Answers to referee#1 's comments:

We thank the reviewer for their very valuable comments. Below are mentioned responses to them point-by-point:

1. General comments

In relation to historical data, although they reference previous works, it is necessary a more detailed explanation, in particular on the information density in past.

> We agree with your observation. A new paragraph has been introduced in order to clarify this issue (in bold letters):
>
> "..in perception and exposed assets (Barrera et al., 2006; Barredo et al., 2012; Llasat et al., 2013).
>
> **Historical flood evidences are mainly based on the impact descriptions and, consequently, they refer to the floods as a holistic risk, being difficult to separate the "natural" causes from the rest. The flood chronologies that can be constructed from instrumental records and flow series for Europe do not usually extend further back than the 19th century (the 20th century for Spain). Flood historical records can arrive until the 14th century, except for those in Italy dating from the Roman Empire. Besides this, information density in past is heterogeneous, not only due to the lack of records (i.e. Macdonald, 2014), but also due to the relative youth of the science that encompasses historical climatology with the modern understanding of climate dynamics, meteorology and hydrology (Glaser, 1996; Camuffo and Enzi, 1996; Brázdil et al., 1999; Lang and Cœur, 2002). The major documentary historical sources containing climatic information and details of its effects are local and state government records, religious collections, private collections, notaries' archives and taxation records (Barriendos et al., 2003; Brázdil et al., 2014). Whenever possible, the historical flood classification should be based on discharge estimates, with a sensitivity analysis to assess the specific errors of the hydraulic model for the conversion of historical flood levels into discharge (Brázdil et al., 2006; Herget et al., 2014). On the contrary, in order to have the longest possible flood series, a scale of event magnitude can be proposed using the effects of the floods on the river channel system and surrounding areas. This is the approach more commonly used (Llasat et al., 2005; Barriendos et al., 2014; Retsö, 2014). In this sense, the objective of the FLOODCHANGE project is to improve at European scale the built of long historical flood records in order to build a flood-change model (http://floodchange.hydro.tuwien.ac.at/deciphering-river-flood-change/). We would like to address the reader to the papers published in this special issue to find more details about historical floods data and their analysis (Kiss et al., 2014).**
>
> In this context, analysis of long-term homogeneous..."
>
> Barriendos, M., Ruiz-Bellet, J.L., Tuset, J., Mazón, J., Balasch, J.C., Pino, D., Ayala, J.L.: The "Prediflood" database of historical floods in Catalonia (NE Iberian Peninsula) AD 1035–2013, and its potential applications in flood analysis, Hydrol. Earth Syst. Sci. Discuss., 11, 7935-7975, 2014.

Brázdil, R., Kundzewicz, Z.W., and Benito, G.: Historical hydrology for studying flood risk in Europe, Hydrolog. Sci. J., 51, 739–764, 2006.

Brázdil, R., Chromá, K., Řezníčková, L., Valášek, H., Dolák, L., Stachoň, Z., Soukalová, E., and Dobrovolný, P.: The use of taxation records in assessing historical floods in South Moravia, Czech Republic, Hydrol. Earth Syst. Sci., 18, 3873-3889, 2014.

Glaser, R.: Data and methods of climatological evaluation in historical climatology, Hist. Soc. Res., 21, 56–88, 1996.

Herget, J., Roggenkamp, T., and Krell, M.: Estimation of peak discharges of historical floods, Hydrol. Earth Syst. Sci., 18, 4029-4037, 2014.

Kiss, A., Brázdil, R., and Blöschl, G. (eds.): Floods and their changes in historical times - a European perspective, HESSD special issue, 2014.

Macdonald, N.: Millennial scale variability in high magnitude flooding across Britain, Hydrol. Earth Syst. Sci. Discuss., 11, 10157-10178, 2014.

Retsö, D.: Documentary evidence of historical floods and extreme rainfall events in Sweden 1400–1800, Hydrol. Earth Syst. Sci. Discuss., 11, 10085-10116, 2014.

The classification of floods is based on the impacts they provoked. This feature may be misleading, taking into account the changing vulnerability of human infrastructures in time.

Of course, vulnerability of human infrastructures changes in time, but the only way to compare current floods with those taken place in the past before the existence of instrumental data is considering the impacts they provoked. This is also the only way to have long flooding series. Obviously, the changing vulnerability in time is a significant fact that has to be borne in mind when analysing this kind of flood data period. This is, for instance, the case of Barcelona city showed in Barrera et al. (2006). However, this kind of classification (based on the flood impacts) is the commonly used when series of historical floods are analysed (i.e. Brázdil et al., 1999; Sturm et al., 2001; Glaser et al., 2010; Petrucci et al., 2012 among others) but also for present floods (i.e. Adhikari et al., 2010; Petrucci 2012). It does not introduce any mistake, because it refers to the flood as a risk, including all the factors that could be involved in the produced impact (hazard, vulnerability, exposure, emergency management...). On the contrary, it would be a mistake to analyse the flood hazard evolution attending exclusively to this kind of series. We have already discussed this fact in Barriendos et al. (2003).

A new paragraph with new references has been introduced in the new version of the manuscript to make it clearer, as follows (in bold letters):

“This classification allows us to compare historic floods and those that were documented with instrumental records. It also matches similar criteria or methodologies used in other European countries such as in the study by Sturm et al. (2001)**, Glaser et al. (2010) or Petrucci et al. (2012). This kind of classification refers to the flood as a risk, including all the factors that could be involved in the produced impact (hazard, vulnerability, exposure, emergency management...). Consequently, the change in anyone of these factors may affect the evolution of risk and impact.”**

Adhikari, P., Hong, Y., Douglas, K. R., Kirschbaum, D. B., Gourley, J., Adler, R., and Brakenridge, G. R.: A digitized global flood inventory (1998–2008): compilation and preliminary results, Nat. Hazards, 55, 405-422, 2010.

Barriendos, M., Cœur, D., Lang, M., Llasat, M. C., Naulet, R., Lemaitre, F., and Barrera, A.: Stationarity analysis of historical flood in France and Spain (14th-20th centuries), Nat. Hazards Earth Syst. Sci., 3, 583-592, 2003.

Brázdil, R., Glaser, R., Pfister, C., Antoine, J. M., Barriendos, M., Camuffo, D., Deutsch, M., Enzi, S., Guidoboni, E., and Rodrigo, F. S.: Flood events of selected rivers of Europe in the Sixteenth Century, Clim. Change, 43, 239-285, 1999.

Glaser, R., Riemann, D., Schönbein, J., Barriendos, M., Brázdil, R., Bertolin, C., Camuffo, D., Deutsch, M., Dobrovolný, P., van Engelen, A., Enzi, S., Halíčková, Koening, S. J., Kotyza, O., Limanówka, D., Macková, J., Sghedoni, M., Martin. B., and Himmelsbach, I.: The variability of European floods since AD 1500, Clim. Change, 101, 235-256, 2010.

Petrucci, O., Pasqua, A. A., and Polemio, M.: Flash flood occurrences since 17th century in steep drainage basins in southern Italy, Environ. Manage., 50, 807-818, 2012.

Sturm, K., Glaser, R., Jacobeit, J., Deutsch, M., Brázdil, R., and Pfister, C.: Floods in Central Europe since AD 1500 and their relation to the atmospheric circulation, PGM, 148, 18-27, 2001.

The discussion on the forcing factors is in my opinion very speculative (more details in specific comments). In this sense, I suggest to change the title of the manuscript to "Evolving flood patterns in a Mediterranean region (1301-2012) and climatic factors".

We have changed the paper title as it is suggested by both referees as follows:

Evolving flood patterns in a Mediterranean region (1301-2012) and climatic factors. The case of Catalonia.

2. Specific comments

1) *Abstract. Page 9146.Lines 5-6. Authors summarize their results for catastrophic and extraordinary floods, but these categories are not defined yet*.

We have not detailed them because these categories have been widely explained in previous papers cited within the text. However, attending your comment, a brief explanation about flood categories has been included within the new version of the abstract, as follows (in bold letters):

"Catastrophic floods **(those that produce complete or partial destruction of infrastructure close to the river, and major damages in the overflowed area, including some zones away from the channels)** do not present a statistically significant trend, whereas extraordinary floods **(the channel is overflowed and some punctual severe damages can be produced in the infrastructures placed in the river course or near it, but usually damages are slight)**, have seen a significant rise, especially from 1850 on, and were responsible for the total increase in flooding in the region."

2) *Table 1. Flood chronologies. Periods are different for the different river basins. In what way this feature may affect the results? What is the information density for past centuries? In historical climatology is always possible to find new evidences that compel to refine the analyses. What criteria have used the authors to trust in their reconstructions? In other words, historical data are sufficient to try statistical analyses?*

> The analysis of past flood events using historical data can be of benefit to the understanding of large flood processes. It enlarges the flood chronology and increases the number of observations of extreme events. Historical data is the only information available before instrumental data period. In the case of flow data the oldest series usually begin in the 19th century. In Catalonia, the oldest series start in the 1910s. In this sense, the FloodChange project ("Deciphering River Flood Change": http://floodchange.hydro.tuwien.ac.at/deciphering-river-flood-change/) leaded by Prof. Dr. Günter Blöschl, which is promoting this HESS special issue, and it has as one of the main objectives the compilation of flow and flood data European series to be statistically analysed, following the proposal of the COST Action ES0901 (FloodFreq: "European procedures for flood frequency estimation": http://www.cost-floodfreq.eu/).
>
> We have maintained different periods in order to take benefit from the maximum available information for each location and increase the number of "observations" (see our answer to your first general comment). As you suspect, homogeneity problems can be caused by the quality of documentary sources, by human activities or by natural climatic variability patterns. This fact does not affect the results because a standardisation procedure has been used. Lang et al. (1999) provided some guidelines to apply statistical tests on extreme values to this kind of series, which were applied to the series of historical floods of Ter, Segre and Llobregat rivers in Barriendos et al. (2003).
>
> We have added some sentences in the new version of the paper to make this issue clearer as follows (in bold letters):
>
> "...where n is the yearly flood occurrence; m is the annual-mean value; and s is the standard deviation. **This procedure has also been applied in Barriendos et al. (2003) where the homogeneity of the series were analysed following the methodology proposed by Lang et al. (1999). On the other hand, this normalisation is necessary in order to cope with different data series and to construct a geographically representative series**. Finally, in order to show the changes in..."

3) *Page 9150. Lines 26-29. Please, include a reference on the annual mean average areal precipitation series.*

> The reference has been included in the new version of the paper as follows (in bold letters):
>
> A representative annual mean average areal precipitation series for the North-Eastern Iberian Peninsula (NEIP), with records for over 100 years, has been also used to

complete the analysis. **This areal precipitation series has been computed from all available monthly precipitation series within the NEIP with a continuous temporal record greater than 90 years (Barrera and Llasat, 2004).**

4) *Page 9151. Lines 15-25. Classification of floods is based on impacts. Vulnerability of river basins may change in time due to human activities (cleaning of river beds, irrigation channels, dams, etc.). Information on these changes in Catalonian rivers is necessary. In statistical terms, this is a homogeneity problem. Have the authors investigated the homogeneity of their time series?*

We agree with your comment about the changing vulnerability and its influence on flood damage. These aspects are also commented within our paper. This kind of information for all Catalan rivers is not always available. This is one of the future aims of our research and our collaboration with other scientists involved in the FloodChange project. Beside this, the studies, which analyse all the vulnerability factors in a river basins, are usually focussed on a part of the catchment but not to the entire region. This last question implies a great deal of work that it will be interesting to develop in a near future within the framework of an international multidisciplinary project. As we have previously explained, homogeneity issues were analysed in Barriendos et al. (2003) and the introduction of new data in the last period does not any significantly change in homogeneity (not important changes in vulnerability have been produced in the last few years; Llasat et al., 2014).

Llasat, M.C., R. Marcos, M. Llasat-Botija, J. Gilabert, M. Turco, P. Quintana. Flash flood evolution in North-Western Mediterranean. Atmospheric Research 149, 230–243, 2014.

5) *Page 9152. Line 8. Why the reference period is 1901-2000? Have you compared with the results using other reference periods, as the usual 30 yr period 1971-2000?*

We have used 1901-2000 period because we want to compare our data respect to a long period (100 years), and taken into account only a 30-year period could introduced a bias because floods are scarce events in time, especially catastrophic ones. In this paper we are analysing long oscillations, in some occasions lasting more than 30 years. Historical climatology usually considers long temporal periods as a reference.

6) *Page 9152. Lines 21-28. “The anomalous values were those with a flood index greater than or equal to 0.1 (Llasat et al., 2005)”. “Anomalous values” means “extreme values”? Although this item is referenced, the index is defined in standard deviations units, and in my opinion this threshold value is very low to establish “anomalous” or “extreme” values.*

In this paper anomalous values are associated with periods of high frequency in flood occurrence, because we are interested in analysing any potential climatic influence. Floods itself are related to extreme flows, and the objective of this paper is not to develop a statistical analysis of the extremes of the extremes. This will imply a specific and robust mathematical treatment that could be the goal of another paper.

The final index is defined in standard deviations units, but the final flood index also comes from the average of individual flood index series in standard deviations units.

These particular flood series are normalised because each one has quite different temporal behaviour from each other, and this procedure is the only way to equally compare all flood chronologies together. The final flood index series cannot be understood as a normalised singular series. If we compute the statistics for the final flood index series, we obtain a mean value close to 0.0 and standard deviation close to 0.1. Therefore, this is the main reason to consider this value in order to identify anomalous periods (this does not imply extreme periods).

Regarding this comment and other ones made by you and the other referee, the paragraph with the methodology has been modified as follows:

“... computed using unsmoothed data. **The anomalous periods are those with a high frequency in flood occurrence, which are estimated from the mean value plus the standard deviation of a temporal series. In this work, they have been obtained only for catastrophic floods which are the most related to climatic factors. The catastrophic flood series have been smoothed using a low-pass Gaussian filter of 31 years like in other studies (i.e. Llasat et al., 2005; Glaser et al., 2010), and the threshold to consider an anomalous period is defined by flood indexes greater than or equal to 0.1 (mean value + standard deviation ~ 0.1).**

The relationship between flood evolution...”

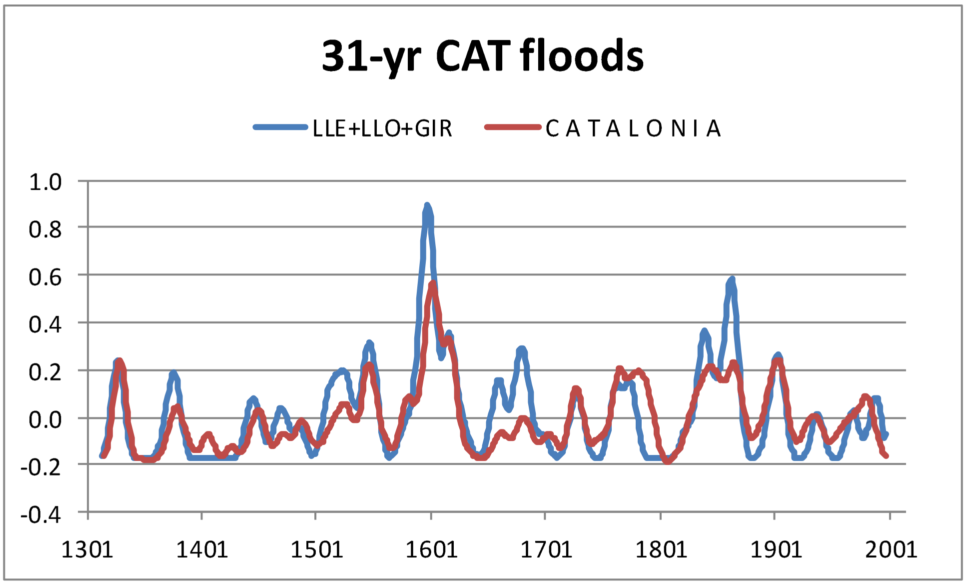
7) *Figure 3. Time period is common to all the chronologies? Only 3 chronologies begin in 1301 (Table 1). How have you averaged to obtain this figure?*

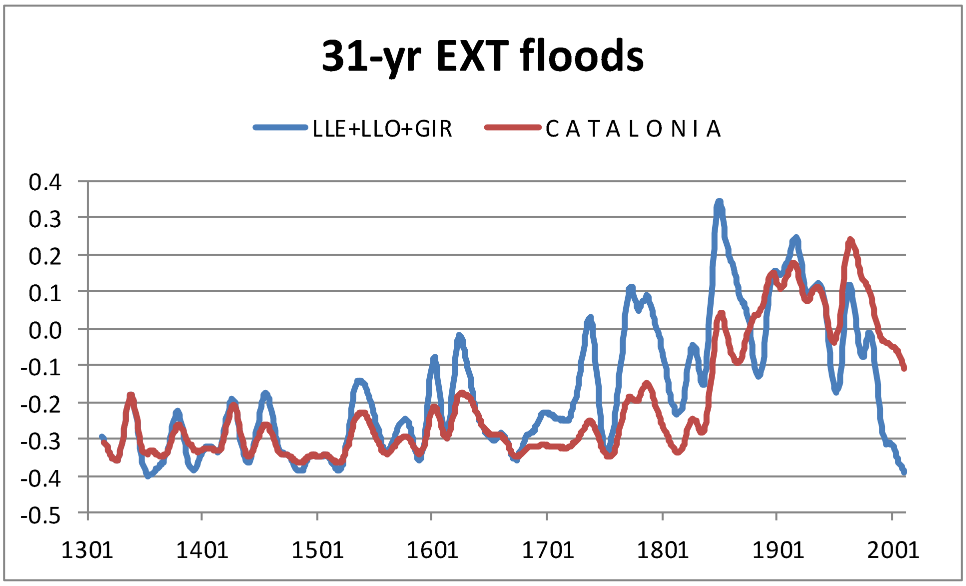
Time period is not common to all the chronologies. We have maintained different periods in order to take benefit from the maximum available information for each location and increase the number of “observations” (see our answer to your first general comment).

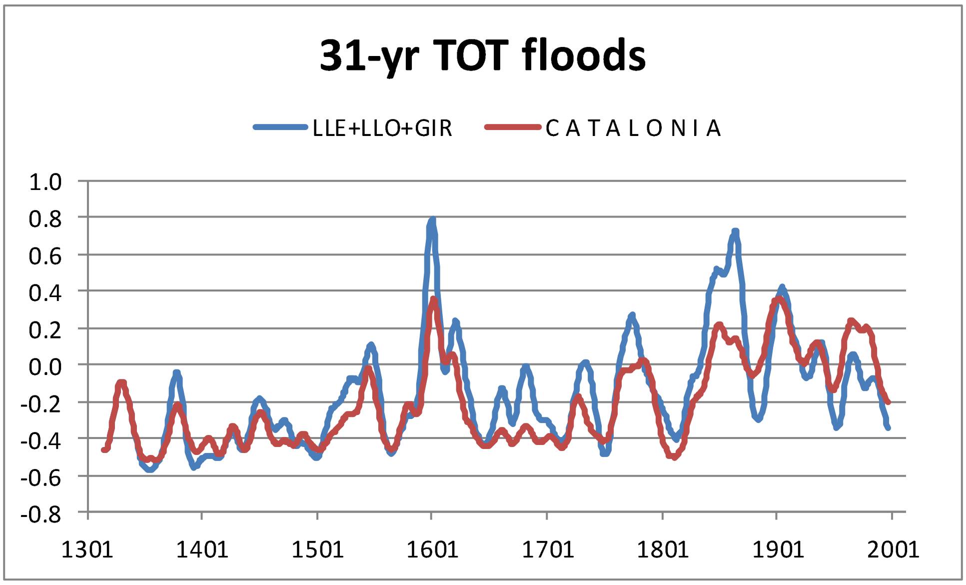
The average has been obtained taking into account only the available data, so at the end of the final series there are more data to compute the final average value. However, due to the fact that the final flood index is based on individual normalised values we think that the addition of new data at the end of the final series do not significantly modify the average. Anyway, all data used in this work are the most complete at the moment in Catalonia related to historical floods. In addition, the only three chronologies beginning in 1301 are quite representative for all Catalonia, and the other flood chronologies only reinforce and complete the temporal behaviour of those three long series.

Our main goal is to identify periods with a high frequency of catastrophic floods rather than analysing temporal trends. If we only analysed the common temporal period for all chronologies (1739-2012 for all series, or 1671-2012 for all series except Mataró), we would be losing information.

If we only compute the final flood index from the three series beginning in 1301 (LLE=Lleida, LLO=Llobregat and GIR=Girona) the general pattern and flood behaviour is quite similar to the flood series obtained from all chronologies, especially for catastrophic ones (see the following images):







8) *Page 9152, trends and figure 5. In the search of trends, linear regression is used. In my opinion there are methods more reliable, as the non-parametric tests (Mann-Kendall, Senn). In any case, if you use linear regression, you must evaluate the residuals before accepting the model. Residuals must be a random series, and behave as a white noise with null mean. Is this the case?*

Thank very much for your comment, but unfortunately Mann-Kendall and Senn methods are not the most suitable for testing trends in this kind of data series. Flood data contain a lot of tied values (repeated values) and these tests are not suitable for data with a large number of ties. In effect, we have analysed trends for all flood data series following the Mann-Kendall method and we have obtained that all series have a statistically significant trend with values for $|Z_{MK}| > 10$, and this does not make sense. For instance, in the case of catastrophic floods, by a visual inspection, these data do not seem to show any trend.

We have considered searching for linear trends in our data, because it is the simplest way of analysing trend in meteorological and climatological data. The strong point of our procedure is the way of how we test the statistical significance of this linear trend. This technique consists in the following steps: i) Calculation of the linear trend of the original series by the linear fitting of data (minimum squares or linear regression). ii) Generation of 10,000 random permutations of the original series. iii) Calculation of the linear trends for each 10,000 generated series. iv) Calculation of the 97.5 and 2.5 percentiles for the 10,000 calculated linear trends. v) Finally, if the first linear trend calculated was higher than 97.5 percentile for positive trend or lower than 2.5 percentile for negative trend, then the obtained trend would be significant at 95%. We have included this detailed explanation in the new version of the methodology section as follows (in bold letters):

"Temporal trends are calculated using the flood index series (not smoothed) **by means of a linear regression testing its significance level** following a Monte Carlo method (Lizevey and Chen, 1983). **This technique consists in the following steps: 1)**

> **Calculation of the linear trend of the original series by the linear fitting of data (minimum squares or linear regression). 2) Generation of 10,000 random permutations of the original series. 3) Calculation of the linear trends for each 10,000 generated series. 4) Calculation of the 97.5 and 2.5 percentiles for the 10,000 calculated linear trends. 5) Finally, if the first linear trend calculated was higher(lower) than 97.5(2.5) percentile for its positive(negative) value then, the obtained trend would be significant at 95%.** Temporal correlations…"

9) *Page 9154. Line 16 and Figure 6. The authors comment an abrupt change in the middle of the 19th century. First, abrupt changes may be statistically assessed by using tools as the sequential version of the Mann-Kendall test, or the Pettitt test. In this case, it seems a qualitative statement obtained from the visual inspection of the figure. In second place, it is possible that this change is due to a higher density data since this date (curiously the significant increase of extraordinary floods from 1850 onwards 'coincide' with the daily rainfall series for Barcelona from 1854 onwards). Again, information on density data in past centuries is needed. Are they enough to compare with modern data?*

> The fact that the abrupt change started with the beginning of daily rainfall series for Barcelona is a casual fact. Flood data for Barcelona come from documentary sources and not from any rainfall threshold (Barrera et al., 2006). During this period the city and coastal region experienced a great expansion occupying flood-prone areas. However, we agree with referee's comment about the use of the term "abrupt change". We had misused this term in the analysis of flood series. We wanted to comment the strong increase produced in the extraordinary flood series. Therefore, we have rewritten this sentence in order to make it clearer, as follows (in bold letters):
>
> "This trend could be **due to the strong flood occurrence increase in** the middle of the 19th century (Fig. 5), which **could** either be related to the end of the LIA **(in the case of France see Lang et al., 2002)** and a possible corresponding increase in convective precipitation, **and** the notable urban changes in the city (Barrera et al., 2006)."

10) *Page 9154. Lines 18-19. In relation to "notable urban changes in the city", although the authors include a reference, more details are necessary. For instance, these changes are related to the expansion of the city to the river flanks? Please, explain.*

> Yes, the changes in the city are mainly related to the expansion of the city to the river flanks, but especially associated with the demolition of the walls which mainly increased the flood vulnerability within the old city. However, these changes happened during an anomalous climatic period known as the "end of the Little Ice Age" with an increasing frequency of high rainfall events in Catalonia (Llasat et al., 2005). We have added more information in this paragraph as follows (in bold letters):
>
> "…and a possible corresponding increase in convective precipitation, or the notable urban changes in the city. **The expansion of the city to the river flanks, but especially the demolition of the walls that frequently acted as flood protection barriers, increased the flood vulnerability and exposure in the new and old city during a period of increasing frequency of high rainfall events (Llasat et al., 2005; Barrera et**

al., 2006). The construction of the drainage network and the coverage of the wadis in the late 19th century and early 20th century decreased again the vulnerability (Martín-Pascual, 2009).

The large reservoirs…"

Martín-Pascual, M.: Barcelona. Aigua i ciutat, Fundació AGBAR, Barcelona, 455 pp, 2009.

11) *Page 9156. Lines 6-21. This is a confusing discussion. Authors search correlations between floods frequency and rainfall for different time periods, arbitrarily chosen. It would be more interesting, for example, to show moving correlations with a 31-yr window.*

The discussion was based on the analysis of 31-year moving correlations for the whole period, but we did not show them. In order to clarify this discussion and following the referee's suggestion we have included the 31-year moving correlations between flood frequency and rainfall thresholds within the panels showing temporal evolutions for different rainfall thresholds (old Fig. 9, now Fig. 8). We have also rebuilt old Fig. 8a (now Fig. 7a) in order to show 31-year moving correlation between annual precipitation and catastrophic floods in Barcelona city. Finally, we have also rewritten these lines and moved some paragraphs as follows (in bold letters):

"The correlation between annual precipitation and the annual index for different types of floods (1786-2012) is very low and changes over time. The 31-year moving correlations between annual precipitation and catastrophic floods in Barcelona (Fig. 7a) show a maximum value (r=+0.59) for 1860-1890 related to the end of the LIA (characterised by very wet years and without flood protection measures). From 1957 on, there is null correlation, maybe as a result of different hydraulic works developed within the city to diminish flood risk and less climatic variability (Barrera et al., 2006; Martín-Pascual, 2009).

In Barcelona, the temporal correlation **(Fig. 8)** between total annual floods and the number of days exceeding thresholds of 20 mm/d, 30 mm/d, 50 mm/d and 100 mm/d is relatively low for the 1854-2012 period, which shows the most significant correlation for the number of days exceeding 50 mm (+0.24). **The correlation between the previous thresholds and the catastrophic flood index also shows the same pattern.** Barrera et al. (2006) outlined that urban growth in the city of Barcelona has had an impact on flood vulnerability and **the flood frequency** from the 14th century onwards, especially from the late 19th and early 20th century. **This fact is corroborated when analysing the 31-year moving correlations for the above-mentioned variables for raw data (Fig. 8). Considering the total annual number of floods and number of days above 50 mm/d they reached values above +0.60 for 1936-1985, which could be considered as an homogenous period because the city drainage system did not experience significant changes (Martín-Pascual, 2009). The construction of water tanks, from 1990s on, diminished the correlation with the 50-mm threshold and improved the one with the 100-mm threshold arriving to +0.61. On the contrary, after the wall demolition and initial urban occupation of flood-prone areas, the 20-**

mm threshold shows the best correlations. This fact corroborates the strong sensitivity of rainfall threshold associated with floods to changes in vulnerability."

The new images and their respective figure captions are the following (new Fig 7a and Fig. 8):

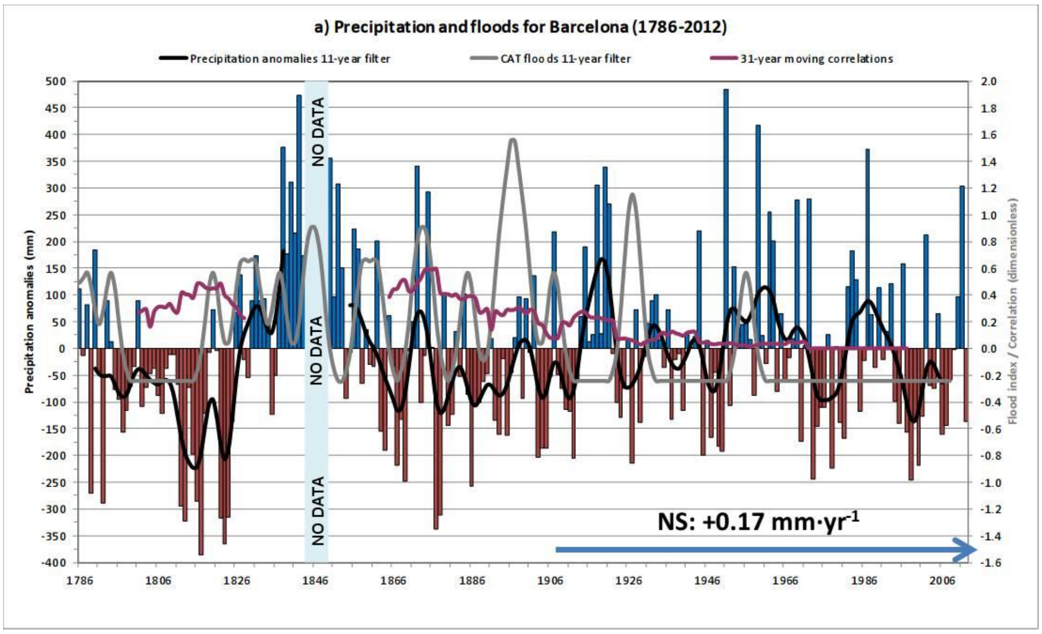


Figure 7. a) Temporal evolution **(1786-2012)** of annual-mean precipitation anomalies (coloured bars)**,** catastrophic flood index series smoothed by an 11-year low-pass Gaussian filter (grey line) **and the 31-year moving correlations between precipitation and catastrophic floods (pink line) for Barcelona.** b) Temporal evolution **(1898-2012)** of annual-mean…

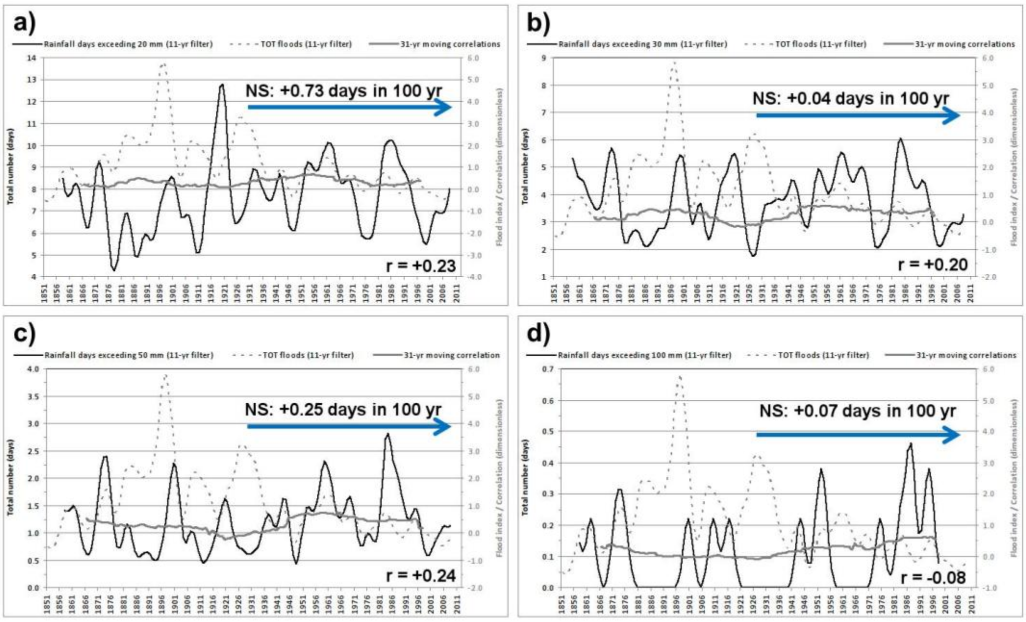


Figure 8. Temporal evolutions of total flood index series and the number of days exceeding a daily precipitation threshold for Barcelona (1854-2012): a) 20 mm, b) 30

mm, c) 50 mm and d) 100 mm. Data have been smoothed by an 11-year Gaussian low-pass filter. **The 31-year moving correlations between floods and the different daily precipitation thresholds are also displayed in each panel**. The results of applying a trend analysis in the number of days **and the temporal correlations between them and floods for all the period** are also shown.

12) *Page 9158. Lines 3-9. Have you searched correlations between flood index and NAO for the 'beginning' of the LIA and the 'modernist' period? Again, moving correlations may help in this case. Your comments seems a qualitative statement from the visual inspection of the figure 10. This is speculative, taking into account that some important negative phases of the NAO are not related to high floods frequency (for instance in the 18th century, around 1701 and 1751).*

We acknowledge the referee's comments, so we have remade this part of the article including the temporal evolution of the 31-year moving correlations between NAO and flood index in old Fig. 10 (new Fig. 9) in order to make the discussion clearer and following the referee's suggestions.

The new paragraph is as follows (modification in bold letters):

"...For this reason, it does not make sense to analyse the potential relationship between NAO and summer floods.

Following the previous discussion, the influence of general circulation on catastrophic floods in Catalonia has only been analysed for the autumn season (accounting for 55% of all catastrophic floods, see Fig. 2), by means of the NAO reconstruction set out by Luterbacher et al. (2002) for **1500-2000** (Fig 9). The **temporal correlation** between these variables is fairly low with a significant value of **+0.09**. The low level of correlation is not unusual because some floods are isolated local events produced by short heavy rainfall that can take place under positive or negative NAO phases, depending more on mesoscale features than synoptic patterns. Besides this, the frequency of flood events is extremely low, and this affects the significance of any potential correlation. **Seasonal shifts in flood distribution could also be produced as a consequence of changes in atmospheric conditions and their effect in precipitation features and snowmelt.** On the other hand, the relationship between the NAO and precipitation **has changed** over time **for the 20th century** (Knippertz et al., 2003; Trigo et al., 2004; Beranová and Huth, 2008). **For the last 500 years, the temporal evolution of the 31-year moving correlations between floods and NAO (Fig. 9) also show a similar behaviour with a high variability. The highest correlations were found during the central part of the LIA: a maximum value of +0.54 for 1673-1703 and a minimum value of −0.35 for 1618-1648; both periods with low flood frequency. The most important peak in floods was at the beginning of the LIA, a period with the minimum NAO values. The end of the LIA, this so called "Modernist" Oscillation and the 1970s-1980s also correspond to a negative NAO phase. On the contrary**, the "Maldà" Oscillation was a **special** period with both floods and droughts, mainly associated with **a great NAO variability (but with a predominance of positive values). A major occurrence of unusual winter thunderstorms and heavy rainfalls related to zonal circulation could explain this anomalous period at annual scale (Barriendos and**

Llasat, 2003). Finally, some periods of relatively high flood frequency occur within periods of **strong** changes to the NAO."

The new Fig. 9 (old Fig. 10) and its figure caption are as follows:

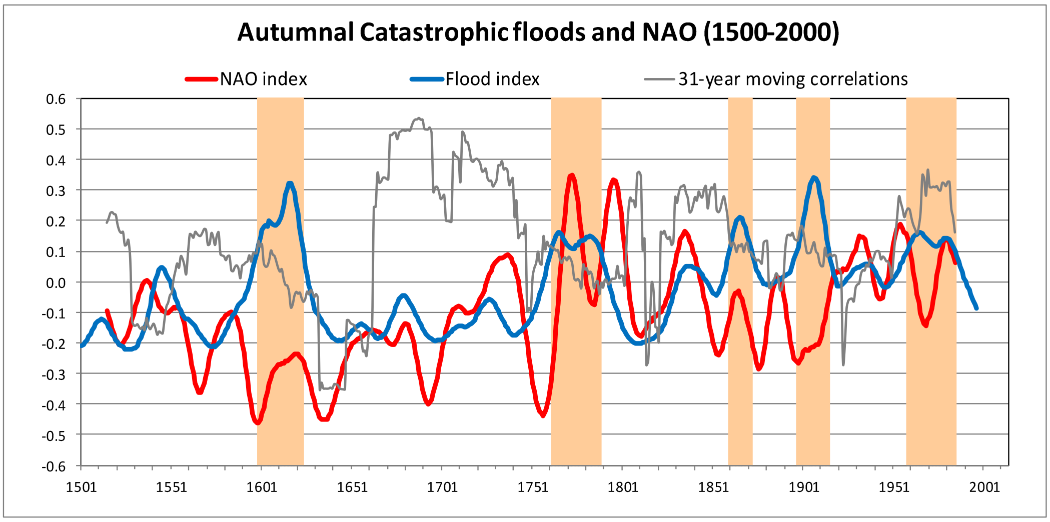


Figure 9. Temporal evolution **(1500-2000)** of autumnal NAO (Luterbacher et al., 2002; **red line**), autumnal catastrophic flood index series for Catalonia **(blue line) and 31-year moving correlations between both variables (grey line).** Data are smoothed by a 31-year low-pass Gaussian filter. The anomalous periods of high flood frequency are highlighted.

13) *Page 9159. Line 16 onwards. The discussion on the possible relationship between flooding and solar activity is again highly speculative. Although the authors recognize the scientific discussion on the problem, they try to search relationships using a method that in my opinion is incorrect. They search correlations using smoothed data, and no raw data. But the use of filters (as, for instance, moving averages), may introduce spurious cycles and trends in the series, that is, mathematical artifacts without physical sense. In consequence, relationships found are very doubtful.*

As we have explained, flood index series are considerable different from typical meteorological or hydrological series, because they are mainly constituted by zero values and peak values for the years or months that record any flood. Consequently, authors work with smoothed data (see for instance, Benito et al., 2003) or decadal data (see for instance the analysis of correlations between taxation records and floods in Brázdil et al., 2014 in this special issue). This is also the case of the paper of Vaquero (2004) in which he visually correlates the smoothed flood data series produced by Benito et al. (2003) (30-yr moving average and floods per decade) with the maximum and minimum periods of solar activity. This kind of "visual" comparison between smoothed flood series and specific periods of minimum/maximum solar variability can be found in the works of Macdonald (2014) or Brázdil et al. (1999) among others. Besides this, the estimation and identification of solar cycles and variability by proxy data such as ^{10}Be or ^{14}C are not exact. Therefore, authors usually work with filtered data or moving average values (i.e. Usoskin et al., 2007).

Following the referee's suggestion we have computed the temporal correlation between floods and solar activity taking into account only raw data, but any correlation has been found ($r=-0.06$; for the whole period 1500-2000). This is not strange because solar dates are not exactly and it is necessary working with smoothing data, also in astrophysics works like this one of Usoskin et al. (2007) or Martín-Puertas et al. (2012). On the other hand, the correlation analysis with smoothed data (31-year low-pass Gaussian filter) shows a higher correlation ($r=-0.33$). This value implies a certain physical relationship between both variables. This last result agrees with other studies relating floods and solar activity (Brázdil et al., 1999; Benito et al., 2003; Vaquero, 2004; Brázdil et al., 2014; Macdonal, 2014; among others).

Taking into consideration the above-mentioned comments, for this part of the article we have maintained the discussion on the analysis correlation with smoothed data for the whole period, but we have also analysed 31-year moving correlations with raw data and show them in the new Fig. 10 (old Fig. 11) as follows (in bold letters):

"As previously mentioned, the most significant oscillations are shown in different basins in Europe and are correlated with the main phases of the LIA (Camuffo and Enzi, 1996; Brázdil et al., 1999; Pfister, 1999; Benito et al., 2003; Llasat et al., 2005; Glaser et al., 2010). **The first oscillation (LMA) was produced at the end of Wolf Minimum, while the second one (m16) corresponded to the end of Spörer Minimum (Fig. 3a). On the contrary,** the most significant period of high flood frequency (bLIA) was recorded near maximum solar activity levels that started in **1580** at the beginning of the LIA, and during the Maunder Minimum flooding activity decreased (Fig. 3a). **The Wolf, Spörer and Maunder are considered the last "grand minima" (Usoskin et al., 2007), for which sunspot activity decreased considerably more than for the other minima.** The first half of Dalton Minimum coincided with the Maldà Oscillation, which was characterised by high climatic irregularity accompanied by hydrologic extremes. The maximum period of flood frequency for the end of the LIA (eLIA) corresponds with the highest levels of solar activity recorded between 1849 and 1875. **Summarising, flood-rich periods are only related to maximum solar activity at the beginning and end of the LIA.**

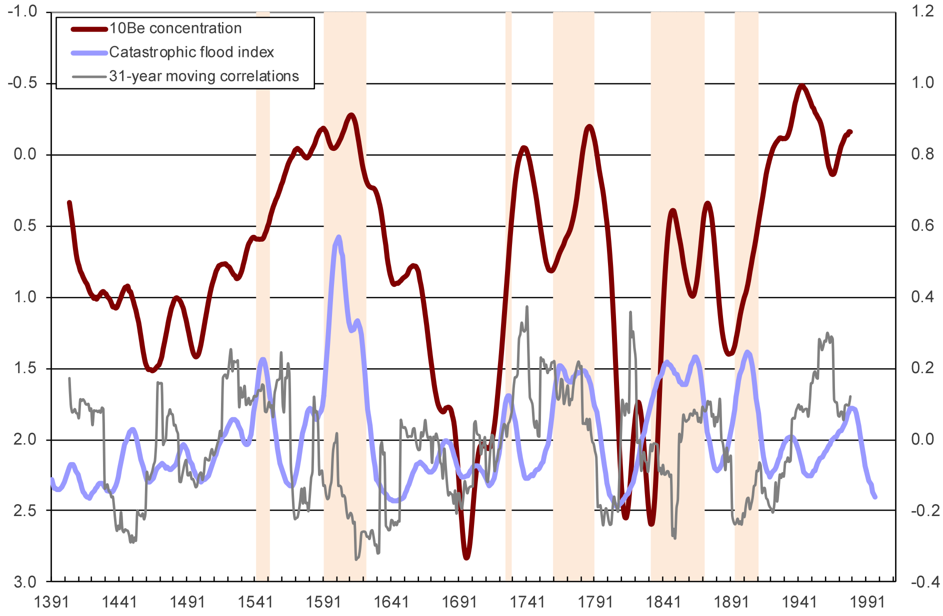
In Central Europe (Brázdil et al., 1999), the periods with the most flooding were recorded in the mid-16th century and in the late Maunder Minimum (1675-1715), corresponding to periods with less solar activity. **On the contrary, Vaquero (2004), from a visual inspection, points to a major flood frequency in Tagus River (Iberian Peninsula) associated with maxima solar activity. This suggests that the regional component is very important. This fact is not strange if we consider the different circulation patterns associated with heavy rainfalls and floods (including snowmelt) and their potential seasonal shift for different periods.** Other authors (Borgmark, 2005; Versteegh, 2005; Wilhelm et al., 2012) also attribute the periodicities found in many geological flood records to extraterrestrial forcings, such as centennial and decadal solar cycles.

Fig. 10a shows a comparison of the annual evolution in solar activity (1389-1994) taken **from the ^{10}Be** concentration and the catastrophic flood index series for Catalonia (1301-2012). **^{10}Be concentration** is high for periods of low solar activity and low for periods of high solar activity. The **temporal correlation** between **raw data** is **extremely low (r=–0.06), but its long-term correlation (with 31-year filtered data) arrive to r=–0.33. This last value implies that lower ^{10}Be concentration (greater solar activity) would be related to periods with higher flooding activity. However, the 31-year moving correlations between them have changed over the time and shown a great variability, with a minimum value of –0.34 for 1600-1630 (period with a high solar activity and the maximum flood frequency) and a maximum value of +0.37 for 1726-1756 (period with a decrease in flood frequency). Then, the most flood-rich period recorded at the beginning of LIA period, would be related with a maximum of solar activity and strongly negative NAO values. On the contrary, visual inspection shows that secondary flood peaks could be related with the Wolf, Spörer and Dalton Minima, mainly characterised by positive NAO values (Fig. 9).** If the analysis focuses solely on autumn (SON; Fig. 10b), the temporal correlation between solar activity and floods is higher, reaching **values of –0.08 for raw data and –0.42 for smoothed data. The related 31-year moving correlations also show higher correlations with a minimum value of –0.38 for 1616-1646 and a maximum value of +0.62 for 1726-1756. Finally, it** is also interesting to note that a significant change in flood occurrence **could be** associated with transient periods between solar maxima and minima, and periods of solar maximum **(Fig. 10)**. In addition to this observation, we should mention that the reconstruction of solar activity from **^{10}Be** concentration does not give the exact dates of the maxima due to dating uncertainties and the length of periods of minimum solar activity are not strictly delimitated (Berggren et al., 2009).

The possible link …
…Given that floods produced by heavy rainfall are associated with different circulation patterns, the effect of solar variability could change from one region to another. **These explanations are coherent with our previous results that correlate positive (negative) NAO with minimum (maximum) solar activity.**

Furthermore, maximum solar activity is associated with low intensity cosmic rays...”

a) Annual catastrophic flood index for Catalonia vs annual Solar activity



b) Autumnal catastrophic flood index for Catalonia vs annual Solar activitty

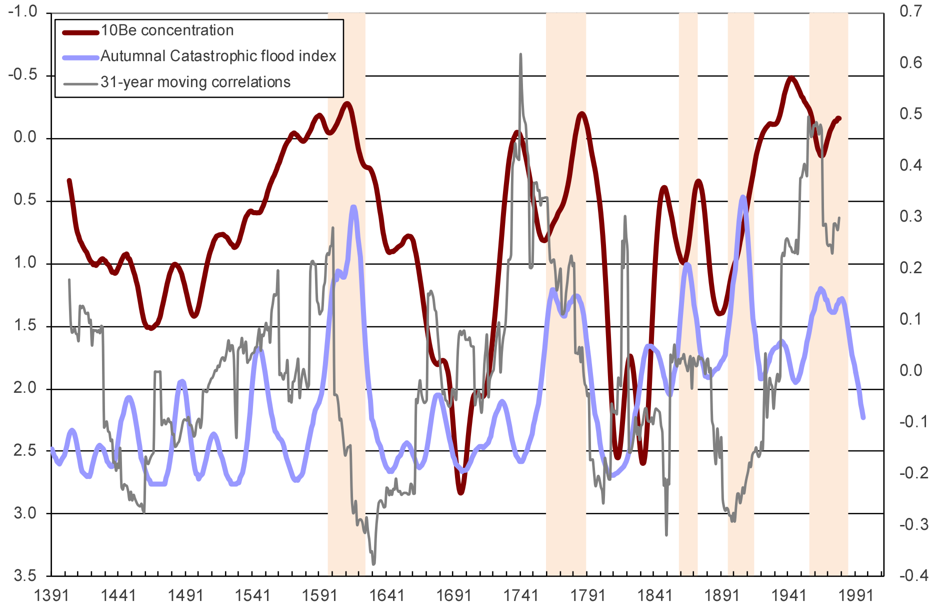


Figure 10. Temporal evolution **(1389-2012)** of solar activity taken from ^{10}Be (Berggren et al., 2009**; brown lines**) versus annual (a) and autumnal (b) catastrophic flood index series for Catalonia **(blue lines). The temporal evolution of the 31-year moving correlations between solar activity and floods are also displayed (grey lines). Solar activity and flood d**ata are smoothed by a 31-year low-pass Gaussian filter. The scale for ^{10}Be concentration is inverted because its concentration is high for periods of minimum solar activity, and low for periods of maximum solar activity. The anomalous periods of high flood frequency are highlighted in both figures.

14) *Other important forcing is the volcanic activity. There are interesting studies relating volcanic eruptions with climate, for instance Wagner and Zorita (2005),The influence of volcanic, solar and CO2 forcing on the temperatures in the Dalton Minimum(1790-1830): a model study. Climate Dynamics, 25: 205-218, or Brázdil et al. (2010) European floods during the winter 1783/1784: scenarios of an extreme event during the 'Little Ice Age'. Theor. Appl. Climatol. 100: 163-189. The role of volcanic eruptions may be important, modulating or amplifying the effects of other forcing. Have you considered the possibility of including them in your study?*

> We agree with your observation but it is far from the scope of this paper that has been extended a lot after the inclusion of all the referee's suggestions. On the other hand,the effect of volcanic eruptions on climate are only observable within 2-3 years after the great volcanic eruptions, and can affect the climate of the anomalous period itself, like the Dalton minimum, being extremely difficult to distinguish their individual role in the flood production. In this HESS special issue McDonald analyses the potential impact of volcanic activity in the floods produced in Great Britain and does not find any relationship So, in this work we do not consider to directly include them. Anyway, many thanks for your suggestion that could be interesting to develop another study or future research.

3. Technical comments

1) *Figures 1 and 2 may merge in a single figure.*

> These two figures have been merged in a single figure (new Fig. 1) in the new version of the manuscript. The figure capture has been modified to include new information (in bold letters) and the rest of figures have accordingly been renumbered:

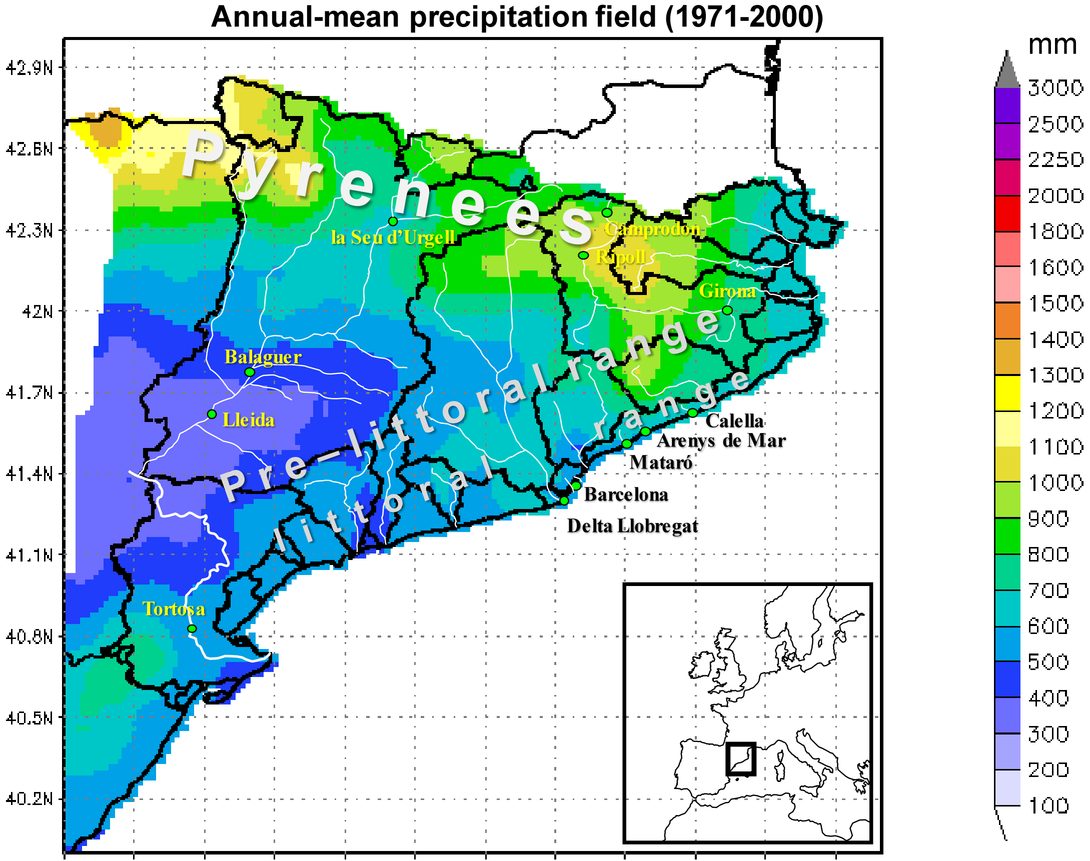
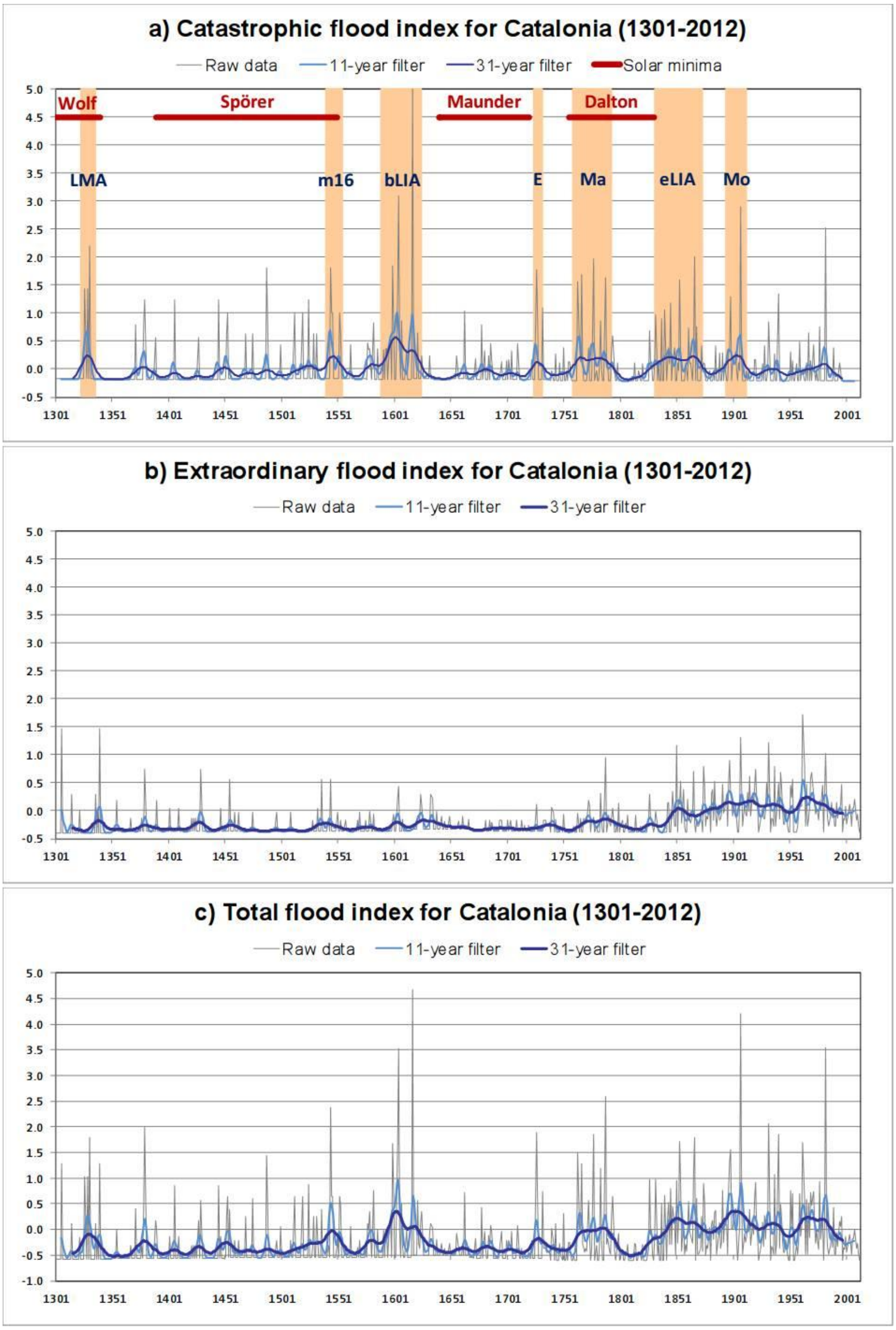


Figure 1. Annual-mean precipitation field for Catalonia (1971-2000) at 5-km resolution and computed from a high-density network of observations (Adapted from Altava-Ortiz, 2010). The three main mountain ranges of Catalonia are shown over the map. The Catalan river basins **and their related main water courses** are also displayed. **Finally, the location of the analysed flood chronologies is also shown.**

2) *Figure 4. Include not smoothed data.*

Raw data and new information have been included in the new version of the figure (new Fig. 3) and the figure caption has accordingly been modified (in bold letters) as follows:


a) Catastrophic flood index for Catalonia (1301-2012)

b) Extraordinary flood index for Catalonia (1301-2012)

c) Total flood index for Catalonia (1301-2012)

Figure 3. Temporal evolution of catastrophic (a), extraordinary (b) and total (c) flood index series for Catalonia (1301-2012). **Data smoothed by low-pass Gaussian filters of**

31 and 11 years are also displayed. Anomalous periods of high catastrophic flood frequency **and periods of solar minimum (following Usoskin et al., 2007)** are highlighted **in figure a**: **LMA (Late Middle Age Oscillation), m16 (Mid-16th century Osc.), bLIA (Beginning of LIA Osc.), E (“Enlightened” Osc.), Ma (Maldà Osc.), eLIA (End of LIA Osc.) and Mo (“Modernist” Osc.)**.