Effective Radiative Forcing of Contrail Cirrus
Michael Ponater, Marius Bickel, Lisa Bock, Svenja Reineke and Ulrike Burkhardt

Aviation Climate Impact
Aviation impacts on global climate by CO₂ increase from fuel burning but also by non-CO₂ emission components (NOx, H₂O aerosols). Exact quantitative knowledge on each contribution is necessary to assess the mitigation potential of operational or technological measures (e.g., alternative fuels, flight route optimization). The relative importance of the various contributions is generally given in terms of the respective radiative forcing (RF), or by metrics derived from RF like the global warming potential.

Contrail Cirrus: Radiative Forcing and Effective Radiative Forcing
Effective radiative forcing (ERF) can be estimated via simulations with fixed sea-surface temperature (Shine et al., 2003). It includes rapid feedbacks (adjustments) to the forcing. ERF has considerably higher statistical uncertainty in comparison to the classical RF (ΔRF). Hence, in the contrail case scaling of the forcing is necessary to quantify ERF.

The increase of both RF and ERF is damped for larger scaling of air traffic, as a consequence of saturation effects. ERF of contrail cirrus is significantly lower compared to its RF.

CO₂ simulations (red) were designed to fit the RF of contrail cirrus (blue). ERF is more strongly reduced for contrail cirrus than for CO₂. Obviously, rapid adjustments are working differently (and more efficiently) for contrail cirrus.

Some more simulations are necessary (and underway) to ensure the validity of these conclusions for unscaled contrail cirrus.

Efficacy of Line-shaped Contrails
Radiative forcing, temperature response, and climate sensitivity
RF is linked to equilibrium global surface temperature change ΔT due to the climate sensitivity parameter λ. Non-CO₂ radiative forcings such as contrails are said to have reduced or enhanced efficacy r, if the surface temperature response per unit radiative forcing (i.e., λ) is smaller or larger than the reference climate sensitivity parameter λ₀ (Hansen et al., 2005):

\[ ΔT = λ \cdot RF = r \cdot λ₀ \cdot RF = λ₀ \cdot ERF \]

There are several studies indicating that line-shaped contrails have substantially reduced efficacy (Ponater et al., 2005; Rap et al., 2010). It is unknown whether this is true for contrail cirrus as well. The feedbacks causing this deviation from CO₂-related RF are not known either.

Radiative Forcing of Contrail Cirrus

2006
RF = 0.05 W/m²

2050
RF = 0.16 W/m²

Contrail Cirrus: Radiative Forcing and Effective Radiative Forcing

Explaining Efficacy Variations by Feedback Analysis
The physical origin of ERF and efficacy deviations will be investigated using complete radiative feedback analysis (or radiation adjustment, respectively) later in the project. This method has shown promising results in an attempt to explore the reasons for reduced efficacy of ozone precursor (NOx and CO) emissions (picture left).

Preliminarily, rapid adjustments (ΔRF) to both types of forcing have been calculated for the simulations shown above (example for 12xair traffic, +65ppmv CO₂ below)

Non-Linearities Involved in Contrail Cirrus Scaling
Non-linearity due to saturation damping mainly occurs for contrail cirrus cover, most strongly in regions with high air traffic already in the reference (unscaled 2050) simulation. Optical depth per unit coverage, in contrast, increases with scaling as ever more emitted aerosols compete for the available ambient supersaturated water vapour, reducing mean ice crystal size (Bock and Burkhardt, 2016a). Both effects impact on RF and ERF. RF per unit coverage is higher at tropical than at mid latitudes due to different optical depth and shortwave longwave compensation, which also affects the RF scaling behaviour.

Deutsches Zentrum für Luft- und Raumfahrt e.V.
Institut für Physik der Atmosphäre
http://www.dlr.de/ftp/a