What made the June 2013 flood in Germany an exceptional event? A hydro-meteorological evaluation

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Reply to comments of Massimiliano Zappa

First of all we want to thank Massimiliano Zappa for his valuable and thoughtful comments. Following, we will reply to each of the comments made.

General remarks:

This manuscript is a nice example of (in the words of the Authors') "Forensic disaster analysis" (FDA). This kind of studies is needed in order to understand gaps in the knowledge concerning the triggering and management of extreme (flood) events.

The manuscript uses a solid base of data and nicely combines established evaluation techniques. In the introduction I miss some paragraphs on the methods adopted (See below). The methods adopted are presented and adopted in a straight-forward manner, no sensitivities are assessed. This should be improved, because I have much the impression of reading a cook-book, which is here adopted for assessing the severity of a "random" event. The "hydraulic load" is in my opinion also an aspect that needs to me more highlighted in the introduction (novel to me).

I found that the referencing adequate, but in my opinion some useful paper have been not considered (see minor comments and reference list). Most of the references I missed stem from NHESS, a journal which could also have been an adequate recipient for this manuscript.

Issues to be addressed (Page(s) – Line(s)):

Referee Comment:

Introduction: I completely miss some paragraphs on previous applications of the adopted methodologies (API, Wetness-Index, EVS and so on). I would expect that you introduce them and clarify how novel is the application you realize here (e.g. the specific combination of the approaches).

Authors' response:

We overworked the introduction and also included an overview of the adopted methodologies as suggested.

Referee Comment:

8131-4-13: In the section methods you explain the different measures you use in the assessment. One central question is the selection of the event start date, which varies within the stream network. Now, from an HESS manuscript I expect somewhat less straight-forward application of the methods. I would like you to consider introducing some basic analysis of sensitivities. I really like your Figure 12 and it would be nice to have in there some error-bars (both for API and the wetness index). What if you use API20 instead of API30? What if you do not start the API estimation the day prior to the 3days maximum, but two days prior to the 5 days maximum? These examples should bring you to "experiment" with your methodology and finally tell us that for these kinds of analyses API30 and starting API the day before the 3 days precipitation maximum are a solid way to proceed in these kinds of analyses. Without such contribution is like reading a technical report on the event.

You write on Page 8132 that "*We have performed this analysis for maximum precipitation total of 3 to 7 days duration*". These analyses should be shown and the sensitivities should be propagated until "Figure 12". You can also vary the "decay" within the API equation (you use 0.9).

Authors' response:

We followed this suggestion and included a sensitivity analysis of several factors and assumptions made within the methodology (see new Section '3.6 Sensitivity Analysis'). This includes varying duration of event precipitation, duration of antecedent precipitation index,

different values for the depletion constant for the calculation of API as well as several reference levels for the calculation of severity indices.

For the most sensitive variations – in terms of changes in the according Severity indices (cf. new Figure 13) – we now show the results of the LOWESS interpolation model in additional charts in Figure 12.

Further, we included a new Figure that shows the spatial patterns of 7-day precipitation maxima related return periods and briefly discussed them in the text. Because the differences to the 3-day maxima are not that large (especially the estimated return periods), we put those in the Appendix (Fig. A2).

We mainly considered 3-day precipitation maxima for meteorological reasons. Persistent heavy precipitation may occur on 3 consecutive days, but only extreme rarely on seven days (in Southwest Germany, for example, only once in 30 years). Within 7 days, atmospheric conditions usually change with the effect that the precipitation patterns can hardly be related to ambient conditions (e.g., flow from different directions lead to different locations of orographically-induced precipitation). 3-day totals better represent rainfall associated with floods occurring in summer as it is the case for the three events investigated in this study. In contrast, 7-day precipitation totals are more related winter floods.

Referee Comment:

8133-6: Why 5 year RP? Again I would be interested in the sensitivity of the methodology you use in this “Forensic Disaster Analysis” and I am not very interested in reading a cook-book.

Authors’ response:

We considered a variation of reference levels for calculating the different severity indices (see above). In Uhlemann et al. (2010) the flood severity index was tested for a variety of return periods 1.5 to 20 years). A return period of 2 years refers approximately to bankful discharge in a typical European lowland river. The higher the return period reference level, the more weight is put on extreme runoff in relation to spatial extent which leads to a lower ranking of moderate intensity, large scale winter floods. A 5-years return period is regarded as the best compromise to generate a balanced event set when concentrating on the analysis of very large events.

Minor comments:

Referee Comment:

8127-5-11: When speaking about flood losses you might cite the papers of Hilker et al. (2009) and Barredo (2009)

Authors' response:

We added Barredo (2009) as another suitable reference; Hilker et al. (2009) appear to be more relevant for Switzerland. This reference does not provide additional information for Germany about the 2002 flood damage.

Referee Comment:

8128-6-15: Here you might find also some interesting discussion in Alfieri et al. (2014)

Authors' response:

We included the issues raised by Alfieri et al., 2014 and in other references mentioned therein in the revised introduction.

Referee Comment:

8129-6: You consider a relative long period and this might allow you using the "block maxima" approach. Why you select POT?

Authors' response:

For the extreme value statistics of flood peak discharges we applied a 'block maxima' approach, i.e. we used annual maximum series of mean daily discharges at the 162 gauges. The peak over threshold criterion was used by Uhlemann et al. 2010 to identify potential large scale floods from the spatial time series at 162 gauges. As the use of the term POT in this context might be confusing we changed the text.

Referee Comment:

8130-8: Am I the only one wishing an illustration of "low central Europe (TM)" and "trough central Europe (TRM)"? Add TRM and TM in Figure 1.

Authors' response:

Fig. 1 shows the geopotential height averaged between 16 and 31 May. During that time, both RM and TRM persisted. Thus, we cannot relate this mean to any of the two weather patterns. Anyway, we decided to delete the paragraph with the large-scale weather patterns because it provides no useful insight.

Referee Comment:

8135-5: GEV computations generally allow estimating uncertainty ranges (which in case of RP of 5 years might result very narrow). But again, it would be another piece that can be added for quantifying the sensitivity of this methodology.

Authors' response:

We think that the variation of the different factors addressed within the sensitivity analysis (see above) in particular the variation of return periods chosen as reference levels in calculation of severity indices have a stronger impact on the evaluation results than the uncertainty associated with return period estimates. Therefore we did not include this aspect to the analysis.

Referee Comment:

8136-8137: You make large use of regional geographic terminology. Thank you very much for Figure A1.

Authors' response:

The figure has been updated to include additional locations that were still missing

Referee Comment:

8138-15-20: Is there any literature on LCL, or is it assumed that HESS readers are familiar with this?

Authors' response:

We added an explanation for the LCL: "…the lifting condensation level (LCL), which represents the level of the cloud base in case of synoptic-scale or orographic lifting,…"

Referee Comment:

8139-10: The propagation of this statistical uncertainty up to Figure 12 is what I want to see.

Authors' response:

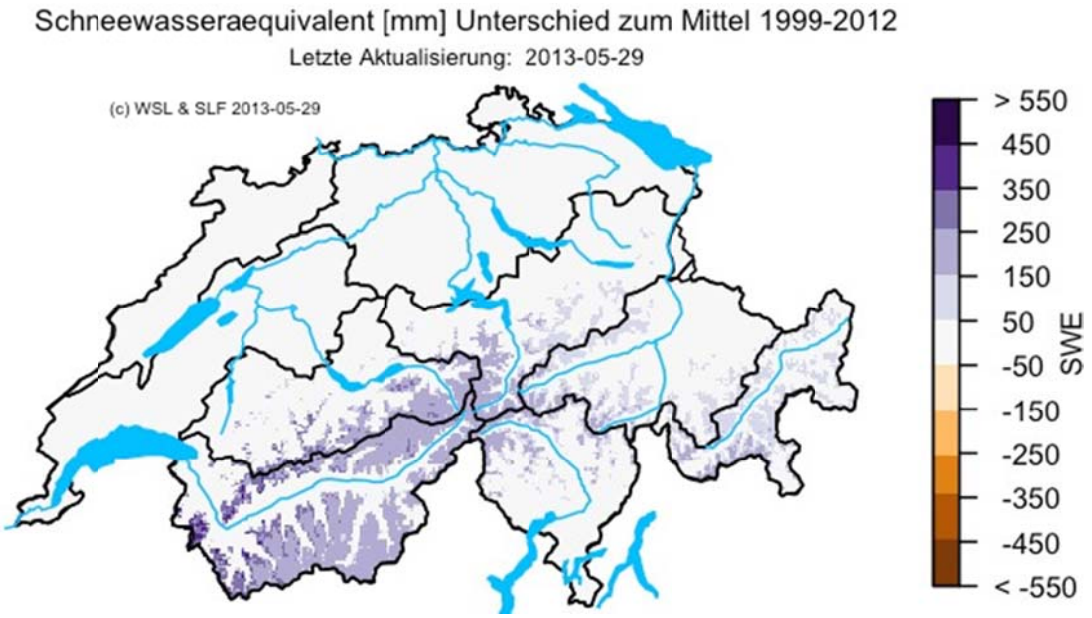
Please refer to our response to the comment on GEV estimation uncertainty above.

Referee Comment:

8141-23: I really like this "Hydraulic load" approach.

Referee Comment:

8142-15-20: It should be possible to access a snow-depth measurement in order to confirm this statement. Here below an assessment of snow-resources anomalies in Switzerland on May 29 2013. Source T. Jonas, SLF (see also Jörg-Hess et al.., 2014 and Zappa et al., 2014). A slight positive anomaly can be seen in the highest areas.



Authors' response:

We agree that snowmelt can play an important role in the generation of floods. However, in the case of summer floods in Germany as in July 1954, August 2002 and June 2013 this was not an important factor. On the contrary, both in June 2013 and in July 1954 snow was accumulated above elevations of 1,600 m and 800 m respectively (e.g. Blöschl et al., 2013), and thus attenuated runoff generation in the Alps. Likewise in August 2002 snow did not play an important role. As the focus area of our analysis is Germany we decided to exclude the aspects of snow melt and accumulation.

Referee Comment:

8144-23: Very interesting section, just add some sensitivity to this as proposed before.

Authors' response:

For the most sensitive variations identified within the sensitivity analysis (see above response to major comment) we added plots for the LOWESS interpolation model to Figure 12 and included some discussion on the variations observed in the text.

Referee Comment:

8145-19: No new line needed.

Authors' response:

This has been changed.

Referee Comment:

Figure 12: Caption: "Upper right corner", I guess.

Authors' response:

This has been corrected.

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Reply to comments C3532

First of all we want to thank the reviewer for his/her valuable and thoughtful comments. Following, we will reply to each of the comments made.

General comments:

This paper is a very interesting analysis of the relevant processes and triggering factors that lead to widespread extreme floods in a large region, e.g. in Germany. Due to very detailed (in time and space) comprehensive data sets on precipitation, whether types and river flows, it was possible to analyze the initial and the actual conditions of rainfall and runoff in a homogeneous way all over the time of more than 50 years. This was done, I think, for the first time in this extensive manner. The comparison of three large flooding events (1954 2002, 2013) lead to the result, that these three cases, different main reasons were responsible for the development of widespread floods over Germany and their neighboring countries.

Specific comments:

Referee Comment:

Soil moisture/wetness: several times (among others in the abstract) the term soil moisture or wetness is used in a way that the reader thinks, there are some data on soil moisture. In the text however, it is mentioned, that API is used as a proxy for soil wetness. I think we must be careful. API is indeed a proxy, but only for the potential of initial conditions of soil moisture conditions. The quality of this proxy depends a lot on soil structure and soil depth as well as on land use. And additionally it depends on the length of the API-period. Did you perform any sensitivity analysis on this?

Authors' response:

We agree that any confusion concerning the use of soil moisture data has to be avoided. We checked the text and changed this accordingly.

Certainly, soil and land use characteristics control hydrological processes relevant for flood generation. In our study we use API as a proxy for wetness conditions before the onset of large scale floods in Germany. Depending on the site specific soil characteristics antecedent precipitation might exceed soil water storage capacity. However, in the context of our study we do not target at a comparison of regional differences in flood generation throughout Germany. Instead we evaluate the wetness situation before the historic large scale floods. API represents accumulated precipitation in the time period before the onset of the flood and as such indicates potential wetness in the catchment. For a relative comparison of different large scale flood events this information is sufficient.

We think the following sentence in 2.2.3 Antecedent precipitation makes this clear:

"The API is used as a proxy for wetness conditions in a catchment in the period before the event precipitation."

Within the sensitivity analysis we used different length of API periods (30 days and 15 days). The results show that the implications of this variation for the ranking of the wetness indices for the set of flood events are rather low.

Referee Comment:

Initial hydraulic load: This is certainly a very important factor. But I feel it is somehow redundant/dependent to API. Did you check correlations?

Authors' response:

Intuitively high API should be related to increased streamflow in the river network. On a small scale this relation should be stronger than on a larger scale where additional interfering factors become important, e.g. hydraulic processes such as translation and retention of discharge in the river network. Further, the initial hydraulic load index I accounts for seasonal variation of flow levels in the river network as for instance increased discharge due to snowmelt which is not included in the API based proxy and the wetness index W. The correlation between I and W indices among the large-scale flood event set is low ($r = 0.25$).

Referee Comment:

Drainage basins surface and time resolution: It is mentioned, that drainage basins are used from 500 km2 upwards. Unfortunately here is no overview on the distribution of drainage basins surfaces. At the other hand the Authors' use daily means of discharge in the analysis. In my view, flood peaks cannot be detected/assessed in basins smaller that about 3-5000 km2 with daily runoff resolution.

Authors' response:

The set of gauges has been adopted from Uhlemann et al., (2010). Therein the reasoning for the selection of gauges and also information about the distribution of drainage basins is provided. We have included some details on the distribution of drainage basins in the paper.

Concerning the detectability of flood peaks in time series of daily mean discharges we do not fully agree with the reviewer because catchment size is not the only relevant factor in this regard. Also other characteristics as for instance topography and hydraulic regime play an important role. Records of daily mean discharges from gauges with similar basin areas have been successfully used for several flood related studies in Germany, e.g. Uhlemann et al. 2010, Beurton and Thieken 2009, Petrow and Merz 2009

Beurton, S. and Thieken, A.: Seasonality of floods in Germany, Hydrol. Sci. J., 54(1), 62–76, doi:10.1623/hysj.54.1.62, 2009.

Petrow, T. and Merz, B.: Trends in flood magnitude, frequency and seasonality in Germany in the period 1951–2002, J. Hydrol., 371(1–4), 129–141, doi:10.1016/j.jhydrol.2009.03.024, 2009.

Technical corrections

Referee Comment:

Chapter 2: This chapter should be reorganized. 2.1 should be “Data”, following by 2.1.1 etc., and then (as it is) 2.2 “Methods”. Now, in 2.1 and 2.3, both are dealing with hydrological data (floods)

Authors’ response:

We changed the organization of chapters accordingly.

Referee Comment:

Page 8130, line 3 ff: which classification was finally used by the Authors’?

Authors’ response:

We decided to delete this paragraph with the large-scale weather patterns because it provides no useful insight.

Referee Comment:

Chapter 2.4.2: How the analysis on precip. was done for the 1954 event?

Authors’ response:

For this event (and the 2013) we also used the REGNIE data; we changed the text to clarify this.

Referee Comment:

Page 8136, line 17: Do you have references for this statement?

Authors’ response:

During the changes made to the manuscript this sentence has been deleted.

Referee Comment:

Page 8137, line10: “Highest precip. …” Compared with what? I cannot see this on fig 3a

Authors’ response:

This is related to the time period of 30-days shown. In the Elbe catchment, the areal rainfall 3 days ahead is approx. 75 mm; this is the highest value during the whole period. We reformulated this sentence to make it clearer.

Referee Comment:

Chapter 3.3.1: API: can we really compare API between regions or between different events. It might be a problem, that water storage capacity in the soil is smaller than API, so we compare high API that is no realistic and therefore not relevant.

Authors' response:

Please refer to the specific comment above.

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Reply to Comments of Review C4043

First of all we want to thank the reviewer for his/her valuable and thoughtful comments. Following, we will reply to each of the comments made.

Referee statement

In this paper, the 2013 flood is compared to two large-scale summer floods (1954 and 2002) using extreme value statistics and severity indices. The focus of this paper is the floods in Germany, and the analyses are carried out with a consistent data base of precipitation and discharge data was used.

I enjoyed reading the paper; however, some issues were not entirely clear. After reading the other comments in the interactive discussion (which I did after writing down my comments) I realized that some have been mentioned there already.

In my opinion, the scientific significance can be rated 1-2, the scientific quality 1 and the presentation quality 2. As for the scientific significance, I don't know if there are any substantial new concepts or methods, but it is certainly important to understand large scale floods and the processes behind them. I liked the database, even though some issues concerning this data were not entirely clear. As for the presentation quality, there is some improvement possible. Some values were used without any further explanation (e.g., API30,

return period rp5) which should be clarified; also the description of the interpolation of the 1954 precipitation is missing.

I have three larger issues, and several minor which I have listed below.

Major comments

Referee Comment:

You use a number of geographical locations and you also provide a map (Figure A1) in which several of these locations are shown. However, there are a number of stations mentioned in the paper not shown on this map.

Authors' response:

Figure A1 has been completed accordingly.

Referee Comment:

You have used a discharge database from 1952 to 2002. Somewhere you say that you have identified 74 events from 1960-2009. But you analyze the 1954 and 2013 events. Is there some confusion with the years? Or is there a different reason? Please clarify.

Authors' response:

The reference period for long-term analyses is 1960 to 2009 (50 years). The selection of this period was guided by balancing the trade-off between length of reference period and both data quality and consistency:

- For statistical analysis a time frame of 50 years is sufficient. Note that in meteorology usually a 30 years period is used to describe the climatological context.
- For the long-term classification of the three specific events, 1954, 2002, and 2013, it is not necessary that they are within the reference period. We selected these three events because they were that extreme.
- Official discharge data available for most of the 162 gauges have only been checked for plausibility until end of 2009 and thus the update of the flood event set identified by Uhlemann et al. (2010) beyond 2009 would not have been consistent. The data availability and quality varies considerably between the federal states of Germany. For the flood in June 2013 we made an exception and worked with raw data.

- The quality of REGNIE data before 1960 is relatively low due to a reduced number of measurement stations available at that time. For the evaluation of the flood in July 1954 the data are appropriate but we decided not to include this period in the statistical analysis.

We reformulated the second last paragraph in the introduction and also separated between the reference period and the three events in the Sections 2.1 and 2.2 (now 2.1.2 and 2.1.3).

Referee Comment:

How was the precipitation data for the 1954 interpolated? There is no information given. You have used the REGNIE data set for 1960-2009 and 2013.

Authors' response:

See above.

Yes, all the precipitation data were obtained from REGNIE. In Section 2.2 (now 2.1.2) we included a statement ("…and for the single events 2013 (April-June) and 1954 (June-July)…"

Minor comments

Referee Comment:

Page 8126, lines 1-2:.… since at least 1952 the year 1952 is mentioned a few times in the paper. Is this year only mentioned as it is the start of the data base in the Uhlemann et al. (2010) paper? To my knowledge (or at least from the paper) there has been no flood in 1952.

Authors' response:

The year 1952 is referred to as it is the start date of the period examined in Uhlemann et al., 2010.

Referee Comment:

Page 8127, line 14: Blöschl et al. (2013) has been published in HESS

Hydrol. Earth Syst. Sci., 17, 5197–5212, 2013, www.hydrol-earth-syst-sci.net/17/5197/2013/doi:10.5194/hess-17-5197-2013

Authors' response:

This has been changed.

Referee Comment:

Page 8127, Line 28-29: This hypothesis has also been one of the findings of Blöschl et al. (2013)

Authors' response:

This part of the manuscript has been revised; we have included references to the statements concerning the role of initial soil moisture for the June 2013 flood in BfG (2013) and Blöschl et al. (2013).

Referee Comment:

Page 8128, line 15… with the event of Uhlemann …Should probably be paper instead of event.

Authors' response:

Yes, we included event set

Referee Comment:

Page 8129, line 3: Now the first point becomes clear, Uhlemann's data set starts in 1952 and has been expanded to 2009. To my understanding, you updated the database from 2002 to 2009 (and I assume, also the 2013 event). Why did you not include the years 2010-2012? Because it is raw data? Also for the 2013, you have used raw data (see page 8130, line 18).

Authors' response:

See response to major comment above.

Referee Comment:

Page 8129, line 11: You say that there are 74 large scale floods in Germany in the period 1960-2009. Does this number include the 2002 event? Why are the 1954 and 2013 events not included in this number? What is the reason for this? You use the number 74 several times throughout the paper.

Authors' response:

The 2002 event is included, but not the 1954 and 2013 events. The reasons for the reference period are stated above.

Referee Comment:

Page 8129, line 21: The 1954 event is not included in the data set? How did you analyze the precipitation data for this event? Please clarify.

Authors' response:

This is now explained in the manuscript (see answer to major comment 2).

Referee Comment:

Page 8129, line 28: Maybe it should be „underestimates".

Authors' response:

This has been changed.

Referee Comment:

Page 8130, line 9-11: Compared to the past … this persistency is not significant and cannot explain the extraordinary situation in 2013. From this I would say there was at least one other event with a more significant persistency of the weather patterns. Could you clarify and give some more details?

Authors' response:

We decided to delete this paragraph with the large-scale weather patterns because it provides no useful insight.

Referee Comment:

Page 8130 – Section 2.3: In both, sections 2.1 and 2.3, you talk about hydrological data. Maybe you can combine these two sections.

Authors' response:

We agree that both section 2.1 and 2.3 provide information about hydrological data. However, the focus of section 2.1 is to provide background information about the large scale flood data base which provides general guidance for the analysis of meteorological and hydrological data. Section 2.2 and 2.3 provide more specific information on the data used for the evaluation of the June 2013 and the other events. Due to the suggestion of another reviewer the organization of sections has been changed.

Referee Comment:

Page 8132, line 7: What about the 1954 event? And the 2013 event?

Authors' response:

Yes, the two other events are also quantified in the same way. We considered this in the manuscript.

Referee Comment:

Page 8132, line 15: Is there a reason for using API30? Why not API20 or some other period?

Authors' response:

As shown in the time series of Figure 3, the month of May 2013 was extraordinarily wet, which is considered using API30; for API20 we would cut off some precipitation that already contributed to catchment wetness. However, note that the first 10 days account only for 8.3% of the total API (due to the weighting). Thus, the differences between API30 and API20 on average are small. In the revised manuscript we added some sensitivity analysis which also includes a variation of the API duration (30 and 15 days).

Referee Comment:

Page 8132, line 19: Where does the factor 0.9 come from?

Authors' response:

Several Authors use a value of 0.9 for the depletion factor. We added some references to this section. In the revised manuscript we added some sensitivity analyses which also include a variation of the factor k in the calculation of API namely k= 0.8, k=0.9 and k = 0.98 which covers the range of values proposed in the literature.

Referee Comment:

Page 8132, line 24: What about the 1954 event? And the 2013 event?

Authors' response:

Note that our reference period is 1960 to 2009 (reasons for that are stated above).

Referee Comment:

Page 8133, line 5: Why 5 year return period?

Authors' response:

In the revised manuscript we added some sensitivity analyses which also includes a variation of the return period used as the reference level in the calculation of severity indices.

Referee Comment:

Page 8134, line 5: See previous comment.

Authors' response:

Please refer to the answer given above.

Referee Comment:

Page 8134, line 17: Here you use the annual maximum series of daily mean discharge. In section 2.1, the database was compiled using the peak over threshold criterion. Does this mean, you reduced the number of 74 flood events to 60 (annual maximum values)?

Authors' response:

For the extreme value statistics of flood peak discharges we applied a 'block maxima' approach, i.e. we used annual maximum series of mean daily discharges at the 162 gauges. The peak over threshold criterion was used by Uhlemann et al. 2010 to identify potential large scale floods from the spatial time series at 162 gauges. As the use of the term POT in this context might be confusing we changed the text.

Referee Comment:

Page 8134, line 20: Why 5 year return period?

Authors' response:

We considered a variation of reference levels for calculating the different severity indices. In Uhlemann et al. (2010) the flood severity index was tested for a variety of return periods 1.5 to 20 years). A return period of 2 years refers approximately to bankful discharge in a typical European lowland river. The higher the return period reference level, the more weight is put on extreme runoff in relation to spatial extent which leads to a lower ranking of moderate intensity, large scale winter floods. A 5-years return period is regarded as the best compromise to generate a balanced event set when concentrating on the analysis of very large events.

Referee Comment:

Page 8137, line 12: Could you add some details about the size of the upper Elbe and upper Danube catchments in the figure caption? Or add a table with area of the catchments, mean precipitation, precipitation during the 3 events.

Authors' response:

We included the size of the catchments in the caption of Fig. 3.

Referee Comment:

Page 8137, line 26: If possible, add the location of the station Aschau-Stein in figure A1.

Authors' response:

The location has been included in Figure A1 as meteorological station

Referee Comment:

Page 8138, line 6 (Figure 5): Please use the same legend for all three subfigures, so that in each figure you have the same color for days 1, 2, 3,… 7 from the first day? The right figure will not change, as the difference between day 1 and day 7 is the biggest time difference, but for the middle (only little change) and left figure (big change) it will. I think, the patterns will not change much, but it will be more easily comparable and most likely, the homogeneity will be visible even better.

Authors' response:

We followed this suggestion and used for all three events a 7-day color bar.

Referee Comment:

Page 8138, line 22: Can you give a description of the LCL? What is a very low LCL, what is a high LCL?

Authors' response:

We added a short description: "…the lifting condensation level (LCL), which represents the level of the cloud base in case of synoptic-scale or orographic lifting,…". Furthermore, we provided more details and added the average values for the station of Kümmersbruck (which is located between the two precipitation maxima).

Referee Comment:

Page 8138, line 24: You can tell from the figures where Munich and Stuttgart are. But how about Meiningen and Kümmersbruck? Is it really necessary to name these stations? If possible, add the location in figure A1.

Authors' response:

The location of these stations has been included in Figure A1 as meteorological station

Referee Comment:

Line 8138, line 26ff: … precipitable water pw … was large …What are typical values for pw, why is a pw of 25 mm large? Could you add some details?

… which is far outside the interquartile range …Could you give the values in this paper? I know that I could check the values in Kunz (2011).

Authors' response:

We added a few more details and included the value of the 90% percentiles of the study of Kunz (2011).

Referee Comment:

Page 8139, line 15: Again, where exactly is Aschau-Stein?

Authors' response:

The location of these stations has been included in Figure A1 as meteorological station

Referee Comment:

Page 8140, line 2: Just as the previous comment, where is Zinnwald-Georgenfeld?

Authors' response:

The location has been included in Figure A1 as meteorological station

Referee Comment:

Page 8140, section 3.3.1: You show that the API 30 is high over large parts of Germany, and you give estimates of the return periods of the API, which are on the order of 5-30 years in large parts of Bavaria and 50 and more in the North of Bavaria. In the report of the BfG (Das Juni-Hochwasser des Jahres 2013 in Deutschland. BfG Bericht Nr 1793, Bundesanstalt für Gewässerkunde, Koblenz), there is a figure with results of soil moisture simulation. From this figure I would say that in the Northern parts of Bavaria the soil moisture was the highest value in the period 1962-2012. This would mean that the return period was around 50 years. The numbers correspond approximately.

My question is – are the results of your APIs and the soil moisture values of the BfG comparable?

Authors' response:

Both APIs and soil moisture values provided by BfG indicate a strong wetness anomaly in May 2013. The values provided by BfG refer to a specific date, namely the 31st May. For this specific date the values of 2013 are ranked in comparison to the values from 1962 to 2012.

In contrast, the sample used for the statistical analysis of API in our study is conditioned on the occurrence of a large-scale flood in the reference period (1960 to 2009). Hence our approach targets on the comparison of initial conditions before floods whereas the BfG evaluation is related to a very constrained time window during the year. This means that in our analysis the wetness conditions in May 2013 are compared to wetness conditions for instance in winter or spring if these periods are in advance to a large-scale flood. Given these differences the values are not necessarily comparable.

Referee Comment:

Page 8143, line 5: … comparison to other large-scale summer flood events…Why summer flood events? First, you mentioned POT, then AMS and now summer flood events – did you just concentrate on summer floods?

Authors' response:

This was just a mistake from a previous version, where we actually concentrated on summer floods. But we decided to consider all events. We changed this accordingly.

Referee Comment:

Page 8144, line 12:… less extended in August 2002 …„in" is missing

Authors' response:

This has been corrected.

Referee Comment:

Page 8145, line 23: … above around 40 increase …Increase - should be plural, not singular.

Authors' response:

This has been corrected.

Referee Comment:

Page 8145, line 11, Figure 12: Should be upper right corner.

Authors' response:

This has been corrected.

Referee Comment:

Page 8145, line 27: ERMS=13.2 What does this value say? Where does it come from?

Authors' response:

ERMS is the Root Mean Square Error of the LOWESS-Model interpolation compared to the sample of data used for the interpolation. The Root Mean Square Error can be interpreted as the standard deviation of unexplained variance and thus provides a metric of LOWESS Model accuracy. We provided this context also in the paper.

Referee Comment:

Page 8147, line 4: 1952? Again, the beginning of the Uhlemann data set?

Authors' response:

Yes, this year is mentioned as it is the start date of the period examined in Uhlemann et al., 2010.

Referee Comment:

Page 8147, line 10: In contrast to … Blöschl et al. (2013)…I think this statement needs to be clarified for several reasons.

First, you state that „initial wetness was a minor factor for the 1954 flood in Germany", whereas Blöschl et al. just looked at the Danube Basin. Second, Blöschl et al. said that the defining feature of the event was the spatial distribution with high precipitation (which is in line with your results); however, there was a pre-event which increased soil moisture. E.g., the Inn river had two peaks, one smaller (the pre-event) and the more extreme second event. The Danube in Germany just has one peak during this event. Third, you looked at the API30 and figure 7 clearly shows values of up to 150 mm along the alpine ridge in an area that is even larger than 2013. Your API30 includes the first block of precipitation mentioned before. Could you comment on this and clarify this in the paper?

Authors' response:

We agree that from a more localized perspective initial wetness is an important factor for the flood generation particularly at the Northern ridge of the Alps. We changed the text accordingly.

What made the June 2013 flood in Germany an exceptional event? A hydro-meteorological evaluation

Kai Schröter[1,3], Michael Kunz[2,3], Florian Elmer[1,3], Bernhard Mühr[2,3], Bruno Merz[1,3]

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Reply to comments of Christian Reszler

First of all we want to thank the Christian Reszler for his valuable and thoughtful comments. Following, we will reply to each of the comments made.

General comments

Referee Comment:

The paper by Schröter et al. evaluates the June 2013 flood in Germany from a hydro-meteorological perspective and compares this flood with two large flood events in the past. They build on a very nice data base of gridded daily precipitation and a compilation of large scale flood events in Germany. They point out the main driver for the exceptional flood, the high soil moisture status in the catchments prior to the event, and illustrate the importance of the antecedent soil moisture for high return periods.

The valuable data base using different spatial indices makes this well written paper a valuable contribution to flood event and flood risk analysis. It is worth being published. However, what would even increase the strength of the conclusions are implications regarding design flood estimation. The Authors' address the importance of scenario definition ("unusual combinations") for flood risk analysis, i.e. pronounced precipitation and high antecedent soil moisture, but, in the light of the large floods in recent years and the comprehensive flood data

base they could try to refer their conclusions to the usual statistical measures in design flood estimation.

Authors' response:

The introduction and conclusions have been overworked. We now also refer to advanced approaches for flood frequency analysis and design flood estimation.

Specific comments

I have a few comments that should be considered before publishing.

Referee Comment:

P. 8128, line 1:"... hypothesis is contrary to ..." This is a rather strict formulation, also in the next sentence "... only secondly ..."

Authors' response:

We reformulated the sentence: "This hypothesis is of interest in the context that the influence of initial catchment wetness is seen to be of decreasing importance…"

Referee Comment:

P. 8132, Sect. 2.4.3: What is the role of evapotranspiration (summer events) for the antecedent moisture status? Can other data sources be used to confirm API? (e.g. DWD actual soil moisture maps, remote sensing data, hydrological models in operational use).

Authors' response:

API is used as a proxy for soil moisture depending on rainfall in the period before the onset of the flood. The potentiation of k with the number of days corresponds to the assignment of continuously decreasing weights to rainfall that has occurred earlier. This relation approximates the decrease of soil moisture due to evapotranspiration and percolation to deeper soil layers. We complemented these details to the text.

Alternative data sources are available as for instance the soil water index (SWI) of TU Vienna which is based on Metop ASCAT remote sensing data. However these data and also other data sources such as hydrological models are not available continuously for a 50 years period, such as our reference period from 1960 to 2009, to draw consistent comparisons for May/June 2013 and the floods of the event set.

The extraordinary soil moisture situation in May/June 2013 is confirmed by a map of ranked soil moisture values provided by BfG (2013).

BfG: Länderübergreifende Analyse des Juni Hochwassers 2013, Bundesanstalt für Gewässerkunde, Deutscher Wetterdienst, Koblenz., 2013.

Referee Comment:

P. 8137, Sect. 3.1: There are a lot of meteorological details given, please clarify some very specific parts (e.g. weather types), or, since it is a hydrological paper, I propose to shorten this part, also in the light of "... cannot explain the extraordinary situation in 2013", as mentioned previously in the text (p. 8130, line 10).

Authors' response:

We shortened this paragraph and clarified or deleted some very specific details. Furthermore, we deleted the mentioned paragraph (p. 8130) with the large-scale weather patterns because it provides no useful insight.

Referee Comment:

P. 8137, Sect. 3.2 and further pages: Please clarify the date of the event in August 2002 used in this study. On p. 8140, line 1 the 24 hour sum from 7 to 8 Aug. 2002 is given, but at the Danube and the Elbe the second flood from 12 to 17 Aug. caused the higher flood peak. Is this peak - showing high return periods with high antecedent wetness - incorporated in the study?

Authors' response:

This was a mistake, sorry. The period of the 24-h maximum, which triggered the second flood peak (considered in our study), was 12-13 August. We corrected this.

Referee Comment:

P. 8143, line 28: Are there other factors? To what extent could this be the effect also of the shape of the hydrograph, i.e. the large volume of the (single) flood wave, as illustrated e.g. by Blöschl et al. (2013) for the Danube? Furthermore, did flood protection measures, possibly installed after the 2002 flood, affect wave propagation in 2013?

Authors' response:

The shape of the hydrograph, superposition of flood waves in the river network and flood protection measures are important factors that may aggravate a flood. Similarly, dike breaches may alleviate the flood level downstream. During the flood in June 2013 the superposition of flood waves played an important role at the confluence of the Inn and Danube (also shown by Blöschl et al., 2013) as well as in the Elbe catchment at the confluence of the Saale and Elbe

rivers. However these hydraulic issues were not within the focus of this paper. Anyway, these effects were not important for the upstream parts of the Saale, Werra and Main rivers. We restricted our statement to the *'upstream parts of the Saale, Werra and Main catchments'*

Technical comments

There are not many typing errors I found in the text:

Referee Comment:

P. 8228, line 11: possibly set a comma after "Germany, ..."

Authors' response:

We overworked this paragraph and this sentence does not longer exist.

Referee Comment:

P. 8228, line 15: events of Uhlemann ...

Authors' response:

This has been changed ("event set of Uhlemann…").

Referee Comment:

P. 8142, line 15: increased

Authors' response:

This has been changed.

Referee Comment:

P. 8146, line 21: Why put "antecedent" in quotes?

Authors' response:

This indeed does not make sense. We deleted the quotes.

Referee Comment:

P. 8159 and following pages: see above: please clarify the date of the 2002 flood in the Figures (or in the text)

Authors' response:

The date of the 2002 flood has been clarified, see comment above.

What made the June 2013 flood in Germany an exceptional event? A hydro-meteorological evaluation

Kai Schröter[1,3], Michael Kunz[2,3], Florian Elmer[1,3], Bernhard Mühr[2,3], Bruno Merz[1,3]

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Reply to Short Comment of Michel Lang

First of all we want to thank Michel Lang for his valuable and thoughtful comments. Following, we will reply to each of the comments made.

Principal Criteria Excellent (1) Good (2) Fair (3) Poor (4)

Scientific Significance: X

Does the manuscript represent a substantial contribution to scientific progress within the scope of Hydrology and Earth System Sciences (substantial new concepts, ideas, methods, or data)?

Scientific Quality: X

Is the scientific approach and applied methods valid? Are the results discussed in an appropriate and balanced way (consideration of related work, including appropriate references)?

Presentation Quality: X

Are the scientific results and conclusions presented in a clear, concise, and well-structured way (number and quality of figures/tables, appropriate use of English language)?

1. Does the paper address relevant scientific questions within the scope of HESS?

The paper presents a hydro-meteorological comparison of three major flood events that occurred in Germany these last decades: July 1954, August 2002 and June 2013. It addresses several components that can explain the severity of these events: meteorological conditions, initial wetness conditions and rainfall intensity. This is a valuable contribution to the analysis of past flood events and the improvement of the understanding of the physical mechanisms of extreme floods.

2. Does the paper present novel concepts, ideas, tools, or data?

The paper provides very clear maps on the spatial variability of different indexes: 3days maximum rainfall - cumulated amount and return period; antecedent precipitation index - cumulated amount and return period; initial flow condition - normalized ratio and return period; peak discharge - return period. It gives also interesting information on the weather conditions, the repartition of the areal rainfall during the rainy period, the date of the maximum of the rainfall, the position of the three flood events within a 2D graph (wetness index and precipitation index).

All these information provide a very valuable insight of the characteristics of flood events.

3. Are substantial conclusions reached?

Yes, the paper shows clearly the importance of antecedent soil moisture conditions for the height return period of the June 2013 flood.

4. Are the scientific methods and assumptions valid and clearly outlined?

Yes

5. Are the results sufficient to support the interpretations and conclusions?

Referee Comment:

There is one possible improvement related to the role of snowmelt contributions. This point is addressed (end of section 3.5) in one sentence. I wonder if some index could be added (analysis of snow cover plus air temperature).

Authors' Response

We agree that snowmelt can play an important role in the generation of floods. However, in the case of summer floods in Germany as in July 1954, August 2002 and June 2013 this was not an important factor. On the contrary, both in June 2013 and in July 1954 snow was accumulated above elevations of 800 m in the Alps (Blöschl et al., 2013) and attenuated runoff generation. Likewise in August 2002 snow did not play an important role. As the focus

area of our analysis is Germany we decided to exclude the aspects of snow melt and accumulation. The derivation of a snow-melt index for the set of historic flood events would be interesting, yet reliable data for a consistent comparison are not available.

6. Is the description of experiments and calculations sufficiently complete and precise to allow their reproduction by fellow scientists (traceability of results)?

Referee Comment:

One point could be highlighted: I didn't understand how the event start dates were selected (see section 2.4.1). Is it related to the date when the flow does significantly increase? The sentence is easy to write, but we need some mathematical criteria to define what is a significant increase (we can have some secondary peaks).

Authors' Response:

Actually, we have two different event start dates. One is related to the onset of large-scale floods which form the data base of large-scale floods, the other one is based on the maximum precipitation that triggers the flood.

We overworked subsection 2.4.1 (now 2.2.1) and added further explanations.

7. Do the Authors' give proper credit to related work and clearly indicate their own new/original contribution?

Yes

8. Does the title clearly reflect the contents of the paper? Yes
9. Does the abstract provide a concise and complete summary? Yes
10. Is the overall presentation well-structured and clear? Yes
11. Is the language fluent and precise? Yes
12. Are mathematical formulae, symbols, abbreviations, and units correctly defined and used?

Referee Comment:

Please give comment of the value of 0.9 in equation (1). Is it a well-known planetary invariant coefficient (??) or something specific to the time-autocorrelation of rainfall in Germany? Add some references on this point.

Authors' Response:

There are several suggestions in the literature to use a value between 0.8 and 0.98 (which depends especially on climate and season). Since the purpose of our study was to compare past flood events with the same methods, we decided to use a constant value between, thus we selected 0.9. The implications of varying k within the range are now examined within a sensitivity analysis.

In the manuscript we added some references and explained the use of this value for the depletion constant. Further we examined the sensitivity of the Wetness-Severity-Index with regard to this factor. See new section.3.6 Sensitivity analysis.

13. Should any parts of the paper (text, formulae, figures, tables) be clarified, reduced, combined, or eliminated?

Referee Comment:

Section 1: The sentence "This hypothesis is contrary to the notion that the influence of catchment wetness is greater ..." is somewhat overstated. The main idea of flood frequency analysis based on rainfall information is that the extreme tail of distribution is driven by the extreme tail of the rainfall distribution. It is characterized by an asymptotic parallelism between the two distributions (see for example the Schadex method, Paquet *et al.*, 2013). But these methods clearly account that flood hazard is a combination of antecedent moisture conditions and rainfall intensities. That is to say that all possible combinations are possible for specific flood events.

Authors' changes:

We reformulated the introduction: "…On the one hand, catchment wetness state is an important factor for the generation of floods (Merz and Blöschl, 2003). As such it is a useful indicator in flood early warning schemes (e. g. Van Steenbergen and Willems, 2013; Alfieri et al. 2014; Reager et al. 2014) and is also incorporated in procedures for extreme flood estimation (e. g. Paquet et al. 2013). …"

The issues raised by the referee in reference to Paquet et al., (2013) are also included in the conclusions.

Referee Comment:

Page 8128, line 22: “Section 4”

Authors’ response:

This has been corrected.

Referee Comment:

Page 8138, line 26: “(pw)”

Authors’ response:

This has been changed.

Referee Comment:

Page 8139; line 10: The sentence is not clear. I understand that the Authors’ do not want to extrapolate beyond the 200 year return period. It means that the estimated values of return period have been upper-bounded to 200 years (and not neglected).

Authors’ response:

We followed this suggestion and reformulated the sentence: “The estimated values of the return periods have been truncated to 200 years…”

Referee Comment:

Page 8144, line 6: “(see Fig. 11, middle and right panels)”

Authors’ response:

This has been corrected.

Referee Comment:

Page 8148, line 30: paper of Bloschl *et al.* (2013) has been published in HESS (no more in HESSD).

Authors’ response:

This has been corrected.

14. Are the number and quality of references appropriate?

Yes

15. Is the amount and quality of supplementary material appropriate?

No relevant