Project: **832**

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

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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 paths (Sölch & Kärcher, 2010). The simulations can be grouped into two categories: Simulations of young contrails (age < 5min) and simulations of contrail-cirrus and natural cirrus.

The BMBF-project "FORMIC" project deals with the potential climate benefits of formation flight. During a formation flight, several aircraft fly in a pattern similar to that of migrating birds. Fuel usage and CO2-emissions are reduced compared to isolated flights due to aerodynamic benefits of this special flight pattern. Besides this fuel effect, the climate impact of contrails may be strongly altered, as several contrails start to overlap and interact already at a very early stage of their lifetime. This saturation effect is expected to reduce the contrail radiative forcing (RF), i.e the RF of one contrail cluster formed by two aircraft flying in a formation is smaller than that of two isolated contrails.

Short summary

This year I was not able to constantly perform simulations and the project's consumption is less than anticipated in last year's proposal (also because of the expiration of resources each quarter of a year). Unfortunately, this can happen in small teams. Currently, I am the only investigator in this project. However, this will change next year.

Few simulations of young contrails have been performed. Those were final sensitivity studies before submitting a manuscript on this topic.

Simulations, in particular those of the contrail-to-cirrus transition, that were planned for 2018, have been performed at the end of the year 2017 (after the report deadline at the end of October). The simulations gave already a first good overview on this topic and more simulations have been performed only very recently.

Young contrails

One main task of this year was to prepare a manuscript based on young contrail simulations of formation flight scenarios. To my knowledge, those simulations are the first ones that simulate the so called far field evolution of the wake vortices of formation flight scenarios. As such, the results are unprecedented and a publication focusing on those aspects and the implications on young contrail properties treats novel aspects and is soon submitted. In this study EULAG simulation are also compared to an alternative LES code. The according MGLET simulations have been performed at LRZ this year. Only a few sensitivity studies checking the significance of the turbulence initialisations have been performed with EULAG at DKRZ explaining the rather low consumption. Around 2000Nh have been used for this. Possible further sensitivity tests required during the review process would follow in 2019.

Contrail-cirrus simulations

Generally, we use the output of vortex phase simulations (contrails after 5-10 minutes) to initialise contrail-cirrus simulations which cover the remaining life cycle of a contrail. We carried out a limited set of such simulations for formation flight scenarios. As mentioned above, most simulations have been performed at the end of last year. Figure 1 shows a summary of those results. Each data point is created by averaging over 4 instances of the same simulation (similar to members of an ensemble forecast). In this application, "same simulation" means that all physical and numerical parameters are not touched; the individual instances are obtained by using different turbulent background fields.

The various data points are normalized in the sense that the given values are relative to the

classical case with an isolated contrail produced by a single aircraft. The left panel shows the lifetime integrated total extinction and is a metric of the shortwave radiative effect, whereas the right panel shows the lifetime integrated total ice mass and is a metric for the longwave radiative effect.

Values < 1 indicate that the radiative impact is smaller than in the classical case and values > 1 would show that radiative impact is larger than in the classical case. Each data point represents a specific synoptic scenario (e.g. a specific initial relative humidity, synoptic-scale updraught speed and vertical wind shear) or a specific formation flight scenario (variation of formation flight geometry). In any scenario, the radiative effect of a formation flight contrail-cirrus is reduced by 20%-50% compared to a single aircraft contrail. Hence, those simulations reveal a strong possible impact on the radiation budget and are a promising first step in studying the contrail mitigation potential by formation flight.

Originally, we intended to run 8 different simulations for each atmospheric scenario (three single aircraft simulations are compared to five “multicontrail” formation flight simulations). We found that the variation across the various multicontrail simulations is only moderate (see blue symbols in the plots), and it suffices to compare two different single aircraft simulations with one standard multicontrail simulation (i.e three simulations in total) for most of the analysed atmospheric scenarios. So far, we analysed nine different atmospheric scenarios (only four are shown in the present figure, see red symbols in figure). This reduces the required CPU time compared to the initial estimate of 12000Nh.

For this block, around 3000Nh have been used in total since October 2017. Further simulations are postponed to 2019 as the budget for this year is almost used up.

Publications

Two publications (Unterstrasser et al, 2017a,b) appeared after submitting the last years report. Both studies heavily rely on simulations performed at DKRZ and their content has been described in earlier reports. Regional contrail simulations with the COSMO model focusing on the reduction of photovoltaic power production by contrails have been lately performed (Gruber et al, 2018, simulation not performed at DKRZ), where the initialisation and evaluation is based on earlier EULAG-LCM simulations of Unterstrasser, 2016 and Unterstrasser et al, 2017a.

References

Gruber, S., **S. Unterstrasser**, J. Bechtold, H. Vogel, M. Jung, H. Pak, B. Vogel, 2018: *Contrails and their impact on shortwave radiation and photovoltaic power production - A regional model study*, Atmos. Chem. Phys., 18, 6393-6411

Sölch, I. and Kärcher, B, 2010.: *A large-eddy model for cirrus clouds with explicit aerosol and ice microphysics and Lagrangian ice particle tracking*, Q. J. R. Meteorolog. Soc., 136, 2074–2093

Unterstrasser, S., 2016*: Properties of young contrails - a parametrisation based on large eddy simulations*, Atmos. Chem. Phys., 16, 2713-2733

Unterstrasser, S., K. Gierens, I. Sölch and **M. Lainer**, 2017a: *Numerical simulations of homogeneously nucleated natural cirrus and contrail-cirrus. Part 1: How different are they?*, Meteorl. Z., 26, 621-642

Unterstrasser, S., K. Gierens, I Sölch and M. Wirth, 2017b: *Numerical simulations of homogeneously nucleated natural cirrus and contrail-cirrus. Part 2: Interaction on local scale*, Meteorl. Z., 26, 643-661

Unterstrasser, S. and Stephan, A.: *Far field wake vortex evolution of two aircraft formation flight scenarios and implications on young contrails*, to be submitted