Dear Dr. Lucas Harris,

Thank you very much for your detailed comments and suggestions on this manuscript. Your feedback has been tremendously helpful to us. Below are our responses and the modifications made in light of some of the issues you raised.

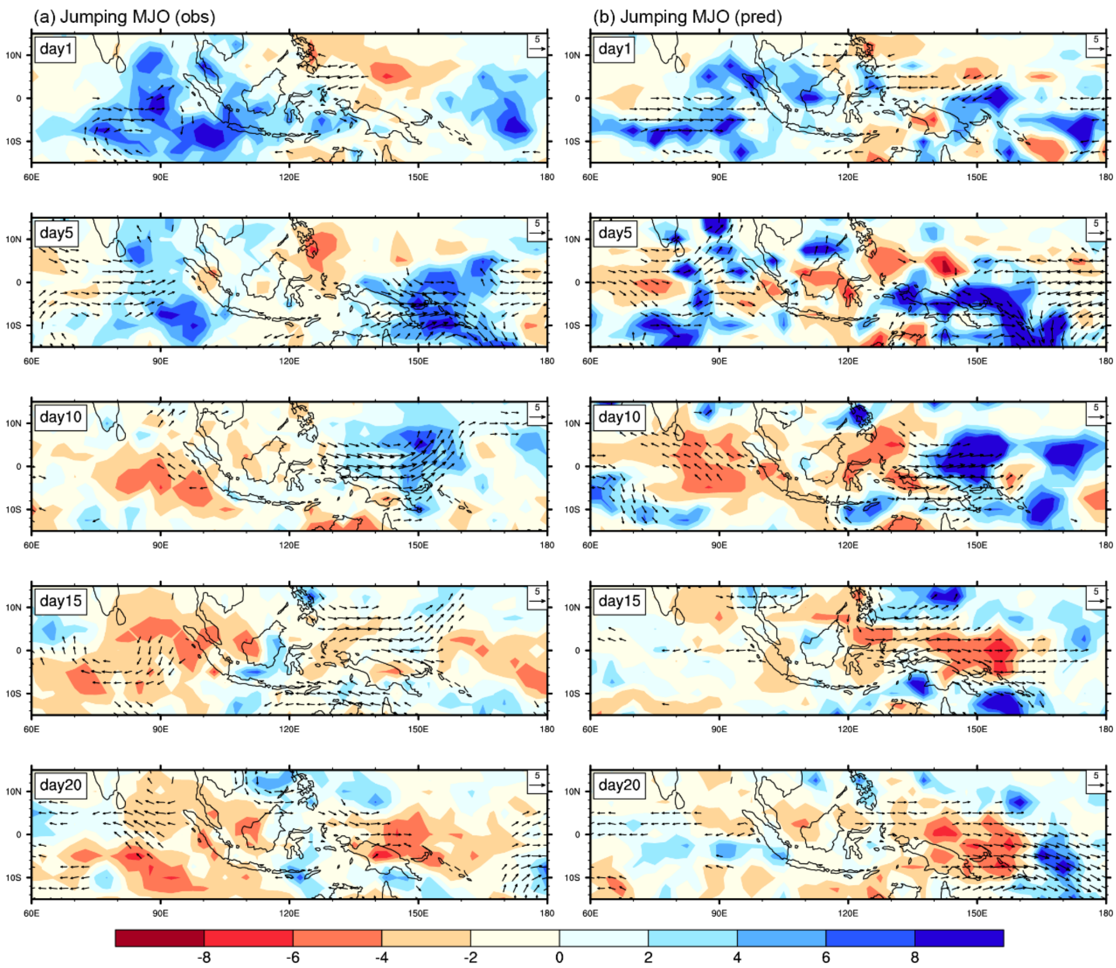
Broad comments:

<u>Comment 1:</u>

Breaking down the MJO into different types is a useful way to determine model biases. One thing I note from Figure 5 is that the simulated "jumping" MJOs look much more like the simulated slow MJOs than the observed jumping structure. Is part of the difficulty simulating these modes that the model lacks the ability to correctly simulate the distinct jumping and slow modes?

Response:

Thank you for your constructive comments about the jumping and slow modes of the MJO. Since Figure 5 depicts zonal averages, some nuances may indeed be obscured. However, upon closer examination of the Evolution patterns for the jumping MJO (see the figure below), it becomes evident that the model simulations also capture signals indicative of "jumping". By the fifth day, we observe interruptions in convective signals over the MC region. However, due to potentially stronger convective activity, these signals may not be as pronounced in the zonal averages depicted in the Hovmöller diagram. Thus, while the distinction may not be as clear in Figure 5, the model does exhibit characteristics of the jumping MJO, albeit potentially overshadowed in zonal averages. We have revised the manuscript (see lines 317-319 and Figure A3 of the revised manuscript) and clarified these points further.



<u>Comment 2:</u>

The composite simulated MJO structures shown in Figure 6 appear to be significantly disrupted; most notably, the fast mode has a strange equatorial dry anomaly and enhanced westerlies at day 20 extending all the way to nearly 180° longitude. This appears to be something like an anomalous westerly wind burst which could in turn have impacts on ENSO prediction. Could the authors comment on what this physically might represent, or is it a model anomaly that is challenging to explain?

Response:

We think this phenomenon is also related to the model's bias in moisture. As mentioned in the revised manuscript (Lines 324-333), a positive moisture bias may lead to enhanced convection. During the convective development phase, this results in strengthened easterly winds dominating the convective activity, thus accelerating the MJO's propagation. Conversely, after the MJO traverses the MC region, during its decaying phase, the persistently strong convection also leads to intensified westerly winds dominating the convective activity in the western part, hastening the MJO's decay process (Page 14 of the revised manuscript).

Comment 3:

The authors' attribution of the MJO propagation errors and over-convection to a moist bias is certainly plausible and supported by the evidence. What I find strange is that the moisture bias is smallest near the Maritime Continent but the MC barrier is still a challenge for these simulations. Is the MC barrier a separate problem for the model not directly related to the propagation biases?

Response:

In the IAP-CAS model, although some moisture bias is present, we can relatively accurately capture the gradient of background moisture over the Maritime Continent during the winter (see Figure 10). As a result, the IAP-CAS model performs relatively well in simulating the propagation of the MJO over the Maritime Continent region. However, it may lead to MJO decay due to the robust development of the simulated propagating MJO negative phase after crossing the MC region (see lines 305-316 of the revised manuscript). Many other models may still encounter challenges with the "MC barrier" due to inaccuracies in simulating the gradient of background moisture over the Maritime Continent during the winter, as highlighted by Gonzalez and Jiang (2017).

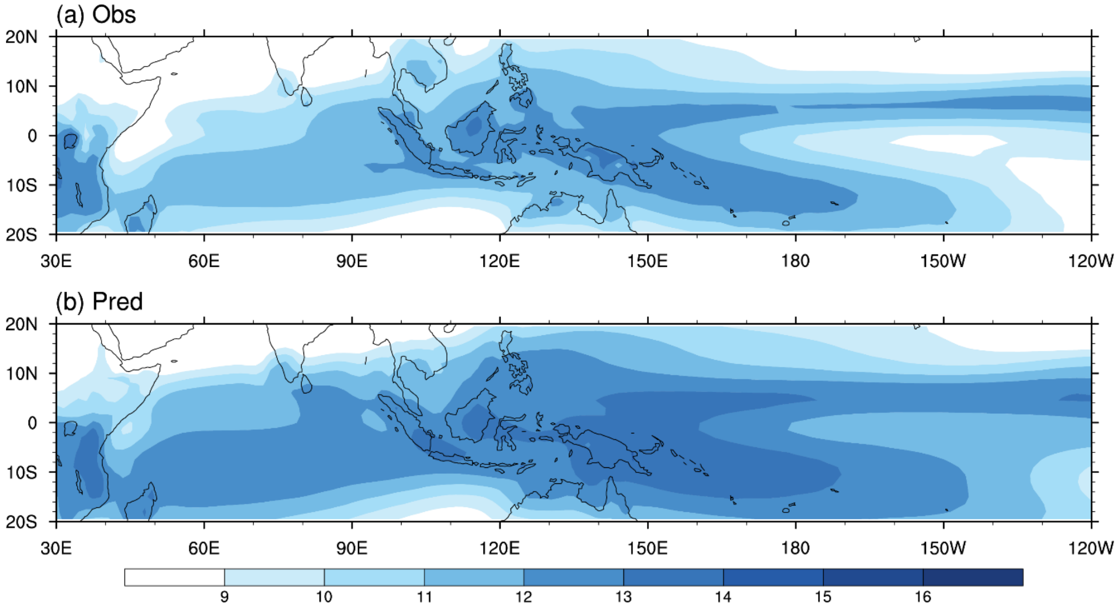
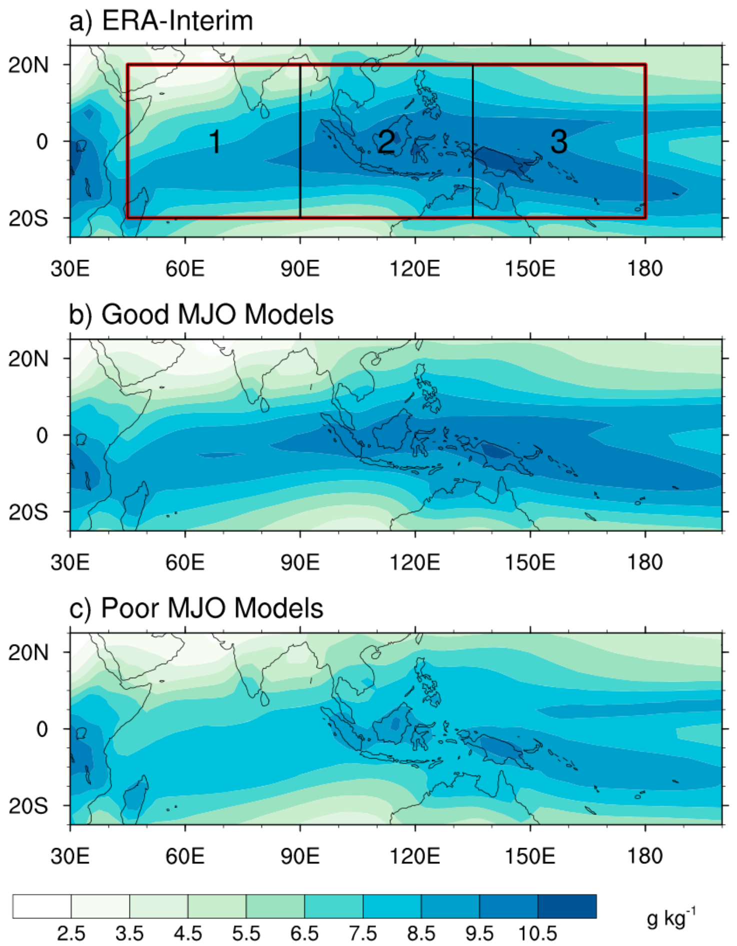


Figure 10. The winter (November–April) mean specific humidity (g kg^{-1}) on 850hPa for (a) observation and (b) IAP-CAS model.



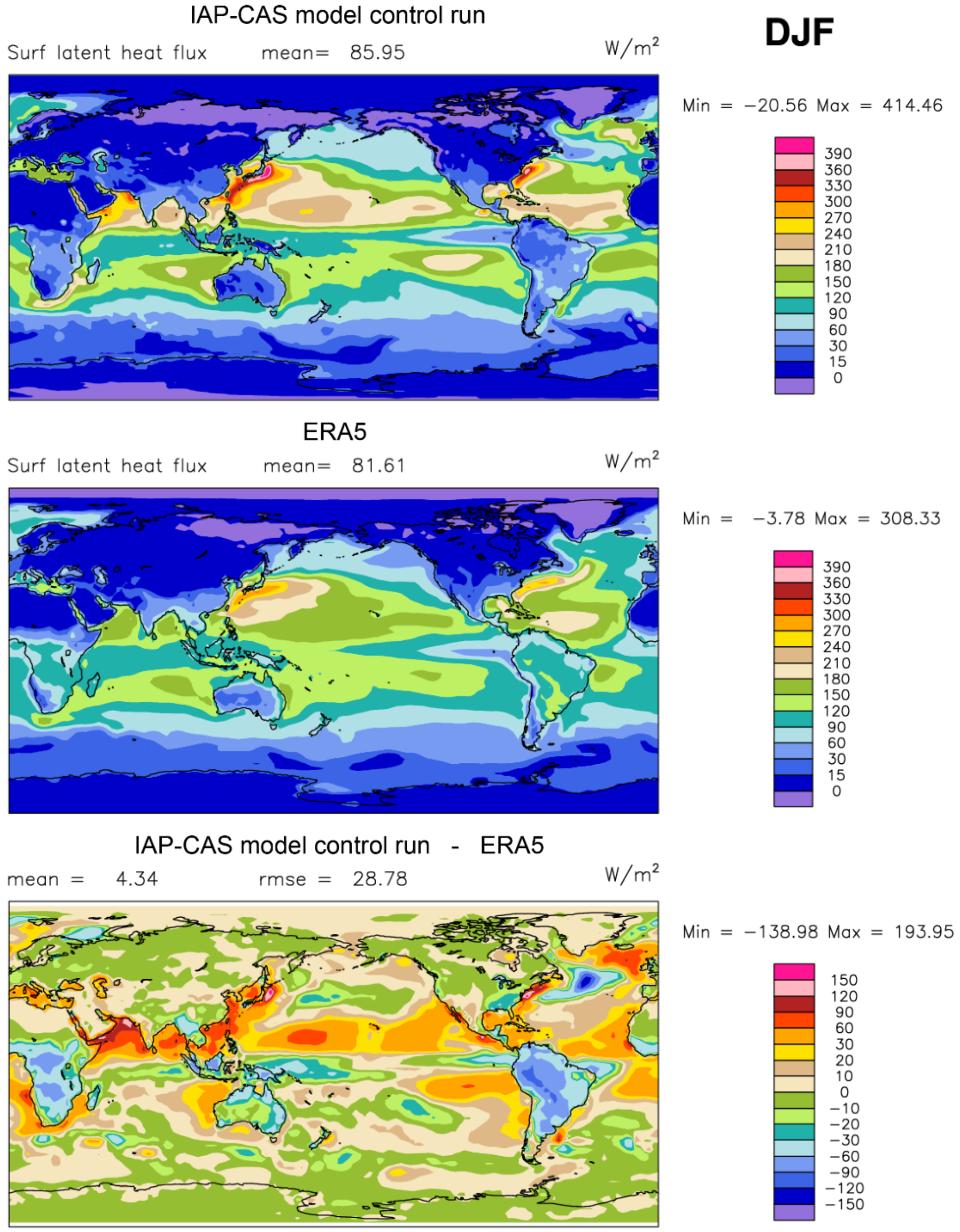
Gonzalez, A. O. and Jiang, X.: Winter mean lower tropospheric moisture over the Maritime Continent as a climate model diagnostic metric for the propagation of the Madden-Julian oscillation, Geophysical Research Letters, 44, 2588–2596, https://doi.org/10.1002/2016GL072430, 2017.

Comment 4:

The authors believe that a positive bias in evaporative fluxes could be causing the positive moisture bias; is it possible to check this?

Response:

After reviewing your suggestions, we investigated the potential cause in IAP-CAS model control run and summarized our findings in the figure below. As depicted in the figure below, during the boreal winter (December, January, and February, in short of DJF), when comparing with ERA40 data, we utilize the Surface Latent Heat Flux variable, which to some extent reflects the evaporation conditions. In the equatorial regions, it is evident that the evaporation in the IAP-CAS model is significantly larger.



Surface latent heat flux in the IAP-CAS model

Comment 5:

The target analysis in Figure 4b is a nice alternate way of assessing the predictive skill of the system. Can this be interpreted as a prediction of the development of the MJO and/or even of the genesis of MJO events?

Response:

The target analysis involves selecting cases where the amplitude of the MJO exceeds 1 and analyzing the forecasts for the 65 days preceding these cases. This analysis serves as a metric for evaluating the forecasting system's performance in capturing MJO event precursors. When combined with the initial analysis, we gain insight into the forecast skill before and after the occurrence of strong and weak MJO events.

Minor comments:

<u>Comment 1:</u>

There is too much detail in the tables. I think tables 2–5 are unnecessary for the body of the paper and can be moved into the supplemental data.

Response:

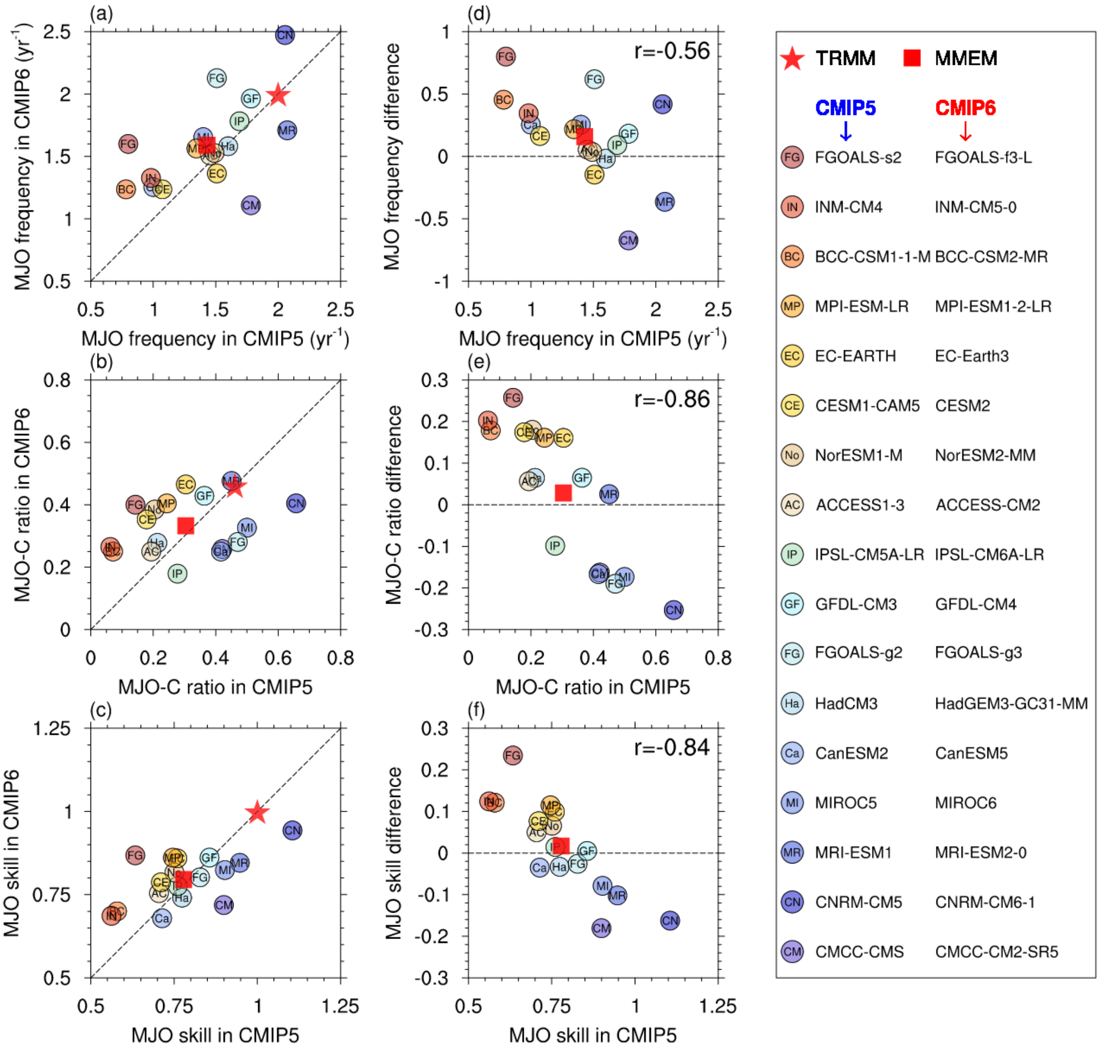
Thank you for your thoughtful suggestion. We have now revised the manuscript accordingly, moving tables 2–5 into the supplemental data as per your recommendation. Your feedback is greatly appreciated.

<u>Comment 2:</u>

Lines 49–51: I didn't understand the statement "models that exhibited lower forecast skills in [CMIP5] have demonstrated noteworthy improvements in the simulation of MJO". Did you mean that models with poor MJOs in CMIP5 had significantly improved MJOs in CMIP6? Note that these should not be the skill of MJO forecasts since CMIP simulations are long uninitialized simulations.

Response:

From CMIP5 to CMIP6, certain models exhibited a notable enhancement in their MJO skills, as well as the IAP-CAS model. The IAP-CAS model in CMIP5 is FGOALS-s2, while in CMIP6 is FGOALS-f3-L/H. (see the figure below). Here, the emphasis lies on improvements in the physical frameworks of the models for simulating MJO, excluding the impact of initialization.



Chen, G., Ling, J., Zhang, R., Xiao, Z., and Li, C.: The MJO From CMIP5 to CMIP6: Perspectives From Tracking MJO Precipitation, Geophysical Research Letters, 49, https://doi.org/10.1029/2021GL095241, 2022.

Comment 3:

Section 2.1: FV3 only needs the semi-implicit sound wave solver if run nonhydrostatic; I believe these simulations are hydrostatic as are most FV3-based climate models.

Response:

Yes, we fully agree with you. The FV3 dynamic core in the IAP-CAS model is currently used by the hydrostatic solver. This choice is based on the IAP-CAS model's resolution of C96, where the difference between hydrostatic and nonhydrostatic solvers can be neglected. However, a nonhydrostatic solver entails higher computational costs. Therefore, we selected the hydrostatic solver. Nevertheless, as we plan to enhance the model resolution from C96 to C384, we'll certainly switch to the nonhydrostatic solver.

Comment 4:

Section 2.2: That the S2S forecasts are nudged to GFS forecasts for the first ten days is interesting. Is this to avoid coupling shock at initialization?

Response:

Indeed, that is one of the reasons. Additionally, we know that the S2S forecast lies between weather prediction and climate projection, influenced by both initial conditions and external forcing. Initially, S2S prediction skills lag behind those of weather forecasts for a certain period. Thus, we aim to enhance the quality of initial forecasts in S2S by nudging GFS weather forecast data to ultimately improve S2S prediction accuracy. In our system (the IAP-CAS model v1.3) described in this manuscript, we employed 10 days of GFS data for nudging. However, through further investigation, we have found that perhaps the optimal nudging duration is 5 days (Zeng et al., 2023). This refinement will be integrated into our forthcoming S2S system upgrade (the IAP-CAS model v1.4).

we have updated the manuscript with these explanations. Please refer to lines 148-151 in the revised manuscript.

Zeng, L., Bao, Q., Wu, X., He, B., Yang, J., Wang, T., Liu, Y., Wu, G., and Liu, Y.: Impacts of humidity initialization on MJO prediction: A study in an operational sub-seasonal to seasonal system, Atmospheric Research, 294, 106946, https://doi.org/10.1016/j.atmosres.2023.106946, 2023.

Comment 5:

Section 2.4: Am I correct that there are 4 ensemble members initialized each day over a 20-year period? This would then be a very large dataset.

Response:

You're right, this is indeed a rather large dataset, with a total size of approximately 11TB. Evaluating this dataset, I believe, would greatly benefit the further enhancement of the model. The details regarding the dataset size have also been updated in the revised manuscript. Please refer to lines 116-119.

Comment 6:

Section 3.3: What is "silhouette clustering"?

Response:

"Silhouette clustering" is a technique used in cluster analysis to assess the quality of clustering results. It calculates a silhouette coefficient for each data point, which measures how similar that point is to its own cluster compared to other clusters.

Essentially, it helps to determine the appropriateness of the clustering by quantifying the compactness and separation of clusters. Details are in the following paper and we have also updated the necessary references in the revised manuscript, see lines 255-256.

Rousseeuw, P.: Silhouettes - a Graphical Aid to the Interpretation and Validation of Cluster-Analysis, J. Comput. Appl. Math., 20, 53–65, https://doi.org/10.1016/0377-0427(87)90125-7, 1987.

Comment 7:

Equation 11: Is this calculation used to compute condensational heating in both the model and observations? Why was the condensational heating output by ERA5 and the model not used? (I understand if this was not output from the model, and ERA's condensational heating estimate may be skewed by the data assimilation used by the reanalysis.)

Response:

Yes, condensational heating is indeed computed both in the model and observations. The purpose of this approach is to mitigate the influence of other factors, including the potential impact of data assimilation, and ensure an equitable comparison between the model and observations.

Comment 8:

Figure 14: Is this the same as Figure 6, but the shading is Q850 instead of precipitation?

Response:

Yes, in this figure, we aimed to illustrate that besides the winter mean moisture state, MJO-related moisture anomalies also have a significant impact on MJO prediction. Adding wind vectors allows us to more intuitively observe the advection of MJO-related moisture anomalies, even though this wind field is the same as in Figure 6 (which has been modified and referenced as Figure 7 in the revised manuscript).

Comment 9:

Figure A2: I see FGOALS-f2 is the model shown in this paper. Are the other models shown here earlier versions of FGOALS, and in what order were they developed?

Response:

These models don't correspond to a simple new-to-old version relationship. All these models originate from the Institute of Atmospheric Physics, Chinese Academy of Sciences. FGOALS-g1, FGOALS-g2, and FGOALS-g3 represent successive versions of the Flexible Global Ocean-Atmosphere-Land System model Grid-point, participating in CMIP3, CMIP5, and CMIP6, respectively. Conversely, FGOALS-f2 and FGOALS-f3 are Finite Volume versions. While FGOALS-f2 primarily focuses on seamless prediction, FGOALS-f3 emphasizes climate simulation. FGOALS-f3 also participated in CMIP6 experiments.

Comment 10:

For the most part, the article is well-written. I do see some English usage that could be improved. Here are some examples:

- Title "Dynamic" → "Dynamical" and "of IAP-CAS" → "of the IAP-CAS"

- Line 66: "low" → "lower"

- Lines 78–82: recommend using future or present tense instead of past tense in this paragraph.

- Line 234: "inconsecutive movement"; do you mean discontinuous propagation/movement?

- Line 235: "coupling" → "coupled.

Response:

Thanks for your careful checks. We are sorry for our carelessness. Based on your comments, we made the corrections to make the word harmonized within the whole manuscript.

We sincerely appreciate the time and effort invested by the reviewers in evaluating our manuscript. We look forward to any additional feedback or suggestions.

Thank you and best regards.

Sincerely,

Qing Bao

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