S2-4 Derivation of Aerosol Extinction-to-Backscattering Ratio using a Multi-Wavelength Lidar and a Sun Photometer

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1. Introduction

A sound knowledge of lidar ratio (S_1 parameter) is essential for the lidar inversion scheme[1]. Mie calculation shows that values of the lidar ratio are in a range of 10 to 100 sr for a variety of particle size distributions and refractive indices encountered in the troposhere[2]. The factor of 10 for the range of lidar ratio implies a factor of 10-40 for the uncertainty in the retrieved optical thickness[2]. This is considered to be too large to provide reliable information on the aerosol extinction profile for many practical purposes, e.g. the atmospheric correction of satellite data[3]. Since it is impossible to determine the lidar ratio only from the elastic backscattering lidar measurements, a few calibration approaches have been proposed on the basis of simultaneous measurements with other instruments. Kinjo *et al*[4] proposed the use of a ground-level extinction coefficient measured by an integrating nephelometer for the calibration of lidar data at a wavelength of 532 nm. A sun photometer provides columnar aerosol optical thickness, and it is often used to specify the lidar ratio and to calibrate the aerosol extinction. Takamura *et al.*[5] showed that the lidar ratio has values between 30-70 sr at a wavelength of 532 nm. Representative sets of the lidar ratio for several wavelengths from the actual measurements would contribute to extract more substantial information from remotely sensed aerosol data. In this research we discuss a method to derive the lidar ratio using a multi-wavelength lidar and a sun photometer.

2. Experimental

The multi-wavelength lidar is operated at three wavelengths (1064, 532, and 355 nm) from a Nd:YAG laser, or at four wavelengths (additionally, 756 nm from a Ti:Sapphire laser) at 10 Hz. Simultaneously, a sun photometer is operated at eight wavelengths (368, 420, 500, 532, 675, 778, 880, and 1033 nm). These instruments are located at an elevation height of approximately 30 m above mean sea level in our laboratory at Chiba University, about 30 km east of Tokyo. The optical thickness at each lidar wavelength is found by a least squares fitting of sun photometer observations to an Angstrom exponential expression.

3. Procedure

The tropospheric optical thickness is obtained by subtracting the stratospheric thickness from the columnar thickness. As a result of the eruption of Mt. Pinatubo in June, 1991, the stratospheric aerosol optical thickness increased by a factor of 20-50 above the pre-eruption level[6]. By 1997, however, the stratospheric aerosol loading had fallen to levels close to those of before Mt. Pinatubo[6]. Employing the values of integrated backscatter and extinction-to-backscattering ratio reported by Kent *et al.*[6], here we assume that the stratospheric optical thicknesses for 355, 532, 756 and 1064 nm are 0.0043, 0.0024, 0.0014 and 0.00088, respectively.

In the derivation of the lidar ratio (S_1) from the lidar and sun photometer data, we postulate that the value of S_1 is constant for each wavelength in the whole troposphere. In our approach, first, the S_1 parameter is determined at 532 nm by comparing the optical thickness derived from the lidar data with the columnar optical thickness obtained from the sun photometer. At each altitude z, it is assumed that the aerosol extinction coefficient $\alpha_1(\lambda_i, z)$ at each wavelength λ_i (i=355, 756, and 1064 nm) is proportional to $\alpha_1(\lambda_{532}, z)$, the coefficient at 532 nm :

$$\alpha_1^{(\mathrm{ref})}(\lambda_i, z) = K_i \alpha_1(\lambda_{532}, z) , \tag{1}$$

where $K_i = \tau(\lambda_i)/\tau(\lambda_{532})$, with $\tau(\lambda_{532})$ and $\tau(\lambda_i)$ representing the optical thickness at λ_{532} and at λ_i as derived from the sun photometer. In this manner the "reference profile" $\alpha_1^{(\mathrm{ref})} = \alpha_1(\lambda_i, z)$ is determined. Subsequently the lidar signal at the wavelength λ_i is inverted using the conventional method[1] with several plausible values of the S_1 parameter. This profile is denoted as $\alpha_1^{(\mathrm{obs})}$. The rms difference between $\alpha_1^{(\mathrm{obs})}$ and $\alpha_1^{(\mathrm{ref})}$ is computed as

$$D = \left[\frac{\int_{z_0}^{z_c} \left[\ln \alpha_1^{\mathrm{obs}}(z') - \ln \alpha_1^{\mathrm{ref}}(z') \right]^2 dz'}{z_c - z_0} \right]^{1/2} , (2)$$

where z_0 and z_c are the overlap altitude of the laser beam with the telescope field-of-view and the boundary altitude, respectively. Then, we can determine the value of S_1 by minimizing D .

4. Result

The algorithm described above is applied to three cases that are considered to be representative. If the interval between z_0 and z_c is too small, local inhomogeneities might lead to an error of S_1. On the contrary, if z_c is too large the noise of $\alpha_1^{(\mathrm{obs})}$ may obscure the minimum of the rms difference D . Taking these considerations into account, here we take z_0 to be 750 m and z_c to be 3000 m. The results are shown in Fig. 1(a) (1 June 1999, 14:50), Fig. 1(b) (9 August 1998, 13:00) and Fig. 1(c) (11 April 1998, 12:45).

Table 1. Aerosol extinction-to-backscattering ratio obtained form the lidar and sun photometer measurents

Wavelength	355 nm	532 nm	756 nm	1064 nm
1 Jun. 1999	54	39	28	27
9 Oct. 1998	50	44	36	15
11 Apr. 1998	31	72	84	82

Table 1 shows the values the S_1 derived from the measurements. The values of S_1 for Fig. 1(a) are similar to that of Fig. 1(b). In contrast, in the case of Fig. 1(c), the values show remarkable difference. This may be ascribed to the contribution of the concentrated aerosol layer from an altitude of 2000 m to 3000 m, presumably due to the Kosa (yellow sand) effect. This result shows the homogeneity of the tropospheric aerosol is prerequisite for the present method.

It is also noted that for the ground level the values of lidar ratio are calculated on the basis of chemical composition measurements in Japan and South-East Asia with Andersen low-volume samplers.

5. Summary

In this research we have proposed a method to determine the lidar ratio using the lidar and sun photometer measurements. This will be useful both for the precise determination of the aerosol extinction and for the investigation of aerosol properties in the troposphere.

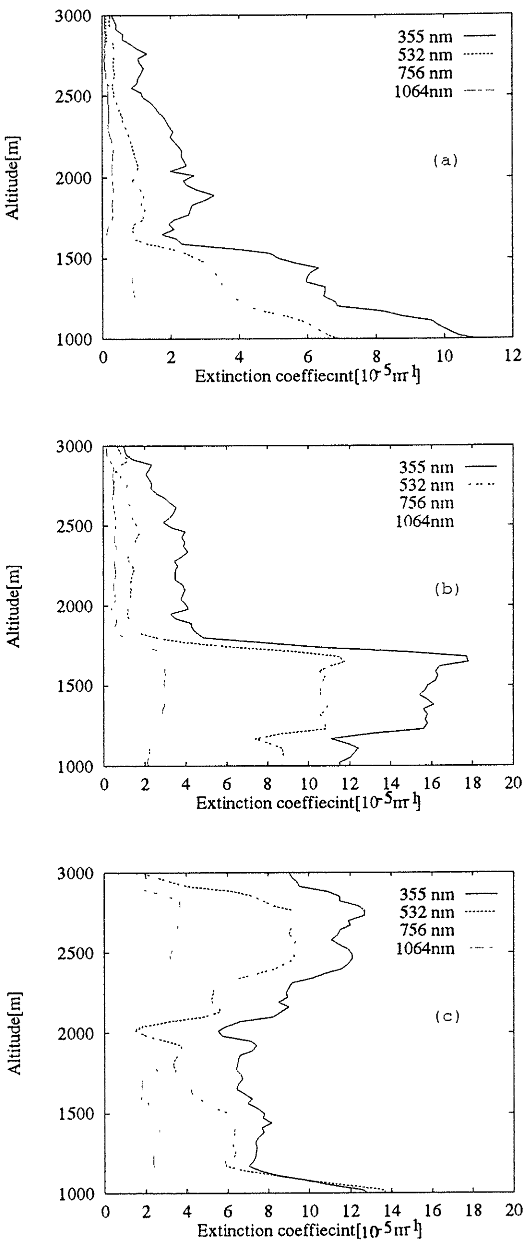

Fig. 1 Results of the present method to the multi-wavelength lidar data measured at (a)1 June 1999, 14:50, (b) 9 August 1998, 13:00 and (c) 11 April 1998, 12:45.

References

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