



## ***Interactive comment on “EC-Earth3-AerChem, a global climate model with interactive aerosols and atmospheric chemistry participating in CMIP6” by Twan van Noije et al.***

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We thank referee #2 for his/her positive and helpful review of our paper. Below we respond to all points raised by the referee.

*The description of the aerosol part is quite complete, thanks for that. However, it invites for even more questions. How do you justify the choices made? I believe it would be good to have a discussion paragraph on this. How to test which of the many aerosol parameterisations is really important for the aerosol ERF?*

C1

That's a fair point. When developing the model, we have critically assessed various aspects of the models. As part of this exercise parameter settings were revised in accordance with recent literature, and sensitivity simulations were performed to test the outcome against observations, mainly aerosol optical depth. Later, more in-depth evaluations have been performed using a variety of observational data sets. Recent examples are the study by Bergman et al. (2021), which focuses on secondary organic aerosols and new particle formation, and the model intercomparison studies by Glibš et al. (2021) and Checa-Garcia et al. (2021). The latter studies show that the model is among the best ones when it comes to aerosol metrics. The main purpose of this paper, however, is not to justify the choices made but to document the model and present some first results from our CMIP6 simulations. In Sect. 3 we give one example of how an adjustment in the treatment of emissions of carbonaceous aerosols has led to a reduction of the aerosol ERF. In general, perturbed parameter experiments (PPEs) can be used to test the impact on the aerosol ERF. Such experiments have been proposed within AeroCom and are currently being discussed as part of the EU Horizon 2020 project FORCeS.

*I find the chemistry description a bit short.*

This is because the chemistry scheme is largely the same as in the TM5 model version described by Williams et al. (2017), which documents it in great detail. We didn't want to repeat that information in our paper. We therefore described the general characteristics and specified the changes and new features in more detail.

*I understand that a more detailed evaluation of the model may be out of scope, but the comparison to EC-Earth3 could be more detailed. That version has quite a different aerosol prescription, so what is the conclusion on having a more complex and more simple aerosol in the same ESM? Do you understand the difference? What are the differences? Why is the ECS higher in EC-Earth3.*

C2

The differences between the two configurations are due to a combination of the effects of the different representation of aerosols (and chemistry) and a retuning of the atmosphere. As described in Sect. 3, switching to interactive aerosols and atmospheric chemistry under pre-industrial conditions had a substantial impact on the model's climate, especially in the Northern Hemisphere high-latitude regions where zonal mean surface air temperatures went up by a few degrees and cold biases were converted into warm biases. The most likely explanation is that correlations between aerosols and clouds on submonthly time scales are better represented. We have clarified this in the revised manuscript. We subsequently reduced these warm biases by adjusting three parameters in the atmospheric GCM. The final configuration is somewhat warmer and exhibits lower natural variability than EC-Earth3 (Sect. 4.1). The main impact is seen in the Northern Hemisphere, where cold biases are substantially reduced in EC-Earth3-AerChem. In the first version of the manuscript we estimated the hemispheric mean pre-industrial temperature biases using a proxy of pre-industrial temperatures estimated from ERA5 and observed hemispheric warming estimates from GISTEMP (Sect. 4.3). In the revised manuscript we have included a more spatially detailed analysis of the pre-industrial temperature bias for both configurations. This indicates more clearly that biases are generally smaller in EC-Earth3-AerChem. We have also extended the pre-industrial control simulation to 500 years and have updated the manuscript accordingly. A better understanding of the impact of the complex aerosol scheme in the historical period would involve a comparison of the transient and present-day (2014) aerosol ERF, preferably including a decomposition into direct radiative forcing, cloud radiative forcing and surface albedo forcing (Ghan, 2013). Such a comparison is beyond the scope of our paper, and can only be made once the required diagnostics from the relevant atmosphere-only simulations for both configurations will be available (see our answer to the next point). We currently do not have an explanation for the difference in effective equilibrium climate sensitivity and transient climate response between the two configurations.

C3

*The spurious interdecadal variability is striking in the PI control. However, does it really explain the negative GSAT anomaly in the 70s?*

In the first version of the manuscript we wrote: "The cooling of the Northern Hemisphere simulated in the 1950s and 1960s may also be caused or enhanced by aerosol effects. To what extent this is the case needs further investigation. Simulations that provide more information on the role of aerosols and their effective radiative forcing contributions are in production." More output has become available since we submitted the first version of our manuscript. In particular, we have completed the historical simulation with aerosol precursor emissions kept at pre-industrial levels (hist-piAer). We have added this experiment in Figs. 7 and 8. This provides additional information about the role of aerosols in the cooling simulated in the 1950s and 1960s. A more comprehensive analysis of the role played by aerosols would involve estimating the transient and present-day (2014) aerosol effective radiative forcing (ERF). Since the submission of the first version of the manuscript we have completed histSST, histSST-piNTCF, piClim-control and piClim-NTCF, but the aerosol-specific experiments, histSST-piAer and piClim-Aer, are not available yet. We therefore will not be able to present estimates of aerosol ERF in this paper. An in-depth analysis of the transient aerosol ERF and the role played by aerosols in the historical period is planned as part of the EU Horizon 2020 project FORCeS.

*The small change in net TOA flux ( $0.5 \text{ W m}^{-2}$ ) between historical and hist-piNTCF leads to almost 1 K difference (Figure 7). That would imply a large TCR in that period. Can you comment on possible reasons for that?*

To make such an inference, one needs information about the effective radiative forcing by NTCFs. This can be estimated by differencing histSST and histSST-piNTCF. The difference in the TOA fluxes shown in Fig. 7 doesn't provide the ERF, as it is

C4

modified by the response of SSTs and sea ice concentrations.

*Small comments:*

*L753-755: "surface air and water temperatures may be very different" over the ocean?*

Yes, according to the GISTEMP website: "SATs and SSTs may be very different (since air warms and cools much faster than water)".

*"a more robust blend of air and water temperatures also from the model" would be better => I wonder if this is more confusing than helpful. I thought the GISTEMP uses SST as a proxy but still pretends that the anomalies reflect SAT also over the ocean.*

That's correct.

*Is Cowtan 2015 suggesting that one should rather use SST from obs and model?*

Correct, that would be the most consistent way to make the comparison.

*Is the result really more meaningful?*

For the purpose of our paper, it wouldn't make much of a difference. We only included this sentence to justify the method adopted for comparing our model with the observations.

*L57-58: A little confusing: You simulate methane and ozone, ... although they are not fully described. please rewrite.*

Okay, we have clarified this sentence.

C5

*Figure 1: Sea spray factors as a function of SST . not sure this detail is needed. Why this figure and not others on parameterisation details?*

The reason the temperature dependence of sea spray formation is described in detail is that the scale factors applied in our model are not exactly the same as the expression from Salter et al. (2015). Moreover, these are single-variable functional relations that can easily be shown in a graph.

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C6