Response to the comment of Anonymous Referee # 2

We would like to thank the reviewer for his detailed assessment of the manuscript. Below is our response to the issues raised in the review. The original comment is printed in plain font, our response is printed in italics.

The manuscript describes the 2015 streamflow drought event relative to the 2003 event based on observed low flow conditions derived over a set of stations. Results are compared also with the corresponding 2015 meteorological drought event analysed in detail in a companion work. I find that the analysis presented provides limited advances for a better understanding of hydrological drought processes and many parts of the manuscript are too qualitative and descriptive.

The question of advanced understanding based on descriptive statistics and analysis is certainly an important one to assess the significance and potential impact of a study such as ours. We would like to argue that the analysis presented does indeed add to a better understanding of the characteristics of hydrological drought at the large cross-country scale in Europe. The scope of the work was to study a major hydrological event on the European scale soon after its occurrence. Unlike climatological information, the timely observational-based analysis of a hydrological event at a pan-European scale (across country boundaries) has not previously been undertaken due to the lack of hydrological data. Streamflow data are commonly only available in national databases in near-real time and updated large-scale databases would have a significant lag in the order of years between each update. The study thus presents a unique community effort and opportunity to capitalize on our common knowledge and enhanced local detailed information. We have explicitly chosen an approach based on extreme value statistics and seasonality indices, which allows us to interpret processes from spatio-temporal patterns directly, with a minimum number of modeling steps and assumptions. Interpreting patterns of indices and process indicators is often regarded to be superior to classification techniques and modeling because of the minimum number of assumptions made (Grayson and Blöschl, 2001; Laaha and Bloschl, 2006). In the revision, we will further highlighted the added value of our work using additional quantitative analysis (specified in our detailed responses below).

My major concerns are:

– The influence of antecedent moisture conditions on drought developments is interesting and novel aspect, maybe the most relevant in the work. However it is analysed only on two stations. I suggest the authors to extent this investigation on the whole set of data to derive their conclusions in a more robust manner and spatially over the domain. The use of cluster analysis (or similar more objective techniques) to group stations with similar hydro-meteorological response may be an option. More details on the characteristics of antecedent moisture conditions, for instance timing and magnitude of antecedent precipitation that may reduce the probability of subsequent extreme drought events, would be relevant as well in view of an enhanced predictability and monitoring of low flow conditions.

The regional perspective is indeed important, hence it was also analyzed and discussed in our paper. An inductive approach has been chosen which infers the significance of the timing of low flow events from antecedent catchment conditions from single example catchments. Seasonality maps (Figure 6) of the relative timing of events were employed to analyze the regional perspective and to generalize the finding to the Pan-European scale. From pattern similarity between onset and severity of the low flow event, we deduced that the seasonality of the onset, being an indicator of antecedent conditions, is clearly related to drought severity at the regional scale.

To underpin the general relevance of our finding, and in accordance with the referee comment, we will conduct an additional functional cluster analysis of standardized hydrographs to generalize the local fingerprints provided by the hydrographs of two catchments at the European scale. The clusters will be interpreted with respect to spatio-temporal patterns of low flow and drought indices. In the supplement Fig. S2 we have added draft maps of the clustering to illustrate the value of the additional analysis.

We agree that more details on the characteristics of antecedent moisture conditions, for instance timing and magnitude of antecedent precipitation that may reduce the probability of subsequent extreme drought events, would be relevant and provide a view of an enhanced predictability and monitoring of low flow conditions. In the supplement (Fig. S1) we have added maps of the standardized precipitation index (different aggregation intervals were tested) that summarize antecedent conditions from meteorological measurements (ref. reply to Reviewer#1). The maps will be compared to the seasonality indices used to summarize antecedent conditions based on streamflow observations. Note that soil moisture measurements were not available to undertake similar analysis.

– Section 5.2 is too descriptive and qualitative, and it does not add relevant new knowledge. Furthermore, it suffers of a poor methodological approach. There have been developed automated research algorithms to collect events and information from web and media in a systematic manner. I suggest the authors to implement such methods or to remove completely this section.

We wish there were automated methods, but they do not exist. The US Drought impact reporter and the European drought impact report inventory (EDII) differ in the way they collect data, but each entry is moderated, i.e. manually checked and coded into the system and manually transcribed as it is not legally possible otherwise to store the data. The JRC media monitor is only a real-time tool, which provides many false hits and so far has not been used in any quantitative analyses due to these difficulties. In reality, this process is not at all automated and data for 2015 does not yet exist as a consolidated dataset. For the revision of the paper we see two options, (a) delete the section, (b) improve the section by citing some key impact reports as anecdotal evidence and discuss the ways forward and difficulties of a more comprehensive impact report collection from web and media better. We clearly prefer option b) but will await the Editor's decision on the issue. We would further like to remark that the EDII has received considerable international attention for its relevance and being a first effort to collect impact data consistently for different sectors at the pan-European scale, see e.g.

http://www.nat-hazards-earth-syst-sci.net/16/801/2016/nhess-16-801-2016-discussion.html

http://www.hydrol-earth-syst-sci.net/20/2779/2016/hess-20-2779-2016-discussion.html

As one reviewer for the last paper above writes: "The fact that systematic drought impact collection is sorely lacking, or non-existent in many cases, illustrates the need for more resources to be directed at such efforts moving forward as a way of establishing a baseline for how we have been, are and will be affected by future droughts in a changing climate. The lack of a long, comprehensive record of impacts is not the fault of the authors and in fact the development and maintenance of the EDII moving forward is critical for future works like this."

– Description of methods needs to be improved. In particular it is not specified what time series is used to derive fitting functions and return periods. I suppose the reference period, but this should be better clarified.

We will clarify the issues raised and carefully review and improve the method section.

In the comparison with meteorological droughts the following references may be relevant.
Bachmair et al., 2016 (http://onlinelibrary.wiley.com/doi/10.1002/wat2.1154/full)
Van Loon and Laaha, 2015
(http://www.sciencedirect.com/science/article/pii/S0022169414008543).
Barker et al., 2016 (http://www.hydrol-earth-syst-sci.net/20/2483/2016/),

These recently published studies will be considered in the revision

Minor comments:
Page 1, line 29: please, consider to remove "in this second paper"
Sentence will be rephrased.

Page 1, line 30: stream gauge stations instead of records?
We prefer to keep the term streamflow records as the second part of the sentence refers to records and not to stations.

Page 2, line 11: please, add the relevant references to support this sentence
Reference will be added.

Page 2, line 16: "Droughts… to analyse", too vague, consider to rephrase or remove.
Sentence will be rephrased.

Page 2, line 19-20: This concept needs to be better expressed.
Sentence will be rephrased.

Page 3, line 1: move the reference to the end of the sentence.
Done

Page 3, line 8: please do not abbreviate South, North, East and West throughout the manuscript. Such abbreviation is not a standard.
They are indeed contained in the list of common abbreviations in Oxford English Dictionary.

Page 5 lines 9-13: this information is not relevant for this work, consider removing it.
We suggest to shorten, rather than delete, the description of the software packages.

Page 5, line 15: the 2013 is also compared to the 2003 event, this should be clarified.
We will add "(…and relative to the year 2003)"

Page 5 lines 20-25: I would suggest to synthesize this content and move to the next sections for a better organization of the text and to avoid redundancy. Are the low-flow indices calculated for the 2015, 2003 and reference period? Please, clarify.
We will clarify this paragraph and consider its placement in the text.

Page 6, line 18: how do you define "totally recovered", please clarify.
We will clarify this paragraph.

Page 6, Section 3.2. Please clarify on what time series you estimate the fitting functions to derive return periods for reference period, 2015 and 2003. Why did you use such fitting functions instead of generalized extreme value or pareto distribution?
We have described the standard approach of low flow and drought frequency analysis. As this is standard in low flow hydrology, we don't believe it necessary to elaborate. However, we have clarified the data used by extending the text of step (1): "Sample the annual extremes series AES" with "from daily discharge records of the reference period".

Page 7 line 21: contrasting response instead of dipole?
We will change the text accordingly.

Page 7, line 23: the patter discussed seems not including North-Austria. Maybe, because the graphical representation is not very clear in colours and symbols. I strongly suggest improving figures with maps by showing more contrasted colours.
The figure was carefully designed for the Pan-European scale, and hence can be difficult to read at a local scale. We will do our best to increase the readability of the figures using more contrasting colours.

Page 7, line 26: the 2015 drought-affected area? Clarify
We will add a definition of what is meant by 'drought affected area' in the paper referred to.

Page 8, line 10: Please, clarify.
We will modify the sentence: "…with the largest deficits occurring in S-Germany, west of the area with lowest flows…"

Page 9, line 3-4: Consider to remove winter plots from the graph, they do not add relevant information.
Although this group of stations is not of prime relevance for the paper we prefer to keep the winter boxplots, for the sake of completeness of the analysis.

Page 9, line 13: low flow threshold? I understood that you were looking at the minimum flows here. Please clarify.
Thanks, this is a typo and will be corrected to "average annual low flow discharge".

Page 10 Section 4.5 please, rephrase without using bullet points.
Done.

Page 14 line 7: the extreme is most extreme… please rephrase.
We will change to "when the extreme event was most extreme"

Page 14 line 25: add "streamflow" to drought.
Done (this is p14 line 31 in our original document).

Page 15, line 10-11. Is there any additional drought self-propagation mechanism linked to land atmosphere interactions that could contribute in explaining these processes? Dry soils may lead to lower probability of precipitation and thus cause intensified droughts. See for instance Senevitarne et al. 2010 (Earth-Science Reviews 99 (2010) 125–161).
This aspect will be considered and a remark added to the paper.

Page 15 lines 20-33. This text is very speculative and not related to the work presented, please

consider removing it.
We will carefully evaluate the paragraph and its relevance for the paper and accordingly revise the text.

References:

Grayson, R. and Blöschl, G., Eds.: Spatial patterns in catchment hydrology: observations and modelling, Cambridge University Press, Cambridge, U.K. ; New York., 2001.

Laaha, G. and Bloschl, G.: A comparison of low flow regionalisation methods–catchment grouping, J. Hydrol., 323(1–4), 193–214, 2006.

Blauhut, V., Stahl, K., Stagge, J. H., Tallaksen, L. M., De Stefano, L., and Vogt, J. (2016): Estimating drought risk across Europe from reported drought impacts, drought indices, and vulnerability factors, Hydrol. Earth Syst. Sci., 20, 2779-2800, doi:10.5194/hess-20-2779-2016, 2016.

Stahl, K., Kohn, I., Blauhut, V., Urquijo, J., De Stefano, L., Acácio, V., Dias, S., Stagge, J. H., Tallaksen, L. M., Kampragou, E., Van Loon, A. F., Barker, L. J., Melsen, L. A., Bifulco, C., Musolino, D., de Carli, A., Massarutto, A., Assimacopoulos, D., and Van Lanen, H. A. J. (2016) Impacts of European drought events: insights from an international database of text-based reports. *Nat. Hazards Earth Syst. Sci.*, 16, 801-819, doi:10.5194/nhess-16-801-2016.

Figures

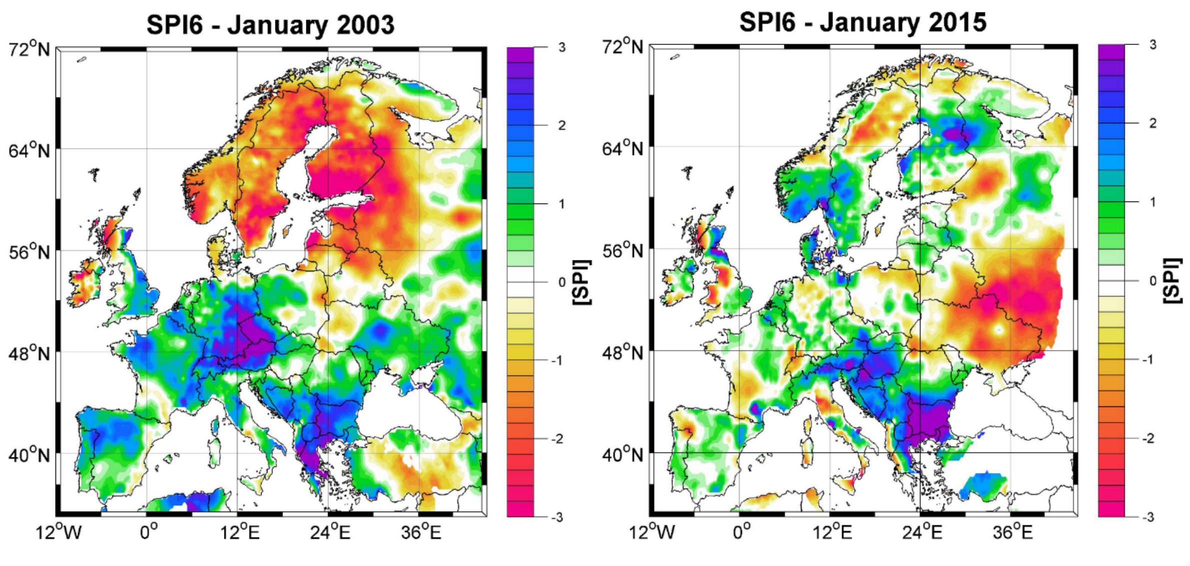

Figure S1. SPI6 for January 2003 (left) and January 2015 (right). Reference period 1971-2000.

2003

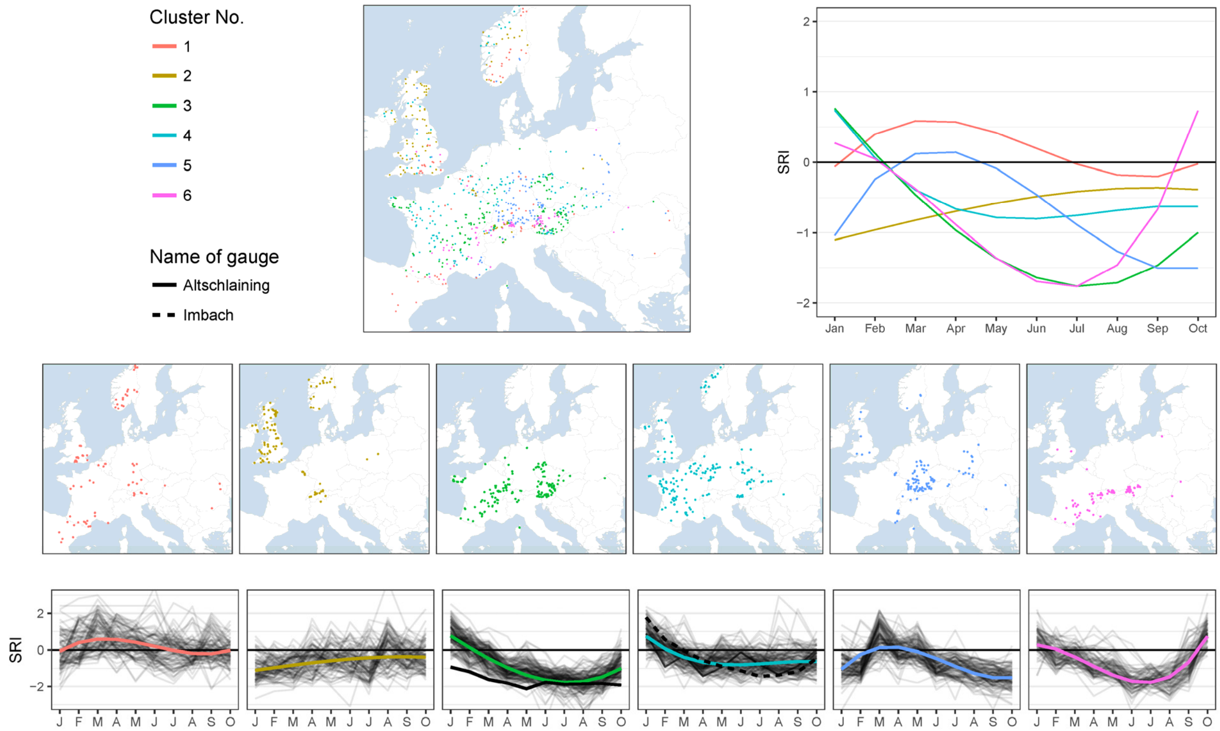

Figure S2. Functional clustering of the low flow event of 2003 based on monthly standardized streamflow index values SSI of the Jan – Oct period. a) combined cluster map showing allocation of catchments to the clusters, b) combined map of functional models of each cluster, c – h) cluster component maps, i– n) synoptic plots of standardized monthly hydrographs of Cluster 1 – 6 (thin black lines) together with the functional model of each cluster center (bold colored line). Altschlaining is marked by a bold black line, Imbach is marked by a dashed black line.

2015

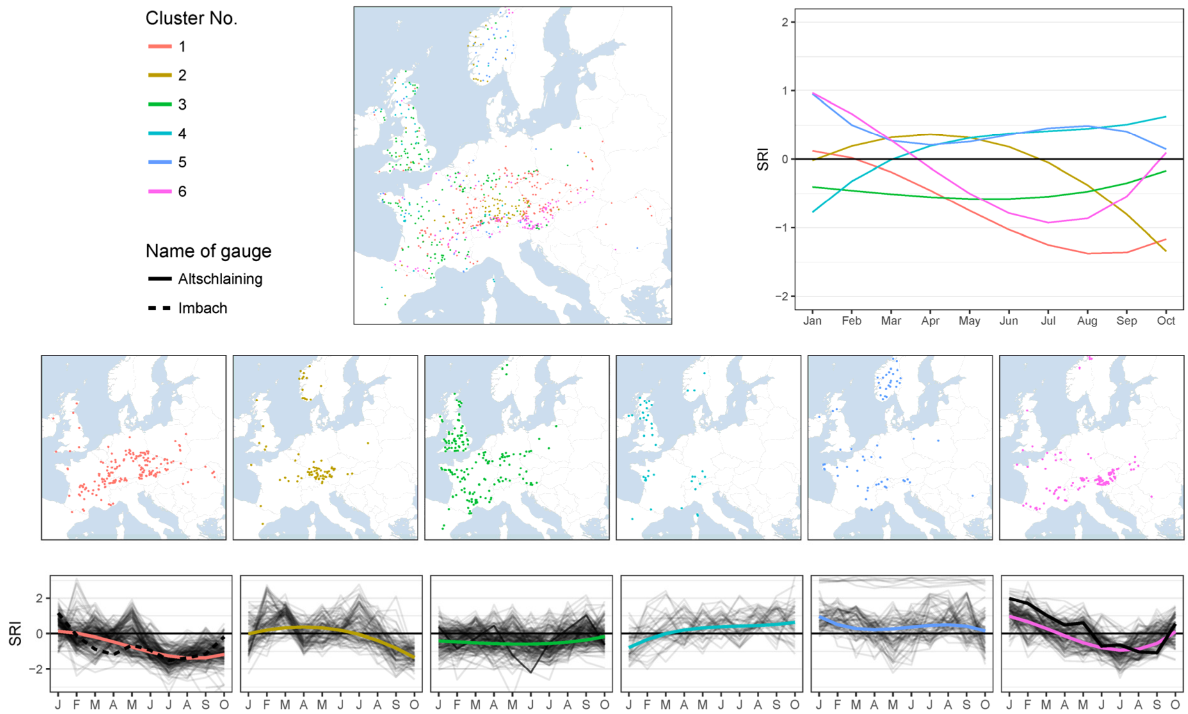

Figure S3. Functional clustering of the low flow event of 2015 based on monthly standardized streamflow index values SSI of the Jan – Oct period. a) combined cluster map showing allocation of catchments to the clusters, b) combined map of functional models of each cluster, c – h) cluster component maps, i– n) synoptic plots of standardized monthly hydrographs of Cluster 1 – 6 (thin black lines) together with the functional model of each cluster center (bold colored line). Altschlaining is marked by a bold black line, Imbach is marked by a dashed black line.