Project: **1395**

Project title: **Numerical modelling for transport research**

Principal investigator: **Johannes Hendricks**

Report period: **2023-11-01 to 2024-10-31**

## Summary

| Experiment | Status |
|---|---|
| Hydrogen | **Not carried out** due to unexpected announcement of EC funding for a 12-party project on hydrogen emission effects. Thus, instead of running the experiment, the focus was on project and simulation planning with partners. The experiment is now re-planned for 2025. |
| ELK emissions | Test experiments with the emission inventories for the transport sectors from the ELK project were **carried out successfully**. |
| Response model aerosol | **Parts of the requested experiments carried out:** Due to the reduced computing resources, the focus was on simulations on the impact of land-based transport emissions. Two approaches were applied: the linearized model approach (simulations have been completed) and the perturbed parameter ensemble (PPE) approach (simulations have been completed for two regions and are to be continued in 2025). Simulations on the impact of international shipping using the PPE approach have only been run for a few test cases and will be performed in 2025 in the context of DKRZ Project 1393, which has a more specific focus on aerosol effects of shipping. |
| Response model gas phase | **Not conducted** as the "Response model aerosol" experiment should first be completed in order to serve as a template. Instead, we derived ERF efficiencies for the effects of ship emissions from former simulations in DKRZ Project 80 to use in the next step of TransClim development. This is regarded as a temporary solution which needs to be replaced in the medium term. |

## Detailed report

### Experiment “Hydrogen”

DLR needs a configuration of the chemistry-climate model system EMAC to simulate transportation-related effects of hydrogen leakage. We had planned to start the development of such a configuration as part of the DLR scientific project “MoDa” (Models and Data for Future Mobility_Supporting Services) in 2024. In January, however, we unexpectedly received good news regarding funding from the EC for the project “HYway” (Climate impacts of a HYdrogen economy: the pathWAY to knowledge), which started in September with 11 partners (7 other global models). (The proposal was rejected in July 2023, but had been put on the reserve list.)

Hence, instead of running the experiment on transportation-related effects of hydrogen leakage, the actual focus was on project and simulation planning with partners in the project HYway. The preparations for the project required personnel resources that would otherwise have been free for model development. We found it reasonable to wait for the discussions with the modeling partners to avoid double work and take advantage of the overlap of the two projects. We have now prepared a roadmap for model development and plan to begin soon with the first simulations (see project proposal for 2025).

### Experiment “ELK Emissions”

In the context of the DLR impulse project ELK (*EmissionsLandKarte*), new emission inventories for land-based transport, shipping and aviation have been generated using a bottom-up approach supplied with data from many different sources, including observations. During the reporting period, the beta version of this data was made available and, as part of a quality-control procedure, it was tested in the global model EMAC (in the configuration by Righi et al., 2023, with the aerosol sub-model MADE3). The goal was to prove the technical usability of the data in atmospheric models. This is important, since the atmospheric modelling community is one of the target groups for these inventories and significant efforts have been invested in the ELK project to ensure data usability in models, including standard data formatting following common conventions and data documentation with metadata. Some of the resources in this project were also used for the analysis of the ELK emission data and the comparison with other well-established inventories (such as CEDS/CMIP6, CAMS-GLOB and EDGAR8). A publication documenting the ELK inventories is currently in preparation for the Journal “Earth System Science Data”.

**Experiment “Response model aerosol”**

In order to develop aerosol response functions for the climate response model TransClim (Rieger and Grewe, 2022), a large number of training simulations has been performed to characterize the aerosol radiative forcing as a function of the emissions of four aerosol and aerosol precursor species, namely $NO_x$, $SO_x$, black carbon (BC) and organic carbon (OC). During the reporting period, the focus was on the climate impact of land-based transport emissions. To assess the climate impact of this sector, emission variation experiments were performed for five regions of interests: Europe, Asia, North America, South America, and Rest of the World. These variation experiments were realized by scaling the anthropogenic emissions of the four aforementioned species in each of these regions. Note that scaling the anthropogenic emissions, instead of the land-based transport emissions only, is required in order to obtain statistically significant results.

Two approaches were tested. First, we used a linearized approach to estimate the aerosol radiative forcing induced by emission perturbations by varying the emissions of one species at a time. We applied five emission scaling factors (0%, 25%, 50%, 150% and 200%) to each species, calculated the resulting radiative forcings and derived linear fitting functions for the radiative forcing as a function of the emission level for each species and region. This required performing 25 simulations (five scaling factors times four species plus one with all species varied simultaneously as a closure test) for each region. This resulted in 125 simulations in total. These simulations have been completed and assessed during the reporting period. The resulting response functions were then evaluated against the results of Righi et al. (2023), i.e. using the response functions to reproduce the global land-based transport effect quantified in that study. The agreement was fairly good, although the linearized approach underestimated the effect by about 20%.

To improve this and to further investigate the non-linearities in the aerosol response to land-based transport emissions, a more advanced approach has been designed and tested. This is based on the perturbed parameter ensemble (PPE) method and, unlike the linearized method, considers the variation of the emissions of all four species simultaneously in a multi-dimensional (in this case four dimensional) parameter space. The model simulations required to properly sample the parameter space are defined using the Latin Hypercube method (McKay et al. 1979), which generates evenly distributed values of the four parameters using a given number of realizations. Here, we used 40 realizations, thus requiring 40 simulations for each region and 200 simulations in total for the five regions. Two regions (Europe and Asia, i.e. 80 simulations) could be completed during the reporting period. The results look promising, so we plan to continue with the experiments for the remaining three regions in 2025. The simulation design with the PPE method was realized during Q1/24, together with some short tests. Therefore, no production simulations could be started until Q2/24, resulting in expired resources in the first quarter.

**Experiment “Response model gas phase”**

This experiment was not conducted as the "Response model aerosol" experiment should first be completed in order to serve as a template. Instead, we derived ERF efficiencies for emissions from international shipping, i.e. the effective radiative forcing resulting from a given amount of emissions of specific emission components, based on former simulations of shipping effects carried out in DKRZ Project 80. These ERF efficiencies will be applied as a provisional solution in first test applications of the TransClim model to assess maritime transport impacts. However, the ERF efficiencies represent a simplified linear approach based only on $NO_x$ emissions. Nonlinearities and emissions of other species cannot be represented. To replace this approach by a more advanced method, we plan to perform variation studies in analogy to the development of the aerosol response model in 2025.

## References

McKay, M. D., Beckman, R. J., and Conover, W. J.: A Comparison of Three Methods for Selecting Values of Input Variables in the Analysis of Output from a Computer Code, Technometrics, 21, 239-245. 1979.

Rieger, V. S., and Grewe, V.: TransClim (v1.0): a chemistry–climate response model for assessing the effect of mitigation strategies for road traffic on ozone, Geosci. Model Dev., 15, 5883–5903, https://doi.org/10.5194/gmd-15-5883-2022, 2022.

Righi, M., Hendricks, J., and Brinkop, S.: The global impact of the transport sectors on aerosol and the resulting climate effects under the Shared Socioeconomic Pathways (SSPs), Earth Syst. Dynam., 14, 835-859, https://doi.org/10.5194/esd-14-835-2023, 2023.