Project: **832**

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

Principal investigator: **Simon Unterstrasser**

Report period: **2023-11-01 to 2024-10-31**

Maximum of 2 pages including figures. 9 pt minimum font size.

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).

Six researchers belong to project 832 and the group size has grown a lot recently.

	Levante CPU nodes (Nh); Levante storage (TiB), Archive project (TiB)		
	Asked	Granted	Used by Oct 21st 2024
Proposal 2023/10	16200**;** 7, 10	7128; 6, 5	
Proposal 2024/4	17500; 9, 10	14350; 9, 9	
Totals		~21500; 15, 14	16600; 14, 12

First of all, we acknowledge the small cut of the 17500Nh request in April this year. This allowed us to pursue our goals very smoothly.

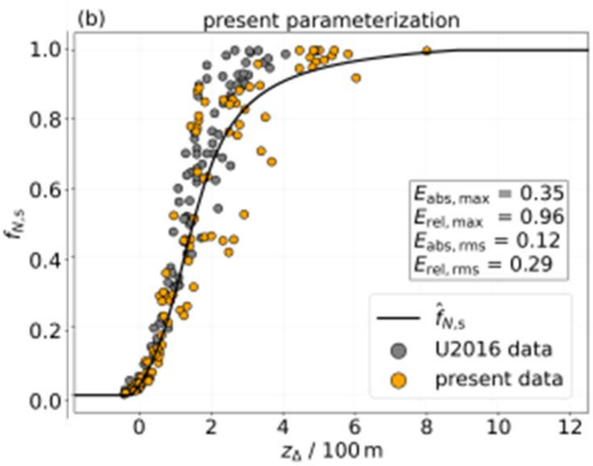
SIMULATION ACTIVITIES

H2CONTRAIL-VP

This block appeared already in last year's report and the simulation work has progressed continuously. It deals with high-resolution simulations of young contrails during the vortex phase (VP) that is characterised by an interplay of ice microphysics and wake vortex dynamics. For typical kerosene combustion, contrail ice crystals form on emitted soot particles (Bier et al, 2022). Hydrogen combustion is a promising technological mitigation option of the aviation's climate impact. When burning hydrogen (H2), no soot particles are emitted and fewer ice crystals form on entrained ambient aerosol particles (Bier et al, 2024). In a comprehensive modelling study, the sensitivity of the subsequent contrail evolution during the vortex phase to the initial ice crystal number was examined. For a large set of meteorological conditions and two different aircraft types, simulations with different initial ice crystal numbers were performed (factor 10 and 100 up and down relative to a typical "kerosene" contrail). In the last years, reviewers of our proposal were often concerned about a lack of justification of the manifold sensitivity studies. The following table is extracted from a current paper draft (Lottermoser & Unterstrasser, in prep) and lists 150 simulations (each needs resources of 40 to 80 Nh) that were all performed inside the

Nr	AC	T_{amb} (K)	$RH_{i,amb}$ (%)	N_{BV} ($10^{-2}s^{-1}$)	N_0 #sim	I_0 ($g\,m^{-1}$)	r_{SD}
1,2,3,4,5	B777	217	120	1.15	5	15.0	3
6,7,8,9,10	B777	217	110	1.15	5	15.0	3
11,12,13,14,15,16	B777	217	120	1.15	6	38.55	3
17,18,19,20,21	B777	217	110	1.15	5	38.55	3
22,23,24	B777	217	120	1.15	3	15.0	1
25,26,27	B777	217	120	1.15	3	15.0	4
28,29,30	B777	217	110	1.15	3	15.0	1
31,32,33	B777	217	110	1.15	3	15.0	4
34,35,36	B777	217	120	1.15	3	38.55	1
37,38,39	B777	217	120	1.15	3	38.55	4
40,41,42	B777	217	110	1.15	3	38.55	1
43,44,45	B777	217	110	1.15	3	38.55	4
46,47,48	B777	217	120	0.5	3	15.0	3
49,50,51	B777	217	110	0.5	3	15.0	3
52,53,54	B777	217	120	0.5	3	38.55	3
55,56,57	B777	217	110	0.5	3	38.55	3
Simulations at higher ambient temperatures							
58,59,60,61,62	B777	225	120	1.15	5	15.0	3
63,64,65,66,67	B777	225	110	1.15	5	15.0	3
68,69,70,71,72	B777	225	120	1.15	5	38.55	3
73,74,75,76,77	B777	225	110	1.15	5	38.55	3
78,79,80,81,82	B777	230	120	1.15	5	38.55	3
83,84,85,86,87	B777	230	110	1.15	5	38.55	3
88,89,90,91,92	B777	233	120	1.15	5	38.55	3
93,94,95,96,97	B777	233	110	1.15	5	38.55	3
98,99,100	B777	233	120	1.15	3	38.55	1
101,102,103	B777	233	120	1.15	3	38.55	4
104,105,106	B777	233	110	1.15	3	38.55	1
107,108,109	B777	233	110	1.15	3	38.55	4
110,111,112,113,114	B777	235	120	1.15	5	38.55	3
115,116,117,178,119	B777	235	110	1.15	5	38.55	3
Simulations with A320/B737-like aircraft							
120	B737	217	120	1.15	1	3.7	3
121,122,123	B737	225	120	1.15	3	3.7	3
124,125,126	B737	225	110	1.15	3	3.7	3
127,128,129	B737	225	120	1.15	3	9.51	3
130,131,132	B737	225	110	1.15	3	9.51	3
133,134,135	B737	230	120	1.15	3	9.51	3
136,137,138	B737	230	110	1.15	3	9.51	3
139,140,141	B737	233	120	1.15	3	9.51	3
142,143,144	B737	233	110	1.15	3	9.51	3
145,146,147	B737	235	120	1.15	3	9.51	3
148,149,150	B737	235	110	1.15	3	9.51	3

H2CONTRAIL-VP block over the last two years. The different columns show the set of setup parameters (see top row) that have been varied: the aircraft (AC) type, ambient temperature T_{amb}, relative humidity $RH_{i,amb}$, Brunt-Väisälä frequency N_{BV}, initial number of ice crystals N_0, amount of emitted water vapour I_0 and the width of the ice crystal size distribution r_{SD}. It is clearly out of scope to explain the motivation behind each simulation here.



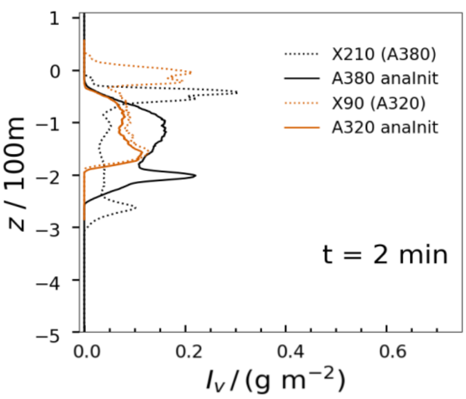
One crucial process during the vortex phase is the partial loss of ice crystals (due to adiabatic heating in the descending wake vortices with ice trapped inside) and the simulations are used to quantify the ice crystal survival fraction f_{Ns} (the fraction of the ice crystal that is not lost during the vortex phase). Unterstrasser (2016) designed an analytical parametrisation of f_{Ns} as a function of the aforementioned parameters. In the meantime, this parametrisation has been implemented in the ECHAM GCM for a refined contrail initialisation and an updated contrail radiative forcing estimate (Bier & Burkhardt, 2022). Based on the extended set of new simulations, in particular in the high temperature range (T_{amb}>=225K) and for a large N_0 variation, an updated version of the f_{Ns} parametrisation was delivered lately and is currently already implemented in ECHAM. This enables robust estimates of the H2 contrail radiative forcing.

H2CONTRAIL-DP

The block called "H2CONTRAIL-DP" deals with high-resolution dispersion phase (DP) simulations of aging contrail-cirrus. With such simulations, changes in climate-relevant contrail-cirrus properties are evaluated and its dependence on the initial ice crystal number is explored. Those simulations use the simulation data from **H2CONTRAIL-VP** as initialization. In addtion to the parameters listed above, the synopic evolution of ambient temperature and RH_i ("updraught scenarios") serve as additional degrees of freedom in the simulation setup. In total, 210 simulations have been performed (each simulation needs 4-8 Nh). The simulation work is nearly finished and the results will be basis of a manuscript.

Improved VortexPhase Initialisation (VP-Init)

In this activity, simulation data from a-priori RANS simulations were used to initialize the wake vortex flow field of our contrail vortex phase simulations. These results ("X210", "X90") were compared with the previous analytical wake vortex initialization ("anaInit") for two different aircraft types (A320, A380) and various atmospheric conditions. The new way of initializing affects the interaction between wake vortices and ice crystals, resulting in a different vertical transport and distribution of ice crystals. In particular, not all ice crystals are entrained in the wake vortex systems, but remain at the emission altitude. Also, a different number of ice crystals survive the vortex phase, influencing the ice mass of the whole contrail and also the size of the ice crystals.



There is not enough space to describe the results in more detail. The results are summarized in a conference paper (Pauen et al, 2024).

REFERENCES

*In **bold** current and former members of DKRZ project 0832.*

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Lottermoser, A. and **Unterstrasser, S.:** High-resolution modelling of early contrail evolution from hydrogen-powered aircraft, soon to be subm. to ACP

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