# Emissions Inventory Preparation in Support of High-Resolution CMAQ Modelling Applications

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The Regional Municipality of Peel (Peel Region) has a population of more than one million people and is situated just west of and adjacent to the City of Toronto in Ontario, Canada. Peel Region has embarked on a project to develop a flexible and comprehensive air quality modelling and monitoring system, the purpose of which is to study the impacts of potential emission scenarios and guide policy decisions relating to public health, urban growth, and sustainability programs.

The modeling system is based on WRF/SMOKE/CMAQ and has been used with nested 36-km, 12-km, 4-km and 1-km resolution grids to perform year-long model simulations for 2012. The parent 36-km domain covers most of northeastern North America. The inner-most, 1-km resolution domain covers Peel Region and much of the rest of the heavily urbanized region around the western portion of Lake Ontario, referred to locally as the "Golden Horseshoe". Major urban centres within the 1-km domain include the Cities of Toronto, Mississauga, Burlington, Hamilton, St. Catharines and the Town of Oakville. Emissions processing was performed using SMOKE to arrive at hourly, gridded, and chemically speciated emissions for each model domain. This paper provides a commentary on the challenges, benefits and pitfalls of preparing input emissions fields for high-resolution model grids. Particular focus will be placed on the need to develop high-resolution spatial surrogates to ensure an accurate allocation of emissions within the 1-km model domain.

## INTRODUCTION

Over the past several years regulations and public policies have been promulgated and developed to ease air pollution and particularly photochemical smog afflicting many urban areas across the country. There are many local, upwind and trans-boundary sources of primary and secondary

pollutants that contribute to air quality in the Region of Peel (Peel). Understanding how these sources influence air quality at both region-wide and local scales is important to developing public policies for managing growth in a healthy and sustainable manner.
In response to Official Policy Plan 2.2.3.3.8, Peel Public Health (PPH) commissioned a study to develop an air quality monitoring and modelling program (AQMMP) to assist in evaluating public policy decisions and how these decisions may affect air quality in Peel.

The AQMMP includes an air quality modelling system (AQMS) and an ambient monitoring program. The AQMS requires several unique features that not only capture the cumulative effects of local and regional emission sources on local air quality, but also represent the complex and dynamic atmospheric conditions that regulate the distribution, transport, and photochemical behavior of pollutants. Pollutants are known as either primary (emitted directly) or secondary (created or formed in the atmosphere from other pollutants). Examples of primary pollutants include oxides of nitrogen and sulphur dioxide. Secondary pollutants include ozone and fine particulate matter ($PM_{2.5}$). Some pollutants, such as $PM_{2.5}$, are composed of both primary and secondary constituents.

Secondary pollutants are created through complex photochemical reactions that take place in the atmosphere. For this reason, standard (i.e., regulatory) air dispersion models are not applicable. The US Environmental Protection Agency's (EPA) Community Multiscale Air Quality (CMAQ) modelling system was selected for the AQMS as this model is capable of modelling complex photochemical reactions in the atmosphere. This model can be used to predict air quality at spatial and temporal scales that can be used to evaluate air quality at local and regional levels and allow tracking of changes over time. Most importantly, it can also be used to help understand and address sources of poor air quality and how population growth and land use, including transportation policy decisions, may impact air quality in the future. Ultimately, the system can lead to better informed planning, educational programs and health protection campaigns.

The added complexity of modelling atmospheric chemistry requires the use of numerous inputs, pre-processors, etc. The AQMS contains a meteorological model to describe atmospheric states and motions, emissions models and pre-processors for anthropogenic (man-made) and biogenic (natural) emissions, and the CMAQ chemistry-transport model for simulating chemical transformations and the fate of airborne pollutants. A schematic of the main components of the AQMS is provided in Figure 2; additional descriptions of the various models, inputs and outputs are provided in subsequent sections of this report.

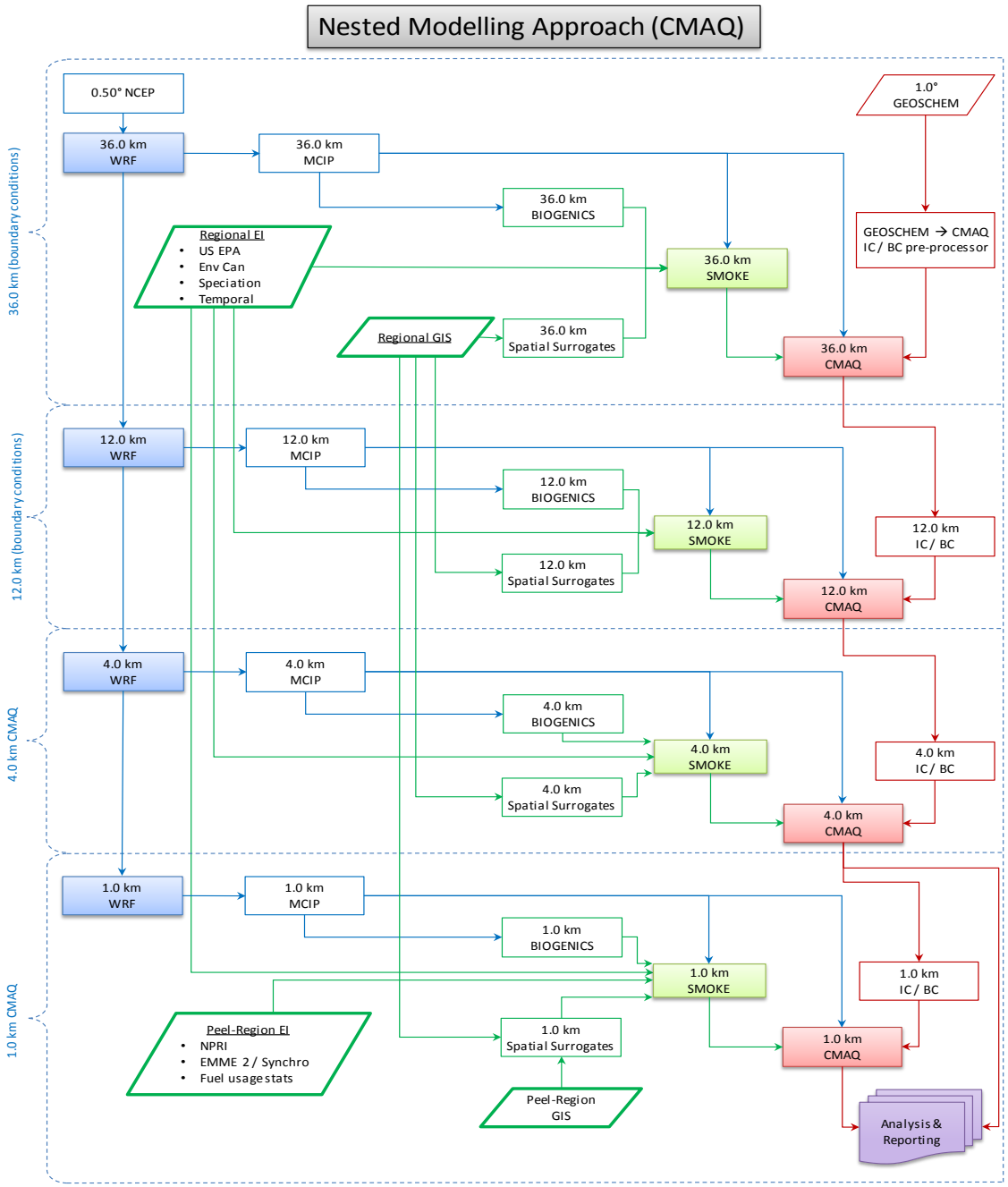
The first year of the study focused on compiling meteorological and emission data, and setting up and testing the AQMS for selected time periods in 2012. The work completed in the first year is summarized in a report dated June 20, 2014.

In the second year, there were two primary goals:

- Improve emission information within the 1 km domain for selected categories including rail, marine, and airports; and,
- run the AQMS for the full 2012 calendar year.

Passive ambient air quality measurements continued in order to provide data for use in future model performance evaluations. The passive monitor is installed in north Peel near Caledon Village to supplement the air quality monitoring data currently being collected by the Ministry of the Environment and Climate Change at two stations in south Peel. The installation and operation of a continuous monitor (i.e., airpointer®) was planned for Year 2 however was delayed to Year 3. There were initial discussions with Environment Canada to use one of their portable continuous monitoring stations however that did not materialize. The remainder of this report details the associated tasks performed during Year 2 of the project.

**Figure 2:** Conceptual Flowchart of the AQMS Model Components



## MODEL DOMAINS AND PERIOD

### Model Domains

The AQMS is configured using a nested domain paradigm in which a larger, more coarse resolution 'parent' domain is used to provide boundary conditions for one or more higher resolution inner domains ('child' domains or 'nests'). The model outputs from one nest provide the boundary conditions for the next, finer resolution domain and so on.

The model domains were carried over from Year 1 without change. They were selected to achieve a compromise between various factors, such as: a desire to cover the largest area practical without being too computationally cumbersome; accounting for local geographic features (namely the Niagara escarpment and Lake Ontario); accounting for upwind emission source regions during different seasons and wind events; general consistency with model domains being considered by the MOECC and EC; etc.

Table 1 describes the AQMS nested model domains for the CMAQ chemistry-transport model (domains for the corresponding meteorological model are somewhat larger to account for edge effects). The domains are also shown graphically in Figures 3 through 6.

**Table 1:** Domain Specifications and Extents

| Nest / Resolution (km) | Rows (#) Distance (km) | Cols (#) Distance (km) | Cells (#) | Spatial Coverage ($km^2$) |
|---|---|---|---|---|
| 36 | 59 | 59 | 3,481 | 4,511,376 |
| | 2124 | 2124 | | |
| 12 | 108 | 108 | 11,664 | 1,679,616 |
| | 1296 | 1296 | | |
| 4 | 93 | 93 | 8,649 | 138,384 |
| | 372 | 372 | | |
| 1 | 100 | 108 | 10,800 | 10,800 |
| | 100 | 108 | | |

The models employ a total of 34 vertical layers extending from the ground surface up to the 5 kPa pressure level (approximately 16 km in altitude), with narrower bands between layers closer to ground level to provide greater resolution of near-surface phenomena such as pollutant transport and mixing within the atmospheric boundary layer.

**Figure 3:** Model Domains and Grid Cells; Nested 36 km and 12 km Domains

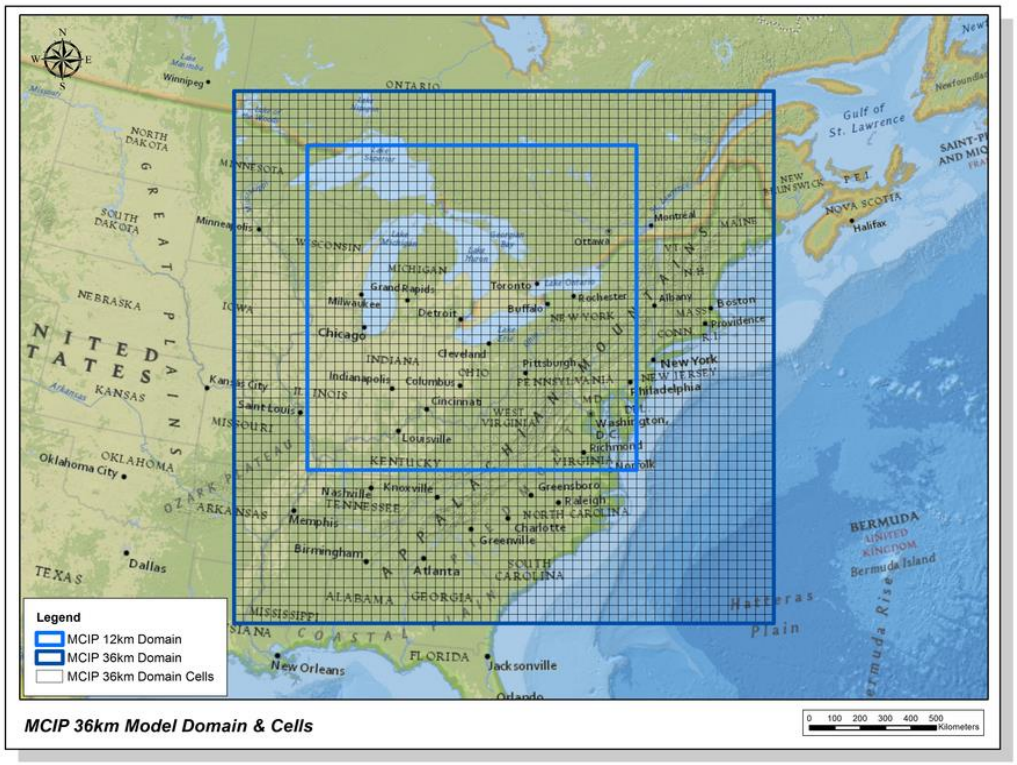



**Figure 4:** Model Domains and Grid Cells; Nested 12 km and 4 km Domains

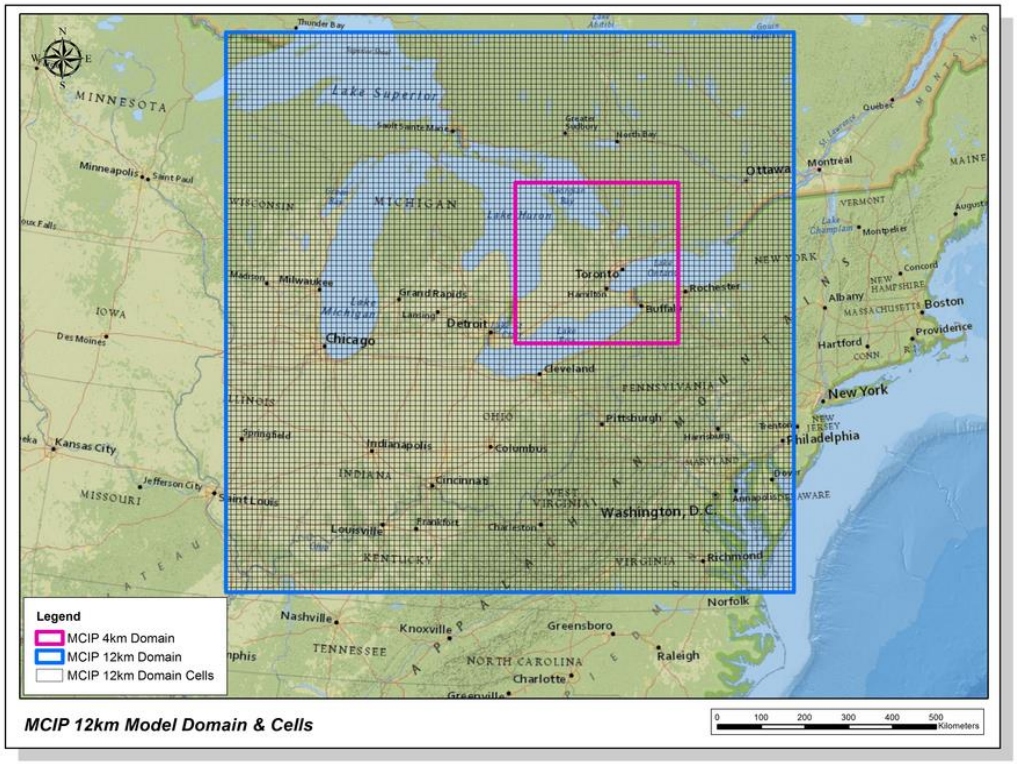


**Figure 5:** Model Domains and Grid Cells; Nested 4 km and 1 km Domains

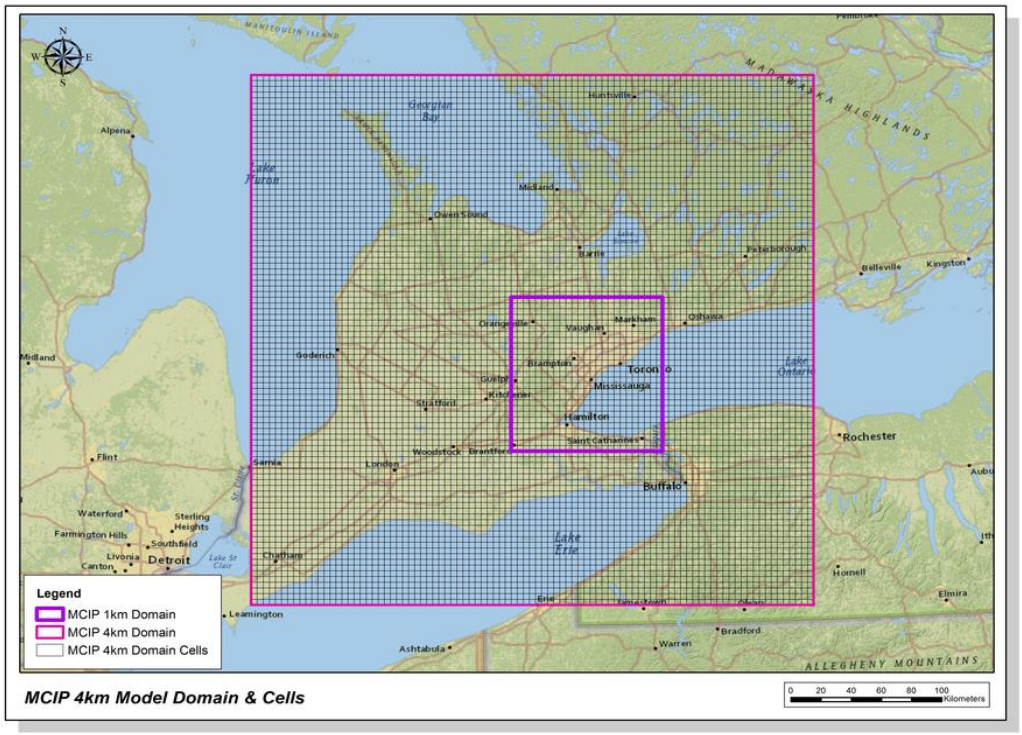
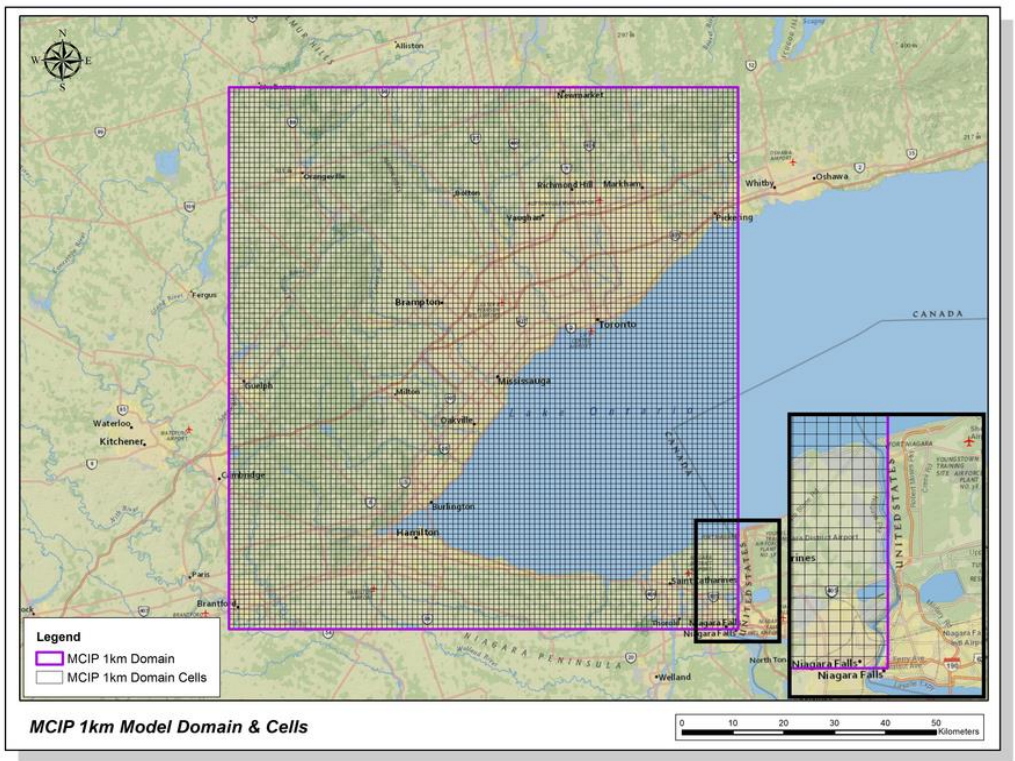



**Figure 6:** Model Domain and Grid Cells; Innermost 1 km Domain



## Model Period

The period modelled extended from January 1, 2012 through to December 31, 2012. The weather experienced in the Region of Peel was generally typical with the exception of warmer than normal periods in March and July. March 2012 began with record low temperatures in the region, followed by a high pressure system that brought uncharacteristically warm air to much of Ontario along with high fine particulate matter levels (likely influenced by pollen bursts associated with an early and drastic leaf-out of vegetation).

In July the air quality was characterized by relatively high ozone and particulate matter concentrations over Peel and the surrounding areas as a result of a high pressure system lingering over southwestern Ontario. During and leading up to this air pollution event winds from the southwest carried primary and secondary pollutant precursors from south of Lake Michigan and the Ohio River Valley into southwestern Ontario. This type of summer smog event is typical for the area and is an ideal synoptic weather condition for reviewing model results of both ozone and fine particulate matter.

## Meteorological Modelling

The Weather Research and Forecasting (WRF) model used to create the meteorological inputs for the AQMS is a prognostic mesoscale numerical weather prediction system originally designed to serve both operational weather forecasting and atmospheric research needs. The WRF model solves the fundamental equations of atmospheric motion on a 3-dimensional grid and incorporates parameterizations for various grid-scale and sub-grid-scale physical processes that influence atmospheric conditions including: wind speed and direction, temperature, humidity, boundary layer turbulence, deep convection and cloud formation, precipitation, radiation, heat transfer and moisture flux.

Version 3.4.1 of the WRF numerical model was incorporated to replicate the meteorological conditions during 2012 calendar modelling period. Initial and boundary conditions for WRF were defined using outputs from the North American Regional Reanalysis (NARR) as described in http://www.emc.ncep.noaa.gov/mmb/rreanl/. These model outputs are available at 32 km resolution every 3 hours over most of North America.

Geophysical data, such as terrain elevation and land cover characterization, were derived from available US Geological Society global data sets from the online WRF model depository and processed using the WRF Preprocessing System (WPS).

WRF model outputs are used in a number of the AQMS modules such as MEGAN (biogenic emissions model), the SMOKE emissions pre-processing system, and the CMAQ chemistry-transport model. The WRF model outputs are not directly usable by these modules and therefore were pre-processed using the US EPA's Meteorology-Chemistry Interface Processor (MCIP version 4.1).

As per EPA guidance for air quality simulations, WRF was run in 5.5 day long segments to prevent the model solution from diverging from the NARR boundary conditions. For each

segment, the model is allowed to adjust or 'spin-up' to the domain boundary conditions provided by NARR for the first 12 hours of each run. This period is discarded and the last 5 days of each WRF run are retained. The boundary conditions were updated every three hours as per EPA guidance (http://www.epa.gov/AMD /Research/Air/meteorologicalModeling.html). This process was repeated to cover the full 2012 calendar year. WRF outputs were then processed with MCIP to produce the daily meteorological files used by MEGAN, SMOKE and CMAQ.

**Emissions**

To simulate the complex photochemical reactions that take place in the atmosphere it is important to replicate, as accurately as possible, the complex space and time varying emissions from all sources of pollution within each of the model domains, with a particular emphasis on the highest resolution, inner-most (1.0 km) domain. Emissions are generally categorized into the following four major classes:

- **Point sources** – typically representing major facilities or industrial activities, point sources are defined as single emission points that are associated with geographic coordinates and stack characteristics. Examples of point sources include smoke stacks from power plants, cement manufacturing facilities, etc.

- **Area sources** – area sources contain emission sources that are inventoried as spatial totals (i.e., province-wide or regional totals). Emissions are typically distributed across the model grid using geospatial activity information, such as population or employment statistics. Examples of area sources include agricultural operations, commercial solvent use and fugitive dust from construction activities.

- **Mobile sources** - mobile sources refer to emissions associated with all manners of transportation, be it ground, water, or air. Accordingly, emissions from mobile sources are distributed spatially using geospatial information about the locations of transportation networks (e.g., roadways, airports, shipping lanes) and / or areas associated with non-road vehicular activities (e.g., construction sites). Mobile emissions are often subdivided into 'non-road' and 'on-road' source groups for ease of data compilation and processing. Examples of mobile sources include light-duty gasoline vehicles, trains, aircraft, marine vessels, bulldozers, etc.

- **Biogenic sources** - natural emissions from plants and soils are referred to as 'biogenic' and are typically estimated using models that associate land cover and vegetation type with seasonal and meteorology-dependent emissions factors. Version 2.1 of the Model of Emissions of Gases and Aerosols from Nature (MEGAN) model was configured to generate hourly emissions from biogenic sources.

Emissions from anthropogenic (human) activities are typically compiled as spatially, temporally, and chemically lumped emissions inventories (e.g., total annual VOCs from commercial fuel usage) in spreadsheets, databases, or other model-specific file formats. The calendar year for which emission data are available rarely coincides exactly with the meteorological period being modelled. As such, there is often an inherent mismatch of years between different emissions

data sets and the meteorology. This is a common challenge to regional modelling applications and not something that is unique to this study. In each instance the most up to date and 'stable' (i.e., tested and reviewed) data sources were used.

A summary of the emission inventories used are provided in Table 2. These emission inventories were selected as they were the most up to date, quality assured data files available at the start of Year 2 as per discussions with the primary providers of regional emissions inventory data; namely the US EPA and Environment Canada. These inventories reflect estimates prior to the economic downturn in 2008-2011 and are more representative of the 2012 period being modelled, even though some major industries and coal fire power plants in the U.S. and Canada may have shut down. Future tasks for year 3 and beyond include updating both regional, and more importantly local, emissions data to address for some of these specific challenges.

**Table 2:** Emission Data and Pre-Processing Requirements

| **Canada** |
|---|
| **POINTS**<br>• 2006 chemically lumped (total VOCs) emissions plus associated temporal profiles and allocation factors. Based on National Pollutant Release Inventory (NPRI) submissions, hence facility-wide (not stack by stack) emissions provided with NPRI IDs used in place of SCC codes<br>• 2010 pre-speciated for CB5 chemical mechanism provided in MSAccess format with emissions again based on NPRI submissions, hence facility-wide (not by stack) with NPRI IDs used in place of SCCs<br>• Reconciliation of changes between 2006 and 2010 used to populate updated 2010 temporal factor tables |
| **AREA**<br>• Emissions provided by SCC as annual totals and temporally allocated using temporal profiles provided by Environment Canada.<br>• Lumped / aggregated VOCs emissions chemically speciated to CB5 chemical mechanism using speciation profiles provided by Environment Canada.<br>• 2011 agricultural emissions provided by NAESI (provided by EC) and allocated using custom surrogates<br>• All other emissions provided as provincial totals and allocated to model grid using spatial surrogates |
| **MOBILE**<br>• Non-road and on-road emissions provided by SCC as annual totals and temporally allocated using temporal profiles provided by Environment Canada.<br>• Lumped / aggregated VOCs emissions chemically speciated to CB5 chemical mechanism using speciation profiles provided by Environment Canada.<br>• 2006 on-road mobile sources provided for 6 zones and allocated using custom surrogates<br>• All other emissions provided as provincial totals and allocated to model grid using spatial surrogates |
| **US** |
| **POINTS, AREA, MOBILE**<br>• 2008 National Emissions Inventory used for all sources types.<br>• Emissions provided as chemically lumped, annual total, county-wide totals.<br>• Emissions spatially / temporally allocated and chemically speciated using US EPA and SMOKE defaults. |

Pre-processing of emissions inventory data was performed using version 3.1 of the Sparse Matrix Operating Kernel for Emissions (SMOKE) processing system. Most of the emissions preparation for Year 2 was completed in Year 1. However, some of the spatial surrogates (files used to allocate geographically aggregated emissions to the model grid) used in Year 1 were found to be particularly problematic and hence further refinement for these was performed in Year 2.

Specifically, the following surrogates were updated using better spatially resolved activity data for the 1.0 km domain: rail; airports; and marine.

Refinements to the surrogates listed above were accommodated by further breaking down the sub-category mapping and/or refining activity geometries used in the allocation process using GIS techniques.

Table 3 depicts the total gridded emissions in tonnes per year in the 1 km domain obtained when processing the emission inventory with SMOKE. As might be expected, the combination of On-Road Urban and Rural mobile sectors contribute the most to both CO and NOx emissions. The transportation and the industry sectors are the highest VOC emitters in the 1 km domain.

**Table 3:** Emission Summary in the Region of Peel 1.0 km domain (metric tonnes per year).

| SOURCE CATEGORY | CO | $NO_X$ | VOC | $NH_3$ | $SO_2$ | $PM_{10}$ | $PM_{2.5}$ |
|---|---|---|---|---|---|---|---|
| **TRANSPORTATION** | | | | | | | |
| Air Transportation | 8,746 | 4,226 | 2,081 | 3 | 342 | 0 | 149 |
| Rail Transportation | 853 | 5,546 | 146 | 5 | 250 | 0 | 177 |
| Marine Transportation | 9,492 | 1,460 | 2,898 | 2 | 715 | 0 | 232 |
| OnRoad Urban mobile | 302,282 | 48,008 | 29,388 | 3,290 | 245 | 1,433 | 10,883 |
| OnRoad Rural mobile | 68,926 | 16,058 | 6,716 | 752 | 56 | 453 | 308 |
| Unpaved Roads | 9,473 | 43 | 2,101 | 1 | 1 | 0 | 3,886 |
| **INDUSTRY** | | | | | | | |
| Metals, Mining and Mineral Production | 18,982 | 838 | 52 | 1 | 58 | 0 | 3,448 |
| Utilities | 245 | 826 | 16 | 10 | 111 | 0 | 26 |
| Forestry and Wood Products | 187 | 61 | 1,787 | 0 | 56 | 0 | 7 |
| Manufacturing and Assembly | 0 | 0 | 32,226 | 0 | 0 | 0 | 0 |
| Printing and Related Industries | 0 | 0 | 9,224 | 0 | 0 | 0 | 0 |
| Industrial use of off-road engines (e.g., forklifts, heavy equipmen | 24,685 | 11,829 | 1,533 | 2 | 537 | 0 | 212 |
| Industrial Point Sources | 19,440 | 16,816 | 7 | 1,219 | 18,765 | 3,419 | 2,497 |
| Primary industry | 0 | 0 | 38,852 | 0 | 0 | 0 | 0 |
| **ANTHROPOGENIC & MISC** | | | | | | | |
| Waste Management | 2,085 | 142 | 2,180 | 27 | 413 | 0 | 302 |
| Commercial Fuel Combustion | 211,677 | 9,312 | 7,316 | 72 | 3,719 | 0 | 901 |
| Construction Activities | 10,606 | 7,482 | 1,125 | 6 | 390 | 0 | 673 |
| Gasoline Stations and Petroleum Wholesales | 0 | 0 | 4,497 | 0 | 0 | 0 | 269 |
| Population, Urban and Rural Dwellings | 50,805 | 7,351 | 2,423 | 213 | 1,451 | 0 | 2,090 |
| Residential Wood Combustion | 71,493 | 1,033 | 15,285 | 93 | 148 | 0 | 10,791 |
| Farms / Agriculture | 5,780 | 9,056 | 2,743 | 1,243 | 413 | 0 | 1,224 |
| Other / Miscellaneous | 0 | 0 | 58 | 0 | 0 | 0 | 81 |
| **Total without fugitive dust** | **815,756** | **140,086** | **162,656** | **6,938** | **27,669** | **5,306** | **38,158** |
| Fugitive Dust (including agricultural, construction and road dust) | 0 | 0 | 0 | 0 | 0 | 77,937 | 14,585 |
| ***Total including fugitive dust*** | ***815,756*** | ***140,086*** | ***162,656*** | ***6,938*** | ***27,669*** | ***83,243*** | ***52,742*** |

***Notes: emissions of gasses from soils and vegetation (Biogenics) not included***

The following sections provide further details regarding the refinements of spatial surrogates completed in Year 2.

### *Marine Surrogates*

Two emission categories were maintained for marine emissions, one for commercial vessels and one for pleasure craft. Spatially resolved activity data for commercial vessels were obtained

from the US EPA in GIS format (LADCO_Great_Lakes_Emissions_Inventory_EERA_2011.shp) and further refined using vessel routes from nautical charts and satellite imagery.

A unique spatial activity layer for pleasure craft was generated using a buffer approach based on the assumption that most pleasure craft remain within a distance of approximately 3 km of the shoreline, and/or wider portions of major tributaries within the model domain.

A comparison of Year 1 and Year 2 commercial vessel and pleasure craft gridded spatial surrogates (emission allocation factors) is presented in Figures 7 and 8, respectively.

**Figure 7:** Comparison of Commercial Vessel Activity

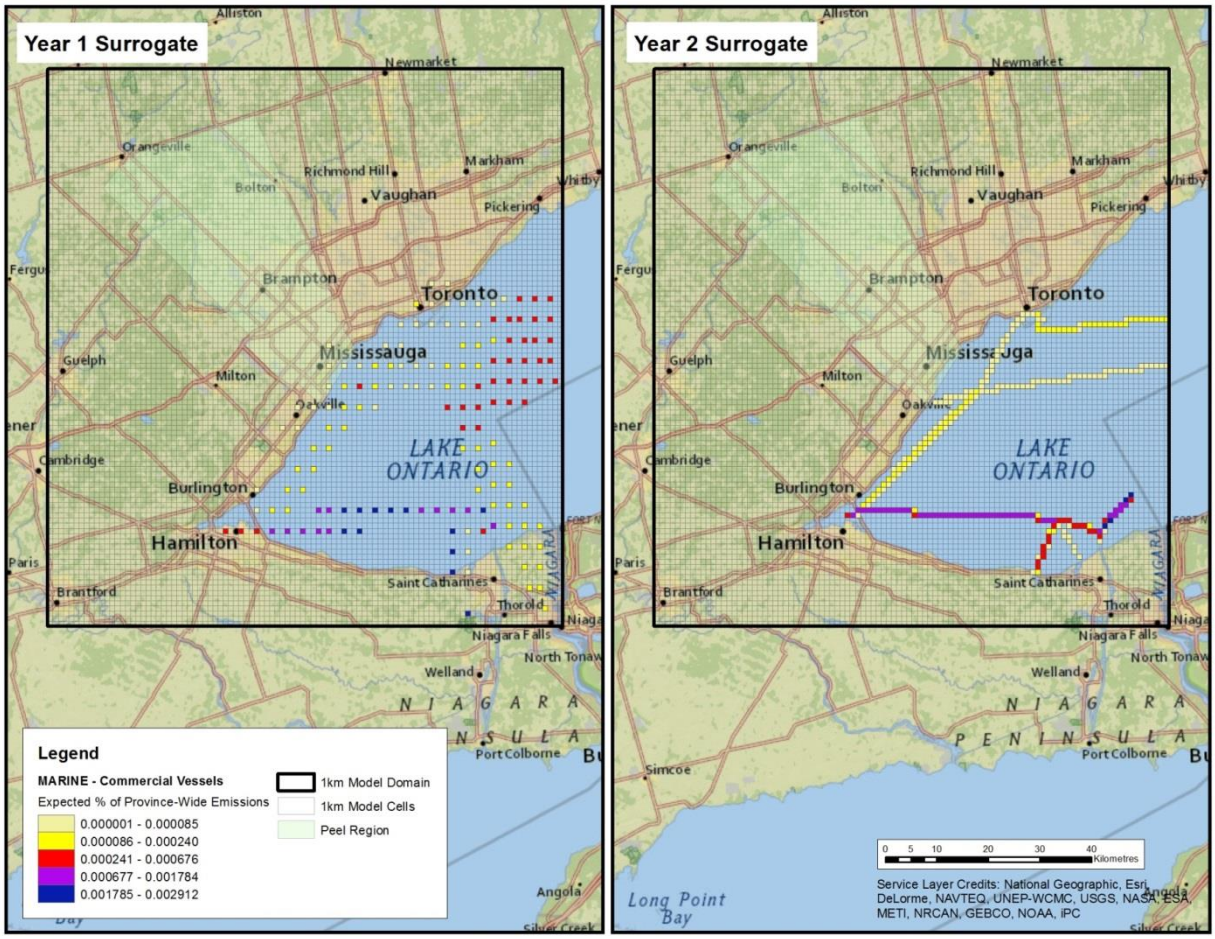
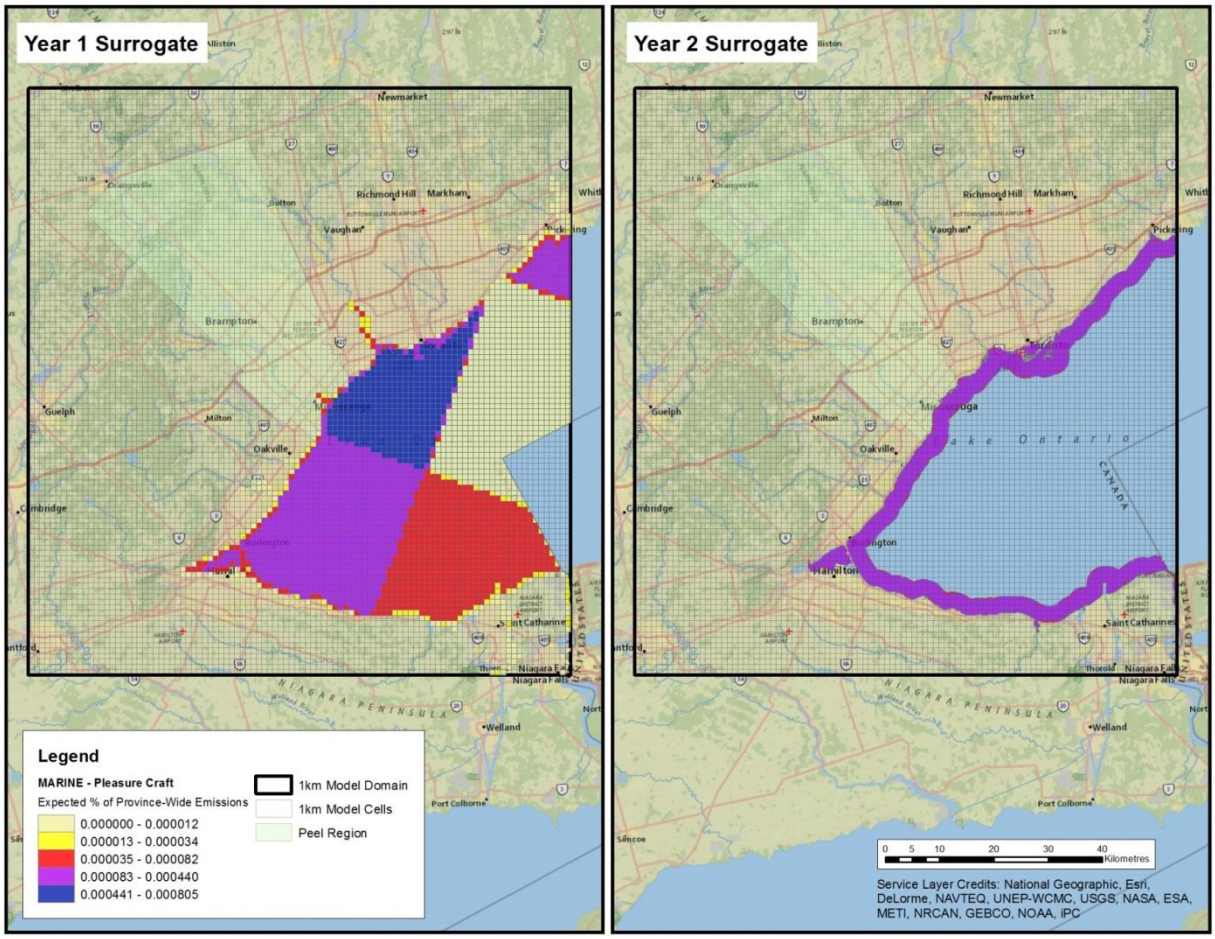


**Figure 8:** Comparison of Pleasure Craft Activity

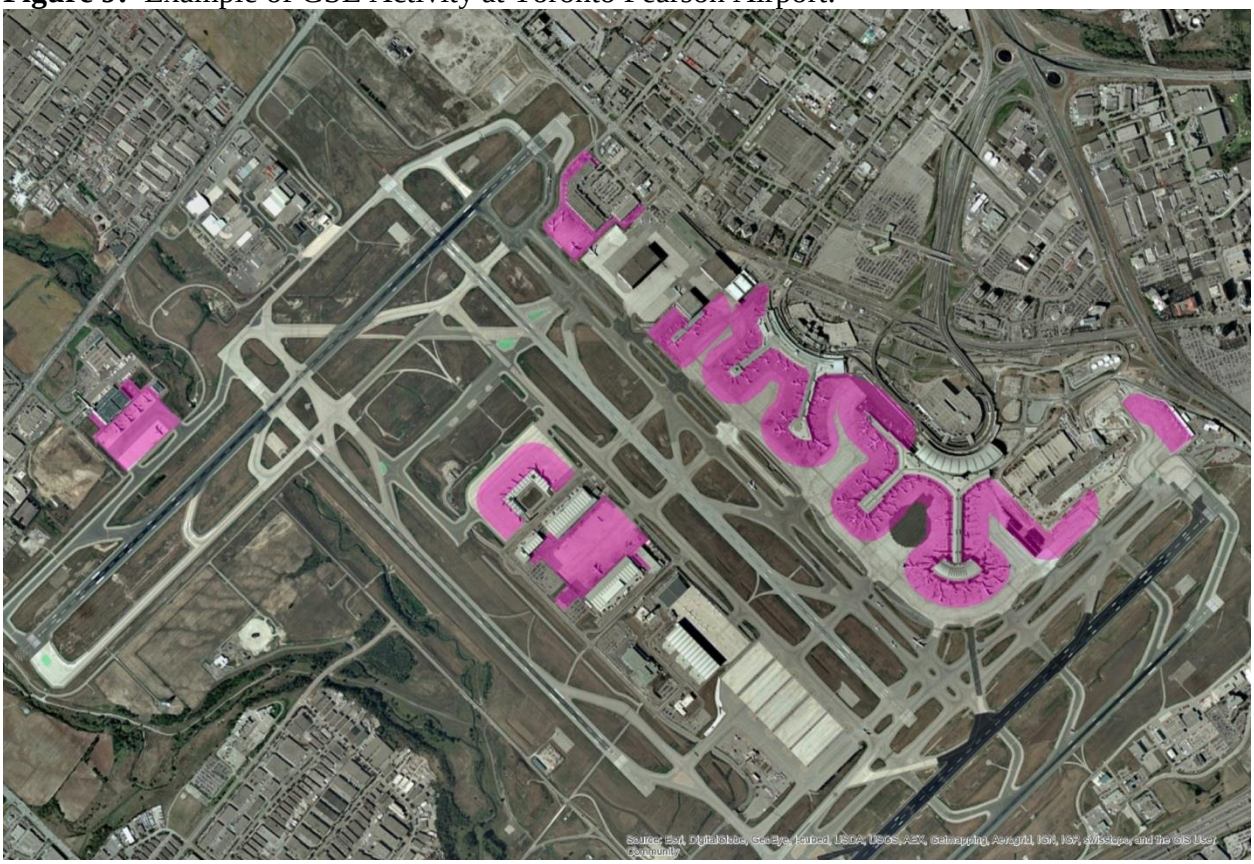



***Airport Surrogates***

Airport-related surrogates were split into several sub-categories to better align with the emissions data provided. These included: ground support equipment (GSE); commercial aircraft; general aviation; and, airplane taxi.

The geometry or area of operations for GSE was updated using ArcGIS using imagery and airport diagrams to identify areas where GSE activity typically occurs. Specifically, GSE was allocated to areas where aircraft loading/unloading occurs, and in the vicinity of passenger terminal buildings and air cargo buildings. The GSE surrogate was further refined by incorporating the number of movements by airport (2011 data) into the surrogate calculation. As a result, GSE emissions were concentrated to airport locations with the greatest emissions. An illustration of the refined GSE activity is provided in Figure 9.

**Figure 9:** Example of GSE Activity at Toronto Pearson Airport.



Emissions were also updated for the other three sub-categories using an activity dataset obtained from Environment Canada that incorporated landing-takeoff statistics at all Canadian airports. The dataset was edited to eliminate surrogates for the Guelph airport ("0" movement data) and the Niagara Central airport (erroneous location and low movement statistics).

A comparison of Year 1 and Year 2 activity for commercial aircraft, general aviation, and air taxi is included in Figures 10 through 12, respectively.

**Figure 10:** Comparison of Year 1 and Year 2 Commercial Aviation Activity

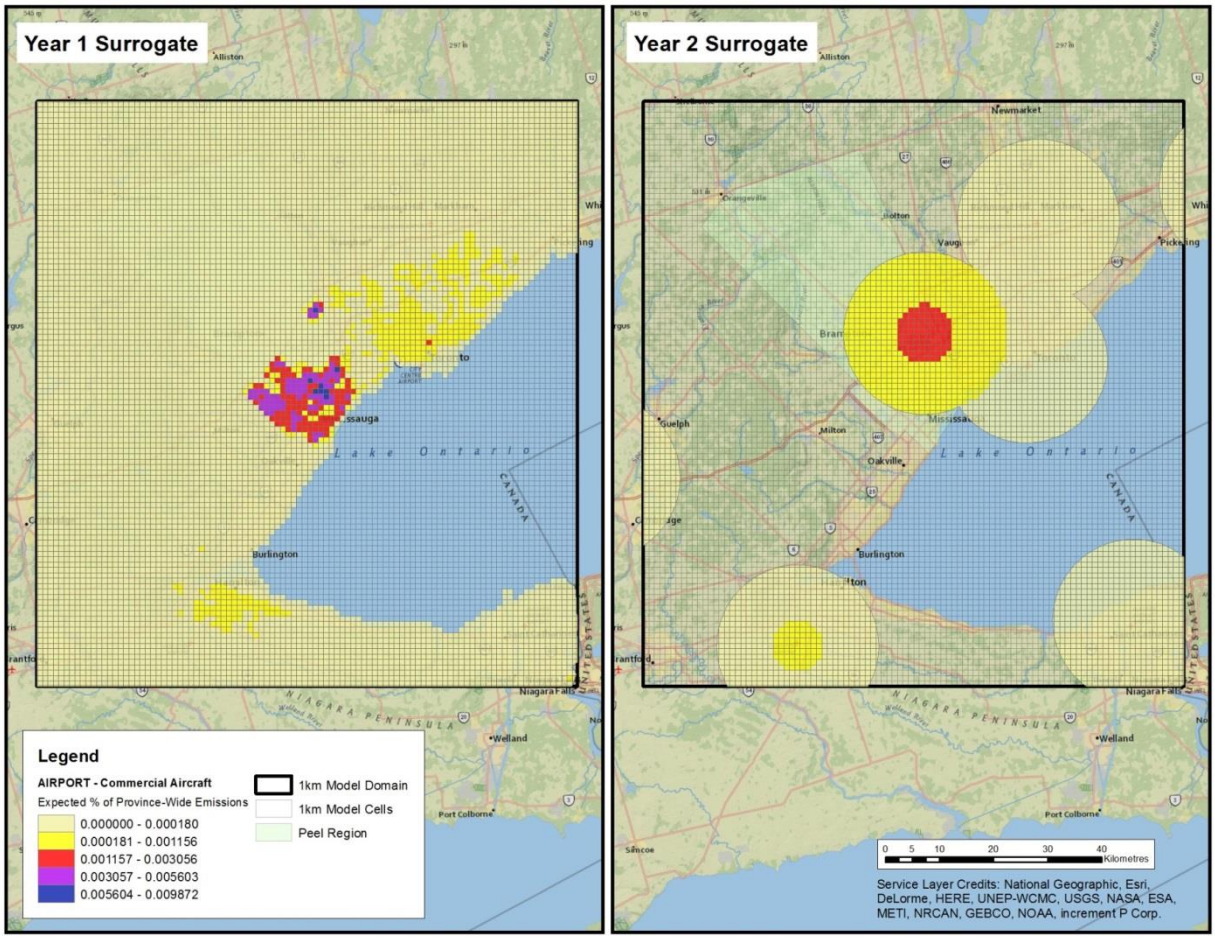


**Figure 11:** Comparison of Year 1 and Year 2 General Aviation Activity

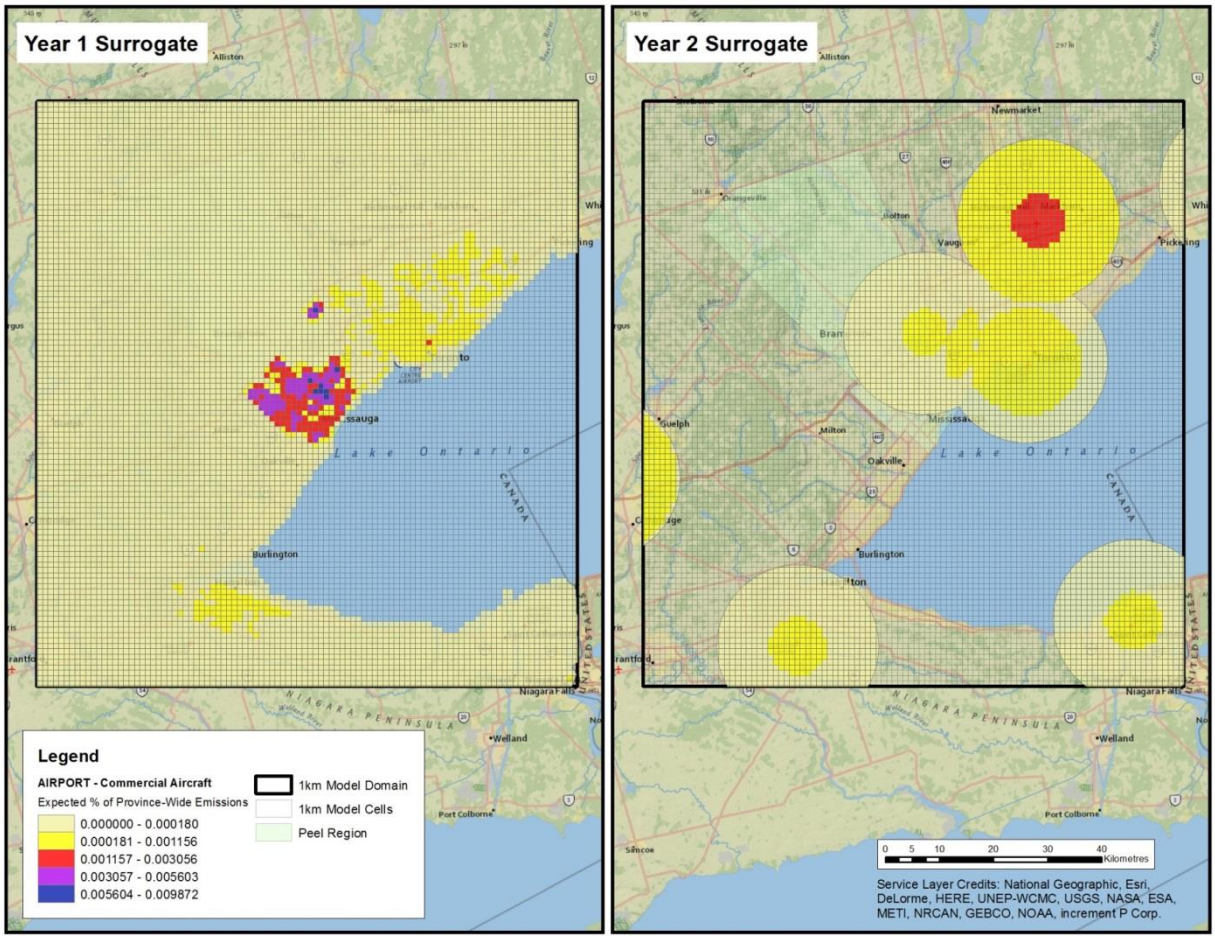
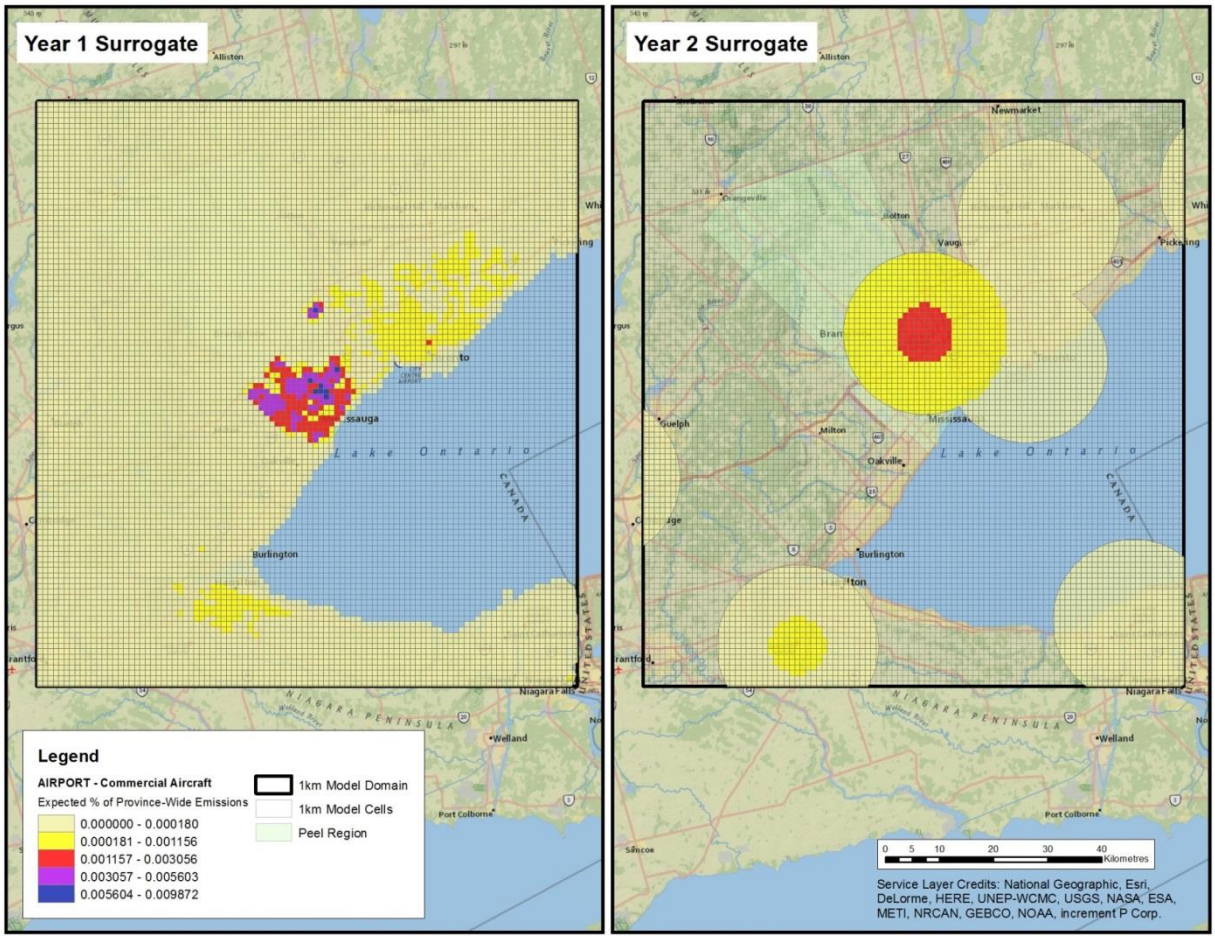


**Figure 12:** Comparison of Year 1 and Year 2 Air Taxi Activity




***Rail Surrogates***

Rail-related surrogates were split into 3 sub-categories (per the emissions inventory provided). Activity data by railway classification was adopted from a newly-released National Railway dataset then available via Geobase (www.geobase.ca) but currently available via GeoGratis from Natural Resources Canada (http://geogratis.gc.ca/geogratis/Home?lang=en). The National dataset was further refined for use in the Region of Peel by creating a hybrid dataset with the most recent railway dataset from Peel Region (i.e., rail lines within Peel were replaced with Peel Region's dataset).

The rail datasets included classifications of rail geometries, which allowed for the creation of a third sub-category to be added specific to rail yards (Figure 13). Figures 13 through 15 provide a comparison between Year 1 and Year 2 rail activity.

**Figure 13:** Comparison of Rail Yard Activity

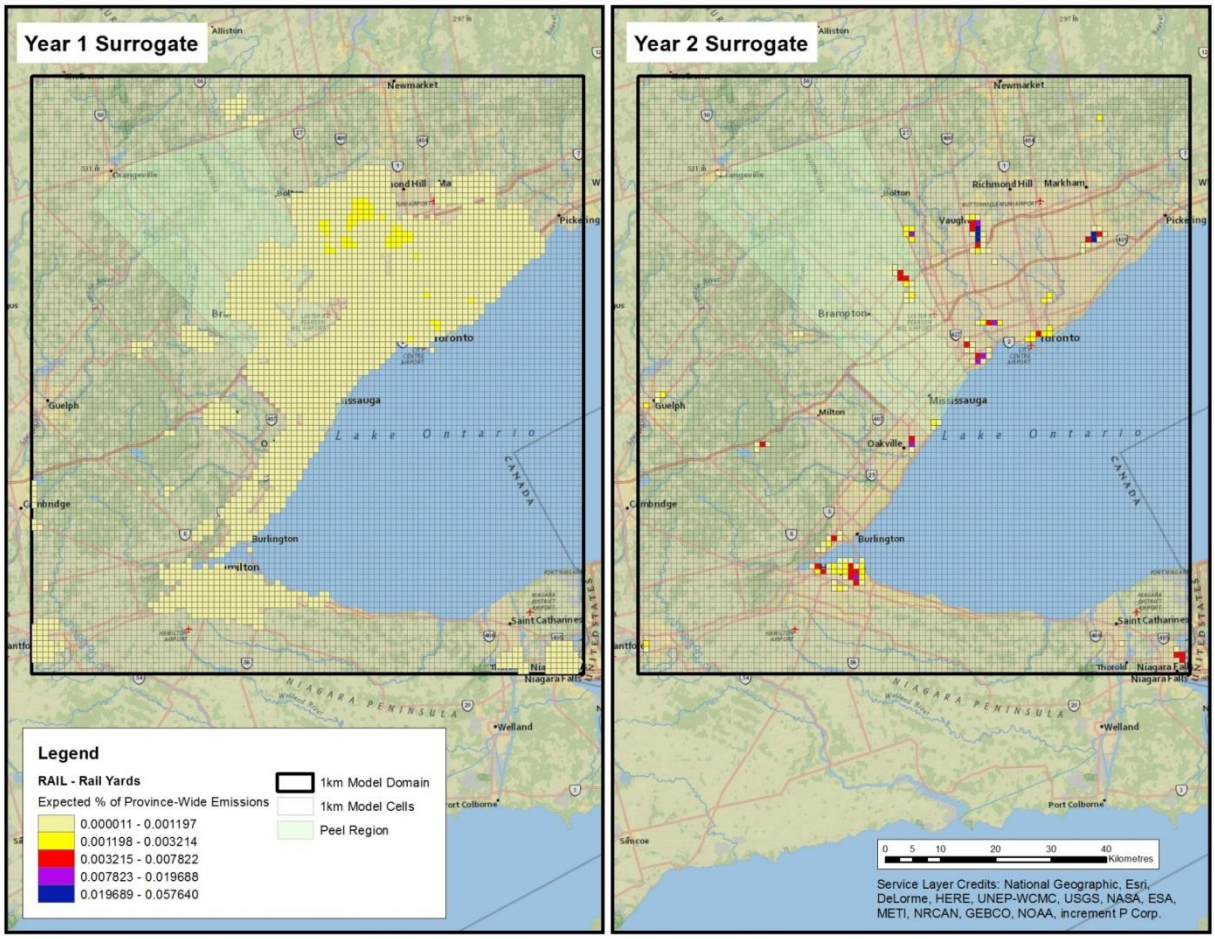


**Figure 14:** Comparison of Line Haul Locomotive Activity

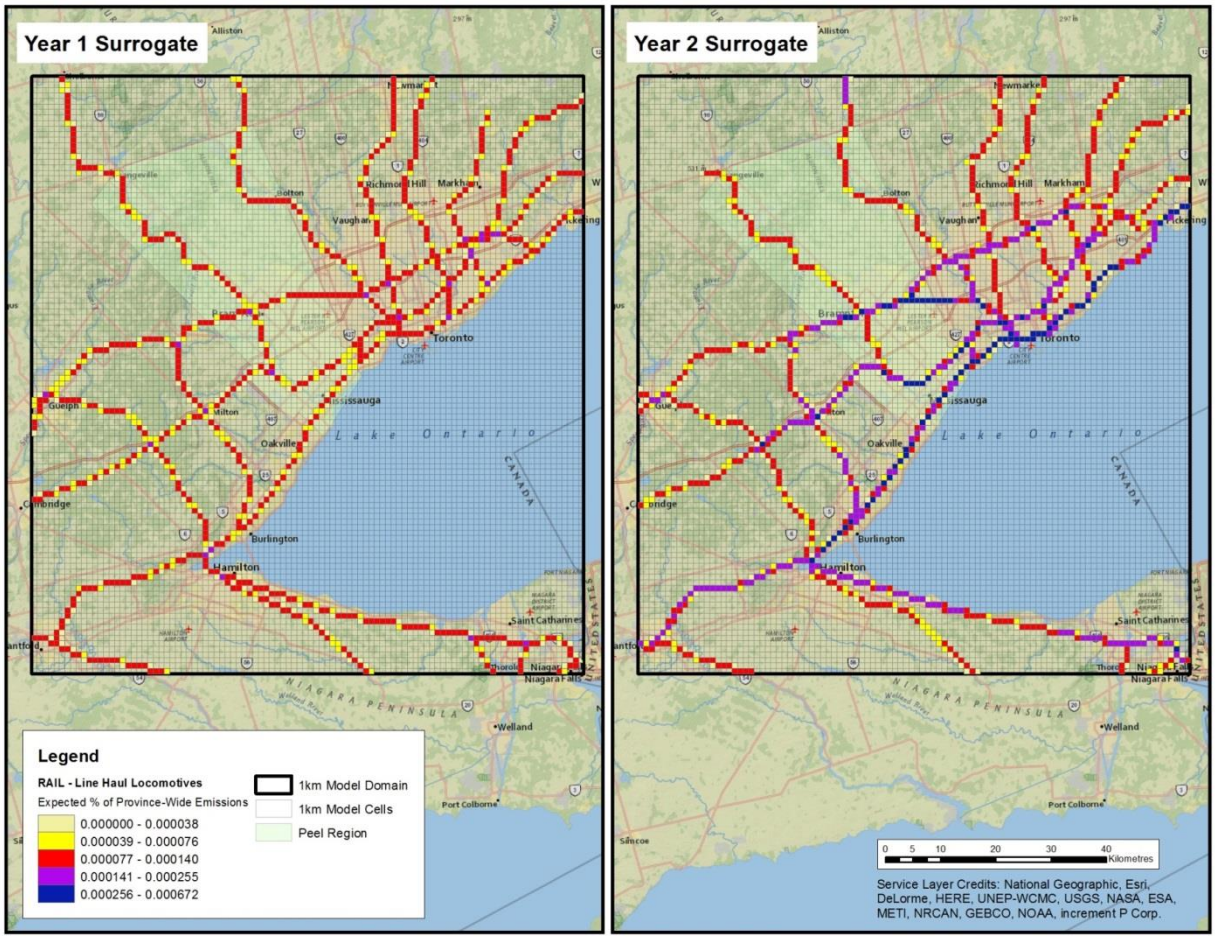
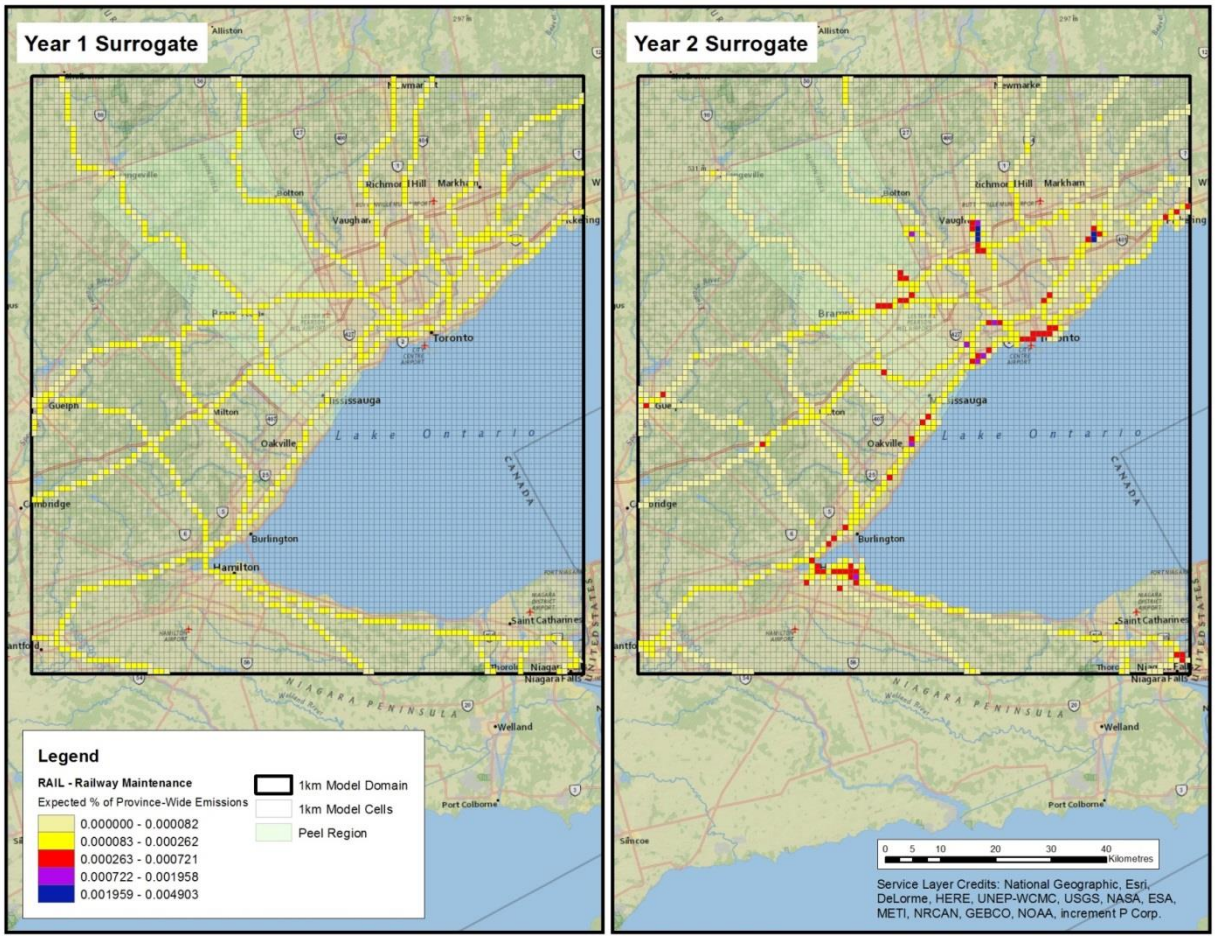


**Figure 15:** Comparison of Railway Maintenance Activity




## CHEMISTRY-TRANSPORT MODEL (CMAQ)

At the core of the AQMS is the US EPA's Community Multiscale Air Quality (CMAQ) modelling system (http://www.cmaq-model.org/); referred to as the CMAQ chemistry-transport model or 'CCTM'. Under contract to the US EPA, the CMAQ model, MCIP, SMOKE and several other pre- and post-processing tools are supported and distributed by the Community Modeling and Analysis System (CMAS) Center at the University of North Carolina at Chapel Hill; a project partner.

CMAQ has a world-wide community of users in government, academic and private industry and is the most widely applied and accepted photochemical model currently in common use. The model employs a standardized NetCDF file format for inputs and outputs, which enables users to leverage a variety of existing tools and programming / scripting languages written for NetCDF files. CMAQ is open source and hence available for use by anyone without licensing fees. Version 5.0 of the CMAQ model was configured and tested within RWDI's LINUX computing environment. Key technical details pertaining to the configuration of the CMAQ model are provided in Table 4.

**Table 4:** CMAQ Model Configuration

| MODEL CONFIGURATION | |
|---|---|
| **Model Version** | CMAQ_v5.0 |
| **Horizontal Advection** | Yamartino |
| **Vertical Advection** | Per WRF outputs |
| **Horizontal Diffusion** | Multiscale |
| **Vertical Diffusion** | ACM2 |
| **Gas Chemistry Mechanism** | CB05 (without Chlorine) |
| **Gas Chemistry Solver** | Euler Backward Iterative (EBI) |
| **Aerosol Mechanism** | CMAQ 6$^{th}$ generation model (aero6) |
| **Clouds/Aqueous Chemistry** | Cloud ACM AE6 |
| **Plume in Grid** | none |

## YEAR 2 RESULTS

A full year model run was completed in Year 2 for the 2012 model period. An evaluation of the model performance was performed using the Atmospheric Model Evaluation Tool (AMET). AMET is designed to simplify the analysis and evaluation of meteorological and air quality models and was developed by project partner UNC-IE. AMET compares model output for one or more particular locations to observed values from one or more corresponding monitoring stations. An analysis of the comparison between model and observation values can then be completed to assess model's performance, biases, etc.

A preliminary model performance evaluation was performed in Year 2 with additional analyses continuing on into Year 3. The review in Year 2 was intended to assess how well the model was able to reproduce results (i.e., within the right order of magnitude) for at least one of the key secondary pollutants important to Peel region. This initial review indicated that for ozone, CMAQ results are in-line with expectations and, for the period modelled, in good agreement with ambient monitoring data from the MOE ambient monitoring stations in south Peel.

Figures 16a through 16c depict the hourly, domain-wide average (unpaired in space but paired in time) ground level ozone concentrations across 13 stations in the 1.0 km modelling domain as follows:

- Figure 16a illustrates an annual time series comparison between modelled and measured (observed) hourly ozone in the topmost graph (modelled = red; observed NAPS Stations = black) and the associated bias in the model results in the bottom graph.

- Figure 16b presents hourly box plots of monthly modelled (median = red dashed line with triangle symbols, 25$^{th}$ to 75$^{th}$ percentile range = dark grey boxes) and measured (median = black line with crosses, 25$^{th}$ to 75$^{th}$ percentile range = light grey boxes) ozone concentrations by hour of day for March (left), and July (right).

- Figure 16c presents a 1:1 plot of modelled (CMAQ, vertical axis) versus measured (Observation, horizontal axis) hourly ozone concentrations for the months of March (left) and July (right).

**Figure 16a:** Timeseries Comparison of Predicted and Measured Ozone

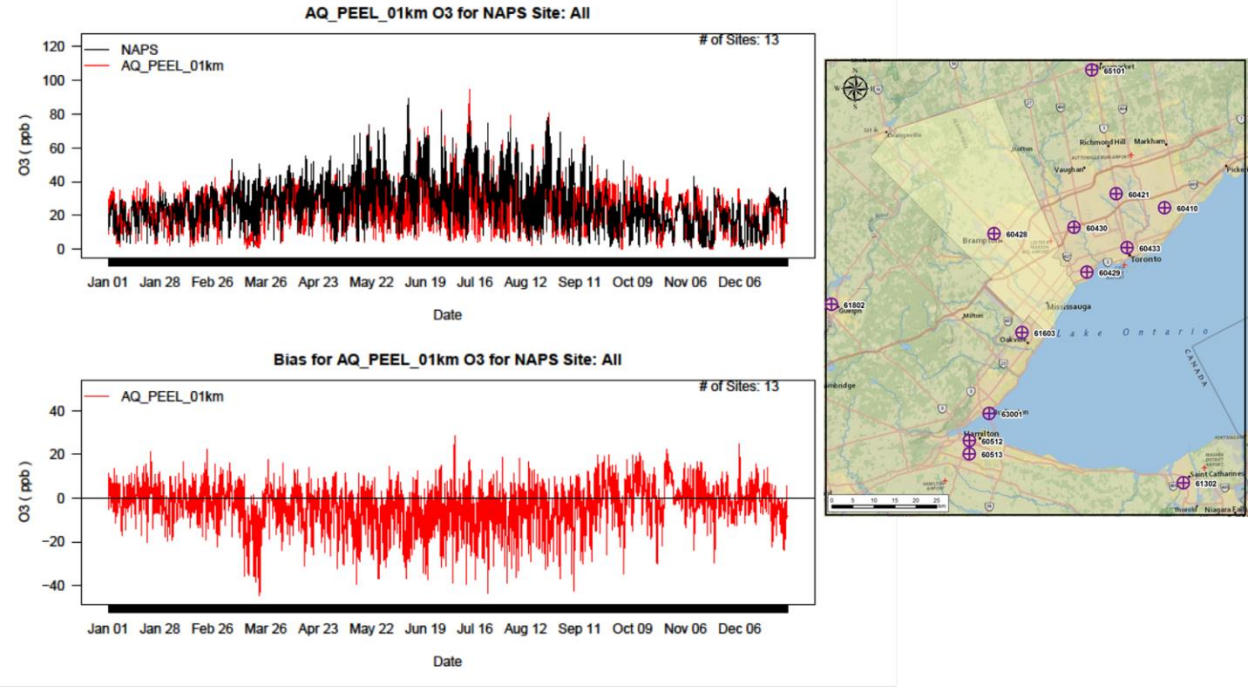



**Figure 16b:** Hourly Box Plots of Predicted and Measured Ozone (Left: March; Right: July)

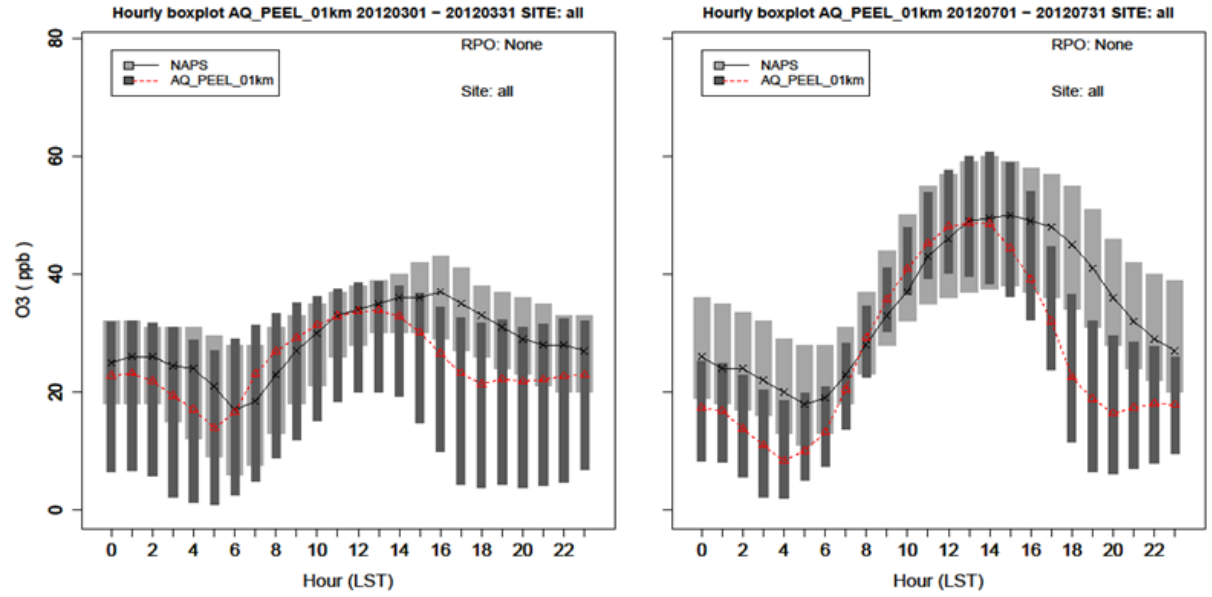
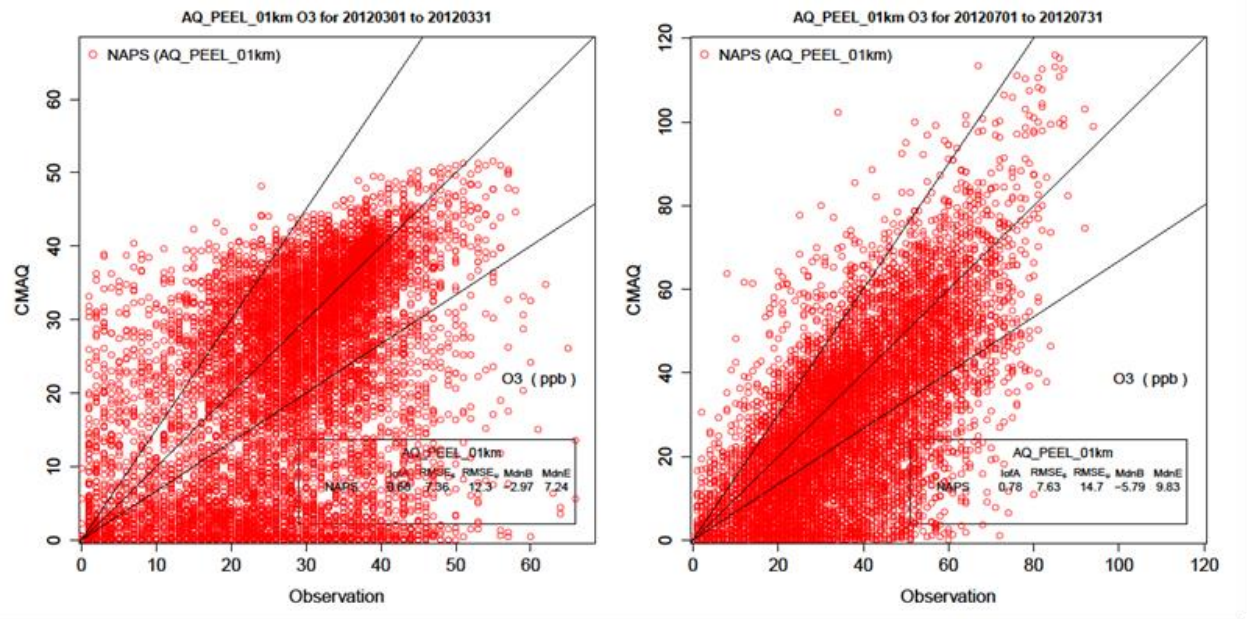


**Figure 16c:** Scatter Plots of Predicted and Measured Ozone (Left: March; Right: July)




Overall, the AQMS generally predicted correctly the magnitude of peak hourly ozone concentrations with a slight negative bias. Further analysis of the station-by-station performance to be performed in Year 3 is expected to indicate that the under prediction of ozone, or more likely the over-prediction of ozone titration (depletion), may be attributed in part to the magnitude as well as temporal and spatial allocation of $NO_X$ emissions; from on-road vehicles being the primary source.

Figures 17a to 17c show similar plots as 16a to 16c but for fine particulate matter ($PM_{2.5}$) concentrations over 10 observing stations within the 1.0 km domain.

**Figure 17a**: Timeseries of Predicted and Measured $PM_{2.5}$

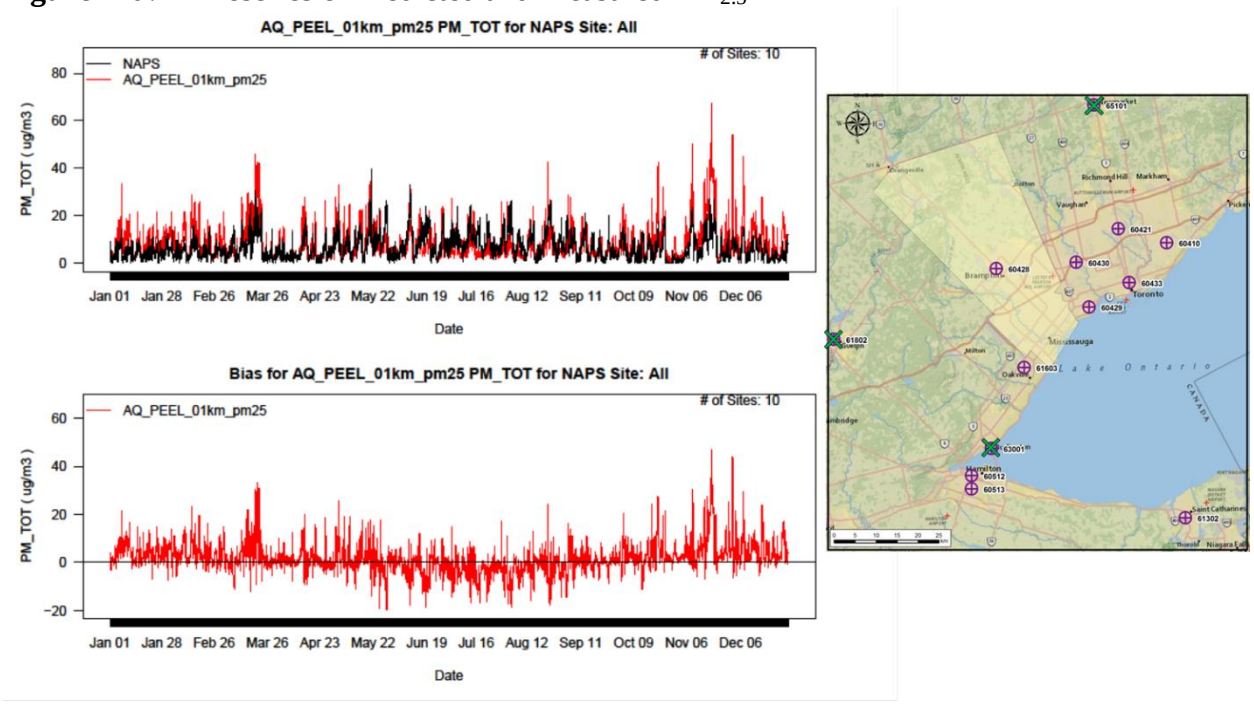



**Figure 17b:** Hourly Box Plots of Predicted and Measured $PM_{2.5}$ (Left: March; Right: July)

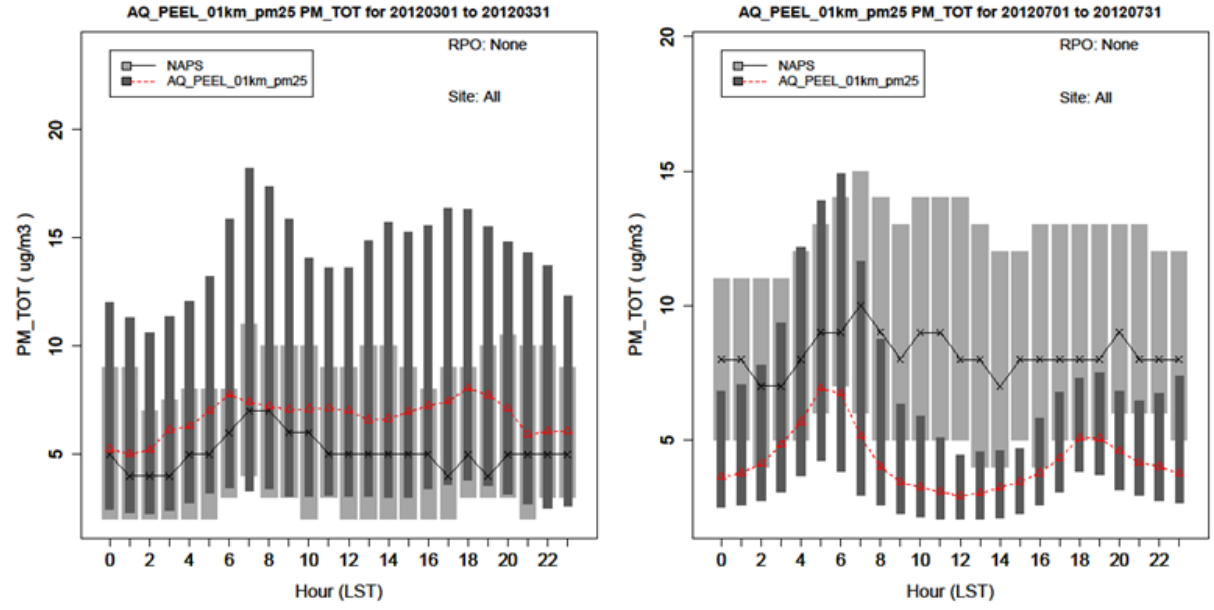
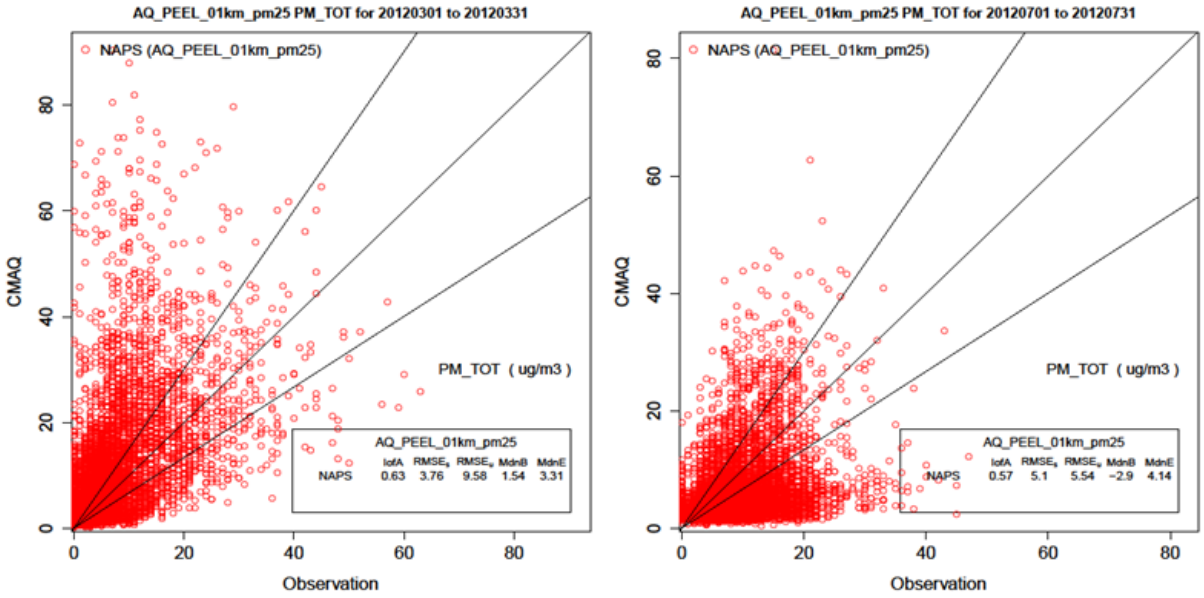


**Figure 17c:** Scatter Plots of Predicted and Measured $PM_{2.5}$ (Left: March; Right: July)



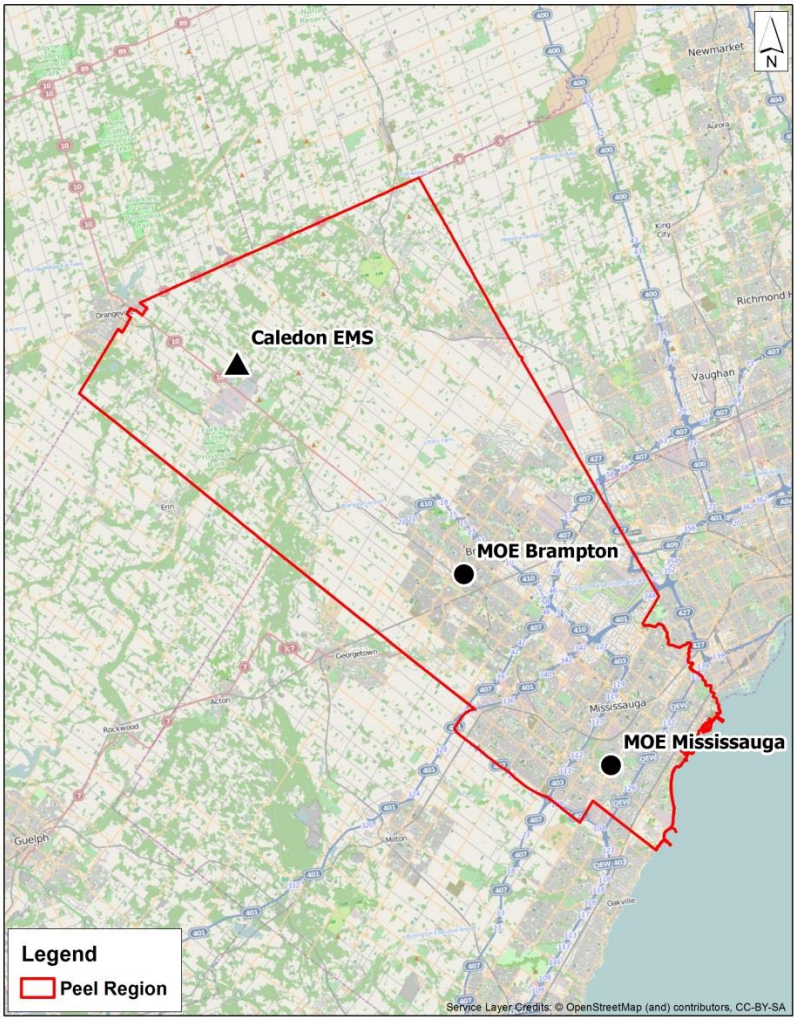

Overall, the AQMS generally predicted the magnitude of peak $PM_{2.5}$ concentrations better in winter than in summer with a slight over-prediction in winter and a more modest under-prediction in summer (resulting in an overall slight negative bias on the annual average). Further investigation into model performance for both ozone and fine particulate matter ($PM_{2.5}$) is planned for Year 3 with a goal of improving the emissions and AQMS model results and understanding any resulting biases. This in turn will assist in the interpretation of subsequent results from emission change scenarios (also planned for Year 3). These activities are further described in Section 9.

## AIR QUALITY MONITORING

The Region of Peel currently has two permanent air quality monitoring stations located within its boundary. The stations are operated and maintained by the Ontario MOECC and are part of the Canada-wide National Air Pollution Surveillance (NAPS) Network; Mississauga (60434), and Brampton (60428).

A passive monitor was installed in north Peel to supplement the air quality monitoring data currently being collected by the MOECC in south Peel. The passive monitor was located at the Caledon EMS facility on Charleston Side Road in the Town of Caledon. The locations of the passive sampler and the two MOECC stations in south Peel are indicated in Figure 8.

**Figure 8:** Location of Passive Sampler and MOE Ambient Monitoring Stations




Passive monitoring commenced on September 25, 2012 and continued through Year 2. Weekly and bi-weekly sampling for sulphur dioxide ($SO_2$), nitrogen dioxide ($NO_2$), oxides of nitrogen ($NO_X$), ozone ($O_3$), and ammonia ($NH_3$) was performed. During colder months (i.e., November through to March), bi-weekly sampling was completed instead of weekly due to lower detection limits that coincide with low ambient temperatures. "Blank" analyses for each contaminant were completed as per standard passive sampling methods. The passive samplers are located in an all-season shelter. Maxxam Analytics provided the shelters and sample media and also performed the laboratory analyses of the samples.

The pollutant concentrations measured at the two NAPS ambient monitoring stations located within the Region of Peel for 2012 are compared to the measured concentrations at the Caledon passive monitor location in Tables 5 through 8. The NAPS values represent averaged hourly values over the same sample period over which passive samples were collected as indicated in the tables. The Ambient Air Quality Criteria (AAQC) is also provided in the table where applicable. The influence of increased road traffic in south Peel on local air quality as compared to north Peel is evident as the measured concentrations of ozone are higher and the measured

concentrations of $NO_X$ and $NO_2$ are generally lower in north Peel. Sulphur dioxide ($SO_2$) concentrations (Table 8) are also typically lower in north Peel compared to the south which is indicative of the greater concentration of industrial emission sources in the south.

**Table 5:** Measured Ozone Concentrations

| | | | Caledon (Passive) | Brampton (NAPS) | Mississauga (NAPS) |
|---|---|---|---|---|---|
| Week No. | Start Date | End Date | $O_3$ (ppb) | $O_3$ (ppb) | $O_3$ (ppb) |
| 1 | 2012-09-25 | 2012-10-02 | 18.2 | 17.3 | 18.8 |
| 2 | 2012-10-02 | 2012-10-09 | 18.3 | 19.6 | 20.3 |
| 3 | 2012-10-09 | 2012-10-16 | 21.3 | 15.7 | 18.0 |
| 4 | 2012-10-16 | 2012-10-25 | 18.7 | 12.4 | 11.8 |
| 5 | 2012-10-25 | 2012-11-01 | 16.5 | 21.8 | 20.9 |
| 6 | 2012-11-01 | 2012-11-08 | 25.3 | 17.2 | 17.0 |
| 7 | 2012-11-08 | 2012-11-15 | 21.6 | 14.2 | 16.6 |
| 8 | 2012-11-15 | 2012-11-29 | 20.4 | 14.6 | 15.3 |
| 10 | 2012-11-29 | 2012-12-13 | 20.0 | 18.4 | 18.8 |
| 12 | 2012-12-13 | 2012-12-27 | 23.8 | 25.3 | 23.9 |

Note: 1 hr AAQC = 80 ppb

**Table 6:** Measured Oxides of Nitrogen Concentrations

| | | | Caledon (Passive) | Brampton (NAPS) | Mississauga (NAPS) |
|---|---|---|---|---|---|
| Week No. | Start Date | End Date | $NO_x$ (ppb) | $NO_x$ (ppb) | $NO_x$ (ppb) |
| 1 | 2012-09-25 | 2012-10-02 | 1.7 | 9.9 | 6.6 |
| 2 | 2012-10-02 | 2012-10-09 | 2.9 | 10.1 | 7.7 |
| 3 | 2012-10-09 | 2012-10-16 | 5.8 | 17.2 | 9.0 |
| 4 | 2012-10-16 | 2012-10-25 | 12.0 | 10.0 | 8.3 |
| 5 | 2012-10-25 | 2012-11-01 | 4.6 | 10.2 | 10.4 |
| 6 | 2012-11-01 | 2012-11-08 | 3.7 | 13.8 | 12.6 |
| 7 | 2012-11-08 | 2012-11-15 | 2.8 | 18.5 | 12.0 |
| 8 | 2012-11-15 | 2012-11-29 | 10.3 | 14.6 | 13.8 |
| 10 | 2012-11-29 | 2012-12-13 | 13.0 | 9.0 | 10.5 |
| 12 | 2012-12-13 | 2012-12-27 | 8.6 | 9.3 | 11.9 |

**Table 7:** Measured Nitrogen Dioxide Concentrations

| | | | Caledon (Passive) | Brampton (NAPS) | Mississauga (NAPS) |
|---|---|---|---|---|---|
| Week No. | Start Date | End Date | $NO_2$ (ppb) | $NO_2$ (ppb) | $NO_2$ (ppb) |
| 1 | 2012-09-25 | 2012-10-02 | 1.2 | 9.9 | 6.6 |
| 2 | 2012-10-02 | 2012-10-09 | 1.7 | 10.1 | 7.7 |
| 3 | 2012-10-09 | 2012-10-16 | 1.3 | 17.2 | 9.0 |
| 4 | 2012-10-16 | 2012-10-25 | 3.7 | 10.0 | 8.3 |
| 5 | 2012-10-25 | 2012-11-01 | 1.3 | 10.2 | 10.4 |
| 6 | 2012-11-01 | 2012-11-08 | 1.6 | 13.8 | 12.6 |
| 7 | 2012-11-08 | 2012-11-15 | 3.5 | 18.5 | 12.0 |
| 8 | 2012-11-15 | 2012-11-29 | 2.8 | 14.6 | 13.8 |
| 10 | 2012-11-29 | 2012-12-13 | 4.0 | 9.0 | 10.5 |
| 12 | 2012-12-13 | 2012-12-27 | 3.2 | 9.3 | 11.9 |

Note: 24 hr AAQC = 100 ppb

**Table 8:** Measured Sulphur Dioxide Concentrations

| | | | Caledon (Passive) | Mississauga (NAPS) |
|---|---|---|---|---|
| Week No. | Start Date | End Date | $SO_2$ (ppb) | $SO_2$ (ppb) |
| 1 | 2012-09-25 | 2012-10-02 | 1.6 | 0.4 |
| 2 | 2012-10-02 | 2012-10-09 | <0.4 | 0.8 |
| 3 | 2012-10-09 | 2012-10-16 | <0.4 | 0.5 |
| 4 | 2012-10-16 | 2012-10-25 | 0.3 | 0.8 |
| 5 | 2012-10-25 | 2012-11-01 | <0.4 | 0.9 |
| 6 | 2012-11-01 | 2012-11-08 | 0.1 | 0.9 |
| 7 | 2012-11-08 | 2012-11-15 | 0.8 | 0.5 |
| 8 | 2012-11-15 | 2012-11-29 | 1.0 | 0.3 |
| 10 | 2012-11-29 | 2012-12-13 | 0.7 | 0.5 |
| 12 | 2012-12-13 | 2012-12-27 | 0.7 | 0.9 |

Note: 24 hr AAQC = 100 ppb

## YEAR 3 DEVELOPMENTS

A number of observations were made throughout the various workflows that highlighted areas where further improvement or refinement may be worth further consideration. For example, missing stack parameters in the 2010 NPRI large point source database are believed to have contributed to elevated ground level concentrations of certain pollutants (e.g., $SO_2$, $PM_{2.5}$) in some locations. Also, as already discussed, NOx emissions from OnRoad mobile sources appear to be overestimated in the 2006 emission inventory; although spatial surrogates and / or temporal profiles may also be leading to elevated NOx emissions at certain times of day along major highways; etc. The following is a list of proposed refinements for Year 3:

- Update the Canadian point sources from 2010 to 2012.
- Provide / infill more appropriate stack parameters where missing.
- Update the Canadian OnRoad, NonRoad and Area sources from 2006 to 2010.
- Consider updating the US emissions inventories from 2008 to 2011 (although there are no US emissions within the inner-most, 1.0 km model domain).
- Develop improved spatial allocation surrogates marine sources using outputs from the latest version of Environment Canada's Marine Emissions Inventory Tool (MEIT)
- Explore further opportunities to refine spatial surrogates for other sources leveraging generic or default activity data (e.g., population).

## SUMMARY AND CONCLUSIONS

This report details Year 2 of a multi-year project being performed in response to Official Policy Plan 2.2.3.3.8. Peel Public Health (PPH) commissioned a study to develop an air quality monitoring and modelling program (AQMMP) to assist in evaluating public policy decisions and how these decisions may affect air quality in Peel.

This second year of the project focused on refining model inputs, completing a full year of model runs for the 2012 base year, and assessing the model performance for ozone and $PM_{2.5}$. Initial comparisons of model results to ambient measurements indicate good agreement for these secondary pollutants. Further improvements to the base year 2012 model are planned for Year 3, followed by an assessment of the change in air quality concentrations associated with up to three emission change scenarios.

Passive monitoring continued in north Peel near the Town of Caledon throughout Year 2 to supplement air quality monitoring data currently being collected by the Ministry of the Environment at two stations in south Peel. It is anticipated that passive monitoring will continue during Year 3. The addition of a real-time monitoring system (e.g., Airpointer®) will be reviewed.

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