# HGF-VI ACI

## The Contributions of DLR-IPA to the VI-ACI: Processes, Cloud and Climate Modeling and Links With Partners


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HELMHOLTZ | GEMEINSCHAFT

Ludwig Maximilians Universität München LMU

DLR

# Milestones: Process-oriented modeling

**WP1**

M1A Cirrus parameterization scheme available for use in ECHAM (DLR, month 6).

M1B Model runs on aerosol mixing state in cirrus finished (DLR, month 12).

M1C Validated microphysical models, expressions and parameterizations regarding CCN activation for selected aerosol systems (IfT, month 12)

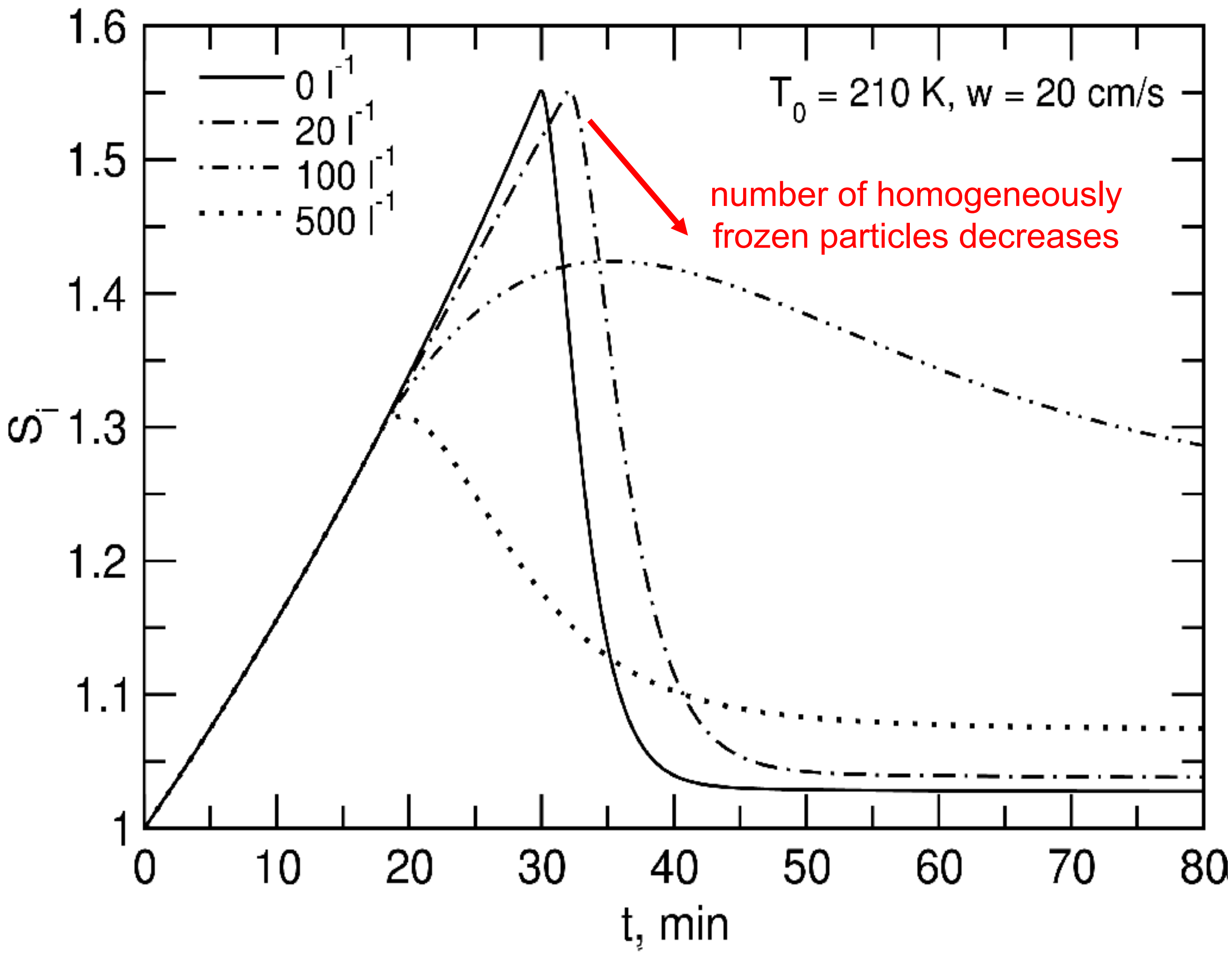
M1D Ice nucleation properties in mixed-phase clouds assessed (FZK, month 18).

M1E Ice nucleation properties in cirrus clouds assessed (DLR, FZK, month 24).

M1F Process model with new IN schemes applied to cirrus data sets (ICG-I, month 24).

M1G Validated microphysical models, expressions and parameterizations regarding freezing temperatures for selected aerosol systems (IfT, month 24)

# Saturation history in a rising air parcel




Assumed IN added to liquid aerosols nucleate ice sharply at $S_{cr}$ = 1.3.

# The saturation equation revisited

nucleation and depositional growth

cooling

$$\frac{dS_i}{dt} = \overbrace{a_1 S_i w}^{\text{cooling}} - \overbrace{(a_2 + a_3 S_i)(R_i + R_i^{IN})}^{\text{nucleation and depositional growth}}$$

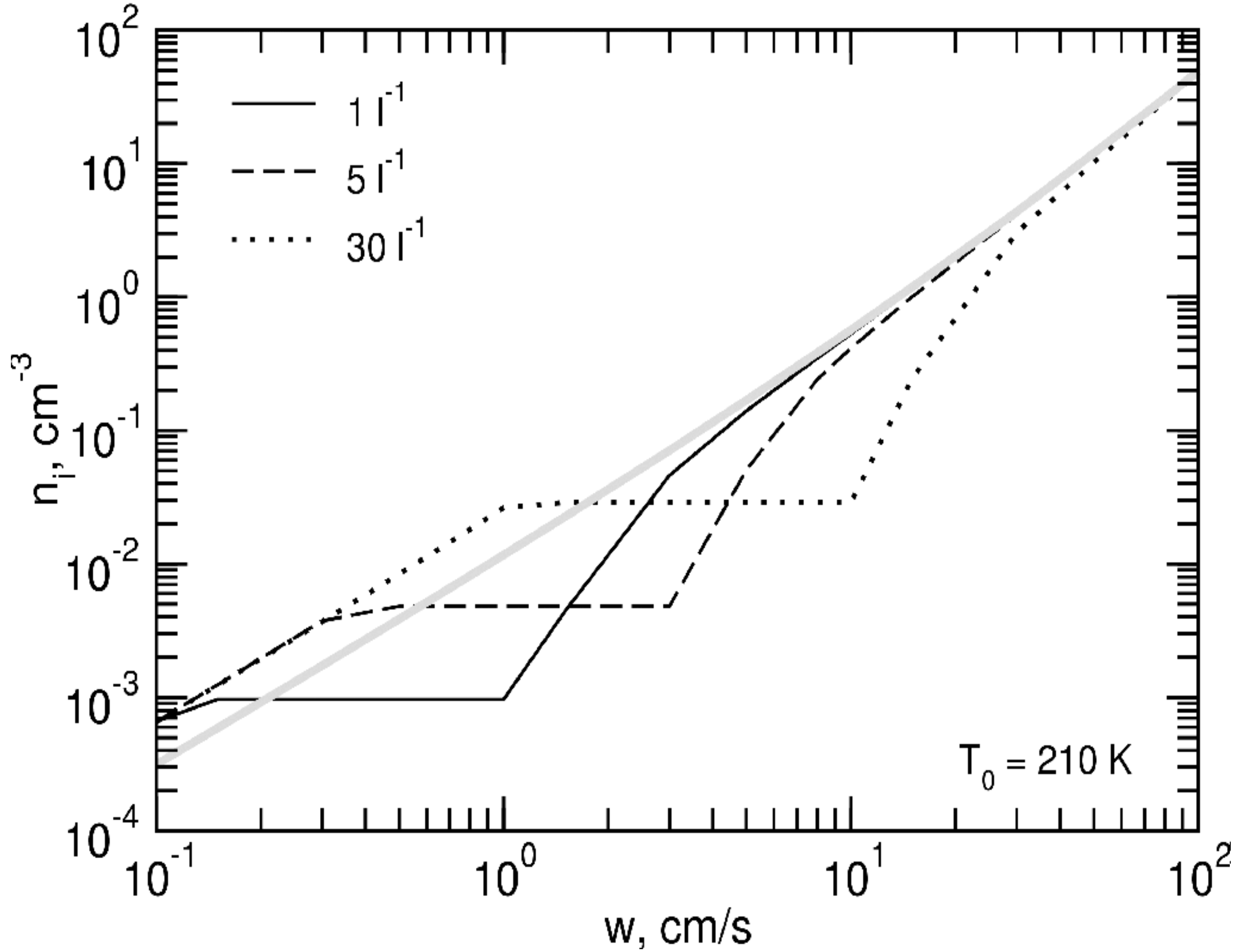
preexisting ice grown on IN

$$\frac{dS_i}{dt} = a_1 S_i (w - w_p) - (a_2 + a_3 S_i) R_i, \quad w_p = \frac{a_2 + a_3 S_i}{a_1 S_i} R_i^{IN}$$

apparent downdraft acts to reduce the number of subsequently produced ice crystals

# What are the indirect effects caused by heterogeneous IN?

..... a *negative* Twomey effect



# Process-oriented modeling

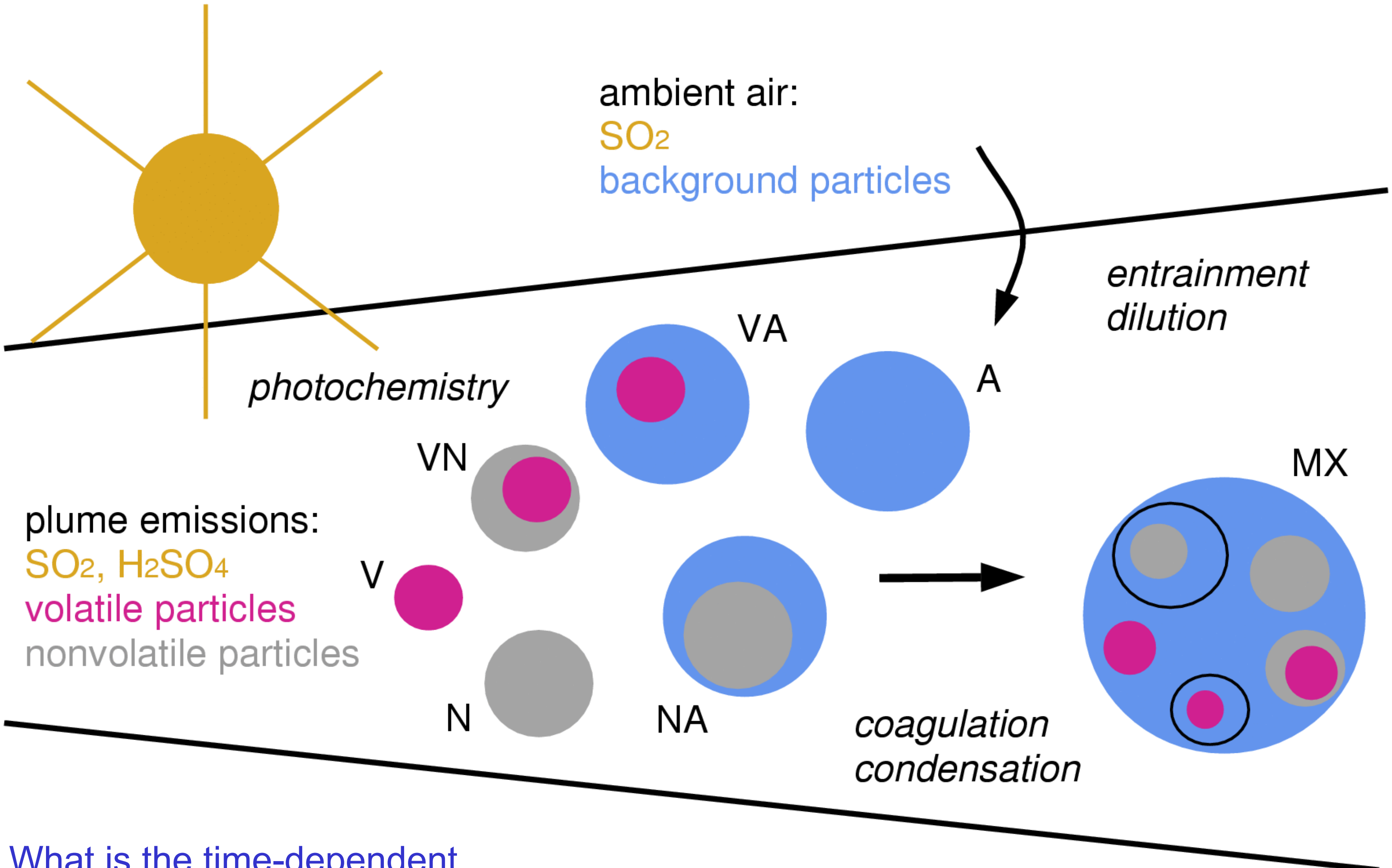
## Indirect effect of soot aerosols on cirrus

- Soot is ubiquitous and arises from a number of sources
- Laboratory measurements are inconclusive about IN properties
- Aircraft emissions could double the number of upper tropospheric soot particles

⟶ focus on cirrus modification by aircraft emissions

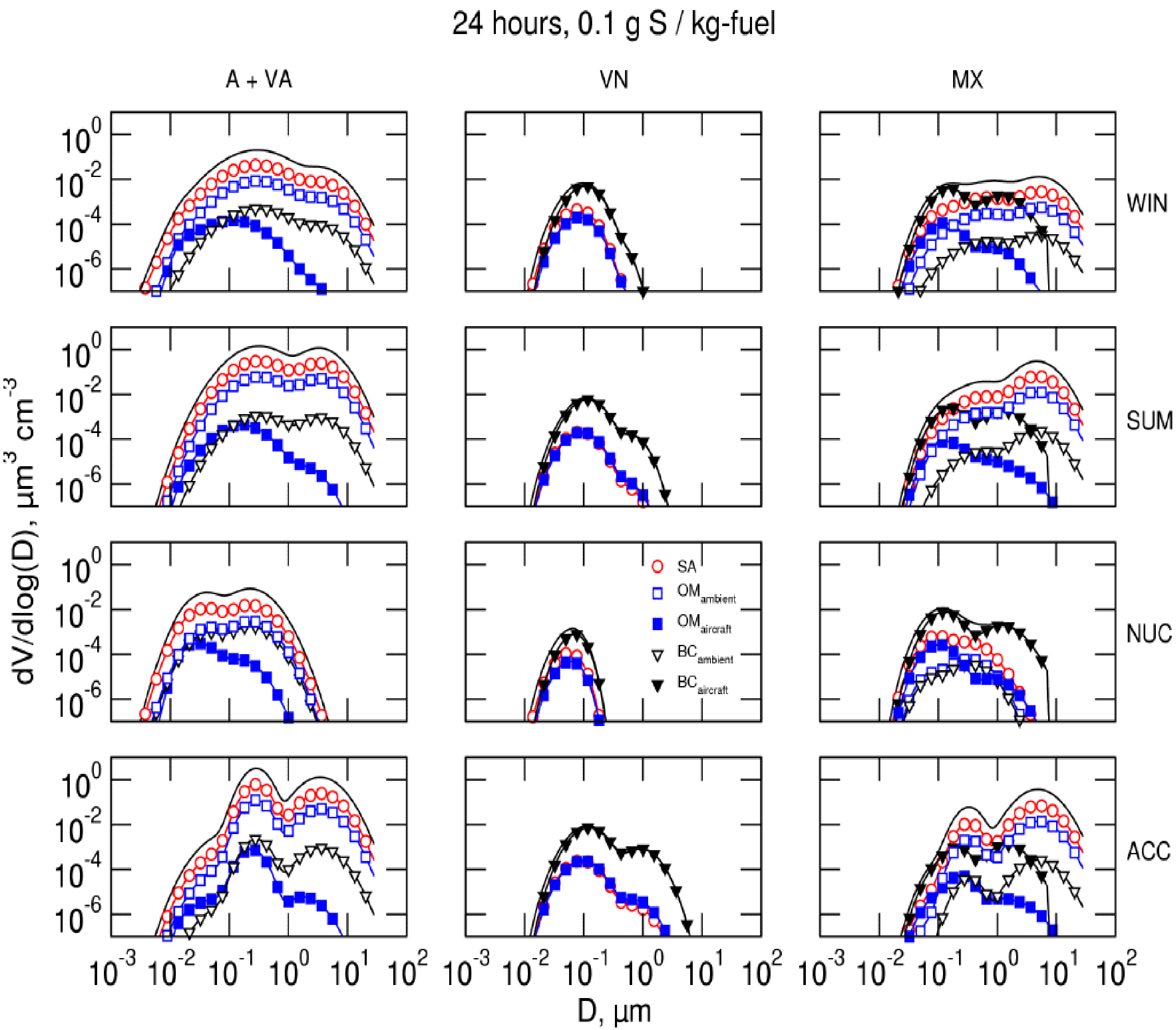
# Process-oriented modeling

## Indirect effect of aircraft soot




What is the time-dependent concentration and composition of BC-containing particles?

# Process-oriented modeling




Under which conditions do these particles initiate the ice phase relative to unperturbed background particles?

We need $J_{het}$ of complex multicomponent mixtures that represent real atmospheric soot.

# Summary: Process-oriented modeling

## Objective and Status

| | | |
|---|---|---|
| | Improve cirrus microphysics in global models. | |
| M1A | Cirrus parameterization scheme available for use in ECHAM. | **m6** |
| | Scheme has been developed and thoroughly tested for use in ECHAM4. | |
| | Investigate role of (aviation) soot aerosols in cirrus cloud formation. | |
| M1B | Model runs on aerosol mixing state in cirrus finished. | **m12** |
| | Mixing states have been determined and laboratory studies assessed. | |
| | Provide parameterized heterogeneous ice nucleation rates from AIDA measurements. | |
| M1E | Ice nucleation properties in cirrus clouds assessed. | **m24** |
| | First data for mineral dust are available. | |

## Links

With IMK-AAF. DLR-IPA will give advice to adjust shifted-activity nucleation rates and shares experience from previous AIDA modeling exercises.

# Milestones: Cloud modeling

**WP2**

M2A Lagrangian ice particle tracking module for Large Eddy* simulations of cirrus clouds developed (DLR-IPA, month 12).

M2B Ice microphysics module for small and regional-scale contrail studies developed (DLR-IPA, month 12).

M2C Case studies on cirrus clouds obtained during field campaigns (ICG-I, ETH, month 12).

M2D TAU-2D model runs finished (Uni-TA, IMK-AAF, month 30).

M2E Cloud-resolving model runs using the multi-scale dynamical model EULAG finished (DLR-IPA, month 30).

M2F Investigation and interpretation of field measurements (ETH, ICG-I, month 36).

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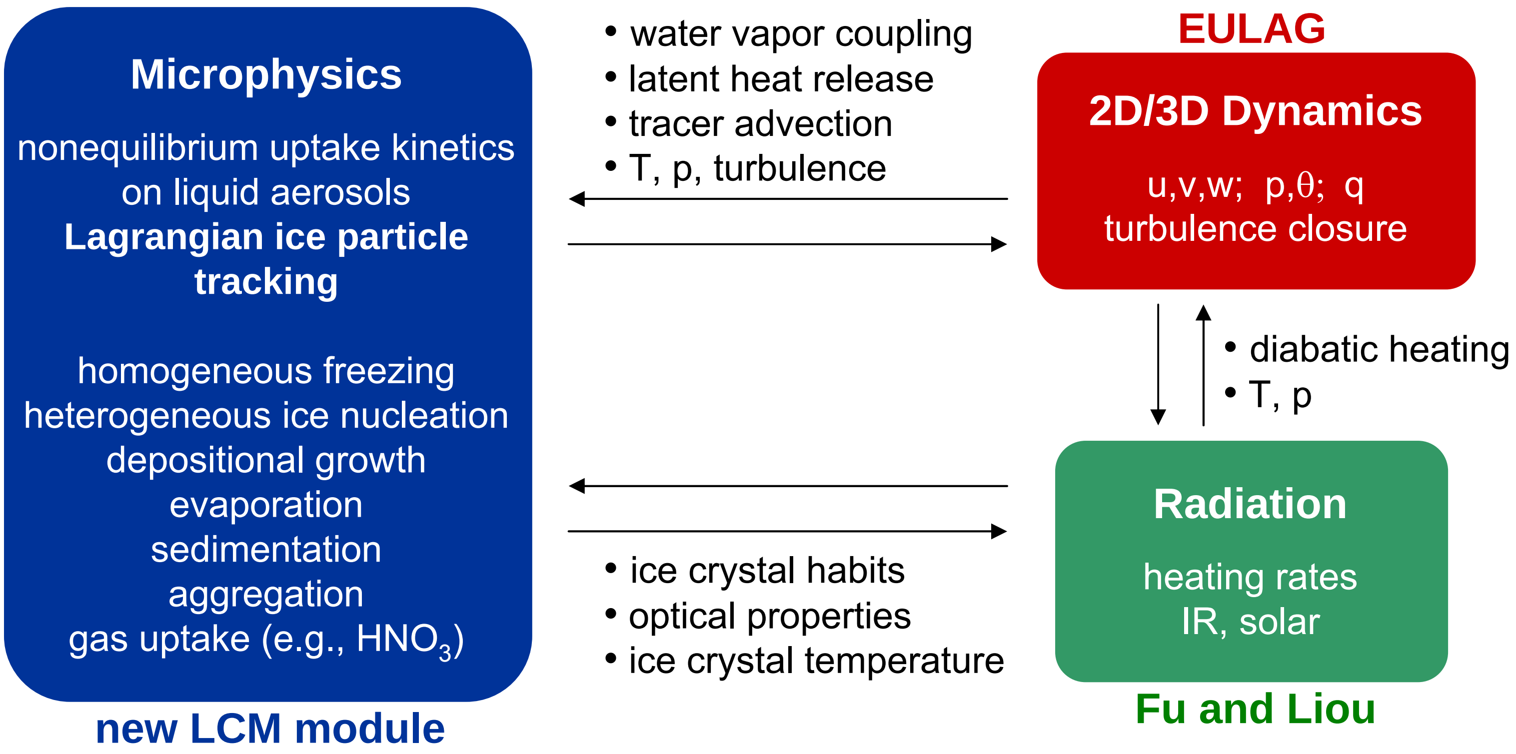
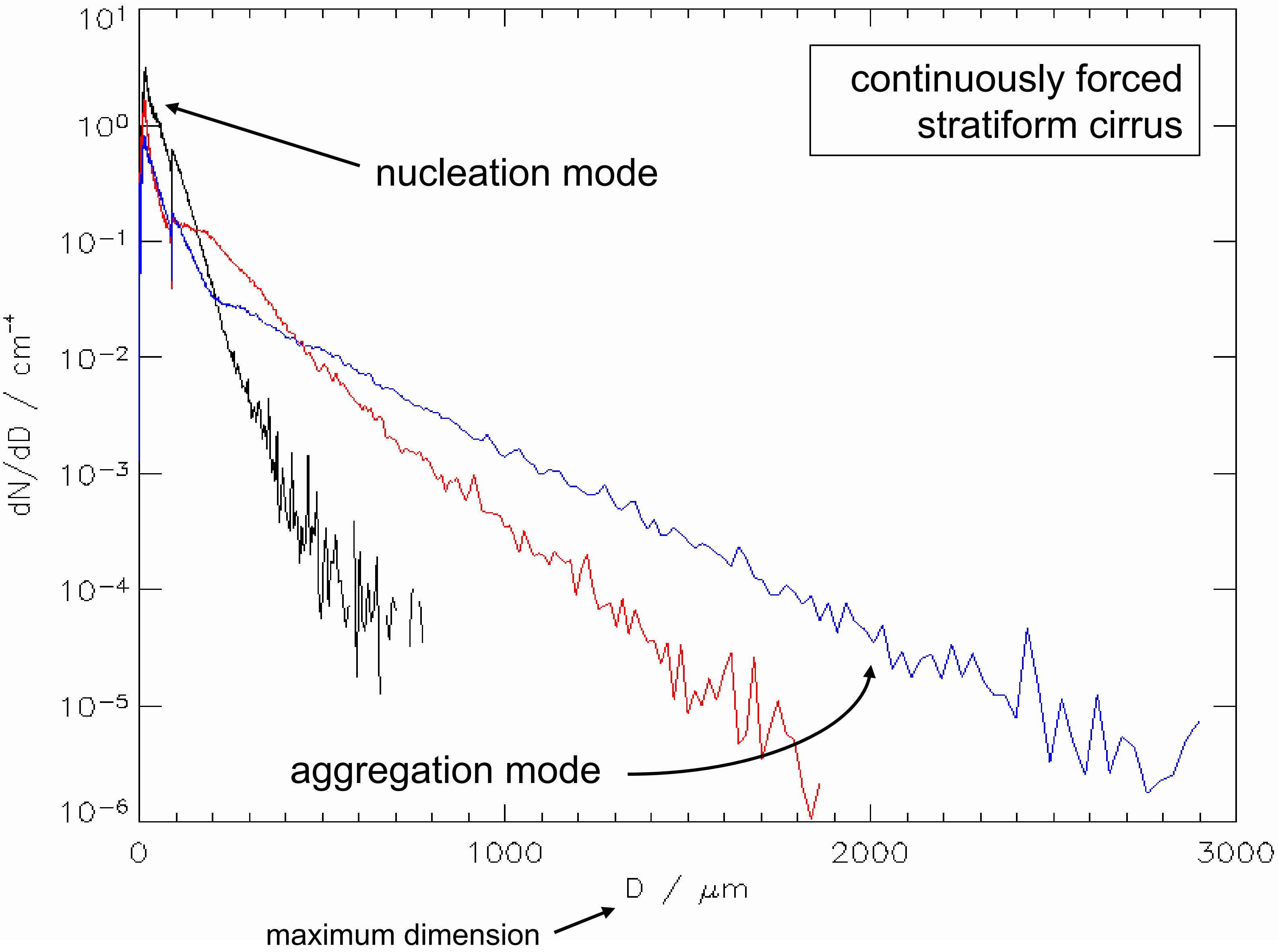
*originally: small and mesoscale

# EULAG-LCM

2D/3D LES model including radiation-turbulence-microphysics interactions in combination with explicit aerosol representation



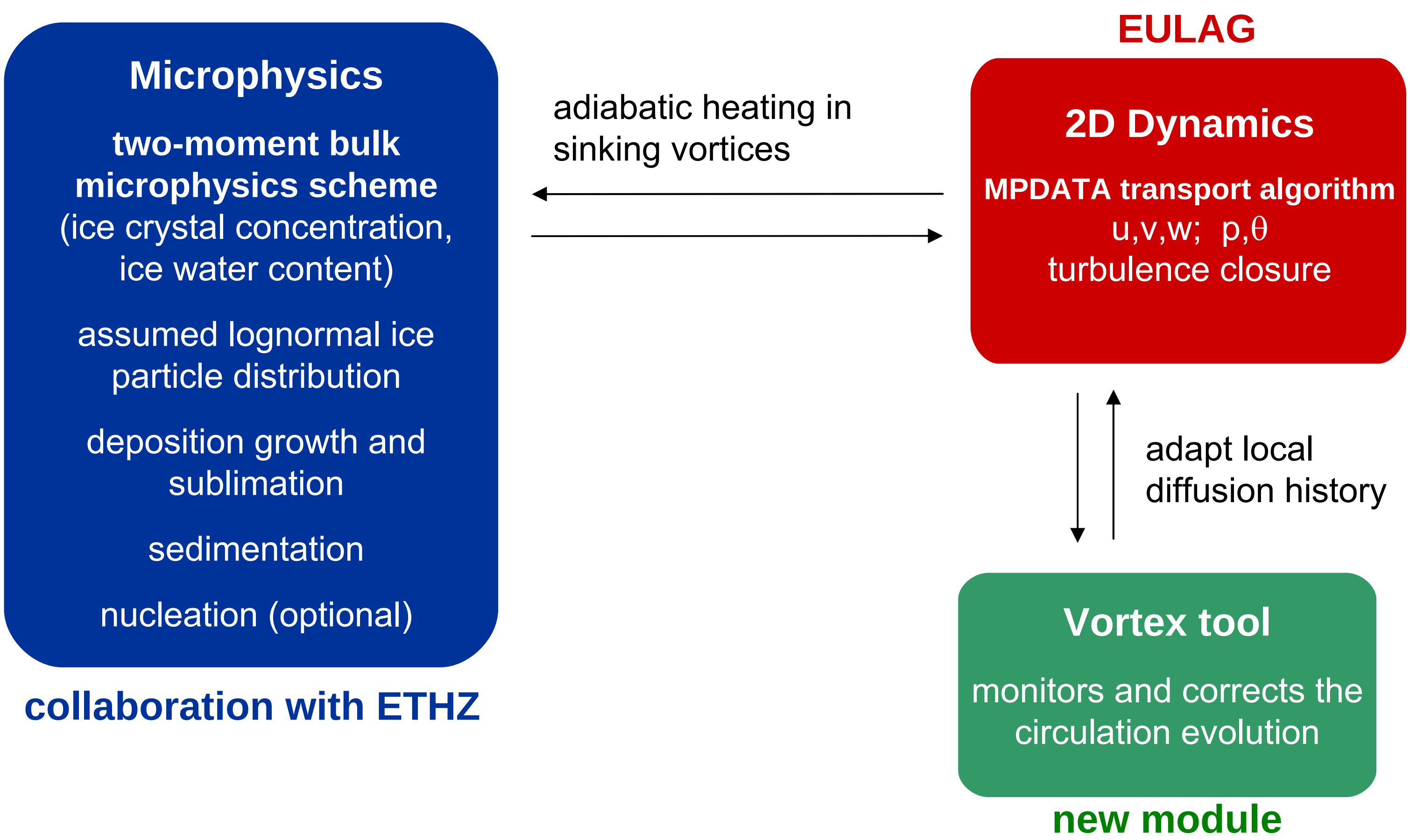
# EULAG-LCM



continuously forced
stratiform cirrus
nucleation mode
aggregation mode
$10^{1}$
$10^{0}$
$10^{-1}$
$10^{-2}$
$10^{-3}$
$10^{-4}$
$10^{-5}$
$10^{-6}$
dN/dD / cm$^{-4}$
0
1000
2000
3000
D / $\mu$m
maximum dimension

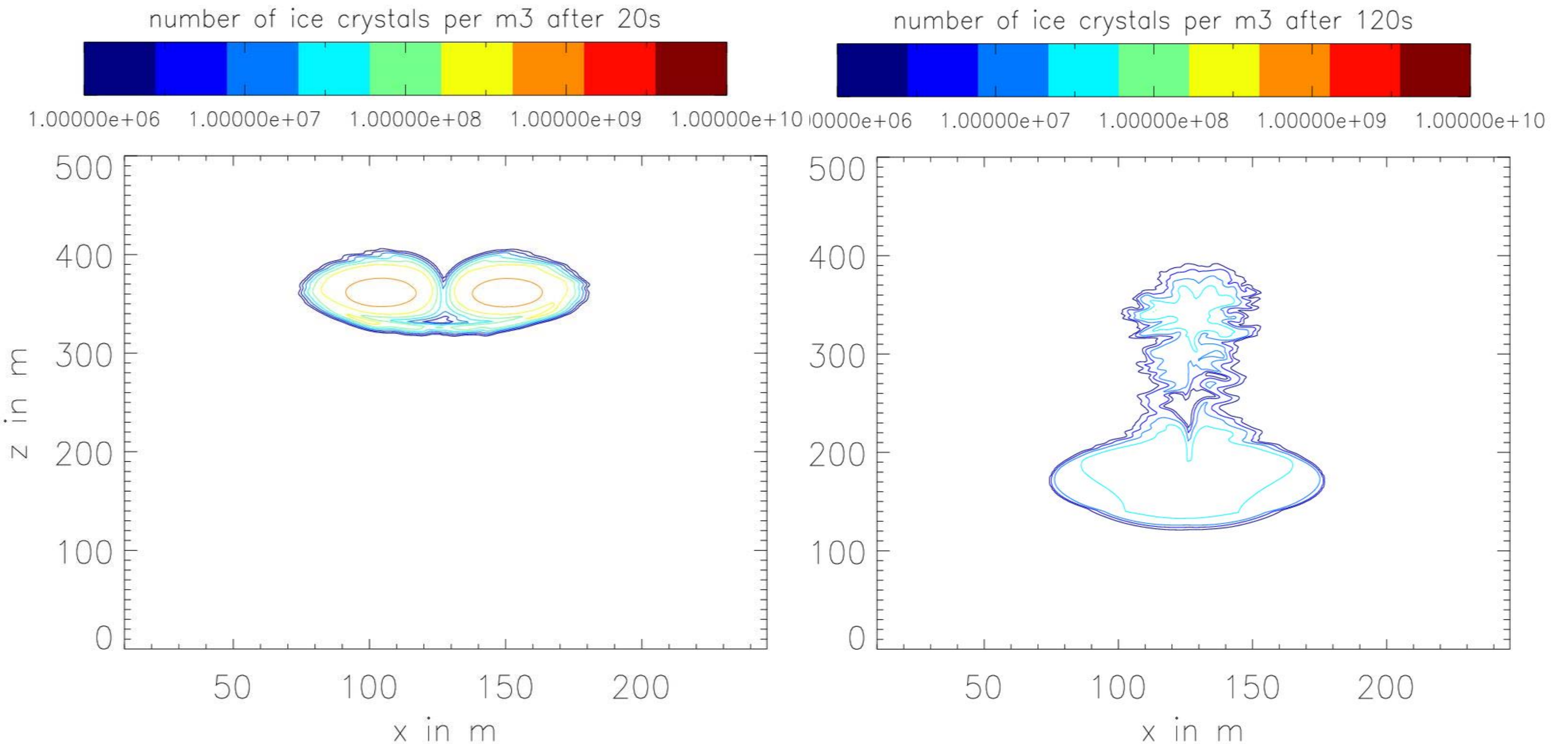
# EULAG-CON

2D model for mesoscale contrail studies including
a tool ensuring realistic decay of aircraft vortices.



# EULAG-CON

Analysis of ice particle number surviving adiabatic heating in sinking vortex pair as a function of ambient RHI, T, turbulence, stratification and aircraft weight.



# Summary: Cloud modeling

## Objective and Status

| | | |
|---|---|---|
| | Develop a state-of-the-art 2D/3D model for benchmark simulations and basic UTLS studies. | |
| M2A | Lagrangian ice particle tracking module for Large Eddy simulations of cirrus clouds developed. | **m12** |
| | Module with interactive aerosols has been integrated and is being tested in EULAG. | |
| | Study and categorize contrail-to-cirrus transition. | |
| M2B | Ice microphysics module for small and regional-scale contrail studies developed. | **m12** |
| | Model has been set up and simulations of vortex evolution and break-up have been started. | |
| | Study and analyze cirrus formation and evolution. | |
| M2E | Cloud-resolving model runs using the multi-scale dynamical model EULAG finished. | **m30** |
| | Not yet initiated. | |

## Links

With ETH. Both institutions benefit from a common development of an efficient, bulk microphysical ice scheme for use in EULAG.
With partners outside of the VI in the GEWEX GCSS WG2 cirrus model intercomparison exercise.

# Milestones: Climate modeling

**WP3**

M3A Fully coupled parameterization of cirrus cloud formation implemented in ECHAM (DLR, month 12)

M3B Subgrid-scale parameterization for contrail-cirrus ready in ECHAM (DLR, month 12)

M3C Simulations with varying mineral dust composition (ETH, month 18)

M3D Global impact of contrail-cirrus on cirrus cover and properties quantified (DLR, month 30)

M3E Impact of natural and anthropogenic ice nuclei (including aviation soot) on global cirrus cloud properties quantified (DLR, month 30)

M3F Simulations with changed freezing efficiency due to aged aerosols (ETH, month 36)

# Climate modeling

Homogeneous freezing is working and yields more realistic cirrus cloud properties globally. It allows supersaturation to occur and feedbacks with resolved radiation and dynamics to be simulated.

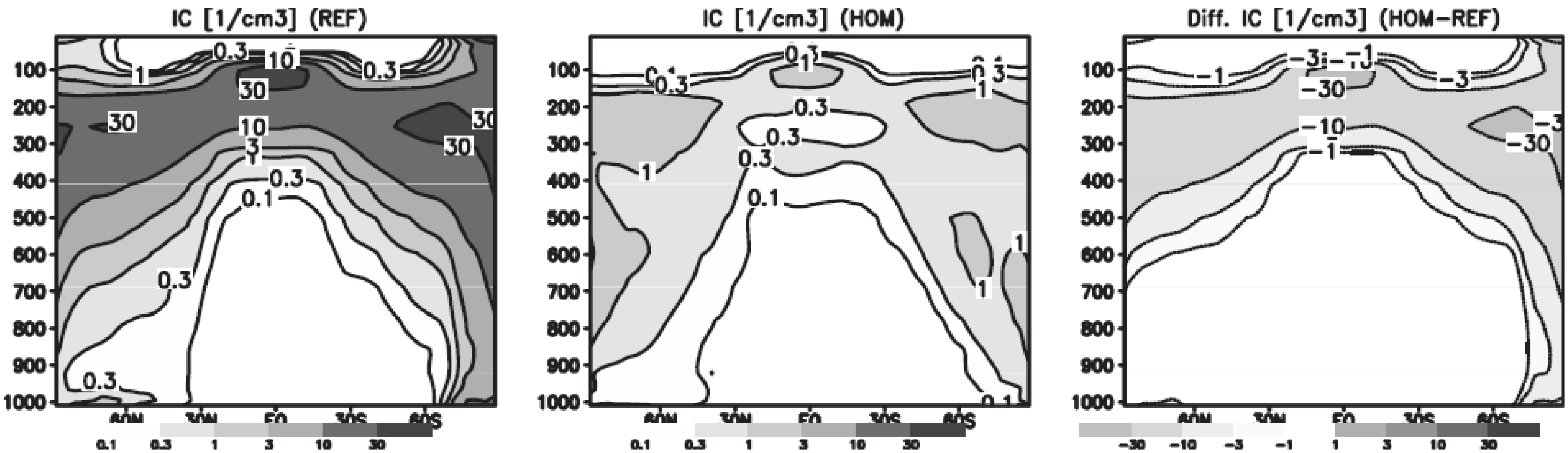


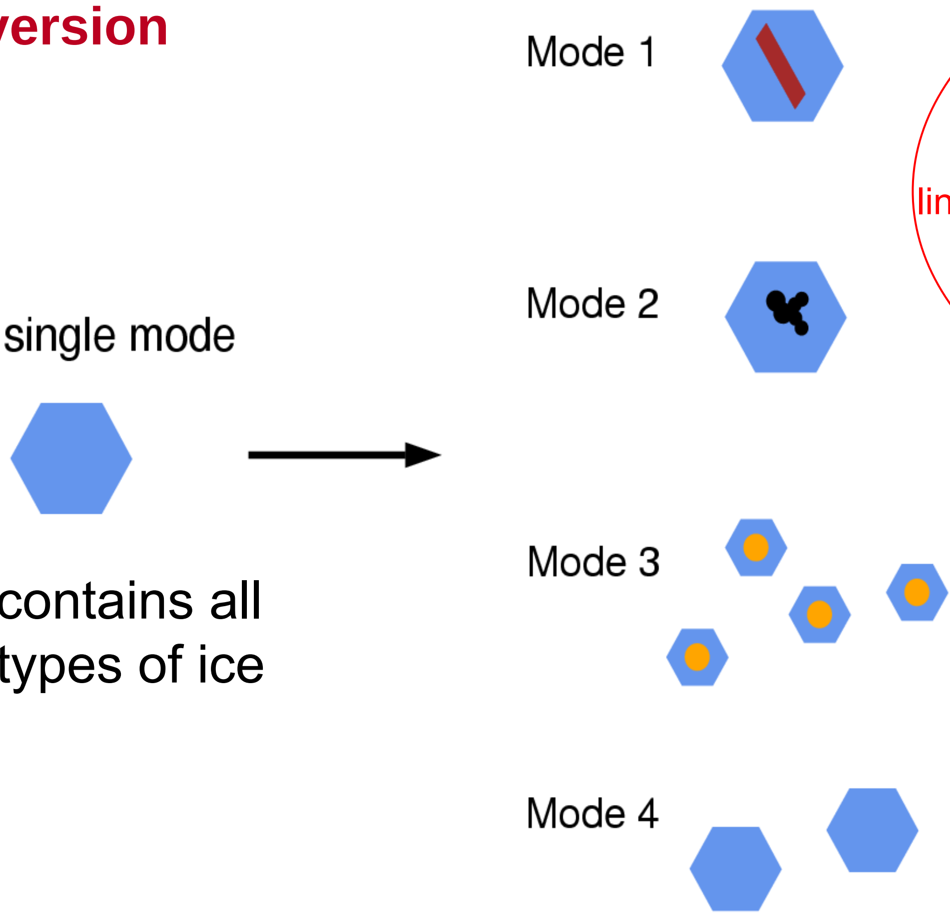

**Figure 5.** Annual zonal mean latitude versus pressure cross sections of ice water content (mg m$^{-3}$) and ice crystal number concentrations (cm$^{-3}$) for the simulations REF, HOM, and the difference HOM − REF.

Dynamical forcing *via* tuned subgrid-scale vertical winds: $v' \propto \sqrt{TKE}$

# Climate modeling

**Previous ECHAM4 version**

**New ECHAM4 version**




contains all types of ice

Ice from heterogeneous nucleation on mineral dust

link to AIDA data and WP1

Ice from heterogeneous nucleation on soot

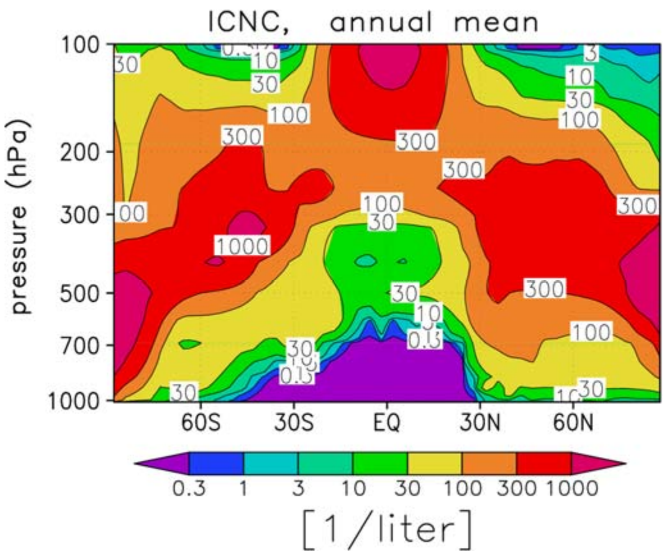
Ice from homogeneous freezing

Ice from other freezing pathways

# Climate modeling

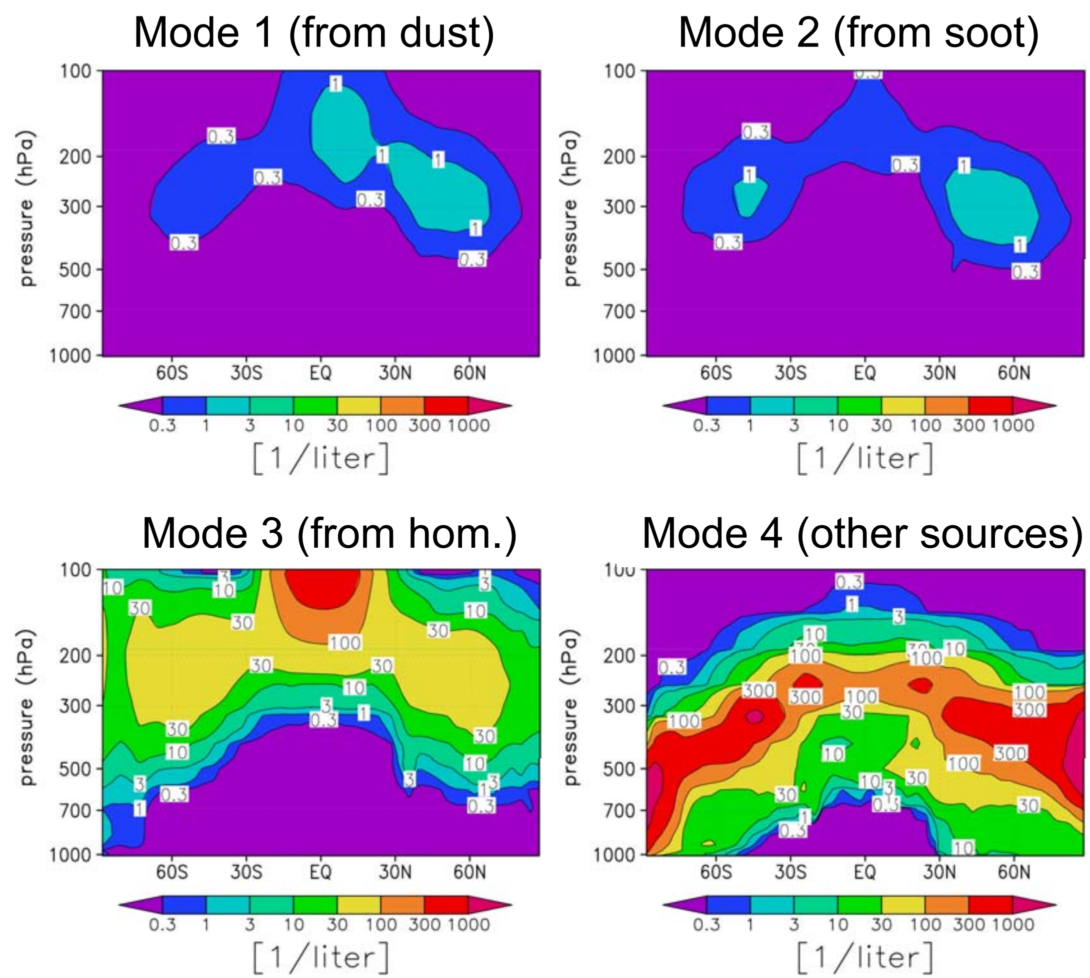
## Test with simplified assumption for nucleation

## Previous ECHAM4 version




contains all types of ice

## New ECHAM4 version




first step has been taken to include coupling to full parameterization

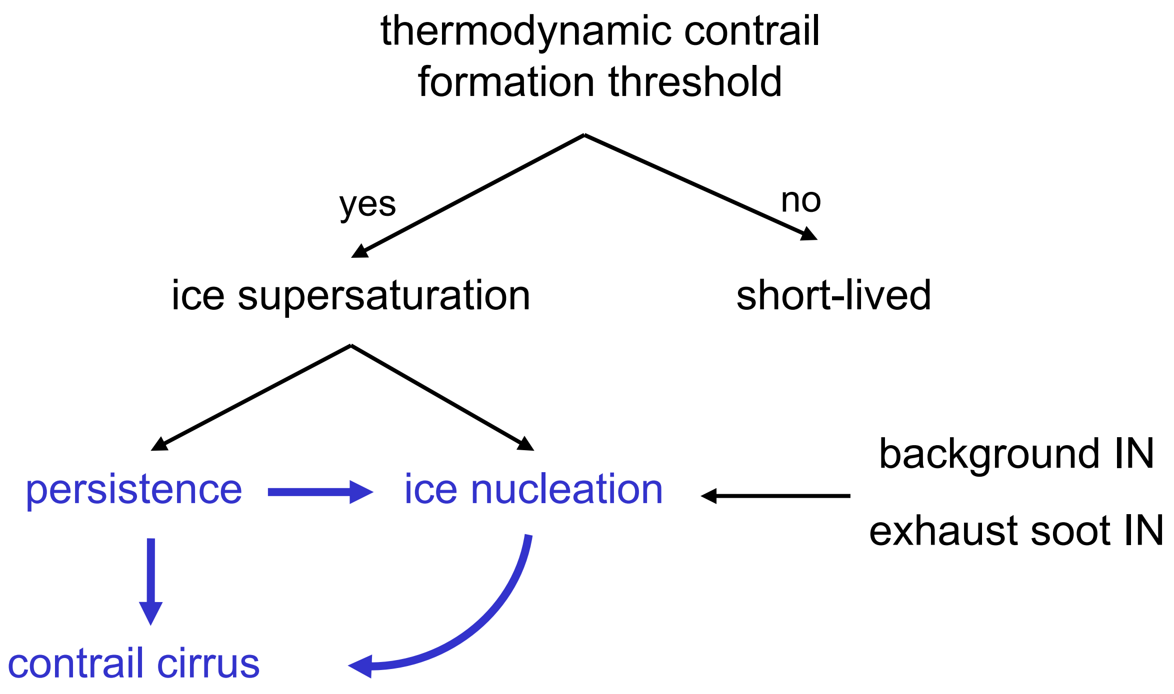
# Climate modeling

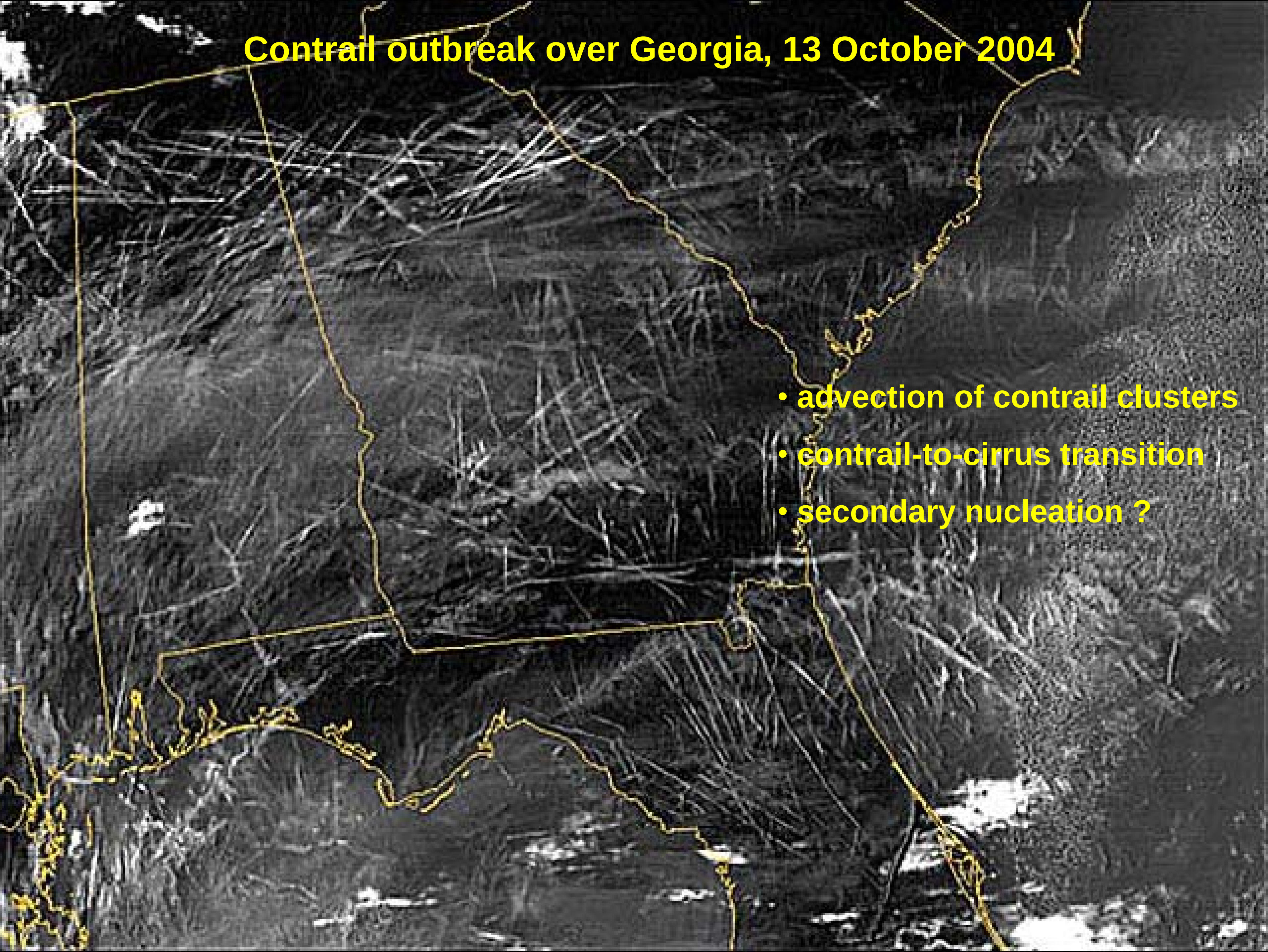
## Inclusion of contrail studies

• Importance for future cirrus studies:

> Progostic cloud fraction
> Growth of coverage due to wind shear

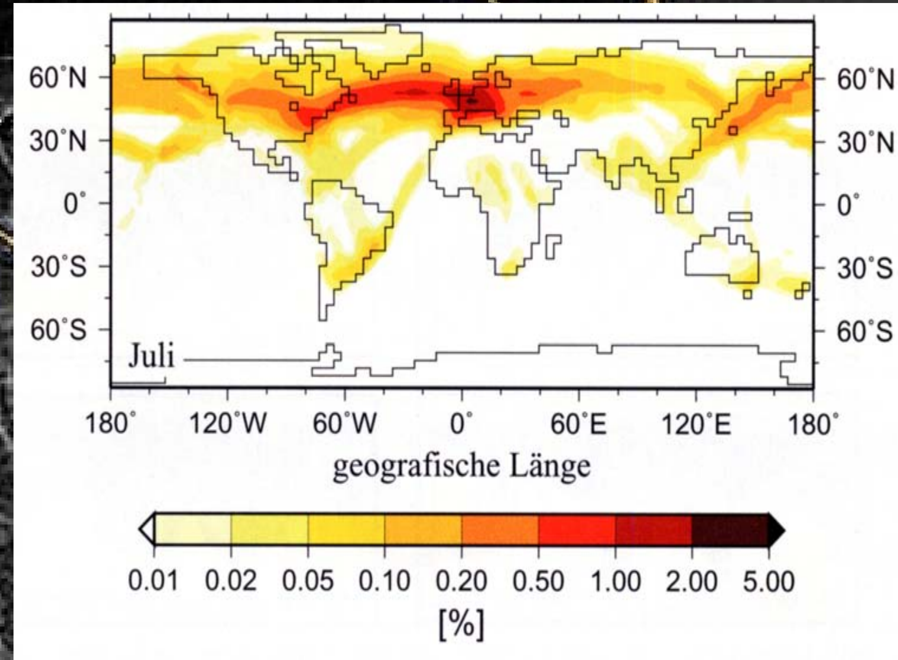
• Contrail and IN effects on cirrus are coupled:




Contrail outbreak over Georgia, 13 October 2004
• advection of contrail clusters
• contrail-to-cirrus transition
• secondary nucleation ?

## Previous **contrail** parameterization

- calculation of the formation of contrails
- tuning to observed coverages




## New **contrail cirrus** parameterization

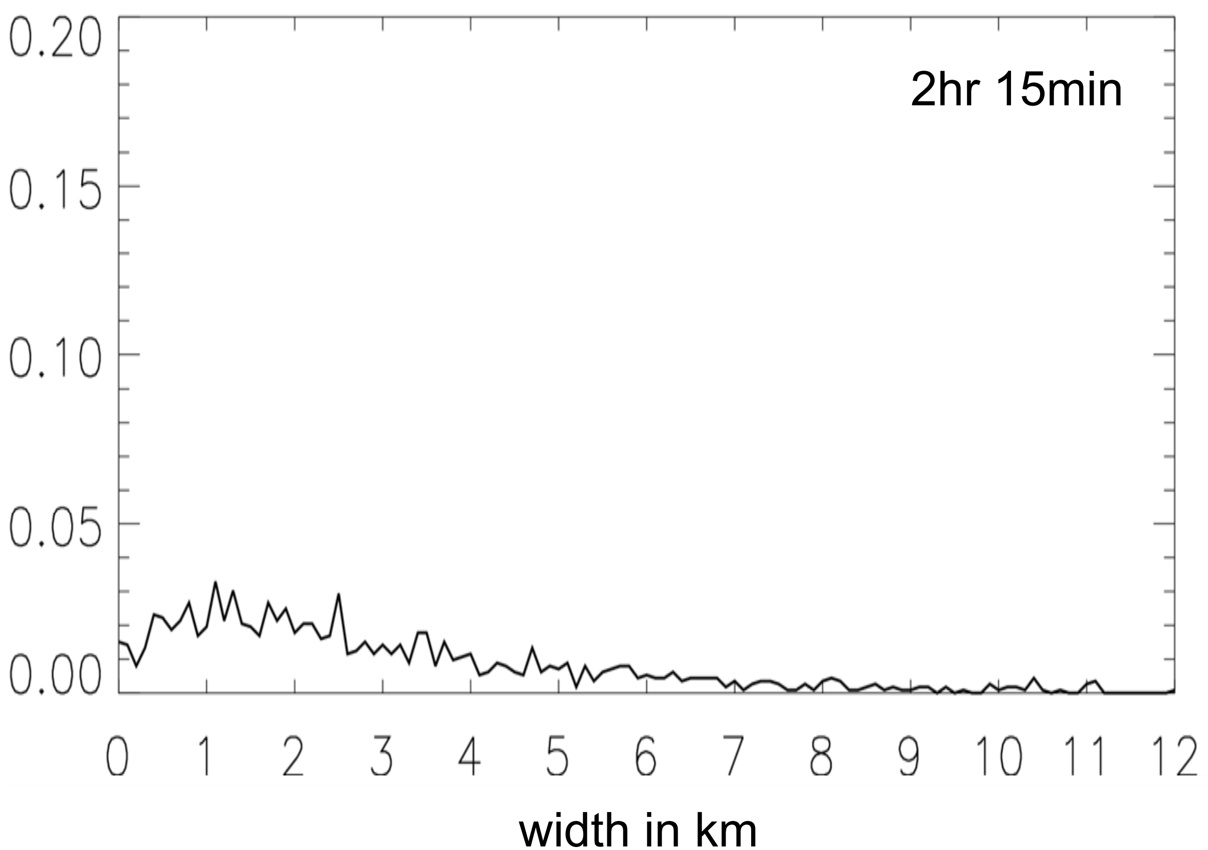
- persistence of contrails
- parameterization of processes influencing contrail/contrail cirrus cover:
  contrail formation, advection, spreading, mixing, and evaporation
- processes constrained using observations of supersaturation and spreading
- evolving ice water content of contrail cirrus

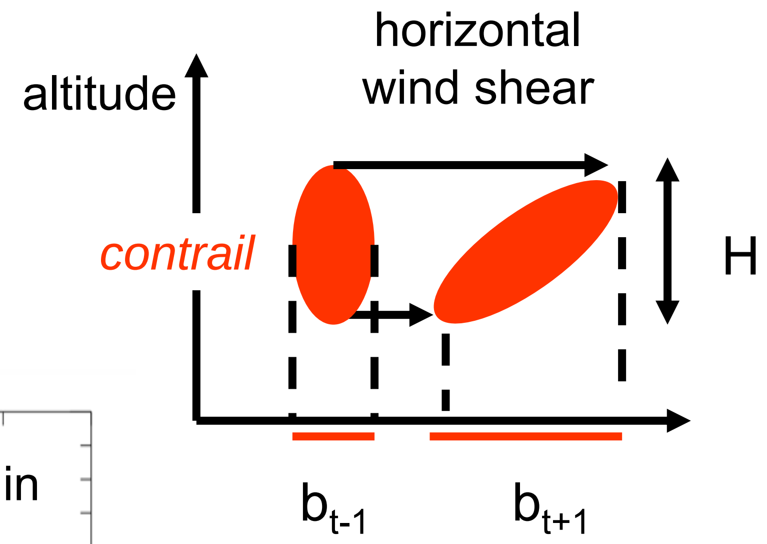
- now constrain model using observations of: supersaturation, spreading rates

# Climate modeling

## Process parameterization and validation: Spreading

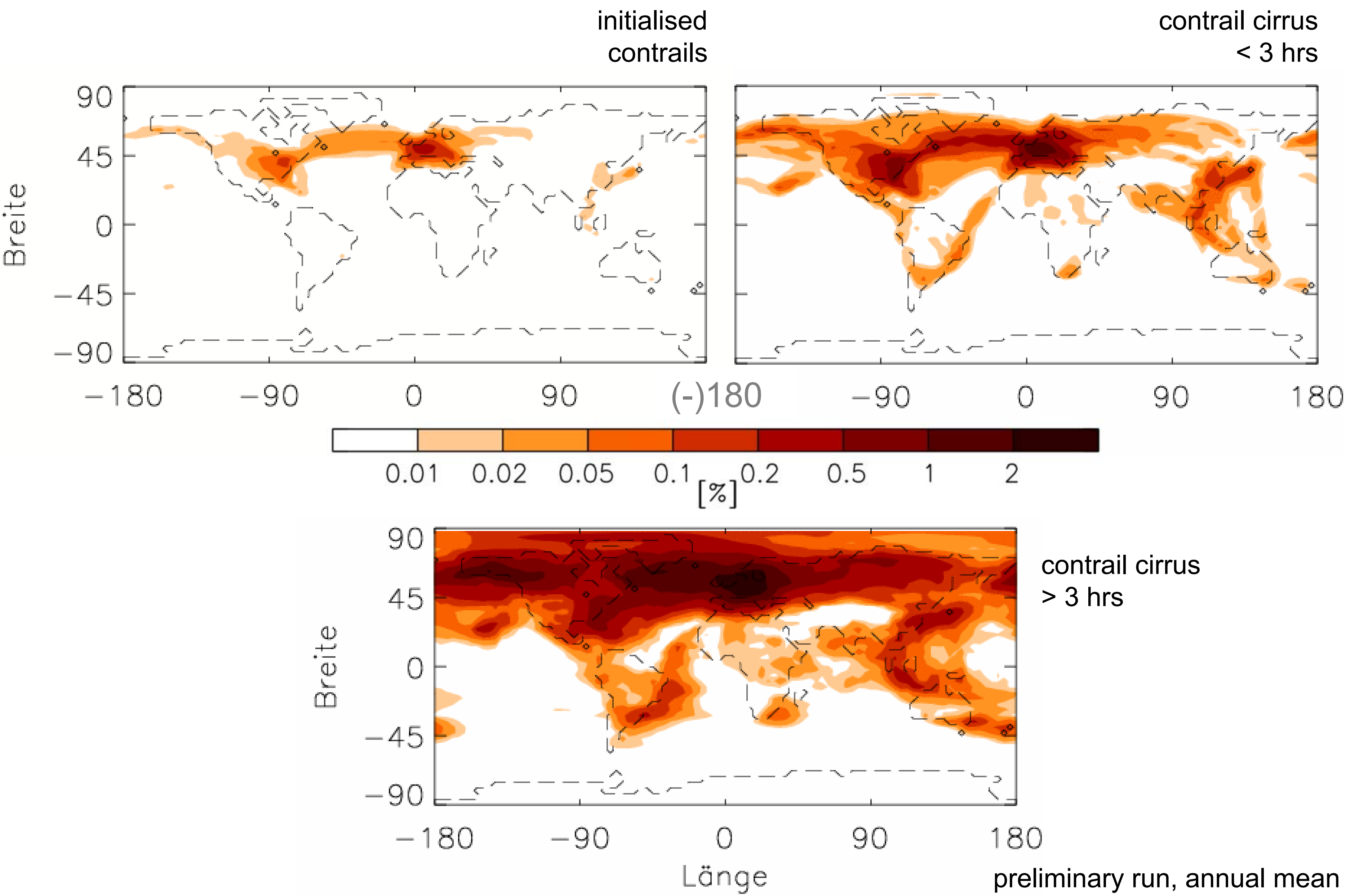
distributions of contrail width over Europe



# Climate modeling

## Evolution of contrail cirrus coverage




preliminary run, annual mean

# Summary: Climate modeling

## Objective and Status

| | | |
|---|---|---|
| | Enable climate model to simulate IN effects realistically. | |
| M3A | Fully coupled parameterization of cirrus cloud formation implemented in ECHAM. | **m12** |
| | Scheme has been implemented into ECHAM4 and is currently being tested. | |
| | Enable climate model to simulate contrail-cirrus self-consistently. | |
| M3B | Subgrid-scale parameterization for contrail-cirrus ready in ECHAM. | **m12** |
| | Scheme has been developed and implemented into ECHAM4 and is currently being tested. | |
| | Study and analyze effects of contrail-cirrus on high cloudiness and climate. | |
| M3D | Global impact of contrail-cirrus on cirrus cover and properties quantified. | **m30** |
| | Not yet initiated. | |
| | Study and analyze effects of natural and anthropogenic IN on global cirrus cloud properties. | |
| M3E | Impact of natural and anthropogenic ice nuclei (including aviation soot) on global cirrus cloud properties quantified. | **m30** |
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## Links

With ETH and IMK-AAF. Also concerning a crucial improvement in GCM cloud schemes .....