Comparisons of Florida Thunderstorm Cirrus Clouds using Concurrent Radar and Aircraft Measurements

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Introduction

The North Dakota Citation Research Aircraft conducted measurements of cirrus cloud particles produced by Florida thunderstorms in 2015 (CAPE2015 field project). Cloud sampling instruments included the Two-Dimensional Stereographic particle imaging probe (2D-S) and the Nevzorov Water Content Probe (Nevzorov). Concurrent with the aircraft measurements, remote sensing observations were made by the United States Navy's Mid-Course Radar (MCR). The CAPE2015 field project observed pure ice particles between an altitude of 29,000 ft and 40,000 ft during eight research flights. Comparison between derived radar reflectivity from in-situ probe data and observed MCR data using both the narrowband (NB) and wideband (WB) beams is explored.

Methodology

2D-S ice water content and radar reflectivity are derived assuming spherical ice particles from measurements taken by the 2D-S and Nevzorov. The MCR is a C-band, dual-polarization Doppler radar that alternates transmissions between two wave forms with range resolutions of either 37 m or 0.546 m (Schmidt et al. 2012). The aircraft position is downlinked in real-time to the MCR which enables the aircraft to be located and followed by the beams of the MCR, thus ensuring concurrent measurements. A dielectric factor of ice of $|K|_i^2 = 0.208$ is used to derive equivalent radar reflectivity factor (Smith 1984). Total particle density is calculated by

$$\rho_{part} = m_{Nev}/V_{2DS}, \qquad (1)$$

where m_{Nev} is the mass from the Nevzorov and V_{2DS} is the total particle volume defined by

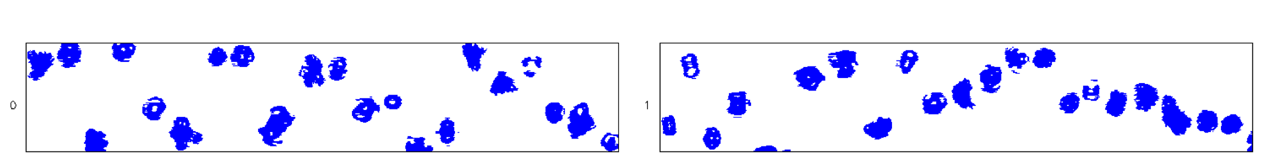
$$V_{2DS} = \sum_n \frac{\pi}{6} {D_n}^3, \qquad (2)$$

where *n* is the number of 2D-S size bins and *D* is the diameter of the 2D-S size bin. The mass of ice and volume of water, assuming mass of ice is equal to mass of water, are calculated per 2D-S size bin and used to calculate liquid-equivalent diameter (LED) of the melted particles per 2D-S size bin by

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

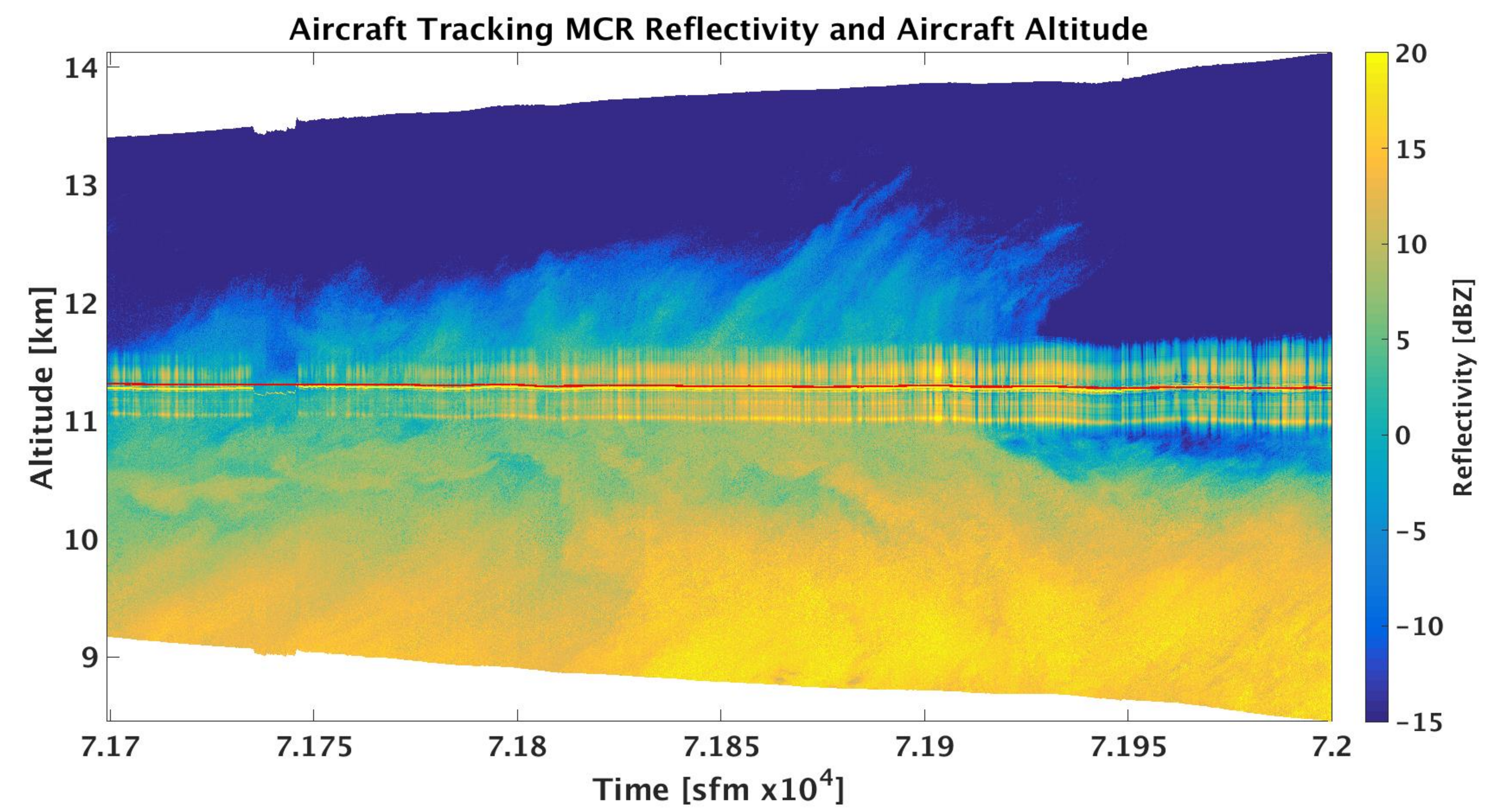
where V_n is the volume of the 2D-S size bin and ρ_i and ρ_w are the densities of ice and water, respectively. Radar reflectivity and equivalent radar reflectivity factor per 2D-S size bin are then calculated using LEDs.

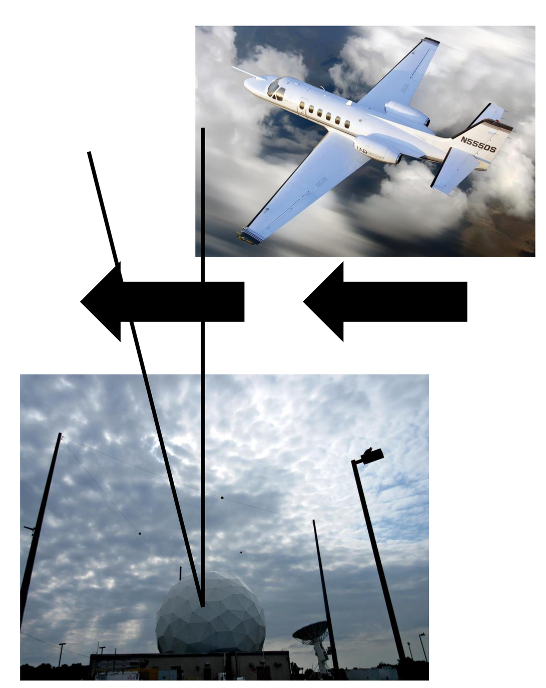
Aircraft Measurements



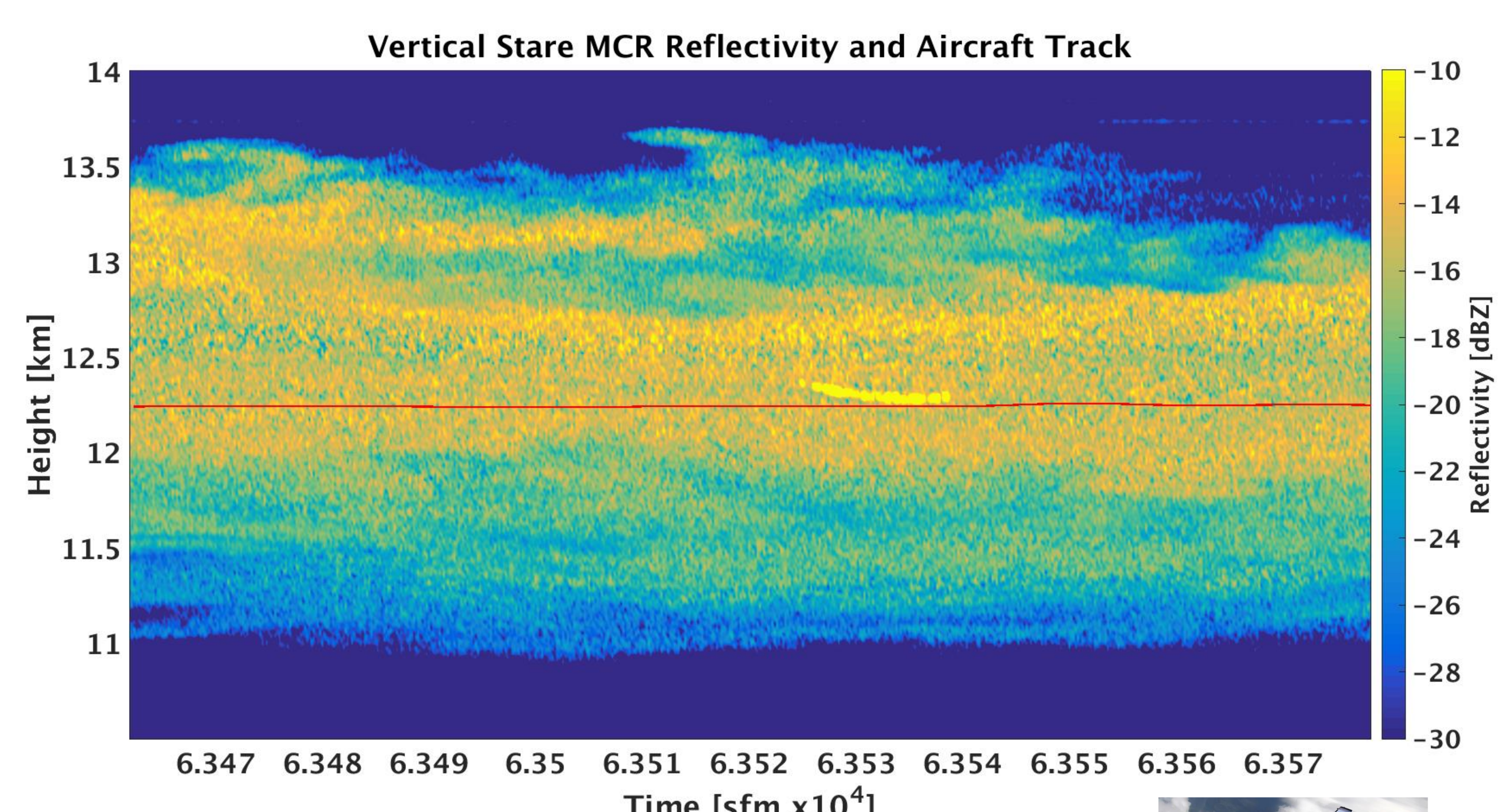
The cloud physics instruments onboard the Citation Research Aircraft are shown to the right. The Two-Dimensional Stereographic probe (2D-S, top right) provides two-dimensional images of particles (above) using lasers oriented horizontally and vertically that each illuminate an array of 128 10-um photodiodes. The Nevzorov Probe (bottom right) measures total and liquid water using hot wire sensors and provides total particle mass after processing using routines from the Airborne Data Processing and Analysis software package (Delene 2011).

Radar Measurements

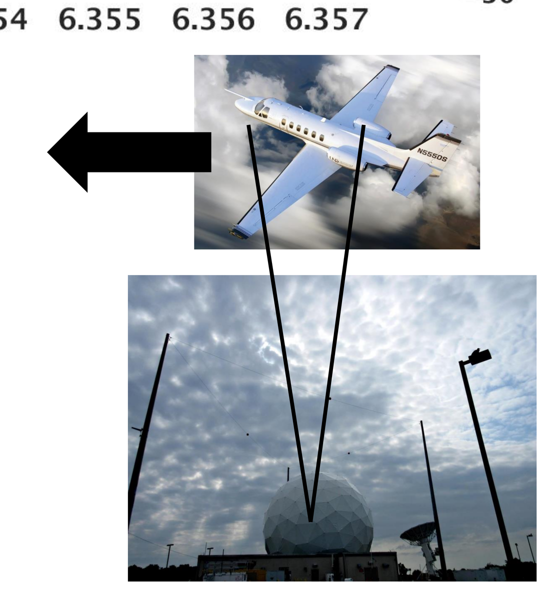




An aircraft tracking scanning strategy from 2015 August 01 (above) showing the overlay of aircraft GPS altitude (red line) and MCR narrowband reflectivity. The radar range of the MCR reflectivity is converted to height of beam above ground using the 4/3 Earth radius model for a radar beam. The "stripe" of high radar reflectivity values is contamination from the aircraft. A depiction of the aircraft tracking scanning strategy (left) shows the movement (block arrows) of both the MCR's beams (black lines) and the aircraft as the MCR tracks the aircraft's motions through the sky.

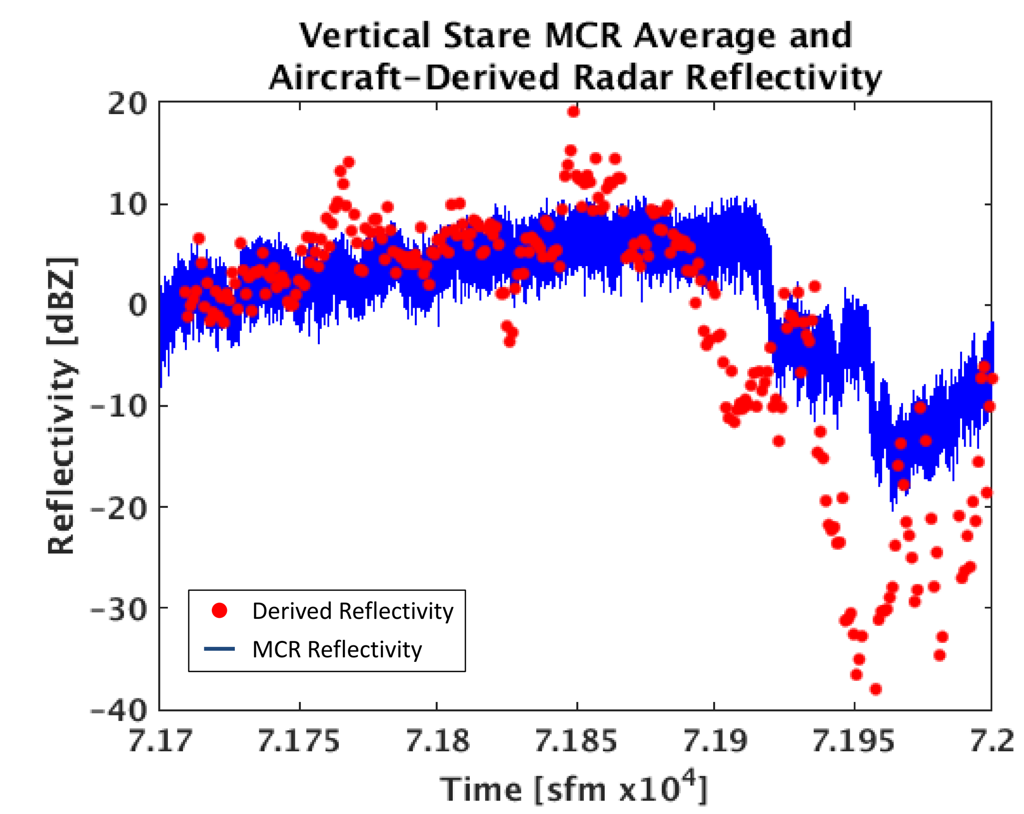


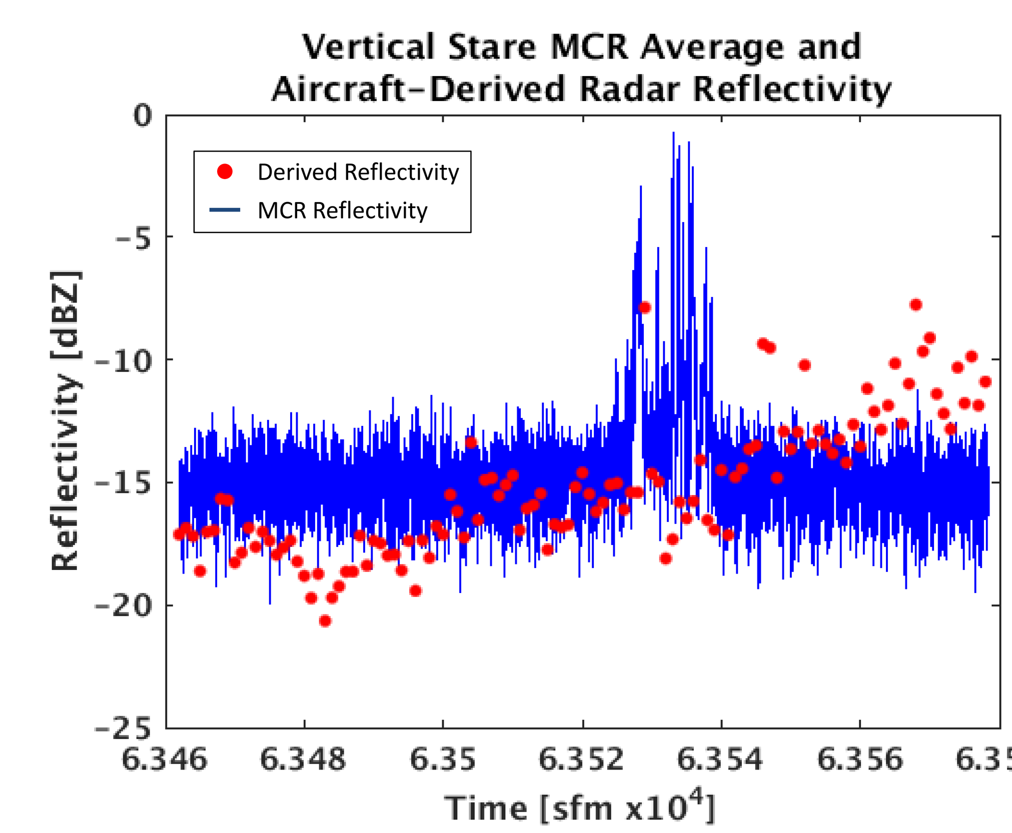
A vertical stare scanning strategy from 2015 August 01 (above) showing the overlay of aircraft GPS altitude (red line) and MCR narrowband reflectivity. The maximum in the MCR reflectivity between 63525-63545 sfm is the aircraft as it passes over the MCR. A depiction of the vertical stare scanning strategy (right) shows the movement of the aircraft (block arrow) through the fixed, vertically pointing beams of the MCR.



Radar Analysis

A comparison between the derived aircraft radar reflectivity and the measured MCR reflectivity from 2015 August 01 is shown for the aircraft tracking scanning strategy. The MCR reflectivity is averaged over a 500 m column above and below the "stripe" of aircraft contamination. The spatial separation stays constant between the MCR's beams and the aircraft.





The same as above except for the vertical stare scanning strategy from 2015 August 08 is shown. MCR reflectivity is averaged over a 500 m column of the aircraft's mean altitude. The spike in MCR reflectivity (about 63545 sfm) is due to contamination by the aircraft. The spatial separation between the aircraft and beams of the MCR increases with increasing distance from either side of the spike.

Conclusions and Future Work

- The MCR and aircraft data agree with each other.
- Aircraft data is highly variable. Determine a reasonable out-of-cloud threshold to apply to the aircraft data to reduce measurement variability.
- Incorporate area ratio of cloud particles into reflectivity calculation.
- Obtain a precise radar reflectivity-liquid water content relationship for the radar.

References and Acknowledgements

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