



Observations of black carbon induced semi direct effect over Northeast India



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HIGHLIGHTS

- Black Carbon (BC) induced cloud burning were observed over North east India (NEI).
- Elevated BC layers were observed inside cloud regime over NEI.
- Elevated BC heating found to be reducing liquid water content and cloud fraction.

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ABSTRACT

This article reports observational evidence of Black Carbon (BC) induced cloud burning effect (Semi direct effect) for the first time over a mountainous location in North east India. Simultaneous aircraft observations of Black Carbon (BC) mass concentrations and cloud microphysical parameters were carried out over Guwahati, in Northeast India during Cloud Aerosol Interactions and Precipitation Enhancement Experiment (CAIPEEX) Phase-I in 2009. Elevated pollution layers of BC (concentration exceeding $1 \mu\text{g m}^{-3}$) were observed over the site up to 7 km on different experimental days (August 30, September 4 and 6 in 2009) in the cloud regime. The vertical heating rate and radiative forcing induced by elevated BC layers in the cloud regime were estimated using an optical model along with a radiative transfer model. The instantaneous vertical heating rate induced by BC in cloud layers is found to be as high as 2.65 K/day. The instantaneous vertical heating by BC is found to be inducing a significant reduction in the measured cloud liquid water content (LWC) over the site. Subsequently, the BC stimulated heating has been found to be reducing the cloud fraction (CFR) and thus inducing a “cloud burning effect (Semi direct effect)”, over the region. The estimated instantaneous BC induced radiative forcing in the cloud regime is found to be $+12.7$ – $+45.1 \text{ W m}^{-2}$ during the experimental periods. This large warming and reduction in cloudiness can decrease the precipitation over the region. However, more simultaneous BC-cloud observations and further research are necessary to establish a stable “semi-direct effect” over the region.

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1. Introduction

Aerosols influence the climate directly and indirectly through radiative forcing. Black carbon (BC) aerosols directly influence the climate by absorbing incoming solar radiation. BC stimulated direct radiative forcing could significantly offset the radiative forcing due to aerosol scattering (Schwartz, 1996; Haywood and Shine, 1997). Different aerosol species, including BC indirectly influence the climate by modifying the cloud microphysics, known as the Aerosol

Indirect effect (AIE) (Panicker et al., 2010a; Ravikiran et al., 2009; Manoj et al., 2012). There are such two major identified indirect effects. If more aerosols competes for fixed liquid water content, the cloud droplet size retards and such a cloud enhances the albedo (Twomey, 1977), known as first AIE. Second AIE (Cloud life time effect) describes that, if more aerosols compete for fixed liquid water content, the cloud droplet size retards, which in turn will decrease the precipitation efficiency of the cloud (Albrecht, 1989). BC is also proposed to influence the climate by “cloud burning effect”, or “semi-direct effect”, by reducing the cloud liquid water content (LWC) and cloud covers (Ackerman et al., 2000; Hansen et al., 1997). Aerosol direct and indirect effects have been given adequate attention in the past; however studies on semi direct effect are sparse across the globe. Most of the studies on semidirect

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effect are model based, as there are very few simultaneous vertical measurements of BC and cloud microphysical parameters to validate it. The Aircraft-based Cloud Aerosol Interactions and Precipitation Enhancement Experiment (CAIPEEX) phase-I conducted during May to September 2009 was a unique attempt to measure simultaneous aerosol and cloud microphysical properties over India. The objective of this project was to bring out a proper insight towards the cloud processes modulated by different aerosol types, including BC. CAIPEEX was conducted for three days over Guwahati (on 30th August, 4th and 6th September 2009) to carryout simultaneous measurements of different aerosol types, BC and cloud microphysical parameters. In this study, we analyze the influence of BC induced vertical heating on time averaged cloud liquid water content (LWC) and cloud fraction (CF) over the cloud regimes in the region. This study is believed to be first of its kind over Indian subcontinent addressing this topic. Data and methodology of study are described in Section 2. A detailed description of results is explained in Section 3 and conclusions are provided in Section 4.

2. Data and methodology

2.1. Data

Simultaneous BC and-cloud microphysics data sets were collected over Guwahati (23–29°N; 89–94°E), located in the Brahmaputra river valley region in Northeast India. The region has reportedly been experiencing an extreme regional climate change in recent decades (Pathak et al., 2010; Chakrabarty et al., 2012; Konwar et al., 2012). Observations were carried out using a twin-engine Piper Cheyenne II research aircraft over the site as a part of CAIPEEX phase-I campaign. The cloud data presented in this study were obtained using aircraft mounted Cloud Droplet Probe (CDP) from Droplet Measurement Technologies (DMT Inc.). CDP was mainly deployed to measure the cloud effective radius (R_e) and cloud droplet size distribution. A Hot-Wire Liquid Water Content sensor (LWC-100, range 0.0–5 g m⁻³) was used to measure Cloud Liquid water content (LWC) and an Airborne Integrated Meteorological Measurement System (AIMMS-20) probe was used for measuring vertical velocity (w), humidity, temperature and altitude. These measurements were made at an interval of 1 s and the aircraft flew at an average speed of 100 m s⁻¹. Detailed descriptions of instrumentation used in the air craft for cloud/meteorological observations and its calibration details during CAIPEEX phase-I Campaign are available elsewhere (Kulkarni et al., 2012; Padmakumari et al., 2013; Pandithurai et al., 2012; Prabha et al., 2012).

Profiling of BC during CAIPEEX Phase-I were carried out using a dual wavelength Aethalometer (Magee Sci. Inc., USA, AE-42), that was located in the unpressurized part of the twin-engine Piper Cheyenne N361 JC pressurized aircraft. It was operated at a flow rate of 6.5 L per minute and the observations were taken at 1 min interval. The sampling inlet of the Aethalometer was connected by using a 1.5 m long polyurethane tube to the common isokinetic Brechtel double diffuser inlet (Safai et al., 2012). The polyurethane conductive tubing was used to minimize the particle losses. The sample was passed through dehumidification system to get rid off moisture content in it. However, there might be some possibility of small moisture incorporation with air sample, which could not be avoided. These limitations of observations are applied not only to BC measurements but also to all other simultaneous measurements during this campaign such as those for aerosol (PCASP) & trace gases, especially during the period when aircraft was in clouds. However, since BC generally is a hydrophobic aerosol species, may least be affected by humidity factor. The inlet was mounted on the pressurized part of the aircraft facing the airflow through a manifold within the fuselage. Additional pump was used to boost the

sampling flow even at higher altitudes. A supplementary external battery power back up was utilized to make sure the proper working of the instrument. In the Aethalometer, atmospheric air is pumped through an inlet which impinges on a quartz micro fiber filter tape. A light beam at 880 nm from a high-intensity LED lamp is transmitted through the sample deposit on the filter strip. The quantity of the attenuation of light beam is linearly proportional to the quantity of BC deposited on filter strip. The measurement accuracy of the equipment is 5 ng m⁻³, according to the manufacturer. The specific absorption of BC is 16.6 m² g⁻¹ used in calculation of BC mass concentration (Hansen, 2003). Moorthy et al. (2004) have used the same value of specific absorption of BC for aircraft observations over Hyderabad, India. Uncertainty in the observations was reported up to 10% by the manufacturer. The sampling technique used in Aethalometer (filter based technique) has shown good comparison with other methods (Allen et al., 1999; Babich et al., 2000). The instrument was calibrated for flow rate and optical attenuation test just before the CAIPEEX- 2009 campaign and hence the instrumental error bias could be minimal. Aerosol parameters, such as scattering interference, filter loading, composition, size, etc., can induce errors in the filter based methods. There are several methods of correction suggested in literature by different investigators for these errors (Corrigan et al., 2006; Arnott et al., 2005; Weingartner et al., 2003; Sheridan et al., 2005). However, the bias arising from the above described factors could not be corrected for the present data as they require additional information (aerosol type, size, chemical composition and scattering coefficients), which is not obtainable for the present data (Panicker et al., 2010b). Due to the lack of radiation parameters as well as information on chemical composition of aerosols during these flight observations; certain corrections such as shadowing effect and amplification factor as suggested by Weingartner et al. (2003) could not be applied to the present BC data. However, it is to be mentioned here that the impact of the above mentioned corrections such as shadowing effect and amplification factor will be very meager at least as far as aircraft observations are concerned because these effects will be effective in case of long term monitoring where the tape advancement of Aethalometer is involved (which is not the case with present aircraft observations as each flight lasted for about 2–3 h duration only) and we have to apply corrections to attenuation due to filter load which is assumed to be directly proportional to the BC mass concentration.

Aethalometer provided BC mass at every minute; based on its flow rate determined by its internal pump. It operated under mass flow condition and was programmed to maintain a mass flow which is equivalent to 6.5 L per minute under standard temperature (T_0 , 293 K) and pressure (P_0 , 1017 hPa) or the pump maintained a constant flow rate $V_0 = 6.5$ standard liter per minute. However, as the ambient pressure decreases while the aircraft ascends higher heights, the pumping speed is increased to maintain the set mass flow rate, and hence more volume of air is aspirated. The actual volume V of ambient air aspirated at an ambient pressure P and temperature T is thus,

$$V = V_0[P_0T/PT_0] \quad (1)$$

Since the measured BC concentrations are calculated based on standard flow rate V_0 , the actual BC concentration after correcting for the change in flow rate is

$$BC_{\text{corrected}} = BC_{\text{measured}}/[P_0T/PT_0] \quad (2)$$

Each measurement of BC was converted to the true BC concentration using this correction. Similar method has been used by Moorthy et al. (2004) and Tripathi et al. (2007) for air craft observations of BC over Hyderabad and Kanpur in India. A detailed

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