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Spatial distributions of aerosol loadings and depositions in East Asia during the year 2010

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HIGHLIGHTS

- Aerosol Modeling System simulates well all kinds of aerosols in the atmosphere.
- Aerosols in Asia are a mixture of the Asian dust (AD) and the anthropogenic aerosol.
- Annual mean surface AD concentration exceeds 200 μg m^{-3} in the source region.
- Annual total deposition of aerosols in the Asian domain is about 4.9×10^8 t.
- Annual total dry deposition (wet deposition) is about 3.2×10^8 t (1.7×10^8 t).

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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 geographical distributions of both the annual averaged Asian dust aerosol and the anthropogenic aerosols concentrations and their total depositions in the East Asia region for the year 2010. It is found that AMS simulates quite well the monitored PM_{10} concentration with a root mean square error (RMSE) of 9.2 μg m^{-3} and a normalized mean square error (NMSE) of 5.5% in South Korea and the RMSE of less than 33 μg m^{-3} with a NMSE of less than 7.8% at the monitoring sites in China. The annual mean surface (column integrated) aerosol concentrations in the East Asia region affect in a wide region as a complex mixture of the Asian dust (AD) aerosol and the anthropogenic aerosol (AA), more predominated by the AD aerosol in the Asian dust source region of northern China and Mongolia with the annual mean (column integrated) PM_{10} concentration of more than 200 μg m^{-3} (350 mg m^{-2}). Whereas AA is dominated in the high pollutant emission regions of southern and eastern China and northern India with the annual mean surface (column integrated) concentration of more than 110 μg m^{-3} (140 mg m^{-2}) in eastern China. On the other hand the mixed aerosols (AD + AA) are dominated in the downwind regions of the Yellow Sea, the East China Sea, the Korean peninsula, Japan, and the Northwest Pacific Ocean. It is also found that the annual total deposition of aerosols in the model domain is 4.9×10^8 t (3.7×10^8 t by AD aerosol and 1.2×10^8 t by AA), of which 66% (3.2×10^8 t) is found to be contributed by the dry deposition (3.1×10^8 t by AD aerosol and 1.3×10^7 t by AA) and 34% (1.7×10^8 t) by the wet deposition (1.0×10^8 t by AA and 6.6×10^7 t by AD aerosol), suggesting significant impacts of aerosols on environment and the terrestrial and marine eco-systems in East Asia.

1. Introduction

Atmospheric aerosols can affect the quality of our lives significantly because of their potential impacts on human health and the environment. The sub-micrometer size of aerosols can be inhaled and thus may pose certain health hazards (Bates et al., 1966; Pope et al., 1993; 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

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the aesthetic scenery (IPCC, 1996; Jacobson, 2001; Lee and Sequerira, 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., 1998; In and Park, 2003; Park and In, 2003; Park and Lee, 2004; Yu et al., 2011) and has its increasing occurrence trend due to desertification in some of regions. Anthropogenic aerosols that are mainly originated from human activities and the formation by gas to aerosol conversion of pollutants have also 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) Version 4.7.1 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 data set of aerosols for a year to make it possible to assess the effects of aerosols on health and environment.

The purpose of this study is to examine the spatial distributions of annual mean 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 column integrated concentrations and the annual total depositions of these aerosols simulated by the Aerosol Modeling System (AMS) in the East Asian domain for the year 2010.

2. Model descriptions

2.1. Meteorological model

The meteorological model used in this study is the fifth generation meso-scale 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 27×27 km^2 with 30 vertical layers in the Asian region excluding Middle East (East Asia).

The NCEP FNL re-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, b) for the simulation of the Asian dust aerosol and the Community Multi-scale Air Quality (CMAQ) Version 4.7.1 modeling system (http://www.cmaq-model.org) for the estimation of anthropogenic aerosols 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 (Fig. 1). The detailed description of the model is given in Park et al. (2010a).

2.2.2. CMAQ model

The U.S. Environmental Protection Agency (EPA) Community Multi-scale Air Quality (CMAQ) Version 4.7.1 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 4.7.1 model has the particle size distribution as the superposition of three log-normal sub-distributions, called modes. Fine particles with diameters less than 2.5 μm ($PM_{2.5}$) are represented by two sub-distributions 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 geometric standard deviations are 1.70 μm, 2.00 μm and 2.20 μm for the Aitken, accumulation and coarse modes, respectively. The model includes the processes of coagulation, particle growth by the addition of mass and new particle formation (Binkowski and Roselle, 2003). The model domain of the CAMQ Version 4.7.1 is the same as that of the MM5 having the horizontal resolution of 27×27 km^2 with 30 vertical layers.

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, excluding biomass burning (Zhang et al., 2009). More than 60% of the total Asian anthropogenic emissions are contributed by China. Pollutants emissions from biomass burning may have some impacts on aerosol loadings in South East Asia especially during the spring season. However the acceptable emission inventory data are not available at present.

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 3×3 km^2 grid scheme. These emission data are regridded in a 27×27 km^2 scheme for the simulation of aerosols in the model. The difference between the INTEX-B emission data and the regridded CAPSS data over South Korea is slight so that the impact of it is negligible.