A simulation of Aerosols in Asia with the use of ADAM2 and CMAQ

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Abstract: The Aerosol Modeling System (AMS) has been developed to estimate aerosol concentrations of both natural (dust) and anthropogenic aerosols and implemented to simulate the observed PM10 concentration for the period from 10 to 17 March 2010 when a couple of Asian dust events are observed in South Korea. The system is based on the Asian Dust Aerosol Model 2 (ADAM2) for the dust aerosol and the Community Multiscale Air Quality (CMAQ) modeling system of the US Environmental Protection Agency (EPA) for the anthropogenic aerosol. The AMS has been employed to simulate aerosol concentrations in the Asian domain at 27 km horizontal grid spacing with the Intercontinental Chemical Transport Experiment – Phase B (INTEX-B) pollutant emission data in Asia and in the nested East Asian domain at 9 km horizontal grid spacing with emission data from the INTEX-B in Asia and the Clear Air Policy Supporting System (CAPSS) of Korea Ministry of Environment in the South Korean region. It is found that the AMS model with the 27 km horizontal grid scheme (Model 1) tends to underestimate the concentrations of both the dust (natural) and the anthropogenic aerosols, whereas the model with the 9 km horizontal grid scheme (Model 2) quite successfully simulates the observed Asian dust and anthropogenic aerosol concentrations. This suggests that AMS has a great potential for the use of Asian aerosol forecast model in Asia.

Key-Words: Aerosol Modeling System (AMS), ADAM2, Anthropogenic aerosol, Asian dust aerosol, CMAQ

1 Introduction

In recent years, atmospheric aerosols have become an emerging issue due to their important role in atmospheric processes, including their number concentration, their mass, size, chemical composition, and aerodynamic and optical properties. Of these, size is the most important; it not only reflects the nature of the source of the aerosols but also relates to their health effects (Bates et al., 1966; Pope et al., 1992; Dockery et al., 1992, 1993; Balášázy et al., 2003) and to their aesthetic and climate effects via their light scattering properties (Chang and Park, 2004; Park et al., 2005; IPCC, 1996; Jacobson, 2001; Kanfman et al., 2002; Penner et al., 2004; Crutzen, 2004).

Current estimates suggest that anthropogenic aerosols and biomass burning have climate forcing enough to offset warming caused by greenhouse gases such as carbon dioxide (Kiehl and Briegle, 1993). However, a large uncertainty of key properties of aerosols makes it difficult to correctly quantify the radiative forcing (Chang and Park, 2004). The uncertainties are due to in part to the limited data on aerosol climatology, and in part to the lack of our understanding on the processes responsible for the production, transport, physical and chemical evolution and the removal of aerosols at various spatial and time scales that are largely dependent on the aerosol size distribution (Clarke et al., 2004).

East Asia is a major source of natural (Asian dust) and anthropogenic aerosols over the Northern Hemisphere due to rapid economic expansion in many Asian countries. Asian dust (Hwangsa in Korean) which is a typical example of mineral aerosol occurs in the Sand desert, Gobi desert and Loess plateau in northern China and Mongolia more frequently during the spring season (Park and In, 2003; In and Park, 2003; Park and Lee, 2004). Tropospheric aerosols that originate in China are the complex mixture of various aerosols such as Asian dust and anthropogenic particles from a variety of sources. The dust particles raised in the source regions of inland China will experience pollutants emitted from the industrialized regions that are heavily concentrated in the eastern part of China during long-range transport of dust. Consequently, a significant transformation of chemical composition of the dust is expected as indicated by observations (Saxena and Seigneur, 1983; Gao et al., 1991; Kang and Sang, 1991; Park et al., 2005).

Recently Park et al. (2010a) have developed the Asian Dust Aerosol Model 2 (ADAM2) and used to
simulate successfully the Asian dust events (Park et al., 2010b, Park et al., 2010 c). However, this model cannot be used to simulate the anthropogenic aerosols. Therefore, the Community Multiscale Air Quality (CAMQ) model (Otte et al., 2005; Byun and Schere, 2006) has been coupled with ADAM2 to simulate all kinds of aerosols including natural and anthropogenic aerosols.

The purpose of this study is to simulate aerosols in Asia using the Aerosol Modeling System (AMS) that entails coupling the ADAM2 model with the CAMQ model for the period of 10 to 17 March 2010 when Asian dust events occurred in Asia and to test the performance of the AMS model.

2 Model description

2.1 Meteorological Model
The meteorological model used in this study is the fifth generation mesoscale model of non-hydrostatic version (MM5, Pennsylvania State University/National Center for Atmospheric Research) defined in the x, y, and σ coordinate (Grell et al., 1994; Dudhia et al., 1998).

The model domain (Fig. 1) has horizontal resolution of 27 x 27 km\(^2\) for the Asian domain (Fig. 1a) with nested domains of 9 x 9 km\(^2\) for the East Asia domain (Fig. 1b). Each domain has 25 vertical layers. For our convenience the model with the Asian domain is referred to “Model 1” and that of the East Asian domain to “Model 2”.

![Fig. 1 Model domains and the Asian dust source region with surface soil types (Gobi, Sand, Loess and Mixed) in (a) Model 1 (Asian domain) and (b) Model 2 (East Asian domain).](image)

2.2 Aerosol Modeling System (AMS)
The Aerosol Modeling System (AMS) is consisted of the Asian Dust Aerosol Model 2 (ADAM2, Park et al., 2010a), the Community Multiscale Air Quality (CMAQ) modeling system (http://www.cmaq-model.org) with pollutants emission data.

2.2.1 ADAM2 model
The ADAM2 model is an Eulerian dust transport model that includes the specifications of the dust source regions, delineated by the statistical analysis of the World Meteorological Organization (WMO) dust reporting data and statistically derived dust emission conditions in Sand, Gobi, Loess and mixed soil surface in the domain in Fig. 1a. The model uses the suspended particle-size distribution parameterized by the several log-normal distributions in the source regions, based on the concept of the minimally and fully dispersed particle-size distribution. It has 11-size of bins with near the same logarithm interval for particles of 0.15-37 µm in radius (Park and In, 2003; Park and Lee, 2004). The model can be run for a whole year round with a temporally varying emission reduction factors derived statistically using the normalized difference vegetation index (NDVI) in the different surface soil types in the Asian dust source region. The detailed description is given in Park et al. (2010a).

2.2.2 CMAQ model
The EPA Community Multiscale Air Quality (CMAQ) modeling system (http://www.cmaq-model.org) is a three-dimensional Eulerian atmospheric chemistry and transport modeling system that simulates ozone, particulate matter, toxic airborne pollutants, visibility, and acidic and nutrient pollutant species throughout the troposphere (University of North Carolina, 2010).

The aerosol component of the CMAQ model has the particle size distribution as the superposition of three lognormal subdistributions, called modes. Fine particles with diameters less than 2.5 µm (PM\(_{2.5}\)) are represented by two subdistributions called the Aitken and accumulation modes. The Aitken mode includes particles with diameters up to approximately 0.1 µm for mass distribution and the accumulation mode covers the mass distribution in the range from 0.1 to 2.5 µm. The coarse mode covers the mass distribution in the range from 2.5 µm to 10 µm. The model includes the processes of coagulation, particle growth by the addition of mass...
and new particle formation (Binkowski and Roselle, 2003).

### 2.2.3 Emission data

Air pollutant emissions in Asia (Fig. 2) in the year 2006 are obtained from the Intercontinental Chemical Transport Experiment – Phase B (INTEX-B, Zhang et al., 2009) that includes all major anthropogenic sources, excluding biomass burning.

The estimated total Asian (China’s) anthropogenic emissions in the year 2006 are 47.1 Tg (31.0 Tg) SO$_2$, 36.7 Tg (20.8 Tg) NO$_x$, 54.6 Tg (23.2 Tg) VOC, 298.2 Tg (166.9 Tg) CO, 29.2 Tg (18.2 Tg) PM$_{10}$, 22.2 Tg (13.3 Tg) PM$_{2.5}$, suggesting more than 60 % of the total anthropogenic emissions being contributed by China.

Fig. 3 Horizontal distributions of emission rate (t day$^{-1}$ grid$^{-1}$) of (a) SO$_2$, (b) NOx, (c) NH$_3$, and (d) PM$_{10}$ (1 grid: 3x3 km$^2$) on March 2006.

Air pollutant emissions in South Korea (Fig. 3) in the year 2007 are obtained from the Clean Air Policy Supporting System (CAPSS, Korean Ministry of Environment) in a 1 x 1 km$^2$ grid scheme. These emission data over South Korea are used for the simulation of aerosols in Model 2.

### 3 A simulation of aerosols for the period of 10 to 17 March 2010

An aerosol simulation has been done with the use of AMS for the period of 10 to 17 March 2010 in the Asian domain (Fig. 1a) with the use of emission data in Fig. 2 and the nested East Asia domain (Fig. 1b) with emission data in Figs. 2 and 3.

Fig. 4 Horizontal distribution of near surface (a) total PM$_{10}$ concentration and (b) anthropogenic aerosol (PM$_{10}$) concentration simulated by Model 1 at 00 UTC 16 March 2010.
The anthropogenic aerosols include SO$_4^{2-}$, NO$_3^-$, NH$_4^+$, OC, BC, sea salt, emitted PM$_{10}$. It is quite clear that the contribution of the anthropogenic aerosols to the total aerosols is quite significant especially in the south eastern part of China were the pollutant emission rate is large. The enhanced anthropogenic aerosol in this region may cause the frequent occurrence of the haze.

Fig. 5 shows the spatial distributions of the near surface total PM$_{10}$ concentration (Fig. 5a) simulated by Model 2 at the same time in Fig. 4.

The total PM$_{10}$ concentration in the nested domain is enhanced compared with that in the Asian domain (Figs. 4 and 5) toward the downwind region due to the enhanced wind speed in the lower level that results in the enhancement of dust rise in the source regions in northeastern China.

![Fig. 5](image1)

**Fig. 5** The same as in Fig. 4 except for by Model 2.

To examine more closely the impact of the nested grid domain on the aerosol concentration, the time series of observed and modeled PM$_{10}$ concentrations estimated by Model 1 and Model 2 are compared at several sites located in the downwind region of South Korea.

Fig. 6 shows the time series of the observed total PM$_{10}$ concentration, the modeled total PM$_{10}$ concentration and the anthropogenic aerosol concentration estimated by Model 1 and Model 2 at Seoul, Jeonju, Ulsan and Busan in Korea (Fig. 1b).

![Fig. 6](image2)

**Fig. 6** Time series of observed (solid-dot line), total (solid line), anthropogenic (dotted line) PM$_{10}$ concentration simulated by Model 1 and Model 2 at (a) Seoul, (b) Jeonju, (c) Ulsan, and (d) Busan.
It is quite clear that the observed aerosol concentrations more than 100 µg m\(^{-3}\) are mainly contributed by the Asian dust aerosol and the Model 2 simulates much better peak aerosol contribution during the dust event period and the anthropogenic aerosol concentration during the non-dust event period than those by the Model 1 at all sites (Fig. 6), suggesting the importance of the nested grid model for the simulation of the total aerosols.

Fig. 7 shows the time series of modeled total aerosol concentration and the anthropogenic aerosol concentration simulated by Model 1 and Model 2 at Beijing in China. Although the direct comparison of aerosol concentrations simulated by Model 1 and Model 2 is difficult without the observed data, the time series of wind speed (not shown) implies better result of Model 2 than that of Model 1. The anthropogenic aerosol concentration can be more than 200 µg m\(^{-3}\) during the non-dust event period causing a haze problem. The dust event occurred in the later afternoon on 15 March (Fig. 7) may be associated with the dust event observed in the morning on 16 March in Korea (Fig. 6).

**Fig. 7.** Time series of total PM\(_{10}\) concentration (solid line) and anthropogenic PM\(_{10}\) concentration (dotted line) simulated by (a) Model 1 and (b) Model 2.

**4 Conclusion**

The presently developed Aerosol Modeling System (AMS) on the basis of the ADAM2 model for the Asian dust aerosols and the CMAQ model for the anthropogenic aerosols has been employed to estimate the total aerosol concentration (natural + anthropogenic aerosols) in Asia for the period from 10 to 17 March 2010 when a couple of dust events are observed in Korea.

It is found that the AMS model has demonstrated its ability to simulate quite reasonably the observed PM\(_{10}\) concentration and to distinguish the contribution of anthropogenic aerosol concentration from the total observed PM\(_{10}\) concentration. The observed high PM\(_{10}\) concentrations exceeding 100 µg m\(^{-3}\) in Korea are found to be mainly contributed by the Asian dust aerosol whereas the anthropogenic aerosol concentrations exceeding 200 µg m\(^{-3}\) are often found in the southeastern part of China where the pollutant emissions are highest. This may cause frequent occurrences of haze events in this region.

It is also found that Model 2 (horizontal grid distance of 9 km) simulates much better total aerosol concentration by simulating better meteorological fields than Model 1 (horizontal grid distance of 27 km).

The present study mainly pertains to the performance test of the AMS model for a short time period. More accurate prediction of the aerosol concentration requires a proper parameterization of interaction processes between the aerosol and gaseous pollutants and among different aerosols. This is now on hand.

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**References:**


