Deutsches Zentrum
für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft
Institut für Physik der Atmosphäre

Numerical Models for Contrail(-Cirrus) simulations

S. Unterstraßer, I. Sölch, K. Gierens

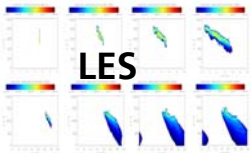
Introduction

- The global coverage and radiative forcing of contrail-cirrus is presently not known
- Contrail-cirrus may not be distinguishable from naturally formed cirrus
- Observations of aged (non-linear) contrails virtually not available

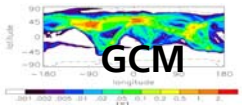
Model-based approach

- LES-simulations can help to improve GCM-initialization of contrails
- Simulated transition may further help to improve GCM-parameterization of contrails (in future)

Simulation of contrail life cycle



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



Coverage of contrails <5h

Burkhardt & Kärcher, in press

LES-Model with ice microphysics (MP)

- Basic model EULAG solves the anelastic approximation of the Navier-Stokes-equations
- 2-moment bulk microphysics routine with lognormal ice crystal size distribution

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

⟷

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

Smolarkiewicz & Margolin, 1997, 1998

Spichtinger & Gierens, 2009

Vortex phase model

T_{sim} = 120 - 200s
Δt = 0.01s
L × H=256m × 500m
Δx = Δz = 1m

- Fast 2D-simulation with adjusted vortex decay (CC-Tool)
- Crystal loss and vertical expansion are important features for the latter contrail-cirrus properties

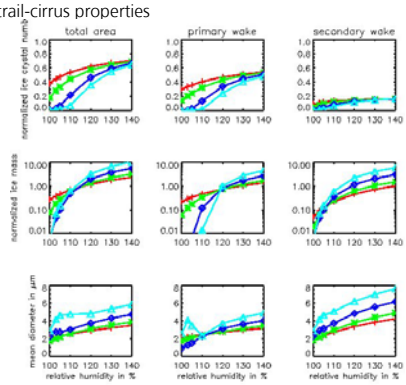
Unterstrasser et al., 2008

CC-Tool
assures realistic vortex decay in 2D

monitors and corrects circulation evolution by increasing diffusion locally

EULAG

Bulk MP



Unterstrasser et al., 2008

Unterstrasser, 2008 (PhD thesis)

Dispersion phase model

T_{sim} = 7000s - 20000s
Δt = 1s - 15s
L =17 - 81km
H = 1.5 - 5km
Δx , Δz = 5 - 20m

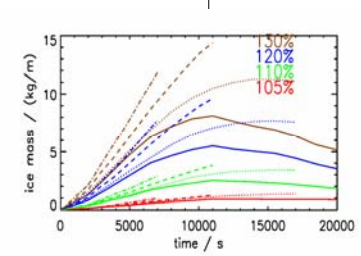
- Include radiation routine
- Simulate contrail to cirrus transition over 6 hours

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

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

EULAG

Bulk MP



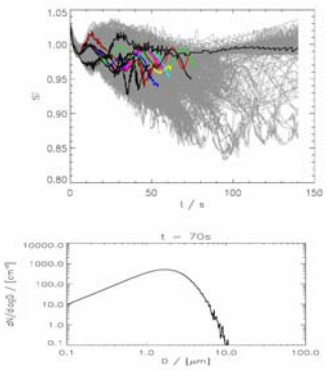
Unterstrasser & Gierens: Contrail to Cirrus transition, Part 1 and Part 2 to be submitted to ACPD
Unterstrasser, 2008 (PhD thesis)

New MP code with Lagrangian ice particle tracking

- Further insight into the life cycle of contrail ice crystals (trajectories)
- Direct simulation of microphysical processes and the crystal size distribution

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, 2009 (PhD thesis)

Selected findings

- The number of ice crystals surviving the vortex phase depends sensitively on relative humidity and temperature
- Substantial spreading of contrails only visible if RH_i > 120%
- Contrails become invisible in a sheared environment with RH_i <110%
- Due to vortex phase crystal loss the average ice crystal size in a contrail-cirrus depends more sensitively on temperature T than on humidity RH_i
- Sedimentation limits lifetime of contrails in absence of synoptic updraft
- Radiation can prolong the lifetime under favourable conditions
- The number of ice crystals formed at t < 1s affects the optical depth and the lifetime of the evolving contrail-cirrus

Acknowledgement

The simulations were carried out on the high performance computing facilities at the ECMWF (special project "Ice supersaturation and cirrus clouds")