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| Project: | 1033 |
| Project title: | Luftverkehr, Zirruswolken und Klima |
| Project leader: | Dr. Ulrike Burkhardt (DLR-Institut für Physik der Atmosphäre) |
| Report period: | 01.01.2026 - 31.12.2026 |

## 2.1 Climate impact of contrails for new eco-friendly forms of propulsion

The project investigates the climate impact of contrail cirrus caused by new forms of propulsion and, therefore, contributes to the evaluation of mitigation strategies.

### 2.1.1 Contrail cirrus climate impact for liquid hydrogen combustion (H2C)

*Responsible: Weiß-Rehm (b309218), Burkhardt (b309022)*

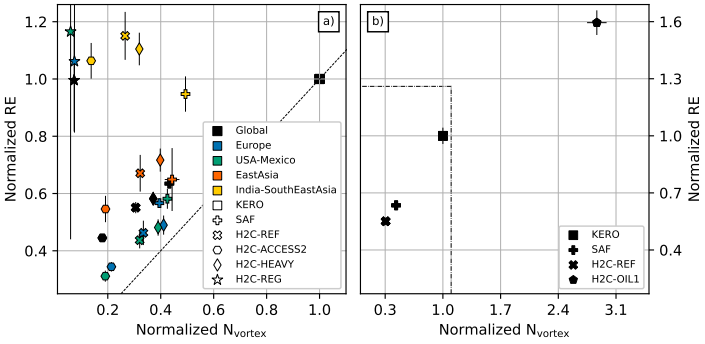



Figure 1: Normalized radiative effect over normalized initial ice crystal number $N_{vortex}$ for powering aircraft with kerosene, 100 % SAF and liquid hydrogen combustion for different regions.

We used the newly implemented ice nucleation parameterization [Zink et al., 2026], in ECHAM5-CCMod to expand our analysis of the contrail cirrus radiative effect when using H2 combustion (H2C-REF). We ran sensitivity simulations for changed background aerosol concentrations (H2C-ACCESS2), for a different aircraft mass (H2C-HEAVY), for different SSP emission scenarios and for air traffic vertically shifted by a few flight levels for both medium-range and regional air traffic. As recent measurements within aircraft plumes have shown that lubrication oil droplets lost from the engine may have an impact on contrail ice nucleation, we also performed simulations for an lubrication-oil-dominated nucleation process (H2C-OIL1). Finally, a number of simulations had to be repeated in order to improve the dependency of ice nucleation on the fuel flow into the engine and the pre-mixing of the exhaust with environmental air before emission. Our results show that the contrail cirrus radiative effect for 2050 decreases for our reference H2C case, assuming ice nucleation on ambient aerosols only, compared to kerosene and 100% SAF (Fig. 1a). For the lubrication-oil-dominated ice nucleation the radiative effect increases due to the increase in the initial ice crystal number (Fig. 1b). This emphasizes that the exact location of the venting of engine lubrication oil has a very large impact on contrail cirrus properties and radiative effect and needs to happen as far away from the exhaust plume as possible. A publication covering a detailed comparison of the effects of the reduction in contrail ice nucleation is published in Weiß-Rehm and Burkhardt [2026]. The study covering our results on H2 combustion and the ice nucleation on entrained ambient aerosols and oil droplets is currently in internal review (Weiß-Rehm et al., to be submitted).

### 2.1.2 Contrail cirrus climate impact of Fuel cell (H2FC) propulsion

*Responsible: Weiß-Rehm (b309218), Burkhardt (b309022)*

In this sub-project, we analyze the climate impact of contrail cirrus induced by fuel cell propulsion (H2FC), that may be used for regional aircraft (REG), for the year 2050. We evaluated the newly implemented AI-based ice nucleation parameterization in ECHAM5-CCMod further, ran sensitivity simulations and compared the results for the new fuel cell design to

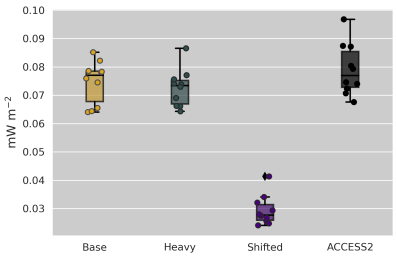



Figure 2: Inter-annual variability of contrail cirrus radiative effect for the new H2FC design and three sensitivity simulation for an increased aircraft mass (heavy), downwards shifted air traffic (shifted) and a decreased background aerosol concentration (ACCESS2).

kerosene, SAF, liquid hydrogen combustion (H2C) and the previous fuel cell design. The new fuel cell design results in a reduced ice crystal number relative to Kerosene, SAF, H2C and the old fuel cell design. But since the contrail formation probability is higher, the decrease in the radiative effect due to the decrease in the initial ice crystal number is compensated by the increase in the radiative effect due to the increased probability of persistent contrail formation. The contrail cirrus radiative effect of regional air traffic appears to be lowest for SAF. We conducted several sensitivity simulations for the new fuel cell design with respect to aircraft mass (Heavy), a shift of air traffic to lower atmospheric levels (Shifted) and an adaption of the entrained background aerosol concentration towards in-flight observations (ACCESS-2), resulting in a reduction in the background aerosol number concentration. As regional air traffic is only a small subset of all air traffic and associated flight levels are low so that the contrail formation probability is small, the sensitivity simulations showed no significant differences except for the significant decrease in the radiative effect connected with the shift in air traffic to lower atmospheric levels (Fig. 2).

### 2.1.3 GCM simulations for development of a statistical response model

*Responsible: Burkhardt (b309022)*

After the evaluation of dedicated flight campaign data, the ice nucleation parameterization had been supposed to be updated in project bd0832 and then used within this subproject to perform simulations needed to set up a statistical response model OpenAIRCLIM (project bd1062). After the flight campaign, it was decided that a quick update of the ice nucleation parameterization was not possible, as further basic research is needed. Therefore, we could not perform the simulations for the development of OpenAIRCLIM and the associated computing time was not used.

## 2.2 Impact of sedimenting contrail ice on liquid cloudiness

*Responsible: Verma (b309131), Burkhardt (b309022)*

The BMBF-Lufo project was again delayed by the ministry and the postdoc that had been expected to do the work had to leave. The computing time was not used. The new project start is now planned for the beginning of 2027. We will therefore apply again for the computing time connected with this sub-project in next years proposal. Nevertheless, we managed to do the revisions for our last paper using the ICON-LEM model that is coupled with our new contrail scheme [Verma and Burkhardt, 2026]. Some computing time was used for this revision.

# References

P. Verma and U. Burkhardt. Contrail formation within cirrus: Contrail induced perturbations and cirrus adjustments. *Journal of Geophysical Research: Atmospheres*, 131(8):e2025JD045269, 2026. doi: https://doi.org/10.1029/2025JD045269.

C. Weiß-Rehm and U. Burkhardt. Regional and seasonal variability in decreasing contrail cirrus cloudiness using sustainable aviation fuel. *Journal of Geophysical Research: Atmospheres*, 131(16):e2026JD046500, 2026. doi: https://doi.org/10.1029/2026JD046500.

C. Weiß-Rehm, U. Burkhardt, J. Zink, S. Unterstrasser, C. Renard, M. Righi, and C. Weder. Liquid hydrogen combustion reduces contrail cirrus radiative effect. To be submitted.

J. Zink, C. Weiß-Rehm, S. Unterstrasser, and U. Burkhardt. Contrail formation for aircraft with hydrogen combustion – part 3: A neural-network-based parameterization of ice crystal number. *EGUsphere*, 2026:1–29, 2026. doi: 10.5194/egusphere-2026-1088.