Referee#3

The manuscript uses climate modeling to compare the effect from the uplift of the Himalaya (HM) and Iranian Plateau (IP) and the increase of atmospheric CO2 to the intensified SASM during the Middle Miocene (17-12 Ma) with coupled atmosphere-ocean global climate model CESM. The results indicate the IP uplift plays a dominant role in the intensification of the SASM, and the effect of the HM uplift is confined to the range of the HM and its vicinity. In the case of extremely atmospheric CO2 variation, the effects of two factors are comparable in the SASM region. Although some results are similar to previse modeling studies, this study compares the effect from topographic forcing and atmospheric CO2 variation, which are also interesting and important. However, there are still several limitations. Particularly, because the main purpose of this study is to compare the effect from topographic forcing and atmospheric CO2 variation, the uncertainties in used topographic change and CO2 variation should be mentioned, these uncertainties may affect the main conclusions of this study.

Response: We thank the referee for summarizing and providing insightful comments on the issues addressed in our manuscript. These comments and valuable inputs help us to improve the quality of this paper. Recognizing the significant uncertainties inherent in reconstructing topography and CO2 variation during the Middle Miocene, we fully agree with your comments/suggestions regarding the uncertainties surrounding these factors and their potential impacts on our conclusions. We have incorporated a discussion addressing these uncertainties in the updated version of the manuscript.

Lines 60-67, Can you give an estimate of the raised height of the IP during the Middle Miocene?

Response: Thank for this reminder. We acknowledge that there are currently very few studies available for constraining the paleo-height of the IP. However, we extent this paragraph by providing the evolution history of the IP.

“The evolution history of the IP uplift remains hotly debated (Agard et al., 2011; McQuarrie et al., 2003; Mouthereau, 2011; Ballato et al., 2017). Nevertheless, most studies suggest a Miocene age for the uplift of most landforms. Geological evidence indicates that in the northern sectors of the IP, the uplift likely occurred between 16.5-10.7 Ma (Ballato et al., 2016), particularly accelerated after 12.4 Ma (Mothereau, 2011), while in regions bordering the IP to the south between 15 and 5 Ma (Mouthereau, 2011). The Zagros orogen, a significant part of the IP, developed in three distinct pulses within the last ~20 Ma (Agard et al., 2011; Mouthereau, 2011). Our IP relevant sensitivity experiments reflect the possible range of IP uplift during the Middle Miocene. However, the configuration of Tethys/Paratethys in our simulations leads to small size of the IP.”

Lines 85-87, during mid- to late Miocene, the CO2 decreases according to the reconstruction, why increased CO2 is considered here?

Response: Thanks for this comment. We correct the mis-description of the modeling results of a previous study (Thomson et al., 2021). It is corrected as follow:

"…during the mid-to-late Miocene, its contribution to rainfall change is comparable to that of orographic uplift even when the pCO_2 is set **from 560 ppm to 280 ppm** (Thomason et al., 2021)."

Line 111, is the ice sheet model active during the simulation?

Response: the ice-sheet model is inactive during the simulation. We add this information in the updated version.

Lines 154 and 175, it's better to show the times series of the surface temperature and net top of the atmosphere radiation imbalance in these experiments.

Response: Thanks for this suggestion. 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 (FigS1). The SST and Rnet curves from other experiments generally lie between IP0HM0 and IP100HM100. 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 are regarded to reach quasi-equilibrium.

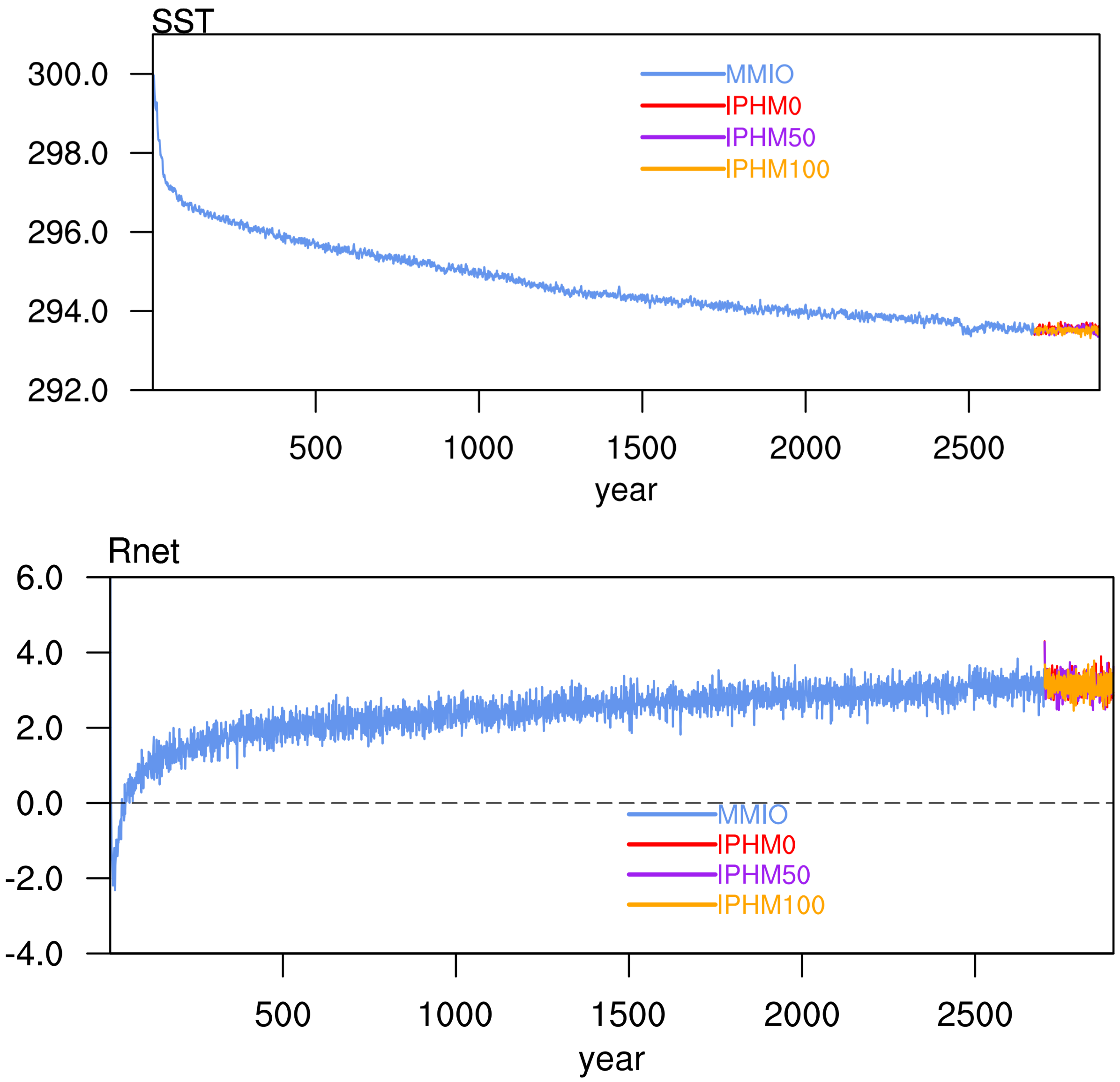

Fig. S1. The global averaged annual mean (a) sea surface temperature (SST; K) and net radiation flux (Rnet; W/ m^2, downwards is positive) at TOA (top of atmosphere) for the 2700-year MMIO (blue curves) and 200-year IP0HM0 (red curves), IP50HM50 (violotta curves) and IP100HM100 (orange curves) runs.

Lines 159-160, why the reference height is different between HM and IP?

Response: Thanks for this question. In the Middle Miocene, despite HM notable increase in height, its position remained relatively stable, making its modern height a suitable reference point. However, the evolution of the IP during this period is complex and largely uncertain, presenting challenges in using its modern height and size as a reference. Moreover, by comparing IP100HM100 and MMIO (IP100HM80), we can investigate whether the uplift of HM above the Tibetan Plateau indeed leads to the intensification of the South Asian Summer

Monsoon (SASM), as hypothesized by some researchers. Therefore, we've opted for different reference heights for the two mountains to address these considerations.

Lines160-164, the experimental design for the uplift of HM and IP from flat to 100% is too idealized compared to the geological evidence (Lines 53-56, 60-67) during the Middle Miocene.

Response: Thanks for this comment. Given the coarse spatial resolution in our model, our experimental design necessitates idealization while incorporating the evolution of orogeny.

1）For instance, the experimental setups IP100HM100 and MMIO(that is, IP100HM80) reflect the uplift of HM above the TP after 15 Ma. Although the pattern of precipitation changes in (IP100HM100 – MMIO) closely resembles that of (IP100HM100 – IP0HM0), it exhibits a smaller intensity. We add this information in Section 3.2 in the updated version as follow:

“Notably, the patterns of precipitation and low-level circulation changes between IP100HM100 and MMIO (not shown) closely resemble those illustrated in Fig. 4c, albeit with lesser intensity. This underscores that further uplift of HM above the TP does not lead to an intensified SASM.”

2）Considering the significant uncertainty in the build-up of IP, we varied its height change from 0% to 100% to encompass the widest range of possibilities. While different height changes quantitatively impact the intensity of the South Asian Summer Monsoon (SASM), they do not alter the circulation pattern, suggesting a consistent underlying mechanism.

In the updated version, we include a discussion on the uncertainty in the utilized topographic changes and their impact on the experimental design as your suggestion.

Lines 180-181, annual or seasonal precipitation?

Response: It is seasonal mean. We correct it:

“(1) All Indian rainfall (AIR): regional **summer** mean precipitation over the land points within the domain of 7-30°N, 65-95°E.”

Figure 1, in the experimental design, how do the authors determine the extent of the HM and IP? The extent of the HM looks larger in Fig. S2.

Response: Thanks for these questions concerning technique treatment.

We determine the Miocene HM extent according its modern extend, but with 3-5 westward shift due to the TP is about 3-5 °C west than present day. We manually adjust the disconnected grids.

We first determine the extent of modern HM, then apply this mask to the Miocene orography but westward shift of 3-5 degree due to the Tibetan Plateau 3-5 °C west compared to its modern location. As for the IP, its orography at Miocene is considerable different from present-day, so "we lumped together all the mountain ranges west of the Himalayan, including the Hindu Kush region and Pamir as the IP. The northern part of the IP reached a near modern elevation as 1000-2000 m, but its southern part was lower than 1000 m (Please see Section 2.2)."

The extend of the HM looks larger in Fig. S2 than in Fig. 1 because their spatial resolutions are different. Fig. S2 is at 1.9x2.5 (lat x lon), which is the one actually used in our simulations. Conversely, Fig. 1 is at 0.5 x0.5, based on the boundary conditions from Frigola et al. (2018). This discrepancy is a common challenge in paleoclimate modeling when transforming the land-sea configuration and topography from high to low resolution.

Lines 228-229, it's better to point out the inconsistencies between model results and records. How about the ODP 359 and 758?

Response: Thanks for these suggestions. Here, we briefly provide the spatial distribution of the sites and the general picture of monsoon-like region. More detailed modelling and proxy data comparison is given in Section 5.1 "Application to monsoonal reconstruction".

As suggested, here we add a sentence to describe the features of site ODP 359 and 758 as the follow: "The two sites ODP 359 and 758 are not located in the monsoon-like region, but they indicate enhanced wind and monsoonal upwelling at 12.9 Ma and 13.9 Ma, respectively."

Discussion on the inconsistences between modelling results and records at the two sites are added in Section 5.1 the updated version as in the follow：

"The findings from the two sites indicate an abrupt strengthening of monsoonal circulations in the SASM regions at 12.9 Ma and 13.9 Ma. However, our modeling efforts cannot replicate these enhancements through either the uplift of the IP and HM or a reduction in CO2 levels. Consequently, it is probable that other factors exert a more significant influence on the reorganization of the SASM system. Examples include Antarctic glaciation (Flower et al., 1994), as suggested in Ali et al. (2021; Sarr et al., 2021), as well as the closure of the Tethys, as discussed in research by Betzler et al. (2016) and Bialik et al. (2019)."

Line 279, where is the 'core' region?

Response: It is the region (7-30°N, 65-95°E) where the AIR index is defined. We add this information here.

Line 307, "to its west" should be "to its east"?

Response: Yes, it's "to its east". Thanks for this correction.

Line 399, "southeasterly" should be "southwesterly"?

Response: Yes, it's "southwestly". Thanks for this correction.

Line 404, from Figure 9d, LCL is increased over the IP.

Response: Please note the unit of LCL in hPa.

"(d) Lifting condensation level (LCL, unit: hPa, positive value represents lower LCL);"

Line 468, where is "American region"?

Response: Yes, it's American region. This sentence is to cite the teleconnection effect on precipitation change in the eastern HM from previous modeling studies (Chakraborty et al., 2006; Miao et al., 2022), possibly reconciling the model-proxies discrepancy. The removal of American orography delays the onset of the SASM thus reduces its intensity via a shift in position of the Rossby wave pattern (Chakraborty et al., 2006).

Lines 484-486, the different used extent of the HM between these studies can explain the disagreement the author mentioned.

Response: Thanks for this suggestion. The primary reason for the discrepancy between our results and the one mentioned (Zhang et al., 2012) is that if the Tibetan Plateau exists before the uplift of the HM. Zhang et al. (2012) assumed first the uplift of HM, contrary to the current understanding of the evolution history of the HM-TP. Our findings aligh with other studies (Liu et al., 2017; Zhang et al., 2015; Acosta and Huber, 2020; Tardif et al., 2020, 2023) that considering the TP's existence prior to HM uplift even if the HM represented in these climate models are very different due to large differences in used geography (paleo or modern) and spatial resolution (from 0.23° × 0.31° to 3.75° × 0.1.9°).

Line 506, the uncertainties in used topographic change and CO2 variation should be discussed.

Response: Thanks for this valuable suggestion. We add a discussion on these aspects.

Line 539, Zhang et al., 2017 is not a modeling study.

Response: It is "Zhang et al., 2015". We correct it. Thanks.

Table 2 No 3, the change in ODP 722 at 11 Ma is out of the Middle Miocene (17-12 Ma).

Response: Thanks for this comment. This reference is removed from Table 2 as the evidence of SASM intensification during the Middle Miocene, which has no essential impact on our conclusions and discussions.

References:

Chakraborty, A., Nanjundiah, R.S., Srinivasan, J., 2006. Theoretical aspects of the onset of Indian summer monsoon from perturbed orography simulations in a GCM. Annales Geophysicae 24, 2075–2089.

Flower, B. P. & Kennett, J. P. The middle Miocene climatic transition: East Antarctic ice sheet development, deep ocean circulation and global carbon cycling. Palaeogeogr. Palaeoclimatol. Palaeoecol. 108, 537–555 (1994).

Miao, Y., Fang, X., Sun, J., Xiao, W., Yang, Y., Wang, X., Farnsworth, A., Huang, K., Ren, Y., Wu, F., Qiao, Q., Zhang, W., Meng, Q., Yan, X., Zheng, Z., Song, C., Utescher, T., 2022. A new biologic paleoaltimetry indicating Late Miocene rapid uplift of northern Tibet Plateau. Science 378, 1074–1079. https://doi.org/10.1126/science.abo2475

Zhang, R., Jiang, D., Zhang, Z., Yu, E., 2015. The impact of regional uplift of the Tibetan Plateau on the Asian monsoon climate. Palaeogeography, Palaeoclimatology, Palaeoecology 417, 137–150. https://doi.org/10.1016/j.palaeo.2014.10.030