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Effective Radiative Forcing of Contrail Cirrus

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Aviation Climate Impact

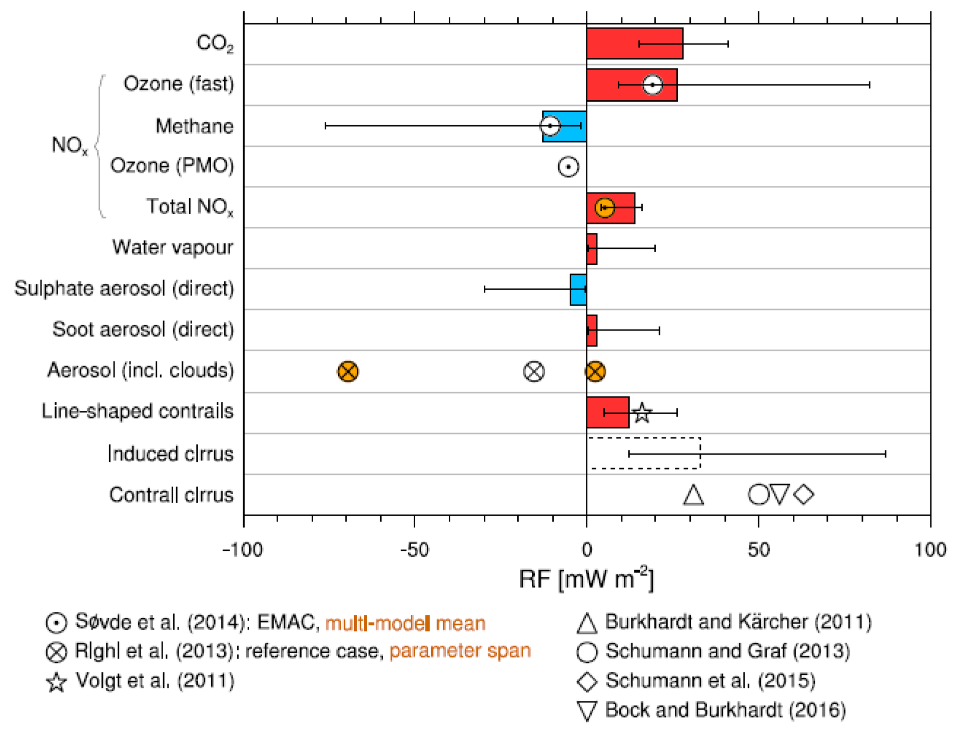


Figure: Aviation induced radiative forcing from different impact components, according to Grewe et al., 2017.

Aviation impacts on global climate by CO_2 increase from fuel burning but also by non-CO_2 emission components (NO_x, H_2O, 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 by the respective radiative forcing (RF), or by metrics derived from RF like the global warming potential.

Contrail Cirrus, i.e. long-lived persistent contrails that have lost their initial line-shaped structure, probably forms the largest individual RF component to total aircraft climate impact (Lee et al., 2009; Burkhardt and Kärcher, 2011).

Efficacy of Line-shaped Contrails

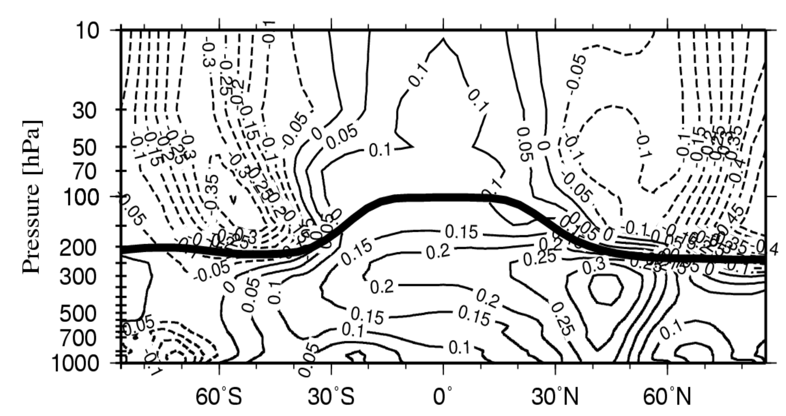
Radiative forcing, temperature response, and climate sensitivity

RF is linked to equilibrium global surface temperature change ΔT_S via the climate sensitivity parameter λ.

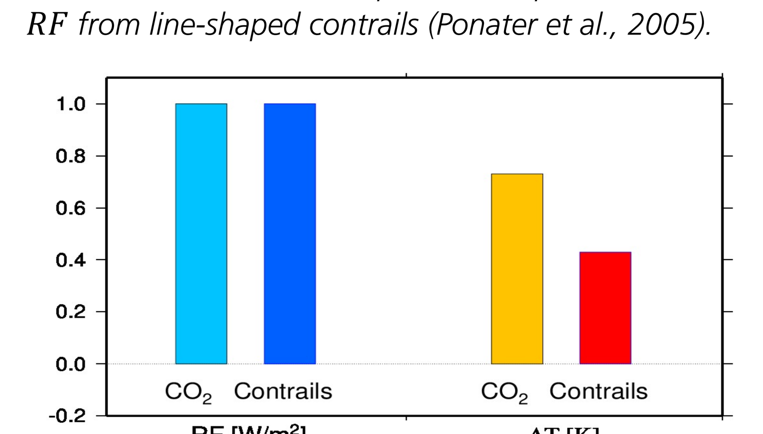
Non-CO_2 radiative forcings such as contrails are said to have reduced or enhanced efficacy r, if the surface temperature response per unit radiative forcing (i.e, λ) is smaller or larger than the reference climate sensitivity parameter λ_{CO_2} (Hansen et al., 2005):

$$\Delta T_S = \lambda \cdot RF = r \cdot \lambda_{CO_2} \cdot RF = \lambda_{CO_2} \cdot ERF$$

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 CO_2-related RF are not known either.

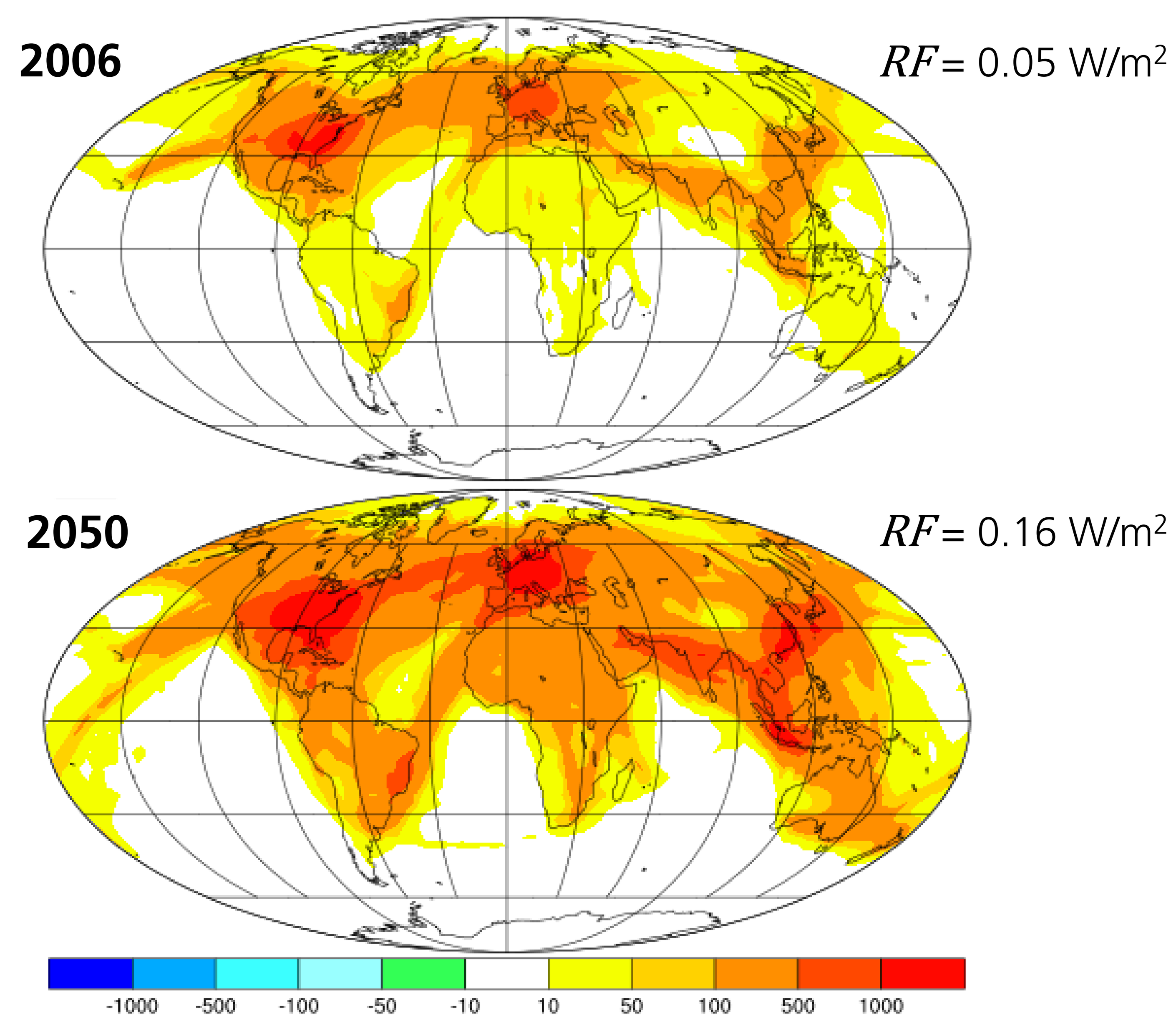


Simulated zonal mean temperature response to scaled RF from line-shaped contrails (Ponater et al., 2005).



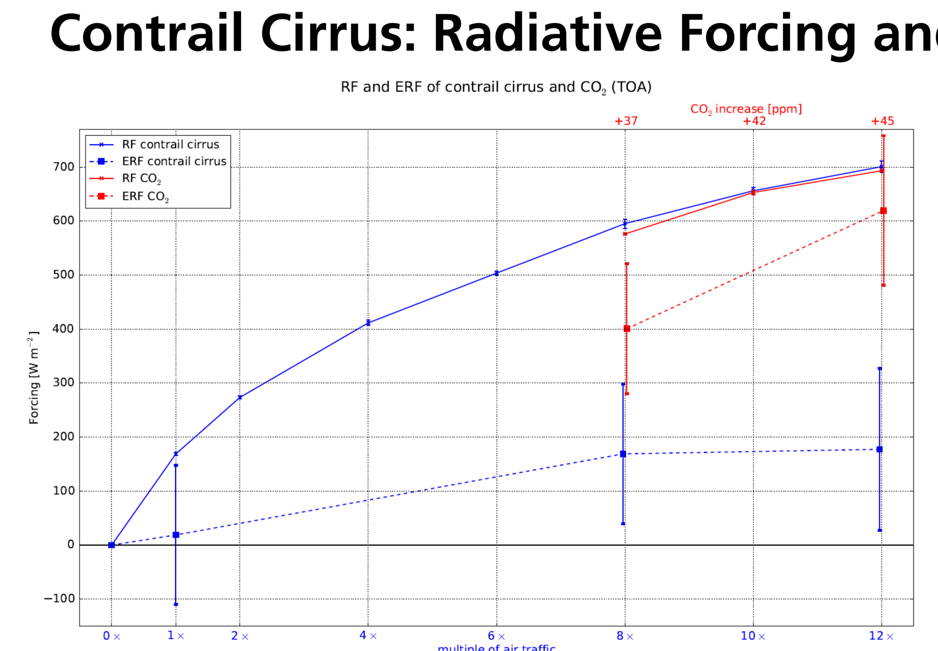
Efficacy of line-shaped contrails is reduced to about 60%, according to Ponater et al. (2005).

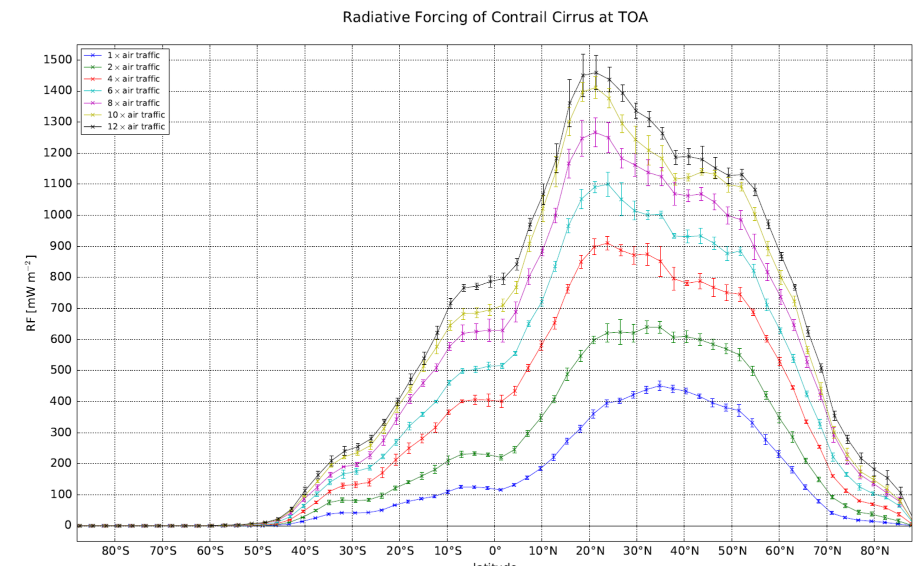
Radiative Forcing of Contrail Cirrus



Bock and Burkhardt (2016a, b) have developed a parameterization of contrail cirrus in the framework of the ECHAM5 climate model (Roeckner et al., 2003). Contrail cirrus RF has been estimated from aircraft emissions inventories for 2006 and 2050. This model can be used for simulations aiming at determination of the effective radiative forcing (ERF) and the efficacy (r) of contrail cirrus.

Contrail Cirrus: Radiative Forcing and Effective Radiative Forcing





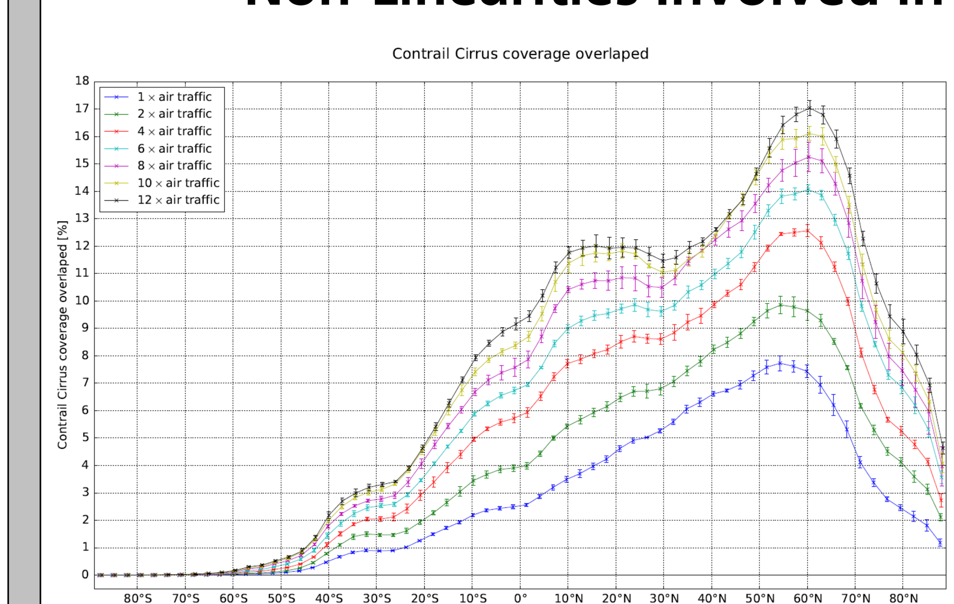
Effective radiative forcing (ERF,■) can be estimated via simulations with fixed sea-surface-temperature (Shine et al., 2003). It includes rapid feedbacks (adjustments) to the forcing. ERF has considerably higher statistical uncertainty in comparison to the classical $RF(\mathbf{x})$. Hence, in the contrail cirrus case scaling of the forcing is necessary to quantify ERF.

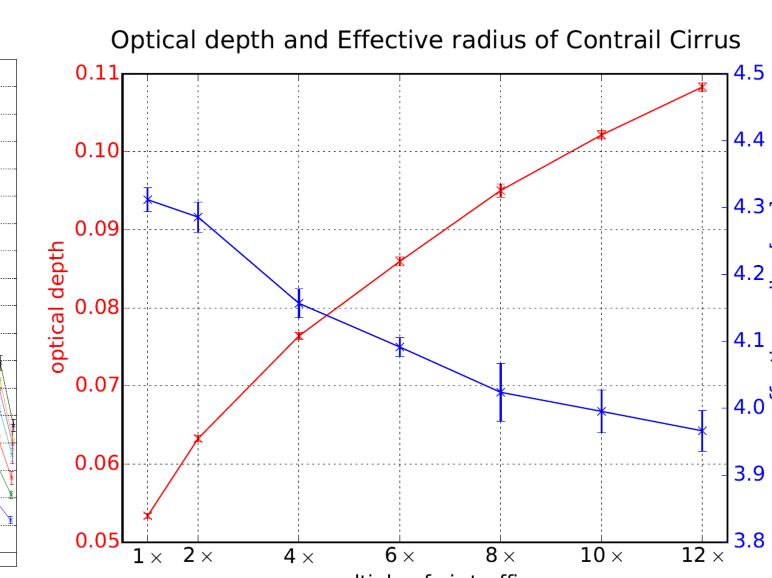
The increase of both RF and ERF is damped for larger scaling of air traffic, as a consequence of saturation effects. **ERF of contrail cirrus is significantly lower compared to its RF.**

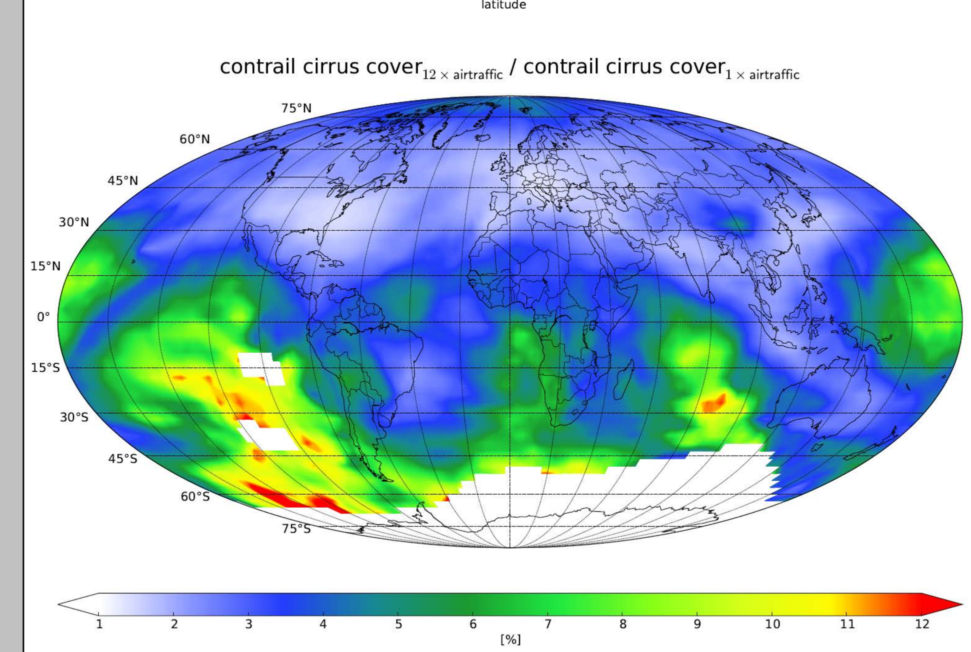
CO_2 simulations (red) were designed to fit the RF of contrail cirrus (blue). **ERF is more strongly reduced for contrail cirrus than for CO_2.** Obviously, rapid adjustments are working differently (and more efficiently) for contrail cirrus.

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

Non-Linearities Involved in Contrail Cirrus Scaling

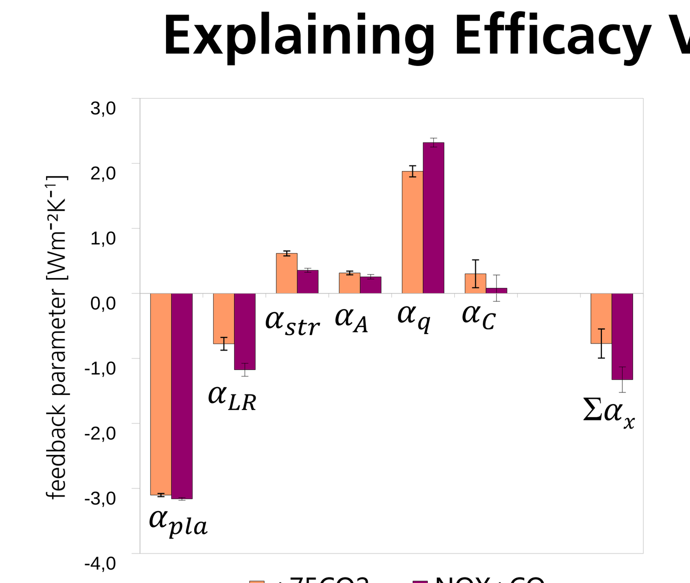






Non-linearity due to saturation damping mainly occurs for contrail cirrus cover, most strongly in regions with high air traffic already in the reference (unscaled 2050) simulation. Optical depth per unit coverage, in contrast, *increases* with scaling as ever more emitted aerosols compete for the available 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.

Explaining Efficacy Variations by Feedback Analysis



Partial radiative perturbation (PRP) feedback analysis (e.g., Rieger et al. 2017)

$$\alpha = \sum_x \alpha_x = \sum_x \frac{\Delta R_x}{\Delta T_S}$$

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

Preliminarily, rapid adjustments (ΔF) to both types of forcing have been calculated for the simulations shown above (example for 12xair traffic, +45ppmv CO_2, below):

	Contrail Cirrus	CO_2	
all-sky ΔF	−0.52 ± 0.15	−0.07 ± 0.09	W/m^2
clear-sky ΔF	+0.04 ± 0.07	+0.08 ± 0.08	W/m^2
cloudy-sky ΔF	−0.56 ± 0.15	−0.15 ± 0.11	W/m^2

It is indicated that **contrail cirrus ERF is substantially diminished by induced rapid adjustments from natural clouds**, while net clear-sky adjustment is small.

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