Validation of CERES ST Retrieved MODIS Cloud Properties Using DOE AMF-China and Cloudsat/CALIPSO Observations

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Objectives

1. Compare ARM radar-lidar derived cloud base and top heights with MODIS derived effective cloud height over Shouxian, China (ARM Mobile Facility, AMF, 32°33’N, 116°47’E).

2. Compare cloud microphysical properties derived from ARM radar-radiometer with CERES-MODIS retrievals.

3. Compare cloud profiles observed/retrieved from CloudSat and ARM radar-radiometer with
DOE AMF-China Measurements and Retrievals

**Hbase and Htop:** Cloud-base and -top heights determined by ARM cloud radar-lidar measurements

**Liquid water path (LWP):** Microwave radiometer

**Cloud droplet effective radius re:** retrieved by radar reflectivity and LWP

**Optical depth Tau:** $1.5 \times \text{LWP}/\text{re}$

All results are averaged over 1-hr period centered on TERRA overpass AMF-China site during Oct. 15 - Dec. 15, 2008.
CERES-MODIS cloud height and Microphysics
(Ed_2G SSF products, TERRA only)

**Effective cloud height** $H_{\text{eff}}$: defined as the lowest altitude having $T_{\text{eff}}$ in the GEOS vertical profile of atmospheric temperature.

Note that $H_{\text{eff}}$ is the cloud radiative center from satellite point of view, not cloud physical center.

**Daytime:** the 4-channel VISST (Visible Infrared Solar-Infrared Split-window Technique).

**Nighttime:** the 3-channel Solar-infrared Infrared Split-window Technique [SIST].

**Effective radius** $r_e$: derived from 3.7-um radiance

**Optical depth** $\tau$: visible (day) and solar-infrared (night)

$LWP \sim r_e \times \tau$
CloudSat/CALIPSO measurements/retrievals

- **CloudSat/Calipso (CC):** (Results from CSU and CCCM)
  Level 2B data products, averages over a $1^\circ \times 1^\circ$ grid box

**Hbase/Htop heights:** determined by both 94 GHz radar and Lidar with a vertical resolution of 240 m.

**Liquid/ice particle sizes and contents/paths:** retrieved from 94 GHz radar (Radar only, works for both day and night time with higher uncertainty than radar+ visible optical depth)
Objective 1:

Compare ARM radar-lidar derived cloud base and top heights with CERES-MODIS derived effective cloud height over Shouxian, China (ARM Mobile Facility, AMF, 32°33’N, 116°47’E).
1. Most of CERES-MODIS derived effective cloud heights $H_{eff}$ are within ARM radar-lidar derived cloud bases and tops.

2. But why some $H_{eff}$ are close to cloud tops (Samples 5 and 6), while some (Samples 10 and 11) are near cloud centers or bases.
What results do we expect to get from the cloud height comparison?

Optically thick

Optically thin

Top

Center

Base

Note that MODIS derived $H_{eff}$ is the cloud radiative center, not cloud physical center.
As $\tau \sim 5 \Rightarrow \varepsilon \sim 1$, the radiance mostly from cloud top $\Rightarrow H_{\text{eff}} \sim H_{\text{top}}$

For $\tau < 1$, $H_{\text{eff}} \sim H_{\text{base}}$

Effective Emittance

$\varepsilon(\text{Sassen}) = 1 - \exp(-0.51\tau_{\text{vis}})$

$\varepsilon(\text{Minnis}) = 1 - \exp[-0.471(\tau_{\text{vis}}/u)^{1.01}]$
$H_{\text{eff}}$ near cloud top (Sample 6)

MODIS: $H_{\text{eff}}=8$ km, $\tau=60$
$H_{\text{eff}}$ near cloud base (Sample 11)

MODIS: $\tau = 6.3$

$H_{\text{eff}} = 8.3$ km (radiative center)
Comparison of TERRA MODIS with AMF–China (10/15–12/15, 2008)

Nighttime

Cloud Base = 4.04
Cloud Top = 8.23
Effective Height = 7.39

Nighttime comparison is similar to its daytime counterpart
1) Most of MODIS $H_{eff}$ are around cloud centers (▲).
2) $H_{eff}$ values have higher correlation with cloud tops.
Objective 2

Compare cloud microphysical properties derived from ARM radar-radiometer with MODIS retrievals (liquid-phase only)
1) The difference between ARM and MODIS is 1.7 µm with low correlation because MODIS represents cloud top.
2) Correlations for optical depth and LWP are high, but MODIS values are smaller than ARM results, mainly from samples 2 and 8.
Sample 2: 20081028_02 UTC (daytime)

ARM: \( \tau = 78 \), \( \text{LWP} = 561 \)

MODIS: \( \tau = 35 \), \( \text{LWP} = 261 \)

IWP = 300
Sample 8: 20081107_14 UTC (Nighttime)

ARM: $\tau = 82, \text{LWP} = 342$

MODIS: $\tau = 13, \text{LWP} = 95$

$IWP = 57$

It is beyond the upper limit of MODIS night-time retrievals
Objective 3

Compare cloud profiles observed/retrieved from CloudSat and ARM radar-radiometer with MODIS retrievals
Case 1

Excellent agreement in CloudSat and ARM radar reflectivity measurements.
Case 1: 20081031

1) Excellent agreement in radar reflectivity between Cloudsat and ARM

2) MODIS retrieved ice particle diameter is close to Cloudsat retrieval, but why its height is much higher than ARM and CloudSat/CALIPSO?
Case 2

There is some difference, but they are at the same range and Cloudsat is about 10 km away from AMF-China.
1) ARM radar reflectivity is slightly higher than CloudSat.
2) MODIS retrieved effective radius agree very well with CloudSat retrievals.
Conclusions

1) Cloud height comparison:
Most of CERES-MODIS effective cloud heights $H_{\text{eff}}$ fall within ARM radar-lidar derived cloud bases & tops, and have highest correlation with cloud top.

2) Cloud Microphysics comparison:
- The re difference between ARM and MODIS is 1.7 µm with low correlation because MODIS re represents cloud top.
- Correlations for optical depth and LWP are high, but MODIS values are smaller than ARM results.
3) Cloud Profile comparison:
- ARM and CloudSat radar reflectivity agree well in both cases.
- CERES-MODIS retrieved liquid and ice particle size agree well with CloudSat retrievals. Only 2 samples.
Thanks for your attention
What are sensitivities of ARM cloud radar and CloudSat (94 GHz)

**Case 1**
- ARM (blue line): -60 dbz at 1 km
- -40 dbz at 10 km (due to water vapor attention)

**Case 2**
- CloudSat (red): -60 dbz at upper level
- 0 dbz at 1 km
- 0 dbz at 10 km

**Clouds**
CloudSat/CALIPSO (CC)

- Part of A-train constellation of satellites
  - Trails Aqua by one minute
- CloudSat: On-board 94 GHz cloud profiling radar
  - Obtains cloud profile information in addition to cloud microphysical properties
  - 1.7 km along-track resolution by 1.4 km cross-track resolution
- CALIPSO: On-board Cloud Aerosol Lidar
  - Operates at 532 and 1064 nm
  - 100 m footprint
  - 333 m horizontal resolution
  - 30-60 m vertical resolution