Dear Prof. Liu,

We greatly appreciate your insightful and helpful comments regarding our manuscript, especially concerning the physical explanation for the rapid propagation speed of MJO in the model. We have carefully revised the manuscript in response to your comments, primarily focusing on Sections 5 and 6, as well as addressing various specific details. Below are the point-by-point replies to your comments and concerns.

<u>Comment 1:</u>

It appears that the IAP-CAS model has already been involved in the S2S project, and we can download the hindcast data from the S2S project. Is the model used in this work the same version as the one from the S2S project?

Response:

Yes, the hindcast data available on the S2S website and the model described in the manuscript are indeed the same version (IAP-CAS-V1.3). Our team's research has found that incorporating moisture initialization has improved the model's skill, as referenced in the following article. Therefore, real-time forecast data has now transitioned to the new version (with moisture initialization, increasing ensemble size to 16 members, IAP-CAS-V1.4). We're going to send the hindcast GRIB datasets of the new version to the S2S data archive.

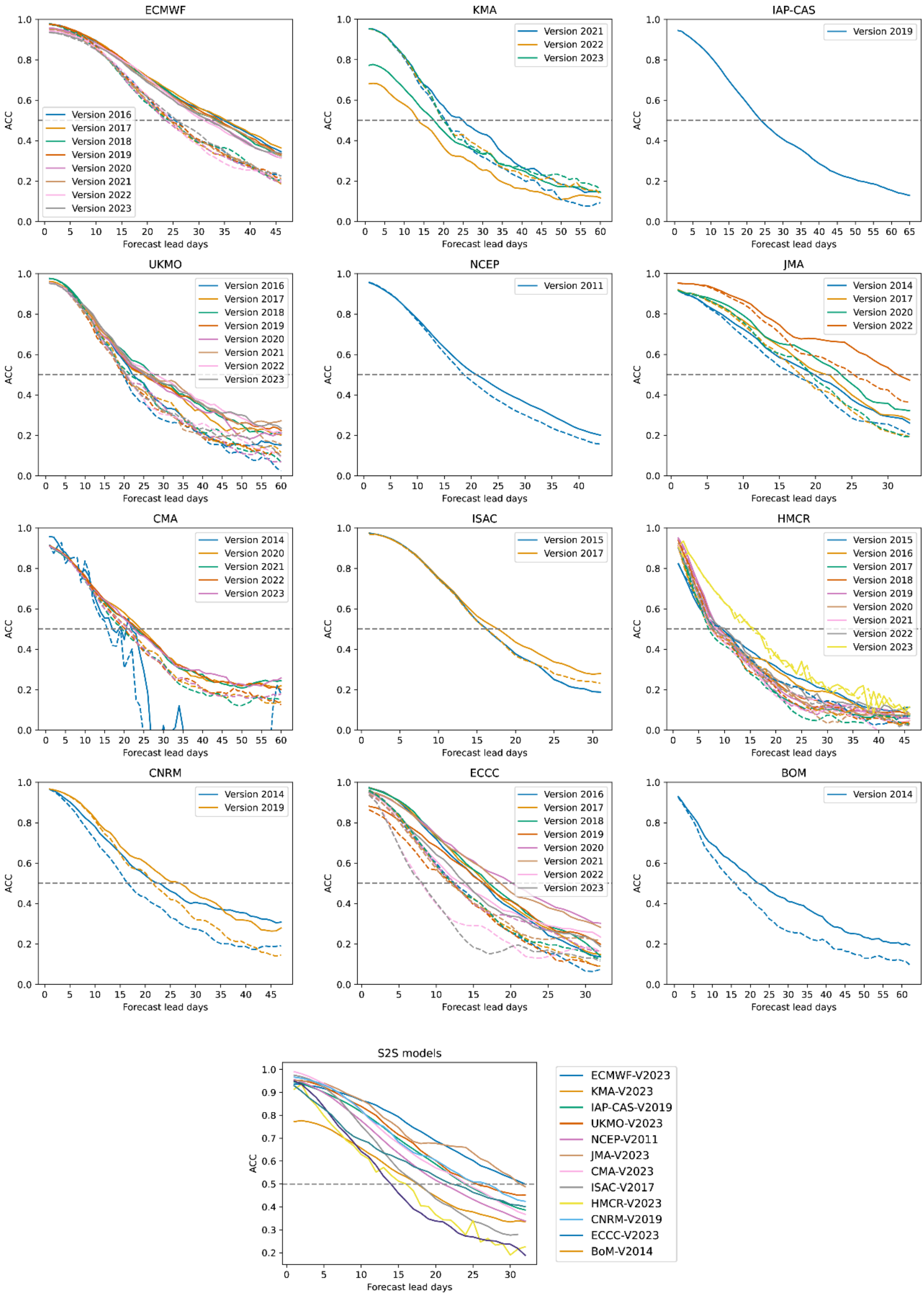
Zeng, L., Bao, Q., Wu, X., He, B., Yang, J., Wang, T., Liu, Y., Wu, G., and Liu, Y.: Impacts of humidity initialization on MJO prediction: A study in an operational sub-seasonal to seasonal system, Atmospheric Research, 294, 106946, https://doi.org/10.1016/j.atmosres.2023.106946, 2023.

<u>Comment 2:</u>

Why not create a figure comparing the prediction skill among all S2S models? Some studies have conducted such comparisons, and it is necessary to present the average and best skill among the current S2S models.

Response:

Your suggestion is excellent, and we have compared the prediction skills of 12 S2S models for MJO in the Appendix (Figure A4), using the latest versions of each model. We have revised the figure to include comparisons across multiple models and their different versions. Additionally, we have also assessed the skill of deterministic forecasts versus ensemble forecasts. The modified figure is provided below.



The MJO index of 12 S2S models and ERA-Interim from the S2S website (http://www.s2sprediction.net/) is used for evaluation during the standard hindcast period 2001-2010, except for CMA, which spans from 2008 to 2013. The solid lines represent the skill of ensemble mean forecasts, while the dashed lines represent the skill of deterministic forecasts.

Comment 3:

Was the prediction skill of 24 days calculated for the annual MJO or for the boreal winter MJO? It is important to clearly state whether the main conclusions are for the annual mean or for the boreal winter. (Sometimes you show the results for the annual mean, while some figures were drawn for the boreal winter), as S2S models exhibit a significant annual cycle in the prediction of MJO.

Response:

The prediction skill of 24 days is calculated for the annual MJO. In section 4 of the paper, our evaluation primarily focuses on the annual MJO, whereas sections 5 and 6 delve further into different types of boreal winter MJO events. We have included clarifications in the revised manuscript, which can be found in lines 232 and 268, as well as in the captions of Figures 3 and 5.

Comment 4:

Lines 168-170, you only have 16 ensembles since 2019, while in Fig. 3, you also presented 16 ensembles for the long period of 1999-2018.

Response:

The mention of "Since June 1st, 2019, the IAP-CAS S2S system has been operating 16 ensemble members daily' in lines 168-170 refers to real-time forecast results, whereas only four ensembles are available for hindcast data. However, in Figure 3(c), we employed the time-lagged method to increase the ensemble size from 4 to 16, primarily to assess the extent to which the time-lag method enhances MJO skill. Appropriate clarification has been added in the paper to prevent misunderstandings, as indicated in the caption of Figure 3.

Comment 6:

Line 42: The impact of MJO on sub-subseasonal prediction of each sub-monsoon precipitation has been well discussed (Liu et al., 2022), and should be referenced.

Response:

We appreciate the suggestion to reference the work of Liu et al. (2022), which discusses the impact of MJO on the sub-subseasonal prediction of each sub-monsoon precipitation. We have incorporated this reference into our manuscript accordingly, as seen in line 43 of the revised manuscript.

Comment 7:

Lines 117-119: There were many phenomena that affect the MJO propagation. I suggest deleting this statement as it is not directly related to this work.

Response:

Thank you for your suggestion. The statement has been removed.

<u>Comment 8:</u>

Lines 145: I cannot follow why you use the 10-day forecast nudging from the GFS forecast. Should we attribute the good prediction skill of 24 days to IAP-CAS or GFS?

Response:

Thank you for your feedback. Our aim is to improve S2S forecast skills, which require different strategies than traditional climate predictions. According to general consensus, numerical weather predictions are more accurate than climate predictions for the first 10 days. While we use 10-day GFS weather forecast data to enhance S2S forecasts, our experiments have revealed that the optimal nudging duration is 5 days (Zeng et al. 2023). This adjustment will be implemented in our next-generation S2S system.

<u>Comment 9:</u>

Lines 245: Was this underdispersive due to weak initial perturbation of the time-lag method?

Response:

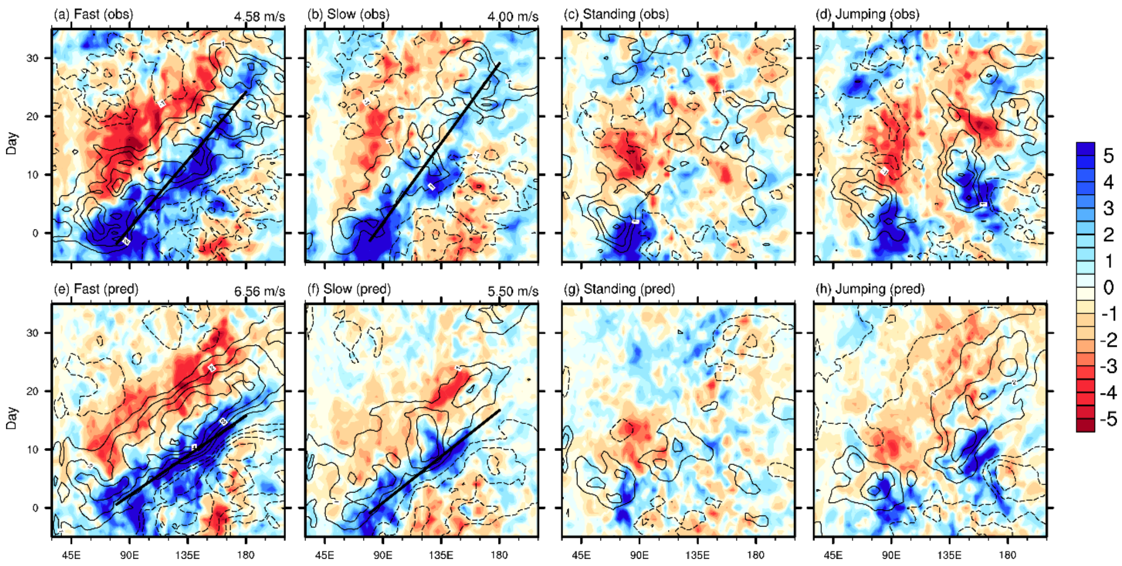
Yes, we think so. Hence, we are also considering adopting a new ensemble generation method to address this issue.

<u>Comment 10:</u>

Lines 306-310: You can calculate the phase speed in this Hovmöller diagram directly.

Response:

Thank you for your suggestion! We now directly calculate the phase speed in this Hovmöller diagram, as shown in the figure below. We have also made corresponding modifications in Section 5 to align with the adjustments.



Comment 11:

I have a different explanation for the phase speed difference. In Fig. 6, the predicted zonal scale of the MJO, represented by the easterly wind anomalies to the east of the MJO convective center, covers a larger region than observed, which is more obvious for the slow-propagating mode. The moist central Pacific in IAP-CAS overestimates the zonal scale of the MJO, which will increase the eastward propagation speed of the MJO, since the phase speed is inversely proportional to the wave number, as shown in previous work (Wang et al. 2019Sci. Adv. Diversity of MJO). The increased MSE tendency to the east of the MJO can explain the increased amplitude of the MJO, rather than the propagation speed. Let's make an assumption: for the same speed, the stronger MJO also has a larger MSE tendency to the east than the weaker MJO.

Response:

Thank you for your insightful perspective. After careful consideration, we agree with your explanation regarding the phase speed difference. We appreciate your suggestion to supplement our analysis in Section 6 accordingly. In this section, we have elaborated on how moisture theory can elucidate the development of intensity in propagating MJO events, thereby leading to an amplification in the intensity and zonal scale of the coupled wave, consequently resulting in the observed faster MJO propagation speed.

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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