Dear reviewer,

We appreciate the time and effort that you have dedicated to providing your valuable and constructive feedback on our manuscript. We have considered all comments and outline the changes we propose below. Below the reviewer comments are in black font and our responses in red.

General comments:

The manuscript investigates the uncertainty contributions from different components of the modeling chain in future flood magnitude of four Irish catchments. Using ANOVA, the study considers several sources of uncertainty: GCMs, bias-correction, hydrological model parameter, and extreme value distribution and their interactions. Although the manuscript is generally well written and figures are clear, I think it ends up being merely descriptive and is somewhat incomplete as it does not tackle the reasons why uncertainty varies across catchments.

We attempt to link hypotheses as to why the uncertainty partitioning differs between catchments in the discussion section using information, we have about each catchment to infer dominant processes on flood generation. In our revised manuscript we will further develop this discussion as is possible.

In fact, the main finding I retained after reading the paper was that hydrological model parameter is the least important source of uncertainty (I also don't think there is novelty in stating that sources of uncertainty vary across catchments as emphasized in the conclusions).

We disagree somewhat here. While it is not unsurprising that components of uncertainty differ in catchments it is surprising to us that the dominant source of uncertainty can vary to the extent we show. It is widely communicated in the literature that climate models are the dominant source of uncertainty in impact modelling chains. Each of the studies we cited in the manuscript find this, while Addor et al. (2018), who investigated uncertainty partitioning in mean flows for six Swiss catchments also highlight the dominance of climate models. The point is further illustrated by Giuntoli et al. (2018) who considered four factors (GCMs, GIM, Ivar, RCPs) in partitioning uncertainty of future flow. Their findings confirmed that GCMs are the most dominant factors over the selected study. Lawrence (2020) also compared the uncertainty originated from three factors (CMs, FF models, and hydro pars). Their results confirmed that climate models and extreme frequency models' contribution is similar and followed by the hydrological model parameter. Steinschneider et al., 2014 similarly evaluated the uncertainty from hydrological models, internal climate variability, and hydrological parameters in the observed time series in the US. They concluded that the internal climate variability and hydrologic uncertainty had similar impact on flood risk magnitude. We will reframe this finding to emphasis that the dominant sources of uncertainty change across catchments, even in a small domain like Ireland. We hold this is an important finding, especially for assessment of flood hazards, whereby the inclusion of multiple extreme value distributions is rarely considered.

As the authors noted in the manuscript, the number of catchments analyzed is small, therefore results do not allow to pinpoint aspects that can further our understanding of why uncertainty shares vary across catchments. The authors themselves write in the final phrase of the conclusions something that I think they should have tackled in their work: “Future work to better understand the link between the key components of the cascade of uncertainty and catchment characteristics is therefore recommended”.

Our research questions revolved around examining the partitioning and interaction of uncertainties in future flood magnitude. Blöschl et al., 2019, highlight uncertainty in hydrology as one of the 25 challenges in hydrology science. Our findings highlight that it may (not certain) be possible to a priori identify these features from catchment characteristics. We think it is fair for science to operate in such an incremental way. We agree that in an ideal case we would have many more catchments to more fully interrogate the links between catchment characteristics and the uncertainty cascade. However, we also argue that research is always limited by resources and time. We have used the resource and time available to us to highlight important findings that can be used to inform future work that can more fully unpack these issues and therefore contribute to the science.

<u>In my opinion, this work could improve through the following:</u>

The authors could take the advantage of having scrutinized three variables (temperature, precipitation, and runoff) in the control period, using observed data, to select model runs that behaved better, and use them to estimate future magnitudes. This would provide valuable information, because though limited to few catchments it would show the value of forming constrained chains of models and to assess how these compare to the original “big ensemble of runs” in terms of the uncertainty that is associated to return periods of future floods. For instance, once the best bias correction methods are identified (e.g. Figure 4, or L. 431 DGQM, SGQM), these could be used to form a constrained ensemble. This could affect results in uncertainty shares and, importantly, would help reducing the uncertainty.

Thanks for this recommendation. We don’t agree that selecting model chains based purely on performance for the observed period ‘reduces’ uncertainty (e.g. Smith et al. 2020; Clark et al., 2016). This has been shown for bias correction methods (see discussion in paper) and literature on weighting climate model projections (e.g. Weigel et al., 2010). Use of a single ‘best’ chain does not provide more information to catchment managers and decision managers with respect to their interaction and prediction error (Benke et al., 2008). For Example, using the 95 CI of each factor and their respective interaction, we can provide more information about the role of factors we considered than a single point estimate value using a single approach and informs a single adaptation and mitigation policy about the future flood risk. Rather, as highlighted by Clark et al.,2016, reducing uncertainty is most likely through excluding poor models/methods. We argue that this is very different to selecting the ‘best’ components of the model chain. We will discuss prospects for reducing uncertainty and sub selecting smaller subsets from large ensembles to assist decision makers. We also cannot see how we apply the selection of ‘best’ consistently to the full modelling chain, as this would involve selecting a ‘best’ climate model.

Avoid the word risk (In the title too). What is done in this paper does not deal with flood risk, but rather with changes in future flood magnitude.

Agreed, we will avoid use of risk.

A word of caution on the return periods of 100 years, based on periods of 30 years. Extrapolation of extreme value fits to a domain well outside the range of the reference period

(30-yrs) may itself add considerable uncertainty to the estimate. Extreme values are already hard to sample for their rare nature. I would limit return periods to 30yrs to avoid calculation of return values for return periods exceeding the record length. This aspect should be at least discussed.

Thank you for the comment. Yes, at least we need 2/3 data of the return period year (for example, 100 RT from 66 years record data) (Lanxin Hu, et al.,2019). In fact, in this paper, we assumed that the frequency distribution model's extrapolation error is constant for the selected distribution model types. Such assumption is prevalent in many European studies (Kay et al., 2006; Lawrence Debroh, 2020; Meresa and Romanowicz, 2017). We would like to keep our analysis of return periods but will highlight the challenges mentioned in our revised discussion.

Scenarios. Multiple SSP scenarios are employed at one stage, but they are not considered among the different shares of uncertainty (e.g., Fig 13). The authors should justify this choice.

We argue in the text that SSPs can be selected a-priori given the future world that impact assessments are considered for. For instance, studies may want to examine changes in flood magnitude for a more sustainable future, others for a more fossil fuel intensive future. Given this we examine the other uncertainties and their interactions that cannot be decided upon a piori. We will further emphasise this point in the paper and in discussion.

Use of variables: variables are used both at daily and at monthly scales. When dealing with events that have short onset and duration like floods. Possibly, I suggest using the daily time scale at all times.

Yes, we use daily timestep throughout the paper. We see how this was unclear and will clarify in our revisions.

L. 225 - From this sentence it seems like for a given catchment a single distribution is not sufficient to sample extreme events. I think this is misleading as the practice is to test several and then choose the one that fits best. In this case you employ multiple distribution types to assess the uncertainty that is brought about by this source of uncertainty.

Yes, we compare different frequency distribution models, and it is possible to choose the one that fits best using AIC. However, it does not mean that it is true across all catchments and climate models and time periods (Table S1). That's why we considered flood frequency distribution models as a very crucial source of uncertainty.

<u>Technical corrections</u>:

We will implement all technical correction listed and thank the reviewer for such detailed commentary.

L. 30 - Would avoid word "significant" (strong statistical connotation).

L. 34 - are shifting -> have shifted

Changed from 'are shifting' to 'have shifted'

L. 53-57 - I would add Shepherd et al. 2018.

L. 69-71 - It is stated that “an important step [. . .] contribution of different components of uncertainty and their interaction to be quantified and partitioned to help scientists and decision-makers better navigate the cascade of uncertainty”. The authors could hint or provide examples on how this information could be used to “better navigate the cascade of uncertainty” and why it is helpful/important.

L. 115-130 - Could this go into the introduction?

L. 230-232 - I would swap order in sentence to respect that of the equations that are listed below.

L. 239-240 - The assessment of future high flows using multiple scenarios has been done, the authors might add Giuntoli et al. 2018.

L. 266 - Why not daily?

L. 275-280 - Possible reasons behind the variety of projected changes?

L. 285 - Please add “in the range of” after “to be”.

L. 290 - Please justify the choice of 30000 as number of parameter sets.

L. 338 - Reference to Figure 12: I think showing the median does not add much, it is also hard to see it on the figure.

L. 375 - “We examined future flood risk”. I would rephrase with something like “we examined changes in future flood magnitude”. (In line with what is written at line 459).

L. 394-395 - I would attenuate the sensational tone of the sentence.

L. 397 - I counted one.

L 404 - It this stated “results suggest that rather than being the same across catchments” - I don’t think anyone has ever presumed that sources of uncertainty remain constant across catchments, and there are studies in the literature showing this already. Please reformulate.

L. 464-465 - rather than “that the dominant sources of unc. vary on a cathment basis” I suggest writing “our results show how dominant sources of unc. may vary on a catchment basis”. I don’t find the end of the sentence convincing provided that two adjacent catchments can have entirely different hydrological processes that contribute to flood generation - and in turn different shares of uncertainty sources.

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