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Numerical study of the effects of local atmospheric circulations on a pollution event over Beijing–Tianjin–Hebei, China

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ABSTRACT

Currently, the Chinese central government is considering plans to build a trilateral economic sphere in the Bohai Bay area, including Beijing, Tianjin and Hebei (BTH), where haze pollution frequently occurs. To achieve sustainable development, it is necessary to understand the physical mechanism of the haze pollution there. Therefore, the pollutant transport mechanisms of a haze event over the BTH region from 23 to 24 September 2011 were studied using the Weather Research and Forecasting model and the FLEXible-PARTicle dispersion model to understand the effects of the local atmospheric circulations and atmospheric boundary layer structure. Results suggested that the penetration by sea-breeze could strengthen the vertical dispersion by lifting up the planetary boundary layer height (PBLH) and carry the local pollutants to the downstream areas; in the early night, two elevated pollution layers (EPLs) may be generated over the mountain areas: the pollutants in the upper EPL at the altitude of 2–2.5 km were favored to disperse by long-range transport, while the lower EPL at the altitude of 1 km may serve as a reservoir, and the pollutants there could be transported downward and contribute to the surface air pollution. The intensity of the sea–land and mountain–valley breeze circulations played an important role in the vertical transport and distribution of pollutants. It was also found that the diurnal evolution of the PBLH is important for the vertical dispersion of the pollutants, which is strongly affected by the local atmospheric circulations and the distribution of urban areas.

Introduction

Currently, the Chinese central government is considering plans to build a trilateral economic sphere in the Bohai Bay area, including Beijing, Tianjin and Hebei (BTH); the Bohai Bay area is considered China's third economic engine, alongside the Pearl and Yangtze River deltas. With the rapid economic and social development in the past 30 years, the BTH region has become one of China's most economically developed regions, with a region 216,000 km^2 in size and over 100 million in population; meanwhile, the rapid program of urbanization and industrial development has resulted in frequent heavy

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haze pollution in the BTH region (Bian et al., 2007; Zhang et al., 2013; Quan et al., 2011; Tao et al., 2012). The haze pollution can not only delay the traffic but also induce serious health problems, from respiratory illness to cardiovascular disease (Tie et al., 2009).

The coordinated development of the BTH region needs to strike a balance among the development, environment, population and resources. To better manage the rapidly deteriorating air quality in the BTH region and achieve sustainable development, a better understanding of the formation of the heavy haze pollution there is necessary. Due to the unique topography and geographical location, the air pollution occurring in the BTH region is particularly complicated, and the local air quality could be strongly affected by the local atmospheric circulations (Liu et al., 2009; Chen et al., 2009; Lo et al., 2006). In terms of landform, the BTH region is surrounded by mountains on the north and west, making it frequently affected by the mountain–valley breeze (MVB) circulation. Besides, facing the Bohai Sea on the east, the BTH region is also under the influence of sea–land breeze (SLB) circulations. In addition, the presence of the mega-cities (*i.e.* Beijing and Tianjin) could generate significant urban heat island (UHI) phenomena there (Miao et al., 2009).

However, available studies on the haze pollution have mostly focused on the chemical compositions of aerosols (Fu et al., 2008; Duan et al., 2014; Sun et al., 2004; Wang et al., 2006; He et al., 2001; Zhang et al., 2013) and scarcely on the effects of the local atmospheric circulations (Liu et al., 2009; Chen et al., 2009). The physical mechanisms of the pollution events have never been fully understood or qualified.

A severe haze event that occurred 20–27 September 2011 over the BTH region was reported by Liu et al. (2013); high concentrations of $PM_{2.5}$, NO, NO_2, SO_2, O_3 and CO were observed during 23–27 September, 2011, exceeding the national ambient air quality standards for residents. During the pollution period, the BTH region was dominated by weak synoptic systems with calm stable wind background (Liu et al., 2013), favoring the development of the local atmospheric circulations and accumulation of the air pollutants. In this paper, we focus on the features of the MVB and SLB circulations during this pollution period, and their influences on pollutant transport over the BTH region, which would be useful for air quality forecasting and would provide scientific support for the government to take effective measures to reduce the incidence of regional haze.

1. Model description and numerical setup

In this study, a mesoscale meteorological model was first used to replicate the atmospheric conditions during the pollution episode from 23 to 24 September 2011, and then an atmospheric dispersion model was employed to reveal the transport paths of air pollutants.

1.1. *WRF model*

The mesoscale meteorological model employed in this study is the Weather Research and Forecasting (WRF) model version 3.5.1, with 3 two-way nested domains (Fig. 1a and Table 1). The innermost domain is a 3-km fine-resolution domain, covering Beijing, Tianjin and most of Hebei Province. The configurations of the computational domains and the physical parameterization schemes utilized in this study are summarized in Table 1. In the vertical dimension, 55 vertical layers were set from the surface to the 50-hPa level to resolve characteristics of the local atmospheric circulations. To simulate the cloud physics processes, the Thompson Graupel scheme (Thompson et al., 2008) was employed, and the radiation processes were parameterized using the updated Rapid Radiative Transfer Model

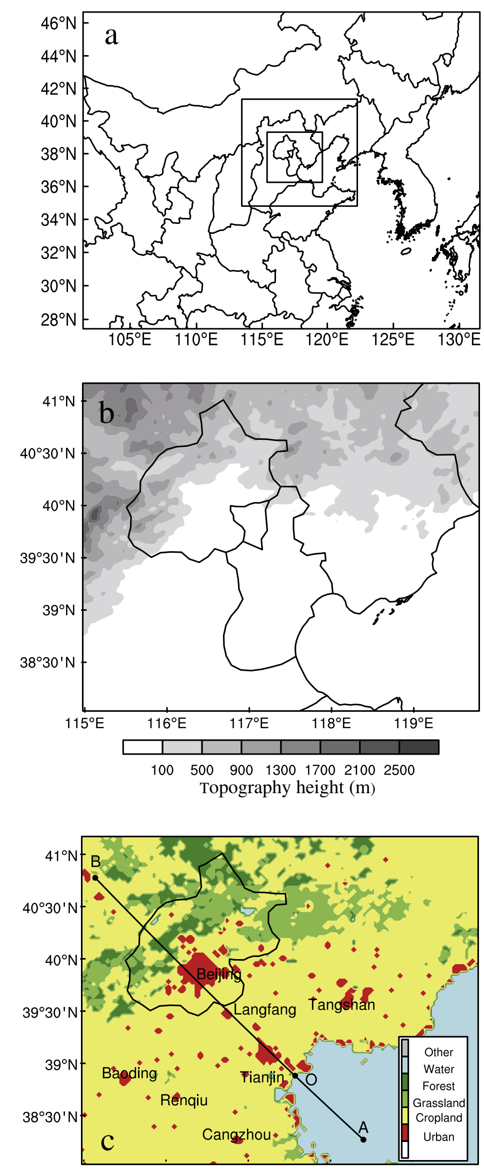

Fig. 1 – (a) The nested domains of the WRF simulation. The topography height (b) and the land use category (c) of the innermost domain. The solid line in (c) indicates the route of the vertical cross sections made from point A to B given in Figs. 11–12 and 14–15, and the point O located at the border of land and sea is used as the reference point (0, 0) in the vertical cross sections.