List of changes compared to the previous manuscript

- Changes in the text regarding

    - The methodology
    - The quality of the data and its shortcomings
    - The potential implementation of the method in early warning schemes
    - The interpretation of the results

- Methodology

    - Define the 7-day precipitation based on SPI calculation (in order to address Reviewer #1 comment #3a)
    - Calculate the Risk Ratio and its confidence intervals (in order to address Reviewer #1 comment #3c and the Editor's comment #3)
    - Change Figures 7, 8, 9
    - Create Figures for the supplementary material (S.1-S.16)

- Extra references
    - Other studies that have used Munich Re database in their analysis
    - Methodology of estimating the Risk Ratio and its confidence intervals
    - Studies that have used the Risk Ratio

Response to reviewers and to the editor

Title: The influence of antecedent conditions on flood risk in sub-Saharan Africa

Authors: Konstantinos Bischiniotis, Bart van den Hurk, Brenden Jongman, Erin Coughlan de Perez, Ted Veldkamp, Hans de Moel, Jeroen Aerts

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General response

We thank the two reviewers and the editor for the time taken to review and process our manuscript. In response to their comments, we have further revised our manuscript, and we have made additions and changes as outlined in this document. In the following sections, we respond to each of the reviewers' remarks or questions. Our responses are colored in blue.

Editor:

Thanks a lot for your revised manuscript. The 2 referees of the original version have looked at the revisions and have come to conflicting recommendations. Reviewer #2 is happy with your revisions, whereas Reviewer #1 recommends to reject the paper, although he/she acknowledges that the manuscript has improved compared to the original version. Given this situation, I have had a close look at the manuscript and decided on major revisions. I feel that, on the one hand, the concerns of Reviewer #1 are valid, but on the other hand, I think that the paper can hopefully be published after further revisions. I comment the 3 major concerns that reviewer #1 has raised:

We thank the editor for his detailed comments and for the valuable suggestions to further improve manuscript. We also think that Reviewer #1 comments are valid and we have revised the manuscript so as to address them as good as possible.

1) I agree with the reviewer that there is little information on the climatic and hydrological setting, and the Köppen classification used does not seem to bring further insight to the topic. It would be great if the variation of flood generation across your study area could be discussed – but on the other hand I would understand that, given the coarseness of the data and the study design (pooling of all data across the study area), the actual benefit of such a discussion might be small and might not be worth a large effort.

We agree with the editor and with Reviewer #1 that not much information that could further bring insight to the topic can be derived from the Köppen classification. When classifying the reported flood events per climatological areas, our sample size per area becomes even smaller, as the editor suggested. For example, when using Level 9 Köppen classification, the average sample size per area is 60 floods. This, in combination with the fact that local conditions play a substantial role in flood generation, are likely he main reasons that no robust conclusions can be drawn. We have addressed these issues in the revised paper. We have not drawn any conclusions based on this, and simply present the locations, where the floods were reported.

2) Concerning the 'data quality' issue, the reviewer might be right that the data quality is so low, and the confounding factors so various, that a statistical analysis always contains weak signals and much noise. My recommendation is that you check whether all your statements on the use of the results and the potential for improving/implementing early warning and preparedness schemes are valid. I feel that there would be a very long way to go, and in the end it might not be possible to gain much along this path.

We thank the editor for his comment and recommendation. Throughout the text, we have explicitly mentioned that the analysis is conducted using floods from Munich Re disaster database, acknowledging its shortcomings. Nevertheless, we argue that Munich Re is the most detailed and most complete disaster database currently available at the scales and regions we apply our method. For example, according to Vries, M. (2017), Munich Re has reported the most flood events in Tanzania, Malaysia and Ireland, including all the events that have been reported in FloodList, Flood Observatory and EM_DAT. Moreover, Munich Re database has also been applied in several scientific studies (e.g. Hoeppe, 2016; Jongman et al., 2014a) Based on the editor's suggestion, we have checked the statements we have made regarding the quality of the data, how this is related with improving/implementing early warning systems and why this study is useful to the humanitarian sector.

3) I feel that the concerns of the referee on 'statistical methods' should be taken very seriously. To use simple, pragmatic methods is not a problem in case they are appropriate and robust, but I ask you to really consider his/her questions about the methodology, in particular his/her point about the robustness of the results. For example, would it be possible to provide uncertainty intervals for the 'relative odds of floods vs NF'? Figures 7 and 8 show a

strange behaviour for large SPEI values which somehow undermines the confidence in the analysis. Further, the statement (based on Fig. 5b) that max-7-day-precip is significantly different between floods and non-floods should be carefully interpreted: The difference might be statistically significant (partly because statistical tests tend to find significance when the sample size gets large), but maybe not relevant given the variability in both samples.

We thank the editor for his comments and suggestions. In the new revised version, we have taken into account Reviewer #1 comments, and we have further extended the statistical analysis to address his/her concerns.

First, we have altered the name 'relative odds' to 'risk ratio' (RR) as it is a term that is frequently used in literature, especially in medical and epidemiology studies (e.g. Katz, 2006; Shrier and Steele, 2006; Zhang, 1998).
Subsequently, following the methodology of Moris and Gardner (1988), we calculated the confidence intervals of this risk ratio. The principle in this methodology is that although the sample does not follow a normal distribution, its natural logarithm is approximately normally distributed to produce the 95% confidence intervals. Therefore, first, a confidence interval is generated for $\log_e(RR)$ and subsequently, the antilog of the upper and lower limits of the confidence interval for $\log_e(RR)$ are computed to give the upper and lower limits of the confidence interval for the RR). In case, the upper limit is above 1 and the lower limit below 1, the risk ratio is not statistically significant. An analytical description is given in Section 2 of the revised manuscript.
For each case of Figures 1, 2, and 3 (see the end of this document), which correspond to Figures 7, 8, and 9 of the original manuscript, we have created a graph that shows the confidence intervals (Figures 4-19). The fact that high SPEI values show a strange behaviour is a consequence of the large confidence intervals that the small number of floods and no-floods produce. Note that for SPEI0, which includes the period in which the reported floods occurred, an expected monotonous increase of risk ratio with SPEI-value is shown, supporting the notion that there is a relation between SPEI0 and the likelihood of a flood to occur. Nevertheless, as the editor suggests, the conclusions drawn by this analysis are carefully interpreted in the revised manuscript.

Furthermore, in order to address Reviewer #1 concern about the normalization of PRE7 and MAX7, we re-defined them in line with the definition of the Standardized Precipitation Index (SPI), by fitting a gamma distribution to the precipitation values that are used for the calculation of PRE7 and MAX7 (See also response to reviewer #1). Although, as expected, results do not change substantially, we follow editor's recommendation and we carefully interpret and explain the statistical significance that is found between floods and no-floods, and in the revised paper, we now discuss the possible explanations and conclusions of differences between PRE7 and MAX7.

Reviewer #1:

I reviewed the revised manuscript „Influence of antecedent conditions on flood risk in sub-Saharan Africa". The authors tried to extent their statistical analysis and compare the antecedent short- and seasonal scale conditions of reported floods by MunicRe with the conditions in years, where no flood occurred. Simple statistical tests are conducted in order to test the significance of precipitation anomalies at different temporal scales.
I appreciate the effort and I believe, that the manuscript has improved from a methodological point of view. However, I am unfortunately not convinced that the findings are yet sufficient for publication. The major conclusion, that floods are triggered by a combination of the catchment state (as represented by SPEI) and high precipitation during the build-up period is rather trivial and has been investigated in various studies, mostly by means of more complex methods. The differences reported in the manuscript are mostly not very clear and often not statistically significant. Further the shortcomings of the datasets and methods impede the interpretation of the results.

Thus, as much as I regret it, I cannot recommend publication at the current state. I would like to encourage the authors to further advance their methods (particularly to use more complex inferential methods, which are suitable for the data) and re-submit a new-version, if more robust results could be achieved.

We thank Reviewer #1 for his/her comments and we are happy that he/she finds that the manuscript has improved compared to the latest version. The reviewer has point, and in the revised version, we have further improved our statistical analysis, taking into account his/her comments.

As for the issue of existing research on the same topic, indeed, various studies have examined the influence of high precipitation during the flood build-up period in the past. However, to our knowledge, they do not explicitly distinguish between the weather- and the seasonal-scale flood build up period, which is particularly relevant for the alert function under data-sparse conditions in Africa. Moreover, they either conduct the analysis based on modelled floods, or they examine only very few flood events. Hence, by examining a relatively big number –compared to the previous studies- of real flood events, we have demonstrated that long-term antecedent conditions should not be a priori neglected as in several past events, they have played a role in flood mitigation.

Hence, we believe that the conclusions drawn in our revised version are both relevant and novel, as the paper integrates short- and long-term flood antecedent conditions based on a relatively large group of reported flood events. However, perhaps this was not clear in our discussion section, and we have further clarified the novelties of our methods as compared to existing literature

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1) Introduction, climatic and hydrological setting:
The study covers a large target region with various different climatic settings. No information is provided on climate-variability, large scale climatic circulation modes and on typical flood generation processes in different parts of the region. The Köppen classificastion (Fig.4) is not sufficient to describe the climate of the region (especially the very basic version, which classifies the center of the continent as oceanic?). It might be a step into the right direction to analyse the spatial climatic variability (SPEI). Maybe one could then find different flood types in different regions, which are characterized by different SPEI-flood relationships.

Although we have tried different climatological classifications, using also the latest versions of Köppen climatology, we did not manage to produce any statistically significant differences between the climate areas for the SPEI-flood relationship. By using the basic version of Köppen that includes only 3 climatological areas, we aimed to include as many floods as possible in each area, in order to increase our sample size. However, even in such a way, we did not find any statistically robust results. Identifying different flood types in different regions could be a step forward, but we believe that flood generation depends highly on local characteristics of both climatic and non-climatic nature. With the limited number of floods and reported characteristics we cannot derive a robust spatial classification of floods.

2) Data Quality:
One major problem of the study remains the quality of the MunichRe data set. The comparison of observed and non-observed floods assumes, that the data set is a) somehow complete and b) that the climate-flood link is stationary. However, as the authors admit, there is a strong trend in the data, which points to increasing settlements in flood-prone areas or an increase of flood reports. Those problems might blur important statistical relationship.
In their recent publication ("Should seasonal rainfall forecasts be used for flood preparedness?") the authors show (based on modelling results), that the precipitation-flood link varies over the target region and is highly dependent on the climatic conditions. In the presented manuscript, all floods are pooled, which also might blur clear results. I fear, that the

quality MunichRe data set alone might be too poor and the number of reported floods too low to draw statistically significant conclusions and to derive interesting/new results.

We understand that Reviewer #1 is concerned about the quality of a reported database such as Munich Re. Throughout the manuscript, we have explicitly mentioned its weaknesses and how this might blur the statistical conclusions drawn, emphasizing that the analysis has been conducted, naming as 'floods' only the ones reported. To our knowledge, Munich Re is not only the most detailed dataset, it is also the most complete one. A recent thesis by Vries (2017) supports this claim, by showing that Munich Re presents the highest number of flood events in Tanzania, Malaysia and Ireland and it also includes the events reported in other databases such as FloodList, Flood Obseratory and EM_DAT. As we stated in the revised manuscript, we expect that by including the reported damaging flood events, this research will also be useful to the humanitarian sector.

Moreover, as Reviewer #1 mentions, our recent publication "Should seasonal rainfall forecasts be used for flood preparedness?" was based on modelling results and explored the usability of precipitation forecasts at seasonal time scales. Trying to validate/compare it with the real world, in this research we use reported floods, whose number is obviously much lower, and include explicitly the short-range forecasting time scale, which gives a clearly better description of the precipitation-flood relationship. To increase the statistical sample the events are pooled. Acknowledging the difficulties and the uncertainties of this, we believe that the novelty of this research, which examines the 'real world' instead of the modelling outputs, is of value.

In the text, we have checked all our statements on the accuracy of the datasets in detail, so as to make sure that they reflect all these issues.

3) Statistical Methods:
There are quite a few methodological problems.

a) The assumptions of statistical tests are often violated by data sets. E.g. event-precipitation (Pre7 and Max7) have been z-normalized, although short-term precipitation is certainly not normal-distributed. Likewise the significance of different mean SPEI values for flood and non-flood are based on a z-test and results are questionable.

We agree with Reviewer #1 that short-term precipitation is not normally distributed. In the analysis, we followed this simplification in order to assign a single numeric value to the short-term precipitation that can be compared across the different areas. In order to address Reviewer's #1 concern, we changed the way that PRE7 and MAX7 are defined; instead of a z-normalization, we defined them in line with the definition of the Standardized Precipitation Index (SPI), by fitting a gamma distribution to the precipitation values that are used for the calculation of PRE7 and MAX7. The cumulative probability calculated from the gamma distribution was transposed to the equivalent cumulative probability of the standard normal distribution. Hence, the resulting values are the standardization of total gamma-transformed accumulated precipitation values. Based on that, we applied a z-test to evaluate the difference from the medians of floods and no-floods.

b) The 75%-quantiles in Fig. 6 clearly overlap, doesn't that actually indicate, that differences are not significant?

We use boxplots in order to show the (slightly) increased SPEI values of floods compared to the no-floods. We claim that the medians of the two groups are statistically different at the 5% level, since the comparison intervals (notches) do not overlap. Other definitions of significance may be used that come to different conclusions.

c) Also the comparison of "flood probabilities" (Fig. 7) is not very robust, since it includes classes with different numbers of cases. Thus, single floods with anomalous pre-conditions can change the entire plot (and thus the interpretation of results). E.g. the sudden drop of SPEI0 is certainly a statistical artefact. Again I would rather use boxplots or similar methods, which include the range of values and some measure of significance.

Indeed, the comparison of 'flood probabilities', which in the revised version is mentioned as 'risk ratio', includes different number of cases. For each case of Figures 1, 2, and 3 (see the end of this document), which correspond to Figures 7, 8 and 9 of the original manuscript, we have created a graph that shows the confidence intervals (Figures 4-19), as calculated by Moris and Gardner (1988), the results of the risk ratio are statistically significant in case the confidence interval does not include values below 1 (in our analysis).

Regarding the sudden drop of SPEI0, this probably happens due to the absence of flood events with SPEI0 larger than 3. In the new versions of the plots we don't show events for SPEI>2.5 due to the poor population of events in these extreme classes, which results in not statistically significant results

d) Further I wonder, why flood-likelihood-ratio is always >1, even if SPEI is clearly negative. This might indicate either a data problem or a problem of the method.

In Figure 7, the ratio is either 1 or a bit higher than 1, when SPEI is negative. This is expected, as it compares (mutually exclusive) samples of floods and no-floods exceeding an SPEI-threshold are counted. Therefore, for SPEI = -3, the ratio is 1 and it slightly increases when SPEI -1, showing that there are proportionally slightly more floods than no floods exceeding at higher values of SPEI.

On the other hand, in Figure 8 and 9, the ratio is higher than 1 even in negative SPEI thresholds as this threshold is combined with positive seasonal SPEI and PRE7 thresholds, pointing at the importance of precipitation as a flood-generating process.

Reviewer #2:

Dear authors,

thanks for all your replies to my comments to your original manuscript (reviewer #2). Mostly thanks for accepting the advice of using box-plots in some of the figures.

In your comment you declare you adjusted everywhere the use of "lead time" and replaced it with antecedent conditions. I am not sure whether you missed to do it in Figure 3.

We thank Reviewer #2 of his/her substantial contribution on the improvement of this paper.

Additional References

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New Figures

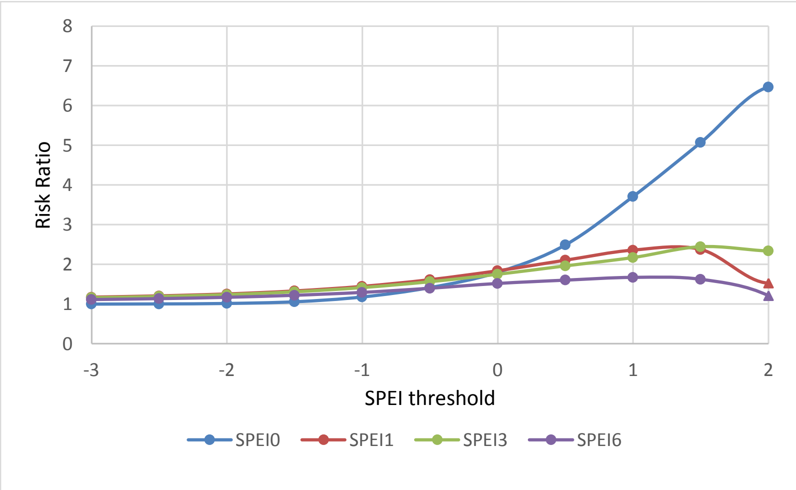

Figure 1 Risk ratio between flood and no-floods likelihood as function of SPEI exceedance values. The circles are used when the ratio is statistically significant and the triangles when it is not. (To replace figure 7 of the original manuscript)

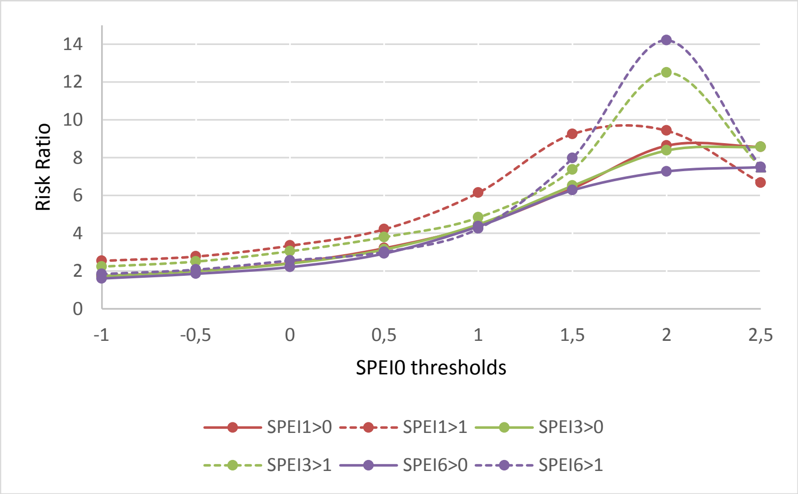

Figure 2 Risk ratio between floods and no-floods for given SPEI0 thresholds conditional to certain seasonal SPEI values. The circles are used when the ratio is statistically significant and the triangles when it is not. (To replace figure 8 of the original manuscript)

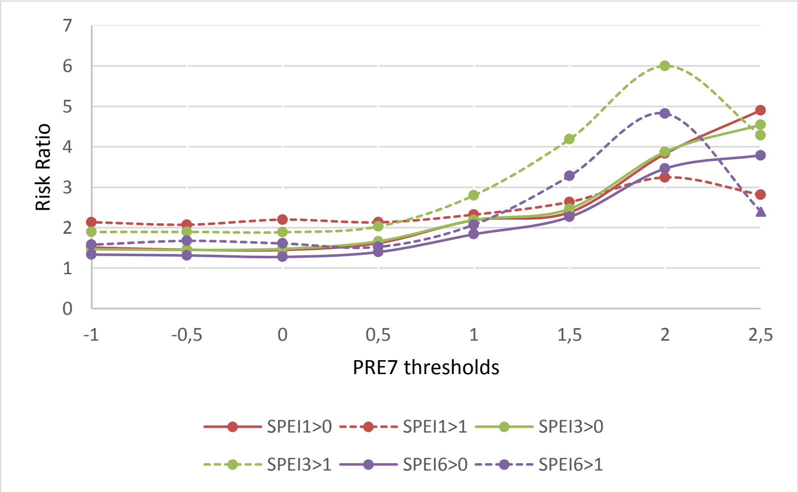

Figure 3 Risk ratio between floods and no-floods given PRE7 thresholds conditional to certain seasonal SPEI values. The circles are used when the ratio is statistically significant and the triangles when it is not. (To replace figure 9 of the original manuscript)

Figures for supplementary material

Confidence intervals for lines of Figure 1 (Figure 7 of the original manuscript)

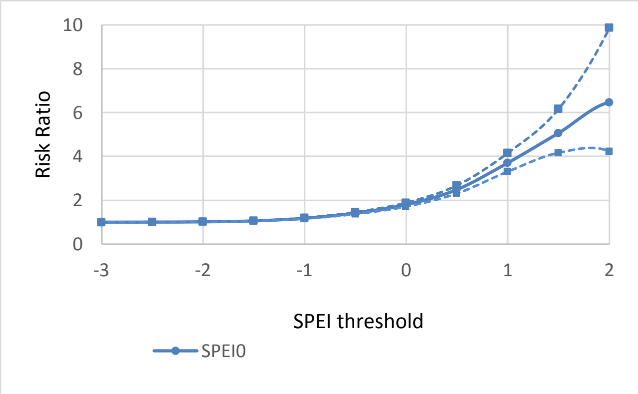

Figure S.1 Confidence intervals for SPEI0 thresholds

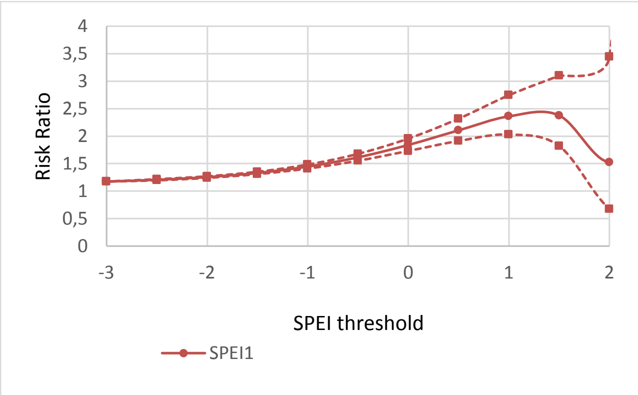

Figure S.2 Confidence intervals for SPEI1 thresholds

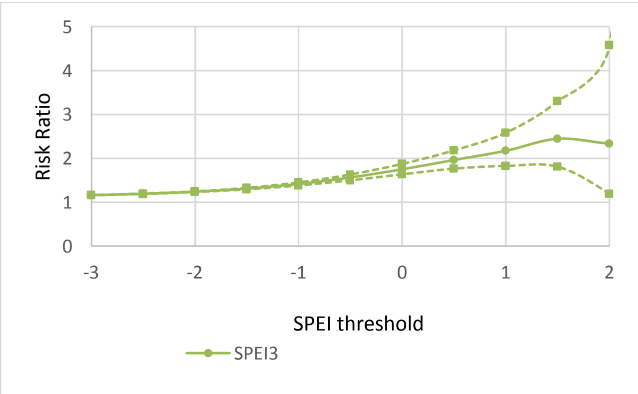

Figure S.3 Confidence intervals for SPEI3 thresholds

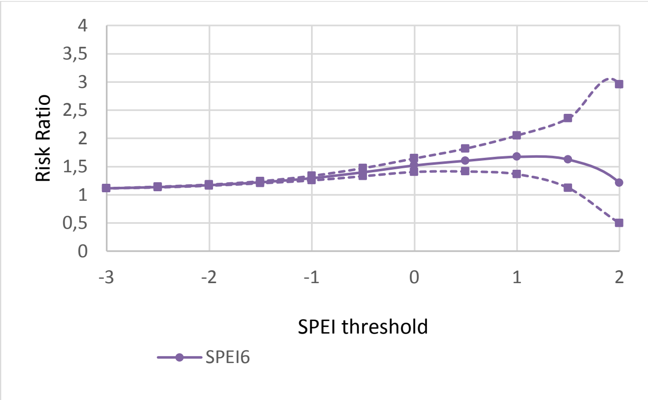

Figure S.4 Confidence intervals for SPEI6 thresholds

<u>Confidence intervals for lines of Figure 2 (Figure 8 of the original manuscript)</u>

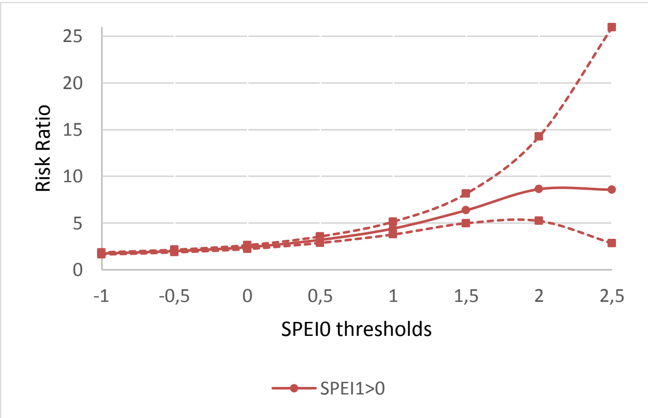

Figure S.5 Confidence intervals for SPEI1>0 and SPEI0 thresholds

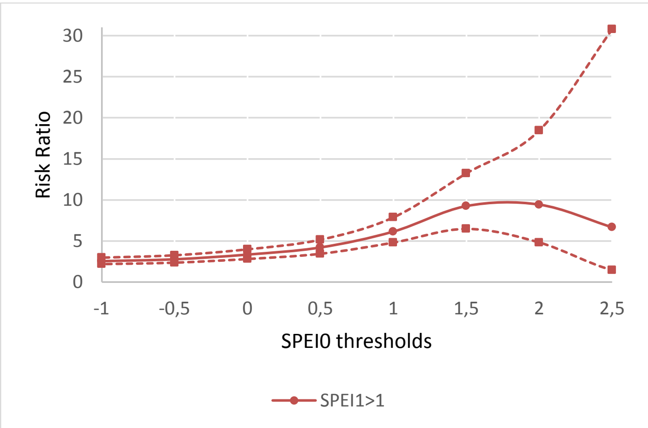

Figure S.6 Confidence intervals for SPEI1>1 and SPEI0 thresholds

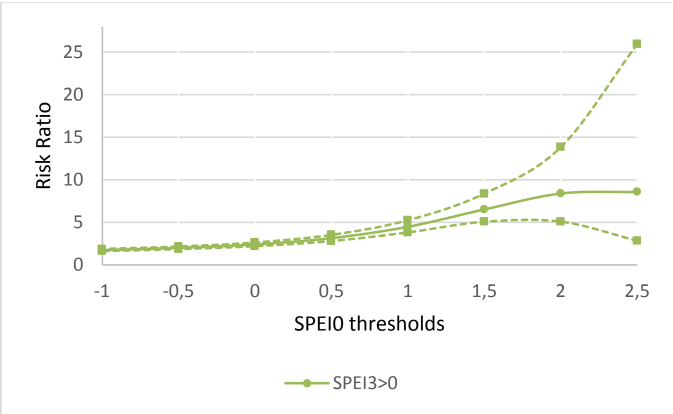

Figure S.7 Confidence intervals for SPEI3>0 and SPEI0 thresholds

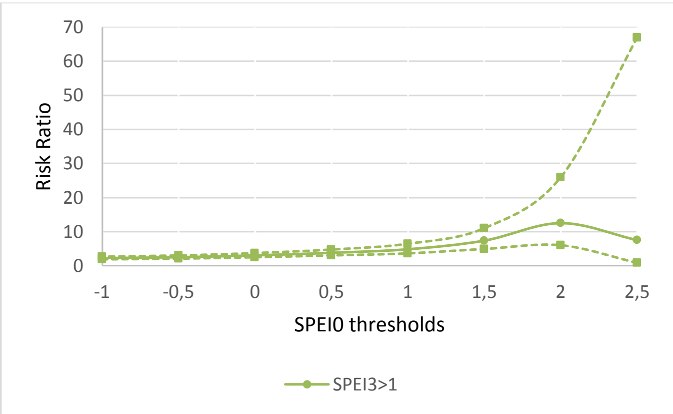

Figure S.8 Confidence intervals for SPEI3>1 and SPEI0 thresholds

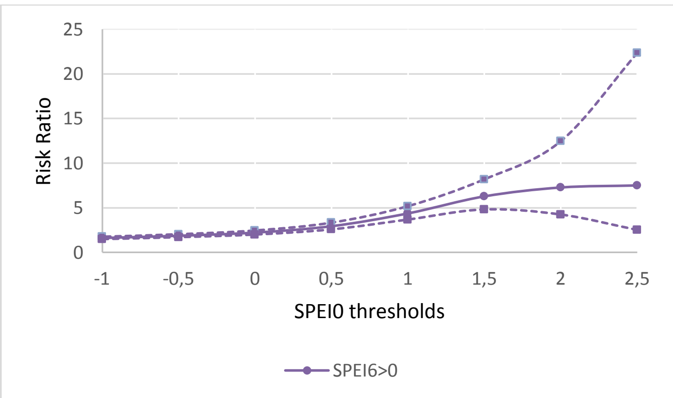

Figure S.9 Confidence intervals for SPEI6>0 and SPEI0 thresholds

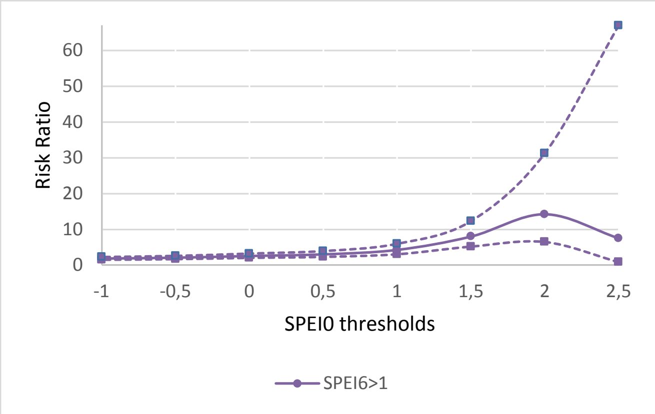

Figure S.10 Confidence intervals for SPEI6>1 and SPEI0 thresholds

<u>Confidence intervals for lines of Figure 3 (Figure 9 of the original manuscript)</u>

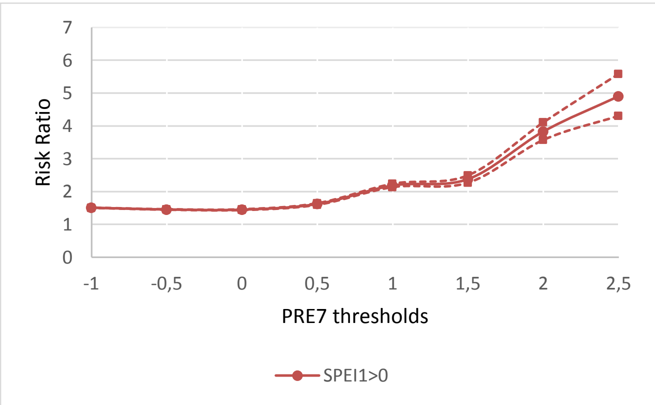

Figure S.11 Confidence intervals for SPEI1>0 and PRE7 thresholds

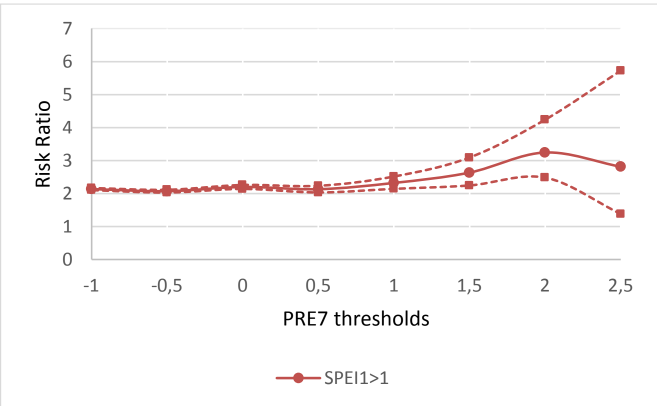

Figure S.12 Confidence intervals for SPEI1>1 and PRE7 thresholds

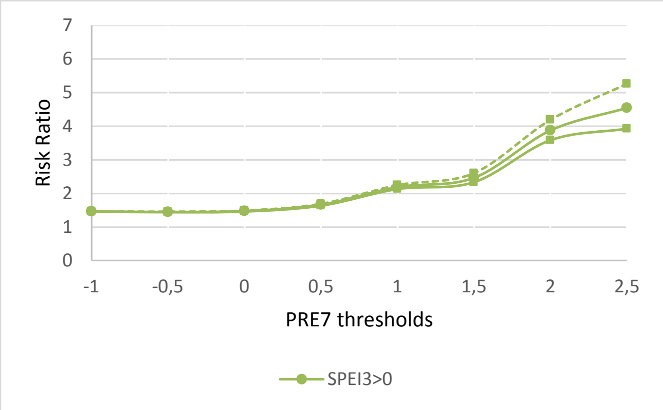

Figure S.13 Confidence intervals for SPEI3>0 and PRE7 thresholds

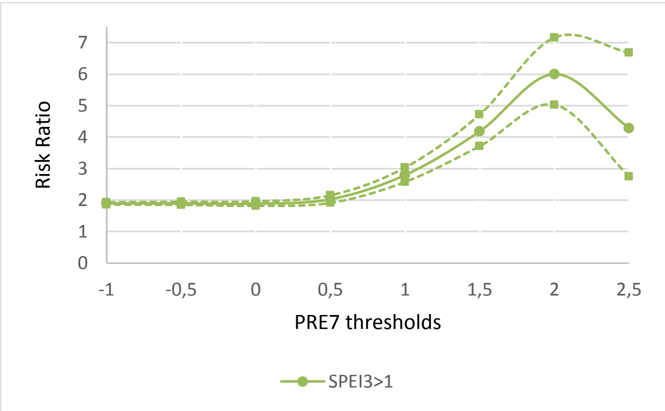

Figure S.14 Confidence intervals for SPEI3>1 and PRE7 thresholds

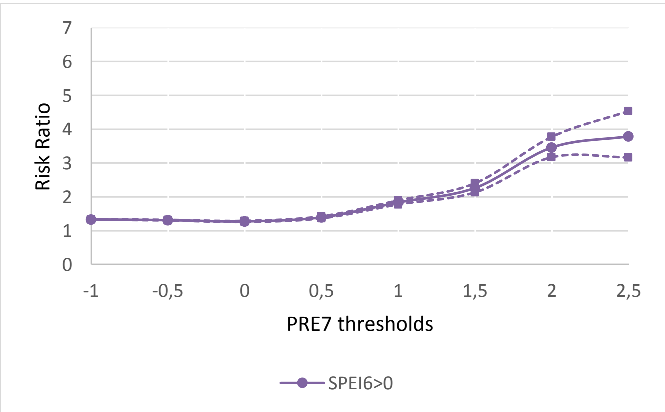

Figure S.15 Confidence intervals for SPEI6>0 and PRE7 thresholds

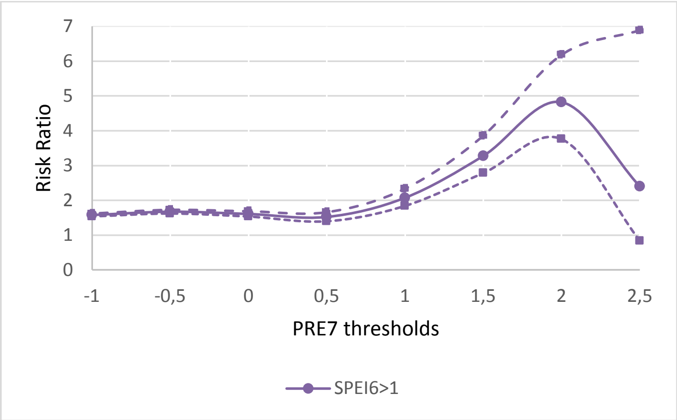

Figure S.16 Confidence intervals for SPEI6>1 and PRE7 thresholds

The influence of antecedent conditions on flood risk in sub-Saharan Africa

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Abstract Most flood early warning systems have predominantly focused on forecasting floods with lead times of hours or days. However, physical processes during longer time scales can also contribute to flood generation. In this study, we follow a pragmatic approach to analyse the hydro-meteorological pre-conditions of 501 historical damaging floods ~~over the period~~from 1980 ~~to~~till 2010 in sub-Saharan Africa. These are separated into a) weather time scale (0-6 days) and b) seasonal time scale conditions (up to 6 months) before the event. The 7-day precipitation preceding a flood event (PRE7) and the Standardized Precipitation Evapotranspiration Index (SPEI) are analysed for the two time scale domains, respectively. Results indicate that high PRE7 does not always generate floods by itself. Seasonal SPEIs, which are not directly correlated with PRE7, exhibit positive (wet) values prior to most flood events across different averaging times, indicating a relationship with flooding. The paper provides evidence that bringing together weather and seasonal conditions can lead to improved flood risk preparedness.

1 Introduction

In recent decades, weather-related disasters have accounted for about 90% of all natural disasters (UNISDR, 2015a). There is an upward trend in disaster loss, which is driven by global climate change and the increasing concentration of populations and economic assets in flood-prone areas (Bouwer et al. 2007; Prenger-Berninghoff et al. 2014). Flooding affects millions of people across the globe each year. Between 1980 and 2012 the average annual reported losses and fatalities due to floods exceeded $23 billion and 5,900 people, respectively (EM-DAT, 2012; Jongman et al., 2015).

Flood risk management has traditionally focused on long-term flood protection techniques such as levees and dams (Kellet and Caravani, 2013). Today, people employ complex combinations of flood risk strategies, ranging from technical flood protection measures to financial compensation mechanisms such as insurance, as well as nature-based solutions (Aerts et al., 2014). Lower-income countries often cannot afford and implement preventive measures, mainly due to the high investment costs (e.g. Douben, 2006). Consequently, they are more reliant on post-disaster response and preparedness activities, often assisted by international donors and humanitarian organizations.

The role of science in disaster risk reduction has been globally recognized in the Sendai Framework (UNISDR, 2015b). Preparedness activities and flood forecasting have received increasing attention and have led to new science-based early

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action systems (~~Coughlan de Perez et al., 2014)~~Coughlan de Perez et al., 2014). Weather forecasts, with typical lead times of some hours or days, have become the basis of such systems (Alfieri et al., 2012), and they have played an important role in reducing flood impacts not only in developed countries (Rogers and Tsirkunov, 2010), but also in several lower-income ones (Golnaraghi, 2010; Webster, 2013). Therefore, research stresses the importance of their improvement. For example, the devastating 2010 Pakistan floods could have been predicted 6-8 days in advance if quantitative precipitation forecasts had been available, providing sufficient time for reaction (Webster et al., 2011).

On longer time scales, seasonal forecasts have been used in early warning and early action systems. A seasonal forecast was used to successfully prepare for floods in West Africa by the International Federation of Red Cross and Red Crescent Societies (IFRC) (Tall et al., 2012; Braman et al., 2013). With regard to floods, seasonal forecasts are used for signaling a likelihood of increased precipitation. Recently, the ECMWF System 4 seasonal precipitation forecast has shown higher predictive skill than climatology for the Niger, Blue Nile and Limpopo basins (Dutra el al., 2013; Seibert et al. 2017), and advances have been achieved in prediction skill and resolution for seasonal precipitation in western Ethiopia (Zhang et al. 2017). However, Stephens et al. (2015) showed that mean monthly precipitation is not well correlated with global floodiness, demonstrating the shortcomings of using seasonal precipitation as a proxy for flood hazard by itself and stressing the importance of modeling the hydrological systems before issuing warnings based on precipitation forecasts.

Depending on the region, factors other than precipitation can also play a role in ~~generating floods.~~flood generation. For instance, evapotranspiration and soil saturation are considered important in flood forecasting (Sivapalan et al., 2005; Merz et al., 2006; Parajka et al., 2010; Fundel and Zappa, 2011). Reager et al. (2014) demonstrated that basin-scale estimates of total water storage, including soil moisture, could be used to characterize regional flood potential for the Missouri 2011 floods several months in advance. Floodiness in Southern and Eastern Africa also showed strong correlations with seasonal average soil moisture (Coughlan de Perez, 2017), and the large role of antecedent moisture, rather than high rainfall, was demonstrated by Schröter et al. (2015) on the June 2013 floods in Germany. These physical factors are likely to influence the length of the flood build-up period, which can range from a few days to several months before an event (Nied et al., 2014). So, as forecast skills are inversely proportional to lead time (Molteni et al., 2011), the likelihood of taking action against flood in vain increases with ~~the~~ longer warning lead times. This requires further research on weather and seasonal flooding drivers that may lead to improved flood preparedness.

This study assesses the role of the antecedent conditions on short to long time scales prior to flood generation. We ~~ask~~investigate what conditions often preceded major flood events, offering insights on how to extend lead times for preparedness by relying on observational systems. For that, we take into account reported damaging flood events from 1980 ~~to~~till 2010 in sub-Saharan Africa. We discuss the potential role of seasonal-scale indicators complementary to the weather-scale phenomena for indicating an increased flooding likelihood. More specifically, we analyse the correlation between floods and hydro-meteorological variables, both on a weather (0-6 days before each flood event), and on a seasonal time scale (up to 6 months before each flood event). Weather scale conditions are evaluated by the 7-day precipitation (PRE7) that preceded the flood event. Seasonal scale conditions were drawn from the Standardized Precipitation Evapotranspiration Index (SPEI). Although SPEI has been applied in studies focusing on seasonal drought forecasting~~ of droughts~~ (Mossad and Alazba, 2015; Xiao et al., 2016), we argue that it could also be used in flood monitoring and forecasting. The findings of this study contribute to the emerging literature on this topic (Goddard et al., 2014; White et al., 2015) and may be of use to humanitarian organizations and decision-makers for preventive flood risk management planning.

The remainder of this paper is structured as follows. Section 2 outlines the methodological framework and the data used in the analysis, followed in Section 3 by the results. Section 4 discusses the findings and the limitations of the study, including suggestions for further research. Section 5 provides a brief conclusion.

2 Methodology

Figure 1 shows the different steps in the approach taken by this study. The analysis is based on damaging flood events in sub-Saharan Africa ~~for the period~~from 1980~~-~~ till 2010 that are reported in the NatCatSERVICE database (Munich Re, 2014).We assessed the antecedent weather and climate conditions in the locations of reported floods using two indicators: ~~(~~a) the short-memory anomaly ('weather-scale') evaluated by the cumulative rainfall over the 7 days preceding the event (PRE7), and ~~(~~b) the long-memory anomaly ('seasonal-scale') reflected in the SPEI for the preceding 1, 3 and 6 months (SPEI1, SPEI3, SPEI6).

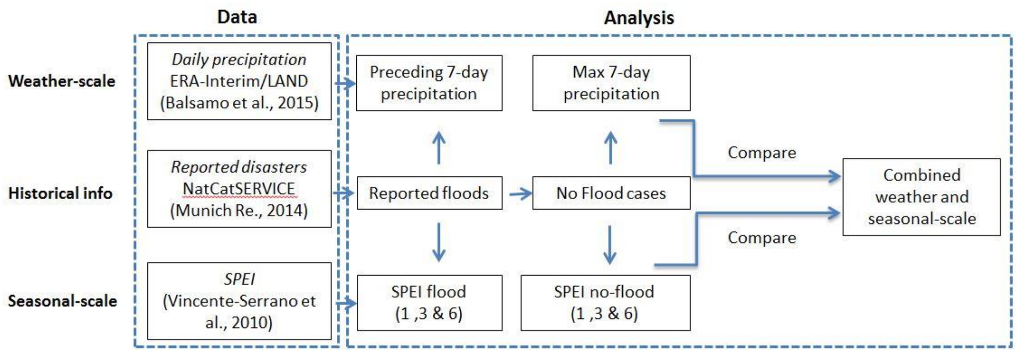

Figure 4: Schematic overview of the approach followed in this study.

2.1 Datasets and their limitations

Study area and reported floods

We used the NatCatSERVICE, a natural disaster database maintained by Munich Reinsurance Company (Munich Re, 2014) to identify the reported flood events in sub-Saharan Africa. This area includes many flood-prone countries (UNISDR, 2015a), which lack hard protective infrastructure against flooding. Hence, early warning and timely preparation play an important role in risk reduction. Events in the database are entered on a country level when there is property damage and/or there are people affected (injured, dead). So, not all the hydrologically defined floods (i.e. unusually high discharges and peak water levels) fulfil the entry criteria in the insurance databases. Hence, many hydrological floods are likely not included in the database as they did not cause any severe damages. By taking into account only the damaging events, we expect the research will be especially useful to the humanitarian sector. Recorded information includes fatalities, affected population, economic losses, onset and end dates and a pair of coordinates of each event. The sources of the database include national insurance agencies, online databases from news agencies, governmental and non-governmental organisations, and a worldwide network of scientific and insurance contacts (Tschoegl et al. 2006). NatCatSERVICE is a widely applied reference database in scientific studies (e.g. Hoeppe, 2016; Jongman et al., 2014a).

The NatCatSERVICE data includes two categories of inland flooding: a) riverine floods and b) flash floods. This study focused on riverine floods, as flash floods usually have a smaller extent, shorter build-up period and antecedent conditions play a less important role in their generation (Nied et al., 2014). We identified 501 damaging reported riverine flood events in sub-Saharan Africa between 1980 and 2010. Figure 2 shows the number of reported floods ~~per year over the period 1980-2010~~ and the economic losses ~~per year~~ caused by these floods per year. The upward trend in flood number over time could be attributed to increased exposure due to population growth and urbanization (Jongman et al., 2012) and underreporting of events in the earlier years due to limited penetration of communication technology (Kron et al., 2012).

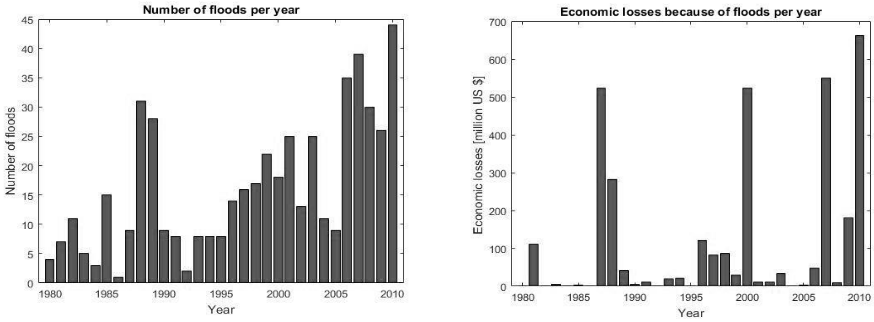

Figure 2: Number of floods per year that are analysed in this study (left) and economic losses in million US $ per year caused by these floods (right) in sub-Saharan Africa between 1980 and 2010 (Munich Re, 2014).

Daily precipitation

Daily precipitation was derived from the European Centre for Medium-Range Weather Forecasts (ECMWF) global reanalysis of land-surface parameters, ERA-Interim/Land, ~~over the period~~from 1980~~-~~ till 2010 (Balsamo et al., 2015) (available online at http://apps.ecmwf.int/datasets/). The gridded daily time series were extracted at 2.5° x 2.5° horizontal resolution. This large resolution was chosen a) because it corresponds to the average flooded areas (64,000 km2) (Douben, 2006), and b) to reduce the likelihood of possible errors in the reported coordinates from the NatCatSERVICE database.

Standardized Precipitation Evapotranspiration Index (SPEI)

The SPEI, developed by Vicente-Serrano et al. (2010), was used to evaluate the antecedent soil conditions before the reported flood events. The SPEI is a normalized variable for a long time-series of at least 50 years, comparing monthly net precipitation totals (precipitation minus potential evapotranspiration) with their long-term means over different time scales (1, 3, 6 or 12 months). An x-month SPEI (e.g. SPEI for January 1984) provides a comparison ~~over~~with the same x-month ~~period~~conditions (e.g. SPEI for all other January's between 1980 and 2010) for all years in the historical record. Shorter accumulation periods (1 month) represent surface soil water content, while longer ones (3, 6, 12 months) indicate the subsurface state (e.g. soil moisture, groundwater discharge) (Du et al., 2013). Unlike the Standardized Precipitation Index (SPI), the SPEI takes potential evapotranspiration into account, which can consume a large portion of total rainfall (Abramopoulos et al., 1988). Precipitation and evapotranspiration together largely determine soil moisture variability, and thus indirectly affect the flood build-up period through links between soil moisture, river discharge, and groundwater storage (Vicente-Serrano et al., 2010). Although some studies have successfully applied SPI as a flood indicator (Seiler et al. 2002; Guerreiro et al. 2008), SPEI has not yet been applied.

In this study SPEI values ~~were first derived~~develop by Vicente-Serrano et al. (2010) have been used. These were first acquired at a 0.5° x 0.5° spatial resolution (available online at http://sac.csic.es/spei/index.html), and subsequently they were ~~upscaled to2~~scaled up to 2.5° x 2.5° resolution by taking the mean value in order to be consistent with the daily precipitation dataset. Mean monthly temperature from the NOAA GHCN_CAMS gridded dataset (Fan and van den Dool, 2008) and mean monthly precipitation from the Global Precipitation Climatology Centre (GPCC) (Schneider et al., 2015) beginning in 1950 were used to estimate the monthly potential evapotranspiration (PET), ~~as in~~using Thornthwaite (1948) (see Vicente-Serrano et al., 2010, for more detail on the processing of the SPEI index). The ECMWF's ERA-Interim reanalysis dataset was not used for this as it ~~is~~covers a considerably shorter ~~in~~ time span. The SPEI values are given for the end of each calendar month. Positive and negative SPEI values indicate relatively wet and dry periods, respectively (Table 1).

SPEI class	Class description
≤-2	Extremely dry

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-2 : -1.5	Severely dry
-1.5 : -1	Moderately dry
-1 : -0.5	Mild ~~drought~~dry
-0.5: 0	Near normal dry
0: 0.5	Near normal wet
0.5 :1	Mild wet
1 : 1.5	Moderately wet
1.5 :2	Severely wet
>2	Extremely wet

Table 1: Classification of SPEI values (based on Edossa et al., 2014).

2.2 Analysis

Temporal scale

An illustrative example of discharge in relation to time, before, during, and after a hypothetical flood event is given in Figure 3. The time points of the different flood phases that were used in the analysis are mentioned. The start date of each flood, as reported in the NatCatSERVICE flood dataset (Munich Re, 2014), is the end of the 'flood build-up' period, during which we assumed that the physical processes that led to flooding took place (Nied et al., 2014).

The build-up period was divided into two parts: a preconditioning period at the seasonal scale (up to 6 months before the flood onset), and a flood triggering episode of a 7-day duration at the weather-scale period. In this way, we aimed to distinguish between the antecedent conditions that may have led to an increased flooding likelihood from the intense ~~raifall~~rainfall prior to the event. The build~~-~~-up period ends with the month before the rainfall event so as the two periods do not overlap. The seasonal-scale period was split into 1, 3, and 6 month periods, and the SPEIs (SPEI1, SPEI3, SPEI6) with corresponding accumulation time periods were used. SPEI0, which is independent from the seasonal SPEIs, has a 1 month accumulation time period and refers to the flood onset month itself.

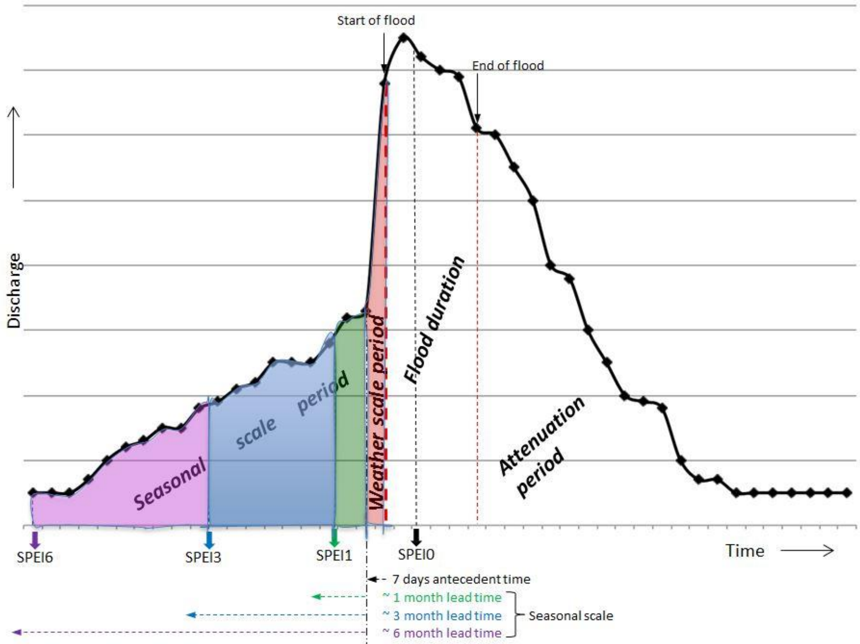

Figure 3: Theoretical discharge before, during and after a hypothetical flood event. Weather scale period starts 7 days before flood onset date. Seasonal scale period is split into 1-, 3- and 6-month accumulation periods. It starts 6 months before flood onset date and continues until the last month before the one that includes the 7-day precipitation. SPEI0 is defined as the SPEI over the calendar month in which the flood onset took place.

7-day precipitation (PRE7)

Using ECMWF's ERA Interim/Land dataset, we calculated the 7-day preceding precipitation (PRE7), having as ending point the reported onset date of each flood ~~and~~, as well as the maximum 7-day precipitation (MAX7) during the month that each flood was reported. The length of the precipitation period leading to a flood depends highly on the local characteristics. For example, a 2-day precipitation sum is best correlated with flood frequency and magnitude in the high ranges of the Swiss Alps, but longer-duration precipitation affects flood occurrence more in the western and eastern Swiss Plateau (Froidevaux et al., 2015). Hence, we expect to be on the safe side by using a relatively long synoptic time window (7 days), similarly to Webster et al. (2011).

Subsequently, for each flood, we used its particular onset month and location to identify the maximum 7-day precipitation within that month of the other dataset years, in which no flood was reported. ~~Using both PRE7 and MAX7 we standardized the 31 values (1 flood and 30 no-floods) over the entire 31 year dataset, with a mean of 0 and standard deviation of 1. The year with the flood event was labelled separately (F) from the remaining 30 no-flood events (NF).~~Following the way that the Standardized Precipitation Index (SPI) is calculated (Mckee et al., 1993), for both PRE7 and MAX7, we used a Gamma distribution to fit the 31 values (1 flood and 30 no-floods) over the entire 31 year dataset and we standardized them so that the mean is 0 and the standard deviation 1. The year with the flood event (F) was labelled differently from the remaining 30 no-flood events (NF). We repeated this procedure for all 501 flood events. Then, we compared PRE7 and MAX7 and we performed a two-tailed z-test of unpaired samples to evaluate whether the medians of PRE7and MAX7 in case of a flood differed significantly from that of the NF cases.

Preceding SPEI values and SPEI0

SPEI values for the months before a flood event are labelled SPEI1, SPEI3 and SPEI6, indicating accumulation time scales of 1, 3 and 6 months, respectively (Figure 3). These seasonal SPEI values are not independent, as shorter-period SPEIs (e.g. SPEI1, 3) are part of the calculation of longer-period ones (e.g. SPEI6).

SPEI0 has 1 month accumulation period and refers to the end of the month that includes the flood's reported start date. So, it is independent from the other SPEIs. This was used to evaluate the wetness in the end of this month and check whether it could be used as a flood monitoring tool. All month definitions were based on calendar days.

For each of the 501 flood events individually, we used the same flood onset month and the same location in order to get the SPEIs of all the NF cases. ~~We~~Subsequently, we performed a two-tailed z-test of unpaired samples to compare the median SPEI values of the different time periods of NF events (n=15030) with those of flood events (n=501). ~~Then, after counting the frequency of floods and NFs using several SPEI thresholds (from SPEI> 3 up to SPEI>3), we divided it with the total number of flood and NF respectively, to compare the different flooding probabilities.~~

Then, we calculated the probability of having a flood (F) and the probability of not having a flood (NF) given certain SPEI thresholds (for instance, using all data points corresponding to months with an SPEI3 value larger than 1). In order to enable appropriate comparisons between the two groups, we calculated the risk ratio (RR) or relative risk. This is a relative measure that quantifies the risk of prevalence of one group against another one by taking the ratio of two proportions, i.e. dividing the probability of a flood by the probability of no flood Morris and Gardner(1988) (Table 2, Eq.1). The RR is commonly used on medical and epidemiology studies (e.g. Katz, 2006; Shrier and Steele, 2006; Zhang and Yu, 1998). Although it does not follow a normal distribution, the natural logarithm of the sample is approximately normally distributed to produce the 95% confidence intervals, which are calculated according to Morris and Gardner(1988) and Daly (1998). Therefore, first, a confidence interval is generated for $\log_e$(RR) and subsequently, the antilog of the upper and lower limits of the confidence interval for $\log_e$(RR) are computed to give the upper and lower limits of the confidence interval for the RR (Eq. 2, 3, 4, 5, 6). In case, the upper limit is above 1 and the lower limit below 1, the RR is not statistically significant.

	SPEI>threshold		
Group	Yes	No	Total
Floods	A	C	A+C
No-Floods	B	D	B+D

Table 2: Parameters for calculation of risk ratio as used in equations (1) and (2).

$$\mathrm{RR} = \frac{\frac{A}{A+C}}{\frac{B}{B+D}} \quad (1)$$

$$\mathrm{SE}(\log_e R) = \sqrt{\frac{1}{A} - \frac{1}{A+C} + \frac{1}{B} - \frac{1}{B+D}} \quad (2)$$

$$W = \log_e R - (1.96 \text{ x } \mathrm{SE}(\log_e R)) \quad (3)$$

$$X = \log_e R + (1.96 \text{ x } \mathrm{SE}(\log_e R)) \quad (4)$$

Lower Limit of confidence interval: e^W (5)

Upper Limit of confidence interval: e^X (6)

Combination of PRE7 and SPEI0 with preceding SPEIs

In a final assessment, we used the preceding seasonal scale SPEIs in combination with SPEI0 and PRE7 (denoting conditions at the time of flooding) to calculate the ~~frequency~~RR of ~~floods~~F events and ~~NFs under~~NF events using various SPEI and PRE7 thresholds~~, which range from -1 to +3.~~. In this way, we ~~compared the joint probabilities of flood cases and no flood cases,~~evaluated the RR by bringing together the preceding seasonal-scale conditions ~~with~~and the conditions during the month of the flood~~ for a simple risk assessment. ~~.

3 Results

3.1 Floods in sub-Saharan Africa

Figure 4 shows the spatial distribution of the 501 selected flood events ~~over the period ~~from 1980 to 2010 on the Köppen climatological map. The tropical climate areas (in green) experience 43% of all reported floods, the dry climate areas (in yellow) 36% and the oceanic climate areas (brown) 22%. Most floods were reported in continental sub-Saharan countries. South Africa faced the highest number of reported flood events, followed by Kenya, Somalia, Mozambique, and Ethiopia. In southern Africa, a considerable number of floods were reported in the areas of the Limpopo and Zambezi river basins and along the coast of South Africa. Eastern Africa also experienced a significant number of flood events, mainly in the southern part of the Nile and near lakes Turkana and Victoria. In West Africa, there is a concentration of floods along the Volta, Niger and Senegal rivers. The pattern shows consistency with the floods reported by Dartmouth Flood Observatory (Global Archive of Large Flood Events, 2010, available at http://floodobservatory.colorado.edu/), which shows that most recent deadly floods happened in places where the population has increased more rapidly in recent years (Di Baldassarre et al., 2010).

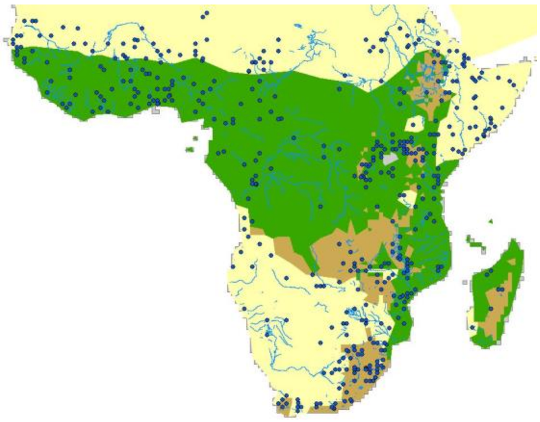

Figure 4 Floods in sub-Saharan Africa from 1980 ~~to 2010on~~till 2010 on the Köppen climatological map (green: tropical climate, yellow: dry climate, brown: oceanic climate)

3.2 Relation of 7-day precipitation with flooding

Figure 5 (left panel) presents the standardized 7-day precipitation (PRE7) of flood (F) and no-~~floods~~flood (NF) events. On each boxplot, the central red line is the median and the edges of each box are the 25th and 75th percentiles. The whiskers extend to the most extreme data points, covering the 99% of the values and the outliers are plotted individually (+). The results of the z-test showed that the median of the preceding PRE7 of floods did not exhibit any significant difference with that of no-floods (p=0.1). This reveals that although PRE7 is high, it cannot explain by itself the generation of the flood. Similar magnitude events, in the same locations and during the same months that floods were reported occurred without resulting in a (reported) flood.

Figure 5 (right panel) ~~shows~~compares the MAX7 of F events to the MAX7 of NF events. Although it appears that the median of MAX7 was significantly higher than the median of the NF cases (p= 0.05~~). From the two panels,~~), we ~~can see~~should be aware of the fact that ~~the median of MAX7 differs significantly from the PRE7. The~~statistical tests tend to find significance when the sample size gets large. Nevertheless, the difference between ~~them~~PRE7 and MAX7, implies that these events occur at different moments within the month of the flood, and that the PRE7 value does not always capture the highest precipitation amount within that month. This ~~may reflect~~might be subject to several reasons such as inaccuracies of the reported flood onset date, more precipitation before the ~~7~~PRE7 days, which created flood favorable conditions, or more precipitation after the flood onset date, which contributed to ~~a~~ longer flood duration.

However~~, from this figure, we see~~ Figure 5 also shows that in many occasions very intense precipitation events did not produce any flood, implying that there should be also other factors other than high precipitation that have contributed to flood generation.

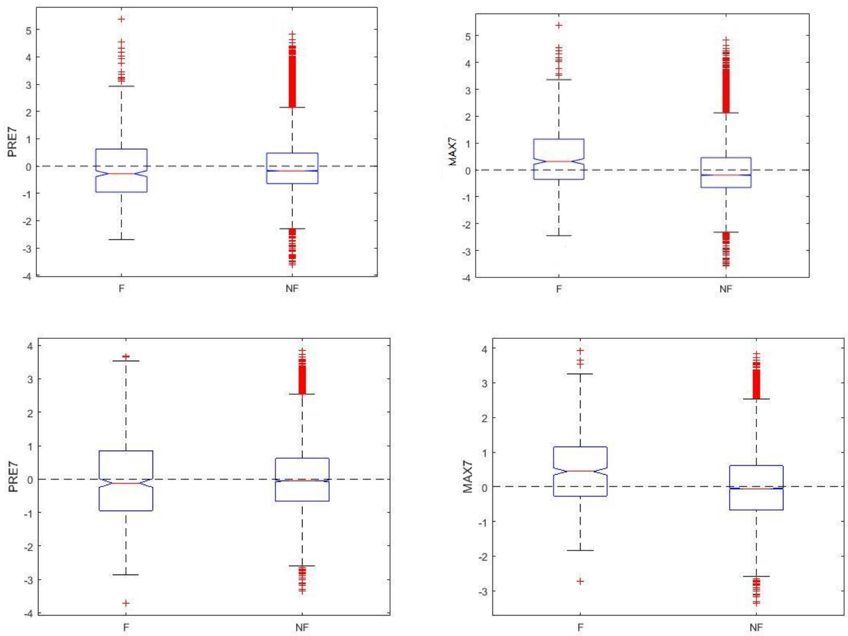

Figure 5 Standardized 7-day preceding precipitation (PRE7; left panel) and maximum 7-day precipitation (MAX7; right panel) of Floods (F; left bars) and No-Flood (NF; right bars) events collected over all 501 reported flood events. **3.3 Relation between SPEI0 and seasonal-scale SPEIs with flooding**

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~~**3.3 Relation between SPEI0 and seasonal-scale SPEIs with flooding**~~

Figure 6 shows the SPEI values of ~~all floods (~~F~~)~~ and ~~no flood (~~NF~~)~~ events on different time scales (0, 1, 3 and 6 months prior to the flood onset month). ~~The no flood cases that are taken into account refer to the particular flood onset month of the no-flood years. For no flood~~For NF events, the median value of SPEI is slightly below zero for all time scales. The median SPEI0-SPEI6 values representing the ~~flood cases~~F events are significantly higher, which is underpinned by the results of the z-tests (p values < 0.05). More specifically, the median value of SPEI0 for ~~flood~~F events exhibits a value close to 1, which indicates that the wetness in the end of these months was high. The high ~~SPEI0~~ values found for SPEI0 demonstrate, moreover, that ~~it~~SPEI0 could be used as a flood monitoring tool. ~~The~~Further, the median value of seasonal SPEIs, which are independent from SPEI0, constantly lays in the wet categories (>0), for all the time scales, showing that the wet antecedent conditions have likely played a role in flood generation. The highest median values are found for SPEI1, followed by SPEI3. The median value of SPEI6 is significantly lower than both of them, showing, finally, that when the accumulation period is longer, the SPEI tends to climatological conditions and flood signals become ~~more vague~~vaguer. The percentage of floods that exhibit wetter than normal condition (SPEI greater than 0) is 78%, 70%, 65% and 57% for SPEI0, SPEI1, SPEI3 and SPEI6, respectively.

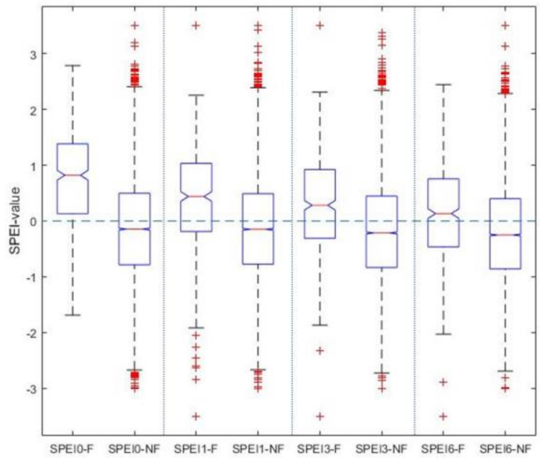
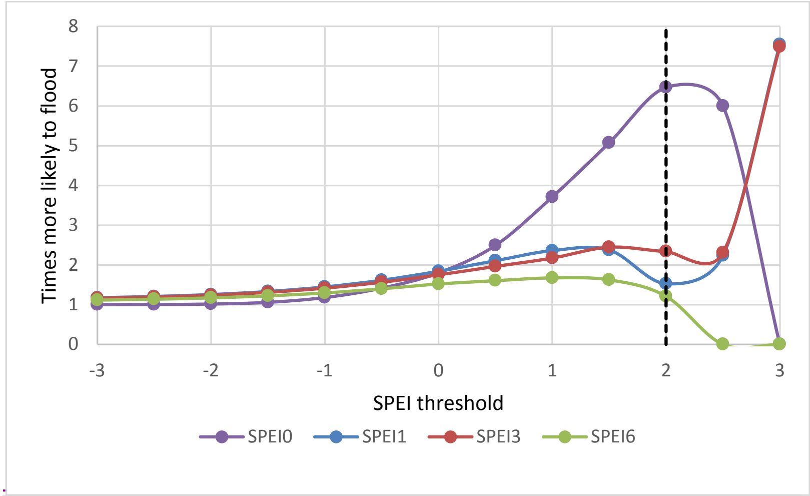


Figure 6 SPEI0 and seasonal-scale SPEIs for Flood (F) and No-Flood (NF) events

Figure 7 shows the ~~relative odds~~risk ratio (RR) using several exceedance thresholds for the SPEIs, which range from -3 to +~~3~~2 (horizontal axis). ~~Basically, this ratio shows how much more likely it is that a flood event may happen given a specific SPEI~~A value ~~compared to a no-flood (with a value~~ of 1 ~~denoting no elevated probability).~~denotes equal risk likelihood, while higher values indicate that the risk of F is bigger than the risk of NF. Each line represents SPEI values for the different lead times (SPEI0-~~purple~~blue, SPEI1-~~blue~~red, SPEI3-~~red~~green and SPEI6-~~green).~~purple). Based on the confidence intervals as presented in Figures S1-S4, we plot a circle in the cases that the RR is statistically significant and triangle in the cases that it is not. For SPEI values below -1, the probability of having a ~~flood~~F event and a ~~no-flood~~NF event is ~~the same for all SPEIs (ratio is~~ ~1~~). After that~~, irrespectively of the SPEI (SPEI0 to SPEI6) used. With increasing threshold levels higher than -1, a slight increase in ~~flooding frequency~~the RR is observed for the seasonal SPEIs, denoting that when hitting these SPEI threshold values the probability of encountering a F event is relatively higher compared to the probability of encountering a NF event. When looking at SPEI values over 1.5, it becomes approximately 2.5 times more likely to have a flood when SPEI1 and SPEI3 exceed this threshold. While the SPEI1 and SPEI3 exhibit similar values, the SPEI6 shows considerably lower ratios, indicating that the flood events, which were preceded by such a long wet period are few. For the month that the floods were reported (SPEI0), the maximum ratio is reached when looking at SPEI values over +2, when it becomes 6.5 times more likely to have a flood event. The big difference in the increased probability of flooding of SPEI0 and seasonal SPEIs shows the importance of the hydro-meteorological conditions during the flood onset month. Using thresholds higher than +2 (black dashed line), the ~~SPEIs behave more erratic because they have only very few observations (less than 10 floods). Hence the data-points right~~confidence intervals of the ~~dashed line should~~RR becomes enormous and the RR is not ~~be considered reliable~~statistically significant.



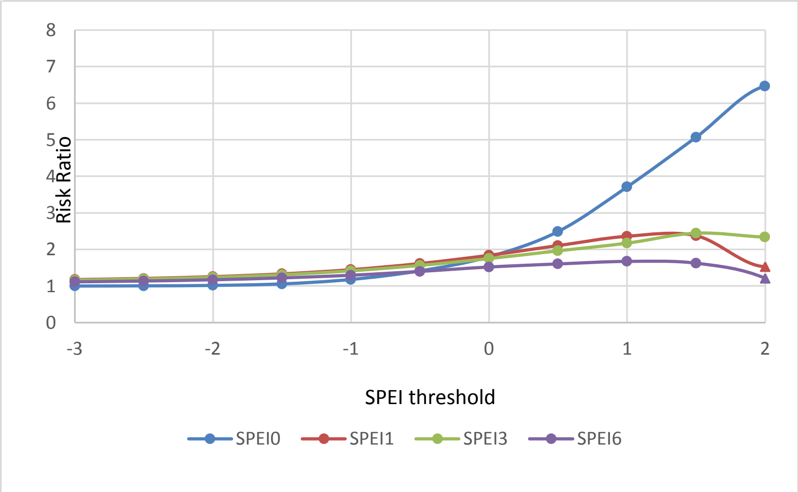
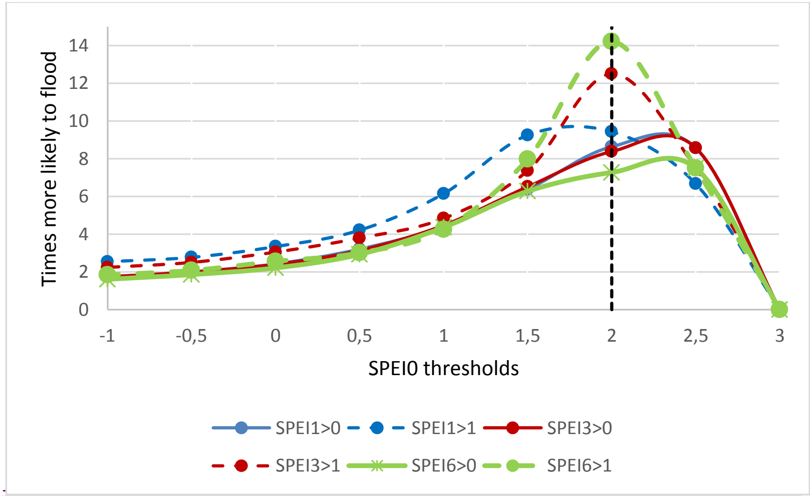


Figure 7: ~~Relative odds~~Risk ratio between ~~flood~~F and ~~no flood likelihood~~NF as function of ~~the~~ SPEI exceedance ~~value~~values. The ~~black dashed line is~~ circles are used ~~as a boundary, after which there are few flood events (less than 10)~~when the ratio is statistically significant and the triangles when it is not.

3.4 Combination of seasonal-scale SPEIs with SPEI0 and PRE7

We now discuss the flood probability focusing on the joint occurrence of conditions at the preceding seasonal time scale and conditions during the flood onset month. Figure 8 shows the ~~relative odds of flood and no flood~~RR given SPEI0 threshold values conditional to certain seasonal SPEI values. In the x axis, the thresholds of SPEI0 are given. Each line in the graph represents the combination of SPEI0 with seasonal SPEIs of different thresholds (SPEI1~~-blue, SPEI1~~-red, SPEI3-green, SPEI6-purple).

The ~~relative odd~~RR of ~~flood versus~~F and NF events increases when seasonal SPEI thresholds increase (~~comparing the~~ dashed lines ~~with the~~versus solid lines). Compared to Figure 7, the probabilities are higher showing that taking into account both the conditions during the months that preceded the flood (SPEI1 to SPEI6) and the conditions during the flood onset month (SPEI0) results in even higher increased flooding likelihoods. In this case, the maximum values are found when SPEI0 exceeds 2 and the seasonal SPEI thresholds are above 1 (dashed lines). For instance, using SPEI6 > 1, it is 14 times more likely to flood. The combination of SPEI1>1 and SPEI0 exhibits the highest ~~elevated probability~~RR up to the SPEI0 threshold of 1.5, where ~~the~~ it becomes 9 times more likely to have a flood event. Although the ~~number~~confidence intervals are relatively wide (fig. S5-S10), caused by the variability of ~~flood events in this case~~the two samples, statistical significance was ~~still not high (i.e. 37 flood events, which corresponds to 7.5% of all reported floods), it should be taken into account that only a very small percentage of no-floods fulfilled this criterion. We discuss results until the black dashed line, as right of it there are fewer than 10 flood events per data point.~~ found for the RR.



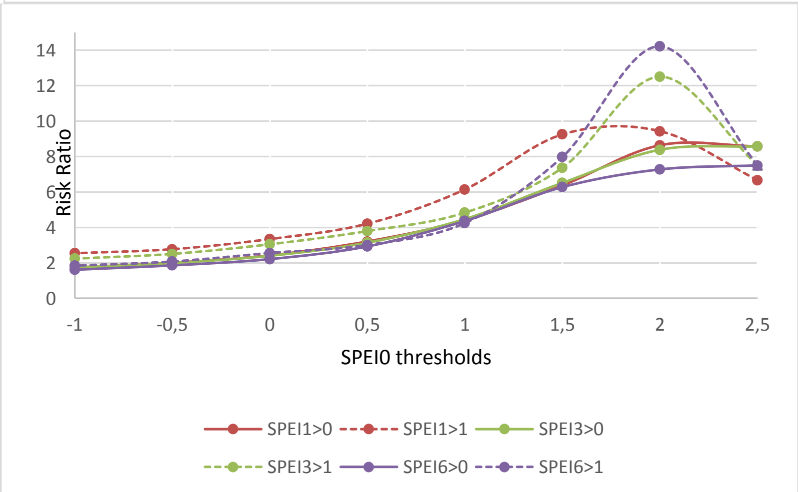


Figure 8 ~~Relative odds~~Risk ratio between ~~flood~~F and ~~no-flood likelihood~~NF for given SPEI0 thresholds conditional to certain seasonal SPEI values ~~(blue: SPEI1, red: SPEI3, green: SPEI6).~~. The ~~black dashed line is~~ circles are used ~~as a boundary, after which there are few flood events (less than 10)~~when the ratio is statistically significant and the triangles when it is not.

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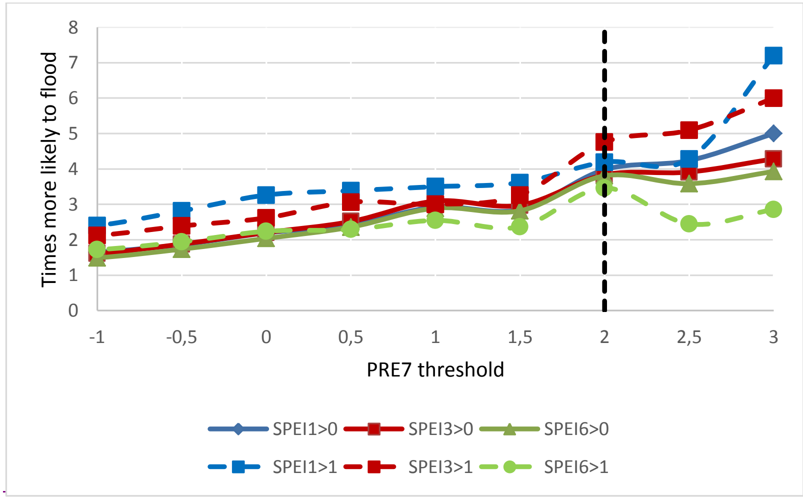
Finally, we present the ~~relative odds between flood and no-flood likelihood~~RR for ~~the joint probability~~ combinations of PRE7 and seasonal SPEI thresholds (SPEI1-blue, SPEI3-red, SPEI6-green) (Figure 9). ~~We~~Again, we see that for increasing thresholds, it becomes more likely to have a ~~flood~~F event compared to a ~~no-flood~~NF event. The maximum ~~values~~RR observed are ~~4.8~~6 and 4.~~3~~8, when PRE7 is higher than 2 and ~~SPEI1~~SPEI3 and ~~SPEI3~~SPEI6 higher than 1~~. This~~ respectively. The results of this figure ~~clearly shows~~show that ~~bringing together~~ the combination of short-term (PRE7) and ~~seasonal~~ long-term conditions (SPEIs ~~leads to~~) significantly increase the RR, indicating a clear increased ~~flooding likelihood~~probability to encounter a F event, when the thresholds become higher.



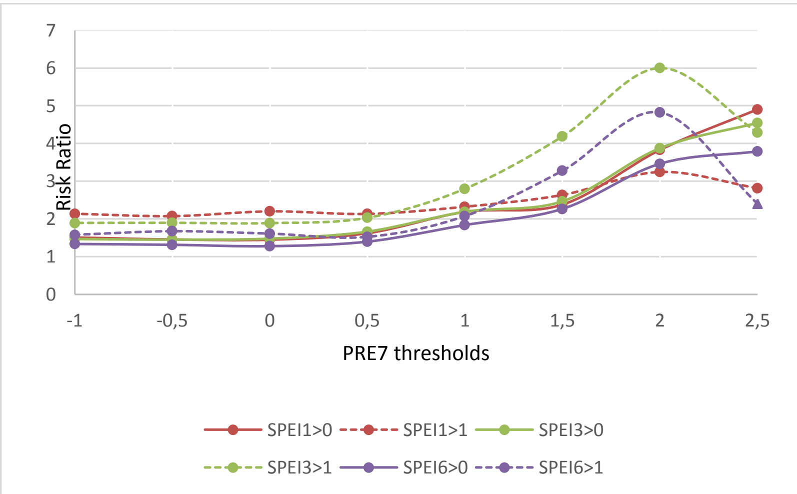


Figure 9 ~~Relative odds~~Risk ratio between ~~flood~~F and ~~no flood likelihood for~~NF given PRE7 thresholds conditional to certain seasonal SPEI values~~ (blue: SPEI1, red: SPEI3, green: SPEI6). The black dashed line is ~~. The circles are used ~~as a boundary, after which there are few flood events (less than 10)~~when the ratio is statistically significant and the triangles when it is not.

4 Discussion

Role and limitations of the weather-scale conditions

The role of weather-scale meteorological conditions (particularly rainfall) in flood generation is generally accepted (Webster et al., 2011; Jongman et al. 2014; Froidevaux et al., 2015~~)~~). Our results showed that the flood events were preceded by 7-day precipitation (PRE7~~), comparable~~) of similar magnitude compared to the maximum observed 7-day precipitation ~~of the flood onset months~~ during the same month in the no-flood years. This indicates that although PRE7 was high, it is not able to fully justify the flood generation by itself, ~~-~~leading us to hypothesize that there should be other factors~~ or explanations~~, other than intense rainfall, that have led to the flood event. ~~These factors can be subject to either poor~~ Alternatively, inaccuracies in the data used (i.e. reanalysis datasets, disaster database) ~~or to the conditions that preceded the~~can also be (partly) of influence for not finding a strong relation between PRE7 ~~event~~and flood events.

Despite the absence of high quality daily precipitation datasets in Africa (Lorenz and Kunstmann, 2012; Rogers and Tsirkunov, 2013; Zhang et al. 2013), precipitation reanalysis data offers valuable information over poorly monitored regions such as sub-Saharan Africa (Zhan et al. 2016). However, due to the lack of valuable ground-based precipitation records, especially in developing countries, the reliability of precipitation extremes in reanalysis datasets over land varies in location and time period and it can be very sensitive to reanalysis product and resolution choice (Herold et al. 2017). Particularly, the daily precipitation values on a coarse grid are largely uncertain as they do not capture local scale convective events, which are often responsible for high-intensity precipitation and could ~~significantly~~ affect our weather-scale results.

The rationale to perform the analysis over a large area around the reported flood coordinates is to deal with the uncertainty in the presented location of the reported flood and to capture the impact of the rainfall in neighbouring areas, including some upstream, which may have contributed to the flood generation mechanisms. ~~Due to insufficient information in the disaster dataset, it is difficult to determine~~This simplified approach was necessary because we did not have the exact delineation of the upstream area.~~ So, we followed this simplified approach.~~ The real world is much more complicated, as the response of hydrological systems to precipitation varies considerably depending on time and place (Eltahir and Yeh, 1999). Further studies should give this serious consideration, carrying out analyses on local spatial scales and using hydrological models to estimate the travel and the concentration time of the upstream rainfall to each flood location.

Finally, in order to gain insights into the uncertainty of the flood onset date, we compared the maximum 7-day precipitation (MAX7) during the onset month of each flood~~,~~ with ~~a)~~ PRE7~~ and b) the maximum 7-day precipitation~~. The median of ~~no-flood events. In both cases,~~ MAX7 was found to be significantly higher. This ~~shows~~indicates that the 7 days prior to the reported onset date (PRE7) ~~did~~do not always exhibit the highest precipitation during the flood month, as one might have expected. This means that either the flood reported date was not accurate or that the MAX7 worked complementary to PRE7 leading to the flood generation~~.~~ (i.e. flooding was already triggered before the maximum 7-day precipitation had taken place). Again, focusing on a local scale, getting accurate information on the onset date, precipitation, discharges, etc. would be an important addition in future research.

Role of seasonal-scale conditions

Our results showed that the most reported floods were preceded by relatively wet seasonal conditions, as ~~all the~~their SPEIs were greater than 0 (SPEI1-70%, SPEI3-65%, SPEI6-57%). Comparing the seasonal SPEI value of ~~floods~~F events to that of ~~no-floods~~NF events, we see that the median of the first is significantly higher than that of the ~~second~~latter across the different seasonal timescales~~,~~ (SPEI1 to SPEI6), indicating ~~there were several cases~~ that – in general - SPEI could have served as an early warning indicator, in case it had been monitored or forecasted. However, the median SPEI of floods goes towards climatological conditions for longer accumulation periods. This should be considered together with the decreasing forecast skill over the lead time (Molteni et al., 2011) in order to identify whether and at which point SPEI could be used as a flood warning indicator.

In a ~~simple~~ quantification of the flooding ~~probabilities~~likelihood, we ~~found~~used for the ~~relative odds of floods~~first time in a flood risk research the risk ratio (RR), which is widely used in medical and ~~no-floods~~epidemiology studies, comparing the likelihood of F events to NF events under various SPEI thresholds. When using a threshold of 1.5 for SPEI1 and SPEI3, we found ~~that it is around~~a RR of 2.5~~ times more likely for a flood to occur.~~, indicating an increased probability to encounter an F event. Although this number is not high, and the confidence intervals are quite wide, it is still first evidence that seasonal parameters could be used in flood warning systems. Using ~~the same~~a threshold of 2 for SPEI0, which refers to the conditions during the flood onset month, ~~we found that it was~~the RR becomes 6.5~~ times more likely a flood to have occurred~~. This shows that SPEI0 has captured in several cases the unusually wet conditions during the flood and that it could be used as a flood monitoring tool.

Finally, by bringing together the short- and the long-term conditions, we saw that the conditions during different time scales ~~can~~could possibly be used complementary to each other for flood ~~warnings~~warning. Using thresholds for both seasonal SPEIs and SPEI0, the likelihood of having ~~a flood~~an F event compared to ~~a no-flood~~an NF event is considerably increased compared to the same likelihood when taking into account only weather or seasonal scale conditions. For instance, when SPEI0 is above 2 and SPEI1, SPEI3 and SPEI6 are above 1, ~~it~~the RR becomes around 10, 12 and 14 times~~ more likely to have a flood compared to a no-flood~~. Nevertheless, SPEI0 refers to the entire month, when the flood was reported and not to the conditions that preceded its generation. Therefore, an early warning early action system could monitor rainfall and temperature observations, getting ready when the previous three months have had a high SPEI, and taking further action if the upcoming month is forecasted to also have a high SPEI.

On the other hand, when connecting PRE7 with seasonal SPEIs, the ~~relative odds ratio~~RR did not exhibit so high values as before. However, ~~the resulting~~there is still considerably increased ~~probabilities (around 4 and 5 times more likely~~probability of having an F compared to ~~have a flood~~an NF event (e.g. RR is 6, when PRE7~~ is above ~~>2 and ~~SPEI1 and ~~SPEI3~~ are greater than ~~>1), ~~demonstrate~~demonstrating that in ~~several cases the~~many reported floods seasonal scale conditions created flood favourable conditions, which turned into flood events by the high PRE7. This result stresses ~~ ~~the significance of ~~the~~a joint evaluation of weather and seasonal conditions in flood risk ~~assessment~~assessments.

~~Our findings are in line with those of Berthet et al. (2009), who demonstrated that the variety in preceding moisture plays a major role in flood generation in France at similar levels of flood-triggering precipitation, and with Nied et al. (2014), who showed that a small amount of rainfall can result in flood generation when the soil is saturated. The combination of weather- and seasonal-scale condition is also supported by Pathiraja et al. (2012), who showed that there was an underestimation of the magnitude of flood flows in the Murray-Darling Basin in Australia when the joint influence of flood-producing rain events and antecedent wetness was not taken into consideration. Nevertheless, performing a more detailed analysis focusing on a (sub-)catchment area, including ground observations and the use of a hydrological model, could provide more information regarding the antecedent conditions.~~

~~*Uncertainty in disaster database*~~

~~In this research we followed a pragmatic analysis using reported damaging flood events in sub-Saharan Africa from NatCatSERVICE database.~~

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Uncertainty in disaster database

In this research we followed a pragmatic analysis using reported damaging flood events in sub-Saharan Africa from the NatCatSERVICE database. Natural disaster databases are lacking standardized procedures in monitoring and collection of disaster loss data and therefore, numerous biases and wide disparities in the number and type of disasters is observed among them ~~(Wirtz and Below, 2009; Gall et al.,~~(Wirtz and Below, 2009; Gall et al., 2009). For this reason, we did not perform any cross-validation and we chose to use events only from one database for the sake of consistency. NatCatSERVICE provided the highest number of reported events and also provided georeferenced data and onset dates, which were necessary for the analysis.

~~Uncertainties regarding the accuracy of the reported onset date and the exact place of the event exist, as these datasets are often susceptible to human errors and omissions (Jongman et al., 2015). Furthermore, in the dataset used, there is an increasing trend in flood numbers over the years, which may be caused by an upward trend in reporting frequency rather than occurrence frequency. Finally, regarding the no-flood cases that are used in this analysis, we should acknowledge that we cannot declare with certainty that there were no floods in these cases, as it is likely that they were not reported (e.g. omission in the dataset, not significant impact etc.).~~

Uncertainties regarding the accuracy of the reported onset date and the exact place of the event exist, as these datasets are often susceptible to human errors and omissions (Jongman et al., 2015). However, the fact that the median value of SPEI0 exhibits high values is evidence that the flood locations and the onset months are correct. Furthermore, in the dataset used, there is an increasing trend in flood numbers over the years, which may be caused by an upward trend in reporting frequency rather than occurrence frequency. So, regarding the NF cases that are used in this analysis, we should acknowledge that we cannot declare with certainty that a flood did not occur, as it is likely that that they were not reported (e.g. omission in the dataset, not significant impact etc.). So, by considering only the damaging reported floods, we expect that our results are useful to the humanitarian organizations, which are more interested in the catastrophic events.

We acknowledge that our sample (501 events) is small, and ~~it was probably~~this might be one of the reasons that we did not ~~produce~~manage to find any statistically significant results ~~in~~between different geographical areas. Conducting the analysis in local scale flood prone areas, and identifying different types of floods, could be a step forward for further improving the approach developed in this study. Nevertheless, to our knowledge, ~~it~~this is the first study that analyses the preconditions of so many historical flood events, trying to link the reality with physical parameters.

Policy Relevance

The approach applied in this study fits well in the global policy on disaster management: the Sendai Framework of Disaster Risk Reduction (SFDRR) (UNISDR, 2015b). The Framework calls for enhanced efforts to reduce risk from natural hazards (including floods), such as protection, financial risk transfer and early warning systems (Mysiak et al., 2016). Seasonal forecasting systems are promising measures that can complement existing warning systems, and support post disaster risk reduction strategies such as relief operations. For this, the SPEI-based approach of using seasonal information to prepare for flood events could be further developed and ~~eventually used~~tested, having as an overall target to support disaster preparedness activities in the regions at risk. For example, it could be a useful tool in the Forecast-based Financing~~ (FbF)~~ approach, which is currently being developed by the Climate Centre of the Red Cross/Red Crescent (Coughlan De Perez et al., 2015) and aims to disburse humanitarian funding based on forecast information. The idea behind it is to take action based on the progressively increasing flood warning information. This could be implemented by the 'Ready-Set-Go' concept (Goddard et al., 2014), where each of disaster preparedness is activated when the output of different forecast types (e.g.

seasonal, weather), exceeds a certain threshold. In this case, such a threshold could be based on SPEI values as presented in this paper.

4 Conclusions

This paper explores the influence of antecedent conditions of reported damaging floods in sub-Saharan Africa ~~for the period~~from 1980~~-~~ till 2010. Our analysis follows a pragmatic approach, being based on 501 large-scale reported floods taken from Munich Re's NatCatSERVICE disaster database~~ (Munich Re, 2014).~~. While most studies base their analyses on modeled discharges and floods, this research tries to link a considerable amount of real events to physical parameters that have contributed to their generation. We have examined both separately and together the impact of short- and long-term antecedent conditions prior to each event. To do so, we have clearly distinguished the flood antecedent conditions between weather and seasonal scales based on their reported onset date. The weather scale conditions encompass 0-6 days prior to each flood onset date and are captured by the 7-day accumulated precipitation (PRE7) and the seasonal-scale conditions are reflected in the values of the Standardized Precipitation Evapotranspiration Index (SPEI), 1, 3 and 6 months before each flood event.

~~The~~Taking into account all reported flood events, the results indicate that although ~~7-day precipitation (~~PRE7~~)~~ prior to ~~floods was~~flood generationwas high, it did not exhibit any statistically significant differences with maximum 7-day precipitation ~~observed on the same locations and~~ during the same ~~onset~~ months ~~that floods were reported.~~in the no-flood years. On the other hand, the median of the maximum 7-day precipitation during the flood onset month (MAX7) was significantly higher than ~~both PRE7 and maximum 7-day precipitation of the no-flood cases~~PRE7, which shows that in several cases, ~~an extreme~~a severe rainfall event occurred during the flood onset month and might have served complementary to PRE7 for the flood generation. Although the outcomes demonstrate the catalytic role of hydro-meteorological phenomena in flood generation during the days close to the flood onset, emphasizing the importance of weather forecasts in flood forecasting, ~~they do not explain the fact~~we have seen that ~~extreme~~severe precipitation ~~does~~events do not always lead to flood ~~events~~generation.

At the seasonal scale, high SPEIs values are associated with flooding, denoting wet conditions across the different time scales before the flood event. ~~Given the long SPEI accumulation periods used (i.e. 1 to 6 months), that~~ Having disengaged seasonal from weather-scale conditions, ~~the relation of~~ seasonal ~~SPEI and flooding does~~SPEIs do not ~~need~~ include ~~weather-scale~~short-term precipitation before the flood event, implying that there should be other factors that ~~are related~~relate SPEI to ~~SPEI~~flooding. Given the long accumulation periods used (i.e. 1 to 6 months) this factor could be the soil saturation of each place, probably because of limited water storage capacity. Setting a threshold of seasonal SPEI>1.5, we ~~see~~find that ~~it~~the risk ratio (RR) for SPEI1 and SPEI3 becomes ~~up to~~ 2.5~~ times more likely to have~~, demonstrating the increased likelihood of having a flood compared to a no flood event~~ (for SPEI1 and SPEI3). Using the same threshold for~~, and providing evidence that seasonal parameters should not be excluded a priori from flood warning systems. When using SPEI0>2 the RR is 6, showing that SPEI0, which ~~represent~~represents the conditions during the flood onset month, ~~it is 5 times more likely a flood to have occurred, demonstrating that SPEI0~~has captured the unusually wet conditions and it could be used as a flood monitoring tool.

The combined analysis of weather- and seasonal-scale flood antecedent conditions reveals that their joint influence affects flood generation, exhibiting higher ~~flood elevated probabilities~~RR than when taking into account either PRE7 or SPEI. Exploring various combinations of weather and seasonal scale thresholds, the results show that ~~flooding probabilities~~the RR further increase with increasing thresholds. Translating them into practice, we conclude that a decision-makers should not neglect the degree of seasonal-scale wetness as this could be a useful inputaddition to the weather-scale flood forecasts based on which disaster actions are to be taken.

EarlyIn case this approach is further developed and tested, it could be used by early warning systems can use the results of this research to set up operational programming toand take action before flood events. First, if they are monitoring SPEI6, SPEI3, and SPEI1, people cancould take general preparation actions when the valueslocal thresholds set increase, knowing that the risk of flooding is slightly elevated for the coming month. Once they see that the observations from the past season show high SPEIs, then they can check forecasts for the SPEI of the coming month, and 7-day rainfall forecasts, to take additional preparedness actions if those also show high values. An actionAlthough the risk of acting in vain will still exist, a system based on this combination of observations and forecasts could instigate major preparedness., increasing the probabilities of a correct hit In order to enable such a system, both monitoring and forecasts of SPEI should be made available. Locallocal SPEI-related indicators tailored to specific river basins can also be derived and forecastedshould be made available.

Acknowledgments

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