Improvements to SMOKE Processing of Canadian On-Road Mobile Emissions

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ABSTRACT

On-road motor vehicles are important sources of pollutants that affect air quality, especially in cities. A previous study found that there was a strong qualitative difference in SMOKE-processed on-road mobile emissions across the Canada-U.S. border, due mainly to differences in the spatial surrogates and temporal profiles used for the two countries[1]. To better represent Canadian on-road mobile emissions spatially, temporally, and chemically in air quality models, SMOKE processing of Canadian on-road mobile emissions was investigated and the following improvements were made: (1) a new set of spatial surrogates was generated based on the Canadian National Road Network and population shapefiles and the Canadian on-road inventory was modified to split emissions between different road types in order to allow use of the new surrogates; (2) a new set of Canadian weekday/weekend diurnal profiles was created based on vehicle-type traffic-count data for a major Canadian highway and existing EPA temporal profiles; (3) a new set of province-specific monthly temporal profiles was calculated for fugitive dust emissions from paved and unpaved roads based on monthly Vehicle Kilometres Travelled (VKT) statistics; (4) a new set of PM chemical speciation profiles was built based on the SPECIATE 4.3 database. These improvements are described in more detail and the impacts of these improvements on processed Canadian on-road mobile emissions are shown and discussed in this paper.

1. INTRODUCTION

Motor vehicle emissions consist of gases and particulate matter (PM) emitted from the engine exhaust system and other emissions such as VOC emissions from gasoline evaporation and PM emissions from tire and brake wear. These emissions contribute significantly to air pollution, especially in cities where emissions of NOx and VOC from motor vehicles and other sources are the main precursors of smog. Mobile sources also emit air toxics, which can have serious health effects (e.g., http://www.epa.gov/oms/toxics.htm). In Canada, according to the 2006 Canadian national emissions inventory, on-road mobile sources contributed about 22% of total anthropogenic NOx emissions, 46% of CO emissions, and 12% of VOC emissions. As well, fugitive dust emissions from paved and unpaved roads are estimated to contribute 55% of PM_{10} and 48% of $PM_{2.5}$ emissions (see http://www.ec.gc.ca/pdb/websol/emissions/ap/ap_query_e.cfm).

Air quality (AQ) modeling systems are often used to understand the impact of emissions on air quality, to assess potential air pollution control strategies, and to forecast short-term air quality. One of the essential inputs required by an air quality model is a set of gridded emissions from various sources, including on-road mobile emissions. For regional AQ modeling, emissions are usually processed by a top-down method in which annual/monthly emissions inventory at a national/provincial/county (or other regional) level are spatially and temporally disaggregated to each model grid cell. Spatial disaggregation is usually performed by using a set of gridded spatial surrogate fields that was generated from statistical proxies, such as population, road network, dwellings, crop distributions, etc. Temporal disaggregation is usually done by applying monthly, weekly, and diurnal temporal profiles established from statistical data, such as plant operating schedules and vehicle counts on different road types at different times of the day. For this method to succeed, the representativeness and accuracy of spatial surrogates and temporal profiles are key for processing accurate emissions for AQ models. A number of emissions processing systems exist to calculate emissions for AQ modeling using the top-down method. Among these, SMOKE (Sparse Matrix Operator Kernel Emissions; http://www.smoke-model.org/index.cfm) is widely used by the AQ modeling community and is also the one used for this study.

During AQ modeling performed for the 2007 BAQS-Met (Border Air-Quality Study–Meteorology) study (see http://www.atmos-chem-phys.net/special_issue205.html), significant differences were seen in the spatial and temporal distribution of on-road mobile emissions across the U.S.-Canada border. Temporal and spatial allocations of emissions from Light Duty Gasoline Vehicles (LDGV) were investigated and the following four main differences were identified[1]:

1) U.S. on-road mobile emissions were apportioned in the U.S. national emissions inventory to 12 subcategories by road type (e.g., rural interstate, urban collector), whereas no such apportionment was made for Canadian on-road mobile emissions in the Canadian national emissions inventory.
2) 6 spatial surrogates at the county level were applied to disaggregate the U.S. on-road emissions spatially by road type, whereas only a single spatial surrogate at the province level was applied to Canadian on-road emissions.
3) For Canada, unrealistically high mobile emissions levels were allocated to rural areas with long roads but low population density and to city centers with high population density.
4) 12 different diurnal profiles, one for each of the 12 road classes and with distinct weekday/weekend versions, were used to distribute the U.S. LDGV emissions temporally, but only one profile without weekday/weekend differences was used for processing Canadian LDGV emissions temporally.

Since then, a number of improvements have been made to address these issues in processing the Canadian on-road mobile emissions. These improvements and their impacts on processed emissions are discussed in this paper.

2. IMPROVEMENTS TO SPATIAL DISAGGREGATION

Since the Canadian on-road mobile emissions inventory is based only on vehicle type and does not take road class into consideration, emissions were spatially disaggregated using a single surrogate built from roadway miles for all road classes weighted by population[2]. This is one of the main causes for the cross-border discontinuity problems seen in the Canadian on-road mobile emissions[1]. To address this issue, the following steps were taken:

1) a new unified Canadian road network shapefile was created;
2) a new set of 6 Canadian on-road mobile spatial surrogates was generated comparable to the U.S. spatial surrogates for on-road mobile sources;
3) the Canadian on-road emissions inventory was split by road type for each province based on sets of splitting factors calculated from the U.S on-road mobile emissions inventory for proxy U.S. states.

2.1 Creation of a Unified Canadian Road Network Shapefile

The Canadian "national" road network shapefile actually consists of 13 heterogeneous provincial and territorial road network shapefiles available from GeoBase - National Road Network (NRN) (http://www.geobase.ca/geobase/en/data/nrn/index.html). The road classification is based on the importance of the role that the road element performs in the connectivity of the total road network, and a total of 13 possible road types are considered as listed in Table 1 (from http://www.geobase.ca/geobase/en/data/nrn/description.html - Feature Catalogue).

Table 1. Canadian national road network road class definition.

Code	Label	Definition
1	Freeway	An unimpeded, high-speed controlled access thoroughfare for through traffic with typically no at-grade intersections, usually with no property access or direct access, and which is accessed by a ramp. Pedestrians are prohibited.
2	Expressway / Highway	A high-speed thoroughfare with a combination of controlled access intersections at any grade.
3	Arterial	A major thoroughfare with medium to large traffic capacity.
4	Collector	A minor thoroughfare mainly used to access properties and to feed traffic with right of way.
5	Local / Street	A low-speed thoroughfare dedicated to provide full access to the front of properties.
6	Local / Strata	A low-speed thoroughfare dedicated to provide access to properties with potential public restriction such as: trailer parks, First Nations, strata, private estates, seasonal residences.
7	Local / Unknown	A low-speed thoroughfare dedicated to provide access to the front of properties but for which the access regulations are unknown.
8	Alleyway / Lane	A low-speed thoroughfare dedicated to provide access to the rear of properties.
9	Ramp	A system of interconnecting roadways providing for the controlled movement between two or more roadways.
10	Resource / Recreation	A narrow passage whose primary function is to provide access for resource extraction and may also have service in providing public access to the backcountry.
11	Rapid Transit	A thoroughfare restricted to public transit buses.
12	Service Lane	A stretch of road permitting vehicles to come to a stop along a freeway or highway. Scale, service lane, emergency lane, lookout, and rest area.
13	Winter	A road that is only useable during the winter when conditions allow for passage over lakes, rivers, and wetlands.

Despite the 13 road types defined in NRN (Table 1), the road types actually included in the individual provincial shapefile vary from province to province. Table 2 summarizes the number of segments of the five relevant major road types contained in the road-network shapefile for each Canadian province/territory.

Table 2. Number of segments of five major road types for the 13 provinces/territories.

Province	Freeway	Expressway/Highway	Ramp	Arterial	Collector
Alberta	0	6345	8260	25696	160977
British Columbia	1535	9051	3299	18684	29841
Manitoba	57	19475	1023	0	42897
New Brunswick	1421	10817	1458	0	17124
Newfoundland and Labrador	429	6533	589	18	12179
Northwest Territories	0	800	14	184	465
Nova Scotia	875	1538	1097	5423	5528
Nunavut	0	0	0	0	890
Ontario	6285	12840	8967	84078	41631
Prince Edward Island	0	105	134	1209	4866
Quebec	7684	20815	7007	13998	30953
Saskatchewan	173	18904	842	7	141285
Yukon	0	1083	0	350	170

In the present study the first objective was to build a single homogeneous national road network shapefile in which major (i.e., non-local) road types were re-classified into two composite road types: primary highways and secondary highways, similar to the U.S. Census Bureau's TIGER roads shapefile (http://www.geographynetwork.com/data/tiger2000/), which is used by the U.S. EPA to generate surrogates for allocating on-road mobile emissions in SMOKE (ftp://ftp.epa.gov/EmisInventory/emiss_shp2003/us/usrds_2000). The primary highways include nationally and regionally important highways and may be classified as "Freeway", "Expressway / Highway", and "Ramp" in the Canadian NRN system (see Table 1). The secondary highways include most provincial and municipal highways and the highways that connect smaller towns, subdivisions, and neighborhoods, which are generally smaller than primary highways and which may be classified as "Arterial", "Collector", or even "Local" roads in the NRN system. The geometric road length of each road segment was supplemented by a new total road length, which consists of the product of geometric road length and number of lanes. All local and other minor roads are excluded, as traffic emissions on these roads will be represented with rural/urban population density, again similar to the U.S. EPA methodology.

Since the Canadian provincial road network shapefiles are heterogeneous in nature and some important road types (e.g. Arterial road) are not available for some provinces (see Table 2), it was necessary to use a different set of assignments for each province between the set of provincial road types and the two composite highway types. Moreover, for some provinces it was necessary to re-assign some road types manually based on other GIS sources. For example, there are too many "Arterial" roads in Alberta. Some of them were manually re-assigned to primary highways according to the ArcGIS basemap "OpenStreetMap". In contrast, "Arterial" roads are completely missing in Manitoba and too many roads were defined as "Expressway/Highway". Again based on the ArcGIS basemap "OpenStreetMap", most of the "Expressway/Highway" roads in Manitoba were manually re-assigned to the secondary highway type. After all of the provincial shapefiles were checked and properly modified, they were then merged into one national shapefile to be used for surrogate generation. Figure 1 shows the primary and secondary highway networks in the merged national shapefile over all of Canada (Fig. 1a) and over the province of Ontario (Fig. 1b).

Figure 1a. Primary and second highway networks over Canada.

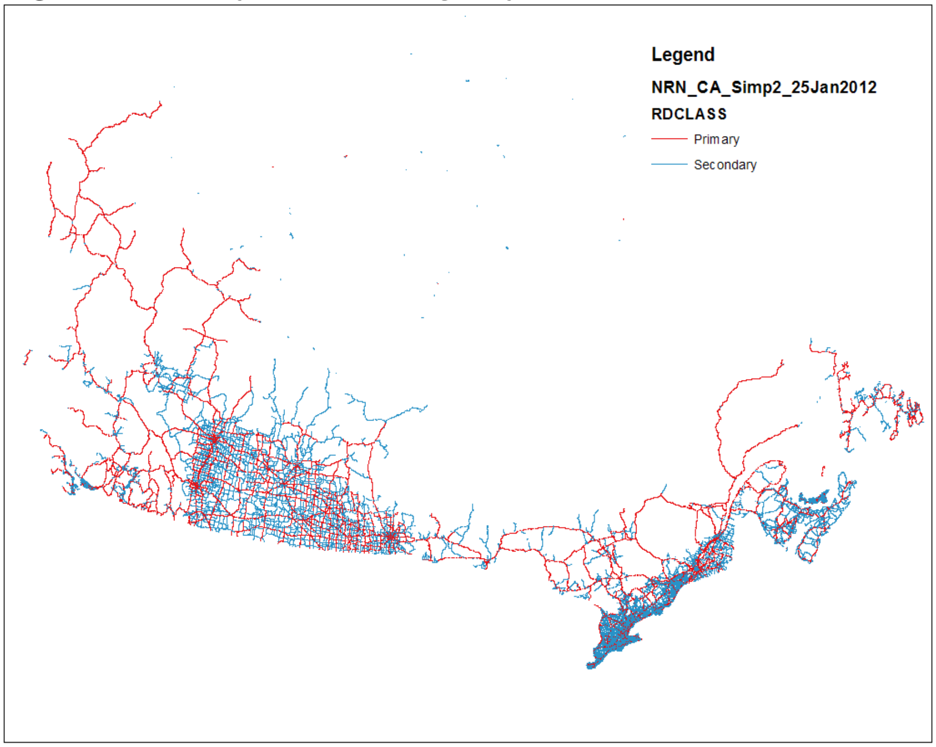
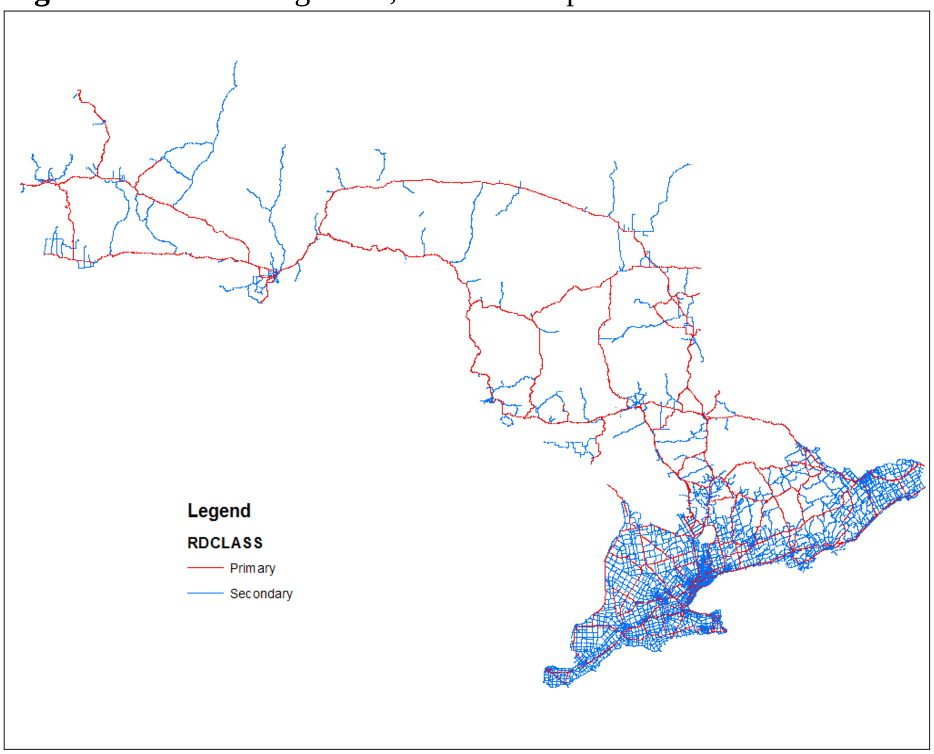


Figure 1b. Same as Figure 1a, but over the province of Ontario.

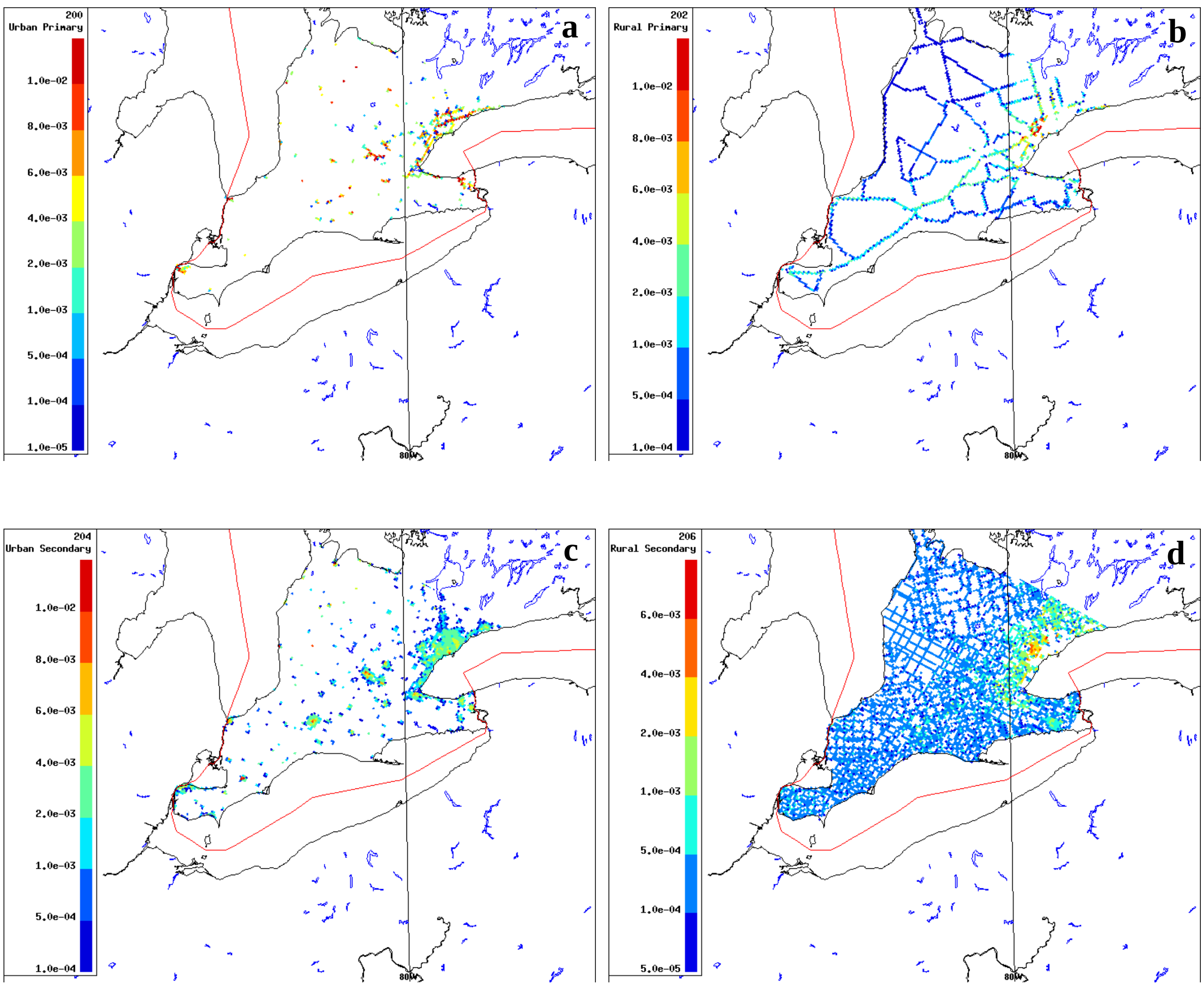


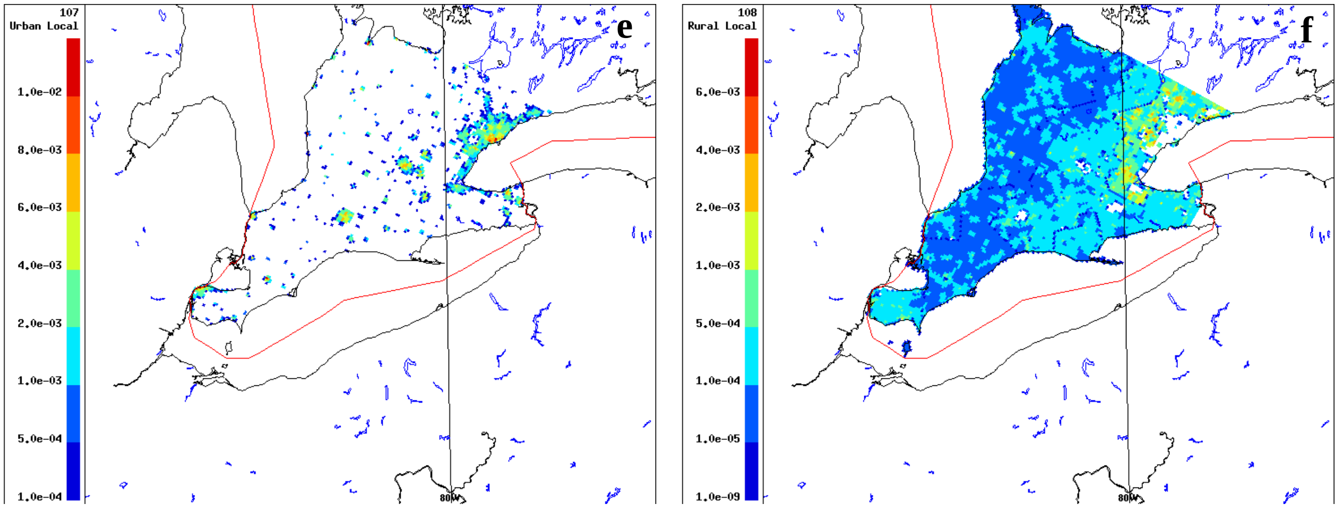
Both the primary and second highways were further split into urban and rural highways based on a population density threshold. To do this, a Canadian population data set from the 2006 national census was used to calculate population density for each dissemination area (DA), a neighborhood-level area with a population of 400 to 700. DAs with a population density of at least 200 persons per square kilometer were classified as urban and the rest were classified as rural (similar to the density threshold of minimum 500 people/mile^2 used in the U.S. to define urbanized area and urban clusters, a threshold equivalent to about 193 people/km^2). Then the population shapefile was intersected with the new unified NRN shapefile to clip the roads at each population polygon and transfer the Urban/Rural attributes to each road segment in the unified NRN shapefile to create four attributes: (1) urban primary highway length; (2) rural primary highway length; (3) urban secondary highway length; and (4) rural secondary highway length.

2.2 Generation of On-road Mobile Spatial Surrogates

Six new spatial surrogates were generated for each Canadian province and territory to process provincial and territorial on-road mobile emissions. Four of them were generated from the newly created unified NRN shapefile representing the following 4 road classes: (1) urban primary highways; (2) rural primary highways; (3) urban secondary highways; and (4) rural secondary highways. The additional two surrogates were generated from Canadian 2006 census urban and rural populations to represent urban and rural local roads. As an example, Figure 2 shows the six surrogates generated for the 2.5-km BAQS-Met AURAMS (A Unified Regional Air-quality Modelling System) model domain.

Figure 2. Spatial surrogates generated to process Canadian on-road mobile emissions for the 2.5-km BAQS-Met AURAMS model domain: (a) urban primary highways; (b) rural primary highways; (c) urban secondary highways; (d) rural secondary highways; (e) urban local road; and (f) rural local roads.





2.3 Split of Canadian On-road Mobile Emissions Inventory by Road Type

As discussed earlier, mobile source emissions are separated by vehicle type in the Canadian national emissions inventory but not by road type. To use the new set of road-type-specific on-road spatial surrogates described in the previous section, the Canadian on-road mobile inventory needed to be split by road type. Emissions from 12 road types, which are defined by the Aerometric Information Retrieval System (AIRS), are available in the U.S. EPA on-road mobile emissions inventory (http://www.epa.gov/ttn/chief/eiinformation.html). Table 3 lists these 12 road types together with the AIRS AMS (Area and Mobile Source) codes.

Table 3. Name and AIRS AMS code for the 12 road classes.

Road Class Name	AIRS AMS Road Class code
Rural Interstate	110
Rural Principal Arterial	130
Rural Minor Arterial	150
Rural Major Collector	170
Rural Minor Collector	190
Rural Local	210
Urban Interstate	230
Urban Freeway	250
Urban Principal Arterial	270
Urban Minor Arterial	290
Urban Collector	310
Urban Local	330

The split of Canadian on-road emissions by road type was done based on the assumption that the road-type splitting factors for a specific Canadian province are likely to be similar to the ones in a nearby US state with similar urban-rural population ratio and similar topographic and climatic characteristics. Following this assumption, the province-state proxy pairings listed in Table 4 were set up for splitting the 2006 Canadian on-road mobile emissions between the 12 road types. The state-specific pollutant-averaged splitting factors for the 12 road types were then calculated from version 4 of the 2005 U.S. on-road mobile emissions inventory. For example, state-level splitting factors for Colorado were used to split vehicle-type emissions for Alberta into vehicle-and-road-type emissions.

Table 4. Proxy pairings selected for splitting the 2006Canadian on-road emissions by road type.

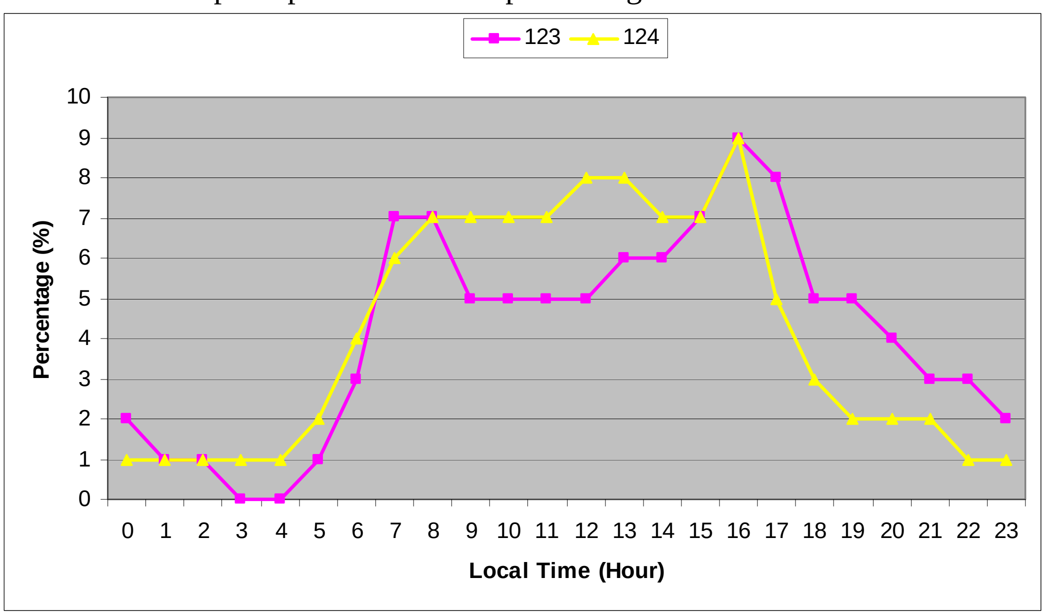
Canadian Province	**U.S. State**
British Columbia	Washington
Alberta	Colorado
Saskatchewan	Minnesota
Manitoba	Minnesota
Ontario	New York
Quebec	Pennsylvania
New Brunswick	Maine
Nova Scotia	Maine
Prince Edward Island	Maine
Newfoundland and Labrador	Maine
Yukon	Montana
Northwest Territories	Montana
Nunavut	Vermont

3. IMPROVEMENTS TO TEMPORAL DISAGGREGATION

3.1 Diurnal and Weekly Temporal Profiles for On-road Mobile Emissions

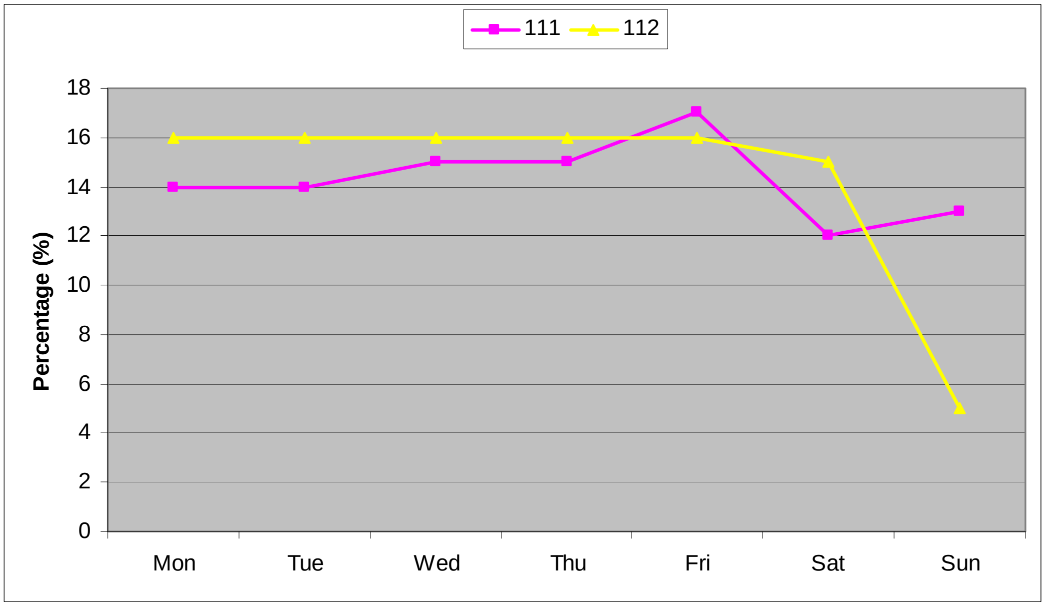
The Canadian 2006 on-road mobile emissions inventory consists of 12 monthly files. Thus only diurnal and weekly temporal profiles are discussed here. Figure 3 shows the two diurnal temporal profiles were being used previously to allocate most Canadian on-road mobile hourly emissions for all road classes. Profile #123 was mainly used for light duty vehicles and profile #124 was used for heavy duty vehicles. Neither of them differentiated between weekdays and weekends. As a result, emissions peaked in the morning and evening rush hours even on the weekends. Furthermore, profile #123 has zero emissions at 3:00 and 4:00 a.m. local time, which might be reasonable for some type of vehicles on some road classes. However, it is unrealistic for the majority of road classes.

Figure 3. Diurnal temporal profiles used for processing Canadian on-road mobile emissions.



There were also two weekly temporal profiles (shown in Figure 4) that were used for processing the daily Canadian on-road mobile emissions. Profile #111 was used for light duty vehicles and profile #112 was used for heavy duty vehicles. These profiles look reasonable to a degree, but there are still some issues. For example, it is hard to explain why emissions from light duty vehicles are higher on Wednesday and Thursday than on Monday and Tuesday, and why emissions on Sunday are higher than emissions on Saturday.

Figure 4. Weekly temporal profiles used for processing Canadian on-road mobile emissions.

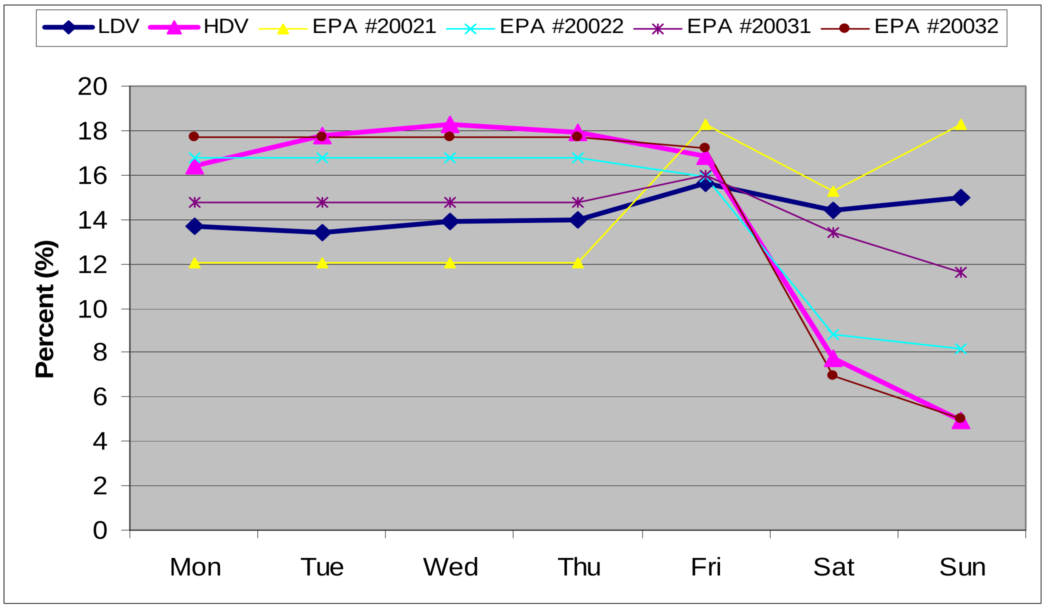


By contrast, 12 diurnal profiles with different weekday/weekend versions are used by the U.S. EPA to process U.S. on-road mobile emissions for the 12 road types listed in Table 3. In addition, four weekly profiles are used to account for the day-of-week variations of emissions from light duty and heavy duty vehicles traveling on rural and urban roads. Since the Canadian on-road emissions have been split into 12 road types as discussed in Section 2.3, it is now possible to adopt the U.S. EPA weekly and diurnal profiles for processing Canadian emissions. However, due to the different climate between the two countries, driving patterns may also be different. It is thus important to verify that the U.S. EPA temporal profiles are suitable for processing Canadian emissions. This has been done using recent traffic count data from Canada.

In the summer of 2010, a field campaign named FEVER (Fast Evolution of Vehicle Emissions from Roadways) was conducted on a multi-lane highway in the Toronto area in Ontario, Canada[3,4,5]. A traffic camera was used to record the traffic. Traffic density, composition and speed were then determined from the video recording. Based on the traffic count during the one-month campaign period (Aug. 17 – Sep. 17), weekly profiles were derived for light duty vehicles (LDV) and heavy duty vehicles (HDV) as shown in Figure 5. EPA weekly profiles for rural LDV (#20021), rural HDV (#20022), urban LDV (#20031), and urban HDV (#20032) are also included in Figure 5 for comparison purposes.

Figure 5 shows that the HDV weekly profile derived from the FEVER traffic-count data agrees reasonably well with the U.S. EPA urban HDV weekly profile #20032. Compared with the previous Canadian HDV weekly profile (#112 shown in Figure 4), emissions are much lower on Saturdays. The LDV profile derived from the FEVER data is most similar to the U.S. EPA urban LDV profile (#20031), but it also shares some similarities to the U.S. EPA rural LDV profile (#20021) such as higher emissions on weekends than on weekdays and emissions on Sundays that are slightly higher than on Saturdays. The reason may be that this highway usually serves as a commuter highway for people traveling into downtown Toronto on weekdays. During the summertime, it is also one of the main roads used by urban dwellers to leave the city on the weekend, resulting in high volumes of traffic on Friday afternoons when people leave the city and on Sundays when people return. Since the temporal profiles used for emissions processing are assumed to apply to all roads of the same type, it thus appears reasonable to adapt the EPA weekly temporal profiles to process Canadian emissions

Figure 5. Weekly profiles derived from traffic count data for a Canadian highway (think lines) vs. those used by the U.S. EPA (thin lines).



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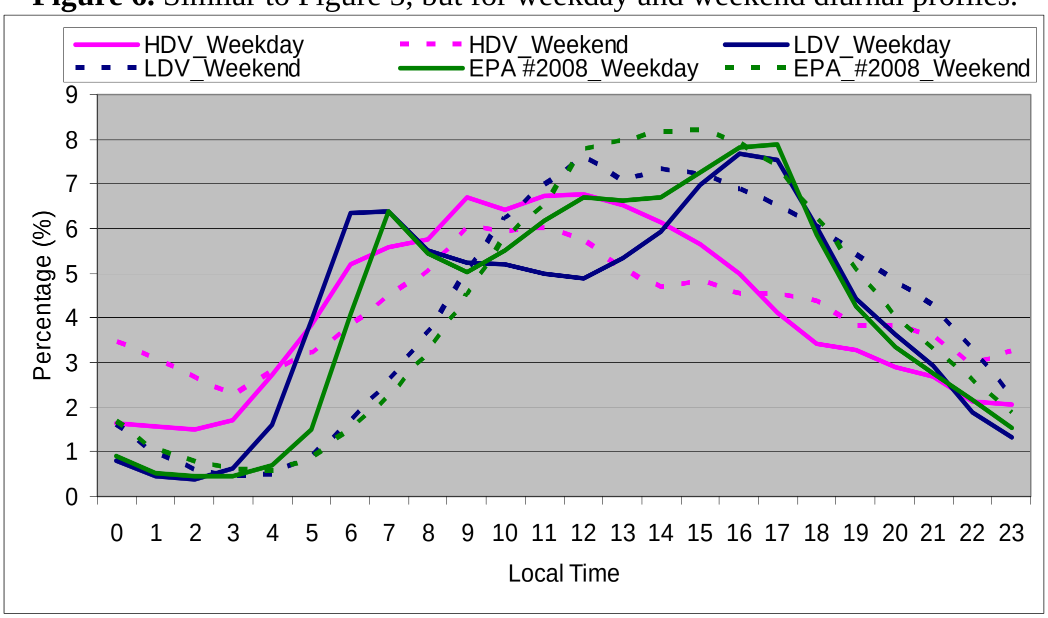
Weekday and weekend diurnal profiles were also derived from the FEVER traffic count data for LDV and HDV as shown in Figure 6. Similar to Figure 5, U.S. EPA weekday and weekend diurnal profiles for a similar type of road (urban freeway, profile #2008) have also been included for comparison purposes.

Figure 6. Similar to Figure 5, but for weekday and weekend diurnal profiles.

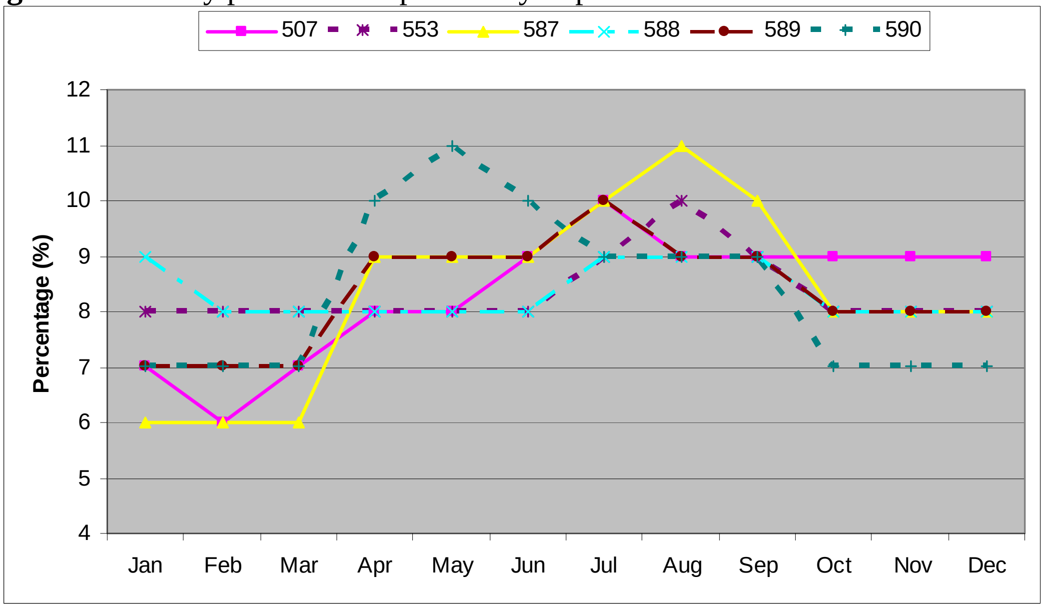


We can see that the weekday and weekend diurnal profiles derived for LDV look similar to the U.S. EPA urban freeway profile #2008, especially on weekends. For weekdays, the morning and afternoon peaks are also agree reasonably well, except that the real data shows that the morning rush hour period starts earlier and lasts longer than in the EPA profile. During midday, the real traffic count data indicates less traffic on this road. These features are probably due to the fact that the main function of the road is for commuting. More people travel on it during rush hours, but fewer during the middle of the day. Figure 6 also shows that the derived HDV profiles are significantly different from the LDV ones in three areas: (1) HDV traffic peaks during the middle of the day and there is no peak during the morning and afternoon rush hours; (2) there is a smaller difference between weekday and weekend profiles, although traffic is flatter during the weekends; and (3) there is a larger fraction of HDV traffic than LDV traffic during the night. The derived HDV profiles are consistent with the driving pattern of HDV in that large HDV are used mainly for the transportation of goods. Most of them travel during the middle of the day but a significant number travel during the night when highways are less congested. Therefore, the new HDV diurnal profiles derived from FEVER traffic-count data appear to be better choices for processing emissions from HDV, and they will be used for all road types instead of using the 12 EPA diurnal profiles for the 12 road types, since the EPA diurnal profiles do not distinguish between HDV and LDV.

3.2 Monthly Profiles for Road Dust Emissions

As discussed in the introduction, about 50% of Canadian PM emissions are estimated to come from road dust. Thus, it is important to accurately disaggregate road dust emissions both spatially and temporally. Currently only annual total road dust emissions at the provincial level are available in the Canadian national emissions inventory. Province-specific monthly temporal profiles are then used to allocate the annual emissions to each month. Previously six different monthly profiles, some shared between different provinces/territories, were used; these profiles are plotted in Figure 7.

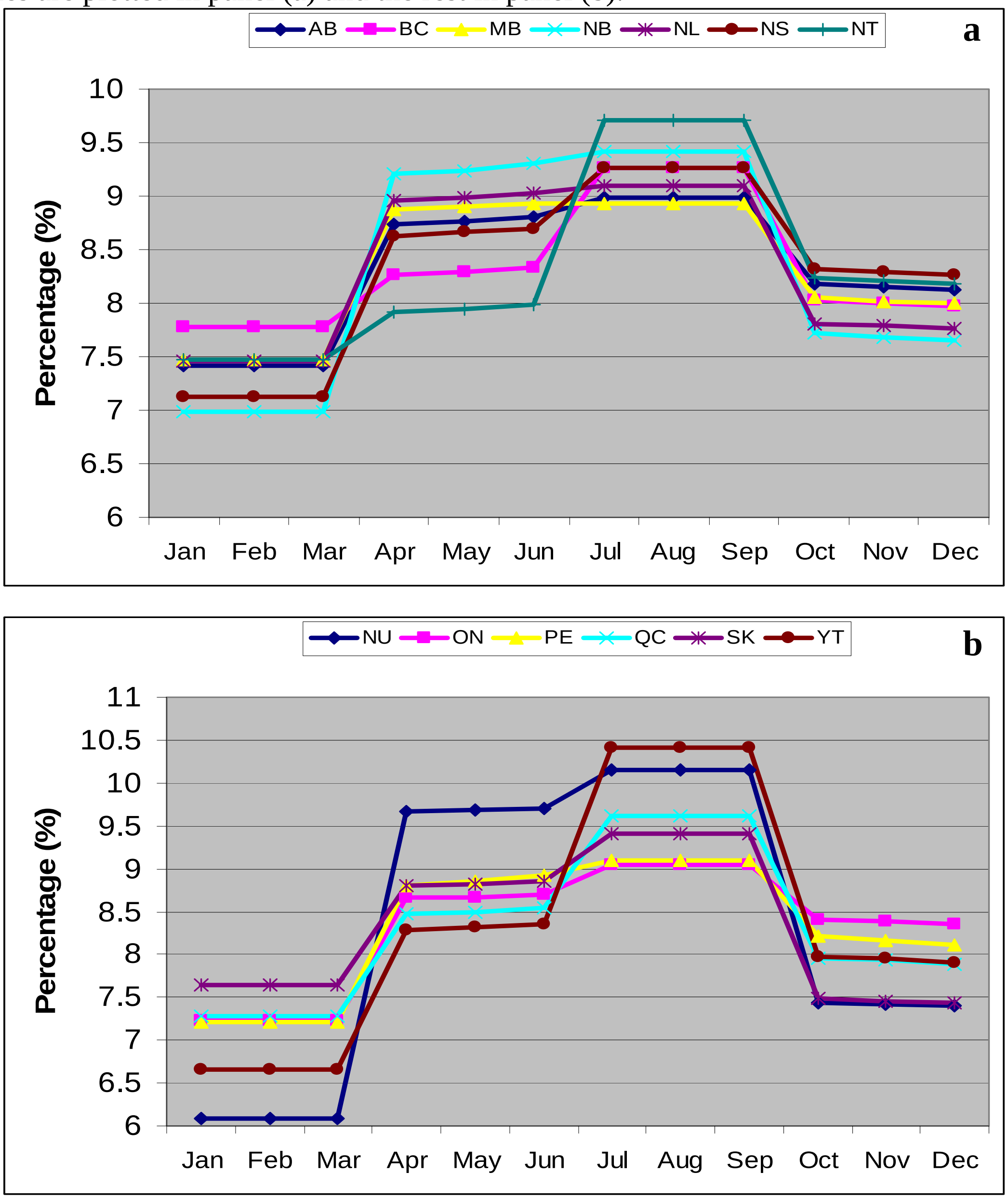
Figure 7. Monthly profiles used previously to process Canadian road dust emissions.



Although some of the profiles, such as 589, seem reasonable in that they peak in the summer months, most of them are questionable. For example, profile 588, which was used for the province of Prince Edward Island, has a peak in January, which contradicts real traffic statistics in that region for that time of year.

Since quarterly VKT (Vehicle Kilometers Traveled) statistics for each Canadian province are available for 2006 from Statistics Canada, province-specific monthly temporal profiles were built from these VKT statistics in order to process road dust emissions in the 2006 inventory. Figure 8 shows the 13 profiles constructed for the 13 Canadian provinces and territories. These new monthly profiles are now being used in place of the profiles shown in Figure 7.

Figure 8. Monthly profiles built from VKT statistics for the 13 Canadian provinces and territories: seven profiles are plotted in panel (a) and the rest in panel (b).



4. IMPROVEMENTS TO PM SPECIATION

This improvement is specific to the Canadian regional AQ research model AURAMS and regional AQ forecast model GEM-MACH (Global Environmental Multi-scale model–Modelling Air quality and CHemistry). Until recently, these AQ models took bulk $PM_{2.5}$ and PM_{10} emissions as input and then performed chemical speciation and size disaggregation internally to 5 chemical components (sulphate, nitrate, crustal material, black carbon, and organic matter) and 12 size bins. Only 3 composite PM speciation profiles, for area and off-road mobile sources, for on-road mobile sources, and for point sources, were considered in the models, no matter which activities the PM was emitted from[6]. On the other hand, there are 95 simplified PM speciation profiles available in the U.S. EPA's SPECIATE4.2 database for a variety of detailed source categories (http://www.epa.gov/ttnchie1/software/speciate/) along with recent updates by Reff et al. that reflected new speciation profiles in the new SPECIATE 4.3 profile library[7].

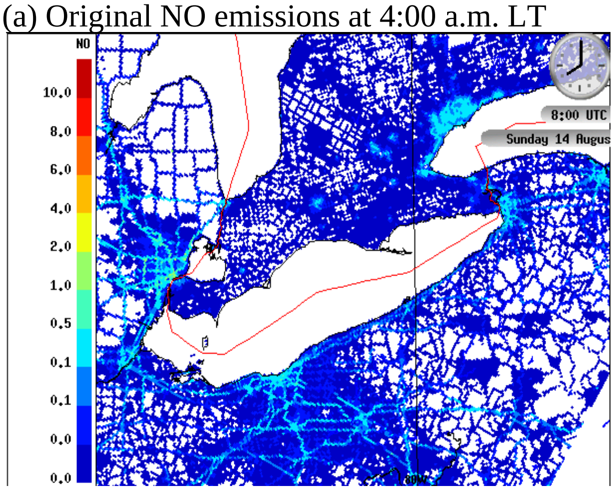
To better represent PM species in the Canadian AQ models, a new set of PM chemical speciation profiles were generated for SMOKE based on the study done by Reff et al.[7]. Having these new profiles allows PM emissions to be chemically speciated in SMOKE and then supplied to AURAMS and GEM-MACH. And in addition to the five PM model species listed above, ammonium was added as a sixth species. For PM emissions from on-road mobile sources, this improvement means that a single PM speciation profile for all on-road mobile sources has been replaced by five PM speciation profiles for (1) exhaust PM from gasoline vehicles, (2) exhaust PM from light duty-diesel vehicles, (3) exhaust PM from heavy-duty diesel vehicles, (4) brake-lining dust from all vehicle types, and (5) tire dust from all vehicle types.

5. DISCUSSION AND CONCLUSIONS

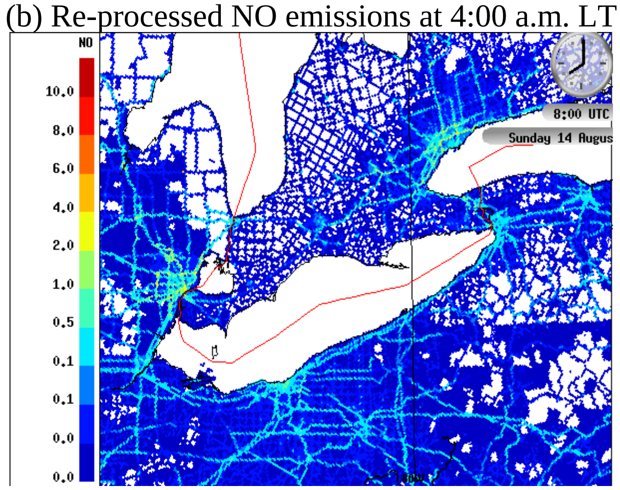
Emissions were re-processed for the BAQS-Met 2.5km AURAMS domain after all of these improvements were implemented in SMOKE. Compared with the previously processed emissions, significant changes can be seen. As examples, "before-and-after" comparisons of 2.5-km NO emissions at local time (LT) 4:00 a.m. (08:00 UTC) and 12:00 p.m. (16:00 UTC) are shown in Figure 9.

Figure 9. Comparisons of original and re-processed NO emissions at 4:00 a.m. LT (08:00 UTC) and 12:00 p.m. LT (16:00 UTC).

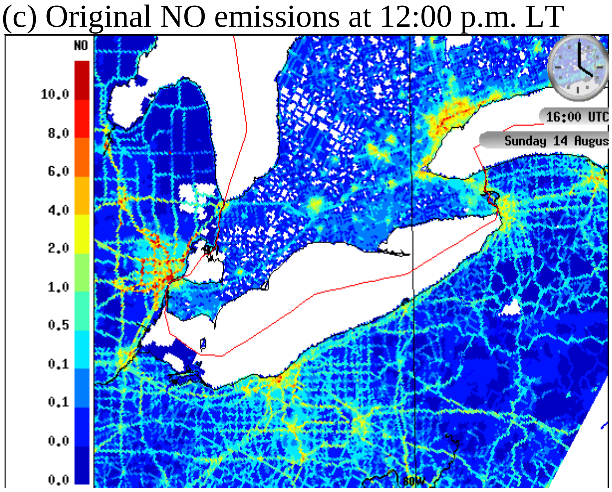
(a) Original NO emissions at 4:00 a.m. LT



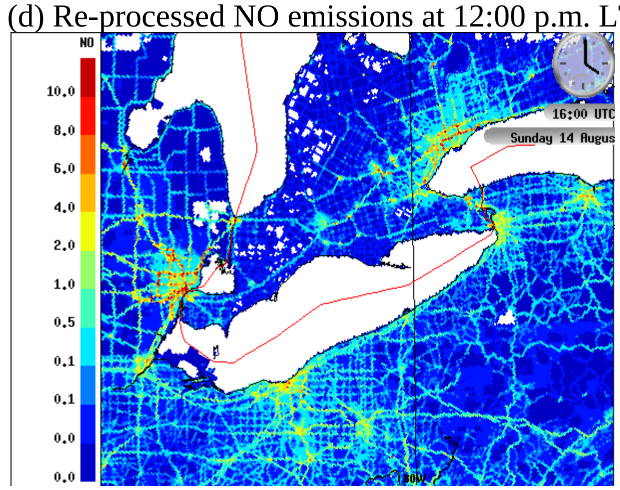
(b) Re-processed NO emissions at 4:00 a.m. LT



(c) Original NO emissions at 12:00 p.m. LT



(d) Re-processed NO emissions at 12:00 p.m. LT



At 4:00 a.m. LT, the original NO emissions (Fig. 9a) in southwestern Ontario, unlike the U.S. states of Michigan, Ohio, Pennsylvania, and New York, are mainly concentrated over cities such as Toronto and the major highways can barely be seen. During the day, the main road networks are still not well defined over southwestern Ontario in the original emissions (Fig. 9c) and it seems that too many emissions have been allocated to rural Ontario. Over Ontario cities, the major roads are not clear in the original emissions even at 2.5-km resolution, unlike major roads in Detroit, Cleveland, Buffalo, and Rochester. By contrast, the Ontario road networks are now very clear in the re-processed emissions for both night and day (Figs. 9b and 9d). Compared with the original emissions, fewer NO emissions are distributed to rural Ontario in the re-processed emissions. Overall, the re-processed NO emissions on the Canadian side of the domain are now more comparable with NO emissions on the U.S. side for both rural and urban areas.

Comparing Fig. 9a with Fig. 9b, we can also see that there are now more NO emissions visible on the U.S. side of the domain in the early morning in the re-processed emissions. These extra emissions come from heavy duty vehicles due to the fact that the new HDV diurnal profile described in Section 3 was also used for processing the U.S. emissions. As discussed in Section 3, the new HDV profile has more emissions during early morning hours than any of the 12 EPA diurnal profiles used previously (e.g., Figure 6). However, since this new diurnal profile was derived from traffic-count data from a single highway during a short period of time, more data should be considered in the future to assess how good this new profile is.

Because the improvements to PM speciation are AQ-model-specific, the AQ models need to be run to evaluate the impacts of this improvement on model performance. This task is beyond the scope of this study and will not be discussed here, but it will be addressed in other studies. Also, there are still further improvements that can be made in addition to the ones described here. For example, future Canadian on-road mobile emissions inventories should be prepared by both vehicle type and road type so that *ad hoc* splitting factors derived from the U.S. on-road mobile emissions inventory do not need to be used; paved road dust emissions for both Canada and the U.S. should be prepared by road type as well so that the newly generated on-road spatial and temporal surrogates can be used to process road dust emissions; and using monthly VKT statistics to build monthly profiles for road dust emissions would be better than the quarterly VKT statistics that have been used here. These issues will be addressed in future studies.

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KEY WORDS

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