Measurements of aerosol distribution by an elastic-backscatter lidar in summer 2008 in Beijing

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Elastic lidar observations of profiles of the aerosol extinction, backscattering coefficients, and the lidar ratio have been performed in Beijing. The elastic lidar transmitts wavelengths of 532 and 355 nm. The measurement altitude can reach up to 6 km. The similarity of the extinction and backscattering profiles suggests a close relation between the mean transmission and reflection properties. The lidar ratio on July 22, 2008 varied from 10 to 30 sr with the mean value of 20 sr. The profiles of the aerosol properties indicate the cirrus at 6–km altitude and a well-mixed boundary layer from July 22 to 24, 2008. The detected boundary layer also agrees well with the high and stable ozone concentration obtained from the differential optical absorption spectroscopy (DOAS) system.

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Megacities are defined as urban agglomerations with population of 10 million or more in 2000, according to a report of the United Nations Environment Program (UNEP) and the World Health Organization[1]. Beijing City is one of the megacities in North China most affected by air pollution. A number of factors contribute to the high pollutant levels in the city. The most important factors include the overpopulation (over 17 million) and the specific topography which makes the pollutants not easy to transport. The latter leads to the formation of strong inversions at night and a well-mixed convective boundary layer. An environmental experiment jointly launched by the Beijing Municipal Government and the Chinese Academy of Sciences (CAS) was carried out in the summer of 2008 to better understand the pollution level in Beijing. Anhui Institute of Optics and Fine Mechanics (AIOFM) took part in the experiment with an elastic lidar to measure the aerosol backscattering coefficient and the boundary layer in summer in Beijing.

Lidar techniques using molecular and aerosol backscattering provide a useful method to study the atmosphere properties and constituents[2]. A lidar system transmits a laser pulse at a certain wavelength into the atmosphere and a telescope collects the return signals. The lidar permits the determination of height profiles of the particle backscattering coefficient and the evolution of the boundary layer can thus be attained.

The elastic lidar was made up of three sub-systems including emitting system, receiving system, and signal analogue system. The specific parameters of the lidar are presented in Table 1. The laser source was a pulsed Nd:YAG laser emitting short pulses at 532 and 355 nm. The pulse repetition rate was typically 20 Hz. The pulse duration was of the order of 6–9 ns. The light beam was expanded by a factor of 4, which reduced the divergence of the expanded beam to 2 mrad. The reflective mirrors with a high reflection (>98%) at the reflected wavelength were used to transmit the light into the atmosphere and keep the light beam as close as possible to the line of sight of the receiver telescope.

The receiving telescope of the lidar system was based on a Cassegrainian design. The primary reflective mirror had a diameter of 400 mm and the secondary reflective mirror of 9 mm. The backscattered signals were then collected and focused on the telescope's focal point. Different interference filters suited to each wavelength were chosen to select the lidar wavelengths and reject the atmospheric background radiation during daytime and nighttime operation[3]. After being separated and passing the respective interference filters, the photons elastically backscattered at the 532–nm wavelength were detected with photomultiplier tubes (PMTs, Hamamatsu R740).

The Licel transient recorder was used for data acquisition in analog and photon counting with the first time analog detection of the photomultiplier current and single photon counting combined in one acquisition system. The combination of a powerful analog-to-digital (A/D) converter (12 bit at 40 MHz) with a 250–MHz fast photon counting system increased the dynamic range

Table 1. Specific Parameters of the Lidar

Transmitter	Wavelength (nm)	532, 355
	Pulse Energy (mJ)	50.0 (532), 76.5 (355)
	Repetition Rate (Hz)	20
	Beam Expander	5
Receiver	Telescope Type	Cassegrainian
	Field of View (mrad)	2
Detector	Transient Recorder	AD Converter and Photon Counting
	Detection Mode	Analogue and Photon Counting

of the acquired signal substantially compared with conventional systems. With the 20–MHz sampling rate, the spatial resolution of 7 m could be attained. The control over the transient recorder and the preliminary and final treatment of the data were performed by LabView programs on a PC.

From Hitschfeld and Bordan's radar application, the particle extinction or backscattering coefficient is obtained by solving a Bernoulli equation that is derived from the basic lidar equation of a power-law relationship between aerosol extinction and backscattering. This technique is called Klett method which is widely used in elastic lidars[4]. Figure 1 shows the typical backscatter raw signal with the background removed. At the heights of 2.0, 2.5, 2.7, and 2.8 km, the amplitude of the signal increases dramatically, indicating the existence of clouds, haze, precipitation, or larger particles[5]. Figure 2 shows the aerosol extinction coefficient, backscattering coefficient, and lidar ratio profiles measured at 532 and 355 nm, respectively. It shows a profile of the properties of the particles with the dramatic signal strength at the height of 6 km on July 22, 2008. The lidar ratio varies from 10 to 30 sr with the mean value of 20 sr. Such measurements of the profiles, especially the lidar ratio, can probably provide information on the transmission and reflection properties of clouds because the lidar ratio depends on shape, size, and orientation of the anisotropic particles[6]. The vertical distribution of the lidar ratio suggests different microphysical characteristics in the lower and upper parts of the cloud. Although it is difficult to explain the ratio because of the uncertainties of multiple scattering, we can still have reasons to take it as the cloud. According to the

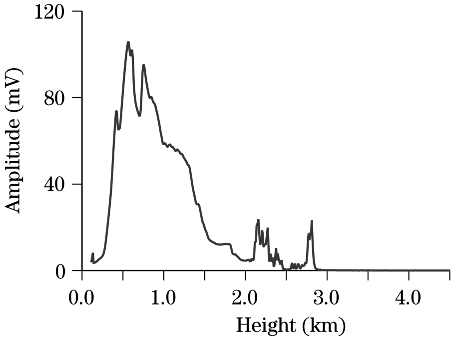

Fig. 1. Range corrected signal of the backscattering raw signal.

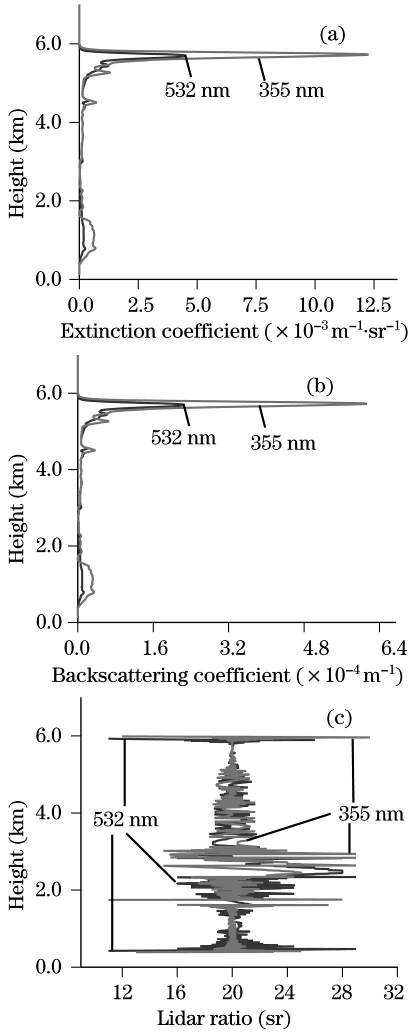

Fig. 2. (a) Aerosol extinction coefficient, (b) backscattering coefficient, and (c) corresponding lidar ratio at 532 and 355 nm on July 22, 2008.

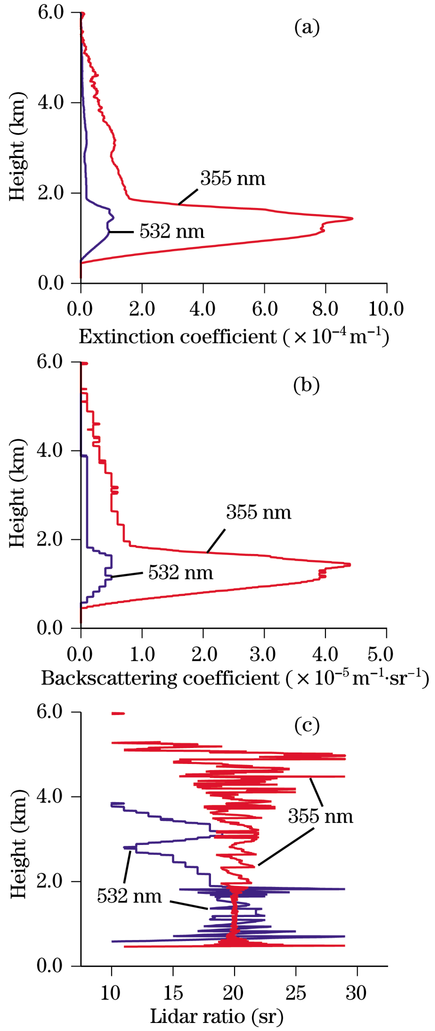

Fig. 3. (a) Aerosol extinction coefficient, (b) backscattering coefficient, and (c) corresponding lidar ratio at 532 and 355 nm on July 23, 2008.

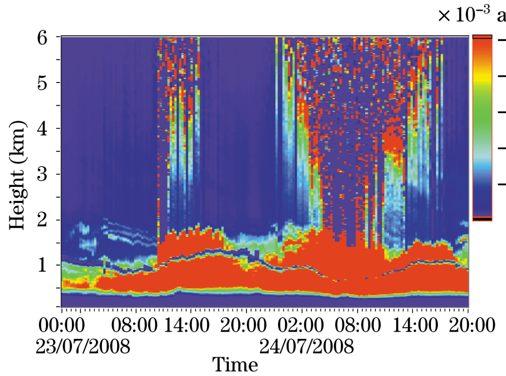

Fig. 4. Evolution of the extinction coefficient from July 23 to 24, 2008.

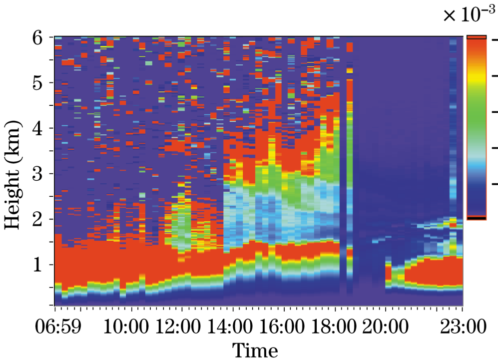

Fig. 5. Evolution of the extinction coefficient on July 24, 2008.

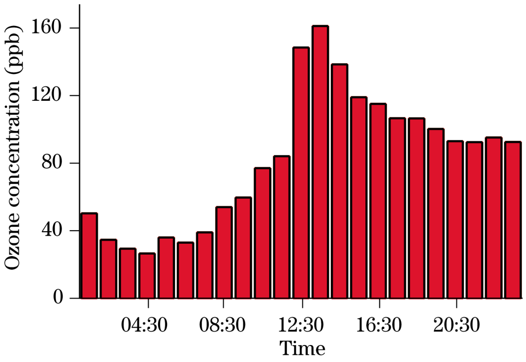

Fig. 6. Concentration of ozone on July 24, 2008.

existing calculations, the lidar ratio is about 10 sr for typical cirrus clouds[7], including cirrostratus, and 17 sr for cirrus uncinus, i.e., for an ice cloud with more larger particles[8].

Figure 3 shows that in the lower height range, aerosol is present up to 1.5 km of the altitude, which is the representative of a typical aerosol load in a well-developed planetary boundary layer. The similarity of the extinction and backscattering profiles suggests a close relation between the mean transmission and reflection properties. The mean optical depth, derived from the extinction coefficient, is 0.1281. Taking into account the effects of multiple scattering (about 5%—10%)[9], we can obtain a single-scattering optical depth of 0.15.

Figures 4 and 5 show the evolution of the boundary layer from 23 July to 24 July and the whole day of July 24, 2008. The aerosol measurements were taken at the wavelength of 532 nm at altitudes higher than 6 km in the daytime. The boundary layer kept a stable height of about 1.5 km from the morning 07:00 to the late afternoon 18:00. This phenomenon is in line with the diurnal variations of the ozone concentration in Fig. 6. The ozone concentration data were attained by the differential optical absorption spectroscopy (DOAS) system of AIOFM located at the same position of the lidar. In Fig. 6, there is a steady increase in the daily values of the ozone concentrations, reaching the maxima of 160 ppb at noon 12:30. Combining Figs. 5 and 6, the conclusion of the boundary layer height is reliable since the high and almost stable ozone concentrations indicate a well-mixed boundary layer. According to the meteorological data, the wind direction at that day began to change rapidly at the altitude between 0.5 and 1.5 km from PM 11:00, which can probably explain the sudden rising signal of the extinction profile.

In conclusion, the aerosol properties in Beijing were measured in the summer of 2008. The results of the elastic lidar from AIOFM, including the extinction coefficient, backscattering coefficient, and lidar ratio demonstrated the existence of the clouds, probably the cirrus with the mean lidar ratio of 25 sr. A boundary layer was also observed and the data offered the explanation to the steady ozone concentration measured by the DOAS system.

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