Author's Response to Editor's Comments

Manuscript ID: EGUSPHERE-2025-912

Title (revised): Evaluation of Microphysics and Boundary Layer Schemes for Simulating Extreme Rainfall Events over Saudi Arabia using WRF-ARW.

Dear Prof. Ulbrich,

We thank you for the positive evaluation of the revised manuscript and for summarizing the key remaining points. In what follows, we address all comments from the Editor and Reviewers in detail and have revised the manuscript accordingly. A tracked-changes version has been provided.

comment 1: Title: Please leave out the model version number in the title.

Response: We agree and have removed the explicit model version number from the title. The revised title now reads:

"Evaluation of Microphysics and Boundary Layer Schemes for Simulating Extreme Rainfall Events over Saudi Arabia using WRF-ARW"

This also aligns with Reviewer 1's suggestion.

Comment 2: References: Including a large number of references in the introductory text is not beneficial for readers. You should concentrate on a couple of citations which are particularly adequate in the context of the paper.

Response: We agree and have substantially streamlined the references in the introduction. In sentences where we previously cited many studies (e.g., statements about the increasing intensity/frequency of extreme rainfall and Clausius–Clapeyron scaling), we now retain only the most relevant and representative references. This improves readability and keeps the focus on the most pertinent literature.

Comment 3. Study aims: I agree with the reviewer that your list of study aims/research questions is not the optimum approach. Reading them again, they are mostly not individual questions but belong to each other. For example, a and b refer to two components of the model, and it is not clear per se if they should/can be considered separate from each other. This can be communicated in a text, better than in bullet points. The question of statistical significance may not have to be addressed in a separate bullet point (d). All in all, I am convinced that a short description of the research goals is better suited than the bullet points.

Response: The previous list of nine key questions has been removed and concisely integrated into the text. The revised paragraph (in the Introduction, "Study aims" paragraph) reads:

"Our study addresses this gap by conducting an extensive evaluation of WRF-ARW PBL and MP schemes for simulating EREs over the AP at convection-permitting resolution (3~km) to determine the best combination of PBL and MP schemes. We simulate the EREs using a two-way nested domain configuration with 53 vertical levels and horizontal resolutions of 9 and 3~km. We analyze 17 EREs from 2010 to 2022 across the AP, testing 36 different combinations

of PBL and MP schemes. The Kling–Gupta Efficiency (KGE) is used to evaluate the model's performance. We also analyze which component of the KGE exerts the dominant control on the overall KGE scores and whether the performance ranking of schemes is statistically significant and robust across other meteorological variables (2-m air temperature, 2-m relative humidity, and 10-m wind speed). Additionally, we investigate the temporal and spatial consistency of the rainfall evaluation. Lastly, we compare the PBL and MP schemes identified by our assessment as the most effective with those frequently used in previous studies." (Page No. 3, Lines 66-84)

Comment 4: With respect to the white areas in Figs. 6 and 7, I think that there is no need for an additional grey color. Rather, it must be clear that there is no values below 0 (i.e. the color bar has to be adapted). You should describe in the captions what "0" means (0.1. mm?) and explain what value is assigned to the white areas.

Response: We thank the Editor for this helpful comment. In the revised Figs. 6 and 7, the colour bar has been adapted so that it starts at 0.1 mm and does not include values below 0. We have updated the figure captions to clarify that the white areas indicate grid points with rainfall < 0.1 mm.

We trust these revisions meet your expectations and thank you for guiding us to improve the clarity and quality of our manuscript.

Sincerely,
Dr. Rajesh Kumar Sahu
(on behalf of all co-authors)
KAUST, Saudi Arabia

Pointwise replies to reviewer's comments on the manuscript "Evaluation of Microphysics and Boundary Layer Schemes for Simulating Extreme Rainfall Events over Saudi Arabia using WRF-ARW" (egusphere-2025-912)

Response to the comments of Reviewer 1

We thank Reviewer 1 for their positive evaluation of the revised manuscript and for the remaining helpful comments, which we have addressed as follows.

Comment 1: Although this was proposed by a fellow reviewer, for conciseness, I would remove the version of the model from the title ("-ARW v4.4"). In any case, I leave this decision to the authors.

Response: We agree. As also requested by the Editor, we have removed the explicit version number from the title, and now refer simply to "WRF-ARW" (see revised title above).

Comment 2: In several instances, mainly in the introduction, some statements are supported by an excessively large number of references (for example: "These events are becoming more frequent and intense as atmospheric moisture increases by about 7% per degree of warming, following Clausius-Clapeyron scaling"). In such cases, citing one or two key references should suffice.

Response: We agree and have reduced the number of references in the introduction, keeping only a few key citations for each general statement to make the text more concise and readable.

Comment 3: A previous remark suggested presenting the study's aims as a paragraph rather than a list of questions. This aspect remains unchanged, though I continue to believe that a paragraph format would be more appropriate. The same applies to the style of the section headings.

Response: We thank the reviewer for this suggestion. We have integrated the questions into a single paragraph summarising the study aims and approach. (Page no. 3, Lines 66-84)

Comment 4: In Table 2, under the 'Simulation Start' column, I recommend removing the time indication, since all simulations start at 00:00 (presumably UTC)."

Response: We agree. In Table 2, we have removed the redundant time indication in the "Simulation Start" column and now list only the date. The text clarifies that all simulations start at 00:00 UTC, so the table is now cleaner without losing information.

Response to the comments of Reviewer 2

We thank Reviewer 2 for the careful re-evaluation and for acknowledging the substantial improvement of the manuscript. We appreciate the remaining detailed minor comments and address them point-by-point below.

Comment 1: For Fig. 1 I suggest using a different color table. Depending on the screen and printer of the reader, the reddish/orange colors can hardly be distinguished. I suggest a color table like this: https://www.ncl.ucar.edu/Document/Graphics/ColorTables/topo_15lev.shtml

Response: Thank you for this suggestion. We have updated the colour table used in Figure 1 to a multi-level, topography-style colour map inspired by the "topo_15lev" palette. The figure caption has been updated accordingly.

Comment 2: Please briefly mention the advantage of the 2-way nesting approach in the manuscript. Then it is fully clear for the reader what your reasons are.

Response: We have added a short explanation in the WRF-ARW model configuration section. The text now states that "We used a two-way nesting approach to allow feedback between the high-resolution inner domain and the coarser parent domain. This is essential for capturing small-scale processes like convection, PBL turbulence, and orographic effects, which can influence larger-scale circulation. The dynamic interaction improves physical consistency and is crucial for realistically simulating mesoscale convective systems (MCS) and associated rainfall." (Page no. 6, Lines 134-137)

Comment 3: Concerning the application of ERA5 pressure level data: I fully understand that running lots of simulations is computationally expensive, but I clearly see the benefit of using ERA5 model level data for initialization of your 17 EREs. The ERA5 data volume for the initial conditions from ERA5 would have increased by a factor of three while there is no change in the data volume of the simulations itself. Please add a brief explanation about potential drawbacks using ERA5 data on pressure levels instead of model levels for model initialization.

Response: We agree this clarification is important. In the data and methods section, we now include a brief discussion:

"ERA5 also provides model-level fields, which offer a finer native representation of the vertical structure, particularly in the boundary layer and near the tropopause. Using model levels for all 17 EREs and 36 parameterization combinations (612 simulations) would substantially increase the initial-condition data volume and I/O burden, particularly when combined with a denser WRF vertical grid, which further increases computational cost. We therefore used pressure levels as a pragmatic compromise, and our results should be interpreted with the caveat that some small-scale vertical features may be under-resolved." (Page no. 5, Lines 114-119)

Comment 4: Please check the grid sizes in Table 3. The numbers are incorrect.

Response: Thank you for pointing this out. We have re-checked and corrected the grid spacing values in Table 3.

Comment 5: Regarding the interpolation of the WRF simulation data to the IMERGE grid: I still see the potential for a double penalty of the model. It is not about improving your results but rather than doing it more realistically in light of the model's ability to represent features which are in the range of 3-6 times the grid distance (see e.g., Skamarock 2004: https://journals.ametsoc.org/view/journals/mwre/132/12/mwr2830.1.xml)

Response: We appreciate this comment. As described in the model assessment approach, WRF-ARW rainfall at 3-km resolution is resampled to the 0.1° IMERG grid using averaging, which is more than three times the grid spacing (consistent with Skamarock, 2004), to enable consistent grid-cell-to-grid-cell comparison and largely avoid the double-penalty issue.

Comment 6: I suggest applying a grey background and setting the minimum value to either 0.1 mm or 1.0 mm and then using white colors below 0.1 mm. E.g., 0.1 mm d-1 is hard to be measured (there may also be dewfall).

Response: We appreciate the reviewer's comment. In the revised Figs. 6 and 7, the colour bar has been adapted so that it starts at 0.1 mm and does not include values below 0. We have updated the figure captions to clarify that the white areas indicate grid points with rainfall < 0.1 mm.

To keep the figures visually simple and consistent with the Editor's comment, we did not introduce a grey background, but we believe the explicit caption now fully prevents misinterpretation.

Comment 7: Regarding your answer to my comment 65: Keep in mind that you do the surface evaluation with only nine stations over an area of approx. 3000km*2700 km and that the variables you evaluate are diagnostic variables in the model. You may consider the study of Branch et al. (2021) who evaluated WRF simulations (although with an older version of WRF) over the United Arab Emirates (which likely has a similar climate during summer) using ~50 surface stations (https://doi.org/10.5194/gmd-14-1615-2021). Their study shows that a wind bias is apparent in the desert.

Response: We thank the reviewer for this helpful comment and for bringing Branch et al. (2021) to our attention. We fully agree that a dense surface network and a longer-term evaluation of diagnostic near-surface variables are highly valuable. However, our study is explicitly designed around 17 selected EREs, so both the WRF simulations and the verification strategy are event-focused, and reliable concurrent observations are only available at nine stations near these events. Note that most of the Arabian Peninsula is very sparsely observed, with only a few dozen unevenly distributed gauges over a vast area, unlike the UAE.