Concurrent Radar and Aircraft Measurements of Florida Thunderstorm Cirrus Clouds

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Introduction

The North Dakota Citation Research Aircraft conducted measurements of cirrus cloud particles above 30,000 feet produced by Florida thunderstorms in the summers of 2015 (CAPE2015 field project) and 2019 (CapeEx19 field project). Concurrent with the aircraft measurements, remote sensing observations were made by the United States Navy's Mid-Course Radar (MCR). Comparison between derived reflectivity factor from in-situ probe data and observed MCR data using the wideband beam is explored.

Methodology

Ice water content and reflectivity factor are derived assuming spherical ice particles observed by airborne cloud physics instruments. The MCR is a C-band, dual-polarization Doppler radar that alternates transmissions between two wave forms with range resolutions during CAPE2015 of either 37 m (narrowband) or 0.546 m (wideband) (Schmidt et al. 2019). The aircraft's position (flight tracks below) is downlinked to the MCR, enabling real-time tracking of the aircraft and ensuring concurrent measurements.

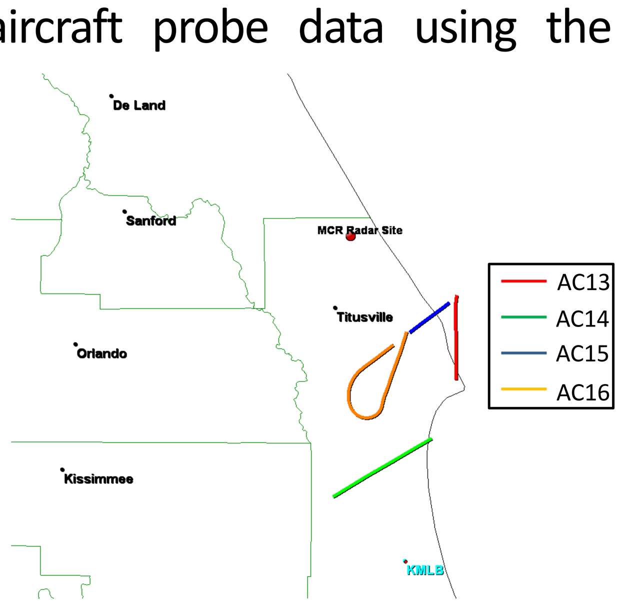
Reflectivity factor is calculated from aircraft probe data using the following equations (Gapp 2019):

$$V_i = \sum_n \frac{\pi}{6} N_n {D_n}^3 , \qquad (1)$$

$$\rho_e = m_{Nev}/V_i , \qquad (2)$$

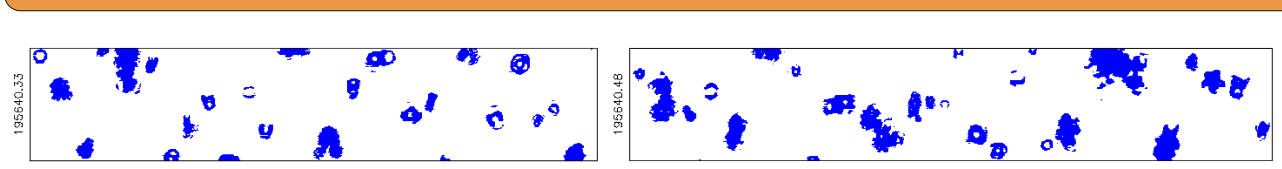
$$LED = \sum_n \sqrt[3]{6 V_n \rho_e / \pi \rho_w} , \qquad (3)$$

$$Z_e = 0.224 \sum_n N_n \, (LED)_n{}^6 , \qquad (4)$$

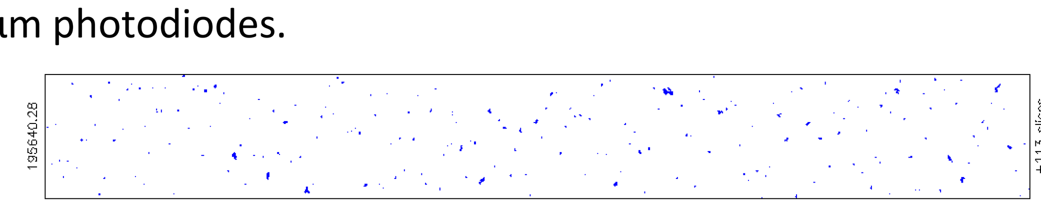


where V_i is the total volume of ice from the observed particle size distribution (PSD), subscript n is the PSD bin number, N is the particle concentration, D is the mean diameter, ρ_e is the effective particle density, m_{Nev} is the particle mass observed by the Nevzorov, LED is liquid-equivalent diameter, V_n is the volume of the size bin, ρ_w is the density of water, and Z_e is equivalent derived radar reflectivity factor (Smith 1984).

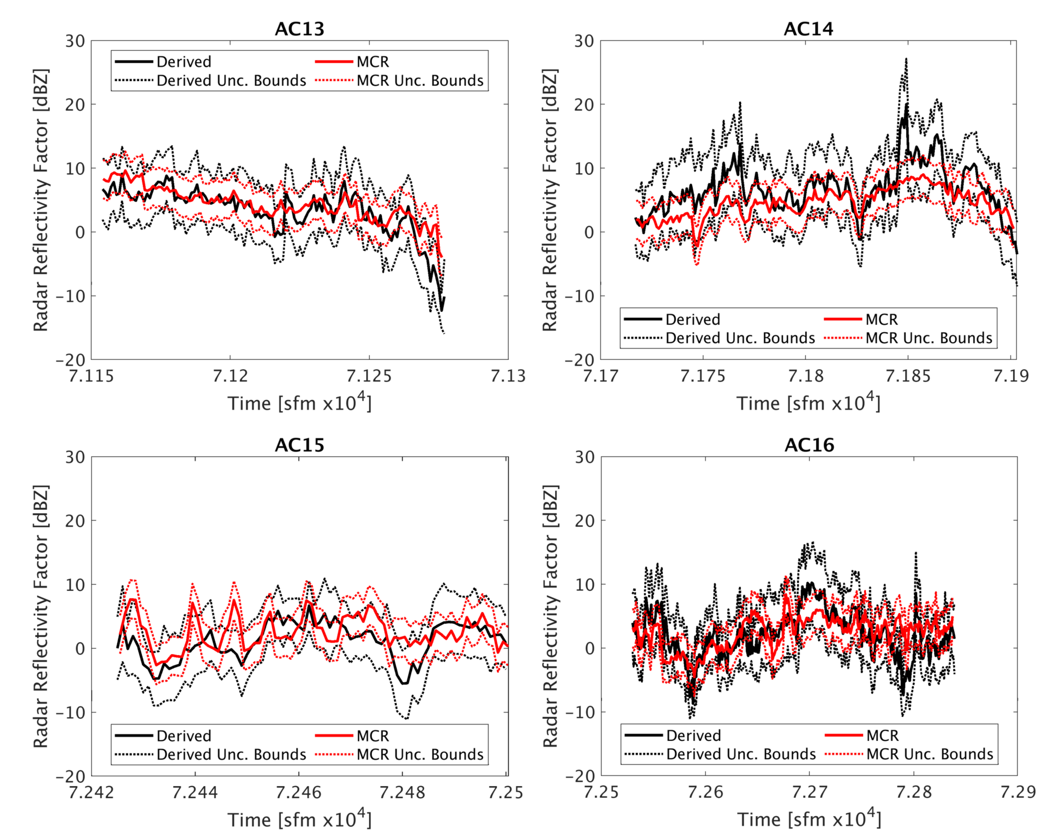
CAPE2015 Aircraft Measurements



The cloud physics instruments onboard the Citation Research Aircraft used in this study are shown. The Two-Dimensional Stereo probe (2D-S, top right) provides shadow images of particles (above) using orthogonal lasers that each illuminate an array of 128 10-µm photodiodes. The Nevzorov Water Content Probe (middle right) measures total and liquid water using constant-temperature hot-wire sensors and provides total particle mass after data processing with routines from Airborne Data Processing and Analysis (Delene 2011). The High Volume Precipitation Spectrometer Version 3 (HVPS3, bottom right) provides shadow images of particles (below) using one laser that illuminates an array of 128 150-µm photodiodes.

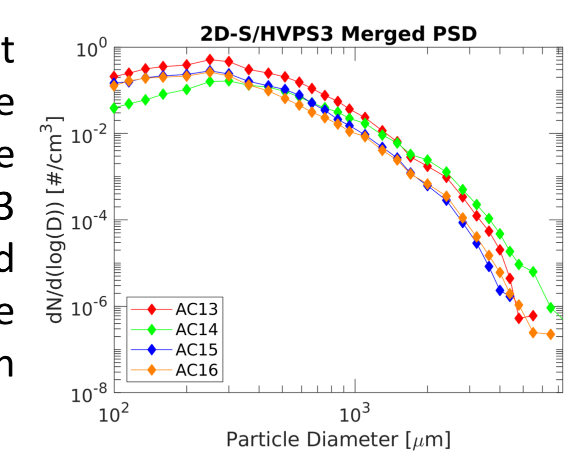


CAPE2015 Data and Results

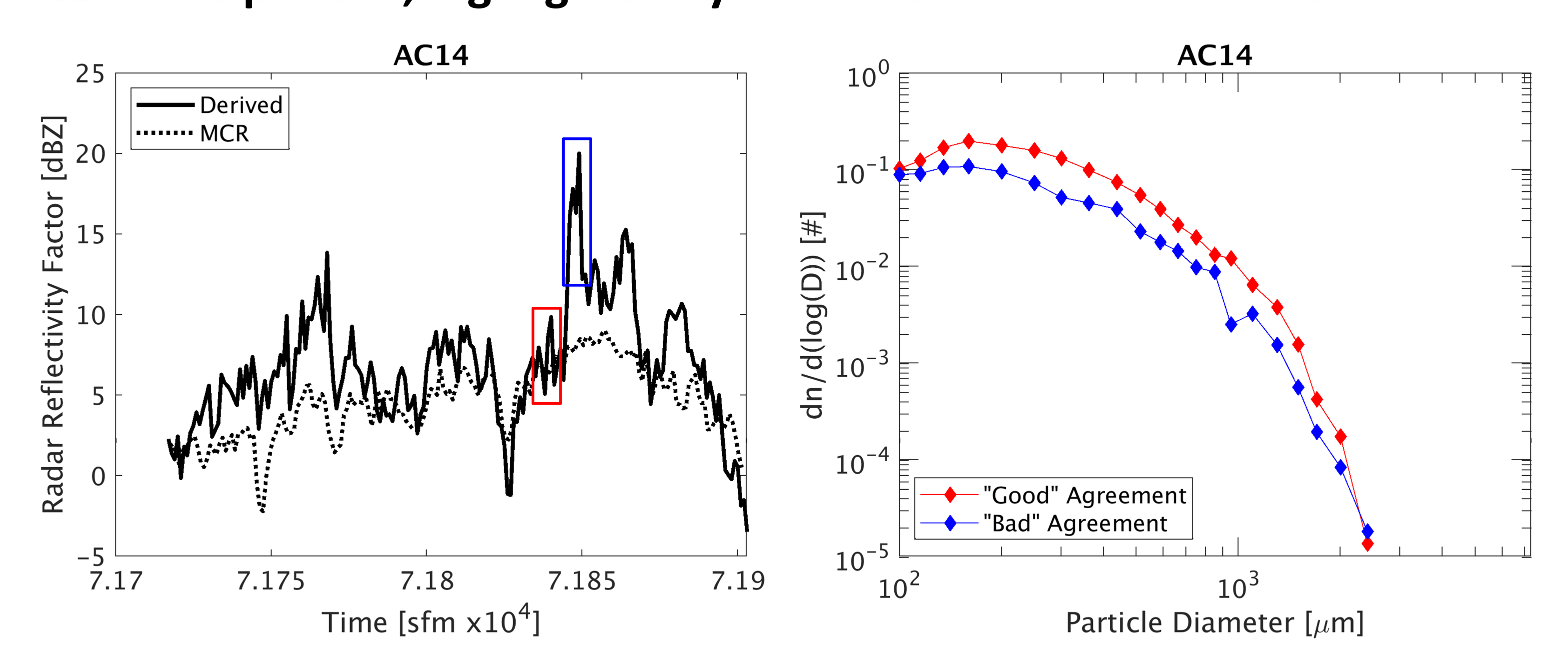


Comparisons of 1 Hz derived (center-in, area-equivalent; black lines) and MCR wideband (red lines) reflectivity factor from CAPE2015 on 01 August 2015 are shown. The MCR reflectivity factor shown is an average taken within ±5 m of the aircraft's range. The upper and lower uncertainty (unc.) bounds for the derived (black dotted lines) and MCR-observed (red dotted lines) reflectivity factor values are shown as well (Gapp 2019).

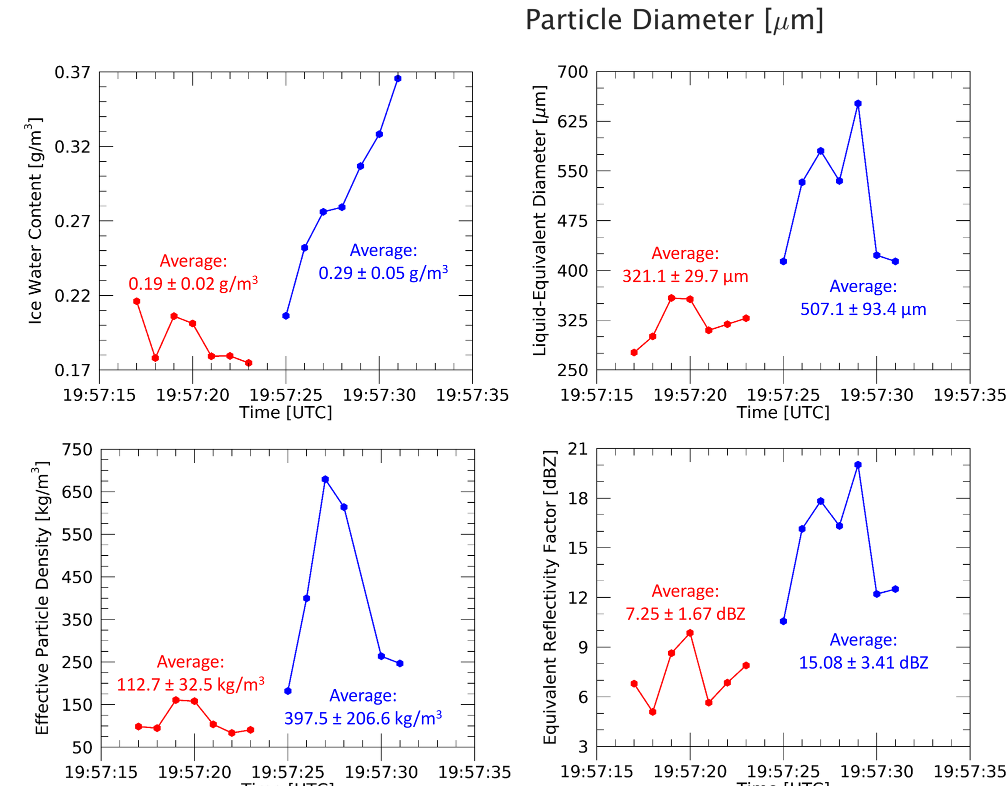
Center-in (Heymsfield et al. 1978), area-equivalent particle size distributions (PSDs) averaged across the entirety of each case above are shown. 2D-S particle concentrations are plotted below 1,000 µm and HVPS3 particle concentrations are plotted from 1,000 µm and above ("merged PSD"). The diamonds represent the midpoint of each size bin that makes up the distribution (Gapp 2019).



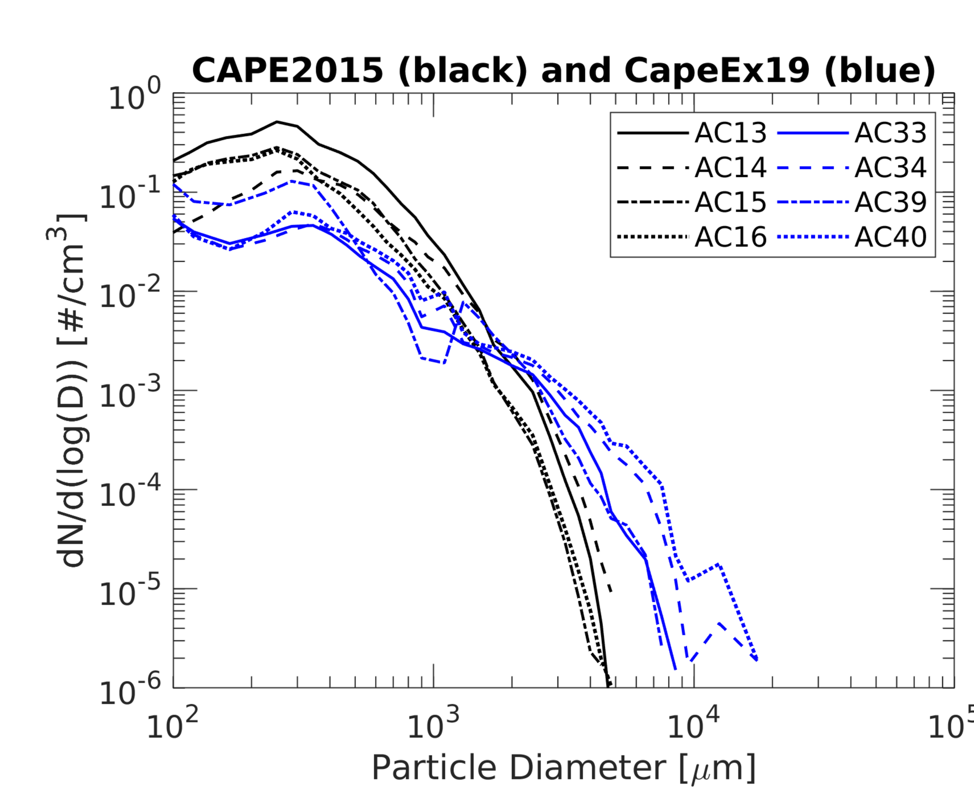
The agreement during case AC14 is not as strong as the other three cases even though the cases have similar particle size distributions. Possible reason for the disagreement is investigated by focusing on two AC14 time periods, highlighted by the red and blue boxes below.

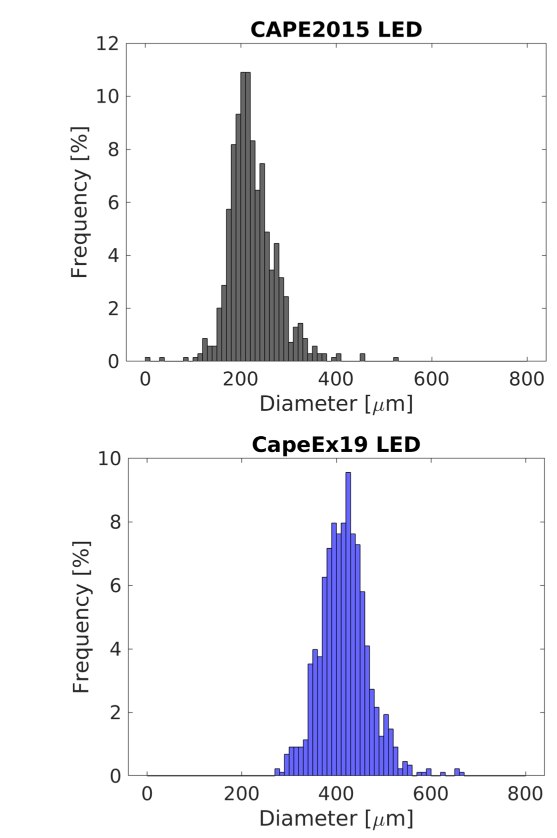


Lower values of reflectivity factor during times of "good" agreement (71837-71843 sfm; red square and lines) are due to lower ice water content and higher total volume (Eq. 1) than times of "bad" agreement (71845-71851 sfm; blue square and lines); therefore, effective particle densities (Eq. 2), LEDs (Eq. 3), and derived reflectivity factors (Eq. 4) are lower as well.

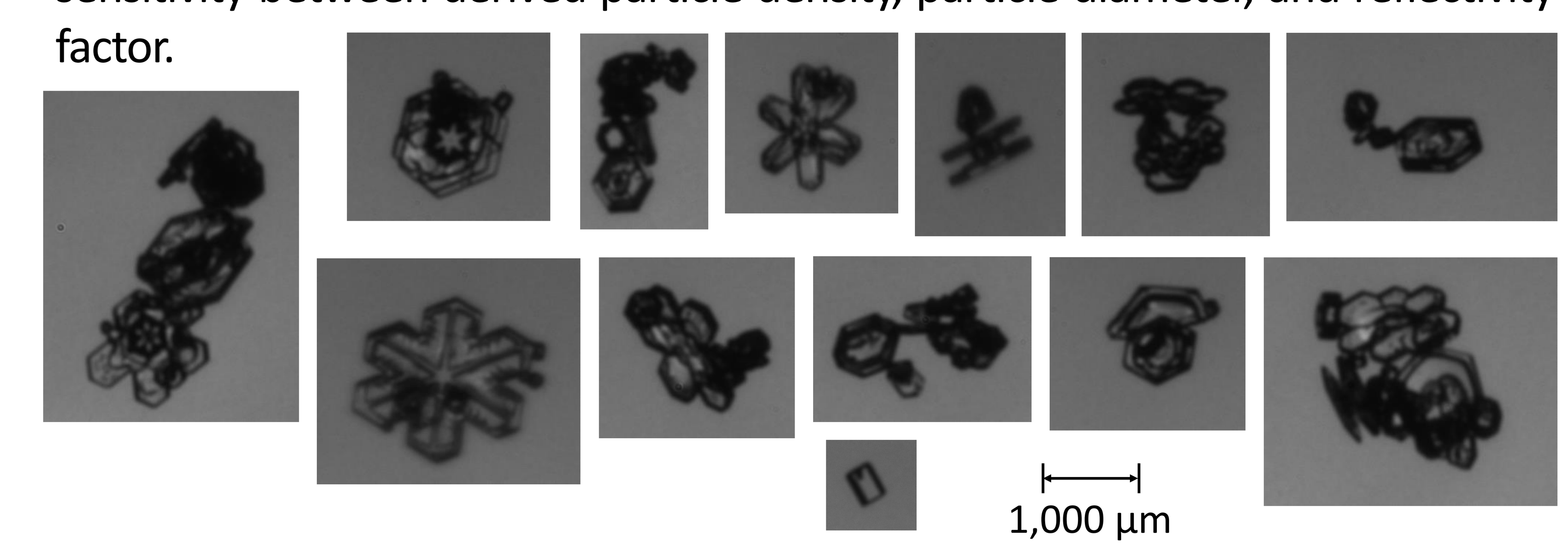


CapeEx19 Data





Similarities exist in the PSDs from CapeEx19 (above), but particles are slightly larger than those observed during CAPE2015 (histograms above). Particle Habit Imaging and Polar Scattering (PHIPS) probe images from 03 August 2019 are below. The extra data from CapeEx19 will help to determine the sensitivity between derived particle density, particle diameter, and reflectivity factor.



Conclusions and Future Work

- Hydrometeor attenuation likely has a large role in the disagreement, especially for case AC14 since aircraft is at largest range from MCR.
- A single bulk density is applied across entire size spectrum for deriving reflectivity factor, which could also be the reason for the disagreement between derived and MCR reflectivity factors.
- Future work will investigate the sensitivity of the relationships to derived particle density, particle diameter, and reflectivity factor.

References and Acknowledgements

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