Reviewer #1

The authors investigated the responses of global and India precipitation to CO2 and aerosol forcing with a set of LUMIP model simulations, and found the different responses to CO2 and aerosols on both global and regional scales. The main mechanisms driving the responses are dynamical responses. The results are robust and well presented. However, this paper needs substantial revisions before considerations for publication.

We first thank the reviewer for the constructive comments and for showing interest in this study. Please find below the comments (in black) and responses addressed in light blue italics with specified line numbers in the revised version of the manuscript.

Major comments:

1. The main concern regarding this study is that the results are not new. Many literatures have documented the impact of greenhouses and aerosols on India monsoon. The authors just qualitatively analyzed some dynamical responses, contributing limited new insights.

   We agree with the reviewer that there are studies that documented the impact of greenhouse gases and aerosols on the Indian monsoon. However, using the PDRMIP set of experiments, there has been no comprehensive study regarding Indian monsoon responses to greenhouse and aerosol forcings. Further, the comparative analysis i.e., global vs. Indian precipitation responses presented in this study used multiple models which is very limited in the existing literature. While the study may not have presented entirely novel findings, it can still contribute to the scientific discourse and help build a more comprehensive understanding of the problem addressed in this paper.

2. The direct comparison between different simulations throughout this paper does not have meaning. For example, the authors compared the precipitation response in BCx10 experiment with that in the CO2x2 experiment (Line 221). The global effective radiative forcing (ERF) in the CO2x2 is roughly 3.7 W m-2 while the forcing in the BCx10 experiment is around 1.4 W m-2. The forcing in the BCasiax10 would be even smaller. It is not surprising that the response in the CO2x2 experiment is larger than BC in most regions due to its larger forcing and larger temperature change, which does not contribute any new insights. I suggest the authors normalize the results by warming level or TOA forcing. In that case, the results shown would be precipitation change per K (e.g., Figure 4 of Myhre et al., 2017) or change per unit forcing (e.g., Tang et al., 2018), following earlier PDRMIP studies. An advantage of normalized results is that you can find how sensitive the

precipitation is in India to different forcing agent, and if scaled by historical forcing, you can then compare their historical contributions.

We thank the reviewer for this comment. We have now added a new Figure 3 showing precipitation change per K denoting apparent hydrological sensitivity. The analysis suggests that precipitation over India is more sensitive to regional perturbed experiments, especially in bc×10asia and sul×10asia. We have added subsequent discussion in the line nos. 245-250, 262-265, 283-288 and 527-529 in the revised version of the manuscript.

3. The linear relationship between global precipitation change and temperature or energy change has been discussed by previous work, including using PDRMIP. The results presented here are not new. What the authors conclude from these analyses (Figure 3-5)?

   We agree with the reviewer that the relationship between global precipitation change and temperature change has been shown in Myhre et al., (2017). However, they discuss in terms of fast and slow precipitation response. We show the total precipitation response here. We need to point out that the differences between global precipitation change and Indian precipitation change (regional) and their relationship with changes in temperature, dry energy, and vertical velocity is missing in the previous works. In addition, the energy change (i.e., the dry energy budget) used in this paper is different from previous work. We have mentioned in the revised version of the manuscript (line no. 219-238).

   Here we conclude that at the global scale, there exists a strong linear relationship between change in precipitation and temperature (as well as dry energy) whereas the relationship is not so linear at the regional scale i.e., over India (Figures 5 and 6). Figure 7, shows the changes in the vertical velocity at 500 hPa are more strongly related to the precipitation change over India compared to global ones. Further, a discussion on horizontal energy flow is added to enhance the section.

Minor comments:

1. Line 57-59, we have so many precipitation data (obs. Station, satellite, radar, balloon). Why quantifying precipitation change is challenging?

   We here wanted to specify that quantifying the changes in the precipitation due to individual climate-forcing agents is challenging. Dedicated modeling experiments are required to quantify such precipitation changes.

2. Line 62, a comma after 1.5C.

Changes implemented.

2. Line 83, "Zhao and Suzuki (2019) using…" or "used"?

   Changes implemented. Please see line no. 87 in the revised version of the manuscript.

3. Line 88, "decreases…"

   Changes redundant.

4. Line 89-90, precipitation decreases over NH caused southward migration of ITCZ or the latter caused the former?

   Thanks for the correction. The southward migration of ITCZ decreases precipitation over NH. Please see line no. 91-93 in the revised version of the manuscript.

6. Line 92, uniform?

   Changes implemented (line no. 95).

7. Line 94, play?

   Changes implemented (line no. 97).

8. Line 109-110, attributed…due to or to?

   Changes implemented (line no. 113).

9. Line 113, comma after 'seas',

   Changes implemented (line no. 116).

10. Line 122, Ganguly et al., (2012), using or used

    Changes implemented (line no. 140).

11. Line 129-130, "due to computational constraints", any literature on this statement?

    This is based on our perception. We have removed now from the text.

12. Line 131-134, any literature supporting this claim? There are many studies using coupled model simulations.

Changes redundant. It should be noted that most of the coupled model studies have used one particular model with few perturbed experiment types and periods of simulations. A set of dedicated multi-model aerosol perturbed (8) experiments along with GHGs (e.g., PDRMIP) for longer scales are limited. Here, we used 11 models to provide an overall assessment of the responses both at a global scale as well as over India.

13. Line 152, due to or to?

    Changes redundant.

14. Line 185, grammar error

    Changes implemented. Please see line no. 193 to 196 in the revised version of the manuscript.

15. Line 244-247, grammar error.

    Changes redundant.

16. Line 296-298, any evidence to support this claim?

    Sillmann et al. (2019) using PDRMIP simulations found that sulfate aerosols reduce both mean and precipitation extremes. Please see line no. 345-346 in the revised version of the manuscript.

17. Line 306 to 308, why these models are inconsistent? Any explanations?

    *This inconsistency i.e., a decrease in precipitation could be due to substantial negative delH, implying a significant horizontal energy flow into the region. The negative delH compensates the decreases in precipitation (negative Lc*delP) and decreases in dry heat, which represents an increase in the losses, i.e., positive delQ. We have mentioned this point in the lines nos. 363-367 in the revised version of the manuscript.*

References

Myhre, G., and Coauthors, 2017: PDRMIP: A Precipitation Driver and Response Model Intercomparison Project—Protocol and Preliminary Results. Bull. Amer. Meteor. Soc., 98, 1185–1198, https://doi.org/10.1175/BAMS-D-16-0019.1.

Tang, T., Shindell, D., Samset, B. H., Boucher, O., Forster, P. M., Hodnebrog, Ø., Myhre, G., Sillmann, J., Voulgarakis, A., Andrews, T., Faluvegi, G., Fläschner, D., Iversen, T., Kasoar, M., Kharin, V., Kirkevåg, A., Lamarque, J.-F., Olivié, D., Richardson, T., Stjern, C. W., and Takemura, T.: Dynamical response of Mediterranean precipitation to greenhouse gases and aerosols, Atmos. Chem. Phys., 18, 8439–8452, https://doi.org/10.5194/acp-18-8439-2018, 2018

Sillmann, J., Stjern, C. W., Myhre, G., Samset, B. H., Hodnebrog, Ø., Andrews, T., Boucher, O., Faluvegi, G., Forster, P., Kasoar, M. R., Kharin, V. V., Kirkevåg, A., Lamarque, J.-F., Olivié, D. J. L., Richardson, T. B., Shindell, D., Takemura, T., Voulgarakis, A., and Zwiers, F. W.: Extreme wet and dry conditions affected differently by greenhouse gases and aerosols, npj Clim Atmos Sci, 2, 24, https://doi.org/10.1038/s41612-019-0079-3, 2019.