Monitoring Aerosol Pollutant Layer by Lidar Combined with some other Instruments

Huanling Hu, Qingshan Xu, Chen Li, Xuebin Li
Atmospheric Optics Lab
Anhui Institute of Optics and Fine Mechanics, CAS
P.O.Box 1125, Hefei, Anhui 230031, China
Tel & Fax: +86-551-5591012, E-mail: hlhu@aiofm.ac.cn

ABSTRACT

Lidar is a powerful tool for monitoring vertical profile of aerosol pollutant layer (APL) and its variation. The extinction-to-backscatter ratio, S_1, is a crucial parameter for quantitative interpretation of lidar data. Because of the large and quick variation of S_1 in APL, it is necessary to measure real-timely S_1. A multi-instrument method is introduced for monitoring APL by lidar combined with some other instruments. Some experiments were completed for monitoring APL variation at Beijing, China in several periods during 2001-2004. The statistic of APL can be analyzed upon the data of aerosol profile, such as APL top-height, the total mass of aerosol loading in APL.

1. INTRODUCTION

Aerosol and dust produced by nature and human activities are trapped within the layer near the ground, which may be called as "aerosol pollutant layer (APL)". The APL is an important link between the earth's surface and the free atmosphere. It plays an important role in atmospheric circulation. The aerosols of APL have also important impact on human living condition. The knowledge of the aerosol vertical structure and their time variation in the layer is important for prediction and further improving air quality, especially at the urban area. In order to monitor the variation of aerosol profiles in the APL, lidar is a powerful tool. The extinction-to-backscatter ratio, S_1, is a crucial parameter for quantitative interpretation of lidar data. Sasano and Nakane[1] examined the dependence of the lidar solution on the values of S_1 by numerical simulations. They showed that the errors in the solution caused by erroneous values of S_1 depended on the atmospheric turbidity. Aerosol turbidity varies in wide range in APL actually. The empirical knowledge of S_1 for the layer is extremely limited. Therefore, a proper value of S_1 must be given in order to obtain quantitative profiles of aerosol extinction coefficients. It is essential to establish a method for the real time measurement of aerosol extinction-to-backscatter ratio in the layer.

The parameter S_1 may be calculated by MIE theory from aerosol size distribution and the its refractive index

$$S_1 = \alpha_a/\beta_a$$

where α_a is aerosol extinction coefficient, and β_a is its back-scattering coefficient. They may be written as

$$\alpha_a = \int Q_{ext}(m, r, \lambda)\pi r^2 N(r)\,dr$$

$$\beta_a = \int \frac{\lambda^2}{8\pi^2}[M_1(180^o) + M_2(180^o)]N(r)\,dr$$

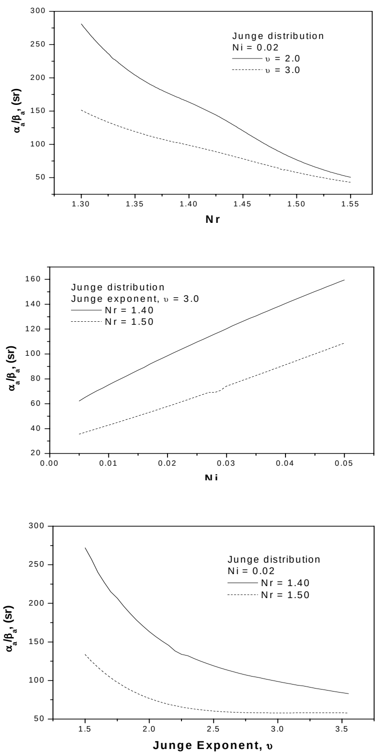

Fig. 1 Variation of S_1 with N_r, N_i, and ν

where Q_{ext}, M_1, and M_2 are the functions of refractive index m, particle radius r, and wavelength λ, which may be calculated by

MIE theory. Junge function is the simplest model of aerosol

$$\frac{dN(r)}{dr} = N_0\, r^{-(\upsilon+1)}$$

where N_0 is Junge coefficient, ν is Junge exponent. Fig. 1 shows the variation of S_1 with n_r, n_i, and Junge exponent ν for Junge size distribution of aerosol, respectively. Actually, for usually encountered particle size distribution and its refractive index, the S_1 value may vary in a wide range in the APL.

Some instruments were used to measure the properties of aerosol, which are an optical particle counter (OPC, DLJ92, AIOFM), a visibility meter (VM, FD12, Vaisala), two particle monitors (PM10 and PM2.5, 1400a, R&P Co.), at the suburb of Beijing 30km south far from its downtown in some periods between 2001 and 2004. In this paper, a method is introduced for obtaining S_1 by using OPC, VM and PMs, and the results of APL variation and its statistic will be presented according to the measurements.

2. METHOD FOR MEASURING S_1 AND VARIATION OF S_1

OPC-DLJ92 is with 17 channels. In its optical unit, the convergent illuminating and collecting semi-angles are same 20°, and the inclined angle of both axes is 60°. Figs. 2 shows OPC-DLJ92 response curves with different real and imaginary

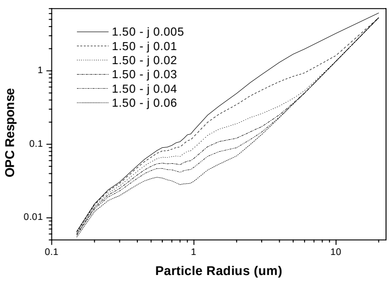

Fig. 2 OPC-DLJ92 response curves with n_r and n_i

parts, respectively, of its refractive index m(=n_r-jn_i). It can be seen from the figure that the response curves are sensitive to aerosol refractive index. Because of the high sensitivity[2, 3] of OPC response to aerosol refractive index, especial to its imaginary part n_i, the different distributions of aerosol can be deduced from same one set of OPC 17-channel data with respect to different refractive indexes. According to the response curve of definite real and imaginary parts of refractive index, aerosol size distribution can be obtained from a set of 17-channel data measured by OPC, whose spectrum curve corresponds to the used values of n_r and n_i. Figs. 3 is two families of volume spectra of aerosol with different values of n_r and n_i for same one set of 17-channel data measured by OPC-DLJ92 at Beijing at 3:00 on Aug. 13, 2001, which is called as 01081303-data in following discussion. The aerosol extinction coefficient α_a and visibility range, vis, can be deduced, according to MIE scattering theory, from every spectrum and its n_r and n_i.

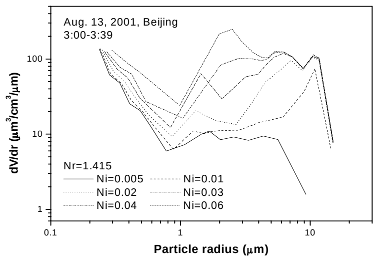

Fig. 3 Aerosol volume spectra with n_r and n_i

Figure 4 shows some vis-curves with n_i for six n_r-values for 01081303-data. In the figure, vis0 (8.8km) is actual visibility measured simultaneously by VM at same site, whose points of intersection on the vis-curves represent these pairs of n_r and n_i with same visibility (vis0). In this way, the n_i and n_r values may be obtained with the same visibility of

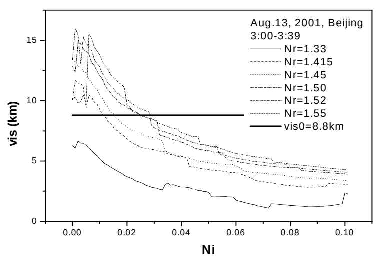

Fig. 4 visibility with n_i

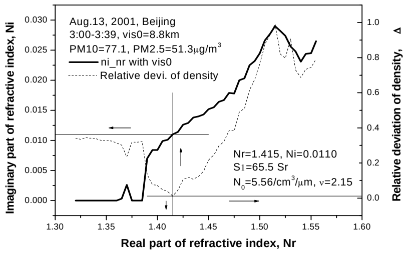

Fig. 5 Solutions for n_r, n_i

vis0 for the 01081303-data, which is showed as a bold curve in figure 5. PM10 and PM2.5 represent the weights whose diameters of particles are less than 10μm and 2.5μm, respectively. The PM-values were measured by using Particle Monitors at same time with 01081303-data, whose values are showed in fig. 5. Corresponding to PM10 and PM2.5, the particle-volumes V10 and

V2.5 can be deduced from opc-data with a pair of n_r and n_i, those diameters are less than 10 and 2.5μm, respectively. Let ρ10 and ρ2.5 be the nominal averaged mass density parameters,

$$\rho 10 = \frac{PM10}{V10} \qquad \rho 2.5 = \frac{PM2.5}{V2.5}$$

Their relative deviation Δ is defined as

Δ = abs(ρ10- ρ2.5) /[(ρ10+ρ2.5)/2]

In Fig. 5, the dash curve represents the relative deviation Δ curve corresponding to the bold curve of n_i with n_r for the 01081303-data. If the Δ value becomes minimum, the interrelated refractive index is the solution, which is m=1.415-j0.0110 for 01081303-data of OPC. The extinction-to-backscatter ratio S_1=65.5Sr can be calculated from the value of refractive index and 01081303-data of OPC with its response relationship.

Both 120-hour data and 304-hour data have been obtained which were measured simultaneously by OPC, VM, and PMs at Beijing in the two periods of Aug. 1-18, 2001 (summer) and Jan. 1-28, 2002 (winter), respectively. Fig. 6 and Fig. 7 show two examples of daily-variation and two sets of the diurnal variation for S_1 in the both periods, respectively.

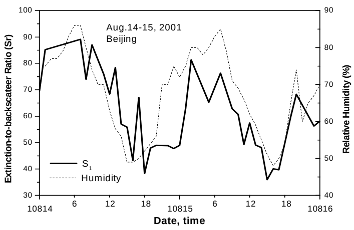

Fig. 6 One example of daily-variation of S_1

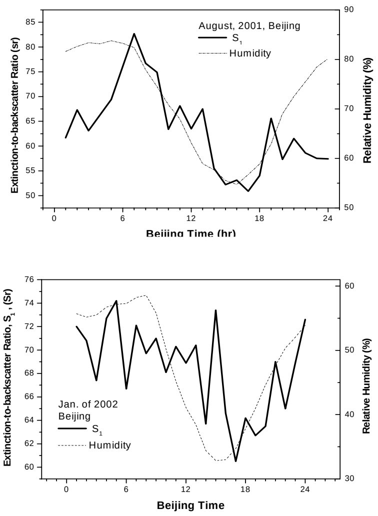

Fig. 7 Diurnal variations of S_1 in summer and winter

The daily variation of S_1 is largely during day and night. The S_1 value may change 100% sometime. According to the measured data, S_1 varied from about 33 to 89 in August of 2001 and from about 18 to 90 in January of 2002. Generally, the S_1 has large value in the morning and small value in the afternoon in summer. It can be seen clearly in Fig. 7 that there is peak-valley shape in summer, and there are more fast-variation in morning in winter. Mie theory indicates that S_1 is decided from aerosol size distribution and its refractive index. These properties of aerosol depend on the particle resource and ambient relative humidity. It can be seen from figs. 6-7 that there is some positive relationship between S_1 and relative humidity. Table 1-2 summarized the averages of S_1, relative humidity, refractive index, and the parameters of Junge distribution of aerosol for whole-day(1:00-24:00), day (9:00-21:00), and night(22:00-8:00) in the both periods of summer (August of 2001) and winter (January of 2002). The whole-day averages of n_i and N_0 are much larger in winter than in summer, which indicates much heavier pollution in winter at Beijing. Highly absorbing leads larger S_1 in winter. The differences of day- and night-averages are small for n_i and ν in summer or winter. The relative humidity is much higher at night than at day, which makes smaller value of n_r at night. Smaller n_r leads a larger value of S_1 at night.

3. APL AND ITS VARIATION AT BEIJING

Aerosol extinction coefficient α_a can be calculated from MPL return signals by Fernald's method[4] according to lidar equation. Fig.8 shows the examples of aerosol extinction coefficient profiles. It can be seen obviously that a large part of particles are trapped in the layer near the ground, which may be called as "Aerosol Pollutant Layer (APL)". In order for environment scientists to study APL more conveniently, it is needed to connect aerosol extinction coefficient α_a with PM_{10}. In the experiments, PM_{10} and visibility vis were measured simultaneously by R&P Co. 1400a PM10 instrument and Vaisala FD12 instrument, respectively. The aerosol extinction coefficient α_a may be retrieved from the visibility data. Based on the data, and the correlation relationships may be founded between α_a and PM_{10}. The following equations are relationships for July of 2001 and January of 2002 where PM_{10} is in unit of $\mu g/m^3$ and α_a in km^{-1}.

$$PM_{10} = 142.2\,\alpha_a^{0.74} \quad \text{for July of 2001}$$

$$PM_{10} = 278.5\,\alpha_a^{0.84} \quad \text{for January of 2002}$$

Assuming the relationships are same in APL with the ones on the ground, α_a profile can be transferred into PM_{10} profile (Fig. 9). The relationship between α_a and PM_{10} depends on the properties of aerosol. Therefore, it would vary with place and season.

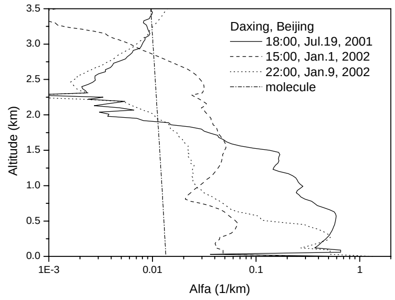

Fig. 8 α_a profiles

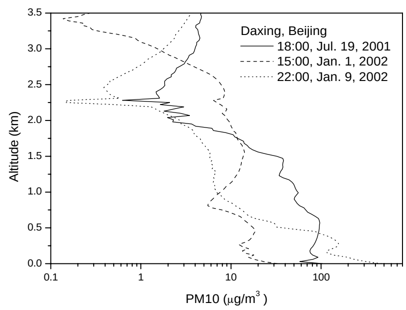

Fig. 9 PM_{10} profiles

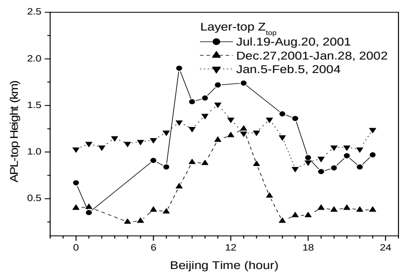

Fig. 10 Diurnal variation of PM_{10}

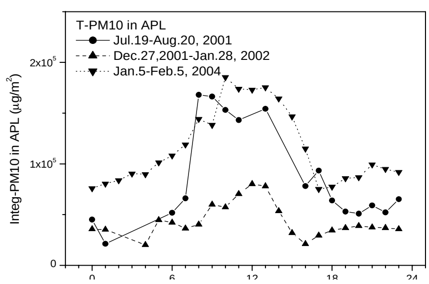

Fig. 11 Diurnal variation of Integrated PM_{10}

In order to analyze APL quantitatively, Aerosol pollutant layer (APL) is defined as the layer near the ground, where PM_{10} is larger than 50μg/m^3, which equals 50μg/m^3 at the APL top height. Figs. 10 and 11 indicate diurnal variation of APL top-height (z_{top}) and the integrated PM_{10} (TPM_{10}) in APL in periods during 2001 and 2004. Tables 3 and 4 contain the average and day-night variation of some parameters, such as PM_{10} measured on the ground, the top-height (Z_{top}) of APL, and the integrated PM_{10} (TPM_{10}) from the ground to the top of APL.

1) Averaged PM_{10} value is smaller on the ground in summer than the one in winter. The averaged PM_{10} is larger for January of 2001 than the one for January of 2004. As the stronger convection in the day-time of summer, averaged PM_{10} is smaller in day-time than the one in night-time. In winter, PM_{10} is higher for day-time than the one for night-time.

2) The averaged APL top-height z_{top} is 1.14km in the summer of 2001. The z_{top} may vary largely in winter of different years. The z_{top} is only 0.56km in January of 2002, and upto 1.15km in January of 2004. Day-night variation of APL top-height is obvious.

3) The averaged value of integrated PM_{10} (TPM_{10}) of APL is 87.4kg/km^2 in summer of 2001. The ones are 43.5kg/km^2 and 115.6kg/km^2 in January of 2002 and 2004, respectively, which show lager different between them. TPM_{10} is larger in day-time than the one in night-time, generally.

4. SUMMARY

APL and its variation can be monitored by lidar combined with an optical particle counter (OPC), a visibility meter (VM) and two particle monitors (PM_{10} and $PM_{2.5}$). The real time variation of aerosol extinction-to-backscatter ratio S_1 may be deduced from their data measured simultaneously by using OPC, VM and PMs, which is necessary for determination of quantitative profiles of aerosol extinction coefficients from lidar return signal data. A relationship between aerosol extinction coefficient α_a and PM_{10} may be founded also according to the data measured simultaneously by using VM and PM_{10} instruments. By using the relationship, it is easy for aerosol extinction coefficient profiles to be transferred into PM_{10} profiles, which is familiar for environmental scientists. The statistic of APL can be analyzed upon the data of aerosol profiles, such as APL top-height, the total mass of aerosol loading in APL.

REFERENCES

[1] Sasano, Y.. and H. Nakane: ‘‘Significance of the extinction/backscatter ratio and the boundary value term in

[2] Hu, H., F. Zhao, Z. Gong: ‘‘Effects of particle refractive index on accuracy of aerosol measurement with optical particle counters, *Bulletin of Chinese Science* ” (English press), 33, 428-432, 1988.

[3] Liu, Y., P.H. Daum: ‘‘The effect of refractive index on size distributions and light scattering coefficients derived from optical particle counters”, *J. Aerosol Sci*., 31, 8, 945-957, 2000.

[4] Fernald, F. G.: ‘‘Analysis of atmospheric lidar observations: some comments”, *Appl. Opt*., 23, 5, 652-653, 1984.

solution for the two-component lidar equation”, *Appl. Opt.*, 23, 11-13, 1984.