Response to Editor

Dear Nadav,

Thank you for taking the time to review our paper and provide feedback.

In the most recent round of referee reports, two reviewers recommended that the paper be accepted subject to minor revisions, while one reviewer questioned the suitability of this paper for HESS.

To re-iterate, the aim of this study was to explore hydrological model parameter uncertainties within a national climate impact study. We selected the UKCP18 climate projections to help us meet this aim as they include a measure of climate uncertainty through the use of an RCM ensemble, they are the only projections available for GB that are high resolution (12km), and they have full spatial and temporal coherence which is needed to evaluate future climate change impacts on high flows in a spatially distributed hydrological model. While we recognize that we do not consider all uncertainty sources, this is comprehensively discussed in the paper and should not detract from the core scientific novelties of the paper which are of significant interest to the wide readership of HESS as follows:

1. The paper provides the first spatially consistent GB projections to include both climate ensembles and hydrological model parameter uncertainties.
2. It highlights the value in considering hydrological model parameter uncertainties in climate impact studies. For example, we demonstrate that hydrological model parameter uncertainties are important for climate change projections of high flows in east and south-east England.
3. There are many papers with ensembles of different GCMs/RCMs, and for good reasons this is seen as best-practice in standard impact studies. However, we show how variable results can be even when using just one single GCM/RCM structure. This indicates that the usual approach of ensembles of different GCM/RCM, but each only with one realisation, might not fully cover the simulation variability.
4. We evaluate the relationship between meteorological changes (precipitation and PET) and high flow changes across a large sample of catchments, which will have relevance beyond the UK.

We have addressed the minor revisions raised by the reviewers below and the helpful editorial suggestions made by yourself, including revisiting the previous round of comments to ensure the novelty and scientific contribution of the paper is clear. We have made significant edits to the paper as follows (please also see full list of changes at end of this document):

1. Rewritten the abstract, the aims within the introduction and the conclusions to more clearly highlight the key scientific contributions of the paper and emphasize the relevance of the findings beyond Great Britain.
2. Added an extra figure to the results section which shows the regional changes to Q10 flows separately for each RCM ensemble member and hydrological model parameter set. This strengthens the discussion of the relative impact of hydrological/RCM uncertainties. Additional figures for other flow metrics have also been added to the supplement.

3. Strengthened the discussion, including the addition of a new section on study limitations that discusses many of the issues raised in the previous round of reviews.

We provide detailed responses to the reviewer comments below. Their reviews are in blue and our responses are in black.

Best Wishes,

Rosanna Lane on behalf of all co-authors

Response to Reviewers

Anonymous Referee #1

I have read the response to the reviewers and the revised manuscript. Here my response:

My impression is that the authors have done the minimum to respond to the reviewers. There are a few things I would like to clarify.. Maybe my review was formulated too harsh or not nuanced enough, but while reading the first manuscript I had the feeling that many decisions were not explained. This does not automatically mean that I think those decisions were wrong, it just meant I could not follow where they came from. Of course, there is always room to disagree with a reviewer, but this seems more in place when discussing whether a certain method is appropriate or not. I don't think you can really disagree with a reviewer, if a reviewer indicates that certain choices seem to be not substantiated. Now for instance, it is much clearer why these climate scenarios are chosen - I think it is perfectly legit to ask for such explanations. Same for Fig.7 which shows median parameter value results: I am just a reviewer, I don't know whether you evaluated different options and concluded that there was no variation and thus that median parameter values would do. Now, with the extra supplement, I can see and understand that. But if I don't know the process, I don't know this choice. So yes, for me many choices were not substantiated and it seems a weird response to "disagree" with that - but as I wrote at the beginning, maybe I did not formulate my review well enough either. It does however feel a bit awkward because I provided my name under the review, and the last thing I want is to end up in any unpleasant discussion, because after all you are all highly appreciated colleagues.

Lieke Melsen

RESPONSE:

We thank Lieke for reading and reviewing the revised paper.

We apologize for the phrasing of our response to reviewers if it has offended - we appreciate the time you have put into reviewing our paper and providing feedback. It is of course useful to know that you could not follow where decisions came from, as if it is not clear to you then it would not be clear to other readers, and we took this feedback on board adding further justifications and reasoning into the text.

Regarding our efforts on the revised paper, we spent significant time providing additional clarification to the revised paper including substantial changes to the text and new figures as part of the responses to reviewers. We provided strong scientific justification on why we believed further modelling and/or analysis was not needed given that the primary focus of this paper is to explore the complex issues of uncertainty evaluation within national catchment responses under climate change. Significantly, this paper highlights the value in considering hydrological model parameter uncertainties and investigates how predicted responses to climatic change differ over regions and national scales that also depend on catchment characteristics and geoclimatic regimes.

No minor revisions or additional clarifications are requested as part of the review. However, we would like to re-iterate that we value your input on this paper as a highly appreciated colleague.

Anonymous Referee #3

Thank you for revising the paper. I would like to respond to one comment by the authors: "While bias in precipitation persistence has been evaluated in the climate modelling community (Armal et al. 2020; Kumar et al. 2013; Moon et al. 2019), we have not seen any papers where it has been addressed for hydrological modelling."

Please refer to many of the papers where the Nested Bias Correction approach has been used to see applications where persistence biases are corrected prior to hydrological modelling. This approach was developed solely with the intention of correcting persistence biases across time-scales (daily/monthly/annual). There is a software that presents its multivariate version, which is quite widely used (see https://www.hydrology.unsw.edu.au/multivariate-bias-correction-mbc) and even taught in graduate classes given the importance correcting persistence biases has in water resources applications. If persistence bias is an issue in the RCM simulations adopted, I am confident this approach (or other alternatives that correct for low-frequency variability bias) will help.

Thank you for taking the time to review our paper and for highlighting this particular area of research to us, which we have added to the paper to strengthen our methods. As we noted in the previous round of reviews, whilst this is a potentially interesting avenue of research in bias correction, we decided not to pursue these analyses as the matter is complex and requires a more dedicated paper on these issues and potential impacts.

We have added text to the methods to highlight this approach (see list of changes below) and note that we added text in the discussion to address this issue in the previous round of reviews.

Anonymous Referee #4

All three original reviewers suggested major revisions to the paper to undertake a substantial extra amount of work incorporating additional modelling using projections from other GCMs to make this paper of interest to the broader HESS readership. The authors have argued that this additional work is beyond the scope of the paper. I think that this is a neat paper with useful results, but primarily of interest to UK hydrologists and may be more appropriate for publishing in a journal such as the Journal of Hydrology regional studies

We thank the reviewer for their time to review our manuscript and their positive assessment of the useful results presented in the paper.

However, we disagree that this paper is primarily of interest to UK hydrologists, rather than the broader HESS readership. Many recent papers in HESS focus on climate change impacts on river flows at basin (e.g. Dembele et al, 2022; Hanus et al, 2021; Hoang et al, 2016; Rottler et al, 2021) to regional and national scales (e.g. Brunner et al, 2019; Muelchi et al, 2021). While many

of these studies have incorporated uncertainties from GCMs and RCP scenarios, none of these studies used an ensemble of different realisations of the same GCM/RCM. Also, other studies do not consider hydrological modeling and regional climate model uncertainty across a national domain. Our results indicate that the variability in hydrological simulations is large even when simulations from the same GCM/RCM are huge, which means that the usual strategy to use different GCM/RCM but each only with one realisation might not fully cover the climate model uncertainties. This paper demonstrates the value in considering hydrological model parameter uncertainties (in this case, found to be especially important for catchments in southeast England), and shows that responses to climatic change differ over regions and national scales depending on catchment characteristics and geoclimatic regimes. These findings are relevant to a wide scientific audience that are undertaking climate change impact case studies globally.

We have further clarified these key messages in the paper, as described in the list of changes below:

List of Changes

The changes made to the manuscript, and reasons for making these changes, are summarised here. For full details of all changes please see the tracked changes version of the manuscript.

Abstract: We have rewritten the abstract, with the following goals: 1) to reduce the GB-focus where possible, 2) to state the paper novelties (first spatially consistent GB projections to include climate ensembles and hydrological model parameter uncertainties) earlier in the abstract, 3) to include that we are using a perturbed-physics RCM ensemble to explore climate model parameter uncertainties instead of the more typical multiple GCM approach, 4) to end the abstract with a statement that will be of interest to a wide audience beyond GB.

Introduction: We have re-phrased some statements to make it clear that we are researching issues which are important beyond GB. For example, we re-phrased "However, there are currently no studies providing spatially coherent projections of future changes in flooding across entire Great Britain, which include both RCM and hydrological model parameter uncertainties." to "However, there is still a lack of studies providing spatially coherent projections of future changes in flooding across national domains while including both RCM and hydrological parameter uncertainties, and no studies for Great Britain."

Introduction aims: We have included a new aim: "How large is the hydrological variability resulting from different realisations of the same climate model structure?"

Methods: We have added an extra sentence and reference for persistence bias into the introduction, following additional feedback from anonymous referee #3.

Results (Figure 6): An additional figure (Figure 6) was added to the results, showing the changes in Q10 flow magnitude when using different RCM parameters vs the changes using different hydrological model parameters. This was to strengthen the response to referee #1's comment in the previous round of reviews, saying "I think there are some missed opportunities

in analyzing and presenting the effect of uncertainty…I still don't have the feeling I fully comprehend the uncertainty in the projections and their implications for the results." This new figure helps to show how the RCM parameters have a much larger impact on the changes to Q10 magnitude (helping to justify why we focused on RCM parameters in Figure 8 and 9), but also highlights that some hydrological model parameter sets result in particularly low/high projections. It also highlights that hydrological model parameter selection has the most impact in the south, supporting the message of Figure 7.

Results: Figures 2 and 3 have been swapped to keep figure numbering consistent with the order that figures are mentioned in the text. Figure numbers throughout the manuscript have been updated following this change and the addition of Figure 6.

Discussion section 4.1: The paragraph comparing our results with previous studies has been extended to include new literature, which is based on other GCMs.

Discussion section 4.3: We added a paragraph discussing our findings from the use of a perturbed-parameter RCM ensemble, highlighting how climate uncertainties were high even using a single GCM/RCM model structure. We also added extra literature to this section.

Discussion section 4.4: In response to referee comments, we split the discussion to add a new section on "Limitations and future work." This further discussed our use of a single GCM structure. In response to all reviewers suggesting we do further modelling using other projections we also discussed how UKCP18 provided the only high resolution, spatially consistent projections covering GB for a continuous period, and how there is therefore a need for the development of high resolution projections from other GCMs/RCMs to fully assess the impact of climate uncertainty on high flows.

Conclusions: we have re-phrased the conclusions, aiming to improve the flow and demonstrate the relevance beyond GB.

Supplement: Added five additional figures to the supplement (S4). These are versions of the new Figure 6 for all flow metrics.

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