Asian Journal of Atmospheric Environment
Vol. 2-1, pp.34-46, June 2008

Korea Emissions Inventory Processing Using the US EPA's SMOKE System

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ABSTRACT

Emissions inputs for use in air quality modeling of Korea were generated with the emissions inventory data from the National Institute of Environmental Research (NIER), maintained under the Clean Air Policy Support System (CAPSS) database. Source Classification Codes (SCC) in the Korea emissions inventory were adapted to use with the U.S. EPA's Sparse Matrix Operator Kernel Emissions (SMOKE) by finding the best-matching SMOKE default SCCs for the chemical speciation and temporal allocation. A set of 19 surrogate spatial allocation factors for South Korea were developed utilizing the Multi-scale Integrated Modeling System (MIMS) Spatial Allocator and Korean GIS databases.

The mobile and area source emissions data, after temporal allocation, show typical sinusoidal diurnal variations with high peaks during daytime, while point source emissions show weak diurnal variations. The model-ready emissions are speciated for the carbon bond version 4 (CB-4) chemical mechanism. Volatile organic carbon (VOC) emissions from painting related industries in area source category significantly contribute to TOL (Toluene) and XYL (Xylene) emissions. ETH (Ethylene) emissions are largely contributed from point industrial incineration facilities and various mobile sources. On the other hand, a large portion of OLE (Olefin) emissions are speciated from mobile sources in addition to those contributed by the polypropylene industry in point source. It was found that FORM (Formaldehyde) is mostly emitted from petroleum industry and heavy duty diesel vehicles. Chemical speciation of PM2.5 emissions shows that PEC (primary fine elemental carbon) and POA (primary fine organic aerosol) are the most abundant species from diesel and gasoline vehicles.

To reduce uncertainties in processing the Korea emission inventory due to the mapping of Korean SCCs to those of U.S., it would be practical to develop and use domestic source profiles for the top 10 SCCs for area and point sources and top 5 SCCs for on-road mobile sources when VOC emissions from the sources are more than 90% of the total.

Key words: Emissions inventory, CAPSS, SMOKE, Air quality, Internal database

1. INTRODUCTION

Air quality modeling is used to understand source-receptor relationship of the present air quality problems and to predict effectiveness of an emission reduction plan. It requires fundamental inputs such as emissions and meteorology data to simulate concentrations of air pollutants in the atmosphere. The raw emissions inventory (EI) data that represent regional emission characteristics must be processed to provide inputs for air quality models.

The National Institute of Environmental Research (NIER), Korea, has implemented emissions processing methods to build the emissions inventory that can be used for air quality researches and policy-making decisions in Korea. The resulting emissions inventory includes the country-specific information such as different emission characteristics, source classifications, data formats and availability, and a map projection for source locations. However, the diverse information and different formats of the inventory data make it difficult for researchers to process the emissions inventory with existing emissions processors such as the Sparse Matrix Operator Kernel Emissions (SMOKE) (CEP, 2004; Benjey *et al.*, 2001; Coats *et al.*, 1996, 1995) or the Emissions Preprocessing System (EPS) (U.S. EPA, 1992).

Another problem encountered when processing the emissions inventory is related to the internal data that characterize chemical species and spatial and temporal distributions of emission sources. The emission processing systems depend on cross-reference tables and profiles for chemical speciation, spatial allocation, and temporal allocations. For successful air quality

Table 1. The CAPSS Emissions Inventory used in this study.

Source	EI category	Emission type
Non-point emissions	Area	Annual, County-based, reclassified with SCC codes from non-point emissions
	Non-road mobile	Annual, County-based, reclassified with SCC codes
	Mobile	Annual, County-based, reclassified with SCC codes
	Biogenic	Annual, County-based, reclassified with SCC codes from non-point emissions,Currently NH_3 only
Point emissions	Major point sources	Annual and Month emission rates, A TRM map projection used for the location, Stack parameters are available for each source.
	Small point sources	Annual, County-based, Stack parameters are not available.

Note: "County-based" represents the emissions are prepared for each city ('Si') or 'Gu'.

simulations, it is essential to establish such internal data that represent characteristics of an emissions inventory adequately. For example, the US EPA releases the cross-reference table for VOC chemical speciation and emission shape files to generate surrogates for spatial allocation. Currently, these internal data for the Korea emissions inventory were not yet available for the national use, and the users need to take responsibility of choosing and preparing them prior to processing the inventory. Therefore, it is desirable to build a set of internal data specifically developed to process the Korea emissions inventory.

In this study, we intend to process the Korea emissions inventory developed for the Clean Air Policy Support System (CAPSS) to generate model-ready emission inputs for air quality models using the US EPA's SMOKE system. We discuss how the Korea emissions inventory is reformatted, what information for each source type is used in the data conversions, and what difficulties and limitations are involved with the work. Considering a set of internal data to process the domestic emissions inventory needs to be developed actively, the default internal data in the SMOKE system are utilized in this initiation work, after SCC mapping for individual sources. However the SCC mapping is not a straightforward work, and there would be uncertainties in identifying source characteristics in different classifications between two countries. Emphasizing the importance of the domestic internal data to process an emissions inventory, this study tries to prioritize emission sources in each source type for which the internal data needs to be prepared first to assure the emission characteristics in the country.

2. EXPERIMENTAL DATA AND MODEL

2.1 SMOKE

The SMOKE has been continuously improved over the years with the support of the U.S. EPA for use with the Models-3 Community Multiscale Air Quality (CMAQ) modeling system (Byun and Schere, 2006; Byun and Ching, 1999). The SMOKE system enables fast and efficient processing of emissions inventories utilizing high-performance-computing sparse-matrix algorithms (Houyoux *et al.*, 2000; Coats *et al.*, 1996). It supports various data input formats such as Inventory Data Analyzer (IDA), Emissions Modeling System (EMS), and AIRS Area and Mobile Source (AMS) /AIRS Facility subsystem (AFS) formats. One of the key scientific benefits of using the SMOKE system is that it allows easy extension of the chemical mechanisms, permitting investigation of the effects of the specific chemical components (e.g., highly reactive C2 -C4 olefin species). With some additional efforts, the SMOKE system can be extended to include particulate emissions and air toxic species. The computational benefits of the SMOKE system include the ability to process emissions much faster than other systems, to minimize redundant data storage for decreased file sizes, and to provide outputs for the air quality models (AQM) such as CMAQ and CAMx (Comprehensive Air Quality Model with Extension) modeling systems.

2.2 Korea Emissions Inventory

The 2004 Korea emissions inventory, developed as an effort in the Clean Air Policy Support System (CAPSS) database, was utilized in this study. Hereafter, the emissions inventory will be referred as the Korea emissions inventory. The emissions inventory can be divided into point and non-point source emissions for seven criteria species; a) NO_x, b) VOC, c) CO, d) NH_3, e) SO_2, f) PM10, and g) TSP. Table 1 lists the emissions inventory category for each source type.

2.3 Emission Shape Files for Spatial Allocation

The SMOKE system does not provide surrogate information for Korea, and therefore it is necessary to prepare them for spatial allocation of emissions based on a map projection used for a model domain setup.

2. 4 Internal Data for Chemical Speciation and Temporal Allocation

The same emissions inventory processed with an emission processing system such as SMOKE or EPS can result in different model-ready emissions because of their dependencies on cross-reference tables and profiles used for spatial and temporal allocations, and chemical speciation (Hogrefe *et al.*, 2003). The cross-reference tables are used to assign a profile for an emission source based on source information such as SCC, and the profiles include split factors for chemical speciation, fractional coverage for spatial allocation, and monthly/weekly/hourly emission rates for temporal allocation. To process the Korea emissions inventory with SMOKE, the default cross-reference and profiles implemented in SMOKE were used for chemical speciation and temporal allocation in this study. For this, the Source Classification Codes (SCCs) used in the Korea inventory must be properly assigned to the best-matching profiles in the internal data of SMOKE. Currently the U.S. has prepared around 10,000 SCCs to describe emission sources. On the other hand, the CAPSS sets up around 800 SCCs based on an independent set of numbering system that is not compatible with that from the U.S. EPA. We assumed that similar emissions sources in the two systems represent the same temporal variation and chemical compositions although the default internal data in SMOKE prepared for emissions sources in the North America were not yet validated for emissions sources in Korea.

2. 5 Meteorological Data

For the SMOKE processing, we have prepared the meteorological data such as winds and air temperature with MCIP (Meteorology-Chemistry Interface Processor) using a set of MM5 (Mesoscale Model) simulations. The meteorological information was used for plume rise of major point sources to allocate emissions vertically.

3. DATA PREPARATION

3. 1 Development of Surrogates for Spatial Allocation

In order to prepare a set of spatial surrogates for a modeling domain, a spatial surrogate generator in the Multi-scale Integrated Modeling System (MIMS) was used by processing a set of GIS shape files that include socio-geographical information over Korea, such as population, roads, railroads, ports, forests, and so on. Quality assurance of the shape files acquired through municipal governments was first conducted using the Arc GIS® before they were used as inputs for the MIMS spatial allocator. For example, data resolution, location, and coverage were generally examined. Map projections used in the shape files were checked and converted to another one for convenient processing, if necessary. Also, the shape files were manipulated to extract selected information only (i.e., extraction of highways from all road networks). Table 2 lists the emissions shape classes to process the Korea emissions inventory in this study. Shape types and attributes used to generate surrogates are also presented. For instance, area of agricultural land was used to estimate the fractional coverage for each cell. In case of airports (point) and roads (line), the locations and total lengths on the corresponding cells were calculated respectively to generate the surrogates. Fig. 1 shows examples of shape files and gridded data over a modeling domain at a 9-km resolution. These surrogates were used in SMOKE processing to create the gridded emissions for county-based emissions such as area, mobile, and biogenic emissions.

Table 2. Shape types and attributes of surrogates to process the Korea emissions inventory.

	Surrogate	Shape type	Attribute
1	Agriculture	Polygon	Area
2	Airport	Point	Location
3	Land area	Polygon	Area
4	Household	Polygon	Area
5	Highways	Line	Length
6	Population	Polygon	Population
7	Port	Point	Location
8	Railroad	Line	Length
9	Navigable	Line	Length
10	Rural area	Polygon	Area
11	Urban area	Polygon	Area
12	Forest	Polygon	Area
13	Urban primary road	Line	Length
14	Rural primary road	Line	Length
15	Urban secondary road	Line	Length
16	Rural secondary road	Line	Length
17	Urban population	Polygon	Population
18	Rural population	Polygon	Population
19	County	Polygon	Area

3. 2 Source Classification Code Mapping

3. 2. 1 Reclassification of the SCCs in the Korea Emissions Inventory

As described in Table 1, the Korea emissions inventory used in this study was prepared in two data formats; one for non-point sources and the other for point sources. To process emissions for each source type

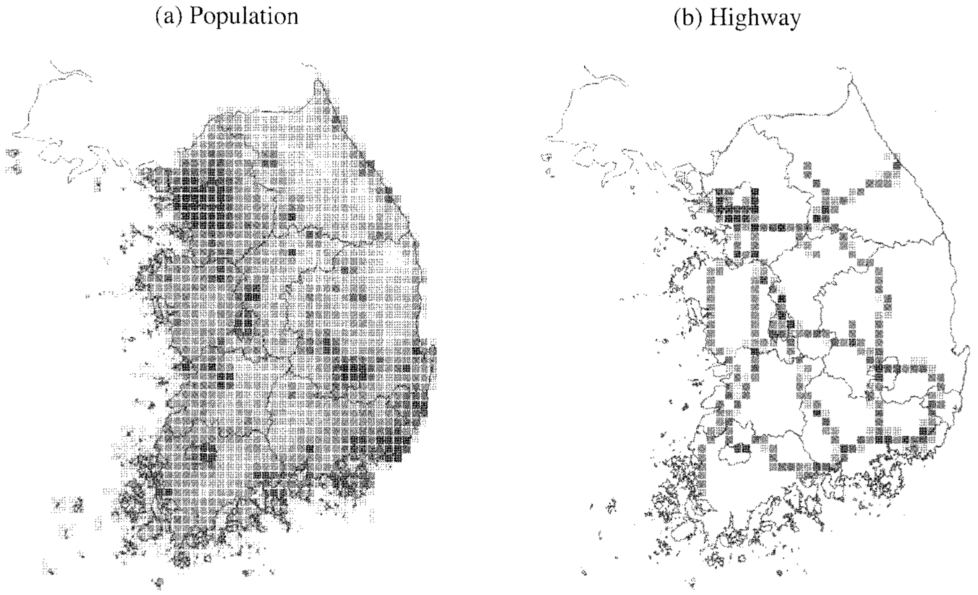


Fig. 1. Surrogates of (a) population and (b) highway gridded for a 9-km domain to process Korea emissions inventory.

Table 3. Descriptions and numbers of source classification codes in Korea.

SCC[1]	Description	Number of SCCs
01	Electric generating utility (EGU) combustion	34
02	Non-electric generating utility (NEGU) combustion	22
03	Industrial combustion	53
04	Industrial Processes	240
05	Storage and Transport	5
06	Solvent utilization	22
07	On-road mobile	128
08	Non-road mobile	138
09	Waste treatment	26
10	Biogenic	103
11	Agriculture	32

[1] The first level SCC classification in the Korea emissions inventory is used.

Table 4. Descriptions and numbers of source classification codes in the US.

SCC[1]	Description	Source type	Number of SCCs
1	External combustion boilers	Point	227
21	Stationary source fuel combustion	Area	76
2	Internal combustion engines	Point	229
22	Mobile sources	Area	1226
3	Industrial processes	Point	4338
23		Area	98
4	Petroleum and solvent evaporation	Point	1548
24	Solvent utilization	Area	190
25	Storage and transport	Area	459
5	Waste disposal	Point	306
26		Area	71
6	MACT source categories	Point	685
27	Natural sources	Area	81
28	Miscellaneous area sources	Area	209
28	Wildfire and burning	Area	17

[1] The first one digit and two digits in SCC codes are used for point and area sources respectively to classify the US SCCs.

and to better match SCCs between Korea and the U.S., the non-point emissions were reclassified to area, non-road, on-road mobile, and biogenic emissions based on the first level SCC descriptions. Here, the first level SCC represents the first two characters used SCC as shown in Table 3. Descriptions of the first level SCCs and numbers of SCCs available for each are also presented in the table. Among 800 SCCs in the CPASS, around 500 SCCs are currently being used in the Korea emissions inventory and they are mapped to those from the U.S. EPA (http://www.epa.gov/ttn/chief/codes/index.html) to assign profiles for chemical speciation and temporal allocation. Similar to Table 3, classifications of the U.S. EPA's SCC system are presented in Table 4.

3.2.2 SCC Mapping between Korea and the U.S.

During this step, SCCs for all emissions inventory records in the Korea emission inventory were mapped to those in the U.S. (Refer to the description of each SCC at levels 1 to 4). Here, level 1 means a major classification, and the higher level represents more

Table 5. Examples of SCC mapping between Korea and the U.S.

SCC		Descriptions			
		Level 1	Level 2	Level 3	Level 4
Korea	04010100	Manufacturing process	Petroleum product industry	Petroleum product process	Point source
The U.S.	30699998	Industrial processes	Petroleum industry	Petroleum products	Not classified
Korea	06010300	Organic solvent	Painting facility	Architecture & building	Area source
The U.S.	2401001000	Solvent utilization	Surface coating	Architectural coatings	Total: all solvent types

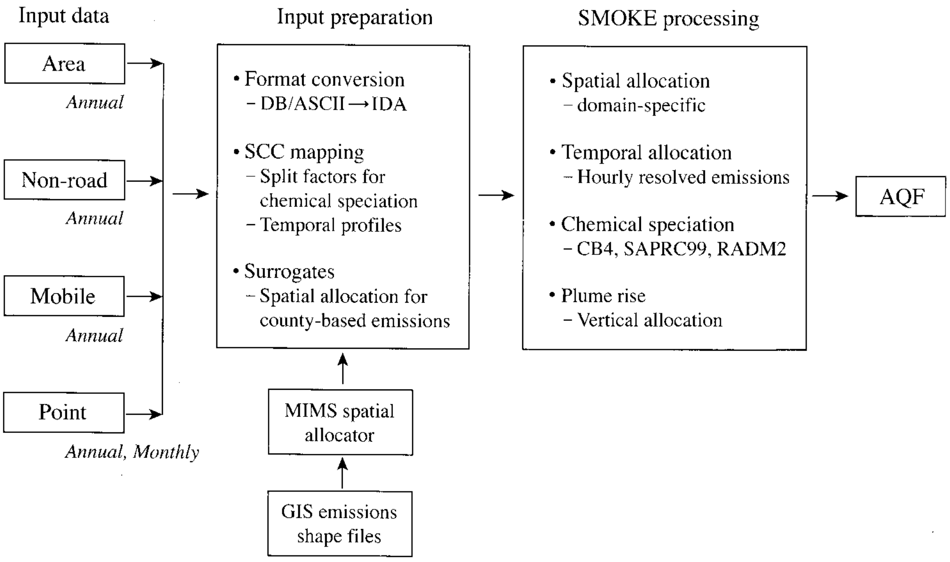


Fig. 2. A schematic diagram showing how the Korea emissions inventory is processed with the SMOKE system. Emissions inventory data in the CAPSS are reformatted to the SMOKE-ready format. A SCC mapping is used to have internal data for temporal allocation and chemical speciation. A set of shape files is used to prepare spatial surrogates for a domain with the MIMS spatial allocator.

detailed classification. Table 5 shows examples of SCC mapping for petroleum product (04010100) and organic solvent (06010300) in the Korea emissions inventory. More detailed SCC mapping used in this study can be found from the Korean Environment Institute report (2007).

3.3 Emissions Input Preparation

Once the Korea emissions inventory data are converted to one of the SMOKE-ready formats, they are processed with SMOKE to generate model-ready emission inputs for simulating ozone and particulate matter concentrations over Korea with an air quality model.

3.3.1 Non-point Source Emissions

Emissions data from area, non-road and on-road mobile sources were converted into the IDA format for area sources to prepare individual emissions record for each subregion such as Si, Gun, and Gu. Each record includes an administration code for each subregion, SCC, and emissions rate for each emission pollutant. The Korea emissions inventory for these sources is available as the annual emission rates. The optional peak ozone day average emissions are assigned to be zero in the IDA formatted emission records.

3.3.2 Point Source Emissions

The IDA format was used for point source inventory to convert the Korea emission inventory. Unlike other types of emissions, the inventory provides point source emissions in both annual and monthly emissions rates. Thus, in addition to annual emission files for each pollutant, monthly emission files were prepared separately to provide an option to choose proper point source emissions for a specific modeling episode of interest. Each emission record includes an administration code, SCC, stack parameters such as stack height, stack diameter, temperature and exit velocity of exhausting gas for plume rise, and locations in latitude and longitude. If available, plant ID, point ID, stack ID, and plant name are written together.

4. RESULTS AND DISCUSSION

Fig. 2 shows the processing steps in the Korea National Emissions Inventory Processing System: (1)

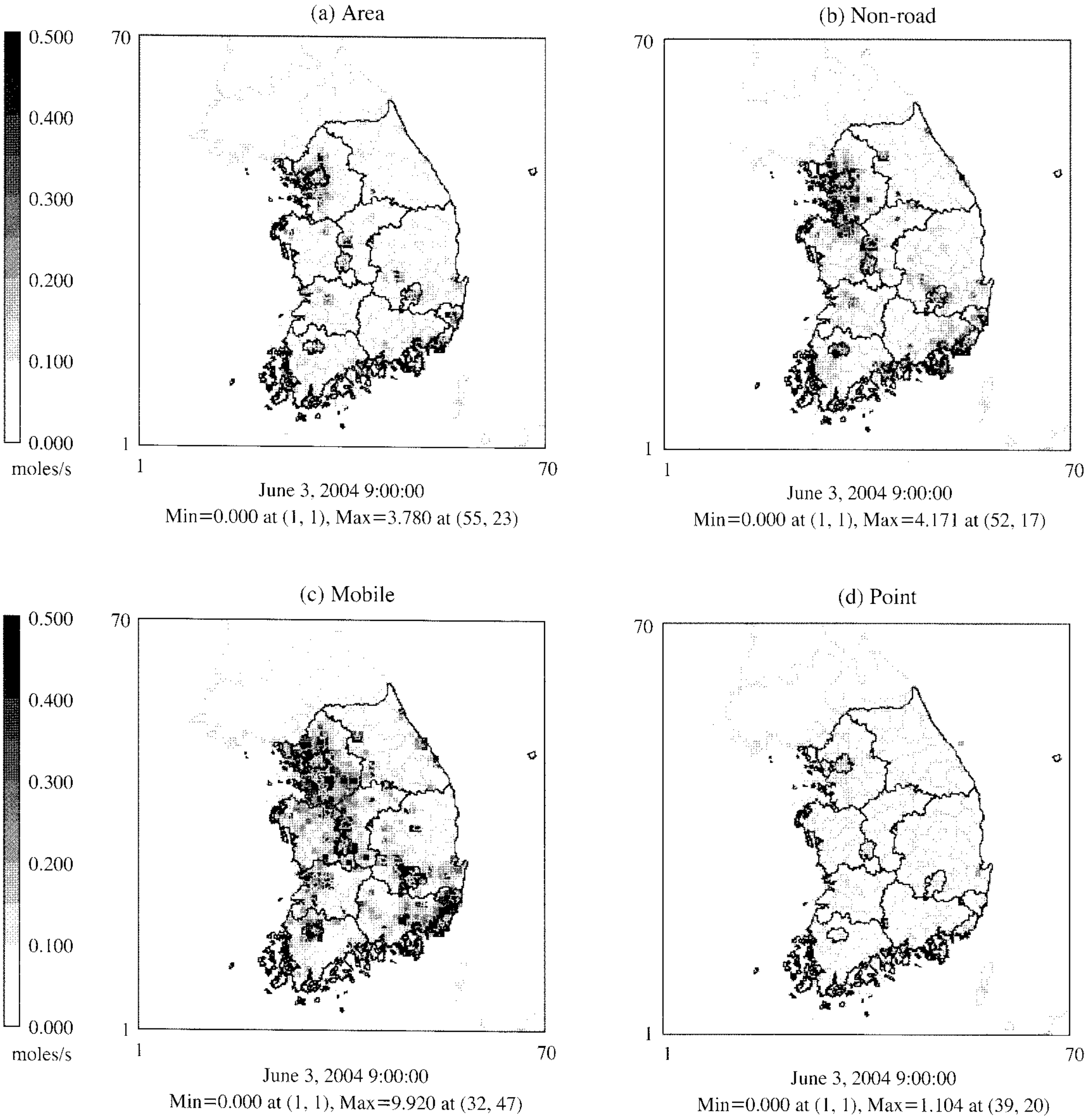


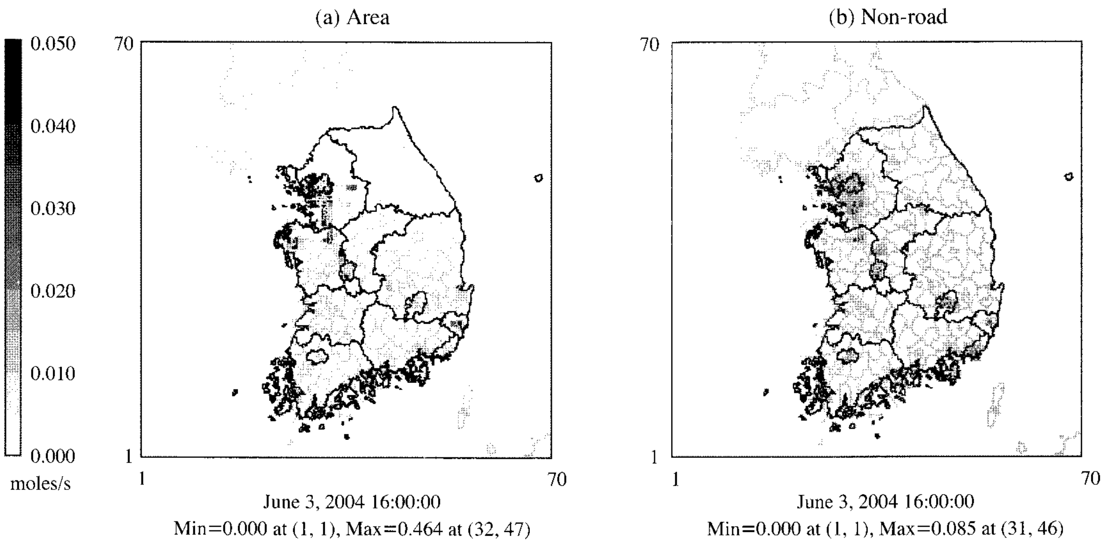
Fig. 3. Spatial distributions of NO emissions processed by SMOKE for a 9-km resolution domain. For point sources, the emissions rates are shown for the surface layer only.

conversion of the CAPSS emissions inventory into one of input formats, (2) mapping of SCCs for chemical speciation, (3) temporal and spatial allocations utilizing the spatial surrogates prepared for the target modeling domains, and (4) estimation of plume rise of point sources with SMOKE.

To validate the system implementation, model-ready emissions inputs were prepared with the carbon bond version 4 (CB-4) chemical mechanism for the 9-km and 3-km resolution domains for a high ozone episode in 2004 (June 1st-June 10th). The 9-km resolution domain includes the whole area of South Korea, and the 3-km resolution domain encompasses the Seoul and Gyeonggi-Do. For the SMOKE processing, a set of MM5-MCIP outputs were used to vertically allocate major point sources, depending on the stack parameters and meteorology conditions. In this test run, a 23-layer vertical structure was used, and the height of surface layer was ~33 meters.

4.1 Spatial Allocation

In addition to emissions for each subregion (i.e., Si, Gun, Gu), Korea emissions inventory is available on a map initially gridded with the TM (Transverse Mercator) projection at a 1-km resolution. The gridded emissions can help the users avoid the spatial allocation step and the efforts in surrogate preparation. However, it imposes a restriction that the same map

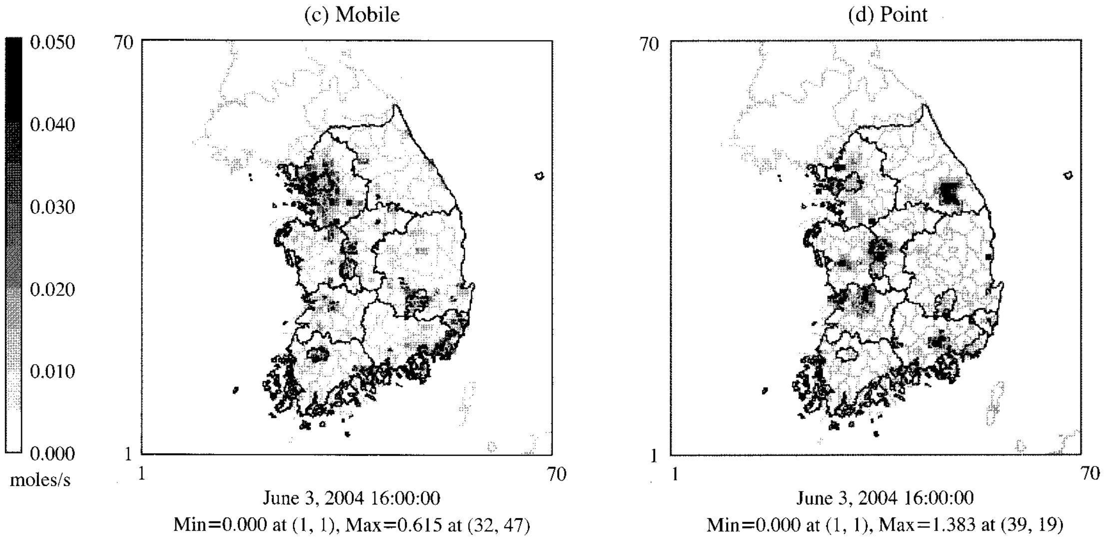


(a) Area

June 3, 2004 16:00:00
Min=0.000 at (1, 1), Max=0.464 at (32, 47)

(b) Non-road

June 3, 2004 16:00:00
Min=0.000 at (1, 1), Max=0.085 at (31, 46)



(c) Mobile

June 3, 2004 16:00:00
Min=0.000 at (1, 1), Max=0.615 at (32, 47)

(d) Point

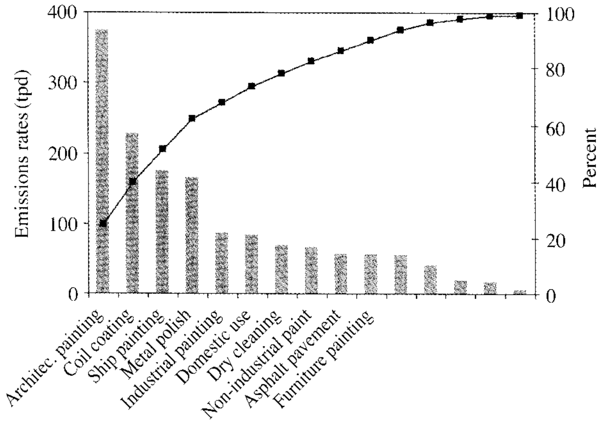
June 3, 2004 16:00:00
Min=0.000 at (1, 1), Max=1.383 at (39, 19)

Fig. 4. Spatial distributions of the ETH emissions processed by SMOKE for a 9-km resolution domain. For point sources, the emissions rates are shown for the surface layer only.

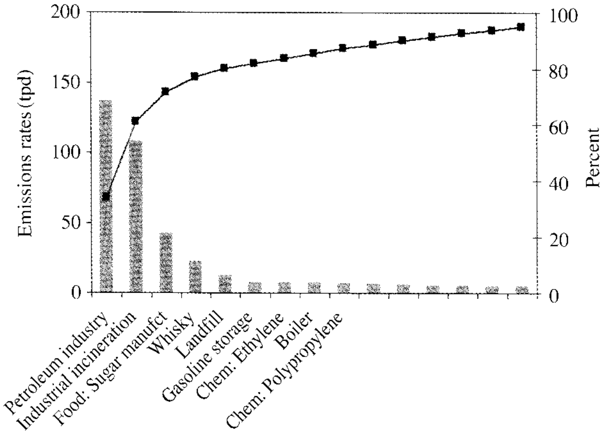
projection to be used for processing the emissions inventory data further. Moreover, it makes difficult for the users to preserve individual source characteristics such as exact location, emission composition, and temporal variation, which is essential when control measures are planned.

With the MIMS, the Korea emissions inventory can be processed for a user-defined domain on a specified map projection through preparation of surrogates for spatial allocation. A key step for the spatial allocation is to prepare surrogates for a targeted domain on which the emissions inventory is processed as described in the section 3.1. Fig. 3 represents spatial distributions of NO emissions on the 9-km resolution domain for June 11th, 2004 at 12 UTC. As expected, NO emissions rates from large cities such as Seoul and Busan are higher than other neighboring cities and rural areas. Similarly, it can be seen that there are high ETH (ethylene) emission from Seoul and Ulsan from the area source component (Fig. 4).

To perform spatially allocation of emissions related to port activities, two surrogates named "port" and "navigable" were used for the processing. However there still exist difficulties in representing the port emissions spatially. This problem was caused in part by the fact that the surrogates for spatial allocation in SMOKE are estimated based on inland city boundaries, while some emissions from onshore area (i.e.



(a) Area



(b) Point

Fig. 5. A top-10 VOC emissions source classifications for (a) area and (b) point sources in Korea emissions inventory. Bars represent the emissions rate for each source classification, and line for cumulative emissions in percentage.

harbor emissions away from land) were not enclosed by them. In order to resolve this problem, coastal city boundaries that include the offshore boundaries are needed. Also it would be practical to prepare onshore and offshore emissions over prescribed sea areas by assigning different administration codes. As an alternative method, port and ocean emissions can be treated as point sources.

4.2 Chemical Speciation

Lumped VOC emissions in an emissions inventory needs to be speciated for a chemical mechanism selected. Therefore it is important not only to estimate the amounts of VOC emission rates but also to have correct VOC compositions for air quality simulations. Fig. 5 shows which sources emit large amounts of VOC emissions from area and point sources. Among area sources, VOC emissions from architecture painting are around 370 tons/day in the Korea emissions inventory, followed by coil coating and ship painting. VOC emissions summed for those three large area sources amount to 780 tons/day, taking about 50% of total VOC emissions from area sources. It is shown that the top 10 area source categories contribute to more than 90% of the VOC emissions from area sources. Among point sources, VOC emissions from petroleum products and storage are 137 tons/day, accounting 34% of total point source VOC emissions, followed by industrial incineration and sugar manufacture of which VOC emissions are 108 tons/day and 42 tons/day, respectively. These three large point sources and the top 10 point sources represent around 70% and 90% of total VOC emissions, respectively, from the source type. For on-road mobile sources, VOC emissions from passenger cars and taxies are 181 tons /day, representing ~54% of total on-road mobile source VOC emissions, followed by heavy duty diesel vehicles including buses of which VOC emissions are 98 tons/day (Fig. 6). It appears that motorcycles show higher VOC emissions than light duty trucks and vans in the emissions inventory. For VOC emissions from taxies and buses, it is assumed that they are equipped with gasoline combustion engines. However it would be necessary to include chemical speciation factors for LPG and CNG combustion engines in the future work to better represent chemical composition in a chemical mechanism selected.

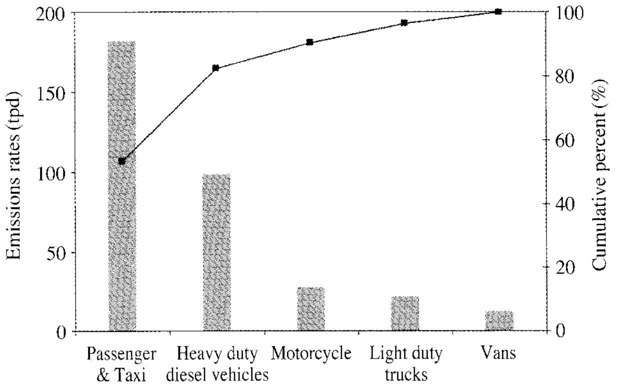


Fig. 6. VOC emissions from on-road mobile sources in the Korea emissions inventory. Bars represent the emissions rate for each source classification, and line for cumulative emissions in percentage.

When the major VOC emissions in the emissions inventory are speciated for the CB-4 chemical mechanism (Fig. 7), more than half of total VOC emissions from area sources are speciated to PAR (Paraffin). Most of TOL (Toluene) and XYL (Xylene) are

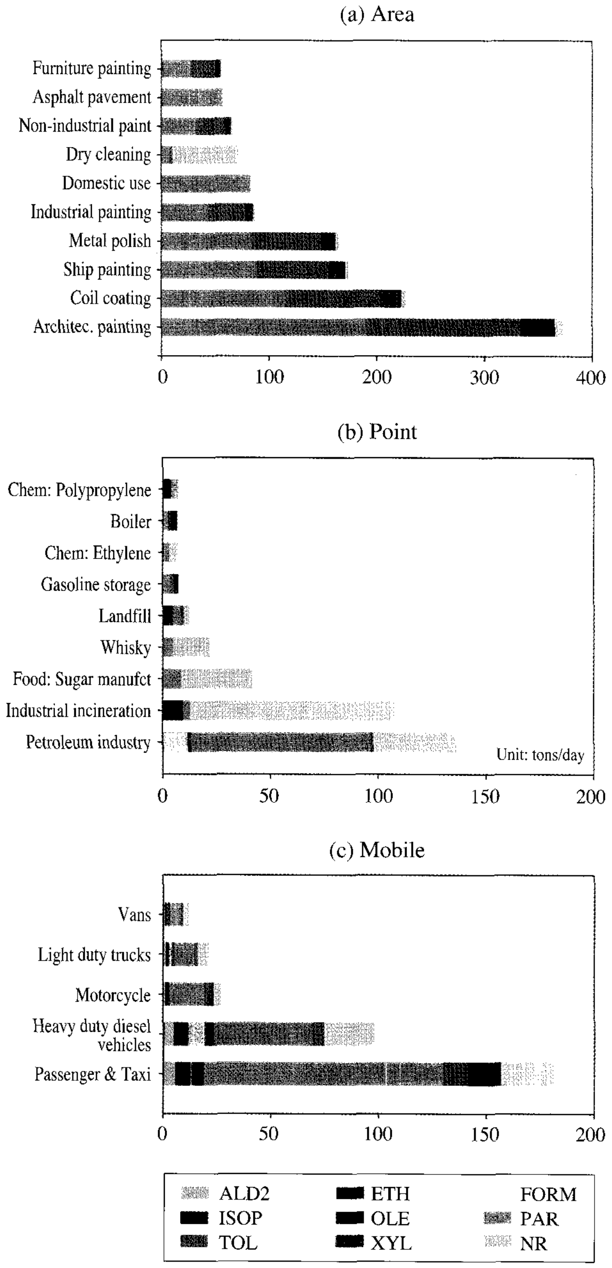


Fig. 7. Major VOC emissions from (a) area, (b) point, and (c) mobile sources speciated for the CB-4 chemical mechanism.

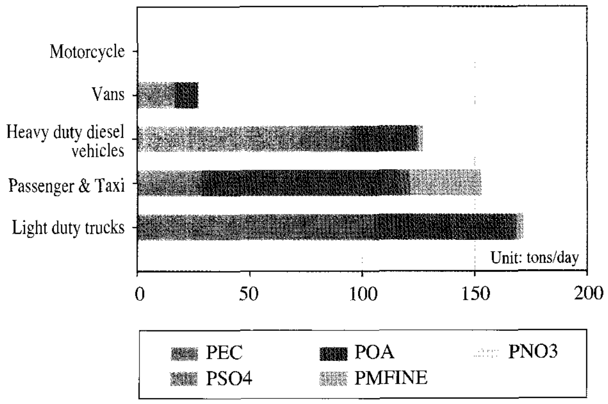


Fig. 8. Speciated PM2.5 emissions from mobile sources.

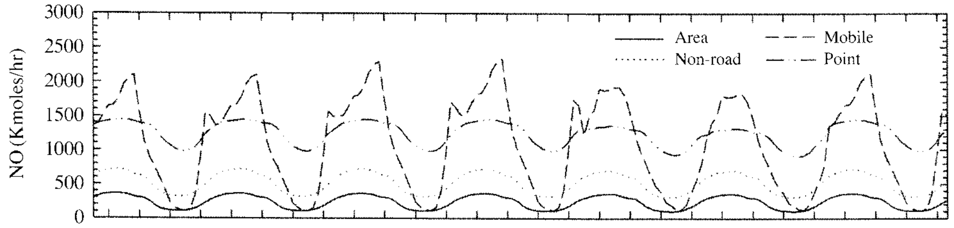
speciated from area VOC emissions followed by passenger cars and taxies in mobile sources. Note that these aromatic species are mainly emitted from painting related industries in area sources. In case of highly reactive VOC species, ETH (Ethylene) is emitted from industrial incineration in point sources and various mobile sources. Many of OLE (Olefin) emissions are also emitted from mobile sources as well as polypropylene industry in point source. It can be seen that FORM (Formaldehyde) is mostly emitted from petroleum industry in point source and heavy duty diesel vehicles. It should be noted that characterization on emissions source and compositions should be carried out again for a selected modeling domain because each region presents different emissions patterns associated with different industry, residential, and traffic environments.

As discussed previously, the SMOKE system largely depends on SCC to have the best matching profiles for the chemical speciation, and temporal and spatial allocations.

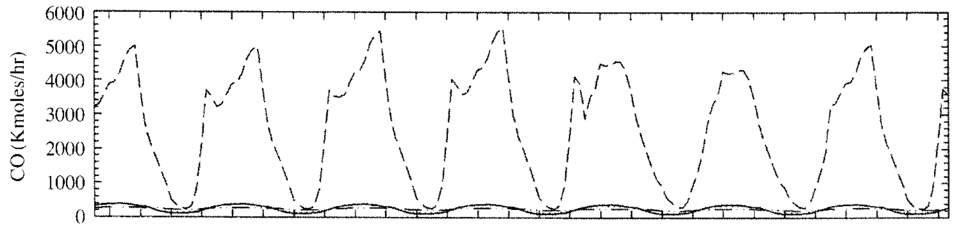
While finding the corresponding SCCs from the U.S. EPA's list is easy and straightforward for some SCCs in the Korea emissions inventory, there are other SCCs that are difficult to match. Also, there is some possibility to misinterpret descriptions for the SCCs during the mapping work. In such a case there is a danger that quite different SCCs in the Korea emissions inventory could be mapped to the U.S. EPA's SCCs. Therefore, it is required to develop the processing steps for the cross-reference tables and profiles that better represent emissions characteristics in Korea. Developing such complete internal data for emissions processing for all the SCCs is beyond current scope of the project which requires national efforts. In the present study, we suggest to update internal data for major sources first (i.e., top 10 SCCs for area and point sources and top 5 SCCs for on-road mobile sources) by examining VOC emissions amounts for each source types shown in Figs. 5 and 6, to minimize uncertainties during the emissions processing.

In order to simulate ambient PM (Particulate Matters) concentrations, the precursor emissions such as SO_2, NH_3 and VOC as well as PM should be prepared. PM10 and total suspended particulate (TSP) emissions are available form the Korea emissions inventory, but

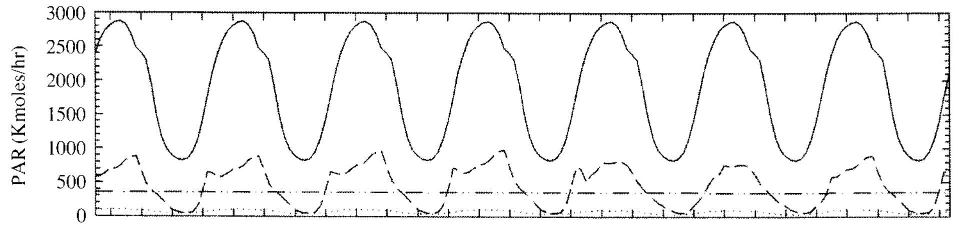
(a) NO



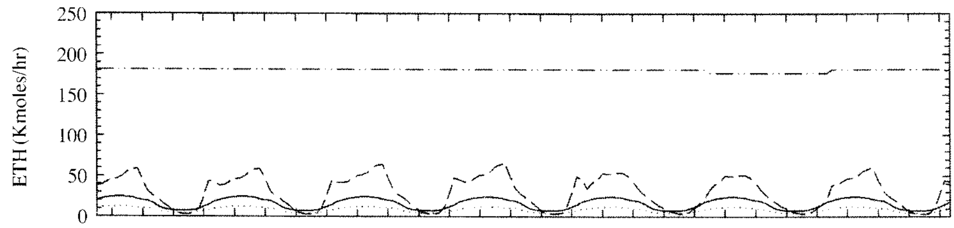
(b) CO



(c) PAR



(d) ETH



(e) OLE

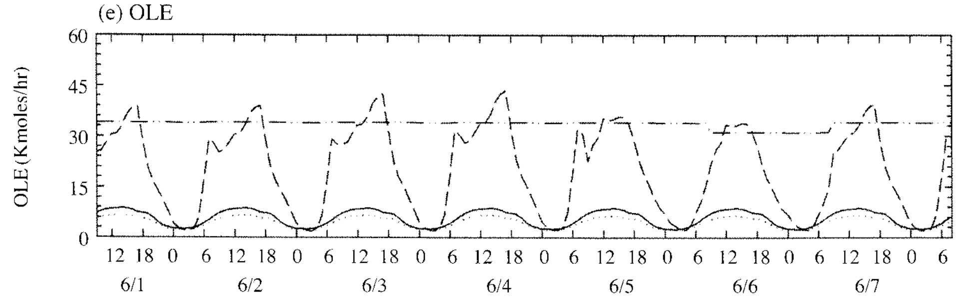


Fig. 9. Temporal variations of (a) NO, (b) CO, (c) PAR, (d) ETH, and (e) OLE emissions for a 9-km resolution domain.

the PM2.5 emissions rates are not available currently. Because it is essential to have the emissions to simulate particulate matter concentrations in air quality models, we have tentatively obtained the PM2.5 emissions by multiplying an arbitrarily chosen factor 0.5 to the PM10 emissions rates in this study. A new PM2.5 inventory must be collected to remedy this problem. The PM2.5 inventory is then speciated into PEC (primary fine elemental carbon), POA (primary fine organic carbon), PNO3 (primary fine nitrate), PSO4 (primary fine sulfate), and PMFINE (unspeciated fine aerosol) in SMOKE.

The major sources of PM2.5 emissions in the Korea emissions inventory are mobile sources, which take ~90% of the total. Fig. 8 depicts that light and heavy duty diesel vehicles are the largest PM2.5 emission sources among mobile sources, and passenger cars and taxies also emit considerable PM2.5 emissions. Speciation results indicate that diesel vehicle PM2.5 emissions are mainly composed of PEC (~60%) and POA (~35%), representing ~80% of total PEC are emitted from those diesel vehicles in the emissions inventory. In case of passenger cars, around 20% of the PM2.5 emissions are speciated to each PEC and PMFINE species while ~55% of the emissions are speciated to POA. Note that PM emissions from motorcycles are not estimated in the Korea emissions inventory.

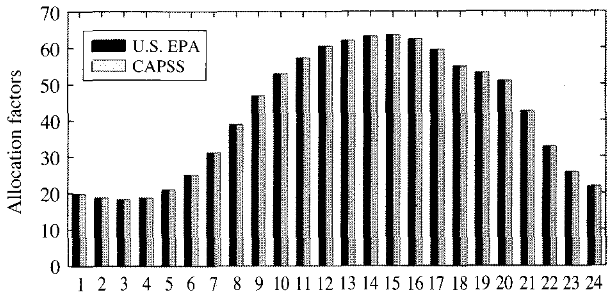
4.3 Temporal Allocation

Fig. 9 shows hourly emission rates of domain-wide NO, CO, PAR, ETH, and OLE emissions after temporal allocation over the 9-km resolution domain which covers the whole South Korea, which includes all the emissions in the emissions inventory. On-road mobile emissions during weekends (June 5th and 6th, 2004) showed slightly different diurnal variations than those for weekdays. Emissions rates from non-road and area sources present typical sinusoidal diurnal variations, showing the highest peak during daytime when activity levels reach the peaks.

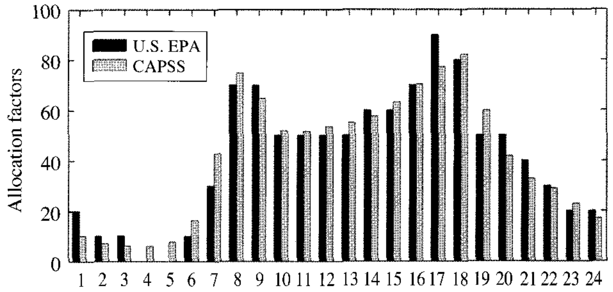
For the whole South Korea domain, on-road mobile sources compose ~50% of total NO emissions during day time, showing morning and evening peaks, followed by point, non-road, and area sources. Compared to other sources, emissions rates for point sources show small diurnal variations due to the continuous operation patterns assumed and thus higher NO emission rates during nighttime. It is seen that the nationwide CO emissions is heavily dependant on mobile sources in the emissions inventory. CO emissions rates are mostly explained by mobile sources and the contributions from other sources are smaller than 20%.

After chemical speciation of lumped VOC emissions, it is found that PAR emissions from area sources are higher than those form other sources, increasing in the morning and decreasing in the evening. It is also shown that PAR emissions from on-road mobile sources increase during daytime, while PAR emissions from non-road mobile sources are insignificant. For the ETH emissions, point sources show higher contribution than other sources. It is noticed that on-road mobile and area sources become important during daytime with increased ETH emissions compared to nighttime. For OLE emissions, on-road mobile sources become the dominant sources followed by point sources.

(a) Area



(b) Mobile



(c) Point

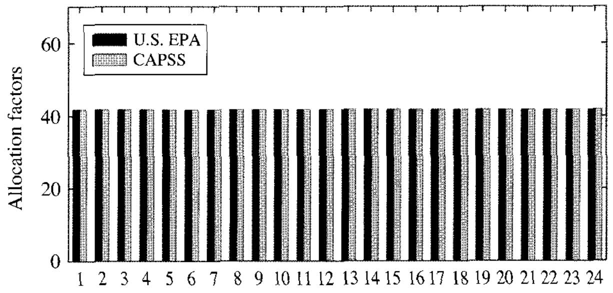


Fig. 10. Hourly profiles for a representative SCC in (a) area, (b) mobile, and (c) point sources. The representative SCCs can be seen from Figs. 5 and 6.

While the default profiles in the SMOKE system are used in this study, internal data to process the Korea emissions inventory are in part available from the CAPSS system. As an example, Fig. 10 compares hourly temporal allocation factors for a representative SCC from area, mobile, and point sources, respectively, between the SMOKE and CAPSS systems. The temporal allocation factors for area and point sources appear identical, but there are some differences in the hourly factors for mobile sources. It would be necessary to compare hourly resolved emission rates after applying the different temporal profiles. However, even though the weekly and hourly temporal profiles are prepared to process the Korea emissions inventory, the total numbers of available profiles are limited and would be not enough to represent all the emission source types at this moment. For example, around 800 monthly, 45 weekly, and 80 hourly profiles available in the SMOKE system while less than 10 monthly,

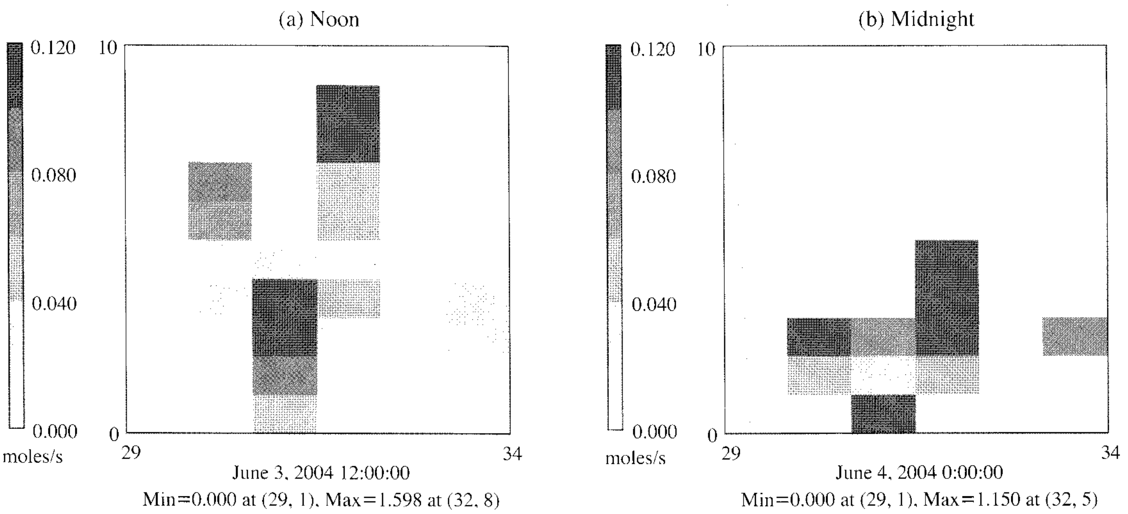


Fig. 11. Vertical cross-sections of NO emissions between columns 29-34 at row 37 in the layers of 1-10 for June 3rd, 2004 at (a) noon and (b) midnight.

weekly, and hourly profiles are prepared in the CAPSS system. Therefore it is desirable to develop more detailed profiles to process the domestic emissions inventory more accurately.

4.4 Plume Rise of Point Source Emissions

With MM5-MCIP outputs describing hourly meteorological conditions, point source emissions are vertically allocated to generate fractional emission distribution in the vertical layers. The SMOKE plume-rise algorithms compute plume top and bottom heights based on stack parameters such as stack height and diameter, and exit temperature and velocity of exhausting plume for given meteorological conditions. Once plume top and bottom heights are determined, fractional portion of emissions rates for each species is estimated for each vertical layer, depending on a vertical structure setup. Fig. 11 shows an example of vertical allocation of NO emissions. It is seen that emission rates for each layer varies depending on meteorological conditions even though stack parameters for a source are fixed. Considering vertical emission apportionment is affecting concentration gradients between surface and aloft near a large source (Byun *et al.*, 2007), the importance of developing accurate stack parameters should be recognized.

5. CONCLUDING REMARKS

In this study, we attempted to process the Korea emissions inventory with the U.S. EPA's SMOKE system to prepare emission inputs for air quality simulations. To utilize the SMOKE system, SCCs in the Korea emissions inventory were linked to the US EPA's SMOKE default SCCs to best match profiles for the chemical speciation, and the cross-reference tables and profiles for temporal and spatial allocations. Mapping the different SCCs between two countries may introduce a significant uncertainty in the estimated emissions. Furthermore, some apparently similar source profiles of one country could be significantly different from those of another country. Therefore, development of domestic source profiles would be one of the most desirable approaches to process the emissions data. In practice, serious efforts will be required to develop the accurate domestic profiles for all the source classifications. It is suggested to prioritize major source classifications for each emissions source type first and then develop the domestic profiles for them. Also it would be necessary to organize a pool of experts to develop plans to build an advanced Korea emissions inventory databases to better answer to the questions such as 1) how to improve the SCC mapping between Korea and the U.S., or 2) how to develop and use internal cross-reference tables and profiles for the Korea emissions inventory, and 3) what "standard" format of the Korea emissions inventory is useful for air quality simulations.

As an initiative work to demonstrate how the Korea emissions inventory can be utilized in the comprehensive air quality modeling, the present study used the SMOKE system by developing surrogates for Korea and SCC mapping for chemical speciation and temporal allocation.

ACKNOWLEDGEMENTS

This study was supported by Korea Environment Institute (Project No. KEI I 2006 I RE-11).

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(Received 26 May 2008, accepted 10 July 2008)