We are grateful for the constructive comments provided by the editor and referees, which has helped improve our manuscript substantially. We have addressed all the issues raised by the editor and referees by implementing their comments into the revised manuscript. Please see our point-by-point response in the following section.

Response to Executive editor

In my role as Executive editor of GMD, I would like to bring to your attention our Editorial version 1.2:
https://www.geosci-model-dev.net/12/2215/2019/
This highlights some requirements of papers published in GMD, which is also available on the GMD website in the 'Manuscript Types' section:
http://www.geoscientific-model-development.net/submission/manuscript_types.html
In particular, please note that for your paper, the following requirements have not been met in the Discussions paper:

Thank you for pointing this out. We have implemented these great suggestions into the revised manuscript.

- The main paper must give the model name and version number (or other unique identifier) in the title.

Thank you for your guidance regarding the paper's title. We have modified the title to "Global variable-resolution simulations of extreme precipitation over Henan, China in 2021 with MPAS-Atmosphere v7.3" to reflect the model name and version number as per the journal's requirements.

- If the model development relates to a single model then the model name and the version number must be included in the title of the paper. If the main intention of an article is to make a general (i.e. model independent) statement about the usefulness of a new development, but the usefulness is shown with the help of one specific model,the model name and version number must be stated in the title. The title could have a form such as, "Title outlining amazing generic advance: a case study with Model XXX (version Y)".

Thank you. This study is focused on a single model, and in line with your advice, we have already revised the title to include the specific model name and version number shown as "Global variable-resolution simulations of extreme precipitation over Henan, China in 2021 with MPAS-Atmosphere v7.3."

- Code must be published on a persistent public archive with a unique identifier for the exact model version described in the paper or uploaded to the supplement, unless this is impossible for reasons beyond the control of authors. All papers must include a section, at the end of the paper, entitled "Code availability". Here, either instructions for obtaining the code, or the reasons why the code is not available should be clearly stated. It is preferred for the code to be uploaded as a supplement or to be made available at a data repository with an associated DOI (digital object identifier) for the exact model version described in the paper. Alternatively, for established models, there may be an existing means of accessing the code through a particular system. In this case, there must exist a means of permanently accessing the precise model version described in the paper. In some cases, authors may prefer to put models on their own website, or to act as a point of contact for obtaining the code. Given the impermanence of websites and email addresses, this is not encouraged, and authors should consider improving the availability with a more permanent arrangement. Making code available through personal websites or via email contact to the authors is not sufficient. After the paper is accepted the model archive should be updated to include a link to the GMD paper.

Thanks for your suggestions. We have uploaded the model code (MPAS-A v7.3) and all relevant data used in this study to Zenodo (https://zenodo.org/doi/10.5281/zenodo.10503571), ensuring a persistent and public archive with a unique identifier. This includes the CMA observation data, ERA5 reanalysis data, model mesh data, and GFS input fields. We have also revised "Code and Data Availability" section in our paper. Please refer to that section in the revised manuscript for details.

- Thus the title of your article should be expanded by a statement like : ".. a case study with MPAS 7.3". Additionally, the data and the exact version of the code used needs to be made available in permanent archives (e.g. zenodo).

As previously mentioned, we have incorporated all the suggested modifications, including expanding the title to include "... a case study with MPAS 7.3" and ensuring the availability of the data and exact version of the code on a permanent archive such as Zenodo.

Response to Review #1

General Comments

- This study indicates higher resolution and scale-aware parameterization greatly enhance simulation accuracy for extreme weather events, and considerations of computational efficiency and appropriate scale selection remain essential through a case study based on extreme precipitation over Henan. The manuscript is articulated with commendable clarity, and the modeling methodology exhibits a high degree of rigor. However, I remain uncertain about the potential implications of this study.

Thank you for your insightful comments. By following your suggestions, we've added more content in the Conclusion and Discussion Section about the potential implication of this study in the revised manuscript. Please see line 378-400.

- Concerns revolve around how representative the model's results are, considering the unique characteristics of the "7.20" event and possible influences of local features like terrain. It would be beneficial for the authors to compare their findings with existing research in their discussion to offer a more complete view of the impact of using scale-aware parameterization in their models.
  Upon review of the manuscript, I commend the rigorous methodological approach. However, the applicability of the results and conclusions beyond this specific incident to other geographical locales potentially affected by extreme weather events remains unclear.
  Research should go beyond reacting to one-time events and aim to create a strong framework for future studies, especially in predictive modeling. Regrettably, the manuscript falls short in addressing its findings' broader applicability, as outlined in lines 42 and 60, and the discussion from line 298 lacks depth, raising concerns about the study's relevance beyond the specific case examined.
  Therefore, I recommend the manuscript could be strengthened by demonstrating how its conclusions might be applied to similar events in other regions. Such an expansion of scope would not only clarify the transferability of the study's insights for future predictive efforts and mitigation strategies for extreme precipitation but also enhance the manuscript's utility for a wider audience. This paper is impressive, and this revision would improve the manuscript's suitability for publication.

Thanks for your important suggestions. Now in the revised manuscript we've added more discussion regarding how the MPAS variable-resolution model could be applied to other events. Please see line 378-409.

Response to Review #2

Major Comments

- Given that this paper centers around the recreation of one weather event, why did the authors not perform an ensemble of simulations with slightly perturbed initial conditions to highlight internal variability impacts on precipitation intensity and spatial distribution? Was the computational demand too high to do so? If so, as mentioned below, it would benefit the reader to know this type of information explicitly. If not, why not perform, at least, a small ensemble of simulations. Related to this, it does concern me that all of the conclusions in this manuscript are based on single-member ensembles of a single event. Would these results hold if the authors simulated another event, perhaps in another season? The authors should at least acknowledge this limitation of their study, and at best run a few additional simulations to explore whether new simulations qualitatively alter their conclusions.

We appreciate the reviewer's insightful comments regarding the potential benefits of conducting ensemble simulations to highlight internal variability of the model. We acknowledge the importance of performing ensemble simulations, especially for high-resolution simulations. To address this concern, it is crucial to highlight the significant computational and storage requirements of our experiments, particularly for the QU15km and V3km simulations, with computational demands as 2,528CPU h and 3,120CPU h and storage demands as of 1.6TB and 0.6TB, respectively, as detailed in the updated Table 2 of the revised manuscript. Given these constraints, we opted for a single-member ensemble simulation in this study. Meanwhile, this study employs bootstrapping statistical analysis to address the internal variability of the model with a specific given confidence level (e.g., 95%). While we acknowledge the limitation of using single-member ensembles, nevertheless we believe that our approach still provides valuable insights. For the future work, we plan to perform ensemble simulations to better evaluate the internal variability of simulated precipitation intensity and spatial distribution. In the revised manuscript, we have included additional details for each simulation in Table 2, encompassing information such as cost (CPU hours) and storage (TB), along with corresponding text (line 133-139) as follows.

Table 2: Description of the numerical experiments conducted in this study.

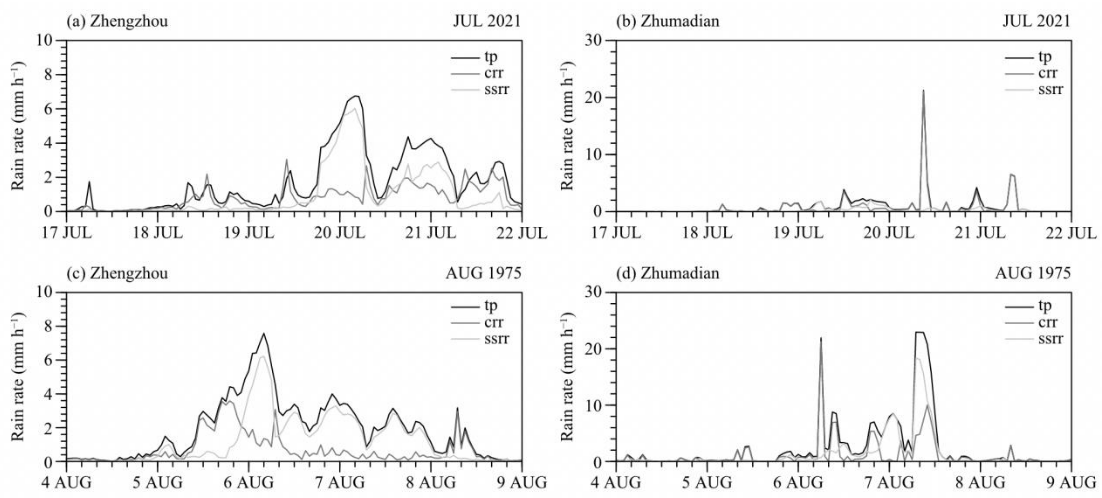
	MPAS experiments					
	U60km.MS	U15km.MS	U15km.CP	V15km.MS	V15km.CP	V3km.CP
Scheme	MS	MS	CP	MS	CP	CP
Resolution	U60km	U15km	U15km	V15km	V15km	V3km
Num. of cells	163,842	2,621,442	2,621,442	535,554	535,554	835,586
Timestep (s)	90	60	60	60	60	20
Cost (CPU h)	1,289	2,316	2,528	571	726	3,120
Storage (TB)	0.3	1.5	1.6	0.4	0.4	0.6

- Lack of discussion of physical meaning of results: Overall, the manuscript reads more like a technical report than a scientific manuscript; it focuses much more on questions of 'what' than questions of 'why'. In my opinion, this severely limits the usefulness of the paper. In its current form, I suspect that the only readers who might find the manuscript interesting would be users of the MPAS-Atmosphere model, since it essentially only focuses on describing how precipitation depend on resolution and parameterization schemes suite. Instead, if the manuscript had a stronger emphasis on why, the manuscript might be of interest to other model users facing similar questions about the effects of resolution and parameterization. For example, all of the figures basically focus on the precipitation itself, and while there are some references to the effects of large-scale circulation, but their analysis of this is somewhat superficial. Adding more analysis of how resolution or parameterization schemes lead to differences in large-scale circulation and precipitation will improve the paper.

Thank you for your valuable suggestions. We acknowledge the lack of in-depth physical discussions of the results in the original manuscript. The revised manuscript incorporates more detailed analysis on how different resolutions and parameterization schemes lead to different large-scale atmospheric circulation and precipitation. as the reviewer pointed out. Specifically, we found that at 15km resolution the CP parameterization scheme generally gives rise of excessive cooling effect over the refined mesh region relative to the default MS parameterization scheme such that this leads to an easterly wind component anomaly which tends to mislocate the simulated precipitation maximum. Details can be found in line 237-258 in the revised manuscript. In addition, we’ve added four more new figures (Figure 9-Figure 13) in the revised manuscript to facilitate the explanation of mechanisms behind the 850-mb wind simulation bias associated with CP parameterization scheme. Furthermore, we have delved deeper into the discussion on convective rain and grid-scale rain, exploring how different parameterization schemes perform on the 60-3km global variable-resolution mesh. Details can be found on line 261-306 and 309-323.

- What is the basis for dividing the extreme precipitation event into two separate periods and analyzing them separately?

Thank you for your valuable suggestion. We sincerely apologize for not explicitly stating the reasons for analyzing two separate periods in the original manuscript. As illustrated in Figure 2(a) of Rao et al., (2022) as shown below, during the "7.20" extreme precipitation event, Zhengzhou meteorological station recorded three distinct peaks, with the first peak occurring on July 20th (from 20 July 00:00 to 21 July 00:00 UTC) and the second peak on July 21st (from 20 July 00:00 to 21 July 00:00 UTC). The precipitation from these two peaks accounts for the majority of the total precipitation during the entire event (over 80%). We chose to analyze these two periods separately to better showcase the modeling capability of MPAS in capturing the extremeness of precipitation intensity, as these periods dominate the overall event. Furthermore, we found that for the 15-km simulations with the CP scheme suite (QU15km.CP and V15km.CP) they tend to produce poorer prediction of precipitation and atmospheric circulation in the second peak, compared to the first peak. Hence, we've thoroughly discussed the reason behind it for the second peak period in the revised manuscript. Please see line 155 to 160.



(Taken from Rao et al., 2022) Fig. 2. Hourly evolutions of precipitation extracted from the ERA5 dataset for (a, c) Zhengzhou and (b, d) Zhumadian during the two rainstorms. The total rain rate is shown as black lines, whereas the convective rain rate and the synoptic-scale rain rate are shown as dark gray and light gray lines, respectively. In the legends, tp: total precipitation; crr: convective rain rate; and ssrr: synoptic-scale rain rate.

Rao, J., Xie, J., Cao, Y., Zhu, S., and Lu, Q.: Record Flood-Producing Rainstorms of July 2021 and August 1975 in Henan of China: Comparative Synoptic Analysis Using ERA5, Journal of Meteorological Research, 36, 809–823, 2022.

- Lines 166-172: the authors emphasize the relationship between the precipitation and atmospheric wind field. In Figure 3c, the wind filed predicted by GFS is very close to the ERA5 reanalysis, but the location and intensity of precipitation is still poorly forecasted. In addition to the wind field, other factors affecting precipitation can be discussed.

Thank you for your suggestion. We apologize for not explicitly stating in the original manuscript that the overlaid wind fields in Figures 3a-c and Figures 6a-c are based on ERA5 due to the absence of observation and GFS data. In the revised manuscript, we have addressed this by correcting the GFS wind fields at 850 mb (Figure 3c and Figure 6c). Due to the coarse resolution used in GFS, it failed to capture the finer features associated with this extreme precipitation event such as the terrain effect so that it led to a poor forecasting of the precipitation intensity and location. For instance, Sun et al. (2023) and Yin et al. (2021) emphasize the role of the unique terrain of the Taihang and Funiu Mountains played in this event. In addition, The reviewer is right that despite close resemblance between the wind field in ERA5 and GFS, the location and intensity of precipitation is still poorly forecasted as more factors rather than just wind field alone have contributed to the simulated precipitation bias such as the temperature field and diabatic heating term. Detailed analysis has been added and can be found in line 396-400 and 403-406 in the revised manuscript.

Sun, J., LI, R., Zhang, Q., Trier, S. B., Ying, Z., and Xu, J.: Mesoscale factors contributing to the extreme rainstorm on 20 July 2021 in Zhengzhou, China as revealed by rapid update 4DVar analysis, Monthly Weather Review, 2023

Yin, J., Gu, H., Liang, X., Yu, M., Sun, J., Xie, Y., Li, F., and Wu, C.: A possible dynamic mechanism for rapid production of the extreme hourly rainfall in Zhengzhou City on 20 July 2021, Journal of Meteorological Research, 36, 6–25, 2021.

- Lines 258-267: Although the V3km.CP reproduced the third precipitation peak compared to 15km.CP, the authors should be note that the magnitude of the third precipitation peak simulated by V3km.CP is much smaller than the observation, rather than just praising the V3km.CP simulation.

Yes, we agree with the reviewer that the magnitude of the third precipitation peak simulated by V3km.CP is comparatively smaller than observation. We have revised the statements following the reviewer's suggestion. Details of the revised part can be found in line 335-337.

- Some conclusion statements are "common sense". For example, "This implies that, when the resolution of the refined region is coarser than the cloud-resolving scale, the convection-permitting parameterization scheme suite does not necessarily work better than the default mesoscale suite, but once the refined mesh is close to the cloud-resolving scale, the convection-permitting suite becomes scale aware such that it can intelligently distinguish the convective precipitation and grid-scale precipitation, respectively." This kind of statements should be deleted. This is the purpose of designing these suites in this model, and cannot be the findings of this study.

Thank you for the suggestion. Now we've deleted these statements and added more solid conclusion statements. Please see line 351-365 and 366-377.

- In addition, some conclusions are not supported by the analysis. For example, line 295, "Consequently, the latent heat release from the simulated peak precipitation would further feed back to the large-scale wind field such that the impact of the wind field upon the simulated peak precipitation is amplified." I cannot find the results to support this conclusion. So is the line 302, "This implies that the seamless mesh transition of the global variable-resolution model is superior in simulating the extreme precipitation event." Please add more analysis and discussion before drawing these conclusions.

Thank you for your insightful comments. In the revised manuscript, we have deleted these unsupported statements and added more corroborated conclusions there. Please see line 237-258, 261-323 and 351-365.

Minor Comments

- Line 21: "(Jinfang et al., 2021)" maybe "(Yin et al. 2021)".

Thanks for your suggestion. It is now fixed.

- The nine-dash line is missing from all the maps.

Thanks for your suggestion. We've added it in the revised manuscript (Fig. 2 and Fig. 15).

- Line 213: "westerly wind" maybe "easterly wind".

Thanks for your suggestion. It's done in the revised manuscript.

- The authors mention in Lines 259-260 and Lines 271-272 that "the forecast performance of the CP suite and MS suite at 15km is comparable", but in fact all the CP simulations clearly miss the third precipitation peak, the differences are significant. I suggest rewording this statement.

Thanks for your suggestion. Now we've reworded this part as "The forecast performance of the CP suite and MS suite at 15km is comparable for the first peak period, but the performance of the CP suite worsened for the second and third peak periods. In particular, all simulations with the CP suite at 15km missed the third peak indeed." Please see line 335-337.

- In addition to the correlation coefficients, I suggest that the authors add root-mean-square error or mean deviation characterizing the forecasted precipitation intensity.

Thanks for your suggestion. Now we've added root-mean-square error (RMSE) and mean bias (Bias) in the updated Table 3 and Table 4. Please see page 11.

References

Liu, Z., Dong, L., Qiu, Z., Li, X., Yuan, H., Meng, D., Qiu, X., Liang, D., and Wang, Y.: Global variable-resolution simulations of extreme precipitation over Henan, China in 2021 with MPAS- Atmosphere v7.3, Zenodo [data set], https://doi.org/10.5281/zenodo.10503572, 2024.

Rao, J., Xie, J., Cao, Y., Zhu, S., and Lu, Q.: Record Flood-Producing Rainstorms of July 2021 and August 1975 in Henan of China: Comparative Synoptic Analysis Using ERA5, Journal of Meteorological Research, 36, 809–823, 2022.

Sun, J., LI, R., Zhang, Q., Trier, S. B., Ying, Z., and Xu, J.: Mesoscale factors contributing to the extreme rainstorm on 20 July 2021 in Zhengzhou, China as revealed by rapid update 4DVar analysis, Monthly Weather Review, 2023

Yin, J., Gu, H., Liang, X., Yu, M., Sun, J., Xie, Y., Li, F., and Wu, C.: A possible dynamic mechanism for rapid production of the extreme hourly rainfall in Zhengzhou City on 20 July 2021, Journal of Meteorological Research, 36, 6–25, 2021.