Satellite-based model constraint on cloud microphysical processes and its link to radiative forcing of aerosol-cloud interaction

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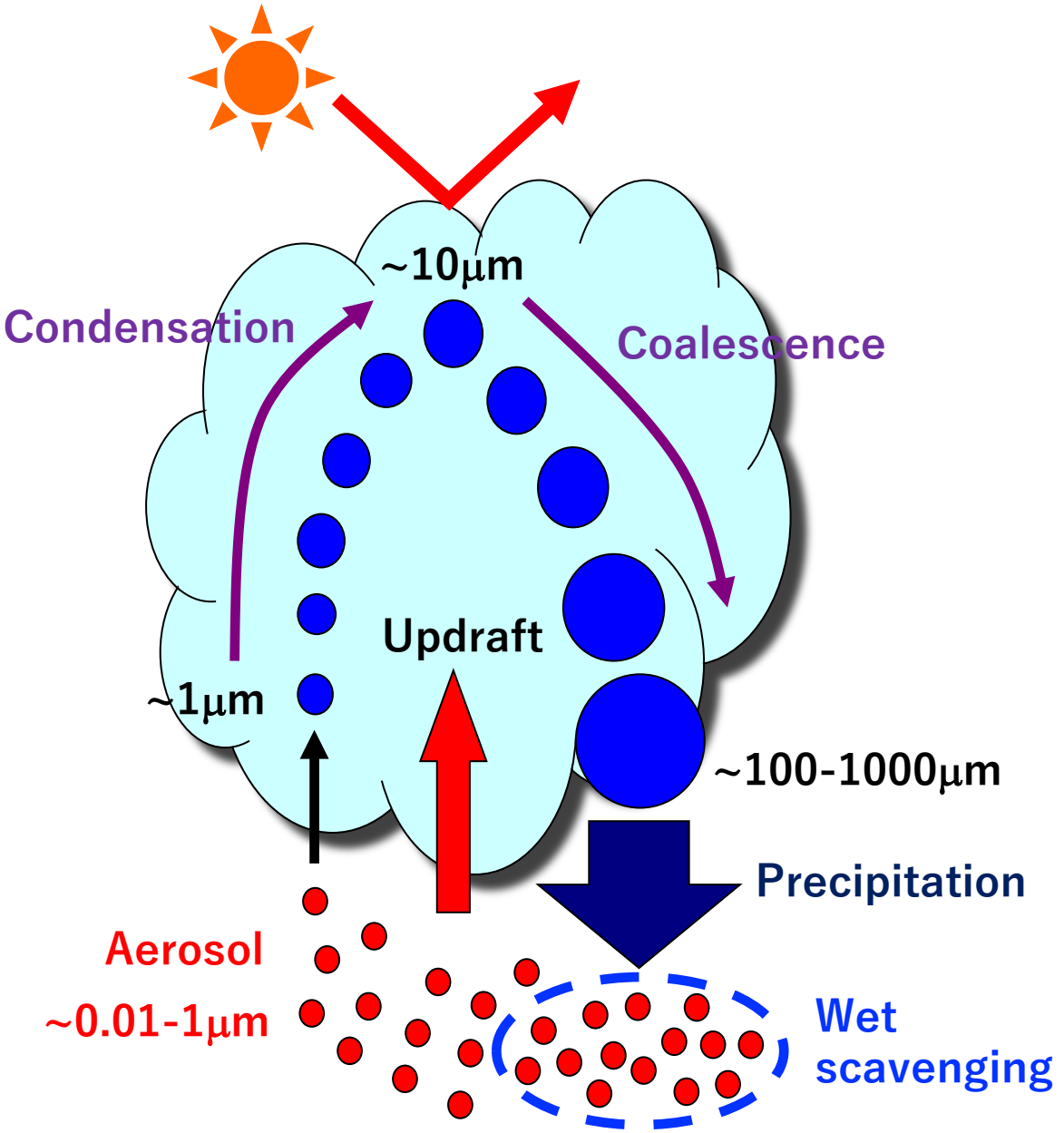
Focus: Aerosol-cloud-precipitation interaction

- Aerosol perturbation influences the cloud water budget
  - => Cloud radiative effect
  - => Precipitation
- How do microphysical processes mediate the aerosol effect on cloud water budget and forcing?
- How can satellite observations constrain the processes to help reduce the forcing uncertainty?

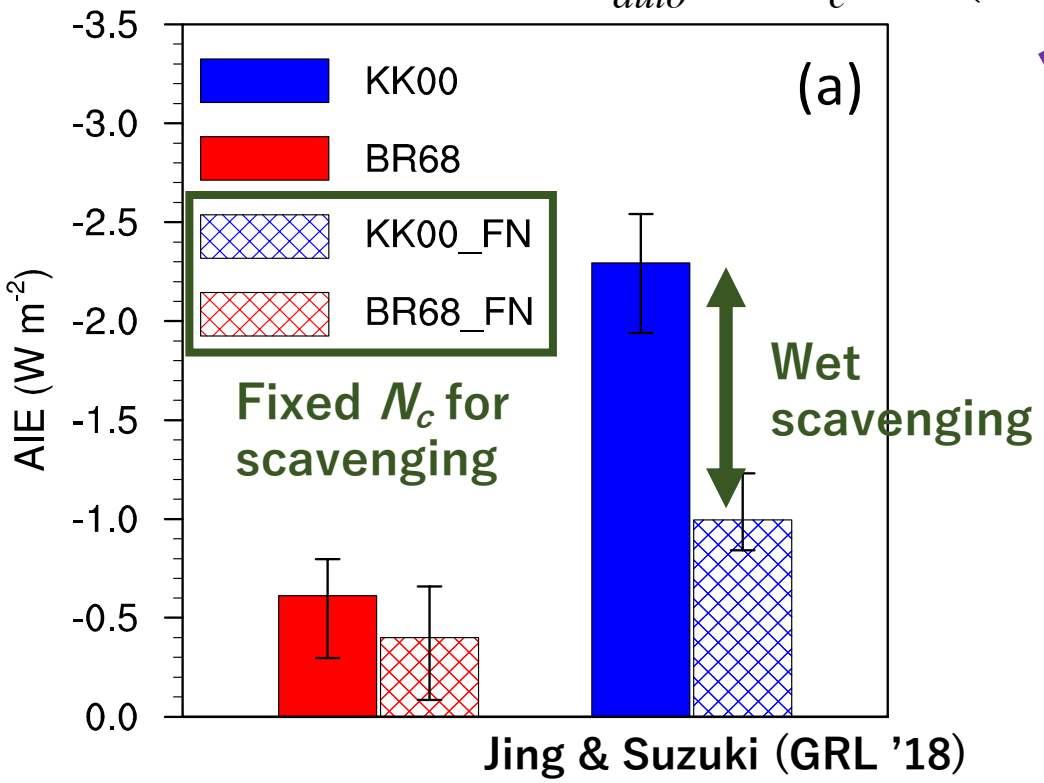


Significance of aerosol-precip coupling in radiative forcing

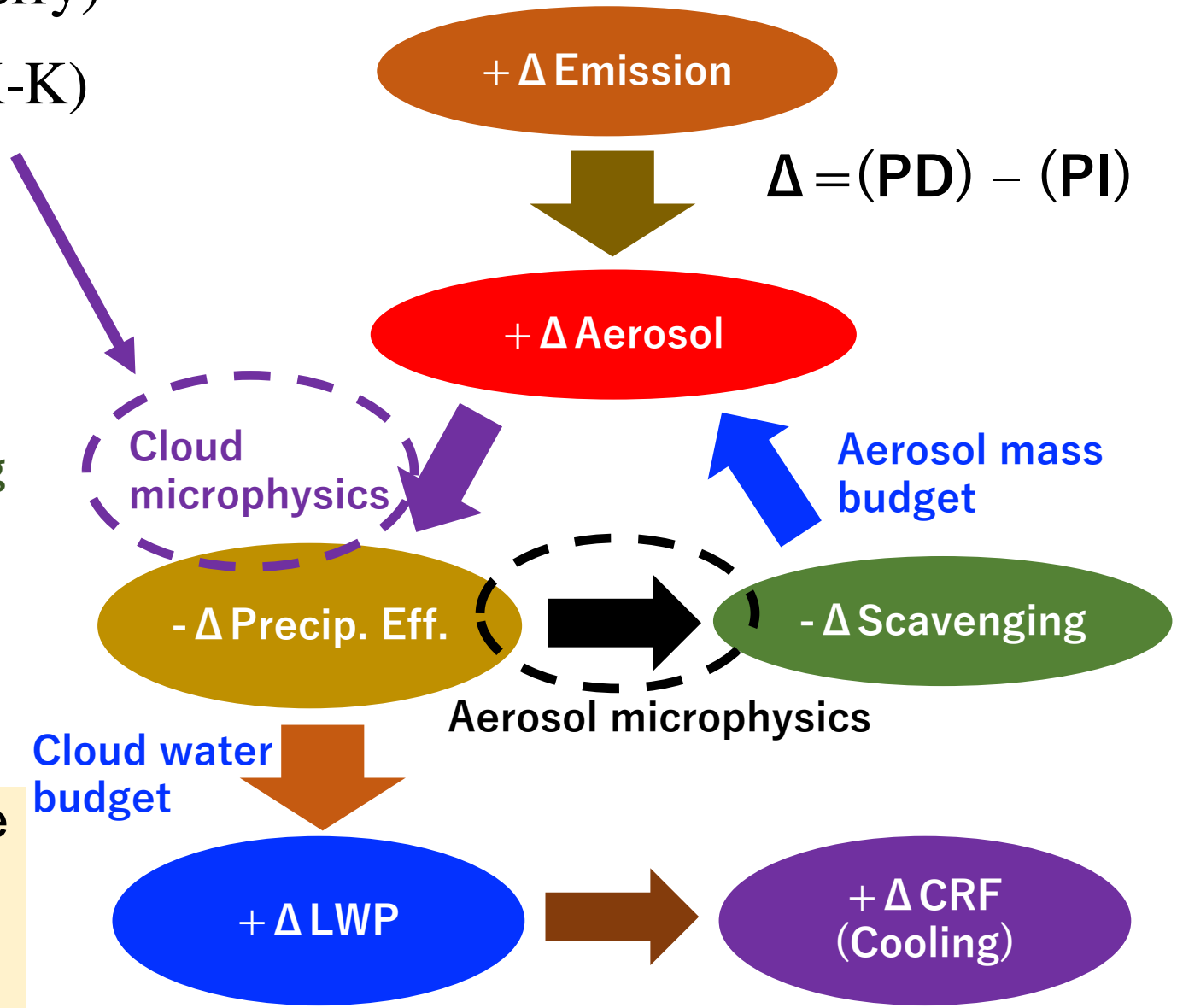
$$P_{auto} \propto N_c^{-1.0}\,(\text{Berry})$$

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

MIROC5 AGCM

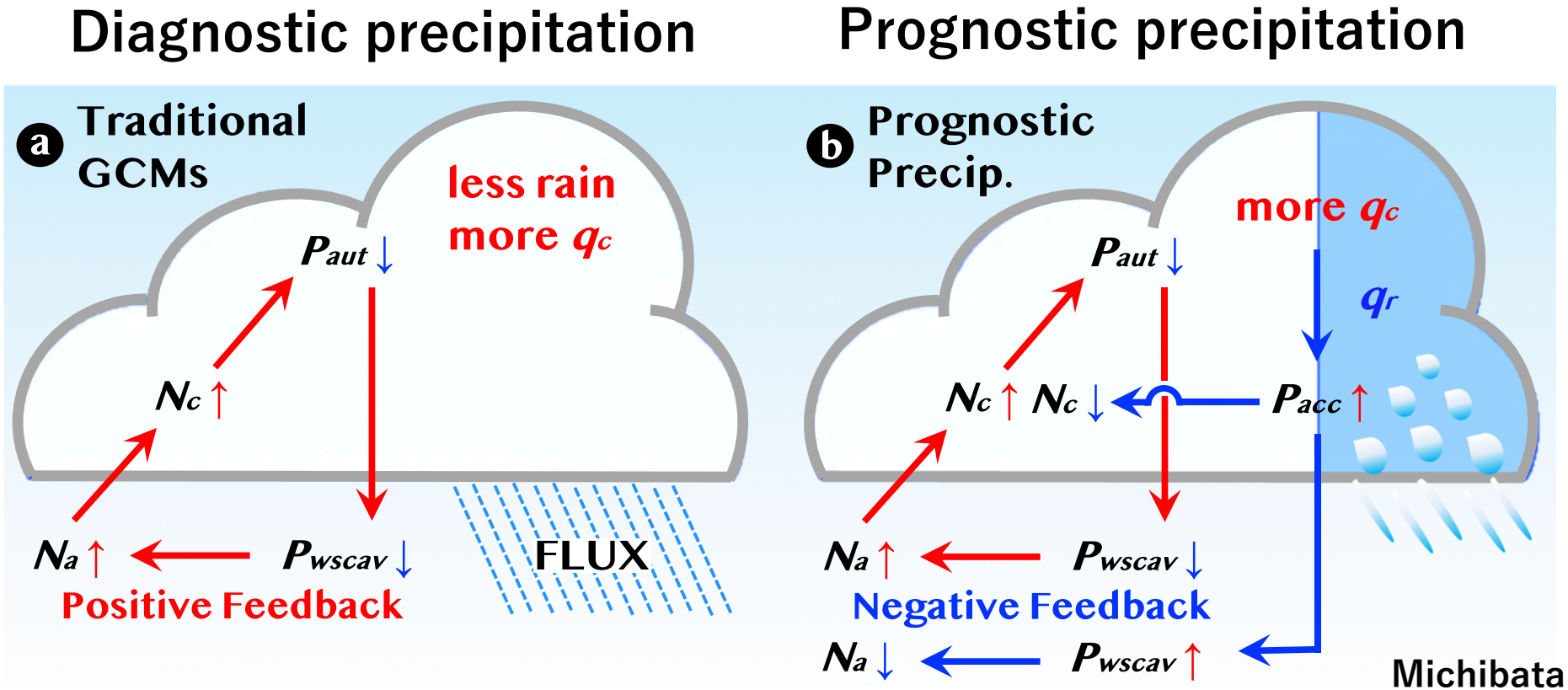


Jing & Suzuki (GRL '18)



- Wet scavenging amplifies cloud response to aerosols due to rain suppression
- This leads to too-negative ACI forcing
- Based on diagnostic precip modeling

Diagnostic vs Prognostic precipitation in MIROC6



Michibata & Suzuki (GRL '20)

- Diagnostic precipitation: Primarily one pathway (Autoconv), sensitive to aerosols, is active, exerting a positive feedback via wet-scavenging
- Prognostic precipitation: Another pathway (Accretion), insensitive to aerosols, is also active, which "buffers" the cloud response to aerosols

Responses to Δemission: Sensitivity to auto-conversion

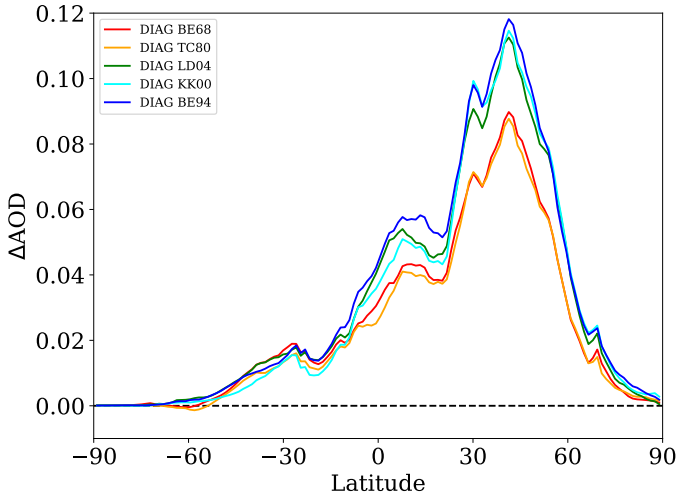
DIAG Precip

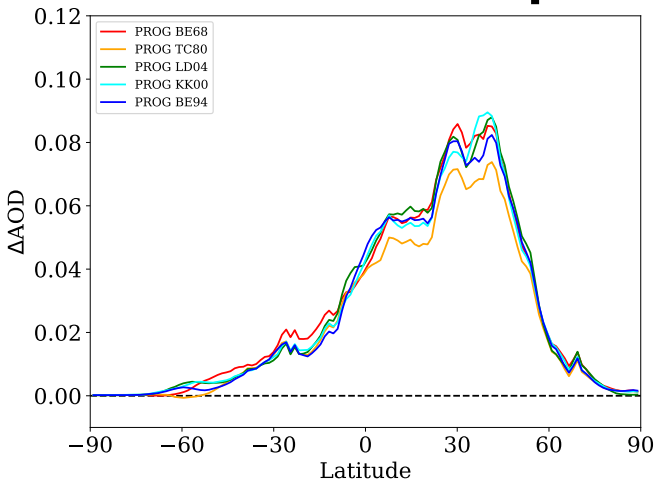
PROG Precip

MIROC6 AGCM

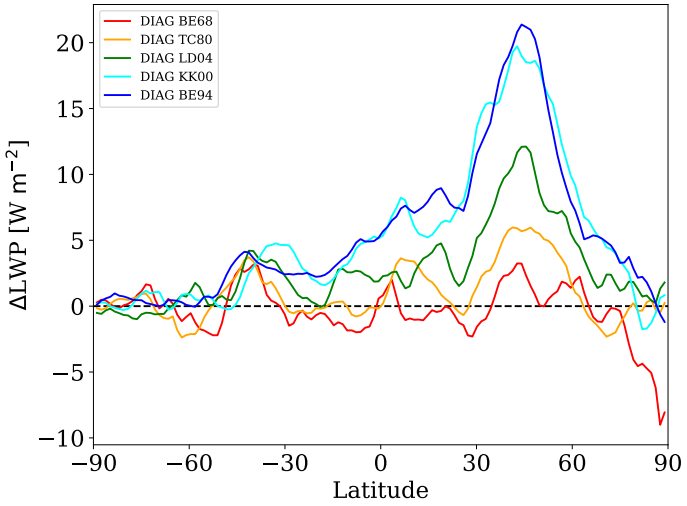
$\Delta = (PD) - (PI)$

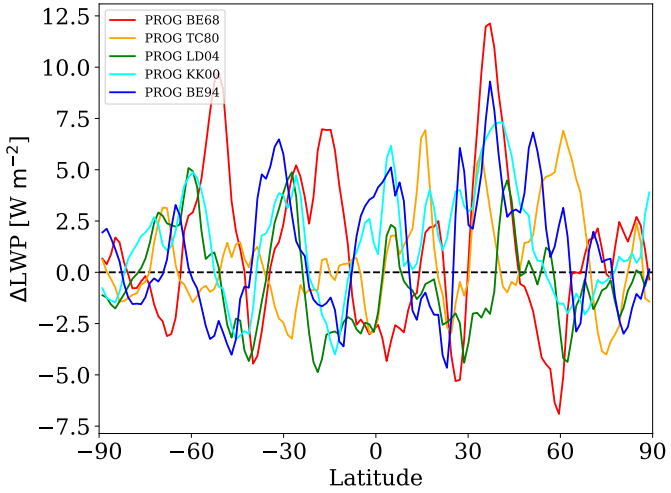
ΔAOT





ΔLWP





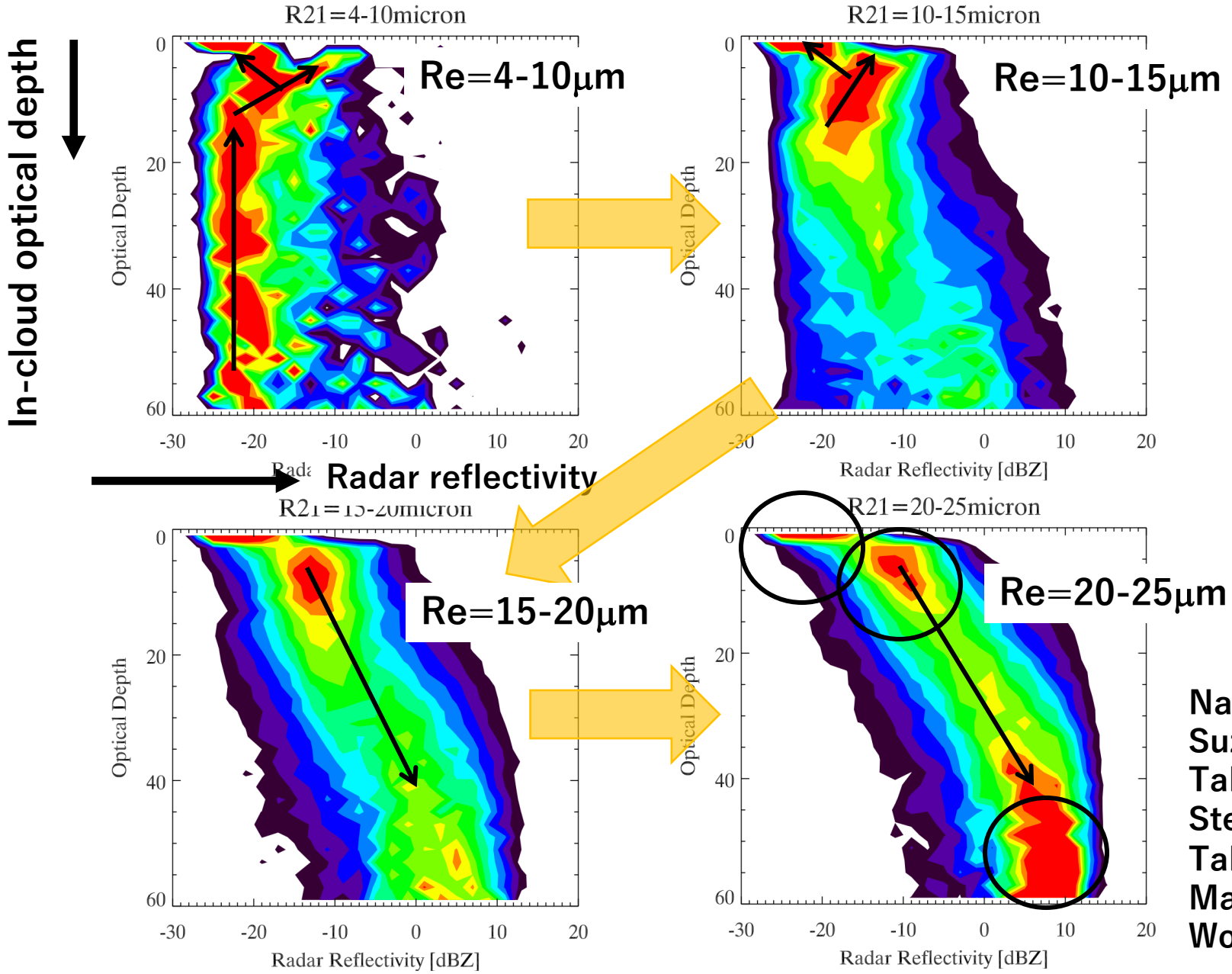
Different colors: Alternate auto-conversion schemes

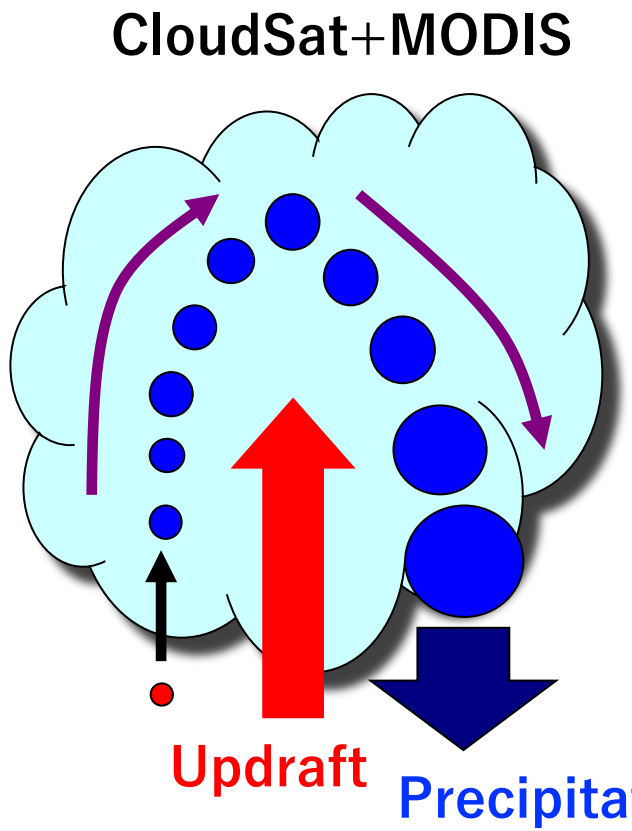
- Berry ('68)
- Tripoli-Cotton ('80)
- Liu-Daum ('04)
- K-K ('00)
- Beheng ('94)

Suzuki & Imura (In prep.)

- DIAG precip model is more sensitive to model cloud physics (auto-conversion)
- This different sensitivity is also found in aerosol loading as well as cloud water response

Satellite-based diagnostics of warm rain process



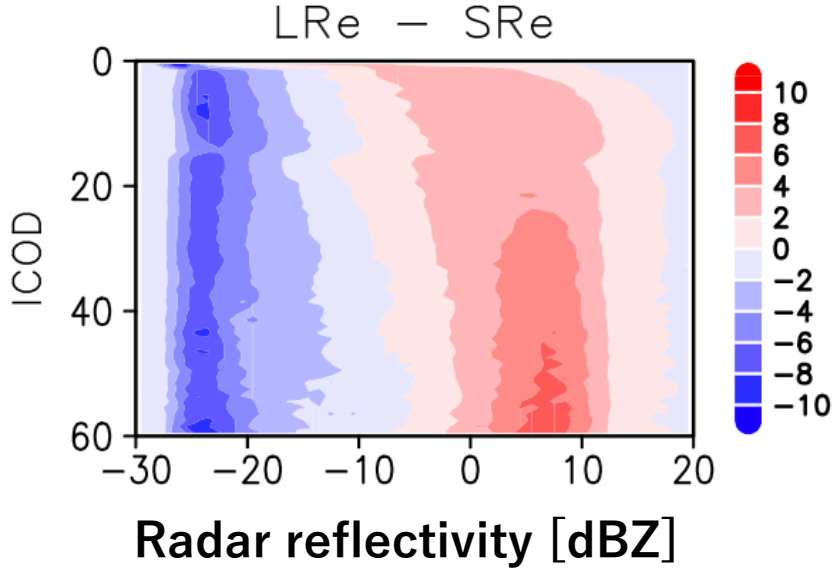


Nakajima et al. (JAS '10)
Suzuki et al. (JAS '10)
Takahashi et al. (QJRMS '17)
Stephens et al. (BAMS '18)
Takahashi et al. (JAS '21)
Matsumoto et al. (SOLA '23)
Wongnim et al. (JMSJ '24)

Satellite-based model evaluation of vertical structure

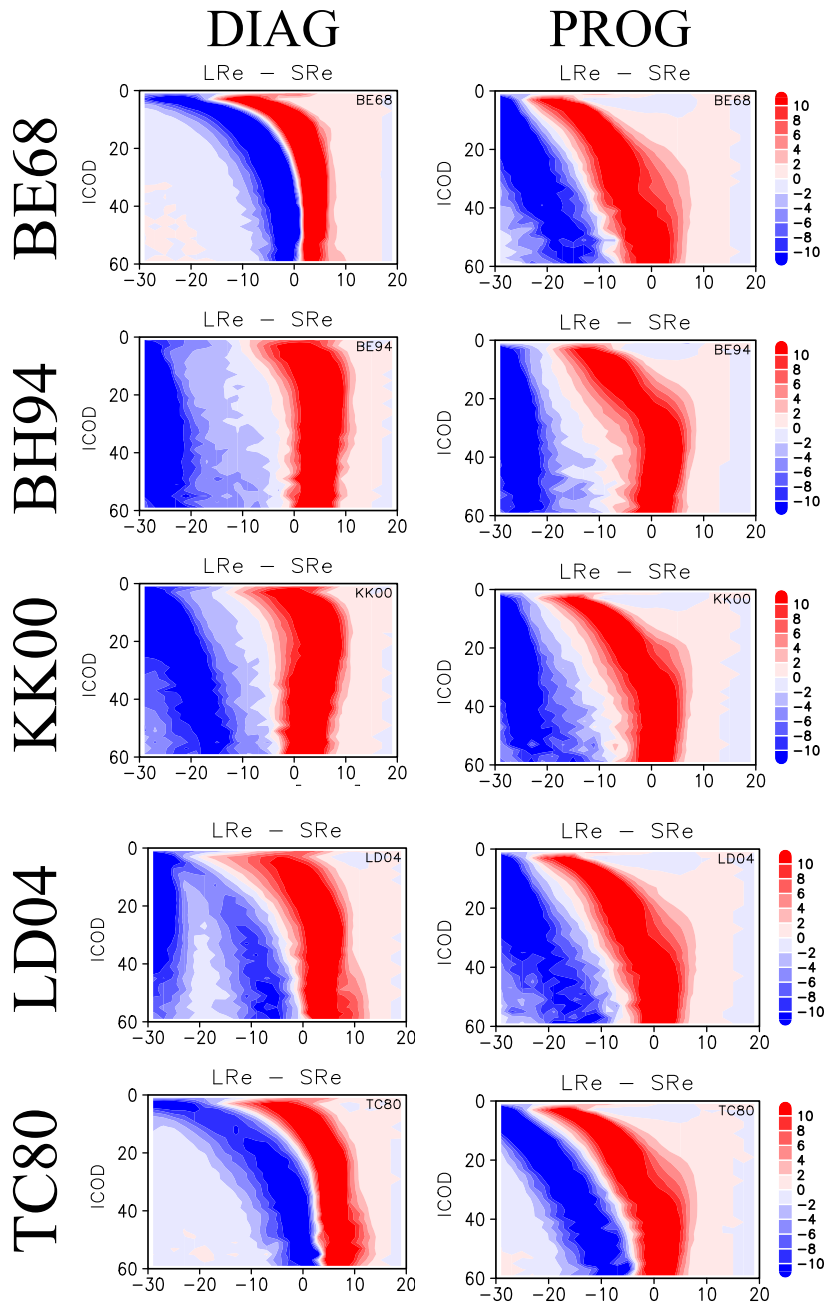
$(18<R_e<35) - (5<R_e<12)$

Satellite Obs.



- The statistics serve as a constraint on auto-conversion process
- How does this constraint impact the ACI forcing estimate?

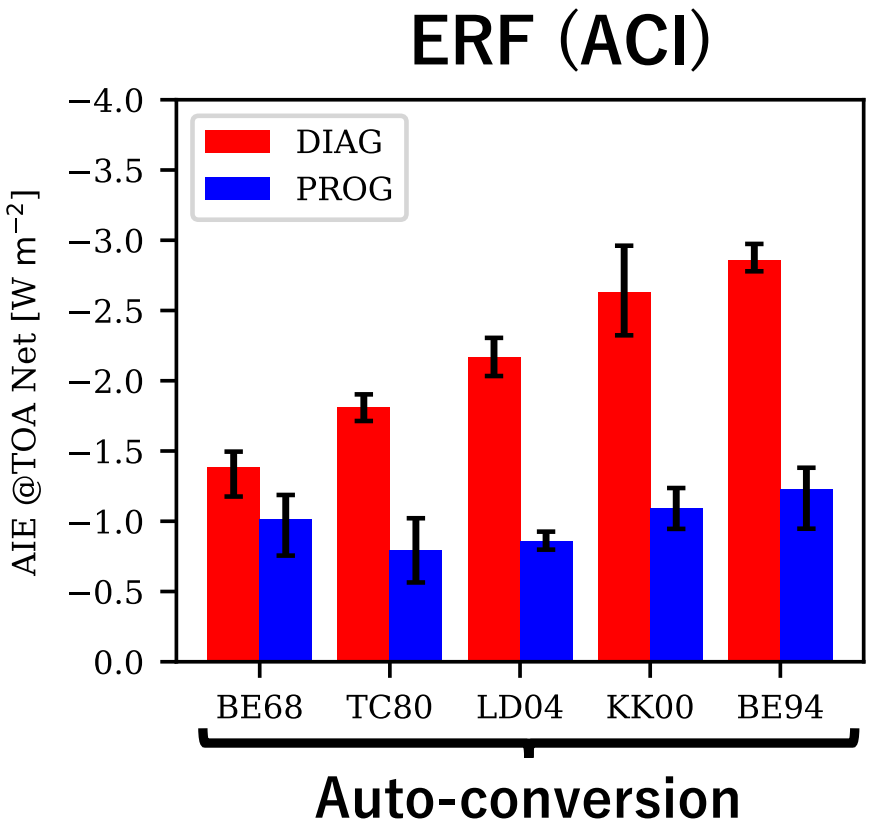
Suzuki & Imura (In prep.)

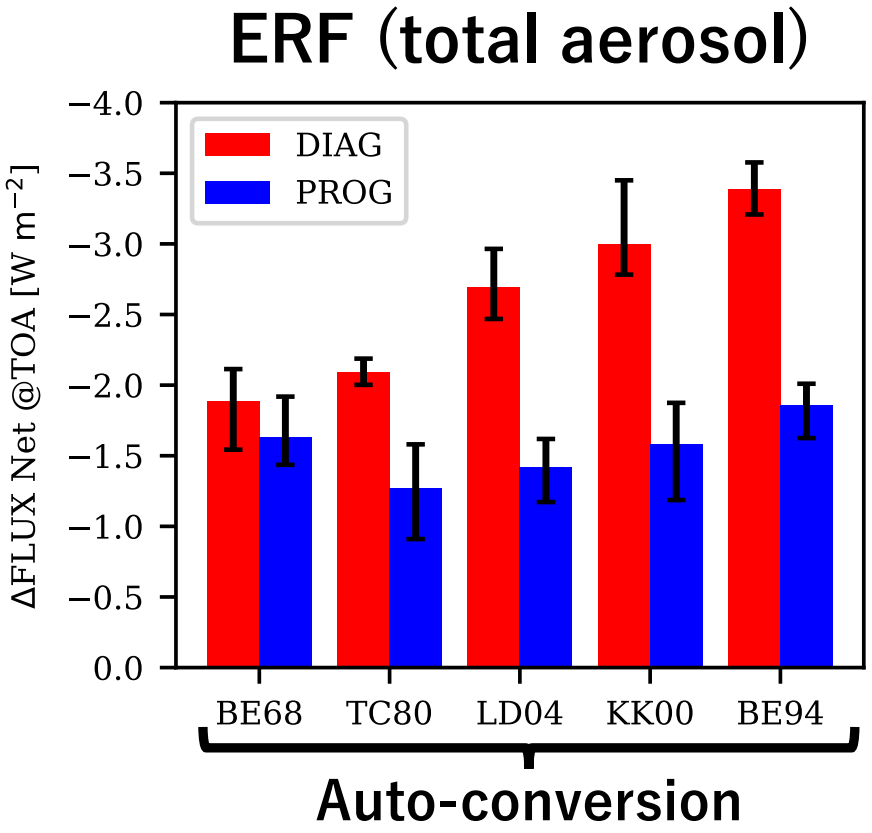


$$\frac{\partial(\rho q_c)}{\partial t} = -\frac{\rho q_c}{\tau_p}$$

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

Aerosol radiative forcing (PD-PI): PROG vs DIAG





MIROC6 AGCM

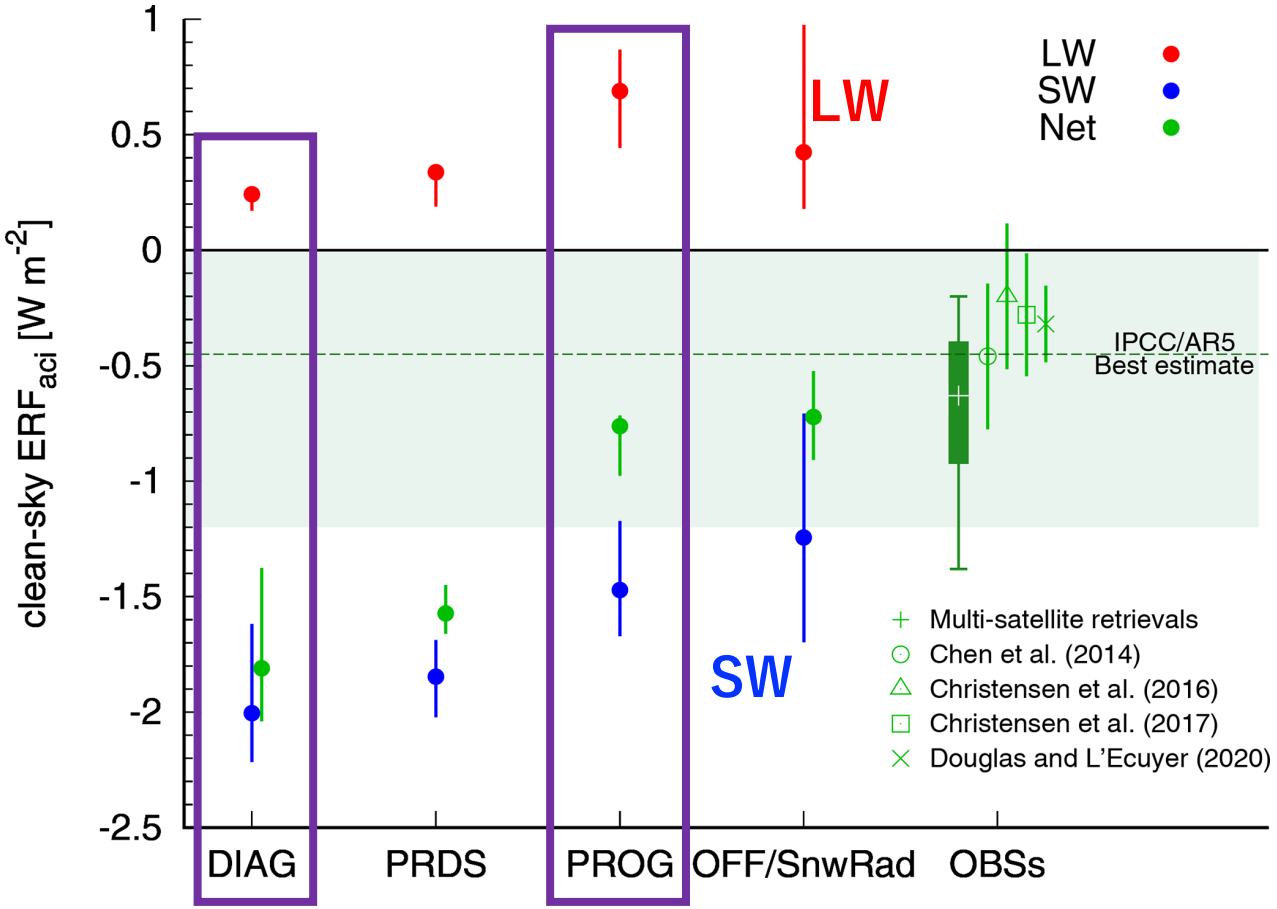
Compatible with historical T record (Bellouin et al. '20)

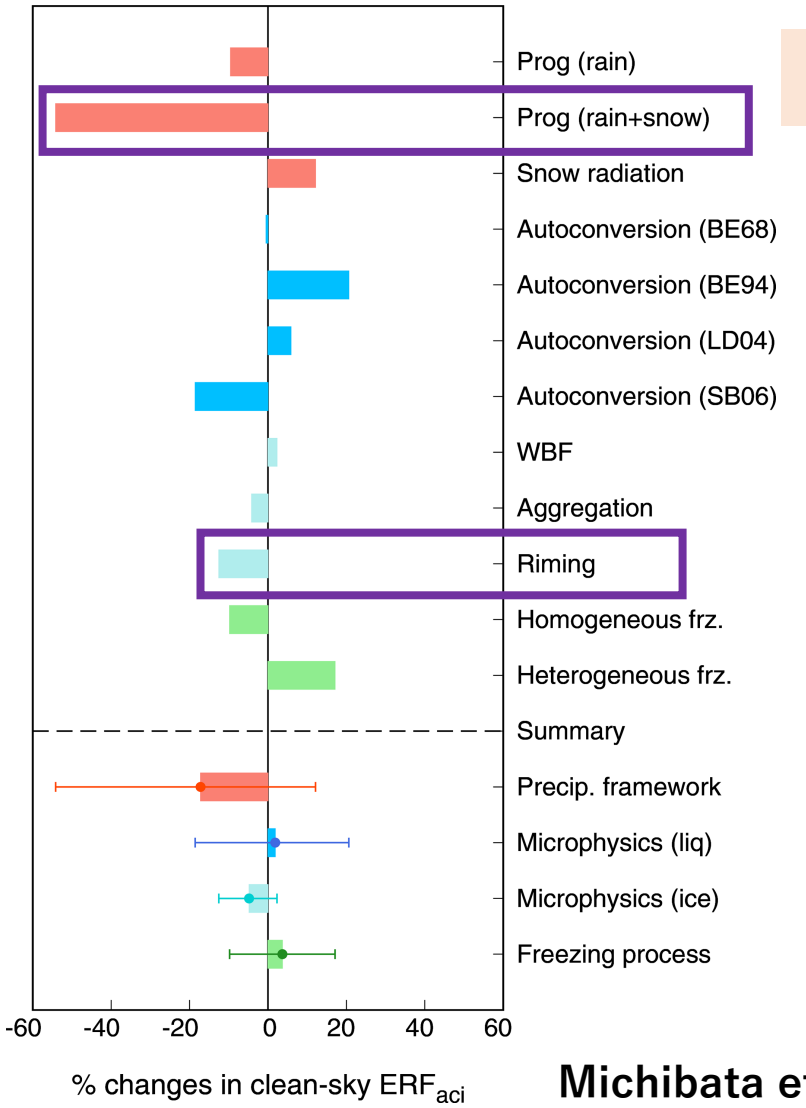
Suzuki & Imura (In prep.)

~closer to satellite **~closer to satellite**

- **Satellite-based constraint on autoconv exerts differing impacts on forcing estimates b/w two precip modeling: Larger sensitivity in DIAG than PROG**
- **This difference occurs via differing pathways of aerosol-precip coupling: Further constraint is required for other processes (e.g. wet-scavenging)**

Another complexity: Ice process





Michibata et al. (ACP '20)

- MIROC PROG weakens ACI forcing relative to DIAG due to snow process
- Riming is the largest contributor to this "buffering", besides scavenging
- Obs-based constraints are required also for ice/mixed-phase cloud process

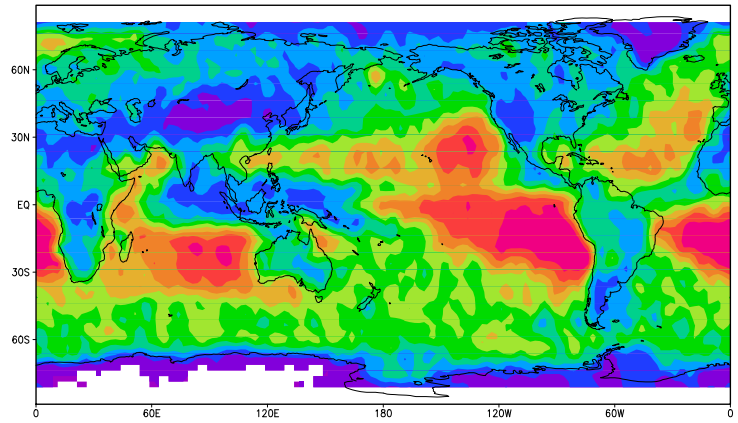
Satellite-based characterization of mixed-phase clouds

Fractional occurrences of different phase categories

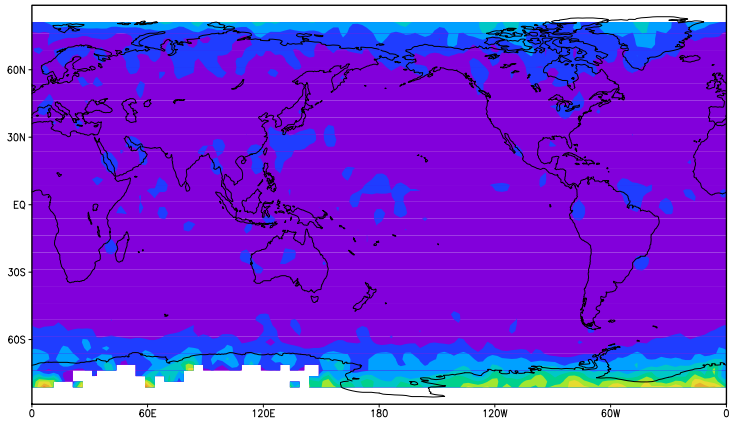
CALIPSO=Liq
MODIS=Liq

Liq

(a) Liquid/Liquid



(b) Liquid/Ice



Liq

Ice

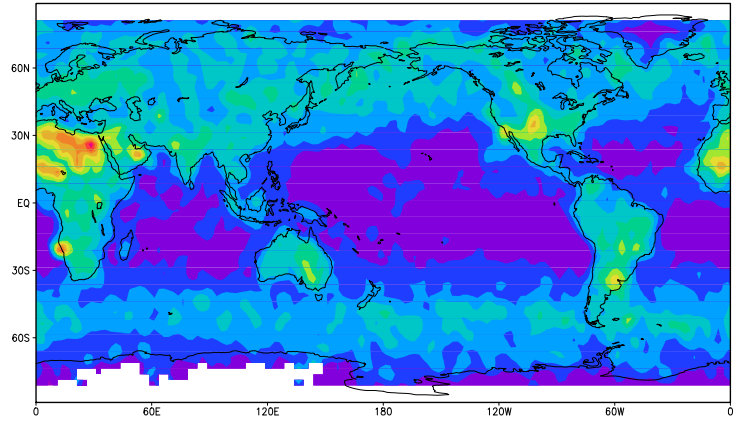
CALIPSO=Liq
MODIS=Ice

Ice

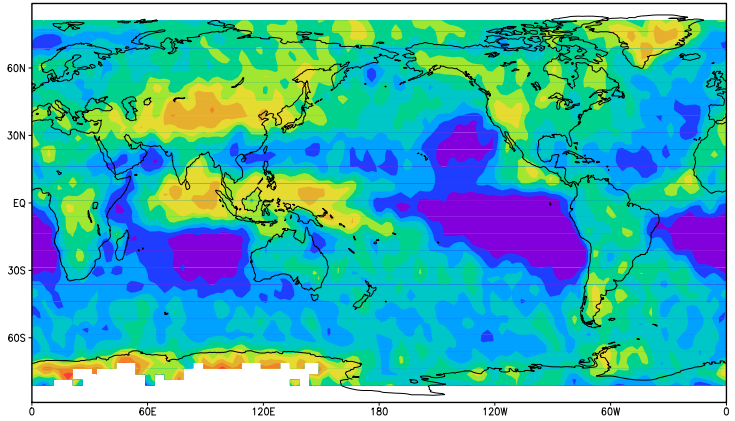
Liq

CALIPSO=Ice
MODIS=Liq

(c) Ice/Liquid



(d) Ice/Ice



Ice

CALIPSO=Ice
MODIS=Ice

How do different cloud phases relate to precip process?

Suzuki et al. (GRL in press)

Extending rain diagnostics into mixed-phase precip

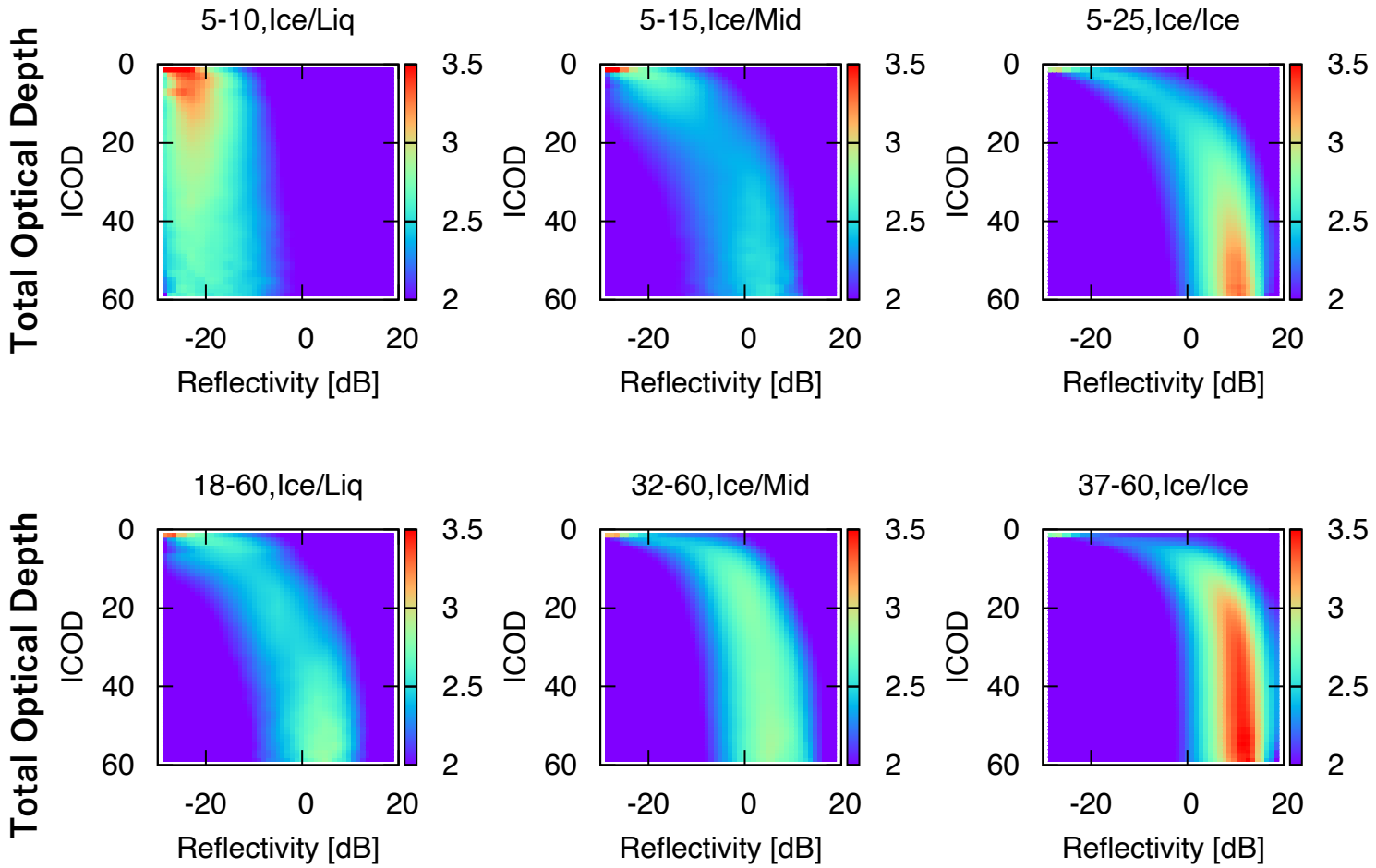
MODIS ice COT ratio: 0-0.1 (Liquid) 0.45-0.55 (Mixed) 0.9-1 (Ice)

CALIPSO = ICE

Cloud-Top Particle Size

0-25%

75-100%

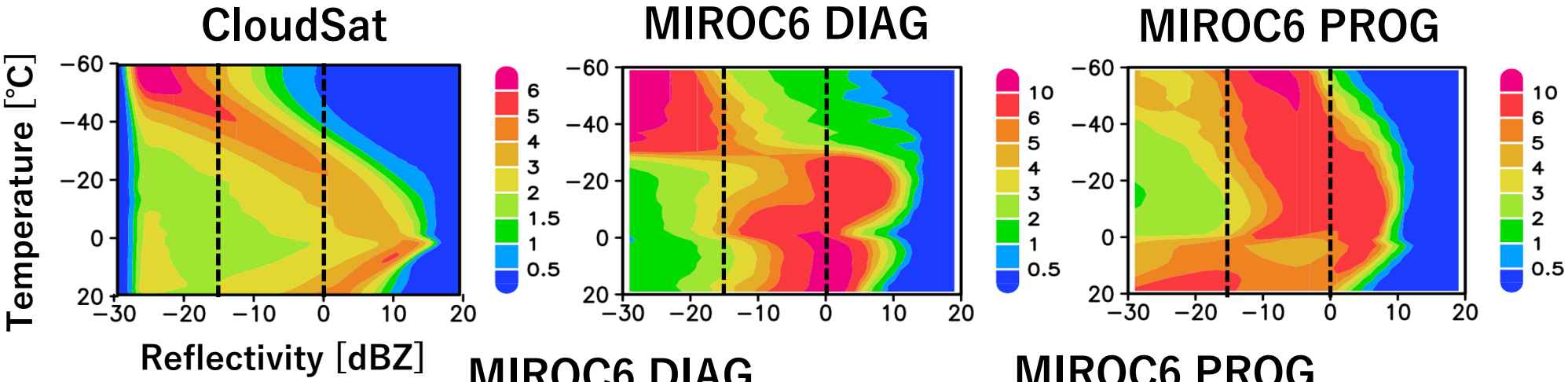


Suzuki et al. (GRL in press)

- Liquid-rich clouds: Precip occurrence varies with cloud-top particle size
- Ice-rich clouds: Precipitating regardless of cloud-top particle size

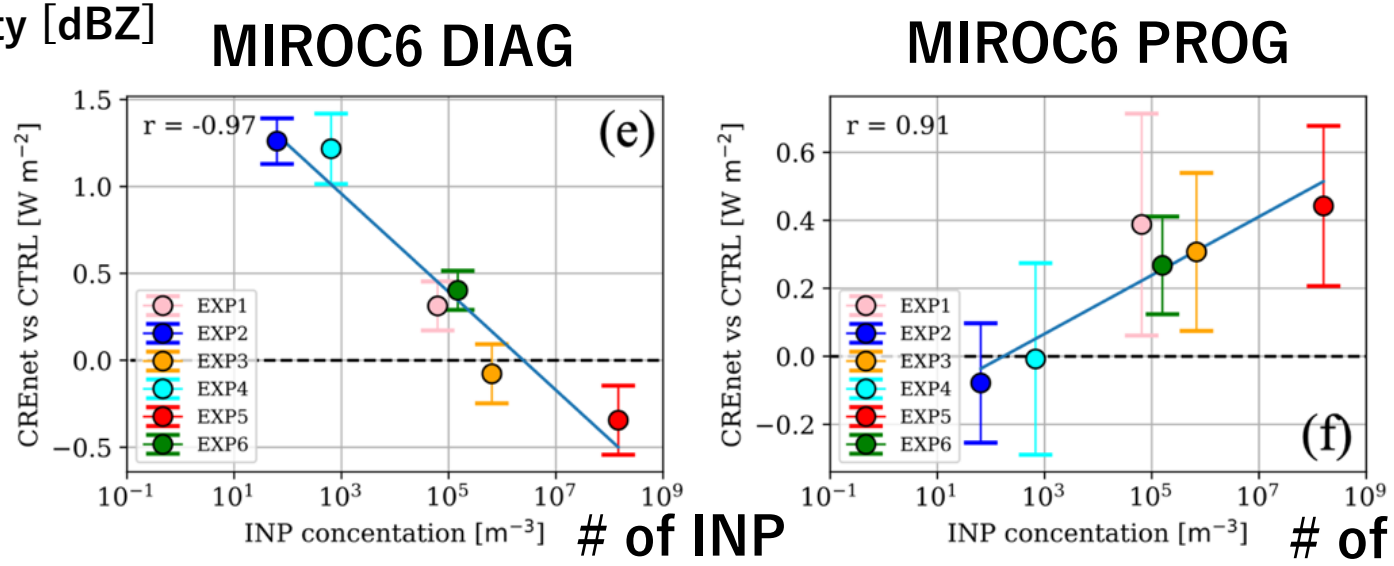
Mixed-phase precip process linked to INP effect

Vertical structure



INP impact on CRE

Net CRE



# of INP

# of INP

Imura & Suzuki (JCLI in revision)

- Vertical microphysical structures depend on precip modeling (DIAG vs PROG)
- This induces opposite impacts of INP on CRE via differing perturbations to mass/number budgets of cloud ice b/w DIAG & PROG

Summary

- The ACI forcing is affected by cloud microphysical process modeling through perturbations to cloud water budget
- Satellite-based constraint on warm rain process has different impacts on the forcing estimate b/w DIAG & PROG via different representations of aerosol-cloud-precip interplay
- The forcing difference also arises from ice-phase processes that tend to “buffer” the cloud water response to aerosols
- Satellite-based process diagnostics are extended from warm rain into mixed-phase precipitation to elucidate how precipitation characteristic varies with particle size and cloud phase
- Different characters of mixed-phase precipitation b/w DIAG & PROG link to distinct INP effects on climate via ice water budget