Convective self-aggregation in a cloud resolving model at very low temperatures

Ringberg, 25 March, 2014

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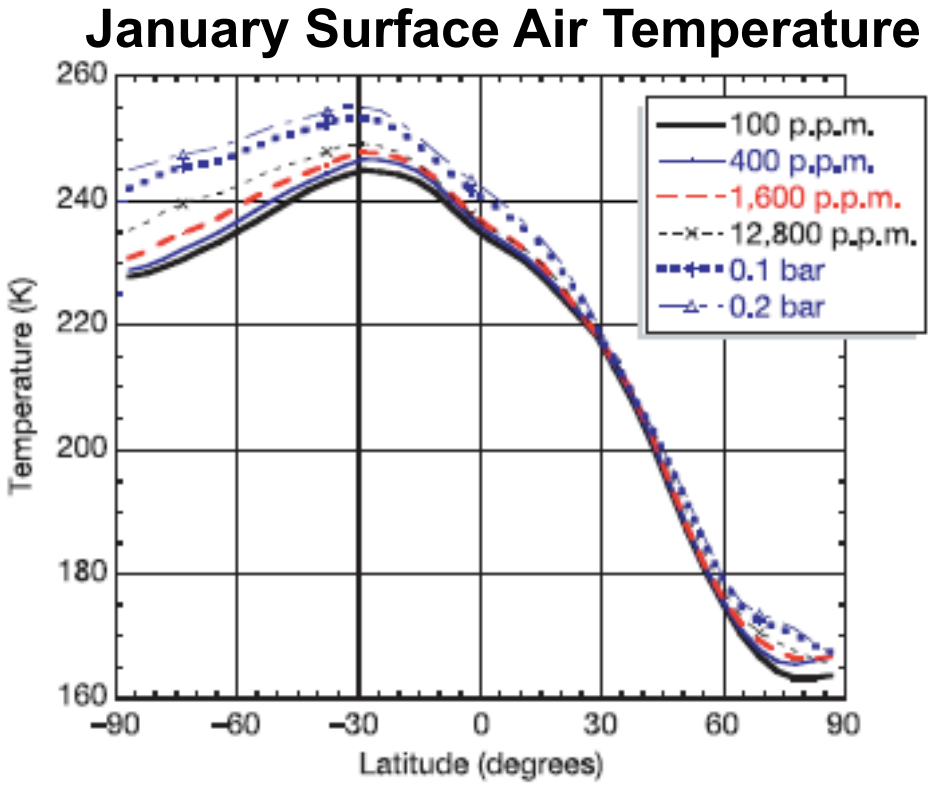
An ENIGMA: Model-data mismatch for Snowball deglaciation.

Pioneering FOAM GCM results indicated that **>>20% CO_2** might be needed to deglaciate a Snowball.



[Pierrehumbert, 04,05]

But geological observations seem to indicate the maximum CO_2 was 1-8%!!!

[Bao et al., 08,09]

Clouds can warm a Snowball enough to explain deglaciation when CO_2 is increased.

Model	CRF_{LW}	CRF_{SW}	CRF
FOAM	3	-1	1
LMDz	15	-4	11
SAM	16	-2	14
CAM	18	-4	15
SP-CAM	23	-4	19
ECHAM	22	-2	21
GENESIS	34	1	35

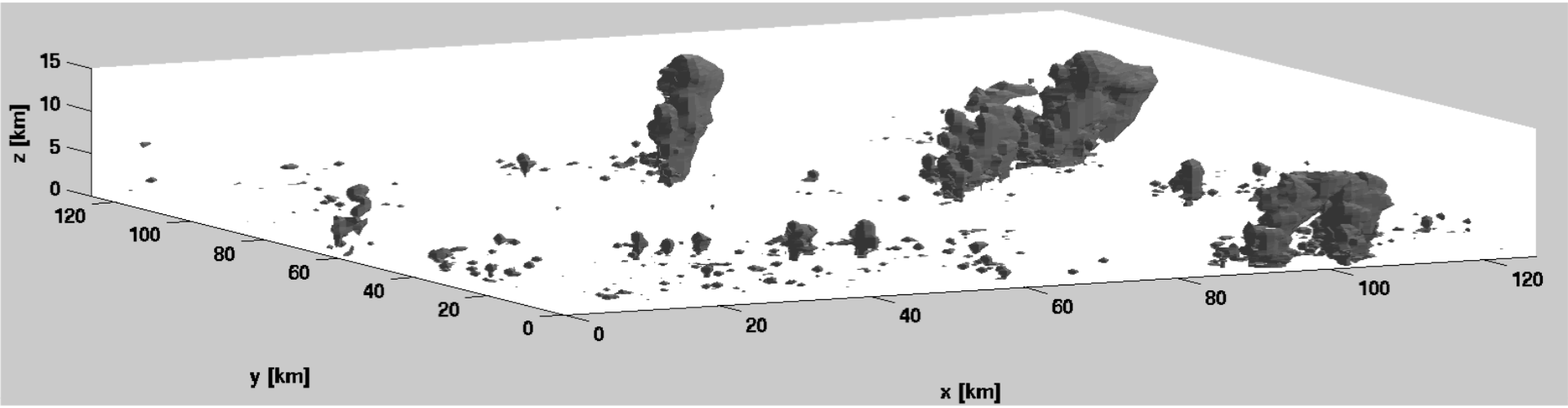
Within a factor of two is good enough for this problem.

IPCC Class GCM
Superparameterized GCM
Cloud Resolving Model

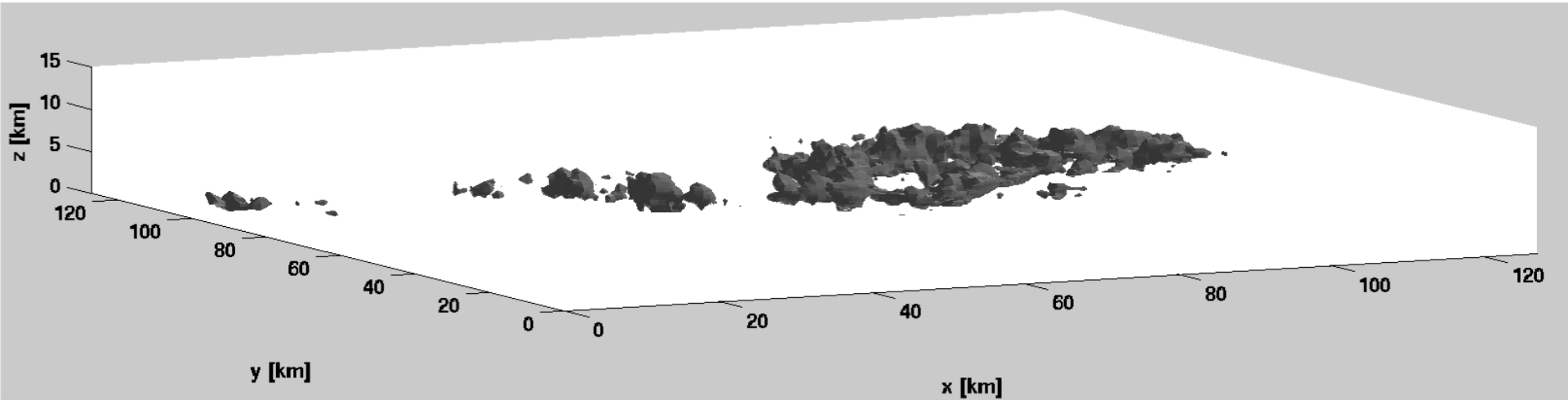
Abbot et al., GRL, 2012
Abbot, J. Cli., 2014

Snowball clouds somewhat resemble thin stratocumulus clouds under an inversion in the modern climate.

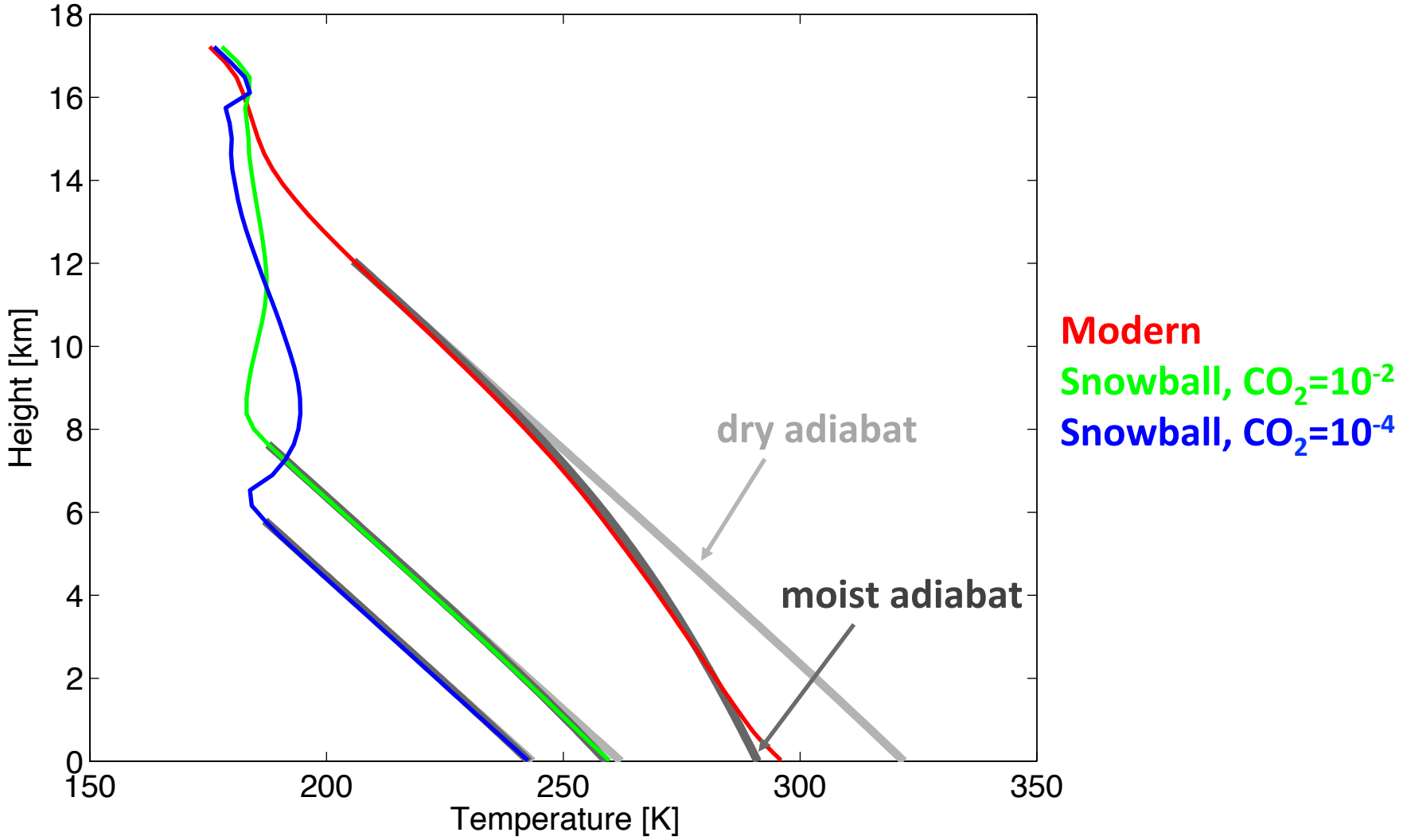
Clouds in modern tropics simulation in SAM



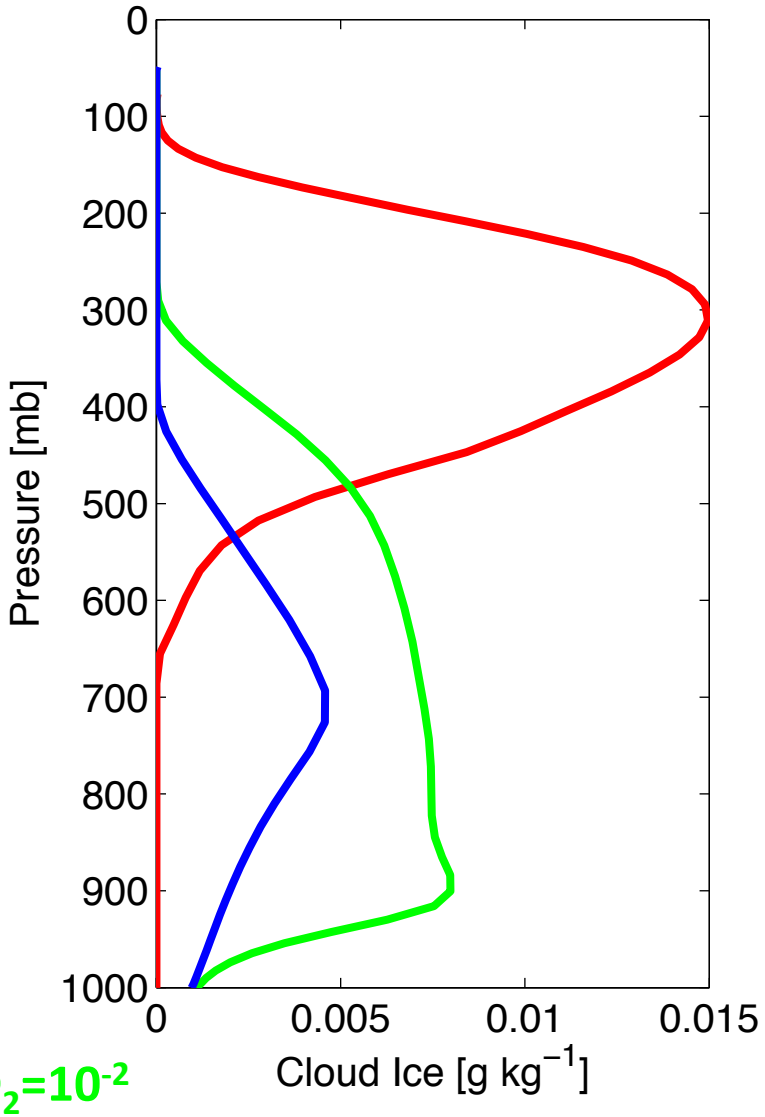
Clouds in Snowball simulation in SAM

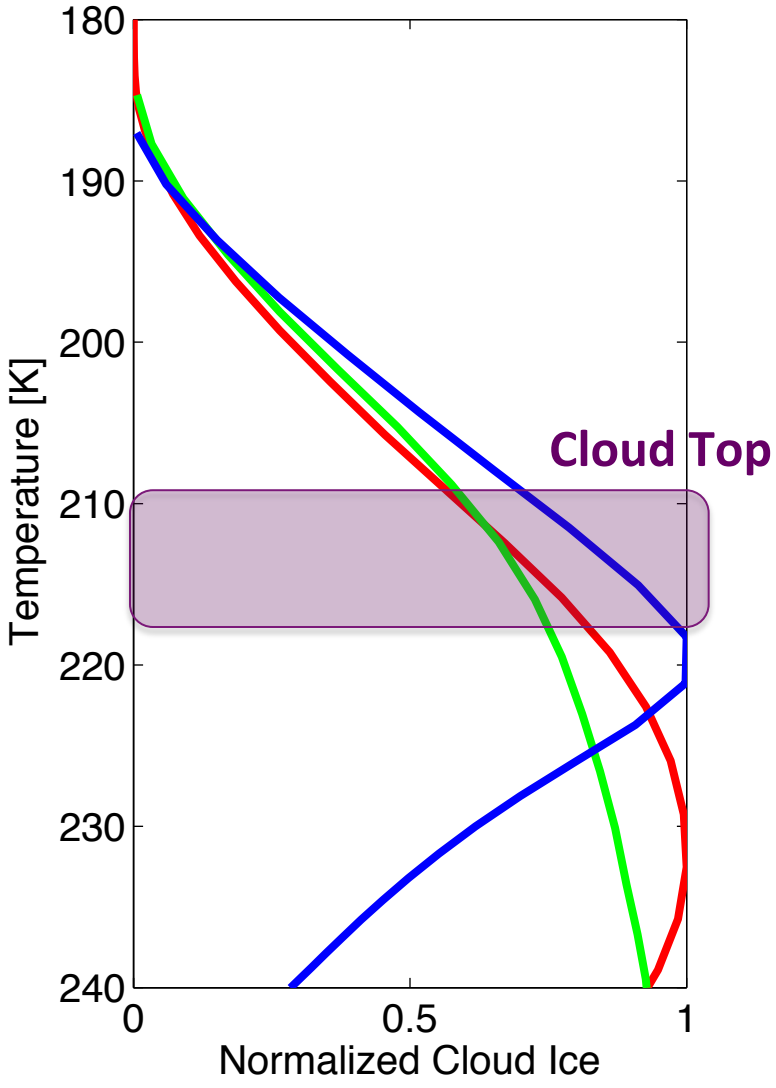


Snowball convection is dry in the sense that condensation does not significantly alter the temperature profile.



The Fixed Anvil Temperature (FAT) hypothesis is useful for understanding the height of Snowball convection.





Modern

Snowball, CO_2=10^{-2}

Snowball, CO_2=10^{-4}

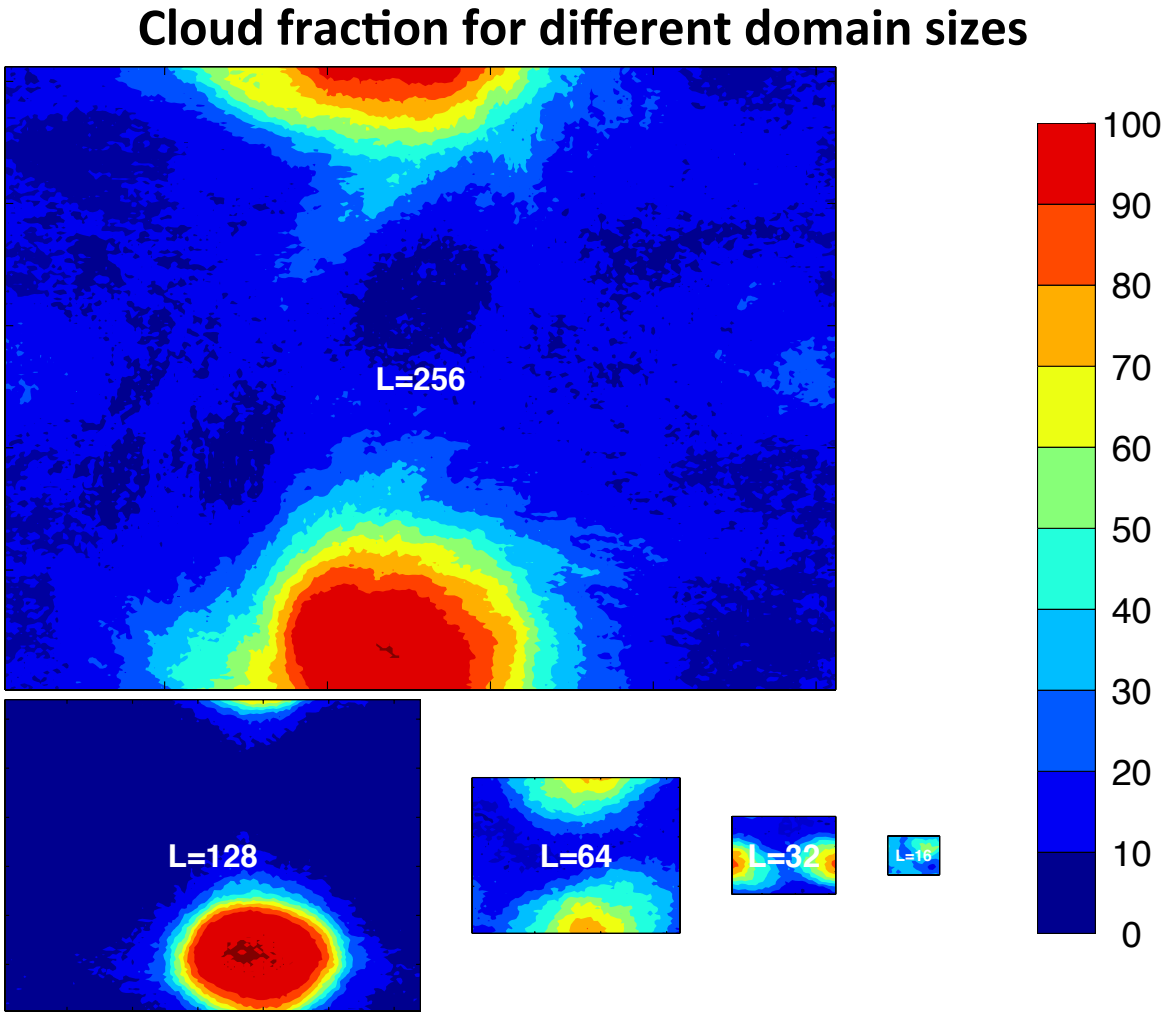
FAT due to Hartmann and Larson, 2002

Because LW dominates Snowball CRF, results are insensitive to large changes in the microphysical scheme.

test simulation	T_s [K]	CRF_{sw} [W m^{-2}]	CRF_{lw} [W m^{-2}]	CRF [W m^{-2}]
reference, CO_2=10^{-4} vmr	245	-2	16	14
$E_{si} \downarrow$	245	-2	16	14
$E_{si} \uparrow$	245	-2	16	14
$E_{gi} \downarrow$	245	-2	16	14
$E_{gi} \uparrow$	245	-2	16	14
$q_{ci} \downarrow$	245	-1	16	15
$q_{ci} \uparrow$	245	-2	16	14
$\beta \downarrow$	245	-2	16	14
$\beta \uparrow$	245	-2	16	14
$T_{l0} \downarrow$	245	-2	18	15
$v_i \downarrow$	257	-5	37	31
$v_i \uparrow$	242	0	10	9
r_{ei}, $r_{el} \downarrow$	244	-5	19	14
r_{ei}, $r_{el} \uparrow$	245	1	13	14

Slow sedimentation is the main cloud ice removal process.

With no shear, convective self-aggregation is extremely favorable in the Snowball climate, even for very small grid sizes.



The surface temperature of these simulations is 243-254 K!

Any convective self-aggregation theory should be able to explain why it is so favorable in the Snowball.

Cold pools are common where there is vigorous deep convection and destroy convective self-aggregation (Jeevanjee and Romps 2013). Maybe the Snowball runs have fewer/weaker cold pools?

LW cooling could be very high in cold, dry regions, which would promote convective self-aggretation (Muller and Held 2012).