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Evaluation of the Models-3 Community Multi-scale Air Quality (CMAQ) modeling system with observations obtained during the TRACE-P experiment: Comparison of ozone and its related species

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Abstract

The Models-3 Community Multi-scale Air Quality (CMAQ) modeling system with meteorological fields calculated by the Regional Atmospheric Modeling System (RAMS) was applied to East Asia to investigate the transport and photochemical transformation of tropospheric ozone during the Transport and Chemical Evolution over the Pacific (TRACE-P) field campaign. Modeled concentrations of hydroxyl radical, hydroperoxyl radical, nitric oxide, nitrogen dioxide, ethene, ethane, carbon monoxide, and ozone were compared with observations obtained onboard of two aircrafts in order to evaluate the model performance. Comparison indicates that the model reproduced the tempo-spatial distributions of ozone and its related chemical species reasonably well, and most model results were within a factor of 2 of the observations.

Keywords: Chemical transport model; Long-range transport; Tropospheric ozone; Hydroxyl radical; East Asia

1. Introduction

East Asia is a region of the world with large and rapidly increasing anthropogenic emissions of photochemically active pollutants, such as nitrogen oxides (NO_x), carbon monoxide (CO), and non-methane hydrocarbons (NMHCs) (Akimoto and Narita, 1994; Streets and Waldhoff, 2000). In the last three decades, China experienced a period of

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rapid economic development and industrial expansion, and its anthropogenic emissions associated with fossil fuel burning have grown significantly (e.g., Streets and Waldhoff, 2000). Most emissions in China are dispersed along the east coast. In addition to their impacts on air quality in the continental boundary layer near pollution sources (e.g., Zhang et al., 2003b, 2004), the effect of the emissions from China on chemical characteristics of the whole troposphere, particularly over the Western Pacific, is subjected to be considerable (e.g., Jaffe et al., 1997; Crawford et al., 1997; Talbot et al., 1997; Mauzerall et al., 2000, Zhang et al., 2002). Recent researches suggest that tropospheric ozone (O_3) concentrations have increased in the lower troposphere over East Asia in recent decades and that the rate of increase is larger than in other areas of the northern mid-latitudes (Oltmans et al., 1998; Lee et al., 1998). In contrast to Europe, the trend of increasing boundary layer ozone was still continuing in the 1990s in this area, and this was probably due to a trend of increasing emissions of precursors on a regional scale (Lee et al., 1998).

Ozone in the troposphere has several sources, including photochemical production from anthropogenic and natural precursors, the most important being NO_x, hydrocarbons and CO. The distributions of these precursors, the ozone generation from them, and the governing transport mechanisms are complex and nonlinear. A three-dimension chemical transport model provides a means of estimating the importance of the key factors which determine ozone concentrations.

The Models-3 Community Multi-scale Air Quality (CMAQ) modeling system is a Eulerian-type model developed by the US Environmental Protection Agency to address tropospheric ozone, acid deposition, visibility, particulate matter and other pollutant issues in the context of a "one atmosphere" perspective where complex interactions between atmospheric pollutants and regional and urban scales are confronted (Byun and Ching, 1999). We apply this model system with meteorological fields provided by the Regional Atmospheric Modeling System (RAMS; Pielke et al., 1992) to elucidate these processes determining the temporal and spatial distributions of tropospheric ozone over East Asia. This paper is focusing on evaluation of the model performances by comparing modeled concentrations of ozone and its closely related chemical species with observations obtained during the Transport and Chemical Evolution over the Pacific (TRACE-P) field campaign from the end of February to early April of 2001 (Jacob et al., 2003).

2. Model description

The production and transport of tropospheric O_3 in East Asia is examined here by use of CMAQ. CMAQ is designed to be flexible so that different levels of configuration can be achieved. The current version of CMAQ uses meteorological fields from RAMS version 4.3 instead of its default meteorological driver—the Mesoscale Modeling System (MM5; Anthes and Warner, 1978). This is a challenge in utilizing the flexibility of CMAQ. RAMS and MM5 are all three-dimensional, primitive equation, relocatable, regional mesoscale models, and are widely used to drive air quality models. They have much in common, but there are some important differences between them, such as the vertical coordinate system, the horizontal map projection, and available meteorological parameters in the model outputs. Besides, CMAQ is configured with the chemical mechanism of the Regional Acid Deposition version 2 (RADM2) (Stockwell et al., 1990), extended to include the four-product Carter isoprene mechanism (Carter, 1996), and aerosol processes from direct emissions and production from sulfur dioxide, long-chain alkanes, alkyl-substituted benzene, etc. A general description of CMAQ and its capabilities are given in Byun and Ching (1999).

For CMAQ, the anthropogenic emissions of NO_x, CO, and volatile organic compounds (VOCs) were obtained from the emission inventory of $1^\circ \times 1^\circ$ specially prepared to support TRACE-P (Streets et al., 2003) and from the Emission Database for Global Atmospheric Research (EDGAR) (Olivier et al., 1996). NO_x emissions from soils and natural hydrocarbon emissions were obtained from the global emissions inventory activity (GEIA) $1^\circ \times 1^\circ$ monthly global inventory (Guenther et al., 1995) for the month of March. VOC emissions were apportioned appropriately among the lumped-hydrocarbon categories used in RADM2.

Biomass burning is an important source of CO and NO_x in Asia in the springtime, because spring is the dry season, and there is extensive biomass burning in Southeast Asia and India, mainly due to burning of agricultural waste (rice straw) and deforestation (Nguyen et al., 1994). In this study,