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Air Quality Modeling Studies over Mega-City Regions in East Asia

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1. Introduction

East Asia is the region where rapid growing industrial activities have been causing large increases in emissions of pollutants. These pollutants have significant impact on air quality and likely on regional climate in Asia through formation of ozone (O3) and aerosol. Considering a further increase in anthropogenic emissions in coming decades in Asia, quantitative understanding of formation processes of these species are very important.

In this study, we made model calculation studies using WRF-Chem for Tokyo metropolitan area Japan, which is one of the largest mega-cities in the world. In this area, meteorological measurements have been well established and many studies on meteorological field have been made. Emission inventories have also been well characterized. Consequently, modeling studies in this area are suitable to evaluate impact of anthropogenic emissions in Asia and to test our understanding on atmospheric chemistry.

In this study, very preliminary modeling results are presented for the summer 2003. These results are compared with intensive measurements of O3 and aerosols made near the center of Tokyo and network measurements over the Tokyo metropolitan area. A degree of agreement with observations is shown. Spatial distribution of O3 and aerosols are presented.

2. Model Configuration and Measurement

2.1. Model Configuration

In this study, we use WRF-chem version 2.2 for regional three-dimensional model.

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For WRF-chem model calculations following physics and chemical process options are used; "RRTM" scheme for longwave radiation, "Goddard" scheme for boundary layer, "Kain-Fritsch" scheme for cumulus scheme, "Lin et al" scheme modified by PNNL [*Gustafson et al*., 2006] for cloud microphysics, "CBM-Z" scheme [*Zaveri and Peters*, 1999] for gas-phase chemistry, "MOSAIC" sectional aerosol module [*Fast et al.*, 2006; *Zaveri et al*., 2005a,b, 2007] for aerosol chemistry, and "Fast-J" scheme [*Barnard et al*., 2004; *Wild et al*., 2000] for photolysis process. In this study, 8 particle size sections are used in MOSAIC. Direct and indirect radiative effects caused by aerosols are considered as shown in *Fast et al.*, [2006] and *Gustafson et al*., [2006].

Simulation domains were selected as shown in Figure 1. Domain1 covers an area, which corresponds about half of Japan and Domain2 covers entire Kanto District which includes Tokyo metropolitan and surrounding area. Domain1 and Domain2 contain 30 x 30 and 28 x 28 grid cells, with horizontal resolutions of 27 and 9km, respectively. Both domains have 18 vertical layers with finer resolutions near the ground (lowest layer is placed at altitude of about 30m). Model calculation was made for a period between July 26 and August 7, 2003.

For initial and boundary condition of the meteorological field, four-dimensional regional objective analysis data (RANAL) provided by Japan Meteorological Agency (JMA) were used. In this study, no data assimulation (nudging) was applied.

Anthropogenic and biogenic emission inventories developed by *Kannari et al*., [2004] were used. The anthropogenic emissions were developed for the year 1998. All emissions are provided with a horizontal resolution of 10 x 10 km and both the seasonal and diurnal dependences are taken into account.

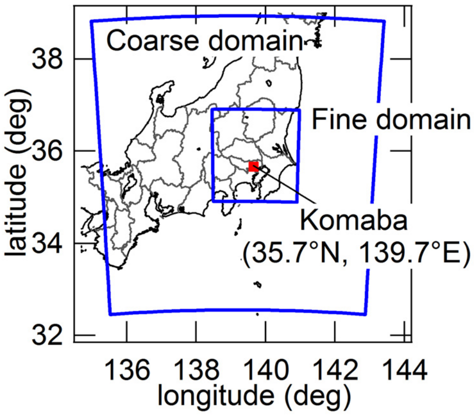

Fig. 1. Location of measurement site at Komaba campus of the University of Tokyo, and simulation domains employed by WRF-chem.

2.2. Measurement

To evaluate the performance of model calculations, we used gaseous and aerosol measurements made during the Integrated Measurement Program for Aerosol and oxidant Chemistry in Tokyo (IMPACT) conducted at Komaba campus of the University of Tokyo, in July and August 2003 (e.g., *Takegawa et al*., [2006]). Komaba site is located near the center of Tokyo (35.7 N, 139.7 E; Figure 1), and the measurements were made on the top (fifth) floor of a building (about 18m above the ground level). PM1 Inorganic and organic aerosol mass concentrations were measured using an Aerodyne Aerosol Mass Spectrometer (AMS) [*Takegawa et al*., 2005, 2006]. PM2.5 Elemental (EC) and organic carbon (OC) mass concentrations were measured with a semicontinuous EC and OC analyzer manufactured by Sunset Laboratory Inc. using a thermal-optical method [*Kondo et al*., 2006].

3. Model Results and Comparison with Measurements

3.1. Meteorological Field

The Kanto District (almost equivalent to Domain2 in Figure 1), in which Tokyo is located, is a plain facing to the Pacific Ocean and surrounded by mountains higher than a thousand meters. In summer, large-scale airflow patterns over Japan are characterized by Pacific high, which brings warm moist air from the Pacific Ocean to Kanto District. In addition, sea-land breeze circulation takes place over the Kanto District especially on clear days under stable anticyclonic condition in conjunction with other meteorological mechanisms. Consequently, during the IMPACT campaign, southerly wind generally dominated near the surface around Tokyo during daytime. During the nighttime variable wind with weak north or west components resulted from the land breeze is sometimes observed. Southerly wind during daytime brings relatively cleaner Pacific air into Tokyo area and freshly emitted pollutants are transported to the Komaba site. A distance of the Komaba site from the coast of Tokyo bay is about 20 km and therefore, 2-3 m/s wind will take about 2-3 hours to reach the Komaba site from the bay area.

Calculated meteorological parameters are compared with measurements at Komaba site. For this comparison, calculated values at the lowest layer (15 m) were compared in every hour. An agreement is evaluated by a mean ratio and a correlation (*r*); the former and latter are used as a measure of a mean bias and an agreement in temporal variation. The mean calculated/observed ratios of temperature, relative humidity are 1.00 and 1.08, respectively, and *r* values are 0.89 and 0.70, indicating a good agreement. The variation of wind speeds is also reproduced reasonably well (*r* value of 0.60 and 0.73 for hourly *u* and *v* component, respectively), although an absolute value of wind speed is overestimated (mean ratio is 1.89).

3.2. Ozone

A comparison between observed and calculated O3 mixing ratios at Komaba site is shown in Figure 2. The average calculated/observed ratio is 0.94, and *r* value is 0.81. Both diurnal variations with a maximum in early afternoon and a day-to-day variation were generally well reproduced.

In addition to the comparison at Komaba

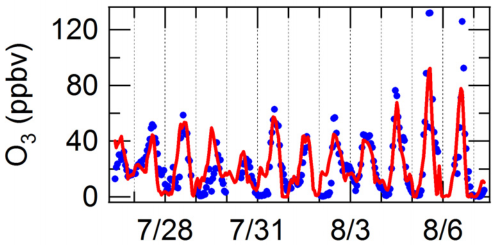

Fig. 2. Time series of observed (blue points) and calculated (red line) O3 concentrations at Komaba site. Calculated concentration shown here are those for the lowest layer (15 m). Gray vertical lines indicate 00 LT for individual days.

site, we also compared O3 mixing ratios obtained by network surface measurements of Atmospheric Environment Regional Observation System (AEROS) operated by the Ministry of the Environment of Japan. There are about 600 monitoring stations over Kanto District.

Observed and calculated O3 mixing ratios in Domain 2 are shown in Figure 3. Results are at 12 and 14 LT on 28 July. At noon, observation shows that high O3 concentration surrounded Tokyo Bay. Observation also shows that in the afternoon air parcels with high O3 concentrations were transported to suburbs by southerly wind with increasing its concentration likely due to photochemical O3 production during the transport. As seen in Figure 3, model calculation reasonably captured these observed features. The agreement found here indicate that factors and processes affecting regional O3 concentration were generally good in our calculations; namely, transport processes, emissions of O3 precursor species, and photochemical O3 production mechanisms.

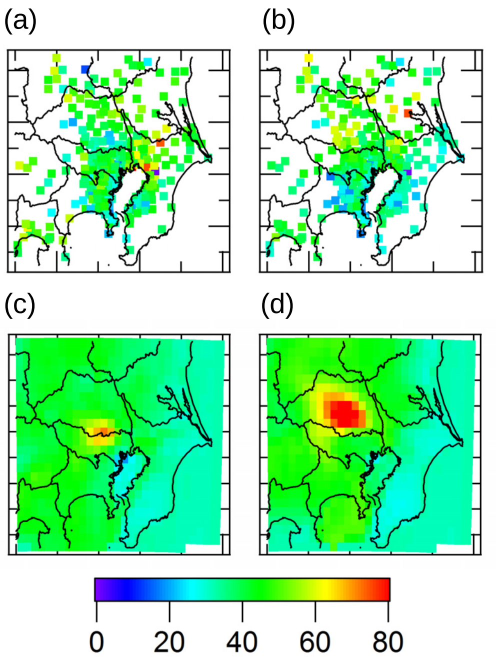

Fig. 3. Spatial distributions of observed and calculated O3 mixing ratios (ppbv) over the Kanto District (Domain2) on 28 July. (a) Observation at 12 LT, (b) Observation at 14 LT, (c) Calculation at 12 LT, and (d) Calculation at 14 LT.

3.3. PM2.5 Aerosol

We compared observed and calculated aerosol mass concentrations for each inorganic and organic species. Average calculated/observed ratios of sulfate, ammonium, nitrate, EC and OC were 0.88, 0.77, 0.73, 1.16 and 0.42, respectively, indicating that model calculations reproduced average concentrations reasonably well except for OC. One of the most important causes of the underestimation for OC is that only primary organic aerosol (POA) is calculated and secondary organic aerosols (SOA) is not considered in the WRF-chem, which we used in this study. On the other hand, an agreement in the diurnal and day-to-day variations of these species is generally not so good.

Calculated PM2.5 mass concentrations in Kanto District are shown in Figure 4. Results are shown for the same local time with that chosen for Figure 3. From these figures, it is found that a horizontal distribution of PM2.5 aerosol is quite similar to that of O3; maximum appears in metropolitan area at noon and high PM2.5 air parcels are transport to suburbs in the afternoon with increasing their concentrations). These results suggest that inorganic aerosols are formed concurrently with O3 during the transport from their precursor species emitted within metropolitan area and possibly along their trajectories.

(a) (b)

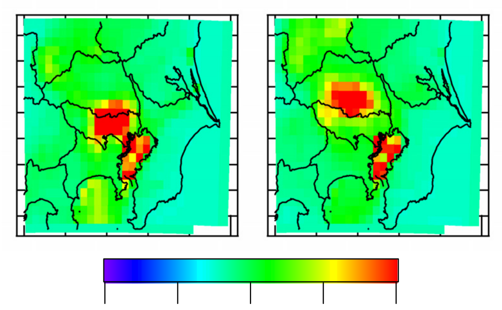

Fig. 4. Calculated spatial distributions of PM2.5 mass concentrations (μg/m^3) over the Kanto District at (a) 12 and (b) 14 LST 28 July.

4. Summary

In this study, we present very preliminary model calculation results using WRF-Chem for Tokyo Japan, which is one of the largest mega-cities in the world. Model-calculated results were compared with the intensive measurements made near the center of Tokyo to evaluate the performance of model calculations.

1) Both absolute values and temporal variations of meteorological parameters (temperature, relative humidity and wind speed and direction) and O3 were reasonably well reproduced.

2) Absolute values of aerosol species were reproduced to some extent except for OC, although the temporal variation was not well reproduced.

3) Features of horizontal distribution and its evolution of O3 over the Kanto District (maximum in Tokyo at noon and following transport to the suburbs in the afternoon with increasing its concentration) are reproduced reasonably. Similar features are found for PM2.5 model calculations, suggesting that concurrent formation of O3 and aerosols during the transport. These results indicate that enhancement of aerosols is regional phenomenon as for O3 and people living in downward regions suffer from pollution more than people living in the central Tokyo.

In this study, calculations have been done with limited nodes to save CPU and test the model. In the future, high-resolution (both vertical and horizontal) simulations will be done to better characterize the spatial variations. And then temporal and spatial variations of each aerosol species will be further investigated. Comparison with radiation measurements will be also conducted. Systematic sensitivity studies of possible impacts of aerosols on radiation and dynamics will be conducted.

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