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Evaluation of summertime surface ozone in Kanto area of Japan using a semi-regional model and observation

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HIGHLIGHTS

- A regional chemical transport model for short-lived gases (surface ozone) is introduced.
- Lack of NOx, CO and high VOC emission inventories cause overestimated surface ozone.
- A vital role of meteorological conditions in the model performance is analysed.

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ABSTRACT

Surface ozone is an air pollutant and harmful to human life. The spatial distribution of the air pollution has been estimated by chemical transport models, but still there are large uncertainties depending on detailed condition of the region. In this study, we extended Goto et al. (2015a) for implementing a chemical transport model to simulate short-lived gases such as ozone over Kanto area (around Tokyo in Japan) for August 2010. Comparison of simulation results with observed data indicated that the model had ability to capture observed ozone diurnal cycles over the target region with high correlation coefficients (0.69–0.81). The simulation result showed a vital role of meteorological conditions in the model performance. The correlation coefficients were much higher (0.78–0.87) and biases were lower (<35%) when the meteorological conditions were stable. In contrast, dominance of local pressure system and an associated complex wind field were main reasons for overestimated surface ozone concentrations in the unstable weather conditions.

This study helped achieve a better understanding of the chemistry transport model performance under unstable meteorological conditions in the Kanto area. Maximal association between meteorological factors and surface ozone distribution was revealed. In addition, uncertainty of emission inventories of ozone precursors especially the underestimate NO_x level certainly contributed to high level surface ozone during nighttime in this study.

1. Introduction

The dangers of surface ozone are well known as causing respiratory diseases, lung cancer and serious damage to crops (David A Grantz, 2005; Yang and Omaye, 2009; Yu et al., 2011). Therefore, investigations of impacts of surface ozone on human life and environment are always required (Brunekreef and Holgate, 2002). The summer in the Kanto area with dominant sunny days provides a favourable condition for high-level surface ozone concentrations as well as an ideal climate condition for testing the performance of the models. Surface ozone in summer time in the Kanto area has been thus focused by past studies: Niwano et al. (2007) examined the vertical profile of ozone at Tsukuba in Kanto by comparing

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simulated result from the Weather Research and Forecasting (WRF)/Chem model with Lidar-observed one. They found that ozone plumes in Kanto entered the free troposphere through vertical transport and mixing near the sea breeze front and underwent southward transport. Ooka et al. (2011) quantified a relationship between high peak summer ozone and meteorological conditions using both long term measurement analysis and the Community Multiscale Air Quality (CMAQ) model and up to 84% of long-term variations in peak ozone concentrations may be accounted for by changes in the seasonally averaged daily maximum temperatures and seasonally averaged wind speeds. Also evaluating the performance of CMAQ model, Morino et al. (2010) concluded that 31% of the daily maximum O_3 concentration was reproduced at four sites in the Kanto area in summer 2007. Khandakar and Moritomi (2013) used WRF/Chem and observation data to investigate high ozone episode at Kawasaki city in Kanto area. Besides, Kiriyama et al. (2015a) clarified the causes of high ozone level in the morning in Kanto area by using both WRF and CMAQ models. They indicated that downward transportation of residual ozone resulting in increased early morning ozone concentration. By the same tools, effects of NO_x and VOC to surface ozone level were also investigated by Kiriyama et al. (2015b). While NO_x and VOC reduction increases the daytime maximum ozone in surrounding area of the central Tokyo but decreases in other parts of Kanto area, VOC reduction effectively works to decrease the ozone concentration in the entire Kanto region.

None of these studies, however, focus on model comparison with observation data at various sites in Kanto and detailed analysis of the ozone impacts of weather conditions and its precursors. Also there are few investigations on causes of overestimation of ozone concentration by most models (e.g., Niwano et al., 2007; Chatani et al., 2011). Therefore, the present study focuses on summertime ozone levels at nine sites in Kanto to investigate the impact of not only weather conditions but also variation of precursors to ozone concentration.

In the present work, we use a new generation atmospheric transport model, named NICAM (Tomita and Satoh, 2004; Satoh et al., 2008, 2014), coupled with physical and chemical modules for simulating air pollution with high resolution (Suzuki et al., 2008; Goto, 2014). The model grid sizes and nesting system are key factors of an effective simulation of the air pollution. For this purpose, a stretching grid system developed by Tomita (2008a) was applied to previous studies for simulating the air pollutants around Japan with high resolution and also without nesting boundary (Goto, 2014; Goto et al., 2015a, 2016). We applied the NICAM model in this study to get the realistic distribution of surface ozone during summer time in Kanto area.

Remains of this paper are structured as follows: Section 2 introduces studied area and model framework as well as experiments for ozone simulation, Section 3 presents simulation result and validation by observed data, discussion is shown in Section 4 and conclusion is drawn in Section 5.

2. Methods

2.1. Study domain and period

The Kanto is the Japan's largest plain and very densely populated which consists of seven prefectures. The large metropolises of Tokyo and Yokohama are located in the Kanto Region. This study mainly focused on modelling of surface ozone in five prefectures as Gunma, Tokyo, Saitama, Ibaraki and Tochigi (Fig. 1). The target period is 1–18 August 2010, which is summer season in Japan.

2.2. Model description

NICAM Nonhydrostatic ICosahedral Atmospheric Model – (Tomita and Satoh, 2004; Satoh et al., 2008 and Satoh et al., 2014) was used as a host model for simulating the ozone distribution. It has a capability of simulating atmospheric processes with a high resolution grid spacing up to 0.87 km in global simulation (Miyamoto et al., 2013). A low-resolution grid spacing of

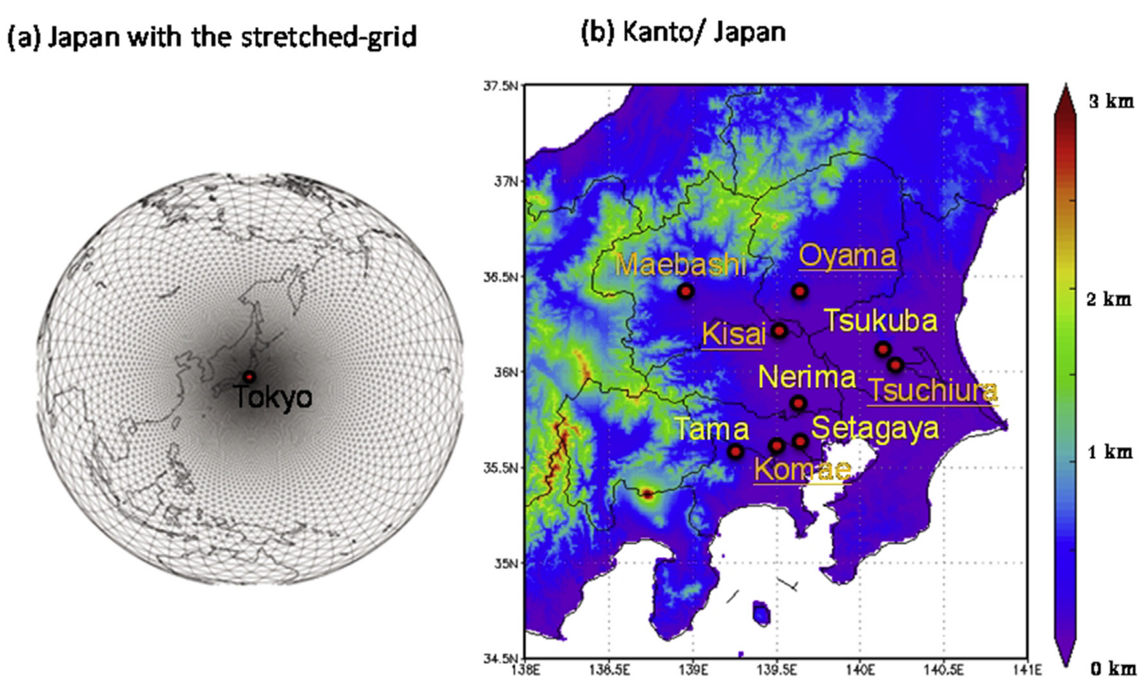

Fig. 1. Topographical maps of Japan with the stretched-grid (a) and Kanto/Japan (b), including the observation sites used in the model validation. The topography is based on GTOPO30 (horizontal resolution is 30 arc seconds, that is, approximately 1 km), courtesy of the U.S. Geological Survey.