Project: **1393**

Project title: **Global aerosol modelling for transport and aviation research**

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The planned scientific work in Project 1393 during 2025 focused on six main scientific topics. The computing resources were already fully consumed in the first part of the year, but thanks to the relatively good availability of Levante in the remaining months it was possible to run additional experiments and address all the planned topics.

1. Shipping impact on climate under low-sulphur emission scenarios

The simulations to quantify the impact of the IMO2020 shipping regulations on air quality and climate have been completed successfully. This includes 1 experiment to quantify the impact of IMO2020 fuel sulphur content regulations on climate and air quality; 2 experiments to compare with pre-IMO conditions assuming scaled 2010 and 2000 emissions, respectively; and 2 experiments assessing two hypothetical scenarios where the IMO2020 regulations are implemented only in coastal regions and only over open ocean, respectively. Another experiment without shipping emissions was conducted as a baseline for the quantification of the effects (perturbation method).

The results showed that IMO2020 regulations lead to a loss of aerosol cooling of 67 mW m^{-2} globally, while ship-induced $PM_{2.5}$ simultaneously drop by ~60% across continents. Sensitivity simulations demonstrated that the strongest air quality improvements occur when IMO2020 regulations are enforced in coastal regions where population density is high, while open-ocean regulations have little effect on air quality. However, the largest loss of aerosol cooling is also attributable to sulphur reductions in coastal regions, where ship traffic is dense and cloud albedo highly susceptible to aerosol perturbations. Consequently, the results highlight a fundamental trade-off: efforts to reduce air pollution from shipping simultaneously lead to a substantial loss of aerosol cooling.

For further details see the Master Thesis by Isselhorst, 2025.

2. Global aerosol dataset in support of life-cycle modelling for aircraft engines

Within the DiSTAnS project (*Digital Service Twin for Aeroengines and electrified propulsion Systems*) a global highly-resolved atmospheric dataset has been provided to Rolls-Royce Deutschland to model the impact of atmospheric aerosol and other environmental factors on the wearing and corrosion of aircraft engines. The time period of the delivered datasets has been extended by another two years (2023-2024). This dataset consists of a temporally highly-resolved model output at 1h resolution for 44 selected variables (meteorological parameters, gases and aerosol).

An advanced statistical analysis of the data based on the clustering method developed by our group (Li et al. 2022), which enables a significant reduction of the data burden by clustering the data in specific regimes over different regions and altitude ranges, has been developed and extended to the 3-dimensional case accounting for all model levels. This enables a consistent definition of aerosol regimes through the atmosphere and a smooth transition of aerosol regimes, which is particularly important for the envisaged application in the aviation sector.

3. Training simulations for an aerosol response model

The original plan was to run a set of training simulations for the aerosol response model developed in the companion project 1395 (*Numerical modelling for transport research*) targeting the shipping sector. The definition of the target regions for shipping, however, took longer than expected, as different solutions were discussed during the reporting period. The computing resources were used instead to further refine the response model for road transport. Since the emissions from road transport are relatively small, this approach is limited by the large variability of the climate response. For this reason, the training simulations in project 1395 have been conducted varying the overall land-based anthropogenic emissions, under the assumptions that these are representative for the road transport emissions. To address this, we performed a set of simulations varying only the road emissions at the global scale. This allowed us to derive scaling factors between the responses to road and land-based anthropogenic emissions, which can then be used to scale the radiative forcing estimates of the response model. An additional set of simulations was performed targeting road emissions in Europe. The goal was to analyse the internal variability of the response in the road-only case (which indeed proved to be larger than the signal we want to quantify) and to explore a more advanced concept for the response model, which separates the response of aerosol number concentration from the cloud response and should enable more statistically robust quantification of the response functions by factoring out the cloud response. Preliminary analyses look promising and the concept will be further explored in the next reporting period.

4. Impact of ice-nucleating particles on cirrus cloud properties

To investigate the influence of ice-nucleating particles (INPs) on cirrus clouds we conducted combined analyses and comparisons of model simulations and observations from recent aircraft campaigns (ML-CIRRUS, CIRRUS-HL). By analysing the simulated ice-formation processes along backward trajectories originating from the measurement location, the difference between measured cirrus cloud properties between mid- and high latitudes could be attributed to the varying availability of INPs and different freezing processes. By using ice crystal measurements from convective CIRRUS-HL episodes, the model representation of convective ice crystals could be improved to reduce an bias in ice crystal number concentrations compared with various observational data sets. For further details see De La Torre Castro et al., 2025.

5. Improved representation of secondary organic aerosol particles

The representation of secondary organic aerosol (SOA) in EMAC (MADE3) has been improved by including a nucleation parametrization for the formation of particles from organic precursor vapours, according to the scheme by Riccobono et al. (2014). In addition to biogenic precursors, e.g. natural terpenes emitted by vegetation, anthropogenic SOA precursors, e.g. benzene, toluene, or xylene emitted by the combustion of fossil fuels, have been included using state-of-the-art emission inventories (e.g. EDGAR, CEDS). The condensation and nucleation schemes have been adapted to also represent the condensation of these anthropogenic vapours on pre-existing particles and their contribution to new particle formation. Test simulations and first evaluation runs for the new SOA scheme have been performed in order to analyse the effect on the model quality when comparing against a variety of observational data. First results show an improved agreement with particle number concentrations measured during the EMERGE campaign.

6. Model development for the transition of EMAC to ICON and towards GPU capabilities

Model development concerning infrastructural changes of the MADE3 submodel has been performed for the future transition to the new base-model ICON. The development focused on the capability to use GPUs to run the model. First test simulations of the new configuration have been performed with the current aerosol setups and the base-model EMAC. A new model setup for the application with ICON will be developed in the next reporting period to test the implemented functionalities in an actual ICON/GPU simulation.

7. Data management

The simulation data from two projects (DLR-project Eco2Fly and EU-project ACACIA) have been submitted for transfer to the long-term archive Doku, as planned.