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 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. 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 Gliß et 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.