Exploring the uncertainties in the aviation soot-cirrus effect

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The aviation sector contributes about 2.4% of the global anthropogenic CO_2 and is one of the fastest growing anthropogenic sectors, which makes it one of the key targets for mitigating the anthropogenic impact on climate (Lee et al., 2021).

In addition to the well-understood impact of CO_2 and the related mitigation measures, aircraft emit also a number of non-CO_2 components, whose climate impact is still uncertain. This concerns, for instance, the role of nitrogen oxides (NO_x = NO + NO_2), which control ozone formation and affect methane lifetime (Grewe et al., 2019), aerosol particles and their interactions with clouds (Righi et al., 2013; Penner et al., 2018), as well as the formation and growth of contrails and contrail cirrus (Bock and Burkhardt, 2016).

Among these various aviation effects, the impact of aviation soot on natural cirrus clouds has gained attention in recent years due to its potentially large climate impact, possibly exceeding the contribution of most of the aforementioned components, including CO_2 (Penner et al., 2018).

In this study, the global aerosol-climate model EMAC-MADE3, coupled with a two-moment cloud microphysical scheme and a parametrization for aerosol-induced ice formation in cirrus clouds, is applied in order to quantify the impact of aviation soot on natural cirrus clouds. Sensitivity experiments are performed to assess the uncertainties in this effect related to:

- The assumptions on the ice nucleation abilities of aviation soot.
- The representation of vertical updrafts in the model.
- The use of reanalysis data to relax the model dynamics (the so-called nudging technique).

Based on the results of the model simulations, a radiative forcing from the aviation soot-cirrus effect in the range of −35 to 13 mW m^{-2} is quantified, depending on the assumed critical saturation ratio for ice nucleation and active fraction of aviation soot, but with a confidence level below 95% in several cases (Fig. 1).

Simple idealized experiments with prescribed vertical velocities further show that the uncertainties on this aspect of the model dynamics are critical for the investigated effect and could potentially add a factor of about two of further uncertainty to the model estimates of the resulting radiative forcing.

The use of the nudging technique to relax model dynamics is proved essential in order to identify a statistically significant signal from the model internal variability, while simulations performed in free-running mode are shown to be unable to provide robust estimates of the investigated effect.

A comparison with analogous model studies on the aviation-soot cirrus effect show a very large model diversity, with a conspicuous lack of consensus across the various estimates, which points to the need for more in-depth analyses on the roots of such discrepancies.

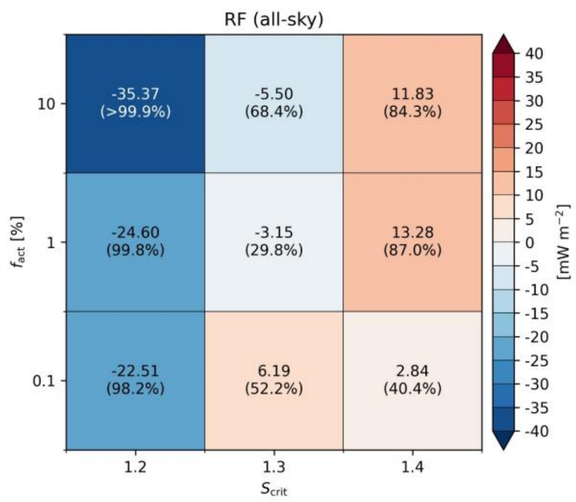

Fig. 1. Multi-year average (2001–2015) top-of-the-atmosphere all-sky RF due to the effect of aviation soot on natural cirrus clouds, under different assumptions for the ice nucleation efficiency of aviation soot ice nucleating particles (S_{crit} and f_{act}). The values in brackets within each box indicate the confidence level.

References

Bock, L. and Burkhardt, U.: The temporal evolution of a long-lived contrail cirrus cluster: Simulations with a global climate model, *J. Geophys. Res. Atmos.*, 121, 3548-3565, 2016.

Lee, D., Fahey, D., Skowron, A., et al.: The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018, *Atmos. Environ.*, 244, 117834, 2021.

Grewe, V., Matthes, S., and Dahlmann, K.: The contribution of aviation NO_x emissions to climate change: are we ignoring methodological flaws?, *Environ. Res. Lett.*, 14, 121003, 2019.

Penner, J. E., Zhou, C., Garnier, A., et al.: Anthropogenic Aerosol Indirect Effects in Cirrus Clouds, *J. Geophys. Res. Atmos.*, 725 123, 2018.

Righi, M., Hendricks, J., and Sausen, R.: The global impact of the transport sectors on atmospheric aerosol: simulations for year 2000 emissions, *Atmos. Chem. Phys.*, 13, 9939-9970, 2013.