Reviewer #2:

We sincerely thank the reviewer for the careful reading of our manuscript and for the constructive comments. In response to these suggestions, we have revised the manuscript to improve the clarity of the study goals, methodological contribution, experimental design, and result interpretation. We have strengthened the figure descriptions by adding clearer objectives and panel references. Our responses to the reviewers' comments are inserted after each comment below in blue text and preceded by the word "Response". We believe these revisions have improved the clarity of the manuscript.

L21: This sentence appears incomplete. Do the authors intend to state that nudging is a data assimilation technique that constrains model simulations using observations while keeping them close to a predefined reference state? Please clarify.

Response: Thank you for pointing this out. We agree that the original sentence was incomplete and did not clearly describe how nudging constrains model simulations. We have revised the sentence around Lines 23-24 to clarify that nudging.

Revised text: Nudging, also known as Newtonian relaxation, is a four-dimensional data assimilation technique in which additional relaxation terms are added to the model equations to constrain selected prognostic variables toward a prescribed reference state, usually derived from observations or reanalysis (Anthes, 1974).

Section 1: The goals and research questions of the manuscript are not clearly stated. What does this work contribute beyond previous studies? This should be explicitly stated.

Response: Thank you for pointing this out. We have revised the final paragraph of Section 1 to state the goals, research questions, and contributions more explicitly. The revised text clarifies that the goal is to constrain large-scale circulation while preserving smaller-scale variability, and that the implementation provides a practical framework for parameterization sensitivity experiments under prescribed large-scale dynamical conditions.

Revision around Lines 73–81:

Building on the MPAS-A analysis nudging framework of Bullock et al., this study extends conventional full-field relaxation to scale-selective relaxation in MPAS-A version 8.2.2. To achieve this, we incorporate the diffusion-based filtering framework of Grooms et al. (2021), which enables efficient spatial filtering on unstructured meshes through repeated applications of the discrete Laplacian. Our goal is to constrain large-scale circulation toward the reference analysis while preserving smaller-scale degrees of freedom in the refined region, and to evaluate whether the scale-selective nudging provides the intended scale-dependent nudging behaviour. This implementation provides a practical scale-selective nudging framework for variable resolution model, enabling parameterization sensitivity experiments under prescribed large-scale dynamical conditions while retaining the distinctive responses of different physics schemes that would otherwise be suppressed by full analysis nudging.

I suggest dividing Section 2 into 2 sections: 2. methodology and 3. model configuration and experimental design

Response: Thank you for this helpful suggestion. We have reorganized the manuscript accordingly. The original Section 2 has been divided into two separate sections: Section 2, “Nudging implementation,” which describes the analysis nudging and scale-selective nudging methods, and Section 3, “Model configuration,” which presents the model setup and experimental design. We believe this revised structure improves the clarity and readability of the manuscript.

This section needs to be reorganized to clearly highlight the authors’ contributions to nudging method development. At present, it is unclear whether the manuscript aims to develop/improve a nudging method or simply apply an existing one. Additionally, the equations require careful verification. For example, what does n represent in Eq. (2)? Please also double-check Eq. (4) for correctness.

Response: Thank you for pointing out that the methodological contribution was not clearly separated from the existing nudging framework. We have reorganized this section to distinguish the conventional full-field analysis nudging formulation from our scale-selective extension. We have revised the notation in Eq. (2), where the superscript $n$denotes the model time step and $n+1$denotes the updated state after one time step Δt. In addition, we have checked Eq. (4) and added definitions of the eigenvectors and eigenvalues used in the spectral representation.

Revision around Line 107: Equation (2) represents the conventional full-field analysis nudging formulation. In this study, the MPAS-A analysis nudging framework originally developed by Bullock et al. for MPAS-A version 4.0 is ported to MPAS-A version 8.2.2 and then extended to support scale-selective nudging. The key extension is that the horizontal nudging tendency diagnosed from Eq. (2) is not directly added to the model state; instead, it is first passed through a spatial low-pass filter, so that only the large-scale component of the nudging tendency is retained.

Revision for Eq. (4): where $q_i$are the eigenvectors of L, and $k_i^2$are the corresponding eigenvalues.

Table 1: The two experiment suites differ not only in convective parameterizations, but also in microphysics and boundary layer/surface layer schemes. This should be clearly stated and discussed.

Response: We thank the reviewer for this important comment. We agree that the original TK and GF experiments differ not only in the convective parameterization, but also in the associated PBL and microphysics schemes. In the original experiment design, we used these two configurations as internally consistent MPAS-A physics suites, rather than as single-parameter perturbation experiments.

We performed an additional 1-month sensitivity experiment in which only the convective parameterization was changed to GF, while the other physics options, including the PBL and microphysics schemes, were kept the same as in the TK suite.

The daily precipitation frequency is now shown below. The green and red curves represent the original freerun_GF experiment and the new sensitivity experiment, respectively. The comparison shows that the precipitation-frequency distribution remains close to that of the original GF suite. This indicates that the GF convective parameterization plays a dominant role in shaping the precipitation-frequency characteristics discussed in this study. As stated around Lines 214–216, the additional sensitivity experiment indicates that the convective parameterization plays the dominant role in shaping the precipitation-frequency characteristics discussed in this study.

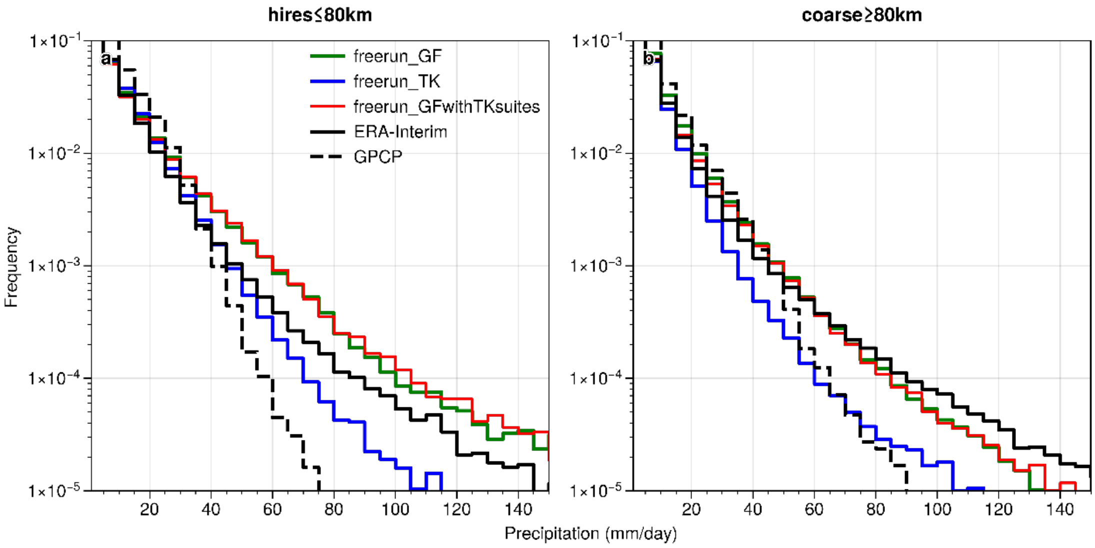

Figure 1. Daily precipitation frequency distributions comparing the original GF suite (green) and the GF-convection-only (red) sensitivity experiment.

200-202: These technical details would be more appropriate in the methodology section rather than here.

Response: Thank you for this suggestion. We agree that these technical details are more appropriate in the methodology section. We have moved the discussion of the iteration number and computational efficiency to the end of Section 2.2 around Lines 194–197. We have also shortened the later description around Lines 246–252 by removing the repeated explanation of halo-region exchanges.

L206: What is the purpose of using two filters and the selected cutoff scales? How were these cutoff scales determined? The experimental design lacks sufficient justification, making it difficult for the reader to follow.

Response: Thank you for this comment. We have clarified the rationale for using the two filter shapes and the selected cutoff scales around Lines 255–265: the taper filter is used to provide a sharper and more scale-selective transition, while the Gaussian filter provides a smoother response with a broader transition range. The nominal cutoff scales of 500, 1000, and 2000 km are defined on the coarse-resolution reference mesh and are used to test different strengths of scale-selective constraint. We also added the corresponding effective cutoff scales and transition bands in the 25-km refined region to make the experimental design clearer.

L219: It seems that GPCP rather than GPCP1DD is used in later text.

Response: Thank you for pointing this out. The precipitation dataset used in this study is the GPCP Daily Version 1.3 Combined Precipitation Dataset, hereafter referred to as GPCP1DD. In the original manuscript, some later occurrences were written simply as "GPCP," which could be confused with other GPCP products. We have revised these occurrences to "GPCP1DD" consistently, including those around Lines 330 and 370.

Figure 1: Does this figure show wind bias between the nudged simulation and ERA-Interim? If so, ERA-Interim is not an independent dataset, as it is used to constrain the MPAS forecasts. The authors need to clarify this.

Response: Thank you for this important comment. We agree that ERA-Interim is not an independent dataset for evaluating the nudged simulations, because it is also used as the reference field for the nudging. The purpose of the manuscript is not to provide an independent validation of the nudging experiments, but to diagnose how closely the simulations remain constrained to the prescribed large-scale reference state and whether additional model responses develop relative to that reference. Therefore, the wind differences shown in Fig. 1 should be interpreted as deviations from the nudging reference field rather than independent model biases. For variables that are not directly nudged, such as precipitation, we further use GPCP1DD as an independent observational reference.

the purpose of Figure 2 and several subsequent figures is not clearly explained. Currently, figures appear to be presented without sufficient context or interpretation. The authors should clearly state the objective of each figure and how it supports the study's conclusions.

Response: Thank you for this comment. We agree that the objectives of Figure 2 and several subsequent figures were not sufficiently introduced. We have revised the text to add clearer context before these figures and to explain how each diagnostic supports the conclusions of the study.

Revisions:

Around Line 306, we added:

Figure 2 is used as a benchmark summary to show how different nudging scales and variables control the directly nudged circulation and how this control propagates into moisture across the refined and coarse mesh regions.

Around Line 350, we added:

The refined East Asian sector exhibits strong daily-to-subseasonal precipitation evolution associated with the seasonal migration of the monsoon rainband. This makes the time–latitude structure of precipitation a useful diagnostic for testing whether nudging improves the large-scale circulation phase while still allowing regional rainfall variability to develop.

Around Line 366, we added:

The daily precipitation frequency is used to diagnose how scale-selective nudging affects precipitation characteristics across resolutions.

Around Line 449, we added:

To evaluate whether scale-selective nudging also affects temporal variability, we further examine the temporal frequency spectra of the nudged and freerun simulations.

L271: What is the rationale for selecting these variables? Please provide justification

Response: Thank you for this comment. We have clarified the rationale for selecting these variables around Lines 313–315.

Revision around Lines 313–315:

Wind speed is selected because it is the primary directly nudged variable in the main experiments, while precipitable water is used to assess whether the dynamical constraint indirectly propagates into moisture-related fields that are closely linked to precipitation responses.

L275-287: Please refer explicitly to figure panel indices when describing results. For example, which panels support the statement that "GF and TK converge to nearly identical patterns and statistical scores"?

Response: Thank you for pointing this out. The statement that the GF and TK cases converge to nearly identical patterns and statistical scores under analysis nudging is now supported by explicit references to Fig. 3d and Fig. 3e. We have also added panel references for the other nudging experiments in the discussion of Fig. 3 around Lines 335–345 and Fig. 4 around Lines 355–365, so that the interpretation can be more directly linked to the displayed results.

Differences shown in several figures (e.g., between GF and TK suites in Figure 5 and others) are not adequately explained. A complete manuscript should provide physical interpretations and, where possible, hypotheses to explain these differences.

Response: We agree that the differences between the GF and TK suites require more physical interpretation. We have added a discussion of the possible mechanism underlying the suppressed precipitation variability in the GF suite. Based on the precipitation-frequency analysis below, strong nudging appears to suppress diurnal-scale precipitation variability, likely by repeatedly constraining the large-scale dynamical environment and limiting the release of convective instability. This may partly explain the dry bias in the analysis-nudging precipitation evolution shown in

Fig. 3.

Revision around Lines 496–498:

This suggests that strong nudging may suppress diurnal-scale precipitation variability, especially in the GF suite, by limiting the daily buildup and release of convective instability under a strongly constrained large-scale dynamical environment.

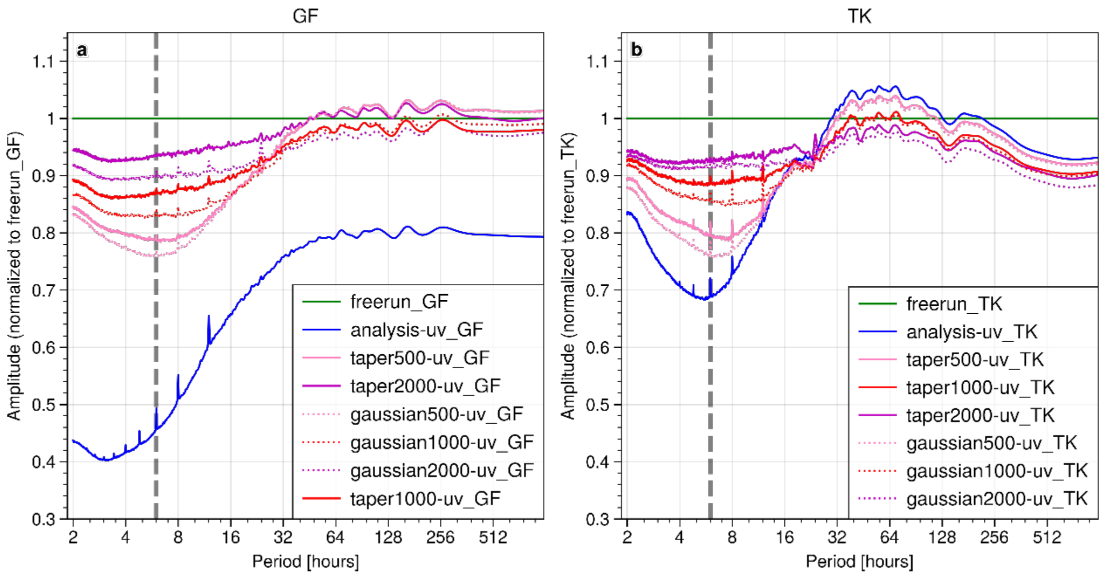

Figure 2. FFT amplitude spectra of globally averaged hourly precipitation, normalized by the corresponding freerun case.