# Investigating Ice Nucleation with an Aerosol Enabled Multi-scale Modeling Framework (PNNL MMF)

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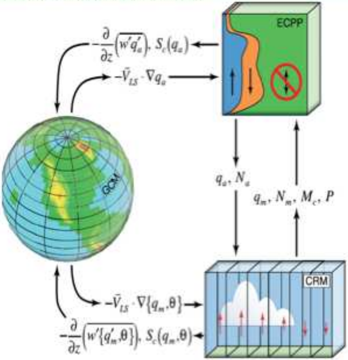
# PNNL Multi-scale Modeling Framework

**ECPP**: Explicit-Cloud-Parameterized-Pollutant
Aerosol processes in convective clouds are explicitly treated

**GCM:** NCAR CAM5
with modal aerosols.
Three log-normal modes representing aerosol size distributions:
Aitken mode
accumulation mode
and coarse mode.




Wang et al. 2011,
Gustafson et al., 2008,GRL

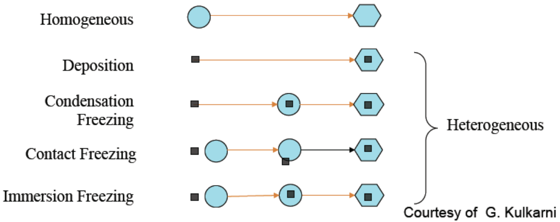
**CRM : Cloud Resolving Model** SAM (System of Atmospheric Modeling) embedded in each **GCM** column, explicitly simulating convective and stratiform clouds, with two moment microphysics

# Motivations

- This model is a powerful tool to examine aerosols, clouds, and precipitation interactions at the global scale, improvement on ice nucleation is needed.
- The simulated change in SWCF from anthropogenic aerosols in the MMF is much smaller than that in CAM5 (-0.77 $W/m^2$ vs. -1.79 $W/m^2$), suggesting the LWP is less sensitive to the change of aerosols (Wang et. al., 2011).
- Our study implements an aerosol-dependent ice nucleation scheme to understand how IWP responds to the change of aerosols.

# Review Ice Nucleation

- Ice nucleation processes involving aerosols are key to the formation and properties of cirrus and mixed-phase clouds, and 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




- Difficulty in representing ice nucleation process in climate models also results from large space and time resolutions.

# Implementation

- Based on CAM released with NCAR SPCESM 1.1.1
- **Ice Nucleation Scheme on SAM grid**
  MMF0: Cooper (1986): Temperature-dependent
  MMF LP:Liu and Penner (2005) ice cloud only
  MMF LPHI: MMFLP with higher aerosol setting
- Ice clouds (T $<$ -37°C): homogeneous freezing on sulfate aerosol competing with heterogeneous immersion nucleation on mineral dust in ice clouds.

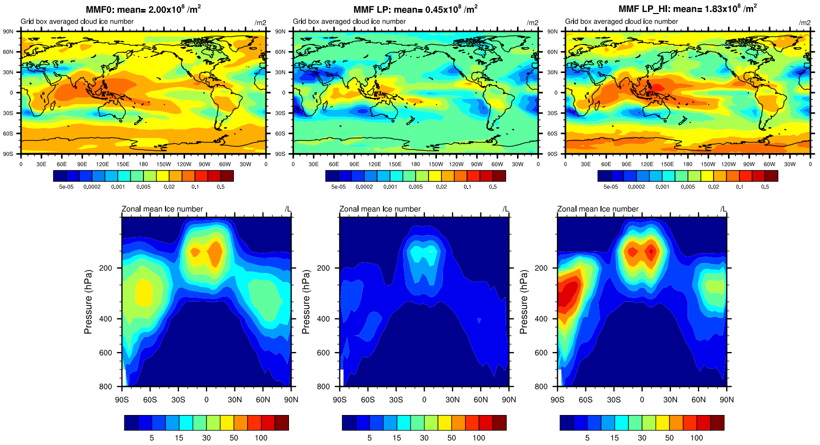
# Experiment

Simulation setup:

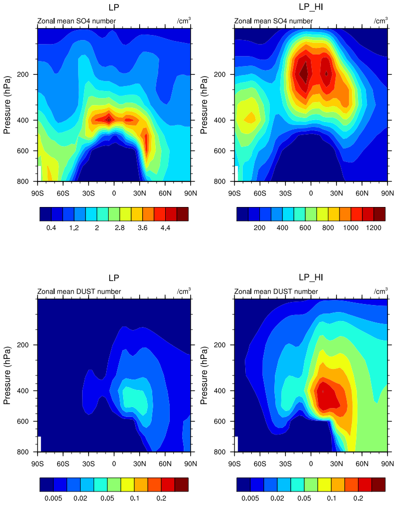
1. 15-month simulations
2. 4x5 resolution
3. 32 4-km CRM columns
4. 20 seconds CRM and 10 minutes GCM time step

# ANN. Global Distribution of Ice Number Concentration

MMF0 LP LP HI



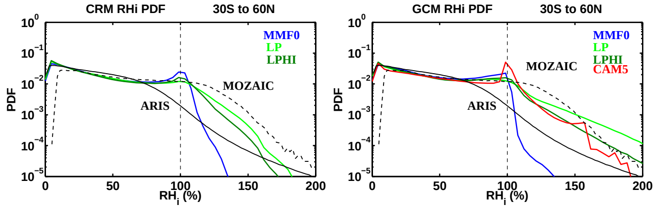
# ANN. Zonal Mean Sulfate and Dust Number ($cm^{-3}$)

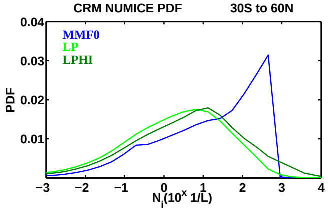



- **Sulfate Aerosol**
  Corresponds to the high ice number region
- **Mineral Dust**
  High number of heterogeneous IN in the NH midlatitudes from dust sources in North African and Asian deserts

# Relative Humidity w.r.t Ice in Upper Troposphere (150-300hPa)

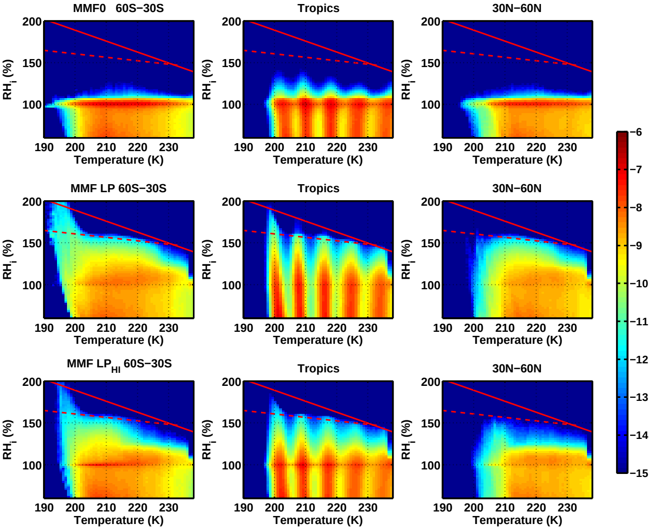
RHi is a driver for ice nucleation.
In-situ (MOZAIC) and satellite (ARIS) measurements
Use 3 hourly instantaneous output from CRM and GCM grids



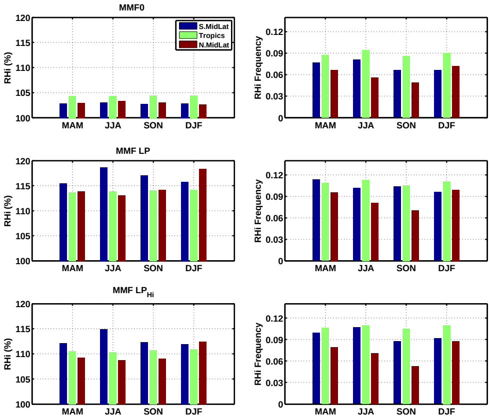



# RHi vs. Temperature

- **MMF0**
- **LP**
- **LPHI**

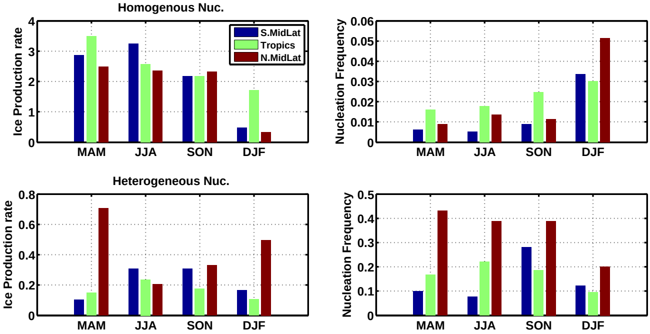


# Ice Supersaturation and the Frequency




- **Seasonal & Interhemispheric**
  Higher supersaturation frequency in
  SH and Winter Hemisphere
  Agree with observation
- Suggest temperature variation may be the decisive factor
- MMF0 has lowest RHi values

# In-Cloud Ice Production Rate and Nucleation Frequency




Homogeneous nuc. has higher rate then heterogenous nuc.

# Summay

1. An aerosol-dependent ice nucleation scheme has been implemented in PNNL MMF.

2. The new MMF is sensitive to the aerosol settings. The predicted global mean ice number concentration can be 4 times larger with higher aerosol setting.

3. Initial tests show that simulated ice supersaturation from the new MMF matches observation.

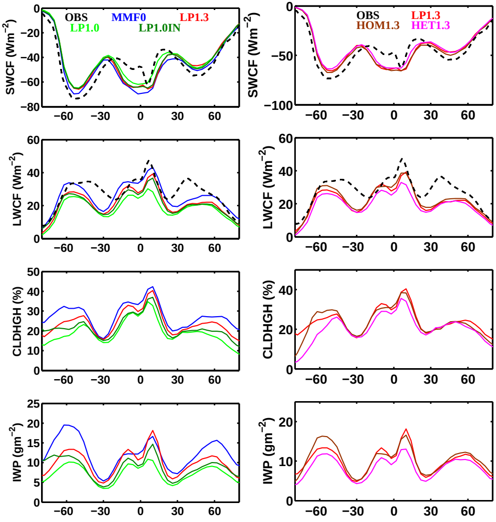
4. New MMF simulates the observed phenomenon that in-cloud RHi PDF shift towards higher values at low temperature.

# Global Mean

| Case | Desc. | SWCF | LWCF | LWP | IWP | CT | CH | NUM |
|---|---|---|---|---|---|---|---|---|
| MMF0 | Cooper1986 | -50.5 | 27.0 | 53.2 | 11.1 | 50.0 | 28.0 | 2.00 |
| LP | LP | -45.6 | 19.6 | 52.3 | 6.8 | 45.3 | 20.7 | 0.45 |
| LPHI | LP High IN | -47.8 | 21.9 | 53.0 | 8.1 | 46.5 | 22.6 | 1.82 |
| LP1.3 | LP sub1.3 | -47.8 | 23.1 | 51.3 | 9.5 | 48.2 | 25.0 | 0.94 |
| HOM1.3 | LP hom. | -48.9 | 24.2 | 53.5 | 9.8 | 47.5 | 24.8 | 1.65 |
| HET1.3 | LP het. | -46.1 | 20.8 | 50.5 | 8.0 | 46.4 | 22.1 | 1.10 |
| CAM5 | LP sub1.2 | -50.1 | 21.9 | 48.4 | 16.1 | 62.7 | 37.6 | 1.00 |

Table: Global annual mean cloud properties from sensitivity simulations listed in Table 1 for liquid water path (LWP, gm/2), ice water path (IWP, gm/2), shortwave cloud forcing (SWCF, Wm/2), longwave cloud forcing (LWCF, Wm/2), total cloud cover (CLDTOT, %),high cloud cover (CLDHGH, %), and column ice number concentration (NUMICE, $10^8$ m/2).

# Zonal Variation



# In Cloud Ice Number