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AEROSOL OPTICAL CHARACTERISTICS DURING A SUMMER DUST STORM IN A METROPOLITAN CITY : A CASE STUDY

1. Particulates, also called aerosols, in the sub-micron range, find their way into the atmosphere from a variety of natural and human sources. Natural sources include volcanic eruptions, meteoric debris, sea salt and wind blown dust. Forest fires, biomass burning, industrial processes, fuel sources and various other man-made sources can introduce particulates and smoke into the atmosphere directly or through gas-to-particle conversion. Wind is an important natural source of aerosol in the atmosphere especially in the lower troposphere. Winds can whip some dust from land into the atmosphere, but a combination of strong winds and dry land can cause major episodes of particulate pollution (Eagelman, 1991). Ordinary ground dust picked up by winds accounts for 30 % or more of the particulates in the atmosphere. In large urban areas the aerosols lifted up into the lower layers of the atmosphere can contain combustion products as well. Aerosols thus introduced into the atmosphere produce a variety of effects. In the lower troposphere they play an important role in the formation of fog, mist and clouds, besides affecting visibility, whereas in the upper regions they produce chemical and electrical effects. Aerosols affect the climate by altering the earth-atmosphere radiation balance (*e.g*. WCP-55, 1983). Stratospheric aerosols having long residence time induce long-term and large-scale effects while the short-lived tropospheric aerosols introduce local perturbations in shorter time scales. Aerosols in the urban areas being a complex combination of natural and anthropogenic origin, have a large variability in their characteristics as well as their effects on man and environment. Thus, occurrence of a dust storm in a large urban area can have many implications on air quality and presents an interesting case for optical monitoring. Dust storms fall into two categories: the localized convective type typified by the dust devil and the large-scale storm caused by strong

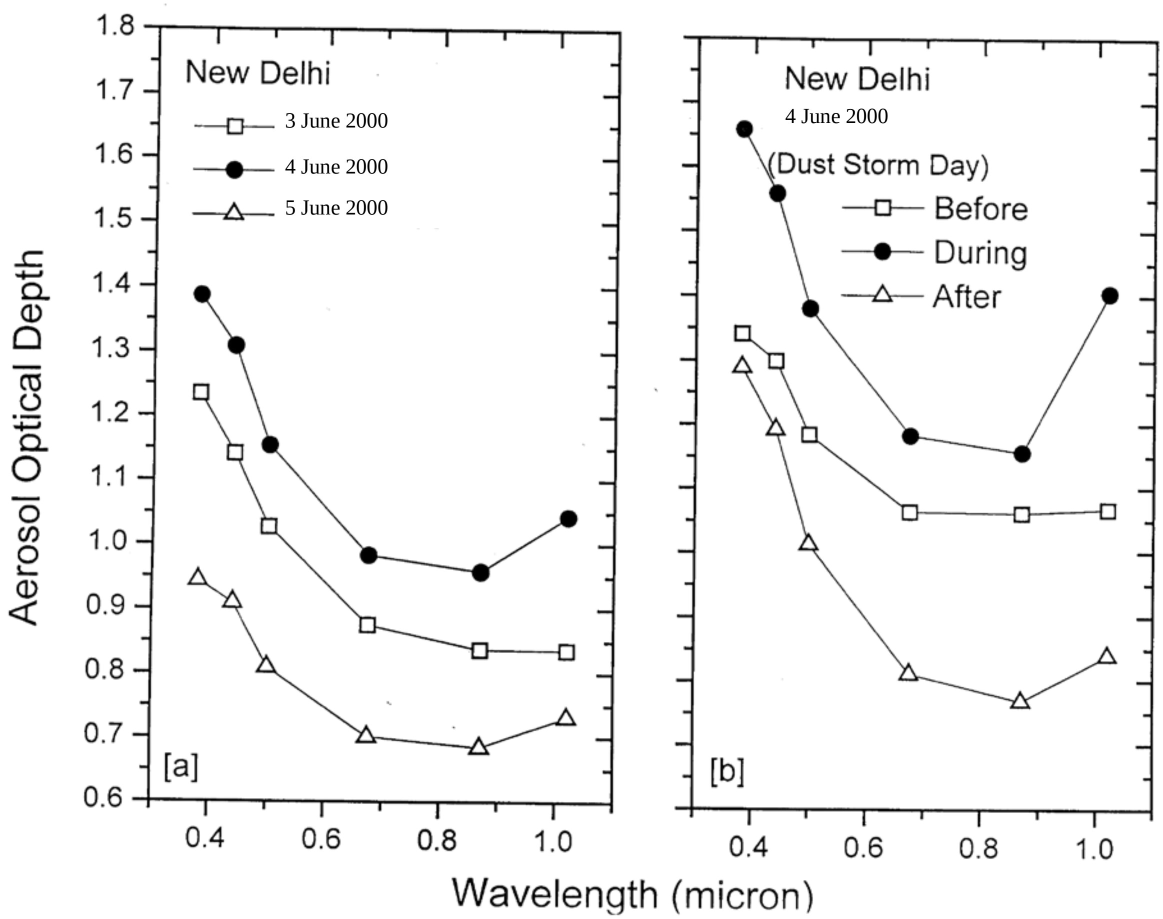
winds over dry terrains. Besides causing short-term particulate pollution episode in a localized region, the aerosols lifted up by a dust storm can effect environments farther away too by transport and dispersion. For example, mineral surface materials lifted by dust storms over the arid areas of North Africa (Saharan dust) has frequently been detected in aerosols sampled at Garmisch-Partenkirchen, Germany (Reiter *et al*., 1985; Jager *et al*., 1988). Asian dust storm (Kosa) particles are transported to the North China to Japan Islands (Iwasaka *et al*., 1983) and the North Pacific Ocean (Uematsu *et al*., 1983). Summer-time dust storm events are common feature in the thickly populated metropolitan city of New Delhi (28° 37' N, 77° 10' E, 217 m amsl) causing short duration pollution episodes with poor visibility. It is fairly well known that during the months of April, May and June dust storms occur frequently in Northwest India, when dust raised by strong winds can reduce the visibility drastically. India Meteorological Department has classified these dust storms into light, moderate and severe. Two types of dust storms have been described by Joseph *et al*. (1980); the 'pressure gradient type' and 'convective type'. The local/Indian name for the convective type dust storm is 'Andhi'. Most of the dust storms that occur at Delhi are of this 'Andhi' type. The frequency of dust storms at Delhi is 1 in April and 3 each in May and June. Some details of such dust storms have been given by Joseph *et al*. (1980) along with measurements of horizontal visibility made with a transmissometer. It would be interesting to monitor optically the aerosol loading and size distributions during such short-lived but intense dust load events and one such attempt has been described in this paper using the data collected in June 2000 at New Delhi for three days.

2. Delhi experiences hot and humid (~45° C) summers and cold winters, with lot of commercial and cultural activity. The old Delhi as it still survives today was built by the Mughal emperors around 1648 A.D. on the banks of river Yamuna. In 1931, the British built New Delhi, south of the then existing city of Delhi. Since then the Old and New Delhi have merged in to a sprawling metropolitan city and has grown in large proportions in terms of area, population, industries, transportation etc. The current population of the city would be over 8.5 million roughly. In addition, several industrial towns have developed around the metropolitan city during the last two decades, all of which contribute to the urbanization of New Delhi. Thus the city presents a typical environment with a mixture of natural and anthropogenic influences, for atmospheric studies.

2.1. *Sun photometer* - Multi-spectral aerosol observations have been made at the above mentioned urban location during 3-5 June 2000 using two hand-held multi-wavelength Sun photometers (Microtops-II, Solar Light Inc., USA). One sun photometer gives instantaneous aerosol optical depth (AOD) values at the five wavelengths of 380, 440, 500, 675 and 870 nm. The other one identical in design but is basically an ozone monitor which makes direct solar measurements for retrieval of total columnar ozone (in DU) and precipitable water content in cm. The aerosol optical depth at 1020 nm obtained from this monitor makes the sixth channel of AOD measurement. Each of the above instruments is equipped with 5 optical collimators, accurately aligned, with a full field of view of 2.5° and internal baffles to eliminate internal reflection of light. Each AOD measuring channel is fitted with an interference filter of FWHM 10 nm and a photodiode suitable for the particular wavelength range. Both the sun photometer and the ozone monitor have been mounted side-by-side on a rigid strip which itself has been fixed on a tripod stand for alt-azimuth steer ability and portability. The detailed design and calibration aspects of the above systems can be found in a recent paper by Morys *et al*. (2001). These sun photometers are periodically calibrated by intercomparison observations made simultaneously with a set of identical systems available with another organization, in Ahmedabad, by the Langley method with observations made on clear sky days and also by taking them to high altitude clean environments where aerosol loadings are expected to be near background levels (Dani *et al*., 2002).

2.2. *Aerosol measurements* – Columnar aerosol optical depth data at the above six wavelengths at 10 to 30 minute interval from 0800 hrs to 1800 hr LT have been collected on 3, 4 and 5 June 2000 in the central metropolitan area of the city of New Delhi. The number of sets of AOD data collected on each of the three days are 26, 18 and 28 respectively and were used for further analysis. A typical summer dust storm of a short duration occurred on 4 June between 1300 and 1330 hrs LT. Very strong winds were experienced during the short span of time. Most of the lighter and moderately heavy objects were moved or thrown away and some of the observational equipment like the weather monitor installed on the terrace of a building was displaced due to the winds. There was a local electric power failure soon after. The sky turned turbid immediately till sunset. A brief spell of light rain shower occurred following the dust storm after 1430 hr. The results of the analysis are presented and discussed here as a case study.

3.1. *Aerosol optical depth* – The overall average aerosol optical depth values at the six wavelengths at New Delhi ranged from 0.8 to 1.1 which are higher compared to the AODs at other stations. Sun photometric measurements were also made at some remote high



Figs. 1(a&b). Mean wavelength dependence of AOD at six wavelengths (a) on 3, 4 and 5 June 2000 and (b) before, during and after the dust storm on 4 June 2000

altitude locations north of Delhi a few days prior to the Delhi observations and the analysis of the AOD shows that aerosol loading over Delhi is, on an average, 4 times that observed at the remote locations. Daily mean of aerosol optical depth at the six wavelengths are computed and the mean wavelength dependence of AOD on 3, 4 and 5 June is shown in Fig. 1(a). It is seen that AOD on all the three days is higher at shorter wavelengths, decreases rapidly with increasing wavelength up to 675 nm. At higher wavelengths AOD was almost constant or even showed an increase. In terms of magnitude, it can be clearly seen that AOD at all the wavelengths on dust storm day was substantially higher compared to that on the other two days. For example, the mean AOD at 500 nm on the storm day was 1.15 while the mean for the other two days is 0.92. The increase in AOD from 3 to 4 June, on an average, was around 15% and the decrease to the next day (5 June) from storm day was nearly 35%. Thus even the day's average shows the effect of dust storm and how the aerosol loading in the atmosphere was enhanced due to the short duration dust storm which lasted barely 15-20 minutes at 1300 hr LT on 4 June. A short duration rain shower occurred in the evening hours (around 1430 hr) of 4 June. Kamra (1969) describing visual observations of a dust storm made at another north Indian city (Roorkee) reported the occurrence of a very short duration (~30 minutes) rain shower with very large raindrops that followed soon after a dust-storm. Report of occurrence of a thunderstorm following a severe dust storm in the region close to Delhi is also available in literature (Dhavan, 1985). Thus the higher percentage decrease in AOD from dust storm day to the following day was partially due to the rain washout effect. The mean wavelength dependence of AOD before (1000-1230 hrs), during (1300-1315 hr) and after the dust storm event on 4 June is shown plotted in Fig. 1(b). At all the wavelengths, AOD increased from the period before dust storm to the period of the actual event. This increase was about 19% on an average. From dust storm period to the post-storm period on the same day, AOD decreased by almost about 30%. The increase was especially higher at 380 nm and also at 1020 nm. At the typical wavelength of 500 nm, the

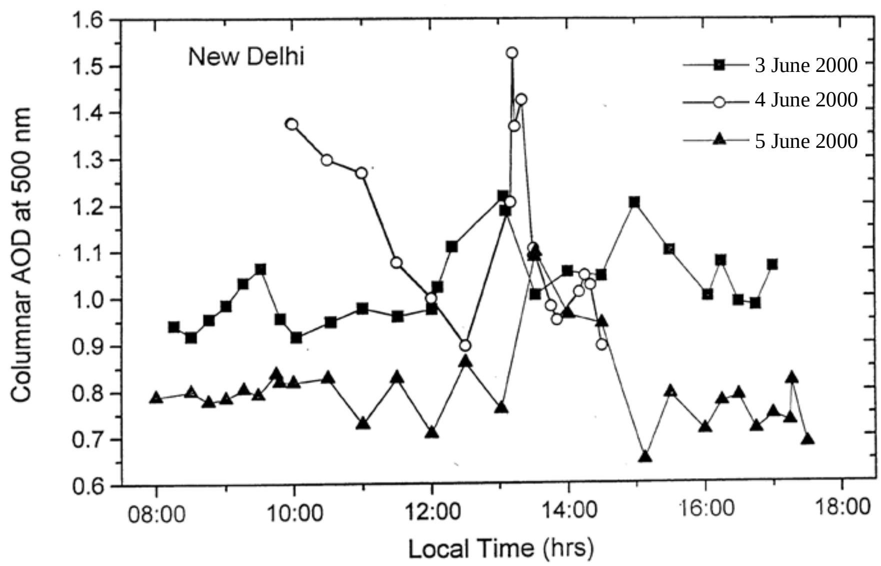
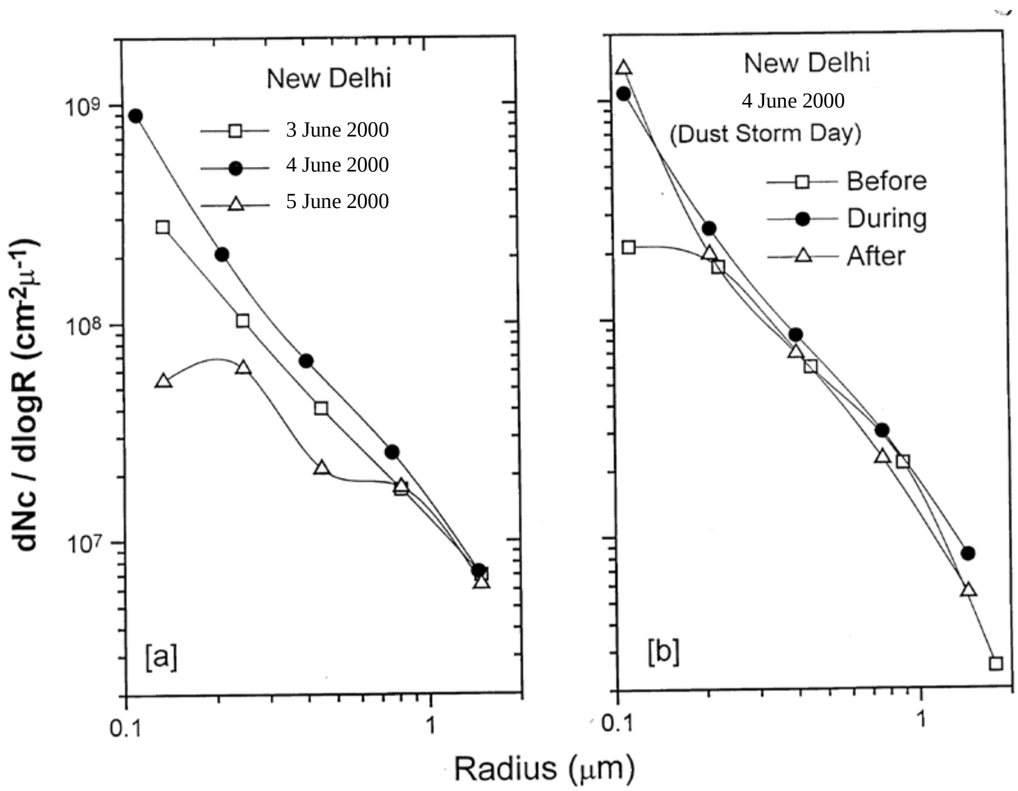


Fig. 2. Temporal variation of columnar AOD at 500 nm on 3, 4 and 5 June 2000

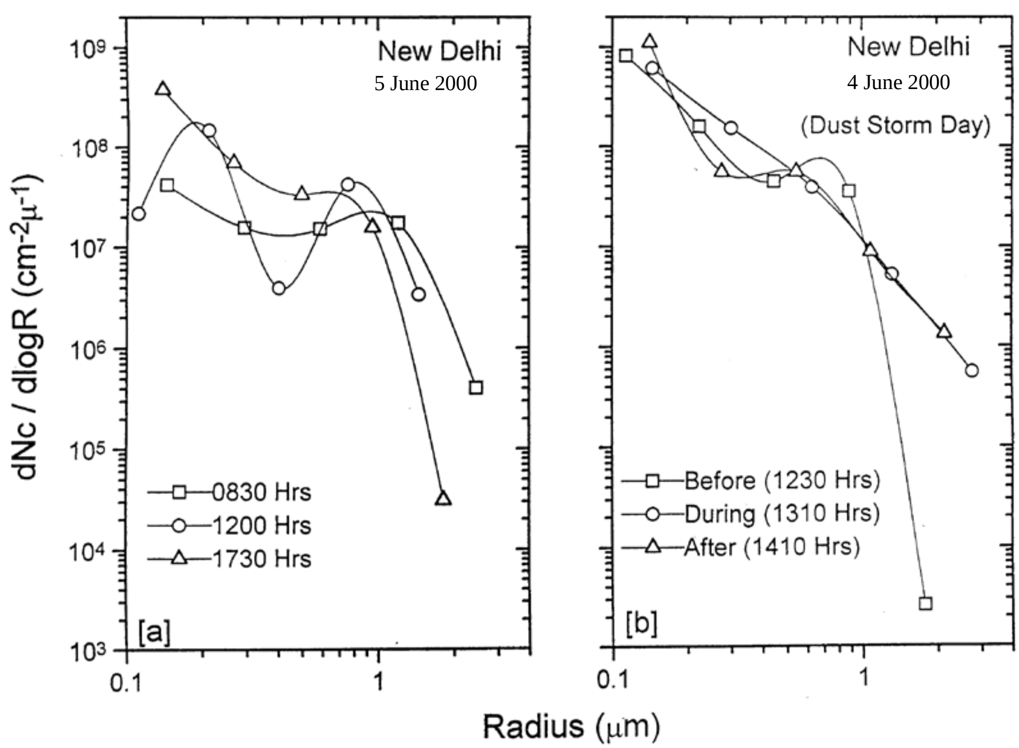
mean AOD during the storm was 1.38 and that for the rest of the day (before and after) was 1.10. The decrease of AOD after the storm was higher at larger wavelengths and may be partly due to the conversion efficiency of large sized particles in to cloud droplets and also due to their quick settlement after calm conditions are attained.

3.2. *Temporal variations* – Diurnal variation of AOD at a typical wavelength of 500 nm between 0730 and 1730 hr LT on 3, 4 and 5 June has been plotted and shown in Fig. 2. One can see the substantial and abrupt short-duration increase in AOD on the dust storm day (4 June) around 1300 hr LT which lasted up to 1330 hrs LT. On the other two days there is no significant diurnal variation in AOD at this urban location, except for some higher values of AOD around noon and during post-noon time. The absence of any marked diurnal variation suggests that aerosols in large numbers may already be prevailing in the atmosphere from morning hours due to various human activities associated with urban locations. On 5 June smaller AOD values are observed throughout the day mainly because of the wash out effect due to rain shower that occurred during the evening hours of 4 June. More or less very similar temporal variations have been seen at other wavelengths also and hence not shown here.

3.3. *Aerosol size distributions* – It is well recognized that the optical properties of the aerosols are effectively characterized by their chemical composition and size distributions. Atmospheric aerosols produced as a result of both natural and anthropogenic processes are essentially polydisperse having sizes ranging from one thousandth of a micrometer to a few tens of micrometers. Within this size range, the number concentration of particles varies with the particle size. A clear knowledge of the nature of this size distribution at any location, especially in urban locations is important to understand their sources, sinks and possible effects. A bimodal size distribution is often employed to describe the optically effective size range. It consists of an accumulation mode (small size particles) which is associated with anthropogenic activity and a coarse mode (larger size particles) which may be mainly due to soil or sea origin. Study of aerosol size distribution at an urban location would present an interesting case for study especially for data collected during intense events like dust storms. Spectral dependence of AOD is predominantly dependent on the aerosol size distribution according to Mie scattering theory and by using such data, size distributions can be reasonably determined by employing inversion techniques. Thus from the wavelength dependence of AOD information available at Delhi, columnar aerosol number size distributions have been inferred by numerically inverting the AOD data adopting the algorithm of King *et al*., (1978). Initially size distributions have been retrieved for the average data shown in Fig. 1. The mean size distributions (number of particles per unit area per unit log radius interval, dNc/dlogR, *versus* the radius in microns) for 3, 4 and 5 June 2000 are shown in Fig. 3(a). A nearly mono modal size distribution can be seen on 3 and 4 June. Number concentrations are high at all size ranges below 1 μm on 4 June, the dust storm day compared to that on the other two days. The mono modal size distribution mainly indicates



Figs. 3(a&b). Mean aerosol size distributions (a) on 3, 4 and 5 June 2000 and (b) before, during and after the dust storm on 4 June 2000



Figs. 4(a&b). Typical aerosol size distributions representative of (a) the morning, noon and evening times on 5 June 2000 and (b) the period before, during and after the dust storm event on 4 June 2000

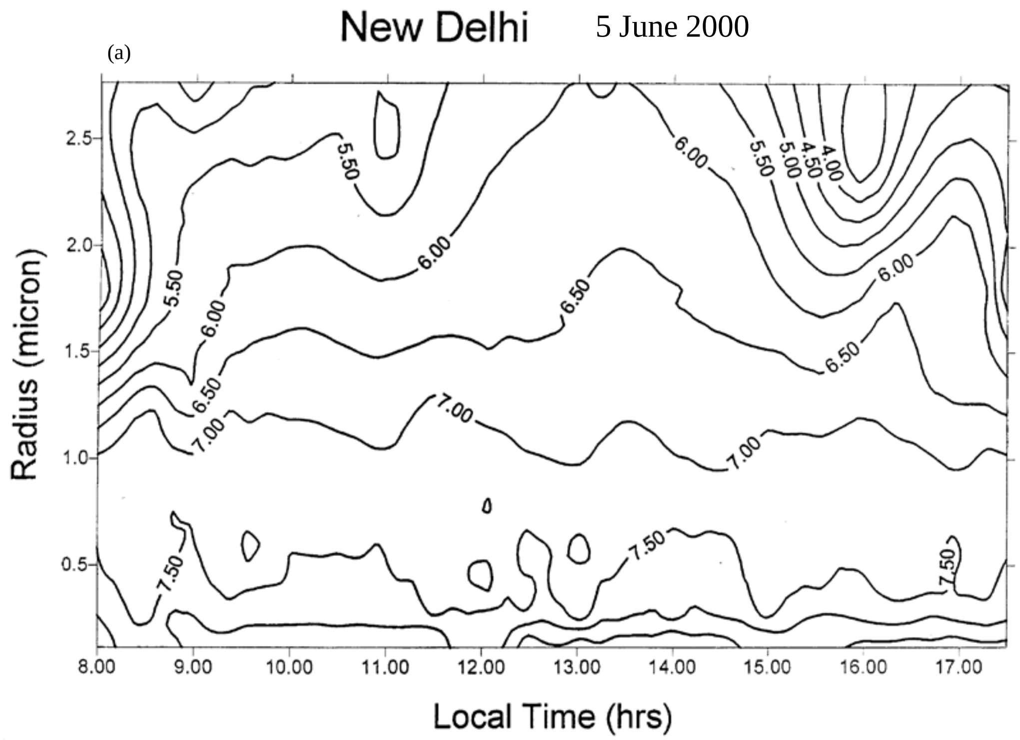


Fig. 5(a). Time evolution of columnar aerosol size distribution on a typical clear day (5 June 2000)

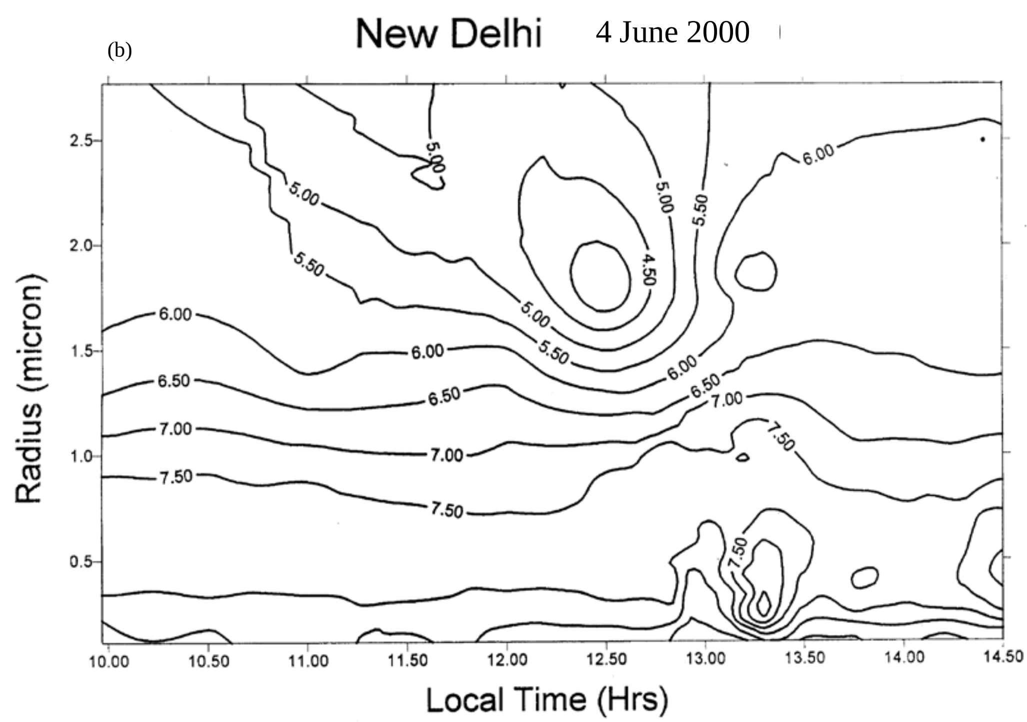


Fig. 5(b). Time evolution of columnar aerosol size distribution on dust storm day (4 June 2000) that aerosols of smaller size (due to urban activity) are present in large numbers in addition to aerosols of all size ranges. A bimodal size distribution is noticed on 5 June, typical of an urban environment. Fig. 3(b) shows the mean aerosol size distribution for the dust storm day for the period before, during and after the dust storm event. It broadly shows that number concentrations are higher during and after the dust storm episode as one would expect, especially in the smaller size range. It is to be noted here that the fine structure if any, in the size distributions can be masked in the average data although it would provide an idea of the average picture. For this purpose, the actual wavelength dependence of AOD data sets for a typical morning, noontime and afternoon time have been taken and subjected to the size distribution inversion. Fig. 4(a) shows these individual size distribution curves of the data of 5 June. Here one can see the bimodal size distributions more clearly, which is typical of the urban environment. It also shows how from morning to evening hours the relative number concentrations of different size particles vary. Fig. 4(b) shows the individual aerosol size distribution curves corresponding to the periods before, during and after the dust storm event on 4 June. Bimodal size distribution was seen before and after the storm, while the data during the actual dust storm event showed a near mono modal size distribution. This is possible because during that period aerosols of all sizes may be present in the atmosphere. It would be thus interesting to see the time evolution of this size distribution on a real-time scale from morning till evening hours. Such an attempt has been made by taking all the data sets collected on each day and Fig. 5(a) shows the time evolution of aerosol size distribution on 5 June, a relatively clean day with clear-sky. The contour values in the figure show the logarithmic values of dNc/dlogR shown in Fig. 3. Here one can see that there is considerable variability with time in the number concentration of aerosols in the size range below 0.5 μm. This can be expected as these small particles have predominantly urban source and may be mostly confined to the lowest layers of the atmosphere. Aerosols of sizes greater than 1.0 μm started increasing in number from 0800 hrs LT (upward sloping contours), till 1300 hrs. Then onwards, their number concentrations started falling rapidly by evening hours. Fig. 5(b) shows the similar temporal evolution of aerosol size distributions on the dust storm day. Aerosol concentration of particles up to the size 1.5 μm remained more or less constant from morning hours on this day. Around 1300 hrs LT, there was the sudden perturbation due to the dust storm. Particle concentrations of all sizes started increasing around the time of the storm. The smaller sized particles (less than 0.5 μm radius) increased abruptly and then within about half-an-hour their concentrations fell abruptly. Particles of sizes greater than 0.5 μm started getting added in the atmosphere more gradually till the end time of the observations on that day, that is until 1430 hr LT. Thus the perturbation due to the strong surface winds of gusty nature lifted aerosols of all size ranges into the atmosphere, which remained suspended in the lower atmosphere during the post storm period also. This fact is evident from the variations in columnar AODs seen in the earlier figures discussed above. During dust storm the large momentum transfer to the soil is sufficient to overcome forces binding soil particles together and thus the dust and other surface particles can be carried to greater heights by the mixing processes of the storm (Gillette *et al*., 1978). Therefore the columnar aerosol optical depths and size distributions in this case study showed temporal variations and significant changes from no storm days to the dust storm day and on the dust storm day too they were different in the periods before, during and after the storm event.

4. The authors are thankful to the Director, IITM for his constant encouragement. The authors acknowledge with thanks the cooperation from scientists of the Rain and Cloud Physics Research Unit of IITM at New Delhi during the observational campaign.

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(*4 February 2002, Modified 23 September 2002*)