

REPLY TO THE COMMENTS OF THE REFEREE #2

Dear Editor and Reviewer,

First of all, we would like to thank you for the time you have spent reviewing our manuscript. We strongly appreciate the constructive comments and valuable feedback made. We have carefully addressed the reviewer's comments and suggestions. Below are our point-by-point responses to the comments in blue.

Thank you very much again for your review.

Author and Co-Authors

The study addresses the added value of convection-permitting modeling in extreme precipitation from regional to local scale, and the ability of convection-permitting model (HCLIM3) in reproducing orographic effects on precipitation in a topographically diverse country like Norway, by comparing it with those where convection is parameterized (HCLIM12). The evaluation considers both gridded datasets and in-situ observation (10 hourly rain-gauges and 192 daily rain-gauges), and provides a robust evaluation of the performance that HCLIM3 offers in the context of extreme precipitation modelling. A key contribution of the paper is its examination of the magnitude, frequency, seasonality and orographic effect of hourly and daily

extremes between HCLIM3 and HCLIM12 at both regional and local scales.

The results show that HCLIM3 provides added value over the HCLIM12 model in most regions of Norway, particularly at the hourly scale. They highlight the critical role of the convection-permitting regional climate model (HCLIM3) in capturing the characteristics of extreme precipitation compared to HCLIM12. This work holds great value for the application of regional climate models to simulate and predict the severe meteorological hazards, particularly in the context of localised extreme weather conditions. It provides critical benchmarks the performance of convection-permitting model in local extremes simulation.

Overall, this paper offers significant value and is suitable for publication in HESS. The topic is of interest and fits the journal scope, but I have several suggestions and comments before publication in HESS:

Major comments

1. Ten hourly rain gauges is a bit uncertain, so I suggest that you use it as additional remarks in the daily rain gauges section. You can delete it or remove some results related to hourly rain gauges to the Supplement, and indicate the uncertainty in the discussion.

[Reply: Thank you for your valuable comment. We acknowledge that relying on only ten hourly rain gauges introduces uncertainty. However, we emphasize the importance of using both gridded and station data for analyzing hourly](#)

extremes, as they provide complementary perspectives. The 9-year hourly gridded dataset corroborates the conclusions derived from the ten hourly rain gauges, showing that HCLIM12 underestimates the annual maximum 1-hour precipitation amount over Norway. Similarly, the ten hourly rain gauges consistently highlight this underestimation. Both the gridded dataset and rain gauge observations also underscore the added value of HCLIM3 compared to HCLIM12 for hourly extreme precipitation.

While we recognize the limitations of assessing HCLIM3's performance with this limited set of hourly rain gauges, we believe the data still offer valuable insights into the added value of convection-permitting regional climate models (CPRCMs). In response to your suggestion, we will revise the discussion and conclusions to explicitly address these uncertainties and clarify their implications. Additionally, we will move the results related to the 10 hourly rain gauges to the Supplement and include them as supplementary remarks in the rain gauge section, ensuring the main text remains focused and concise.

2. Conclusions should be drawn with caution, especially for hourly scale. Given that the length of the hourly gridded dataset is only nine years and that there are only ten hourly rain-gauges, it is therefore essential to exercise particular caution and awareness when considering the conclusions drawn from hourly in-situ observation.

Reply: Thanks for your valuable comment. We agree that the quality and availability of hourly observations are limited compared to daily data. While the 9-year gridded dataset is relatively short for robust statistical analysis, it provides comprehensive regional coverage, and we complemented it with in-situ observations spanning 20 years from ten stations. Despite these limitations, both datasets consistently show that HCLIM12 underestimates the hourly extreme precipitation, while HCLIM3 demonstrates clear improvements.

We acknowledge the uncertainties in hourly-scale analysis due to data constraints and will revise the discussion and conclusions to explicitly address these limitations and emphasize caution in interpreting the results.

3. The text uses a lot of acronyms for HCLIMs, but you don't define it.

Please define this acronym at the first instance of its use.

Reply: Thanks for your valuable comment. We have added the definition of it in the revised manuscript: "HCLIMs indicates both HCLIM3 and HCLIM12."

4. Although this manuscript is well written, it should be edited further to ensure clarity for the reader. This should include attention to sentence structure, as well as minor spelling and grammatical errors.

Reply: Thanks for your valuable comment. We will revise the English language throughout the manuscript to enhance readability.

Minor comments

1. Figure 2, 6, 7: What do the dashed lines represent?

Reply: Thanks for your comment. The dashed lines represent the mean bias.

We have added the explanation of the dashed lines in the revised manuscript.

2. Figure 10, 11, 12, 15: Replace the "Station ID" with "Name". Revise the corresponding text.

Reply: Thanks for your comment. We have updated the plots and corrected the text in the revised manuscript.

3. Figure 13-15: the unit is missing.

Reply: Thanks for your comment. We have added the unit of the plots in the Figures.

4. Figure 16, 17, 18: The title of the figure is unclear, please revise it.

Reply: Thanks for your comment. We have rewritten the titles of these figures in the revised manuscript. Please see below:

"Figure 16: Relationship between elevation and Rx1d (maximum 1-day precipitation) for (a) winter, (b) spring, (c) summer, and (d) autumn, as derived from SeNorge and HCLIMs (i.e., HCLIM3 and HCLIM12) across mainland Norwegian during the period of 1999-2018."

"Figure 17: Relationship between elevation and Rx1d (maximum 1-day precipitation) for (a) winter, (b) spring, (c) summer, and (d) autumn, based on

daily in-situ observation and HCLIMs (i.e., HCLIM3 and HCLIM12) across mainland Norwegian during the period of 1999-2018.”

“Figure 18: Relationship between elevation and Rx1h (maximum 1-hour precipitation) for (a) winter, (b) spring, (c) summer, and (d) autumn, as derived from SeNorge2 and HCLIMs (i.e., HCLIM3 and HCLIM12) across mainland Norwegian during the period of 2010-2018.”

5. Table 1: Unit of the “Elevation” is missing. Check and move to supplement. If it is possible, a corresponding Table for the detail information of daily rain-gauges is necessary.

Reply: Thanks for your comment. We have added the unit of the Elevation (m) and moved the table to supplement. We also added the information of daily rain-gauges in Table S2 in the supplement.

6. Line 200 and Figure 5, 9: Why statistic the frequency exceeding 10, 15 and 20 mm, how to define the threshold? Given the focus of your paper on extreme precipitation, it would be advisable to remove these results.

Reply: Thanks for your comment. Precipitation intensity of 20 mm/hour are considered rare extreme events that can trigger severe flooding. To assess these events, we calculate the frequency of precipitation exceeding 20 mm/hour, as well as smaller thresholds of 10 mm/hour and 15 mm/hour. Upon review, we found Figures 5, 9, and 12 redundant, as Figures 13, 14, and 15 already present the precipitation frequency data. Therefore, we will remove Figures 5, 9, and 12 to streamline the analysis.

7. Line 49-51: Please rewrite the sentence.

Reply: Thanks for your comment. We have rewritten the sentence as follows:

“However, most previous research in this field has relied on coarse-resolution GCMs with grid sizes exceeding 100 km, which struggle to accurately simulate extreme precipitation events and their frequency due to the limitations of their coarser resolution”.

8. Line 62: “improve the estimates of short-duration extremes”. Please correct it.

Reply: Done.

9. Line 64-65: Replace “atmospheric deep convection” with “deep atmospheric convection”.

Reply: Done.

10. Line 84: Replace “coarser-scale model” with “a coarser-scale model”.

Reply: Done.

11. Line 87: Delete “were”.

Reply: Done.

12. Line 128-135: Please use either CPRCM or CPRCMs consistently.

Reply: Thanks for your comment. We have uniformed them in the revised manuscript as below.

“Convection-permitting Climate Models (CPRCMs)”

13. Line 132-134: “The main objectives of this study are (1) enhance...; (2) assess...”. Please revise it.

Reply: Thanks for your comment. We have revised it:

“The main objectives of this study are to: (1) enhance understanding of convection-permitting climate models by comparing their effectiveness in simulating extreme precipitation with that of regional climate models from regional to local scales, highlighting the added value of CPRCMs; (2) assess HCLIM3's capability in depicting orographic effects on seasonal extreme precipitation. This research explores whether the benefits provided by CPRCMs hold consistently in different regions driven by varying physical processes for precipitation.”

14. Line 161-165: This contradicts the AR argument as ARs are always associated with extratropical cyclones.

Reply: Thanks for your comment. We will revise this part according to your comments.

15. Line 177, 178, 264: Replace “Norway mainland” with “Norwegian mainland”.

Reply: Done. We will unify the term in the whole paper: Norwegian mainland.

16. Line 193: Please elucidate the rationale behind the decision to resample to HCLIM12 (~12 km). What are the distinguishing factors between resampling to HCLIM3 (~3 km) and the aforementioned approach?

Reply: Thanks for your comment. We have clarified this point in the revised manuscript.

Resampling coarse-resolution data (e.g., HCLIM12, 12 km) to finer resolution

can introduce artificial variability or spurious details, which not present in the original data, potentially leading to misleading conclusions. Conversely, resampling finer-resolution data to a coarser resolution reduces the influence of such artifacts by averaging out the variability. This approach aligns with methodology used by Lind et al. (2020) and Médus et al. (2022), who also remapped all data to a coarser grid when comparing the performance of HCLIM3 and HCLIM12. Lind et al. (2020) observed that the differences between HCLIM3 data remapped to the coarser native grid of HCLIM3 and the HCLIM12 grid were minimal. Importantly, they found that the improved performance of HCLIM3 persisted even after spatial aggregation, indicating that the model's enhanced resolution offered benefits that were preserved when viewed on a coarser grid. Please see the contexts in the revised manuscript as follow:

17. Line 207-209: This is quite confusing. Please write it.

Reply: Thanks for your comment. We have rewritten it as: "The Generalized Extreme Value (GEV) distribution was used to estimate precipitation intensity for specified return periods (e.g., 5, 10, 20, and 50 years). This was done by fitting the GEV distribution to the cumulative distribution functions derived from the annual maximum precipitation intensities, including Rx1d and Rx1h, in the precipitation series from SeNorge, in-situ observation, HCLIM3 and HCLIM12."

18. Line 224: Replace "relations" with "relationship".

Reply: Done.

19. Line 276: The sentence is not clear. Please rewrite it.

Reply: Thanks for your comment. We have rewritten the sentence as follows: "In the southern and southwestern regions, the annual Rx1d empirical distribution from both HCLIMs models closely align with those from SeNorge, making it difficult to distinguish which model performs better."

20. Line 385-386: The sentence is not clear. Please rewrite it.

Reply: Thanks for your comment. We have rewritten it as follows: " For example, the added value of HCLIM3 is shown at the regional scale in the middle-coastal region, but this advantage diminishes when analyzed at the local scale."

21. Line 386: Replace "in the middle-coastal" with "in the middle-coastal region".

Reply: Done.

22. Line 411-413: The sentence is not clear. Please rewrite it.

Reply: Thanks for your comment. We have rewritten it to be: "Based on station statistics for the mean annual Rx1d in Norway (Fig. 8), the boxplot shows that the mean annual Rx1d from HCLIM3 lines within the range of observed values. In contrast, HCLIM12 consistently underestimates Rx1d, with all its values falling below the observed minimum."

23. Line 431: Replace "that of HCLIM12" with "that from HCLIM12".

Reply: Done.

24. Line 481: "The CPRCM excels.....". Check and rewrite it.

Reply: Thanks for your comment. We have rewritten it as follows: "The CPRCMs demonstrate better potential performance in reproducing Rx1h compared to RCMs, at both regional and station scales, with particularly improved accuracy at the localized scale."

25. Line 560-562: The sentence is not clear. Please correct it.

Reply: Thanks for your comment. We have rewritten the sentence as follow: "The comparison of HCLIM3 and HCLIM12 for seasonal Rx1d reveals that HCLIM3 provides a better representation overall although it exhibits a dry bias in the southwestern region. This dry bias may be attributed to the limitations of HCLIM3 in capturing unique precipitation mechanisms within this region."

26. Line 567-569: The sentence is not clear. Please rewrite it.

Reply: Thanks for your comment. We have rewritten it to be: "The impacts of station density on errors in gridded datasets was also highlighted by Gervais et al. (2014b), who identified low station density as a significant source of errors in such datasets."

27. Line 579: Replace "and found....." with "finding.....".

Reply: Done.

28. Line 591: Replace "may attribute to" with "may be attribute to".

Reply: Done.

29. Line 594: "attributable to". Check and rewrite it.

Reply: Thanks for your comment. We have rewritten it:

“We observe an underestimation of extremes, including return levels and their temporal evolution, in HCLIM12 at the local scale, likely due to limitations in its convection-parameterization scheme.”

30. Line 596: “especially at highly localized local scale”. Check and rewrite it.

Reply: Thanks for your comment. We have rewritten it to be: “especially at highly localized scales”.

31. Line 598: Replace “recognize” with “acknowledge”.

Reply: Done.

32. Line 599: “The performance of RCM ~10 km in representing sub-daily rainfall was limited.....”. Please correct it.

Reply: Thanks for your comment. We have corrected it in the revised manuscript to be: “The performance of RCMs with a resolution of approximately 10 km in representing sub-daily rainfall is limited, as it has been shown to be challenging to capture sub-daily extreme rainfall, particularly in the southwestern United States.”

33. Line 637: Replace the “shows ” with “show”.

Reply: Done.

34. Line 659: Delete “underestimation and”.

Reply: Done.

35. Line 692: Replace the “HCLIM3 also have” with “HCLIM3 also has”

Reply: Done.

Lind, P., Belušić, D., Christensen, O. B., Dobler, A., Kjellström, E., Landgren, O., Lindstedt, D., Matte, D., Pedersen, R. A., Toivonen, E., and Wang, F.: Benefits and added value of convection-permitting climate modeling over Fenno-Scandinavia, *Climate Dynamics*, 55, 1893-1912, 10.1007/s00382-020-05359-3, 2020.

Médus, E., Thomassen, E. D., Belušić, D., Lind, P., Berg, P., Christensen, J. H., Christensen, O. B., Dobler, A., Kjellström, E., Olsson, J., and Yang, W.: Characteristics of precipitation extremes over the Nordic region: added value of convection-permitting modeling, *Nat. Hazards Earth Syst. Sci.*, 22, 693-711, 10.5194/nhess-22-693-2022, 2022.

Thanks very much for your input, which helps us improve the quality and clarity of our manuscript!