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Vertical profiles of black carbon aerosols over the urban locations in South India

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ABSTRACT

Vertical profiles of black carbon (BC) aerosol were determined from aircraft measurements under the Cloud Aerosol Interaction and Precipitation Enhancement Experiment (CAIPEEX) program conducted by the Indian Institute of Tropical Meteorology, India during 2009 over Bangalore and Hyderabad in south India. BC mass loadings decreased approximately monotonically from 10^3 to 10^4 ng/m^3 at the surface to ~10^2 ng/m^3 at an altitude of about 7 km; although layers at intermediate levels containing anomalously high BC loadings were frequently encountered that were attributed mainly to the convective transport from surface sources accompanied by changes in the local boundary layer and atmospheric stability. In addition, as evidenced from air mass back trajectories; long range transport from distant sources contributed to some anomalous spikes in BC concentration. The presence of BC in cloud forming regions of the free troposphere could have important implications for cloud microphysics and subsequent rainfall mechanism over this region. Apart from this, the effects on human health are equally important.

1. Introduction

Black carbon (BC) aerosols, the graphitic form of carbonaceous material, are the primary particles emitted into the atmosphere as a byproduct of all combustion processes. The large atmospheric absorption of solar radiation by BC and its consequent potential to alter the radiation budget of the earth's atmosphere is well recognized (Novakov et al., 2000; Ramanathan et al., 2001; Jacobson, 2001). The radiative forcing as estimated by Intergovernmental Panel on Climate Change (2007) is $+0.2$ [± 0.15] W/m^2 for BC from fossil fuel and $+0.03$ [± 0.12] W/m^2 for BC from biomass burning. The large uncertainty in forcing by BC arises from the uncertainties in estimates of BC and its absorption cross-section. Fossil fuel and biomass burning at the surface are the major sources of BC in the lower troposphere whereas, in the upper troposphere and lower stratosphere, an additional significant source of BC is aircraft engine exhaust (Blake and Kato, 1995). Radiative forcing due to BC crucially depends on the vertical profile (Haywood and Ramaswamy, 1998). The atmospheric radiative forcing is enhanced by the presence of BC in free troposphere, where it can trap and retain energy reflected from layers of lower clouds. Inside clouds, BC surrounded by water and ice droplets acts to decrease the albedo of clouds, absorbing additional energy. Due to its existence in submicron size and inertness at normal atmospheric conditions, BC has a lifetime of about 8 to 10 days in the atmosphere and can be carried to thousands of kilometers both vertically as well as horizontally. Measurable existence of BC over the Arctic and Antarctic regions in the absence of any major combustion activity in the nearby surroundings is the manifestation of its long range transport (Barrie et al., 1981; Hansen and Rosen, 1984; Hansen et al., 1988, 2001; Hara et al., 2008; Chaubey et al., 2010).

BC is reported to contribute to the atmospheric brown clouds (ABC) that further develop into the trans-continental plumes which have been hypothesized to show large impacts on cloud microphysics and subsequent rainfall patterns in different regions. It is also reported to contribute to enhancement in glacier melting (Ramanathan et al., 2005; Menon et al., 2002, 2010; Flanner et al., 2009; Quinn et al., 2008; Lau et al., 2010; UNEP, United Nations Environmental Programme, 2008; USEPA, U.S. Environmental Protection Agency, 2011). Also, BC has a large direct negative impact on human health as well as indoor and outdoor air quality. Due to the long range transport and widespread expanse covering large population, the ABC poses a great threat to the health of human beings directly through exposure to toxic agents, or indirectly through climate change and global warming and their influence on life-support systems on earth (Ruchirawat et al., 2008). So far there is no threshold limit prescribed either by the Environmental Protection Agency, USA or by the Central Pollution Control Board, India for ambient levels of BC aerosols like those for PM_{10} and $PM_{2.5}$ (particulate matter below 10 μm and 2.5 μm size respectively). However, there is an urgent need for such a threshold limit, especially in a developing country like India where the use of both fossil fuel as well as biofuel is plenty. BC aerosols are also observed and reported in the upper troposphere and lower stratosphere. BC concentrations of 3.35 ng/m^3 at 9.5 km (upper troposphere) and 0.005 ng/m^3 at about 19 km (lower stratosphere) have been reported by Blake and Kato (1995) during 1990–1993 over the latitudes of 90° N to 45° S. Very high values of BC up to 12,000 ng/m^3 were reported at altitudes

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of 2.5 km from aircraft measurements during TRACE-A experiment over Brazilian forests (Pereira et al., 1996). During the Indian Ocean Experiment (INDOEX), Mayol-Bracero et al. (2002) reported mean BC concentration of 3200 ng/m^3 in the residual continental boundary layer over the Northern Indian Ocean which formed about 14% of the total aerosol. Studies during ACE-Asia have indicated the presence of BC (200 to 1800 ng/m^3) at below 3 km altitude over the East Asian region (Mader et al., 2002). However, the available information on vertical distribution of BC is limited especially over India, except for a few reported studies (Moorthy et al., 2004; Tripathi et al., 2005, 2007; Babu et al., 2008, 2010) that are discussed in subsequent sections of this paper for inter-comparison with the present study. Recently, Babu et al. (2011) have reported balloon borne BC observations over Hyderabad. They have observed altitude distributions of BC which showed multiple peaks with two large peaks, one at about 4.5 km and another above 8 km that the authors assumed are probably associated with high altitude aircraft emissions.

The Cloud Aerosol Interaction and precipitation Enhancement Experiment (CAIPEEX) undertaken by the Indian Institute of Tropical Meteorology, Pune aims to study and understand the interactions between aerosols and clouds that influence the precipitation mechanism (http://www.tropmet.res.in/~caipeex/). Under Phase I of this program, aircraft observations of BC along with observations of meteorological parameters and cloud microphysical parameters were undertaken over different regions in India from June to September 2009. In the present study, we report observations of the vertical distribution of BC aerosols over two urban locations in south India namely, Bangalore (BLR) (12° 97′ N to 77° 56′ E, 920 m amsl i.e. above mean sea level) during 27 June to 3 July 2009 and Hyderabad (HYD) (17° 20′ N to 78° 30′ E, 536 m amsl) during 11 to 21 June 2009. Fig. 1 shows the locations of HYD and BLR (the boxes at both sites indicate the aircraft study domains under the CAIPEEX program).

2. Experimental details

A twin engine Piper Cheyenne N361 JC pressurized aircraft from Southern Ogallala Aquifer Rainfall (SOAR) Program, TX, USA was employed for observations. The aircraft speed while sampling varied between 90 and 100 m/s. Each flight lasted for about 2 to 3 h duration during the period 12.00 to 16.00 LT when the boundary layer is generally fully evolved leading to the establishment of strong convective motions prior to the initiation of sampling. Aircraft flights were carried out covering the area from 16° N to 19° N latitudes and 77° E to 79° E longitudes over HYD and from 11° N to 13° N latitudes and 74° E to 79° E longitudes over BLR reaching a maximum altitude of about 7.1 km at both locations. The aircraft made several ascents and descents to penetrate the clouds during the course of each flight, as the chief objective of the mission was to study the cloud microphysics and aerosol–cloud interactions. Observations on vertical profiles of BC were carried out for a period of 11 days over HYD (11 to 21 June 2009) and 5 days over BLR (28–29 June 2009 and 1 to 3 July 2009). Fig. 2a and b shows the flight tracks for the aircraft observations over HYD and BLR, respectively on two typical days (11 and 21 June 2009 over HYD and 28 June and 2 July 2009 over BLR) during this campaign for which results are discussed in detail.

BC observations were carried out using an Aethalometer (Magee Sci. Inc., USA, AE-42) that was located in an unpressurized part of the aircraft. The sampling inlet of the Aethalometer was connected by using a 1.5 m long polyurethane tube (a non-conductive tubing to minimize the particle losses) to the common isokinetic Brechtel double diffuser inlet that was mounted on the pressurized part of the aircraft facing the airflow through a manifold within the fuselage. The flow rate of the air sampling was 6.5 l per minute and the observations were taken at one minute interval. The instrument was powered with an additional external battery for power back up.

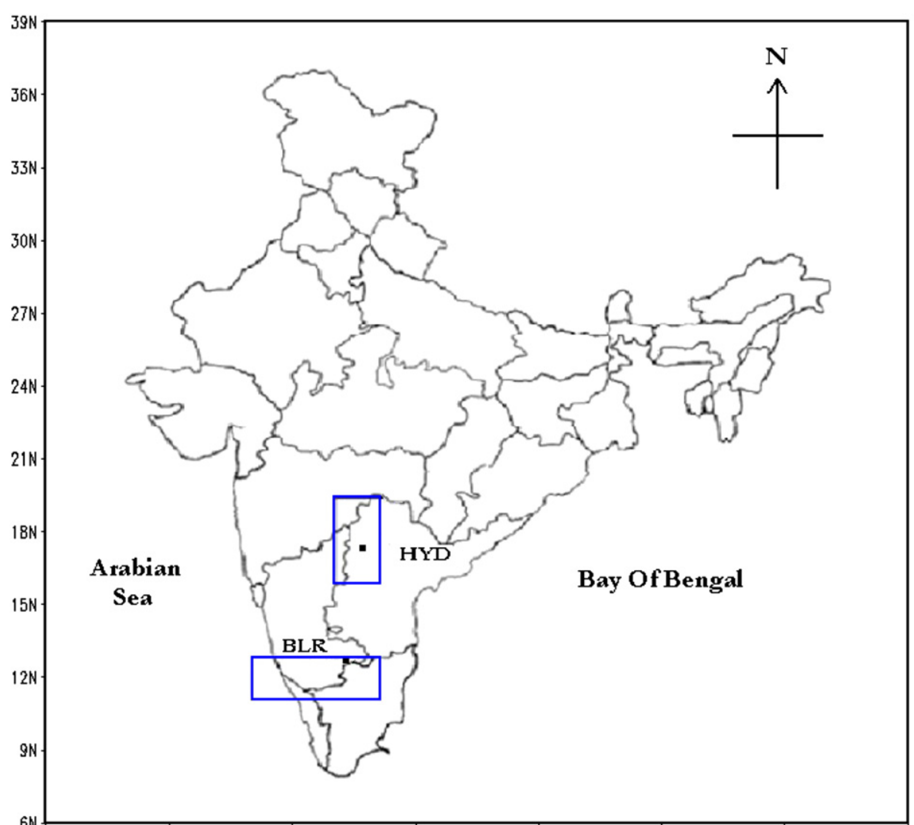

Fig. 1. Locations of HYD and BLR in India map. The boxes at both sites indicate the extent of total area covered during the aircraft observations under CAIPEEX program.