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Climate change impacts on the seasonality and generation processes of floods in catchments with mixed snowmelt/rainfall regimes: projections and uncertainties

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Final response to referee #2

We want to thank referee #2 for her/his helpful comments on our manuscript. Please find below our replies referring to each of his/her points. For convenience, the comments by the referee are repeated in *gray and italic*. Text designated for inclusion in a revised manuscript is given in blue:

One important point that is not stressed in the paper, but somewhat relevant for the whole study, is the fact that you assume stationary conditions for the whole reference period for which you calibrate your hydrological model. ...would be interesting to see whether changes in seasonality can already be observed in the measured data. If so, this may influence your modelling results for future time periods as model parameters may not be stationary for the reference period

We agree that this point requires further discussion in a revised manuscript since it has been recognized in some form or another by all three referees. In fact, it would be interesting to calibrate the hydrological model for sub-periods which potentially show similar hydrometeorological conditions as the projected future period. This may help to identify parameter sets which are specialized for modeling the future period. However, only Kråkfoss as one of the catchments being affected with considerable seasonal change may show notable differences already in the observation data.

We calibrated the hydrological model over a long (probably non-stationary) time period since it implies that we potentially cover all relevant processes. The longer the time period for calibration, the better the chance to sample varied hydrometeorological conditions leading to potentially more robust parameter sets, which may be even suitable for conditions that have not been observed during the calibration period (Merz et al., 2009). Thus, calibrating a hydrological model under non-stationary conditions does not necessarily imply that the model parameters are non-stationary. Please see also our reply to D. Viviroli's first Specific Comment, where we give suggestions on how to discuss that topic in a revised manuscript.

FURTHER COMMENTS

Page 6280, lines 16-17: *Why did you choose the 2071-2099 as future period? Did you also have a look at changes in nearer future?*

We only focused on the far future period (2071-2099) in this study since the change signal in the climate projections is more pronounced as compared to a near future period (e.g. 2021-2050). Moreover, climate change adaptation strategies in Norway are usually focusing on adapting measures for climate change impacts towards the end of the century. It is nonetheless worth mentioning, that focusing on a near future period would probably imply more 'roboustness' regarding the emission scenarios and would thus, lead to more 'reliable' climate projections. We will have a comment on this in a revised manuscript.

Page 6284, line11-12: *How did you determine the "normal flood duration" for the catchments?*

We agree that this is not pointed out clearly enough, so we suggest adding a paragraph to section 3.5.:

The normal flood duration has been derived for the six catchments considered by a simple experiment using the HBV model: each catchment was artificially drained to baseflow conditions before twice the amount of annual rainfall was added to completely saturate the catchment again. Concentration and recession time to baseflow was estimated from the resulting hydrographs; concentration and recession time together give the normal flood duration.

Page 6286, lines 15-24 and Figure 2: *In the Figure you specify that for certain simulations you only apply one best-fit HBV parameter set? Why? And why is this not discussed in the related text?*

We only use one best-fit HBV parameter set for the simulations based on the raw and the locally adjusted RCM data (iii-v). Thus, the range in the distribution of the POT events emerges only from the range in the different input data. That way, we were able to study the effects of the LAMs compared to the using raw RCM data. For a better understanding, we suggest adding a sentence to p.6287, line 17:

The simulations iii-v are based on only one best-fit HBV parameter set assuring that the ranges in the distribution of the events are solely based on the range of the input data.

Page 6287, line 5: *Can you specify any reason for the lower performance? Are certain processes not represented well with the model?*

The comparatively lower performance of the HBV model for Junkerdalselv results mainly from the underestimation of some prominent flood peaks. We are, however, curious about the reasons why the automatic calibration does not lead to better parameter sets with higher NSE_w values. Junkerdalselv is a snowmelt-dominated catchments with a low percentage of lakes, marsh, and bogs. Also upstream, there are no signs for considerable disturbances, and there are no indications for some extraordinary geographical or climatological features which would lead to difficulties in the calibration of parameters. Note however, that Junkerdalselv turned out to show comparatively lower performances also in other calibration studies (e.g. Lawrence et al., 2009).

Page 6287, lines 7-14 and Page 6288, lines 8-9: *The performance of the HBV model regarding POT events for the validation period (Figure 2) shows a low performance for the catchments Fustvatn and Junkerdalselv which is mainly relevant for the assessment of changes in flood magnitudes for the future period, while regarding the representation for flood seasonalities the performance of the model for the Krakfoss catchment is rather low (Figure 3) which is important for the assessment of changes in flood seasonalities (You could stress this aspect more clearly in the paper). Can you comment on why e.g. model performance in the Krakfoss catchment is low regarding seasonality and high regarding flood magnitudes?*

In a revised manuscript, we will stress this aspect in some detail. The overestimation of spring/summer seasonality is due to an overestimation of the frequency of POT events when using the locally adjusted RCM data as input for the hydrological model. We will add a comment both to section 4.2. and 4.3.:

4.2.: … Simulated S_D values based on observed input data and the 25 best-fit parameter sets show to be very similar compared to the observed one (not shown in the Figure). Thus, the overestimation of spring/summer events emerges from climate input data.

4.3.: … The match of the observed seasonal median POT event magnitudes at Kråkfoss is comparatively better than for the observed seasonality index S_D (Fig. 3). Since the distribution of the POT event magnitudes are very similar for the spring/summer and autumn/winter season, the overestimation of S_D towards spring/summer results from an overestimation of the event frequency for this season by the climate input data.

Figure 2: *Add the info on what the NSE_w is in the Figure caption.*

This will be considered. The new figure caption should be:

The NSE_w values given for each catchment represent the goodness-of-fit of the HBV model for the entire series (not only POT events) using the best parameter set identified by the calibration. Note that the ordinate's point is not zero and differs between the single plots. Note, that we will also update the NSE_w values in Figure 2 since the NSE_w for Kråkfoss is actually higher (0.87) than given in the current version of the figure (0.77). Our apologies for that mistake.

Figure 4: *Are the changes shown here all significant or not?*

The boxes are plotted with notches, which are very narrow in most cases. They are indicating a very small range of the 95% confidence interval. Since none of the notches of the boxes compared in each group are overlapping, there is strong evidence (95% confidence) that the medians of the distribution differ (see e.g. Chambers (1983)). We will add a note to section 4.3.:

The median changes in the POT event magnitudes from the references to the future period are significant (with 95 % confidence) since none of the illustrated notches for the respective period is overlapping.

Please, see also the suggested modifications of Figure 4 following to Minor Comment #9 by referee #1.

REFERENCES

Chambers, J.: Graphical Methods for Data Analysis, Wadsworth & Brooks/Cole, Pacific Grove, CA, USA., 1983.

Lawrence, D., Haddeland, I. and Langsholt, E.: Calibration of HBV hydrological models using PEST parameter estimation, Oslo., 2009.

Merz, R., Parajka, J. and Blöschl, G.: Scale effects in conceptual hydrological modeling, Water Resour. Res., 45(9), W09405, doi:10.1029/2009WR007872, 2009.