Project: **1004**

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

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

Report period: **2024-07-01 to 2025-06-30**

The aim of his project is the on-going evaluation and coordination of further developments of the aerosol model HAM in close collaboration with scientists from the HAMMOZ consortium. The 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 the Universities of Oxford and Leipzig, the Finish Meteorological Institute (FMI), as well as the German research institutes MPI Hamburg and TROPOS. It simulates the lifecycles of the climate-relevant aerosols including microphysical transformation processes, and their impact on clouds, radiation and climate. The model system includes the atmospheric climate model ECHAM, the aerosol module HAM, and the atmospheric chemistry model MOZART. TROPOS coordinates the model development and tests how changes in aerosol parameterizations affect the modelled aerosol.

The aerosol-climate model ICON-HAM (Salzmann et al., 2022) was released in 2021. It couples the aerosol module HAM (v2.3) with the climate model ICON-A. The latest version is based on icon-2.6.4 – the latest ICON version that contains the physical parameterizations inherited from the ECHAM model (schemes for, e.g., moist convection, cloud cover, vertical diffusion, and gravity wave drag). They are needed for coarse resolution runs (>10 km). The latest ICON-HAM development includes HAM-lite, a simplified and computationally efficient version of HAM (Weiss et al., 2024). It is designed for convection-resolving runs (<5 km) and was adapted for limited-area mode (LAM) (Heinold et al., 2025, in prep.). In addition, the ICON-ART model has been used for large eddy simulations. 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>Simulation of the Hunga-Tonga-Hunga Ha'apai eruption in 2022</u>
The Hunga Tonga–Hunga Ha'apai (hereafter HT) volcano eruption on 15 January 2022 released vast amounts of SO_2, water vapor, and sea salt up to unprecedented 57 km into the mesosphere (Proud et al., 2022). To study the effects on atmospheric composition, a simulation with the aerosol-chemistry-climate model ECHAM6-HAMMOZ (Schultz et al., 2018) was set up. To this end, some modifications of the volcanic aerosol emission input scheme became necessary to enable emissions of water vapour or sea salt by volcanic eruptions. The emissions were estimated from satellite measurements with amounts of 0.42 Tg SO_2, 5 Tg sea salt and 142 Tg water vapour (Khaykin et al., 2022; Millán et al., 2022). The model was run in T63L47 resolution and in nudged mode until the day of eruption and freely afterwards. A reference simulation including the HT eruption is paired with a control simulation without the eruption. Sensitivity experiments included varying volcanic emissions (SO_2 only, SO_2 with sea salt) and eruption timing (one year earlier during the QBO's westerly phase). Each simulation ran for two years, following a 3-month spin-up. Anthropogenic emissions from the CMIP6 IAMC inventory were used, with 2010–2022 climatological sea-surface temperatures and sea ice from AMIP (v 1.1.9).

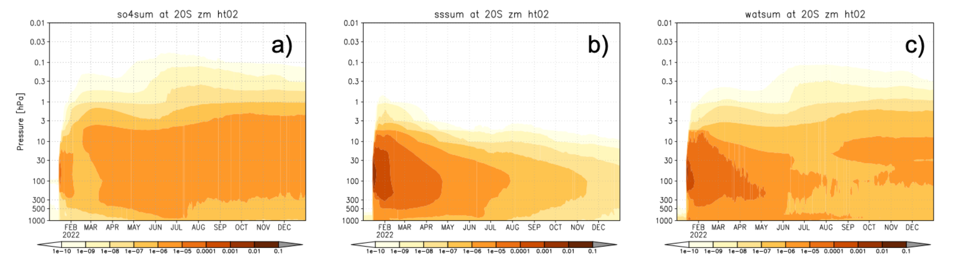

***Figure 1**:* ECHAM6-HAMMOZ simulation of the HT eruption on 15 Jan 2022. Altitude-time sections of zonal mean sulphate (a), sea salt (b) and aerosol water (c) mixing ratio at 20°S (kg/kg).

First analyses show the modelled volcanic plume in the stratosphere and troposphere containing sulphate, sea salt and a significant amount of aerosol water (Fig. 1). This is in line with an ICON-ART study of the eruption's initial weeks by Bruckert et al. (2025).

b) <u>Online interpolation of oxidant species in ICON-2.6.4-HAM</u>

ICON-2.6.4-HAM is supposed to be used in high spatial resolutions up to km-scale. For the processing of SO_2 to SO_4 and ultimately H_2SO_4 in the model atmosphere, the abundances of oxidant species (H_2O_2, OH, O_3, NO_2 and NO_3) has to be prescribed in the desired horizontal and vertical resolution. ICON lacks fixed vertical discretization per horizontal resolution, making pre-generating various grid files impractical. To address this, online vertical interpolation can be used if oxidants are on the correct horizontal grid. However, HAM's current routine can't extrapolate beyond the input file's vertical range. This leads to a strong underestimation of H_2O_2 and, thus, to an overestimation of OH near the ground (Fig. 2a, b). As a result, there is an incorrrect shift in the gas phase (by OH) and aqueous phase (by H_2O_2) partitioning of H_2SO_4 production at the lowest levels (Fig. 2).

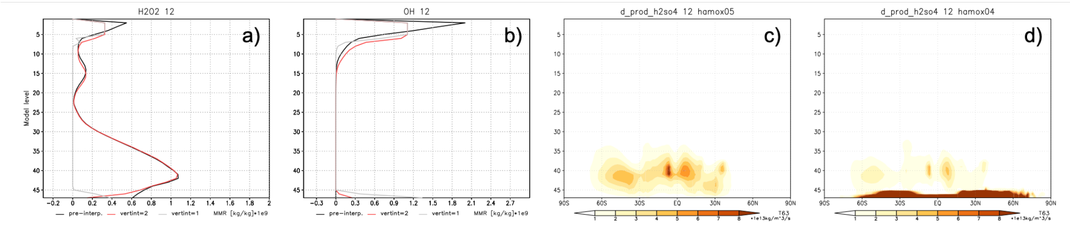

Figure 2: December mean profiles of H_2O_2 (a) and OH (b) in ICON-HAM using pre-interpolated (black), simple (grey), and weighted (red) online interpolation; c–d) Zonal mean H_2SO_4 production with pre-interpolated (c) and weighted online interpolation (d).

c) <u>Simulations of dusty cirrus clouds with ICON-ART</u>

A large part of granted computing time was used to simulate dusty cirrus clouds with the dust-transport model ICON-ART. Dusty cirrus is a still poorly researched cloud type, as it is not yet fully established how the peculiar cloud properties result from the dust effects on cloud microphysics (Seifert et al., 2023). The simulations at 400 m horizontal grid spacing focused on a thunderstorm-generated case over the western Mediterranean on 19 June 2024. They included on-line dust-radiation and dust-INP effects. Preliminary results show that the model could partially represent dusty cirrus dynamics (Fig. 3), however the ice water content and IR cloud top temperatures are still under-/overestimated, respectively. A parameter tuning in the 2-moment microphysics scheme effectively reducing the ice fallout rate resulted in a much better representation. This may indicate that standard microphysics schemes are not suitable to representthe very small ice crystals in a dusty cirrus.

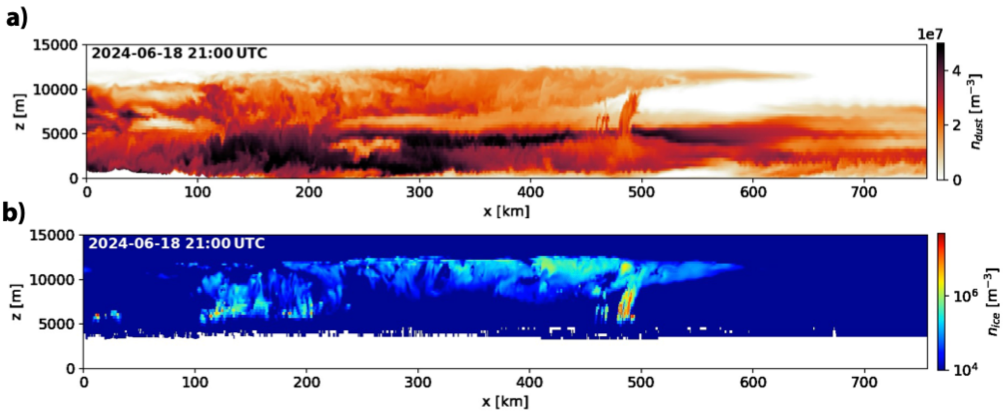

Figure 3*: Mediterranean dusty cirrus case on 18 June 2024 simulated with ICON-ART. (a) Dust number and (b) ice number concentration through the thunderstorms, causing the dusty cirrus.*

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