Project: **1215**

Project title: **A big unknown in the climate impact of atmospheric aerosol: Mineral soil dust**

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Report period: **2021-11-01 to 2022-10-31**

Project overview

Aerosols and clouds contribute the largest uncertainty to estimates of the Earth's energy budget. Mineral soil dust is the dominant contributor to the global aerosol mass. Dust has severe impacts on climate, air quality, transportation, health, economy, and solar-power generation in many areas of the world including Europe. The particle-size distribution, shape, and composition of dust aerosol mainly determine its climate impact. Recent observations show that much larger dust particles than previously thought are transported over long. Numerical models are currently unable to reproduce the transport, neither the emission, of such giant particles. We aim to reduce uncertainty related to mineral dust aerosol and its cloud interactions by combining un-precedented field and laboratory experiments, theory, and advanced numerical modeling.

Our modeling efforts are conducted using the ICON-ART modeling system and focus on three key parts: (1) quantify the impact of land-surface heterogeneity on dust emission and improve the surface representation in models; (2) advance the parameterizations of dust emission and dust-cloud interactions; and (3) determine the impact of model advancements on estimated dust-climate effects and compare dust with other aerosols. Our model simulations range from idealized short-term, small-domain, and high-resolution runs to multi-year global medium- resolution runs.

The project is part of the Helmholtz Young Investigator Group "Mineral Dust" at KIT IMK-TRO (https://www.imk-tro.kit.edu/10519.php), a six-year research program, which started in November 2020.

Project results in the report period

During the report period, we have made considerable progress on the modelling tasks within the Helmholtz Young Investigator Group "Mineral Dust":

Large-eddy simulation of mineral dust emission:

We applied the ICON-ART model in large-eddy simulation setup to study mineral dust emission and its sensitivity to land-surface characteristics such as vegetation cover or soil type, both key characteristics that contribute to determining the magnitude and particle size of emitted dust. The model represents the size distribution at emission using three different lognormal modes with mass median diameter of 1.5 µm (mode A), 6.7 µm (mode B), and 14.2 µm (mode C). Sensitivity runs were performed using three grid resolutions (20m, 40m, and 80m) with and without vegetation. Only resolution was changed in the runs with vegetation, whereas the domain total vegetation cover fraction as well as its spatial distribution was held constant. Our preliminary results reveal the important impact of resolution on dust emission (Fig. 1). Simulations including variable soil texture and shifting the mass median diameter of mode C to larger particle size are in preparation, and will help to constrain the magnitude and particle size of emitted dust under complex land-surface conditions.

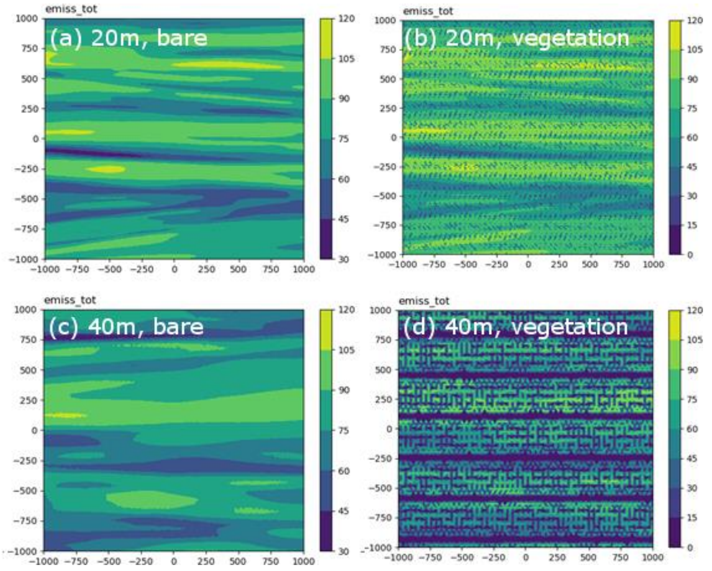

Fig. 1 Horizontal distribution of total dust emission flux (µg m-2 s-1) at grid resolutions of (a,b) 20 m and (c,d) 40 m. (a) and (c) assume a bare ground; (c) and (d) include a scattered vegetation cover with a domain average of 20%.

Global dust emissions:

Mineral dust emission depends non-linearly on surface wind intensity and hence will directly benefit from increased model resolution and a correspondingly improved representation of wind variability. Initial tests were conducted using a fully dynamic global high-resolution (R2B09, i.e. ~5 km horizontal grid spacing; 90 vertical layers up to 75 km domain height) setup of ICON-ART. The ART extension allows for online simulation of processes affecting the dust cycle, including emissions, horizontal and vertical turbulent mixing, gravitational settling (sedimentation), deposition due to turbulent diffusion, and washout. Our work during this period includes preparations of input data, domain grids, and initialization files, as well as identifying an optimum configuration best suited for a longer simulation period.

Dust-climate interactions:

During transport, dust particles can undergo aging processes through interaction with atmospheric gases and other aerosols, forming soluble coatings and altering the dust physical and chemical properties. This changes how dust interacts with radiation and clouds and hence the dust climate effects.

A global simulation with 80km resolution (R2B05) was conducted for the 2018, including anthropogenic and biomass burning emissions of SO2, HNO3, NO, CO, CO2, CH4. MECCA chemistry was incorporated to simulate the gas species for secondary aerosol formation. To simulate dust aging, we used the new aerosol dynamics module (AERODYN) recently developed for ICON-ART. AERODYN includes soluble, insoluble, and mixed aerosol modes and aerosol dynamic processes such as nucleation, condensation and coagulation.

Fig. 2 (top) shows average dust surface concentrations in March 2018. Dust is most prevalent over desert regions, e.g. North Africa. Insoluble dust particles can become mixed when coated with soluble components during transport. The ratio of mixed to total dust indicates the aging extent. Fig. 2. Shows that aging increases significantly (from about 5 to 30%) during atmospheric transport. The shell concentrations of mixed dust (composed by H2O, sulphate, nitrate and ammonium in mixed phase) indicate interaction of dust with anthropogenic species and is pronounced, e.g. over India, central China, and Europe.

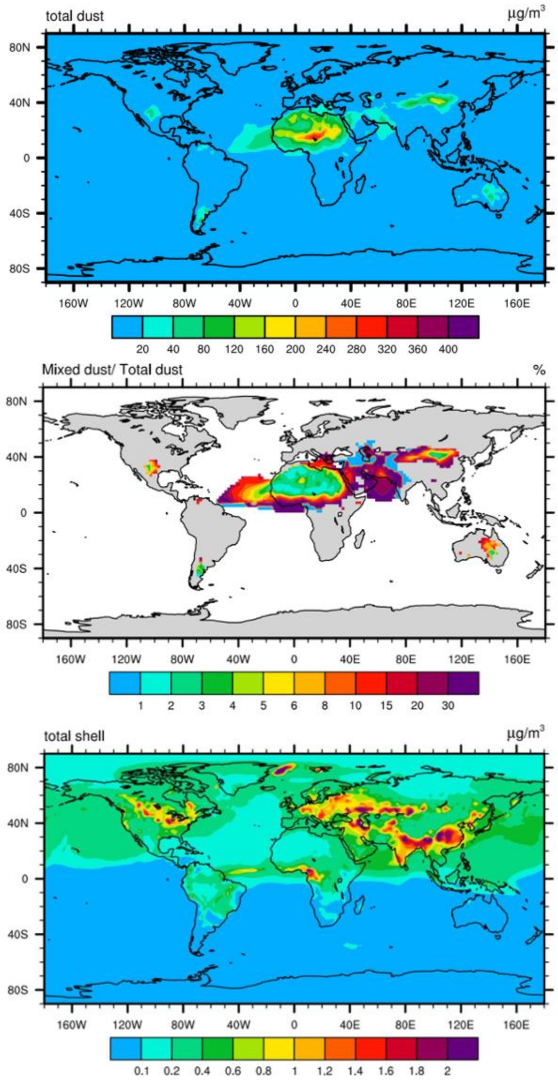

Fig. 2 Average surface concentrations of total dust (g m-3), ratio of mixed to total dust (%), and shell concentrations in the mixed dust (g m-3) during March in 2018.

Changes compared to planned work

Some changes regarding the planned work became necessary. Due to delays in hiring staff, the planned implementation of additional dust emission schemes and case studies on dust-cloud interactions are also delayed and needed to be postponed. However, as presented above, we have made very good progress on other aspects even beyond what was planned. Due to initial difficulties to configure ICON-ART for HLRE-4, the allocated resources could not be fully exploited during the first two quarters. Since then, we were able to make efficient use of the assigned resources.