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Reply on RC1

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Author comment on "Assessing internal changes in the future structure of dry–hot compound events: the case of the Pyrenees" by Marc Lemus-Canovas and Joan Albert Lopez-Bustins, Nat. Hazards Earth Syst. Sci. Discuss., https://doi.org/10.5194/nhess-2021-5-AC1, 2021

This paper assesses changes in the duration of dry spells and temperatures during spells over the Pyrenees for a given observation period (1981-2015) and in future projections from an ensemble of regional climate models. The authors find a significant increase in temperatures during dry spells over the observation period and in projections from future climate simulations, but little change in the duration of dry spells. The paper is generally well presented but there remains many aspects that need clarification in their methods and in the presentation of their results. For instance, it is unclear in many figures what exactly has been done to produce the specified result. There is also a major issue with the use of bias correction, which is unjustified in this case, particularly with respect to bias correcting the duration of dry spells. These biases likely result from biases in the persistence of large-scale anti- cyclones which cannot be corrected simply via quantile mapping. Therefore, I unfortunately cannot recommend the paper for publication in its current state. However, I feel this research is very relevant and could be brought to publication standard. Specifically, through better discussion of the model biases, the potential sources of such biases, and the how such climate model limitations impact the confidence we can have in the future projections of such events. The reasoning behind my decision is explained in more detail below.

“We gratefully acknowledge the reviewer's comments and the revision of our manuscript. The article has been revised in accordance with the referee's comments and suggestions, which are addressed below. We have paid particular attention to improving the presentation of the results because the principal weakness of the paper detected by the referee involves a degree of uncertainty in the projected outcome as a result of bias correction methods. We believe that his comments have helped to make a significant improvement in the manuscript. Our answers appear in italics and in quotation marks”

Comments (**P: Page, L: Line Number**):

- P3 L84: The analysis by Jacob et al. (2014) does not include any validation, only an analysis of future changes in a range of metrics in these

"We agree with the reviewer; we have eliminated the term validation from this sentence. See L93-94".

- Regionalisation:
  - P4 L97-105: The authors suggest that there is no variability throughout the assessed region when long dry spells occur as there is an "identical synoptic behaviour pattern throughout the region". What is the motivation is for using this regionalisation approach for the analysis of long dry spells?

"We agree with the reviewer. This paragraph was somewhat confusing. We have added a new paragraph between L113-117 to explain our reason for dividing the Pyrenees into a few basic regions. In short, although Hot-Dry events are derived from synoptic situations arising in subtropical ridges (Fig. 5), this kind of situation exerts a greater impact upon the southern area of the Pyrenees than on the northern sector, thus producing different intensities of Hot-Dry compound events throughout the study area. It is therefore of interest to divide the Pyrenees into a number of basic regions that can differ in their behavior patterns."

- P4 L112: what is meant by iterations in this case, and how does this ensure a robust regionalisation? Please explain more precisely.

"We extended the explanation in L124-126 to make it more comprehensible"

- P4 L113-114: What variance is it explaining? Daily temperature and precipitation?

"The variance explained is approximately 48 % (See L128-134). This percentage appears to be low, but this is because we are selecting few regions in a study area presenting a high topographic complexity. In addition, using two variables (temperature and precipitation, previously scaled), provides greater variability to this area. Selecting a higher percentage of variance would involve excessive division of the study area."

- P4 L113-114: How is the total explained variance calculated? What output is given from the k-means algorithm to do this? Please be more precise.

"We added to the text a precise explanation about how to compute the explained variance (%). See L128-134."

- Event definition:
  - P6 L139-140: What is meant by annually? Do you mean that you extract only one event per year?

"In each year we selected the consecutive days comprising dry spells with a duration greater than the 95th percentile of each year. By way of an example, in the grid cell i,j based on the 95th percentile of dry spell lengths of 1981, there were 2 dry spells accounting for 15 and 20 days, respectively. This process is repeated for each year. We

have rephrased it in the manuscript. See L.159-160."

"We detected an error in Figs. 3 and 4, which were not calculated annually, but rather for the whole study period. For this reason, some dry spells lasted longer than 100 days in Fig. 3 (when summer and spring separately only score approximately 90 days)."

- P6 L140-142: Does this mean that there are multiple EM events in one dry spell? If so, do you consider all of these 'EM events' as independent events such that there would be more EM events than M or D events by definition? Please explain more

"EM events depend on the occurrence of D events. Throughout the text we emphasize that M and EM events only occur during a D occurrence. M is only the temperature of each day of a D (extreme dry spell), and EM is the p95 temperature occurring during an extreme dry spell. Extreme temperatures outside these dry spells are not considered." (See L162-163)

- Bias correction

"We are truly grateful for your extensive comments on the bias correction performance. We have now addressed all your questions at the end of this section"

- I'm not convinced that bias correction via quantile mapping is appropriate here. It is a simple method that is used to make simple corrections to climate model The method only adjusts each quantile of the RCM distribution to the corresponding quantile of the observed distribution, and so it is trivial that the bias corrected distribution will be similar to the observed distribution, as is shown in Figure 6. See Maraun et al. (2017) who consider an extreme example of quantile mapping in which the distribution of temperature from the Pacific Ocean to precipitation in central Europe. If using quantile mapping, it should be clear what is driving the bias in a given variable.
- Quantile mapping is particularly inappropriate in the case of The biases seen in duration (Figure 6) are derived from the lack of persistence of dry days in the underlying precipitation time series. This itself is driven by a lack of persistence in large-scale drivers (e.g. persistent anti-cyclones). A simple bias correction via quantile mapping of the Duration distribution cannot correct biases in the large-scale circulation and will result in fictitious events in the bias corrected distribution.
- Furthermore, quantile mapping in this case will just hide significant and relevant uncertainties in these climate model simulations. For instance, if the models cannot represent the persistence of long dry spells, then we cannot know with any confidence how such events might change in the future. This is a reality we are faced with in the community which cannot be simply fixed via quantile
- The uncertainty is hidden in the results obtained from the bias corrected distributions, and I would not be confident in the robustness of the I think it would be more informative for the authors to present the relevant biases of these models and discuss the implications of such biases for the future projections. This could help as feedback to model developers in order to improve these climate model biases.

"The authors have made structural changes in the performance of the bias correction to guarantee more correct and transparent results in terms of the uncertainty of this type of correction in climate simulations. Below we summarize the changes made in the methodological aspect (integral restructuring of section 2.4) and to the assessment of the results of the bias correction methods (section 4):"

- *"We first applied empirical quantile mapping (EQM) to the original temperature and precipitation data, rather than directly to D, M and EM. If the correction is performed* *for D, M and EM, the physical connection between the original precipitation and temperature can be omitted (i.e. the physical mechanisms are lost)."*

- *"Subsequently, we incorporated a multivariate BC method, the Multivariate Bias Correction with N-dimensional probability density function transform (MBCn), proposed by Cannon (2018). This method enabled us to maintain the structural dependence between temperature and precipitation (see Fig. 7, section 4), which is relevant when working with compound events. Throughout section 4, the performance of MBCn is compared to EQM."*

- *"To analyse the uncertainty in the estimation of dry spells in the climate models and in the subsequent correction, the D-statistic of the Kolmogorov-Smirnov test (L217-222) was used. Section 4 shows that the results are very irregular, which for the CANT region are acceptable, since the distribution simulated by the BC methods is close to the observed one; but this is not the case for the NMED region, where the distribution of the dry spells simulated and corrected by the two BC methods is clearly different according to the KS test. See Fig. 8."*

- *"Finally, the performance of the two BC methods in modelling daily temperature has also been analysed, with emphasis on the daily extreme values above p95 of Tx for each year (spring and summer), as well as on the daily extreme values of TX for each year within a dry spell. Section 4 explains that the EQM (denoted as UBC in the text (Univariate Bias Correction)) performs quite well, but when reaching the most extreme temperature values, those occurring within a dry spell, the MBCn is more accurate (Fig. 9 and Fig. S4)."*

- *"All these results suggest the need to employ MBCn when correcting future projections. This has led to some changes in section 5."*

- Figure 3: Have you taken the average of all events that exceed the local 90th percentile? Is this average sensitive to the occurrence of single events? The figure seems a little noisy in places which might not be expected for metrics of such large-scale I'd imagine looking at the 95th percentile would be more robust.

"We also detected an error in Figs. 3 and 4, which were not calculated annually, but rather for the whole study period. Consequently, some dry spells lasted over 100 days in Fig. 3 (when summer and spring separately only have 90 days approximately). We also took into account the reviewer's suggestion and we applied the 95th percentile throughout the study"

- Figure 4: The average of EM is larger than that of M by construction of the analysis, it is a trivial result. You are comparing the unconditional distribution of M with the distribution of EM which is a conditional distribution of temperature given that it exceeds the 90th EM is different from M because you impose a threshold on temperature. Maybe I have missed the point but I do not see the relevance of this figure, please explain the significance of this result. Is it simply that the average temperature of dry spells with temperatures above the 90th percentile are warmer than dry spells where no threshold is imposed?

"The authors consider that it is vital to conserve this figure in the manuscript, because it indicates that a dry spell "per se" implies slightly positive temperature anomalies, but during this drought period, maximum temperatures can reach extreme values, which can

cause large wildfires, for example. We explain this in L167-168. In addition, we added to the manuscript a new figure (Fig. 5) which attempts to account for the physical mechanisms at play in these compound events. In this figure, a flash heat anomaly is seen to occur over the Pyrenees during the EM events."

- Figure 5: What were these trends calculated for? Are all events considered or just the annual maximum? If it's the former, how is the resulting slope interpreted given that there will be a different number of events each year?

"Now Fig. 6, the figure caption is rephrased and is now more coherent."

- Figure 6: What are the biases calculated between? The mean of the distributions or some other metric? Please

"This figure was removed. Please note the new figures provided in this new version of the manuscript (Fig. 7, Fig. 8 and Fig. 9)"

- Figure 8: What is the 7-year moving average taken of? From all events in the 7-year period? Please specify.

"Now, Fig. 10. The authors considered that it is already specified clearly in the caption of this figure. We changed from a 7-year moving average to a 5-year moving average to be more consistent with most of the studies in this material"

- Figures 10, 11, 12: This is a nice of visualising the change in the bivariate However, there are a number of aspects that need clarification:
  - Is this figure for one model only? Or do you pool the events from all models into one distribution?

"We provide the results for the ensemble of all the models used. We have specified this in the caption of figure 12."

- How do you compute the linear regression shown in each panel? Specifically, what values are used to construct it?

"We have specified its construction in the caption of Fig. 12."

- From your definition of EM, you would obtain multiple values of EM per event. What do you plot against Duration in these figures? Is it one EM value per event? Or is each EM value considered such that the same event would be repeated multiple times in the scatter plot?

"The linear fit regression was computed using the annual mean anomalies of EM and D for the 2006-2100 period. Therefore, each year has a unique value of D and EM, which can serve to visualize the scatterplot"

- 22 L337-338: It is mentioned that there is no change in duration, but the NMED and SMED regions show an increase in mean Duration for RCP8.5 in Spring and Summer (Figures 10 and 11), and it seems there are more very long duration events also from counting the number of dots in the scatter plot.

"We have rewritten the text from L377 to L403. Further explanation of Figures 12, 13 and 14 is now provided."