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Numerical simulations of persisting contrails with Lagrangian microphysics

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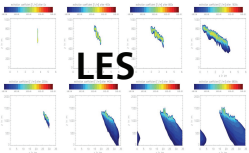
Introduction

- Estimates of global coverage and radiative forcing of contrail-cirrus still with large uncertainties
- Contrail-cirrus hardly distinguishable from naturally formed cirrus
- Observations of aged (non-linear) contrails virtually not available

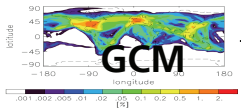
Model-based approach

- Cloud resolving simulations can help to improve the initialization and parameterization of contrails in regional/global scale simulations.

Simulation of contrail life cycle:



Use GCM approach to obtain global contrail-cirrus coverage and radiative forcing:



Coverage of contrails <5h

Burkhardt & Kärcher, 2009

Core model EULAG

- Basic model EULAG solves the anelastic approximation of the Navier-Stokes-equations (including a 1D radiation routine). 2 microphysics modules available.

with Bulk ice microphysics (EULAG-BULK)

- 2-moment bulk microphysics routine with assumed lognormal ice crystal size distribution
- Assumed ice crystal shape: hexagonal columns

with Lagrangian ice microphysics (EULAG-LCM)

- Lagrangian tracking of ice crystals, crystal size distribution develops freely.
- Microphysical processes solved for individual particles

Model overview

Smolarkiewicz & Margolin, 1997

EULAG
2D/3D dynamics
MPDATA advection algorithm
u,v,w; p, θ
turbulence closure

1D-Radiation
heating rates
6 solar bands
12 thermal bands
optimized for
ice clouds

Fu & Liou, 1993; Fu, 1996; Fu et al., 1998

LCM
nonequilibrium uptake kinetics on liquid aerosols
Lagrangian ice particle tracking

homogeneous freezing,
heterogeneous ice nucleation,
depositional growth,
Sublimation,
Sedimentation,
Aggregation,
gas uptake (e.g., HNO_3)

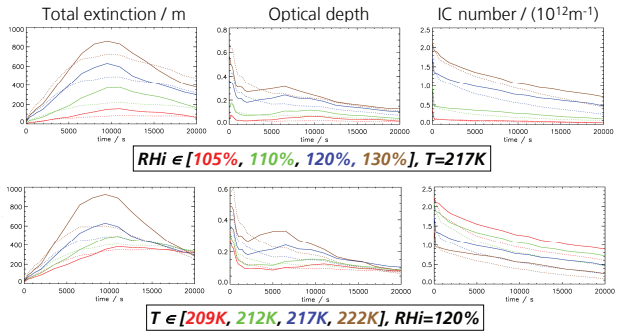
Sölch & Kärcher, 2010, 2011

or

2 -moment
Bulk microphysics
ice crystal number N,
ice water content IWC
depositional growth,
sublimation,
sedimentation,
homogeneous freezing,
heterogeneous nucleation

Spichtinger & Gierens, 2009

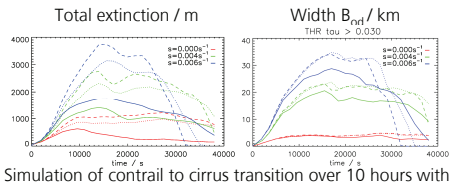
Evolution of contrail (microphysical) properties during the dispersion phase – Comparison



Simulation of contrail to cirrus transition over 6 hours without wind shear.
EULAG-LCM (solid lines) / EULAG-BULK (dotted lines)

Model setup:
Δt ∈ [2s, 10s]
L ∈ [5.7km, 17.3km]
H ∈ [1.0km, 1.5km]
Δx ∈ [5m, 15m]
Δz ∈ [5m, 10m]

Impact of idealized synoptic scale lifting and vertical wind shear on contrail lifecycle (EULAG-LCM)



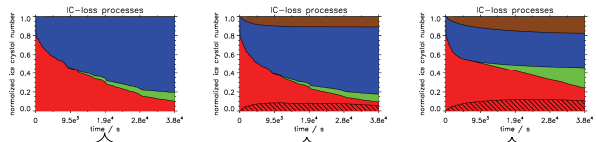
Environmental parameters:
T=217K, RHi=120%

Lifting scenarios:
w_{syn} = 0cm/s (solid lines)
w_{syn} = 1cm/s (dotted lines)
w_{syn} = 2cm/s (dashed lines)

Simulation of contrail to cirrus transition over 10 hours with wind shear s and constant synoptic-scale lifting (w_{syn} > 0cm/s).

Extent of ice crystal (IC) aggregation in a contrail

T=217K, RHi=120%, s=0s^{-1}, start point of lifting: 2000s, end point of lifting: 22000s



No aggregation, w_{syn} = 0cm/s | **w_{syn} = 0cm/s** | **w_{syn} = 2cm/s**

Existing IC / Existing aggregates / Sedimentation loss / Sublimation loss / Aggregation loss

Selected findings

- Substantial sublimation loss in w_{syn}=0-scenario found in both models. Turbulent fluctuations in RHi around saturation cause sublimation (due to Kelvin-effect, Lewellen, 2012).
- Comparison of two microphysical models: Qualitatively similar evolution of contrail properties.
- Total extinction of contrail higher for larger wind shear and stronger uplift. However, reduced lifetime for "bigger" contrails since larger ice crystals fall out faster.
- After 10 hours, only about 11% (18%) of total ice crystals are lost by aggregation if w_{syn}=0cm/s (2cm/s). Nevertheless, after 6 hours over 35% (30%) of the present ice crystals are aggregates; after 10 hours 65% (45%).

Acknowledgement

The EULAG-LCM simulations were carried out at the high performance computing facilities of the DKRZ in Hamburg. We want to thank I. Sölch for assistance with the EULAG-LCM model.