Aerosol Size Distribution Variation in Anantapur (14.62°N, 77.65°E) Semi Arid Zone and its Impact on Aerosol Effective Radius

R.R. Reddy[*], K. Rama Gopal, K. Narasimhulu, L. Siva Sankara Reddy, K. Raghavendra Kumar

Aerosol & Atmospheric Research Laboratory, Department of Physics, Sri Krishnadevaraya University, Anantapur, India.

Abstract

Measurements on size distribution of atmospheric aerosol were made at Anantapur, during January to December 2005. A ten channel Quartz Crystal Microbalance Cascade Impactor (QCM) is used to study the response of aerosol characteristics to mesoscale and synoptic processes. The accumulation mode aerosol mass concentration (submicron $M_a \approx 0.4$ to 0.05 μm) is found to be minimum (~10 μg/m^3) and maximum (~ 27 μg/m^3) during the months March–August and November–December, 2005 respectively. Coarse mode aerosol mass concentration (supermicron $M_c \approx 12.5$ to 0.8 μm) is found to be maximum (~ 17 μg/m^3) during the months of July and September 2005. The effect of wind on the concentration of M_c and M_a has been studied. The variation in the effective radius (R_{eff}) from 0.1 μm to 0.4 μm indicates how the size of the particles varied seasonally. The present study brings out the fact that the size distributions on aerosols are very much affected by the meteorological parameters.

Keywords: Aerosols; Mass size distribution; Submicron and supermicron particles; Effective radius; Meteorological parameters.

[*] Corresponding author. Tel.: +91-8554255710; Fax: +91-8554255710

E-*mail address*: rajururreddy@yahoo.co.uk

INTRODUCTION

Atmospheric aerosols, particularly those near the surface, have strong direct and indirect influence on environment, air quality, visibility and human health with immediate repercussions, while they alter the radiation budget of the Earth-atmosphere system through radiative forcing thereby affecting the climate on a long-term scale (Charlson and Rodhe, 1982; Charlson *et al*., 1992; Boucher and Anderson, 1995). Even though the significance of aerosols in these processes are globally recognized and several efforts have been made to model their characteristics from the above perspective, there still exists large uncertainties not only globally (Penner *et al*., 2001) but also regionally (Ramanathan *et al*., 2001; Moorthy *et al*., 2001; 2003). This arises mainly because of the large heterogeneity (spatial and temporal) in their properties (physical and chemical composition) and lack of experimental data with adequate spatiotemporal resolution. Near the surface, where the boundary layer process are active, the variabilities in aerosol characteristics are considerably higher, primarily because of the large diversity in the sources and sinks of aerosols (Pillai and Moorthy, 2001; Moorthy *et al*., 2003). Aerosol size distribution influences the dynamics of aerosol number density; their production process; the size transformation and lifetime. By acting as condensation nuclei, aerosols modify the macrostructure of clouds (Ramakrishna Reddy et al., 2003). So characterization of the size distribution of atmospheric aerosols is valuable (Clarke and Whitby, 1967; Khemani *et al*., 1982; Kulshrestha, 1995). In addition to the micro-scale aerosol mechanisms such as coagulation and condensational growth, larger scale atmospheric processes have profound effects on the size distribution (Hoppel *et al*., 1990; Arimoto *et al*., 1997).The synoptic processes such as changes in prevailing circulation systems, rainfall, land surface heating, air mass types etc., produce distinct signatures in the size distributions (Moorthy *et al*., 1991; Smirnov *et al*., 1994).

Anantapur district in Rayalaseema region of Andhra Pradesh, is geographically situated in a nearly semi arid zone, occupying the second place to Rajasthan in India. Anantapur district is the driest part of the state of Andhra Pradesh. Being far away from east and west coasts, this district is deprived of the full benefits of both the monsoons and consequently droughts are frequently experienced here. It receives the lowest average rainfall of about 450 mm compared to the Andhra Pradesh state average of about 900-1100 mm. Nearly 85 percent of the population is affected by drought in this district, due to low rainfall, high temperature and severe dry winds during monsoon periods. Anantapur district geographically lies in between 13°40' and 15°15' North latitudes and 76°50' and 78°30' East longitudes. The district is bounded by Kadapa and Chittoor districts towards east and by Kurnool district towards north. Karnataka state is bordered towards south and west of the district. The total geographical area of the district is 19,125 km^2. Anantapur town and its surroundings experience strong winds (>10 m/s) during part of July, August and part of September months in a year. Rayalaseema area has a number of cement plants, limekilns and slab polishing industries. These industries release into the atmosphere large quantities of particulate matter everyday. The observation site, Sri Krishnadevaraya University (Fig. 1) is situated at the southern edge of the Anantapur town. Anantapur having population of about 0.6 million and total number vehicles are about 0.12 million of which vehicles with two stroke engines are about 0.10 million. Industries, national highway and town area situated in the north to south-western region, 10-15 km away from the observational site. In this paper we present the near-surface aerosol characteristics in a semiarid zone. The time evolution of aerosol loading, size distribution, effective radius, and their association with the prevailing meteorological conditions are presented and the implications are discussed.

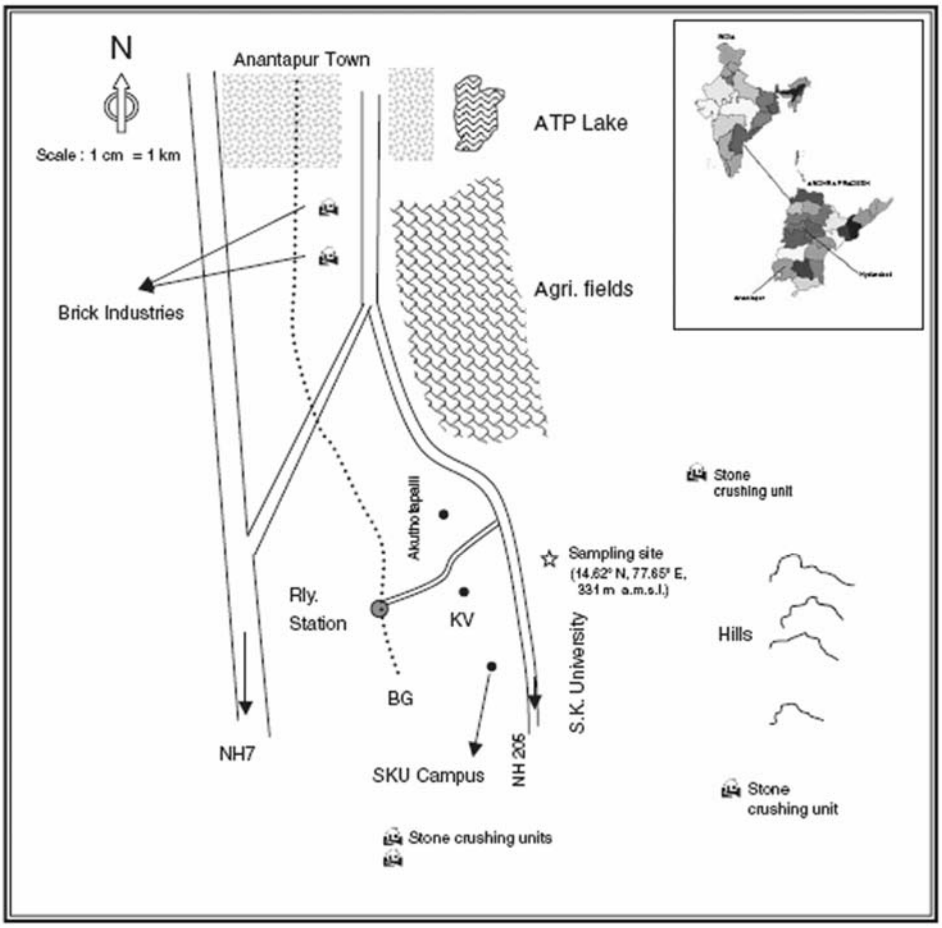

Fig. 1. Observational site (☆) and surroundings, showing the position of the University Campus, town area, National Highways, small-scale industries, etc

Measurement site

The observation site, Sri Krishnadevaraya University (14.62°N, 77.65°E, 331m asl), represents a very dry continental region of Andhra Pradesh, it is situated on the boundary of semi-arid zone and also center of south India Fig.1. The climate is hot and dry in summer (March – May), hot and humid in monsoon (June–November) and dry in winter (December–February). The weather at the measurement site during May is very hot due to intense solar radiation. The day time temperature reaches above 44°C and night time 35°C . Normal rainfall is of the order of 450 mm during the whole year. The winter season is fair weather condition prevailing with wind speed of the order of 3-4 m/s with south easterly direction and moderate relative humidity exists during this season.

Analysis of QCM data

Near real time measurements for mass-size distribution of aerosols are made regularly using a Quartz Crystal Microbalance Impactor (model PC-2 of California Measurements Inc.) The instrument sucks in the ambient air and segregates the aerosols in accordance with the aerodynamic diameter into one of its ten size bins. For spherical particles with a density ρ, the aerodynamic diameter (d_{ai}) and the particle diameter (d_{pi}) (also known as the Stokes diameter) are related through

$$d_{pi} = \frac{d_{ai}}{\sqrt{\rho}} \tag{1}$$

The particle diameter (d_{pi}), the geometric mean diameter ($d_{gi} = \sqrt{d_{p(i-1)} d_{pi}}$) and aerodynamic diameter (d_{ai}) for all the stages are given in Table. 1 where $d_{p(i-1)}$ and d_{pi} are the lower cut off diameters of (i-1) and ith stage, i varying from 2 to 10.

Table 1. Stages and cut points for QCM Impactor.

Stage No	Lower cut off Diameter (μm)		
	Particle diameter (d_{pi})	Geometric mean diameter (d_{pi})	Aerodynamic diameter (d_{pi})
1	25.0	--	35.37
2	12.5	17.58	17.68
3	6.4	8.94	9.05
4	3.2	4.53	4.53
5	1.6	2.26	2.26
6	0.8	1.13	1.13
7	0.4	0.57	0.57
8	0.2	0.28	0.28
9	0.1	0.14	0.14
10	0.05	0.07	0.07

The QCM provides mass concentration of the particles collected in each stage (m_{ci}) as a function of particle diameter assuming a value of 2000 kg/m^3 for ρ. Accordingly, it yields mass concentration in ten size bins; the 50% cut-off diameter and the (geometric) mean diameter (d_i) of these bins are given in Table 1. Stage one collects all particles with diameter > 25 μm, and hence no mean diameter is assigned to that stage.

The instrument is operated at 331 m above msl and during periods when the ambient relative humidity (RH) < 75%. Below 75% RH, the instrument is not very susceptible to the moisture. The dual unsealed crystal approach used in the Model PC-2 reduces the thermal and humidity effects to a minimum. Typically, samples are collected every hour. Each sampling duration varied between 5 and 6 min. Data collected for 44 days from January to December 2005 formed the database for this investigation. Measurements are made approximately at hourly intervals for 4-5 days in each month (approximately once a week). The raw data from QCM provided the total mass concentration (M_t) as well as the size segregated mass concentration (m_{ci} for the ith size bin) for each size bin, for each measurement. Besides yielding characteristic information by themselves, they can also be used to derive physically meaningful.

$$M_t = \sum_{i=1}^{10} m_{ci} \tag{2}$$

The study of the submicron aerosols is important because of their longer residence times and also because these aerosols contribute more to the scattering and indirect radiative forcing through clouds (Charlson *et al*., 1987; Toon *et al*., 2000), whereas the concentration and size spectrum of continental aerosols strongly depend on the wind speed (Lovett *et al*., 1978; Exton *et al*., 1985). As such, we have separated M_t into M_a and M_c where M_a is the mass concentration in the submicron size range and M_c that in the supermicron size range, such that

$$M_t = M_a + M_c \tag{3}$$

For the configuration of the QCM, we took the cut-off diameter as 0.8 μm to demarcate the two regimes and thus

$$M_c = \sum_{i=2}^{6} m_{ci}\ ,\ M_a = \sum_{i=7}^{10} m_{ci} \tag{4}$$

From the mass concentration m_{ci} measured at each size bin the corresponding volume v_{ci} and area a_{ci} are estimated (Pillai and Moorthy, 2001).

$$v_{ci} = \frac{m_{ci}}{\rho} \tag{5}$$

Where ρ is taken as 2000 kg/m^3, dividing v_{ci} by the geometric mean particle radius (r_i) of the ith size bin, we get an estimate of the surface area of the aerosols (a_{ci}) in the ith size bin

$$a_{ci} = \frac{v_{ci}}{r_i}, \qquad r_i = \frac{d_{g\,i}}{2} \tag{6}$$

The volume (equivalent to sphere) and area estimates are used to estimate the effective radius of aerosols R_{eff}

$$R_{eff} = \frac{\sum_{i=2}^{10} v_{ci}}{\sum_{i=2}^{10} a_{ci}} \tag{7}$$

In estimating R_{eff}, Eq. (7), the summation is made only over stages 2-10. Stage one is not considered because it collects all particles with size exceeding 25 μm and hence that stage cannot be assigned a meaningful mean radius. The symbols have their usual significance and the detailed description of above relation are available in literature (Pillai and Moorthy, 2001; Moorthy *et al*., 2003).

General meteorological conditions

A summary of the average prevailing meteorological conditions during the study period is shown in Fig. 2. The monthly mean wind speeds, direction and relative humidity, maximum and minimum temperatures and monthly total rainfall are obtained from the MET facility established in the observational site. The winds (1104.7 hPa level at an altitude of 331 m amsl.) are basically low (speed ~ 3 m/s) in southwest direction i.e., during the months of January to May. The prevailing winds start shifting from June to August. During this period, the wind speeds are high and reach to a peak value of 4-5 m/s in June-July months. The change in the prevailing winds, the mean air temperature increases initially in pre-monsoon months, (March to May) and decreasing in the monsoon periods; and the ambient RH varies from 70-80% to 40-50%. Thus there are scenarios of the period from January to May when the winds are from southeast and June to October when the winds are directed from southwest. The maximum and minimum temperatures are high with diurnal variations in temperature (~ 13–15 ^{o}C) and low relative humidity, between

45 to 60% (Fig. 2). This period is also marked by rainfall (bottom panel); dry surface conditions and high convective activity during the daytime owing to high sensible heat flux caused by increased surface heating (Kunhikrishnan *et al*., 1990; Prakash *et al*.,1992). This is followed by the summer season extending from March to May during which the mean land temperature increases.

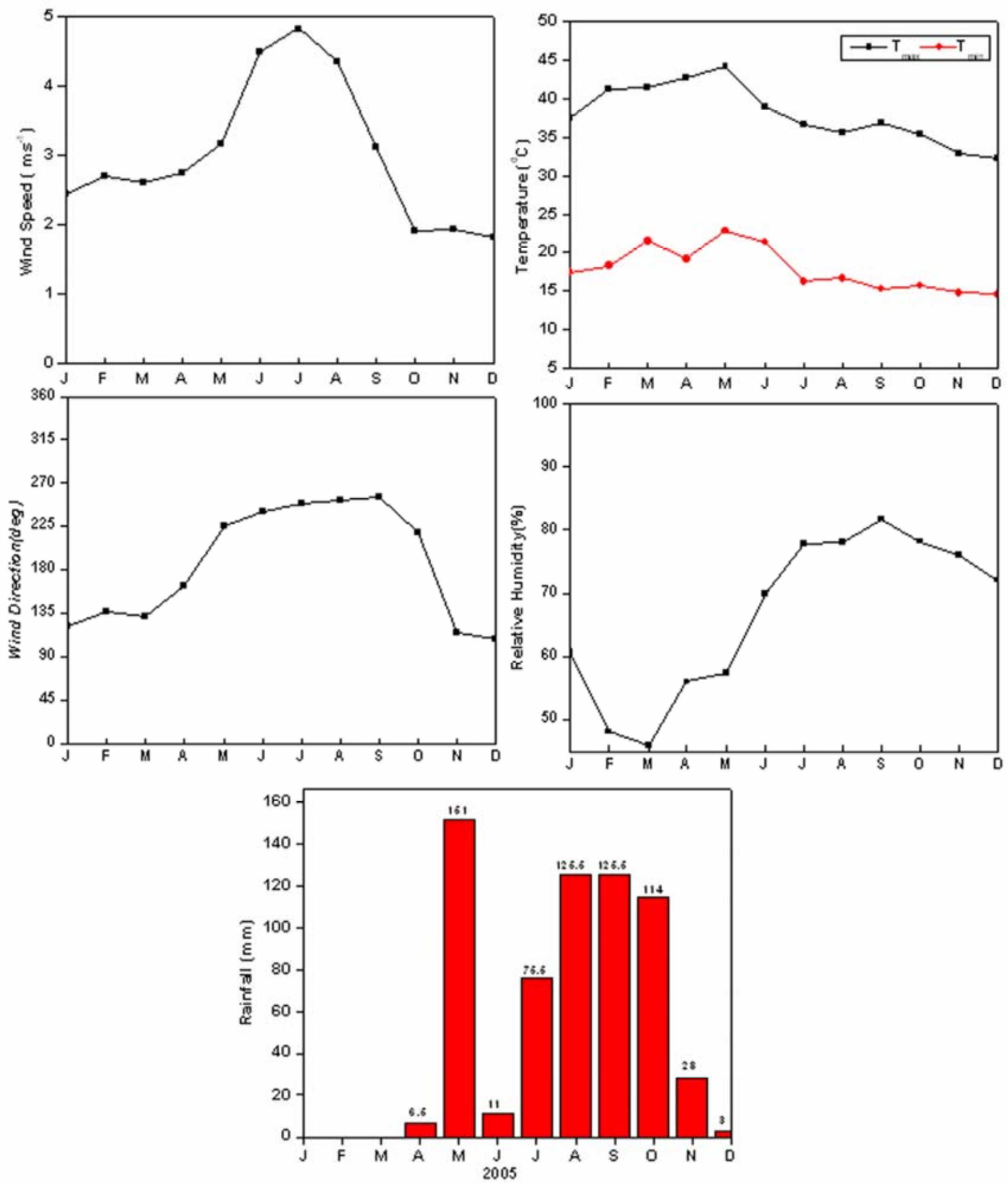

Fig. 2. Prevailing meteorological features of Anantapur during the year 2005. Panels from the top to bottom, respectively, represent the wind speed, wind direction, monthly mean maximum and minimum temperature, relative humidity and the monthly total rainfall.

RESULTS AND DISCUSSION

Aerosol mass concentration in different size regimes

Fig. 3 represents the monthly averaged submicron (M_a), supermicron (M_c) and total mass concentration (M_t) aerosols during the period between January and December 2005. The vertical bars over the points represent the standard deviation of the mean. The supermicron range aerosol mass concentration remains low (6 to 10 μg/m^3) in winter (December – February) and exhibits a maximum value during March (15.2 μg/m^3). Subsequently it increases to maximum value in July (17.28 μg/m^3) and remains high till September (16.59 μg/m^3). Thus the supermicron range mass concentration exhibits high value during summer and monsoon periods. In sharp contrast to the above, the submicron range mass concentration increases from a low value in January and reaches a peak value (19.46 μg/m^3) by March and from April it decreases and during May to September it remains low (7 to 14.5 μg/m^3), from October to December it remains high. In the case of total mass concentration it reaches a peak value in March (34.69 μg/m^3) and decreases from April onwards. It remains high in month of July (30.58 μg/m^3), subsequently the concentration increases and remains high from September to December. Examining the above variations, it is known that they exhibit similar behaviour and vary slightly in magnitude and great contribution and influence of M_a is observed towards the total aerosol concentration M_t.

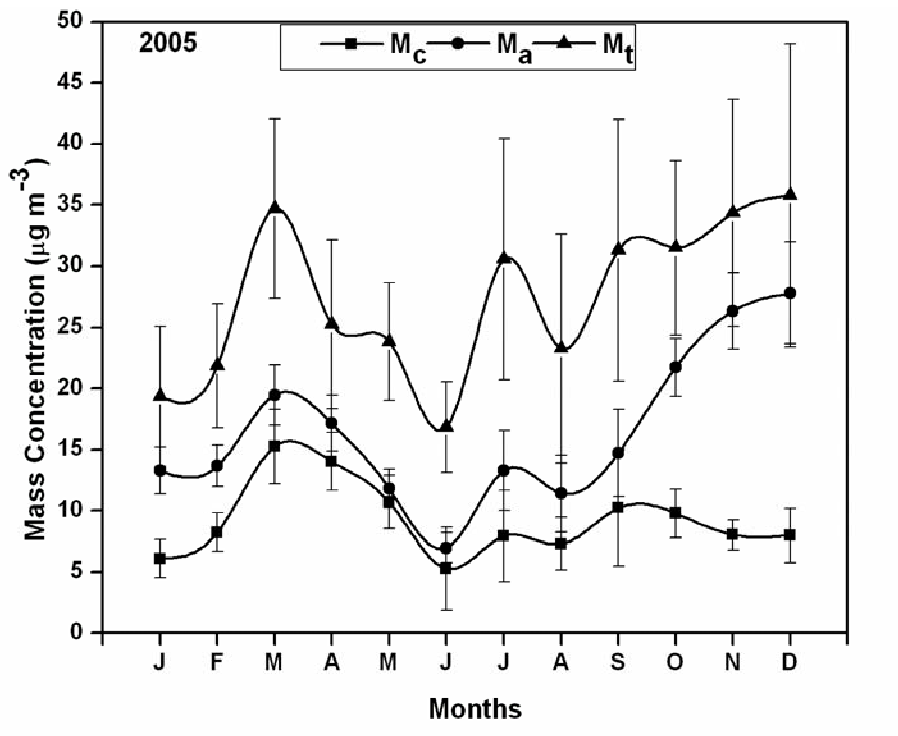

Fig. 3. Monthly variation of submicron (M_a), supermicron (M_c) and total mass (M_t) load concentration for the year 2005.

Diurnal variation

The QCM is operated every week on Wednesday systematically and the total number of days in a year will be around 44. Diurnal variation of submicron mass loading (M_a) and supermicron mass loading (M_c) on a typical days have been shown in Fig. 4. Diurnal variation of M_a and M_c showed a primary peak at 03:00LT and then a sharp increase secondary peak 07:00LT, followed by increase in 16:00LT. Lowest average concentrations of M_a and M_c of the order of 2.5 and 3 μg m^{-3} were observed, respectively. Enhancement in aerosol mass concentration during morning hours has been attributed to the increase in vehicular traffic and related human activities in the study area. As night advances there have been a drastic reduction in the anthropogenic and rural activities leading to reduction in aerosol generation. In the early morning hours aerosols closer to the surface are lost by sedimentation, which results in decrease in aerosol concentrations. The solar heating of land during the day increases convective activity leading to increase in boundary layer height. This increases the ventilation coefficient which results to faster dispersion of aerosols due to which lower aerosol concentration has been observed during noon hours. In general solar radiative forcing is reduced by evening and the boundary layer height decreases which results in increasing particle concentrations in the evening hours. Similar observations have been reported in other regions over India (Parameswaran *et al*., 1997; Pillai *et al*., 2001). Fig. 5 shows the trend between M_c, M_a and wind speed. It is evident from the graph that as wind speed increases particles related to M_a are found to decrease and vice-versa during the study period. It is pertinent to mention that accumulated type aerosols are more strongly depend on the wind speed.

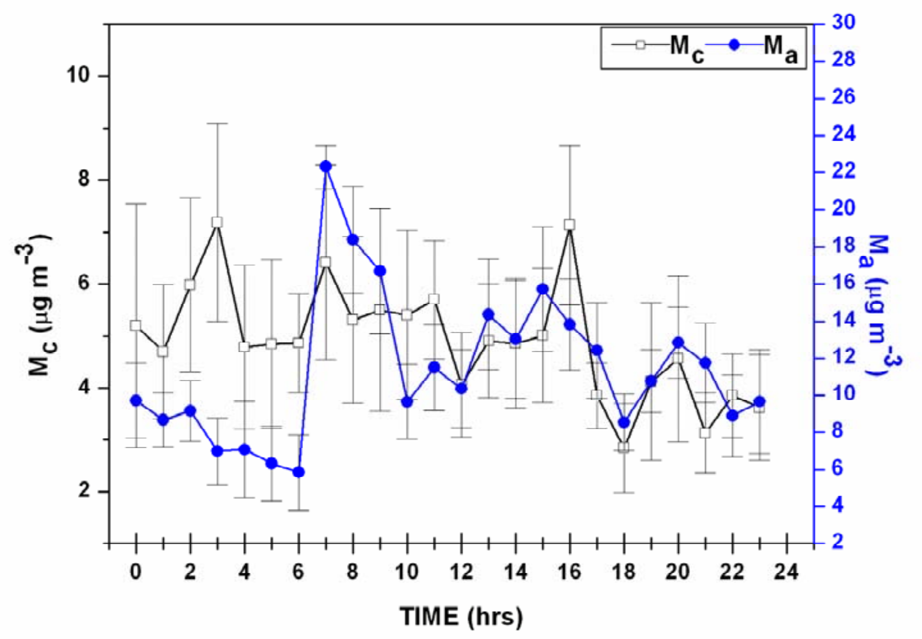

Fig. 4. Diurnal variation of average submicron (M_a) and supermicron (M_c) concentrations for the year 2005 observed at Anantapur. The vertical bars are the standard errors.

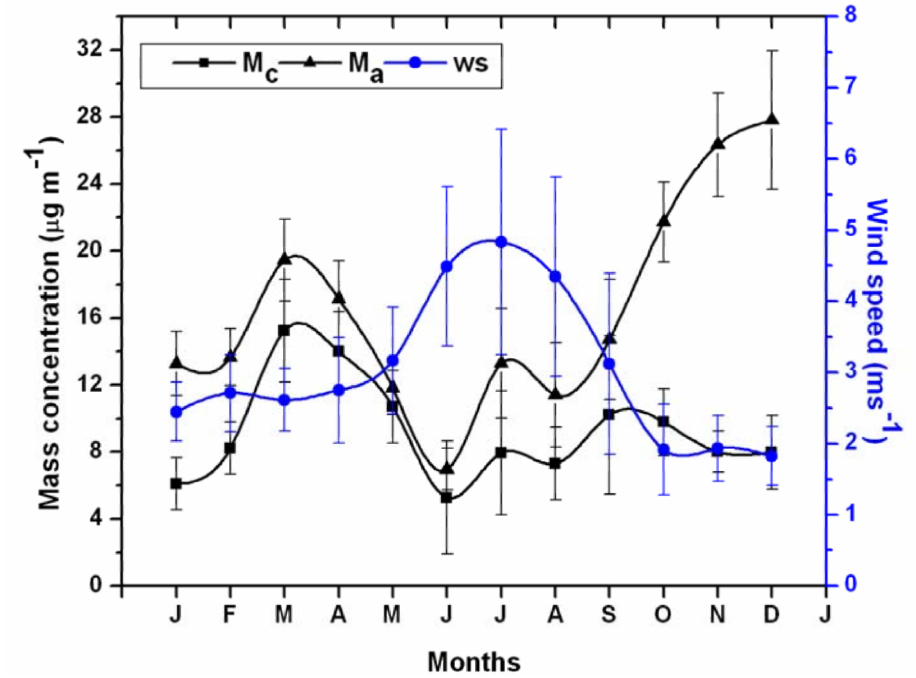

Fig. 5. Monthly variation of aerosol mass concentration (M_a & M_c) and mean wind speed for the year 2005.

Effective radius

Fig. 6 shows month-to-month variation in average effective radius (R_{eff}) and wind speed. The effective radius of a polydispersive aerosol system is equivalent to the radius required for a monodisperse aerosol to exhibit the same total scattering characteristics as polydispersion (Hanseen and Travis. 1974; Mc Cartney. 1976). It is defined as the ratio of third moment to the second moment of the aerosol size distribution (or the ratio of the total volume to total area). The R_{eff} remain around a low value (0.12 to 0.14 μm) till the end of May and starts increasing from June onwards. It reaches the peak value (~ 0.45 μm) by the month of August; this very clearly indicates that the seasonal winds become stronger. These aerosols are advected to the surface of the earth by the favourable winds to produce characteristics on size distribution and chemical composition. In order to see the association between R_{eff} and wind speed, the surface wind speed data are collected from the same location for the days in which QCM observations are made. In Fig. 6 the surface wind speed (averaged and smoothed as per R_{eff}) is shown. Wind speeds are quite low (~ 2 m/s) during October–March; from April, the wind speed increases and remains at a high mean level of ~ fs4-5 m/s till September. These variations are quite similar in nature to those of R_{eff} shown in Fig. 6. It may be seen that, like the prevailing winds, the surface wind speeds are also generally high during the monsoon season and low during the winter season. The winds with peak values reaching up to 5 m/s are experienced during monsoon.

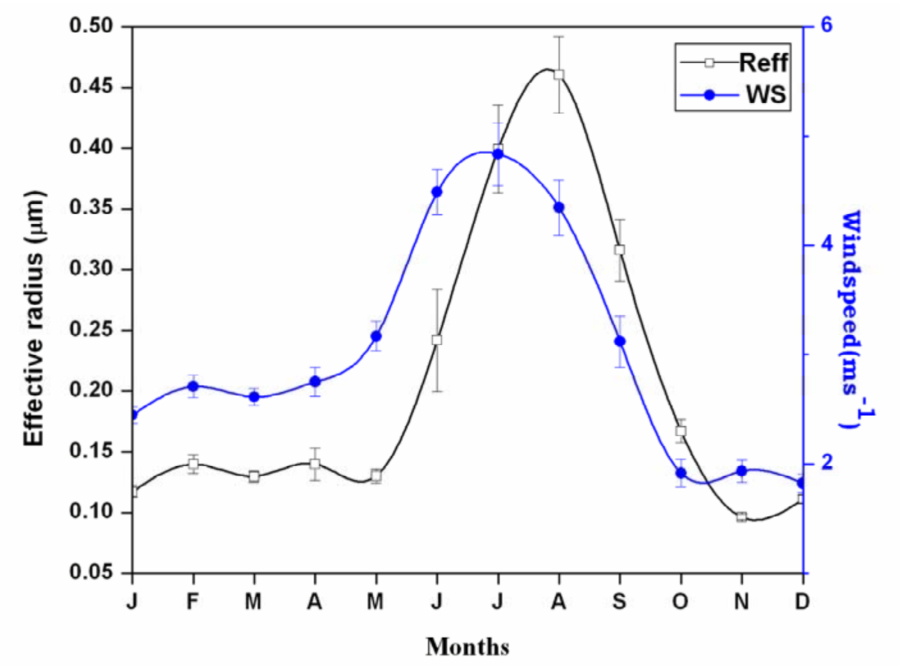

Fig. 6. Monthly variation of effective radius and mean wind speed for the year 2005.

SUMMARY AND CONCLUSION

The aerosol characteristics over semiarid zone of Anantapur were made and collocated measurements of the mass concentration and size distribution of near-surface aerosols were carriedout during January to December 2005. Spectral variation of aerosol mass concentration showed generally high value (25 to 35 μg/m^3) and low (15 to 20 μg/m^3). Examination the variations of aerosol it is known that submicron contribution to the total mass concentration is quite significant. Diurnal variation of aerosol mass concentration during morning hours has been attributed to the increase in vehicular traffic and related human activities in the study area. As night advances there have been a drastic reduction in the anthropogenic and rural activities leading to reduction in aerosol generation. In the early morning hours aerosols closer to the surface are lost by sedimentation, which results in decrease in aerosol concentrations. The solar heating of land during the day increases convective activity leading to increase in boundary layer height. The effective radius is low (0.12 to 0.14 μm) till the end of May and starts increasing from June onwards. The R_{eff} and wind speed has good correlation and has been shown in Fig. 6. The R_{eff} value (~ 0.45 μm) is observed high in the month of August. The surface wind speeds are also generally high during the monsoon season and low during the winter season.

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