Project: **1004**

Title: **Development and evaluation of aerosol processes in the community aerosol chemistry model HAMMOZ**

Project lead: **Bernd Heinold, Ina Tegen**

Report period: **2023-07-01 to 2024-06-30**

The aim of his project is the on-going evaluation and coordination of further developments of the aerosol model HAM (Versions 2.2, 2.3) in close collaboration with scientists from the HAMMOZ consortium. The well-established global aerosol-chemistry-climate model ECHAM6-HAMMOZ is jointly developed by partners from several European universities and research institutes. The model code is hosted at the ETH Zurich where it is made accessible to the research community; partners include scientists at the Universities of Oxford and Leipzig, at the Finish Meteorological Institute (FMI), as well as at the German research institutes MPI Hamburg, TROPOS and GEOMAR. It simulates the lifecycles of the climate-relevant aerosol species including microphysical transformation processes, and their impact on clouds, radiation and climate. The model system includes the global atmospheric climate model ECHAM, the aerosol-microphysics model HAM, and the atmospheric chemistry model MOZART. The role of TROPOS in this project is to bring together the different aspects of the model development and to test the subsequent modifications in the aerosol distribution resulting from the changes of the aerosol parameterisation.

The new aerosol-climate model ICON-HAM (Salzmann et al., 2022) was released 2021. Here, the HAM (version 2.3) aerosol model is coupled to the climate model ICON-A (icon-aes-1.3.00). At ETH Zurich, a version of ICON-HAM has been developed that is based on icon-2.6.4, i.e. the latest ICON version that contains the physical parameterizations inherited from the ECHAM model (e.g., the convection scheme, the cloud cover scheme, the vertical diffusion scheme and the gravity wave drag parameterizations for sub-gridscale orographic and non-orographic gravity waves). These are necessary to run the model at rather coarse resolutions like r2b4. This ICON-HAM version was installed on Levante and several tests are ongoing. TROPOS has the responsibility to prepare and maintain the input data for ECHAM6.3-HAM2.3-MOZ1.0 and ICON-HAM. Thus, to enable users to fully explore both models, a comprehensive set of input data is maintained and continuously developed on demand of the users.

Computing time granted for the report period was used for:

a) <u>Test simulations with ECHAM6-HAMMOZ with a more recent anthropogenic emission data set</u>
Simulations with aerosol-chemistry-climate model ECHAM6-HAMMOZ so far used anthropogenic and biomass burning emissions of reactive gases, aerosols, VOCs and aerosol precursor substances from the ACCMIP inventory (Lamarque et al., 2010) combined with the Representative Concentration Pathway (RCP) scenarios (van Vuuren et al., 2010) prepared for CMIP5. This has been replaced by the more recent CEDS data set (Hoesly et al., 2018) for the historic period and the IAMC inventory (Gidden et al., 2019) from 2015 onward as used for CMIP6. To get an impression of the effects of the new data sets, different scenarios (ssp126, ssp245, ssp370, ssp585 and rcp26, rcp45, rcp85) were simulated for the common time period 2024-2028 with an appropriate spin-up period before. The test was run in T63 horizontal resolution and with 47 levels in the vertical. At the lower boundary sea surface temperatures and sea ice conditions were prescribed using a climatology over the years 2000-2015.
Species that are most likely affected by the change in emissions are ozone (O_3), carbon monoxide (CO), and nitrogen dioxide (NO_2) (see, e.g., Fig. 1). The focus of the analyses is on the troposphere. Pairs of new and old emission scenarios were compared, comparisons to observations were made whenever possible.

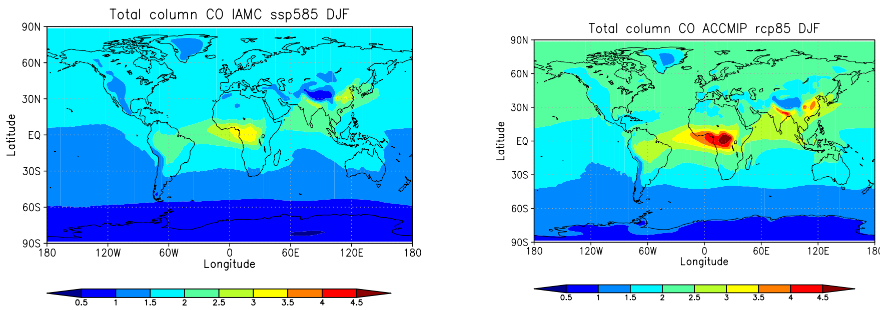

***Figure 1**:* Total column carbon monoxide (10^{18} molec./cm^2) in ECHAM6-HAMMOZ with CMIP6 IAMC ssp585 emission scenario (left) and the CMIP5 ACCMIP RCP85 emissions (right), multi-year seasonal mean Dec-Feb.

b) <u>Dust simulations with ICON-2.6.4-HAM</u>
From earlier test simulations it is known that ICON-HAM in the released version (Salzmann et al. 2022) produces annual amounts of mineral dust that are near the lower limit of the results from a global intercomparison project (AeroCom Phase I). The range of model results reaches from 500 to about 4000 Tg (Teragram) dust emission

per year (Huneeus et al., 2011) with ICON-HAM procucing dust emissions at the low end of the estimates (Wagner and Schepanski, 2024). New tests with the ETH-Zurich version ICON-2.6.4-HAM, however, resulted in much higher global dust emissions of up to ~3600 Tg per year. Comparisons to the satellite-based dataset MIDAS (Gkikas et al., 2021) shows that dust optipcal depth is likely overestimated by up to a factor of four (Fig. 2).

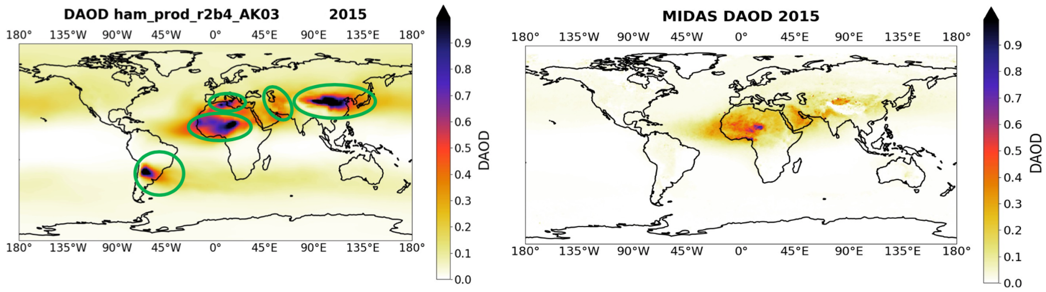

***Figure 2**:* Dust aerosol optical thickness (AOT) in 2015. Left: ICON-HAM based on ICON-2.6.4, right: MIDAS data set based on MODIS satellite observations (Gkikas et al., 2021).

c) <u>Simulations of the warm North Atlantic and the possible role of reduced ship emissions</u>
Observations showed extraordinary high sea-surface temperatures in the North Atlantic Ocean in spring and early summer 2023, which were suspected to be due to a combination of circulation changes and reduced air pollution (anomalously weak Azores high, weak surface winds, absence of Saharan dust over the ocean). Another assumption was that reduced emissions of SO_2 from international ship traffic due to the next step in legislation taken in 2020 might have led to a decrease in ship track related cloud cover (Watson-Parris et al., 2022) and, thus, contributed to the warming. We tested this assumption in a set of ECHAM6-HAM sensitivity simulations where SO_x emissions were reduced by either 80% or 100% and compared to a control simulation. Other ship emission (BC, OC) were left unchanged. The model was run for 2010-2014 without nudging. The effect of the complete ship SO_x emission reduction on the AOD fraction (noShip/control) is most pronounced over the N-Atlantic. It amounts to 20-30% less AOD in the simulation without ship emissions. The short-wave radiative forcing at the surface under all-sky conditions shows a positive anomaly of up to 0.2 W/m^2, which is quite substantial.

d) <u>Simulation of the Hunga-Tonga-Hunga Ha'apai eruption in 2022</u>
The eruption of the Hunga-Tonga-Hunga Ha'apai volcano on 15 January 2022 emitted large amounts of SO_2, but also water vapour and sea salt into unprecedented altitude regions up to the mesosphere at about 57 km (Proud et al., 2022). To study the effects on atmospheric composition a simulation with the aerosol-chemistry-climate model ECHAM6-HAMMOZ was set up. Hitherto, it was not possible to emit water vapour or sea salt by volcanic eruptions into the model atmosphere. Thus, some modifications of the volcanic aerosol emission input scheme became necessary. Emissions were estimated from satellite measurements (Khaykin et al., 2022) with amounts of 0.42 Tg SO_2, 5 Tg sea salt and 142 Tg water vapour. The model was run in nudged mode until the day of eruption and freely (i.e., w/o nudging) afterwards.

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