Atmospheric Environment 125 (2016) 346–359

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Investigations of aerosol black carbon from a semi-urban site in the Indo-Gangetic Plain region

Hema Joshi [a,b], Manish Naja [a,*], K.P. Singh [c], Rajesh Kumar [d], P. Bhardwaj [a], S. Suresh Babu [e], S.K. Satheesh [f], K. Krishna Moorthy [g], H.C. Chandola [b]

[a] Aryabhatta Research Institute of Observational Sciences (ARIES), Nainital, India
[b] Centre of Advanced Studies, Physics Department, Kumaun University, Nainital, India
[c] G. B. Pant University of Agriculture and Technology, Pantnagar, India
[d] Advanced Study Program, National Center for Atmospheric Research, Boulder, CO, USA
[e] Space Physics Laboratory, Vikram Sarabhai Space Centre, Thiruvananthapuram, India
[f] Centre for Atmospheric and Oceanic Sciences, Indian Institute of Science, Bangalore, India
[g] Indian Space Research Organization Head Quarters, Bangalore, India

HIGHLIGHTS

- A complete seasonal variation of BC from a semi-urban site in the IGP region.
- Large diurnal and seasonal variation with maximum amplitude and levels in winter.
- Surface BC is maximum in winter, unlike emission estimates showing spring maxima.
- Unlike BC, CALIPSO extinctions at higher height and AOD reveal higher values in spring.
- WRF-Chem simulated BC shows important features but underestimate observations.

ARTICLE INFO

Article history:
Received 12 November 2014
Received in revised form 1 April 2015
Accepted 4 April 2015
Available online 11 April 2015

Keywords:
Aerosols
Black carbon
Aerosol optical depth
Boundary layer
Indo-Gangetic Plain
Himalayas

ABSTRACT

Long-term (2009–2012) data from ground-based measurements of aerosol black carbon (BC) from a semi-urban site, Pantnagar (29.0°N, 79.5°E, 231 m amsl), in the Indo-Gangetic Plain (IGP) near the Himalayan foothills are analyzed to study the regional characterization. Large variations are seen in BC at both diurnal and seasonal scales, associated with the mesoscale and synoptic meteorological processes, and local/regional anthropogenic activities. BC diurnal variations show two peaks (morning and evening) arising from the combined effects of the atmospheric boundary layer (ABL) dynamics and local emissions. The diurnal amplitudes as well as the rates of diurnal evolution are the highest in winter season, followed by autumn, and the lowest in summer-monsoon. BC exhibits nearly an inverse relation with mixing layer depth in all seasons; being strongest in winter ($R^2 = 0.89$) and weakest ($R^2 = 0.33$) in monsoon (July–August). Unlike BC, co-located aerosol optical depths (AOD) and aerosol absorption are highest in spring over IGP, probably due to the presence of higher abundances of aerosols (including dust) above the ABL (in the free troposphere). AOD (500 nm) showed annual peak (>0.6) in May–June, dominated by coarse mode, while fine mode aerosols dominated in late autumn and early winter. Aerosols profiles from CALIPSO show highest values close to the surface in winter/autumn, similar to the feature seen in surface BC, whereas at altitudes > 2 km, the extinction is maximum in spring/summer. WRF-Chem model is used to simulate BC temporal variations and then compared with observed BC. The model captures most of the important features of the diurnal and seasonal variations but significantly underestimated the observed BC levels, suggesting improvements in diurnal and seasonal varying BC emissions apart from the boundary layer processes.

1. Introduction

Atmospheric aerosols play an important role in the Earth's radiation budget (Satheesh and Ramanathan, 2000; Moorthy, 2001). Aerosols influence the climate directly by scattering and absorbing

* Corresponding author. ARIES, Manora Peak, Nainital, UK 263002, India.
E-mail address: manish@aries.res.in (M. Naja).

http://dx.doi.org/10.1016/j.atmosenv.2015.04.007

solar radiation and by changing optical properties of the atmosphere. However, there exist large uncertainties in their estimates, not only globally but also regionally (Ramanathan and Carmichael, 2008), due to non-uniform distribution of aerosols over the globe and limited availability of observations. Over the Indian subcontinent, strong seasonal variations in aerosols are observed along with large spatial and temporal variations (Moorthy, 2001). In addition, the increase in aerosols emissions have also been reported over this region (e.g. Streets et al., 2009; Moorthy et al., 2013a) Ground based aerosol observations over the Indian region revealed increase of aerosol loading by 2.3% per year since 1985 (Moorthy et al., 2013a).

In the recent years, carbonaceous aerosols, among other aerosols have also gained considerable and foremost importance. The importance of BC in global radiative forcing has been strongly emphasized in a number of recent studies (Bond et al., 2013 and references therein). Amongst others, BC is the most efficient and significant absorber of solar radiation over a wide spectral range and is suggested to second to that of CO_2 in contributing to warming (Ramanathan and Carmichael, 2008). This is in contrast to other aerosol species which predominately backscatter radiation and thus cool the surface and lower atmosphere. The magnitude of climate forcing due to BC is under debate as the processes controlling its distributions are not well understood. In this context, Samset et al. (2014) showed that direct BC forcing get reduced by 25% if the current state-of-the-art global models are adjusted to match observed BC in the remote regions and higher altitudes.

Apart from significant radiative and climate effects, BC also have health effects. BC is also suggested to be responsible for disruption in the monsoon, especially in South Asia and in East Asia (Lau et al., 2008). The total global emission of BC is 7500 Gg per year in the year 2000 with a large uncertainty range of 2000–29,000 (Bond et al., 2013). Over India, total BC emission estimate is 0.41 Tg per year; with fossil fuel, biofuel and open burning combustion contribution of 25%, 42% and 33% (Venkataraman et al., 2005). Present day global and regional models predict much lower BC in South Asia (Nair et al., 2012; Bond et al., 2013), which in turn point towards the need of more ground based observations in the regions of limited observations such as South Asia. In light of the above conditions, BC measurements are initiated at a semi-urban site 'Pantnagar' in the Indo-Gangetic Plain (IGP).

The IGP region encompasses a vast area stretching from the Indus river system in Pakistan to the delta of Ganges River in Bangladesh. This region resembles a channel, guided by the Satpura ranges and Bihar Plateau to the south and elevated Himalayas to the north, that slopes down and narrows as we move from west to east across the landmass and is very conducive for confinement of pollutants; both of local origin and those advected from the west (Nair et al., 2007). This particular topography, along with the high anthropogenic activities (thermal plants, industries and other uses of fuel) lead to very high pollution loadings, which have been clearly reported in previous studies based on ground-based and satellite observations (Jethva et al., 2005; Ojha et al., 2012). Elevated pollution levels over the IGP not only affects the regional air quality including those of the pristine Himalayan locations (Pant et al., 2006; Lau et al., 2010; Gautam et al., 2011), but also affects the adjacent oceanic regions (Lelieveld et al., 2001; Satheesh et al., 2001; Naja et al., 2004).

2. Aim of the study

The columnar abundance of aerosols is relatively well studied over the IGP region using the Satellite data (MODIS, MISR etc.), ground based AERONET setup and few other ground based studies. However, the ground based regular surface measurements of BC are very limited and are available from a few isolated sites in IGP region, mostly for a short period during campaigns and thus provide limited information in terms of seasonal variability. Here, we present regular BC measurements from a semi-urban site Pantnagar (29.0°N, 79.5°E, 231 m amsl) located in the IGP but close to the Himalayan foothills during 2009–2012. The temporal variations are characterized and the role of meteorology (both mesoscale and synoptic) in them are delineated. BC values are compared with those reported at other Indian locations. We further use ground based AOD data, and satellite retrieved aerosol index to qualitatively understand whether BC is a dominant component of the total and absorbing aerosol load over Pantnagar, and vertical profiles of aerosol extinction coefficient from CALIPSO to examine seasonal variation in vertical distribution of aerosols over Pantnagar. In the end, we evaluate the ability of WRF-Chem model in simulating the observed diurnal variation of BC at Pantnagar.

3. Site description, techniques, database and data analysis

Measurements of BC were initiated in the campus of Govind Ballabh Pant University of Agriculture and Technology, Pantnagar (29.0°N, 79.5°E, ~231 m amsl; Fig. 1) in May 2009. This university campus is spread in an area of about 40.5 km^2 (Fig. 1b, image shown in inset) and located at a distance of about 250 km due northeast of Delhi (Fig. 1d). Elevated Himalayan Mountains of ~2000 m altitude are due north and east of the observation site at an aerial distance of 20–30 km, while low altitude plains regions are due west and east of the site. Mountains of much higher altitudes range of 4000–5000 m are around 100 km from the observation site. The population density around Pantnagar is 250–1000 per km^2 but is much less (<250 persons per km^2) due north of the site (http://sedac.ciesin.columbia.edu/gpw). A small airport is located ~2.5 km west of the observation site, which is occasionally operated. A few small scale industries are located in nearby towns, Rudrapur (16 km, southwest of Pantnagar) and Haldwani (25 km, northeast of Pantnagar). A paper manufacturing unit is located at a distance of ~9 km to the north-east of the observation site. The other small scale industries of automobiles, food and agricultural products, etc. are about ~7 km towards south-west, but none of them involve any extensive combustion processes. Fig. 1c shows spatial distribution of anthropogenic BC emissions in this region. High BC emissions along the IGP region are also observed. Like BC emissions, AOD, retrieved from MODIS also shows elevated levels along the IGP (Fig. 1d).

3.1. General meteorology

Surface wind speed and wind direction data are obtained from an Automatic Weather Station setup by the Indian Meteorological Department (IMD). Analysis of these wind datasets shows that the observational site is mostly under the influence of easterly and westerly winds (Fig. 2). The surface winds in summer-monsoon emanates from west. In autumn, wind arises from relatively diverse direction as well (Fig. 2). The wind speeds are generally low (<1.5 ms^{-1}) in winter and high (>3 ms^{-1}) in monsoon months. The in-situ measurement of solar radiation, relative humidity and rainfall were not available from ground based station, so solar radiation, and relative humidity were used from the Global Data Assimilation System (GDAS; ftp://gdas-server.iarc.uaf.edu/gdas1/) available every 6 h at the spatial resolution of 1° × 1°, and rainfall data from the Tropical Rainfall Measuring Mission (TRMM) at a spatial resolution of 0.25° × 0.25° to examine seasonal variation in these meteorological parameters around Pantnagar (Fig. 3).