

Dear Editor,

Thank you for the constructive evaluation. Please find our responses below.

We answer individually to all the comments (**in bold**). Our line numbers refer to the revised track-changed version of the manuscript.

Best regards,

Anna Luisa Hemshorn de Sánchez (on behalf of all authors)

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## Anonymous Reviewer 1

### General comment

This study analyses the streamflow elasticities (considered as sensitivities) to climate described as observed percentage changes in river flow per percentage change of a climate driver. The authors have used a large hydrometeorological dataset to draw data from over 8,000 catchments, and provide a pan-European quantification of elasticities of annual mean and extreme streamflow to precipitation and temperature. In a second part, they intend to analyze the dependence of the elasticities to precipitation in using a random forest model with 20 climate and catchment factors to explain regional difference in elasticity value.

The objective is to demonstrate that such empirical strategy advances understanding of hydrological resilience of stream flows to climate change highlighting amplified and dampened streamflow response to climate which can ultimately support water management and disaster risk mitigation across Europe.

I acknowledge that the authors have addressed most of my previous comments, thereby improving the clarity, readability, and precision of the manuscript, and I thank them for that. After this second round of review, however, I consider that additional discussion and clarification are still necessary before the paper can be published in the journal. I summarize my comments below in the hope that they will help the authors prepare an improved version of the manuscript.

**We thank you for the constructive review and respond to the individual comments below.**

### Main comments

(line number refer to the track-changed version of the manuscript)

#### R1.C1

The authors do not sufficiently explain several key statistical and data-analysis concepts:

- The p-value (L 185) is given without the statistic test used nor the null-hypothesis that is tested
  - **In the revised manuscript (L157-158), we added information on the kind of statistical test that is conducted and the null hypotheses it tests for.**
- The importance plot (L473) is presented without explaining how feature importance is computed in the random forest model (i.e. what exactly “importance” refers to and how it is measured).

- **In L419-423 of the revised manuscript, we have added information on what the feature importance measures highlighting what it refers to.**

## R1.C2

The authors introduce the significance of their estimates, but do not consistently account for it in the analysis. As a result, some interpretations may sound overstated:

**We understand this concern but decided to include the elasticities that are also statistically insignificant in subsequent analyses, because by definition lower elasticities are more likely to be statistically insignificant as the null hypothesis test whether the elasticity is 0. As elaborated in L234-237, the spatial consistency of low but statistical insignificant values suggests that elasticity values are actually low and reflect that precipitation is a weak driver of annual variations in those regions. Using only statistically significant elasticities would bias analyses towards more sensitive catchments.**

- Are the given elasticity mean value (L257, L426) computed only based on the significant number ? This information must be explicitly stated.
  - **We now state that the mean elasticity value is based on all elasticities, including the statistical insignificant ones (L208 and L373-374). The reason for this choice is mentioned above.**
- Is the seasonal dominance computed even when one of the seasonal sensitivities is not significant?
  - **Yes, seasonal dominance is also computed for statistical not significant elasticities. The reason to this choice is equivalent to what was mentioned above.**
- In the random forest analysis, is the model trained on all sensitivity estimates, or only on the significant ones?
  - **Also in the random forest analysis, the model is trained for all estimates for the same reasons.**
- Concerning sensitivity to temperature, fewer than 30%, and in some cases as low as 10%, of the sensitivity estimates are significant.
  - **This is correct and reflects the weak sensitivity of streamflow to temperature.**

I encourage the authors to better distinguish between significant and non-significant values in their figures, for example by using larger markers for significant estimates, and to nuance the discussion in the main text accordingly. I acknowledge that the fraction of significant estimates is reported in the figure captions, but this point deserves more explicit treatment in the main text.

**In the figures of the revised manuscript, we worked further on differentiating between significant and non-significant values by increasing the difference in marker size and converting the insignificant values to unfilled circles while the significant ones remain filled triangles. We have emphasized this in L208, L373-374, L377 and L384.**

## R1.C3

-L394: the added paragraph remains rather unclear, and I do not fully follow the logic behind expressions such as “reflected by” (L395) and “This is consistent with” (L397). Why does the weak correlation between annual precipitation maxima and (annual mean ?) flow support the statement regarding antecedent wetness and maximum streamflow? Also, the sentence “their correlations with the elasticity of maximum flows to mean precipitation (Spearman  $r = 0.14$ )” seems to refer to two quantities: i) the correlation between elasticity and mean precipitation, and ii) the correlation between elasticity and maximum precipitation. this paragraph is unclear and should be revised following the clearer (and similar) paragraph L323.

**We agree that the paragraph could be clearer, so we rephrased it in the revised manuscript (L338-347), where we also refer to the supplement.**

## Specific comments

(line number refer to the track-changed version of the manuscript)

- Abstract L17 : what does the \tilde symbol in “\tilde{\epsilon}” represent ? The mean is usually indicated by “\bar” not tilde, if it is the median value, it must be specified.
  - **In the revised abstract (L16) we have defined the “median elasticity” in the first bracket to clarify what we mean.**
- Eq.1 and L145: \hat{P}, usually, \hat{\cdot} refers to an estimate (as \hat{Q}), use \bar{\cdot} for mean.
  - **We wanted to specify that Q and P are normalized. In Eq. 1 of the revised manuscript, we changed this notation now to Q<sub>n</sub> and P<sub>n</sub> as normalized versions of Q and P.**
- Eq. 2 can be simplified in  $s = (|e_c| - |e_w|) / (|e_c| + |e_w|)$ 
  - **Indeed, it could indeed be rewritten this way, but we decided the for the other form because it is easier to understand that it compares the magnitude of one season to the sum of both.**
- Table 1: What is meant by “precipitation seasonality” in the random forest analysis? Does it refer to seasonal precipitation across the 12 calendar months (i.e. a vector of 12 values), to 3-month aggregated values, or to the variance across seasons? This information is important to understand how dependent this predictor is on the sensitivity computed with respect to mean precipitation.

- **We use the precipitation seasonality provided by EStreams which is computed using Eq. 14 in Woods (2009) (see excerpt below). This seasonality describes timing and strength (phase and amplitude) of precipitation over the year, with negative values indicating winter-dominated precipitation and positive values indicating summer-dominated precipitation. We have rephrased the description in Table 1 accordingly.**

The proportion of mean annual precipitation which falls as snow,  $f_s$ , is found by integrating the modeled precipitation  $P(t)$  (Eq. (2)) over the snow accumulation period between  $t = t_s$  and  $t = t_e$  and dividing by the total annual precipitation ( $\bar{P}\tau$ ):

$$f_s = \frac{t_e - t_s}{\tau} - \frac{\delta_p}{2\pi} [\cos(2\pi(t_e - s_p)/\tau) - \cos(2\pi(t_s - s_p)/\tau)]. \quad (12)$$

Using the results of [Appendices A and B](#) to express the difference of cosines as another cosine, and using the previously derived expressions for  $t_s$  and  $t_e$ , Eq. (12) simplifies to

$$f_s(\bar{T}^*, \delta_p^*) = \frac{1}{2} - \frac{\sin^{-1}(\bar{T}^*)}{\pi} - \frac{\delta_p^*}{\pi} \sqrt{1 - \bar{T}^{*2}}. \quad (13)$$

Note that a new dimensionless variable,  $\delta_p^*$ , which represents seasonality of precipitation in relation to seasonality of temperature, has arisen as part of the analytical solution, with

$$\delta_p^* = \delta_p \text{sgn}(\Delta_T) \cos(2\pi(s_p - s_T)/\tau). \quad (14)$$

The dimensionless variable  $\delta_p^*$  concisely summarizes relevant information on the amplitude and phase of both temperature and precipitation into a single variable. From Eq. (13), the mean annual snow fraction,  $f_s$ , depends on two dimensionless variables,  $\delta_p^*$  and  $\bar{T}^*$ :  $\delta_p^*$  quantifies the magnitude of the seasonal variation of precipitation, and its temporal distribution relative to temperature;  $\bar{T}^*$  is a dimensionless measure of mean temperature. In this context,  $\bar{T}^*$  quantifies the amount of time when the temperature is suitable for snow to fall (see [Fig. 3](#) or Eq. (11)), whereas  $\delta_p^*$  quantifies how much precipitation falls during that part of the year. [Fig. 5](#) shows

- L 434-435: it is no more a multiple linear regression if only one predicant is used.
  - **In L381 of the revised manuscript, we have removed the word “multiple”.**