Interactive Discussion: Author Response to Referee #1

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: ***[...] after reading the article, a general question that remains is the following. The motivation that leads to the definition of WEI is quite clear, we can say -simplifying a lot- that WEI takes the "maximum of maximums" to classify an extreme event. On the other hand, xWEI is somewhat closer to an average WEI across spatio-temporal scales. In this sense, the final xWEI ranking of events might not differ from one obtained using simpler metrics, such as the total precipitation amount integrated over the same spatial scales (e.g. upscale the amounts on coarser grids, by averaging, then integrate). [...] it might be worth showing that the index is more informative than coarser/simpler . In fact, among important users of indices like xWEI there are the providers of climate services. For them, it is quite important that the information delivered conveys an immediate message to the final user. In this sense, a ranking of the events based on e.g. rainfall intensity, rainfall duration, or return period/probability of exceedance may be more appealing. For future research, I suggest you focus also on the comparison against ranking of extreme events based on simpler indicators. It would be interesting to understand the additional information content of xWEI in terms of correlation with registered damages after a catastrophic event, for instance.***

AR: We thank the referee for these ideas, and we agree. As the referee pointed out, these are all valid research questions for future research. While we are hesitant to assume that the *WEI* shows a straightforward relationship to "conventional" event properties such as event intensity or depth, we agree that - once we have established that the *xWEI* conveys important (impact-relevant) properties of extreme precipitation – it could be useful find ways to approximate the *xWEI* by simpler or maybe more intuitive metrics (or combinations of such).

We very much agree with the idea to relate the *xWEI* to observed damages and impacts in order to explore

whether it is able to explain specific damages or damage magnitudes better than other metrics. We had tried to highlight the importance of such an endeavor in ll. 358-360 of the preprint.

RC: ***Title: You may consider to add "quantifying extremeness of precipitation across scales using the cross-scale weather extremity index xWEI"***

AR: We thank the referee for the suggestion, and we agree that it would be informative to mention that we actually suggest an index to measure cross-scale extremity. However, we would like to keep the acronym xWEI from the title, and we would also like to avoid redundancy in the wording (mentioning extremeness and extremity, as well as across scales and cross-scale). We hence suggest to change the title to "A new index to quantify the extremeness of precipitation across scales".

RC: ***Abstract. The abstract can be shortened significantly. Try to be short and snappy. For instance, your first 12 lines could be rephrased as (what follows is just an example) "Quantifying the extremeness of a heavy precipitation event is important to classify it. The impact of an event depends on its spatial extent and duration, many indices neglect at least one of these aspects. The weather extremity index (WEI) quantifies the extremeness of an event and identifies the spatial and temporal scale at which the event was most extreme. However, the WEI does not account for the fact that an event can be extreme simultaneously at various spatial and temporal scales. To better understand and detect the compound nature of precipitation events, we suggest to complement the original WEI, and refer to this complement as the "cross-scale weather extremity index" (xWEI). xWEI does not aim to detect the spatio-temporal scale of maximum extremeness, instead it integrates extremeness over relevant scales."***

AR: We thank the referee for the specific suggestions, and we agree that the abstract could and should be shortened. In particular, we will focus the abstract more towards outlining the concept of the cross-scale extremity index instead of providing a comprehensive record of study results. We gladly used your suggestions and shortened the abstract by more than one third, so it becomes:

> Quantifying the extremeness of heavy precipitation allows for the comparison of events. Conventional quantitative indices, however, typically neglect the spatial extent or the duration while both are important to understand potential impacts. In 2014, the weather extremity index (*WEI*) was suggested to quantify the extremeness of an event and to identify the spatial and temporal scale at which the event was most extreme. However, the *WEI* does not account for the fact that one event can be extreme at various spatial and temporal scales. To better understand and detect such compound nature of precipitation events, we suggest to complement the original *WEI* by a "cross-scale weather extremity index" (*xWEI*) which integrates extremeness over relevant scales instead of determining its maximum.
>
> Based on a set of 101 extreme precipitation events in Germany, we outline and demonstrate the computation of both *WEI* and *xWEI*. We find that the choice of the index can lead to considerable differences in the assessment of past events, but that the most extreme events are ranked consistently, independently of the index. Even then, the *xWEI* index can reveal cross-scale properties which would otherwise remain hidden. This also applies to the disastrous event from July 2021 which clearly outranks all other analysed events with regard to both *WEI* and *xWEI*.
>
> While demonstrating the added value of *xWEI*, we also identify various methodological challenges along the required computational workflow: these include the parameter estimation for the extreme value distributions, the definition of maximum spatial extent and temporal duration, as well as the weighting of extremeness at different scales. These challenges, however, also represent opportunities to adjust the retrieval of *WEI* and *xWEI* to specific user requirements and application scenarios.

RC: ***Sec. 2.1. Line 118. When you write that "RADKLIM provides a promising dataset for climatological application", do you mean that it is consistent in time? Can you be a bit more specific***

AR: As an operational procedure, RADOLAN is subject to e.g. hard- and software updates over the years or to some rain gauge observations being unavailable in real-time. Therefore, RADKLIM provides a "consistent" reanalysis by using state-of-the-art processing techniques, including new correction algorithms (e.g., for distance- and height-dependent signal reduction) and an enhanced set of of rain gauges for adjustment. The DWD developed RADKLIM with the intent to enable radar-based climatological research and especially heavy rainfall analyses. For these reasons, other authors described RADKLIM as more suitable for climatological studies. We use the term "consistent" instead of "homogeneous" because the issue of heterogeneity due to e.g. changes in radar locations and hardware cannot be entirely resolved by the reanalysis. Furthermore, some parts in the very North, East and South of Germany were only covered for a few years. In general, however, the data coverage over Germany is very good with missing hours of less then 10 % in most areas. Regions of data coverage around 90 % in central Germany are due to exchanges of radar systems. We added additional information and corresponding references in section 2.1.

> The DWD developed RADKLIM with the intent to enable radar-based climatological research and especially heavy rainfall analysis (Kreklow et al. (2019), Winterrath et al. (2018b)). Therefore, the data from 2001 to 2020 was reanalysed by using consistent state-of-the-art algorithms as well as an extended set of rain gauge observations for the adjustment step. It was shown that this procedure minimizes the occurrence of artifacts (Lengfeld et al., 2019) making RADKLIM to a promising dataset for climatological applications (Pöschmann et al., 2019). The resulting dataset is a Germany-wide precipitation field of hourly precipitation sums at an extent of 1100 x 900 km and at a resolution of 1 x 1 km and is available on the DWD open data server (Winterrath et al., 2018a). Parts in the very North, East and South of Germany were only covered for a few years. Otherwise the data coverage is good over Germany with missing hours of less then 10 % in most areas (Lengfeld et al., 2019).

RC: ***Sec. 3.2. I like your idea of using an example to introduce the WEI. However, I think that: i) you should better describe the initial configuration of your example. At line 174, before "Starting with the pixel…" you may consider adding something like "we will refer to the following example, shown in figure 1, let's consider an event as follows …"; ii) the definition of the area A is a critical point of the procedure that you discuss again in Sec. 4.3.1, I think that you should let the reader know that you are going to discuss further this point and introduce a reference to Sec 4.3.1 within Sec 3.2. In general, try to create better links between related sections.***

AR: We entirely agree, and we will revise the manuscript along the referee's suggestions, including an improved cross-referencing between (sub-)sections. At the same time, we will try to avoid redundancies between the caption of Fig. 1 and the main text.

RC: ***Sec 3.3. The ratio behind the definition of xWEI is explained in a clear way. I do not completely understand why you need to interpolate the WEI value onto a regular grid (Fig. 2c). It looks to me that one may sum all the areas of the colored curves in Fig 2b and that's it. Since Fig 2b should include all the durations that a user may be interested in, I do not see the risk of overemphasising long durations. Could you add something more on this point?***

AR: We very much agree that the referee has a point. We ourselves had the exact same thought: to just sum up or average the area under the individual curves for each duration. This approach is certainly more computationally efficient. Yet, we decided to take the additional step of interpolation for mainly two reasons:

first, the interpolation addresses the effect that the selection of specific duration intervals is somewhat arbitrary: hence we hope that the interpolation allows for a higher level of generalisation, formalisation, and also comparability by acknowledging that there is in fact a surface which we just need to efficiently approximate. The second reason is that we considered, from a visual perspective, the interpolated surface as a more intuitive and coherent representation of the index.

Having said that, we agree that a prospective scrutinization of the xWEI might establish general recommendations on duration choices and weights which allow to approximate the volume under the surface more efficiently, but still consistently.

In order to address the referee's comment, we tried to convey these points in the section 3.3 about the *xWEI* calculation:

> Even though it is computationally more demanding, we chose to interpolate a surface instead of just summing up the integrals of the individual curves (Fig. 2b) to ensure that we seamlessly represent all possible durations, and to avoid overemphasising the arbitrary choice of specific duration levels. Furthermore, we consider the volume under the surface as a more intuitive representation of the index.

RC: ***Fig 2a. If this is the same as Fig. 1d, then I think you should write it explicitly somewhere in the caption.***

Figure 1d and Figure 2a do not display the same event. The data for Figure 1, although based on an actual event, is simplified and partially altered to improve the clarity of the figure.

References

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