Point-by-point response to Reviewer #2

Florian Ehmele on behalf of all co-authors

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Dear Reviewer No. 2, Thank you very much for your work and the useful and valuable comments that will help to improve the scientific quality of our manuscript. Below you will find your comments given in gray and our responses to the individual points in black. Please also consider our comments to Reviewer 1 as there is some coincidence of the comments and the corresponding answers.

The manuscript by Ehmele et al. investigates the use of a large ensemble of RCM simulations instead of very long observational times series (of precipitation and river discharge) in estimation of return periods. This is very interesting, esp. because of the possibility to use a consistent meteorological dataset in forcing a hydrological model for discharge calculations. Still, I have questions which are detailed below.

Thank you very much. We hope to implement your comments and answer your questions in a sufficient way.

The approach is successful only after bias correction of the RCM output as is shown in literature and by the authors. The bias correction of precipitation relies on a quantile method applying the Gamma distribution. Does this imply some statistical behavior of the return period derived? It follows quite nicely the observation-based return periods extrapolated assuming the Gamma distribution (in Fig. 7). Asked differently: is there an added value of LAERTES-EU in return period estimation as it must rely on bias-correction using observational data and some statistical assumption?

Thank you for this comment. If the catchment consists only of one precipitation cell, then there is strong link between the precipitation distribution and distribution of discharges. However, the rainfall-runoff model is non-linear and the response varies a lot catchment by catchment, so the transformation is not simple. For small mountain catchments where most of rain immediately transforms to discharge the link could be so strong that it may imply a Gamma distribution of discharges as well. But this is not a general relation as for the bigger catchments, the sum of precipitation over the whole catchment and also the timing play a much bigger role than one actual value of precipitation in an individual cell, so the link is much weaker. The added value of using the bias corrected forcing from the LAERTES-EU is to provide more robust estimation of extreme floods of large return periods. This is evident from Figure 7. The estimated flood return periods obtained from LAERTES-EU BC shows the closest match with the Q obs. The uncorrected LAERTES-EU forcing leads to considerable under-estimation of the return periods. E-OBS or HYRAS forcing also leads to under-estimation of the return periods because of limited data length, and hence unreliable estimation. We will add a comment on that in the text.

Why is there some precipitation bias in the Alpine area after bias correction (Fig. 2)?

Figure 2 shows the ensemble mean of LAERTES-EU data block 2 which consist of multiple decadal simulations (see Sect. 2.1 and Table 1). The gamma distribution used for the quantile mapping bias correction is calibrated using the data in total and not for every single ensemble member by itself. The main intention was to preserve the natural variability of the ensemble. Consequently, there are ensemble members for which the bias correction work well, for some a positive bias will remain and others have a negative bias. In the ensemble mean, a small absolute positive bias of roughly 0.2-0.4mm remains but the relative bias is even smaller.

The intensity-probability curve of the uncorrected RCM precipitation follows nicely the HYRAS near-observation curve and less the E-Obs curve in Fig. 3. If we assume that HYRAS is better in Germany than E-OBs, why can we not conclude that bias-correction deteriorates the probabilities?

The bias correction always depends on the quality of the used references/observations. As shown, for example, by Haas et al. (2014)[1] for wind speed, a sparse data density or data availability can worsen the results during and after bias correction. For Central Europe, or in particular Germany and the Rhine Basin, the data density is quite high, so we expect also a high quality of the bias correction. We totally agree that better results can be expected for Germany using HYRAS as reference due to the higher spatial resolution and the underlying number of stations HYRAS used for the interpolation. Nevertheless, a broader context has to be taken into account as the main aim is to bias-correct LAERTES-EU for a much larger domain that goes beyond the Rhine basin where we would need to reply on E-OBS only. The Rhine Basin in this study served as a pilot area. The overall domain of LAERTES-EU is the EURO-CORDEX domain and the overall aim is a bias correction on that large region. Therefore, a reference covering the entire EURO-CORDEX domain and for a sufficiently long time period was needed which is E-OBS. We will include some remarks on this in the revised manuscript.

[1]Haas, R., Pinto, J. G., and Born, K. (2014), Can dynamically downscaled windstorm footprints be improved by observations through a probabilistic approach?, J. Geophys. Res. Atmos., 119, 713– 725, doi:10.1002/2013JD020882.

LAERTES-EU downscales different MPI-ESM GCM versions and ensembles. Still, how important is the imprint of MPI-ESM on the representation on extremes? Can we expect substantially different return periods fi using a different GCM?

The differences between the blocks of simulations are in fact quite small (cf. Ehmele et al., 2020 Fig. 2 and Table 2). For LAERTES-EU the setup of the RCM (COSMO-CLM) remains the same in all simulations. The forcing GCM is MPI-ESM in different resolutions (high = HR; low = LR) and with different emission protocols (CMIP5 and CMIP6). However, both are applied mainly over the historical period with observed greenhouse gas forcing. The most important aspect w.r.t. the choice of the forcing GCM is a good representation of the relevant weather pattern in the region of interest. Several studies show such a good representation for the European sector as well for MPI-ESM-LR and MPI-ESM-HR (e.g. Cannon et al., 2020)[2]. We would expect comparable results from using a GCM with a similar quality. And major discrepancies only for GCMs with an unrealistic representation of the regional climate.

[2]Cannon 2020: Reductions in daily continental-scale atmospheric circulation biases between generations of global climate models: CMIP5 to CMIP6 Environ. Res. Lett. 15 064006, https://doi.org/10.1088/1748-9326/ab7e4f

Line 8: What means "fixed" here?

"Fixed" in this context means, that we used the quantile mapping technique with a parameterized probability density function, here a two-parameter gamma distribution. The alternative way would be an empirical distribution which would strongly follow the observed/modeled values with a significant impact not only on the shape of the distribution but also for the range of values. We explicitly decided to use a parameterized function to preserved to a certain extend the heavy tail of the precipitation distribution

which represent the unknown or not yet observed events which would have been corrected using an empirical approach. We will rewrite this sentence for clarification.

Tab. 1: block 3: EMS -> ESM, block 4 is given two times, and why not using the new CMIP6 ensemble?

We will fix the typo in Table 1. In alignment with Ehmele et al. (2020), block 4 is divided into two sub-parts. Both parts consist of decadal simulations and the driving model for both parts is the MPI-ESM-HR. For the first part, the CMIP5 based simulations are used and for the second part the newer CMIP6. As the driving model (MPI-ESM-HR) and the methodology (decadal simulations) are the same, these two parts concatenated to one block of LAERTES-EU. All the simulations within LAERTES-EU have been performed within the BMBF (German ministry of education and research) project MiKlip (medium-range climate predictions) which ended in 2019, where CMIP6 had limited availability. As requested by Reviewer #1, we will add some more information on LAERTES-EU from the original Ehmele et al. (2020) study in the revised manuscript which hopefully make it clearer.