Project: **883**
Project title: **Modelling of Saharan mineral dust**
Project lead: **Bernd Heinold**
Report period: **1.1.2024 - 31.12.2024**

Progress Report

The central aim of this DKRZ project is to evaluate and continuously improve the representation of mineral dust in the aerosol-climate model ECHAM6.3-HAM2.3 (Tegen et al., 2019) and its successor ICON(MPI-M)-HAM2.3 (Salzmann et al., 2021). The 2024 allocation period essentially served two objectives: (1) The development of the limited area functionality in the coupled model system ICON-HAM, which has not yet existed, and (2) the improvement of the model representation of dust-cloud interactions.

In the EU's Horizon 2020 project nextGEMS (next Generation Earth Modelling Systems), storm-resolving Earth-system models are developed. In order to perform km-scale interactive aerosol-climate simulations, the University of Oxford developed the reduced-complexity aerosol module HAM-lite that is coupled to the climate model ICON(MPI-M) (Sapphire). While based on the full and complex aerosol module HAM, HAM-lite represents aerosols as an ensemble of log-normal modes with prescribed sizes and compositions. There are two pure modes – one for dust, one for sea salt – and two internally mixed modes containing organic carbon, black carbon, and sulfate. Here we developed a version of HAM-lite which can be run not only globally but also in limited area mode (LAM). Initial LAM simulations with ICON(MPI-M) and HAM-lite at resolutions of around 2.5 km were performed for test purposes for periods of a few hours to days. However, the model performance on Levante indicates that even several years are easy to achieve. The simulations use sea surface temperature and sea ice as lower boundary conditions from AMIP, and the initial and lateral boundary conditions of the atmosphere and land are prescribed from the operational analysis of ECMWF. The initial and lateral boundary conditions for the aerosols are taken from the operational reanalysis of the Copernicus Atmosphere Monitoring service (EAC4 CAMS). First results for the Amazon region in August 2007 show plausible patterns of atmospheric aerosol transport (Fig. 1). Nevertheless, further detailed tests and thorough evaluation are required, which will be continued in the coming allocation period.

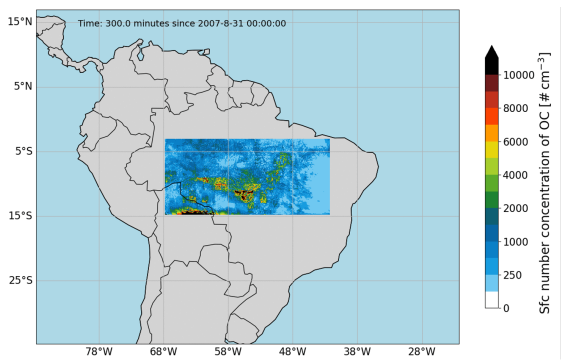

Figure 1*: Initial simulation results of the ICON (MPI-M) – HAM-lite model in LAM mode at 2.5-km grid spacing (r02b10) for Amazon region on 31 August 2007: Surface number concentration of organic carbon (OC) particles.*

Secondly, the role of desert dust in atmospheric freezing was further investigated, specifically, dusty cirrus events over the Mediterranean and southern Europe. Dusty cirrus clouds are extended cirrocumulus decks associated with strong dust outbreaks that are often not represented by numerical weather models even with interactive aerosol (Seifert et al., 2023), and therefore also probably not in the aerosol-climate model ICON-HAM2.3. Seifert et al. (2023) had assumed that the dusty cirrus clouds form due to a mixing instability of moist clean air with dry dusty air and had partially eliminated the model deficit with a sub-grid parameterisation. In collaboration with researchers from Karlsruhe Institute of Technology (KIT) and German weather service DWD, a pilot study was kicked off using the model system ICON-ART (Schröter et al., 2018) to better understand the key processes that need to be included and parameterised in mesoscale modelling. As a base case, the dusty cirrus event March 2022 was reinvestigated using a setup, in which a grid spacing of 3.2 km (R03B09 grid), interactive dust transport and two-moment microphysics were used in the ICON-ART simulations. The comparison of model-derived and the MSG IR imagery in Fig. 2 shows the dramatic underestimation of the cirrus clouds in the dust region by the model.

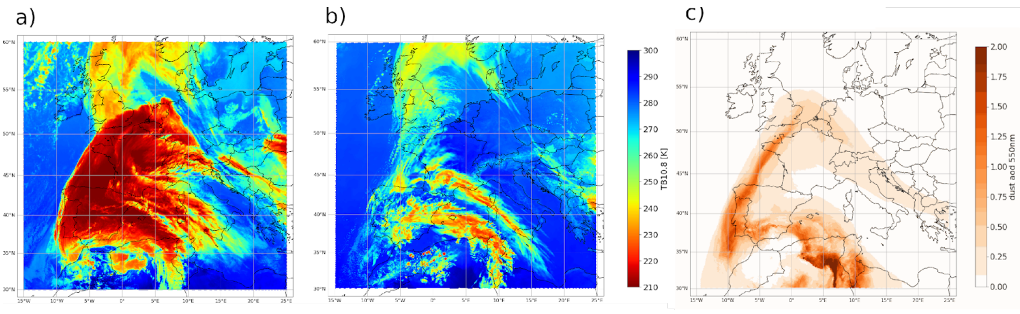

Figure 2*: Cloud conditions during a Saharan dust outbreak on 16 March 2022, 16:30 UTC: Comparison of infrared brightness temperatures (IR10.8) from (a) Meteosat Second Generation (MSG) SEVIRI data of EUMETSAT and (b) derived from ICON-ART simulations. (c) Map of dust optical depth computed by ICON-ART.*

This shows again that mesoscale modelling alone is not sufficient. For ongoing investigations, we have therefore switched to idealized large-eddy-scale (LES) model experiments with about 100 m grid spacing. Initial results already show important observed properties of dusty cirrus clouds (Fig. 3). The LES approach is therefore a promising starting point for more extensive modelling experiments planned for the coming allocation period, although in a separate DKRZ project.

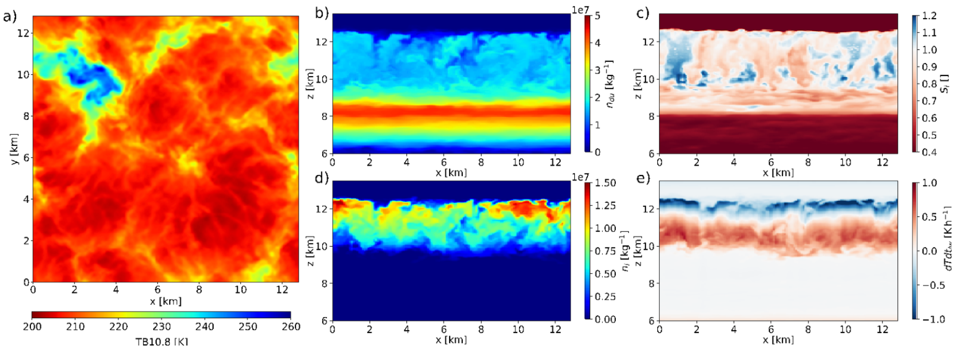

Figure 3*: Idealized LES simulations of dust cirrus: (a) Simulated infrared cloud top temperature of a dusty cirrus layer showing Rayleigh-Bénard convection after 7-hour simulation time. (b) Dust particle mixing ratio, (c) saturation over ice, (d) ice particle numbers, and (e) long-wave heating rate along vertical cross-sections through the cloud layer.*

Perspectives

The new limited-area version of HAM-lite will be evaluated in detail, focusing on the dust processes. The LAM functionality will be extended to the full HAM aerosol module. Scientifically, further model studies are planned on the topic of the desert dust impact on clouds.

Utilisation and Publication

All model developments and required input data are made available to the scientific community through the HAMMOZ website (https://redmine.hammoz.ethz.ch) and repository. The scientific results will be published in open-access journals.

References

Salzmann M., et al.: The global atmosphere-aerosol model ICON-A-HAM2.3 – Initial model evaluation and effects of radiation balance tuning on aerosol optical thickness, J. Adv. Model. Earth Syst., 2021.

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