

Interactive Discussion: Author Response to Referee #1

Southern Germany's 100-year flash flood discharge expected to increase by 30 % under an RCP8.5 climate

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RC: Reviewer Comment, AR: Author Response, ☐ Manuscript text

Dear Alison Kay,

thank you for taking the time and effort to review this manuscript. Surely, incorporating your suggestions will improve the readability and overall quality of the manuscript.

Please find our responses to your comments below. These should be considered as preliminary (part of the interactive discussion) since the actual implementation of changes depends on the editorial decision.

Thanks again for your efforts!

Kind regards,
Paul Voit on behalf of the authors

1. Comments and responses to the Referee 1

RC: *My main issue is that I don't really like the term 'flash-flood' as I feel it is ill-defined in the literature generally. Can you be precise about what you mean by this term, and are you sure that all the events you are analysing fit that definition?*

AR: The definition of "flash-flood" is indeed vague. Most often it is referred to as a flood with a rapid onset and a peak within 6 hours after the rainfall event (or the centroid of the rainfall event). Mainly, these floods can be expected in small catchments with a steep topography. In our case we refer to "flash-floods" because we specifically looked at small headwater catchments in southern-Germany, where we usually have a steep topography. In most studies these small headwater catchments are underrepresented due to the lack of measurements and the often coarse resolution of data. However, we did not confirm the 6-hour onset definition. To relax the terminology, we suggest to refer to "small-scale" floods instead of "flash-floods".

RC: *It is stated in Section 2.2, and shown in Fig 1, that one of the CPMs does not include the whole drainage area. How does this affect modelling of downstream catchments - surely it means some water-input to these catchments is missing? This should be discussed.*

AR: Thank you for this comment. After going through our analysis again, we noticed that the downstream basins

that were affected by this missing data upstream were indeed still included in the analysis. This is a mistake. These 60 downstream basins will be removed from the analysis in the revised version. Fortunately the results for GUF-ECE are not driven by this data gap as the new median ratios are still within the confidence intervals. The exclusion of the 60 affected basins changes the mean flood peak ratio from 1.2062 to 1.2000 and the median peak ratio from 1.2229 to 1.2148.

We agree that the term "headwater catchment" is not helpful in this context. We propose to drop it and just speak of small-scale basins instead as we basically look at basins with a catchment area of less than 750 km².

RC: *In Section 3.2 it says that the modelling is limited to March-October, because you focus on convective rainfall and have no snow routine. But how are antecedent conditions then properly accounted for, if you don't run the model continuously? By antecedent conditions I mainly mean soil moisture, but also is there no snowpack still to melt at the start of March in some places in this region? Can 'flash floods' sometimes be caused by rapid snowmelt and/or rain-on-snow, and how might this change in future?*

AR: The model was run continuously from beginning of March to end of October. The curve number considers the rainfall of the previous five days. This means that for the first five days of our simulation period for each year, the soil moisture might not be fully considered. The case of rain-on-snow or snow melt is not considered in our study but with warming temperatures it could be expected that snow fall is further decreasing in the future. We suggest to discuss this point more explicitly in the limitations.

RC: *Section 2 says that the flash-flood model has been 'proven and tested' previously. A brief outline of what this actually means would be helpful. E.g. presumably this has used observed driving data and compared against observed flows, but where, over what range of catchments/events, how were you judging performance?*

AR: The model was validated on the Ahr-catchment in Western-Germany for the flood in 2021 where it was able to replicate the re-constructed flood peak. The model's uncertainties were discussed in our previous publications. We measure the performance of the model only by the timing and magnitude of the flood peak (see line 132 of the pre-print) because of the model's lightweight design. Generally, it should be noted that, if the model should have any systematic error (bias) in a specific catchment, then this bias should affect the peak discharge of all events simulated for that catchment and hence reflect in all the different GEV distributions fitted for that specific catchment. That way, our comparisons of different GEV distributions should not suffer too much from any such systematic error. Generally, very similar model setups have been used in many flash flood related studies (Gaume et al., 2004; Borga et al., 2007; Grimaldi et al., 2010, e.g.).

We suggest to add this info to line 135:

Our model setup for Germany was able to reproduce the devastating flood discharge in the Ahr-tal in 2021 and was described and applied in several previous studies (Voit and Heistermann, 2024a,b; Voit et al., 2026) in which we also comprehensively discussed resulting uncertainties.

RC: *In Section 3.3, it's rather confusing to describe extracting annual maxima if you are only modelling Mar-Oct...*

AR: Thank you for this comment, we suggest to change this to:

For each basin and each 30-year period of each CPM ensemble member, we extracted the maximum flood peaks between March and October and fitted a generalized extreme value distribution (GEV) to these data.

RC: *Also in Section 3.3, you say that basins where the shape parameter is outside a certain range are excluded, but the number excluded varies by CPM. This means that an inconsistent number of catchments is used for various later plots. Is there a sub-set of catchments that are well-behaved for all CPMs, which could be used subsequently?*

AR: The exclusion due to the shape parameter shows how uncertain GEV fits to a short time series can be. Unfortunately, the common, well-behaved subset would have been too small which is why we decided to explicitly mentioning the number of accepted catchments for each ensemble member instead.

RC: *Section 4.2: I like the pooling of annual maxima from all ensemble members – since you are looking at 100-year return period events this larger sample will be helpful (although the question is whether this could skew results in a certain direction based on members of the ensemble, since it’s an ensemble of opportunity rather designed for this purpose). Can you make it clear that ‘fitting to pooled AM’ is what you mean for the bottom plot in Fig. 2 (i.e. it’s not just taking all the points from the above 6 plots and plotting boxplots for the larger set)?*

AR: Thank you. We suggest to refer to section 3.3 and to change the figure caption accordingly:

Ratios between RCP8.5 and historical 100-year return levels of 1h (grey), 6h (blue) rainfall, 100-year return level flood peak (orange) and maximum flood peak (red) for every pixel (1h and 6h rainfall) or catchment (flood peak) within the Danube catchment and every member of the CPM ensemble and the return levels from the GEV fitted to the pooled dataset (see section 3.3). Median is shown in black.

RC: *Adding a horizontal line at 1 for the plots in Fig 2 would help, since this represents the boundary between increases or decreases.*

AR: We agree. We will add a horizontal line (see new figure at the end of the response letter):

RC: *You could also note that the pooled data might be better used with the empirical distribution rather than fitted EVD, although this might be more the case with initial-condition climate ensembles than the multi-model ensemble you have here (e.g. <https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2019GL081967>).*

AR: Yes, we will add this idea to the Limitations:

We also addressed the limited length of the analysis periods by excluding implausible GEV fits (see Supplement 3) and by pooling the annual maxima series of all ensemble members which led to a remarkable increase in the robustness of the GEV parameter estimates per subbasin. For this longer series of pooled data an empirical distribution could be used rather than assuming and fitting a GEV distribution.

RC: *Line 182: what do you mean by ‘significantly though not substantially’?!*

AR: We are referring to the confidence intervals which are not overlapping. However, we don’t see a substantial difference.

RC: *Line 189: ‘ensure’ or ‘guarantee’.*

AR: Thank you, we will use "guarantee".

RC: *Line 194: I’m confused by the ‘results not shown’ comment. The reduced spread of ratios is in the bottom plot in Fig 2, compared to plots above? Or do you mean that you have checked the robustness of GEV fits. If the latter, could you add this info in the Supp Mat?*

AR: Sorry, this stems from an older version of the manuscript. We suggest to delete "results not shown".

References

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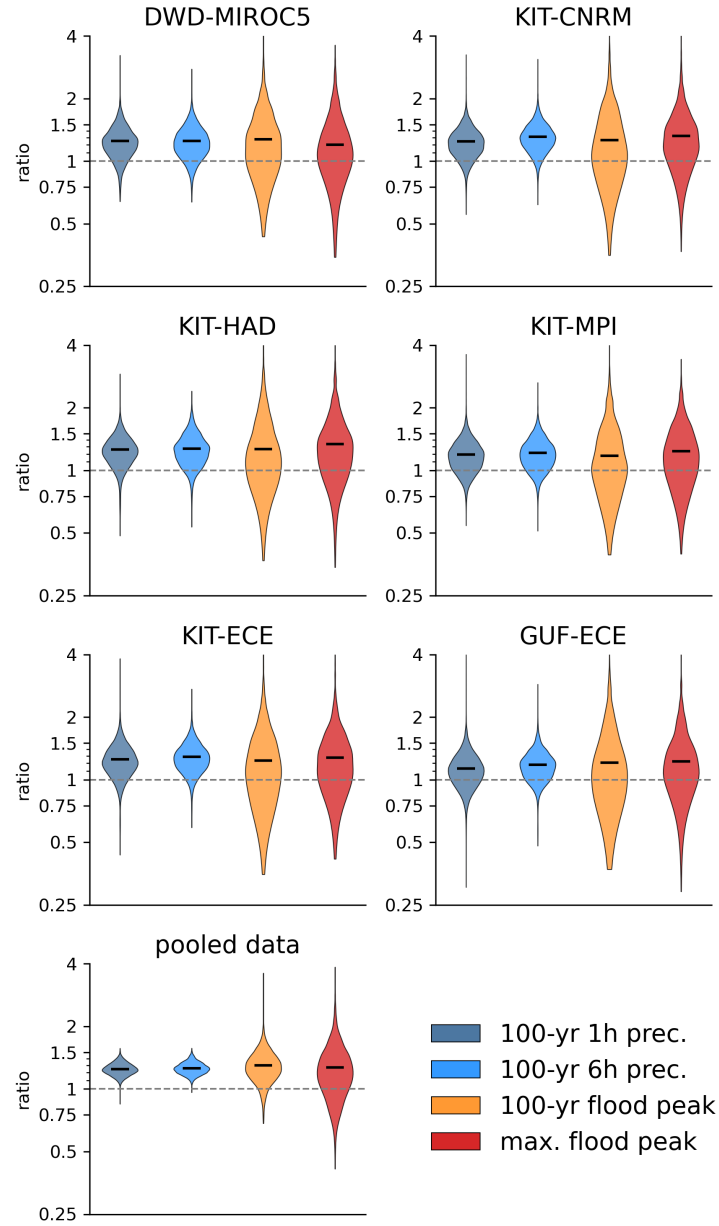


Figure 1: Ratios between RCP8.5 and historical 100-year return levels of 1h (grey), 6h (blue) rainfall, 100-year return level flood peak (orange) and maximum flood peak (red) for every pixel (1h and 6h rainfall) or catchment (flood peak) within the Danube catchment and every member of the CPM ensemble and the return levels from the GEV fitted to the pooled dataset (see section 3.3). Median is shown in black.