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Seasonal characteristics of black carbon aerosols over a high altitude station in Southwest India

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ABSTRACT

Black carbon (BC) aerosol mass concentrations were measured using an Aethalometer at high altitude station Sinhagad, a rural location in south-west India, in the pre-monsoon and post-monsoon seasons during 2009–10. Mean BC concentration was about 67% less during pre-monsoon than that during post-monsoon. During post-monsoon, the surface boundary layer is generally shallow resulting in the trapping of pollutants in a lesser volume near the surface which lead to higher BC concentrations than of pre-monsoon which experiences high convective activity and thereby dispersion of aerosols near the surface. Diurnal variation of BC during pre-monsoon was attributed to the changes in the local boundary layer as well as to the certain anthropogenic activities near the sampling site. BC aerosol mass concentration showed good correlation with temperature gradient and relative humidity in pre-monsoon. However in post-monsoon, a weak correlation was observed with temperature gradient whereas with relative humidity, a good correlation was observed during night hours only. The wind speed and direction using NCEP/NCAR reanalysis data showed a possible transport from Pune city as well as from N/NE Indian regions during post-monsoon. BC also showed good correlation with other anthropogenic components of aerosols like $NssSO_4$, NssK, NO_3, and NH_4; indicating a possible common source for them.

1. Introduction

Atmospheric aerosols are linked to visibility reduction, adverse health effects and radiation balance of the Earth, directly by scattering and absorbing solar radiation and indirectly by influencing the cloud processes by acting as Cloud Condensation Nuclei i.e. CCN (Jarvi et al., 2008; Chatterjee et al., 2010a). Role of aerosols in atmospheric radiation budget and a possible climate impact has been recognized for a long time (Ramanathan et al., 2001). Aerosol black carbon, the byproduct of all the incomplete combustion processes (Cooke and Wilson, 1996; Latha and Badarinath, 2003), is believed to be mostly of anthropogenic origin and is generally in fine size range. As such, it has long atmospheric life time (Babu and Moorthy, 2002) making it amenable for easy transport both horizontally and vertically to higher altitudes of the atmosphere and longer regions on the globe. In the initial state, BC is hydrophobic but as it ages out, it becomes hydrophilic and changes it shape and size (Shrestha et al., 2010). BC aerosols are strong absorber of solar radiation in the visible and near IR wavelengths contributing positive radiative forcing in the range of $+0.16\ Wm^{-2}$ to $+0.80\ Wm^{-2}$ (Jacobson, 2001). Observations on BC aerosols are reported mainly from the urban locations in the Indian region (Sarkar et al., 2001; Latha et al., 2003; Safai et al., 2007; Moorthy et al., 2009; Beegum et al., 2009) however, those from the rural/remote locations are very scarce. In this paper, we report the surface BC observations from the high altitude station in southwest India, Sinhagad during two different seasons, i.e. pre-monsoon (April–May 2009) and post-monsoon (Dec 09–Jan 2010).

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2. Experimental site

Week-long observations of BC aerosols were carried out during April–May 2009 and December 09–January 2010 at Sinhagad (18° 21′N, 73° 45′E 1450 m amsl). Sinhagad is a historical fort situated on the hill top in the Western Ghats region in South-West India (Fig. 1). Arabian Sea is less than 100 km away by aerial distance to the west of this location. It is about 40 km by road, to the southwest of Pune city. The top of the hill is a flat terrain with an area of about 0.5 km^2 and is surrounded by other hill-tops of comparable heights. The area is covered with vegetation during monsoon season (June to September) and also then after during post-monsoon seasons (October to February). The only noticeable local source of pollution is wood burning, which is mainly carried out for cooking and sometimes to clear the forest for agricultural activity. Being a tourist spot, emissions from vehicular exhausts is another source of certain organic and inorganic gaseous as well as particulate pollutants (mainly from cars, jeeps and two-wheelers which are restricted at the entrance of the fort only). Sampling of BC was carried out near a microwave tower building owned by Bharat Sanchar Nigam Limited (BSNL), Government of India. It is a protected site and tourists are not allowed to enter in this area. Thus, the observational site at Sinhagad can be considered as a remote, least polluted site.

3. Methodology

The Aethalometer (Magee Sci., Inc., USA, Model AE-42) is widely used for the real-time measurement of BC aerosols in the atmosphere. This device is portable and easy to mount at any location. The principle of Aethalometer is to measure the attenuation of a beam of light transmitted through a quartz fiber filter tape, while the filter is continuously collecting aerosol sample. This measurement is made at successive regular intervals of time base period. In the present study, a time base interval of 5 min was used. By using appropriate value of the specific attenuation of that particular combination of the filter and optical components, we can determine the BC content of aerosol deposit at each measurement time. A specific attenuation coefficient of 16.6 $m^2 g^{-1}$ (at $\lambda = 880$ nm) was used in this study, as recommended by the manufacturer. The increase in optical attenuation from one period to the next is due to the increment of aerosol BC collected from the air stream during the period. Dividing this increment by the volume of air sampled during that time, we calculate the mean BC concentration in the sampled air stream during the period. More details on the instrument and operational technique are available elsewhere (Hansen et al., 1984; Safai et al., 2007). The filter based absorption technique used in Aethalometer is reported to have shown good comparison with the other methods used for monitoring of BC particles (Allen et al., 1999; Babich et al., 2000). The measured BC concentrations were corrected for the changes in pressure and temperature (Moorthy et al., 2004) as the Aethalometer was operated under mass flow condition that is programmed to maintain mass flow of sampled air at 3 LPM under the standard atmospheric pressure and temperature; which has to be corrected due to the high altitude of Sinhagad. In addition, there are certain other corrections that need to be applied to the Aethalometer BC data. In the Aethalometer, it is assumed that the optical attenuation (ATN) increases only due to light absorption by the accumulation of BC on the filter. Therefore, the BC concentration reported from the Aethalometer is calculated from the rate of change of ATN. It is observed that the BC concentrations obtained using an Aethalometer apparently rise after the filter tape advances (Arnott et al., 1999; Hansen et al., 2007; Kirchstetter and Novakov, 2007; Virkkula et al., 2007) and therefore, the relationship between ATN change and BC concentration is not linear (Bond et al., 1999; Weingartner et al., 2003; Arnott et al., 2005). Therefore, as the ATN increases, the measured BC concentration becomes underestimated. This Loading Effect should be taken into account when using empirical correction algorithms. In order to account for this effect, we have used the correction algorithm presented by Virkkula et al. (2007) and also employed by Park et al. (2010). In the absence of scattering coefficient data, the corrected attenuation coefficient is expressed by Eq. (1):

$$b_{ATN}(\text{corrected}) = (1 + k * \text{ATN}) * b_{ATN}(\text{Aethalometer}) \quad (1)$$

where k is an empirically derived constant. The corrected aerosol BC mass concentration is calculated from Eq. (2):

$$\begin{aligned} \text{BC (corrected)} &= b_{ATN}(\text{corrected}) / \sigma_{ATN} \\ &= (1 + k * \text{ATN}) * \text{BC (Aethalometer)}. \end{aligned} \quad (2)$$

The value of 'k' varies depending on sampling locations, season, aerosol composition and age of the aerosols (Hansen et al., 2007).

4. Temporal variations of black carbon concentrations

4.1. Day-to-day variation during different seasons

Fig. 2(a) and (b) shows the day-to-day variation of BC mass concentration during pre-monsoon and post-monsoon seasons, respectively with vertical bar representing standard deviation. Mean BC concentration during post-monsoon

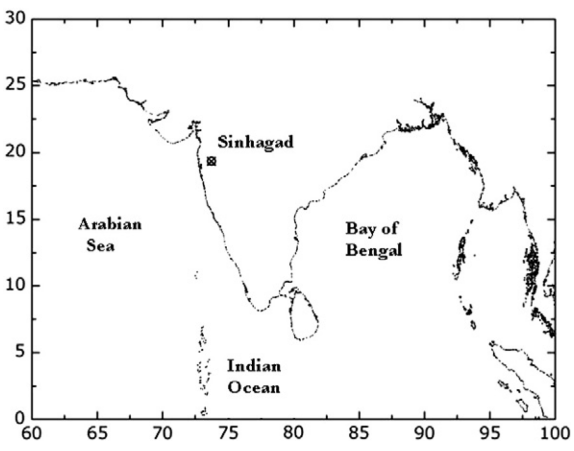

Fig. 1. Map of Indian subcontinent showing the observational site at Sinhagad.