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Improvement of PM10 prediction in East Asia using inverse modeling

Youn-Seo Koo [a,*], Dae-Ryun Choi [a], Hi-Yong Kwon [b], Young-Kee Jang [c], Jin-Seok Han [d]

[a] Dept. of Environmental and Energy Eng., Anyang University, Anyang, Gyeonggi-do, Republic of Korea
[b] Dept. of Computer Eng., Anyang University, Anyang, Gyeonggi-do, Republic of Korea
[c] Dept. of Environmental and Energy Eng., University of Suwon, Gyeonggi-do, Republic of Korea
[d] Dept. of Climate and Air Quality, National Institute of Environmental Research, Incheon, Republic of Korea

HIGHLIGHTS

- Develop a PM10 emission inventory using analytical inverse modeling.
- Anthropogenic PM10 emissions of INTEX-B in China are underestimated.
- There are large uncertainties in estimating dust emissions.
- Emissions in northeastern China are highly underestimated by about 300%.
- Inverse modeling is an effective tool in providing top-down emission inventory.

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ABSTRACT

Aerosols from anthropogenic emissions in industrialized region in China as well as dust emissions from southern Mongolia and northern China that transport along prevailing northwestern wind have a large influence on the air quality in Korea. The emission inventory in the East Asia region is an important factor in chemical transport modeling (CTM) for PM10 (particulate matters less than 10 μm in aerodynamic diameter) forecasts and air quality management in Korea. Most previous studies showed that predictions of PM10 mass concentration by the CTM were underestimated when comparing with observational data. In order to fill the gap in discrepancies between observations and CTM predictions, the inverse Bayesian approach with Comprehensive Air-quality Model with extension (CAMx) forward model was applied to obtain optimized a posteriori PM10 emissions in East Asia. The predicted PM10 concentrations with a priori emission were first compared with observations at monitoring sites in China and Korea for January and August 2008. The comparison showed that PM10 concentrations with a priori PM10 emissions for anthropogenic and dust sources were generally under-predicted. The result from the inverse modeling indicated that anthropogenic PM10 emissions in the industrialized and urbanized areas in China were underestimated while dust emissions from desert and barren soil in southern Mongolia and northern China were overestimated. A priori PM10 emissions from northeastern China regions including Shenyang, Changchun, and Harbin were underestimated by about 300% (i.e., the ratio of a posteriori to a priori PM10 emission was a factor of about 3). The predictions of PM10 concentrations with a posteriori emission showed better agreement with the observations, implying that the inverse modeling minimized the discrepancies in the model predictions by improving PM10 emissions in East Asia.

1. Introduction

The East Asia region is the world's most populous area, and its rapidly growing economy has resulted in large air pollutant emissions. The urban and industrial development of China in this region is especially prominent, causing heavy and complex air pollution problems in Korea (Koo et al., 2008, 2012; Lee et al., 2011b, 2013). News media and research articles have recently reported the frequent occurrence of haze events in China. PM2.5 (Particulate matters less than 2.5 μm in aerodynamic diameter) concentrations in Beijing reached unprecedented levels in 2013. Quan et al. (2014) reported that the hourly mean concentrations of PM2.5 often exceeded 200 μg/m^3, with a maximum concentration

* Corresponding author. Dept. of Environmental and Energy Eng., Anyang University, 708-113, Anyang 5 dong, Manan-gu, Gyeonggi-do 430-714, Republic of Korea.
E-mail address: koo@anyang.ac.kr (Y.-S. Koo).

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of 600 μg/m^3 in Beijing during the smog period in January 2013. There were ample papers reporting severe PM-related haze events in China (Ji et al., 2014; Hu et al., 2014; Zhao et al., 2013; Wang et al., 2014a, 2014b).

The air quality in the Seoul Metropolitan Area (SMA) has deteriorated due to both emissions in the SMA itself and the growing influence from China. The large anthropogenic emissions from megacity clusters in North and East China, such as the Beijing-Tianjin-Hebei Province, the Yangtze River Delta, and Shenyang, can be transported to the SMA by the prevailing northwestern winds in the spring and winter seasons. According to our analysis of PM10 concentrations observed hourly by the beta-ray absorption method at 27 ambient air quality monitoring stations (AAQMS) in Seoul, the air quality in Korea was deteriorating in 2013. The details of PM10 measurement methods and locations are available in Lee et al. (2011b) and Sharma et al. (2014), and the observed data are open to the public in the Korea air quality data site (http://www.airkorea.or.kr/). The annual average of PM10 in Seoul increased from 41 μg/m^3 in 2012 to 45 μg/m^3, and the number of episode days exceeding 80 μg/m^3 also increased from 10 days in 2012 to 20 days in 2013. The dense haze in the episode days was normally initiated by aerosol and precursor species inflows from China and then became worse by adding local emissions and limited ventilation of airflows in the SMA. The haze event in the SMA happened with a one or two day time lag after the occurrence of the haze event in China.

To establish a proper control policy for air quality management and to forecast the high PM episode in Korea, chemical transport modeling (CTM) with a well-defined emission inventory is an effective way to define the relationship between the emission sources and the receptors. According to previous studies, comparisons of surface observations with predictions by the chemical transport model showed large discrepancies due to uncertainties in the emission data, meteorological input, and the model itself. Koo et al. (2012) reported that the Korean Air Quality Forecasting System in East Asia focusing on the SMA had a negative mean bias (MB) in PM10 forecasting. Liu et al. (2010) modeled regional air pollution over China and found that the simulated PM10 concentrations were under-predicted throughout the year with a normalized mean bias (NMB) up to −54.2%.Chatani et al. (2011) developed a framework for a high-resolution, three-dimensional regional air quality simulation; their suspended PM prediction in Japan also showed under-predictions by −37% to −61% NMB, differing by seasons. To our knowledge, most modeling studies in the East Asia region showed under-predictions compared to the observations (Koo et al., 2008, 2012; Shimadera et al., 2009; Huang et al., 2012; In and Kim, 2010; Li et al., 2013; Chatani et al., 2011: Wang et al., 2010). One of the main reasons for underestimations in the aerosol simulation of PM10 in particular is the uncertainty of emissions. The improvement of emission inventory is the most important task for getting a better description of the observations using CTM.

To reduce uncertainties in emissions, Ku and Park (2011) investigated dust emissions using inverse modeling methods over East Asia. According to their results, the inverse modeling analysis improved the spatial pattern of the simulated PM10 concentrations, resulting in better agreement with the observations. Yumimoto et al. (2007, 2008) carried out adjoint inversion modeling of Asian dust emissions using lidar observation to improve dust predictions. Dubovik et al. (2008) estimated the global aerosol emissions of fine and coarse modes using a Moderate Resolution Imaging Spectroradiometer (MODIS) aerosol optical depth (AOD). Huneeus et al. (2012) estimated the global aerosol emissions of multiple aerosol species of desert dust, back carbon, sea salt, and particulate organic matter using MODIS AOD.

In this study, we attempt to optimize PM10 emissions in East Asia by applying an analytical inverse model to improve CTM performance in predicting PM10 concentrations in Korea. The emission inventories of concern in this study for the CTM are anthropogenic and dust emissions. The surface observations of PM10 from Air

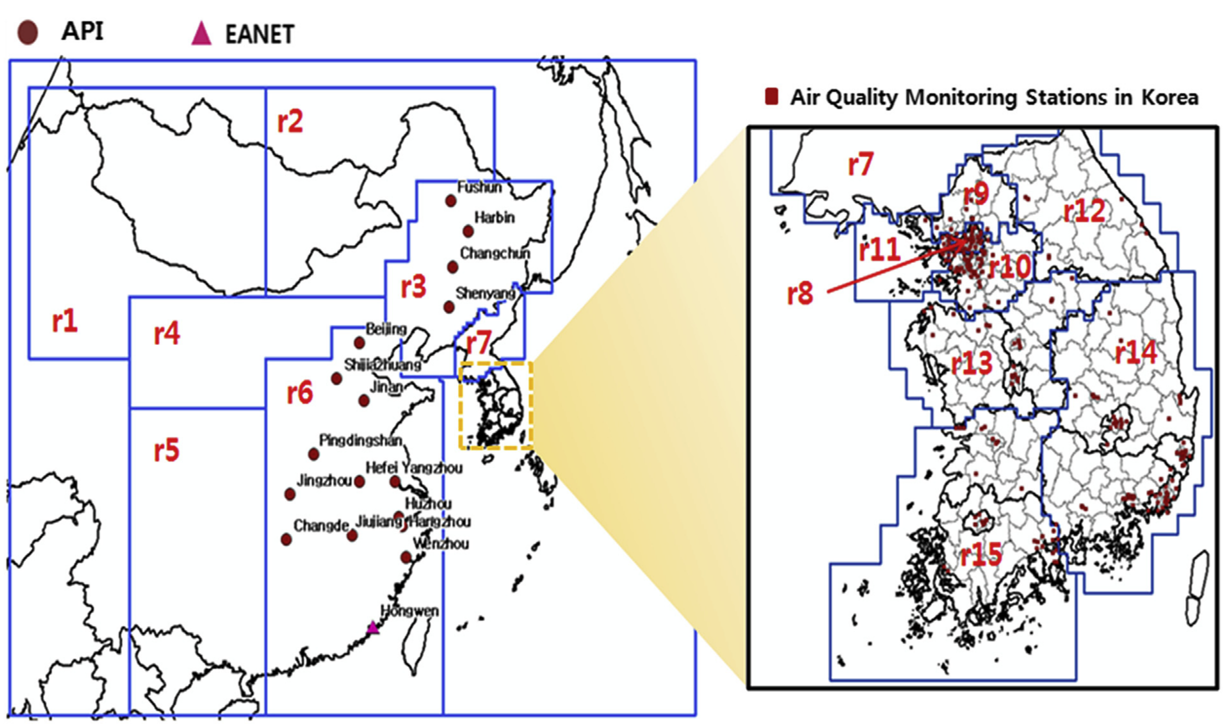

Fig. 1. Locations of PM10 observation sites of API in China and AQMM sites in Korea are denoted by circles, triangles, and squares. PM10 emission regions are divided into 16 source areas (r1–r16) for inverse modeling.