Observations of Ice Particles in 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 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 is explored and the synthesizing of missing water content data is discussed.

Methodology

North Dakota's Cessna Citation II Research Aircraft is used to conduct 21.86 hours of research measurements during eight flights. Ice water content and radar reflectivity are derived assuming spherical ice particles from measurements taken by the 2D-S and Nevzorov probe onboard the aircraft. 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. Data analysis includes data from the 2D-S and Nevzorov to derive radar reflectivity for a statistical comparison to the narrowband radar reflectivity from the MCR. A dielectric factor of ice of $|K|_i^2 = 0.208$ is used to derive equivalent radar reflectivity (Smith 1984). Radar reflectivity is calculated by finding the particle density by

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

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

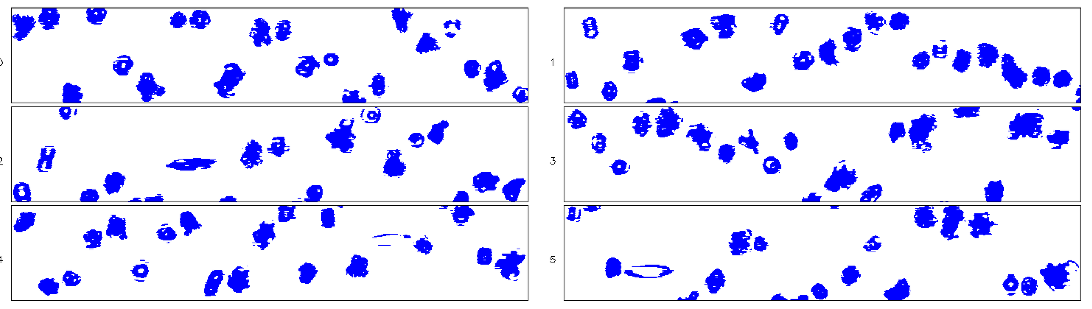
$$V_{2DS} = \sum_n \frac{\pi}{6} {D_n}^3, \quad (2)$$

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

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

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. Finally, radar reflectivity and equivalent radar reflectivity factor per 2D-S size bin are then calculated. The average ice density during flight legs which have constant temperature is evaluated for the relationship between ice crystal density and temperature. The temperature-density relation is used for the 8 August flight when Nevzorov measurements are not available.

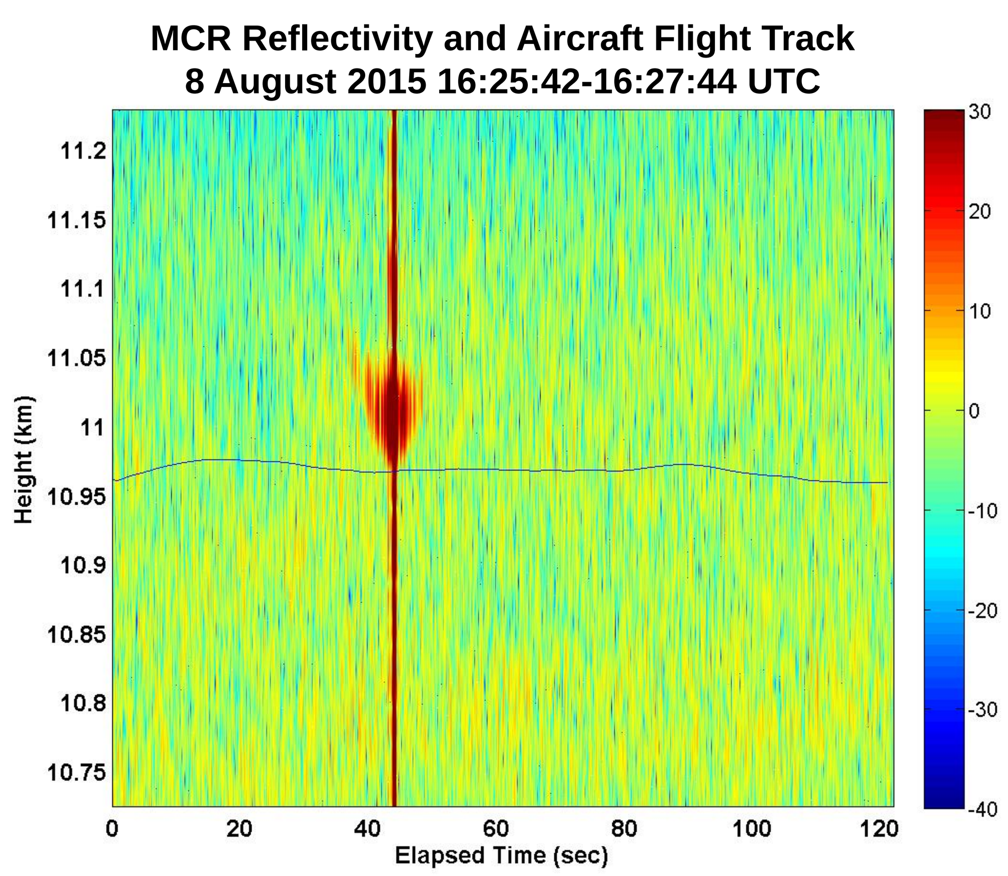
Aircraft Measurements



Representative images of cirrus particles taken by the 2D-S on 30 July 2015.

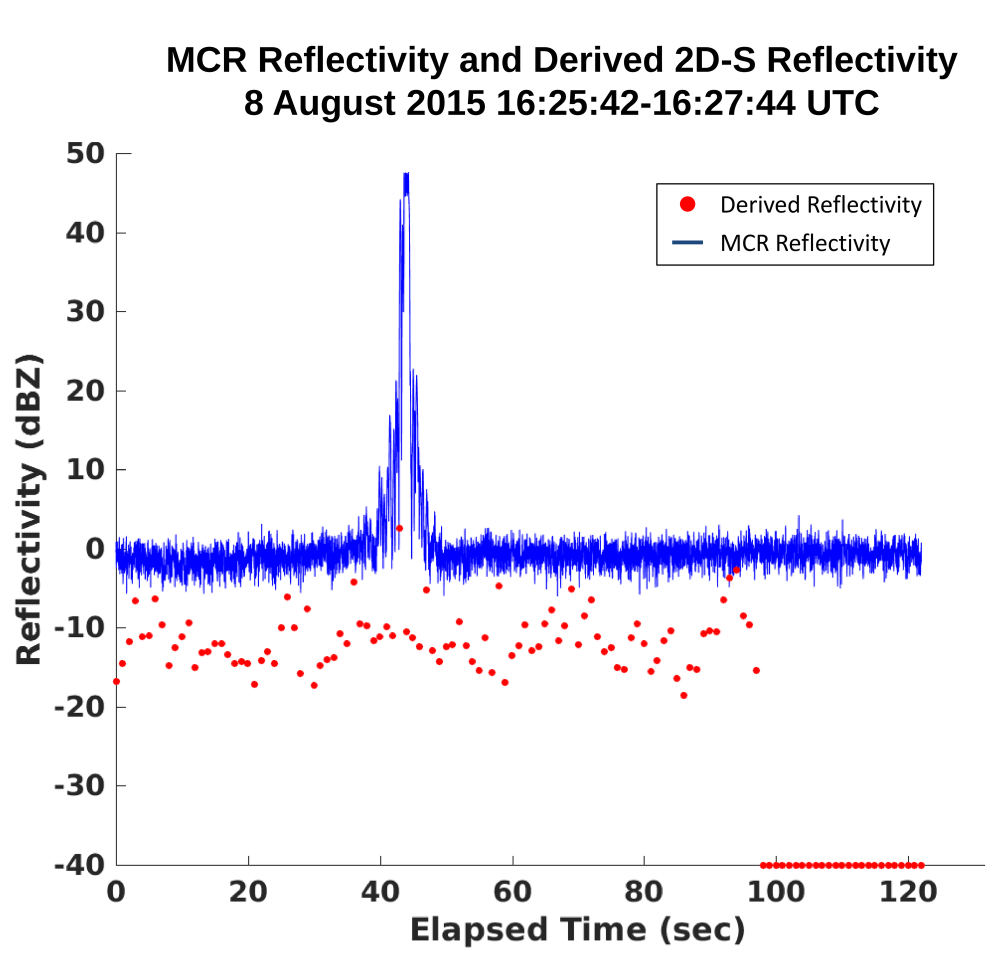
The cloud physics instruments onboard the Citation Research Aircraft are shown to the right. The Two-Dimensional Stereographic probe (2D-S, top) provides two-dimensional images of particles using 128 10-um diode lasers with one laser oriented horizontally and one oriented vertically. The Nevzorov Probe (bottom) 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



A volume scan from the MCR showing reflectivity (shading, values in dBZ) and the track of UND's Cessna Citation II Research Aircraft (blue line) on a time-height plot. The maximum in the MCR reflectivity is the aircraft as it passes over the MCR. Differences in height between the MCR and the aircraft are due to an issue with the range gate spacing with the MCR.

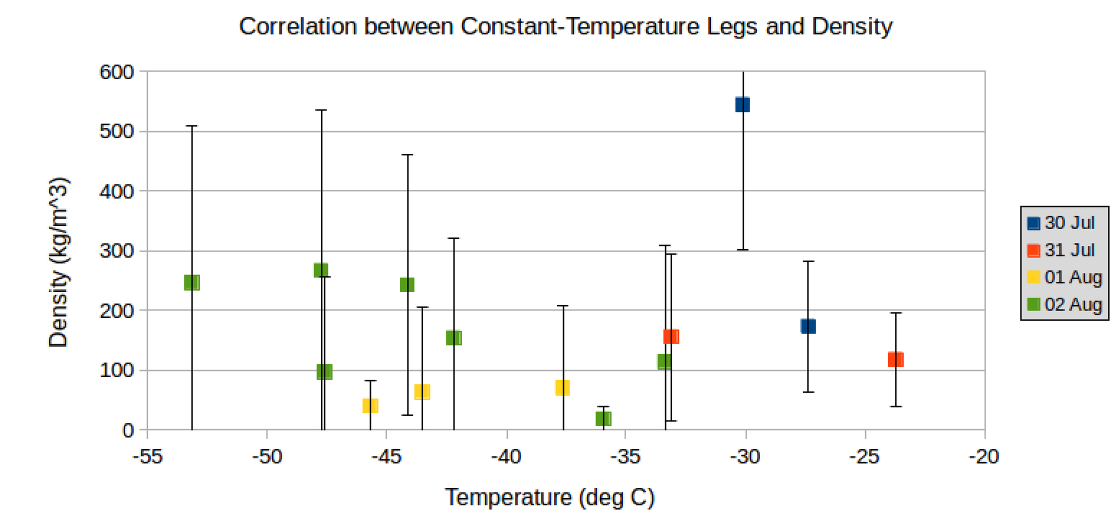
Radar Analysis

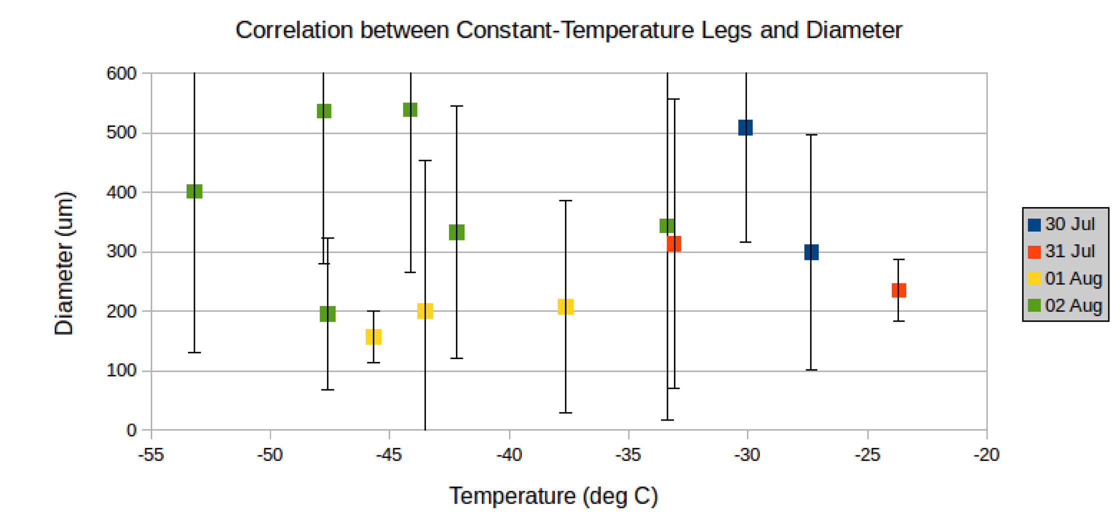


A case where the comparison between the derived aircraft reflectivity and the measured MCR reflectivity shows a difference of 10 dBZ. The MCR reflectivity is averaged over a 500 m column surrounding the aircraft's mean altitude. The spike in MCR reflectivity (about 45 s) is due to contamination of the signal by the aircraft. Generally, the MCR radar reflectivity ranges from 0 to 40 dBZ and derived radar reflectivity ranges from -5 to -15 dBZ.

Cirrus Anvil Temperature Relationship

The average particle mass from the four flights with Nevzorov data is 0.03 g m^{-3}. The mass used for the 8 August 2015 flight is 0.05 g m^{-3}.

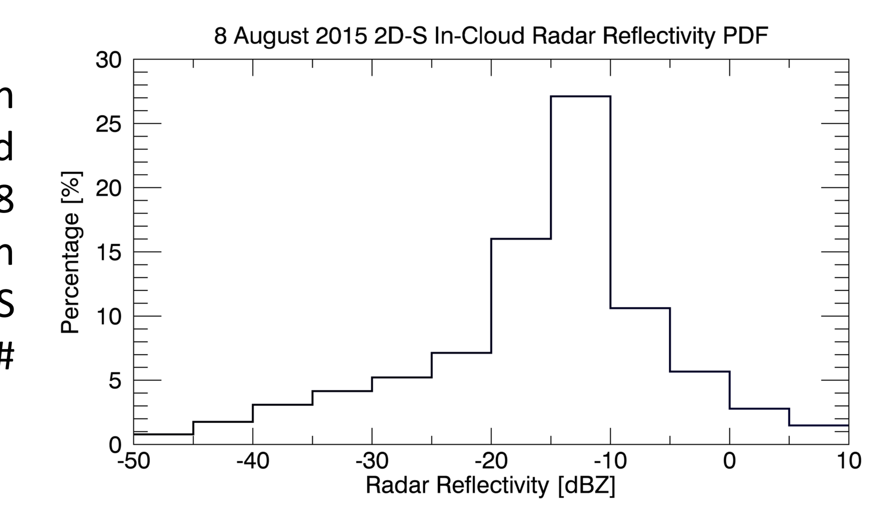




Plots showing the average bulk ice density (top) and average liquid-equivalent diameter (bottom) from 14 flight legs during four CAPE2015 research flights where the temperature remained constant below -20 °C. Error bars show high variability in the density data. Since no correlation is found between temperature and density, the average value is used for determining particle mass for calculation of reflectivity data for the 8 August 2015 case day.

Statistical Radar Reflectivity Analysis

A probability distribution function (PDF) of the derived radar reflectivity from the 8 August 2015 case day when aircraft is in cloud (2D-S concentration above 5000 # m^{-3}).



Future Work

- Compare MCR and aircraft probability distribution functions.
- Compare MCR wideband reflectivity to derived aircraft reflectivity.
- Incorporate area ratio of cloud particles into reflectivity calculation.
- Determine a reasonable out-of-cloud threshold to apply to the aircraft data to reduce measurement variability.

References and Acknowledgements

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