Recent advances in satellite-based aerosol-cloud studies with implications for global modeling

Kentaroh Suzuki (AORI/Univ. of Tokyo)

JAXA PI Workshop
“Aerosol-Cloud-Precipitation Synergy” Session
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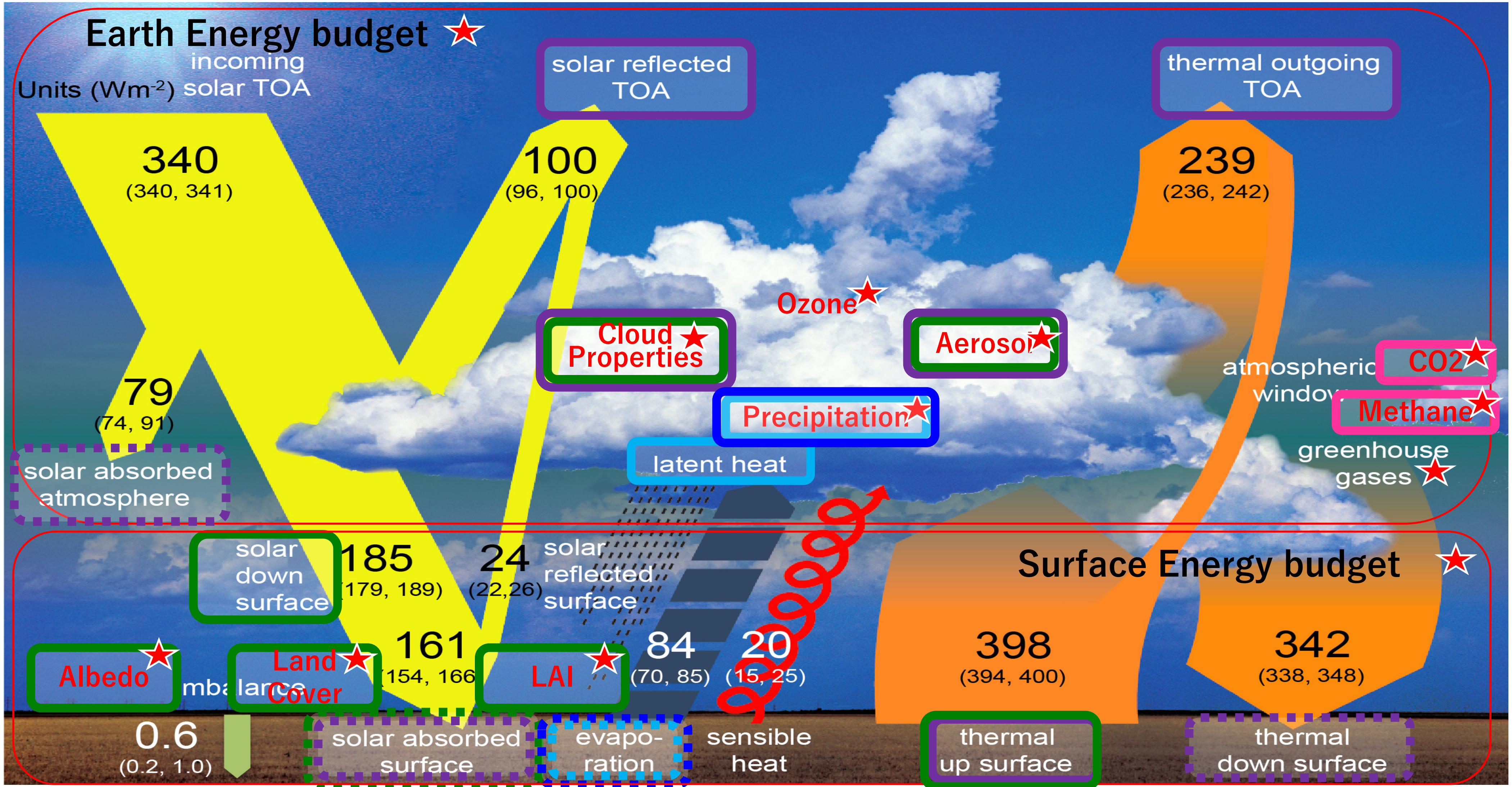
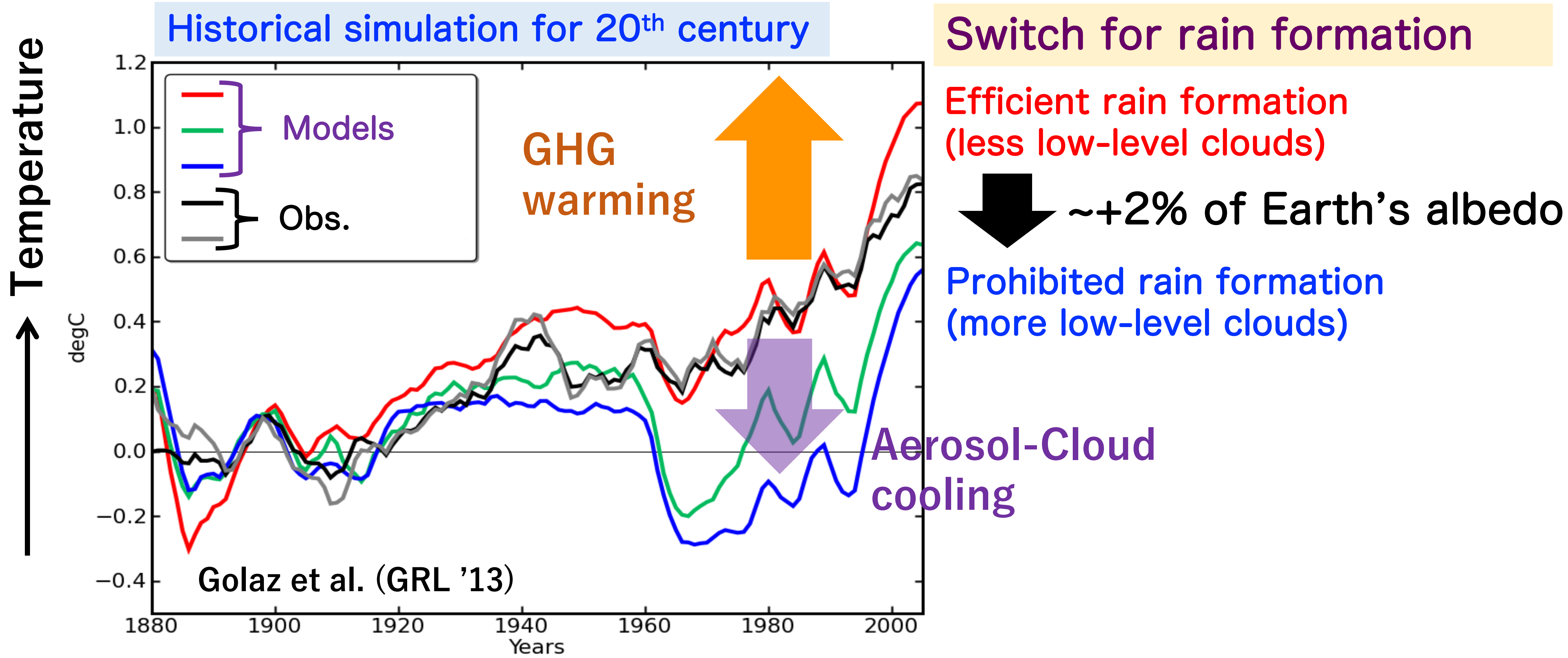
Multiple satellites critical for holistic view of climate



EarthCARE | GCOM-C | GCOM-W
GOSAT | GPM | ECV ★

Adapted from IPCC-AR5; Wild *et al.* (Clim. Dyn. '15)

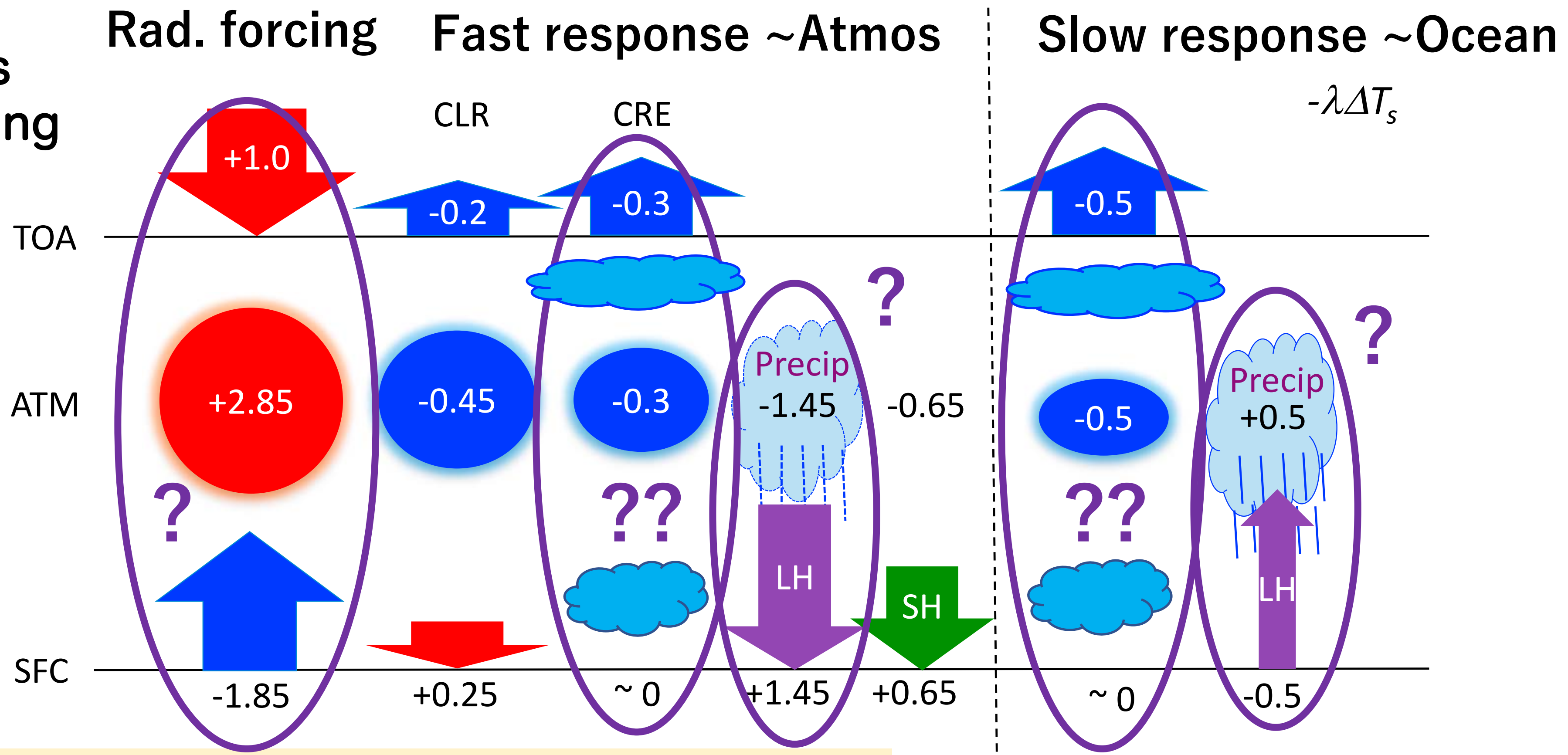
Cloud/Aerosol: A "wild card" in climate modeling



- Climate state is highly sensitive to Earth's albedo ("whiteness")
- Cloud/Aerosol largely controls the albedo

Need to quantify global energy budget change

Energy budget changes in response to BC forcing in MIROC model



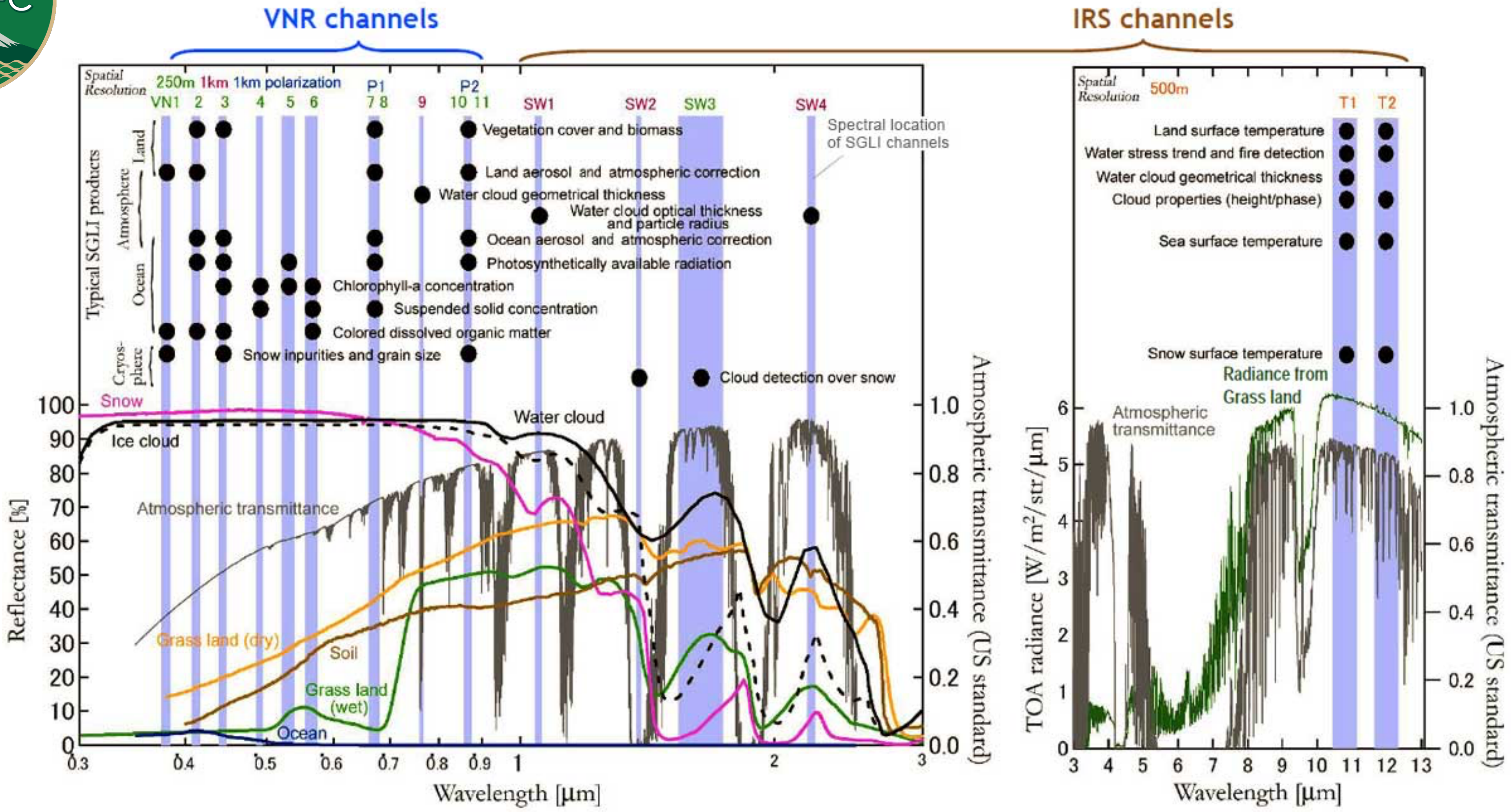
Suzuki & Takemura (JGR '19)

Key uncertain issues:

- Vertical structure of aerosol radiative forcing
- Aerosol effects on cloud and precipitation
- Whole picture of global energy budget change

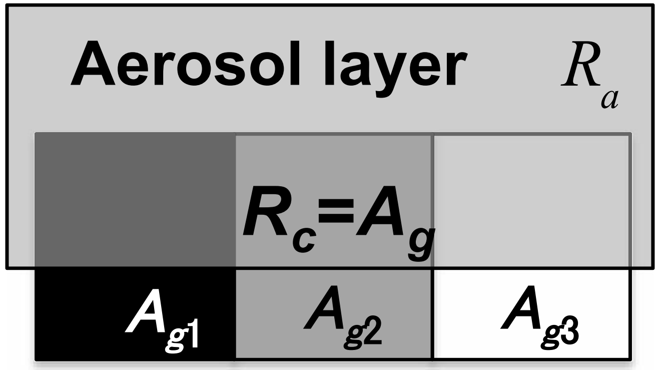
Satellite information 1 - Passive measurement

GCOM-C/SGLI Measurement Wavelengths



Use of multi-pixel/wavelength for aerosol retrievals

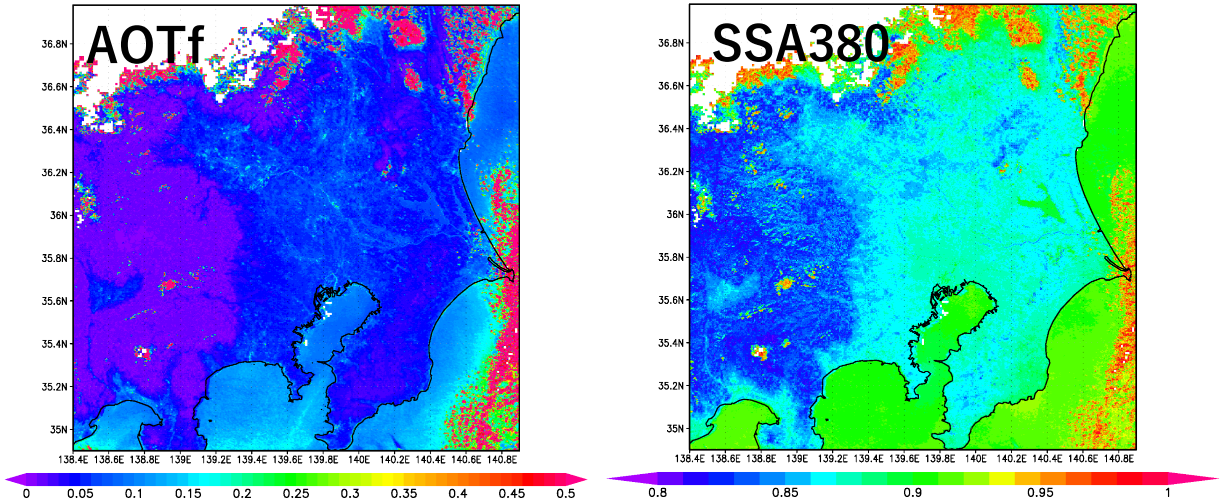
Hashimoto & Nakajima (JGR '17) with NN-based Rad. Trans. (Takenaka et al. JGR '11)



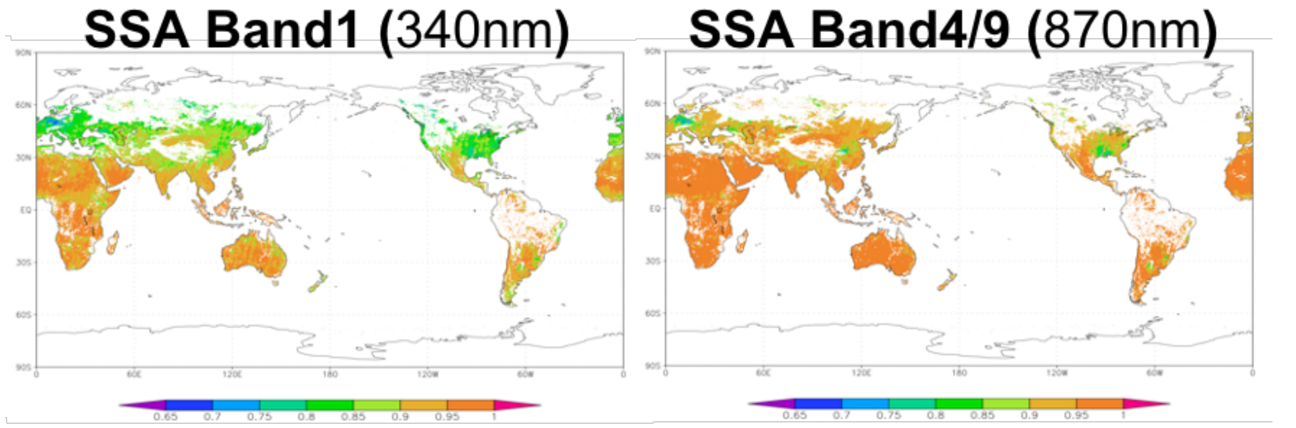
$$\boldsymbol{R}_i = \boldsymbol{R}_{gi} + \boldsymbol{R}_{ai}$$
$$\approx \boldsymbol{A}_{gi} + \tau \cdot [c_1 \cdot \omega P(\Theta) - c_2 \cdot \boldsymbol{A}_{gi}]$$

- Exploiting surface heterogeneity to retrieve aerosols' "whiteness" contrasted against surface albedo
- Performing "online" RT simulations enabled by efficient NN approach
- Capable of global aerosol retrievals

Application to GCOM-C/SGLI (c/o M. Sekiguchi)



Application to GOSAT2/CAI2 (c/o M. Hashimoto)



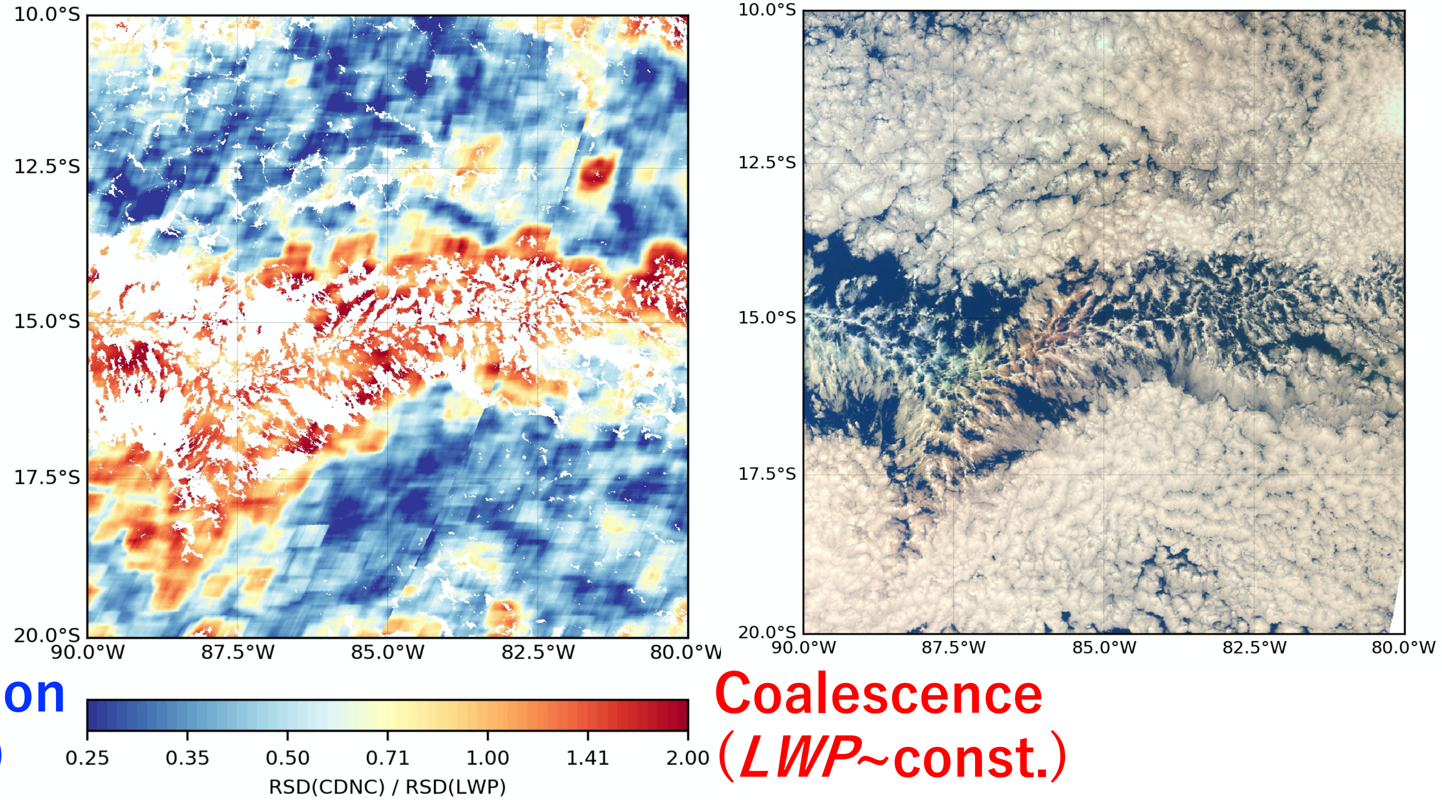
“Mapping” of cloud microphysical processes

$$RSD\ ratio = \frac{RSD[N_c]}{RSD[LWP]}$$

RSD [*X*]: Relative Standard Deviation of *X* (*Spatial Variance*)

N_c: Cloud Droplet Number Conc.
LWP: Liquid Water Path

RSD ratio



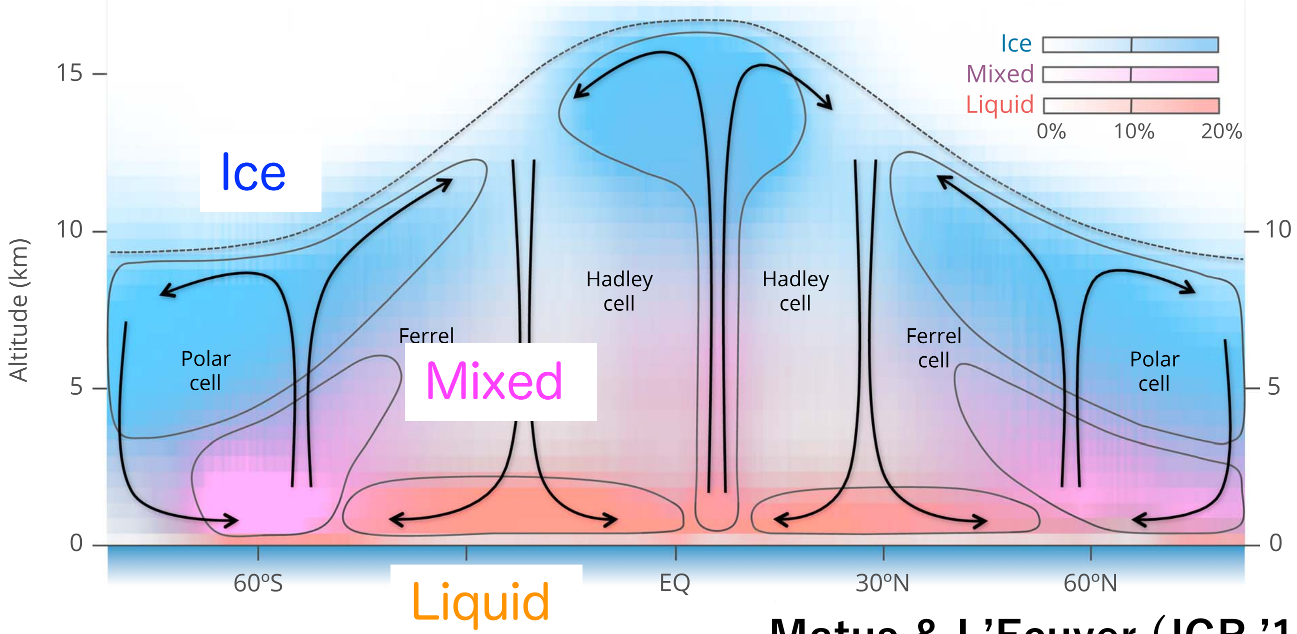
Nagao & Suzuki (GRL ’20)

- Microphysical processes are diagnosed by spatial variance of cloud properties
- The processes identified well correspond to cloud morphology (open/closed cells)

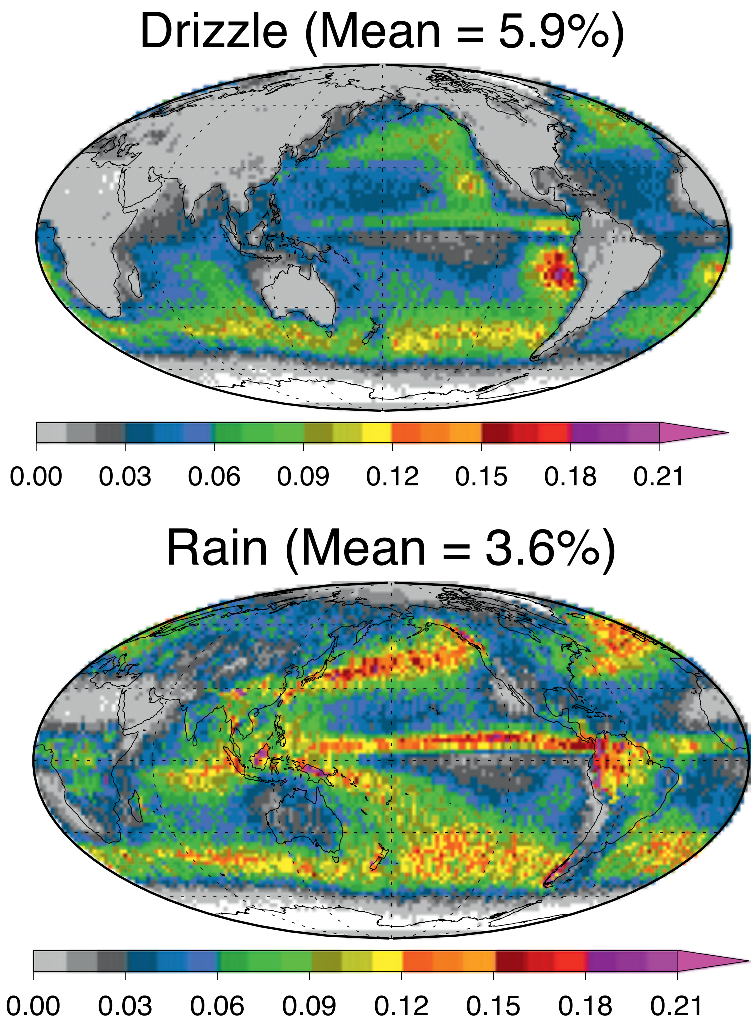
Satellite information 2 - Active measurement

- ■How are clouds suspended in atmos?
  - ✓ Height, Wetness, Liquid/Ice etc.
- ■How does precipitation form?
  - ✓ Frequency, Intensity, Height etc.

-> Detailed knowledge for cloud/precipitation
-> Evaluate/Improve numerical models



Matus & L'Ecuyer (JGR '17)

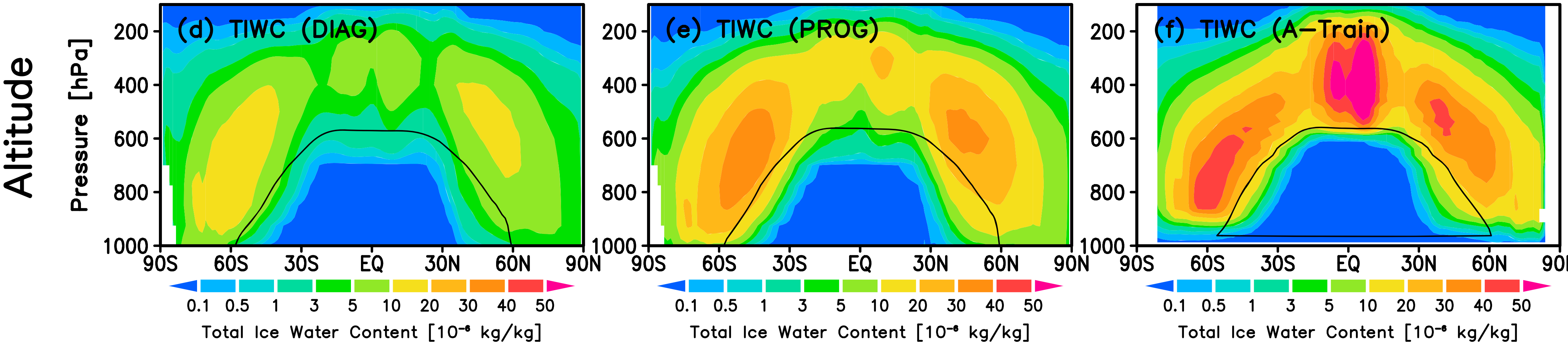


Stephens et al. (BAMS '18)

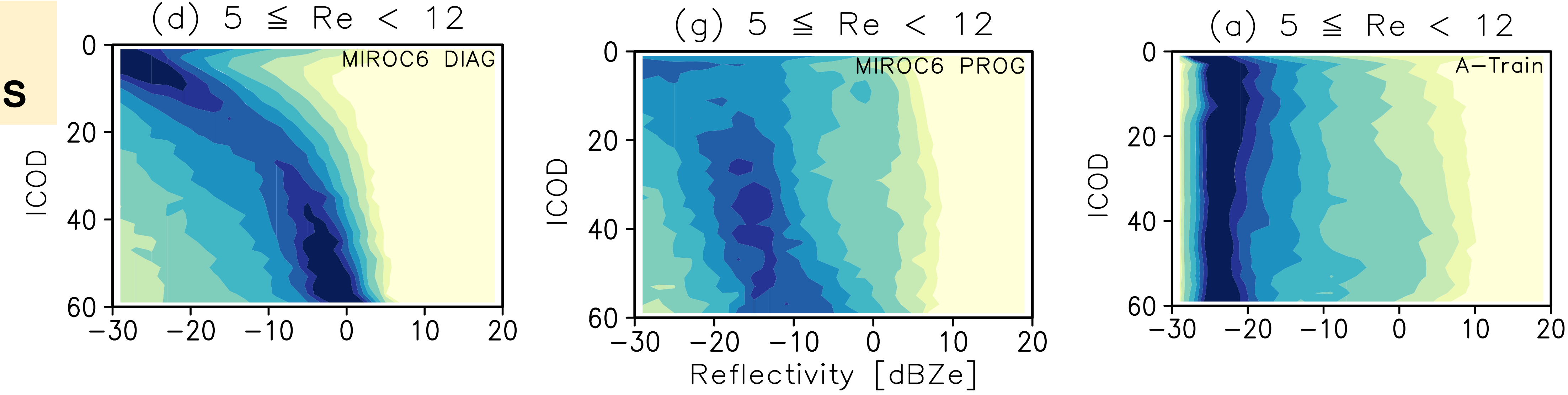
Climate model improvement

Michibata et al. (JAMES ’19; ACP ’20)
Michibata & Suzuki (GRL ’20)

Cloud Ice — Old MIROC6 | New MIROC6 | Satellite Obs.

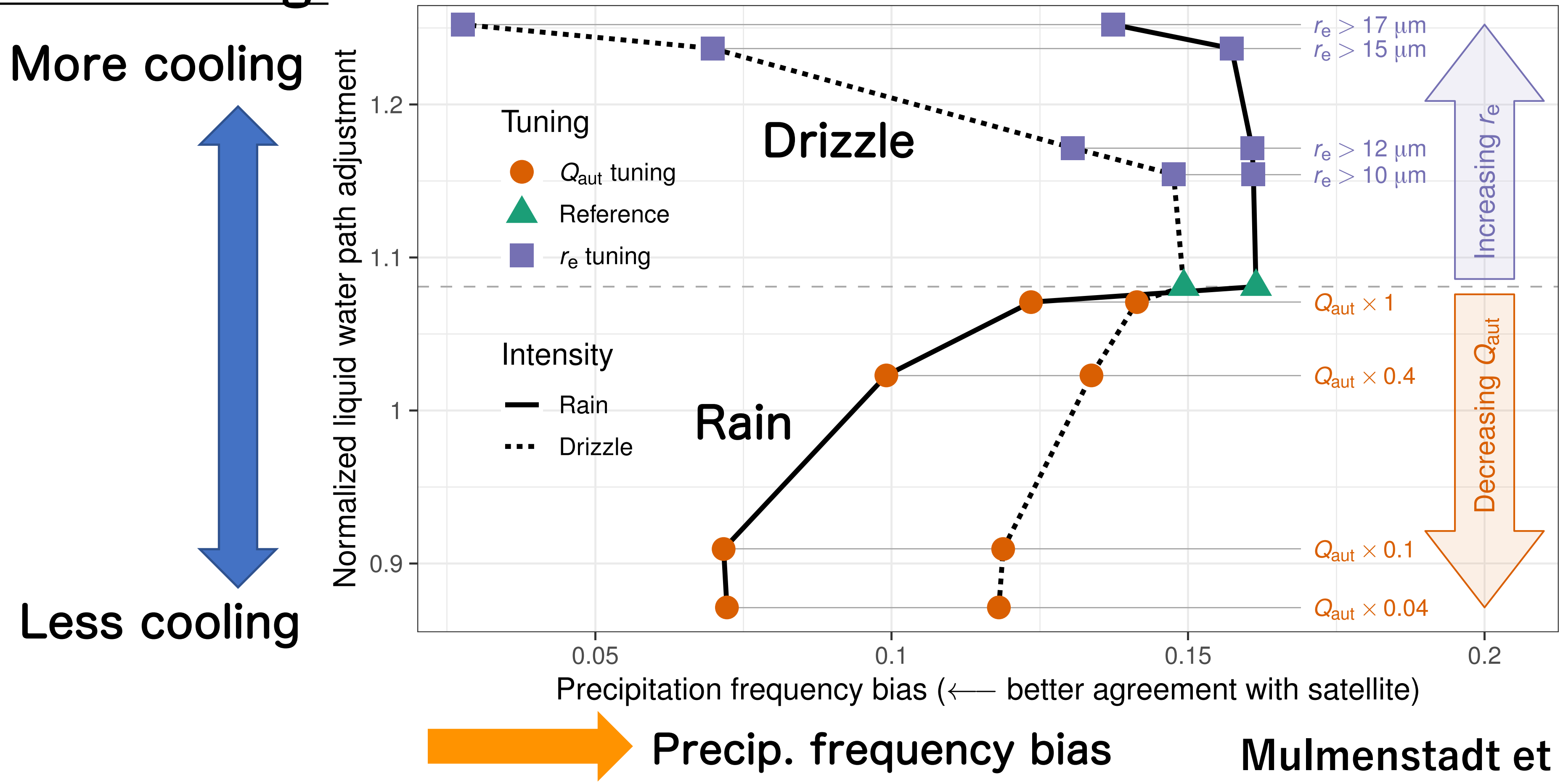


Rain process



How do rain processes link to radiative forcing?

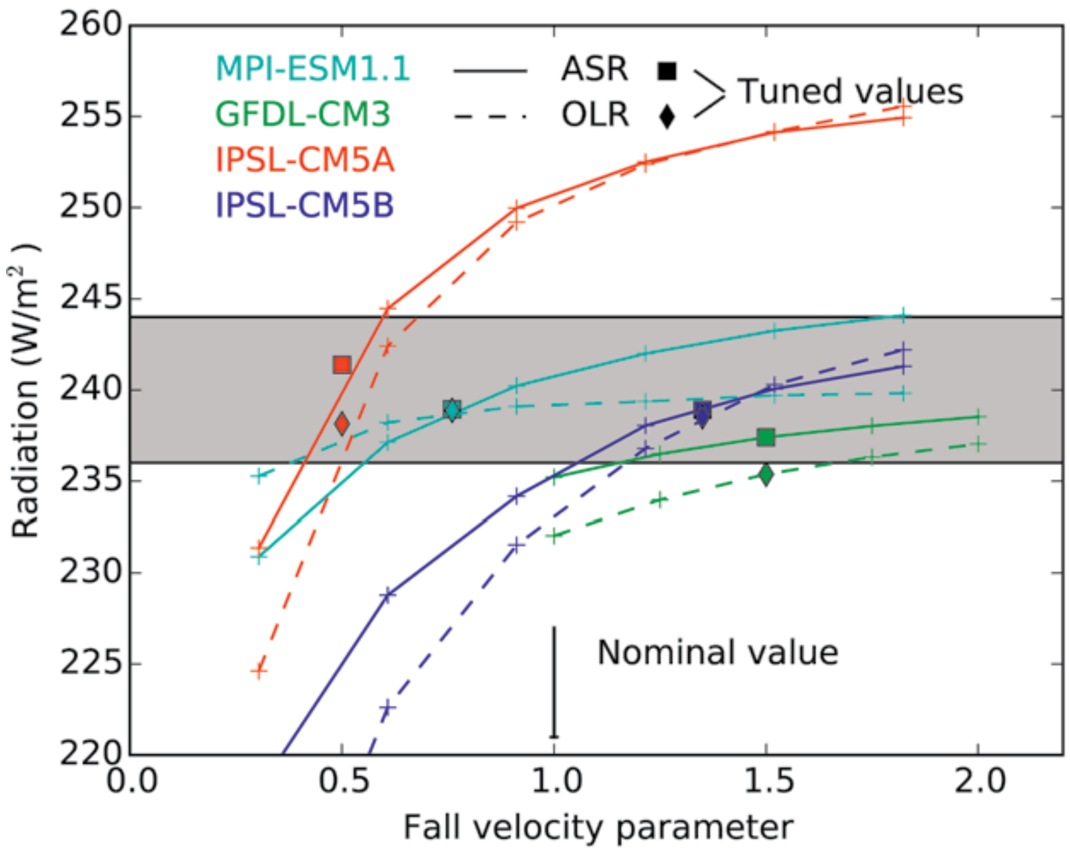
Radiative forcing:



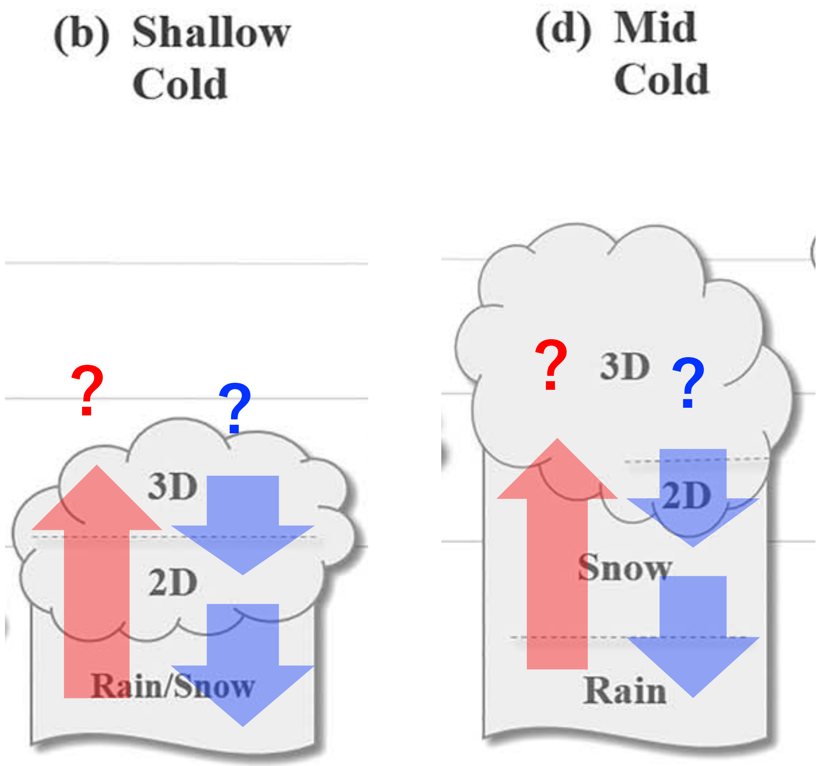
Mulmenstadt et al. (Sci. Adv. '20)

- Simultaneous measurement of rain/drizzle is critical for model precipitation processes
- Process-sensitive information is required for reliable estimates of radiative forcing

Need for understanding cloud dynamics



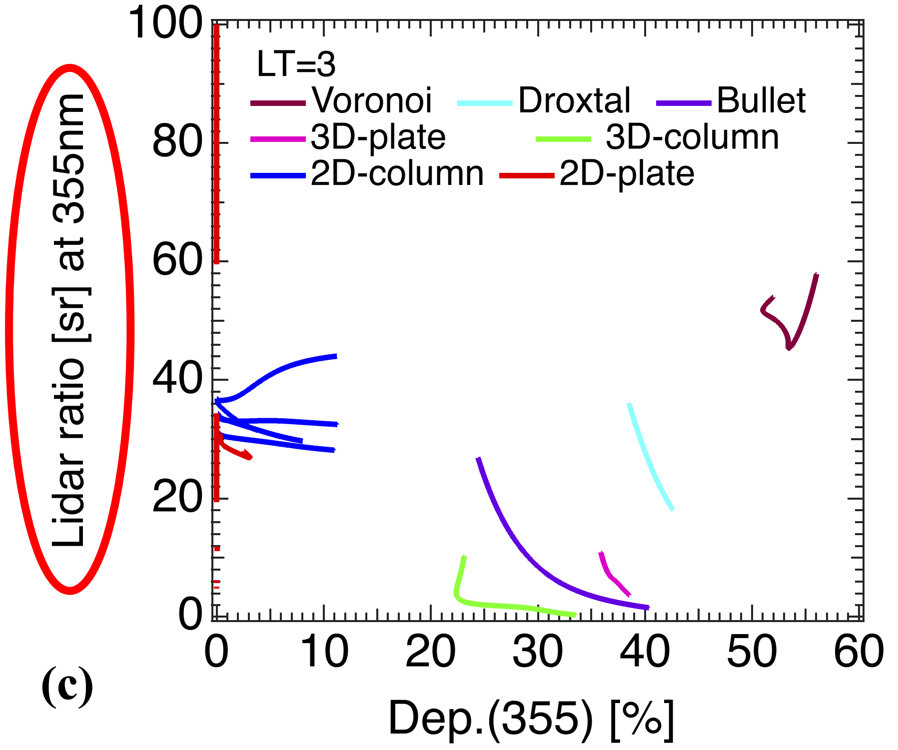
Hourdin et al. (BAMS '17)



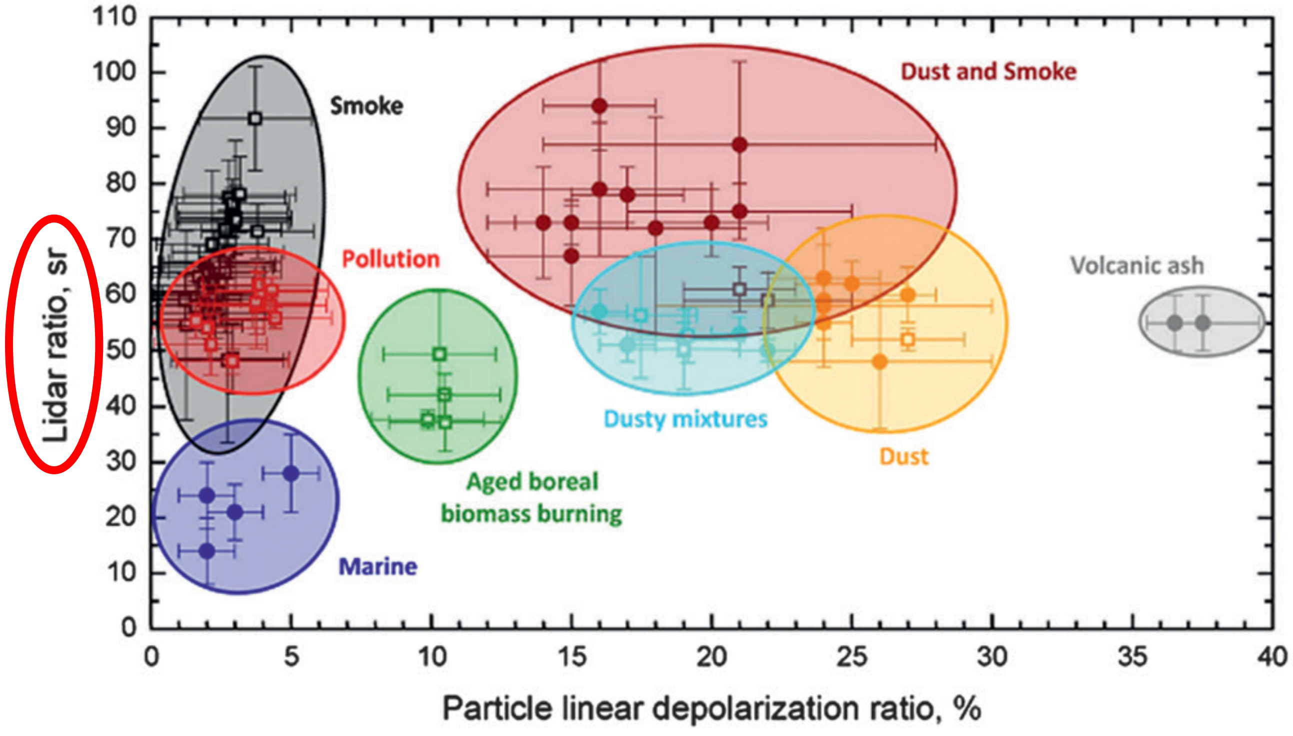
Kikuchi & Suzuki (GRL '19)

- Fall velocity of cloud particles is a "tunable knob" in climate models
- Cloud dynamics measurements are enabled by EarthCARE with Doppler capability

Particle characterization enabled by EarthCARE



Okamoto et al. (Optical Express '19)

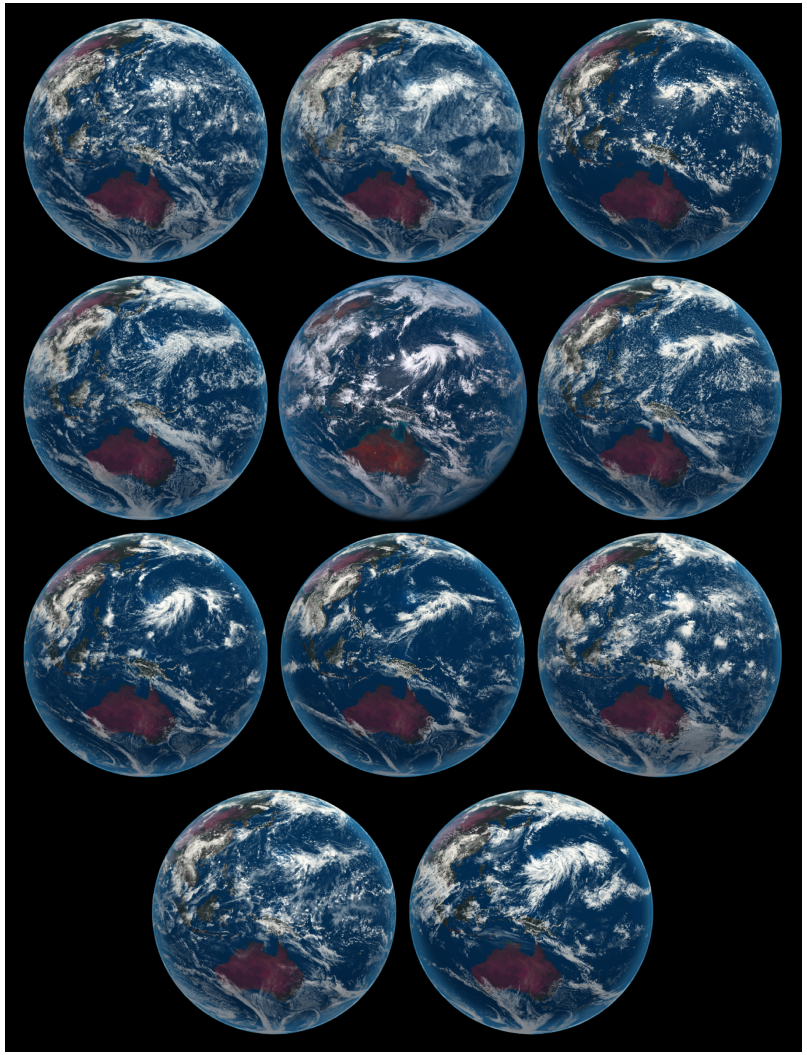


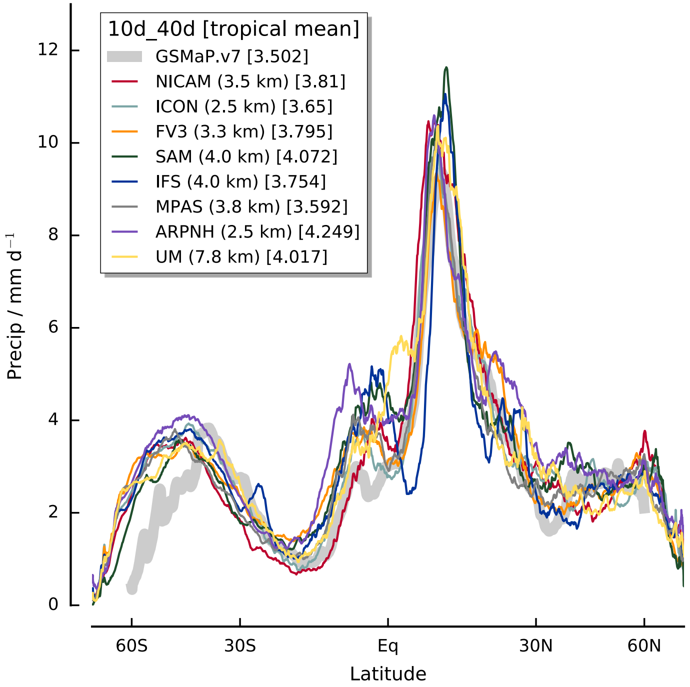
Illingworth et al. (BAMS '15)

High-Spectral Resolution Lidar (HSRL) offers this new information
-> Classification of aerosol species
-> Linking cloud dynamics with particle habits (microphysics)

New era of global cloud-resolving modeling

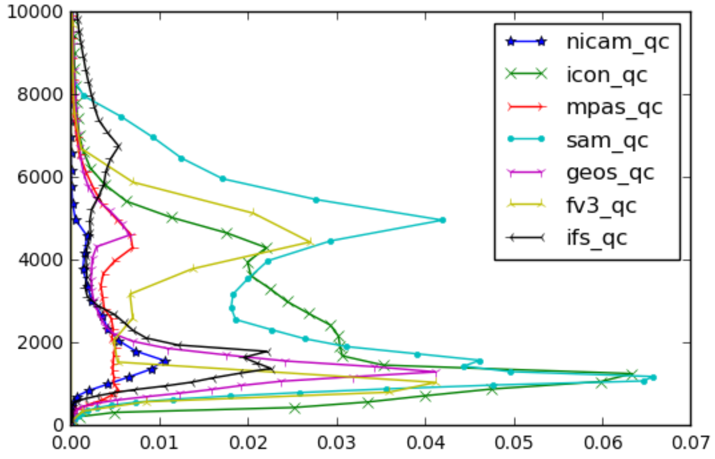
The DYAMOND project (Stevens et al. PEPS '19)



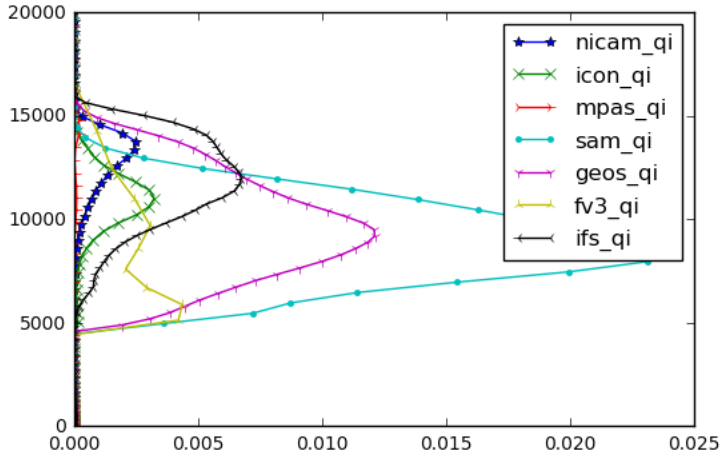


- ■ Precipitation agrees well
- ■ Clouds are still diverse
- ■ Further constraints are required for clouds

Cloud water mixing ratio



Cloud ice mixing ratio



Roh et al. (JMSJ in review)

Summary: Take-home messages

- Passive/Active sensors have started to provide novel information of aerosols/clouds
  - Process information as well as detailed properties
  - From "parameter-centric" to "process-oriented" observations
  - Exploiting multi-sensor/platform measurement capabilities
- Such satellite-based information offers a useful guide for evaluating/improving numerical climate models
  - At fundamental "building-block" levels, and
  - With further need for "process-sensitive" observation information
- The combination of new multiple satellite measurements with global cloud-resolving modeling is a promising way to advance climate science of aerosols and clouds