What processes control ice nucleation and its impact on ice-containing clouds ?

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ASR CAPI “Ice Cloud” Breakout Summary Report

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Outline

- ✧ Challenges
- ✧ Progress Highlights
- ✧ Key Issues
- ✧ Research Needs
- ✧ Action Plan

Challenges

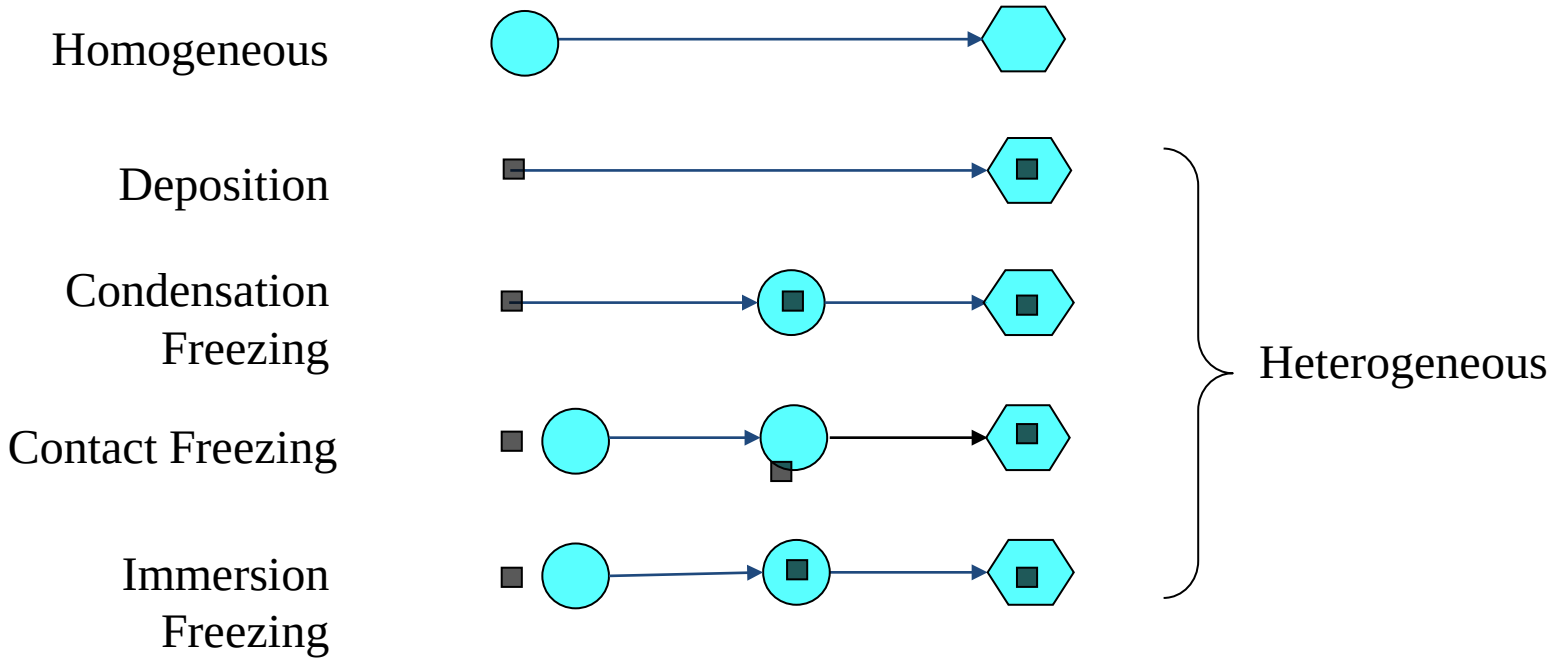
- Ice nucleation processes involving aerosols are key to the formation and properties of cirrus and mixed-phase clouds, and thereby can impact both the atmospheric radiative energy distribution and precipitation processes.

- Compared to droplet formation in warm clouds, ice nucleation is more complicated and much less understood.

- Large uncertainties exist in the representation of ice nucleation processes in climate models, and aerosol effects on mixed-phase and cirrus clouds.

Ice nucleation processes are poorly understood

Multiple Ice Nucleation Mechanisms



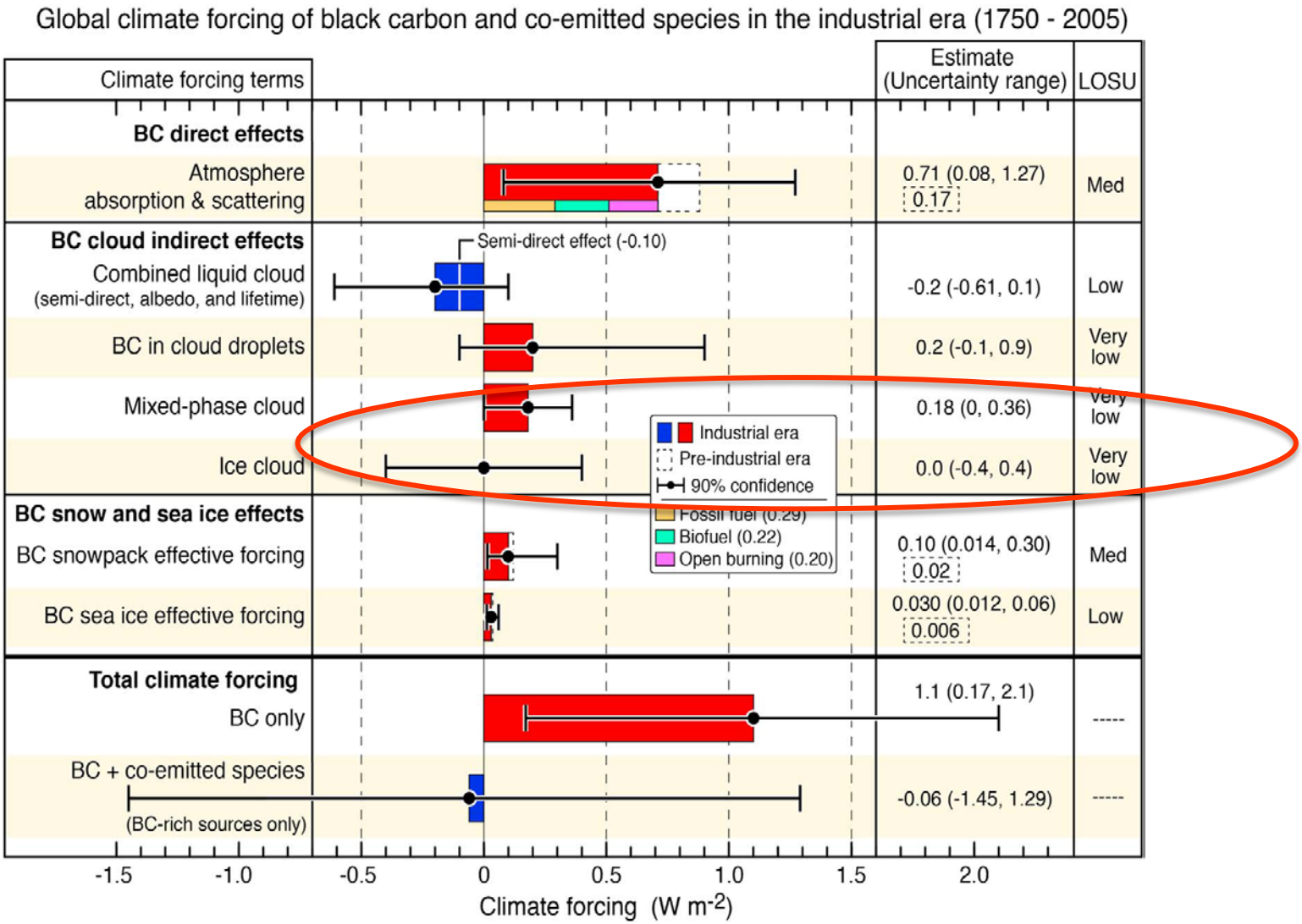
Soluble/insoluble aerosol particle (substrate) (~10^{-3} – 10^{-5} of aerosol population)

Supercooled solution droplet / cloud droplet

Ice crystal

Global Mean *Black Carbon* Radiative Forcing from 1750 to 2005

Bond et al. (2013)



Ice nucleation processes are poorly represented in climate models. Large uncertainties are associated with aerosol effects on mixed-phase and ice clouds.

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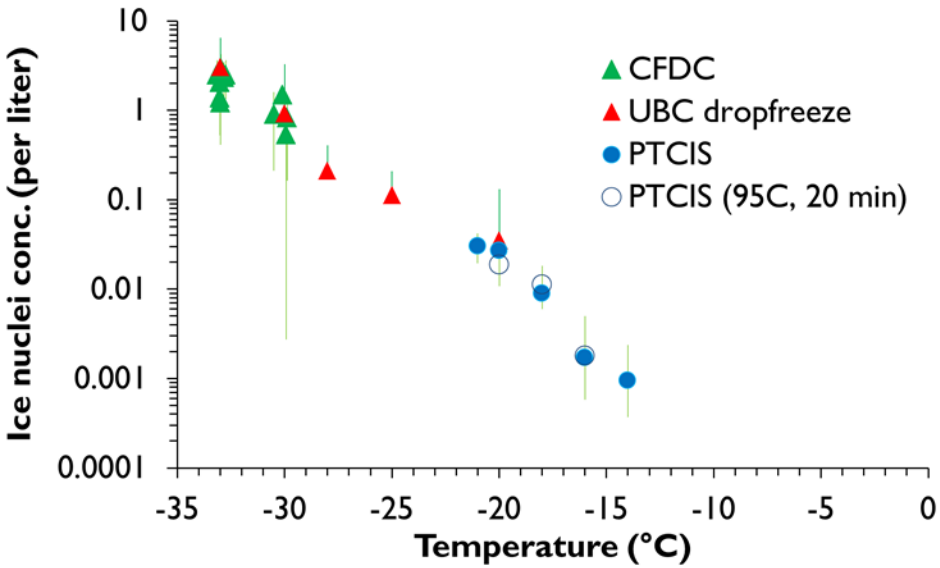
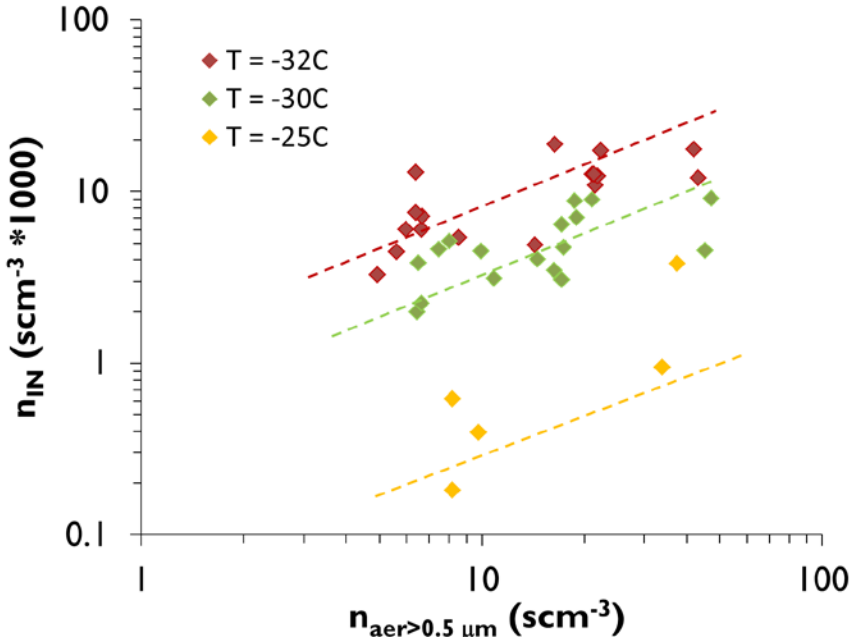
CAICE fresh seawater (Scripps pier) wave-breaking experiments

Basic IN-T spectrum with overlap of methods

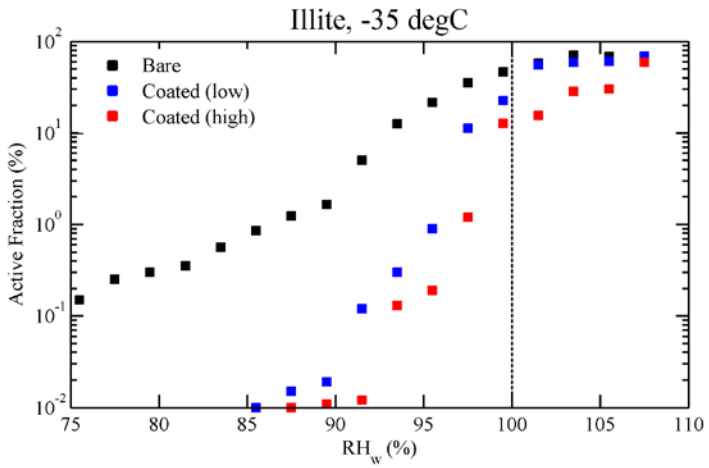


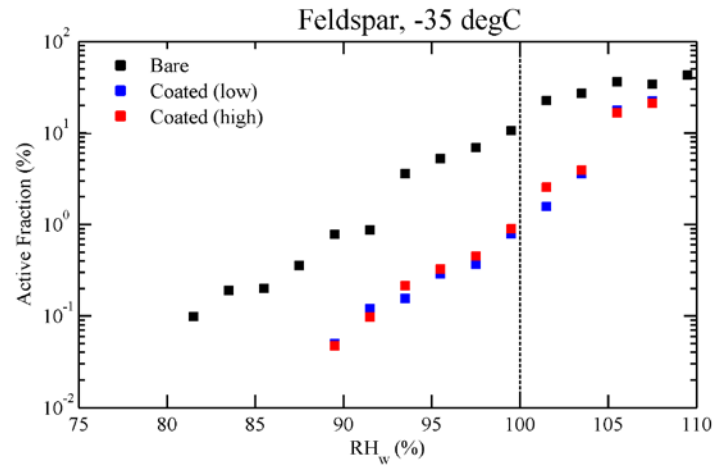
Modest dependence on n>0.5μm (mimics airborne inorganic IN)



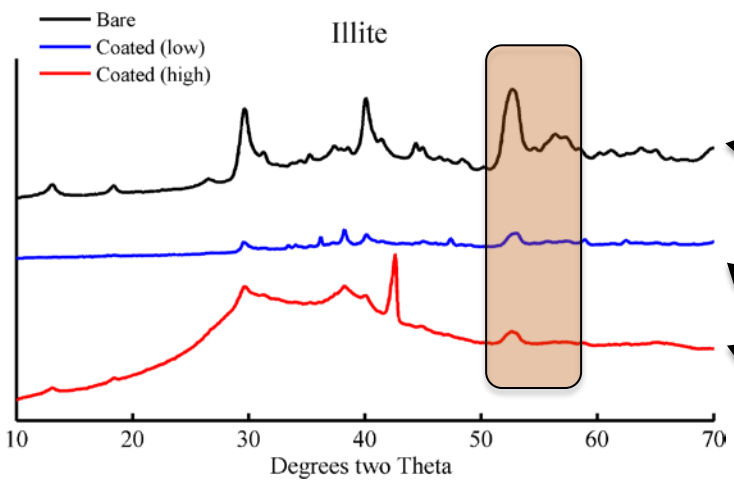
Slide from Paul DeMott (CSU)

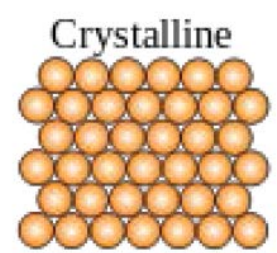
Ice Nucleating properties of coated and uncoated dust particles



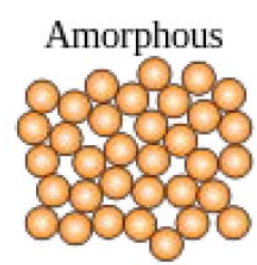


X-Ray Diffraction patterns revealed why coated particles were poor IN





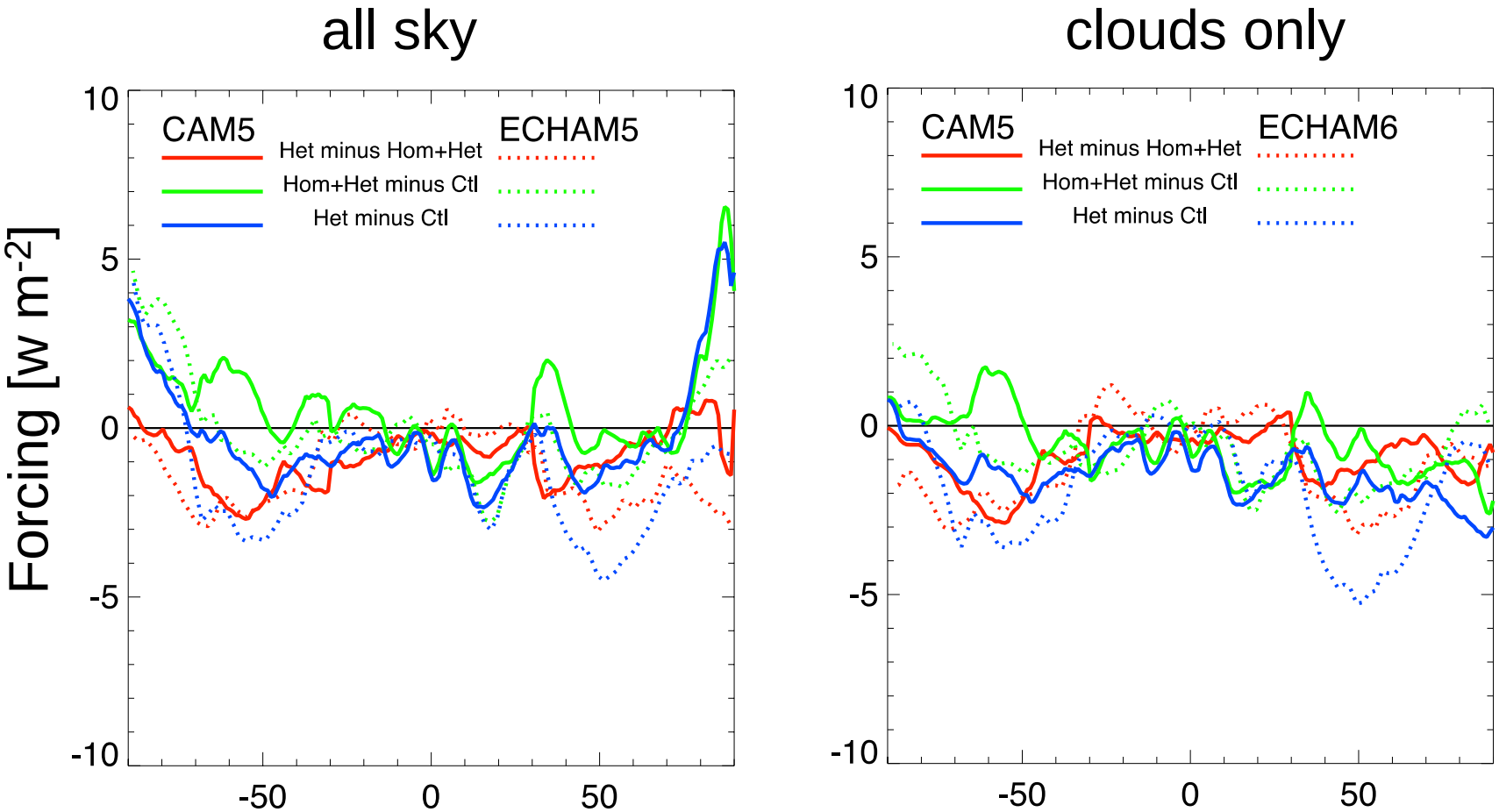
Atoms are in a near-perfect periodic arrangement.



No periodic arrangement of atoms. Lacks the long-range crystalline order.

Slide from Gourihar Kulkarni (PNNL)

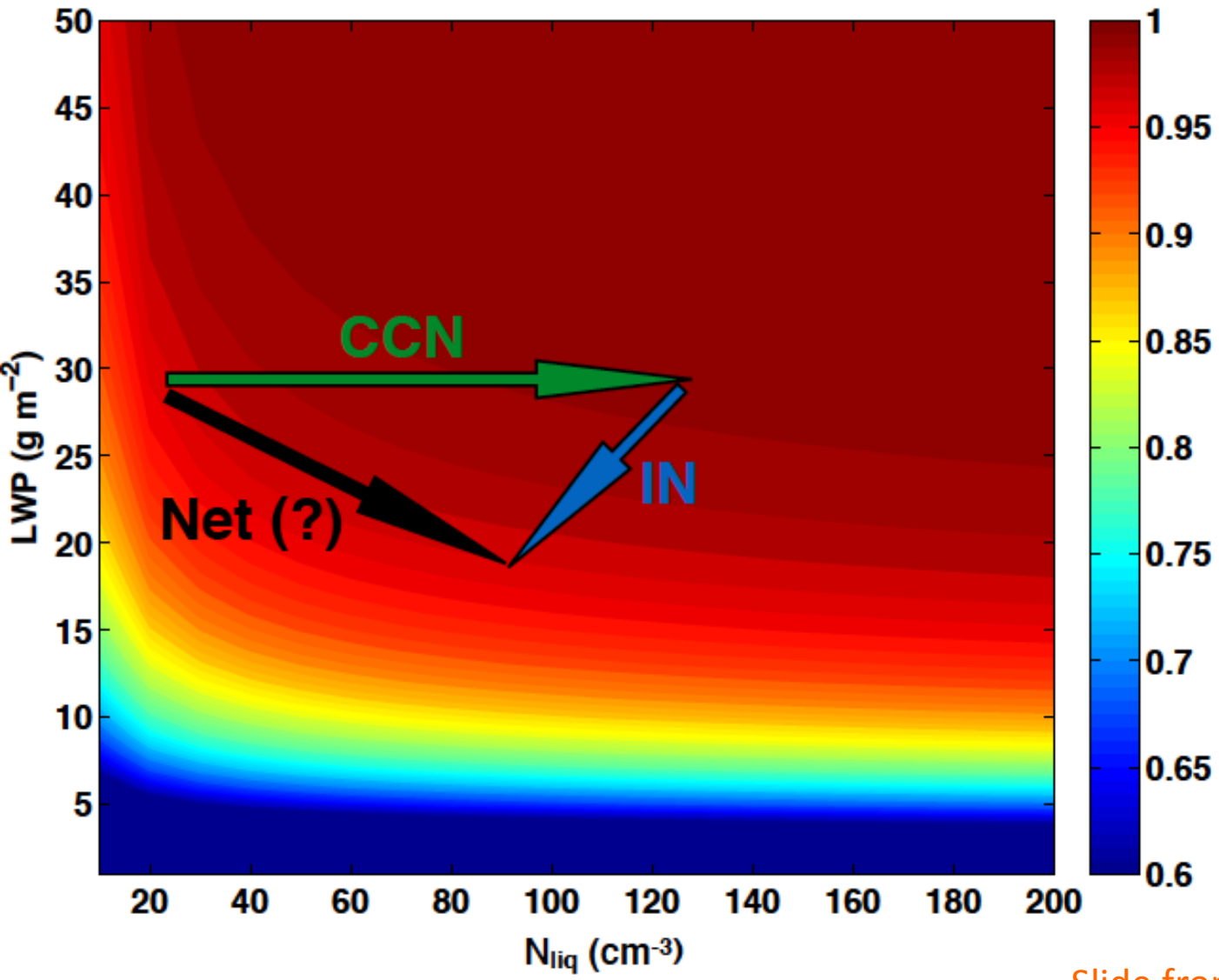
Climate Model Results: Heterogeneous – (Homo- & heterogeneous)



Net radiative forcing differences (all sky)
CAM5 -0.825964
ECHAM6 -1.28051
Net radiative forcing differences (clouds)
CAM5 -0.911210
ECHAM6 -1.17228

Slide from David Mitchell (DRI)

The Role of Ice in mixed-phase indirect effects?



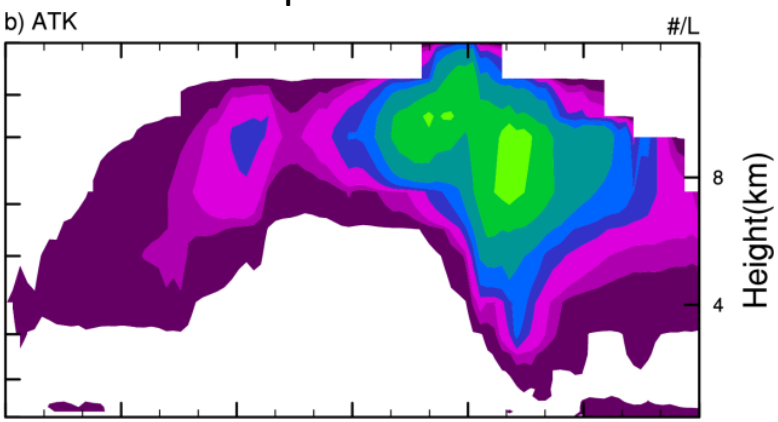
Change of Cloud emissivity to aerosol perturbation

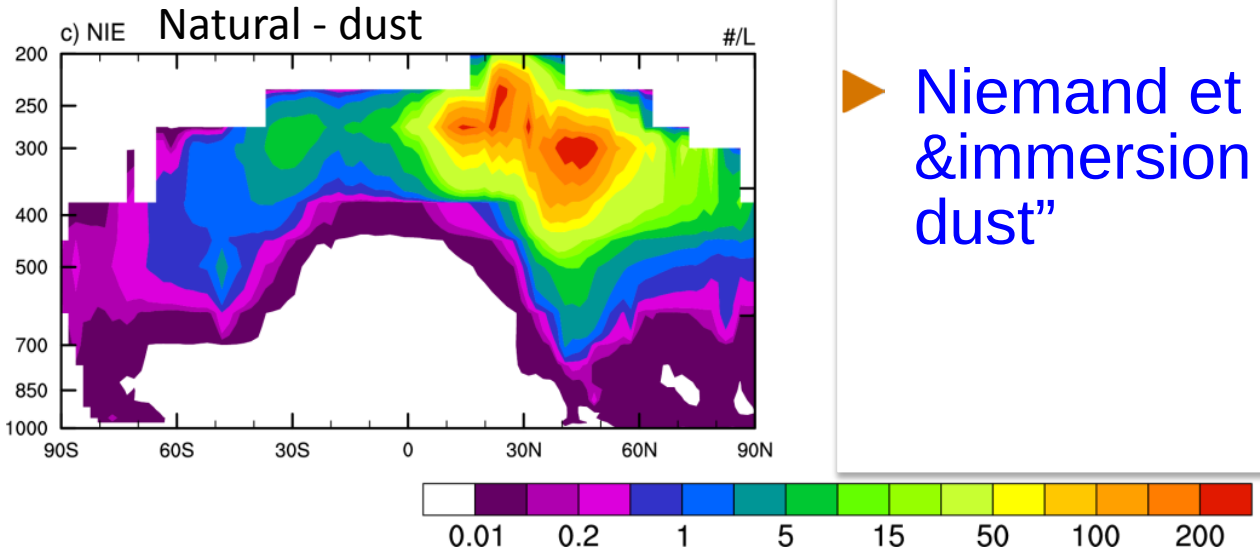
Slide from Gijs de Boer (NOAA)

Ice nuclei number concentrations in mixed-phase clouds

- Atkinson et al. (2013) – immersion on K-feldspar

Feldspar - dust



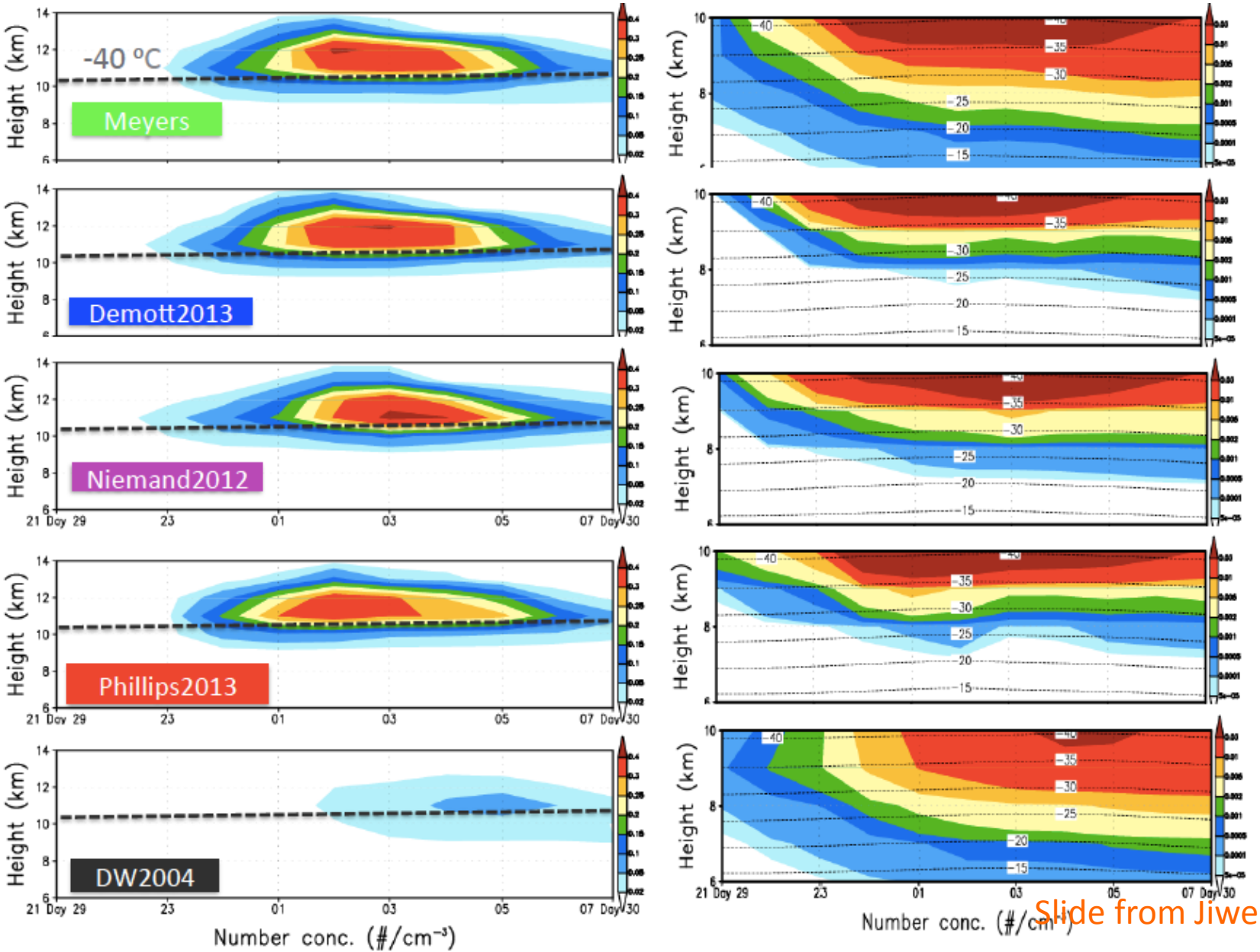


- Niemand et al. (2012) &immersion on “natural dust”

Ice nucleation depends upon the dust mineralogy.
Dust speciation treatment in GCM is important.

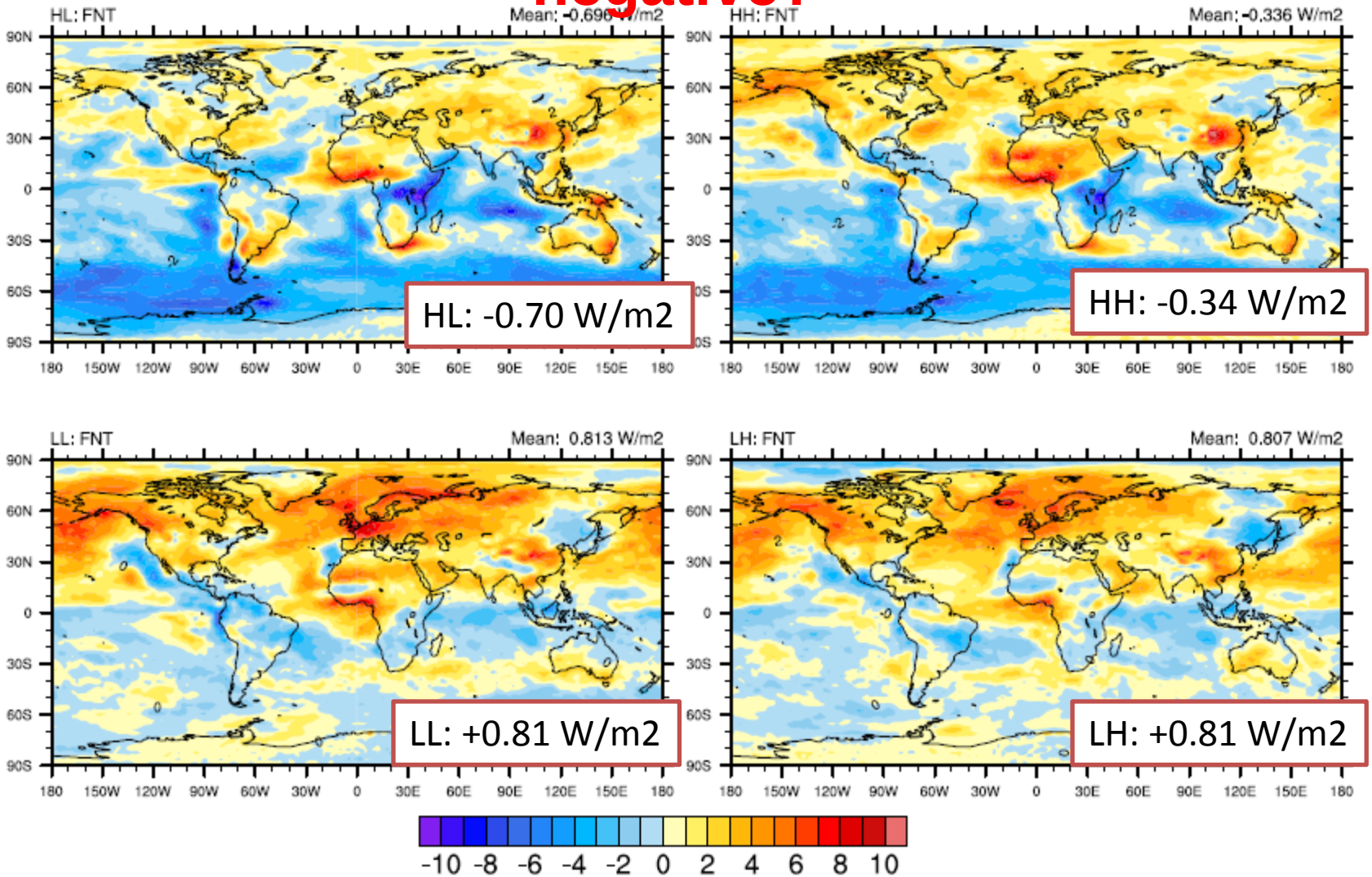
Slide from Xiaohong Liu (Univ. Wyoming)

Evaluation of Ice Nucleation Parameterizations in a Thunderstorm case of DC3



Slide from Jiwen Fan (PNNL)

Is the indirect forcing by aircraft soot positive or negative?



The global mean radiative forcing of aircraft soot on large-scale cirrus strongly depends on the background ice nucleation (ie., sulfate number). It ranges from -0.70 W/m2 to +0.81 W/m2 in our idealized study.

Slide from Joyce Penner (Univ. Michigan)

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Key Issues identified

- Ice Nuclei budget in the atmosphere (sources of IN?). This is needed to constrain the cloud models and, also, the remote sensing retrievals.

- Long-term IN measurements are missing at DOE-ARM sites. These are CRITICALLY needed to advance the Ice Cloud research forward.

- Classify the IN concentration as a function of aerosol size, chemical mixing state, composition to better understand the ice nucleation processes.

- IN instrument comparison workshop to better understand the performance of IN instruments.

- Competition between heterogeneous and homogenous freezing in cirrus clouds.

Key Issues cont.

- Relative importance of Ice Microphysical processes (ice nucleation, ice growth, Bergeron-Findeison process etc.).

- Aerosol vertical profiles (size and number) at DOE-ARM ground sites to constrain ice number concentrations.

- Role of contact freezing in ice formation. Importance of this ice nucleation mechanism is unclear.

- Role of different aerosol size and chemistry (black carbon, biological, coated dust, organics) towards inducing ice. Pre-activation/memory effect on ice nucleation.

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Research Needs to advance science

- We need dedicated IN instrument (CFDC) that can be deployed in the field as well as on the aircraft. Deployed at DOE ARM ground sites will provide long term IN measurements.

- IN closure studies to understand the mixed-phase cloud formation: Field experiment at Barrow site. Deploy IN, CVI, aerosol characterization, and single particle mass spectrometer instruments. Cloud resolving model simulations to examine the sensitivity of various ice microphysical processes.

- Participate in the international IN instrument comparison workshop.

- Future in-situ ice cloud experiments should include aircraft CVI to determine the composition of ice crystal residues.

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Action Plan

Short Term Goals (0 to 2 years)

- ✓ Purchase commercial IN instrument (CFDC).
- ✓ Deploy at Barrow ground ARM site, and start collecting IN data when boundary layer is well mixed.
- ✓ Use IN measurements to validate the remote sensing retrievals and constrain the models.

(Let's begin making progress to understand Ice Nucleation!!!)

Long Term Goals (2 to 5 years)

- ✓ IOP at Barrow for IN closure studies.
- ✓ Deploy IN instrument at various ARM sites.
- ✓ Participate in the proposed multi-agency Southern ocean field experiment (SOCRATES) to understand the importance of biological particles towards ice formation.