This paper by Geeta G. Persad shows how precipitation response depends on aerosol emission regions. The paper is well written and the topic is relevant for the community.

Author use CESM2-CAM5 model with slab ocean configuration. Experimental setup consists of 8 regions where the author has changed regional emissions to correspond to China's emissions from the year 2000. Author clearly shows how the fast and slow precipitation responses depend on the emissions regions, and discusses thoroughly on the mechanisms behind the changes.

I thank the reviewer for their careful assessment of the paper and their overall favorable review of its clarity and relevance to the community.

Major comments

The role of natural variability is not discussed. As the runs are equilibrium runs, the year-to-year variability can be used as an estimate for natural variability.  Are the results significant compared to year-to-year variability.

The focus of the paper is on the forced signal, thus extensive discussion of the role of natural variability is outside the scope. However, the statistical significance estimates provided on all figures assesses the significance of the forced signal compared to year-to-year variability. I have now enhanced the presentation of the statistical significance estimates and added explicit discussion of their relation to year-to-year variability.

I use 60 years of simulations in the slab-ocean configuration to characterize the equilibrium precipitation response to aerosol perturbations and use the year-to-year variability as an estimate of natural variability. Standard errors derived from the interannual variability in the difference between the slab ocean PI control and each perturbation experiment were previously given in Figure 1 and have now been updated to provide the 95% confidence range. This 95% confidence range is also provided as error bars on the fast and slow precipitation responses in Figure 2. <u>From this significance calculation, it is clear that for all regional perturbations aside from Indian and East African emissions the global-mean total precipitation response is statistically distinguishable from zero at the 95% confidence level after accounting for internal variability and thus is highly unlikely to have arisen from internal variability alone.</u> Similar statistical significance estimates have been provided for all other figures.

The following improvements will be made to the revised manuscript, including explicit discussion of how the statistical significance calculations reflect the role of year-to-year variability:

- I now more explicitly discuss the interpretation of the statistical significance calculation in the context of internal year-to-year variability as follows:
    - L120-122 (Methods): “The 95% confidence level (i.e. 1.96σ) based on year-to-year variability in the difference between the control simulation and each perturbation experiment is provided for all global-mean values.”
    - L139-145 (Results): “The global-mean precipitation response to Indian and East African emissions, which constitute the weakest of the precipitation responses, are statistically indistinguishable from zero and from each other in the presence of internal variability. All other global-mean precipitation responses are statistically significant at the 95% confidence level, and thus highly unlikely to arise from internal variability alone. Although the 95% confidence interval in the global-mean response to some regional emissions are overlapping, it is clear that there is statistically significant diversity in the global-mean response to identical aerosol emissions from different regions.”
- The above information on statistical significance was previously omitted accidentally from the figure captions, as the reviewer has noted in the minor comments. I have now updated the figure captions in Figures 2, 3, and 4 to make clearer that the 95% confidence interval is indicated.
- All error ranges or statistical significance markings shown on all figures now use the 95% confidence interval (instead of the standard error) to provide explicit indication of whether the signal can be confidently distinguished from year-to-year variability.

How do these results compare to other similar experiments with other models? Example PDRMIP regional experiments

Much of the Discussion section is devoted to comparing the results of this paper to similar experiments in other models, including the PDRMIP regional experiments analyzed in Liu et al., 2018. In general, the fundamental physical behavior exhibited by these simulations is well-aligned with the results of other similar experiments. I now more explicitly indicate the experimental design and models used in the studies that are compared with throughout the discussion section as follows:

L286-294: “The dependence of the atmospheric absorption and fast precipitation response strength on aerosol location seen here aligns with results from highly idealized studies. Dagan et al. (2019) forced an aquaplanet atmospheric general circulation model (ICON) with equivalent, radially symmetric absorbing aerosol optical depth plumes in the deep tropics versus mid latitudes and found higher resulting atmospheric absorption in the deep tropics due to stronger cloud feedbacks. However, the aquaplanet formulation reduces the comparability of the resulting fast precipitation responses with those seen in this study. A follow-on study in the same atmosphere-only model with a realistic land surface found a stronger local fast precipitation reduction over land in response to a tropical scattering AOD plume than to a comparable higher latitude plume, though the use of a purely scattering plume as opposed to the mixed scattering and absorbing aerosols used in this study again limits direct comparison (Dagan et al., 2021)."

L303-316: "The regions that manifest local fast versus slow precipitation responses in the simulations analyzed here also overlap with regions identified in existing studies, including those utilizing Precipitation Driver and Response Model Intercomparison Project simulations (PDRMIP, Myhre et al., 2016). Samset et al. (2018) evaluated the regions for which fast precipitation responses dominate slow precipitation responses for PDRMIP multi-model simulations of idealized global forcings, including 10 times present-day global black carbon emissions and 5 times present-day global sulphate emissions. Although the spatial pattern of imposed perturbation differs from this study (i.e. globally distributed vs. regionally confined perturbations), they also find that the total precipitation response to both global BC and global sulphate are dominated by the fast response over parts of South Asia and most of the African continent. High latitude precipitation responses to these two forcers, meanwhile, are dominated by the slow precipitation response in the multi-model simulations (Samset et al., 2016), though individual models show conflicting results (Zhang et al., 2021). Similar PDRMIP multi-model simulations with regional idealized aerosol emissions over Asia and Europe (Liu et al., 2018), however, also showed a strong local fast precipitation response to Asian aerosols and almost no fast precipitation response to European aerosols. The appearance of a fast precipitation response in low latitude continental regions in response to both localized and global-scale aerosol forcing and the absence of one at high latitudes thus appears to be a robust feature across models and aerosol perturbation set-ups. "

L346-353: "The greater capability of higher latitude emission sources at generating total global-mean precipitation change also appears to be a robust feature of the response to aerosols. Studies analysing the global-mean precipitation response to removal of present-day aerosols from individual regions find that removal of European or North American emissions generates stronger global-mean precipitation per unit of radiative forcing than removal of South or East Asian emissions (via fully coupled HadGEM3-GA4 simulations in Kasoar et al., 2018; via fully coupled GISS E2, GFDL CM3, and NCAR CESM1 simulations in Westervelt et al., 2018), in line with the findings here. This reinforces the latitudinal dependence in the climate response to heterogeneous regional forcing found in earlier studies (Shindell & Faluvegi, 2009; Shindell et al., 2012) and indicates that it continues to apply as the forcings become more regionalized."

minor comments:

Figure 2. Lack of explanation for the black lines

Thank you for catching this omission. All black lines are the error bars associated with the 95% confidence interval. The caption for the figure has been updated to describe this as follows:

“Error bars provide the 95% confidence interval (±1.96σ).”

Figure 1,figure 6,figure 5. It is somewhat hard to read where the precipitation change is significant when the statistical significance is indicated via gridlines. Meaby change to dots?

The density of gridlines has been increased to make the regions of statistical significance more clearly distinguishable. A different output format has also been used to reduce issues with rendering when saving to PDF, which altered the visibility of the gridlines.

Figure 3. Lack of explanation for the black lines

Thank you for catching this omission. These black lines are the error bars associated with the 95% confidence interval. Note that this has been updated from the previous version of this figure, which used standard error rather than 95% confidence interval (see response to Major Comments above). The caption for the figure has been updated to describe this as follows:

“Error bars provide the 95% confidence interval (±1.96σ).”

Lines 150-155. Here author list different feedbacks due to sea surface changes. I would like to see also how this is limited by the slab ocean configuration

I do expect that some aspects of the responses seen here would be modified by use of a fully dynamical rather than slab ocean, as is discussed in detail at L355-365. In the context of the slow precipitation scaling and associated driving processes discussed at L150-155, however, it is important to note that one of the seminal papers to identify this 2-3%/K precipitation increase per degree K and the associated driving moist convective feedbacks and dynamical constraints was conducted in a slab ocean configuration like the one use here (Held and Soden, 2006). Although that analysis was done on the total rather than slow precipitation response, it was done in the context of the response to $CO_2$ forcing for which the fast precipitation response is expected to be overwhelmed by the slow precipitation response. This behavior has since been confirmed in response to a broader range of forcings and using dynamical ocean set-ups in Samset et al., 2016 and Sillman et al., 2017. Notably, the slab ocean simulations used here also exhibit this 2-3%/K scaling in the slow precipitation response to regional aerosol emissions (identifiable from Figure 2b). Unfortunately, explicit assessment of whether the same tropical mass flux constraint identified by Held and Soden (2006) is operating here would require analysis of the convective mass flux, which was not saved out in these simulations.

I have added the below language at L165-167 to summarize the above discussion:

“Indeed, the slow precipitation response to regional aerosol perturbations seen here follows the 2-3%/K scaling previously identified in both fully dynamical ocean and slab ocean coupled set-ups (Held & Soden, 2006; Samset et al., 2016; Sillmann et al., 2017).”

line 115-120,145-146: Change word couple to slab ocean, to indicate that runs are not done with fully coupled ocean.

These modifications have been made. Note that I have replaced “coupled” with “slab ocean coupled” at L152 and 153 to distinguish from the atmosphere-only results, as these responses do involve atmosphere-ocean coupling (just to a slab rather than fully dynamical ocean).

Figure 4a. should show also if the change is significant or not, example by hatching the squares.

Thank you for this suggestion. I have now updated Figure 4a to indicate the regional-mean responses that are statistically significant at the 95% confidence level (black asterisks). However, it should be noted that many of the regions that do not exhibit a statistically significant regional-mean precipitation response do exhibit statistically significant precipitation responses in some grid cells. I have therefore also distinguished the regional-mean responses that do not have any statistically significant within-region precipitation responses (grey asterisks) from those that do (no asterisk).

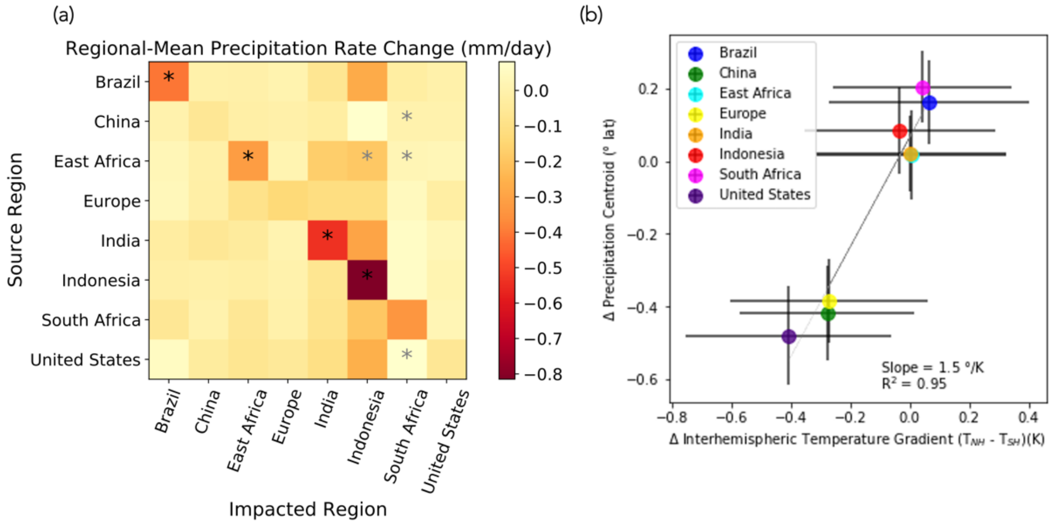

**Figure 4**. (a) Regional-mean changes in precipitation rate (mm/day) in each of the 8 regions (columns) due to emissions from each of the 8 regions (rows) are shown. (b) Shifts in the location of the intertropical convergence zone, quantified as the change in the meridional centroid of zonally averaged precipitation between 20° S and 20° N (° latitude, y-axis), correlate with the change in interhemispheric temperature gradient, quantified as the differences between Northern Hemisphere and Southern Hemisphere mean surface temperature (K, x-axis). Error bars on panel (b) provide the 95% confidence interval ($\pm 1.96\sigma$). Black asterisks on panel (a) indicate regional-mean precipitation changes that are significantly different than zero with 95% confidence. Grey asterisks on panel (a) indicate regions with no statistically significant precipitation response in any grid cell; All others show statistically significant precipitation responses in some grid boxes within the region (see Figure 1), although the regional-mean change is not statistically significant.