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Aerosol Impacts on Deep Convective Clouds (DCCs): A New Mechanism for Ubiquitous Invigoration from Observations

JIWEN FAN

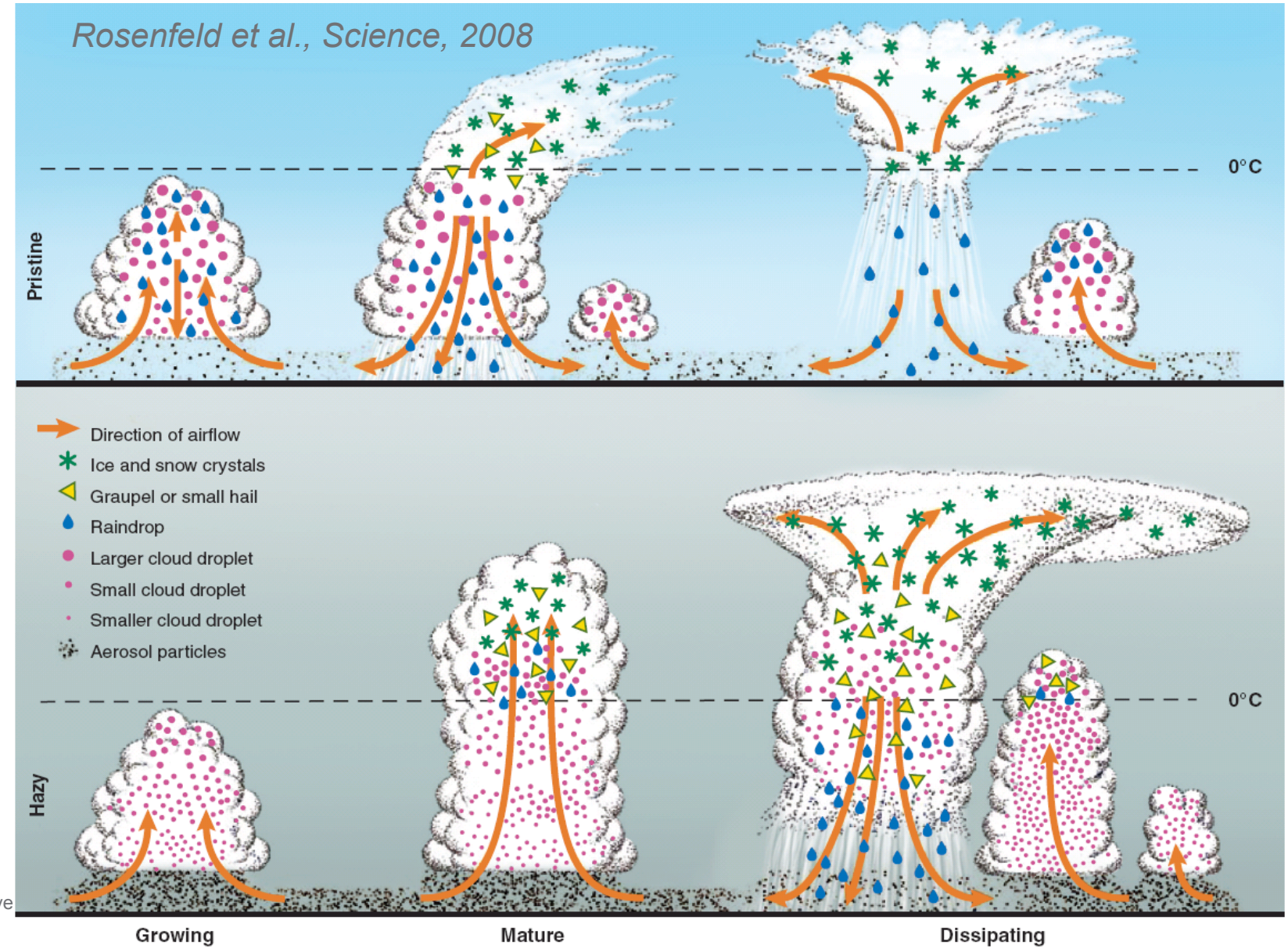
Pacific Northwest National Laboratory

Richland, WA

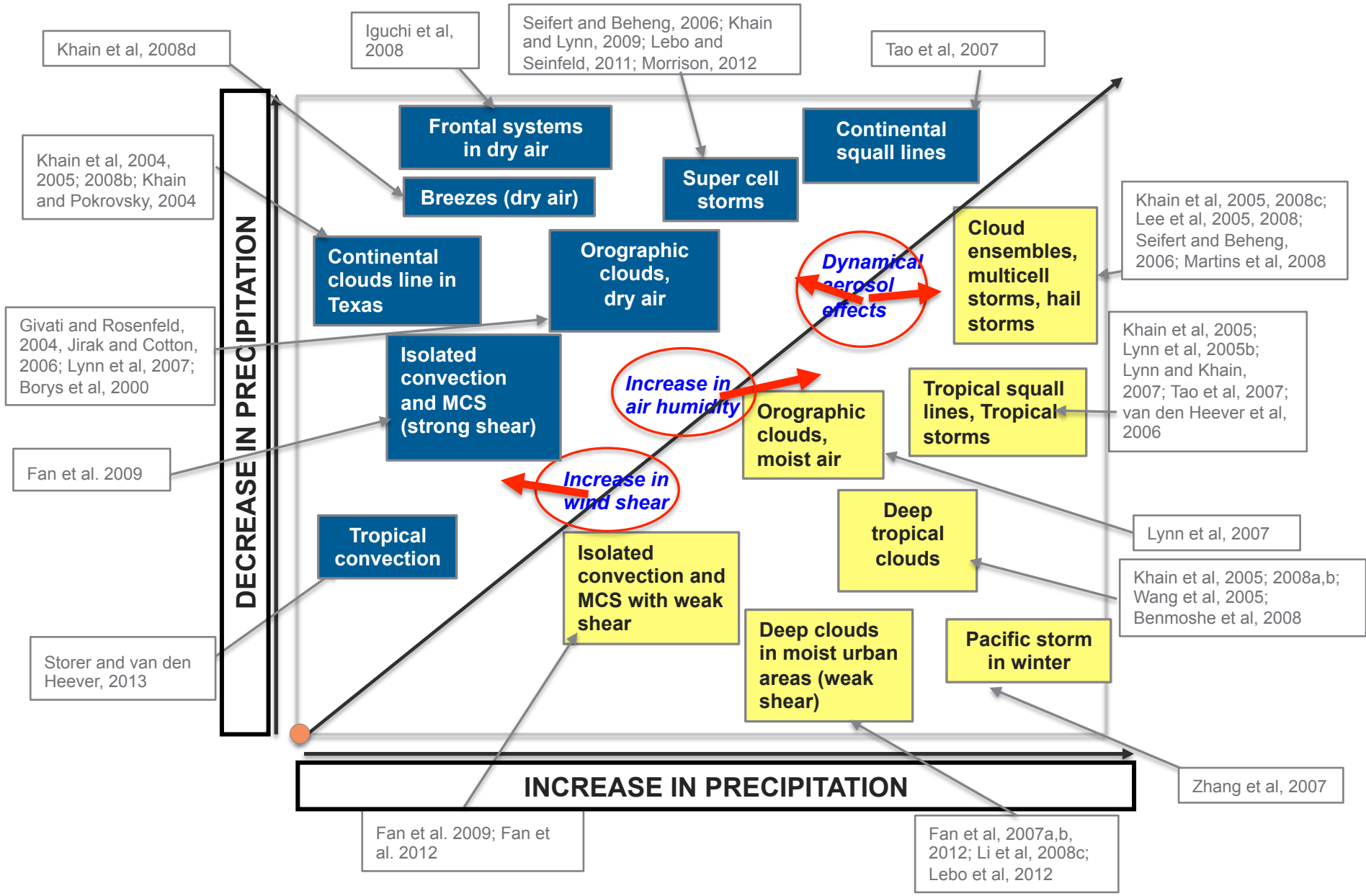
Acknowledgement:

- Visiting scholar: Qian Chen
- Collaborators: Ruby Leung, Daniel Rosenfeld, Zhanqing Li, Jinqiang Zhang, Hongru Yan
- Support from ASR, China and EaSM projects

Concept model – cloud scale

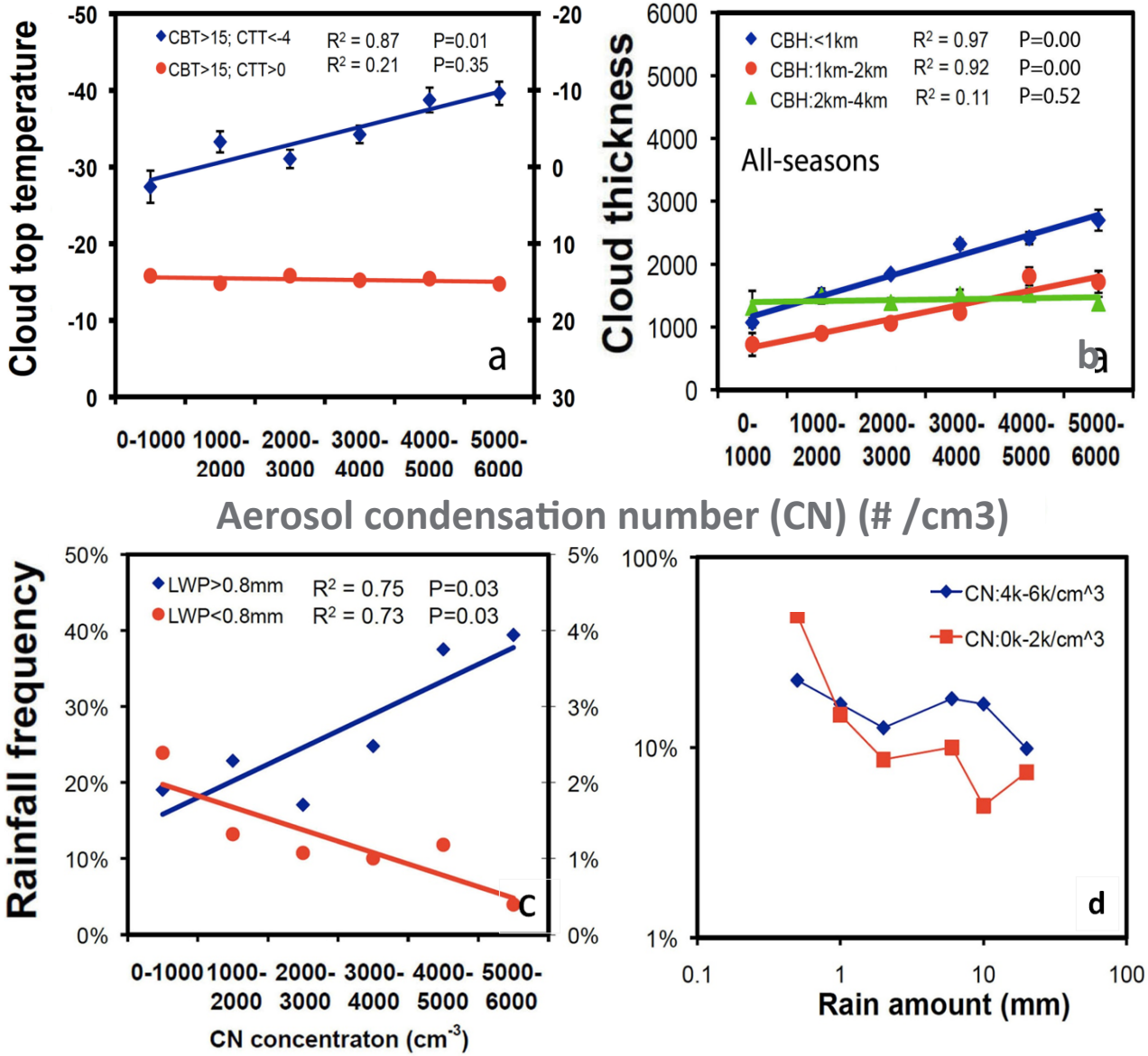


Short-time CRM Modeling



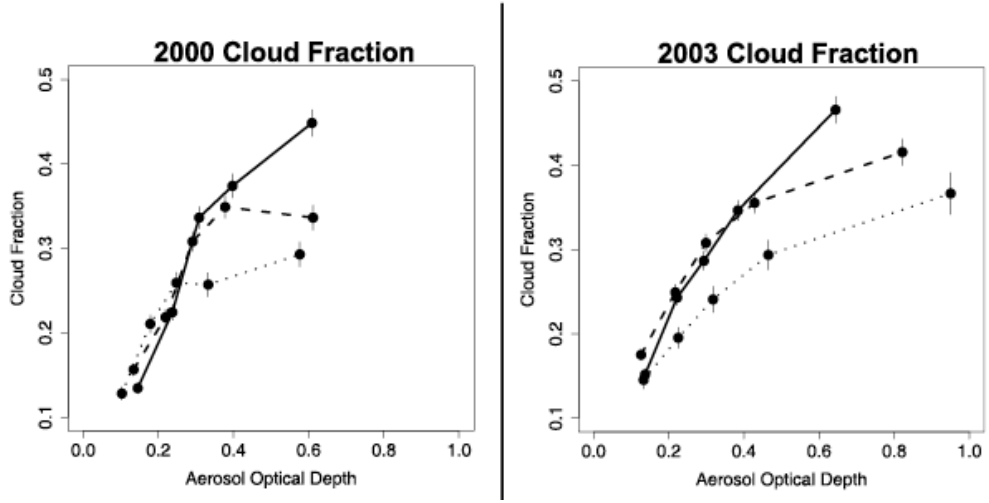
Modified based on Khain (2009), Environ. Res. Lett.

Ground-based Observations

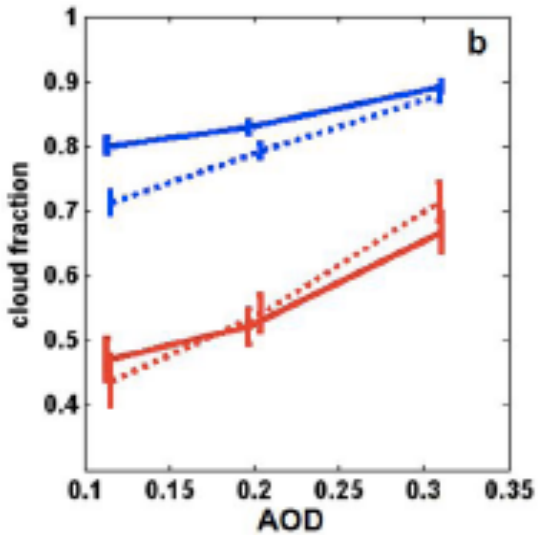


Li et al. (Nature-Geosci., 2011)

Satellite Observations



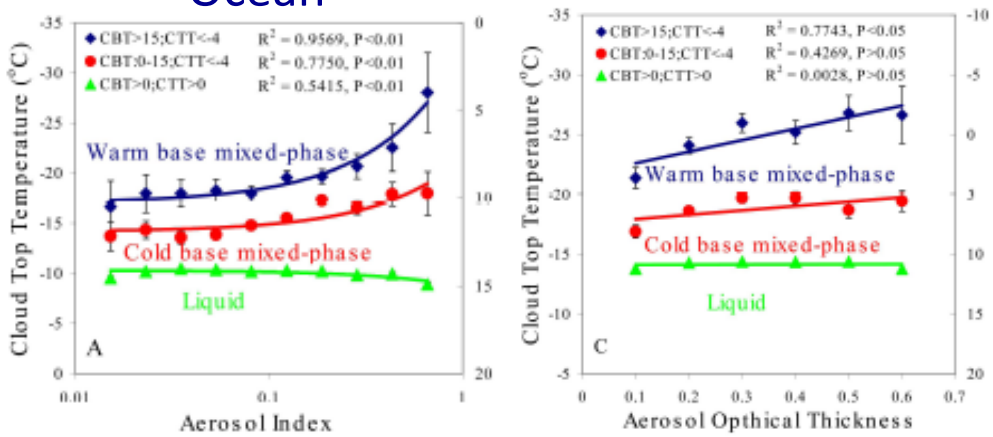
Lin et al., 2006



Koren et al., 2010

Ocean

Land



Niu and Li, 2012

Invigoration, really?

Long-time SBM simulations

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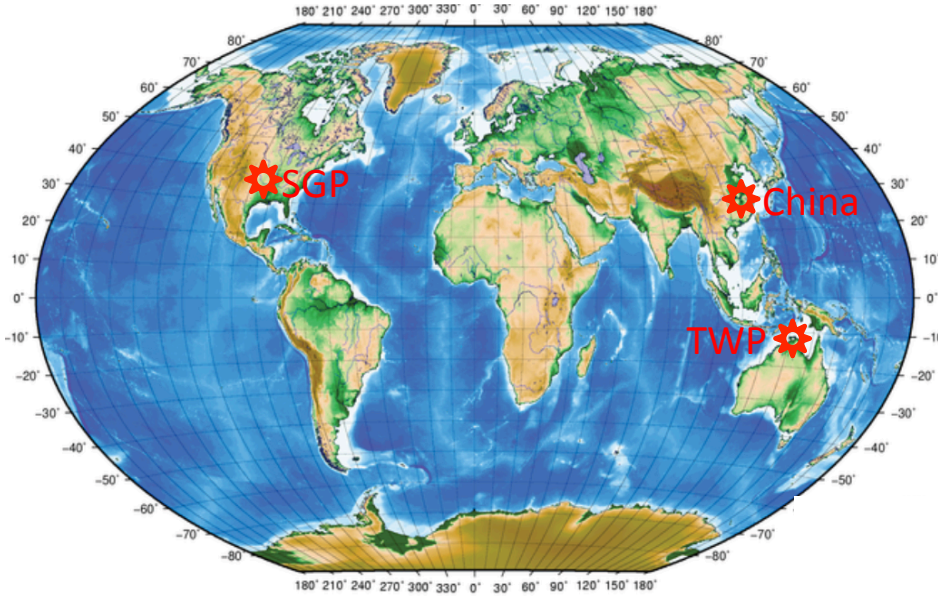
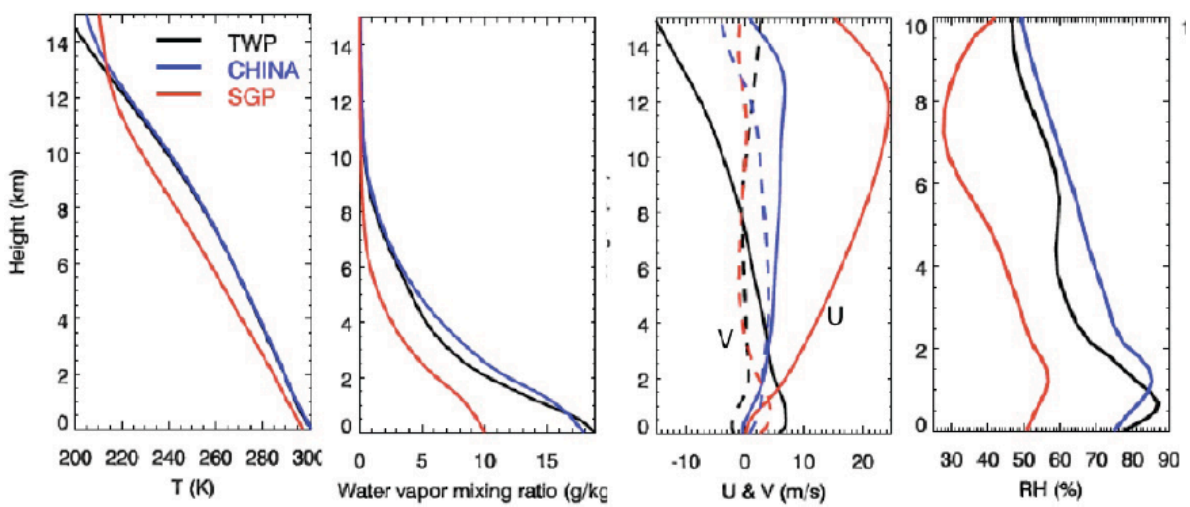
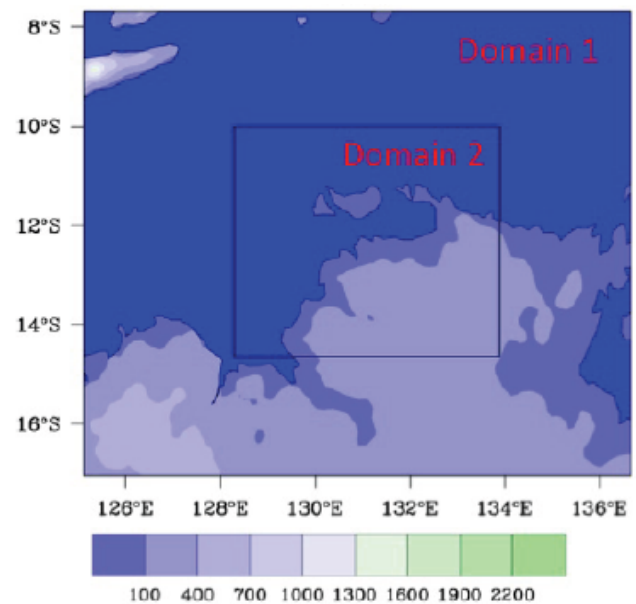
- One-month regional CRM simulations with Spectral-bin cloud microphysics
- TWP (Jan.15-Feb.15, 2006): tropic oceanic convection
- China (July 2008): summer convection of mid-latitude coastal area
- SGP (June 2008): mid-latitude inland summer convection.







Validation of Model simulations

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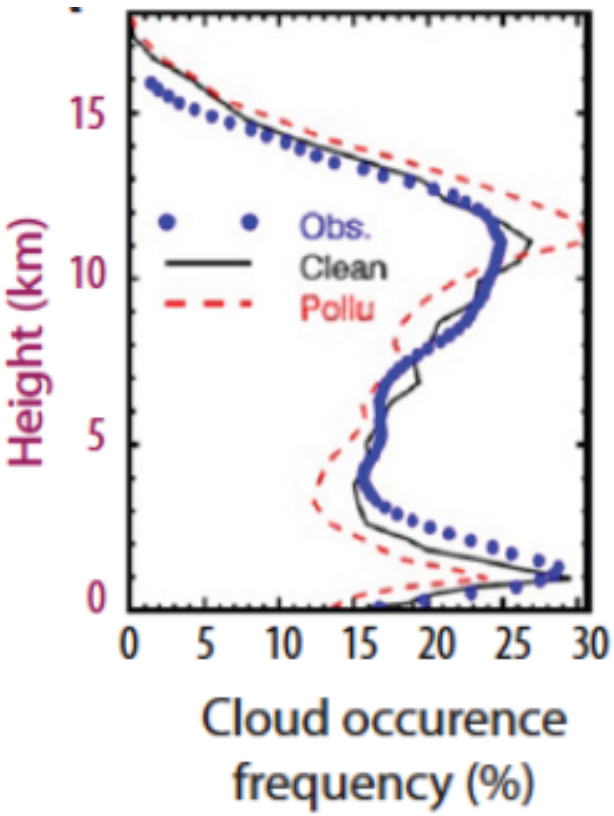
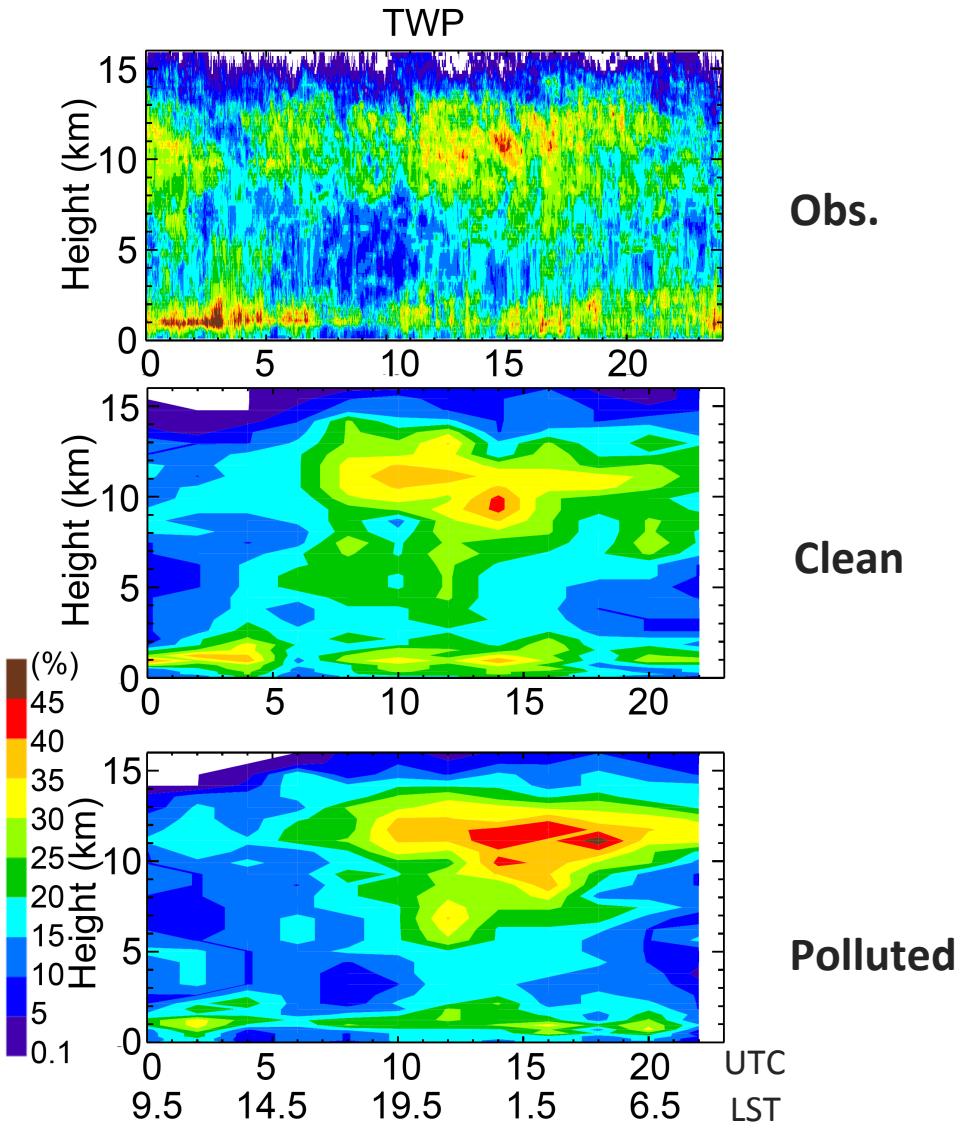
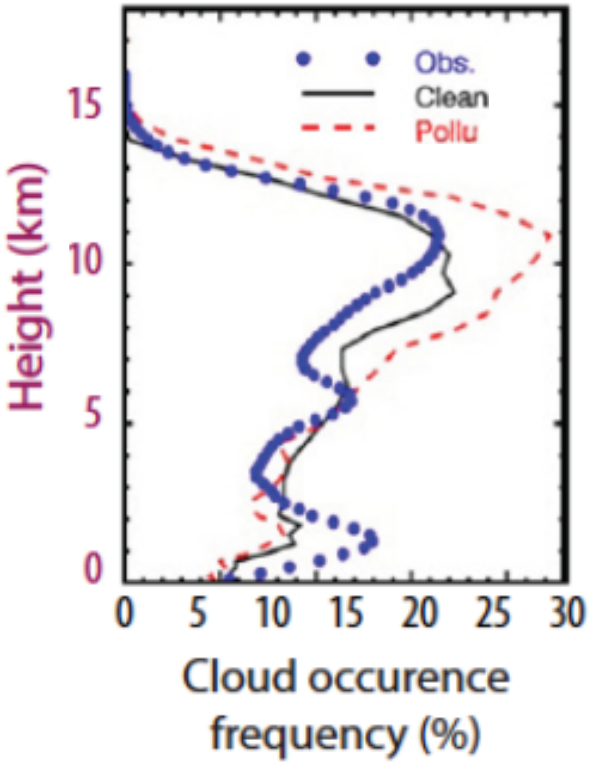
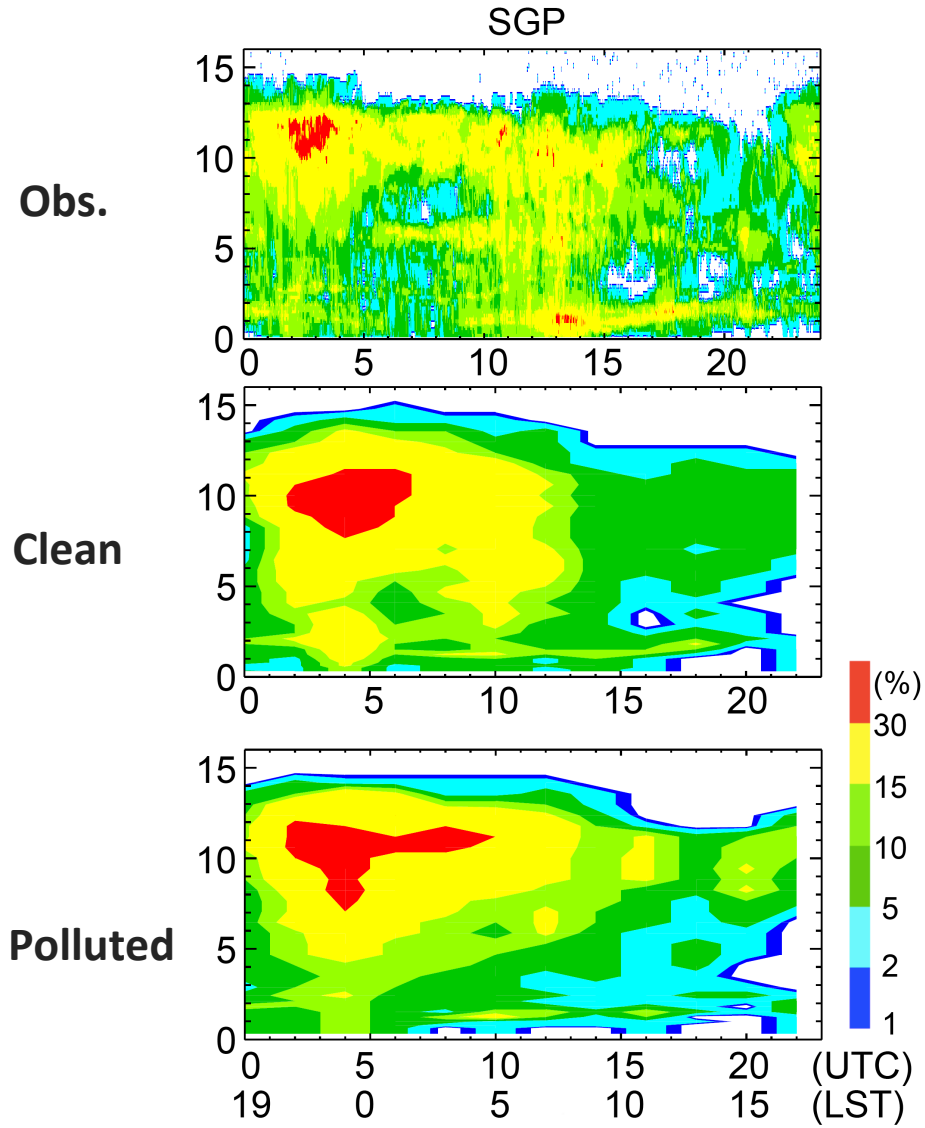
TWP





SGP


Obs.
Clean
Pollu
Height (km)
0
5
10
15
0
5
10
15
20
25
30
Cloud occurence
frequency (%)

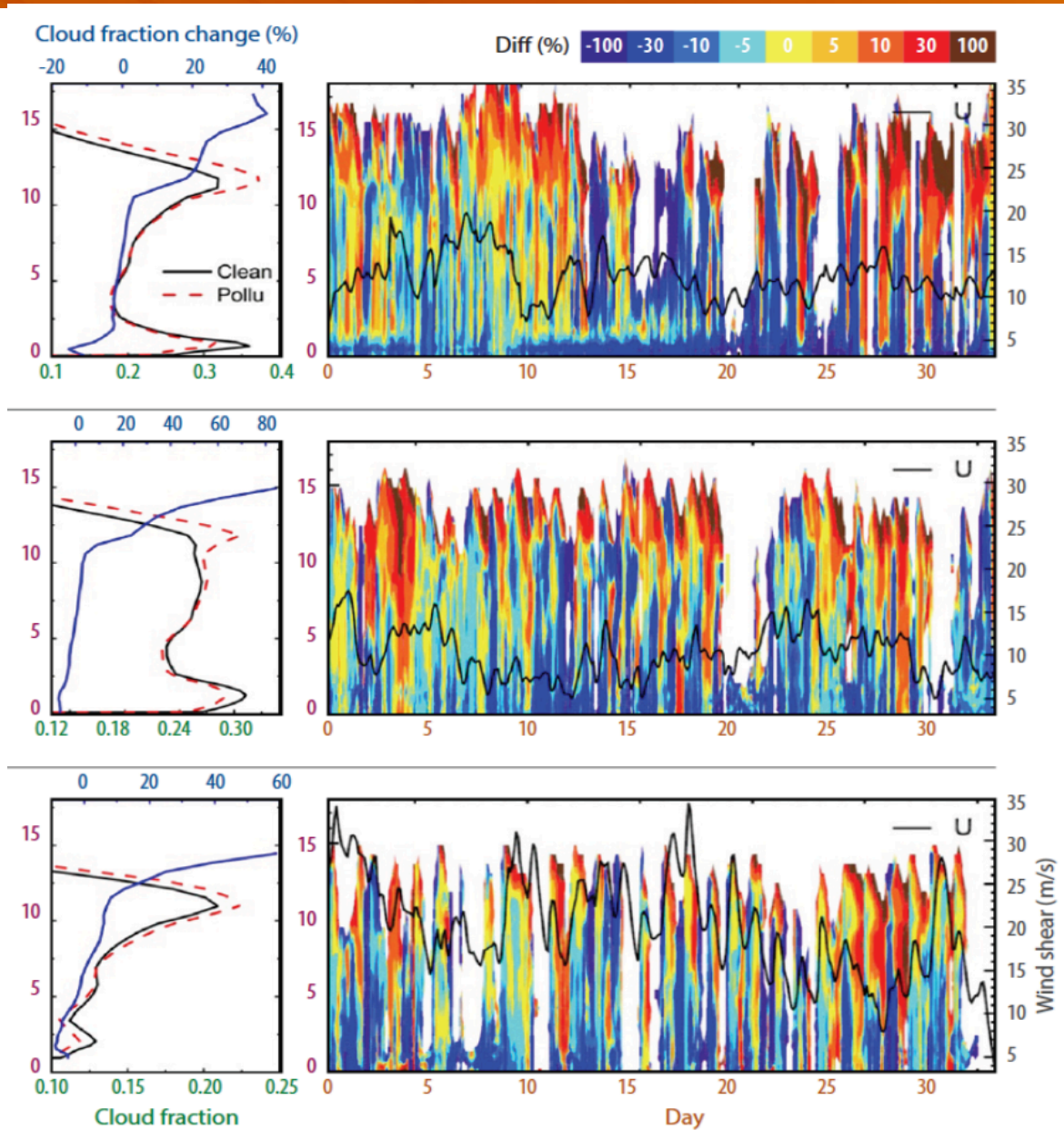

SGP
Obs.
Clean
Polluted
0
5
10
15
0
5
10
15
20
(%)
30
15
10
5
2
1
0
5
10
15
20
(UTC)
19
0
5
10
15
(LST)

Cloud Fraction

TWP

China

SGP

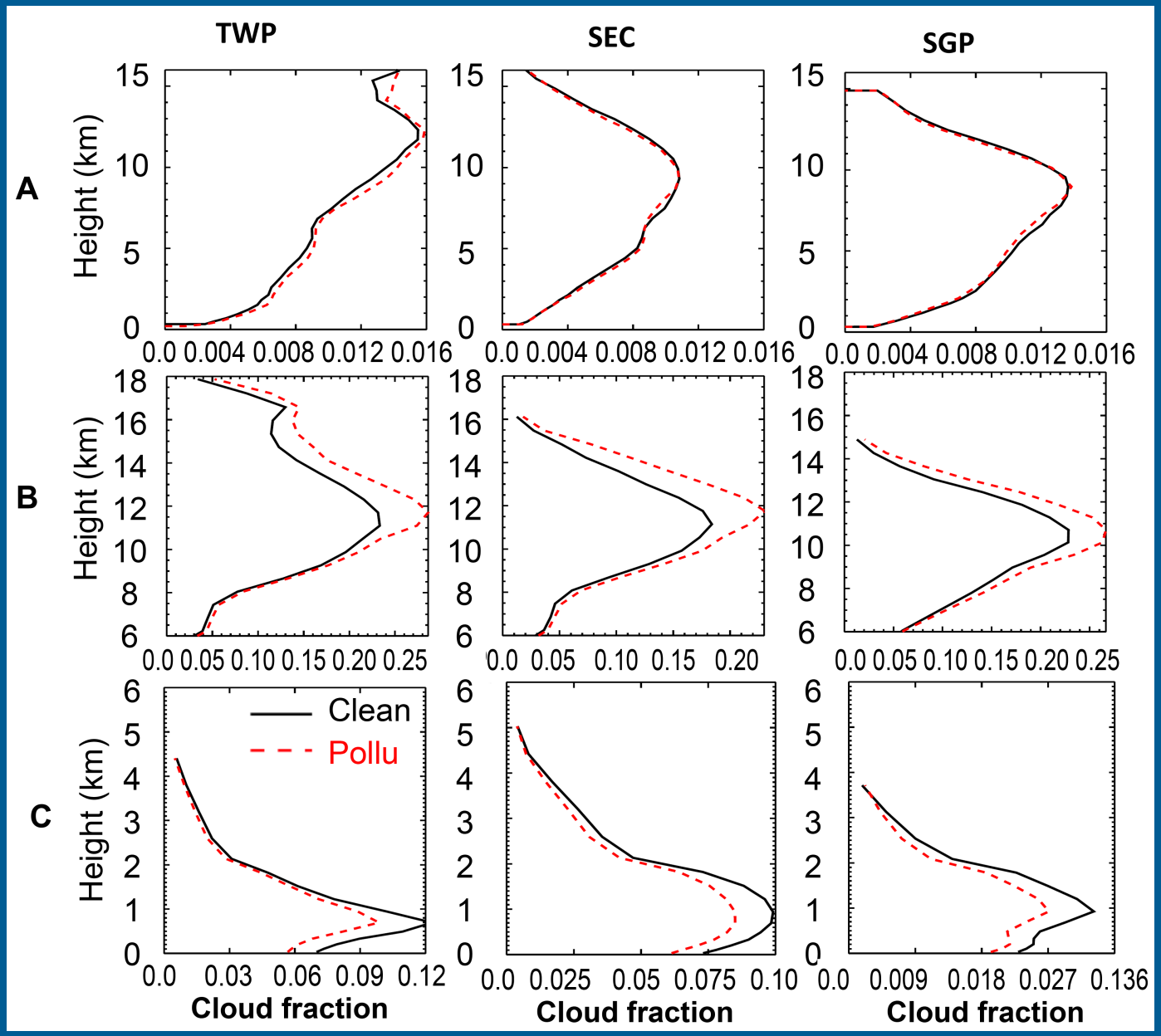


TWP China SGP

Conv.

Strat./ anvil

Shallow

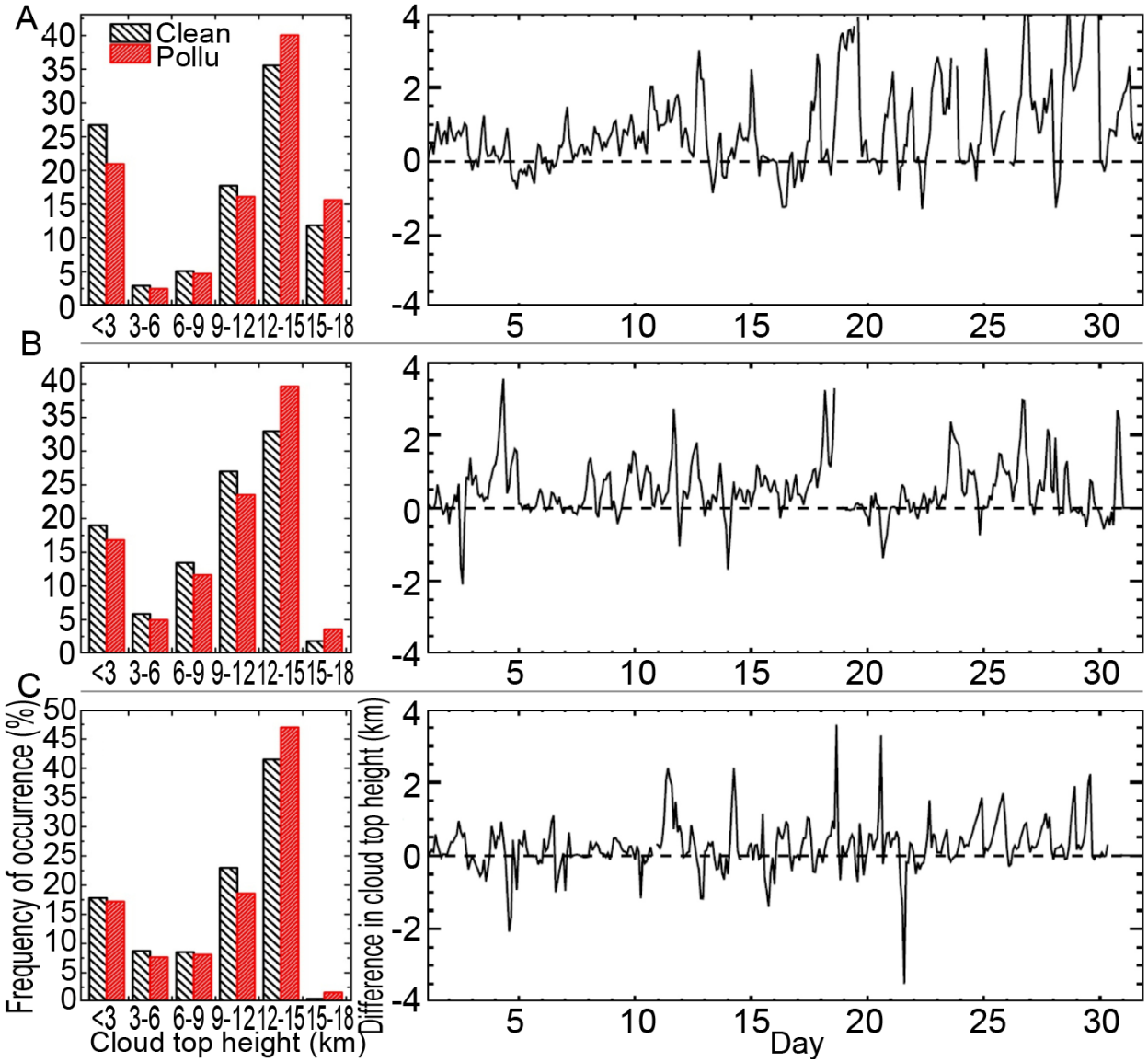


Cloud Top Height

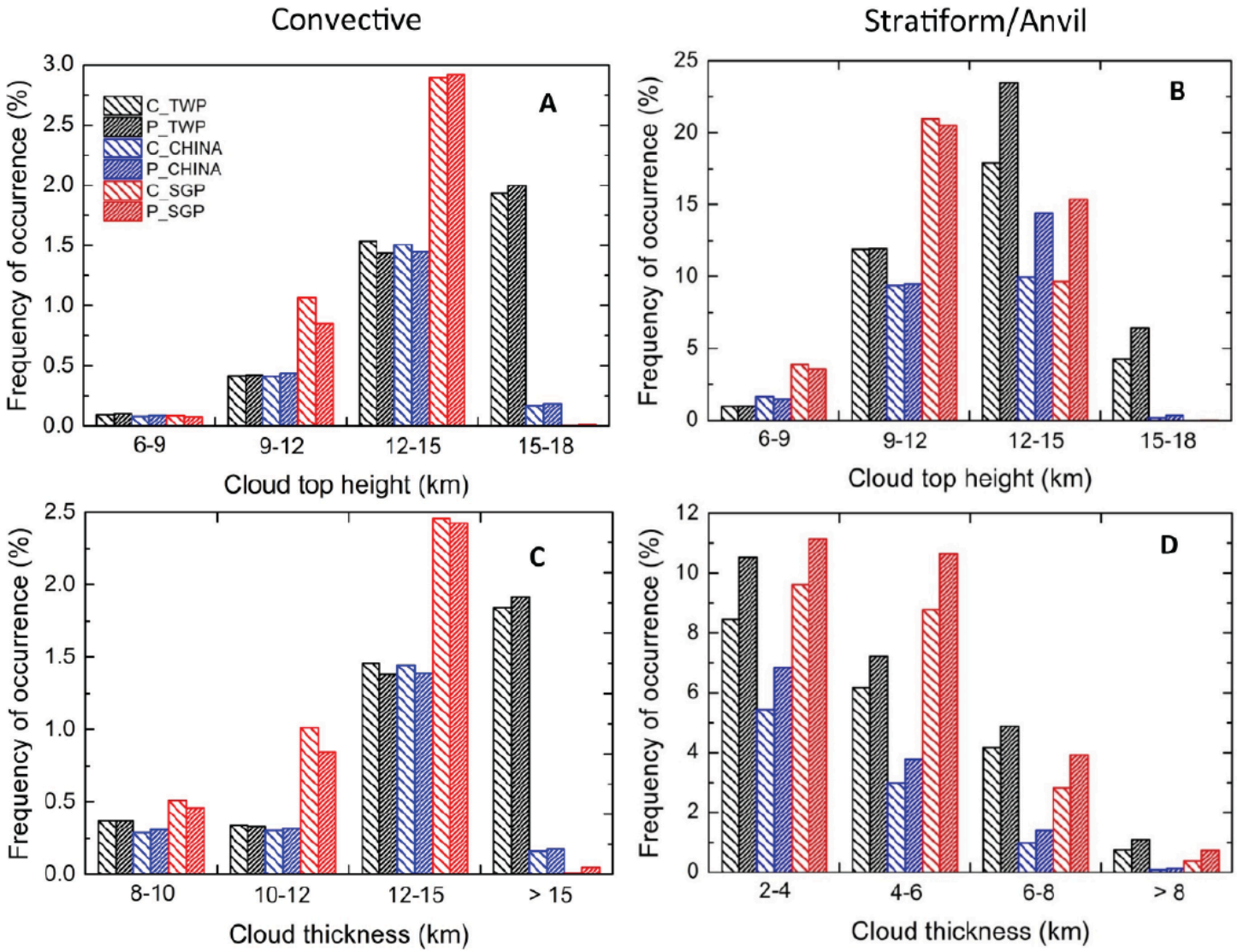
TWP

China

SGP



CTH and Cloud Thickness



Dynamical Effects (DE)

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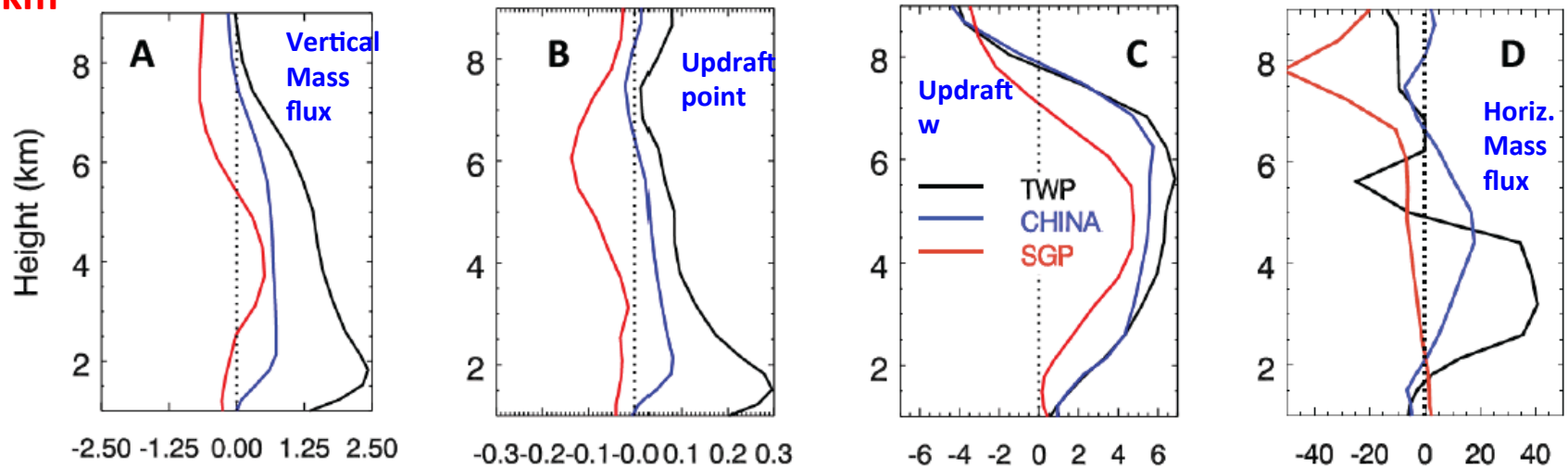
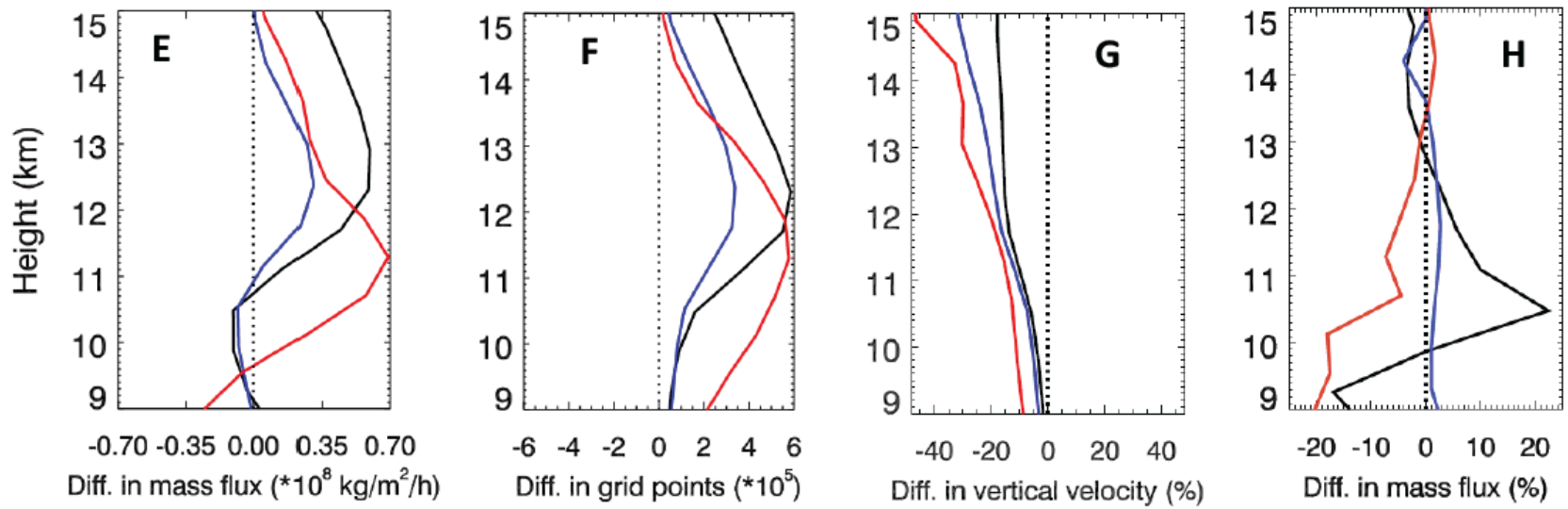
1-9 km



9-15 km



Microphysical Effects (ME)

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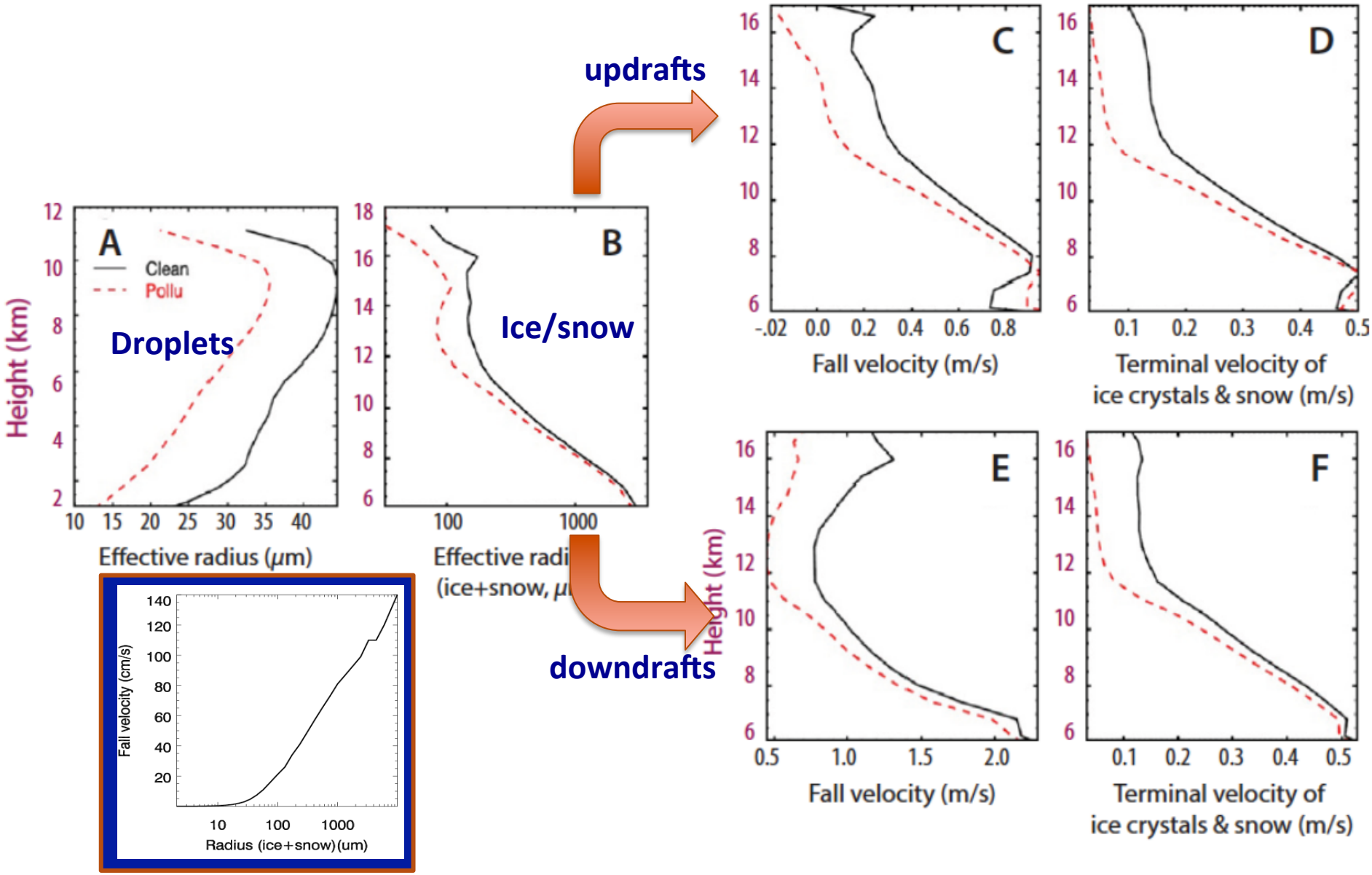
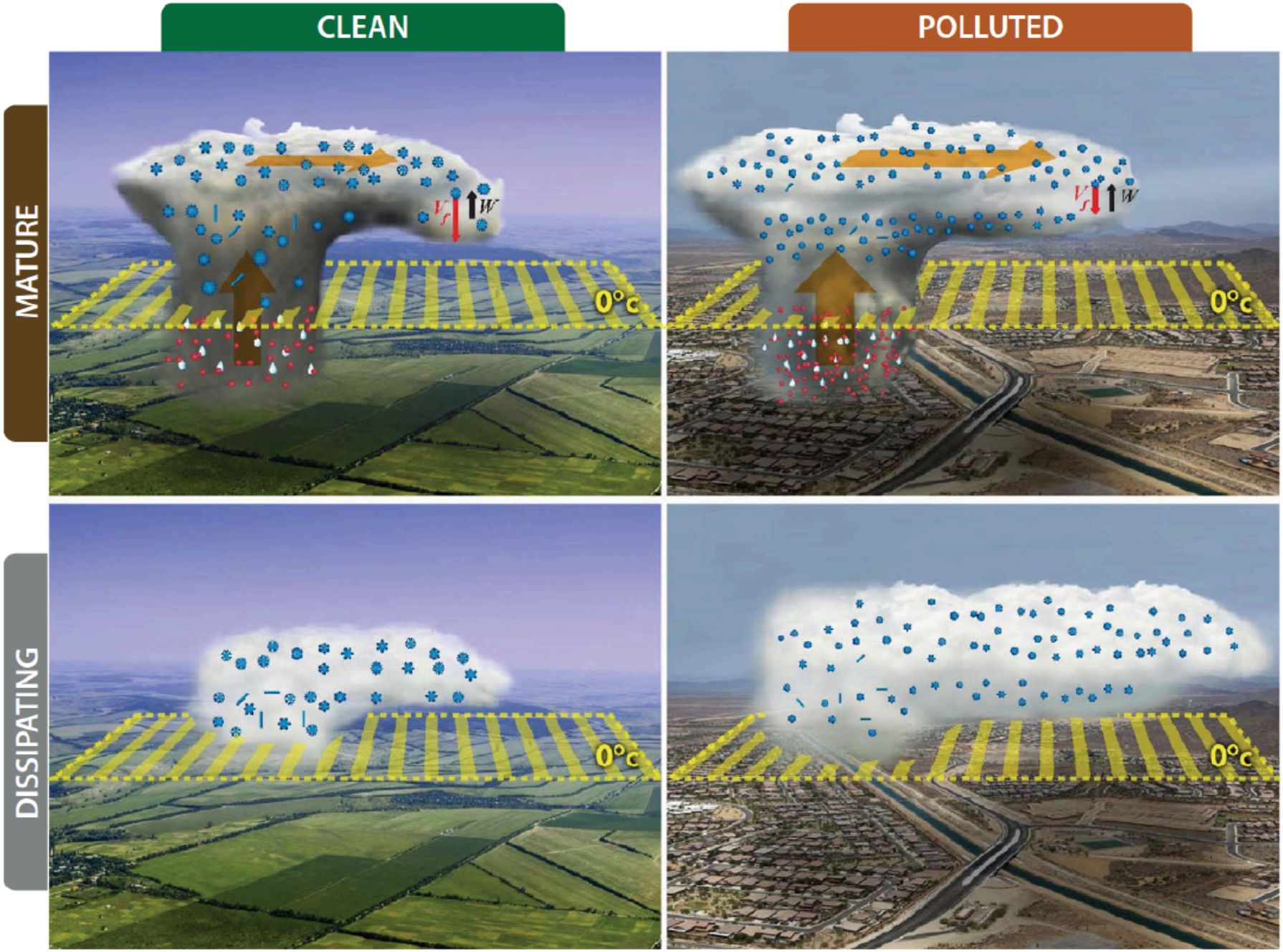
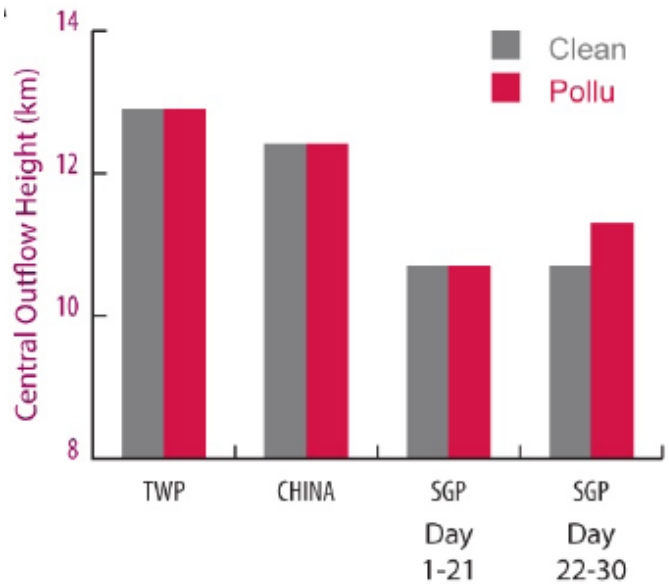



CLEAN
POLLUTED
MATURE
DISSIPATING
0°c
0°c
0°c
0°c

Separation of Microphysical and Invigoration Effects

Contributions to CTH:

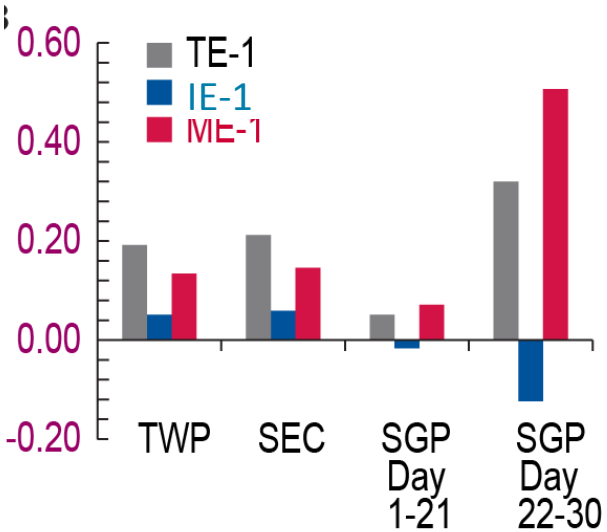
- **The difference in central outflow height (COH) between Pollu and Clean represents the invigoration effect (IE) on CTH**



Contributions to cloud fraction:

- **IE on cloud fraction is** $IE = \frac{MF_p}{MF_c}$ **at COH**

$$TE = \frac{f_p}{f_c} \qquad TE = IE \times ME$$



- **Consistent with Morrison and Grabowski (JAS, 2013) which found that invigoration of heating is limited beyond the convective adjustment timescale.**

Radiative Effects

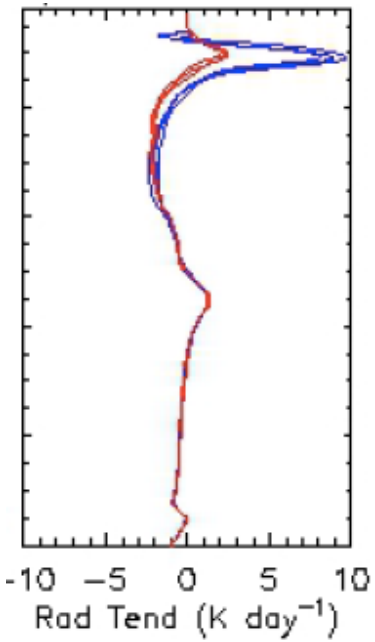
Morrison and Grabowski, ACP, 2011

C

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

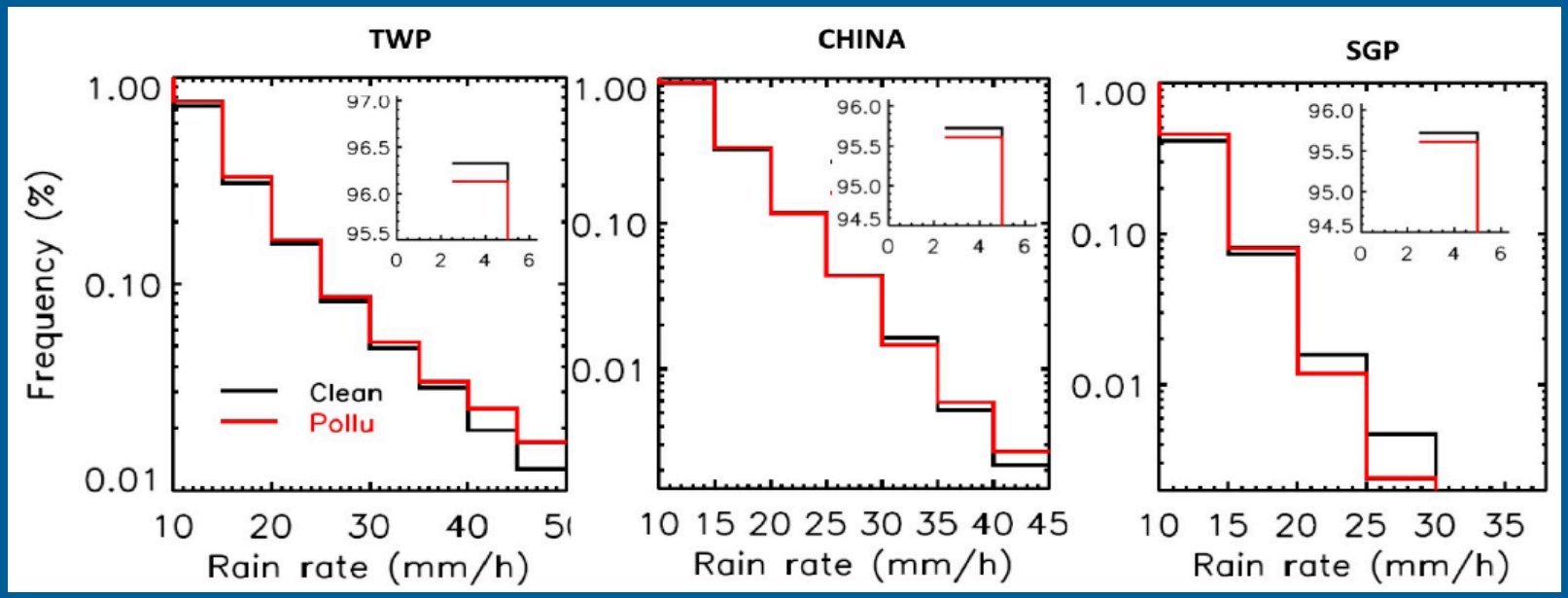
D

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

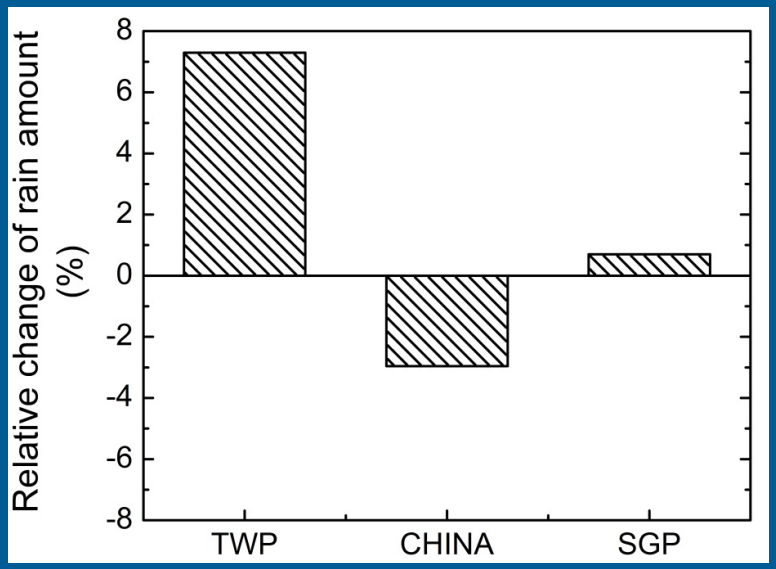


- Strong upper level radiative warming stabilizes atmosphere, leading to weaker convection.

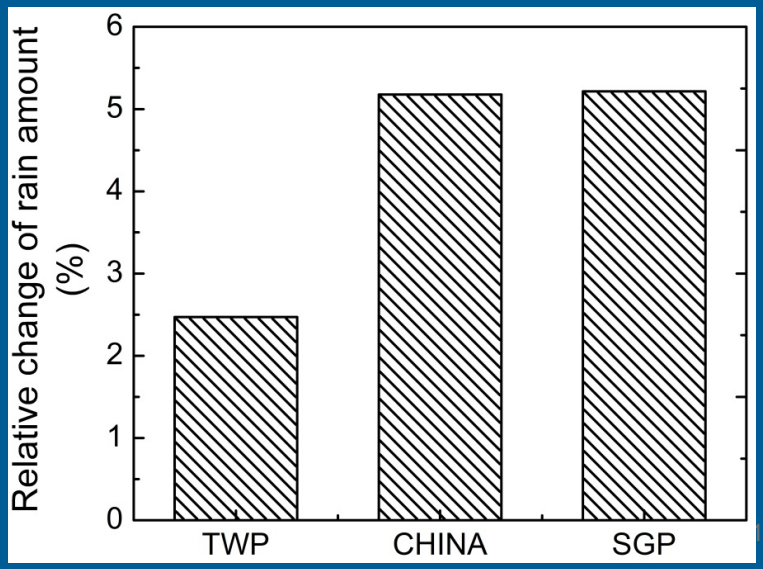
Precipitation



Convective



Stratiform/Anvil



Other studies with bulk schemes

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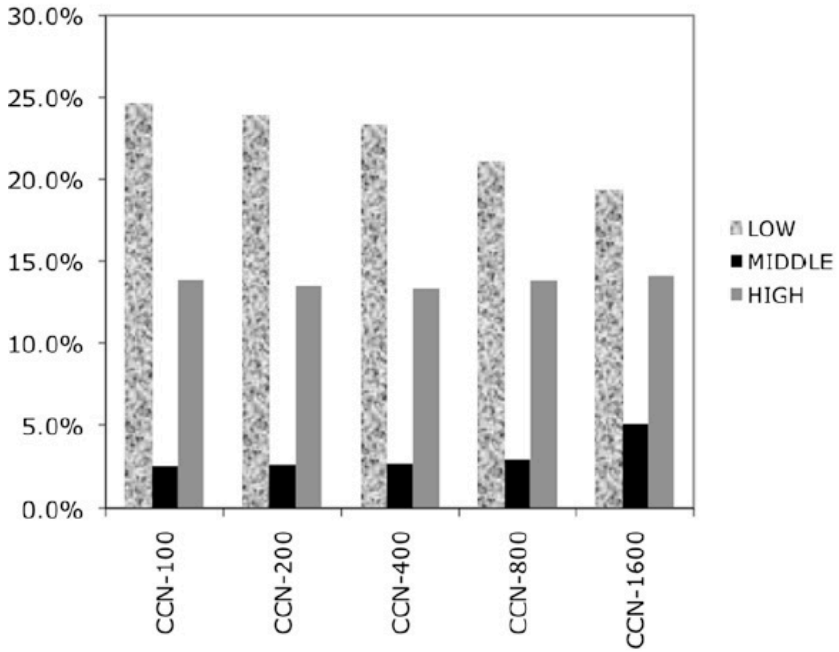
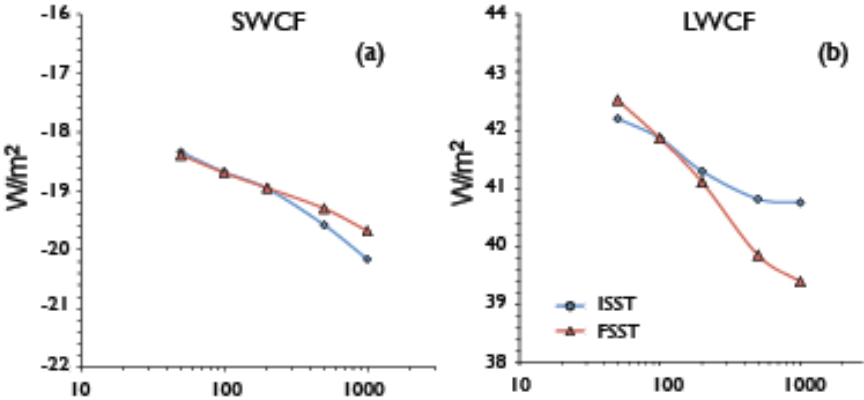
Van Den Heever et al. 2011



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



Summary

- Microphysical aerosol effect is the fundamental determinant of the increases in cloud cover, CTH, and cloud thickness by inducing larger amount of smaller but longer-lasting ice particles in the stratiform/anvils of DCCs.
- This microphysical mechanism explains the consistent signatures of increased cloud top area and height in polluted DCCs revealed by observations, even when invigoration of convection is absent.
- The microphysical effect produces strong surface/TOA cooling and atmospheric warming and reduces diurnal temperature variation.
- Over a large region and long time period, the invigoration effect by increasing aerosols is buffered partially by the feedback of radiative forcing to the system, leaving the microphysical effect to dominate the changes on cloud properties.

Observed Aerosol Effects

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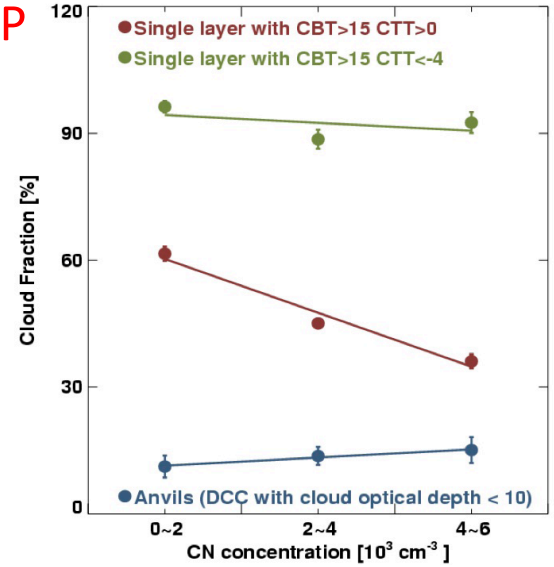
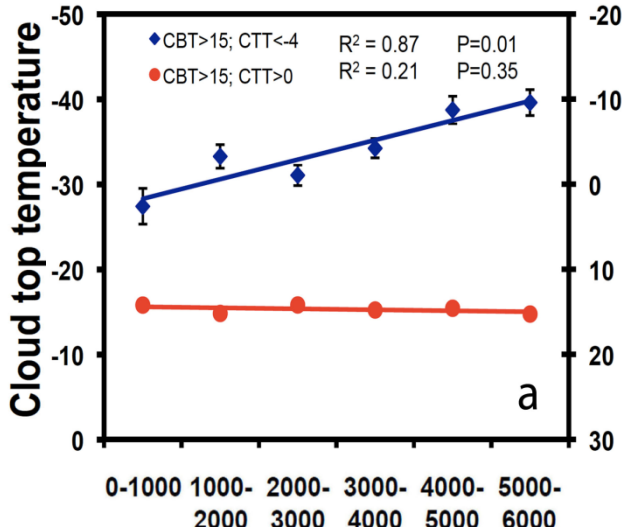
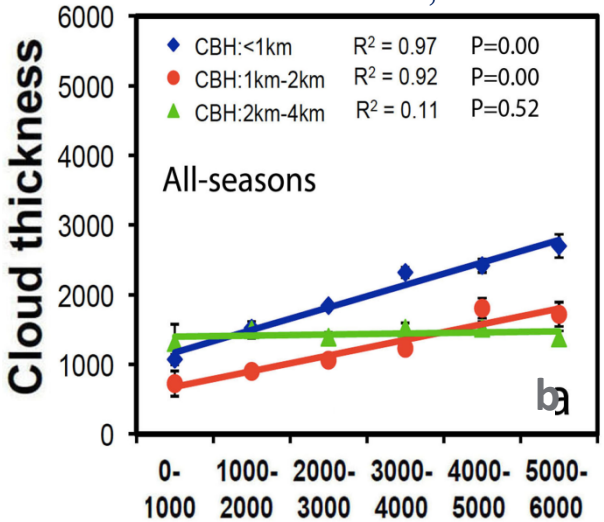
Li et al. 2011, 2012

SGP



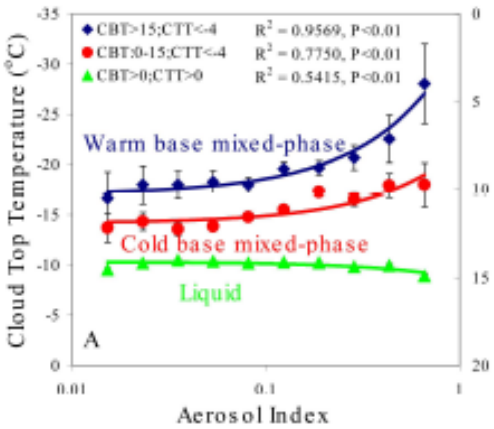




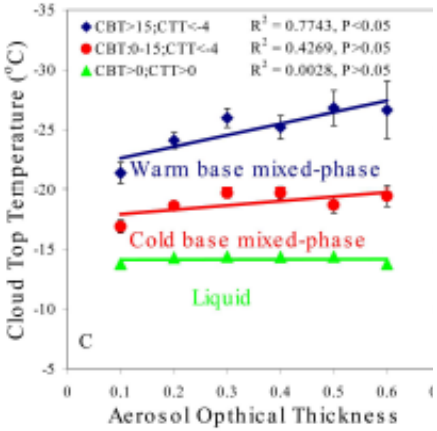
Aerosol condensation number (CN) (# /cm3)

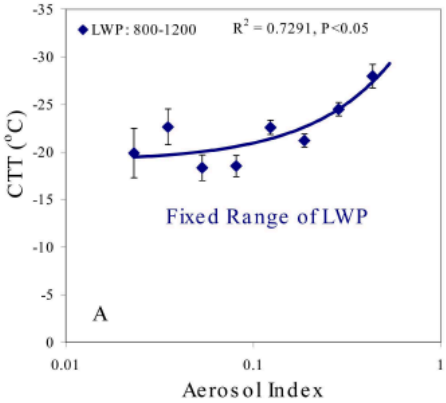
Tropics

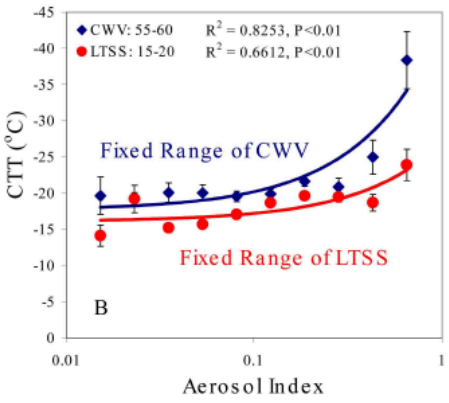
Ocean



Land







Niu and Li, 2012