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Impacts of biogenic emissions of VOC and NO_x on tropospheric ozone during summertime in eastern China

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ABSTRACT

This study is intended to understand and quantify the impacts of biogenic emissions of volatile organic compounds (VOC) and nitrogen oxides (NO_x) on the formation of tropospheric ozone during summertime in eastern China. The model system consists of the non-hydrostatic mesoscale meteorological model (MM5) and a tropospheric chemical and transport model (TCTM) with the updated carbon-bond chemical reaction mechanism (CBM-IV). The spatial resolution of the system domain is 30 km×30 km. The impacts of biogenic emissions are investigated by performing simulations (36 h) with and without biogenic emissions, while anthropogenic emissions are constant. The results indicate that biogenic emissions have remarkable impacts on surface ozone in eastern China. In big cities and their surrounding areas, surface ozone formation tends to be VOC-limited. The increase in ozone concentration by biogenic VOC is generally 5 ppbv or less, but could be more than 10 ppbv or even 30 ppbv in some local places. The impacts of biogenic NO_x are different or even contrary in different regions, depending on the relative availability of NO_x and VOC. The surface ozone concentrations reduced or increased by the biogenic NO_x could be as much as 10 ppbv or 20 ppbv, respectively. The impacts of biogenic emissions on ozone aloft are generally restricted to the boundary layer and generally more obvious during the daytime than during the nighttime. This study is useful for understanding the role of biogenic emissions and for planning strategies for surface ozone abatement in eastern China. Due to limitations of the emission inventories used and the highly non-linear nature of zone formation, however, some uncertainties remain in the results.

1. Introduction

Tropospheric ozone is a major environmental concern because of its adverse impacts on human health and crops and forest ecosystems (Rabl and Eyre, 1998). In the troposphere, especially, in the polluted boundary layer, ozone is mainly formed by photochemical reactions of volatile organic compounds (VOC) and nitrogen oxides ($NO_x = NO + NO_2$). Both VOC and NO_x have anthropogenic and biogenic sources. Under favorable meteorological conditions such as strong sunlight and high temperature that frequently occur during summer time, extremely high ozone levels can be produced by the complex interactions of anthropogenic and biogenic sources. As such, a key question before laying out an ozone abatement strategy is "Should one control NO_x emissions, VOC emissions, or both simultaneously, and to what degree?" In this case, the terms of VOC and NO_x cover both biogenic and anthropogenic origins, meaning that it is essential for an ozone-level reduction policy to estimate the potential importance of biogenic VOC and NO_x on ozone formation.

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Eastern China has intensive emissions of the ozone precursors from both anthropogenic and biogenic origins. High ozone concentrations have been observed in many urban and rural areas (Xu et al., 1999; Chameides et al., 1999; Cheung and Wang, 2001). This has been given great attention by scientific communities, policy makers, and the public as well.

In the past decade, many studies worldwide have been conducted on biogenic emissions and their potential impacts on atmospheric chemistry, especially tropospheric ozone (e.g., Vlachogiannis, et al., 2000; Thunis and Cuvelier, 2000). In China, however, limited studies have been done. Some of them are mainly focused on field observation of ozone and its precursors (e.g., Zhou, 1997); some on emissions of ozone precursors, both anthropogenic and biogenic (e.g., Bai, 1995; Streets et al., 2003, 2006; Shao et al., 2000; Klinger et al., 2002; Wang et al., 2005, 2007); and a few on the processes and mechanism of ozone formation in China (e.g., Yang et al., 1999, Luo et al., 2000). In general, biogenic emissions in these studies are either neglected or handled in a simple way. Recently, some studies started paying more attention to the impact of biogenic VOC on ozone. For example, Wei et al. (2007) studied the impact of biogenic VOC emissions on a tropical cyclone-related ozone episode in the Pearl River Delta (PRD) region, China. In the same region, Wang X. et al. (2005) studied the impacts of different emission sources, including biogenic VOC, on air quality during March 2001. Han et al. (2005) studied the impact of biogenic VOC on surface ozone and emission reduction scenarios over eastern China. In these studies, the estimates of biogenic VOC emissions are essentially dependent on the database of GEIA (global emission inventory activity, Guenther et al., 1995), which was not developed specifically for China (Wang et al., 2007). More importantly, due to the great amount of fertilizers applied to the farmland in eastern China, NO_x emission from soils is very remarkable and potentially plays a significant role in ozone formation through the highly non-linear interaction with VOC (Wang et al., 2005). So far, research in this respect is even more limited in China and the issue deserves further study.

This study extends the work by Han et al. (2005). The biogenic emission models newly developed by Wang et al. (2005, 2007) are used to provide real time estimates of both vegetative VOC and soil NO_x emissions. Combined impacts of the two biogenic emissions on horizontal and vertical distributions of summertime ozone in eastern China are investigated by performing model simulations for scenarios with and without biogenic emissions, while keeping anthropogenic emission unchanged. This study is useful for understanding the role of biogenic emissions and for designing strategies for ozone abatement in eastern China. Due to limitations of the emission inventories and the highly non-linear nature of zone formation, however, some uncertainties remain in the results.

2. Methodology and data

2.1. Model description

Meteorological fields were provided by the non-hydrostatic mesoscale model MM5 (Dudhia et al., 2003), which has been widely used in predicting meteorology at a variety of scales. Specific physical options were chosen for MM5 simulation, such as MRF scheme for the planetary boundary layer (PBL), Grell for Cumulus, CCM2 for radiation, Mixed-Phase for explicit moisture, and five-layer soil model for land–air process. Four-dimensional data assimilation (FDDA) was utilized to improve model results, especially for wind field and temperature. A regional scale tropospheric chemistry and transport model (TCTM), developed by Han et al. (2005), was applied to simulate tropospheric ozone formation and ozone responses to various emission scenarios. The TCTM utilizes the basic structure of the regional acid deposition model (RADM) (Chang et al., 1987) with major modifications in turbulent diffusion and dry removal processes. The updated carbon-bond chemical reaction mechanism (CBM-IV) (Gery et al., 1989) with an isoprene mechanism, includes 91 reactions and 37 individual species, was incorporated into the TCTM to represent gas chemistry.

The center of the model domain for the TCTM locates at (118.25 E, 35.75 N). The domain of interest is 3900 km in the north–south direction and 2400 km in the west–east direction with a grid resolution of 30×30 km^2 (see Fig. 1). In order to reduce the impact of boundary conditions, a larger domain of 4050×3550 km^2 is used for the meteorological modeling with the same center and horizontal resolution as for the TCTM.

In the vertical direction, there are 23 sigma levels for meteorological modeling. From the surface to the 100hpa, the 24 full-sigma-level values are 1.00, 0.99, 0.98, 0.96, 0.93, 0.89, 0.85, 0.80, 0.75, 0.70, 0.65, 0.60, 0.55, 0.50, 0.45, 0.40, 0.35, 0.30,

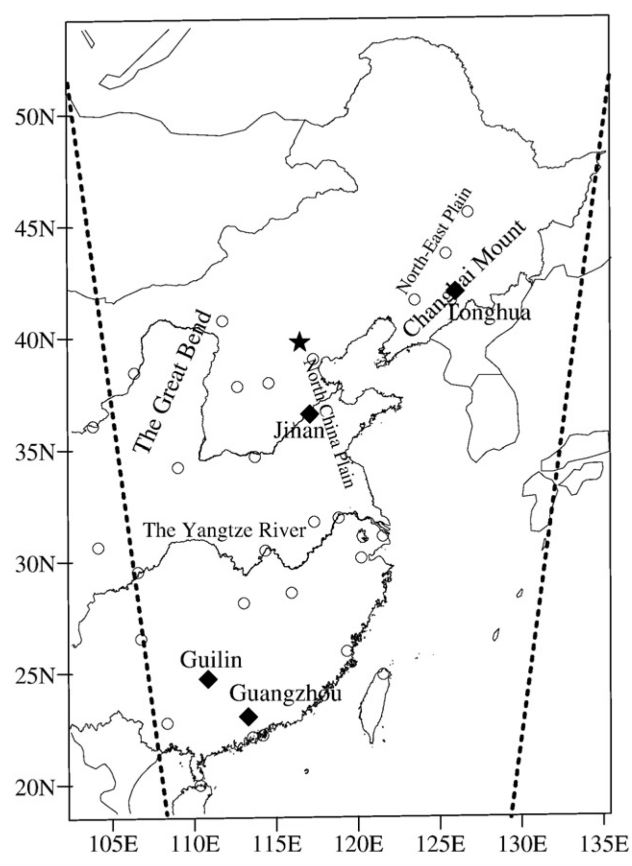

Fig. 1 – Model domain and specific locations mentioned in this paper.