SEASONAL VARIATION OF LIDAR RATIO PROFILE OBSERVED BY A MULTI-WAVELENTH RAMAN LIDAR SYSTEM AT GWANGJU, KOREA

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ABSTRACT

Vertical profiles of lidar ratio at 355 and 532 nm were measured with the GIST/ADEMRC multi-wavelength Raman lidar at Gwangju, Korea (35.10ºN, 126.53ºE). Observation had been made for six months in 2004 and four months in 2005. Average lidar ratios and aerosol optical depth (AOD) at two wavelengths, 355 nm and 532 nm, were calculated for each vertical aerosol layer. Average lidar ratio was determined to be 56.7±9.6 and 54.32±7.54 sr at 355 and 532 nm, respectively, in spring and 58.04±11.14 and 63.14±12.88 sr at 355 and 532 nm, respectively in fall. Reverse spectral behavior between the lidar ratio at 355 and 532 nm was detected in spring. Seasonal variation of lidar ratio was dependent on the air mass characteristics observed at different layers.
Keywords: Lidar ratio, aerosol, Raman lidar, AOD.

1. INTRODUCTION

Due to combined effects of expansion of arid dust production regions and increasing regional population and fossil fuel usage the East Asian region often experiences very high loadings of atmospheric aerosols [1]. These aerosols can be dispersed over wide downwind areas depending on the meteorological conditions. Because of its downwind location in the East Asia region, Korean peninsular is often affected by the long range transported aerosols such as Asian dust, forest fires smoke particles, and anthropogenic aerosols. Therefore, optical properties of atmospheric aerosols above the Korean peninsula show different seasonal characteristics [2]. Information on the vertical distribution and optical properties of atmospheric aerosols are quite important to assess and predict aerosols' effects on atmospheric environment and regional radiative forcing. Therefore, a Raman Lidar system had been built at GIST/ADEMRC, which can measure the distributions for extinction coefficient and backscattering coefficient without any assumptions about the lidar ratio. Furthermore, lidar ratio can be used to track back pollution outbreaks utilizing its dependence on aerosol type (particle size distribution and chemical composition) [3].

In this study, Raman lidar observations of vertically resolved lidar ratios at 355 and 532nm and depolarization ratio had been conducted at Gwangju, Korea (35.10ºN, 126.53ºE) using the GIST/ADEMRC multi-wavelength Raman lidar system. The observation was made 10 February ~ 11 March, 13 ~ 15 June, 6 October ~ 7 December 2004 and 23 February ~ 9 May 2005.

2. GIST LIDAR SYSTEM and DATA PROCESSING

The GIST/ADEMRC multi-wavelength Raman lidar system was built in cooperation with Nagoya University in 2000 and operated at Gosan, Jeju island during the ACE-Asia period in 2001 [10]. It was then moved to GIST (35.10ºN, 126.53ºE) in 2002 and installed in a mobile trailer. The system schematic diagram of the lidar system is shown in Figure 1. The light source is a Nd:YAG laser which emits pulses at a rate of 20 Hz at 355nm, 532nm, and 1064nm wavelengths with power of 60, 80, and 80 mJ, respectively. A $\lambda/2$ plate is used to control of the light angle incident onto the beam splitter of the receiver. The laser beam is expanded 5 times using a beam expander so that the laser beam divergence is controlled to less than 0.2mrad. The receiver part consists of one 14 inch and two 8 inch Cassegrain telescopes and 7 photomultiplier tube (PMT) detectors, which measure three elastic backscattered signals at 355 nm, 532nm, signals at 355 nm, 532 nm, and 1064 nm, two polarization channels at 532nm (532S and 532P), and two inelastic channels of atmospheric N_2 Raman backscattering at 387nm and 607nm. Spatial resolution of 7.5 m is achieved with the detector system. 532P and 532S signals are used to calculate the depolarization ratio, which can be considered as an indicator of the aerosol's nonsphericity. Aerosol can be considered as Asian dust if the depolarization ratio was in the range of 0.15~0.3, which is the typical range of Asian dust depolarization ratio observed in the Northeast Asia region [4]. The

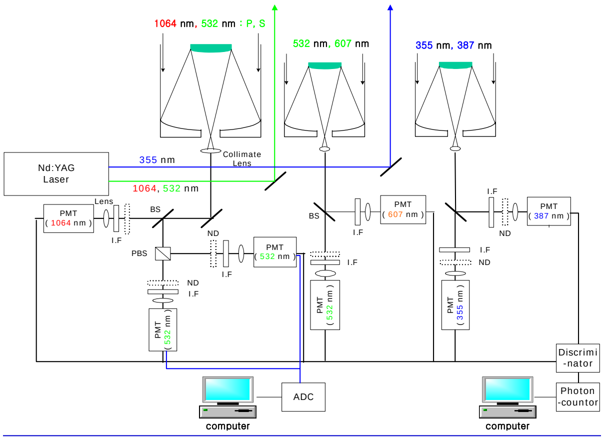

Fig. 1. Schematic diagram of GIST Multi-wavelength Raman lidar system

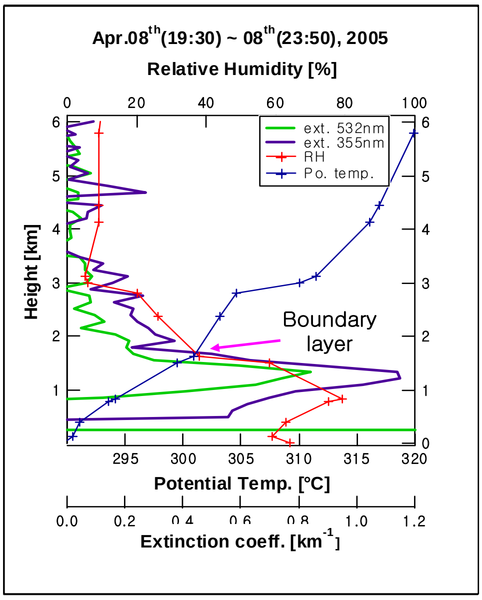

Fig.2. Vertical profiles of extinction coefficient at 355 and 532nm from lidar and relative humidity and potential temperature by radiosonde

Raman signals are usually 10^3~10^4 times weaker than the elastic signals. For the Raman signal analysis, the spatial resolution was therefore increased to 120 m by summing the 16 data points along the vertical path. Temporal resolution of Raman measurement was also increased to 3 ~ 8 hrs by summing the data observed only under cloud free atmospheric conditions. Data obtained during the periods of co-existing clouds and aerosols were eliminated from the summation. Total time of data summation in one night observation was typically 3 ~8 hours. Observed aerosol layers were classified into below and above planetary boundary layer (PBL) cases based on the potential temperature and relative humidity profiles obtained by a radiosonde as shown in Figure 2. After distinguishing aerosol layer, average lidar ratio of each layer was calculated at two wavelengths, 355nm and 532nm. However, because of high uncertainties associated with the correction of the incomplete overlap region between the laser beam and the receiver field of view aerosol extinction coefficient was measured only above 780m with the nitrogen Raman signals. Single scattering albedo (SSA) and volume size distribution of aerosols were also derived from the surface-based sunphotometer data collected at the Gwangju AERONET site.

3. RESULTS and DISCUSSION

During the observation period, 52 cases of lidar ratio datasets were obtained at both 355 and 532nm wavelengths during a total of 73 observation days. The lidar ratio showed wide variation; 32 ~ 93 sr at 355nm and 32 ~ 95 at 532nm, respectively. Lidar ratio data sets are averaged for each month and each season. Figure 3 shows monthly averaged lidar ratios at two wavelengths for all aerosol layers, aerosol layer above PBL, and aerosol layer below PBL. Average values of lidar ratio observed below PBL were 54.61 ± 9.54 and 57.52 ± 10.48 sr at 355 and 532 nm, respectively. Those are higher than those observed below PBL, which were 58.34 ± 12.55 and 59.84 ± 14.29 sr at 355 and 532 nm, respectively. Lidar ratios ≥ 60-70 sr indicate considerably light-absorbing particles [5]. Lidar ratios of 30 ~ 60 sr are typically found from anthropogenic non-absorbing ammonium-sulfate particles. It thus appears that lidar ratios ≥ 60 sr observed during our measurements were affected by light absorbing pollutants particles abundant in the Northeast Asia. Lidar ratios in February 2004 and February ~ May 2005 showed reverse spectral behavior compared to those of other months as shown in Figure 3(a) and (b), in which lidar ratios at 355nm were higher than those at 532 nm. This spectral behavior agreed with the dust aerosol's lidar ratio characteristics simulated by Ackermann [3]. However, Figure 3(c) shows different patterns for the case of the aerosol layers below PBL in February and March 2005. Monthly averaged AODs at both wavelengths are shown in Figure 4. Figure 5 shows the monthly averaged values of volume size distribution, Angstrom exponent between 440 and 870 nm, and single scattering albedo (SSA), which were derived using the AERONET algorithm based on the ground-based sunphotometer data. Fine mode aerosols were dominant in June, October, and November 2004 as shown in Figure 5 (a). Lidar ratios higher than other periods were obtained in these months. Lidar ratio exhibits relatively low values when coarse mode aerosols are dominant on the contrary. Same monthly variation patterns of angstrom exponent were observed as shown in Figure 5(c). However, different patterns were observed in February and March 2005. Although they showed coarse

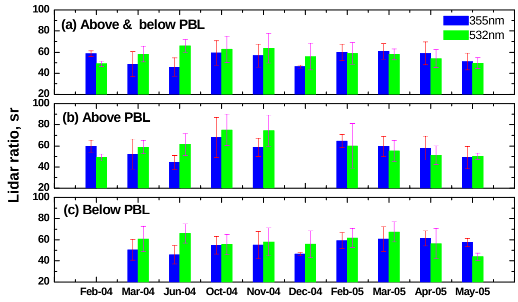

Fig. 3. Monthly averaged lidar ratios at 355 and 532 nm observed by the Raman lidar.

mode dominant distribution, their lidar ratios were still high due to high absorptive characteristic of aerosols. Three categorized (below PBL, above PBL, and total layers) data sets of lidar ratio, volume size distribution, and SSA are derived into spring season (Feb., Mar. 2004, Feb., Mar., Apr., May 2005) and fall season (Oct., Nov., December 2004). The results are shown in Figure 6. The average lidar ratios of total layer were 56.7±9.6 and 54.32±7.54 sr at 355 and 532 nm, respectively in spring and 58.04±11.14 and 63.14±12.88 sr at 355 and 532 nm, respectively in fall. The values of fall season are higher than the spring season. These differences increased for the above PBL layer cases. The values of spring season showed opposite spectral variation feature compared to those of fall season for the all categories. For the above PBL layer cases these difference becomes more severe in spring season, which is believed to be due to the seasonal difference in aerosol type. Non-spherical dust particles are dominant in spring. High depolarization ratios higher than 0.15 and coarse mode aerosol dominant characteristics observed in spring as shown in Figure 6(a) confirm the presence of Asian dust aerosols. Sakai et al. [2003] reported that the lidar ratio of Asian dust aerosol was 47±18 sr at 532nm wavelength over Tsukuba in Japan. Lie et al. [6] also measured with a High Spectral Resolution Lidar the lidar ratio of Asian dust particles to be 42~55 sr at 532nm wavelength over Tsukuba, Japan. Murayama et al. [7] observed it to be 48.6 ± 8.5 sr at 355nm and 43.1 ± 7.0 sr at 532nm, respectively in Tokyo,

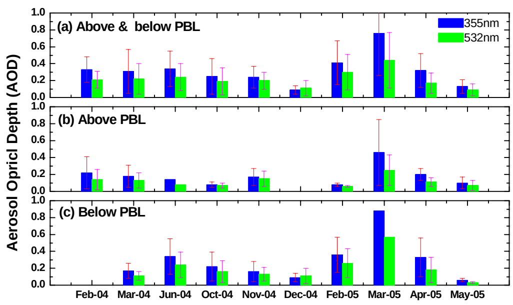

Fig. 4. Monthly averaged aerosol optical depth determined from Raman lidar data

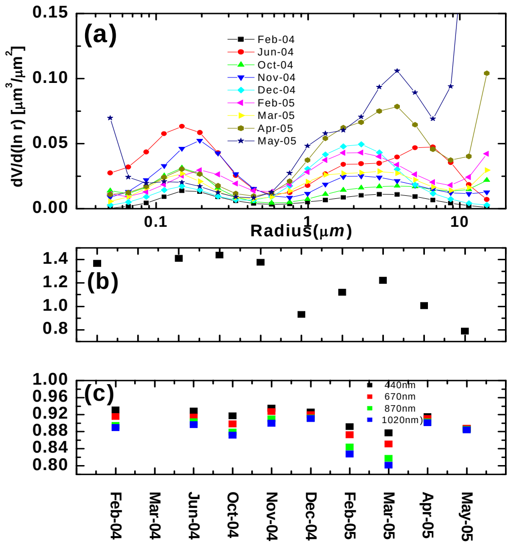

Fig. 5. Monthly averaged volume size distribution (a), angstrom exponent, 440 – 870 nm (b), and single scattering albedo (c) determined from the AERONET sunphotometer data collected at Gwangju, Korea.

Japan. Our spring season results of lidar ratio show similar spectral behavior between 355 and 532nm wavelength, but our results are higher values than others, especially in the below PBL layer cases. It supports that the aerosols observed in spring season in this study represent the mixed state of Asian dust and light absorbing particles. Ansmann et al. [8] reported that high lidar ratio of 50~60 sr at 532nm for haze cases during continuous measurement for 22 days through October over Perl River Delta in China. Ferrare et al. [9] also observed a high lidar ratio, 68±12 sr, in the southern Great Plains of north central Oklahoma in U.S. They reported that such high lidar ratio was associated with air masses from urban/industrial areas. Higher lidar ratios observed in this study in fall, especially for the above PBL layer cases, support that light absorbing fine particles transported to Gwangju region are affecting aerosol characteristics.

4. CONCLUSION

For the first time, over ten months of continuous monitoring of lidar ratios at 355 and 532nm was performed with a Raman lidar system in Gwangju, Korea. Seasonal variation of lidar ratio shows that the average lidar ratios were higher in fall, 58.04±11.14 and 63.14±12.88 sr at 355 and 532 nm, respectively than spring season; 56.7±9.6 and 54.32±7.54 sr at 355 and 532 nm, respectively. Reverse spectral behavior between lidar ratios at 355 and 532 nm was observed due to the transport of dust aerosol from Asia eastward during that season. These seasonal variations of lidar ratio were

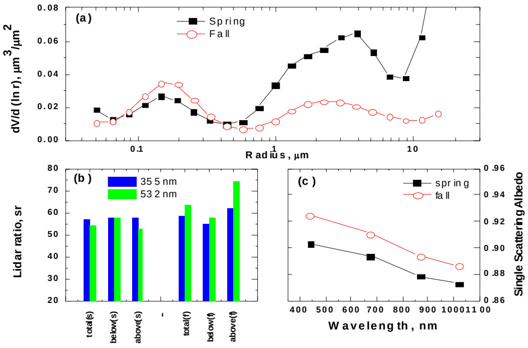

Fig. 6. Aerosol characteristics parameters averaged over spring and fall seasons: (a) volume size distribution, (b) Lidar ratio, (c) SSA.

more apparently detected for the above the PBL cases. However, lidar ratios of the below PBL cases showed lower monthly variations compared to those of the above PBL cases. It can be therefore concluded that seasonal variation of lidar ratios are mostly induced from the aerosols transported above the PBL. Observation results from this study can provide very useful information about the optical characteristics of northeast Asian aerosols.

5. ACKNOWLEDGEMENT

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