TRIC Research and Information Center

Satellite Remote Sensing of Clouds - Retrievals and Validations -

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Introduction

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

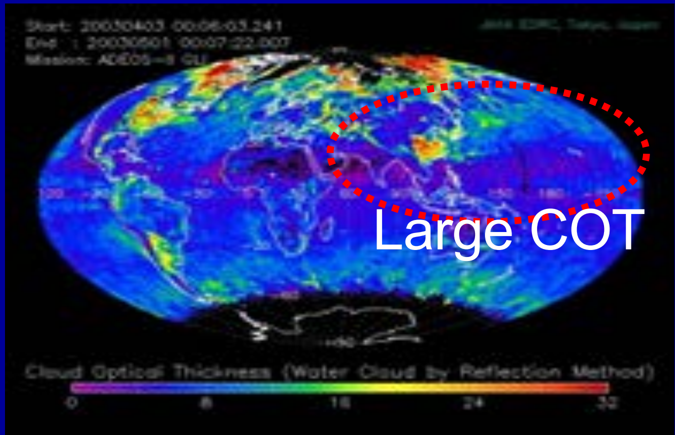
  e.g. Randall et al. (1984) pointed out that a mere 4% increase of the Earth's area covered by low-level clouds, compensates for a projected 2–3 K rise in global temperature due to a doubling of CO_2.

- We have long history of the passive sensing of clouds, using the NOAA, ADEOS-2, TRMM, Terra/Aqua, and Geostationary satellites …

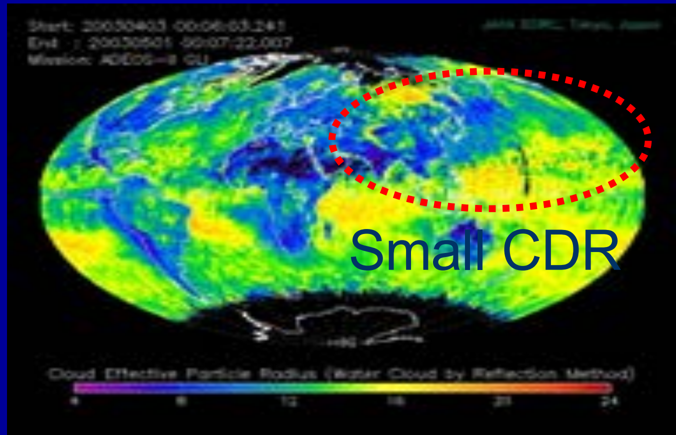
- Recently, active sensing open the door toward better understanding of clouds, in terms of cloud evolution process.

Statistically consistent with our understanding of the aerosol effects, but how about the process is?

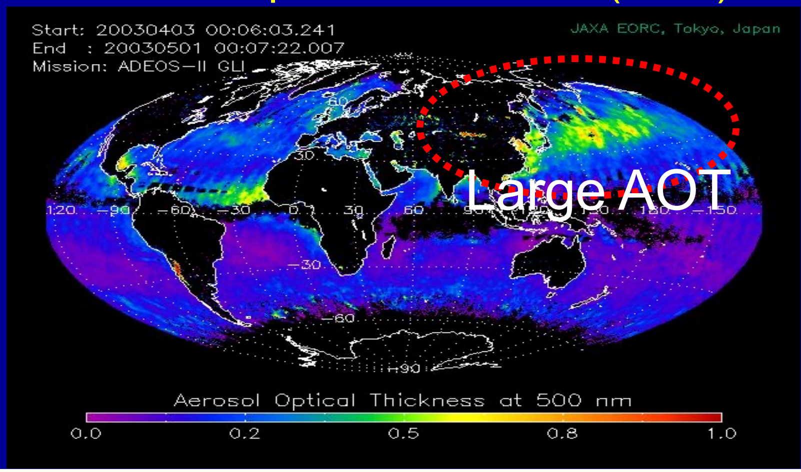
Cloud Optical Thickness (COT)



Cloud Droplet Radius (CDR)



Aerosol Optical Thickness (AOT)

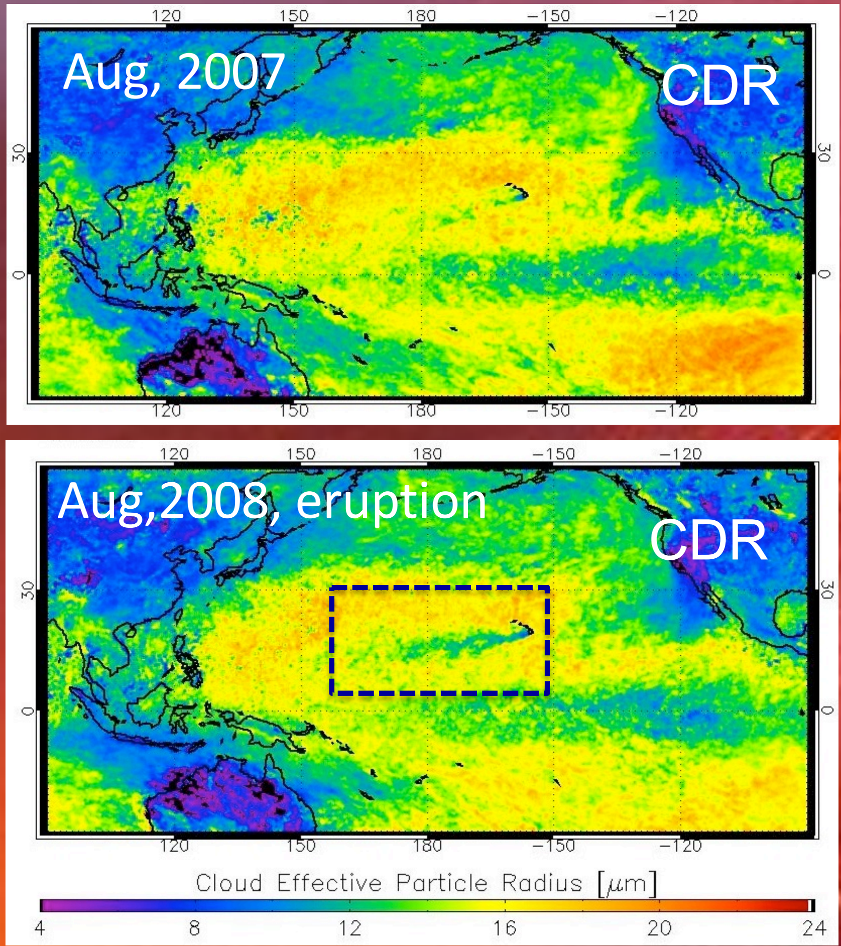


ADEOS-II
Global Imager

<u>April, 2003</u>

Cloud properties were drastically modified by volcanic ash

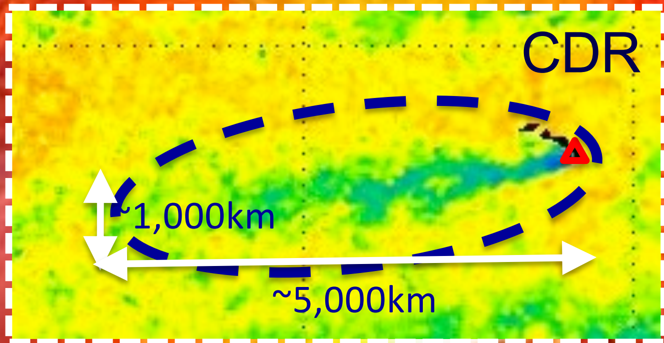
（Mt. Kilauea, Hawaii eruption in 2008）



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

Data ： Terra/ MODIS

Algorithm : CAPCOM Ve4.02



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

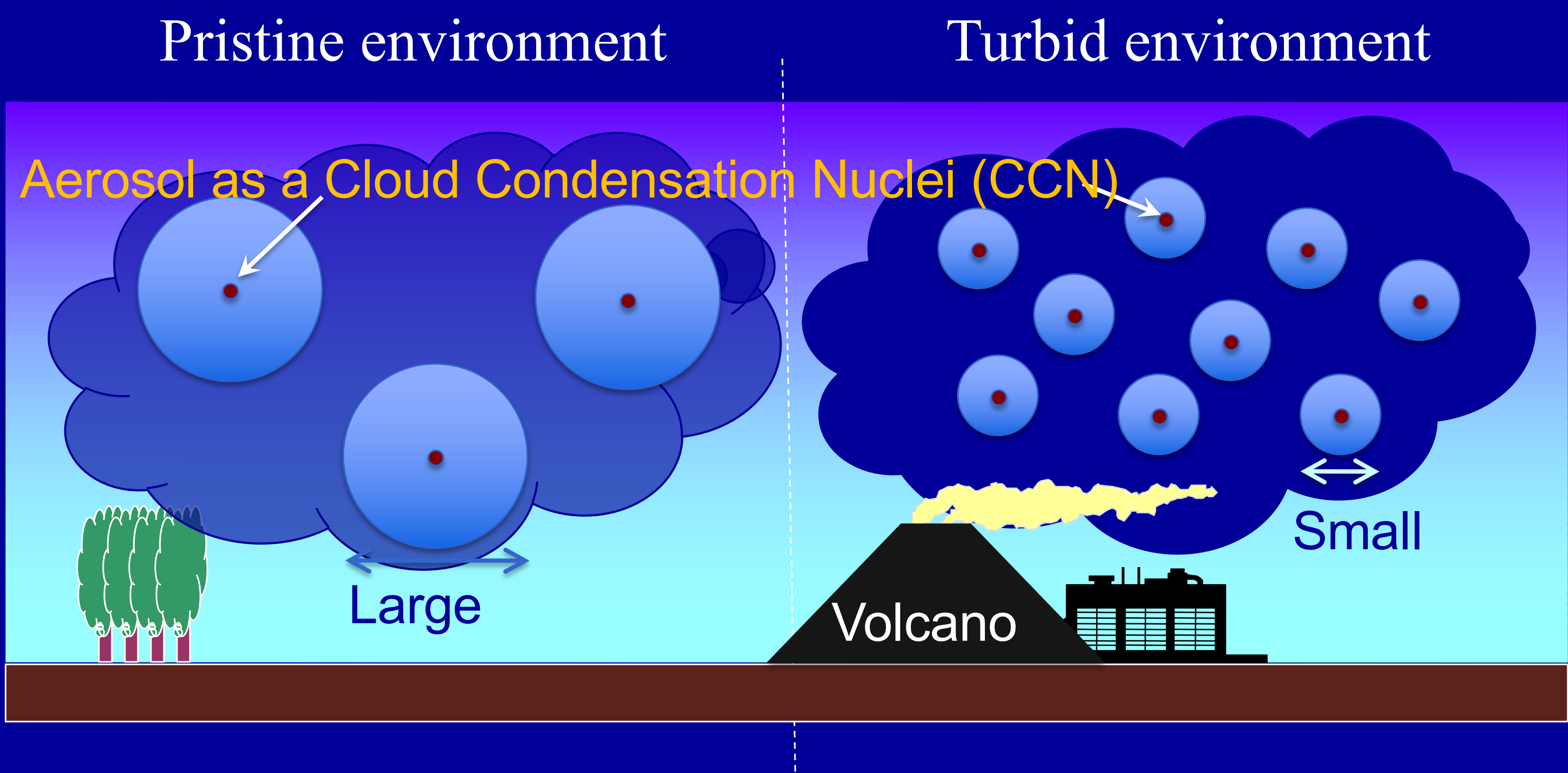
Due to SO2 release, CDR decreased 15μm → 12μm

- 5 W/m^2 change in SW radiation (Eguchi et al. 2011)

Eguchi, K., I. Uno, K. Yumimoto, T. Takemura, T. Y. Nakajima, M. Uematsu, 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.

Indirect effect of aerosols

1st kind



Directions of the cloud research

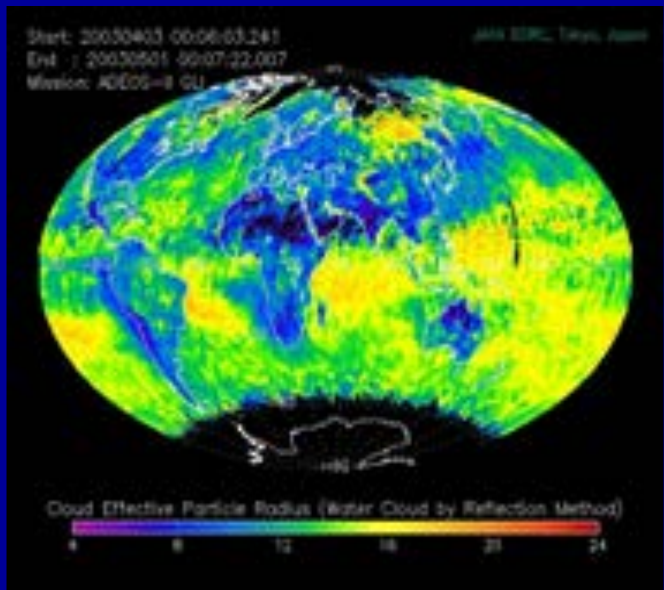
- Long term record → climate change study

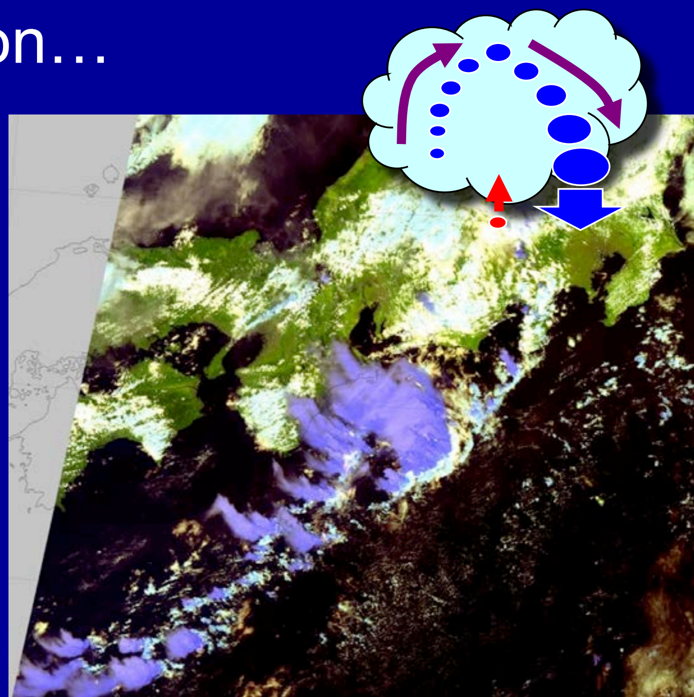
  AVHRR→MODIS→VIIRS→GLI→GCOM, and Geostationary(s)…

- 3-D observation → cloud evolution process

  CloudSat, Calipso, EarthCARE, Active + Passive sensors

- Observation + Model simulation…





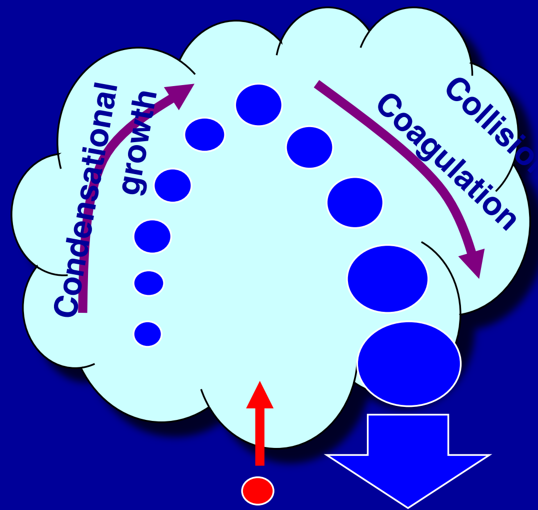
Simulation of the cloud evolution

K-computer

SCALE/LES
by Y. Sato

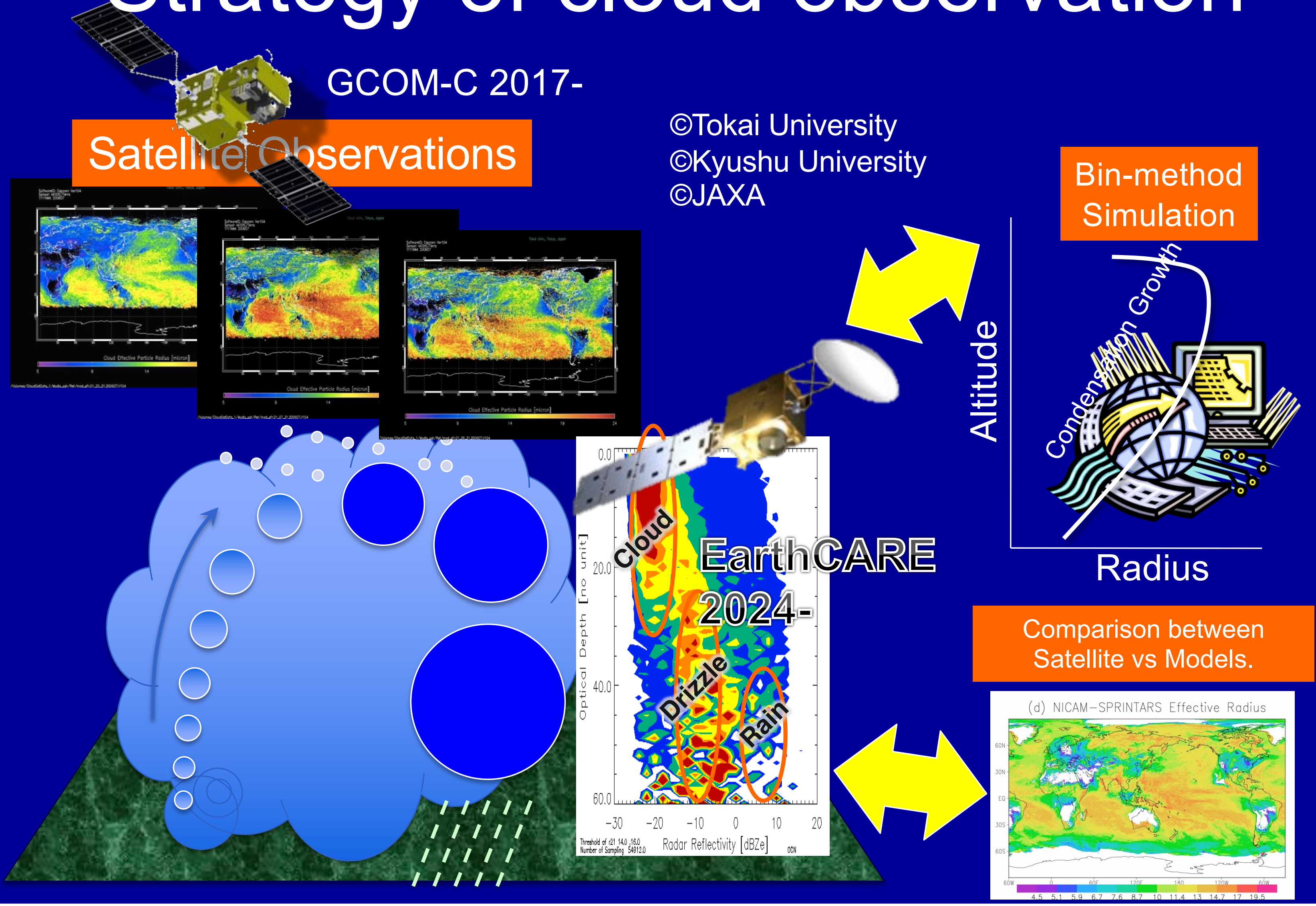
dx=dy=dz=5m

Stratocumulus clouds



- Need investigating consistency/difference between model and observation
- How to observe vertical structure of clouds?

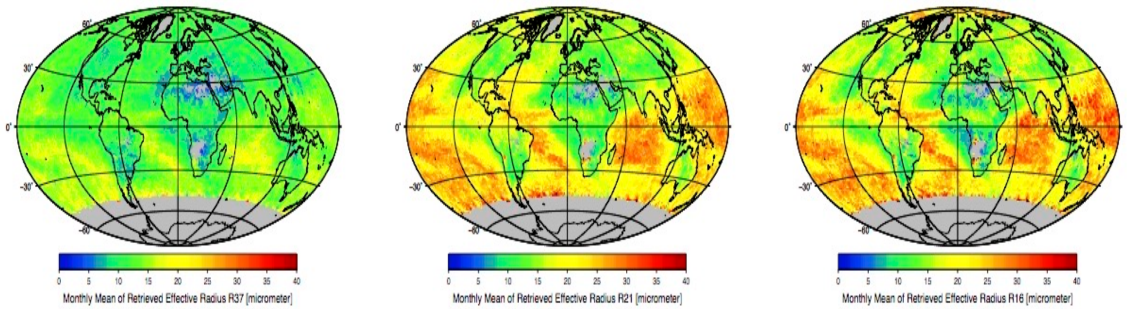
Strategy of cloud observation

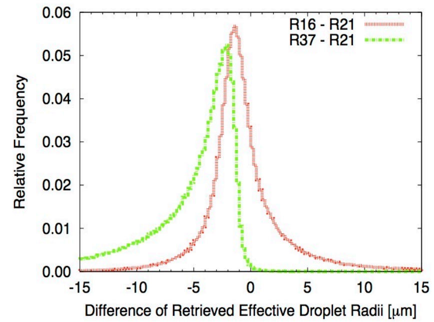


Sounding of cloud properties using passive imager

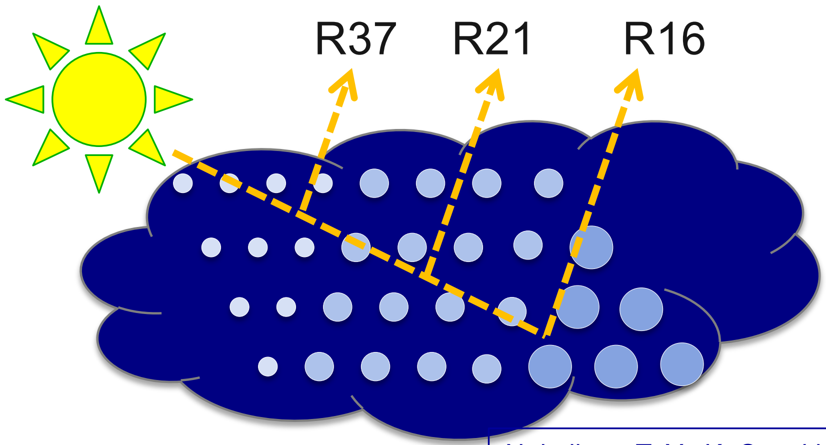
Observations suggested the differences between R37, R21.(Nakajima et al. 2009 etc)

R37 (3.7μm) **R21** (2.1μm) **R16** (1.6μm)





Different **penetration efficiencies** & Different **sensitivities to droplet size** may induce the differences. (Nakajima *et al*., 2010a)



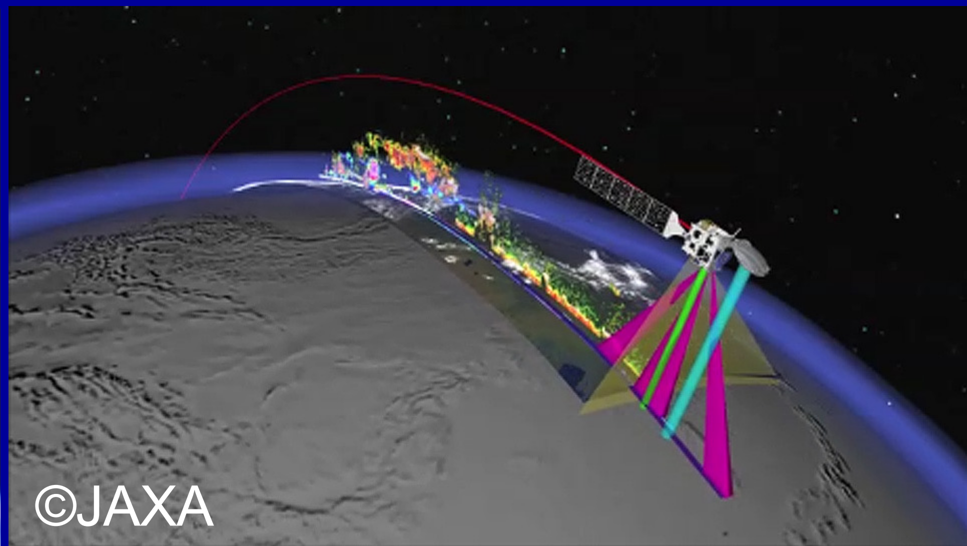
More investigations by…

- Simulate cloud remote sensing using a spectral-bin microphysical cloud model.
- Estimate 2-D Weighting Function of R16, R21, R37 as functions of COD & CDR. (an extended Platnick's W.F.)

Nakajima, T. Y., K. Suzuki, and G. L. Stephens, 2010: 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.

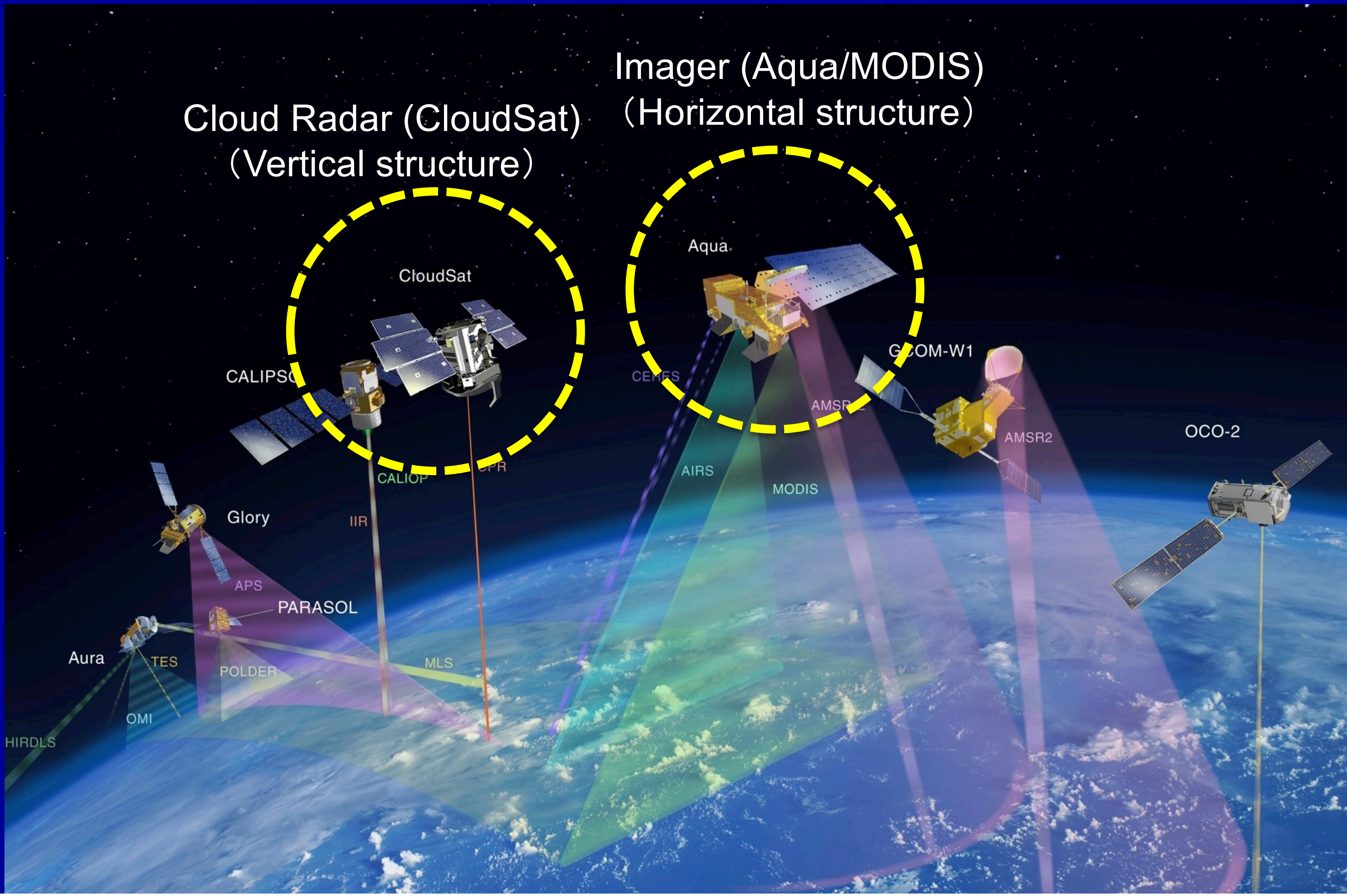
EarthCARE

EarthCARE
- will be launched in middle 2024.
- has Cloud Profiling Radar (CPR), Multispectral Imager (MSI), Broad Band Radiometer (BBR)



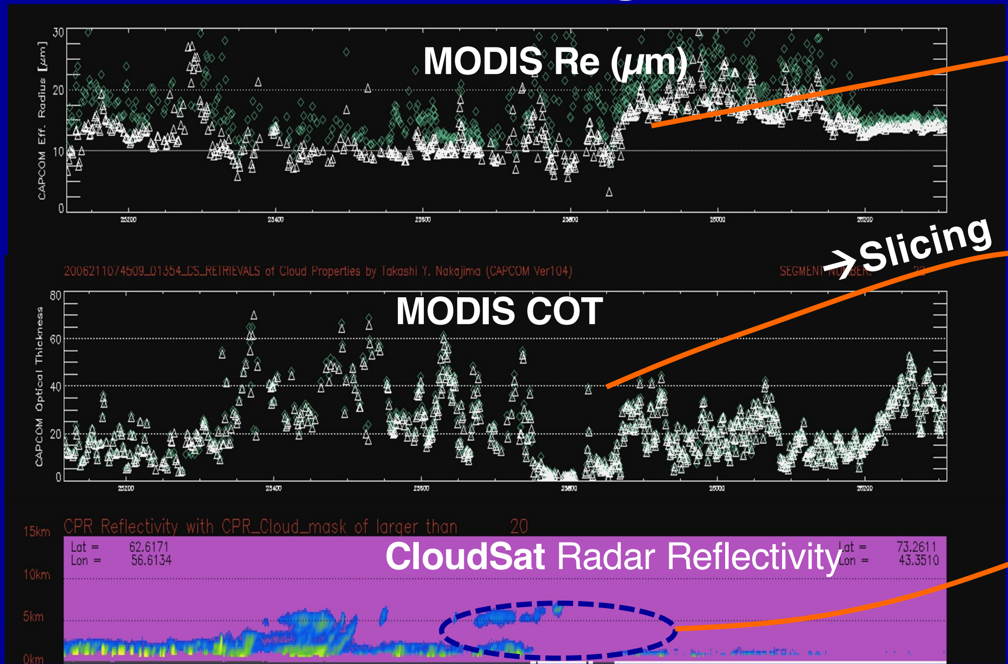
Illingworth, A., and Coauthors, 2015: THE EARTHCARE SATELLITE: THE NEXT STEP FORWARD IN GLOBAL MEASUREMENTS OF CLOUDS, AEROSOLS, PRECIPITATION AND RADIATION. Bulletin of the American Meteorological Society, 96, 1311-1332.

A-Train : CloudSat (2006-) + Aqua (2002-)



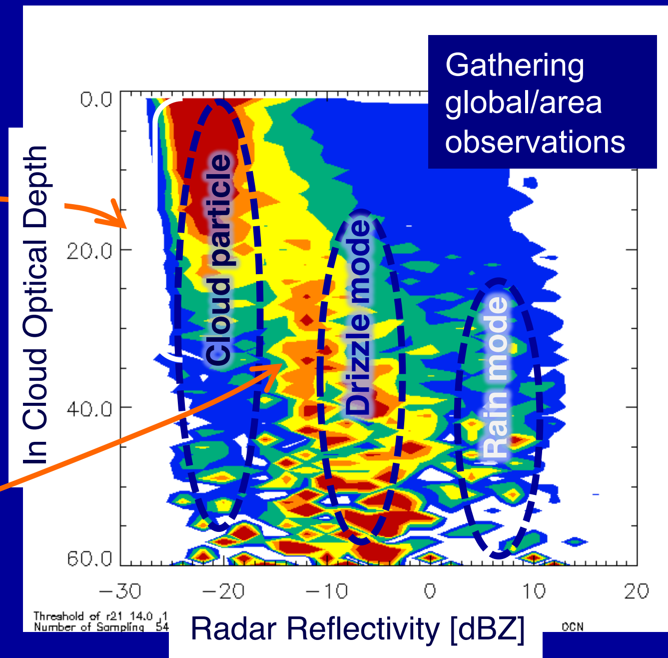
New visualization method of the radar reflectivity, CFODD (Contoured Frequency by Optical Depth Diagram)

A-Train flight direction →



A-Train flight direction →

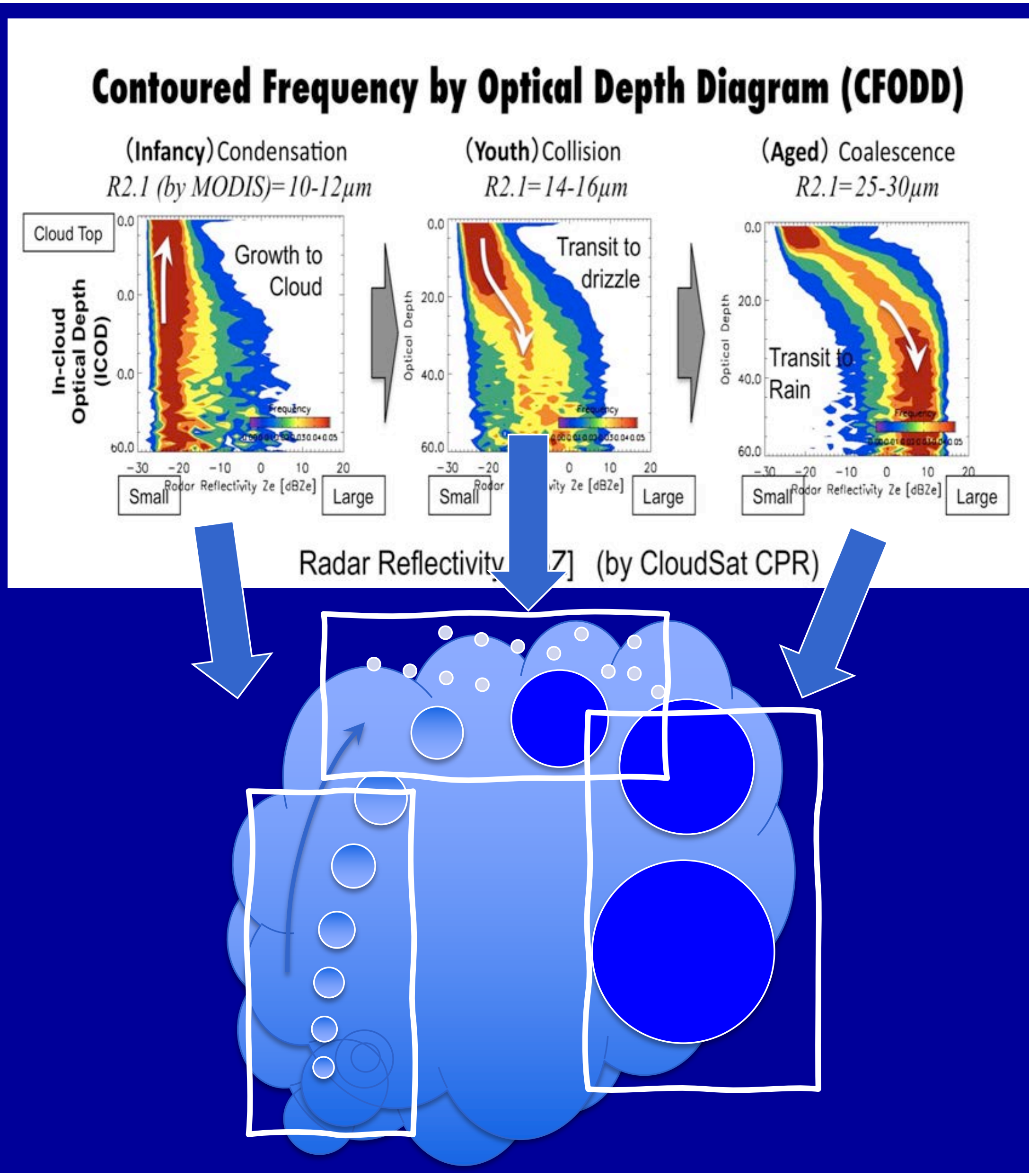
A case of,
14μm<Re<16μm



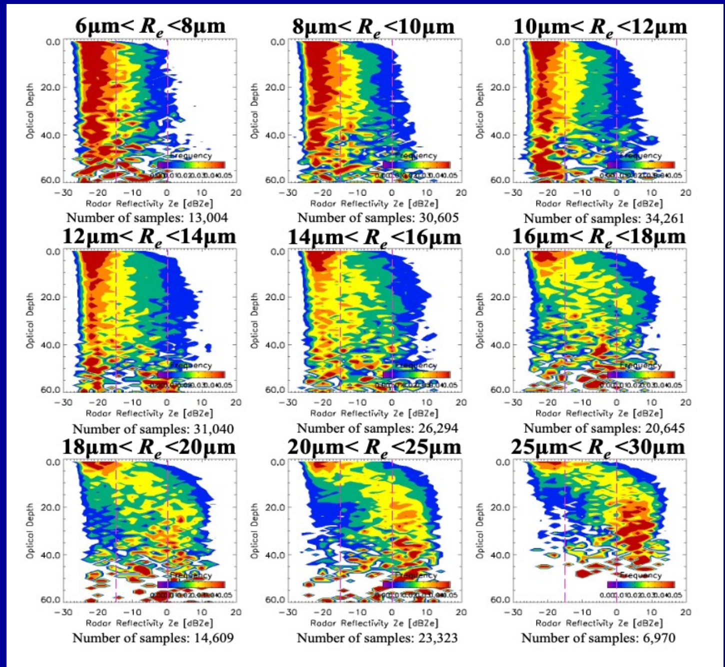
Nakajima, T. Y., K. Suzuki, and G. L. Stephens, 2010: Droplet growth in warm water clouds observed by the A-Train. Part II: A Multi-sensor view. J. Atmos. Sci., 67, 1897-1907.

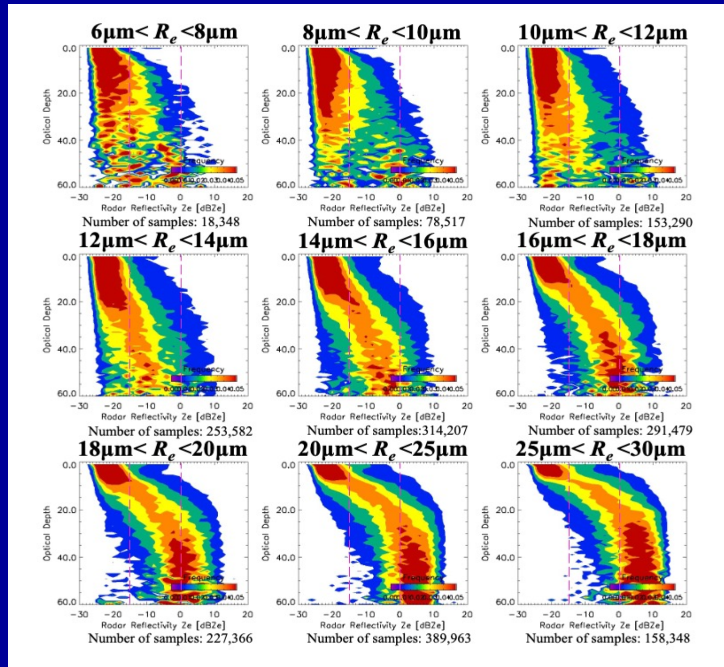
Visualizing Cloud Growth from space

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



The Global CFODD obtained by A-Train (CloudSat+Aqua)



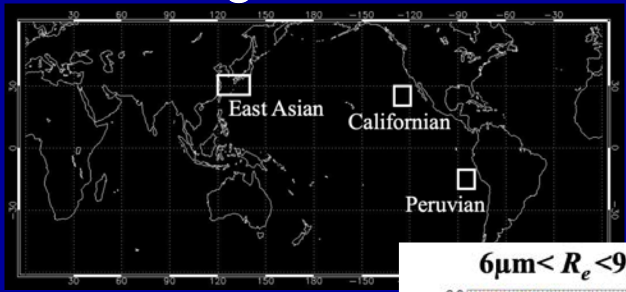


Global (Land) Global (Ocean)

Satellite Data (April, 2007 to 2014)

Matsumoto et al. 2022

The Regional CFODD obtained by A-Train (CloudSat+Aqua)

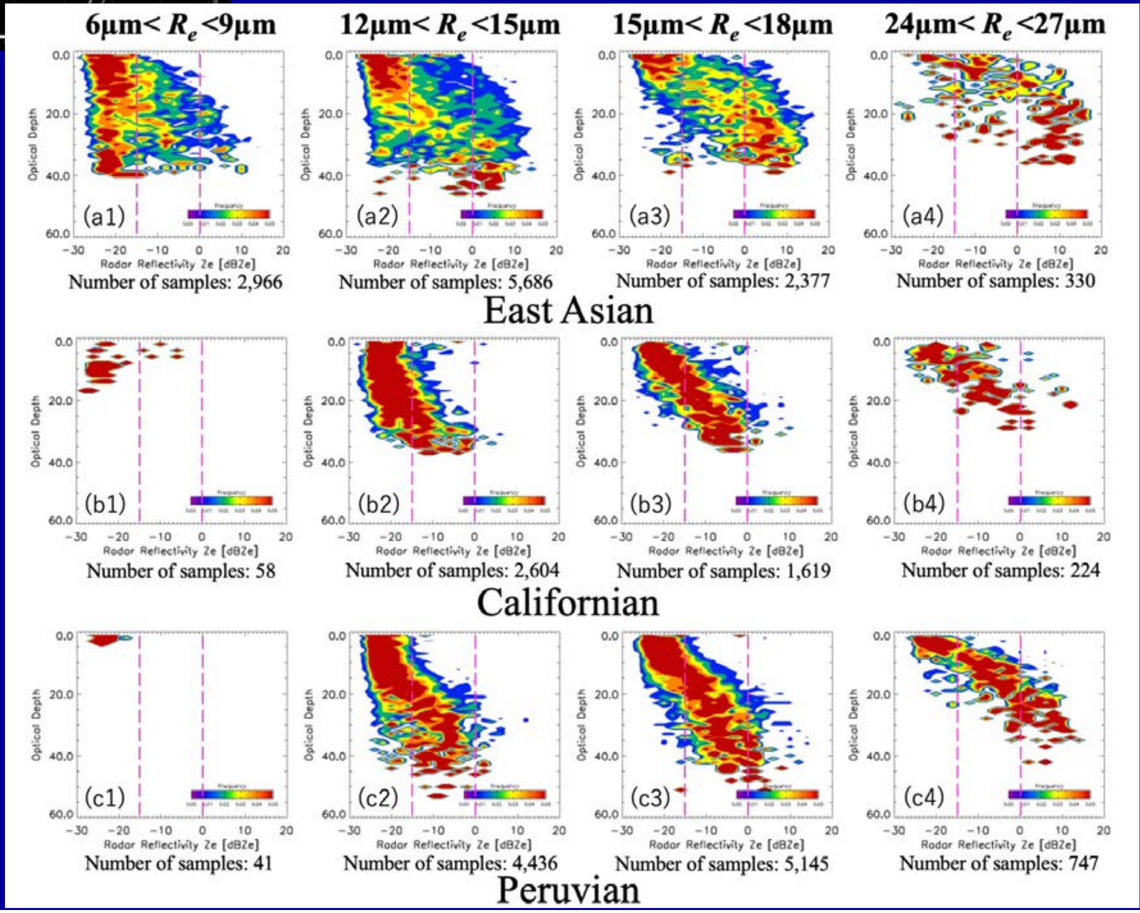


Matsumoto, Y., M. Wang, Y. Sato, and T. Y. Nakajima, 2023: Regional dependency of the cloud droplet growth process in combined analysis of Aqua MODIS and CloudSat CPR. *SOLA*, **19,** 63-69.

East Asian→

Californian →

Peruvian →



Diagnosis of the Aerosol Effects using CFODD

$$AI = \tau_a \alpha$$

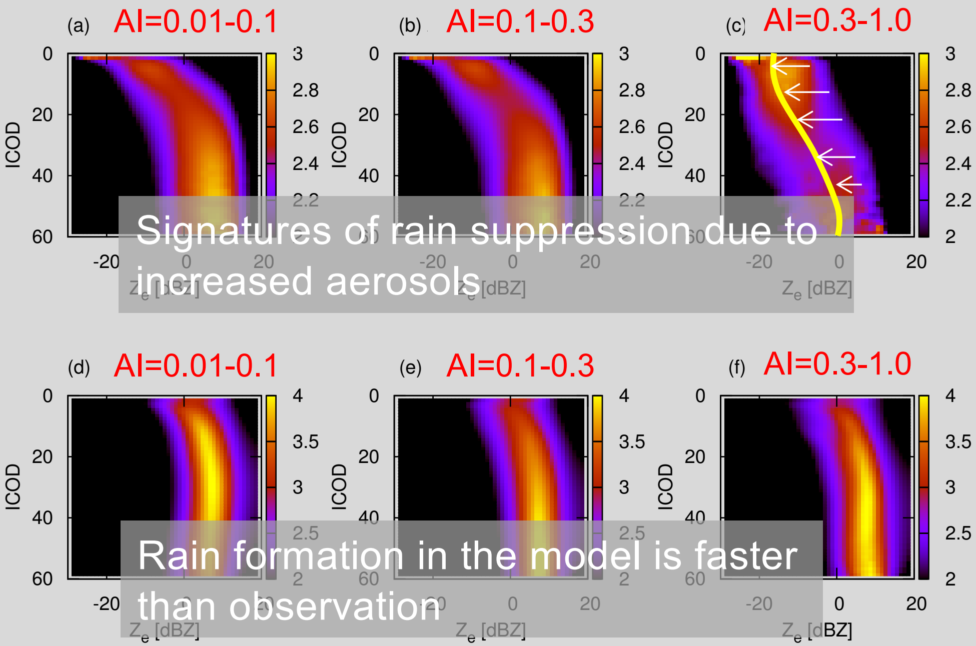
Pristine | Moderate | Polluted

A-Train Observation

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

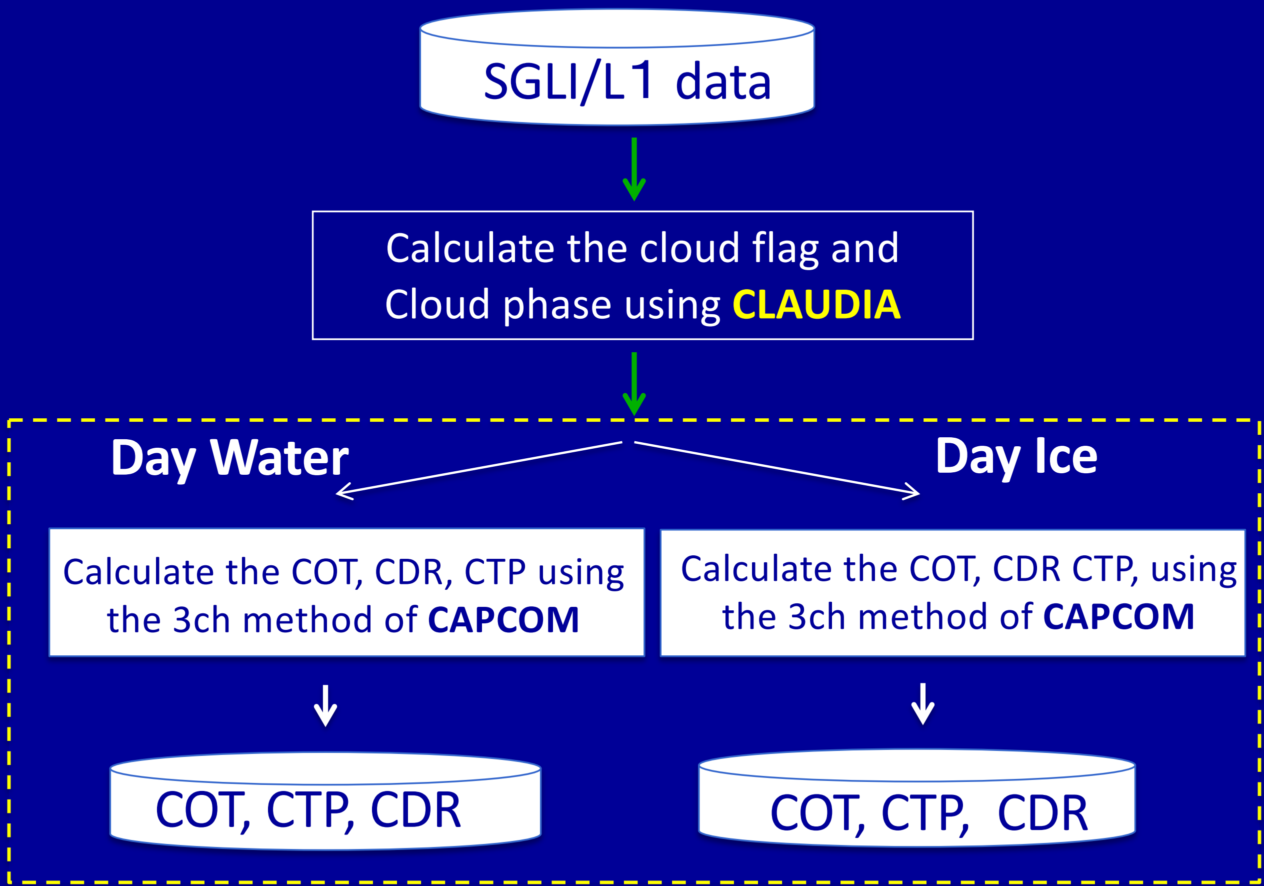
NICAM-SPRINTARS

A Global Cloud Resolving model

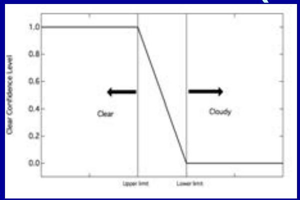


Suzuki, K. J-C. Golaz, G. L. Stephens, 2013: Evaluating cloud tuning in a climate model with satellite observations, Geo. Res. Lett., 40, 4464-4468.

GCOM-C/SGLI cloud product process



CLAUDIA algorithm (for cloud flags)



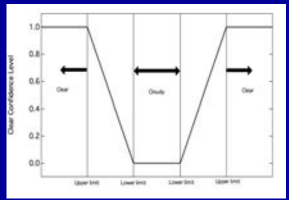
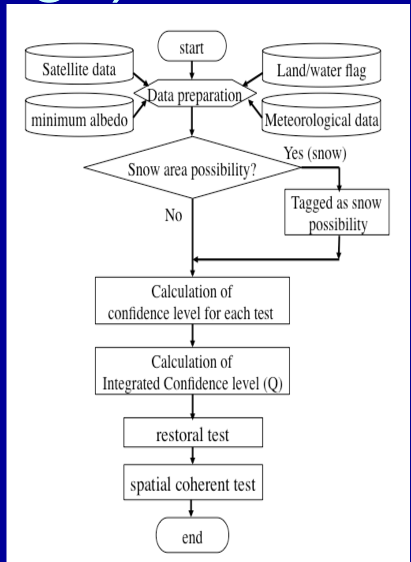
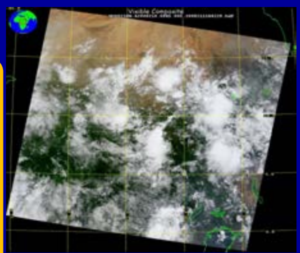


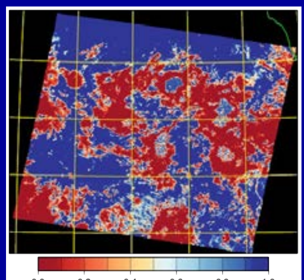
Table 6. Individual Tests and Thresholds[a]

Tests	Ocean Group	Ocean Threshold	Land Group	Land Threshold	Polar Group	Polar Threshold
R0.67 (land or polar) or R0.87 ocean)	1	R min +0.12∓0.075	1	R min +0.18∓0.075	1	R min +0.16∓0.04
R0.87/R0.67	1	0.78 ± 0.12 1.25∓0.1	1	0.78 ± 0.12 1.4∓0.3	—	—
NDVI = (R0.87 − R0.67)/(R0.87 + R0.67)	1	−0.16 ± 0.06 0.34∓0.12	1	−0.16 ± 0.06 0.34∓0.12	1	−0.2 ± 0.02 0.4∓0.05
R0.87/R1.64	—	—	1	0.96 ± 0.1	—	—
R1.24/R0.55	—	—	1	1.86∓0.12	—	—
SW BT3.9-BT3.7				> − 11[K]		
SW BT11-BT3.7				> − 15[K]		
R0.905/R0.935	1	2.9∓0.1	—	—	—	—
SW BT11-BT3.7		> − 15[K]				
SW R0.905		<0.08				
BT11	2	267[K]∓6[K]	R	297.5[K]∓5[K]	—	—
R1.38	2	0.04∓0.01	—	—	—	—
BT6.7	2	220[K]∓10[K]	2	220[K]∓10[K]	—	—
BT11-BT3.9	2	−8[K]∓4[K]	2	−20[K]∓4[K]	1	−7[K]∓3[K]-
BT13.9	2	226[K]∓4[K]	2	224[K]∓4[K]	—	—

[a] $x∓y$ denotes that the lower and upper limit are $x - y$ and $x + y$, respectively. R in a group name denotes a restoral test, SW denotes "switch."

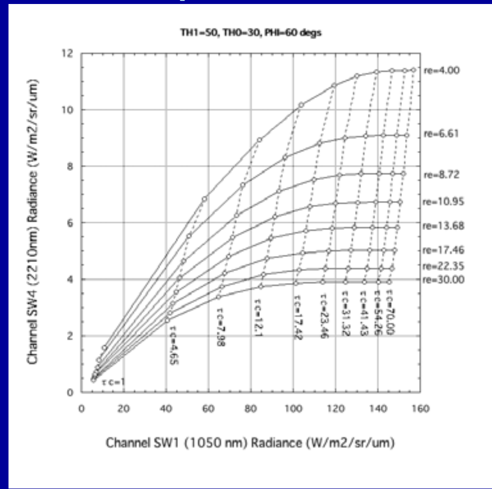


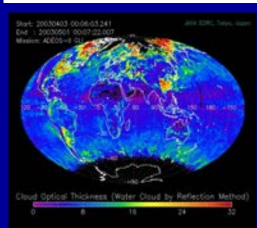


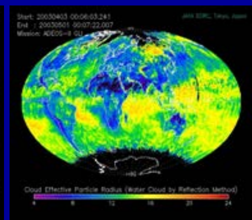


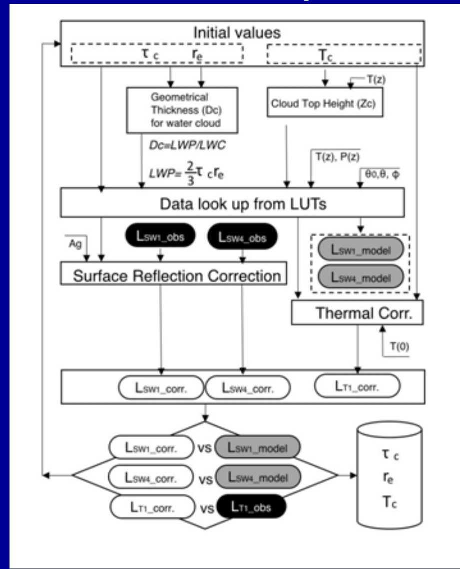
Ishida, H., and T. Y. Nakajima, 2009: Development of an unbiased cloud detection algorithm for a spaceborne multispectral imager. Journal of Geophysical Research-Atmospheres, 114, doi:10.1029/2008JD010710.
Nakajima, T. Y., T. Tsuchiya, H. Ishida, and H. Shimoda, 2011: Cloud detection performance of spaceborne visible-to-infrared multispectral imagers. Applied Optics, 50, 2601-2616

CAPCOM algorithm (for cloud properties)









Nakajima, T. Y., and T. Nakajima, 1995: Wide-area determination of cloud microphysical properties from NOAA AVHRR measurements for FIRE and ASTEX regions. Journal of the Atmospheric Sciences, 52, 4043-4059.
Kawamoto, K., T. Nakajima, and T. Y. Nakajima, 2001: A global determination of cloud microphysics with AVHRR remote sensing. Journal of Climate, 14, 2054-2068.

Introduction

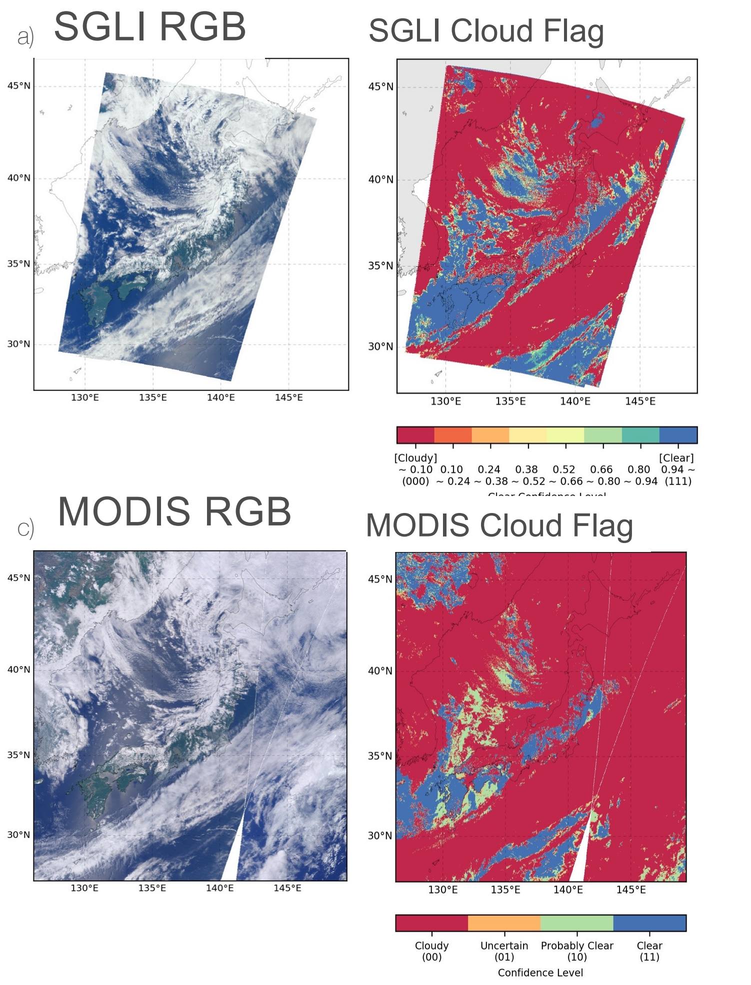
Strategy

CFODD

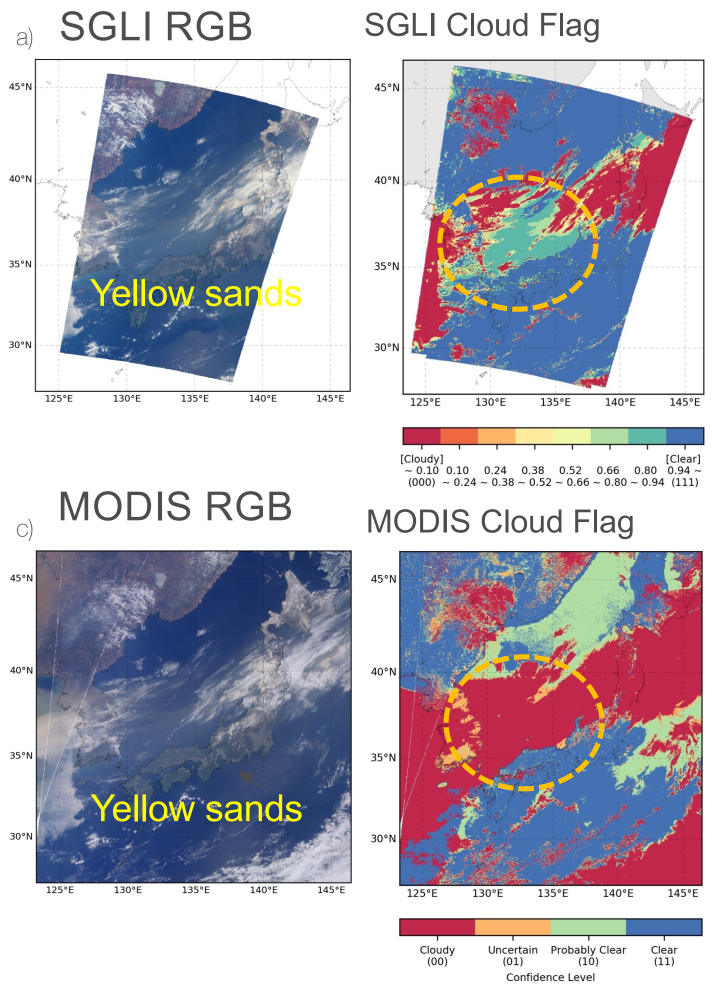
Validation

Summary

SGLI vs MODIS (Cloud Flag)

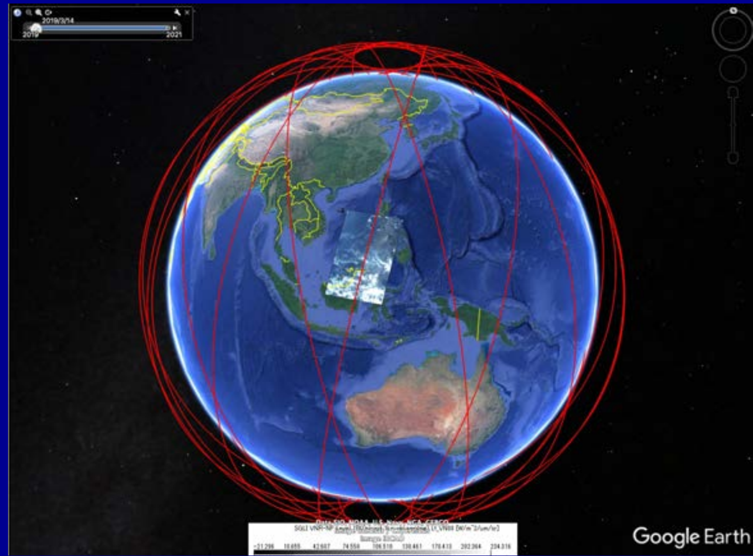


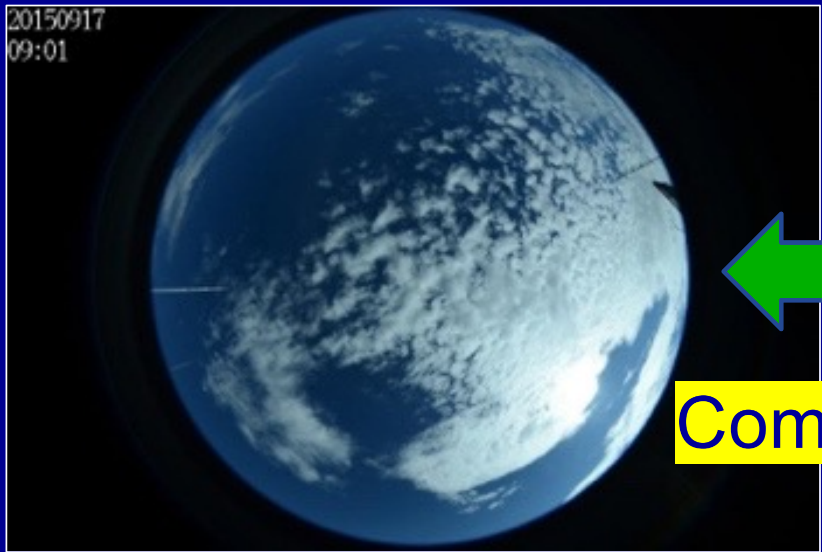
MODIS cloud flag is “clear conservative”



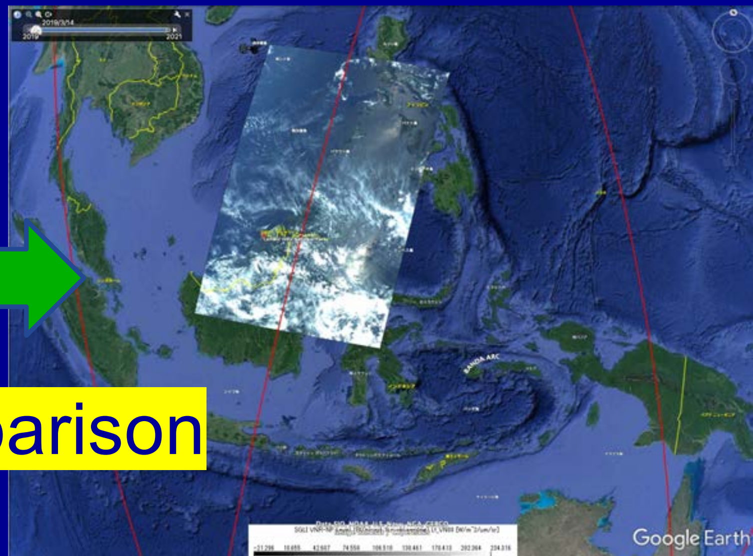
MODIS cloud flag discriminated yellow sands as clouds

Validation of the satellite-derived cloud flag, using ground-based sky camera images

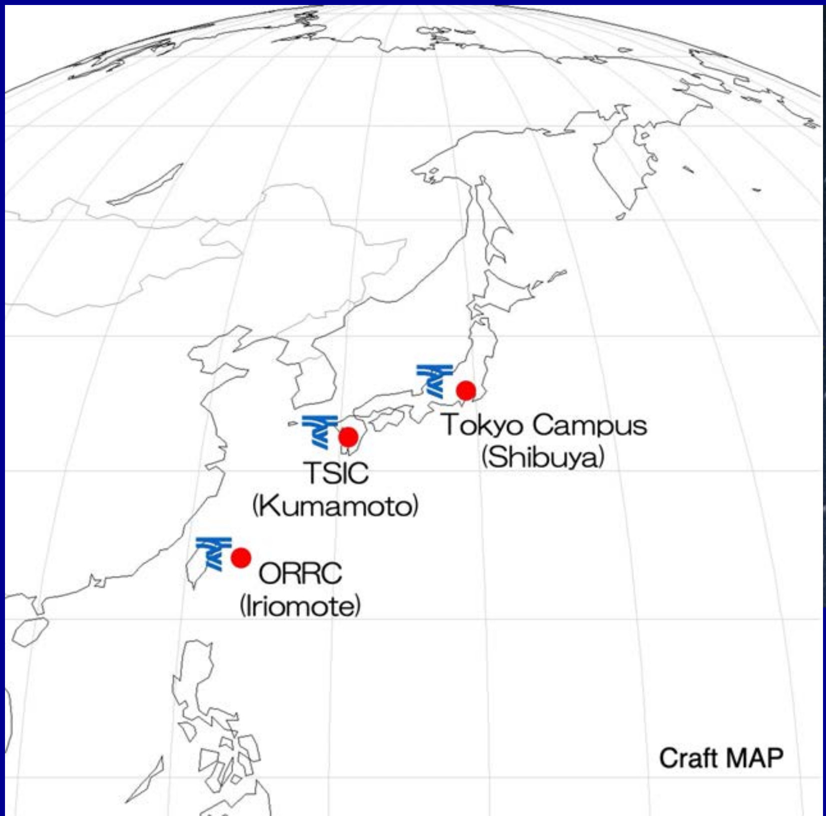


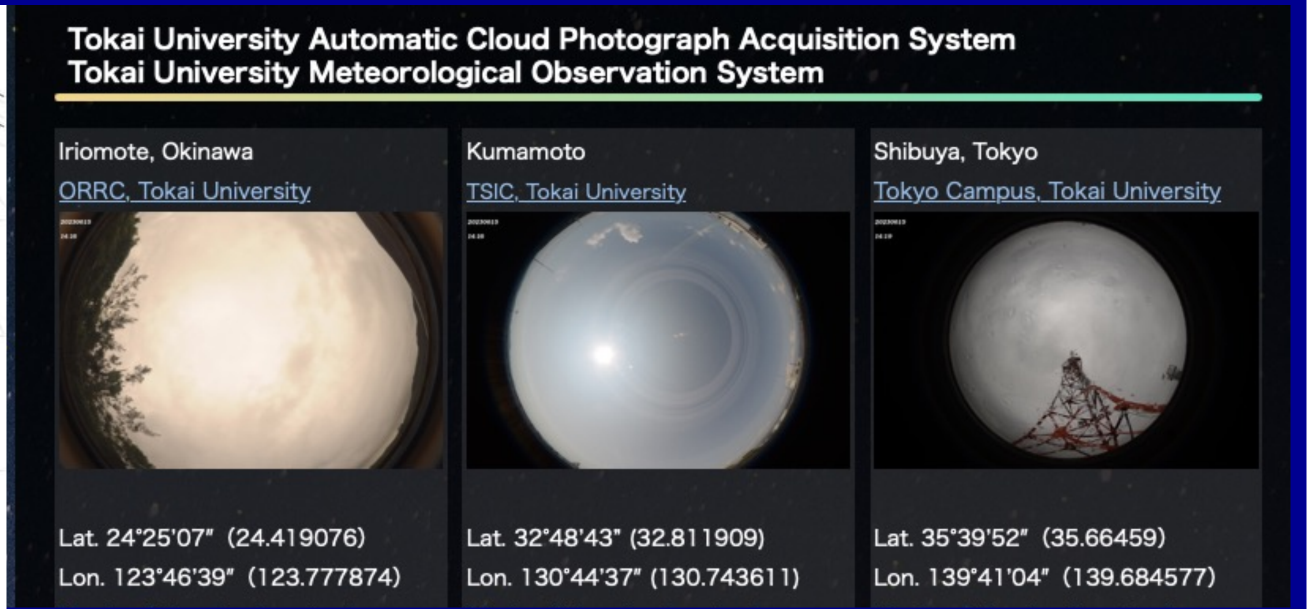


Comparison

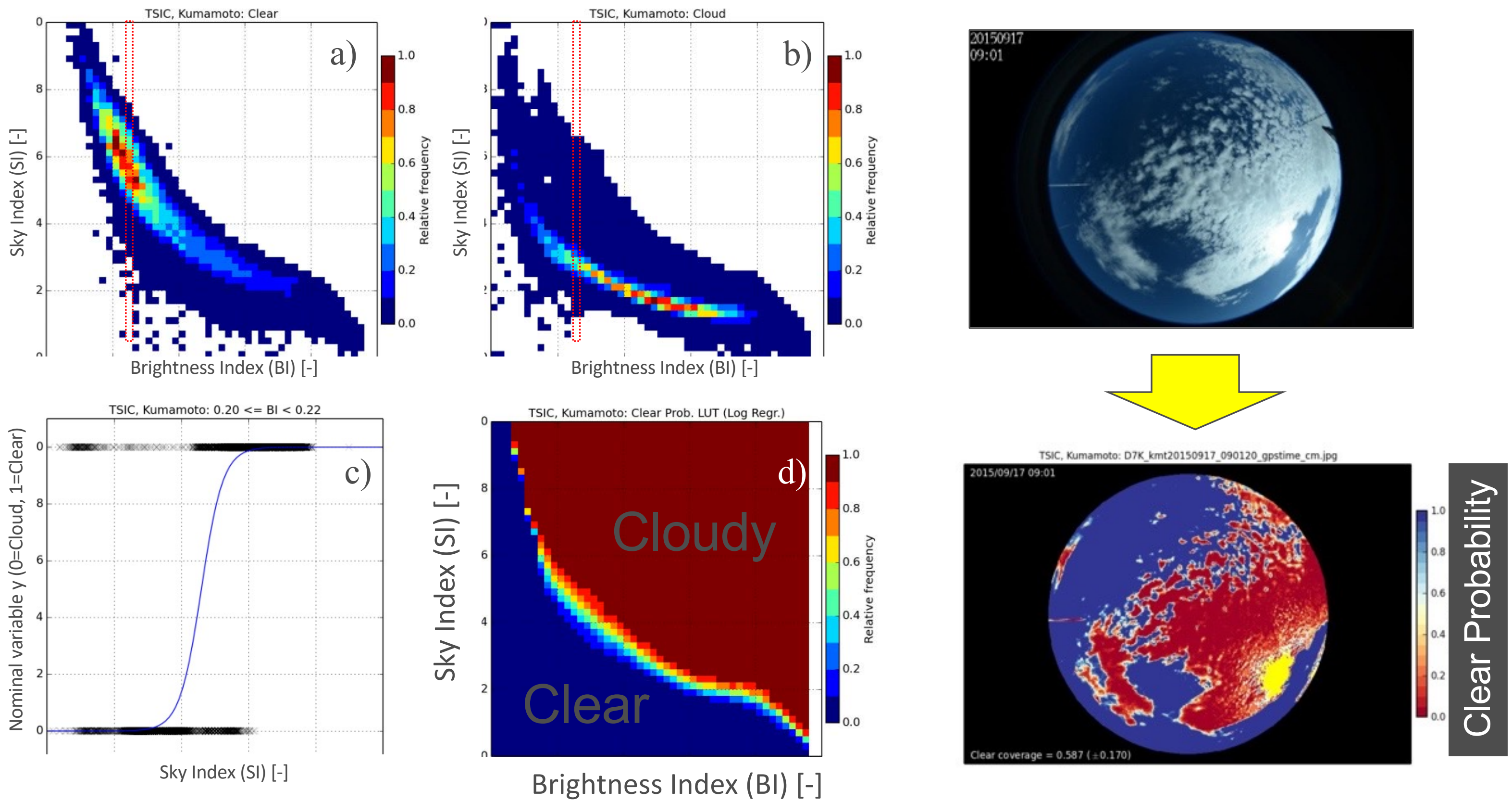


Whole Sky Camera system in Tokai University



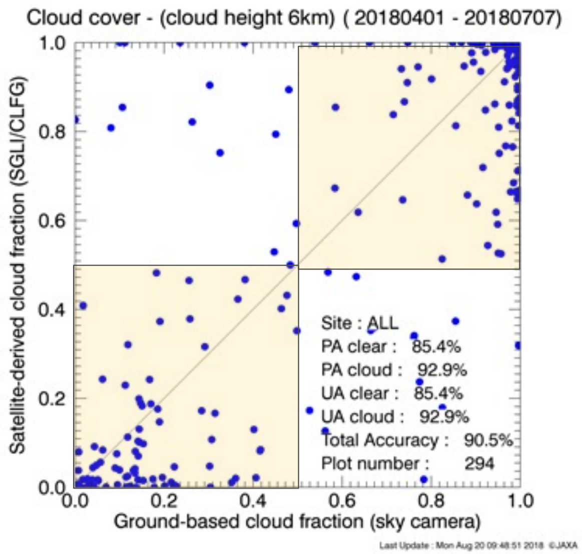


Validation: Whole Sky Camera Analysis



- Sky index, **SI=**(Blue-Red)/(Blue+Red)
- Brightness Index, **BI=**(Red+Green+Blue)/(255*3)

Validation of cloud flag by using Sky camera systems



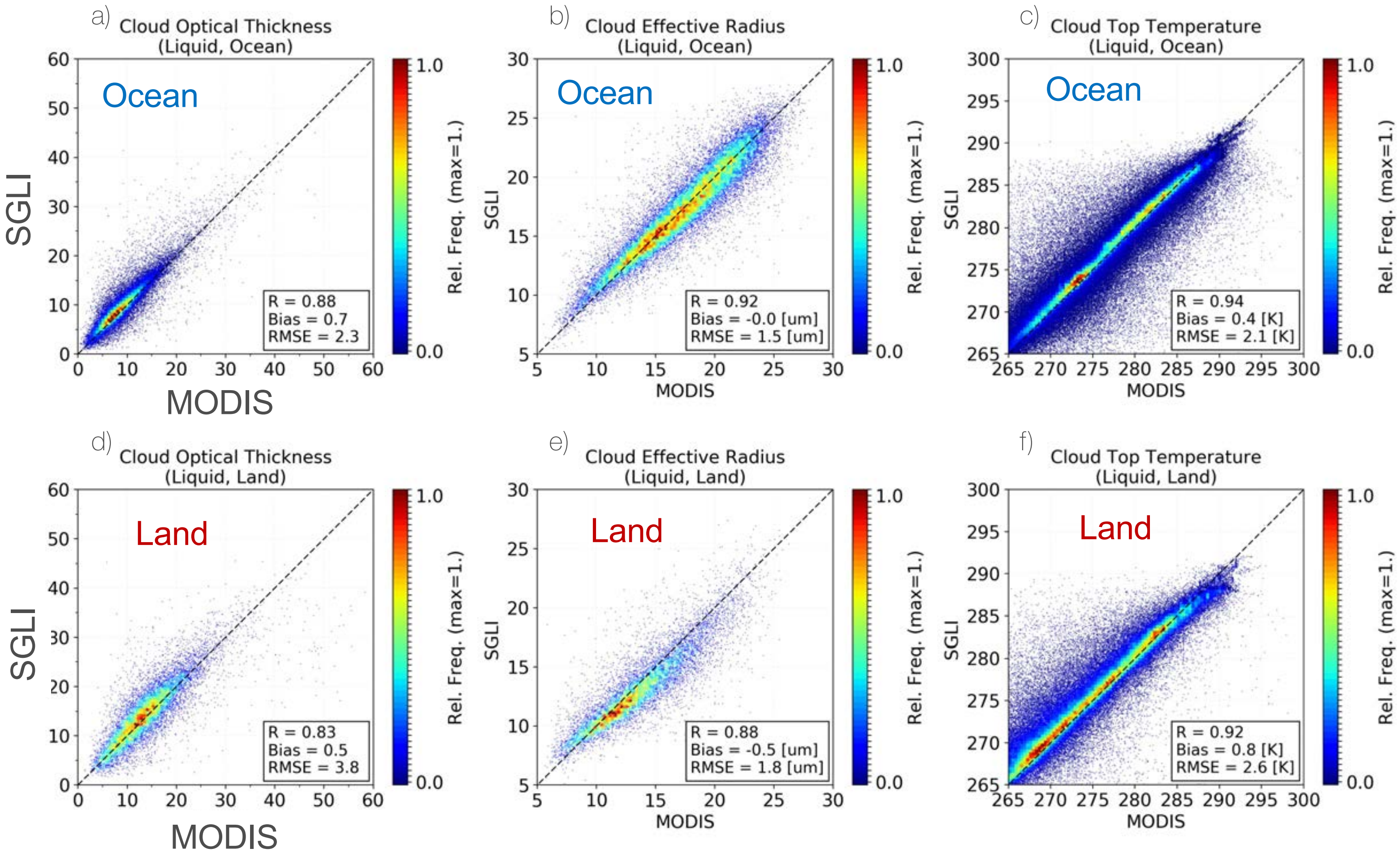
Accuracies *1	Ny-Alesund	Sapporo	Tsukuba TKSC	Tsukuba MRI	Kumamoto	Miyako-jima	Syowa Station	All
N	53	25	58	25	53	47	33	294
Accuracy (%)	94.3	88.0	94.8	100.0	88.7	83.0	84.8	**90.5**

*1 In the case of cloud height at 6 km

=> Meet the release criterion

Nakajima, T. Y., and Coauthors, 2019: Theoretical basis of the algorithms and early phase results of the GCOM-C (Shikisai) SGLI cloud products. Prog Earth Planet Sci 6:52.

Comparison between SGLI and MODIS (**Water Cloud** Properties)



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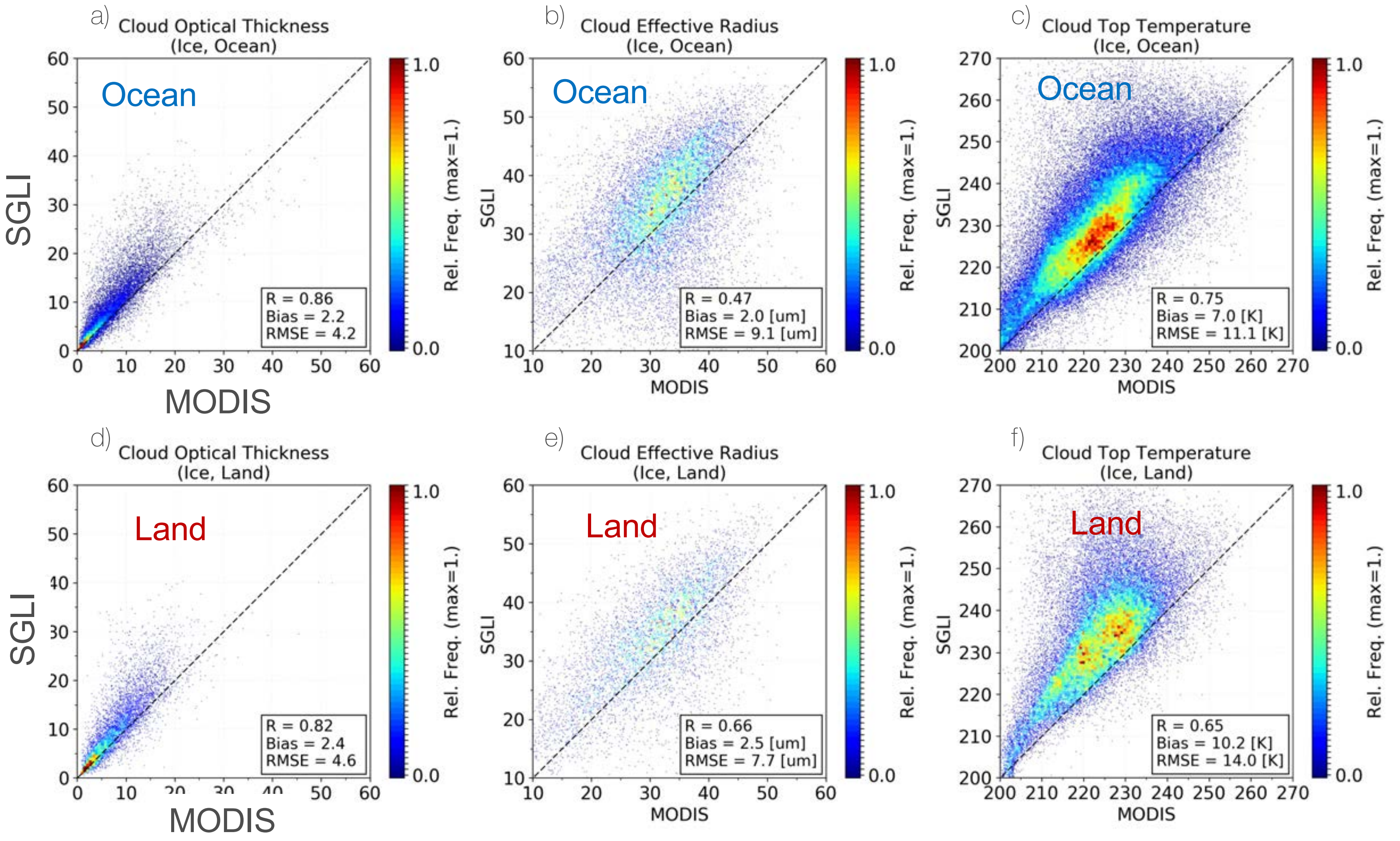
Comparison between SGLI and MODIS (**Ice Cloud** Properties)



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Summary

- Clouds exert an important influence on the *water* and *energy* balances and processes, thus, more observations are required for understanding of *cloud lifecycle*.
  e.g. Randall et al. (1984) pointed out that a mere 4% increase of the Earth's area covered by low-level clouds, compensates for a projected 2–3 K rise in global temperature due to a doubling of CO_2.
- 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, MODIS.
  - useful for model evaluations.
- A Doppler capability of the EarthCARE/CPR improves our understanding of cloud evolution process (2024-).
- 3rd generation geostationary satellites will observe time-series of cloud evolution, every 2.5 min to 10 min.

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References

- Randall, D. A., J. A. Coakley, Jr., C. W. Fairall, R. A. Kropfli, and D. H. Lenschow, 1984: Outlook for research on subtropical marine stratiform clouds. Bull. Amer. Meteor. Soc., 65, 1290–1301.
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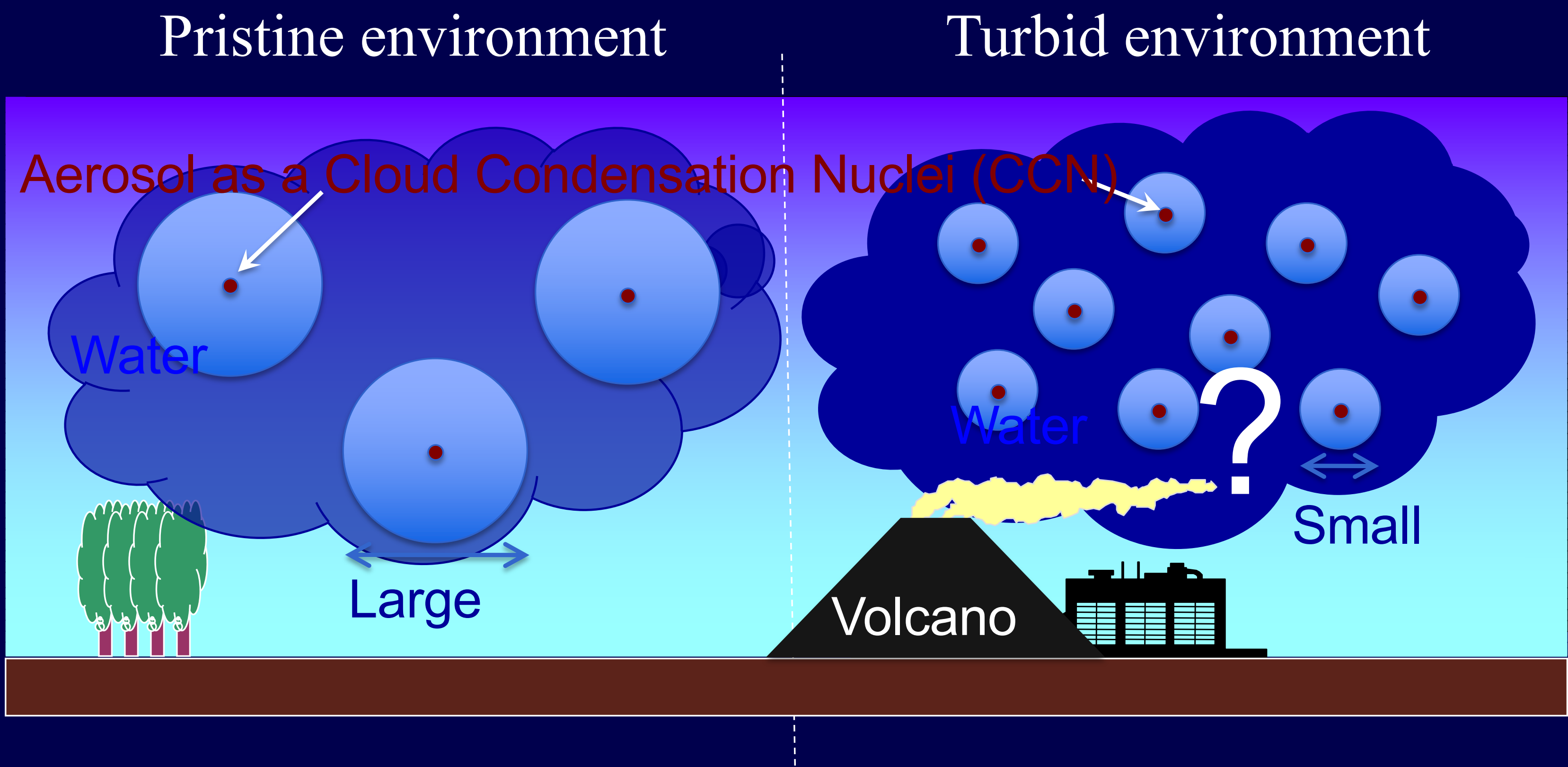
backup

Indirect effect of aerosols

1st kind



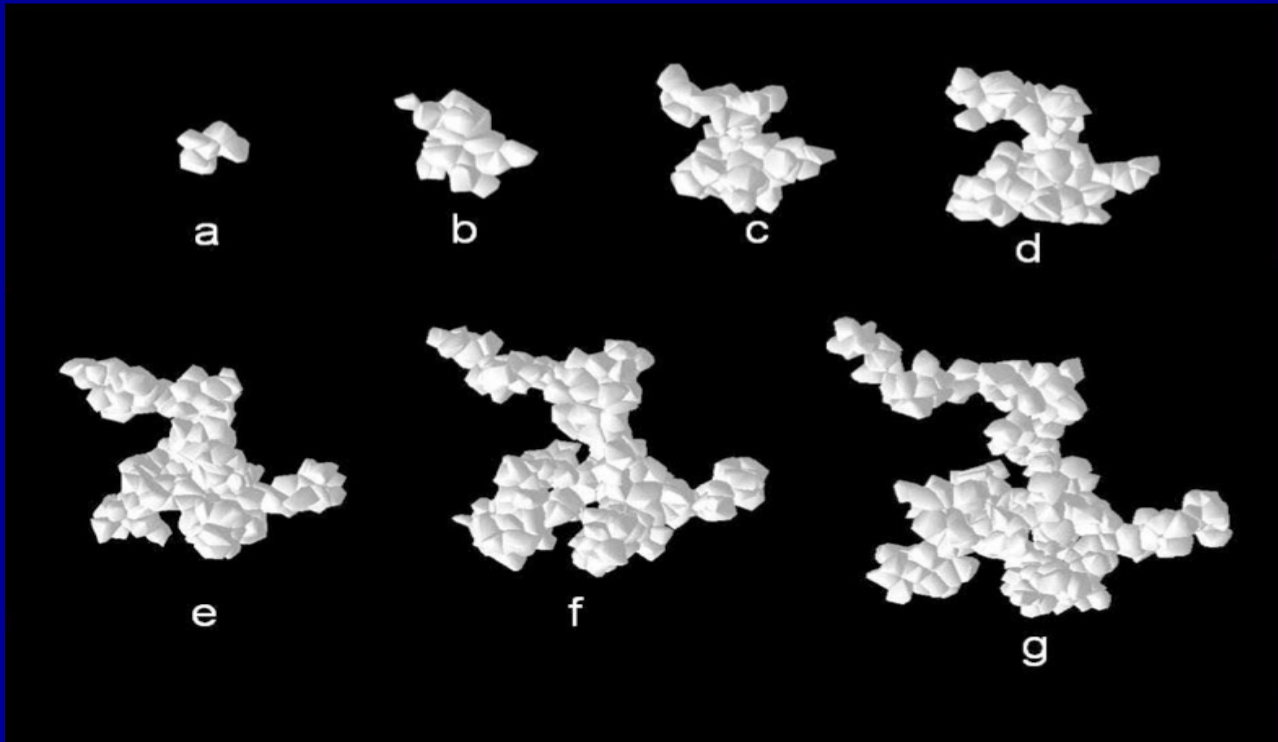
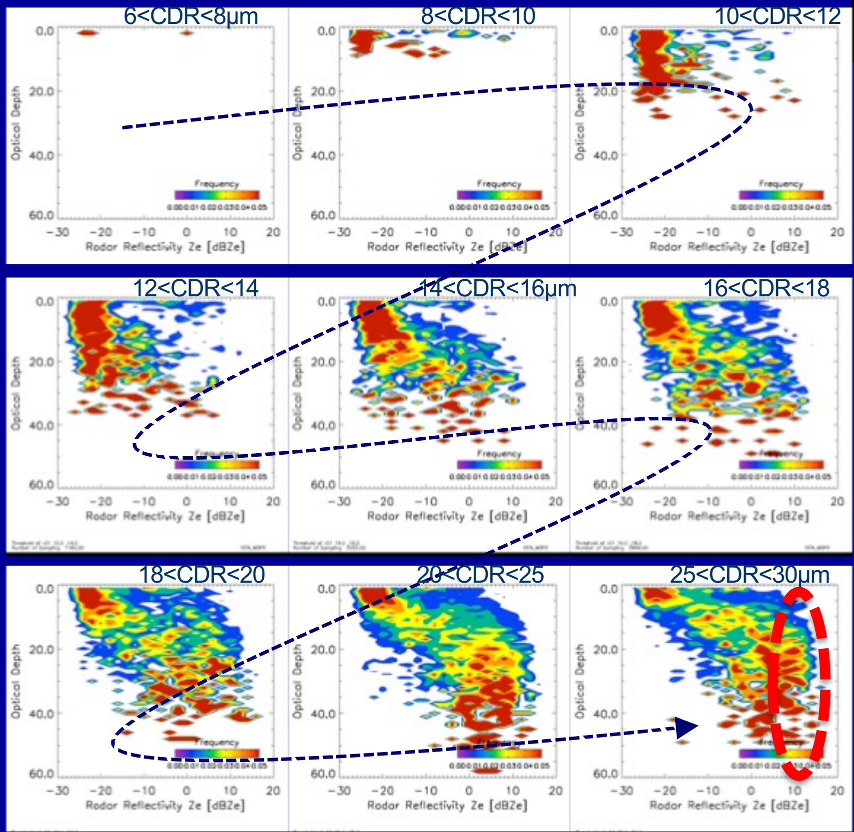


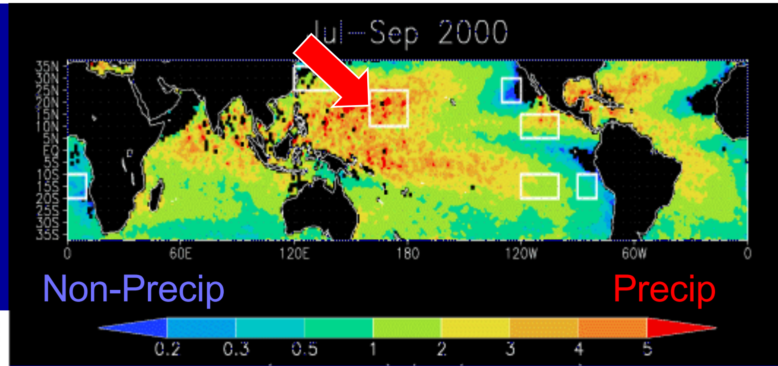
Figure : Various size and habit of Voronoi models (Ishimoto et al., 2012) (shape (a): size parameter (SZP) < 660; shape (b) – (g): 660 < SZP < 2250)

OCEAN
Precipitating area

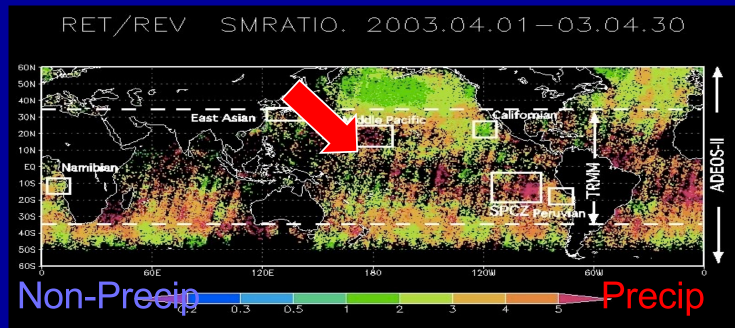
Mid-Pacific OCEAN (2007 data)



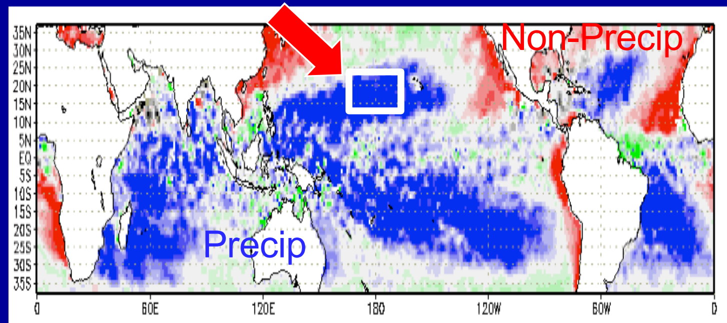
CFODD obtained by CloudSat+MODIS



↑**Masunaga** et al. (JGR 2002) by TRMM



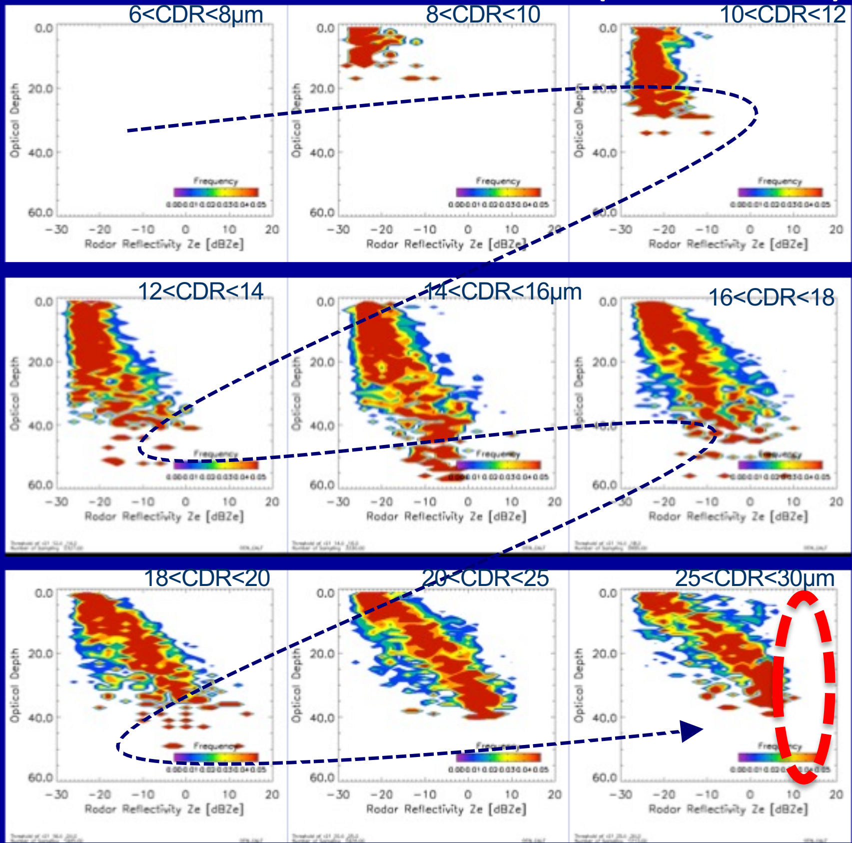
↑**Nakajima** et al. (RSSJ 2009) by ADEOS2



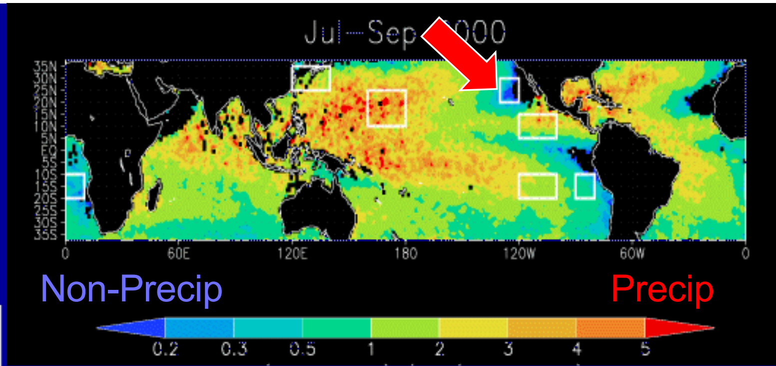
↑**Matsui** et al. (GRL 2004) by TRMM

OCEAN
Non-Precipitating area

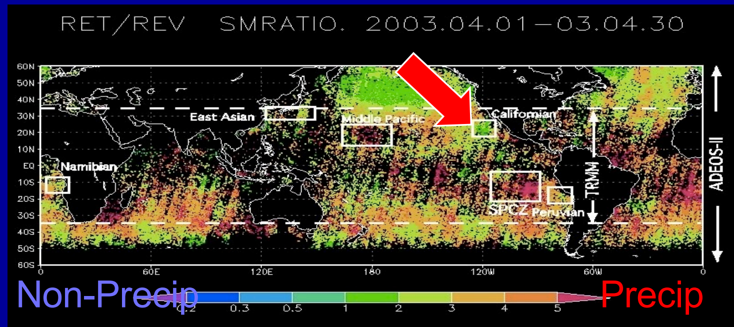
Californian (2007 data)



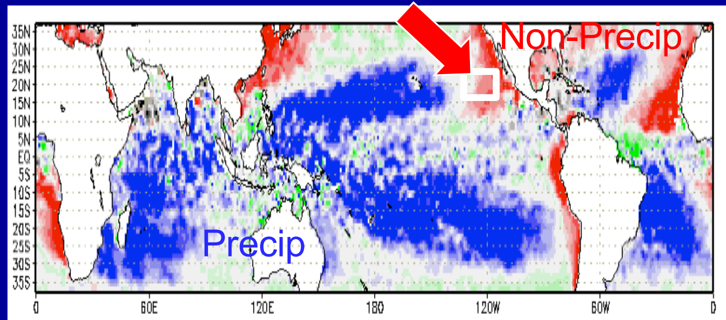
CFODD obtained by CloudSat+MODIS



↑**Masunaga** et al. (JGR 2002) by TRMM



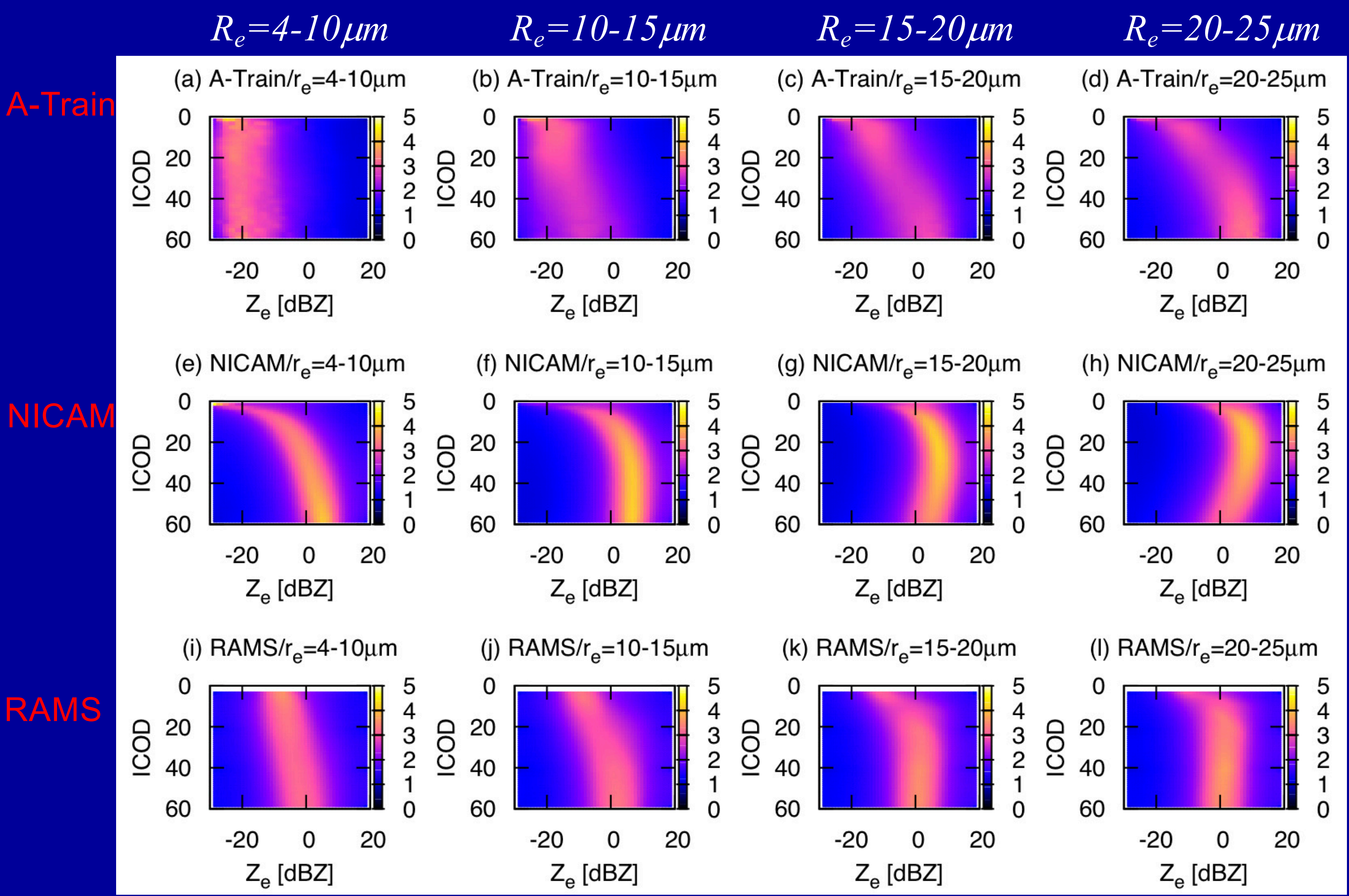
↑**Nakajima** et al. (RSSJ 2009) by ADEOS2



↑**Matsui** et al. (GRL 2004) by TRMM

Application to model evaluation

Suzuki *et al.* (JAS'11)



COD (Cloud Optical Depth) slicing?

- Nakajima, Suzuki, Stephens (JAS, 2010b)
  - Use the 2B-TAU products from the CloudSat mission
  - Were not independent from CPR signals
- Suzuki, Nakajima, Stephens (JAS, 2010)
  - Adiabatic condensation growth assumption.

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

h : height from the cloud bottom, H : geometrical thickness of cloud