Algorithm developments for the EarthCARE MSI cloud products and the early phase analysis of warm-water clouds by the combined use of the cloud radar and the imager

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EarthCARE Workshop in 2023

Introduction

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

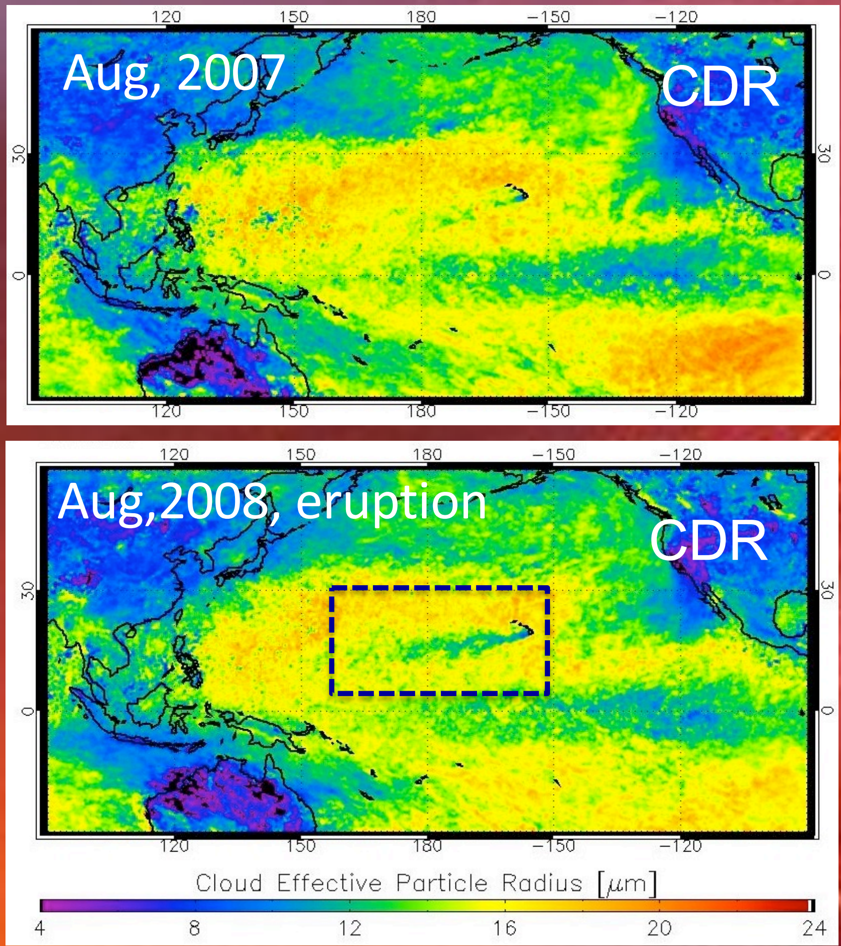
  e.g. Randall et al. (1984) pointed out that a mere 4% increase of the Earth's area covered by low-level clouds, compensates for a projected 2–3 K rise in global temperature due to a doubling of CO_2.

- 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.

Cloud properties were drastically modified by volcanic ash

（Mt. Kilauea, Hawaii eruption in 2008）

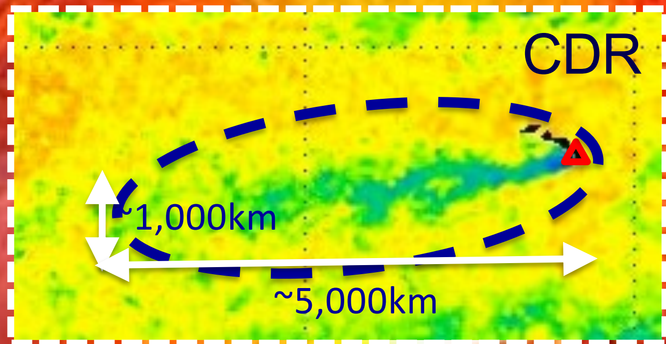


http://www.darkroastedblend.com/2007/11/hawaiian-volcanoes-beauty-terror.html

CDR (Effective particle radius)

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)

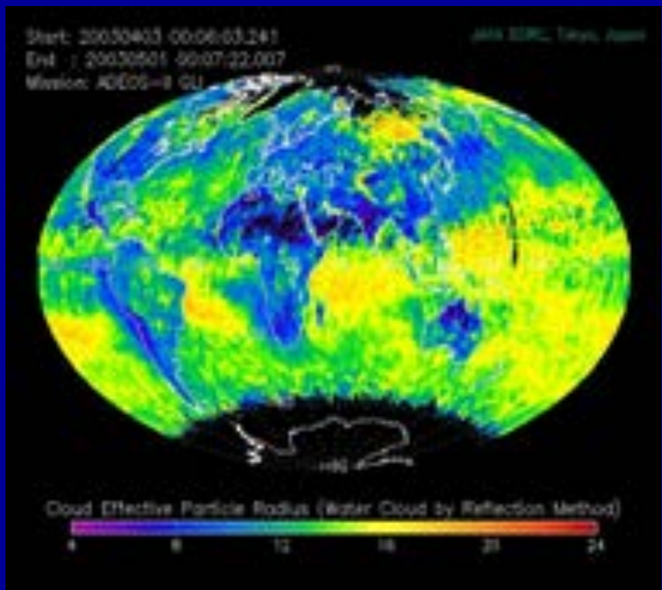
Eguchi, K., I. Uno, K. Yumimoto, T. Takemura, T. Y. Nakajima, M. Uematsu, and Z. Liu, 2011: Modulation of cloud droplets and radiation over the North Pacific by sulfate aerosol erupted from Mount Kilauea. *SOLA*, **7**, 77-80.

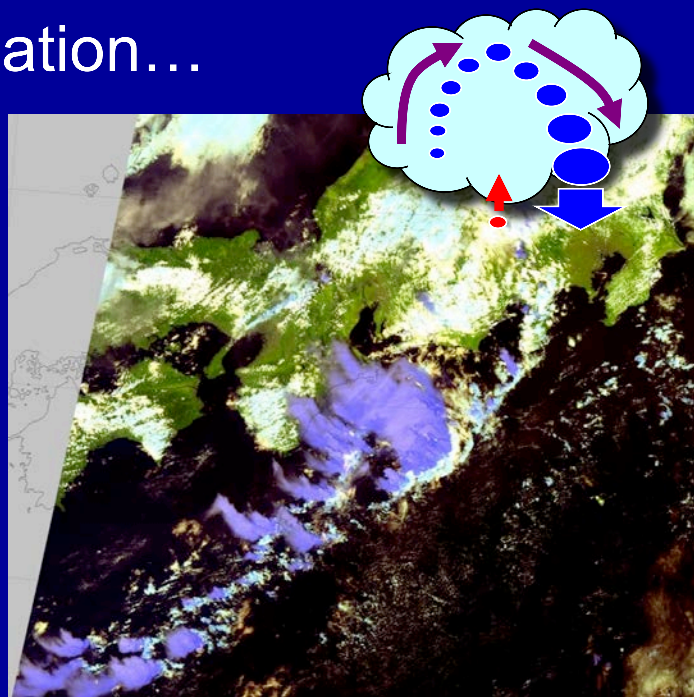
Directions of the cloud research

- Long term record → climate change study

  AVHRR, MODIS, VIIRS, GLI, GCOM, Geostationary…
- 3-D observation → cloud evolution process

  CloudSat, Calipso, EarthCARE, + Passive sensors
- Observation + Model simulation…





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Satellites
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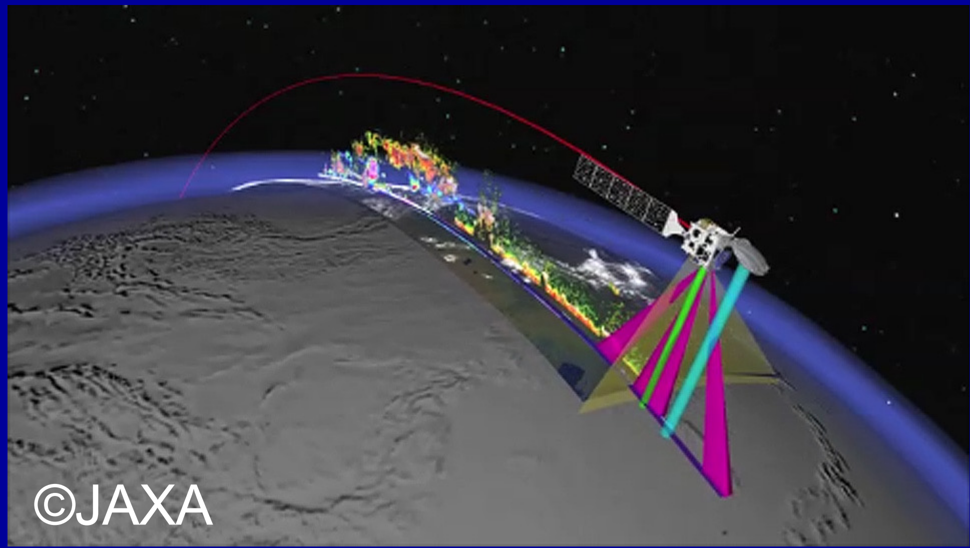
Summary

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.

	λ (μm)	Δλ (μm)
Visible channel	0.67	0.02
NIR channel	0.865	0.02
SWIR1 channel	1.65	0.05
SWIR2 channel	2.21	0.10
TIR1 channel	8.8	0.9
TIR2 channel	10.8	0.9
TIR3 channel	12.0	0.9
Swath width	150 km	
Spatial sampling distance	500 m	
Spatial co-registration	0.15 SSD	
Radiometric accuracy	10 % or 1 K	
Inter channel accuracy	1 % or 0.25 K	
Radiometric stability	1 % or 0.3 K/year	

Table 5. Key performance parameters of MSI.

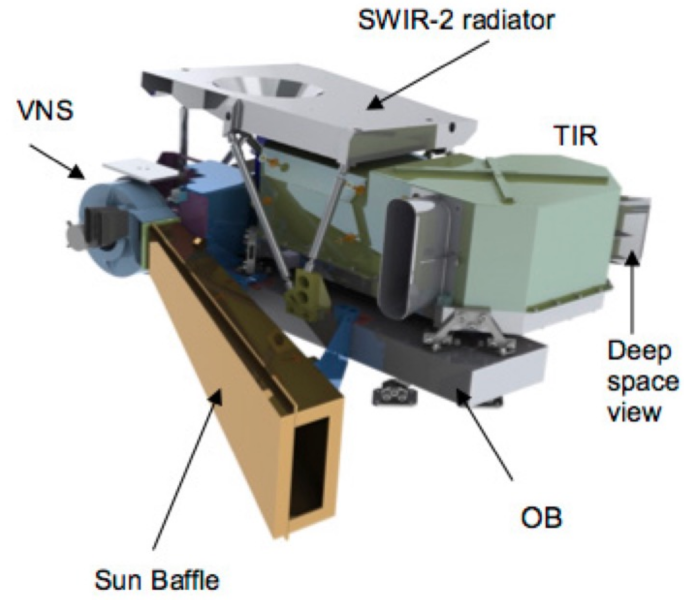
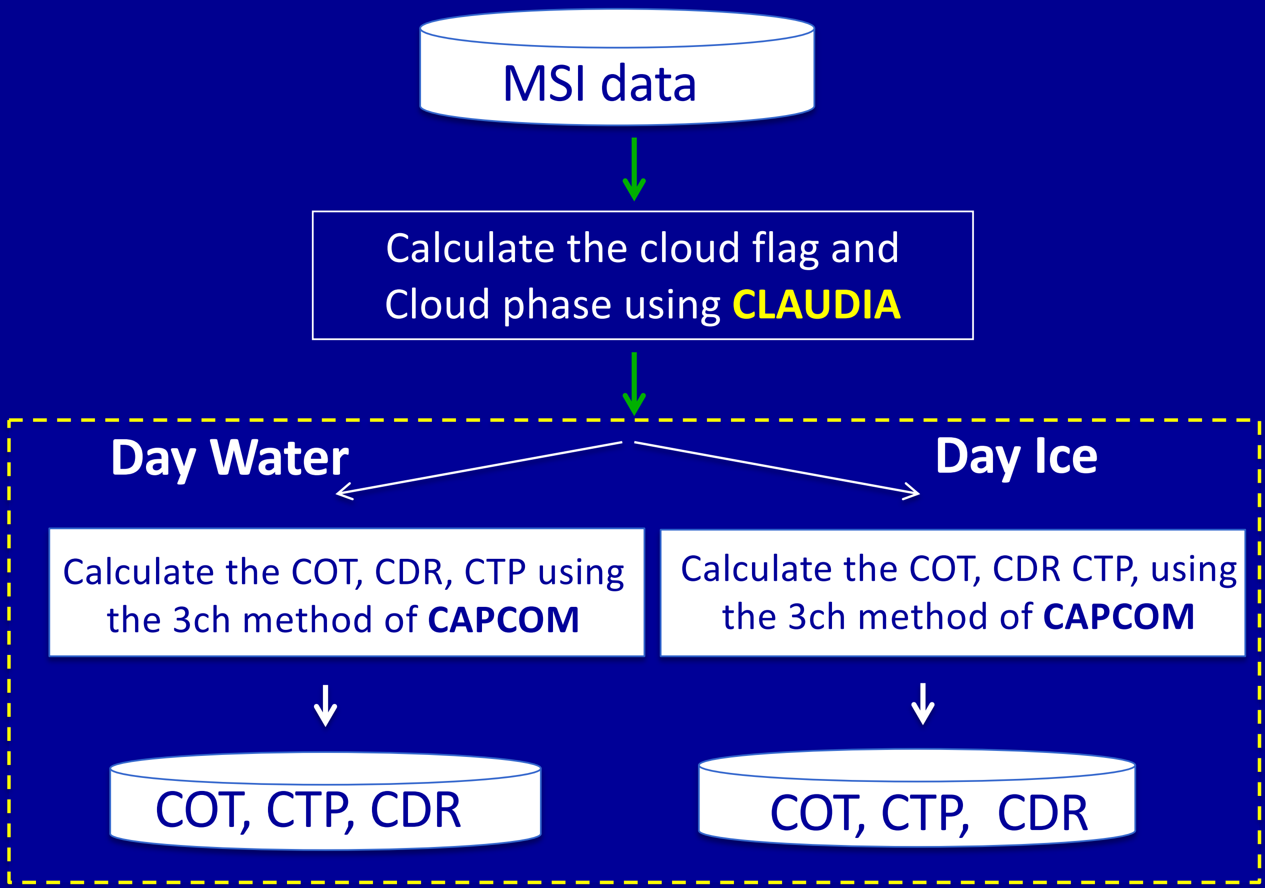
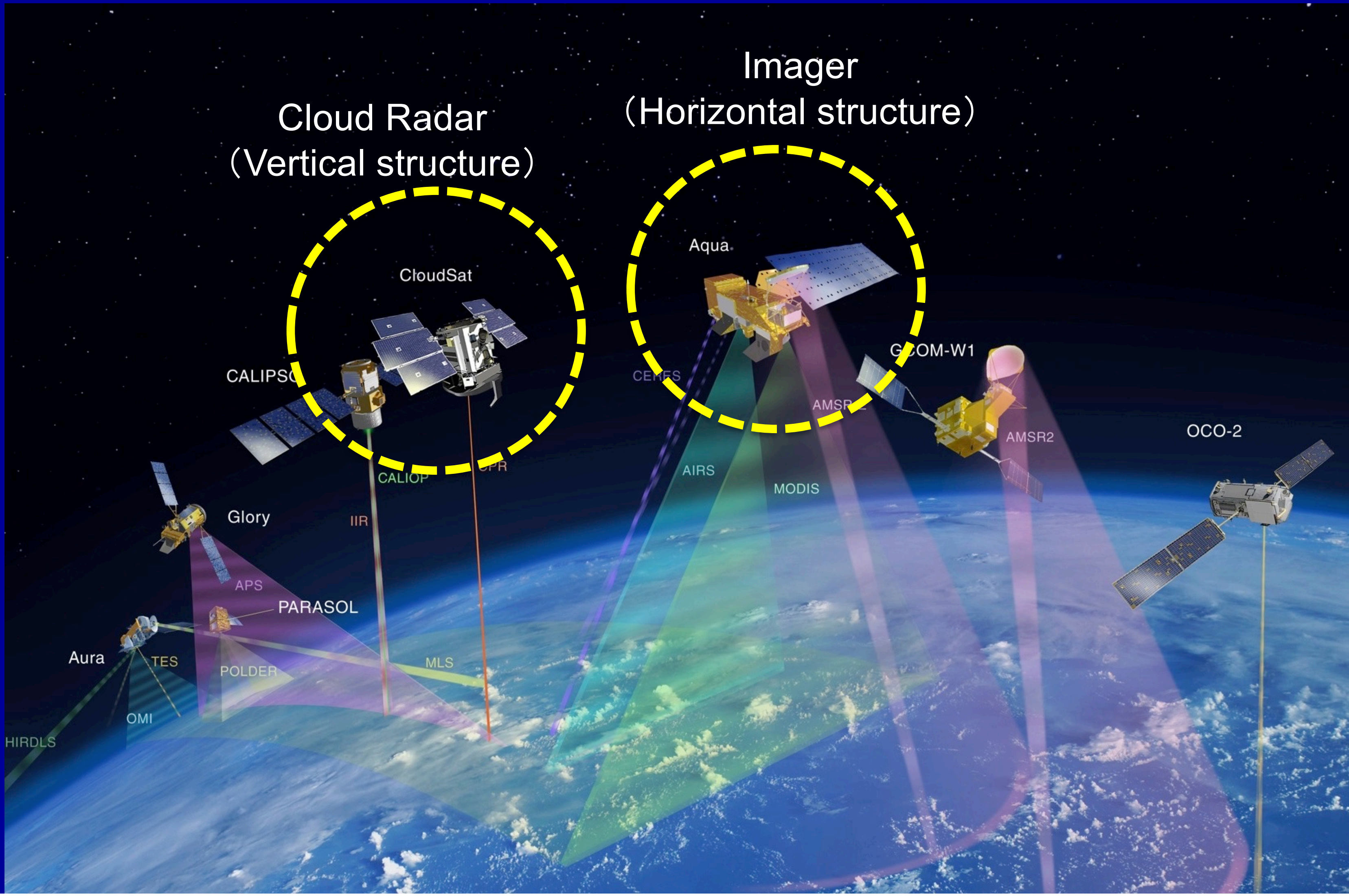


Figure 28. The MSI Optical Bench

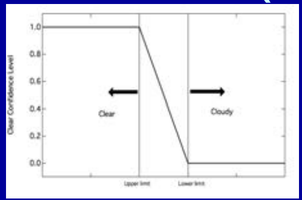
MSI cloud product process



A-Train :　CloudSat + Aqua/MODIS



CLAUDIA algorithm (for cloud flags)



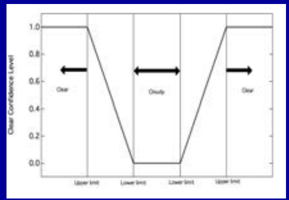
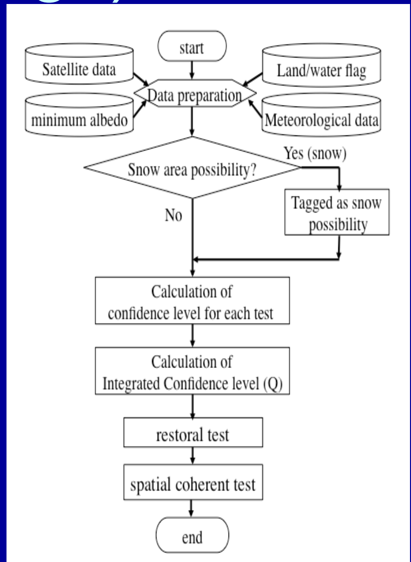
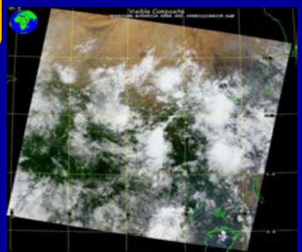


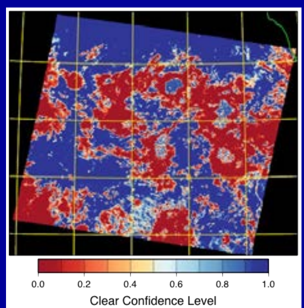
Table 6. Individual Tests and Thresholds[a]

Tests	Ocean Group	Ocean Threshold	Land Group	Land Threshold	Polar Group	Polar Threshold
R0.67 (land or polar) or R0.87 ocean)	1	Rmin +0.12∓0.075	1	Rmin +0.18∓0.075	1	Rmin +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."

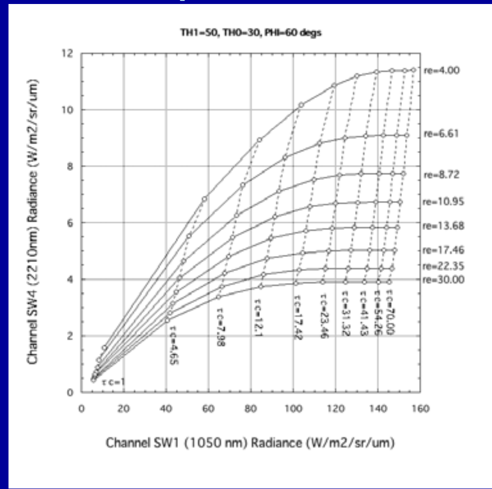


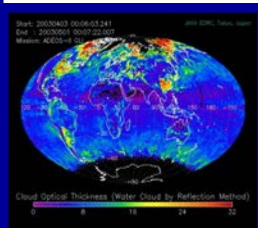


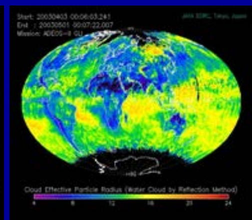


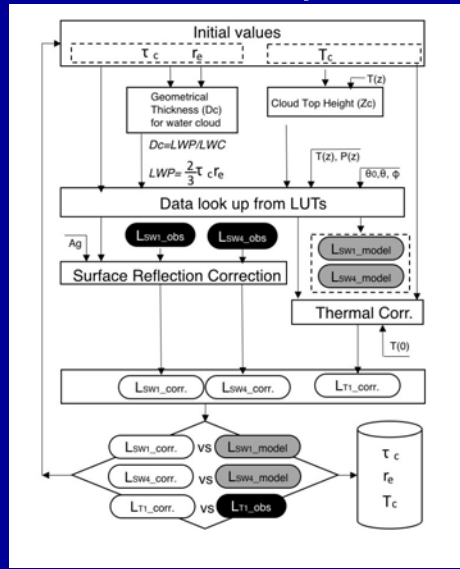
Ishida, H., and T. Y. Nakajima, 2009: Development of an unbiased cloud detection algorithm for a spaceborne multispectral imager. Journal of Geophysical Research-Atmospheres, 114, doi:10.1029/2008JD010710.
Nakajima, T. Y., T. Tsuchiya, H. Ishida, and H. Shimoda, 2011: Cloud detection performance of spaceborne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

CAPCOM algorithm (for cloud properties)







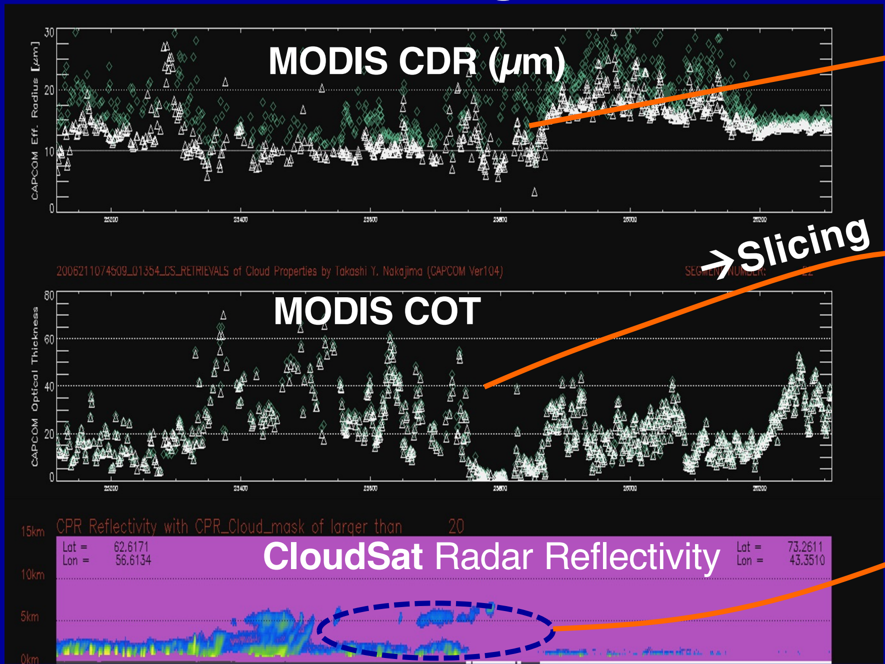


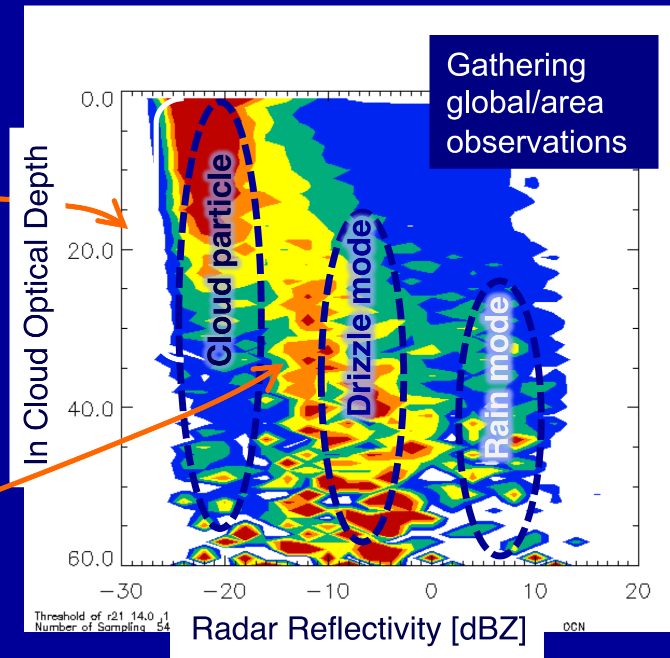
Nakajima, T. Y., and T. Nakajima, 1995: Wide-area determination of cloud microphysical properties from NOAA AVHRR measurements for FIRE and ASTEX regions. Journal of the Atmospheric Sciences, 52, 4043-4059.
Kawamoto, K., T. Nakajima, and T. Y. Nakajima, 2001: A global determination of cloud microphysics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

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

A-Train flight direction →

A case of, 14μm<CDR<16μm

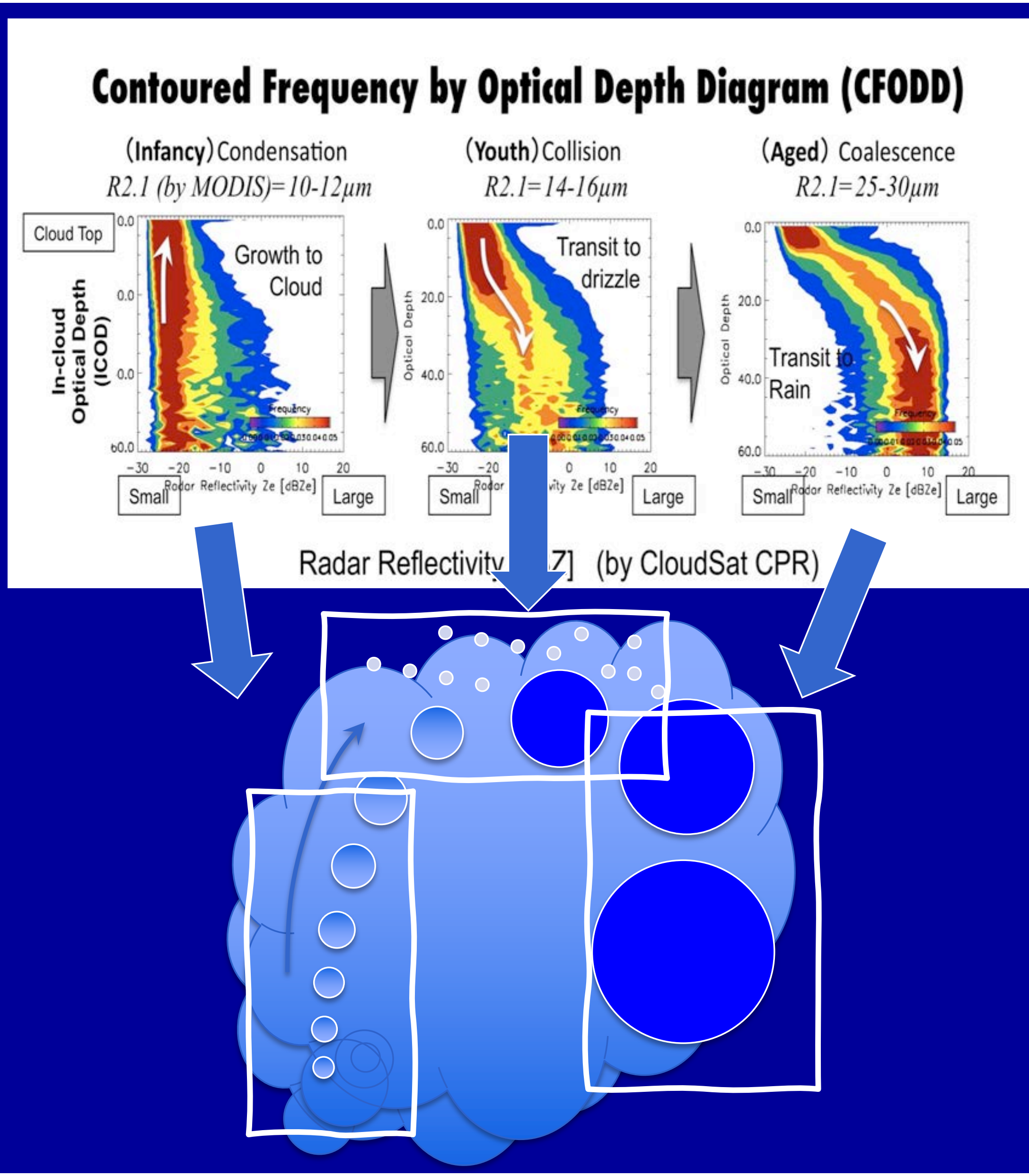




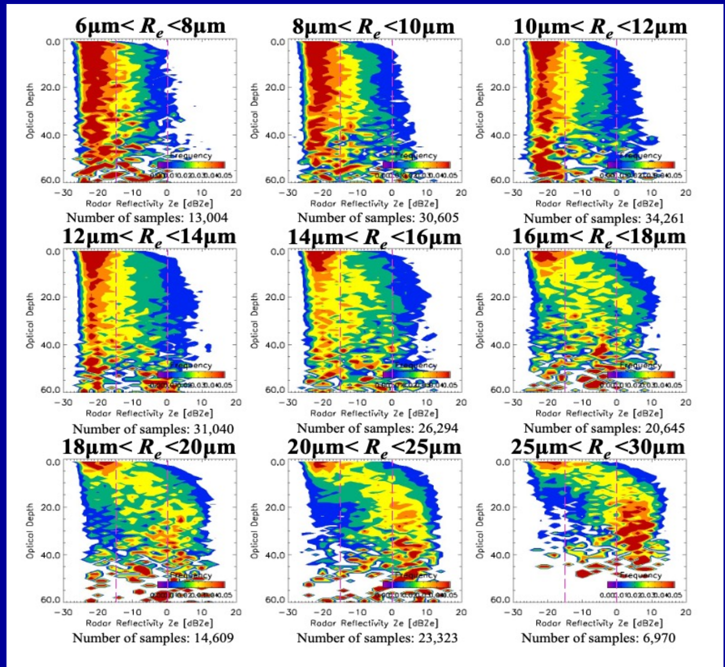
Nakajima, T. Y., K. Suzuki, and G. L. Stephens, 2010: Droplet growth in warm water clouds observed by the A-Train. Part II: A Multi-sensor view. J. Atmos. Sci., 67, 1897-1907.

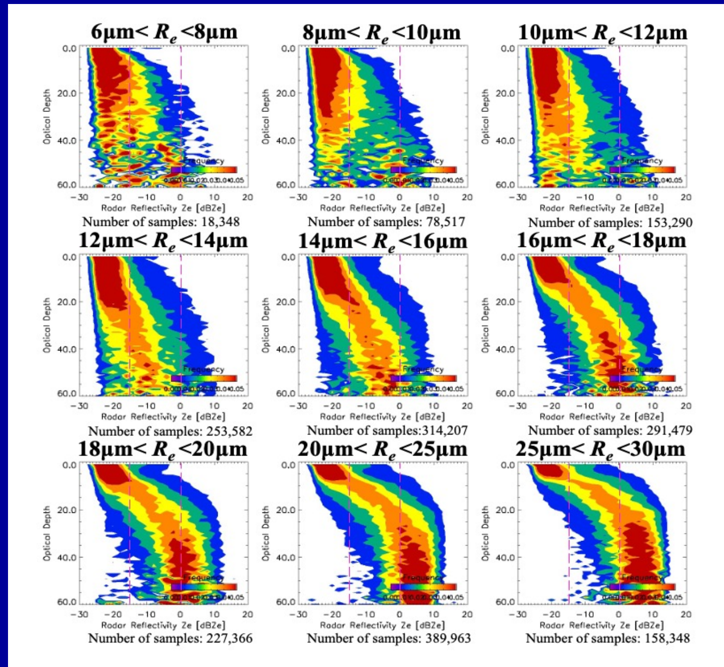
Visualizing Cloud Growth from space

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



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



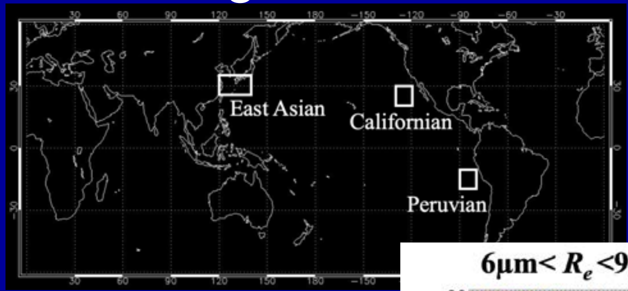


Global (Land) Global (Ocean)

Satellite Data (April, 2007 to 2014)

Matsumoto et al. 2022

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

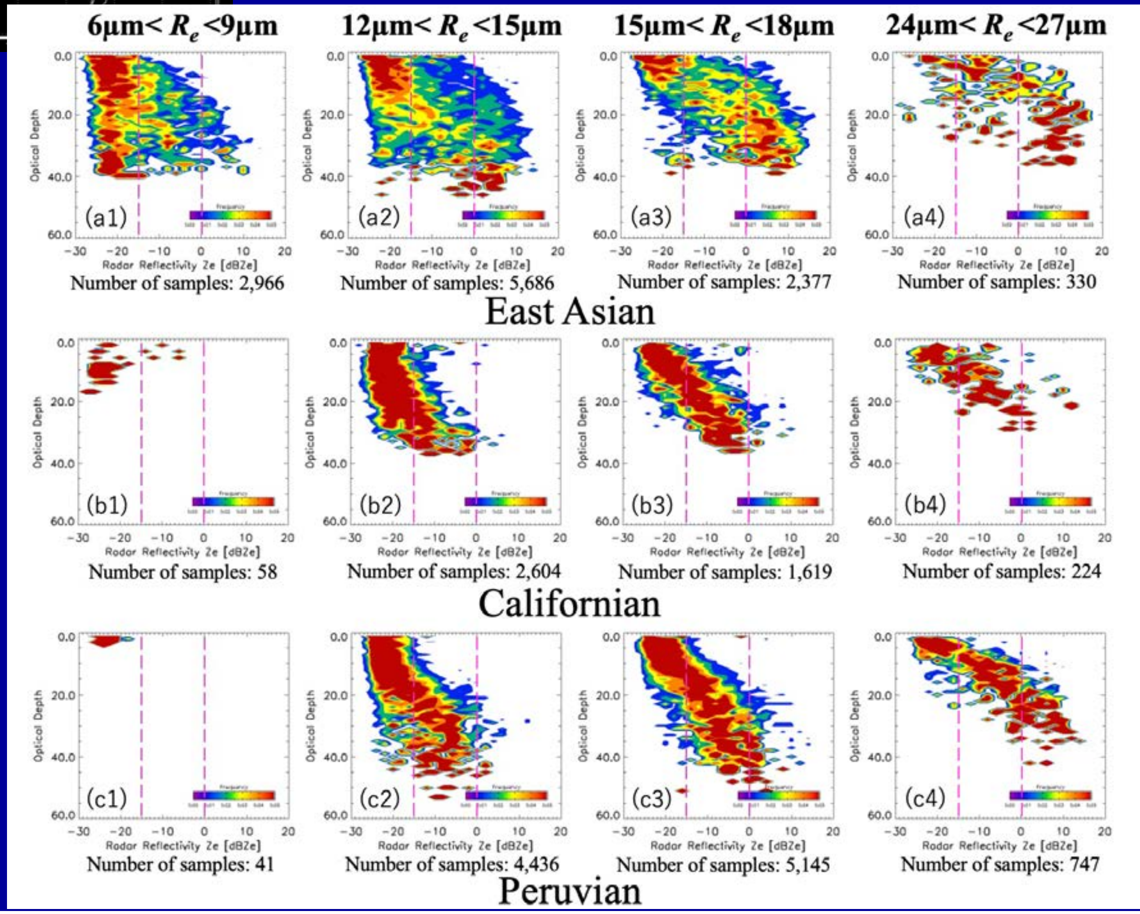


Matsumoto, Y., M. Wang, Y. Sato, and T. Y. Nakajima, 2023: Regional dependency of the cloud droplet growth process in combined analysis of Aqua MODIS and CloudSat CPR. *SOLA*, **19,** 63-69.

East Asian →

Californian →

Peruvian →



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Diagnosis of the Aerosol Effects using CFODD

$$AI = \tau_a \alpha$$

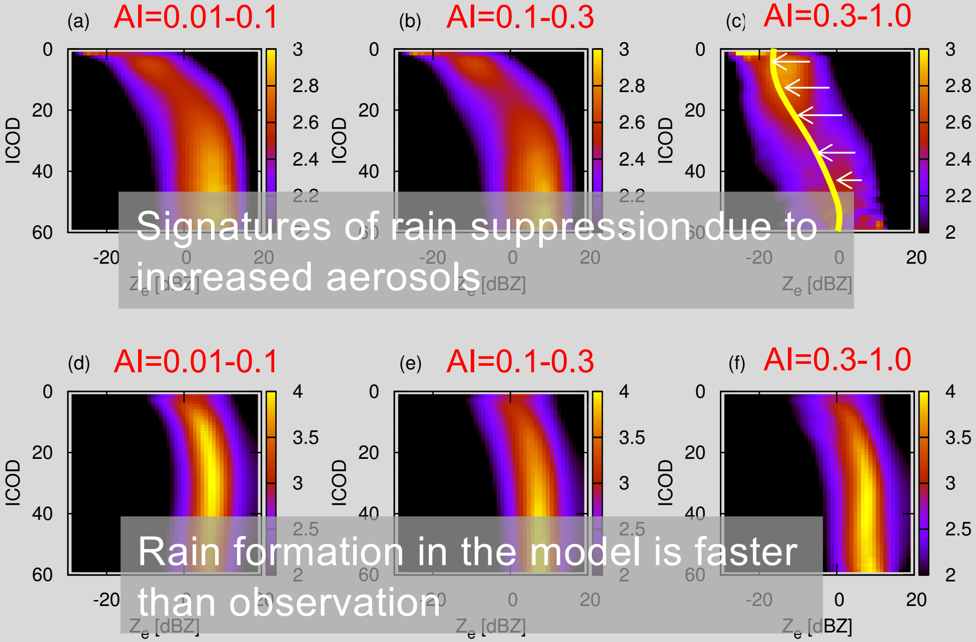
Pristine | Moderate | Polluted

A-Train Observation

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

NICAM-SPRINTARS

A Global Cloud Resolving model



Signatures of rain suppression due to increased aerosols

Rain formation in the model is faster than observation

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.

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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

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