

Reply on Referee #2 Comments

This manuscript investigates the performance of the RegCM5 model with a hydrostatic dynamical core in simulating precipitation over the complex terrain of the Upper Blue Nile Basin (UBNB). The study leverages high-resolution ERA5 reanalysis data to evaluate various convective and microphysical parameterization schemes, ultimately identifying the Emanuel convection scheme coupled with the Nogherotto-Tompkins (NoTo) microphysics scheme as the optimal configuration. The following points should be addressed to improve the clarity, robustness, and overall quality of the manuscript:

Major points:

1. The statement that even the best parameterization shows a 66% bias is significant. This level of error raises concerns about the model's credibility for the region. The authors should provide a more comprehensive discussion on how to interpret this result. Specifically, they should: a) Clearly state what level of bias is considered acceptable for the intended applications of the model in this study. b) Discuss whether the model, despite the bias, successfully captures the dominant spatial and temporal patterns of climate variability, which can sometimes be more important than the absolute values for certain applications.

We thank the reviewer for this valuable comment. We have revised the discussion part in the results and discussion section to provide a clearer interpretation of the model bias and to explain its implications for the intended applications of this study. Specifically, we clarified that there is no universally accepted threshold for “acceptable” bias in RCM simulations. Instead, many previous studies have emphasized that the model’s ability to reproduce the dominant spatial and temporal variability of climate variables is often more critical than the absolute magnitude of bias (L203-213). In addition, based on that, the abstract was also modified in L16-17.

2. The methodology does not mention a threshold for defining a "wet day" (e.g., >0.1 mm/day). Please clarify if all precipitation values, including trace amounts, were used in the analysis. The low frequency of zero precipitation values shown in Figure 7 suggests the model (and possibly the observations) rarely simulates completely dry days. Confirming the wet-day threshold is important for interpreting intensity and frequency results.

We thank the reviewer for this important observation. In the initial analysis, all precipitation values, including trace amounts, were considered. Following the reviewer’s recommendation, we have revised the methodology and identified a wet-day threshold of precipitation > 1 mm/day to exclude trace rainfall and ensure consistency in interpreting intensity and frequency analyses. This clarification has been added to the methodology section (L175-177). Consequently, the figure (L247) has been updated based on this threshold. The overall interpretation of the results remains essentially unchanged and consistent with the previous version.

3. The manuscript compares different parameterizations but lacks a detailed discussion on the physical reasons why the optimal scheme (Emanuel + NoTo) performed best. The authors should elaborate on the key physical differences between the schemes (e.g., in their triggering of convection, closure assumptions, or ice-phase processes) and provide a hypothesis for why this specific combination is more suitable for representing the dominant atmospheric processes in the UBNB.

We sincerely thank the reviewer for this valuable suggestion. Accordingly, we have added a detailed explanation of the physical reasons behind the superior performance of the Emanuel + NoTo combination in the discussion part in the results and discussion section (L306-313). Specifically, we discuss how the Emanuel convective scheme, which represents convection as a buoyancy-driven, quasi-equilibrium process with entrainment–detrainment effects and moisture adjustment, tends to better capture the deep convective systems prevalent over UBNB. When coupled with the NoTo large-scale condensation scheme, known for its improved representation of microphysical processes and reduced excessive condensation under weakly saturated conditions, the combination provides a more realistic simulation of both convective and stratiform rainfall.

Minor points:

1. The 10km resolution may be insufficient to capture local processes in the UBNB's complex terrain. Justification for this choice (e.g., computational limits or sensitivity tests) should be provided, along with discussion on how resolution impacts simulation accuracy.

The chosen resolution of 10 km represents a common mesoscale configuration in regional climate modeling that balances physical realism and computational feasibility. This resolution has been shown to enhance the representation of precipitation, especially over complex terrain. In earlier studies that relied on ERA-Interim reanalysis, achieving such resolutions typically required double nesting (e.g., downscaling from ~50 km to ~12–10 km) (e.g., (Prein et al., 2016; Torma et al., 2015)). In addition, the tropical climate of the UBNB, where rainfall is dominated by seasonal systems, a 10 km resolution provides sufficient fidelity for the current study. Nonetheless, for some applications, such as assessing land use and land cover change impacts (e.g., due to new reservoirs impounded upstream, existing and potential dams along the basin), there is a need for a higher resolution. Maybe in future work, we will exploit the MOLOCH non-hydrostatic core and test it for using the convective permitting approach that will enable us to better represent the very small change in land surface features that couldn't be represented in lower resolutions and thereby capture any change in the localized land-atmosphere interactions.

2. Figures 1 and 2 should be merged to clearly show the UBNB within the larger model domain, improving readability.

Done in L124, Thanks.

3. L158 - Although monthly evaluation is common, adding daily-scale metrics would strengthen the assessment of rainfall distribution and intensity.

We appreciate the reviewer's valuable suggestion. In fact, daily-scale analysis was also conducted in our study. The probability density function (PDF) analysis, which evaluates the distribution and intensity of daily precipitation, was performed based on daily data and is already described in the Methodology section. Accordingly, we clarified this point in the manuscript to make it more explicit.

4. The spatial discontinuities in simulated precipitation (Fig. 4), especially in the northeast, require physical explanation—g., topography representation, land-atmosphere feedbacks, or convective processes.

We thank the reviewer for this insightful comment. Following Reviewer 1's suggestion, the spatial distribution figure (previously Figure 4 and now Figure 3) was removed and combined with the bias plots to avoid redundancy, as both presented similar information. However, the spatial discontinuities mentioned by the reviewer remain visible in the updated bias plots, which helped us to further interpret their causes. The discontinuities are mainly attributed to the strong topographic gradients and land-atmosphere interactions over the northeastern highlands of the basin, where local convective triggering is highly sensitive to terrain-induced uplift and land surface heterogeneity. This is added in L221-224.

5. The selection of Emanuel+NoTo needs clarification, as Kain-Fritsch+NoTo performed well in explained variance for key seasons (Fig. 6). The trade-offs and reasons for the final choice should be explicitly explained.

We thank the reviewer for this valuable comment. While the Kain–Fritsch + NoTo configuration indeed showed a relatively higher explained variance during the short rain (FMAM) and dry (ONDJ) seasons, it performed poorly during the long rain season (JJAS), which contributes approximately 70% of the total annual precipitation over the UBNB. However, the text has been modified in L235.

References

- Prein, A. F., Gobiet, A., Truhetz, H., Keuler, K., Goergen, K., Teichmann, C., Fox Maule, C., van Meijgaard, E., Déqué, M., Nikulin, G., Vautard, R., Colette, A., Kjellström, E., and Jacob, D.: Precipitation in the EURO-CORDEX 0.11° and 0.44° simulations: high resolution, high benefits?, *Clim Dyn*, 46, 383–412, <https://doi.org/10.1007/S00382-015-2589-Y/FIGURES/19>, 2016.
- Torma, C., Giorgi, F., and Coppola, E.: Added value of regional climate modeling over areas characterized by complex terrain-precipitation over the Alps, *J Geophys Res*, 120, 3957–3972, <https://doi.org/10.1002/2014JD022781>;REQUESTEDJOURNAL:JOURNAL:21698996;WEBSITE:WEBSITE:AGUPUBS;JOURNAL:JOURNAL:21562202D;WGROU:STRING:PUBLICATION, 2015.