DCS cloud comparison between MODIS/GOES and ARM surface-aircraft measurements during MC3E at ARM SGP

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ARM observations/retrievals during MC3E

- **Cloud top height:** KAZR radar at DOE ARM SGP site;
- **Particle size:** using newly developed retrieval algorithms
  
  **Method 1:** retrieved re based on KAZR reflectivity and number concentration measured by UND Citation;
  
  **Method 2:** retrieved re based on the terminal velocity;

Both are compared with UND aircraft in situ data
Cloud-top height comparison between radars and MODIS/GOES (May 20th, 2011)
Terra MODIS heights (T1 & T2) agree with radar cloud-top heights; $Z_{top}$ at Aqua overpass (A2) is lower than the radar measured cloud top. This is reasonable for optically thin clouds. $Z_{top}$ at A1 is ~ 1 km higher than the radar cloud top because it is surrounded by the convective core and the radar signal might be attenuated by the precipitation, but NEXRAD detected $Z_{top}$ ~ 14 km.
System moved from SW to NE, passed over ARM SGP site
GOES retrieved cloud properties at 15:45Z

Ice phase

T_{top} = 210K

H_{top} = 13 km

Thickness = 10 km

10 am: Core Passed SGP
Conclusion: Both MODIS and GOES retrieved cloud-top heights for DCS are within ARM Cloud and NEXRAD radar observations for this case.
Two new methods are developed to retrieve DCS particle size \( re \)

- Black lines are aircraft flight tracks. The aircraft measurements above 6 km will be used for validating M1 and M2 ice cloud \( re \) values.
- M1 \( re \) values have much finer vertical resolution than those from M2.
- M1 \( re \) values increase from 50 um at cloud top to 300 um at 7 km, they are about 25-50 um smaller than those from M2 at upper levels.
Validation of **M1** and **M2** results using aircraft data

Although their means are close to each other, the correlation of **M1** retrieved \( r_e \) with aircraft data is 0.7, while **M2** is 0.11. Both methods need to be further validated by aircraft data with more cases during MC3E IOP.
Method 1: Combined KAZR reflectivity with Aircraft measured cloud number concentration.

<table>
<thead>
<tr>
<th></th>
<th>M1 re</th>
<th>MODIS re</th>
<th>Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>50-75um;</td>
<td>25.6 um</td>
<td>NO</td>
</tr>
<tr>
<td>A1</td>
<td>5-25 um;</td>
<td>25.5 um</td>
<td>YES</td>
</tr>
<tr>
<td>T2</td>
<td>50-75um;</td>
<td>53.2 um</td>
<td>YES</td>
</tr>
<tr>
<td>A2</td>
<td>100-125um</td>
<td>35.0 um</td>
<td>NO</td>
</tr>
</tbody>
</table>

More cases will be compared for next CERES STM, and will refine our retrieval methods.
GOES retrieved cloud properties at 15:45Z

ARM re values range from 75-125 um, GOES De values range from 75-120 um.
Thanks for your attention!
Parameterization of Cloud thickness vs cloud LWP and cloud-top temp

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Data

• Data used
  – ARM SGP Site (Oklahoma) 10 years of data (1997-2006)
  – ARM Azores site (Atlantic) 19 months of data (2009-2010)
  – ARM NSA site (Barrow, Alaska) 6 years of data (1999-2004)
    • Only use May-September data for NSA site

• Variables
  – Liquid Water Path
  – Cloud Thickness
  – Cloud Top Temperature
Methods

• Cloud Top Temperature Threshold = 260K+
• Low Clouds (Cloud Top Height < 4km)
• Removed twilight hours (except NSA site)
• Cloud Thickness > 50 m
• Liquid Water Path must be between 20 and 700 g/m²
• Bin
  – Took average of all values every 250 meters of cloud thickness
• Multiple Linear Regression line fit
• Statistics
  – Multiple linear correlation coefficient (R-Value)
\[ \Delta Z = 0.0021 \times \text{LWP} - 0.004 \times (T_{\text{top}} - T_0) + 0.588 \]

\[ \text{R-value} = 0.458 \]
• $\Delta Z = 0.0029 \times LWP - 0.037 \times (T_{\text{top}} - T_0) + 0.784$
• R-value = 0.72
$$\Delta Z = 0.0025 \times LWP - 0.015 \times (T_{\text{top}} - T_0) + 0.359$$

- R-value = 0.45
Conclusion/Future Improvements

• Similarities between ARM sites
  – Linear relationship between Cloud Top temperature and Cloud Thickness
  – Logarithmic relationship between Liquid Water Path and Cloud Thickness

• Differences between ARM sites
  – Due to the high variability of data at the NSA the slope of the line is much smaller compared to the other sites.

• SGP data has better relationship for $\Delta Z$ and LWP, but not for cloud temp.
  – Derived seasonal relationships?

• Azores data has better linear correlation
  – Less extreme seasons

• Include weighting to account for instrumental error
Method 1: assume $\rho = 1$ (water)

Re at T2 overpass is the most close one to our retrieval, and the other 3 are much smaller than Re retrieved by M1.

$IWP(SFC) = 648 / 1190 \text{ gm}^{-2}$
$IWP(CERES) = 515 / 878 \text{ gm}^{-2}$. 
Bulk density: $\rho$

$\rho(Z) = a \times \exp(bZ)$
Re retrieved by Method 2: assume $\rho(Z) = a \times \exp(bZ)$
Since there is aircraft measurement (IWC) closed to T2 overpass, we compared the IWP calculated by using aircraft measured IWC and NEXRAD cloud thickness over 30x30 km$^2$ and 100x100 km$^2$ centered at SGP.
A2: Aqua over pass at 19:55Z over SGP
Provided by Yan Chen
## Cloud droplet terminal fall speed

**TABLE 8.1. Terminal Fall Speed as a Function of Drop Size (equivalent spherical diameter) (From Cima and Kessler, 1979)**

<table>
<thead>
<tr>
<th>Diam. (mm)</th>
<th>Fallspeed (m/s)</th>
<th>Diam. (mm)</th>
<th>Fallspeed (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>0.27</td>
<td>1.6</td>
<td>2.5</td>
</tr>
<tr>
<td>0.2</td>
<td>0.72</td>
<td>2.0</td>
<td>2.8</td>
</tr>
<tr>
<td>0.3</td>
<td>1.17</td>
<td>2.4</td>
<td>3.0</td>
</tr>
<tr>
<td>0.4</td>
<td>1.62</td>
<td>2.8</td>
<td>3.2</td>
</tr>
<tr>
<td>0.5</td>
<td>2.06</td>
<td>3.2</td>
<td>3.4</td>
</tr>
<tr>
<td>0.6</td>
<td>2.47</td>
<td>3.6</td>
<td>3.6</td>
</tr>
<tr>
<td>0.7</td>
<td>2.97</td>
<td>3.8</td>
<td>3.8</td>
</tr>
<tr>
<td>0.8</td>
<td>3.27</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>0.9</td>
<td>3.53</td>
<td>4.2</td>
<td>4.2</td>
</tr>
<tr>
<td>1.0</td>
<td>3.83</td>
<td>4.4</td>
<td>4.4</td>
</tr>
<tr>
<td>1.2</td>
<td>4.61</td>
<td>4.6</td>
<td>4.6</td>
</tr>
<tr>
<td>1.4</td>
<td>5.17</td>
<td>4.8</td>
<td>4.8</td>
</tr>
<tr>
<td>1.6</td>
<td>5.65</td>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td>1.8</td>
<td>6.09</td>
<td>5.2</td>
<td>5.2</td>
</tr>
<tr>
<td>2.0</td>
<td>6.49</td>
<td>5.4</td>
<td>5.4</td>
</tr>
<tr>
<td>2.2</td>
<td>6.80</td>
<td>5.6</td>
<td>5.6</td>
</tr>
<tr>
<td>2.4</td>
<td>7.27</td>
<td>5.8</td>
<td>5.8</td>
</tr>
</tbody>
</table>

1) $0 < r < 40 \text{ um}$, $V_f = K_1 r^2$, Stokes’ law, $K_1 = 1.19 \times 10^6 \text{ cm}^{-1} \text{ S}^{-1}$
2) $40 < r < 0.6 \text{ mm}$, $V_f = K_2 r$, linear law, $K_2 = 8 \times 10^3 \text{ S}^{-1}$
3) $0.6 < r < 2 \text{ mm}$, $V_f = K_3 r^{1/2}$, Square root law, $K_3 = 2.2 \times 10^3 (\rho/\rho_0)^{1/2} \text{ cm}^{-1} \text{ S}^{-1}$, $\rho$ is air density, $\rho_0$ is a reference density of 1.2 kg/m3. (Rogers and Yau book, P124-126)
how to get $z$ (radar reflectivity factor)

- All the Doppler weather radars provide a measurement of equivalent radar reflectivity factor.

- use drop size distribution, particle size data

$$Z = \int_{0}^{\infty} N(D)D^6 dD$$

When particle size data are analyzed to determine radar variables, the quantity usually calculated is the radar reflectivity factor $Z$ and not the equivalent radar reflectivity factor $Ze$. (Smith, 1984)
equivalent radar reflectivity factor—radar reflectivity factor relationship for ice particles:

For ice particles:

\[ Z_e = \frac{|K|^2_i}{|K|^2_w} Z. \]

From KAZR

Dielectric factor: 0.88

(Atlas, 1995; Smith, 1984; Wang 2001)
\( \frac{K_i}{\rho_i} \) is nearly constant as particle bulk density changes. For solid ice, bulk density is about 0.92 g cm\(^{-3}\), and \( K_i^2 = 0.176 \). (ATLAS, 1995)

\[
\left( \frac{K_i}{\rho_i} \right)^2 \approx 0.208.
\]

\[
K_i^2 = 0.208 \times \rho_i^2
\]
Cirrus layer microphysical properties derived from surface-based millimeter radar and infrared interferometer data

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\[ N(D) = N_x \exp(\alpha) \left( \frac{D}{D_x} \right)^\alpha \exp \left( -\frac{D \alpha}{D_x} \right) \]  

(2)

where \( D_x \) is the modal diameter and \( N_x \) is the number of particles per unit volume per unit length at the functional maximum. Analysis of in situ data [Dowling and Radke, 1990] suggests that for cirrus \( \alpha \leq 2 \). We therefore set \( \alpha = 1 \) and use observations to estimate \( D_x \) and \( N_x \).
\[ Z = \int_0^\infty N(D)D^6 dD \]

\[ N(D) = N_x \exp(\alpha \left( \frac{D}{D_x} \right)^\alpha) \exp \left[ -\frac{D\alpha}{D_x} \right] \]

\[ Z = N_x e^{\alpha} D_x^7 \frac{(6+\alpha)!}{\alpha^7+\alpha} \]

\[ N_T = D_x N_x e^{\alpha} \frac{\alpha}{\alpha^{\alpha+1}} \]

\[ r_e = \frac{D_x}{2} \frac{(3+\alpha)!}{(2+\alpha)!} \alpha^{\alpha} \]

Nt is the total particle concentration

e is the effective spherical radius

\[ Z = N_T * 2^6 * r_e^6 * \frac{(6+\alpha)!}{\alpha^{6\alpha+7} * (3+\alpha)^6} * 10^{-12} \quad (mm^6 / m^3) \]