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Transport of airborne particulate matters originating from Mentougou, Beijing, China

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Abstract

In this study, a coupled regional air quality modeling system is applied to investigate the time spatial variations in airborne particulate matters (PM_{10}), originating from Mentougou to Beijing municipal area in the period of April 1–7, 2004, and the influences of complex terrain and meteorological conditions upon boundary layer structure and PM_{10} concentration distributions. An intercomparison of the performance with CALPUFF against the observed data is presented and an examination of scatter plots is provided. The statistics show that the correlation coefficient and STD between the modeled and observed data are 0.86 and 0.03, respectively. Analysis of model results illustrates that the pollutants emitted from Mentougou can be transported to Beijing municipal area along certain transport pathways, and PM_{10} concentration distributions show heterogeneity characteristics. Contributions of the Mentougou sources to the PM_{10} concentrations in Beijing municipal area are up to 0.1–15 μg/m^3.

Keywords: Airborne particulate matters; CALPUFF; PM_{10}; SMOKE; Emission inventory

1. Introduction

Atmospheric aerosols consist of a mixture of solid and liquid particles suspended in ambient air (Zhang, Wang, Sheng, Kanai, & Ohta, 2004; Zhang, Wang, & Xia, 2002), ranging in size from the smallest superfine nano-meters (nm) particles, to coarse particles, with diameters of several micrometers (μm) or more (Zhang et al., 2003). Their importance arises from their ability to interact with visible radiation and to affect cloud properties, as well as their long atmospheric residence times (IPCC, 1995). 'Particulate matter', also known as particle pollution or PM, is a complex mixture of extremely small particles and liquid droplets. Particle pollution is made up of a set of components, including acids (such as nitrates and sulfates), organic chemicals, metals, and soil or dust particles (Sokolik & Toon, 1996). The size of particles is directly linked to their potential for causing health problems. PM particles 10 μm in size or smaller, referred to as PM_{10}, are typically formed by "crustal" or earth-based material and enter the air through a variety of actions including "entrainment" into the atmosphere as wind blown dust. The even smaller or "fine" PM material, referred to as $PM_{2.5}$ (2.5 μm or smaller), are understood to be more a product of combustion (Streets et al., 2003). $PM_{2.5}$ is believed to penetrate deeper into the lungs and remain lodged there rather than exhaled, causing adverse impacts on health. In the last decade a variety of transport and deposition models have been applied to address PM transport and deposition over Beijing (Zhou, Levy, Hammitt, & Evans, 2003). This study is another attempt to investigate the behavior of PM_{10} over Beijing, and to examine the relative role of meteorological fields and removal mechanisms in regulating PM_{10} behavior with CALPUFF (Bennett et al., 2002; Scire, Strimaitis, & Yamartino, 1999) model on the basis of a newly estimated emission inventory for Mentougou with a resolution of 1 km × 1 km. In this study both temporal and spatial variations in airborne particulate matters (PM_{10}) as well as transport processes of PM_{10} originating from Mentougou to Beijing municipal area in the period of April 1–7, 2004, and the influences of complex terrain and meteorological conditions upon PM_{10} concentration distributions are discussed.

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2. Model configuration and setup

The initial phase of CALPUFF which we used for our primary model involves deriving meteorological files using CALMET (Scire, Robe, Fernau, & Yamartino, 2000; Yang, Chen, Liu, & Zhao, 2006), which is a simple diagnostic windfield model. Much of the structure in the wind fields is determined by CALMET using its diagnostic wind field module (Douglas & Kessler, 1988). As shown in Fig. 1, the basic coordinate grid for CALPUFF/CALMET consists of 100 grid cells along the *x*-axis (east–west) and 100 grid cells along the *y*-axis (north–south), spaced 1 km apart. The coordinate system was converted to a Lambert Conical Projection grid. The 10 vertical layers incorporated into the CALMET processing had heights of 20, 50, 100, 150, 300, 600, 1000, 1500, 2200 and 3000 m. The MM5 mesoscale model was used in this study to develop high-resolution, three-dimensional meteorological fields (i.e., wind, temperature, pressure, etc.) through FDDA simulations (Stauffer & Seaman, 1994). MM5 generated the meteorological fields, which we used to improve the wind distribution results from CALMET. This is an important step since the MM5 model can resolve wind features caused by topography, such as terrain channeling and gravity-driven slope flows (Levy, Spengler, Hlinka, Sullivan, & Moon, 2002; Zhou et al., 2003). The first-guess atmosphere data for MM5 are extracted from the NCAR/NCEP FNL archives. The NCEP Final Analysis (FNL) data archived at NCAR is for every 6 h at a spatial resolution of $1^\circ \times 1^\circ$ at standard pressure levels under 100 hPa. This data set includes two-dimensional variables, sea surface temperature, sea level pressure, three-dimensional variables of temperature, geo-potential height, U and V velocity components, and relative humidity (Bromwich et al., 2001). We combined the MM5 prognostic model (Douglas & Kessler, 1988) outputs with mesoscale data assimilation systems for 7 days (April 1, 2004, 00:00:00–April 7, 2004, 23:00:00). The present MM5 model domain has 32 vertical levels, going up to about 13 km AGL, with vertical grid spacing stretched from about 20 m near the ground to 800 m near the top of the domain. This allowed CALMET to interpolate from a higher-to-a-lower-resolution grid (since CALMET uses 10 vertical layers). One-way nesting was used to generate ambient wind fields at multiple grid-cell resolutions (27, 9, 3 km). For each domain, the basic coordinate grid for MM5 consisted of 103 grid cells along the *x*-axis (east–west) and 103 grid cells along the *y*-axis (north–south), with the center point of the model domain set to (39.58°N, 116.58°E) (Yang, Chen, & Zhang, 2006). CALPUFF is the Lagrangian, non-steady-state, gridded puff model to simulate the transport, dispersion, chemical reactions and deposition of the air pollutants in the atmosphere. The plume rise, stack tip downwash and vertical wind shear above the stack top were modeled in our case. PM dry deposition was included with the default data of size distribution (Scire et al., 2000). As to wet deposition, the scavenging coefficient for liquid precipitations was set at $1 \times 10^{-4}\,s^{-1}$ for PM_{10} (Zhou et al., 2003).

In the following figures Mentougou is located at the center-left side and Beijing municipal area (Beijing, described in

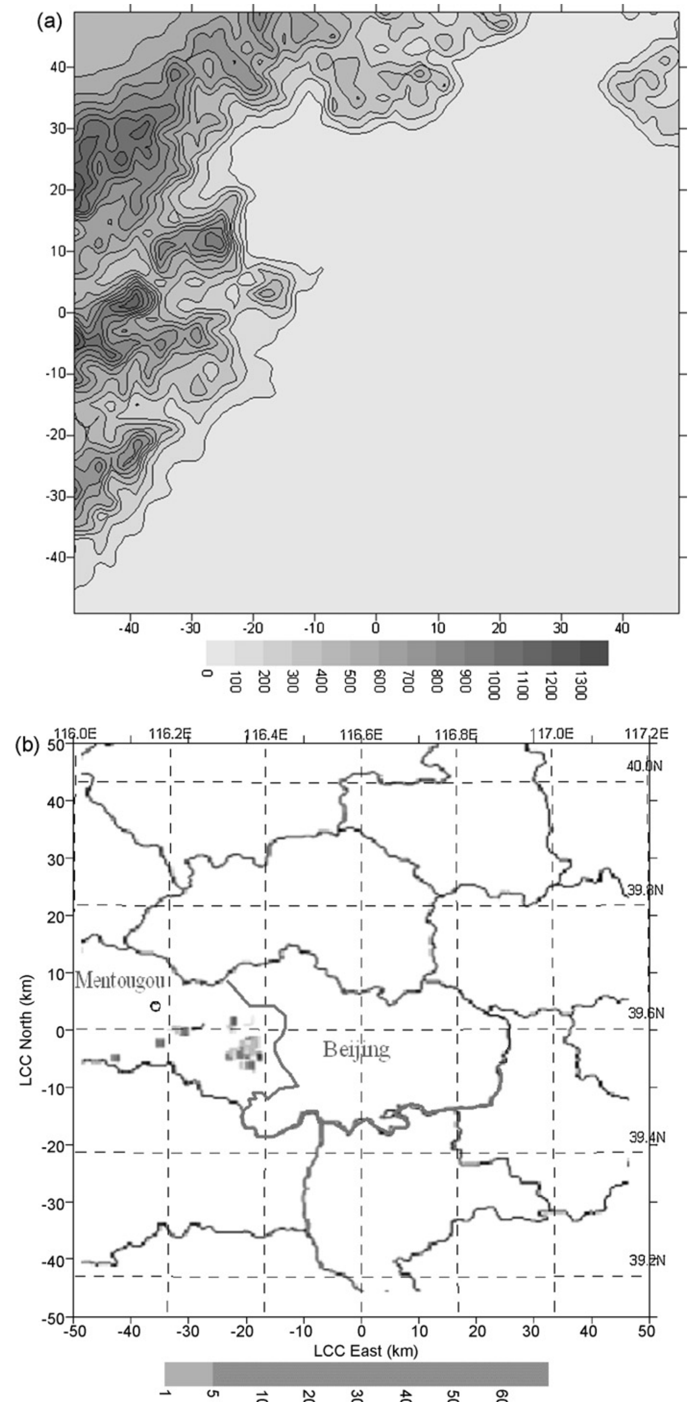

Fig. 1. Source characteristics. (a) Domain configuration for CALPUFF and terrain characteristics (m); (b) emission distributions of PM_{10} in the study domain ($\mu g/(s\,m^2)$). Also shown is the location of the observation site (open circle).

Fig. 1(b)) in the center-right and upper-right side of the maps. The southwest corner of Beijing municipal area is located at longitude 116.4°E, latitude 39.4°N; the northeast corner is located at longitude 117.0°E, latitude 39.8°N. While the southwest corner of Mentougou (Mentougou, described in Fig. 1(b)) is located at longitude 116.0°E, latitude 39.5°N; the northeast corner is located at longitude 116.4°E, latitude 39.7°N.