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Variability of winter and summertime aerosols over eastern India urban environment

S.K. Pani [a], S. Verma [a,b,*]

[a] Centre for Oceans, Rivers, Atmosphere Land Sciences, Indian Institute of Technology Kharagpur, Kharagpur 721302, India
[b] Department of Civil Engineering, Indian Institute of Technology Kharagpur, Kharagpur 721302, India

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ABSTRACT

We examined the variability of aerosols during winter and summer months in an urban environment in eastern India, under contrasting meteorological conditions and air-mass pathways. Hourly mean black carbon (BC) and submicron aerosol (aerosol-submic) surface concentrations showed large diurnal variability (BC: 13–73 μg m^{-3}; aerosol-submic: 157–585 μg m^{-3}) during the winter month. However, these concentrations during the summer month exhibited low variability (BC: 2–6 μg m^{-3}; aerosol-submic: 19–37 μg m^{-3}). Values of monthly mean and daytime monthly mean surface BC (aerosol-submic) mass concentrations were 36 (373) μg m^{-3} and 12 (195) μg m^{-3} respectively during the winter month compared to their values being only 4 (28) μg m^{-3} and 5 (38) μg m^{-3} respectively, during the summer month. Variability in AOD at 0.5 μm ($AOD_{0.5}$) between winter (0.82) and summer (0.71) was much lower than variability in surface concentrations between the two seasons. Wintertime mean angstrom exponent (AE, 0.34–0.5 μm) was 1.33 compared to that of 0.71 during summer, thereby indicating relatively predominant contribution from submicron aerosols to columnar loading during winter, in contrast to that from coarser aerosols during summer. Vertical profile of aerosol extinction coefficient revealed that 76% of the total extinction was within 0.5 km during winter, whereas 72% was between 1 and 5 km above surface during summer. High AOD during summer was due to elevated aerosol layer attributed to uplifting of surface aerosols, contribution from air mass originating in far-off regions at higher heights, and aerosols arising from open biomass burning emissions in India. Higher aerosol concentration during winter than during summer month in an urban environment in east India was mostly due to increased contribution from surface BC and submicron aerosol particles arising from wintertime anthropogenic activities, confinement of aerosols due to existing meteorological conditions, and contribution from air-mass mostly originating in the Indo-Gangetic plain (IGP) at the surface during winter, compared to those originating in the Bay of Bengal (BoB) during summer.

1. Introduction

Anthropogenic aerosols influence the climate system directly by scattering and absorbing sunlight (Forster et al., 2007; Schulz et al., 2006) and indirectly by altering the microphysical, optical properties and lifetime of clouds (Twomey, 1977). Since pre-industrial era, most of the anthropogenic aerosols in atmosphere have increased by more than a factor of two due to increase in emissions from human activities (Tsigaridis et al., 2006), such as industrial, agricultural, commercial, and residential. While aerosols arising from near-surface emissions exhibit large concentrations in the atmospheric boundary layer, they can also be uplifted to upper atmospheric layers due to meteorological phenomena such as convective activity and sea breeze activity (Verma et al., 2006). Further, aerosols arising from open burning activities, wild fires, and volcanic eruptions can be injected above boundary layer. Aerosols present in elevated layers of atmosphere have

* Corresponding author at: Department of Civil Engineering, Indian Institute of Technology Kharagpur, Kharagpur 721302, India.
E-mail address: shubha@iitkgp.ac.in (S. Verma).

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larger residence time and thereby could lead to a greater impact on climate. Aerosols generated from different sources are distributed in the atmosphere over a wide spatial scale through their transport with air masses. Aerosols exhibit large spatial and temporal heterogeneity due to non-uniform distribution of their sources and sinks and their short atmospheric lifetimes. This heterogeneity necessitates understanding and quantifying the impact of aerosols on climate on a regional basis and under distinct meteorological conditions.

Quantifying and assessing the climatic impact of atmospheric aerosols require knowledge of their physical, chemical, optical, and radiative properties (Penner et al., 1994; Yoon et al., 2005). Amount of solar light absorbed and scattered by airborne particles in the atmosphere is quantified by aerosol optical depth (AOD). Aerosols in the submicrometer regime or submicron aerosols (particles having aerodynamic diameter <1.0 μm) arising largely from anthropogenic activities are the most effective, per unit aerosol mass in interacting with the solar radiation in the visible portion of the spectrum (0.4–0.7 μm), where most of the solar energy is concentrated (Seinfeld and Pandis, 1998). Hence, these particles play an important role in the Earth's radiation balance. Aerosols arising from anthropogenic activities are composed of various constituents including black carbon (BC) and water-solubles such as sulphates, nitrates, and organics. Aerosols are also contributed from natural sources such as those comprising of soil-derived mineral dust and sea-salt of marine origin. Of all aerosol constituents, BC exerts most complex effect on climate (Seinfeld and Pandis, 1998). Unlike other aerosol constituents (such as sulphate, organics, dust, sea salt), BC absorbs solar radiation from visible to infrared spectrum and cause atmospheric heating. Aerosol modelling studies in general circulation model showed contribution of BC to total AOD as 10–16% over the Indian subcontinent (Verma et al., 2011) and the balance of the total AOD to be largely contributed by scattering aerosol constituents (mainly composed of sulphate, organic matter). BC aerosols are emitted directly into the atmosphere mostly by incomplete combustion processes such as fossil fuel combustion; biomass combustion (Penner and Novakov, 1996; Cooke and Wilson, 1996) and motor vehicle exhaust (Fruin et al., 2004).

Surface BC concentration measured at some of the urban stations in the Indian subcontinent (e.g. Delhi, Kanpur, Ahmedabad, Hyderabad, Trivandrum) has been reported to be usually higher during November–February (BC: 6–29 μg m^{-3}) than during March–May (1.2–14 μg m^{-3}); AOD (at 0.5 μm) values during these months (November–May) were in the range 0.21–1.2 (Niranjan et al., 2011; Singh et al., 2010; Ram et al., 2010; Ramachandran and Kedia, 2010; Nair et al., 2007; Ganguly et al., 2006; Latha and Badarinath, 2005). BC (AOD) values at non-urban or at environmentally cleaner locations (e.g. Nainital, Manora peak, Mount Abu) were reported to be considerably lower (0.65–2 μg m^{-3} (0.06–0.12)) than that at urban locations (Dumka et al., 2010; Ram et al., 2008; Srivastava et al., 2006; Sagar et al., 2004). Chemical characterisation of submicron aerosols carried out at an urban location in northern India (Kanpur) indicated major contribution from secondary sources and predominantly constituting of sulphates and nitrates (Chakraborty and Gupta, 2010). A study on source apportionment of airborne fine particulate matter (PM) ($PM_{2.5}$, PM with an aerodynamic diameter less than 2.5 μm) through chemical analysis of filter-based aerosol samples during the period 2001–2002 at some of the Indian cities, including Kolkata showed the seasonal and spatial patterns of impact of sources on fine PM (Chowdhury et al., 2007). This study inferred an average contribution of 37–57% and 13–18% of $PM_{2.5}$ mass at Kolkata from emissions of fossil fuel and biomass combustion respectively. An analysis of estimates from BC simulations in a general circulation model has shown most of BC surface concentration and BC optical depth in an urban environment in eastern India to be contributed from emissions of biofuel and fossil fuel combustion over the Indo-Gangetic plain (Verma et al., 2013). Inter-annual variation in AOD extracted from satellite-based measurements, Moderate Resolution Imaging Spectroradiometer (MODIS) during the period 1982–1993 (Sarkar et al., 2006) for major cities, including Kolkata, indicated an increasing trend in annually averaged aerosol loading (Sarkar et al., 2006), with a higher AOD over northern India comprising of the Ganga-basin (Prasad et al., 2004) than over southern India.

In the present work, we examine possibly for the first time, variability of winter and summertime aerosols from in-situ ground-based measurements of surface concentration of BC, submicron aerosols, and columnar AOD in an urban environment in eastern India (Kolkata). Simultaneous measurements of surface aerosol concentration and columnar AOD are helpful to evaluate possible contribution from aerosols in upper atmospheric layers. Kolkata, an urban agglomeration, is located on the east bank of Hooghly River and is one of the mega cities in south Asia. Aerosol characteristics at Kolkata still need to be adequately understood in order to understand potential impacts of aerosol on solar radiation in this urban environment and transport potential of pollution from the Indian subcontinent towards the Bay of Bengal (BoB). In this study, temporal features of aerosol are evaluated over eastern India urban environment (Kolkata) during a typical winter month of December, when winter season is well developed in India and when the Indian subcontinent has the highest pollution-loading potential, and that during a typical summer month of April. These months are chosen in study to examine aerosol characteristics under contrasting features of meteorological conditions (discussed in Section 3.1) in an urban environment. Measurements of BC and AOD carried out at other stations over India corresponding to the periods of the present study (winter and summer months) are summarised and compared with those from the present study in Section 3. The specific objectives of the present study are to examine (i) diurnal variability of surface BC and submicron aerosol mass concentrations during winter and summer months under contrasting meteorological conditions, (ii) daily mean values of surface BC, submicron aerosol mass concentrations, and AOD, and evaluate influence of air mass originating in different regions through back trajectory analysis, (iii) vertical profile of aerosol extinction coefficient in order to understand the vertical distribution of aerosols during winter and summer months in an urban environment.

2. Instruments and sampling

2.1. Measurement of BC, submicron aerosols, and AOD

We present here the results from ground-based measurements of BC, submicron aerosols, and AOD analysed during a