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Investigate the relationship between multiwavelength lidar ratios and aerosol size distributions using aerodynamic particle sizer spectrometer

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ABSTRACT

The real aerosol size distributions were obtained by aerodynamic particle sizer spectrometer (APS) in China YinChuan. The lidar ratios at wavelengths of 355 nm, 532 nm and 1064 nm were calculated using Mie theory. The effective radius of aerosol particles r_{eff} and volume *C*/*F* ratio (coarse/fine) $V_{c/f}$ were retrieved from the real aerosol size distributions. The relationship between multiwavelength lidar ratios and particle r_{eff} and $V_{c/f}$ were investigated. The results indicate that the lidar ratio is positive correlated to the particle r_{eff} and $V_{c/f}$. The lidar ratio is more sensitive to the coarse particles. The short wavelength lidar ratio is more sensitive to the particle $V_{c/f}$ and the long wavelength lidar ratio is more sensitive to the particle r_{eff}. The wavelength dependency indicated that the lidar ratios decrease with increasing the wavelength. The lidar ratios are almost irrelevant to the shape and total particles of aerosol size distributions.

1. Introduction

Nowadays, elastic backscatter lidar has been proven to be a very useful remote sensing tool to obtain the optical properties of atmospheric aerosols at high spatial and temporal resolution [1–4]. However, the backscatter lidar equation includes two unknowns, backscatter coefficient and extinction coefficient [5–7]. The aerosol extinction-to-backscatter ratio or lidar ratio *S* is a key parameter in backscatter lidar inversions to derive aerosol optical properties. There are many studies of determination of the lidar ratio. Such as a combined Raman elastic-backscatter lidar has been developed to derive the lidar ratio [8]. A high spectral resolution lidar (HSRL) can be used to measure the lidar ratio directly [9]. A method of combining ground-based and spaceborne lidar to determine the lidar ratio has been developed [10]. A novel retrieval technique that combines a Raman and multiwavelength elastic backscattered signals to retrieve multiwavelength lidar ratio profiles of aerosol has been proposed [11].This parameter can also be selected based on an aerosol model in the backscatter lidar data analysis [12]. Nevertheless, the lidar ratio is the indicator of the aerosol characterization, it is related to the wavelength of the incident light, the aerosol size distribution and the refractive index [13,14], and its behavior is not obvious in real atmospheric aerosols. Distributions of the effective lidar ratio (ELR) were analyzed using (CALIOP) data acquired during nighttime [15]. The vertical distributions of the dust aerosol extinction coefficient are derived from the CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations) lidar measurements [16]. How the aerosol size distribution affects multiwavelength lidar ratios and what are the key factors? Therefore, it is important to find out the relationship between the lidar ratio and the aerosol size distribution and the wavelength of the incident light. Several studies have

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been conducted to determine the relationship between the aerosol optical properties and the microphysical properties of the aerosols [17–20]. However the relationship between the multiwavelength lidar ratio and the aerosol size distribution and the wavelength dependency of the lidar ratio has not been discussed in the above papers.

The purpose of this paper is to clarify the relationship between the lidar ratio and the aerosol size distribution by measuring the real aerosol size distribution continuously with the aerodynamic particle sizer spectrometer (APS) and calculating the multiwavelength lidar ratio by Mie scattering theory [21]. The volume C/F ratio (coarse/fine), effective radius are used to investigate the size and wavelength dependency of the lidar ratios. The wavelengths of 1064 nm, 532 nm and 355 nm of Nd:YAG laser are selected as basis of calculation, for the three wavelengths are commonly used as the emission source of multiwavelength lidar. The relationship between wavelength and lidar ratios is studied at the three wavelengths.

2. Methodology

Typically, the aerosol number size distributions can be modeled as the sum of lognormal distributions. It is defined by:

$$n(r) = \frac{dN}{dr} = \sum_{j=1}^{M} \frac{N_{t,j}}{\sqrt{2\pi} r \ln \sigma_j} \exp\left(-\frac{(\ln r - \ln r_{med,j})^2}{2(\ln \sigma_j)^2} \right) \tag{1}$$

Here $N_{t,j}$ is the total number concentration of the mode j, σ_j the geometric standard deviation represents the width of the distribution and $r_{med,\ j}$ the median radius of the mode j. The number of modes is described by M. In general situation, the number of particles decreases with increasing particle radius. Therefore, the size distribution on a log scale $n(lnr)=dN/dlnr=rn(r)$ is used. The extinction α_λ and backscatter β_λ coefficients are related to the aerosol size distribution $n(r)$ by Fredholm integral equations of the first kind:

$$\alpha_\lambda = \int_{r_{min}}^{r_{max}} \pi r^2 Q_{ext}(r, \lambda; m) n(r) dr \tag{2}$$

$$\beta_\lambda = \int_{r_{min}}^{r_{max}} \pi r^2 Q_{bac}(r, \lambda; m) n(r) dr \tag{3}$$

Here r denotes the particle radius, λ is the wavelength, m is the refractive index, and the upper and lower limits of the particle sizes are r_{min} and r_{max}. Q_{ext} and Q_{bac} denote the extinction and backscatter efficiencies for individual particles weighted by their geometric cross-section πr^2 which can be calculated by Mie theory.

Fig. 1 illustrates an example Q_{ext} and Q_{bac} for 355 nm, 532 nm and 1064 nm with the typical continental insoluble refractive index $m=1.53–0.008i$.

Consider, knowing a real number size distribution $n(r)$ of the aerosol particles, we can obtain the extinction and backscatter coefficients. Accordingly, the lidar ratio S_λ at different wavelength is given by:

$$S_\lambda = \frac{\int_{r_{min}}^{r_{max}} \pi r^2 Q_{ext}(r, \lambda; m) n(r) dr}{\int_{r_{min}}^{r_{max}} \pi r^2 Q_{bac}(r, \lambda; m) n(r) dr} \tag{4}$$

Assuming the aerosol particles are well mixed, the aerosol number size distribution $n(r)$ changes with height z is a continuous function $f(z)$. The aerosol number size distribution can be expressed by:

$$n(r, z) = n_0(r) f(z) \tag{5}$$

When we substitute Eq. (5) into Eqs. (2) and (3), we can get the following results:

$$\alpha_\lambda(z) = \int_{r_{min}}^{r_{max}} \pi r^2 Q_{ext}(r, \lambda; m) n_0(r) f(z) dr = \alpha_\lambda(0) f(z) \tag{6}$$

$$\beta_\lambda(z) = \int_{r_{min}}^{r_{max}} \pi r^2 Q_{bac}(r, \lambda; m) n_0(r) f(z) dr = \beta_\lambda(0) f(z) \tag{7}$$

Here the $\alpha_\lambda(0)$ and $\beta_\lambda(0)$ are the extinction and backscatter coefficient of the near surface. Then the lidar ratio $S_\lambda(z)$ can be written as:

$$S_\lambda(z) = \frac{\alpha_\lambda(0) f(z)}{\beta_\lambda(0) f(z)} = \frac{\alpha_\lambda(0)}{\beta_\lambda(0)} = S_\lambda(0) \tag{8}$$

From Eq. (8) we know that the lidar ratio $S_\lambda(z)$ is only related to the extinction and backscatter coefficient of the near surface when the number concentration of aerosols are continuously changed with height z, especially when the aerosol particles are mixed homogeneously within the PBL. Therefore, when there is no turbulence, and the

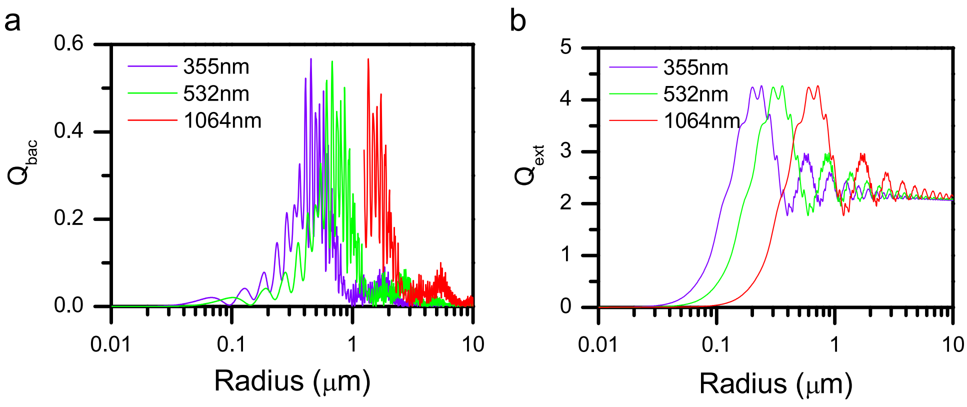

Fig. 1. Efficiencies of extinction (a) and backscatter (b) for single particle at 355 nm, 532 nm and 1064 nm.