Development of a Local-Scale Emissions Inventory for the Cleveland Multiple Air Pollutant Study

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ABSTRACT

The Cleveland Multiple Air Pollutant Study (CMAPS) is an air pollution measurement and modeling research study investigating sources of air pollution in Cleveland, Ohio, and the distribution of pollutants across the metropolitan area. The U.S. Environmental Protection Agency (EPA) began this study in July 2009 and has worked in collaboration with partner agencies such as the Cleveland Division of Air Quality, the Akron Regional Air Quality Management District, and the State of Ohio.

To support air quality modeling conducted as part of CMAPS, Sonoma Technology, Inc. (STI) developed updated emissions inventories for the Cleveland area that reflect conditions during the CMAPS measurement period, with a special focus on August 2009 and February 2010—months when EPA was conducting intensive ambient measurements. Updated emissions estimates were based on information gathered from facility surveys, travel demand modeling for the region, vessel call data for the Port of Cleveland, and other local sources of data. Pollutants addressed in the emissions inventory will include speciated mercury and other air toxics. Final 2009 and 2010 inventories were processed through the Sparse Matrix Operator Kernel Emissions Modeling System (SMOKE) to develop emissions inputs for the Community Multiscale Air Quality model (CMAQ).

INTRODUCTION

In July 2009, the U.S. Environmental Protection Agency (EPA) began the Cleveland Multiple Air Pollutant Study (CMAPS) in partnership with several state and local agencies, including the Cleveland Division of Air Quality (CDAQ), the Akron Regional Air Quality Management District, and the State of Ohio[1]. The purpose of CMAPS is to investigate sources of air pollution in Cleveland, Ohio, and the distribution of pollutants across the metropolitan area. Study results will be used by CDAQ and EPA Region 5 to develop air pollution control strategies.

As part of CMAPS, EPA conducted a year-long particulate matter (PM) and mercury (Hg) measurement campaign from August 2009 to August 2010, including two intensive measurement periods in August 2009 and February 2010. EPA will also perform air quality modeling with the Community Multiscale Air Quality (CMAQ) model to simulate concentrations of PM, Hg, and other pollutants across the Cleveland metropolitan area. CMAQ simulations will be conducted with a 12-km grid resolution over the eastern United States and a 4-km grid resolution over the Great Lakes and Ohio Valley (see **Figure 1**).

Figure 1. Boundaries of the 12-km and 4-km modeling domains being used for CMAQ modeling.

Data characterizing emissions of air pollutants from all sources in the modeling domain are a key input to air quality models such as CMAQ. To develop CMAQ-ready emissions inputs for the CMAQ study period, we began by compiling existing estimates of emissions for the 4-km modeling domain, including data from the 2005 National Emissions Inventory (NEI) and a 2008 point source inventory for the State of Ohio provided by Ohio EPA. However, to accurately depict the air quality impacts from specific sources in the Cleveland area, this study requires emissions data that are representative of the 2009-2010 CMAPS measurement period, when industrial sources in Cleveland were impacted by the recent economic downturn. Therefore, STI worked with EPA and CDAQ to collect local data that could be used to update existing criteria pollutant and Hg emissions estimates for Cleveland available from the 2005 NEI and the Ohio EPA point source data, with a special focus on the two month-long intensive measurement periods of August 2009 and February 2010.

During the development of an updated emissions inventory for Cleveland, updated activity and emissions data were collected for three key source sectors: (1) stationary sources, including industrial facilities in Cleveland and electrical generating units (EGUs) across Ohio and the western parts of Pennsylvania and West Virginia; (2) on-road mobile sources in Cleveland and the remainder of Cuyahoga County; and (3) non-road mobile sources, including commercial marine vessels at the Port of Cleveland. The selection of these source sectors was based on the estimated magnitude of emissions for various sources and the proximity of sources to air quality monitors.

Once data collection and emissions inventory development efforts were complete, STI used the Sparse Matrix Operator Kernel Emissions Modeling System (SMOKE) to prepare emissions input files for the CMAQ 4-km modeling domain. The following sections describe the methods and data sets used to develop an updated emissions inventory for CMAPS and prepare that inventory for use in CMAQ.

STATIONARY SOURCES

The Cleveland area has a complex mix of industrial sources and is impacted by coal-fired power plants in Cleveland and across the region[1]. During the development of the CMAPS emissions inventories, emissions estimates for Cleveland industrial sources and regional power plants were updated to reflect the CMAPS measurement period (2009-2010).

Cleveland Area Facilities

As part of the preparation for CMAPS, EPA and CDAQ compiled a list of 21 Cleveland area facilities to be prioritized for emissions inventory updates. The selection of individual facilities was based on historical emissions of particulate matter less than 2.5 microns in diameter ($PM_{2.5}$), nitrogen oxides (NO_x), sulfur dioxide (SO_2), and carbon monoxide (CO), as well as proximity to air quality monitors. STI subsequently used this list as the basis for facility-level data collection efforts. **Figure 2** shows the locations of the 21 prioritized facilities, along with the locations of urban monitoring sites deployed for the study.

Figure 2. Locations of Cleveland area facilities prioritized for local data collection efforts.

To begin the process of collecting emissions and operating data from local facilities, representatives from each facility were invited to a meeting at CDAQ's offices on March 8, 2010. At this meeting, EPA staff provided background information on CMAPS and presented preliminary findings from air quality monitoring efforts; STI staff described the emissions inventory portion of the project and the types of data that would be required to develop an updated stationary source inventory for Cleveland for the CMAPS study period.

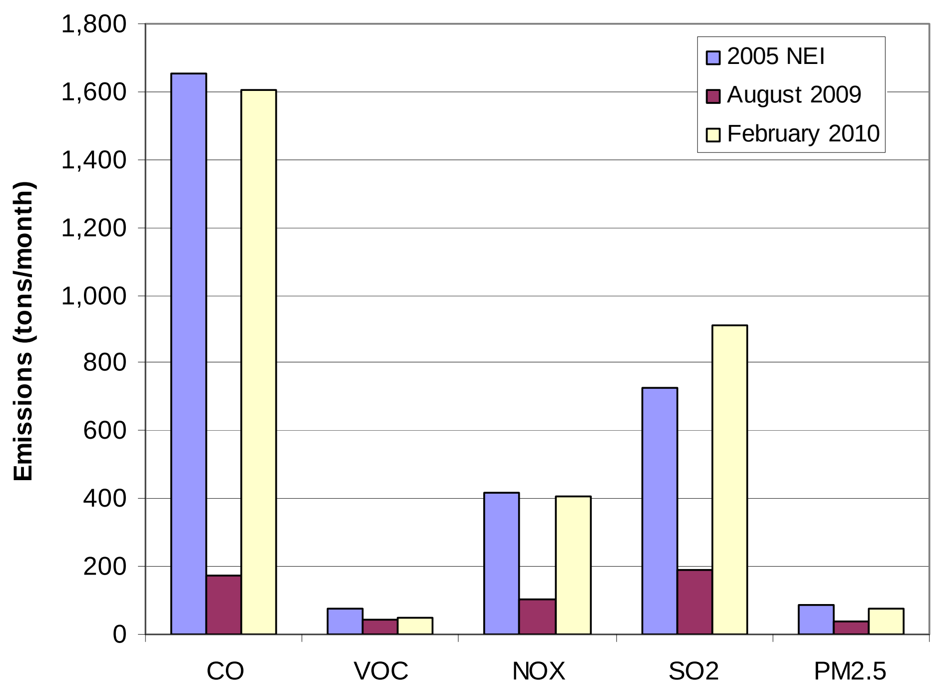
Following this initial meeting, STI contacted each of the 21 prioritized facilities by telephone and/or email to collect information on emissions and operations during the CMAPS study period, particularly the intensive monitoring periods of August 2009 and February 2010. Specific data requested from each facility included:

- Annual emissions or production data for 2009 that could be used to update annualized emissions data from the 2005 NEI;
- Monthly operations data (e.g., production, throughput, or fuel combustion) for 2009 and January-February 2010 that could be used to allocate annual 2009 emissions to months of the year;

- Daily operations data (e.g., production, throughput, or fuel combustion) for August 2009 and February 2010 that could be used to determine daily emission levels for the two intensive monitoring periods;
- General information on typical daily and weekly operating patterns, as well as any unusual operating conditions during the two intensive monitoring periods (e.g., temporary shutdowns, excess emissions from upset conditions, etc.).

Of the 21 facilities contacted, 17 were able to provide part or all of the data requested in time for use in updating the Cleveland stationary source emissions inventory. These data were used to replace 2005 NEI emissions data (where current emissions data were provided) or to scale 2005 NEI emissions estimates to 2009-2010 levels (where production or fuel consumption data were provided). For facilities that did not provide updated emissions or production data, 2005 emissions were replaced with 2008 emissions provided by Ohio EPA. **Figure 3** shows a comparison of average monthly emissions for key facilities for 2005 with updated emissions estimates developed for August 2009 and February 2010. For all facilities combined, August 2009 emissions were 39% to 90% lower than average monthly emissions in 2005, largely because a large steel plant and a power plant were not active during that month. Total February 2010 emissions from all facilities combined were comparable to 2005 levels (±30%), as the plants were back in operation during that month.

Figure 3. Comparison of 2005 and 2009/2010 point source emissions for key facilities in Cleveland.



Regional Power Plants

Coal-fired power plants are a significant source of SO_2, NO_x, and Hg emissions in the Ohio River Valley. To ensure that the CMAPS emissions inventories contain current power plant data for a radius of at least 100 km from the Cleveland-area monitoring sites, STI updated 2005 NEI emissions data for 52 power plants across Ohio and western parts of Pennsylvania and West Virginia. In all, STI updated emissions data for 137 boiler units at these 52 facilities.

Large power plants are required to collect continuous emissions monitoring (CEM) data and report these emissions to EPA. EPA's Clean Air Markets Division (CAMD) maintains an online database (http://camddataandmaps.epa.gov/gdm/index.cfm?fuseaction=emissions.wizard) that provides CEM data summaries, including monthly, unit-level emissions of SO_2 and NO_x; unit-level heat input (mmBTU); and gross output (megawatt hours). The CAMD database also contains information on SO_2, NO_x, and PM control methods applied to each unit.

STI downloaded CAMD data for the states of Ohio, Pennsylvania, and West Virginia for 2009 and the first quarter of 2010 and used these data to update 2005 NEI emissions for all power plants in those states that fall within the 4-km modeling domain. For SO_2 and NO_x, annualized unit-level emissions from the 2005 NEI were replaced with month-specific unit-level emissions for March 2009 through April 2010 from the CAMD data. Total SO_2 and NO_x emissions for the most recent 12 months of data available from CAMD were used to generate a new annualized inventory for 2009-2010, and monthly SO_2 and NO_x emissions were used to create monthly temporal profiles for each unit. These profiles were then used to allocate the annualized inventory to individual months during the emissions modeling phase of the project (described in Section 5). For pollutants other than SO_2 and NO_x, annualized 2005 NEI emissions were adjusted for 2009-2010 according to the change in unit-level heat input between the 2005 NEI data and the most recent 12 months of CAMD data for March 2009 through April 2010 (e.g., if the annualized heat input increased by 10%, emissions were assumed to increase by 10% as well). Monthly heat input data from CAMD was then used to generate monthly temporal profiles for each unit for pollutants other than SO_2 and NO_x.

Mercury Emissions Processing

In addition to projecting the change in emissions between 2005 and 2009-2010, STI carried out an evaluation to estimate the impact of recently installed control measures on mercury emissions. Mercury removal is a co-benefit of PM, NO_x, and SO_2 control measures such as electrostatic precipitators (ESP), selective catalytic reduction (SCR), and wet flue gas desulfurization (FGD) [2], and the CAMD data show that since 2005, several new wet FGD systems for the control of SO_2 have been installed on coal-fired units in the region of interest. Though the impacts of these control technologies are already reflected in the CAMD data for SO_2 emissions, we had to estimate their impact on mercury emissions, which were projected from the 2005 NEI using heat input data.

The impact of wet FGD systems on mercury emissions depends on a number of factors, including coal type, existing control configurations, and the forms of mercury (i.e., speciation) in the flue gas. When coal is burned in a utility boiler, the mercury in the coal is vaporized under the high combustion temperatures and released as gaseous elemental mercury (Hg^0).

Subsequently, flue gas cooling and interactions with other combustion products convert a portion of the Hg^0 to divalent gaseous mercury (Hg^{2+}) and particle-bound mercury (Hg^p) [3]. Unlike Hg^0, Hg^{2+} is water soluble and can be removed from flue gases by wet FGD units, while Hg^p can be captured by PM control devices such as ESP and fabric filter (FF) baghouses [4].

Between 2005 and 2010, wet FGD systems were installed on 28 coal-fired units at 13 power plants in the region of interest. After consultation with EPA staff, it was determined that these systems could be expected to capture virtually all of the Hg^{2+} in the flue gas emitted by these units [5]. Because speciated mercury emissions are reported for coal-fired power plants in the 2005 NEI (i.e., the emissions are broken out as Hg^0, Hg^{2+}, etc.) a mercury capture efficiency of 95% was applied to the projected 2009/2010 Hg^{2+} emissions for these 28 units.

<u>Power Plant Emissions Summary</u>

Table 1 shows a comparison of average monthly power plant emissions of SO_2, NO_x, and mercury (Hg^0 and Hg^{2+}) for 2005 with updated emissions estimates developed for August 2009 and February 2010. State-level emissions are shown for all power plants in Ohio, Pennsylvania, and West Virginia that fall within the 4-km modeling domain, and overall, emission levels were consistently lower during the CMAPS intensive months than monthly average emissions for 2005. For example, SO_2 emissions in August 2009 and February 2010 were 37% and 50% lower, respectively, than average monthly SO_2 levels in 2005. Similarly, Hg^{2+} emissions in August 2009 and February 2010 were 37% and 42% lower than monthly average Hg^{2+} emissions in 2005, with these SO_2 and Hg^{2+} reductions being largely attributable to the wet FGD control systems that have been installed at various facilities since 2005, as discussed in the section above. Also note that SO_2 and Hg^{2+} emissions in Pennsylvania and West Virginia are lower in February 2010 relative to August 2009 due to the installation of wet FGD systems at Pennsylvania's Hatfield's Ferry and Keystone power plants and West Virginia's Fort Martin power plant in Fall 2009.

Table 1. Comparison of 2005 and 2009/2010 EGU emissions by state.

State	Period	NO_x (tons)	SO_2 (tons)	Hg^0 (lbs)	Hg^{2+} (lbs)
Ohio (19 facilities)	2005 monthly average	20,594	87,327	302	270
	August 2009	8,259	50,565	276	163
	February 2010	9,946	50,814	282	160
Pennsylvania (19 facilities)	2005 monthly average	13,305	54,547	238	326
	August 2009	7,081	48,654	232	209
	February 2010	8,581	27,790	234	190
West Virginia (14 facilities)	2005 monthly average	10,158	38,931	136	241
	August 2009	3,188	15,493	121	158
	February 2010	4,482	11,877	127	132
Total (all states)	2005 monthly average	44,058	180,805	676	838
	August 2009	18,528	114,712	630	530
	February 2010	23,010	90,481	643	483

ON-ROAD MOBILE SOURCES

Emissions estimates for on-road mobile sources in the 2005 NEI were developed using EPA's National Mobile Inventory Model (NMIM), which combines emission factors from the MOBILE6 model with vehicle miles traveled (VMT) data to calculate county-level on-road mobile source emissions [6].

Unlike other source categories, on-road mobile source emissions from the 2005 NEI for the Cleveland area could not be directly projected to 2009-2010 on the basis of changes in activity data. On-road emissions must be treated differently for two reasons: (1) simply projecting 2005 emissions to 2009-2010 using VMT changes would not account for decreases in emission rates due to fleet turnover; and (2) the MOBILE6 model used within NMIM for the development of the 2005 NEI has been replaced by EPA's MOVES model, which incorporates more recent emissions data and a more detailed approach to modeling on-road mobile source emissions [7]. Therefore, the MOVES model was used to develop a 2009-2010 on-road mobile source emissions inventory for the 4-km CMAPS modeling domain, as described in the subsections that follow.

MOVES Input Data

To estimate emissions from on-road mobile sources, the MOVES model can use either of two calculation types: emissions inventory or emission rates. With the inventory option, MOVES calculates mass-based emissions from vehicle activity data. With the emission rates option, MOVES calculates a look-up table of emission rates as mass-per-unit activity that must be post-processed to produce an inventory. The latter approach is preferable for large-scale analyses involving multiple counties, as it reduces the overall MOVES run time [8].

With either calculation option, producing an inventory with MOVES requires a variety of input data, including vehicle fleet characteristics, vehicle activity data (e.g., VMT), fuel characteristics, emissions control program information, and meteorology. MOVES includes a default database that contains all this information; however, the default data are not necessarily the most accurate or current information available at the local level. As a result, MOVES includes a County Data Manager (CDM) utility that can be used to import updated county-specific data [8].

To prepare on-road emissions data for Cuyahoga County, STI updated default MOVES data for the county using a variety of data sources, including Northeast Ohio Areawide Coordinating Agency (NOACA) travel demand model outputs and the NMIM county database (NCD) [6]. **Table 2** provides a complete list of data sources used to develop MOVES inputs for Cuyahoga County. MOVES was then run using the inventory option for Cuyahoga County to produce on-road inventories by month and day of week (weekday vs. weekend). For the intensive month of August 2009, day-to-day variations in temperature were taken into account by assigning all August days to one of four temperature bins, calculating average hourly temperatures for each of these bins, and using these temperature profiles as inputs to separate MOVES runs. Temperature bins were based on maximum daily temperatures: (1) ≥90° F; (2) 80-89° F; (3) 70-79° F; and (4) <70° F. This binning approach was used to reduce the number of

MOVES runs required for Cuyahoga County, and was not used for the February 2010 intensive month, which had less variation in day-to-day temperatures.

Table 2. Data sources for updating default MOVES data for Cuyahoga County.

Data Type	Data Source
Annual VMT by vehicle type	NOACA TDM data and NCD data[a]
VMT fraction by month	NCD data
VMT fraction by weekday/weekend	MOVES default
VMT fraction by hour of the day	NCD data
VMT fraction by road type for each source type	NCD data
Vehicle populations	Estimated from Cuyahoga VMT data using MOVES vehicle population-to-VMT ratio
Meteorology data (hourly temperature and relative humidity)	NCDC Climate & Weather Global Surface Data
Age distributions (age fraction by vehicle type and age)	NCD registration distribution data
Average speed distribution (average speed fraction by vehicle/road/hour/day/average speed bin)	NMIM national default data

[a] NOACA TDM data summarize VMT for all vehicle types. These data were disaggregated to Highway Performance Monitoring System (HPMS) vehicle types based on VMT distributions in the NCD data for Cuyahoga County.

For the remainder of the CMAPS 4-km domain (outside Cuyahoga), MOVES was run using the emission rates option with default input data. Emission rates were calculated by month and day of week (weekday vs. weekend) and then applied to county-level VMT data in a post-processing step to estimate emissions.

MOVES Output Data

The MOVES runs described above generated county-level emissions estimates for both criteria and air toxic pollutants. The following pollutants were included in MOVES outputs for later conversion to CMAQ-ready emissions inputs: VOC, NO_x, CO, SO_2, NH_3, PM_{10}, $PM_{2.5}$, benzene, naphthalene, 1,3-butadiene, formaldehyde, acetaldehyde, and acrolein. **Table 3** shows a comparison of MOVES outputs for Cuyahoga County for August 2009 and February 2010 to on-road mobile source emissions for Cuyahoga County from the 2005 NEI; these data indicate that 2009 and 2010 emissions estimates from MOVES are generally lower than corresponding emissions estimates from the 2005 NEI. However, MOVES emissions estimates for PM_{10} and $PM_{2.5}$ are significantly higher than corresponding estimates from the 2005 NEI, which is consistent with previous analyses of differences between MOVES and the MOBILE6 model used to develop the 2005 NEI [9].

Table 3. Summary of MOVES emissions estimates for Cuyahoga County.

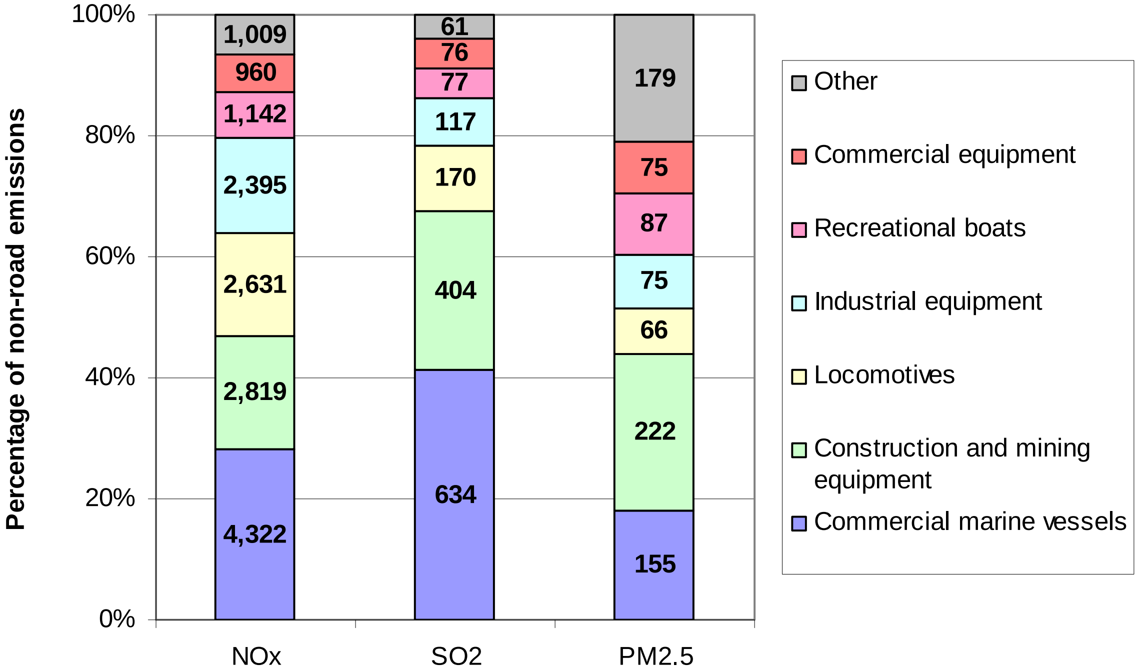
Pollutant	Average Daily Emissions (tons/day)		
	2005 NEI (Annual Average)	MOVES - August 2009	MOVES - February 2010
VOC	42.99	20.56	28.76
CO	551.70	220.93	529.07
NO_x	63.16	57.90	62.07
PM_{10}	1.69	3.44	4.19
$PM_{2.5}$	1.15	2.36	3.02
Benzene	1.59	0.64	0.75
Naphthalene	0.03	0.04	0.11
1,3-Butadiene	0.16	0.09	0.11
Acrolein	0.03	0.02	0.03
Formaldehyde	0.49	0.38	0.47
Acetaldehyde	0.32	0.22	0.43

NON-ROAD MOBILE SOURCES

Diesel-fueled non-road mobile sources can be a significant source of PM and NO_x emissions in urban areas, particularly in cities like Cleveland that have active ports. In the 2005 NEI non-road mobile source inventory for Cuyahoga County, commercial marine vessels, construction equipment, and locomotives account for over half of the total emissions of NO_x, SO_2, and $PM_{2.5}$ (see **Figure 4**). In 2005, these three source categories emitted 9,772 tons of NO_x, 1,208 tons of SO_2, and 442 tons of $PM_{2.5}$, exceeding the 2005 NO_x (419 tons) SO_2 (724 tons) and $PM_{2.5}$ (87 tons) emissions from the 21 key point sources discussed previously.

Because of the relative importance of commercial marine vessels, construction equipment and locomotives, STI prioritized these three non-road mobile sources for local data collection efforts during the development of the CMAPS emissions inventory.

Figure 4. 2005 non-road mobile source emissions by source category for Cuyahoga County, Ohio (emissions data labels are in units of tons).



Commercial Marine Vessels

Port-based emissions estimates for commercial marine vessels are typically based on the number of vessel calls at the port, along with information on vessel characteristics (e.g., engine size) and vessel operating patterns (e.g., speed and time spent in various operating modes such as maneuvering and berthing) [10]. In the 2005 NEI, emissions from large Class 3 vessels, which are powered by engines larger than 30 liters/cylinder and primarily burn residual fuel, are reported as a series of point sources so that the plume rise of exhaust emissions from ship stacks can be accounted for during emissions modeling; emissions from smaller vessels are reported at the county level [11].

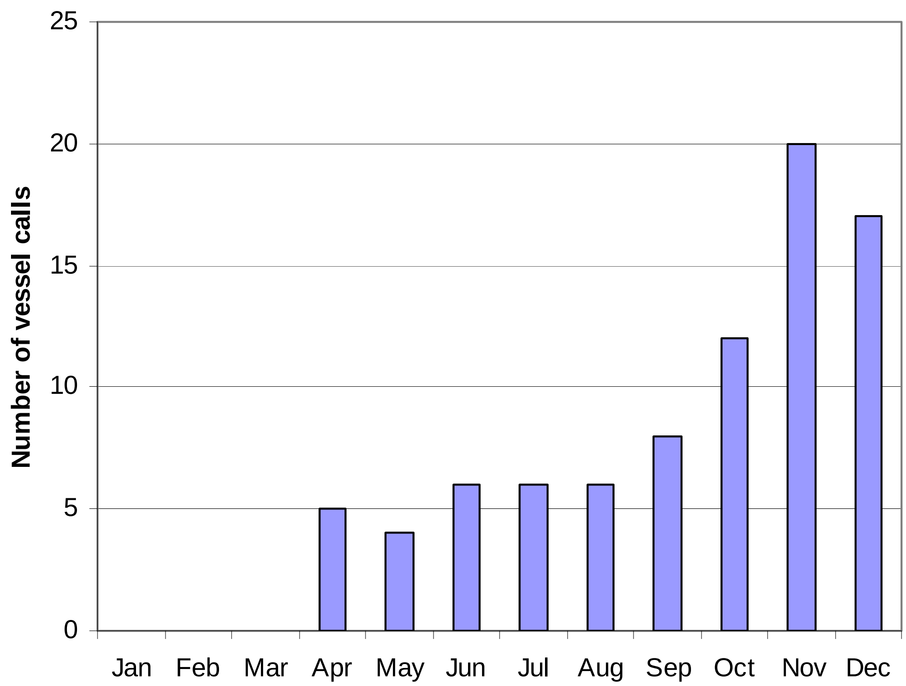
To scale commercial marine vessel emissions estimates from the 2005 NEI emissions to 2009-2010, STI collected monthly vessel call and cargo tonnage data from the Port of Cleveland for 2005 and 2009 [12]. During 2009, vessel traffic at the Port of Cleveland was at a 50-year low, partly due to temporary shutdowns at a large steel plant [13]. Consequently, data obtained from the port show that 2009 vessel calls and freight movements at the port were 91% lower than 2005 levels. This 91% reduction was applied to emissions from all Class 3 ships visiting the Port of Cleveland, as well as to all emissions from smaller vessels associated with the Port of Cleveland, resulting in overall commercial marine vessel emissions estimates for the CMAPS study period that are 34% to 77% lower than corresponding emissions estimates from the 2005 NEI (see **Table 4**).

Table 4. Comparison of 2005 and 2009 commercial marine vessel activity and emissions at the Port of Cleveland.

Metric	2005	2009	Reduction
Cargo tonnage	12,847,551	1,108,239	91%
Vessel calls	959	84	91%
NO_x emissions (tons)	4,322	1,013	77%
SO_2 emissions (tons)	634	421	34%
$PM_{2.5}$ emissions (tons)	155	59	62%

In addition, monthly vessel call data for 2009 were used to allocate emissions to specific months. These data show that the Port of Cleveland was inactive from January through March 2009 (see **Figure 5**). A review of vessel call data for 2004-2009 shows that this pattern of inactivity during the months of January through March is typical for the Port of Cleveland; therefore, no commercial marine vessel emissions were assigned to February 2010 (one of the two intensive monitoring periods).

Figure 5. 2009 vessel calls by month at the Port of Cleveland.



Locomotives and Construction Equipment

In the 2005 NEI, estimates of locomotive emissions were based on fuel consumption data from the Energy Information Administration (EIA), while estimates of construction equipment emissions were made using NMIM, which incorporates EPA's NONROAD2005 model [14]. NONROAD2005 calculated county-level emissions from construction equipment on the basis of default equipment populations and activity data (e.g., hours of operation per year) [15].

To update 2005 NEI locomotive emissions, STI contacted two major railroads operating in Cuyahoga County to request fuel consumption data for the county. However, fuel data were not provided in time for use in the project, so locomotive emissions from the 2005 NEI were retained.

Similarly, to update 2005 NEI construction equipment emissions, STI contacted the City of Cleveland Planning Department to request data on construction permits issued in Cuyahoga County during 2005 and during the 2009-2010 CMAPS study period. However, construction permit data were not provided in time for use in the project, so construction equipment emissions from the 2005 NEI were retained.

EMISSIONS MODELING

In general, the emissions inventory data developed for CMAPS represents county- or facility-level annualized 2005 NEI data that have been adjusted to reflect conditions during the one-year CMAPS monitoring campaign of 2009-2010. However, air quality models such as CMAQ require emissions inputs that have been temporally resolved to an hourly basis for each episode date being modeled and spatially resolved to the grid cell dimensions of the modeling domain. In addition, criteria pollutants such as VOC in the emissions inventory must be disaggregated into model-ready species that are defined by the chemical mechanism being used to represent atmospheric chemistry in the air quality model.

The process of converting an emissions inventory to a model-ready format through temporal allocation, spatial allocation, and chemical speciation is known as emissions modeling. To develop CMAQ-ready emissions inputs for CMAPS, emissions modeling was performed by running SMOKE version 2.5 [16] with EPA's 2005-based modeling platform, version 4 [11]. This modeling platform includes emissions data files in SMOKE-ready format, as well as all ancillary files (e.g., temporal profiles, speciation profiles, etc.) needed to run SMOKE and prepare CMAQ-ready emissions inputs. The SMOKE-ready emissions files in the modeling platform include U.S. data based on the 2005 NEI and 2006 Canadian emissions. These emissions data files are grouped into the source sectors listed in **Table 5**, each of which must be processed through SMOKE and then merged to generate a complete anthropogenic emissions file for a given episode date. Table 5 also provides a description of the sources of data used for each source sector, as well as updates made to these data during the development of the CMAPS inventories.

The 2005-based modeling platform was set up to process the emissions data described above and produce air quality model-ready emissions files that include criteria air pollutants (CAPs) and the following hazardous air pollutants (HAPs): mercury, chlorine, hydrochloric acid, benzene, acetaldehyde, formaldehyde, and methanol. STI modified this platform to include additional HAPs and to incorporate emissions and activity data collected during the CMAPS emissions inventory development process. Specific steps taken to update the SMOKE-ready temporal, spatial, and speciation data files included with EPA's 2005-based modeling platform are described in the subsections that follow.

Table 5. Source sectors included in the 2005-based modeling platform.

Source Sector	Description
EGU	2005 NEI point source EGUs – emissions for facilities in Ohio, Pennsylvania, and West Virginia were updated with 2009-2010 monthly emissions from EPA's CAMD database.
Non-EGU	2005 NEI point sources not included in the EGU sector - emissions for key sources in Cleveland updated with emissions and activity data gathered from individual facilities; remaining Ohio point sources updated with 2008 point source data from Ohio EPA.
Average fire	Average-year wildfire and prescribed burning emissions
Agricultural	NEI ammonia emissions from livestock and fertilizer application
Fugitive dust	NEI PM_{10} and $PM_{2.5}$ emissions from fugitive dust sources (e.g., construction dust, unpaved roads)
Nonpoint	NEI nonpoint sources not included in other sectors
Nonroad	Monthly nonroad emissions from the NONROAD2005 model (run within NMIM)
C3 commercial marine	Point source formatted Class 3 commercial marine vessel emissions
Locomotive/marine	Rail and Class 1 and 2 commercial marine vessel emissions
On-road	2005 on-road mobile source emissions – replaced with 2009 and 2010 outputs from EPA's MOVES model
Other point	Point source emissions from Canada's 2006 inventory
Other nonpoint	Nonpoint source emissions from Canada's 2006 inventory (province resolution)
Other on-road	On-road mobile source emissions from Canada's 2006 inventory (province resolution)

Temporal Allocation

Within SMOKE, temporal profiles are used to generate hourly emissions inputs for CMAQ by adjusting the annualized or average-day emissions that are input to the emissions model. The monthly, weekly, and diurnal temporal profiles and associated cross-reference files (used to match individual source categories in the emissions inventory with appropriate temporal profiles) in the 2005 modeling platform were based on files previously developed for EPA's 2002 modeling platform, though new profiles were developed for some source sectors. For example, state-specific diurnal profiles were developed for non-CEM sources in the EGU sector using 2005 CEM data [11].

On the basis of emissions and activity data collection efforts, STI made the following refinements to the temporal data in the 2005 modeling platform:

- Monthly profiles based on production data for 2009-2010 were developed for individual facilities in Cleveland (see Section 2.1);

- Monthly profiles based on CAMD data (based on month-specific emissions for SO_2 and NO_x and on CAMD heat input data for other pollutants) were developed for EGUs in Ohio, Pennsylvania, and West Virginia (see Section 2.2);
- Day-specific emissions files were developed for August 2009 and February 2010 for Cleveland facilities that reported daily emissions or production for those months (see Section 2.1);

A monthly profile based on vessel call data for the Port of Cleveland was developed for commercial marine vessels, as described above.

Spatial Allocation

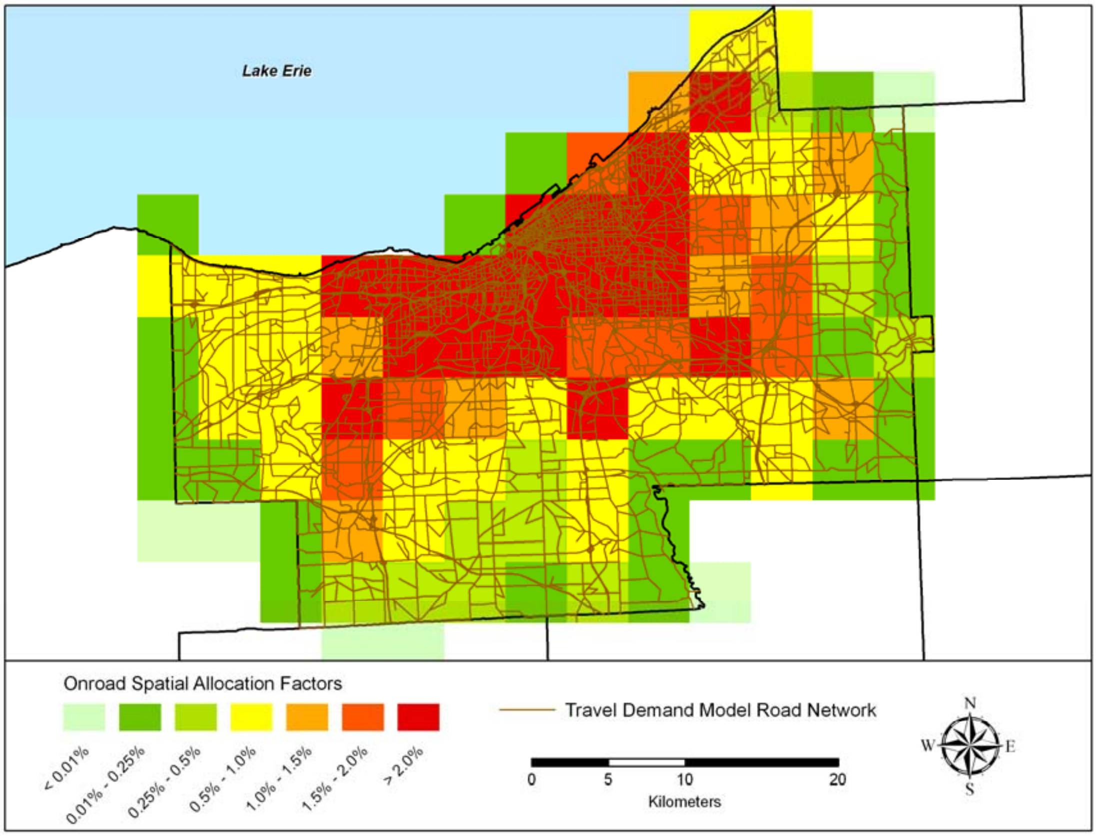
Within SMOKE, spatial allocation factors are used to disaggregate county-level emissions to individual grid cells in the modeling domain. These spatial allocation factors are derived from spatial surrogates (e.g., land cover or land use data) that are used to represent the location of emissions-producing activities.

EPA's 2005 modeling platform was set up to spatially allocate emissions for a 36-km national domain, a 12-km domain for the Eastern United States, and a 12-km domain for the Western United States [11]. Because these spatial surrogate data are not of sufficient spatial resolution for the 4-km CMAPS modeling domain, default 4-km spatial surrogate data provided with the SMOKE modeling system were used instead. These 4-km spatial allocation files were derived from a variety of data sources, including the 2000 Census and National Land Cover Characteristics Data, and include over 60 spatial surrogates [17]. However, the default 4-km surrogates are based on a grid projection that differs from the CMAPS modeling domain definition; specifically, the default 4-km surrogates are based on a meridian central to the entire U.S., while the CMAPS 4-km domain is based on a meridian more central to Ohio. Therefore, STI had to re-project these spatial data in an ArcGIS environment prior to use in the CMAPS emissions modeling.

In addition, STI replaced the default 4-km spatial allocation factors for on-road mobile sources with updated spatial allocation factors based on link-level traffic data from NOACA's 2009 travel demand modeling. These spatial allocation factors, which represent the fraction of county-level emissions assigned to individual grid cells, were developed by overlaying the CMAPS 4-km modeling grid on the link-level traffic data and calculating the fraction of county-total VMT occurring in each grid cell (see **Figure 6**).

Finally, STI checked the location coordinates assigned to key Cleveland area facilities in the 2005 NEI data by mapping the coordinates in Google Earth and verifying that the assigned latitude and longitude values corresponded to satellite images of individual facilities on the ground. Based on this review, STI updated the location coordinates for about 10 facilities in the Cleveland area.

Figure 6. On-road mobile source spatial allocation factors developed for the CMAPS 4-km modeling domain.



Chemical Speciation

Within SMOKE, an inventory table is used to select the pollutants in the emissions inventory that will be processed and output by SMOKE, and chemical speciation profiles are used to convert inventory pollutants to model species. These speciation profiles are based on chemical mechanisms, which use aggregates of chemical compounds to define the model species. The 2005 modeling platform was set up for the carbon bond 5 (CB05) mechanism, which is also the mechanism selected by EPA for the CMAPS modeling.

However, EPA's 2005 modeling platform was set up to process a limited number of HAPs: mercury, chlorine, hydrochloric acid, benzene, acetaldehyde, formaldehyde, and methanol. For the CMAPS modeling, EPA chose to include additional HAPS, such as 1,3-butadiene, acrylonitrile, carbon tetrachloride, and toluene. To accommodate these additional species, STI updated the inventory table and speciation profiles from the 2005 modeling platform to include all HAP species of interest to EPA for the CMAPS study.

For mercury, 2009 and 2010 emissions were derived from the 2005 NEI, which reports speciated mercury from major coal-fired power plants. For other mercury sources where emissions were unspeciated (e.g., reported as total mercury), mercury speciation profiles set up for the 2005 modeling platform were used.

SMOKE Outputs

To support the processing of emissions for the 4-km CMAPS domain, EPA provided STI with gridded, hourly meteorological data for July 15 through August 31, 2009, and January 15 through February 28, 2010. These data were necessary to run SMOKE and produce CMAQ-ready emissions for the two intensive monitoring periods, as SMOKE uses meteorological data to compute plume rise for point sources.

STI performed SMOKE runs for July 15 through August 31, 2009, and January 15 through February 28, 2010, for the source sectors listed in Table 5-1. (Note that model runs typically include the two weeks before the beginning of the period of interest in order to obtain better initial and boundary conditions for the run.) For most source sectors, SMOKE was run for a representative week during July 2009, August 2009, January 2010, and February 2010 to capture temporal variations in emissions produced by the monthly and day-of-week temporal profiles used within SMOKE. For on-road mobile sources, representative weekday and weekend SMOKE runs were performed for each month; however, for Cuyahoga County, additional runs were performed to generate emissions data for the temperature bins described in Section 3.1. Because point-source plume rise calculations are also temperature dependent, day-specific SMOKE runs were performed for all point source-related sectors using the gridded, hourly, meteorological data provided by EPA.

Summaries of the SMOKE output emissions data for Cuyahoga County are shown in **Figures 7 through 12**. Emissions were higher in February 2010 than August 2009, in part because a steel plant and a power plant were not active during August 2009. Daily NO_x emissions averaged 109 tons in August 2009 and 125 tons in February 2010 (see Figures 7 and 8), while daily SO_2 emissions averaged 16 tons in August 2009 and 43 tons in February 2010 (see Figures 9 and 10). Daily $PM_{2.5}$ emissions were more consistent across the two intensive months, averaging 9 tons per day in August 2009 and 10 tons per day in February 2010 (see Figures 11 and 12). It should also be noted that the Lakeshore power plant was minimally active on February 13-15, 2010, and the effect of these reduced point source emissions can be seen in the daily SO_2 chart for February (see Figure 10).

Sample emissions density plots showing the spatial distribution of total NO and SO_2 emissions are provided in **Figure 13**. The distribution of NO emissions shows the location of major roadways and urbanized areas across the 4-km domain, while the distribution of SO_2 emissions also shows the locations of major point sources across the 4-km modeling domain.

STI is delivering all SMOKE-ready emissions data files and supplementary files (e.g., temporal profiles and spatial surrogates) prepared for this project, as well as the CMAQ-ready emissions files for July 21–August 31, 2009, and January 22–March 2, 2010, produced by SMOKE.

Figure 7. Daily NO_x emissions for Cuyahoga County for August 2009.

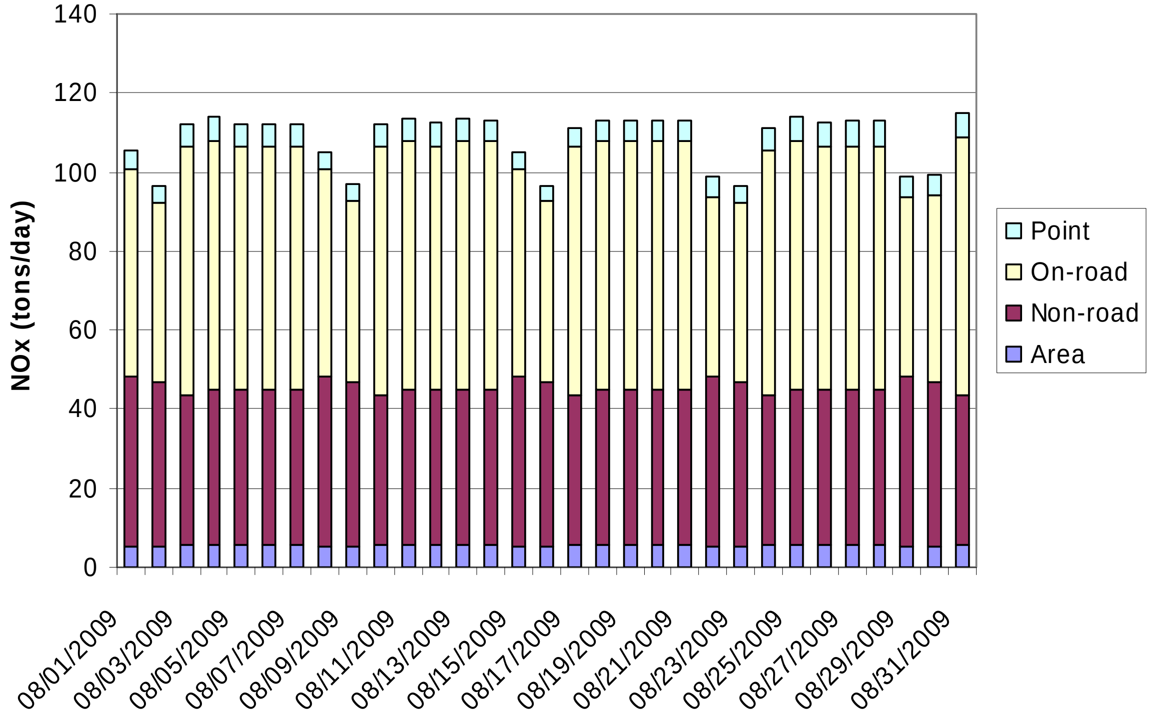


Figure 8. Daily NO_x emissions for Cuyahoga County for February 2010.

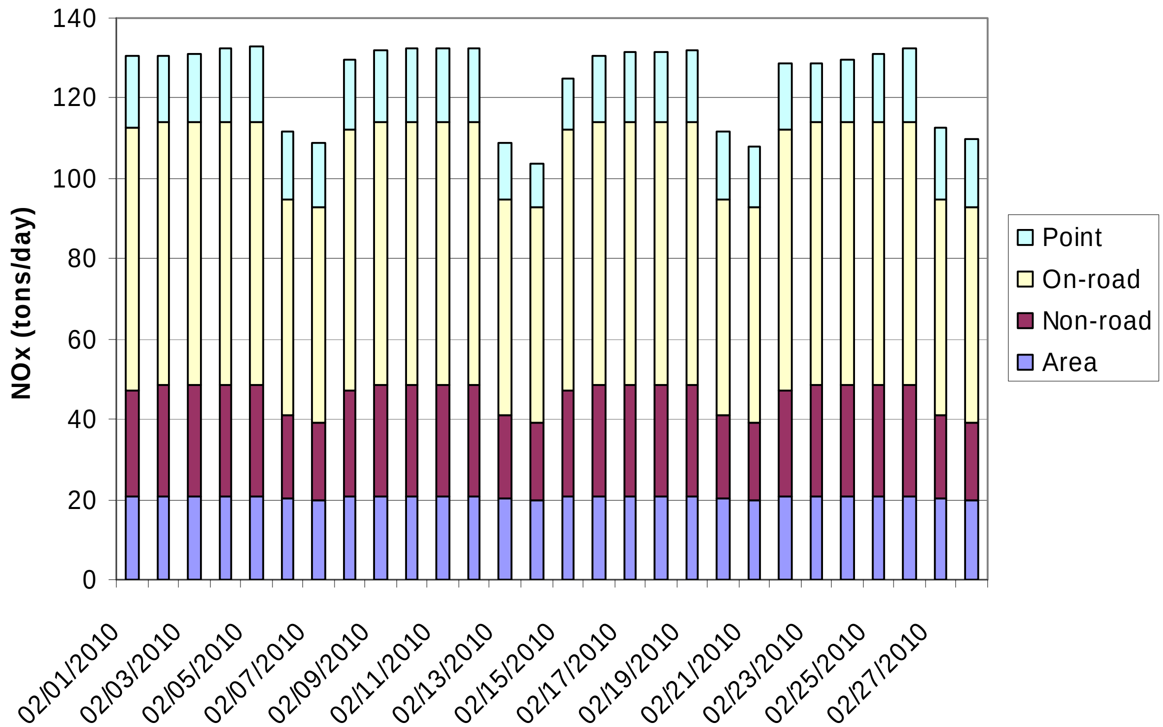


Figure 9. Daily SO_2 emissions for Cuyahoga County for August 2009.

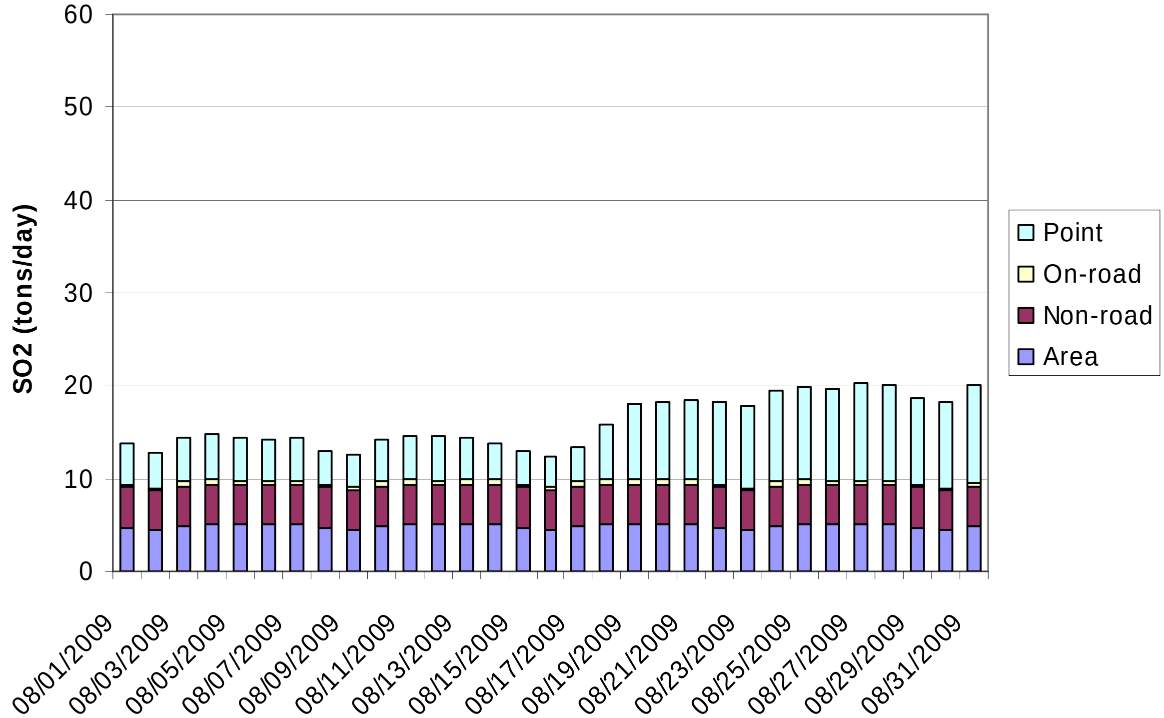


Figure 10. Daily SO_2 emissions for Cuyahoga County for February 2010.

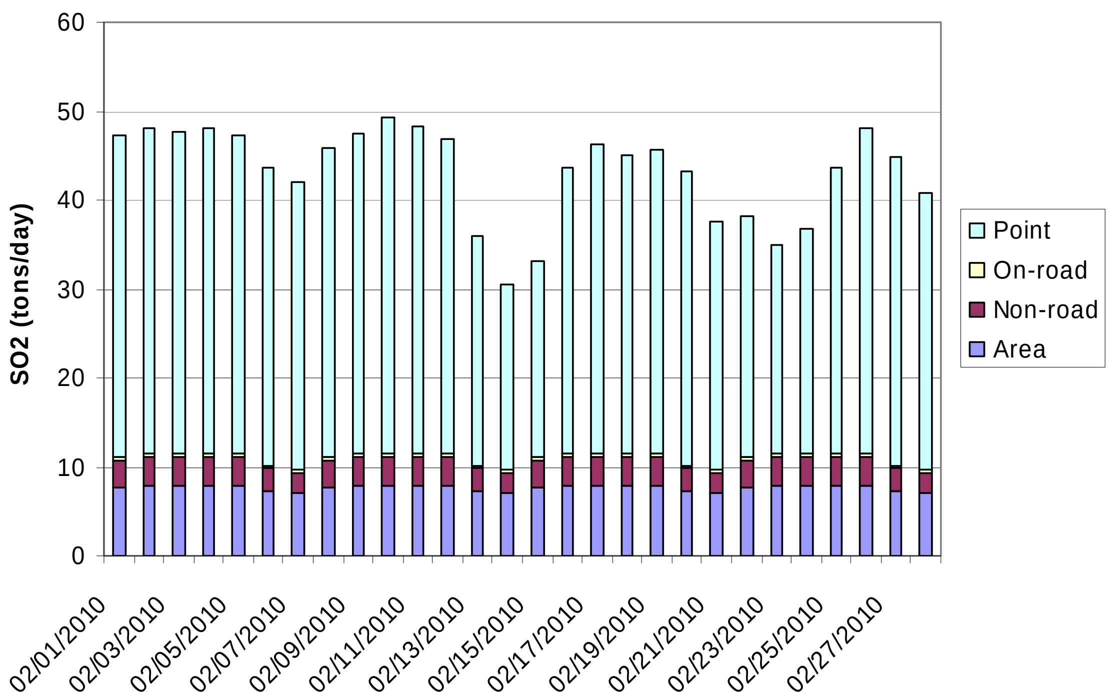


Figure 11. Daily $PM_{2.5}$ emissions for Cuyahoga County for August 2009.

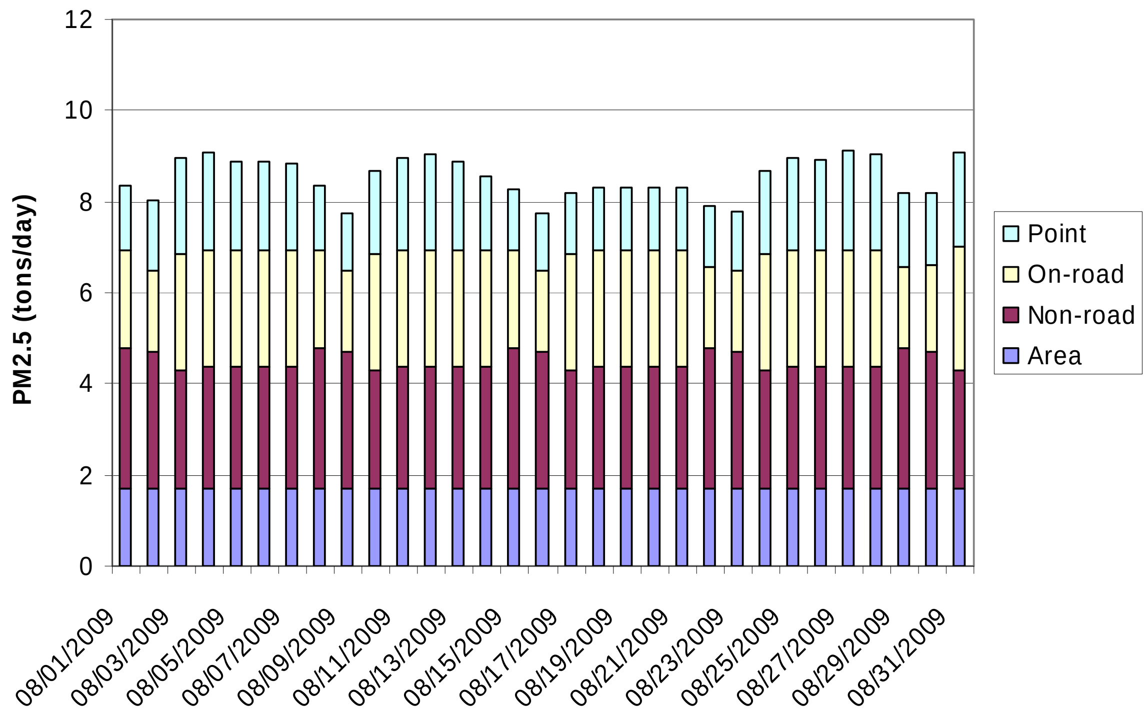


Figure 12. Daily $PM_{2.5}$ emissions for Cuyahoga County for February 2010.

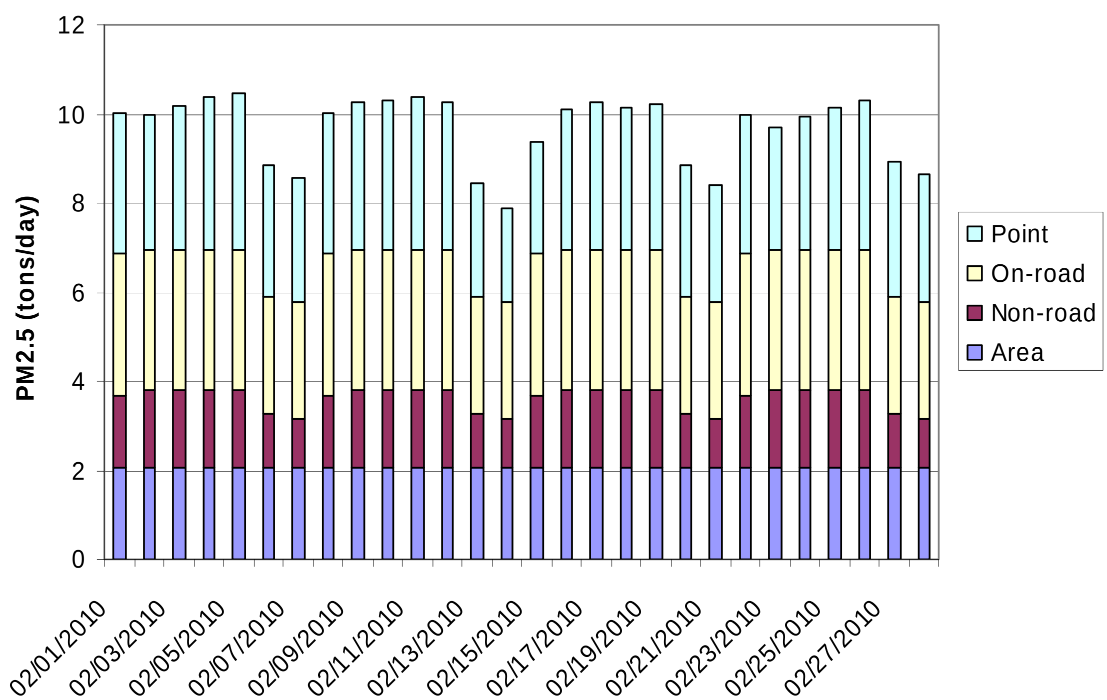
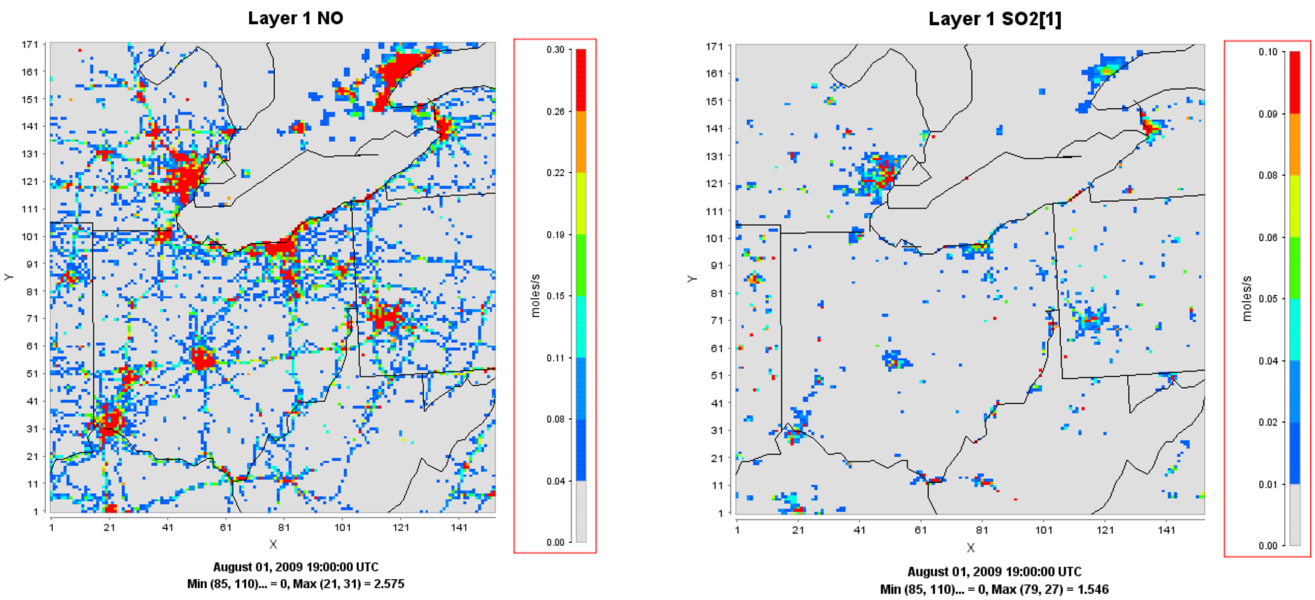


Figure 13. Emissions density plot of total NO and SO_2 emissions for the 4-km CMAPS modeling domain on August 1, 2009.



CONCLUSIONS

To support CMAQ modeling to be conducted by EPA as part of CMAPS, STI developed an emissions inventory for key emissions sources in Cuyahoga County, Ohio, as well as regional power plants in Ohio, parts of Pennsylvania, and parts of West Virginia, that was representative of the CMAPS measurement period (2009–2010), particularly the two month-long intensive measurement periods of August 2009 and February 2010. STI worked with EPA and CDAQ to collect local data for Cleveland that could be used to update the existing criteria pollutant and mercury emissions estimates available from the 2005 NEI and other sources.

Ultimately, STI collected detailed emissions and activity data for 17 key point sources in Cleveland, including day-specific data for the two intensive months for a steel mill and two power plants—three of the largest sources of emissions in the Cleveland metropolitan area. These data, which show that ArcelorMittal and Lakeshore were inactive during August 2009 but back to full operation by February 2010, will allow EPA's modelers to evaluate the air quality impacts of these sources by comparing CMAQ results for the two months.

In addition, STI developed an updated on-road mobile source inventory for Cuyahoga County and the remainder of the CMAPS 4-km modeling domain using MOVES, EPA's new mobile source emissions model. MOVES runs for Cuyahoga County were based on vehicle activity data, derived from NOACA's 2009 travel demand modeling and meteorological data, that were representative of the two intensive months. STI also developed updated emissions estimates for commercial marine vessels operating at the Port of Cleveland, where vessel traffic was at a 50-year low in 2009.

These updated emissions estimates for key sources in Cuyahoga County should provide for improved model performance relative to CMAQ runs with unadjusted 2005 NEI data and should allow EPA modelers to more accurately evaluate the contributions of individual sources to air quality problems in the Cleveland metropolitan area. However, the current 4-km modeling domain may not provide sufficient spatial resolution to resolve local-scale gradients in pollutant concentrations and identify impacts from individual sources, necessitating the development of a 1-km modeling domain (and accompanying emissions inputs) for the Cleveland metropolitan area.

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KEY WORDS
Emissions inventory
Local-scale
Multi-pollutant
SMOKE
CMAQ

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DISCLAIMER

Although this work was reviewed by EPA and approved for presentation, it may not necessarily reflect official Agency policy.