NOTES AND CORRESPONDENCE

Measurements of the Polarization Properties of Kosa (Asian Dust-storm) Particles by a Laser Radar in Spring 1983

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1. Introduction

The measurement of the depolarization ratio by using a laser radar can give us information remotely on the morphology of suspended materials in the atmosphere to some extent. Many researchers performed measurements of the depolarization ratio for clouds (*e.g.*, Schotland, 1971; Pal and Carswell, 1973; Derr *et al.*, 1976). A little has been reported (Reiter *et al.*, 1979; Goad, 1982) for aerosol particles. The depolarization ratio due to stratospheric aerosol particles has been observed at Nagoya since June, 1980. A series of our measurements indicated the changes in the depolarization ratio of stratospheric aerosols after the injection of volcanic materials by St. Helens in 1980 (Iwasaka and Hayashida, 1981) and by El Chichón in 1982 (Hayashida *et al.*, 1984).

Hayashida *et al.* (1984) found that relatively high depolarization ratios were observed just below a main peak of volcanic clouds injected by El Chichón suggesting that mineral particles with irregular shape originated from the eruption of El Chichón. However, knowledge on the depolarization properties of aerosol particles with various shapes from both theoretical and experimental examinations has been insufficient. Kosa (Asian dust-storm) particles are transported from the North China to Japan Islands (*e.g.*, Iwasaka *et al.*, 1983) and the North Pacific Ocean (*e.g.*, Uematsu

et al., 1983). They are recognized to be irregular in shape (Miyake *et al.*, 1956). The aim of this note is to indicate the depolarization ratio owing to Kosa particles by using the laser radar, together with the results of measurements in other seasons.

2. Method

As the definition of the depolarization ratio was presented in the previous note (Iwasaka and Hayashida, 1981), we repeat it here only briefly. The specification of our laser radar system should be referred to Iwasaka and Isono (1977). The wavelength used is 0.6943 μm (ruby).

The total depolarization ratio $\delta(z)$ of backscattered light is defined by

$$\delta(z) = \beta_{\perp}(\pi) / \beta_{\parallel}(\pi), \quad (1)$$

where $\beta_{\parallel}(\pi)$ and $\beta_{\perp}(\pi)$ are parallel and orthogonal components of backscatter coefficient and z is altitude, respectively. These backscatter components satisfy the following lidar equations:

$$Pr_{\parallel}(z) = Pt_{\parallel} K_{\parallel} \beta_{\parallel}(z) \exp[-2\tau_{\parallel}]/z^2, \quad (2)$$

$$Pr_{\perp}(z) = Pt_{\perp} K_{\perp} \beta_{\perp}(z) \exp[-(\tau_{\parallel} + \tau_{\perp})]/z^2, \quad (3)$$

where Pr is received power, Pt transmitted power, K the system constant, τ the attenuation coefficient and subscripts $\parallel$ and $\perp$ refer to measurements made with the plane of polarization of backscattered light parallel and

orthogonal, respectively, to that of transmitted laser pulse.

As shown in the previous report (Iwasaka and Hayashida, 1981), backscattering components of both aerosol particles and air molecules usually contribute to $\delta(z)$. The contribution of air molecules can be neglected since the backscattered light from particulate matter apparently dominates that from air molecules for the interesting altitude ranges. Thus the Eq. (1) is rewritten as

$$\delta(z) \cong \beta_{p\perp}(\pi) / \beta_{p\parallel}(\pi), \quad (4)$$

where p means particle scattering component. Consequently when the depolarization ratio is high, non-spherical particles would be present. On the other hand, spherical particles and air molecules would make a small contribution to $\beta_{\perp}$.

The photon counting method was adopted in our measurements. $Pr_{\parallel}(z)$ was obtained by integrating some decades of returned pulses. Then rotating an optical filter and $Pr_{\perp}(z)$ was obtained by the same way.

The depolarization ratio was measured when no cloud was recognized with the naked eye for the direction of laser beam.

3. Results and discussion

3.1 Measurements of the depolarization ratio of Kosa on 8 May, 1983

According to Nagoya Meteorological Observatory, a Kosa event was recognized during the period from 14:00 to 23:10 LST on 8 May, 1983. The Kosa event was observed far and wide over Japan Islands on this day. Measurements of the depolarization ratio by the laser radar were performed from 21:00 to 22:00 LST. Although the Kosa event was not so conspicuous during the observation, the depolarization ratios were higher than the values observed in the absence of the Kosa event.

Figure 1 shows an optical micrograph of aerosol particles collected at Nagoya University, located on east of Nagoya city, on a slide glass coated with polystyrene film at 20:32 LST. The sampling time was 1 min. This photograph was taken at the relative humidity of 60%. The collection was per-

Fig. 1 Optical micrograph of aerosol particles collected on 8 May, 1983.

formed by an impactor of 2 mm diameter jet. A flow rate of air was adopted to be 5 l min^{-1} . On the basis of the experimental results (Ranz and Wong, 1952), the collection efficiency was evaluated to be 100% for the particles with radii more than $1 \mu\text{m}$. The particles with irregular shape were present in a high number fraction of particles and they would be Kosa particles.

Figure 2a shows the time change in the vertical profile of the depolarization ratio at altitudes between 3 and 8 km in terms of percentage on 8 May, 1983. In all cases in Fig. 2a, the depolarization ratios at altitudes between 3 and 3.5 km were higher than other levels. This suggests that Kosa particles were mainly present at altitudes below about 3 km.

Figure 2a also shows that the depolarization ratios are variable temporally. McNeil and Carswell (1975) indicated that the polarization properties varied substantially with meteorological conditions. It suggests that the spatial and temporal distribution of Kosa particles on 8 May, 1983 was not homogeneous.

Figure 2b shows the vertical profile of the average depolarization ratios for the four cases in Fig. 2a. The average of the depolarization ratio are obtained by substituting summation of $Pr_{\parallel}(z)$ and $Pr_{\perp}(z)$ of the four cases into Eq. (1). The average depolarization ratio decreased with altitude but slightly increased at altitudes of about 6 km. The average depolarization ratio had a high value of about 30% at altitudes between 3 and 3.5 km.

Fig. 2 (a) The vertical profiles of the depolarization ratio and the observation times on 8 May, 1983, (b) The average of the depolarization ratios of the four profiles. Error bars are calculated by one standard deviation of the photon counts.

Range corrected values of returned signals $Pr(z)z^2$ are shown in Fig. 3 with backscattering coefficients originating from Rayleigh scattering β_R , where $Pr(z)$ is received power including both parallel and orthogonal components. β_R in Fig. 3 was calculated based on upper-air synoptic data over Hamamatsu (located on southeastward about 100 km from Nagoya). $Pr(z)z^2$ is proportional to total backscattering coefficient β_{R+M} . $Pr(z)$ in Fig. 3 was derived from the measurements of $Pr(z)$ at 21:01 to 21:03 LST and 21:11 to 21:13 LST. The difference $\beta_{R+M} - \beta_R$ shows particulate backscattering coefficient which is

corresponding to mass concentration of particles. From the comparison between Fig. 3 and Fig. 2b, high depolarization ratios were shown at altitudes where β_{R+M} were relatively high, except for a narrow peak of β_{R+M} at altitudes between 7 and 7.5 km. A minimum of depolarization ratio at around 5 km was corresponding to the small values of β_{R+M} . That is, depolarization ratios were high at altitudes where the amount of particles seemed to be relatively high. Origin of the narrow peak at altitudes between 7 and 7.5 km was unknown.

3.2 Measurements of the depolarization ratio when Kosa event was not recognized

We measured the depolarization ratio when a Kosa event was not reported, in order to compare with the measurements when it was reported. However, we did not confirm whether Kosa particles existed or not at altitudes where high depolarization ratios were measured, as we did not collect aerosol particles *in situ*. Figures 4a and b show the depolarization ratios when a Kosa event was not reported.

Figure 4a shows the vertical profiles of the depolarization ratios on 14 June, 1983. The high depolarization ratios were seen at altitudes at about 7 km. The high depolarization ratios at higher altitudes were present in a relatively thin layer, and the value and peak height of the depolarization ratio varied within several minutes. It would be due to thin ice-crystal clouds invisible with the naked

Fig. 3 The vertical profiles of β_R and $Pr(z)z^2$ in log scale on 8 May, 1983. Error bars denote one standard deviation of the photon counts.

Fig. 4 (a) The vertical profiles of the depolarization ratio and the observation times on 14 June, 1983 and (b) 29 October, 1983.

eye. In such a case depolarization ratios of more than 30% were often observed. However, they can be distinguishable from the Kosa event by the altitudes of their appearance and the narrowness of the peaks of the depolarization ratio. The peak width of the depolarization ratios was often within 0.5 km. The first tropopause height on 14 June was 12380 m over Hamamatsu. The thin layer with high depolarization ratio did not always appear just below the tropopause.

In general the depolarization ratio was low when a Kosa event has not reported. Figure 4b shows the vertical profile of the depolarization ratio on 29 October, 1983. Values of the depolarization ratio were relatively constant and low at altitudes between 3 and 11 km during our observation on this day.

Low depolarization ratios were often observed from June, 1983 to February, 1984 similar to those shown in Fig. 4b. Most of them were less than 5%. This might not result from the nature of the aerosol particles but rather a low number concentration of aerosol particles. Eq. (4) is invalid when the number concentration of aerosol particles is so low that the contribution of air molecules to the depolarization properties is comparable to or larger than that of aerosol particles. Phenomena such as a large amount of aerosol particles with irregular shape can be transported is extraordinary except for a Kosa event in Japan.

3.3 Measurements of the depolarization ratio from April to May, 1983

High depolarization ratios from April to May, 1983 were often seen. Figures 5a and b show the depolarization ratios in this period.

Figure 5a shows the depolarization ratios on 8 April, 1983. In Fig. 5a, the depolarization ratios at altitudes below 4 km were about 30%. The depolarization ratio decreased with altitudes but increased at altitudes around about 6 km. And the depolarization ratio increased again at altitudes above 7.5 km. The latter increase in the depolarization ratio might be due to thin ice-crystal clouds as mentioned above.

Figure 5b shows the depolarization ratios on 2 May, 1983. The depolarization ratios were low at altitudes below 3.5 km unlike those of 8 April and 8 May, 1983. However,

Fig. 5 (a) The vertical profiles of the depolarization ratio and the observation times on 8 April and (b) 2 May, 1983.

the depolarization ratios at altitudes between 4 and 6 km were high and exceeded 20%. High depolarization ratios at this altitude indicated different characteristics from those originating from thin ice crystal clouds. They occurred at lower and deeper altitudes than the thin ice-crystal clouds.

A Kosa event was not reported by Nagoya Meteorological Observatory on these days. However, cyclones passed over Japan Islands before our observations and Kosa event is often recognized under such meteorological circumstances in every spring. Dust storms were reported in China a few days before our observations. Kadowaki (1979) reported that Si and Al in urban aerosols in Nagoya increased in spring. He ascribed the origin of high concentrations of Si and Al in spring to Kosa event. Similar results were obtained over the North Pacific Ocean by Uematsu *et al.* (1983). The seasonal occurrence of Kosa event and high values of the depolarization ratio suggest that Kosa particles came over Nagoya on these days. Profiles of depolarization ratios shown in Figs. 5a and b were different from those regarded as thin ice-crystal clouds and such profiles were not observed in other seasons. Iwasaka *et al.* (1983) reported double layers of Kosa on 14–15 April, 1979. They showed the maximum of the backscattering coefficient of the lower layer to be at 2 km and the upper one at 6 km. And they suggested that the origins of the two Kosa layers were different, that is, probably the upper layer was transported from the Takla-Makan desert and the lower layer from Gobi desert and Huang-Ho basin. Their results and ours make us suggest that Kosa particles can be transported without the recognition of a Kosa event on the ground.

4. Summary

Measurements of the depolarization ratio were performed by using a laser radar. When a Kosa event was recognized on 8 May, 1983, high depolarization ratios were observed. We can conclude that aerosol particles with irregular shape like as Kosa particles cause high values of the depolarization ratio. When Kosa event was not recognized from June, 1983 to

February, 1984, the depolarization ratios were low in general and was distinctly different from those on 8 May, 1983. However, high depolarization ratios were also observed at higher altitudes and were often about 0.5 km in thickness. They would be due to thin ice-crystal clouds. From April to May, 1983, some cases showed high depolarization ratios notwithstanding that Kosa event was not recognized on the ground. In such cases high depolarization ratio would result from Kosa particles. This suggests that measurements of depolarization ratio by a laser radar is useful for discrimination of a dust storm.

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1983 年春に行なったレーザ・レーダによる黄砂の偏光特性の測定

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