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Depolarization properties of Asian dust (KOSA) measured by LIDAR in Okayama in the spring of 1998

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Abstract: In spring of 1998, Asian dust was observed with a Mie LIDAR in Okayama University, which can measure depolarization ratio. Three events of intense Asian dust were occurred in the period and medially detailed structure of atmosphere was found after examining records.

Asian dust was distinguished from water droplets and the possibility to study three dimensional dynamic structure of atmosphere were demonstrated.

Keys words: Mie lidar, Asian dust (KOSA), depolarization ratio, backscattering ratio, range normalized.

1.Introduction.

Tropospheric aerosols play an important role in climates, because of their attribution to cloud formations and sunlight attenuations.[1,2,3] Aerosol have direct and indirect effects on climate. The indirect effect is that they act as condensation nuclei that cause cloud formation; the direct effect is scattering and absorption of solar terrestrial radiation. Scattering aerosol help to cool lower atmosphere caused by the umbrella effect of scattering, on the contrary, absorption type aerosols help to heat the atmosphere, which contribute to the global warming.

Asian dust is one of the tropospheric aerosols. Kosa, the yellow sand covers the sky and falls to the surface, has been well known as the meteorological phenomenon in Japan especially in the spring. Many meteorological researches on Asian dust have been made in the last decades to survey its effect on radiation and the mechanism of its transportation [4]. However, the quantitative investigation and analysis of Asian dust for its total amount, its particle density or size distribution has not yet been well carried out. In order to observe how Asian dust is transported and what kinds of influences does it effect on the environments, an observation station was built at Okayama University in 1997.

Okayama University locates at (N133° , E34°). Okayama is suitable for monitoring Asian dust because clear days prevail through an year and it locates in the middle between Kyushu and Nagoya. A Mie lidar system was built in 1998. The location of the lidar observation site is shown in Fig.1. In this paper, we present some results obtained from the lidar system.

2.Mie Lidar system.

The lidar employs a Nd:YAG laser transmitter with fundamental and second harmonic frequencies at 1064nm and 532nm wavelength, respectively. The maximum power is 400mJ. In ordinary operation, 70mJ with pulse duration of about 14-16nsec is available at pulse repetition rate of 10pps. Diameter of the output beam is 9.5 mm. A Schmidt Cassegrainian telescope with 35cm diameter is employed as the receiver. The schematic diagram of this system is given in Fig.2. An interference filter (IF) with center—wavelength at 532nm and bandwidth of 1.5nm was used to block the background light.

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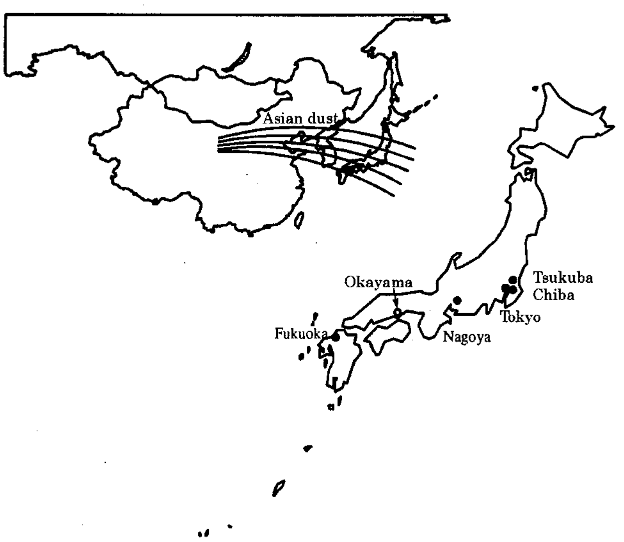

Fig.1. Location of the Lidar observation site: Okayama University.

The system has been designed with multiple receiver channels: Channel one (CH1) is to receive the component parallel to the transmitted laser polarization and Channel two (CH2) is for perpendicular component. Parallel (∥) and perpendicular (⊥) components are separated by using a polarization beam splitter (PBS). Optical path inside system is designed as short as possible for easy alignment. Also, the collimating lens was first positioned to collimate a point image on the primary focal plane, then it was adjusted so as to give the best throughput to photo multiplier tubes (PMT). Field of view (FOV) is 1mrad. Two PMT's were employed to detect perpendicular and parallel components, respectively. The voltages applied to the PMT are limited to avoid current saturation in the parallel channel. Before measuring, the two PMTS were exchanged for calibration. Outputs of PMT are fed to a digital storage oscilloscope (DSO) through a pre-amplifier (AMP). Signals are averaged over 4096 shots to enhance signal to noise ratio. Temporal resolution was 100nsec, which is equivalent to range resolution of 15 m. Averaged data in the DSO are transferred to a personal computer via a GPIB interface. The system is set on the 5th floor of the building of the Graduate School of Natural Science and Technology, Okayama University. The laser beam was launched north through a window with an elevation angle of 45°

3.Experimental results and analysis

Experimental results are illustrated with received range normalized power, depolarization ratio and backscattering ratio as follows. Three parameters have been utilized to discriminate non-spherical particles from droplets in the atmosphere.

The depolarization ratio δ at each altitude is given by[6)]

$$\delta(Z)=P_{\perp}(Z)/P_{\parallel}(Z), \qquad (1)$$

where $P_{\perp}$ and $P_{\parallel}$ refer to the components of backscattered laser power that are polarized perpendicular and parallel to the transmitted polarization axis, respectively. According to Mie scattering theory, for situations in which only spherical particles are involved in the scattering processes (e.g. water droplet clouds and fogs), single scattering in this case retains the incident linear polarization in the backward direction. The depolarization ratio is expected to be essentially zero in such kind of media for single scattering. The depolarization ratio due to atmospheric molecules is usually taken as abut 1.4%[5)]. High depolarization ratio for single scattering can arise from non-spherical particles such as Asian dust and ice cloud. According to our measurement, the depolarization ratio of molecules is about 1-2% at free-aerosol days. Sometimes, the depolarization ratio below 1.5% was found in high moisture atmosphere, or in the water clouds.

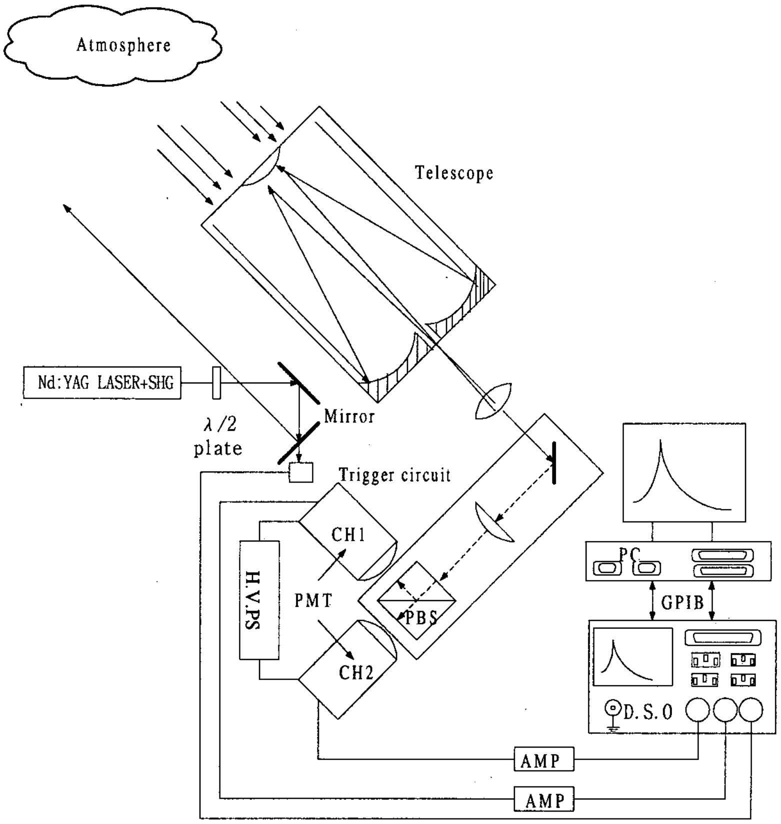

Fig.2. The schematic diagram of Mie Lidar system

The backscattering ratio at each altitude is defined by[6]

$R(Z)=1+\beta_a(Z)/\beta_m(Z)$, (2)

Where β_a and β_m are the backscattering coefficients of aerosol and molecules, respectively. According to the algorithm of Fernald [7], the recursion equation was adapted to our system to be in use. The backscattering ratio was obtained from the received range normalized power.

The observation was conducted both at daytime and at night in the period of 25th March to 25th May 1998. Figure 3 shows range normalized power on different time on April 18,1998, which gives the depolarization ratio and backscattering rates as Fig.4 and Fig.5, respectively. From these figures, height distribution of aerosol and cloud layer changes appreciably in time. Comparing the perpendicular return for each measurement with the parallel in Fig. 3 (a) to (e), their profiles are found not similar.

In Fig. 3 (a) and (b), the parallel signal show a very sharp and prominent peak at lower altitude at about 1.4 km in (a) and at about 1 km in (b), whereas the perpendicular signals have no peaks. This behavior was caused with a layer of spherical water droplets or fogs, which returns the parallel to the incident laser beam. From both Fig. 4 and Fig. 5 (a) and (b), the lower value of δ and backscattering ratio are found at the lower altitude. These explain that water droplets or mist occupy there.

In Fig. 3 (c), the sharp peaks at 1 km overspending to cloud base show the same spatial profile between the parallel and perpendicular signals around. In Fig. 4 (c), the lower value of δ is about 2% there, but in Fig. 5 (c), the backscattering ratio reaches to 37. These explain the cloud layer consists of water droplets.

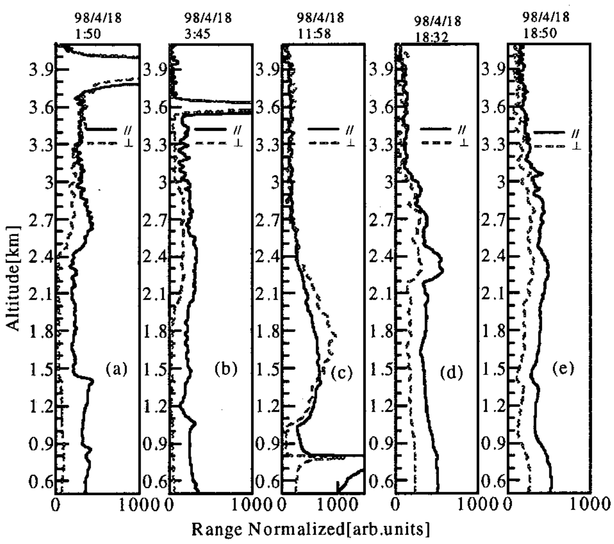

Fig.3. Vertical profiles of range normalized on April 18, 1998. Solid and dashed curves are data taken from parallel (//) and perpendicular(⊥), dashed curves are enlarged 10 times.

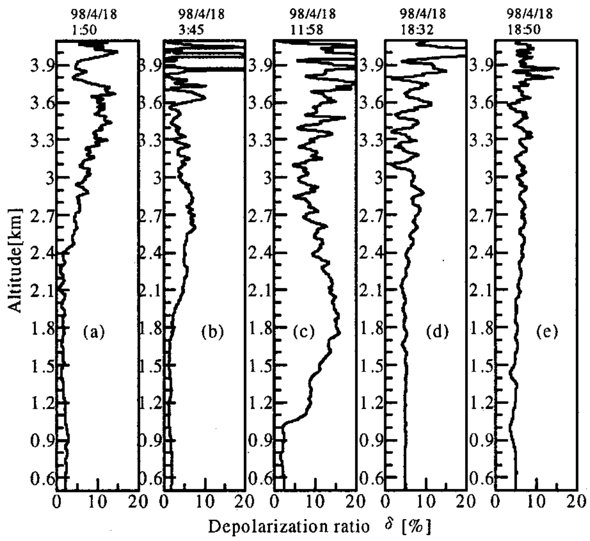

Fig.4. Vertical profiles of depolarization ratio on April 18,1998.

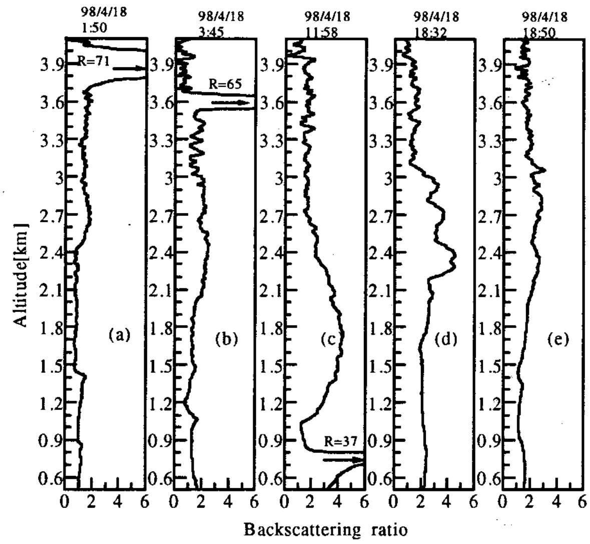

Fig.5. Vertical profiles of backscattering ratio on April 18,1998.

In Fig. 4, higher value is found in the figure (c) compared to others, and the profile occupies thick layer for 1 km to 3 km or higher. Changes in the value are moderate, both in Fig. 4 (c) and Fig. 5 (c) in the altitude range. These feature coincide with Asian dust which has been well diffused in a cell while transferred from central Asian continent to Japan. This is contrary to a layer of cloud, which would have steep altitude distribution in the backscattering ratio.

The Lidar data we have detected in (a) and (b) of Figs. 3, 4 and 5 (i.e. (a) is about 4 km, (b) is about 3.61 km) bring our attention to another phenomenon. From Fig. 4 and 5, it is apparent that they are of cloud, whose backscattering ratio R are high enough to be about 71 and 65, respectively, but the depolarization ratio still remain at about 15% and 10%, respectively. Normally, the depolarization ratio of the cloud in such altitudes are about 30%~50% according to our measurement and the literature[9]. It is known that is a mixed layer with could and water droplet.

In general, the backscattering ratio of Asian dust is often found between 2 and 5, the depolarization ratio δ is often found between 5 and 8. The backscattering ratio will reach to 8 and depolarization ratio δ will reach to 15 if aerosol density is high enough[4].

From curves (d) and (e) of Fig. 3, it is apparent that the curves of two channels show the same spatial distribution, therefore, the depolarization ratio δ is constant below 2 km. At the lower altitude under 1 km the value of δ in Fig.4 (d) and (e) are, however, bigger than that of in Fig. 4 (a) to (c) and gradually increases as time, which means that the Asian dust is mixed up and diffuses into whole atmosphere.

Fig. 6, 7 and 8 show the range normalized, the depolarization ratio and the backscattering ratio measured on April 27, 1998, respectively. It was a free-cloud day. In Fig. 6, comparing the two channels of the return signals, three layers of Asian dust are found in between 2 km and 4 km. The perpendicular signals become higher as altitude. For example, in Fig. 6 (a), intensities of the parallel signals at 2.51 km and at 3.25 km are almost the same, the corresponding perpendicular signals, however, have an intensity ratio of 1:1.28. This behavior apparent depolarization ratio would increase as the laser beam propagates in depolarizing layer because of the forward scattering, not by the backward scattering, as Carswell pointed out[9]. It is confirmed that Asian dust is not homogeneous.

In Fig. 6 (e), an intense layer is found at 3.4 km in the parallel signal, with no significant signal in the perpendicular which was caused by water droplets or liquid, so that the value of δ is found in Fig.7 (e) below 2%. It is clear that the Asian dust was wrapped in liquid or water droplets in the layer at free-cloud day.

From Fig.7 (a) to (c), dense Asian dust layers are found, which is convinced from the depolarization ratio higher than 15%.

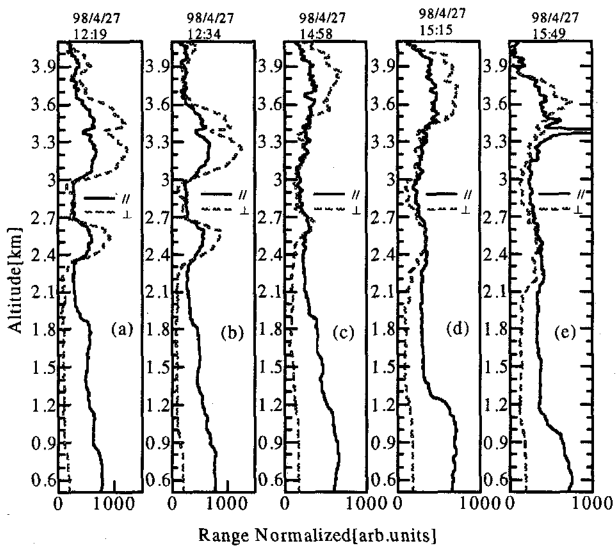

Fig.6. Vertical profiles of range normalized on April 27, 1998. Solid and dashed curves are taken from parallel(//) and perpendicular (⊥), dashed curves are enlarged 10 times.

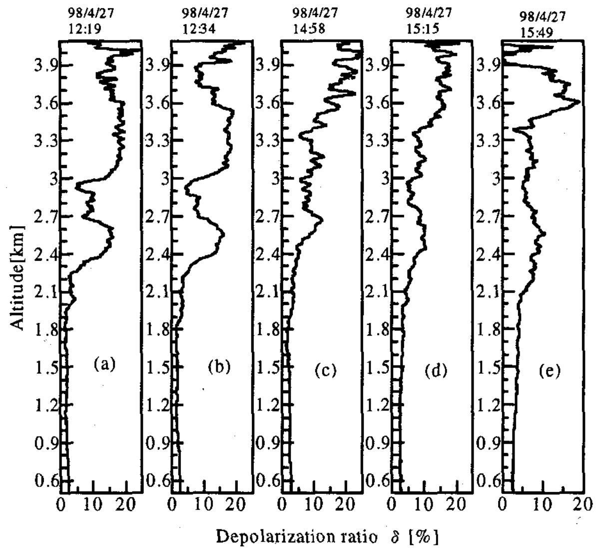

Fig.7. Vertical profiles of depolarization ratio on April 27, 1998

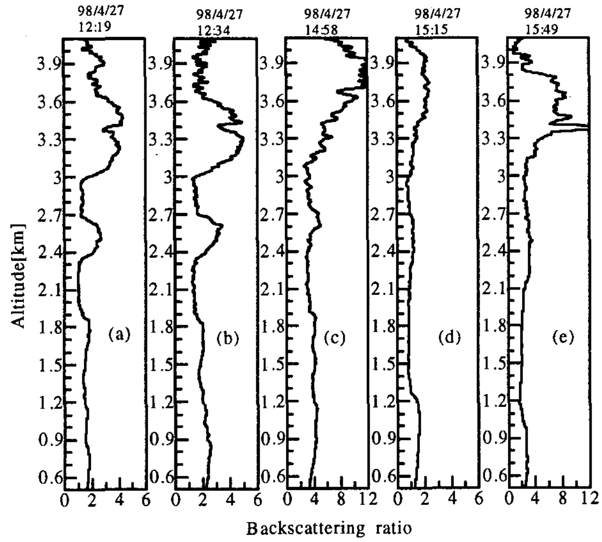

Fig.8. Vertical profiles of backscattering ratio on April 27, 1998

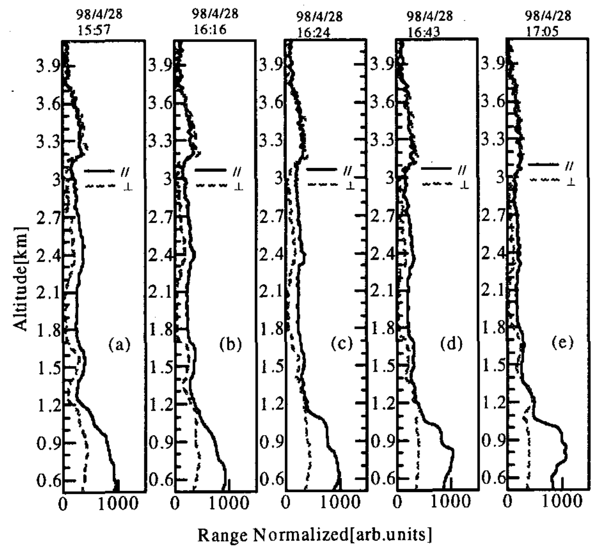

Fig.9. Vertical profiles of range normalized on April 28, 1998. Solid and dashed curves are taken from parallel(//) and perpendicular (⊥), dashed curves are enlarged 10 times.

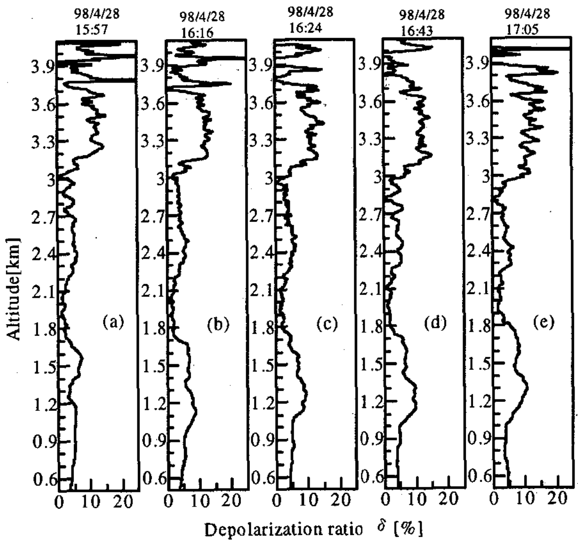

Fig.10. Vertical profiles of depolarization ratio on April 28, 1998

From Fig.8 (c) and (e), backscattering ratio of up to 8 is found above 3.3km , these also explain that aerosol occupied on the day.

Figure 9,10 and 11 show the range normalized, the depolarization ratio and the backscattering ratio measured on April 28, 1998, respectively. It was a clear day. They show distribution of the Asian dust layers are relatively stable in both channels, which means the laminar structure was stable in the day. Western Japan was covered these days by very stable atmosphere which was trapped by a high-pressure of 1022hPa. The steady structure of the Asian dust coincides with the observed signals herein. The curves of δ in Fig. 10 show there are Asian dust layers, in which the upper layer are stronger than the lower, which mean the forward scattering are exist in the upper layer. The Asian dust at about 3.75 km altitude is considered to be wrapped by liquid or water droplets, because local decrease of depolarization ratio in the Asian dust layer were found there.

Fig 12, 13 and 14 show the range normalized, the depolarization ratio and the backscattering ratio measured on clear day on May 9 and 14, 1998, respectively. No peak was found in these figures. In Fig.13 (a) to (e), the value of δ are about 2%, In Fig.14, the backscattering ratio are least between 1 and 2, these curves on May are very different from that on April. It is apparent that only molecular scattered exist on these days.

The results observed in the spring of 1998 well accorded with the data from the data of sunphotometer and TOMS's satellite photography given by NASA[10,11].

4.Disscussion

From the measurement, according to depolarization ratio, it is apparent that the distribution of Asian dust in the atmosphere is imhomongenous. It is unacceptable to calculate backscattering ratio of aerosol by assuming that atmosphere is homogeneous[12]. If a depolarization ratio is constant as altitude, the distribution of Asian dust is homogenous such as at about from 0.5 km to 2.1 km in Fig.7. We can know whether the atmosphere is homogenous at an altitude range or, not based on the shape of δ. Thus, we can assume an initial value of backscatter coefficients to solve backscattering ratio.

The complicated structure of Asian dust was also observed such as supposed to be wrapped by liquid or water droplets, by the sudden changes of depolarization ratio in the Asian dust layer were found, such as Fig.4, 7 and 10. Comparing the measurement data on April with that on May, thick penetration depths of Asian dust were also found in April, 1998.

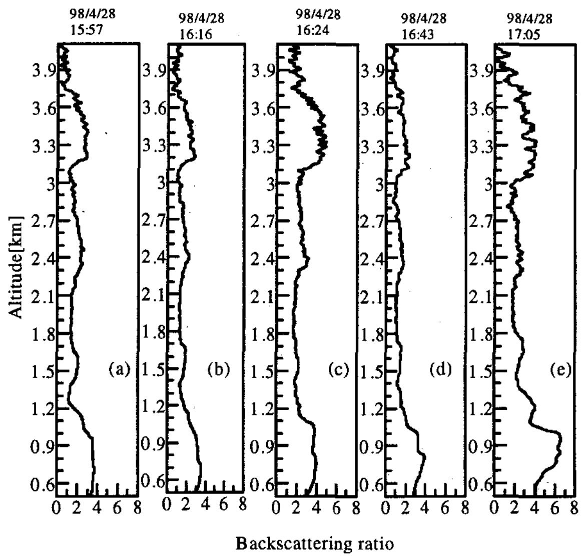

Fig.11. Vertical profiles of backscattering ratio on April 28, 1998

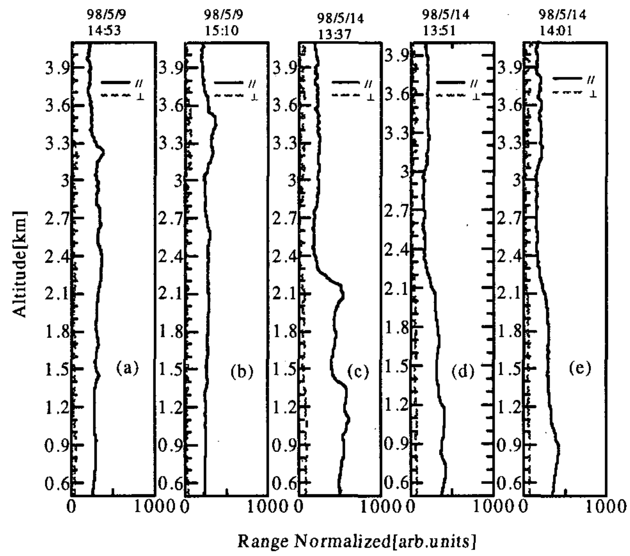

Fig.12. Vertical profiles of range normalized on May 9 and 14, 1998. Solid and dashed curves are taken from parallel(//) and perpendicular (⊥), dashed curves are enlarged 10 times.

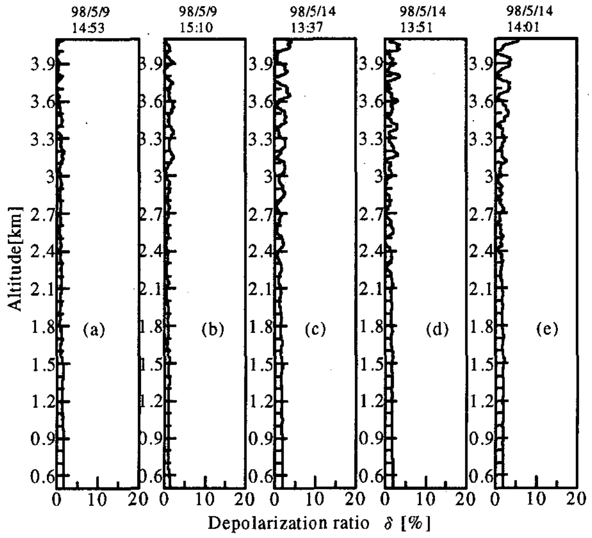

Fig.13. Vertical profiles of depolarization ratio on May 9 and 14, 1998

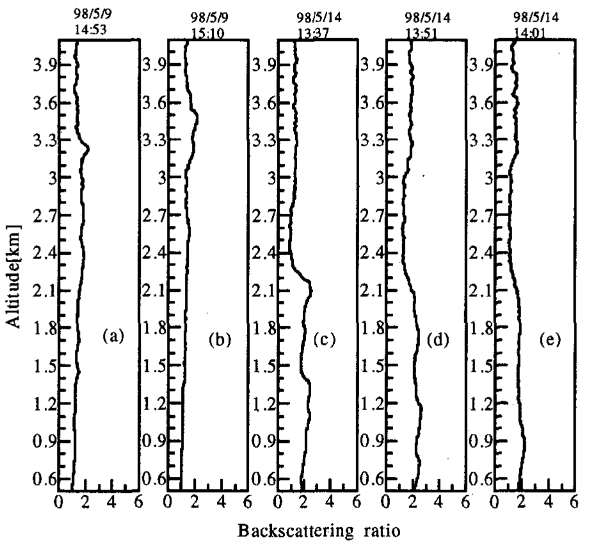

Fig.14. Vertical profiles of backscattering ratio on May 9 and 14, 1998

5. Conclusion

Data have been obtained with high spatial resolution and accuracy in the polarization measurement using this system. Examining the received range normalized, the depolarization ratio and the backscattering ratio from Asian düst, the diagnostics for meso-scopic structure of tropospheric atmosphere could be done.

Asian dust layers appeared over Okayama in the spring of 1998 was measured by the laser radar, and the distribution of Asian dust in the atmosphere was found inhomogeneous. There also exist multiple scattering in Asian dust layer. The complicated structure of Asian dust wrapped by liquid or water droplets was also observed, which caused the sudden changes of depolarization ratio in the Asian dust layer. It is known that the penetration depth of Asian dust is so thick as not to be ignored their influences on scattering or absorption of solar radiation. This method is featured by its meso-macroscopic spatial distribution measurement, though very detailed analysis is impossible. It is, therefore, necessary to investigate and analyze the quantitative, particle density and size distribution of Asian dust.

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