Project: **832**

Project title: **Cloud-resolving modeling of contrails and cirrus**

Principal investigator: **Simon Unterstrasser**

Report period: **2020-11-01 to 2021-08-31**

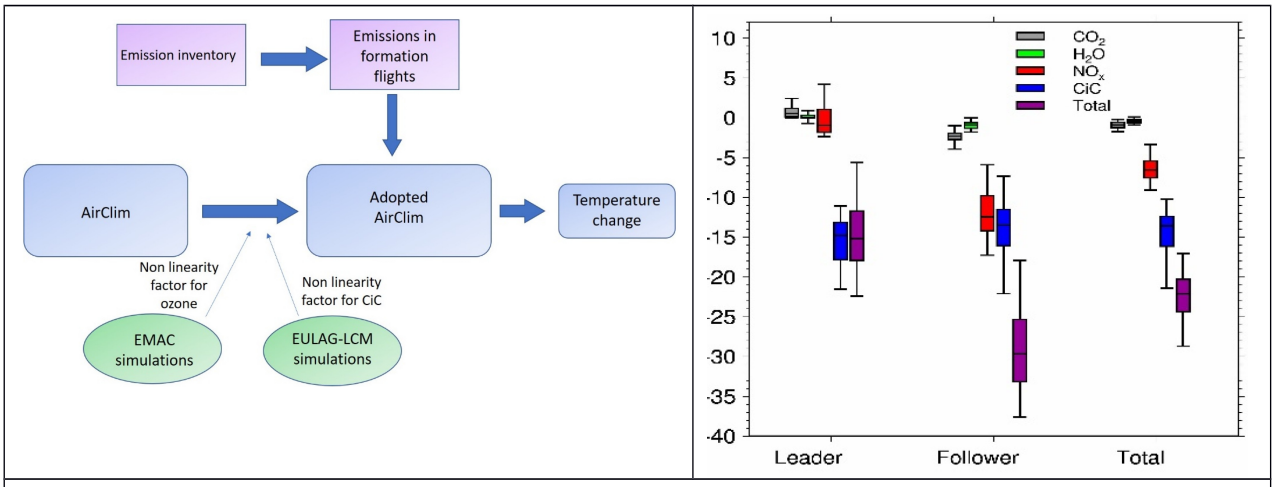
Introduction

We employ the LES model EULAG-LCM for simulations of naturally forming cirrus and for aircraft induced cirrus, so-called contrail-cirrus. The microphysical module LCM uses Lagrangian particles to transport the ice crystals and calculate the microphysical processes along their trajectories (Sölch & Kärcher, 2010). The simulations can be grouped into three categories: Simulations of contrail formation (first few seconds), young contrails (age < 5min) and simulations of contrail-cirrus and natural cirrus (time scale of hours).

The **expressions** in bold refer to simulation blocks in last year's proposal.

FORMIC

The BMBF-project "FORMIC" project dealt with the potential climate benefits of formation flight and simulation results have been described over the last few reports. The project was concluded with three publications that appeared in Dec 2020 and Jan 2021. In Unterstrasser (2020) contrail-cirrus simulations are described. In last year's proposal we had a block called "**FORMIC-DP**" for potential additional simulations during the review stage, however we didn't need those extra resources. The two other FORMIC publications give a comprehensive climate impact assessment of formation flight and build upon results of the previous publication. Major reductions in the climate impact can be expected, in particular due to saturation effects during contrail spreading (label 'CiC' = contrail-cirrus).

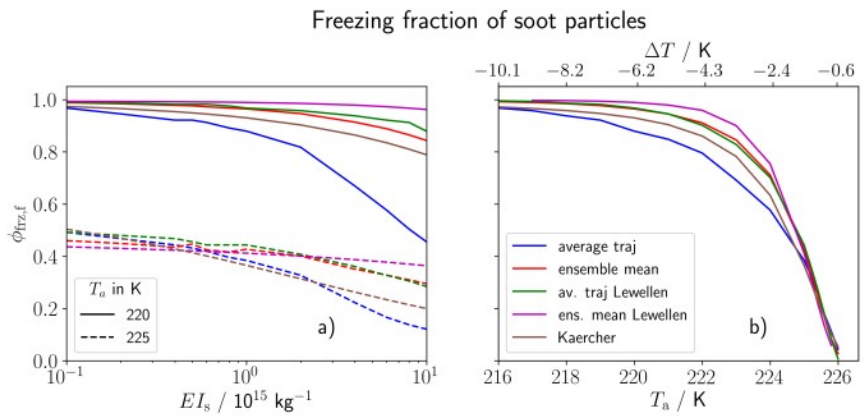


left: Model chain for a comprehensive climate impact assessment of formation flight; right: Change in total climate impact when formation flights are considered. separately for the different species (CiC stands for contrail-cirrus). The bars indicate the 25% and 50% percentile and the whiskers indicate the 95% confidence interval of the different formations in one data set. *Taken from Dahlmann et al; 2020.*

ConForm

The DFG-funded project of A. Bier on contrail formation started in March 2019. It deals with high-resolution 3D simulations of contrail formation in expanding exhaust jets. In the past, contrail formation was either studied with box models (with detailed microphysics, but simplified dynamics) or with 3D LES models (detailed dynamics, but simplified microphysics). The current project aims at bringing those two worlds together and extending EULAG-LCM such that high-resolution 3D simulations of contrail formation with adequate dynamics and microphysics can be performed. A manuscript on LCM box model simulations with the newly developed contrail-formation microphysics is currently under review. The project is currently interrupted, as A. Bier works as a Post-Doc for the project described next. Hence, the simulation work described in

"**DFG-JP"** has not yet started. ConForm will be resumed in April 2022.



The fraction of emitted soot particles that are activated into ice crystals is displayed as a function of the soot emission index EI_s and the ambient temperature. The various lines show different model configurations. *Taken from Bier et al, 2021*

<u>H_2CONTRAIL</u>

The DLR-internally funded research group deals with contrails effects of hydrogen-driven aircraft. A. Bier works as a Post-Doc in this project and works on contrail formation from a propulsion system with direct combustion of H2. Currently, he performs box model simulations, which do not require HPC resources. A new PhD student will start in October and may start to work this year on the topic described under "**H_2CONTRAIL-VP".**

<u>LCM model development</u>

The LCM model improvement regarding aggregation is now published in Unterstrasser et al, 2020.

Short summary

All in all, no simulations have been performed this year and the project's consumption will eventually be less than anticipated in last year's proposal. Unfortunately, this can happen in small teams. Currently, we are two investigators in this project; me and Andreas Bier. During the last year we were mainly involved in validation studies with lower-dimensional models, which clearly do not require high-computing facilities.

Publications (the team member are in bold font):

- **Unterstrasser, S.** , F. Hoffmann, M. Lerch: Collisional growth in a particle-based cloud microphysical model: Insights from column model simulations using LCM1D (v1.0), *13, 5119–5145, 2020.*
- **Unterstrasser, S.** : The contrail mitigation potential of aircraft formation flight derived from high-resolution simulations, *Aerospace 7(12), 170, 2020*
- Marks, T.; Dahlmann, K.; Grewe, V.; Gollnick, V.; Linke, F.; Matthes, S.; Stumpf, E.; **Unterstrasser, S.**; Yamashita, H.; Zumegen, C. Climate Impact Mitigation Potential of Formation Flight*, Aerospace 8(1), 14, 2021*
- Dahlmann, K.; Matthes, S.; Yamashita, H.; **Unterstrasser, S**. and Grewe, V.; Marks, T. Assessing the climate impact of formation flights*, Aerospace 7(12), 172*
- **Bier, A., S. Unterstrasser**, and X. Vancassel: Box model trajectory studies of contrail formation using a particle-based cloud microphysics scheme, *ACPD, 2021, https://acp.copernicus.org/preprints/acp-2021-361/*