Project: **832**

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

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INTRODUCTION

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

Table A1
Properties of the Initialized Contrails[a]

Aircraft type	T_{CA}/K	$RH_{i,amb}$/%	I_{00}/(g m^{-1})	N_0/(10^{12} m^{-1})	I_0/(g m^{-1})
A350/B777	217	110	15.0	0.02, 0.15, 0.95, 3.34, 6.93	4.7, 7.1, 7.5, 7.0, 6.2
			38.6	0.03, 0.27, 2.13, 9.25, 22.08	7.8, 12.0, 13.7, 14.0, 13.2
		120	15.0	0.03, 0.3, 2.18, 7.74, 16.36	12.7, 19.6, 21.4, 21.9, 20.8
			38.6	0.03, 0.33, 2.85, 13.14, 31.84	15.0, 22.3, 24.5, 24.4, 23.7
	225	110	15.0	0.02, 0.08, 0.43, 1.19, 2.19	9.7, 11.5, 11.3, 10.2, 9.1
			38.6	0.02, 0.16, 0.98, 3.25, 6.8	14.8, 21.3, 23.7, 21.6, 19.5
		120	15.0	0.03, 0.26, 1.51, 4.21, 8.2	34.0, 50.9, 53.2, 50.3, 45.5
			38.6	0.03, 0.3, 2.12, 7.1, 15.03	37.5, 55.4, 59.1, 59.0, 54.6
	230	110	38.6	0.02, 0.11, 0.59, 1.71, 3.35	24.6, 31.0, 29.8, 26.1, 23.2
		120	38.6	0.03, 0.28, 1.73, 4.91, 9.94	74.7, 105.2, 112.3, 106.8, 98.5
	233	110	38.6	0.02, 0.09, 0.46, 1.25, 2.37	31.3, 37.5, 35.8, 31.6, 28.2
		120	38.6	0.03, 0.26, 1.52, 4.14, 8.17	107.0, 149.6, 159.9, 151.3, 138.1
	235	110	38.6	0.01, 0.08, 0.4, 1.04, 1.92	37.3, 43.8, 41.9, 36.9, 32.7
		120	38.6	0.03, 0.25, 1.45, 3.75, 7.41	136.7, 189.0, 200.5, 189.8, 174.0
A320/B737	225	110	3.7	0.01, 0.25, 1.13	5.0, 9.5, 6.9
			9.5	0.01, 0.44, 2.97	5.9, 12.5, 11.5
		120	3.7	0.01, 0.66, 3.86	13.3, 25.8, 23.2
			9.5	0.01, 0.72, 5.71	14.0, 27.0, 24.9
	230	110	9.5	0.01, 0.3, 1.55	8.6, 18.1, 15.5
		120	9.5	0.01, 0.68, 4.19	23.2, 44.5, 42.2
	233	110	9.5	0.01, 0.25, 1.2	12.3, 24.3, 19.2
		120	9.5	0.01, 0.66, 3.78	33.6, 64.6, 60.6
	235	110	9.5	0.01, 0.23, 1.04	15.6, 29.8, 22.6
		120	9.5	0.01, 0.65, 3.46	43.4, 81.0, 76.7

[a]Total ice crystal number N_0 and mass I_0 after vortex phase as functions of the respective aircraft, ambient temperature, ambient relative humidity with respect to ice, and initial amount of emitted water vapor according to Table 1. For the A350/B777-like aircraft, five values are provided for N_0 and I_0, which denote the N_{00}-scaling simulations with scaling factors 0.01, 0.1, 1, 10, and 100. For the smaller A320/B737-like aircraft, N_0 and I_0 values are available for scalings of 0.01, 1, and 100.

Table adapted from Lottermoser and Unterstrasser (2026), illustrating the approach of systematic sensitivity simulations with EULAG-LCM. For each given ice crystal number concentration N_0 (fifth column) and the parameter values given in the first four columns, a set of simulations was performed in which further ambient parameters (not listed in the table) were varied. The total number of LES simulations was >1000.

SIMULATION ACTIVITIES

H2CONTRAIL-DP

The block called "H2CONTRAIL-DP" deals with high-resolution dispersion-phase (DP) simulations of ageing contrail-cirrus. Our recent work analysed contrail-cirrus properties for different initial ice crystal numbers **N_0** and a large set of meteorological background conditions. A first systematic study has been completed and published (Lottermoser and Unterstrasser, 2026). The table above showcases our LES approach using a large number of sensitivity experiments.

As a spin-off, a subset of these simulations and several new simulations contribute to a model intercomparison exercise involving three different contrail-cirrus models (Akhtar-Martínez et al., under review). The figure below is taken from the submitted manuscript and summarises the response of three different contrail-cirrus models to variations of key meteorological parameters (listed on the x-axis). Here, EULAG-LCM results serve as a reference for the more simplified and faster models APCEMM and CoCiP.

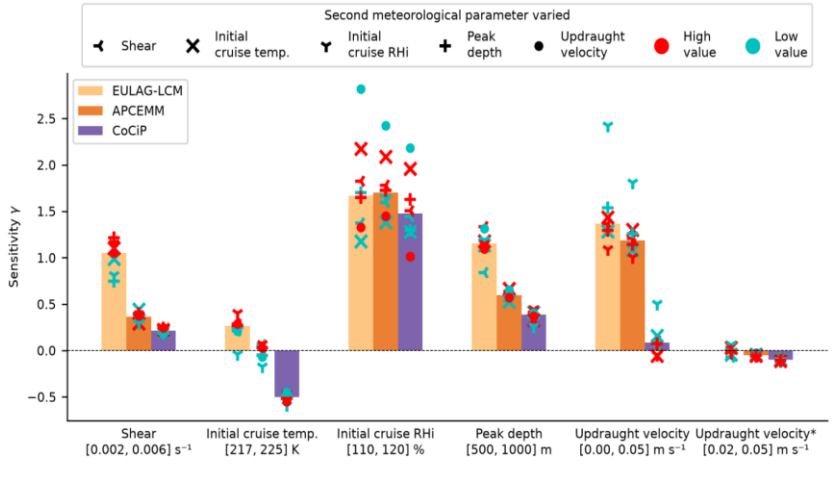
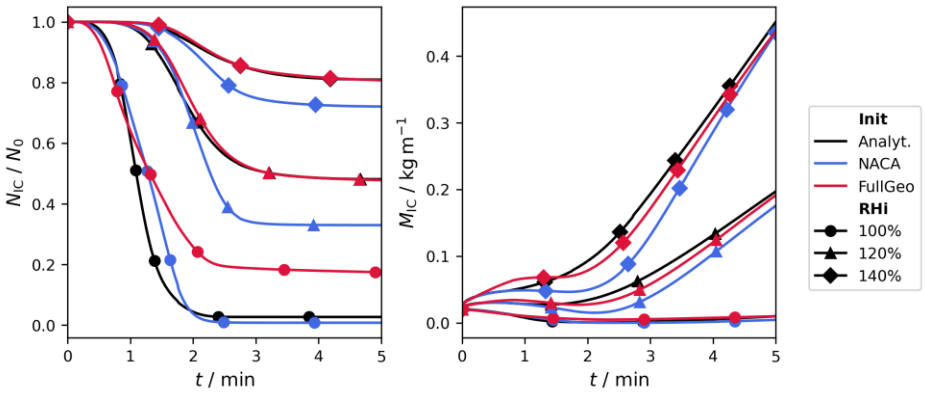


Figure adapted from Akhtar-Martínez et al. (submitted to ACP); description in text.

Moreover, the H2CONTRAIL-DP block in last year's report mentioned a more lightweight study that concisely addresses the relevance of early contrail properties for the contrail-cirrus radiative effect. This is a currently ongoing effort, and a manuscript will be prepared over the next few months.

Improved Vortex Phase Initialisation (VP-Init)

Further contrail vortex-phase (VP) simulations with more realistic flow-field initialisations have been performed for single-aircraft contrails.



Currently, a manuscript on this topic is in preparation (Rabe et al., in prep). The figure below shows early contrail properties like total ice crystal number and mass for three types of wake vortex initialisations (Analytical, NACA wing and full aircraft geometry) and three levels of relative humidity RHi. For a robust assessment, such simulations were carried out for aircraft of different sizes, while this plot shows only one selected aircraft type.

GEESE-VP and GEESE-DP

Formation-flight scenarios (two aircraft fly with a separation of 2 to3 km along flight direction) of the contrail vortex phase (GEESE-VP) and of the subsequent contrail-to-cirrus transition (GEESE-DP) have been investigated. The simulation work on GEESE-VP has been completed. A manuscript has been finalised for submission (Pauen et al., to be submitted). The figure to the right displays the survival fraction f_N of ice crystals and the thickness H and width W of early contrails (age around 8 min) for several formation-flight scenarios with different lateral separation (cases DX2, DX1 and DX0). Colour and line style distinguish simulations with different ambient relative humidity and initialisation type. A major advancement of the present study is the inclusion of a more realistic flow-field initialisation based on a-priori CFD simulations (labelled 'CFDInit'). In the remainder of this year, the focus will shift toward GEESE-DP simulations.

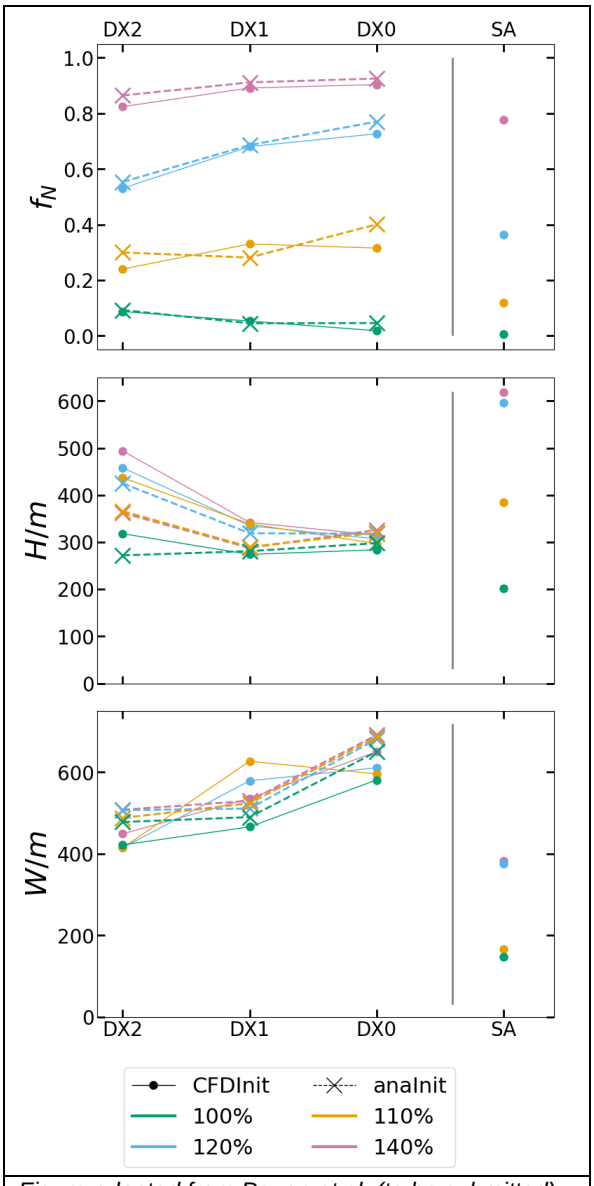


Figure adapted from Pauen et al. (to be submitted); description in text.

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

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