Lidar Studies on Atmospheric Aerosols at a Semi-Urban Station Cheeryal (17.51° N, 78.62° E) near Hyderabad, India with Range Dependant Lidar Ratio

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ABSTRACT

Deriving the optical properties of aerosols and clouds from the experimentally obtained lidar data is one of the most interesting and challenging tasks. Various lidar methods have been developed so far, to obtain the quantitative profiles of extinction /backscattering coefficient of aerosols and clouds from the pulsed backscattering lidar measurements. In order to obtain an analytical solution to the lidar equation, it has been a common practice to assume that these parameters are related in the form of the extinction-to-backscatter ratio or Lidar Ratio (LR). The LR depends on the size distribution, shape and chemical composition of the aerosols. These properties of aerosols are highly variable and mainly depend on their sources and the local meteorological parameters. In order to enhance the accuracy of the derived extinction/backscatter profile, it is necessary to obtain the lidar ratio also along with the backscattered signal, called as *Range Dependant Lidar Ratio (RDLR)*. In this study, we derive the RDLR while carrying out investigations on aerosol characteristics in the Cheeryal Village (17.51° N, 78.62° E), which is located at a distance of about 20 Km in the suburbs of Hyderabad, India. For this study the Multi-wavelength laser radar which is developed in-house and made operational at this location is used. The Nd:YAG laser (M/S Bright Solutions, Italy) based multi-wavelength lidar operates at 532 nm and 1064 nm with a pulse energy of 50uJ at both the wavelengths. The two wavelengths are generated coaxially with a pulse width of 10ns and the laser operates up to a PRF of 4 KHz. The receiver system consists of a 360 mm Newtonian optical telescope, 10 nm of interference filters and the Licel Gmbh, Germany make 250 MHz Photon Counting recorder.

Keywords:

Lidar, Remote sensing, Anthropogenic aerosols, Semi-urban region, transport of aerosols, Range Dependant Lidar Ratio

1. INTRODUCTION

Deriving the optical properties of aerosols and clouds from the experimentally obtained lidar data is one of the most interesting and challenging tasks for atmospheric researchers. Various lidar methods have been developed so far to derive the quantitative profiles of extinction and or backscattering coefficient of aerosols and clouds from the pulsed backscattering lidar measurements, such as *the slope method, the boundary point solution and the optical depth solution.* The slope method is applicable to homogeneous atmosphere only [1]. In this method, the mean value of the extinction coefficient over the range of lidar observation is obtained. The drawback of this method is that it determines the mean extinction coefficient only. The boundary point solution gives the range resolved parameters. This method can be used both for the homogeneous and non-homogeneous atmosphere. It requires the knowledge of extinction coefficient value at some reference altitude within the lidar measurement range. The popular

Klett's *(1981)* and Fernald's *(1984)* methods fall under this group. The optical depth solution is similar to boundary point method, in which the transmittance or the total optical depth over the lidar measurement range is used as boundary value instead of extinction coefficient as in the case of boundary point method.

2. Lidar System description

A Multi-wavelength laser radar is developed in-house and made operational. The Nd:YAG laser (M/S Bright Solutions, Italy) based multi-wavelength lidar operates at 532 nm and 1064 nm with a pulse energy of 50uJ at both the wavelengths. The two wavelengths are generated coaxially with a pulse width of 10ns and the laser operates up to a PRF of 4 KHz. The receiver system consists of a 360 mm Newtonian optical telescope, 10 nm of interference filters and the Licel Gmbh, Germany make 250 MHz Photon Counting recorder. A number of pre-processing techniques are used before performing the inversion of the detected signal namely, Range-correction, Time-averaging, Photon counting channel dead-time correction, Overlap correction, Rayleigh-fitting and Gluing of both channels. Lidar inversion techniques, with range dependant lidar ratio are used for extracting the meaningful information. Lidar observations are conducted on relatively clear days. The aerosol extinction profiles are derived and compared with the model values corresponding to the Hyderabad urban region. It is observed that there is a heavy aerosol loading periodically at this location in relation to the sources of anthropogenic aerosols at Hyderabad urban area. The role of prevailing meteorological conditions, measured in real time, on the transport of the urban aerosol to this region is studied.

3. Estimation of Range Dependant Lidar Ratio

A procedure for estimating the RDLR from the measured lidar data is elucidated here. To use this method, one should have the data bank of the station. For a mono-static single-wavelength pulsed lidar, the assumed basic governing form is the single-scattering lidar equation. A standard form of the fundamental Lidar equation describing the backscattered power incident upon the receiver as a function of range R is given by [2].

$$\mathrm{P(r)} = \mathrm{P_o}\,\frac{\mathrm{C\tau}}{2}\,\frac{\mathrm{A_r}}{\mathrm{r^2}}\,\beta(\mathrm{r})\exp\left[-2\int_0^{\mathrm{r}}\alpha(\mathrm{r'})\mathrm{dr'}\right] \text{ ------ (1)}$$

Where
P_o = Laser transmitted pulse power
C = Speed of the light
τ = pulse width
A_r = receiver collecting area, m^2
$\beta(r)$ = is the integrated volume backscatter function (expressed in $m^{-1}\,sr^{-1}$) and
$\alpha(r)$= is the integrated volume extinction function (expressed in m^{-1})
The volume backscatter function is given by

$$\beta_t(r) = n_a(r)\sigma_a + n_g(r)\sigma_m \text{ ----- (2)}$$

Where n_a *and* n_g are number densities of aerosols and gas molecules respectively, and σ_a and σ_m are the Mie and Rayleigh backscattering cross-sections respectively.

Similarly,

$$\beta_t t(r) = n_a(r)\rho_a + n_g(r)\rho_m \text{ ----- (3)}$$

Where ρ_a and ρ_m are the Mie and Rayleigh extinction cross-sections respectively.

The relationship between $\beta_a(r)$ *and* $\alpha_a(r)$ of aerosol can be expressed in a slightly different form as,

$$\alpha_a^k(r) = M\beta_a(r) \text{ -------(4)}$$

Where, *M* is a range dependent parameter determined by the size and nature of aerosols, probing laser wavelength etc. and the exponent k is generally assumed to be a range independent constant. When the value of k and the range dependent parameter *M* is known (4) can be written in the form of LR as,

$$\frac{\alpha_a^k(r)}{\beta_a(r)} = LR \text{ -------(5)}$$

The kletts solution for the equation (1) is

$$\alpha_t(r) = \frac{\exp[(S-Sm)/k]}{\left\{\alpha_m^{-1} + \frac{2}{k}\int_r^{rm}\exp[(S-Sm)/k]dr'\right\}} \text{-----------(6)}$$

where Sm = S(rm) and $\alpha_m = \alpha\ (rm)$.

A modified Klett's solution incorporating range dependant M value can be expressed as [3],

$$\alpha_t(r) = \frac{\left[\frac{LR(r)}{LRm}\right]^{\frac{1}{k}} \exp[(S-Sm)/k]}{\left\{\alpha_m^{-1} + \frac{2}{k}\int_r^{rm} \left[\frac{LR(r)}{LRm}\right]^{\frac{1}{k}} \exp[(S-Sm)/k]dr'\right\}} \text{-------(7)}$$

Where LRm=LR(rm)

4. Results

To start with, take the seasons Lidar data of the station. Estimate the extinction coefficient from this data using the equation (6) and choosing constant k=1 and LR=20. Now from the measured lidar data estimate the extinction coefficient using equation (7). Choose the values of k within the practical range such that extinction coefficient calculated approximately coincides with that of the estimated extinction coefficient of the seasons data. Now fix the constant k and vary LR range bin wise such that deviation of the extinction coefficients is approximately zero. This gives the Range Dependent Lidar Ratio. The procedure is explained below for the data obtained at the Cheeryal Village (17.51° N, 78.62° E). Fig. 1 shows the seasons extinction coefficient and the extinction coefficient of the current data (Lidar data obtained on 15-Sep-2015)

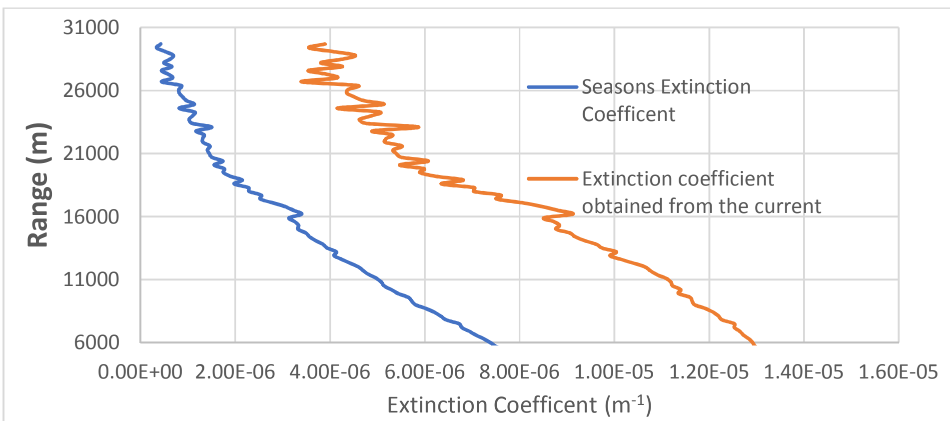

Fig.1 Comparison of the seasons extinction coefficient with extinction coefficient of the current data

Extinction coefficients calculated for different values of k and the fixed value of LR (=20) are shown in fig.2.

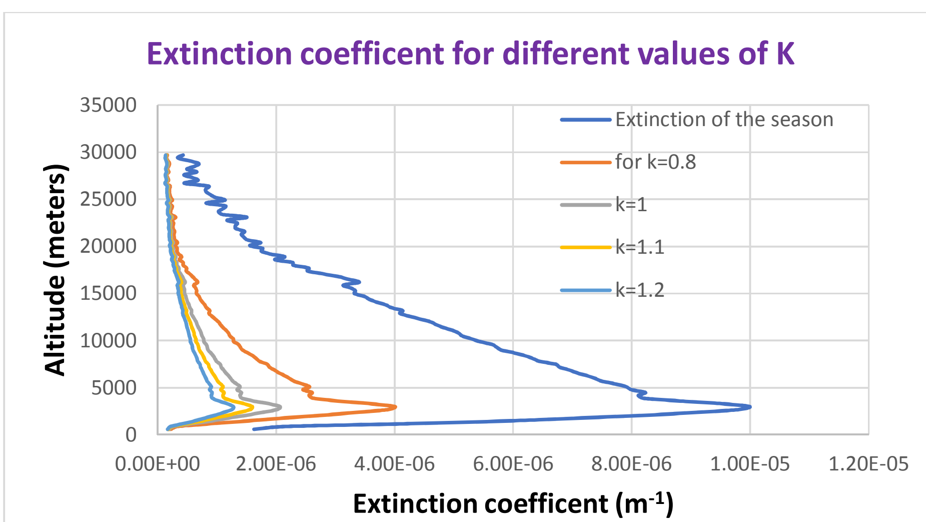

Fig.2 Extinction coefficients calculated for different values of k LR =20

The range bin wise estimated Lidar is shown in Fig 3. It can be seen that the LR is varying from 10 to 30. The RDLR can be represented in by a second order polynomial equation RDLR = = = $-5E\text{-}08r^2 + 0.0004r + 54.06$. Now the RDLR can be used to estimate the extinction coefficients. Fig. 4 shows the comparison of extinction coefficients derived from fixed LR and RDLR.

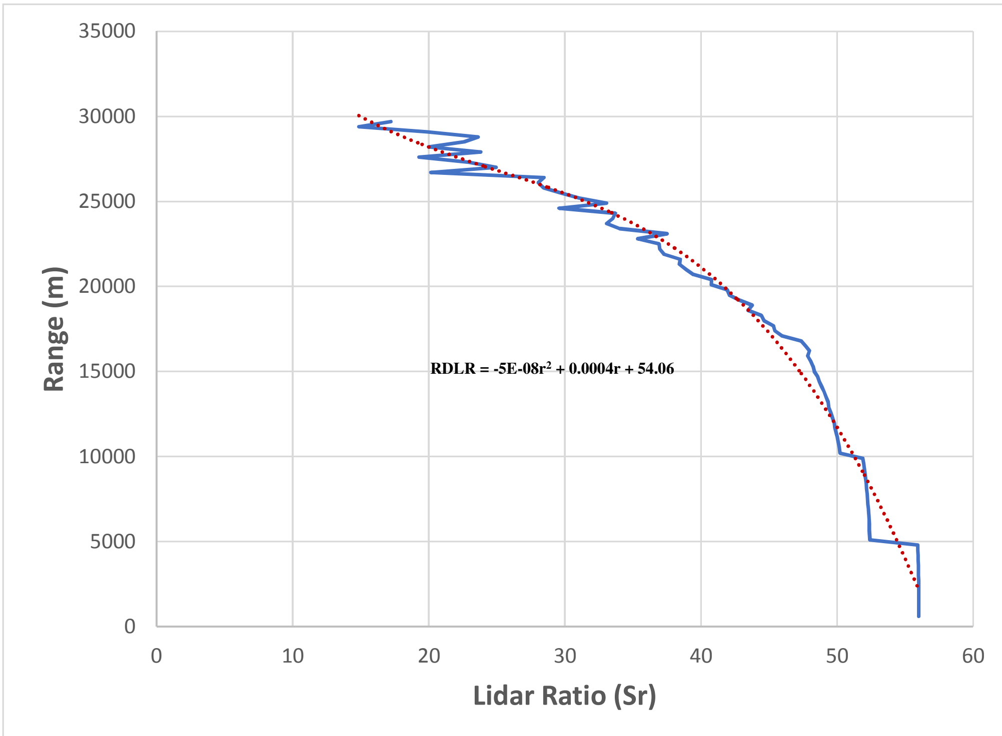

Fig. 3 Range bin wise estimated Lidar ratio

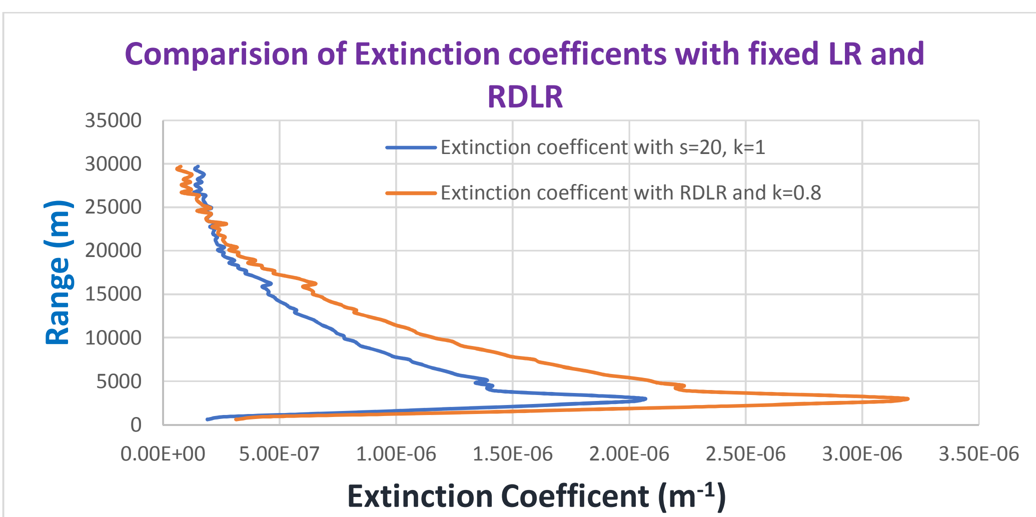

Fig.4 Comparison of the estimated extinction coefficients with fixed LR and RDLR

5. Conclusion

A new method of estimating the range dependent Lidar ration is presented. The estimated RDLR is with in the practical range of the LR. This method estimates the RDLR from the measured Lidar data itself. The method is applied to the station, Cheeryal Village (17.51° N, 78.62° E), near Hyderabad, where an in house developed multi wavelength lidar is deployed.

6. References

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