Effects of Preexisting Ice Crystals on Ice Nucleation in Cirrus Clouds

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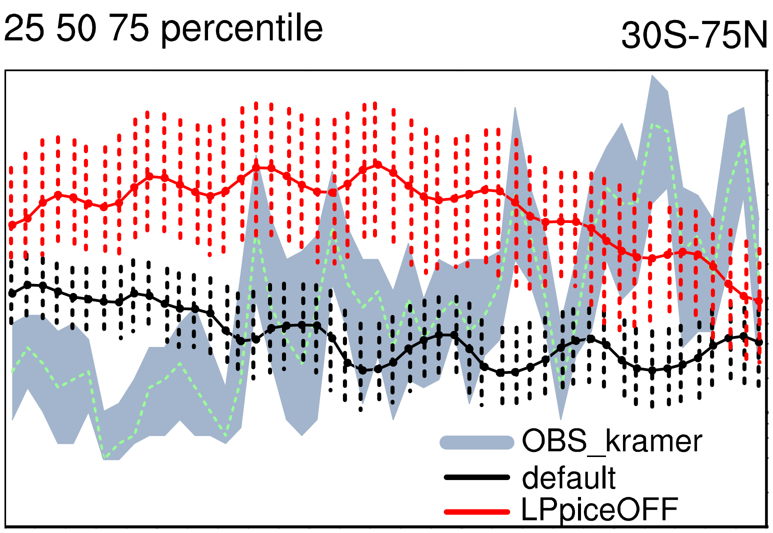
Motivations

Issues with representation of ice nucleation in CAM5

- An upper limit (0.2 m/s) is used for Wsubi, which drives ice nucleation parameterization in cirrus clouds
- A lower limit (0.1 μm) is used for sulfate aerosol size distribution in ice nucleation parameterization in cirrus clouds



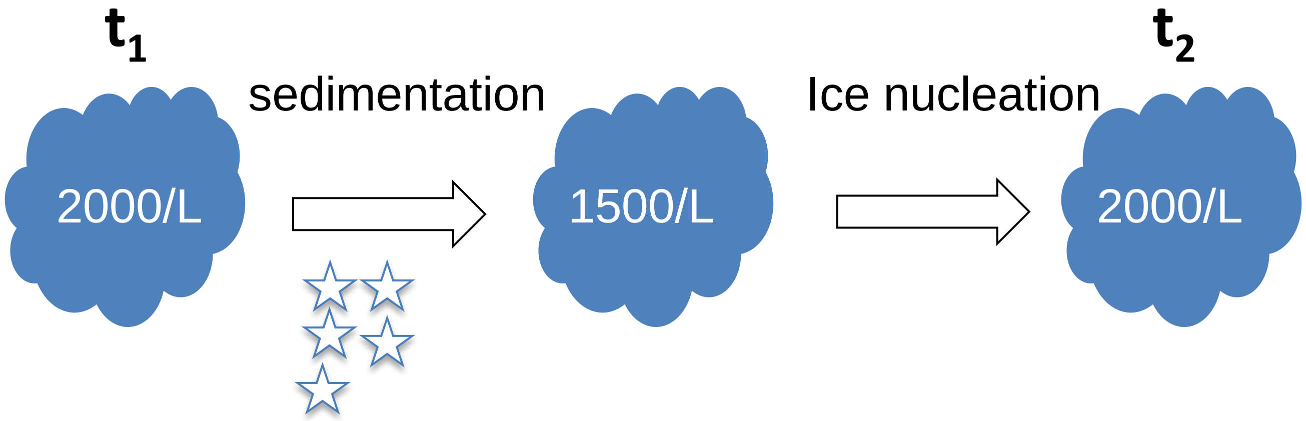
Ice nucleation treatment in cirrus clouds

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;

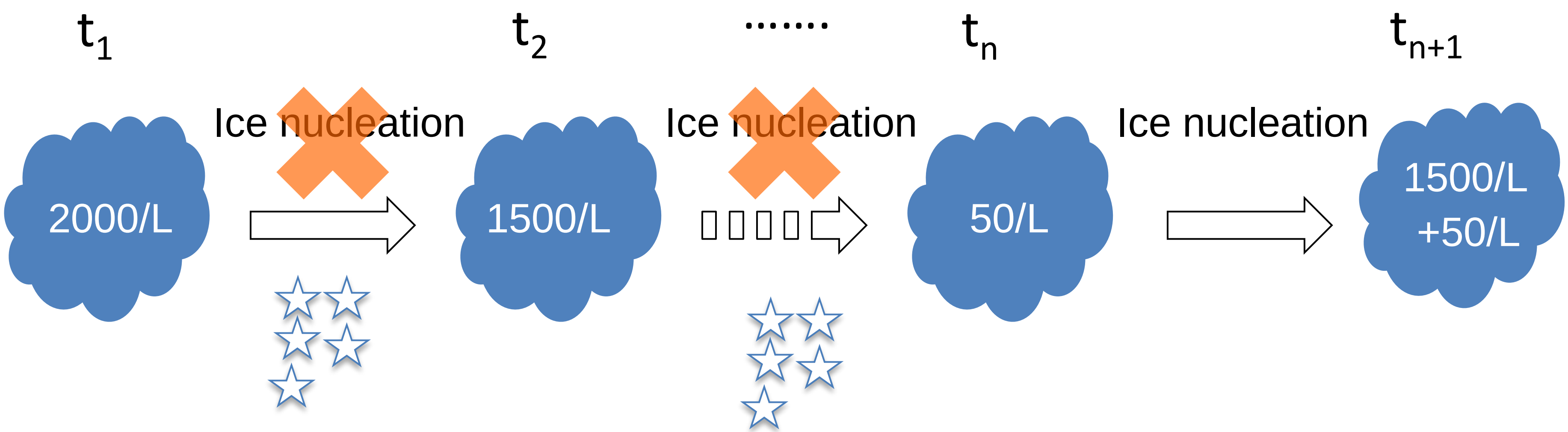
Schematic diagram of cirrus ice nucleation



Do not consider preexisting ice effect (default version)

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

Schematic diagram of cirrus ice nucleation



Consider preexisting ice crystals to consume water vapor during ice nucleation (this study)

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

$$\frac{\mathrm{re}}{\mathrm{d}t}$$

Deposition of water vapor on preexisting ice

$$w_{\mathrm{sub,\,pre}} = w_{\mathrm{sub}} \max\left(1 - \frac{N_{\mathrm{i,\,pre}}\pi\beta c\rho_{\mathrm{i}}A_{\mathrm{i}}(S_{\mathrm{hom}} - 1)}{2\lambda_{\mathrm{i,\,pre}}\alpha w_{\mathrm{sub}} S_{\mathrm{hom}}},\ 0\right)$$

Reducing vertical velocity (Wice)

Barahona et al. 2013; Kärcher et al. 2006

T=223 K	Rmean=10 μm	Rmean=25 μm	Rmean=50 μm
Ni (L^{-1})	Wice (cm/s)	Wice (cm/s)	Wice (cm/s)
1.	0.221	0.580	1.181
2.	0.441	1.161	2.363
5.	1.103	2.902	5.907
10.	2.206	5.804	11.813
20.	4.412	11.607	23.626
50.	11.030	29.018	59.066
100.	22.061	58.036	118.132
200.	44.121	116.072	236.263

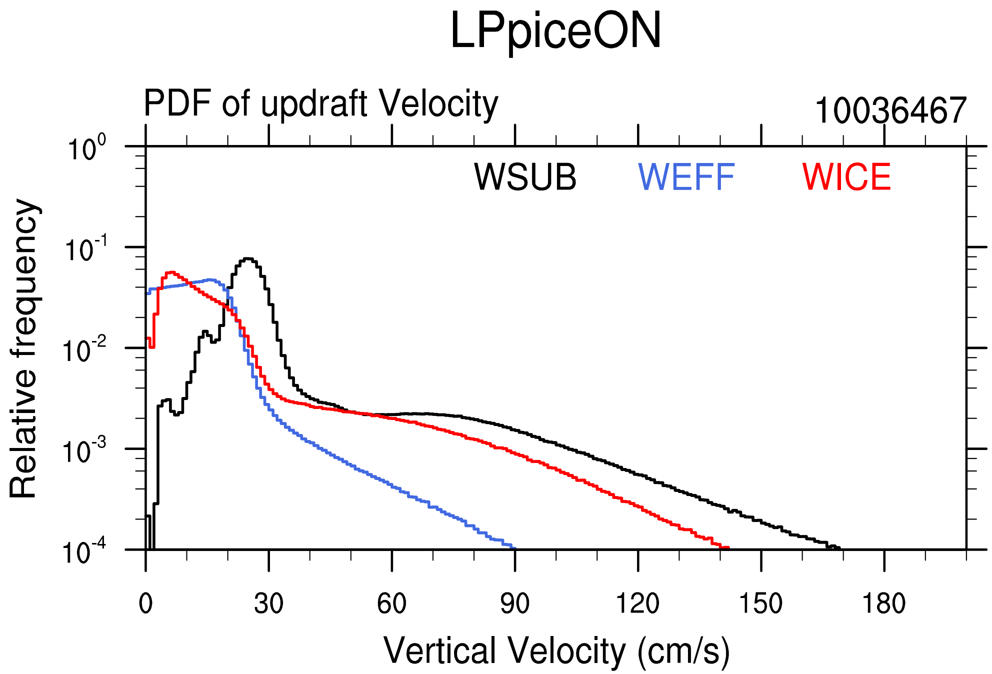
Rmean: mean preexisting ice radius
Ni: preexisting ice number

Si=1.5

Implement preexisting ice effect in CAM5.3

Liu & Penner 2005 (default); Barahona et al. 2013; Kärcher et al. 2006

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



3-hourly output at the grids where ice nucleation occurs

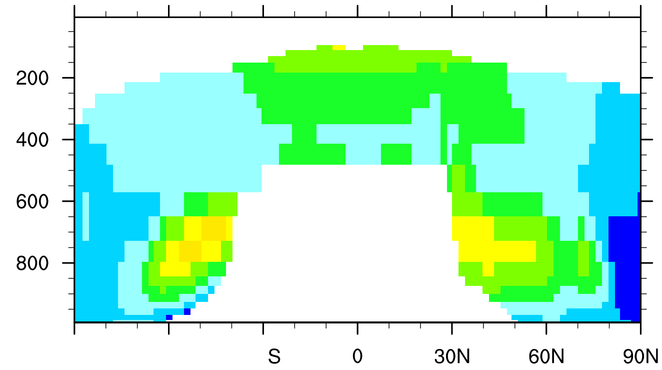
CAM5.3 simulations

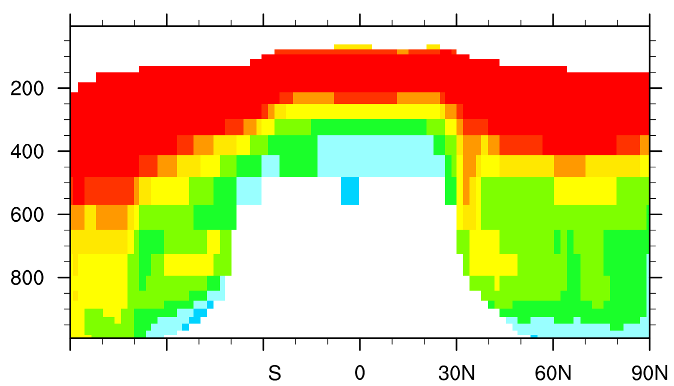
Simulation	Wsubi upper limiter Sulfate size limiter	Preexisting ice	Ice nucleation parameterization
Default	yes	off	LP
LPpiceOFF	no	off	LP
LPpiceON	no	on	LP
BNpiceOFF	no	off	BN
BNpiceON	no	on	BN
KLpiceOFF	no	off	KL
KLpiceON	no	on	KL

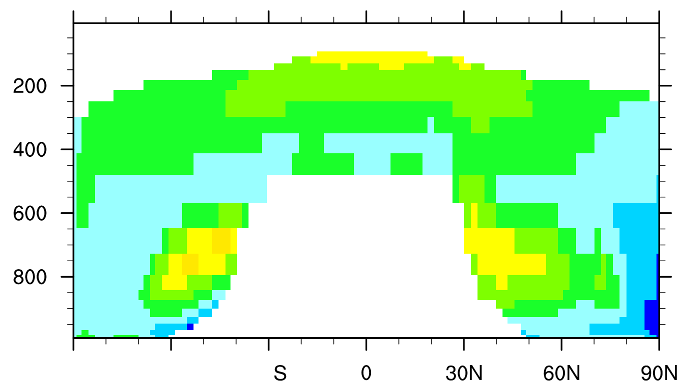
LP: Liu & Penner 2005
BN: Barahona et al. 2013
KL: Kärcher et al. 2006

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

In-cloud ice number concentration



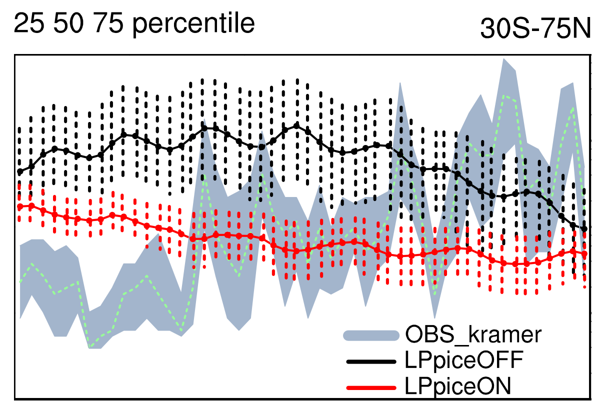


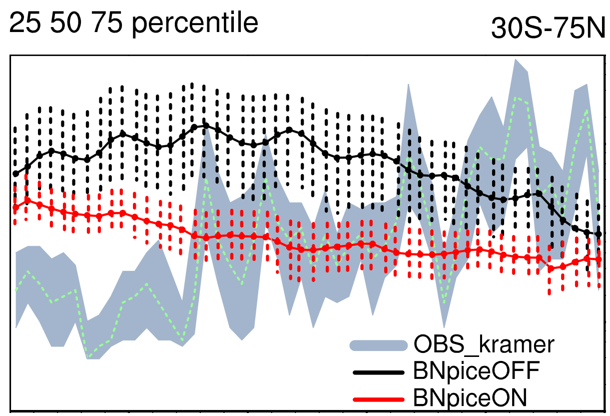


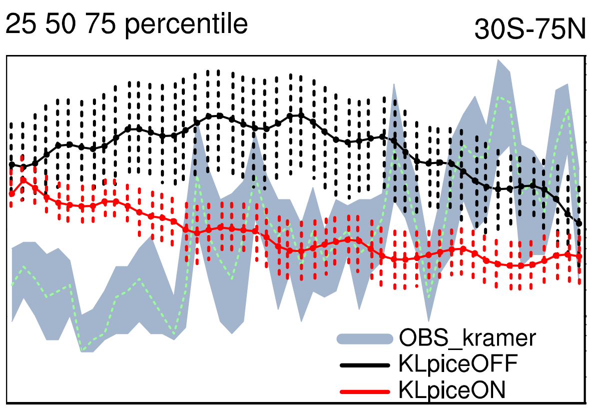
Liu & Penner (2005)

Ice number versus temperature

Liu & Penner 2005



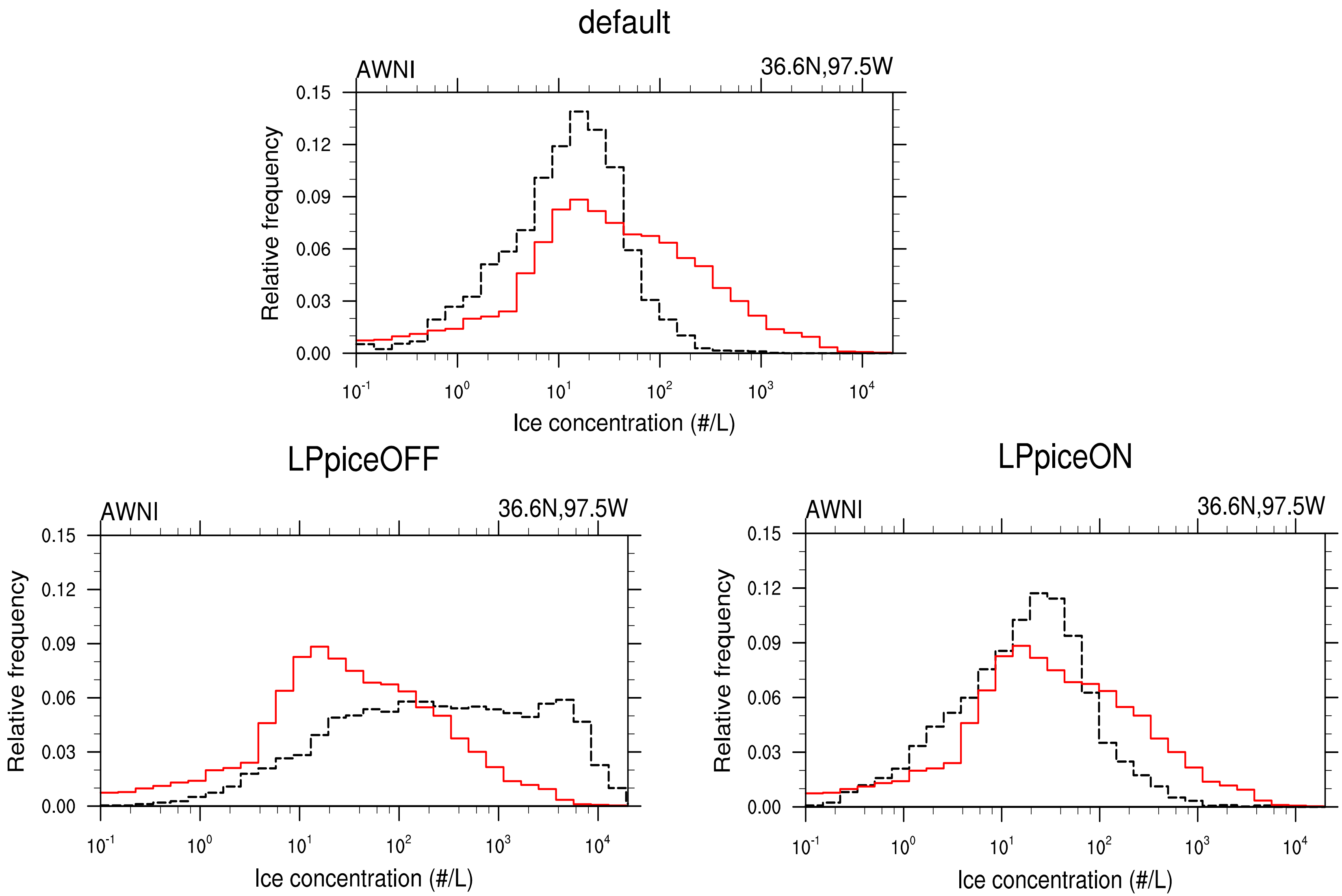




Barahona et al. 2013

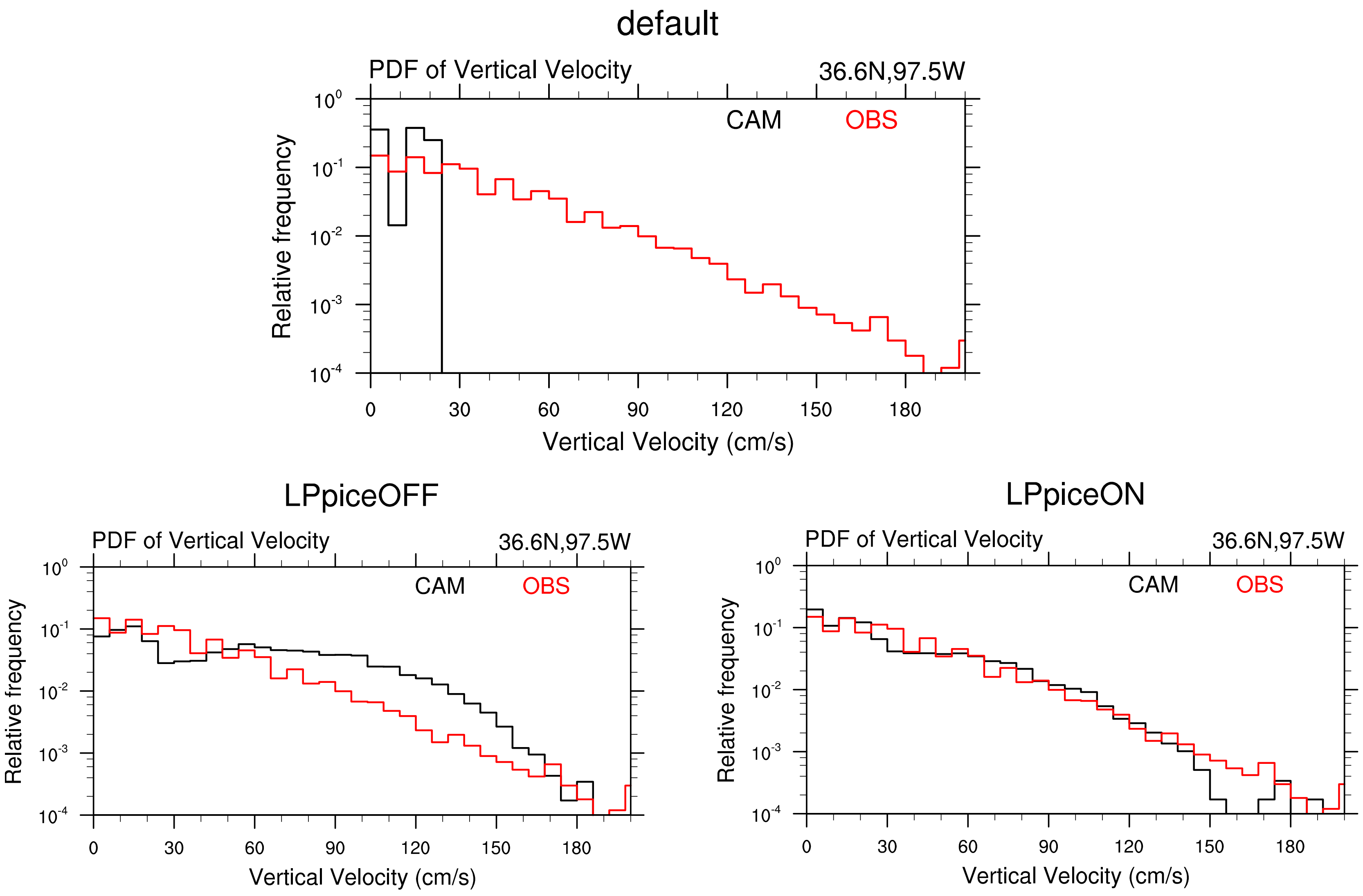
Kärcher et al. 2006

PDF of in-cloud ice number



Red line: SPARTICUS observations over ARM SGP site (Jan-Jun 2010)
Black line: model results output 3 hourly

PDF of sub-grid updraft velocity (Wsub)



Red line: SPARTICUS observations over ARM SGP site (Jan-Jun 2010)
Black line: model results output 3 hourly

Global means

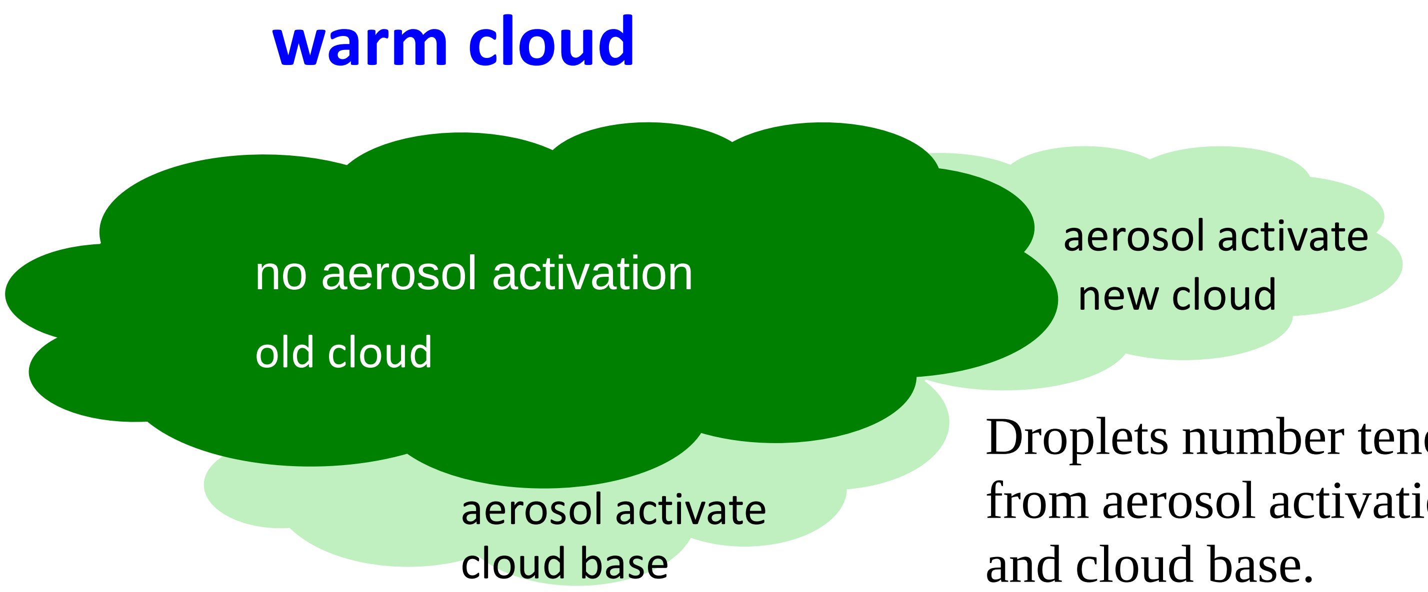
Simulation	LWCF	SWCF	CF	IWP	CLDHGH
Default	24.0	-53.2	-29.1	17.7	38.2
LPpiceON	25.8	-54.5	-28.8	19.2	37.4
BNpiceON	26.4	-54.9	-28.5	19.2	37.6
KLpiceON	26.3	-55.0	-28.7	19.2	37.9

Simulation	LWCF	SWCF	NET	IWP	CLDHGH
Default(PD-PI)	0.54	-1.65	-1.11	0.17	0.07
LPprice(PD-PI)	0.42	-1.64	-1.22	0.17	0.18
BNprice(PD-PI)	0.41	-1.57	-1.16	0.12	0.06
KLprice(PD-PI)	0.22	-1.46	-1.24	0.00	-0.03

Summary

- Preexisting ice crystal effect on ice nucleation in cirrus clouds is implemented in CAM5.3
- Remove the two limiters in the representation of ice nucleation
- 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 indirect forcing is ~0.1 W/m^2

Droplet activation in warm clouds



Droplets number tendency comes from aerosol activation in new cloud and cloud base.