Using “Perturbed Microphysics” to Determine Cloud Susceptibilities

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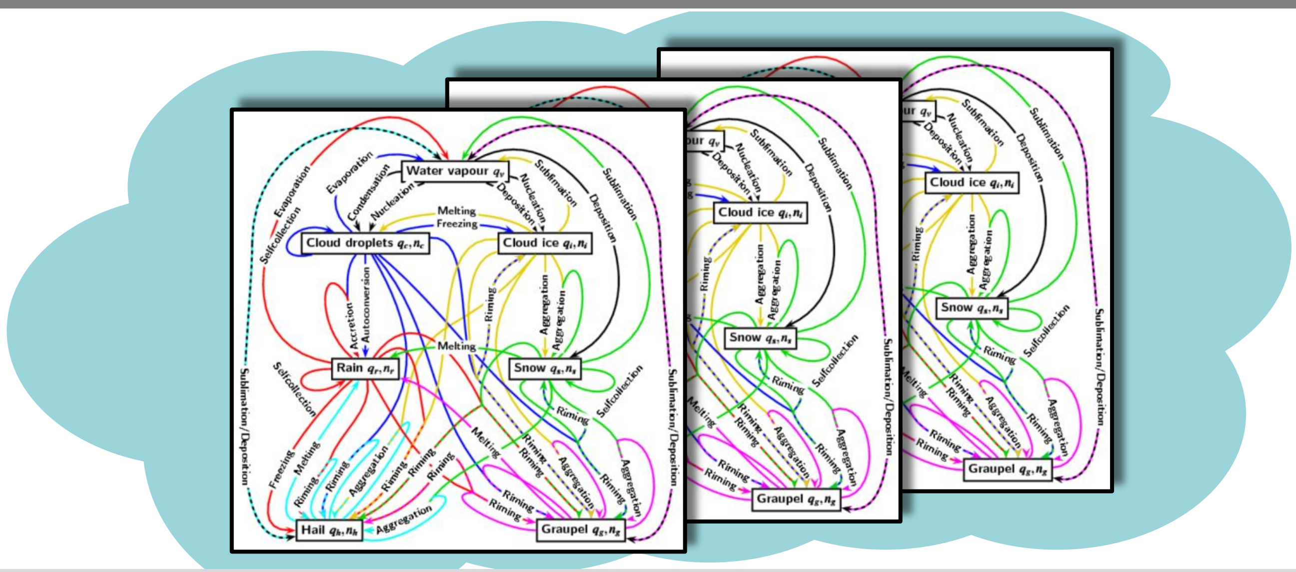


„Untangling aerosol effects on clouds…“

(Stevens and Feingold, 2009 Nature)

- **aerosols as ice nuclei**
  small subset of aerosols triggering of cloud ice formation at T>-38°C
  modification of cloud optical properties and cloud lifetime

- **buffering** mechanisms may reduce cloud response to aerosol perturbations
  cloud-dynamical buffers, e.g. due to modified circulation
  microphysical buffers, e.g. modified process rates

- **cloud susceptibility** dA/dN_d (Platnick & Twomey, 1994)
  change of albedo with change of absolute cloud droplet number

- **this study**
  - what is the effect of additional ice introduced in clouds?
  - adapt susceptibility concept to integral cloud properties and ice nuclei
    - e.g., $dLWP/dN_{aer}$, dF_{LW}/dN_{aer},
    - N_{aer} = ice nucleating aerosols, e.g. mineral dust
  - isolate microphysical from cloud-dynamical feedbacks
    - how does restructuring of circulation patterns contribute?

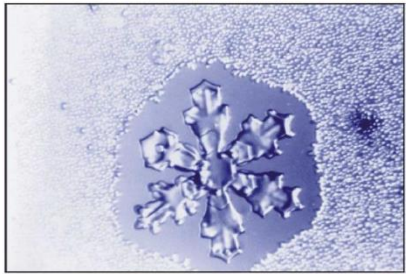


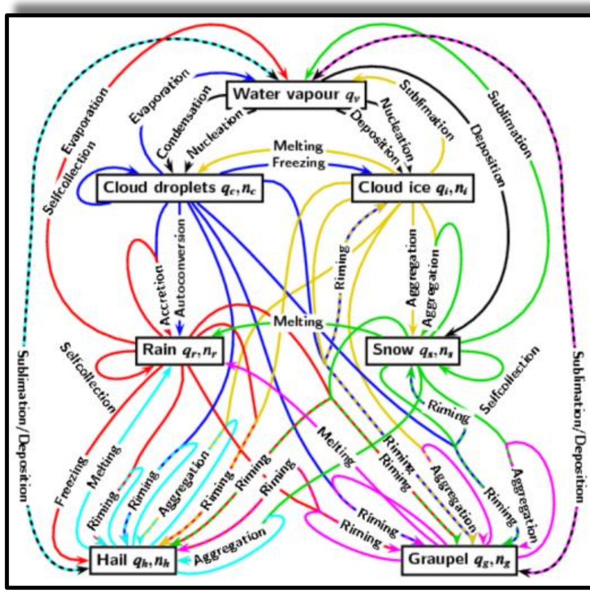
photo: R. Pitter

Impacts on the temperature field feed back on the circulation

Karlsruhe Institute of Technology

model core

T, p, u, v, w



(A. Seifert / U. Blahak)

radiation scheme

$r_{eff,cloud}$

$r_{eff,ice}$

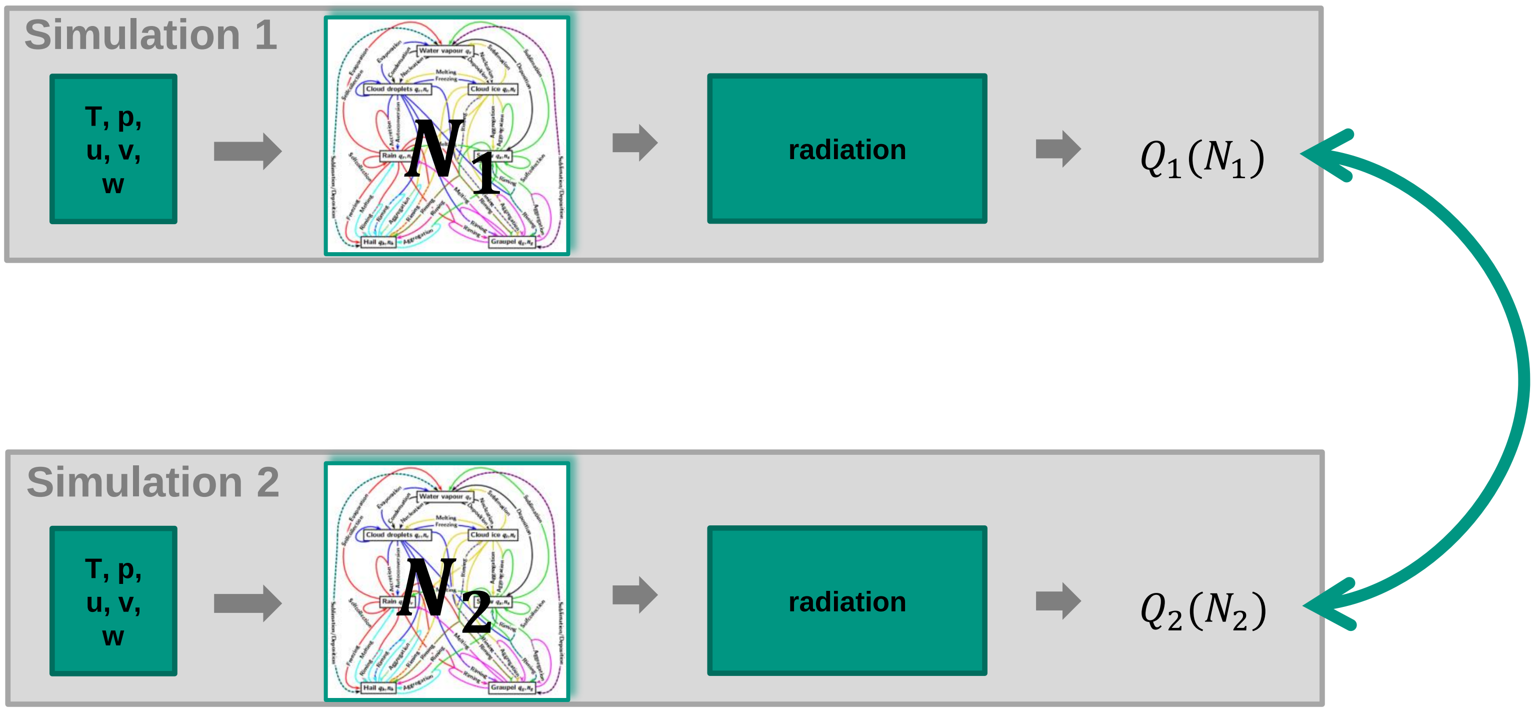
ΔT

latent heat

radiation absorption & emission

Ways to calculate susceptibilities

- $\boldsymbol{Q}$: quantity of interest, e.g. liquid water path, radiative flux
- $\boldsymbol{S}$: susceptibility with respect to perturbed aerosol concentrations

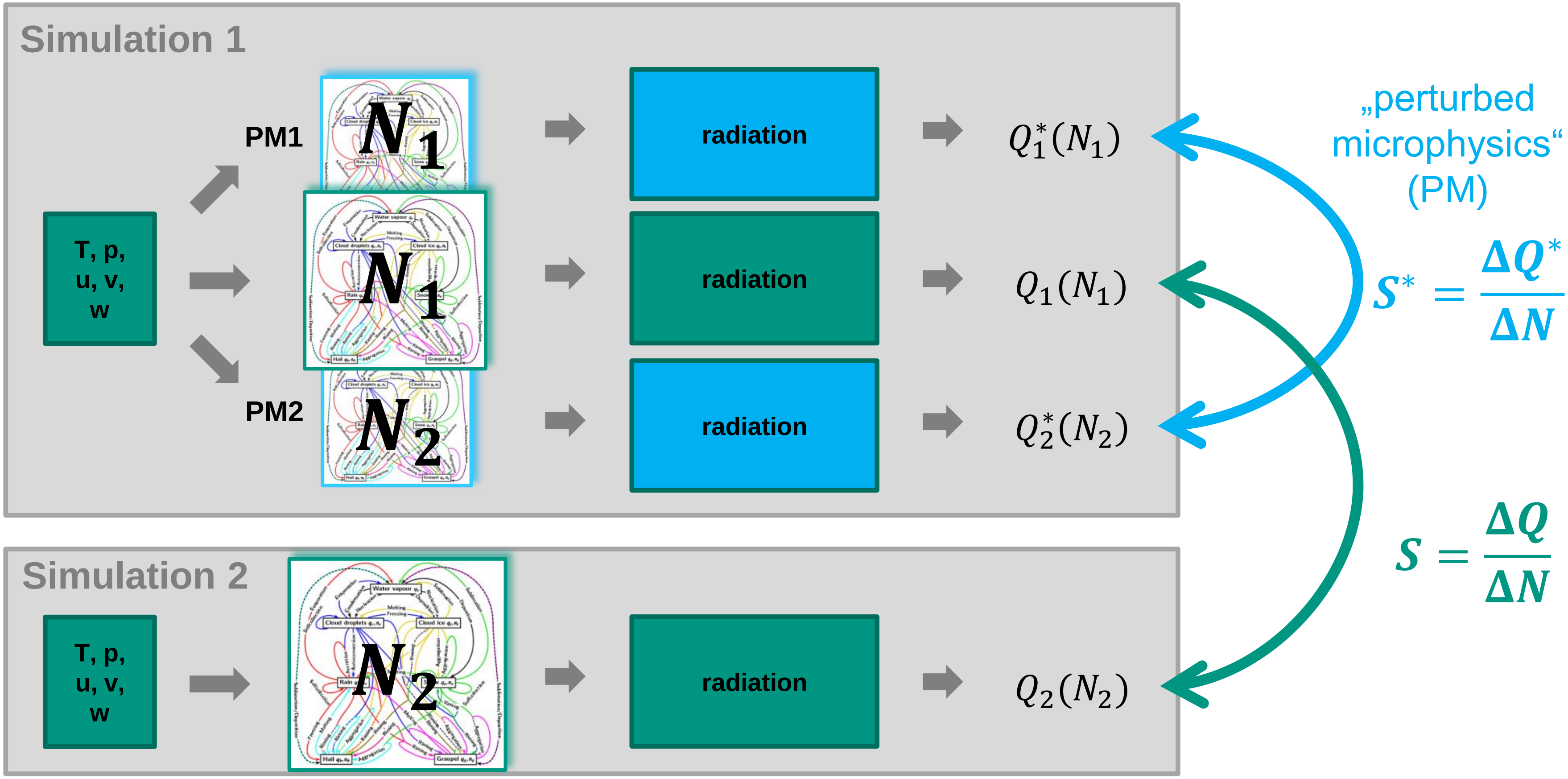


$$S = \frac{\Delta Q}{\Delta N}$$

Ways to calculate susceptibilities

$\boldsymbol{Q}$: quantity of interest, e.g. liquid water path, radiative flux

$\boldsymbol{S}$: susceptibility with respect to perturbed aerosol concentrations



„How large / important is - ? “

CONSORTIUM FOR SMALL SCALE MODELING COSMO

configuration

- **semi-idealized** setup
  - Arctic stratocumulus: ISDAC-based, Ovchinnikov et al., 2014
  - deep convection: Weisman and Klemp (1982) profile

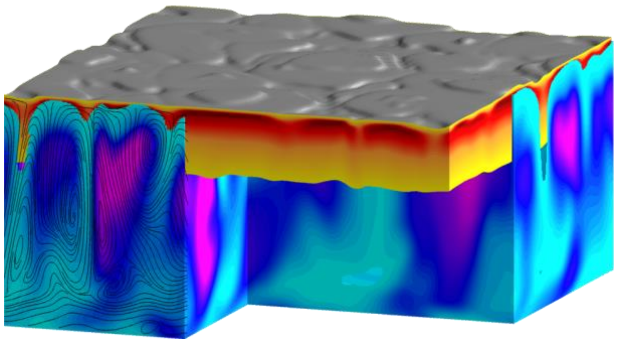
- $\Delta x \approx 100m$, some hours simulation time

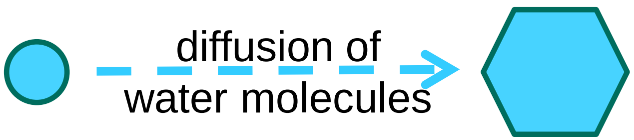
- **COSMO-ART** (Vogel et al., 2009)
  pollen module used for tracers

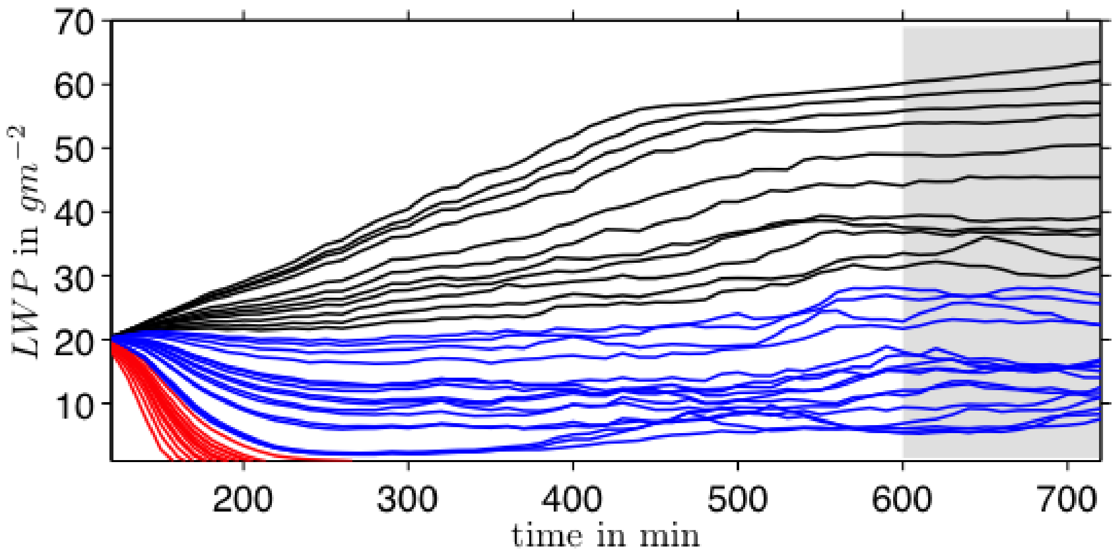
- **two moment scheme** for warm and cold cloud microphysics
  (Seifert and Beheng 2006)

- ice formation extended by **ice nuclei depletion**
  (Paukert and Hoose, 2014)
  aerosol-dependent **immersion freezing** and **deposition nucleation**
  (Niemand et al., 2012; Ullrich et al., in prep.)

Arctic mixed-phase cloud







more ice nuclei

less cloud water,
i.e. thinner cloud

Paukert and Hoose, 2014

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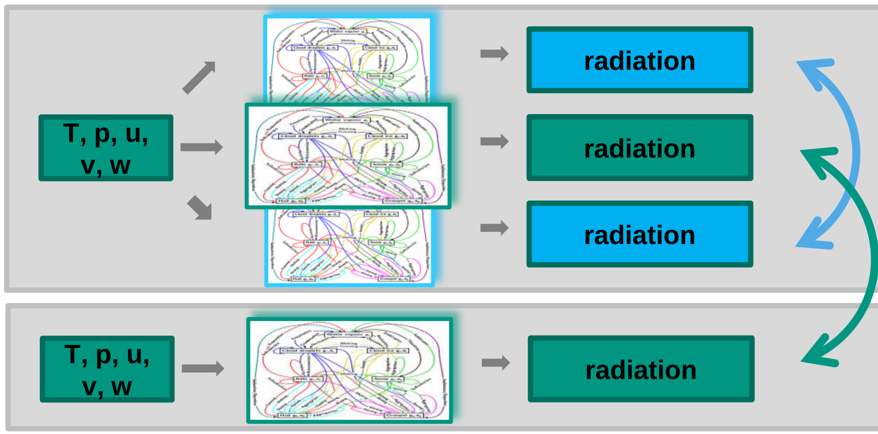
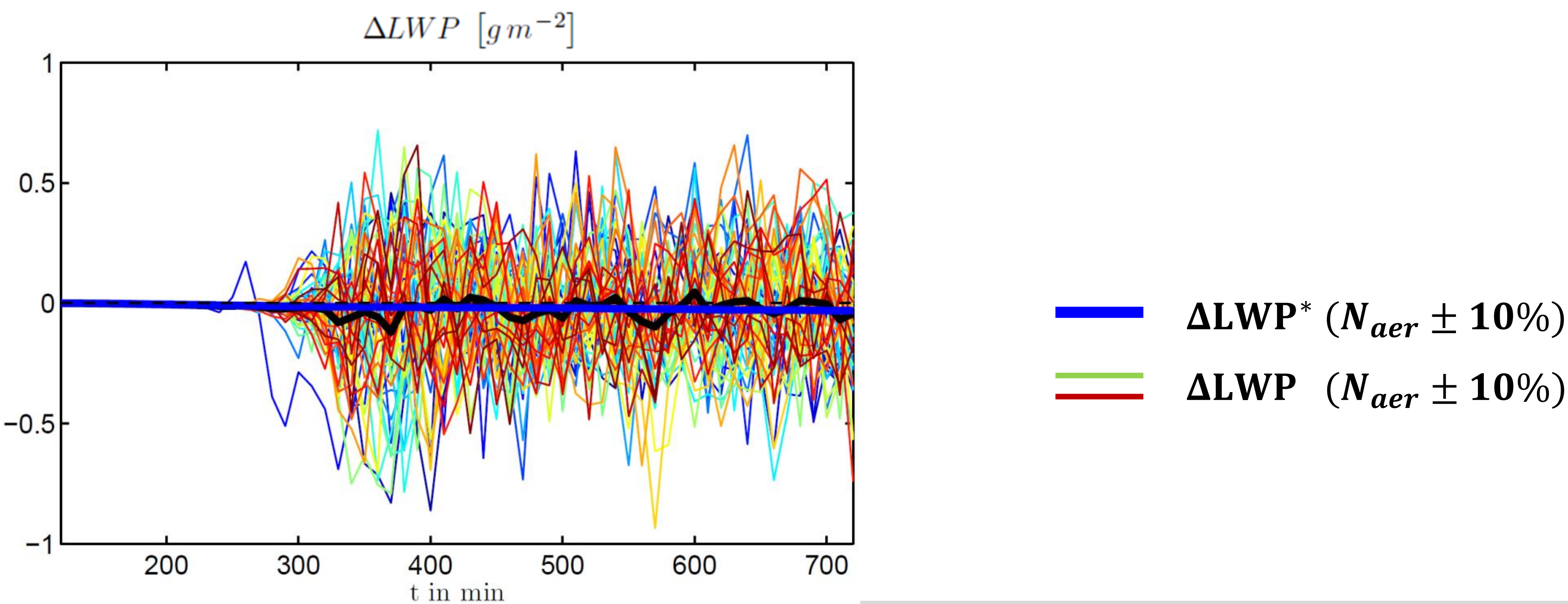
Extracting the effect of modified dynamics



$$S^* = \frac{\Delta LWP^*}{\Delta N}$$

$$S = \frac{\Delta LWP}{\Delta N}$$



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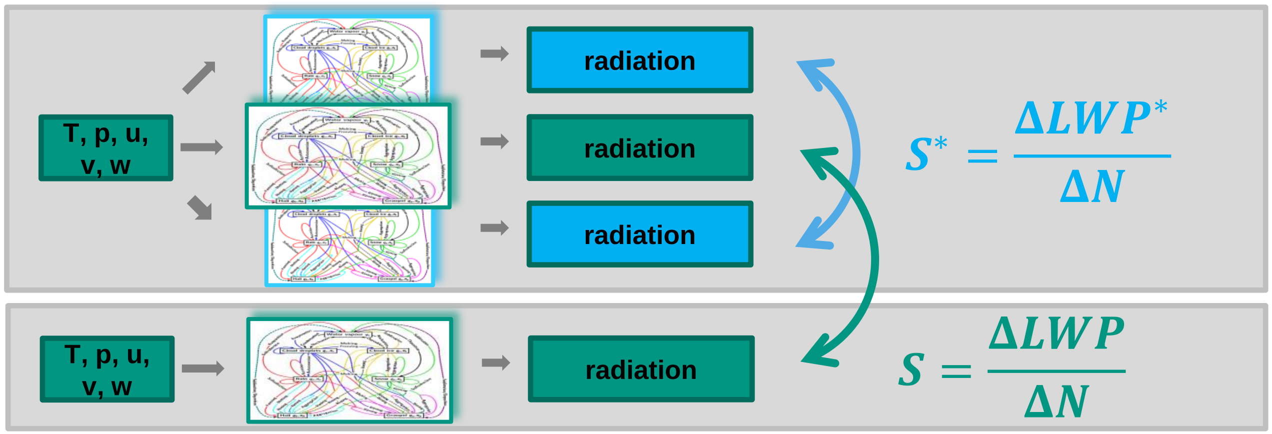
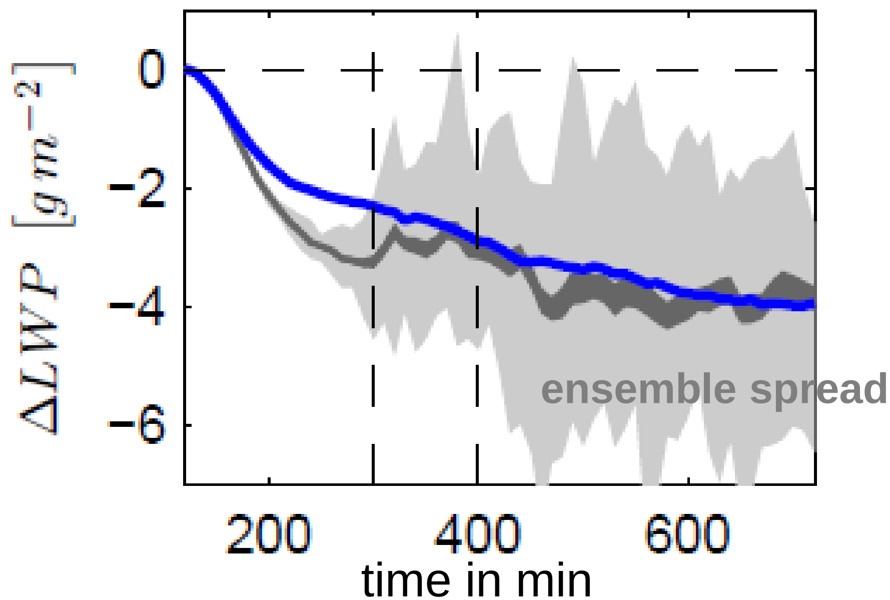
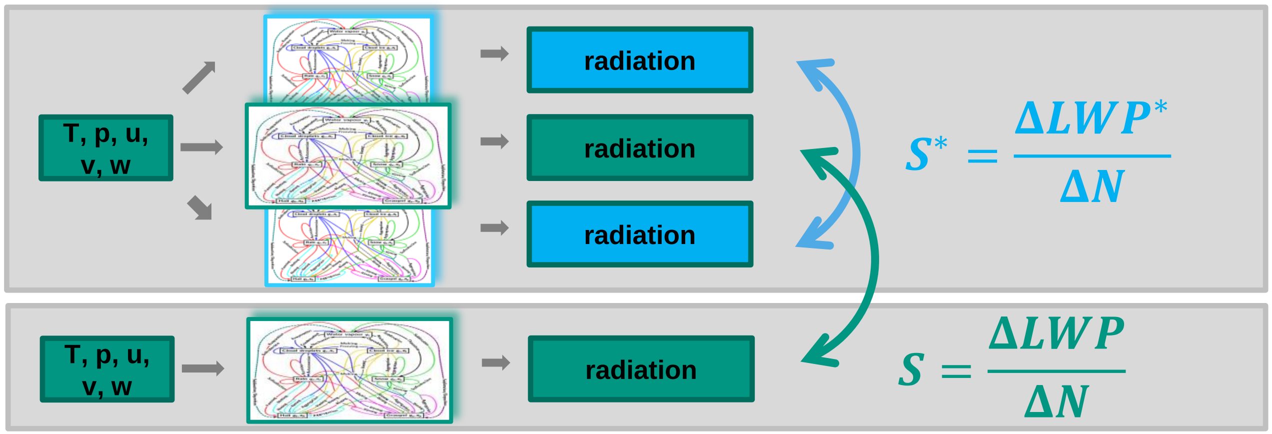




$\Delta \mathrm{LWP}^* \ (N_{aer} \pm 10\%)$

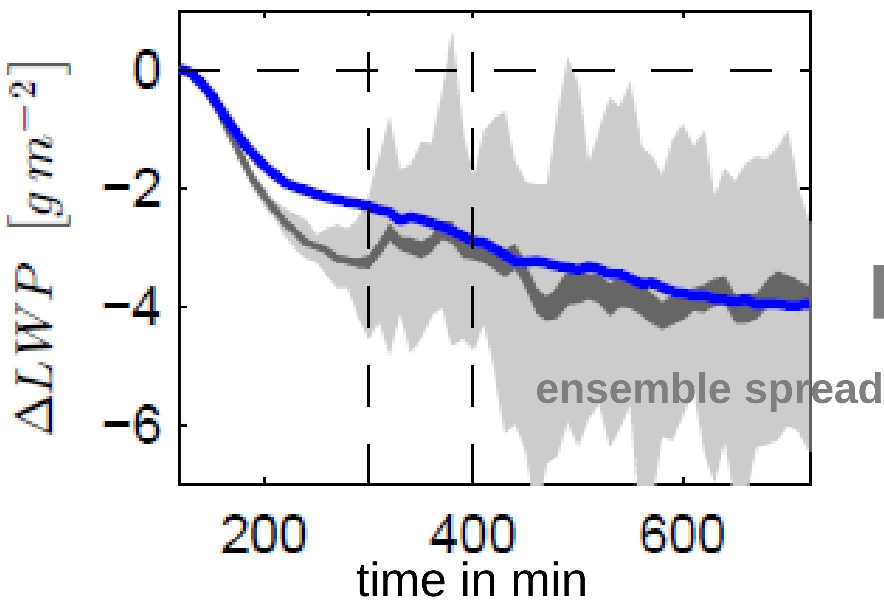
$\Delta \mathrm{LWP} \ (N_{aer} \pm 10\%)$
ensemble mean of 30 members

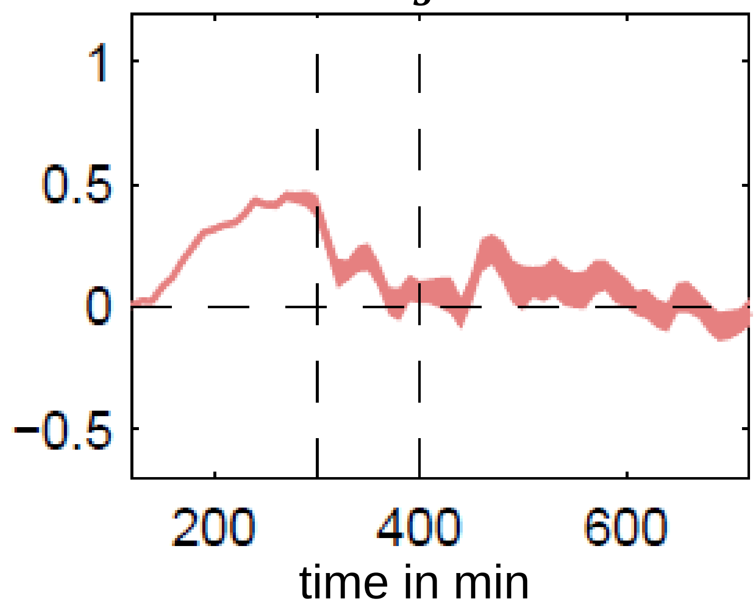
Extracting the effect of modified dynamics



cloud-dynamical enhancement of the microphysical susceptibilitiy

$$\frac{S - S^*}{S^*}$$





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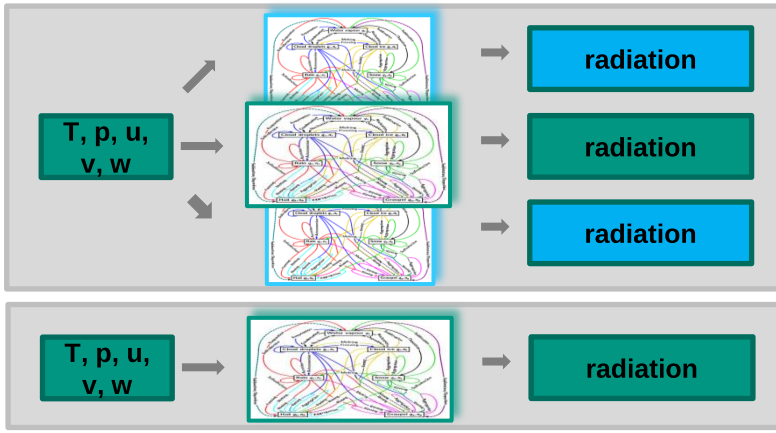


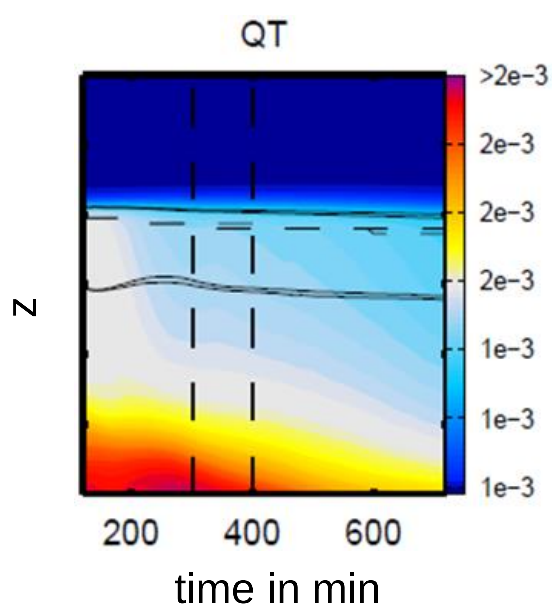
$$S^* = \frac{\Delta LWP^*}{\Delta N}$$

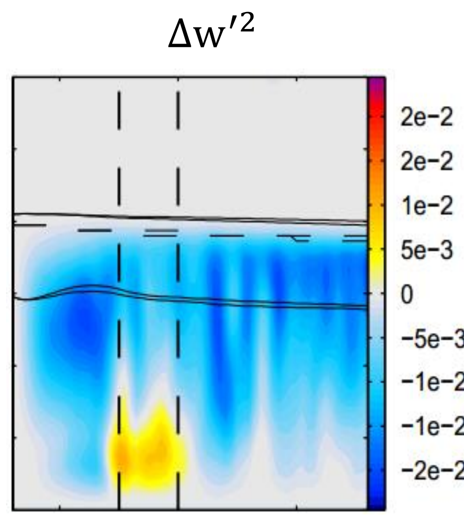
$$S = \frac{\Delta LWP}{\Delta N}$$

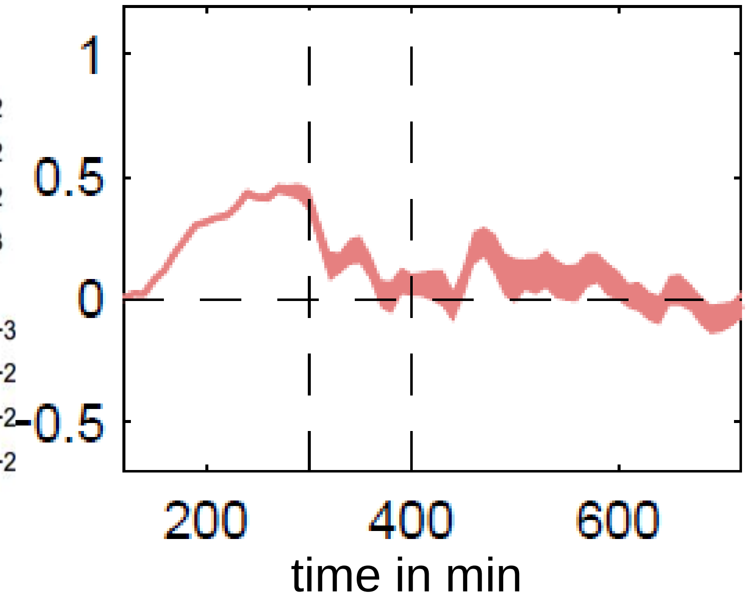
cloud-dynamical enhancement of the microphysical susceptibilitiy

$$\frac{S - S^*}{S^*}$$

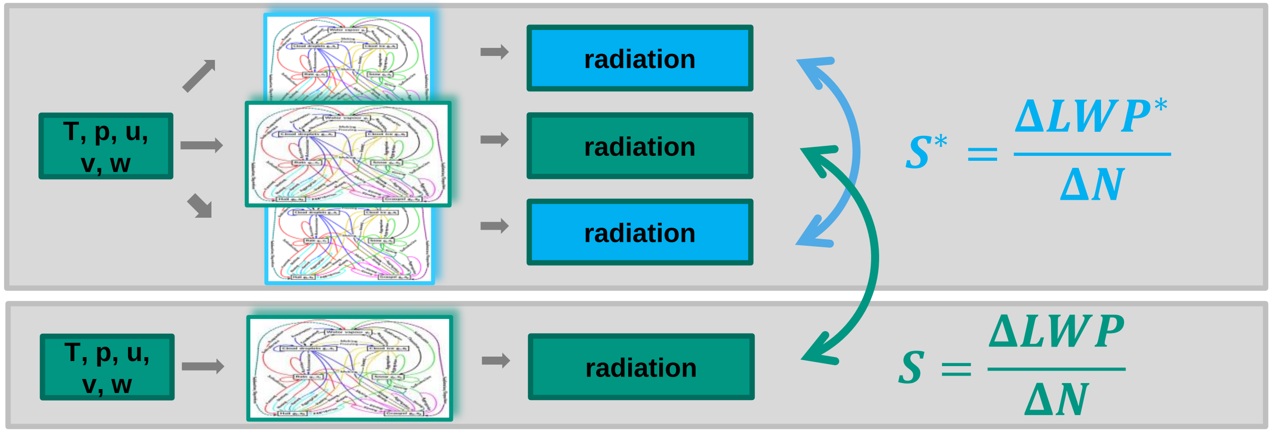
transport of humidity:



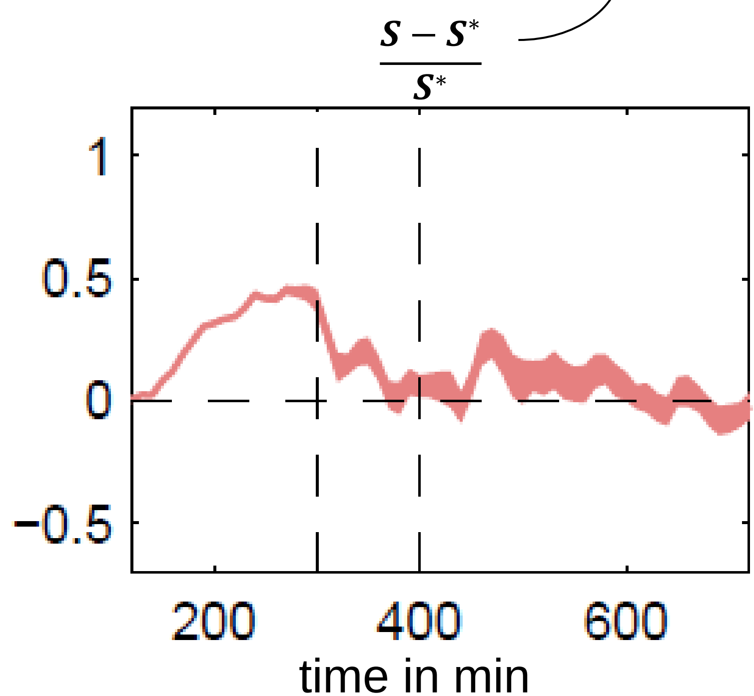




Extracting the effect of modified dynamics

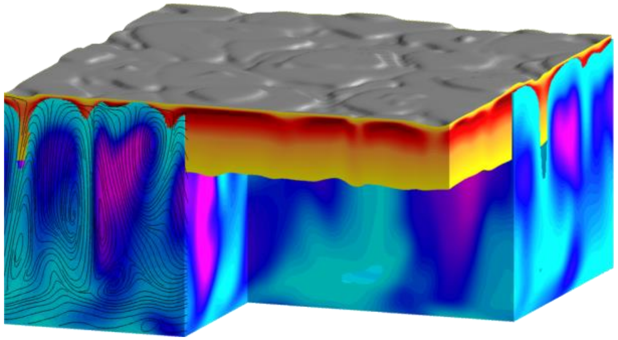


cloud-dynamical enhancement of the microphysical susceptibilitiy

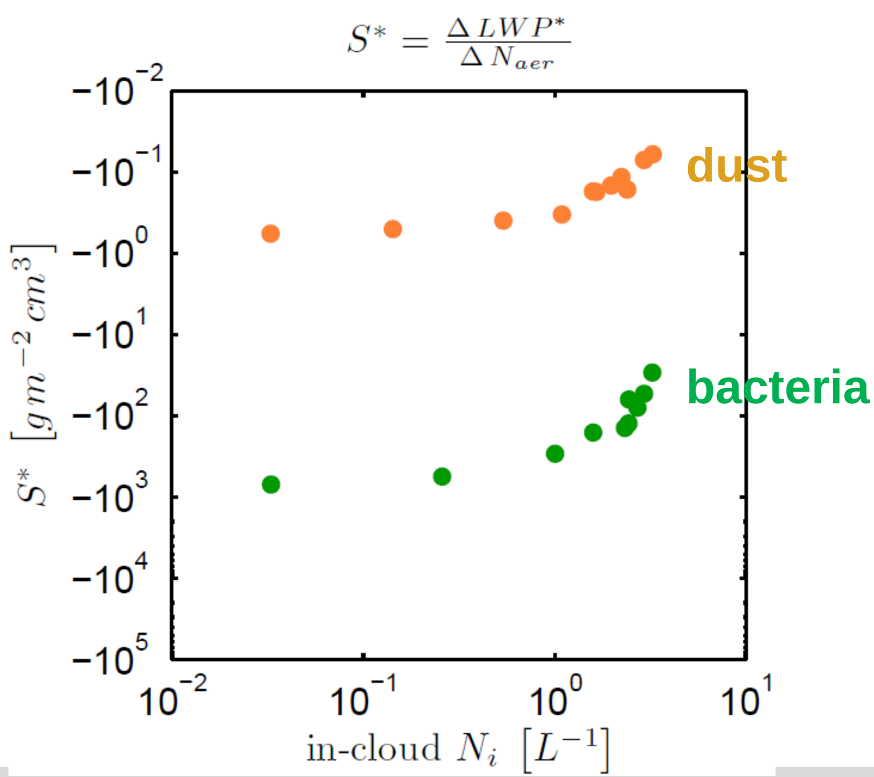


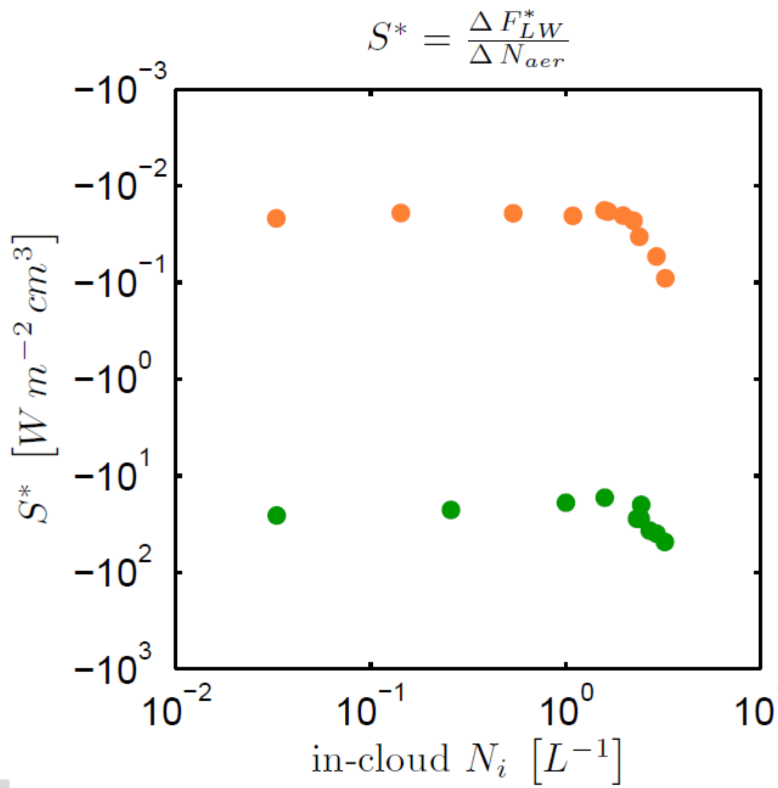
- **t>300min:**
  - enhancement decays
  - adjustment of turbulent transport: vapor, ice nuclei
  - shear production of turbulence modulates the vertical transport

Susceptibilies: Arctic mixed-phase cloud



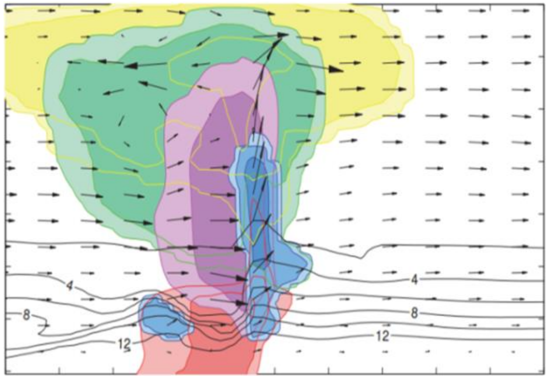
- S^* derived from „perturbed microphysics“
  - negative: decreasing LWP
  - higher magnitude for bacteria
  - base state dependent susceptibility



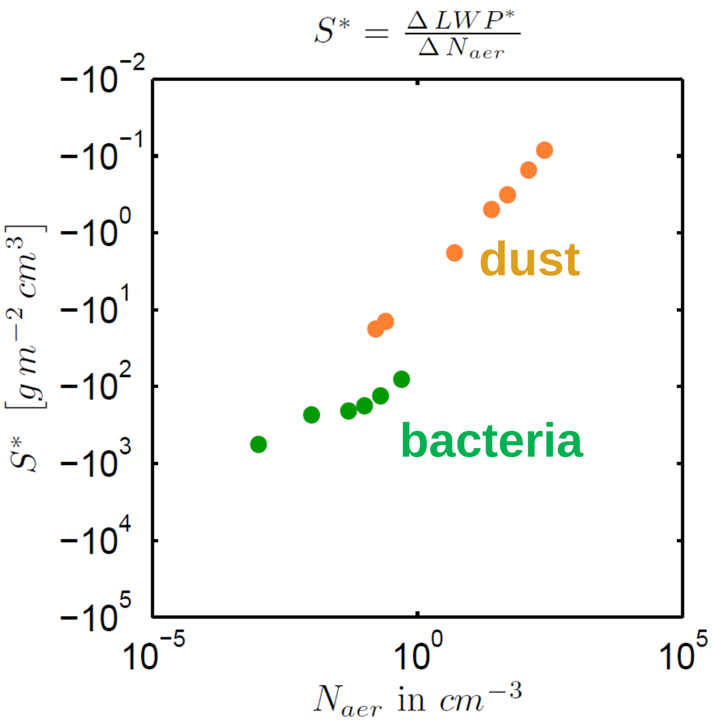


Deep Convection

- Weisman, Klemp (1982) profile
  - no equilibrium state, complex structure
  - strong updrafts / cooling rates
  - whole range of freezing temperatures and mechanisms is covered
  - dozens of interactions between cloud particles
- general results
  - bacteria show higher S^* than dust despite lower maximum IN activity
    → higher impact at lower levels
  - $S^*(N_{aer})$ more variable than in stratocumulus



(W. Straub, dissertation 2008)



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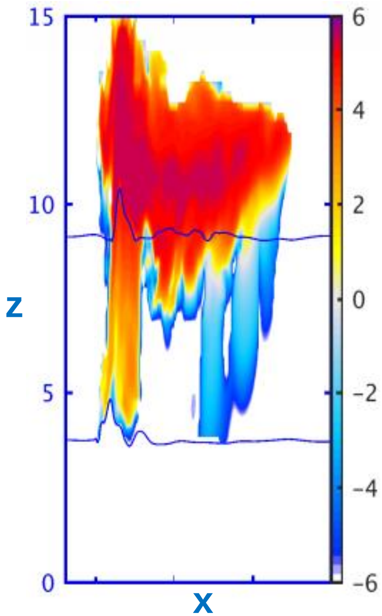
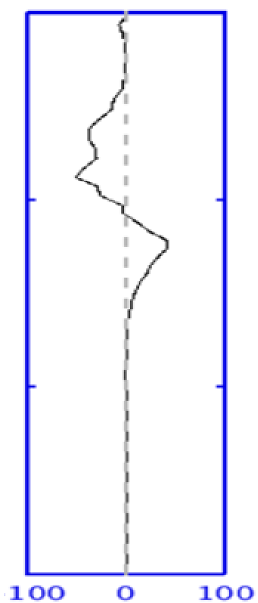
Deep Convection: microphysics

- PM results as horizontal averages
- t0 = 1hr after initialization
- trigger: $\boldsymbol{\Delta N_{aer} = \pm 10\%}$
- here more ice nuclei yield less rain

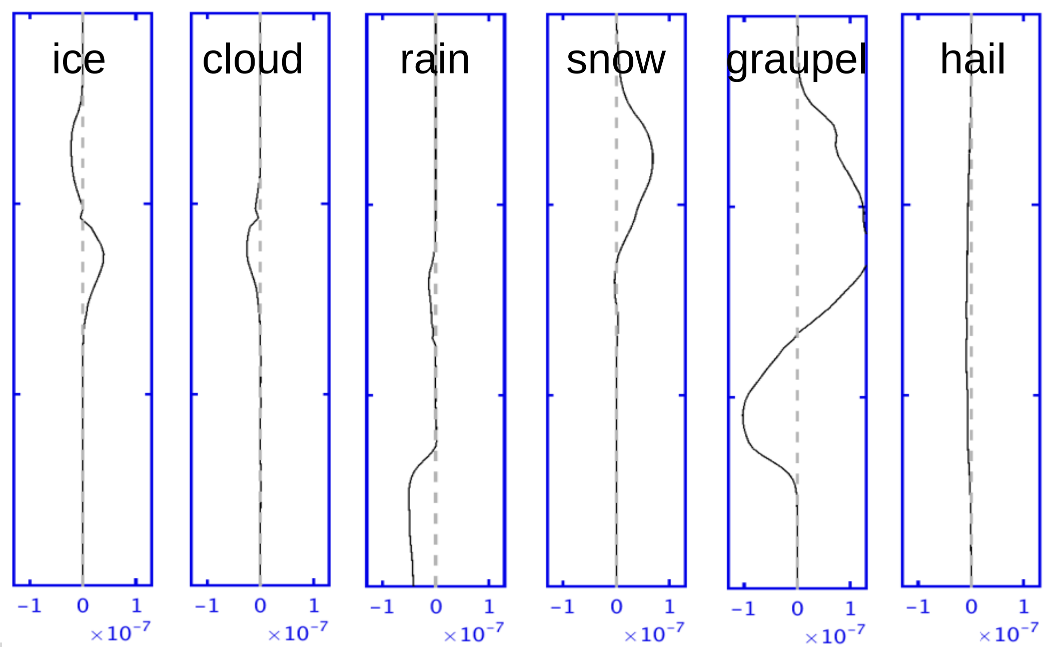
$log_{10}(n_{ice}[m^{-3}])$

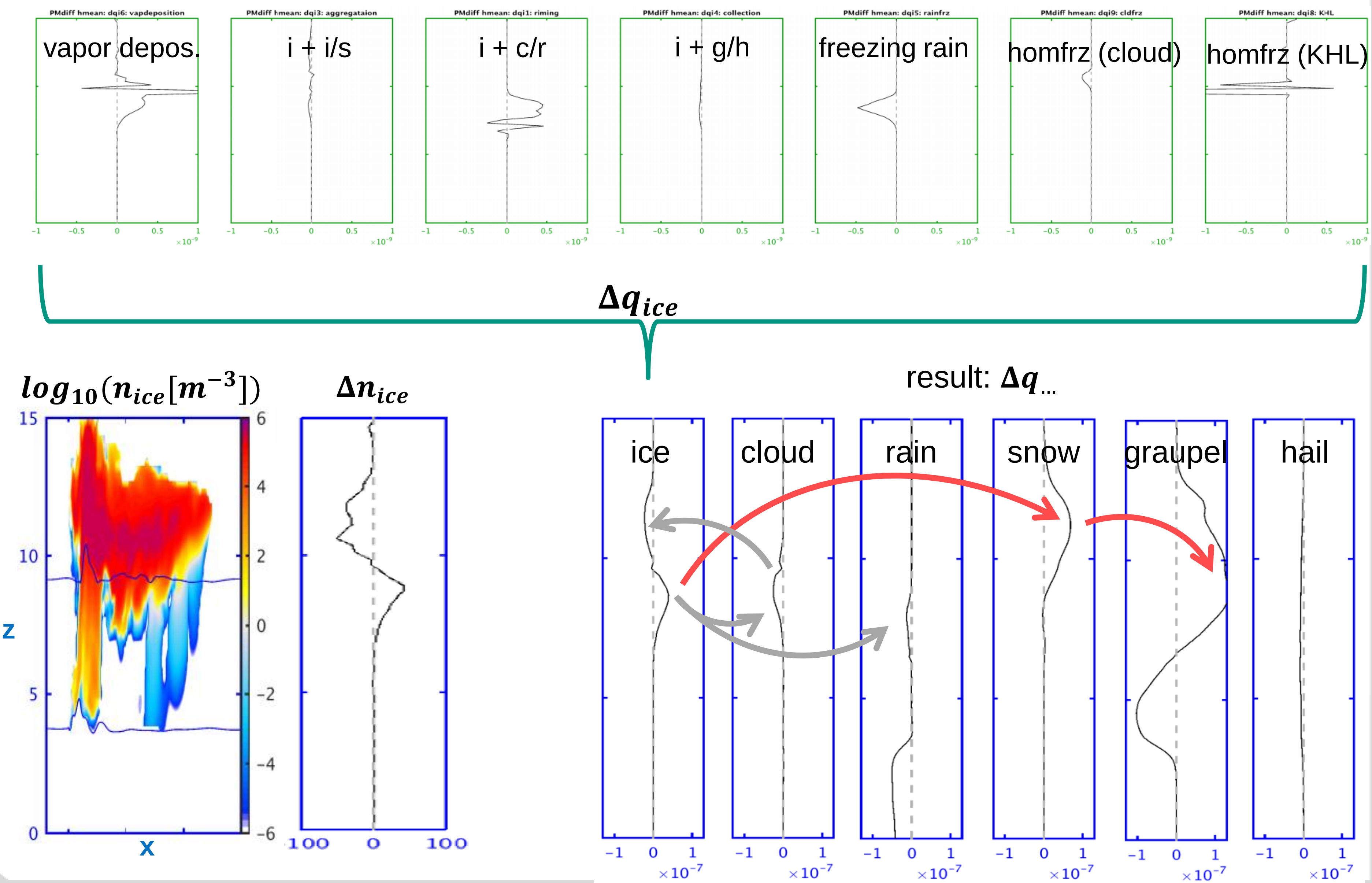


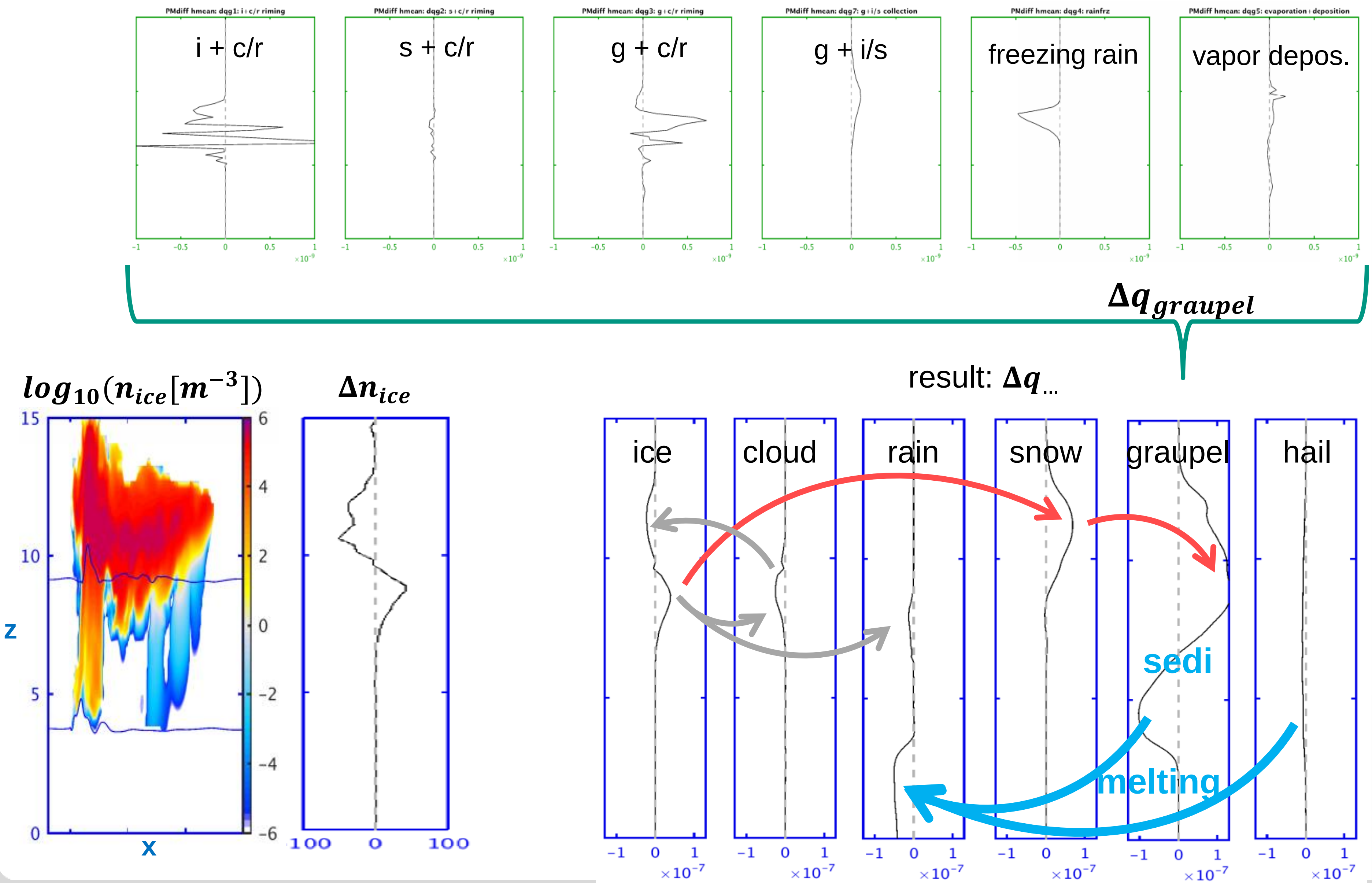
Δn_{ice}



result: $\boldsymbol{\Delta q}$...




vapor depos.
i + i/s
i + c/r
i + g/h
freezing rain
homfrz (cloud)
homfrz (KHL)
Δq_{ice}
$log_{10}(n_{ice}[m^{-3}])$
Δn_{ice}
result: $\Delta q_{...}$
ice
cloud
rain
snow
graupel
hail
z
x



i + c/r
s + c/r
g + c/r
g + i/s
freezing rain
vapor depos.
$\Delta q_{graupel}$
$log_{10}(n_{ice}[m^{-3}])$
Δn_{ice}
result: $\Delta q_{...}$
ice
cloud
rain
snow
graupel
hail
sedi
melting
z
x

Summary and Outlook

- **perturbed microphysics vs. ensemble runs**

  $\boldsymbol{S}$ derived from simulations with dynamical feedbacks is highly variable

  „perturbed microphysics“ with unaffected dynamics can yield $\boldsymbol{S}^*$ without ensemble

- $\boldsymbol{S}^*$ vs. $\boldsymbol{S}$

  enhancement of S due to feedbacks on dynamics

  ~ 50% in Arctic stratocumulus (temporary effect)

- **deep convection**

  more pronounced dependence of $\boldsymbol{S}^*$ on $\boldsymbol{N}_{aer}$

  more ice nuclei $\not\to$ more precipitation

- **ongoing work**

  some more cloud systems and IN species

  non-idealized simulations