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Spatial and temporal distributions of aerosol concentrations and depositions in Asia during the year 2010

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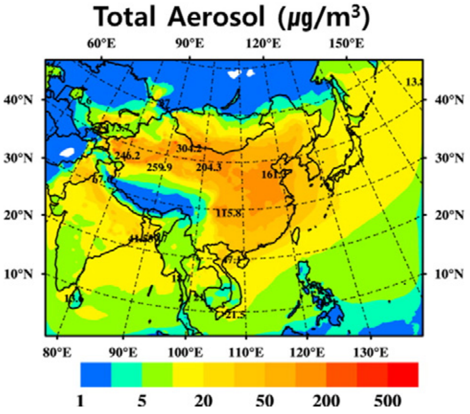
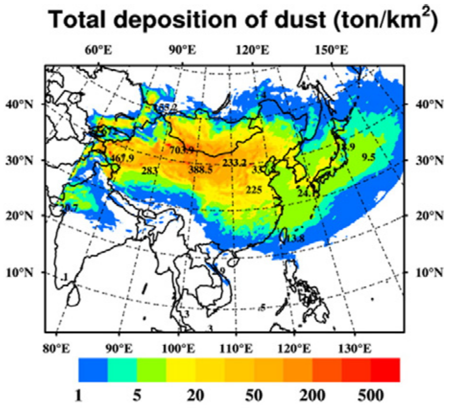
HIGHLIGHTS

- Aerosol Modeling System can simulate Asian dust (AD) and anthropogenic aerosols (AA)
- Aerosols in Asia are a mixture of AD and AA
- Annual mean concentration of AD (AA) exceeds 300 μg m^{-3} (110 μg m^{-3}) in the source region
- Annual total aerosol deposition in Asia is 485 Tg (372 Tg by AD and 113 Tg by AA)
- The dry deposition process is effective for AD while the wet deposition for AA

GRAPHICAL ABSTRACT





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ABSTRACT

Aerosol Modeling System (AMS) that is consisted of the Asian Dust Aerosol Model2 (ADAM2) and the Community Multi-scale Air Quality (CMAQ) modeling system has been employed to document the spatial distributions of the monthly and the annual averaged concentration of both the Asian dust (AD) aerosol and the anthropogenic aerosol (AA), and their total depositions in the Asian region for the year 2010. It is found that the annual mean surface aerosol (PM_{10}) concentrations in the Asian region affect in a wide region as a complex mixture of AA and AD aerosols; they are predominated by the AD aerosol in the AD source region of northern China and Mongolia with a maximum concentration exceeding 300 μg m^{-3}; AAs are predominated in the high pollutant emission regions of southern and eastern China and northern India with a maximum concentration exceeding 110 μg m^{-3}; while the mixture of AA and AD aerosols is dominated in the downwind regions extending from the Yellow Sea to the Northwest Pacific Ocean. It is also found that the annual total deposition of aerosols in the model domain is found to be 485 Tg (372 Tg by AD aerosol and 113 Tg by AA), of which 66% (319 Tg) is contributed by the dry deposition (305 Tg by AD aerosol and 14 Tg by AA) and 34% (166 Tg) by the wet deposition (66 Tg by AD aerosol and 100 Tg by AA), suggesting about 77% of the annual total deposition being contributed by the AD aerosol mainly through the dry deposition process and 24% of it by AA through the wet deposition process. The monthly mean aerosol concentration and the monthly total deposition show a significant seasonal variation with high in winter and spring, and low in summer.

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1. Introduction

Atmospheric aerosols can affect significantly the quality of our lives because of its potential impacts on human health and the environment. The submicrometer size of aerosols can be inhaled and thus may pose certain health hazards (Bates et al., 1966; Dockery et al., 1992; Binkowski and Shankar, 1995; Balásházy et al., 2003; Yadav et al., 2003; Davis et al., 2010), resulting in an increase in mortality (Perez et al., 2008; Sajani et al., 2010) and in respiratory (Cowie et al., 2010) and cardiovascular diseases(Chan et al., 2008; Middleton et al., 2008). Because aerosols also scatter light, they strongly influence the radiative budget of the Earth-atmosphere system; they also reduce visibility and diminish the esthetic scenery (IPCC (Intergovernmental Panel on Climate Change), 1996; Jacobson, 2001; Lee and Sequeira, 2001; Kaufman et al., 2002; Watson, 2002; Crutzen, 2004; Chang and Park, 2004; Penner et al., 2004; Park et al., 2005; Jung et al., 2009). Depositions of aerosols can affect significantly the terrestrial and marine eco-systems (Baker and Croot, 2010).

Asia is a major source of both natural aerosol (Asian dust) and anthropogenic aerosols over the Northern Hemisphere. Asian dust that is a typical example of mineral aerosol occurs in northern China and Mongolia more frequently during the spring season (Gao et al., 2000; Husar et al., 2001; Park and In, 2003; Park and Lee, 2004; Yu et al., 2011). Anthropogenic aerosols that are mainly originated from human activities and the formation by gas to aerosol conversion of pollutants have an increasing trend due to the rapid economic expansion in many Asian countries (Chun and Lim, 2004; Lee et al., 2006; Kim et al., 2008; Park et al., 2012). Therefore, the atmospheric aerosols in this region are the complex mixture of various aerosols including Asian dust and anthropogenic aerosols (Secondary inorganic aerosol, Secondary organic aerosol, Black carbon, Organic carbon, Water droplet and emitted particulate matter) (Park et al., 2013a;b).

Recently Park et al. (2012) have developed the Aerosol Modeling System (AMS) that is composed of the Asian Dust Aerosol Model2 (ADAM2) for the Asian dust aerosol modeling and the Community Multi-scale Air Quality (CMAQ) model for the anthropogenic aerosol modeling to predict high aerosol concentration events in Asia. This model has been used to simulate dense haze events occurred in May 2010 (Park et al., 2013a) and in January 2013 (Park et al., 2013b) in East Asia and found to simulate successfully these events.

Impact assessments of aerosols on the health, environment, ecosystems and climate variation require temporal and spatial distributions of aerosols with chemical compositions for a long term. However, long-term statistical data of aerosols are not usually available. The present study will provide a year-long data set of aerosols to make it possible to assess the effects of aerosols on health and environment in near future.

The purpose of this study is to examine the spatial and temporal distributions of both Asian dust and anthropogenic aerosols including Secondary Inorganic aerosol (SIA), Black Carbon (BC), Organic Carbon (OC), Secondary organic aerosol (SOA) and anthropogenic PM_{10} concentrations and their depositions simulated by the Aerosol Modeling System (AMS) in the Asian domain for the year 2010.

2. Model descriptions

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 the horizontal resolution of $27 \times 27\ km^2$ with 30 vertical layers in the Asian region.

The NCEP FNL operational global analysis data on a $1.0 \times 1.0°$ grid are used for the initial and lateral boundary conditions for the model.

2.2. Aerosol Modeling System (AMS)

The Aerosol Modeling System (AMS) is consisted of the Asian Dust Aerosol Model2 (ADAM2; Park et al., 2010a) and the Community Multiscale Air Quality (CMAQ) modeling system with emission data of pollutants (SO_2, NO_X, VOC, CO, NH_3, BC, OC and PM_{10}) in the model domain.

2.2.1. ADAM2

The ADAM2 model is an Eulerian dust transport model that includes the specification of the dust source regions delineated by the statistical analysis of the World Meteorological Organization (WMO) 3 hourly reporting dust data and statistically derived dust emission conditions in Sand, Gobi, Loess and Mixed surface soil in the model domain (Fig. 1). The model uses the suspended particle-size distribution parameterized by the several log-normal distributions in the source regions, based on the parent soil particle-size distributions with the used of the concept of the minimally and fully dispersed particle-size distribution (Lu and Shao, 1999; Gomes et al., 1990; Shao et al., 2002; Park and Lee, 2004). It has 11-size of bins with near the same logarithm interval for particles of 0.15–35 μm in radius (Park and In, 2003; Park and Lee, 2004). The model has 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 U.S. Environmental Protection Agency (EPA) Community Multiscale Air Quality (CMAQ) modeling system is a three-dimensional eulerian atmospheric chemistry and transport modeling system that simulates airborne pollutants, ozone concentration, particulate matters, visibility, and acidic and nutrient pollutant species throughout the troposphere (University of North Carolina, 2010).

The aerosol component of the CMAQ Version 8.7.1 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 the 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 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) that includes all major anthropogenic sources (Zhang et al., 2009). More than 60% of the total Asian anthropogenic emissions are contributed by China.

Air pollutant emissions in South Korea in the year 2007 are obtained from the Clean Air Policy Supporting System (CAPSS, Korea Ministry of Environment) in a $3 \times 3\ km^2$ grid scheme (Fig. 3). These emission data over South Korea are regridded in a $27 \times 27\ km^2$ grid scheme for the simulation of aerosols in the model.

3. Results of the model simulation

3.1. Comparison of observed and simulated aerosol (PM_{10}) concentration over South Korea

The Aerosol Modeling System (AMS) has been employed to simulate concentrations of PM_{10} for the whole year of 2010 in the model domain (Fig. 1).