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Characterization of black carbon in an urban-rural fringe area of Beijing☆

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ABSTRACT

Measuring black carbon (BC) is critical to understand the impact of combustion aerosols on air quality and climate change. In this study, BC was measured in 2014 at a unique community formed with rapid economic development and urbanization in an urban-rural fringe area of Beijing. Hourly BC concentrations were 0.1–33.5 μg/m^3 with the annual average of 4.4 ± 3.7 μg/m^3. BC concentrations had clear diurnal, weekly, and seasonal variations, and were closely related with atmospheric visibility. The absorption coefficient of aerosols increased while its contribution to extinction coefficient decreased with the enhancement of $PM_{2.5}$ concentration. The high mass absorption efficiency (MAE) of EC was attributed to a combination of coal combustion, vehicular emission and rapidly coating by water-soluble ions and organic carbon (OC). BC concentrations followed a typical lognormal pattern, with over 88% samples in 0.1–10.0 μg/m^3. Low BC levels were mostly bounded up with winds from north and northwest. Coal combustion and biomass burning were closely associated with severe haze pollution events. Firework discharge had significant UV absorption contribution. During the Asia-Pacific Economic Cooperation (APEC) forum in November 2014, air quality obviously improved due to various control strategies.

1. Introduction

Black carbon (BC), also known as elemental carbon (EC), is a component of particulate matter (PM) in the atmosphere, and widely described as a solid pure carbon material formed during combustion of fossil fuels and various types of biomass fuels from small-scale residential wood combustion to large forest fires. In addition to acting as air pollutants and having adverse health effects (Smith et al., 2009), BC also contributes significantly to climate change by absorbing incoming solar radiation (IPCC AR5, 2013). It is also known that the radiative forcing ability of particles can be enhanced by BC mixing state after secondary PM forms as coating materials (Wang et al., 2013; Zhang et al., 2008, 2014). Thus, it is essential to recognize the characteristics of BC, assess its radiative properties, and clarify its contribution to air pollutants in different areas.

Monitoring of BC in the atmosphere (Cao et al., 2007; Cheng et al., 2006, 2010; Zhang et al., 2009; Zhuang et al., 2014) and investigation of its optical properties (Wang et al., 2014; Xia et al., 2007) have been widely conducted across China. Zhuang et al. (2014) studied BC characteristics in urban Nanjing and found out BC concentration was 4.2 ± 2.6 μg/m^3 and high levels in early June were caused by biomass burning. Pan et al. (2011) investigated the correlation of BC and CO in high-altitude environment of Mountain Huang and indicated that annual mean BC mass concentration was 1.0 ± 0.9 μg/m^3 with maximums in spring and autumn. Ding et al. (2016) found out that BC enhanced haze pollution in megacities based on model simulations and data analysis from various field observations in December 2013. Ran et al. (2016) studied BC and wavelength-dependent aerosol absorption in North China and

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found high annual mean BC concentration of 5 μg/m^3 at Xianghe in Hebei and identified differences in aerosol absorption between heating and non-heating seasons. However, previous researches seldom studied BC in urban-rural fringe areas, which are unique communities formed during the fast economic development and urbanization in China. These areas are characterized by high population, high emission and complex sources (including central heating, private coal stoves for cooking and heating, open biomass burning, open-air incineration, and plenty of construction activities), which result in high BC concentrations and uncertain impacts on air quality and climate change (Peng et al., 2016).

To improve air quality and abate high emission from complex sources, the Chinese government issued Air Pollution Prevention and Control Action Plan with the strictest measures since October 2013. Large investments are being put in and significant impacts occur on human living and economic development. To assess effectiveness of emission abatement measures, it is necessary to study characteristics of BC, which is closely associated with combustion of fossil fuels and open biomass burning in urban-rural fringe areas. The results will be helpful to constrain BC emissions in populated and rapidly urbanized areas in developing megacities.

In this study, BC was measured during the whole year of 2014 in an urban-rural fringe area of Beijing, a rapidly developing megacity. The concentrations, temporal variations, and optical properties of BC were analyzed. This study discussed sources of BC and constrained uncertainties in calculation of optical properties, which are helpful to understand the impact of BC on air quality and climate change.

2. Methodology

2.1. Description of sampling site

The sampling site (40.04° N, 116.41° E) is located in the urban-rural fringe area near the Tiantongyuan community in Beijing (Fig. S1). It is one of the largest residential areas in Asia with the population of approximately 0.7 million. The site is 1.7 km north of the 5th Ring Road, 6.0 km west of Jing-Cheng Highway (S11), and 5.5 km east of Jing-Zang Highway (G6). No industrial sources are located in the vicinity. With the development of urban construction, dirty and mess villages in the urban-rural fringe area have been progressively replaced by modern buildings since 2008. BC was also measured at a comparison site situated in the main urbanized area of Beijing (Fig. S1). The detailed description of the site has been introduced by Ji et al. (2016a).

As shown in Fig. S2, significant correlation was found between BC concentrations in the urban-rural fringe site and the urban site. BC concentrations were slightly higher and the concentrations larger than 25 μg/m^3 were more frequent in the urban-rural fringe area compared to the urban site. Fig. S3 shows that most high BC concentrations at both sites were observed as calm wind prevailed and some high concentrations were associated with southerly winds. The northerly winds with high speeds were favorable for low BC concentrations at both sites. Thus, it is inferred that the study site situated in the north of urban Beijing is affected by both long-range transport and local emissions.

2.2. Instruments

Near-real-time continuous measurement of BC was conducted from January 1 to December 31, 2014 using an aethalometer (model AE-31 of Magee Scientific, USA). The AE-31 aethalometer has seven channels at the wavelengths of 370, 470, 520, 590, 660, 880 and 950 nm, respectively. The flow rate was 5 L min^{-1}, with a cyclic observation every 5 min. Air came through a 1.5 m-long black tube coated with Teflon on the inner wall and connected to the instrument. An inset with 2.5 μm cut-size was used to make sure only BC within $PM_{2.5}$ range was measured. A Teflon particle filter kit was added to determine the state of particle free in front of the air inlet when zero calibrations were performed. The aethalometer was checked every three months for sample flow and zero setting. Flow corrections were made in accordance with the check-up results. The stability of light sources was also examined whenever needed. In addition, the load of BC aerosols on film was preset by adjusting the instrument parameters so that transparent light attenuation was controlled to raise no more than 100%. The BC minimum detection limit (MDL) was below 10 ng/m^3. All data measured at the study site were above MDL. The 5-min BC data were subsequently averaged to 1 h resolution using the arithmetic mean method to lessen uncertainties arising from instrumental noise, flow rate, filter spot area, and detector response (Corrigan et al., 2006). In this study, all the data were analyzed and processed based on hourly values. Data will be rendered invalid if the monitor records are less than forty-five minutes for any hour. The uncertainty in BC concentrations was estimated to be within ±10% (Saha and Despiau, 2009). In order to exclude the impact of mineral aerosols (Fialho et al., 2005), the data collected in dust events were excluded.

The filter absorption method employed in the aethalometer has two known impediments that interfere with accurate measurements (Corrigan et al., 2006). To address the uncertainties, several correction algorithms have been developed, including the Weingartner, Arnott, Schmid, Virkkula and Collaud corrections, as listed in Collaud Coen et al. (2010). In this study, Virkkula correction (Virkkula et al., 2007) was chosen, which was developed based on an assumption that the last three values measured on spot i and the first three values measured on spot $i+1$ should be equal. Thus, the corrected concentration could be described as below (Virkkula et al., 2007):

$$BC_{corrected} = (1 + k^{*}ATN) \times BC_{Noncorrected} \quad (1)$$

where ATN is the measured filter attenuation and k is the correcting factor. The value of k is calculated using Eq (2) for each filter spot.

$$k = 1/ATN(t_{i,last}) \times \left(BC_0\left(t_{i+1,first}\right)\Big/BC_0(t_{i,last})\text{-}1\right) \quad (2)$$

The factor is then used to correct the two-wavelength (370 nm and 880 nm) BC data for filter spot i in Eq (1). In practice, k factor is calculated from Eq (2) using average BC concentration (BC_0) of the last two measurements from filter spot i and the first two measurements of filter spot i+1 with 5-min resolution. This algorithm has been discussed and used in previous studies (Virkkula et al., 2007; Collaud Coen et al., 2010).

Atmospheric visibility was measured by a visibility sensor (Belfort Model 6000, visual range: 200 m–50 km) with 1-min time resolution. Hourly visibility was obtained as the arithmetic mean of raw data. Calibration of the sensor was performed using the 90 001 Calibration Kit recommended by the manufacturer (Visibility Sensor Manual, Belfort Instrument Company). The instruments were regularly checked every six months to insure accuracy.

PM_{10} and $PM_{2.5}$ were measured using two synchronized hybrid ambient real-time particulate monitors (SHARP 5030, Thermo-Fisher Scientific, Massachusetts, USA). One monitor was equipped with PM_{10} inlet, and the other with BGI Very Sharp Cut Cyclone $PM_{2.5}$ impactor was a US EPA Federal Equivalent Method $PM_{2.5}$ analyzer. The accuracy was ±5% for 24 h. Calibration and glass fiber filter tape changes were performed every six months. Commercial instrument from Thermo Fisher Scientific, USA was used to measure CO (model 48I). The analyzer of CO was calibrated using 5000 ppmv CO standard gas (Scott-Marrin gases, Riverside, CA, USA).