Hydrology and Earth System Sciences Discussions

Hydrol. Earth Syst. Sci. Discuss., author comment AC3
https://doi.org/10.5194/hess-2021-321-AC3, 2021

Reply on RC3

Rosanna A. Lane et al.

Author comment on "A large-sample investigation into uncertain climate change impacts on high flows across Great Britain" by Rosanna A. Lane et al., Hydrol. Earth Syst. Sci. Discuss., https://doi.org/10.5194/hess-2021-321-AC3, 2021

Response to Reviewer 3. Review comments have been included in **bold**, with our responses to each comment below.

RC: This is a well written paper by a strong team of researchers.

Response: Thank you for taking the time to review our manuscript and for your suggestions.

RC: My main comment is on their Section 2.3 - The authors are limiting their investigation by using a single GCM and scenario for projecting into the future.

Response:

We defer to the same responses we provided to reviewers 1 and 2.

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 have many advantages over other products, including 1) they were the nationally recognised highest resolution RCM climate model outputs available for a continuous time period over GB, 2) they were specifically developed for the UK and previous UKCP products have formed the basis of UK climate policy (Murphy et al. 2018), 3) they include a measure of climate uncertainty through the use of an RCM ensemble, 4) as RCM projections they are high resolution (12km) and have full spatial and temporal coherence which is needed to evaluate future climate change impacts on high flows in a spatially distributed hydrological model, 5) they are the newest national climate projections for GB, including the latest developments in climate modelling capability and scientific understanding, and have not yet been comprehensively analysed in other studies.

The UKCP18 projections only included RCM simulations for a single GCM, but still explored some climate uncertainties through the use of an RCM ensemble. This approach was also used for the UKCP09 climate projections which have been used in many UK climate impact studies (e.g. Prudhomme et al. 2013, Bell et al. 2016, Kay et al. 2018). The RCM ensemble was considered sufficient for our aim of assessing the hydrological model uncertainties within a national climate impact study. Importantly, we also found that minor differences between the RCM runs resulted in a huge variation of hydrological implications, showing that the RCM parameterisations which may be expected to be less influential were crucial after all. We are aware that the use of a different GCM would produce differing results, and this limitation is recognised in our discussion (lines 445-452). In response to all reviewers commenting on the use of a single GCM, we will clarify why the UKCP18 product was chosen in section 2.3. We will also make the limitations of this clearer in the discussion, adding that other GCMs may result in different precipitation trends into the future.

UKCP18 also only included RCM projections for the RCP8.5 scenario. We considered this the most important scenario to look at for two reasons: 1) it shows the 'worst case' and so will most likely show the largest expected changes, 2) the emissions in RCP8.5 are in close agreement with historical total cumulative CO2 emissions and more and more are looking like a plausible future (Schwalm et al. 2020). But again we recognise that our results would have been different if an alternative scenario had been used, and we acknowledge that it is best to use multiple scenarios if the information is available. In response to reviewer comments, we will 1) add a sentence to section 2.3 emphasizing that the RCP8.5 was the only available scenario and gives a 'worst case' and at this time 'most likely' future projection, 2) expand on the discussion of missing uncertainty sources to include emissions scenario and the impact this might have.

RC: RCMs are essentially interpolators although with good physical realism. They work off lower and lateral boundaries that are simulated by the GCM. These lower and lateral boundaries have considerable biases unfortunately, and I often feel the use of RCMs without accounting for these biases as doing disservice to the use the simulation may have. We know that RCMs are well grounded to the topography, and hence one needs to question whether the RCM simulations with biased boundary conditions are essentially simulating the effect of the topography or the true change warming is about to unfold. There are two ways of correcting this limitation and unfortunately, both require a bit of work on the part of the authors. The first of these is to remove systematic biases in the lateral and lower boundaries that form the inputs into the RCMs. By this I am not referring to the post-processing bias correction the authors have perfomed here, but the bias in the boundary conditions before the RCM is run. This, however, requires new RCM runs which is a significant effort in terms of computing and time. The authors may want to go through the papers below that illustrate how useful this can be:

Rocheta, E., Evans, J. P. & Sharma, A. Correcting lateral boundary biases in regional climate modelling: the effect of the relaxation zone. Climate Dynamics 55, 2511-2521, doi:10.1007/s00382-020-05393-1 (2020).

Kim, Y., Evans, J. P., Sharma, A. & Rocheta, E., Geophysical Research Letters, Spatial, temporal, and multivariate bias in regional climate model simulations. 48, e2020GL092058 (2021).

The other way of addressing this limitation is to use multiple GCMs as the basis for boundary variables that feed into the RCM. While this does not address the biased boundary inputs the RCMs is subject to, it atleast produces an envelope of the uncertainty that results from the use of a single (biased) GCM. This is the approach most researchers use in climate change assessment, often coupled with a post-processing step involving bias correction. I realise the authors may be limited in their access to RCM simulations from other GCMs, but, if so, need to at least discuss the implications this may have on their overall findings.

Response: Thank you for these suggestions. We are not running the RCMs ourselves, so while this is an interesting idea it is not feasible in the context of our study. We do note in the discussion that a single GCM was used and therefore we do not sample the full range of climate uncertainty. In response to these reviewer comments we will extend the discussion on implications of using a single GCM but with an ensemble of RCM's (as stated in response to the comment above).

RC: The only other comment I have is regarding the use of the distributional bias correction adopted. Given the importance of antecedent conditions (which the authors have noted), not considering bias in persistence attributes can misrepresent the relationship between pre-storm wetness and storm extremes. This is evident even in urban catchments where one would usually not expect antecedent conditions to matter. It may be worthwhile for the authors to assess this dependence in their bias corrected precipitations and observations, incase there is a bias present. This may be especially important in those catchments where they are seeing a decrease in flood magnitudes.

Response:

We agree that bias in persistence attributes is an important and challenging issue. 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.

The choice of bias correction methodology is difficult, with a balance between correcting the data as much as necessary for meaningful hydrological simulations, but not making those methodologies too complex and thus even more difficult to justify as being plausible in future climates. We selected the distributional bias correction approach as it suitably corrects both high and low precipitation events (opposed to for example monthly mean bias correction which simply scales both light and heavy rainfall by the same percentage). This was successful in correcting the overall distribution of precipitation, including the mean daily rainfall bias and heavy rainfall biases discussed in the supplement S1. The bias correction we applied also significantly improved RCM overestimation of the number of rainy days (Figure S4), resulting in the RCMs having a similar number of wet days to the observations. It's important to recognise here that we cannot correct weather sequences that are likely to hold in future scenarios. We can only readily correct a statistical distribution approach to climate model output, indeed some colleagues do not correct at all and only look at the delta changes between current and future periods (e.g. Bell et al. 2009, Bell et al. 2012). Whilst we recognise the dangers in doing that (i.e. that you might be in a different non-linear rainfall-runoff response of catchment states by using uncorrected simulations), at least such approaches are not changing the physics within the models. Here we believe, for current best practice, we have taken the rational approach to statistical correcting that has improved wet/dry day RCM outputs and thus in part has improved such biases. We believe exploring these issues further would take a considerable amount of research to understand the nuances and impacts and how persistence bias changes are relevant for future scenario simulations, this is a very challenging piece of research. We will write more about this in our revised manuscript and discuss the issues.

In response to this comment, we will therefore note that climate models have biases in persistence attributes, and therefore may not be able to simulate persistent wet/dry periods well.

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