Interactive Discussion: Author Response to Referee #2

Quantifying the extremeness of precipitation across scales

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RC: ***Reviewer Comment***, AR: *Author Response*, ☐ Manuscript text

Dear Referee,

we would like to thank you very much for your willingness to review this paper, and for your swift, positive and constructive response to the manuscript.

Please find our responses to your comments below. These should be considered as preliminary (part of the interactive discussion). The final implementation of changes also depends on another referee report.

Thanks again for your efforts!

Kind regards,
Paul Voit and Maik Heistermann

RC: ***The authors analyzed 100+1 events with extra high WEI values and determined the xWEI for these events. While I do not suppose that there could be an event with a very high xWEI and yet a WEI so low that it would not belong to the 101 events analyzed, the authors should check this possibility.***

AR: We agree that this possibility exists. The aim of this study, however, is not an exhaustive search for extreme events in the RADKLIM dataset. Instead, we intend to introduce the concept of the *xWEI* and compare *WEI* and *xWEI* for a set of 100+1 events which we selected based on the *WEI* in the CatRaRE catalog. After we have now established that *xWEI* is informative, we will, in the next step, start to systematically and comprehensively extract extreme events from the RADKLIM dataset and compare them with regard to *WEI* and *xWEI*. We had outlined this (computationally expensive) perspective in ll. 360-361 of the preprint. Based on the referee's comment, we suggest to add another sentence thereafter, so the statement will become:

> To extend the limited scope of this study, future applications should aim at a comprehensive detection and ranking of extreme events from the RADKLIM data set or other similar data sets. That way, we might possibly find events with a very high xWEI which were not yet represented in the 100+1 events selected for the present study (based on the CatRaRE catalog).

RC: ***An important parameter is not only the size of the considered area, but also its shape. The authors should mention this aspect in the article, because the affected area is often elongated in one direction compared to a square.***

AR: We agree that the shape of the precipitation area is a relevant parameter that deserves further attention for two reasons.

The first reason is more about the relationship between shape and impact. Depending on shape and orientation, the generated runoff might concentrate in a single basin or in multiple neighbouring basins which is likely to have an effect on flood peaks and corresponding impacts. However, this effect also depends on the orientation and shape of affected basins. In general, measures of eccentricity or anisotropy of a rain field could be used as additional metrics in combination with extremity measures such as *WEI* or *xWEI*. To investigate such effects - the interplay of rainfall field attributes and surface properties - should be subject to future research, but is beyond the scope of the present study. We suggest not to discuss this in depth.

The second reason is more at the heart of the present study: a square region of interest might not be able to capture the extent of an event in case of elongated structures. That is, however, a special case of the more general problem in that a region of fixed size might limit the ability to capture the extremeness across scales. In turn, using variable/adjustable regions of interest (variable in size or even shape) makes it difficult to compare (and hence rank) events among each other. One way out of this dilemma could be to normalize *WEI* and *xWEI*, similarly to Gvoždíková et al. (2019). However, such a normalization again introduces further parameters which need to be quantified.

Apart from these specific issues, the actual concept of *xWEI* appears valid and becomes most intriguing if events are to be compared for a region of interest that is not only fixed in size but also in location (see ll. 316 ff. of the preprint): for instance, we can compute the extremeness of events that affected a specific river basin. In that case, it does not play a role whether outside that basin the rainfall process continues to be extreme, as we only want to rank the rainfall that actually affected a well-defined region.

We will emphasize the specific challenge of elongated (frontal) structures in section 4.3.2 in which we discuss setting the spatial domain. In ll. 315-316 of the preprint, we already stated:

> For many events, though, the value of xWEI will grow further if we increase the spatial domain of analysis.

We will add, to this sentence:

> Furthermore, the square shape of the spatial domain might not be an optimal choice to appreciate the extremity of elongated precipitation structures as they e.g. occur along frontal lines [...].

RC: ***It is also not clear from the paper how the authors dealt with the situation where the core of the event was located at the German border and the 200x200 km square extended beyond the area covered by the data.***

AR: In lines 322-323 of the preprint, we mentioned the fundamental issue of edge effects:

> In the context of the spatial domain, we also need to be aware that the resulting indices might not represent the full level of extremeness in case the spatial domain of analysis is partly outside the spatial domain for which observations are available. For example, the WG/Jul2021 event extended considerably towards Belgium so that parts of the event were not captured by the radar composite of the German Weather Service.

The problem of the spatial window extending beyond the actual precipitation dataset is not a computational issue in itself (missing values can be treated as zero rainfall). The problem arises in case we have to suspect that substantial parts of the extreme event are hidden behind these missing values, i.e. occured outside the observational domain. As a result, we will underestimate the extremity of events that are close to the edges of the RADKLIM dataset. In the present study, we simply accepted this issue. Instead, one could, for example, discard extreme events of which the centroid is closer than say 100 km to the edge of the data domain. That way, we avoid underestimation, but instead just entirely *miss* important events. Alternatively, we could try to fill missing values around the edges from other data sources, e.g. radar composites or rain gauge data from neighbouring states, or reanalysis model data. Apart from the fact that this would introduce heterogeneity in the data and hence decrease the comparability of events, it would also increase the required resources for data collection and processing. And in the end, there will still be edges.

Altogether, this issue is important to be aware of, but difficult to resolve. As a response to the referee's comment, we propose to enhance the above statement a bit to that it becomes:

> In the context of the spatial domain, we also need to be aware that the resulting indices might not represent the full level of extremeness in case the spatial domain of analysis and the precipitation event extend beyond the spatial domain for which observations are available. For example, the WG/Jul2021 event extended considerably towards Belgium so that parts of the event were not captured by the radar composite of the German Weather Service. The same applies to the SN/Aug2002 event which extended far into the Czech Republic. In fact, we need to acknowledge that the extremeness of events close to the edges of the dataset will, on average, be systematically underestimated. We still decided, for this study, not to discard events that occurred close to the German borders - otherwise, some of the most important events would be entirely missing. Future research, however, could attempt to quantify the systematic errors that are introduced by edge effects.

In section 3.4 we added following part after line 218:

> It is possible that events are not fully captured by this window shape and size but to keep events comparable we decided to stick to a uniform window for all events. Events which are situated close to the state borders of Germany contain more missing rainfall values which adds uncertainty to the evaluation of these events. In some cases the centroid of the event was outside the state borders of Germany. In this case we moved the centroid to the closest pixel with higher rainfall and thereby shifted the spatial domain of the event slightly inwards the borders of Germany. Potential implications of such choices are discussed in section 4.3.

RC: ***The authors note that the NI/Jul2017 event ranked higher than SN/Aug2002 in the WEI, but offer no explanation (Figure 4 does not include NI/Jul2017). Could the reason be the state-border effect, where SN/Aug2002 significantly affected also the neighboring Czech Republic (Müller et al., 2015)?***

AR: We agree that this could be a reason, based on the discussion of the referee's previous comment. As a response, we would like to extend our previous statement from ll. 245-246:

> Interestingly, the NI/Jul2017 (*WEI* rank: 2, *xWEI* rank: 6) event outranks the famous SN/Aug2002 event that flooded the city of Dresden (*WEI* rank: 3, *sWEI* rank: 2) when ranked by the *WEI*. However, we need to be aware that the SN/Aug2002 event might not have been captured in its full extent by the RADKLIM data as it also affected significant parts of the Czech republic (Müller et al., 2015).

RC: ***In my opinion, flash- or pluvial floods are mainly related to infiltration excess (line 40) while saturation excess is more typical in case of large-scale fluvial floods (e.g., Rogger et al., 2013).***

AR: We thank the referee for this comment, and we tend to agree. However, we are hesitant to engage, in the context of this paper, specifically in the discussion of runoff generation mechanisms as the relationships between scale, runoff generation and flood processes can be complex (see e.g. Vivoni, 2007). Hence, we suggest to remove the reference to specific runoff generation mechanisms, so that the statement becomes:

> "Short duration rainfall with high intensities is associated to flash- or pluvial floods while persistent precipitation episodes on the daily scale can lead to large-scale fluvial floods."

RC: ***If the form of the short names of HPEs is your choice, I suggest to replace "NI" by "LS" which seems to be more intuitive in English.***

AR: In order to be as consistent as possible regarding the naming of the events, we appreciate this comment. "NI" will be changed to "LS" in all plots and in the text, as Lower-Saxony is the English name of this German state. This will affect the two events NI/Jul2017 and NI/Jul2002 which will be called LS/Jul2017 and LS/Jul2002 in updated version of the manuscript.

RC: ***Date formats should be unified, compare e.g. beginnings of both case studies.***

AR: We unified the data formats and hope that all the mentioned dates are now in the same format.

RC: ***I recommend expanding the beginning of Figure 6 and Figure 7 captions so that they are not just short names of the events. On the other hand, in my opinion, the interpretation of the two pictures does not belong in the captions, its place is in the text.***

AR: We thank the referee for the suggestion. We added the full name corresponding to the text in case study 1 and 2 and removed redundant information about the extremeness of these events to the captions of Figure 6 and Figure 7.

RC: ***Typos***

AR: The typos have been fixed according to the referees notifications.

References

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