Comparison of Marine Boundary Layer Cloud Properties From CERES-MODIS Edition 4 and DOE ARM AMF Measurements at the Azores

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Objectives: (1) Compare CERES team derived cloud height/temperature from MODIS (CERES-MODIS) with ARM ground-based observations during daytime (Figs 1A to 1C) and nighttime (Figs. 2A to 2C);
(2) Compare cloud microphysical retrievals during daytime only (Figure 3A to 3D);
(3) Analyze the impacts of drizzling on both ground-based and satellite cloud retrievals (Figs. 4 to 6).

Data sets: ***Time periods***: 200906-201012;

Ground-based measurements from the following instruments: (1) WACR 95 GHz cloud radar provides cloud-top height (H_{top}); (2) Ceilometer provides cloud base height (H_{base}); (3)MWR provides liquid water path (LWP); (4) PSP provides solar flux; (5) Merged sounding provides temperature profiles.

Satellite measurements: CERES-MODIS (CM) Ed4 both daytime and nighttime overpasses over AZORES.

Methods: 1-hour averaged properties for ground-based; 30 km×30 km averaged properties from CM.

Cloud-base and –top height and temp Comparisons (Daytime)

Figure 1A

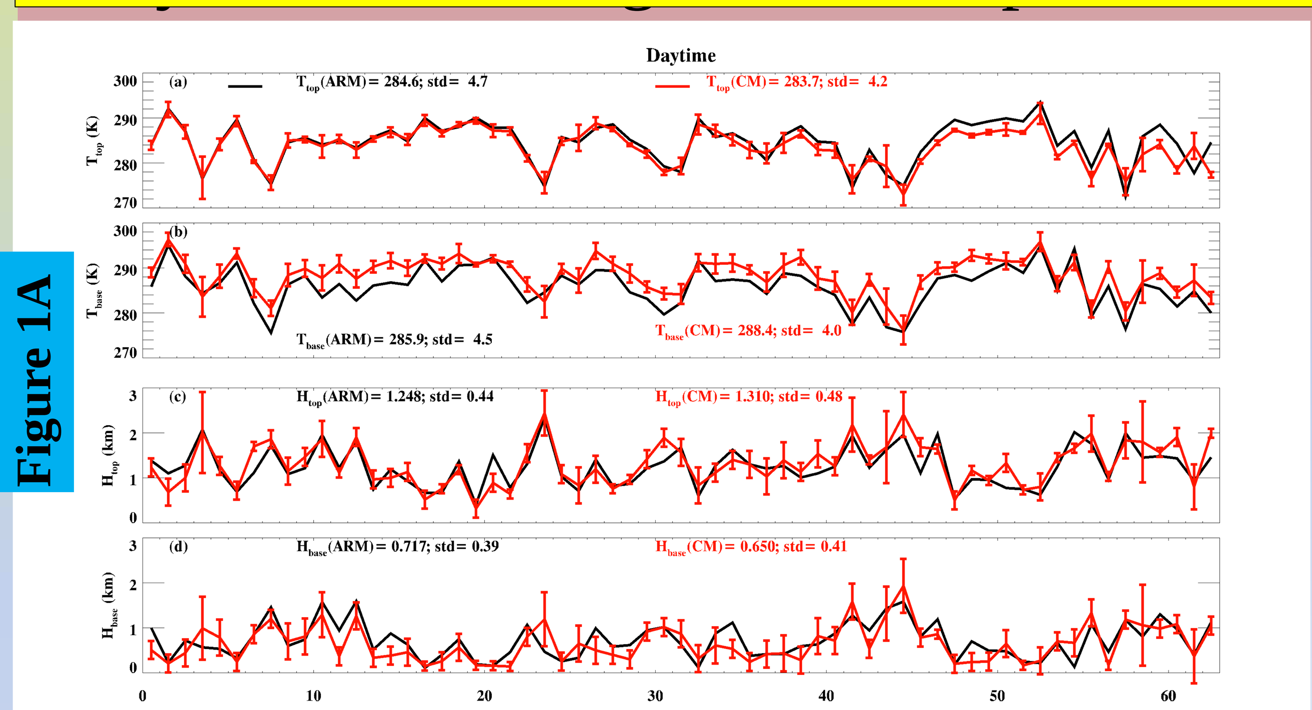
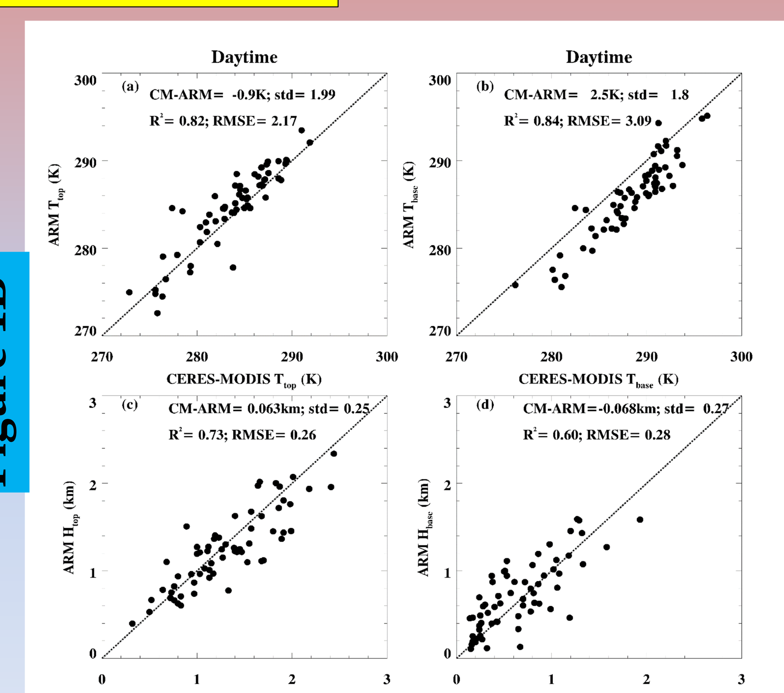


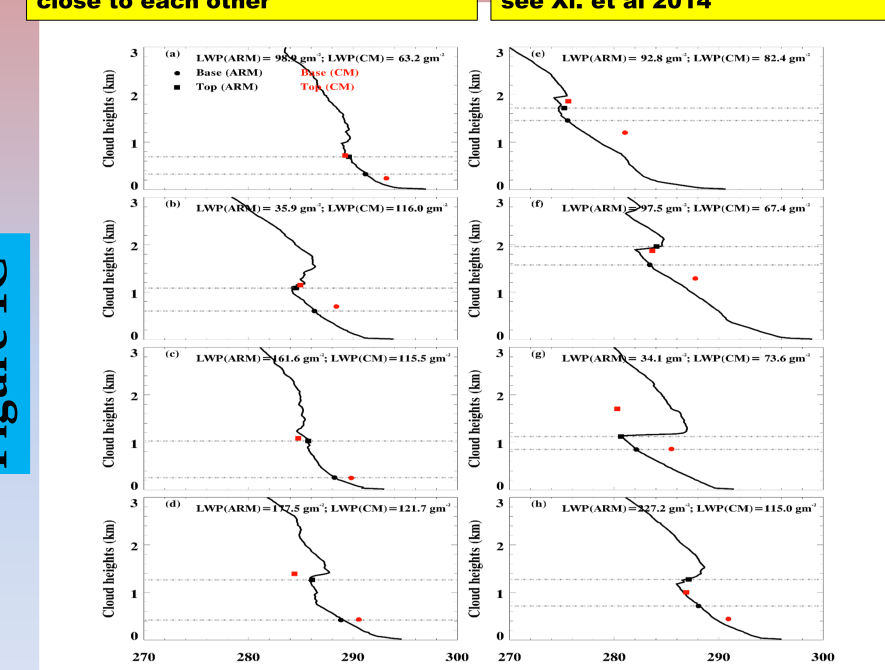
Figure 1B



Left: Both H_{base} and H_{top} agree between ARM and CM even when their related temperatures are not close to each other

Right: Neither H_{base} / H_{top} or T_{base}/T_{top} do not agree between ARM and CM. For detailed reasons see Xi. et al 2014

Figure 1C



For daytime, the CM-derived H_{top} (H_{base}), on average, is 0.063 km (0.068 km) higher (lower) than its ARM radar-lidar observed counterpart, and the CM-derived T_{top} and T_{base} are 0.9 K less and 2.5 K greater than the surface values with high correlations (R^2=0.82 and 0.84, respectively).
In general, the cloud-top comparisons agree better than cloud-base comparisons because the CM cloud-base temperatures and heights are secondary products determined from cloud-top temperatures and heights. No significant day-night difference was found in the analyses.

Nighttime

Figure 2A

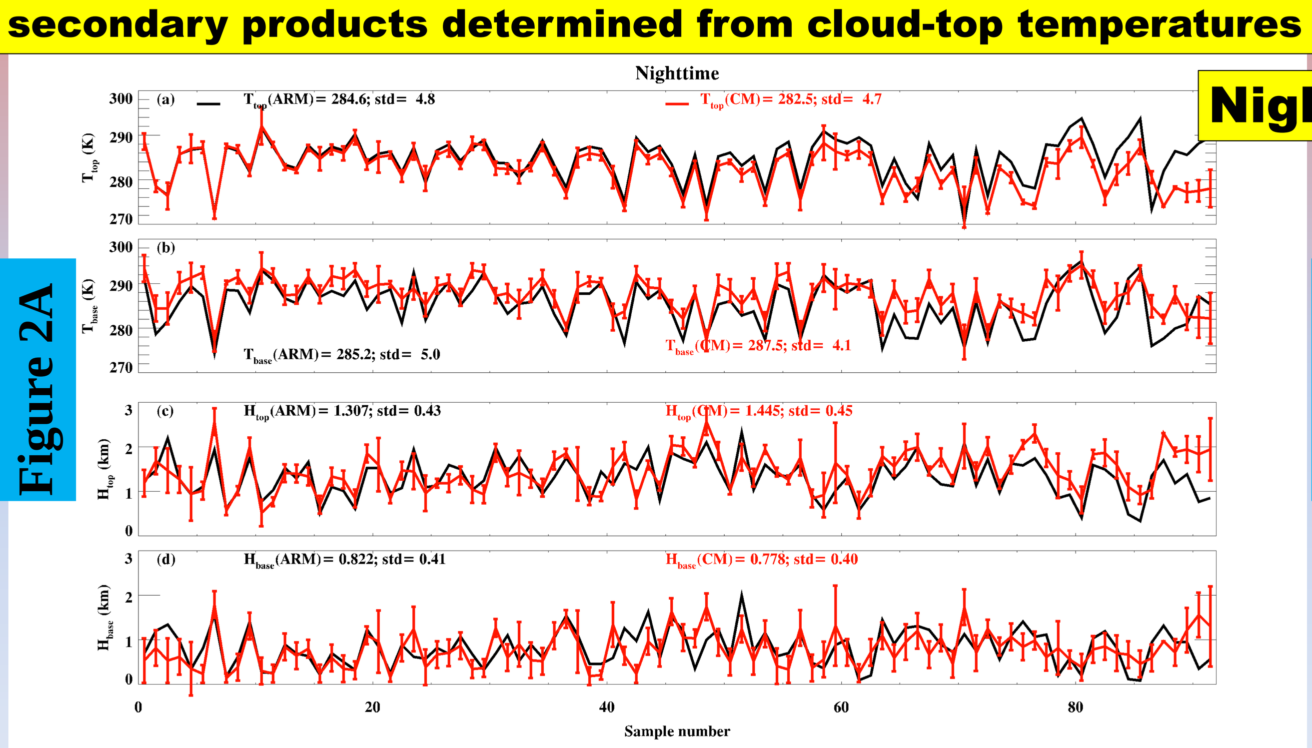


Figure 2B

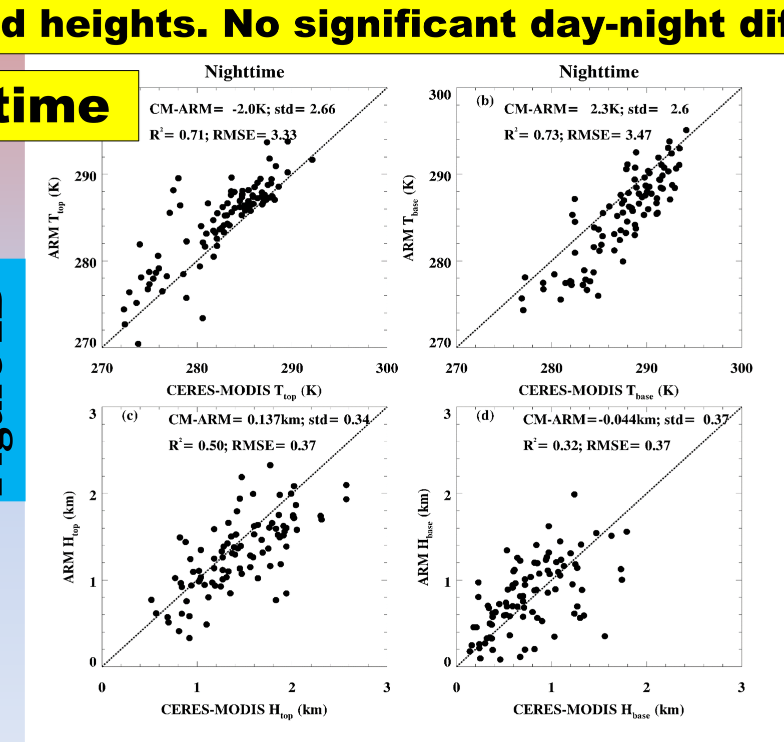
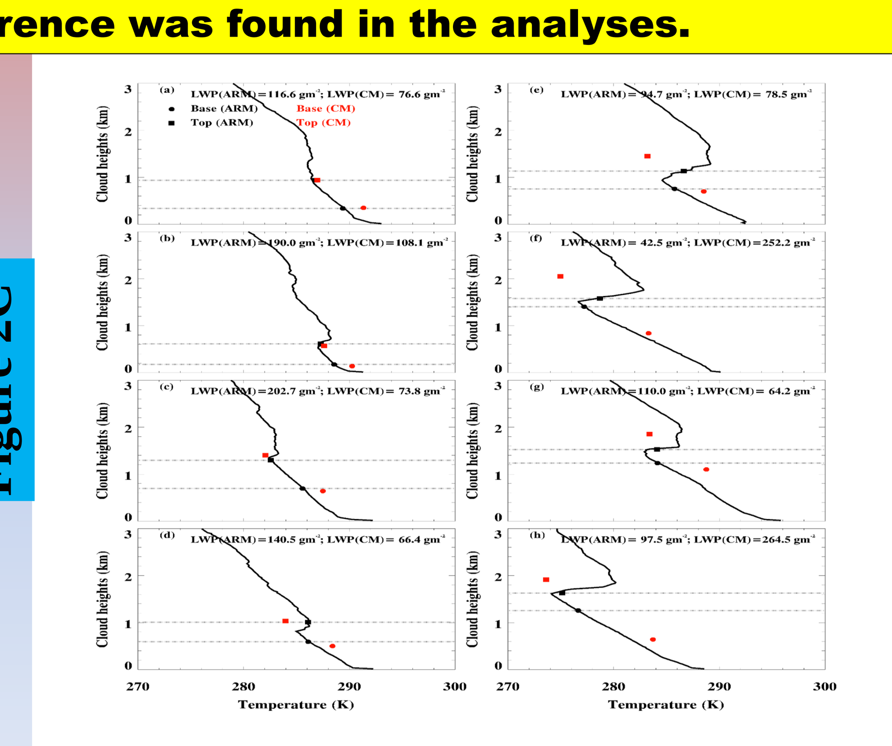


Figure 2C



Cloud microphysical property Comparisons (Daytime)

Figure 3A

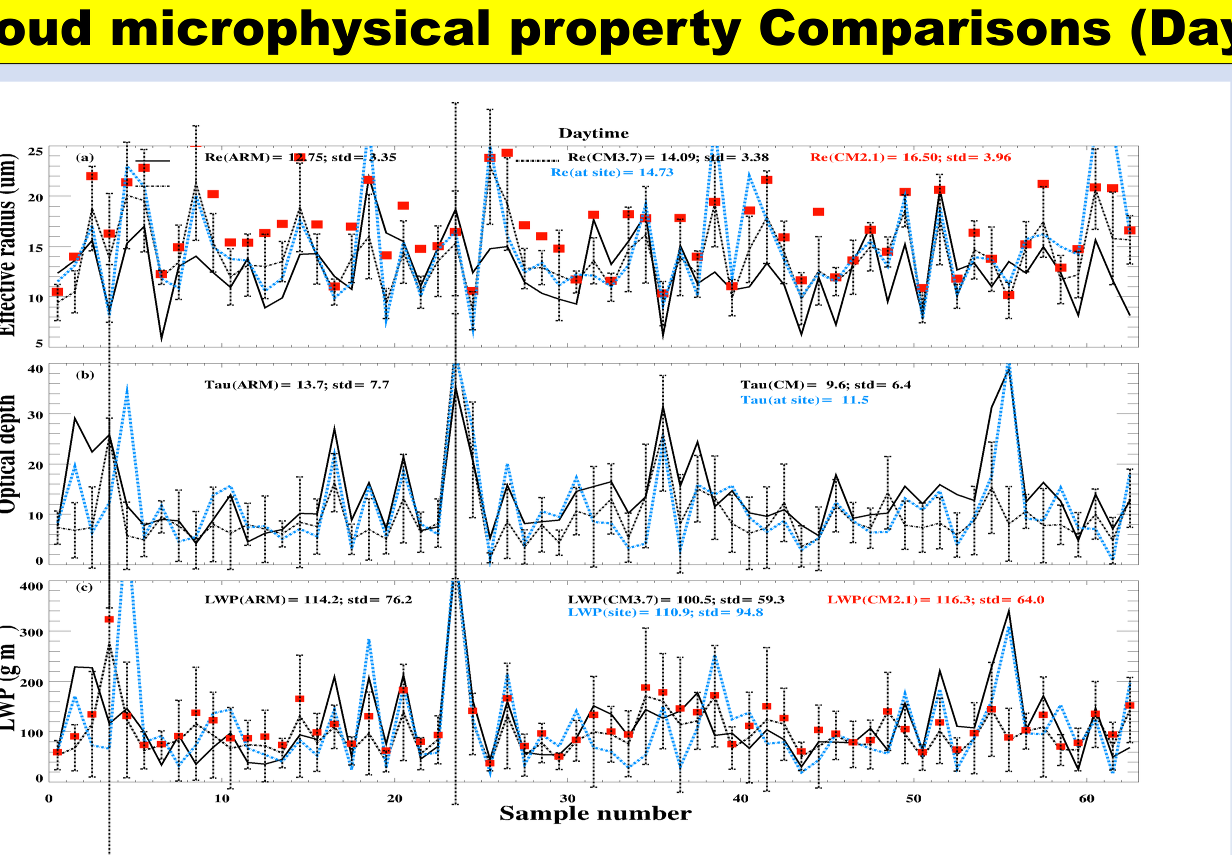
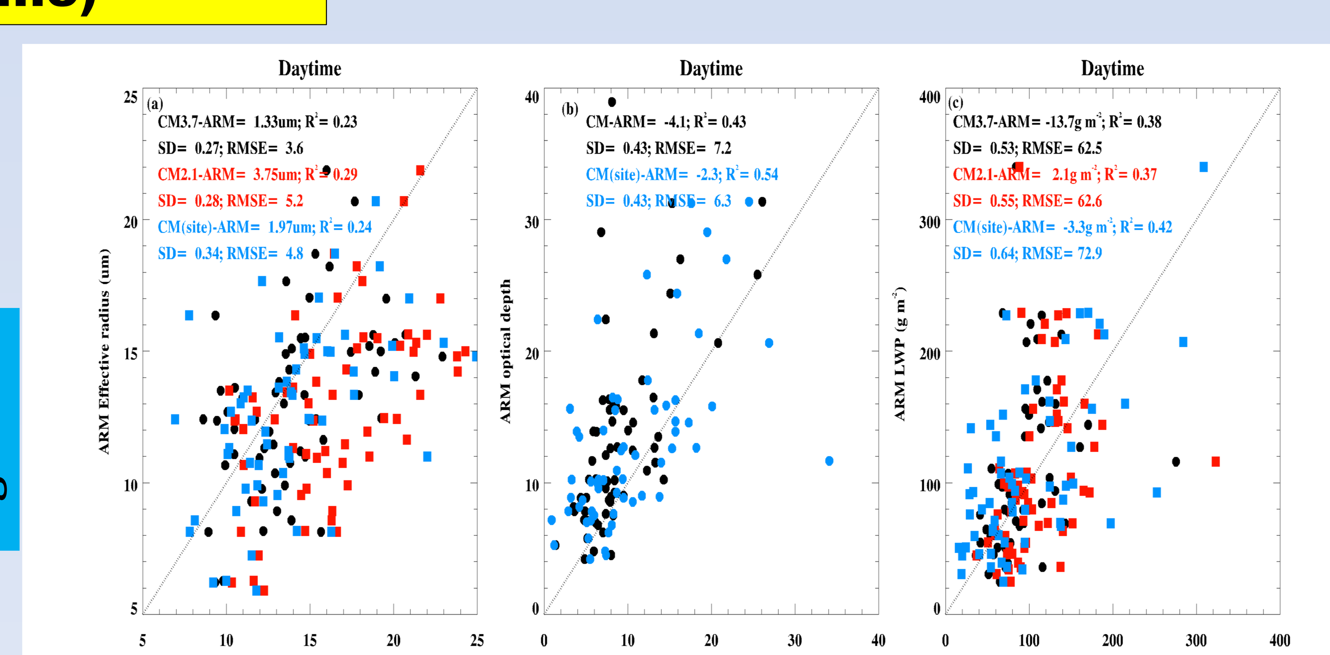
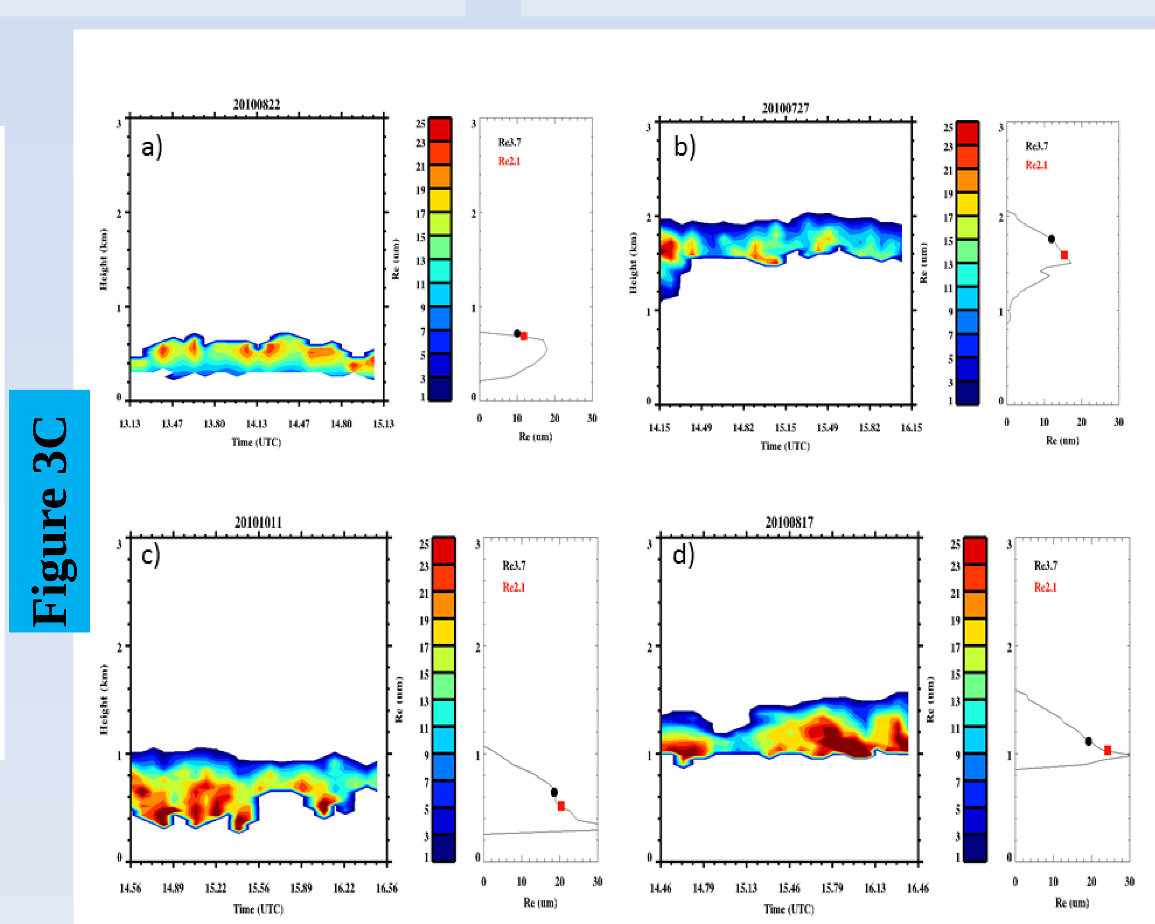


Figure 3B



CM-retrieved cloud-droplet effective radius (r_e) at 3.7 μm is 1.3 μm larger than that from the ARM retrievals (12.8 μm). While the CM-retrieved cloud liquid water path (LWP) is 13.5 gm^{-2} less than its ARM counterpart (114.2 gm^{-2}) due to its small optical depth (9.6 vs. 13.7). The differences are reduced by 50% when the CM averages are computed only using the MODIS pixel nearest the AMF site. Using effective radius retrieved at 2.1-μm channel to calculate LWP can reduce the difference between the CM and ARM microwave radiometer retrievals from -13.7 to 2.1 gm^{-2}.

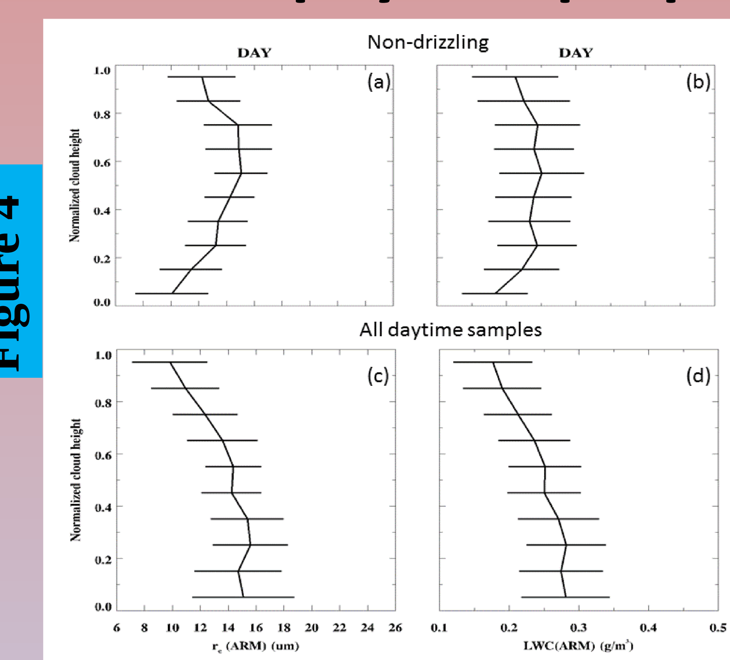
Figure 3C



The ARM radar-MWR derived re profiles [Dong and Mace, 2003] plotted for 2 h centered on the satellite overpass. Note that the ARM re values in Fig. 3C are vertically and temporally (1-h centered at satellite overpass the ARM AMF site) averaged results.
The right column represents the 1-h averaged ARM r_e profiles with matched r_e(3.7) and r_e(2.1) retrievals (regardless of CM retrieved H_{eff}). Cases (a, sample 53 in Figure 7) and (b, sample 11) assume adiabatic increase from cloud base to top, while cases (c, sample 50) and (d, sample 27) have drizzle near the cloud base.

Impact of drizzling underneath cloud base to the microphysical properties (Daytime only)

Figure 4

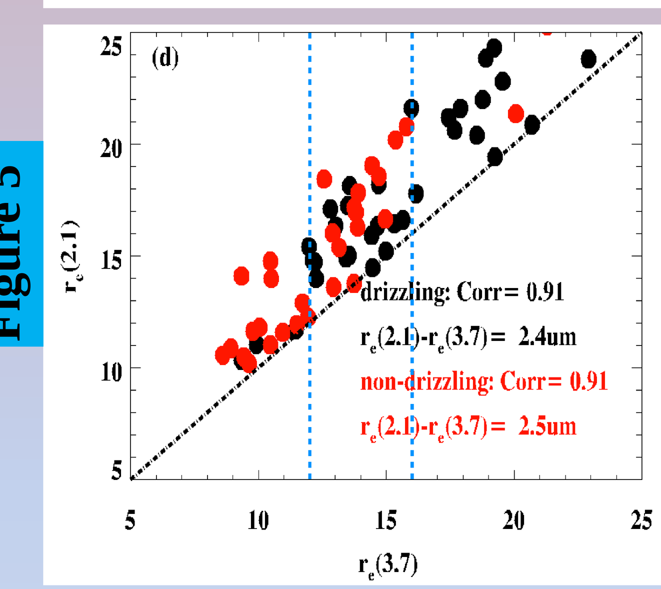


Normalized the ARM r_e(Z) and LWC(Z) retrievals from cloud base (0.0) to cloud top (1.0) for (a-b) the 26 non-drizzle cases and (c-d) the 63 daytime cases.

For non-drizzling: both r_e(Z) and LWC(Z) increased with heights but decrease near cloud top due to the cloud top entrainments.

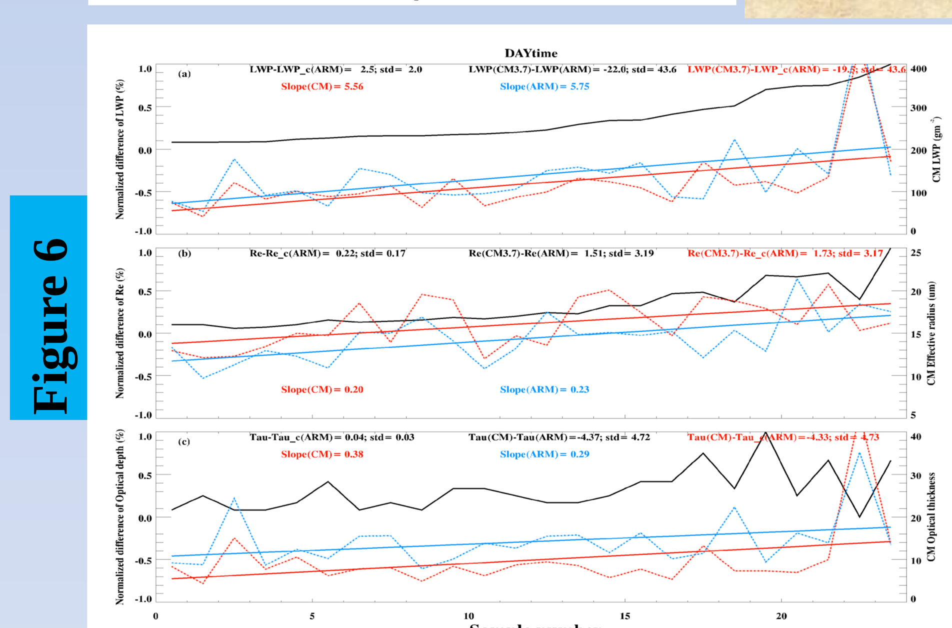
For all the cases: both r_e(Z) and LWC(Z) decreased from cloud base to cloud top. The drizzles near cloud base increase both re and LWC.

Figure 5



a) r_e(3.7) < 12 μm, few drizzle cases
b) 12 μm < r_e(3.7) < 16 μm, the drizzle and non-drizzle size overlap
c) r_e(3.7) > 16 μm, **drizzle events is highly likely**
We concluded that drizzle has an impact on the MBL cloud r_e retrievals, and the 13-14 μm found from previous studies is a reasonable threshold for identifying drizzle in satellite retrievals. However, it can only be used with caution given the large overlap in the drizzle and non-drizzle size distributions .

Figure 6



The top panel shows the normalized cloud LWP contributed by drizzling and the both LWP (ARM) and LWP (CM) in response to drizzling;
Middle panel: r_e retrievals from both ground-based and satellite in response to drizzling underneath the cloud base;
Bottom panel, same as middle panel, but for τ.
Following the sorted drizzle cases (solid black lines), both ground-based and satellite LWP/r_e/τ retrievals increase with increased drizzling underneath the cloud base, and their slopes are similar to each other.

Summary and Conclusions

- **The averaged daytime r_e(3.7) and r_e(2.1) means are 1.3 μm (10%) and 3.8 μm (29%) larger than the ARM retrievals; the average τ values are about 4.1 (30%) lower than their ARM counterparts; and the LWP(3.7) and LWP(2.1) means are 13.7 g m^{-2} (12%) lower and 2.1 g m^{-2} (2%) greater than the ARM retrievals. The 10% differences between ARM and CERES-MODIS LWP and r_e retrievals are within the uncertainties of ARM LWP (~ 20 g m^{-2}) and r_e (~ 10%) retrievals, however, the 30% difference in τ is significant.**
- **Analyzing all ARM LWC profiles for the 63 daytime cases, we find that non-drizzle cases (26) basically follow adiabatic growth from cloud base to a given height within the cloud, and drizzle cases (37) have a low degree of adiabaticity, primarily due to drizzle occurrence near the cloud base.**
- **The retrieved r_e and τ from both ARM and CM increased as increasing contribution from drizzling LWP (LWP_d>0.5g/m²).**

Acknowledgements

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