Estimating Aerosol Optical Properties in Urban Environments using LIDAR and Shadowband Radiometer

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Introduction

We are interested in developing algorithms for graphical analyses of lidar observations and calculation of aerosol extinction coefficient. Lidar observations are used in combination with aerosol optical depth estimates derived from shadowband radiometer to examine aerosol properties.

Kovalev and Eichinger's Elastic Lidar states: "Despite the wide variety of the lidar systems developed for periodical and routine atmospheric measurements, no widely accepted method of lidar data inversion or analysis has been developed or adopted… no standard analysis method exists that can be used even for the simplest lidar measurements."

Lidar is a vertically pointing optical remote sensing device that uses pulses of light at 355, 532, and 1064 nanometer wavelengths (UV, visible, and near-IR, respectively) to derive vertical profiles of aerosols by measuring backscattered radiation.

The shadowband radiometer measures total and diffuse horizontal solar irradiance at six wavelengths, ranging through the visible spectrum to the near-infrared.

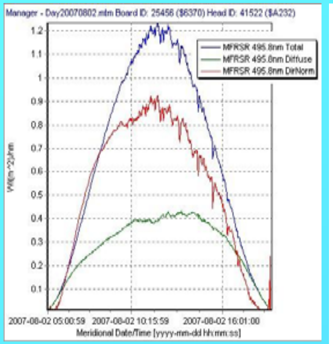

Fig. 1. Calibrated solar irradiance plot on Aug 02, 2007 at 495.8 nm in Princeton site. The higher total solar irradiance curve is expected when there are no clouds in the atmosphere. Figure from YESDAS Network.

An ideal date for development and testing of algorithms is August 02, 2007.

- Clear sky - cirrus and cumulus cloud free – lack of interference in calibrated irradiance plot from radiometer (Fig. 1) and natural log of range corrected power plots from lidar (Fig. 3 and Fig. 4).
- Elevated aerosol plume at 4.5 km throughout the day, shown in both near-IR and visible lidar plots (Fig. 3 and Fig. 4).
- Sounding data on Aug 02, 2007 available to provide specific pressure and temperature data at varying heights. Used to calculate molecular backscatter and molecular extinction.
- Darkfiles from Jul 26, 2007 used to remove irrelevant equipment noise.

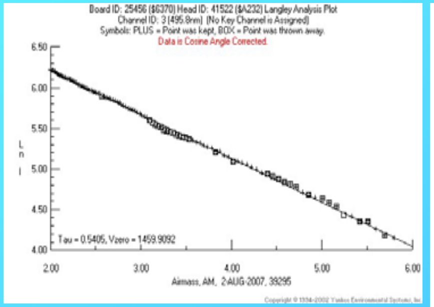

Fig. 2. Natural log of direct solar irradiance versus air mass Langley plot on Aug 02, 2007 at 495.8 nm in Princeton site. τ = .54 and I_0 = 1460 W/m². Figure from YESDAS Network.

- $I/I_0 = e^{-m\tau}$, derived from Beer's law, relates solar irradiance to optical depth.
- The slope of the line, calculated as **–τ**, represents the total optical depth. Vzero can be used to estimate I_0, the irradiance at the top of the aerosol-free atmosphere where the extrapolated air mass, m, equals zero.
- Total optical depth decreases with increasing wavelength.

Methodology

The elastic lidar equation has four variables, assuming no molecular absorption: Molecular backscatter, molecular extinction, aerosol backscatter, and aerosol extinction.

- Molecular backscatter is computed using atmospheric sounding data from weather balloons.
- The 3/8 π relationship between molecular backscatter and extinction yields molecular extinction.
- Assume constant relationship between aerosol backscatter and extinction: Lidar ratio = 35.

$$P(r) = E_0 \frac{cA}{2r^2}\left[\frac{3}{8\pi}\beta_m(r) + \frac{\wp(\pi,r)}{4\pi}\beta_a(r)\right] e^{-2\int_0^r \beta_e(r')}$$

The radiometer algorithm uses inputted current latitude, date, and time of day with measured irradiance to compute direct normal irradiance, solar elevation, and air mass, yielding a time series plot of aerosol optical depth (AOD). AOD is a quantitative measure of light extinguished by aerosols due to scattering from the top of the aerosol-free, zero air mass atmosphere to the detection point. It is isolated from total optical depth (Fig. 2) by subtracting out Rayleigh optical depth.

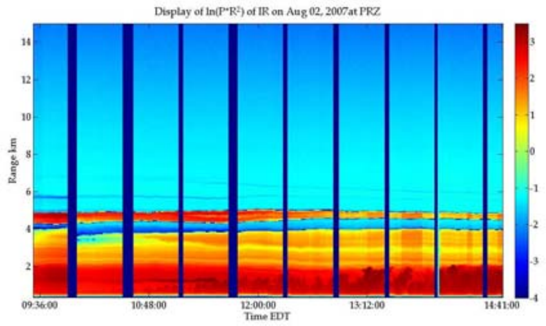

Fig. 3. Backscattered graphical representation of natural log range corrected power from Princeton (PRZ) lidar on Aug 02, 2007 at 1064 nm wavelength from 9:30AM to 2:30PM. Figure created using Matlab.

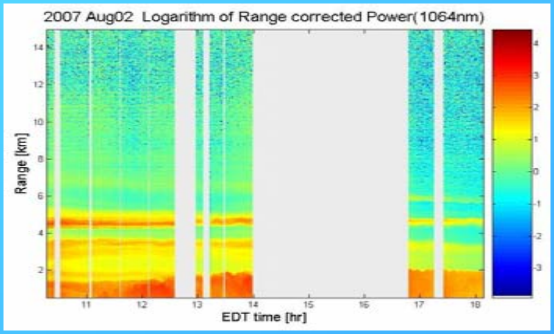

Fig. 4. Backscattered graphical representation of natural log range corrected power from CCNY lidar on Aug 02, 2007 at 532 nm wavelength from 10AM to 6PM. Figure from CCNY Lidar Image Library.

Results

The Fernald and Kovalev algorithms for solving the lidar equation and estimating aerosol extinction profiles from lidar observations was implemented in Matlab. The estimated extinction profile for 10:37AM yields the following results:

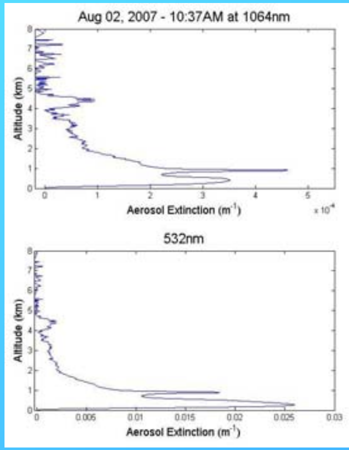

Fig. 5. Aerosol extinction versus altitude plot at 1064 nm and 532 nm from Princeton lidar at 10:37AM on Aug 02, 2007. Figure created using Matlab.

- Strong aerosol layer represented by dark orange/red color in Fig. 3 and Fig. 4 correlates to sharp extinction peaks within first kilometer in atmosphere, shown in Fig. 5.
- Distinct aerosol layer at 4.5 km represented by yellow/orange color correlates to extinction spike, also at 4.5 km in near-IR and visible wavelengths.
- Minimal noise above 5 km in graphical plots accurately reflected in extinction plots, particularly at visible wavelength.
- Calculated Radiometer AOD = .73 at 495.8 nm at 10:37AM, shown in Fig. 6. Langley analysis shows total optical depth = .54 in Fig. 2.

Conclusion

Algorithms for estimating aerosol extinction from lidar observations have been successfully implemented, along with procedures to estimate AOD from radiometer observations.

Stability problems in solving the lidar equation have been overcome.

AOD calculations compare favorably with Langley plots. Similarly, aerosol extinction plots compare favorably with their graphical counterparts.

Future research will address overestimates of aerosol extinction in visible wavelengths in the atmospheric boundary layer.

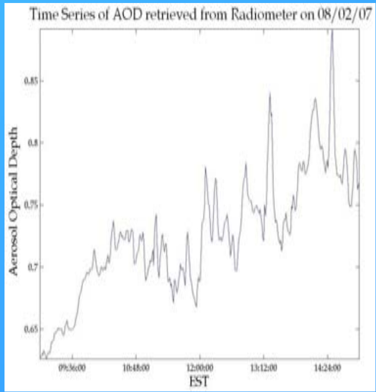

Fig. 6. Time series aerosol optical depth plot at 495.8 nm in Princeton on Aug 02, 2007 from Radiometer. Figure created using Matlab.

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