Impacts of Heterogeneous Ice Nuclei on Cirrus Clouds and Climate in NCAR CAM5

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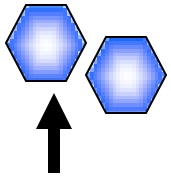
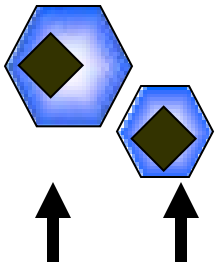
Introduction

- Homogeneous ice nucleation is relatively well understood, while there are still large unknowns on heterogeneous ice nuclei (IN) (properties and number concentrations)
- The goal of this study is to investigate the IN effects on cirrus clouds and climate using CAM5 with two ice nucleation parameterizations

Cirrus (Ice) Ice Nucleation

Ice Crystal Population





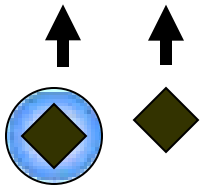
Homogeneous Freezing

Mainly depends on RH_i and T

Heterogeneous Freezing (Immersion, deposition, …)

Also depends on the material and surface area

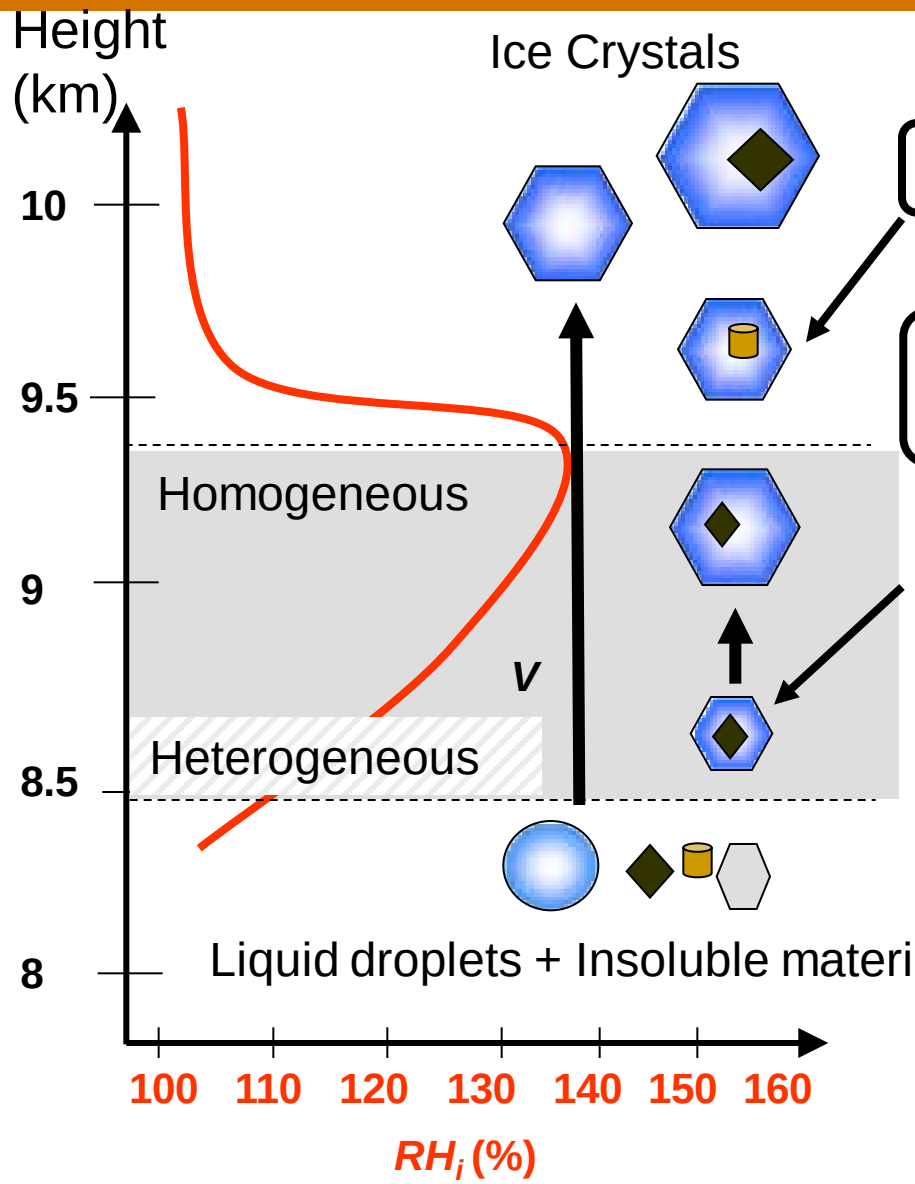
Wet aerosol particles



+ Insoluble Material ("Ice Nuclei")

Multiple mechanisms for ice formation can be active.

Conceptual Model of Ice Formation in Cirrus



Homogeneous freezing of droplets

Crystal growth, fresh IN continue to freeze and deplete vapor

Heterogeneous IN freezing begin forming ice

Expansion cooling and ice supersaturation development

Soluble and insoluble aerosol initial distribution

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Cloud Microphysics Scheme in CAM5

Morrison & Gettelman 2008; Gettelman et al. 2010

- 2-moment stratiform microphysics
  - Prognostic '*cloud mass*' and '*cloud droplet number*' (Γ-function size distributions)
  - Diagnostic 'precipitation mass' and 'precipitation droplet number'

- Ice-phase cloud microphysics
  - Ice crystal nucleation link to aerosols (Liu and Penner, 2005)
  - Allow ice supersaturation (Liu et al., 2007)

Parameterizations of Ice Nucleation in CAM5

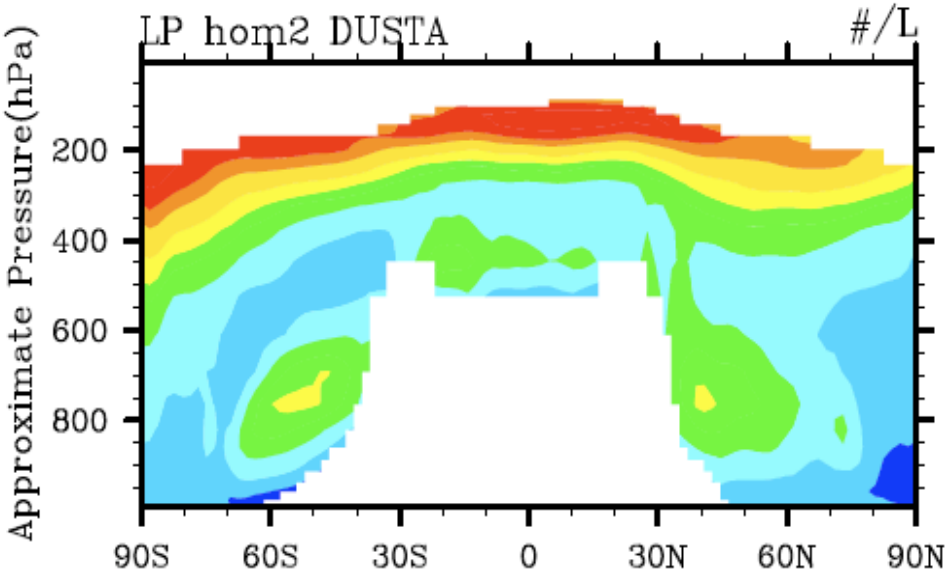
- *Liu and Penner (2005)*: consider the competition between homogeneous (HOM) and heterogeneous immersion nucleation (HET) (hereafter **LP**). HET based on classical nucleation theory (CNT).
- *Barahona and Nenes (2008a,b; 2009)*: develop a framework that can use different IN *nucleation spectra* (CNT,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

CAM5 Simulations

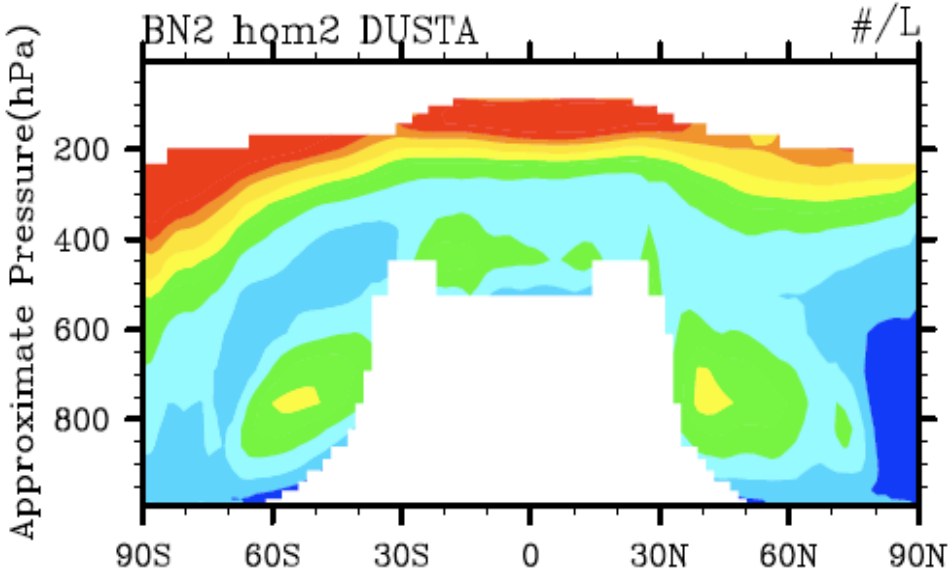
Case Name	Description
LP	LP2005, combined nucleation
LP-hom	LP2005, pure hom. nucleation
LP-het	LP2005, pure het. nucleation
BN	BN2009, combined nucleation
BN-hom	BN2009, pure hom. nucleation
BN-het	BN2009, pure het. nucleation

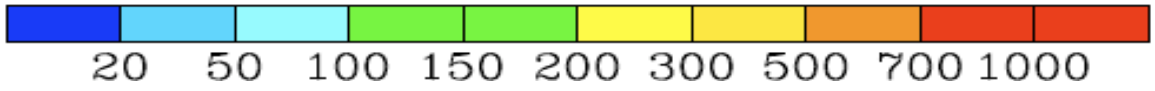
Comparison between LP and BN scheme

LP-hom



BN-hom





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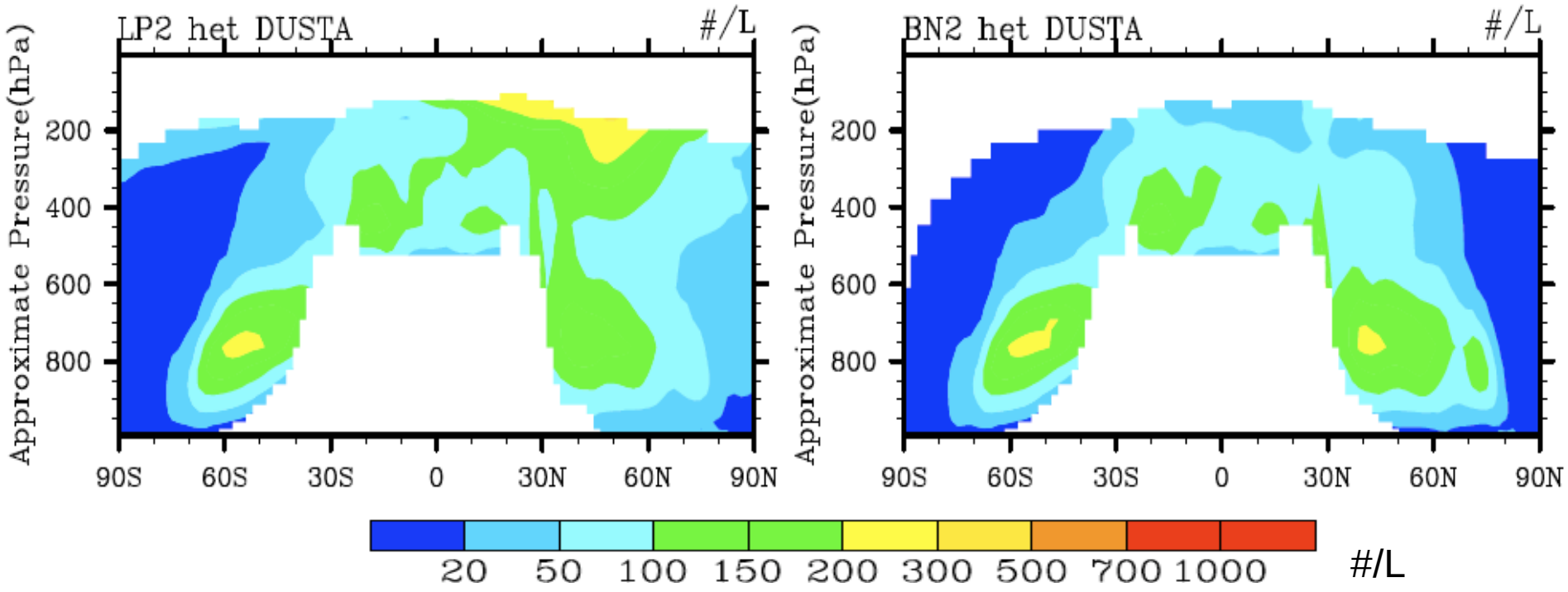
Comparison between LP and BN scheme

LP-het

BN-het



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

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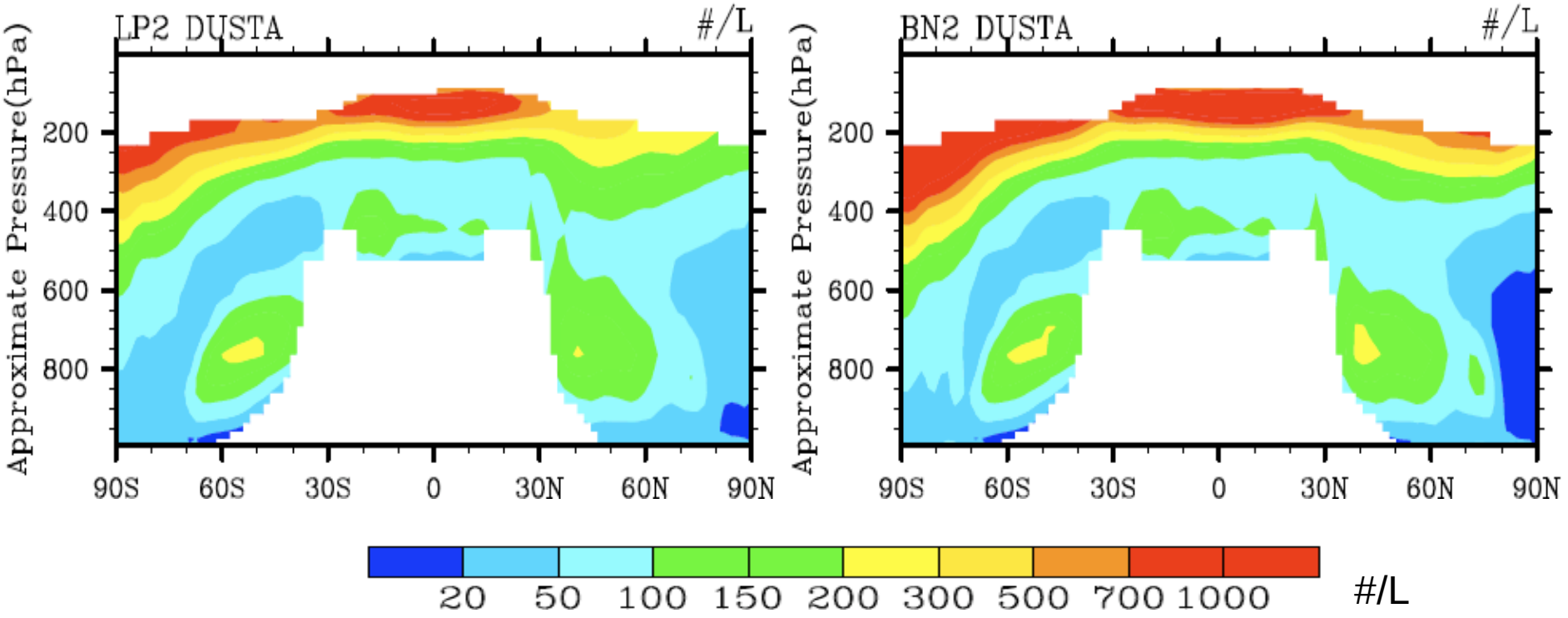
Comparison between LP and BN scheme

LP **BN**



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

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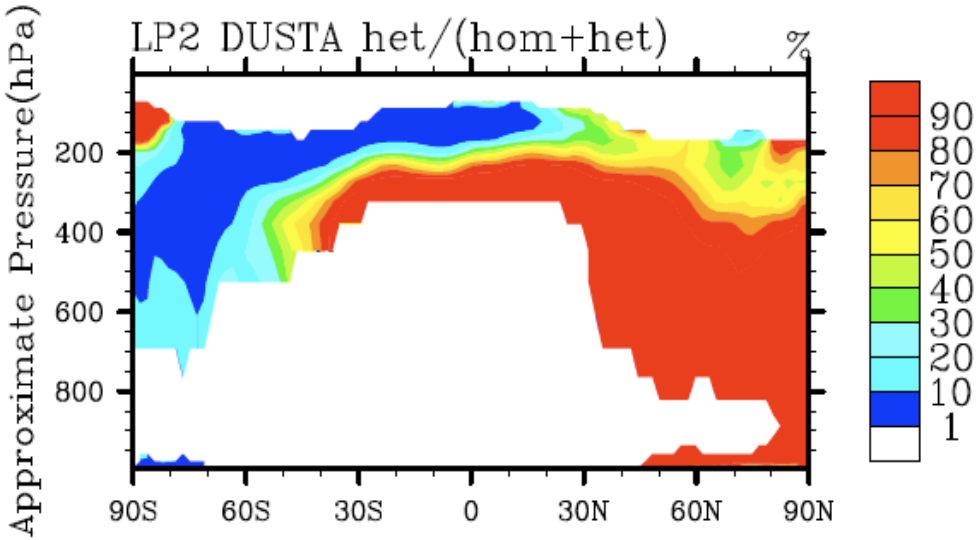
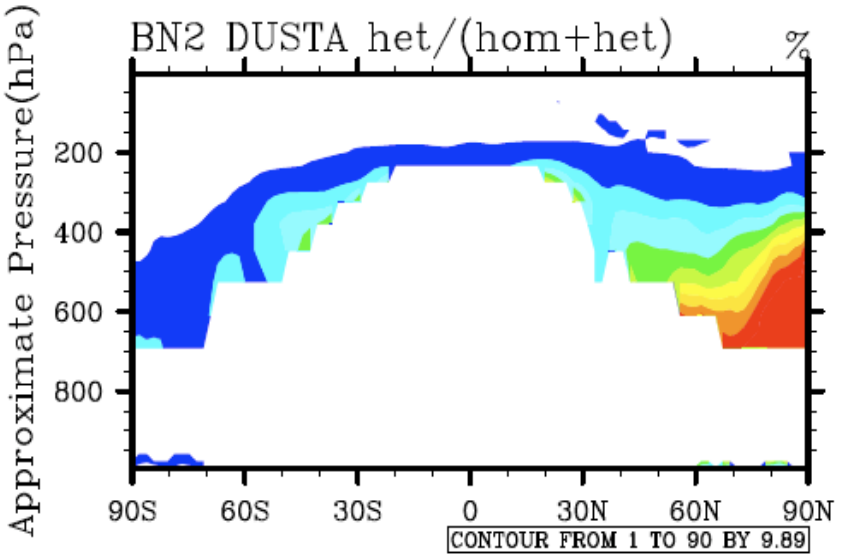
Comparison between LP and BN scheme

LP



BN



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

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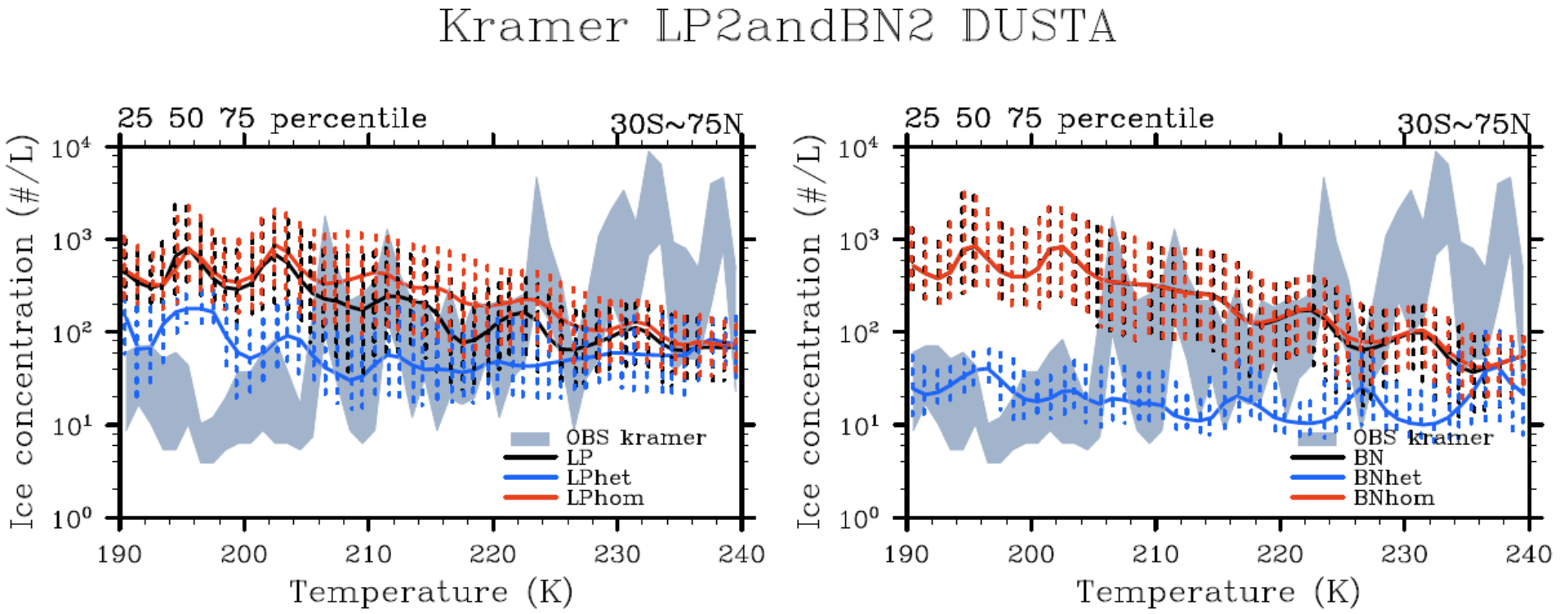
Ni vs. T

LP **BN**



LP and BN in comparison with Kramer et al. (2009)

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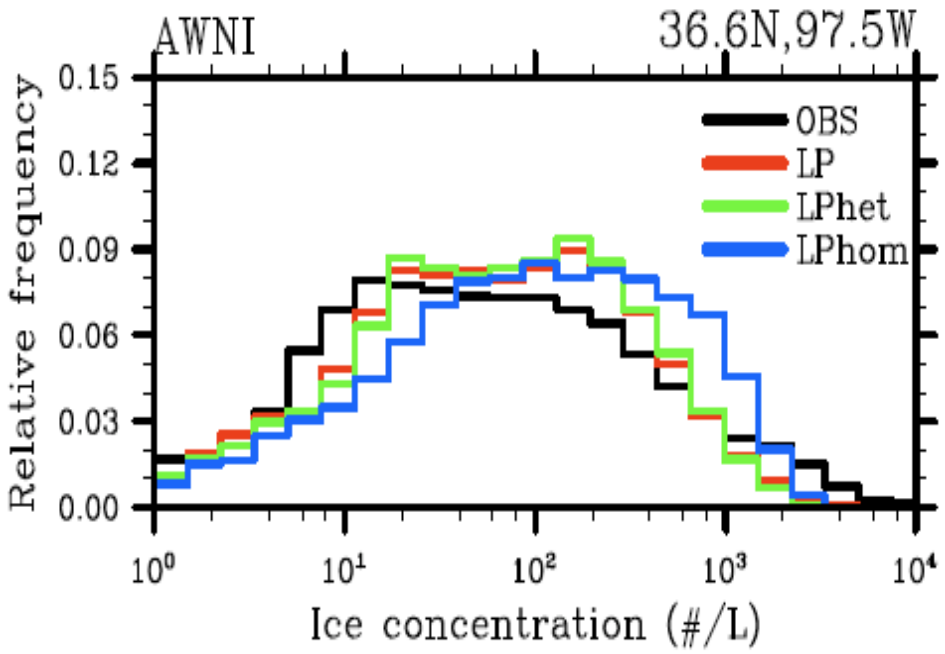
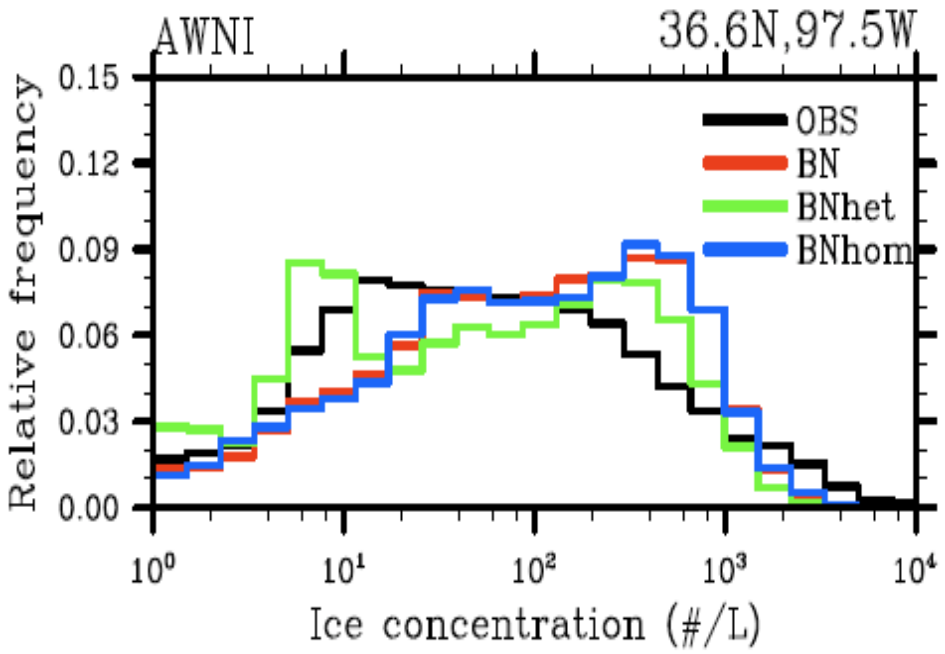
PDF(Ni)

LP



BN



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

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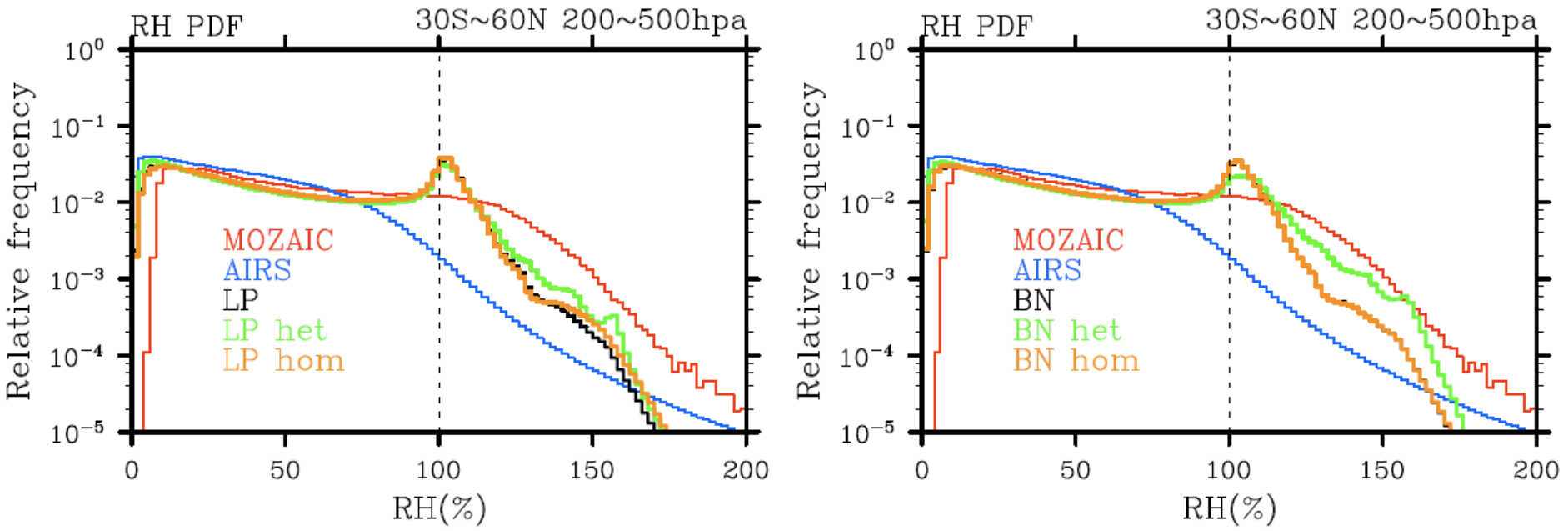
PDF (RHi)

LP

BN



LP and BN in comparison with MOZAIC and AIRS

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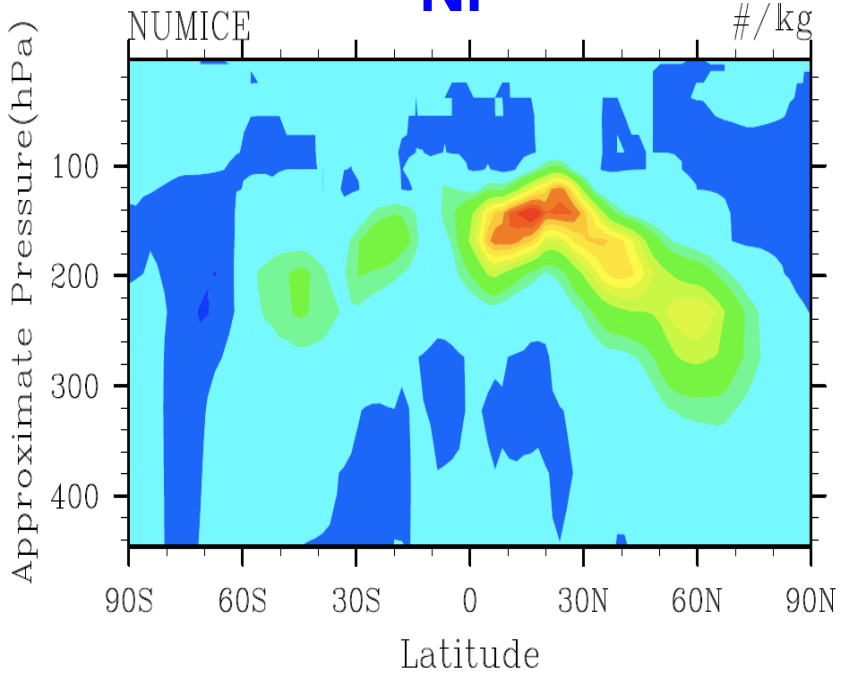
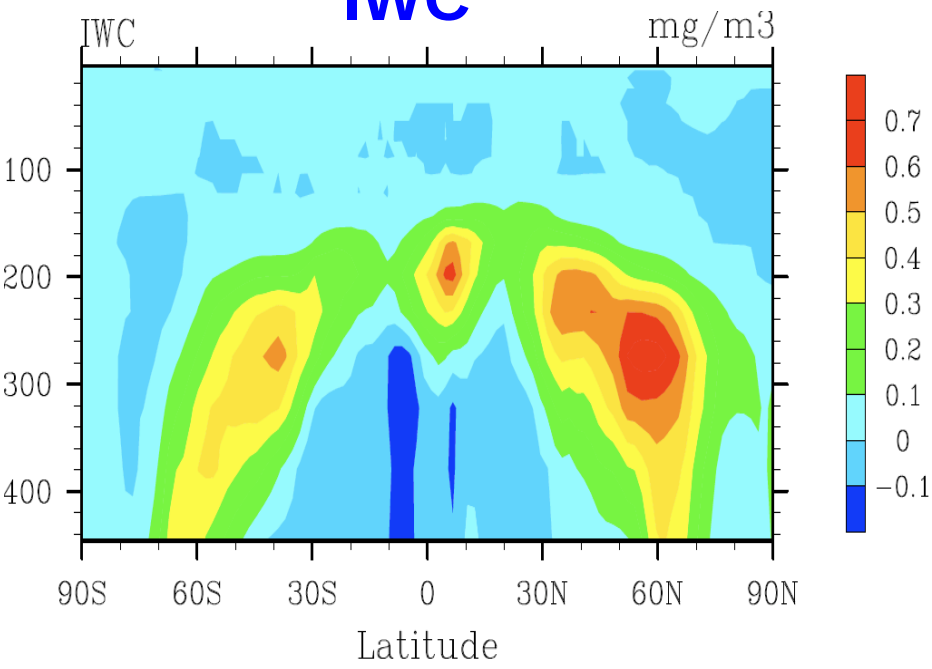
Climate Impacts

Ni



IWC



Difference of LP-hom and LP

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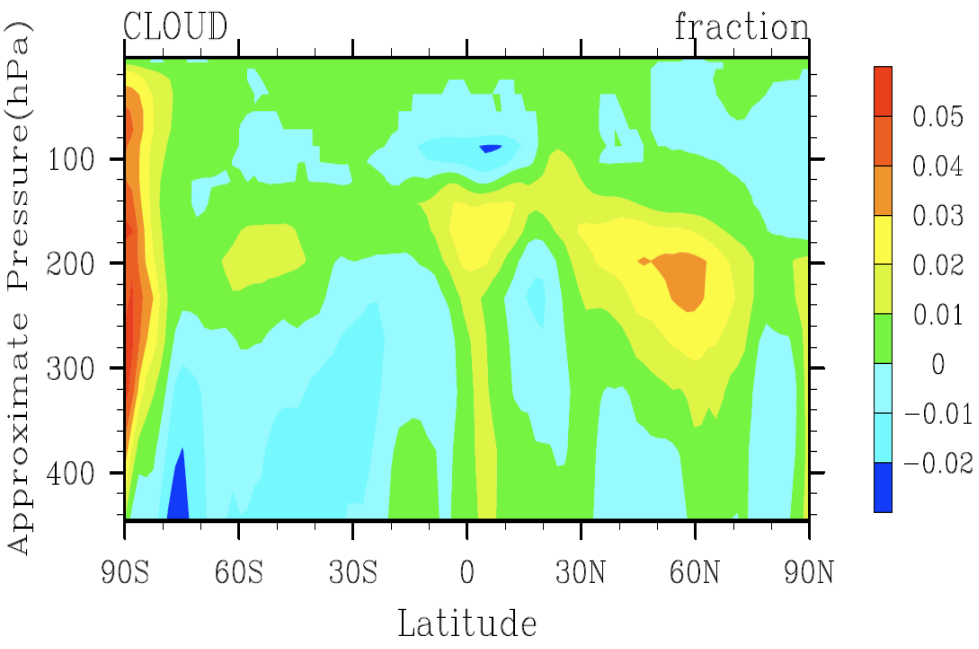
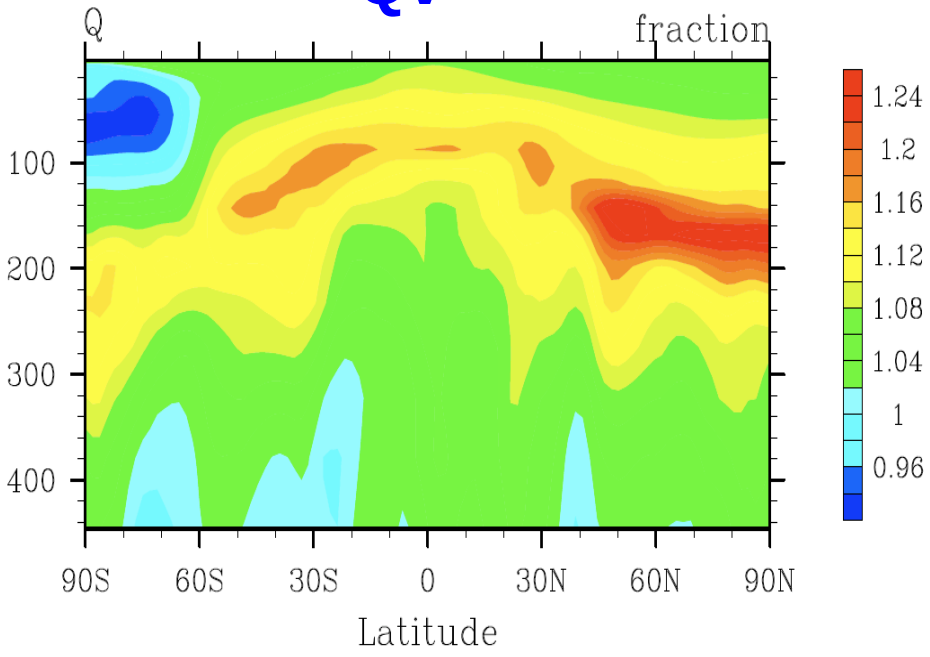
Climate Impacts

Cloud



Qv



Difference of LP-hom and LP

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Global Annual Means

	SWCF	LWCF	CLDHGH	CLDTOT
LP	-53.0	29.5	42.5	65.4
LP_HOM	-55.0	31.9	42.6	65.6
LP_HET	-46.3	22.6	38.8	62.1
BN	-52.9	28.8	41.1	64.5
BN_HOM	-52.9	29.1	41.6	64.7
BN_HET	-43.8	18.6	37.5	61.0

Δ (CF) = -0.4 W/m2 (LP), -0.3 W/m2 (BN)

Summary

- Heterogeneous IN effects are investigated using CAM5 with two ice nucleation parameterizations
- Ice nucleation may be dominated by homogeneous nucleation in the midlatitudes cirrus (200<T<230 K), however, in SGP site it overestimates PDF(Ni).
- IN has a net cloud forcing change of 0.3-0.4 W/m2