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Characteristics of individual particles in Beijing before, during and after the 2014 APEC meeting

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ABSTRACT

To understand the characteristics of individual aerosol particles as well as the effects of emission control measures on the air quality in Beijing before, during and after the 2014 APEC meeting, aerosol samples collected in Beijing from Oct. 8 to Nov. 24 were investigated by a scanning electron microscopy (SEM) coupled with an energy-dispersive X-ray (EDX). Individual particles were classified into fly ash, ammonium sulfate, carbonaceous particle, tar ball, soot aggregates, Fe/Ti oxide, Ca/Mg carbonate, calcium sulfate and aluminosilicates/quartz. The results showed that $PM_{0.5-1.0}$ was predominant in aerosol particles while $PM_{2.5-10}$ was the fewest in aerosol particles. Soot aggregates and carbonaceous particles mainly located in the size range of 0.5–2.5 μm and mineral particles were dominant in the size range of 2.5–10 μm. The tough emission control measures taken by the local government greatly improved the air quality. Reducing vehicles on the roads substantially decreased the amount of soot aggregates, and restricting coal combustion decreased the amount of tar ball during the APEC meeting. The concentrations of carbonaceous and mineral particles abated probably owing to the control on VOCs emission, and water spray and demolition layoff, respectively, during the APEC meeting.

1. Introduction

With the rapid development of industrialization and urbanization in the absence of effective measures for air pollution abatement, China suffered from serious air pollution problem over the past decades (Chan and Yao, 2008). To improve the worsening air quality in China, the government updated the Ambient Air Quality Standards and issued the 12th Five-Year Plan on Air Pollution Prevention and Control in Key Regions in 2012. Subsequently, the State Council of China had released the Action Plan for Air Pollution Prevention and Control in 2013. Nevertheless, air pollution is still getting worse in China, especially in North China where haze episodes have happened frequently in recent years (Guo et al., 2014; Su et al., 2015).

As Beijing hosted the 2014 APEC meeting, Beijing and its neighboring regions would take tough actions to reduce the emissions of air pollutants from industry, road traffic, and construction sites. From June 1, the control of air pollution in Beijing began with the implementation of specific measures including the closure of some coal-fired power plants, the elimination of heavily polluting vehicles, and the use of clean energy alternatives. During the APEC meeting, roughly 10,000 factories in the regions, including Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia, Shandong, and Henan, were forced to suspend their production, and an additional 39,000 factories ran on reduced schedules to largely alleviate pollution. Additionally, the demolition and other procedures that might generate dust in all construction sites were required to stop. In Beijing, half of the city's 5.3 million vehicles were kept off the roads according to a ban on alternative days on cars with even-or-odd numbered license plates, and 6-day mandatory holidays were implemented in state-owned enterprises, local government offices and educational institutions. As a result, the emission reduction measures decreased the emissions of SO_2, NOx, VOCs, PM_{10}, and $PM_{2.5}$ by 39.2%, 49.6%, 33.6%, 66.6% and 61.6% in Beijing, respectively (BJEPB, 2014). The similar emission reduction measures taken in the 2008 Olympic Games also drastically reduced the emission of air pollutants (Wang et al., 2010; Li et al., 2012). Both events demonstrated that a haze can be eliminated in a short term by a human-perturbing campaign although a permanent solution for air pollution is still a tremendous challenge, which provided opportunities to investigate the effect of pollutant emissions on the air quality of Beijing and the surrounding regions.

Particulate matter (PM) is one of the most important air pollutants in urban areas. Usually, aerosol particles consist of various composites including inorganic substances (e.g., metal ions, sulfate, ammonium, and nitrate) and organic compounds (e.g., alkanes, PAHs, carboxylic

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acids) (Gnauk et al., 2008; Barros et al., 2010; Filippo et al., 2010; Holzinger et al., 2010). Obviously, these particles can cause short-term and long-term adverse health effects. Considering that PM is reported to be the major air pollutant on about 90% days per year in Beijing (Chan and Yao, 2008), studies on PM before (pre-APEC, Oct. 8–31), during (Nov. 1–12) and after the 2014 APEC meeting (post-APEC, Nov. 13–24) provided useful insights into the effect of the emission reduction measures on the air quality in Beijing.

For example, a study based on remote sensing technique indicated that the aerosol optical depth reduced by 40% in Beijing and 23% in Hebei during the APEC meeting compared with the corresponding period of 2011–2013 (Huang et al., 2015). An assessment by Liu et al. (2015) suggested that the concentrations of PM_1, $PM_{2.5}$ and PM_{10} decreased by 77%, 72% and 68% during the APEC meeting compared with the late October in Beijing. Gao et al. (2015) reported that $PM_{2.5}$ increased by 11.5% and water-soluble ions in $PM_{2.5}$ obviously increased in Tianjin after the APEC meeting.

Although the bulk particle analysis has provided useful insights into the general characteristics of aerosols, the average composition based on the bulk particle analysis cannot describe the composition and morphology of individual particles, which can be provided by the single particle analysis (Lu et al., 2006; Fu et al., 2012; Weinbruch et al., 2014). In this study, morphologies and compositions of individual particles were investigated by a scanning electron microscopy (SEM) coupled with an energy-dispersive X-ray (EDX). The objective of this study was to understand the changes in aerosol morphologies, chemical compositions, particle size distributions and sources as well as the effects of pollution control measures on these variables in Beijing before, during and after the 2014 APEC meeting. Also, this work may help researchers and the local government to better understand the mechanisms of PM pollution and abatement in megacities.

2. Methods

2.1. Sampling site

The sampling campaigns were conducted in Beijing from Oct. 8 to Nov. 24 in 2014. The sampling site is located at the Chinese Research Academy of Environmental Sciences (116°24′E, 40°02′N), 4 km north of the 5th ring road, 15 km from the city center (Fig. 1). The site is set on the rooftop of a three-floor building in the academy, 12 m above the ground. During the sampling, meteorological data on temperature, relative humidity (RH) and wind vector were recorded concurrently (Fig. 2).

2.2. Aerosol sampling

Total suspended particle (TSP) samples were collected on polycarbonate filters (Isopore™ Membrane Filters, 0.4 μm pore size, Merck Millipore Ltd.) using a portable air sampler (Minivol, Airmetrics, USA) with a TSP sampling head every morning. The sampling air flowrate was set at 5.0 L min^{-1}. The sampling duration depended on the local air quality at the beginning of sampling, and the procedure is listed in Table 1. During sampling, PM_{10} and $PM_{2.5}$ from the air monitoring station on the same rooftop were recorded concurrently (Fig. 3). During the experiment, 48 samples obtained for the subsequent SEM-EDX analysis.

2.3. Sample analysis

Individual aerosol particles in PM_{10} were analyzed manually using a scanning electron microscopy (Hitachi S-2700) equipped with an energy dispersive X-ray analysis (EDAX Inc., U.S.A.). X-ray analysis was carried out with an energy-dispersive Si (Li) detector Model Saphire, SUTW (super ultrathin window), allowing analysis for elements higher than boron (Z > 5). Prior to the analysis, 2.0 cm × 0.7 cm area of total filter was cut off from the edge to the center of polycarbonate filter. Then the detached filter was fixed to aluminium stubs by self-adhesive carbon discs and coated with an ultra-thin Au/Pd layer to provide sufficient electrical conductivity to minimize charge effects due to interaction with the electron beam. Approximately 200 particles were analyzed on each sample to examine particle morphology, size (equivalent projected area diameter) and elemental composition. An accurate particle numbers in each sample filter were counted for calculating the number concentration of the sample. Operating conditions were: accelerating voltage 20 kV, beam current 35 μA, and spectral acquisition time 30–60 s. Particle imaging was done by acquiring secondary electrons (SE). The intensities of the characteristic X-ray lines were converted to the corresponding elemental concentration by the standardless atomic number, absorption and fluorescence (ZAF)

Fig. 1. The location of Beijing city in China and the sampling site in Beijing.