Significance of cloud and precipitation processes in aerosol effect* on climate

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Thanks to contributions from:
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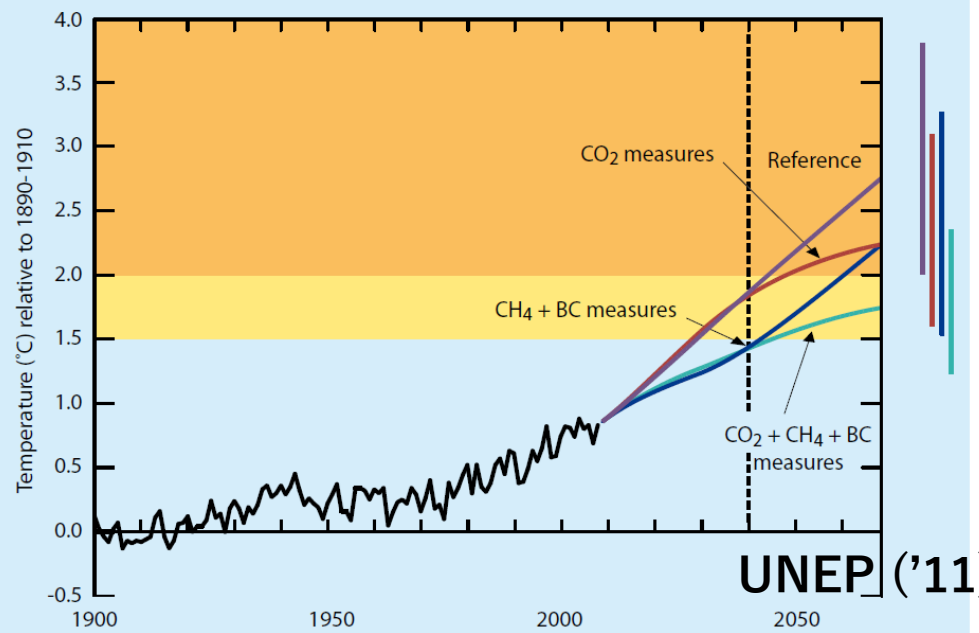
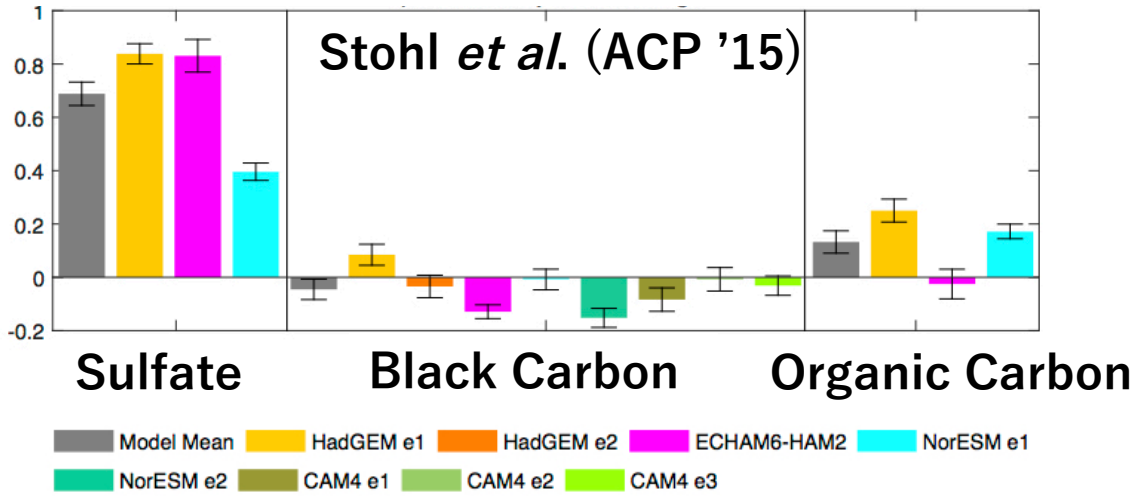
*Direct and Indirect effects

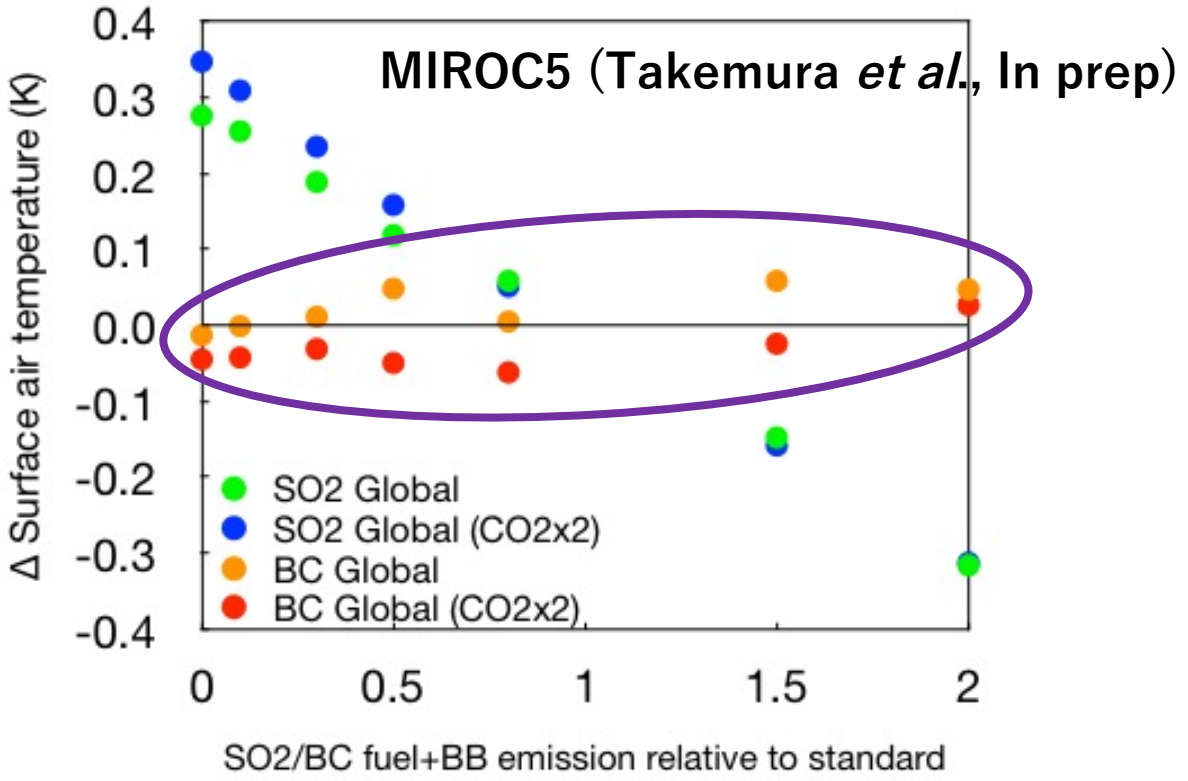
Motivation: Climate impact of short-lived climate pollutants



- Why BC/SF climate effects different?
  - Why BC impact seemingly small?
  - What's impact on global precipitation?
- How to use satellite obs to constrain aerosol effects on climate?

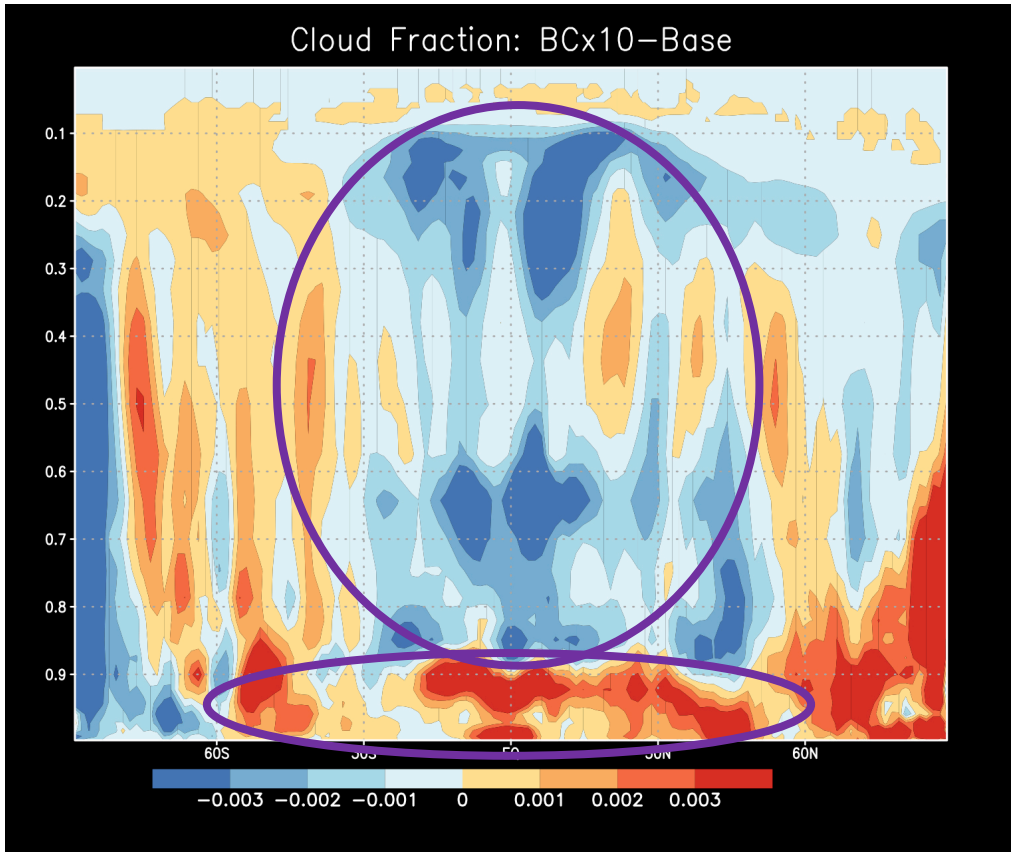
Surface temperature response to emission control





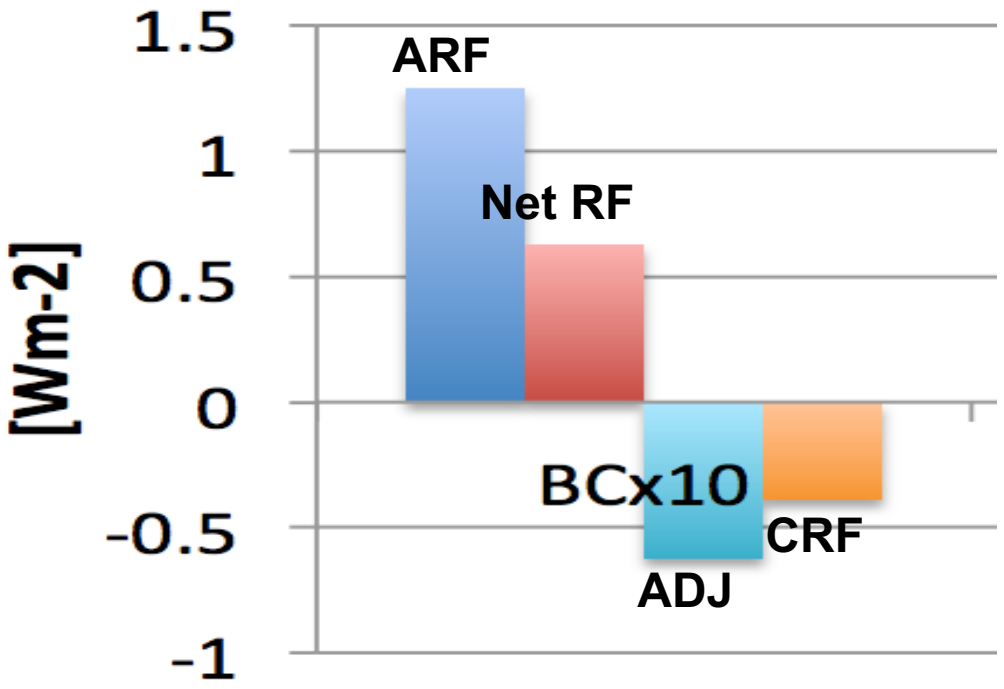
Climate response to BC forcing in SPRINTARS

Response of cloudiness to BCx10 emission in MIROC



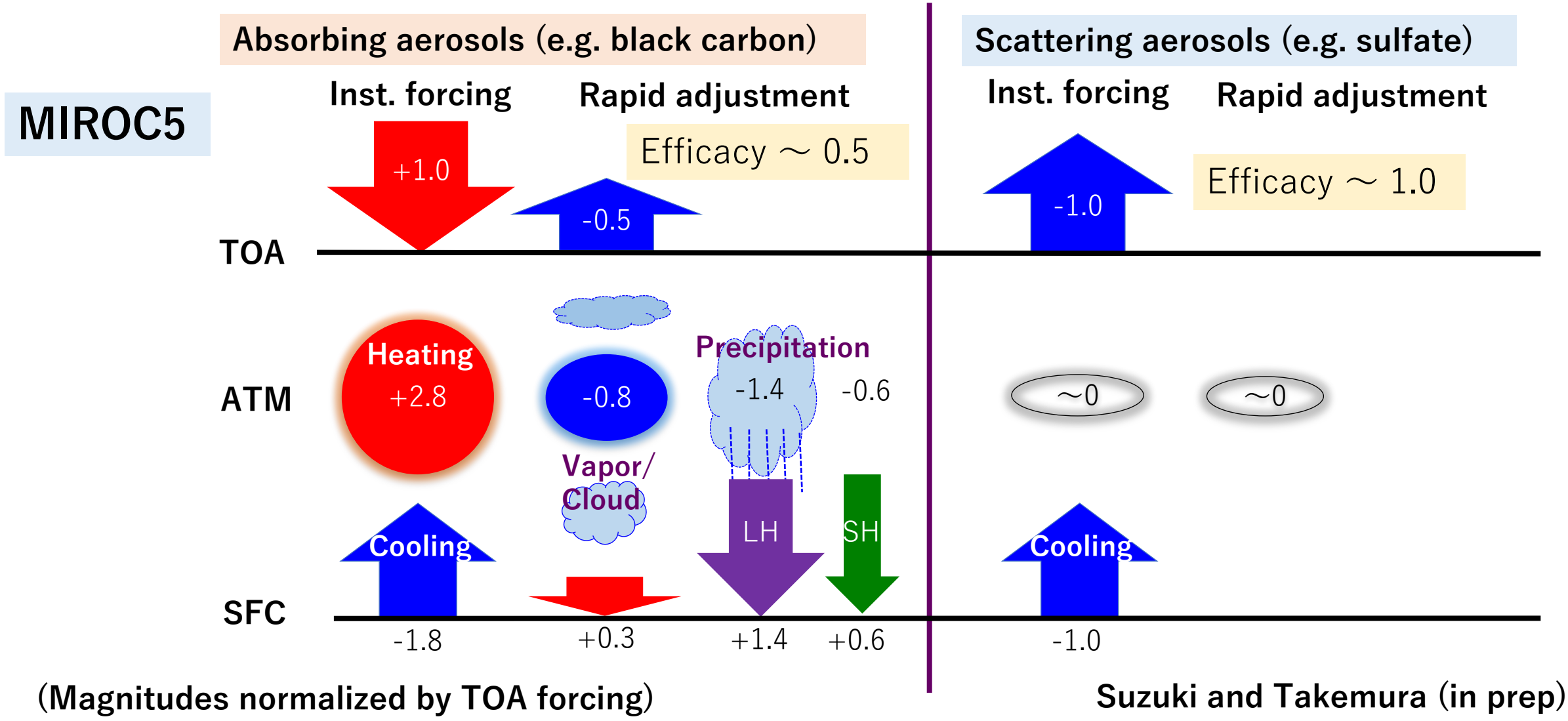
Suzuki *et al.* (In prep)

TOA energy perturbation



- BC stabilizes ATM to induce adjustments
- Significance of cloud responses
- This makes the forcing “efficacy” small

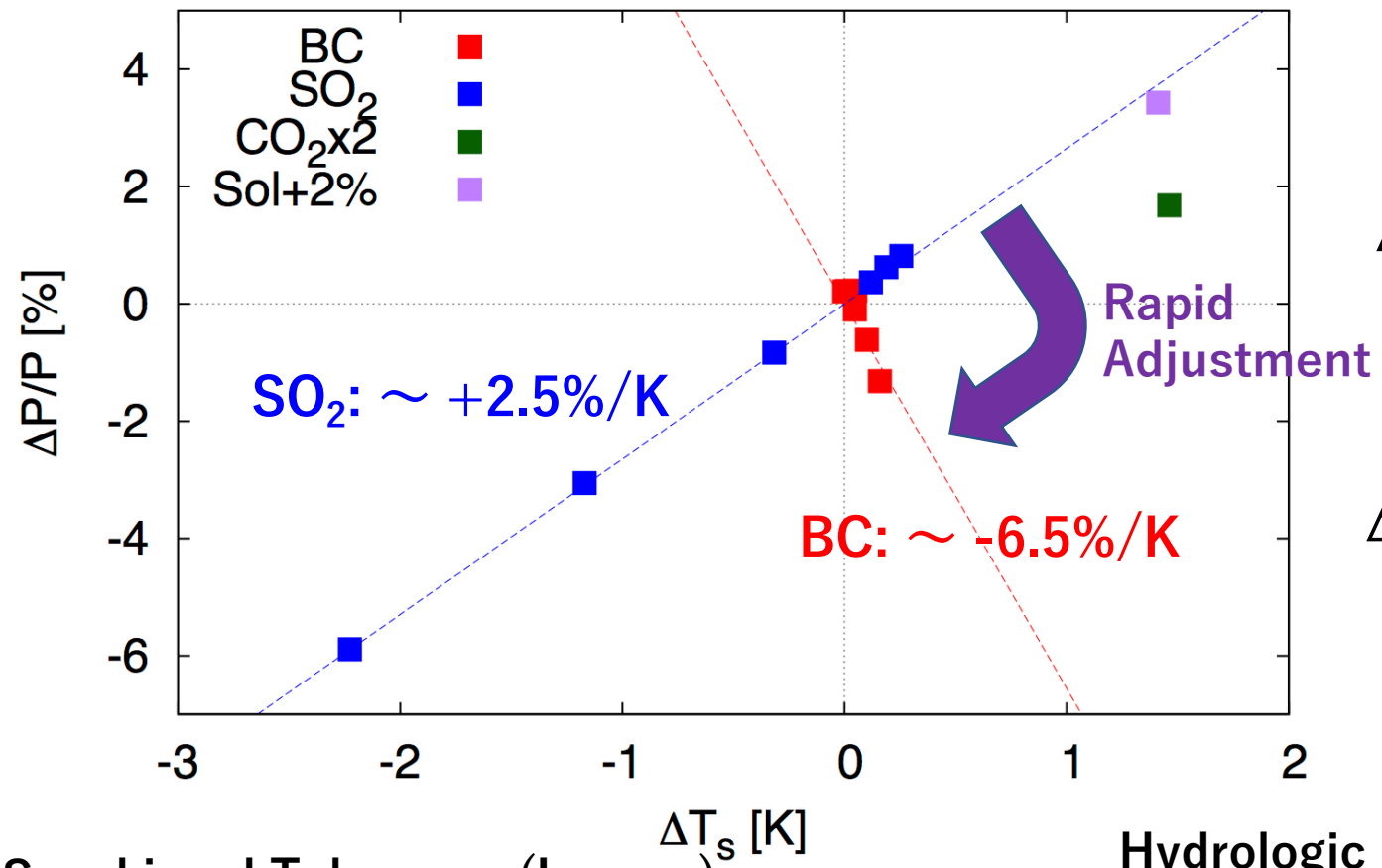
Different forcing natures of absorbing/scattering aerosols



- Two types of aerosols differently re-distribute energy into ATM/SFC
- This causes distinctly different responses of the atmosphere

Different climatic effects of scattering/absorbing aerosols

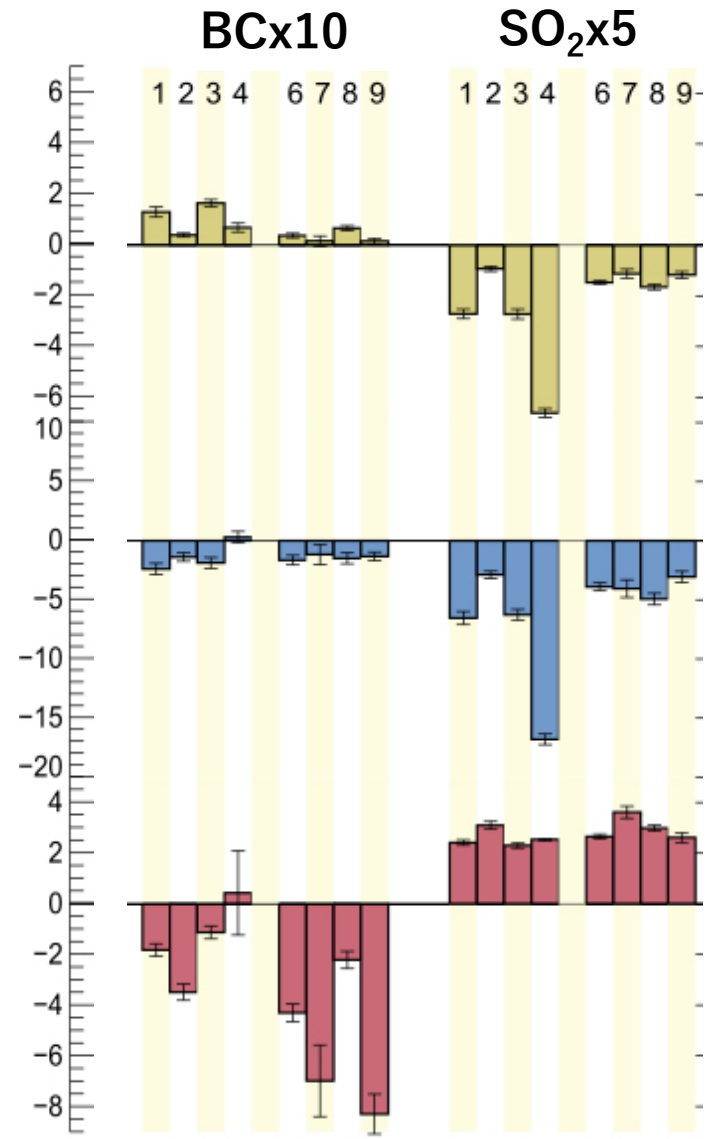
MIROC5-SPRINTARS



Suzuki and Takemura (In prep)

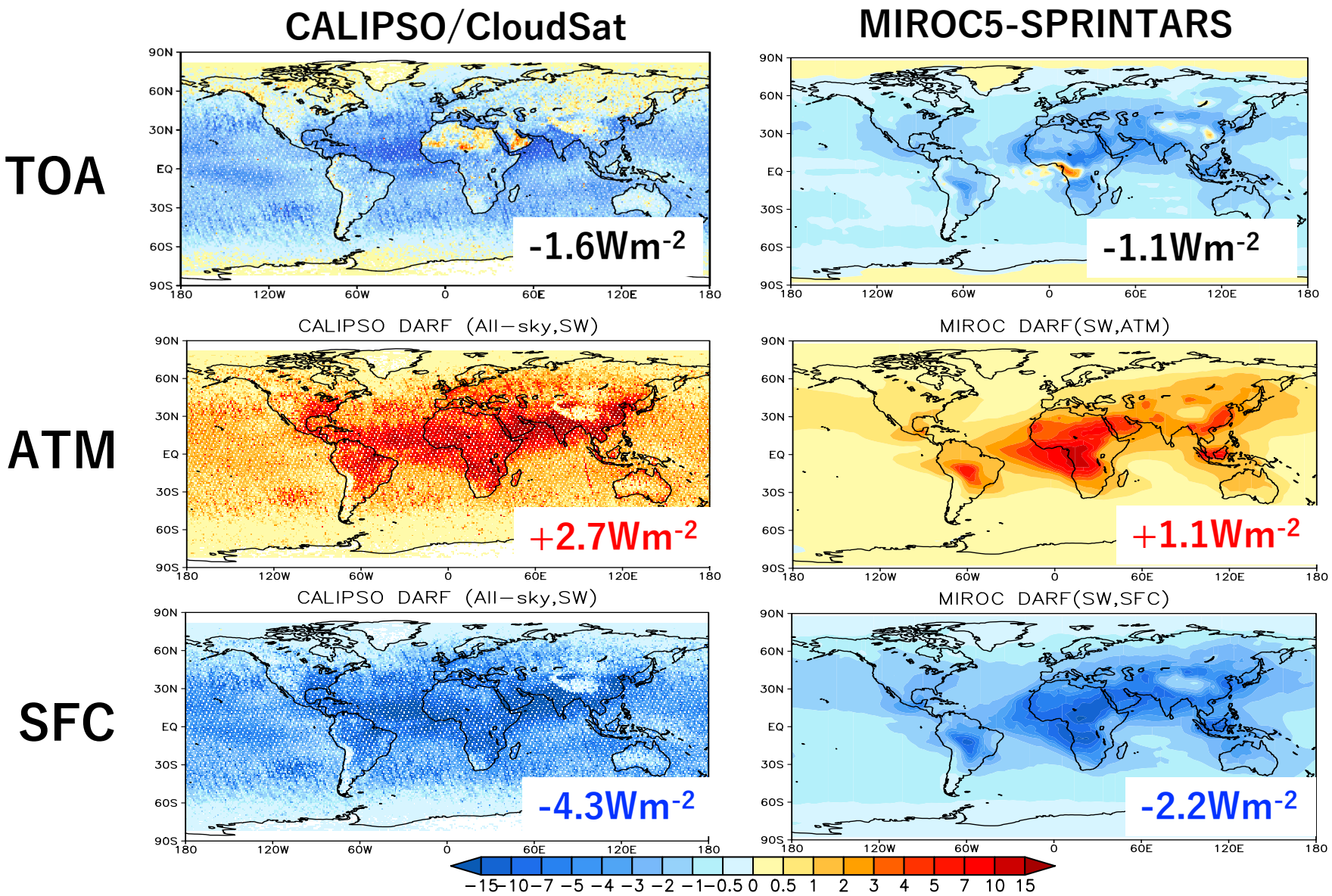
- BC: BCx10, x5, x2, x0.5, x0.3, x0.1
- SO_2: SO_2x10, x5, x2, x0.5, x0.3, x0.1
- CO_2: CO_2x2
- Sol: Solar irradiance +2%

PDRMIP; Samset *et al.* (GRL '16)



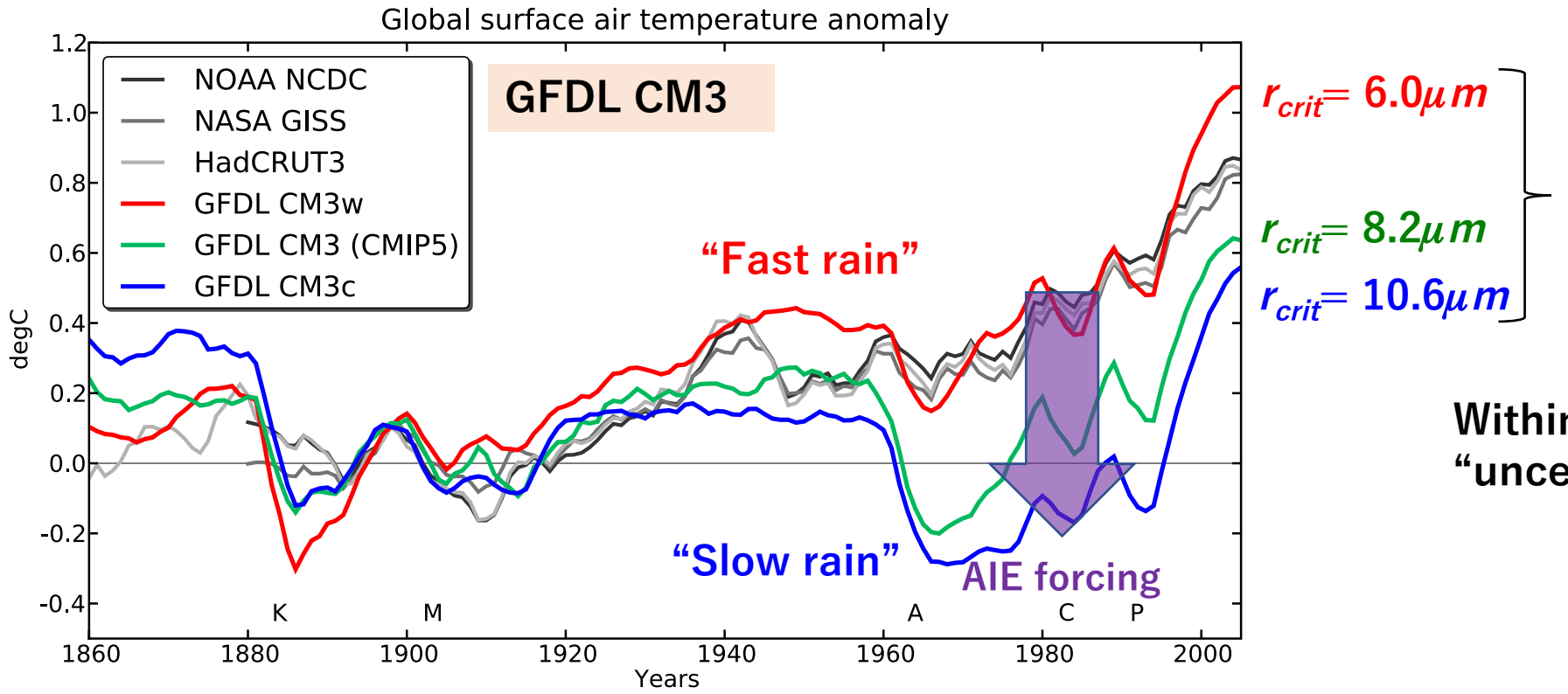
Aerosol forcing “stratification”: Satellite vs MIROC5

Oikawa *et al.*



➢ Different ATM/SFC proportions b/w Satellite & SPRINTARS

Indirect effect: a major uncertainty in climate simulation

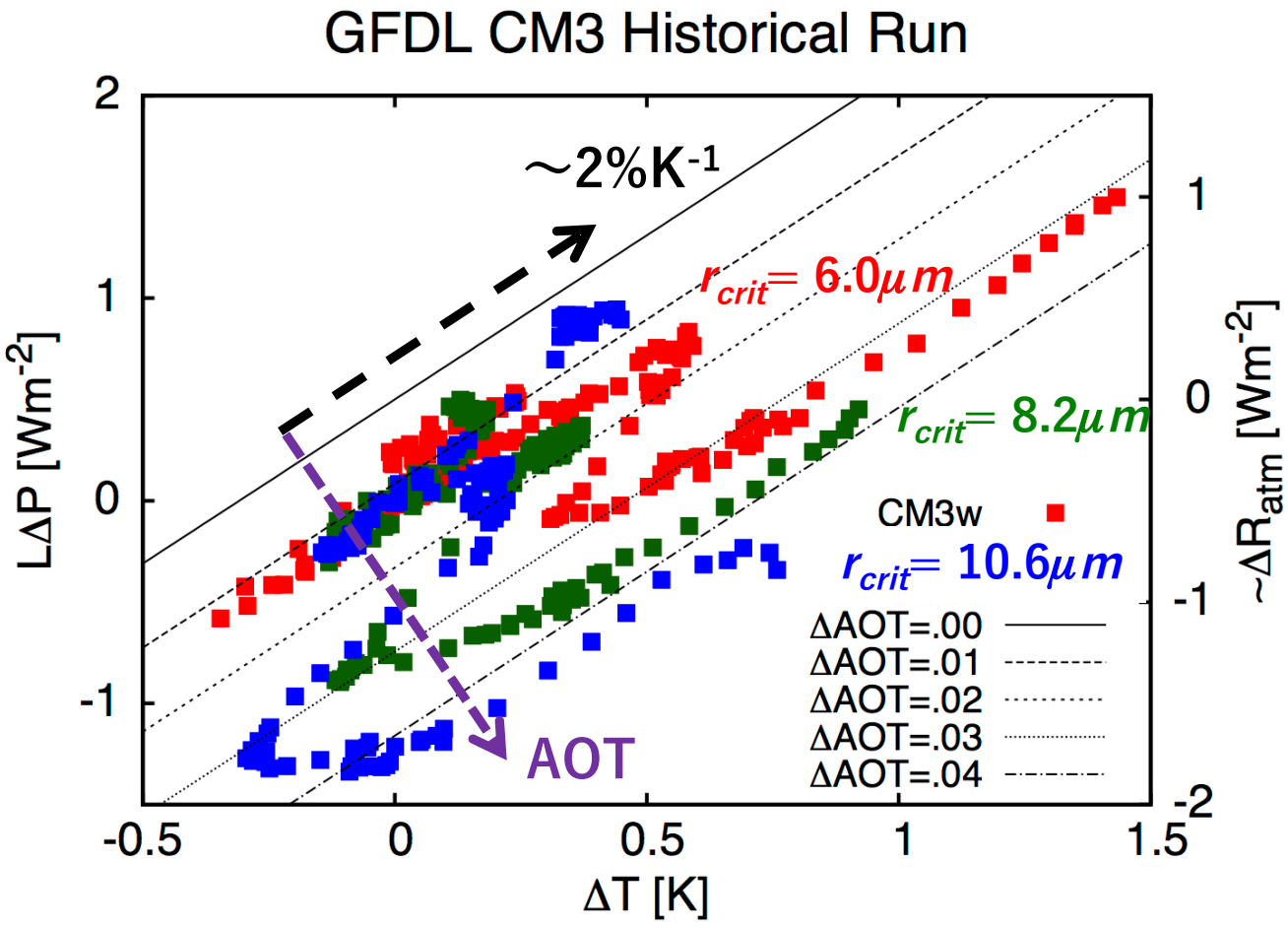


Golaz *et al.* (GRL '13)

r_{crit}: Threshold particle radius for warm rain to occur

- A "tunable" parameter in (some) models controlling precipitation efficiency
- Significantly modulates magnitude of the aerosol indirect forcing
- Leads to different historical temperature trends

Possible coupling of indirect effect with direct effect



Suzuki *et al.* (*Atmos. Sci. Lett.* to appear)
(*cf.* Pendergrass and Hartmann, GRL '12)

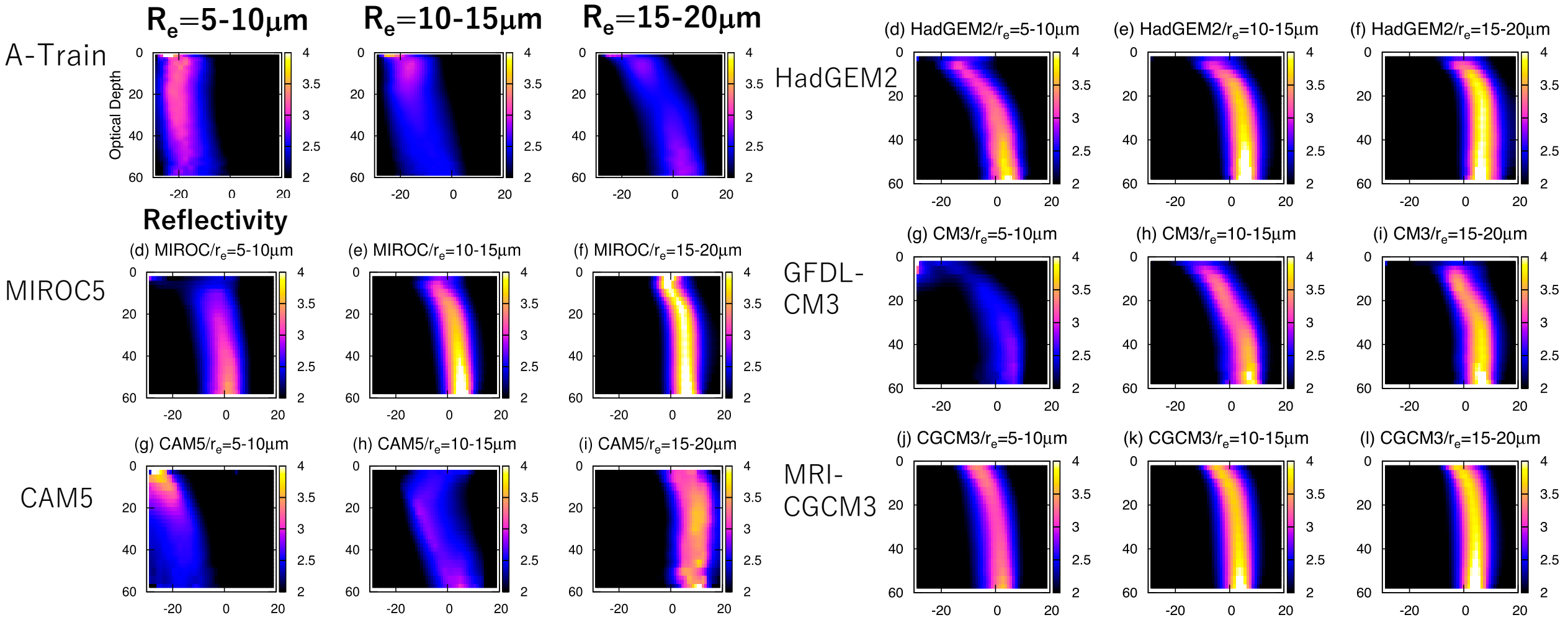
Energy-balance control on global precipitation

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

WV cooling — Cloud feedback — Aerosol radiative heating on ATM

- Cloud μ-physical assumption (r_{crit}) influences the aerosol loading via scavenging process
- ARE perturbs energy balance to modulate global precipitation
- How to constrain cloud μ-physics (e.g. r_{crit}) with satellite obs?

Satellite-based model diagnostics of the warm rain process

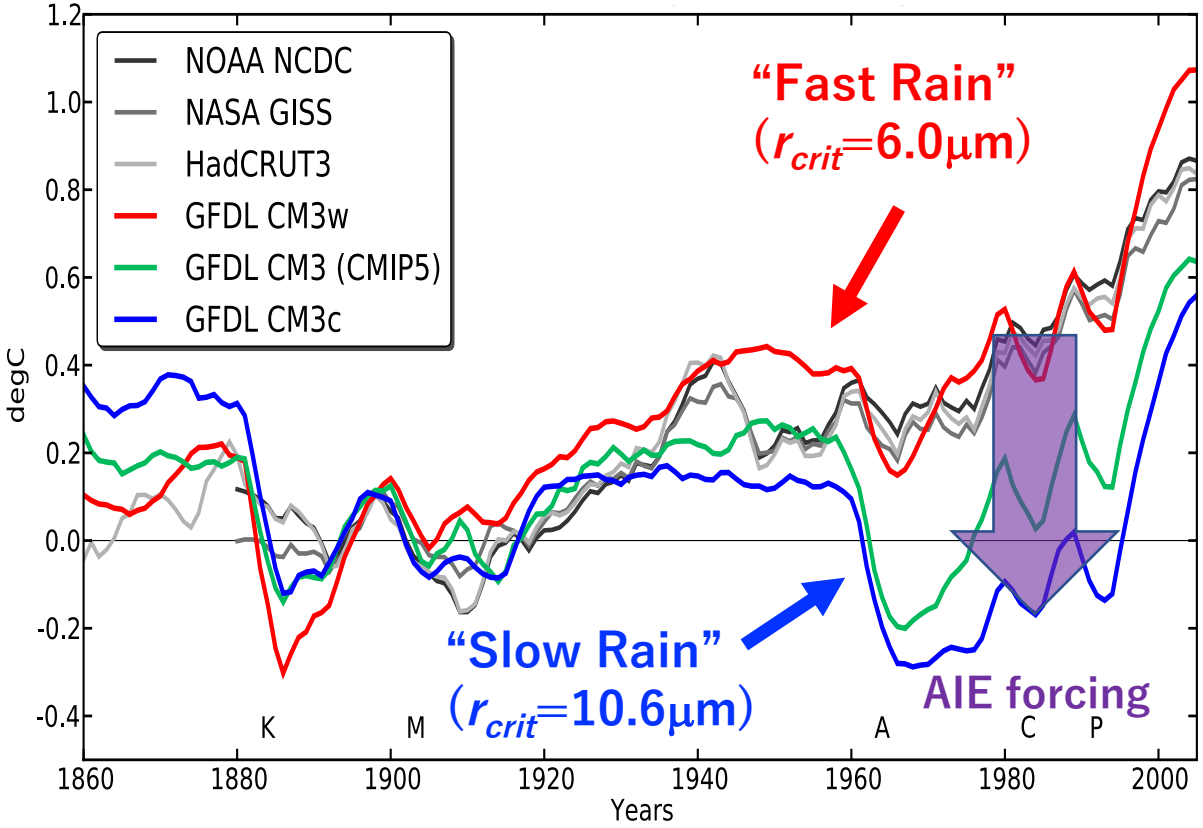


- Contoured Frequency by Optical Depth Diagram (CFODD)
- Global models tend to form rain too efficiently

Suzuki *et al.* (JAS '15)

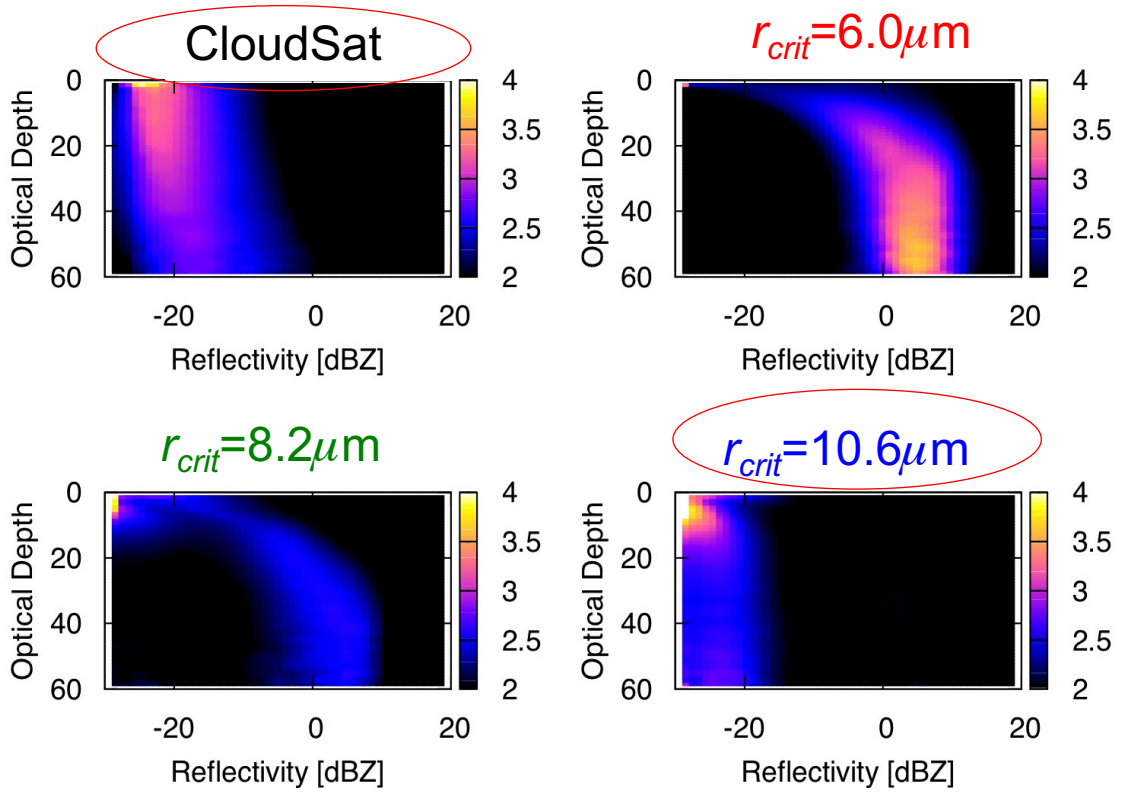
Two levels of constraints on aerosol indirect forcing

"Top-down" constraint



Golaz *et al.* (GRL '13)

"Bottom-up" constraint



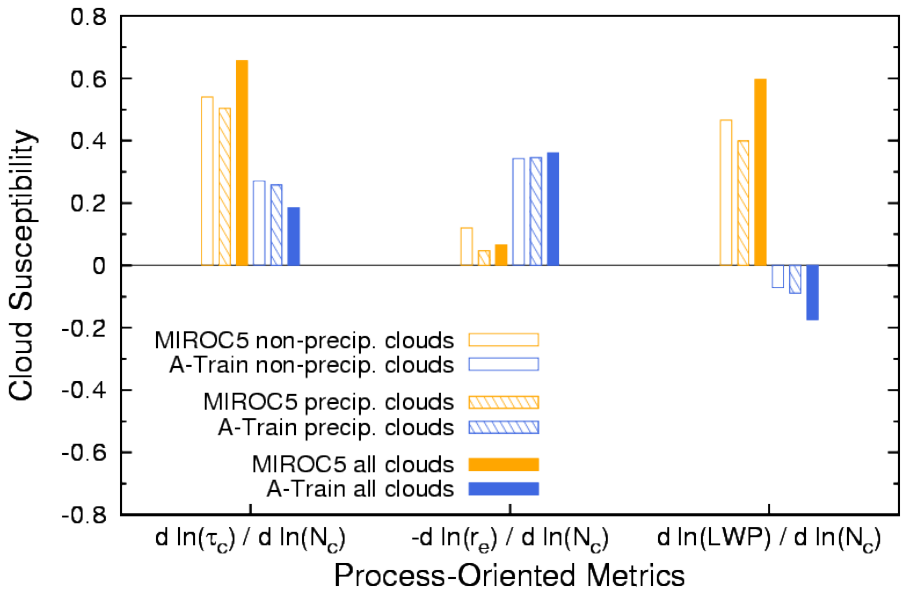
Suzuki *et al.* (GRL '13)

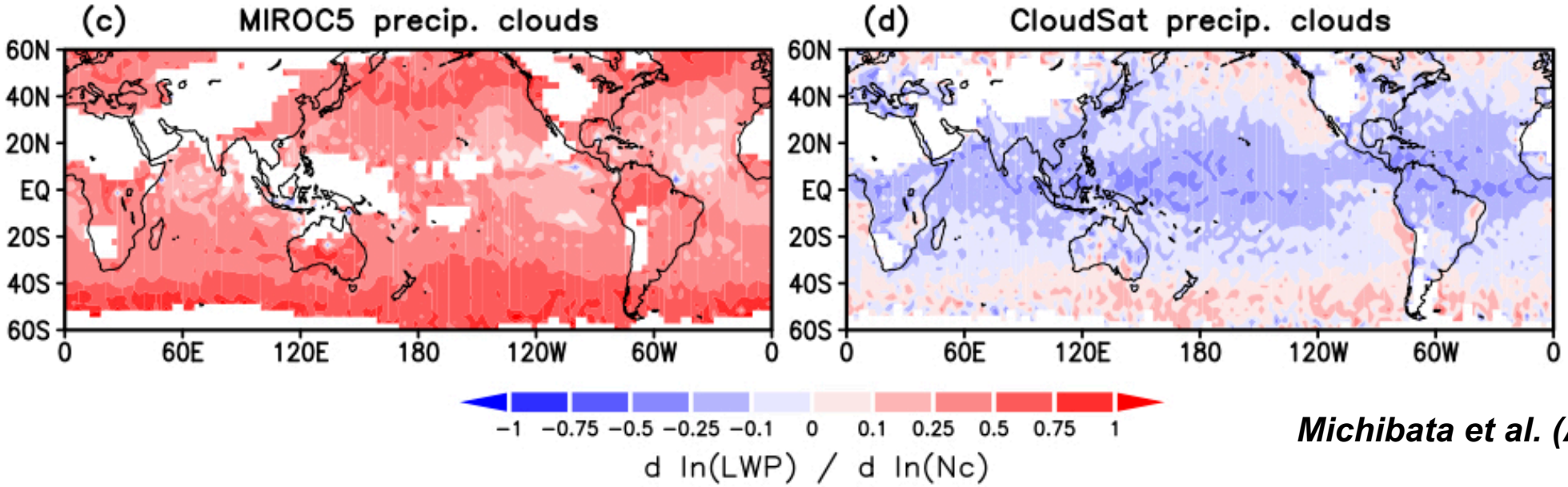
- Dichotomy between the two constraints: Error compensation at a fundamental level
- "Slowing down" the rain (matching satellites) leads to a "wrong" climate simulation
- Do GCMs overestimate the aerosol indirect forcing?

Possible overestimate of indirect forcing in GCMs?

$$\frac{d \ln \tau_c}{d \ln N_c} = -\frac{d \ln r_e}{d \ln N_c} + \frac{d \ln \mathrm{LWP}}{d \ln N_c}$$

Twomey effect **Lifetime effect**





Michibata et al. (ACP '16)

Summary

- The BC and SF forcings have different ATM/SFC “stratification”, leading to different climate impacts on global temperature and precipitation – this may explain small temperature response to BC forcing.
- The climatic change of global-mean precipitation is influenced by aerosol radiative effect in the manner modulated by cloud microphysical assumption controlling the precipitation efficiency.
- Satellite-based process-level (“bottom-up”) constraint on cloud microphysics leads to a “wrong” climate simulation - due to a possible overestimate of AIE?
- MIROC tends to overestimate the cloud susceptibility to aerosols compared to satellite observations.