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AN ANTHROPOGENIC EMISSIONS PROCESSING SYSTEM FOR ASIA USING SMOKE

Jung-Hun Woo* and Ki-Chul Choi
Department of Advanced Technology Fusion, Konkuk University, Seoul, South Korea

Bok H. Baek
Institute for the Environment, The University of North Carolina, Chapel Hill, NC, USA

Meongdo Jang
Korea Meteorological Industry Promotion Agency, Seoul, South Korea

Young-Il Ma
Department of Environmental Engineering, Konkuk University, Seoul, South Korea

1. INTRODUCTION

Asia has been a major contributor to anthropogenic emissions(CO, NOx, NMVOC, SO_2) worldwide. Its total emissions comprises approximately 20-40% of the world's total emissions, based on Olivier et al. [2005]. Total energy consumption in Asia more than doubled between 1980 and 2003. By year 2000, SO_2, NOx, and NMVOC emissions from the Continent of Asia were projected to increase by 22%, 44%, and 99%, respectively (Ohara et al., 2007). Recently, satellite observations have demonstrated that emissions in Asia have accelerated impressively since 1995(Donkelaar et al., 2008; Zhang et al., 2007; Zhang et al., 2008; Lu et al., 2010).

Air quality modeling is a useful methodology for investigating air quality degradation and for predicting effectiveness of emission control measures. Emissions and meteorology information are critical components of the modeling framework. Exercising the atmospheric models requires a coordinated set of emission inputs of all necessary species. It is important that these emission fields correctly reflect the spatial and temporal patterns of the emissions (Streets et al., 2003).

Emissions inventories are typically compiled with an annual emissions value for each administrative boundaries based on statistical data. Air quality models(AQMs), however, require all model species emission data in hourly gridded format. An emissions processing system, capable of transforming emissions data by spatial allocation, chemical speciation, temporal allocation and optionally layer assignment, is needed in support of the air quality modeling.

Recently, the emissions processing system has been developed and implemented by several developed countries, and extensively used for air quality studies (Baldasano et al., 2008; Borge et al., 2008; UNC, 2009). Several emission processing system researches have been conducted in Asia but they were either not fully comprehensive (Kim et al., 1998, Woo et al., 2003, Kannari et al., 2007), or limited to a smaller region(Kim et al., 2008, Wang et al., 2005). We, therefore, have developed a comprehensive anthropogenic emissions processing system which covers Asia entirely, in support of air quality modeling and analysis. The SMOKE(Sparse Matrix Operator kernel Emissions), which was developed by the United States Environmental Protection Agency (U.S. EPA) and has been maintained by the Carolina Environmental Program(CEP) of the University of North Carolina(UNC, 2005), was selected as the base system for developing an Asian emissions processing system. The SMOKE emissions processing system is based on a parallel approach to emissions processing and was redesigned and improved with the support of the U. S. EPA, for use with EPA's Models-3 Air Quality Modeling System. SMOKE can process criteria gaseous pollutants, and particulate matter pollutants as well as a large array of toxic pollutants(UNC, 2004).

Although SMOKE is a powerful and flexible emissions processing system, it's strongly oriented to applications in the United States. Development of emission inventories and processing surrogates base on the regional characteristics are required to build a successful emissions processing system for Asia.

**Corresponding author:* Jung-Hun Woo, Department of Advanced Technology Fusion, Konkuk University, Seoul, South Korea;
e-mail: woojh21@gmail.com

2. METHODOLOGY

2.1 Inventory dataset

In this study, we have reviewed and analyzed a number of existing Asian emissions inventories(Table 1), then developed an up-to-date emission inventory using that information. Evaluation is based on data availability and accessibility, spatial-temporal coverage, resolution, and etc. As a result, a merged version of INTEX 2006(Zhang et al., 2009) and TRACE-P 2000(Streets et al., 2003) inventories was developed and further processed. The emissions domain stretches from Pakistan in the West to Japan in the East and from Indonesia in the South to Mongolia in the North, which is the same as the domain of Streets et al (2003) and Zhang et al., 2009.

Table 1. Characteristics of Asian emission inventories

	LTP *	TRACE-P 2000**	REAS+	INTEX 2006++
Domain	China, Korea, Japan	Asia	Asia (include Afghanistan)	Asia
Spatial resolution	1°X1°	1°X1°	0.5°X0.5°	0.5°X0.5°
Temporal resolution	annual	annual	annual	annual
Base year	1998	2000	Historical: 1980-2003 Base: 2000 Prediction: 2004-2009 Project: 2010, 2020	2006
Pollutants	SO_2, NOx, CO, NH_3, PM_{10}, VOC	SO_2, NOx, CO, VOC, NH_3, BC, OC, CO_2, CH_4	SO_2, NOx, CO, VOC, NH_3, BC, OC, CO_2, CH_4, N_2O	SO_2, NOx, CO, VOC, BC, OC, PM_{10}, $PM_{2.5}$

Source : *Secretariat of Working Group for LTP project, 2006; **Streets et al., 2003; +Ohara et al.,2007; ++Zhang et al., 2009.

To support past-year studies, we developed a 13-years (1997-2009) emissions inventory using REAS projection data(Ohara et al., 2007). The IDA(Inventory Data Analyzer) format was used to create SMOKE-ready emissions.

2.2 Activity and FIPs code

Source Classification Codes(SCCs) are used to classify different types of anthropogenic emission activities, which are also required for SMOKE processing. Asia emission inventories, however, provide only simplified source classification systems, such as the 1st level emission sectors (e.g. power, industry, residential, and transportation). Second level sectors from EDGAR 3.2 FT 2000 (Olivier, 2005) over Asia, therefore, were extracted to develop more detailed SCCs.

As for administrative division codes, SMOKE uses a 6-digit integer code, i.e. FIPS code, to identify the country, state and county for a particular source. Fig. 1 shows administrative regions in Asia which were used as the bases for FIPS code development. 1st level administrative unit (state/province) and 2nd level administrative unit (county) were used to create a SMOKE COSTCY file for Asia.

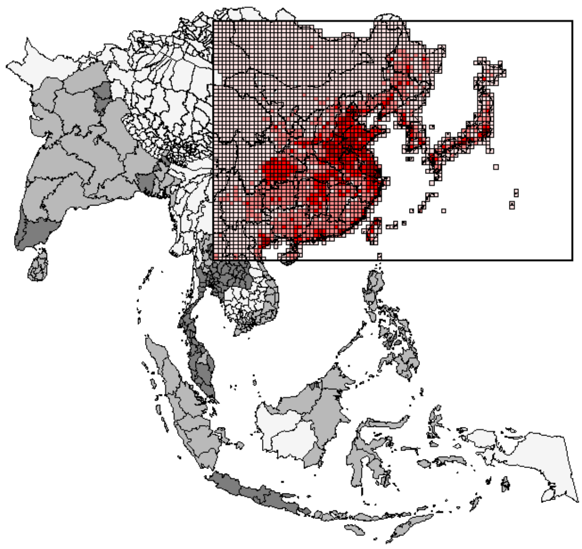

Fig. 1. Generation of geographical administrative codes for SMOKE. Sub-grid domain present our modeling domain.

2.3 Spatial allocation

The spatial processing combines the grid specification for the air quality modeling domain with source locations from the SMOKE inventory file (UNC, 2004). Spatial allocation is important because the geographical location of emissions need to be determined as accurately as possible, to improve air quality modeling performance. For spatial allocation, SMOKE relies on a set of spatial surrogate data and cross-reference files. From these information, the SMOKE Grdmat program creates the gridding matrix for area, mobile, and point sources(UNC, 2004). In order to create the gridding profiles, MIMS(Multi-scale Integrated Modeling System) Spatial Allocator was used to process a set of GIS shape files that include socio-geographical information over Asia. Fig. 2 shows some examples of our spatial surrogates.

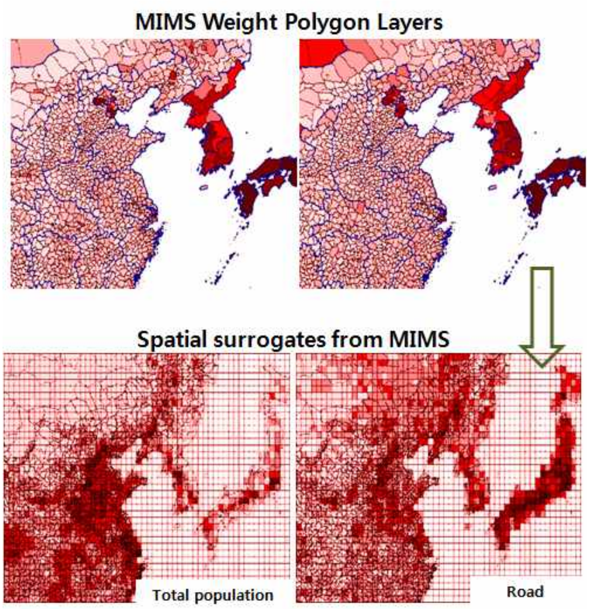

Fig. 2. Schematic of spatial surrogates from MIMS Spatial Allocator

2.4 Temporal allocation

Generally, Asian inventories are intended to report annual emissions, but time resolved emissions are needed to properly simulate air quality through comprehensive Eulerian models such as Models-3/CMAQ(Community Multiscale Air Quality). Annual estimates, therefore, need to be broken down to 1-hour temporal resolutions.

Monthly, weekly and diurnal profiles in the SMOKE package are very comprehensive. However they were developed for the United States. Temporal allocation profiles need to be regionalized to correctly represent temporal variations of Asian activities. We reviewed literatures for the Asian emissions inventory and temporal variation (Table 2), such as Streets et al. [2003], Wang et al. [2005], D.Y. Kim [1998], W.G. Shin [2008] and EDGAR temporal allocation factors(the original set was made by Veldt [1991] for LOTOS, a European climate model).

Table 2. References for temporal allocation in Asia

Region	Sector	Reference
China	Power	W. G. Shin [2008]
	Industry	Streets et al.[2003]; Wang et al.[2005]
	Solvent use	EDGAR (Veldt [1991])
	Residential	Streets et al.[2003]
	Transportation	Streets et al.[2003]; Wang et al.[2005]
S. Korea	Power	W.G. Shin [2008]
	Industry	EDGAR (Veldt [1991])
	Solvent use	EDGAR (Veldt [1991])
	Residential	Kim [1998]
	Transportation	U.S. EPA profile
Japan	Power	EDGAR (Veldt [1991])
	Industry	EDGAR (Veldt [1991])
	Solvent use	EDGAR (Veldt [1991])
	Residential	Kim [1998]
	Transportation	Kannari et al.[2007]
India	Power	EDGAR (Veldt [1991])
	Industry	EDGAR (Veldt [1991])
	Solvent use	EDGAR (Veldt [1991])
	Residential	Streets et al.[2003]
	Transportation	EDGAR (Veldt [1991])
Southeast Asia	Power	EDGAR (Veldt [1991])
	Industry	EDGAR (Veldt [1991])
	Solvent use	EDGAR (Veldt [1991])
	Residential	Streets et al.[2003]
	Transportation	EDGAR (Veldt [1991])
Other Asia	Power	EDGAR (Veldt [1991])
	Industry	EDGAR (Veldt [1991])
	Solvent use	EDGAR (Veldt [1991])
	Residential	EDGAR (Veldt [1991])
	Transportation	EDGAR (Veldt [1991])

2.5 Chemical speciation

Emission inventories are reported for a variety of pollutants, such as CO, NOx, VOC, SO_2, PM_{10} and $PM_{2.5}$. However, chemical mechanisms used by air quality models contain a simplified set of equations that use “model species” to represent atmospheric chemistry(UNC, 2004). SMOKE is capable to convert these “inventory pollutants” into “model species” using speciation profiles and cross-references. Speciation profiles and cross-references in the SMOKE packet were mainly used for our work. Some chemical speciation profiles for Asian emissions were developed using Zhang et al (2006) and Streets et al.(2003). Cross-reference files which link our inventory to speciation profiles were also developed.

3. RESULTS: APPLICATION TO EAST ASIA

3.1 Summary of emissions processing

A SMOKE-based anthropogenic emissions processing system for Asia was developed as illustrated in Fig. 3. Here we named it as "SMOKE-Asia".

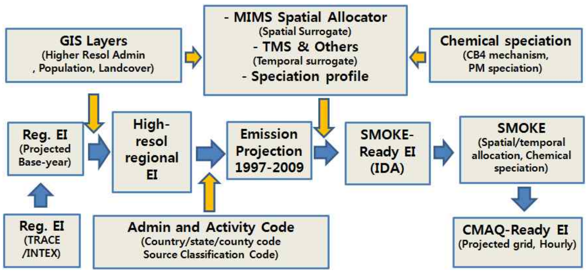

Fig. 3. Scheme of the Emission Modeling/ Processing System for Asia

To validate the SMOKE-Asia implementation, air quality model-ready emission inputs were prepared for the 54km grid East Asia domain for the year 2006.

3.2 Inter-annual trend in Asia

To support past-year studies, we are trying to develop a 13-years (1997-2009) emissions inventory. Fig. 4 presents the inter-annual emission trends of seven criteria air pollutants in Asia. NOx and VOC emissions for the year 2009 will be increased by 50% from those of 1997, and this would increase tropospheric ozone production over Asia. SO_2 emissions increased by 20.2% from 1997 to 2009. The rate of increase, however, show negative values after 2003, due to more stringent control measures adopted in China. In this study, province level projection parameters were extracted from REAS data (Ohara et al., 2007).

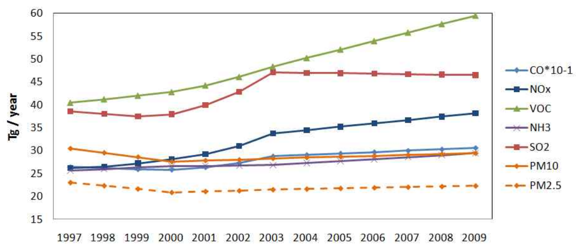

Fig. 4. Inter-annual emissions in Asia (CO multiplied by 10^{-1} times)

3.3 Spatial distribution

An example of spatial distribution of NOx emissions from anthropogenic sources in our modeling domain(54km resolution) is shown in Fig. 5. The emission hotspots, such as large cities and large point sources, are distinguished in the domain. East China shows higher emission rates than any other region.

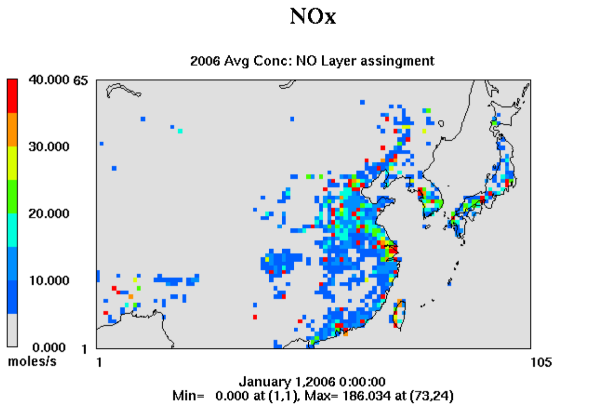

Fig. 5. Average NOx emissions in our modeling domain for year 2006(NO layer assignment)

3.4 Temporal distribution

Hourly distribution of annual emission estimates were carried out using SMOKE-Asia. In the 2006 simulation, emissions rates in winter were generally greater than those of summer due to heating needs. The US type summer emissions peak was not estimated from our work because of low air conditioning needs in Asia. The maximum difference of hourly CO emission rates between flat emissions and hourly-varied emissions was approximately 115% for our modeling domain.

3.5 Chemical speciation

U.S. EPA CB-4 chemical mechanism was applied for this case study. Monthly aggregated chemical compositions of NMVOCs and $PM_{2.5}$ are shown in Fig. 6. The paraffins showed the largest emission rate among VOC species. The XYL (Xylene and other polyalkyl aromatics) took the second largest portion of VOCs. Monthly variation of speciated chemical species revealed January enhancement of XYL emissions by 2.5 times, compared to July.

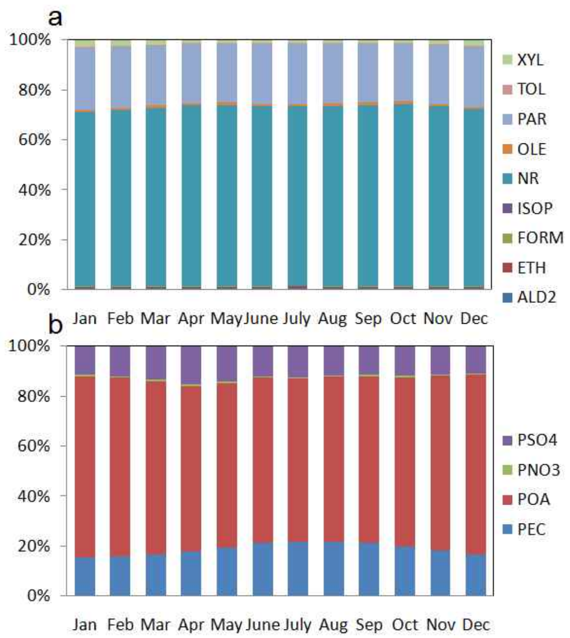

Fig. 6. Fractional emissions of VOC(a) and $PM_{2.5}$(b) species (2006)

3.6 Layer assignment

Point source emission inventory, which derived from Streets et al.[2003], has 115 point sources in Asia. Monthly aggregated vertical distribution for East Asia is shown in Fig. 7. From this study, it was found that no emissions were effectively released beyond the 13th vertical layer of the model (approximately 4900m Above Ground Level, AGL). Most of the emissions are located in layers 3 to 4, which the altitude range reaches 310-550m AGL.

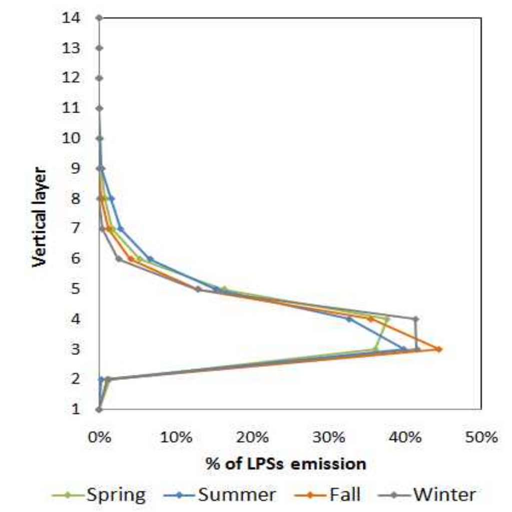

Fig. 7. Point source emission vertical profiles(Spring: Mar.-May, Summer: Jun.-Aug., Fall: Sep.-Nov., Winter: Dec.-Feb.)

4. SUMMARY

An anthropogenic emissions processing system for Asia was developed in support of the air quality modeling and analysis over the continent. The SMOKE system was selected as a system for the Asian emissions processing. A merged version of INTEX 2006(Zhang et al., 2009) and TRACE-P 2000(Streets et al., 2003) inventories was developed in this study. The IDA(Inventory Data Analyer) format was used to create SMOKE-ready emissions for Asia. Source Classification Codes(SCCs) and country/state/county (FIPS) code, which are the two key data fields of SMOKE IDA data structure, were created for Asia. MIMS(Multimedia Integrated Modeling System) Spatial Allocator software was used to create spatial allocation data for Asia. Temporal allocation profiles and chemical speciation profiles were regionalized using Asia-based studies. Qualitative inter-comparison between model output and ground/satellite measurement showed good agreements in terms of spatial and temporal patterns. The results of this study can provide better air quality model input data, which help to improve our understanding for emission impacts on Asian air quality.

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