Evaluation of CERES ED4 MODIS and GEOS Cloud Properties Using ARM SGP Observations

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1) CERES ED4 MODIS Cloud Fraction by Casey Oswant
2) CERES GEO cloud properties by Ted McHardy
Evaluation of CERES ED4 MODIS Cloud Fraction Using ARM SGP Observations

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Objective

Are passive remote sensed clouds (MODIS) comparable to actively sensed clouds (ARM and CC radar-lidar)?

- Data: CERES ED4 SYN1deg (passive), ARM and CCCM radar-lidar (active).
- Time period: March 2000 to December 2010 for both ARM and CERES. 2007-2010 for CCCM.
- Focus on cloud fraction (CF).
Both ARM and CERES follow the same seasonal variation, decrease from spring to summer and increase from summer to fall.

CERES CFs are consistently lower than ARM ones (\(-7\%\))
Both CERES high and low CFs higher than ARM CFs;

If some optically thin high clouds above low level cloud, then ARM “LOW” = LOW + HOL CF is only ~0.5% lower than CERES “LOW” CF.
Profiles of CFs from ARM and CERES

- Using maximum cloud-top heights from ARM, CERES and CCCM
- Comparing to ARM CFs, CERES has positive biases in both high and low clouds, but negative bias in middle clouds, consistent to high and low CF seasonal
- CCCCM detected more high-level clouds
CCCM and ARM CFs agree within 3% → Radar-lidar from space and surface can observe similar clouds, but CCCM detected more optically thin high clouds.

Both ARM and CCCM are 7-10% higher than CERES-MODIS → passive remote sensing does miss some clouds, such as middle clouds.
CERES is 5% lower than ARM

CCCM is 6.3% lower than ARM because low clouds are dominant over Arctic while CCCM missed some clouds < 1 km.
Do MODIS and CC observe same amount of clouds?

All clouds, CF_CM=62%

All clouds, CF_CC=74%

~ 10% difference is due to optically thin clouds (tau<0.3) detected by CALIPSO, but not observed by MODIS and simulated by models.

Stanfield et al. 2014 (J Clim)
Conclusions

- Both ARM and CERES follow the same seasonal variation, but CERES CFs are consistently lower than ARM ones (~ -7%).

- Comparing to ARM CFs, CERES has positive biases in both high and low clouds, but negative bias in middle clouds; CCCM detected more optically thin high clouds.

- CCCM and ARM CFs agree within 3%, ARM missed some optically thin clouds, while CCCM missed some low-level clouds.
Evaluation of CERES GEOS Cloud Properties Using ARM SGP Observations

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Bill Smith, Jr. and Patrick Minnis, NASA Langley
• **Purpose:**
  - To statistically characterize CERES GEO cloud property retrievals of low-level water clouds over land vs. ARM ground-based observations and retrievals
  - Compare GOES East and West retrievals to investigate viewing/solar geometry effects

• **Motivation:**
  - McHardy et al. (2018) found some geometric biases in long-term record of GOES SatCORPS (from ARM data archive)
  - Unique opportunity to study effects of viewing/solar geometry using long-term ARM and CERES GEO cloud properties
# Data

- CERES GEO (~8km) every hour
- DOE ARM SGP surface data (every 5 min.)
- 2000 – 2010 (will add – 2015 later)

<table>
<thead>
<tr>
<th>Cloud Property</th>
<th>Full Name</th>
<th>Uncertainty</th>
<th>Instrument and Retrieval Algorithm</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARM $T_{\text{base}}$ and $T_{\text{top}}$</td>
<td>Cloud base and top temperature (K)</td>
<td>0.2°C</td>
<td>Merged Sounding [Troyan et al., 2012]</td>
</tr>
<tr>
<td>ARM $r_e$</td>
<td>Cloud droplet effective radius ($\mu$m)</td>
<td>~10% for daytime</td>
<td>Dong et al. [1997, 1998, 2002]</td>
</tr>
<tr>
<td>ARM $\tau$</td>
<td>Cloud optical depth</td>
<td>~5-10% for daytime</td>
<td>Dong et al. [1997, 1998, 2002]</td>
</tr>
<tr>
<td>ARM LWP</td>
<td>Cloud liquid water path (g m$^{-2}$)</td>
<td>~10%</td>
<td>Microwave radiometer [Liljegren et al., 2001]</td>
</tr>
</tbody>
</table>
Data Processing

• Collocation:
  • GOES data spatially averaged within 0.3°x0.3° box centered on the ARM SGP site (~ 36.6N, 97.5W)
  • ARM data temporally averaged ±30 min of GOES scan

• Data Filters (to allow only low-level water clouds):
  • Identified by MMCR as low-level clouds (top < 3 km)
  • Daytime only (SZA < 82°)
  • ARM cloud base temp. > 250K
  • GOES (box mean) $H_{eff} < 4$km
  • GOES cloud fraction within box = 1
  • Both GOES E and W have valid data
  • Snow days removed based on sfc albedo > 0.5
  • MWR LWP < 500 g m$^{-2}$
GOES W and E effective cloud temp vs. ARM cloud-top Temp.

Cold bias $\Delta T \approx -1.7 \text{K}$

Will see if there is a relationship between the bias and entrainment or inversion Strength, etc..
Effective cloud temp comparison: GOES W vs. E.

No bias in effective cloud temp between GOES W and E.
Cloud Microphysics Comparison: GOES W vs. ARM

Higher SZA?

High biases in GOES E retrieved re, tau and LWP
Cloud Microphysics Comparison: GOES E vs. ARM

Much of the same as GOES W
GOES E vs GOES W

GOES E Tau > GOES W Tau

(a) GOES E Effective Radius vs GOES W Effective Radius

(b) GOES E Optical Depth vs GOES W Optical Depth

(c) GOES E LWP vs GOES W LWP

(d) Frequency and Cumulative Frequency of Effective Radius, Optical Depth, and LWP.
Dependence of GOES-E retrievals on Scattering angle (SA) and Solar Zenith Angle (SZA)

Shading indicates 10th-90th percentiles

$r_e$ – high bias for lower SA;  \hspace{1cm} \text{Tau} - \hspace{1cm} \text{high bias for higher SZA}$
Shading indicates 10th-90th percentiles

Same as GOES E
Further Investigation of dependence of GOES-E retrievals

- Data first binned by SZA (3 equal sized bins)
- Then binned (3 equal sized) by “heterogeneity parameter”: Low, Medium, High
- Error bars = standard dev.

Y-axis: GOES West – ARM, GOES East – ARM

ΔTau increase with SZA, also vary with cloud heterogeneity
Both $\Delta$ Tau and Std. Dev of $\Delta$ Tau decrease with increasing heterogeneity (from blue to green) – not intuitive.
More intuitive – standard deviation bars are bigger for more heterogenous clouds.
(GOES W – GOES E) Tau binned by SZA and Std dev (ARM CTH)

Samples where GOES W >> GOES E preferentially occur in the evening

Samples where GOES E >> GOES W preferentially occur in the morning

(GOES W – GOES E)/GOES E Tau > 0.5

(GOES W – GOES E)/GOES E Tau < -0.5
Conclusions:

• GOES E and W very well correlated with each other (except maybe $r_e$), but GOES E Tau > GOES W Tau by ~2 – needs further investigation

• $R_e$ - high bias for low SA;
  Tau- high bias for high SZA

• Samples where GOES W >> GOES E preferentially occur in the evening, while the opposite preferentially occurs in the morning
Both ARM and CERES follow the same seasonal variation, decrease from spring to summer and increase from summer to fall.

CERES CFs are consistently lower than ARM ones (~ -7%).
This is not the correct vertical distribution.

The results for CERES are much smaller than expected for high cloud based on previous bar plot.

This inconsistency is a result of plotting total CERES cloud top height which is the average cloud top height detected in each layer (low, mid-low, mid-high, and high).
Area of Focus Over SGP
Daytime Vertical Distribution

- Using maximum cloud top, ARM and CERES have good agreement with their high cloud top height.
  - The agreement is not as good for middle and low clouds because CERES is unable to interpolate them correctly.
- The ground level CERES low cloud heights only occur during the day.
The images depict box plots for various datasets categorized by different ranges of latitudes: 

- **W - E re**: Shows box plots for different latitudinal ranges: 
  - <47° 
  - 47° < x ≤ 61° 
  - > 61° 

- **std(W Teff)**: Similar plots for the standard deviation of the effective temperature.
- **std(W CTH)**: Plots for the standard deviation of cloud-top height.
- **std(W Rvis)**: Plots for the standard deviation of visible transmittance.
- **std(W ARM LWP)**: Plots for the standard deviation of ARM liquid water path.

- **W - E re**: Shows box plots for different latitudinal ranges: 
  - <47° 
  - 47° < x ≤ 61° 
  - > 61° 

Each plot includes a horizontal line indicating the median and box boundaries showing the interquartile range. Whiskers extend to show the range of the data excluding outliers.