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A study of the meteorological causes of a prolonged and severe haze episode in January 2013 over central-eastern China

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HIGHLIGHTS

- Large-scale latitudinal atmospheric circulation is beneficial for the haze forming.
- Local stable stratification and weak turbulent is favorable for the haze formation.
- Pollutants transportation from south Hebei on 850–925 hPa favors Beijing's pollution.

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ABSTRACT

This paper employs meteorological observation data from surface and high-balloon stations, China Meteorological Administration (CMA) model T639 output data, NCEP reanalysis data, $PM_{2.5}$ observations and modeled HYSPLIT4 trajectory results to study the meteorological causes, including large-scale circulation and planetary boundary layer features, which led to the extended haze episode on January 6–16, 2013 in central-eastern China. It discusses the possible impact of pollutants transported from southern Hebei Province on Beijing. The study's results show that: (1) the re-adjustment of atmospheric circulation from a longitudinal to a latitudinal model provides a valuable interpretation of the large-scale circulation background to the haze episode experienced in the metropolitan regions of Beijing, Tianjin, Hebei and their surrounding regions; (2) the regional atmospheric stratification of the planetary boundary layer is stable and the mixing height is low, suppressing air turbulence in the planetary boundary layer and providing favorable meteorological conditions for the formation of haze; and (3) the southwesterly jet stream with wind speeds of 6–11 m/s at a height of 850–950 hPa and the below-700 m air mass trajectory tracking established using the HYSPLIT4 model interdependently suggest a transport of pollutants from southern Hebei Province to Beijing at 850–950 hPa.

1. Introduction

Atmospheric pollution is an increasingly serious environmental problem faced by developing countries (Chan and Yao, 2008; Zhang et al., 2009). The deterioration of air quality is caused by the presence of aerosol components and the accumulation of aerosol concentrations (Zhu et al., 2003; Zhang et al., 2012a,b). According to the statistics published by China's Department of Environmental Protection, ca. 85%–90% of the primary pollutants in most Chinese cities throughout the year are of particulate matter. These pollutants are followed in importance by concentrations of SO_2 (Che, 1999). In general, particulate matter is suspended in the air for a long time, affecting the optical properties of the atmosphere and

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resulting in reduced visibility (Che et al., 2009; Chen et al., 2009; Guo et al., 2011). During stable weather conditions, particulate matter can accumulate over a sustained period to form haze (Xu et al., 2005), causing severe air pollution (Yang et al., 2009). This may have a profound impact on climate change (Luo et al., 1998; Wang et al., 2007a,b; Shi et al., 2008; Ding et al., 2009).

With the rapid urbanization of Beijing municipality and its environs in recent decades, PM_{10} and $PM_{2.5}$ have become the main pollutants responsible for the high levels of air pollution in this region (Wang et al., 2007a,b; Liu et al., 2010). After analyzing sulfate, nitrate, ammonium, organic matter, black carbon and other aerosol chemical components in PM_1 found in urban Beijing on a seasonal basis, it was found that, due to the combination of dust produced in arid areas and fugitive urban dust, mineral aerosol concentrations in China are equal to, or higher than, the sum of all aerosol concentrations found in the urban areas of Europe and America (Zhang et al., 2012a,b). Annual average PM_1 concentrations are ca. 81 $\mu g/m^3$, with organic aerosols accounting for ca. 41%, sulfate for ca. 16%, nitrate for ca. 13%, ammonium for ca. 8%, black carbon for ca. 11%, chloride for ca. 3% and fine mineral aerosols for ca. 7% of the total (Zhang et al., 2012a,b). At the same time, haze episodes have been observed frequently in Beijing in recent years, especially during cold winter and spring seasons (Sun et al., 2006; Wang et al., 2010; Zhang et al., 2013).

In January 2013, central-eastern China experienced severe haze events which affected unusually sizeable areas and were also of long duration. The Jing-Jin-Ji region (contractions of the city names of Beijing and Tianjin, and the regional name for Hebei Province) and its immediate environs were the most polluted regions during these episodes. The haze episode which lasted from January 6 to 16, 2013 was the severest in terms of the size of the region it influenced, its duration and the intensity of the pollution. Multisource observation data covering PM_{10}, SO_2 and NO_2 concentrations, Moderate Resolution Imaging Spectroradiometer (MODIS), China Aerosol Remote Sensing NETwork (CARSNET) aerosol optical depths (AOD), and Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) extinction coefficients were employed to study haze strength, the region affected, and the distribution of pollutants, *etc*. (Wang et al., 2014). This paper focuses on the meteorological formations and weather conditions leading to this haze pollution, ranging from atmospheric circulation to conditions within the planetary boundary layer (PBL), regional transport, and other meteorological factors closely related to this haze episode.

2. Data and methodology

2.1. Data

The data used in this study include meteorological field observations covering haze phenomena, air pressure, geopotential height, wind fields, moisture at surface or high-balloon stations, T639 reanalysis data, and $PM_{2.5}$ concentration monitoring data as recorded by CMA automatic observation stations (Wang et al., 2008; Zhang et al., 2013). NCEP reanalysis data were also used for running the HYSPLIT4 trajectory model.

2.2. Methodology

This paper studies the meteorological causes and formation of the January 6–16, 2013 haze episode by employing a synthetic analysis of atmospheric circulation, physical diagnosis of the PBL's meteorological features, and a three-dimensional structural analysis of wind speeds. The HYSPLIT4 trajectory model developed by the United States National Oceanic and Atmospheric Administration (NOAA) (Junce, 1955; Draxler, 1997) was also employed to study the comprehensive transport of haze pollutants from southern Hebei to Beijing from January 10 to 12, 2013.

3. Study results

3.1. Number of hazy days in China during January, 2013

This study indicated that haze phenomena are closely related to an increase in aerosol particles from recent human activity (Zhang et al., 2013). The severest haze episodes and the greatest number of hazy days occurred in January 2013 in central-eastern China (Fig. 1). New post-1961 records for the greatest number of hazy days per month were broken in January 2013 in this region, with 30 hazy days in Hefei (Anhui Province), 29 hazy days in Nanjing (Jiangsu Province) and Hangzhou (Zhejiang Province) and 27 hazy days in Shijiazhuang (Hebei Province), Zhengzhou (Henan Province) and Nanchang (Jiangxi Province). During this prolonged pollutant haze episode in January 2013, $PM_{2.5}$ concentrations at many monitoring sites also reached a very high level (Fig. 2). The monthly averages of $PM_{2.5}$ concentrations at stations in Harbin, Benxi, Gucheng, Shijiazhuang, Lanzhou and Changsha were above 150 $\mu g/m^3$, far exceeding the national standard of 75 $\mu g/m^3$.

Considering the number of hazy days (Fig. 1) and $PM_{2.5}$ concentrations (Fig. 2) synthetically, it can be seen that, of the polluted cities of eastern China, viz. Beijing (Jing), Tianjin (Jin), Shijiazhuang and Gucheng (southern Hebei Province – Ji), Zhengzhou (northern Henan Province), Jinan (western Shangdong Province) and Taiyuan (eastern Shanxi Province), the highest pollutant concentrations were found in Beijing, Tianjin and Hebei (Jing-Jin-Ji) and their environs. In this study, we have focused on this *region vis-à-vis* our discussion of the meteorological causes of this severe haze episode.

3.2. $PM_{2.5}$ changes in the Jing-Jin-Ji region in January, 2013

Air pollution is closely related to atmospheric aerosol composition and concentrations (He et al., 2001). $PM_{2.5}$ concentrations exhibit clear seasonal variations, with a peak in winter and a trough in summer (Duan et al., 2008). Particles with an aerodynamic diameter less than 10 μm account for 10%–70% of total suspended particulate matter (PM). Such PM is not easily deposited and may be suspended in the atmosphere for a long period, reducing atmospheric visibility through the scattering and absorption of solar radiation, thus forming a 'haze episode' (Zhang et al., 2005a,b; Che et al., 2007). In "static and steady" weather conditions, it is much harder for PM to diffuse, so haze or fog forms and persists much more easily.

Weather conditions favorable to severe pollution and low visibility occurred frequently in January, 2013 in central-eastern China, with the Jing-Jin-Ji region being the worst affected by haze pollution. The daily average $PM_{2.5}$ concentrations in Gucheng, Shijiazhuang, Zhengzhou, Jinan and other stations in the Jing-Jin-Ji region were all higher than 100–150 $\mu g/m^3$ for most days in January (Figs. 2 and 3). Daily variations in $PM_{2.5}$ (Fig. 3) show that the air quality was good for a few days only in early January and that $PM_{2.5}$ concentrations were high thereafter. High concentrations of $PM_{2.5}$ exceeding 500, 600 and 400 $\mu g/m^3$ were measured in Shijiazhuang, located southwest of Beijing, on January 7, 11 and 27, 2013, respectively, when the air quality index reached hazardous levels. It is worth noting that the $PM_{2.5}$ concentration at Shijiazhuang was 540 $\mu g/m^3$ on January 7, while a $PM_{2.5}$ concentration of 131 $\mu g/m^3$ was observed at the Baolian station in Beijing on the same day, indicating that this station had not been affected by the transport of pollutants from southern Hebei at that time. From January 8 to 9, aerosol concentrations in both of the cities