Measurement of atmospheric aerosols during monsoon and winter seasons at Roorkee, India

Deepti Saxena¹, R Yadav¹, Adarsh Kumar²,⁵,⁷ & Jagdish Rai³

¹Faculty of Science, Meerut College, Meerut 250 002, UP
²Department of Physics, Apeejay College of Engineering, Sohna, Gurgaon 122 103, Haryana
³Department of Physics, Indian Institute of Technology, Roorkee 247 667, Uttaranchal

$E$-mail: adarsh_phy@yahoo.co.in

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Measurement of aerosol concentration has been carried out in view of some meteorological parameters like wind speed, temperature, relative humidity and rainfall during south-east (SE) monsoon (June-September 2006) and winter (November 2006-February 2007) at Roorkee, India. The measurements were done with the help of laser beam scatterometer for wide range of aerosols (0.05-3.0 $\mu$m). The present study reveals the fact that the number density of aerosols is very much affected by meteorological parameters. The aerosol concentration was minimum in August, September and November 2006 and remained around maximum during June-July 2006 and January-February 2007. During monsoon period, the rain plays important role in characterizing aerosol density. The aerosol concentration and size were found to be decreased during September 2006 although relative humidity was found to be very high due to scavenging of aerosol particles.

Keywords: Aerosol concentration, Relative humidity, Rainfall

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1 Introduction

Atmospheric aerosols are produced by various processes such as biomass and fossil fuel burning, agricultural activities, desertification, industrial and vehicular pollution, etc. These atmospheric aerosols are important to characterize a number of phenomena occurring in the lower troposphere. A study on the variation of atmospheric aerosol concentration in relation to meteorological parameters, viz. air temperature, relative humidity, wind speed, rainfall, etc. helps in understanding the role of meteorology in aerosol size distribution and vice versa. The determination of size distribution of aerosols at any location is very important not only to characterize the aerosol system over the location but also to study cloud process¹,², radiative properties³ and effect of warming due to greenhouse gases⁴. Park et al.⁵ carried out such studies at high latitudes but studies at low latitudes are rare. Sharma et al.⁶ measured the aerosol number concentration in summer season (April–July 1999) during morning, noon and evening, and the daily variation of aerosol number concentration was related to selected meteorological parameters like relative humidity, temperature, rainfall and wind speed. They found that aerosol number concentration in the upper size range (1–2 and 2–5 $\mu$m) is maximum in June and minimum in July whereas the aerosol number concentration in small size ranges (0.3–0.5 and 0.5–1.0 $\mu$m) decreases monotonically till the end of July.

The atmospheric aerosols are generally hygroscopic, therefore, relative humidity plays important role in altering the radiative property of aerosols⁷. Parmeswaran et al.⁸ studied the variation of aerosol optical depth for the period June 1989 – December 1990 in relation to various meteorological factors like wind speed, rainfall, relative humidity. Shaw⁹ studied the size distribution of atmospheric aerosols in different meteorological conditions. Chakraborty et al.¹⁰ made investigations over the impact of absorbing aerosols on the simulation of climate in the Indian Region using a atmospheric General Circulation Model (GCM). Krishna Moorthy et al.¹¹ studied aerosol characteristics and radiative impacts over the Arabian Sea during inter-monsoon season. Bhawar & Devara¹² worked extensively on
The present paper, the effect of meteorological parameters on aerosol number density of various sizes has been studied during disturbed (south-east monsoon 2006) and fair weather (winter 2006-07) conditions at Roorkee (29°52’N, 77° 53’E, 275 m above the sea level). Since Roorkee is not an industrial place, therefore, the man-made particles are produced only by vehicular traffic and household activities. The study on distribution of aerosols can be done by employing available techniques such as Lidar\textsuperscript{13} and Cascade Impactor\textsuperscript{14}. For the present study, the aerosol concentration has been measured using a laser scatterometer\textsuperscript{15}.

2 Methodology

The technique for measurement of suspended particulate matter concentration uses the laser beam scatterometer. This instrument measures the intensity of the scattered laser beam by particles at angles of 45° and 135°. By using the intensities of the scattered laser beams, the concentration of particulates were computed.

When the particles are illuminated by a beam of laser light (6328 Å), the intensity of scattered light varies with size, shape, refractive index and concentration of particles. The particulate analyzer consists of a hollow cylinder (length 53 cm and inner diameter 12 cm) which is fitted with an air blower. Two phototransistors are fixed at angles 45° and 135° from the direction of incident beam. A 5 mW He-Ne laser having wavelength 6328Å is used for incident radiation. The scattered intensity of laser beam is measured at angles 45° and 135° on a two strip chart recorder. This relative intensity is used to estimate the concentration of pollutants in air. The details of the experimental set up are available\textsuperscript{15}. Mikasa\textsuperscript{16} suggested that a number of instruments based on Mie scattering of light have been manufactured for particle concentration determination. In the present measurement, only the Mie theory of scattering has been considered. However, Rayleigh scattering by the atmospheric molecules also takes place at the same time. For the present study, the effect of molecular scattering has been neglected and the entire scattered intensity is attributed to the Mie scattering. The resultant scattered light intensity \( I(\theta) \) in a given direction \( \theta \) due to the scattering per unit volume is given by

\[
I(\theta) = \frac{1}{2} \int_{x_i}^{x_f} I(x, \theta, m)n(x)dx \tag{1}
\]

where, \( I(x,0,m) \), is the single particle intensity of scattered light at an angle due to particle of size \( x \) and refractive index \( m \). The number concentration of particles \( n(x) \) dx in the size range \( x \) and \( (x+dx) \) is given by

\[
n(x) \; dx = N_o C \exp\left[-(x-M)^2 / 2 \sigma^2 \right] \; dx \tag{2}
\]

where, \( N_o \), is total no. of particles; \( \sigma \), standard deviation; \( C = 1 / (\sigma \sqrt{2 \pi}) \), wavelength of incident radiation; \( r \), radius of scatterer; and \( M \), modal size parameter \((2\pi r / \lambda)\).

The intensity distribution function has been computed by other researchers for different refractive indices and size parameters\textsuperscript{8}. For the present work, the values of intensity distribution function in the modal size parameter range 0.1-30 for the refractive index has been taken as 1.33. Pangonis & Heller\textsuperscript{17} has taken the refractive indices in the range 1.33 - 1.5 for the size parameter range of 0.1-30. The same value of 1.33 was also considered by Herman & Goldberg\textsuperscript{18}. Patel\textsuperscript{19} has used normal Gaussian distribution for their measurements on atmospheric particles which may consist of condensed particles and particulates along with natural aerosols. Therefore, for the present study the normal Gaussian distribution has been used. The ratio of scattered intensities (theoretical values) in the directions \( \theta_1 \) and \( \theta_2 \) can be found using Eq. (1). The experimental ratio can be found by the measured scattered intensities at angles 45° and 135°. The experimentally obtained ratio is matched with the theoretical values and the modal size parameter \( M \) is selected for which the experimental ratio tallies best with the theoretical one. For the computation of size distribution by Mie theory, a sharp peak distribution of aerosol size with standard deviation (\( \sigma = 0.69 \)) has been selected. Once the modal size parameter is known, the particle size can be known easily using Eq. (2).

3 Observations

As the site of observation, Roorkee, is not industrial, therefore, the man-made particles are produced only by vehicular traffic and household activities. Therefore, the observations have been taken during 10 am - 5 pm in order to measure the aerosol concentration due to domestic human
activities and vehicular traffic. The observations have been taken daily between 10 am to 5 pm for monsoon and winter seasons at a height of 12 m from ground at Physics Department, Indian Institute of Technology, Roorkee. Aerosol concentration is measured by exposing the particles to laser light and measuring the scattering intensities at forward (45°) and backward (135°) positions with the help of phototransistors. The scattered intensity of light varies with the particle size and their concentration. The size parameter of particles can be determined by comparing the ratio of scattered intensities with the theoretical values of scattered intensities of visible light. Knowing the size parameter, the size and concentration of aerosol particles for the size range 0.05-3.0 µm can be obtained easily. The meteorological parameters such as air temperature, wind speed, relative humidity and rain fall have been measured by well-known meteorological instruments. Further, the daily mean value has been considered for presenting the results.

4 Results and discussion

The observations on meteorological parameters like temperature, wind speed, relative humidity and rainfall along with aerosol concentration have been shown in Figs (1 and 4) for the monsoon and winter seasons, respectively. The variation of aerosol concentration with wind speed (WS), average temperature (AT), relative humidity (RH) and rainfall (RF) are shown in Figs (2 and 5). The nature of mode radius with these meteorological parameters has been shown in Figs (3 and 6), respectively for both seasons. Observation of these data show that the aerosol concentration decreases during monsoon season while RH was minimum in June and was almost constant during July - September 2006 but having highest values.

In the month of June and July, average aerosol concentration was maximum while RH was minimum in these months (Fig. 1). Also, aerosol concentration varies in phase with temperature and wind speed (Fig. 2). Sharma et al.⁶ and Pahwa et al.¹⁴ suggested that size distribution of atmospheric aerosols varies significantly with change in temperature and RH. Parameswaran et al.⁸ found that RH does not affect significantly the aerosol concentration and size distribution up to a limit of 95 %. Here, at Roorkee in the month of August and September 2006, average RH was almost close to this limit. Devara & Raj¹³ have observed that higher relative humidity and lower temperature during monsoon period at Pune (India) caused the growth of cloud droplets which resulted higher rainfall. The same physical process appears to have happened in 2006 during the SE monsoon at Roorkee. The decrease in aerosol concentration varies in phase with the increasing activity of monsoon. This is attributed to RH, which is a powerful factor to lower aerosol concentration involving rain out process.

The mode radius of aerosols decreases continuously during monsoon season. The wind does not play significant role in governing the mode radius while it varies in phase with average temperature and out of phase with RH. Parameswaran & Vijaykumar²⁰ have found that the aerosol size distribution remains unaffected by relative humidity up to a limit of 95%. After this value, the mode radius increases with RH. However, the finding of this paper is contrary to the work of Parameswaran & Vijaykumar²⁰. During monsoon period, the aerosols are removed from the atmosphere by scavenging which explains our observations that mode radius is inversely correlated with relative humidity. For other seasons, it is not true.

The winter season (November 2006 – February 2007) at Roorkee was quite different from SE monsoon. The rain did not occur significantly during this period. The wind also did not play any effective role during first half (November – December 2006) but varies in phase with the concentration during second half (January – February 2007) [Figs (4 and 5)]. The high humidity and low temperature was observed during this season (Fig. 4). The aerosol concentration increased with increase in RH and decrease in temperature. The same is true for mode radius also.

The wind speed plays an important role in governing the mode radius as more number of particles become airborne and hence take part in condensation due to low temperature and high RH. The average value of RH was found to be above 90% during the second half of winter and about 80% during first half. The average temperature touched a minimum of 10ºC during January 2007. The increased mode radius and aerosol concentration is attributed to the growth of particles due to high RH and low temperature for the whole season.
Fig. 1 — Variation of: (a) aerosol concentration; (b) wind speed; (c) average temperature; (d) relative humidity; and (e) rainfall with days during monsoon season (1 June – 30 September 2006)
Fig. 2 — Variation of aerosol concentration with: (a) wind speed; (b) average temperature; (c) relative humidity; and (d) rainfall during monsoon season (1 June – 30 September 2006)
Fig. 3 — Variation of mode radius with: (a) days; (b) wind speed; (c) average temperature; (d) relative humidity and (e) rainfall during monsoon season (1 June – 30 September 2006)
Fig. 4 — Variation of: (a) aerosol concentration; (b) wind speed; (c) average temperature; and (d) relative humidity with days during winter season (1 November 2006 - 28 February 2007)
Fig. 5 — Variation of aerosol concentration with: (a) wind speed; (b) average temperature; (c) relative humidity during winter season (1 November 2006 - 28 February 2007)
5 Conclusion

The results indicate a strong correlation between aerosol number density, their size distribution and meteorological parameters in different weather conditions. The meteorological parameters like wind speed, relative humidity and temperature play an important role in determining the aerosol behaviour at any location, but heavy rains can alter the number density and size distribution of atmospheric aerosols more effectively than RH and WS. The present study shows that the aerosol number concentration and their size distribution is highly affected by the
meteorological conditions. Although, the observations were taken at Roorkee only, however, the findings are expected to be valid for all subtropical regions.

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References