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Continuous measurement of black carbon aerosol in urban Nanjing of Yangtze River Delta, China

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HIGHLIGHTS

- Continuous measurements of BC and CO were made at an urban site in Nanjing in 2012.
- Annual mean BC and ΔBC/ΔCO in Nanjing was about 4157 ng/m^3 and 7 ng/m^3/ppb.
- Both seasonal and diurnal variation of BC loading in urban Nanjing was significant.
- BC loading in urban Nanjing was lower than that in LinAn, a rural site in YRD.
- Serious pollution episodes with high levels of BC were detected in early June, 2012.

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ABSTRACT

As a short-lived climate forcing agent, black carbon (BC) aerosol plays an important role in climate change, atmospheric environment, and human health. In this study, continuous measurements of BC and trace gases were made at an urban site in Nanjing, Yangtze River Delta (YRD) of China in 2012. The annual mean BC concentration in Nanjing was found to be 4157 ± 2626 ng/m^3, with a range of 221–24,686 ng/m^3. The value was much lower than that in most megacities of China and also lower than that in LinAn, a rural site in YRD. BC concentrations in Nanjing showed strong seasonality, high in spring and autumn and low in summer. The concentrations also varied diurnally, high at rush hours and low in the afternoon. The diurnal cycles of BC loadings in winter to spring 2012 were similar to those in 2011 in magnitude and shape. BC concentrations followed a typical lognormal pattern, with over 75% of data samples between 1000 and 6000 ng/m^3. The maximum frequency occurred in low BC concentrations in summer and high BC concentrations in other seasons. In Nanjing, high levels of BC were mainly caused by local and regional emissions. Low levels of BC were mostly associated with winds from northern and eastern directions of Nanjing. BC and CO varied similarly with season, having a correlation coefficient over 0.7 in most seasons. Annual mean ΔBC/ΔCO was about 7 ng/m^3/ppb, implying that the sources of the BC likely came from combustions of bio-fuel, industry-coal, and vehicle-gasoline. Serious pollution episodes with high levels of BC were detected in early June at the site. Analysis suggested that the episodes were due to biomass burning in northwestern region of Nanjing. During this period, ΔBC/ΔCO reached about 9.7 ng/m^3/ppb and much higher BC levels were found at mid-night.

1. Introduction

Black carbon aerosol (BC) is one of the important aerosols in the atmosphere. It has significant influences on regional or global climate because of its direct and indirect effects. Jacobson (2002) found that the warming effect of BC was preceded only by CO_2. Thus, low-level convergence and increases in vertical velocity induced by BC overcame the stabilizing effects of the aerosols (Randles and Ramaswamy, 2008), and subsequently affecting dynamic and hydrologic fields of the atmosphere (Menon et al., 2002). Optical properties of cloud would be changed once BC was mixed with cloud droplet (Zhuang et al., 2010). In addition to the climate

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effects, BC also can affect atmospheric chemistry (Deng et al., 2010) and air quality (Chameides and Bergin, 2002). China is one of the major source regions of black carbon aerosol. BC emissions in China roughly accounted for one fourth of the global anthropogenic sources (Streets et al., 2001). Relatively high levels of emission were mainly distributed in Southwest, North China, Yangtze River Delta (YRD), and Pearl River Delta (PRD) regions (Zhang et al., 2009). Owing to large uncertainties of the emission inventories, estimations of BC radiative forcing and climatic effect vary largely (Forster et al., 2007). Therefore, it is important to clarify the characteristics of BC to help access optical and radiative properties of BC as well as its regional or global climate effects.

Most of earlier studies were focused on radiative forcing and climate effects of BC based on numerical simulations (Kristjánsson, 2002; Liao and Seinfeld, 2005; Zhuang et al., 2010; 2013). Forster et al. (2007) summarized in his review that simulated global mean direct radiative forcing of BC is $+0.2 \pm 0.1$ W/m^2. Studies on characteristics of BC based on observations were relatively less than this radiative forcing. Derwent et al. (2001) estimated BC emissions in UK and European using three-year observations of BC and CO. Dickerson et al. (2002) analyzed BC and CO observed over Indian Ocean to better understand the uncertainty of emission inventories. Sharma et al. (2004) studied BC concentrations in the Canadian Arctic with long-term observations. Recently, much more observations of BC have been carried out. Murphy et al. (2011) used long-term observations to investigate temporal variations of BC in US and suggested that BC decreased by over 25% between 1990 and 2004. Kondo et al. (2006) studied the temporal variations of element carbon in Tokyo and pointed that EC in Tokyo was about 1800 ± 1800 ng/m^3 Pan et al. (2011) investigated the correlation of BC and CO in high-altitude environment of Mt. Huang and indicated that annual mean BC loading was 1004.5 ± 895.5 ng/m^3. Cape et al. (2012) suggested that the life-time of BC was about 4–12 days by analyzing 3-years observations from a remote rural site in southern Scotland. Kharol et al. (2012) studied the variations of BC over Patiala in India during an agriculture crop residue burning period using ground measurements and satellite data. Srivastava et al. (2012) used observed data to access climate forcing of BC in the Indian Himalayan foothills and indicated that BC in this region was about 980 ± 680 ng/m^3. Sharma et al. (2012) used an Aethalometer to measure BC at Kathmandu valley in Nepal and they found that the highest daily mean concentration of BC exceeding 39,900 ng/m^3. Cristofanelli et al. (2013) studied the influence of biomass burning and anthropogenic emissions on BC at the Mt. Cimone GAW-WMO global station and indicated that averaged BC there was 213 ± 34 ng/m^3. In China, many observations of BC have been made in the recent years (Qin et al., 2007; Gao et al., 2009; Zhao et al., 2008a,b; An et al., 2011; Wang et al., 2011a,b; Zhang et al., 2011; Jing et al., 2011). Zhang et al. (2008, 2012) analyzed the loadings of carbonaceous aerosols in various regions of China from 2006 to 2007 and suggested that annual mean BC averaged from these stations was 5960 ng/m^3. Han et al. (2009) suggested that annual mean elemental carbon in Beijing was 6900 ng/m^3 between 2005 and 2006. Verma et al. (2010) studied the temporal variations of BC in Guangzhou in PRD of China and indicated that BC was about 4700 ± 2300 ng/m^3 in summer 2006. Wang et al. (2011b) reported that the seasonal mean BC at a rural site in Beijing was about 2260 ± 2330 ng/m^3.

YRD region is one of the rapidest growth regions in China. BC emission from this region has been found to be high, which affects regional climate and air quality (Zhang et al., 2009). In this study, continuous observations of BC at an urban station in Nanjing (a typical developing city in YRD) have been made in order to characterize BC in YRD region. We describe the methodology in Section 2. Results and discussions are presented in Section 3, followed by Conclusions in Section 4.

2. Methodologies

2.1. Sampling station

Sampling station was built in the Gulou campus of Nanjing University, Nanjing, the capital of Jiangsu Province. It was located at (32.05° N, 118.78° E) with the altitude of 99.3 m (79.3 m building tall plus 20 m asl). There are no higher buildings near or around the station and there are no industrial pollution sources within a 30 km radius, but several main roads with apparent traffic pollution surround the campus. More details of the stations could be found in Zhu et al. (2012).

2.2. Data and methodology

Near-real-time continuous measurements of mass concentration of BC were made from 1 January to 31 December 2012 using an Aethalometer (model AE-31 of Magee Scientific, USA) at the station. In this technique, atmospheric air is pumped through an inlet at the desired flow rate of 5.0 L/min. Sampling interval was set to 5 min. Routine calibration of AE-31 was carried out on December 2011. There were continuous tape advancements during the sampling period. More information of the Aethalometer could be found in Hansen et al. (1984). To make comparisons, carbon monoxide (CO) was concurrently collected at this station using a Thermo-Model 48i-TLE CO Analyzer. Sampling interval of CO was set to 1 min. Its span and zero calibrations were carried out automatically per weak and hour, respectively. Accuracies of AE-31 and Model 48i-TLE are 1 ng/m^3 and 0.1 ppb, respectively. Meteorological parameters including wind speed, direction, and total precipitation were provided by the National Meteorological Station of Nanjing, which is about 1.5 km far away from our station.

The filter absorption method employed in the AE-31 has two known impediments that interfere with accurate measurements of BC mass (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 recommended because there was no concomitant scattering measurements at our site. Virkkula correction was developed based on an assumption that the three last values measured on the filter spot i and the three first values measured on the next filter spot $i + 1$ should be equal. Thus, the corrected concentration of BC could be described as below (Virkkula et al., 2007):

$$\mathrm{BC}_{\mathrm{Corrected}} = (1 + k \times \mathrm{ATN}) \times \mathrm{BC}_{\mathrm{Noncorrected}} \quad (1)$$

Where, ATN is the filter attenuation measured and recorded by AE-31. k could be calculated according to EQ. 8 in Virkkula et al. (2007) or EQ. 12 in Collaud Coen et al. (2010). Although BC concentration could be recorded at several wavelengths by AE-31, channel 880 nm one was used here to minimize the interference from light absorbing organic carbon.

3. Results and discussions

3.1. Characteristics of black carbon in Nanjing

3.1.1. Temporal variations

Both 5-min (dots) and daily mean (line) BC concentrations from 1 Jan 2012 to 31 Dec 2012 in Nanjing were shown in Fig. 1. Blanks in the figure represented the invalid values. BC in Nanjing was mostly lower than 7000 ng/m^3. Hourly mean concentrations of BC ranged from 221 to 24,686 ng/m^3. Annual mean concentration of BC was