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The heaviest particulate air-pollution episodes occurred in northern China in January, 2013: Insights gained from observation

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HIGHLIGHTS

- The obvious decline in air quality was found in Beijing in January.
- The highest hourly $PM_{2.5}$ concentrations reached approximately 1000 μg/m^3.
- More secondary particles were observed during severe air pollution episodes.

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ABSTRACT

A comprehensive measurement was conducted to analyze the heaviest air pollution episodes, which occurred in January 2013 with the focus on particulate characterization and haze. Based on observation, five heavy pollution episodes were recorded, whose frequencies are far greater than in other years. Among the heavy pollution episodes, two distinct severe regional $PM_{2.5}$ (particulate matter (PM) with an aerodynamic diameter ≤2.5 μm) pollution episodes were selected for investigation. One episode is characterized by an explosive growth in $PM_{2.5}$ concentrations within several hours, which is mainly caused by the high local emission under stagnant conditions; the other episode is characterized by four-day consecutive increases in $PM_{2.5}$ concentrations, which is largely attributed to a combination of slow regional transport and local accumulation. The PM compositions and concentrations including $PM_{2.5}$, PM_1 (PM with an aerodynamic diameter ≤1 μm), nitrate, sulfate, ammonium, organic carbon (OC) and elemental carbon (EC) as well as main gaseous precursor concentrations are analyzed in Beijing during the two episodes. Rapid gas-to-particle conversion, coagulation and collision of particles are discussed under high emission and stagnant weather conditions. High sulfur and nitrogen oxidation ratios were found, suggesting that additional production of sulfate and nitrate occurred during the pollution episodes. In addition, high levels of secondary particles were transported from surrounding regions via vertical mixing and horizontal transport during the polluted days. Notably, the stationary source is still a major contributor to the pollution episodes. Clear evidence is presented indicating that the secondary formation of particulate was one important mechanism in the formation of the heavy pollution episodes. To control the air pollution effectively, more stringent restriction measures on the SO_2 and NO_x emissions should be strictly executed at the regional scale.

1. Introduction

Northern China has experienced rapid economic growth over the past two decades accompanied by the development of large-scale industries and urbanization. This economic boom has led to a general decline in air quality in urban agglomerations (Shao et al.,

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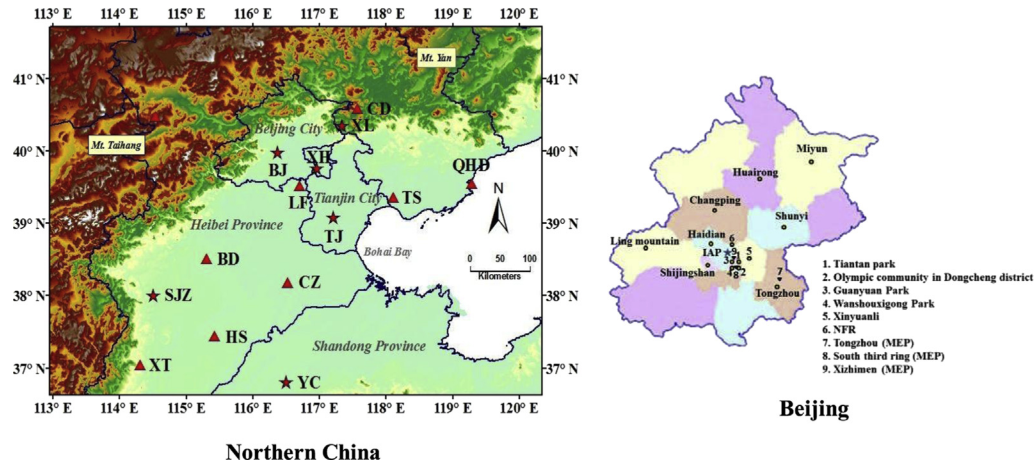

Fig. 1. A map showing the location of the study sites and topography in northern China.

2006). Serious air-pollution problems frequently occur, such as high concentrations of PM accompanying haze, which has attracted widespread attention (Molina and Molina, 2004; He et al., 2011) because exposure to airborne PM could result in adverse effects on public health (Fann and Risley, 2013). In addition, the radiative budget is affected by high PM loadings, which contribute to global climate change (IPCC, 2007). Moreover, some studies showed that the serious particulate air pollution generated over eastern Asia can be transported to the western Pacific Ocean region (Jo and Kim, 2013). It is evident that the impact on air quality due to the long-range transport is expected to increase in downwind regions (Lin et al., 2014).

In January 2013, five hazardous air-pollution episodes occurred, which were considered the most serious pollution events since 2000 (with the exception of dust episodes). These episodes led to the cancellations of hundreds of flights, warnings to avoid all outdoor activities and a spike in respiratory disease cases. Although the domestic and foreign media have reported the severity of this episode and emergent response measures for air pollution, a scientific and professional analysis of these episodes is necessary to recognize the evolving process of air pollution and to evaluate the rationality of instituting policy.

To date, serious PM-pollution episodes have been reported in a large number of studies, including in situ observations and air pollution-monitoring campaigns conducted by research institutions (Fu et al., 2008; Huang et al., 2012). The results showed that regional emissions and weather patterns play important roles in the PM_{10} (PM with an aerodynamic diameter $\leq$10 μm) and $PM_{2.5}$ pollution over a region (He et al., 2011). OC, EC, sulfate, nitrate and ammonium have been found to comprise the major fraction of fine particles. The sources of PM mainly include secondary inorganic species, coal combustion, vehicle exhaust, biomass burning, and mineral dust, depending on the seasons and sites. However, each PM pollution episode has its own unique characteristics. Recognizing the characteristics of each severe PM pollution episode and understanding the causes of these episodes are a prerequisite for authorities and researchers to effectively reduce air pollution. The main challenge for recognizing the characteristics of PM pollution episodes is the identification of the contributions of local emission as well as the long-range transport and linkage of the emissions of PM and its precursors with the transport, transformations and fate of PM under the high emission scenario.

Under the above-mentioned background, this paper will present an in-depth explanation of how local emissions and regional transport differently influence the compositions and concentrations of PM. The evolutions of episodes in different size-segregated PM (PM_1 and $PM_{2.5}$) are also described with the high temporal resolution measurement of chemical species. Knowledge of the rapid evolution processing of PM components is obtained. This study provides clear evidence that the effective management of air pollution requires collaboration among local, regional and state authorities in northern China.

2. Description of the experiment

2.1. Measurement site

The study was conducted using an air quality observation network constructed by the Institute of Atmospheric Physics, Chinese Academy of Sciences, in northern China. Fig. 1 and Table 1 show the locations of these air quality monitoring stations. All the air quality monitoring stations were selected and set up according to the United States Environmental Protection Agency method designation (US EPA, 2007).

Fig. 2 and Table 1 show the location of the study sites in Beijing. The sites include Tiantan Park, Olympic Community in the Dongcheng District (QC), Wanshouxigong Park (WP), Guanyuan park (GP),

Table 1
Locations of the monitoring stations selected for the study.

N	Site	Latitude	Longitude	Altitude
1	IAP	39° 58′ 28″ N	116° 22′ 21″ E	44 m
2	NFR	39° 59′ 18″ N	116° 25′ 53″ E	45 m
3	Xinyuanli	39° 56′ 52″ N	116° 27′ 04″ E	46 m
4	Guanyuan park	39° 56′ 32″ N	116° 18′ 52″ E	55 m
5	Changping	40° 12′ 1″ N	116° 14′ 17″ E	60 m
6	QC	39° 55′ 41″ N	116° 25′ 59″ E	50 m
7	Ling mountain	39° 56′ 52″ N	116° 27′ 04″ E	1041 m
8	Tongzhou	39° 53′ 12″ N	116° 40′ 09″ E	23 m
9	Haidian	39° 56′ 37″ N	116° 27′ 04″ E	57 m
10	Huairou	40° 20′ 9″ N	116° 37′ 58″ E	55 m
11	Miyun	40° 22′ 16″ N	116° 51′ 14″ E	74 m
12	Wanshouxigong Park	39° 54′ 50″ N	116° 22′ 44″ E	51 m
13	Shijingshan	39° 54′ 55″ N	116° 11′ 24″ E	76 m
14	Shunyi	40° 7′ 47″ N	116° 38′ 23″ E	38 m
15	Tiantan Park	39° 52′ 59″ N	116° 24′ 47″ E	45 m
16	Tianjin	39° 4′ 30″ N	117° 12′ 22″ E	−9 m
17	Shijiazhuang	38° 1′ 40″ N	114° 31′ 45″ E	70 m
18	Xianghe	39° 45′ 14″ N	116° 57′ 45″ E	9 m
19	Xinglong	40° 23′ 40″ N	117° 34′ 34″ E	879 m
20	Yucheng	36° 49′ 51″ N	116°34′ 13″ E	22 m