Multi-sensor diagnostics of mixed-phase cloud microphysical processes with implication for EarthCARE

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Thanks to: Takashi M. Nagao, Aya Murai, Rino Maki

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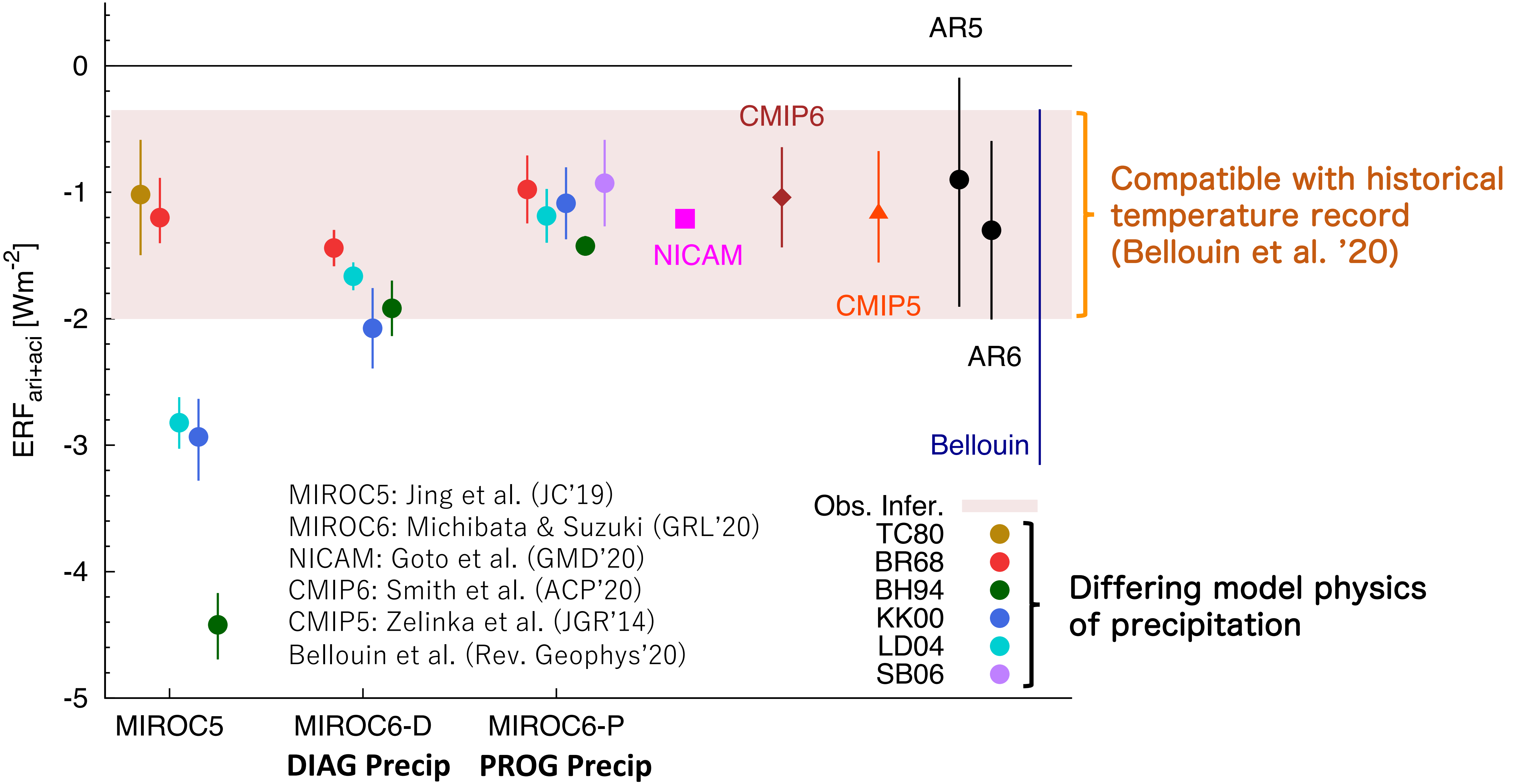
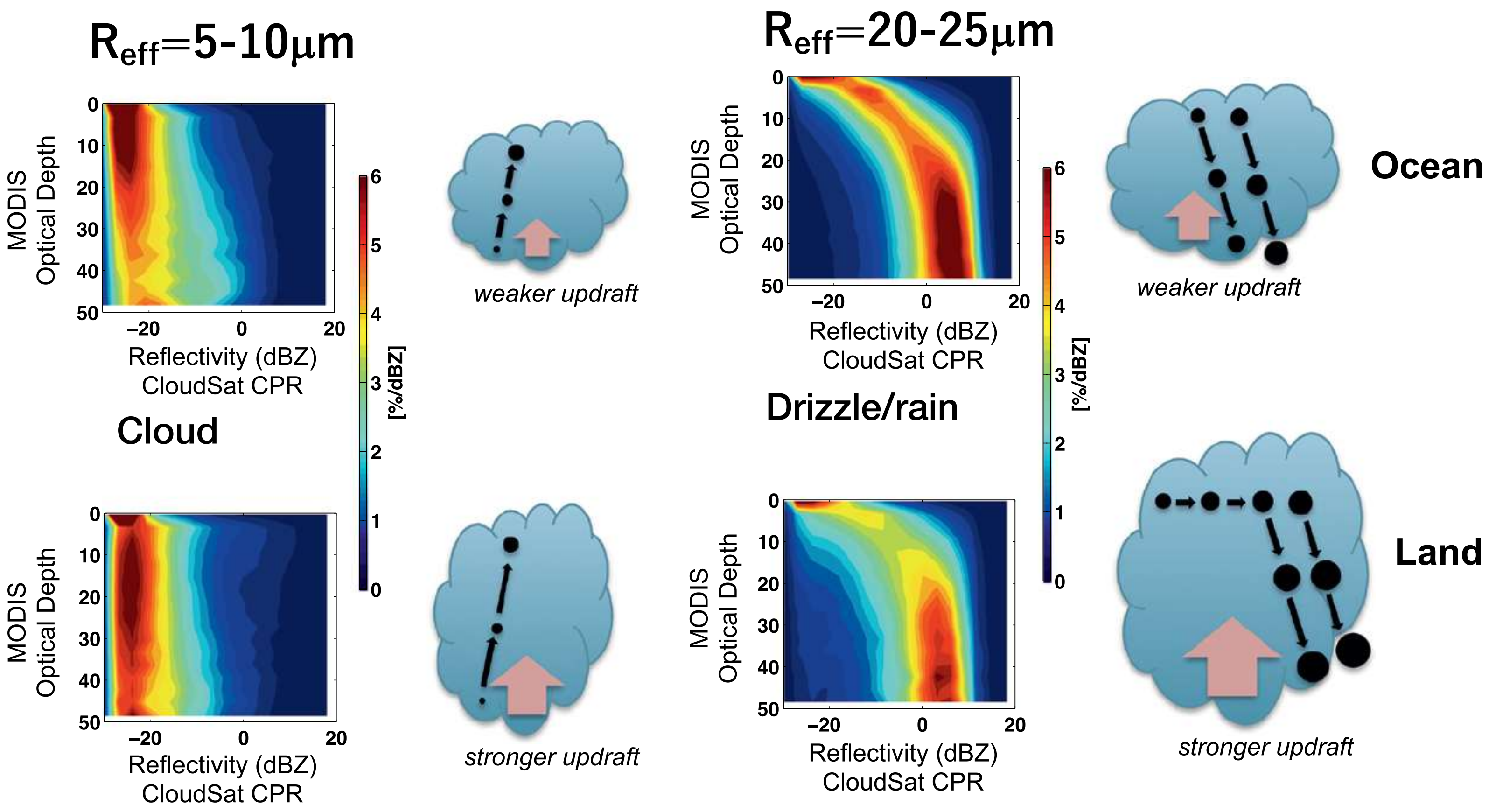
Sensitivity of aerosol forcing to model cloud physics



Satellite-based diagnostics of precipitation processes

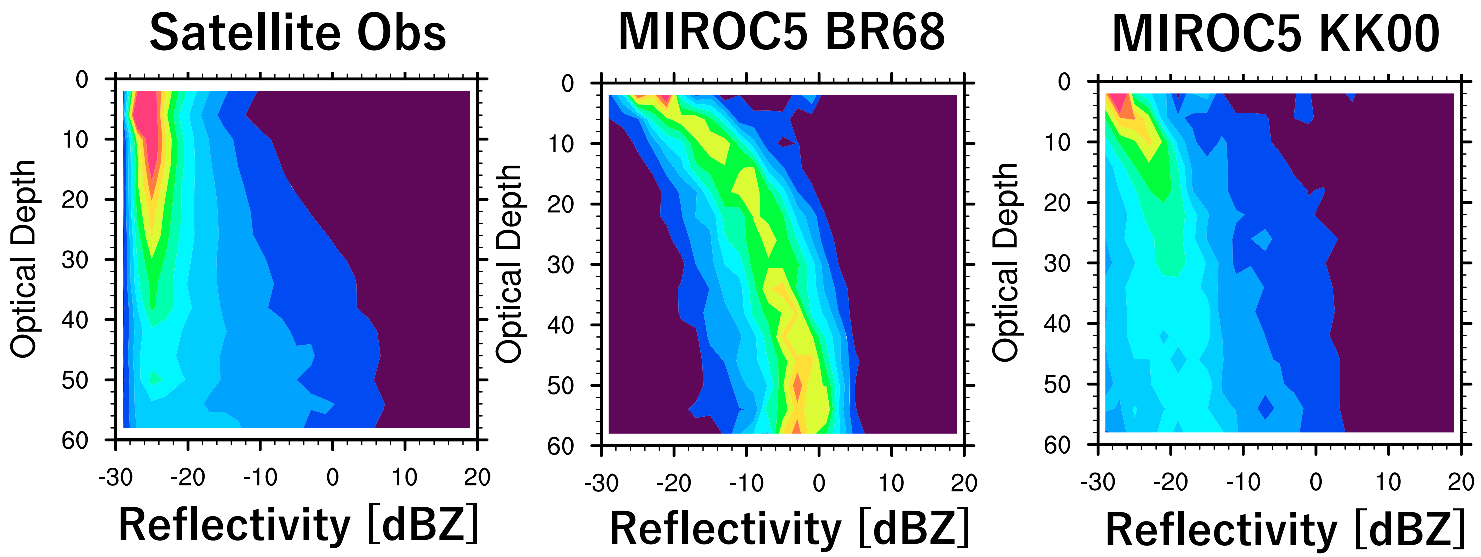


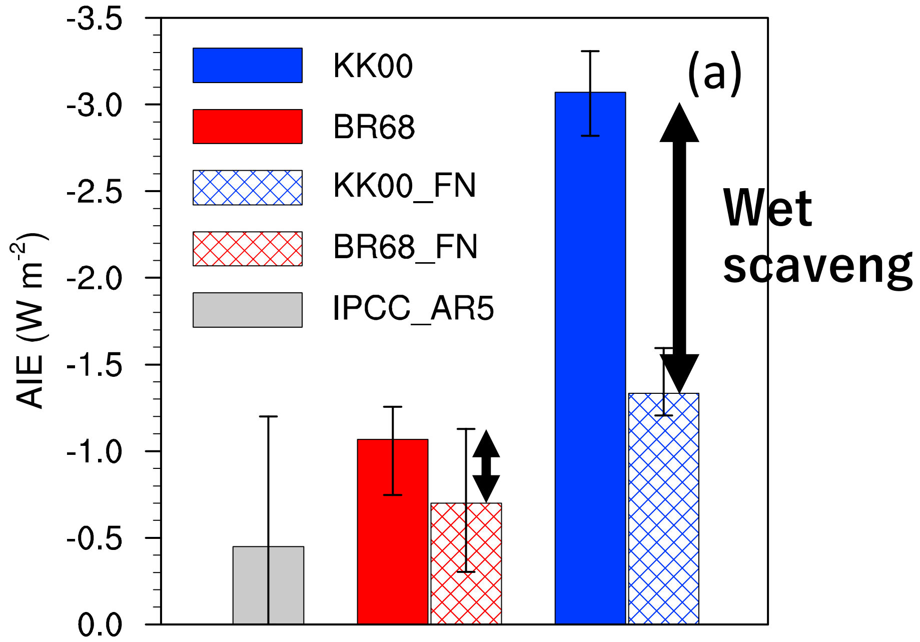
Stephens et al. ('18) (see also Nakajima et al. '10; Suzuki et al. '10)

- Precipitation process "probed" in multi-variate global composites (Z_e, COT, R_{eff}): Contoured Frequency by Optical Depth Diagram (CFODD)
- Serves as a process-oriented model diagnostic tool for CRMs (Suzuki et al. '11; '13) & GCMs (e.g. Suzuki et al. '15; Jing et al. '17, '19; Michibata & Suzuki '20)

Constraint on model cloud physics links to ACI forcing

For R_{eff}=5-10μm

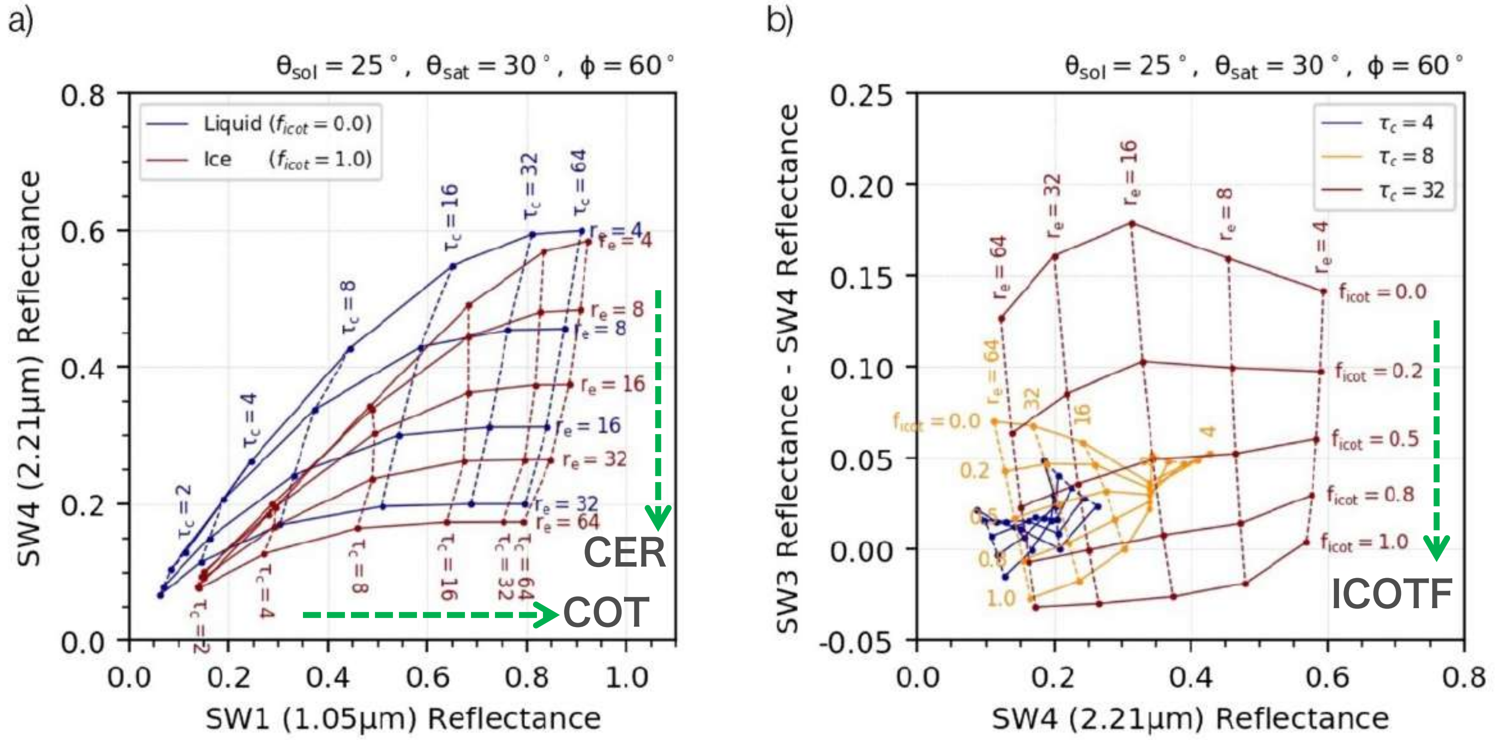




Jing and Suzuki (GRL '18)

- Satellite-based process constraint on model cloud physics helps identify compensating model errors in aerosol-cloud-radiation interaction
- Limited to liquid-phase clouds with "static" accumulations of global data
  - -> How to extend into mixed-phase clouds?
  - -> How to add "dynamical" context to process diagnostics?

Use of cloud phase information from SWIR



Nagao and Suzuki (ESS '21)

Applicable to JAXA GCOM-C/SGLI & NASA Aqua/MODIS

[Assumption]

- Plane-Parallel of Liquid+Ice
- Deriving $COT_{liq,ice}$ and CER_{mix}
- Retrieving mixed-phase state

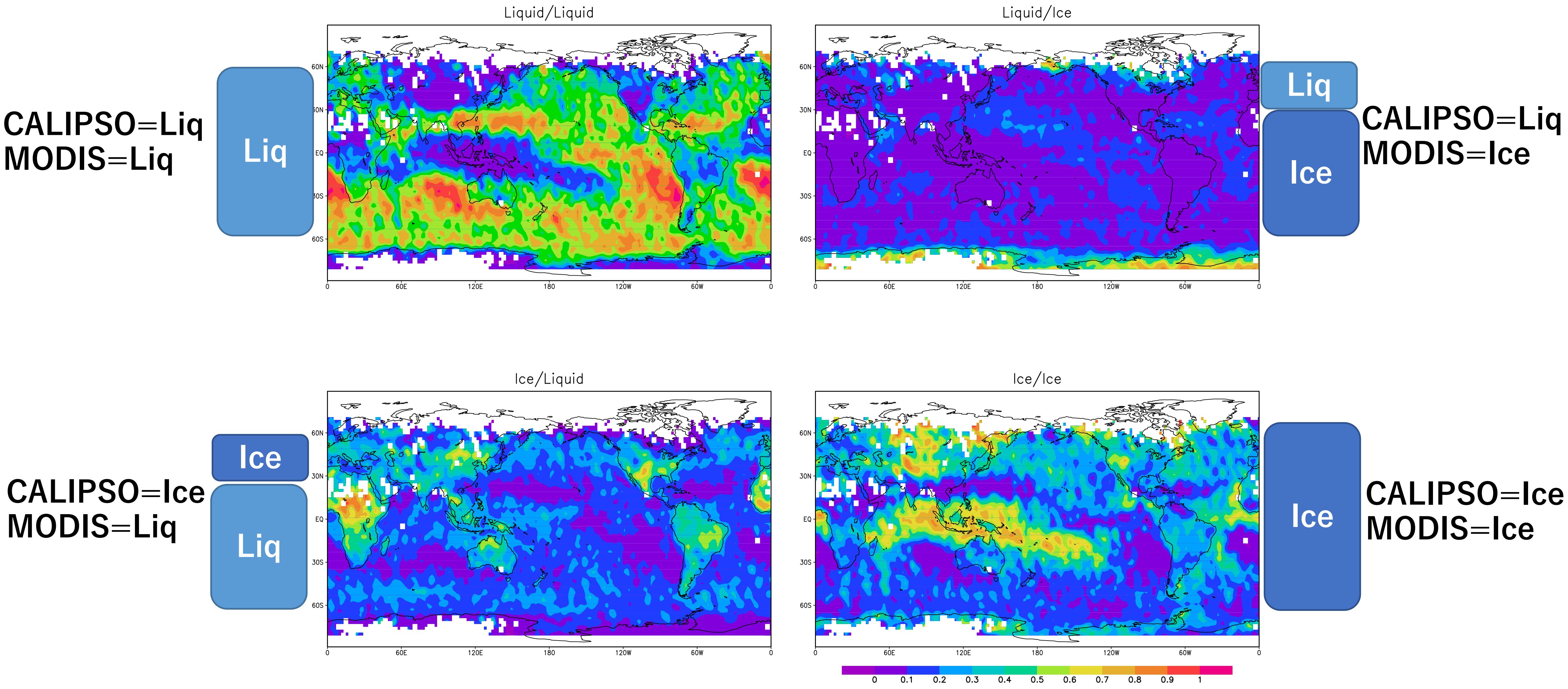
COT_{LIQ} CER_{LIQ}	←→	COT_{ICE} CER_{ICE}

$$F_{ICE} = \frac{COT_{ICE}}{COT_{LIQ} + COT_{ICE}}$$

$$CER_{MIX} = CER_{LIQ}(1 - F_{ICE}) + CER_{ICE}F_{ICE}$$

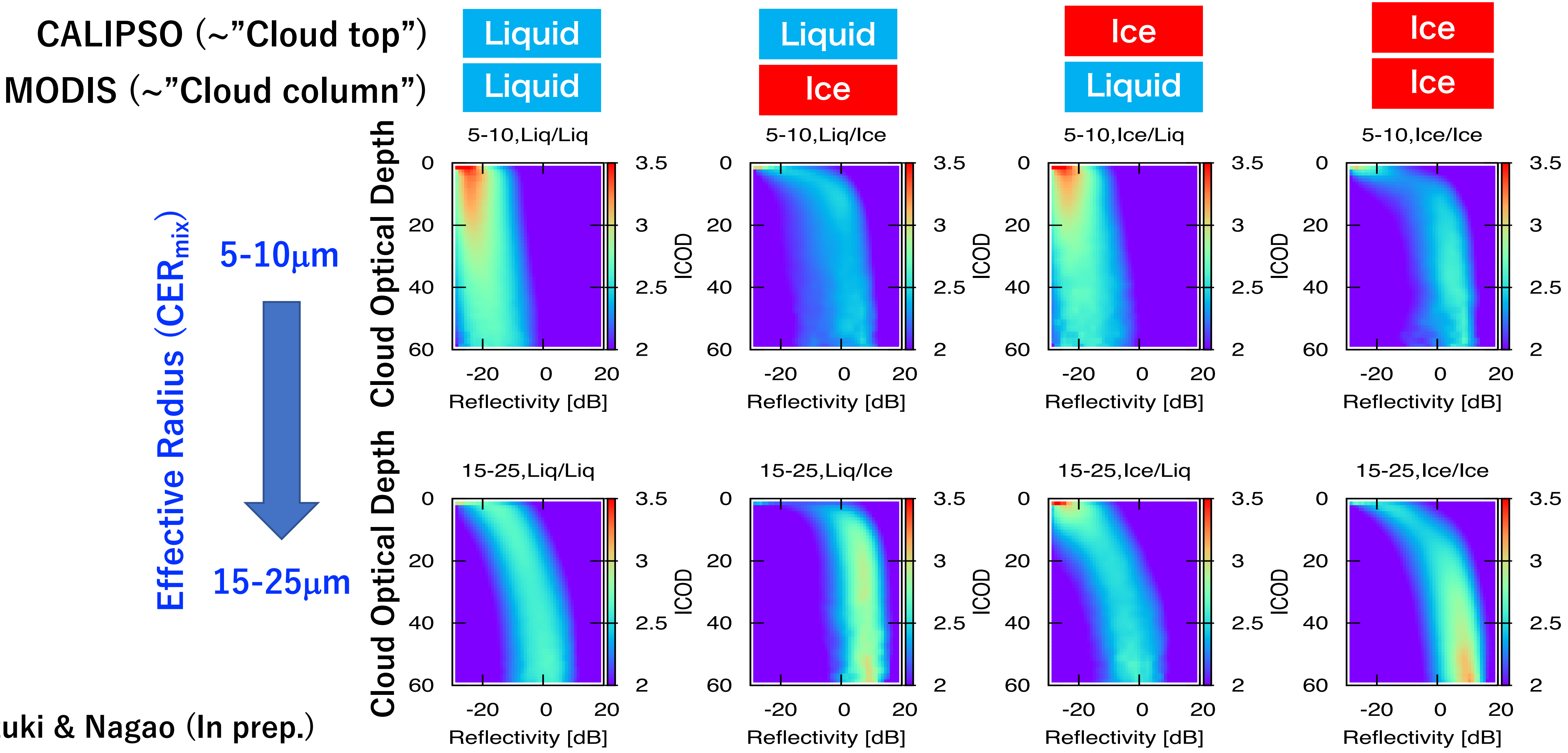
- The liquid-ice light absorption difference at SWIR is exploited to retrieve ice COT fraction ranging b/w liquid & ice in a temperature-independent manner, with (total) COT & CER
- Measurement principle is different from CALIPSO lidar
  - CALIOP "looks at" the vicinity of cloud top (COD <~ 3)
  - SWIR "penetrates" somewhat deeper inside the cloud layer (COD >~ 10)
  - Their combination can characterize vertical phase stratification (Nagao's talk)

Global occurrences of “phase stratification”



How do different phase combinations relate to precipitation?

Linking the phase stratification to radar profile



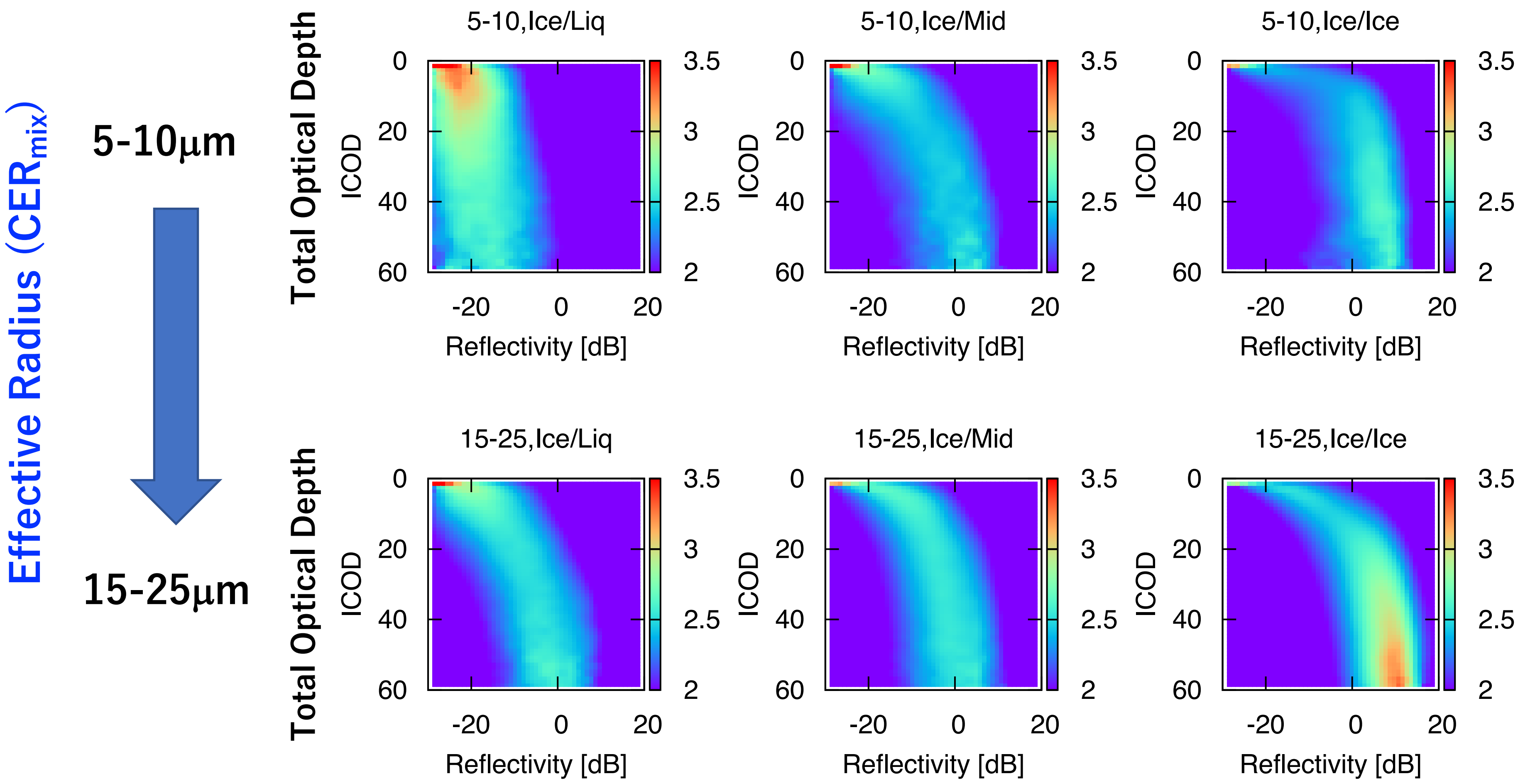
Suzuki & Nagao (In prep.)

- Precipitation characteristics vary with both cloud-top particle size & "cloud-column" phase
- "Cloud-top" phase appears to have a weaker effect on precipitation

How does precipitation vary with cloud phase fraction?

MODIS ice COT ratio: 0-0.2 (Liquid) 0.4-0.6 (Mixed) 0.8-1 (Ice)

CALIPSO = ICE

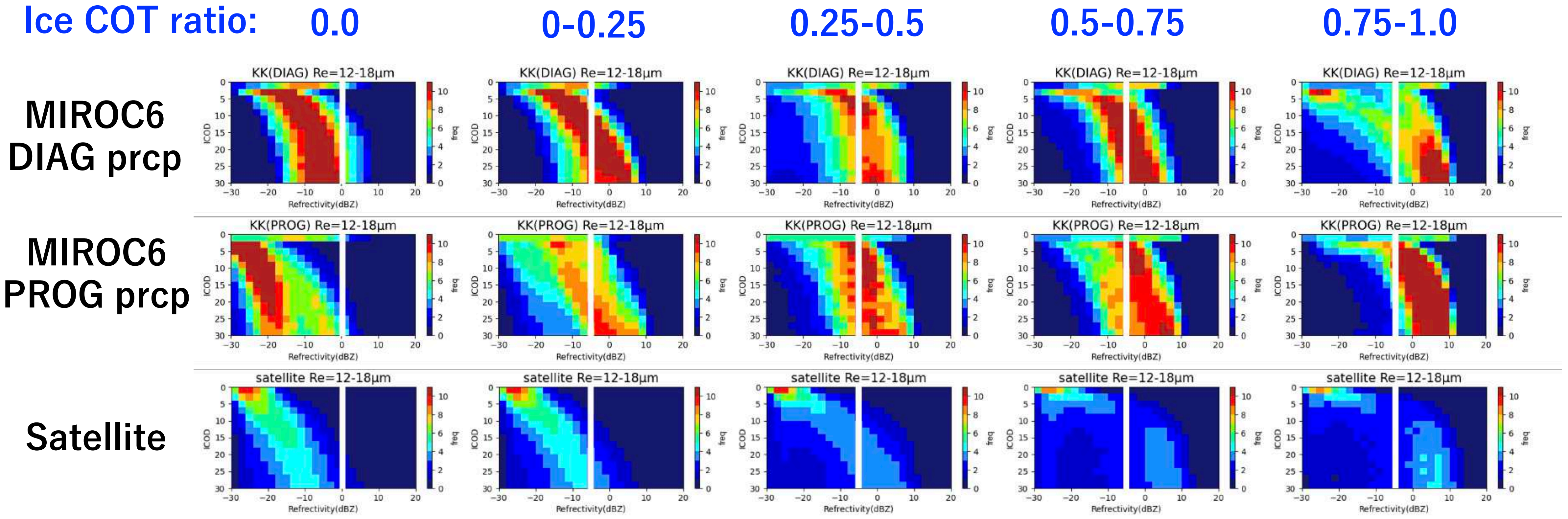


Suzuki & Nagao (In prep.)

- Precipitation continuously varies with column COT phase ratio
- More "icy" clouds tend to produce precipitation more efficiently

Application to model evaluation - Preliminary

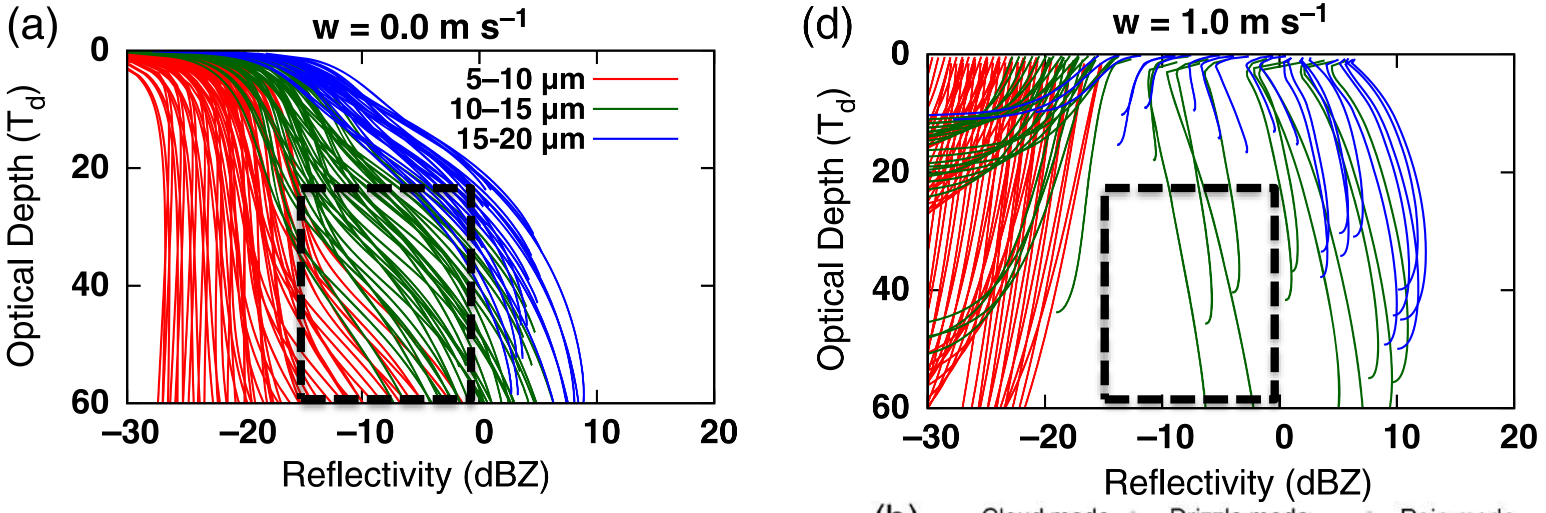
For R_{eff}=12-18μm



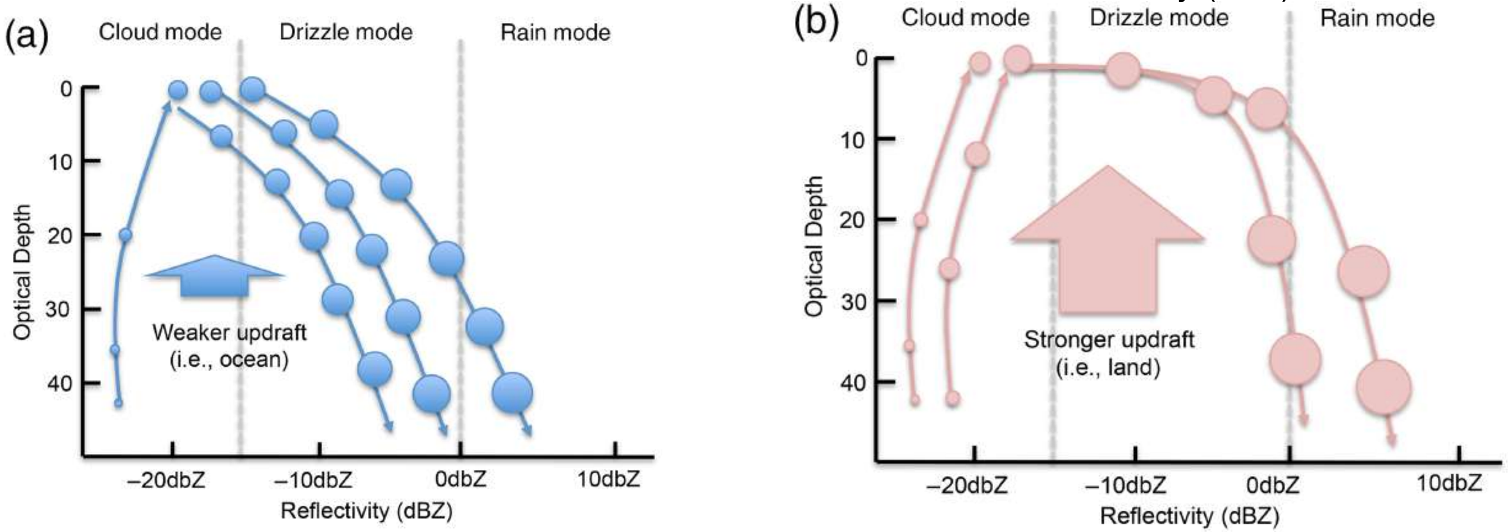
- "Phase dependence" of precipitation varies with model precipitation physics (DIAG vs PROG precipitation)
- PROG shows a larger suppression of precipitation in more liquid-containing clouds, closer to satellite statistics: Implication for cloud-phase feedback?

Perspective of EarthCARE: Adding dynamical context

<u>Bin-microphysics model</u>



<u>Hypothetical schematic</u>



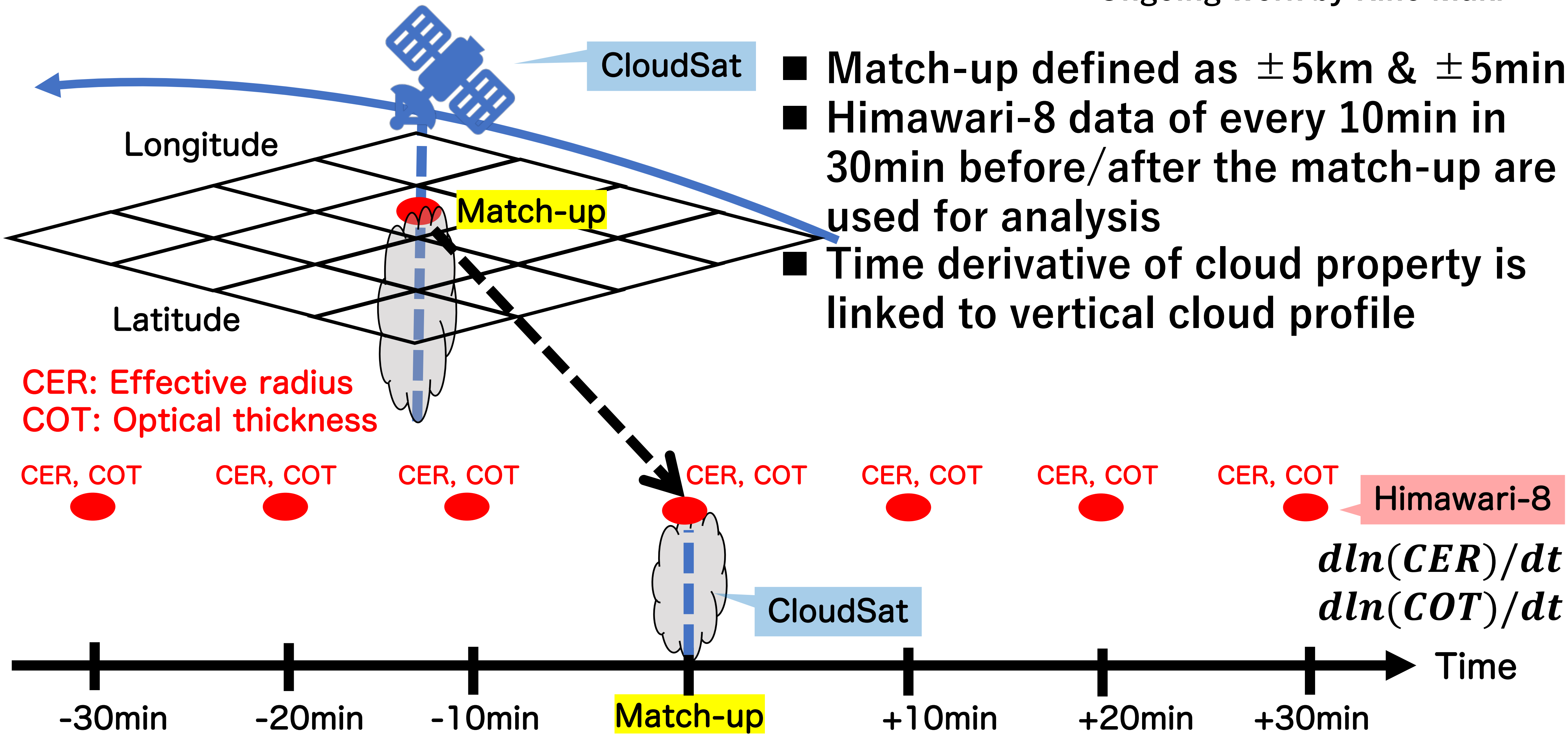
Takahashi, Suzuki & Stephens (QJRMS '17)

- How can EarthCARE/Doppler help untangle the dynamics-microphysics coupling?
- "Time-dimension" also needs to be added to process diagnostics

Adding time dimension: Radar+Geostationary satellites

Ongoing work by Rino Maki

- Match-up defined as ±5km & ±5min
- Himawari-8 data of every 10min in 30min before/after the match-up are used for analysis
- Time derivative of cloud property is linked to vertical cloud profile



Sensitivity of rain process to d(cloud property)/dt

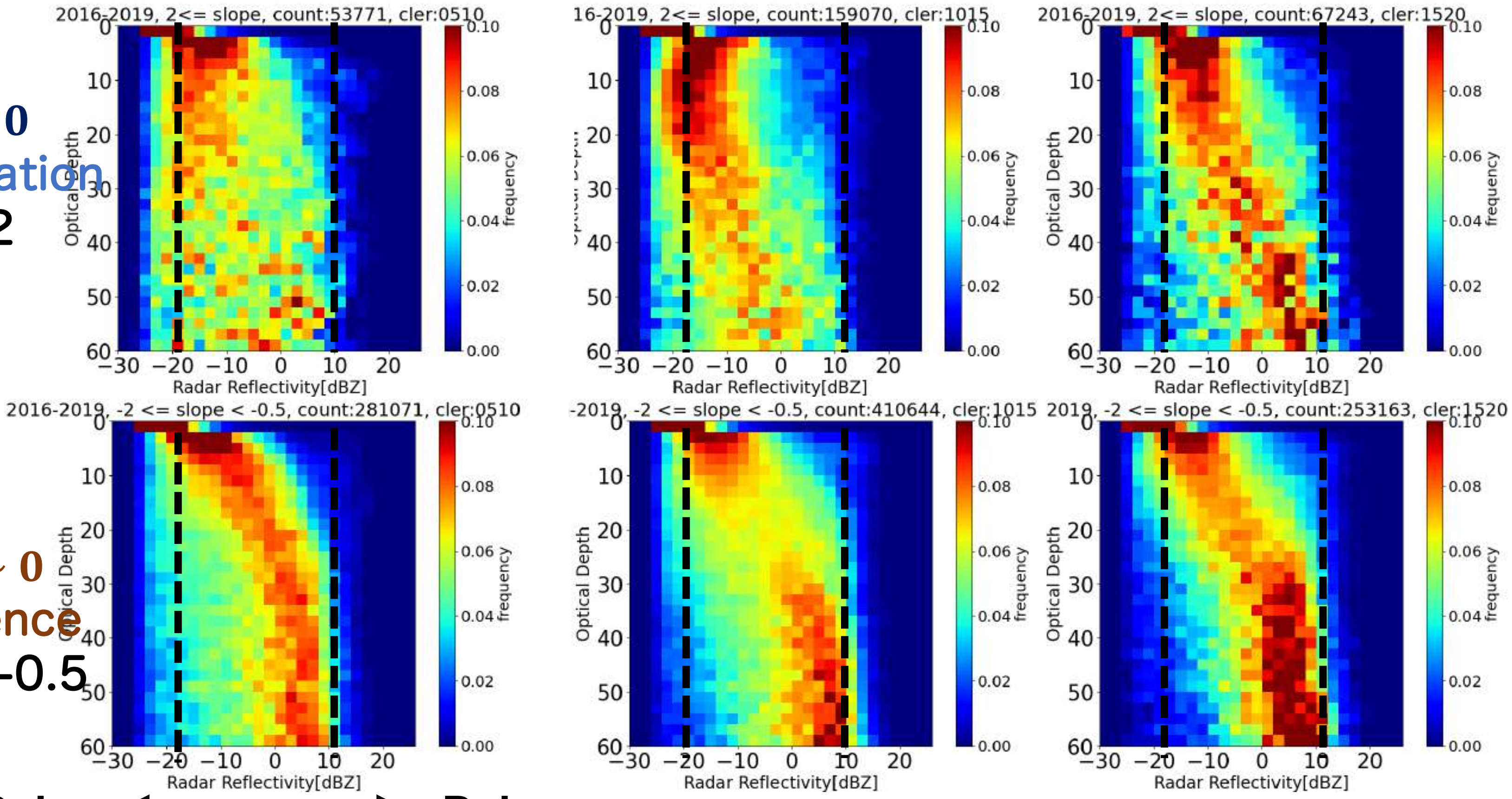
CloudSat+Himawari-8

Maki et al. (In prep.)

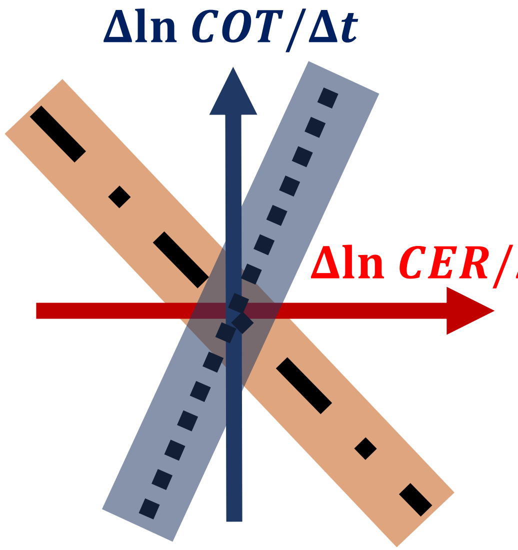
CER: 5-10 μm | 10-15 μm | 15-20 μm

$\Delta N_c \sim 0$
Condensation
$\eta > 2$

$\Delta LWP \sim 0$
Coalescence
$-2 < \eta < -0.5$



No Rain ⟷ Rain



$\Delta N_c = 0$
η=5.0

$\Delta LWP = 0$
η=-1.0

$$\eta := \left(\frac{\frac{\Delta \ln \mathrm{COT}}{\Delta t}}{\frac{\Delta \ln \mathrm{CER}}{\Delta t}} \right)$$

- CER<15μm: Drizzle characteristic is sensitive to time-derivative of cloud property
- CER>15μm: Drizzle forms independent of temporal change of cloud property

Summary

- Two pieces of cloud phase information from CALIOP & MODIS are combined with cloud radar profile to propose precipitation process diagnostics for mixed-phase clouds
- The precipitation characteristics are found to vary with both cloud-top particle size and "cloud-column" phase fraction
  - -> Precipitation occurs more efficiently in more "icy" clouds at given R_{eff}
- Application to climate model evaluation is tested with MIROC6 to compare the phase-dependence of precipitation process
  - -> Prognostic precip tends to generate the statistics closer to satellite
- Combined use of radar and geostationary satellites enables to link time-derivative of cloud properties to vertical microphysical structure
  - -> CFODD statistics are sensitive to d(cloud property)/dt