Diurnal and Seasonal Variation of Spectral Properties of Aerosols over Dehradun, India

Sapna Rana, Yogesh Kant[*], V.K Dadhwal

Indian Institute of Remote Sensing (NRSA), Dept. of Space, Govt. of India,

4 Kalidas Road, Dehradun

Abstract

The diurnal variation of Aerosol Optical Depth (AOD) and its spectral properties over non-cloudy days in summer and winter seasons of two years are studied. Spectral dependence of AOD shows higher values at shorter wavelengths which decreases gradually towards longer wavelengths for the summer as well as the winter period. Results suggest that during high relative humidity and stable conditions, the AOD is found to be relatively low (clear day) as compared to unstable meteorological conditions (turbid). Air mass back trajectory for 5 days of high and low AOD in March indicate that the sources of loading come from far to the west in central Asia, whereas during winter, the sources are from east and south-east direction in the Indo-Gangetic plain. The diurnal variation of Ångström exponent (α) has lowest values in the morning hours with a variation of around 5-17% for clear day and around 11-20% for turbid day, signifying the presence of larger particles. Due to inversion more fine particles lead to an increase in the α value. The intraseasonal variability in March (summer) is high and interseasonal variation in January (winter) is not observed and is also confirmed by 'α' values. Size distribution of aerosols showed peak loading ranging around a 0.07 μm radius. Aerosol loading on turbid days was due to fine mode particles and the simultaneous presence of fine- and coarse-mode particles on clear days.

Keywords: Aerosol optical depth; Multi wavelength solar radiometer; Ångström turbidity parameters; Size distribution; Effective radius.

INTRODUCTION

Atmospheric aerosols are major climatic forcing agents. During recent years, there has

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[*]Corresponding author: Tel: +91-135-2740737

 Fax: +91-135-2740785

 E-mail address: ykanty@yahoo.com

been emphasis on the influence of aerosols on the climate, through both direct and indirect effects (Charlson *et al.,*1992; Andreae, 1995). The direct and indirect effects of atmospheric aerosols on radiative forcing and cloud physics are strongly dependent on particle size characteristics and chemical composition (Hegg *et al.,* 1996; Haywood *et al.,* 1997;

Muller *et al.*, 1999). In addition, they are responsible for visibility impairment and have significant implications for human health (Kumar *et al.*, 2007). Compared to green house gases, radiative forcing from aerosols is uncertain due to their short lifetimes and heterogeneous spatial distribution. While the radiative effects of aerosols work in the opposite direction of greenhouse gases, their climatic effects are not opposing because of their very different spatial and temporal distributions.

One of the important properties of aerosols is the Aerosol Optical Depth (AOD). Measuring AOD at different spectral wavelengths helps in deriving information on the optical properties and size distribution of particles, as well as studying the diurnal and season variability of aerosols. Studies over the Indian region reveal a maximum loading of anthropogenic aerosols during the pre-Indian summer, and a minimum loading during the monsoon season, which increases again in the post-monsoon period (Chakraborty *et al.*, 2004). Regional-scale analysis has been done for the estimation of aerosol properties based on different approaches and objectives. The experiments by Nair *et al.* (2007) over the Indo-Gangetic plain (IGP) revealed very high aerosol concentrations, high average mass concentration of total aerosols (260-300 $\mu g/m^3$) as compared to off IGP locations, as well as black carbon (BC) mass concentration in the range of 20-30 $\mu g/m^3$ during winter season. They also suggested the presence of submicron aerosol species. In a similar study over the region, high levels of suspended particulate matter (SPM) and respirable suspended particulate matter (RSPM) were reported in the urban areas of Ganga Basin (Prasad *et al.*, 2005). The study, carried out in the four hill towns of Himachal Pradesh in 2002, revealed that the average SPM level over Shimla as recorded was 76.42 $\mu g/m^3$ (in November), Jassur 334.40 $\mu g/m^3$ (in May), and Paonta Sahib > 500 $\mu g/m^3$ (in April, May, September and November) (HPEPPCB, 2002). However, the SPM sometimes crossed its permissible limits in residential areas (200 $\mu g/m^3$) showing Shillong, Dehradun, and Parwanoo with 113, 405, 202 $\mu g/m^3$, respectively (CPCB, 2004).

In order to study the behavior of aerosols over Dehradun, this study aimed to analyze the spectral variation of AOD and Ångström parameters for clear and turbid days during the two seasons, summer (March-June) and winter (October-February) over Dehradun using a Multi-Wavelength Solar Radiometer (MWR). Spectral optical depths were used to infer the size distribution of aerosols under different aerosol loading conditions.

INSTRUMENTATION AND DATA ANALYSIS

Dehradun (30°00' N to 30°30' N and 78°18' E to 78°36' E) is the capital of Uttarakhand state, as well as the district headquarters. It is located in the Shiwalik range of the Himalayas at a mean altitude of 700 m a.m.s.l ., extends 80 km in length and ~20 km in average width. Dehradun is located in a valley surrounded by hills. The valley is characterized by undulating topography prominently influenced by the

Indo-Gangetic flood plain and high altitude of the Sub-Himalayan region. To the north and east are hills of high altitude (2000 m). There are small-scale industries in Dehradun and some of the major ones are located to the east and south of Dehradun (30-40 km). Farther to the south lie densely populated regions, including New Delhi (250 km), and to the southeast lies the Indo-Gangetic plain. In almost all seasons, Dehradun has a high frequency of vehicles due to tourism. Since it is a valley, it attracts inversion during much of the year. In addition, the region is influenced by urban pollution, mining activities (mainly limestone), and forest fires.

Multi-Wavelength Radiometer (MWR) is a passive ground-based instrument designed for studying the spatial variation in aerosol characteristics at 10 narrow wavelength bands in the visible and near infrared region. Measurements include the aerosol columnar optical depth at 380, 400, 450, 500, 600, 650, 750, 850, 935 and 1025 nm. Being a passive system using the sun as the source, MWR can be operated only during clear days or on partly clear days when no visible clouds are present.

Continuous measurements on the AOD were carried out at Dehradun during January 2006 using the MWR, which was setup on the premises of Indian Institute of Remote Sensing (IIRS) located 1 km from the city.

Radiation Measurement

Solar radiation was collected at the ground level by means of an appropriate focusing system and measured in the 10 narrow spectral bands, from 380 nm to 1025 nm. The interference filters are characterized by a full width half maximum band width in the range of 6 to 10 nm, the central wavelength coinciding with peak wavelength (Moorthy *et al.,* 1989). The MWR collects the ground-reaching solar flux as a function of solar zenith angles. The well-known Lambert-Beer-Bouguer Law allows the estimation of aerosol optical depth (AOD),

$$I_\lambda = I_{0\lambda} \exp [-\tau_\lambda m_r] \qquad (1)$$

where $I_{0\lambda}$ = extra-atmospheric solar irradiance, m_r = relative air mass, I_λ is the direct solar irradiance at the earth's surface at wavelength λ, τ_λ = total optical thickness and m is the absolute air mass.

As the output voltage V_λ of the MWR at any wavelength is directly proportional to I_λ, by solving a linear square fit between the natural logarithm of V_λ and the corresponding relative air mass. The raw data was edited and further AOD values were estimated following the Langley technique (Shaw *et al*., 1973; Moorthy *et al.,* 1989). The total optical depth τ_λ was estimated as the slope of the regression line following the Langley plot method. The correlation coefficients obtained from the Langley plot for a turbid and clear day in March 2006 were in the range of 0.92-0.98 and 0.94-1.0 respectively. A typical day in January 2007 was 0.95-1.0 and 0.92-1.0 for turbid and clear day respectively.

Considering τ_λ as the sum of the contribution of the different atmospheric components,

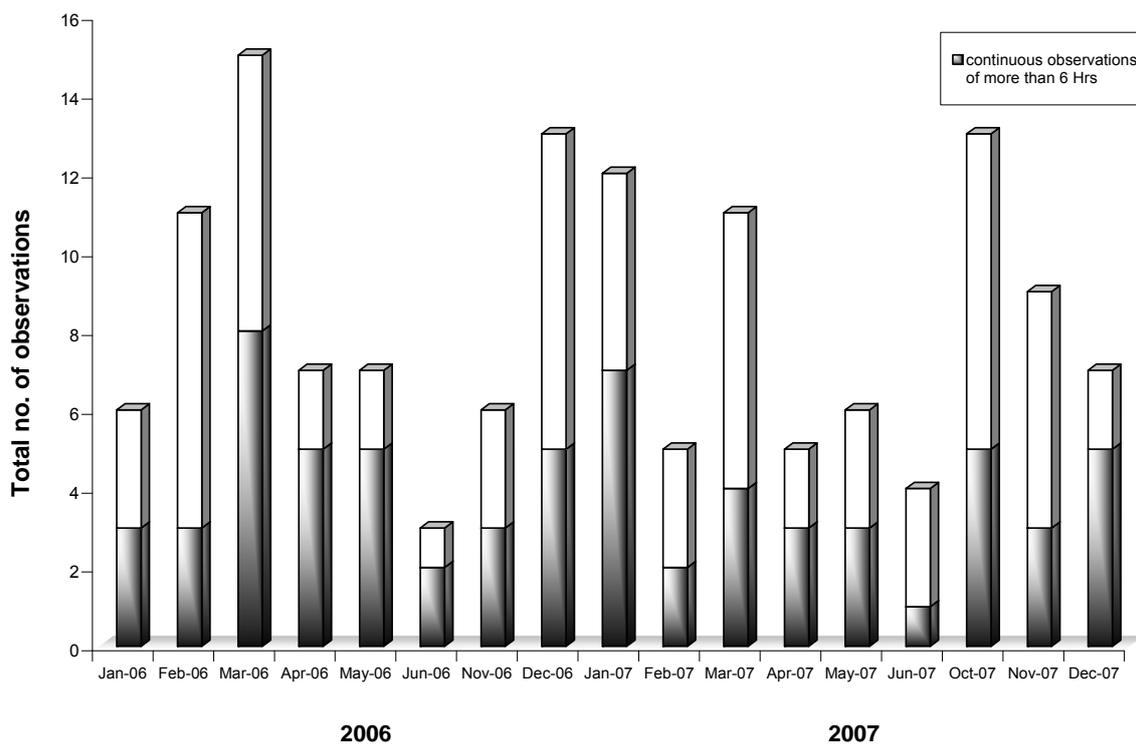$$\tau_\lambda = \tau_{R\lambda} + \tau_{g\lambda} + \tau_{w\lambda} + \tau_{a\lambda} \qquad (2)$$

Fig. 1. Total number of non-cloudy MWR observations collected during 2006 and 2007.

$\tau_{R\lambda}$ = Rayleigh optical thickness, $\tau_{g\lambda}$ = absorption optical depth due to atmospheric gases, $\tau_{w\lambda}$ = water vapor optical depth, $\tau_{a\lambda}$ = aerosol optical depth.

The estimated values of aerosol optical depth, $\tau_{a\lambda}$ has errors (both statistical and those arising out of uncertainties). The error in τ_{λ} arises due to 1-min resolution in time and the statistical errors in regression analysis. The error in Ozone (O_3) model added with the seasonal variations in O_3 contributes an uncertainty of 10% in $\tau_{g\lambda}$ while error in $\tau_{R\lambda}$ is 0.03%. Thus $\tau_{a\lambda}$ may therefore have a maximum uncertainty of ~0.03 at the wavelengths under consideration (Moorthy *et al.,* 1989).

The MWR observations at Dehradun were collected for different months during year 2006

and 2007 on all clear/partly clear sky days. Fig. 1 shows the total number of MWR observations collected under clear sky condition for the two years of 2006 and 2007. As the day progresses and convective mixing occurs, cloudy sky conditions start to prevail in the afternoon hours over Dehradun. In this study, days having continuous observations of more than 6 hours were considered (Fig. 1). While trying to understand the variation of AOD (at 500 nm) during the two seasons, high intraseasonal variability was observed during March and interseasonal variation in January is not observed. The variation of AOD during clear and turbid days during the two seasons, winter (October-February) and summer (March-June) was studied. The highest number of observations were made during January

2007 and March 2006 (more than 6 hours continuous). To specifically emphasize the details of the variability, clear and turbid days in January 2007 and March 2006 were studied. The lowest AOD was observed for January 8, 2007 (clear) and highest AOD for January 10, 2007 (relatively turbid day). Similarly, March 3 and 17, 2006 were selected as turbid and clear day.

Determination of Ångström Parameters

The daily mean AODs measured over the region were further analyzed to determine the Ångström parameters. The spectral aerosol optical depth can be analyzed using the Ångström formula (Ångström, 1961)

$$\tau_{a\lambda} = \beta\lambda^{-\alpha} \quad (3)$$

The wavelength exponent α depends on the size distribution parameter of aerosols, and β is directly proportional to the columnar aerosol content and is equal to the AOD measured at 1 μm. The formula is derived on the premise that the extinction of solar radiation by aerosols is a continuous function of wavelength, without selective bands or lines for scattering or absorption (Ranjan *et al.,* 2007).

Inversion of AOD

The behavior and the atmospheric effects by aerosols depend on their size. The columnar aerosol size distribution (ASD) is derived from the aerosol spectral optical depth (AOD) by numerical inversion of the Mie integral (King *et al.,* 1978) as:

$$\tau_{a\lambda} = \int_{r_a}^{r_b} \pi r^2 Q_{ext}(m, r, \lambda) n_c(r) dr \quad (4)$$

where Q_{ext} is the aerosol extinction efficiency factor which depends on the aerosol refractive index (m), radius (r) and wavelength of incident radiation (λ), $n_c(r)$ is the columnar size distribution function of aerosols, and r_a and r_b are, respectively, the lower and upper radii limits for integration.

Estimation of Mean Radius

Effective means radius (r_{eff}) is also evaluated for each size distribution by using the relation:

$$r_{eff} = \int r^3 n_c(r) \, dr \, / \int r^2 n_c(r) \, dr \quad (5)$$

The effective radius is proportional to the ratio of the total volume of particles to their total surface areas.

Air Mass Back Trajectory

To ascertain the sources of loading, air mass back trajectories were studied. A useful tool for data interpretation is the HYbrid Single Particle Lagrangian Integrated Trajectories (HYSPLIT) model of the National Oceanic and Atmospheric Administration (Draxler and Rolph, 2003). This program allows for the calculation of air mass back trajectories once the trajectory levels, the day and time are fixed.

Meteorological Data

The meteorological parameters were collected from India Meteorological Department (IMD) Dehradun station. The diurnal variation of all days of relative humidity, air temperature,

rainfall, wind speed, wind direction and sky conditions were collected and was used in the analysis. Fig. 2 (a and b) shows the daily average trends of the parameters over Dehradun for March 2006 and January 2007, respectively.
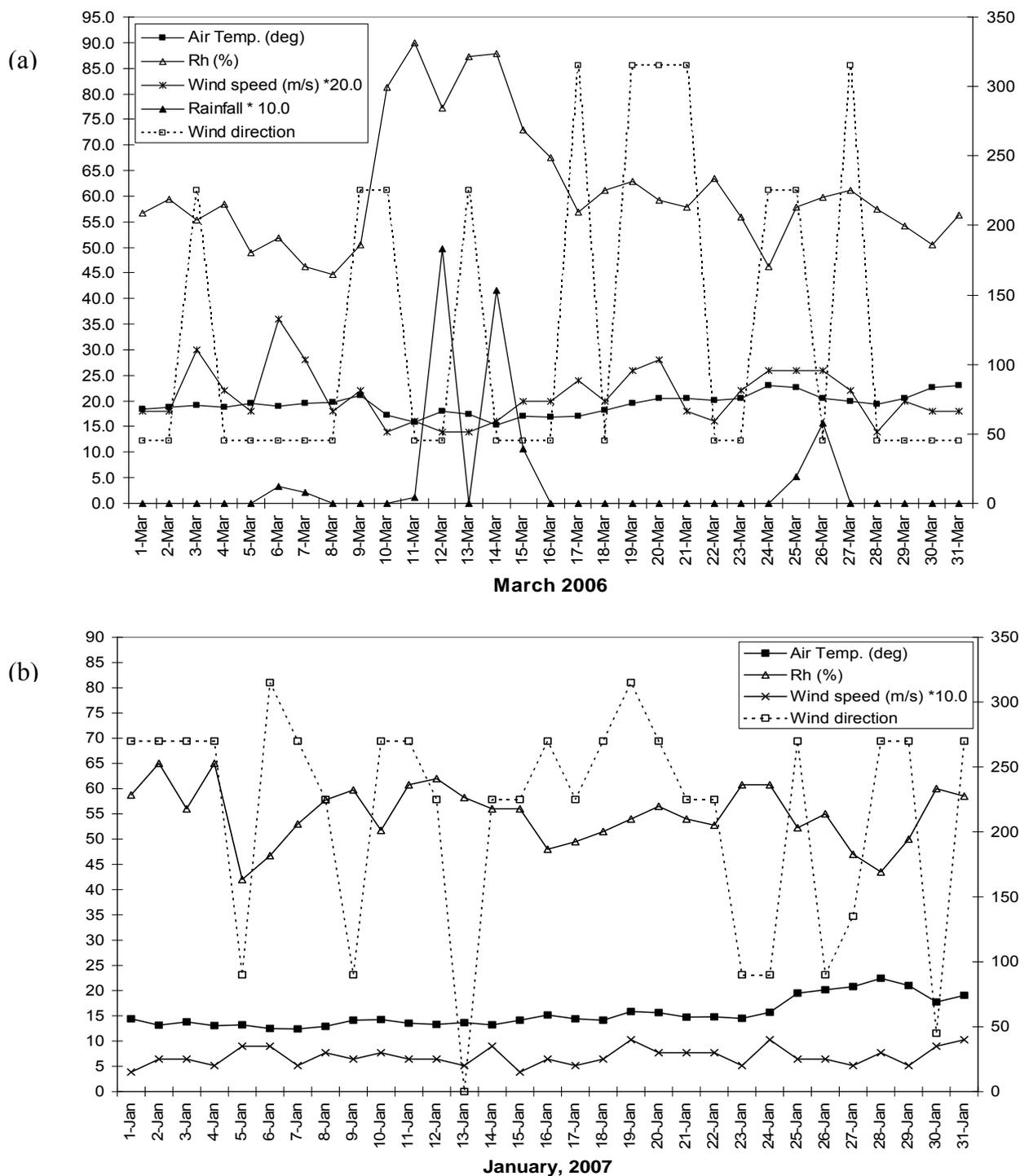

Fig. 2. Daily mean variation of meteorological parameters at Dehradun (Source: IMD, Dehradun).
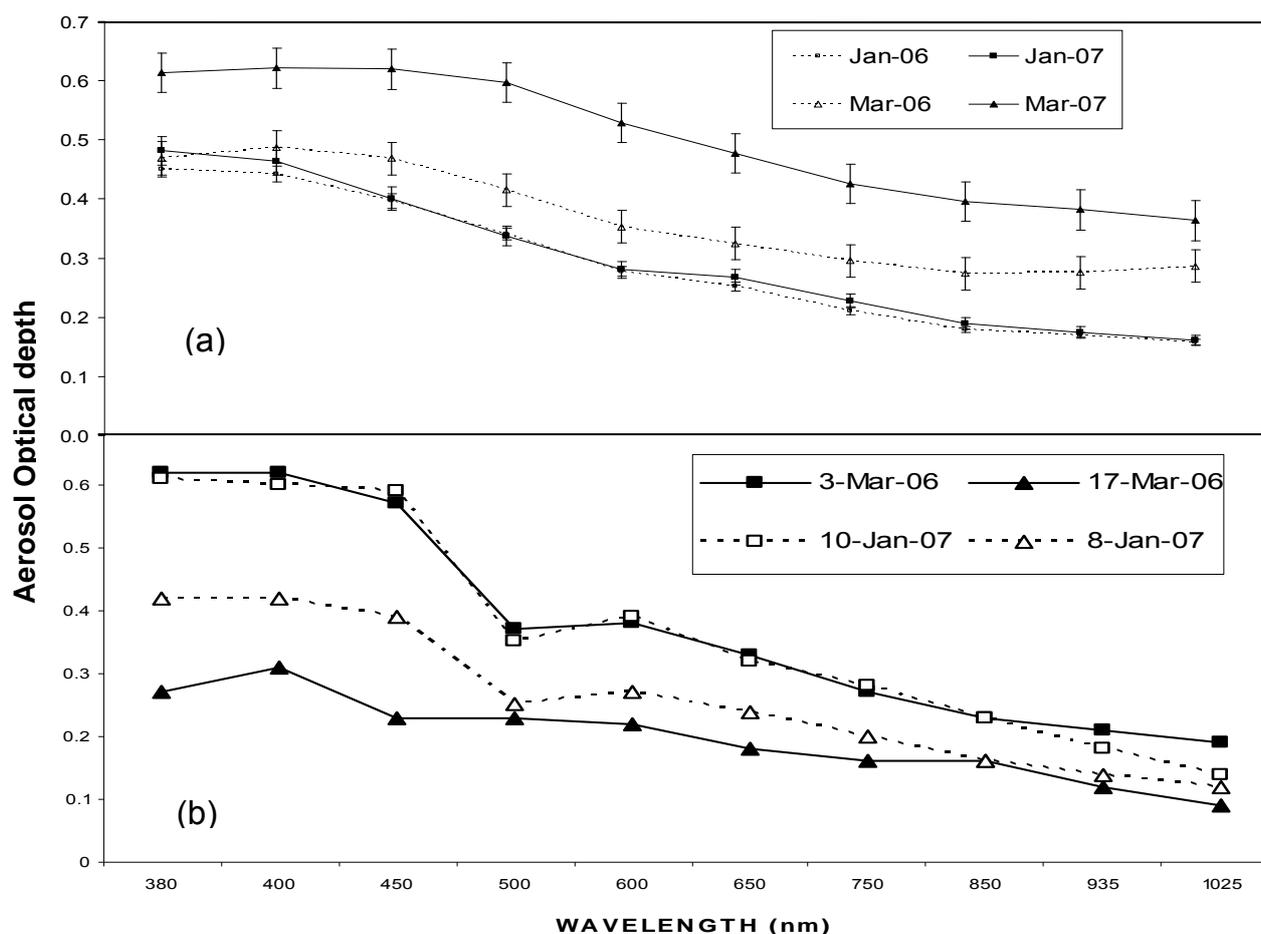
Fig. 3. Spectral variation of AOD: (a) Mean monthly variation during March and January, (b) on clear and turbid days over Dehradun (Vertical bars are S.D ± 1.0).

RESULTS AND DISCUSSION

Spectral Variation of AOD

The inter-seasonal variability of monthly average AOD values for January and March is shown in Fig. 3(a). Studying the spectral profile of AOD at all the 10 wavelengths, it is clear that during winter (October-February) and summer (March-June) the AOD values lie in the range of 0.08-0.45 and 0.21-0.66, respectively. However, the monthly mean AOD for January is ~ 0.25 ± 0.01 and for March the value is ~ 0.33 ± 0.04. Studying the

temporal variations of AOD at Manora Peak near Nanital in the central Himalayas, it is found that during summers, about 90% of the AOD values fall within the range of 0.05-0.5, and in winters 90% of the values are within the range of 0.05-0.2 at four representative wavelengths (380, 500, 750 and 1025 nm) (Dumka *et al.,* 2007).

Fig. 3(b) shows the variation of AOD for two selected days in summer (March 3 and 17, 2006) and two selected days in winter (January 8 and 10, 2007) respectively. It is evident from the figure that there is relatively strong wavelength

dependence of optical depth at shorter wavelengths that gradually decreases towards longer wavelengths irrespective of the seasonal change, attributing to the presence of fine to coarse particles. The presence of a higher concentration of the fine-mode particles which are selective scatters enhances the irradiance scattering, and therefore, the AOD values are high at the shorter wavelength. Likewise, the coarse-mode particles provide similar contributions to the AOD at both wavelengths (Schuster e*t al.*, 2006).

The dependence of AOD on wavelength is further examined in Fig. 4 by analyzing the diurnal variation of AOD at 500 nm (AOD_{500}) for the turbid and clear days in both seasons, respectively. Fig. 4 shows that the AOD values increase gradually during the day as a result of the increased aerosol input caused by surface

heating and vertical mixing, which plays an important role in heating and lifting loose soil. The cause of the dip at 1400 hrs may be due to the simultaneous presence of smaller and larger particles in the atmosphere (Giavis *et al.,* 2005). However, for March 17 the AOD_{500} values show a linear trend throughout the day which might be due to the stability of local meteorological conditions. The AOD values for turbid day in winter shows a similar trend as for the summer turbid day and AOD values were observed to be low during the winter season. This could be due to the weak generation mechanism and to the gas-to-particles conversion process. However, for the clear day of January 8, 2007, the AOD_{500} exhibited an almost linear trend throughout the day due to favorable meteorological conditions (except slightly high
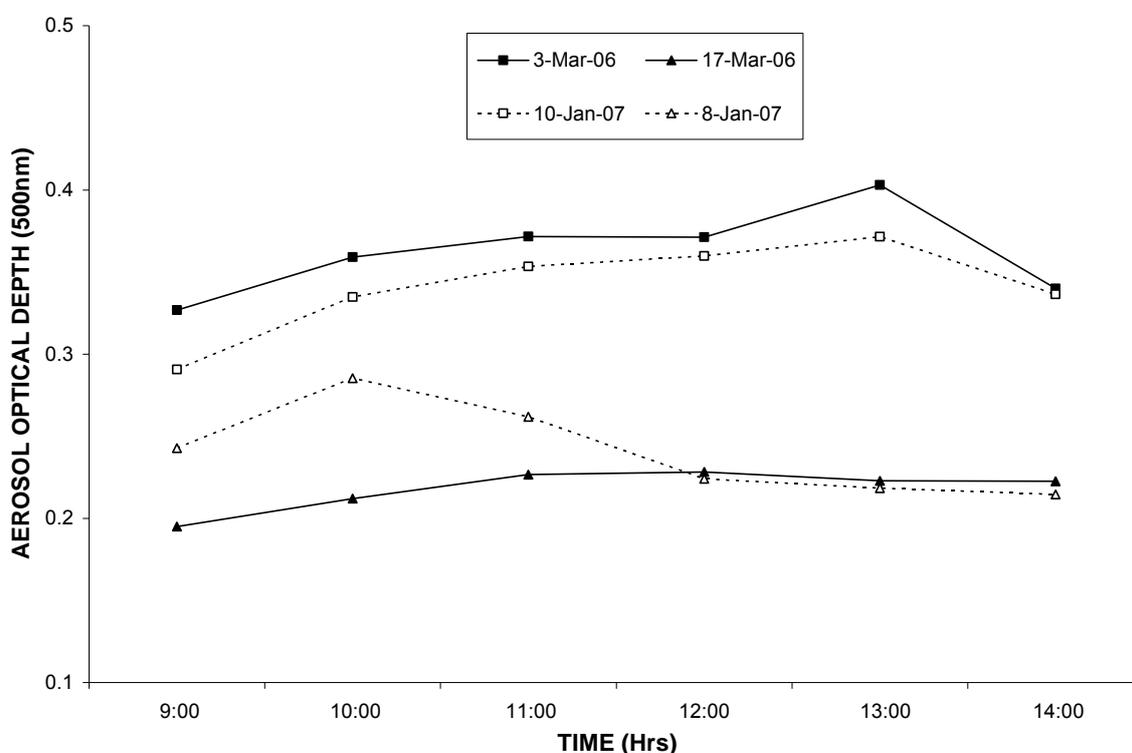

Fig. 4. Diurnal variation of AOD at 500 nm during March 2006 and January 2007.

values in the morning that may have been due to enhanced local activities). A similar trend in the diurnal variation of AOD for a clear and turbid day during January 2006 has been reported for the urban environment of Hyderabad with the only consideration being that the AOD magnitude was at a higher level (Badarinath *et al.*, 2007). Analysis of AOD diurnal variation for March 3 (turbid) during the day reveals an increase until 1300 hrs for all the wavelengths, except 650 nm. However, for March 17 (clear), the AOD values increased until mid-day (1200 hrs), except for 450nm and 935 nm band where the AOD is higher at 1400 hrs.

Similarly for January 8, 2007 (clear), AOD values reached maximum during the forenoon hours at around 1000 hrs, except for the 380 nm band. For January 10 (turbid), the AOD increased until 1300 hrs, except for 650 and the water vapor absorption band. Systematic spectral dependence of AOD exhibits a temporal pattern with high AOD values either in the morning (1030 hrs) or afternoon (1300 hrs), may be due to the local activities and rush hours.

The average value of AOD_{500} over Dehradun on clear and turbid days of March 2006 were in the range of 0.22-0.36 (monthly average at 500 nm~0.34 ± 0.18) and for January 2007 between 0.24-0.34 (monthly average at 500 nm~0.18 ± 0.09), respectively; indicating lower AOD on clear compared to turbid days in both cases. The AOD values at 500 nm for summer season over Dehradun were found to be comparable to those estimated at 500 nm for the summer season (~0.16-0.45) over Nanital (Dumka *et al.,*

2007). However, the winter month values over the study area were much higher than those observed for Manora Peak, Nanital (~0.03-0.12) (Dumka *et al.,* 2007). The reason for the difference in AOD values over Dehradun (700 m a.m.s.l) and Manora Peak (1958 m a.m.s.l) during the winter may be due to the high topography of the site (representative of free-troposphere conditions) affecting boundary layer dynamics, associated with the changes in solar heating over the year. This plays a key role in transporting aerosols from the polluted valley region to higher altitudes and the prevailing meteorological conditions. The main factors responsible for the lower AOD values at the high altitude station include a mean wind speed of ~2 m/s, a Rh (~ 40-90%) with significant rainfall caused by western disturbances and air mass coming from the southern Indian land mass during winter (Sagar *et al.,* 2004).

Studies on the aerosol pollution level along the Ganga Basin showed that high AOD (> 0.6) values are observed along the whole Ganga Basin during the summer season, while low AOD values were observed during winters over the western part of the basin, and comparatively higher (> 0.5) AOD in the eastern part of the basin (Prasad *et al.,* 2005). High AOD_{500} values in the range of 0.45-1.6 were reported over Allahabad (Latha *et al.,* 2005) during December 2004. The reason for high AOD values is attributed to the highly populated urban environment and the fog conditions prevailing over the region during the period. Studies by Gupta *et al.* (2005) over Delhi during the same period found that the
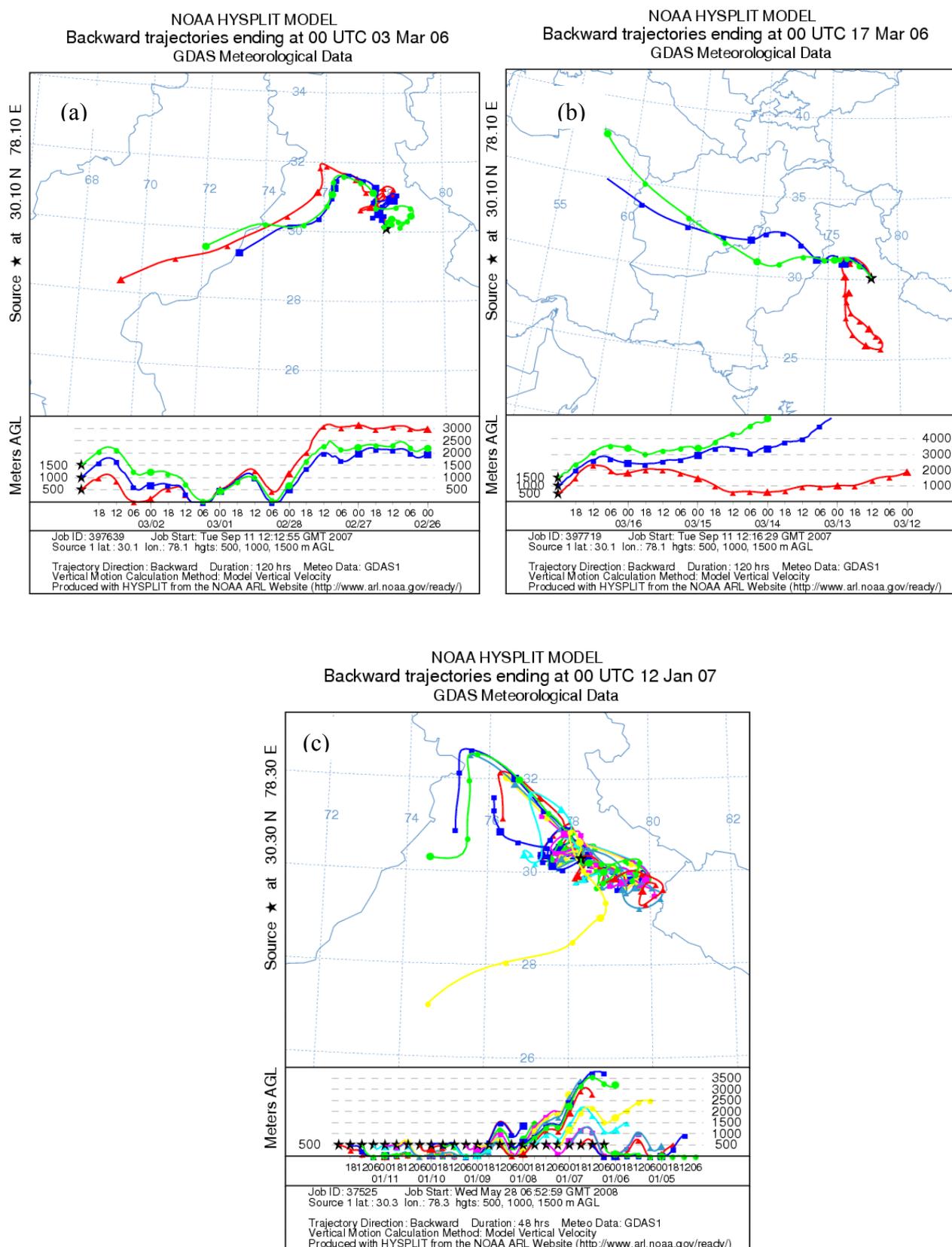
Fig. 5. NOAA-HYSPLIT model trajectory map during clear and turbid days of March 2006 and January 2007.

AOD_{500} values during clear days lie in the range 0.4-1.1 while during misty/hazy days in the range of 1.1-2.3.

Influence of Meteorological Parameters on AOD

The meteorological parameters showed significant fluctuations both within the day as well as day to day. To study these and to infer the effect on the aerosol optical depth, the mean throughout the day was considered. The monthly mean wind speeds were low (< 4.0 m/s) for most of the year. The rainfall was significant from June 15 to September (caused by western disturbances) and accounts for about 70-85% of the total annual rainfall. The relative humidity is generally < 55% in summer, around 60-65% during winter and 80-85% during monsoon. During winters the winds are predominantly southeasterly; westerly and southwesterly during June-September, shifting to northwesterly during March-June. The air mass from the western land mass during summer is responsible for the increase in AOD values over Dehradun, thereby transporting large amounts of desert/mineral aerosols from the far West Asian and Indian deserts. Wind direction data (Fig. 2a) shows that during March the synoptic winds are on an average coming from western direction. This is also evident from the air mass back trajectories using the HYSPLIT data. The trajectories were estimated over a 5-day backwards trajectory with the starting points at 500, 1000 and 1500 m a.g.l. Air mass behavior reveals that during the week of March 3 (Fig. 5a) the air masses from all trajectories come from a western

direction, and for the week of March 17 (Fig. 5b) the lower (500 m) trajectory from southern and higher levels are from a far western direction. The injection of air particles arriving from the far west causes the variation of aerosol optical properties and is evident from the AOD values.

During January 8 and 10 (Fig. 5c) back trajectory reveals that during the experimental days the trajectories are from the east and southeast in the direction of the Indo-Gangetic Plain, and mainly confined to the local region. It is seen that that the concentration gradually increases as the trajectories travel more and more from the west which suggests that advection plays an important role in modulating the aerosol concentration and causing day-to-day changes (Nair *et al.*, 2007).

During March 2006, local rainfall was experienced, particularly on March 14 and 15 (high Rh around 87%), which attributed to the lower AOD on March 17 and relatively higher AOD on March 3, 2006 (Rh around 54%). The ambient air temperature nearly remained steady and varied from 17-20°C during March 1-19, 2006. Relative humidity remained in the range of 48-56% (except during rainfall days where it remained in the range of 70-87%) and did not show any marked trend. The steady nature of the parameters indicates the absence of any strong localized weather fronts influencing the environment. January 2007 experienced no rainfall (except on the 31st) contributing to 8% higher relative humidity on January 8 (clear) compared to January 10 (turbid), 2007, attributing to lower AOD value on the clear day. The prevailing westerly

surface wind on January 10 carried most of the desert dust over the region, enhancing the concentration of aerosols and increasing the turbidity levels; whereas, on January 8 the region experienced southwesterly winds carrying coarser aerosols. The ambient air temperature was almost constant (13-15° C) during these days.

Variation of Ångström Parameters

The Ångström parameters α and β give the instantaneous value of the turbidity of the atmosphere (Cachorro *et al.,* 1987). In spite of the poor correlation between the AOD and the α parameter (Holben *et al.,* 1998; Cachorro *et al.,* 2000) values, both quantities must be considered for a realistic analysis. The studies by Cachorro *et al.* (2001) showed that the α value depends strongly on the spectral range used in its determination. In the present study, Ångström parameters were studied in the spectral ranges of 400-650 nm (VIS); 380-650 nm (UV-VIS); 400-850 nm (VS-NIR) and 380-850 nm (UV-NIR). The α and β values estimated for all wavelengths showed comparable values. Table 1 shows the α and β

values for the selected experimental days. From the table, it is evident that there is not much variation between the values derived in different spectral ranges. For March 3 and March 17 maximum variation in α values are less than 10% and 11% (only major variation of 30% is in VIS range) and for β less than 5% and 19%, respectively. For January 8 and 10, 2007 maximum variation in α values observed were around 11% and 7%, and for β around 13% and 4%, respectively. Hence, the 380-850 nm wavelength band has been taken for the estimation of Ångström parameters. The Ångström exponent values are high for shorter wavelengths and low in longer wavelengths with a variation of 10-17% for clear days and 11-21% for turbid days during March 2006. Similarly, for January 2007 the variation for clear and turbid days were in the range of 5-8% and 9-18%, respectively. The parameters appear to take the lowest values in the morning hours, signifying the presence of larger particles and, due to the inversion of more fine particles, leads to an increase in the α value. For March 2006, the mean α value for a turbid day is found to be 1.232, while for the clear day

Table 1. Mean Ångström parameters for the clear and turbid days in different spectral ranges.

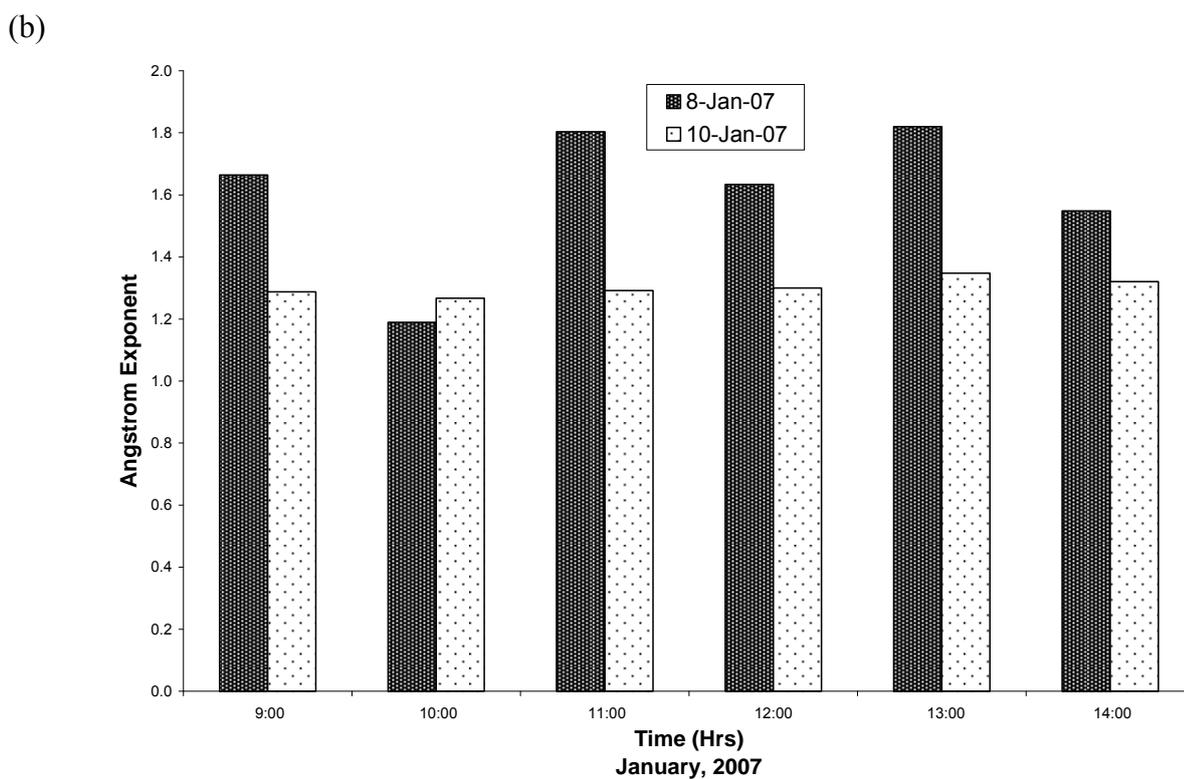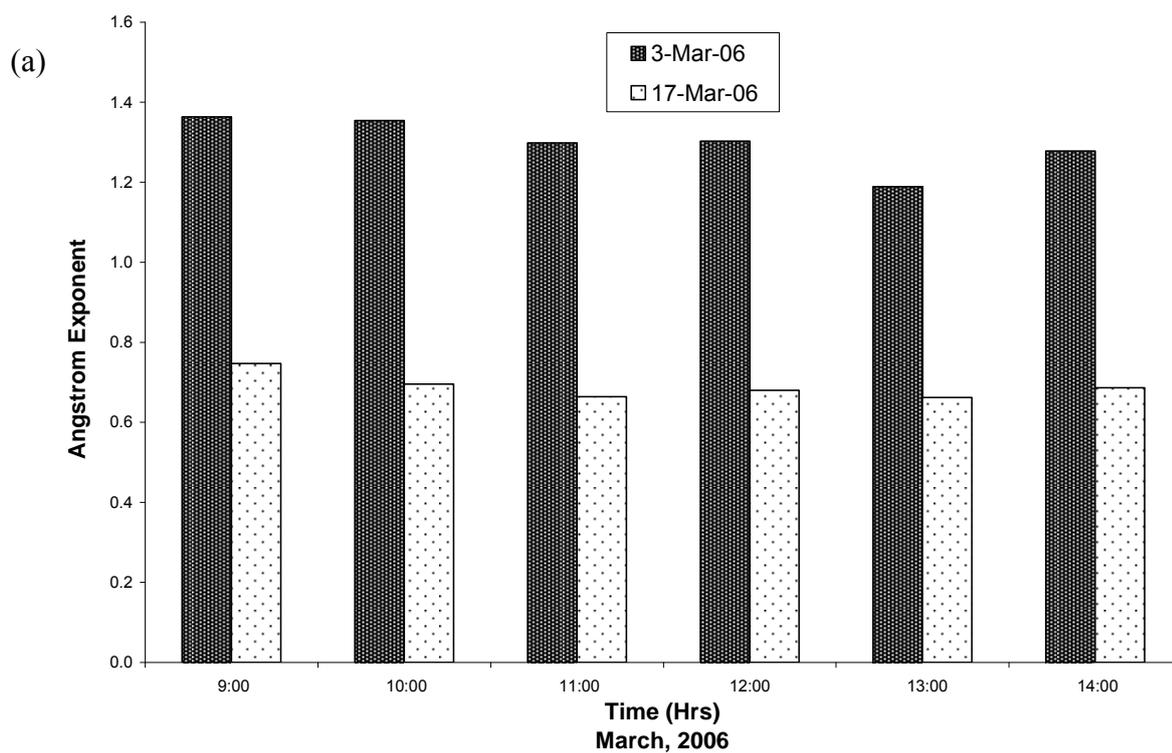| Date	Ångström Parameter	Spectral Range (µm)			
		400-650	380-650	400-850	380-850
March 3, 06		1.299	1.175	1.316	1.232
March 17, 06	α	1.120	0.755	0.878	0.645
January 8, 07		1.153	1.043	1.280	1.199
January 10, 07		1.295	1.202	1.272	1.212
March 3, 06		0.189	0.199	0.186	0.188
March 17, 06	β	0.111	0.130	0.139	0.144
January 8, 07		0.146	0.153	0.130	0.132
January 10, 07		0.183	0.191	0.187	0.189

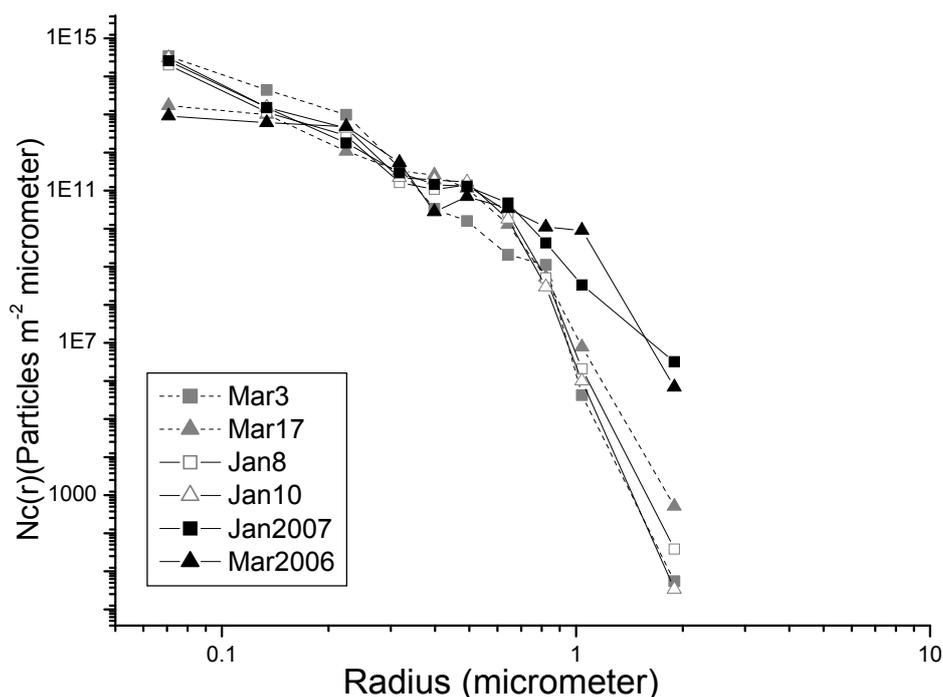**Fig. 6.** Diurnal variation of Ångström exponent for (a) March 3 and 17, 2006, (b) January 8 and 10, 2007.

Fig. 7. Size distribution of aerosols at Dehradun during January 2007 and March 2006 along with the clear and turbid days.

the value decreases to 0.645 as shown in Fig. 6(a). Similarly, as evident from Fig. 6(b) for January 2007 the mean α values for the turbid day is found to be 1.212, while for the clear day it is 1.20. The α values obtained over the region for March and January were found to be in good agreement with those obtained over Manora Peak, Nanital (Sagar *et al.,* 2004; Pant *et al.*, 2006). A similar trend was also reported by Dumka *et al.* (2007). Their study over Nanital indicated high α values during the winter months and minimum values during summer, indicating relative dominance of submicron particles during the winter season and coarser particles during the summer season. Large positive values of α are characteristic of fine-mode-dominated aerosol size distributions (Eck *et al.,* 1999; 2001; Ranjan *et al*., 2007) while near zero and negative values are

characteristic of dominant coarse-mode or bi-modal size distributions, with coarse-mode aerosols having significant magnitude (Eck *et al.,* 1999; O' Neill *et al.,* 2001; Kaskaoutis and Kambezidis, 2006). This explains the dominance of fine and accumulation mode particles over the region. The α values also confirms the fact that January 2007 variation was not observed and high variation was in March 2006.

Aerosol Size Distribution

AOD values have been used in the inversion technique to retrieve aerosol size distribution (ASD). Fig. 7 shows the retrieved size distribution for two days in March and January, as well as the mean monthly distribution of January 2007 and March 2006. Turbidity and wavelength exponent values suggest high

turbid atmosphere in association with dominant accumulation-mode particle loading in the environment. Size distribution suggests maximum particle loading observed at 0.07 μm radius for both the clear and relatively turbid day for March 2006 and January 2007, as well over the whole month. However, it was observed that the particle loading for the turbid days were comparable to each other, while the data for clear days shows a variation of about 30% corresponding to higher particle loading on January 8, 2007, which also contributed to the high AOD values on this day due to the dominance of accumulation-mode particles and greater sensitivity of AOD at shorter wavelengths (Latha and Baradinath, 2004). The measured effective radius (R_{eff}) for the turbid days (March 3 and Jan 10) was 0.13 μm, while for the clear days (March 17 and January 10) was 0.2 μm and 0.14 μm, respectively, similar to the size distribution of aerosols obtained at Mohal (1150 m a.m.s.l) and Kothi (2530 m a.m.s.l) (0.08-2.1 μm dia) contributing to the dominance of fine-size particles as reported by (Kuniyal *et al.*, 2005). The effective radius being one of the best representative parameters signifying fine and coarse modes of the aerosol size distribution (Dey *et al.,* 2005), thus suggesting a higher loading of fine-mode particles on turbid days and simultaneous presence of fine and coarse-mode particles on clear days.

CONCLUSION

The results obtained in the present analysis of the aerosol optical properties for the experimental days of March 2006 and January 2007 shows their dependence on meteorological parameters and local topography. Spectral dependence of AOD showed higher values at shorter wavelengths which decreases gradually towards longer wavelengths for both summer and winter suggesting fine to coarse particle loading. Diurnal AOD variation had been studied for all the experimental days and the derived Ångström exponent showed values for turbid days (1.232 and 1.212) indicating presence of fine mode participles. Air mass back trajectories confirmed that the winds with significant loading originating from far western directions enhances the concentration of aerosols over the area and increases turbidity levels. The size distribution of aerosols suggests that maximum particle loading is around 0.07 μm and the aerosol loading on turbid days is due to fine-mode particles and the simultaneous presence of fine- and accumulation-mode particles on clear days.

ACKNOWLEDGEMENTS

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