Referee#2:

This manuscript discusses the enhancement of the South Asian summer monsoon during the Miocene and explores the drivers of that change. By using an ocean-atmosphere global climate model, the response of the South Asian summer monsoon to the uplift of the Iranian Plateau coincides with observed precipitation and wind speeds compared to reconstructions. The uplift of the Iranian Plateau is found to play a dominant role in the enhancement of the South Asian summer monsoon, especially in north-west India. The research work carries out a large number of simulation experiments, a large amount of analysis and simulation, the article is readable, and the findings are important for understanding the long-term evolution of the South Asian monsoon since the Miocene. It is recommended for publication after detailed revision of the following comments.

Thanks for your recommendation and comments. We agree with you that some unclear information exists in the manuscript. We have revised the manuscript according to your comments.

General:

1. The authors have emphasised that the time period of the study is MMIO, 17-12 Ma, and from the authors' very limited collection of record sites, it appears that the age of all the records is concentrated in the 14-12 Ma range, and the trend of the state of the South Asian monsoon indicated by these sites is "increasing".

Here, the authors need to be more explicit about the motivation for the Iranian Plateau, Himalayan and CO_2 modelling. The reasons are as follows. Firstly, according to the general concept, the atmospheric CO_2 concentration peaked around 15 Ma in the Miocene and then declined (e.g., Toward a Cenozoic history of atmospheric CO2, THE CENOZOIC CO_2 PROXY INTEGRATION PROJECT (CENCO2PIP) CONSORTIUM 2023). Therefore, it is unlikely that CO_2 is responsible for the intensification of the monsoon during this period from 14 to 12 Ma. Secondly, the authors have cited and elaborated that the Himalayas have reached their present height at 15 Ma, which also seems unlikely to be a factor in the 14~12 Ma monsoon intensification, and thus seems to be excluded. Finally, the authors mention that the Iranian Plateau uplifted at 15~12 Ma, but do not give clearer paleo-height constraints, and there is a lack of geographically reconstructed paleo-height evidence for the study.

The authors need to explicitly give the above information. This relates to the design rationale for the height of the Iranian Plateau in the authors' experimental design, as well as the attribution of monsoon intensification in the geological record.

Response: Thanks for these valuable inputs. We agree with your comments and reword the introduction as suggested. The following information is included:

- Considering that CO2 levels in atmosphere peaked around 15 Ma, it is unlikely that CO2 variations alone were responsible for the SASM intensification between 14 and 12 Ma. However, CO2 levels may have been a contributing factor to the peak SASM intensity around 15 Ma inferred from weathering proxies (Clift et al., 2008).

- Although the Himalayas (HM) began rising above the Tibetan Plateau (TP) around 15 Ma, it seems improbable that this uplift significantly influenced the intensification of the SASM between 14 and 12 Ma. However, some argue that the ongoing uplift of the Himalayas above the TP contributes to the intensified SASM (Khan et al., 2014; Bhatia et al., 2021).

- We incorporate the evolutionary history of the IP uplift to limit its paleo-height, although there remains considerable uncertainty regarding the process of its elevation.

Therefore, the effect of the IP and HM uplift, and the variation of CO2 during Middle Miocene are needed to be investigated.

1. The authors excessively cite previous research findings in the experimental analysis section, e.g., P9L227~L228, P11L256~L257, and P14L318~319. which tends to confuse the reader: is this the result of your experiment or the result of previous work? It may even lead to the misunderstanding: your experiment is exactly the same model and experimental design as the previous work? It needs to be revised.

Response: Thanks for these comments. We acknowledge that these citations may lead to confusion. We rephrase these sentences accordingly.

P9L227~L228, the domain of the SAM extends westward both in land and over the Arabian Sea where it nearly connects the African monsoon (Fig. 3c), a feature also presented in the study of Fluteau et al. (1999)".

Response: This sentence is modified as:

Thanks for your comments. We agree with you that some unclear information exists in the manuscript. We have revised the manuscript according to your comments.

"The domain of the SAM extends westward both in land and over the Arabian Sea where it nearly connects the African monsoon (Fig. 3c). This characteristic is also noted in the Miocene study of Fluteau et al. (1999), despite significant differences in the climate model and paleogeography employed in the two studies."

P11L256~L257: This anomaly regarded as the deepening of thermal low is also shown in previous study (Sarr et al., 2022).

Response: This sentence is revised as:
"Interestingly, this anomaly, marked by the deepening of the thermal low, has also been observed in a prior investigation (Sarr et al., 2022) based on late-Miocene geography with a French paleoclimate model, indicating its robustness irrespective of specific paleogeographic details and climate model but rather as a response to Middle Eastern topography change."

P14L318~319: Similar conclusion is also reported in projecting future climate change facing the rising CO_2 (Endo and Kitoh, 2014).

Response: We move this sentence to the end of Section 3.3 as a second example to prove that the SASM response to CO2 forcing in the Middle Miocene is very similar to that of projecting future climate change.

"Endo and Kitoh (2014), drawing from analysis across 20 climate models, demonstrate that in a warmer climate, enhanced SASM precipitation is primarily driven by thermodynamic processes, consistent with our findings from the MBA results shown in Figure 5."

Specific issues:

P4L79~82 Therefore, it is worthy to revisit the response of the SASM to the IP and HM uplift under Miocene boundary conditions with a fully coupled Ocean-Atmosphere Global Climate Model (OAGCM) and investigate the underlying physical processes.

The authors emphasize the coupled experiments in the introduction, but they do not mention the advantages of the coupled ocean-air experiments throughout the analysis and discussion. In addition, considering that each experiment only runs for 200 years and that thousands of years of credits are generally required to carry out a coupled experiment simulation, 200 years is too short a credit for a coupled experiment simulation. Considering the high horizontal resolution used in all experiments, 200 years seems to be acceptable. However, whether the authors have considered biases due to SST disequilibrium or uncertainties in the conclusions of the study due to additional feedbacks would be best discussed briefly in the Discussion section.

Response: Thanks for these excellent comments. We first address the Added value of OAGCM compared to AGCM; then address about the uncertainty of short simulations.

- **Added value of OAGCM vs AGCM**

In fact, to evaluate the added-value by performing simulations with AOGCM, we've made two paired experiments of MMIO and IP0HM0 with AGCM-only. That is, after 2700-year running with OAGCM for the MMIO experiment, we continued the simulations with AGCM-only for another 150 years (named as MMIO_agcm and IP0HM0_agcm) with the last 100 years for analyses. Similarly, the results from 2601 to 2700 model years in OAGCM simulations are used for analyses as we do in the manuscript. Then we compared the responses of surface temperature and precipitation to IP-HM change, that is, differences between (IP0HM0 - MMIO) and (IP0HM0_agcm -MMIO_agcm). From the attached figures (FigS1 and FigS2), we can find that:

1. In AGCM simulations, temperature responses to IP-HM topographic changes are primarily seen in the extended South Asian Monsoon region from northeastern Africa

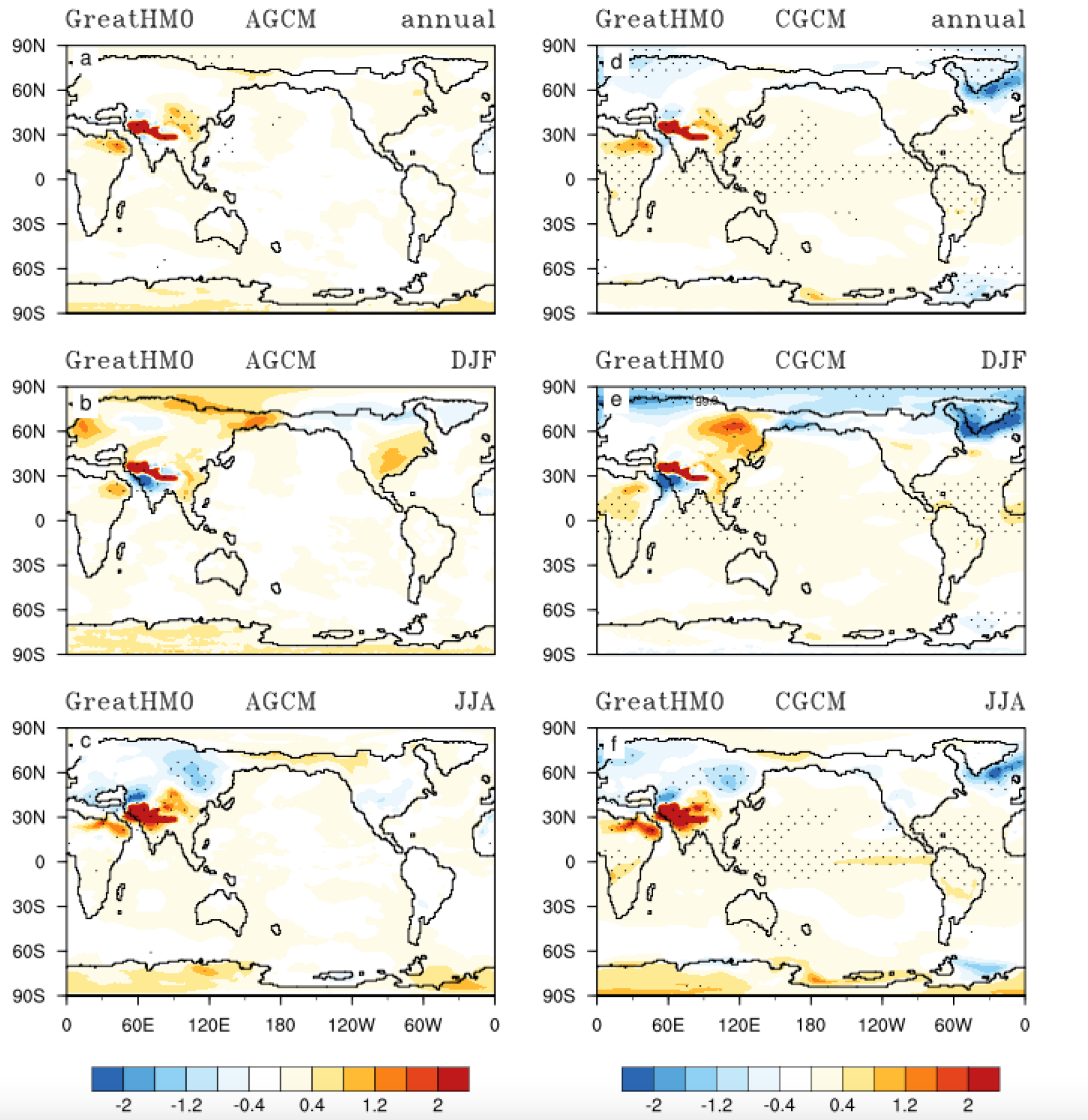
to East Asia, extending to northeast Asia in boreal summer. In OAGCM simulations, along with local responses, temperature differences are also observed in tropical Africa and the Norwegian Sea Basin.

2. Likewise, AGCM simulations indicate local precipitation responses, while OAGCM simulations show broader effects in the tropical Atlantic and Pacific.

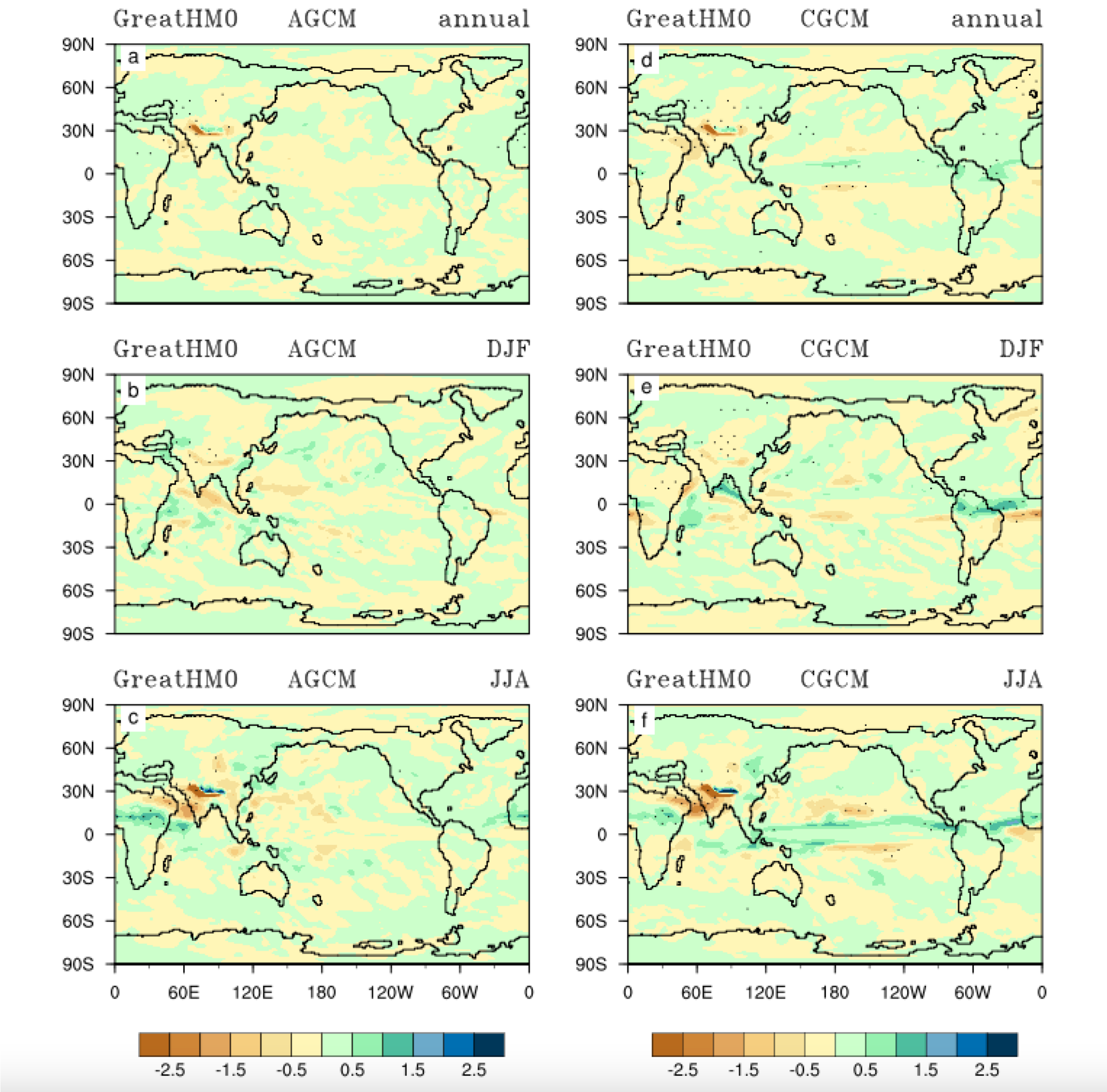
While results from OAGCM compared to AGCM are not significant different for the SASM, they do reveal notable impacts on ocean circulations, evidenced by changes in SSTs and precipitation in tropical oceans and the Norwegian Sea Basin, possibly impacting the SASM. Hence, we opt to employ OAGCM for our topographic sensitivity experiments to better capture the underlying dynamical processes related to the SASM. Another reason of using OAGCM is to investigate the impacts of IP/HM uplift on the East Asian monsoon as a planning work, which is beyond the scope of present study.

Since discussing the added value of OAGCM extends beyond the scope of our current study, we modify this paragraph with less emphasis on this aspect. Besides the limitations of AGCM, we briefly mention the limitations of employing OAGCM such as more computer resources and longer integrations to reach equilibrium.

"Therefore, we opt to use a fully coupled Ocean-Atmosphere Global Climate Model (OAGCM) to revisit the response of the SASM to the IP and HM uplift under Miocene boundary conditions, although it needs more computer resources and longer integrations to reach equilibrium."



FigS1: surface temperature (K) response to IP-HM change from AGCM simulations (Left column) and OAGCM (Right column). (a, d) annual mean; (b, e) DJF mean and (c, f) JJA mean. The black dots in each panel indicate values >99% confidence level based on the *Student's t* test. GreatHM0 indicates (IP0HM0_agcm - MMIO_agcm) or (IP0HM0 - MMIO). We note that MMIO(_agcm) is equal to IP100HM80(_agcm).



FigS2: Precipitation (mm day^{-1}) response to IP-HM change from AGCM simulations (Left column) and OAGCM (Right column). (a, d) annual mean; (b, e) DJF mean and (c, f) JJA mean. The black dots in each panel indicate values >99% confidence level based on the *Student's t* test. GreatHM0 indicates (IP0HM0_agcm - MMIO_agcm) or (IP0HM0 - MMIO). We note that MMIO(_agcm) is equal to IP100HM80(_agcm).

- **Short simulations for orography sensitivity experiments**

The global averaged annual mean SST and Rnet (net radiation flux at the Top of the Atmosphere) in the experiments of MMIO, IP0HM0, IP50HM50 and IP100HM100 are displayed in the attached figure (FigS3). Based on the outputs of the last 100-year of each simulation, the Mann-Kendall trend analysis confirms that there are no statistically obvious trends of SST and Rnet for these experiments despite that the Rnet stays at ca 3.10 W/m2, thus these experiments reach quasi-equilibrium.

Why can the three sensitivity experiments reach quasi-equilibrium after a short simulation period of 200 year? There are two possible reasons: 1) these simulations start from a state of quasi-equilibrium (MMIO); 2) the orographic changes are relatively small leading to weak impacts on global mean ocean circulations.

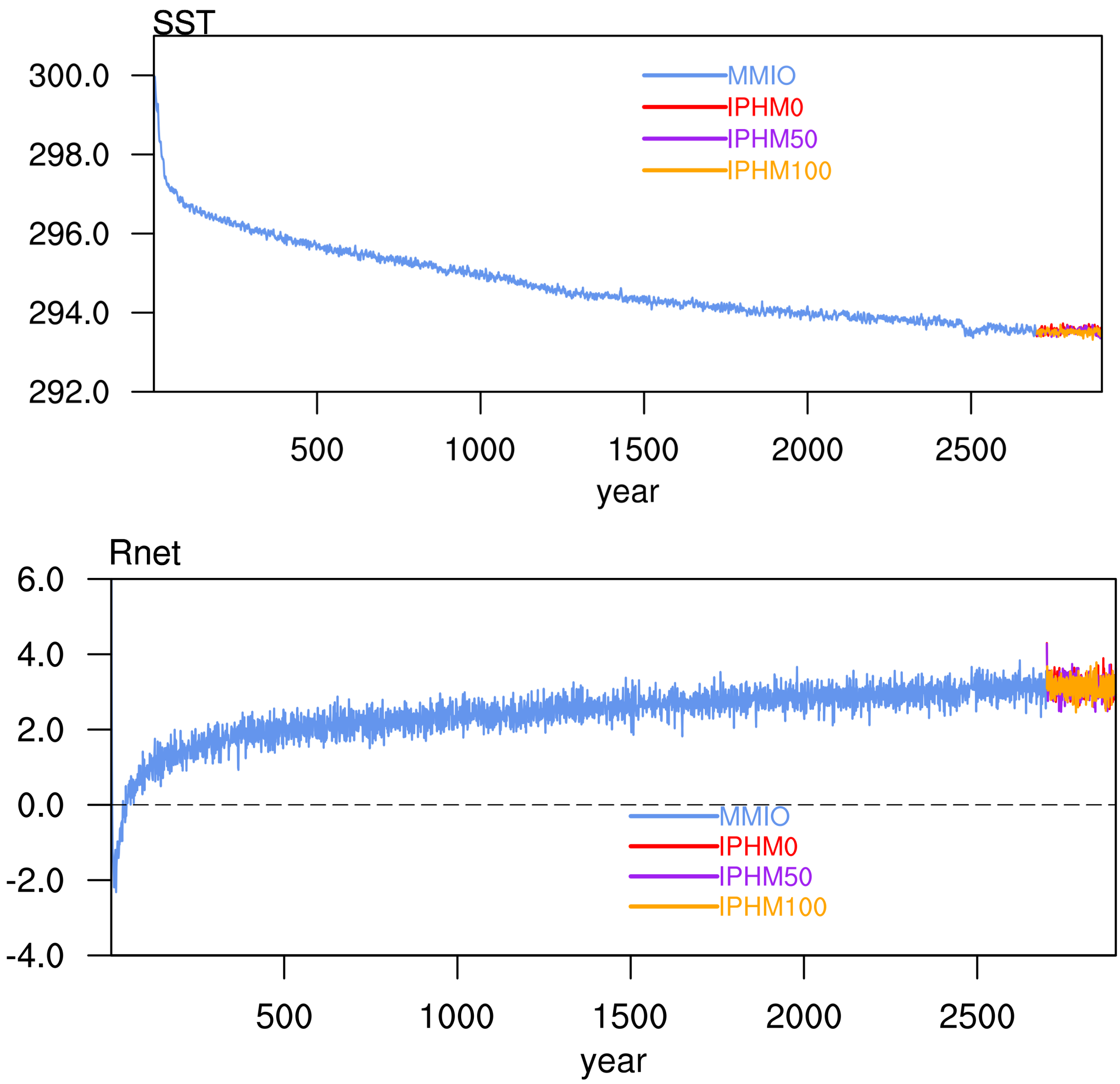


Fig. S2. The global averaged annual mean (a) sea surface temperature (SST; K) and net radiation flux (Rnet; W/ m^2, downwards is positive) at TOA (top of atmosphere) for the 2700-year MMIO (blue curves) and 200-year IP0HM0 (red curves), IP50HM50 (violotta curves) and IP100HM100 (orange curves) runs.

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P6L136~138 Is the topographic palaeoheight design of the Iranian Plateau supported by relevant cited literature?

Response: This palaeoheight of the IP comes from the reconstruction of Frigola et al. (2018, F18 henceforth). We add this reference here and also add a discussion regarding the uncertainties of F18 in the IP and other places in Section 5.3.

P7L182~183 (2) Webster-Yang Index (WYI; Webster and Yang, et al., 1992): meridional wind stress 183 shear between 850 hPa and 200 hPa averaged over 40-110°E, 0-20°N during June-August.

Did the authors use the WY index with the same selected area as in the original work? Did you take into account the uncertainty associated with the index's indication of monsoon circulation due to the inconsistency of the land and sea distribution in the Middle Miocene with the modern era, and did you correct the computed area? Please provide a brief description.

Response: Thanks for this suggestion. In the manuscript, we use the WY index with the same selected area in the original work. We re-calculate this index by shifting the longitude 4 degrees westward and find that the variations/trends are the same although the values are ca 0.7 m/s uniformly higher in the shifted one. Thus, we confirm that our conclusions are insensitive to the selected area. A brief description is added as following:

"We confirm that the variations/trends of WYI index in our study are not sensitive to the selected calculation area given the inconsistency of the land-sea distribution between the Middle Miocene and the modern era."

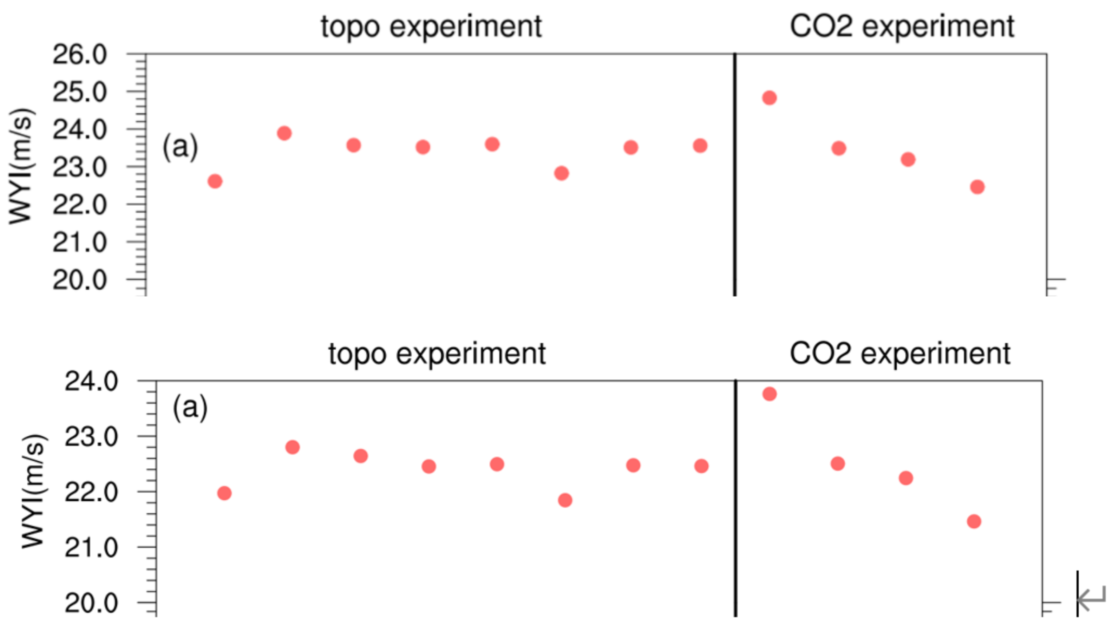

Fig. S3: Webster-Yang Index (meridional wind stress shear between 850 hPa and 200 hPa averaged over (top) 36-106°E, 0-20°N and (bottom) 40-110°E, 0-20°N during June-August).

P2L22: Global Climate Model 22 CESM1.2 through a series of 12 sensitivity experiments, the authors stated 12 sets of experiments, while in Table 1 (P32L845) only 10 sets are shown. Please change!

Response: Thanks for pointing out this mistake. We correct Table 1 by inserting another two sets of CO2 sensitivity experiments (MMIO560 and MMIO800) as described in the experimental design.

P17L367 Fig7 extra experiment 560ppm 800ppm, but the experiment description clearly states that.

Response: The two experiments are added in Table 1 as stated in the experimental description. Thanks for this reminder.

P7L182: Webster and Yang, et al., 1992 is incorrectly cited; it should be Webster and Yang, 1992.

Response: Thanks for this correction.

P12L269: 722B, monsoonal signal is absent in IPHM0 (Fig.3d). What is IPHM0? Is it a writing error?

Response: It's a writing error, so it is corrected to "IP0HM0".

P16L6 The figure is labelled IPHM0 as well?

Response: Thanks for this careful check. We correct the Figure label as "Moisture budget (MMIO100 – IP0HM0)".

P18L399~400 north Africa to North Africa

Response: Thanks for this correction that is done in the updated version.

P18L402 2 Medina et al., 2010? The literature is not cited.

Response: Thanks. The cited literature is added in the updated version.

"Medina, S., Houze Jr., R.A., Kumar, A., Niyogi, D., 2010. Summer monsoon convection in the Himalayan region: terrain and land cover effects. Quarterly Journal of the Royal Meteorological Society 136, 593–616. https://doi.org/10.1002/qj.601"

P19L414 Regarding to change to Regarding or Regard to.

Response: We correct this grammar error. Thanks.

P21L463 bewteen to between. Words are spelled incorrectly, please double-check the entire text

Response: Thank for this reminder. We correct this typo and double-check the entire text.