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Chemical characteristics of size-resolved aerosols in winter in Beijing

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ABSTRACT

Size-resolved aerosols were continuously collected by a Nano Sampler for 13 days at an urban site in Beijing during winter 2012 to measure the chemical composition of ambient aerosol particles. Data collected by the Nano Sampler and an ACSM (Aerodyne Aerosol Chemical Speciation Monitor) were compared. Between the data sets, similar trends and strong correlations were observed, demonstrating the validity of the Nano Sampler. PM_{10} and $PM_{2.5}$ concentrations during the measurement were 150.5 ± 96.0 μg/m^3 (mean ± standard variation) and 106.9 ± 71.6 μg/m^3, respectively. The $PM_{2.5}/PM_{10}$ ratio was 0.70 ± 0.10, indicating that $PM_{2.5}$ dominated PM_{10}. The aerosol size distributions showed that three size bins of 0.5–1, 1–2.5 and 2.5–10 μm contributed 21.8%, 23.3% and 26.0% to the total mass concentration (TMC), respectively. OM (organic matter) and SIA (secondary ionic aerosol, mainly SO_4^{2-}, NO_3^- and NH_4^+) were major components of $PM_{2.5}$. Secondary compounds (SIA and secondary organic carbon) accounted for half of TMC (about 49.8%) in $PM_{2.5}$, and suggested that secondary aerosols significantly contributed to the serious particulate matter pollution observed in winter. Coal burning, biomass combustion, vehicle emissions and SIA were found to be the main sources of $PM_{2.5}$. Mass concentrations of water-soluble ions and undetected materials, as well as their fractions in TMC, strikingly increased with deteriorating particle pollution conditions, while OM and EC (elemental carbon) exhibited different variations, with mass concentrations slightly increasing but fractions in TMC decreasing.

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Introduction

Particulate matter (PM) has become one of the major air pollutants in the megacities of China and has profoundly affected the living environment (Chan and Yao, 2008; Han et al., 2013; Liu et al., 2013b). PM may reduce the visibility (Zhang et al., 2010; Liu et al., 2012, 2013a) and alter global climate by changing the radiation balance (Bardouki et al., 2003; Liu et al., 2013b). Long-term exposure to high PM concentrations also increases morbidity and mortality (Dockery and Pope, 1994; Delfino et al., 2003). It has been demonstrated that PM's environmental and health effects are determined by its size distribution and chemical components (Salma et al., 2002; Mather et al., 2003; Liu et al., 2008). Therefore, it is crucial to study the chemical characteristics and size distributions of PM.

Beijing, the political and cultural center of China, has attracted much more attention domestically and internationally of late due to air pollution. With the rapid economic growth and accelerating urbanization, the vehicle fleet and energy consumption have sharply increased, causing serious air pollution problems. $PM_{2.5}$ (particulate matter with aerodynamic diameter equal or less than 2.5 μm) and O_3 (ozone) have become major air pollutants (Streets et al., 2007; Chan and Yao, 2008; Liu et al., 2013b). Strikingly, in January 2013, Beijing encountered the worst $PM_{2.5}$ pollution in history with the maximum hourly concentration at 886 $\mu g/m^3$, arousing public attention to $PM_{2.5}$ (http://www.nasa.gov/multimedia/imagegallery/image_feature_2425.html). Many studies have focused on the mass concentration, chemical composition and source apportionment of $PM_{2.5}$ in Beijing in the past decade (He et al., 2001; Sun et al., 2004). Compared with megacities of developed countries, the mass concentration of $PM_{2.5}$ in Beijing remains at a much higher level, and usually exceeds the National Ambient Air Quality Standard (He et al., 2001; Sun et al., 2004; Zhang et al., 2013). Carbonaceous materials (organic carbon and elemental carbon), secondary ionic species (ammonium, nitrate and sulfate, *etc.*) and crustal materials are found to be the three major components of $PM_{2.5}$ in Beijing (He et al., 2001; Sun et al., 2004). Carbonaceous material has received more attention in recent years for its impacts on visibility degradation (elemental carbon (EC) is a major component affecting light absorption) and radiative forcing as well as human health (Hansen et al., 2005; Mauderly and Chow, 2008). Dust, biomass burning, coal combustion, vehicle emissions and secondary aerosols are major sources of $PM_{2.5}$ in Beijing (Song et al., 2007; Xie et al., 2008). In addition, regional sources could be crucial contributors to PM pollution in Beijing (Guo et al., 2010; Zhang et al., 2013).

Some studies have been carried out on the chemical characteristics of size-segregated aerosols in Beijing. Yao et al. (2003a, 2003b) investigated the size distribution and formation of inorganic ions and dicarboxylic acids in particulates by MOUDI (MSP, USA) in summer 2001 and spring 2002 in Beijing. Massling et al. (2009) studied the influence of size-segregated chemical components on hygroscopic properties of particles in summer 2004 and winter 2005 in Beijing. Guo et al. (2010) studied size distributions of aerosol samples taken in the summer season in Beijing to explore formation pathways of sulfate, nitrate and oxalate. However, there have been few studies analyzing the inorganic ions, OC and EC of size-resolved aerosols simultaneously in winter in Beijing and few comparisons of chemical characteristics at different pollution levels.

To obtain a better understanding of size distributions and chemical characteristics of ambient aerosols in winter in Beijing, we continuously collected size-resolved aerosols using a Nano Sampler during winter for 13 days at an urban site of Beijing Normal University (BNU). Chemical measurements were used to analyze the major components of $PM_{2.5}$, including water-soluble ions, OC and EC. Furthermore, chemical characteristics and size distributions of PM at different pollution levels were also compared to explore the formation pathways of heavy particle pollution in winter in Beijing.

1. Methods

1.1. Experimental site

Beijing is located at the northwest edge of the North China Plain and is surrounded by high mountains to the west and north, which is not conducive to air pollutant diffusion. Beijing has a typical temperate semi-humid continental monsoon climate, which is hot and rainy in summer, cold and dry in winter. The spring and autumn seasons are generally short. During the monitoring period, the mean temperature was 5 ± 3°C, and relative humidity was 50% ± 13% (Fig. 1).

The sampling site for the Nano Sampler is located on the roof of the School of Environment building (~20 m above the ground level) on the campus of Beijing Normal University (BNU, 39°57.67′N, 116°21.5′E), which lies between the 2nd and 3rd ring roads of Beijing. Major roads nearby are the third ring road about 550 m to the north, Xinjiekou street about 500 m to the east, Xueyuan South road about 500 m to the south and Almond altar road about 300 m to the west. There are no other major local emission sources nearby. The ACSM (Aerodyne Aerosol Chemical Speciation Monitor) is installed on the roof of a building (ca. 8 m above ground level) at the Institute of Atmospheric Physics (IAP), Chinese Academy of Sciences (39°58.47′N, 116°22.27′E), which is about 1.9 km northeast of the BNU site and approximately 0.9 km to the north of the 3rd ring road.

1.2. Instrumentation and measurements

The Nano Sampler (built by Kanazawa University, Japan) was used to collect size-segregated atmospheric particle samples on 16–28 November 2012. The Nano Samper classifies particle sizes by the inertial impact principle, which is similar to that of the porous inertial impact type samplers, like MOUDI (Marple et al., 1991). It has 6 size stages with nominal aerodynamic cut-off diameters at 10 (inlet), 2.5, 1.0, 0.5, 0.1 μm, respectively. The 6 size stages are as follows: Bin 1 < 0.1 μm, Bin 2 0.1–0.5 μm, Bin 3 0.5–1.0 μm, Bin 4 1.0–2.5 μm, Bin 5 2.5–10 μm and Bin 6 > 10 μm. Quartz membrane filters 55 mm in diameter (Gelman Sciences) were used in all bins except Bin 2, with a carbonaceous filter. In order to conduct a closer study on pollution days, we determined the sampling period according to the air quality forecast released by the China National Environmental Monitoring Centre every day: on polluted days we sampled aerosols every 12 hr, while on clean days 24 hr sampling was chosen. For 12-hr samples the sampling was carried out between 8:00 am and 8:00 pm or 8:00 pm and 8:00 am (the next day), respectively. Aerosols were collected between 8:00 am and 8:00 am (the next day) for 24-hr samples. The flow rate was set to 40 L/min. The mass concentration of $PM_{2.5}$ is the sum of the gravitational mass difference before and after sampling of Bins 1–4 (for PM_{10} with Bins 1–5).

Before sampling, the quartz fiber filters and aluminum foil were heated at 500°C in a muffle furnace for 4 hr to remove