Process-oriented versus energy-based constraints on cloud microphysics: Implication for aerosol-cloud interactions

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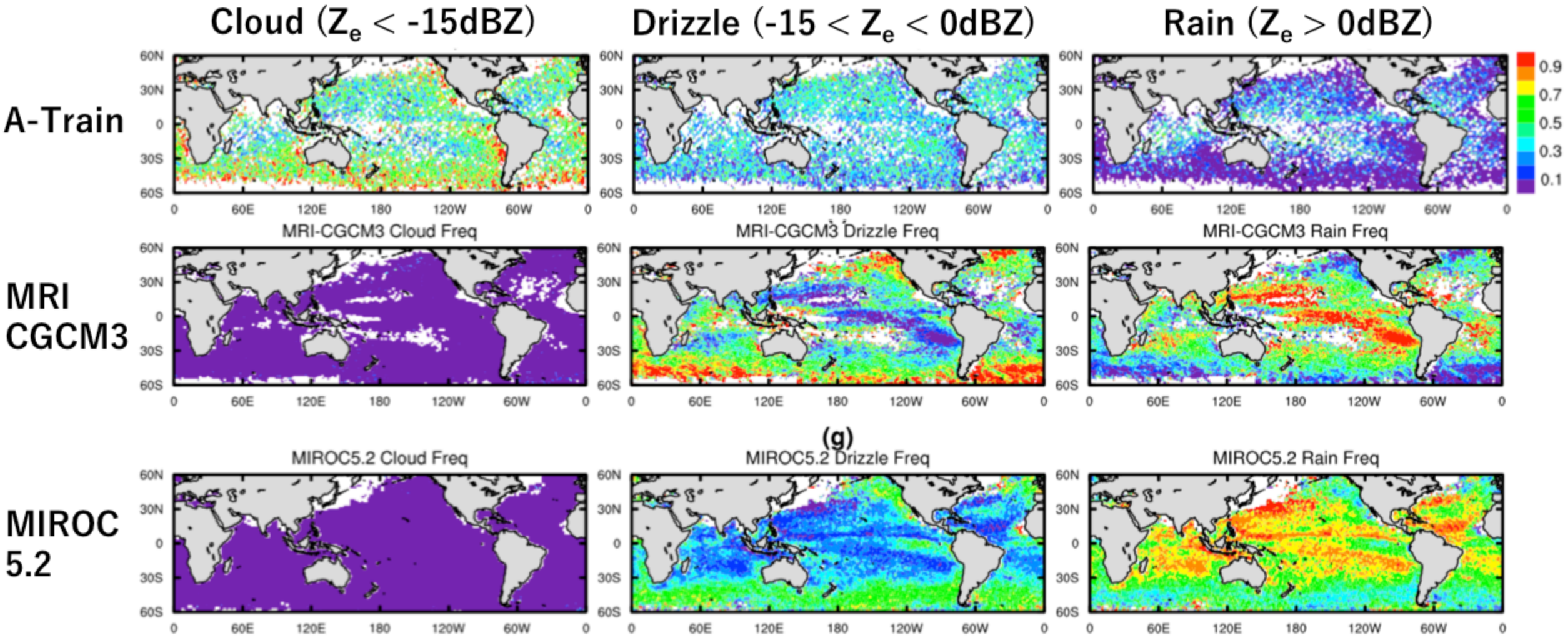
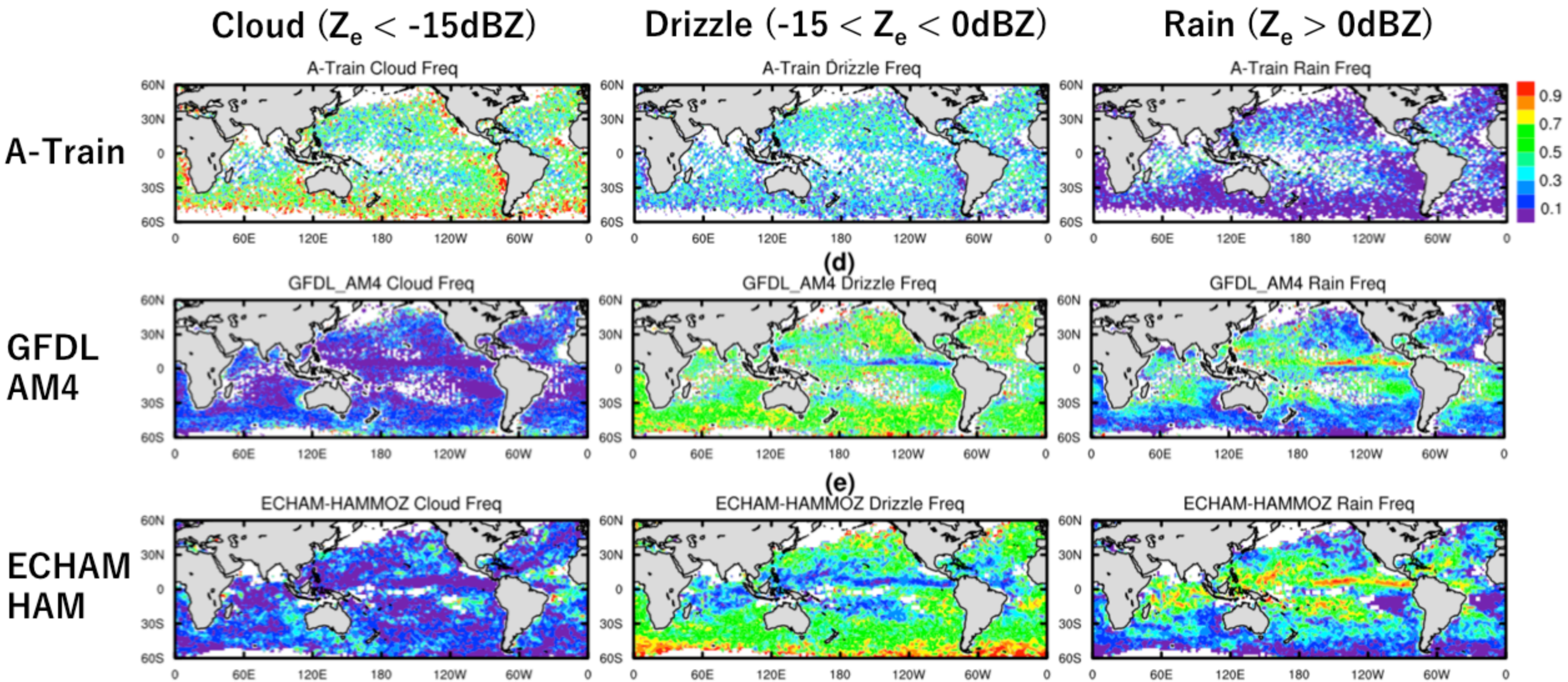
Satellite obs offers information about rain formation



■ Too frequent occurrence of drizzle/rain in models

Jing *et al.* (JGR '17)

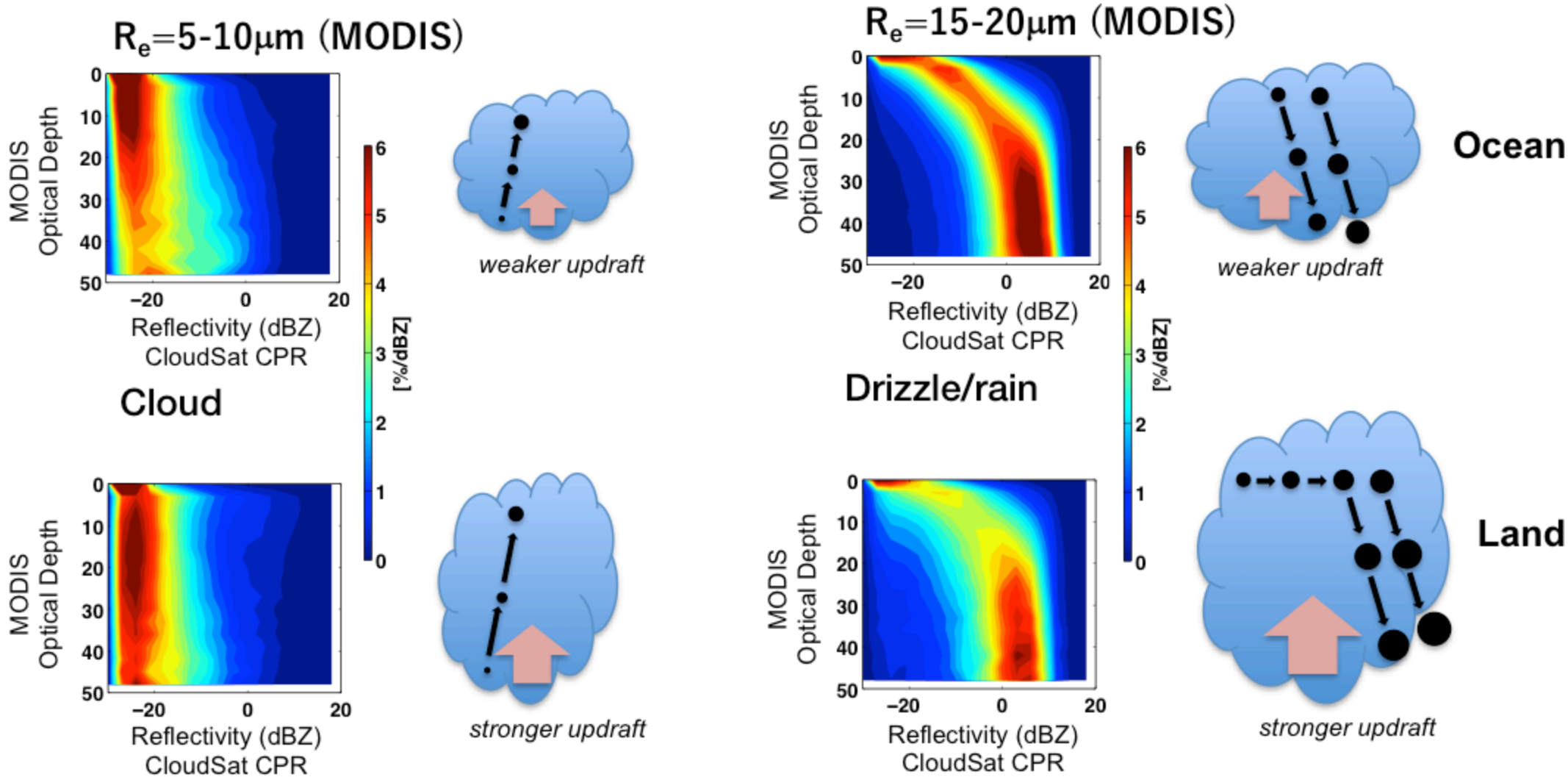
Satellite obs offers information about rain formation



- Too frequent occurrence of drizzle/rain in models: Common issue
- Why this happens? How to fix?

Jing *et al.* (JGR '17)

Satellite-based insight into the warm rain process



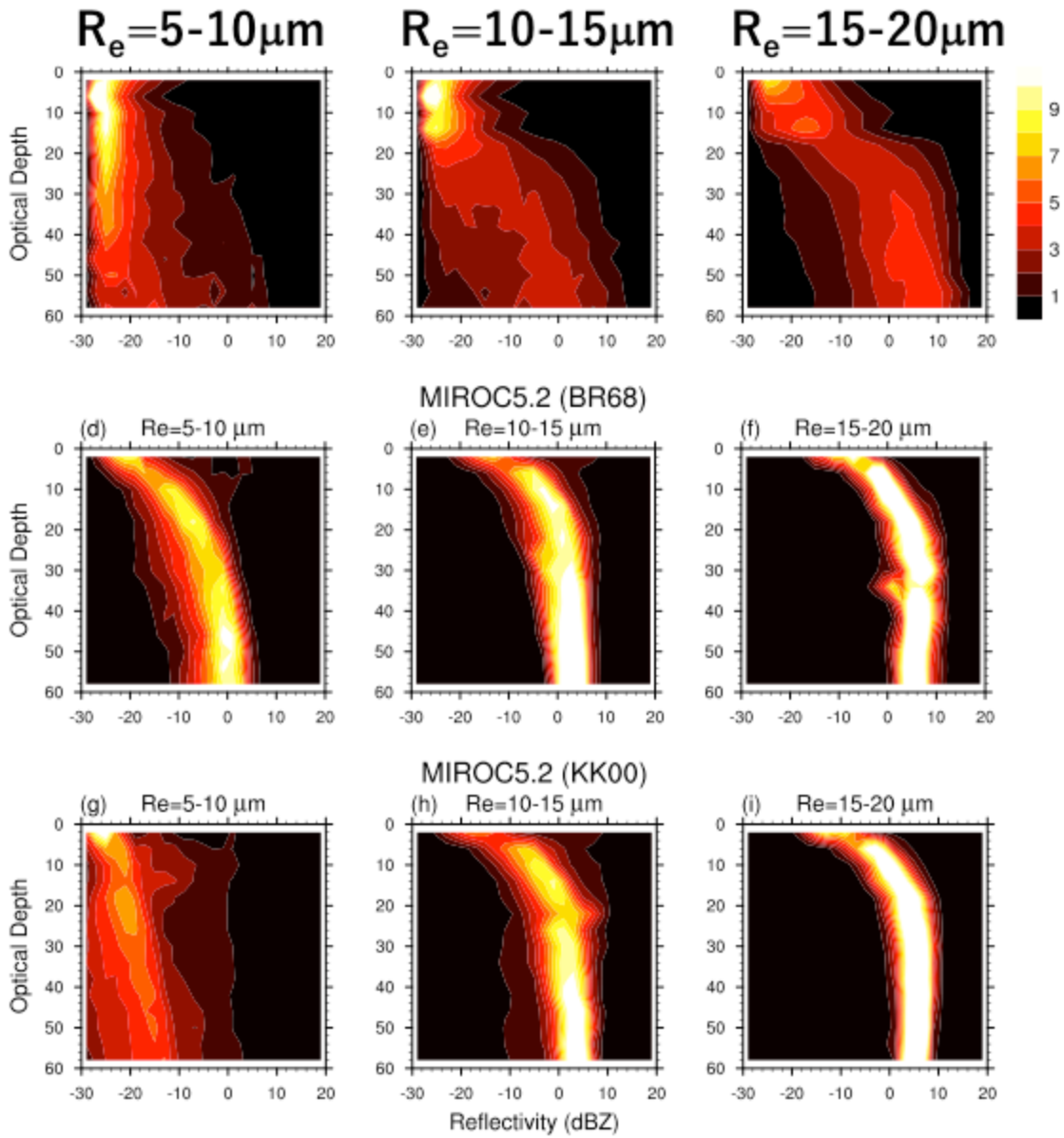
Stephens *et al.* ('18) adapted from Takahashi *et al.* ('17) based on the CFODD method of Suzuki *et al.* ('10)

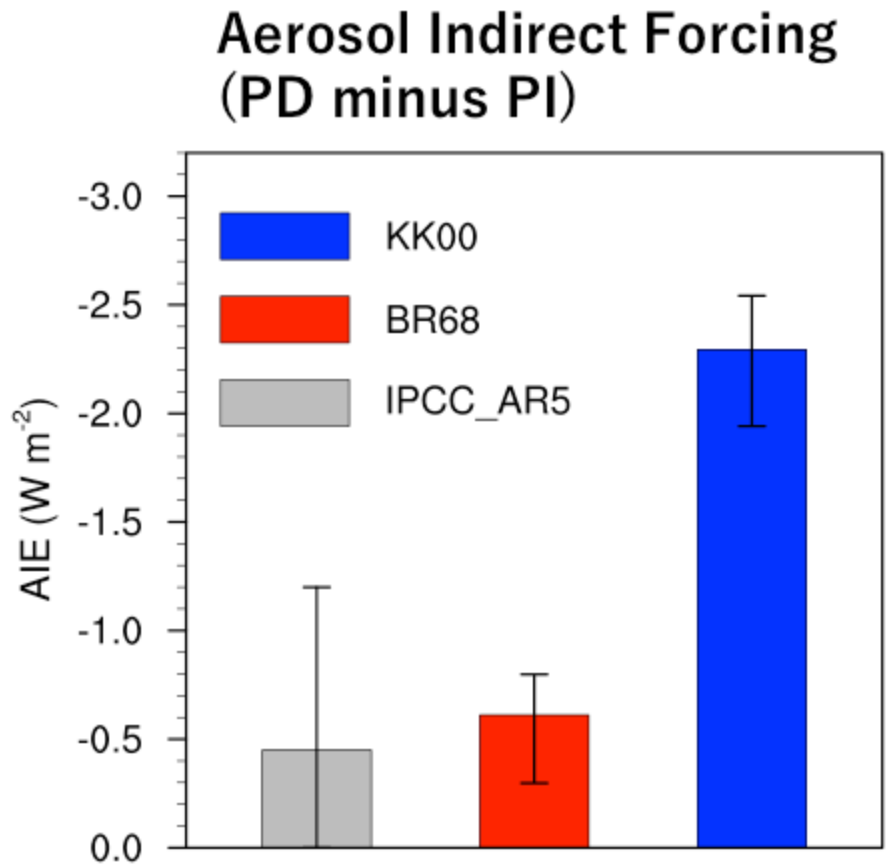
What if the model precipitation constrained with satellite?

Satellite Obs.

MIROC (Berry)

MIROC (K-K)





$$P_{auto} \propto N_c^{-1.0} \text{ (Berry)}$$

$$P_{auto} \propto N_c^{-1.79} \text{ (K-K)}$$

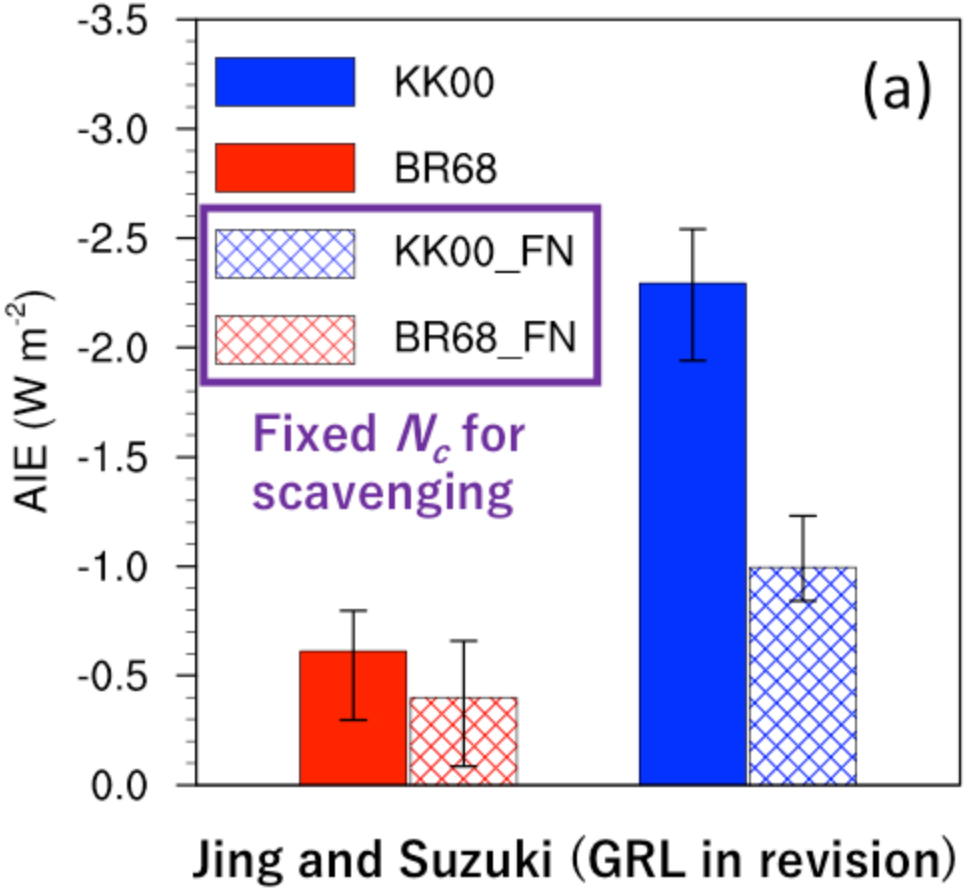
Jing and Suzuki (GRL in revision)

What's happening in the model?

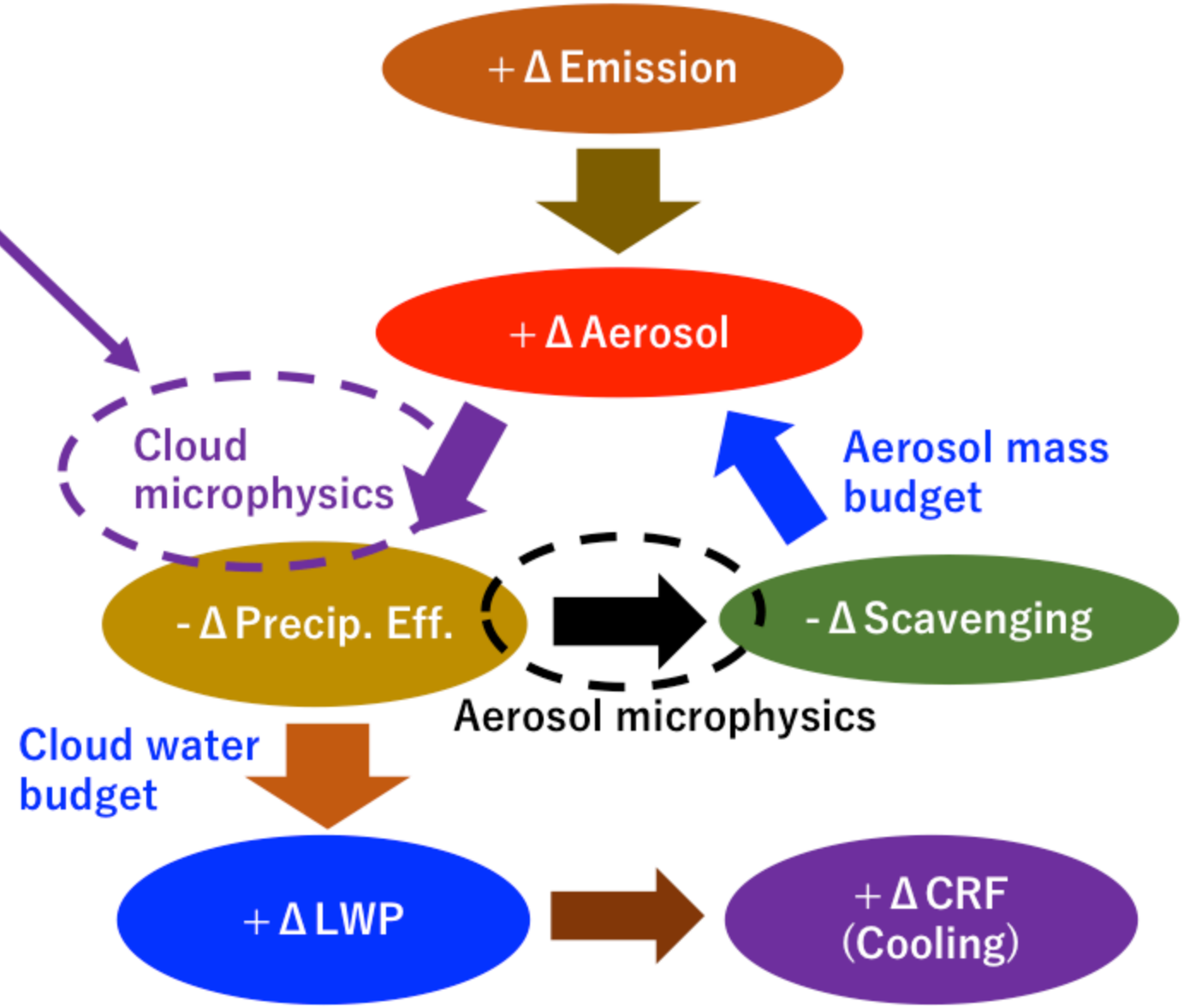
$\Delta = (\mathrm{PD}) - (\mathrm{PI})$

$$P_{auto} \propto N_c^{-1.0}\,(\mathrm{Berry})$$

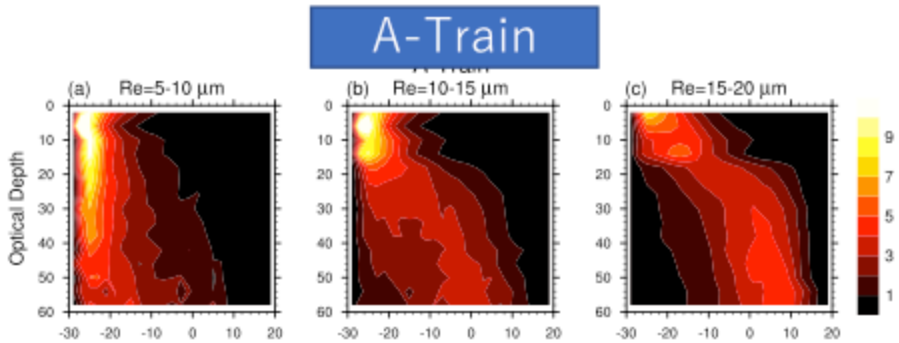
$$P_{auto} \propto N_c^{-1.79}\,(\mathrm{K\text{-}K})$$

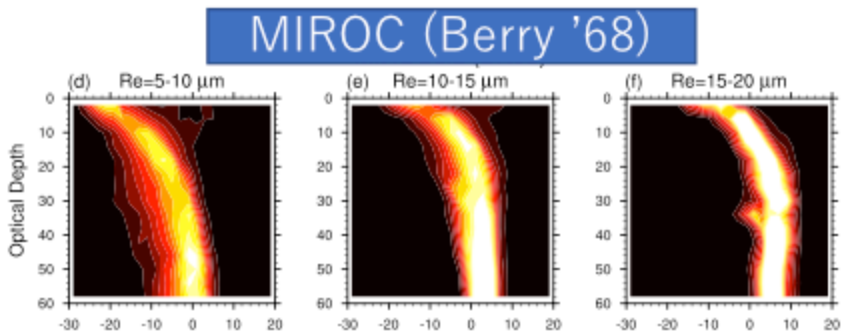


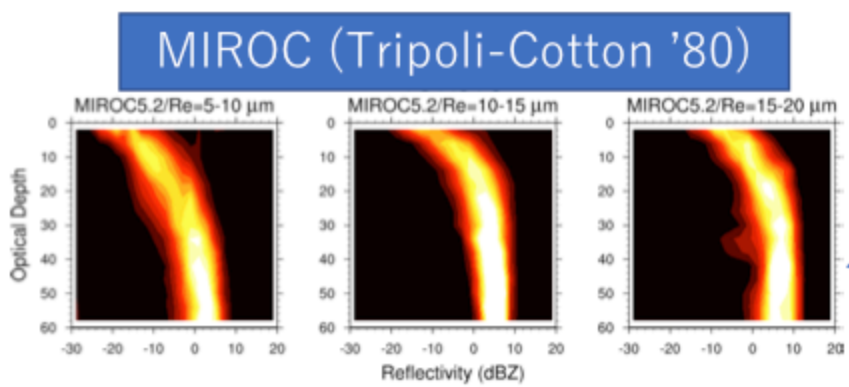
Jing and Suzuki (GRL in revision)

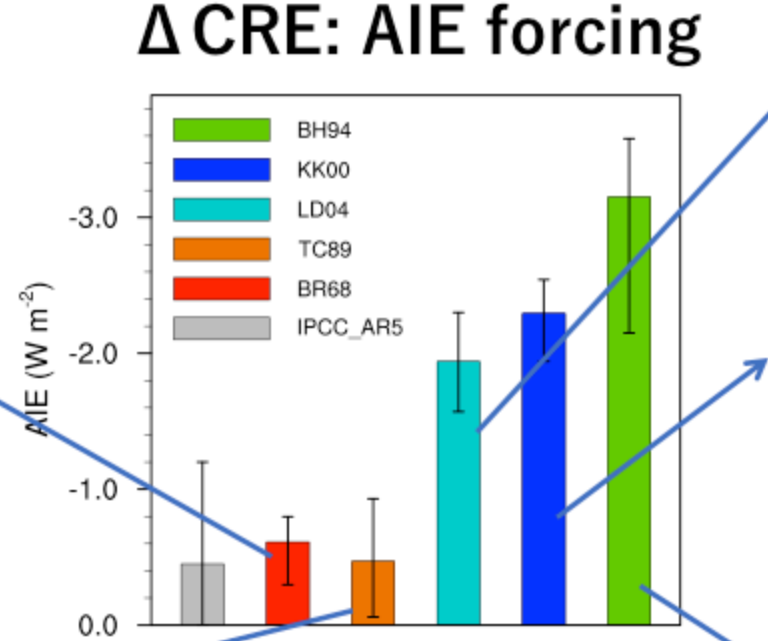


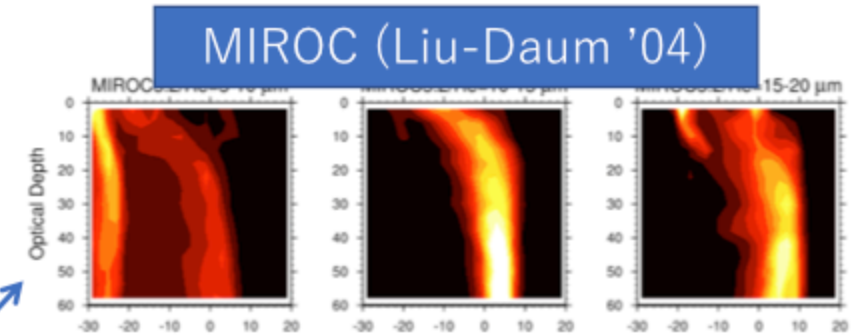
Behaviors of different microphysical schemes

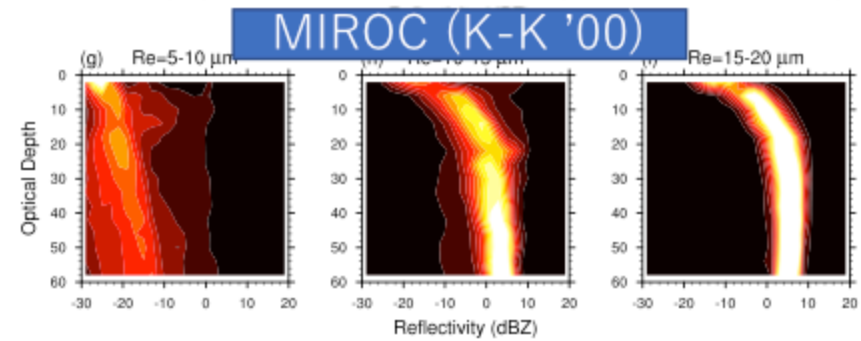


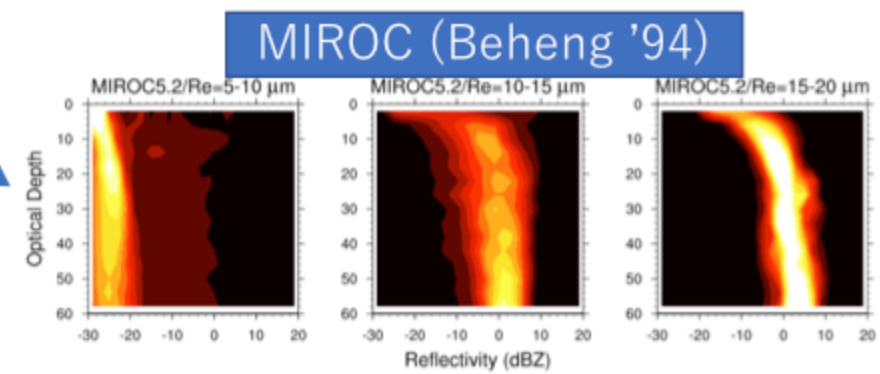










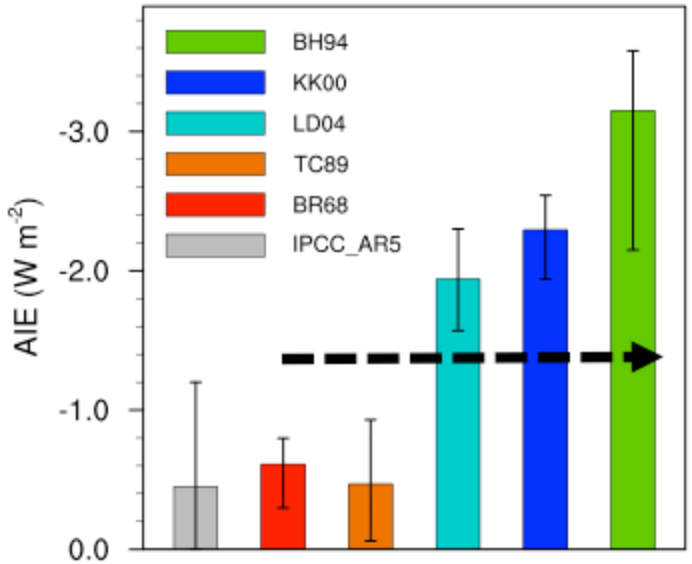


This diagnostic is proposed for GEWEX/PROES-WR (Warm Rain)

Jing and Suzuki (In prep)

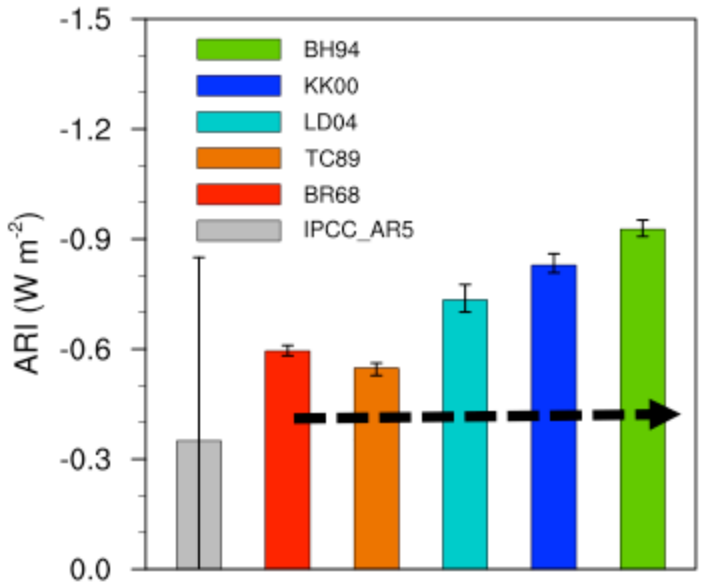
Possible coupling of direct & indirect effects

Aerosol Indirect Forcing



β

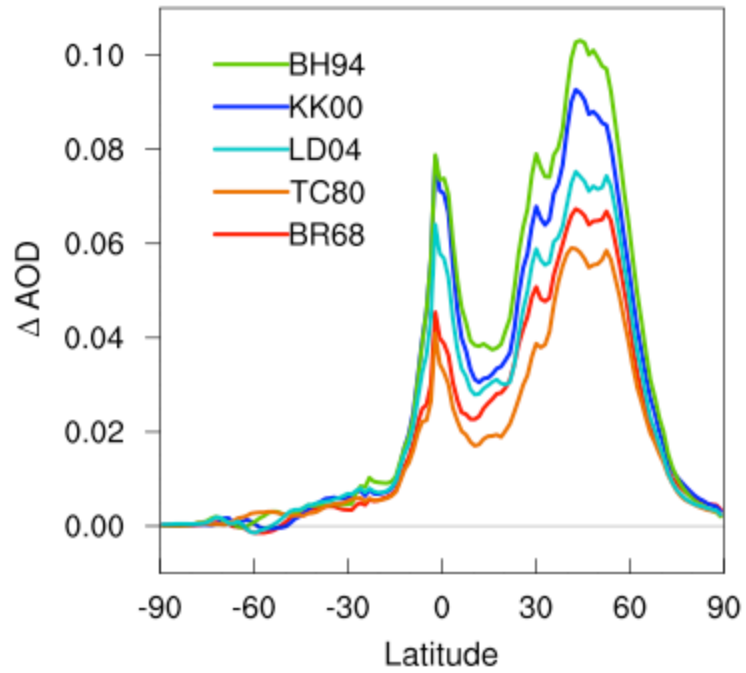
Aerosol Direct Forcing



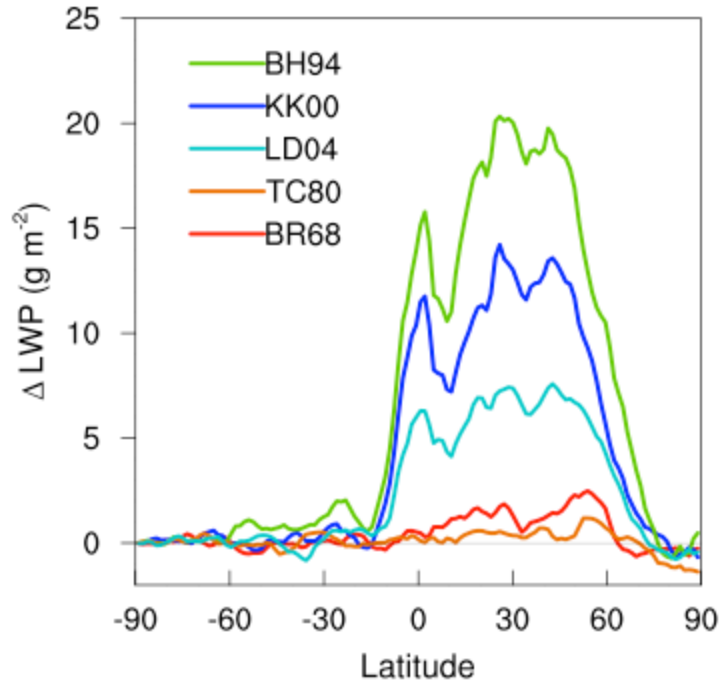
β

Rain formation time scale: $\tau_p \propto (\rho q_c)^{-\alpha} N_c^{\beta}$

ΔAOD (PD-PI)



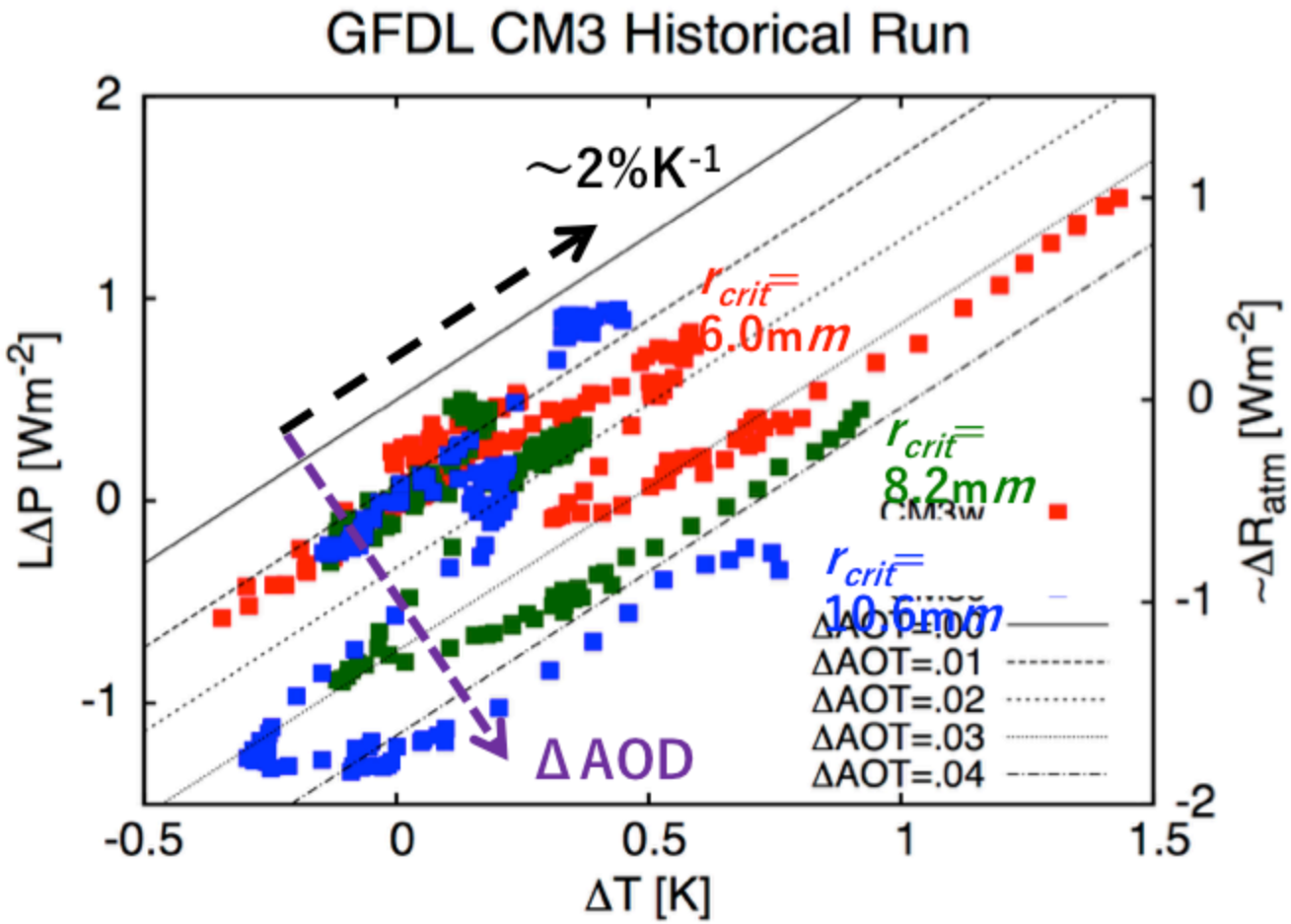
ΔLWP (PD-PI)



- Switching μ-physics scheme changes aerosol loading
- This influences direct as well as indirect radiative forcing
- Possible impact on atmospheric energy balance

Suzuki and Jing (In prep)

Implication for historical change of global precipitation



Suzuki *et al.* (ASL '17)

μ-physical assumption

$$L\Delta P \approx -\Delta R_{atm}$$

$$\approx (\alpha\kappa - \lambda)\Delta T_s - \beta\Delta\tau_a(r_{crit})$$

WV cooling

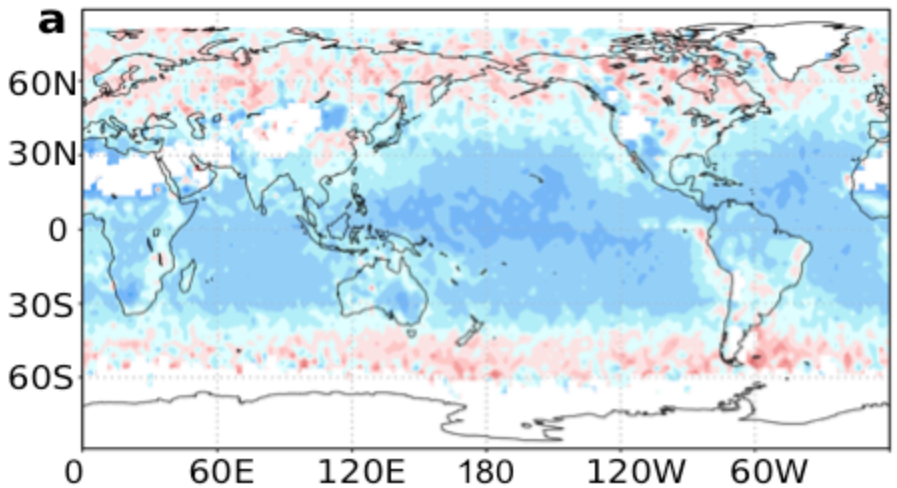
Cloud feedback

Aerosol radiative heating on ATM

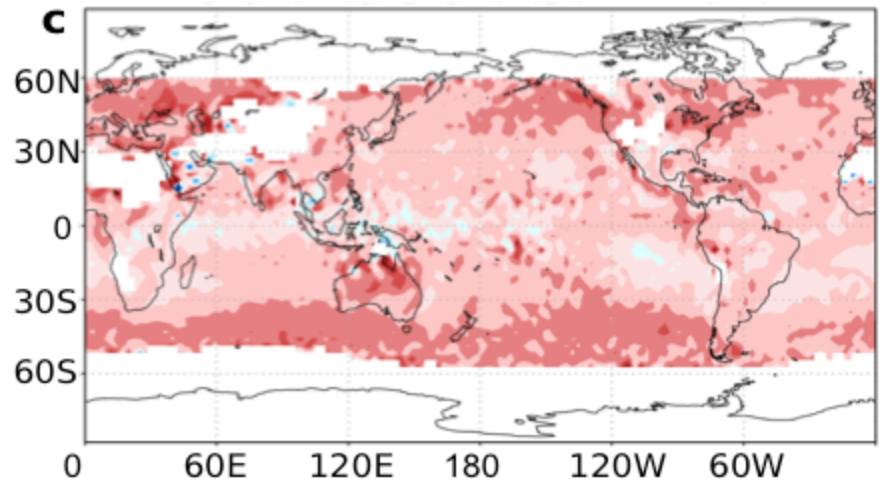
- Cloud μ-physical assumption (r_{crit}) influences the aerosol loading via scavenging process
- Coupling of indirect with direct effect of aerosols perturbs global precipitation

Possible overestimate of indirect effect in traditional GCMs

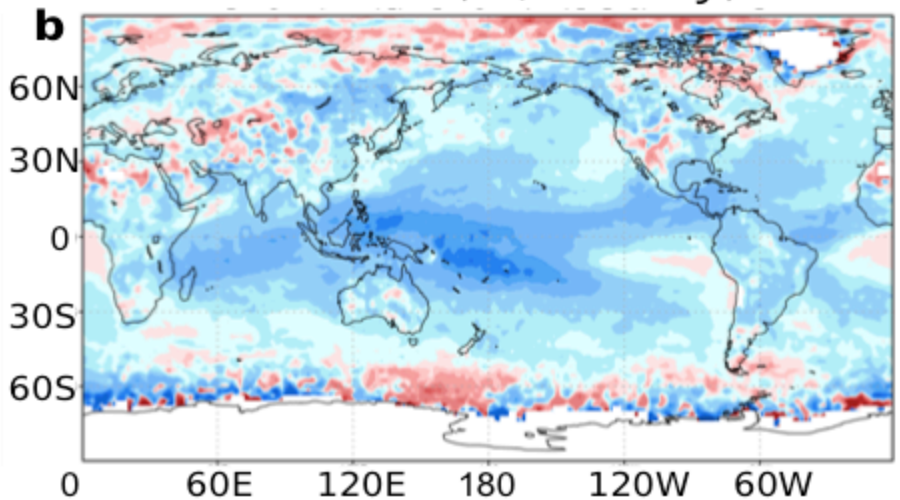
Satellite Obs.



MIROC (w/ Berry)



NICAM (w/ Berry)



- What's different b/w MIROC and NICAM?
  - Resolution: O(100km) vs O(1-10km)
  - DIAG vs PROG rain schemes
- What makes the negative response in NICAM?
  - Enhanced cloud-top evaporation

$\mathrm{d}\mathit{ln}(\mathit{LWP})/\mathrm{d}\mathit{ln}(N_c)$ Y. Sato *et al.* (Nature Comm. '18)

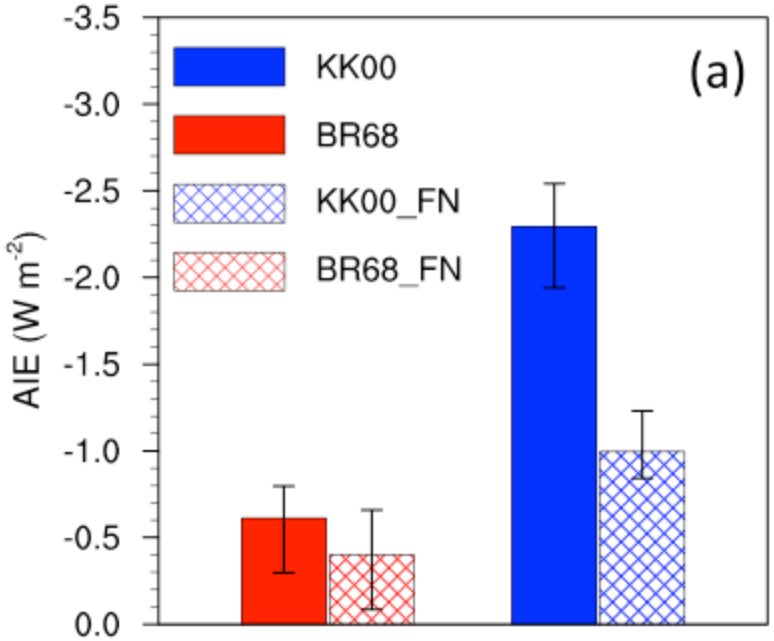
Summary

- GEWEX/PROES Warm Rain (WR) is being proposed exploiting satellite-based insight into the process
- Inconsistency b/w “process” and “energy”: A fundamental gap in our understanding of their linkage
- This is amplified through possible coupling of indirect and direct effects of aerosols: Implication for global precipitation change
- Possible overestimate of aerosol indirect forcing by traditional GCM: NICAM shows a promise

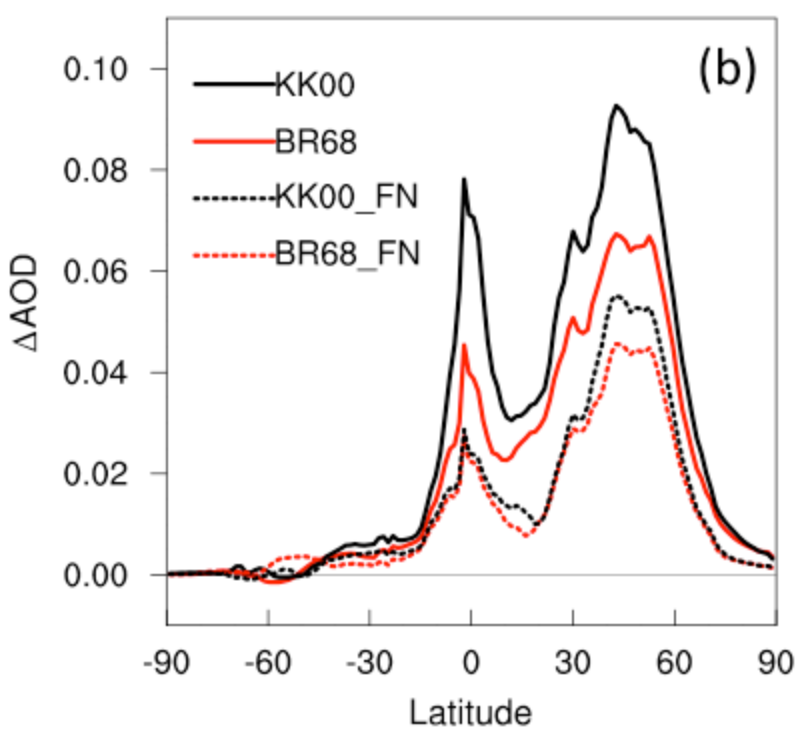
What's happening?

Δ = (Present-Day) − (Pre-Industrial)

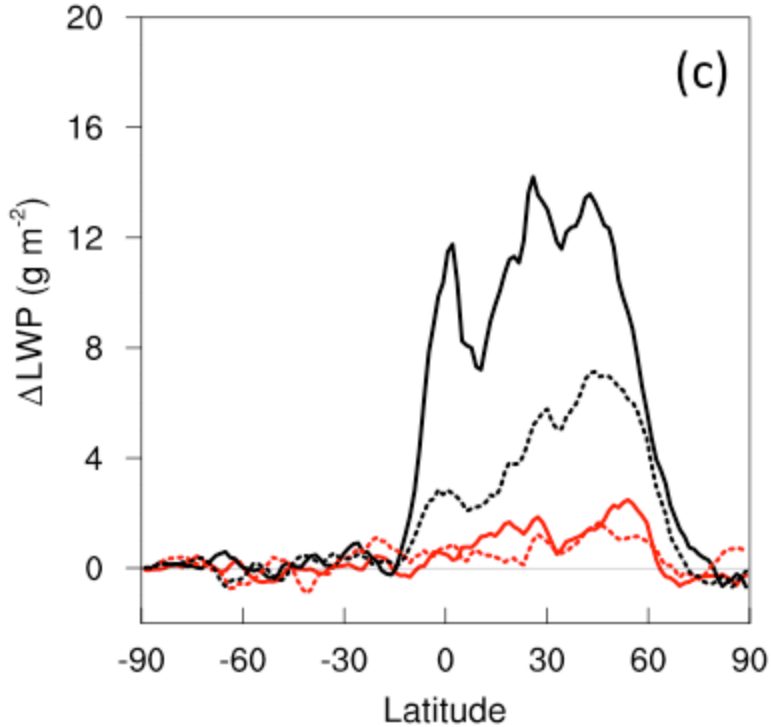
Δ CRE



Δ AOD



Δ LWP



Jing and Suzuki (GRL submitted)

- The cloud response is more pronounced in K-K than in Berry
- This happens via wet-scavenging change with precip efficiency

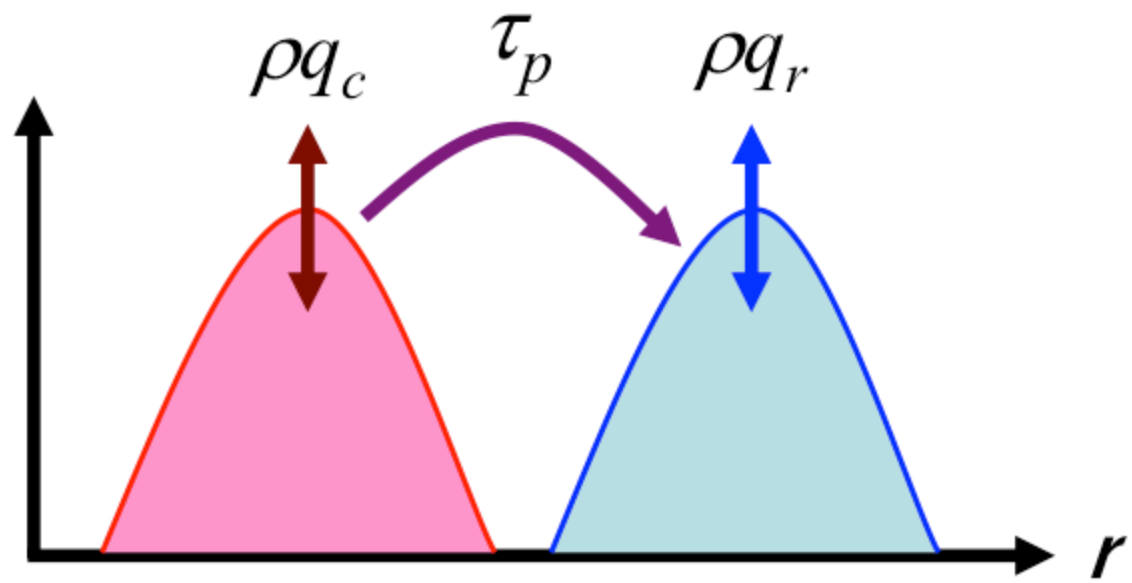
$$P_{auto} \propto N_c^{-1.0} \text{ (Berry)}$$

$$P_{auto} \propto N_c^{-1.79} \text{ (K-K)}$$

Uncertainty of cloud microphysics in global models

$$\frac{\partial(\rho q_c)}{\partial t} = -\frac{\rho q_c}{\tau_p}$$

$$\tau_p \propto (\rho q_c)^{-\alpha} N_c^{\beta}$$



Auto-conversion Scheme	Model	α	β
Berry (1968)	MIROC, NICAM	2.0	1.0
Tripoli and Cotton (1980)	UKMO, GFDL	4/3	1/3
Khairoutdinov and Kogan (2000)	PNNL/MMF, NCAR	1.47	1.79
Beheng (1994)	ECHAM	3.7	3.3