large spatiotemporal-scale events with low propagation speeds, likely associated with synoptic, quasi-stationary systems such as blocked cyclones or persistent frontal zones; (B) large spatiotemporal-scale events with substantially higher propagation speeds, likely dominated by strong large-scale advection, for example rapidly moving frontal systems or cyclones embedded in a strong westerly flow; and (C) small spatiotemporal-scale events that are likely associated with convectively driven precipitation."

The observed relationship between precipitation volume and slower propagation is interesting; clarifying whether this is statistically tested or primarily descriptive would add clarity.

→ We would like to clarify this and suggest the following adjustment in Line 259: "Although no formal statistical test was conducted, this observation is consistent with the physical interpretation of cluster A and cluster B outlined above, where slower-moving, large-scale events tend to accumulate higher precipitation totals."

In the trend analysis, it would benefit the readers by a brief discussion on the implications of limited sample size and short record length would help contextualise the non-significant results.

→ We agree that a further discussion would be beneficial, and we would like to include in Line 266: "For trend analyses, this period is already quite short, so it is not surprising that statistically robust trends are absent."

Physical foundations

The use of independent reanalysis-based variables to assess physical foundations is well motivated; consider briefly noting why they complement the WT-derived metrics to reinforce the added value of incorporating reanalysis data.

→ This is a good point: We would like to add the following in
Line 275: "Taken together, these two variables provide a description of the prevailing atmospheric conditions during each event. This allows us to examine whether the characteristics inferred from precipitation events in the previous section, namely the characteristic scale and characteristic speed, align with the expected atmospheric influences."

A short discussion of why near-surface winds show lower correlation, and what would be the potential reason(s) for 500 hPa showing the highest correlation, could help readers interpret the physical meaning more easily.

→ We agree with this point and would like to include a more detailed discussion:
Line 282: "Precipitation systems, especially those at the synoptic level, are propagated by the prevailing tropospheric flow rather than surface winds, where friction effects are minimal and winds reflect the geostrophically balanced motion of the atmosphere."

Minor- Line 290- Correlation summary is useful. Consider briefly noting variability or exceptions across events (e.g., cases where slowly propagating systems do not produce the largest volumes) to provide a balanced view.

→ We agree that a mor balanced view would be benefitial for the reader. We would like to add a more detailed description as follows:
Line 292: "Although the correlations are not strong, this is consistent with the results in Section **??** suggesting that slow-moving, large-scale systems tend to produce greater accumulated precipitation amounts. Nevertheless, exceptions to this general tendency do occur, as smaller-scale or faster-moving systems can also generate substantial precipitation totals under favorable dynamic or thermodynamic conditions."

Summary and Conclusion

Minor, but conclusions should be in the past tense, e.g., line 300- it should be we 'investigated', line 302- 'considered', 'distinguished', line 306- 'identified', etc.

→ Thanks for noticing. We'd be happy to correct that.

Overall, currently, the conclusions read more like a brief list of the rest of the manuscript. Instead, it would be helpful to have a synthesis of key findings in a broader context, interpreting their meaning, highlighting their significance, and outlining potential directions for future work.

- Thank you for this comment. The second reviewer also noted that the discussion of our method comes a bit short. We will revise the complete section accordingly, and would additionally add the following statements: Line 317: "Using the six most intense precipitation events as illustrative examples, we demonstrated how our three-dimensional WT framework, namely the derived wavelet spectrum reveals contributions from different spatial and temporal scales within precipitation events. To the best of our knowledge, no comparable approach currently exists that enables an equally effective and scale-resolved decomposition.

  We conclude that the wavelet spectrum is particularly suited for analyzing individual events. Possible applications include comparing specific precipitation events or how they are represented in different data sets." Line 341: "In summary, the proposed characteristic variables constitute a robust and transferable tool for quantifying the mean spatiotemporal properties of precipitation events. They are particularly well suited for the systematic analysis and comparison of multiple events. They, E.g. enable, consistent comparisons across different datasets or scenarios. A more comprehensive assessment, including convection-permitting climate model simulations, is planned for future work."

Line 321- briefly clarifying why characteristic scale and speed emerge as dominant would strengthen the interpretation.

→ Thank you for noticing! We would like to include the following to add more clarity:
Line 323: "This separation enables a straightforward interpretation of the spatiotemporal characteristics of precipitation events. An important advantage of considering these two characteristics is that they are independent while at the same time representing physically interpretive quantities. The pronounced dominance of the characteristic scale and propagation speed is likely linked to the mid-latitude focus region, which is governed by prevailing westerlies and the associated advection of precipitation systems. The importance of the spatial scale further reflects the substantial heterogeneity of precipitation structures in this region, arising from the coexistence of different underlying mechanisms, such as convective and synoptic-scale processes."

Lines 324-329- Including a short statement on uncertainty or variability around the observed association between high-impact events and slow-moving, large-scale systems would provide balance.

→ Along with our revision of the section as detailed in the previous comment, we would like to ad the following to add clarity:
Line 324: "Most of the 25 strongest events, measured by their total precipitation within a confined area and time period, are characterized by relatively slow characteristic speeds and large characteristic scales. We however find no significance correlation."

Technical comments

It is observed that 'see' or 'e.g.' is used in most of the citations throughout the manuscript. It would be useful to revise and remove it wherever necessary.

→ Thanks for noticing. We'd be happy to change our manuscript as suggested.

Appendix A: Lines 349-351: The resampling strategy (80% subsamples, without replacement) is well described; stating why 80% was chosen would improve reproducibility.

→ Thanks for noticing. We'd be happy to change our manuscript as suggested.

Appendix C: No text, apart from the section title, has been added to support Fig. C1. It currently reads incomplete.

→ Thanks for noticing. We'd be happy to provide an explanation also for this section.