Contrail Cirrus in EMAC

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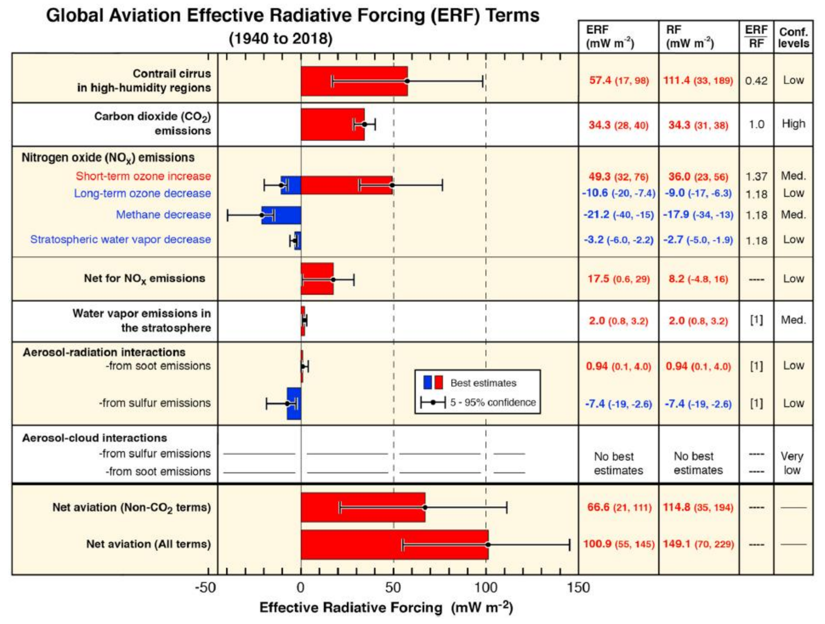
Climate Impact of Air Traffic



Lee et al. (2020)

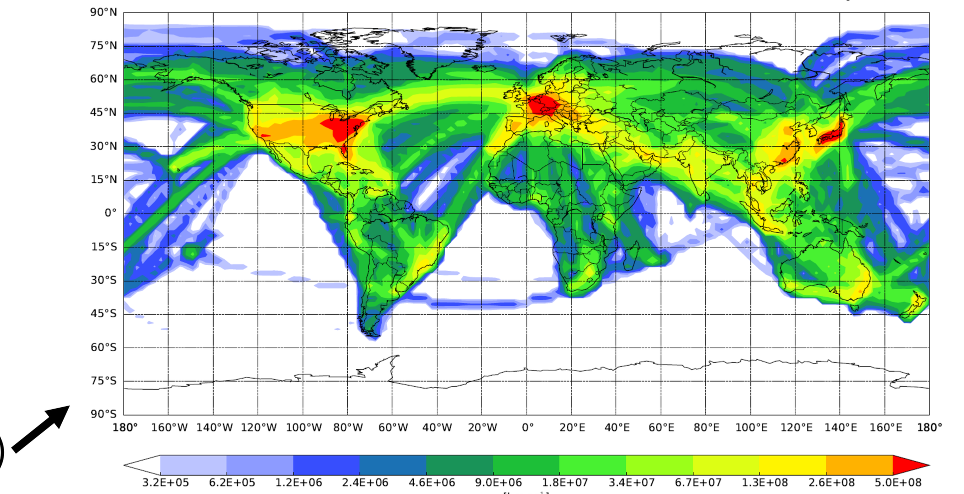
Air traffic affects the global climate mainly through contrails, CO_2 and NO_x emissions. Overall contrail cirrus is regarded to be the largest contributor to aviation induced climate impact (Burkhardt and Kärcher, 2011). Contrail cirrus develops from line-shaped contrails which spread over large areas when the ambient air is cold and humid enough.

Here we present results from fixed sea surface temperature simulations (FSST) and mixed layer ocean simulations (MLO) to derive various types of radiative forcings and surface temperature changes. The simulations were further decomposed by feedback analysis to gain a full understanding of the global climate impact of contrail cirrus.

Contrail Cirrus implementation in EMAC

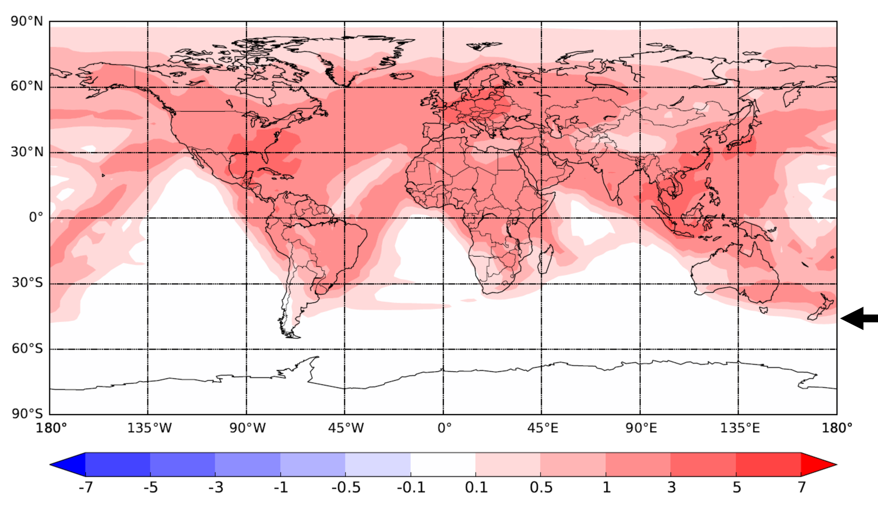
The very recent contrail cirrus parametrization (CCMod) by Bock and Burkhardt (2016a+b), which was originally developed for ECHAM5, has been adopted for EMAC. It has been implemented in the Kuebbeler (2014) cloud module and is completely namelist controlled. CCMod will be available in a future EMAC/MESSy release.

The main feature of CCMod is its microphysical two momentum scheme which means that ice water content (IWC) and ice crystal number concentration (ICNC) are both simulated. During formation contrail cirrus competes with natural clouds for ambient water vapor. Contrail cirrus cover, IWC and ICNC are described as tracers and affected by advection and vertical diffusion. CCMod uses air traffic water vapor emissions and track distance as input. Here we use the AEDT air traffic inventory for the year 2050 (Wilkerson et al. 2010). CCMod was adapted to work with MADE3 aerosols instead of ECHAM-HAM, used in ECHAM5. The re-implementation of the saturation adjustment was needed for consistent embedding of contrail cirrus in K14.



2050 air traffic data set (Wilkerson et al. 2010)

Radiative Forcings



Simulations with Fixed Sea Surface Temperature (FSST) were performed to determine the radiative impact of contrail cirrus. In total three types of Radiative Forcings (RF) were calculated for a 12× scaling of air traffic:

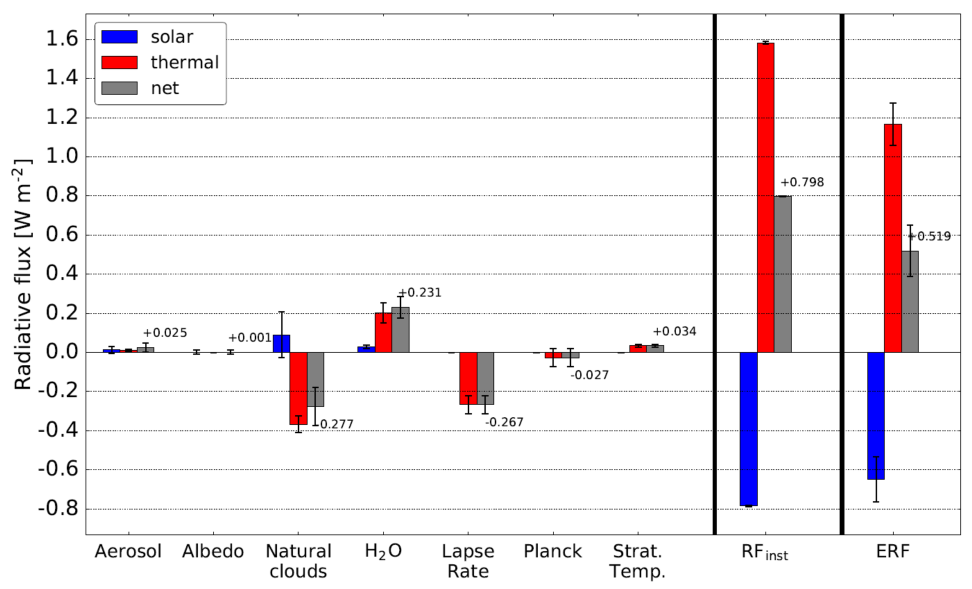
Instantaneous RF (**RF_{inst}**): 843 mW/m²
Stratosphere adjusted RF (**RF_{adj}**): 858 mW/m²
Effective RF (**ERF**): 569 mW/m²

Scaling of air traffic was needed to ensure sufficient statistical significance of ERF.

Reduced ERF suggests smaller global surface temperature response, which can be verified in coupled atmosphere-ocean simulations.

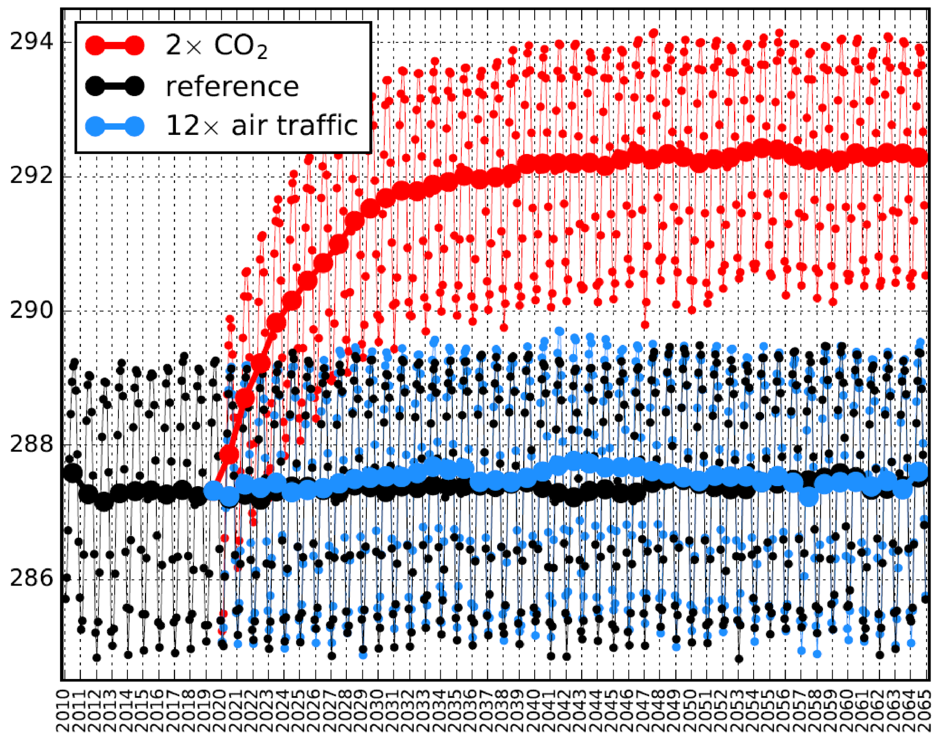
Rapid Radiative Adjustments

The partial radiative perturbation (PRP) method (Rieger et al., 2017) has been applied to determine the rapid radiative adjustments of contrail cirrus (left box). The Rapid radiative adjustments are responsible for the large reduction of ERF (right box) compared to RF_{inst} (mid box). ERF is largely the sum of RF_{inst} and the various rapid radiative adjustments. The PRP calculations are based on the 12× air traffic ERF FSST simulation.



A strong negative natural cloud adjustment (-277 mWm^{-2}) was found to be the main driver of the ERF reduction. Contrail cirrus growth at the expense of decreasing natural cirrus cover. The positive water vapor adjustment is almost completely compensated by the negative lapse rate adjustment. The non-zero planck adjustment is a result of the FSST method where land surface temperatures are not fixed. Albedo and stratospheric temperature adjustment hardly contribute to the reduction of ERF.

Surface Temperature change



Simulations with a coupled Mixed Layer Ocean (MLO) were performed to derive the surface temperature change of a 12× air traffic perturbation. A global mean surface temperature increase of 0.13 K was calculated. For a standard CO_2 doubling experiment (+348 ppm) a temperature increase of 4.9 K was yielded.

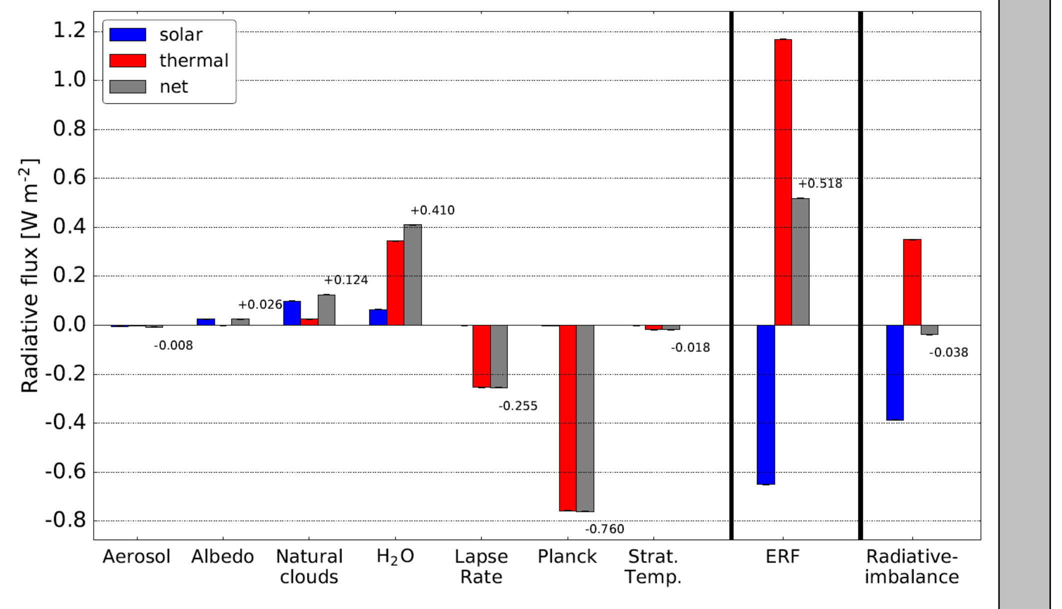
Take home messages

- **Contrail cirrus parameterization CCMod was implemented in MESSy.**
- **EMAC options allow determination of contrail cirrus radiative forcing, effective radiative forcing, and climate sensitivity (see also Poster of Stecher et al.).**
- **In EMAC, CCMod is coupled to the Kuebbeler et al. (2014) cloud parameterization and to the MADE aerosol module (see also talk by Mattia Righi), deviating from the original ECHAM5/CCMod framework.**
- **In EMAC, effective radiative forcing of contrail cirrus amounts to about 65 % of the respective conventional radiative forcing.**
- **The feedback analysis technique reveals the physical origin of this reduction (rapid radiative adjustment of natural clouds)**
- **The climate sensitivity (global surface temperature response per unit radiative forcing) induced by contrail cirrus is much lower than for a CO_2 increase (small efficacy of contrail cirrus).**
- **The analysis of slow (SST-driven) radiative feedbacks will complete the cause-and-effect relationship (ongoing work)**

Slow Feedbacks

Slow feedbacks describe the processes which reduce the ERF forcing to zero while the surface temperature is increasing. If all slow feedbacks (left box) are added to the ERF (mid box) the remaining radiative imbalance is yielded (right box).

A negative planck feedback is responsible for the largest compensation of ERF due to raising surface temperatures which lead to increased thermal emissions to space. As for the rapid adjustments, the water vapor and lapse rate adjustment fairly compensate each other.

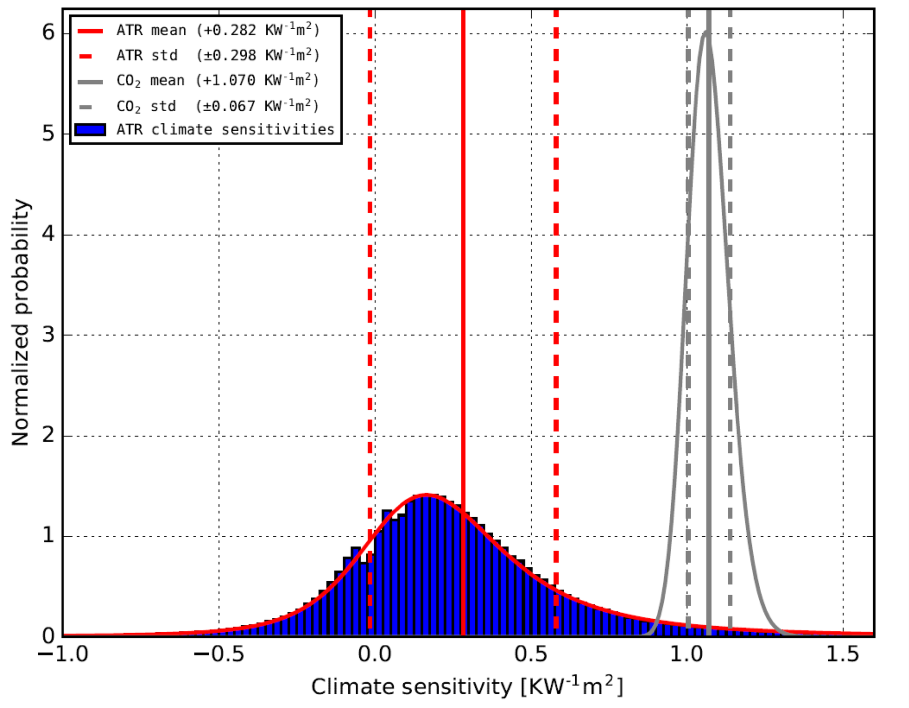


Climate Sensitivity

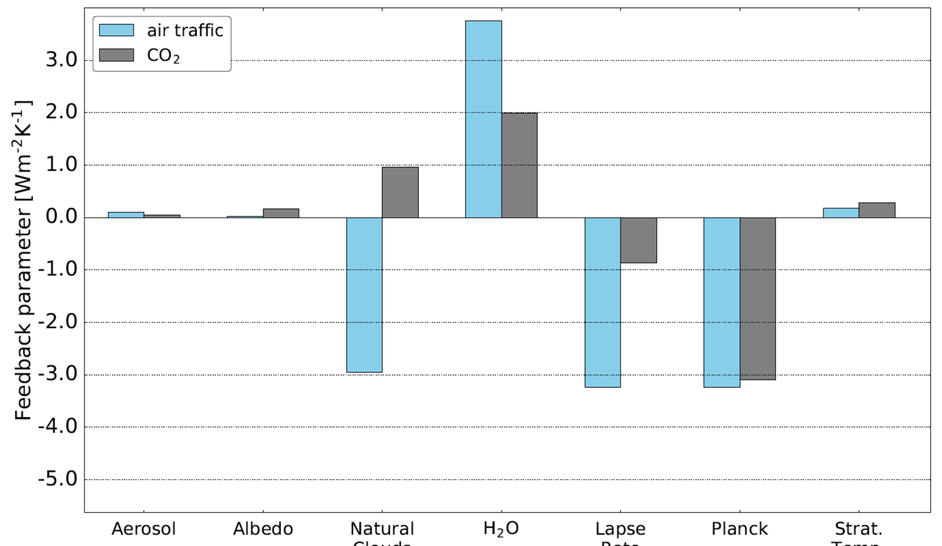
Climate sensitivity describes the connection between surface temperature change and RF:

$$\lambda = \frac{\Delta T_{sfc}}{RF} = \frac{T_{exp\,sfc} - Tref_{sfc}}{F_{exp} - Fref} \ [KW^{-1}m^2]$$

Even with the reduced ERF the climate sensitivity, comes out extremely low and amounts to only 0.28 $KW^{-1}m^2$. In comparison, the climate sensitivity to CO_2 increase yields 1.07 $KW^{-1}m^2$. Obviously (and deviating from the usual concept), ERF fails as a reasonable comparison metric with respect to contrail cirrus.



Comparison with CO_2 experiments



All contrail cirrus simulations were accompanied by CO_2 doubling simulations (+348 ppm). The intention was to directly compare the climate impact of both perturbations and to validate our model against literature.

The net feedback parameter (inverse climate sensitivity) is much larger for the 12× air traffic perturbation. Note that the feedback parameters shown here are based on the sum of rapid radiative adjustments and slow feedbacks. The differences mainly originate from the natural clouds feedback, followed by the Lapse Rate feedback.

References

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