List of Changes

March 16, 2025

All sections, paragraphs, and figures refer to the revised manuscript. In the marked-up version of the revised manuscript, all changes are highlighted in red.

1) We added a version number to the title.

ICON-HAM-lite 1.0: ...

2) In the abstract, we revised the first sentence.

... nuclei for cloud droplets and ice crystals.

3) In the abstract, we revised the last sentence.

... the emission of dust aerosols by cold pool outflows in the Sahara and the interaction of sea salt aerosols and shallow convective storms around the doldrums.

4) In section 1, we revised two sentences in the second paragraph.

... decades (Tegen et al., 2019). ... few years.

5) In section 2.1, we revised a sentence in the first paragraph.

..., also referred to as dry radius, ...

6) In section 2.1, we revised a sentence in the second paragraph.

... dry radius ...

7) In section 2.1, we added a sentence to the second paragraph.

The wet radius and density are used throughout the calculation of aerosol processes as described in section 2.3.

8) **In section 2.1, we added three sentences to the last paragraph.**

We acknowledge that the one-moment scheme HAM-lite has limitations in comparison to the two-moment scheme HAM. Since it carries no information about the aerosol size, there is no explicit representation of nucleation, growth, and ageing. And there is no ability to adjust the aerosol size in response to activation and wet deposition (Stier et al., 2005; Siebesma et al., 2020).

9) **In section 2.2, we corrected a sentence in the second paragraph.**

There are three parameterization schemes, one for cloud microphysics, one for radiation, and one for turbulence ...

10) **In section 2.2, we added revised a sentence in the second paragraph.**

The cloud droplet number and ice particle number are not prognostic but prescribed or diagnosed.

11) **In section 2.2, we added a paragraph.**

Partially resolved processes such as shallow convection or orographic drag are not parameterized. As outlined by Hohenegger et al. (2023), there are three main reasons for this choice. First, a lean code with few parameterization schemes can be ported more easily to new systems such as the new exascale cluster of the Forschungszentrum Jülich (2025). Second, parameterization schemes do not converge as the resolution is refined, which would be problematic for future simulations with ever increasing resolutions. Hohenegger et al. (2020) showed that some large-scale quantities such as net shortwave radiation start to converge at resolutions of about five kilometers. Third, ICON-MPIM is intended for Earth system research and not operational weather forecasting. Simple physics make it easier to understand, for example, the impact of processes that remain partially resolved or parameterized at kilometer scales.

12) **In section 2.3.1, we added two sentences to the first paragraph.**

Due to the absence of microphysical processes, emissions are directly added to modes without any intermediate steps. In reality, precursor gases such as sulphur dioxide form secondary aerosols by nucleation (Siebesma et al., 2020).

13) **In section 2.3.1, we replaced the reference to Tegen et al. (2019) with Tegen et al. (2002) in the first paragraph.**

... Tegen et al. (2002), ...

14) **In section 2.3.1, we revised a sentence in the first paragraph.**

The mass fluxes from the emission sectors are converted into number fluxes based on the radius of average mass of the mode, i.e.,

$$F_{\mathrm{em},j,k,s} = \frac{3}{4\pi\bar{r}_{\mathrm{m},j}^{3}\rho_k} S_{\mathrm{em},k,s}, \tag{1}$$

where $S_{\mathrm{em},k,s}$ is the mass flux of species k in sector s.

15) In section 2.3.6, we corrected the spelling of asymmetry.

... asymmetry ...

16) In section 3.1, we revised the caption of table 2.

Dry radii ... Standard deviations (σ) of modes were also taken from ECHAM6.3-HAM2.3, i.e., 2.00 for the dust and sea salt modes and 1.59 for the carbonaceous and sulfuric modes.

17) In section 3.1, we added the three sentences to the second paragraph.

The biogenic emissions were taken from Guenther et al. (1995). As in HAM (Stier et al., 2005; Tegen et al., 2019), we assume that 15 % of biogenic monoterpene emissions form secondary organic aerosols (SOA) directly at the surface. We acknowledge that, in reality, SOA also form above the surface.

18) In section 3.1, we added a sentence to the second paragraph.

... dry radii ... While the dry radii of the dust and sea salt modes were adjusted only marginally, the dry radii of the two carbonaceous and sulfuric modes were increased significantly since their initial lifetimes were too long.

19) In section 4, we revised a sentence in the first paragraph.

... the emission of dust aerosols by cold pool outflows in the Sahara or the interaction of sea salt aerosols and shallow convective storms around the doldrums.

20) In section 4.1, we revised the first paragraph.

... Table 4 shows the aerosol burdens and fluxes of our simulation and of the CLIM simulation with ECHAM6.3-HAM2.3 averaged over the years 2003 to 2012 (Tegen et al., 2019). Table 5 shows the aerosol burdens, emissions, lifetimes, and optical depths at 550 nm of our simulation and of the AeroCom phase 3 model intercomparison, including ECHAM6.3-HAM2.3, averaged over the year 2010 (Gliß et al., 2021). ECHAM6.3-HAM2.3 used different sea salt emission schemes in the two studies leading to differences in the sea salt emissions and burdens. The values of AeroCom, comparing more than 10 models, are subject to large uncertainties. For example, the standard deviations of the lifetimes range between 29 % for organic aerosol to 91 % for sea salt. ... ECHAM6.3-HAM2.3 and AeroCom. The largest differences are observed for carbonaceous aerosols, which is caused by too low biomass burning emissions (Tegen et al., 2019; Salzmann et al., 2022). In future simulations, we plan to use wildfire emissions from the GFAS database (Kaiser et al., 2012) and anthropogenic emissions from the CEDS database (Hoesly et al., 2018; Feng et al., 2020), which are based on more recent observations and provided at higher resolutions than the AeroCom-II ACCMIP database (Heil et al., 2022).

21) In section 4.1, we revised table 4.

Global mean aerosol burdens and fluxes of ICON-HAM-lite averaged over February 2020 to January 2021 and of ECHAM6.3–HAM2.3 (CLIM simulation) averaged over the years 2003 to 2012 (Tegen et al., 2019).

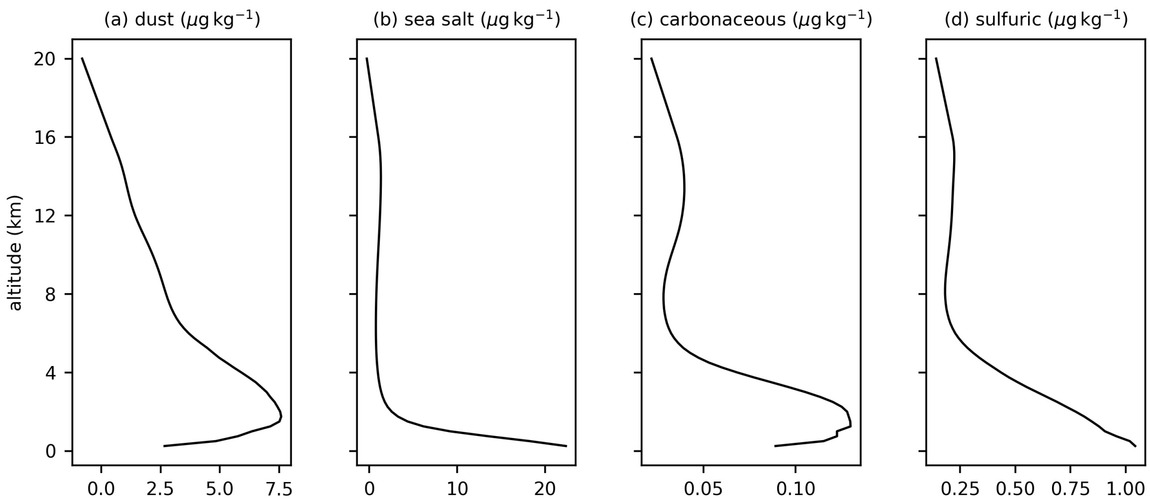
	Burden (Tg)	Emission ($Tg\,yr^{-1}$)	Dry depos. ($Tg\,yr^{-1}$)	Wet depos. ($Tg\,yr^{-1}$)
ICON-HAM-lite				
Dust	19.65	1873	1066	807.1
Sea salt	8.771	2823	369.3	2447
Carbonaceous	0.747	48.05	11.30	36.38
Sulfuric	2.817	219.2	42.90	175.5
ECHAM-HAM				
Dust	16.5	1124	447	687
Sea salt	3.9	1212	353	863
Black carbon	0.14	8.1	0.73	7.4
Organic aerosol	1.0	69.0	5.58	64.4
Sulfate	2.22	218.7	8.33	209.4

22) In section 4.1, we revised table 5.

Global mean aerosol burdens, emissions, lifetimes, and optical depths at 550 nm of ICON-HAM-lite averaged over February 2020 to January 2021 and of ECHAM6.3–HAM2.3 and AeroCom phase 3 averaged over the year 2010 (Gliß et al., 2021).

	Burden (Tg)	Emission ($Tg\,yr^{-1}$)	Lifetime (d)	Optical depth
ICON-HAM-lite				
Dust	19.65	1873	3.828	0.0098
Sea salt	8.771	2823	1.133	0.0397
Carbonaceous	0.747	48.05	5.670	0.0074
Sulfuric	2.817	219.2	4.689	0.0347
ECHAM-HAM				
Dust	19.5	1170	6.0	0.031
Sea salt	10.3	5920	0.63	0.058
Black carbon	0.174	9.8	6.4	0.002
Organic aerosol	1.14	69.2	6.0	0.013
Sulfate	2.58	218.0	4.3	0.045
AeroCom phase 3 (median)				
Dust	16.6	1440	3.7	0.021
Sea salt	8.7	4980	0.56	0.044
Black carbon	0.131	9.7	5.5	0.002
Organic aerosol	1.91	116.0	6.0	0.022
Sulfate	1.80	143.0	4.9	0.035

23) **In section 4.1, we revised figure 5.**



Global mean mass mixing ratios of aerosols averaged over February 2020 to January 2021: dust (a), sea salt (b), carbonaceous aerosol (c), and sulfuric aerosol (d).

24) **In section 4.1, we revised three sentences in the third paragraph.**

Dust aerosols are lifted up to about 6 km by convective storms, and some aerosols rise even further up to about 12 km. In contrast, sea salt aerosols are washed out by low marine clouds, and only few aerosols rise above 2 km. The profile of carbonaceous aerosols shows a local peak at about 14 km, whereas the profile of sulfuric aerosols decreases monotonically with the altitude.

25) **In section 4.1, we revised a sentence in the third paragraph.**

... dry radius ...

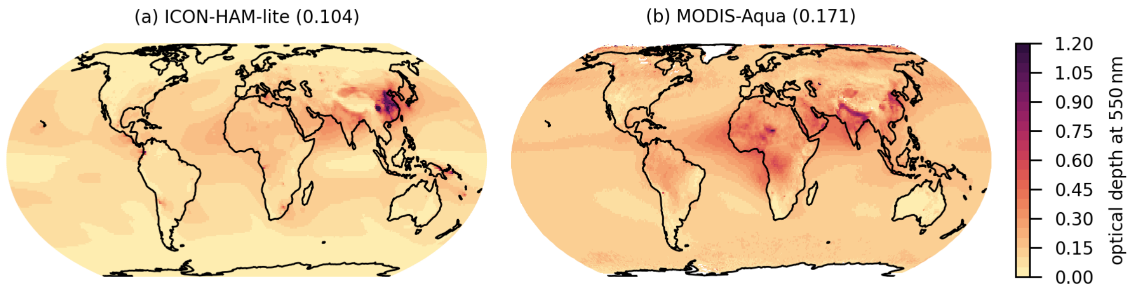
26) **In section 4.1, we revised a sentence in the last paragraph.**

... the optical depth of our simulation and the MODIS-Aqua satellite, i.e., the combined dark target and deep blue product (Platnick et al., 2015).

27) **In section 4.1, we added a sentence to the last paragraph.**

Note that observations from satellites are subject to some uncertainties as discussed by Vogel et al. (2022). On average, the optical depth of MODIS is larger than those of other satellites especially over the ocean (Vogel et al., 2022, tables 2 and 3).

28) In section 4.1, we revised figure 6.



Aerosol optical depth at 550 nm of ICON-HAM-lite averaged over February 2020 to January 2021 (a) and of MODIS-Aqua, i.e., the combined dark target and deep blue product (Platnick et al., 2015), averaged over 2018 to 2022 (b). The spatial average over 60° S to 60° N is given in brackets.

29) In section 4.1, we revised a sentence in the last paragraph.

... (0.171).

30) In section 4.1, we added two sentences to the last paragraph.

The optical depths of these two modes are also lower than those of the MACv2 aerosol climatology of Kinne (2019), which is commonly used in simulations with ICON-MPIM (Hohenegger et al., 2023). The predefined optical depths are 0.031 for dust, 0.028 for sea salt, 0.022 for organic aerosol, and 0.037 for sulfate (Kinne, 2019, table 1). There are several ways to address these biases.

31) In section 4.1, we added a sentences to the last paragraph.

Third, we plan to include secondary aerosols from nucleation (Stier et al., 2005).

32) In section 4.2, we corrected a sentence in the first paragraph.

Carbonaceous aerosols are emitted by wildfires, predominantly in Central Africa and South America, and transported over the ocean by trade winds.

33) In section 4.2, we corrected a sentence in the second paragraph.

Previous studies have shown that aerosol-cloud interactions play an important role in cyclones.

34) In section 4.2, we corrected a sentence in the third paragraph.

... diverging cold pools that originate from convective downdrafts and mesoscale circulation that lifts air at the gust front.

35) In section 4.2, we corrected a sentence in the third paragraph.

... mesoscale dynamics and the associated dust storms and need to compensate for that with the aid of tuning parameters (Marsham et al., 2011; Prein, 2023).

36) In section 5, we revised a sentence in the first paragraph.

... dry radius ...

37) In section 5, we revised a sentence in the second paragraph.

... emitted by trade winds and washed out by low marine clouds.

38) In section 5, we revised a sentence in the second paragraph.

... emitted from wildfires and transported over the ocean.

39) In section 5, we added two sentence to the last paragraph.

We plan to evaluate the aerosol processes more in-depth, to update the emission database, to fine tune parameters like aerosol size, and to add secondary aerosols from nucleation. In particular, we aim to improve the representation of the aerosol optical depth and absorption optical depth, which will be important for studies on aerosol forcing.

40) We revised the code and data availability statement.

The source code that we used to perform the simulation is available on Zenodo (Weiss et al., 2024a). The data and scripts that we used to generate the figures are available on Zenodo as well (Weiss et al., 2024b).

41) We extended the acknowledgements.

ICON-HAM-lite has been developed at the University of Oxford as a reduced complexity version of the ICON-HAM model. ICON-HAM is developed by a consortium composed of the Center for Climate Systems Modeling (ETH Zurich and MeteoSwiss), Max-Planck-Institute for Meteorology, Forschungszentrum Jülich, University of Oxford, Finnish Meteorological Institute, and Leibniz Institute for Tropospheric Research (TROPOS), and managed by TROPOS.

References

Bohren, C. F. and Huffman, D. R.: Absorption and Scattering of Light by Small Particles, John Wiley & Sons, Ltd, ISBN 9783527618156, https://doi.org/10.1002/9783527618156, 1998.

Feng, L., Smith, S. J., Braun, C., Crippa, M., Gidden, M. J., Hoesly, R., Klimont, Z., van Marle, M., van den Berg, M., and van der Werf, G. R.: The generation of gridded emissions data for CMIP6, Geoscientific Model Development, 13, 461–482, https://doi.org/10.5194/gmd-13-461-2020, 2020.

Forschungszentrum Jülich: JUPITER Exascale Development Instrument, `https://www.fz-juelich.de/en/ias/jsc/systems/supercomputers/jedi`, 2025.

Gliß, J., Mortier, A., Schulz, M., Andrews, E., Balkanski, Y., Bauer, S. E., Benedictow, A. M. K., Bian, H., Checa-Garcia, R., Chin, M., Ginoux, P., Griesfeller, J. J., Heckel, A., Kipling, Z., Kirkevåg, A., Kokkola, H., Laj, P., Le Sager, P., Lund, M. T., Lund Myhre, C., Matsui, H., Myhre, G., Neubauer, D., van Noije, T., North, P., Olivié, D. J. L., Rémy, S., Sogacheva, L., Takemura, T., Tsigaridis, K., and Tsyro, S. G.: AeroCom phase III multi-model evaluation of the aerosol life cycle and optical properties using ground- and space-based remote sensing as well as surface in situ observations, Atmospheric Chemistry and Physics, 21, 87–128, https://doi.org/10.5194/acp-21-87-2021, 2021.

Guenther, A., Hewitt, C. N., Erickson, D., Fall, R., Geron, C., Graedel, T., Harley, P., Klinger, L., Lerdau, M., Mckay, W. A., Pierce, T., Scholes, B., Steinbrecher, R., Tallamraju, R., Taylor, J., and Zimmerman, P.: A global model of natural volatile organic compound emissions, Journal of Geophysical Research: Atmospheres, 100, 8873–8892, https://doi.org/https://doi.org/10.1029/94JD02950, 1995.

Heil, A., Schultz, M., and Granier, C.: AeroCom II emission data, `https://aerocom-classic.met.no/DATA/download/emissions/AEROCOM-II-ACCMIP/`, 2022.

Hoesly, R. M., Smith, S. J., Feng, L., Klimont, Z., Janssens-Maenhout, G., Pitkanen, T., Seibert, J. J., Vu, L., Andres, R. J., Bolt, R. M., Bond, T. C., Dawidowski, L., Kholod, N., Kurokawa, J.-I., Li, M., Liu, L., Lu, Z., Moura, M. C. P., O'Rourke, P. R., and Zhang, Q.: Historical (1750–2014) anthropogenic emissions of reactive gases and aerosols from the Community Emissions Data System (CEDS), Geoscientific Model Development, 11, 369–408, https://doi.org/10.5194/gmd-11-369-2018, 2018.

Hohenegger, C., Kornblueh, L., Klocke, D., Becker, T., Cioni, G., Engels, J. F., Schulzweida, U., and Stevens, B.: Climate Statistics in Global Simulations of the Atmosphere, from 80 to 2.5 km Grid Spacing, Journal of the Meteorological Society of Japan. Ser. II, 98, 73 – 91, https://doi.org/10.2151/jmsj.2020-005, 2020.

Hohenegger, C., Korn, P., Linardakis, L., Redler, R., Schnur, R., Adamidis, P., Bao, J., Bastin, S., Behravesh, M., Bergemann, M., Biercamp, J., Bockelmann, H., Brokopf, R., Brüggemann, N., Casaroli, L., Chegini, F., Datseris, G., Esch, M., George, G., Giorgetta, M., Gutjahr, O., Haak, H., Hanke, M., Ilyina, T., Jahns, T., Jungclaus, J., Kern, M., Klocke, D., Kluft, L., Kölling, T., Kornblueh, L., Kosukhin, S., Kroll, C., Lee, J., Mauritsen, T., Mehlmann, C., Mieslinger, T., Naumann, A. K., Paccini, L., Peinado, A., Praturi, D. S., Putrasahan, D., Rast, S., Riddick, T., Roeber, N., Schmidt, H., Schulzweida, U., Schütte, F., Segura, H., Shevchenko, R., Singh, V., Specht, M., Stephan, C. C., von Storch, J.-S., Vogel, R., Wengel, C., Winkler, M., Ziemen, F., Marotzke, J., and Stevens, B.: ICON-Sapphire: simulating the components of the Earth system and their interactions at kilometer and subkilometer scales, Geoscientific Model Development, 16, 779–811, https://doi.org/10.5194/gmd-16-779-2023, 2023.

Kaiser, J. W., Heil, A., Andreae, M. O., Benedetti, A., Chubarova, N., Jones, L., Morcrette, J.-J., Razinger, M., Schultz, M. G., Suttie, M., and van der Werf, G. R.: Biomass burning emissions estimated with a global fire assimilation system based on observed fire radiative power, Biogeosciences, 9, 527–554, https://doi.org/10.5194/bg-9-527-2012, 2012.

Kinne, S.: The MACv2 aerosol climatology, Tellus B: Chemical and Physical Meteorology, 71, 1–21, https://doi.org/10.1080/16000889.2019.1623639, 2019.

Marsham, J. H., Knippertz, P., Dixon, N. S., Parker, D. J., and Lister, G. M. S.: The importance of the representation of deep convection for modeled dust-generating winds over West Africa during summer, Geophysical Research Letters, 38, https://doi.org/10.1029/2011GL048368, 2011.

Platnick, S., Hubanks, P., Meyer, K., and King, M. D.: MODIS Atmosphere L3 Monthly Product (08_L3), `https://modis.gsfc.nasa.gov/data/dataprod/mod08.php`, 2015.

Pöhlker, M. L., Pöhlker, C., Quaas, J., Mülmenstädt, J., Pozzer, A., Andreae, M. O., Artaxo, P., Block, K., Coe, H., Ervens, B., Gallimore, P., Gaston, C. J., Gunthe, S. S., Henning, S., Herrmann, H., Krüger, O. O., McFiggans, G., Poulain, L., Raj, S. S., Reyes-Villegas, E., Royer, H. M., Walter, D., Wang, Y., and Pöschl, U.: Global organic and inorganic aerosol hygroscopicity and its effect on radiative forcing, Nature Communications, 14, 6139, https://doi.org/10.1038/s41467-023-41695-8, 2023.

Prein, A. F.: Thunderstorm straight line winds intensify with climate change, Nature Climate Change, 13, 1353–1359, https://doi.org/10.1038/s41558-023-01852-9, 2023.

Salzmann, M., Ferrachat, S., Tully, C., Münch, S., Watson-Parris, D., Neubauer, D., Siegenthaler-Le Drian, C., Rast, S., Heinold, B., Crueger, T., Brokopf, R., Mülmenstädt, J., Quaas, J., Wan, H., Zhang, K., Lohmann, U., Stier, P., and Tegen, I.: The Global Atmosphere-aerosol Model ICON-A-HAM2.3–Initial Model Evaluation and Effects of Radiation Balance Tuning on Aerosol Optical Thickness, Journal of Advances in Modeling Earth Systems, 14, e2021MS002 699, https://doi.org/10.1029/2021MS002699, 2022.

Seifert, A. and Beheng, K. D.: A two-moment cloud microphysics parameterization for mixed-phase clouds. Part 1: Model description, Meteorology and Atmospheric Physics, 92, 45–66, https://doi.org/10.1007/s00703-005-0112-4, 2006.

Siebesma, A. P., Bony, S., Jakob, C., and Stevens, B., eds.: Clouds and Climate: Climate Science's Greatest Challenge, Cambridge University Press, Cambridge, https://doi.org/10.1017/9781107447738, 2020.

Stier, P., Feichter, J., Kinne, S., Kloster, S., Vignati, E., Wilson, J., Ganzeveld, L., Tegen, I., Werner, M., Balkanski, Y., Schulz, M., Boucher, O., Minikin, A., and Petzold, A.: The aerosol-climate model ECHAM5-HAM, Atmospheric Chemistry and Physics, 5, 1125–1156, https://doi.org/10.5194/acp-5-1125-2005, 2005.

Tegen, I., Harrison, S. P., Kohfeld, K., Prentice, I. C., Coe, M., and Heimann, M.: Impact of vegetation and preferential source areas on global dust aerosol: Results from a model study, Journal of Geophysical Research: Atmospheres, 107, AAC 14–1–AAC 14–27, https://doi.org/https://doi.org/10.1029/2001JD000963, 2002.

Tegen, I., Neubauer, D., Ferrachat, S., Siegenthaler-Le Drian, C., Bey, I., Schutgens, N., Stier, P., Watson-Parris, D., Stanelle, T., Schmidt, H., Rast, S., Kokkola, H., Schultz, M., Schroeder, S., Daskalakis, N., Barthel, S., Heinold, B., and Lohmann, U.: The global aerosol–climate model ECHAM6.3–HAM2.3 – Part 1: Aerosol evaluation, Geoscientific Model Development, 12, 1643–1677, https://doi.org/10.5194/gmd-12-1643-2019, 2019.

Vogel, A., Alessa, G., Scheele, R., Weber, L., Dubovik, O., North, P., and Fiedler, S.: Uncertainty in Aerosol Optical Depth From Modern Aerosol-Climate Models, Reanalyses, and Satellite Products, Journal of Geophysical Research: Atmospheres, 127, e2021JD035 483, https://doi.org/10.1029/2021JD035483, e2021JD035483 2021JD035483, 2022.

Weiss, P., Herbert, R., and Stier, P.: Code for "ICON-HAM-lite: simulating the Earth system with interactive aerosols at kilometer scales", https://doi.org/10.5281/zenodo.14335069, 2024a.

Weiss, P., Herbert, R., and Stier, P.: Data for "ICON-HAM-lite: simulating the Earth system with interactive aerosols at kilometer scales", https://doi.org/10.5281/zenodo.14393773, 2024b.

Response to Referee #1

March 16, 2025

We thank the referee for the valuable comments, which we took into account in the revised manuscript. Below you find the referee's comment and our response.

1) **Comment:** *The model version numbers are missing but the title properly describes the paper contents.*

Response: We added a version number to the title.

⇒ **Change 1**

2) **Comment:** *This model lacks secondary aerosol formation (sulfate and SOA) and this should be explicitly mentioned in the model description. Lack of secondary aerosol affects the optical depth (Figure 6). The authors attribute the deviation from MODIS observations to primary emissions issues on page 13. This is only partially valid. Lack of SOA in the model has a large impact on the carbonaceous aerosol simulated. AeroCom models compared in Table 5 included SOA schemes. SOA accounts for more than half of organic aerosol globally. There is no mention of secondary aerosol anywhere in the manuscript. The paper needs to be revised to outline this model limitation and its impact on comparison with observations.*

Response: Due to the absence of microphysical processes, emissions are directly added to modes without any intermediate steps. We acknowledge that, in reality, precursor gases such as sulphur dioxide form secondary aerosols by nucleation (Siebesma et al., 2020). Secondary organic aerosol (SOA) from biogenic sources are included. As in the aerosol-climate model ECHAM–HAM (Stier et al., 2005; Tegen et al., 2019), it is assumed that 15 % of biogenic monoterpene emissions form SOA directly at the surface. The biogenic monoterpene emissions are taken from Guenther et al. (1995). We acknowledge that, in reality, SOA form also above the surface. We added comments to sections 2.3.1, 3.1, 4.1, and 5.

⇒ **Change 12, 17, 31, and 39**

3) **Comment:** *The resolution of 5 km is not sufficient to resolve convective updrafts and downdrafts which for deep convection have a diameter under 3 km over land and under 1 km over the oceans. Shallow convection is even smaller in scale. Instead of trying to run with a compromise resolution globally, a better approach would have been to use a high-resolution regional domain driven by boundary conditions form a coarser resolution global run. The authors should include more discussion about their choice of the 5 km resolution. Using the term "kilometer scale" to describe a 5 km resolution is not valid even though this has become a widely used term. This resolution does not*

have the dynamical process resolving power of 2 km let alone 1 km.
- The 5 km resolution is in a transition or gray zone between the need for parameterized deep convection at 10 km and relatively reasonably resolved deep convection over land at 2 km. It is possible to apply a scale-ware deep convection scheme at transition zone resolutions (Park et al., 2022) since resolved convection is inadequate. In terms of the smaller scale shallow convection, which is important for tracer transport, the 5 km resolution requires use of a parameterization scheme (Pedruzo-Bagazgoitia et al., 2019).
- The 5 km resolution is not good enough to reject using a 10 km resolution and assuming hydrostatic conditions with deep and shallow convective parameterizations. This would have the benefit of being able to run with a 5-minute timestep instead of 40 seconds. More resources could be expended on aerosol process representation. In spite of progress in computer speed we are still not at the stage of running global cloud resolving models even with highly simplified chemistry and aerosol processes.

Response: The Earth system model ICON-MPIM operates without a convection scheme. As outlined by Hohenegger et al. (2023), there are three main reasons for this choice. First, a lean code with few parameterization schemes can be ported more easily to new systems such as the new exascale cluster of the Forschungszentrum Jülich (2025). Second, parameterization schemes do not converge as the resolution is refined, which would be problematic for future simulations with ever increasing resolutions. Hohenegger et al. (2020) showed that some large-scale quantities such as net shortwave radiation start to converge at resolutions of about five kilometers. Third, ICON-MPIM is intended for Earth system research and not operational weather forecasting. Simple physics make it easier to understand, for example, the impact of processes that remain partially resolved or parameterized at kilometer scales. We added a paragraph to section 2.2.

⇒ **Change 11**

4) **Comment:** *There is no evaluation of the HAM-lite model against the original HAM cited. Comparison of the two schemes for test cases on small domains would give insight into the biases introduced by the simplifications in HAM-lite. It is not particularly clear from the paper how HAM-lite parameters were tuned. This subject is work for another paper, but the authors should include more discussion about how HAM-lite compares to HAM in terms of predicted aerosol distributions and how HAM-Lite parameters were selected.*

Response: As explained in section 3.1, the dry radii of the modes were initially taken from the MACv2 aerosol climatology of Kinne (2019) and then adjusted to roughly match the aerosol lifetimes reported by Glißet al. (2021). For the two coarse modes, the dry radii were adjusted only marginally. For the two fine modes, however, the dry radii were increased significantly since their initial lifetimes were too long. We added a comment to section 3.1.
A direct comparison of HAM and HAM-lite is not possible in the moment since these two modules are coupled to different Earth system models. HAM-lite is coupled to the new km-scale model ICON-MPIM (Hohenegger et al., 2023), whereas HAM is coupled to the coarse-scale models ECHAM (Tegen et al., 2019) and ICON-A (Salzmann et al., 2022). To allow for a comparison, we added the aerosol burdens, fluxes, lifetimes, and optical depths of ECHAM-HAM as reported by Tegen et al. (2019) and Glißet al. (2021) to tables 4 and 5.

⇒ **Change 18, 20, 21, and 22**

5) **Comment:** *L104: Replace reference with (Tegen et al., 2002)*

Response: We replaced the reference.

⇒ **Change 13**

6) **Comment:** *L183: Correct spelling of asymmetry.*

Response: We corrected the spelling.

⇒ **Change 15**

References

Forschungszentrum Jülich: JUPITER Exascale Development Instrument, `https://www.fz-juelich.de/en/ias/jsc/systems/supercomputers/jedi`, 2025.

Gliß, J., Mortier, A., Schulz, M., Andrews, E., Balkanski, Y., Bauer, S. E., Benedictow, A. M. K., Bian, H., Checa-Garcia, R., Chin, M., Ginoux, P., Griesfeller, J. J., Heckel, A., Kipling, Z., Kirkevåg, A., Kokkola, H., Laj, P., Le Sager, P., Lund, M. T., Lund Myhre, C., Matsui, H., Myhre, G., Neubauer, D., van Noije, T., North, P., Olivié, D. J. L., Rémy, S., Sogacheva, L., Takemura, T., Tsigaridis, K., and Tsyro, S. G.: AeroCom phase III multi-model evaluation of the aerosol life cycle and optical properties using ground- and space-based remote sensing as well as surface in situ observations, Atmospheric Chemistry and Physics, 21, 87–128, https://doi.org/10.5194/acp-21-87-2021, 2021.

Guenther, A., Hewitt, C. N., Erickson, D., Fall, R., Geron, C., Graedel, T., Harley, P., Klinger, L., Lerdau, M., Mckay, W. A., Pierce, T., Scholes, B., Steinbrecher, R., Tallamraju, R., Taylor, J., and Zimmerman, P.: A global model of natural volatile organic compound emissions, Journal of Geophysical Research: Atmospheres, 100, 8873–8892, https://doi.org/https://doi.org/10.1029/94JD02950, 1995.

Hohenegger, C., Kornblueh, L., Klocke, D., Becker, T., Cioni, G., Engels, J. F., Schulzweida, U., and Stevens, B.: Climate Statistics in Global Simulations of the Atmosphere, from 80 to 2.5 km Grid Spacing, Journal of the Meteorological Society of Japan. Ser. II, 98, 73 – 91, https://doi.org/10.2151/jmsj.2020-005, 2020.

Hohenegger, C., Korn, P., Linardakis, L., Redler, R., Schnur, R., Adamidis, P., Bao, J., Bastin, S., Behravesh, M., Bergemann, M., Biercamp, J., Bockelmann, H., Brokopf, R., Brüggemann, N., Casaroli, L., Chegini, F., Datseris, G., Esch, M., George, G., Giorgetta, M., Gutjahr, O., Haak, H., Hanke, M., Ilyina, T., Jahns, T., Jungclaus, J., Kern, M., Klocke, D., Kluft, L., Kölling, T., Kornblueh, L., Kosukhin, S., Kroll, C., Lee, J., Mauritsen, T., Mehlmann, C., Mieslinger, T., Naumann, A. K., Paccini, L., Peinado, A., Praturi, D. S., Putrasahan, D., Rast, S., Riddick, T., Roeber, N., Schmidt, H., Schulzweida, U., Schütte, F., Segura, H., Shevchenko, R., Singh, V., Specht, M., Stephan, C. C., von Storch, J.-S., Vogel, R., Wengel, C., Winkler, M., Ziemen, F., Marotzke, J., and Stevens, B.: ICON-Sapphire: simulating the components of the Earth system and their interactions at kilometer and subkilometer scales, Geoscientific Model Development, 16, 779–811, https://doi.org/10.5194/gmd-16-779-2023, 2023.

Kinne, S.: The MACv2 aerosol climatology, Tellus B: Chemical and Physical Meteorology, 71, 1–21, https://doi.org/10.1080/16000889.2019.1623639, 2019.

Park, H., Kim, G., Cha, D.-H., Chang, E.-C., Kim, J., Park, S.-H., and Lee, D.-K.: Effect of a Scale-Aware Convective Parameterization Scheme on the Simulation of Convective Cells-Related Heavy Rainfall in South Korea, Journal of Advances in Modeling Earth Systems, 14, e2021MS002 696, https://doi.org/https://doi.org/10.1029/2021MS002696, e2021MS002696 2021MS002696, 2022.

Pedruzo-Bagazgoitia, X., Jiménez, P. A., Dudhia, J., and de Arellano, J. V.-G.: Shallow Cumulus Representation and Its Interaction with Radiation and Surface at the Convection Gray Zone, Monthly Weather Review, 147, 2467 – 2483, https://doi.org/10.1175/MWR-D-19-0030.1, 2019.

Salzmann, M., Ferrachat, S., Tully, C., Münch, S., Watson-Parris, D., Neubauer, D., Siegenthaler-Le Drian, C., Rast, S., Heinold, B., Crueger, T., Brokopf, R., Mülmenstädt, J., Quaas, J., Wan, H., Zhang, K., Lohmann, U., Stier, P., and Tegen, I.: The Global Atmosphere-aerosol Model ICON-A-HAM2.3–Initial Model Evaluation and Effects of Radiation Balance Tuning on Aerosol Optical Thickness, Journal of Advances in Modeling Earth Systems, 14, e2021MS002 699, https://doi.org/10.1029/2021MS002699, 2022.

Siebesma, A. P., Bony, S., Jakob, C., and Stevens, B., eds.: Clouds and Climate: Climate Science's Greatest Challenge, Cambridge University Press, Cambridge, https://doi.org/10.1017/9781107447738, 2020.

Stier, P., Feichter, J., Kinne, S., Kloster, S., Vignati, E., Wilson, J., Ganzeveld, L., Tegen, I., Werner, M., Balkanski, Y., Schulz, M., Boucher, O., Minikin, A., and Petzold, A.: The aerosol-climate model ECHAM5-HAM, Atmospheric Chemistry and Physics, 5, 1125–1156, https://doi.org/10.5194/acp-5-1125-2005, 2005.

Tegen, I., Harrison, S. P., Kohfeld, K., Prentice, I. C., Coe, M., and Heimann, M.: Impact of vegetation and preferential source areas on global dust aerosol: Results from a model study, Journal of Geophysical Research: Atmospheres, 107, AAC 14–1–AAC 14–27, https://doi.org/https://doi.org/10.1029/2001JD000963, 2002.

Tegen, I., Neubauer, D., Ferrachat, S., Siegenthaler-Le Drian, C., Bey, I., Schutgens, N., Stier, P., Watson-Parris, D., Stanelle, T., Schmidt, H., Rast, S., Kokkola, H., Schultz, M., Schroeder, S., Daskalakis, N., Barthel, S., Heinold, B., and Lohmann, U.: The global aerosol–climate model ECHAM6.3–HAM2.3 – Part 1: Aerosol evaluation, Geoscientific Model Development, 12, 1643–1677, https://doi.org/10.5194/gmd-12-1643-2019, 2019.

Response to Referee #2

March 16, 2025

We thank the referee for the valuable comments, which we took into account in the revised manuscript. Below you find the referee's comment and our response.

1) **Comment:** *Transitions from emission and processing to accumulation and coarse mode is unclear.*

   Response: Due to the absence of microphysical processes, emissions are directly added to modes without any intermediate steps such as nucleation. The mass fluxes are converted into number fluxes based on the radius of average mass of the mode, i.e.,

   $$F_{\mathrm{em},j,k,s} = \frac{3}{4\pi \overline{r}_{\mathrm{m},j}^{3} \rho_k} S_{\mathrm{em},k,s},$$

   where $S_{\mathrm{em},k,s}$ is the mass flux of species k in sector s, $\overline{r}_{\mathrm{m},j}$ is the radius of average mass of mode j, and $F_{\mathrm{em},j,k,s}$ is the number flux. We extended the first paragraph of section 2.3.1.

   ⇒ **Change 12 and 14**

2) **Comment:** *Some emission inputs (e.g. biomass burning) are too coarse for km-scale modeling.*

   Response: We agree with the referee. In future simulations, we plan to use wildfire emissions from the GFAS database (Kaiser et al., 2012) and anthropogenic emissions from the CEDS database (Hoesly et al., 2018; Feng et al., 2020), which are based on more recent observations and provided at higher resolutions. We added a comment to section 4.1.

   ⇒ **Change 20**

3) **Comment:** *Fixed sizes seem too simple for interactions with ambient humidity (sulfate, seasalt).*

   Response: While the dry radius of a mode is constant, the wet radius varies based on the hygroscopic growth factor (f_{g})of Petters and Kreidenweis (2007), i.e.,

   $$\overline{r}_{\mathrm{w},j} = f_{\mathrm{g}}(T, RH, \overline{r}_j, \kappa_j)\overline{r}_j,$$

where $\overline{r}_j$ and $\overline{r}_{\mathrm{w},j}$ are the dry and wet radii of the mode, T is the air temperature, RH is the relative humidity, and κ_j is the hygroscopicity. The wet radius is used to calculate various aerosol processes as shown in section 2.2. We added a comment to section 2.1 and replaced "number median radius" with "dry radius" throughout the manuscript.

⇒ **Change 5, 6, 7, 16, 18, 25, and 36**

4) **Comment:** *60 / 74 is it unclear how humidity (via kappa) come into play, if size is fixed*

Response: As explained in the response to comment 3, the wet radius varies based on the hygroscopic growth factor of Petters and Kreidenweis (2007).

⇒ **Change 5, 6, 7, 16, 18, 25, and 36**

5) **Comment:** *92 interesting ... that no convection scheme/parameterization is needed*

Response: The Earth system model ICON-MPIM operates without a convection scheme. As outlined by Hohenegger et al. (2023), there are three main reasons for this choice. First, a lean code with few parameterization schemes can be ported more easily to new systems such as the new exascale cluster of the Forschungszentrum Jülich (2025). Second, parameterization schemes do not converge as the resolution is refined, which would be problematic for future simulations with ever increasing resolutions. Hohenegger et al. (2020) showed that some large-scale quantities such as net shortwave radiation start to converge at resolutions of about five kilometers. Third, ICON-MPIM is intended for Earth system research and not operational weather forecasting. Simple physics make it easier to understand, for example, the impact of processes that remain partially resolved or parameterized at kilometer scales. We added a paragraph to section 2.2.

⇒ **Change 11**

6) **Comment:** *107 emissions data are relatively coarse for km-scale models .... ?*

Response: As explained in the response to comment 2, we plan to use newer databases that are better resolved in future simulations.

⇒ **Change 20**

7) **Comment:** *191 displaying the reff (effective radii) would be better, as it includes the width information) ... there seems a size inconsistency to the MACv2 reference, as number mode radii are picked for the two coarse modes, while (larger) effective radii are picked for the fine-mode. The kappa approach (values are reasonable) might be useful for CCN estimates in the context of ambient rel. humidity but are they actually used? Densities are reasonable but on the high side for carbon and sulfate, and those might become smaller with increased aerosol water.*

Response: As explained in section 3.1, the dry radii of the modes were initially taken from the MACv2 aerosol climatology of Kinne (2019) and then adjusted to roughly match the aerosol lifetimes reported by Gliß et al. (2021). For the two coarse modes, the dry radii were adjusted only marginally. For the two fine modes, however, the dry radii were increased significantly since their initial lifetimes were too long. As explained in the response to comment 3, the hygroscopicities (κ) are used to calculate the wet radii and densities of the modes. The hygroscopicities are also used to calculate the aerosol activation as described in section 2.3.5. We added a comment to section 3.1.

⇒ **Change 18**

8) **Comment:** *238 is there a difference of Table 4 data between HAM and HAM-lite ?*

Response: We added the burdens and fluxes of ECHAM6.3–HAM2.3, i.e., the values of the CLIM simulation of Tegen et al. (2019), to table 4.

⇒ **Change 20 and 21**

9) **Comment:** *252 the comparison to AeroCom median are quite interesting. Here also the optical depth data of the top-down approach of the MAC climatology can be added (see below). I also provide access to data so that in assessment annual and even monthly component spatial distributions differences can be examined. While global averages for seasalt and sulfate seem ok, global averages for dust and carbonaceous aerosol are ca factor 2.5 too low. Hereby the low dust AOD bias is not helped by the relatively small coarse dust size.*

Response: We extended the last paragraph of section 4.1 including the predefined optical depths of the MACv2 climatology of Kinne (2019).

⇒ **Change 30**

10) **Comment:** *267 MODIS overestimates AOD, especially at low AOD values. In addition, listed global average might even on the low side as the applied dark-target data-set has no data over deserts. I suggest to use for MODIS data comparisons a combined darktarget/deep blue data set.*

Response: We revised figure 6 using the combined dark target and deep blue product.

⇒ **Change 28**

11) **Comment:** *291 if aerosol modulate the intensity of cyclones is unclear ... and highly unlikely by sea-salt, as this type stays a low altitudes.*

Response: We revised the corresponding statements in the abstract and sections 4 and 5.

⇒ **Change 3, 19, 33, and 37**

12) **Comment:** *302 what are the prescribed mean radii and std.dev s (incomplete in Table 2)*

Response: The standard deviation is 2.00 for the coarse modes (dust and sea salt) and 1.59 for the fine modes (carbonaceous and sulfuric). We extended the caption of table 2.

⇒ **Change 16**

13) **Comment:** *324 ... are blown off continents ... not just Africa*

Response: We corrected the sentence.

⇒ **Change 32**

14) **Comment:** *330+ I like most of the ideas for future work, in particular studies involving aerosol cloud interactions. For aerosol forcing, however, a better representation of AOD components and also a validation of assumed absorption (AAODf / AAODc) will be needed*

Response: We extended the outlook.

⇒ **Change 39**

References

Feng, L., Smith, S. J., Braun, C., Crippa, M., Gidden, M. J., Hoesly, R., Klimont, Z., van Marle, M., van den Berg, M., and van der Werf, G. R.: The generation of gridded emissions data for CMIP6, Geoscientific Model Development, 13, 461–482, https://doi.org/10.5194/gmd-13-461-2020, 2020.

Forschungszentrum Jülich: JUPITER Exascale Development Instrument, `https://www.fz-juelich.de/en/ias/jsc/systems/supercomputers/jedi`, 2025.

Gliß, J., Mortier, A., Schulz, M., Andrews, E., Balkanski, Y., Bauer, S. E., Benedictow, A. M. K., Bian, H., Checa-Garcia, R., Chin, M., Ginoux, P., Griesfeller, J. J., Heckel, A., Kipling, Z., Kirkevåg, A., Kokkola, H., Laj, P., Le Sager, P., Lund, M. T., Lund Myhre, C., Matsui, H., Myhre, G., Neubauer, D., van Noije, T., North, P., Olivié, D. J. L., Rémy, S., Sogacheva, L., Takemura, T., Tsigaridis, K., and Tsyro, S. G.: AeroCom phase III multi-model evaluation of the aerosol life cycle and optical properties using ground- and space-based remote sensing as well as surface in situ observations, Atmospheric Chemistry and Physics, 21, 87–128, https://doi.org/10.5194/acp-21-87-2021, 2021.

Hoesly, R. M., Smith, S. J., Feng, L., Klimont, Z., Janssens-Maenhout, G., Pitkanen, T., Seibert, J. J., Vu, L., Andres, R. J., Bolt, R. M., Bond, T. C., Dawidowski, L., Kholod, N., Kurokawa, J.-I., Li, M., Liu, L., Lu, Z., Moura, M. C. P., O'Rourke, P. R., and Zhang, Q.: Historical (1750–2014) anthropogenic emissions of reactive gases and aerosols from the Community Emissions Data System (CEDS), Geoscientific Model Development, 11, 369–408, https://doi.org/10.5194/gmd-11-369-2018, 2018.

Hohenegger, C., Kornblueh, L., Klocke, D., Becker, T., Cioni, G., Engels, J. F., Schulzweida, U., and Stevens, B.: Climate Statistics in Global Simulations of the Atmosphere, from 80 to 2.5 km Grid Spacing, Journal of the Meteorological Society of Japan. Ser. II, 98, 73 – 91, https://doi.org/10.2151/jmsj.2020-005, 2020.

Hohenegger, C., Korn, P., Linardakis, L., Redler, R., Schnur, R., Adamidis, P., Bao, J., Bastin, S., Behravesh, M., Bergemann, M., Biercamp, J., Bockelmann, H., Brokopf, R., Brüggemann, N., Casaroli, L., Chegini, F., Datseris, G., Esch, M., George, G., Giorgetta, M., Gutjahr, O., Haak, H., Hanke, M., Ilyina, T., Jahns, T., Jungclaus, J., Kern, M., Klocke, D., Kluft, L., Kölling, T., Kornblueh, L., Kosukhin, S., Kroll, C., Lee, J., Mauritsen, T., Mehlmann, C., Mieslinger, T., Naumann, A. K., Paccini, L., Peinado, A., Praturi, D. S., Putrasahan, D., Rast, S., Riddick, T., Roeber, N., Schmidt, H., Schulzweida, U., Schütte, F., Segura, H., Shevchenko, R., Singh, V., Specht, M., Stephan, C. C., von Storch, J.-S., Vogel, R., Wengel, C., Winkler, M., Ziemen, F., Marotzke, J., and Stevens, B.: ICON-Sapphire: simulating the components of the Earth system and their interactions at kilometer and subkilometer scales, Geoscientific Model Development, 16, 779–811, https://doi.org/10.5194/gmd-16-779-2023, 2023.

Kaiser, J. W., Heil, A., Andreae, M. O., Benedetti, A., Chubarova, N., Jones, L., Morcrette, J.-J., Razinger, M., Schultz, M. G., Suttie, M., and van der Werf, G. R.: Biomass burning emissions estimated with a global fire assimilation system based on observed fire radiative power, Biogeosciences, 9, 527–554, https://doi.org/10.5194/bg-9-527-2012, 2012.

Kinne, S.: The MACv2 aerosol climatology, Tellus B: Chemical and Physical Meteorology, 71, 1–21, https://doi.org/10.1080/16000889.2019.1623639, 2019.

Petters, M. D. and Kreidenweis, S. M.: A single parameter representation of hygroscopic growth and cloud condensation nucleus activity, Atmospheric Chemistry and Physics, 7, 1961–1971, https://doi.org/10.5194/acp-7-1961-2007, 2007.

Tegen, I., Neubauer, D., Ferrachat, S., Siegenthaler-Le Drian, C., Bey, I., Schutgens, N., Stier, P., Watson-Parris, D., Stanelle, T., Schmidt, H., Rast, S., Kokkola, H., Schultz, M., Schroeder, S., Daskalakis, N., Barthel, S., Heinold, B., and Lohmann, U.: The global aerosol–climate model ECHAM6.3–HAM2.3 – Part 1: Aerosol evaluation, Geoscientific Model Development, 12, 1643–1677, https://doi.org/10.5194/gmd-12-1643-2019, 2019.

Response to Referee #3

March 16, 2025

We thank the referee for the valuable comments, which we took into account in the revised manuscript. Below you find the referee's comment and our response.

1) **Comment:** *You mention that it would be too expensive to run the two-moment module HAM with 5 km grid spacing but I was hoping to see an intercomparison between the original HAM and HAM-lite even if it is only at 10 km or for a short period of time. Such a comparison would shed some light on the differences and potential implications of the simpler scheme and might also help to improve HAM-light. I understand that adding such a comparison would be a lot of work but would also bring a lot of benefits. If you decide to not work on this, I recommend to at least discuss potential differences and work on a comparison in the near future.*

   Response: A direct comparison of HAM and HAM-lite is not possible in the moment since these two modules are coupled to different Earth system models. HAM-lite is coupled to the new km-scale model ICON-MPIM (Hohenegger et al., 2023), whereas HAM is coupled to the coarse-scale models ECHAM (Tegen et al., 2019) and ICON-A (Salzmann et al., 2022). To allow for a comparison, we added the aerosol burdens, fluxes, lifetimes, and optical depths of ECHAM-HAM as reported by Tegen et al. (2019) and Glüß et al. (2021) to tables 4 and 5.

   ⇒ **Change 20, 21, and 22**

2) **Comment:** *Related to the above comment; Could you add a discussion on what the systematic impacts of using a single moment aerosol representation are? What processes would be better captured using a two-moment representation and where should users be careful when using the one moment output for process understanding?*

   Response: We acknowledge that a one-moment scheme imposes limitations in comparison to a two-moment scheme. Since it carries no information about the aerosol size, there is no explicit representation of nucleation, growth, and ageing. And there is no ability to adjust the aerosol size in response to activation and wet deposition (Stier et al., 2005; Siebesma et al., 2020). We added a comment to section 2.1.

   ⇒ **Change 8**

3) **Comment:** *L19: Do CMIP6 type models truly have complex microphysics compared to e.g., modern weather forecasting models. My impression was that they usually use single moment schemes without graupel/hail. Additionally, running deep convection schemes that produce precipitation complicates things.*

Response: We corrected the sentence and replaced the reference to Thornhill et al. (2021) with Tegen et al. (2019). Tegen et al. (2019) preformed simulations with the complex ECHAM-HAM model over the years 2003 to 2012.

⇒ **Change 4**

4) **Comment:** *L84-5: Currently this reads like there are three schemes for microphysics, radiation, and turbulence each. You could write: "There are three parameterization schemes, one for cloud microphysics, one for radiation, and one for turbulence..."*

Response: We corrected the sentence.

⇒ **Change 9**

5) **Comment:** *L109: "To forward emissions to modes,..." what is meant here? Please reformulate.*

Response: Due to the absence of microphysical processes, emissions are directly added to modes without any intermediate steps such as nucleation. The mass fluxes are converted into number fluxes based on the radius of average mass of the mode, i.e.,

$$F_{\mathrm{em},j,k,s} = \frac{3}{4\pi\overline{r}_{\mathrm{m},j}^{3}\rho_k} S_{\mathrm{em},k,s},$$

where $S_{\mathrm{em},k,s}$ is the mass flux of species k in sector s, $\overline{r}_{\mathrm{m},j}$ is the radius of average mass of mode j, and $F_{\mathrm{em},j,k,s}$ is the number flux. We extended the first paragraph of section 2.3.1.

⇒ **Change 12 and 14**

6) **Comment:** *L259-60: I do not see anything special at 500 hPa in the dust concentration profiles. It seems as if the peak of emissions is related to the height of the source region (e.g. dust emissions over the Tibetan Plateau should be around 600 hPa). Plotting the profiles regarding height above surface should help to reduce this effect.*

Response: We revised the figure and plotted the profiles based on the altitude.

⇒ **Change 23 and 24**

7) **Comment:** *L269-70: I appreciate that you mention satellite observation uncertainties. Could you add a sentence on how those might affect this comparison?*

Response: On average, the optical depth of MODIS is larger than those of other satellites especially over the ocean (Vogel et al., 2022, tables 2 and 3). We added a comment to the last paragraph of section 4.1.

⇒ **Change 27**

8) **Comment:** *L296: "The vertical velocities highlight diverging cold pool edges that lift air from convective downdrafts." This should probably be something like: … diverging cold pools that originate from convective downdrafts and mesoscale circulation that lifts air at the gust front.*

Response: We corrected the sentence.

⇒ **Change 34**

9) **Comment:** *L299-300: It is not only the cold pools that are not captured but also the mesoscale circulation (e.g., mesocyclones, rear-inflow jets in MCSs...). One study that discusses this is: Prein (2023).*

Response: We revised the sentence.

⇒ **Change 35**

References

Gliß, J., Mortier, A., Schulz, M., Andrews, E., Balkanski, Y., Bauer, S. E., Benedictow, A. M. K., Bian, H., Checa-Garcia, R., Chin, M., Ginoux, P., Griesfeller, J. J., Heckel, A., Kipling, Z., Kirkevåg, A., Kokkola, H., Laj, P., Le Sager, P., Lund, M. T., Lund Myhre, C., Matsui, H., Myhre, G., Neubauer, D., van Noije, T., North, P., Olivié, D. J. L., Rémy, S., Sogacheva, L., Takemura, T., Tsigaridis, K., and Tsyro, S. G.: AeroCom phase III multi-model evaluation of the aerosol life cycle and optical properties using ground- and space-based remote sensing as well as surface in situ observations, Atmospheric Chemistry and Physics, 21, 87–128, https://doi.org/10.5194/acp-21-87-2021, 2021.

Hohenegger, C., Korn, P., Linardakis, L., Redler, R., Schnur, R., Adamidis, P., Bao, J., Bastin, S., Behravesh, M., Bergemann, M., Biercamp, J., Bockelmann, H., Brokopf, R., Brüggemann, N., Casaroli, L., Chegini, F., Datseris, G., Esch, M., George, G., Giorgetta, M., Gutjahr, O., Haak, H., Hanke, M., Ilyina, T., Jahns, T., Jungclaus, J., Kern, M., Klocke, D., Kluft, L., Kölling, T., Kornblueh, L., Kosukhin, S., Kroll, C., Lee, J., Mauritsen, T., Mehlmann, C., Mieslinger, T., Naumann, A. K., Paccini, L., Peinado, A., Praturi, D. S., Putrasahan, D., Rast, S., Riddick, T., Roeber, N., Schmidt, H., Schulzweida, U., Schütte, F., Segura, H., Shevchenko, R., Singh, V., Specht, M., Stephan, C. C., von Storch, J.-S., Vogel, R., Wengel, C., Winkler, M., Ziemen, F., Marotzke, J., and Stevens, B.: ICON-Sapphire: simulating the components of the Earth system and their interactions at kilometer and subkilometer scales, Geoscientific Model Development, 16, 779–811, https://doi.org/10.5194/gmd-16-779-2023, 2023.

Prein, A. F.: Thunderstorm straight line winds intensify with climate change, Nature Climate Change, 13, 1353–1359, https://doi.org/10.1038/s41558-023-01852-9, 2023.

Salzmann, M., Ferrachat, S., Tully, C., Münch, S., Watson-Parris, D., Neubauer, D., Siegenthaler-Le Drian, C., Rast, S., Heinold, B., Crueger, T., Brokopf, R., Mülmenstädt, J., Quaas, J., Wan, H., Zhang, K., Lohmann, U., Stier, P., and Tegen, I.: The Global Atmosphere-aerosol Model ICON-A-HAM2.3–Initial Model Evaluation and Effects of Radiation Balance Tuning on Aerosol Optical Thickness, Journal of Advances in Modeling Earth Systems, 14, e2021MS002 699, https://doi.org/10.1029/2021MS002699, 2022.

Siebesma, A. P., Bony, S., Jakob, C., and Stevens, B., eds.: Clouds and Climate: Climate Science's Greatest Challenge, Cambridge University Press, Cambridge, https://doi.org/10.1017/9781107447738, 2020.

Stier, P., Feichter, J., Kinne, S., Kloster, S., Vignati, E., Wilson, J., Ganzeveld, L., Tegen, I., Werner, M., Balkanski, Y., Schulz, M., Boucher, O., Minikin, A., and Petzold, A.: The aerosol-climate model ECHAM5-HAM, Atmospheric Chemistry and Physics, 5, 1125–1156, https://doi.org/10.5194/acp-5-1125-2005, 2005.

Tegen, I., Neubauer, D., Ferrachat, S., Siegenthaler-Le Drian, C., Bey, I., Schutgens, N., Stier, P., Watson-Parris, D., Stanelle, T., Schmidt, H., Rast, S., Kokkola, H., Schultz, M., Schroeder, S., Daskalakis, N., Barthel, S., Heinold, B., and Lohmann, U.: The global aerosol–climate model ECHAM6.3–HAM2.3 – Part 1: Aerosol evaluation, Geoscientific Model Development, 12, 1643–1677, https://doi.org/10.5194/gmd-12-1643-2019, 2019.

Thornhill, G. D., Collins, W. J., Kramer, R. J., Olivié, D., Skeie, R. B., O'Connor, F. M., Abraham, N. L., Checa-Garcia, R., Bauer, S. E., Deushi, M., Emmons, L. K., Forster, P. M., Horowitz, L. W., Johnson, B., Keeble, J., Lamarque, J.-F., Michou, M., Mills, M. J., Mulcahy, J. P., Myhre, G., Nabat, P., Naik, V., Oshima, N., Schulz, M., Smith, C. J., Takemura, T., Tilmes, S., Wu, T., Zeng, G., and Zhang, J.: Effective radiative forcing from emissions of reactive gases and aerosols – a multi-model comparison, Atmospheric Chemistry and Physics, 21, 853–874, https://doi.org/10.5194/acp-21-853-2021, 2021.

Vogel, A., Alessa, G., Scheele, R., Weber, L., Dubovik, O., North, P., and Fiedler, S.: Uncertainty in Aerosol Optical Depth From Modern Aerosol-Climate Models, Reanalyses, and Satellite Products, Journal of Geophysical Research: Atmospheres, 127, e2021JD035 483, https://doi.org/10.1029/2021JD035483, e2021JD035483 2021JD035483, 2022.