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Insights into a dust event transported through Beijing in spring 2012: Morphology, chemical composition and impact on surface aerosols

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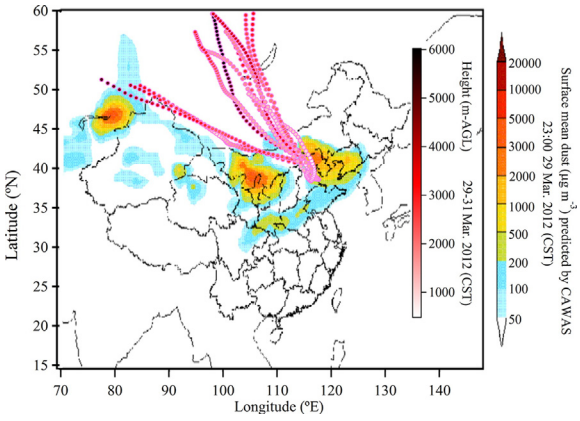
HIGHLIGHTS

- A dust event transported at high altitude through Beijing was investigated.
- The dust event caused high variation in surface aerosol number concentrations.
- Fine particles in the floating dust period probably consisted of ammonium sulfate.
- Passage of the dust induced a favorable condition for new particle formation.

GRAPHICAL ABSTRACT



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ABSTRACT

Multiple approaches were used to investigate the evolution of surface aerosols in Beijing during the passage of a dust event at high altitude, which was from the Gobi areas of southern Mongolia and covered a wide range of North China. Single particle analysis with electron microscope showed that the majority of coarse particles were mineral ones, and most of them were in the size range of 1–7 μm with a peak of number concentration at about 3.5 μm. Based on elemental composition and morphology, the mineral particles could be classified into several groups, including Si-rich (71%), Ca-rich (15%), Fe-rich (6%), and halite-rich (2%), etc., and they were the main contributors to the aerosol optical depth as the dust occurred. The size distributions of surface aerosols were significantly affected by the dust intrusion. The average number concentration of accumulation mode particles during the event was about 400 cm^{-3}, which was much lower than that in heavily polluted days (6300 cm^{-3}). At the stage of floating dust, the number concentration of accumulation mode particles decreased, and coarse particles contributed to total volume concentration of particulate matter as much as 90%. The accumulation mode particles collected in this stage were mostly in the size range of 0.2–0.5 μm, and were rectangular or spherical. They were considered to be particles consisting of ammonium sulfate. New particle formation (NPF) was observed around noon in the three days during the dust event, indicating that the passage of the dust was probably favorable for NPF.

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1. Introduction

Dust storm is a remarkable natural phenomenon, as an important source of mineral particles, which affects many countries in the Northern Hemisphere and has become an interesting research topic. It is directly related to air quality and human health (He et al., 2015; Wu et al., 2009). Under atmospheric circulation, the dust storm could travel globally (e.g., Duce et al., 1980; Prospero, 1999; Sassen et al., 2003), and has a significant direct and indirect effects on climate by producing both positively and negatively radiative forcing (Zhang et al., 2015). However, the details are not well-known because of the difficulty in determining the scattering characteristics of mineral particles (Penner et al., 1994). The chemical history of dust particles in the atmosphere was crucial for assessing their impacts on both the Earth's climate and ecosystem (Tobo et al., 2010). A quantification of chemical compositions and associated physical and optical properties of dust particles is needed for a predictive understanding of their impacts on a regional and global scale.

There are considerable research literatures on the patterns and characteristics of dust particles over Asia (e.g., Ma et al., 2004; Hwang and Ro, 2005; Tsai and Chen, 2006; Tobo et al., 2010). Physicochemical characteristics of dust particles, including size distribution, morphology and chemical composition, are already well-known. However, few observations and studies have focused on the influences of dust events on the surface aerosols.

Beijing, located on the pathway of dust outflows, is frequently invaded by dust storms during the springtime (Hu et al., 2015), which cause severe air quality even for several continuous days. In this study, we focus on a dust event passing through Beijing from 29 to 31 March 2012. Our objective is to investigate the morphology, chemical and optical properties of dust particles, and their impacts on surface aerosols. The size distributions of surface aerosols were measured during and before this event. During the floating dust weather, the samples for single particle analysis were also collected to investigate the physiochemical characteristics of particles. Particularly, the accumulation mode particles in the dust event, which have been rarely studied, were analyzed to distinguish the characteristics between dust and non-dust periods. This study could provide a useful analogue of Asian dust transportation and support of environmental and climate effects of dust.

2. Materials and methods

2.1. Sampling site

The experiments were conducted at an urban site, the PKU Atmosphere Environment MonitoRing Station (PKUERS) in Peking University (39.99° N, 116.31° E), on the loft of an academic building (about 20 m above the ground) on campus. There were no obvious emission sources nearby except two major roads, 200 m to the east and 600 m to the south. Detailed descriptions of the sampling site and surrounding environment can be found in Wu et al. (2007).

Meteorological conditions of wind direction, wind speed, temperature (T), relative humidity (RH), and atmospheric pressure (P) on surface as well as the concentrations of gaseous pollutants and $PM_{2.5}$ measured by the same monitoring station were applied to show the time series of the weather condition. The average PM_{10} concentrations were observed by Beijing Municipal Environmental Monitoring Center (http://zx.bjmemc.com.cn) at 24 sites in Beijing. The dust concentrations over Asia were from the simulations of U.S. Navy Aerosol Analysis and Prediction System (NAAPS), a transport model driven by wind fields from the Navy Operational Global Atmospheric Prediction System (http://nrlmry.navy.mil). All the times in this paper, unless otherwise stated, are given in China Standard Time (CST), 8 h ahead of GMT.

2.2. Particle number size distributions

Number size distributions of surface aerosols between 3 nm and 10 μm were measured in the monitoring station. A TDMPS (Twin Differential Mobility Particle Sizer) system was used to measure the particle size distributions from 3 nm to 800 nm (mobility diameter). It consists of two parallel differential mobility analyzers (Model 3080 long- and nano-DMAs, TSI Inc., USA) and two condensation particle counters (CPCs, TSI model 3775 and 3776). The TDMPS system was described in detail by Wehner et al. (2008). Simultaneously, an aerodynamic particle sizer (APS, TSI model 3321) measured number size distributions of particles from 800 nm to 10 μm (aerodynamic diameter). The resulting distributions of APS system were transformed from aerodynamic to Stokes diameter using a particle density of 1.7 g cm^{-3} (Hu et al., 2012). A low flowrate PM_{10} inlet was used for both systems. The relative humidity within the systems was kept below 30%. Size distributions were scanned every 5 min.

2.3. Single particle analysis by electron microscopy

A three-stage cascade impactor was applied to collect particles onto electron microscope meshes in the floating dust weather on 30 March 2012. The meshes were coated with carbon-sprayed Formvar film. The flow rate was 2.2 l min^{-1}. Assuming that the density of dust particles is 2.3 g cm^{-3}, the 50% cut-off aerodynamic diameters of the first, second and third stages are 0.8 μm, 0.3 μm and 0.3 μm, respectively. The third stage was used to capture particles skipping over the second stage. After particle collection, each mesh was preserved in a plastic capsule. The capsules were sealed in a plastic bag with paper-packaged silica gel and were kept cool in a refrigerator until analysis. The details of sampling periods, relevant meteorological conditions are listed in Table 1.

Particles on the copper meshes of the first stage were investigated and photographed using an environmental scanning electron microscope coupled with an energy dispersive X-ray spectrometer (ESEM–EDX, FEI Quanta 200F) of the Electron Microscopy Laboratory of Peking University at an accelerating voltage of 10 keV, and the photographs were used later for the observation of particle morphology and size. After a photograph was taken, the elemental composition of every particle in the photograph was determined using the EDX attached to the ESEM at an accelerating voltage of 20 keV. Elements with atomic number (Z) larger than 5 in the particles were detected simultaneously. Meanwhile, particles on the copper mesh of the second and third stages were investigated and photographed using the transmission electron microscope (TEM, FEI Tecnai F20) in the same laboratory with the accelerating voltage of 200 keV.

2.4. Aerosol optical depth and aerosol index

The column aerosol optical properties available in this study were derived from the ground-based remote sensing results of an automatic robotic sun and sky scanning measurement program, Aerosol Robotic Network (AERONET, http://aeronet.gsfc.nasa.gov) at the Beijing station

Table 1
Sampling time and surface weather conditions at the sampling site when the particles were collected.

Sample ID	Sampling time (CST[a])	T (°C)	RH (%)	P (hPa)	Wind	
					Speed ($m\ s^{-1}$)	Direction (°)
BD01	1st stage 21:30–21:31 2nd and 3rd stages 21:30–21:31 + 21:32–21:33	10.6	19.5	1011.6	1.0	305.5
BD02	1st stage 22:02–22:03 2nd and 3rd stages 22:02–22:03 + 22:03–22:04	11.0	16.8	1010.6	1.9	239.6

[a] China Standard Time (8 h prior to GMT).