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Black carbon aerosols in a tropical semi-urban coastal environment: Effects of boundary layer dynamics and long range transport

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ABSTRACT

Regular measurements of Black Carbon (BC) aerosol mass concentration have been carried out since March 2011 at a tropical location (12.81°N, 80.03°E) adjoining the mega city, Chennai, on the east coast of India for the first time. As this region is influenced by both the South West and North East monsoons, the BC observations at this site assume importance in understanding the overall BC distribution over India. The data collected until August 2012 has been examined for the general and regionally distinctive features. Spectral absorption characteristics reveal that the BC is mainly from fossil fuel based emissions. The BC concentration shows significant diurnal variation only in the North East monsoon and winter seasons with night time concentration considerably higher than the day time concentration. In the other seasons the day–night contrast in BC is not significant. Seasonal variation is rather subdued with a broad maximum during the Northeast monsoon and winter months and a minimum during the southwest monsoon months. The observed diurnal and seasonal variations are examined in the light of local Atmospheric Boundary Layer dynamics and long range transport. For the first time, an inverse relationship has been established between BC and ABL height on a quantitative basis. A distinctive feature of the region is that in all the seasons transport pathways have long continental overpasses which could lead to the suppressed seasonal variation. It is found that the BC over this region shows distinct diurnal and seasonal features compared to those reported for other coastal and inland regions in India.

1. Introduction

The BC aerosols are known to produce a profound impact on the radiation budget of the earth–atmosphere system (e.g., Babu et al., 2007). The importance of BC in the radiation budget stems mainly from its strong absorption cross section across the wavelength range in the visible and IR, thereby contributing significantly to the green-house effect (Jacobson, 2001), which is believed to offset the 'cooling' effect of sulfate aerosols to a certain extent. The importance of BC in regional and global climate has been recently highlighted in an extensive review article by Bond et al., (2013). When coated with hydrophilic material, BC aerosols can form cloud condensation nuclei contributing to indirect radiative forcing (Lohmann and Lorenz, 2000; Lohmann et al., 2000, Akerman et al., 2000). The sources for BC are mainly of anthropogenic origin, like fossil fuel and biomass burning. Basically, BC aerosols are by-products of incomplete combustion processes. As the sources are highly variable across different regions owing to the level of industrialization, transportation density and fuel usage for electricity generation and in the households, the BC concentrations will necessarily be highly region dependent and temporally varying. The BC aerosols are chemically inert and their main removal process is wet deposition. Gravitational sedimentation process of removal would be a slower process owing to their size being in the sub-micron range. Their atmospheric life time due to the wet removal process could be quite long being about 7 days in the troposphere (Babu and Moorthy, 2002). The long life time makes the BC aerosols subject to long range (horizontal) transport. So, it is imperative that studies on BC concentration are carried out in different regions in order to be able to understand and assess their radiative impacts.

Systematic long-term BC measurements in India commenced from Trivandrum (8°33'N, 77°E), a semi-urban location situated on the south-western coast of India (Babu and Moorthy, 2002) since 2000. The measurements have been extended later to a number of locations covering different environments in India under the 'Aerosol Radiative Forcing over India' (ARFI) project of the Indian Space Research Organization (ISRO). As part of ARFI, regular BC measurements have been initiated in March 2011 at the SRM University Campus located in

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the semi-urban region (12.81°N, 80.03°E, 45 m amsl), ~40 km southwest of the city of Chennai, a mega city with a population of about 4.3 million (as per 2011 data http://censusindia.gov.in/PopulationFinder/Population_Finder.aspx on the east coast of India. BC aerosol measurements over this site on the Bay of Bengal coast (east coast) assume importance in the context of reported (Beegum et al., 2009) higher concentration of BC aerosols over the Bay of Bengal compared to the Arabian Sea (west coast of India) and also due to the fact that the site is affected by both the South West (SW) and North East (NE) monsoons. The temporal features of the BC aerosols over this semi-urban location have been examined and compared with those reported for the other coastal and inland environments in India and the results are presented in this paper. The role of the Atmospheric Boundary Layer (ABL) dynamics and the long range transport in causing the observed features are discussed.

2. Experimental set up and methodology

Near-real-time and continuous measurements of Black Carbon (BC) mass concentration have been carried out using Aethalometer (Model AE-31, Magee Scientific, USA) since March 2011 at SRM University campus, situated in the outskirts of Chennai city, about 40 km southwest of the city center and about 45 m due east of the National Highway (Fig. 1). The campus is about 32 km due west of the west coast of Bay of Bengal and represents a small township, comprising basically of the university and its activities. Chennai city is an industrial hub in the peninsular India, with several manufacturing firms. It is the southern hub of automobile industries in India. It also houses several coal/lignite and gas based thermal power stations with a combined capacity of over 5000 MW; of which two gas turbine and two coal fired stations are due north of the location, in and around Chennai city itself. The continuous data for the period March 2011 to August 2012 is considered for the present study. The measurements are made from one of the University buildings, about 15 m above the ground level.

In the Aethalometer, ambient air is aspirated at a standard mass flow rate of 5 l/min through the inlet tube and BC mass concentration is estimated at every 5 min following the optical attenuation technique. More details of the instrument and operational methods can be found in Hansen, (2005). The Aethalometer gives change in optical attenuation at seven different wavelengths (370, 470, 520, 590, 660, 880 and 970 nm) by measuring the intensity of the light beam passing through pristine portion of the filter and particle laden filter. The BC mass concentration is estimated from the change in attenuation at 880 nm and laboratory calibrated value (16.6 $m^2\,g^{-1}$ at 880 nm) of the mass specific absorption cross section. BC is the chief absorber at 880 nm having the imaginary part of refractive index >0.44; which is two orders higher than that of organics and dust (Lubin et al., 2002).

The change in transmission is related to the Black Carbon (BC) mass concentration by

$$BC = \frac{d(ATN)}{\sigma}\frac{A}{V} \tag{1}$$

Where σ is the specific absorption cross sections ($m^2\,g^{-1}$), A is the spot area, V is the volume of air passed through the filter and d (ATN) is the attenuation of light through the filter due to BC. The manufacturer of the Aethalometer gives an error less than 5% in the BC concentration measurement. Factors such as multiple scattering in filter matrix, shadowing effect and ambient temperature variations may contribute to the error over and above the quoted value (Weingartner et al., 2003; Arnott et al., 2005). Following the error budget described in several earlier papers the maximum uncertainty in the measured BC can be up to 20%, with the higher percentage of error being applicable to lower concentrations (Corrigan et al., 2006; Nair et al., 2007; Moorthy et al., 2007).

The spectral values of absorption coefficients (β_a) are estimated from the attenuation coefficient (β_{ATN}) based on Weingartner et al. (2003).

$$\beta_{ATN} = d(ATN)\frac{A}{V} \tag{2}$$

$$\beta_a = \frac{\beta(ATN)}{CR(ATN)} \tag{3}$$

Here, $C=2.14$ is introduced for the correction of multiple light scattering effects of filter fibers. R (ATN) is an empirical function of ATN accounts for the reduction of optical path length in the filter with increasing filter load. The value of R is taken as 1.

To explore the source characteristics of BC, the wavelength exponent γ is estimated from the spectral values of the absorption

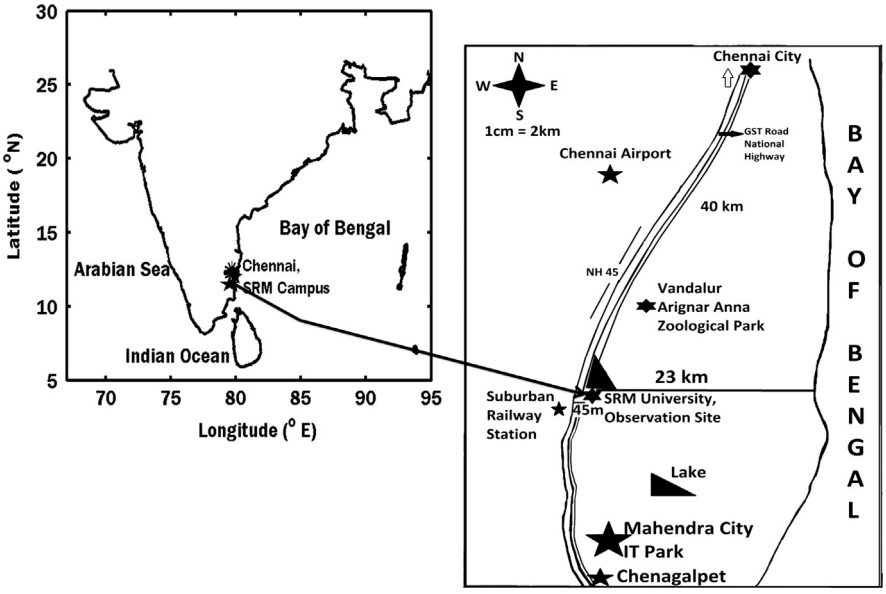

Fig. 1. Location map of the observation site.