

Title: Background-state dependence of aerosol responses in CESM2 boreal-summer climate

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General comments: This study examines the state dependence of climate responses to anthropogenic aerosol forcing in CESM2. I found the results very interesting and a nice follow-up study of Simpson et al. (2023). The manuscript is well-written and structure in a easy-to-follow fashion. In the manuscript, the authors compares aerosol climate responses estimated from aerosol-only simulations (AAER) and the residual ALL-xAER approach in CESM2. The two approaches produce broadly similar responses during the historical period but diverge substantially under future climate conditions, particularly for precipitation over the Asian monsoon and Indo-Pacific regions. The differences are associated with changes in moisture transport, atmospheric circulation, Rossby-wave propagation, and ocean-atmosphere interactions. The results show that aerosol responses are background-state dependent, meaning that aerosol-only and residual approaches are not necessarily dynamically interchangeable. The content should be fitting well to readers' interest in *Weather and Climate Dynamics*, so I am positive for its publication on *Weather and Climate Dynamics*. I have a few specific comments and suggestions for the authors to consider, which focuses on the perspective of radiative forcing, the mechanisms underlying nonlinear responses in large-scale atmospheric circulation and in AMOC, and expand the Discussion section, followed by minor comments and Technical corrections.

Specific comments:

Major comments:

- 1. The aerosol radiative forcing:** I understand that the authors would like to focus on the complex responses in dynamical components, including precipitation over the Asian monsoon and Indo-Pacific regions and the atmosphere-ocean coupling in the North Atlantic. However, for the fundamental understanding of where the nonlinear responses may originate before the climate system begins to adjust, I am wondering have the authors thought about the role of aerosol-induced radiative forcing in AAER and ALL-xAER? If I understand correctly, the aerosol forcing is a consequence of a series of aerosol emission files given when NCAR conducted AAER and xAER simulations. These prescribed aerosol emissions should be perfectly interchangeable in the AAER and ALL-xAER, but may not be necessary for the resultant radiative forcing, which involves with radiative processes, interaction with clouds, or other fast relevant chemical processes. My hypothesis is that, as the radiative and aerosol-chemistry processes are rather complicated, some nonlinear or non-additive responses could emerge. I am wondering is there any approach to quickly inform readers that the non-interchangeable responses are or are not originating from the radiative forcing. I am not sure if NCAR conducted corresponding fixSST simulations for estimating the effective radiative forcing in AAER and ALL-xAER. Some results from RFMIP repository may be useful (Kramer et al. 2026).
- 2. Large-scale atmospheric circulation responses.** If I understand correctly, I think that the authors tried to explain how the large-scale atmospheric circulation responses in high-latitudes, where is closer to local aerosol emission regions, link to the responses in the lower latitudes. The dynamical pathway, involving with zonal wind at 300 hPa, wave activities fluxes, linearized Rossby wave sources, divergent wind response at 200 hPa, seems reasonable (following the order of Figs.6-9). However, the authors also argued that the Rossby wave sources are associated with enhanced monsoon convection (Lines 493-495). I am a little bit

confused by which pathway is thought of as the dominant route? Would the aerosol forcing in the North be more effective in affecting the tropical precipitation via changing mid-latitude jet and subsequent eddy activities, and then exciting southward Rossby wave propagation (although this may be less likely from a Rossby wave dynamical perspective, Woollings et al. 2023)? Or the monsoon-induced Rossby wave source directly drives local precipitation at lower-latitudes. In addition, the two pathways may not be necessarily separated, as the mid-latitude eddies could influence Hadley circulation in the tropics.

3. AMOC responses. The first question is about the timing of AMOC decline in ALL, AAER, and xAER (Fig. 11b). It seems the year when AMOC turns to decline is around 1980, exactly about the time aerosol emissions in the Northern U.S. and Europe, indicating that this response may be a direct response to the radiative forcing change. However, if difference between (SMBB - xAER) AMOC and AAER AMOC (blue and orange lines in Fig. 11a) seems to become larger after 1980 and continue increasing into 200s and afterward, likely reflecting other processes at a slower and longer timescales. Back to comment 1, if the time series of radiative forcing can be somehow presented, it would be helpful to clarify the timing of AMOC decline is a direct response to aerosol-induced radiative forcing or through slower ocean dynamical processes.

The second question is about the oceanic processes. I like the authors showing the cloud and the shortwave cloud radiative effect, which contribute to the AMOC strengthening in (ALL-xAER) - AAER. However, how dominant are the cloud-radiative processes? In Simpson et al. (2023), Isla showed in their Fig. 11, in which the sea-ice melting, freshwater input, and shallower mixed-layer depth are also important, particularly for explaining the nonlinear AMOC responses.

Together, from both the forcing timing and process-level perspectives, I guess that it would be telling a more comprehensive story with additional analysis or discussions on these aspects.

Minor comments:

Line 90: how can aerosol forcing interact with other forcing agents? The forcings, for example carbon dioxide and ozone, in CESM2 are all prescribed.

Line 237: where is the global mean temperature response?

Lines 298-299: I don't see clear enhanced wetting over Australia. Please clarify.

Figures 4-9: how to evaluate the statistical significance?

Line 348: Figs. 2a, b.

Line 362: It is not clear to me the thermally induced cyclonic circulation. Could you clarify?

Line 431: why linearisation of Rossby wave diagnostic only works for tropics, not for mid-latitudes? Can the authors clarify?

Lines 461-463: could cite a few references for this argument.

Line 502: It seems the mid-tropospheric vertical velocity is a key indicator for the underlying mechanism, why not moving Fig. S7 to the main manuscript?

Line 515: what does “substantially amplified” indicate? I do not see much amplitude difference in the left column and right column in Figures 6 and 7. Could the authors clarify?

Technical corrections:

Line 205: Figures 1a-b show?

Line 207: maybe “...across the major industrial regions over the Northern Hemisphere,...”

Line 224: to be consistent throughout the manuscript: Fig. or Figure.

Line 367: Figs. 5a, b.

Line 368: Figs. 3a, b.

Line 475: Figs. 7a, b.

Line 479: Figs. S6a-c.

Figure 11: I guess that SMBB means the all-forcing simulations under smoothed BMB. Please clarify SMBB maybe in the figure caption.

References:

Kramer, R., Smith, C., and Andrews, T.: The Radiative Forcing Model Intercomparison Project (RFMIP2.0) for CMIP7, EGU sphere [preprint], <https://doi.org/10.5194/egusphere-2025-4378>, 2025.

Simpson, I. R., Rosenbloom, N., Danabasoglu, G., Deser, C., Yeager, S. G., McCluskey, C. S., Yamaguchi, R., Lamarque, J.-F., Tilmes, S., Mills, M. J., and Rodgers, K. B.: The CESM2 Single-Forcing Large Ensemble and comparison to CESM1: implications for experimental design, *J. Climate*, 36, 5687–5711, <https://doi.org/10.1175/JCLI-D-22-0666.1>, 2023.

Woollings, T., Li, C., Drouard, M., Dunn-Sigouin, E., Elmestekawy, K. A., Hell, M., Hoskins, B., Mbengue, C., Patterson, M., and Spengler, T.: The role of Rossby waves in polar weather and climate, *Weather Clim. Dynam.*, 4, 61–80, <https://doi.org/10.5194/wcd-4-61-2023>, 2023.