

Some Aspects of Rayleigh and Mie Scattering in the Atmosphere Over Pune

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Abstract

Computations of aerosol mixing ratio $[(N_a + N_m)/N_m]$ have been made using the aerosol number density (N_a) estimated from the laser radar (lidar) observations carried out at the IITM, Pune and air molecular number density (N_m) derived from the radiometer sonde data of temperature and pressure obtained from the IMD, Pune for the days of lidar observations. The results of the study of the seasonal variation in the vertical distribution (up to 5 km AGL) of aerosol mixing ratio (AMR) obtained from the above observations collected for the two-year period, October 1986 - September 1988 are presented in this paper. The results indicate low AMR during the monsoon and high during the winter months. These variations noticed for the monsoon and winter seasons are considered to be mainly due to the differences in N_a . This is consistent with the seasonal variation in the average profiles of aerosols and air molecules, which suggested an increase of about 50% in the case of aerosols and about 2% in the case of air molecules during the winter season as compared to those observed during the monsoon season.

Key words : Atmospheric Optics, Scattering, Lidar.

Introduction

Earth's atmosphere contains both aerosols and molecules. Scattering properties of these constituents are governed by Mie theory in the case of aerosols and by Rayleigh theory in the case of molecules. When a laser beam passes through the atmosphere, it suffers from scattering and absorption due to aerosols and molecules, respectively. Attenuation of laser light by these phenomena, known as extinction, has great importance in making atmospheric studies using lidar. Also, knowledge of the relative contributions of aerosols and air molecules to the mixed character of tropospheric air is essential for better interpretation of lidar signatures of the lower atmosphere.

Rayleigh scattering is due to particles in the atmosphere, such as molecules or fine dust, that are much smaller ($< 0.1\lambda$) than the optical wavelength, λ of the laser. Scattering of this type varies as second power of the particle volume and inversely as fourth power of the wavelength with equal amount of fluxes into the forward and backward hemispheres and also the light scattered at 90° is completely polarised. Mie scattering is associated with larger particles ($> 0.1\lambda$), such as aerosols whose size is of the order of λ . Rayleigh and Mie processes are elastic scattering; the scattered light is the same wavelength as the incident laser beam. Thus the size of the scatterer mainly makes the difference between these two scattering processes and hence the scattering cross-section per particle be around $10^{-27} \text{ cm}^2/\text{ster}$ for molecules and it varies between 10^{-27} and 10^{-8} (depends upon size distribution) for aerosols. This parameter plays an important role in the retrieval of information on atmospheric aerosols and molecules from the lidar backscattered data. Although some experiments to study the atmospheric aerosols using lidar technique began at the end of 1985, regular measurements have been in progress at the IITM since October 1986. Vertical profiles of aerosol number density obtained during clear night sky conditions using the bistatic, CW Argon ion lidar at the IITM and those concurrently obtained radiometersonde observations of IMD were used to study the AMR. This paper presents the theory involved, experimental details and results of the study of seasonal variations in AMR over Pune.

Theory

In the lidar probing of the atmosphere, the scattered light intensity at any angle from a volume in the atmosphere is due to aerosols and air molecules. But the contribution of molecules is quite small and practically constant with time. However, the role of air molecules in absorption is significant in the atmosphere although their contribution to scattering is negligible when compared to that of aerosols (Twomey 1977). Hence, at any time the significant scattering is due to aerosols. This may be true in the lower atmosphere in view of the abundance of a variety of aerosol particles. Though their contribution is small, information on N_m is essential for computing the important parameter, atmospheric transmittance, T in the lidar equation. The bistatic lidar equation is given by

$$P_R = \frac{P_T V T A \eta [N \sigma(\theta)]}{(R_1 R_2)^2 dW_1} \quad (1)$$

where P_T and P_R are power transmitted and received, respectively, V is common scattering volume, A is receiver collecting area, η is system constant, R_1 and R_2 are distances from transmitter and receiver to the centre of V , dW_1 is solid angle of the transmitter, $\sigma(\theta)$ is scattering cross-section at scattering angle θ and N is number density.

Since the atmosphere contains both aerosols and molecules, the term $N\sigma(\theta)$ takes the form

$$N\sigma(\theta) = N_a \sigma_a(\theta) + N_m \sigma_m(\theta) \quad (2)$$

where N_a and N_m are concentrations, and $\sigma_a(\theta)$ and $\sigma_m(\theta)$ are scattering cross-sections of aerosols and molecules, respectively.

For any scattering angle, θ , the optical depth, τ is given by

$$\tau = H_a \alpha_a N_{a0} [1 - \exp(-H_v/H_a)] + H_m \alpha_m N_{m0} [1 - \exp(-H_v/H_m)] \quad (3)$$

where $\alpha_a, \alpha_m; H_a, H_m; N_{a0}$ and N_{m0} are the extinction cross-sections, scale heights and ground-level concentrations of aerosols and molecules, respectively. H_v is the altitude of scattering volume. The average value of H_a varies between 1 and 1.4 km (Penndorf 1951) and H_m and N_{m0} can be obtained from meteorological data over the experimental region. α_m can be evaluated using Rayleigh scattering theory.

The atmospheric transmittance, T can be computed by knowing the value of τ (from equation 3) using the equation

$$T = \exp[-\tau(\cos\theta_T + \cos\theta_R)] \quad (4)$$

where θ_T and θ_R are, respectively, the transmitter and receiver elevation angles.

Once the above parameters are evaluated, the aerosol number density, N can be computed using Equation (1) and these values at different scattering angles give vertical profiles in the case of bistatic lidar configuration.

Experiment

The bistatic lidar system at the ITM, Pune has been described by Devara and Ernest Raj (1987). It consists of an Argon ion laser (CM power, 4 W at multi-line) as an emitter and a 250mm Newtonian telescope equipped with light detection and data acquisition systems as the receiver. By setting the laser beam at 90°, the scattered signal from the atmosphere at different elevation angles of the receiver is collected so as to obtain the scattered signal strength profile, which is inverted later into the aerosol concentration profile using the bistatic lidar equation, as explained in the earlier section. Lidar aerosol measurements are accompanied by the radiometersonde ascents launched by the IMD at a site, situated about 5 km away from lidar site and within an hour before or after the optical sounding to provide temperature and pressure data for the computation of N_m .

Observations and Analysis

Since the lidar measurements reported here were made in the early night hours (1900 hrs), the data from radiometersonde ascents launched in the late evening hours were considered in the computations. As per the lidar observational program at the ITM described by Devara and Ernest Raj (1989), we operate the lidar to get a minimum two and maximum seven aerosol concentration profiles in each month depending upon the atmospheric conditions. Also, lidar observations have been carried out every fortnight (alternate Thursdays) in synchronisation with the radiometersonde observations. Utilising the pressure and temperature data collected from radiometersonde ascents, the air molecular number density profiles have been constructed using the formula

$$N_m(Z_i) = \frac{R_a N_A P(Z_i)}{R^* M_0 T(Z_i)} \quad (5)$$

where R_a is apparent molecular weight of dry air (28.966 gm mol⁻¹), N_A is Avogadro's constant (6.02217×10^{23} mol⁻¹), $P(Z_i)$ is atmospheric pressure (dynes cm⁻²) at height,

(Z_i), R^* is gas constant for 1 gm mol of ideal gas ($8.31436 \times 10^7 \text{ erg mol}^{-1} \text{ K}^{-1}$), M_o is molecular weight of Nitrogen ($28.01 \text{ gm mol}^{-1}$) and $T(Z_i)$ is the absolute temperature of the atmosphere ($^\circ \text{K}$) at height (Z_i).

The AMR profiles are obtained from the aerosol and air molecular number density profiles as

$$AMR = \frac{N_a + N_m}{N_m} = \frac{N_a}{N_m} + 1 \quad (6)$$

Monthly average concentration profiles of aerosols and air molecules have been obtained for the two-year period, October 1986 - September 1988; These monthly mean profiles have been grouped into different seasons according to the meteorological convention. The variations in the parameters under study during the southwest (SW) monsoon (June-Sept) and winter (Nov-Feb) are reported in this paper.

Results and discussion

The lidar-derived aerosol number density profile and radiometersonde-derived air molecular number density profile obtained on 19 Feb.1987 are shown in Fig.1. The vertical distribution of the ratio N_a/N_m (in terms of $AMR - 1$) is also shown in the Figure.

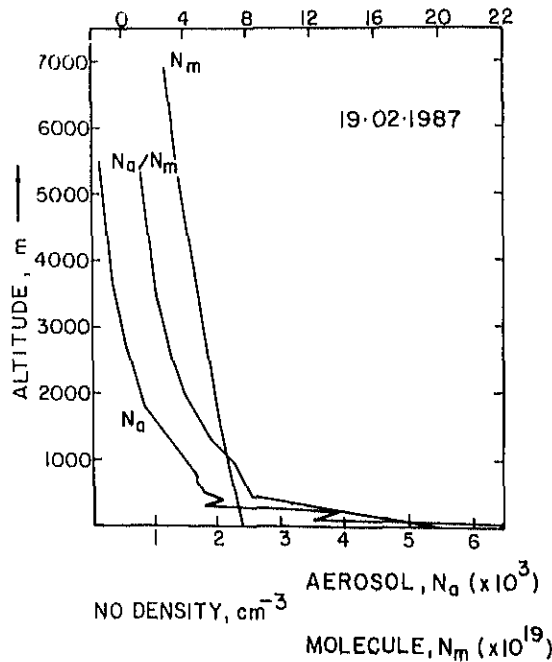


Figure 1. Density profiles with altitude.

The range of variation in aerosol number density is higher than that in molecular number

density. Also, the aerosol profile shows sharp decrease in density up to 200 m and thereafter

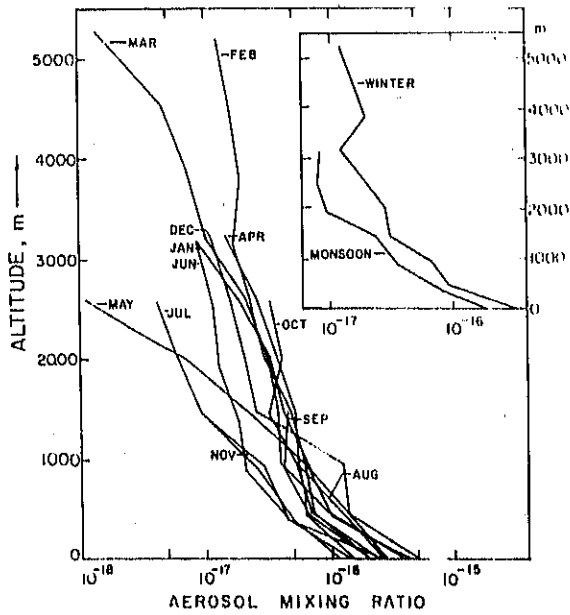


Figure 2. Seasonal AMR profiles with altitude.

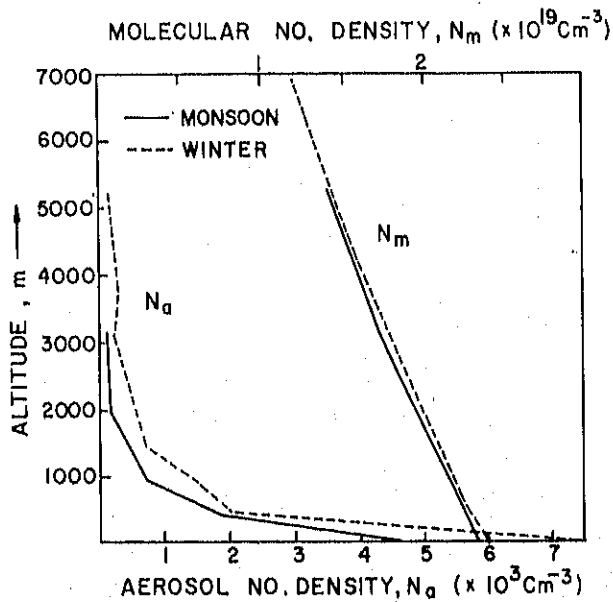


Figure 3. Average seasonal density profiles with altitude.

shows a steady decrease with increase in altitude. Whereas, the N_m profile shows a small negative gradient throughout the height region. Steep negative gradient in the aerosol number density in the lowest few hundred meters is a common feature observed in every profile due to terrain characteristics at the lidar site (Devara & Ernest Raj 1991). Moreover, the vertical distributions in aerosol and air molecule concentrations indicate that the contribution of aerosols to the profile of N_a/N_m is more at lower levels and less at upper levels and vice versa in the case of air molecules. In other words, aerosols contribute more to the mixed character of the scattered signal in the lower atmosphere.

Monthly mean profiles of aerosol mixing ratio ($AMR - 1$), computed from the data collected during Oct.86 - Sept.88 are depicted in Fig. 2. Also, the profiles averaged over the two-year period for the monsoon and winter seasons are also shown as an inset in the Figure. Besides the significant month-to-month variations in the profiles, the aerosol mixing ratios were found to be higher in winter than in monsoon season throughout the height region. These variations are considered to be mainly due to seasonal variations in aerosol number density observed at this location (Ernest Raj & Devara, 1989, 1990). In order to verify this fact, the average profiles of N_a and N_m for the monsoon (1987 and 1988) and winter (1986-87, 87-88) seasons are studied separately and they are shown plotted in Fig. 3. It is clear that the number density is higher in winter than in monsoon for both aerosols and air molecules. But this increase in aerosol concentration is about 50% and increase in molecular concentration is 2% which suggests the significant contribution of seasonal variation of aerosols to that of AMR at lower levels. However, observations from slow speed, low level radiometersonde ascents would be quite useful for studying the fine structure of the AMR , since the lidar aerosol observations at height intervals of 20 m are possible with the present experimental set-up. Closer observations in time and location of lidar and radiometersonde would further improve the quality of information.

Conclusions

It may be concluded from the above study that

- (i) Aerosol mixing ratios are higher during winter than during SW monsoon,
- (ii) Contribution of aerosols is dominant in the lower levels and air molecules contribute significantly to the air mass in the upper layers of the troposphere, and
- (iii) Seasonal variations in the average profiles of aerosols and air molecules show increase of about 50% in the case of aerosols and about 2% in the case of air molecules during the winter season as compared to those observed during the SW monsoon season.

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