REMOTE SENSING OF AEROSOL BY LIDAR AT AIOFM, CHINA

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1. Introduction

Variation of aerosol affects atmospheric minor constituents and climate through changes in the radiation field as well as by dynamic and chemical processes. In order to estimate the impact quantitatively, it is very important to observe aerosol vertical distributions and their time variations. Lidar is a very powerful remote sensing technique for monitoring the aerosols with a high vertical and temporal resolution. The L625 lidar and L300 mobile dual-wavelength lidar were constructed in Anhui Institute of Optics & Fine Mechanics (AIOFM) for measurements of the aerosol profiles in stratosphere and troposphere. A large number of data have been obtained. This paper will introduce the both lidar systems, and analyze the variations of aerosol profiles measured by L625 and L300 lidar systems at Hefei (31.9°N, 117.17°E), China.

2. Lidar systems and lidar equation

L625 lidar was constructed at AIOFM in 1990 to measure the aerosol profile in stratosphere. In 1996, L625 lidar was rebuilt into a UV-DIAL lidar system, which includes still the wavelength of 532nm. L625 lidar system consists of a double frequency YAG laser (wavelength 532nm), emitting 100mJ per pulse at a repetition rate of 10Hz, a receiving telescope of diameter 625mm, and a photon counting unit. A mechanical chopper can cut the strong-intensity signal before it is amplified by the PMT (EMI9817B). The height resolution of measurement was 600m, normally, before 1996, and 120m after then. The whole set on the top floor of a building with a dome system, which is controlled by a PC computer, is ceiling at the suburb of Hefei city. In order for one PMT to cover the whole signal range of about three orders of magnitude from 6km to 35km or higher, the measurement is divided into two steps. In the first step, an averaged profile, for about 1000 laser shots, of return signal is obtained at relatively low altitude (about 6-25km), when the chopper opens at 6km and a neutral attenuator with transmittance of 5% is inserted in front of the PMT. Thus, the photon arrival rate is small enough to eliminate the pulse-pair error. At the second step, the chopper is adjusted to cut off the return signals from the altitudes below 10km, and the attenuator is taken away, so that the return signal can be recorded from higher altitudes (10-35km). Whole measurement takes about 30 minutes. A 'grand composite' profile spanning the altitude region of interest between 6km and 35km can be formed by matching the above two profiles. The lidar backscattering ratio, R(z), is defined as

$$R(z) = [B_a(z) + B_m(z)] / B_m(z) = 1 + B_a(z) / B_m(z) \qquad (1)$$

where $B_a(z)$, $B_m(z)$ are aerosol and molecular back scattering functions, respectively. The $B_m(z)$ can be calculated from radiosonde data or Elterman model. The backscattering ratio R(z) is calculated by evaluating

$$R(z) = k N_s(z) Z^2 / B_m(z) / Q^2(z) \qquad (2)$$

where $N_s(z)$ is photon number of return signal, $Q^2(z)$ is the two-way atmospheric transmittance, and k is a system constant determined by normalizing the right-hand side of Eq. (2) to an expected minimum value (R_{min}=1.01) of R over a specified altitude range (28-32km). In calculation of the transmittance $Q^2(z)$, molecular extinction is

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from radiosonde or model, and aerosol extinction is calculated directly from the aerosol backscattering function by using the extinction-backscattering ratio values (Jager et al., 1991) of 22, 40, 43 during the period of Pinatubo volcanic cloud (June of 1991 - August of 1994), and 34, 52, 58 during the period with normal situation, over the height ranges of 15-20, 20-25, and 25-35km, respectively. The Eq.(2) is solved by using updated value of aerosol extinction for iterations. Integrated Back-scatter Coefficient, IBC,

$$IBC = \int_{16km}^{27km} \beta_A(z)dz \qquad (3)$$

shows aerosol loading in low stratosphere. Aerosol optical depth τ_a can be obtained according to the

$$\tau_a = \int_{16km}^{27km} \alpha_a(z) \qquad (4)$$

integration of aerosol extinction coefficient $\alpha_a(z)$.

L300 lidar was constructed at AIOFM in 1995 for measurement of aerosol profile in the troposphere. It consists of Nd:YAG laser with the both wavelengths of 1064nm and 532nm, a telescope with diameter of 300mm, PMTs, and A/D converter. L300 lidar is used to measure aerosol profile in troposphere, whose extinction coefficient may be calculated according to Eqs. (1) and (2).

3. Stratospheric aerosol measured by L625 lidar at Hefei during 1991-1999

L625 lidar has been running routinely since January of 1991. 573 profiles of stratospheric aerosol, including Pinatubo volcanic cloud, have been obtained at Hefei from January of 1991 to December of 1999 as following:

91	92	93	94	95	96	97	98	99	total
71	89	69	61	48	25	37	95	78	573

Figure 1 and Table 1 show the statistics of aerosol integrated back-scattering coefficient, IBC, from 16km to 27km. According to their statistics, the observed maximum value of IBC is 8.78×10^{-3} sr^{-1} on November 25, 1991. The maximum value of monthly averaged IBC, signed as IBC_{max}, is 4.79×10^{-3} sr^{-1} for November of 1991, whose e-folding value is 1.76×10^{-3} sr^{-1} and 0.1 decay value of IBC_{max} is 4.79×10^{-4} sr^{-1}. The e-folding decay period of monthly averaged IBC was estimated to be approximately 18 months from August of 1991 to January of 1993 with the averaged IBC of 2.83×10^{-3} sr^{-1}. If the volcanic activity is defined with the monthly averaged IBC value larger than 0.1 decay value of IBC_{max}, the Pinatubo volcanic active period is 39 months from June of 1991 to August of 1994 with the averaged IBC of 1.73×10^{-3} sr^{-1}. The pre-background period is between January and May of 1991 with averaged IBC of 1.87×10^{-4} sr^{-1}. If the background is defined with the monthly averaged IBC less than 0.1 decay value of IBC_{max}, and the new background period is between September of 1994 and December of 1999 with averaged IBC of 2.84×10^{-4} sr^{-1}. The averaged IBC is 2.65×10^{-4} sr^{-1} between February of 1996 and December of 1999 .

Table 1 Statistics of IBC during 1991-1999

	mth	Duration	IBC (sr^{-1})
Pre-bkgd	5	91.1-91.5	0.187×10^{-3} ±0.024×10^{-3}
volcanic activity	39	91.6-94.8	0.173×10^{-2} ±120×10^{-2}
e-folding	18	91.8-93.1	0.283×10^{-2} ±0.090×10^{-2}
New Bkgd	64	94.9-99.12	0.284×10^{-3} ±0.075×10^{-3}

mth: month number
bkgd: back-ground

Figs 2-1 and 2-2 show the variation of monthly averaged IBC per 3km sub-layers for 12-15, 15-18, 18-21, 21-24, 24-27, 27-30, 30-33km. There is one cycle every year seemingly for the lower sub-layers of 12-15, 15-18, 18-21km with the direct impact from the troposphere and the ground, and one cycle in the period longer than one year for the upper sub-layers of 21-24, 24-27, 27-30, 30-33km with less impact from the troposphere. Fig 3 indicates the variation of half-yearly averaged IBC for the above sub-layers. The followings can be seen from Fig.3: (1) the IBC values of 18-21, 21-24km sub-layers are the larger than in the other sub-layers during second half of 1991 and first

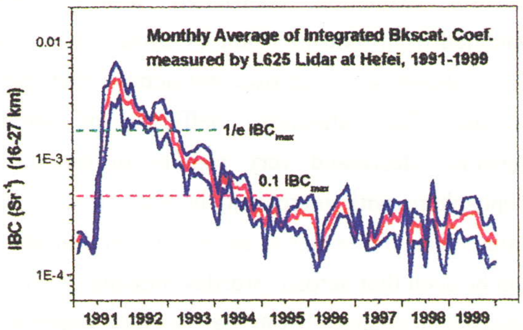

Fig. 1 Variation of monthly averaged IBC

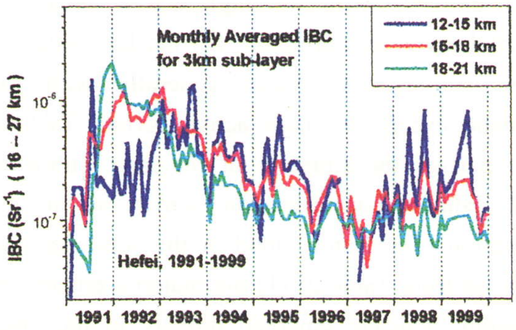

Fig.2-1 Monthly averaged IBC for sub-layer

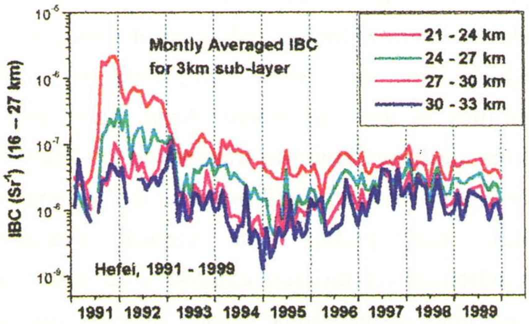

Fig.2-2 Monthly averaged IBC for sub-layer

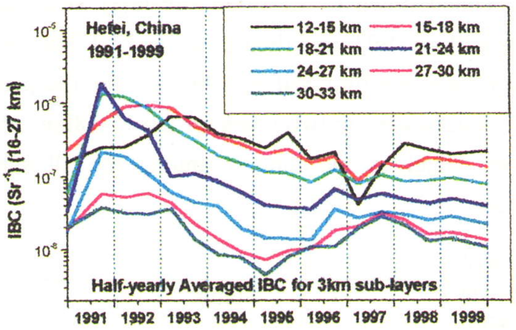

Fig.3 Half-yearly averaged IBC

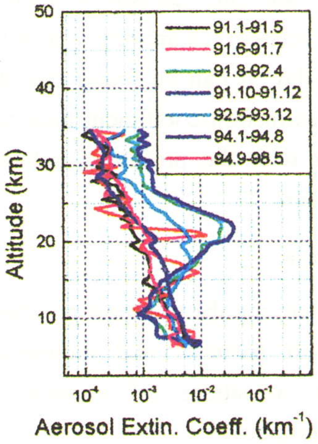

Fig. 4

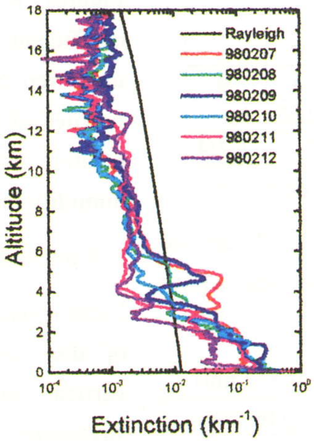

Fig. 5

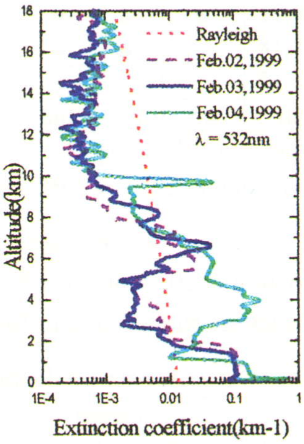

Fig. 6

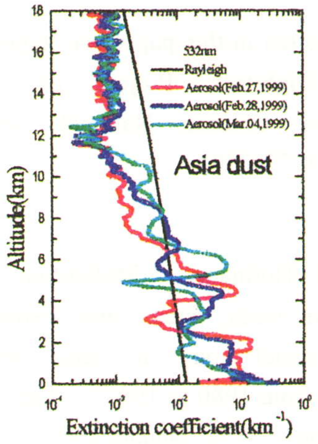

Fig. 7

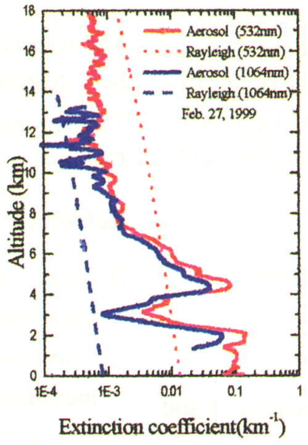

Fig. 8

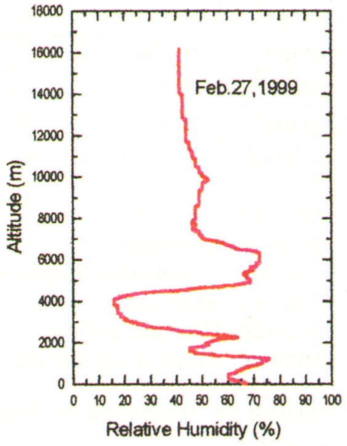

Fig.9

half of 1992 with the high active impact of Pinatubo volcanic eruption; (2) the IBC value of 3km sub-layer decreases generally with the altitude except the high active period. Table 2 summarizes the situation of the large sub-layer IBC value and its decreasing which indicate the variation of volcanic cloud in the sub-layer. We can see from Table 2: (1) the material erupted by Pinatubo volcano emerged directly in the layer from 18-27km at first; (2) the volcanic cloud descended down to 15-18km sub-layer since the first half of 1992, and then down to 12-15km sub-layer since the first half of 1993; (3) the the peak IBC values keep in two years for the 15-18km sub-layer, which is the longest among the all sub-layers.

Table 2

Height (km)	Status					
24-27	♠	♠	♥			
21-24	♠	♥				
18-21	♠	♠	♥			
15-18		♠	♠	♠	♥	
12-15				♠	♠	♥
Half-y	2nd	1st	2nd	1st	2nd	1st
Year	1991	1992		1993		1994

♠: Maximum IBC ♥: IBC starts to decrease

Fig. 4 shows the averaged profiles of aerosol extinction coefficient for different periods, whose statistics are summarized in Table 3.

Table 3 Aerosol optical depths (λ = 0.532 nm)

	Period	mth	τ_a(16-27km)
Pre-bkgd	91.1-91.5	5	0.008±0.001
Volc.begin	91.6-91.7	2	0.020±0.004
High acti	91.8-92.4	9	0.114±0.033
Heaviest	91.10-91.12	3	0.159±0.006
Attenuat#1	92.5-93.11	19	0.044±0.019
Attenuat#2	93.12-94.8	9	0.016±0.003
New bkgd	94.9-99.12	64	0.012±0.001

Note:
mth: month number;
Bkgd: back-ground;
Volc begini: Volcanic beginning period;
High acti: High active period;
Heaviest: Heaviest period;
Attenuat: Attenuating period.

4. Aerosol in troposphere measured by L300 lidar at Hefei

Aerosol extinction coefficient profiles were obtained from 3km to 18km by using L300 lidar. Fig.5 shows some aerosol extinction coefficient profiles. The extinction coefficient of aerosol generally decreased very rapidly in the lower troposphere with increasing height, close to the value of air molecular at about 3-6 km altitude. It can be seen that aerosol profiles indicate generally significant changes from day to day, especially true in the lower region of troposphere. These profiles in Fig.6 indicate well-defined mixed layer, elevated aerosol layers, and cirrus at about 10 km, which show the vertical complexity of aerosol profiles in the troposphere. Asian dust uplifted from northern China was transported to Hefei area by front activities. Fig.7 provides the example of Asia dust profile. The aerosol extinction coefficients for the dust episode were more than one order of magnitude greater than the one for clean period. Asian dust can affect up to 8 ~ 10km. Figures 8 and 9 are the aerosol extinction coefficient and relative humidity profiles measured on same day. It can be found that the profiles of aerosol extinction coefficient have the positive correlation with the profile of relative humidity in troposphere.

5. Conclusion remark

Lidar is useful for studying the transport processes of the volcanic dust particles and monitoring vertical and time variations of aerosol in stratosphere and troposphere.

Acknowledgements

The research reported in this paper was supported by National High-tech Project of Laser Technology, and Chinese National Science Foundation (No. 49775258).

Reference

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