Process-oriented evaluation of warm rain process in global models with satellite observations

Kentaroh Suzuki and Xianwen Jing (AORI/U. Tokyo)

Thanks to collaborations with:

H. Guo (GFDL), D. Goto (NIES), T. Ogura (NIES),

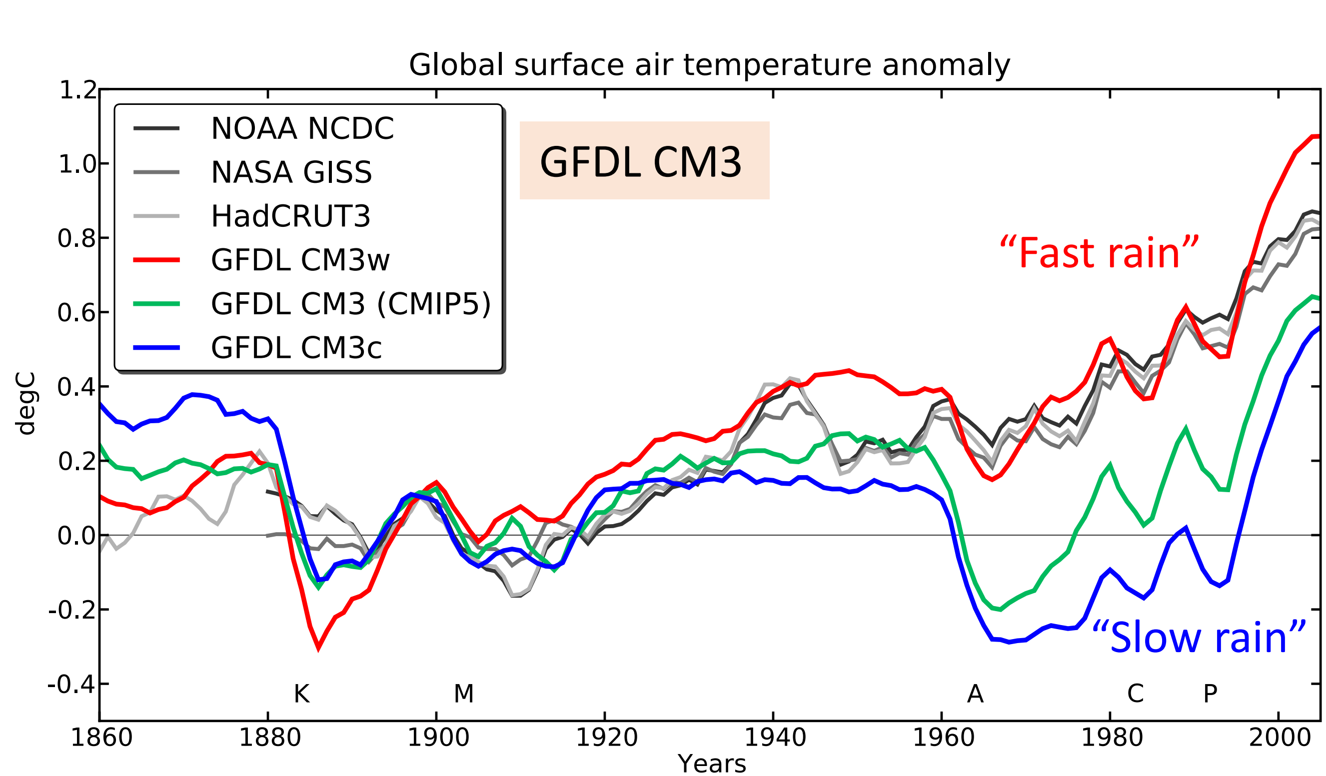
T. Koshiro (JMA/MRI), J. Mulmenstadt (U. Leibzig)

5th WGNE Workshop on Systematic Errors in Weather and Climate Models

June 19-23, 2017 @Montreal

Why warm rain? - A key "tunable knob" in climate modeling

Golaz *et al.* (GRL '13)



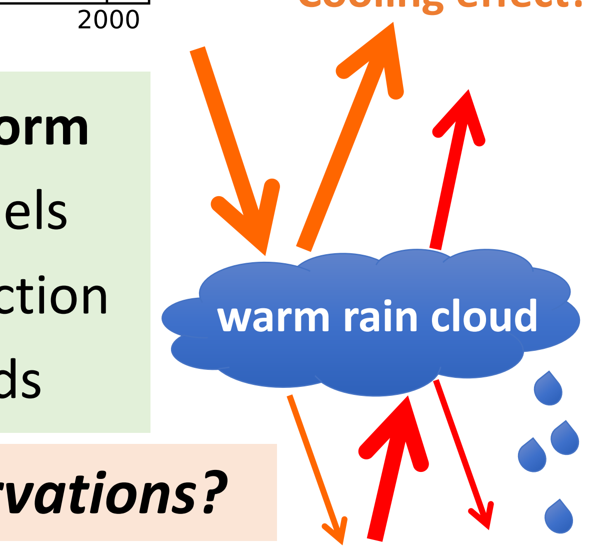
r_{crit}= 6.0μm

r_{crit}= 8.2μm

r_{crit}= 10.6μm

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

- A "tunable" parameter in (some) climate models
- Modulates magnitude of aerosol-cloud interaction
- Leads to different historical temperature trends

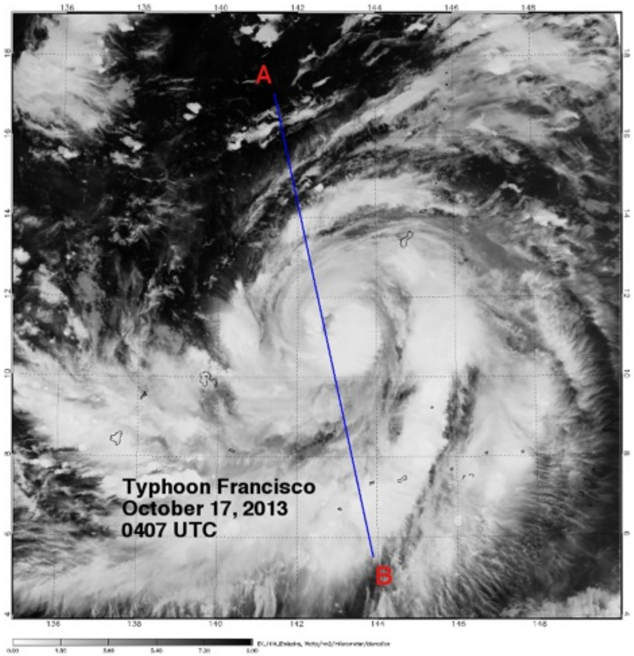


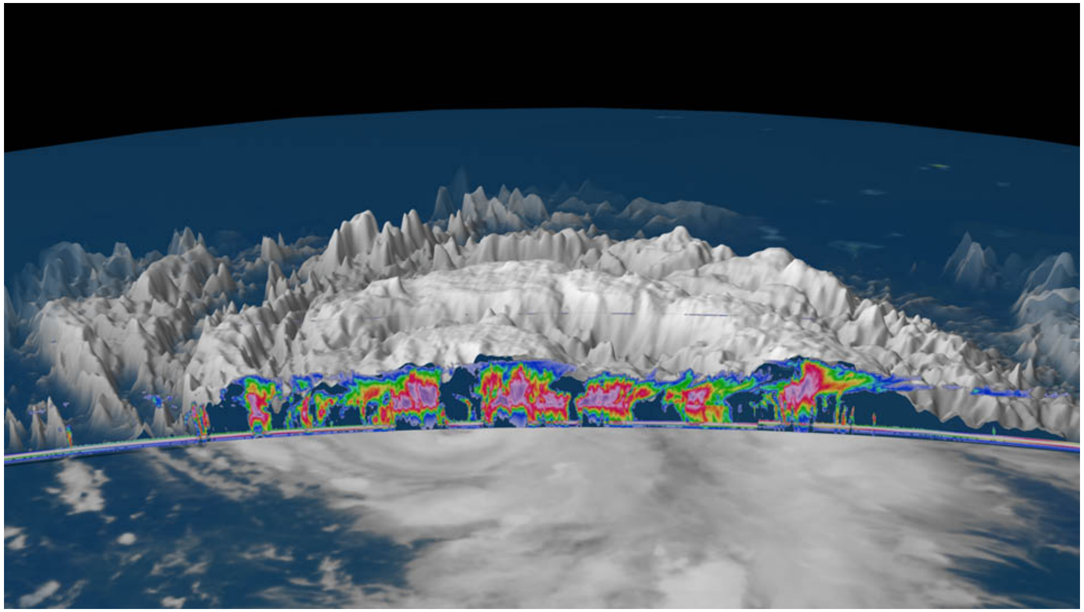
Can we constrain this uncertainty with observations?

New “era” of satellite observations of clouds

Passive (MODIS)

Active (CloudSat)



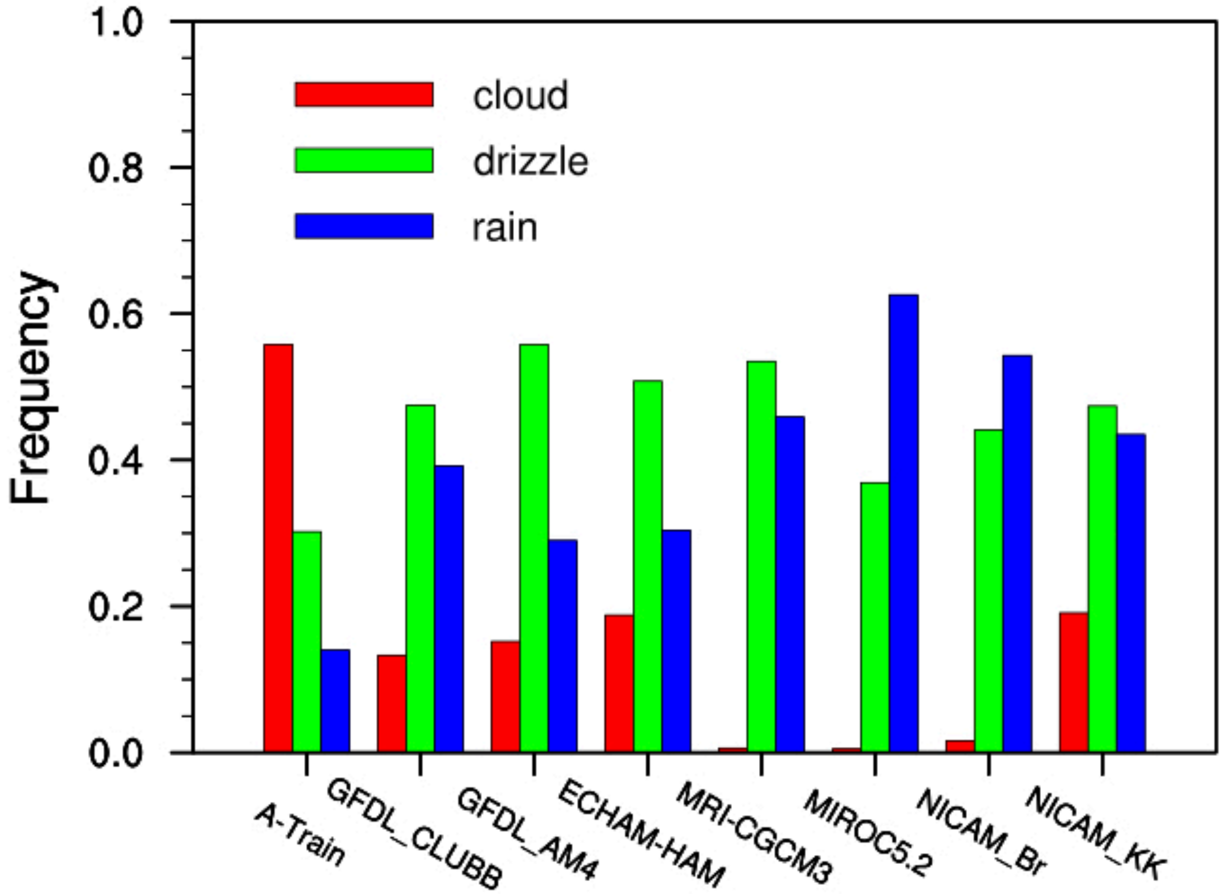


- Novel observations of cloud-precipitation systems
  - ✓ Simultaneous measurement of cloud and precipitation
- How can we better use this novelty for process diagnostics?
- How can we exploit the observational information for better evaluations of climate models (e.g. at the process-level)?
- We need metrics based on these measurement information

First step: A simple use of (single) observable

Z_{max}: Radar Reflectivity at 94GHz

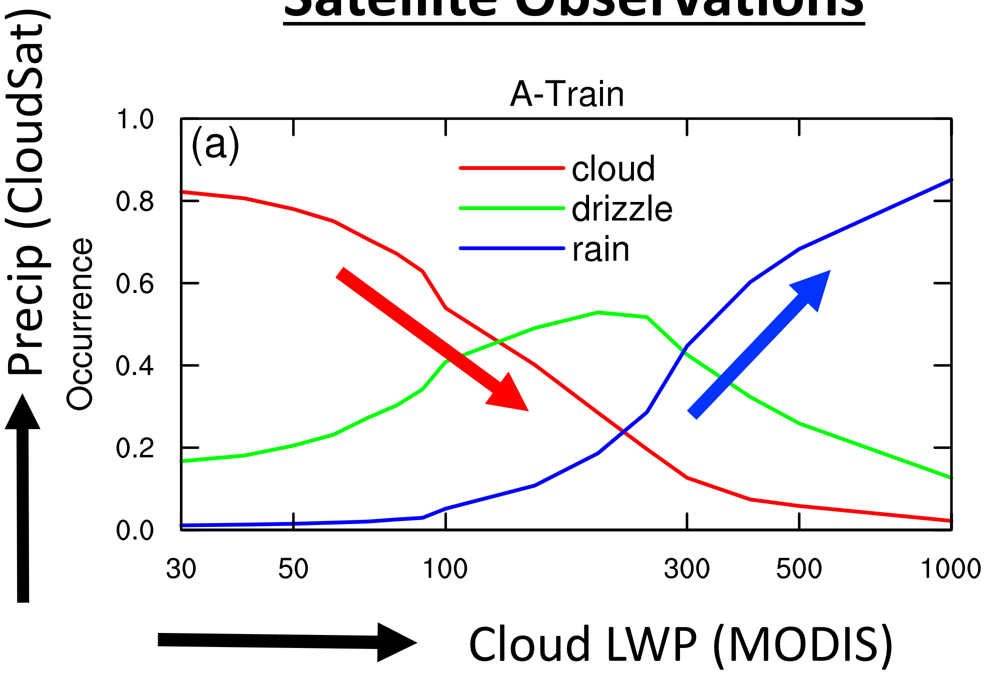
'Cloud' : $-30 < Z_{max} < -15$ dBZ
'Drizzle' : $-15 < Z_{max} < 0$ dBZ
'Rain' : $Z_{max} > 0$ dBZ



Jing *et al*. (JGR submitted)

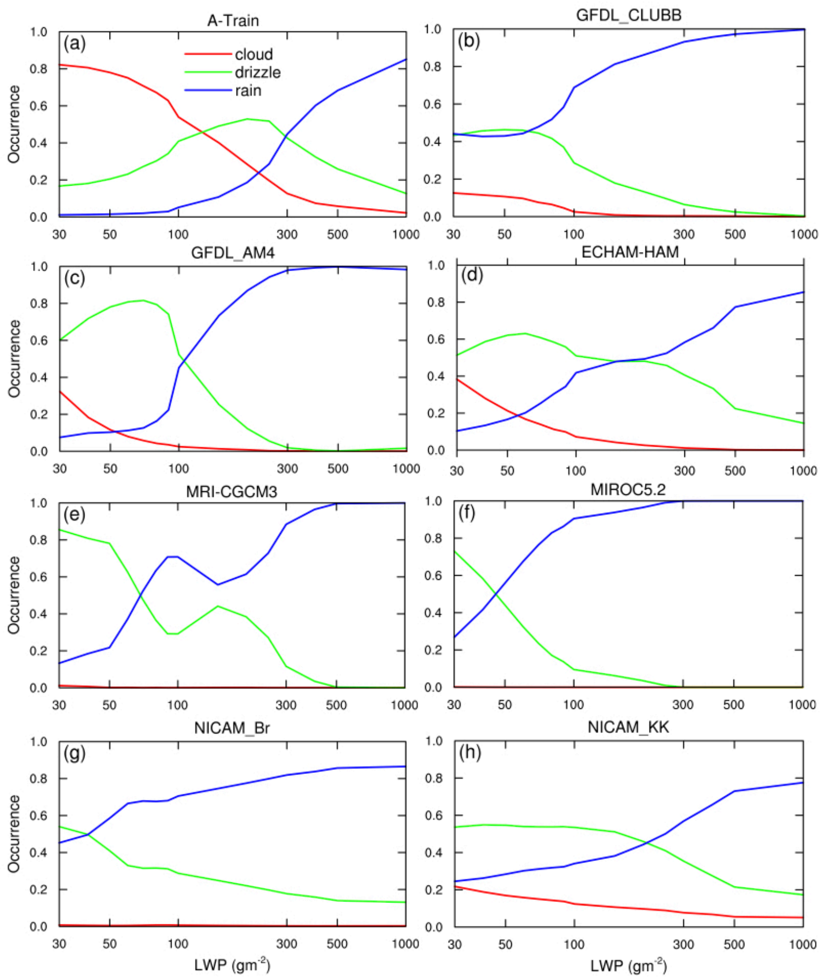
Second step: Multi-variate analysis

Satellite Observations



Suzuki *et al*. (JAS '15)

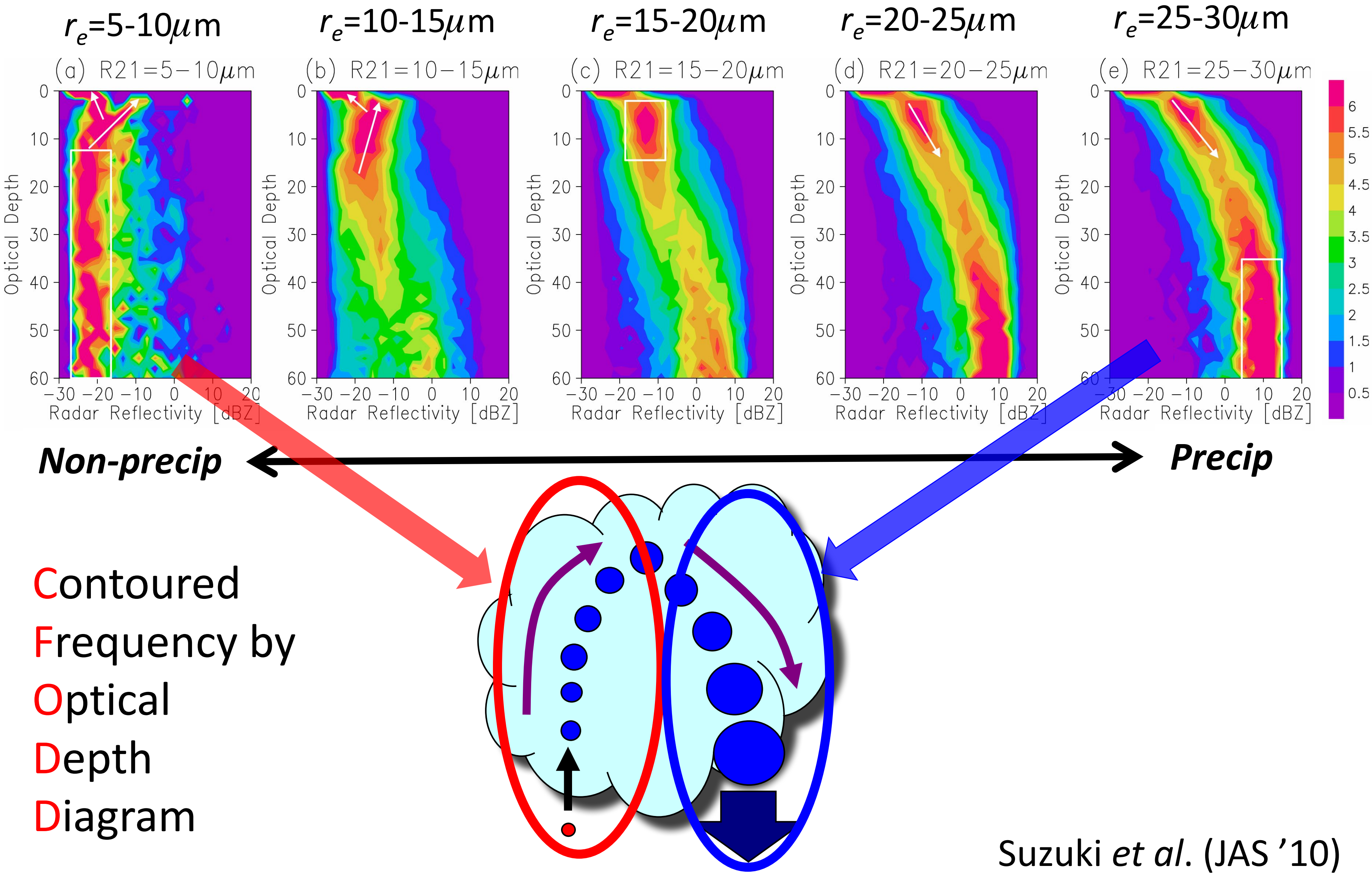
Multiple Climate Models



Jing *et al*. (JGR submitted)

'Cloud' : $-30 < Z_{max} < -15$ dBZ
'Drizzle' : $-15 < Z_{max} < 0$ dBZ
'Rain' : $Z_{max} > 0$ dBZ

Third step: "fingerprinting" signatures of processes

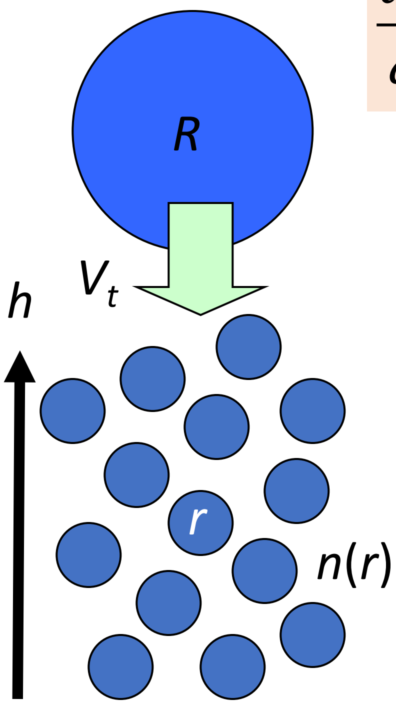


Contoured
Frequency by
Optical
Depth
Diagram

Suzuki *et al*. (JAS '10)

Insight into microphysical processes of warm rain

Continuous Collection Model



$$\frac{dR}{dt} = \frac{E_c V_t(R)}{4\rho_w} q_c$$

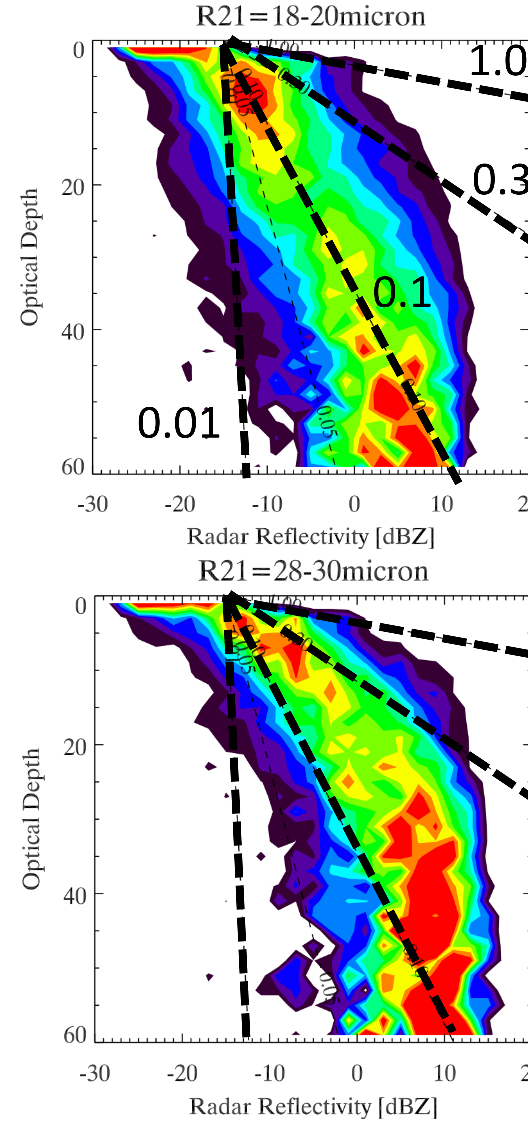
$$\frac{dR}{dh} = -\frac{E_c}{4\rho_w} q_c \qquad dh = -V_t(R)dt$$

$$\frac{dR}{R} = -\frac{E_c}{4\rho_w} \frac{q_c}{R} dh$$

$$\frac{dZ_e}{Z_e} \approx \alpha \frac{dR}{R}$$: "collecting" drop

$$d\tau \approx -\frac{3}{2} \frac{1}{\rho_w} \frac{q_c}{R} dh$$: "collected" droplet

$$\therefore \frac{d \ln Z_e}{d\tau} \approx \frac{\alpha}{6} E_c \qquad \alpha \approx 3-6$$



Suzuki *et al*. (JAS '10)

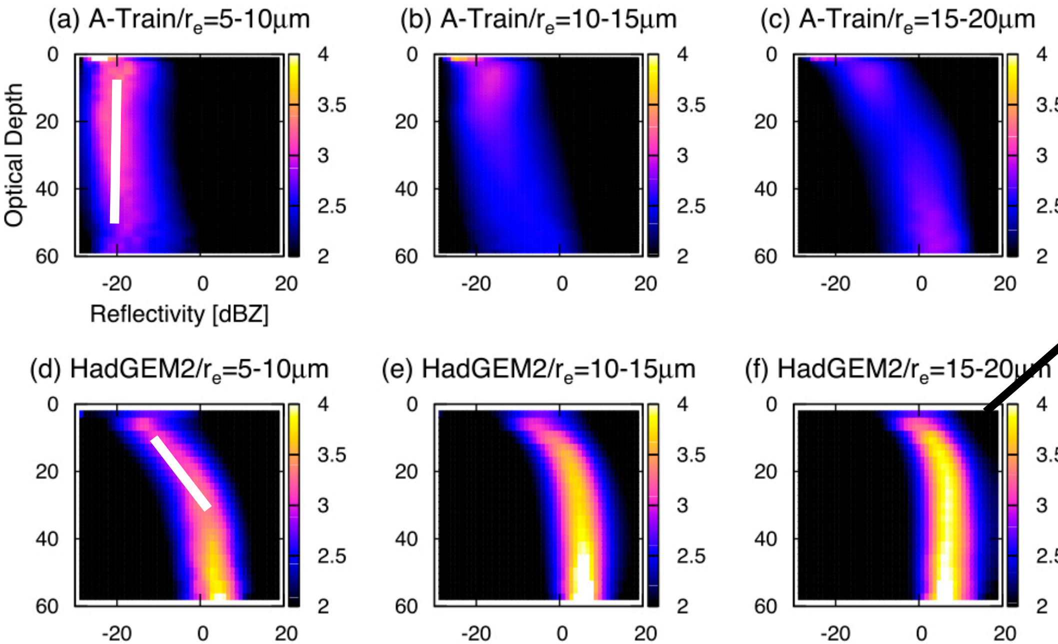
The slope in this diagram is a gross measure of the collection efficiency E_c

Satellite-based model diagnostics for warm rain processes

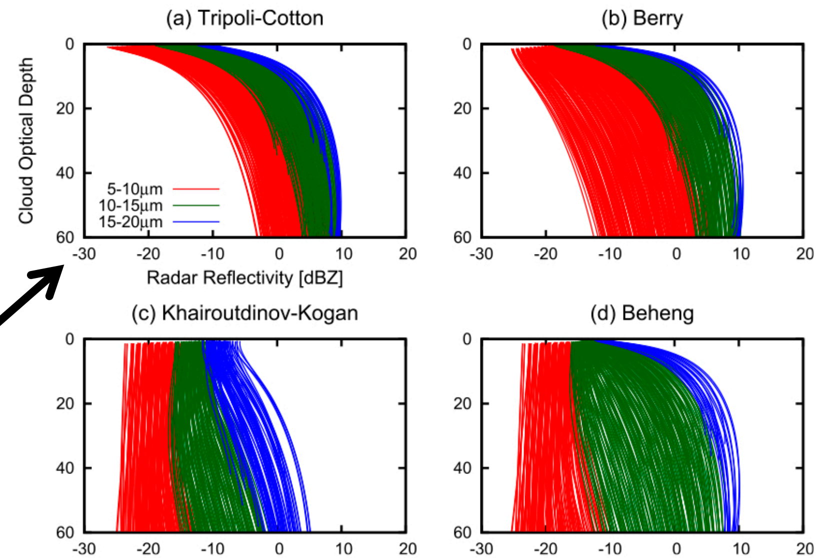
Radar Reflectivity vs Optical Depth for different R_{eff} ranges: A-Train vs GCMs

Suzuki *et al.* (JAS '15)

R_e=5-10μm R_e=10-15μm R_e=15-20μm

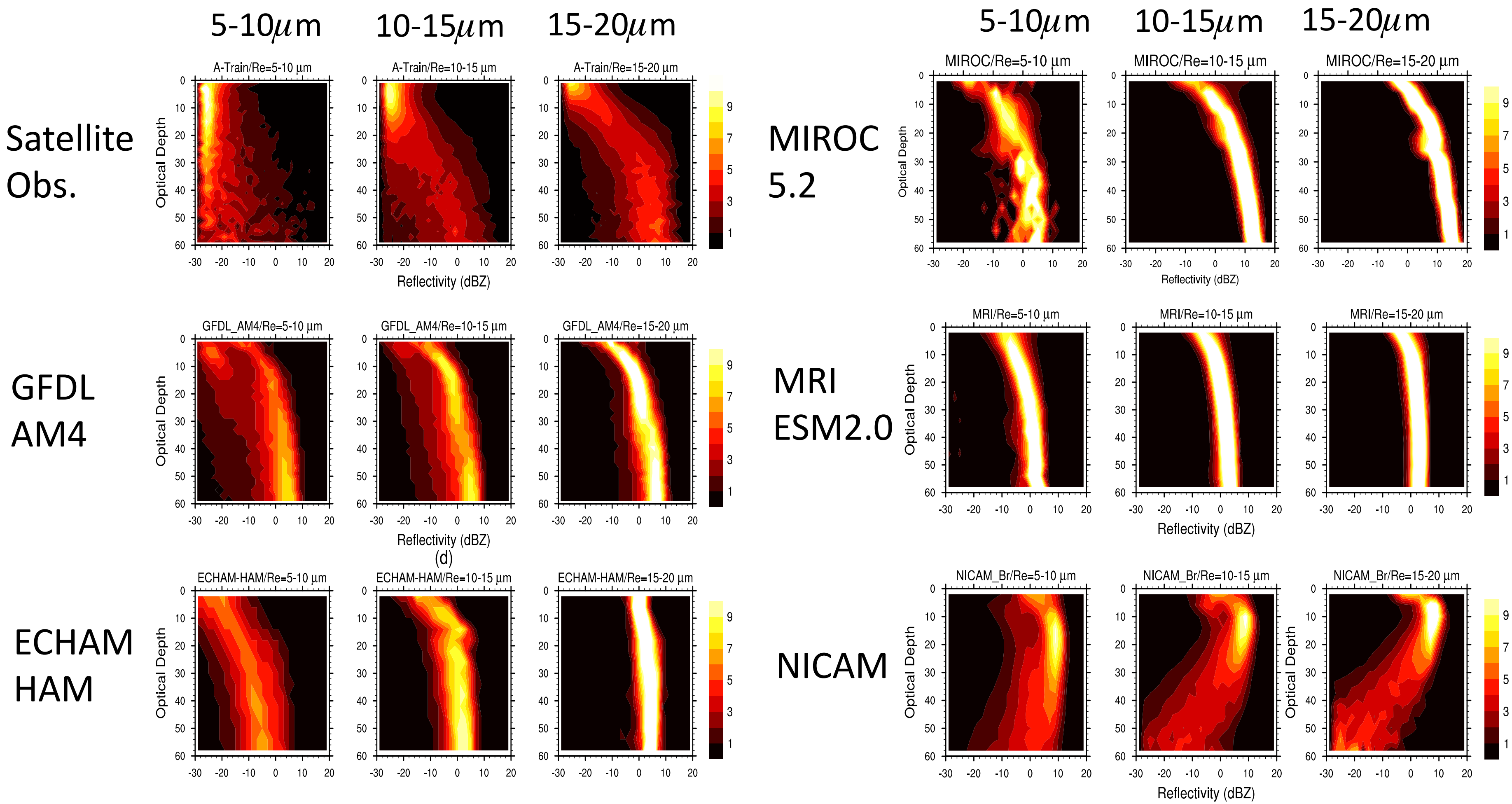


Effect of μ-physics schemes: 1D process model analysis



- The statistics exposes model biases in warm rain formation
- This is traced back to μ-physics process representations
- Satellite + 3D model + process model -> Process diagnostics

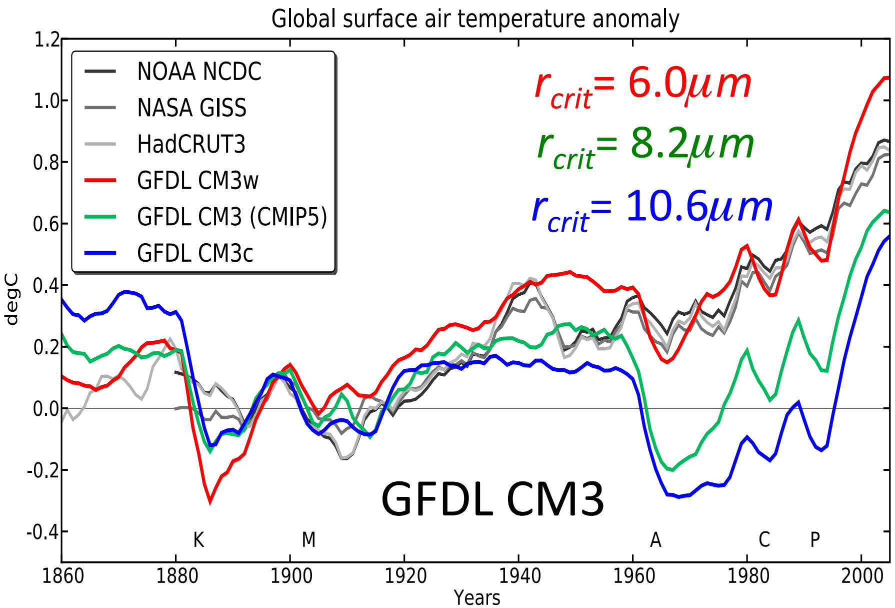
Multi-model diagnostics for up-to-date models



Jing *et al*. (JGR submitted)

- Models share a common bias of “too-fast” rain formation
- The issue still remains in CMIP6 version of some models

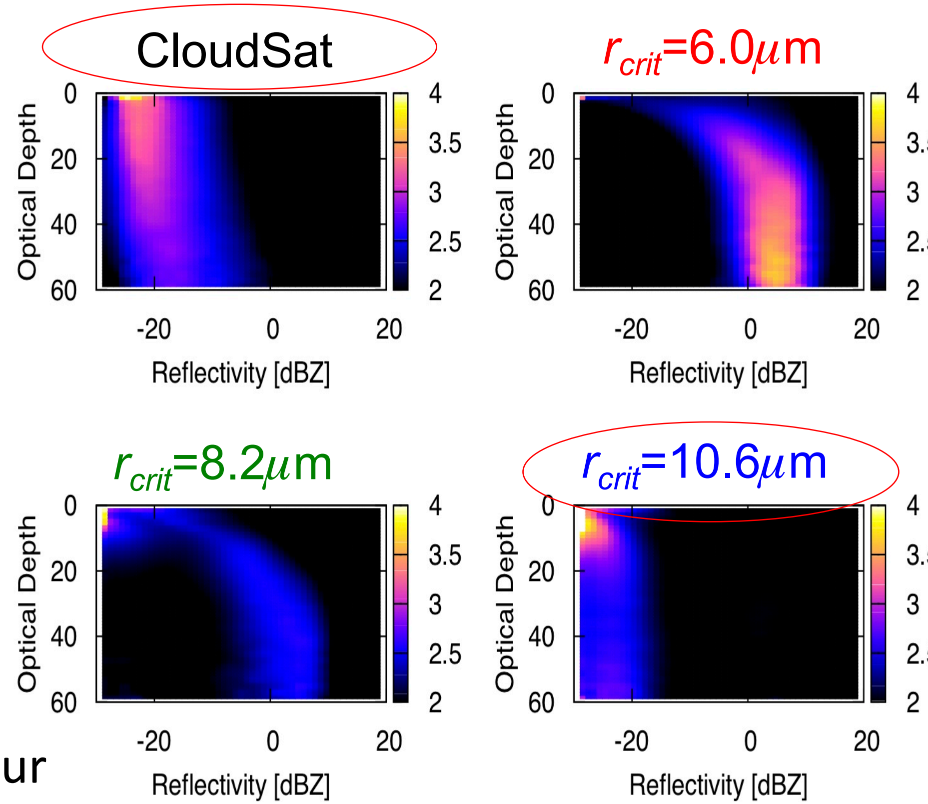
Constraint on "tuning": Implication for climate projection



Golaz *et al*. (GRL '13)

r_{crit}: Threshold particle size for rain to occur

"Incipient stage": R_e=6-10μm



Suzuki *et al*. (GRL '13)

- The red scenario best reproduces the historical temperature trend
- The blue scenario best represents the microphysical "fingerprint"
- The "contradiction" implies the presence of error compensation
- Process-level model diagnostics is required to disentangle this issue

Community efforts for process-oriented model diagnostics

- **GEWEX PROES** (Lead: C. Jacob/G. Stephens)
  - Upper Tropospheric Cloud & Convection (Lead: Stubenraunch)
  - Ice Mass Balance (Lead: Laurour/Nowicki)
  - Radiative Kernels (Lead: Soden)
  - Mid-latitude Storms (Lead: Tselioudis)
  - Warm Rain (Lead: Suzuki; Planned)
- **NOAA Model Diagnostics Task Force** (Lead: E. Maloney)
  Tropical/Extratropical Cyclone, ENSO/Teleconnection, Warm Rain, Land-Atmosphere interaction, MJO, Diurnal cycle, AMOC
- **CFMIP Model Diagnostics Codes Catalogue** (Lead: Y. Tsushima)
  - A suite of diagnostics/metrics (Tsushima *et al*. GMDD; See her poster)
  - A showcase in the form of the code repository

◆ Better use of existing/emerging observations for process diagnostics
◆ Integration as a "Tool Kit" to be used for climate model evaluations

Summary

- Cloud microphysics is a particular "tunable knob" in climate models
- Multi-sensor, multi-platform satellite observations provide novel measurement of cloud-precipitation system
- Particular combinations of multiple observables define the statistics that "fingerprint" signatures of processes
- The satellite-based statistics serve as a reference to be compared with climate models for process diagnostics: Constraint on model "tuning"
- Such a "bottom-up" constraint contradicts the traditional "top-down" constraint: presence of error compensation