

Mapping Cloud Microphysical Properties to Triple-Wavelength Airborne Lidar Measurements in Winter Storms: Results from the IMPACTS Field Campaign

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Abstract: Ice production and growth in mixed-phase clouds give a complicated picture of the radiative and mass characteristics due to the heterogeneity of particle shapes and sizes. Collocated airborne lidar and microphysics datasets from a recent winter storm field study are used to evaluate the effect of ice and liquid hydrometeors, observed in situ, on the multiple-wavelength backscatter coefficient values measured by the NASA Cloud Physics Lidar over the course of three winter deployments in the Midwest and Northeast United States.

1. Introduction

More than half of the global precipitation budget can be tied to ice processes aloft [1], yet understanding the effects of ice in mixed-phase clouds on the mass and radiative properties is challenging given the variability of particle sizes and shapes. Independent observations of in-situ cloud microphysical properties like the ice crystal shape and the presence of supercooled liquid water (SCLW) are useful in relating lidar measurements to microphysical processes and validating retrievals of cloud properties.

Field experiments employing multiple-wavelength active remote sensing instruments have improved the prediction of representative sizes and densities of hydrometeors within the cloud. Triple-wavelength radar studies, for instance, discovered that particle sizes increase as two pairs of dual-wavelength reflectivity ratio increase whereas the particle density is most affected by the reflectivity difference between the two larger wavelengths.

Motivated by these recent radar studies, a similar analysis is conducted on collocated datasets of in-situ particle properties and triple-wavelength backscatter observations from an airborne platform. Section 2 outlines the datasets used and methodology conducted

while Sections 3 and 4 summarize the results from a recent field campaign.

2. Datasets & Methodology

The NASA-led Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms (IMPACTS) project was a three-year mission aimed at understanding the dynamic, thermodynamic, and microphysical properties and processes governing the formation and evolution of locally enhanced, banded precipitation structures within mid-latitude winter cyclones [2]. The project involved careful coordination of a “satellite-simulating” ER-2 aircraft housing a suite of lidars, radars, and microwave radiometers as well as a “storm-penetrating” P-3 aircraft that made in-situ measurements of cloud particle and thermodynamic properties for a range of altitudes and temperatures.

The NASA Goddard Cloud Physics Lidar (CPL) is a triple-wavelength (355, 532, 1064 nm) elastic backscatter lidar [3] that provided 171 hours of profile data through portions of cloud during IMPACTS. Table 1 summarizes the instrument characteristics. Among the closely-coordinated flight segments with the P-3 was 3.0 hours of in-situ microphysical context with the CPL observations as computed by a lidar matching algorithm. By determining the particulate backscatter coefficient (β_p)

values at the P-3 location every 10 s of flight, more direct insight between the remotely sensed observations and cloud particle properties were made. For the individual particle microphysics to be representative of the lidar volume measurements in a given cloud region, the two aircraft were required to be within 4 km and 5 min of each other for an observation to be considered coincident.

Table 1. CPL Characteristics

Property	Value
Backscatter Wavelengths	355, 532, 1064 nm
Depolarization Wavelength	1064 nm
Laser Repetition Rate	5 kHz
Pointing Angle	Near Nadir
Vertical Resolution	30 m
Horizontal Resolution	200 m

Figure 1 illustrates the procedure of obtaining individual particle properties from the Cloud Particle Imager (CPI) [4] on board the P-3. While over a dozen properties describing the size, shape, and complexity were calculated for each particle, only a subset are discussed in detail here. The particle types shown represent extremes in their morphological traits, with more spherical SCLW droplets (a,b) exhibiting a high aspect ratio (defined as the ratio between the minor and major axis of a best-fit ellipse) and circularity parameter (proportional to the ratio between the area and perimeter squared) while more elongated columnar crystals have a lower aspect ratio and circularity (c,d).

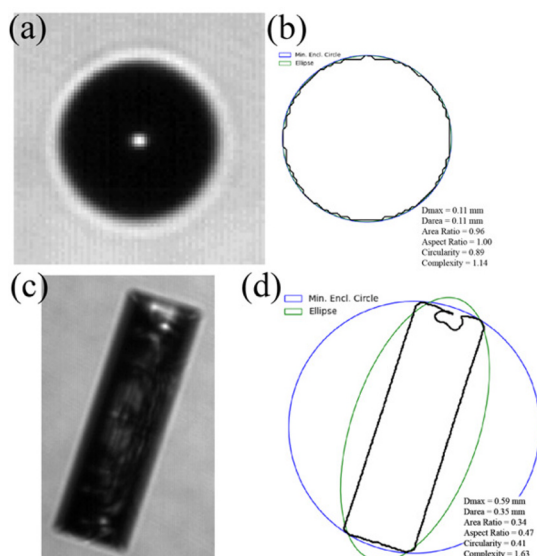


Figure 1. Cloud Particle Imager (CPI) native grayscale representation of individual particles at a 2.3- μm resolution (left) and basic descriptors (right) for a supercooled liquid droplet (top) and columnar crystal (bottom).

3. Results

The color ratio is used here to quantify the particulate backscatter coefficient difference between a higher (λ_1) and lower (λ_2) wavelength and is defined as:

$$\chi = \frac{\beta_{p,\lambda_1}}{\beta_{p,\lambda_2}} \quad (1)$$

From there, particle properties from the CPI are mapped to a triple-wavelength framework of 1064/532 and 532/355 nm backscatter color ratios ($\chi_{1064/532}$ and $\chi_{532/355}$) that relate the characteristic particle size, aspect ratio, circularity, and other thermodynamic and microphysical properties to the different backscatter coefficient ratios.

The mean temperature, liquid water content (LWC) from the King hotwire probe, and particle aspect ratio and circularity for each χ bin are some variables that illustrate the change in cloud particle properties as a function of χ from most coincident periods during IMPACTS (Fig. 2). While particle properties do not vary much with respect to $\chi_{1064/532}$ (Figs. 2c,d), there exists a notable increase in the mean aspect ratio and circularity parameter for $\chi_{532/355} \gtrsim 1$. Most of the exceptions to this relationship, where lower aspect ratios and circularity were associated with $\chi_{532/355} > 2.5$, are primarily explained by a greater cloud penetration depth prior to extinction of the 355-nm signal. Higher $\chi_{532/355}$ were typically observed in marginally warmer ($> -15^\circ\text{C}$) environments with appreciable LWC values, suggesting the presence of SCLW impacted the lower lidar wavelengths more than the higher wavelengths.

4. Summary & Future Work

Collocated lidar backscatter coefficient values and in-situ microphysical properties permitted the unique opportunity of exploring the impact of cloud particle type and shape on the multiple-wavelength CPL measurements during the IMPACTS field campaign. The existence of SCLW appears to impact the 355-nm wavelength most when the particle properties are mapped in a triple-wavelength framework

of different color ratio pairings. This work provides insight on potential avenues regarding the prediction of particle morphological properties and phase using the backscatter coefficient from lidar measurements.

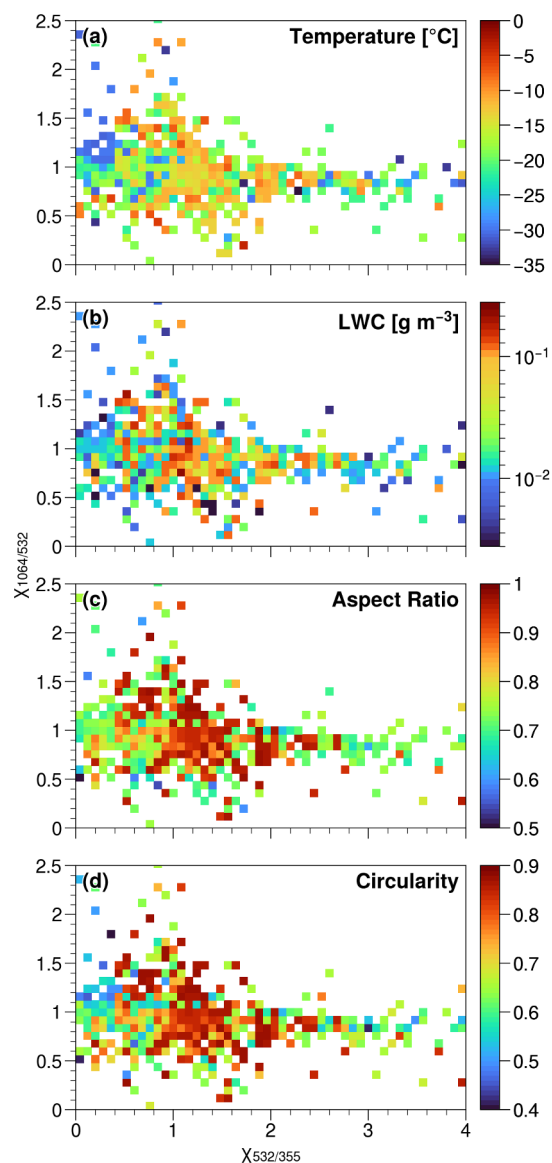


Figure 2. 2D plots of the mean (a) temperature, (b) LWC, (c) aspect ratio, and (d) circularity for each $\chi_{1064/532}$ and $\chi_{532/355}$ bin.

5. References

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