

Identification of Individual Precipitation Particles Using Particle Polarization Lidar

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Abstract: A particle polarization lidar (PPL) was developed to identify raindrops and snowflakes based on the polarization information of individual precipitation particles. In past polarized lidar observations, temporally and spatially averaged depolarization ratios of snow clouds and snowflakes have been measured. Although individual snowflakes vary in shape and size, investigations into the extent of variability in the depolarization ratios of individual snowflakes have not been conducted. Therefore, we artificially created snowflakes and evaluated their depolarization ratios. Moreover, in an experimental measurement using PPL, a dynamic precipitation process with alternating snowfall and rainfall was observed. The capability of the proposed method to identify raindrops, wet snowflakes, and dry snowflakes based on the depolarization ratio and particle size relationship was demonstrated.

1. Introduction

The polarization lidar distinguishes precipitation types by analyzing the depolarization ratio (δ) of clouds and precipitation particles. δ varies between water and snow clouds, as well as raindrops and snowflakes, with typical values of 0.1 or less for rain, around 0.4–0.5 for snow, and -0.7 for melted snowflakes [1,2]. Operating with temporal resolutions from minutes to tens of minutes and spatial resolutions from tens to hundreds of meters, the polarization lidar faces challenges in differentiating raindrops from snowflakes, particularly in mixed-phase precipitation like sleet.

To address this, the particle polarization lidar (PPL) was developed [3]. Emitting a laser beam with a 0.1 mrad divergence, the PPL analyzes the scattering properties of individual precipitation particles. Raindrops and snowflakes (dry or wet) are identified based on the depolarization ratio, which represents the change in polarization state caused by nonspherical particles like snowflakes. Particle size is estimated from individual particle echo intensity.

Historically, limited data processing capabilities hindered per-shot data recording and submeter spatial resolution. However, recent advancements enable per-pulse data recording and achieve submeter spatial resolution. Initial PPL observations revealed

snowflakes with $\delta \leq 0.6$ generally have diameters ≤ 2 mm, while those with $\delta > 0.6$ range from a few millimeters to over 20 mm. Above -5°C , snow crystals of a few millimeters can aggregate to form larger snowflakes.

Artificial snowflakes of varying sizes and shapes were created to validate PPL observations, and their depolarization ratios were measured. This paper presents the results of artificial snowflake depolarization ratios alongside PPL observations from February 2023.

2. Depolarization Ratio Measurement of Artificial Snowflakes

Figure 1 shows artificial snowflake created using the PET bottle chamber to grow snow crystals[4]. Ice grains form on a string stretched vertically, serving as nuclei for the growth of ice crystals into snowflake-like shapes. This artificial snowflake closely resembles large snowflakes with multiple single-crystal snowflakes adhering together.

Pulsed Nd:YAG laser light (1064 nm, 0.7 mJ, 10 ns) with horizontal polarization was directed onto the artificial snowflakes placed 1.8m away. The backscattered light was separated into horizontal and vertical polarization components using a polarizing beam splitter (PBS) and captured by two CMOS cameras (2592×1944 pixels, 256 gray levels). Horizontal and vertical polarization images with a single laser pulse are also shown in Figure 1. To

remove the background and the scattered light from the string, brightness values of the area trimmed by the red frame are used, and δ is calculated using their respective average brightness values. δ is calibrated beforehand. Horizontal polarized laser light is directed onto a reference plate, and the irradiated area is imaged with two cameras. Camera sensitivities are adjusted by swapping the cameras. Additionally, laser light is vertically polarized and imaged again to correct the extinction ratio of the PBS. δ value of the trimming area is 0.56. This value shows good agreement with previous studies by Sassen and Saito et al.

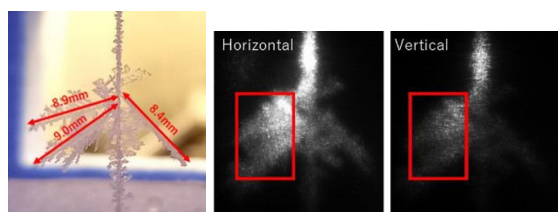


Figure 1. Example of an artificial snowflake and its polarized image

3. PPL observation

The transmitter of PPL is an Nd:YAG laser (1064 nm, 30 mJ, 2 Hz) with a pulse width of 10 ns. Scattered light is collected by a refracting telescope with a 50.8 mm diameter, then separated into horizontal and vertical polarizations by a polarization prism (PBS) and detected by an avalanche photodiode. The transmitted light is adjusted to a beam divergence angle of 0.1 mrad and released into the atmosphere with a diameter of 10mm. The PPL is tilted to an elevation angle of 42° to allow precipitation particles to intersect the laser beam. Each polarization signal is recorded per shot by a 14-bit AD converter.

The PPL observations were conducted on February 10, 2023, during the daytime at the Hino Campus of Tokyo Metropolitan University. Figure 2 presents time-altitude cross-sections for different types of precipitation particles. Clouds were observed around an altitude of 120 m, with precipitation particle echoes observed below. At the beginning of the observation, most of the particles consisted of dry snowflakes, gradually shifting to a mix of wet snowflakes around 15:00 LT, changing to sleet after 16:00 LT, and finally transitioning to rain at 17:00 LT. Additionally, around 17:00 LT, clouds around 120 m altitude dissipated, and precipitation

particles were observed up to around 250 m altitude. Above 200 m altitude were snowflakes, between 140 - 200 m altitude were mixed raindrops and snowflakes, and below 140m altitude were raindrops. This suggests a melting layer between 140 - 200 m altitude.

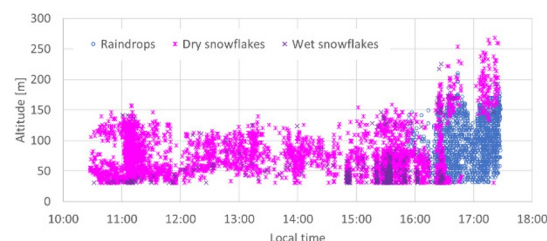


Figure 2. Time–height cross-section of the distribution of raindrops and snowflakes at Hino Campus of Tokyo Metropolitan University from 10:27 to 17:28 on 10 February, 2023.

4. Conclusion

The measurement of artificial snowflake depolarization ratios is closely aligned with previous studies, confirming the reliability of the PPL. This underscores its potential for distinguishing precipitation particles based on their depolarization ratio. February 2023 PPL observations revealed dynamic changes in particle types and altitudes, showcasing its effectiveness in identifying raindrops and snowflakes, including in mixed-phase precipitation like sleet. These findings underscore the PPL's potential to improve our understanding of precipitation processes and their applications in atmospheric research.

5. References

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