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ETH Contributions to VI-ACI (M2/M3)

Peter Spichtinger
& Ulrike Lohmann

ETH Zurich
Institute for Atmospheric
and Climate Science

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Motivation - main question

- Cirrus clouds are important modulators of Earth's radiation budget
- Radiative properties depend crucially on size of ice crystals, i.e. on ice crystal number concentration
- Homogeneous nucleation is dominant ice formation mechanism for cirrus clouds (in terms of number concentration)
- Heterogeneous nucleation can modify homogeneous nucleation

How can IN influence homogeneous nucleation depending on

- external vs. internal mixtures of INs and/or
- size-dependent nucleation thresholds ?

Model setup - general

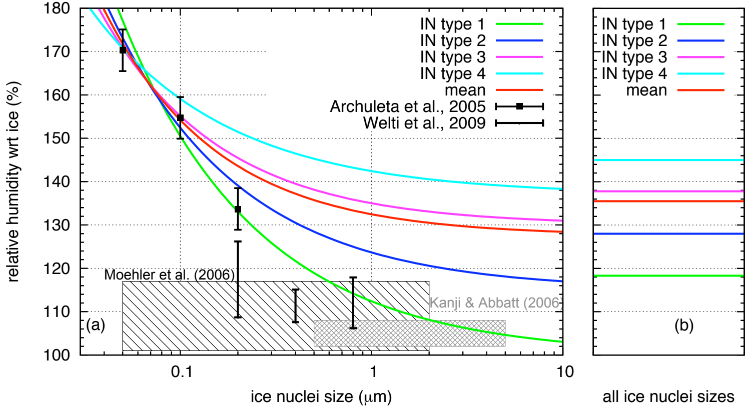
- Boxmodel including bulk ice microphysics (Spichtinger & Gierens, 2009a):
  - homogeneous/heterogeneous nucleation
  - diffusional growth/evaporation
  - sedimentation (Spichtinger & Cziczo, 2010)
- Constant vertical updraft: $w = 0.05/0.10/0.15/0.20$ m/s
- Simulation time (depending on w): 600/300/200/150 min.
- Inital temperature: $T_{init} = 240/230/220/210$ K
- Different sedimentation regimes:
  - $f_{sed} = 0.5$ strong fallout, i.e. representative for cloud top
  - $f_{sed} = 0.9$ weak fallout, i.e. representative for middle of cloud

Setup and results are described in details in:

Spichtinger & Cziczo, 2010, JGR, doi:10.1029/2009JD012168, in press

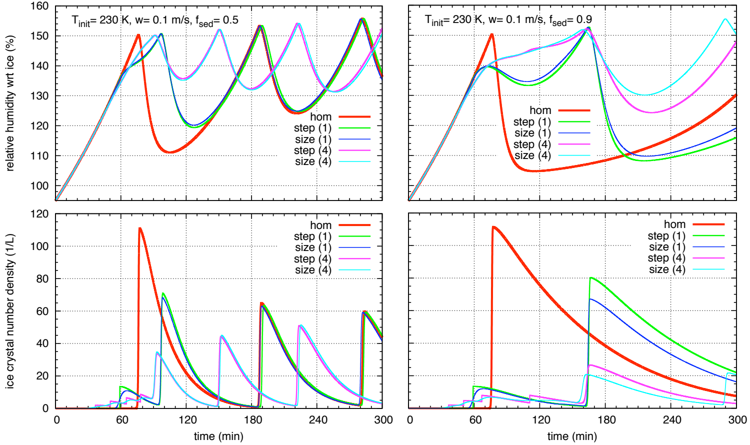
Model setup - heterogeneous nucleation

Different types of INs - size-dependent freezing thresholds



- lognormal size distribution for IN, $L_m = 0.5\,\mu$m, $\sigma_L = 1.4$
- external mixture: $N_{IN,i=1\ldots4} = 2/3/4/5\ \mathrm{L}^{-1}$
- internal mixture: $N_{IN} = 14\ \mathrm{L}^{-1}$

Normal background: $N_{IN} = 14\ \mathbf{L}^{-1}$



- Time shift/phase change
- Delayed recovery of nucleation events

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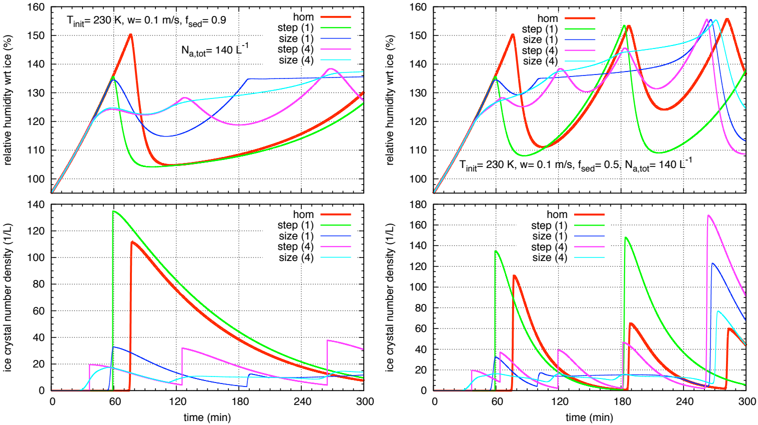
Polluted background: $N_{IN} = 140\ \mathrm{L}^{-1}$



Normal background - summary

$f_{sed} = 0.5$	240 K	230 K	220 K	210 K
0.05 m/s	size	num/size	num	no/num
0.10 m/s	size	num	no	no
0.15 m/s	size	no/num	no	no
0.20 m/s	num/size	no/num	no	no
$f_{sed} = 0.9$	240 K	230 K	220 K	210 K
0.05 m/s	size	size	num/size	num
0.10 m/s	size	size	num	no
0.15 m/s	size	num/size	no	no
0.20 m/s	size	num	no	no

no = no impact of external mixtures and size effects

num = impact of external mixtures visible

size = impact of size-dependent thresholds visible

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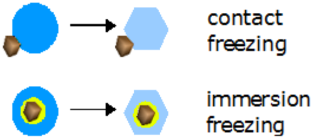
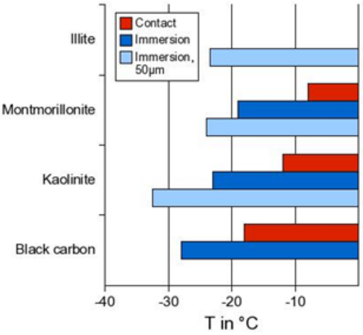
Heterogeneous freezing

- -38 °C<T<0 °C: ice nucleus is required for freezing
- In ECHAM5-HAM: contact and immersion freezing, dust and black carbon



- coated material: only immersion freezing
- IN efficiencies depend on material and drop volume



Median freezing temperatures for different IN from lab experiments. Drop radii 250-350 µm. Adapted from *Diehl et al. (2006)* and *Hoffer (1961)*.

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Sensitivity Simulations with ECHAM5

- 1-year nudged simulations with ECHAM5 (Roeckner et al., 2003) in T42L19 coupled to the M7 aerosol scheme (Stier et al., 2005)
- Internally mixed dust and BC aerosols act as immersion nuclei while externally mixed dust and BC aerosols act as contact nuclei (Hoose et al., 2008)
- Condensation of sulfate on dust and BC can transfer them from the externally mixed to the internally mixed aerosol modes
- Revised treatment of the Bergeron-Findeisen (BF) process: restricted to $e_i < e < e_s$ or $w < w^*$, where $w^* = \frac{e_s - e_i}{e_i} N_i \overline{r_i} \eta$ accounts for the time of ice crystal growth at the expense of cloud droplets
- Rerun each simulation with pre-industrial (1750) aerosol emissions

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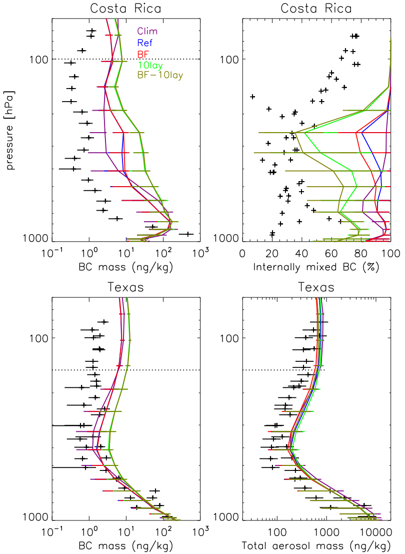
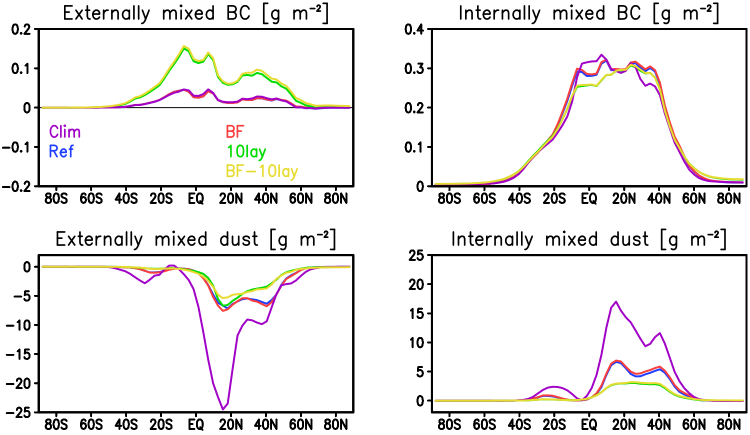
Vertical aerosol profiles

Sensitivity simulations

Sim.	Description
Ref	Nudged sim. with ECHAM5-HAM
Clim	10-yr clim. sim.
10lay	As Ref, but SO_4-crit = 10 mono-layers
BF	As Ref, but revised Bergeron-Findeisen (BF) process
BF-10lay	As 10lay, but revised BF process



Changes in aerosol burden since pre-industrial times



Lohmann and Hoose, ACP, 2009

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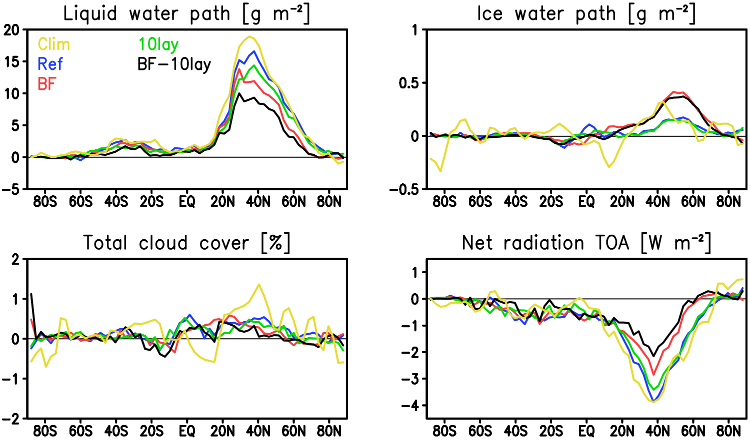
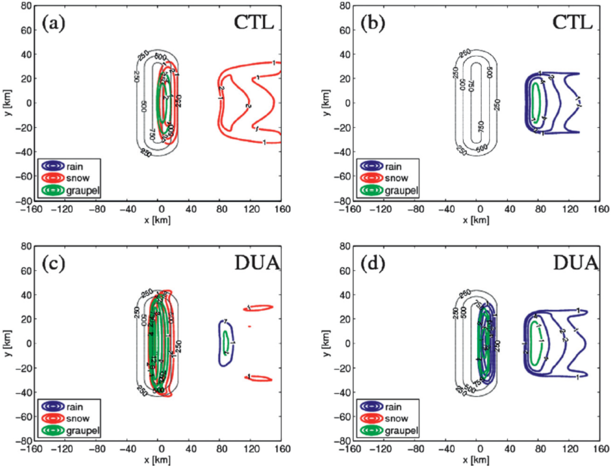
Anthropogenic aerosol effect



Lohmann and Hoose, ACP, 2009

Impact on mixed-phase precipitation



Left: cold sim., right: warm sim. (Muhlbauer & Lohmann, JAS, 2009)

Impact on mixed-phase precipitation

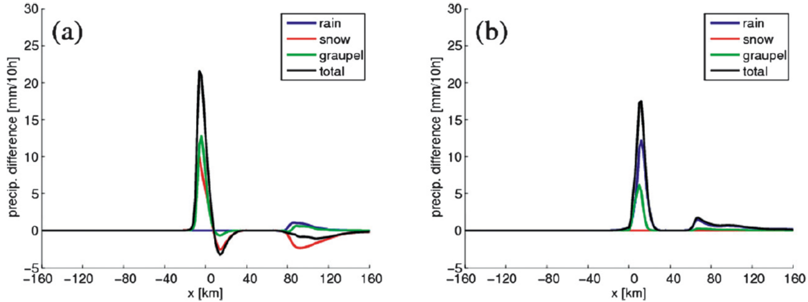
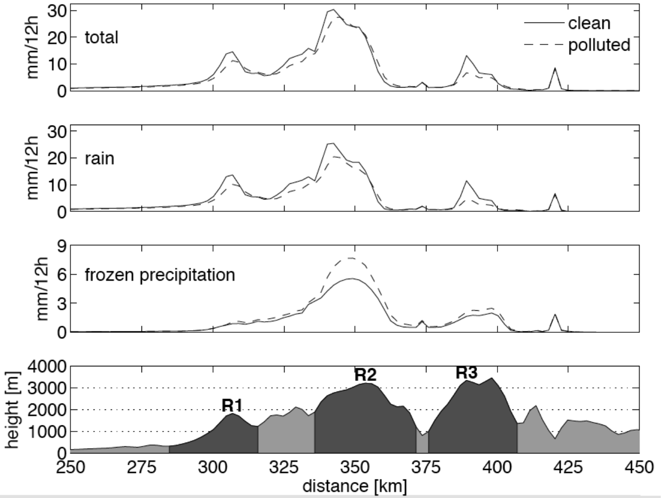


FIG. 9. Precipitation difference at the center line for experiment A after 10 h. Shown is the precipitation difference (DUA − CTL) of rain (blue), snow (red), graupel (green), and total precipitation (black) for the simulations (a) T_{sl} = 273 K and (b) T_{sl} = 280 K, respectively.

Dust anomaly causes earlier freezing → more riming → more precip. (Muhlbauer & Lohmann, JAS, 2009)

Impact on precipitation



(Zubler et al., subm. to JAS)

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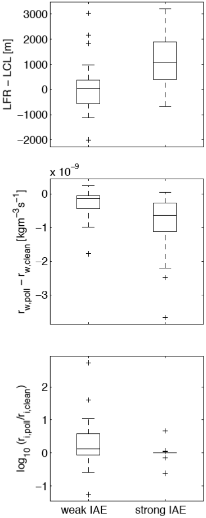
Impact on precipitation



Main findings:

- 23% less rain in polluted cases
- 17% more rain in the cold subset of the polluted cases
- 3.5-5% more precipitation spills over to the leeward side in the polluted cases

(Zubler et al., subm. to JAS)

Conclusions

Cirrus clouds:

- IN always influence homogeneous freezing events
- External vs. interal mixture matters for 'warmer' temperatures and/or lower vertical velocities
- A size-dependent vs. fixed nucleation threshold is important for 'warmer' temperatures and/or lower vertical velocities

Mixed-phase clouds:

- The glaciation effect in stratiform mixed-phase clouds in ECHAM5 amounts to between 0.12 to 0.2 W m^{-2}. It is also positive in COSMO simulations
- However, large uncertainties regarding the ice nucleating efficiencies, especially of black carbon, remain