Authors' Response to Reviews of

Impact-based temporal clustering of multiple meteorological hazard types in southwestern Germany

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RC: ***Reviewers' Comment***, AR: Authors' Response, ☐ Manuscript Text

Reviewer #3

General comments

RC: ***The study "Impact-based temporal clustering of multiple meteorological hazard types in southwestern Germany" is a detailed analysis of multi-hazard occurrence and related insured losses in Baden-Württemberg. I find the study well-written and methodologically sound.***

AR: We would like to thank Dominik Paprotny for reviewing this article and their valuable comments.

RC: ***However, the main issue with the study is its relevance. As noted by the first reviewer, the analysed hazards are mostly clustered because they are physically connected to the same causes. This can be easily derived already from Figure 3 that the hazards are either caused by winter extra-tropical cyclones or summer convective storms. As the events are largely confined to two short seasons, analysing clustering up to 60 days will naturally show strong clustering.***

AR: For the part on potential clustering connected to the same physical causes, please see our answer to Reviewer #1, comment #2.

We agree that Fig. 3 shows a mainly seasonal occurrence and therefore a seasonal clustering. This is visible from Fig. 5a as well. However, Fig. 5b examines clusters forming due to the combination of different hazards, which can not be derived from Fig. 3. By using a clustering window of 21 days in Fig. 5, events occuring within the same season do not necessarily occur within a cluster.

On the other hand, we do analyse clustering up to 60 days using the statistical tool Ripley's K. We agree that due to the seasonal occurrence, an average event in a 'high season' will be surrounded by a relatively large number of events. We however disagree that this will naturally show strong clustering, since the degree of clustering is evaluated against a significance test of a random sample of (seasonal!) homogeneous Poisson processes with the same rate of occurrence. This is why the significance test is important, because it allows us to make statements on the degree of clustering, similarly done e. g. by Barton et al. (2016) or Tuel and Martius (2021). This is already described in detail in the main text (L227ff). We would like to complement this by the following paragraph:

> Note that this significance analysis actually determines the degree of clustering – due to seasonal patterns (see Sect. 4.2), events are likely to be surrounded by other events. The significance analysis serves the purpose of quantifying the deviation from the expected number of surrounding events and thereby provides

> an assessment of clustering.

If we analyse clustering on these seasonal timescales, seasonal clusters are often found (Figs. 6-8), but they require a different interpretation: Seasonal clustering here refers to some seasons showing a higher number of events while in other seasons, not many events are experienced. We already describe this in L225:

> Clustering on the seasonal level in our case compares the occurrence of events between different years (=seasons).

RC: ***One question is how relevant are the losses of clustered events compared to the loss of the "main" event. Were the losses in the past 40 years really clustered, or single major events were strongly dominant and the co-occurring losses (of the same or different type) were not really important?***

AR: Firstly, we would like to refer to Fig. 2 for this point. As directly visible from the figure and stated e. g. in L305–312, the losses throughout 1986–2023 were dominated by a few main events. We also highlight (see Fig. 1) that clustering of the most severe loss events does not occur, but major events dominate the loss. As seen from Fig. 5, these major events are however also connected with other events, thus occurring in clusters (e. g., Lothar in 1999). With an increasing geographic scope, this is expected to become more relevant. In addition, smaller events can also lead to considerable damage, especially in the years with the absence of major events. We argue that those events with medium loss should be considered in relation to each other and not by hazard type. As stated in the next answer, insurance companies and the corresponding damage regulators may still be overburdened by one event, while the next event is already occurring.

However, we acknowledge the relevance of evaluating the losses of the main event vs. the total losses, since this is a common clustering metric applied to insurance data. We would like to address this point in Sect. 5.4, which we would like to rename to "Loss patterns and clustering", and complement this with an additional figure on the ratio of occurrence exceedance probability (OEP), i.e., the loss of the main event in a year, versus the annual exceedance probability (AEP), corresponding to the total loss in a year (see Fig. 3 at the end of the document). In contrast to other studies, OEP and AEP are applied to aggregate losses across hazards. It can be seen that in certain years (e. g., 1999, 2013), the ratio of OEP/AEP is very high, indicating a large contribution of a single event and thus a low degree of clustering. The mean ratio of OEP/AEP across 1986–2023 however equals 0.39, which means that on average, the contribution of several events is relevant to annual losses. It is also visible that the degree of clustering as measured by OEP/AEP is much higher during DJF than during MJJA. When evaluated against the return period, medium loss years never exceed an OEP/AEP ratio of 0.5.

RC: ***I think the authors should more strongly highlight what they think is their contribution with this study, and especially why clustering is of any actual relevance in the study area in terms of societal and economic impacts, or at least for the insurance sector***

We thank Dominik Paprotny for this comment. We would like to split this answer in three parts:

1. **Economic and societal relevance of clustering:** Clustering is of actual relevance in the study area as described in the introduction, e. g. a succession of events in summer 2013 or in 2008. Economic impacts of clustering are evident from Fig. 10: Clustered events should not be neglected since clusters occur, and they lead to an increased loss compared to isolated events. This has also been found by Xoplaki et al. (2023) for Germany and by Hillier et al. (2015) for the UK. Examples of clustered hazards and their damage

amplification in Germany include an increased runoff in case of a heavy rain event after a heatwave, or an increased debris flow with damage potential in case of flooding after a storm event (see e. g., Kreibich et al. (2014)). Societal impacts include, for example, effects of cascading events (of also medium loss) while reparation is still ongoing: Authorities and technical organisations can become overburdened in a series of events due to limited availabilities for repeated action, since many of the organisations are based on volunteers. In longer periods of action, lack of food supply or rest of rescuers can harm recovery.

2. **Relevance for the insurance sector:** Likewise, insurance companies and their regulators can become be overburdened with a succession of several events. Since this depends on the number of major events (see Sect. 2.1.2), we would like to take up the suggestion to include an analysis of the ratio between maximum loss event and total seasonal loss (see previous answer and attached Fig. 1). We furthermore argue that insurance models should increasingly incorporate the view of interacting extremes, since we can see that they do not always occur independently. This is relevant considering our finding that statistically significant clustering can mainly be found if multiple hazards are analysed together. We would also like to point to the relevance of considering accurate event durations by comparing between the Hours Clause (HC) method and a Peaks-over-Threshold approach. Our results show that clustering depends on that event definition and that a fixed event duration (HC method) often overestimates the degree of clustering.

3. **Contribution to the research field:** We argue that our study contributes to the field by bridging between disciplines. For example, we make use of clustering metrics of primarily hydrologic data applied to impact data. By using impact data as a basis and refining it with meteorological data, we work across hazards and across the disciplines of meteorology, hydrology and impact research. This approach could be extended to other (non-meteorological) hazard types. An application regarding different types of impact, e. g. regarding capacities of authorities, would be possible as well.

We will make these points clearer in the main text (Introduction and Conclusions).

RC: ***Other potentially major issue I see is indicated at the beginning of Sect. 2: "This study is based on loss data (Sect. 2.1.1) from a building insurance company". It is understandable that insurance data can't be shared publicly. However, at minimum, the insurance company needs to be identified by name, and in the data availability section, information needs to be provided how other researchers could apply to that company to also have access to that information. Making any verifiability of the study impossible is against the editorial policies:*** ***`https://www.natural-hazards-and-earth-system-sciences.net/policies/data_policy.html`***

AR: We thank Dominik Paprotny for raising this point. We have now included the name of the insurance company in the main text as well as in the data availability statement. We changed L91 and L105 to the following:

> This study is based on loss data (Sect. 2.1.1) from the SV Sparkassenversicherung building insurance company operating mainly in southwestern Germany and covers the period from 1986 to 2023.

> Extreme events, i.e. hydro-meteorological events leading to a major loss, are identified using data from the building insurance company SV Sparkassenversicherung.

as well as the first sentence in the data availability statement:

> The insurance loss data by the SV Sparkassenversicherung are confidential and therefore not freely available.

The underlying data of this analysis are confidential, since it is of interest to the insurance company to avoid that competitors draw conclusions from their data. They have unfortunately been made available for this project exclusively.

RC: ***Finally, in L532: "Furthermore, this increasing trend is also influenced by non-meteorological factors, which could not be factored in." It's not true that it can't factored in. Exposure growth is major driver. Between 1991 and 2023, the value of fixed assets in Germany, in price-adjusted terms, increased by 68% for buildings and similar amount for other types of assets (as per Destatis database). Many studies on exposure-adjusted losses for different hazards are available. Also, strong exposure growth over the study period could affect event detection, creating an artificial upward trend in number of events.***

AR: We thank Dominik Paprotny for pointing this out. As stated in Sect. 2.1.3, the data is 1) adjusted for inflation with a building-specific price index and 2) adjusted for the portfolio variability, which is a proxy for exposure, with the number of contracts. We agree that this does not reflect the market value of the buildings – however, when buildings are adjusted for building-specific inflation, this does reflect the repair costs. The (adjusted) losses should reflect those repair costs, while the market value of the building is unchanged. For example, if shutters become damaged by a hail event, this amounts to a different loss (or: reconstruction costs) today than it would have ten years ago. This difference in losses is reflected in the adjusted reinstatement costs, as reflected by the building price index and the corresponding adaptation factor. Only in very rare cases, buildings become complete write-offs after an extreme event, which would then also affect the market value, justifying an adjustment with the fixed asset values in Germany for buildings. We agree that exposure growth is a major driver of increased risk, but to our understanding, this additional correction is not relevant in our case, since we compare losses and not total market values, also in Fig. 11. Also, the loss history of a building is not directly related to its market value in Germany. We are happy to discuss that further if needed.

However, we agree the sentence in L532 should be reformulated, since factors outside of meteorological conditions, but can partly not be included:

> This increasing trend is also influenced by non-meteorological factors, which are partly accounted for as described in Sect. 2.1.3, and could partly not be factored in, such as changed behavior of citizens, fluctuation in insurance regulation and a change in building vulnerability due to building materials.

Minor comments

RC: ***L20: the statistic refers to Germany, not Europe. For losses in Europe, I would suggest referring to: `https://doi.org/10.2908/CLI_IAD_LOSS`***

AR: We thank Dominik Paprotny for his thorough reading and for pointing that out. We are happy to include the proposed data source and cite it in summarized form the annual briefing of the EEA (`https://www.eea.europa.eu/publications/economic-losses-and-fatalities-from`). We furthermore would like to include a sentence on the losses in Germany with a new reference. The paragraph would then look as follows:

> Between 1980 and 2023, total losses caused by natural hazards are estimated at €738 billion in the European Union (European Environment Agency, 2023). Between 2001 and 2021, extreme events have amounted to annual losses of about 6.6 billion in Germany, including indirect effects ((Trenczek et al., 2022)). Flood and storm events are the major drivers of losses in Germany (Kreibich et al., 2014).

RC: ***Section 2.2: It would be beneficial to know what is the magnitude of minimum and maximum losses of filtered events. Also, Figure 2 doesn't have any scale in the axes.***

AR: Unfortunately, we can neither include the scale on the axes of Fig. 2 nor the minimum and maximum losses of filtered events for confidentiality reasons. We argue that the main point of the manuscript is to analyze clustering, for which the absolute losses of the events do not matter.

RC: ***Section 4.1: This section could be much shortened by moving the analysis why certain events are more damaging to the discussion (the last two paragraphs), because it is not the main topic of the paper.***

AR: We are happy to shorten the section. Some of the results on loss characteristics comparing different meteorological categories could, although not the main topic of the paper, be of general interest. Since, to our knowledge, this has not been published elsewhere, it can serve as an introduction to the topic of comparing between hazard types and their losses. Since we did not include a distinct discussion section, we would like to keep the order as it is.

RC: ***Section 5.2: It would be good to explain to readers unfamiliar with it, that the 21-day window is also taken from insurance practice. Note that you explain this in context of specific 3- and 7-day windows.***

AR: This window is not initially taken from insurance practice but a window which corresponds to sub-seasonal clustering and hydrologically relevant durations (e. g., Barton et al. (2016), Kopp et al. (2021), Tuel and Martius (2021)). We will however include that 504 hours is the maximum hours clause we are aware of after L183. We would also like to include a paragraph explaining this choice when clustering is analysed after L382:

> Clustering is analysed on the timescale of 21 days since this is a common window for clustering analyses in the field of hydrology, since it includes hydrologically relevant durations. It furthermore is the longest time period of event identification with HC we are aware of (see Sect. 2.2.2).

RC: ***Figure 11: Why do you suddenly switch to a 14-day window? Also, the labels shouldn't obscure the graph.***

AR: We thank the reviewer for pointing this out. We will change the graph for the 21-day window. This includes minor changes in the text. We furthermore changed the position of the graph labels so that they don't obscure the lines.

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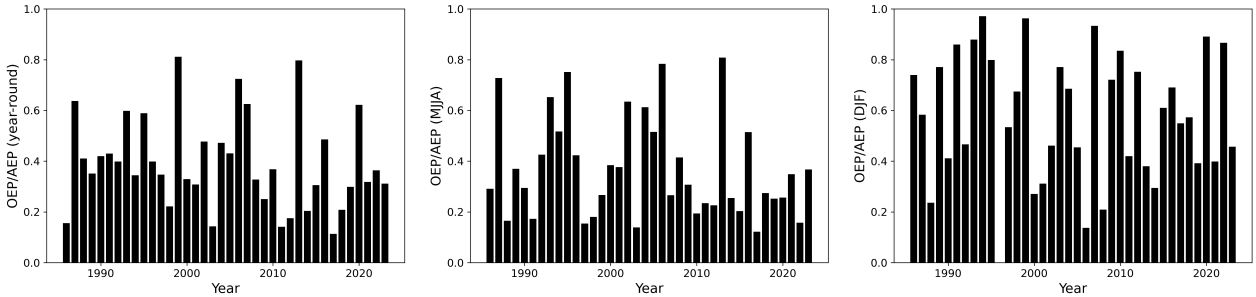

Figure 1: Clustering measure of the main event contribution vs the overall loss: Occurrence Exceedance Probability, relating to the maximum loss event in a season, vs. the Aggregate Exceedance Probability, i. e. the total seasonal loss, during (a) May–August and (b) December–February

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