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Ambient black carbon particulate matter in the coal region of Dhanbad, India

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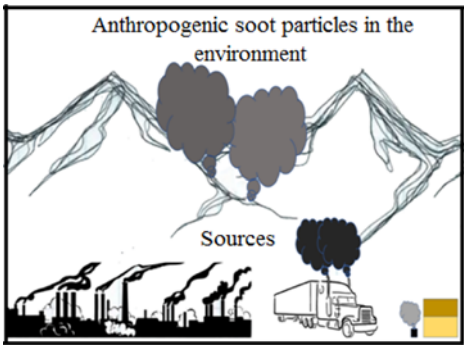
HIGHLIGHTS

- A year-long measurement of BC aerosol in the coalfield area "Dhanbad" in India
- Sources of BC were examined using light absorbance technique.
- Contribution of BC from coal/biomass burning (87%) and remaining from traffic (13%)
- Due to burning of coal/biomass, the Atmospheric hearing rate of UVBC was 1.40 K day^{-1}.

GRAPHICAL ABSTRACT

Sources of soot particles into the atmosphere our industrialized area.



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ABSTRACT

Light-absorbing, atmospheric particles have gained greater attention in recent years because of their direct and indirect impacts on regional and global climate. Atmospheric black carbon (BC) aerosol is a leading climate warming agent, yet uncertainties in the global direct aerosol radiative forcing remain large. Based on a year of aerosol absorption measurements at seven wavelengths, BC concentrations were investigated in Dhanbad, the coal capital of India. Coal is routinely burned for cooking and residential heat as well as in small industries. The mean daily concentrations of ultraviolet-absorbing black carbon measured at 370 nm (UVBC) and black carbon measured at 880 nm (BC) were 9.8 ± 5.7 and 6.5 ± 3.8 μg m^{-3}, respectively. The difference between UVBC and BC, Delta-C, is an indicator of biomass or residential coal burning and averaged 3.29 ± 4.61 μg m^{-3}. An alternative approach uses the Ångstrom Exponent (AE) to estimate the biomass/coal and traffic BC concentrations. Biomass/coal burning contributed ~87% and high temperature, fossil-fuel combustion contributed ~13% to the annual average BC concentration. The post-monsoon seasonal mean UVBC values were 10.9 μg m^{-3} and BC of 7.2 μg m^{-3}. Potential source contribution function analysis showed that in the post-monsoon season, air masses came from the central and northwestern Indo-Gangetic Plains where there is extensive agricultural burning. The mean winter UVBC and BC concentrations were 15.0 and 10.1 μg m^{-3}, respectively. These higher values were largely produced by local sources under poor dispersion conditions. The direct radiative forcing (DRF) due to

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UVBC and BC at the surface (SUR) and the top of the atmosphere (TOA) were calculated. The mean atmospheric heating rates due to UVBC and BC were estimated to be 1.40 °K day^{-1} and 1.18 °K day^{-1}, respectively. This high heating rate may affect the monsoon circulation in this region.

1. Introduction

Atmospheric particulate matter (PM) affects the climate system directly by absorbing and scattering solar radiation and indirectly by affecting precipitation patterns and cloud processes (Ramanathan et al., 2005). In addition, PM has significant impacts on visibility, fog and haze formation, regional air quality, ecosystems, atmospheric heating, and cause human morbidity and premature mortality (Rosenfeld, 1999; Bond and Bergstrom, 2006; Pope and Dockery, 2006; Anenberg et al., 2012; Li et al., 2016). Black carbon (BC) is a short-lived, strong climate forcing agent and warms the Earth's atmosphere by absorbing solar light and heating the lower and middle troposphere; and by reducing the albedo when deposited on ice and/or snow and by interacting with clouds (Bond et al., 2013).

The lifetime of BC in the atmosphere is a few days to weeks and significantly less than that of carbon dioxide (CO_2) (more than a century) (Bond et al., 2013). The climatic effects of atmospheric aerosol are still not well understood as indicated by large uncertainties in their climate forcing estimates. In South and East Asia, ambient aerosol light absorbing properties are poorly characterized but play an important role in the radiation budget providing a net positive climate forcing second only to CO_2 (Ramanathan and Carmichael, 2008). Light absorbing atmospheric particles are classified into two groups: (i) black carbon that is emitted by high-temperature combustion processes and is commonly estimated by measurement of light absorbance at 880 nm, and (ii) brown carbon (BrC) that represents organic species that absorb light more strongly in the blue to UV portion of the solar spectrum.

BC is also commonly termed as soot (Moosmüller et al., 2009; Bond et al., 2013; Petzold et al., 2013). High temperature/flaming combustion tends to produce predominantly BC whereas smoldering combustion produces some BC along with BrC (light brownish color). Optical and thermal analysis have provided strong evidence for the existence of organic carbon containing compounds with strongly light absorbing properties near the ultraviolet wavelengths (Hoffer et al., 2006). BrC includes tar-like materials from biogenic emissions, biomass burning or solid fuel (coal) combustion and aerosolized humic-like substances in soil (Andreae and Gelencsér, 2006; Pavlovic and Hopke, 2012) or oligomeric compounds (HULIS) formed in the atmosphere (Reemtsma et al., 2006; Volkamer et al., 2006; Saleh et al., 2014; Laskin et al., 2015). BrC can also be produced through atmospheric chemical processes from gaseous precursors (Laskin et al., 2015). Both types of carbonaceous particles have large direct and indirect impacts on radiative transfer. Primary BC particles are hydrophobic in nature and their cloud condensation nucleus (CCN) activity is limited. However, chemical aging in the atmosphere can make the soot particles hydrophilic (Moteki et al., 2007). The modified BC particles can have CCN activity that may indirectly affect the radiation budget and/or change cloud albedo (Koehler et al., 2009).

Model-constrained approaches inferred a global BC climate forcing of ~1.1 W m^{-2} varying from +0.17 to +2.1 W m^{-2} (Bond et al., 2013). Chung et al. (2012) estimated the BC forcing was ~0.65 W m^{-2} which is ~85% larger than the Intergovernmental Panel on Climate Change model simulation value (0.35 W m^{-2}). The direct absorption of sunlight by BrC is typically ignored, except in a few studies (Jacobson, 2001). Recent studies indicated that BrC aerosol in the lower troposphere could enhance the absorption of solar radiation and produce reduced surface radiative fluxes (Bahadur et al., 2012; Chung et al., 2012). A global simulation study of BC sources apportioned up to +0.25 W m^{-2} of the light absorption to BrC (19%) relative to the absorption from anthropogenic black carbon aerosol (72%), and sulfate and non-absorbing organic aerosols coated on BC (9%) (Feng et al., 2013). The overall climate forcing due to BrC at the top of the atmosphere was estimated to be +0.11 W m^{-2} (a warming effect), while the effect at the surface, it was −0.14 W m^{-2} (cooling effect). Thus, brown carbon needs to be considered in global climate simulations.

Ramanathan and Carmichael (2008) reported BC emission source contributions in Asia from burning of biofuels (~20%), fossil fuels (~40%) and open biomass burning (~40%). In India, light absorption by atmospheric particles, especially soot, is relatively poorly characterized because of high variability in physical and chemical properties of soot particles in time and space.

Source apportionment of light absorbing aerosols and identification of the sources of BrC and BC have been made using differential light absorption (e.g., Sandradewi et al., 2008a, 2008b; Lanz et al., 2008; Wang et al., 2012). There have been limited studies in India and they have largely been focused on major cities. This study presents the source contributions in a coal field region in the Indian state of Jharkhand in eastern India. Coal combustion has been reported to be an important source of both BC and UVBC in China (Ran et al., 2016; Tan et al., 2016) and thus, coal combustion in this region is expected to contribute to both BrC and BC. The objectives of this work are (i) to understand the behavior of BrC and BC at diel, monthly, and seasonal scales, (ii) to assess the source contributions and regional origins of BrC and BC from biomass/coal burning and fossil fuel (traffic) combustion using wavelength absorption technique and by trajectory analysis, and (iii) to study the regional impact on climate due to carbonaceous aerosol.

2. Method and materials

2.1. Sampling site

Measurements of black carbon were conducted from 1st January to 31st December 2013 on the premises of Central Institute of Mining & Fuel Research (CIMFR), Dhanbad, Jharkhand, India. Dhanbad (23° 47′ N, 86° 30′ E: 222 m above mean sea level) is popularly recognized as the coal capital of India (Fig. 1). The sampling site was CIMFR is located in a forested enclave within an urban setting. The sickle-shaped Jharia

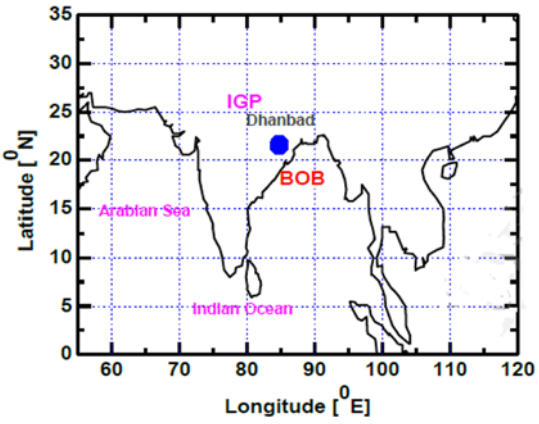

Fig. 1. Sampling site at Dhanbad on the map of India. BOB is the Bay of Bengal and IGP is the Indo-Gangetic Plain.