INPs - from fundamental understanding to climate interventions

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TU Delft

Learning from marine cloud brightening

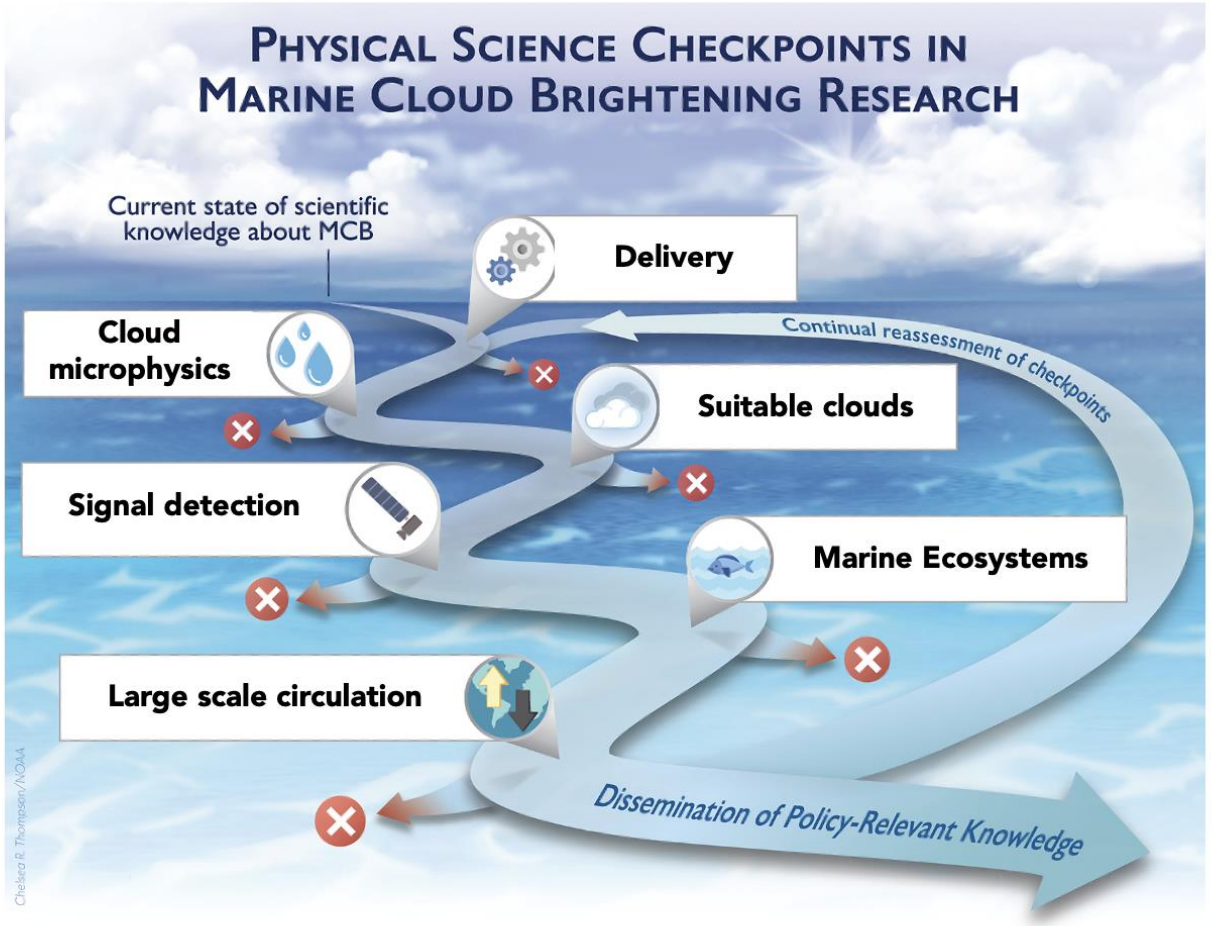
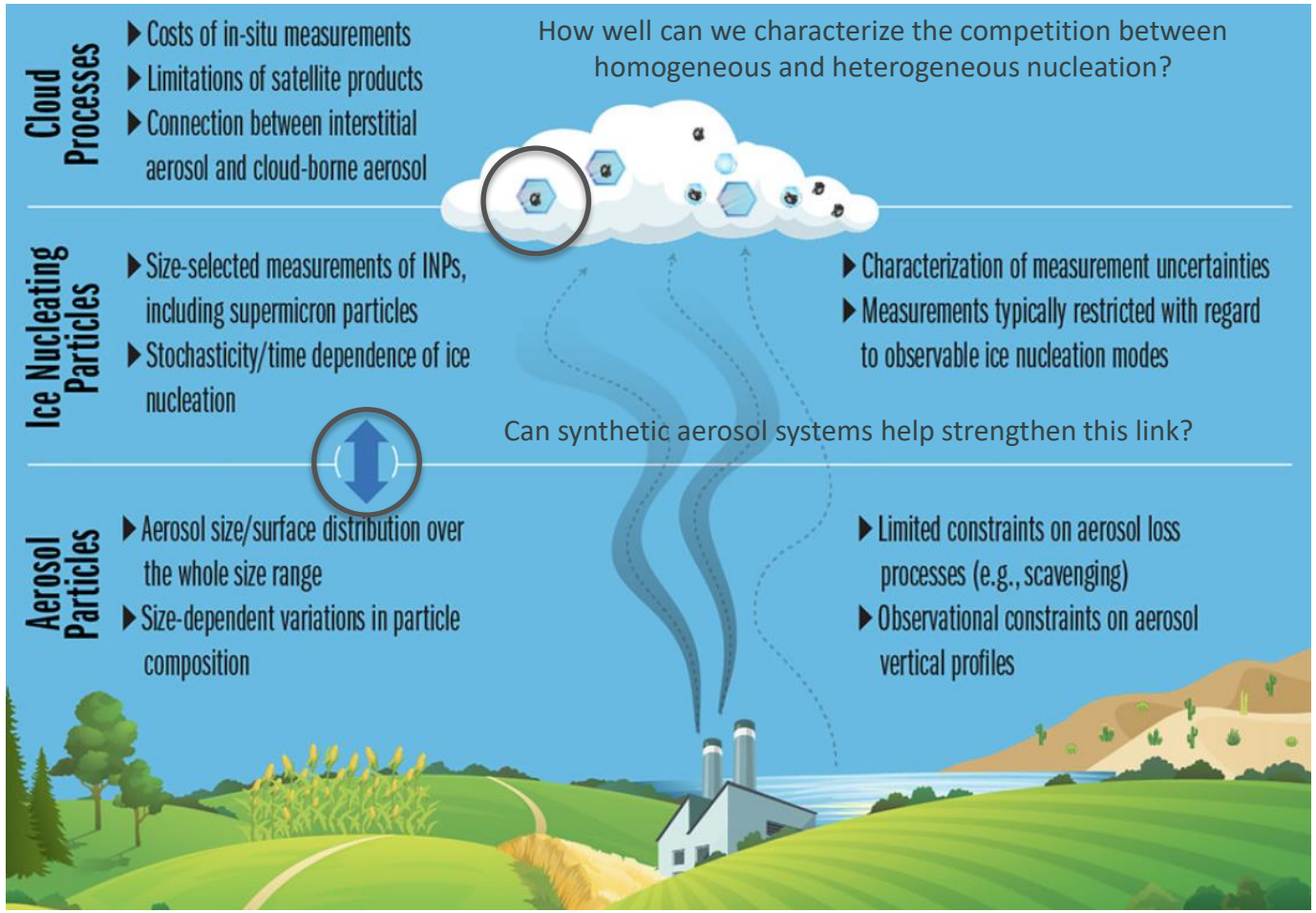


Image credit: Michael Diamond and Chelsea Thompson (CIRES and NOAA CSL, Boulder, CO - adapted

Marine cloud brightening triggering
research questions across disciplinary boundaries

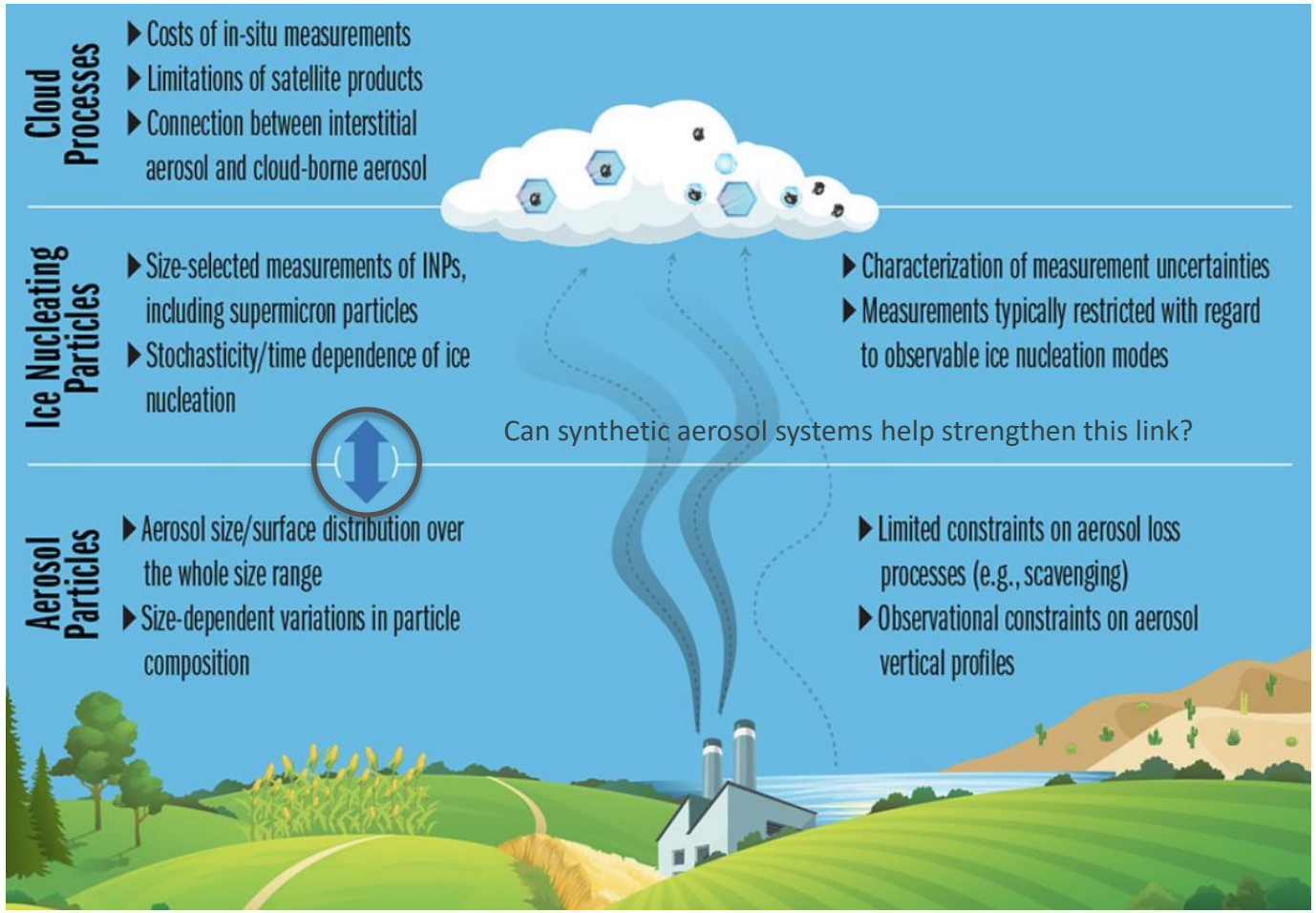
Microphysical processes as one of the biggest unknowns in assessing
cloud-based radiation management

Two flavors of ice nucleation research



Burrows et al., Rev. of Geophysics, 2022

Ice nucleating particles from terrestrial sources



Burrows et al., Rev. of Geophysics, 2022

Ice nucleating particles from terrestrial sources

INP parameterizations based on physico-chemical properties of aerosol particles ⟷ Ambient INPs

Soil particles emitted from terrestrial sources consist of complex mixtures of dust and biogenic particles.

Source: NASA Earth Observatory

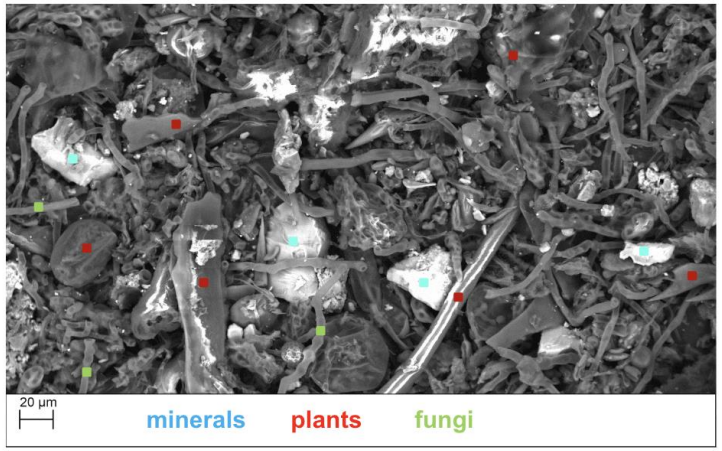


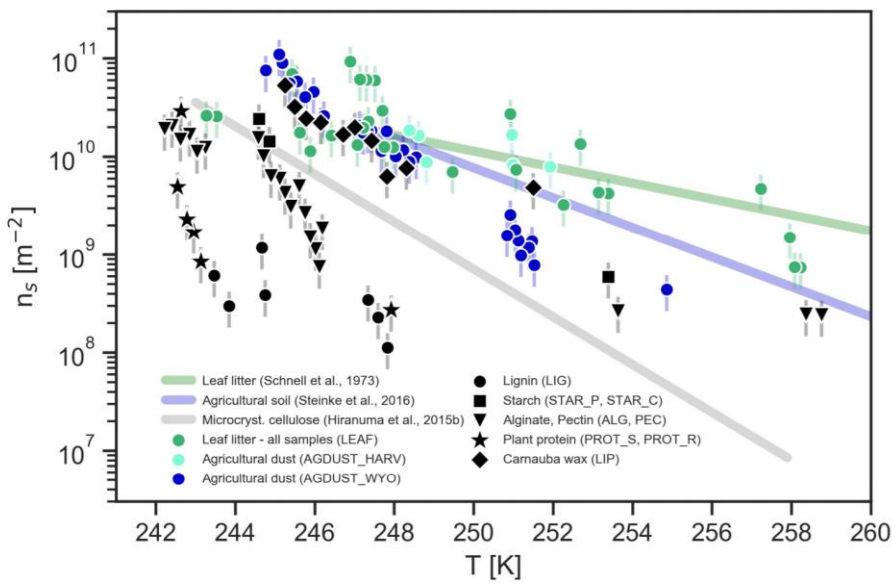
Image: courtesy of J. Busse

Ice nucleating particles from terrestrial sources

INP parameterizations based on physico-chemical properties of aerosol particles

Ambient INPs

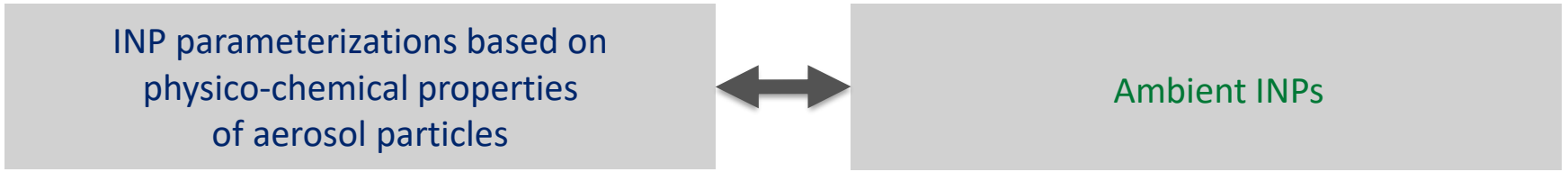
Steinke et al., ACP, 2020



- Large variability in ice nucleation propensities
- Individual biogenic/organic components are less ice-active than ambient samples

What is the relation between ambient samples and their individual components?

Ice nucleating particles from terrestrial sources



Synthetic aerosol proxies

Two-component systems as proxies for soil dust INPs

Ice nucleation propensities ⟷ Two-component systems with well-characterized mixing states

On average 7% surface coverage for internally mixed systems.

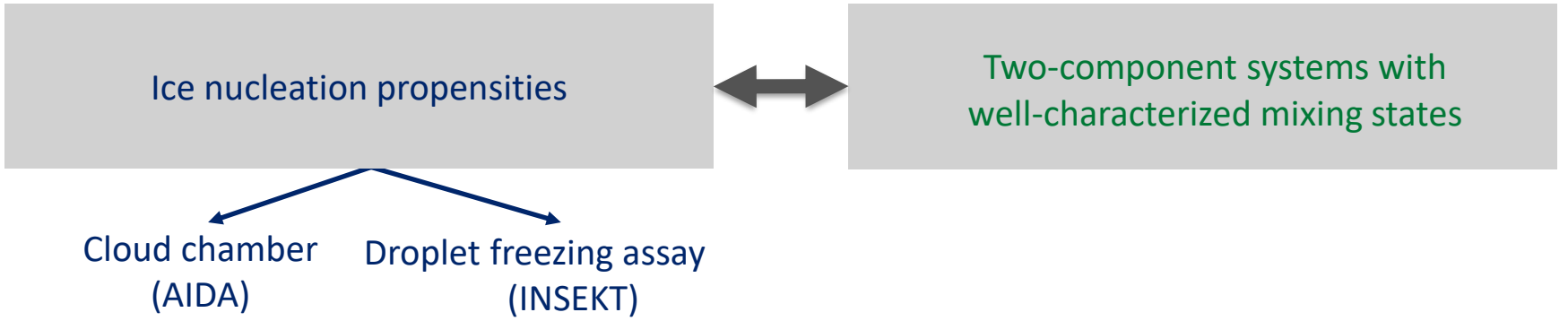
Montmorillonite and arginine (externally mixed)

Montmorillonite and arginine (internally mixed)

Montmorillonite and Snomax (externally mixed)

Montmorillonite and Snomax (internally mixed)

Two-component systems as proxies for soil dust INPs

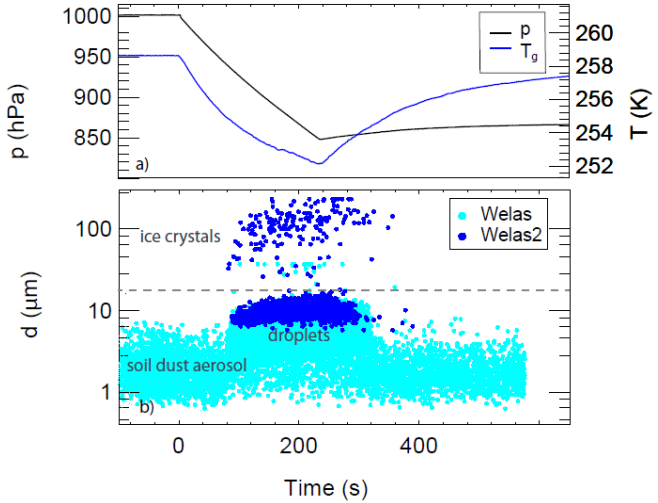


Two-component systems as proxies for soil dust INPs

Ice nucleation propensities ⟷ Two-component systems with well-characterized mixing states

Cloud chamber (AIDA)

Images: https://www.imk-aaf.kit.edu/AIDA_facilities.php (last access: 1/22/2022)

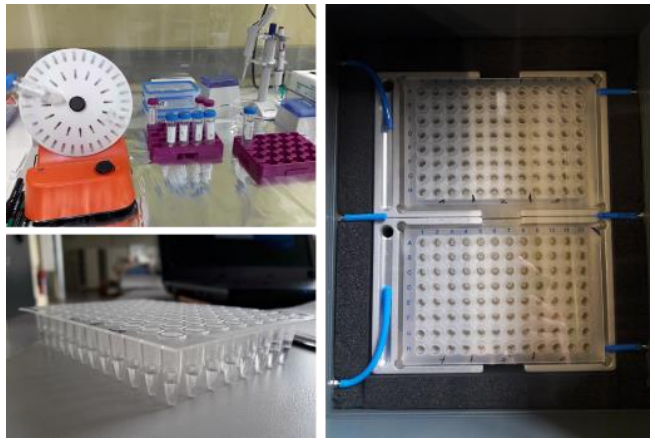


Time series for AIDA expansion experiment :
a) Decrease in gas temperature and pressure inside the AIDA chamber
b) Immersion freezing: Emergence of droplets and ice crystals

Two-component systems as proxies for soil dust INPs

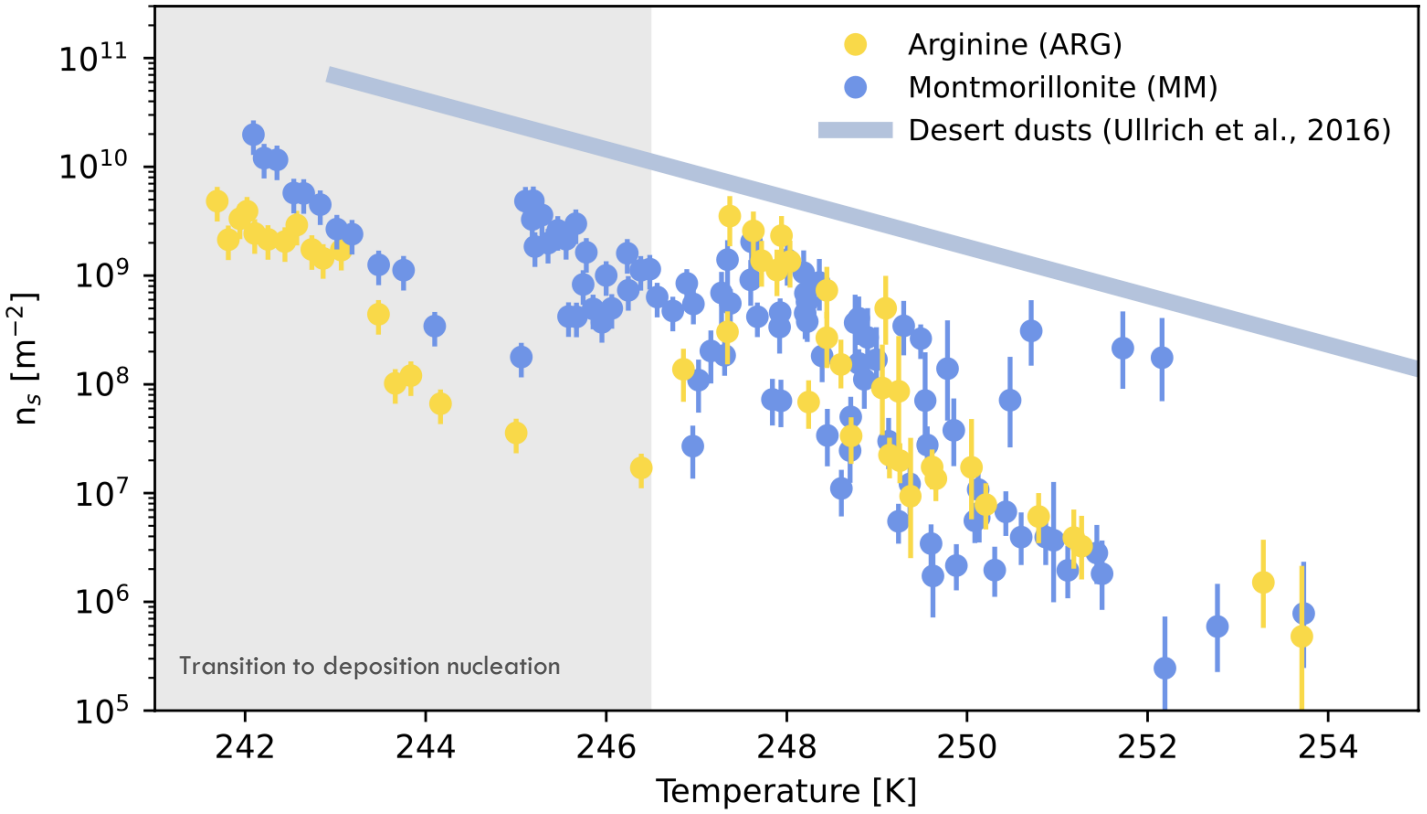
Ice nucleation propensities ⟷ Two-component systems with well-characterized mixing states

Droplet freezing assay (INSEKT)

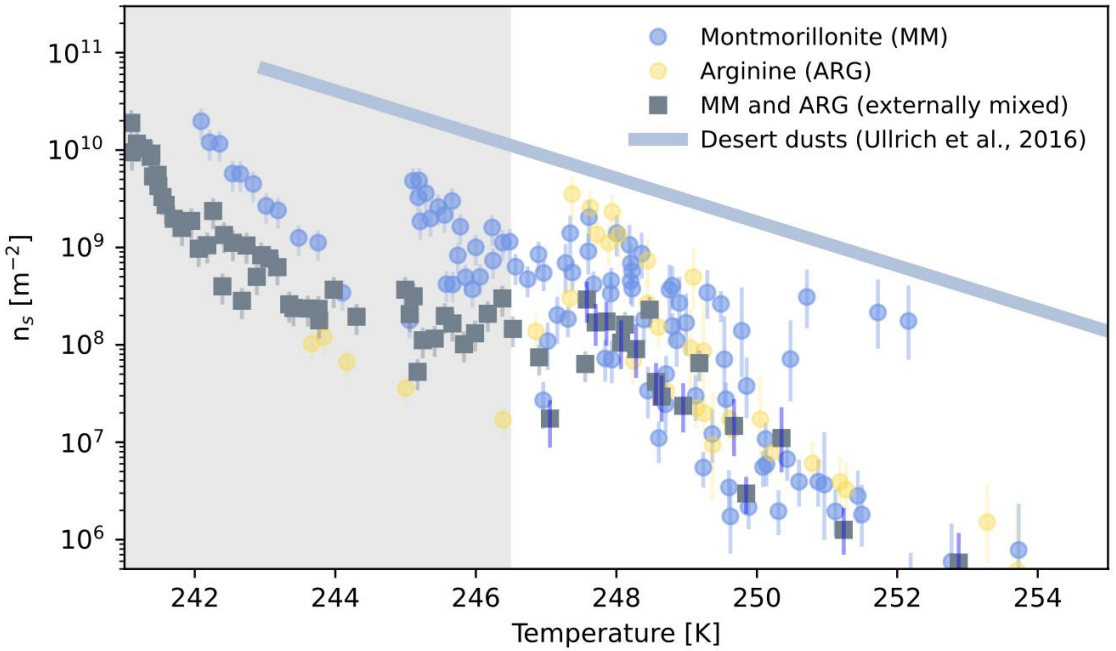


Images: https://www.imk-aaf.kit.edu/freezing_assay_INSEKT.php (last access: 1/22/2022)

Montmorillonite and arginine



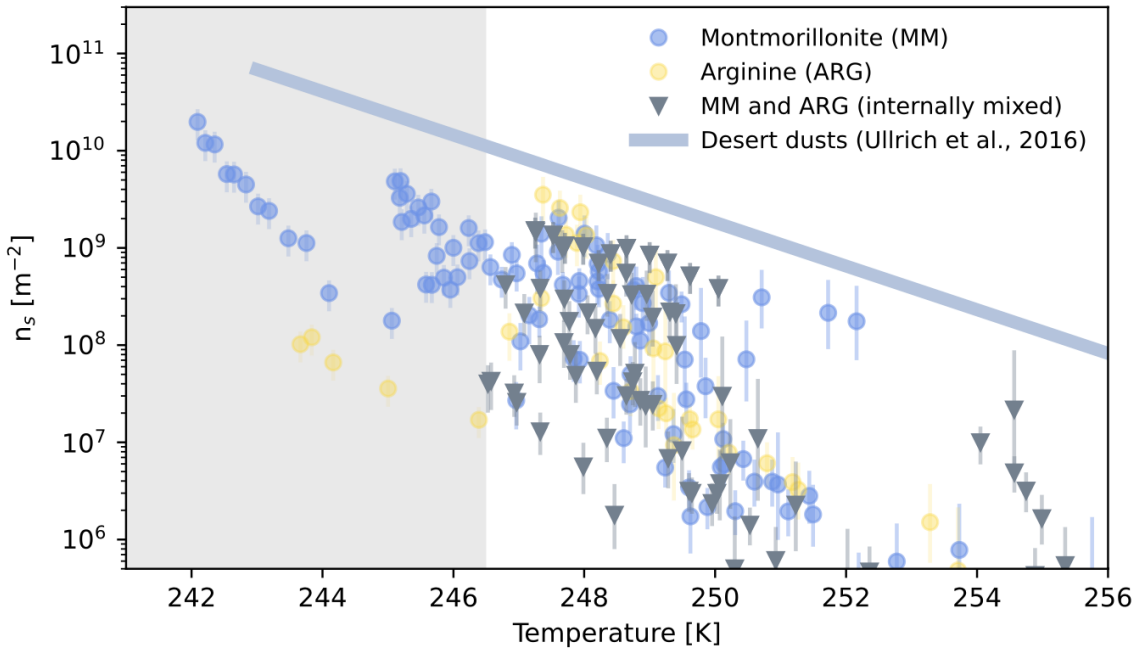
Montmorillonite and arginine



Externally mixed particles

- Equal number or more montmorillonite particles
- Average freezing efficiency similar to montmorillonite

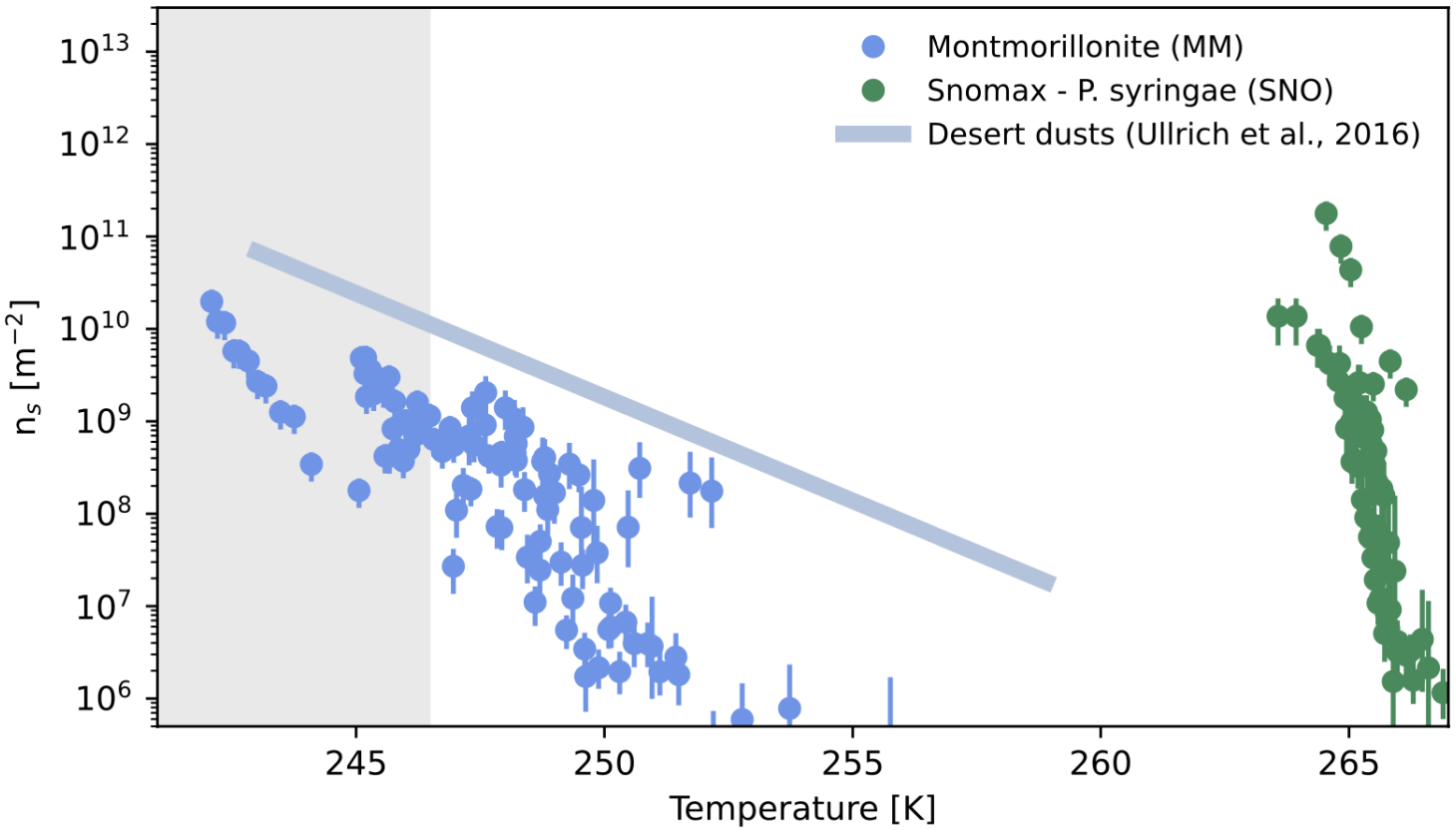
Montmorillonite and arginine



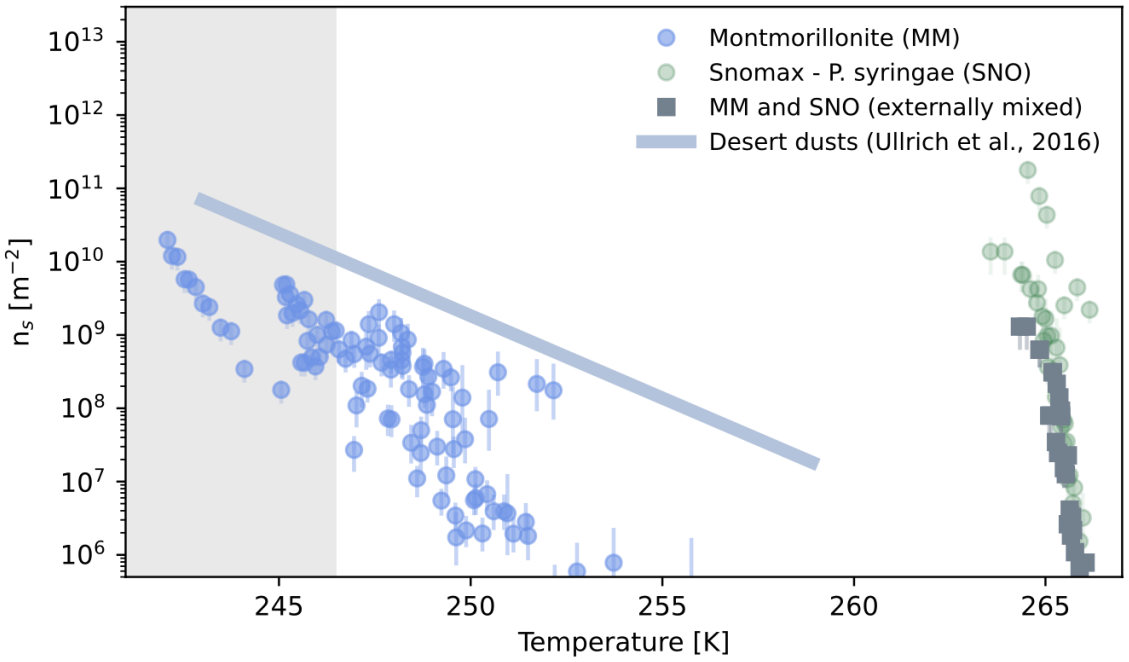
Internally mixed particles

- Arginine adsorbed to montmorillonite
- Average freezing efficiency similar to montmorillonite

Montmorillonite and Snomax



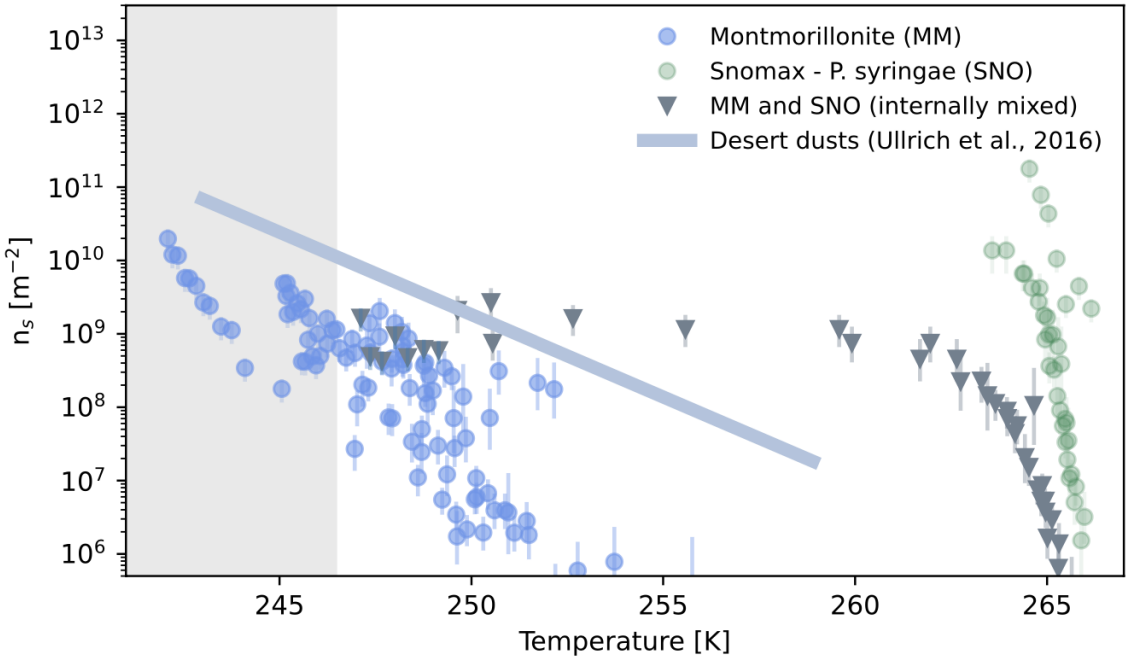
Montmorillonite and Snomax



Externally mixed particles

- Only very few Snomax particles, and mostly montmorillonite
- Snomax clearly dominates freezing in the external mixture

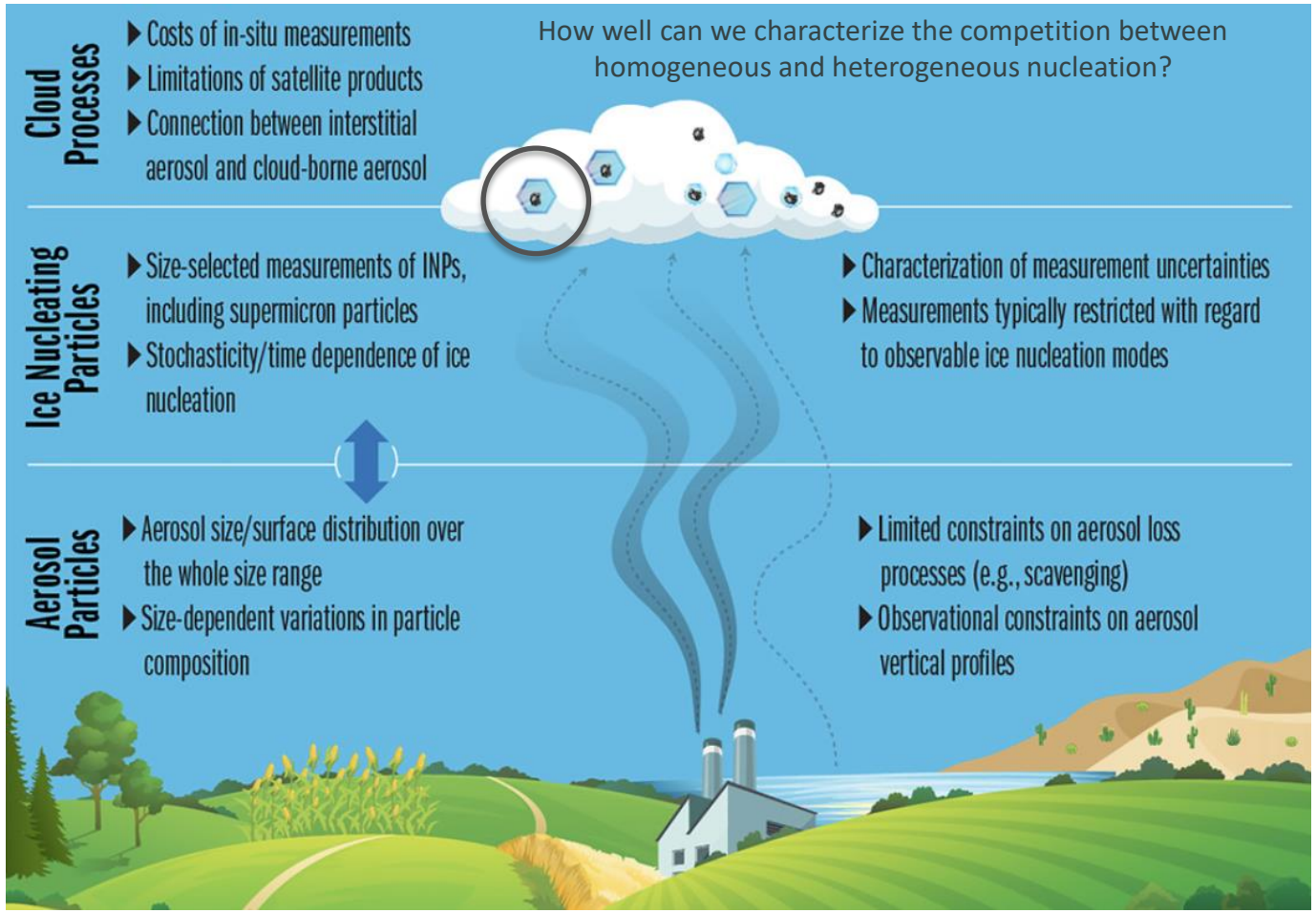
Montmorillonite and Snomax



Internally mixed particles

- Snomax adsorbed to montmorillonite particles
- Freezing plateau scales with the amount of absorbed material

Ice nucleating particles from terrestrial sources



Burrows et al., Rev. of Geophysics, 2022

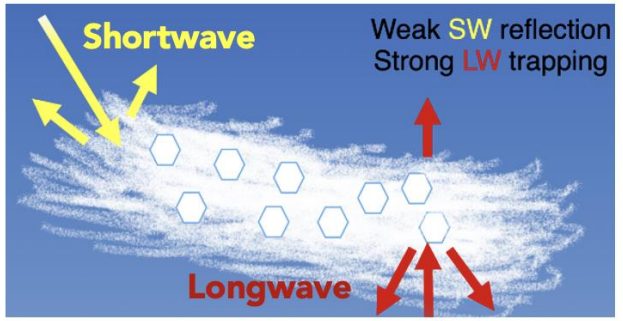
Simulating cirrus cloud thinning (CCT) in the laboratory

Karlsruher Institut für Technologie

Freezing of sulfuric acid droplets

+

Solid (seeding) particles, crystalline silica, amorphous silica and calcium carbonate



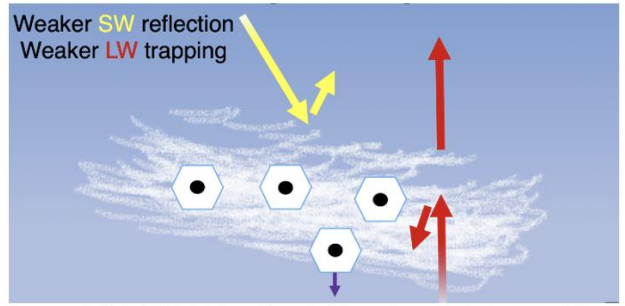


Image credit: IAC, ETH Zurich (https://iac.ethz.ch/group/atmospheric-physics/modelling-group/aerosol-cloud-interactions-aci.html) - adapted

Investigating the competition between homogeneous and heterogeneous ice nucleation

Freezing of sulfuric acid droplets

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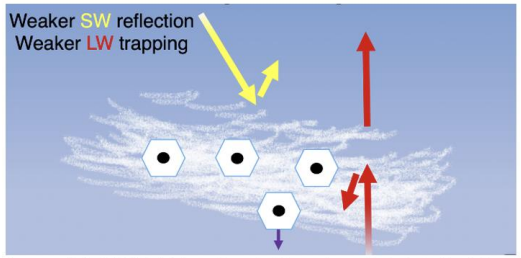
Solid (seeding) particles, crystalline silica, amorphous silica and calcium carbonate



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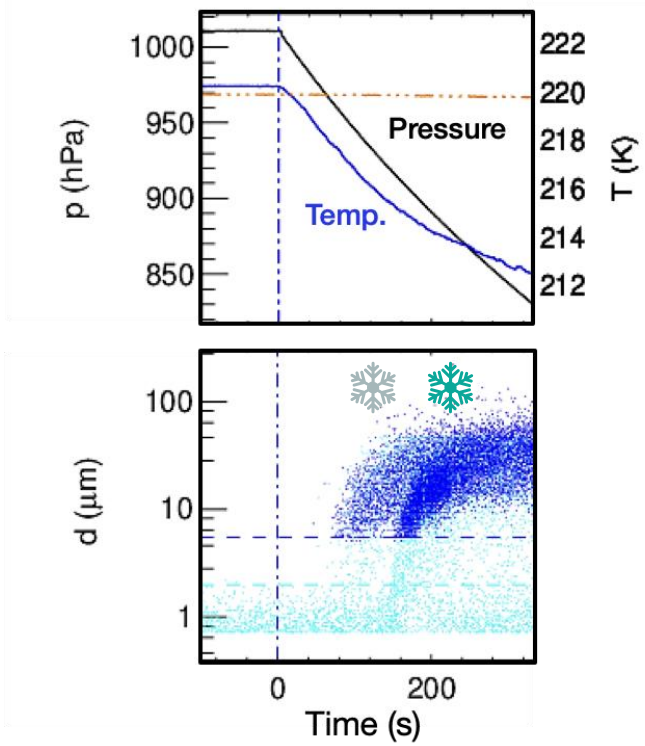

Simulating an ascending air parcel

- Pressure decreases from ambient level to 850 mbar
- Temperature decreases as well

Observing the formation of ice crystals

- Optical particle counters detect the formation of ice crystals
- Two different ice formation events are observed

Investigating the competition between homogeneous and heterogeneous ice nucleation

Freezing of sulfuric acid droplets

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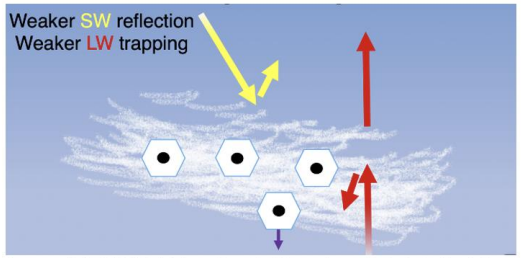
Solid (seeding) particles, crystalline silica, amorphous silica and calcium carbonate



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The ice crystal concentration within a cloud critically depends on the mix between droplets and solid particles

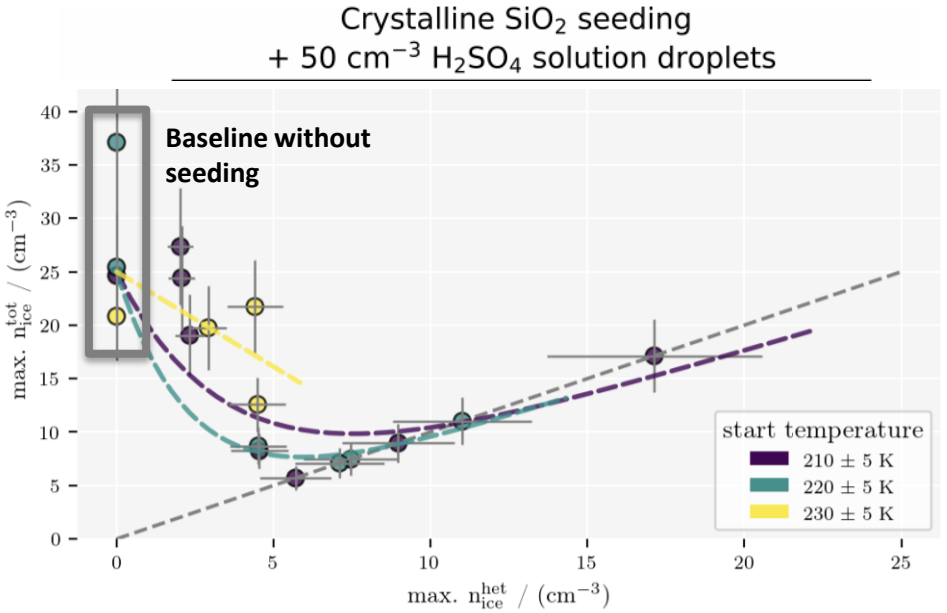


Figure courtesy of T. Schorr

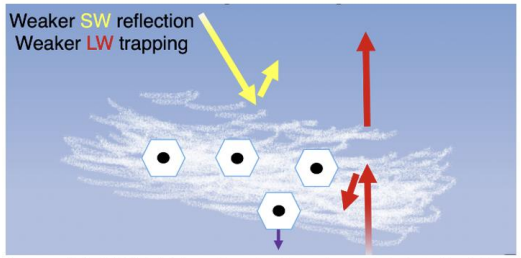
Seeding aerosol concentration

Overseeding is complex – even in the lab!

Freezing of sulfuric acid droplets

+

Solid (seeding) particles, crystalline silica, amorphous silica and calcium carbonate



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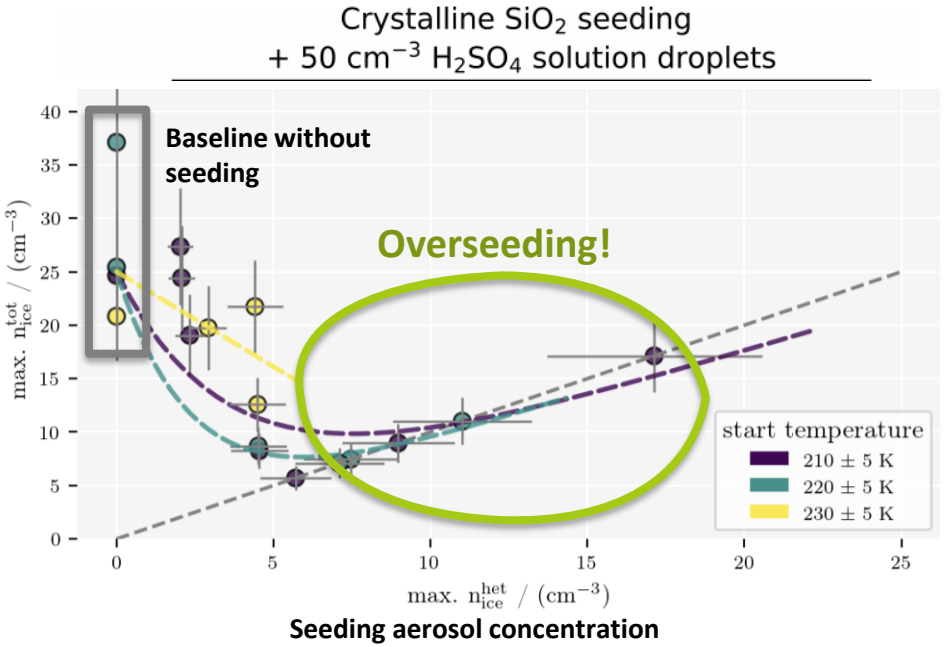


Figure courtesy of T. Schorr

Interplay between updrafts and CCT - simulations

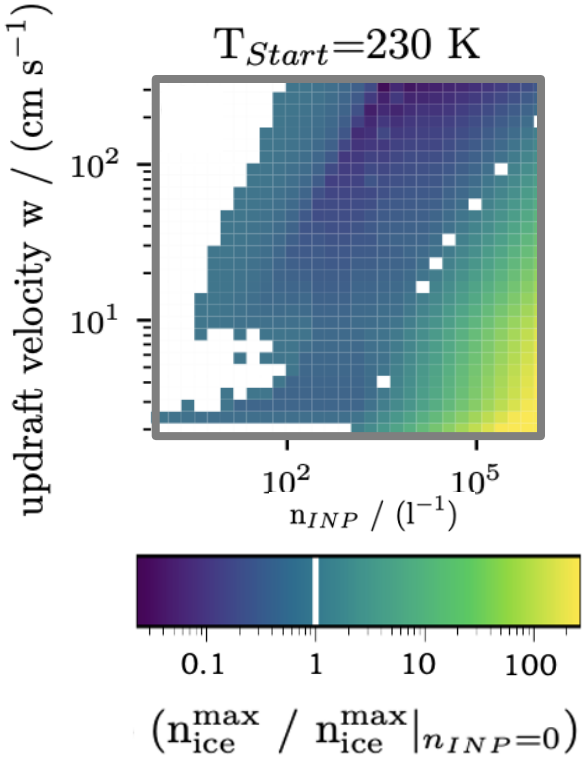
Ice crystal number concentrations

Ice water content

Simulations with the box model MAID along updraft trajectories

Interplay between updrafts and CCT - simulations

Ice crystal number concentrations



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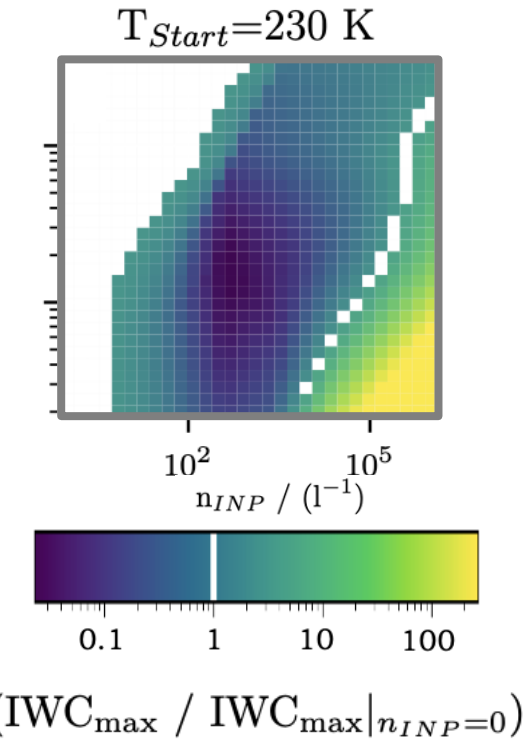


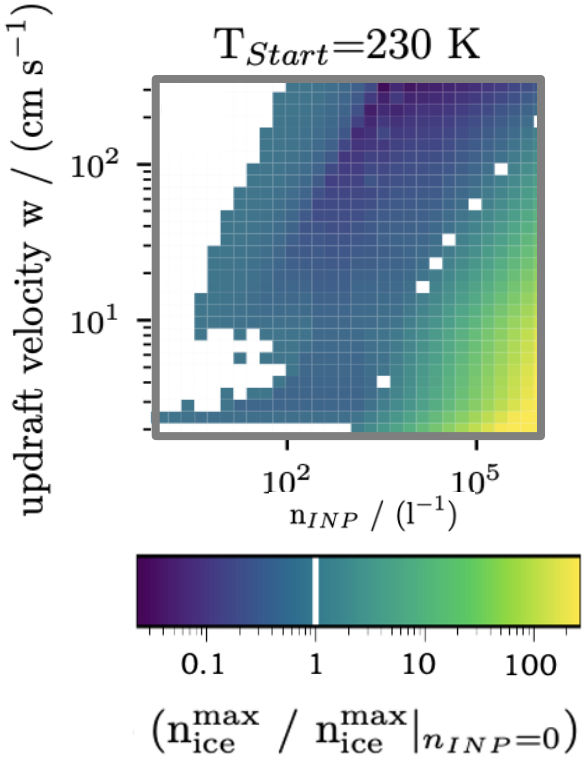
Figures courtesy of T. Schorr

Simulations with the box model MAID along updraft trajectories

There are regions of **successful seeding** and **overseeding**.

Interplay between updrafts and CCT - simulations

Ice crystal number concentrations



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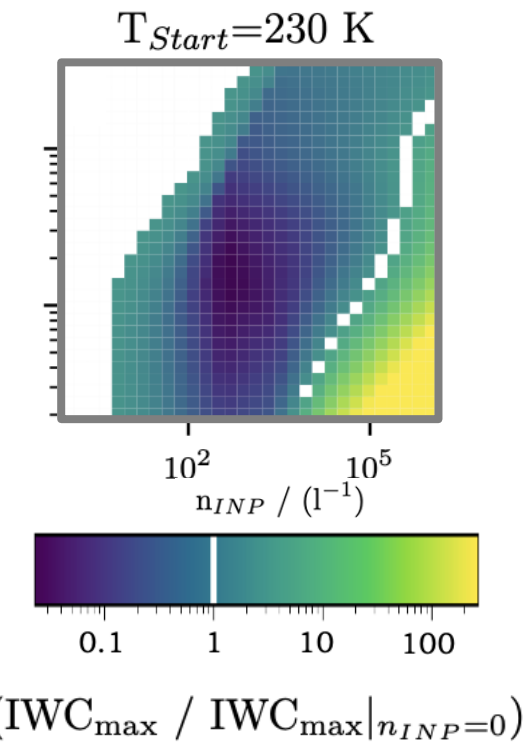


Figures courtesy of T. Schorr

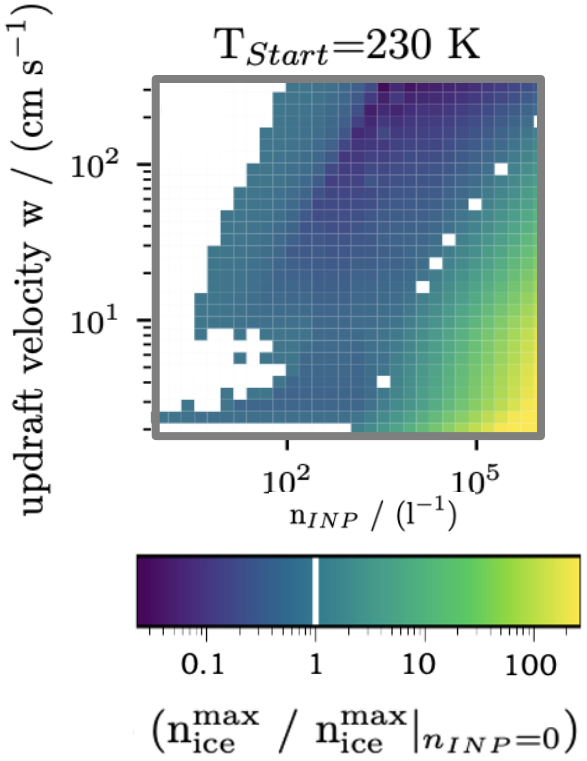
Simulations with the box model MAID along updraft trajectories

There are regions of **successful seeding** and **overseeding**.

At 210 and 220 K, a similar pattern is observed.

Interplay between updrafts and CCT - simulations

Ice crystal number concentrations



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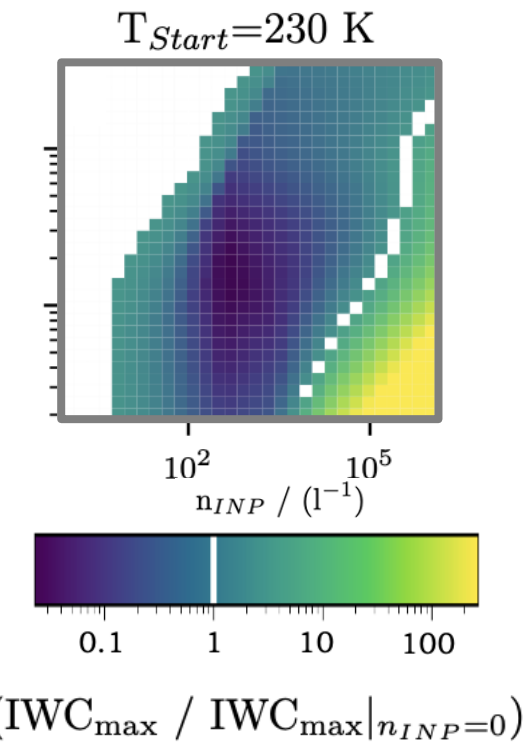


Figures courtesy of T. Schorr

Simulations with the box model MAID along updraft trajectories

There are regions of **successful seeding** and **overseeding**.

Open question

How well is ice crystal growth captured?

Impact of updrafts with fluctuations - simulations

Ice crystal number concentrations

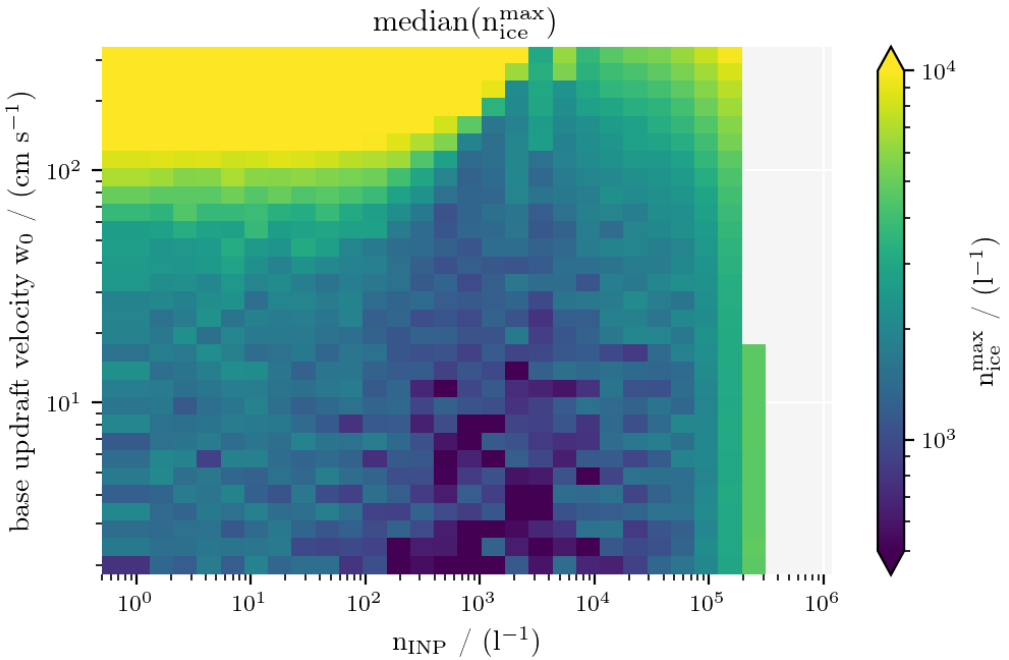


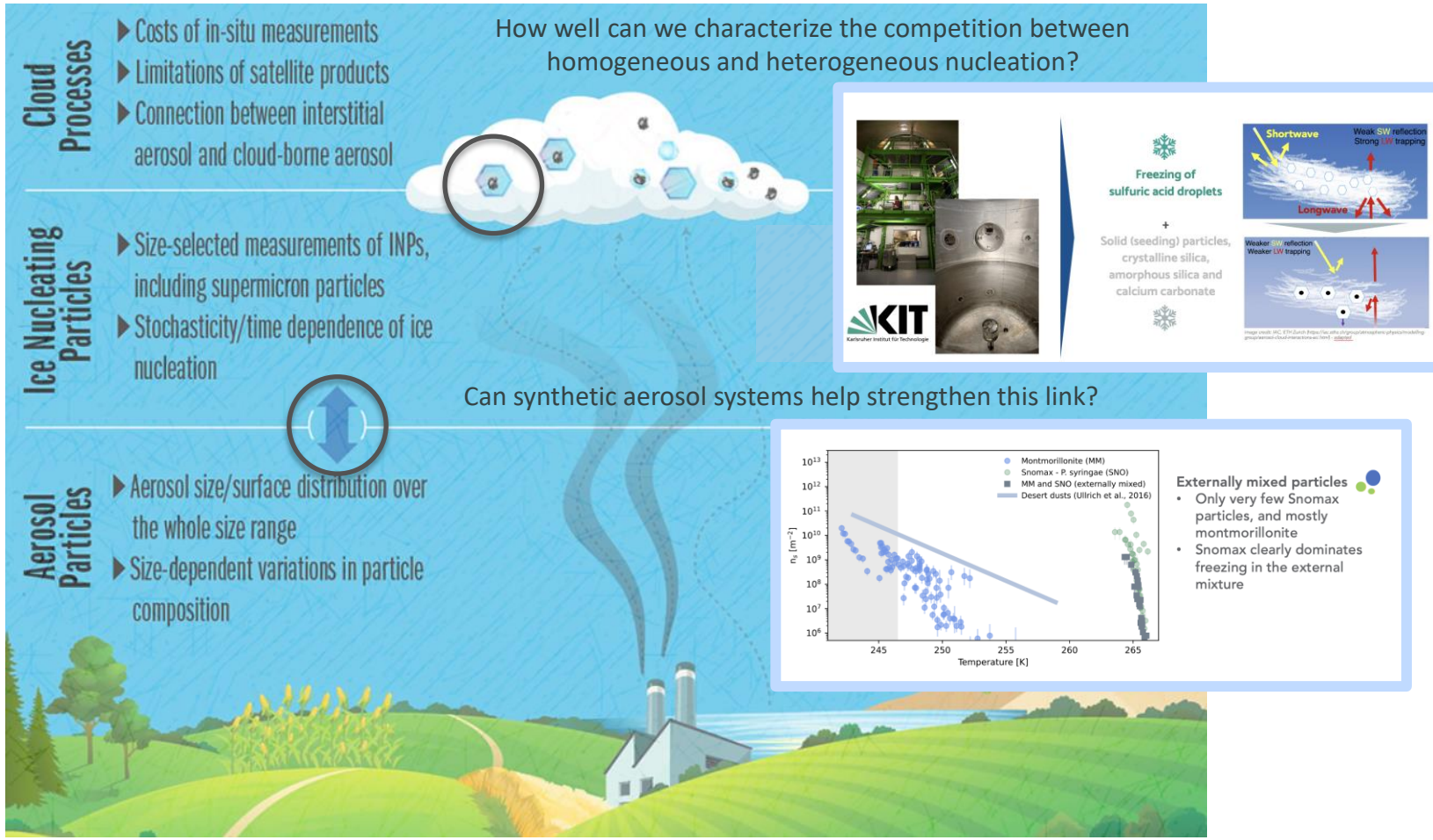
Figure courtesy of T. Schorr – all data available through KITopen (doi: 10.35097/1956)

Simulations with the box model MAID along updraft trajectories with fluctuations (gravity waves)

Regions of **successful seeding** and **overseeding** **are still visible, but the transitions are now blurred out.**

Scenarios should be analyzed with a *probabilistic approach*, reflecting a higher variability in possible outcomes compared to the scenarios with uniform updrafts.

Two flavors of ice nucleation research



Burrows et al., Rev. of Geophysics, 2022