

Nat. Hazards Earth Syst. Sci. Discuss., referee comment RC2  
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## Comment on nhess-2022-187

Anonymous Referee #2

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Referee comment on "Compound flood events: analysing the joint occurrence of extreme river discharge events and storm surges in northern and central Europe" by Philipp Heinrich et al., Nat. Hazards Earth Syst. Sci. Discuss.,  
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The authors contend that copulas add unnecessary uncertainty to the estimation of compound event frequency. They therefore apply a non-parametric randomization test to find the spatial distribution of compound high river discharge -storm surge events across Northern Europe. Similar randomization techniques have been applied in past e.g., Svensson and Jones (2002) and Zhang et al. (2013), but the scale of this analysis arguably provides some novelty. The compound events that impact most of the rivers on the German-Danish west coast are shown to be linked by common metrological drivers as characterized by weather types defined by the German Weather Service. In my opinion, the preprint has the bones of a good paper but more work is required before it is worthy of publication in Natural Hazards and Earth System Science Journal.

### General comments

The introduction contains a wealth of relevant information; however, it does not flow particularly well. I believe a major cause of this is the poor internal structure of certain paragraphs. The first sentence should summarize the main point being in the rest of the paragraph. The paragraph starting on line 31 is a prime example where this is not the case. It starts by stating "Several studies conducted over the last years have shown the importance and catastrophic nature of compound flood events for several locations" but no catastrophic compound flood events are subsequently discussed. Instead studies that explore the correlation between the flooding drivers are listed. The paragraph ends describing results from Hendry et al. (2019), a relevant reference, since this study goes on to investigate potential correlations between a river's catchment size and the number of compound flood events, but out of place here. Finally, paragraphs should never start with linking words such as "therefore" or "Next".

The term "potential compound flood events" needs to be defined. It appears the term

"potential" is adopted in other studies as they only concentrate on the drivers of flooding and not the pathway or receptors component of the flooding process.

The introduction (L62-64) contains some very strong statements regarding the suitability of copulas in climate research. These statements must be either backed up with references or toned down (see specific comments).

The discussion of the limitation of the method could be further developed. For example, imposing a separation criterion of four days means events may not be independent in some of Europe's longest rivers (I agree this problem is not unique to this study). Another limitation is that not fitting a parametric model prevents the estimation of useful engineering quantities such as design events.

Certain Figures can be improved. The maps look distorted and not all rivers are shown. Any locations including rivers, seas and oceans mentioned in the text need to be identified in the Figures. A figure showing the proportion of each weather type responsible for the compound events at each location either as mini pie or bar charts or Figure 7 in Camus et al. (2022) would add value. This would provide evidence for statements such as "For Ireland, a distinct Großwetterlage could not be identified as a driver of compound flood events. We speculate that this might be because it offers a wide angle of attack for storm surges."

In my option the discussion section is very good. However, I suggest considering whether readability would be improved if the discussion and conclusion were disentangled. The conclusion would only need to be a few short sentences addressing the objectives set out at the end of the introduction.

### **Specific comments**

L9 and elsewhere: Consider changing the text to make clear that "common driver" refers to a large scale metrological driver rather than a direct flooding driver like storm surge.

L10: The "than expected" phrase is a little ambiguous. I believe you mean more potential compound events are expected compared to simple random chance but it could be interpreted as meaning more events expected based on similar previous studies.

L20: The sentence starting on this line requires a reference.

L21: "Zscheischler et al. (2018) described in further detail why it is essential to consider compound events for risk assessment." This is not very insightful.

L27: "Potential compound flood events occur when large run-off from, e.g., heavy precipitation, leading to extreme river discharge, is combined with high sea level (storm surge)." So what type of compound event is this in terms of the Seneviratne et al., (2012) definition?

L41: A lot of the listed studies focus on Asia/Oceania whereas much of the introduction concerns the U.S. and Europe. Kim et al. (2022) is a recent U.S. study that could be described here.

L43: I agree there is no established standards for detecting extreme events, however there are studies that compare the results obtained using different methods to identify extremes (e.g., Zheng et al. 2014) and changes in model set-up (e.g., Jane et al. 2022). There are also comparisons between findings from different studies (Ward et al. 2018; Ghanbari et al. 2021).

L44: The items listed here are not equivalent. The percentile approach (inverse of return period) and events per year criteria are really two techniques amongst many for choosing a threshold in the peaks over threshold approach. Univariate extremes are typically identified using either a peak over threshold or block maxima approach. In terms of a bivariate sample, univariate extremes of a variable can be paired with concurrent or near concurrent values of a second variable in a procedure referred to as one-way conditional sampling (Moftakhari et al. 2019). In two-way conditional sampling, the procedure is repeated conditioning on the other variable producing two conditioned samples (Ward et al. 2018). Zheng et al. (2014) discusses the advantages and limitations of three methods of identifying bivariate extremes.

L51: Bevacqua et al. (2020) has some predictions regarding the high emissions scenario for Europe. Also, you need to state that flood damage amounting to a considerable proportion of some countries GPD by the end of the century is a prediction at this stage!

L53: Perhaps discuss the results of the Norway study and remove the sentence about different spatial scales as this feels a bit like repetition. Bermúdez et al. (2021) is a regional study which could be cited here.

L63: The text states that copulas "rely on a huge amount of data points", given that copulas are widely applied in climate studies the following sentence appears to be a contradiction where it states that "the amount of available data points is always insufficient for this kind of analysis with many studies operating at merely 30 extreme events". Changing the first sentence to state that a large number of data points may be

required for the copula fit to be robust will remove the apparent contradiction. Jane et al. (2022) explores the sensitivity of copula family to sample size.

L85: A few automatic threshold techniques could be cited here.

L86: I would be really interested to read studies where local properties, like flood protection or elevation of the surrounding area play a role in threshold selection.

L94: Compound flooding studies such as Ward et al. (2018) where a percentile threshold is applied over a large spatial scale should be noted here.

L97: I suggest requirement for independent events be discussed before describing the variation in the number of (independent) extreme events with river characteristics.

L106: The definition of separated is not clear here. Is it separated by four consecutive days containing no threshold exceedances?

L108-109: I do not understand the point being made in this very short paragraph. "In order to enable a good comparison between different rivers, the number of extreme discharge and sea level data points should be the same for all of them." I don't think the number of extreme discharge and sea level points necessarily need to be the same for a comparison to be valid. Furthermore, with this rational is there not a danger of choosing a threshold that permits events that are not extreme so a comparison can be made?

L114: Please define more clearly which events have an "average return period of 0.5 years for extreme events".

L130: Previous studies which implement a similar procedure should be cited e.g., Svensson and Jones (2002), Zhang et al. (2013) and Nasr et al. (2021). Couasnon et al. (2020) presents a similar approach to the one proposed in this paper that uses the binomial distribution to assess the number of annual maxima storm surge – river discharge co-occurrences expected under the independence assumption.

L136: Couasnon et al. (2020) speaks to this.

L132: "east coast of Great Britain exhibits a low number of compound flood events" This is

repetition of the previous sentence.

L161: Water levels at the mouth of a river are often heavily influenced by sea level (e.g., Moftakhari et al. 2019), and therefore are not desirable in this context since they are not a reliable measure of the river discharge caused by inland rainfall.

L228: What time period?

Figure 1: The choice of color bar makes this figure difficult to interpret. Consider using a cold to hot color scale to more easily identify hotspots (and cold spots).

L241: Could add “and are discussed in the following subsections” to the end of this paragraph to guide the reader.

L248: What pattern are you referring to here?

L260: Here and elsewhere it would be interesting to explore possible causes of these differences.

L284: So what weather systems were responsible for the rest of the compound events in Great Britain?

L298: No need to start a new paragraph here.

Figure 5: Spacing between (a) and (b) needs to be increased.

L345: Check grammar of sentence starting “Additionally, …”.

L350: Remove “very interesting topic” this is subjective.

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