Understanding Ice Nucleation in Cirrus Clouds with NCAR CAM5 and SPartiCus Observations

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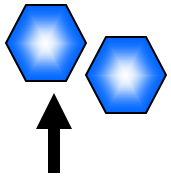
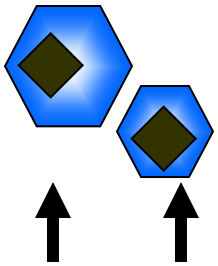
Introduction

- Aerosol effect on cirrus clouds (ice nucleation) are largely unknown.
- While homogeneous ice nucleation is relatively well understood, there are still large unknowns on heterogeneous nucleation by ice nuclei (IN) (properties, number and mechanisms).
- The goal of this study is to understand the ice nucleation mechanisms and effects on cirrus clouds using CAM5 and SPartiCus observations.

Cirrus (Ice) Ice Nucleation

Ice Crystal Population





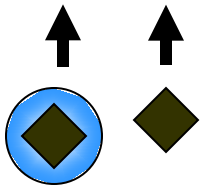
Homogeneous Freezing

Mainly depends on RH_i and T

Heterogeneous Freezing (Immersion, deposition, …)

Also depends on the material and surface area

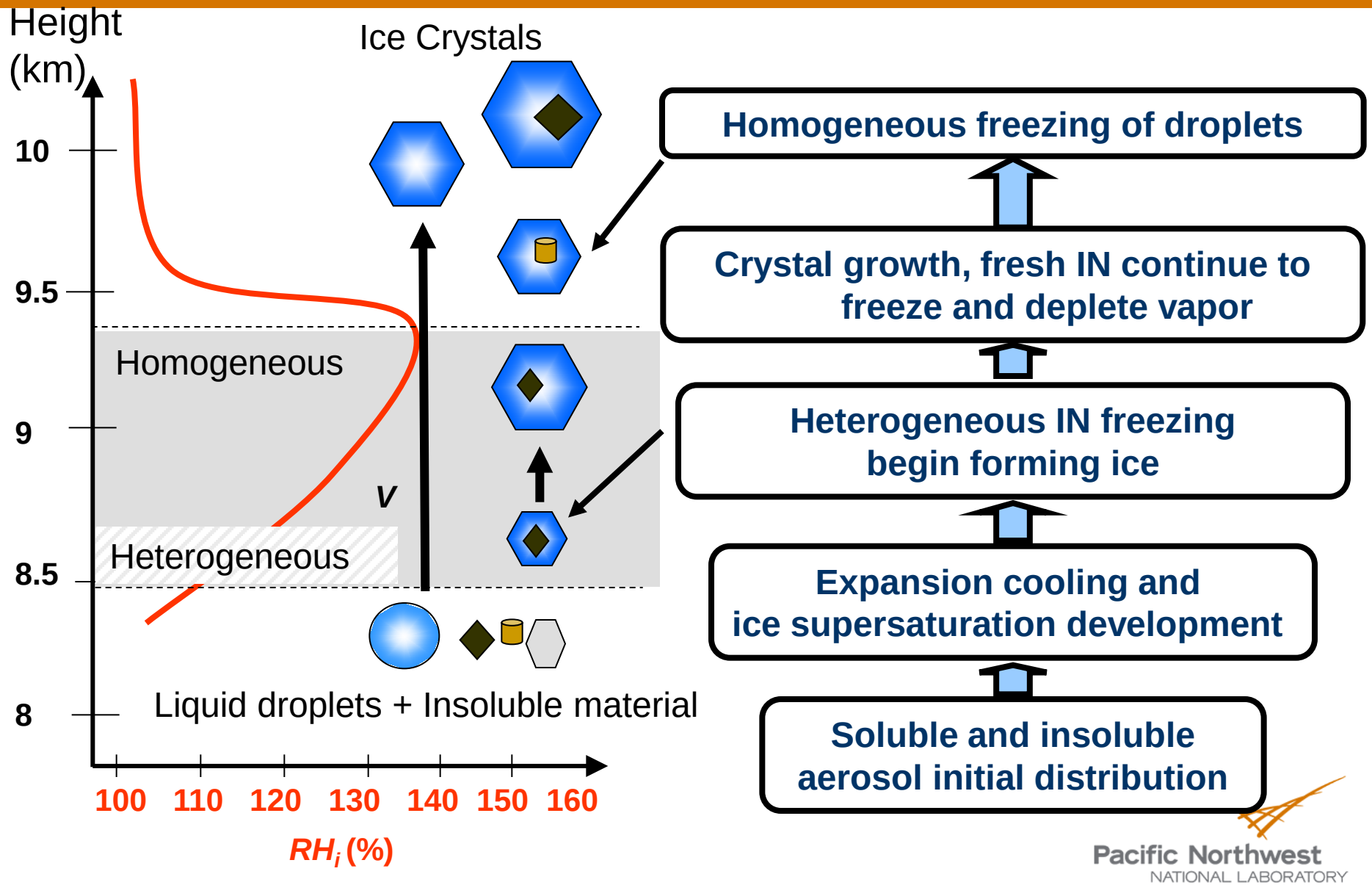
Wet aerosol particles



+ Insoluble Material ("Ice Nuclei")

Multiple mechanisms for ice formation can be active.

Conceptual Model of Ice Formation in Cirrus



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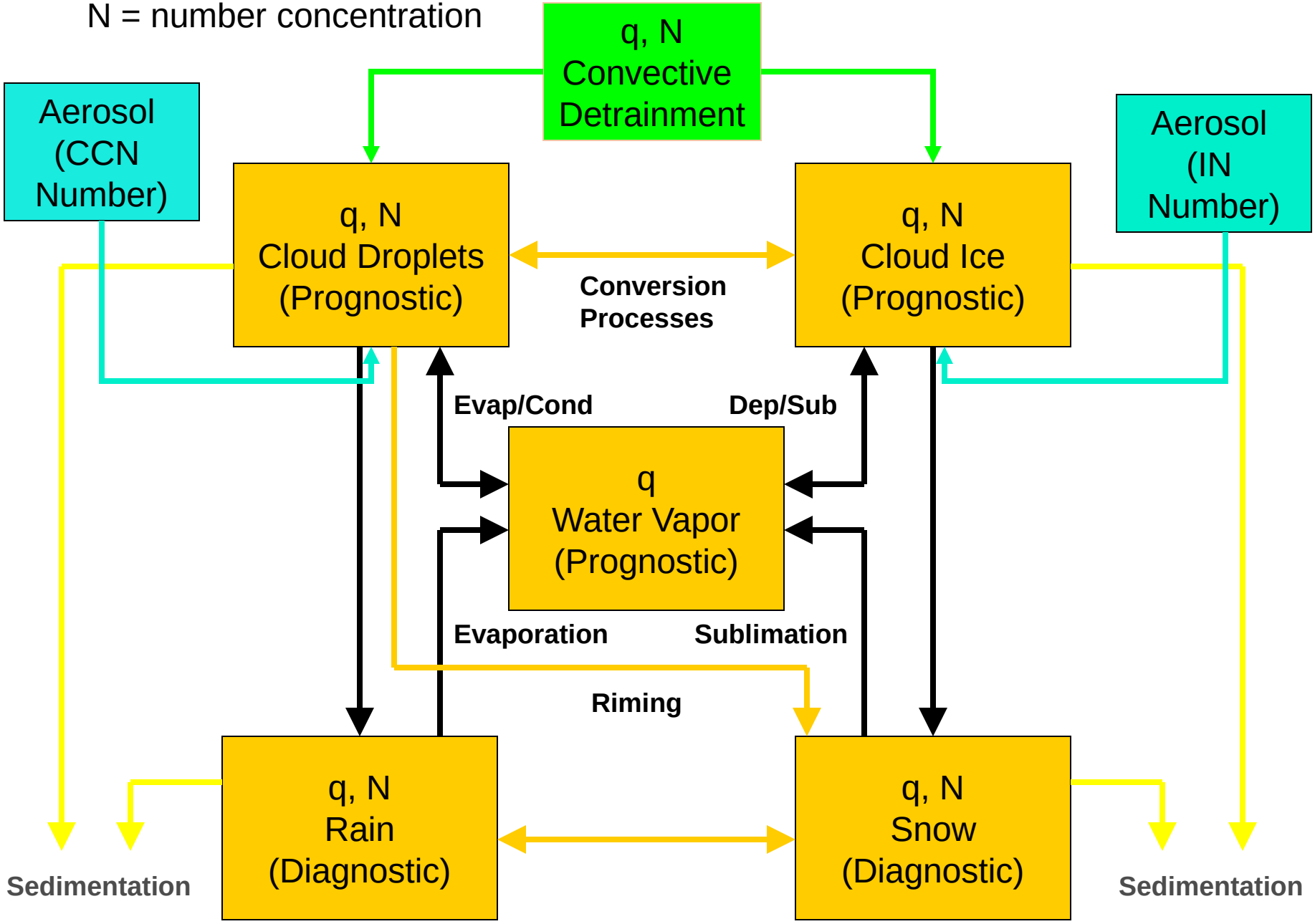
Cloud Microphysics Scheme in CAM5

Morrison & Gettelman 2008; Gettelman et al. 2010

- Two-moment stratiform microphysics
  - Prognostic '*cloud mass*' and '*cloud droplet number*' (Γ-function size distributions)
  - Diagnostic 'precipitation mass' and 'precipitation droplet number'
  - Droplet and ice nucleation
  - Cloud microphysical processes (e.g., vapor deposition on ice crystals)

Morrison & Gettelman (2008)

q = mixing ratio
N = number concentration



Parameterizations of Ice Nucleation in CAM5

- *Liu and Penner (2005)*: consider the competition between homogeneous (HOM) and heterogeneous immersion nucleation (HET) (hereafter **LP**). HET based on classical nucleation theory (CNT).
- *Barahona and Nenes (2008a,b; 2009)*: develop a framework that can use different IN *nucleation spectra* (CNT, CFDC measured IN) for HET, and consider the competition of HOM and HET (hereafter **BN**).

BN-het based on Phillips et al. (2008) from CFDC

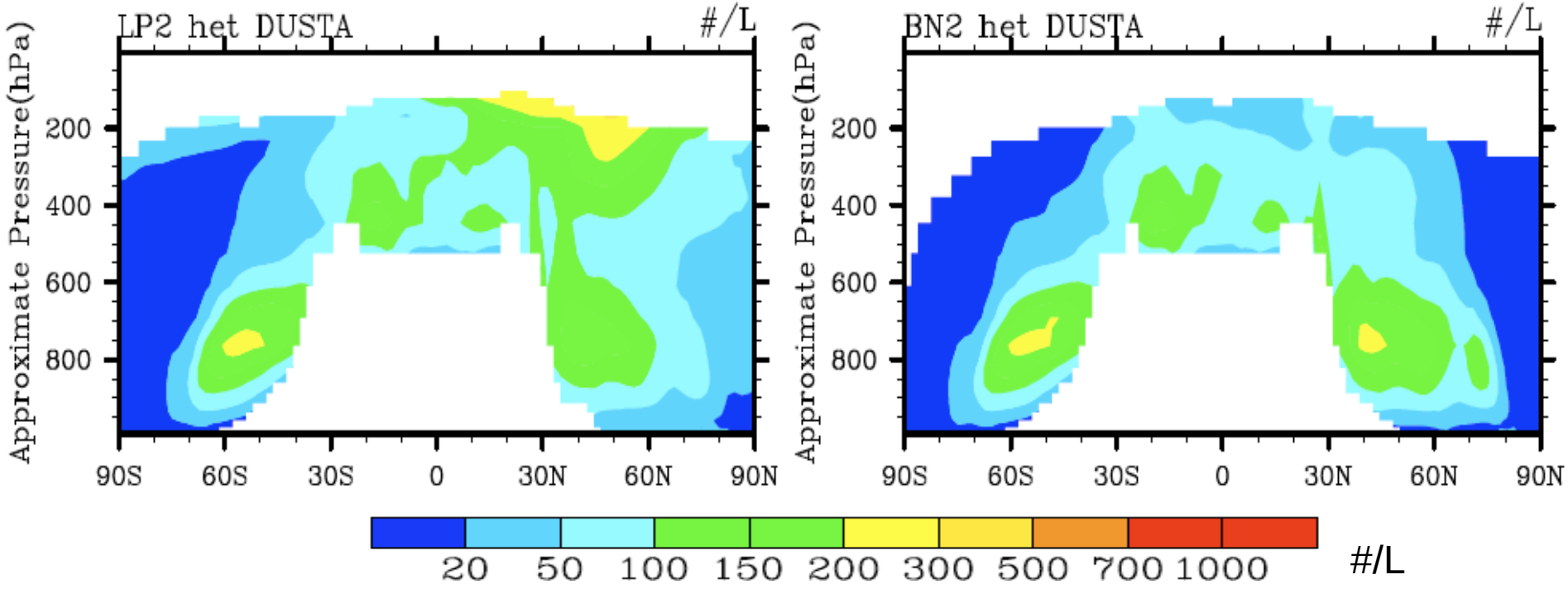
CAM5 Simulations

Case Name	Description
LP	LP2005, combined nucleation
LP-hom	LP2005, pure hom. nucleation
LP-het	LP2005, pure het. nucleation
BN	BN2009, combined nucleation
BN-hom	BN2009, pure hom. nucleation
BN-het	BN2009, pure het. nucleation

IN comparison between LP & BN scheme

LP-het

BN-het



LP-het based on classical nucleation theory

BN-het based on Phillips et al. (2008)

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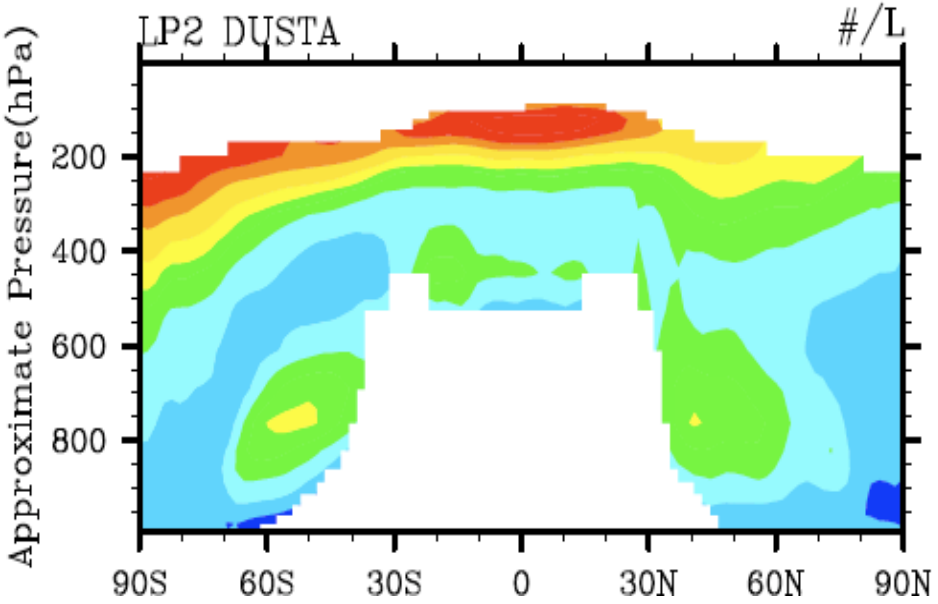
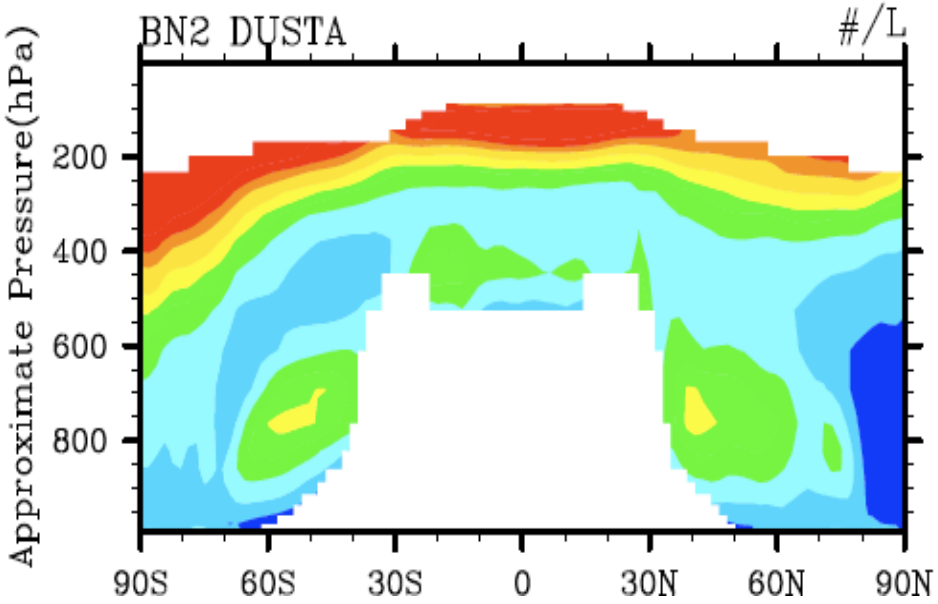
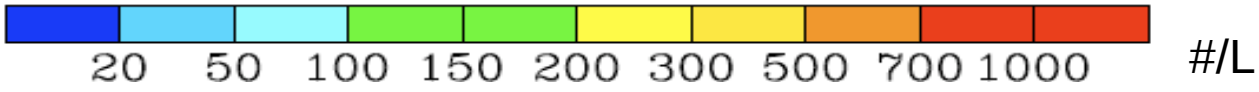
Comparison between LP and BN scheme

LP



BN





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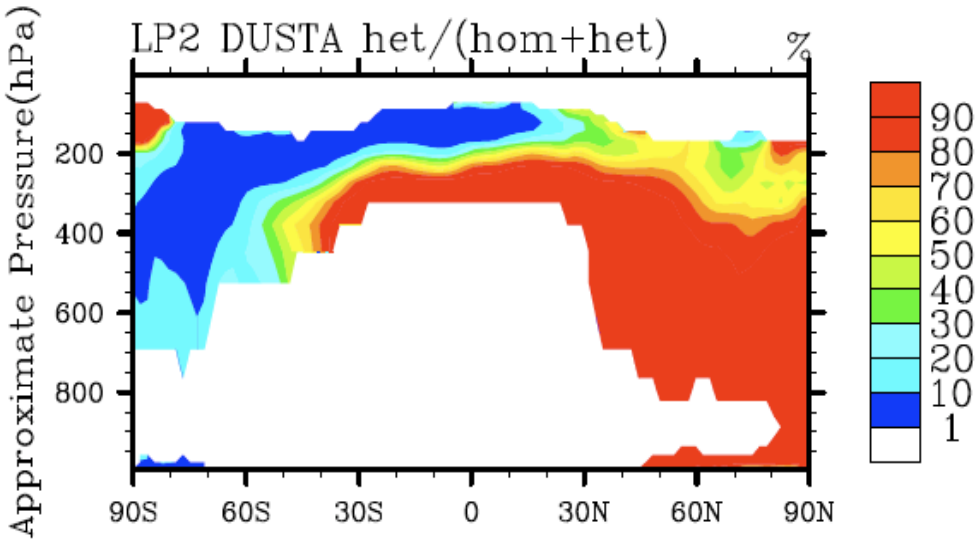
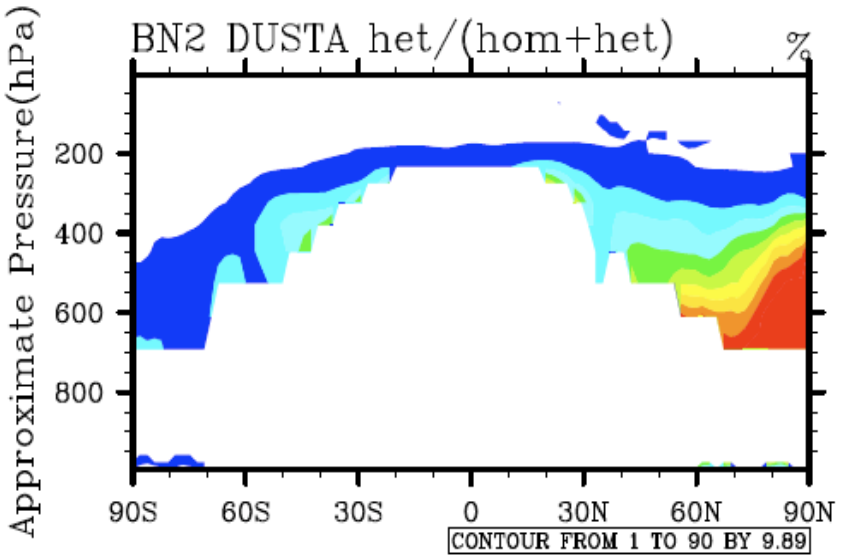
Comparison between LP and BN scheme

LP



BN



Relative contribution of Ni from homogeneous and heterogeneous nucleation in the combined case (LP and BN)

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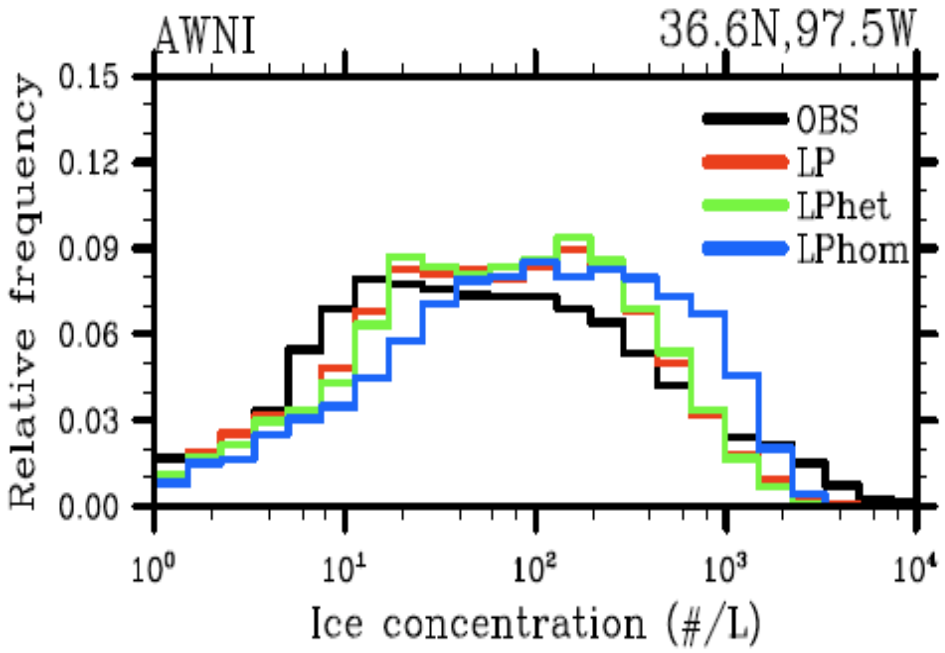
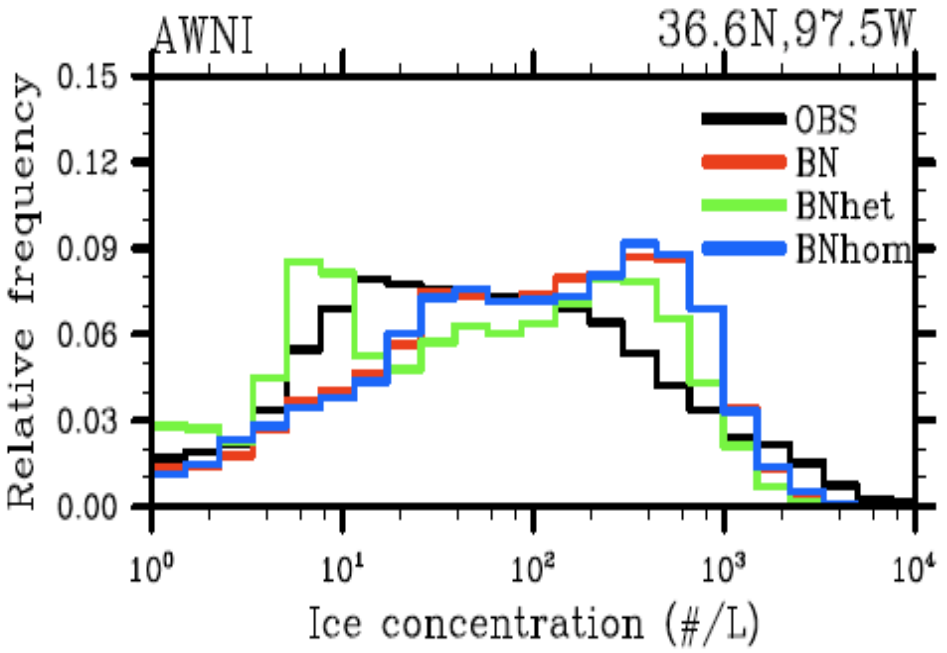
PDF(Ni)

LP



BN



LP and BN in comparison with SPartiCus data (cirrus clouds measurement over SGP site, Jan.-June 2010)

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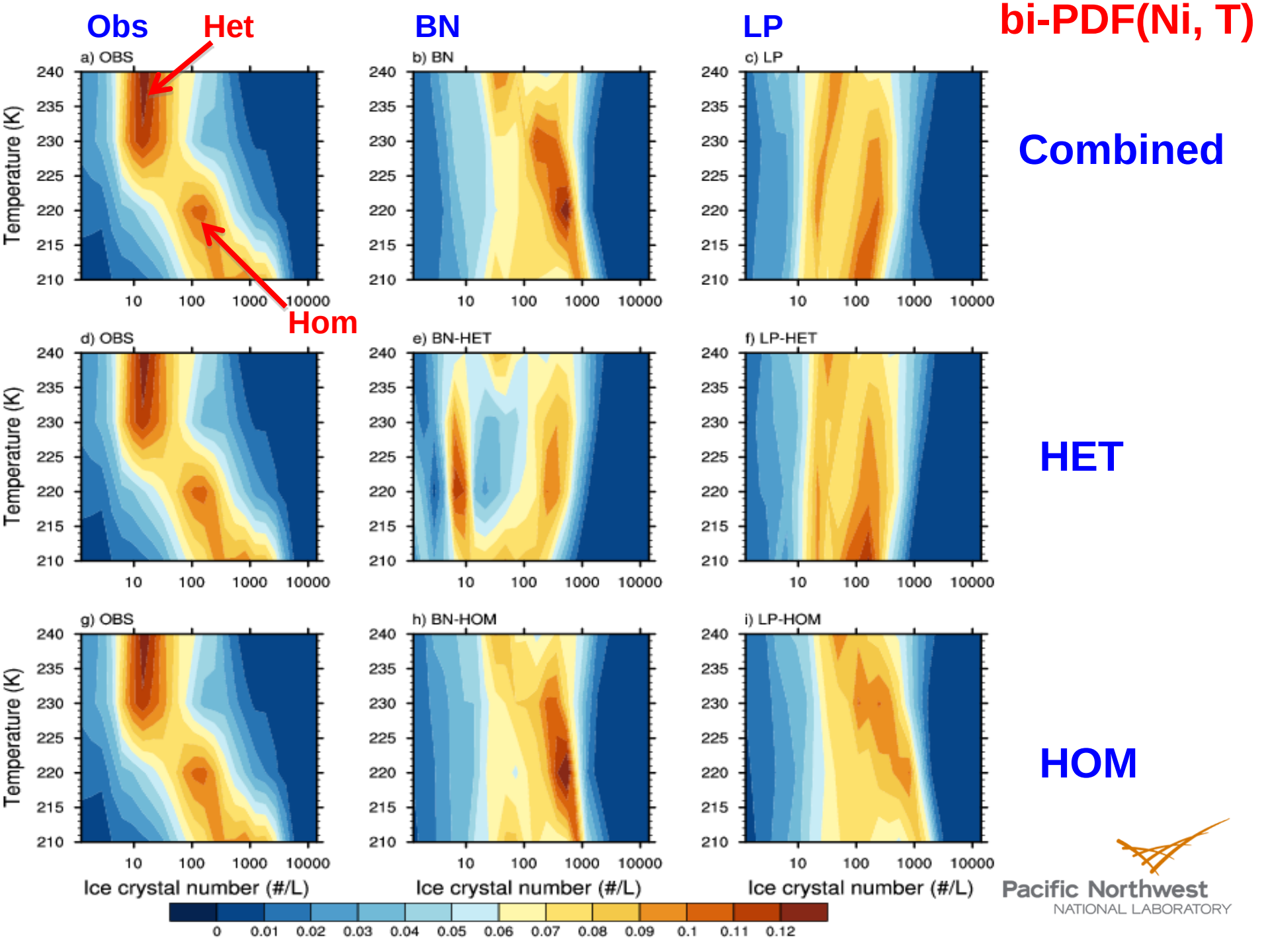
bi-PDF(Ni, T)
Obs
Het
BN
LP
Hom
Combined
HET
HOM
a) OBS
b) BN
c) LP
d) OBS
e) BN-HET
f) LP-HET
g) OBS
h) BN-HOM
i) LP-HOM
Temperature (K)
Ice crystal number (#/L)
240
235
230
225
220
215
210
10
100
1000
10000
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
0.11
0.12
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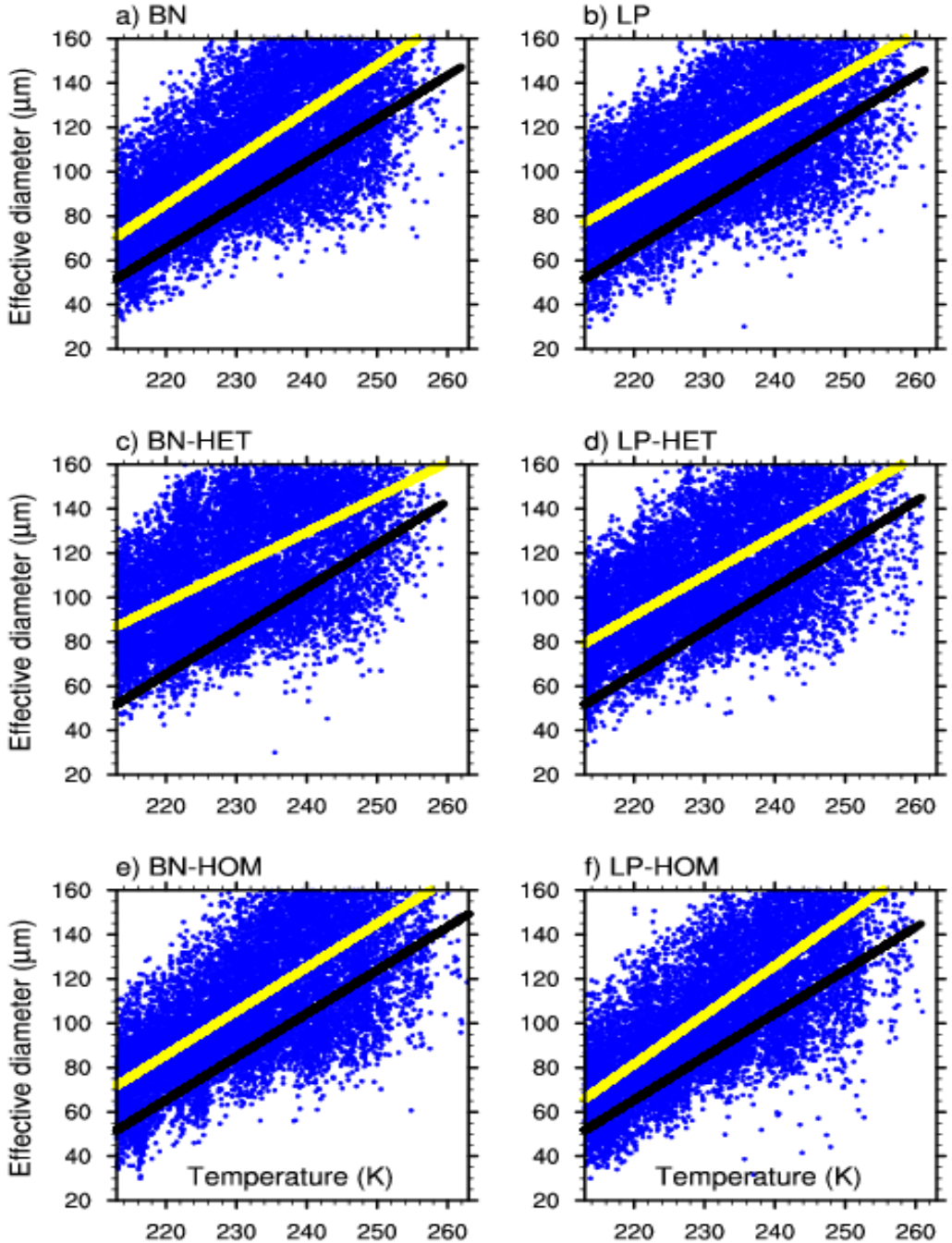
BN LP



$D_{eff} \sim T$

D_{eff} = 169.0871 + 1.9513 T
(D. Mitchell)

Combined

HET

HOM

LWCF in CAM5 is 20 W/m2 compared to CERES of 29 W/m2. need to evaluate IWC.

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Next Plan

X. Liu, J. Comstock, M. Wang

- Continue evaluation of CAM5 ice microphysics (ice fall speed, subgrid water vapor and vertical velocity) with SPartiCus data.
- Continue investigation of ice nucleation mechanisms and relationship to cirrus cloud properties.
- Improve cirrus macrophysics in CAM5 by implementing a statistics PDF cloud scheme (Wang and Penner 2009) and coupled with cirrus microphysics, and further evaluation with SPartiCus data.