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Distribution of atmospheric particulate matter (PM) in rural field, rural village and urban areas of northern China

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ABSTRACT

Atmospheric PM_{10} were measured for 12 months at 18 sites along a 2500 km profile across northern China. Annual mean PM_{10} concentrations in urban, rural village, and rural field sites were 180 ± 171, 182 ± 154, and 128 ± 89 μg/m^3, respectively. The similarities in PM_{10} concentrations between urban and rural village sites suggest that strong localized emissions and severe contamination in rural residential areas are derived from solid fuels combustion in households. High PM_{10} concentrations in Wuwei and Taiyuan were caused by either sandstorms or industrial activities. Relatively low PM_{10} concentrations were observed in coastal areas of Dalian and Yantai. Particulate air pollution was much higher in winter and spring than in summer and fall. Multiple regression analysis indicates that 35% of the total variance can be attributed to sandstorms, precipitation and residential energy consumption. Over 40% of the measurements in both urban and rural village areas exceeded the national ambient air quality standard.

1. Introduction

Atmospheric particulate matter (PM) has drawn much concern because of its adverse health effects and its likely influence on global climate (Kaufman and Fraser, 1997; Pope and Dockery, 2006). Epidemiological studies point to a causal association between population exposure to fine PM in air and cardiovascular and lung cancer mortality (Pope et al., 2002; Pope and Dockery, 2006). Several mechanistic pathways of how PM may affect human health have been proposed (Brook et al., 2004).

Air pollution and particularly high concentrations of PM in air stemming from rapid industrialization, urbanization, and inadequate control strategies, social awareness, and financial investment for abatement, rank among the most critically important environmental issues in China (Vennemo et al., 2009; World Bank, 2007a). Atmospheric PM_{10} (PM with an aerodynamic diameter less than 10 μm) is extensively monitored in most cities, and monitoring on $PM_{2.5}$ (PM with an aerodynamic diameter less than 2.5 μm) has became a routine in many cities in China recently due to its close association with health effects (CNEMC; Yang et al., 2011). As noted by the World Bank (2007b), 12 of the 20 most polluted cities in the world were in China in 2004 and most of those 12 cities were located in northern China. Annual mean PM_{10} concentrations in one third of all routinely monitored cities in China exceed the national ambient air quality standard and most of these heavily polluted cities were also in northern China (Yang et al., 2011).

Atmospheric PM pollution results from both primary emission and secondary causes (Seinfeld and Pandis, 2006). In China, primary PM stems from a variety of anthropogenic activities including power generation, industrial processes, fossil and biomass fuel or agricultural waste combustion, and construction as well as from natural sources such as windblown dust (Sun et al., 2004; Yang et al., 2011). Secondary PM is formed by the reaction of gases or droplets of various origins in the atmosphere (Yang et al., 2011). Due to heavy dependence on coal for energy in China (NBSC, 2008), emissions of various activities are often very high. In general, air pollution is more severe in the north than that in the south because heating is required in north for several months in winter (Liu et al., 2007, 2008; Wang et al., 2011a; Zhang et al., 2009) and north China is affected by spring sandstorms much more often than the south

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(Sun et al., 2001). It is often believed that air pollution occurs mainly in cities where most power stations, industrial facilities, and motor vehicles are concentrated. However, it should be emphasized that air quality in rural China, where half population lives, is also deserving of attention even though such areas are largely not covered by routine environmental monitoring. In China, coal and biomass fuels are extensively used in rural household for cooking and heating, resulting in severe air pollution both in- and outdoors (Ding et al., 2012; Liu et al., 2007). Concentrations of polycyclic aromatic hydrocarbons (PAHs) including carcinogenic benzo[a]pyrene in the ambient environments are just about as high in northern Chinese villages as they are in major cities during the winter (Liu et al., 2007).

The objectives of this study were to investigate the PM_{10} concentrations along a 2500 km profile in northern China from Wuwei to Mou Island, east of Dalian, to compare ambient PM_{10} pollution between urban and rural village areas, and to characterize spatial and temporal variations of PM_{10} pollution. Sources, removal processes, and health effects of PM_{10} particles are discussed.

2. Methodology

2.1. Study area and PM sample collection

This study covers a broad area spanning six provinces in northern China from Gansu in the west to coastal areas in Liaoning and Shandong in the east (Fig. 1). It is generally accepted that the influence of East Asian monsoon can reach the Helan Mountains immediately north and west of Yinchuan (Zhao, 1995). The summer monsoon from the southeast carries moisture from the Pacific Ocean over mainland China in summer, creating a decreasing trend of precipitation from ∼630 mm along the coast to ∼110 mm in Wuwei, Gansu (NBSC, 2011). On the other hand, the cold and dry winter monsoon from the northwest is responsible for the sandstorms from Gobi and other deserts areas to the study area. Seven cities, namely Wuwei, Yinchuan, Taiyuan, Beijing, Dezhou, Yantai, and Dalian between 40°N and 37°N were included in this study. More information on the sampling sites are presented in Table S1 (Supplementary material). Precipitation, sandstorm frequency, and residential energy consumption data were derived from local yearbooks (NBSC, 2011), *Sand-Dust Weather Almanac* (CMA, 2012), and published estimates of local energy consumption in China (Zhu et al., 2013).

A total of 18 active samplers were deployed for our study among three categories of sites: seven urban (core areas of large cities), five rural village (large villages in the countryside), and six rural field (>500 m from the nearest building) (Fig. 1). PM_{10} samples were collected using medium volume (200–400 L/min) cascade impactors (PM10-PUF-300, Guangzhou, China) for 72 h once a month at each site during the interval between April 2010 and March 2011. Most samples (83%) were collected simultaneously during a seven-day period in the middle of each month. PM_{10} samples were collected on glass fiber filters (GFFs, 200 × 150 mm^2), which were baked at 450 °C for 12 h, equilibrated at 25 °C in a desiccator for 24 h, and weighed (XS-105, Mettler Toledo, Switzerland) prior to sampling. After the sampling, GFFs were equilibrated at 25 °C in a desiccator for 24 h and weighed again using the same balance. PM_{10} concentrations were calculated based on the mass differences and the total sampling volumes, which were automatically recorded by the samplers. A procedure blank (GFF through all procedures except taken out for sampling) was analyzed with each batch of samples. Mass differences of the blanks were negligible compared with the samples.

2.2. Backward air mass trajectories and statistical analysis

A NOAA hybrid single-particle Lagrangian integrated trajectory (HYSPLIT) model, driven by meteorological variables from global NOAA-NCEP/NCAR pressure level reanalysis data, was used to back-calculate air mass trajectories (Draxler and Rolph, 2003). Three-day backward trajectories were performed for each sampling period and the initial run times were set for six-hour intervals at 0:00, 6:00, 12:00, and 18:00 h (UTC) of each day. A potential receptor influence function was used to calculate the probability of backward trajectories of air masses reaching sampling sites (Lang et al., 2007).

Statistical analysis was performed using SPSS (IBM Statistical package for the social sciences, version 20.0). One-way analysis of variance with multiple comparisons were carried out. Pearson's method was applied for correlation analysis. A significance level of 0.05 was used for all tests.

3. Results and discussion

3.1. Ambient air PM_{10} concentrations

The measured PM_{10} concentrations at individual sites are listed in Table 1 as means and standard deviations. The detailed monthly PM_{10} concentrations measured at all sites in this study are provided in Table S2 (Supplementary material). The PM_{10} concentrations were normally distributed with coefficients of skewness and kurtosis of 0.11 ($p > 0.05$) and 0.24 ($p > 0.05$) after log-transformation. Accordingly, the annual mean concentration of all sites is presented here as a geometric mean of 123 μg/m^3 (Arithmetic means and standard deviations are estimated as 163 ± 145 μg/m^3).

The arithmetic means and standard deviations of ambient PM_{10} concentrations for the three site categories, were 128 ± 89, 182 ± 154, and 180 ± 171 μg/m^3 for rural field, rural village, and urban sites, respectively (Table 1). There was no significant difference between urban and rural village sites ($p > 0.05$), while the values at rural field sites were significantly lower than those of other two categories ($p < 0.05$). The relatively low concentrations were found at the rural field site at Dalian (47 ± 16 μg/m^3, see in Table 1), which is the sole location distant from mainland and can be regarded as a background site. The values determined for samples from all other rural field sites were relatively high because they are not too far away from cities or villages, and could well have been affected by local pollution. In general, the PM_{10} concentrations measured at urban sites are comparable with those reported in the literature. For instance, Wang et al. (2006) reported a range from 82 to 257 μg/m^3 of PM_{10} concentrations in 14 northern cities in China during 2001–2002. According to Sun et al. (2004), mean PM_{10} concentrations in ambient air in Beijing were 164 and 255 μg/m^3, in 2004 summer and winter, respectively. Among the urban and rural village sites studied, extremely high values of 1336 and 799 μg/m^3

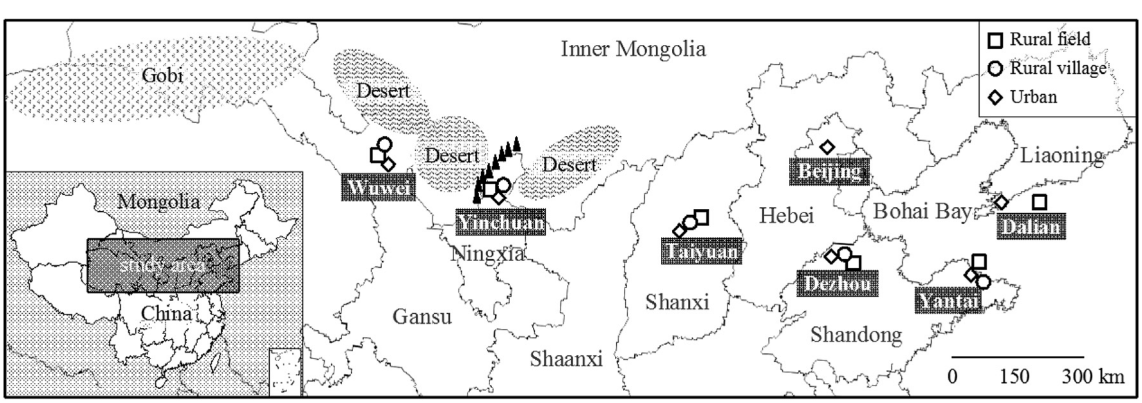

Fig. 1. Sampling locations (the triangles show the location of Helan Mountains).