Thank you for your efforts to address the reviewers' comments. I want to raise just a couple of points where I think there are remaining issues from the discussion.

Response:

We really appreciate your careful read and great comments/suggestions. We have responded to each comment and revised the manuscript accordingly.

The question of linearity was raised by the referees, and it is good to see that you have included some discussion of this in the revised manuscript. However, while you note that there are some clear nonlinearities present in response, you conclude that they are largely insignificant. I have some concerns about this conclusion, as I think there may be an error in the interpretation of the significance test. In all figures with stippling, the caption says that stippling indicates where the response is insignificant. However, the stippling in all figures covers the largest responses, and is absent from the regions with no change. Please can you double check whether your stippling is indicating significant or insignificant responses, and update your discussion accordingly (and update the discussion around the nonlinearities in the response in particular).

Response:

Thanks for the comments.

After checking the figure captions and codes, we found that it was a typo—the stippling in all figures shows the regions with ***significant*** values at the 90% confidence level based on a two-sided t-test. We apologize for the mistake and have updated all the captions and discussions accordingly.

In terms of the significance of the nonlinearity in the climate responses (i.e., total vs. WH+EH), the related discussion is adjusted to be the following:

"*The linear summation of WestFF and EastFF results (denoted as "WestFF+EastFF") presented in Fig. 2d shows greater SST responses in the tropical Pacific and tropical Indian Ocean compared with actual FF results (Fig. 2c). However, most of the warming signals over the central and eastern tropical Pacific calculated from WestFF+EastFF are statistically insignificant. Notably, the equatorial West Pacific (160ºE–180º) exhibits a significant warming signal in WestFF+EastFF, which is missing in FF results. This disagreement between FF and WestFF+EastFF is likely due to the nonlinear interactions between the impacts of EastFF and WestFF. Similarly, in the extratropical North Pacific, WestFF+EastFF closely resembled the EastFF pattern (i.e., the cooling trend in the western*

extratropical Pacific; Fig. 2a) while the actual FF results are dominated by WestFF (Fig. 2b&c). The Atlantic response appears to be largely consistent despite greater magnitudes in WestFF+EastFF, with warming from both EastFF and WestFF. Besides the nonlinearity issue, aerosol forcings outside the two focused regions (i.e., aerosols in Africa and the Arabian Peninsula; see Fig. 1d) could also partially contribute to the differences between FF and WestFF+EastFF, particularly by driving cooling over the western tropical Indian Ocean and weakening the wind anomalies (Fig. 2c&d). Additionally, the aerosols outside the focused region could also impose a remote impact on the tropical Pacific region (Huang et al., 2021; Shi et al., 2022), but such impacts are likely to be smaller compared to the nonlinear interactions between EastFF and WestFF impacts, given the small magnitude of the radiative forcing (Fig. 1d)."

The reviewers also highlighted the recent decline in Chinese aerosol emissions, which isn't captured in the emission dataset used in the CESM1 experiments. You have added some text around line 244 in the tracked changes version of the manuscript. However, while I agree with the reviewers that the emission dataset used in the simulations makes comparison with the real world difficult, I note that you are using ERA5 as 'observations'. I suspect that ERA5 is also using an emission dataset that does not capture the recent decrease in Chinese emissions. Please check what was done with aerosol emissions in ERA5 and update your discussion of the comparison between CESM1 and ERA5 accordingly. In the event that both CESM1 and ERA5 do not capture the recent decline in Chinese emissions, I recommend including a sentence or two about the implications of this for using your analysis to interpret recent observed trends in the Pacific.

Response

Thanks for the constructive suggestion.

We checked the technical details of ERA5 (Hersbach et al., 2020), and yes, ERA5 uses aerosol forcings from CMIP5, which is the same as CESM1 experiments applied in this study. However, we note that ERA5 also assimilated many other observational datasets, including shortwave fluxes and sea surface temperature. Therefore, the negative effect of the bias aerosol forcing (especially the unestimated Chinese aerosol decline since the 2010s) on its fidelity may not be as severe as in free-running climate model simulations.

We now updated the related statement in the revised manuscript as follows:

"One caveat to be noted is that the aerosol forcing scenario (RCP8.5) used in both the Fix_EastFF1920 experiments and ERA5 reanalysis dataset has been shown to overestimate the aerosol emission level in East Asia and miss its observed reduction since the early 2010s despite remaining at a high level (Wang et al., 2021; Xiang et al., 2023). This leads to the overestimation of the EastFF forcing in our model experiments than the real world. On the other hand, similar aerosol forcing biases exist in the ERA5 reanalysis dataset (Hersbach et al., 2020), although the negative impact is mitigated by actually assimilating radiation flux measure and surface temperature. Therefore, although the

simulation results and ERA5 appear largely comparable, cautions should be taken in using them to quantitatively interpret the remote impact of Asian aerosol on the North Pacific in the recent couple of decades. In addition, the South Asia emission trend largely follows the assumed emission scenario, which leads to a dipole of aerosol forcings changes within the EH. The forcing dipole might introduce complex circulation responses and lead to different responses over the North Pacific. Simulations with more updated aerosol emission inventory and forcing trends and new observational datasets are necessary to fully explore the realistic climate responses to Asian aerosol forcings."

I also have an additional question. At L157 you note that your Aleutian Low response doesn't agree with that presented by Smith et al., and attribute this to the use of global aerosol perturbations by Smith et al. (from the CMIP5 DAMIP experiments). I would be curious to see the comparison between the SLP anomalies in your FF simulation and those from Smith et al. Based on the temperature response, I expect this won't change your conclusion. However, it would be interesting to see the comparison between the SLP response in FF, EastFF, WestFF, and WestFF+EastFF.

Response

Thanks for the great question!

The SLP changes in FF, EastFF, WestFF, and BMB are already shown in the bottom panels of Fig. 5 and Fig. 6, and we include a combined figure here that only contains SLP in this response for an easier comparison (Fig. R1). The North Pacific SLP trend in response to FF does not match the “aerosol-only” results in Smith et al. (2016) (see Fig. R2). However, it is not surprising because the CMIP5 “aerosol-only” experiment contains both fossil-fuel-burning aerosol (FF) and biomass-burning aerosol (BMB).

Using the same CESM1 single forcing large ensemble experiments, Deser et al. (2020) used the simple linear addition of FF and BMB to represent climate responses to *total* “aerosol-only” forcings. Similar to the CMIP5 “aerosol-only” results (Fig. 2b), FF+BMB shows an increase in SLP over the North Pacific. This supports our statement in the manuscript regarding the competing role of FF and BMB.

However, different from the large-scale SLP increase over the North Pacific in the CMIP5 results, CESM1’s positive SLP changes in response to FF+BMB cover smaller regions and with smaller magnitudes. This is likely due to the nonlinear interactions between FF and BMB impacts (similar to the discussed nonlinear interactions when adding EastFF and WestFF responses; see the disagreement between Fig. R1 c, and d).

In summary, the Editor raised a very interesting (and important) question that is worth more discussion. However, since we intend to focus our discussions on the comparisons between EastFF and WestFF (which are based on our own regional forcing simulations), we

are keen on keeping the detailed discussions here rather than including them in the manuscript. Instead, We include Fig. R1 as the new Fig.S1 in the supplementary document, and updated our SLP-related statements in the revised manuscript as follows:

"Smith et al. (2016) argued that the AA forcing originating from the East Asia region induces large-scale warming in the North Pacific and leads to a weakening of the Aleutian Low, while our results here, however, do not support such an argument. The reason is that only the total aerosol-only experiments from CMIP5 were analyzed in the previous study, which indeed yields consistent responses when compared to the FF+BMB results in the CESM1 single forcing large ensemble experiments (Deser et al.(2020); also shown in Fig. S1 in the supplement despite a weaker magnitude). Therefore, we suggest the nonlinearity when combining regional (e.g., EH and WH) or sectoral (e.g., FF and BMB) aerosol responses makes it very challenging to clearly distinguish the climate impact due to aerosol forcings from particular sources or regions simply based on those total "aerosol-only" experiments as in CMIP5/6's DAMIPs, hence justifying the importance of running more nuanced regional aerosol perturbation experiments as designed and conducted here in our study."

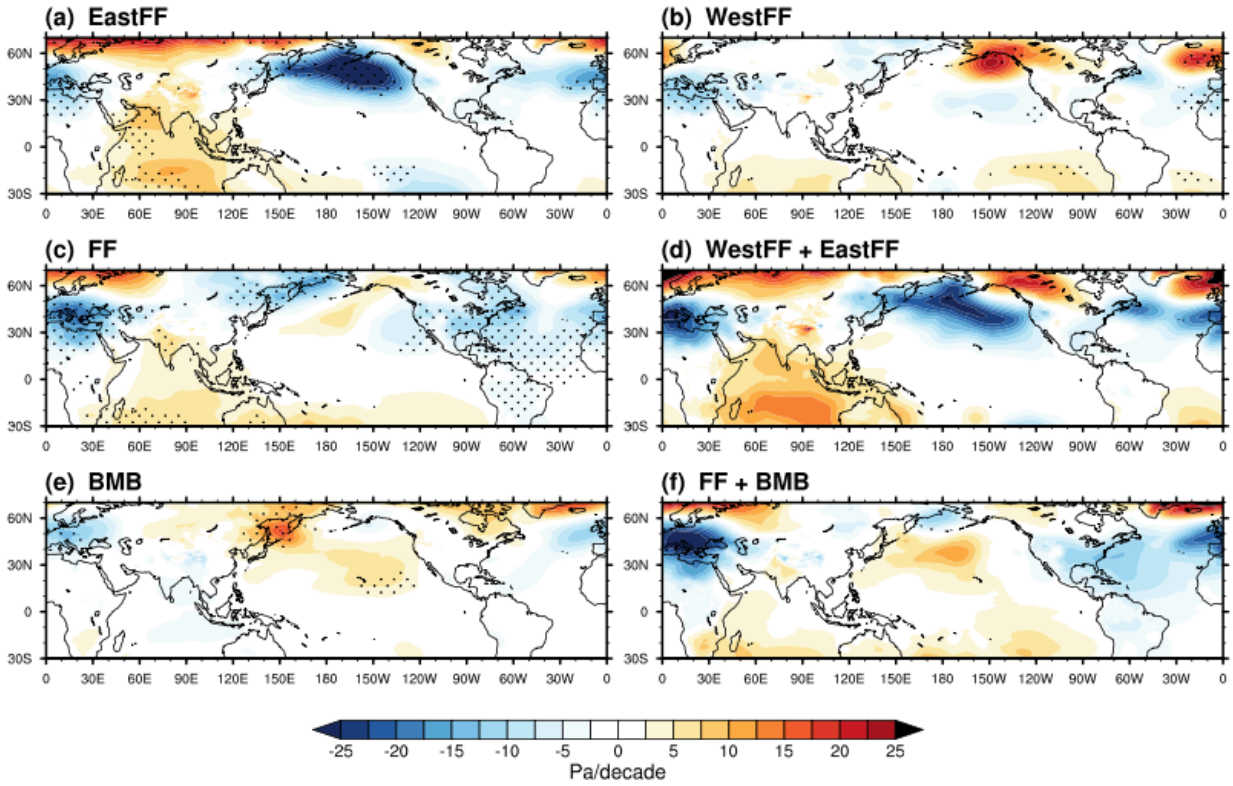

Fig. R1

Decadal changes in sea level pressure (shading; Pa per decade) during 1980–2020 calculated in response to (a) EastFF, (b) WestFF, (c) FF, and (e) BMB. (d) shows the decadal changes in sea level pressure calculated from the linear addition of EastFF and WestFF. (f) is similar to (d) but shows the results from the linear addition of FF and BMB. Stippled regions indicate significant values at the 90% confidence level based on a two-sided t-test.

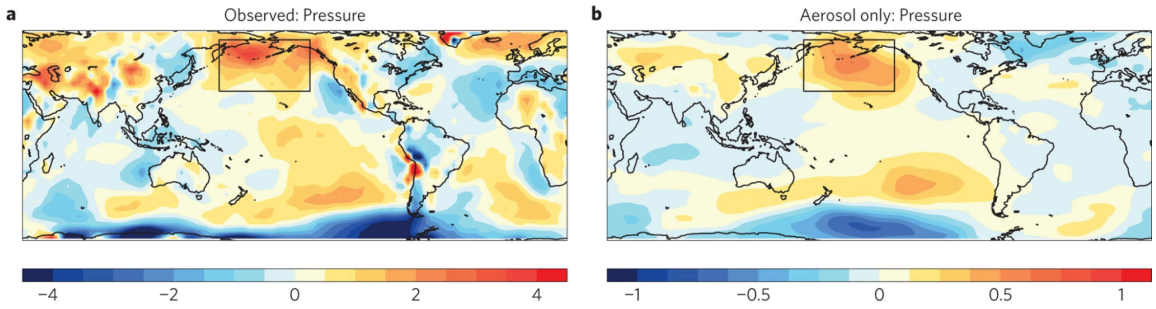

Fig. R2

Decadal trend of sea level pressure (hPa per decade) from (a) observation and (b) CMIP5 model simulations. Figure borrowed from Figure 3 in Smith et al. (2016).

Please also address a few remaining typos etc. All line numbers refer to the marked up version.

L15: 'Based on CESM1' -> 'with CESM1'

— We changed words as suggested.

L59: Revert to your original text here, which was correct. There are a few places throughout the manuscript where citations are incorrectly formatted. Please check for more (e.g. L155, L163, ...)

— Fixed.

L96: additionally -> Additionally

— Fixed.

L174: Depending on the mechanism, the Pacific could also be considered to be downstream. I suggest simply deleting this comment.

—Thanks for the suggestion. We deleted this comment as suggested.

References

Hersbach, H., Bell, B., Berrisford, P., Hirahara, S., Horányi, A., Muñoz-Sabater, J., Nicolas, J., Peubey, C., Radu, R., Schepers, D., Simmons, A., Soci, C., Abdalla, S., Abellan, X., Balsamo, G., Bechtold, P., Biavati, G., Bidlot, J., Bonavita, M., De Chiara, G., Dahlgren, P., Dee, D., Diamantakis, M., Dragani, R., Flemming, J., Forbes, R., Fuentes, M., Geer, A., Haimberger, L., Healy, S., Hogan, R. J., Hólm, E., Janisková, M., Keeley, S., Laloyaux, P., Lopez, P., Lupu, C., Radnoti, G., de Rosnay, P., Rozum, I., Vamborg, F., Villaume, S., and Jean-Noël Thépaut: The ERA5 global reanalysis, Q. J. R. Meteorol. Soc., 146, 1999–2049, 2020.

Deser, C., Phillips, A. S., Simpson, I. R., Rosenbloom, N., Coleman, D., Lehner, F., Pendergrass, A. G., DiNezio, P., and Stevenson, S.: Isolating the evolving contributions of anthropogenic aerosols and greenhouse gases: A new CESM1 large ensemble community resource, J. Clim., 33, 7835–7858, 2020.

Smith, D. M., Booth, B. B. B., Dunstone, N. J., Eade, R., Hermanson, L., Jones, G. S., Scaife, A. A., Sheen, K. L., and Thompson, V.: Role of volcanic and anthropogenic aerosols in the recent global surface warming slowdown, Nat. Clim. Chang., 6, 936–940, 2016.