

**Response to Gerardo Benito (Referee) on “Non-stationary flood frequency analysis in continental Spanish rivers, using climate and reservoir indices as external covariates” by J. López and F. Francés, submitted to Hydrological Earth System Sciences.**

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Dear reviewer,

Authors would like to thank you for your interesting comments and suggestions. We have made the highest effort to follow your recommendations; all the corrections carried out in the manuscript are described below.

ANSWERS TO GENERAL COMMENTS (referee comments in italics):

*... The water dam construction was demonstrated to produce a change of flood regime, at least for the moderate and small floods. Since the analyzed series is short, it was not evident how dams can affect large peak flows, that, when produced, large floods are already full of water and therefore, unable to attenuate flood peak.*

We agree with the reviewer, the analyzed series in the present study are not particularly long, but they are not particularly short: 57 years of data. This is one of the reasons to present results for the 100 years quantile (and not any other less frequency) and to analyze a set of 20 stations. Focusing on the reservoir attenuation, this is a function of flood volume, initial reservoir empty volume, the relationship between reservoir volume and water elevation and spillway discharge characteristics. Even if the reservoir is full, there will be flood attenuation as a function of other factors. In fact, the reservoir index includes partially these important factors. On the other hand, in this paper we have not explicitly consider the initial reservoir level, which means we are assuming it is a random variable with an stationary dependence with the flood peak.

*... As indicated by different authors (e.g. Trigo etc.) these indexes describe a natural mode of atmospheric variability, but it is uncertain how anthropogenic climate change might influence modes of NAO (see Corti et al., 1999; Hurrell et al., 2003). This brings some kind of “unpredictability” and lack of robustness of the resulting flood frequency quantiles, as the statistical parameters change from year to year, producing a high uncertainty on the validity of the results.*

The role of anthropogenic climate change in the internal variability of low-frequency atmospheric circulation patterns is significant with no doubt, but we agree with the reviewer it is needed to improve the prediction in the short and long term. In this regard, it is interesting to analyze whether the observed changes in atmospheric configurations can be explained by increases in emissions of greenhouse gases. To draw conclusions in this line, it will be necessary to use climate models that will allow us to understand the causes of variations in climate indices, particularly whether they are related to anthropogenic forcings or are an expression of natural climate variability. These results will contribute towards to strengthen the role of climate indices as explanatory covariates on the results of frequency analysis. But this is out of the scope of this paper and our research group. Therefore, this work should be considered as a trigger or need for better climate change predictions.

*Another interesting point raised by the authors is that skewness coefficient and other high order dimensionless moments has a low sensibility to climate and dam regulation variations. How this may affect to the sensibility of highest quantiles (>100-year flood) of distribution function?*

This was a statistical result, but it must be considered in the light of the limitations on the parametric distributions and site data length used in this study. And the high return period quantiles are especially sensitive to the skewness coefficient. We were aware of it, and we limited the results to the 100 years flood. To be more conclusive concerning the stationarity of skewness coefficient, longer data series should be used. We will add this idea in the final manuscript.

SPECIFIC COMMENTS (referee comments in italics):

*Title: the word “continental” may be deleted from the title.*

We consider necessary to keep the word "continental" in the title. The reason is the absence of study sites in the Balearic and Canary islands.

*Page 3108, Line 15. What is an empirical orthogonal function analysis? Can you explain what is that and what is suppose to carry out in the analysis? One general sentence explaining the concept of this would be enough.*

The empirical orthogonal function analysis is a multivariate statistical technique similar to principal component analysis, where the objective is to identify which variables can be interrelated (reduce the dimensionality of a data set). We will include this clarification in the final manuscript.

*Page 3115, Line 26. It is observed a lesser influence of PC2 due to a weak correlation with WeMO in modulating flood regimes. There is a major problem in this approach, since all the PCs are apply supposing that all these climate indices are influence flood regimes in the same way. I wonder if a preliminary analysis of the weight of these indices in each of the gauge stations may be use to select the most appropriate index to consider in the analysis instead of consider a blend of all of them.*

For the different GAMLSS models with PCs as covariates, it is during the parameter estimation process when the more significant PCs are selected, using the Akaike Information and Schwarz Bayesian criteria. Not all indices are incorporated in the final model and the result is different for each site (Table 5), but there is a spatial coherence as explained in page 3115 line 18 and following.

*Page 3117, Line 1. According to the authors, there is a decreasing trend in the mean of the peak discharge values. I wonder if this trend may be bias by the short gauge record selected. I wonder if the results would be the same for longer time series.*

Yes, we also think with model 1 the resulting trend can be sensible to the observed sample. This one reason we don't recommend to use only the time as covariate. This malicious effect doesn't appear with model 2.

*Page 3118, Line 16. Peak floods, you may want to say “large floods”??*

Yes, we want to say “large floods”. We will proceed to change it in the final manuscript.

*Page 3121, Line 5. “... which is the result of frontal systems associated with the Atlantic circulation.”*

It will be changed in the final manuscript.

*Page 3122, Line 13. I guess that the term average recurrence interval (in years) is valid but understanding that it represents the average probability resulting for the period of analysis. Otherwise, the whole flood frequency analysis is under question because in the case the return intervals as used for engineering design, there is a high uncertainty on how this may change in the given return interval.*

We don't think that whole flood frequency analysis is under question, but the concepts of return period and risk need to be extended into a non-stationary framework. The use of the common notion of "return period" is no longer appropriate in a non-stationary framework. In this case, the return period associated to any extreme event value depends on time. Recently, Salas and Obeysekera (2013) present a simple and unified framework to estimate the return period and risk for non-stationary hydrologic events. They state risk assessment should include the life time of the considered structure. The concepts of return period and risk are formulated by extending the geometric distribution to allow for changing exceeding probabilities over time. The cited reference is:

J.D. Salas and M.J. Obeysekera, 2013. Revisiting the concepts of return period and risk for nonstationary hydrologic extreme events. Accepted for publication in *Journal of Hydrologic Engineering*.

*Page 3137 Figure 3. In the text it should be indicated what are the selected months for winter. In other words, if it was selected DJF or DJFM, etc...*

Effectively, the reviewer is right. We forgot to incorporate the period for winter climate indices. The selected months for winter were DJF. Thus, we added DJF in the title of Figure 3. "Scatterplots between annual maximum peak discharges and the corresponding values of the principal components (right panel) and winter climatic indices (DJF) (left panel)".

*On the right side of the figure the correlation of peak discharge with the most negative numbers is in fact not too good. The highest discharges were obtained for values close to 0. In the case of the WeMow, the values close to 1 got the largest peak discharges. However, the values of WeMow close to 1 also have associated very low peak flows.*

The relationship between flood events and climate indices is complex and exhibits certain non-linearity and changes over time. In order to address this complexity we studied this relationship using parametric smoothing formulations (cubic splines). And it is difficult (for us impossible) to conclude with a simple qualitative relationship in general and the particular case pointed by the reviewer.

*Page 3139, Figure 5. Looking figure 5, an evident comment is that how if the climate indexes are the main drivers of the non stationarity, the trends or changes in the mean values do not follow a similar pattern across the different stations?*

As explained in the previous comment, the response of continental Spanish rivers to low-frequency atmospheric circulations and existing reservoirs is not simple and is not homogeneous both spatial and temporal. In Fig. 5 each site is located in different climatic region and some of them have altered regime by reservoirs. The different observed behaviour in this figure can be explained for the different climate indexes (with or without the reservoir index) significant at each site. And as expected, there is not any general trend.