P- 10

An intercomparison of aerosol optical properties between Raman lidar and sun photometer measurements over Beijing, China

Chenbo Xie [1, 2], Nobuo Sugimoto [1], Ichiro Matsui [1], Atsushi Shimizu [1], Tomoaki Nishizawa [1], and Zifa Wang [3]

1. National Institute for Environmental Studies (NIES)
2. Anhui Institute of Optics and Fine Mechanics, Chinese Academy of Sciences
3. Institute of Atmospheric Physics, Chinese Academy of Sciences

ABSTRACT

The intercomparison of aerosol optical properties between Raman lidar and sun photometer measurements were conducted from 17 April to 12 June 2008 over Beijing, China. The comparison provides the complete knowledge of aerosol optical and physical properties, especially in pollution and Asian dust events. The averaged aerosol optical depth (AOD) at 675 nm was 0.81 and Angstrom exponent between 440 nm and 675 nm was 0.99 during experiment. The lidar derived AOD at 532 nm in planetary boundary layer (PBL) was 0.48, which implies the half of total AOD is contributed by the aerosol in PBL. The corresponding averaged lidar ratio and total depolarization ratio (TDR) were 48.5 sr and 8.1 %. The negative correlation between lidar ratio and TDR indicates the lidar ratio decreases with aerosol size because that the high TDR associates with the nonspherical and large aerosol. The typical volume size distribution of aerosol clearly demonstrates the coarse mode radius located near 3 μm in dust case, bi-mode with fine particle centered at 0.2 μm and coarse particle at 2 μm was the characteristic size distribution in pollution and clean cases. The difference size distribution of aerosol resulted in its different optical properties. The retrieved lidar ratio and TDR were 41.1 sr and 19.5 % in dust event, 53.8 sr and 6.6 % in pollution event as well as 57.3 sr and 7.2 % in clean event. In conjunction with the observed surface wind field near lidar site, most of pollution aerosols were produced locally or transported from the southeast of Beijing, whereas the dust aerosols associated with the clean air mass were transported by the northwestly or southwestly wind.

1. Introduction

The increasing urbanization and industrialization of the East Asia region, in accordance with the intense dust storm events mostly occurring in spring time, lead to continuously increasing particulate matter particularly in the lower troposphere [1-2]. The air quality in Beijing is drastically affected by both anthropogenic and naturally occurring dust aerosols. The aerosol properties and their spatial and temporal variations over Beijing-especially during Asian dust events-have been studied using ground-based radiometer data in the late years [1-3]. However, the quantitative observation with Raman lidar is still limited [4]. We added the Raman detection channel into National Institute for Environmental Studies (NIES) lidar system in Beijing in December 2007, and took continuous observation until now [5]. This paper reports on the intercomparison of aerosol optical properties between Raman lidar and sun photometer measurements as well as the surface meteorological observations.

2. Instrumentation and Methods

The NIES upgraded Raman lidar system is located in the Institute of Atmospheric Physics, Chinese Academy of Sciences in Beijing, China (39.97N, 116.37 E). It operates in a continuous mode (5 min of data acquisition with 10-min intermission) through a window on the roof of the observation room, regardless of weather. The lidar system employs two-wavelength laser at 1064 nm and 532 nm for detecting two polarization components (parallel and perpendicular polarization) at 532 nm, nitrogen Raman shifted scattering at 607 nm and elastic scattering at 1064 nm. Though the signals from the Raman channel were recorded both in the day and night, only nighttime data were used in the analysis because of the large background radiation in the daytime. Based on these lidar data, aerosol optical properties included extinction and backscatter coefficients, lidar ratio and total depolarization ratio (TDR) at 532 nm were derived in the night time. Due to the limitation of lidar system, we kept our concentration on the study of aerosol in planetary boundary layer (PBL).

The sun photometer and sky radiometer observations were performed in the Aerosol Robotic Network (AERONET), located in Beijing (39 58’ 37”N, 116 22’ 51”E). The daily aerosol optical depth (AOD) and other AOD-dependent products were derived from the level 1.5 (cloud-screened) data. The daily meteorological parameters were observed at the ZBAA station in Beijing. The Air Pollution Index (API) was measured from 1200 LT of the previous day to 1200 LT of the current day, and reported from the Beijing Municipal Environmental Protection Bureau. To determine this API, four chemical substances (SO_2, NO_2, CO, and O_3) and the particulate matter concentration (PM10) are measured; the highest value of these five parameters becomes the API. In China and especially in Beijing PM10 seems always been the highest of the five parameters, which means the aerosol particle is the worst problem.

3. Comparisons and Discussions

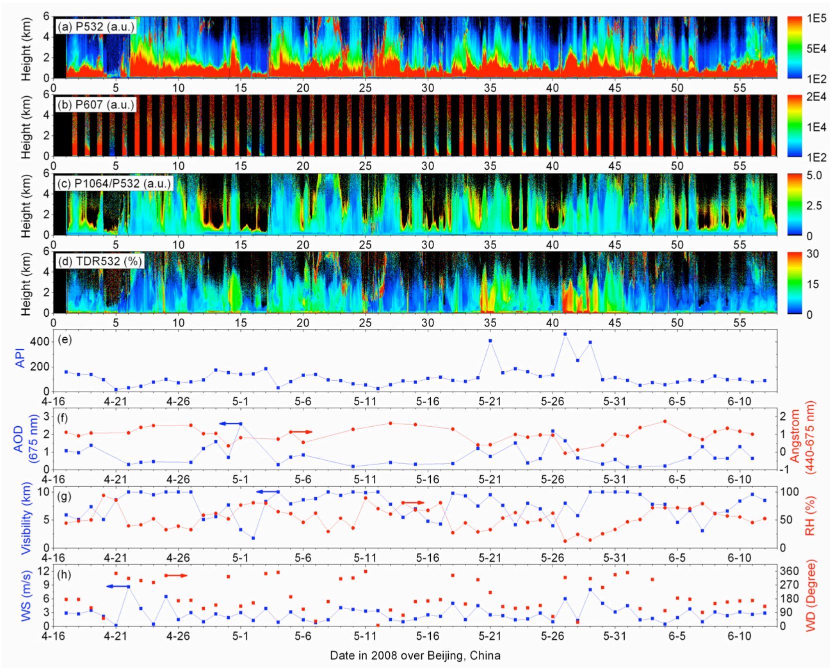

Fig.1 Time-to-height indication of (a) the range-corrected backscatter intensity at 532 nm and (b) Raman shifted scattering intensity at 607 nm, (c) the intensity ratio between 1064 nm to 532 nm and (d) the TDR at 532 nm. The simultaneous observations of (e) API, (f) AOD and Angstrom exponent, (g) surface visibility and relative humidity-RH as well as (h) wind speed-WS and wind direction-WD are presented.

Figure 1 (a) to (d) gives the continuous measurements of aerosol optical properties with Raman lidar in Beijing from 17 April to 12 June 2008. Although the range-corrected backscattering intensity at 532 nm (a) and Raman shifted scattering intensity at 607 nm (b) in arbitrary units has not a clear physical meaning, it is useful to see the full vertical structure of the aerosol in the atmosphere. The intensity ratio between 1064 nm and 532 nm (c) is associated with the size of the aerosol particle, and it is generally high for larger particle. The TDR at 532 nm (d) reflects the non- sphericity of the scatterers and it is indicator for identification of ice cloud and dust particles.

Figure 1 (e) shows the daily API variation, indicating the content of pollution and dust aerosols near surface. Figure 1 (f) gives the daily ADO at 675 nm and Angstrom exponent (440-675 nm) observed by sun photometer in AERONET. Figure 1 (g) to (h) present the daily meteorological parameters during lidar experiment.

On the whole, we can find there has a close association between Raman lidar, sun photometer and surface observations, especially during Asian dust events occurred on 30 April, 20 to 21 May and 27 to 29 May. The averaged API was 124.3, respecting to the larger than 0.15 mg/m^3 for PM10 mass concentration. The maximal value of 463 (0.5-0.6 mg/m^3) on 27 May indicates the occurrence of heavy dust event. The averaged AOD and Angstrom exponent were 0.81 and 0.99 during experiment. The minimal value of Angstrom exponent was -0.06 on 27 May also demonstrates the experience of the larger dust particle on that day. The simultaneous observed meteorological parameters provide the useful information to reveal the ambient conditions of the pollution and dust aerosols and their probable sources.

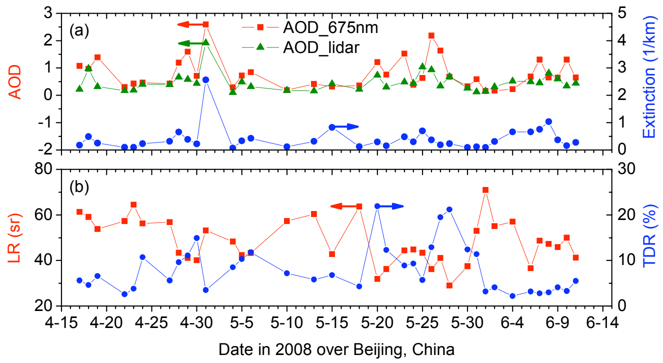

Fig.2 Temporal evolution of (a) AOD measured by sun photometer and Raman lidar as well as the averaged aerosol extinction, (b) lidar ratio and TDR in PBL.

Figure 2 gives the daily variation of aerosol optical properties which includes AOD, averaged aerosol extinction, lidar ratio and TDR in PBL. Sun photometer derived AOD are presented in figure 2 for comparison. These values of AOD are correlated well as a whole, and the disagreement is mainly due to the different observation time, the different wavelength and the different integrated height. The averaged AOD during the period of experiment was 0.81±0.57 at 675 nm for sun photometer measurement and 0.48±0.34 at 532 nm for Raman lidar measurement. Aerosol in PBL contributed about 59 % to the AOD values in total atmosphere, indicating larger amount of aerosols existed in PBL over Beijing city. Lidar derived aerosol extinction varied from 0.07 km^{-1} (4 May) to 2.56 km^{-1} (1 May), and the average value was 0.40±0.44 km^{-1}. Big standard deviation of aerosol extinction demonstrates the large temporal variation of aerosols in PBL.

The lidar ratio during the experiment was in the range of 29.0 sr (28 May) and 70.9 sr (1 June), and the average value was 48.5±9.9 sr, which is close to the mean value of 46.7±5.6 sr found in the south China [6].The corresponding TDR was 8.1±5.2 % with the minimal value of 2.2 % (4 June) and the maximal value of 21.9 % (20 May). There seems to have a negative correlation between lidar ratio and TDR. It could be explained that the high value of TDR indicates the occurrence of dust event, and the large dust particle leads to increase the lidar ratio. We applied the TDR of 10 % as the threshold value for determining the dust particles and spherical aerosols. The result demonstrates that the dust event occurred in 12 days during 37-day experiment, and non-dust event in 25 days. The averaged lidar ratio, TDR and extinction coefficient in dust events were 40.7±7.8 sr, 14.2±4.2 % and 0.25±0.11 km^{-1}, respectively. The lidar ratio was consistent with the previous observation for Asian dust particles [7-8]. The corresponding values in non-dust events were 52.3±8.6 sr, 5.2±2.2 % and 0.47±0.51 km^{-1}. The enhanced lidar ratio associated with the small particles and the light-absorption aerosols. The bigger aerosol extinction in no-dust event than in dust events suggests that the effect of spherical aerosol mostly produced by anthropogenic sources on air quality in Beijing is greater than the dust particles.

Figures 3 gives the representative volume size distributions in the air columns for dust, pollution and clean cases. We can see that the coarse mode radius commonly locates around 3 μm in dust case, which is consistent with previous report on the size of Asian dust [7-8]. The retrieved AOD at 675 nm was 1.64 and the Angstrom exponent was -0.06, the lidar ratio and TDR were 41.1 sr and 19.5 %. A distinctive fine mode centered near 0.2 μm is seen in the size distribution of pollution case, which is characteristic of an urban polluted atmosphere. A coarse mode located near 2 μm is also seen in the pollution case. It reflects the

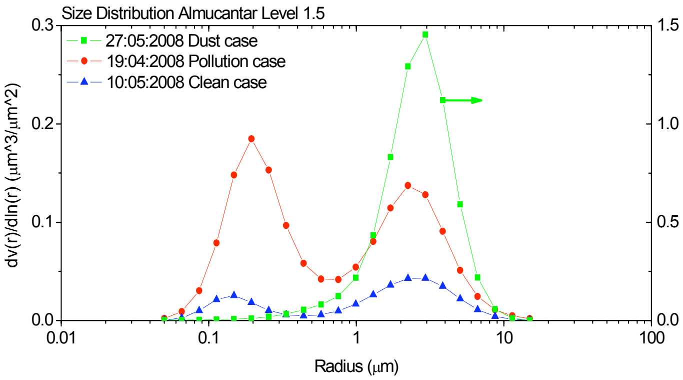

Fig.3 Representative volume size distributions of aerosol retrieved from the sky radiometer in AERONET

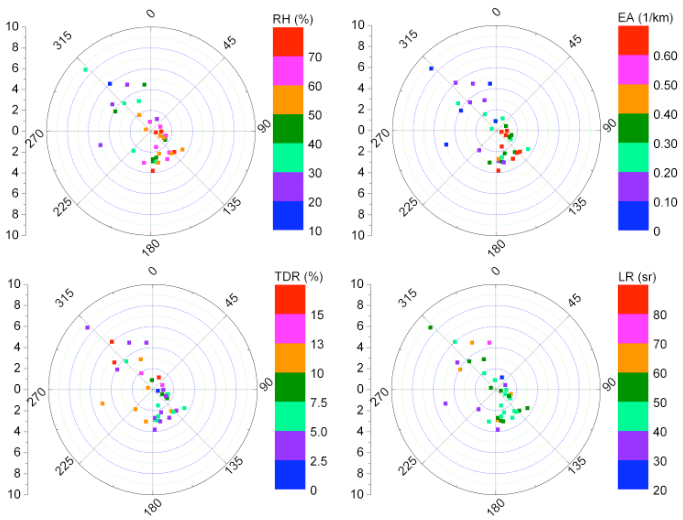

Fig.4 The variation of relative humidity-RH, aerosol extinction-EA, total depolarization ratio-TDR and lidar ratio-LR as a function of wind speed and direction.

presence of large particles which are probably the residue of dust event or the production of incomplete combustion. Such a remarkable bi-mode size distribution is frequently found in the pollution case in Beijing city. The corresponding AOD was 1.38, Angstrom exponent 1.08, lidar ratio 53.8 sr and TDR 6.6 %. Although the bi-mode is seen in the size distribution of clean case, the low volume concentration of aerosol particle leads to improve the air quality. The AOD on that day was 0.22 and Angstrom exponent was 1.74. The lidar ratio and TDR were 57.0 and 2.2 %, respectively.

Figure 4 shows the variation of RH, aerosol extinction, TDR and lidar ratio as a function of wind speed and direction. On the whole, we can find that the southeastly wind and northwestly wind prevailed during the period of experiment. In the condition of the southeastly wind or weak wind, most of RH was greater than 50 %, aerosol extinction was larger than 0.2 km^{-1}, TDR was less than 10 % and lidar ratio ranged between 40 sr and 60 sr. It implies the anthropogenic aerosol was produced locally or transported from the southeast of Beijing city. In the condition of the northwestly wind, there has two different cases. One is the clean air case with RH of 20-50 %, aerosol extinction less than 0.2 km^{-1}, TDR smaller than 5 % and LR varied from 50 sr to 80 sr. The other is the dust case with RH 10-40 %, aerosol extinction less than 0.3 km^{-1}, TDR larger than 10 % and LR ranged between 30 sr and 50 sr. In addition, some dust events were transported by the southwestly wind to Beijing city. The information in the figure 4 is very useful to determine the probable sources of air pollution and dust aerosols.

References

[1] T. F. Eck, et al., *J. Geophys. Res.*, **110**, D06202, doi:10.1029/2004JD005274 (2005).
[2] T. Cheng, et al., *Atmos. Environ.*, **40**, 1495-1509 (2006).
[3] X. A. Xie, et al., *J. Geophys, Res.*, **111**, D05204, doi: 10.1029/2005JD006203 (2006).
[4] M. Tesche, et al., *Appl. Opt.*, **46(25)**, 6302-6308 (2007).
[5] C. Xie, et al., *Appl. Opt.*, in press (2008).
[6] A. Ansmann, et al., *Geophys. Res. Lett.* **32**, doi:10.1029/2005GL023094 (2005).
[7] Z. Liu, N. Sugimoto and T. Murayama, *Appl. Opt.* 41, 2760 (2002).
[8] T. Murayama, and M. Sekiguchi, *Reviewed and revised papers presented at the 24th International Laser Radar Conference*, 943-946 (2008).