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Interactive comment on "The role of flood wave superposition for the severity of large floods" *by* Björn Guse et al.

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General comments:

Comment 1 from reviewer#2: The paper aims quantifying flood wave superposition and their implication on the severity of flood events. Mean daily discharge data from 37 triple points (around the main channel and the main tributary) in Germany were studied. The main conclusion is that the largest floods at the downstream gauge occur not because of a perfect temporal matching of a tributary and the main river, but a few confluences can bear strong flood magnifications. The topic is novel and of high interest for flood wave routing. The data are of good quality. The paper is well written, clear and easy to read.

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Reply 1 from the authors: We thank the reviewer for this positive feedback on our study.

C2: The paper deals only with discharge data, defines indices to characterize flood waves superposition, and discusses the results obtained from statistical correlations and distribution of indices. The main conclusions (e.g. that the largest floods at the down-stream gauge occur not because of a perfect temporal matching of a tributary and the main) are not related to hydrological processes and the main hydrological reasons remains unclear to the reader (see for example lines 10-15 in the abstract). Only Figures 3 and 4 present the methodology, but remain schematic and no real-case examples are shown. The paper can be reinforced by given a discussion on the physical hydrological processes explaining the different cases shown in Figures 3 and 4, and later in the results.

R2: Based on this comment, we think that we have not presented our overall goal clearly enough. In contrast to former studies on flood wave superposition that were mainly focused on a few gauges/catchments and analysed some processes resulting in different degree of superposition for different events, our study focuses on a large set of gauges. Our aim is thus to derive general patterns of flood wave superposition for this set of triple points. In contrast to single catchment studies, we cannot analyse the hydrological processes at each gauge and for each event that drive flood occurrence in detail, since we had 37 triple points with 34-81 flood events for each gauge. This would go beyond the scope of this work. Our analysis was solely based on discharge data and is intended as explorative regional analysis. To explain the processes that drive flood occurrence under consideration of spatial variability and event-specific characteristics, a model analysis would be required. For example, the analysis of soil moisture patterns and related catchment response (time of concentration, flow peak, etc.) would require setting up and calibrating a rainfall-runoff model. In the future work, we intend to analyse the major processes influencing flood wave superposition. However, we believe that this would be an extensive study on its own and would go beyond the scope of this paper.

My main comments concern:

C3: Main hydrological processes and real-case examples: The paper can be reinforced by adding a scheme showing all hydrological processes during flood events around a triple point: i) the two inlets and the outlet hydrographs extensively studied in this paper; ii) Rainfall/runoff on the three intermediate subcatchments, two subcatchments upstream the bifurcation node on the main channel and on the tributary, and one subcatchment downstream the junction between the bifurcation and the outlet; iii) contribution of baseflow; iv) eventual overbank flow; v) role of initial conditions of soil moisture on runoff genesis and floods; vi) geometric and hydraulic characteristics of the channels: sections shape, slope, roughness, etc. This figure will help understanding why there are only four cases in Figure 3 and many combinations in Figure 4, and what is the corresponding processes inducing the superposition of waves (magnitude, time of peak). Then these hydrologic characteristics (rainfall, baseflow, initial soil moisture conditions, water balance, etc.) and hydraulic characteristics (peak magnitude, time of occurrence, etc.) can be shown on some real-case events on Figures 3 and 4. This needs the selection of some flood events (at least four corresponding to the four cases of Figure 3) and some particular triple points (in order to illustrate Figure 4). The hydrologic and hydraulic characteristics of these examples of "an event on a triple point" (noted for example A, B, C, etc.) can be studied showing the terms of the main processes (rainfall, runoff, baseflow, overbank, water balance, peak magnitude, characteristics of times, etc.). The different cases studied (A, B, C, etc.) can be indicated on Figures 5 to 8.

R3: As mentioned in the previous comment, we do not think that a process analysis matches with the goal of our study. Regarding flood process analysis, we can state that floods are highly event-specific and site-specific. Depending on event and location, different processes may drive a flood. Thus, a generalisation of flood process control in a stylized figure seems to be difficult. We do not think that each of the four presented patterns can be assigned to specific process patterns stable for all events at one location and across different locations. Regarding this issue, we would like to highlight that we have analysed between 34 and 81 floods events for the 37 triple points. Our core idea is to explore general superposition patterns and characterise different confluences. A detailed process analysis for this number of locations and events is not intended for this study and would be very laborious. If only few confluences and event cases are selected this would result in a mixture between analyses of a large set of events and a discussion of a few events. As presented in the Introduction, previous studies rather focused on a few confluences and/or few events analysing processes in more details. Given the available dataset, we prefer to keep the focus on an analysis of overall patterns of flood wave superposition.

C4: The characteristics of the intermediate catchment and the channel network: The rainfall/runoff on the intermediate catchment and the geometric and hydraulic properties of the channel network play an important role on wave superposition: impact on velocity/celerity, diffusivity, overbank flow. Also these characteristics can be studied on some real-case examples in order to help understanding what are the main processes inducing the different cases of Figures 3 and 4.

R4: We agree with the reviewer that hydraulic processes impact flood wave superposition and flood severity. But also in this case, we do not see a way of combining our large flood data set analysis at multiple gauges (triple points) with a detailed hydraulic analysis that has to be carried out separately for each event at each location. This would require more detailed information on each flood event (e.g. presence of overbank flow) and/or detailed hydraulic modelling to extract the mentioned hydraulic characteristics. Such detailed information is not available and hydraulic modelling of this complexity and extent seems to be not feasible.

C5: Overbank flow: This is a main process during extreme flood events. When overbank flow occurs, a volume of water may be lost from the water balance, and consequently impact peak magnitude. Overbank flow can occur on one, two or the three reaches (2 upstream and one downstream the junction). Please discuss this process for some real-cases. Is there any information on some of the studied events?

R5: We agree with the reviewer that overbank flow impacts flood event characteristics and that water can be lost from the river. We will mention in the revised version of the manuscript that we have carried out an analysis only on discharge data without using information on overbank flow.

C6: What is the impact of baseflow and of the initial condition of soil moisture on the different cases shown on Figures 3 and 4? And on results?

R6: The impact of baseflow and in particular of soil moisture cannot be assessed in a pure data-based analysis since observational data for the analysed period are not available. To understand this aspect, it is required to reliably reproduce the specific initial conditions in a hydrological model. However, this is beyond the scope and the idea of this manuscript.

C7: Uncertainties on data: What is the impact on results of uncertainty on data, especially the rating curve for extreme flood events? What is the sensitivity of results on the method used to define flood events?

R7: We agree with the reviewer that high flow data are uncertain. However, in using discharge data for the same gauge, we can assume that the uncertainty is similar for different events. Thus, we do not expect that the ranking of events to change significantly when having “perfect” discharge data. Moreover, we do not expect a high impact of this uncertainty on our study, since we discuss several events jointly in relation to each other and the bias is likely to be similar for all gauges at a triple point. We will add a discussion of data uncertainties to the revised version of our manuscript.

C8: Extension for cases with more than two inlets: Using the same datasets and similar approach, the discussion and analysis (Figures 3 and 4) can be extended to the cases of a channel with three or more inlets and one outlet.

R8: Our approach is based on triple point analysis. This is by far the most common

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configuration we have in our dataset. A quadruple point is separated in our approach into two triple points. One can potentially further develop the method in future to consider special cases.

C9: Comparison to the international literature: the paper can also be reinforced by comparing the results to the large international literature presented in the introduction.

R9: We thank the reviewer for this comment. We will add a discussion of our approach and differences and similarities to former studies presented in the literature in the revised version of the manuscript. However, one has to admit that to our knowledge this is a first study that analyses flood wave superposition for a large number of river confluences and tries to identify different superposition patterns. Previous studies mostly focused on the analysis of one or a few confluences and the superposition patterns over time at these specific locations or the looked at potential scenarios that would aggravate flood hazard.

Minor comments:

C10: Page 2, L 10-29: Please explain what hydrological/hydraulic processes behind the results of the reference papers from the literature.

R10: We will give more information of the most relevant cited paper in the introduction.

C11: Page 4, L14: Does the "daily time step" defined between 0h and midnight? What about historical data with daily time step from 6h GMT to next day 6h?

R11: In our analysis, we compared at each step, three gauges for a specific event. Thus, a difference in definition of a day within the data between historical and current period would not impact our analysis. We assume that for three gauges the data is recorded and aggregated consistently.

C12: Page 4, L19 and Figure 2: The paper says that "the ratio of tributary catchment size to downstream catchment sizes may reach 55%". There are three points on Figure 2 which are above the 1:1 diagonal. Please give the definition of the tributary in comparison to the main channel: is it from the names on map or the channel with the highest discharge, the highest specific discharge (what time step: annual?) or other? Please also explain that the tributary may drain an area highest than the mainstream.

R12: We will add this point in the revised version of the manuscript. We refer to upstream and downstream river as the same river by name.

C13: Do the results depend on the distinction between "main" and "tributary"? or do we obtain similar results?

R13: There are no relevant differences. The time lag between main river and tributary peak is negative in the case that the tributary peak occurs earlier. If switching main river and tributary, this value will be positive. However, the absolute values of the time lag are still the same. Since we are interested in how consistent this pattern is for different events, our interpretation of the results won't change.

C14: Page 5, Line 4 – Page 6, Line 3, Section "3.1 Derivation of flood peaks": It is not easy to follow how flood events were defined. Please add a figure showing real cases in order to illustrate the difficulties encountered.

R14: This figure will be added.

C15: What is the sensitivity of the results on the method used to define flood events?

R15: Since we are focusing on the peak discharge and are mostly interested in the largest floods, it does not make a difference how we derive events and if we select annual maxima series, as we did, or peak-over-threshold. Thus, the sensitivity is low.

C16: Page 6, Line 24: The paper says that "Figure 4... shows the ten largest flood" while there is only 8 points and not 10 on Figure 4.

R16: Changed

C17: Page 7, Line 26 says that "both axes are scaled to the same specific discharge". Please explain. It is not clear what are the units of Figure 4 Graphics "B", and on Figure

6? Please add a 1:1 diagonal on Figure 4 Graphics "B" in order to homogenise with Figure 6, and explain what represents this diagonal. The legend of Figures must give all information to understand the figure.

R17: We will modify this accordingly.

C18: Figure 4: i) Graphics "A": please explain what the vertical distance between two points is; is it arbitrarily in order to classify events? ii) Graphics "B": please indicate on the figure or on the legend what represent the different colours (grey, blue, red, etc.). This information is given on Figure 6 with the results on the Weser. iii) Graphics "B": the legend says that the symbol indicates event severity: please give the definition of "severity". Please add the units of x- and y-axes. What means "Discharge" is it Qx, a mean discharge during the flood event and hence depending on the definition of an event, specific maximum discharge or other? Please be clear; iv) Graphics "C": please add a legend explaining the three curves on C1 to C4. Why points are indicated only on the two curves in "blue" and "yellow" and not on the "black" one? What represent the horizontal distance between points; is it arbitrarily to class events? v) There is only 8 points on the figure while in the text it is mentioned that there are 10.

R18: We will improve figure 4 accordingly.

C19: Figure 5: Does the time lag on the x-axis in day? Please add the unit.

R19: We will add the unit.

C20: Figure 6: i) What represents the diagonal on figures? As the x-axis and the y-axis are not identical, the diagonal doesn't represent 1:1. The text Page7, Line 26 says that "both axes are scaled to the same specific discharge"; it is not clear. Please explain on a real-case and in the legend in order to help the interpretation. ii) What are the units of the x- and y-axes? iii) Please also add a legend explaining what represent the size of symbols, what units? It is difficult to distinguish the difference of the different size of symbols.

R20: We will describe the figure clearer in the revised version of the manuscript.

C21: Figure 7: Please add the units on the y-axis.

R21: We will add units.

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