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Temporal variability and radiative impact of black carbon aerosol over tropical urban station Hyderabad

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ABSTRACT

Time variability of black carbon (BC) aerosols over different timescales (daily, weekly and annual) is studied over a tropical urban location Hyderabad in India using seven channel portable Aethalometer. The results for the 2-year period (January 2009–December 2010) show a daily-mean BC variability from $\sim 1.00 \pm 0.12$ μg m^{-3} to 12.50 ± 3.06 μg m^{-3}, with a remarkable annual pattern of winter high and monsoon low. The BC values maximize during winter (December–January), $\sim 6.67 \pm 0.22$ μg m^{-3}, and drop during summer (June–August), $\sim 2.36 \pm 0.09$ μg m^{-3}, which establishes a large seasonal variation. Furthermore, the BC mass concentration exhibits a well-defined diurnal variation, with a morning peak and early afternoon minimum. The magnitude of the diurnal variations is seasonal dependent, which maximizes during the winter months. Air mass back trajectories indicated several different transport pathways, while the concentration weighted trajectory (CWT) analysis reveals that the most important potential sources for BC aerosols are the Indo-Gangetic plain (IGP), central India and some hot spots in Pakistan, Arabian Peninsula and Persian Gulf. The absorbing Ångström exponent (α_{abs}) estimated from the spectral values of absorption coefficient (σ_{abs}) ranges from 0.9 to 1.1 indicating high BC/OC ratio typical of fossil fuel origin. The annual average BC mass fraction to composite aerosols is found to be (10 ± 3) % contributing to the atmospheric forcing by (55 ± 10) %. The BC radiative forcing at the atmosphere shows strong seasonal dependency with higher values in winter (33.49 ± 7.01) and spring (31.78 ± 12.89) and moderate in autumn (18.94 ± 6.71) and summer (13.15 ± 1.66). The BC radiative forcing at the top of the atmosphere (TOA) is positive in all months, suggesting an overall heating of the regional climate over Hyderabad.

1. Introduction

Due to increase in population, industrialization and energy demands, atmospheric aerosols and pollutant emissions have gradually been increasing over south Asia (Lawrence and Lelieveld, 2010 and references therein). The outflow of aerosols and pollutants over the adjoining oceanic regions and Himalayan range has caused serious effects in regional climate, associated with the formation of atmospheric brownish clouds (Ramanathan et al., 2007), precipitation re-distribution (Lau et al., 2006), impact on monsoon onset (Gautam et al., 2009), mid-tropospheric heating (Gautam et al., 2009) and intensity of the solar dimming phenomenon (Badarinath et al., 2010; Kambezidis et al., 2012). Extensive long-term observations over India showed that the aerosol load and pollutants are higher over the densely-populated IGP (Habib et al., 2006; Dey and di Girolamo, 2010) and over major urban centers and power plants (Ramachandran and Rajesh, 2007). Particularly over Hyderabad, previous studies (e.g. Latha and Badarinath, 2005; Badarinath et al., 2007; Gummeneni et al., in press) showed high levels of aerosols, particulate matter (PM) and black carbon (BC) rendering it as one of the most polluted cities in India (Beegum et al., 2009).

The enhanced presence of BC aerosols in the atmosphere has not only adverse health effects, but also modifies the radiation balance that may have potential impact on the hydrological cycle and, thereby, on the weather and climate (Satheesh and Ramanathan, 2000; Menon et al., 2002; Lau et al., 2006; Meehl et al., 2008). Due to the strong absorption of solar light, BC aerosols heat the atmosphere and contribute significantly to the global warming, since studies have shown that it is the second contributor (after CO_2) to the greenhouse effect (Jacobson, 2000; Ramanathan and Carmichael, 2008). Large mass fraction of BC to

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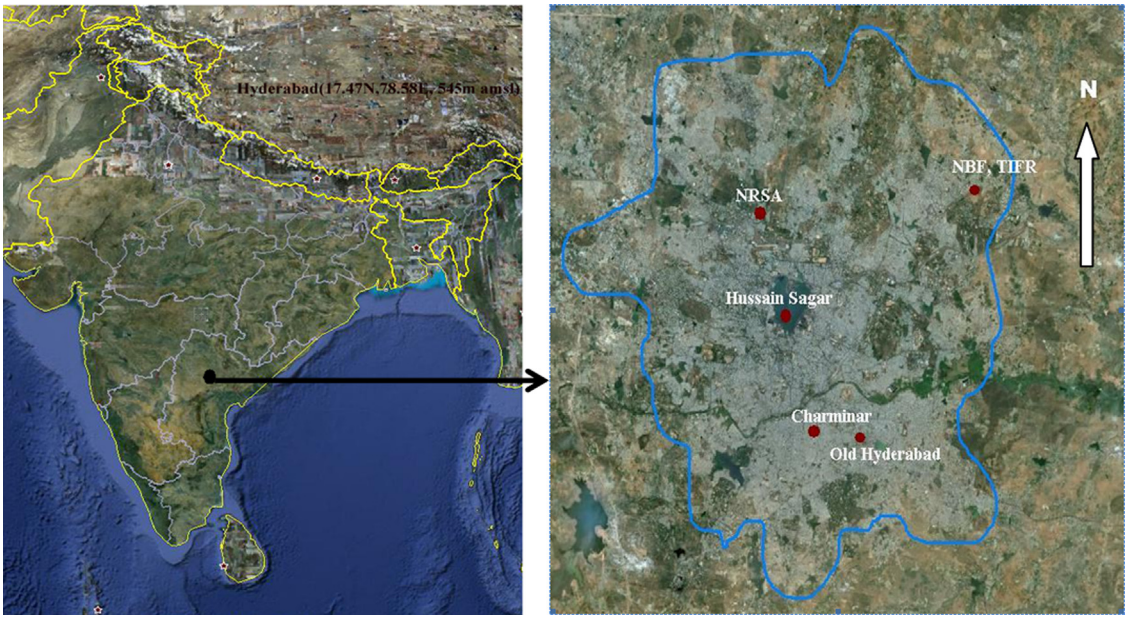

Fig. 1. Terrain of Peninsular India and site map of the measurement location (NBF, TIFR) at the outskirts of Hyderabad.

the total composite aerosols can reverse the sign of aerosol radiative forcing (ARF) in top of atmosphere (TOA) from cooling to heating, thus leading to large atmospheric absorption (Keil et al., 2001; Babu et al., 2002) and offset of the whitehouse aerosol effect (Schwartz, 1996). Previous studies suggest that BC can also alter the cloud lifetime (Ackerman et al., 2000), reflectivity and melting of snow and ice (Hansen and Nazarenko, 2004; Chaubey et al., 2010). Modeling studies also suggest that the direct forcing of BC can cause a significant change in the atmospheric circulation and tropical convective precipitation (Wang et al., 2006). Recently, Ramanathan et al. (2007) demonstrated that the carbonaceous aerosols may contribute to the regional warming over the Indian Ocean as much as the greenhouse gases. Although several studies have modeled the global radiative effects of BC aerosols (Haywood and Shine, 1995; Jacobson, 2000; Reddy and Boucher, 1997), there are still exist large uncertainties due to the inadequacy of observed data.

Due to significance of BC in modification of the regional climate over south Asia, systematic measurements of BC aerosols have been carried out at several locations in the Indian sub-continent, namely Dibrugarh [27.3°N, 4.5°E] (Pathak et al., 2010), Minicoy [8.3°N, 73.04°E] (Vinoj et al. 2010), Nainital [29.23°N, 79.41°E] (Dumka et al., 2010), Kullu valley [31.9°N, 77.11°E] (Guleria et al., 2011), Delhi [28.63°N, 77.17°E], Kanpur [26.47°N, 80.33°E] (Chinnam et al., 2006), Ahmedabad [23.03°N, 72.55°E] (Ganguly and Jayaraman, 2006), Pune [18.53°N, 73.85°E] (Panicker et al., 2010), Visakhapatnam [17.7°N, 83.3°E] (Sreekanth et al., 2007), Bangalore [13.0°N, 77.0°E] (Babu et al., 2002), among many others. Results from these studies reflect the large spatio-temporal variability of BC aerosols specific to the region.

In the present study, systematic measurements of aerosol BC mass concentration for 2 years (January 2009–December 2010) have been performed over Hyderabad, which is a typical tropical urban industrial region. The data were obtained using a seven channel portable Aethalometer aiming to study the seasonal and diurnal variation of BC and their association with the prevailing atmospheric processes. The seasonal variation in the BC aerosol concentration as well as the identification of its potential pathways and assessment of BC radiative forcing constitute the main objectives of the present study that are examined for the first time over Hyderabad.

2. Experimental site description and methodology

The study area pertains to Hyderabad (Fig. 1a), which is the fifth largest city in India and is also considered as one of the most polluted (Beegum et al., 2009). This is a direct result of the growth in population and associated activities that have been observed during the last decade. Greater Hyderabad area consists of twin cities, viz Hyderabad and Secunderabad, with its suburbs extending up to ~26 km. The population of the city and surrounding regions according to 2010 census is ~5.3 million inhabitants with a ~18% decadal growth. The measurements have been carried out at the premises of National Balloon Facility (NBF), Tata Institute of Fundamental Research (TIFR), located at the outskirts of the urban center (17.47°N and 78.58°E) as seen in Fig. 1.

2.1. Aethalometer

Continuous real-time measurements of the black carbon (BC) aerosol mass concentration and absorption coefficient have been carried out during January 2009–December 2010 using a seven wavelengths Aethalometer (model AE-42). A semi-continuous optical absorption method is applied to measure the attenuation of light by aerosols at the seven selected wavelengths (370, 470, 520, 590, 660, 880 and 950 nm). The instrument aspirates ambient air at a standard flow rate of 5 l per minute at an altitude of ~10 m above the ground level. The measurement sampling interval was kept at 5 min. The particles in the incoming airflow are deposited on the quartz filter tape of the Aethalometer and the BC mass concentration is determined by measuring the change in transmittance through the quartz filter tape due to the particle deposition.

It is noticed that filter-based absorption techniques for the measurement of BC aerosol encounter various systematic errors that need to be corrected (Bond et al., 1999). The overestimation of BC mass concentration due to multiple scattering (denoted by C) within the filter is partly compensated by higher particle loading called shadowing effect (denoted by R) in the filter, which decreases the optical path. Based on several experiments Weingartner et al. (2003) found that the shadowing effect and R factor are quite significant for pure soot particles, while almost negligible for aged aerosols (mixture of several components).