CHARACTERIZATION OF PROPERTIES OF AIRBORNE PARTICULATE MATTER FROM OPTICAL SCATTERING USING LIDAR

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Introduction. Characterization of airborne particulate matter has been a major challenge to researchers involved in the field of atmospheric sciences. Knowledge of aerosol optical properties assumes significant importance in the wake of studies strongly correlating airborne particulate matter with adverse health effects. Studies have shown that tropospheric aerosols increase mortality, morbidity and respiratory problems, and pulmonary function decreases with increase in ambient particle mass concentrations[1]. The small aerosol component, $PM_{2.5}$, is of most concern to human health because it can be easily inhaled deep into the lungs. Along with health issues, aerosol distributions have significant implications for natural environmental aesthetics and climatic change conditions. The typical percentage of visual range, compared to the clean molecular atmosphere, is around 50-67 % in the western U.S. and 20 % in eastern U.S.[2] The combustion products from transportation and power sources produce most of the nucleation centers which grow to aerosol sizes that change the visibility and radiative flux at the Earth's surface by optical scattering. We have used Raman lidar and backscatter lidar techniques to measure the optical extinction and scattering properties as part of the NARSTO-NE-OPS (NorthEast-Oxidant and Particle Study)[3] during the summers of 1998 and 1999.

Methods. Raman lidar provides a means of accurately measuring vertical profiles of aerosol extinction and the optical backscatter signal from particles. Airborne particulate matter can be analyzed using the gradients in molecular profiles to determine optical extinction profiles at several wavelengths. The wavelength dependent optical extinction is used to describe changes in particle size as a function of time and altitude[4]. Extinction (km^{-1}) is a measure of the total attenuation of a laser beam due to scattering and absorption. However at the wavelengths used, scattering by aerosols predominates. Extinction is calculated by first subtracting the background signal from the raw photon count signal and corrected for range. An algorithm for the telescope geometrical form factor is used to aid in analyzing signals near the surface (up to altitudes of 800 m).

The Raman molecular profile can be used to determine the extinction profile through optical scattering regions such as clouds. The backscatter signal from the Raman shifted molecular profile contains information about optical extinction from scattering by the particulate matter. The extinction coefficient can be calculated from the change in signal strength through the cloud using the Beer-Lambert law and assuming that multiple scattering is negligible over the interval[5,6]. The transmitted and received signals from the channels at 532 nm and 530 nm are assumed to experience the same extinction and can thus be calculated from

$$a = -\frac{\ln I / I_0}{2x}$$

where α is the extinction coefficient and x equals the range bin size in meters. The backscatter coefficient can be calculated directly from the return signal measured by a PMT at the transmitted wavelength (532 nm). The ratios of measurements of the particle extinction and backscatter coefficient are examined to determine changes in the particle size distribution.

Extinction is the result of both absorption and scattering by molecules and aerosols:

$$\alpha_{ext} = \alpha_{abs}^{aer} + \alpha_{sca}^{aer} + \alpha_{abs}^{mol} + \alpha_{sca}^{mol}$$

For 530 nm channel, the aerosol absorption coefficient and the molecular absorption coefficient can be assumed negligible, and also the molecular scattering coefficient is sufficiently small compared to the aerosol scattering that it can be ignored. The extinction coefficient is therefore considered to be completely determined by aerosol scattering. The aerosol scattering coefficient calculation is simplified by assuming, the particle to be a homogeneous sphere of arbitrary radius, known refractive index, and illuminated by a plane polarized monochromatic wave[7].

Results. Figure 1 demonstrates that the total extinction to backscatter ratio is a constant for small particle size, and increases with increasing particle size between 50 nm to 150 nm. Correlation between backscatter and extinction measurements provides a means of describing variations in small aerosols and particulate matter in the lower atmosphere, where it is important to obtain improved measurements of the distribution of airborne particulate matter.

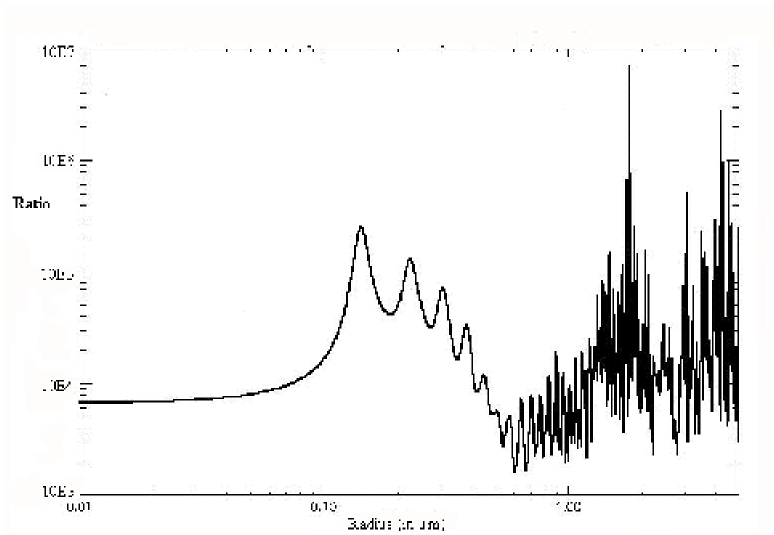
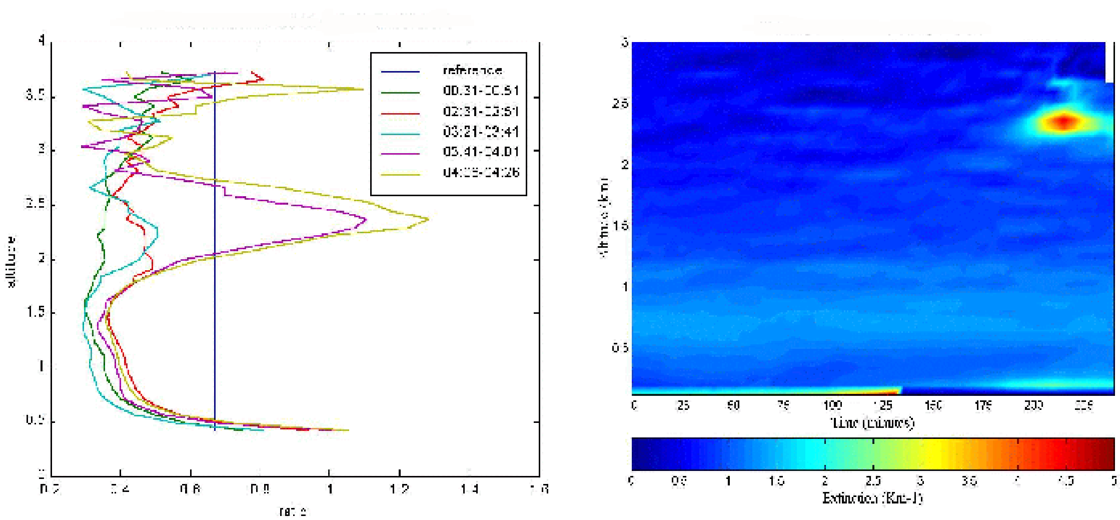


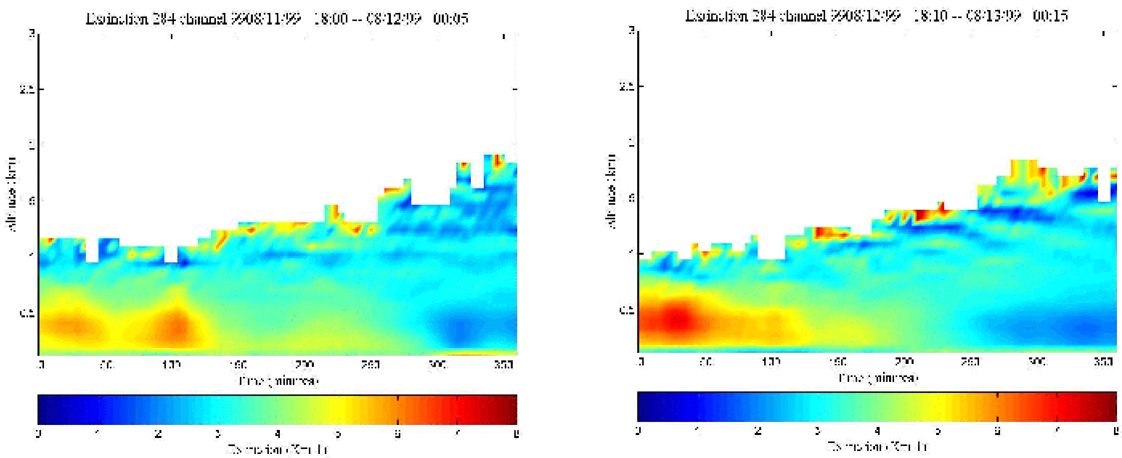
Figure 1. The extinction/backscatter ratio at 530 nm as function of particle size.



(a) (b)

Figure 2. Extinction /Backscatter ratio (a) and vertical extinction profiles from 530 nm channel (b) for the time interval between 00:30 - 04:30 UTC on 8/12/99.

The extinction/backscatter ratio variations with altitude on August 12 ,1999 were studied when a noticeable change in ratio (Figure 2a) is observed as cloud cover approaches (Figure 2b)because of changes in particle size distribution. Figure 3 demonstrates variations in the aerosol density that have been found to occur during sunset. The results in Figure 3 are initial examples of the type of data that can be obtained from time sequences of the Raman lidar extinction profiles.



(a)

(b)

Figure 3. Examples of optical extinction time sequence from Raman lidar results at 284 nm.

Conclusions. The molecular profiles from the Raman scatter signals provide direct measurements of the optical extinction. Small particle size variations can be examined using the ratio of extinction to backscatter signals. A change in ratio corresponds to a change in particle size and not density, as a change in density would correspond to changes in both extinction and backscatter and not affect the ratio by much. Scattering at optical wavelengths provides information on the distribution of small airborne particles and corresponds with the $PM_{2.5}$ particulate matter measured by ground based sensors.

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