We thank the two anonymous reviewers for the valuable comments that contributed to a substantially improved version of the manuscript. The major changes resulting from the two reviewer reports obtained are:

- adding further model evaluation criteria (regarding interannual variability, spatial distribution, 850hPa wind) resulting in some changes in the selected model set

- focusing the results on the best performing models only, called TOP6 throughout the manuscript and adapting previous results accordingly

- focusing on area that additionally fulfills monsoon definition (JJA minus DJF rainfall exceeds 2 mm/day) and providing results only based on this area

- using observational data (GPCC) instead of reanalysis data (W5E5) for reference

- discussing underlying physical mechanisms for changes in mean circulation (by analysing wind 850 hPa) and adding a new subchapter regarding changes in circulation that reveal a northward shift of the ITCZ that is responsible for the increase in rainfall in South China.

- adding a significance measure to give insight into the robustness of the projections following IPCC standards

We are looking forward to the feedback from the reviewers.

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Reviewer #1

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Review of "Consistent increase of East Asian Summer Monsoon rainfall and its variability under climate change over China in 34 coupled climate models" by Anja Katzenberger and Anders Levermann

General Comments: In this paper, the authors examined the future changes in the mean precipitation over the EASM region as well as its variability under different emission scenarios. Their analysis suggests that both mean precipitation and its variability are increasing under all emission scenarios, with a stronger response under stronger emission scenarios. There were many studies using CMIP5/6 model simulations that looked at the precipitation changes over different monsoon regions of the globe. Also, they find that the "wet-gets-wetter" arguments holds true for EASM region. Overall, the types of analyses presented in this paper are useful for regional climate change assessments. I have some specific concerns that need to be addressed before accepting the article.

Specific comments:

1. My major concern in this paper is the way in which the models are grouped. I don't have any issues with the "Group A" models which have a mean precipitation withing +/- 2 std of the observations (reanalysis). However, the Group B consists of the models in both sides of the extremes. This means that when you take the ensemble mean, you are averaging the outliers on two sides and as a result there may not be any

use of grouping the models in this way. You may either focus on the Group A models or have three groups (one group each for outliers on each side).

We agree with the reviewer that focusing on group B models as an individual group does not provide very useful insights. Thus, we follow the reviewer's proposition to focus on these best performing models. In the revised manuscript, we also refined the selection of Group A models by adding further selection criteria (STD, CRSME, WIND 850 hPa) resulting in an adapted group of selected models, called TOP6 (lines 90f and 106f).

We also want to briefly note that it can be useful to show the model results for a multi-model mean of all models (not group B models only), particularly because in this case the overestimating models compensate for the underestimating models and the multi-model mean results in often showing good performance. See e.g.

Sing & AchutaRao (2018): Quantifying uncertainty in twenty-first century climate change over India

Tebaldi, C. & Knutti, R (2007): The use of multi-model ensemble in probabilistic climate projections

2. It would be interesting to see the seasonal mean circulation changes as well. This will give a better understanding of the changes in the underlying dynamics

We strongly agree with the Reviewer that adding mean circulation changes is improving the manuscript which is why we added the change of wind at 850hPa between 2081-2100 compared to the reference period as multi-model mean. We also discuss the most relevant changes and compare individual model projections (lines 160f):

The TOP6 multi-model mean projects that the northeastward winds over the Bay of Bengal in 0-10° N will weaken by up to 3m/s, while they will intensify in 0-20° N. This indicates a northward shift of these southwest winds and strengthens the moisture supply to South China where an increase in rainfall is projected by 5 out of 6 models. This shift in wind patterns is associated with a northward shift of the ITCZ originated in the warming land temperatures due to climate change. The most intense wind change is projected by EC-Earth3 and IPSL-CM6A-LR and the only model that does not project this trend is MRI-ESM2-0.

Additionally, half of the TOP6 models (EC-Earth3, GFDL-CM4, MPI-ESM1-2-LR) project that the southwinds originated in the South China Sea will have an increasing tendency towards east. However, this is not a robust finding given the strong intermodel spread in this region.

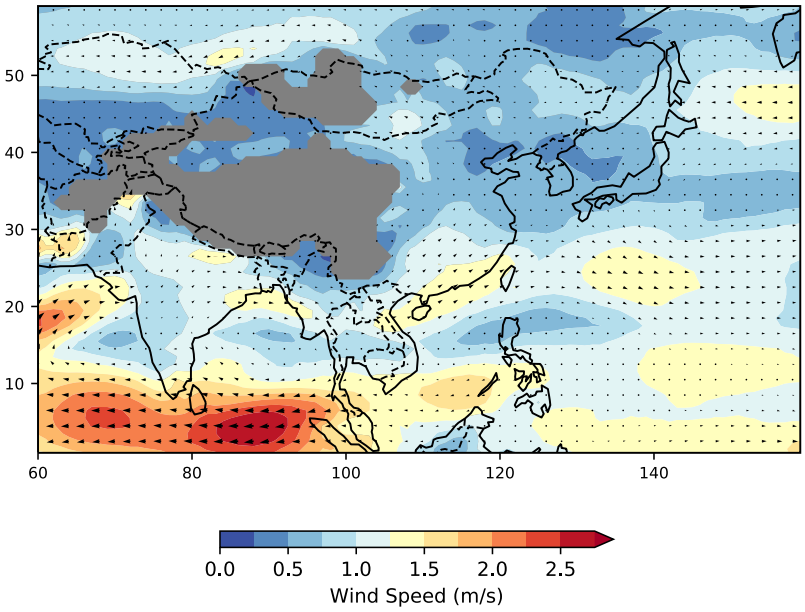

Figure 1. Change in wind vectors (850hPa) and wind speed (m/s) in 2081-2100 (SSP5-8.5) compared to the reference period in the MMM of the TOP6 models.

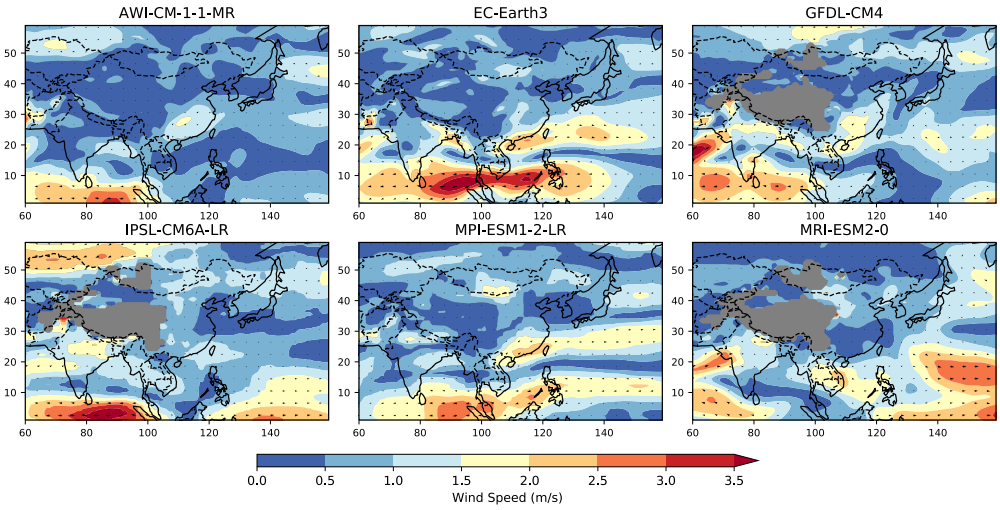

Figure 2. Change in wind vectors (850hPa) and wind speed (m/s) in 2081-2100 compared to the reference period for the TOP6 models.

3. The “wet-getter-wet” argument is not new. If you can look at the thermodynamic and dynamic components of the precipitation change, it can give a better insight.

We agree with the reviewer, that better insight is provided when adding thermodynamic and dynamic components. However, another publication has provided these results in the meantime, which is we decided not to reproduce the same results within this manuscript. We cite this study with regard to this contribution in line 207/208.

Xue, D., Lu, J., Leung, L.R. et al. Robust projection of East Asian summer monsoon rainfall based on dynamical modes of variability. Nat Commun 14, 3856 (2023). https://doi.org/10.1038/s41467-023-39460-y

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Reviewer #2

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General comment:

This study examined future changes of East Asian Summer Monsoon (EASM) including seasonal mean precipitation, interannual variability and extreme wet seasons using CMIP6 models. According to the simulated magnitude of regional, seasonal mean precipitation, the CMIP6 models are divided into two groups. The projections are then based on the group of models with reasonable magnitude of EASM precipitation. It is shown that mean precipitation, interannual variability and extreme wet seasons of EASM will increase in the future under different SSP scenarios.

However, the current analyses lack significance and robustness in a few aspects.

Firstly, many methods are inappropriate.

(1) The model evaluation is based on regional mean and seasonal mean precipitation over East Asia. But the EASM is a complex system, in which the monsoon circulation and spatial pattern of precipitation is very important. Hence this evaluation metric is insufficient to represent the EASM, which means that the model selection is not robust.

We added a broader set of model selection criteria (see lines 90f) including:

- The mean JJA rainfall is within two standard deviations of the observed mean in the GPCC dataset (1995-2014).

- The model's standard deviation is within plus/minus 50% of the observed GPCC standard deviation (1965-2014).

- The centered root mean square error (CRMSE) is smaller than 2 mm/day (1995-2014).

- The main features of the EASM circulation (southwest winds originated from the Bay of Bengal and western flank of the tropical Western Pacific High) are captured according to the JRA-55 dynamics (1995-2014)

In the revised manuscript, we performed the model selection on basis of these criteria resulting in 6 models with better performance regarding the EASM that we call TOP6. We provide new figures and a new table to present the results. Besides, we adapt all results throughout the paper accordingly.

Fig. 1 & 2 give a first insight into the refinement of the model selection criteria. All the details can be found in lines 90f and 105f.

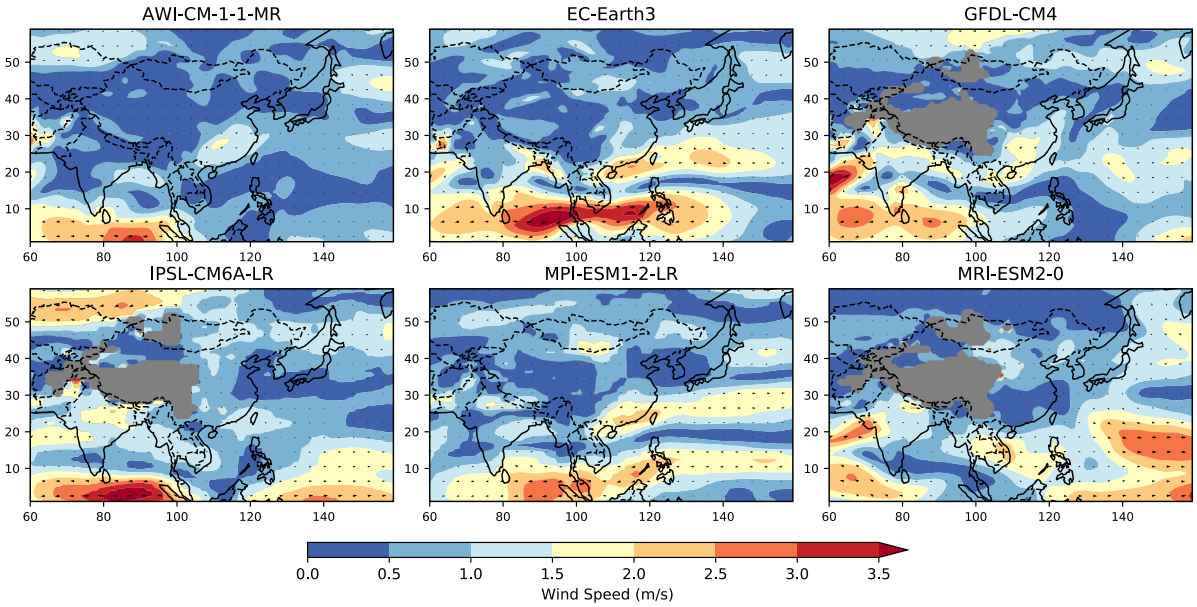

Figure 3. Wind vectors at 850hPa and wind speed (m/s) for 1995-2014 for the CMIP6 models with best performance regarding EASM (TOP6).

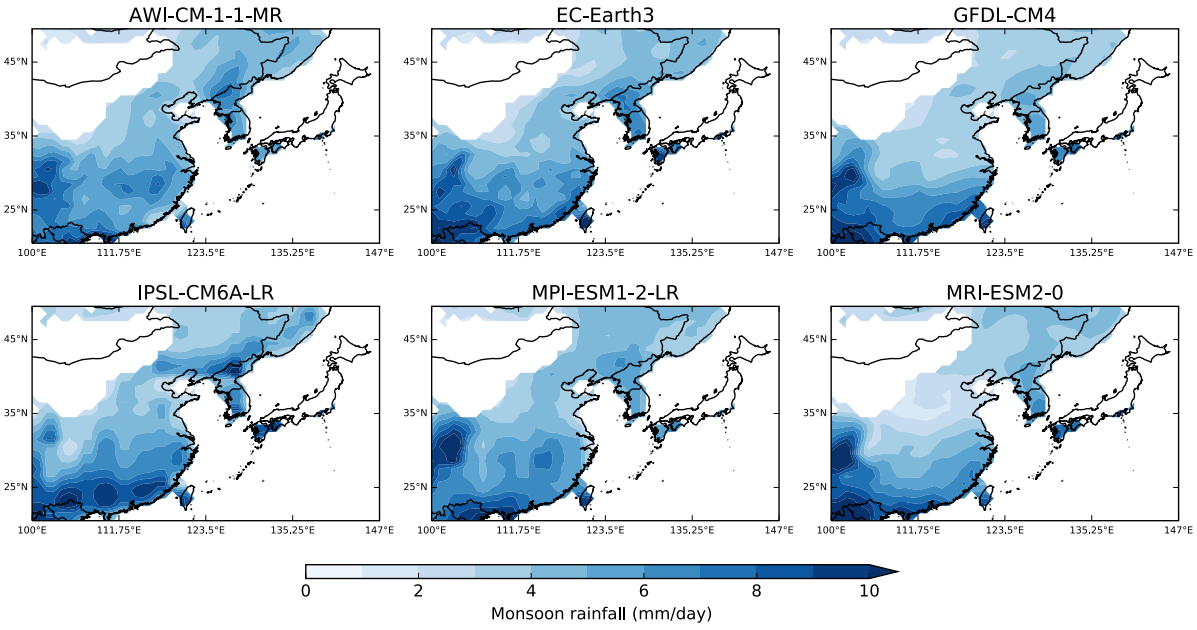

Figure 4. Spatial distribution of EASM averaged over the period 1995-2014 from the TOP6 CMIP6 models

(2) Reanalysis, rather than observational data, is used to evaluate the model simulated precipitation. As there are many observational datasets (e.g., APHRODITE, GPCC, GPCP) in East Asia, they should be used for model evaluation.

In the revised manuscript, we use data from the Global Precipitation Climatology Centre (GPCC) as observational reference data, see Fig. 3.

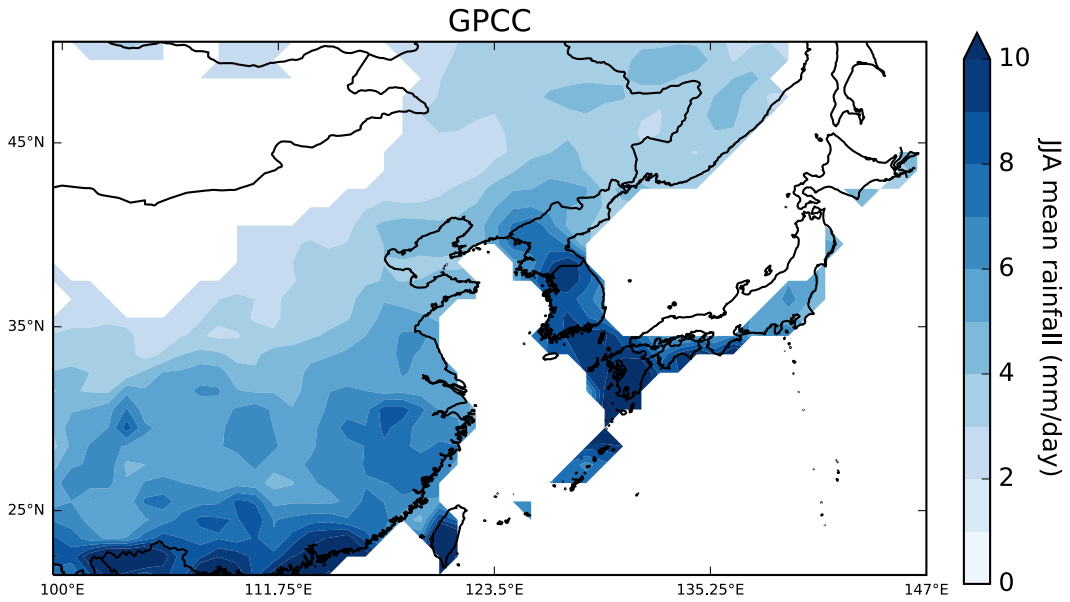

Figure 5. Spatial distribution of EASM averaged over the period 1995-2014 (GPCC data).

(3) As the focus is the EASM, the EASM domain could be defined more appropriately, taking into account many proposed definitions in previous studies.

We adapted now the definition for monsoon domain following the IPCC AR6 (JJA minus DJF mean rainfall exceeding a threshold of 2mm/day). Fig. 4 shows the adapted region.

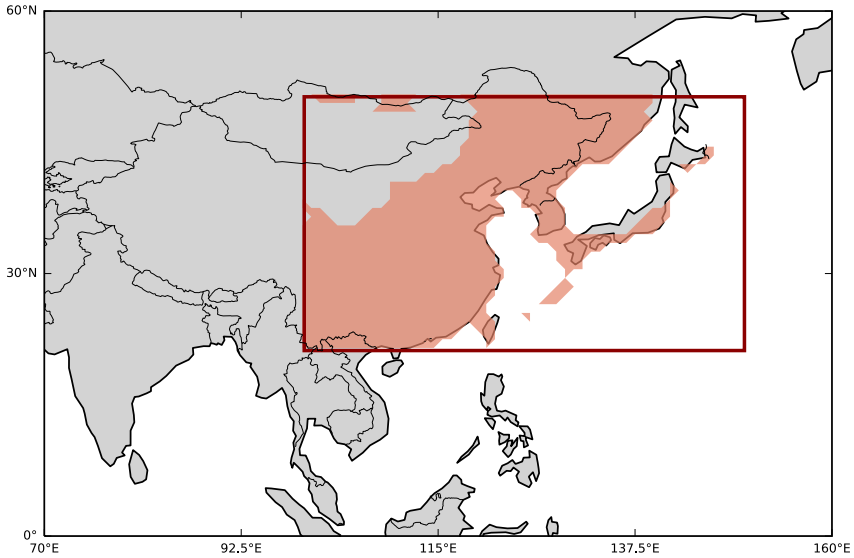

Figure 6. East Asian summer monsoon area within 20-50°N and 100-150°E as covered in the revised manuscript.

(4) Significance test for projected changes needs to be included. These limitations in methods weaken the robustness of the results.

We added significance checks following the IPCC AR6: The signal is classified as robust, where >=66% of models show change greater than the variability threshold and >=80% of all models agree on sign of change. See also lines 143-145.

Secondly, no physical understanding is provided at all. The study focuses on model simulated change in regional mean EASM precipitation, but no physical understanding of EASM change is provided.

We added a subsection that focus on the question: What are the underlying physical mechanism for the projected change in monsoon rainfall? We find that there is a northward shift of the southwest winds that is associated with a northward shift of the ITCZ. We also provide the MME changes of TOP6 model in 850hPa wind speed and direction, see Fig. 5. Changes are in lines 160f of the revised manuscript.

The TOP6 multi-model mean projects that the northeastward winds over the Bay of Bengal in 0-10° N will weaken by up to 3m/s, while they will intensify in 0-20° N. This indicates a northward shift of these southwest winds and strengthens the moisture supply to South China where an increase in rainfall is projected by 5 out of 6 models. This shift in wind patterns is associated with a northward shift of the ITCZ originated in the warming land temperatures due to climate change. The most intense wind change is projected by EC-Earth3 and IPSL-CM6A-LR and the only model that does not project this trend is MRI-ESM2-0.

Additionally, half of the TOP6 models (EC-Earth3, GFDL-CM4,MPI-ESM1-2-LR) project that the southwinds originated in the South China Sea will have an increasing tendency towards east. However, this is not a robust finding given the strong intermodel spread in this region.

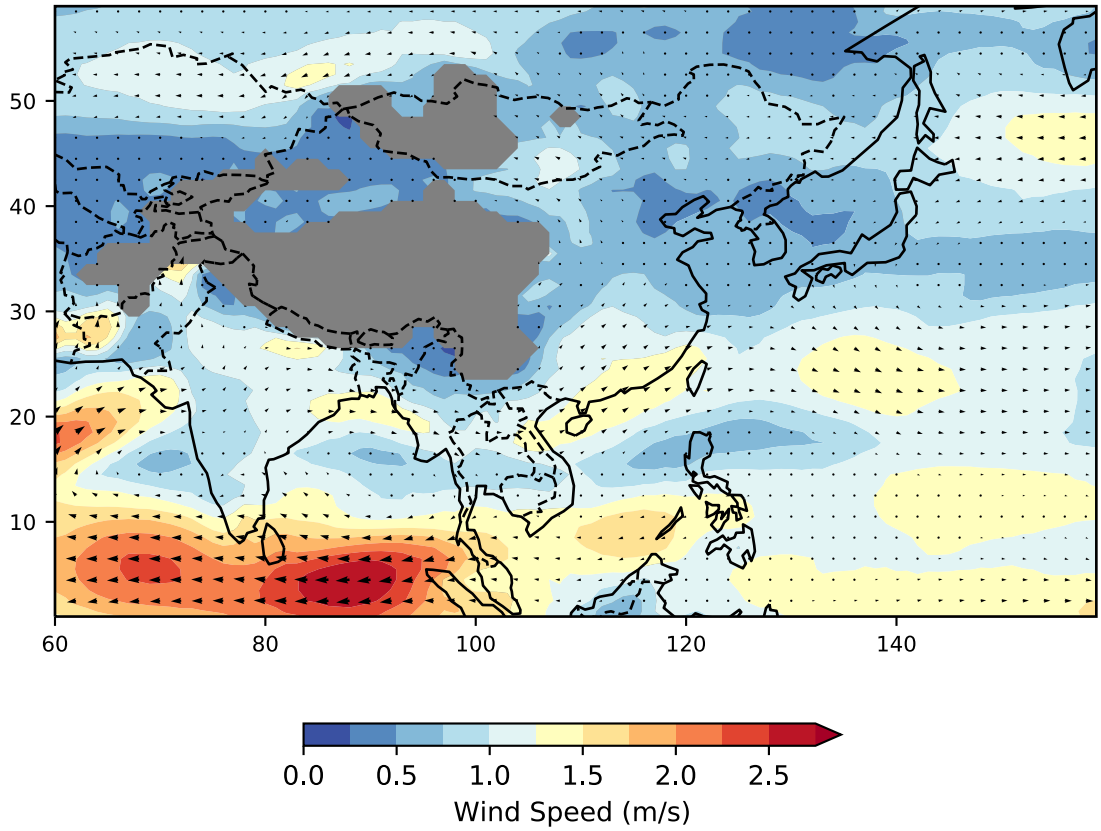

Figure 7. Change in wind vectors (850hPa) and wind speed (m/s) in 2081-2100 (SSP5-8.5) compared to the reference period in the MMM of the TOP6 models.

Most importantly, the scientific question needs to be refined in order to improve our current knowledge about EASM change. There have been plenty of papers investigating the future changes of EASM covering a wide variety of aspects, including process-based projection, spatial pattern of precipitation change, thermodynamic and dynamic processes of monsoon precipitation change, changes in monsoon duration, northern boundary, extremes (see a few references below and references therein). For example, based on CMIP6 multi-models, there is dynamic-based projection of EASM rainfall and variability (Xue et al., 2023), projection of monsoon rainfall and duration with thermodynamic and dynamic understanding (Moon and Ha, 2020; Ha et al., 2020). Overall, these studies so far have provided a relatively robust understanding of future EASM change based on GCMs. The current study, unfortunately, does not add improvements in our current knowledge. Thus, the authors need to evaluate carefully the current knowledge gap regarding EASM change and refine the scientific questions to be investigated.

References:

Xue, D., Lu, J., Leung, L.R. et al. Robust projection of East Asian summer monsoon rainfall based on dynamical modes of variability. Nat Commun 14, 3856 (2023). https://doi.org/10.1038/s41467-023-39460-y

Moon, S., Ha, KJ. Future changes in monsoon duration and precipitation using CMIP6. npj Clim Atmos Sci 3, 45 (2020). https://doi.org/10.1038/s41612-020-00151-w

Ha, K.-J., Moon, S., Timmermann, A.,& Kim, D. (2020). Future changes of summer monsoon characteristics and evaporative demand over Asia in CMIP6 simulations. Geophysical Research Letters,47, e2020GL087492.https://doi.org/10.10

We carefully rechecked the existing literature and came to the conclusion that a comprehensive study including the presented characteristics based on models that are performing well in the specific region is still lacking.

Thus, we are happy to summarize and highlight the aspects that we believe to be relevant and sufficient contributions within the scope of Earth System Dynamics.

None of the listed or other existing studies provides insights regarding (1) the interannual variability and (2) associated extremely wet seasons that have been associated with impactful widespread flooding events (e.g. Volonté et al. 2021; while extremes on other scales have indeed been discussed)

Besides, almost all of the listed studies regarding future projections lack a model selection process that is tailored for the specific EASM region – which is, as the reviewer pointed out correctly when requesting more detailed model selection criteria in the context of this review, a very particular monsoon system with very individual regional conditions and thus requires individual attention. Thus, we think it is also important to (3) provide the mean projections (and other results) based on models with regional satisfying performance in the past climate.

Besides, (4) we added a new subsection that discusses changes in circulation patterns. This includes the finding that the intensification over South East China is associated with a northward shift of the ITCZ.

Additionally, no other study provides (5) the projections for the monsoon region over China specifically, which is of high relevance for policy makers.

We hope that these highlights could convince the reviewer of the relevance of our contribution.