MULTI-ANGLE LIDAR SENSING OF TRAFFIC AEROSOL IN MANILA

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ABSTRACT

Multi-angle lidar sensing of traffic aerosols was conducted in a very busy Manila area. The backscatter coefficients for 355 nm and 532 nm were calculated from Fernald's inversion method using calibration results retrieved from the slant-path method. An aerosol extinction-to-backscatter ratio of 30 sr was assumed in the calculation. Several scans were conducted on 31 July 2003 during peak traffic hours to observe the two-dimensional spatial and temporal distribution of traffic aerosols. The presence of a constant aerosol mass near a busy intersection was observed throughout the scanning period. The calculated backscatter coefficient for these aerosol mass ranged from 3.56×10^{-6} $m^{-1}sr^{-1}$ to 5.01×10^{-6} $m^{-1}sr^{-1}$ for 532 nm and 1.76×10^{-5} $m^{-1}sr^{-1}$ to 2.02×10^{-5} $m^{-1}sr^{-1}$ for 355 nm.

1. INTRODUCTION

Since the inception of lidar in the 1960s, a great deal of atmospheric studies has been made on clouds and aerosols due to their important roles in climate change and air quality issues. Directly, they play a key role in absorbing and scattering solar and terrestrial radiation. On a more local scale, aerosols reduce visibility and can have harmful effects on human health. Several studies have used multi-angle lidar techniques to obtain the optical properties of aerosols. In 1980 Spinhirne et al [1] obtained aerosol extinction and backscatter profiles from layer-averaged multi-zenith angle lidar measurements. They reported that large errors could result from both horizontal atmospheric inhomogeneity of backscatter and from signal noise associated with lidar return data, and thus a direct slant path solution was not possible. Rather, their approach was a procedure that applied atmospheric layer integration to multi-angle return data to ameliorate the effects of the possible sources of error mentioned. D. Powell [2] made a related study in her graduate thesis, using micro-pulse multi-angle lidar for retrieving continental and marine aerosol and dust plume properties in the subtropical North Atlantic. Both the slant method and Fernald two-scatter retrievals were used to obtain the radiative and optical properties of aerosols, and it was reported that the lidar measurements made showed excellent agreement with similar aerosol retrievals obtained from other instruments, although difficulty in dealing with atmospheric inhomogeneity was met. Sicard et al [3] presented a statistical variational method for retrieving the aerosol optical thickness and backscatter coefficient profiles from ground-based multi-angle lidar measurements. Backscatter and optical thickness profiles obtained using the variational method were compared to profiles obtained using the Klett method, and it was found that they compare well.

In this paper, two-wavelength multi-angle lidar sensing of traffic aerosols in the Manila-Pasay City area will be presented. Through this scanning lidar a two-dimensional spatial and temporal distribution of particulate matter in a very busy Manila area could be obtained, which provides more useful information as compared to vertical lidar scanning alone.

2. METHOD

2.1. Slant-sensing retrieval

Meaningful retrieval of optical properties using slant-path lidar sensing can only be achieved if there is reasonable spatial and temporal homogeneity during the period of scanning. For slant sensing techniques we assume that the lidar system can be aimed in various pointing angles θ with respect to the zenith. The lidar equation is expressed as

$$P(\lambda,r)=P_0(\lambda)\eta_{opt}(\lambda)Y(r)\frac{c\tau}{2}\frac{A_r}{r^2}\beta(\lambda,r)T^2(\lambda,r) \quad (1)$$

where $P(\lambda,r)$ is the instantaneous received power at time t, P_0 is the transmitted power at time t_0, c is the speed of light, τ is the pulse duration, β is the volume backscatter coefficient of the atmosphere, A_r/r^2 is the solid angle subtended by the aperture of the receiver, η_{opt} is the optical efficiency of the transmitting and receiving system, $Y(r)$ is the overlap factor, and $T^2(r)$ is the atmospheric round-trip transmittance. A more convenient working form of Eq. (1) is the range-adjusted power $X(\lambda,r)$,

$$X(\lambda,r) = C(\lambda)\beta(\lambda,r)T^2(\lambda,r) \qquad (2)$$

where $C(\lambda)$ is the system constant. For measurements along a slant range r, $T^2(\lambda,r)$ reduces to

$$T^2(\lambda,z,\theta) = \exp[-2\tau(\lambda,z)\sec\theta] \qquad (3)$$

noting that the slant-path range r can be expressed as a function of altitude for a given zenith angle θ by $r = z \sec\theta$. Now consider $S(\lambda,z,\theta)$, the natural logarithm of $X(\lambda,r)$:

$$S(\lambda,z,\theta) = \ln[C(\lambda)\beta(\lambda,z)] - (2\sec\theta)\tau(\lambda,z) \qquad (4)$$

For several observations at various zenith angles θ, a straight-line fit to $S(\lambda,r)$ versus ($-2\sec\theta$) could be made which has a slope equal to the optical depth, $\tau(\lambda,z)$. In this study, the slope of the linear regression line through the considered data points was determined by the method of least squares.

Picking a calibration height z_c just before the region where the signal goes down to the noise level, the system constant could be evaluated using

$$C(\lambda) = \frac{X(\lambda,z_c,\theta)}{\beta_R(\lambda,z_c)\exp[-2\tau(\lambda,z_c)\sec\theta]} \qquad (5)$$

which was derived from Eq. (2), approximating the total backscattering with its Rayleigh component.

Backscattering coefficient profiles can then be calculated from a solution obtained using Fernald's method [4,5], given by

$$\beta(z) = \beta_a(z) + \beta_R(z) = \frac{X(z)\exp\left[-2(S_a - S_R)\int_{z_c}^{z}\beta_R(z')dz'\right]}{CT^2(z_c) + 2S_a\int_{z_c}^{z}X(z)\exp\left[-2(S_a - S_R)\int_{z_c}^{z}\beta_R(z')dz'\right]dz} \qquad (6)$$

which can be implemented in both the backward and forward direction of backscatter coefficient retrieval. The results from the slant-path method are used as input parameters. Finally, the aerosol component of the backscattering is then obtained by subtracting the Rayleigh component from the total backscatter from Eq. (6).

2.2. Multi-angle lidar measurements

The specifications of the scanning lidar system that was employed in the measurements are summarized in Table 1. The lidar system is situated at the De La Salle University (DLSU) Science and Technology Research Center(STRC) in Manila, and aimed along the direction of approximately 12° East of South of the lidar site, towards the Pasay City area, passing over busy roads such as Vito Cruz St. and Gil Puyat Avenue. Vallar et. al.[6] showed a detailed map of the site's vicinity and the lidar path. The lidar site is surrounded by five main thoroughfares in Manila such as Taft Avenue, Mabini St, Vito Cruz St., Quirino Avenue, and Roxas Boulevard. No industrial plants are located near the vicinity and along the lidar path hence most of the aerosols detected by the lidar can be attributed to vehicular emission especially during peak traffic hours. The system is only capable of vertical scanning from 69° to 87° zenith angles because of several obstructions along the lidar path.

Table 1. The Lidar System

Laser		
Model	Continuum I-20 Nd:YAG	
Wavelengths used	355 and 532 nm	
Pulse Frequency	20 Hz	
Telescope		
Type	Newtonian	
Diameter	200 mm	
Focal Length	800 mm	
Optical Filters		
Type	Narrow bandpass filter	
Peak wavelength	532.5 nm	356.4 nm
Bandwidth	3 nm	10 nm
Transmission	60%	25%
Detectors		
Type	Photomultiplier tube	
Spectral Range	160 to 930 nm	
Quantum efficiency	20%	
Data Acquisition		
Oscilloscope	Agilent 54621D MSO	
Sampling rate	100, 200 MSa/s	
Resolution	8 bit	

Multi-angle measurements were conducted on several dates in July 2003, monitoring the transmitted laser power for both wavelengths in each set of experiments. Narrow bandpass filters were used to ensure that the backscattered light received by the photodetectors is reasonably monochromatic and to minimize background

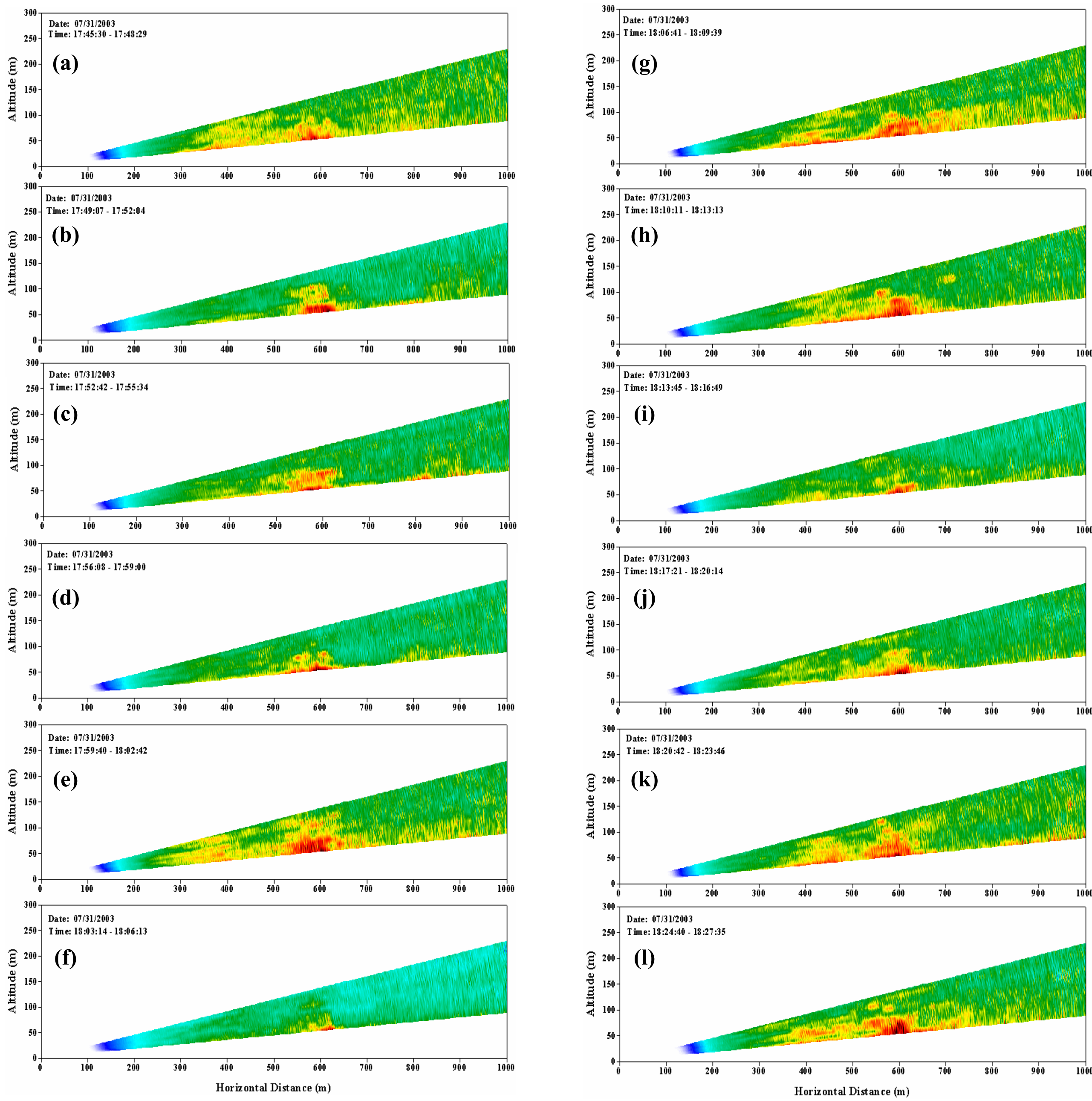

Fig. 1. Scanning plot of the range-squared-corrected signal for 532-nm for a period of 40 minutes. Each scan takes 3.5 mins to complete.

signal especially in daytime measurements. Background signal profiles were also obtained for each scanning profile and were subtracted from the received lidar signals to account for the sky background noise at different pointing angles. The output signals from the PMTs are then received, digitized and averaged by the oscilloscope which is then transferred to a PC via serial port communication.

The volume backscatter coefficients were calculated using the procedure outlined in the previous section. Values for the molecular component of the backscattered signal β_R were calculated from Rayleigh scattering theory using an air number density determined from pressure and temperature values obtained from radiosonde data.

3. RESULTS AND DISCUSSION

To observe the two dimensional temporal and spatial distribution of aerosol during traffic hours in the vicinity, several scan were conducted in the afternoon of 31 July 2003 from 5:45 to 6:31 PM, with each scan taking three and half minutes to complete. At this period of time, heavy traffic is always expected along the busy thoroughfares surrounding the lidar site. Fig. 1 shows the range-squared corrected signal scanning plot for 532 nm for a set of 12 scan. The scanning plot for the 355 nm was not shown here but the two wavelengths illustrated the same feature. Inasmuch as a large number of slant-path measurements are required for a good mapping of the atmosphere for each accumulated profile, temporal variation of the atmosphere is a factor that was greatly considered. To conduct a faster scanning and acquisition, each scan was limited only to 8 profiles corresponding to 8 zenith angles from 85^o to 77^o at one degree intervals. A 128-signal averaging was used since the primary source of delay in the data acquisition process is the averaging done by the oscilloscope used in this study. For this particular setting, the total acquisition time per lidar profile was about 18.66 secs and each acquired profile is comprised of 2000 data points. The most prominent feature that can be seen throughout the scanning period was the consistent aerosol mass at a horizontal distance of 550 m to 650 m from the lidar site. From the map presented in [6], this is exactly near the corner of Vito Cruz St. and Taft Avenue, which is one of the congested areas near DLSU during peak traffic hours. Although the scanning time of 3.5 min for each scan is very slow and the system is limited only to scanning in a vertical plane, to actually observe the movement of traffic aerosols, some noticeable temporal variations in the spatial properties of the aerosols over time can be observed. For example, a diminishing aerosol mass at a horizontal distance of 800 m can be observed in Figs. 1 (a) through (d). Another observable feature, which is located at a horizontal distance of around 400 m, is seen to vary throughout all scans, although it's hard to tell the general direction of its motion with given the limitations of the lidar system.

The optical properties of the aerosol mass located at the horizontal distance of 600 m were calculated. An extinction-to-backscatter value of 30 sr was used in the calculations, and was assumed to be constant with range. Since the scans were limited to the lower angles, a relatively lower reference height had picked. To further minimize the effect of noise in the slant-path method calculation, a range of reference heights was chosen for the calculations, which more precisely is the altitude range of 300 to 350 m. The values of the optical depth estimate for the range was then averaged, and assumed to be the optical depth at the reference height z_c = 325 m. For the 532 nm wavelength, calculations using the slant path method yielded an optical depth estimate $\tau(z_c) = 0.052$. The system calibration constant was then evaluated, yielding $C_{532} = 9.797\times10^9$ Vm^{3}sr. For the 355 nm wavelength, the optical depth at the reference height is 0.089, yielding a calibration constant $C_{355} = 1.450\times10^9$ Vm^{3}sr. Using these, the calculated backscatter coefficient for the aerosols for 532 nm parallel ranged from 3.56×10^{-6} m^{-1}sr^{-1} to 5.01×10^{-6} m^{-1}sr^{-1}. For 355 nm, the backscatter coefficient varied from 1.76×10^{-5} m^{-1}sr^{-1} to 2.02×10^{-5} m^{-1}sr^{-1}. The retrieved backscatter coefficients for 355 nm are higher compared to that for 532 nm. This is due to the wavelength dependence of the backscatter coefficient, which is influenced by particle size distribution.

4. CONCLUSION

Multi-angle lidar sensing of traffic aerosols was presented showing a two-dimensional spatial and temporal variation of traffic aerosols. Although the scanning time of the lidar system presented here was very slow and limited only to 8 scanning zenith angles some interesting features of traffic aerosol distribution in two-dimension in Manila area can be observed like the consistent aerosol mass near the intersection of two major thoroughfares. Difficulty in finding a consistent value of the lidar system calibration constant was encountered in the retrieval of the backscatter coefficients. The horizontal inhomogeneity of the atmosphere is a great factor to be considered. Perhaps lidar scanning during clear atmospheric condition could provide a good approximation. However, it is quite difficult to obtain such measurement in the current location of the lidar system.

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