

Author response to Anonymous Referee #3 (RC3)

Manuscript egusphere-2026-4111: "Cross-scale characteristics of extreme precipitation events under climate change" by Jingkun Yang, Benjamin Poschlod and Felix Ament

We thank Referee #3 for the positive assessment and the constructive comments. Referee comments are shown in grey boxes, followed by our response and the planned revision.

Main planned revisions

- **Model evaluation:** new subsection summarising the evaluation of the COSMO-CLM simulations for extreme precipitation (Rybka et al., 2023).
- **Event selection:** xWEI computed for an enlarged pool of candidate events, so that the top-200 events are selected by xWEI.
- **Robustness:** maps of the event locations, analysis of three sub-regions, seasonal breakdown, alternative area weighting.
- **Driving data and scenario:** comparison of the MIROC5- and ERA5-driven simulations for their common period 1979–2000; addition of global warming levels; results framed as conditional on model chain and scenario.
- **Uncertainty:** dGEV parameter distributions, return period cap, leave-one-year-out test, fixed shape parameter, bootstrap confidence intervals.
- **Interpretation:** clearer definition of the "second-order" effect, extended limitations, corrections.
- **Correction:** During the revision process we identified a sign-convention mismatch in the GEV shape parameter between the R package used for fitting and the Python routine used for return-period calculation. We will correct this in the revised manuscript and recompute the according return periods, WEI and xWEI values.

This reply describes the planned revision; line numbers refer to the preprint.

General comments

Referee comment RC3.0

The manuscript provides an analysis of the characteristics of extreme precipitation in the past, present and future climate. In the study well established methods for detection and categorisation of the extremity of rainfall events are applied to COSMO-CLM simulations under the RCP8.5 scenario spanning four different 30-year periods in the past, the present, the near and the far future. For each period the 200 most extreme events according the cross-scale Weather Extremity Index (xWEI) are investigated in terms of changes in durations and spatial extent. A shift to towards larger and more persistent events is found in the present, the near and far future compared to the past.

The study fits in the scope of NHESS. It is well-written, the goal and methods are clearly explained and the results are easy to follow and well-illustrated. However, the choice of the dataset used is questionable and should be reconsidered before publishing the manuscript. Please, find my comments and suggestions below:

Thank you. As no alternative multi-decadal convection-permitting projections exist for Germany, we will document the influence of the driving model as far as possible, including a direct comparison with the ERA5-driven simulation, report global warming levels, and frame the conclusions as conditional on the model chain and scenario.

Specific comments

Referee comment RC3.1

The authors chose COSMO-CLM simulations forced by boundary conditions from MIROC5 for three of the four datasets investigated. As the authors state themselves, MIROC5 is among the driest models in the CMIP5 ensemble. Therefore, it might not be the best choice for studying changes in extreme precipitation. Expanding the dataset to include further simulations forced by other boundary conditions would significantly strengthen the conclusions drawn in this study.

We agree that additional driving GCMs would be the best way to assess this uncertainty, but no other suitable multi-decadal CPM projections are available for Germany (see also our responses to Referees #1 and #2). Rybka et al. (2023) find that simulated extremes over Germany depend more on the regional model than on the driving GCM, and the projected changes in return levels lie within the CMIP5 EURO-CORDEX range. Summer events dominate the top-200 in the MIROC5-driven historical period as much as in the ERA5-driven period (160 and 146 of 200). We will report the global warming levels (about 1.9 °C and 3.6 °C for 2031–2060 and 2071–2100) and state that the results are conditional on the model chain and scenario.

Planned changes in the revised manuscript

- Data section: role of the regional model versus the GCM; global warming levels. Limitations: single driving GCM.

Referee comment RC3.2

Four time periods are investigated: 1971-2000 (past), 1990-2019 (present), 2031-2020 (near future) and 2071-2100 (far future). Three of the four periods are based on COSMO-CLM forced by boundary conditions from MIROC5, but the simulations representing the present are based on COSMO-CLM driven with ERA5. Therefore, only three of the periods are directly comparable. Especially in the comparison with adapted dGEV it is not clear to me, how much of the change, e.g., between the past and the present is related to an actual shift in the characteristics of extreme precipitation events and how much is related to the differences in the model simulations. A direct comparison of the past (1971-2000) between COSMO-CLM / MIROC5 and COSMO-CLM ERA5 would be beneficial for this study to examine the differences between the simulations.

We fully agree that the contrast between the historical and the present-day period mixes climate change and driving data. The ERA5-driven simulation covers 1971–2019 (ERA-40 boundary conditions before 1979; Rybka et al., 2023), which allows the suggested comparison for 1979–2000. We will fit the dGEV to the ERA5-driven simulation for 1979–2000, detect the events, compute the xWEI and compare both simulations (dGEV parameters, event statistics, top-200 xWEI and composition), also applying each simulation's dGEV to the other's events. A check for 1979–2000 excludes the ERA-40 years. This separates the effect of the driving data from that of the climate state. Note that the step in the adapted-dGEV results (Figure 6) also occurs within the MIROC5-driven chain, so it cannot be explained by the driving data alone.

Planned changes in the revised manuscript

- Comparison of the MIROC5- and ERA5-driven simulations for 1971–2000 (and 1979–2000); ERA5-driven period shown separately in all figures.

Referee comment RC3.3

The study deals only with the 200 most extreme events. Could the authors also comment on the expected structural changes in precipitation events in general and set that into perspective with the extreme events?

In the manuscript, we focus on the top-200 to characterise the high-impact tail. All events exceeding the W3 thresholds (several thousand events per period) are available from our event detection method. We will add their statistics in the Supplement (number per year, duration, area, season, intensity) for all events and for subsets of increasing extremeness, which shows whether the changes in the top-200 reflect the whole population of heavy precipitation events. As the thresholds are fixed, more events are expected in a warmer climate, which itself indicates more frequent exceedances of the DWD warning level.

Planned changes in the revised manuscript

- Results: statistics of all detected events and subsets of increasing extremeness.

Technical comments

Referee comment RC3.T1

P.3, L74: There are two references for Haller et al. (2022). Which one is meant here?

We will cite both data sets (Haller et al., 2022a, b).

Referee comment RC3.T2

P.4, L.124-125: Here it is written that the minimum size of an event must be 9 km² for durations of 3 hours or less and 3 km² times the duration for longer events. The model has a resolution of 3 km, therefore a grid cell has 9 km². Does that mean that an event with a duration of 4 hours must cover at least one grid cell or two?

On the 3 km grid, the criterion of Lengfeld et al. (2021) translates into a minimum number of grid cells: one for durations up to 3 h, two for 4 h and 6 h, four for 12 h, eight for 24 h, 16 for 48 h and 24 for 72 h. A 4-h object thus needs at least two grid cells. We will add this to the Methods.

Referee comment RC3.T3

P.11, L.260-261: Are the authors really refer to Figure 5e and f here? In the previous sentence they compare the historical to the present climate which would be Figure 5a and d.

Correct; we will refer to Figure 5a and 5d.

Referee comment RC3.T4

Fig. 4 and 6: The blue and the black dot are hard to distinguish in the legend. I would suggest using more distinct colours or also different symbols.

We will use distinct colours and symbols.

Referee comment RC3.T5

Fig. 4 and 6: For both, fixed and adapted dGEV, it seems like the most extreme events are quite similar or

even weaker in the future compared to the past. Is there any explanation for this behaviour?

Possible reasons are the large sampling variability of the highest ranks (cf. Lengfeld et al., 2023), the saturation of the xWEI at the return period cap of 1000 years and the fixed window, and, for the adapted dGEV, the inclusion of the more intense future extremes in the fits. We will examine the ten most extreme events of each period individually and add the explanation to the Results.

Referee comment RC3.T6

P.16, L.400-405: The references for Lenderick et al. 2021 und 2017 are not arranged in the alphabetic order.

We will correct the order.

Referee comment RC3.T7

P.17, L432-434: Lengfeld et al. (2023) is not cited in the manuscript.

Lengfeld et al. (2023) will be cited in the Methods and Discussion (sensitivity of WEI and xWEI to the extreme value fits).

References cited in this response

- Haller, M., Brienens, S., Brauch, J., and Früh, B.: Historical simulation with COSMO-CLM5-0-16 version V2022.01, DWD Climate Prediction System data set, https://doi.org/10.5676/DWD/CPS_HIST_V2022.01, 2022a.
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- Lengfeld, K., Walawender, E., Winterrath, T., and Becker, A.: CatRaRE: A Catalogue of radar-based heavy rainfall events in Germany derived from 20 years of data, *Meteorol. Z.*, 30, 469–487, <https://doi.org/10.1127/metz/2021/1088>, 2021.
- Lengfeld, K., Voit, P., Kaspar, F., and Heistermann, M.: Brief communication: On the extremeness of the July 2021 precipitation event in western Germany, *Nat. Hazards Earth Syst. Sci.*, 23, 1227–1232, <https://doi.org/10.5194/nhess-23-1227-2023>, 2023.
- Rybka, H., Haller, M., Brienens, S., Brauch, J., Früh, B., Junghänel, T., Lengfeld, K., Walter, A., and Winterrath, T.: Convection-permitting climate simulations with COSMO-CLM for Germany: Analysis of present and future daily and sub-daily extreme precipitation, *Meteorol. Z.*, 32, 91–111, <https://doi.org/10.1127/metz/2022/1147>, 2023.