Project: 1033
Project title: Luftverkehr, Zirruswolken und Klima
Project leader: Dr. Ulrike Burkhardt (DLR-Institut für Physik der Atmosphäre)
Report period: 01.01.2025 - 31.12.2025

2.1 Klimawirkung von Kondensstreifen für neue umweltfreundliche Antriebsformen

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

2.1.1 Liquid hydrogen combustion (H2C)

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

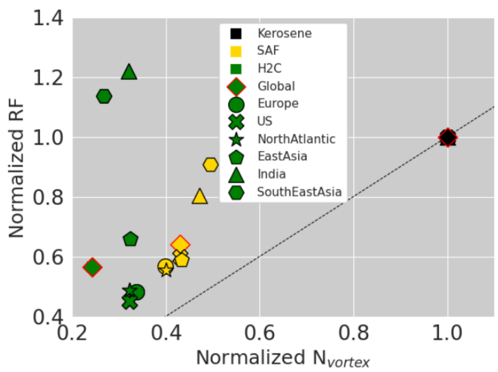

Figure 1: Normalized radiative effect over normalized initial ice crystal number N_{vortex} for powering aircraft with conventional kerosene (black), 100 % SAF (yellow) and liquid hydrogen combustion (green) for different regions .

We implemented a new ice nucleation parameterization (Zink et al., 2025, Zink et al., in prep.) in ECHAM5-CCMod to calculate ice nucleation in contrails when using H2 combustion. As H2 combustion does not emit soot, we assume that nucleation happens on ambient mixed-in aerosols only. We performed simulations for several fuels, kerosene, 100% sustainable aviation fuel (SAF) and H2C, and run several sensitivity simulations varying the background aerosol concentration and adapting towards measurements. We found, that the use of H2C decreases the contrail cirrus radiative forcing relative to the use of kerosene and SAF significantly except in tropical regions where H2C might lead to an increase in the radiative effect Fig. 1, mostly due to the higher contrail formation probability. The contrail cirrus radiative effect when using H2C is only slightly sensitive to changes in ambient aerosol concentrations. Publications covering our results are currently in work (Weiß-Rehm and Burkhardt, in prep.).

2.1.2 Brennstoffzelle (H2FC)

Responsible: Bickel (b309139), Verma (b309131), Burkhardt (b309022)

In the first quarter of the year we ran many simulations estimating the contrail cirrus RF when using fuel cells in regional air traffic. The results showed that depending on the fuel cell design and its emissions the contrail ice nucleation may be as high as for kerosene or significantly reduced. As a result a new design of a fuel cell was introduced. Accordingly, we implemented a new AI-based ice nucleation parameterization within ECHAM5-CCMod, consistent with reduced water emissions and no emission of water droplets. Despite the large reduction in the contrail ice nucleation, the radiative impact of contrail cirrus connected with the new fuel cell design is of a similar magnitude to that of conventional fuels (Figure 2). This is due to two competing processes: Connected with the fuel cell emissions,

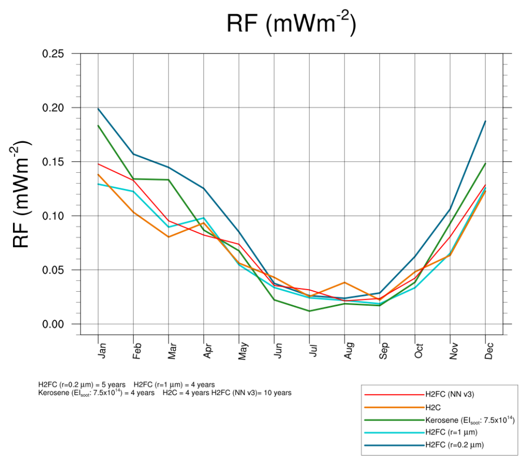

Figure 2: Annual cycle of Radiative Forcing for different propulsion systems.

the contrail formation probability is larger for the fuel cell than for kerosene leading to a larger contrail cirrus coverage. Furthermore, the ice nucleation rate is lower leading to a lower optical depth. The increase in coverage has a large impact when evaluating the climate impact of contrail cirrus from regional air traffic as regional air traffic happens at low altitude where contrail formation conditions are seldomly met when using kerosene as a fuel. A comparison with previous fuel cell simulations reveals that the contrail cirrus radiative forcing connected with the newly designed fuel cell is comparable to that of the earlier fuel cell design assuming droplet emission of 1 µm.

2.1.3 GCM simulations for development of a statistical response model

Responsible: Burkhardt (b309022)

Based on the work within subprojects 2.1.1 and 2.1.2, we performed simulations with ECHAM5-CCMod to determine contrail cirrus properties and associated radiative forcing that are used to build the statistical response model AirCLIM within DKRZ-project 1062. The simulations were run for SMR (short and medium range) air traffic using H2C propulsion and for regional air traffic using H2C and fuel cell propulsion. We varied the amount of air traffic in order to explore the saturation in contrail cirrus properties with the ever increasing amount of air traffic.

2.2 Estimation of the climate impact of contrail avoidance

Responsible: Verma (b309131), Burkhardt (b309022)

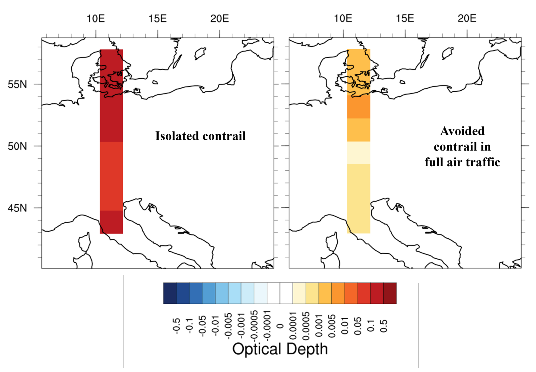

Figure 3: Optical depth of a single isolated contrail (left) and a contrail formed in a full air traffic background (right).

In this sub-project, we investigate the impact of flight rerouting on contrail cirrus properties. We conduct simulations with ECHAM5-CCMod for three different flight inventories containing: a) a single flight, b) full air traffic, and c) full air traffic plus the single flight from (a). We compare the properties of the contrail formed in a contrail-free background (case a) with the avoided contrail with high background air traffic area (case c – b). The isolated contrail experience relatively higher ice supersaturation compared to contrails forming within pre-existing contrail fields. This results in higher ice number concentrations, ice water content, a larger ice water path, and consequently, large optical thickness (Figure 3). In contrast, contrail formed in regions with pre-existing contrails will compete for available water vapor, leading to a lower ice water path and a different further development. This points at a bias in the evaluation of contrail mitigation efforts that commonly assume that the climate impact of the avoided contrail can be estimated while ignoring the contrail cirrus from the background air traffic.