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Seasonal variability of the aerosol parameters over Kanpur, an urban site in Indo-Gangetic basin

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Abstract

With the growing antropogenic activities and urbanization, pollution level is found to be increasing in the Indo-Gangetic (IG) basin. This trend of increasing pollution has direct impact on the climatic conditions, especially the increase of haze, fog and cloudy conditions in the region. A ground-based CIMEL radiometer has been deployed on the campus of the Indian Institute of Technology (IIT) Kanpur, India, as a part of the Aerosol Robotic Network (AERONET) program with an objective to characterize the aerosols in the IG basin. The optical properties of the aerosols over Kanpur, which is one of the largest industrial cities in the IG basin, show strong seasonal and inter-annual variations. The fine mode urban/industrial aerosols contribute more than 75% to the observed aerosol optical depth (AOD) during the post-monsoon and winter seasons, whereas the natural dusts contribute ~60% to the AOD during the pre-monsoon and monsoon seasons. Effective radius (R_{eff}) and volume weighted mean radius (R_V), the two best representative parameter of the coarse and fine modes of aerosol size distribution show maximum values during winter season. The increase in the R_V is attributed to the hygroscopic growth of fine mode particles in presence of high relative humidity and favorable temperature condition; but the increase in r_{eff} is due to the association of the fine mode absorbing particles to the coarser dusts. This is also reflected in low values (< 0.8) of single scattering albedo (SSA) at coarse mode during the season. Higher values of SSA at fine mode indicate dominance of water-soluble aerosols scattering in nature. The linear regression equations between AOD (at 0.67 μm wavelength) and extinction coefficient due to fine and coarse modes also reveal the relative contribution of the fine and coarse mode particles to the observed optical properties during different seasons in Kanpur.

Keywords: Aerosols; Indo-Gangetic basin; Dust; Remote sensing; CIMEL

1. Introduction

Aerosols provide one of the largest uncertainties in climatic forcing due to their variability in space and time and lack of detailed knowledge about their optical properties (Satheesh and Ramanathan, 2000; IPCC, 2001). Aerosol Robotic Network (AERONET), a ground-based aerosol monitoring network has been established across the globe in order to characterize the aerosol optical properties (Holben et al., 1998, 2001). Under the AERONET program, optical properties of the marine (Smirnov et al., 2002), desert dust, biomass-burning and urban aerosols (Dubovik et al., 2002) are studied extensively. In India, ground based monitoring of aerosols was initiated in Trivandram (a coastal city in the southern part of India) in 1980s and a network has been established later on under Indian Space Research Organization Geosphere Biosphere Program (Moorthy et al., 1999) (Fig. 1). However, a substantial gap in ground-based measurements remains mainly in the Indo-Gangetic basin in the northern part (Fig. 1) where

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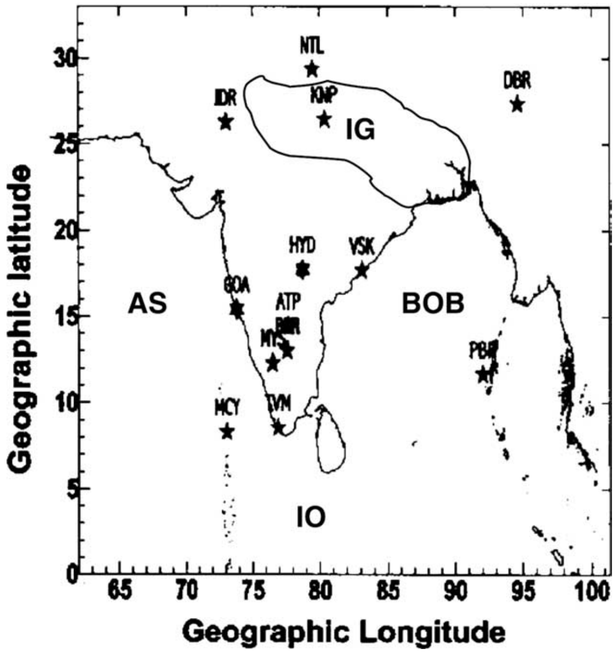

Fig. 1. Location of Kanpur (KNP) in the Indo-Gangetic basin (IG) along with other ground-based aerosol monitoring stations (Nainital, NTL; Jodhpur, JDR; Dibrugarh, DBR; Hyderabad, HYD; Vishakhapatnam, VSK; Goa; Anatpur, ATP; Bangalaore, BNR; Mysore, MYS; Trivandram, TVM; Port Blair, PBR and Minicoy, MCY) in India surrounding by Arabian Sea (AS), Bay of Bengal (BOB) and Indian Ocean (IO).

Kanpur is the lone station, considering the different natural and anthropogenic sources resulting in increasing aerosol loading over the Indian subcontinent (Singh et al., 2004).

An automatic sun and sky CIMEL radiometer has been deployed on the campus of the Indian Institute of Technology, Kanpur (80°20′E, 26°26′ N and 142 m altitude from mean sea level shown in Fig. 1) in joint agreement with NASA in January 2001. Kanpur is located in the heart of the Indo-Gangetic basin and is a representative site in terms of the regional climatology marked by four main seasons, winter (December-February), pre-monsoon (March–May), monsoon (June–August) and post-monsoon (September–November). Both ground-based (Dey et al., 2004; Singh et al., 2004) and satellite observations (Girolamo et al., 2004; Prasad et al., 2004, 2005) have revealed high aerosol loading in recent years over the Indo-Gangetic basin, which requires detailed characterization. The source of the aerosols in this region is local industries and automobiles, street dust and desert dusts carried by the south-westerly winds during the pre-monsoon and monsoon seasons (Dey et al., 2004; Singh et al., 2004). Biomass burning is not a common feature in this region except during the winter season (Singh et al., 2004). The seasonal variability of aerosol parameters over Kanpur from 2001 to 2003 has been reported by Singh et al. (2004).

The knowledge of optical properties of fine and coarse mode aerosols are important in view of aerosol loading in the region. In this paper, we have presented some new results about the aerosol optical properties which was not discussed by Singh et al. (2004), this will help in understanding the anthropogenic contribution to the pollution. We have also extended our study from January 2001 to November 2004, the period when level 2.0 data is available.

2. Data

CIMEL sun and sky radiometer operates in two modes, direct sun measurements at 0.34, 0.38, 0.44, 0.5, 0.67, 0.87, 0.94 and 1.02 μm wavelengths to retrieve aerosol optical depth (AOD) and water vapor content (WVC) and sky measurements at 0.44, 0.67, 0.87 and 1.02 μm wavelengths to retrieve microphysical and optical properties (Holben et al., 1998, 2001). The aerosol parameters are being retrieved from the measured radiance at the suitable wavelengths using a radiative transfer model for spherical, non-spherical and mixed type of particles (Dubovik and King, 2000). The aerosol volume size distribution is retrieved in the range 0.05 $\leqslant$particle radius $\leqslant$15 μm. Dubovik et al. (2000) have shown that the uncertainties in AOD retrieval is between ±0.01 and 0.02, whereas for the optical properties, it is $<\pm$ 5%. However, the uncertainty increases for low aerosol loading, the details are discussed elsewhere (Dubovik et al., 2000).The AOD data are available in three categories, level 1.0 (unscreened), level 1.5 (cloud screened) and level 2.0 (quality assured), of which level 2.0 data have been used for this study. During January 2001–November 2004, the analysis was carried out on the basis of total 917 daily averaged data, due to technical problem, some data during June–September 2003 was not available.

3. Results and discussion

Aerosol parameters are represented by AOD and Ångström exponent (α), where AOD and α indicate the aerosol burden in the atmosphere and the aerosol particle size distribution respectively. Dominance of sub-micron particles yields high values of α (or higher spectral variation in AOD), whereas high concentration of coarse particles results in low values of α (or lower spectral variation). AOD at 0.5 μm, $\tau_{a,0.5}$ is taken as the representative of the whole AOD spectra as 0.5 μm is closest to the central part of the whole spectral range of AERONET. Fig. 2 shows the seasonal average of AOD and α for 2001–2004. $\tau_{a,0.5}$ and α show inter-annual and seasonal variations. The seasonal variations of AOD was discussed in detail by Singh et al. (2004),

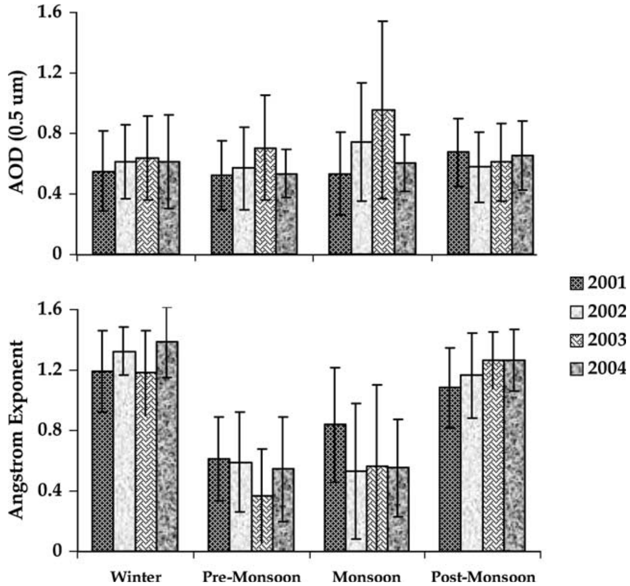

Fig. 2. Seasonal average of AOD at 0.5 μm wavelength and α in Kanpur during 2001–2004 with the vertical bars representing ±1 standard deviation.

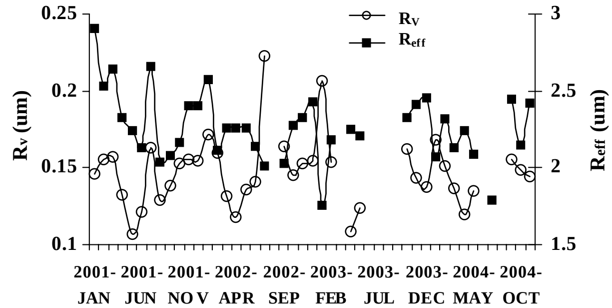

Fig. 3. Monthly mean effective radius (for coarse mode) and volume weighted mean radius (for fine mode) of aerosol size distribution observed over Kanpur.

here we look into the inter-annual variations, which show no definite trend in $\tau_{a,0.5}$, but a slight increasing trend in α during the post-monsoon season. From the frequency distribution of α, Singh et al. (2004) have shown that in Kanpur, $\alpha < 1$ indicates dusty condition and $\alpha > 1$ indicates dominance of anthropogenic aerosols. The seasonal averages of $\tau_{a,0.5}$ and α reveal that the winter and post-monsoon seasons are completely dominated by anthropogenic activities.

Effective radius (R_{eff}) is quite representative of the optical properties of coarser particles, whereas for fine particles, volume weighted mean radius (R_V) is more appropriate parameter (Tanre et al., 2001). R_{eff} and R_V are defined as

$$R_{\text{eff}} = \frac{\int_0^\infty r^3 n(r)\mathrm{d}r}{\int_0^\infty r^2 n(r)\mathrm{d}r}$$

$$\text{and} \quad R_V = \frac{\int_0^{r_{\max}} r(\frac{\mathrm{d}v}{\mathrm{d}r})\mathrm{d}r}{\int_0^{r_{\max}} (\frac{\mathrm{d}v}{\mathrm{d}r})\mathrm{d}r} \quad \text{(Tanre et al., 2001).}$$

The monthly mean R_{eff} (for coarse mode) and R_V (for fine mode) are shown in Fig. 3, R_V is found to be higher (>0.15 μm) during monsoon and winter seasons. The increase in R_V is attributed to the hygroscopic growth of the fine mode particles (Parameswaran and Vijayakumar, 1994; Singh et al., 2004) in the presence of high relative humidity. However, the hygroscopic growth of the fine particles is more pre-dominant during winter season, when the temperature condition is more favorable. R_V is observed to be low (<0.1 μm) during the pre-monsoon season indicating the relatively higher contribution of the coarse mode particles to the observed AOD. R_{eff} is found to be higher during the pre-monsoon and winter seasons. The high values in R_{eff} during the pre-monsoon season are attributed to the abundant dust loading in the region, which increases the loading of coarse mode particles (Dey et al., 2004). Late arrival of monsoon in 2002 is reflected in the late rise of R_{eff} curve. Though the volume concentration of the coarse mode particles is increased three times during the pre-monsoon dust-loading season (Dey et al., 2004), R_{eff} has not been found to increase significantly, because it is more influenced by the number concentration compared to the volume concentration. For further investigation of the assessment of the relative contribution of the fine and coarse mode particles to the observed optical depth over Kanpur, percentage contribution of the fine and coarse mode particles to the total extinction has been studied and the seasonal average of the share of fine mode particles is shown in Table 1. The relative contribution of the fine mode particles is very high (>70%) during the seasons influenced by mainly anthropogenic activities. It is noteworthy that the contribution of fine particles during the post-monsoon seasons increases drastically after 2002, which is supported by the increase in α (Fig. 2).

The increase in R_{eff} during winter season is interesting, although no significant coarse particle loading take place and the hygroscopic growth of these particles are unlikely. The effective radius of coarse mode may increase if the fine particles get attached to the surface of the coarse particles. The nature of the fine particles, which are getting attached in the coarse mode, can be inferred from the single scattering albedo (SSA) of fine

Table 1
Percentage contribution of fine mode particles to the total extinction at 0.67 μm in different seasons

	Winter	Pre-monsoon	Monsoon	Post-monsoon
2001	75.61	38.98	55.92	65.95
2002	79.80	37.27	34.93	65.57
2003	81.37	30.37		82.56
2004	85.15	41.52	39.95	80.04
Average	80.06	37.64	46.26	72.71

and coarse modes. In Kanpur, fine particles mainly include sulfate (most abundant) (Singh et al., 2004). SSA at 0.67 μm wavelength for coarse (ω_c) and fine (ω_f) modes shows significant difference in their absolute values (Fig. 4) with maximum difference during the post-monsoon and winter seasons. ω_f is always >0.9 indicating the dominance of water-soluble scattering aerosols in Kanpur; however, ω_c is found to vary between 0.71 ± 0.05 and 0.91 ± 0.03. Dey et al. (2004) have pointed out that during the pre-monsoon and monsoon seasons, dust is being transported from the western desert to Kanpur by southwesterly wind. The desert dusts have some absorbing component (in form of iron) and the SSA at 1.02 μm should be higher than 0.44 μm (Dubovik et al., 2002). From the AERONET data measured at sites located near the deserts, Dubovik et al. (2002) have shown that the spectral difference in SSA (i.e. $SSA_{1.02} - SSA_{0.44}$) is more than 0.05, whereas in Kanpur, it is not more than 0.03. This indicates the presence of anthropogenic pollutants, which reduces the spectral variability of SSA in Kanpur. Also it is noticeable that the dust alone can not be so absorptive ($\omega_c < 0.8$), it is likely that absorbing black carbon particles are likely to be associated with coarse mode dust particles, which reduces ω_c substantially. Several studies have indicated that the dusts during transport over a polluted region become absorbing in nature due to the mixing with black carbon particles (Chandra et al., 2004; Derimian et al., 2004; Deepshikha et al., 2004; Seinfeld et al., 2004). Even, for ω_f, the value is observed to be lowest during the winter season.

Regression analysis has been carried out between the extinction coefficient at fine ($b_{ext,f}$) and coarse modes ($b_{ext,c}$) and AOD at 0.67 μm wavelength and the result is shown in Fig. 5. Singh et al. (2004) have shown that over this region, $\alpha = 1$ can be taken as the boundary between the dust (attributing the coarse mode) and non-dust urban industrial (attributing the fine mode) aerosols and this value is taken in the present study to distinguish between the two modal class. During the fine mode aerosol dominated period, the linear regression equation yields

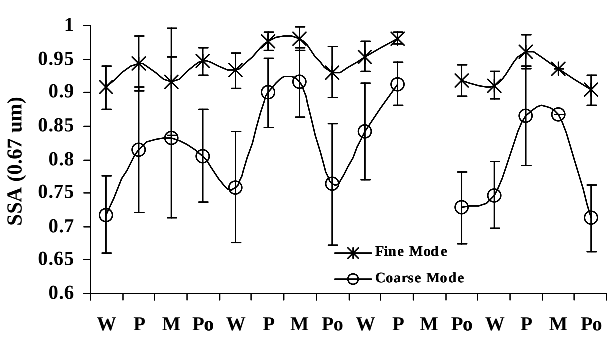

Fig. 4. Seasonal average of SSA at fine and coarse modes with the vertical bars representing ± 1 standard deviation.

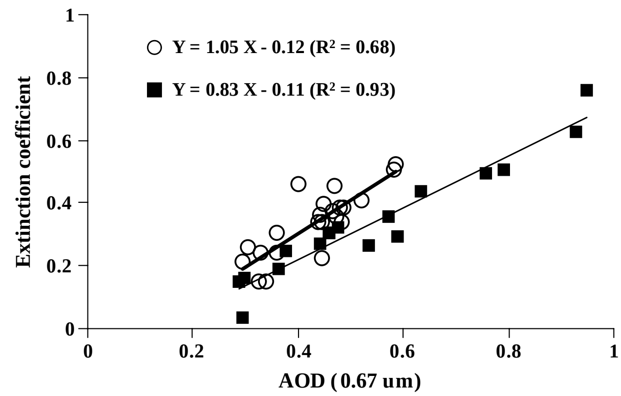

Fig. 5. Scatter plot between extinction coefficient for fine (open circle) and coarse (closed square) modes and AOD at 0.67 μm wavelength in Kanpur.

$$b_{ext,f} = 1.05\,AOD - 0.12$$

with a correlation coefficient of 0.68, whereas during the dust dominated period, the linear regression equation is

$$b_{ext,c} = 0.83\,AOD - 0.11$$

with a correlation coefficient of 0.93. These two regression equations suggest that the total extinction (and hence AOD) is less dependent on coarse particles during the pre-monsoon and monsoon seasons compared to fine particles during winter and post-monsoon seasons. In other words, for AOD (at 0.67 μm) of 1, $b_{ext,f}$ and $b_{ext,c}$ are 0.93 and 0.72, respectively; i.e. the relative contribution of fine particles to the total extinction is much higher during winter and post-monsoon seasons compared to the relative contribution of coarse particles during pre-monsoon and monsoon seasons. The negative values (0.12 and 0.11) of the intercepts of the curves are due to the fact that although the relative contribution of fine and coarse mode particles vary seasonally, eventually both contribute to the observed AOD.

4. Conclusions

The aerosol parameters show dominate fine mode aerosols (contributing more than 75%) produced by anthropogenic activities during winter and post-monsoon seasons, whereas coarse mode aerosols dominate during the pre-monsoon and monsoon seasons. The favorable condition in winter season results in hygroscopic growth of fine particles reflected in the higher values of R_V. The mixing of fine black carbon particles with the coarse mode particles increases R_{eff} at coarse mode as well as decreases the ω_c in the winter season significantly. Anthropogenic input in form of scattering water-soluble components is present through out all the seasons, whereas absorbing component is found to be high during winter and post-monsoon seasons.

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