Response to Anonymous Reviewer-2

This study illustrated the importance of aerosols, clouds, and their interactions in the climate system and the potential impact of accurately modeling these processes on the uncertainty of future climate projections, and analyzed in detail the latest improvements in aerosol and cloud properties and maximum covariance analyses in the EC-Earth3-AerChem model. This study is of great significance for improving the accuracy of global Earth system models in climate prediction. It is recommended that the manuscript can be published after minor revisions.

We thank the reviewer for the encouraging comments and constructive suggestions. Please find below a point by point response to the queries raised.

1. In studying the covariance of AOD and CD, why was the maximum covariance analysis method used? What are the advantages over other analysis methods?

MCA is an efficient method which identifies coupled patterns that explain the maximum covariance between the two variables. Similar tools, such as, for example, canonical correlation analysis (CCA) aim to find patterns with maximum temporal correlation, which may not necessarily explain much covariance. MCA is simpler to implement and interpret, and is robust compared to other methods like CCA and regression. This is clarified in the revised manuscript.

2. The spatial distribution of the difference between ECE3-FORCeS and observations can be added in Fig. 1 to reflect the comparison between simulations and observations.

We have added this subplot in Fig. 1.

3. The article mentions in section 3.1 that the ECE3-FORCeS model better reproduces the spatial distribution of the total cloud amount, but is biased higher in the polar regions and explains that it is due to low clouds. Could you explain more about the bias. What caused the bias to be much higher in the polar regions than in the equatorial and mid-latitude regions?

4. It looks to me that the changes in cloud fraction are mostly at high latitude regions. Does that mean the updates within FORCeS only work for limited regions?

We are addressing 3 & 4 here:

The FORCeS project aimed at improving the representation of aerosol and cloud processes in Earth System Models. Some of the model updates target liquid water clouds (e.g. for EC-Earth3 the cloud droplet activation) while other improvements were done for ice clouds (e.g. secondary ice production). Bringing it all together in one model could lead to trade-offs between the different developments that possibly could explain why model performance hasn't uniformly improved. Model development is a continuous process, future versions of the EC-Earth model will address remaining biases.

5. Line 380: Please add relevant references.

The following two references are added to the revised manuscript.

Bourgeois, Q., A. M. L. Ekman, and R. Krejci (2015), Aerosol transport over the Andes from the Amazon Basin to the remote Pacific Ocean: A multiyear CALIOP assessment, J. Geophys. Res. Atmos., 120, 8411–8425, doi:10.1002/2015JD023254.

Bourgeois, Q., Ekman, A. M. L., Renard, J.-B., Krejci, R., Devasthale, A., Bender, F. A.-M., Riipinen, I., Berthet, G., and Tackett, J. L.: How much of the global aerosol optical depth is found in the boundary layer and free troposphere?, Atmos. Chem. Phys., 18, 7709–7720, https://doi.org/10.5194/acp-18-7709-2018, 2018.

6. It is recommended that the conclusion section further explicitly summarize the contribution of model improvements to climate prediction and the innovation and limitation of this study.

The following paragraph is added to the manuscript 'The updates to the EC-Earth3-AerChem model described in this work improve the representation of aerosols and aerosol-cloud interactions. They address previously missing processes, such as secondary ice particles, and improve existing parameterizations, such as cloud droplet activation. These modifications make the model more realistic and closer to what is observed, but, there are still biases in the cloud microphysical properties. One of the reasons may be that the model was re-tuned using a subset of the parameters identified in the tuning strategy of the CMIP6 version of the model. However, finding a new set of tuning parameters to improve clouds while maintaining radiation balance, cloud forcing, surface temperatures, precipitation patterns, etc., is challenging. A complete re-tuning was beyond the scope of this project. Future model developments aim to reduce biases through new parametrizations for updraft velocity and secondary ice production (RaFSIP v2). The extent to which these changes, along with re-tuning, could mitigate the biases requires further investigation. The goal is to incorporate these improvements that were achieved during the FORCeS project, into the next version of the EC-Earth model which will then be used to contribute to CMIP7, particularly AerChemMIP, to provide a better understanding of the role of various aerosols in the climate and its sensitivity.'