Site Specific Aerosol Optical Thickness Characteristics over Mysore

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Abstract

As a part of Indian Space Research Organization's RESPOND programme, a study has been carried out on clear sky days of the winter months December 2005 and January 2006. Spectral Aerosol Optical Thicknesses (AOT) were measured with a MICROTOPS II sun photometer at four sites of specific topography: a hill top, busy downtown, a calm water bed, and university campus with greenery. These sites are situated within the urban agglomeration of Mysore, a low latitude (12.3°N) continental location. Daytime decreasing trend in AOT was observed. Forenoon-afternoon asymmetry was exhibited at all the sites. These features were also found to be site-specific in nature. The present work focuses on the characteristics of atmospheric aerosols at different sites located in and around Mysore City. The future interest is to cover some more sites around Mysore City having varied aerosol characteristics.

Keywords: Atmospheric aerosols; AOT; Asymmetry factor.

INTRODUCTION

Earth's atmosphere is an envelope of gases surrounding the globe. Many natural phenomena, such as meteors, volcanic eruptions, sand storms, ocean spray, forest fires, and the green world, inject the atmosphere with particulate matter. Contributing on a lesser scale are anthropogenic activities, such as industry, use of internal combustion engines, construction activities, etc. Particulate matter, either insolid or liquid form, depending on the size, remain suspended in the air occupying less than one percent by volume. Such particles constitute the world of aerosols (d'Almeida *et al.*, 1991).

Being an important minor constituent in the atmosphere, aerosols play an important role in Earth's climate system and the global biogeochemical cycle (Duce, 1995; Sokolik and Toon, 1996). They interact with solar and terrestrial radiation and influence the energy balance of the Earth-atmosphere climate system. Increasing human activities will affect the energy balance (Andreae, 1995; Subbaraya *et al.*, 2000). The effects of aerosols in the atmosphere remain largely uncertain due to the poor understanding of

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aerosol properties and their spatial and temporal variations (IPCC, 2001). Dependent upon their chemical composition, aerosols interact with incoming radiation, and hence, affect the atmospheric radiation budget. In recent years, it has been realized that aerosols have a potential to induce changes in climate not only due to major volcanic eruptions, such as the El Chichón and Mt. Pinatubo, but also due to the impact of ever-increasing anthropogenic activities. For example, subsequent to major volcanic eruptions like El Chichón (Hoffman, 1987: Hoffman,1988) and Mt. Pinatubo (Dutton and Christy, 1992; Labitzke and McCormick, 1992) transmission of direct solar radiation to the lower atmosphere and the earth's surface could be reduced by as much as 15%, with a rather slow recovery time on the order of a year or more (Torres *et al.*, 1995). This can cause a global cooling of 0.5 to 1 K (Ackermann, 1988), while there can be a warming at lower stratosphere levels by about 3 to 4 K (Labitzke *et al.,* 1983). There are suggestions that major volcanic eruptions can induce climatic instabilities (Reiter, 1988).

Aerosols also play a significant role in chemistry and ionization phenomenon in the middle atmosphere. They provide the surfaces for heterogeneous chemistry (between gas and liquid, or gas and solid) which in recent years has been found to be the dominant process responsible not only for the Antarctic and Arctic ozone holes, but also for the global ozone depletion (Hoffmann and Solomon, 1989). Aerosols act as the condensation nuclei in the formation of fog, mist and clouds. These clouds form an important component of the Earth-atmosphere climate system. Hence, the study of aerosols constitutes an important component of atmospheric science research. Tropospheric aerosols are short-lived due to gravitational settling and rain washout, and produce only local and seasonal effects. They are largely dominated by mineral dust, soot and water droplets (McCartney, 1976).

Aerosols exist over a wide range of scale sizes, extending from 10^{-4} μ (1 μ = 10^{-4} cm) to about 100 μ. Depending upon their sizes, they are classified by Junge (1963): Aitken nuclei (10^{-4} μ to about 10^{-1} μ), large particles (10^{-1} μ to about 1 μ) and giant particles (1 μ to about 100 μ). These size ranges are also termed respectively as nucleation, accumulation and coarse mode (Whitby, 1978). Aerosols of different sizes take part in different atmospheric phenomena. For atmospheric radiation budget and climate studies, the aerosols of interest—the so called optically active aerosols—are in the size range $0.05\ \mu \leq r \leq 5\ \mu$. In a clear atmosphere without clouds, aerosols govern absorption, scattering and reflection of solar radiation (Preining, 1991). Atmospheric extinction for any given site depends strongly on the location of that site and the nature of its surroundings (Robert *et al.*, 1973). It has been further established that atmospheric aerosols exhibit characteristics dependent on spatial features, such as altitude, water bodies, vegetation (McCartney, 1976; Iqbal, 1983). This paper presents the study of aerosols at a low latitude, where a portable sun photometer was used to carry out experimental observations. Data were collected at different sites, each having specific topographic features. Analysis of the data produced site-specific aerosol characteristics. Similar type of work was carried out by Suresh & Elgar (2005) for the coastal site Dona Paula on the west coast of India.

THEORY

Solar radiation traversing through the terrestrial atmosphere undergoes extinction due to three processes. Rayleigh scattering by air molecules, Mie scattering by aerosols, and molecular absorption. Solar radiation is a composite of monochromatic radiations, each of wavelength λ. Spectral flux F_λ reaching the ground is related to the extra-terrestrial solar flux $F_{0\lambda}$ through the Bouguer-Lambert-Beer law.

$$F_\lambda = F_{0\lambda} \left(\frac{r_0}{r} \right)^2 \exp\left(-mT_\lambda\right) \qquad (1)$$

In this equation, r_0 and r are the sun-earth distances, mean and the actual, respectively; m is the relative air mass which in terms of solar zenith angle χ becomes $m = \sec \chi$; and the last term T_λ is the integrated columnar extinction, also referred to as total optical depth/thickness. The flux F_λ is being generally measured with a sun photometer, the output is an electrical signal of voltage V, volts proportional to the flux. Replacing F by V and on logarithmic scale, the Eq. (1) is linearized as:

$$\ln V_\lambda = \left[\ln V_{0\lambda} + 2 \ln \left(\frac{r_0}{r} \right) \right] - mT_\lambda \qquad (2)$$

The graphical representation of this equation is referred to as Langley plot. Zero air mass intercept determined from the intercept, serves as a calibration constant. The total optical depth T_λ is given by the slope. By subtracting the contributions due to Rayleigh scattering and molecular absorptions from T_λ aerosol optical thickness (AOT) τ_λ is determined. All these calculations are done instantly by the built-in algorithm in the MICROTOPS II. In order to obtain instantaneous value of AOT, the calibration constant is pre-determined and linearized with the signal voltage at any instant.

LOCATION FEATURES

Mysore (12° 19′ N and 76° 39′ E) situated at an altitude of 767 m above sea level on the Deccan Plateau of Peninsular India is a low-latitude station. On the east, west and south, about 300-500 km away, are the Bay of Bengal, Arabian Sea and Indian Ocean, respectively. To the north lies the Asiatic continent. Geographic climate is moderate. In any year, the period June to November receives monsoon rains, which account for 73% of the average annual rainfall of 760 mm. Following the rainy season, winter prevails December through February. During this season the temperature is low and the rainfall is about 3%. The hot summer months of March through May account for 24% of the year's rainfall. An overall range of temperature of the year lies between 18-36℃.

To study site-specific features of aerosol within the district of Mysore, four sites were selected, each with specific topography:

Site 1: Sri Chamundi Hills (CHH)

Situated southeast of Mysore.

The height of the Hill is about 300 m from ground level.

Site 2: K.R. Circle (KRC)
Bustling anthropogenic activity with vehicular traffic.

Site 3: Kukkara Halli Lake (KHL)
A calm water bed having an area of about 1 km^2.

Site 4: Manasagangotri, Mysore (MGM)
University of Mysore campus spread over 400 hectares of abundant greenery.

INSTRUMENTATION

In order to measure AOT at different wavelengths, a hand-held multi-band sun photometer MICROTOPS II developed by Solar Light Company, USA (2002) was used. The instrument is equipped with five accurately aligned optical collimators, with a full field view of 2.5°. Internal baffles are integrated into the device to eliminate internal reflections. Each channel is fitted with a narrow-band interference filter and a photodiode suitable for the particular wavelength range. The MICROTOPS II used in this study has optical filters transmitting the radiation centered at wavelengths of 440, 500, 675, 936 and 1020 nm. The collimators are encapsulated in a cast aluminum optical block for stability. A sun target and a pointing assembly are permanently attached to the optical block and laser-aligned to ensure accurate alignment with the optical channels. When the sun's image is centered in the bull's-eye of the sun target, all optical channels are oriented directly at the solar disk. Radiation captured by the collimator and band pass filters reaches the photodiodes, producing an electrical current that is proportional to the radiant power intercepted by the photodiodes. The current is first amplified and then converted to a digital signal by a high-resolution analog-to-digital converter. The signals from the photodiodes are processed in series. However, with 20 conversions per second, the results can be treated as if the photodiodes were read simultaneously. Optical depth from other processes, such as O_3 and NO_2 absorption, are ignored in MICROTOPS II. The precipitable water column is determined based on measurements at 936 nm (water absorption peak) and 1020 nm (no absorption by water). The calculation algorithms programmed into the photometer incorporate the pre-determined calibration constants, one for each wavelength and the contribution due to Rayleigh scattering and molecular absorption. The results of all stored scans can be conveniently viewed on the LCD. Raw data are also stored to allow retrospective adjustments of calibration constants.

CALIBRATION

The instrument was calibrated at regular intervals. The degradation of the filters (except 440 nm) or the drift in the calibration values were found to be marginal. The calibration was carried out atop Sri Chamundi Hills which is at a height of about 300 m from the ground using the standard Langley technique. The calibration constants obtained from the data collected atop the hill did not show any large variations from the values obtained from the calibrations at factory.

EXPERIMENTAL

Initially, several MICROTOPS II settings were made with the help of a GPS (Global Positioning System) receiver. These included universal date and time, geographic coordinates, altitude and atmospheric pressure of the measurement site. For the observations, the MICROTOPS II was mounted on a tripod in order to minimize sun-targeting error.

Measurements were made on days with clear skies and no clouds. Data were collected during 04:00-12:00 hrs UT (09:30–17:30 hrs, IST) at 15-30-minute intervals. Each set of data contains five values of spectral AOT and one value of water vapor. Experimental observations were carried out on individual days at different sites. Care was taken during the collection of data so as to avoid the strong seasonal effects such as strong wind, cloudy sky, drizzle. Comparative studies of the sites are thus made under similar conditions.

RESULTS AND DISCUSSION

AOT characteristics

Figs. 1-4 show the diurnal variation of average AOT for the winter months December 2005 and January 2006 at five wavelengths. From the graphs, one can observe that starting from a high value in the early hours, AOT decreases continuously as the day advances in all the cases. During forenoon (*FN*), the decrease is rather high, whereas it is not so large in the afternoon (*AN*)..This type of variation can be seen distinctly at sites other than CHH where the *FN* values are slightly higher than those of *AN*. Shaw (1976) attributes the morning high values to the anthropogenic activities: “AOT would increase in the morning hours as urban pollutants are emitted under a capping radiative inversion. By noon or shortly after, the radiative inversion normally starts to break up under the action of solar heating, thereby allowing the early morning trapped pollutants to be ventilated out of the city by convection.” Furthermore, the increasing temperature gives rise to larger water content in the atmosphere.

The coalescing process results in aerosols of appropriate size for the scattering of solar radiation. While these processes increase AOT in the *FN*, reduced anthropogenic activity, together with less water vapor content due to lowering of temperature, are the causes for smaller AOT in *AN*.

Figs. 1-4 clearly show that during daylight hours, the AOTs at KRC are the highest, and at CHH, the lowest. For a quantitative description, the AOTs are averaged for *FN* and *AN* separately. The values are given in the Table 1. Average AOT versus wavelength plots are shown in Figs. 7 and 8. It may be noticed that the AOTs of the sites differ largely at shorter wavelengths and the difference becomes smaller as the wavelength increases. This is in accordance with the power law operating between the parameters, AOT and the wavelength. The high values of AOT at KRC, which were the highest of all the sites under study, can be attributed to large-scale anthropogenic activity with high vehicular traffic. A cleaner atmosphere at higher altitude is responsible for the AOT being least for CHH. For all the wavelengths, the AOT is higher during *FN* than in the *AN*. A clear demonstration of this

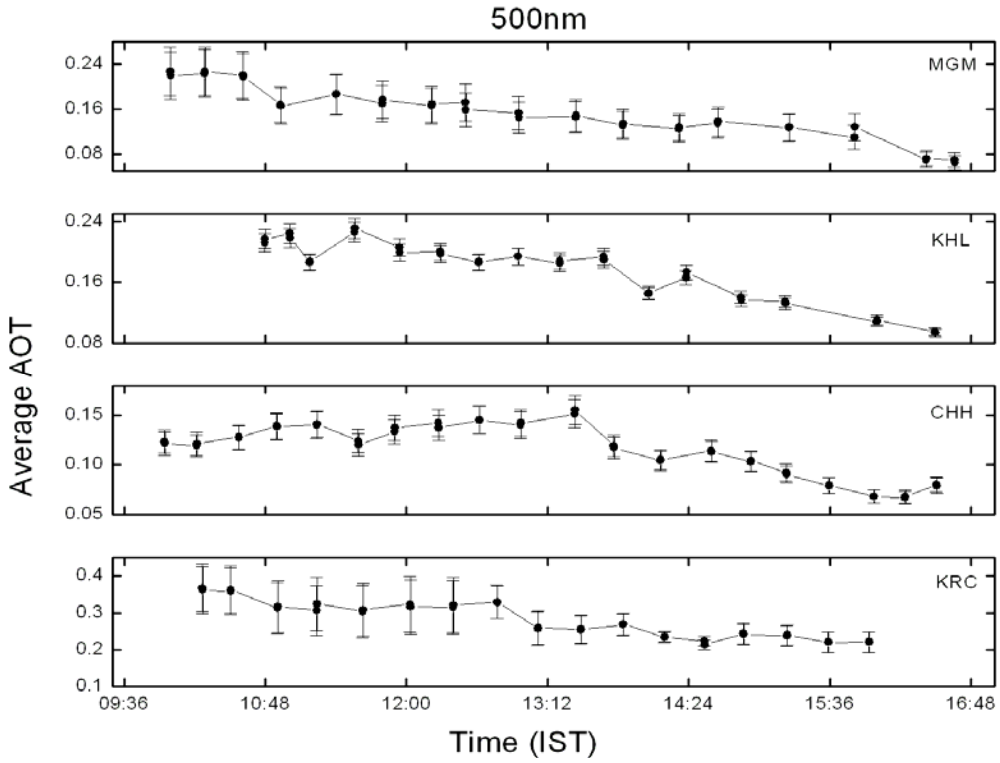

Fig. 1. Spectral variation of site specific average AOT.

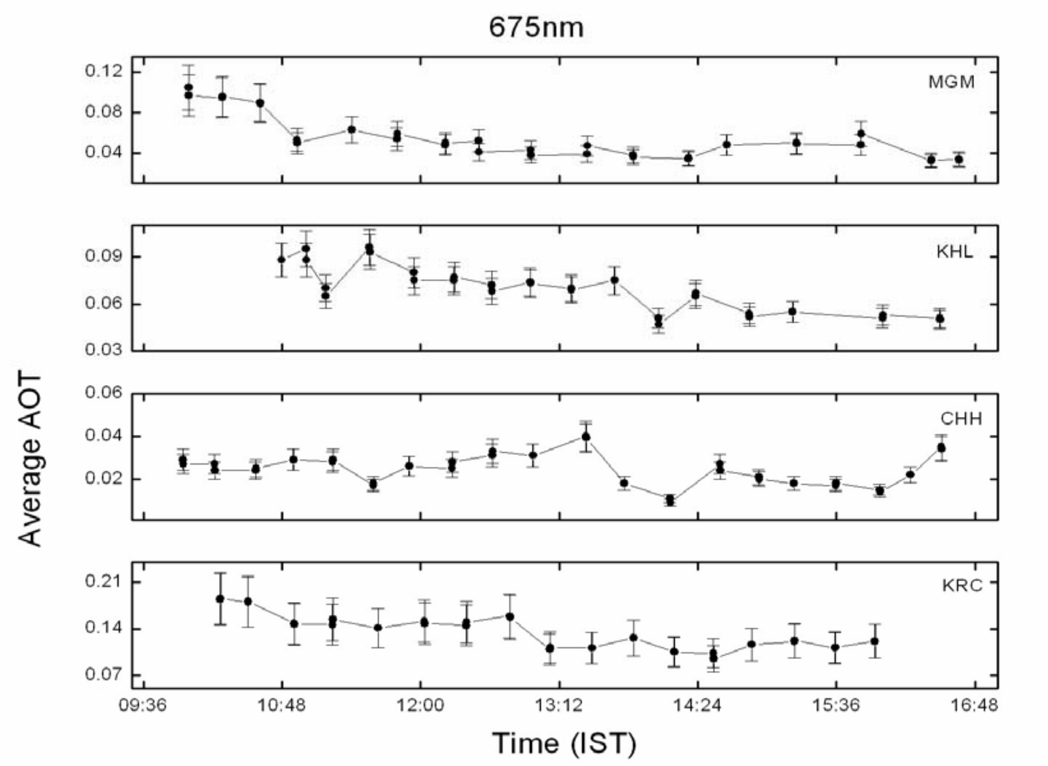

Fig. 2. Spectral variation of site specific average AOT.

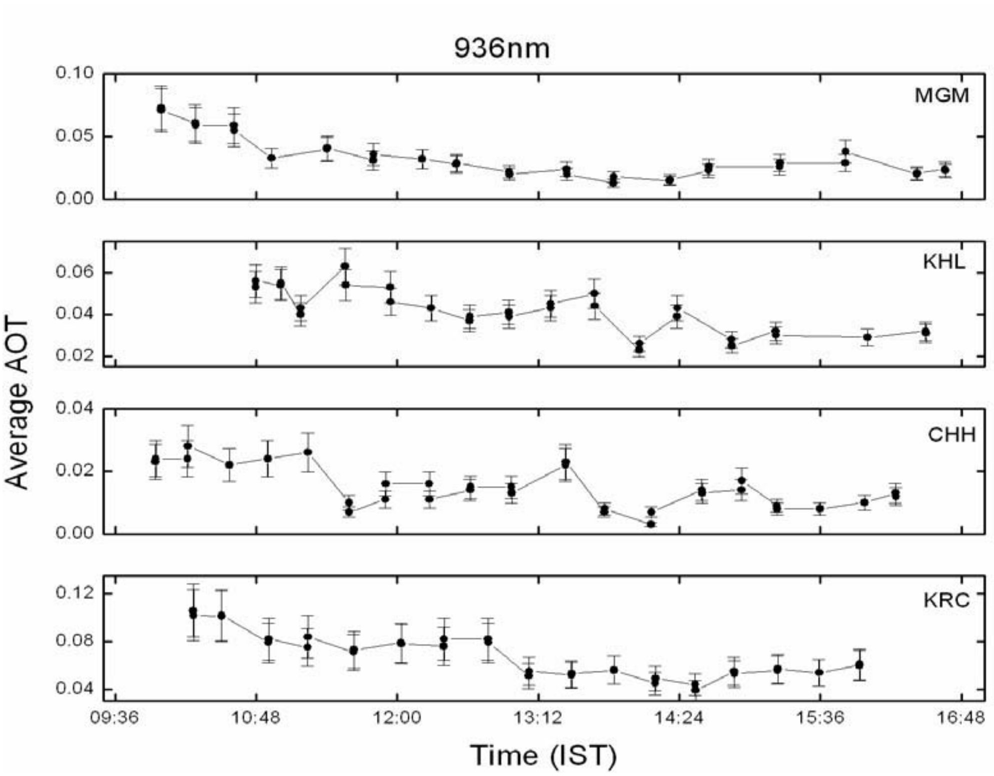

Fig. 3. Spectral variation of site specific average AOT.

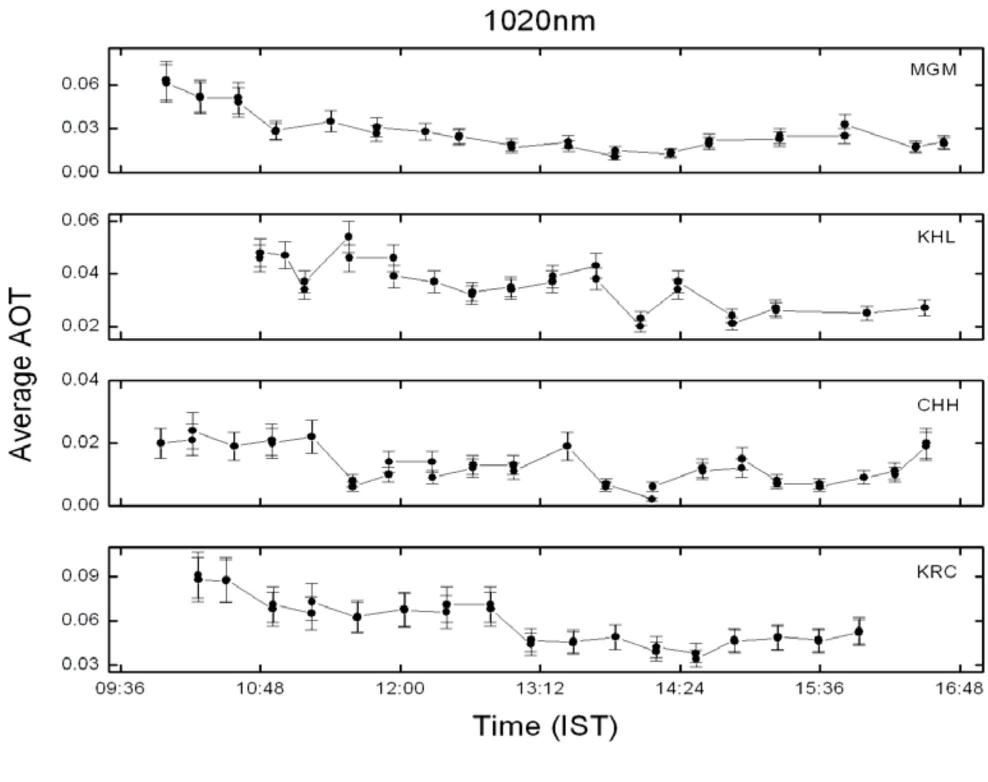

Fig. 4. Spectral variation of site specific average AOT.

scenario can be seen in Fig. 4 for 1020 nm. During *AN*, particulate density decreases due to the depletion resulting from condensation caused by lowering of temperature and subsequent gravity settling.

Referring to the graphs of MGM and KHL in Figs. 3 & 4, it can be seen that the MGM-AOT's are lowered to a larger extent in *AN* than in *FN*. Foliage-produced organic aerosols are predominant on the campus abundant with greenery. During *AN*, because of reduced sun-light, aerosol production decreases resulting in AOT being lowered (McCartney, 1976; Rasmussen and Went, 1965; Went, 1955). Also

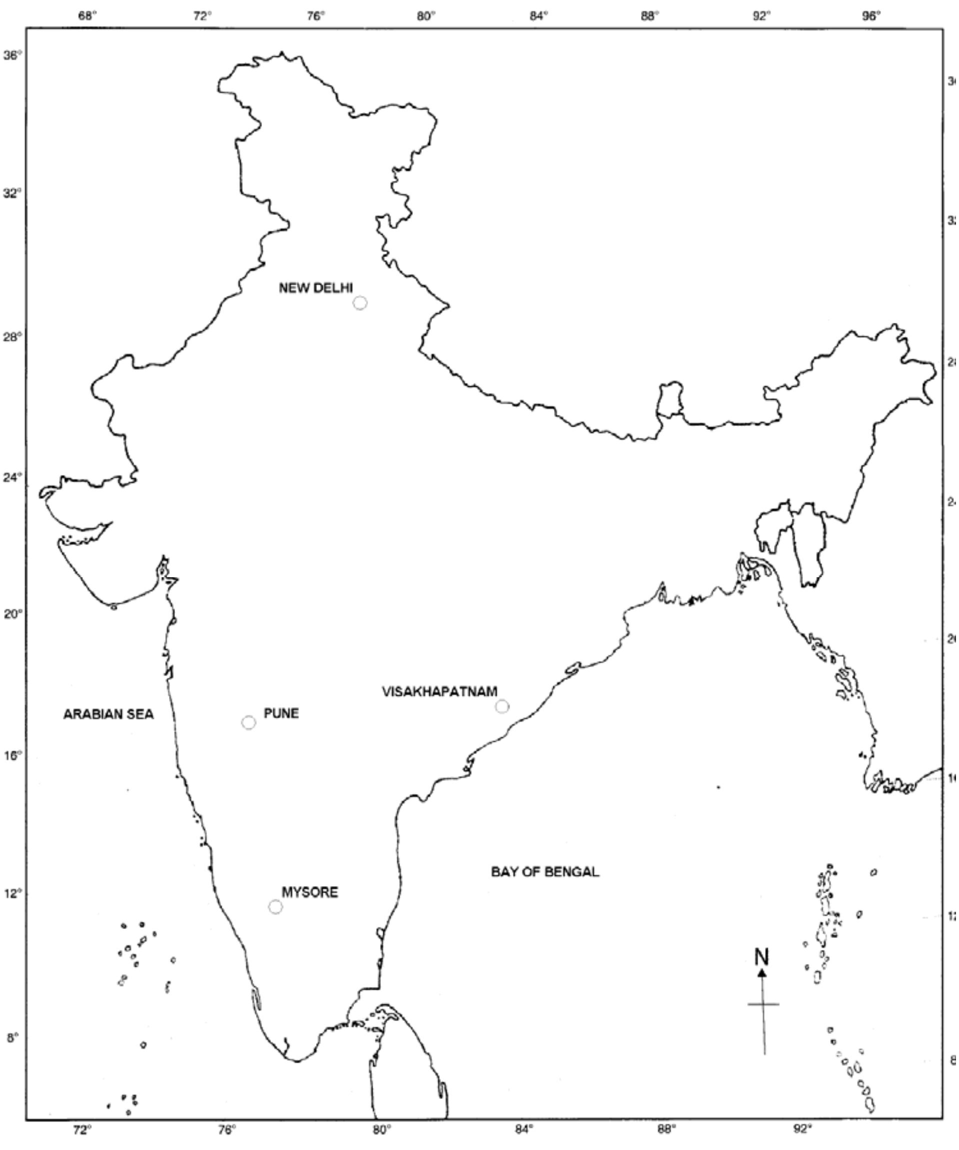

Fig. 5. Geographic identity of Mysore.

KRC

KHL

CHH

MGM

Fig. 6. Site-specific snapshots.

Table 1. Average values of AOT for *FN* & *AN*.

Site	500 nm		675 nm		936 nm		1020 nm	
	FN	*AN*	*FN*	*AN*	*FN*	*AN*	*FN*	*AN*
CHH	0.132	0.103	0.026	0.021	0.019	0.011	0.016	0.010
KHL	0.208	0.154	0.082	0.061	0.050	0.035	0.043	0.030
MGM	0.191	0.120	0.069	0.041	0.045	0.023	0.039	0.020
KRC	0.327	0.247	0.157	0.118	0.085	0.055	0.073	0.048

the concentration of small-sized aerosol reduces due to meteorological factors. Thus at smaller wavelengths, the AOT gets lowered to a larger extent. This explains the difference in AOT observed at KHL and MGM.

Forenoon (FN)-Afternoon (AN) asymmetry

Large difference between the AOT values of *FN* and *AN* is said to be the asymmetry of AOT. The extent of asymmetry varies with the site, as well as with the wavelength, as is evident from the graphs. For a quantitative study, a symmetry factor η_λ is defined through the expression

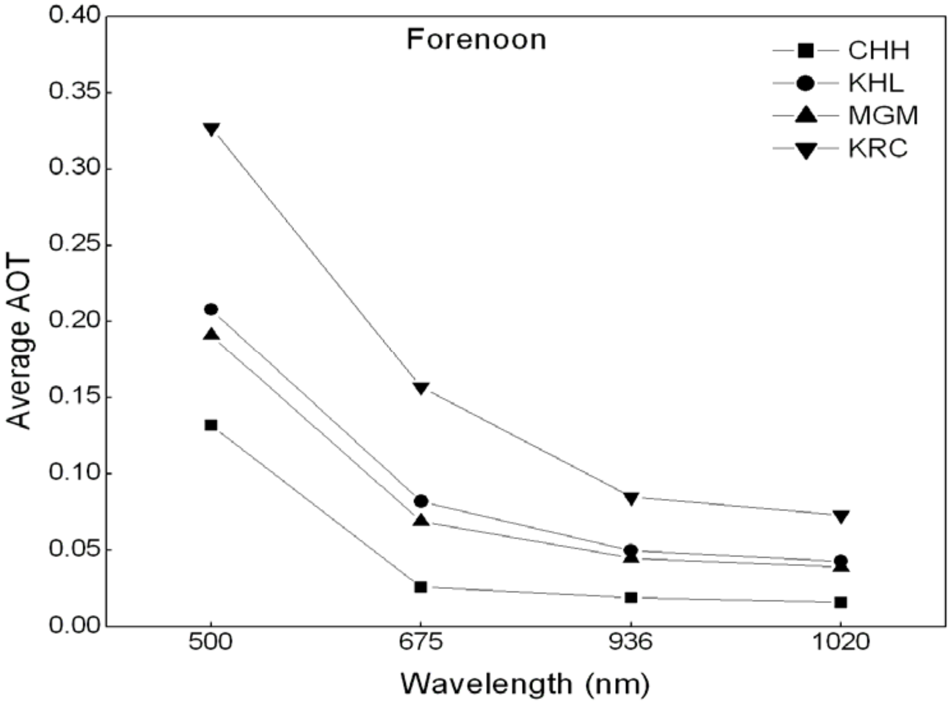

Fig. 7. Variation of average AOT with wavelength for forenoon.

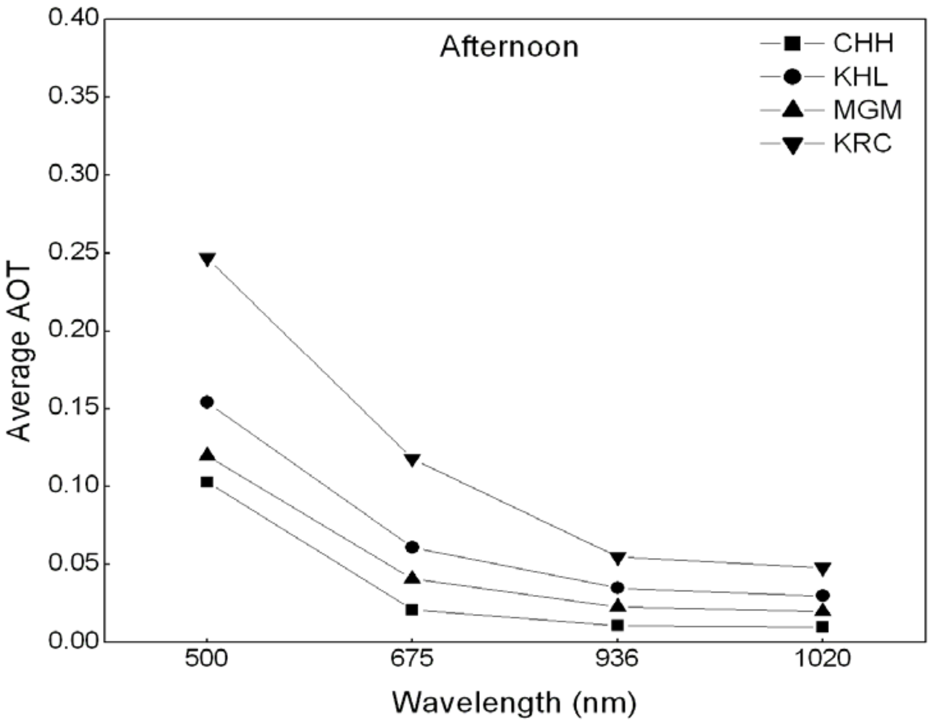

Fig. 8. Variation of average AOT with wavelength for afternoon.

Table 2. Asymmetry factor.

Site	Asymmetry factor (η) %			
	500 nm	675 nm	936 nm	1020 nm
CHH	21	15	37	38
KHL	26	26	30	30
MGM	37	40	49	49
KRC	24	25	34	34

$$\eta_\lambda = \left[\frac{\tau_{FN} - \tau_{AN}}{\tau_{FN}} \right] x\, 100 \qquad (3)$$

where τ_{FN} and τ_{AN} are the average AOT for *FN* and *AN*, respectively, at wavelength λ. The asymmetry in AOT for *FN* and *AN* observed at different locations in and around Mysore can be accounted for in terms of water vapor content in the atmosphere. Due to low temperature in the morning hours, water vapor is in the condensed form, while a part of it will be condensed on aerosols, also. Particle growth due to water-vapor condensation results in increased solar extinction. On the other hand, due to the increase in temperature during *AN*, evaporation takes place, and thereby water droplets will decrease in concentration and size, resulting in reduced extinction.

Table 2 gives the asymmetry factors for the studied sites. The campus has the highest asymmetry factor followed by Hill and Lake. The least asymmetry factor corresponds to KRC. At longer wavelengths, asymmetry tends to be more when compared to shorter wavelengths. At the longer wavelengths of 936 nm and 1020 nm, the asymmetry factors do not exhibit much difference. This indicates the prevalence of aerosols of a discrete size spectrum (Krishna Moorthy *et al.*, 1999). The difference exhibited at shorter wavelengths can be attributed to anthropogenic activities and to the plant kingdom.

CONCLUSION

It has been observed that AOT values decrease continuously starting from a high value as the day advances. This scenario was found to be exhibited at all the observation sites. During *FN*, the decrease was rather high compared to *AN* except for the location, CHH. Because of the capping action of aerosols generated during the previous night, the *FN* AOT did not show a rapid decrease at CHH. Of all the sites under study, highest AOT was observed at KRC because of large-scale anthropogenic activities and high vehicular traffic. Asymmetry in the *FN* and *AN* values of AOT was observed at locations selected for the study. The observed asymmetry was also found to vary with wavelength.

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