JOURNAL OF ENVIRONMENTAL SCIENCES XX (2017) XXX–XXX

Available online at www.sciencedirect.com

ScienceDirect

www.elsevier.com/locate/jes

ELSEVIER

JES JOURNAL OF ENVIRONMENTAL SCIENCES

www.jesc.ac.cn

Multi-dimension apportionment of clean air “parade blue” phenomenon in Beijing

Yifeng Xue[1,2], Yong Wang[1,3], Xuefeng Li[2], Hezhong Tian[1,3,*], Lei Nie[2], Xiaoqing Wu[2], Junrui Zhou[1,4], Zhen Zhou[2,*]

1. State Key Joint Laboratory of Environmental Simulation & Pollution Control, School of Environment, Beijing Normal University, Beijing 100875, China
2. National Engineering Research Center of Urban Environmental Pollution Control, Beijing Municipal Research Institute of Environmental Protection, Beijing 100037, China
3. Center of Atmospheric Environmental Studies, Beijing Normal University, Beijing 100875, China
4. Wuhan Environmental Protection Sciences Research Institute, Wuhan 43005, China

ARTICLE INFO

Article history:
Received 14 November 2016
Revised 13 March 2017
Accepted 28 March 2017
Available online xxxx

Keywords:
$PM_{2.5}$
Parade Blue in Beijing
Emission reduction
Air quality
Source apportionment
Meteorological conditions

ABSTRACT

The mass concentration and major chemical components of fine particulate matter were measured before, during and after Beijing's massive parade commemorating 70th anniversary of the Chinese Victory in World War II on September 3, 2015. Regional emission inventory, positive matrix factorization (PMF), observations from space and backward air mass trajectories were jointly applied to identify the major pollution sources and their temporal and spatial variations. The contributions of emissions, their variations and the meteorological conditions related to the “parade blue” phenomenon in Beijing and its surrounding areas were investigated in detail. The main cause of the decreased $PM_{2.5}$ mass concentration was attributed to the absolute reduction in emissions of primary air pollutants. The chemical composition of $PM_{2.5}$ varied significantly before, during and after the parade. Fugitive dust particles were well controlled, the secondary formation of $PM_{2.5}$ was reduced along with the controlled gaseous precursors' emissions from vehicles and industrial sources during the temporary intensified control period. During the parade period, the SO_2 and NO_2 column concentrations in Beijing and the surrounding areas decreased sharply, indicating that the coordinated reduction in primary emissions from the surrounding areas of Beijing played an important role in lowering the ambient concentration of SO_2 and NO_2 and accordingly lowered $PM_{2.5}$ and improved the regional air quality. A comparison of the temperature, humidity, and wind speed and direction during the same periods in 2014 and 2015 showed that the meteorological conditions positively influenced the achievement of “parade blue”.

Introduction

Particulate matter (PM) with an aerodynamic diameter of 2.5 μm or less ($PM_{2.5}$) is the primary air pollutant in Beijing (Guo et al., 2014; Y. Liu et al., 2015; Zhang et al., 2015). The annual average $PM_{2.5}$ concentration has decreased over the last decade due to significant efforts by the national and local governments to reduce various air pollutant emissions from

---

[*] *Corresponding authors.* E-mail: hztian@bnu.edu.cn (Hezhong Tian), zhouzhen@cee.cn (Zhen Zhou).

http://dx.doi.org/10.1016/j.jes.2017.03.035

Please cite this article as: Xue, Y., et al., Multi-dimension apportionment of clean air “parade blue” phenomenon in Beijing, J. Environ. Sci. (2017), http://dx.doi.org/10.1016/j.jes.2017.03.035

major pollution sources (Amil et al., 2015; Lv et al., 2016; S. Zheng et al., 2015). However, according to the Beijing Environmental Statements, the annual average $PM_{2.5}$ mass concentration was still as high as 85.9 $\mu g/m^3$ in 2014, nearly 2.5 times the Chinese National Ambient Air Quality Standards (NAAQS) (annual average of 35 $\mu g/m^3$) and far exceeding the WHO guidelines, indicating that Beijing still faces severe fine particle pollution (Sun et al., 2015).

Q7

As the capital of China, Beijing is a typical fast growing megacity with a population of more than 20 million and a vehicle fleet of more than 5.6 million. The acceleration in urbanization and economic development, high consumption of coal, rapid construction activities, and booming vehicle fleet have contributed to higher emissions of $PM_{2.5}$, sulfur dioxide (SO_2), nitrogen oxide (NO_x) and volatile organic compounds (VOCs) in Beijing (Gao et al., 2015; J. Huang et al., 2015; Wang et al., 2010, 2015; G.J. Zheng et al., 2015). In addition, Beijing is geographically surrounded by the Yanshan and Taihang Mountains in the north and west, respectively, which effectively trap air pollutants, to the west, north, and northeast. The high amount of local emissions and regional air pollutants transport combined with adverse terrain and unfavorable meteorological conditions have made it quite difficult to improve the air quality in Beijing (Z.R. Liu et al., 2015; Sun et al., 2013).

Q8

Although the air quality in Beijing has temporarily improved to achieve very low $PM_{2.5}$ concentration and very good visibility — the so called "blue sky" in the past years by implementing temporary control measures to limit atmospheric emissions of various sources. For example, private vehicles use was restricted based on even- and odd-numbered license plates to effectively ban millions of registered cars from driving on the urban highways and streets. In addition, hundreds of manufacturing factories were suspended or even shutdown during particular short-time periods to achieve the impressive "Olympic blue" in 2008 and "APEC blue" in 2014 (K. Huang et al., 2015; Lv et al., 2016; Wang et al., 2014; Xing et al., 2011; Yu et al., 2015; Zhou et al., 2010). Several long-term measurements and source analyses have been conducted to explore the temporal and spatial distributions and seasonal and diurnal variations in pollution properties for better understanding air pollution formation (Guo et al., 2012; Liu et al., 2009; Sun et al., 2006, 2013, 2015; Gao et al., 2015). Several studies of the air quality and the implications of implementing control measures during special events held in Beijing, including the Olympic Games and Asia-Pacific Economic Cooperation (APEC), have been reported in literature (Chen et al., 2013; Guo et al., 2013; Liu et al., 2012; Y. Liu et al., 2015; Lv et al., 2016; Wang et al., 2015; Yang et al., 2016; Yu et al., 2015). Quantitative assessment of the improvements in the air quality due to various control measures is desirable and will inevitably benefit policy makers of the Department of Environmental Protection both locally in Beijing and at a national level.

During the IAAF (International Association of Athletics Federations) World Athletics Championships (8/22–30/2015) and the massive parade (9/3/2015) commemorating the 70th anniversary of World War II, extensive short-term mitigation measures were adopted to ensure good air quality and visibility. For instance, local governments in Beijing and Tianjin municipality, as well as the 5 surrounding provinces (Hebei, Shanxi, Shandong, Henan and Inner Mongolia), implemented comprehensive control measures including limiting traffic, restricting construction activities, and shutting down manufacturing factories. These temporary control measures were basically similar to those implemented during the APEC meeting in November of 2014, but the corresponding meteorological conditions and emission sources as well as their emission intensity were quite different. Therefore, the impact of human emission on the air quality deserves to be evaluated with multi-dimensional and integrated methods, so as to advance our knowledge of air pollution mitigation and develop future control strategies for further lowering $PM_{2.5}$ concentration in Beijing.

The objectives of this study are to (1) analyze the variations of Beijing's atmospheric $PM_{2.5}$ pollution characteristics before and after the short-term control measures were implemented for special events; (2) assess the effects of meteorological conditions on the $PM_{2.5}$ mass concentration; (3) identify the primary sources that impact Beijing's $PM_{2.5}$ concentration and the effectiveness of source control strategies in reducing $PM_{2.5}$ pollution; (4) explore the inspiration and implications for further improving the daily air quality of Beijing and other megacities now and in the future.

1. Materials and methods

1.1. Sampling sites

Offline field measurements were performed from August 16 to September 10, 2015, at three atmospheric environmental monitoring sites which represent urban, rural and regional air pollution transport, respectively (see Fig. 1). The first sampling site is located at the Beijing Normal University (BNU) campus between 2nd and 3rd Ring Roads north of downtown Beijing and represents a typical urban environment in downtown Beijing. The sampling station is set up on the roof of the School of Environment Building, approximately 20 m above the ground.

The second site, the Shixia monitoring station, is located in Miyun County approximately 100 km away from northeastern urban Beijing. Miyun County is well known for the Miyun Reservoir, which is one of the largest reservoirs in northern China and supplies Beijing residents with fresh water. This monitoring site is largely surrounded by rural villages, and no large industrial pollution point sources are located within 20 km (Zhang et al., 2013).

The third site, the Daijiayun monitoring station, is located in the Daxing District approximately 40 km away from southern urban Beijing and only 4 km from the boundary of Beijing and Hebei Province. The emission sources in urban Beijing are considered to be the local sources for this monitoring station. The regional sources for this site are the emissions from provinces in the North China Plain (NCP), such as Beijing, Tianjin, Hebei, northern Henan and western Shandong. Therefore, in this study, this station is used to represent regional air pollution transport. Offline $PM_{2.5}$ samples were collected on quartz filters (Pallflex Tissuquartz™, 90 mm, USA) using a high-volume air sampler equipped with a $PM_{2.5}$ impactor (Wuhan Tianhong Instruments Co., Ltd.) operated at a flow

Please cite this article as: Xue, Y., et al., Multi-dimension apportionment of clean air "parade blue" phenomenon in Beijing, J. Environ. Sci. (2017), http://dx.doi.org/10.1016/j.jes.2017.03.035