CONTRASTING LIDAR RETRIEVED CIRRUS OPTICAL PROPERTIES WITH IN-SITU AND ASSOCIATED CRF: RETHINC FIELD CAMPAIGN HOUSTON, TX - AUG 2017

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July 12th

15th AMS Cloud & Radiation Conference
Radiative Effects of Thin Cirrus

More accurately quantify cirrus radiative effects
- Synoptic vs. Convectively developed Cirrus

NRL sponsored campaign
- Ellington Field Houston, TX.
- NASA JSC WB-57 aircraft (~60k feet)

3 year campaign
- 2 Years Houston, TX (2017 & 2018)
- Last year Fairbanks, AK (2019)

SPEC inc. (Boulder, CO)
- Crystal habit
  - (Large variation with formation mechanism)
- Effective Crystal size
- Size distribution
- Ice water content
- Derived extinction coefficient

Radiometer Array (NRL)
- Direct irradiance measurements above and below cirrus cloud layer

Cloud Physics Lidar (GSFC)
- Cloud height & thickness
- Parameterized microphysical & optical properties
- Compare lidar derived microphysical & optical properties to in-situ profile
- Average lidar segment in step function
- Analyzed 4 of 6 flights from campaign
### CPL MICROPHYSICAL & OPTICAL PROPERTIES

#### Extinction Coefficient
- **Lidar Ratio**
  - (Extinction/Backscatter)
  - Klett Method (Klett 1981; 1985)
- LR assumed vertically constant through layer
  - Can be directly calculated (constrained)
  - Transmission loss method
  - Use of look up table

#### Ice Water Content & Particle Effective Diameter
- Heymsfield *et al.* 2014
  - CATS (ISS)
  - CALIPSO (A-Train)
- Effective diameter function of temperature profile
- IWC function of extinction and effective diameter
CPL & SPEC
PROFILE COMPARISONS

August 11th 2017

RMSE : 30.5 µm

CPL COD: 0.15
SPEC COD: 0.07
## IWC AND EXTINCTION

<table>
<thead>
<tr>
<th>Date</th>
<th>Extinction (km(^{-1})) Mean &amp; Std Dev</th>
<th>IWC (g m(^{-3})) Mean &amp; Std Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CPL</td>
<td>SPEC</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>July 27(^{th})</td>
<td>0.22</td>
<td>0.20</td>
</tr>
<tr>
<td></td>
<td>+/- 0.10</td>
<td>+/- 0.21</td>
</tr>
<tr>
<td>Aug 06(^{th}) * Thick Anvil</td>
<td>0.23</td>
<td>0.92</td>
</tr>
<tr>
<td></td>
<td>+/- 0.12</td>
<td>+/- 1.29</td>
</tr>
<tr>
<td>Aug 10(^{th})</td>
<td>0.29</td>
<td>0.033</td>
</tr>
<tr>
<td></td>
<td>+/- 0.16</td>
<td>+/- 0.033</td>
</tr>
<tr>
<td>Aug 11(^{th})</td>
<td>0.050</td>
<td>0.027</td>
</tr>
<tr>
<td></td>
<td>+/- 0.062</td>
<td>+/- 0.072</td>
</tr>
</tbody>
</table>
## EFFECTIVE DIAMETER COMPARISON

<table>
<thead>
<tr>
<th>Date</th>
<th>CPL Mean $D_{\text{eff}}$</th>
<th>SPEC Mean $D_{\text{eff}}$</th>
<th>$D_{\text{eff}}$ RMSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>July 27\textsuperscript{th}</td>
<td>65.0 µm +/- 23.1</td>
<td>114.9 µm +/- 41.2</td>
<td>48.9 µm</td>
</tr>
<tr>
<td>Aug 06\textsuperscript{th} *</td>
<td>163.4 µm +/- 32.3</td>
<td>141.0 µm +/- 54.6</td>
<td>50.2 µm</td>
</tr>
<tr>
<td>Aug 10\textsuperscript{th}</td>
<td>102.3 µm +/- 48.0</td>
<td>100.6 µm +/- 19.2</td>
<td>28.0 µm</td>
</tr>
<tr>
<td>Aug 11\textsuperscript{th}</td>
<td>65.0 µm +/- 47.7</td>
<td>64.7 µm +/- 40.2</td>
<td>30.5 µm</td>
</tr>
</tbody>
</table>
LIDAR VS. SPEC
CRYSTAL EFFECTIVE DIAMETER

**July 27th 2017**

Altitude (km) vs. Effective Diameter (µm)

*RMSE: 48.9 µm*

**August 6th 2017**

Altitude (km) vs. Effective Diameter (µm)

*RMSE: 50.2 µm*

**August 10th 2017**

Altitude (km) vs. Effective Diameter (µm)

*RMSE: 28.0 µm*

**August 11th 2017**

Altitude (km) vs. Effective Diameter (µm)

*RMSE: 30.5 µm*
RADIATIVE FORCING SIMULATIONS

- LibRadtran Model (Mayer and Kylling, 2005)
- Thermodynamic profile each flight period
  - GEOS-5
  - Pressure, Altitude, Temperature, Water Vapor, Ozone
- Surface Albedo: 0.2
- Zenith Angle: 24° (Average over all flight periods)
- Ice Optical Properties: Ping Yang et al. 2013
  - Scattering properties & asymmetry parameter
- Lidar prescribed COD input instead of extinction parameterized by model
- Cirrus layer defined by IWC and effective diameter
**SIMULATED TOA RADIATIVE FORCING**

<table>
<thead>
<tr>
<th>Date</th>
<th>Estimated TOA Radiative Forcing</th>
<th>Estimated TOA Radiative Forcing</th>
</tr>
</thead>
<tbody>
<tr>
<td>July 27th</td>
<td>73.4 W m⁻²</td>
<td>15.0 W m⁻²</td>
</tr>
<tr>
<td>August 6th *</td>
<td>41.9 W m⁻²</td>
<td>-14.3 W m⁻²</td>
</tr>
<tr>
<td>August 10th</td>
<td>65.2 W m⁻²</td>
<td>3.10 W m⁻²</td>
</tr>
<tr>
<td>August 11th</td>
<td>17.4 W m⁻²</td>
<td>3.30 W m⁻²</td>
</tr>
</tbody>
</table>

- Large variability in retrieved cloud optical depth and ice water content (~60%)
- Sampling discontinuities
  - Varying horizontal and vertical resolutions
- Temporal variability in cloud layer
  - SPEC in-situ flight profile ~20-40 minutes after CPL overpass
TOA CIRRUS RADIATIVE FORCING

Crystal Habit: Bullet Rosette
(common synoptic cirrus)

Mean Lidar Ratios (sr)

<table>
<thead>
<tr>
<th>Date</th>
<th>Mean LR</th>
</tr>
</thead>
<tbody>
<tr>
<td>July 27th</td>
<td>20.6</td>
</tr>
<tr>
<td>Aug 6th *</td>
<td>23.7</td>
</tr>
<tr>
<td>Aug 10th</td>
<td>21.1</td>
</tr>
<tr>
<td>Aug 11th</td>
<td>25.4</td>
</tr>
</tbody>
</table>
FUTURE WORK

Cirrus Optical Depth

TOA Radiative Forcing (W/m²)

All CPL REThinC Profiles

Crystal Habit: Aggregate of Columns
(more common convective cirrus)

- Analyze CRF dependency on crystal habit
  - To be provided by SPEC upon complete data delivery

- Compare with radiometer measurements from REThinC flights
  - Also to be ready later this summer
CONCLUSIONS

- CPL averaged profile of extinction and ice water content did not agree well with the in-situ
  - Sampling discontinuities
  - Temporal variability/evolution of cirrus layer
    - In-situ flight profile ~20–40 minutes after CPL overpass
    - Large variability in estimated TOA cloud radiative forcing

- CPL parameterized effective diameter agreed moderately well with the in-situ
  - Less horizontal variability

- CRF vs. COD values follow a parabolic trajectory more dependent on layer microphysical properties (habit) than lidar ratio
QUESTIONS?
BACK UP SLIDES
## CPL & SPEC Profile Comparisons

<table>
<thead>
<tr>
<th>Date</th>
<th>Cloud Optical Depth</th>
<th>Ice Water Path (g m(^{-2}))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CPL</td>
<td>SPEC</td>
</tr>
<tr>
<td>July 27(^{th})</td>
<td>0.27</td>
<td>0.27</td>
</tr>
<tr>
<td>Aug 06(^{th}) *</td>
<td>1.22</td>
<td>3.00</td>
</tr>
<tr>
<td>Aug 10(^{th})</td>
<td>0.86</td>
<td>0.31</td>
</tr>
<tr>
<td>Aug 11(^{th})</td>
<td>0.15</td>
<td>0.07</td>
</tr>
<tr>
<td><strong>Mean % Difference</strong></td>
<td><strong>66.8 %</strong></td>
<td></td>
</tr>
</tbody>
</table>
LIDAR VS. SPEC
EXTINCTION COEFFICIENT
Substitute lidar ratio in for extinction

\[
[\beta_A(r) + \beta_M(r)]\exp\{-2\int [\alpha_A(r) + \alpha_M(r)]dr\} = ATB
\]

\[
[\beta_A(r) + \beta_M(r)]\exp\{-2\int [S_A(r)\beta_A(r) + \alpha_M(r)]dr\} = ATB
\]

Then solve for \(\beta_A\) assuming a constant value of \(S_A\)

You can then solve for extinction

\[
\alpha_A(r) = S_A(r)\beta_A(r)
\]

This technique is often referred to as the Klett method