Precipitation particle distribution measurement by particle polarization lidar

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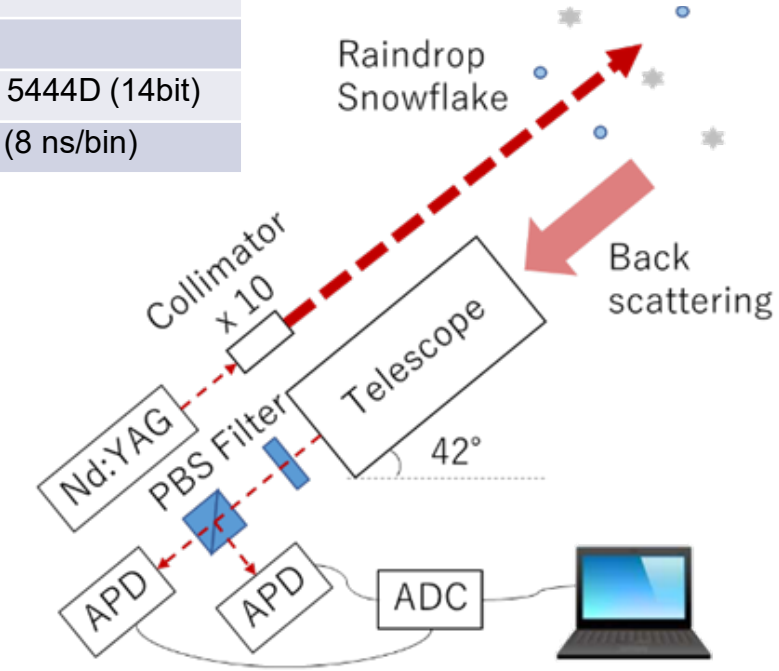
This study proposes a particle polarization lidar that classifies raindrops and snowflakes based on the polarization information of individual precipitation particles. As precipitation particles are several millimeters, the lidar signal from individual precipitation particles can be detected with a single laser pulse. Therefore, particle polarization lidar observation can obtain the range distribution of raindrops and snowflakes from the polarization information of individual precipitation particles.

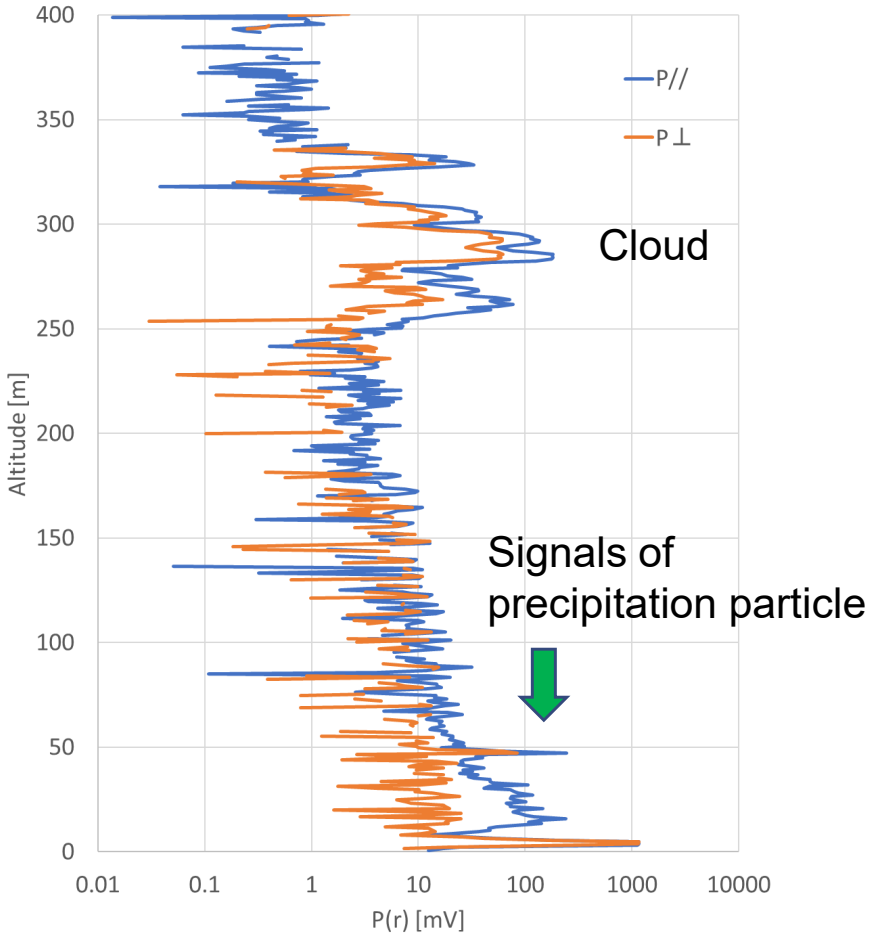
Particle polarization lidar measurements were performed at Tokyo Metropolitan University on 10 February 2022. We report the relationship between depolarization ratio and particle size and the vertical distribution of raindrops and snowflakes.

Ref. *Y. Shibata, "Particle polarization lidar for precipitation particle classification," Appl. Opt. 61,8 (2022): 1856-1862*

Particle polarization lidar (PPL)

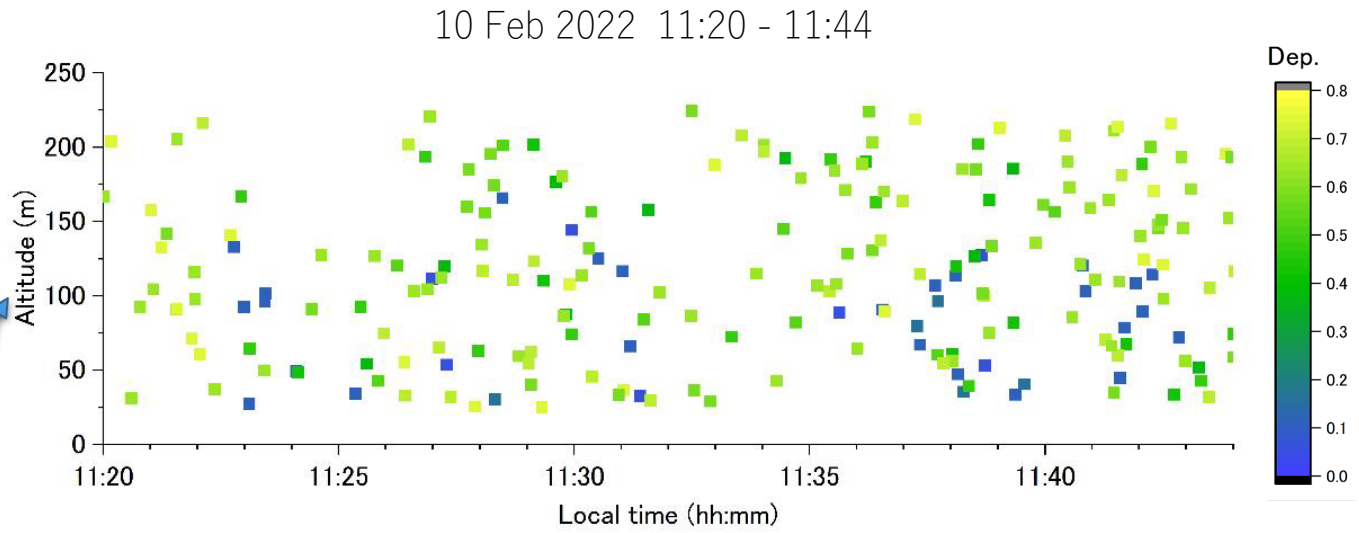
Table 1. System parameters	
Laser	Nd:YAG (DPS-1064-A)
Wavelength	1064 nm
Pulse energy	10 mJ
Pulse width	10 ns
Repetition rate	2 Hz
Beam diameter	10 mm
Elevation	42°
Telescope	ϕ 50.8 mm
Detector	APD
ADC	Picoscope 5444D (14bit)
Sampling	125 MS/s (8 ns/bin)



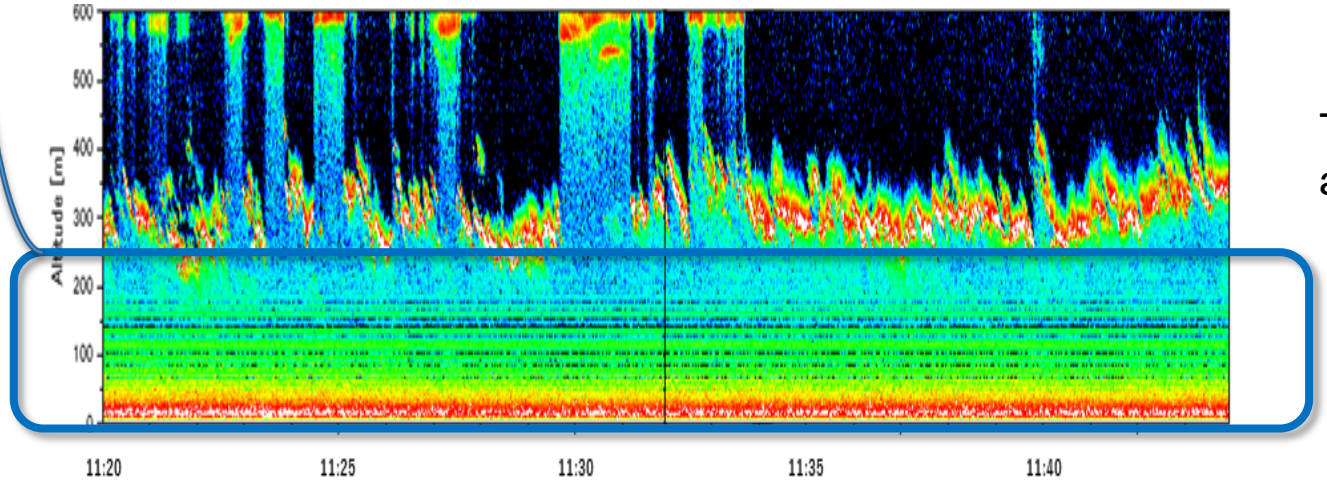


Example of PPL signals with a single shot.

Depolarization ratio δ of precipitation particles



Time-height cross section of the depolarization ratio of precipitation particles.



Range corrected signal.

- Precipitation particles were detected at an altitude of 250 m or less.
- The range of δ is 0.05 to 0.8.
- Precipitation particles with δ < 0.2 have fallen near the ground every few minutes.

There were clouds around 300 m altitude and around 600 m.

← The height range of precipitation particles detection

Estimation of particle size D_{pp}

- Lidar signal from precipitation particles P_{PP}

$$P_{PP}(r) = P_0 C \frac{A}{r^2}\left[\beta_{air}(r) + \frac{\rho_{PP}(r)}{\pi}\right]\Delta r O(r)\exp\left[-2\left\{\int_0^r \alpha_{air}(r')dr' + \frac{1}{\Delta r}\sum_{R=0}^{r}\rho_{PP}(R)\right\}\right]$$

$$\rho_{PP}(r) = \sum_{i=1}^{k}\Delta r \rho_{s,i}\frac{Q_{ext}\pi {D_{PP,i}}^2}{4A_L(r)}$$

P_0 : Laser energy, C: System parameter, β_{air} : Backscattering coefficient,
α_{air} : Extinction, ρ_{s} : Reflectance of precipitation particles, Q_{exe} ; extinction efficiency,
D_{pp} : Particle size, A_{L} : Beam diameter

- Lidar signal from atmosphere P

$$P(r) = P_0 C \frac{A}{r^2}\beta_{air}(r)\Delta r O(r)\exp\left[-2\left\{\int_0^r \alpha_{air}(r')dr' + \frac{1}{\Delta r}\sum_{R=0}^{r}\rho_{PP}(R)\right\}\right]$$

- Estimation of particle size D_{pp} (Assuming one precipitation particles in the optical pulse volume)

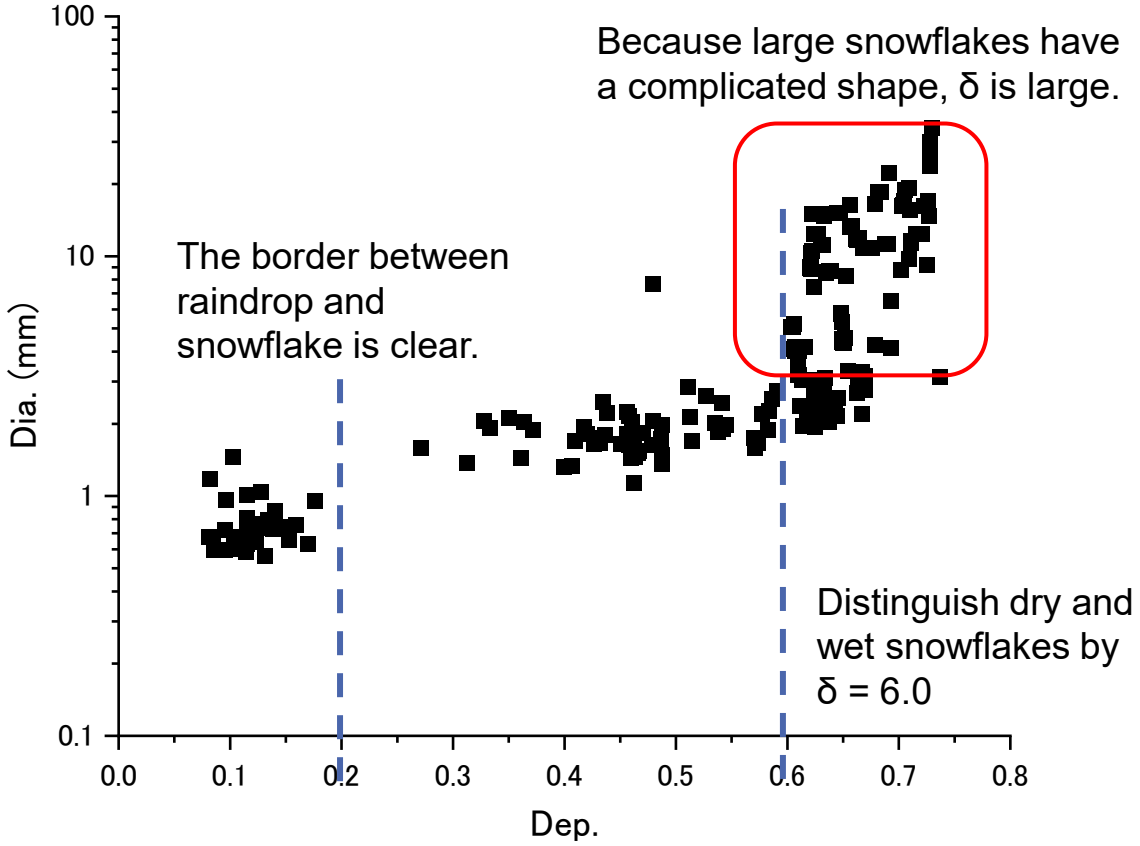
$$\frac{P_{pp}(r)}{P(r)} = 1 + \frac{1}{\beta_{air}(r)}\frac{\rho_{PP}(r)}{\pi} = 1 + \frac{1}{\pi\beta_{air}(r)}\rho_s\frac{Q_{ext}\pi {D_{PP}}^2}{4A_L(r)} = 1 + \frac{\rho_s Q_{ext}{D_{PP}}^2}{4\beta_{air}(r)A_L(r)}$$

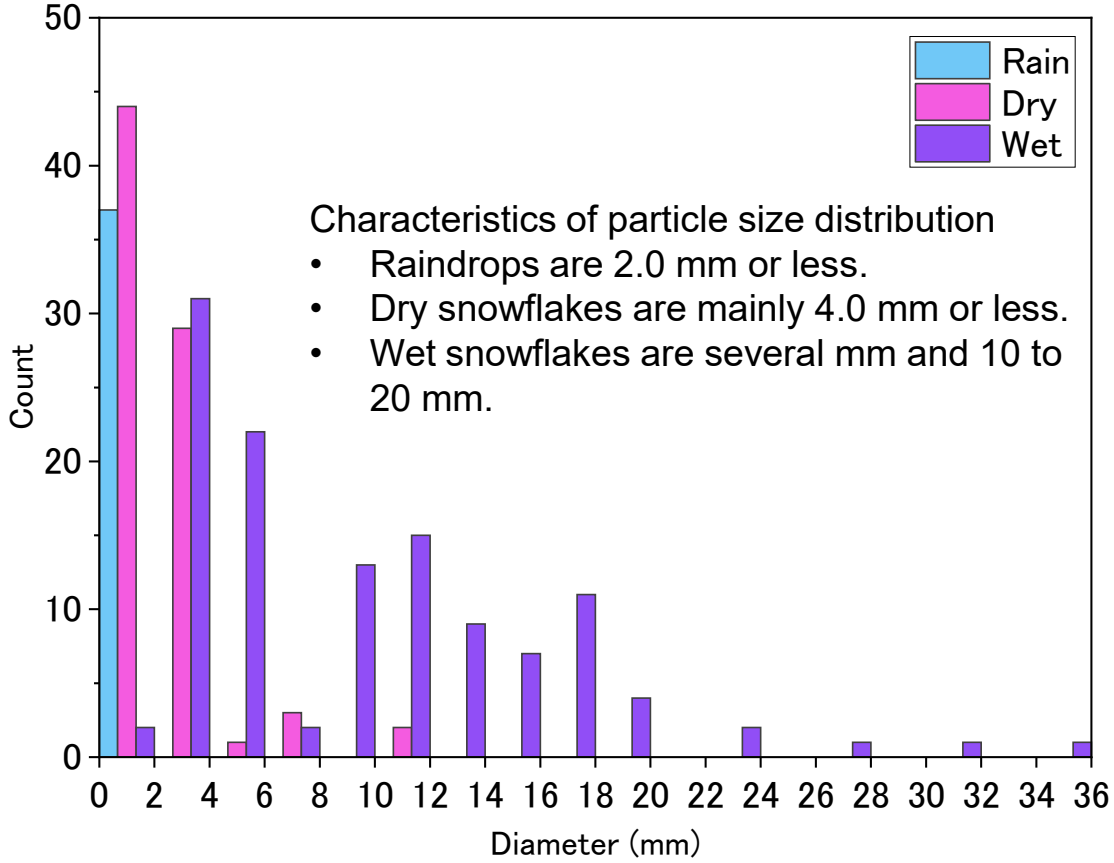
$$\therefore {D_{PP}}^2 = \left(\frac{P_{pp}}{P} - 1\right)\frac{4\beta_{air}(r)A_L(r)}{\rho_s Q_{ext}}$$

- The parameters are as follows.

$Q_{\mathrm{ext}} = 2.0$, $A_{\mathrm{L}} = 10.0$ mm, $\rho_{\mathrm{s}} = 0.02$ (Raindrop) , 0.05 (Snowflake)

Relationship between δ and D_{pp}



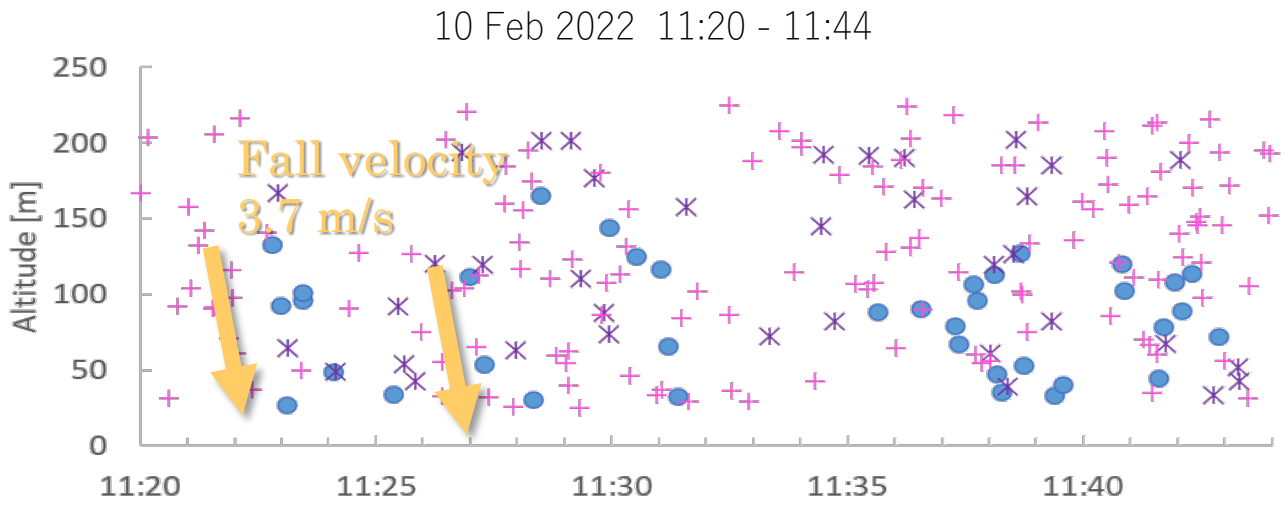


- The wet snowflakes join with multiple snowflakes and increase the particle size.
- δ of the melted snowflake is around 0.7 (Sassen, 1975)

Future task : It is necessary to know the reflectance ρs of large snowflakes to improve the accuracy of D_{PP}.

	Raindrop	Snowflake (dry)	Snowflake (wet)
Average (mm)	0.76	2.45	9.01
Standard deviation (mm)	0.18	1.92	6.53

Classification result

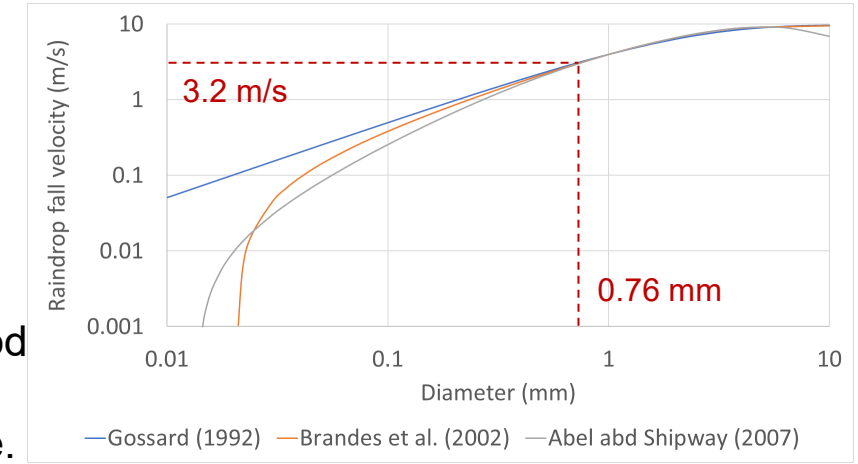


Classification result of raindrops and snowflakes

● : Raindrop, ✱ : Snowflake (dry). + : Snowflake (wet)

- Many precipitation particles were wet snowflakes.
- Sometimes raindrops were mixed in snowflakes.
- The falling of raindrops was measured.

- The fall velocity of raindrops is a good match with about 3.2 m/s obtained from the theoretical calculation value.



Conclusion

The particle polarization lidar (PPL) can classify individual precipitation particles as raindrops, dry snowflakes, and wet snowflakes (including melting snowflakes). Moreover, particle size can be estimated by the characteristic lidar signal from the precipitation particle.

We performed the PPL measurement on 10 February 2022 for 24 min. As the outside temperature was 1.4 C during the observation period, many wet snowflakes were detected. Regarding the particle size distribution, raindrops were concentrated below 2 mm. Dry snowflakes were composed of particles with a diameter of about a few mm, and wet snowflakes ranged from a few mm to 20 mm in diameter.