# Evaluating and Constraining Ice Cloud Parameterizations in CAM5 with Observations

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# Motivation

- There are still large uncertainties in our understanding of ice cloud properties and processes and their treatments (parameterizations) in climate models.
- Ice crystal properties, e.g.,
  - Size distribution
  - Number and mass concentrations
  - Shape, density
- Ice microphysics processes, e.g.,
  - Ice nucleation (large uncertain)
  - Autoconversion of cloud ice to snow (one big knob in the model tuning)
- The goal of this study is to evaluate and constrain ice microphysics parameterizations in CAM5 using observations.

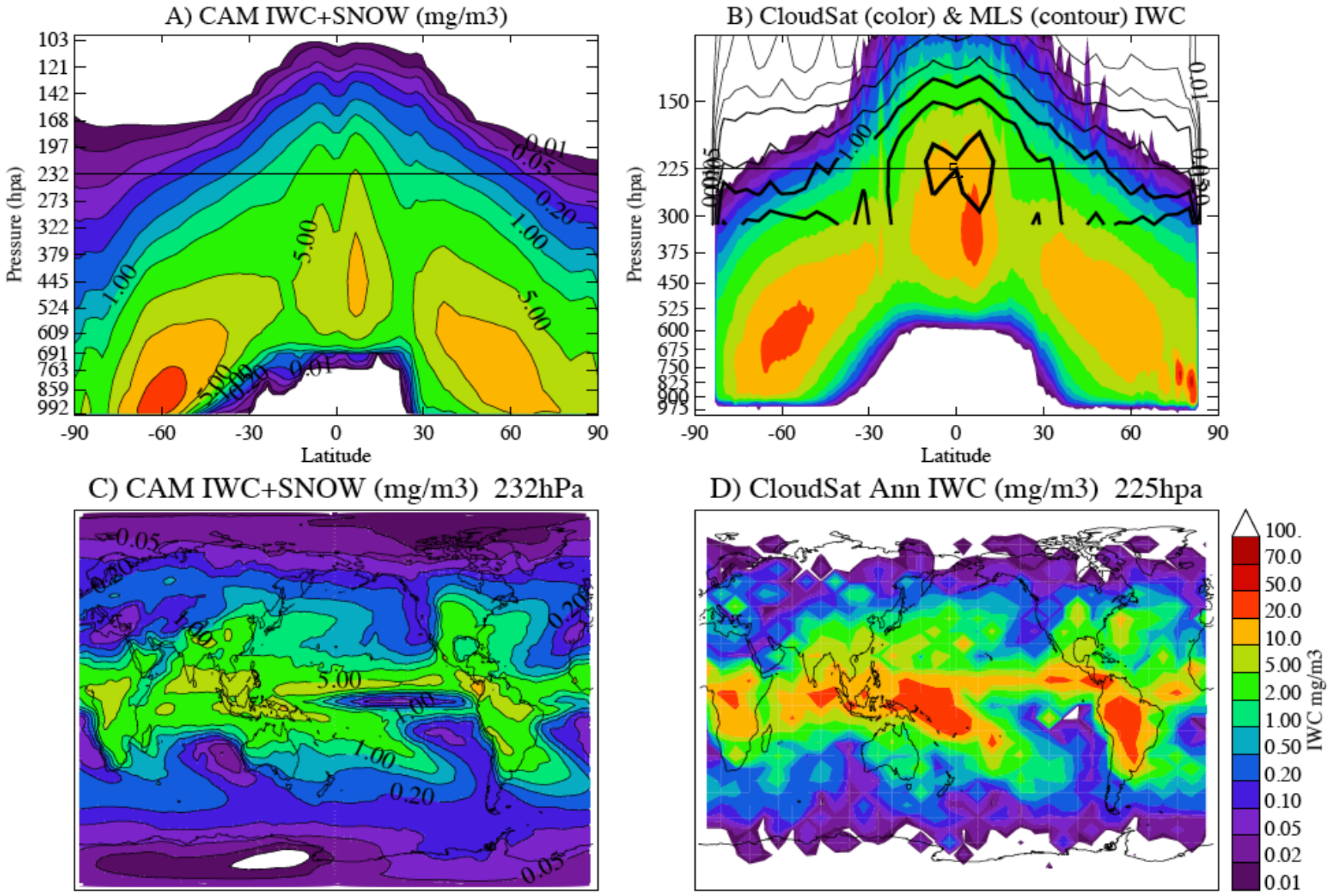
# Cloud Microphysics Scheme in CAM5

***Morrison & Gettelman 2008; Gettelman et al. 2010***

- Two-moment stratiform microphysics
  - Prognostic mass and number of cloud liquid and cloud ice ( $\Gamma$-function size distributions )
  - Diagnostic mass and number of rain and snow
  - Droplet and ice nucleation links to aerosols
  - Ice supersaturation and explicit vapor deposition
  - Other ice microphysics processes: autoconversion, accretion, sedimentation, sublimation, melting, etc.

# Evaluation of current CAM5 ice microphysics with satellite observations

# Ice Mass vs. CloudSat

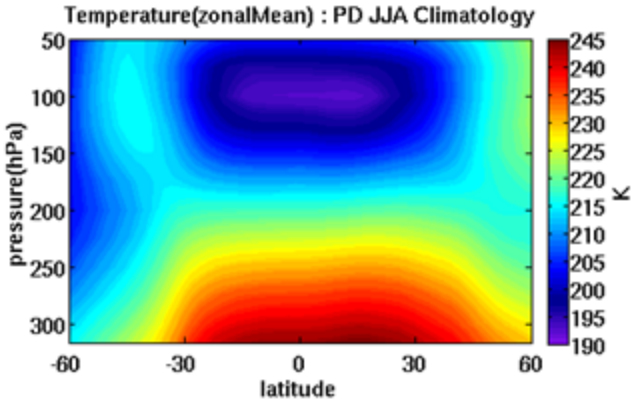



Gettelman et al 2010, JGR

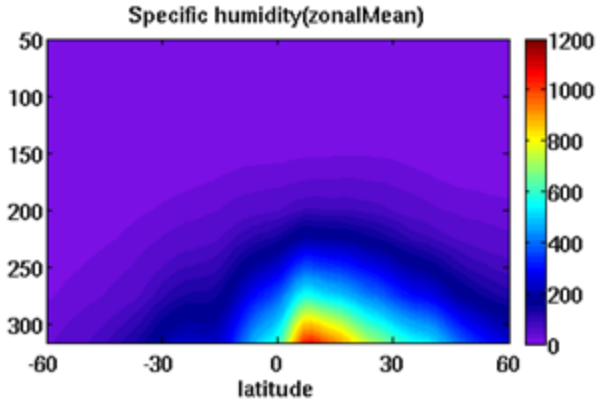
# Comparison of Zonal-Means with Aura MLS

## CAM5 JJA Climatology

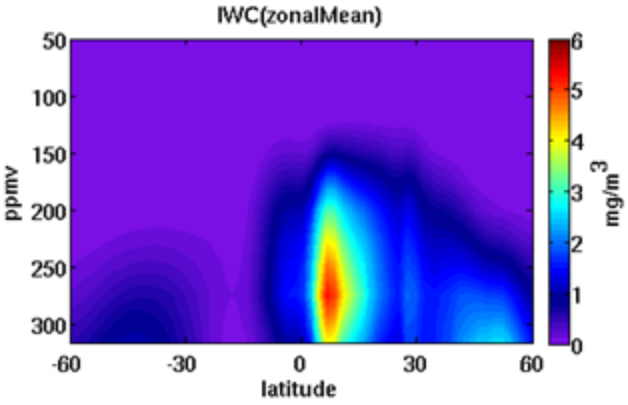
T



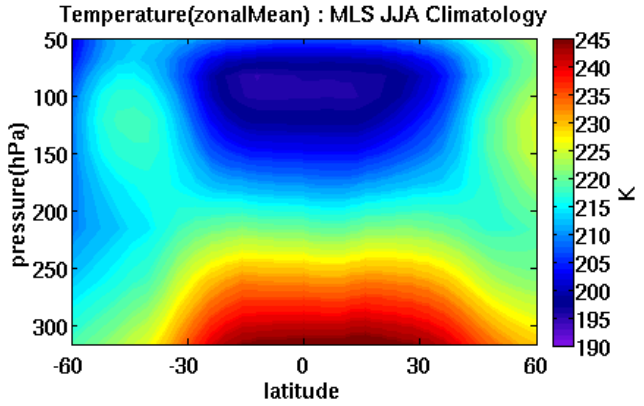

H2O

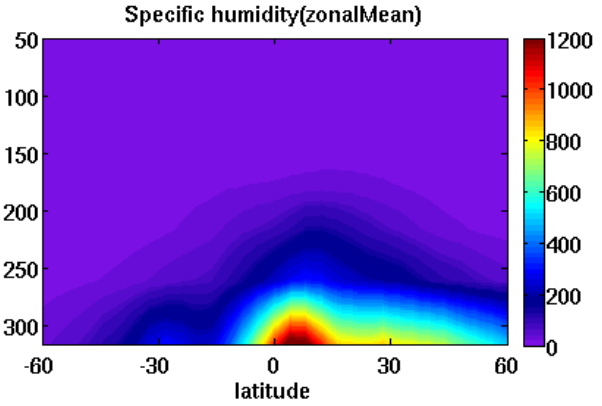


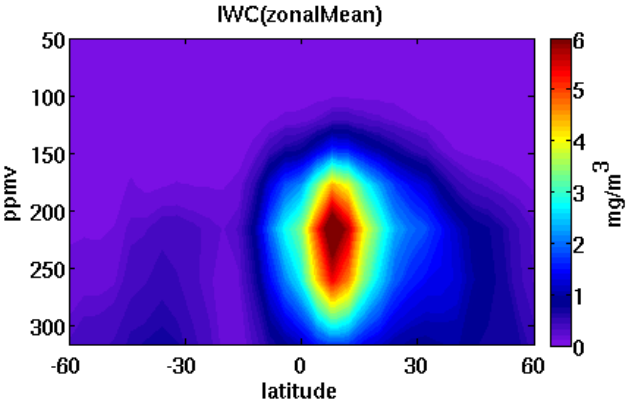

IWC




## MLS JJA Climatology



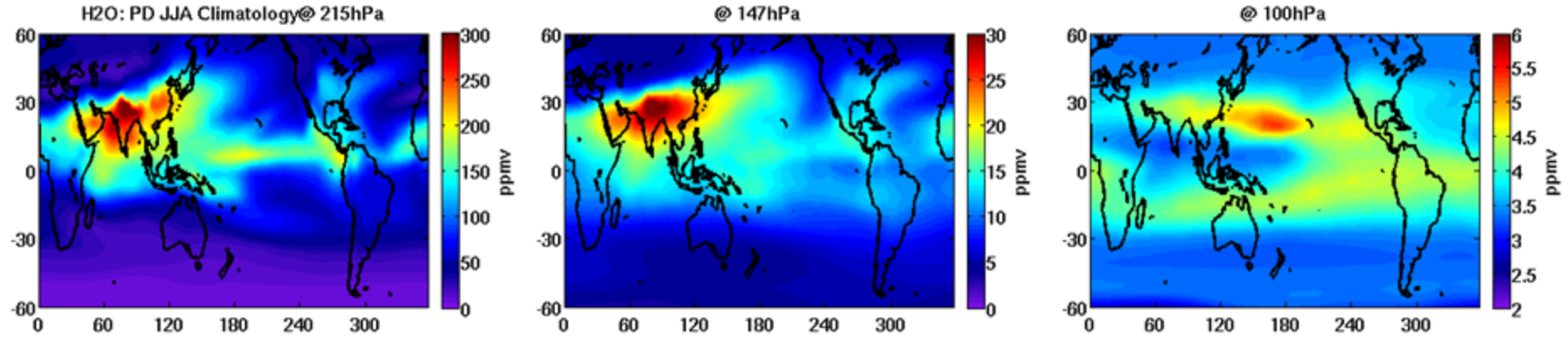




- CAM5 simulates well the UTLS regions. The magnitude of modeled IWC is smaller than observed.

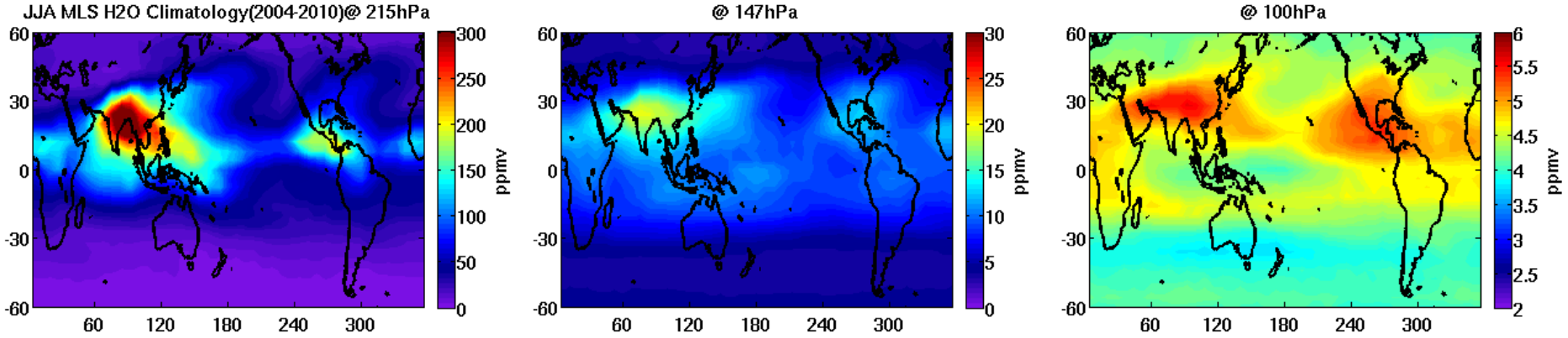
Su et al. (2011)

# Comparison of $H_2O$ with Aura MLS

## CAM5 $H_2O$ JJA Climatology




## MLS $H_2O$ JJA Climatology

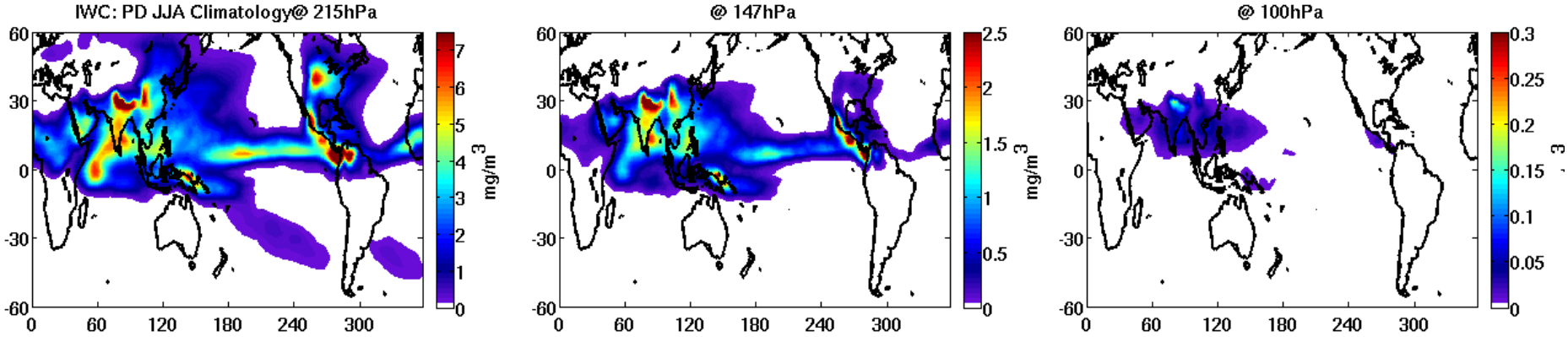



- The simulated $H_2O$ at 215 hPa is similar to the observation. The model is biased wet at 147 hPa but dry at 100 hPa.

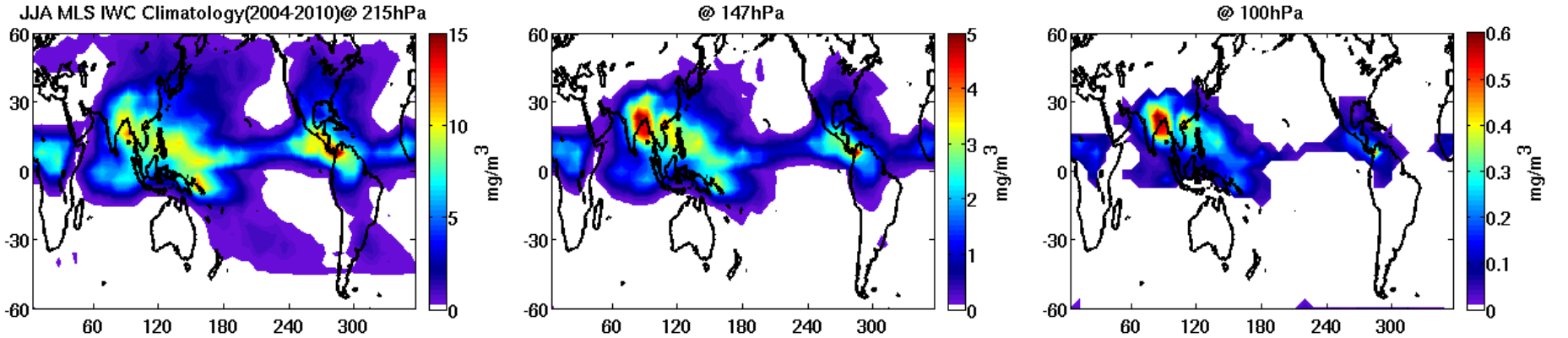
Su et al. (2011)

# Comparison of IWC with Aura MLS

## CAM5 IWC JJA Climatology




## MLS IWC JJA Climatology




- The cloud ice simulations are fairly good. Modeled IWC is biased low by a factor of ~2.

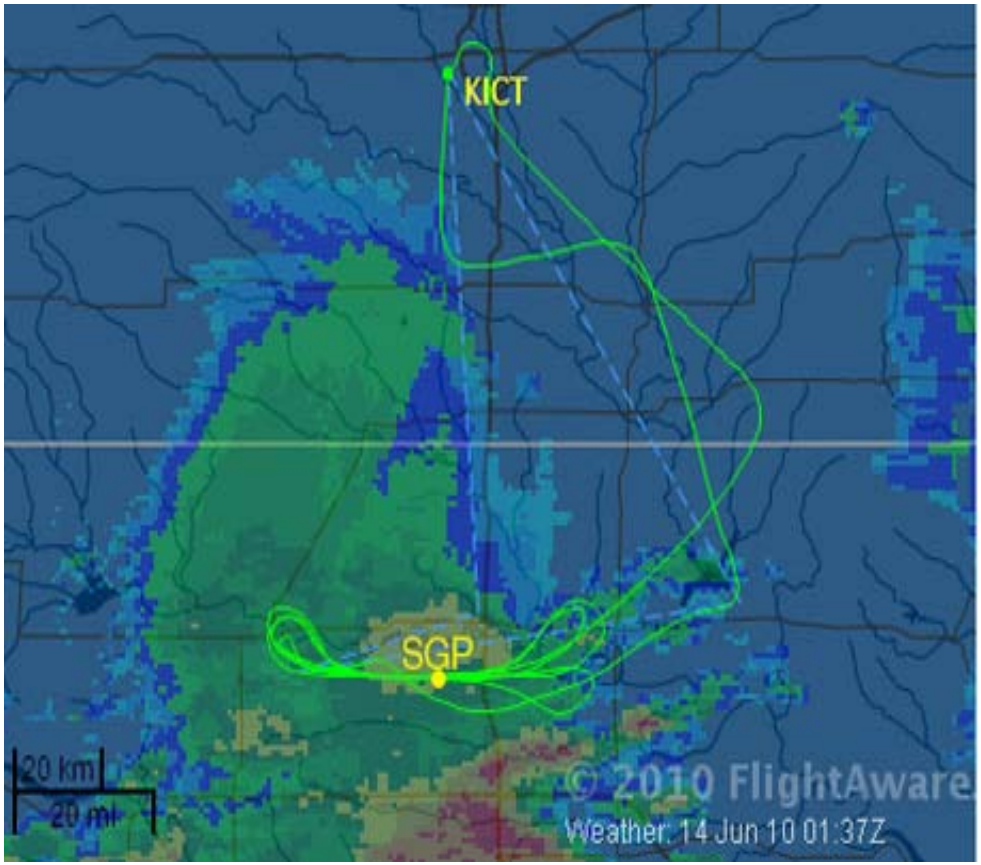
Su et al. (2011)

# Evaluation of CAM5 ice microphysics with in situ observations

# SPartICus: Small Particles In Cirrus Jan-June 2010

**Routine aircraft in situ measurements in cirrus over ARM SGP and along NASA A-Train orbit**

- Evaluate modeled statistics of Ni, IWC, RH, etc.
- Constrain the formation mechanism of ice crystals
- Constrain the aggregational growth of ice crystals




**Anvil Investigation over the ARM SGP on 14 June 2010**

new generation of probes designed to minimize artifacts due to ice shattering; relatively long-term statistics (~150 hours)

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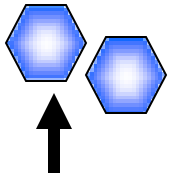
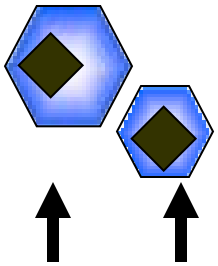
# Cirrus (Ice) Ice Nucleation

**Ice Crystal Population**





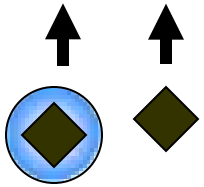
**Homogeneous Freezing**

Mainly depends on $RH_i$ and $T$

**Heterogeneous Freezing** (Immersion, deposition, …)

Also depends on the material and surface area

**Wet aerosol particles**

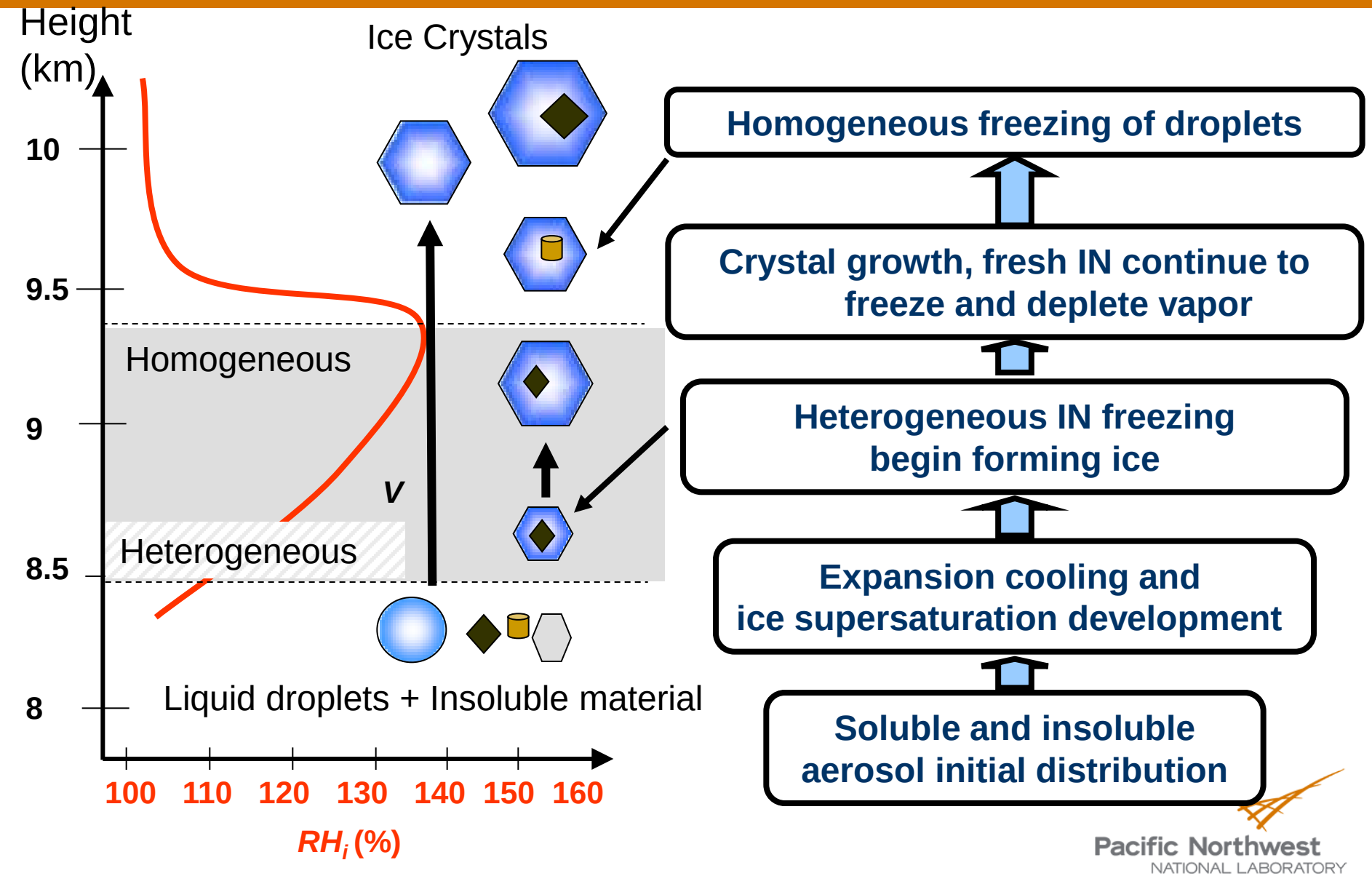


**+ Insoluble Material ("Ice Nuclei")**

*Multiple* mechanisms for ice formation can be active.


Courtesy of Barahana & Nenes

# Conceptual Model of Ice Formation in Cirrus




Courtesy of Barahana & Nenes

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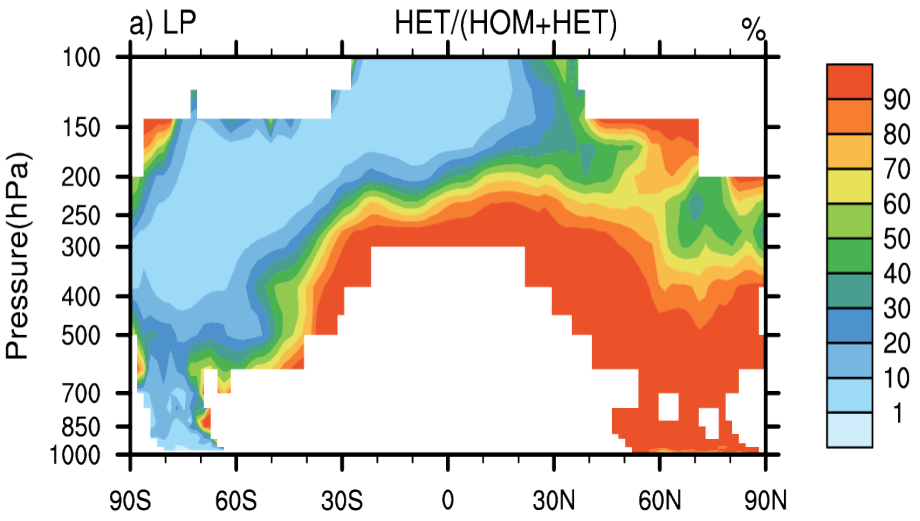
# Ice Nucleation Parameterizations in CAM5

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

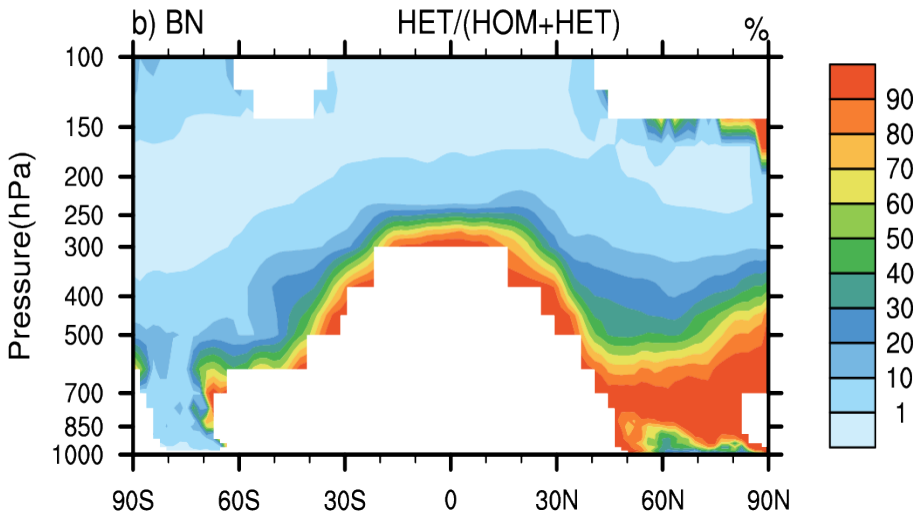
BN-HET uses Phillips et al. (2008) from CSU CFDC

# Comparison between LP and BN scheme

## LP



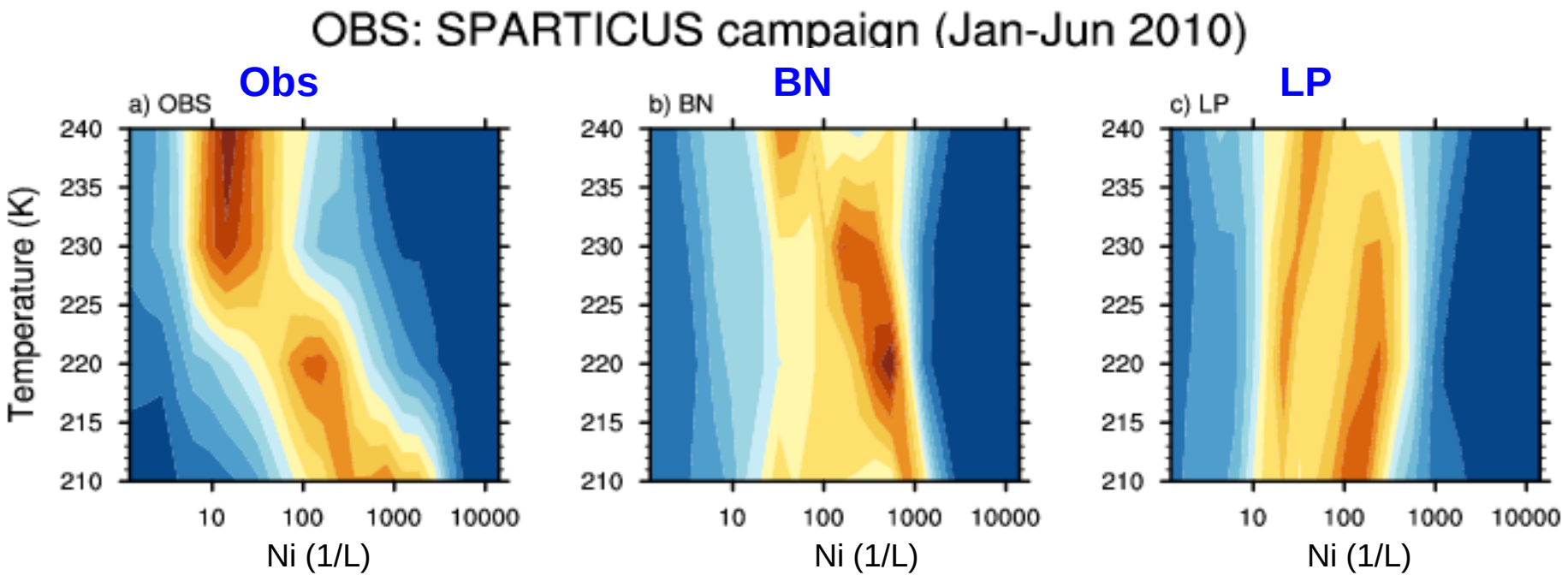

## BN




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

BN: het based on Phillips et al. (2008) from CFDC
LP: het based on classical nucleation theory

# bi-PDF (Ni, T)




Model outputs every 3 hours over SGP site

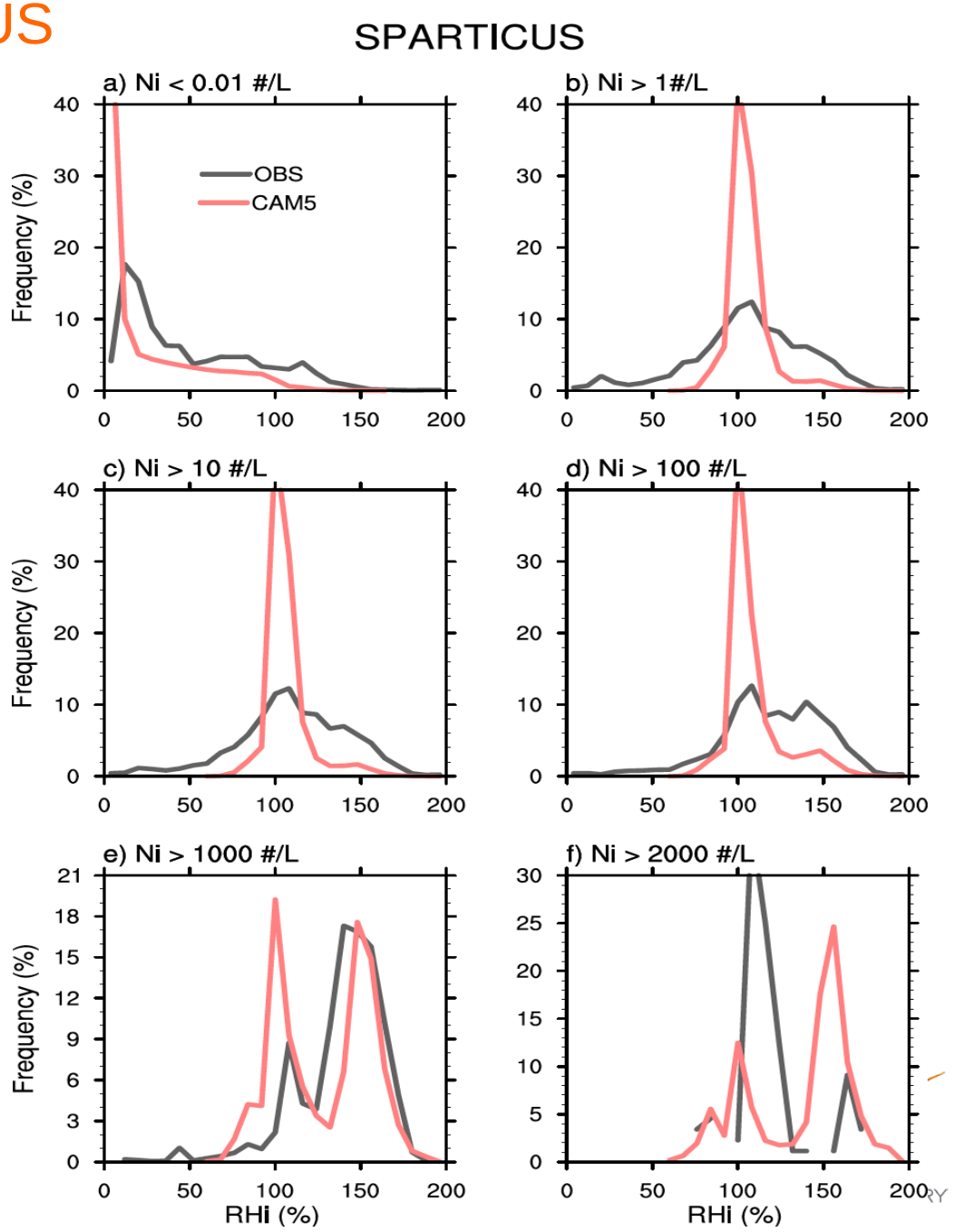
# RHi PDF during SPARTICUS

Simulated RHi peaks at 100% with smaller standard deviation

Very high supersaturation when Ni > 1000 #/L in both OBS and CAM5

BN with Philips et al. (2008)

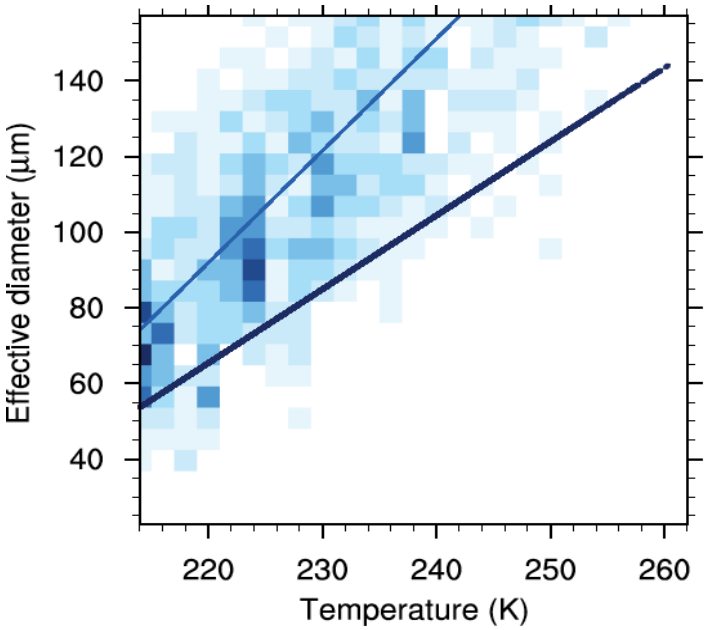
OBS data from DRH from January to June 2010



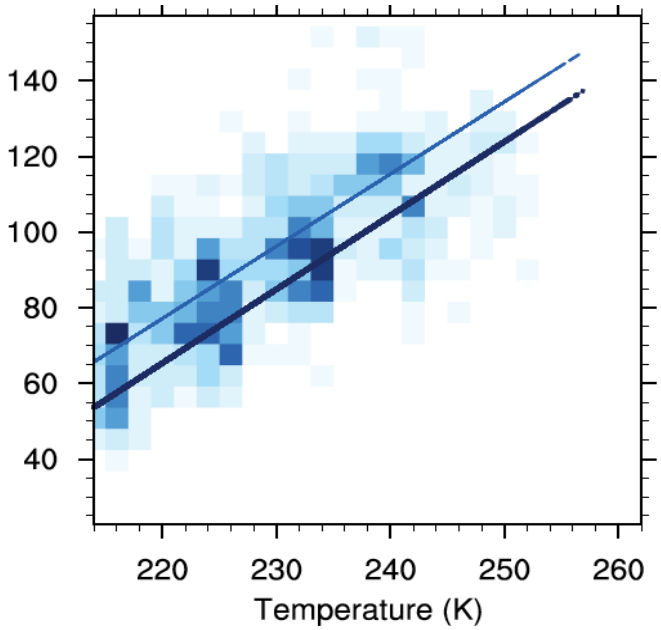
# Sensitivity to autoconversion rate from ice to snow (Dcs: threshold size)

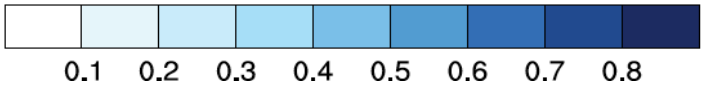
**$D_{eff}$ = 169.0871 + 1.9513 T (D. Mitchell)**

Dcs = 400 um (CAM5.1)




Dcs = 250 um (original MG)

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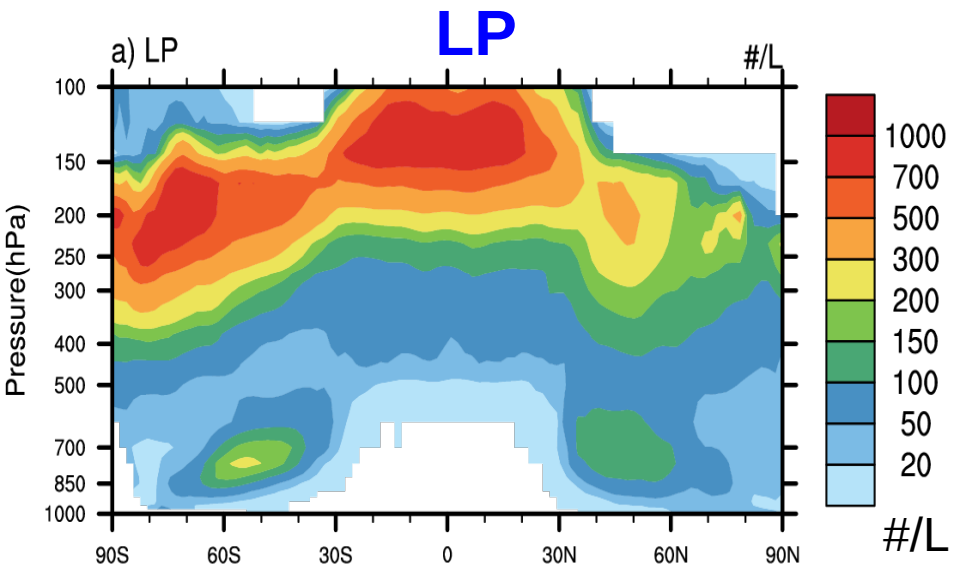
# Summary

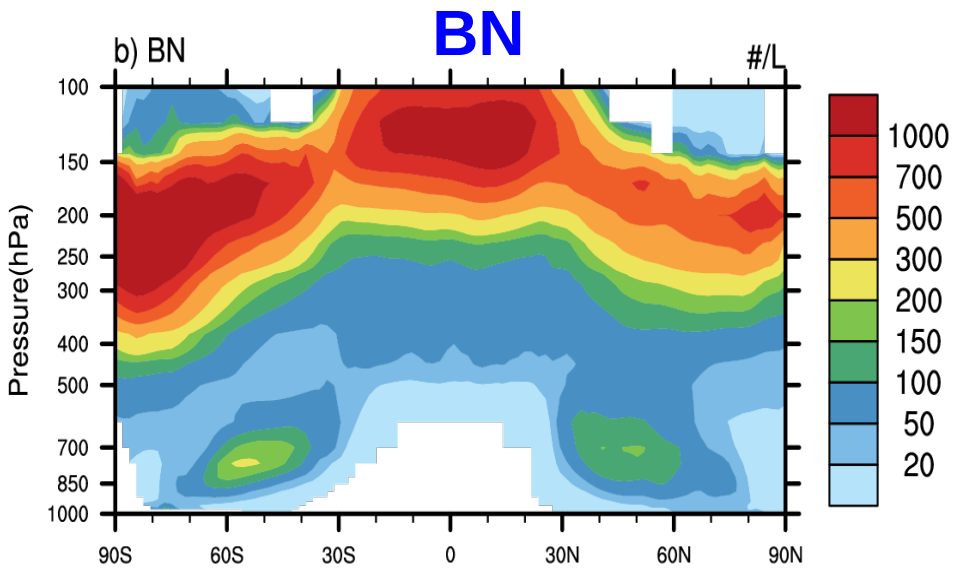
- CAM5 reasonably captures the spatial distributions of IWC, H2O in UTLS. However, The model is biased wet at 147 hPa but dry at 100 hPa. It underestimates IWC by a factor of ~2.
- Homogeneous nucleation may dominate ice nucleation in cirrus clouds at T < -40 C over SGP site during the SPartICus.
- CAM5 reproduces some statistical features of Ni vs T, RHi PDF observed during the SPartICus. However, it
  - Overestimate frequency of occurrence of high Ni (>100/L)
  - Underestimate frequency of occurrence of low Ni (<30/L)
  - Aggregation growth of cloud ice too slow (Dcs ~ 400 um), consistent with Reff vs. T relationship
  - In-cloud RHi PDF too narrow (subgrid variability)

# Comparison of Ni between LP and BN scheme

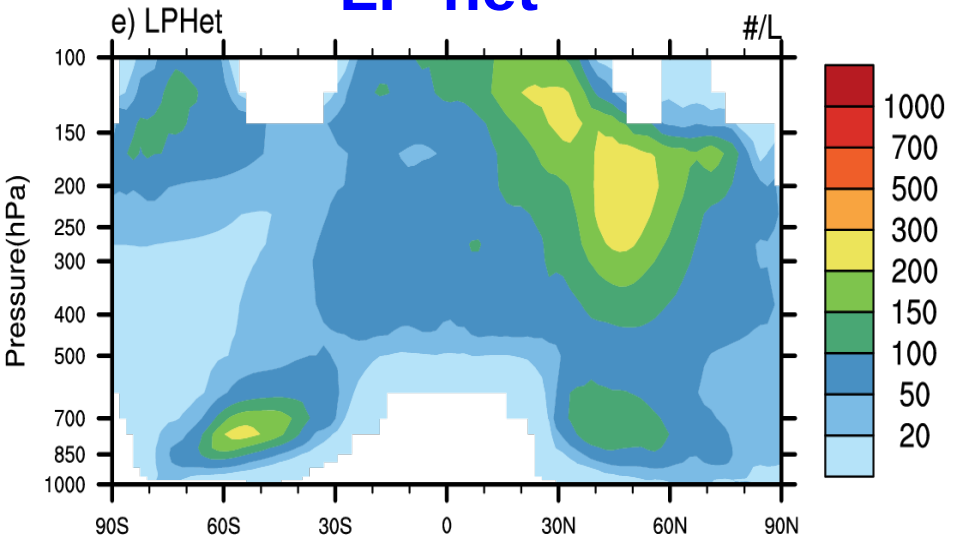
## LP



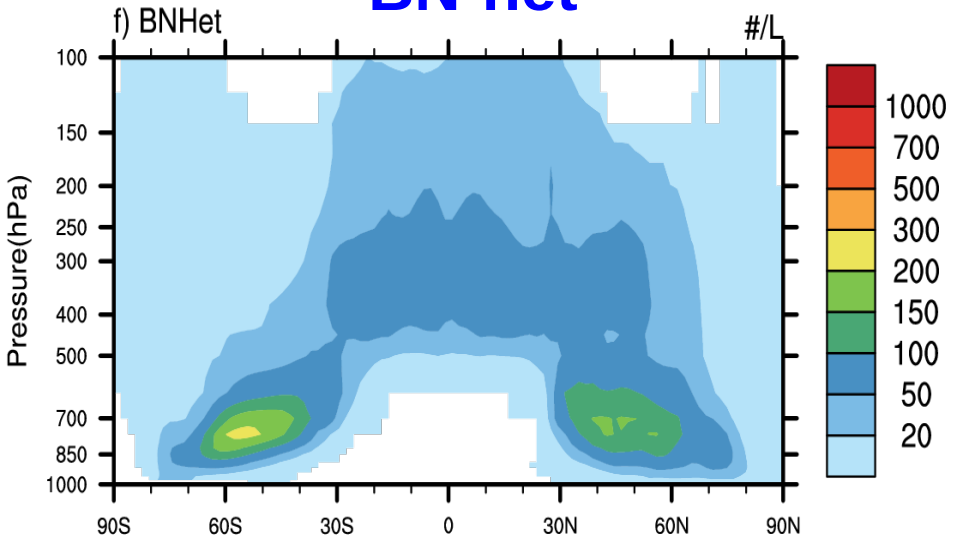

## BN




## LP-het

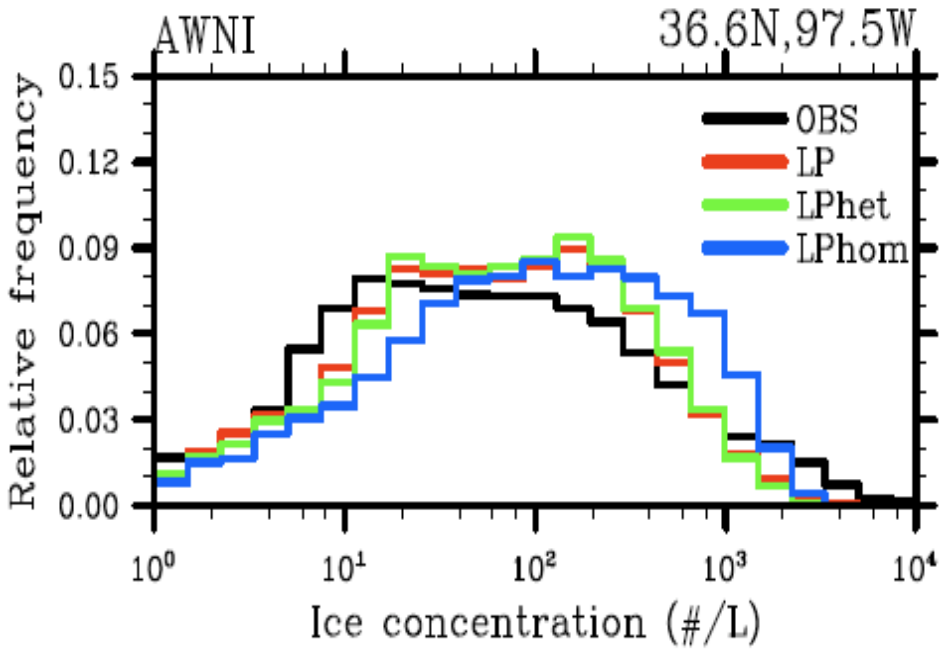



## BN-het

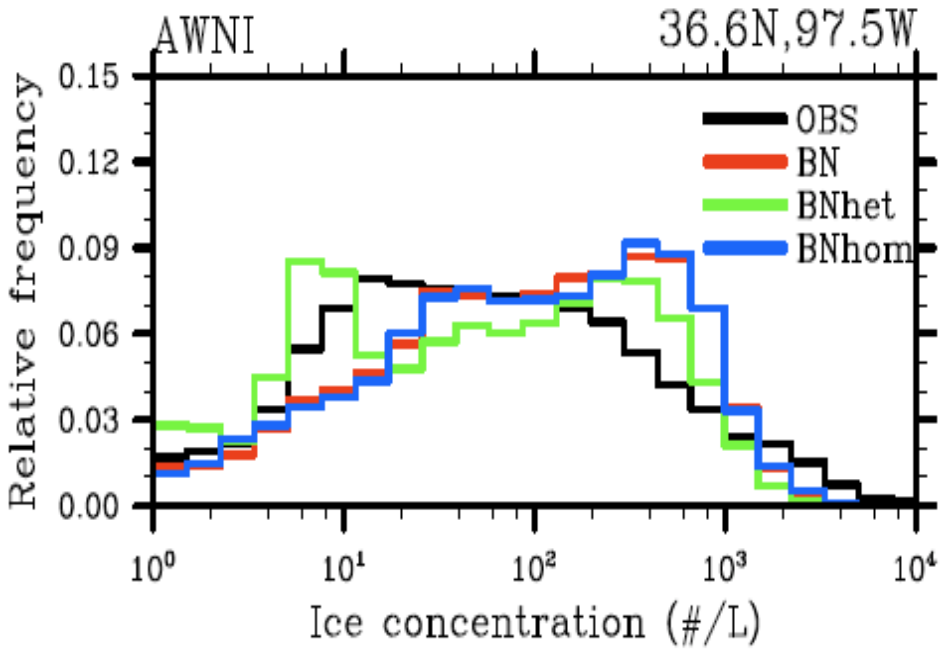


# PDF(Ni)

**LP**

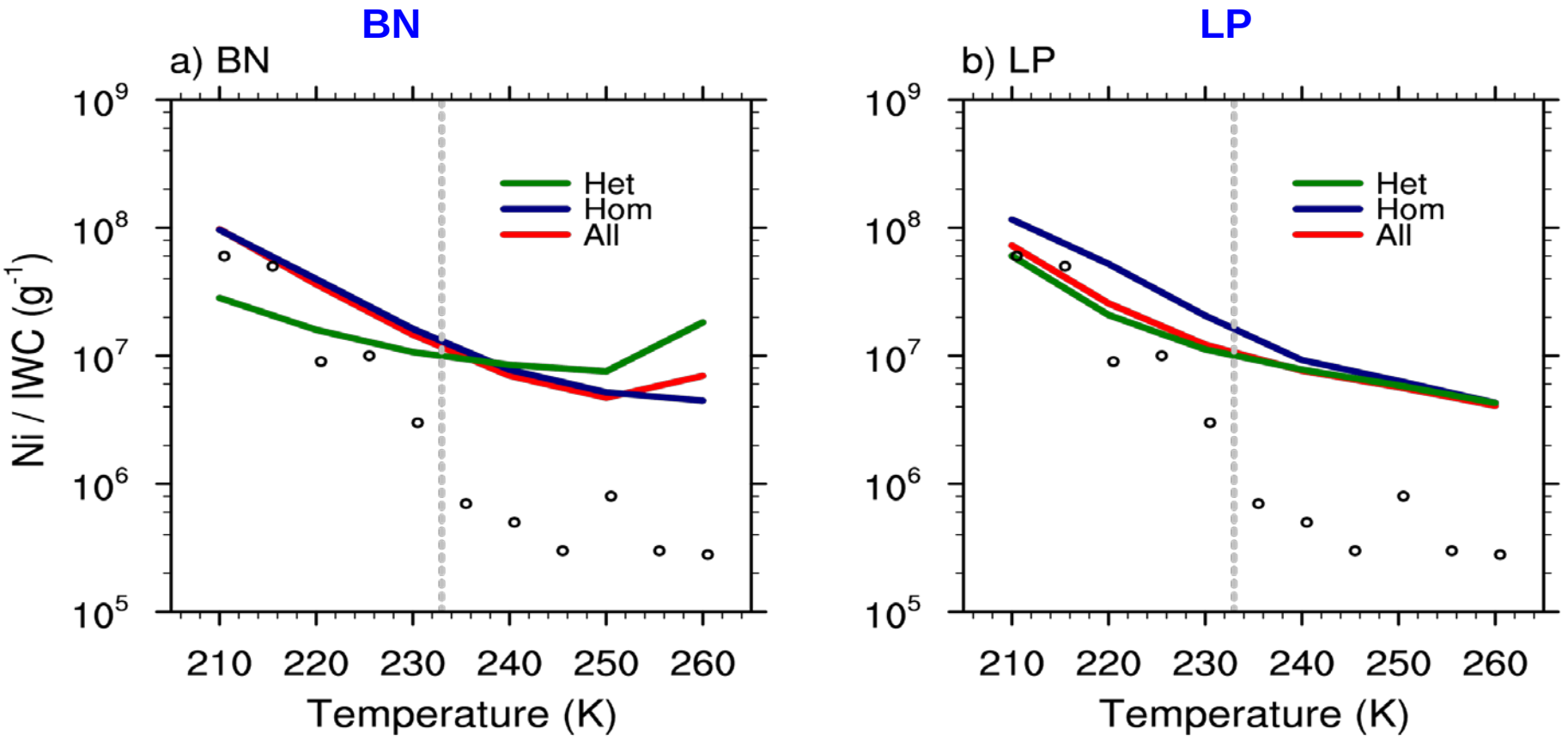



**BN**



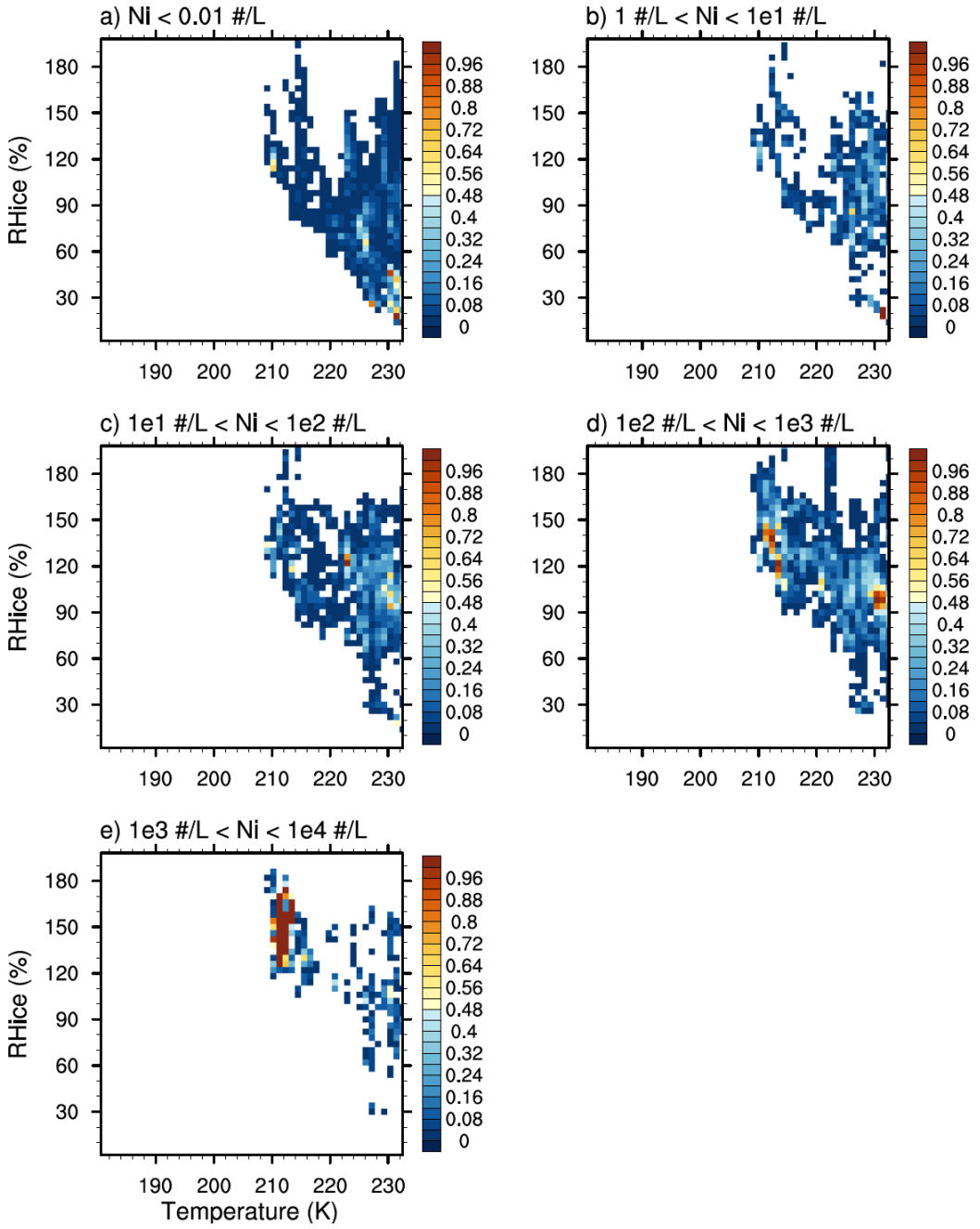

Comparison of CAM5 simulations with SpartiCus data (cirrus clouds measurement over SGP site, Jan.-June 2010)

# $N_i$ / IWC vs T

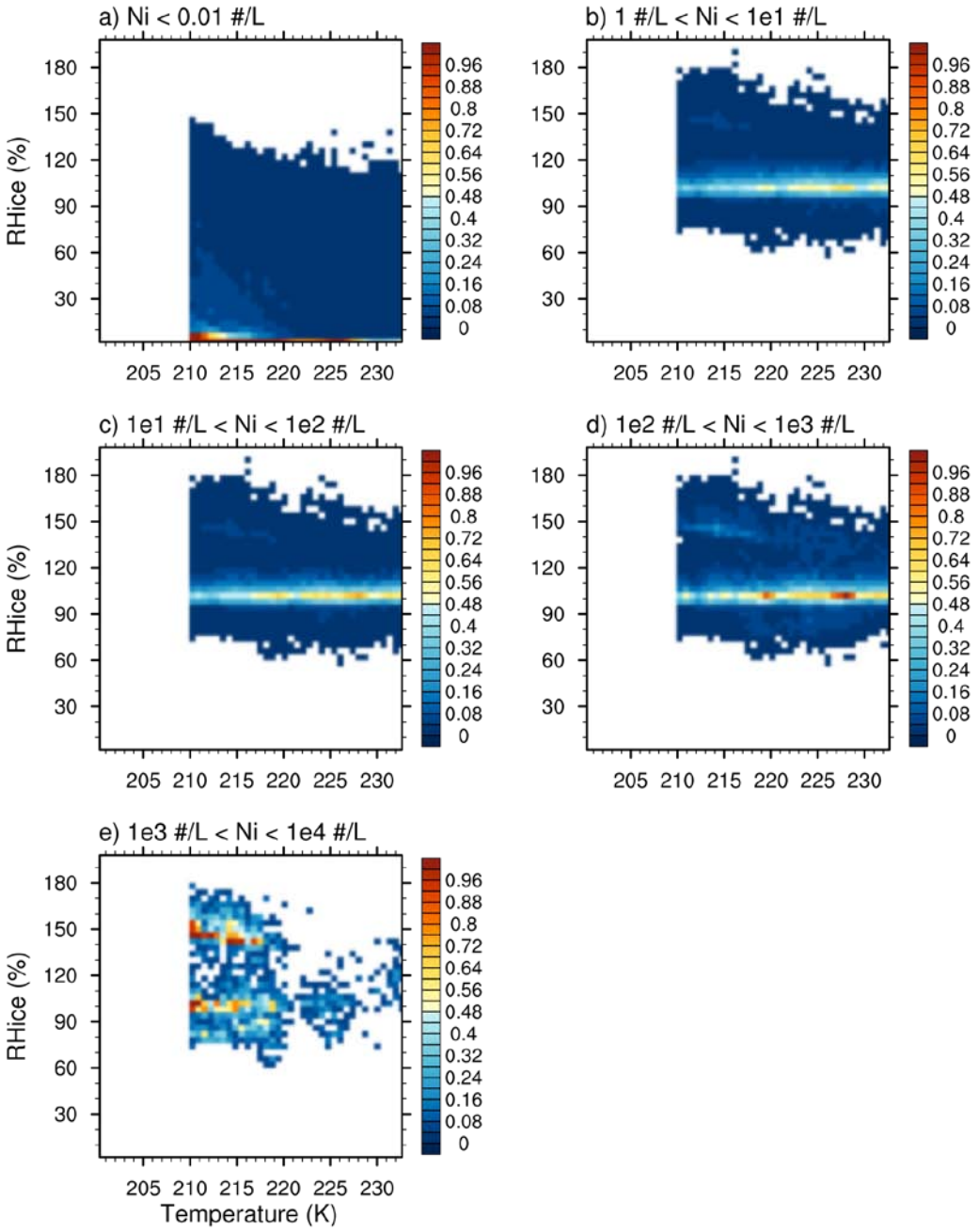

BN
LP
a) BN
b) LP
Het
Hom
All
Ni / IWC (g-1)
Temperature (K)
10^9
10^8
10^7
10^6
10^5
210
220
230
240
250
260

SPARTICUS OBS

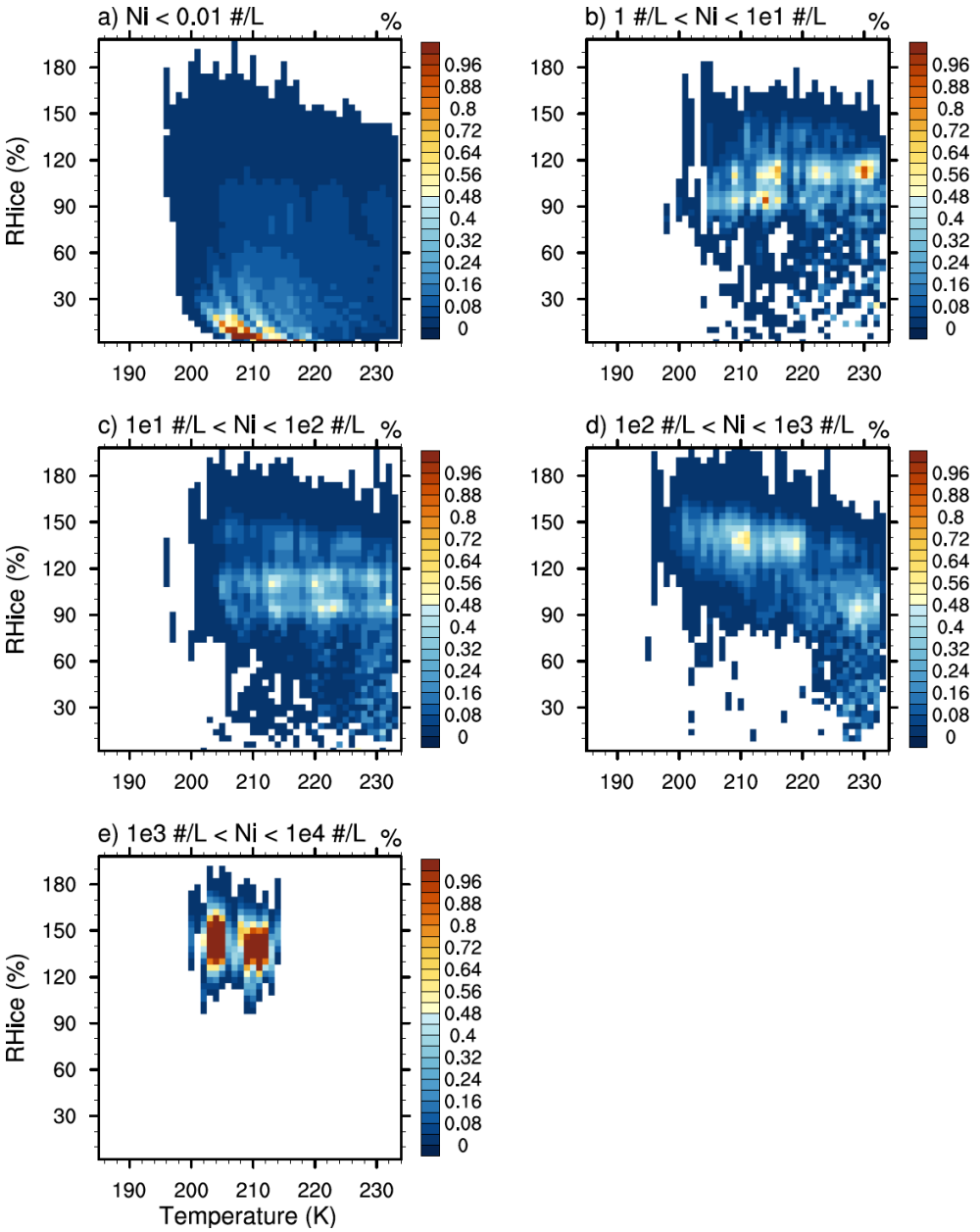
bi-PDF (RHi and T)

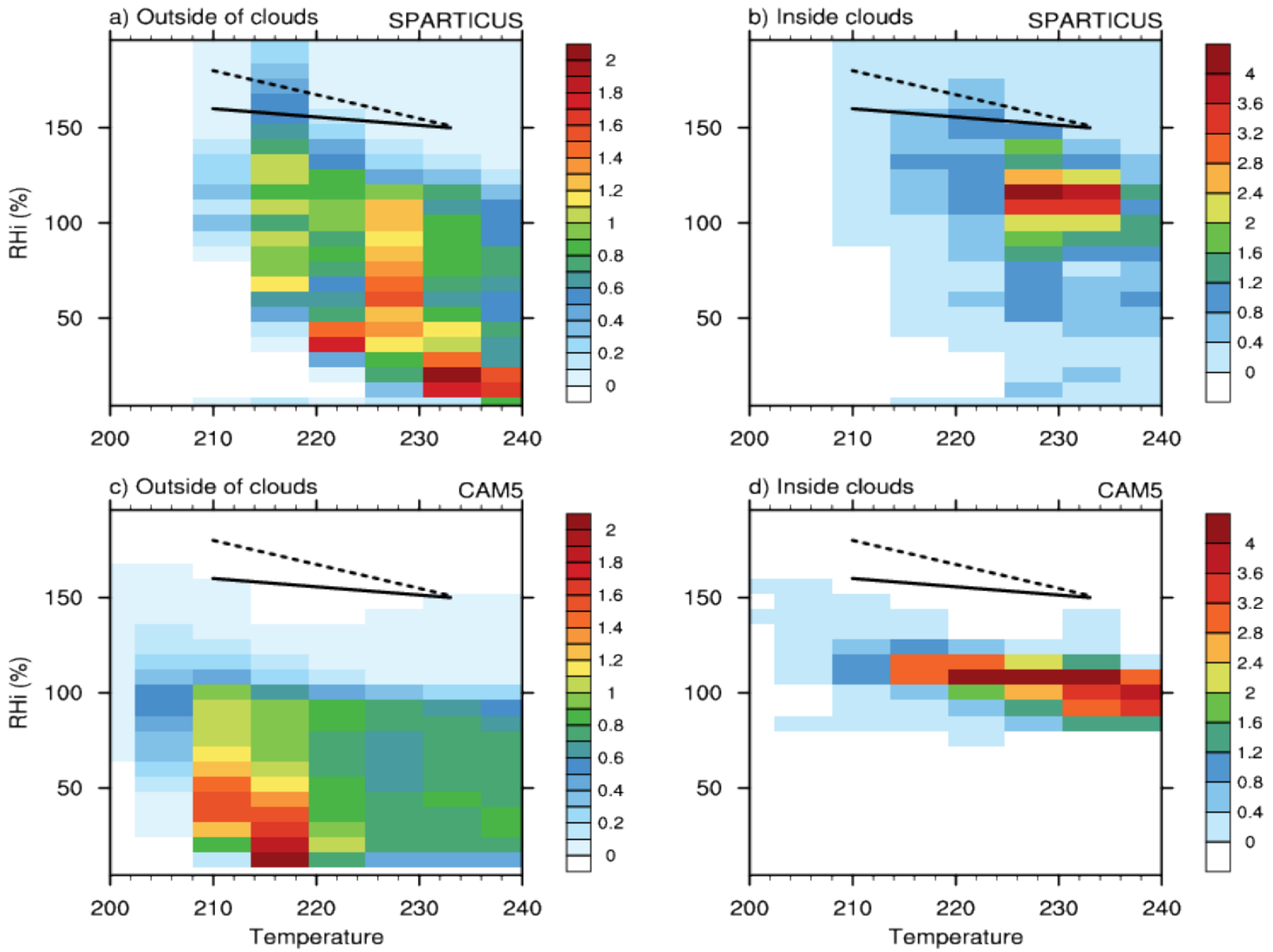


# SPARTICUS CAM5



**SPARTICUS**
**CAM5 -** with a statistical PDF cirrus macrophysics scheme (Karcher and Burkhardt 2008) and coupled with microphysics




a) Outside of clouds
SPARTICUS
b) Inside clouds
SPARTICUS
c) Outside of clouds
CAM5
d) Inside clouds
CAM5
RHi (%)
150
100
50
200
210
220
230
240
Temperature
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
4
3.6
3.2
2.8
2.4
2
1.6
1.2
0.8
0.4
0