Point-by-point Response to Reviewer's Comments

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We would like to express our sincere thanks to Dr. William Collins for his very insightful and constructive comments and suggestions. His second review helped us to further improve the manuscript substantially. Our detailed responses can be found below in black. The reviewer's comments are shown in blue.

In addition, we would like to ask for the Topical Editor's approval for adding a few words to the title of the manuscript to reveal what aspects of the EAM simulations are analyzed in this study.

- Old title: *Further improvement and evaluation of nudging in the E3SM Atmosphere Model version 1 (EAMv1)*

- Revised title: *Further improvement and evaluation of nudging in the E3SM Atmosphere Model version 1 (EAMv1): simulations of the mean climate, weather events, and anthropogenic aerosol effects*

Responses to reviewer's comments

Comment 1:

I wish to thank the authors for their careful consideration of my comments, particularly to my question on temperature nudging. Their response and the text lines 400-430 shows that there are two effects – a mean-state correction in ERA5, and a suppression of adjustments in CLIM PD. It would be helpful to explicitly explain it in these terms.

Thanks for the positive feedback and the nice summary of the issues associated with temperature nudging. Following the reviewer's suggestion, we have significantly revised the abstract, Section 5, and the conclusions section:

- The 3rd paragraph of the abstract has been rewritten.
- Section 5 ("Estimation of the anthropogenic aerosol effects") has been significantly rewritten. In addition, we added the following subsection titles to help guide the readers through our reasoning and make our point:
    - Section 5.1 Results from the free-running EAMv1
    - Section 5.2 Impacts of temperature nudging

        - Section 5.2.1 Mean bias correction
        - Section 5.2.2 Suppression of temperature changes
        - Section 5.2.3 Combined effects
    - Section 5.3 Impact of the frequency of constraining data
- The second last paragraph in the conclusions section, which summarized our results on the estimation of the aerosol effects, has also been rewritten.

Please see the revised manuscript or the file with tracked changes for the details of our revision.

Comment 2:

The mean-state correction is presumably a more realistic calculation of the ice-cloud forcing so it is not obvious that ignoring this correction should be the preferred calculation (which line 433 states). Line 22 refers to the temperature-nudged calculation as "a slightly biased estimate". However figure 13 shows that the ERA5 temperature nudging actually removes a systematic bias, so it could be argued that this is "a less biased estimate". The problem is that ERA5 temperature nudging also removes the temperature adjustment.

We agree that whether an estimate is biased depends on what the reference is and what our goal is, so the phrase "biased estimate" in our earlier version lacked clarity. In the revised manuscript, we clarify that our preferred configurations of nudging are those capable of producing estimates of anthropogenic aerosol effects that agree with the results from the free-running EAM simulations. For this reason, the mean bias correction caused by nudging temperature to ERA5 and the resulting changes in the anthropogenic aerosol effects are undesirable for our intended applications of nudging. We have clarified this perspective in the abstract, Section 5, and the conclusions section in the revised manuscript. Also, we no longer use the phrase "biased estimate" but use instead "differences" or "discrepancies" with respect to the free-running simulations.

Regarding the comment "The problem is that ERA5 temperature nudging also removes the temperature adjustment", we clarify in the revised manuscript that ERA5 temperature nudging has both effects: mean bias correction and removal of the temperature response to aerosol forcing.

Comment 3:

The calculation of the temperature-mediated adjustment is +24% in FSNT (i.e. from -1.862 to -2.453 W/m2 in table 3), but smaller (+8%) in the net. This is a useful scientific point that helps our understanding of the overall radiative effects of aerosols and so should be mentioned in section 5 and also in the conclusions, for instance the adjustment would be absent from an offline calculation and from the classical split into "direct" and "albedo" effects.

Thanks for pointing this out. We have added the following statements to Section 5 after describing the impact of temperature nudging on the shortwave and longwave components of the TOA fluxes and the cloud radiative effects in Section 5.2.3:

"It is worth noting that the discrepancies in ΔF_{NET} might appear to be not as large. For example, we see a 15% difference in the global mean in (Fig. 12a and Table S4) and a 17% difference in the tropical average (Fig. 12b and Table S5). But the smaller differences in the net fluxes are results of the cancellation of large changes in the shortwave and longwave components caused by temperature nudging."

The following statement has been added to the second last paragraph of the conclusions:

"While the percentage discrepancies in the net TOA flux and CRE appeared to be considerably smaller, this was the result of the cancellation of large discrepancies in the shortwave and longwave components."

Comment 4:

I suggest lines 431-435 are rewritten to explain that nudging to ERA5 might remove a mean-state bias, but because it also supresses a temperature-mediated adjustment it is not the preferred estimate. Similar wording changes are needed in the abstract lines 20-22.

This has been addressed during the rewrite of Section 5 and the 3rd paragraph of Section 5.

Comment 5:

Line 125: This needs a short explanation to say that Faer is the Effective Radiative Forcing including all meteorological adjustments (citing for instance AR5 or AR6) defined using fixed-SSTs. You can then refer back to this explanation when you find suppression of adjustments in section 5.

Thanks for the helpful suggestion. We have added a new paragraph to Section 2.3 ("Simulation"):

"The anthropogenic aerosol effects we are interested in estimating in this study is the effective radiative forcing (ERF) defined in the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, namely the changes in the TOA radiative fluxes when all physical variables in a climate model are allowed to respond to perturbations except for those concerning the ocean and sea ice (Myhre et al., 2014). Our primary focus is the net TOA flux and its shortwave and longwave components. These are denoted by F_{NET}, F_{SW} and F_{LW}, respectively, in the remainder of the paper, with positive values indicating fluxes downward (i.e., into the atmosphere). For the readers who have worked with EAM's output, we note that the F_{SW} presented here is EAM's output variable FSNT while the F_{LW} here is −FLNT, as FLNT in EAM is defined to be positive upward. The net flux is calculated as

$$F_{NET} = F_{SW} + F_{LW} = FSNT - FLNT$$

The changes in F_{NET}, F_{SW} and F_{LW}, caused by anthropogenic aerosols are denoted by ΔF_{NET}, ΔF_{SW} and ΔF_{LW}, respectively."

In Section 5 of the revised manuscript, we clarify again that the aerosol effects we try to estimate are the Effective Radiative Forcing (ERF).

Comment 6:

Line 173: Please explain how CF is calculated. Is it a double-call model diagnostic with clear and cloudy-sky, or is it an offline calculation?

To help clarify this, we have added a second new paragraph to Section 2.3 ("Simulation"):

"We are also interested in the impact of anthropogenic aerosols on the cloud radiative effect (CRE). CRE is defined as the change in a TOA radiative flux caused by the presence of clouds; here we denote the CRE on the net, shortwave and longwave TOA radiative flux by CRE_{NET}, CRE_{SW} and CRE_{LW}, respectively, with positive values indicating more fluxes into the atmosphere. The CRE_{SW} and CRE_{LW} presented here are EAM's output variables SWCF and LWCF, respectively, both of which are diagnosed during a simulation by performing the radiation calculations twice (with and without clouds) and then computing the difference. The net CRE is calculated by

$$CRE_{NET} = CRE_{SW} + CRE_{LW} = SWCF + LWCF$$

The changes in CRE_{NET}, CRE_{SW} and CRE_{LW} caused by anthropogenic aerosols are denoted by ΔCRE_{NET}, ΔCRE_{SW} and ΔCRE_{LW}, respectively."

Please also note that we have changed our wording from Cloud Forcing (CF) to Cloud Radiative Effect (CRE) to be consistent with most recent IPCC reports.

Comment 7:

Line 388 and table S3. The sign convention for the LW forcing should be explained. I assume it is downward. It might be clearer to use the same direction (outgoing) for both SW and LW.

Sorry about the confusion. Some of the EAM output variables define downward fluxes to be positive and some other fluxes are positive upward. To help improve clarity,

- We introduced two sets of new notations (for the TOA fluxes and CRE, respectively), to use consistent sign convention and to distinguish from EAM's output variables. These new notations are introduced in the two new paragraphs quoted in our replies to comments 5 and 6 above and are used throughout the manuscript.

- We added a new table S1 to the Supplementary Materials to explain the meaning and sign convention of the EAM output variables shown in the tables in the Supplementary Materials.

Hope these are helpful for avoiding further confusion.