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Comparison of two serious winter and summer air pollution episodes in Beijing

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A B S T R A C T

Characteristics of two serious air pollution episodes (9–15 January, as the winter case; and 30 June to 1 July, as the summer case), which occurred in Beijing in 2013 were investigated and compared using multi-method observations and numerical simulations. During these two air pollution episodes, $PM_{2.5}$ concentrations varied significantly within Beijing, with $PM_{2.5}$ concentrations in southern parts of Beijing being significantly higher than in northern areas. Typically, heavy air pollution episodes begin in the southern parts and disperse towards the northern parts of Beijing. Clearly, synoptic patterns and the stability of atmospheric circulation patterns were the main factors controlling air pollution in Beijing. During the winter case, a warm center above 900 hPa occurred over Beijing. Meanwhile, in the summer case, although there was only a weak inversion, the convective inhibition energy was strong (over 200 J/kG). This clearly influenced the duration of the air pollution event. Except for the local accumulation and secondary atmospheric reactions in both cases, regional straw burnings contributed a lot to the $PM_{2.5}$ concentrations in summer case. Using the CAM_x model, we established that regional transport contributed almost 59% to the $PM_{2.5}$ concentration in Beijing in the winter case, but only 31% in the summer case. Thus, the winter case was a typical regional air pollution episode, while the summer case resulted from local accumulation and strong secondary atmospheric reactions. Given that air pollution is a regional problem in China, consistent and simultaneous implementation of regional prevention and control strategies is necessary to improve regional air quality.

Introduction

In recent years, Eastern China has frequently experienced heavy air pollution or haze, reflecting its rapid urbanization and industrialization (Cao et al., 2007; Liu and Diamond, 2005). Such heavy air pollution has attracted considerable attention, because of its effects on visibility, public health, transportation, and even global climate (Deng et al., 2011; Dominici et al., 2014; Guo et al., 2014; Nel, 2005; Zhang et al., 2014).

Air pollution, as one of the major environmental issues in China, has been mostly studied in three polluted areas within China: the Jing-Jin-Ji region (Ji et al., 2014; Liu et al., 2013; Wang et al., 2012; Wang et al., 2013; Wang et al., 2014a; Wang et al., 2014b; Wang et al., 2014c; Zhang et al., 2014), the Yangtze River

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Delta region (Hu *et al.*, 2014; Li *et al.*, 2011; Shao et al., 2006;Wang et al., 2011; Zhou et al., 2015), and the Pearl River Delta region (Deng et al., 2008; Peng et al., 2011; Tie and Cao, 2009;Wu et al., 2013). To improve air quality and protect public health, the Chinese government published a New National Ambient Air Quality Standard (NNAAQS) (GB3095-2012) (MEP, 2013a). According to this NNAAQS, an Air Quality Index (AQI) of more than 200, *i.e.*, >150 μg/m^3 concentration of particulate matter having a diameter of ≤2.5 μm ($PM_{2.5}$; daily-averaged concentration), indicates heavy air pollution. Typically, most of the primary air pollutants during heavy air pollution events are $PM_{2.5}$ (MEP, 2013b). Most studies of air pollution have focused on changes of chemical composition, evolutions, and relationships between meteorological factors and air pollution (Wang et al., 2011; Zhou et al., 2016;Wang et al., 2014a, 2014b, 2014c). Several studies reveal the formation mechanism and causes of severe air pollution episodes during winter and autumn in China mainly attributed three aspects: (1) stable synoptic meteorological conditions; (2) secondary chemical reactions; (3) regional transport (Zheng et al., 2015; Yang et al., 2015). Such aspects are mostly evaluated from a few monitoring sites, applying data obtained from satellites and simulation results from air quality model (Huang et al., 2014; Zhang et al., 2014). Guo et al. (2014) pointed out that the impact of the regional $PM_{2.5}$ transport is negligible during the polluted periods while many studies supposed that regional transport of air pollutants played an important role even in the stationary conditions (Streets et al., 2007; Wang et al., 2014b, 2014c; Wu et al., 2013). Moreover, few studies have comprehensively analyzed the influence of vertical meteorological factors on pollutant concentration, the strength of secondary chemical reactions, quantitative relationships between local regional transport and local contribution. Moreover, the differences between different air pollution episodes over different seasons also need further research and analysis in near future.

As the capital and most polluted city of China, Beijing has attracted the concern of both domestic and foreign scholars, because of its severe air pollution (Chan and Yao, 2008). In recent years, the air quality in Beijing has been improved under enhanced air pollution prevention and control measures (*e.g.*, reduction of coal use, limitation of vehicles, industrial adjustments, cleaning of construction dust, regional joint prevention actions, and other measures). However, heavy air pollution continues to occur under adverse weather conditions (Zhou et al., 2016; Zhang et al., 2014). From 2013 to 2015, Beijing experienced several episodes of severe haze pollution during winter, along with other air-polluted Chinese cities (Huang et al., 2014; Ji et al., 2014; Liu et al., 2013; Tao et al., 2014). In December 2015, Beijing experienced two red alerts for heavy air pollution and these red alerts were highlighted in the media, as one of the 10 keywords dealing with clean air actions (http://www.chinanews.com/gn/2016/01-18/7721268.shtml), thereby raising considerable public attention. Compared with the severe air pollution occurring in winter, air pollution in summer is usually slight and has seldom been studied (Duan et al., 2012; Li et al., 2010; Streets et al., 2007; Sun et al., 2006a, b; Wang et al., 2012). Moreover, a study of regional air pollution comparisons can be useful for air quality forecasting and can provide scientific support for effective and urgent measures to protect public health at both National and local government levels (Zhang et al., 2012; Zhang et al., 2014).

Beijing experienced a severe air pollution episode from 9 to 15 January, 2013 characterized by an AQI > 200 for five consecutive days, triggering considerable public concern (Huang et al., 2014; Ji et al., 2014; Tao et al., 2014; Liu et al., 2013; Zhang et al., 2014). Beijing also suffered from a heavy summer air pollution episode from 30 June to 1 July, 2013 (with an AQI > 200 for two consecutive days) (Li et al., 2010; Duan et al., 2012). To improve our understanding of the characteristics, causes, and formation mechanisms of these heavy air pollution episodes occurring in different seasons, we combined multi-source data of $PM_{2.5}$ concentrations, meteorological elements, $PM_{2.5}$ components, and regional transport contributions from the Comprehensive Air Quality Model with Extensions (CAM_x) to investigate the differences between these two typical air pollution episodes in Beijing. In this study, the authors focused on the key concerns of the air pollution episodes aforementioned: (1) compare the differences between two typical air pollution episodes in summer and winter in Beijing including the sharp increase and non-uniformity of the $PM_{2.5}$ spatial distribution;(2) calculate the quantitative relationships between the air pollution evolutions and major influencing factors especially the quantitative relationships between regional transport and local contribution; the convective inhibition energy was innovatively used to evaluate the intensity of vertical diffusion over Beijing; (3) propose some suggestions for heavy air pollution treatment in different seasons in Beijing.

1. Material and methods

1.1. Instruments and observations

Beijing is located at 115.7–117.4°E, 39.4–41.6°N, on the northwest edge of the North China Plain. The average altitude of Beijing is 43.5 m, while the general altitude of its local mountains is between 1000 m and 1500 m. The total area of Beijing is 16,410.54 km^2, of which 62% is mountainous. The annual average rainfall was less than 450 mm over the past 10 years, with most rainfall concentrated in June, July, and August (Chinese National Bureau of Statistics, 2013).

In addition to $PM_{2.5}$, we monitored other airborne pollutants for a better understanding of the characteristics, sources, and evolution of air pollution during severe air pollution episodes. Airborne pollutants in Beijing are monitored at 35 observation stations (Fig. 1). Concentrations of $PM_{2.5}$ at different sites were monitored using 1405-F TEOM™ Continuous Ambient Air Monitors (Thermo Scientific™, Waltham, MA, USA), operated according to their ambient air quality and automatic monitoring technical specifications (HJ/T193-2005) (MEP, 2005). Among these 35 observation sites, the DL station is located in suburban areas of the northern part of Beijing, while the JCZX station is located in central urban areas between the 2nd and 3rd ring roads of Beijing, and the YF station is located close to the southern boundary of Beijing. Because there are more monitoring instruments, with better operation and maintenance at these three stations, they were selected as representative stations for monitoring airborne

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