



# **Aerosol-cirrus interactions in the ECHAM-GCM: The competition between homogeneous and heterogeneous ice nucleation (WP M3)**

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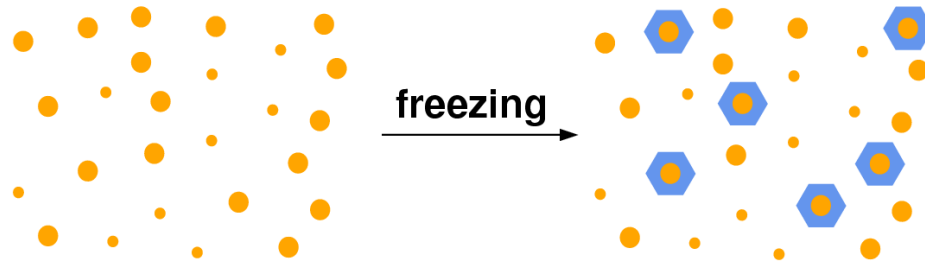
**Thanks:** Bernd Kärcher, Valentina Aquila (DLR-IPA)  
Ulrike Lohmann (ETH-Zurich)



# Global impact of BC from aviation on cirrus clouds ?

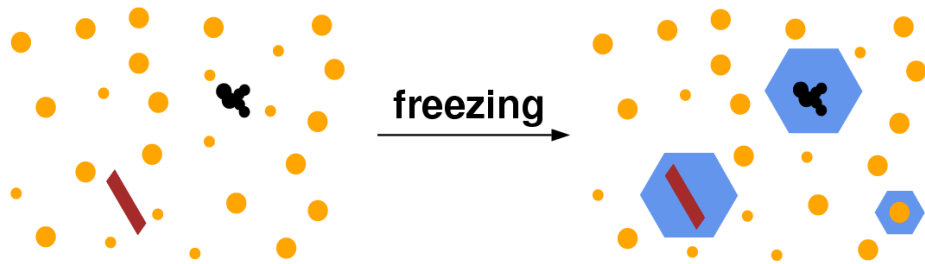
aviation → BC particles → ice clouds → climate

liquid aerosol



homogeneous  
nucleation

liquid aerosol / soot / mineral dust



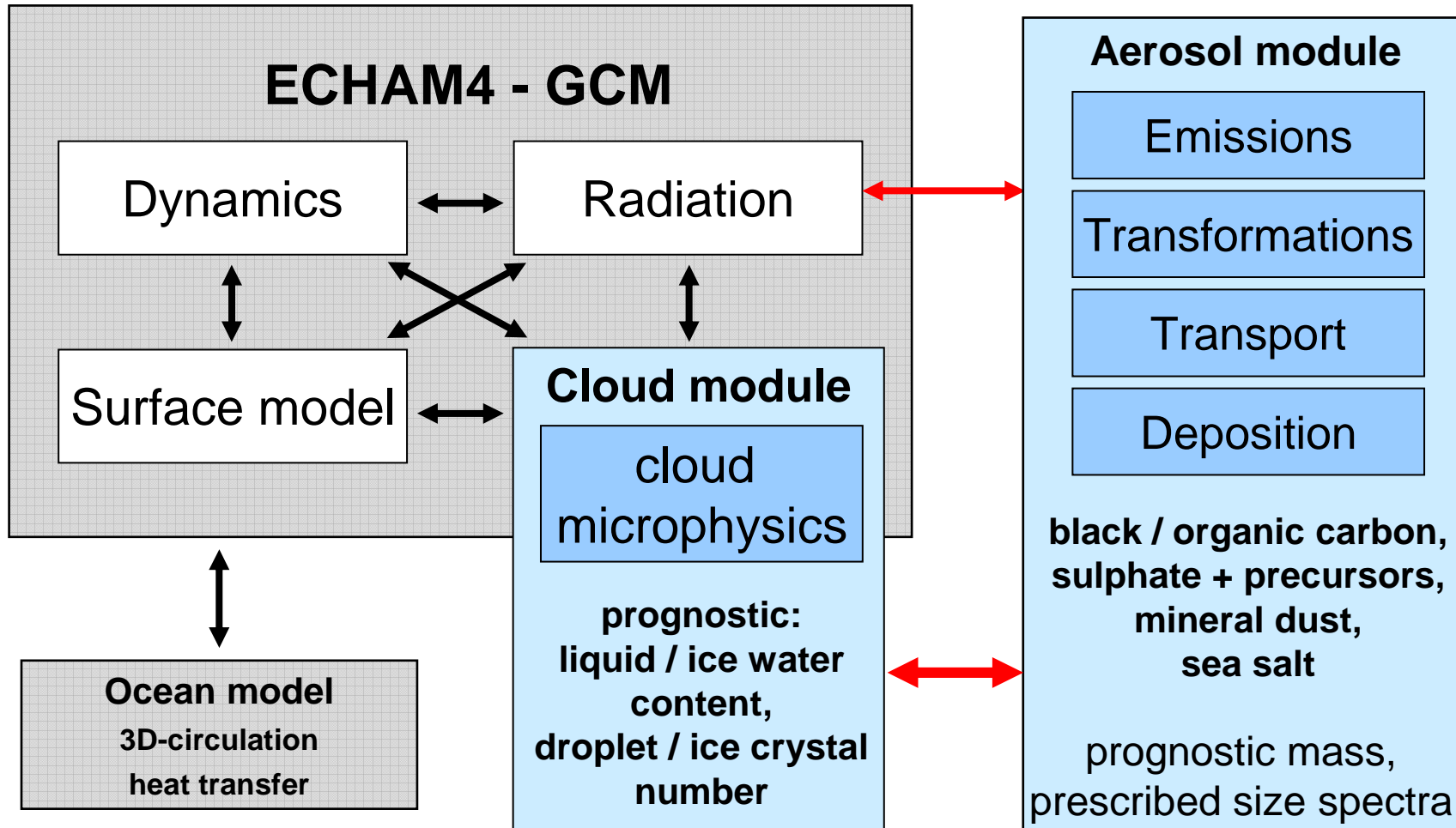
heterogeneous  
nucleation

aircraft → ∙ ∙





## ECHAM4 / AEROSOL / CLOUD - model set up

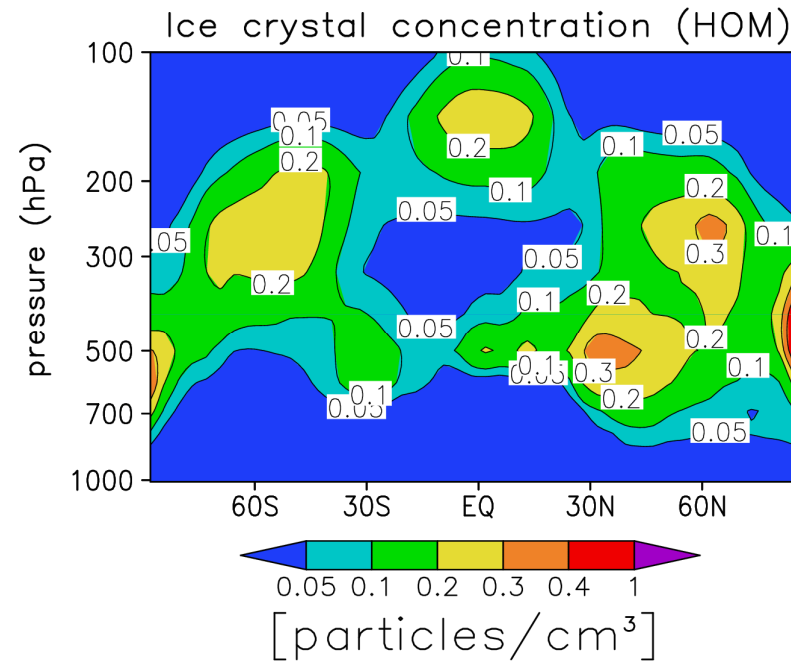
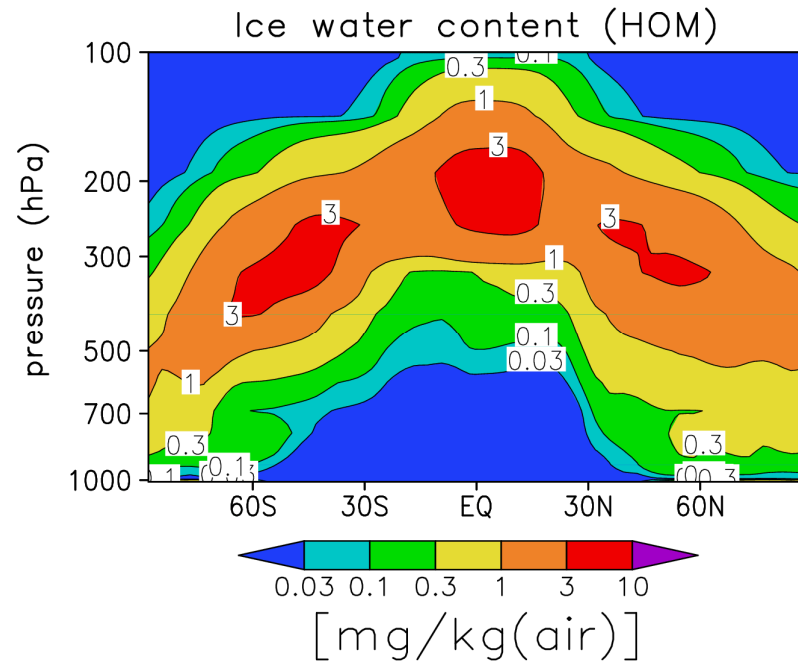


Thanks to: U.Lohmann (ETH-Zurich), J.Feichter (MPI, Hamburg)



# ECHAM4 / AEROSOL / CLOUD - simulation

## Annual mean ice cloud properties



**! Cloud free periods included**

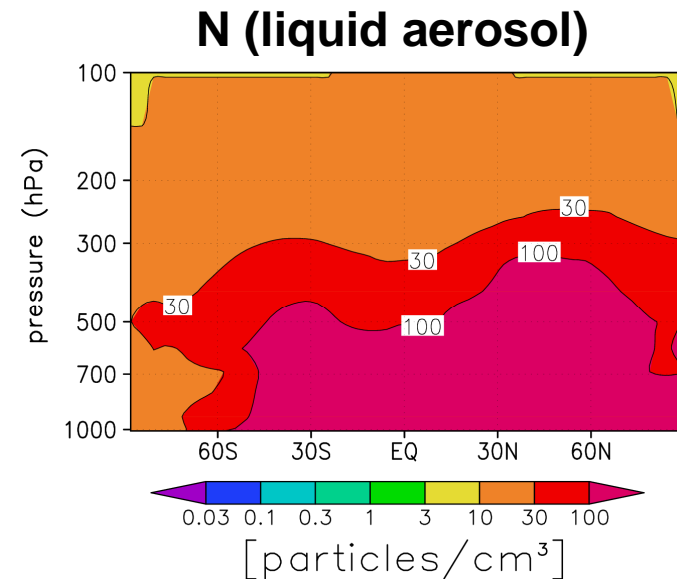
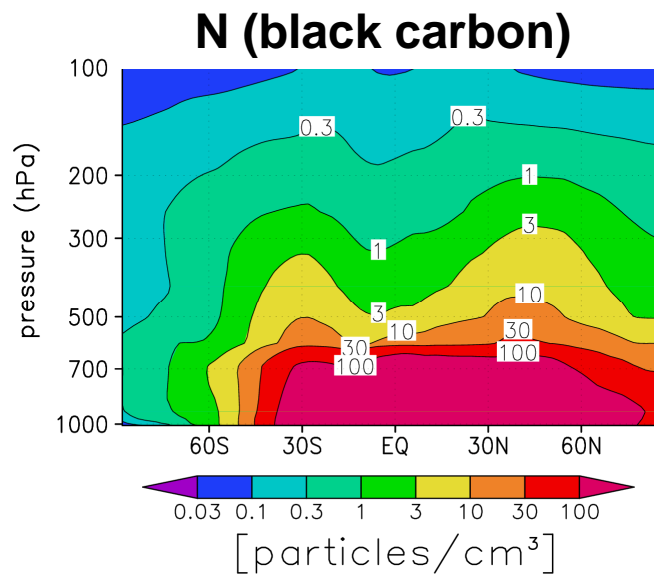
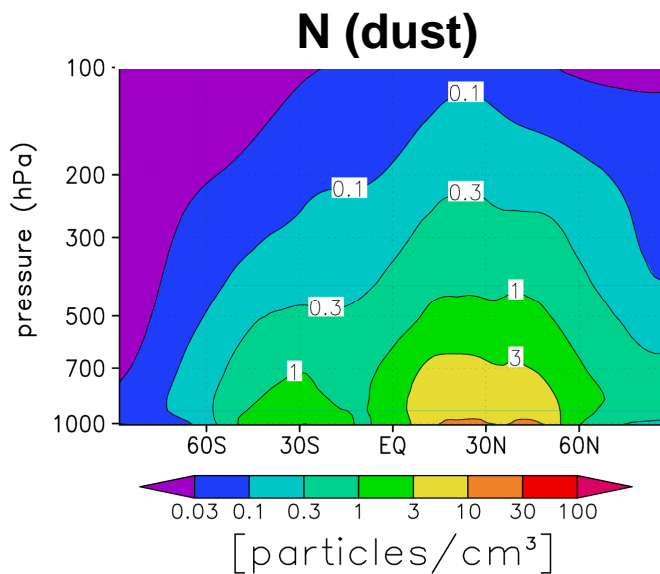
10 year averages

Hendricks et al. (2005)



# Ice forming aerosols in ECHAM

Annual zonal mean aerosol number concentration in ECHAM4  
(estimated from mass conc.)



Hendricks et al. (ACP, 2004)



# Aerosol impact on cirrus clouds

## SCENARIO 1

Cirrus forms by  
**heterogeneous nucleation**

## SCENARIO 2

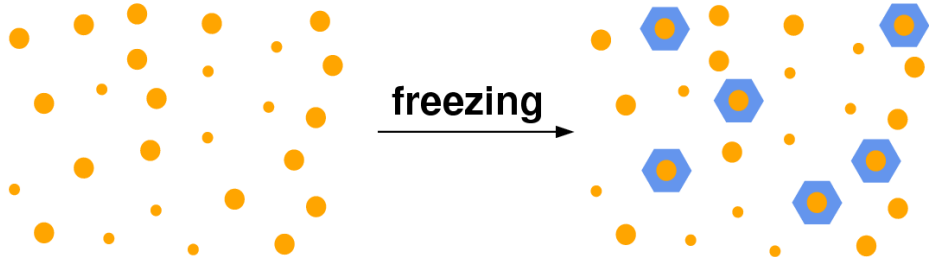
Cirrus forms by  
**homogeneous nucleation**



# Global impact of BC from aviation on cirrus clouds ?

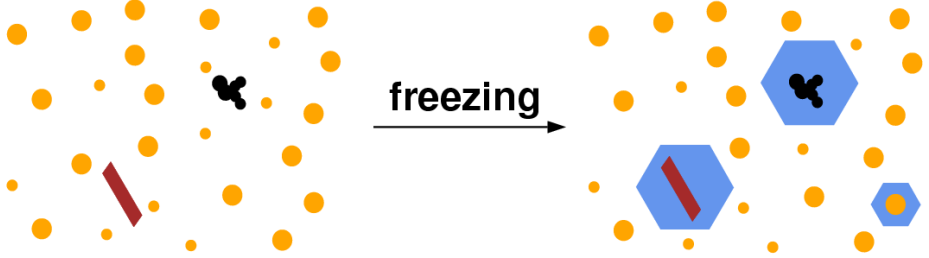
aviation → BC particles → ice clouds → climate

liquid aerosol



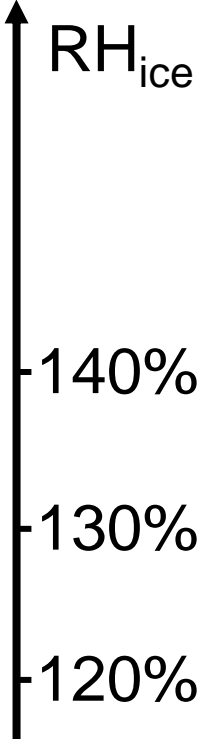
homogeneous nucleation

liquid aerosol / soot / mineral dust



heterogeneous nucleation

aircraft → ••







# Aerosol impact on cirrus clouds

## SCENARIO 3

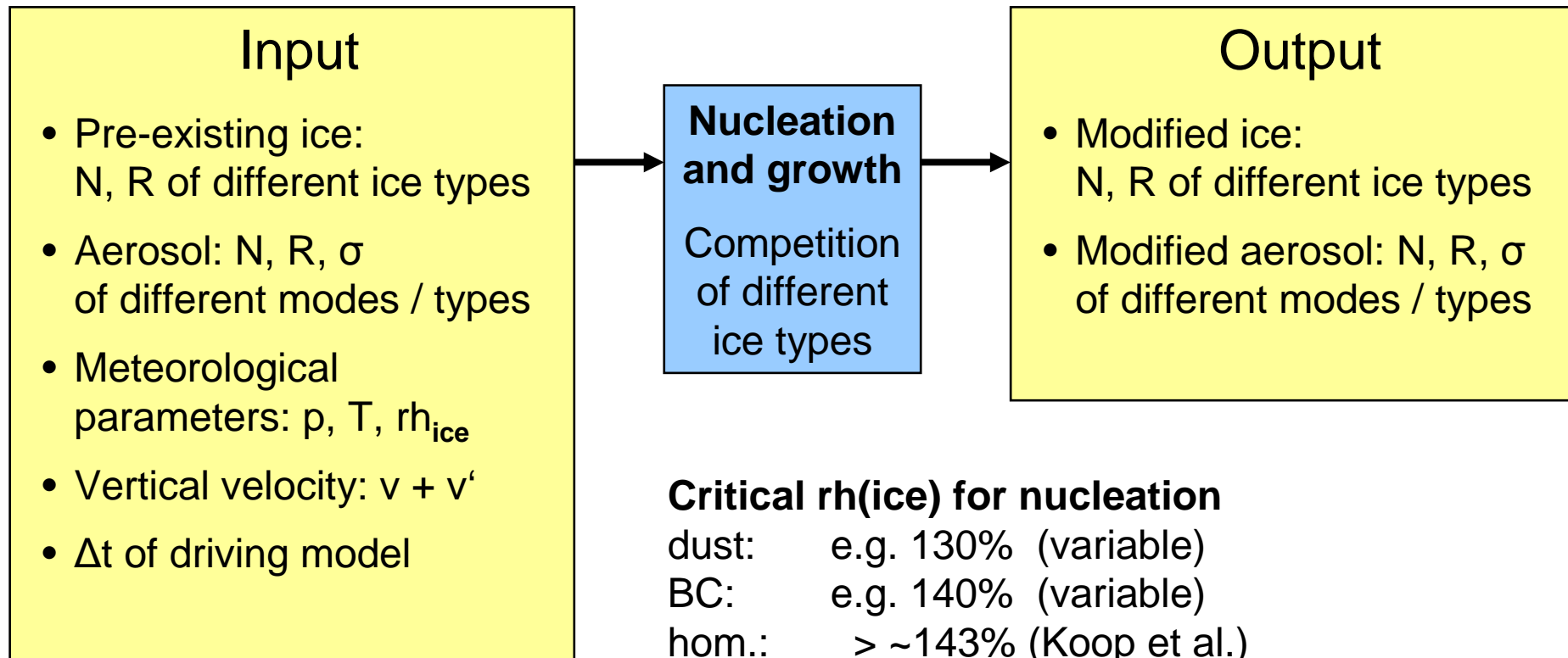
**Competition between  
homogeneous and heterogeneous nucleation**



# Nucleation

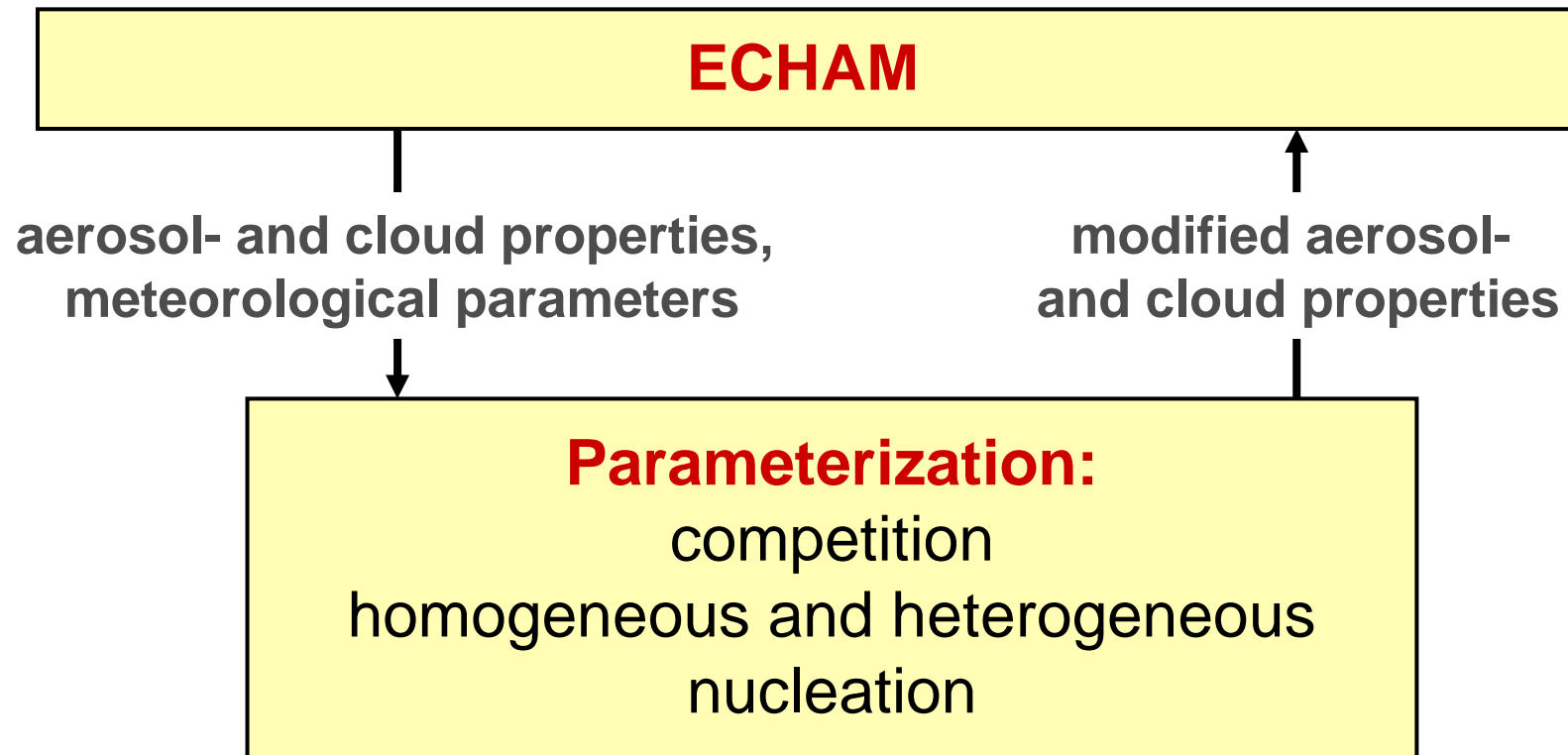
(Kärcher et al., JGR, 2006)

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





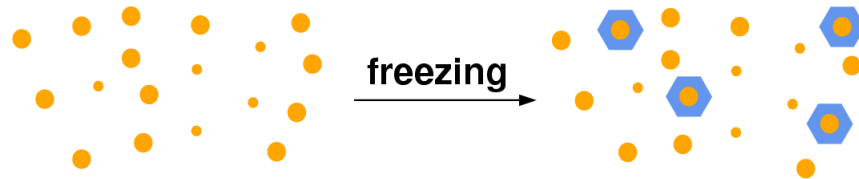
## Realization in ECHAM





# Ice formation: competing mechanisms

liquid aerosol



Homogeneous nucleation

liquid aerosol / mineral dust



Heterogeneous nucleation  
on mineral dust

liquid aerosol / soot



Heterogeneous nucleation  
on soot

cloud droplets



Freezing of cloud droplets  
(various mechanisms)



# Multi-modal ice microphysics in ECHAM (stratiform clouds!!)

## Previous ECHAM version

single mode



includes all ice types



## New ECHAM version

Mode 1



Ice from heterogeneous nucleation on mineral dust

Mode 2



Ice from heterogeneous nucleation on soot

Mode 3



Ice from homogeneous nucleation

Mode 4



Ice from other sources





# Multi-modal ice microphysics in ECHAM

## First results

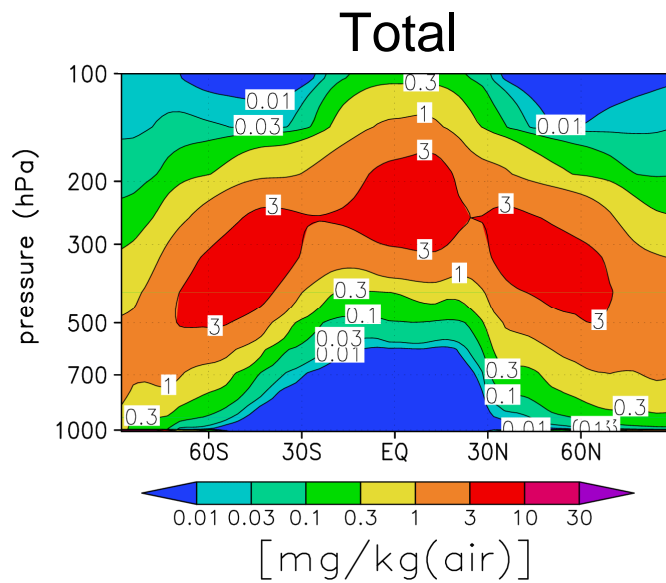


# Multi-modal ice microphysics in ECHAM

## Total ice population

Zonal averages of annual mean ice water content

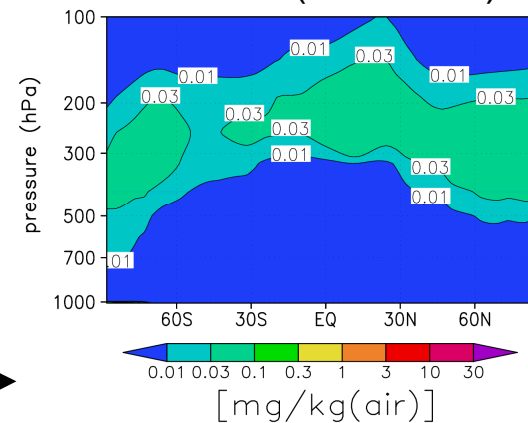
! Cloud free periods included



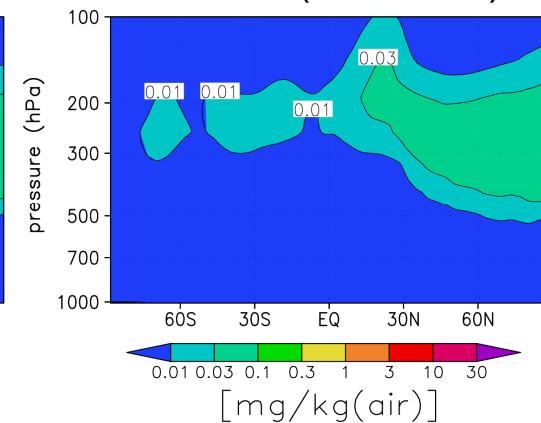
Includes all ice types

## Different modes

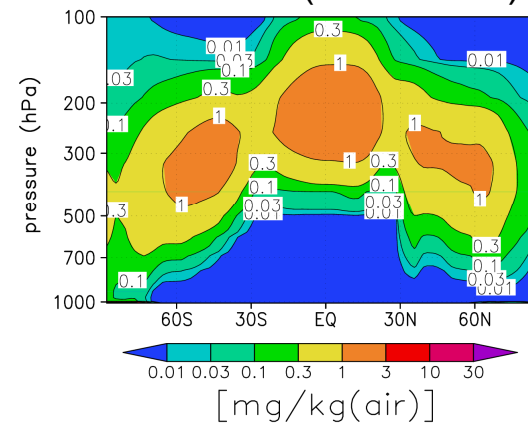
Mode 1 (from dust)



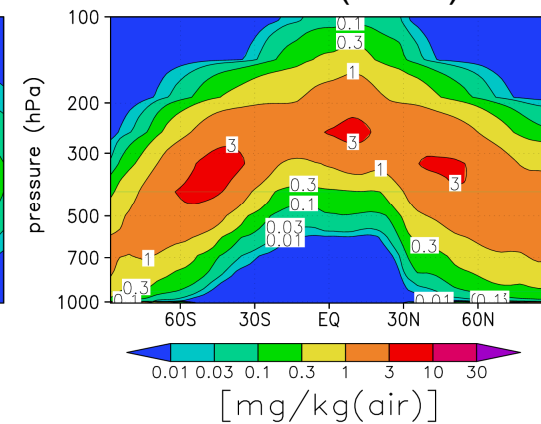
Mode 2 (from soot)



Mode 3 (from hom.)



Mode 4 (other)



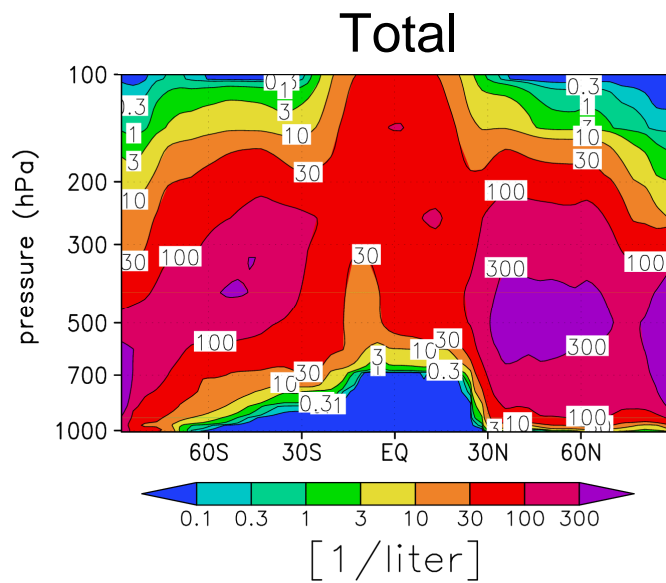


# Multi-modal ice microphysics in ECHAM

## Total ice population

Zonal averages of annual mean  
crystal concentration

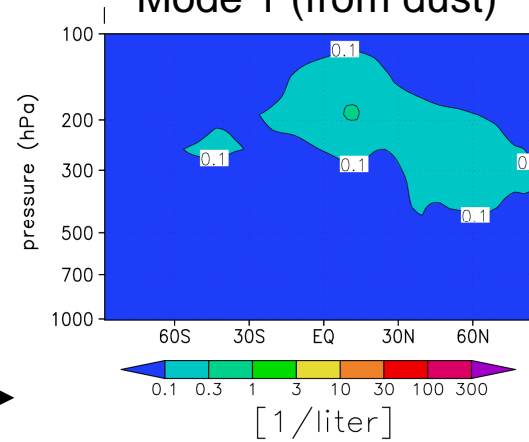
**! Cloud free periods included**



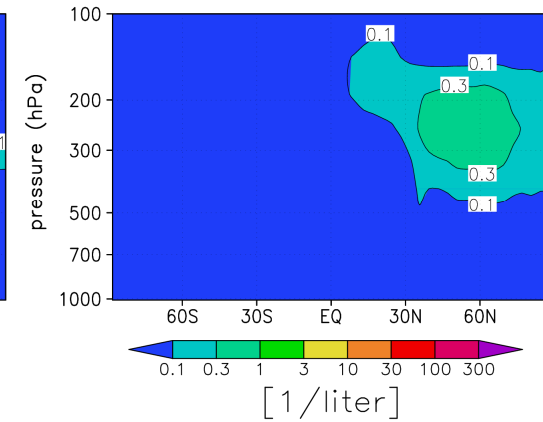
Includes all ice  
types

## Different modes

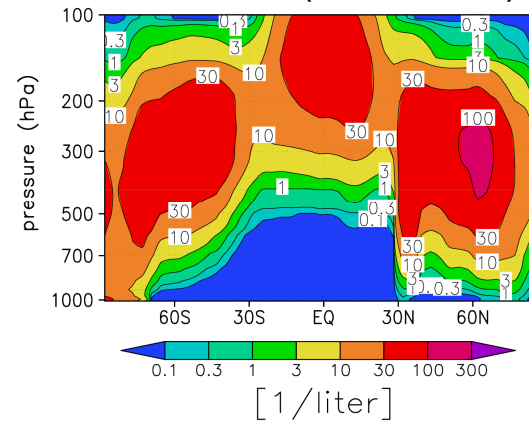
Mode 1 (from dust)



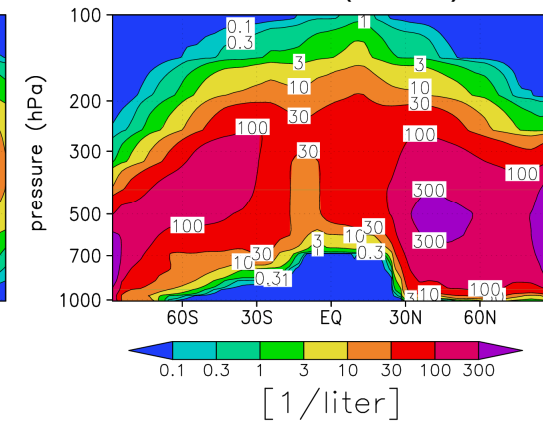
Mode 2 (from soot)



Mode 3 (from hom.)



Mode 4 (other)







# Multi-modal ice microphysics in ECHAM

Effects of IN on cirrus ?

**Ongoing simulations !**



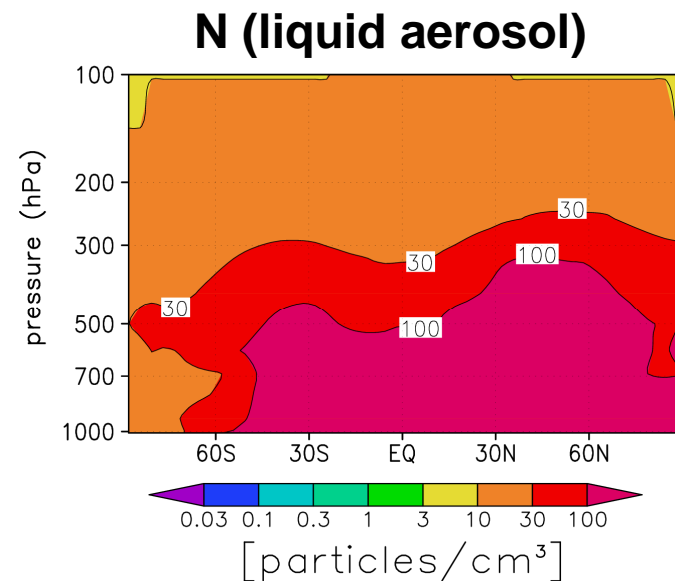
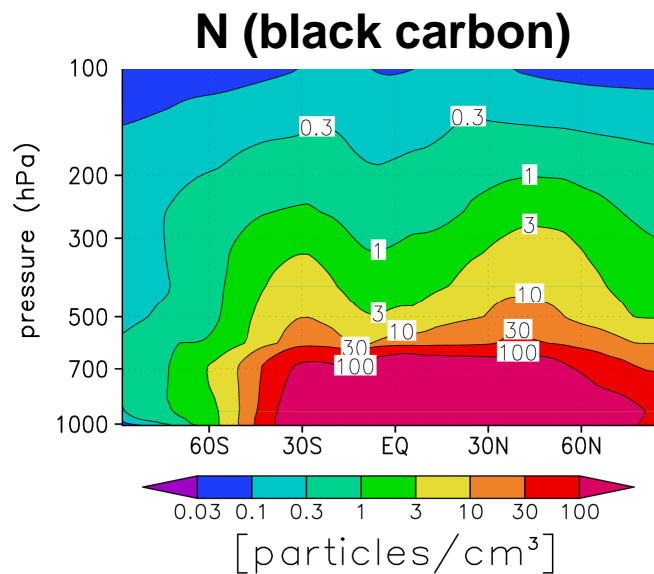
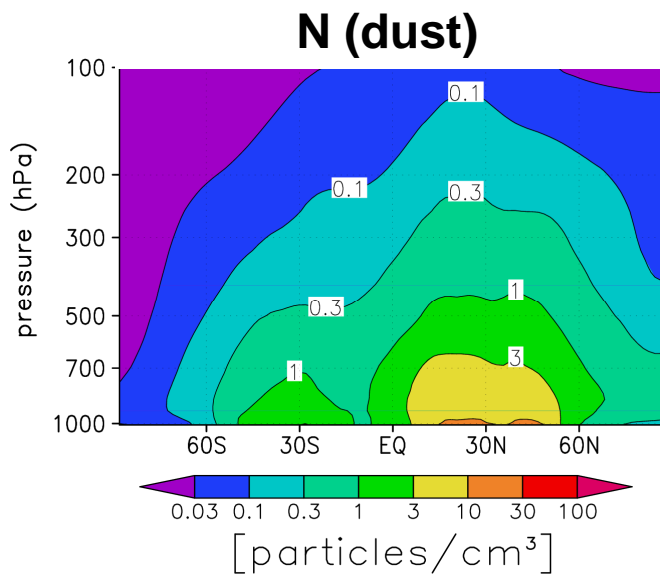
# Multi-modal ice microphysics in ECHAM

**Aerosols / ice nuclei ?**



# Ice forming aerosols in ECHAM

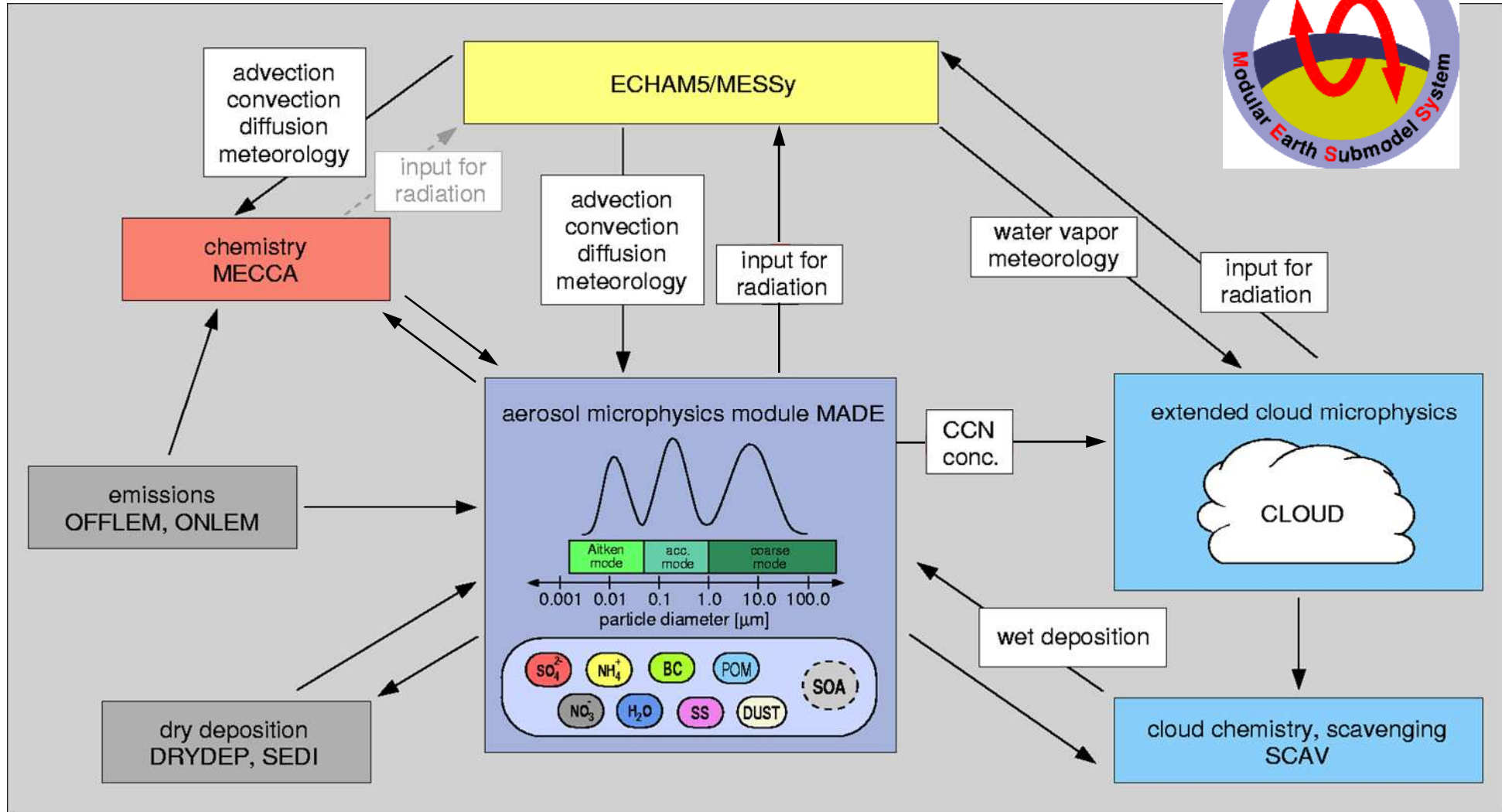
Annual zonal mean aerosol number concentration in ECHAM4  
(estimated from mass conc.)



Hendricks et al. (ACP, 2004)



# ECHAM5/MESSy1-MADE

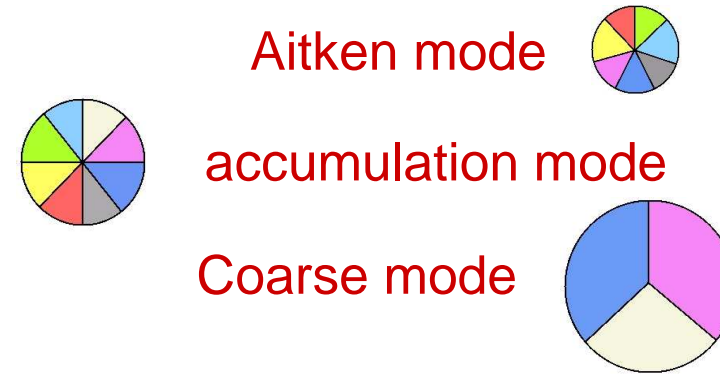
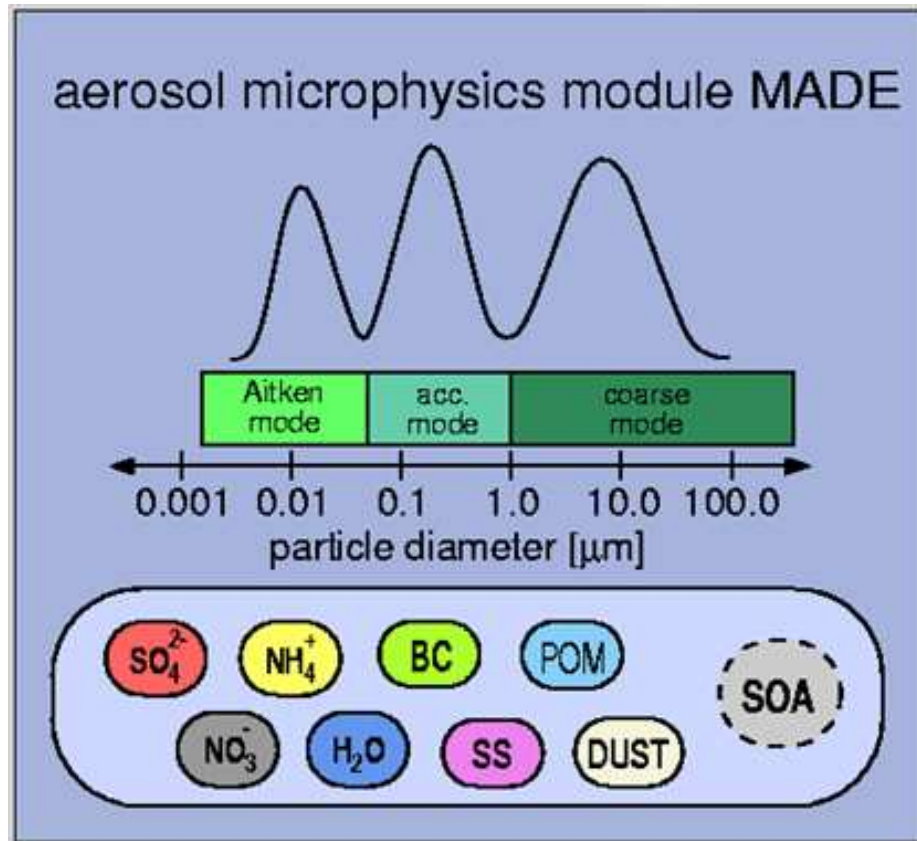


Lauer et al. (ACP, 2007); Jöckel et al. (ACP, 2005)



# Aerosolmodule MADE

MADE = Modal Aerosol Dynamics Model for Europe (RIU / EURAD)



## Processes:

- nucleation
- condensation
- coagulation
- gas/particle equilibrium (NH<sub>3</sub>/NH<sub>4</sub>, HNO<sub>3</sub>/NO<sub>3</sub>, H<sub>2</sub>O)

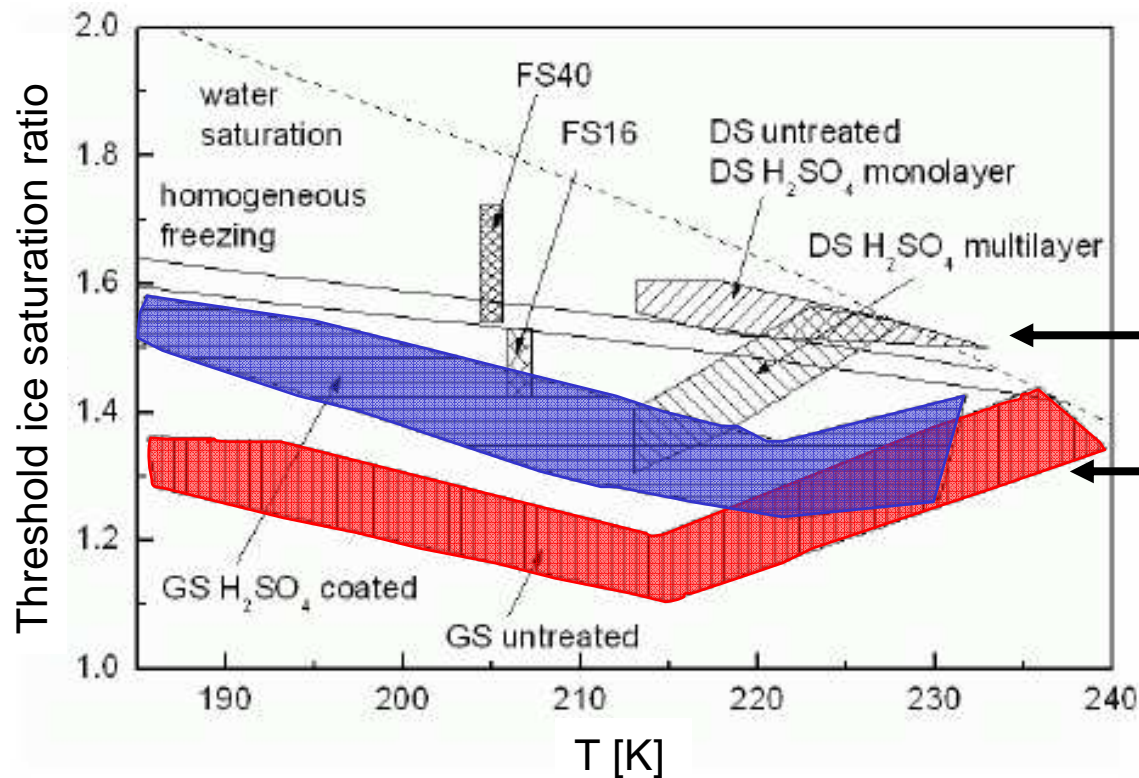
Refs: Ackermann et al., 1998 (Atm. Env.); Schell et al., 2001 (JGR); Lauer et al., 2005 (ACP); Lauer and Hendricks, 2006 (ACP)





# Ice nucleation mechanisms

## Heterogeneous ice nucleation on soot



Impact of coating on nucleation ability

DeMott et al.

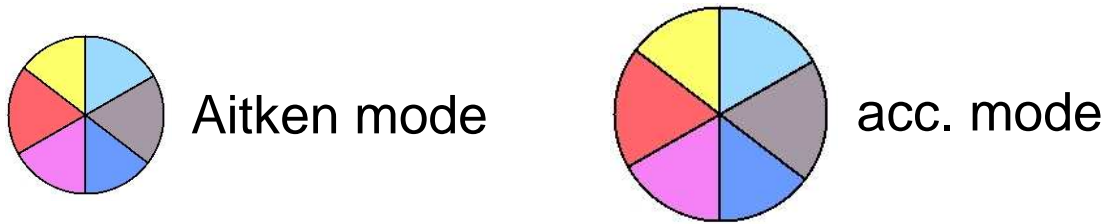
Möhler et al., AIDA

Kärcher et al, ACP 2007

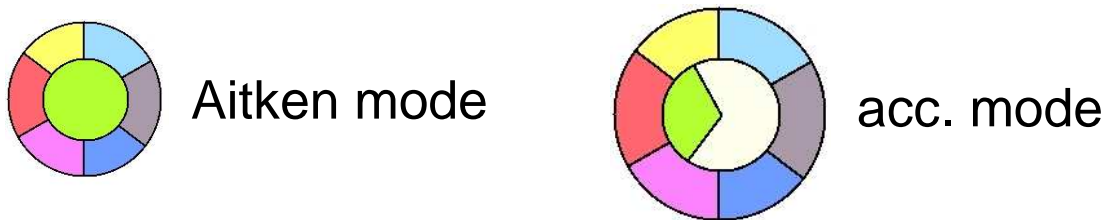


# Modification of ECHAM / MADE

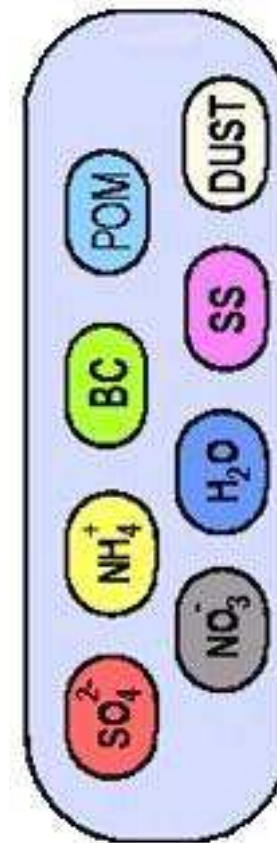
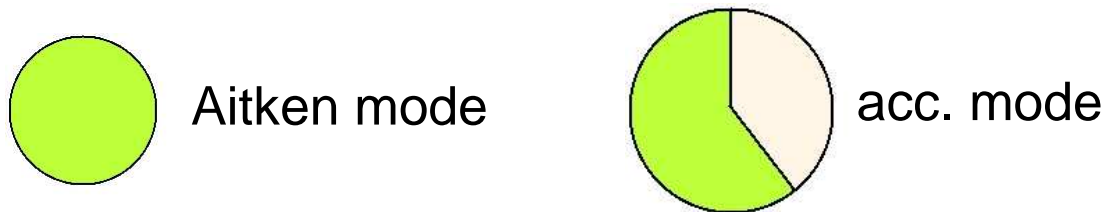
## Internally mixed soluble particles



## Internally mixed particles with insoluble core



## Externally mixed insoluble particles



Dissertation: Valentina Aquila





# Multi-modal ice microphysics in ECHAM

## Conclusions:

- **Multi-modal ice microphysics** implemented in ECHAM4
- Coupling with Kärcher et al. (2006) **nucleation parametrization** finished, **MS M3A !**
- **Modification of aerosol module** started.

## Requirements:

- **Critical RHi** for heterogeneous nucleation; dependence on IN composition?
- Typical **IN number concentration**?
- **IN fraction** of soot / dust particles?



# ECHAM5/MESSy1

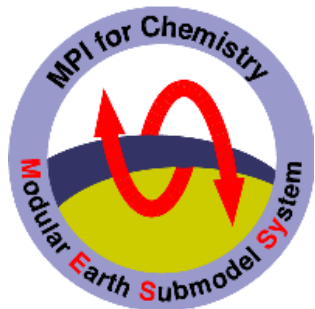
ECHAM = ECMWF-model, version HAMburg

General circulation model

Reference: Roeckner et al. , MPI-Report No.349



MESSy = Modular Earth Submodel System (Version 1.4)



- an interface with infrastructure to couple 'processes' (submodels) to a GCM (base model)
- a set of processes coded as switchable submodels
- a coding standard

Reference: Jöckel et al., 2005 (*Atmos. Chem. Phys.*)