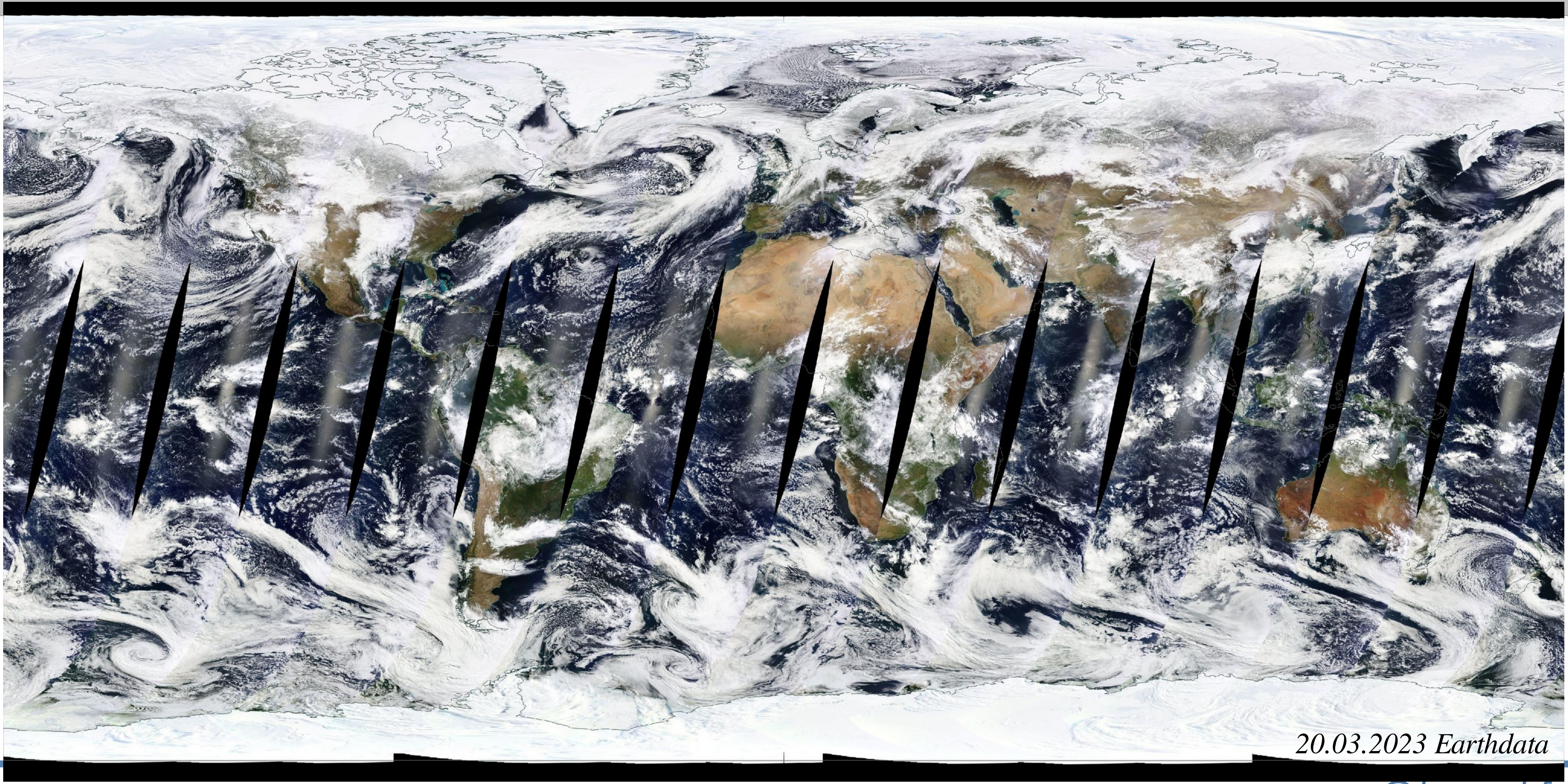
Understanding and simulating low-level mixed-phase clouds in the extratropics and polar regions

A. Possner



20.03.2023 Earthdata

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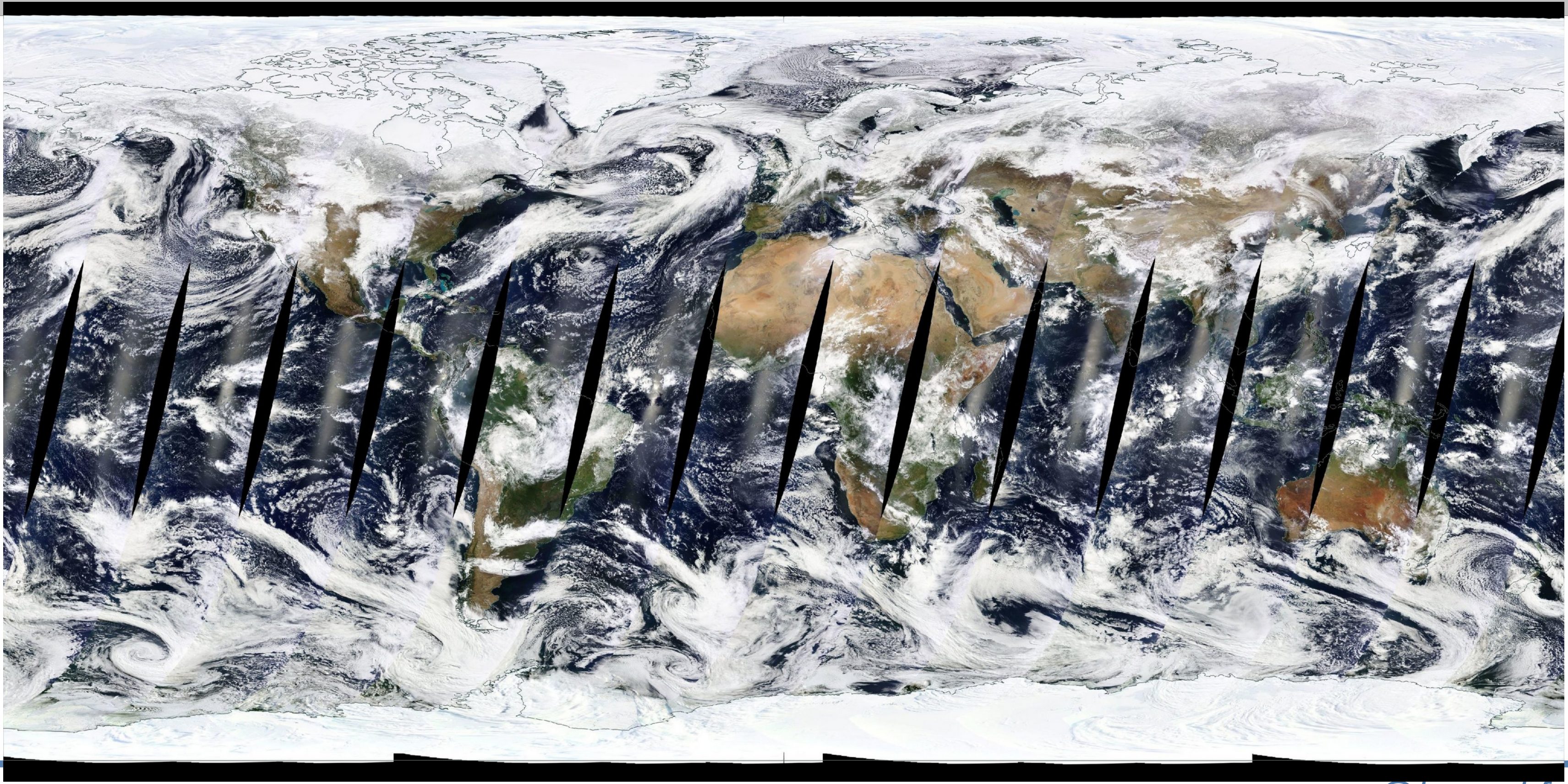

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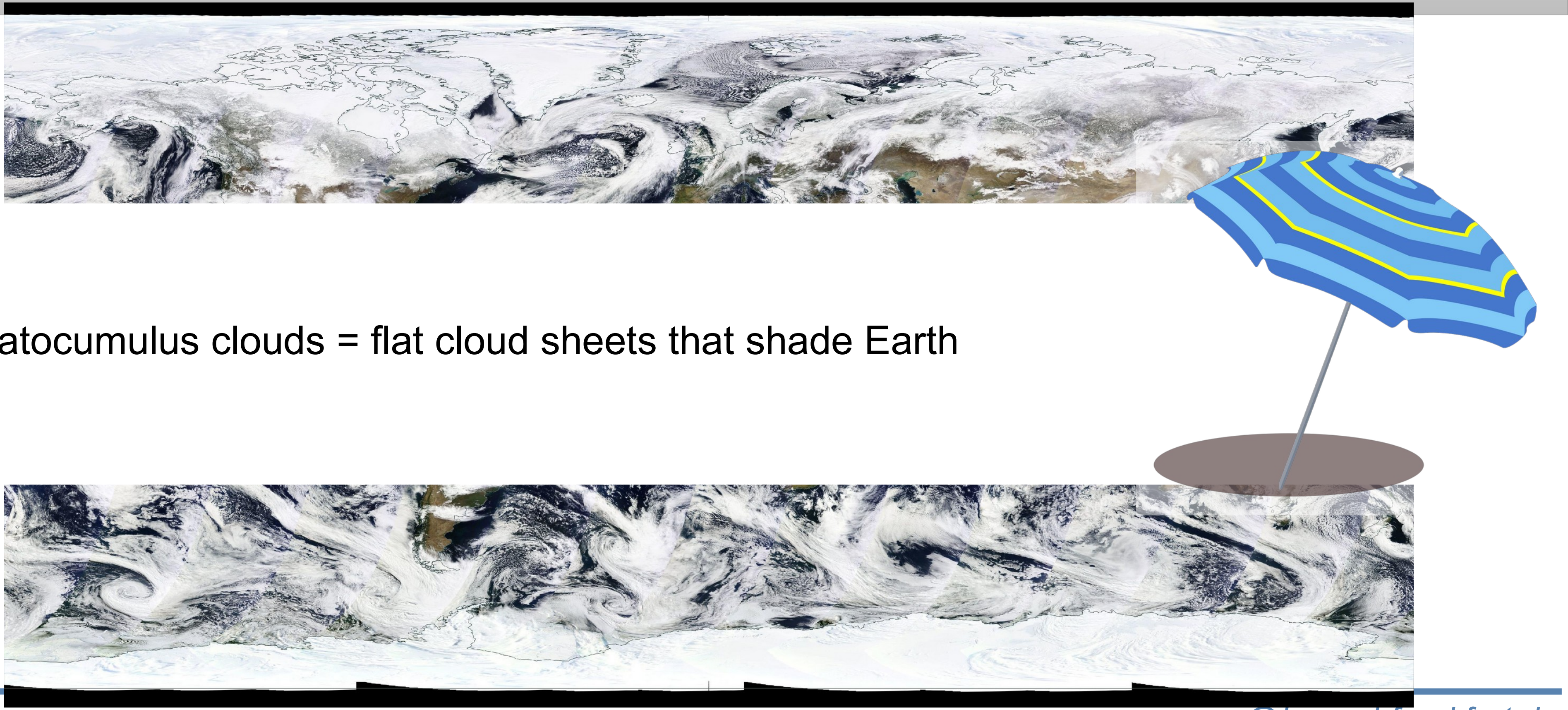

Stratocumulus clouds = flat cloud sheets that shade Earth

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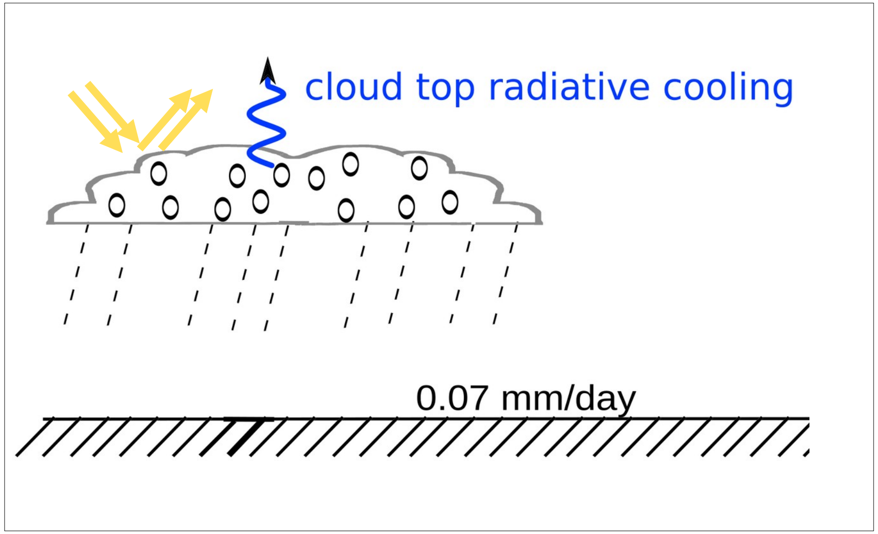

<u>pure liquid stratocumulus (Wood et al. 2012):</u>

occurs above all ocean basins, but predominantly in the subtropics;
reflect between 27-38% of solar radiation

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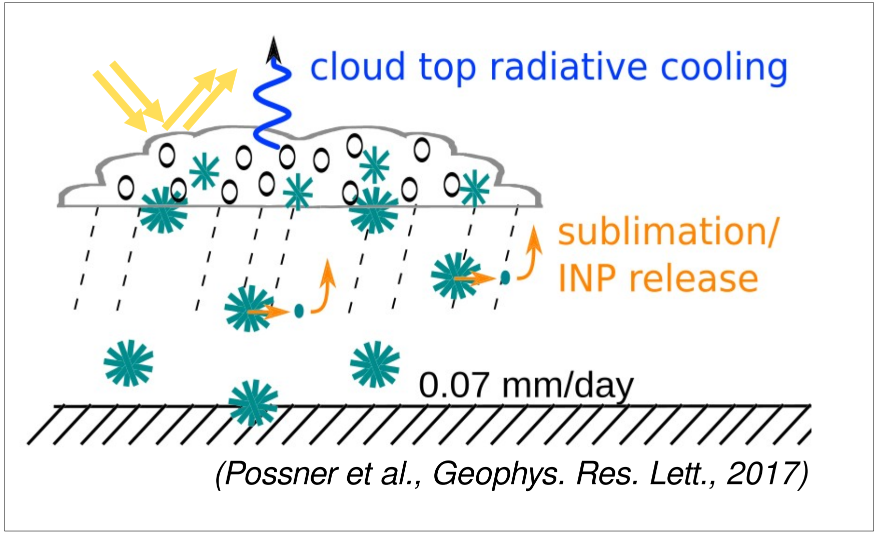

(Possner et al., Geophys. Res. Lett., 2017)

pure liquid stratocumulus (Wood et al. 2012):
occurs above all ocean basins, but predominantly in the subtropics; reflect between 27-38% of solar radiation

mixed-phase stratocumuli *(Morrison et al. 2012)*:
contain liquid and ice, are thermodynamically unstable, but persist for days

Understanding and simulating low-level mixed-phase clouds in the extratropics and polar regions

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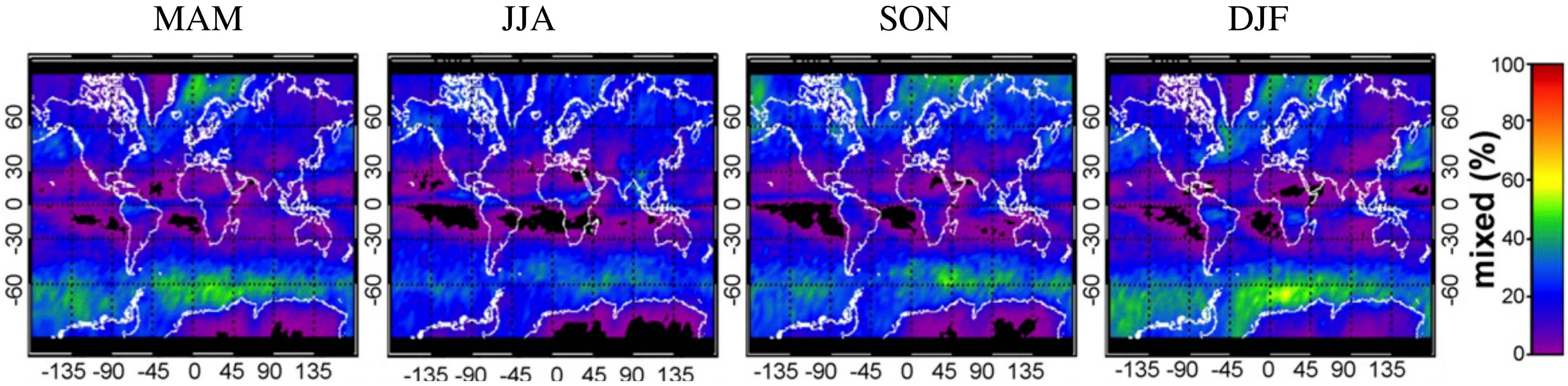


(*Korolev et al. 2017*)

phase classification based on active remote sensing (2006-2010)

apossner@iau.uni-frankfurt.de

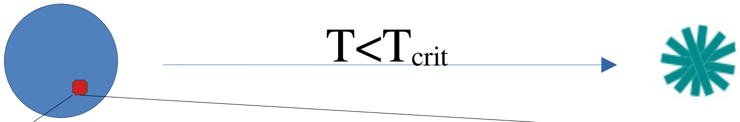
Outline of talk

- Origins of cloud ice
- Cloud radiative effects
- Cloud regime changes

INP = ice nucleating particle

Where does the ice come from – part I

primary nucleation governed by immersion freezing (Murray et al. 2012)



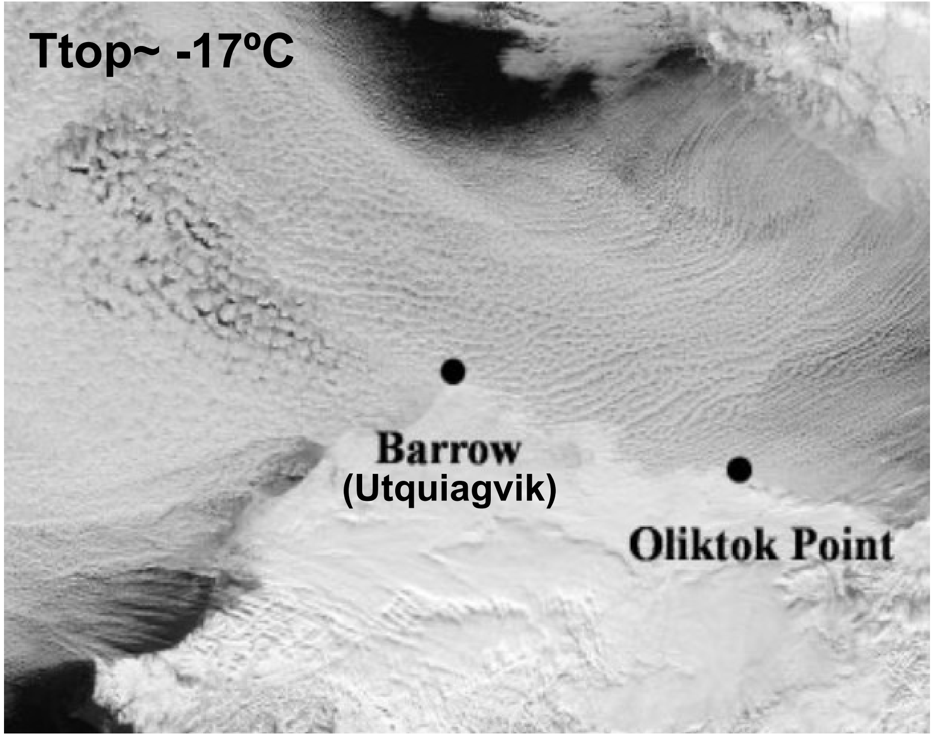
- dust are very good INP (Murray et al. 2012, Brunner et al. 2021)
- sea spray are also good INP (DeMott et al. 2016)
- anthropogenic aerosol (black carbon, organic carbon) are inefficient in this regime (Wex et al. 2019)

INP = ice nucleating particle, T=temperature

apossner@iau.uni-frankfurt.de

Measurements in the field

M-PACE: 09.10. - 10.10. 2004 *(Verlinde et al. 2007)*



INP: 0.16 l^{-1}
Prenni et al. (2007)

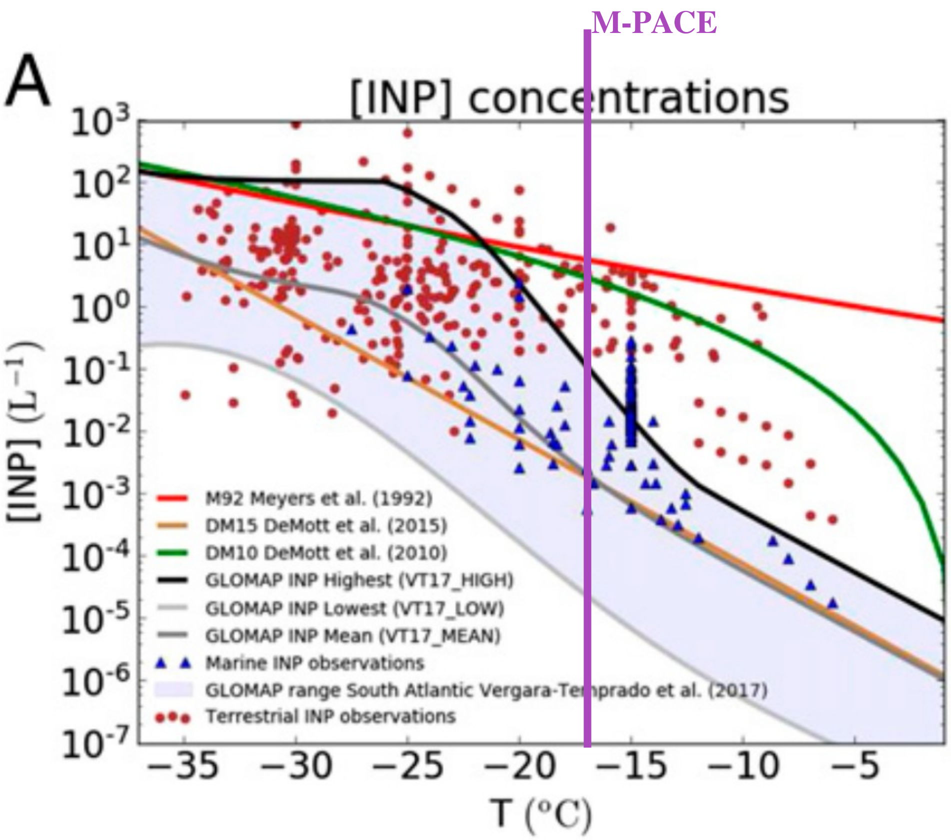
?

N_i: 0.8 l^{-1}
McFarquhar et al. (2007)

⚠ more ice crystals than INP ⚠

Ni = ice crystal number concentration

Just uncertainty?



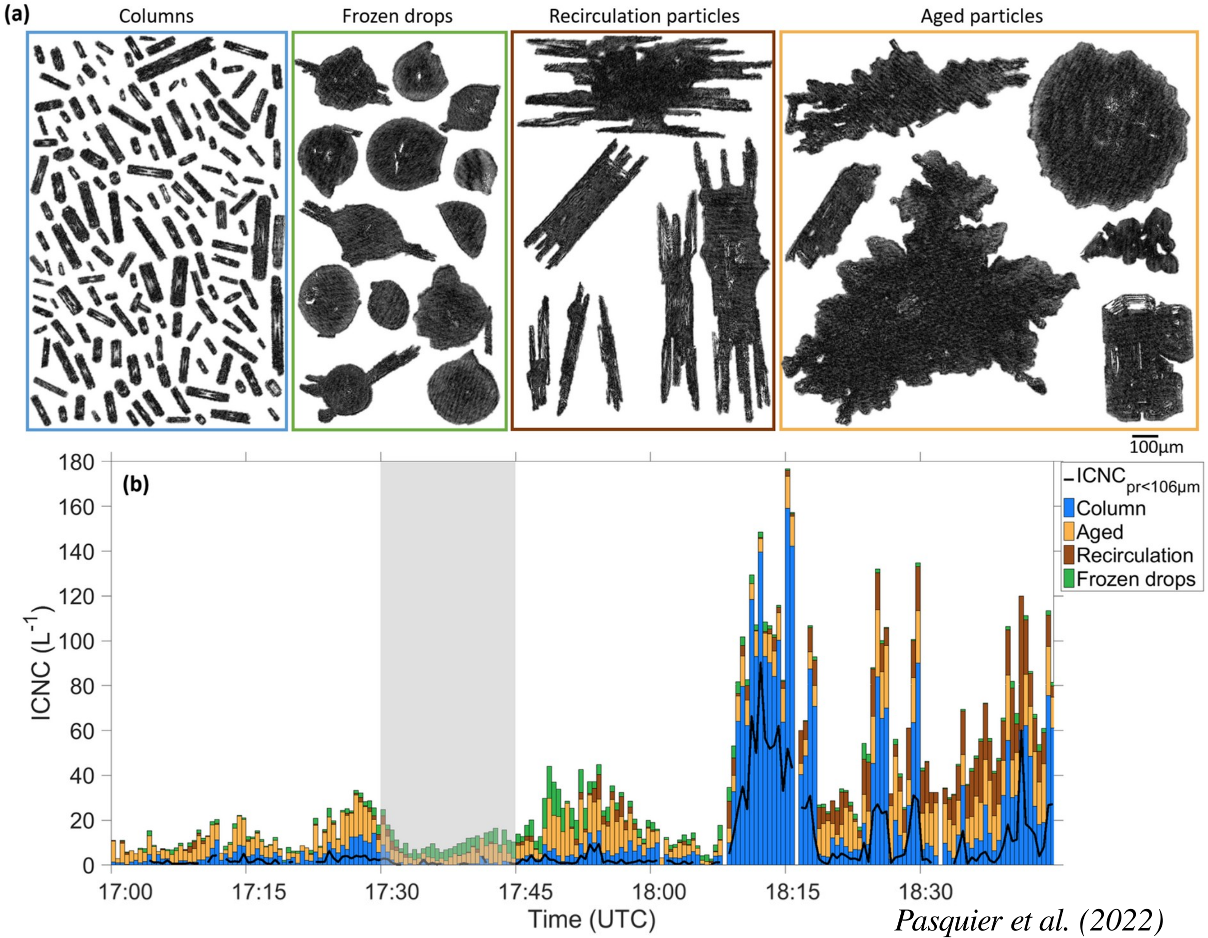
Vergara-Temprado et al. (2018)

→ large uncertainty between INP measurements

(Hiranuma et al. 2015)

Ni = ice crystal number concentration

Just uncertainty? - No



Pasquier et al. (2022)

→ increasing empirical and observed evidence for SIP in mixed-phase stratocumuli

(Rangno & Hobbs 2001, Luke et al. 2021, Pasquier et al. 2022)

Ni = ice crystal number concentration

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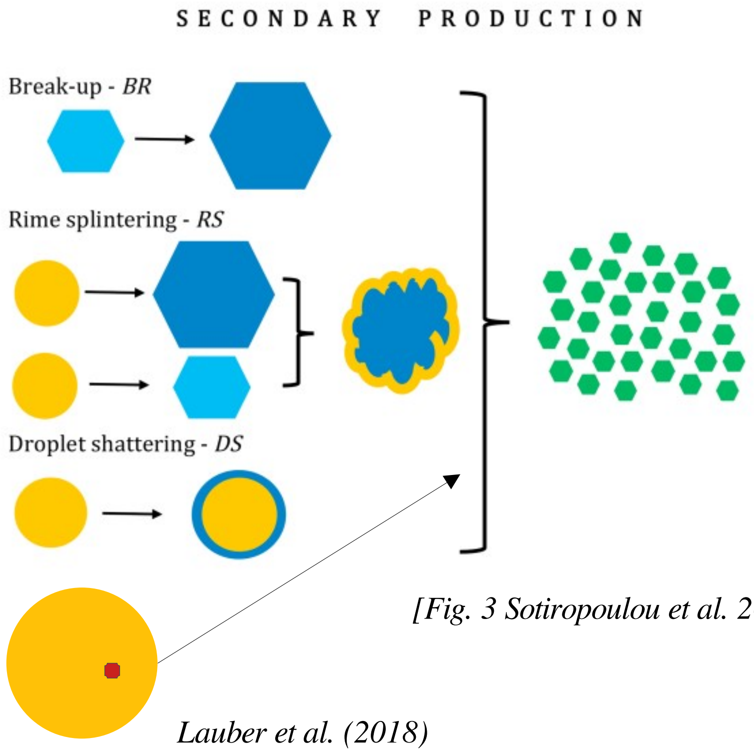
Where does the ice come from – part II

Secondary ice production (SIP)



[Fig. 3 Sotiropoulou et al. 2020a]

Lauber et al. (2018)

Where does the ice come from – part II

Secondary ice production (SIP)

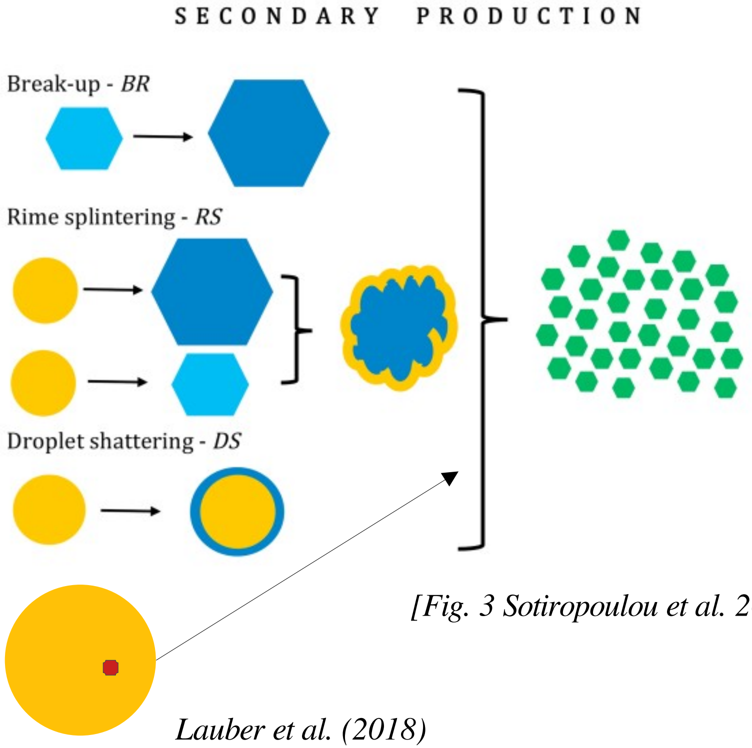
GCMs

X

✓

X

X



[Fig. 3 Sotiropoulou et al. 2020a]

Lauber et al. (2018)

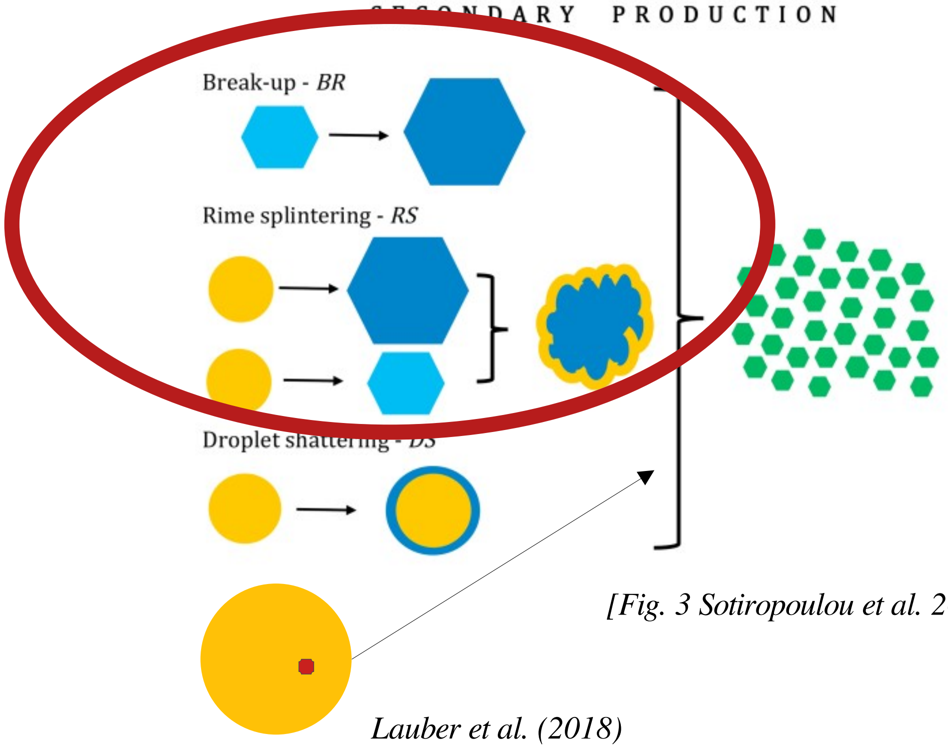
GCM = global climate model

apossner@iau.uni-frankfurt.de

Where does the ice come from – part II

Secondary ice production (SIP)

- SIP through ice phase can close gap between observed N_i and INP in relatively warm (T_{ct} > -5°C) Arctic MPCs *(Sotiropoulou et al. 2020a).*



[Fig. 3 Sotiropoulou et al. 2020a]

Lauber et al. (2018)

Where does the ice come from – part II

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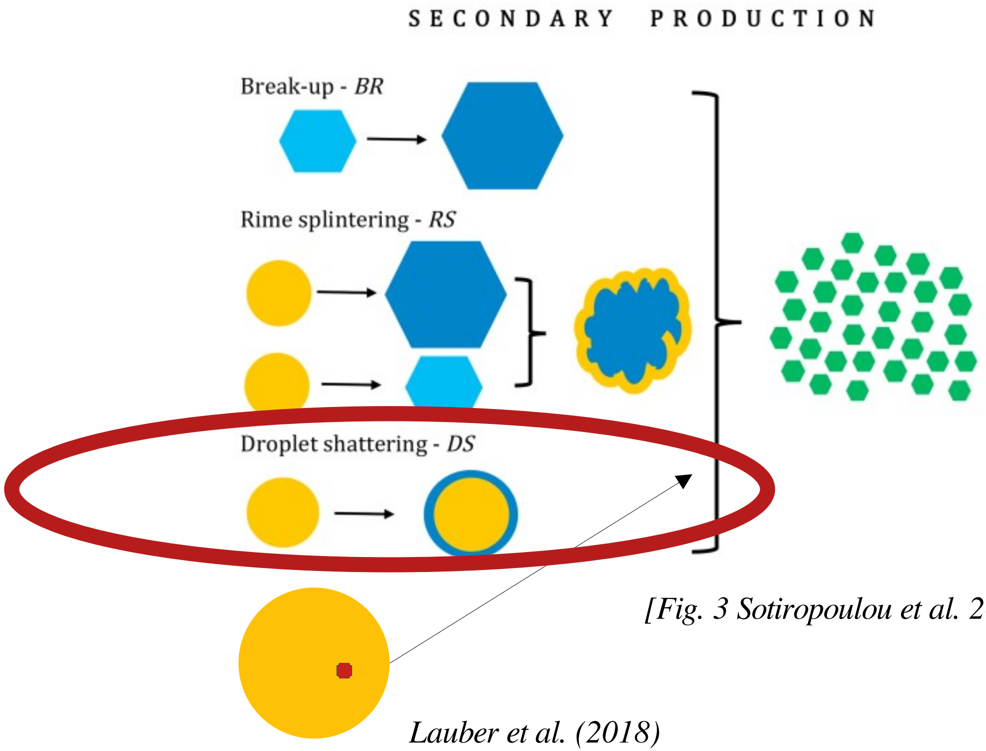
- Process less efficient at cold temperatures (T_{ct} < -10°C) and implementation dependent on rimed fraction (*RF*) and crystal shape assumptions *(Sotiropoulou et al. 2020b, Zhao et al. 2021).*



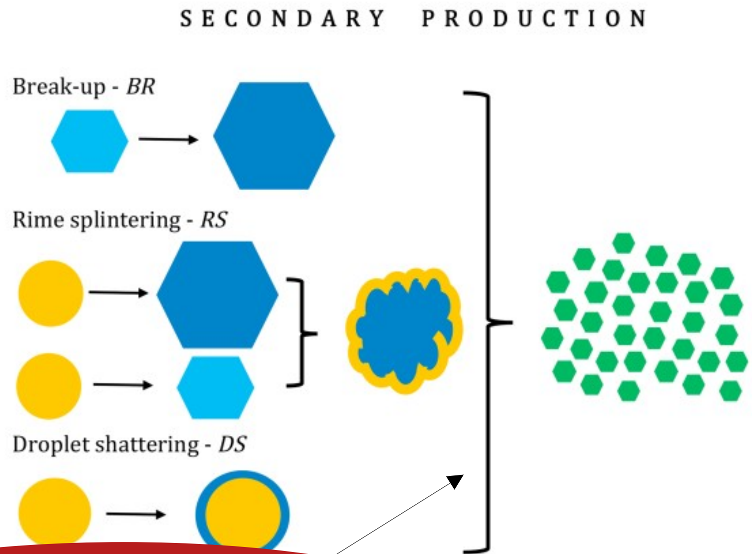
[Fig. 3 Sotiropoulou et al. 2020a]

Lauber et al. (2018)

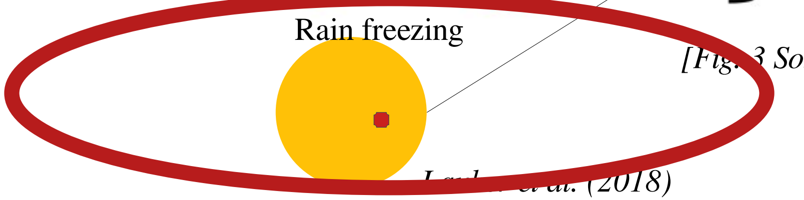
Where does the ice come from – part II

Secondary ice production (SIP)

- SIP through ice phase can close gap between observed N_i and INP in relatively warm (T_{ct} > -5°C) Arctic MPCs *(Sotiropoulou et al. 2020a).*
- Process less efficient at cold temperatures (T_{ct} < -10°C) and implementation dependent on rimed fraction (*RF*) and crystal shape assumptions *(Sotiropoulou et al. 2020b, Zhao et al. 2021).*
- Warm cloud bases are needed to generate sufficiently large raindrops for efficient fragmentation through droplet freezing *(Sullivan et al. 2018).*



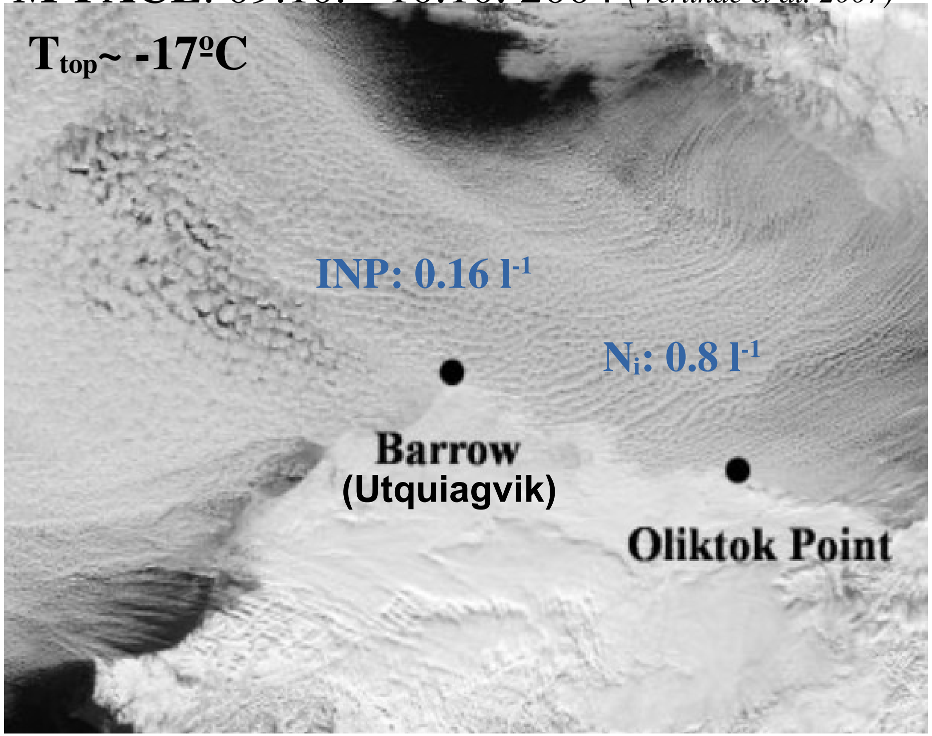
[Fig. 3 Sotiropoulou et al. 2020a]



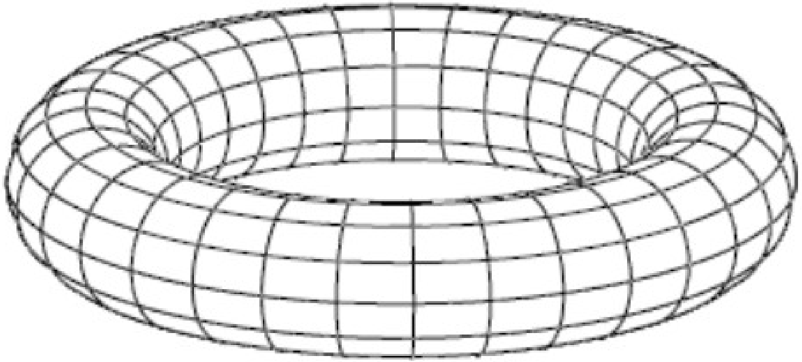
[illegible] et al. (2018)

Idealised M-PACE simulations

M-PACE: 09.10. - 10.10. 2004 *(Verlinde et al. 2007)*



200x200 grid points, 24h (one diurnal cycle)



- $\Delta x, \Delta t, \Delta z$: 125m, 1s, 25m
- fixed large-scale forcing & advection (Klein et al. 2009)
- 2M bulk microphysics parameterisation (Seifert & Beheng, 2006)
- \+ Break up (Phillips et al. 2017)
  \+ Droplet shattering (Phillips et al. 2018)

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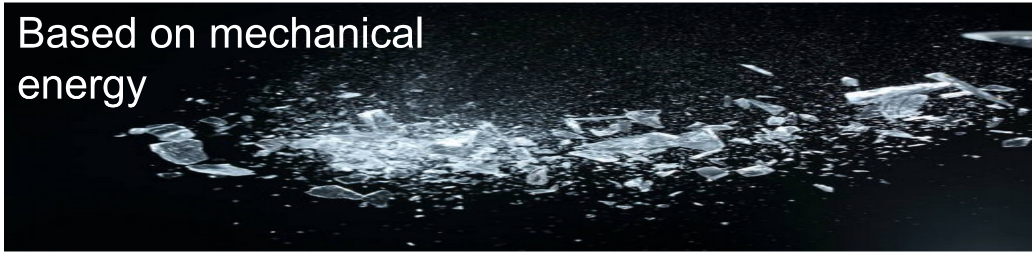
Parameterisation collisional breakup



Based on mechanical energy

Phillips et al. 2017

Collisional kinetic energy

surface area

$$\mathcal{N} = \alpha A(\mathbf{M})\left(1-\exp\left\{-\left[\frac{CK_0}{\alpha A(\mathbf{M})}\right]^{\gamma}\right\}\right)$$

#density of asperities in collisional surface cross section

$$\boxed{A, C, \gamma = F(RF, S)} \longrightarrow \boxed{N = F(RF, S)}$$

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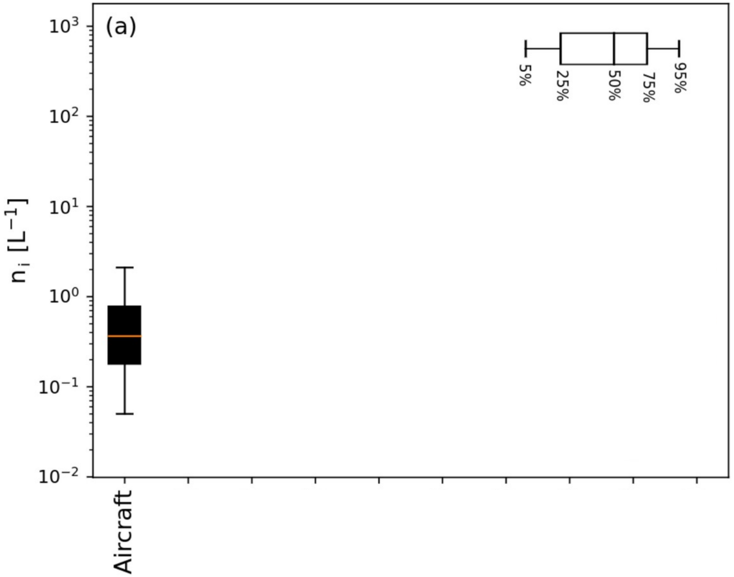
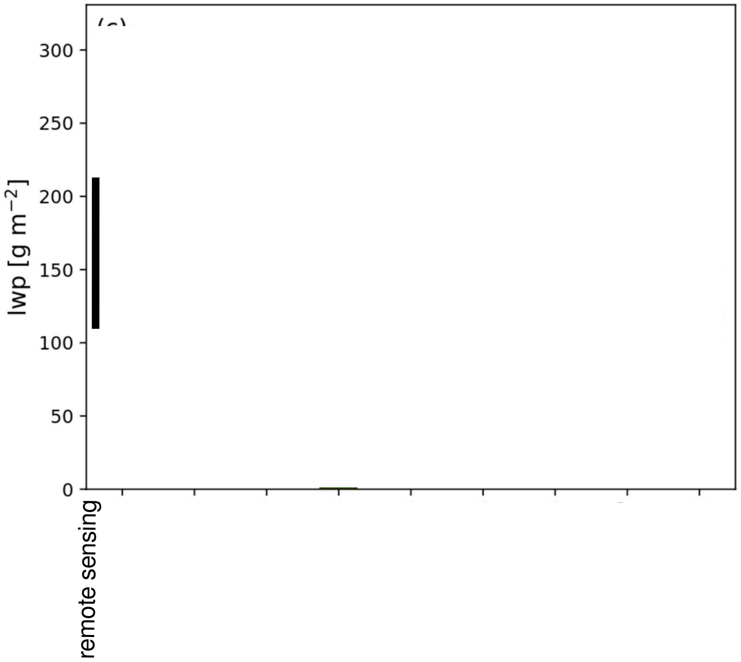
Impact on N_i and LWP





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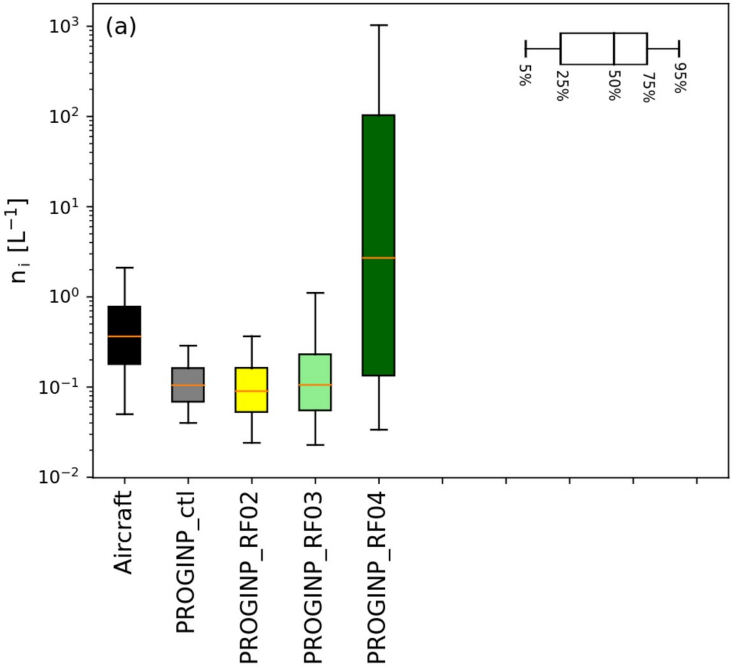
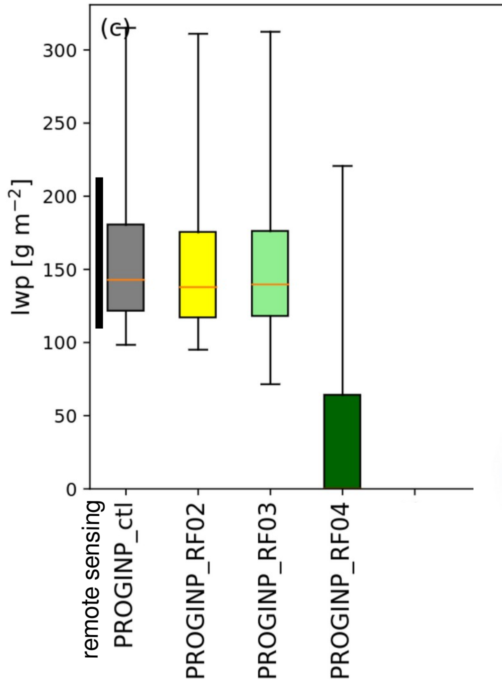
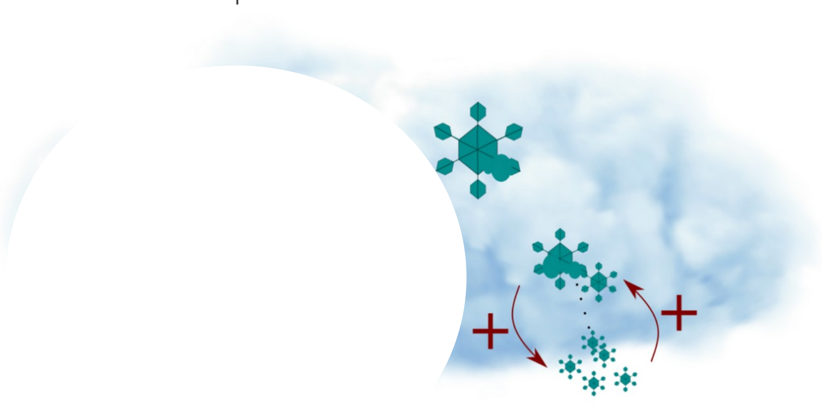
Impact on N_i and LWP







Collisional breakup does not produce stable mixed-phase cloud with correct ice-phase properties

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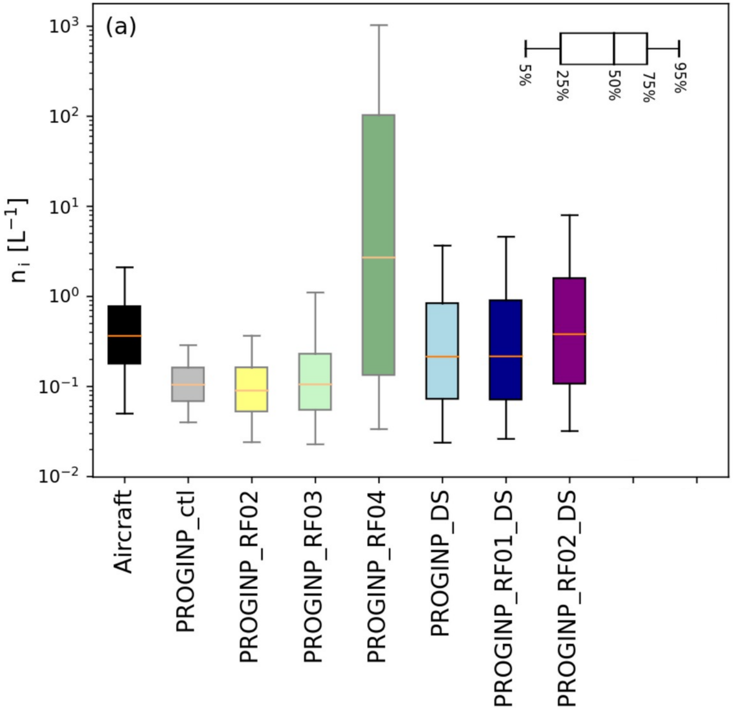
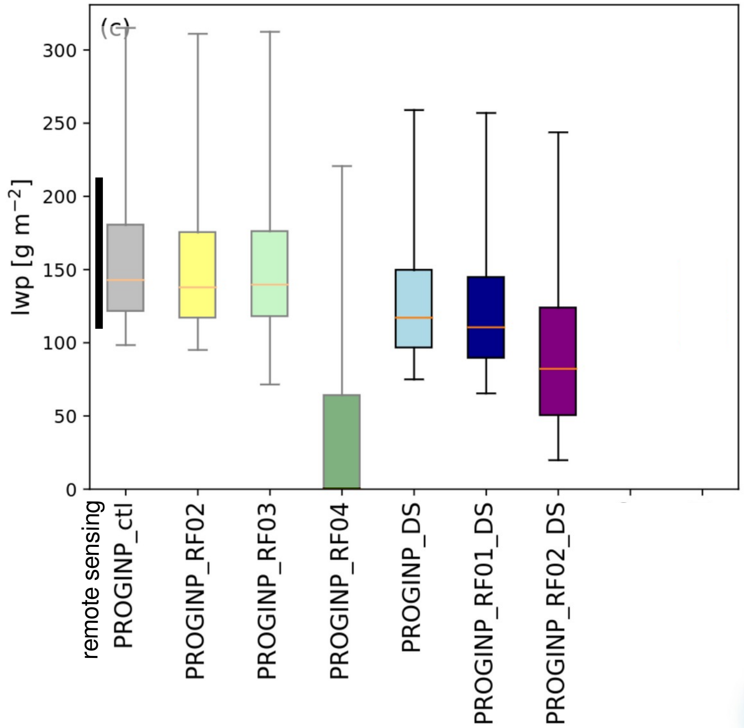
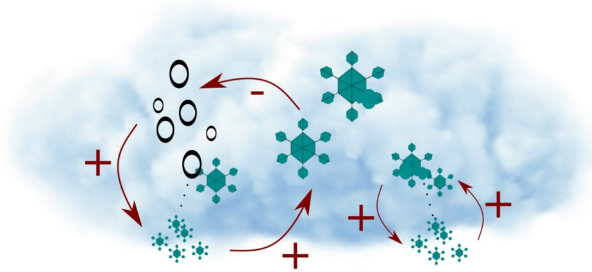
Impact on N_i and LWP







Simulations with droplet shattering (+ potential amplification by breakup) match ice & liquid-phase observations

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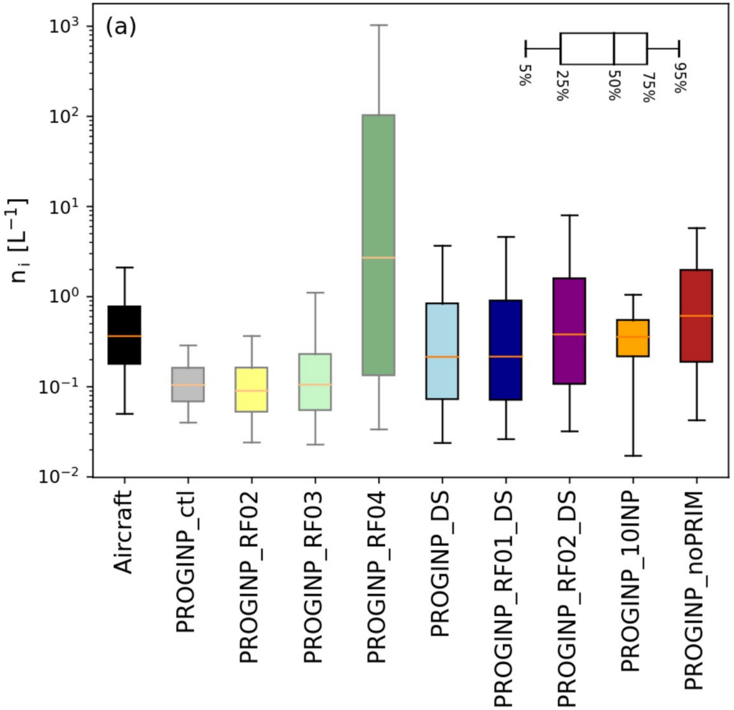
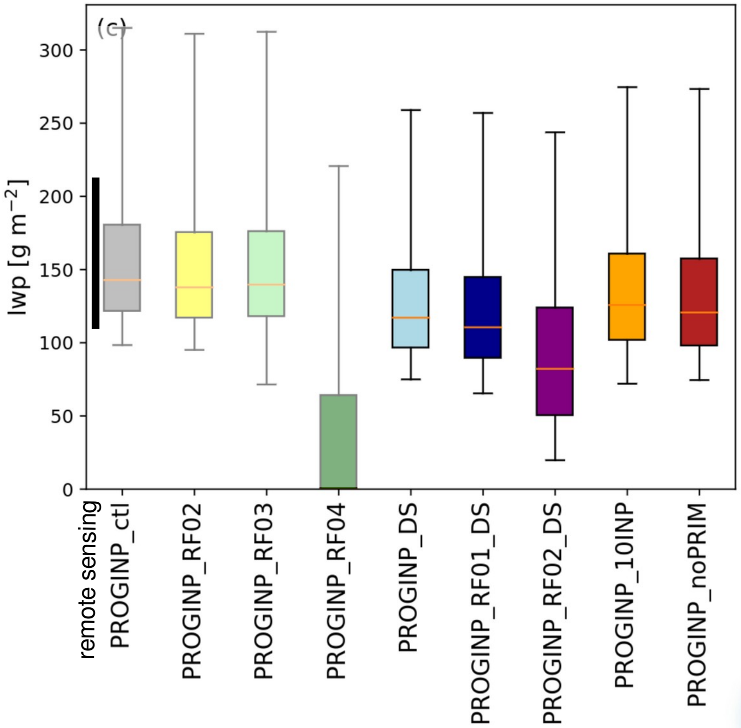
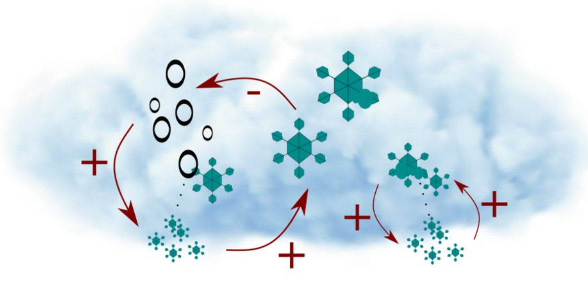
Impact on N_i and LWP



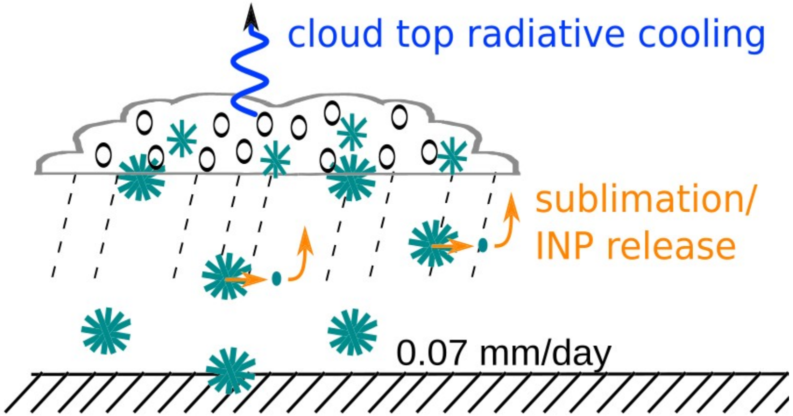


SIP once triggered is self-sustaining over at least 14 hours



Summary: Origins of cloud ice

- immersion freezing is dominant primary nucleation mechanism
- building evidence of SIP, **BUT**:
  - mechanistic understanding incomplete
  - insufficiently constrained by observations
  - model implementations strongly dependent on assumptions



-> regions of enhanced research activity: Arctic, Atlantic cold air outbreaks, Southern Ocean

apossner@iau.uni-frankfurt.de

Outline of talk

- Origins of cloud ice
- **Cloud radiative effects**
- Cloud regime changes

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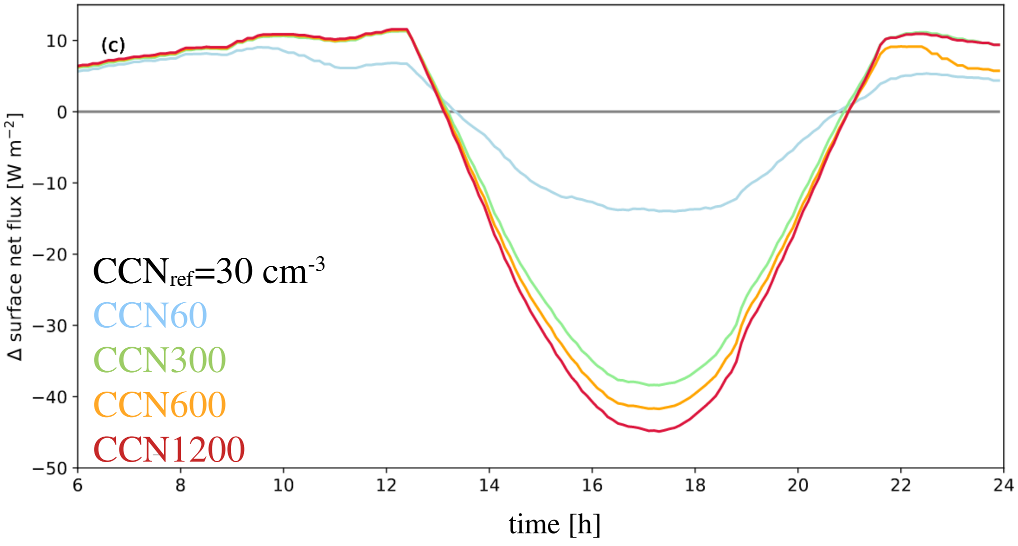
apossner@iau.uni-frankfurt.de

Impact on surface radiation



difference in net surface radiation ~ $\mathrm{SW}_{\downarrow} + \mathrm{LW}_{\downarrow} + \mathrm{LW}_{\uparrow}$

($\mathrm{SW}_{\uparrow}$ ~ 0 Wm^{-2} at sfc)

(convention: +*ve* downward)

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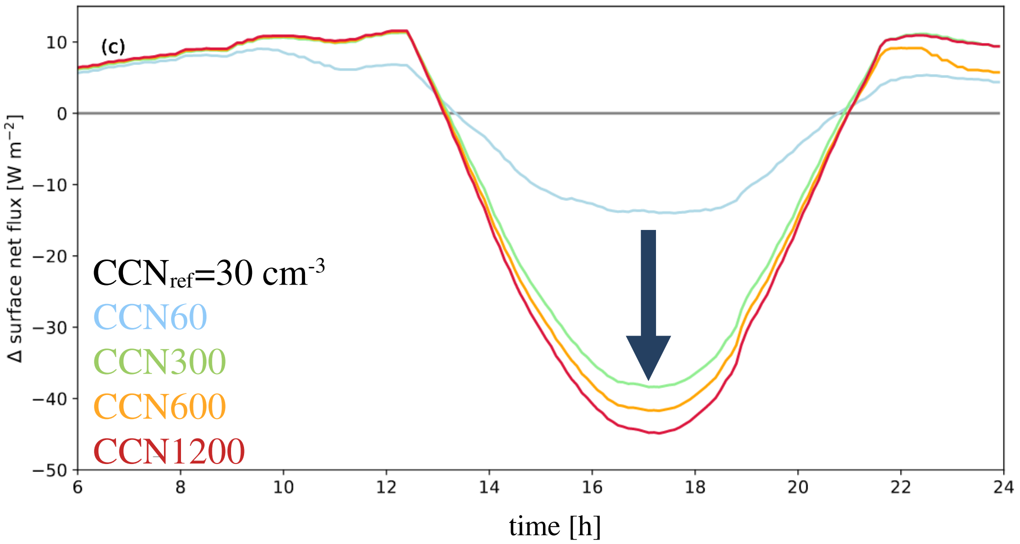
Impact on surface radiation



shut off of rain suppresses ice-phase and WBF
depletion of LWP

(convention: +*ve* downward)

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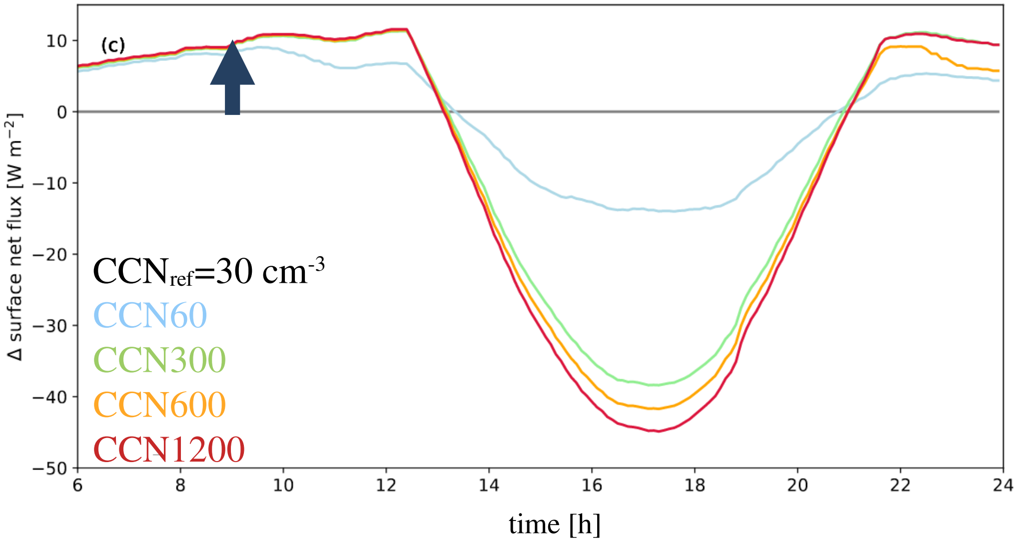
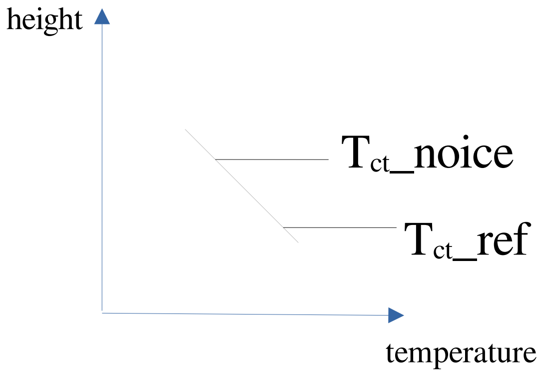
Impact on surface radiation



deeper cloud increases warming



T_{ct}= cloud-top temperature

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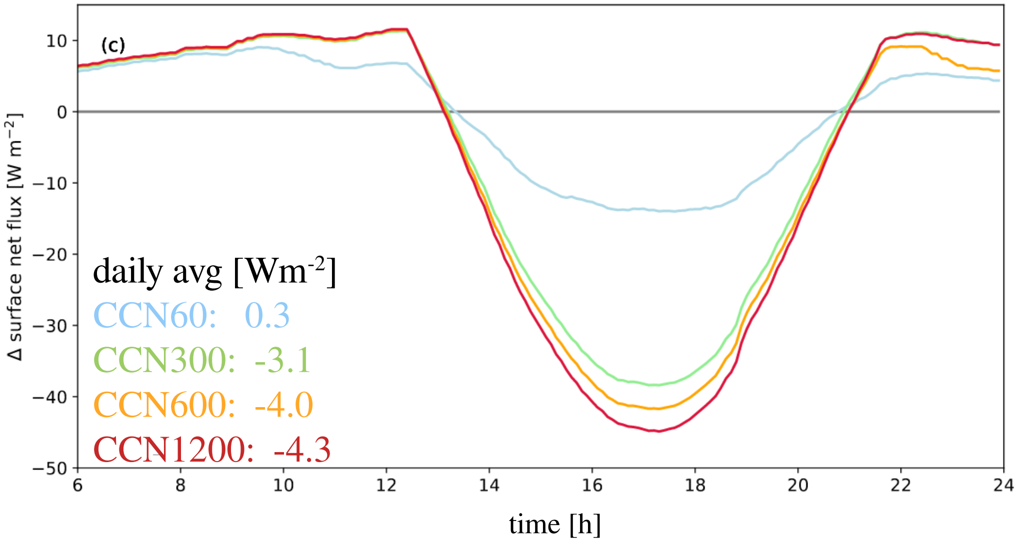
Impact on surface radiation



- ➢ **LW compensates SW and net radiative impact is moderate**

(convention: +*ve*

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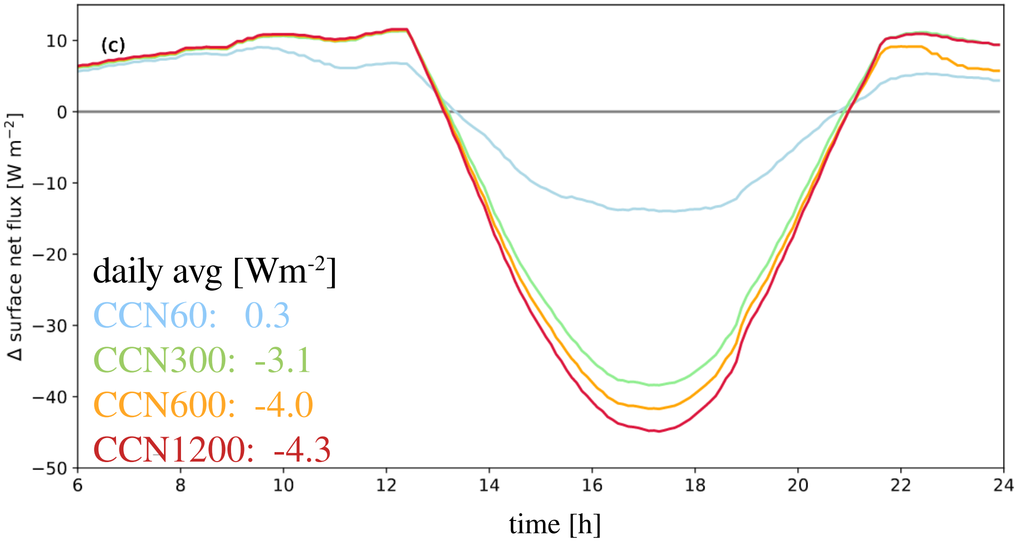
Impact on surface radiation



at lower latitudes SW radiative effect dominates!

- **LW compensates SW and net radiative impact is moderate**

(convention: +*ve* downward)

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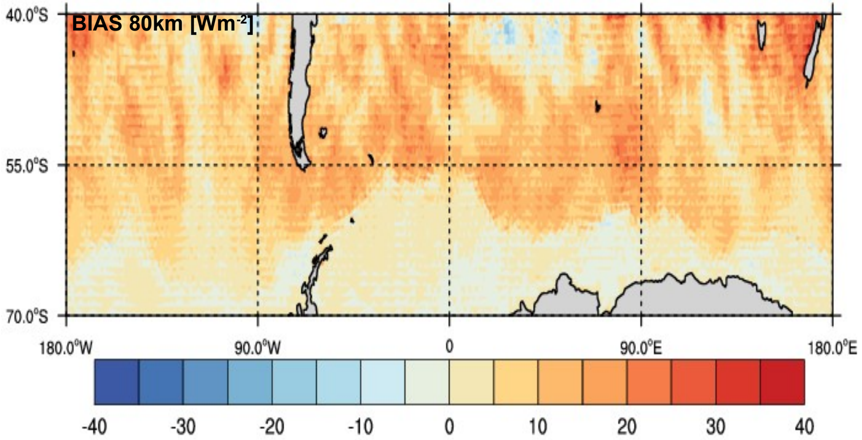
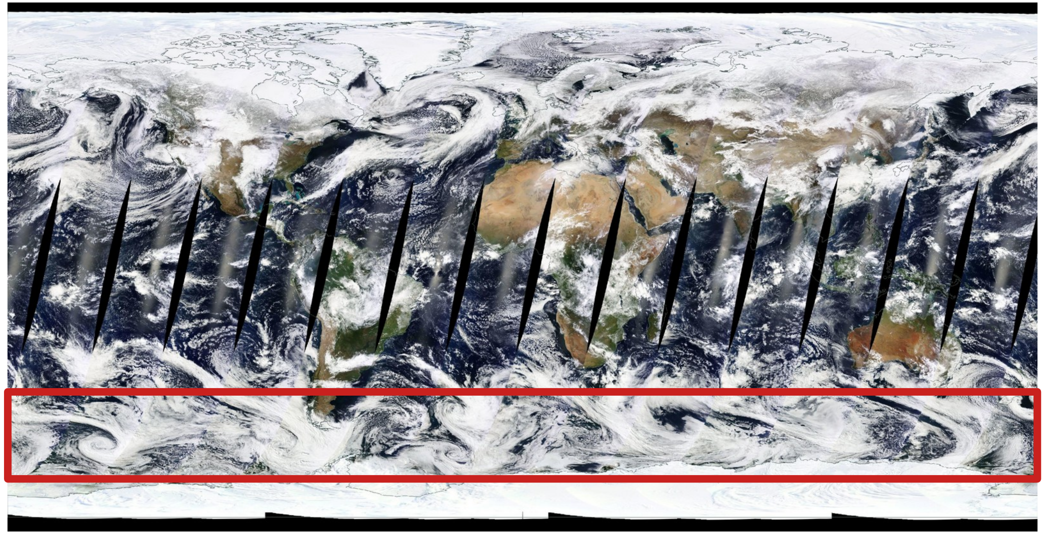
Southern Ocean radiative bias in ICON



→radiative bias in SO 8 Wm^{-2}

→ underestimation of supercooled low-level cloud water



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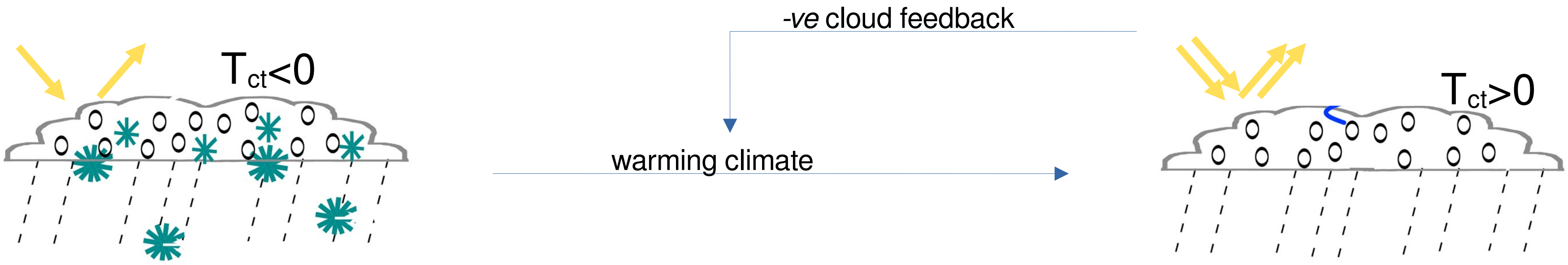
Cloud phase feedback and climate sensitivity



- Supercooled liquid and SW$_\downarrow$ overestimated in previos generation of climate models (Bodas-Salcedo et al. 2014)
- cloud-phase feedback overestimated in CMIP5 models *(Tan et al. 2016)*

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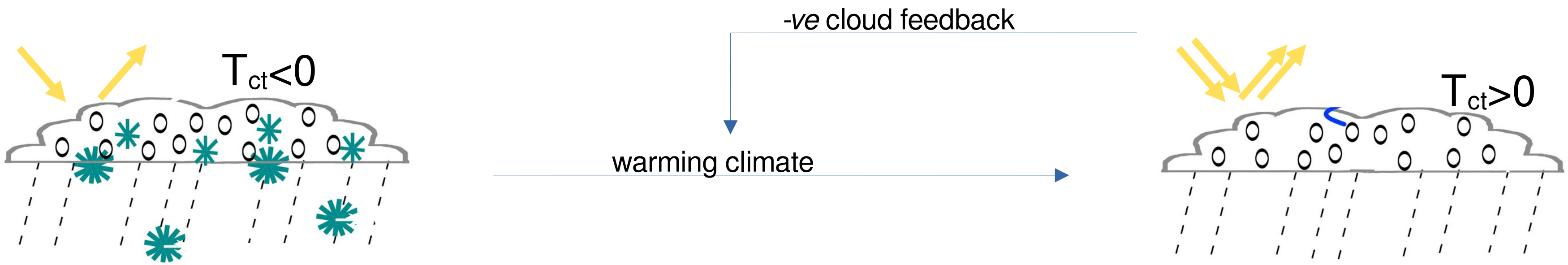
Cloud phase feedback and climate sensitivity



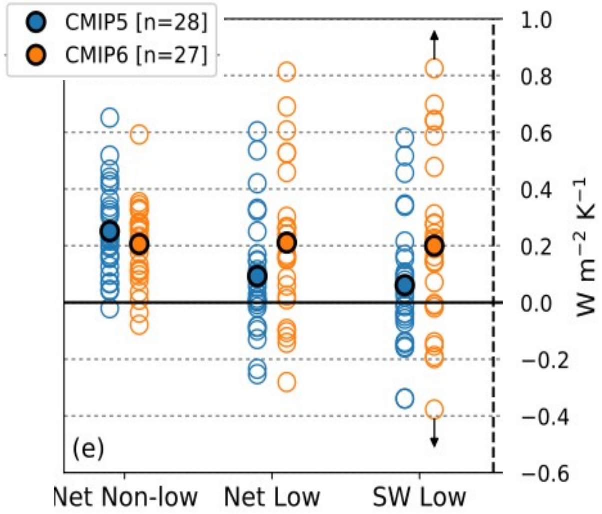
$T_{ct}<0$

-ve cloud feedback

warming climate

$T_{ct}>0$

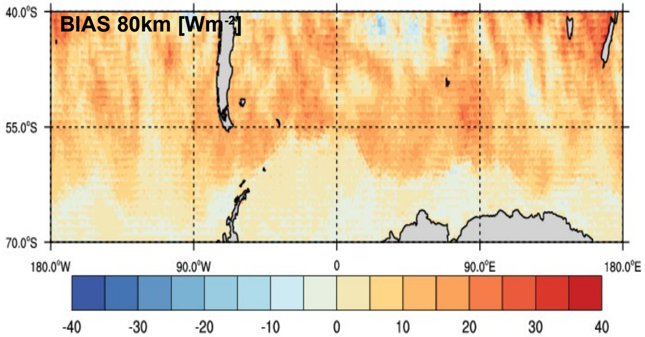
- Supercooled liquid and $SW_{\downarrow}$ overestimated in previos generation of climate models (Bodas-Salcedo et al. 2014)
- cloud-phase feedback overestimated in CMIP5 models *(Tan et al. 2016)*
- global cloud feedback more positive with bias correction



(Zelinka at al. 2020)

Summary: Cloud radiative effect

- in the Arctic low-level mixed-phase clouds warm the surface (annual mean), everywhere else they cool
- accurate supercooled liquid cloud amount representation in climate models is key for estimates of regional and global low-cloud feedback
- uncertainties in process understanding limit confidence in extrapolation of cloud feedback in extratropics



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Outline of talk

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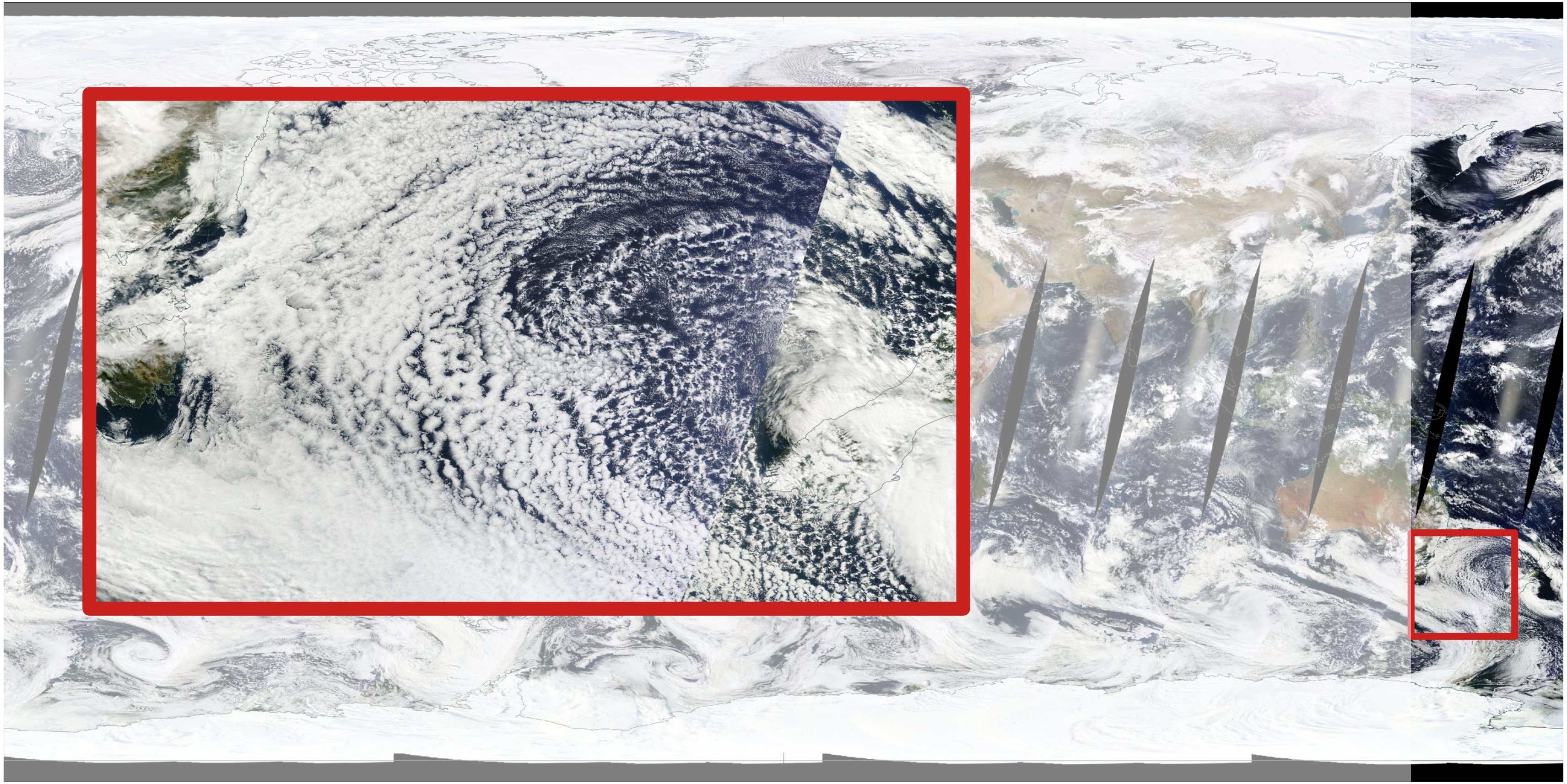
Importance of mesoscale organisation



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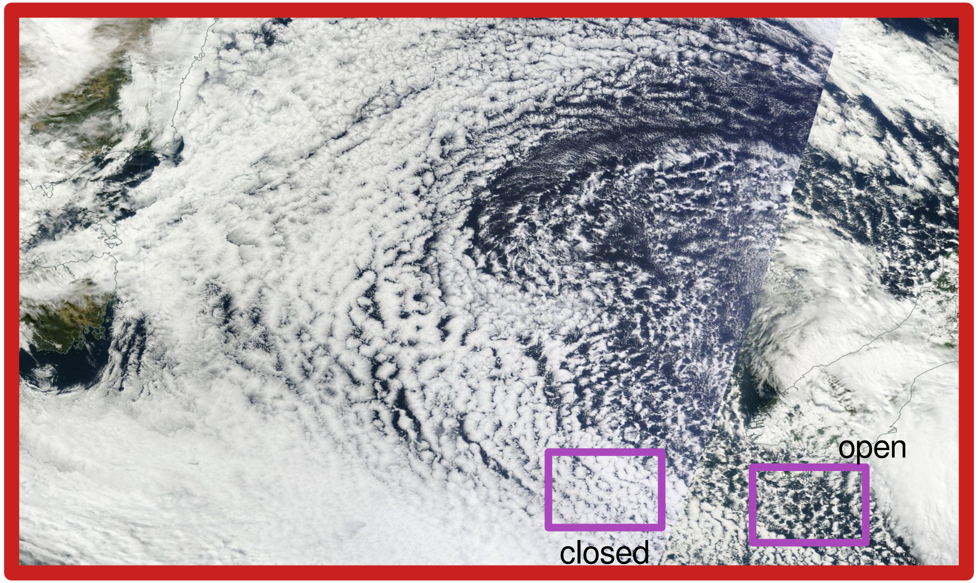
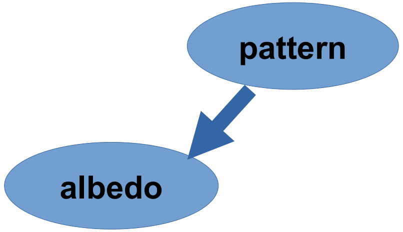
Importance of mesoscale organisation

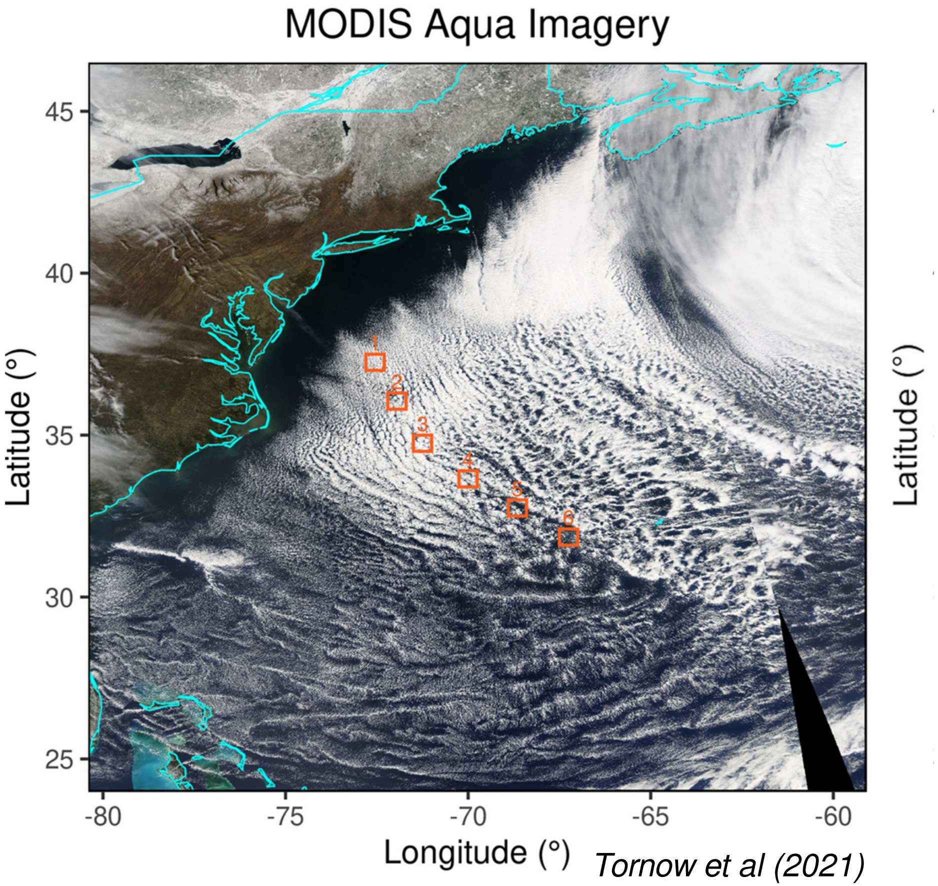


→ cloud pattern influences albedo

(McCoy et al. 2017)



Importance of mesoscale organisation

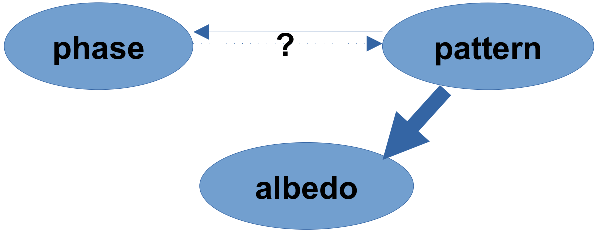


Tornow et al (2021)

→ cloud pattern influences albedo

(McCoy et al. 2017)

→ pattern changes can be associated with degree of cloud ice formation *(Eirund et al. 2019, Tornow et al. 2021)*



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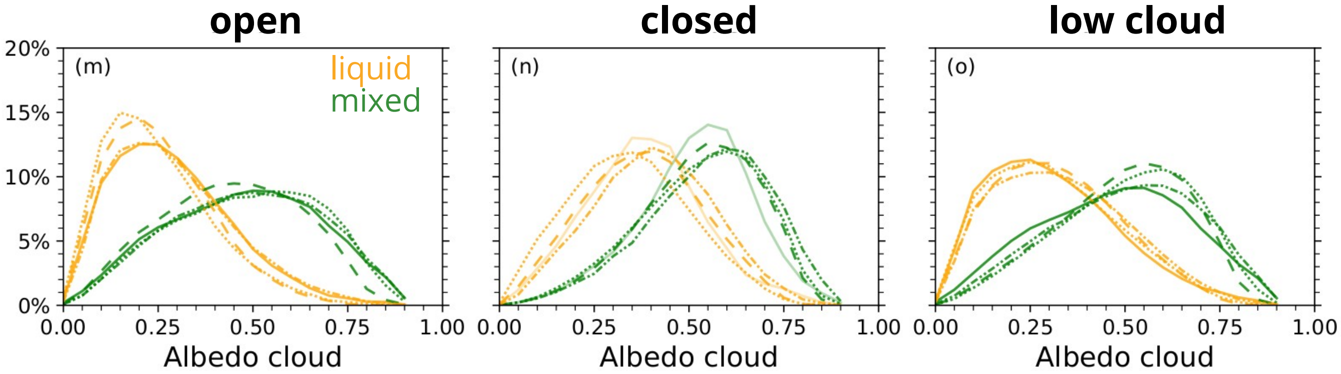
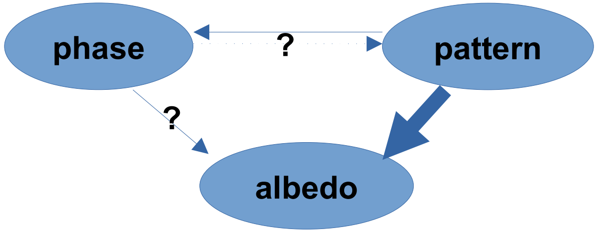
Importance of mesoscale organisation



→ cloud pattern influences albedo *(McCoy et al. 2017)*

→ pattern changes can be associated with degree of cloud ice formation *(Eirund et al. 2019, Tornow et al. 2021)*

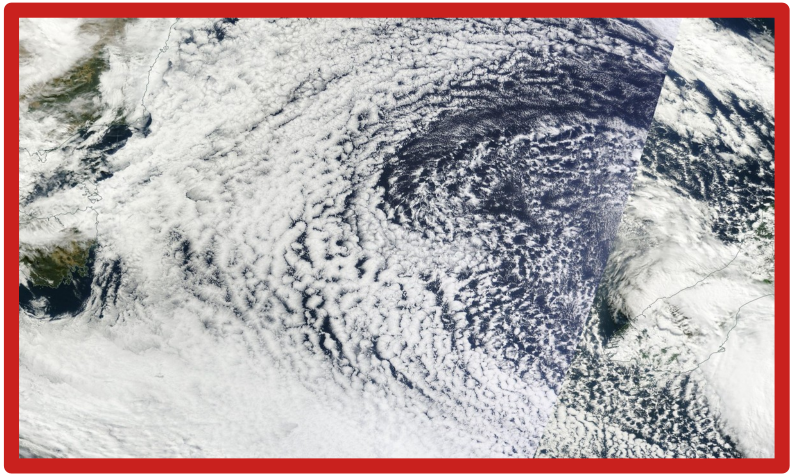
→ no evidence of preconditioning hypothesis in long-term satellite records *(Danker et al. 2022)*



apossner@iau.uni-frankfurt.de

Summary: Cloud regimes

- Clouds organise, which constrains their mesoscale variability
- Little is known about potential connections between phase variability and mesoscale organisation
- Going hypothesis of „preconditioning“ (Tornow et al. 2021) remains to be verified



apossner@iau.uni-frankfurt.de

The team at GUF looking at cloud physics

Group Members from left to right:

top row: Kevin Pfannkuch, Christopher Reichel, Luise Schulte, Veeramanikandan Ramadoss.

bottom row: Lianet Hernandez Pardo, Jessica Danker, Anna Possner

Contact details for all staff members are listed here.

www.anna-possner.com

apossner@iau.uni-frankfurt.de

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Home The Team Projects Research CV Publications

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2 positions to be filled
summer this year

www.anna-possner.com

apossner@iau.uni-frankfurt.de