Atmospheric Environment 77 (2013) 365–375

Contents lists available at SciVerse ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Performance evaluation of atmospheric particulate matter modeling for East Asia

Tu-Fu Chen, Chang-You Tsai, Ken-Hui Chang*

Department of Safety, Health and Environmental Engineering, National Yunlin University of Science and Technology, Touliu 64002, Yunlin, Taiwan

HIGHLIGHTS

- We simulated the PM, compositions and precursors in East Asia for a whole year.
- We used API-derived and Satellite-derived data in China and East Asia for evaluation.
- PM_{10} and $PM_{2.5}$ in Taiwan were underestimated by 11 and 10%, respectively.
- The overall bias of PM_{10} in six regions of China are ranging between −55 and +52%.
- Grid resolution and error in emission should be responsible for the difference.

ARTICLE INFO

Article history:
Received 5 September 2012
Received in revised form
7 May 2013
Accepted 13 May 2013

Keywords:
Long range transport
PM simulation
Monitoring PM data
Satellite-derived PM data
PM model performance

ABSTRACT

This study used the Community Multi-scale Air Quality modeling system associated with emission and meteorological datasets to conduct a one-year Particulate Matter (PM) simulation in East Asia. The performance of the PM simulation results was evaluated against observed data using high-spatial resolution monitoring data from Taiwan (e.g., concentration of PM and its compositions and precursors), Air Pollution Index-derived data in 82 cities of China, and satellite-derived surface $PM_{2.5}$ concentrations. Based on error analysis of two indicators (overall bias and gross error), the validity of model performance is demonstrated. Daily comparison results at the various stations (cities) in 2007 indicate that the simulations at Taiwan's monitoring stations were superior to those in cities in China. Overall, the PM_{10} and $PM_{2.5}$ concentrations in Taiwan were underestimated by 11 and 10%, respectively, whereas the simulated PM_{10} concentrations in six regions of China showed significant differences, with the simulation overall bias ranging between −55 and 52%. There are two primary reasons for the large differences in model performance between Taiwan and China. First, the grid resolution for China was coarser than that for Taiwan because of the limitation of emission data resolution in the Regional Emission Inventory in Asia (REAS). Second, the spatial distribution and magnitude of emissions in the REAS might be incorrect in some regions, particularly in the domain boundary areas of China. In addition to the relatively good emission database for Taiwan, the reasonable emission estimates for the central areas of China may be partially responsible for better model performance of PM in Taiwan.

1. Introduction

The emission of SO_2 and NO_2 has increased significantly since 1990s in East Asia, particularly in China (Zhang et al., 2007; Tanimoto, 2009; Wang et al., 2009; Lu et al., 2010). In fact, China with its rapid economical development is the primary pollutant source in East Asia (Ohara et al., 2007). Thus, the impact of increased pollutant emissions from East Asia and particularly from China on neighboring countries is expected. Consequently, an air quality modeling system developed for accurately simulating the temporal and spatial concentration variations of different air pollutants is necessary to investigate regional air pollution issues in East Asia (e.g., the mutual effect of long-range transport (LRT) of pollutants across Taiwan Strait between China and Taiwan).

Although modeling LRT of particulate matter (PM) in East Asia has been performed before (e.g., Koo et al., 2008; Chuang et al., 2008; Shimadera et al., 2009; Aikawa et al., 2010; Itahashi et al., 2012), the validity of the model performance remains unclear. For example, the previous modeling pollutant simulations are most for

* Corresponding author. Tel.: +886 5 5342601; fax: +886 5 5312069.
E-mail addresses: changken@yuntech.edu.tw, ken@airlab.yuntech.edu.tw (K.-H. Chang).

1352-2310/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.atmosenv.2013.05.025

short-term evaluations (e.g., several days (Chuang et al., 2008; Koo et al., 2008)) to one month (Shimadera et al., 2009; Itahashi et al., 2012). Further, although some of these studies were evaluated in large-scale simulations, e.g., ground-level observations in 27–32 stations (Aikawa et al., 2010; Koo et al., 2008), there was a lack of monitoring data in China in these studies, which certainly hinders the evaluation of model performance not only in China but also in adjacent countries. Still, few studies include modeling results of PM compositions and their precursors (e.g., Shimadera et al., 2009). Thus, to analyze model simulation results for LRT pollutants, long term simulations including a wide range of meteorological conditions as well as more monitoring stations to ensure adequate observed data are needed.

Consequently, the present study was undertaken to evaluate model performance of LRT of pollutants from China. Basically, Community Multi-scale Air Quality (CMAQ) modeling system (Byun and Ching, 1999; Byun and Schere, 2006) along with Mesoscale Model ver. 5 (MM5) (Grell et al., 1995) was used in the present study. The performance of the simulation results of the modeling system was conducted based on air quality data in China, monitoring data from monitoring stations from Taiwan and satellite-derived surface data for East Asia. In particular, error analysis was performed for 5 regions in Taiwan and 82 cites in China for the entire 2007 year. Hopefully, the validity of the modeling system would render the air quality models useful in investigating air pollution issues in East Asia, and subsequently formulating control strategies for enhancing air quality in East Asia in general and in Taiwan in particular.

2. Materials and methods

2.1. Modeling system

For this study, we used the CMAQ ver. 4.6 model (CMAS, 2007) as the basis of an air quality modeling system for the PM in East Asia. The system employs three-level nested domains (Fig. 1), where domain 1 (D1) covers East Asia (81 km × 81 km), domain 2 (D2) covers Southeast China and Taiwan (27 km × 27 km), and domain 3 (D3) covers Taiwan (9 km × 9 km). The model includes three subsystems: initial and boundary conditions, meteorology preprocessor, and emissions data preprocessor. Initial and boundary conditions were first established based on the default (profile) values in the model that typically differed from actual conditions; therefore, the nesting techniques and a 5-day spin-up run were used to reduce the uncertainty effect of initial conditions. Meteorology–Chemistry Interface Processor ver. 3.3 (Byun et al., 1999) used the 4-D meteorological field simulated by MM5 to generate the meteorological inputs for the air quality model. Hourly biogenic emission data for Taiwan were estimated using the Taiwan Biogenic Emissions Inventory System (TBEIS) (Chang et al., 2009) with meteorological information from MM5, while the data for East Asia were estimated using the East Asia Biogenic Emissions Inventory System (EABEIS) (Chang et al., 2005). The EABEIS was established based on the TBEIS combined with the East Asia Land Use Database (http://landcover.usgs.gov/landcoverdata.php) and the corresponding emission factor databases. Anthropogenic emissions in Taiwan were obtained from the Taiwan Emission Data System (TEDS 7.1) (CTCI, 2009) published by the Taiwan EPA, with a data resolution of 1 km × 1 km, which was used to calculate the 3-D spatial (horizontal coordinates of sources and their effective heights with plume rise) and temporal distribution of pollutant emission rates. The anthropogenic emissions for East Asia, excluding those in Taiwan, adopted the Regional Emission Inventory in Asia (REAS) with a data resolution of 0.5° × 0.5° (Ohara et al., 2007). The REAS includes historical emissions for the years 1980–2003 and projected emissions for the years 2010 and 2020. The REAS data for 2007 that were used in this study were estimated by interpolating emissions between 2003 and 2010 (Ohara et al., 2007). The REAS covers four primary pollutant source sectors: non-point sources, large point sources, airline and ship emissions. However, the large point sources do not have stack parameters (i.e., stack height and diameter, flue gas temperature and velocity) to calculate plume rise. Therefore, the data in the TEDS were used to calculate appropriate stack parameters for the large point sources in the REAS. Also the REAS does not include PM emissions data; its estimation was based on NO_X and NMHC (non-methane hydrocarbons) emissions. The PM emission of each grid cell (0.5° × 0.5°) and the large point sources in the REAS were estimated by the regression equations derived from empirical relationship between PM and NO_X/NMHC of the TEDS. Additionally, because the 2007 REAS emissions were estimated by interpolations, the emissions may have a larger uncertainty and need to be adjusted. After an emissions sensitivity test based on the comparison of results between simulated and observation data in two monitoring stations, nearest to China (Sites D and E in Fig. 2a), a 100% increase for NMHC and SO_X emissions and a 60% increase for NH_3 emissions in the REAS were applied for the final air quality simulation.

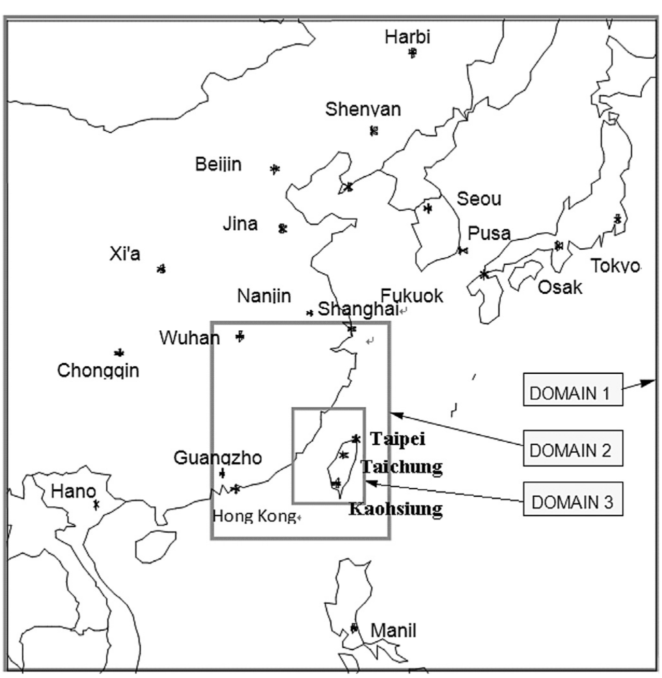

Fig. 1. Configuration of three-level nesting domains in this study.

2.2. Methodology for PM concentration simulations

The CMAQ model uses three overlapped log-normal distribution functions (i.e., Aitken (i), accumulation (j), and coarse (k) mode particles) to describe the distribution of particles in the atmosphere (CMAS, 2007). Previously, the total dry mass concentration ($PM_{i+j,dry}$) of the i and j modes was used to represent $PM_{2.5}$, and $PM_{i+j+k,dry}$ was used to represent PM_{10}. These definitions are suitable for low humidity areas; however, applying these to high humid areas can lead to significant errors (Jiang et al., 2006). Because of Taiwan's highly humid environment, the actual PM mass concentrations must be calculated using both the particle size distribution and moisture content. Consequently, the subsequent simulated concentrations of $PM_{2.5}$ and PM_{10} in this study were