Size Distribution of Atmospheric Aerosol over Semi-Arid Region: Rajkot, Gujarat

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Abstract:
This paper presents the Size Distribution of atmospheric aerosol estimated by inversion of spectral aerosol optical depth measurement over Rajkot ($22^0$18N, $70^0$44 E, 142 m above mean sea level) and studied for the period of two years (March 2005-07). For complete characterization of atmospheric aerosol Angstrom parameters are used. Influence of meteorological condition on aerosol optical depth is also studied. Aerosol loading inferred from Angstrom turbidity coefficient showed that it is highest in summer season. Wavelength exponent showed that this site has larger sized particles in the atmosphere in summer rather than winter and monsoon. Aerosol size distributions were predominantly bimodal type indicating the presence of both marine and land aerosols. This type of size distributions were observed over the year. The mean effective radius is highest (~ 0.52 µm) in May-June and it is lowest (~ 0.35 µm) in October, November and December. The seasonal variation of ASD showed the influence of meteorological condition as well as source region.

Keywords: *Atmospheric aerosol, Size Distribution*

1. Introduction

Aerosols are defined as the suspended particles in the atmosphere having solid or liquid phase over a wide range of sizes extending from 10^{-3} µm to 10^3 µm. Aerosols affect the climate in several ways. They can influence the Earth's radiation budget directly and indirectly. They can also have adverse impact on human health, materials and visibility. Recently the concentrations of atmospheric aerosols of anthropogenic origin appear to have increased (Satheesh et.a.,2006, Ritweej et al. 2007a, 2007b). The optical properties of the aerosols are effectively characterized by their chemical composition and size distribution, while the physical properties are strong functions of their sources. One of the most important parameters of aerosol characterization is the size distribution of particles. Atmospheric aerosols produced as a result of both natural and anthropogenic processes are essentially poly disperse having sizes ranging from10^{-3} µm to 10^3 µm. Within this size range the number of particles varies with particle size. A clear knowledge of the nature of this size distribution at any location is important not only to characterize the atmospheric aerosol system over that location, but also to study their various effects. There have been many observational results concerning particle size distributions which have been complied for several typical models and which include multimodal, bimodal, Junge and log normal distribution. Bimodal size distribution is frequently employed to describe the optically effective size range. It consist of an accumulation mode (small size) and a coarse mode (large size) particles which are associated with different sources of the particles.

The small mode may be formed through gas to particle conversion processes and is also called a secondary particle mode. The aerosols in this mode vary widely in concentration in the lower troposphere close to the surface and are optically effective for visible light. Moreover, they may contain the primary particles such as carbon particles from human activities. On the other hand, the large mode may mainly be formed by primary particle such as soil derived particles, sea salt particle etc. The processes which are responsible for various size distributions include biomass burning

combustion of fossil fuel from urban industrial sources, volcanic eruptions, wind blown soil particles etc (Subbaraya et.al., 2000; Satheesh et.a.,2006). The Indian Ocean Experiment (INDOEX) conducted above the Indian Ocean was the most ambitious research project so far in India in this field. A primary goal of INDOEX was to quantify the direct and the indirect aerosol forcing from observations. The INDOEX observations were made over the tropical Indian Ocean during the Northern Hemisphere dry monsoon (December to April). Since 1996, an international group of scientists has been collecting aerosol, chemical and radiation data from ships, satellites and surface stations. This culminated in a major field experiment with five aircraft, two ships, several satellites and numerous surface observations conducted during January through March, 1999.

With a view to examining seasonal variations in columnar aerosol size distribution in a typical semiarid urban environment, the aerosol optical depth measurements data have been taken from Department of Physics, Saurashtra University, Rajkot, for a period of two years (March 2005-07). The results of the study has been presented and discussed here.

2. Methodology

Hourly AOD measurements were made using a MICROTOPS II sun photometer whenever sky was clear from March 2005 to March 2007. MICROTOPS II is a portable sun photometer with five filters to measure the instantaneous AOD from individual measurements of direct solar radiation (Morys et al., 2001). Geographical latitude, longitude and altitude of the site of measurement are collected using global positioning system (GPS) receiver. One instrument (version 5.5) is capable to measure AOD at five different wavelengths centered about 380, 440, 500, 675 and 870 nm. AOD at 1020 nm is measured using the other version 2.43 of the same instrument.

Typically during a clear sky day, the number of observations was in the range of 8 to 10. The number of days of observations during dry season (November to May) was in the range 20 to 25, but during the rest of the year (except july and august) the number of days of observations was in the range 10 to 15 restricted by the sky conditions.

To investigate the seasonal features more quantitatively, the complete data is regrouped in terms of seasons so that much of the shorter period fluctuations are smoothed out. For the above purpose three seasons are considered namely summer/pre-monsoon seasons from March to June, monsoon/rainy season from July to October and a rather dry winter season from November to February.

Angstrom parameters are used to characterize the AOD. These parameters were determined using angstrom formula (Angstrom, 1961) given by

$\tau(\lambda) = \beta\lambda^{-\alpha}$ .....(1)

where α is wavelength exponent related to the size distribution of the scattering particles and β is the turbidity coefficient related to the total aerosol content.

Having obtained AOD at different wavelengths, aerosol size distribution (ASD) can be determined by following the inversion scheme suggested by King et al (1978) which connects the AOD and ASD as

$$\tau_a(\lambda) = \int_0^\infty \pi r^2 Q_{ext}(r,\lambda,m) n_c(r) dr \qquad \text{.....(2)}$$

where r is the particle radius, m is the complex refractive index of aerosol particles; $Q_{ext}(r,\lambda,m)$ is the Mie extinction efficiency parameter, $n_c(r)$ is the columnar aerosol size distribution (the number of particles per unit area per radius interval in a vertical column through the atmosphere).

In the complex refractive index, the real quantity represents contribution due to particulate scattering while the imaginary quantity denotes the particles absorption. In the present analysis the imaginary component of m is assumed to be negligible as this value at present is very small for the aerosol particles present over the experimental station.

Since n(r) cannot be written analytically, a numerical approach is followed to separate $n_c(r)$ into two parts as $n_c(r)=h(r).f(r)$, where h(r) is rapidly varying function with r and f(r) is slowly varying function. Hence the above equation changes to

$$\tau_a(\lambda) = \sum_{j=1}^{q} \int_{r_j}^{r_{j+1}} \pi r^2 Q_{ext}(r,\lambda,m) h(r) f(r) dr \ \ldots\ldots..(3)$$

in the above equation , the quadrature error will be less if f(r) is assumed to be constant. In that case , a system of linear equations results, which may be written as

$$\tau_a(\lambda) = Af(r) + \varepsilon \quad \ldots\ldots\ldots(c)$$

where $A = \int \pi r^2 Q_{ext}(r,\lambda,m) h(r) dr$

and ε is an error which arises due to deviation between the measured τ_a and theoretical $\tau_a (= \sum A_{ij} f_i)$. Initially, Junge exponent (ν) is computed from the wavelength dependence of AOD (i.e., $\nu = \alpha+2$) and used as zero-order weighting function $h^0(r)$ as an initial guess, first order $f^{(1)}$ values are evaluated using the equation

$$f^{(1)} = (A^T S_\varepsilon^{-1} A + \gamma H)^{-1} A^T S_\varepsilon^{-1} \tau_m \ldots(4)$$

where γ is non–negative Langrangian multiplier and S_ε is the measured covariance matrix, H is a mean diagonal matrix and superscript T denotes matrix transposition. This iteration procedure is repeated till the observed τ_a comes closer to the re-computed τ_a.

Columnar ASD and effective radii of dominated aerosols are estimated for different months (data collected during quite and stable days are taken into consideration).

3. Results and Discussion

The seasonal variation of AOD at six wavelengths has been studied over the period March 2005 to March 2007.

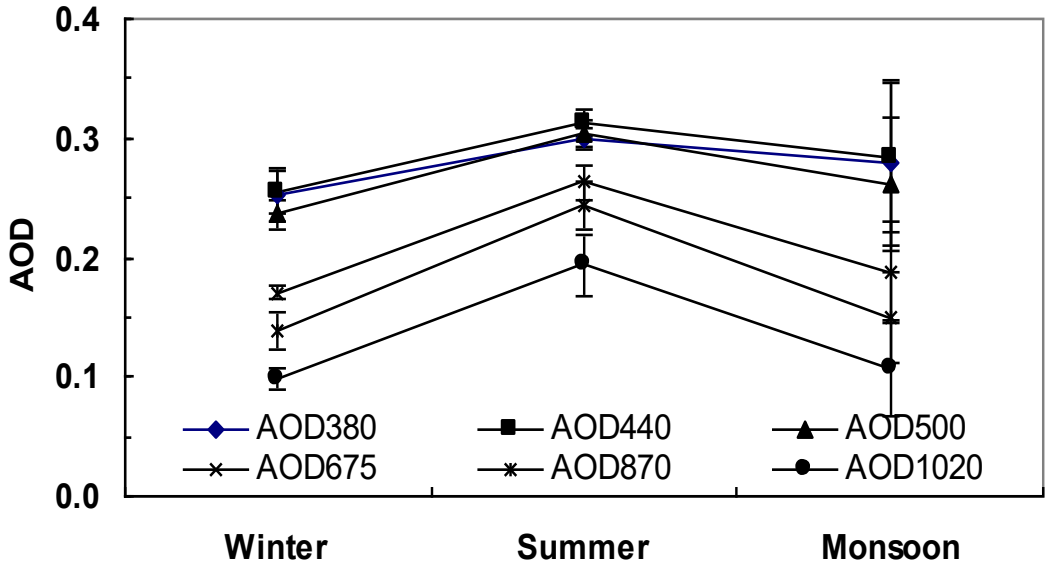

Figure-1: Seasonal variation of AOD at six wavelengths from 380 nm to 1020nm.

Figure-1 shows the variation in seasonally averaged aerosol optical depth which clearly reveals a peak occurring during summer and a deep minimum in winter. Vertical bars in Figure-1 represent standard deviations of the seasonally mean AOD.

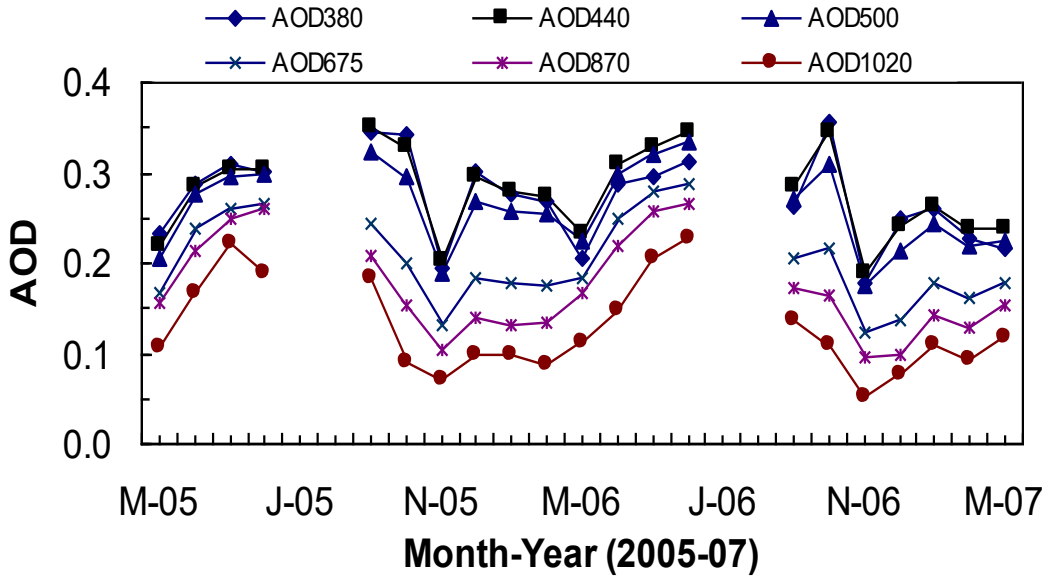

Figure-2: Monthly variation of AOD at six wavelengths from 380 nm to 1020nm.

Figure-2 shows month-to-month variation of AOD at different wavelengths. Variation is more at shorter wavelengths. The monthly variation exhibits secondary peak like coastal Indian stations. The above picture is more or less consistent at all the wavelengths and in both the years.

Table 1 - Average columnar aerosol optical depth(AOD), Angstrom's wavelength exponent (□) nd turbidity coefficient (□) over Rajkot for the Year 2005-07

Wavelength	Jan	Feb.	Mar.	Apr.	May.	Jun.	Sep.	Oct.	Nov	Dec.
380 nm	0.270	0.247	0.218	0.288	0.303	0.307	0.305	0.349	0.186	0.276
440 nm	0.271	0.256	0.226	0.297	0.316	0.324	0.318	0.336	0.196	0.268
500 nm	0.250	0.236	0.215	0.288	0.308	0.317	0.298	0.303	0.182	0.242
675 nm	0.178	0.168	0.175	0.243	0.270	0.277	0.226	0.209	0.128	0.161
870 nm	0.138	0.132	0.162	0.217	0.252	0.262	0.192	0.160	0.100	0.119
1020 nm	0.105	0.091	0.111	0.158	0.215	0.207	0.160	0.100	0.062	0.087
□	0.990	1.026	0.638	0.571	0.354	0.381	0.706	1.223	1.102	1.199
□	0.116	0.106	0.131	0.183	0.230	0.231	0.170	0.121	0.076	0.097
Eff. Radius(□m)	0.39	0.37	0.45	0.45	0.52	0.52	0.46	0.33	0.37	0.35

From Table-1 it is clear that AOD is maximum in April to June (~0.31 at 400 nm) and minimum during November to March (~0.24). At lower wavelength (□<0.6□m), AOD was always greater than 0.18 (for the entire data period) when compared to the longer wavelength region (□>0.6 □m) where the lowest AOD was around 0.06. Steady increase in AOD from March to June, seen consistently in the data, could be attributed to the dry conditions prevailing over the station. Meteorological condition could be the main reason for the observation of relatively higher increase in AOD at higher wavelengths and urban activity could be the main reason for the observation of relatively higher optical depth at lower wavelengths.

Generally monsoon is active over Rajkot form mid June and clouds are seen till October. Most of the month sky is almost clear.

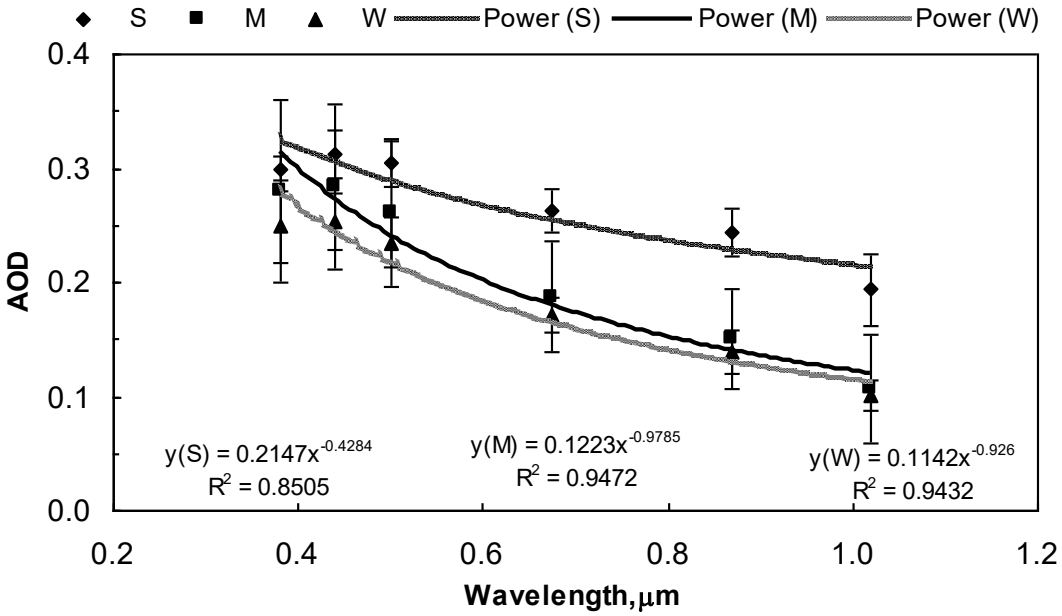

Figure-3: The spectral variation of aerosol optical depth in different seasons (S-Summer, M-Monsoon and W-Winter).

Figure-3 shows the wavelength dependence of AOD in different season. Spectral dependence of AOD is higher at smaller wavelengths and vice-versa.

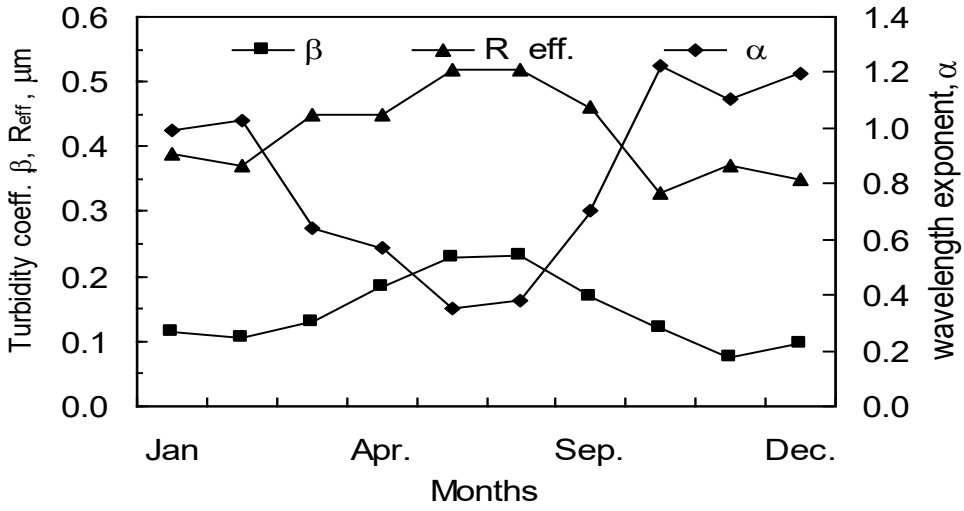

Figure-4: Monthly variation of Turbidity coefficient (□), effective radius (R_{eff}) of dominant aerosol particles and wavelength exponent (□).

Monthly variations in effective radius and Ångström parameters (α & β) are plotted in Figure-4. Effective radius is high (~0.52) micron in summer and low (~0.35) micron in winter and monsoon. Wavelength exponent (α) is low (~0.35) in summer and high (~1.20) in winter. Turbidity coefficient (β) is high (~0.23) in summer and low (~0.09) in winter. The low value of wavelength exponent (α) and high value of turbidity coefficient (β) indicate abundance of coarse-mode aerosols (originating from marine air mass and wind blown dust) particles with greater extinction during summer season (April, May and June) due to local meteorology and vice-versa in winter and

monsoon (Devara et al., 20005). This result is also consistence with the effective radii estimated for different months. Consistency among these parameters, angstrom parameters and effective radii is seen during the whole year.

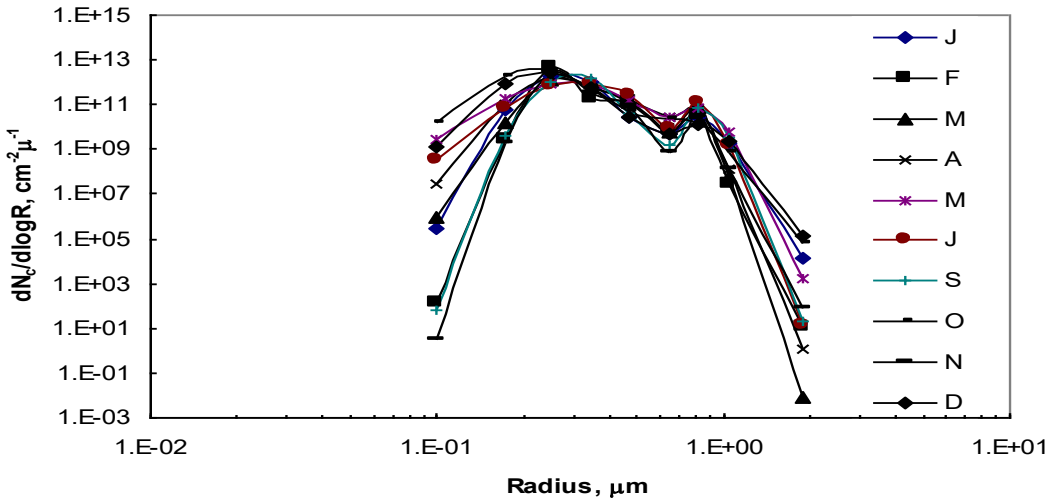

Figure-5: Average aerosol number-size distribution from January to December.

Figure-5 shows the size distribution of aerosol particle in different months. The aerosol size spectra show bimodal distribution indicating the presence of both marine and land aerosols. The dominance of accumulation-mode particles in summer represents more aerosols of land origin.

4. Conclusions

1. Meteorological condition could be the main reason for the observation of relatively higher increase in AOD at higher wavelengths and urban activity could be the main reason for the observation of relatively higher optical depth at lower wavelengths.
2. Effective radius is high ~0.52 micron in summer and low ~0.35 micron in winter and monsoon.
3. Aerosol number-size distribution is bimodal over Rajkot with maximum concentration of particles at primary mode around 0.52 □m (in summer) radius and secondary mode around 1.0 □m particles of fairly high concentrations indicating the presence of both marine and land aerosols. Smaller wavelength exponent (□) and larger Ångström turbidity coefficient (□) indicating abundance of larger aerosol particles with greater extinction in summer and vice versa in winter also confirms this.
4. Sharp fall in AOD during monsoon is considered to be due to cloud –scavenging and rain wash-out processes.

Acknowledgments

We are thankful to Prof. K. N. Iyer Former Head of Department of Physics, Saurashtra University, Rajkot and Prof. H. P. Joshi, Department of Physics, Saurashtra University, Rajkot, for providing me aerosol data, valuable discussions and suggestions.

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