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 #2

General comments

RC: ***The study examines how clusters of extreme weather events in southwestern Germany lead to higher losses than random occurrences. They analyzed insurance loss data from 1986 to 2023, adjusted for inflation and contract changes, using algorithms and clustering metrics to assess the significance of clustering for different hazards and their combinations. The research shows that clusters, particularly involving hail, floods, and storms, mainly happen in the summer and are linked to increased losses. The study highlights the growing number of extreme weather clusters over 38 years and their impact on risk assessment and insurance. The authors advocate for a holistic approach to hazard and risk analysis, considering the amplified risks of multiple combined hazards, especially in the context of climate change.***

AR: We would like to thank anonymus reviewer #2 for reviewing this manuscript and their valuable ideas and comments.

RC: ***The work is of great relevance for the multi-hazard community and makes a step forward towards the understanding of complex risk dynamics. I would recommend the publication of the manuscript if the authors are able to further clarify or justify the following points: 1. I understand the data cannot be made publicly available but the authors should at least share the code so that a reader can follow the detailed steps of the analysis and perhaps reproduce it with different datasets.***

AR: We thank the anonymous reviewer for the comment. We are happy to share the code used and will provide it with the final manuscript.

RC: ***2. The clustering for both single and multi hazard only takes into account the temporal dimension. Wouldn't it be better to do a spatio-temporal clustering especially considering that the weather data comes at 1 km2 resolution? How the results would change?***

AR: We agree that a spatio-temporal clustering would also be interesting to analyse. However, the underlying insurance dataset is only available in a spatially aggregated form, i. e., for the whole domain of Baden-Württemberg. Therefore, we cannot perform a spatio-temporal clustering analysis. Furthermore, we are interested in aggregated impacts over the domain of Baden-Württemberg with a limited extent of $36\,000$ km^2. Please see the following sentence (L112-114):

> As there is no finer spatial information (such as e.g. on the municipality level) available in our dataset, we use the spatially aggregated losses per day for the whole region. Due to the limited size of BW, we can assume that there is only a single synoptic cause of major events at the same time.

RC: ***3. Can we assume that the percentage of insured assets is constant across the considered region and over time? How would this influence the results of the analysis?***

AR: The percentage of insured assets fluctuates across time. This is taken into account by adjusting for the number of contracts the insurance company holds (L146ff, slightly modified):

> The portfolio variability is adjusted as follows: following the abolition of the insurance obligation in 1994 in BW, the portfolio has declined almost continuously. We therefore additionally adjust the insured losses with a factor that captures the number of contracts (NC) in the course of time, where NC_{mean} refers to the mean contract number over the entire time period [...]

We do unfortunately not have any recent information on the regional variability of the portfolio since the data is only available for the spatial resolution of BW (see previous answer). However, in past data from the insurance company with a higher spatial resolution, the regional variability was negligible (not published). We will therefore include a sentence in the manuscript after L156:

> The regional variability is assumed to be uniform due to past analyses of this data in a higher spatial resolution (not published).

Since we are not investigating regional differences, we therefore assume a uniform insurance coverage across the geographic scope and take into account temporal variability by adjusting with the number of contracts.

RC: ***4. It would be interesting to add the vulnerability dimension in the study since the loss declared would depend also on that and not just the hazard number.***

AR: We agree that it would be interesting to add the vulnerability dimension in the study. Vulnerability functions in insurance models are usually depicted using, e. g., inundation depth in the case of flooding or hail size for a hail model, both compared to the damage. To determine these functions, object or at least georeferenced data would be required. Unfortunately, for this region, data is not available in such a fine spatial resolution. Furthermore, our goal is not to assess the risk, but to determine clustering of events based on insured losses.

RC: ***5. Why not trying a loss independent clustering too? e.g. based on hazard intensity or other parameters.***

AR: We agree that this is an interesting point. As impact-based clustering is the main goal of this study and there is already vast literature on clustering independent of impacts (summarized in L55-59), we are afraid that we cannot take this suggestion. Furthermore, we expect robustness to the choice of input data by taking a relatively low percentile (90th percentile), a high population density in BW and a high coverage by the SV SparkassenVersicherung. For these reasons, we assume that a large part of all hazards of the types considered are impact-related and included within the adjusted insurance dataset. We would like to include these arguments in a modified paragraph in Sect. 5.3 (L495ff):

> To our knowledge, there are no other studies quantifying the degree of temporal clustering with respect to different types of (meteorological) hazards. We therefore contribute to the literature by considering a variety of meteorological hazard types related to impact data and finding that they do cluster when combined, irrespective of the event definition. We expect that these results are robust with regard to the choice of input data for this region, since we can assume that a large part of all major natural hazards are included in our impact datasets for the following reasons: Firstly, population density is generally high in Germany, and exceeded 100 inhabitants/km^2 for all districts in Baden-Württemberg as of 2022 (Statistisches Landesamt Baden-Württemberg, 2022). Secondly, insurance coverage against all hazards included in this analysis is very high across BW, and the SV Sparkassenversicherung has a high market share (see Sect. 2.2.1). Finally, by using the 90th percentile across all years, we include a large number of events (see e g., Fig. 4). Thereby, a major part of meteorological hazards, also in less densely populated regions with lower insured losses, should be included as well.

Additionally, we included a statement in the Conclusions after L572 (last sentence in this quote):

> It should furthermore not be neglected that there is a stochastic element within impact data, which may lead to the effect that a meteorologically relevant event at the local scale is not captured due to low population density and therefore low losses. We argue that these events are less relevant to the public, since they do not create major damage. Nevertheless, future research could be directed at analysing these clustering patterns with larger datasets and including larger geographic scopes.

RC: ***6. I would also discuss more why daily insured damage. At a first glance it seems too short as a temporal window and prone to errors, double counting and so on.***

AR: Agreed, daily insured damage could lead to errors, that is why we aggregate events to either single-day or multi-day events using the Peaks-over-Threshold and the Hours Clause method. This is a way of declustering, which removes double counting (see Sect. 2.2, L165–166). This is already discussed (L435-441).

RC: ***7. How is exposure taken into account? Is it assumed to be uniform over the whole region? Somewhat related to question 3. & 4.***

AR: Please see our answer to reviewer #3, comment #6 as well as our answers to comments #3 and #4 by reviewer #2.

RC: ***I would like the authors to discuss further these points in the main text or at least provide an explanation behind their choices. Having said that, I acknowledge the relevance as well as the technical robustness of the work done by the authors.***

AR: We would like to thank reviewer #2 again for their comments. Above, we stated for each comment whether we included a discussion in the text or explained our choices in the author response.