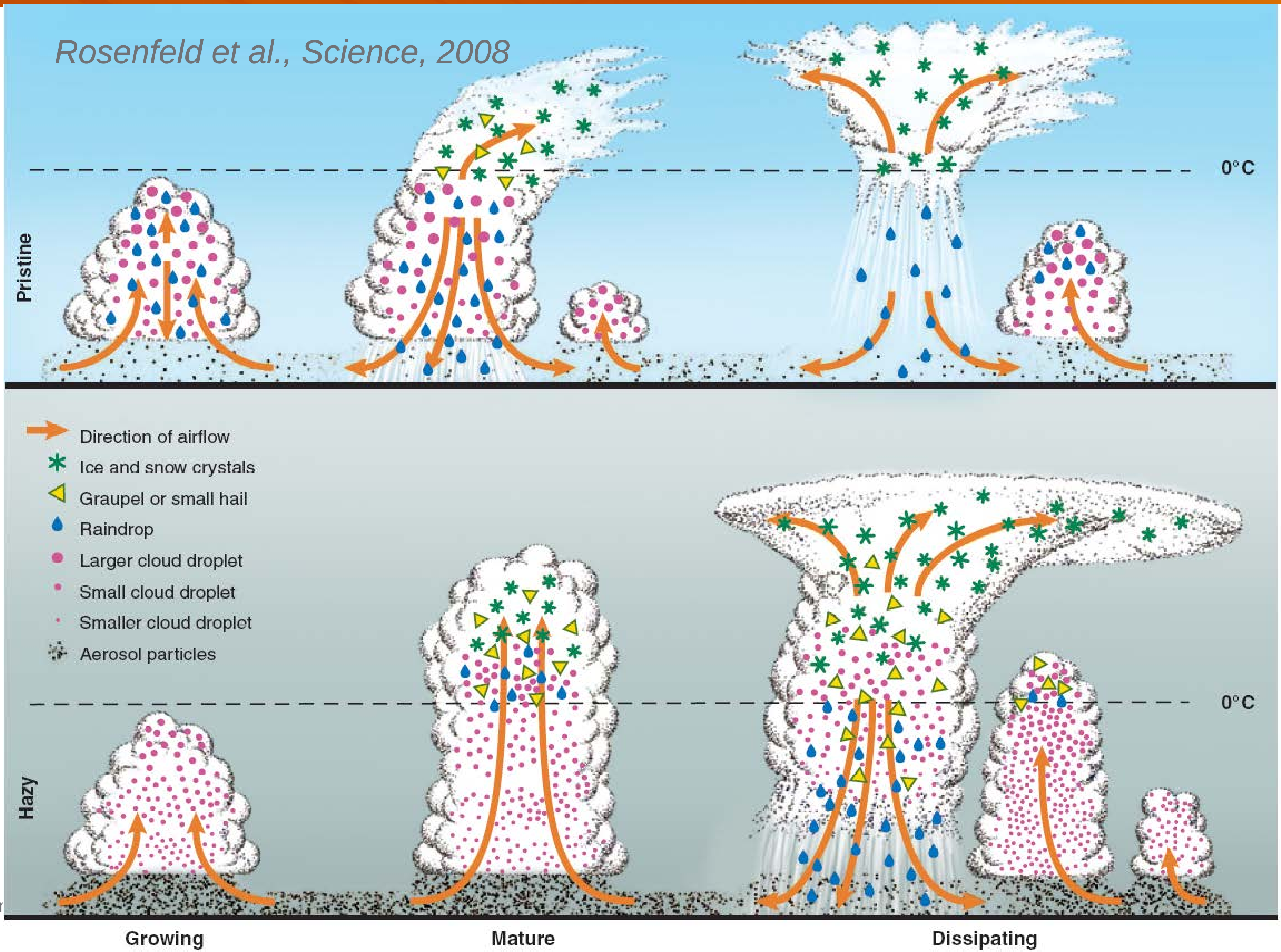
Challenges for Aerosol Effects on Deep Convective Clouds

JIWEN FAN

Pacific Northwest National Laboratory

Richland, WA

Concept model – cloud scale

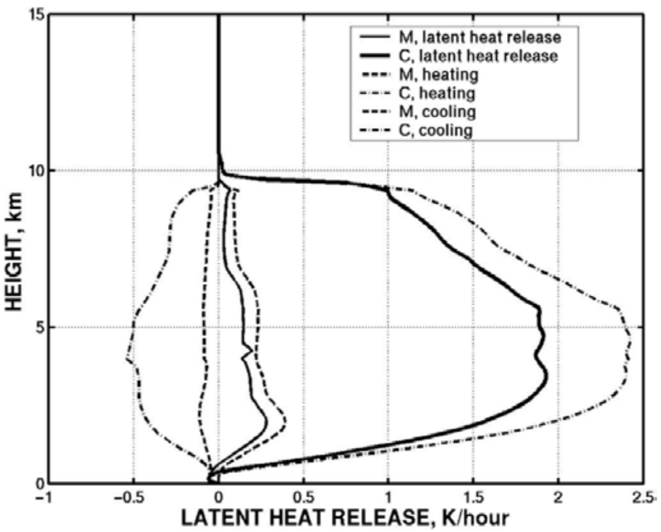


- The timescale of dynamical responses (i.e., system adjustment timescale) to latent heating, and the feedback to/from the large-scale environment.
- Impact of wind shear on buoyancy and cold pool in different storm systems; Storm dynamics: wind shear-cold pool interactions.
- How significant are the microphysical effect of aerosols? Is microphysical effect or invigoration effect dominating at longer time scale over large space?

1. System adjustment timescale to latent heating

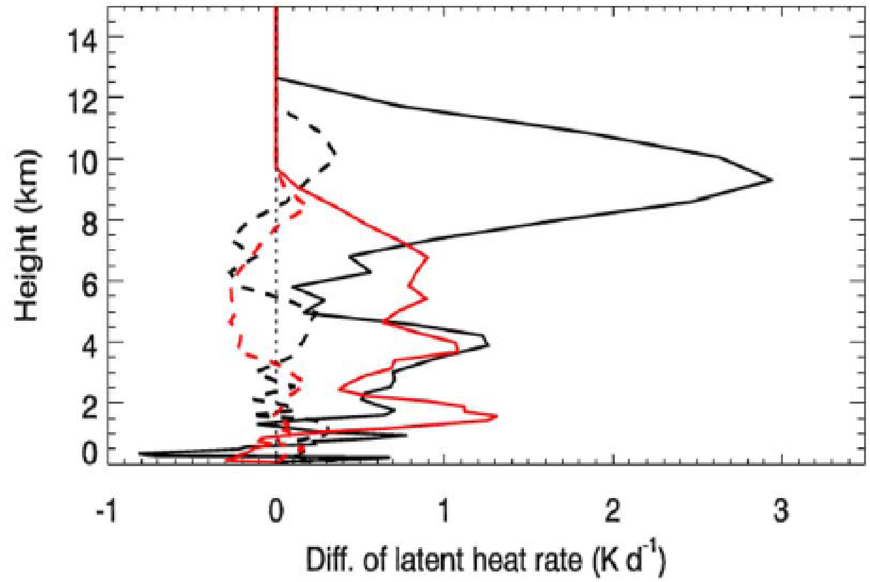
Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

Tropical oceanic convection - GATE



Khain et al. 2005, QJR

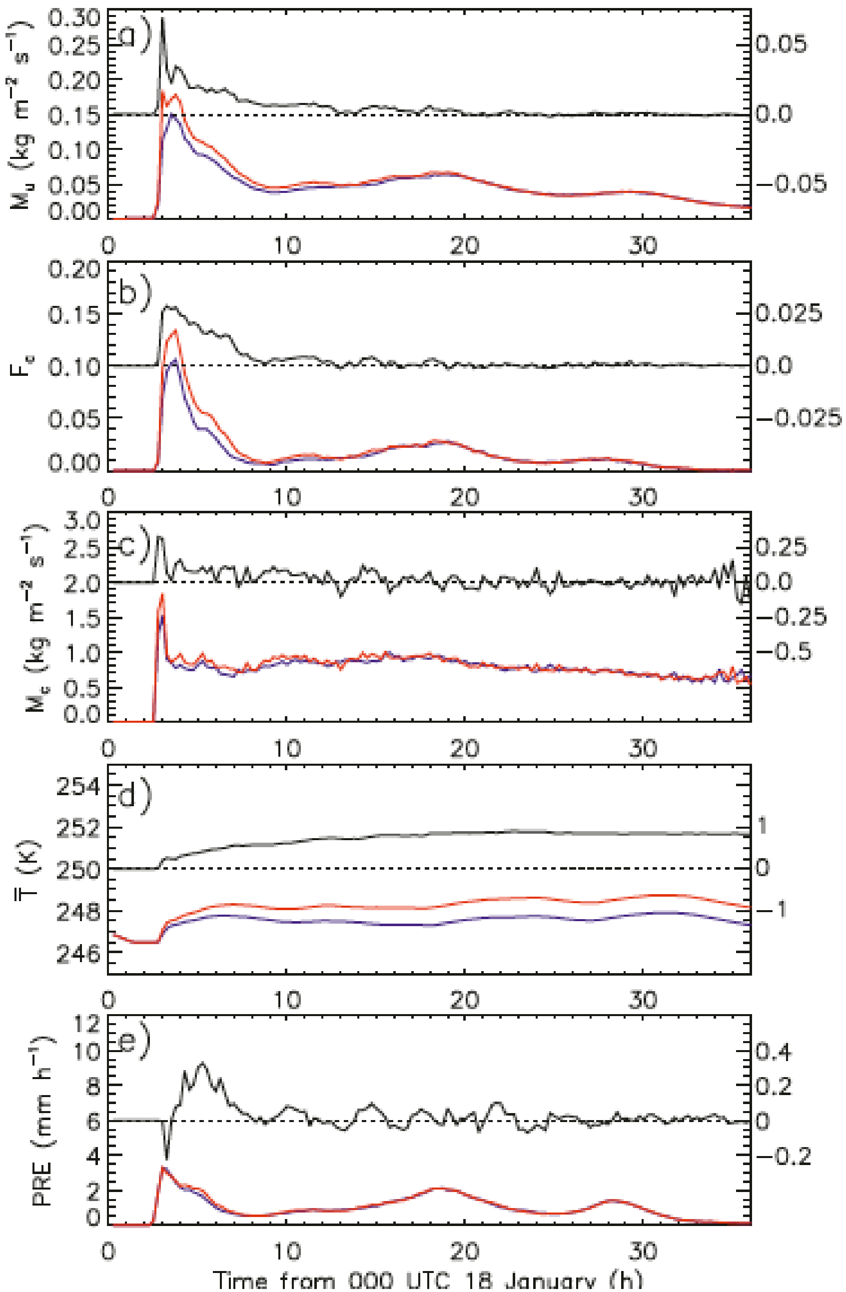
Mid-latitude warmed-based (black) and cold-based (red) convection



Fan et al. 2012, GRL

Response to heating and cooling

Morrison and Grabowski, 2013, JAS



- Rapid adjustment within the first few hours after convective initiation
- Convective vertical mixing timescale is ~ 1 d

Response to partially perturbed domain

unperturbed **perturbed** **unperturbed**

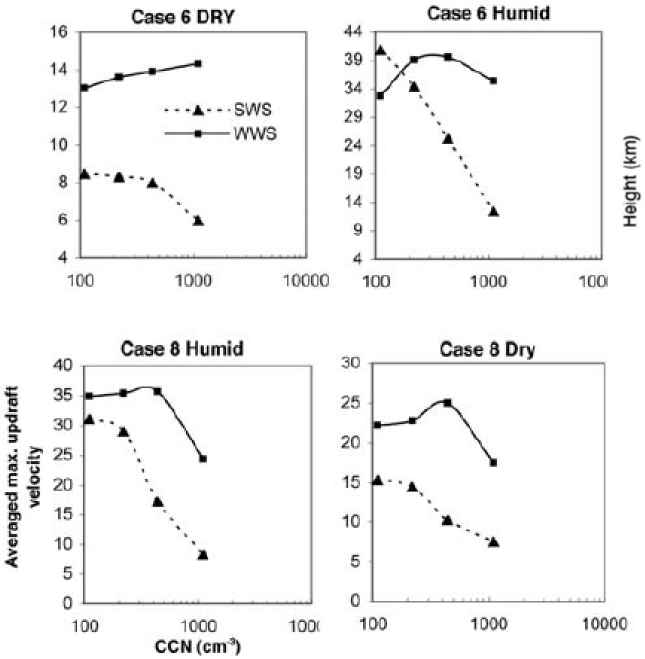
0° C

- Buoyancy anomalies were rapidly dispersed by gravity waves. Little heating directly drives convective invigoration.

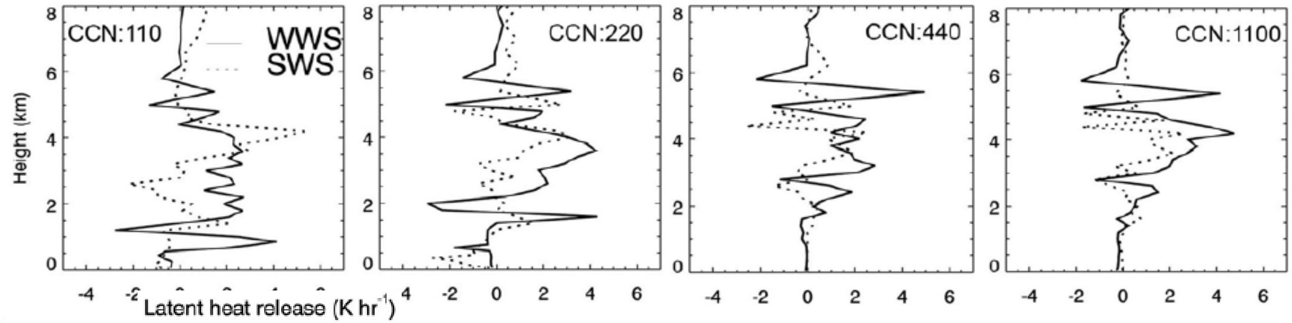
- **Tropical convection: convection was in near-equilibrium with the large-scale forcing**

- **Mid-latitude convection: non-equilibrium with its environment; system may not be able to adjust like the equilibrium system. Effects of latent heat may have a greater effect on convection.**

2. Impact of wind shear for different storm systems on buoyancy and cold pool; Knowledge on storm dynamics.



Fan et al. 2009, JGR

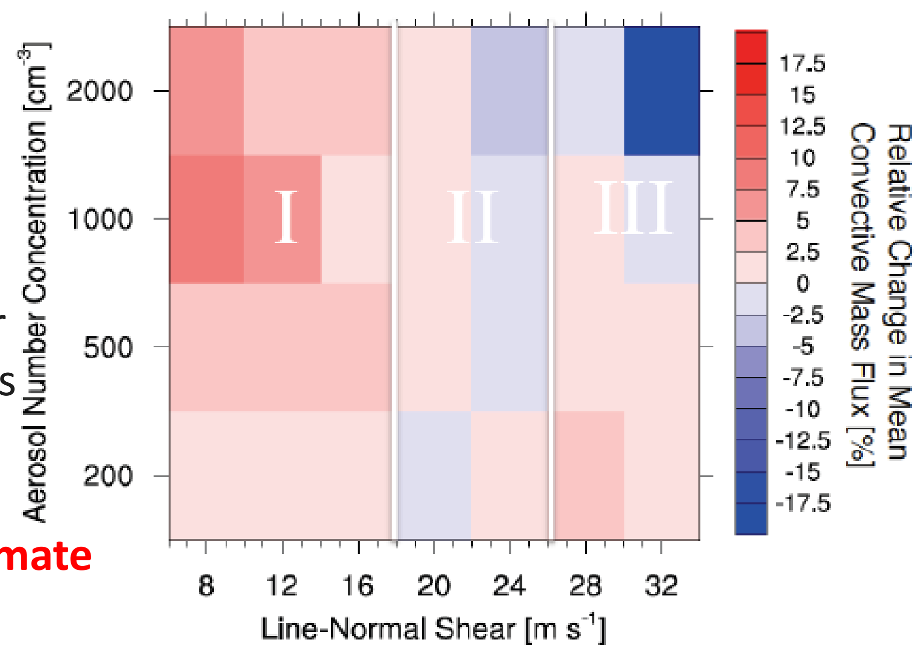


- **“RKW” theory (Rotunno et al. 1988)**

$\frac{c}{\Delta u}$ is closer to 1, the updraft is more upright

Lebo and Morrison, MWR, 2013

- Region I (weak wind shear): C/ΔU>> 1, C decreases as aerosol increases, leading to more upright updraft.
- Region II and III (stronger shear): C/ΔU≈ 1 or < 1, decreasing C in the polluted case leads to more tilted updraft.



Storm Dynamics session in 6th Aerosol-Cloud-Climate Interactions Symposium!

3. Microphysical and invigoration effects of aerosols

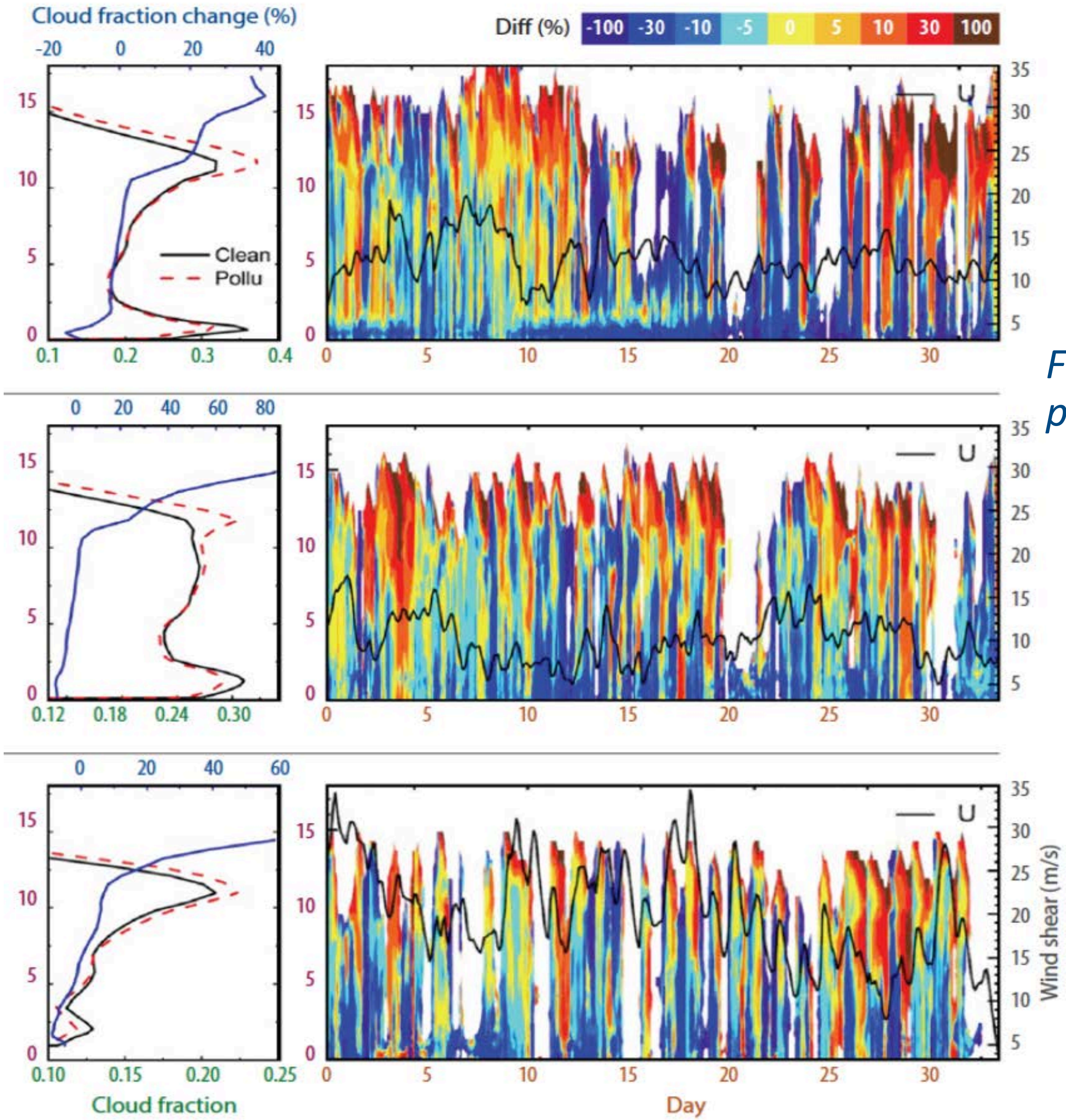
Pacific Northwest NATIONAL LABORATORY

Proudly Operated by Battelle Since 1965

TWP

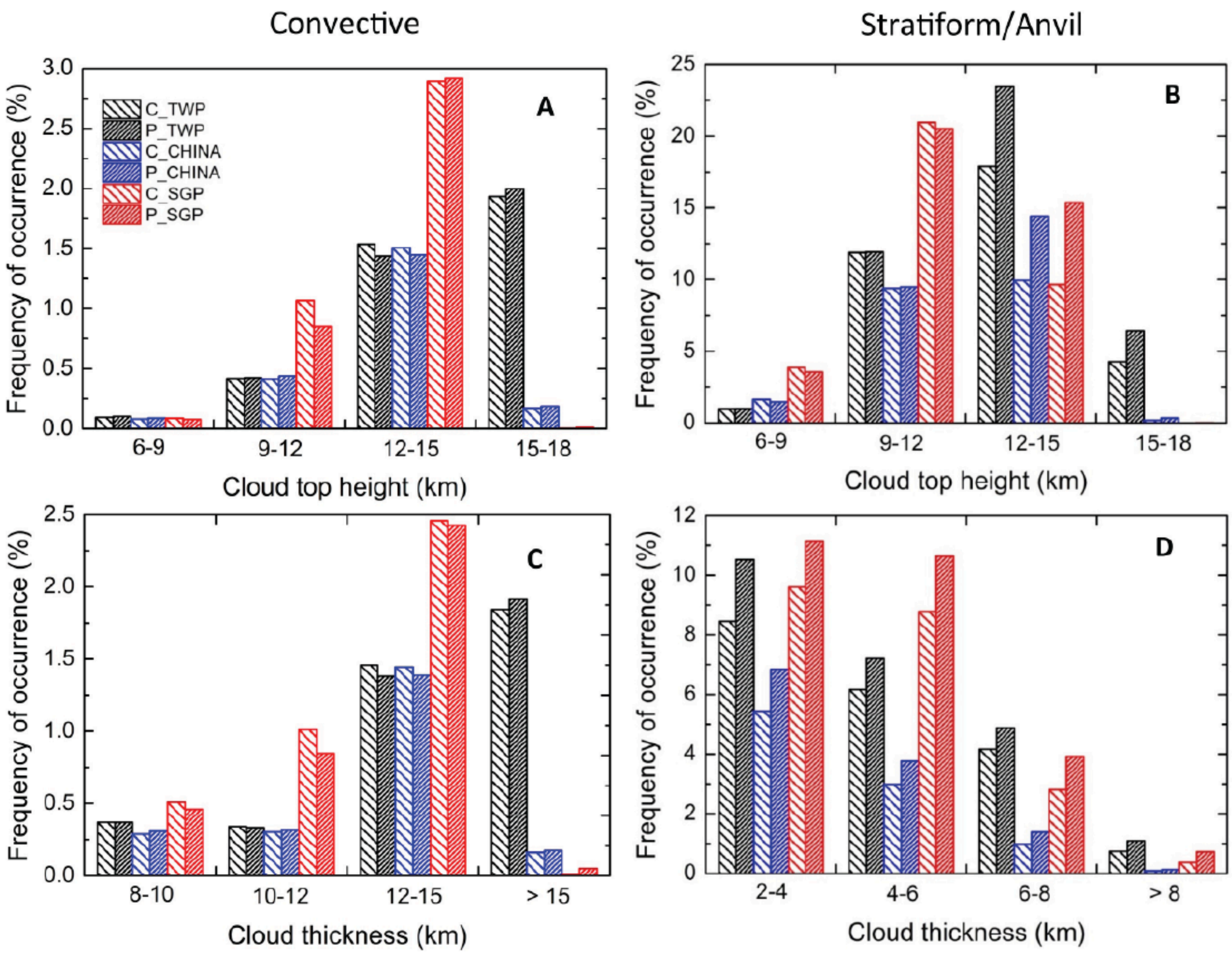
China

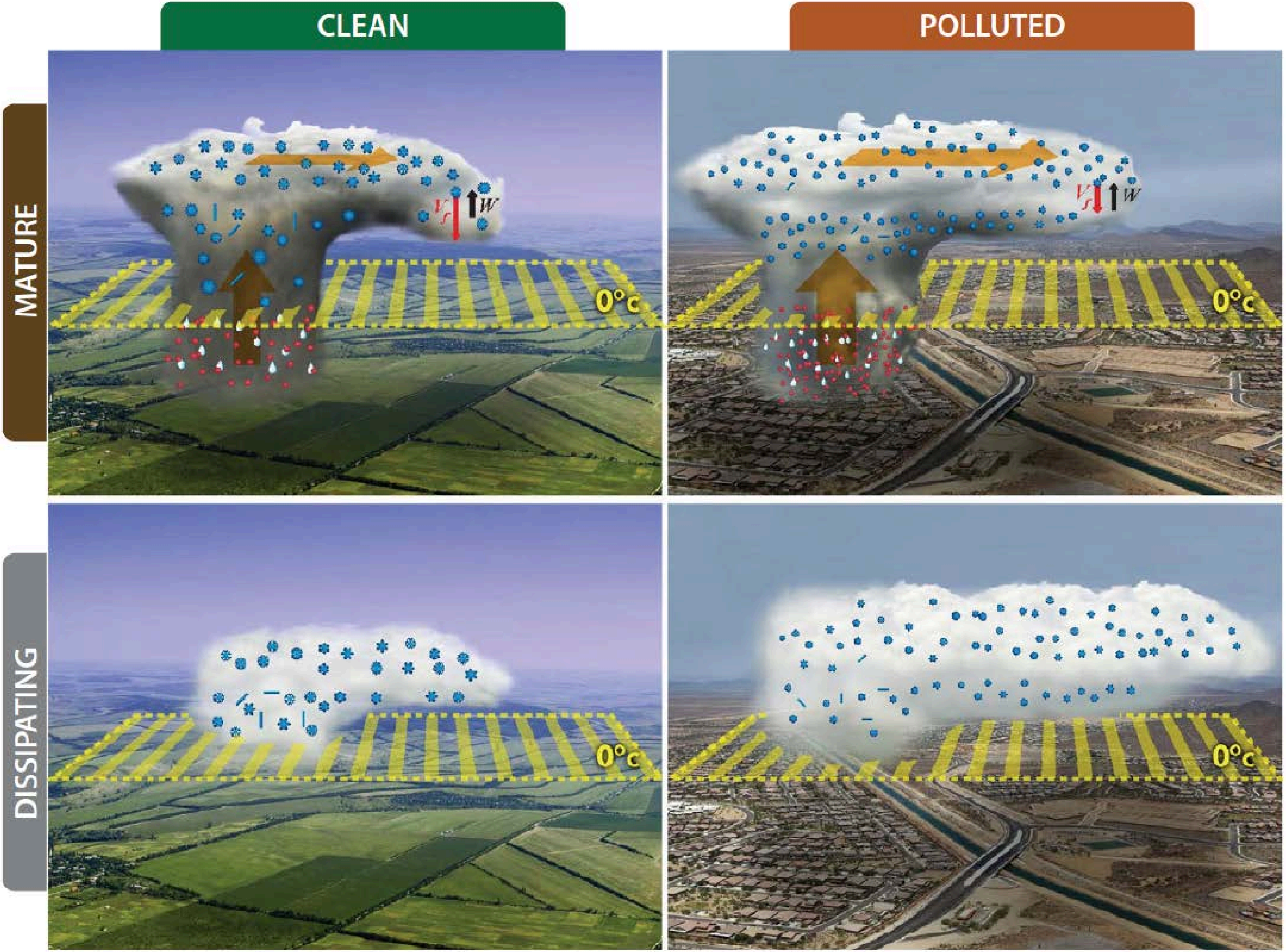
SGP



Fan et al., 2013, PNAS, in press

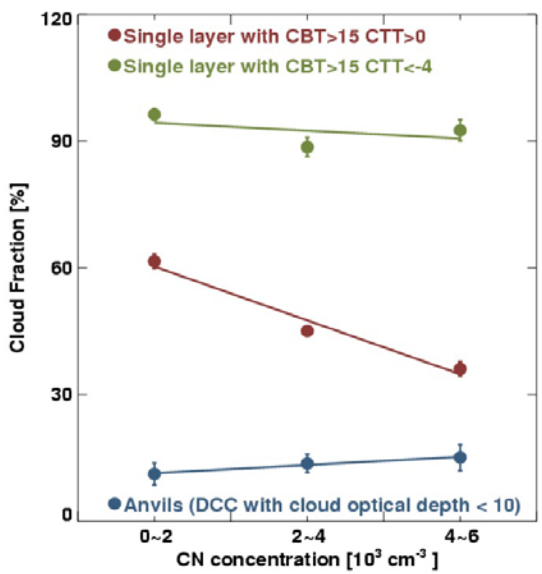
CTH and Cloud Thickness



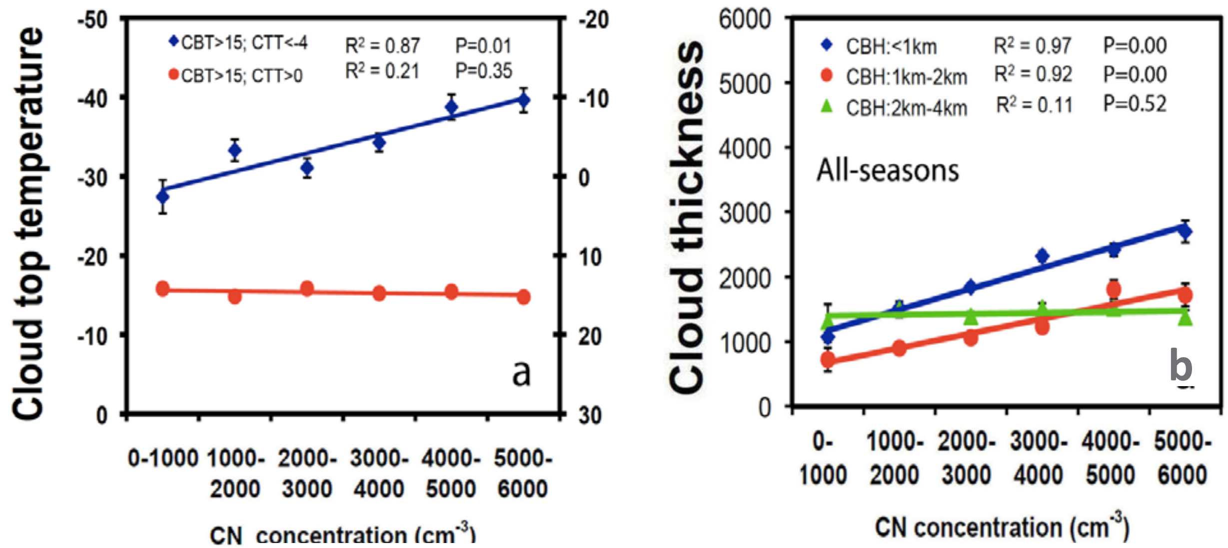


CLEAN
POLLUTED
MATURE
DISSIPATING
V_f
W
V_f
W
0°c
0°c
0°c
0°c

SGP

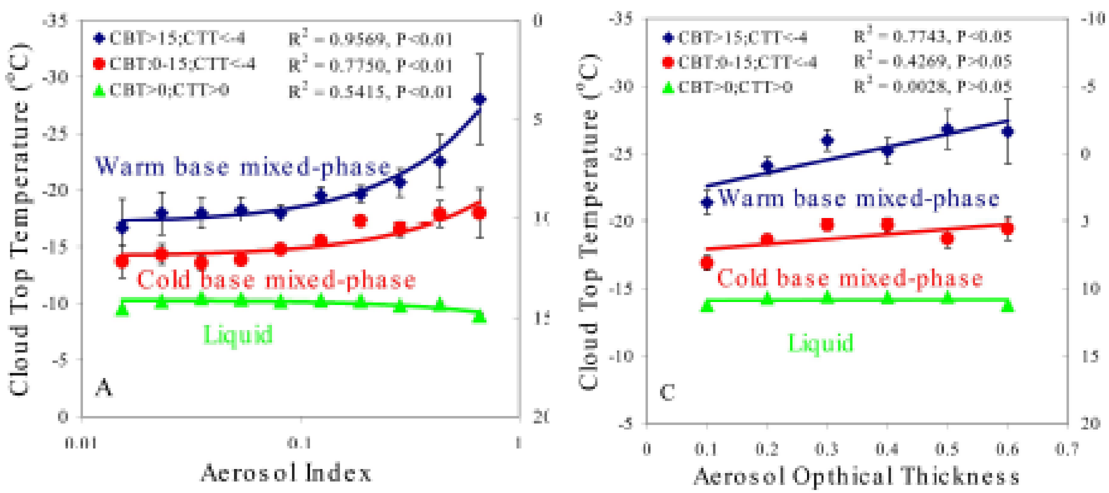


Li et al. (Nature-Geosci., 2011)

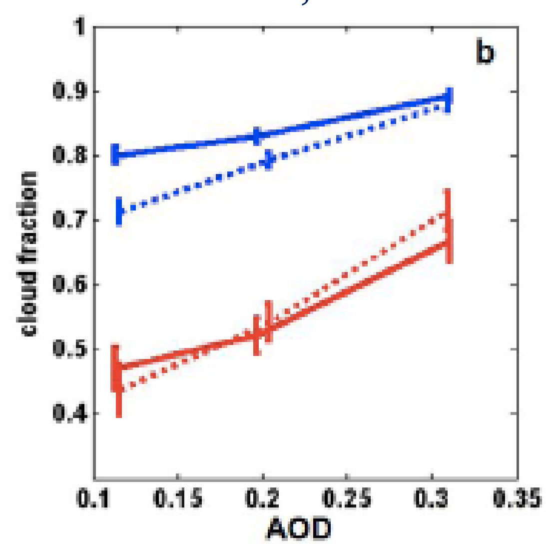


Aerosol condensation number (CN) (# /cm3)

Niu and Li, 2012



Koren et al., 2010



Radiative Effects

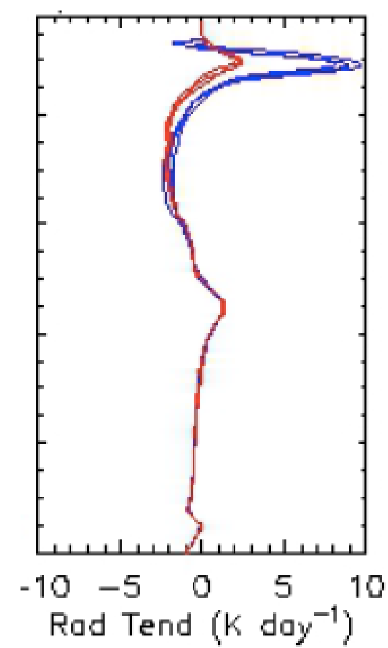
Morrison and Grabowski, ACP, 2011

C

		SW	+	LW	=	NET
TOA	(TWP)	-8.6±0.9		+5.6±0.5	=	-3.0
	(SEC)	-8.0±0.8		+4.3±0.5		-3.7
	(SGP)	-6.3±0.9		+4.4±0.5		-1.9
Atmosphere		-0.5		+5.2		+4.7
		-0.3		+3.4		+3.1
		-0.4		+3.4		+3.0
Surface		-8.1±0.8		+0.4±0.1		-7.7
		-7.7±0.7		+0.9±0.1		-6.8
		-5.9±0.9		+1.0±0.1		-4.9

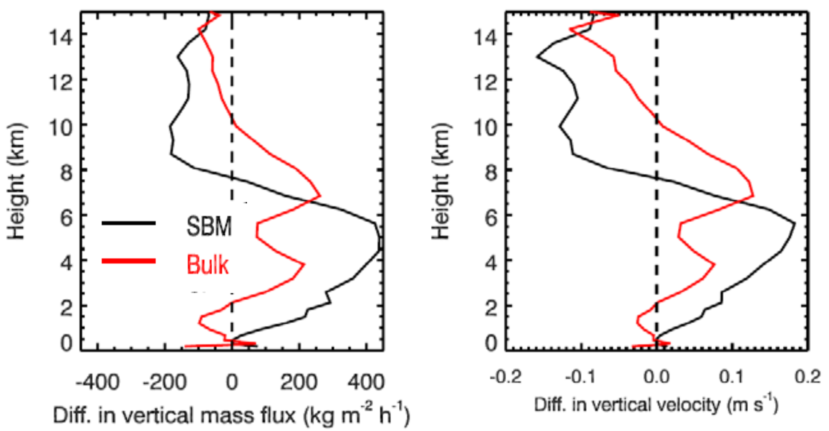
D

		SW	LW	LW
TOA	(TWP)	-17.8±1.5	+4.9±0.7	+6.7±0.8
	(SEC)	-14.3±1.2	+3.4±0.6	+5.8±0.8
	(SGP)	-9.7±1.4	+3.7±0.7	+5.7±0.7
Atmosphere		-0.9	+4.2	+6.7
		-0.6	+2.1	+5.4
		-0.6	+2.4	+5.3
Surface		-16.9±1.4	+0.7±0.1	0.0±0.0
		-13.7±1.1	+1.3±0.1	+0.4±0.0
		-9.1±1.3	+1.3±0.2	+0.4±0.1



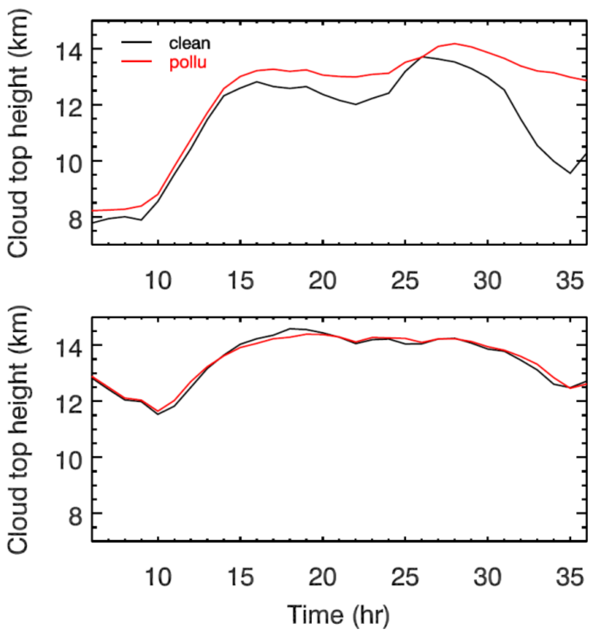
- Strong upper level radiative warming stabilizes atmosphere, leading to weaker convection.

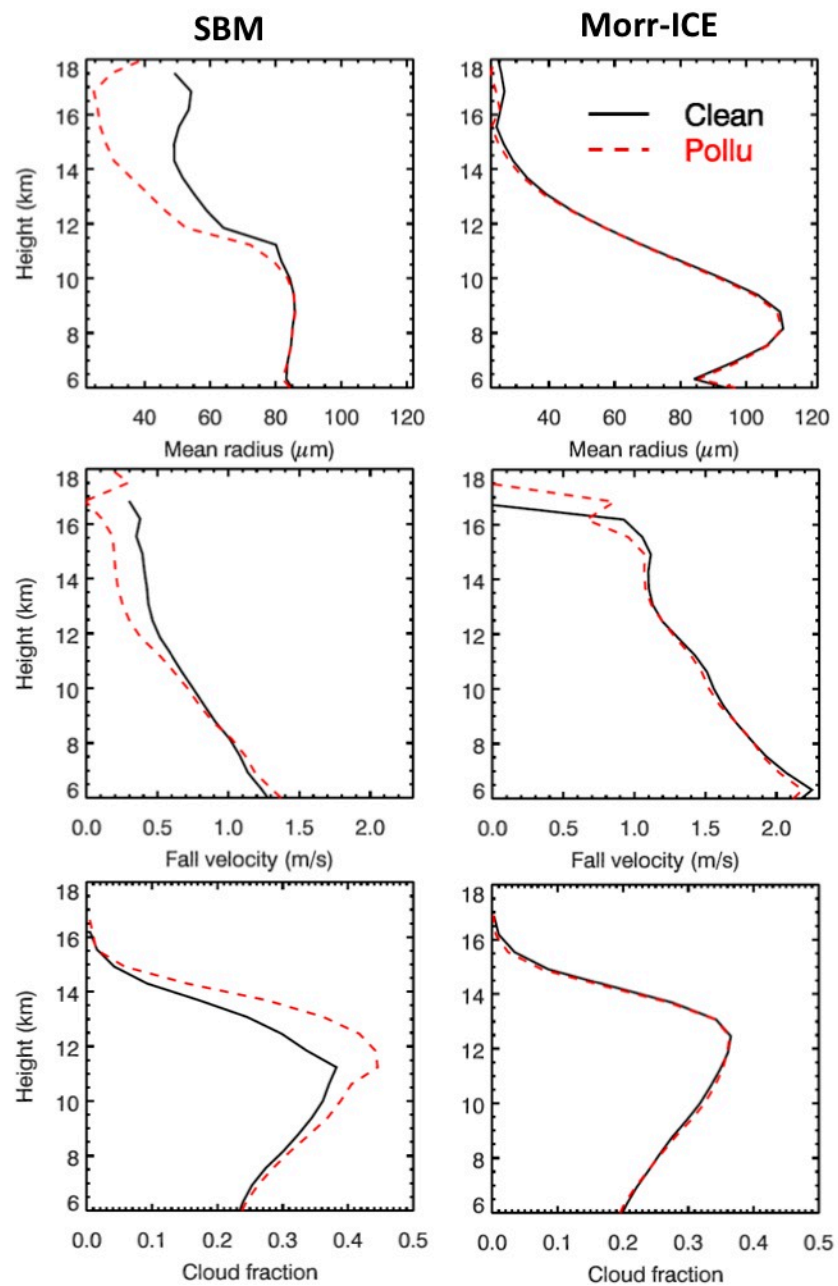
4. Two-moment bulk scheme problems



SBM

Morr-ICE

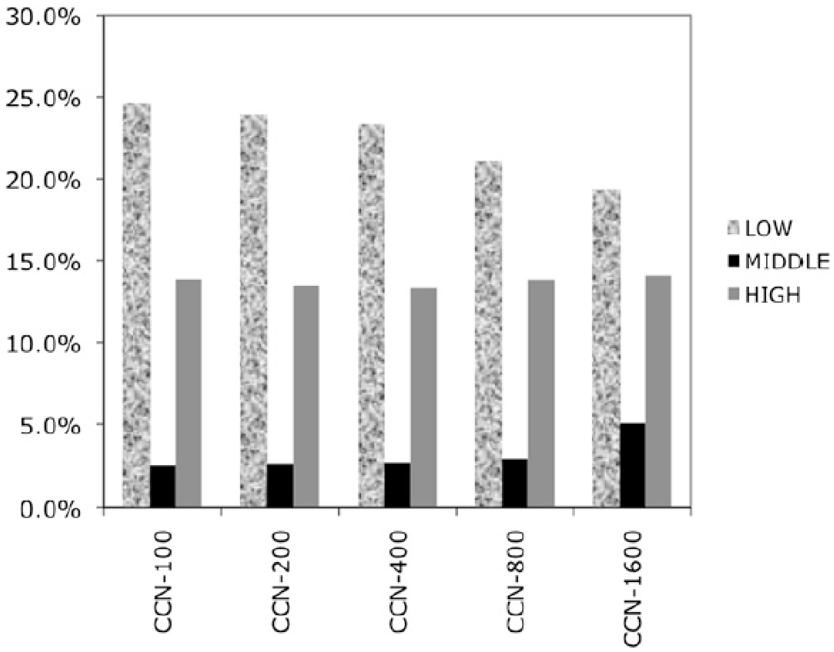




Other studies with bulk schemes

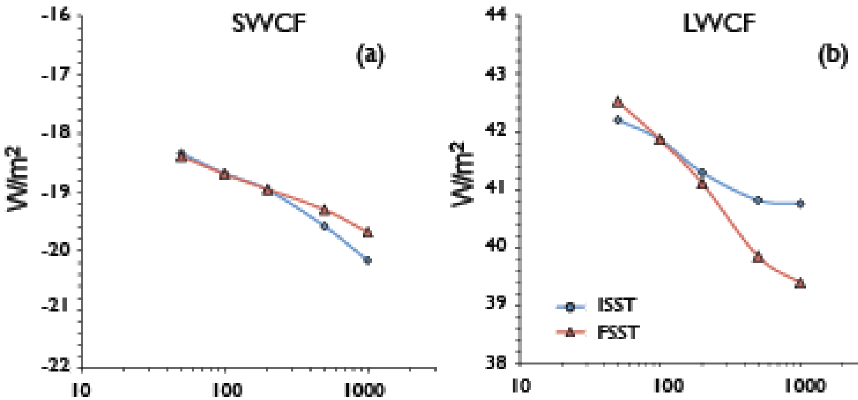
Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

Van Den Heever et al. 2011



Khairoutdinov and Yang 2013

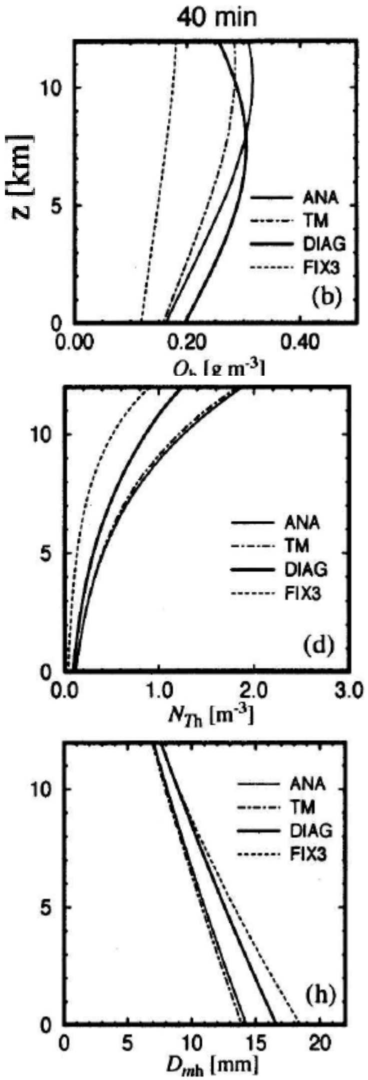
Case	LCLD (%)	MCLD (%)	HCLD (%)	TCLD (%)
IA50	3.04	2.61	51.86	57.51
IA100	2.88	2.67	51.81	57.36
IA200	2.81	2.77	51.45	57.02
IA500	2.76	2.89	50.62	56.27
IA1000	2.73	3.14	51.36	57.22
IA2CO2	3.20	2.53	49.92	55.64
FA50	2.93	2.55	51.71	57.20
FA100	2.87	2.66	51.81	57.34
FA200	2.85	2.79	51.44	57.08
FA500	2.85	2.88	50.21	55.94
FA1000	2.82	3.02	50.19	56.04



Impacts of shape factor

$$N(D) = N_0 D^{\alpha} e^{-\lambda D}$$

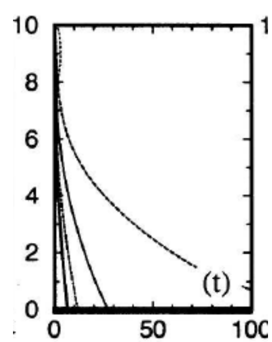
Sedimentation



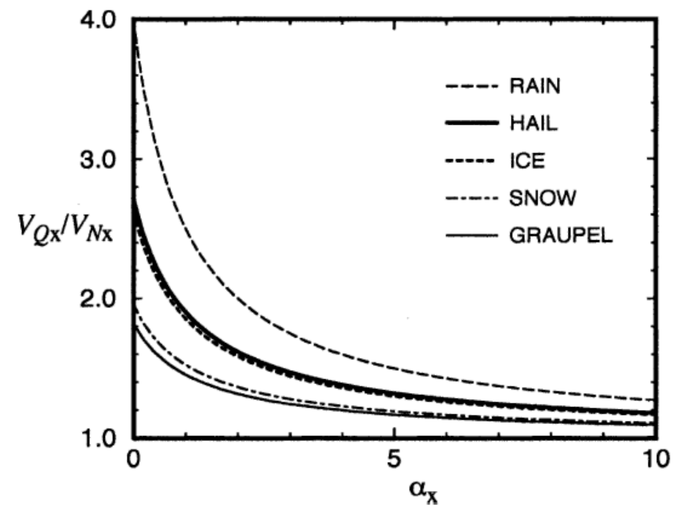
Excessive size sorting!

- **Smaller condensate content and number conc.**
- **Larger precipitating particle sizes**

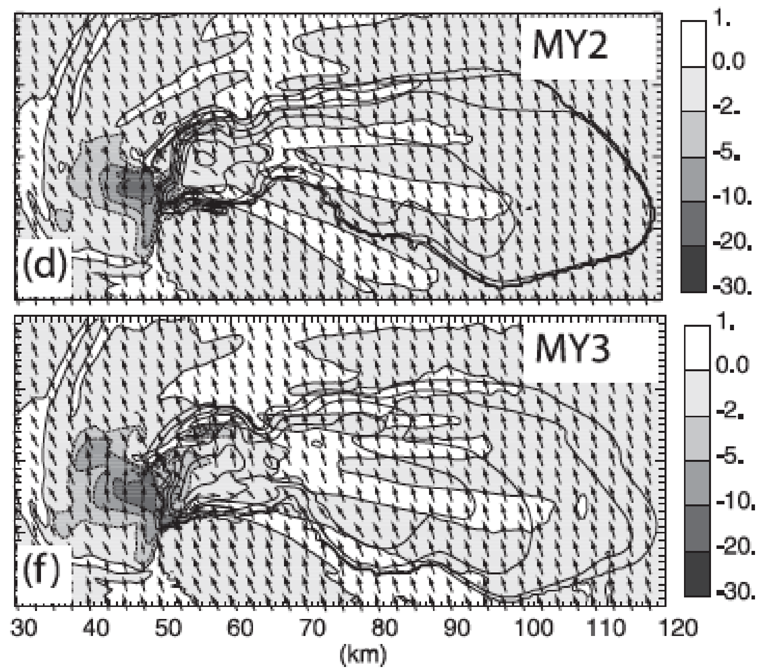
20 min for α=0



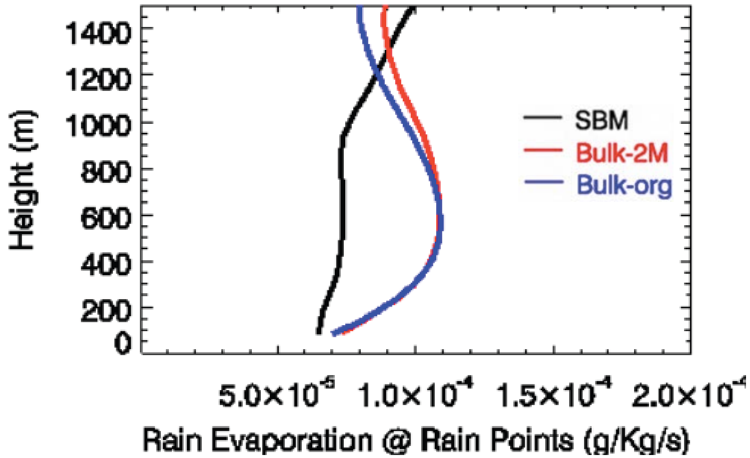
Milbrandt and Yau, 2005



Dawson et al. 2009, MWR

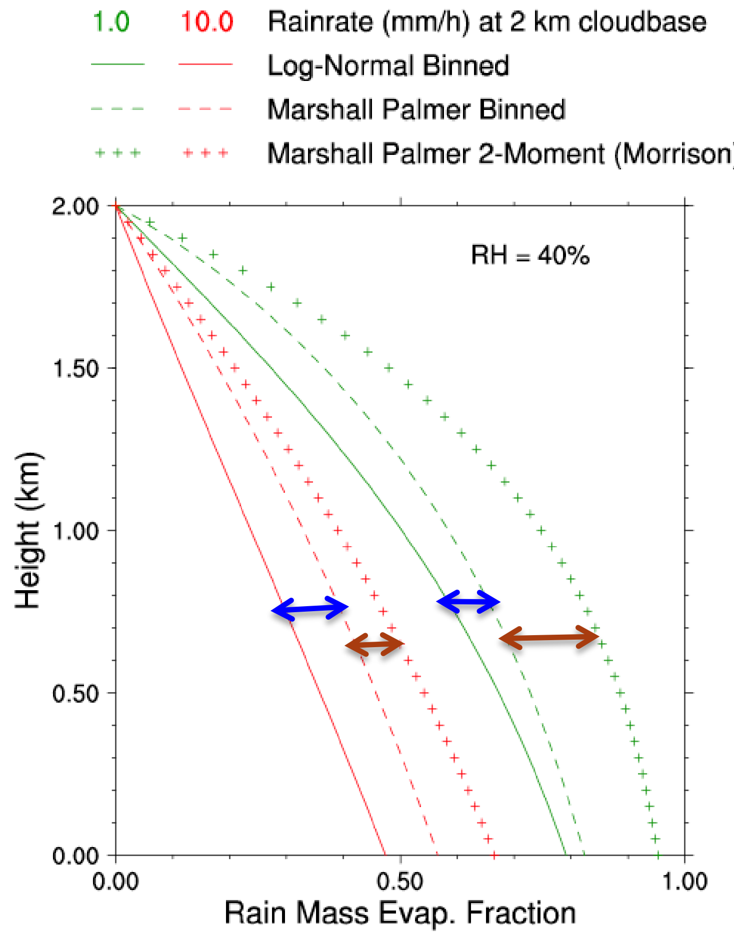


Evaporation/Sublimation



Wang et al. 2013, JGR

Figure courtesy Richard Easter



- **Leading to stronger low-level downdrafts and cold pool.**

Depositional growth

- Water vapor deposition increases as the shape parameter increases and ice spectrum becomes narrower under a certain N_i and q_i (*Ovchinnikov et al. 2013, to be submitted*)

Saturation adjustment

- When bulk schemes are applied to LES/CRM, saturation adjustment for condensation is not appropriate due to small model timestep (*Leo et al. 2012, ACP; Wang et al. 2013*)

5. Aerosol-cumulus cloud interactions in large – scale models

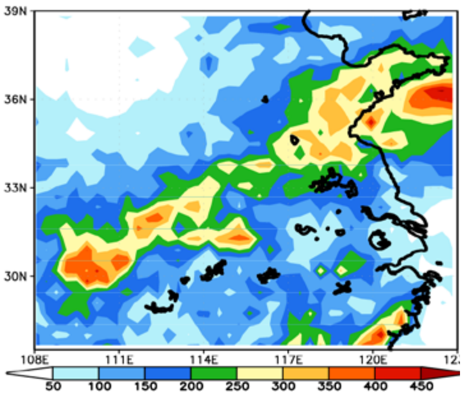
Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

- Cumulus convection is parameterized in the regional and global climate models.
- Mass-flux based, no much microphysics
- No aerosol-cloud interactions considered by acting as CCN/IN.

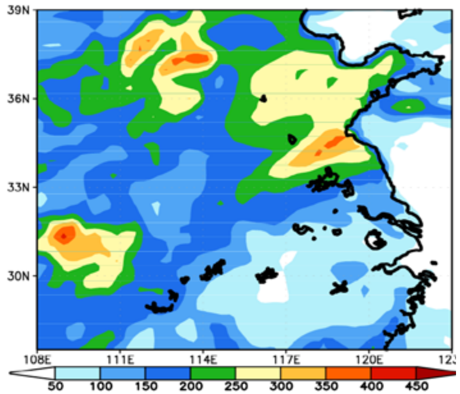
- Recent progress:
- Grell scheme has been modified to be scale and aerosol aware (*Grell and 2013, ACPD*): very simplified connection in rain formation and evaporation.
- Zhang and McFarlane cumulus scheme includes a two-moment cloud microphysics (*Song and Zhang,* 2011; Lim et al. 2013)

Lim et al. 2013, JGR, in review

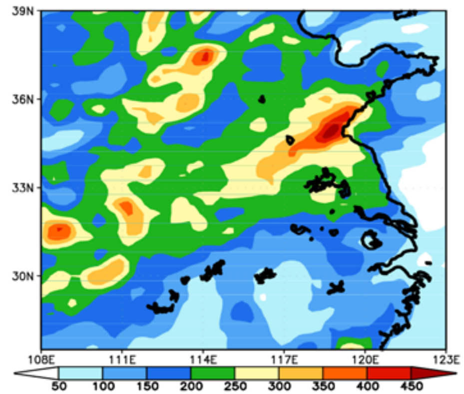
Rain gauge



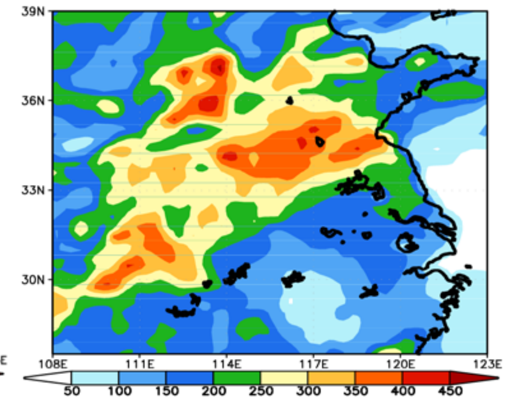
NOMP



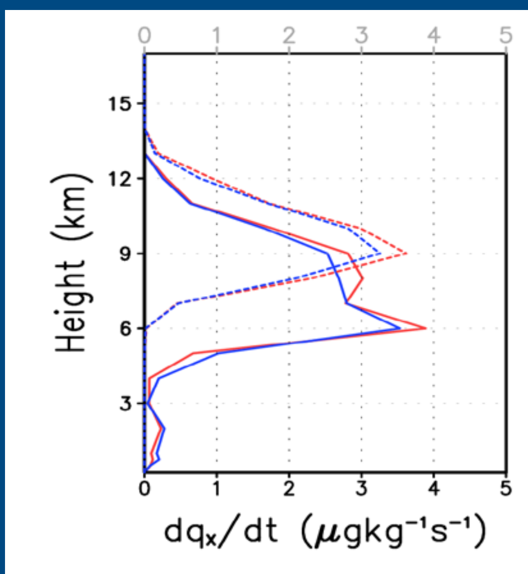
MP

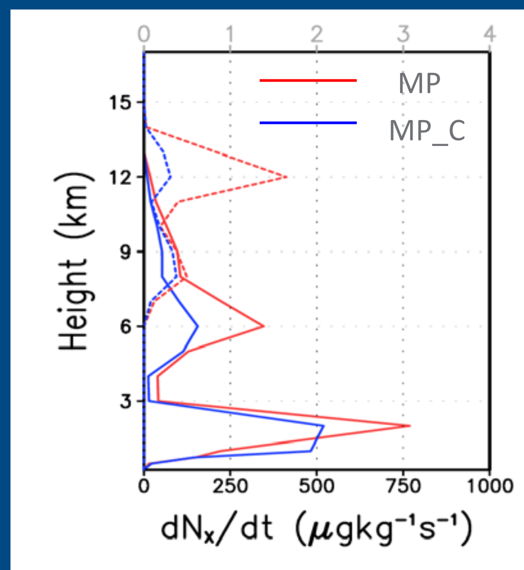


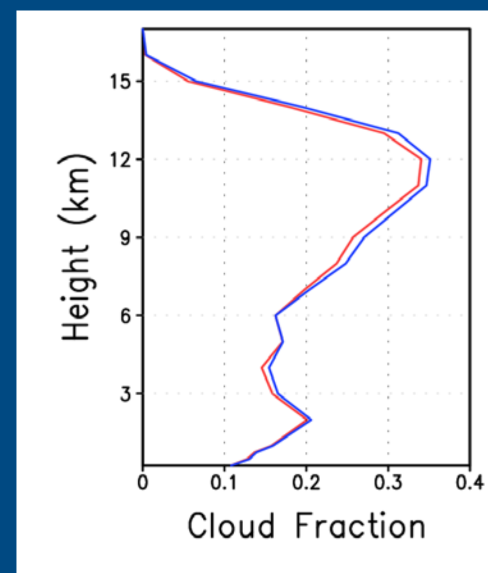
MP_C



Detained hydrometeors and cloud fraction





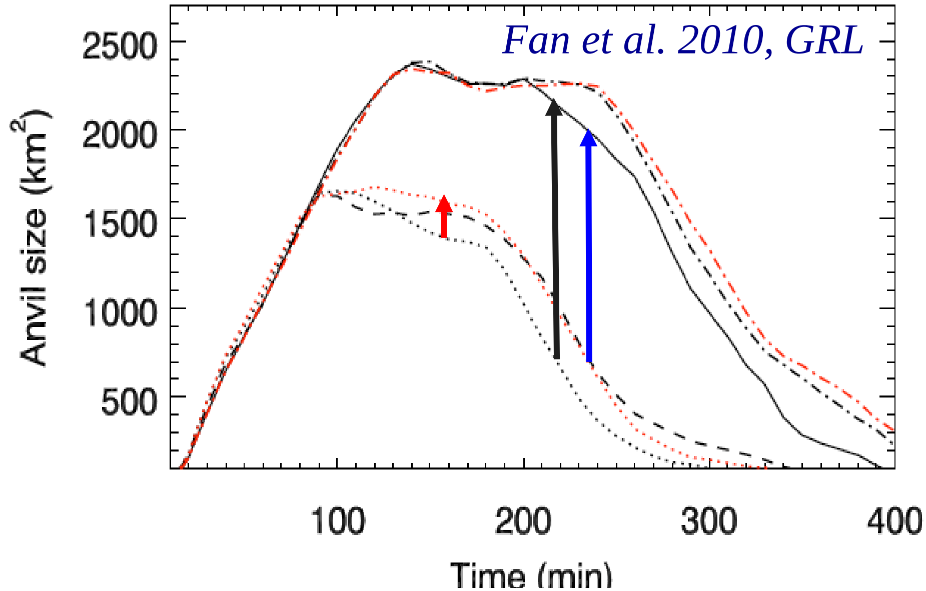


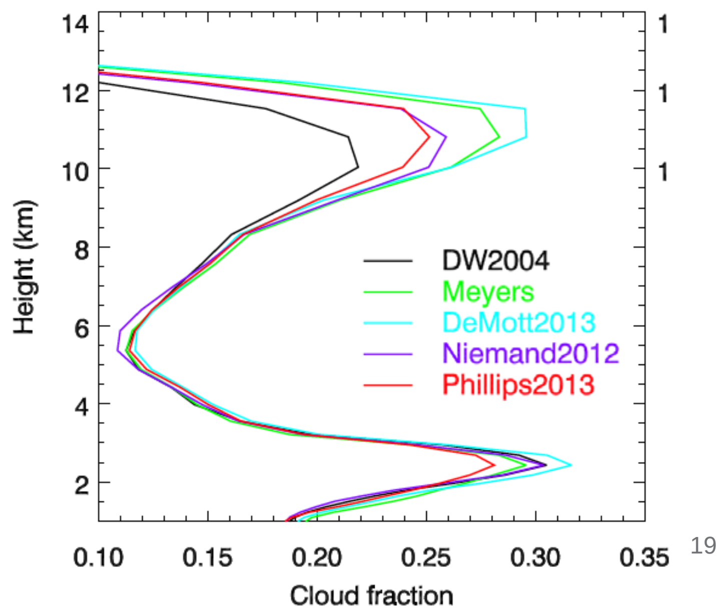
6. Impact of Ice Nuclei (IN)

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

- What species are good IN?
  - Mineral dusts
  - Soot, biological, biomass burning particles?

- Ice nucleation parameterizations
  - Recent parameterizations agree with each other much better!
  - Changing ice and liquid properties in the mixed-phase clouds complicates things!





7. Lack of validation of model simulations

Pacific Northwest NATIONAL LABORATORY

Proudly Operated by Battelle Since 1965

- Most of model simulations are idealized sensitivity studies (*Milbrandt and Yau 2005 a,b; Dawson et al. 2009; Morrison and Grabowski 2011;2013; Morrison 2012; Lebo et al. 2012; van den Heever et al. 2006;2011*, etc)

- Difficulty to trust model results (some may be way off).
- Difficulty to understand if there is improvement for a change/parameterization.

- Real-case simulations and validation of model simulations with in-situ aircraft and ground-based measurements (*Fan et al. 2009; Fan et al. 2010; Fan et al. 2012; Li et al. 2011, Fan et al. 2013*).

- Future studies have to build on validation of model simulations with observations first, and ARM data have made extensive validation possible!

Summary/Recommendations

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by **Battelle** *Since 1965*

- Microphysical effects, cloud life cycle, and large-scale feedback.
- Improve bulk scheme (e.g., predicted shape factor; Morrison new ice scheme) for regional and climate models.
- Cumulus schemes with cloud microphysics and aerosol-cloud interactions.
- Extensive collaboration is required among GCM developers, LES/CRM modelers, and observers to identify problems, evaluate and further develop parameterizations. ADCI focus group serves to this purpose!