M3E: Impact of natural and anthropogenic ice nuclei on global cirrus properties

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Ice nucleation parameterization in ECHAM

Parameterization of ice formation ($T < T_{hom}$)

Input

- Pre-existing ice: N, R of different ice types
- Aerosol: N, R, σ of different modes / types
- Meteorological parameters: p, T, rh_{ice}
- Vertical velocity: v + v‘
- Δt of driving model

→ **Nucleation and growth**

Competition of different ice types

Kärcher et al. (2006)

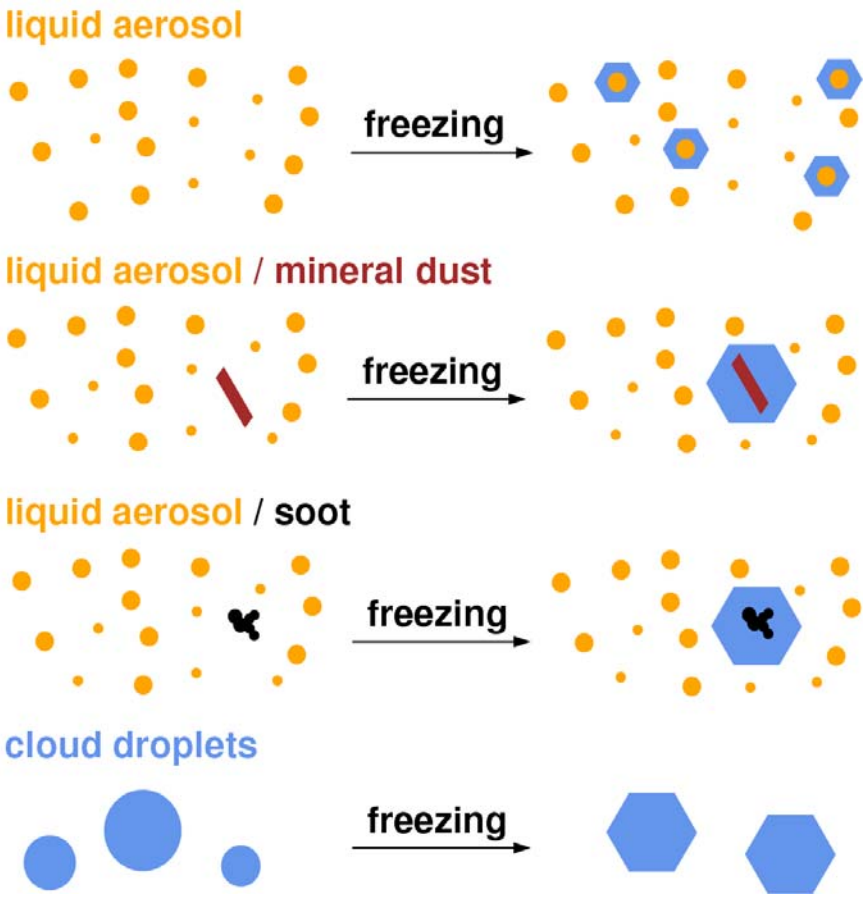
→ **Output**

- Modified ice: N, R of different ice types
- Modified aerosol: N, R, σ of different modes / types

Critical rh(ice) for nucleation

dust: e.g. 130% (variable)
BC: e.g. 120% (variable)
hom.: > ~143% (Koop et al.)

Ice formation mechanisms in multi-modal ECHAM cloud scheme



homogeneous freezing

heterogeneous nucleation on mineral dust

heterogeneous nucleation on soot

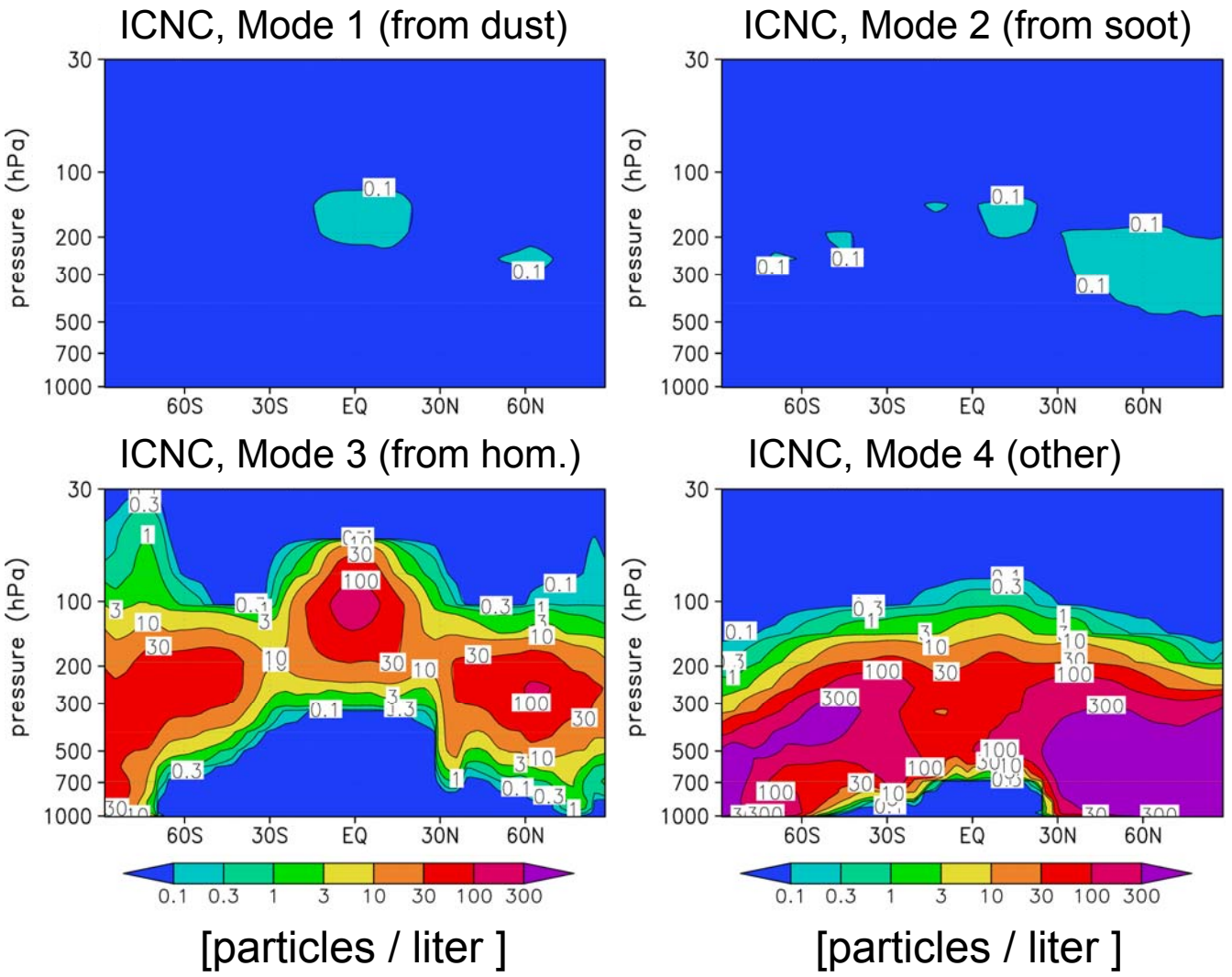
freezing of cloud droplets (different mechanisms)

Multi-modal ice microphysics in ECHAM

ECHAM4 version;
Multi modal ice;
Kärcher et al. (2006) parameterization

Zonal mean ice crystal number concentration
[particles / liter]
Cloudy and clear sky mean

10-year simulation



Global modelling of soot/dust impact on cirrus

ECHAM4: Global effect of heterogeneous IN (BC, dust) on cirrus:

Simulations:

HOM: N(IN) = 0, homogeneous freezing only

HET: $N(IN) = N(IN_{background})$

HETA: $N(IN) = N(IN_{background}) + N(IN_{aircraft})$

$RHi_{crit,BC}$ = 120%, $RHi_{crit,dust}$ = 130%

Activation fraction: 0.25% (BC), 1% (dust), → N(IN) observed, SUCCESS
10% (BC from aircraft) Rogers / Chen et al. (1998)

ECHAM4 / T30L19

Hendricks et al. (2005) configuration

10 model years

Global modelling of soot/dust impact on cirrus

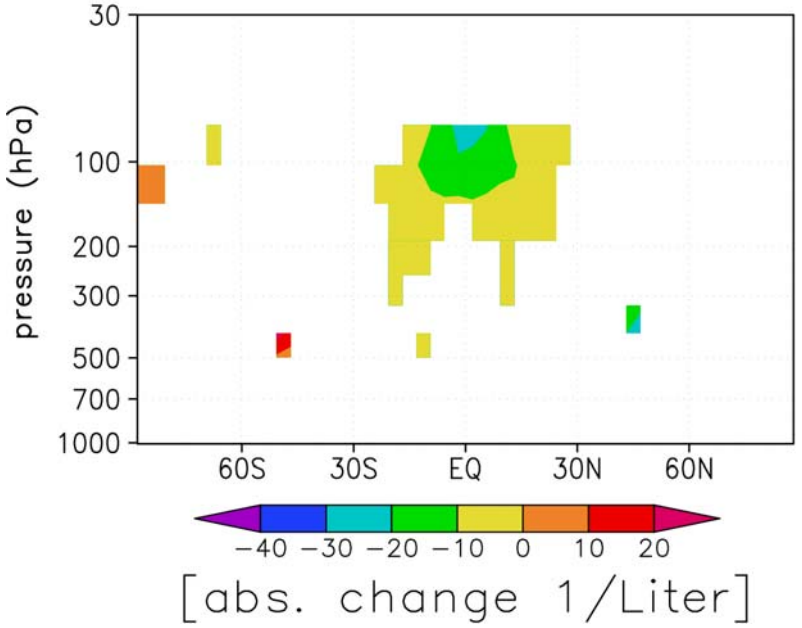
ECHAM4: Global impact of heterogeneous IN (BC+dust) on ice clouds

Impact of ‚background IN'
(HET – HOM)

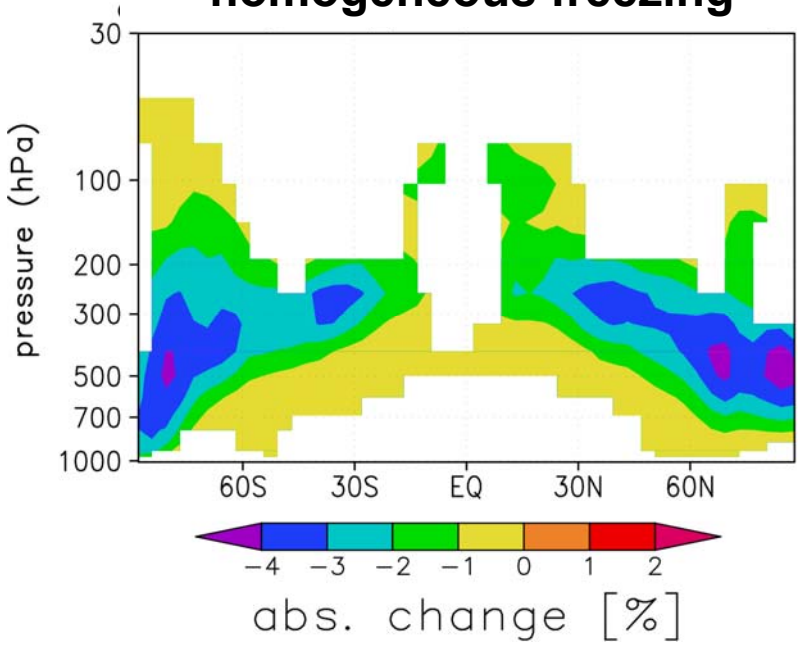
Global modelling of soot/dust impact on cirrus

ECHAM4: Global impact of heterogeneous IN (BC+dust) on ice clouds

Δ N(ice), cloudy + clear sky mean



Δ frequency of ice from homogeneous freezing



Annual mean zonal averages (10 model years)

Significance level: 90% (t-test)

Heterogeneous freezing significantly reduces N(ice) in tropical UT and frequency of ice formed by homogeneous nucleation in midlatitudes!

Δ N(ice) in midlatitues ?

Global modelling of soot/dust impact on cirrus

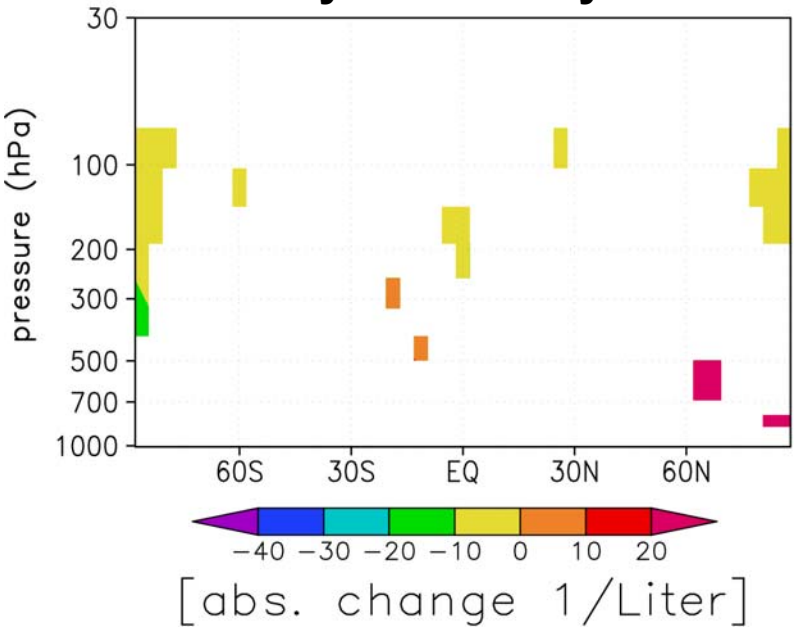
ECHAM4: Global impact of heterogeneous IN (BC+dust) on ice clouds

Impact of IN from aircraft
(HETA – HET)

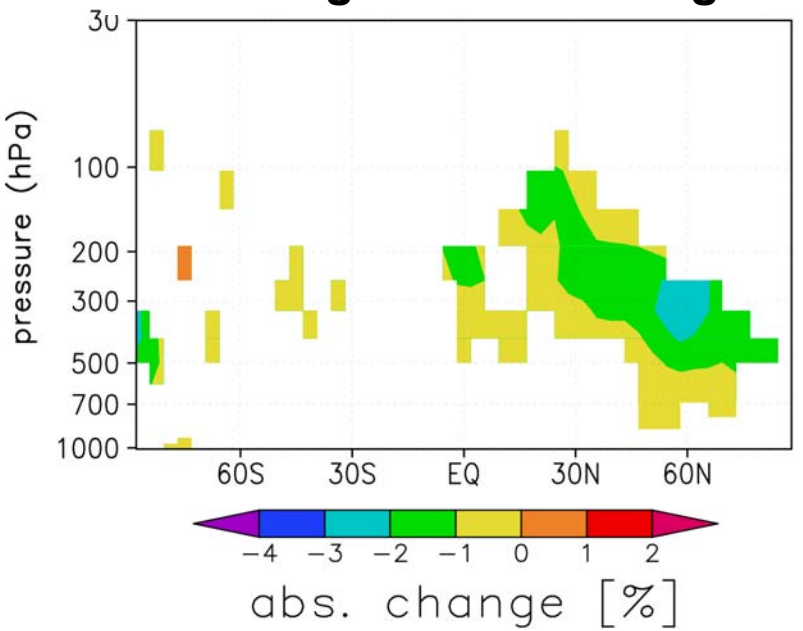
Global modelling of soot/dust impact on cirrus

ECHAM4: Global impact of aircraft BC on ice clouds

Δ N(ice), Cloudy + clear sky mean



Δ frequency of ice from homogeneous freezing



Annual mean zonal averages (10 model years)

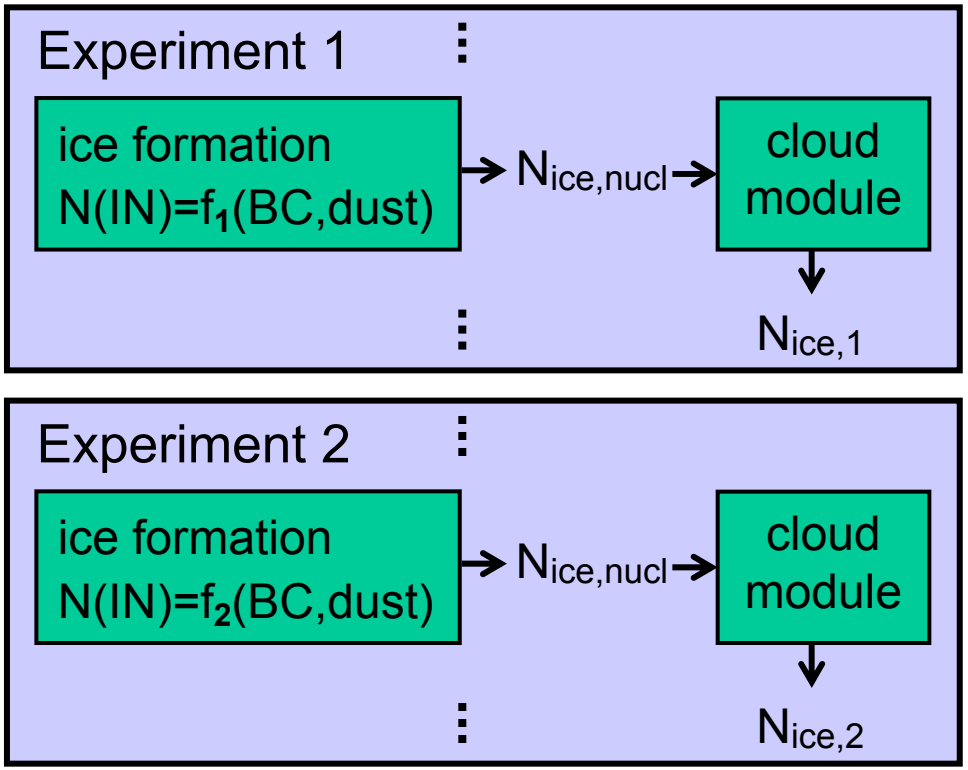
Significance level: 90% (t-test)

Heterogeneous freezing on aircraft BC significantly reduces frequency of ice formed by homogeneous nucleation in northern midlatitudes!

Corresponding changes in N(ice) ?

Global modelling of BC/dust impact on cirrus

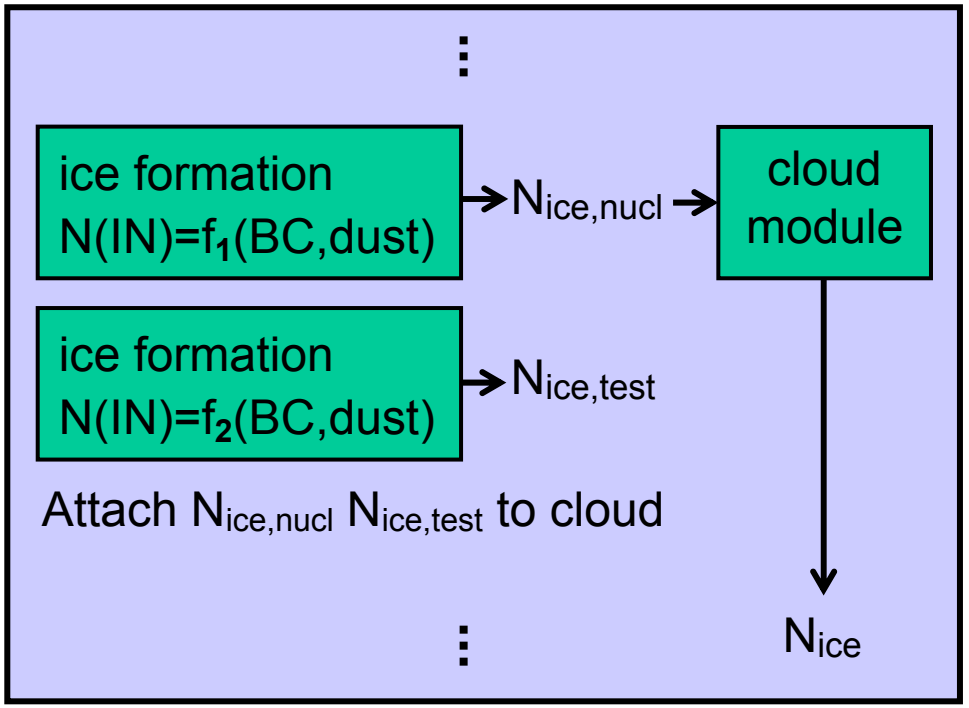
Standard method



→ ***Difference:***

$\Delta N_{ice} = N_{ice,2} - N_{ice,1}$

New method

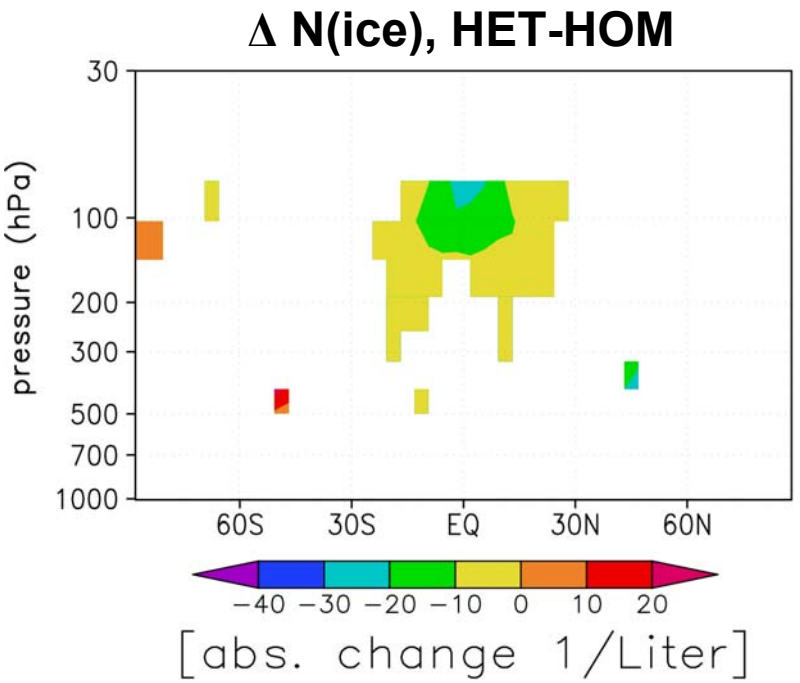


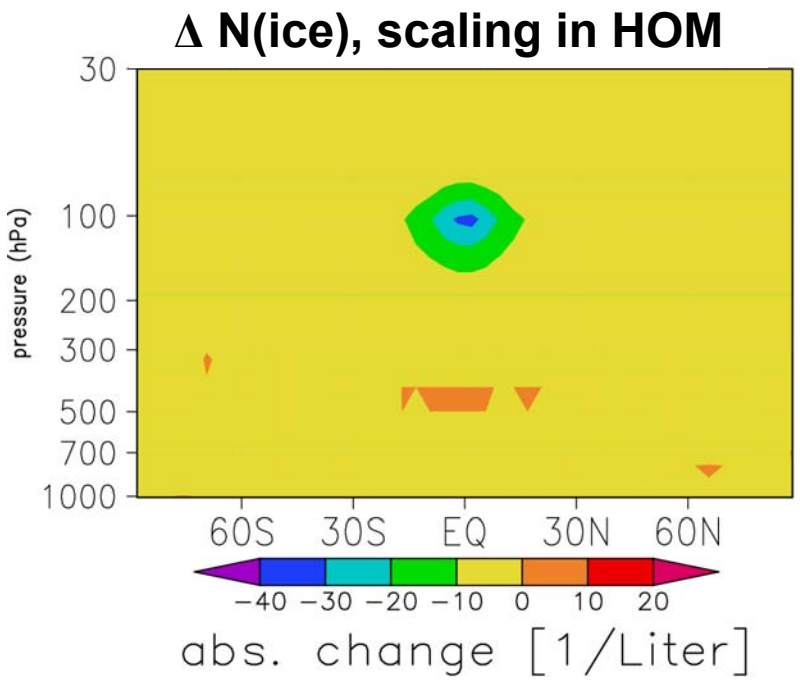
→ ***Scaling:***

$\Delta N_{ice} = N_{ice} \times (N_{ice,test} / N_{ice,nucl} - 1)$

Global modelling of soot/dust impact on cirrus

ΔN(ice) due to background IN, cloudy + clear sky mean





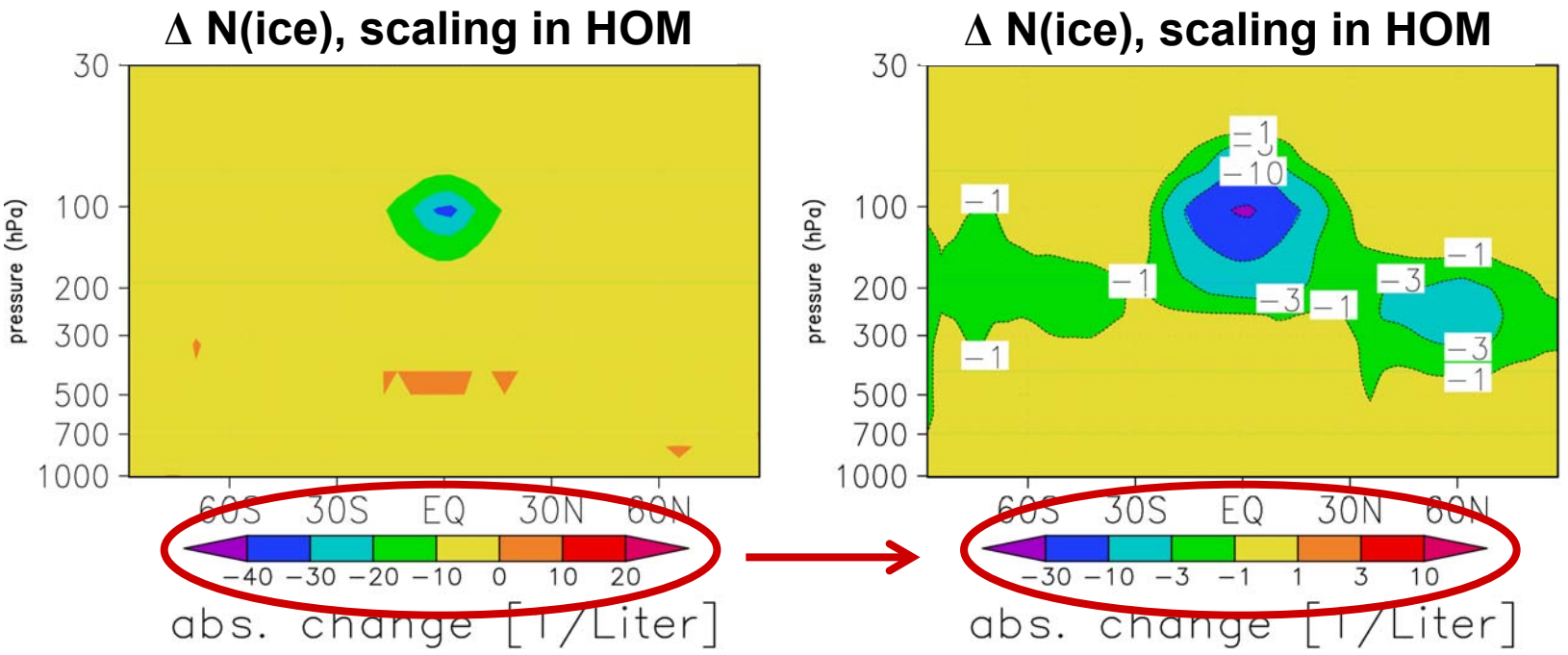
Annual mean zonal averages (10 model years)
Significance level (HET-HOM): 90% (t-test)

Scaling leads to similar signal as difference HET-HOM.

Reasons for discrepancies: sedimentation, ageing.

Global modelling of soot/dust impact on cirrus

ΔN(ice) due to background IN, cloudy + clear sky mean



Annual mean zonal averages (10 model years)

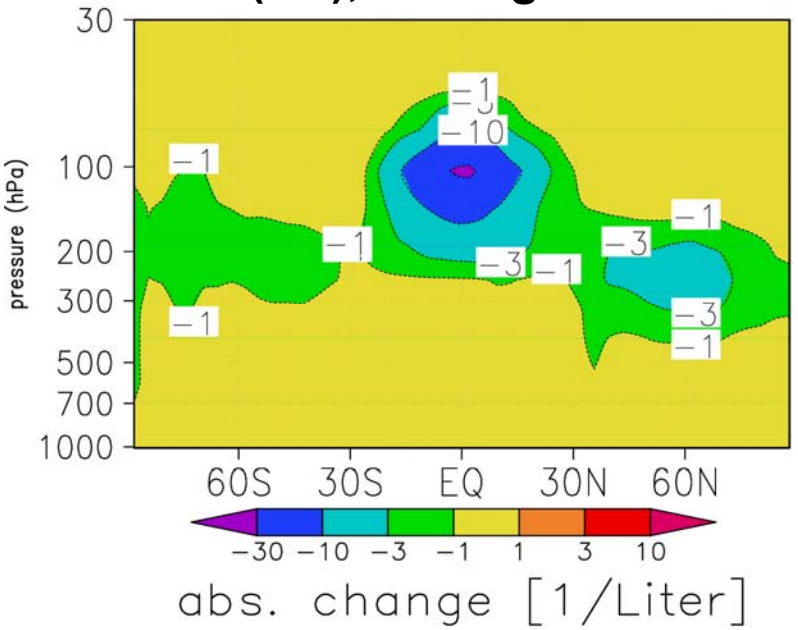
Scaling highlights potential midlatitude effect !

Global modelling of soot/dust impact on cirrus

ΔN(ice) due to IN, cloudy + clear sky mean

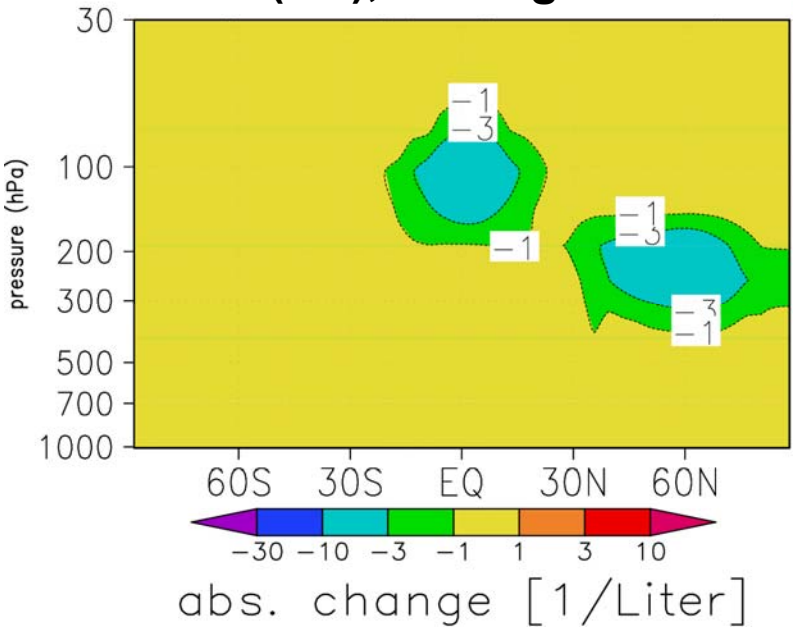
Effect of background IN

Δ N(ice), scaling in HOM



Effect of aircraft BC

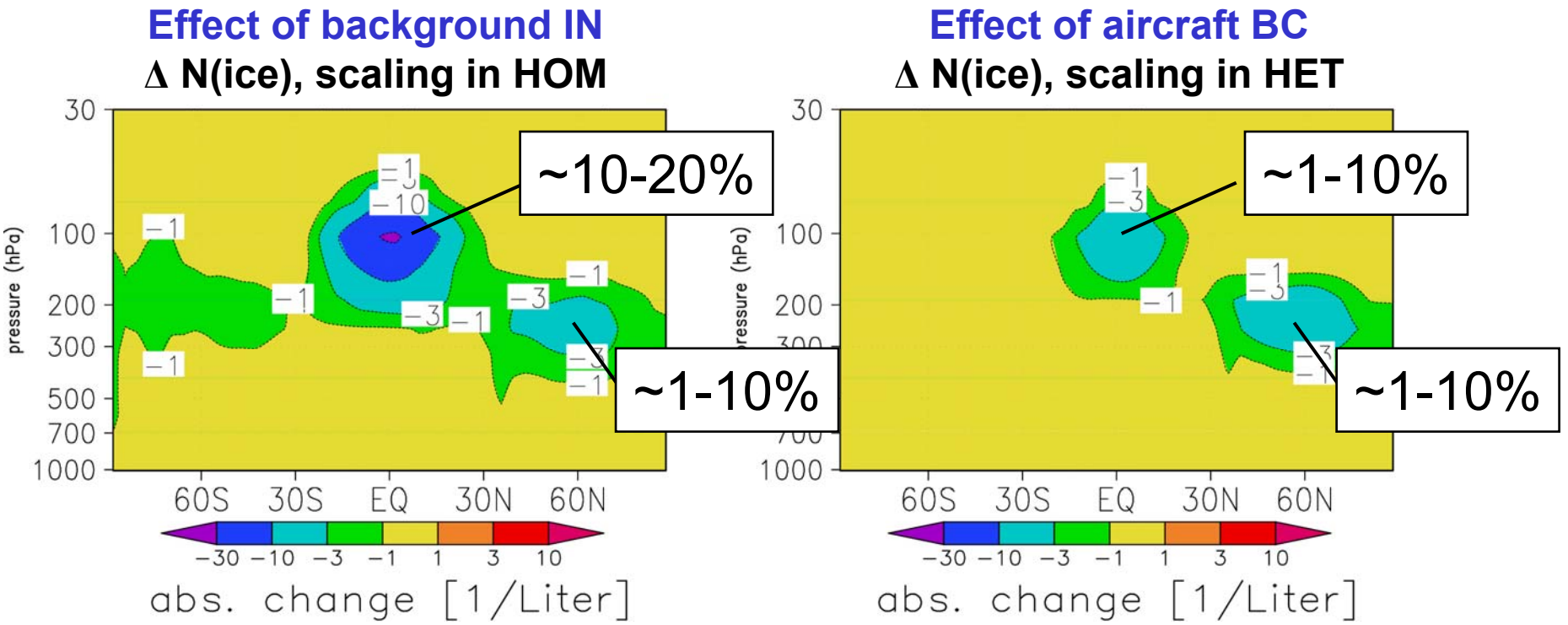
Δ N(ice), scaling in HET



Annual mean zonal averages (10 model years)

Global modelling of soot/dust impact on cirrus

ΔN(ice) due to IN, cloudy + clear sky mean



Annual mean zonal averages (10 model years)

Global modelling of soot/dust impact on cirrus

Conclusions

- ECHAM simulations suggest reduction in mean ice crystal number concentration in cirrus due to heterogeneous nucleation on BC / mineral dust:
  - Background effect: $\Delta N_{ice} \sim -$ 1-10 % in midlatitudes
    $\Delta N_{ice} \sim -$ 10 - 20 % in tropics
  - Aviation effect: $\Delta N_{ice} \sim -$ 1-10 % in NH midlatitudes and tropics
- Enhanced sedimentation due to heterogeneous nucleation causes reductions in ice water content and water vapour.
- Liu et al. (2009) simulate larger aviation effect on crystal number, with opposite sign.
- Effect strongly sensitive to assumptions on ice formation efficiency of heterogeneous IN (e.g. BC, dust particles).
- Data from laboratory / field measurements essential to reduce uncertainties.

Global model studies on the distribution and composition of potential atmospheric ice nuclei

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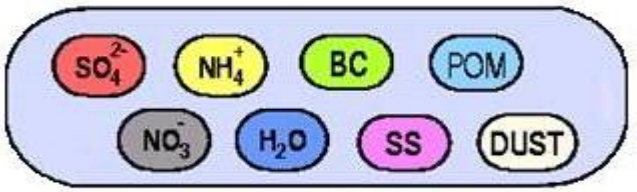
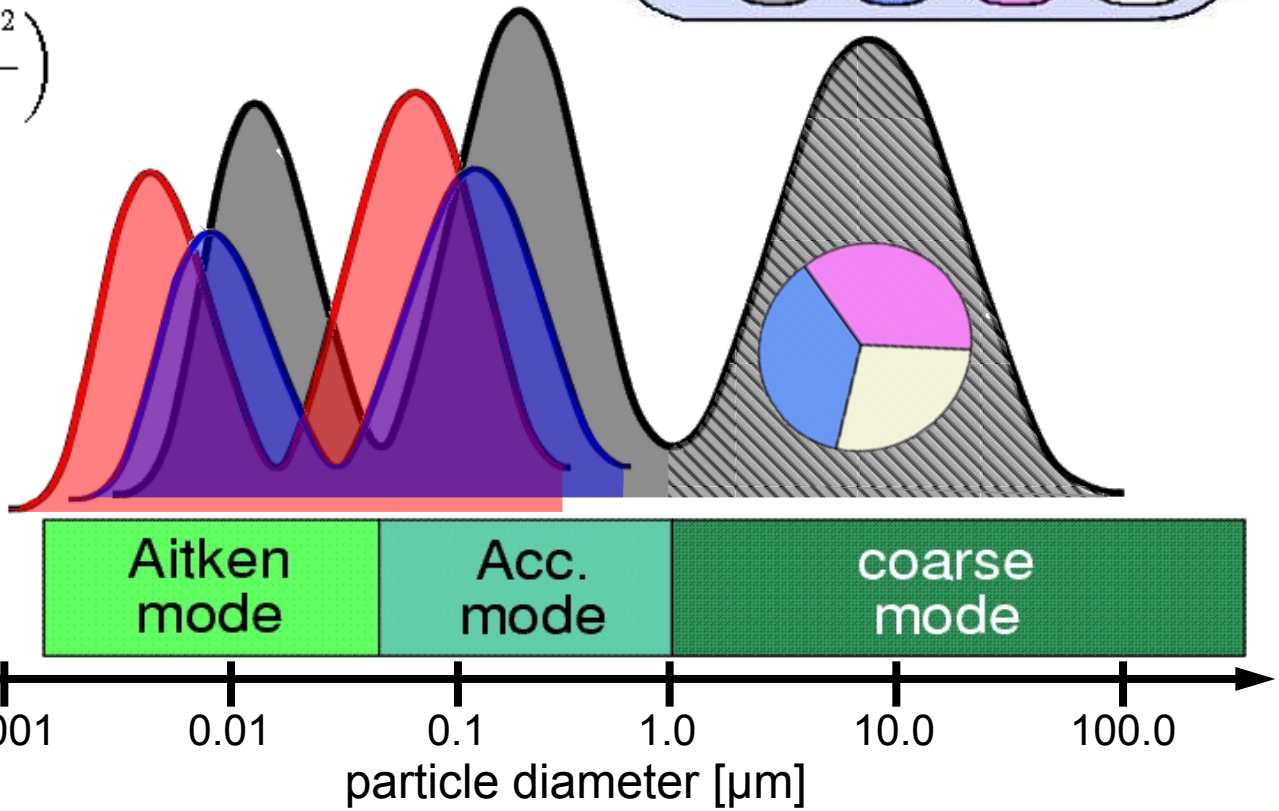
A new aerosol module: MADE*soot*

$$n(d) = \frac{N}{\sqrt{2\pi}\ln\sigma_g}\exp\left(-\frac{1}{2}\frac{(\ln d - \ln d_g)^2}{\ln^2\sigma_g}\right)$$



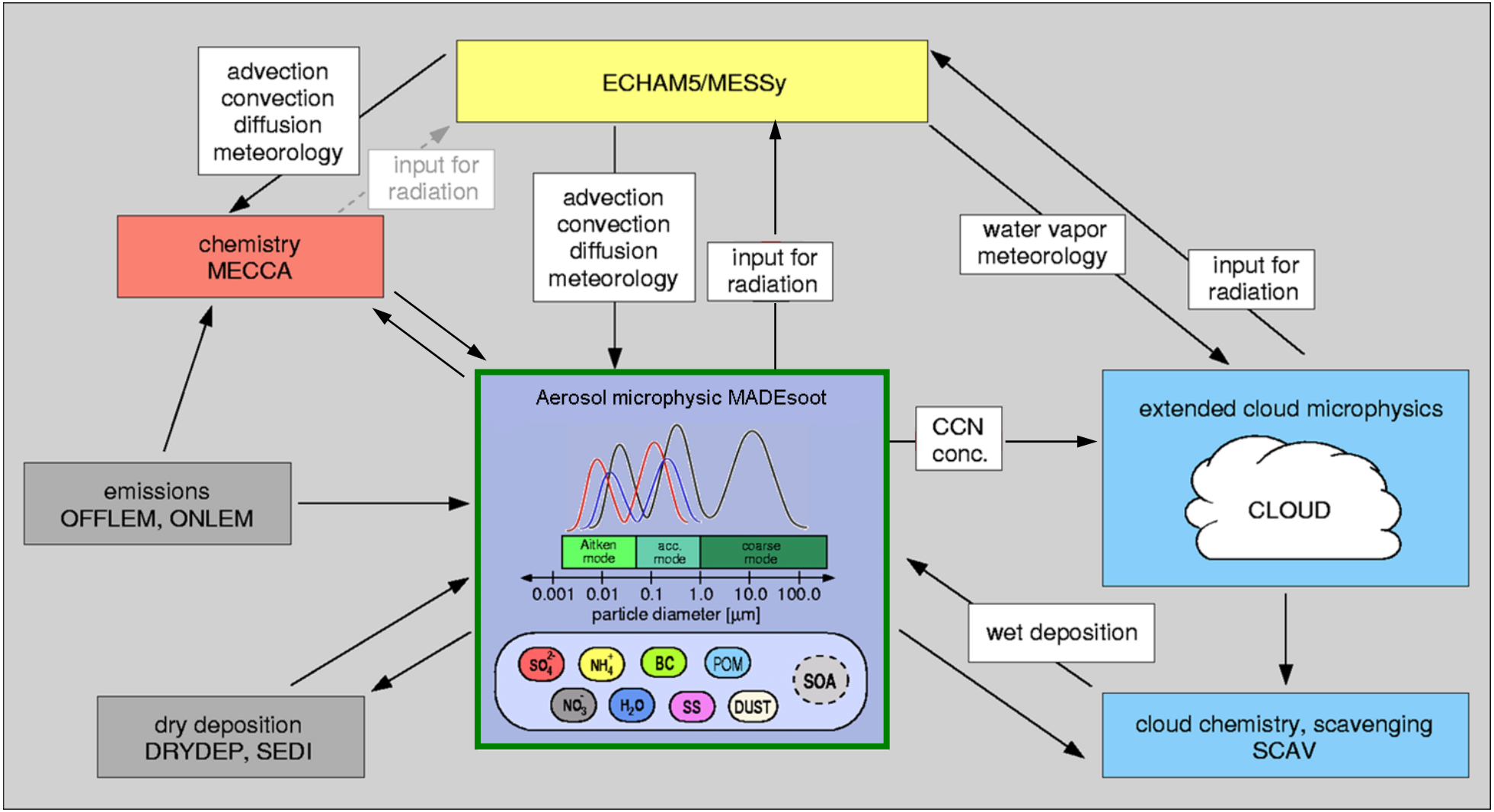


Internally mixed soluble particles

Externally mixed insoluble particles

Internally mixed particles with an insoluble core

ECHAM5/MESSy-MADE*soot*



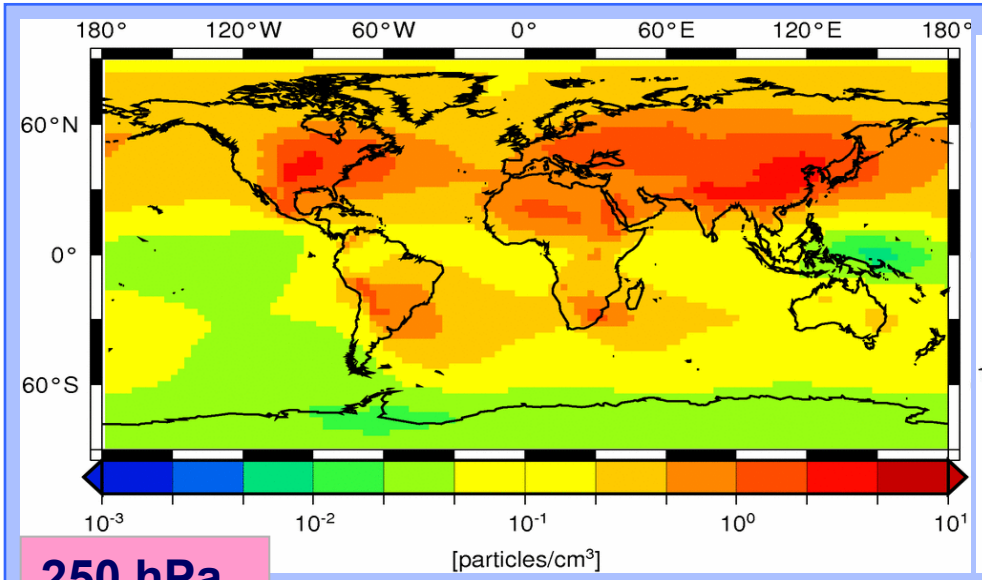
ECHAM5: Roeckner et al., *MPI-Report No.349*

MESSy: Joeckel et al., 2005 (*ACP*)

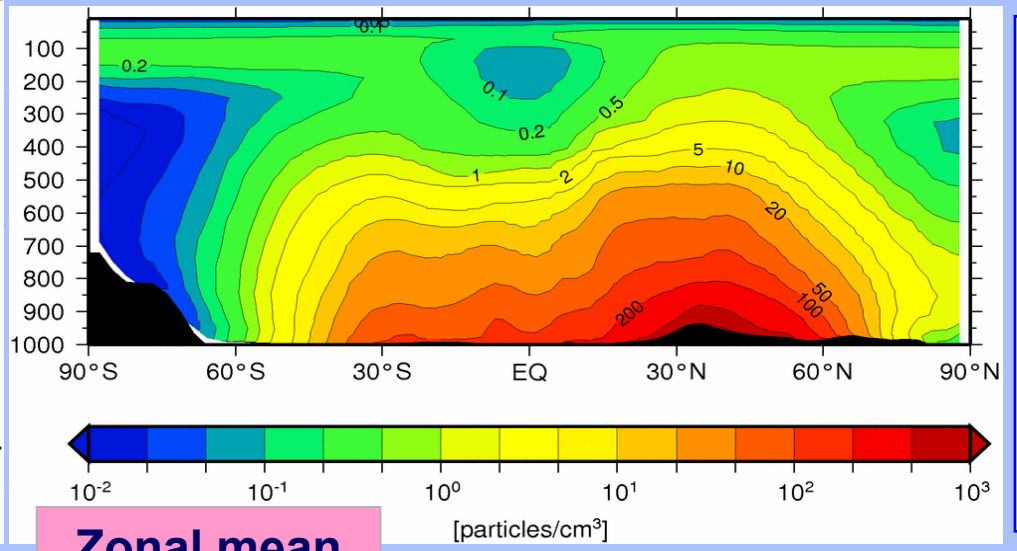
MADE: Ackermann et al., 1998 (*AE*)

ECHAM5/MESSy-MADE*soot*: Model results

Number concentration of potential IN (dust + BC)

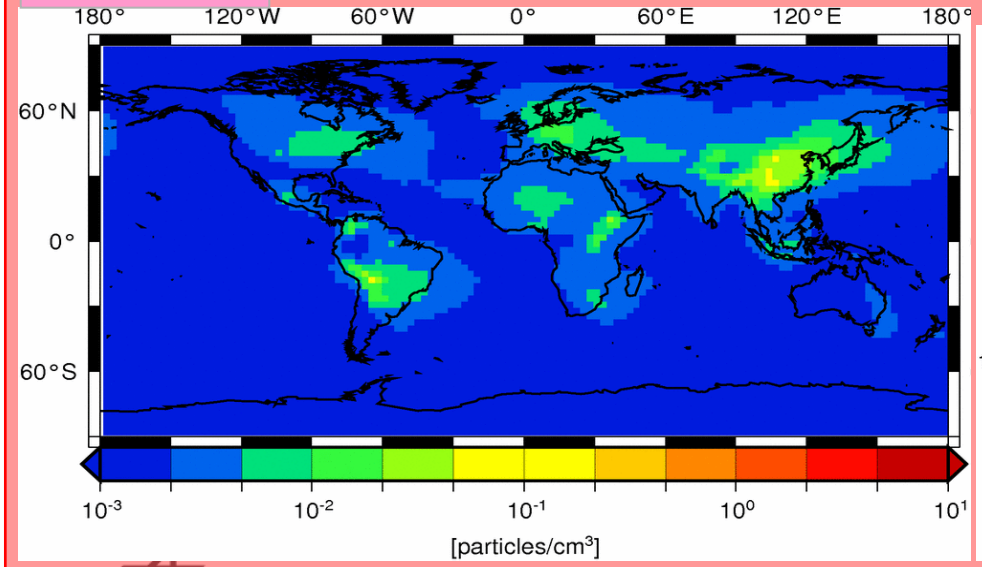


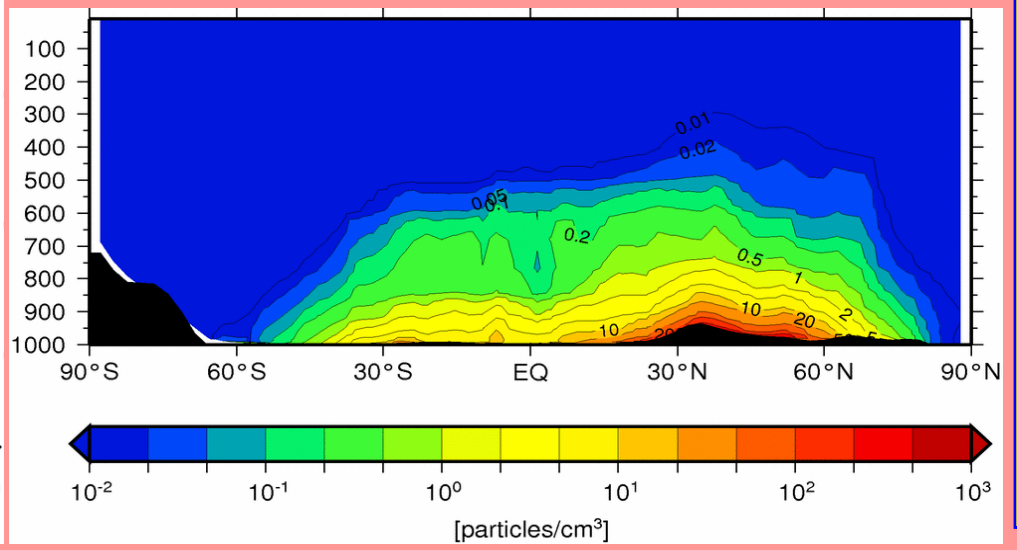
250 hPa



Zonal mean

Internally mixed





Externally mixed