Response to Review Comments

Dear Editor,

We thank you and both reviewers very much for their careful review and valuable comments on our manuscript. We have tried our best to address all concerns and revised the manuscript accordingly. Please note that the reviewer's remarks are in black, our response is highlighted in blue, and extracts from the manuscript are in red, with **new texts** that have been added/edited marked in bold. We hope that you find revised manuscript satisfactory. Thank you very much.

Kind regards,

Zhen LIU, on behalf of all co-authors

Responses to Reviewer #1:

General comments:

This article titled "Impact of Asian aerosols on the summer monsoon strongly modulated by regional precipitation biases" mainly discusses the challenges of the Asian summer monsoon to climate models, as well as the mutual influence between model bias and atmospheric circulation. However, can some updated data be provided in this manuscript?

Response: Thank you for the comments and suggestions. A point-by-point response is given below.

Specific comments:

1. Some images have a poor appearance, such as Figure 3 (g), and the arrows can be adjusted to be thinner. The colorbar can be further refined or a smooth one can be used, as many details cannot be displayed under the current colorbar.

Response: Thanks for your suggestions. The arrows are thinner for all vector plots in the revised manuscript. To keep consistency of all figures, we have carefully adjusted the colorbar scale, which considerably improves the readability of the plot. The figure below is the new Fig. 3.

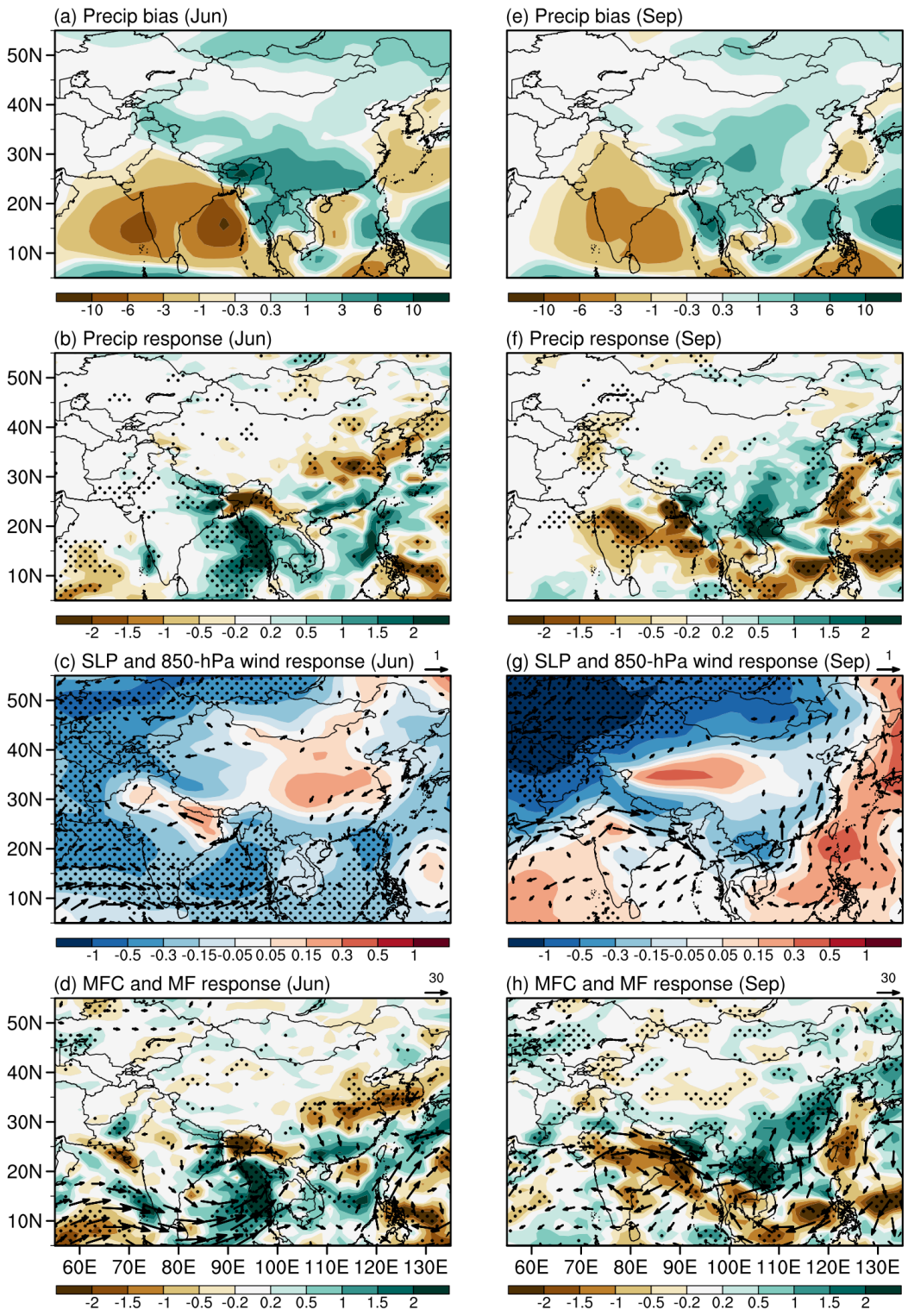

Fig. 3. (a) June precipitation bias (mm day^{-1}) in CONT with respect to the mean of GPCP and CMAP. Model data are averaged over 2003–2012, observations over 1981–2010. June response to Asian anthropogenic aerosols (difference between CONT and CONTfA averaged during 2003-2012) for (b) precipitation (mm day^{-1}), (c) sea-level pressure (hPa, shades) and 850-hPa wind (m s^{-1}), and (d) 1000–300 hPa vertically integrated moisture flux convergence (mm day^{-1}, shades) and moisture flux (kg m^{-1} s^{-1}). (e–h) Same as (a–d) but for September. Black dots in (b) and (f) mark grid-points for which the difference is significant at the 90% confidence level.

2. The dataset used in the article seems to lack a quantifiable validation of its accuracy. A quantifiable validation is needed to evaluate its accuracy.

Response: Thanks for your suggestions. To provide a basic evaluation of the model performance in simulating the key features of the Asian summer monsoon, Figure 1 compares the 1993-2012 June–September average precipitation and 850-hPa winds in the control simulation to observations (GPCP and CMAP average for precipitation, ERA5 for wind). The model reproduces the broad characteristics of the observed rainfall and circulation patterns (pattern correlation of 0.80 for precipitation, which is significant at the 99.9% confidence level). The difference panel indicates that the model is too dry over India due to a weaker southwesterly monsoon flow, but features wet anomalies over southwestern China and the northwestern subtropical Pacific associated with enhanced cyclonic flow. Note that this bias pattern is common across CMIP6 models, although the magnitude of the anomalies vary from model to model (Wilcox et al., 2020), and is also consistent with that in the historical simulations of the CMIP6 Met Office model (Rajendran et al., 2022). A thorough discussion of the model bias and its linkage to regional and remote circulation are documented in Liu et al. (2021). We have integrated this figure and related description in the main text as follows:

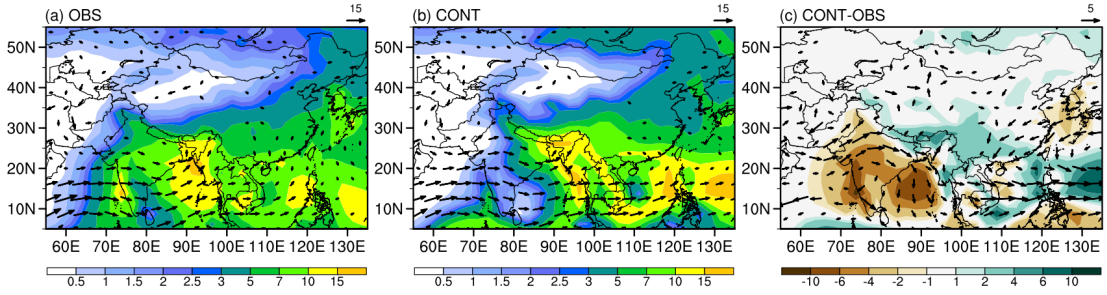

Figure 1. June–September average precipitation (mm day^{-1}) and 850-hPa wind (m s^{-1}) for the observations (GPCP and CMAP average for precipitation, ERA5 for wind), the control simulation, and their differences (model simulations minus observations) during the period 1993 to 2012.

Lines 179–187: "**Figure 1 compares the 1993-2012 June–September average precipitation and 850-hPa winds in the control simulation to observations (GPCP and CMAP average for precipitation, ERA5 for wind). The model reproduces the broad characteristics of the observed rainfall and circulation patterns (pattern correlation of 0.80 for precipitation, which is significant at the 99.9% confidence**

level). The difference panel indicates that the model is too dry over India due to a weaker southwesterly monsoon flow, but features wet anomalies over southwestern China and the northwestern subtropical Pacific associated with enhanced cyclonic flow. Note that this bias pattern is common across CMIP6 models, although the magnitude of the anomalies varies from model to model (Wilcox et al., 2020), and is also consistent with that in the historical simulations of the CMIP6 Met Office model (Rajendran et al., 2022). A thorough discussion of the model bias and its linkage to regional and remote circulation can be found in Liu et al. (2021)."

3. The selection of parameters is usually a crucial step in model development and use, and the article seems to lack detailed explanation of the model's parameter settings.

Response: Thanks for your suggestions. We have provided more details on the selection of the model parameters.

Lines 104–110: "GA7.1 was used as the atmospheric component of the climate model participating in CMIP6, **which reduces the overly negative global-mean anthropogenic aerosol effective radiative forcing in the previous model version, GA7.0 (Walters et al., 2019). A single-moment microphysics is used based on Wilson and Ballard (1999), with extensive improvement of the warm rain scheme (Boutle et al., 2014a, b). To account for aerosol-cloud interactions, the cloud droplet number concentration is calculated using prognostic aerosol concentration according to the UK Chemistry and Aerosol (UKCA)-Activate scheme (West et al., 2014). The atmospheric boundary layer and convection schemes are based on Lock et al. (2000) and Gregory and Rowntree (1990), respectively. A detailed description of the HadGEM3-GA7.1 physics is provided by Walters et al. (2019).**"

Technical comments:

4. Line 53: "could albedo" → "cloud albedo"

Response: Changed.

5. Line 53: "cloud albedo and lifetime, and precipitation processes"→ “cloud albedo, lifetime, and precipitation processes” There are other errors like this in the text, please check carefully

Response: Thank you for spotting the error. We have gone through the whole manuscript carefully and revised it accordingly.

6. Line 67: "South and East Asian aerosols separately exert a strong influence"→"South and East Asian aerosols exert a strong influence separately"

Response: Thank you for your comment. Here, we are trying to say that either South or East Asian aerosols can affect both the South and East Asian monsoons. Sorry for the confusion. We revised the sentence as follows:

Lines 67–69: “In particular, **either** South **or** East Asian aerosols **can** exert a strong influence on both the South and East Asian monsoons, with contrasting, if not opposite, changes as well as strong non-linear interactions between the responses to individual emission sources.”

7. Line 72: "the Asian monsoon march" There is a spelling error or misuse of vocabulary here.

Response: We revise the word “march” to “progression”.

8. Line 141: "in coupled mode ((Liu et al., 2018)." →" in coupled mode (Liu et al., 2018)."

Response: Done.

9. Line 218: "Inspection of monthly precipitation and low-level circulation changes reveals a stark contrast over the Indian subcontinent and adjacent ocean between the early and late monsoon season: increased precipitation and anomalous cyclonic flow over the BOB in June, consistent with the seasonal mean, and decreased precipitation

and anomalous anticyclonic winds over India in September (Figs. S2 and S3)." This sentence may be too long, consider splitting it into two or more concise sentences.

Response: Thanks for your suggestions. We split it into three sentences:

Lines 239–242: "Inspection of monthly precipitation and low-level circulation changes reveals a stark contrast over the Indian subcontinent and adjacent ocean between the early and late monsoon season (Figs. S2 and S3). In June, **there is** increased precipitation and anomalous cyclonic flow over the BOB, consistent with the seasonal mean. **On the contrary**, decreased precipitation and anomalous anticyclonic winds **are seen** over India in September."

10. Line 241: "The accuracy of the simulated regional climate change signal and its attribution to anthropogenic drivers have been suggested to be strongly dependent on the model performance in reproducing the corresponding mean climatological conditions, which represent the baseline state on top of which changes occur (Matsueda and Palmer, 2011; Christidis et al., 2013)." → "has been"

Response: Per your suggestions.

11. Line 452: "For consistency with the analysis of the fixed SST experiments" → "For consistency with the analysis of the experiments with fixed SST"

Response: Per your suggestions.

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148 **References**

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