Deutsches Zentrum für Luft- und Raumfahrt e.V.
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The global aerosol-climate model ECHAM5/MESSy1-MADE(soot)

M. Righi[1], V. Aquila[1], J. Hendricks[1], V. Eyring[1], A. Lauer[2], U. Lohmann[3], N. Riemer[4] and H. Vogel[5]

[1] DLR Institut für Physik der Atmosphäre, Oberpfaffenhofen, Germany - [2] International Pacific Research Center, University of Hawaii, Honolulu, USA – [3]Institute of Atmospheric and Climate Science, ETH, Zurich, Switzerland
[4]Department of Atmospheric Sciences, University of Illinois at Urbana-Champaign, Urbana, USA - [5]Institut für Meteorologie und Klimaforschung, Forschungszentrum Karlsruhe, Germany

Abstract

We present the new global aerosol model **ECHAM5/MESSy-MADE** which consists of the ECHAM5 general circulation model, coupled to the aerosol microphysics module MADE within the framework of the Modular Earth Submodel System MESSy. Aerosols are described by three log-normally distributed modes and include sulphate, nitrate, ammonium, aerosol liquid water, mineral dust, sea salt, black carbon (BC) and particulate organic matter. The model includes aerosol microphysical processes (coagulation, condensation, nucleation, wet and dry deposition etc.) as well as tropospheric aerosol precursor chemistry. As an example of application, we show the results of global simulations to characterize the impact of international shipping on aerosol, clouds and the Earth's radiation budget. An indirect aerosol radiative forcing in the range [-0.19, -0.60] W/m2 is estimated, with SO4 being the most important aerosol component from shipping. We also illustrate the new aerosol submodule **MADEsoot**, which includes separate aerosol modes to characterize BC and dust particles in their different state of mixing (internally or externally mixed) and BC and dust free aerosols, as well as the relevant aging processes of externally mixed particles. MADEsoot was implemented in ECHAM5/MESSy and applied to assess the global variation of the number concentration, size distribution and mixing state of BC and dust particles as well as the timescales of the transformation of externally mixed BC and dust into an internal mixture. A special focus is the investigation of BC and dust properties in the middle and upper troposphere since here these particles can be important agents in the formation of ice clouds.

ECHAM5/MESSy

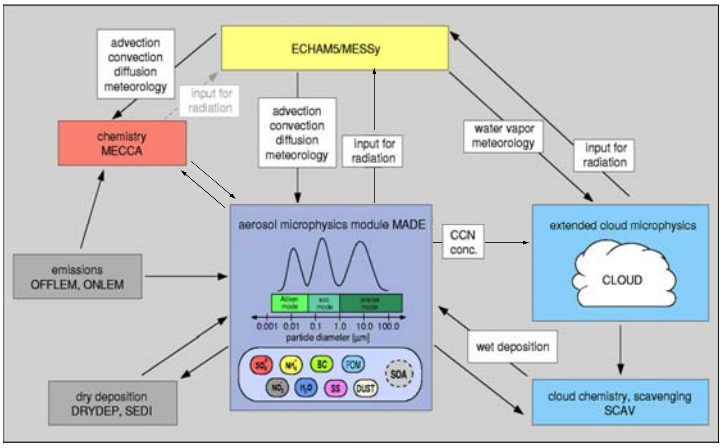
The **ECHAM5/MESSy** model is a global climate model that includes sub-models to describe physical and chemical processes of the troposphere and stratosphere. **ECHAM5** (Roeckner et al., 2006) is the core general circulation model. The **horizontal resolution** used in this work is T42, that corresponds to a cell of approximately 2.8° × 2.8°. The atmosphere up to 10 hPa is divided in 19 non-equidistant **vertical levels** with σ-p hybrid vertical coordinate. The standard ECHAM5 time step for the resolution T42L19 is 30 minutes. **MESSy** (Modular Earth Sub-model System, Jöckel et al., 2006) is the link between the sub-models and ECHAM5 and among the sub-models themselves. The model was extended with the aerosol sub-module **MADE** by Lauer et al. (2007), which was further expanded in **MADEsoot** by Aquila et al. (in prep.)

MADE

The aerosol module MADE simulates the particle **number concentration**, size distribution and chemical composition. It describes the aerosol population through three modes, depending on the particle size, under the assumption that all particles are spherical and **internally mixed**. The three modes are:

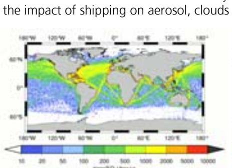
- **Aitken mode (10<d<100 nm):** composed of SO_4^{2-}, NH_4^+, NO_3^-, particulate organic matter (POM), H_2O, black carbon (BC);
- **accumulation mode (100<d<1000 nm):** SO_4^{2-}, NH_4^+, NO_3^-, POM, H_2O, BC, SS and mineral dust (DU);
- **coarse mode (d>1 μm):** H_2O, SS and DU.

In the Aitken and in the accumulation mode two mass tracers are used to keep track of the mass of hydrophilic (i.e. internally mixed) and hydrophobic (i.e. externally mixed) BC. The transfer from the internal to the external mixture is assumed to be an exponential decay with e-folding time of one day. Mineral dust is assumed to be hydrophobic. For a detailed description see Lauer et al. (2005) and Lauer and Hendricks (2006).

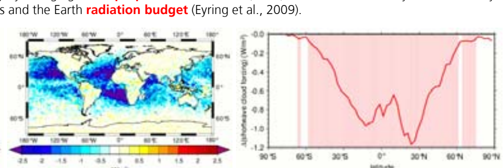


MADE ➔ Impact of international shipping

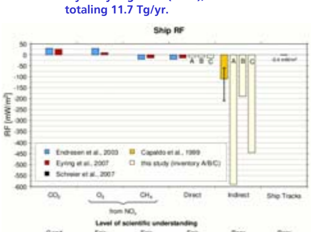
International shipping contributes significantly to the fuel consumption of all transport related activities and to the total budget of anthropogenic emissions and has been recognized as a growing problem by both policymakers and scientists. Specific emissions of pollutants such as **sulfur dioxide (SO_2)** per kg of burned fuel are higher than for road transport or aviation. Ships also emit various types of **particulate matter**. The aerosol impacts the Earth's radiation budget directly by scattering and absorbing the solar and thermal radiation and indirectly by changing **cloud properties**. Lauer et al. (2007) used ECHAM5/MESSy-MADE to study the impact of shipping on aerosol, clouds and the Earth **radiation budget** (Eyring et al., 2009).



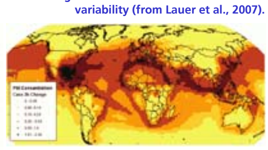
Annual emission of SO_2 from international shipping according to the inventory of Eyring et al. (2005), totaling 11.7 Tg/yr.



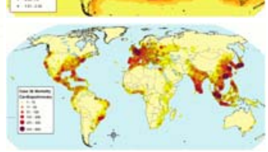
Multi-year average of simulated changes in shortwave cloud forcing due to shipping at ToA: geographical distribution (left) and zonal mean (right). Shaded areas show differences which are significant at the 99% confidence level compared to interannual variability (from Lauer et al., 2007).



Annual mean radiative forcing due to emissions from international shipping in mW/m².



Annual average contribution of shipping to $PM_{2.5}$ concentrations (in μg/m3), from Corbett et al. (2007).

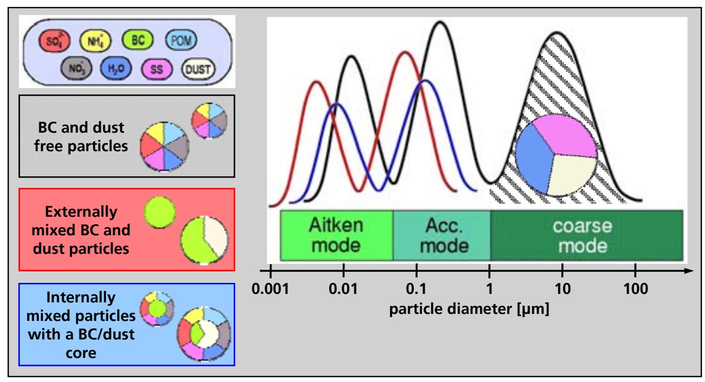


Cardiopulmonary mortality attributable to ship $PM_{2.5}$ emissions worldwide, from Corbett et al. (2007).

- With emissions of international shipping taking place both in coastal areas and open oceans their **impact on the atmosphere, climate and human health** can be significant.
- The plume processes may significantly affect the large scale distribution of chemical species in the atmosphere and effects of these **subgrid-scale processes** need to be accounted for in global models.
- If land-based emissions decrease but ship emissions continue to grow, shipping will significantly counteract the benefits derived from land-based emission reductions, in particular for sulphur emissions.
- There is clear evidence in satellite data that ship emissions directly perturb marine stratiform clouds (ship tracks). However, ship tracks are short lived and cover a very small fraction of the globe so that their radiative effect is negligible (–0.4 mW/m²). The larger scale impact of ship emissions on aerosols and clouds gives a **direct effect** in the range –0.01 to –0.038 W/m² while the **indirect effect** is larger and ranges between –0.19 to –0.6 W/m².

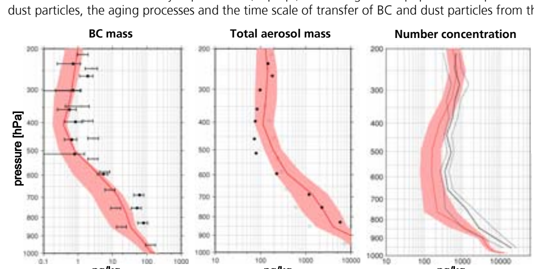
MADEsoot

MADEsoot describes the sub-micrometer aerosol population by means of 6 interacting log-normal modes. Two modes are assigned to BC and dust free particles, two to **internally mixed BC and dust** particles and two to **externally mixed BC** and dust particles. When the externally mixed BC and dust modes gain enough soluble material through coagulation with other particles, condensation of vapor and cloud processing, their mass and number concentrations are transferred to the internally mixed modes (**aging**). See also Riemer et al. (2003).

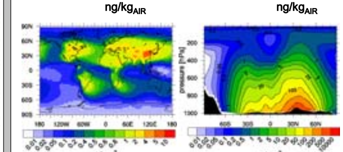


MADEsoot ➔ Potential atmospheric ice nuclei

MADEsoot has been used by Aquila et al. (in prep.) to investigate the population of potential ice nuclei (IN), particularly BC and dust particles, the aging processes and the time scale of transfer of BC and dust particles from the external to the internal mixture.

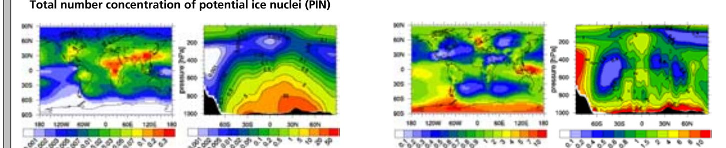


← Comparison of vertical profiles of BC mass, total aerosol mass and number concentration simulated by ECHAM5/Messy-MADEsoot and measured during different campaigns.



← Horizontal annual distribution at 300 hPa and vertical distribution of the zonal mean of the number concentration of potential ice nuclei (PIN, annual mean), of the fraction of total aerosol particles which is contributed by PIN and of the fraction of PIN which is externally mixed.

Total number concentration of potential ice nuclei (PIN)



PIN over the total aerosol number concentration — Externally mixed PIN over total number of PIN

- The number concentration of PIN in the UTLS ranges between 0.1 – 10 particles/cm³, of which between 0.1 – 1% are externally mixed.
- PIN (dust and BC) contributes to 0.02% of the total aerosol number concentration at 300 hPa and up to more than 20% at the surface.
- Coagulation, condensation and cloud processing are the most important aging processes. Condensation is the most efficient, scavenging is globally the least, but can be locally relevant.
- The aging time of externally mixed BC and dust shows large regional and seasonal variability: in the northern hemisphere amounts to 0.5 – 8 hours at surface level and up to 6 days at 250 hPa.

References

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E-Mail: Mattia.Righi@dlr.de