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)

Due to SO2 release, CDR decreased 15μm → 12μm - 5 W/m² change in SW radiation (Eguchi et al. 2011)

CDR (Effective particle radius)
Data: Terra/MODIS
Algorithm: CAPCOM Ve4.02

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, **CFOODD** (Contoured Frequency by Optical Depth Diagram)

A-Train flight direction ➔

A case of, 14µm<CDR<16µm

![Diagram of CloudSat Radar Reflectivity, MODIS CDR (µm), MODIS COT, and radar reflectivity plot](image)

- **CloudSat Radar Reflectivity**
- **MODIS CDR (µm)**
- **MODIS COT**
- **Gathering global observations**

Slicing

Rain mode

Drizzle mode

Cloud particle

In Cloud Optical Depth

Radar Reflectivity [dBZ]
Visualizing Cloud Growth from space

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

Contoured Frequency by Optical Depth Diagram (CFODDD)

Condensation
CDR (by MODIS) = 10-12μm

Collision
CDR (by MODIS) = 14-16μm

Coalescence
CDR (by MODIS) = 25-30μm

Condensation
Growth to Cloud

Collision
Transit to drizzle

Coalescence
Transit to Rain

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**

$$AI = \tau_a \alpha$$

### A-Train Observation
- MODIS Cloud products
- MODIS Aerosol Products
- CloudSat CPR Reflectivity

### NICAM-SPRINTARS
A Global Cloud Resolving model

**Pristine**
- $AI=0.01-0.1$

**Moderate**
- $AI=0.1-0.3$

**Polluted**
- $AI=0.3-1.0$

- **Signatures of rain suppression due to increased aerosols**
- **Rain formation in the model is faster than observation**

Suzuki et al. (2012, JGR in press)
found that hexagonal cell structures (i.e., open cell structures) are produced in the pristine experiment. Precipitation occurs in the pristine experiment at the center of the hexagonal cells. This cloud structure and its aerosol dependence are the same as found by Wang and Feingold (2009), and are also consistent with proposals of cloud field changes caused by aerosol effects (Twomey 1974; Albrecht 1989).

Figure 4 shows CFODDs obtained from model results at $t = 6$ h, while Fig. 5 presents CFODDs obtained from satellite observations in the East Asian region (Figs. 5a–e) and in the California coast region (Figs. 5f–j). Arrows and rectangles are described in the text, and Arabic and capital Greek numbers are used for rectangles and arrows, respectively.

3-D Spectral Bin Microphysical model (SBM) simulation

[Sato et al. 2012]
Research plots for understanding retrieved cloud properties

**Numerical Experiment**
- Vertical (±drizzle)
  - Nakajima T. Y. et al. 2010a [2-layer model]
  - Nagao T. M. et al. 2013 (in revision) [Bin-model + 1DRT]
- Sub-pixel Horizontal
  - Zinner et al., 2010 [LES+3DRT]
- 3D-RT
  - Zhang and Platnick et al., 2011

**Satellite**
- 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

Satellite Observations
Satellite Observations
GCOM-W GCOM-C

Bin-method Simulation

Radius

Altitude

Comparison between Sat. vs Models.

(d) NICAM-SPRINTARS Effective Radius
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-).


Nakajima, T. Y., 2012: Algorithm development for the satellite measurements of cloud properties, Tenki. 59.11, 3-16. (in Japanese)


