# Improving Ice Nucleation Parameterization for Mixed-Phase Clouds in CAM5

**Xiaohong Liu, Y. Wang**

***Pacific Northwest National Laboratory***

**C. Hoose**

***Karlsruhe Institute of Technology***

**A. Gettelman, J. English, J. Kay**

***National Center for Atmospheric Research***

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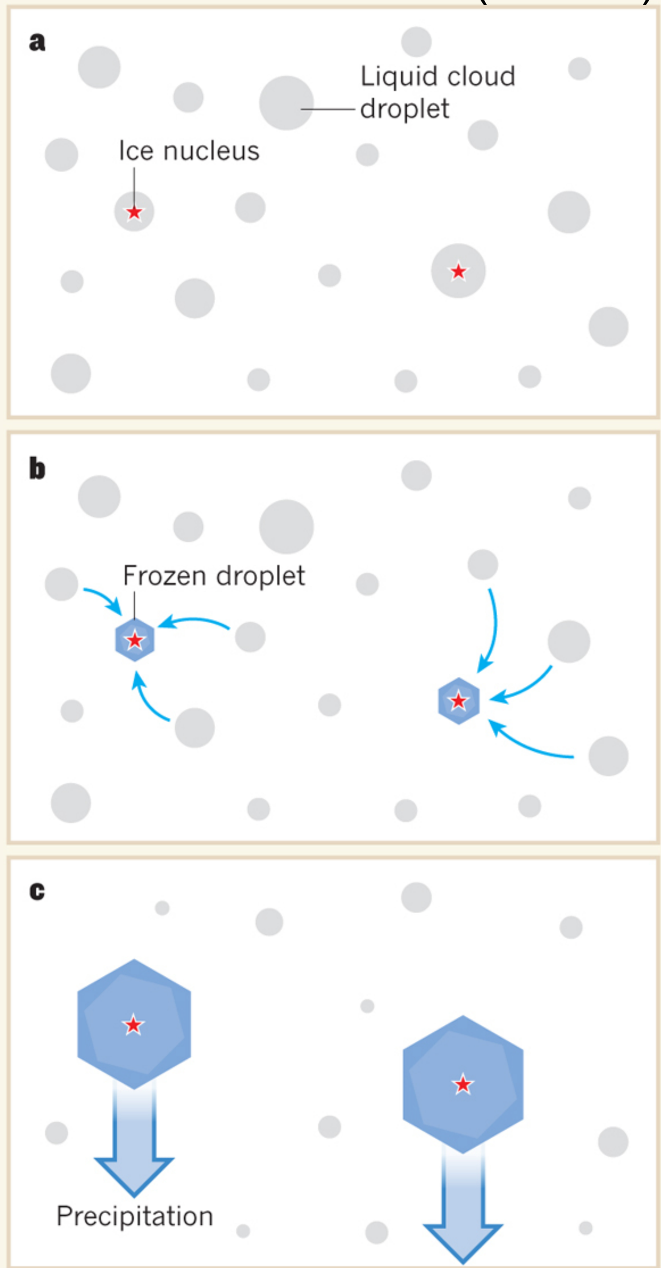
# Ice nucleation important for radiation and precipitation formation in mixed-phase clouds

(T<0 °C)

Ice Nucleation

Bergeron-F. Process

Precipitation Initiation




Koop, Nature (2013)

# Classical nucleation theory

Nucleation rate $J = A' r_N^2 \sqrt{f} \exp(\frac{-\Delta g^{\#} - f \Delta g_g^o}{kT})$

f(α), α is contact angle

Pruppacher and Klett (1997)

Hoose et al. (2010)

## Immersion/condensation

$$r_{g,imm} = \frac{2 \upsilon_w \sigma_{i/w}}{kT \ln(a_w e_{sw} / e_{si})}$$

$$\Delta N_{i,imm} = \sum_x Min\{f_{l,x} N_{aer,x} f_{i,\max,x}, f_{l,x} N_{aer,x} [1 - \exp(-J_{imm,x} \Delta t)]\}$$

Activated/cloud-borne aerosol

## Deposition

$$r_{g,dep} = \frac{2 \upsilon_w \sigma_{i/v}}{kT \ln(e / e_{si})}$$

Interstitial & uncoated aerosol

$$\Delta N_{i,dep} = \sum_x Min\{(1 - f_{l,x})(1 - f_{x,coated}) N_{aer,x} f_{i,\max,x}, (1 - f_{l,x})(1 - f_{x,coated}) N_{aer,x} \times [1 - \exp(-J_{dep,x,RH_W=0.98} \Delta t)]\}$$

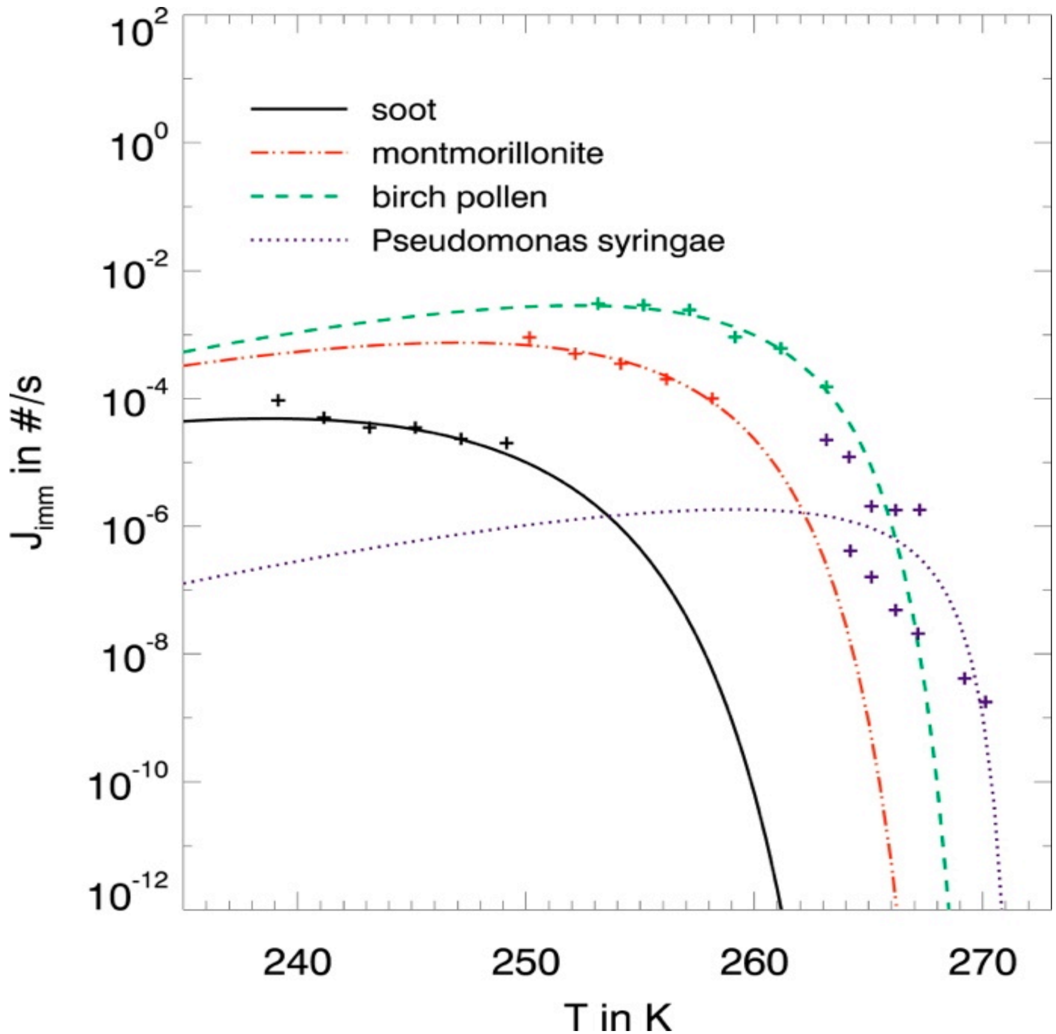
## Contact

$$N_{g,contact} \approx 4 \pi r_N^2 \frac{e}{v_s \sqrt{2 \pi m_w kT}} \times \exp[-\frac{\Delta g_{dep}^{\#} + f \Delta g_{g,dep}^o (r_{g,imm})}{kT}]$$

$$\Delta N_{i,contact} = \sum_x Min\{(1 - f_{l,x})(1 - f_{x,coated}) N_{aer,x} f_{i,\max,x}, (1 - f_{l,x})(1 - f_{x,coated}) N_{aer,x} \times [1 - \exp[-K_{coll}(r_{N,x}, r_l) N_l Max(N_{g.contact,x}, 1) \Delta t]\}$$

PDF-α model: integrate over the PDF of contact angle α

# Classical theory links ice nucleation rate to aerosol properties, constrained by experiments




Hoose et al. (2010)

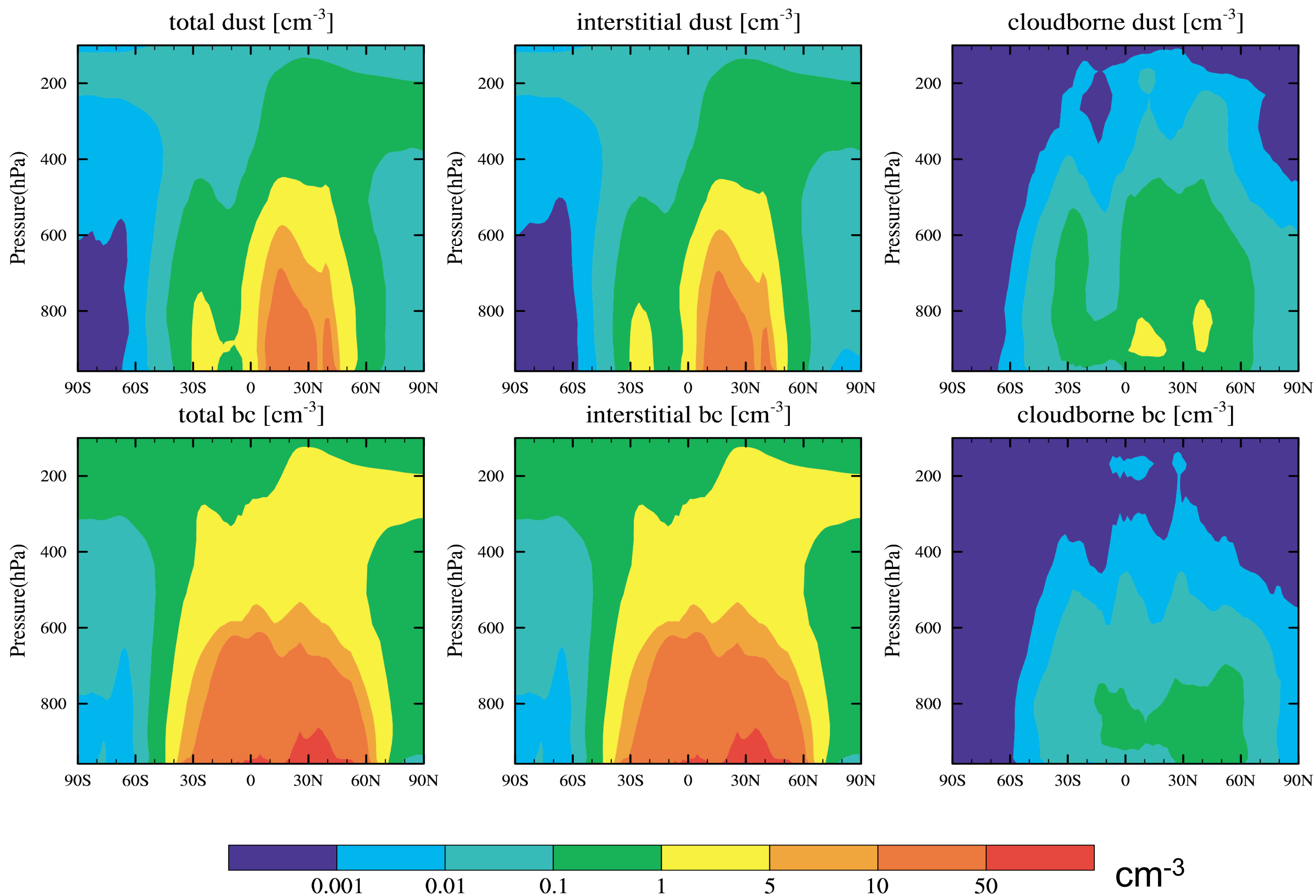
α=40.2° (soot, immersion); α=31.0° (dust, immersion)
α=28.0° (soot, deposition); α=12.7° (dust, deposition)

# Model Experiments

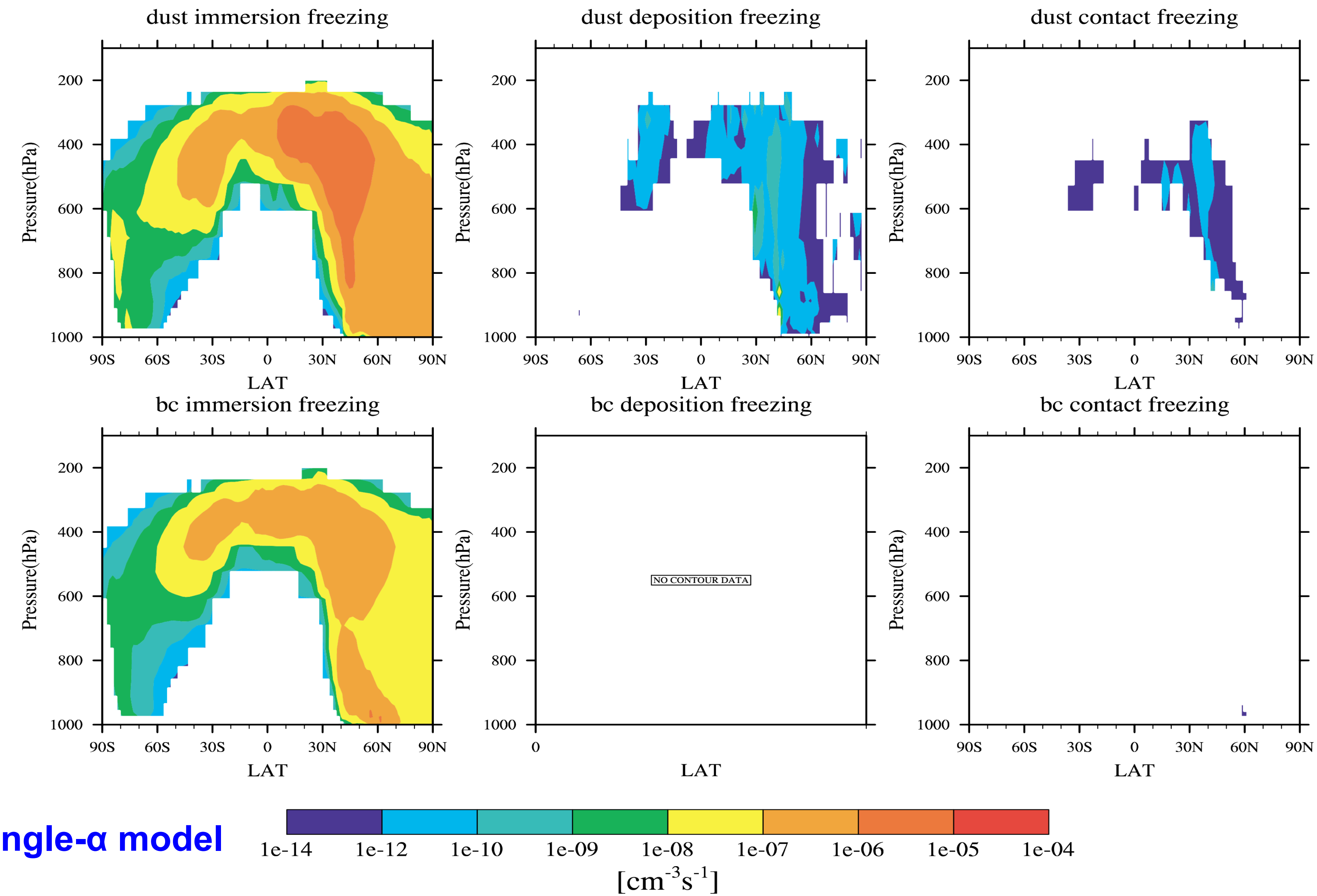
- CAM5.1 with FV dynamic core, 1.9° x 2.5°, 30 levels
- 6-yr climate runs with prescribed SST and sea ice (AMIP II type of run)

- Default : Meyers et al. (1992) for deposition/condensation/ immersion in mixed-phase clouds, with no link to aerosol
- single-α : Classical nucleation theory with single contact angle (Hoose et al. 2010)
- PDF-α : Classical nucleation theory with PDF-contact angle, mean of PDF same as single α with standard deviation 0.1

# Dust and BC number (interstitial vs. cloud-borne)

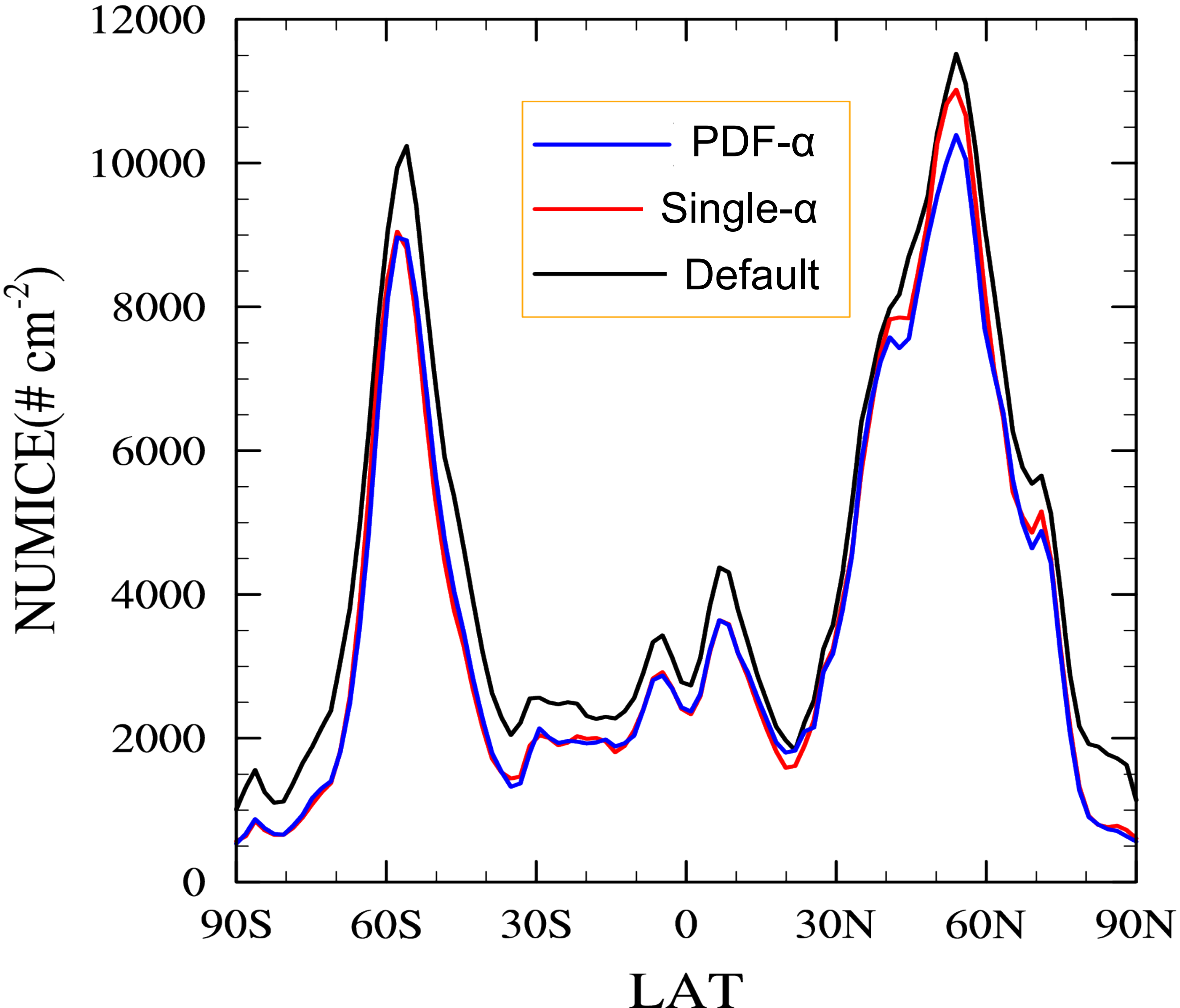


# Ice nucleation in mixed-phase clouds: immersion vs. deposition vs. contact mode

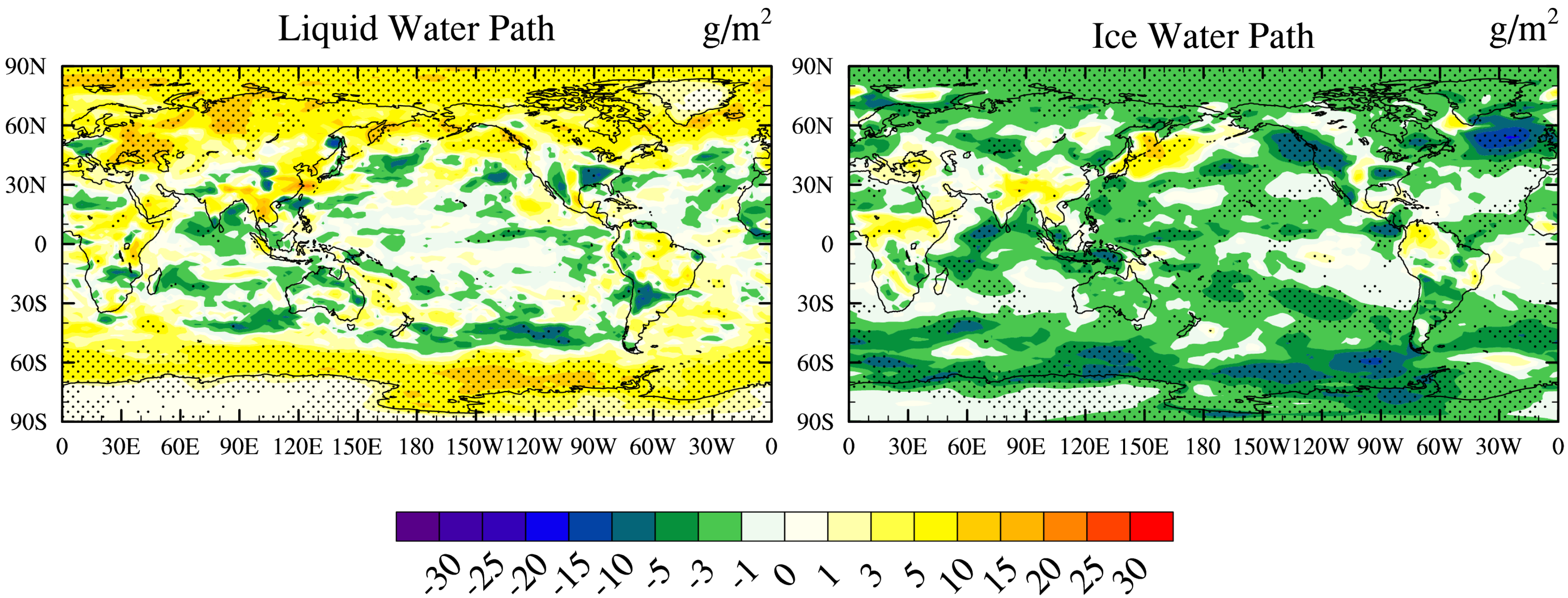



**Single-α model**

# Column Ice Crystal Number Concentration in Mixed-Phase Clouds



# Difference in Cloud Water (single α - default)




Fewer Ni → More Liquid, Less Ice

through slowing down the Bergeron process

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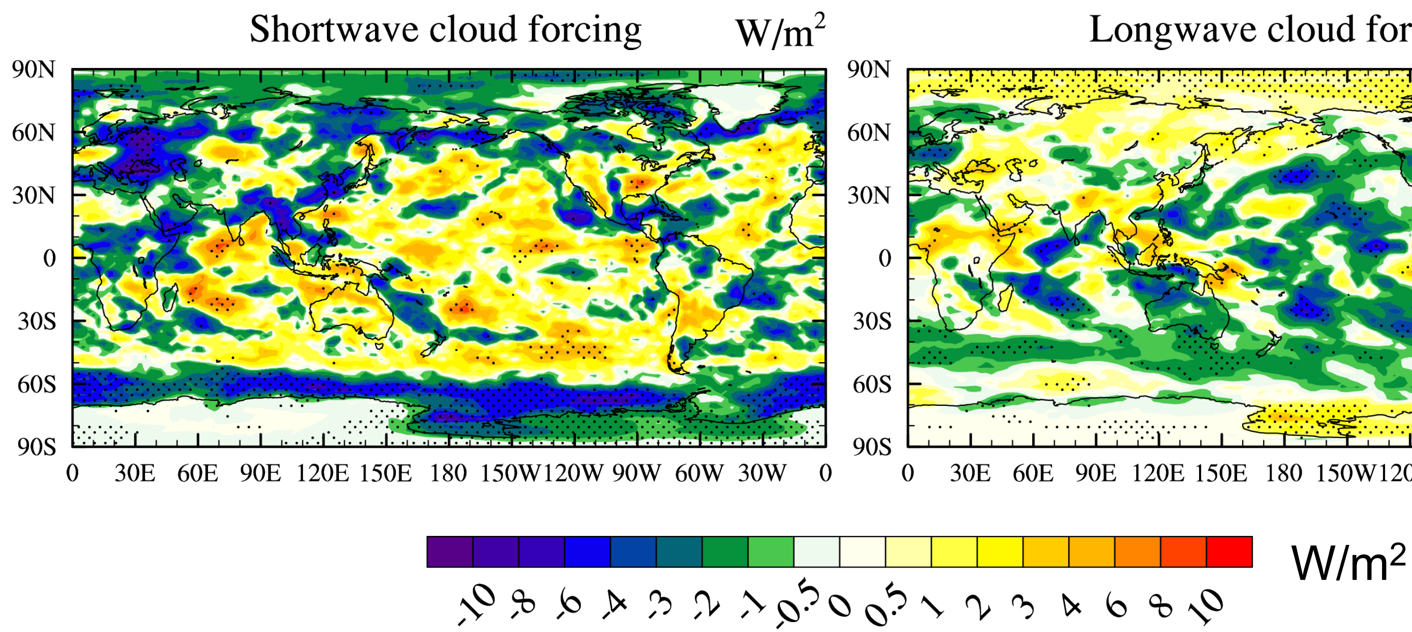
# Difference in Cloud Forcing (single α - default)

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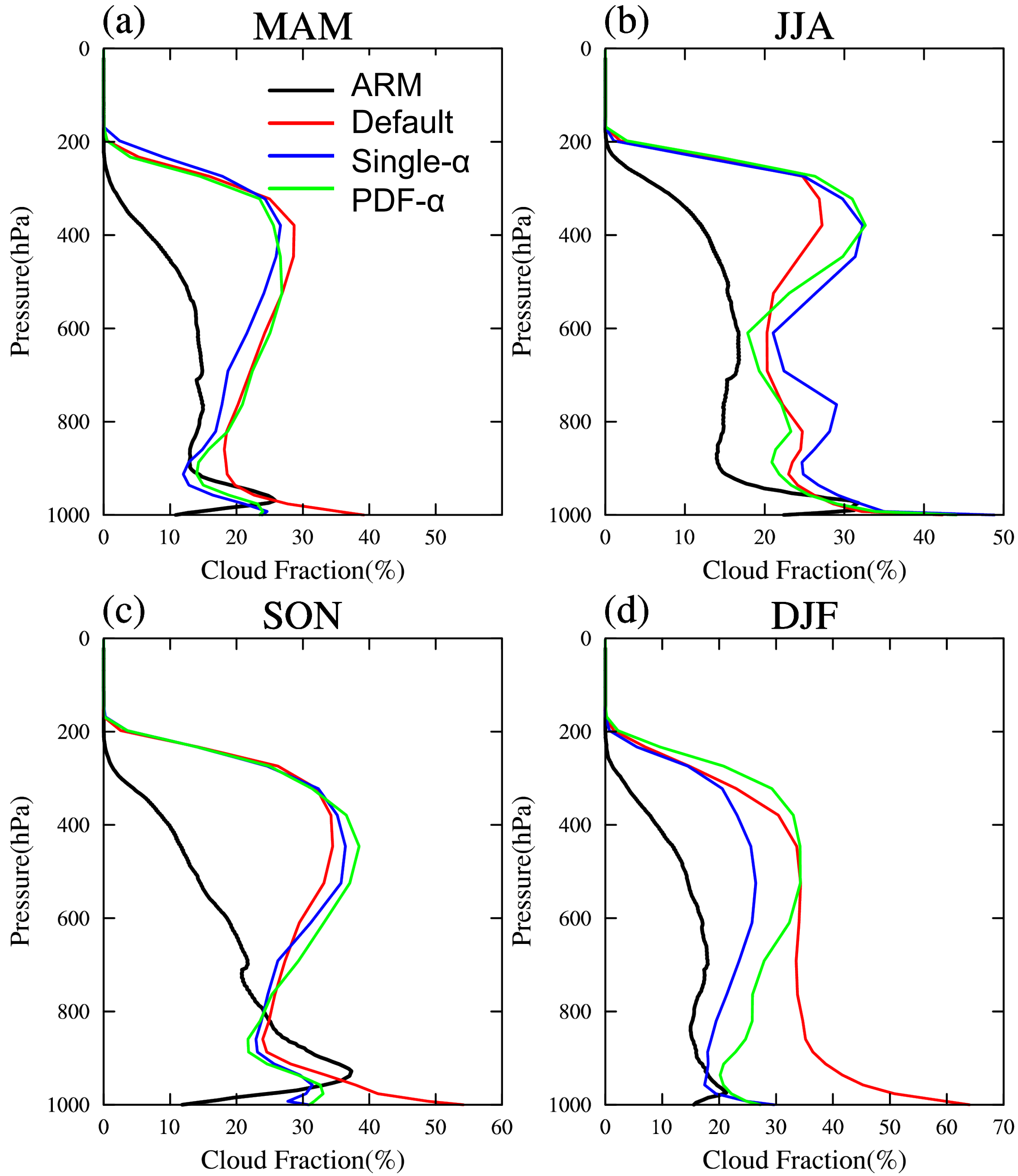
# Cloud cover at ARM Barrow

LWP -> Ts -> LTS -> LLC -> RH -> MLC & HLC

Xie et al. (2013)



# Summary

- A framework of ice nucleation based on classical nucleation theory has been implemented in CAM5, which links ice nucleation to aerosol (e.g., dust, soot, biological aerosol) properties

- Compared to Meyers et al. (default), new parameterization has a significant effect on cloud water and cloud cover, especially in high latitudes:

  - Improved comparison with long-term ARM observations