Journal of Quantitative Spectroscopy & Radiative Transfer 109 (2008) 1187–1195

Journal of Quantitative Spectroscopy & Radiative Transfer

www.elsevier.com/locate/jqsrt

An iterative calculation to derive extinction-to-backscatter ratio based on lidar measurements

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Received 1 May 2007; received in revised form 12 October 2007; accepted 16 October 2007

Abstract

The aerosol optical thickness (AOT) is an important parameter for understanding the radiative impact of aerosols. AOT based on lidar measurements is often limited by its finite detection range. In this paper, we have reported a method of fitting and iterative calculation to derive the extinction profile of background aerosols from 0 to 30 km at 532 nm, which is virtually the AOT of the entire atmosphere. The mean extinction derived from this method at the ground level tallies with visibility measurement and it is also consistent with the sun-photometer data, within experimental error. These data have been further treated to study the dust cases. For most of the cases, transmission losses were determined to estimate the extinction as well as lidar ratio. The result of the analysis shows that for background aerosols, a mean lidar ratio of 47 ± 15 sr was found. For dust layers, a mean lidar ratio of 44 ± 19 sr and an optical thickness of 0.53 ± 0.49 were determined at 532 nm.

Keywords: Lidar ratio; Aerosols; Dust; Depolarization ratio; Optical thickness

1. Introduction

The capability of tracing the vertical profiles of background aerosol/dust makes lidar an important tool for atmospheric research. Lidar measurements consist of deriving the backscattering ratios of molecules, aerosols, and all materials presented in the path that laser travels. To derive the extinction coefficient (κ_a) or transmission (T) from the backscattering coefficients (β_a) for different aerosols, such as pollutants and dust, an empirical factor known as extinction-to-backscatter or lidar ratio (S_a) is required. Accurate lidar ratio for background aerosols/dust is very important for estimating the optical properties of background aerosols/dust. This ratio depends on the shape, size distribution and, the refractive index of the aerosol particles as well as on the lidar wavelength (λ) [1–3]. The lidar ratio is also a useful parameter to understand factors such as transmission and reflection at the interested λ. Without accurate estimation of lidar ratio and optical depth of background aerosols/dust, it is difficult to understand their radiative impact on the atmosphere.

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0022-4073/$ - see front matter
doi:10.1016/j.jqsrt.2007.10.011

There are a few problems related with the derivation of lidar ratio. First, lidar measurement is range limited because of system overlapping problem between the laser beam and the field view of the telescope. Second, the lidar equation is mathematically unsolvable due to its dependence on the two unknown variables κ and β for both molecules and particles. The molecular scattering variables κ_r and β_r can be determined either from the standard atmospheric model or from meteorological data of temperature and pressure. But the aerosol scattering variables κ_a and β_a are still unknown, and to solve lidar equation some kind of relation is required between these two unknown parameters. This relation is known as extinction-to-backscatter ratio, commonly known as lidar ratio. There are some methods to calculate lidar ratio such as the combination of independent backscattering signals of Raman lidar and elastic-backscatter lidar [4], and also by using high spectral resolution lidar which provides independent measurements of scattering properties for aerosols and molecules [5]. But the former method is limited due to the weakness of Raman backscatter signals and the latter are complex to use. To overcome this limitation, we have reported a numerical and fitting method to determine the lidar ratio from the lidar backscatter at $\lambda = 532$ nm. The received backscatter is due to Mie scattering.

In the measurement location, background aerosol typically consists of pollutants, sea salts, and other unidentified aerosol types which are in trace quantities. During the observation made by lidar, the mineral dust is only traced a couple of times during the spring season (March–May). Therefore, we have chosen to treat dust cases separately from the background cases. It is noted, however, that dust co-exists with the background aerosol and, thus, in the derivation of dust properties, knowledge about the background aerosol is also needed.

In this paper, we have discussed a method to derive the extinction of background aerosol and later used it for studying dust. We have also derived lidar ratios and optical thicknesses for both background aerosols and dust events over Chung-li (24.58°N, 121.10°E, altitude 167 m, MSL) during the period of 2002–2004. This paper is organized in the following manner: in Section 2, a brief description of the system and methodology are presented. In Section 3, there will be results and discussion, and finally in Section 4 we will summarize our result.

2. Instrument and methodology

2.1. Lidar system

The lidar measurements were carried out in Chung-li, Taiwan, by using a vertically pointed Nd:YAG lidar operating at $\lambda = 532$ nm. The vertical resolution of the measurements is 24 m, and each measured vertical profile was obtained by integrating over 1000 transmitted pulses for a time interval of 33 s. Due to the biaxial configuration of the transmitter and receiver system, the lowest part of the atmosphere cannot be monitored. Rather, the field of view of the receiving telescope starts to overlap with the transmitted laser beam at 0.25 km altitude (corresponding to 0.417 km from the mean sea level), and the full overlap is obtained at 0.7 km from the instrument. The detailed description of our lidar system can be found in Nee et al. [6]. The optical power measured by lidar is proportional to the signal backscattered by particles and molecules present in the atmosphere. The lidar equation for the elastic backscattering signals by molecules and aerosols can be expressed as

$$P_R(z) = P_L \frac{A_T}{z^2}(\beta_r(z) + \beta_a(z))T^2, \tag{1}$$

where $P_R(z)$ is the total signal due to molecules and particles scattering received from the height range z, P_L is the laser output energy, A_T is a calibration factor that is constant for a given lidar system, T^2 is the total round-trip atmospheric transmittance, and β_r and β_a are volume molecule and particulate backscattering coefficient, respectively. The backscattering coefficient of molecules is derived from the molecular concentration measured by radiosonde multiplied by total Rayleigh scattering cross section. The backscatter solution to the above lidar equation based on Fernald's method [7] can be written as

$$\beta_r(z) + \beta_a(z) = \frac{P_R(z)z^2 \exp\left[-2(S_a - S_r)\int_{z_1}^{z}\beta_r(z)\,dz\right]}{P_R(z_1)z_1^2/(\beta_r(z_1)+\beta_a(z_1)) - 2S_a\int_{z_1}^{z} P_R(z)z^2\exp\left[-2(S_a - S_r)\int_{z_1}^{z}\beta_r(z)\,dz\right]dz}, \tag{2}$$