Refining Ice Nucleation Parameterization in Cirrus Clouds in CAM5

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Motivations

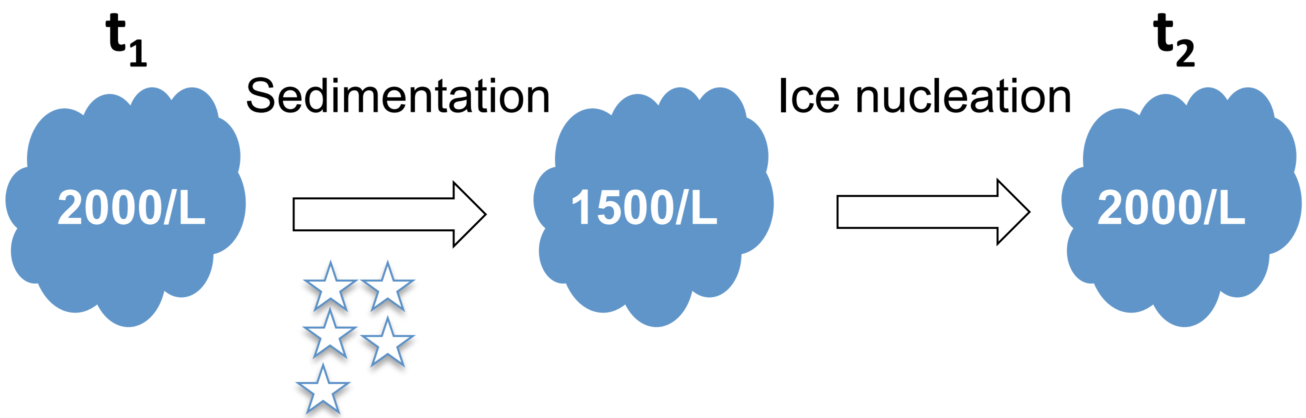
Current ice nucleation treatment in cirrus clouds in CAM5

Ice nucleation occurs in both new and old clouds

$$\frac{\Delta Ni}{\Delta t} = \max(0, \frac{Naai - Ni}{\Delta t})$$

Ni indicates in-cloud **preexisting ice** number;
Naai indicates ice number after ice nucleation;

Schematic diagram of cirrus ice nucleation



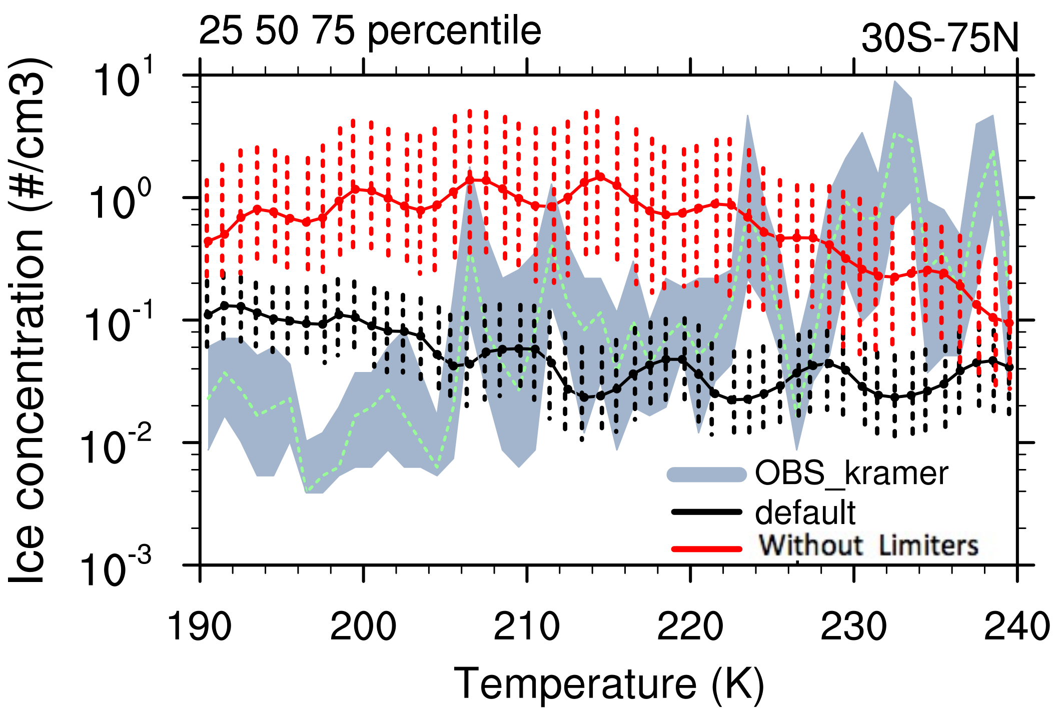
Do not consider preexisting ice effect (default CAM5 version)

Assume a constant ambient condition. Under this condition, the ice crystals from homogeneous freezing is 2000/L

Issues with representation of ice nucleation in CAM5

- An upper limiter (0.2 m/s) is used for Wsubi, which drives ice nucleation parameterization in cirrus clouds

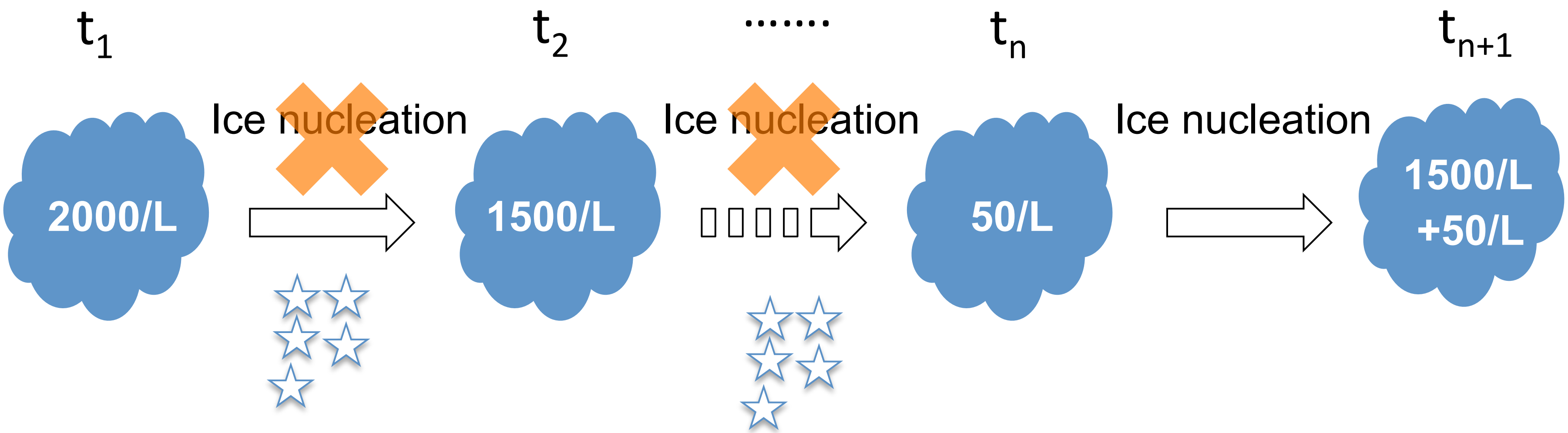
- A lower limiter (0.1 µm) is used for sulfate aerosol size distribution used in ice nucleation parameterization in cirrus clouds



Observations:
Krämer et al. (2009)

Refining ice nucleation parameterization in cirrus clouds

1) Consider ***preexisting ice crystals*** to consume water vapor during ice nucleation (reducing occurrence frequency)
2) Remove the ***two unphysical limiters***



Assume a constant ambient condition. Under this condition the homogeneous freezing can not happen when preexisting ice number density is greater than 100/L; the ice crystals formed from homogeneous freezing is 1500/L at preexisting ice number of 50/L.

Preexisting ice crystal effect

Preexisting ice crystal effect can be parameterized by *reducing the vertical velocity* used for ice nucleation parameterization

Barahona et al. 2013; Kärcher et al. 2006

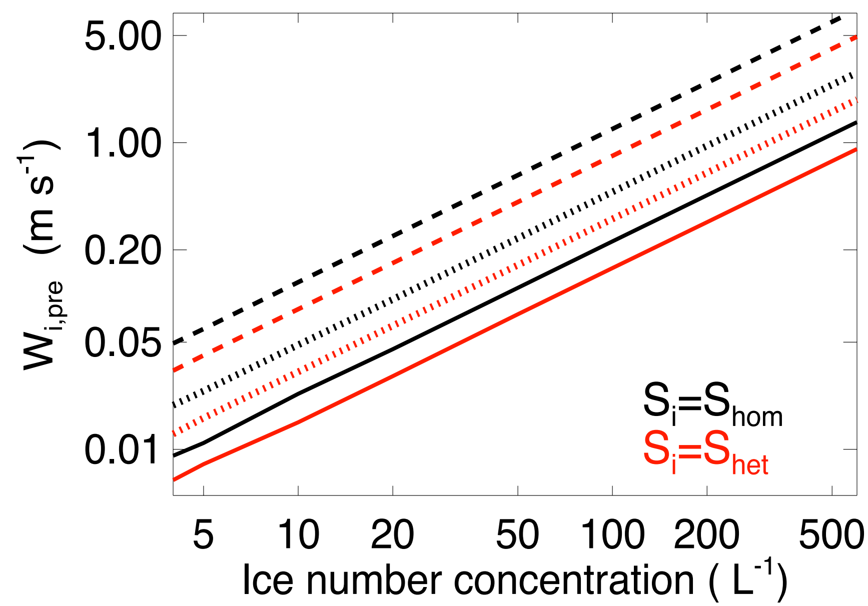
$$\frac{dS_i}{dt} = a_1 S_i W - (a_2 + a_3 S_i)\left(\frac{dq_{i,nuc}}{dt} + \boxed{\frac{dq_{i,pre}}{dt}}\right)$$

Deposition of water vapor on preexisting ice crystals

$$\frac{dS_i}{dt} = a_1 S_i (W - \boxed{W_{i,pre}}) - (a_2 + a_3 S_i)\frac{dq_{i,nuc}}{dt}$$

$$W_{i,pre} = \frac{a_2 + a_3 S_i}{a_1 S_i}\boxed{\frac{dq_{i,pre}}{dt}}$$

$$\frac{dq_{i,pre}}{dt} = \frac{4\pi\rho_i}{m_w}\, n_{i,pre} R_{i,pre}^2 \frac{b_1}{1 + R_{i,pre} b_2}$$

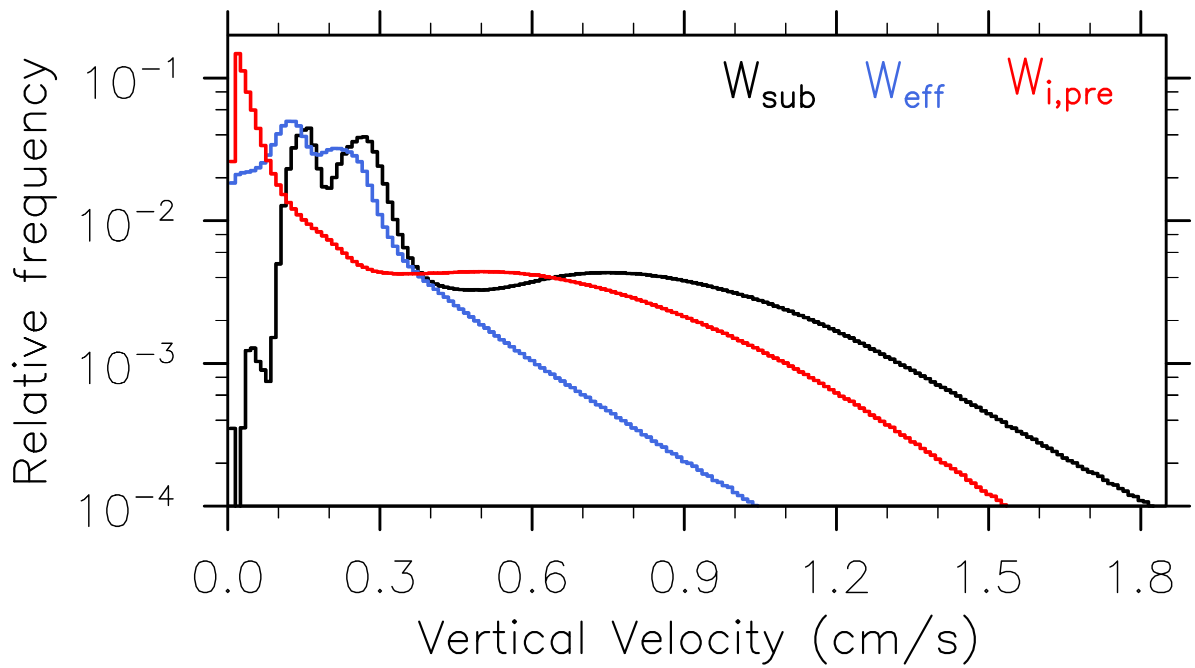


Results are shown for different ice radius, 10 µm (solid line), 25 µm (dotted line) and 50 µm (dash line).

Implement preexisting ice effect in CAM5.3

Liu & Penner (2005) ice nucleation parameterization

Wsub: sub-grid vertical velocity diagnosed from TKE
Wpre: vertical velocity reduction by preexisting ice crystals
Weff=Wsub-Wpre: *effective vertical velocity* used for ice nucleation para.
Remove limiters: upper limit 0.2 m s^{-1} for Wsubi; lower limit 0.1 μm for sulfate aerosol size distribution



3-hourly output at the grids where ice nucleation occurs

Refining ice nucleation parameterization in cirrus clouds

3) Homogeneous nucleation fraction (**fhom**)

Considering in-cloud variability in ice saturation ratio: homogeneous nucleation takes place *spatially only in a portion of cirrus cloud* rather than in the whole area of cirrus cloud.

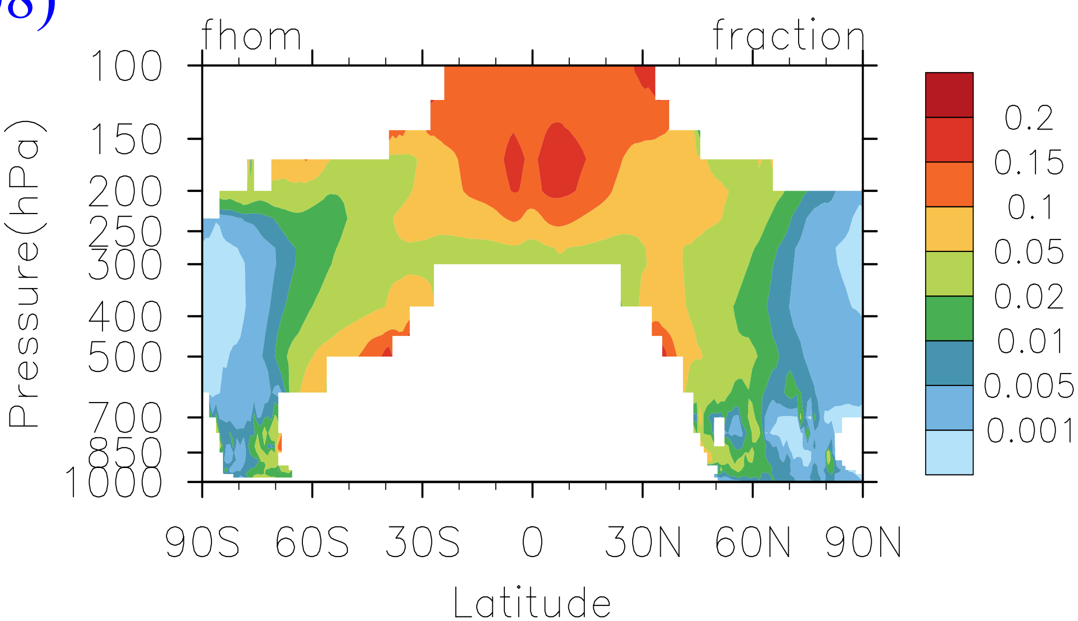
Kärcher and Burkhardt (2008)

$$S_i(T') \cong S_0 \exp\left[\frac{(T_0 - T')\theta}{T_0{}^2}\right]$$

$$\frac{dP_{T'}}{dT'} = \frac{1}{\delta_T}\frac{1}{\sqrt{2\pi}} exp\left[-\frac{(T_0 - T')^2}{2\delta_T{}^2}\right]$$

Hoyle et al. (2005)

$$\delta_T \cong 4.3 W_{sub}$$



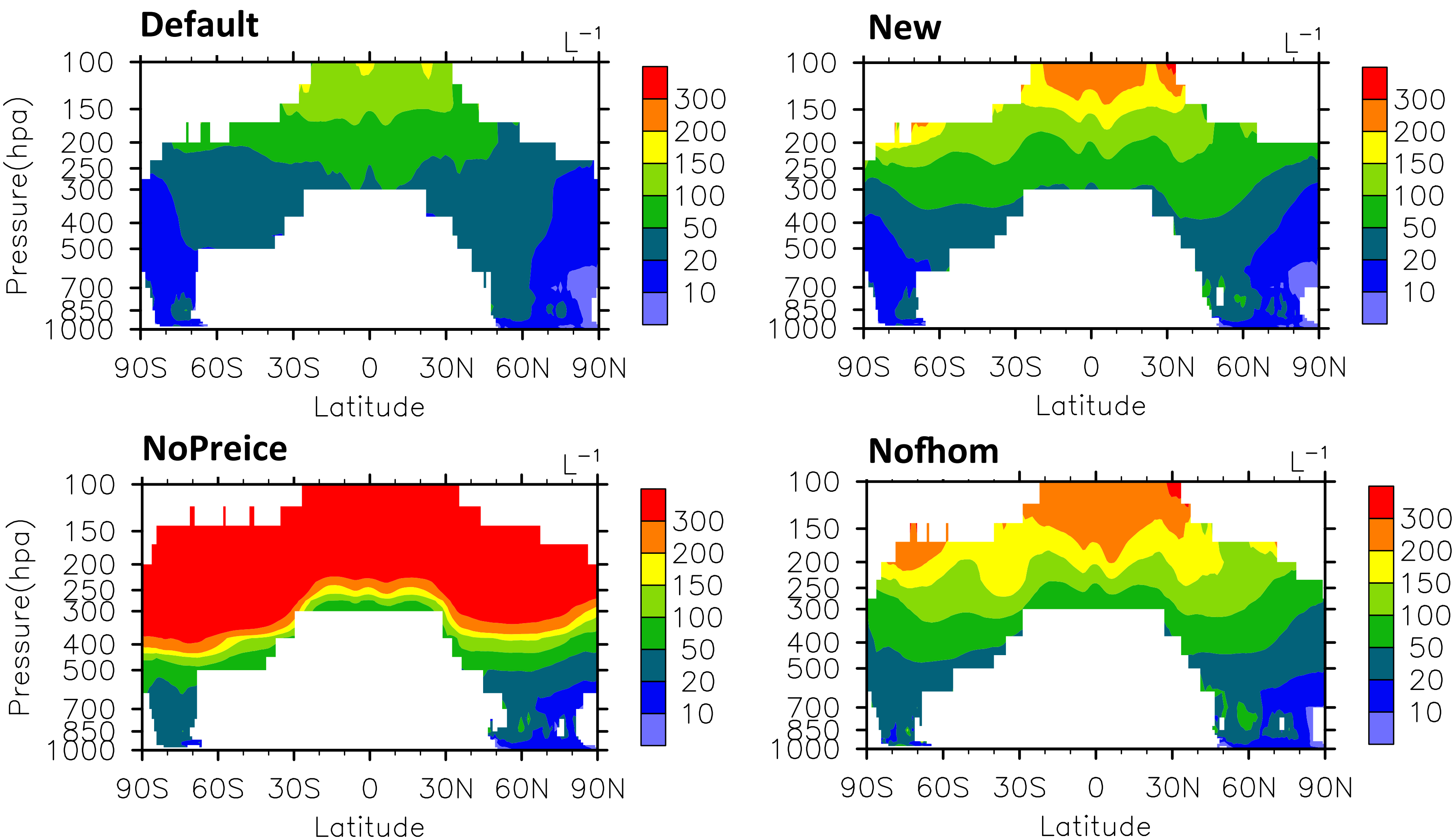
fhom: the fraction of cirrus cloud where homogeneous freezing occur

CAM5.3 experiments

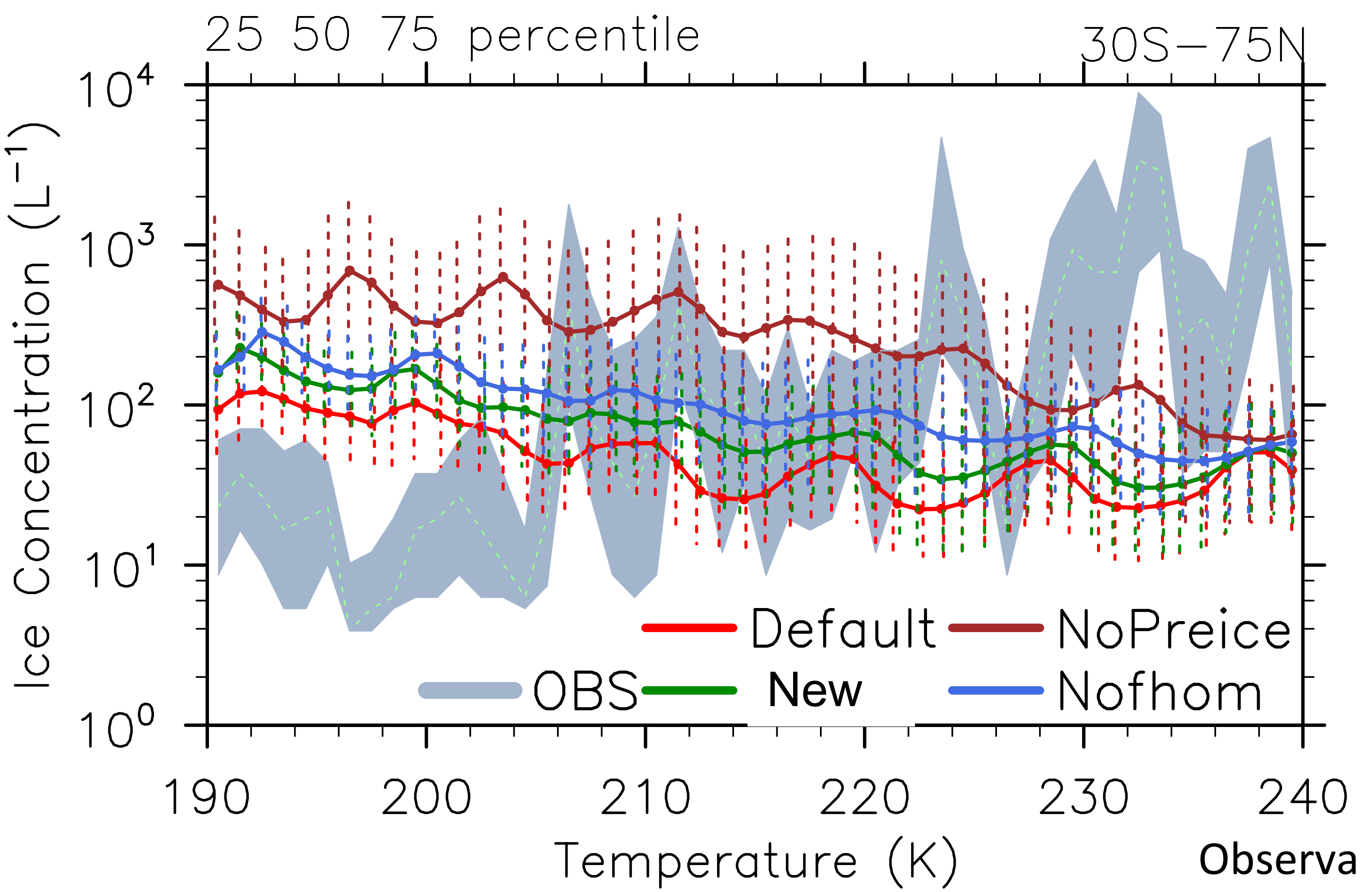
Simulation	Two limiters	Preexisting ice	fhom
Default	Yes	No	No
New	No	Yes	Yes
NoPreice	No	No	Yes
Nofhom	No	Yes	No

All simulations run 5 years after 3 months spin-up.

In-cloud ice number concentration



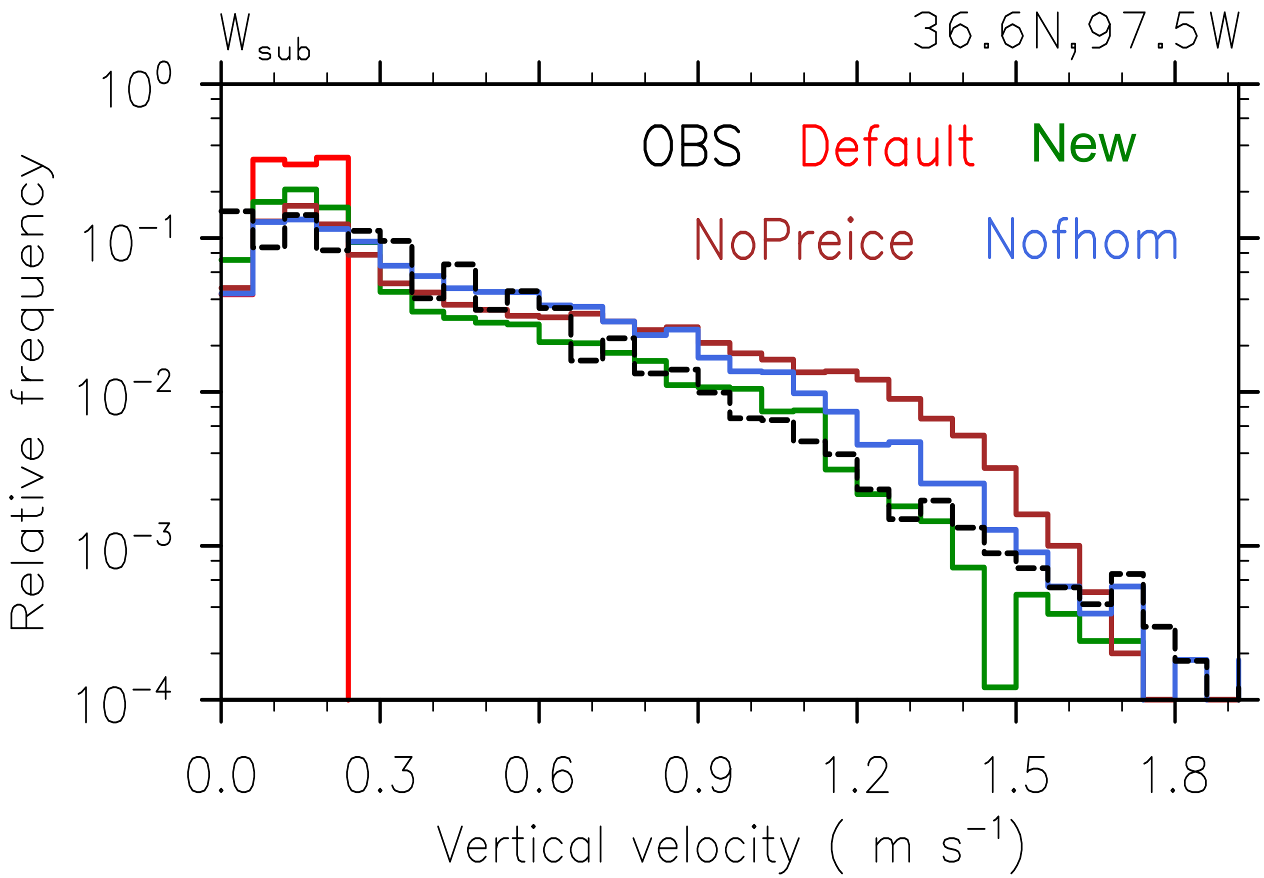
Ice number versus temperature



Observations:
Krämer et al. (2009)

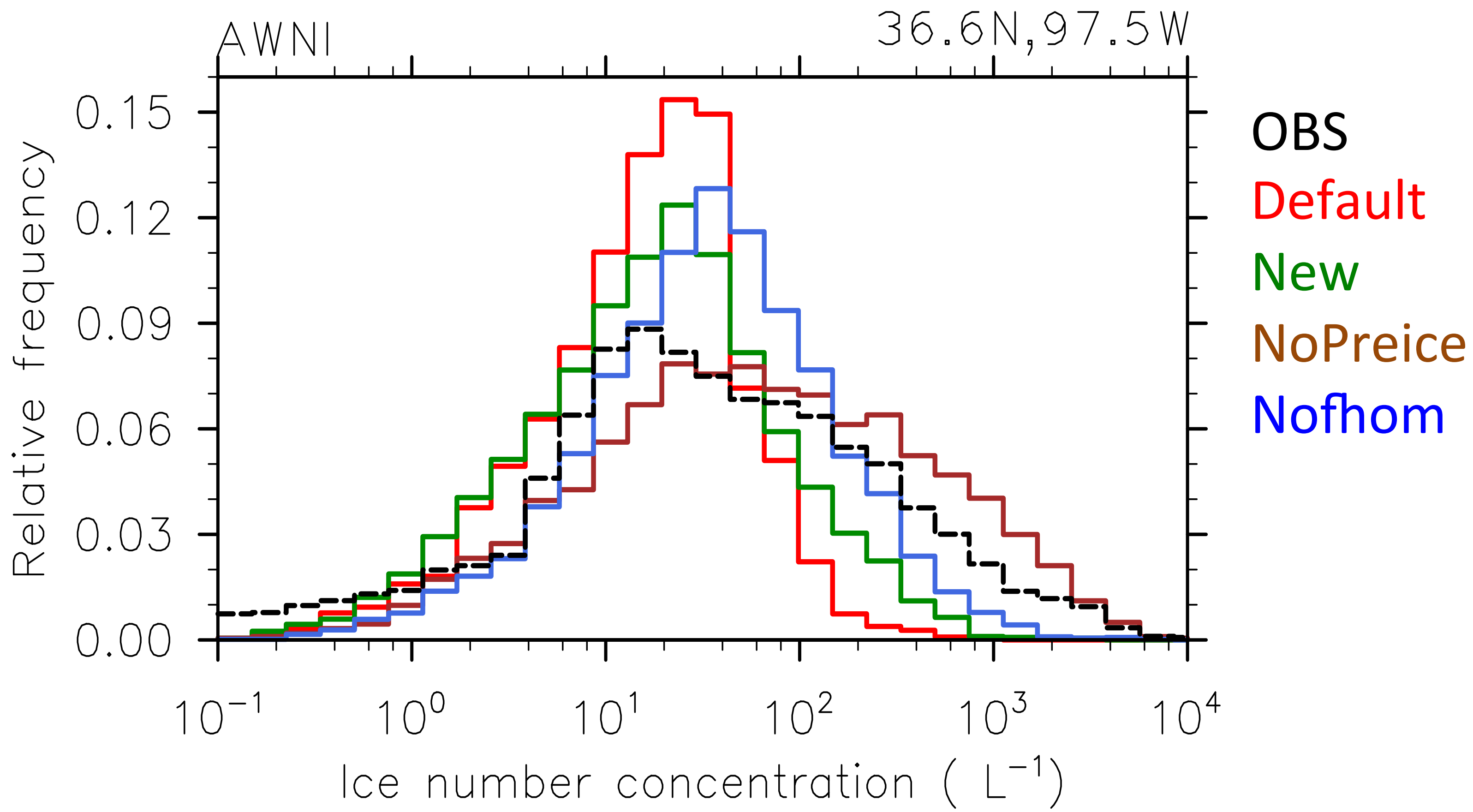
The 50% percentile (solid line), 25% and 75% percentiles (error bar) are shown for each 1-K temperature bin. The gray color indicates observations between 25% and 75% percentiles. Model results are sampled every three hours.

PDF of sub-grid updraft velocity (Wsubi)



Black-dashed line: SPARTICUS observations over ARM SGP site (Jan-Jun 2010).
Model results are sampled over the field measurement site every three hours.

PDF of in-cloud ice number (Ni)



Black-dashed line: SPARTICUS observations over ARM SGP site (Jan-Jun 2010).
Model results are sampled over the field measurement site every three hours.

Global means

Simulation	LWCF	SWCF	CF	IWP	CDNUMI
Default	22.42	-50.25	-27.83	16.37	83.20
New	23.65	-51.52	-27.87	17.60	119.32
NoPreice	34.81	-62.67	-27.86	24.33	1021.05
Nofhom	27.12	-53.96	-26.84	19.55	193.30

Simulation	Δ LWCF	Δ SWCF	Δ CF	Δ IWP	Δ CDNUMI
Default	0.51	-1.95	-1.44	0.12	5.60
New	0.46	-2.01	-1.55	0.12	8.46
NoPreice	2.37	-4.51	-2.14	1.21	327.38
Nofhom	0.53	-2.13	-1.60	0.14	13.10

Δ indicate the changes (present-day minus pre-industrial times).

Summary

- Refining ice nucleation parameterization in cirrus clouds in CAM5
  1) Remove the two limiters in the representation of ice nucleation
  2) Implement the preexisting ice crystal effect on ice nucleation
  3) Introduce the homogeneous nucleation fraction by considering in-cloud variability in ice saturation ratio & temperature
- Improve the comparison with ice microphysics observations, compared to the default model
- SWCF and LWCF are 1-2 W m^{-2} difference from those in default model; Aerosol LW indirect forcing is reduced by ~0.1 W m^{-2}