# Use of the CloudSat/A-Train satellite observations for model diagnosis of cloud microphysical processes*

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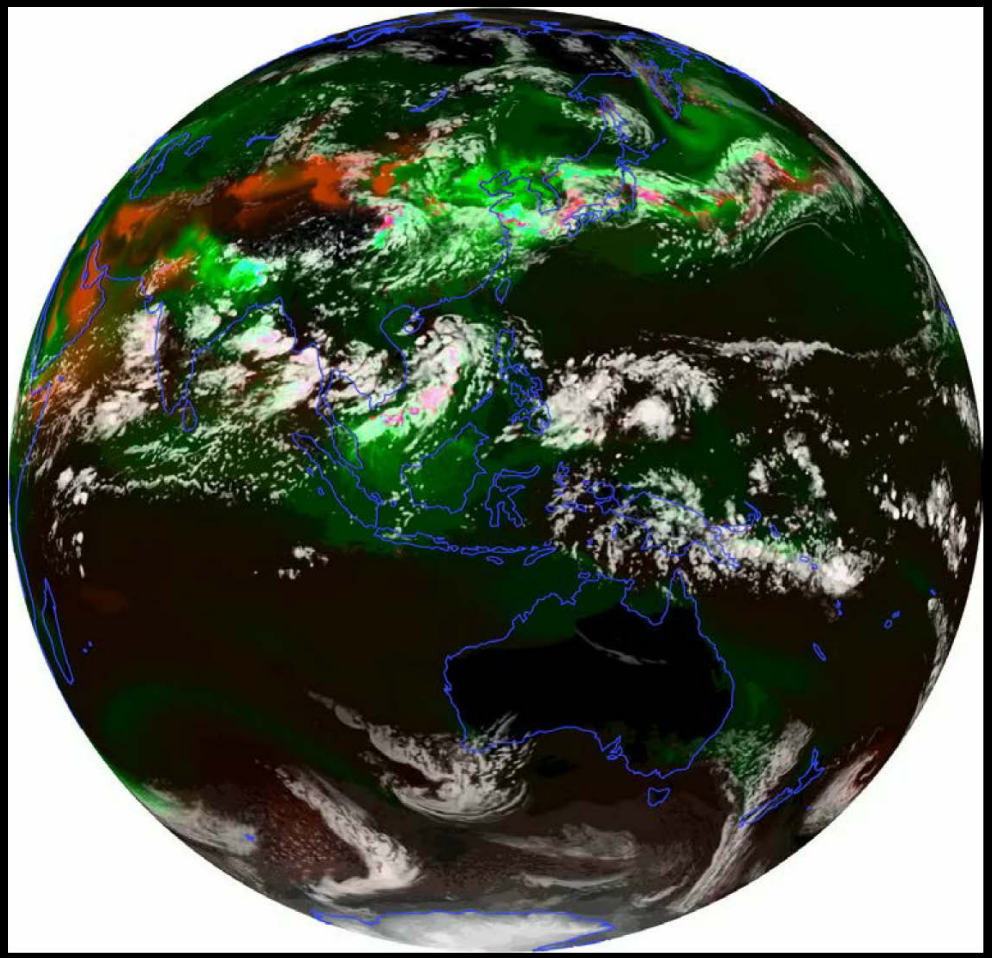
***Only warm liquid clouds**

# Recent progress in high-resolution global modeling

**Red: Coarse aerosols (Soil dust, Sea salt)**
**Green: Fine aerosols (Carbonaceous, Sulfate)**
**White: Clouds (OLR)**

The NICAM-SPRINTARS model
Satoh et al. ('08), Suzuki et al. ('08)
$\Delta x$=7km July 1-8, 2006



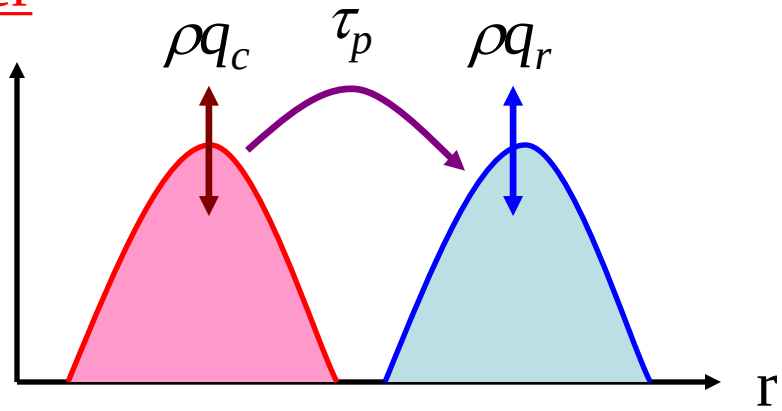
- ✓ Cloud microphysics is still highly uncertain
- ✓ Microphysics representation directly links to aerosol indirect effect
- ✓ We need detailed analysis of microphysical processes

# Liquid cloud microphysics in global models

## Conversion of cloud water into rain water

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

$$\frac{1}{\tau_p} = \frac{1}{\tau_{aut}(\rho q_c, N_c)} + \frac{1}{\tau_{acc}(\rho q_r, N_r)}$$




Auto-conversion:

$$\tau_{aut} = \tau_{aut}(\rho q_c, N_c) \propto \frac{N_c^{\beta}}{(\rho q_c)^{\alpha}}$$

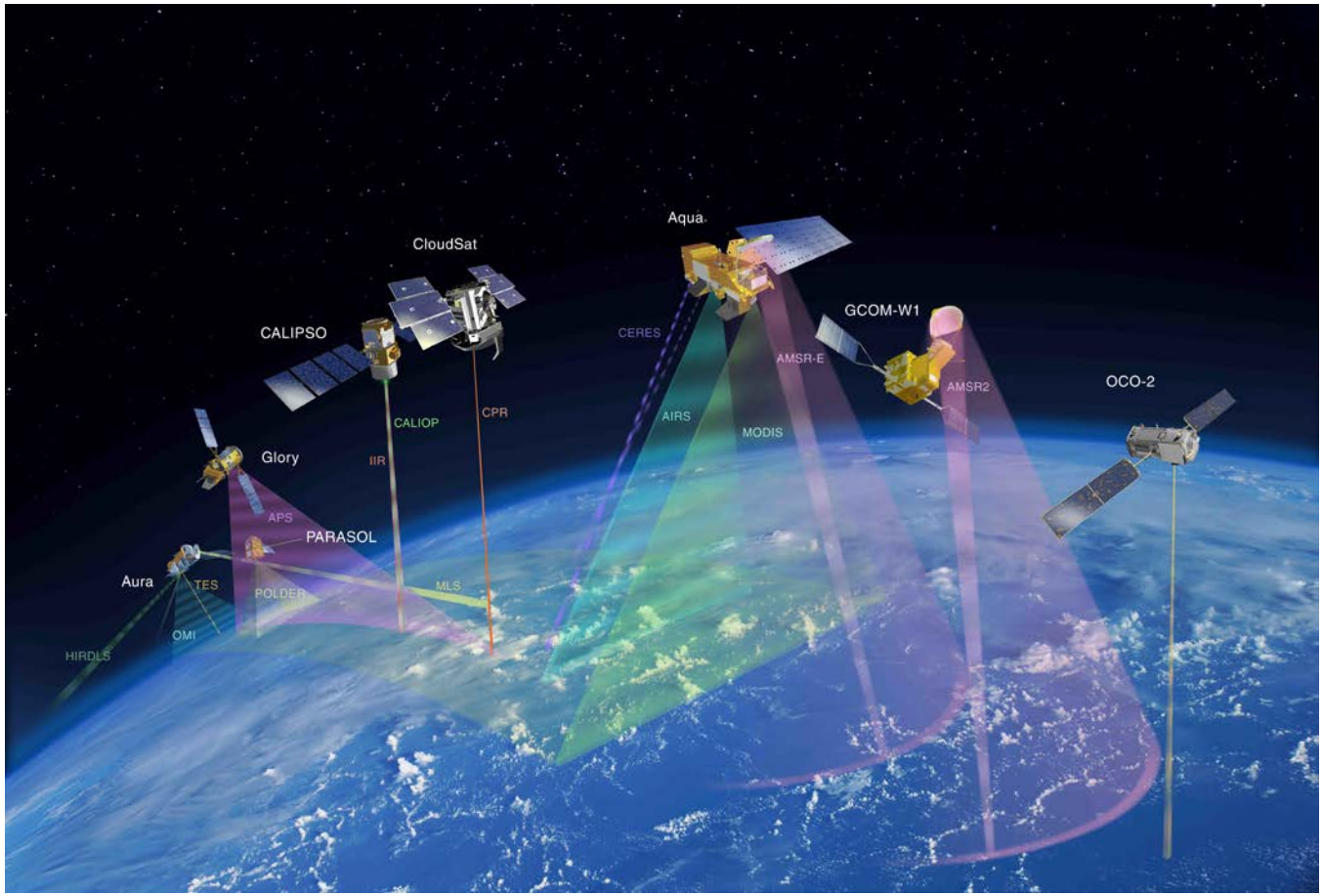
Linkage to aerosols: 2nd indirect effect

$$N_c = f(N_a, w, species, \ldots)$$

| Auto-conversion Scheme | Model | $\alpha$ | $\beta$ |
|---|---|---|---|
| Berry (1968) | MIROC, NICAM | 2.0 | 1.0 |
| Tripoli and Cotton (1980) | UKMO, GFDL | 4/3 | 1/3 |
| Khairoutdinov and Kogan (2000) | PNNL/MMF, NCAR | 1.47 | 1.79 |
| Beheng (1994) | | 3.7 | 3.3 |

*How well do these parameterizations represent the reality?*

# Observational capability: A-Train satellite constellation

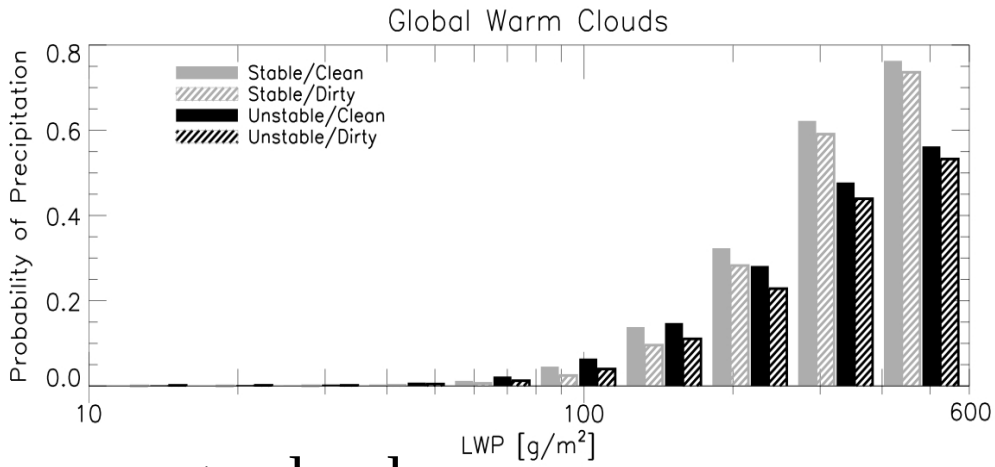



- ✓ Simultaneous measurement of cloud and precipitation
- ✓ How can we use satellite observations for process understanding and model evaluation?

# Insight into the rain formation process

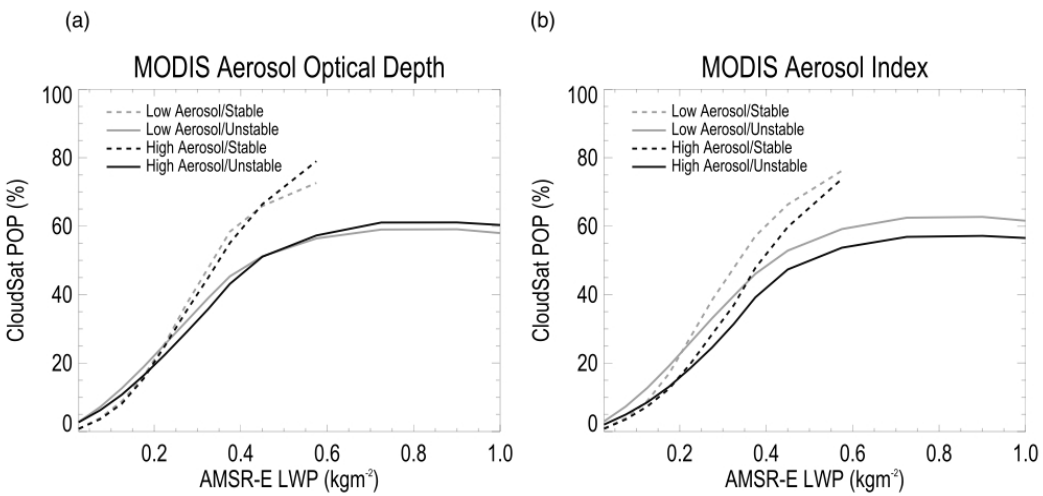
## A-Train: CloudSat+AMSR-E+MODIS

precipitation



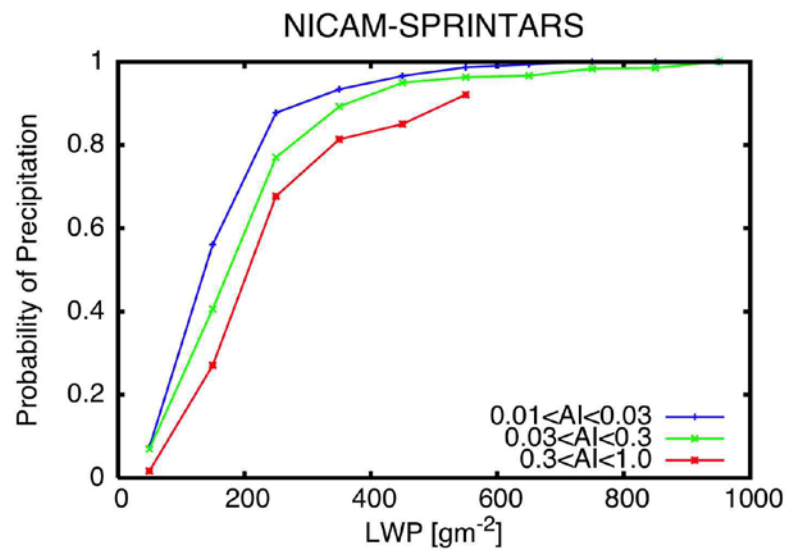

cloud

Lebsock *et al*. (2008)




L'Ecuyer *et al*. (2009)

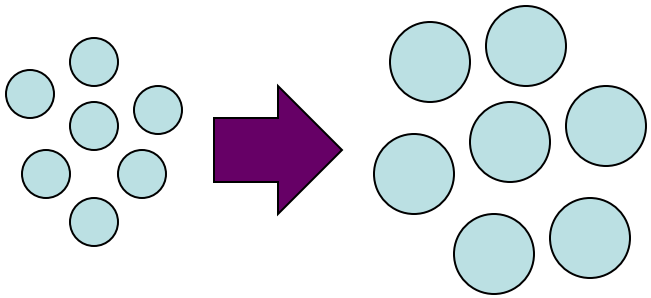
## NICAM-SPRINTARS




- ✓ Increase in POP with LWP
- ✓ Aerosol suppression of Precip.
- ✓ Faster water conversion in NICAM

# Microphysical Process Assessment for Warm Clouds

## Condensation Growth

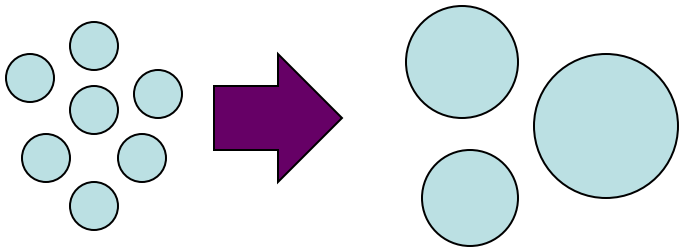


*Each cloud particle absorbs water vapor without interactions among cloud particles*

=> *N: constant, q: increasing*

$$Z_e \propto N R_e^{\,6}$$

## Collision-Coalescence



*Particles collide and coagulate with each other* => *N: varying, q: constant*

$$Z_e \propto q R_e^{\,3} \quad \because q \propto N R_e^{\,3}$$

*Suzuki and Stephens (GRL'08)*

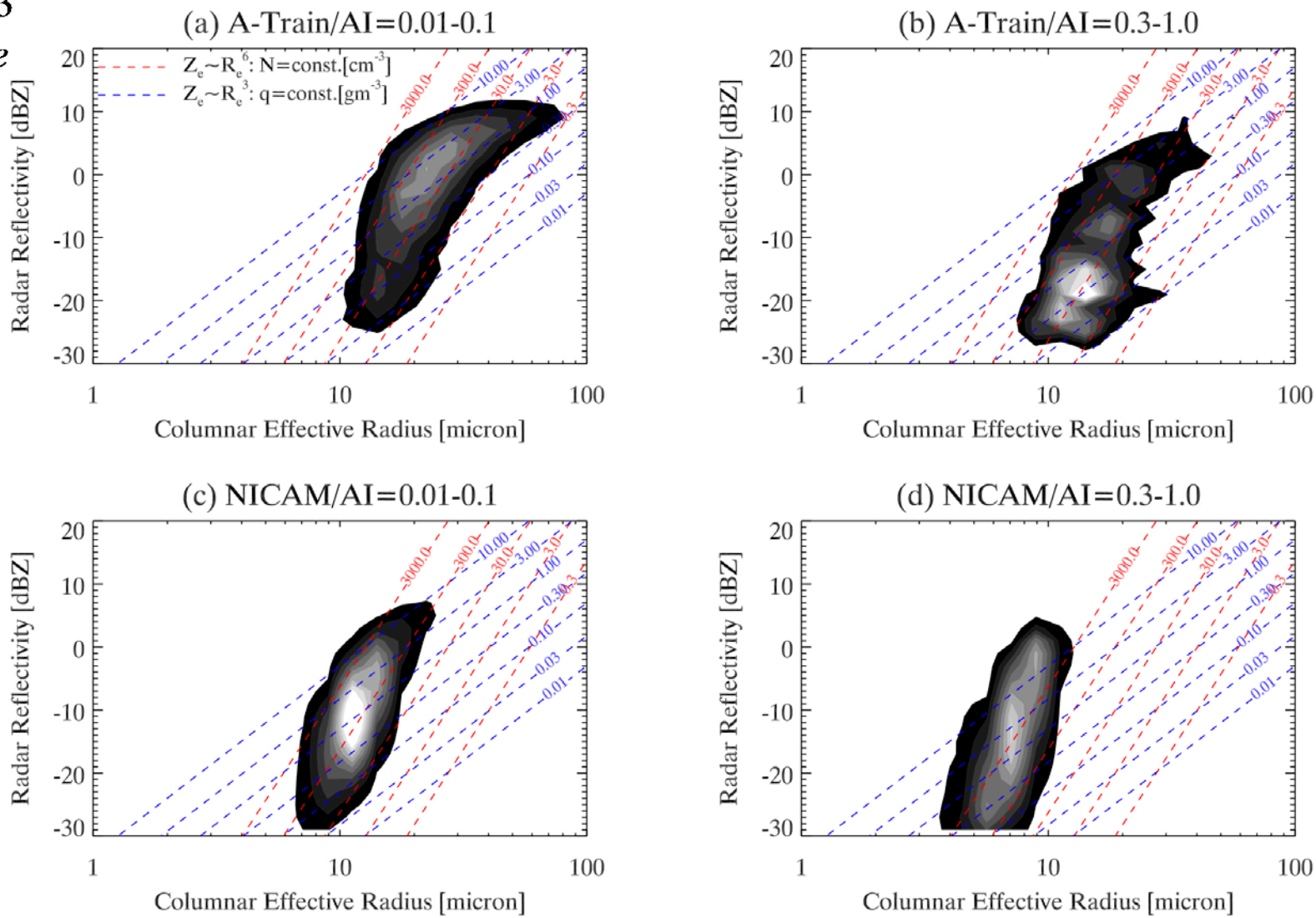
# Aerosol effect on microphysical transition

$$Z_e \propto NR_e^6$$
$$Z_e \propto qR_e^3$$

*Pristine* *Polluted*

*A-Train*

*NICAM*



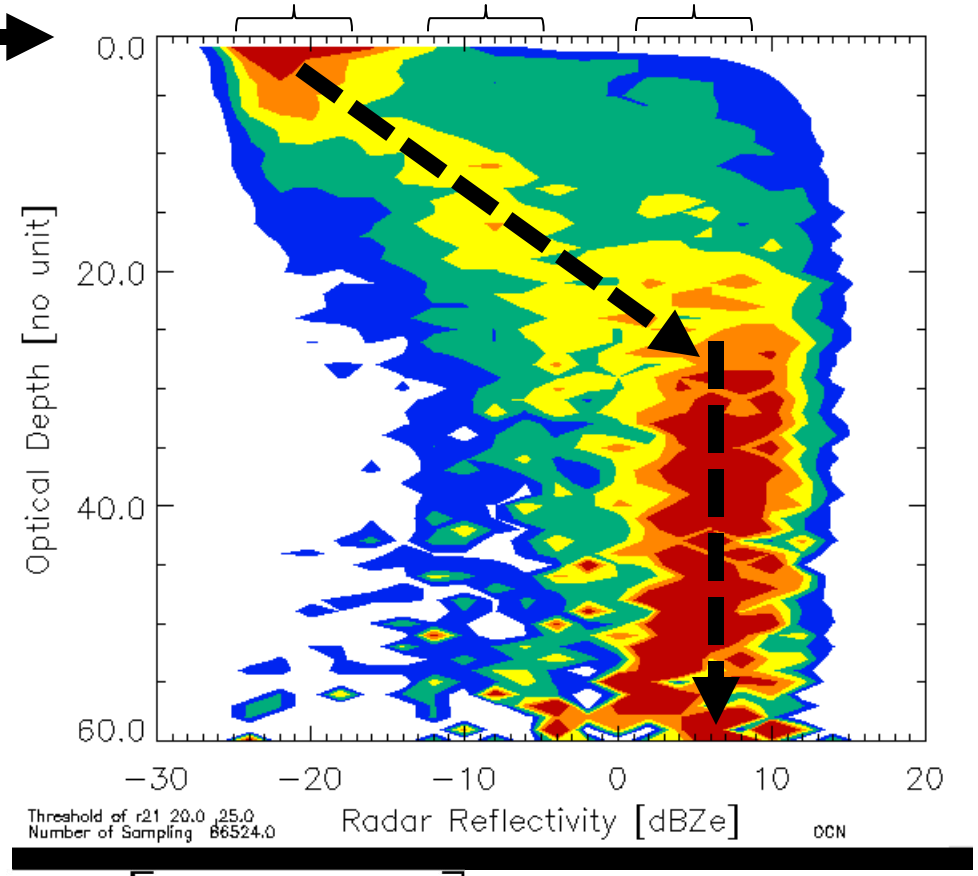
# What can CloudSat+MODIS tell us about vertical cloud structure?

Radar Reflectivity [dBZe] $\propto ND^6$

Cloud Top

Altitude

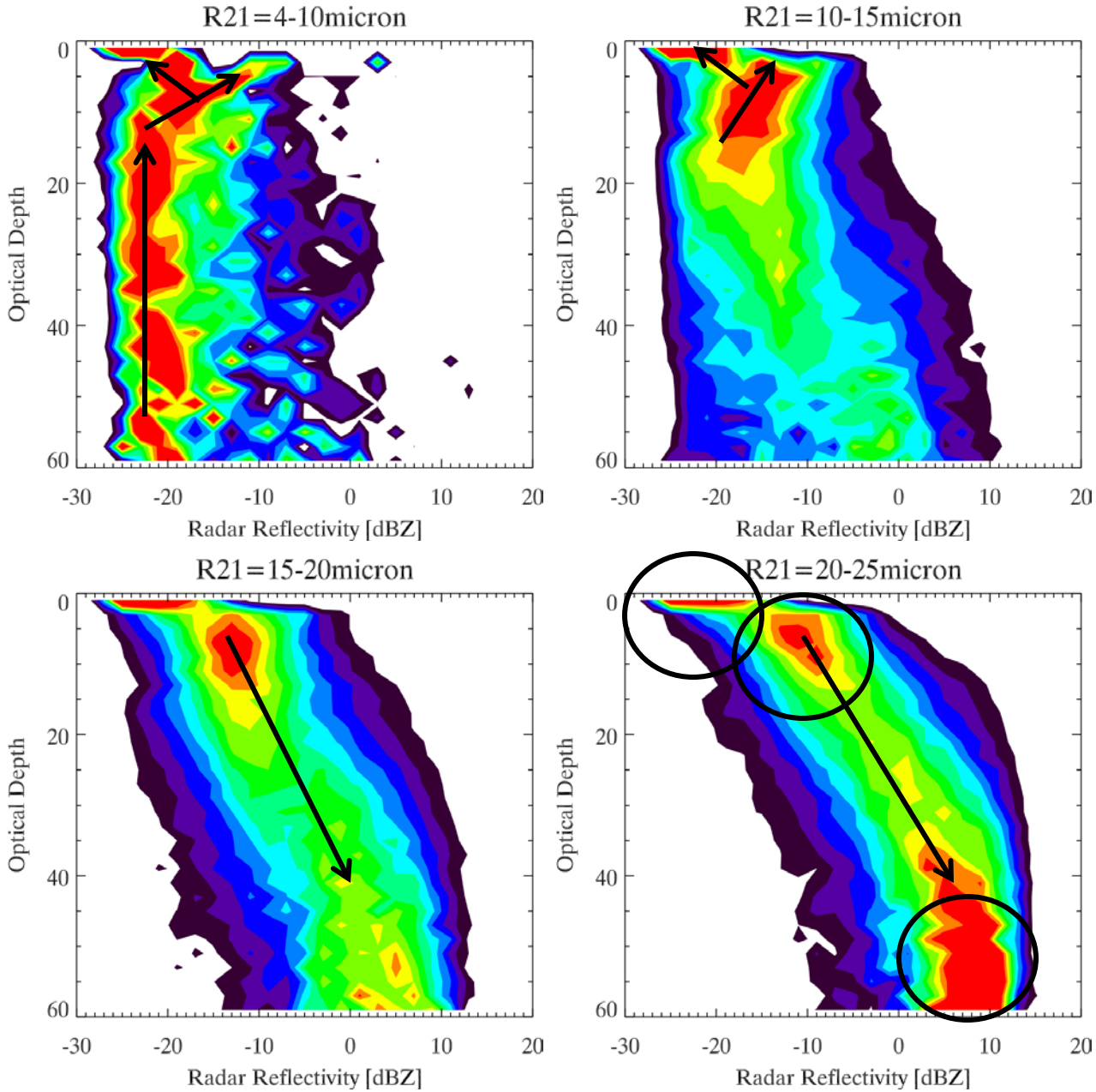
Cloud Optical Depth



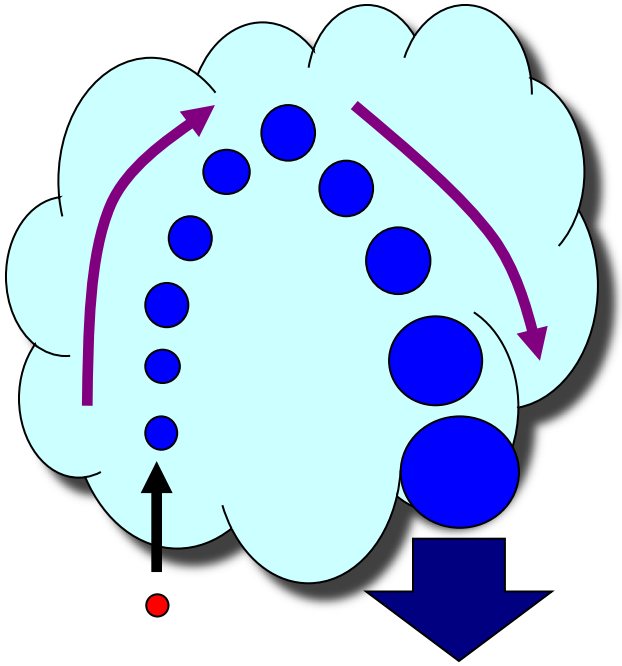

$$\tau_d(h) = \tau_{MODIS}\left[1-\left(h/H\right)^{5/3}\right]$$

Suzuki *et al*. (2010),
Nakajima *et al*. (2010)

# Observed "fingerprint" of microphysical processes



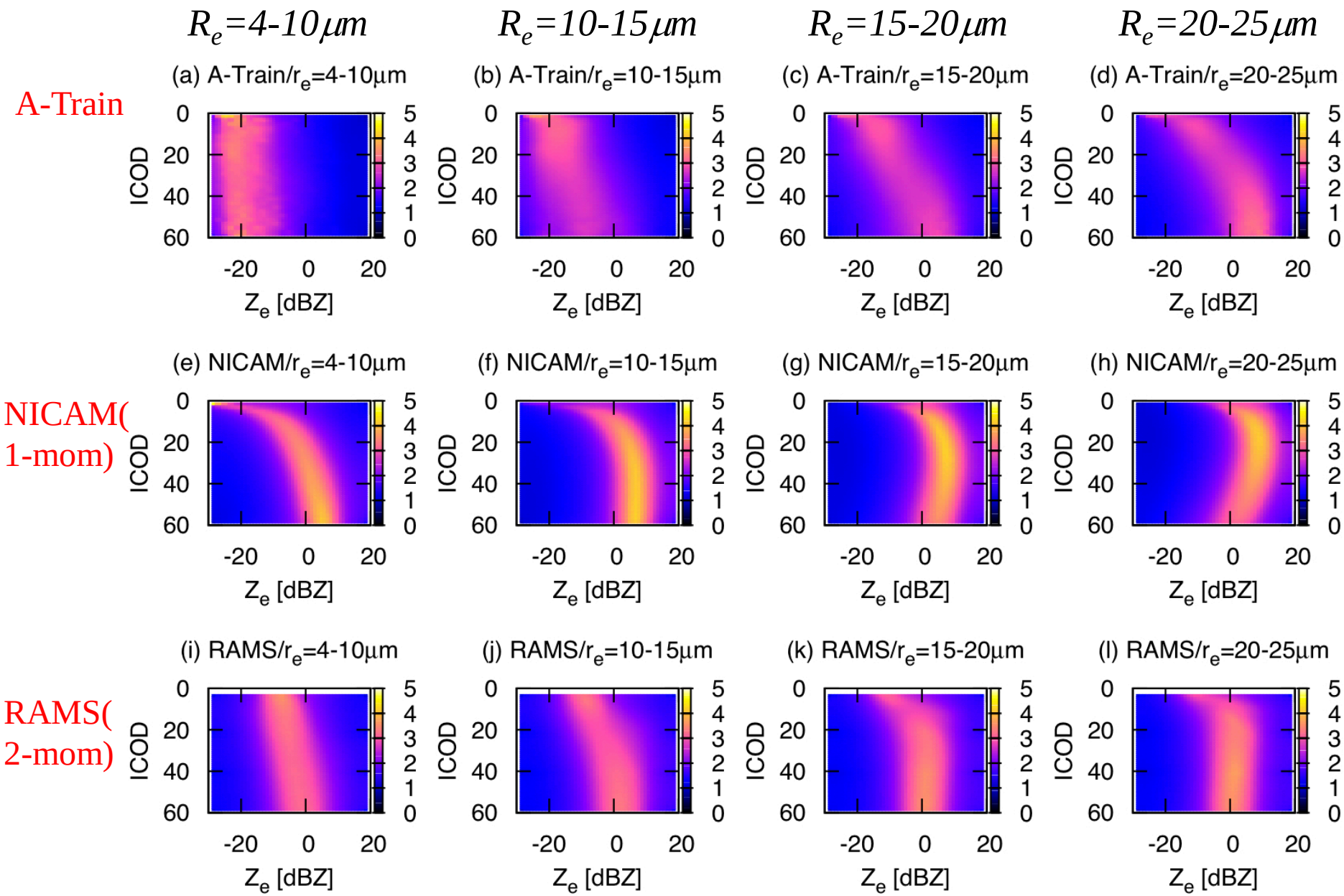

CloudSat+MODIS



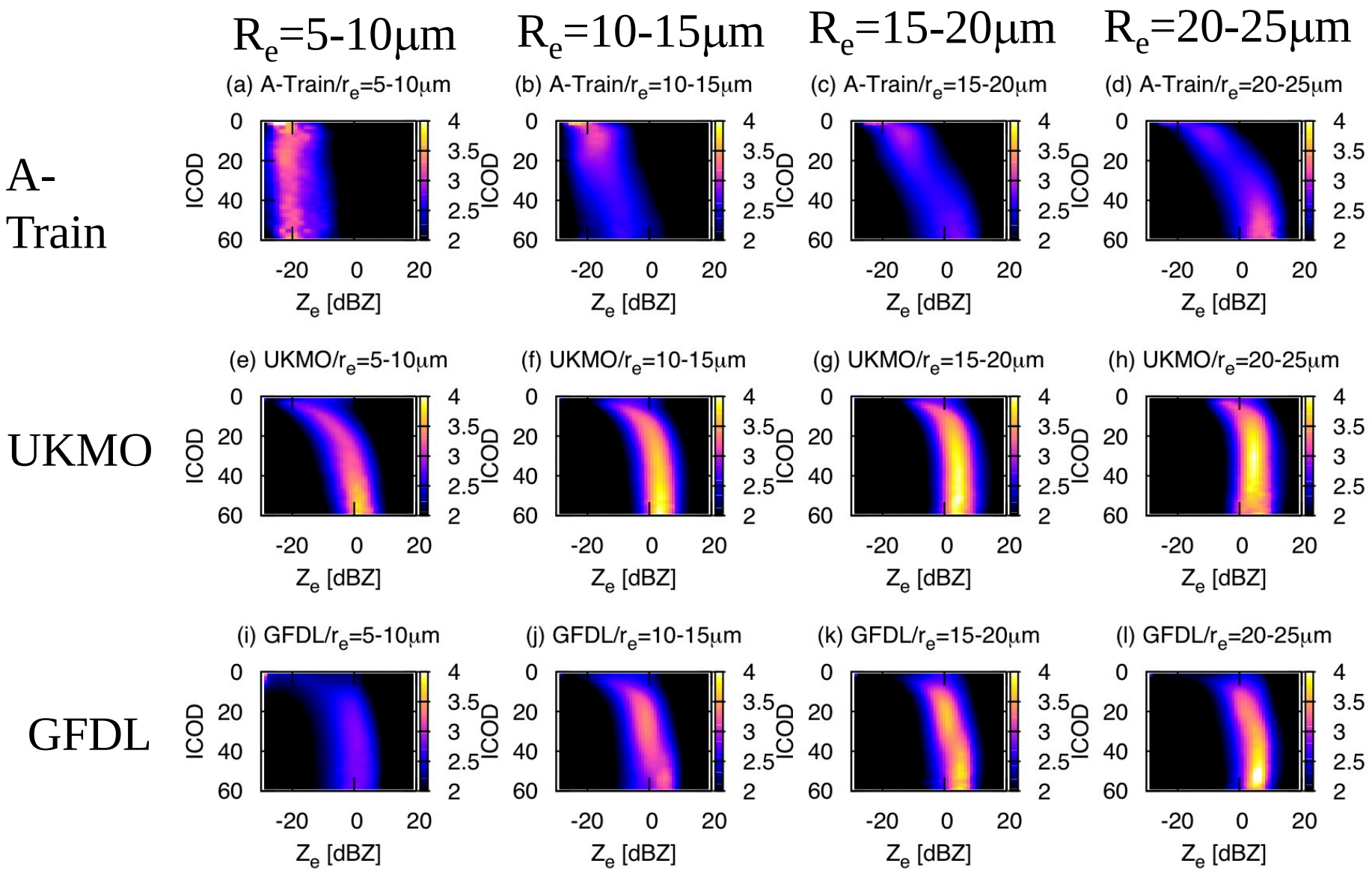
Suzuki *et al*. (JAS'10)

# Application to model diagnostics

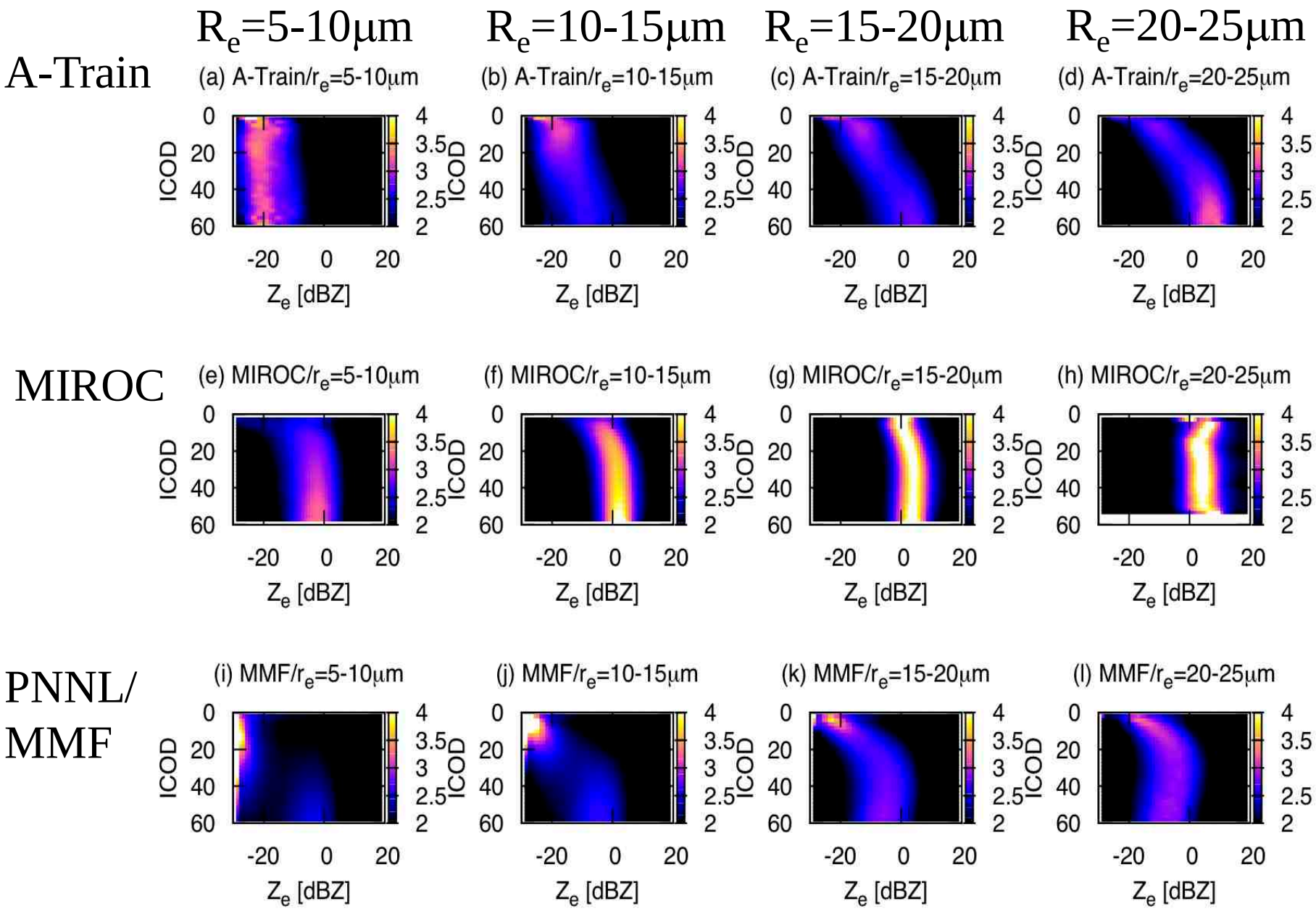
Suzuki *et al.* (JAS'11)



# Evaluation of climate models w/ COSP



# Evaluation of climate models w/ COSP (cont'd)



# Single-column model approach to interpret the model biases

***Single-Column Model analysis***

$$\frac{\partial(\rho q_c(z))}{\partial t} = -\frac{\rho q_c(z) - \rho q_{adb}(z)}{\tau_r} - \frac{\rho q_c(z)}{\tau_p}$$

$$\frac{\partial(\rho q_r(z))}{\partial t} = +\frac{\rho q_c(z)}{\tau_p} + V_t \frac{\partial(\rho q_r(z))}{\partial z}$$

$\rho q_c$: cloud water content

$\rho q_r$: rain water content

$\rho q_{adb}(z) = \Gamma(z)\lambda(p,T)z$: adiabatic value

$V_t = V_t(\rho q_r)$: fall velocity of rain water

Rain formation = Auto-conversion + Accretion

$$\frac{1}{\tau_p} = \frac{1}{\tau_{aut}} + \frac{1}{\tau_{acc}}$$

Auto-conversion: $\tau_{aut} = \tau_{aut}(\rho q_c, N_c)$

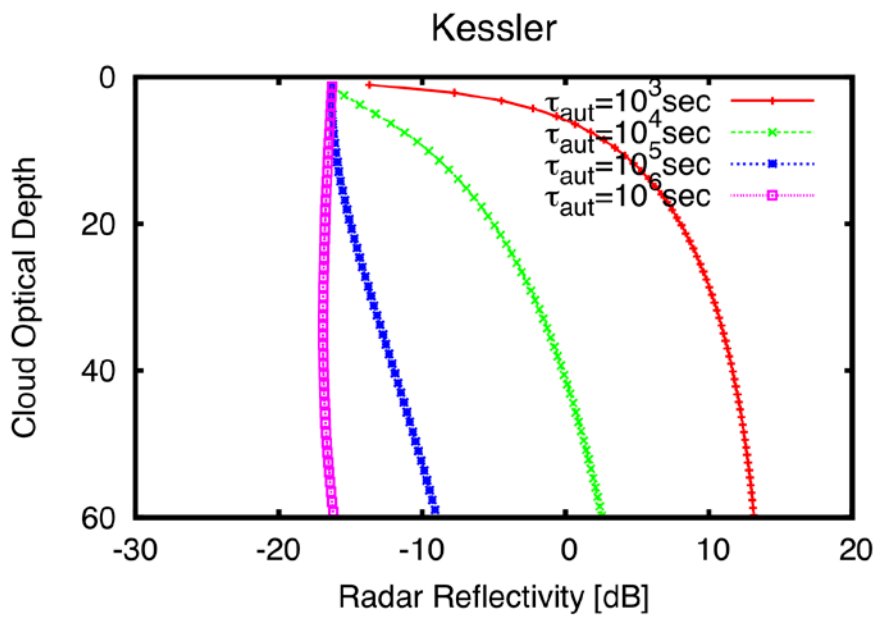
Accretion: $\tau_{acc} = \tau_{acc}(\rho q_r, N_r) = cN_r^{-1/6}(\rho q_r)^{-5/6}$

Kessler ('69) $\tau_{aut} = \text{const.}$

Berry ('67) $\tau_{aut}(\rho q_c, N_c) = \dfrac{\beta + \gamma N_c / \rho q_c}{\alpha \rho q_c}$

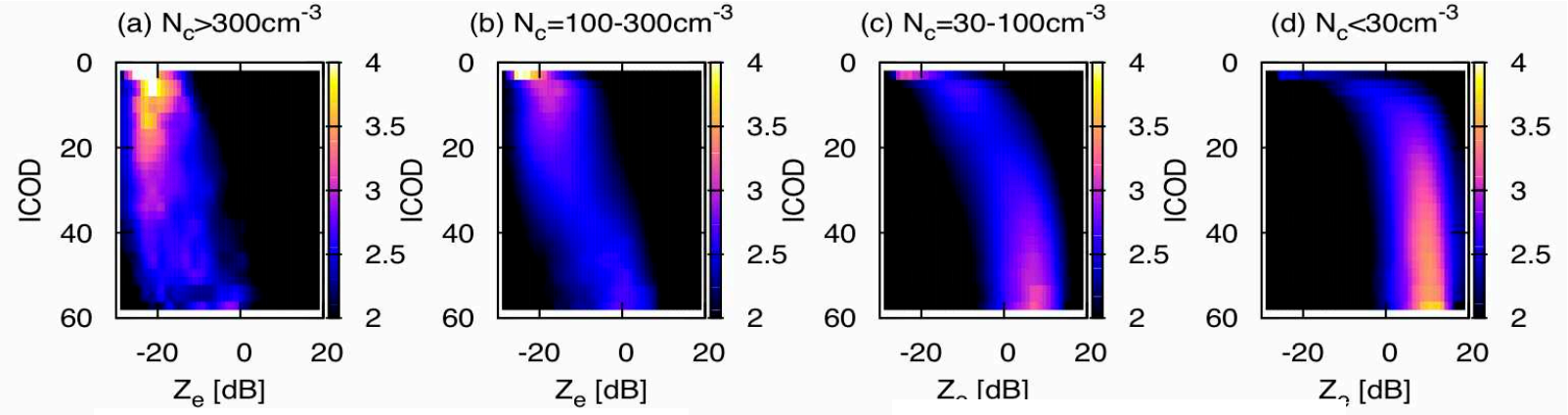
Khairoutdinov and Kogan ('00) $\tau_{aut}(\rho q_c, N_c) = c_1 \dfrac{N_c^{1.79}}{(\rho q_c)^{1.47}}$

Beheng ('94) $\tau_{aut}(\rho q_c, N_c) = c_2 \dfrac{N_c^{3.3}}{(\rho q_c)^{3.7}}$



# Behavior of parameterizations

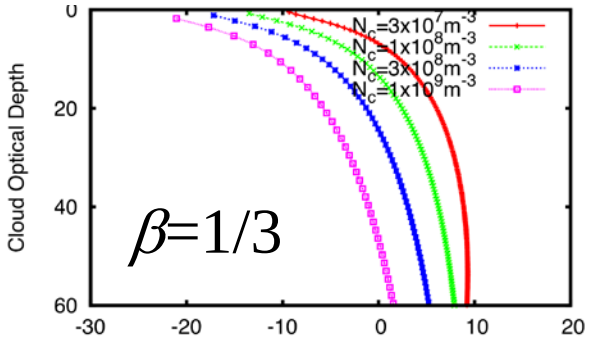
A-Train



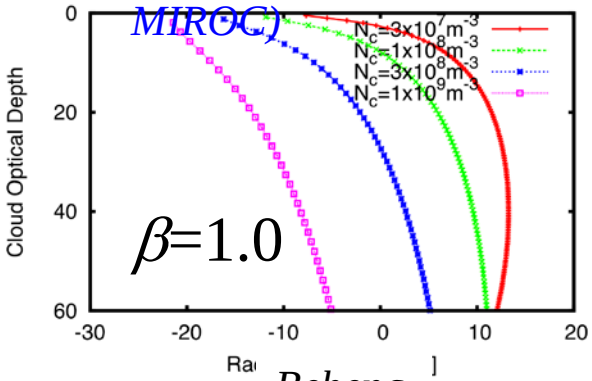

SCM

$$\tau_{aut} \propto N_c^{\beta}$$

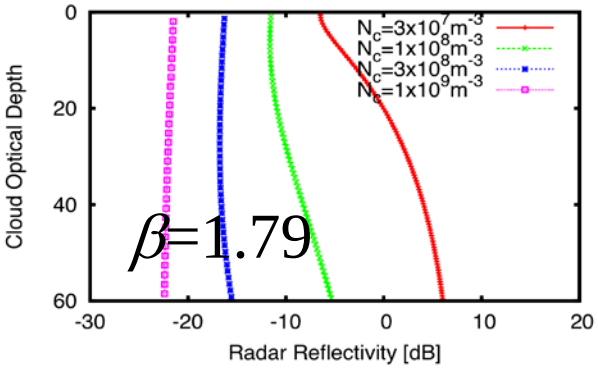
*Tripoli-Cotton (UKMO, GFDL)*



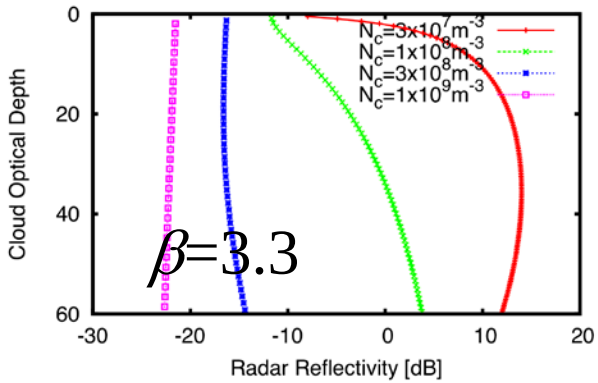

*Berry (NICAM, MIROC)*




*Khairoutdinov-Kogan (PNNL/MMF)*




*Beheng*



# Implication for the aerosol indirect radiative forcing

$$\Delta F \propto b(COT)\Delta \ln N_a$$

$$b(COT) = -b(CDR) + b(LWP)$$

$$b(X) = \frac{d\ln X}{d\ln N_a}, X = (CDR, COT, LWP)$$

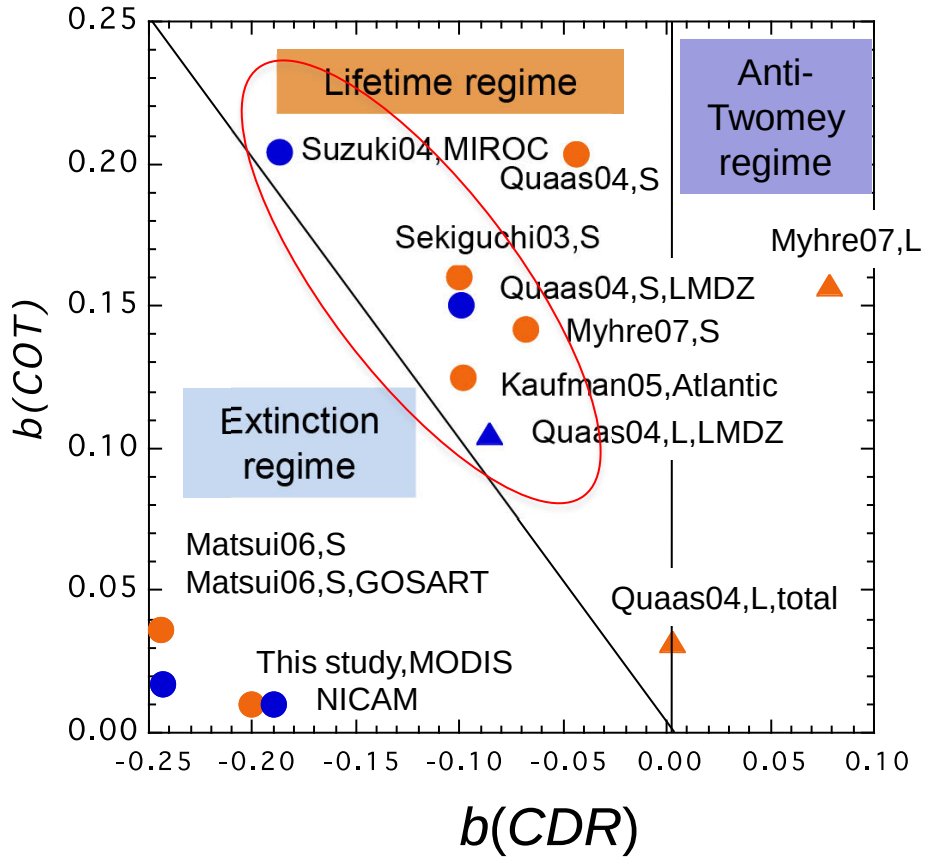
$$b(LWP) \sim f(k, \beta, \ldots)$$

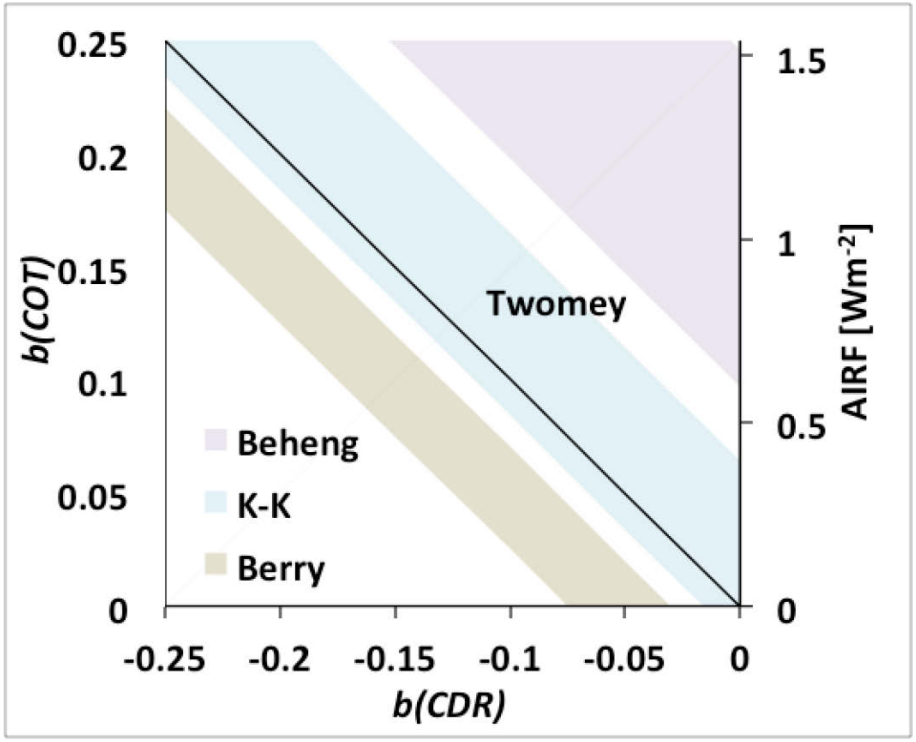
$$N_c \propto N_a^k$$

$$\tau_p \propto N_c^\beta$$

Berry: $\beta$=1.0
K-K: $\beta$=1.79
Beheng: $\beta$=3.3

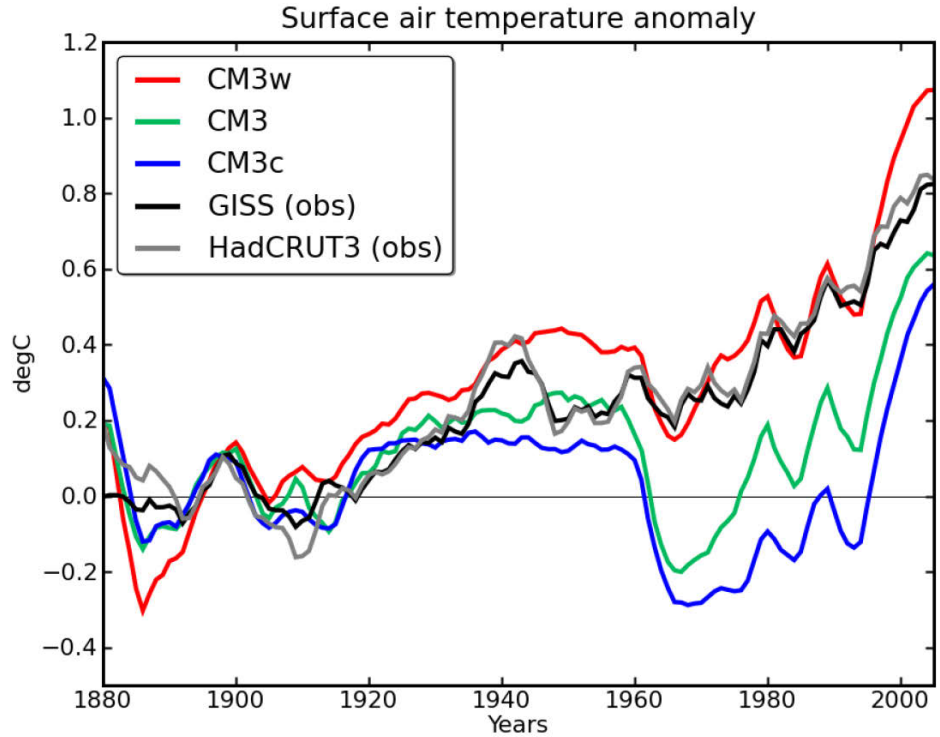
**T. Nakajima (per comm)**



# Impact of the auto-conversion assumptions on climate projection

GFDL CM3




$r_{crit}$=6$\mu$m

$r_{crit}$=8.2$\mu$m

$r_{crit}$=10.6$\mu$m

*Courtesy of Chris Golaz*

Satellite observations could be used to constrain the temperature trend through constraining the auto-conversion parameterization (??)

# Summary

- Multi-sensor satellite observations can be used to evaluate the model microphysics parameterizations and possibly to constrain their key parameters.
  - Combination of the observed variables in particular ways provides useful insight into microphysical processes
  - Corresponding statistics from the model can be compared to observations for model diagnosis and characterization
- More detailed model analysis with systematic sensitivity experiments changing parameters/formulations in global models will be necessary for more solid understanding of model parameterizations.
  - Coupling with other key processes should be carefully studied
  - Combined analysis of modeling and observations is important