Atmospheric Environment 148 (2017) 30–41

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Characteristics of aerosol size distribution and vertical backscattering coefficient profile during 2014 APEC in Beijing

Jiaoshi Zhang [a, b], Zhenyi Chen [a], Yihuai Lu [a], Huaqiao Gui [a, b, *], Jianguo Liu [a, b], Wenqing Liu [a, b], Jie Wang [a], Tongzhu Yu [a], Yin Cheng [a], Yong Chen [c], Baozhu Ge [c], Yu Fan [d], Xisheng Luo [d]

[a] Key Laboratory of Environmental Optics and Technology, Anhui Institute of Optics and Fine Mechanics, Chinese Academy of Sciences, Hefei 230031, China
[b] CAS Center for Excellence in Regional Atmospheric Environment, Institute of Urban Environment, Chinese Academy of Sciences, Xiamen 361021, China
[c] Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing 100029, China
[d] Advanced Propulsion Laboratory, Department of Modern Mechanics, University of Science and Technology of China, Hefei 230026, China

HIGHLIGHTS

- Characteristics of regional transport during haze episode in Beijing were studied.
- Emission reduction measures taken during the APEC conference period were evaluated.
- Haze occurred during APEC conference period was mainly induced by regional transport through southwest pathway.

ARTICLE INFO

Article history:
Received 4 March 2016
Received in revised form
21 September 2016
Accepted 12 October 2016
Available online 13 October 2016

Keywords:
Haze
APEC
Regional transport
Southwest pathway
Beijing

ABSTRACT

During the 2014 Asia-Pacific Economic Cooperation (APEC) conference period, Beijing's air quality was greatly improved as a result of a series of tough emission control measures being implemented in Beijing and its surrounding provinces. However, a moderate haze occurred during the period of 4–5 November. In order to evaluate the emission control measures and study the formation mechanism of the haze, a comprehensive field observation based on a supersite and a lidar network was carried out from 25 October 2014 to 20 January 2015. By investigating the variations in aerosol number concentration and mean backscattering coefficient before, during and after the APEC period, it was found that number concentration of accumulation mode and coarse mode particles experienced the most significant decrease by 47% and 68%, and mean backscattering coefficient below 1 km decreased by 34% during the APEC period. Being characterized as "rapidly accumulating and rapidly dispersing", the moderate haze occurred during the APEC period was probably initiated by a wind direction change to south and an increase of wind speed to 4 m/s. Sulfur dioxide involved plume nucleation without growth in size as well as a burst of particles ranging between 100 and 300 nm were observed simultaneously during the haze episode. The elevation of sulfur dioxide concentration and particle number concentration was highly correlated with the southerly wind, signifying the contribution of regional transport. It was observed by the lidar network that the aerosol backscattering coefficient increased in sequence among three sites along the southwest pathway, suggesting that aerosols might be transported from the southwest to the northeast of Beijing with a speed of approximately 17 km/h, which agreed with the movement of air masses modeled by Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT). The dual-wavelength lidar (355 and 532 nm) observation suggested that transportation of fine particles from high-level atmosphere (approximately 2 km) could be the potential sources of the haze. Our result showed that regional transport would contribute to haze formation in Beijing under such meteorological conditions, thus, to maintain the "APEC blue", significant attention should be paid to controlling regional transport through the southwest pathway.

* Corresponding author. Key Laboratory of Environmental Optics and Technology, Anhui Institute of Optics and Fine Mechanics, Chinese Academy of Sciences, Hefei 230031, China.
E-mail address: hqgui@aiofm.ac.cn (H. Gui).

http://dx.doi.org/10.1016/j.atmosenv.2016.10.020
1352-2310/

1. Introduction

China has been experiencing severe haze pollution as a result of its rapid economic development and urbanization. Most of the haze episodes occur on a regional scale, especially in megacity clusters, such as the region of Beijing, Tianjin, and Hebei (BTH), Pearl River Delta, and Yangtze River Delta (Parrish and Zhu, 2009). Extensive studies have been done in recent years to investigate the sources and formation mechanisms of regional haze (Sun et al., 2014; Zhao et al., 2013; Zheng et al., 2015). However, the sources of regional haze, such as local sources versus regional transport, and primary emissions versus secondary production, remain highly uncertain.

Beijing, one of the biggest cities in China, has been suffering from severe haze pollution for years. The government has taken stringent measures to cut the number of heavy industrial enterprises, such as steel mills and coal-fired power plants, and to limit the number of motorized vehicles to reduce pollutant emissions from local sources. However, despite the intensive efforts to reduce air pollutant emissions, haze days have been happening more frequently than ever before (Cao et al., 2014). One significant factor in haze formation is the regional transport of pollutants from surrounding industrial areas to Beijing under particular meteorological conditions.

Beijing is located in the hinterland of the North China Plain (NCP), with its three sides surrounded by the Mountains. The city suffers from regionally transported pollutants from the south; stagnant weather conditions and semi-basin topography cause these pollutants to remain in Beijing, resulting in regional haze (Zhu et al., 2011). Wang et al. (2013a), by using the Nested Air Quality Prediction Modeling System, found that the regional transport of particulate matter from neighboring sources contributes considerably to the concentration of $PM_{2.5}$ in Beijing. Pu et al. (2015) investigated the effect of long-range transport on aerosol properties at a background site in the NCP based on a set of 6-year $PM_{2.5}$ data and a trajectory clustering method; they concluded that trajectories on polluted days consisted mainly of air masses from the south and southeast of the NCP. Wang et al. (2015), who investigated the transport and regional sources of $PM_{2.5}$ in Beijing by means of the potential source contribution function and trajectory sector analysis, found that the probable locations of regional emission sources were mainly in the south and west of Beijing.

The above-mentioned studies investigated regional transport from the perspectives of modeling (Pu et al., 2015; Wang et al., 2013a, 2015; Wu et al., 2011). However, few studies have explored regional transport from the perspective of field campaign, and the characteristics of regional transport still remained uncertain. In this study, a comprehensive field campaign with the use of various techniques was carried out to investigate the characteristics of regional transport and its potential pathways.

The 2014 APEC conference was hosted by Beijing, China, on 5 to 11 November 2014, with the APEC Economic Leaders' Meeting (AELM) held at Yanqi Lake. To achieve good air quality during the conference period, a series of tough emission control measures were taken before and during the APEC conference period, including traffic reduction and suspension of production by polluting factories. Simultaneously, many neighboring cities in Inner Mongolia and in the provinces of Hebei, Shanxi, and Shandong implemented aggressive controls on vehicles and industrial plants to reduce emissions. As a result, the air quality in Beijing during the APEC conference period was almost good. However, a moderate haze occurred in spite of the efficiently implement of emission control measures. To evaluate the emission control measures and study the formation mechanism of the moderate haze, we set up a supersite near Yanqi Lake and a lidar network along the southwest pathway. The field campaign lasted for nearly three months, from 25 October 2014 to 20 January 2015.

2. Methodology

2.1. Supersite in University of Chinese Academy of Sciences

A supersite was established on the Yanqi Lake campus of the University of Chinese Academy of Sciences (UCAS), which is located in Huairou District, northeast of Beijing, indicated by a blue hollow circle in Fig. 1. The site lies in the north of Yanqi Lake; across the lake is the new Sunrise Kempinski Hotel where the AELM was held. Yanqi Lake lies at the edge of the Yanshan Mountains where northwestern mountain breeze and southerly air flow prevail. The western mountain breeze is relatively clean; however, the air flow coming from the southern urban areas may bring anthropogenic emissions. The site is mainly influenced by mobile sources of vehicle emission on China National Highway 111 and stationary sources from the rural settlement across the highway. The gaseous pollutant concentrations and aerosol properties, including mass concentration, size distribution, and optical properties, were measured simultaneously by using a suite of sophisticated instruments that were stationed on the top floor of the teaching building of UCAS.

The aerosol number size distributions were measured by using a scanning mobility particle sizer (SMPS) and an aerodynamic particle sizer (APS). The SMPS (Grimm Aerosol Technik Gmbh, Germany) consists of an Am-241 neutralizer (Model 5.522), a long Vienna-type differential mobility analyzer (L-DMA, model 55-990) and a condensation particle counter (CPC, model 5.403), measuring particle mobility sizes ranging from 11.1 to 1083.3 nm (Heim et al., 2004). The size distributions inversion was carried out using the manufacturer-provided software (GRIMM 5.477 Version 1.35), developed and described in detail by Reischl (1991). The APS (model 3321; TSI Inc., St. Paul, MN, USA) measures particle aerodynamic sizes ranging from 0.5 to 20 μm (Peters and Leith, 2003). The inversion of aerodynamic particle size distribution was performed by the Aerosol Instrument Manager software (AIM, TSI). To combine both measurements, the APS results were transformed from aerodynamic to Stokes diameters by using a particle density of 1.7 g cm^{-3} for particles larger than 500 nm (Wehner et al., 2008). In addition, particle losses in the sampling lines due to Brownian diffusion and gravitational settling were taken into account.

The RH of ambient aerosol was dried to <30% by using a diffusion drier before being passed into a flow splitter that split the flow into SMPS and APS as the sample flow. The RH of the sheath flow of SMPS was dried to <20% with the use of another diffusion drier and then passed through a HEPA filter before being sent to the DMA. The temperature and humidity of the sample flow and sheath flow were measured by a digital humidity and temperature sensor (SHT11; Sensirion China Co., Ltd) and logged every minute to ensure that the aerosol size distributions were measured under dry conditions; therefore, hygroscopic growth was not considered.

The $PM_{2.5}$ was continuously monitored by using a tapered element oscillating microbalance (TEOM 1405; Thermo Scientific). Sulfur dioxide (SO_2) was measured by pulsed fluorescence (model 43i; Thermo Scientific), carbon monoxide (CO) by gas filter correlation (model 48i; Thermo Scientific), ozone (O_3) by UV photometry (model 49i; Thermo Scientific), and nitrogen oxide (NO, NO_2, and NO_x) by chemiluminescence (model 42i; Thermo Scientific). These four gas analyzers had precision values of 1.0 ppb, 0.1 ppm, 0.5 ppb, and 0.4 ppb, respectively.

The meteorological data, including temperature, relative humidity, atmospheric pressure, wind direction, and wind speed, were recorded by a MetPak automatic weather station (Gill