Remote sensing of clouds from A-Train

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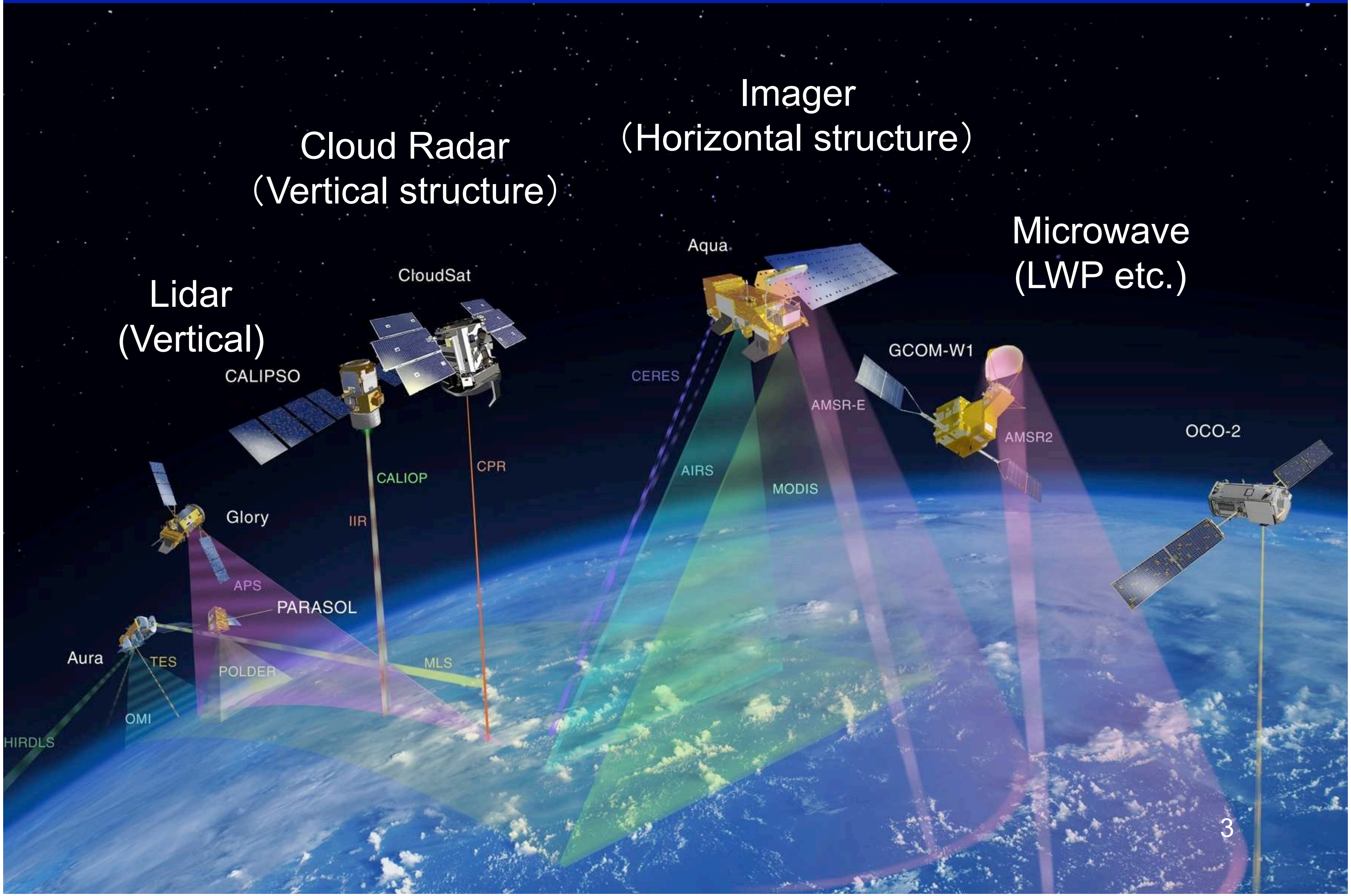
Introduction

- Clouds exert an important influence on the *water* and *energy* balances and processes, thus, more observations are required.

- We have long history of the passive sensing of clouds, using the NOAA, ADEOS2, TRMM, Terra/Aqua, ENVISAT, …

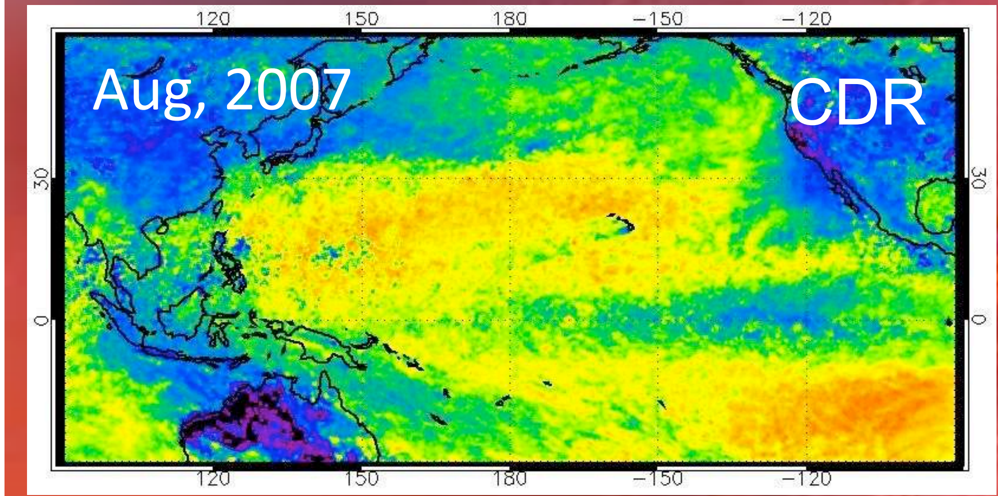
- Recently, active sensing open the door toward better understanding of clouds, in terms of cloud evolution process.

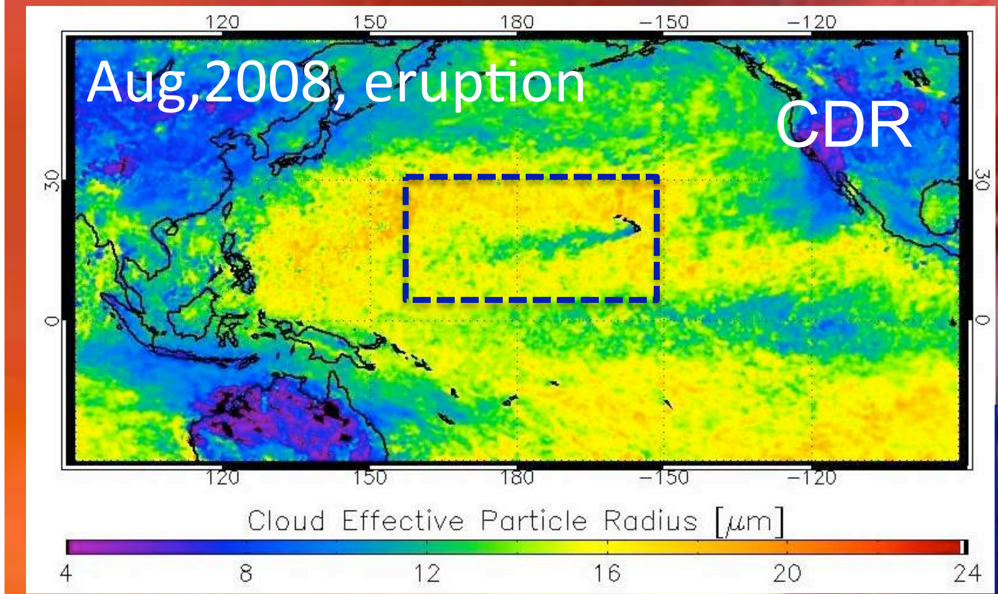
Synergistic analysis of clouds : CloudSat + Aqua/MODIS



Cloud properties were drastically modified by volcanic ash

（Mt. Kilauea, Hawaii eruption in 2008）



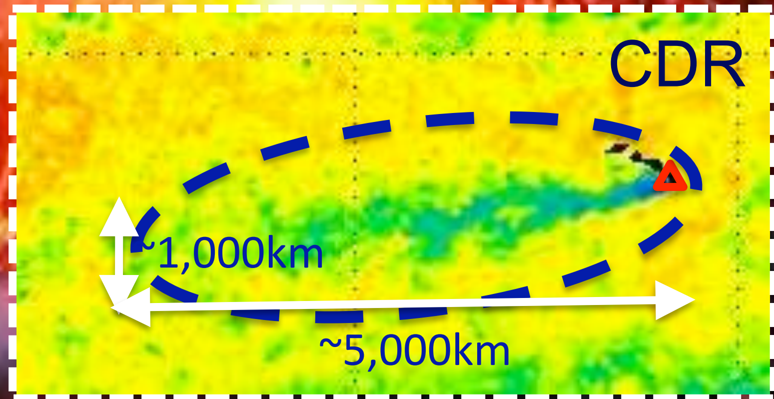


http://www.darkroastedblend.com/2007/11/hawaiian-volcanoes-beauty-terror.html

<u>CDR (Effective particle radius)</u>

Data ： Terra/ MODIS

Algorithm : CAPCOM Ve4.02



Due to SO2 release,
CDR decreased 15μm → 12μm
- 5 W/m^2 change in SW radiation (Eguchi et al. 2011)

Directions of the cloud research

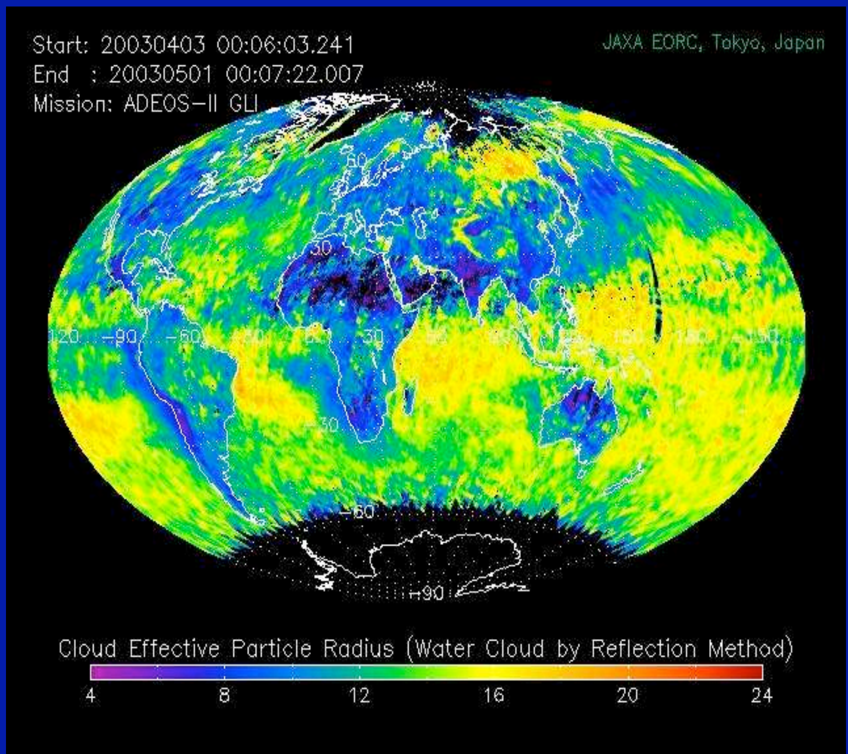
- Climate change study→Long term record

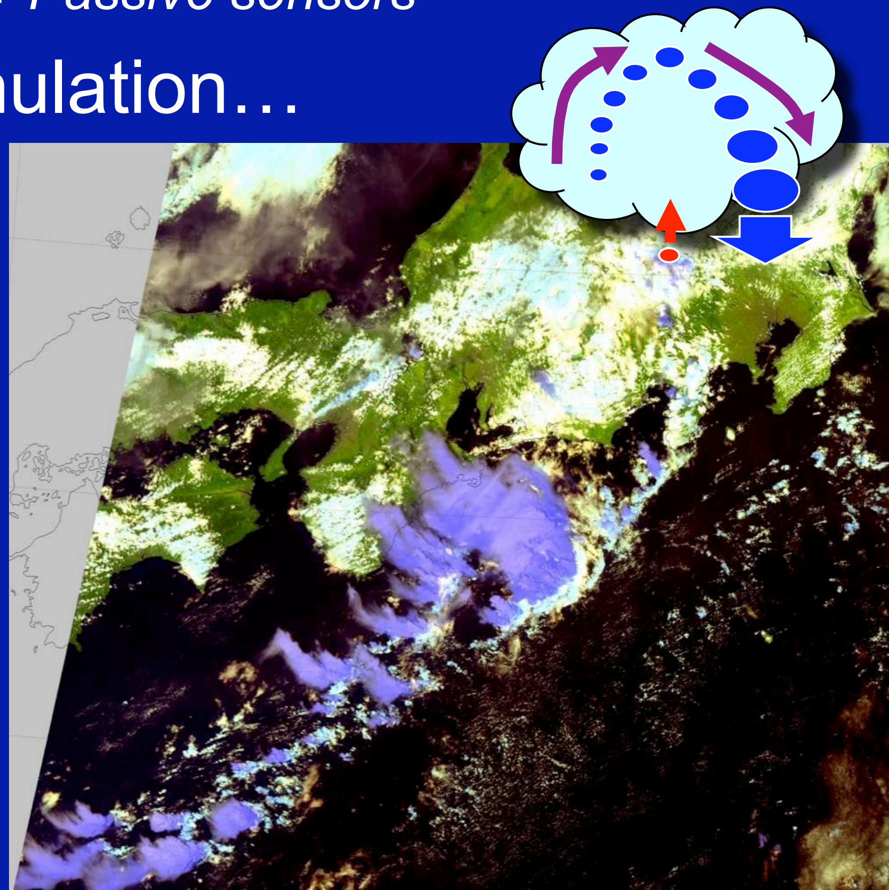
  AVHRR, MODIS, GLI, etc, and GCOM in future…

- Cloud evolution process→3-D observation

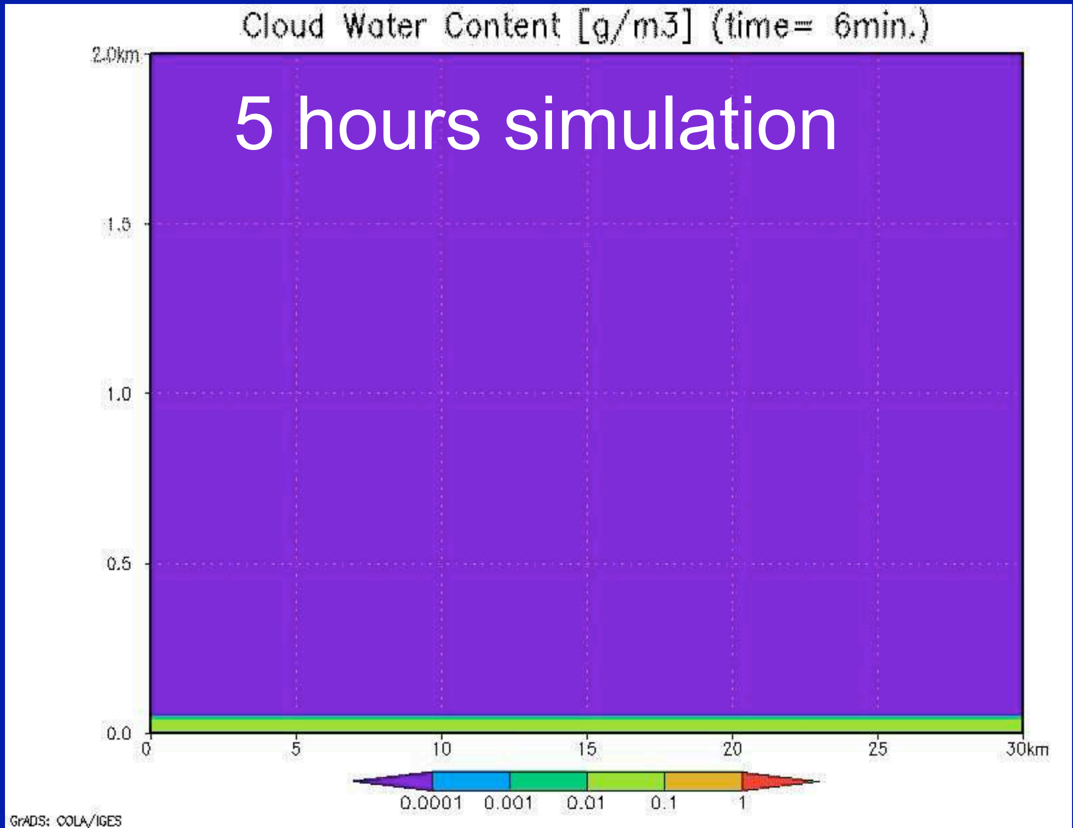
  CloudSat, Calipso, EarthCARE, + Passive sensors

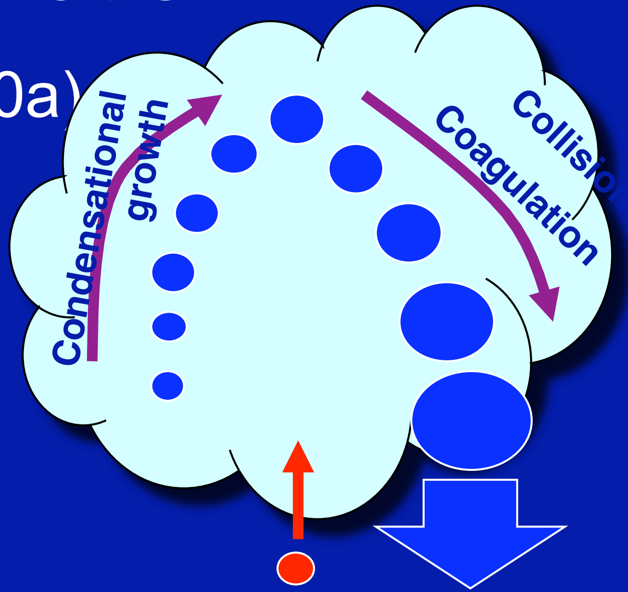
- Observation + Model simulation…





Simulation of the cloud evolution by Bin-method (Suzuki et al. 2010a)



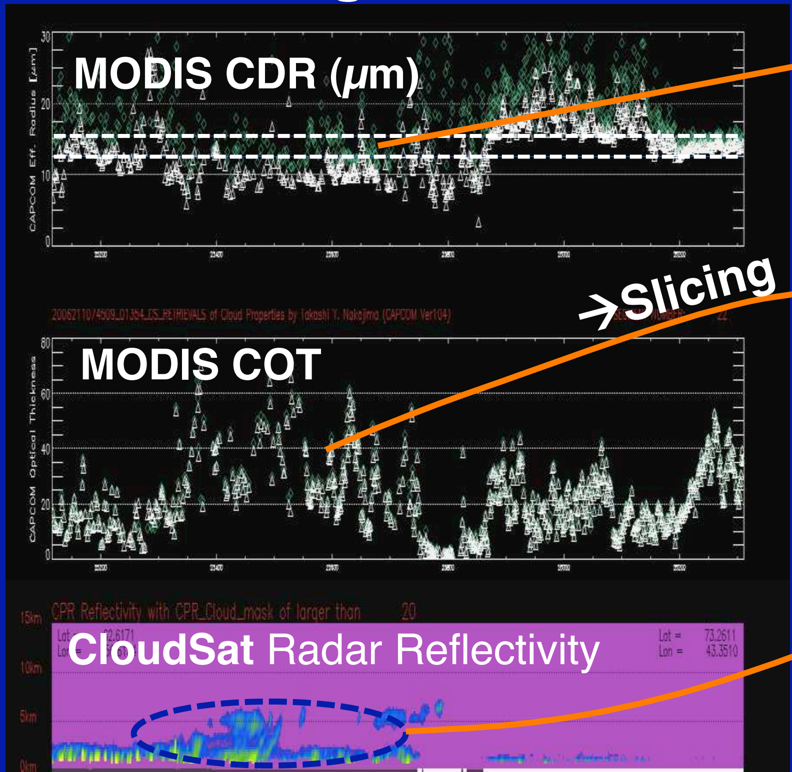


- Need investigating consistency/difference between model and observation

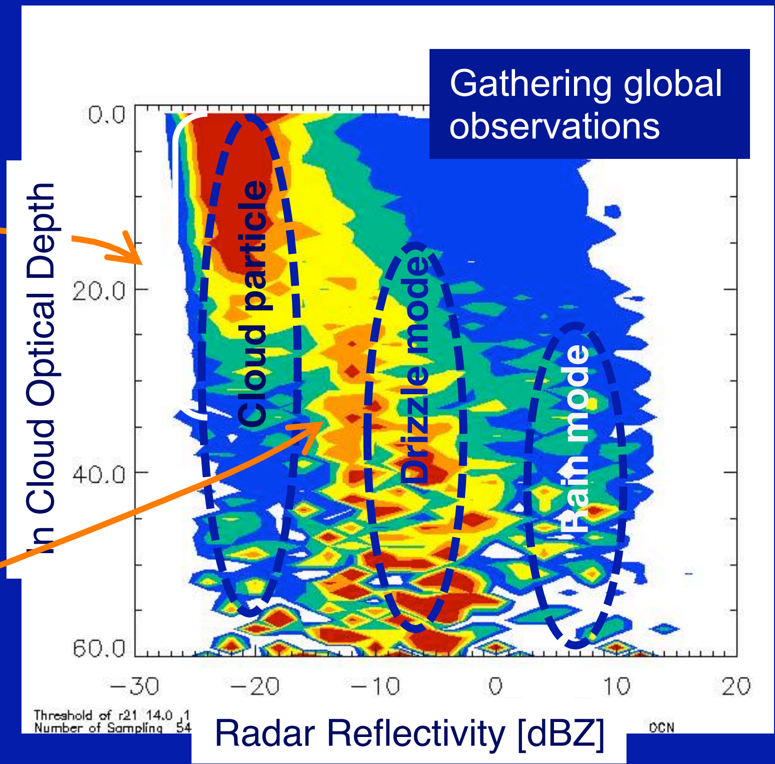
Aerosol 20 bins (0.01-1um)
Cloud 60 bins (3 – 3000um)

New visualization method of the radar reflectivity, CFODD (Contoured Frequency by Optical Depth Diagram)

A-Train flight direction →

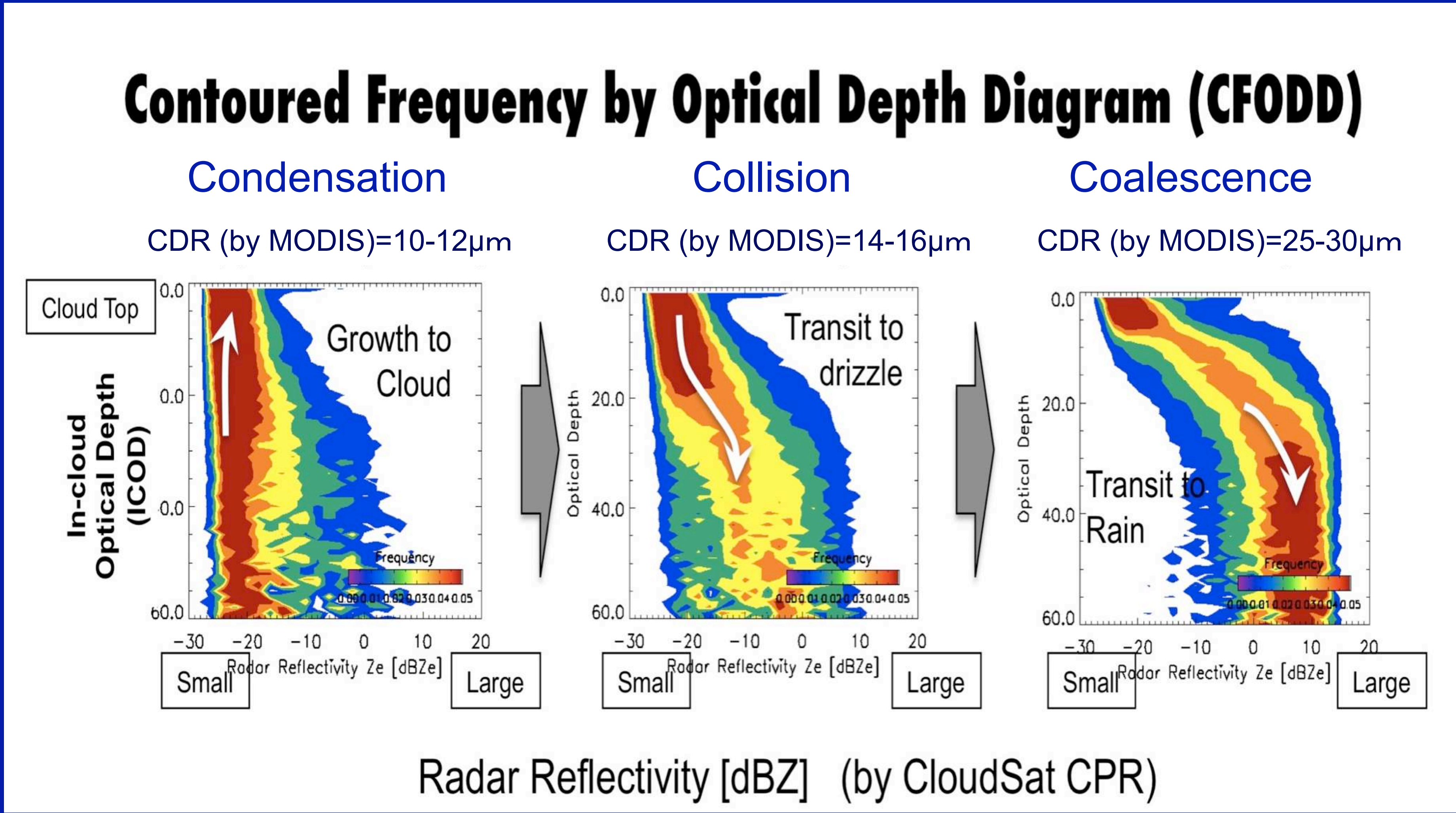


A case of,
$14\mu m < CDR < 16\mu m$



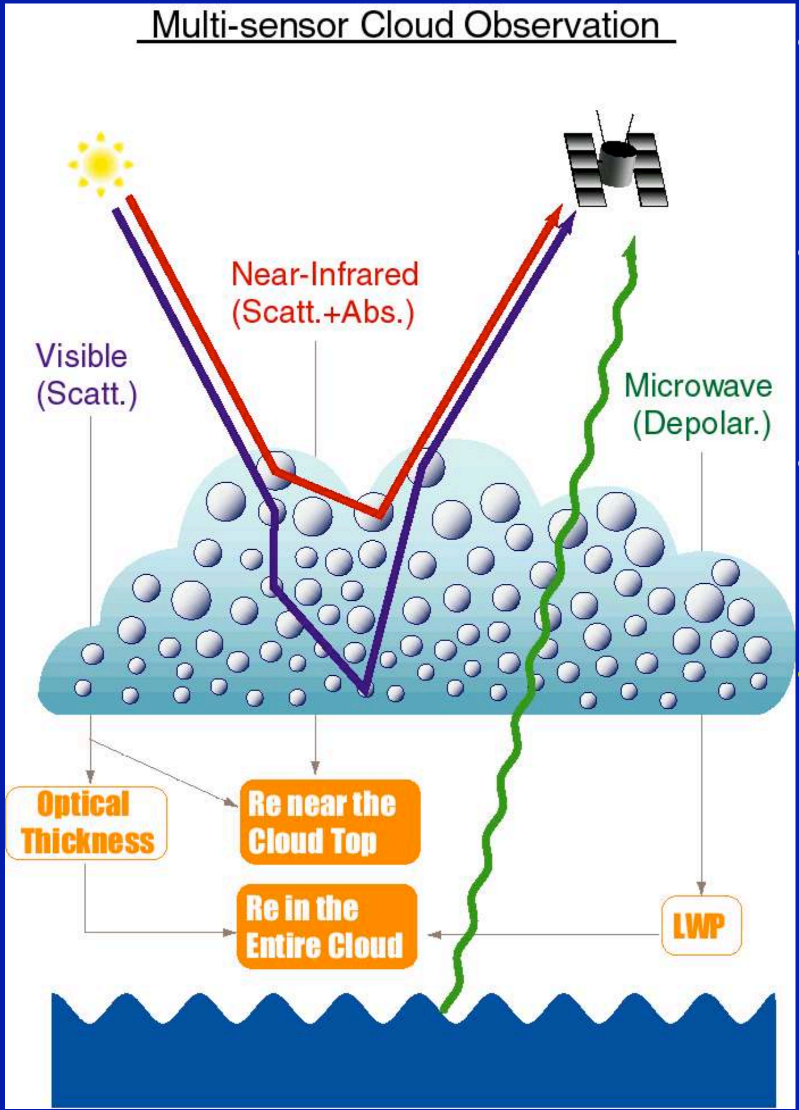
Visualizing Cloud Growth from space

Nakajima et al. (JAS, 2010b), Suzuki et al. (JAS, 2010b)



July 2006, One month data of the Aqua/MODIS and CloudSat/CPR

Synergistic analysis of clouds (2) : VIS-IR + Microwave



- TRMM VIRS (VIS-IR imager) retrieves
  - COT
  - CDR_virs
- TRMM TMI (Microwave scanner) retrieves
  - LWP (Liquid Water Path)

- (Combination of VIRS and TMI….)
  - CDR_tmi ~ LWP / COT

- CDR_tmi / CDR_virs

-> Vertical structure of clouds

~ Precipitability

Masunaga et al. (JGR 2002a, 2002b) for TRMM VIRS-TMI
Nakajima et al. (RSSJ, 2009) for ADEOS-2 GLI+AMSR

Diagnosis of the Aerosol Effects using CFODD

Suzuki et al. (2012, JGR in press)

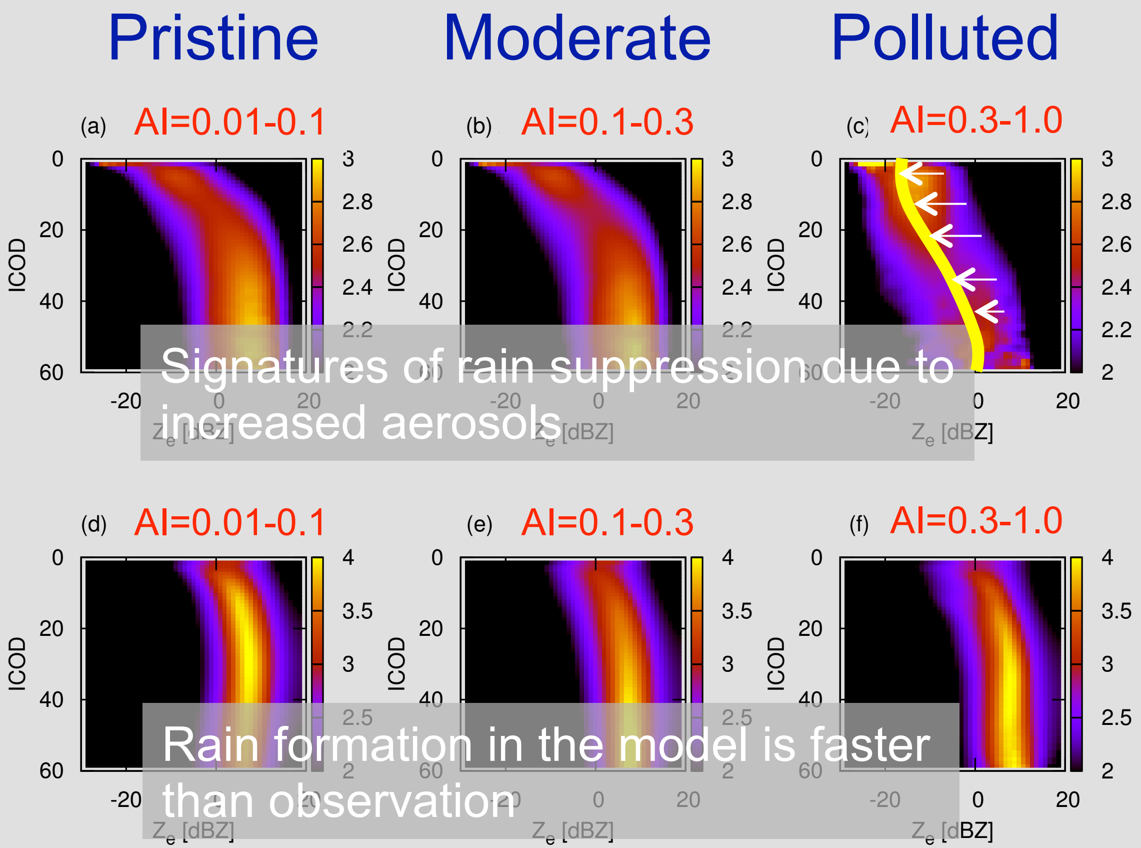
$$AI = \tau_a \alpha$$

A-Train Observation

- ✓ MODIS Cloud products
- ✓ MODIS Aerosol Products
- ✓ CloudSat CPR Reflectivity

NICAM-SPRINTARS

A Global Cloud Resolving model

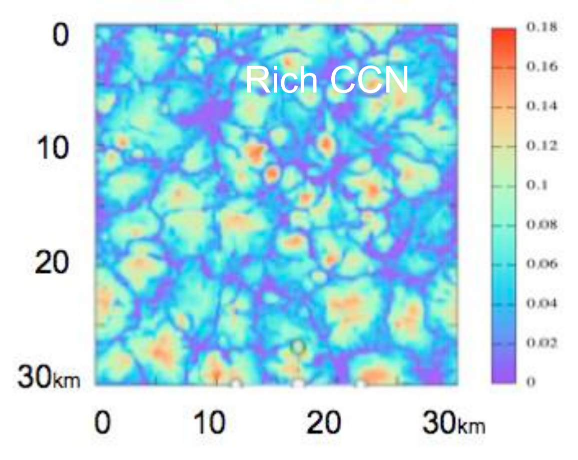


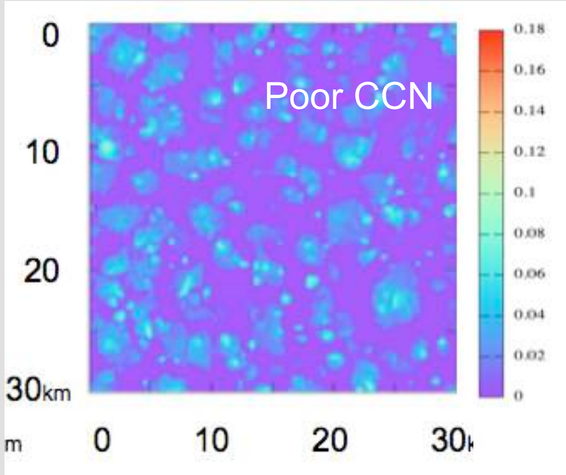
Signatures of rain suppression due to increased aerosols

Rain formation in the model is faster than observation

3-D Spectral Bin Microphysical model (SBM) simulation

[Sato et al. 2012]





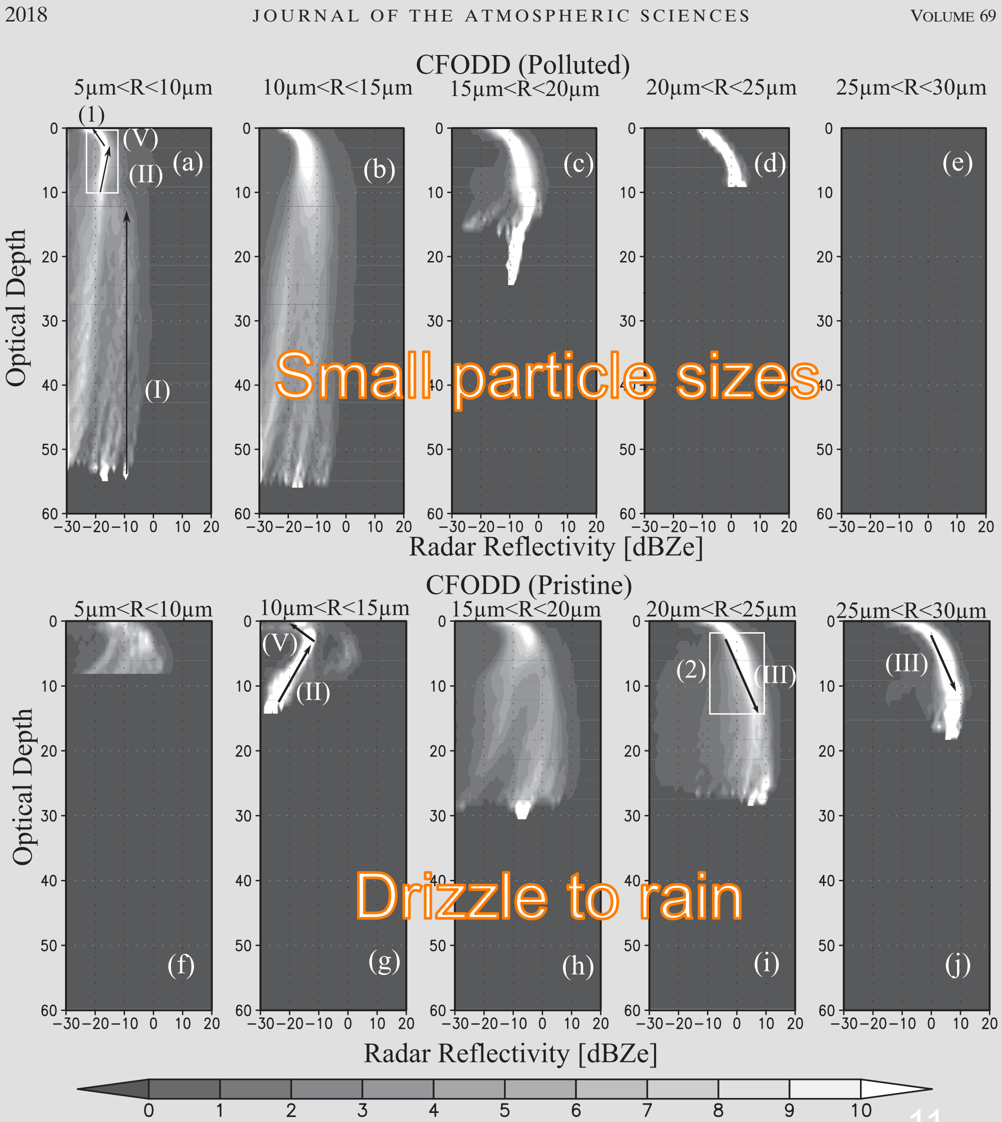
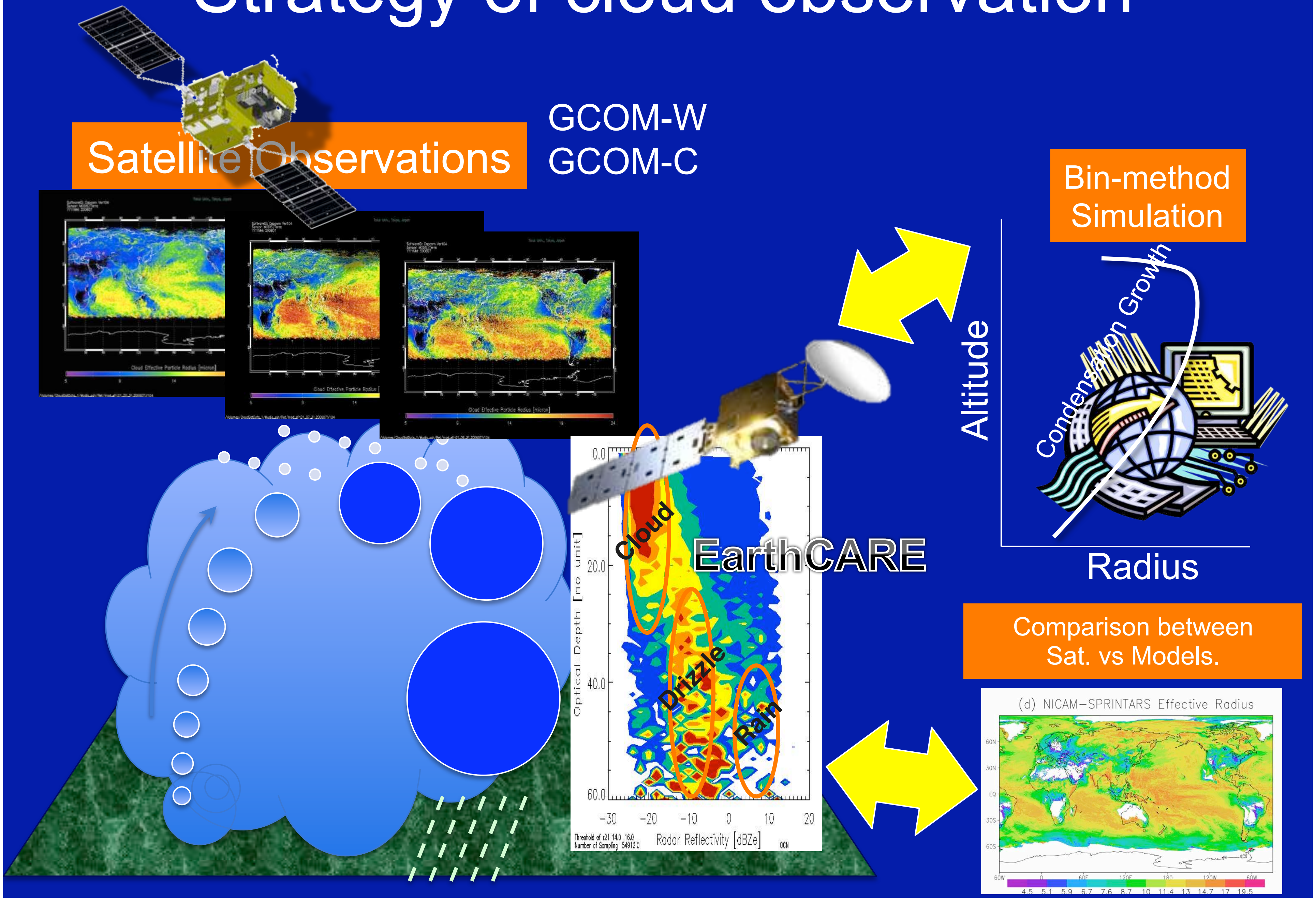


FIG. 4. CFODDs at t = 6 h obtained from (a)–(e) polluted and (f)–(j) pristine experiments, divided by RE = (a),(f) 5–10, (b),(g) 10–15, (c),(h) 15–20, (d),(i) 20–25, and (e),(j) 25–30 μm. Arrows and rectangles are described in the text, and Arabic and capital Greek numbers are used for rectangles and arrows, respectively.

Research plots for understanding retrieved cloud properties

	Vertical (+drizzle)	Sub-pixel Horizontal	3D-RT
Numerical Experiment	Nakajima T. Y. et al. 2010a [2-layer model] Nagao T. M. et al. 2013 (in revision) [Bin-model + 1DRT]	Zinner et al., 2010 [LES+3DRT] Zhang and Platnick et al., 2011	
Satellite	Nakajima T. Y. et al. 2010b [CFODD] Chang and Li, 2002, 2003 (R vertical profile) Seethala and Horváth, 2010 (Validate MOD06)	Painemal et al, 2011 (Validation of MOD06)	
In-situ	Nakajima T. Y. et al. 2010a [FIRE]		

Strategy of cloud observation



Summary

- Need more observations of clouds from satellites for,
  - generating cloud climatology database
  - investigating cloud evolution process
- The CFODD presents
  - cloud evolution process, clearly.
  - results are consistent with past studies by TRMM, ADEOS2…
  - useful for model evaluations.
- A Doppler capability of the EarthCARE/CPR improves our understanding of cloud evolution process (2015-).

Selected papers (2010-2013)

- ✓ Nagao, T. M., K. Suzuki, and T. Y. Nakajima, 2013: Interpretation of multiwavelength-retrieved droplet effective radii for warm water clouds in terms of in-cloud vertical inhomogeneity by using spectral bin microphysics cloud model. *J. Atmos. Sci.*, in revision.
- ✓ Koike, M., and Coauthors, 2012: Measurements of Regional-Scale Aerosol Impacts on Cloud Microphysics over the East China Sea: Possible Influences of Warm Sea Surface Temperature over the Kuroshio Ocean Current. *J. Geophys. Res.*, 117, D17205, doi: 10.1029/2011JD017324.
- ✓ Letu, H., T. Y. Nakajima, and T. M. Nagao, 2012: Development of the ice crystal scattering database for the GCOM-C/SGLI satellite mission: investigating the refractive index grid system and potential retrieval error, *App. Opt.*, 51, 6172-6178.
- ✓ Sato Y., T. Y. Nakajima, and T. Nakajima, 2012: Investigation of the vertical structure of warm cloud microphysical properties using the cloud evolution diagram, CFODD, simulated by three-dimensional spectral bin microphysical model. *J. Atmos. Sci.*, 69, 2012-2030.
- ✓ Nakajima, T. Y.,2012: Algorithm development for the satellite measurements of cloud properties, Tenki. 59.11, 3-16. (in Japanese)
- ✓ Suzuki, K., G. L. Stephens, S. C. van den Heever, T. Y. Nakajima, 2011: Evaluation of the warm rain formation process in cloud-resolving models using joint CloudSat and MODIS observatoins, J. Atmos. Sci.,68, 2655-2670.
- ✓ Eguchi, K., and I. Uno, K. Yumimoto, T. Takemura, T. Y. Nakajima, M. Uematsui, and Z. Liu, 2011: Modulation of cloud droplets and radiation over the North Pacific by sulfate aerosol erupted from Mount Kilauea, SOLA, 7, 77-80.
- ✓ Ishida, H., T. Y. Nakajima, T. Yokota, N. Kikuchi, and H. Watanabe, 2011:Investigation of GOSAT TANSO-CAI cloud screening ability through an inter-satellite comparison., J. Appl. Meteor. and Climat., 50, 1571-1586.
- ✓ Dim, J., H. Murakami, T. Y. Nakajima, B. Nordell, A. Heidinger, and T. Takamura, 2011: The Recent State of the Climate: Driving Components of Cloud Type Variability., J. Geophys. Res.,116, D11117, doi:10.1029/2010JD014559.
- ✓ Nakajima, T. Y., T. Tsuchiya, H. Ishida, T. N. Matsui, and H. Shimoda, 2011: Cloud detection performance of spaceborne visible-to-infrared multispectral imager. Applied Optics,50, 2601-2616
- ✓ Masunaga, H., and Coauthors, 2010: Satellite data simulator unit (SDSU) : A multi-sensor, multi-spectral satellite simulator package. Bull. Amer. Meteor. Soc., 91, 1625-1632. doi:10.1175/2010BAMS2809.1
- ✓ Suzuki, K., T. Y. Nakajima, and G. L. Stephens, 2010b: Particle growth and drop collection efficiency of warm clouds as inferred from joint CloudSat and MODIS observations. Journal of the Atmospheric Sciences, 67, 3019-3032.
- ✓ Suzuki, K., T. Nakajima, T. Y. Nakajima, and G. L. Stepehns, 2010a: Effect of droplet activation process on microphysical properties of warm clouds. Environmental Research Letters,5, 024012.
- ✓ Nakajima, T.Y., K. Suzuki, and G. L. Stephens, 2010b: Droplet growth in warm water clouds observed by the A-Train. Part I: Sensitivity analysis of the MODIS-derived cloud droplet size., J. Atmos. Sci., 67, 1884-1896.
- ✓ Nakajima, T.Y., K. Suzuki, and G. L. Stephens, 2010a: Droplet growth in warm water clouds observed by the A-Train. Part II: A Multi-sensor view., J. Atmos. Sci., 67, 1897-1907.
- ✓ Suzuki, K., T. Nakajima, T. Y. Nakajima, and A. P. Khain, 2010:A Study of Microphysical Mechanisms for Correlation Patterns between Droplet Radius and Optical Thickness of Warm Clouds with a Spectral Bin Microphysics Cloud Model. J. Atmos. Sci., 67, 1126-1141.