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Intra-seasonal variability of black carbon aerosols over a coal field area at Dhanbad, India

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ABSTRACT

Black carbon (BC) aerosols, which are optically absorbing parts of carbonaceous aerosols and have significantly different optical and radiative properties were continuously measured at a coal field area in Dhanbad (23° 47′ N, 86° 30′ E: 222 m amsl), India for the first time from 1st January to 31st December, 2012. Daily BC mass concentrations varied within the range of 0.84–17.0 μg m^{-3} with an annual average of 6.3 ± 2.7 μg m^{-3}. About 45% of samples of the measured days exceeded the mean level of BC indicating the high loading of soot particles over the study region. Intra-seasonal variation in BC concentrations exhibited a strong seasonal cycle with the highest concentrations during winter (8.2 ± 2.8 μg m^{-3}), followed by post-monsoon (6.4 ± 2.6 μg m^{-3}), pre-monsoon (5.5 ± 1.9 μg m^{-3}) and monsoon (4.6 ± 1.7 μg m^{-3}). In diurnal analysis, BC showed a significant peak from 06:00 to 10:00 local time (LT) during all the seasons whereas the lowest concentrations were found during 14:00 to 17:00 LT in the late afternoon. The difference between maximum and minimum concentrations of BC was found to be higher during winter (8.3 μg m^{-3}) followed by post-monsoon (4.7 μg m^{-3}), pre-monsoon (4.3 μg m^{-3}) and monsoon (1.7 μg m^{-3}). An interesting feature was seen in the difference between morning and evening peaks, it was maximum during winter (4.8 μg m^{-3}) followed by pre-monsoon (1.5 μg m^{-3}) and post-monsoon (1.3 μg m^{-3}), however, during monsoon, it was opposite i.e. ~23% lower during morning time. During day-time and night-time variability analyses, it fluctuated largely, varying from 1% (December) to 35% (June) higher during night-time as compared to day-time as whole mean was ~19%. Data of BC were separated as stable (<1 m s^{-1}) and unstable weather conditions (>1 m s^{-1}), the corresponding values of BC were 6.06 and 3.75 μg m^{-3} respectively which is ~38% higher during stable weather condition indicating that the major portion of BC was mainly emitted from local sources instead of transported from remote sources. Apart from this, it was observed that the concentration of BC mass during winter was ~78% higher (8.2 μg m^{-3}) as compared to monsoon (4.6 μg m^{-3}) when the winds were from the SE (158°) direction.

1. Introduction

Black carbon (BC) aerosol is an important part of the combustion product such as fossil fuels (diesel and coal) and the usage of biofuel/biomass material such as wood, dung and crop residues, commonly referred to as soot particles (Andreae & Crutzen, 1997; Ramanathan & Carmichael, 2008). In the atmosphere, it absorbs solar radiation due to its low single scattering albedo and higher aerosol forcing efficiency (Bond et al., 2007; Venkataraman et al., 2010; Ramanathan et al., 2011; Huang et al., 2012; Tiwari et al., 2013a,b; Srivastava and Ramchandran, 2013). Globally, the annual emissions of BC are ~8 Tg yr^{-1} (Bond et al., 2004) and their source contributions are: from biofuels (~20%), fossil fuels (~40%) and open biomass burning (~40%). The atmospheric lifetime of BC is in the order of few days to weeks and can be transported far away from emission sources (IPCC, 2007) and the sources of BC vary from region to region.

The transportation of soot particle on regional or global scales leads to visibility degradation and haze formation in wide downwind regions (Kumar et al., 2011; Du et al., 2011). According to the Intergovernmental Panel on Climate Change (IPCC, 2007), the global mean clear sky radiative forcing of BC was 0.23 ± 0.25 W m^{-2}, which is nearly half of the value of methane and the second most important greenhouse gas after carbon dioxide (CO_2). Primary emitted BC mass aerosols tend to be hydrophobic as they age in the atmosphere and tend to acquire a hydrophilic coating (Safai et al., 2014). BC aerosol, mixed with other hydrophilic particles, can also affect the concentrations of the number of cloud droplets and cloud microphysical properties and even reduce precipitation (Chen et al., 2010; Bauer et al., 2010; Ramanathan et al.,

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2011). Ramanathan et al. (2005) reported that due to high concentrations of BC mass aerosols the rainfall pattern is affected, especially the Asian monsoon system (Frieler et al., 2011). Being chemically inert and in fine size-range, wet-deposition is the only effective removal mechanism of BC from the atmosphere (Babu and Moorthy, 2001). It has been found that due to fine size ranges of aerosols which easily penetrate into the human respiratory system it affects health seriously (Gauderman et al., 2004; Herich et al., 2011).

Due to rapid urbanization and industrialization for the last three decades, India and China are regarded as one of the largest BC emitters in the world on global annual emissions of BC from both anthropogenic as well as biofuel/biomass burning (Bond et al., 2004; Ramanathan and Carmichael, 2008; Wang et al., 2011). To date, a lot of literature mostly from urban areas has reported the field measurements of BC mass aerosol in South Asian region (Bergin et al., 2001; Zhou et al., 2009; Chen et al., 2010; Huang et al., 2012; reference therein) but still some regions are not studied. In India, several studies are reported over the Indo-Gangetic Plains (Tripathi et al., 2005; Nair et al., 2007; Dumka et al., 2010; Ramachandran and Kedia, 2010; Praveen et al., 2012; Srivastava et al., 2012; Tiwari et al. 2013a; Srivastava and Ramchandran, 2013; Kanawade et al., 2014; etc.) as well as the eastern part of India (Das, 2010; Pathak et al., 2010; Chatterjee et al., 2012; Chakrabarty et al., 2012; Sarkar et al., 2014; etc.). In the present study, continuous measurement of BC mass concentrations was made for the first time over the coal field area in Dhanbad, India. The aim of this study was to provide a more comprehensive understanding of BC mass concentrations as daily, monthly, seasonally (intra-seasonal) and yearly variations in coal field area. Also, the variability of BC mass in relation with changing meteorological conditions throughout the year was studied. The impact of measured surface BC mass aerosols on columnar optical properties of atmospheric aerosols such aerosol optical depth (AOD) and Angstrom exponent (α) was also presented. These findings further help to assess the health effects of BC mass aerosols and their source regions over coal field environment.

2. Measurements and instrument

2.1. Observational site

Dhanbad (23° 47′ N, 86° 30′ E; 222 m above mean sea level) is a city in the state of Jharkhand, and known as the 'coal capital of India' and actively associated with the mining activities for more than a century (Fig. 1). There are many working and abandoned coal mines in and around over Dhanbad city. It is among the top 100 fastest growing cities of the world. Recent census report (2011) population count indicated that the district has ~2.6 million inhabitants. The city abounds underground and open cast colliery of Jharia coal fields which is the only reserve of prime coal in India. The sickle shaped Jharia coal fields occupy an area ~450 km^2 stretching from west to south of Dhanbad city and the major portion of it is operated by Bharat Coking Coal Limited a subsidiary of Coal India Ltd. In the Jharia coal fields, ~7 km^2 is identified as coal mine fire area. Due to this, the area produces huge amount of aerosols over this region (Stracher and Taylor, 2004). Apart from coal mines and associated industries, six major thermal power plants namely Maithon Power Limited (~34 km, E), Bokaro Thermal Power Station (~53 km, W), Chandrapura Thermal Power Station (~33 km, WSW), Durgapur Steel Thermal Power Station (~85 km, ESE), Mejia Thermal Power Station (~83 km, SE) and Santaldih Power Station (~22 km, S) are located within the 100 km crow fly distance from the sampling location. These companies have developed townships for their employees. Dhanbad city is located in the eastern part of India below the Indo-Gangetic Plains which is a highly polluted region due to high loading on aerosols (Singh and Mondal, 2008). The major activities in and around the city are associated with coalmines and steel production and power plants in these regions served the status of air quality. Besides these mining and industrial sources, ever increasing transport sector contributes more to air quality deterioration by means of elevated PM, CO_2, and NOx and un-burnt hydrocarbons (Rai, 2014; Venkatesh et al., 2010).

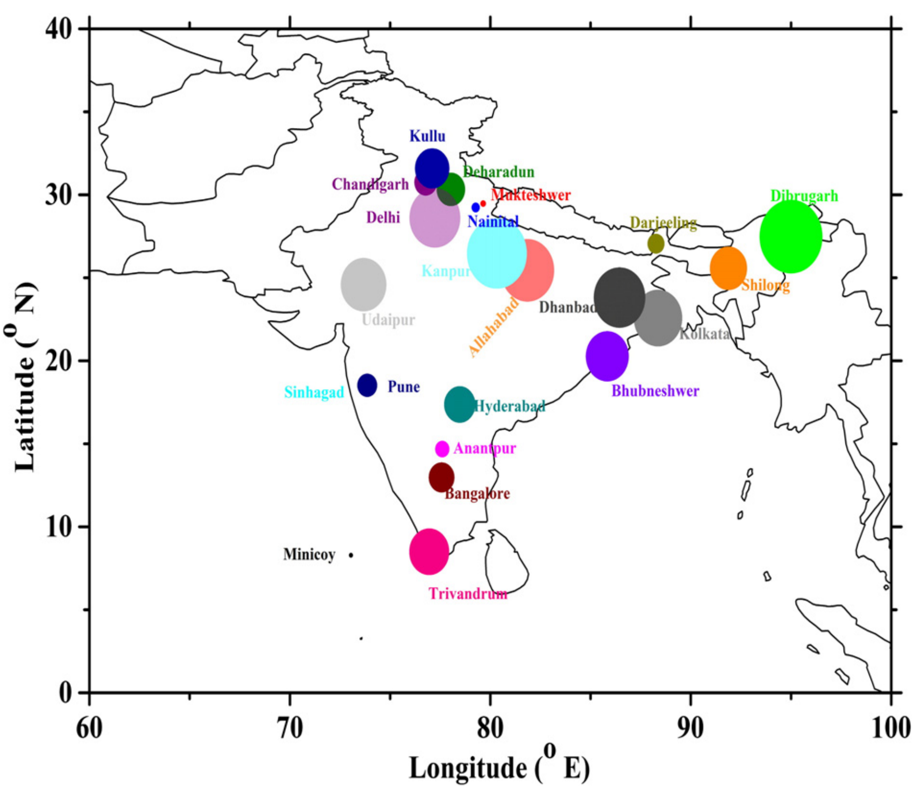

Fig. 1. Map of India and observational site (Dhanbad). Spatial pattern of atmospheric BC mass concentrations over India. The size of filled circles indicates the magnitude of the BC mass concentration.