

We thank the reviewers for their constructive comments. Our response to the comments is as follow:

Response to Reviewer 1:

The grammatical mistakes spotted by Reviewer 1 are corrected. A title (“Normalized sensitivity index (unitless)”) is added to the color bar of figure 9 as suggested.

Response to Reviewer 2:

Climate effects are parameterised exclusively through atmospheric CO₂ concentration, while methane is included solely as a chemical driver. This separates methane’s chemical and radiative roles and implicitly assumes that CO₂ adequately represents total radiative forcing across scenarios. Although the authors note that CO₂ may misrepresent total radiative forcing when greenhouse gas trends decouple, no targeted experiments are presented to quantify the resulting systematic error. It would strengthen the manuscript to evaluate emulator performance under scenarios in which forcing composition diverges from the training data. Particularly in high CH₄ pathways.

Response: The additional experiment is a great suggestion. Unfortunately, we only have meteorological fields compatible with GCHP-CAM from 3 scenarios (Monier et al., 2015, 2018), and none of them exhibit significant decoupling in emission trends of different GHG. Simulating the climate for a high CH₄ scenario is beyond the scope of this paper. We further emphasize the limitation of our emulator in the conclusion:

L 635: ...This shows our emulator can provide reasonable predictions under climate scenarios (in this case, SSP3-7.0) other than that used to train the emulator (i.e. the 10W m⁻² scenario from IGSM), **with the caveat that the magnitudes of climate change (and therefore climate impact on PM_{2.5}) could be misrepresented under overshoot scenarios, large decoupling between emission trajectories of CO₂ and other important GHGs (e.g. high CH₄ scenarios), and a significant difference in climate response with that simulated by IGSM-CAM (see section 2.3.1).** We also find that the emulator may underperform when...

While the framework appears generalisable, the present emulator is trained on meteorology drawn from a single IGSM CAM trajectory. It would be helpful for the authors to clarify whether they view this emulator instance as portable across alternative climate trajectories, or whether retraining would be required under different forcing compositions or climate sensitivities. This is particularly important so as to give an idea as to how often the training simulations would need to be run.

Response: Conceptually, the IGSM-CAM-GCHP pipeline can be run for any given climate scenarios. The emulator, which aims at statistically reproducing the anthropogenic PM_{2.5} output

of IGSM-CAM-GCHP, can be run for any emission scenarios (with the caveat stated in the last response). Retraining is only required if we want to emulate another modeling system (e.g. to get different climate sensitivity and spatial pattern of climate change), or when new dataset is available to address the drawbacks outlined above. The SSP3-7.0 and SSP3-7.0-lowNTCF exercise are designed to answer the question of portability, since both the GHG and air pollutant emission trajectories are different from that of the 10W m⁻² scenario used in training, and the CT/AA scenario used in validation. We further clarify this in our conclusion:

L 635: ...within the range of full-scale models in the AerChemMIP archive under SSP3-7.0 and SSP3-7.0-lowNTCF scenarios. **This shows our emulator can provide reasonable predictions under climate scenarios (in this case, SSP3-7.0) other than that used to train the emulator (i.e. the 10W m⁻² scenario from IGSM)**, with the caveat that the magnitudes of climate change (and therefore climate impact on PM_{2.5}) could be misrepresented under overshoot scenarios, large decoupling between emission trajectories of CO₂ and other important GHGs (e.g. high CH₄ scenarios), and a significant difference in climate response with that simulated by IGSM-CAM (see section 2.3.1)...

The author mentions that CO₂ is a good proxy as it directly impacts SOA production, but this seems a bit out of place to the story the author is telling as the authors specifically omit SOA from their PM_{2.5}. Also TRF effects on other emission areas such as wetlands and wildfires are ignored.

Response: In L175, we refer to how CO₂-induced isoprene inhibition could affect the production of secondary **inorganic** aerosol through changing atmospheric oxidation capacity. The TRF effects on other natural emissions is a good point. We add discussion about them at conclusion:

L670: ...Future work includes applying the PM_{2.5} emulator to study more global change scenarios, **representing other important climate-sensitive emission sources (e.g. wetland methane, dust, fire)**, improving and extending the emulator to calculate...

A sentence on how GCHPs wildfire emissions are being handled would be useful as the authors consider all BC and OC to be anthropogenic.

Response: We thank the reviewer for this suggestion. We now describe fire emissions as follow:

L132: ...mineral dust (Meng et al., 2021), lightning NO_x (Murray et al., 2012) and **wildfire (from Global Fire Emission Database, version 4.1 (Van Der Werf et al., 2017))** emissions are held at 2014 level.

I would like to see where the 4 scenarios lie relative to the LHS samples. Are they meaningfully different from all the training simulations?

Response: We thank the reviewer for this suggestion, which helps us highlight why the 4 scenarios are valid for evaluating our emulator:

L320: ...are shown in Fig. 6. The 4 scenarios have distinct emission scaling factors at each region, with less than 1% of the region-scenario combinations having emission changes > 100% (upper limit of training set). With these scenarios, we can test whether the emulator (trained on GCHP-CAM runs with globally uniform emission scaling factors) can perform reasonably under spatially heterogeneous emission scaling factors, and within the intended range of emission changes.