Title: Sensitivity of modeled Indian Monsoon to Chinese and Indian aerosol emissions

Response to Review #1

We would like to thank the editor and reviewers for the helpful comments and for the thorough review of our paper.

We thank the reviewer for the careful review of our paper. We have addressed reference issues and questions from Reviewer #1. Detailed responses to the reviewer is given below. All of the changes in the manuscript are indicated in red in the Additional Material file.

Response to Anonymous Reviewers

Reviewer: 1

Reviewer comments to the author:

This paper presents a detailed analysis of the Indian monsoon precipitation response to both idealised and more realistic regional aerosol perturbations, conducted with several different current-generation composition-climate models. The paper is notable for bringing together simulations from several different models in its analysis. The multimodel aspect of this study allows identification of robust features of the response which represents a significant update on previous literature which have studies this problem typically with single models at a time. As a result, I would recommend that this paper be accepted for publication in ACP, subject to satisfactorily addressing a handful of minor comments/corrections I have below, which I hope should all be straightforward.

We thank the reviewer for the helpful comments throughout the review process. We have addressed the comments and corrections suggested by the reviewer here.

1. Figure S1: I'm a little curious about the stippling in the multi-model mean Fig S1(l) - the caption says it indicates where >70% of the models agree on the sign. However, all except one of the individual models seem to show +ve responses in the south-west corner, and yet this is the only bit of panel (l) which isn't stippled... Conversely, several of the models seem to disagree about the response in the north-east corner, but panel (l) shows stippling here. Could the authors just double-check that the stippling has been applied correctly, to set my mind as ease.

We thank the reviewer for pointing out this issue, and have fixed the stippling issue.

2. Also on Figure S1, and the associated discussion in L65-68: I'm surprised by the magnitude of the response by up to 30-40% in some models. The caption suggests that this is after 30 years of 1% per year CO_2 increase on pre-industrial concentrations, which would take the simulations up to ~380ppm, slightly below present-day levels, at which you would expect a little under 1K warming. Consequently, this precipitation increase would seem to be far greater than what can be explained purely from the Clausius-Clapeyron relationship. Are there additional factors contributing to this?

We thank the reviewer for pointing this out. There was an issue in the code for this figure and the actual change in precipitation was smaller in magnitude. We switched this figure to the $4xCO_2$ CMIP6 runs in order to get a larger signal. The magnitude of these changes can be very large in some locations (~60% for some models), which may be due in part to Clausius-Clapeyron, but also to a shift in the strength and position of the ITCZ.

3. Figure S2: What is the source for this emissions dataset? The caption says that it is a 2000-2015 average of the input emissions to the PDRMIP and RAEI experiments, but the methods section indicates that both these sets of simulations used timeslice 2000 or 2005 emissions.

We thank the reviewer for making this point. The emissions data used in this figure are the black carbon and sulfur emissions from the CEDS anthropogenic emissions data. We chose to average over the period 2000-2015 as the different models studied here all use slightly different emissions years. We have now included a reference to Hoesly et al. in the figure caption.

4. Table 1: The info for the indirect effects for HadGEM3 and IPSL seems to contradict the equivalent Table

1 of Liu et al., J. Clim. (2018), which describes the PDRMIP regional experiments. According to Liu et al., HadGEM3 includes both 1st and 2nd indirect effects for HadGEM3 sulfate, whilst IPSL includes 1st indirect effect only, which differ from the descriptions given here. Please double check the info.

We thank the reviewer for pointing this out and have corrected this error in the manuscript.

5. The present study uses 6 PDRMIP models (L142 and Table 1), but Liu et al. (2018) describes 7 PDRMIP models that ran the regional aerosol experiments. Why was CESM1-CAM4 not included in the present study, given that this model had apparently also run the PDRMIP regional experiments?

We chose not to include the CESM1-CAM4 in our study because output from its PDRMIP BC10xASIA run was not available through NIRD. While it would be nice to include, we don't think its additional results would have significant bearing on the conclusions presented here, anyway.

6. Methods and Results sections: On that point, the Liu et al. (2018) is not properly credited in this manuscript. The Liu et al. (2018) paper describes and presents initial analysis of the precipitation response to the PDRMIP regional experiments, including a brief discussion of the Asian monsoon response. This by no means detracts from the present study, which provides a much more in depth analysis of the Indian monsoon response in these PDRMIP experiments, however Liu et al. needs to be appropriately cited. Currently the only place I can find it referenced is in L223 where it is incorrectly referenced with regard to the global PDRMIP experiments, when in actual fact this paper analysed the regional experiments, and was the first to do so.

We thank the reviewer for making this important point. We have now updated the citation in two places. We have replaced our initial description with: "The first regional analysis of the PDRMIP experiments by Liu et al. (2018) found also a weak precipitation response to BC changes, attributed to insignificant circulation changes relative to those induced by the sulfur experiments". We have also included a brief parantetical in the conclusions section.

7. L246-247: I think this should say Figure S6 not S7.

The reviewer is correct and we have now fixed this error.

8. L282: "Almost all models" - there's only three models, so maybe just say "2 out of 3", otherwise it sounds more confident than it really is

We thank the reviewer for pointing this out, and we note that the wording of our sentence was unclear. We meant that almost all scenarios across the multi-model ensemble show this increasing trend in precipitation, with the exception of just one scenario from one model. We have now corrected this sentence to say: "All scenarios across the multi-model ensemble (with the exception of CESM's CHN 20% SO2 scenario) show an increase in summer precipitation in India when SO2 emissions in China and/or India are reduced."

9. Section 3.3/3.4: The authors could consider also referencing Shawki et al., JGRA (2018) in the discussion here, which found the same response of increased Indian monsoon precip in response to reducing Chinese SO2 emissions, using HadGEM3 (precursor to UKESM1), and attributed this to the increased land-sea temperature contrast. This supports your results here, and it could be good to note the consistency with this previous study.

We thank the reviewer for making this point and have now added a sentence in section 3.4 addressing this point: "A similar analysis by Shawki et al. (2018) also found that reduced Chinese SO2 emissions strengthened the land-sea temperature contrast and consequently precipitation over India."

10. L298-299: "For all reduced BC scenarios, the changes in India's precipitation are generally small (~5% locally) and not statistically significant at a 90% confidence level". Looking at Figure S8, this statement doesn't seem to be true for UKESM1.

The reviewer is correct and we have added a short parenthetical to address this point.

11. L361-362: Again Liu et al. (2018) should also be referenced here, as it previously showed this for the regional Asian BC PDRMIP experiment as well.

We have now updated the sentence to include a reference to Liu et al.