Reviewer #3

This manuscript addresses a relevant question for Geoscientific Model Development: how parameter sensitivities can inform the evaluation and improvement of MJO simulation in CAM6. Its contribution is the integration of a 128-member perturbed parameter ensemble with process-oriented moist static energy (MSE) diagnostics to connect parameter changes with moisture and cloud–radiation pathways. The targeted experiment shows improved MJO simulation in enhanced eastward propagation and a higher eastward-to-westward spectral power ratio. The approach is suitable for the modelling question, and the comparison with observations and CTL provides a useful basis for interpreting the combined parameter changes.

The manuscript is generally well structured. The code and data availability statement describes an archive of parameter settings, run configurations, diagnostic scripts, figure scripts, and simulation data, providing a useful basis for reproducibility. The methodological clarifications below would further improve the traceability of the reported diagnostics.

Therefore, I recommend acceptance after minor revision, with the following comments aimed at refining the interpretation, clarifying the methods, and improving the figures and wording.

Author Response: We greatly appreciate the reviewer's insightful and constructive comments, which have helped us improve the clarity and coherence of the manuscript. In response, we have corrected several inaccurate or unclear statements and provided additional methodological details. We have also expanded the analysis of eastward-propagating spectral power, assessed the statistical significance of the GLM coefficients, and conducted sensitivity tests to examine the influence of the projection domain on the MSE budget. Detailed responses to each comment are provided below (black indicates the reviewers' comments, blue indicates our responses, and green indicates the revised text in the manuscript).

Minor comments

1. Lines 253–259 and 321–324: Please describe the E/W ratio as a measure of the relative dominance of eastward over westward spectral power. Since the ratio can increase through changes in either component, it would be helpful to clarify that. If available, the eastward spectral power could provide complementary context for the MJO amplitude discussion.

Response: We agree with the reviewer that the E/W ratio measures the relative dominance of eastward- over westward-propagating spectral power, rather than directly representing MJO amplitude. An increase in this ratio can result from enhanced eastward power, reduced westward power, or both. To further clarify its physical interpretation in our study, we calculated the total eastward spectral power within the MJO band, which increases from approximately 38 in CTL to 58 in DTA. This indicates that the increase in the E/W ratio from 0.94 to 1.46 is primarily driven by enhanced eastward spectral power, supporting its use as an indirect indicator of MJO strength in the present CTL–DTA comparison. We have clarified the interpretation of the E/W ratio in Section 2.3.3 (Lines 259–263) and incorporated the additional spectral power analysis into Section 3.2 (Lines 355–357).

2. Lines 260–266 and Figure 2d-f: It's difficult to understand why regressing OLR on its domain-averaged time series would lead to negative values around day 0 over the same domain. I'm suspecting that the authors flipped the sign of the domain-averaged OLR time series. If that is the case, please specify it. Also, it would be helpful to know if the OLR time series is standardized before regression, as the regressed OLR values seem high. A brief statement of these conventions for observations and simulations would help readers interpret the regression patterns.

Response: Thank you for pointing this out. We reversed the sign of the regression coefficients so that negative OLR anomalies at Day 0 correspond to enhanced convection over the EIO. The regression coefficients were then multiplied by the standard deviation of the EIO OLR index, which is mathematically equivalent to regressing OLR onto the negative standardized EIO OLR index. The resulting patterns therefore represent OLR anomalies (W m^{-2}) associated with a one-standard-deviation decrease in EIO OLR. The same procedure was applied to observations and simulations. We have clarified these conventions in Section 2.3.3 (Lines 267–270) and the caption of Fig. 2.

3. Table.1: are the values used in CTL simulation the same as CAM6 default ones? If yes, it's surprising to see the much biased MJO propagation in CTL simulation, e.g., Fig.2e. If not, please specify that.

Response: Yes, all 12 physical parameters in CTL are set to their default CAM6 values, as listed in Table 1. The poor MJO propagation in CTL is not entirely unexpected, as similar deficiencies have been reported in previous studies using default CAM configurations (Lappen and Schumacher, 2012; Boyle et al., 2015; Goswami et al., 2025). For example, Boyle et al. (2015) showed that the default CAM5 simulation exhibits nearly stationary intraseasonal precipitation anomalies over the Indian Ocean, accompanied by westward-propagating low-level wind anomalies (their Fig. 6b). These findings highlight the persistent challenges in simulating realistic MJO propagation with standard model configurations.

Boyle, J. S., Klein, S. A., Lucas, D. D., Ma, H.-Y., Tannahill, J., and Xie, S.: The parametric sensitivity of CAM5's MJO, J. Geophy. Res. Atmos., 120, 1424–1444, https://doi.org/10.1002/2014JD022507, 2015.

Goswami, B. B., Polesello, A., and Muller, C.: An Assessment of Representing Land-Ocean Heterogeneity via CAPE Relaxation Timescale in the Community Atmospheric Model 6 (CAM6), J. Adv. Model. Earth Syst., 17, e2025MS005035, https://doi.org/10.1029/2025MS005035, 2025.

Lappen, C. L. and Schumacher, C.: Heating in the tropical atmosphere: what level of detail is critical for accurate MJO simulations in GCMs?, Clim. Dyn., 39, 2547–2568, https://doi.org/10.1007/s00382-012-1327-y, 2012.

4. Lines 303–310: It would be helpful to indicate whether the GLM coefficients are statistically significant and, where available, report their uncertainty or significance levels.

Response: Thank you for this suggestion. We have applied Student's t-test to assess the statistical

significance of the GLM regression coefficients, following the approach of Guo et al. (2014). The results show that the coefficients associated with *dmpdz*, *tau*, and *ai* are statistically significant for both the E/W ratio and PCC ($p < 0.05$). We have highlighted the parameters with statistically significant regression coefficients in red in Fig. 3.

Guo, Z., Wang, M., Qian, Y., Larson, V. E., Ghan, S., Ovchinnikov, M., Bogenschutz, P. A., Zhao, C., Lin, G., and Zhou, T.: A sensitivity analysis of cloud properties to CLUBB parameters in the single-column Community Atmosphere Model (SCAM5), J. Adv. Model. Earth Syst., 6, 829–858, https://doi.org/10.1002/2014MS000315, 2014.

5. Figure 4 and lines 248–251, 354–355, and 366–371: Please add a brief explanation for choosing 130°E as the eastern boundary of the MSE projection domain, since the observed eastward tendency maximum extends beyond this boundary. A short discussion of how the domain choice may affect the projections would be useful.

Response: We thank the reviewer for this helpful comment. The projection domain (10°S–10°N, 60°–130°E) was selected to encompass the main MSE anomaly center and the east–west asymmetry in MSE tendency near the MJO convective center. We agree that the maximum positive MSE tendency in observations extends beyond 130°E. To assess the sensitivity to this boundary, we repeated the projection analysis by extending the eastern boundary to 140°E, 150°E, and 160°E, while keeping the other boundaries unchanged.

The results show that, although the projection coefficient of meridional MSE advection (vadv) in DTA decreases to approximately 0.5 as the domain extends eastward, the difference between DTA and CTL remains pronounced. Meanwhile, the projection coefficient of radiative heating (Qr) changes little. These results indicate that the leading roles of vadv and Qr in the improved MJO propagation and maintenance, respectively, are robust to the choice of eastern boundary. We have clarified the rationale for the domain selection (Lines 410–413) and added a brief discussion of these sensitivity results to the revised manuscript (Lines 442–446).

"The projection domain (10°S–10°N, 60°–130°E; red box in Fig. 4) is selected to encompasses the maximum MSE anomaly center and the east–west asymmetry in MSE tendency near the MJO convective center, although the maximum positive MSE tendency in observations extends farther east."

"To assess the sensitivity to the projection domain, we extended the eastern boundary from 130°E to 140°E, 150°E, and 160°E. Although the vadv projection coefficient in DTA decreases to approximately 0.5, the difference between DTA and CTL remains pronounced, while the Qr projection coefficient changes little. These results suggest that the leading roles of vadv in MJO propagation and Qr in MJO maintenance are robust to the choice of eastern boundary (not shown)."

6. Lines 361–365 and Figures 2 and 4: The improvements in DTA are encouraging. Please also briefly discuss the remaining differences from observations in the strength and spatial structure of the MSE anomaly and tendency patterns.

Response: We have added a more detailed comparison of MSE and its tendency anomalies between observations and DTA to the revised manuscript as follows (Lines 403–407):

"Nevertheless, some discrepancies remain between DTA and observations. The MSE anomalies in DTA are slightly weaker than observed, while the negative MSE tendency anomalies over the eastern Indian Ocean are more concentrated north of the equator. In addition, the positive MSE tendency center over the western Pacific is displaced eastward relative to observations. These differences indicate that the simulated MJO-related MSE structure still has room for improvement."

7. Figure 9: Please specify the precipitation bin width or increment, whether the bins are linear or logarithmic.

Response: Following Kim et al. (2015), precipitation anomalies ranging from 0 to 1000 mm day^{-1} are divided into 51 bins. The first and last bins cover 0–0.09797 mm day^{-1} and 150–1000 mm day^{-1}, respectively. The intermediate bins are logarithmically spaced with an increment of 0.065 in $\log_{10}$. We have clarified this detail in the revised manuscript (Lines 542–545).

Kim, D., Ahn, M.-S., Kang, I.-S., and Del Genio, A. D.: Role of Longwave Cloud–Radiation Feedback in the Simulation of the Madden–Julian Oscillation, J. Clim., 28, 6979–6994, https://doi.org/10.1175/JCLI-D-14-00767.1, 2015.

8. Figure 11 and lines 520–523: This looks like a new way to test uncertainty. It would be helpful to know how many sensitivity tests were done to generate the error bars. Also, any justifications for this?

Response: Thank you for this comment. The error bars in Fig. 11 are intended to assess the sensitivity of the results to the choice of analysis domain. We conducted eight sensitivity tests by independently shifting each boundary of the reference region (15°S–10°N, 90°E–180°). Specifically, the eastern and western boundaries were shifted by ±10°, and the northern and southern boundaries by ±5°, while the other three boundaries remained unchanged. The error bars represent the minimum-to-maximum range across the tested domains, rather than statistical uncertainty. The consistently larger values in DTA than in CTL indicate that our conclusions are robust to these changes in the analysis domain. We have clarified the procedure and its rationale in the caption of Fig. 11.

9. Lines 526–537: Please refine the explanation of the vertical structure by distinguishing lower-tropospheric moisture convergence leading MJO convection from upper-tropospheric processes supporting stratiform anvils. Since the pressure-velocity diagnostic is averaged over 1000–200 hPa, a brief qualification of the inferred vertical structure and timing would help align the discussion with the diagnostics shown.

Response: Thank you for this careful observation. We further checked the vertical profiles of pressure velocity anomalies and found that the enhanced upward motion in DTA relative to CTL occurs primarily below 600 hPa. This stronger lower-tropospheric upward motion may facilitate vertical moisture transport and favor convective development, whereas the increased high cloud cover is associated with enhanced upper-tropospheric longwave radiative trapping. We have revised Section 4.3 to distinguish these processes and clarify that their temporal sequence cannot be

determined from the present diagnostics (Lines 574–579).

"The increased high cloud cover and greater column moisture in DTA favor stronger longwave radiative trapping. Further examination of the vertical profiles of pressure velocity indicates that the enhanced upward motion in DTA occurs primarily below 600 hPa (not shown), potentially facilitating vertical moisture transport and convective development. These changes are consistent with enhanced cloud–radiation feedback under weak precipitation conditions, although their temporal relationships cannot be directly established from the present diagnostics."

10. Lines 59–62: "convection schemes" -> convective parameterization schemes.

Response: Corrected as suggested.

11. Lines 98–101: Please clarify what is meant by "did not conduct targeted experiments to verify their effects". As far as I know, Huang et al., (2019) did examine how the changed parameter values may impact MJO simulation from process-oriented diagnostics.

Response: Thank you for this clarification. We agree that Huang et al. (2019) examined the physical processes associated with parameter changes, particularly the role of moisture preconditioning and shallow-convection feedback in MJO simulation. Our original statement did not adequately acknowledge this contribution. We have therefore revised the Introduction to more accurately describe their work and clarify the focus of our study (Lines 90–94). The revised text reads:

"Using the same PPE simulations in the BCC model, Huang et al. (2019) identified three influential cloud and convection parameters by comparing good and poor MJO simulations and highlighted the importance of moisture–shallow convection feedback. Nevertheless, a systematic connection between parameter sensitivities and the distinct physical processes governing MJO propagation and maintenance remains to be established in CAM6."

12. Lines 166–167: Please specify which earlier PPE studies you are referring to by adding the relevant citations.

Response: Thank you for the reminder. We have added references to the revised manuscript.

13. Lines 178–179: This is not accurate. Several CTL parameter values are offset from the midpoint, including the default downdraft fraction of 0.1 within 0.01–0.99 and convective timescale of 3600 s within 1800–7200 s. Please also adjust the related wording at lines 325–326.

Response: We agree with the reviewer that the original statement was inaccurate. We have removed the inaccurate descriptions in Sections 2.1 and 3.2 of the revised manuscript.

14. Line 228: "obtained via a 20–90 day band-pass filter" -> obtained via 20–90-day bandpass filtering.

Response: Corrected as suggested.

15. Figure 2 appears twice on consecutive pages. Please remove the duplicate.

Response: The duplicate Figure 2 has been removed.

16. Figure 4 caption, line 352 "obtained by regression total fields" -> obtained by regressing total fields.

Response: Corrected as suggested.

17. Lines 378: Please clarify what "though still about half of the observed value of unity" means.

Response: The observed projection coefficient for the MSE tendency is 1 by definition, as the observed MSE tendency pattern serves as its own reference (Eq. (6)). Therefore, the phrase "though still about half of the observed value of unity" indicates that the projection coefficient in DTA (~0.5) is approximately half the observational value.

18. Figure 12 and lines 606–614: Please provide a separate diverging color scale with negative and positive values for the DTA minus CTL difference in panel (d). The current color bar contains only nonnegative values, making the negative differences discussed in the text difficult to interpret.

Response: Thank you for this suggestion. This issue was also raised by Reviewer #1 (Comment 16). We have revised Fig. 12d to use a separate diverging color scale that clearly displays both positive and negative precipitation differences. The corresponding description in Section 5 has also been updated. The revised figure is provided as Fig. R9 in our response to Reviewer #1.