Proposal for CAPI Ice Nucleation Focus Group

Xiaohong Liu (Univ. Wyoming)

With thanks to: G. Kulkarni (PNNL)

DOE ASR Focus Group Guidelines

Overall Objective:

"To provide a means for organizing, coordinating, and supporting scientific efforts that are of high importance to ASR yet are substantially larger than any individual PI effort. Typically these groups will focus on a specific process that is not well *understood* and *modeled*. The results, products, and/or output from these groups will comprise some of the important deliverables that help to define ASR and its progress."

Challenges

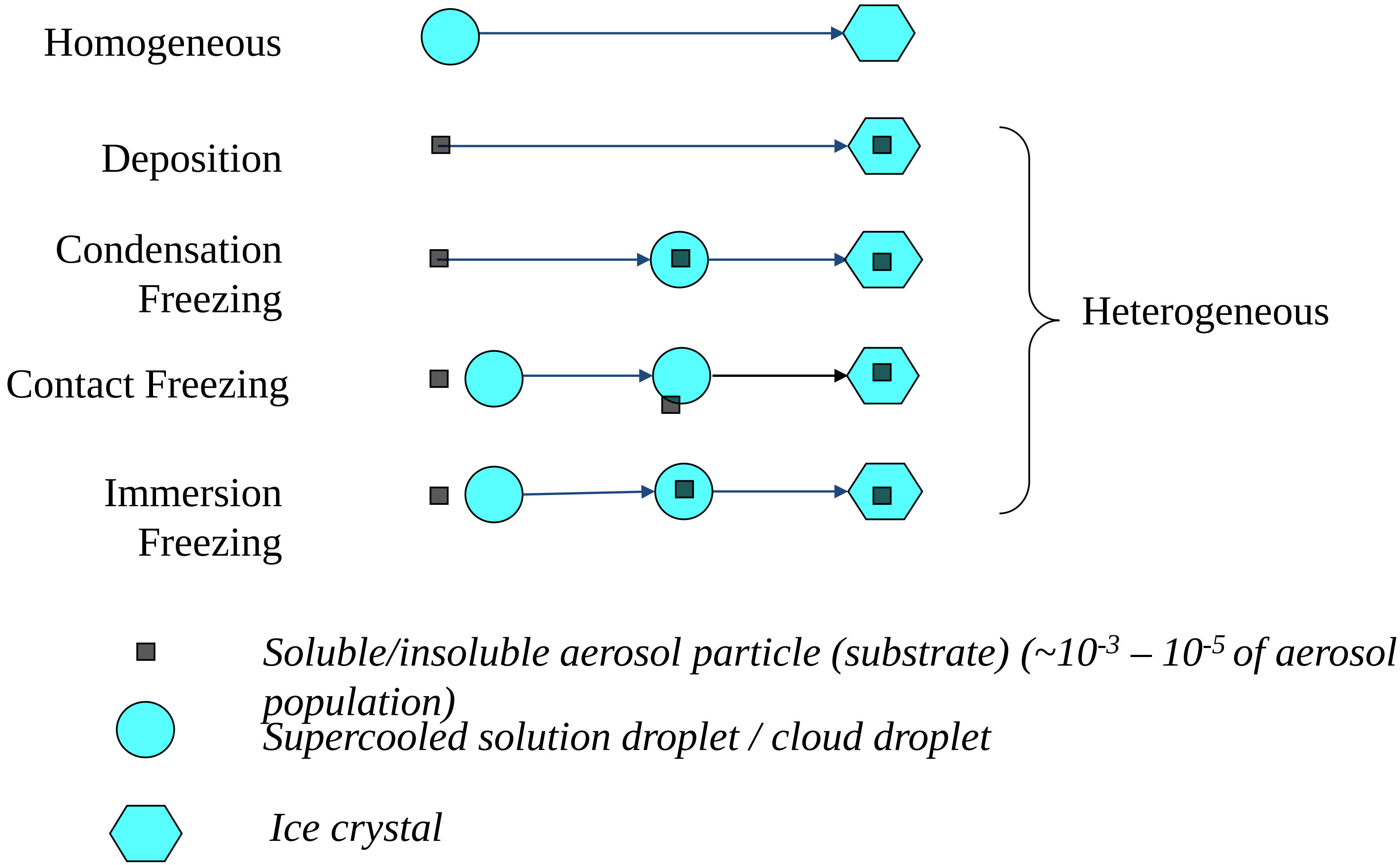
- Ice nucleation processes involving aerosols are key to the formation and properties of cirrus and mixed-phase clouds, and thereby can impact both the atmospheric radiative energy distribution and precipitation processes.

- 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



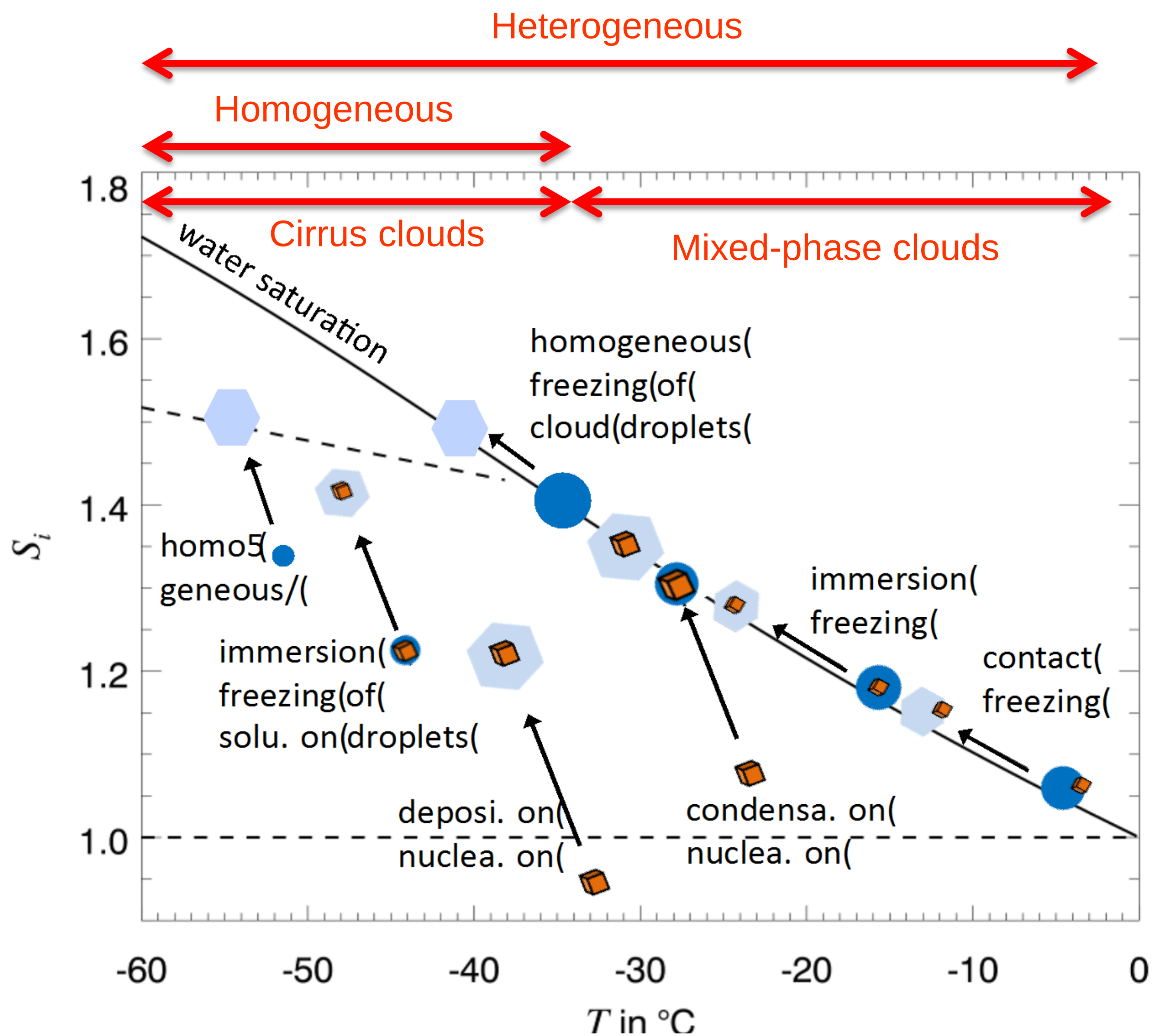
Courtesy of G. Kulkarni

Modes of ice nucleation

No clouds without aerosol particles
➔ CCN

No clouds without aerosol particles
➔IN (ice nuclei)

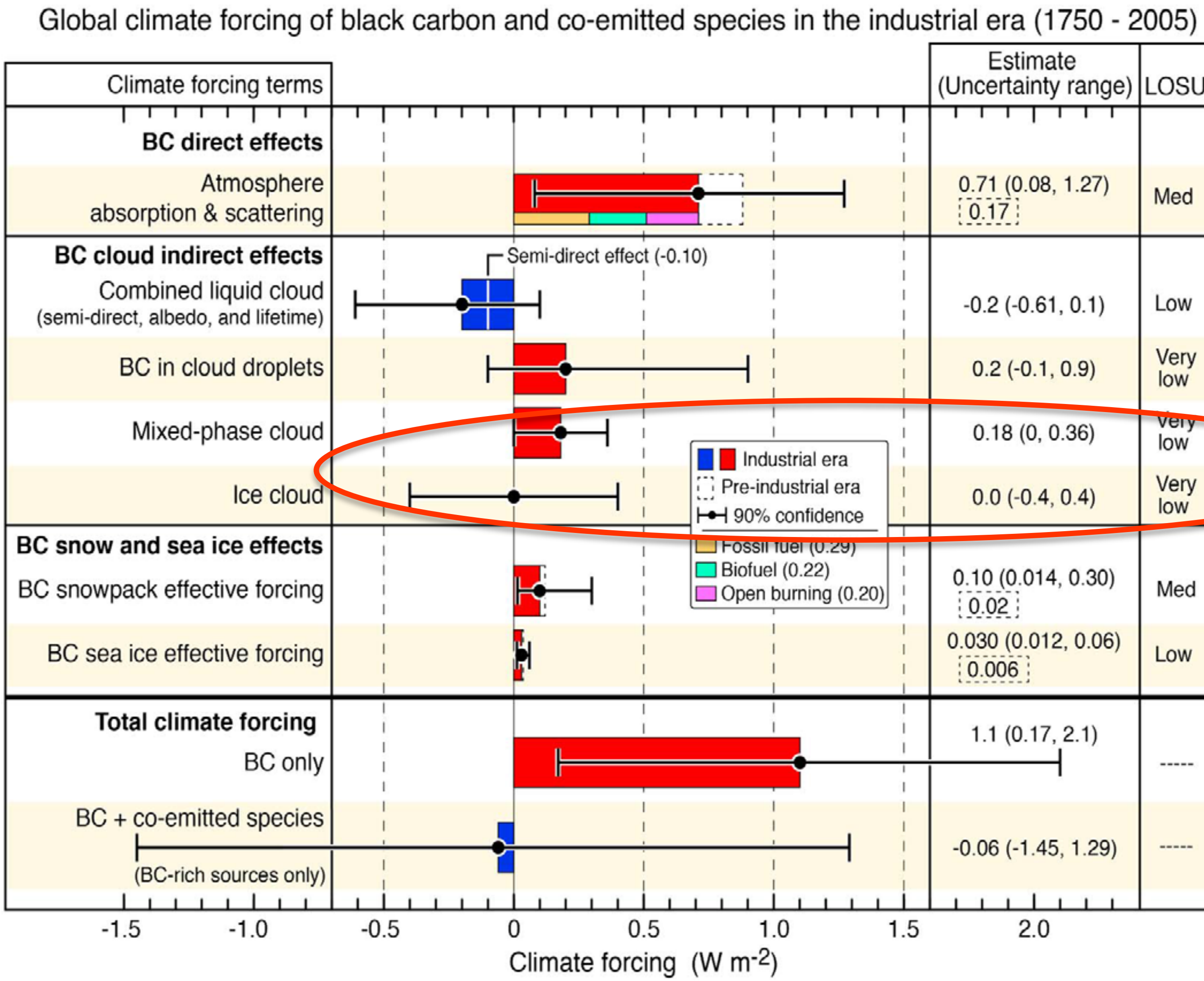
Except freezing of water droplets at -36 ° C



 Hoose and Moeller, ACP (2012)

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.

DOE ASR Focus Group Guidelines

Basic Guidelines for a Focus Group:

- ✧"Have well-defined, focused science objective(s), which are deemed to be of high importance to ASR programmatic objectives by the Science and Infrastructure Steering Committee (SISC) and DOE management."

Objectives

1. **Fundamental understanding of ice nucleation mechanisms and their relationship to overall aerosol properties and environmental conditions**

- IN sources: role of BC, biological aerosols and dust mineralogy
- Effect of atmospheric aging (coating of soluble materials)
- Modes of heterogeneous ice nucleation (e.g., immersion/condensation, deposition, and contact) and their relative importance in different environmental conditions
- Stochastic or deterministic nature of heterogeneous nucleation processes (time dependence)

Objectives

2. Ice nucleation effects on mixed and cirrus clouds

- Phase partitioning in mixed-phase clouds
- Relative importance of homogeneous versus heterogeneous nucleation in cirrus clouds
- Role of cloud dynamics: updrafts on relationships between ice number, ice nucleating aerosols, temperature and relative humidity
- Role of ice crystal properties: habit and fall speed
- Influence of preexisting ice crystals on ice nucleation of aerosols
- Secondary ice formation (ice multiplication)

Objectives

3. Building measurement capacity for understanding ice nucleation

- Intercomparison to quantify uncertainty in ice nuclei measurements by different instruments.
- Ice nuclei closure experiments: CFDC -> CVI -> SPLAT (SPMS)
- Long-term IN measurements at ARM sites (e.g., SGP, NSA), as well as fields campaigns (e.g., GOAMAZON, SOCRATES)

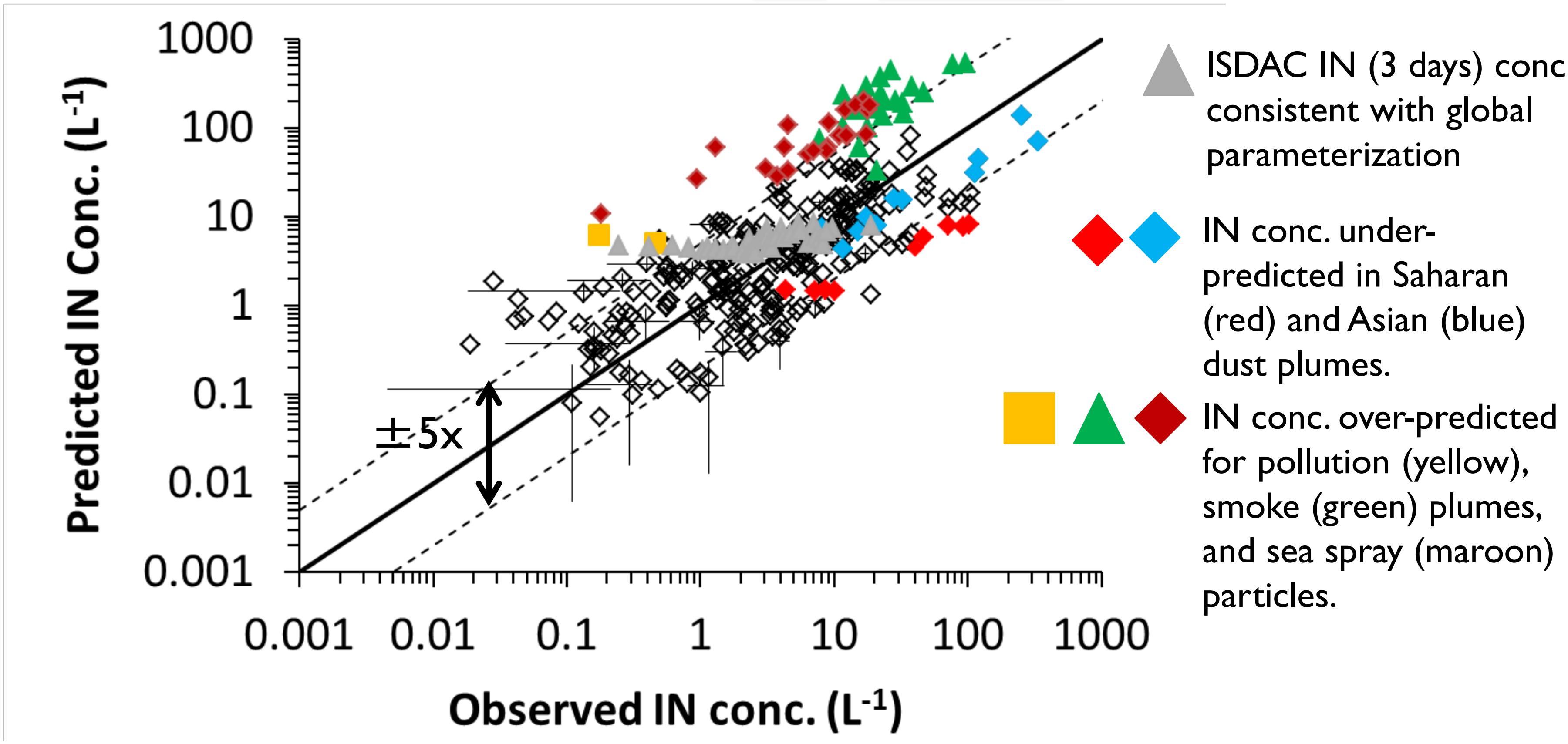
Proposed “Ice Nucleation” Focus Group

Science Question: What processes control ice nucleation and its impact on ice-containing clouds (e.g., Arctic stratus, altostratus, cirrus, convective clouds)?

1. How does ice nucleation depend on aerosol properties, environmental conditions, and time?
2. What are the specific contributions of mineral dust, soot, organics, and biological aerosols toward ice nucleation and IN variability?
3. What measurement approaches are needed to characterize all relevant ice nucleation processes?
4. Can we reach IN closure at current stages of IN measurement? If not, what areas are needed for improvement?
5. What are the roles of ice nucleation on cloud and precipitation properties and climate forcing?

Ice nucleation in mixed-phase clouds

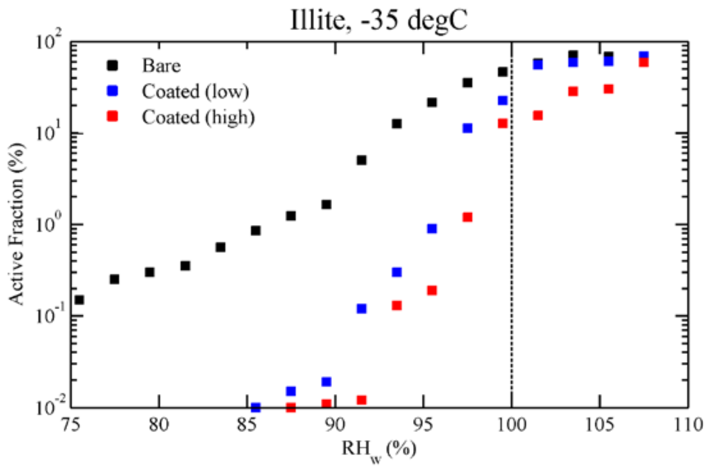
$$n_{IN,T_k} = a(273.16 - T_k)^b (n_{aer,0.5})^{(c(273.16-T_k)+d)}$$

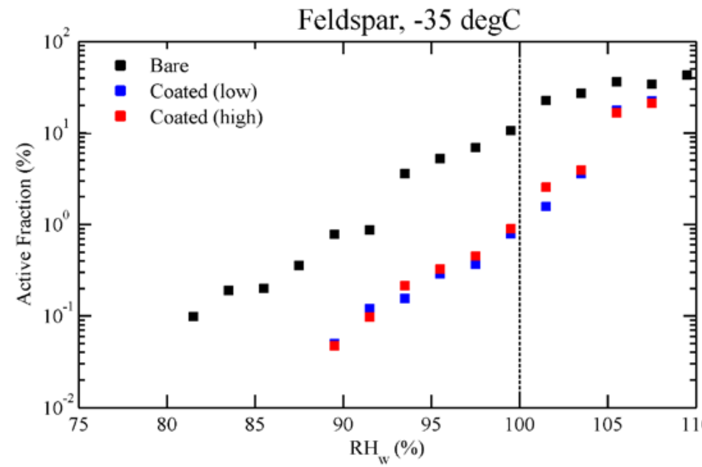


DeMott et al. (2010, PNAS) parameterization: T and $n_{aer,0.5}$

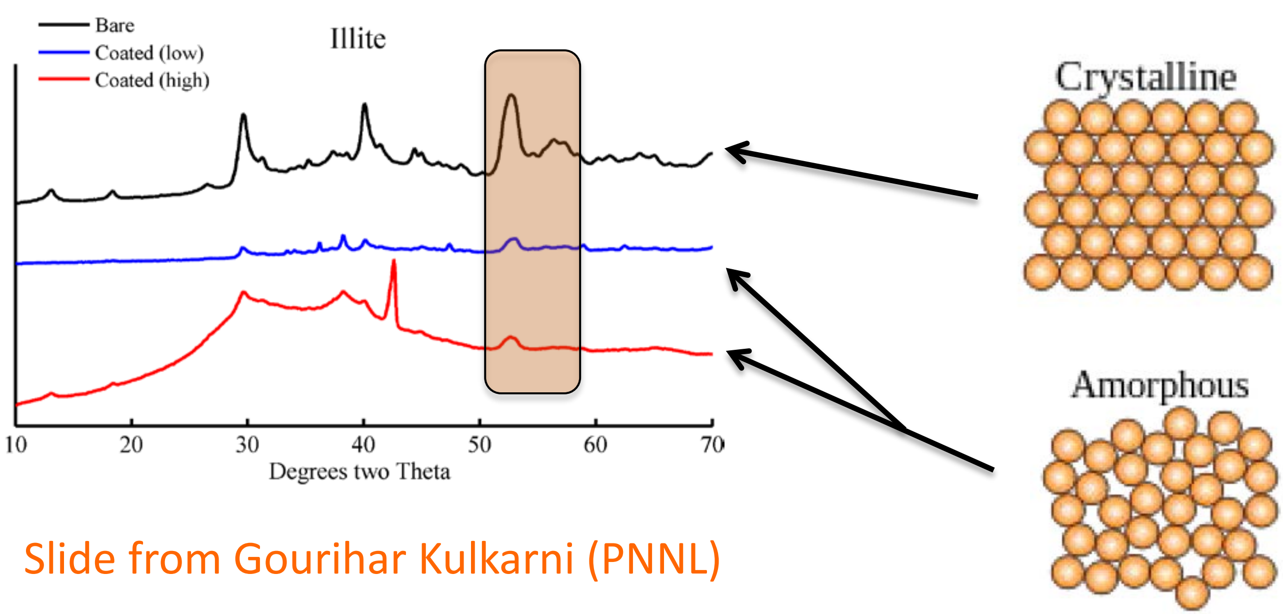
Composition matters as well

Ice nucleating properties of coated and uncoated dust particles





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



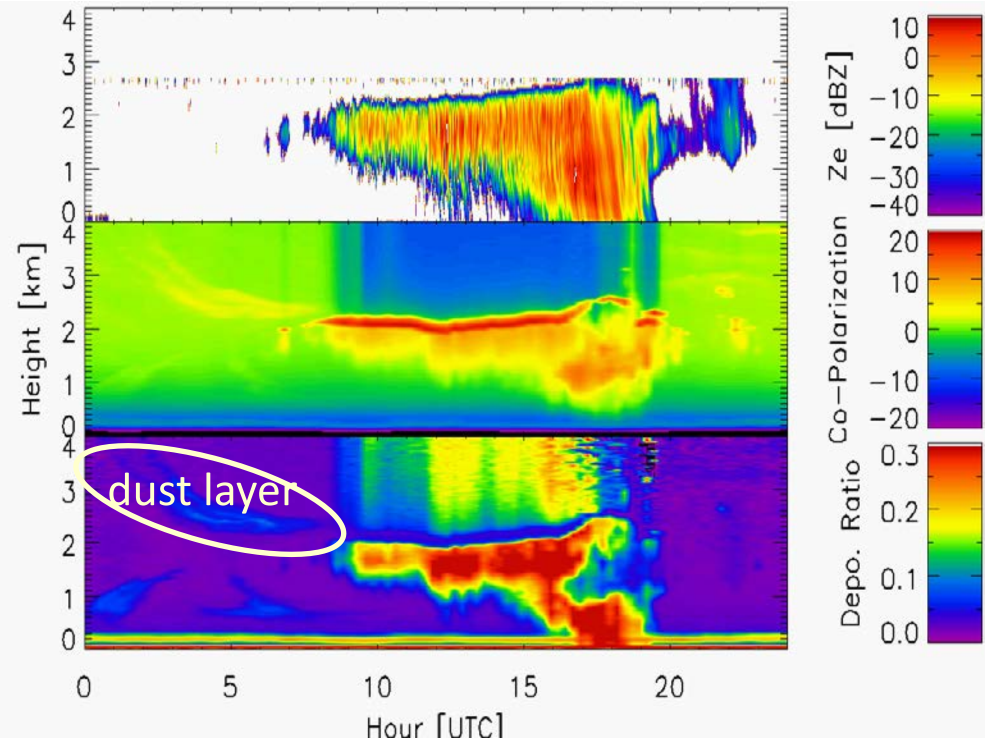
Atoms are in a near-perfect periodic arrangement.

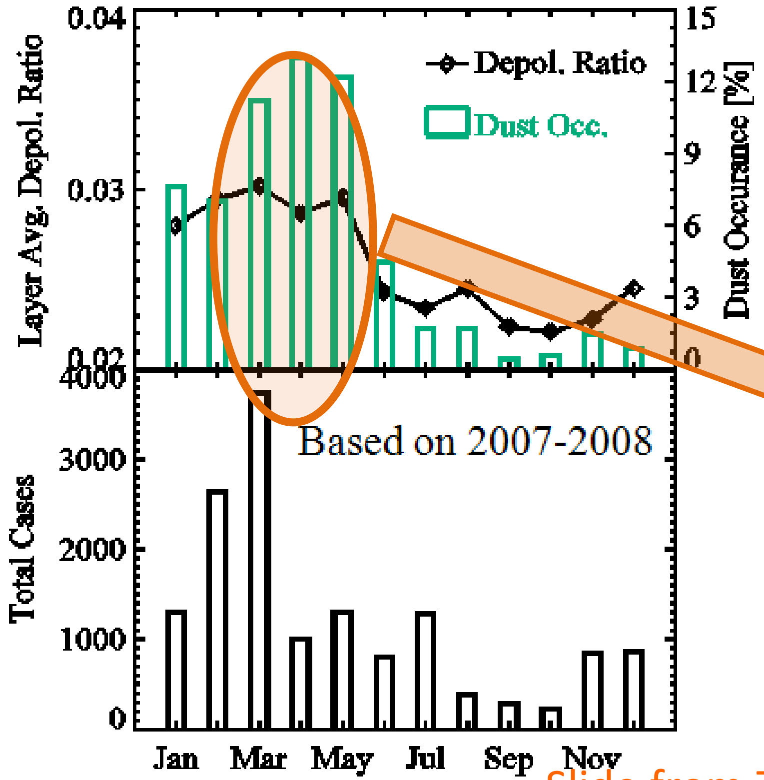
No periodic arrangement of atoms. Lacks the long-range crystalline order.

Slide from Gourihar Kulkarni (PNNL)

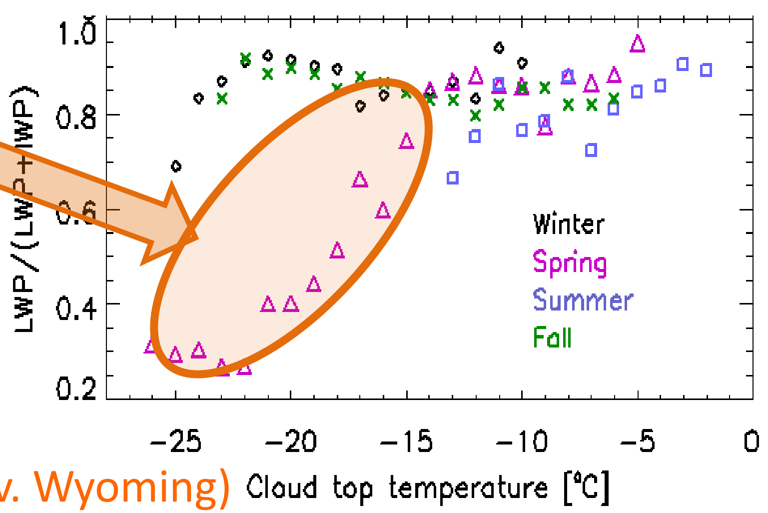
Spring time High Dust Occurrence is one of the potential reasons!

29 March 2008





(c)



Slide from Z. Wang (Univ. Wyoming)

Role of ice number concentration on Arctic mixed-phase clouds (ISDAC April 26, 2008)

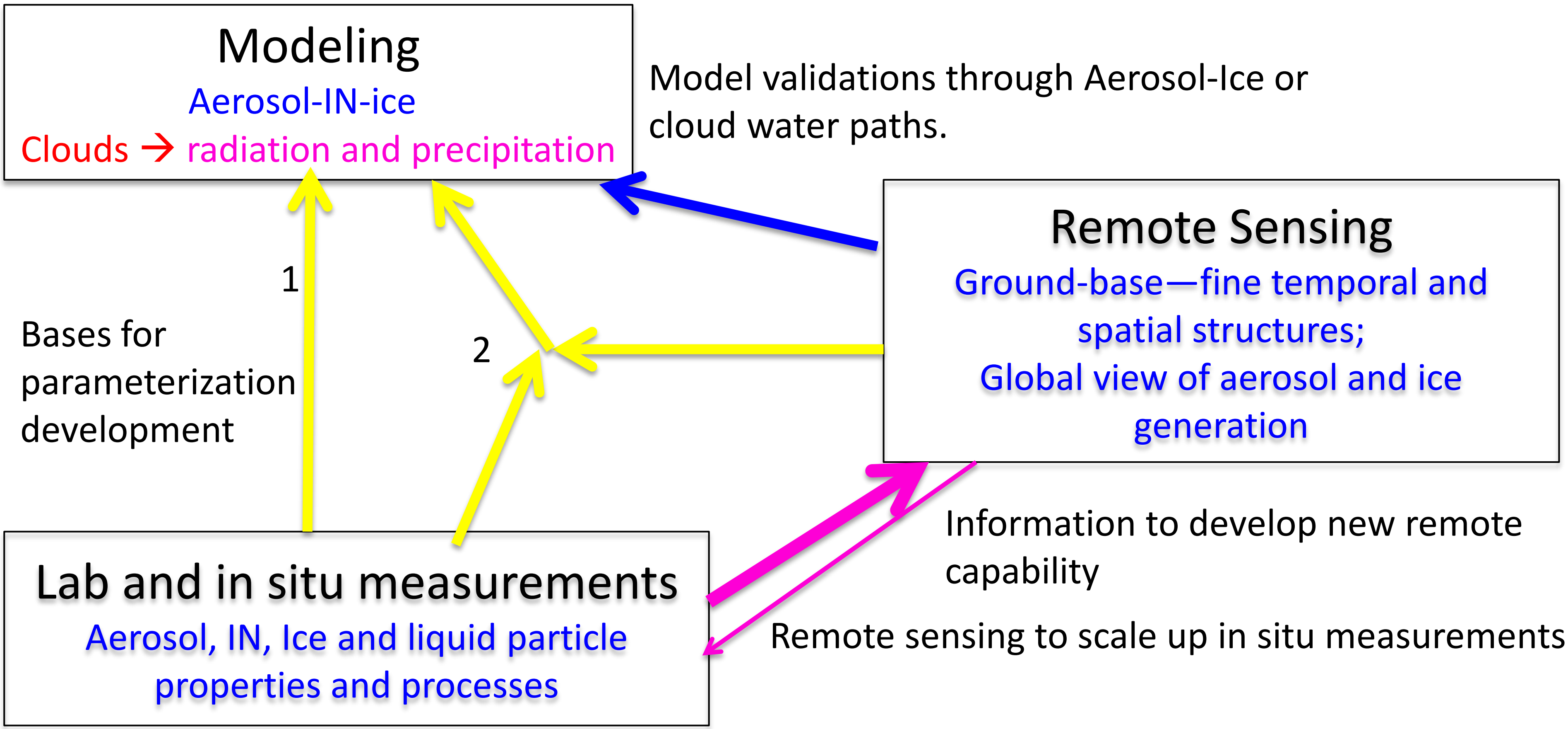
Ovchinnikov et al. JGR (2011)

DOE ASR Focus Group Guidelines

Basic Guidelines for a Focus Group:

- "Have a plan/approach for using ARM/ASR data and coordinated efforts by the group to address the objectives. The plan should outline how the specific activities will lead to improvements in model representation of the specific focus area."

The Path forward



Courtesy of Z. Wang

DOE ASR Focus Group Guidelines

Basic Guidelines for a Focus Group:

- "Obtain measurable and significant progress on a 5 year time scale."

Key Issues identified

- Ice Nuclei (IN) budget in the atmosphere. What are the sources of IN in the atmosphere? This is needed to constrain the 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 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, ice sedimentation, Bergeron-Findeison process, etc.).

- 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.

- Collecting aerosol particles on filter in a field setting, and analyzing these filter samples for ice nucleation. What are the pros and cons of this method?

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.
- ✓ Investigate filter based technique for IN measurement.
- ✓ Participate in the international IN instrument comparison workshop.
- ✓ Use IN measurements to validate remote sensing retrievals and to 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 ARM super-site (SGP).
- ✓ Participate in the proposed multi-agency Southern ocean field experiment (SOCRATES) to understand the importance of biological particles towards ice formation.

DOE ASR Focus Group Guidelines

Basic Guidelines for a Focus Group:

- "A critical mass of participation with identified leadership. Target size is 5 or more individual investigators or research groups. Typically a group will have participation from both observation and model perspectives."

DOE ASR Focus Group Guidelines

Xiaohong Liu, Gourihar Kulkarni, Paul DeMott, Zhien Wang, Matthew Shupe, Ann Fridlind, Raymond Shaw, Gijs de Boer, David Mitchell, Daniel Knopf, Joyce Penner, Jiwen Fan, …

DOE ASR Focus Group Guidelines

Basic Guidelines for a Focus Group:

- “Demonstration of progress via breakout sessions, talks, papers, products, etc.”

“Ice Nucleation” breakout session

Wednesday, September 14, 2011

10:15 a.m.–12:15 p.m. & 1:15 p.m.–1:45 p.m.

1. Xiaohong Liu: Introduction to the session (5 mins)
2. Paul DeMott: Progress and needs for in-situ measurements of atmospheric ice nuclei sources (12 mins)
3. Ann Fridlind: On the observational constraint of atmospheric ice nucleation in entraining cloud types (12 mins)
4. Subhashree Mishra, David Mitchell, Brad Baker and Paul Lawson: Ice nucleation mechanisms in mid-latitude cirrus - results from SPARTICUS (12 mins)
5. Xiping Zeng: Introducing ice nuclei into turbulence parameterizations in CRMs (12 mins)
6. Zhien Wang: Quantifying dust impacts on the ice generation in supercooled stratiform clouds (12 mins)
7. Xiaohong Liu: Ice nucleation in NCAR CAM5 model and evaluation with SPARTICUS observations
8. Qilong Min: Mineral dust impacts on clouds and precipitation (12 mins)
9. Open Discussion/white paper 60 mins

“Ice Nucleation” breakout session

Monday, March 10, 2014, 4:00-6:00 [Room 16]

4:00-4:15 Paul DeMott: Field and Laboratory Explorations of Marine Ice Nuclei

4:15-4:30 Gourihar Kulkarni: Ice nucleating properties of bare, coated, oxidized, coagulated, and thermally treated diesel soot particles

4:30-4:45 Daniel Knopf: What individually identified ice nuclei tell us about the atmospheric glaciation process

4:45-5:00 Damao Zhang: Seasonal Variations of Ice Number Concentration in Stratiform Mixed-phase Clouds over ACRF NSA site

5:00-5:15 David Mitchell: Globally mapping regions of homo- and heterogeneous nucleation as a function of latitude and season: A potential strategy using CALIPSO

5:15-5:30 Xiaohong Liu: Effect of aerosols on the phase partitioning of mixed-phase clouds through comparison of Community Atmospheric Model (CAM5) and CALIPSO observation

5:30-6:00 DISCUSSION

DOE ASR Focus Group Guidelines

Basic Guidelines for a Focus Group:

- “Develop a "white paper" that outlines the objectives, approaches, leadership, metrics for evaluating progress, and other details to acts as the guide for the group's activities.”