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Impacts of mountains on black carbon aerosol under different synoptic meteorology conditions in the Guanzhong region, China

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ABSTRACT

The Xi'an City and the surrounding area (the Guan-Zhong—GZ region) in western China have been suffering severe air pollutions during wintertime in recent years. *In-situ* black carbon (BC) measurement combined with a regional dynamical and chemical model (WRF-Chem model) is used to investigate the formation of a haze episode occurred from Jan. 3rd to Jan. 13th 2013. The results show that the measured BC concentrations exhibit a large day-to-day variability. The impacts of synoptic weather systems, local meteorological parameters and mountain effect on the BC variability are studied. Because the GZ region is surrounded by two major mountains, the Loess Plateau in the north and the Qinling Mountains in the south, especially the peak of the Qinling Mountains higher than 3000 m, we particularly analyze the effects of the Qinling Mountains on the BC pollution. The analysis shows that the BC pollution in Xi'an City and the GZ region is strongly affected by the synoptic weather systems, local meteorological winds and the Qinling Mountains. Under a typical northeast wind condition, winds are blocked by the Qinling Mountains, and BC particles are trapped at the foothill of the mountains, resulting in high BC concentrations in the city of Xi'an. Under a typical east wind condition, BC particles are transported along a river valley and the foothill of the Qinling Mountains. In this case, the mountain-river valley plays a role to accelerate the east wind, resulting in a reduction of the BC pollution. Under a typical calm wind condition, the BC particles are less diffused from their source region, and there is a mountain breeze from the Qinling Mountains to the city of Xi'an, and BC particles accumulate in the city, especially in the north side of the city. This study illustrates that while locating between complicated terrain conditions, such as the GZ region, the mountains play very important roles for the formation of hazes in the region.

1. Introduction

The $PM_{2.5}$ pollution has become a major problem of the air pollution in megacities in China during recent decades (*i.e.* Chan and Yao, 2008; Huang et al., 2014). As an important $PM_{2.5}$ component, black carbon (BC) is of more concerns due to the unique light-absorbing properties. BC particles are generally produced from the incomplete combustion of fossil fuels and biomass burning, and BC emission is closely associated with the energy use in China. At present, coal is still as the indispensable energy in national energy consumption structure, especially in northern China, which means the air pollution problem in megacities will still be the one of the top environmental concerns in the next decade in China (Chan and Yao, 2008). For example, the megacities such as Beijing, Shanghai, Guangzhou and Xi'an in winter have been undergoing the frequent haze events. According to the previous study by Huang et al. (2014), the air pollution in winter at Xi'an is much more serious because the averaged daily $PM_{2.5}$ concentration during the haze events reached to 345 μg/m^3, far more than other megacities (*i.e.*, Beijing, Shanghai and Guangzhou). Traced back to the historical period at Xi'an, the haze events frequently occurred in winter. For example, *in-situ* measurements from Jan. 6th to Jan. 20th, 2003 record the averaged $PM_{2.5}$ concentration reaching to 375.2 μg/m^3, and BC particles contribute to 5.8% to $PM_{2.5}$ concentration, with a concentration of 21.6 ± 5.4 μg/m^3 (Cao et al., 2007), implying a high level of BC concentration during the hazardous haze events. Generally, primary BC particles account for around 5% to $PM_{2.5}$ concentration at Xi'an (Cao et al., 2007; Huang et al., 2014), and BC concentration can directly reflect the air pollution level caused by $PM_{2.5}$. Another characteristic during haze events at Xi'an is that daily averaged BC concentrations have a strong day-to-day variation,

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and the magnitude in the polluted periods is 7.6 times higher than that in clean periods (Wang et al., 2014). However, the cause for the large variability of BC pollution is not fully understood, hindering the mitigation of haze pollution in the region.

Anthropogenic emission and synoptic meteorology are considered as two fundamental factors that determine the variation of aerosol pollution (Tie et al., 2013, 2015). Their study shows that the large variation of synoptic meteorology is a dominated factor that controls the variability of aerosol pollution. Wang et al. (2013) simulated that the activities of typhoon and Indian monsoon as well as impacts of large mountains play important roles in the formation and the height of smoke layer, and also change the transport pathway of the smoke. Tao et al. (2012) show that the pollutants rapidly accumulated to form the heavy pollution in a period of 2–3 days, and can rapidly be changed from heavy pollutions to clean conditions in less one day due to changes in meteorological weather systems (Tie et al., 2015). Previous studies also suggest that surface wind speed and planetary boundary layer height are the two major meteorological parameters in controlling the variability of BC concentration in megacities (He et al., 2014). Liu et al. (2013) suggest that stable anti-cyclone synoptic systems produce decreasing motions and lower PBL height, which are favorable for the formation of the haze episodes. The weak surface winds and a shallow PBL efficiently confine particles near the surface and produce high BC concentration within source regions (Zhao et al., 2013; Quan et al., 2013).

In this study, we analyze a heavy haze episode, which occurred at Xi'an during January 2013. Because the city locates between complicated topographical regions, there are mountains and river valleys near the city, so it provides a good opportunity to study the impact of mountains on the air pollutions. The primary focus includes: (1) to analyze the characteristics and variability of BC concentration during the haze episodes, (2) to investigate the effect of synoptic weather systems on the variability of BC concentrations, and (3) to study the effect of mountains (especially the Qinling Mountains) on the evolution of BC concentrations.

2. Data and methods

2.1. Measurements

The sampling site is in the southwest urban zone at Xi'an (34.23°N, 108.88°E, a.s.l. 410 m). The Xi'an City is one of the largest cities in western China, with a population around 8.5 million until 2013. Topographically, there are three major valleys near the Xi'an City, and they are Guan-Zhong (GZ) Plain, Fenhe Valley and Heluo Plain. These valleys are surrounded by two large mountains (Fig. 1). The Xi'an City roughly locates in the center of the GZ Plain that is sandwiched between the Qinling Mountains in the south and the Loess Plateau in the north. The economic, industrial and agricultural developments in the city are in the mid-upper level in China.

The daily $PM_{2.5}$ samples including BC particles are collected by a mini-volume sampler (Airmetrics, Oregon, USA) with a flow rate of 5 L/min. The sampler is installed at the rooftop of 3-floor building, about 10 m high above the ground. The particulate matters are collected on 47-mm Whatman quartz fiber filters, which are pre-heated at 900 °C for three hours before sampling. Black carbon on the fiber filter is analyzed with a carbon analyzer (the Desert Research Analyzer (DRI) Model 2001), following the IMPROVE thermal/optical reflectance (TOR) protocol (Chow et al., 1993, 2004; Watson et al., 2005). The daily averaged wind speed and direction are observed at the Xi'an weather station (108.93°E, 34.3°N, a.s.l. 398 m), with the accuracy of ± 0.1 m/s of wind speed. Because there are no observations of PBL heights during the period of BC measurement in the region, the reanalysis PBL heights obtained from European Centre for Medium-range

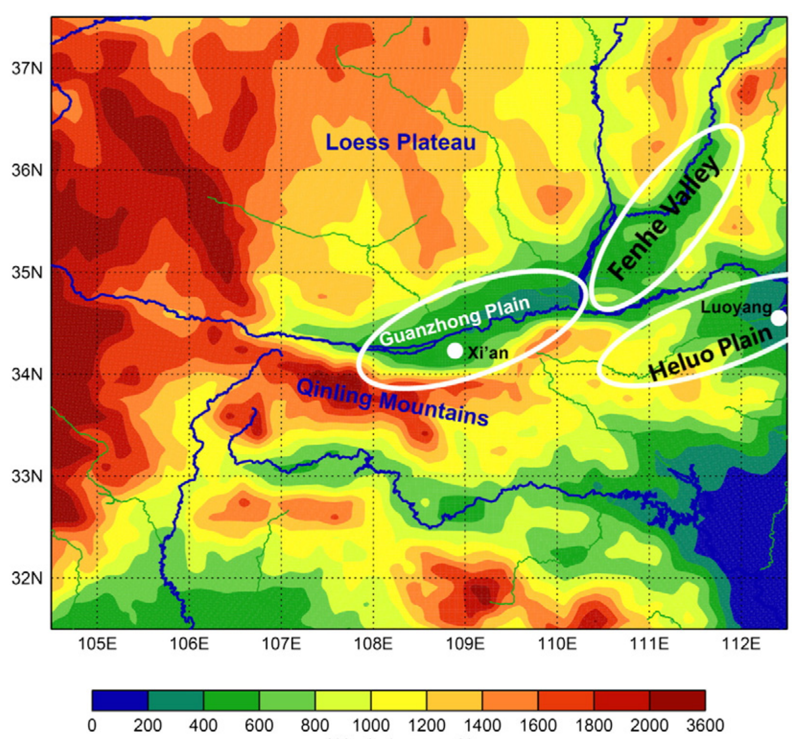

Fig. 1. Topography of the Guan-Zhong(GZ) region. There are two major mountains, and the Qinling Mountains to the south of the GZ region is a high mountain, with a peak altitude of 3800 m. In contrast, the altitudes of the Loess Plateau (a.m.s.l. > 1500 m) to the north side of the GZ region are lower than the Qinling Mountains. There are three major valleys denoted by the white ellipses, the Fenhe Valley, the Heluo Plain and the GZ Plain, and the GZ Plain is sanwiched by the Qinling Mountains and the Loess Plateau, and the Xi'an City locates at the foothill of the Qinling Mountains.