HAMILTON AIRSHED MODELLING SYSTEM (HAMS)

April 16, 2018

Hamilton Board of Health

Matthew Lawson

Manager – Health Hazards

Healthy & Safe Communities Department

Public Health Services - Healthy Environments Division

Hamilton Airshed Modelling System (HAMS)

BACKGROUND

December 2013

- BOH approves development of an airshed model for Hamilton;

December 2014

- Funding agreement reached between City of Hamilton and Hamilton Industrial Environmental Association (HIEA) to procure airshed model;

January 2015

- Golder associates begin developing the Hamilton Airshed Modelling System (HAMS);
- Clean Air Hamilton advisory committee engaged by Golder re: model development (i.e., PHS, HIEA, MOECC, CAH, EH)

January 2018

- HAMS performance validation is successful;
- Project delivered on-budget;
- Accomplishes objective within the AQTF Action Plan (2013)

Hamilton Airshed Modelling System

Anthony Ciccone Ph.D., P. Eng. And Janya Kelly Ph.D.

16 April, 2018

CITY OF HAMILTON BOARD OF HEALTH

Acknowledgements

Golder would gratefully like to acknowledge the following contributions to the project:

- Jim Wilkinson, Ph.D.
  - Technical review of modelling set-up and results
  - Technical expertise during model execution
- Barron Henderson, Ph.D.
  - Initial and Boundary conditions from GEOS-CHEM
- Environment and Climate Change Canada
  - SMOKE ready national emissions inventory for Canada
  - Technical expertise on processing emissions in SMOKE
- Stakeholder Advisory Committee (HIEA, Public Health, Community Stakeholders)
  - Providing direction and data

Project Objectives

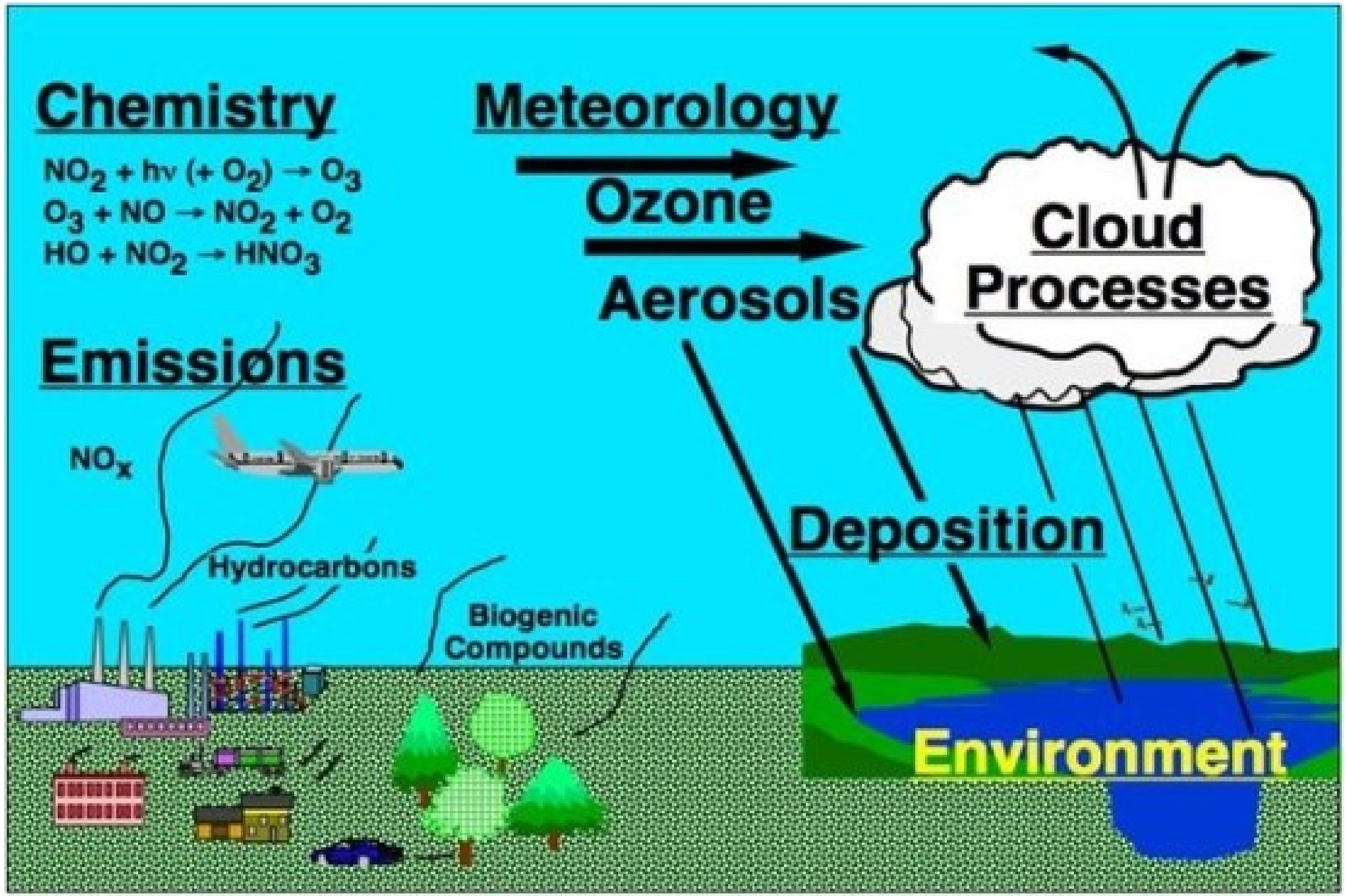
Challenges: The Hamilton Airshed Puzzle

- Who? What? Where? When? and How Much?
- Are levels different in different parts of the City?
- How much is local?
- What is the influence of the USA or outside geographies on Hamilton?

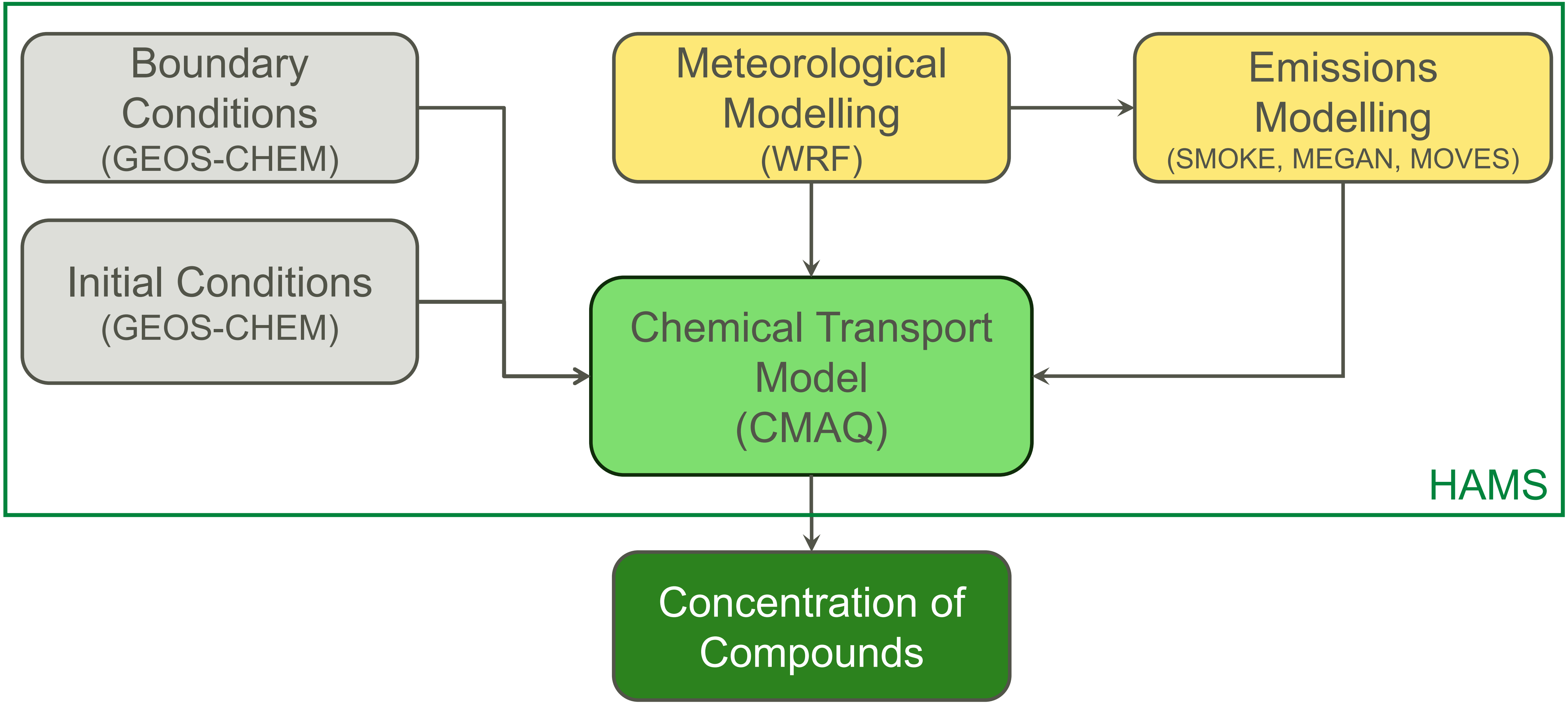
Solution: Hamilton Airshed Modelling System (HAMS)

- Built on understanding of the current state of the science
- Relies on local data as well as transboundary (e.g. land use, roadways, trains, industry, agriculture, etc)
- Handles complex meteorology (e.g. lake effects and escarpment)
- Considers atmospheric chemistry – important part of the puzzle
- Needs a Big computer

The Atmospheric Process

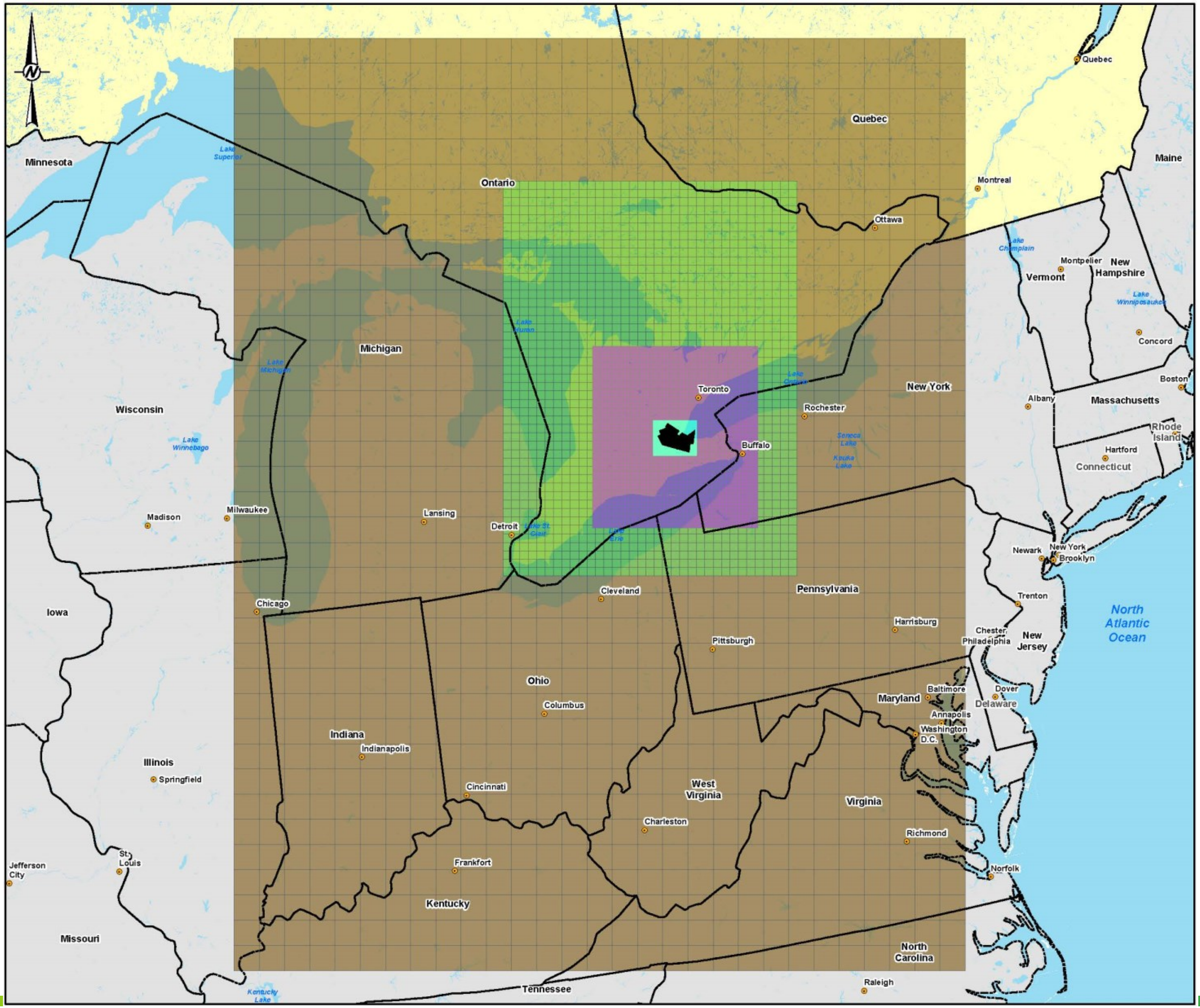


Hamilton Airshed Modelling System



Grid Density: All Tiers – Nested Grids

Tier	Area (km²)	%
Tier I (36 km)	1,390,608	100%
Tier II (12 km)	243,648	17.5%
Tier III (4 km)	46,020	3.3%
Tier IV (1.33 km)	3,159	0.2%



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Compounds of Interest

Studied Compounds*	
Acrolein	Ozone
Ammonia	Volatile Organic Carbons
Benzene	Benzo(a)pyrene
Butadiene 1,3	Cadmium
Carbon Monoxide	Chromium (III)
Formaldehyde	Chromium (VI)
Nitrogen Oxides (NO_2 and NO)	Lead
Sulphur Dioxide	Manganese
PM_{10}	Mercury
$PM_{2.5}$	Nickel

**Please note additional species, including precursors, are available but were not studied*

Presented Compounds*
$PM_{2.5}$
PM_{10}
Nitrogen Oxides
Sulphur Dioxide
Ozone
Benzene
Benzo(a)pyrene

** Selected by the Stakeholder Advisory Committee*

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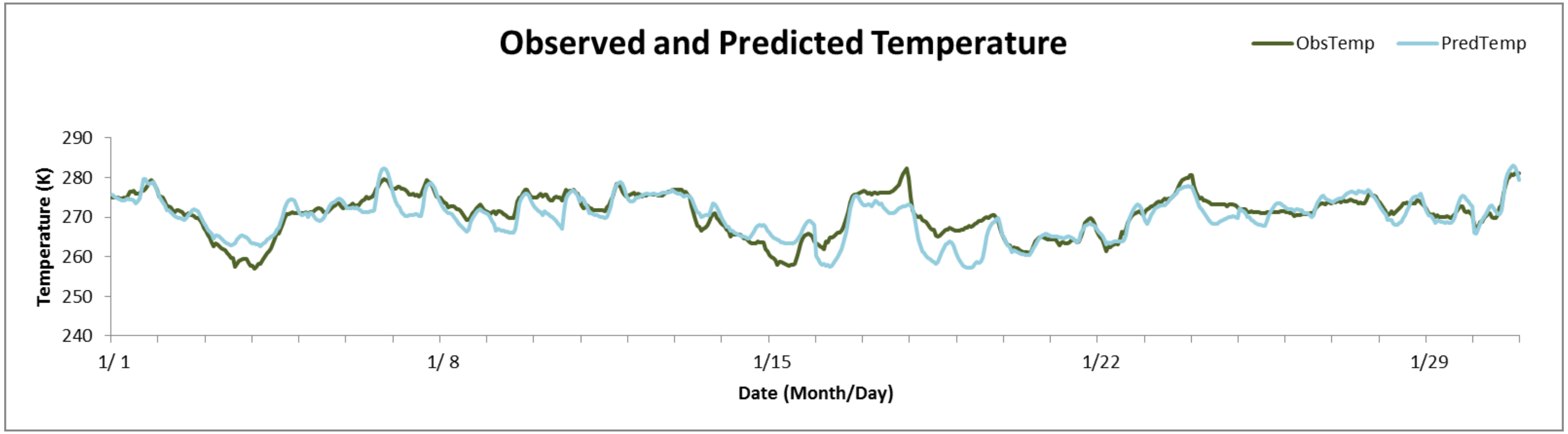
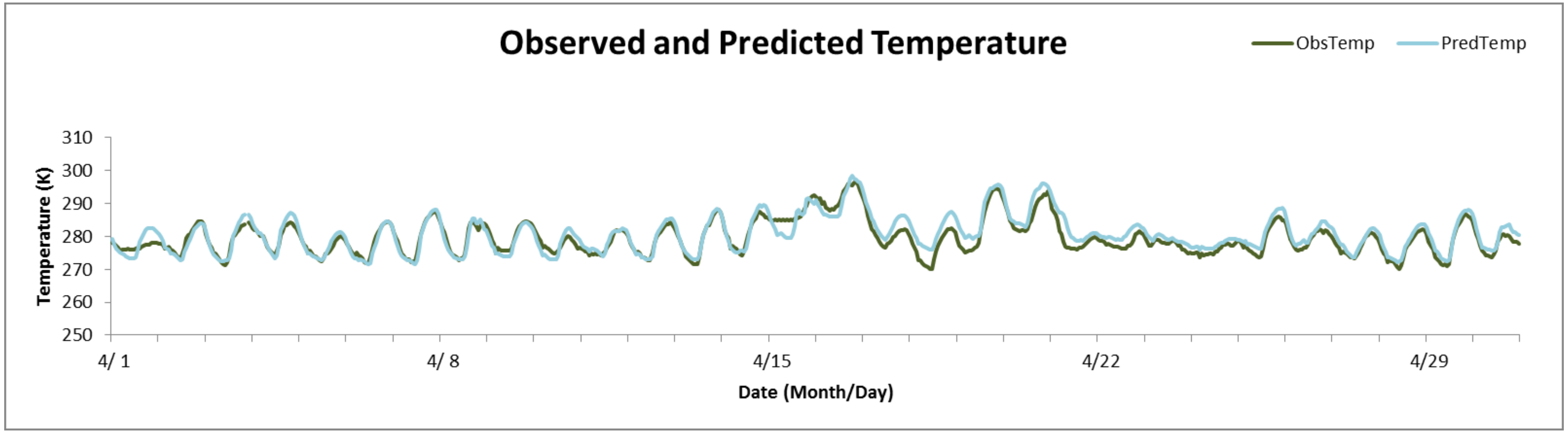
WRF – Meteorological Modelling Results

Tier IV Temperature: Winter and Spring





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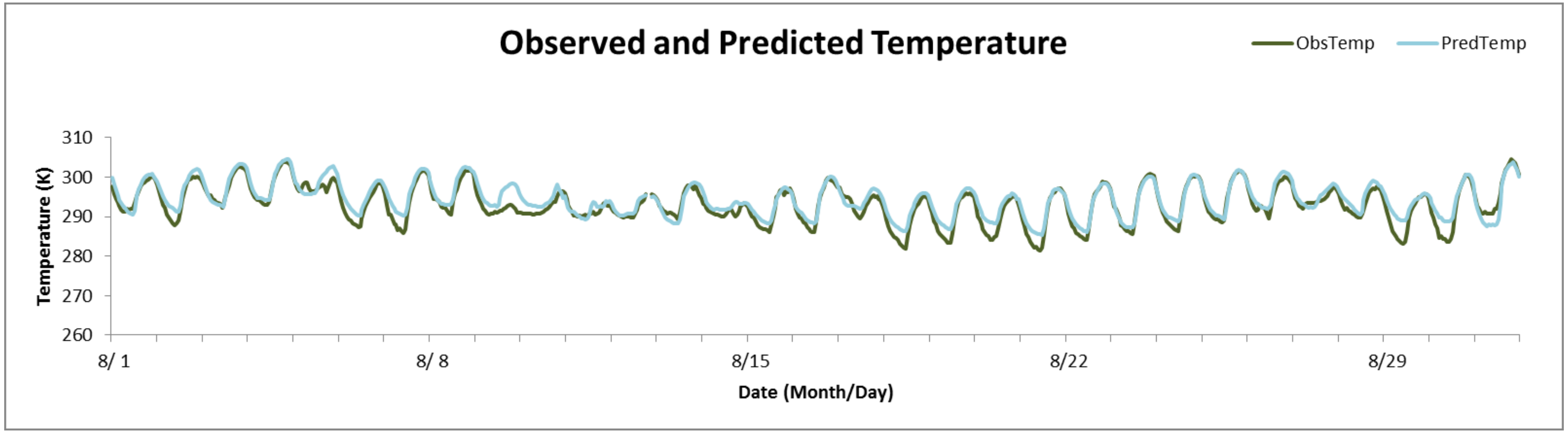
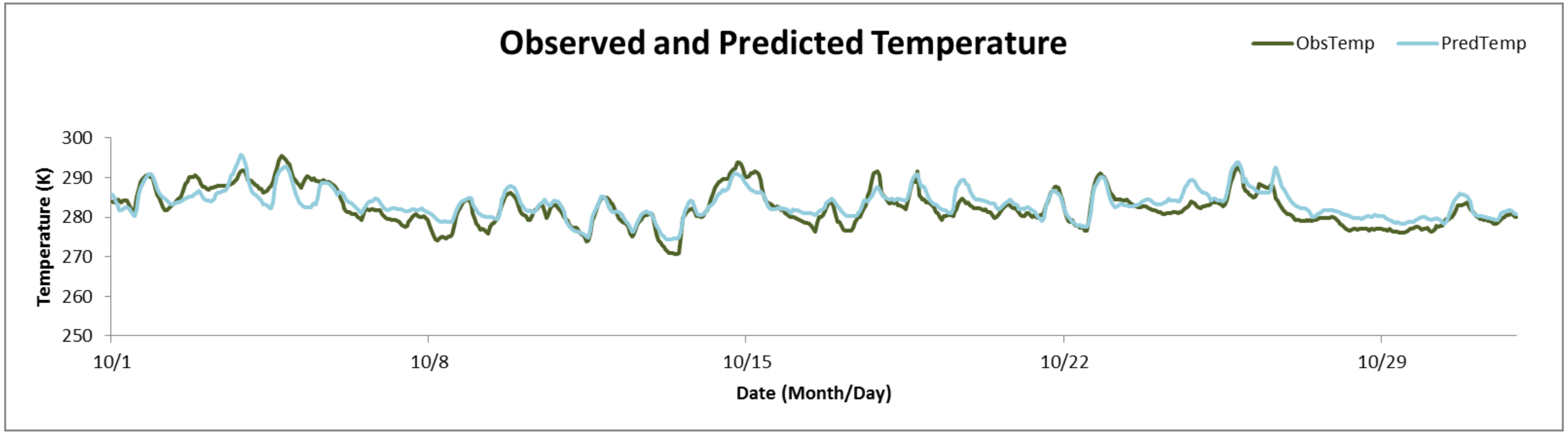
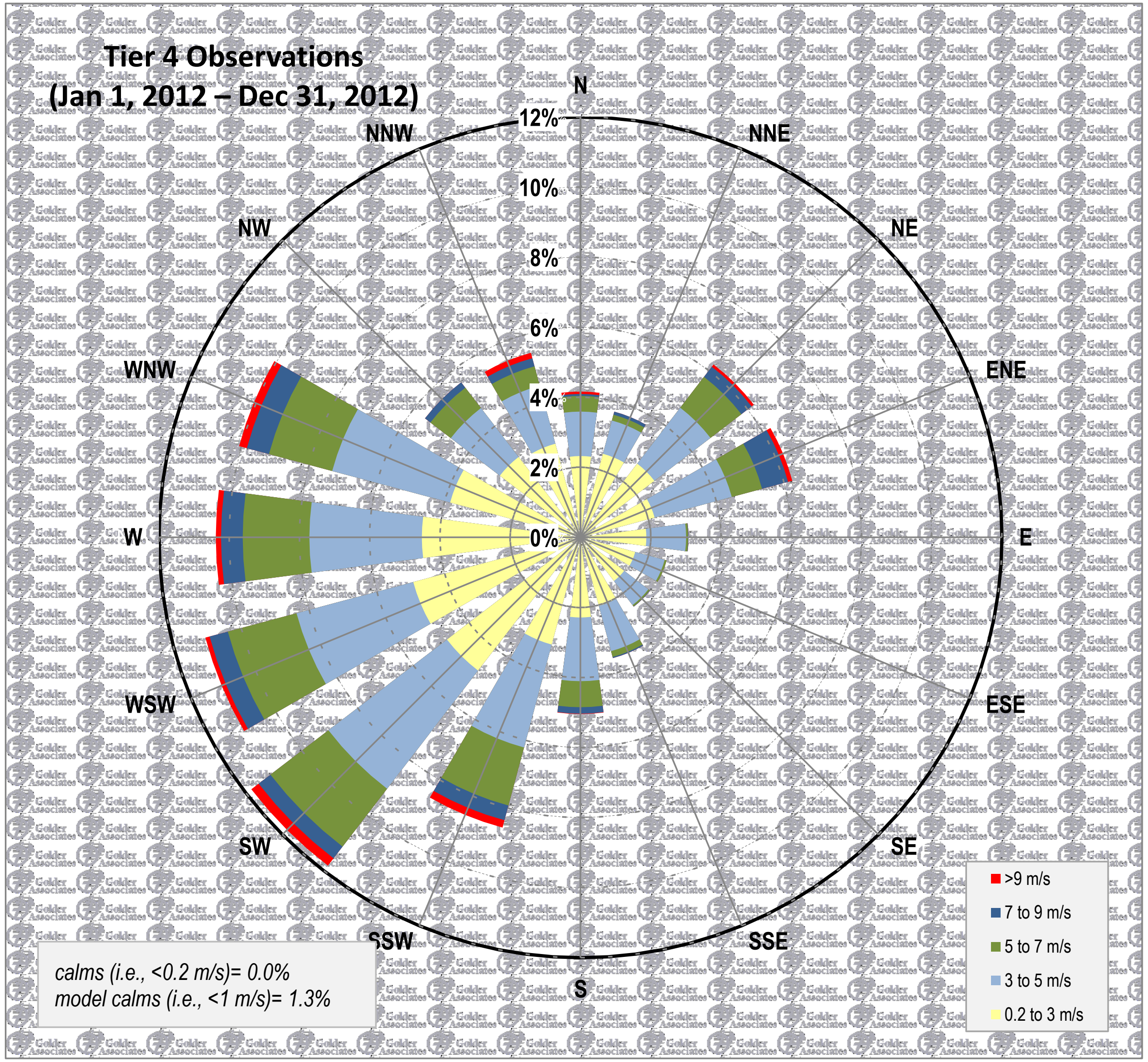
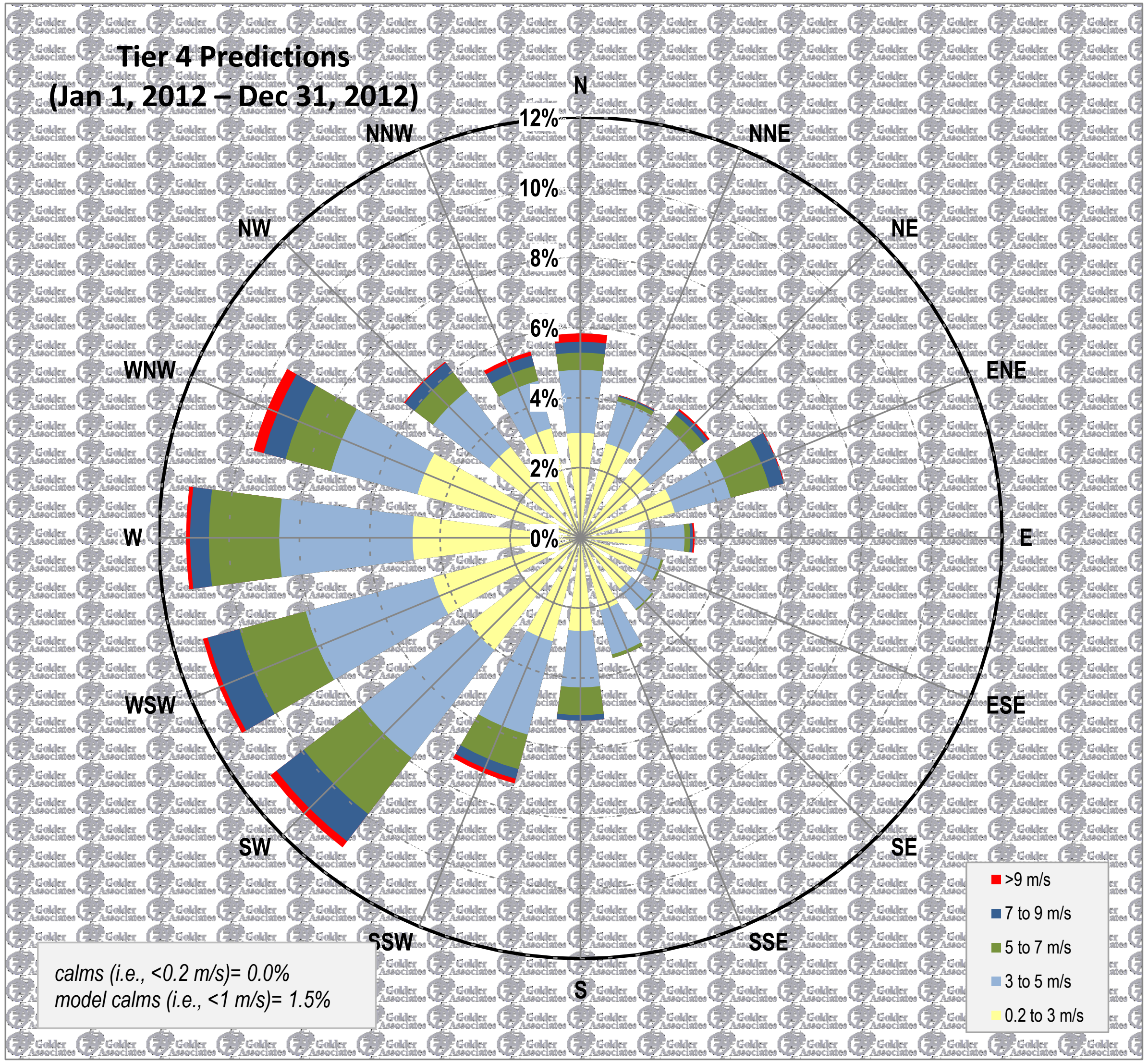
Tier IV Temperature: Summer and Fall





Tier IV Wind Rose Comparison





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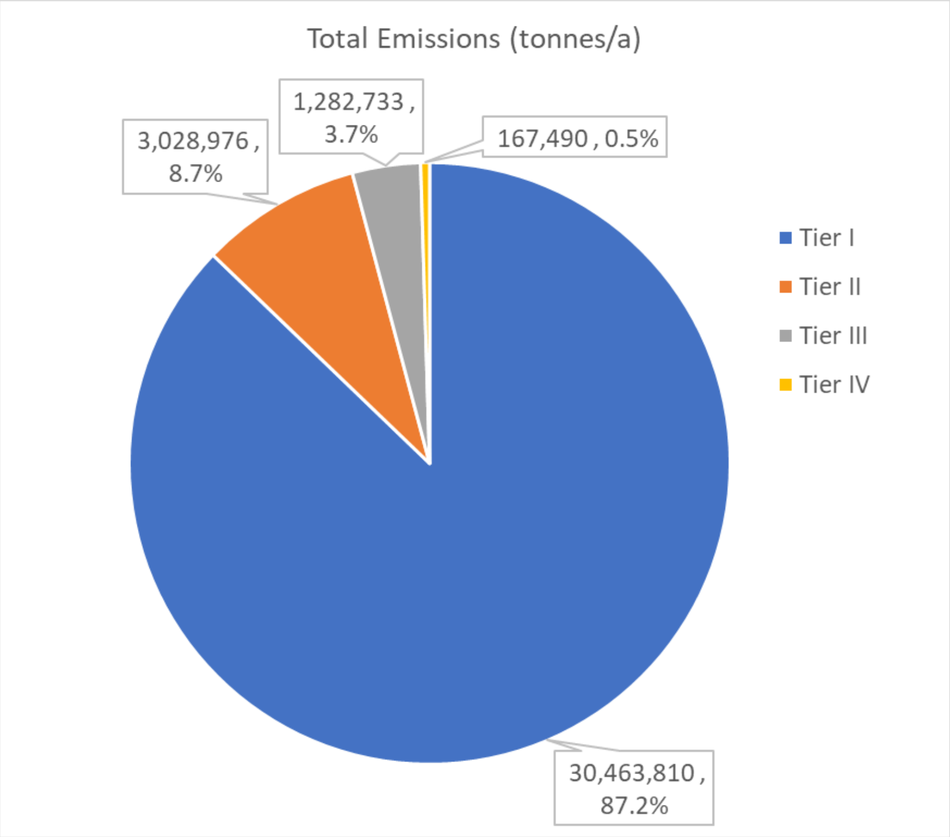
Emissions Inventory Results

Emissions Inventory Sources

GRIDDED, HOURLY EMISSION ESTIMATES BY TIER

Emission Classification	Type	Definition	Source	
			Tier I	Tiers II – IV
Industrial	Point (all tiers)	Elevated stacks from industrial activities	2006 Canadian National Emissions Inventory (NEI) 2011 US NEI	2012 NPRI, 2011 US NEI
	Area	Industrial activities		2012 NPRI, 2011 US NEI
Commercial	Point (Tier I, US Only)	Natural gas usage, auto-body shops, dry cleaners, commercial solvents		2012, ChemTRAC (scaled by population), 2012 Stats Can population data, 2011 US NEI
	Area			
Residential	Area	Natural gas usage, other residential heating sources		2012 natural gas consumption, 2012 Stats Canada energy use, 2011 US NEI
On-Road	Area	On-road vehicles (trucks, cars, motorcycles)		2012 MOVES, 2012 MTO traffic data, 2011 US NEI
Non-Road	Point (Tier I, US Only)	Airport, marine, rail and lawn mowers,		2006 Canadian NEI, 2012 NRCAN data, 2011 US NEI
	Area			
Biogenic / Agricultural	Area	Natural, farmland etc activities	2012 MEGAN, 2006 Canadian NEI, 2011 US NEI	2012 MEGAN, 2012 NONROAD

Total Emissions per Tier over the Computational Domain



Tier	%	Tonne/km²/yr
Tier I (36 km)	87.2%	21.91
Tier II (12 km)	8.7%	12.43
Tier III (4 km)	3.7%	27.87
Tier IV (1.33 km)	0.5%	53.02

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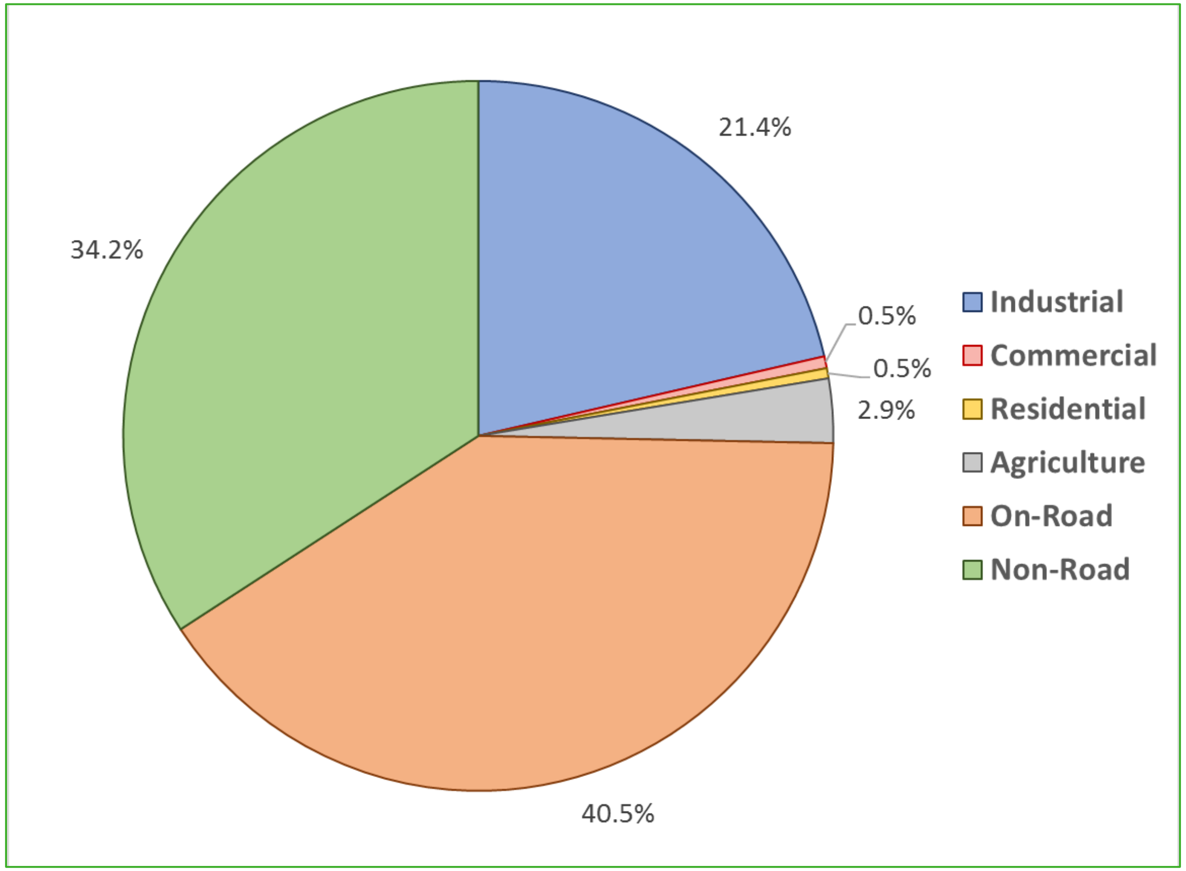
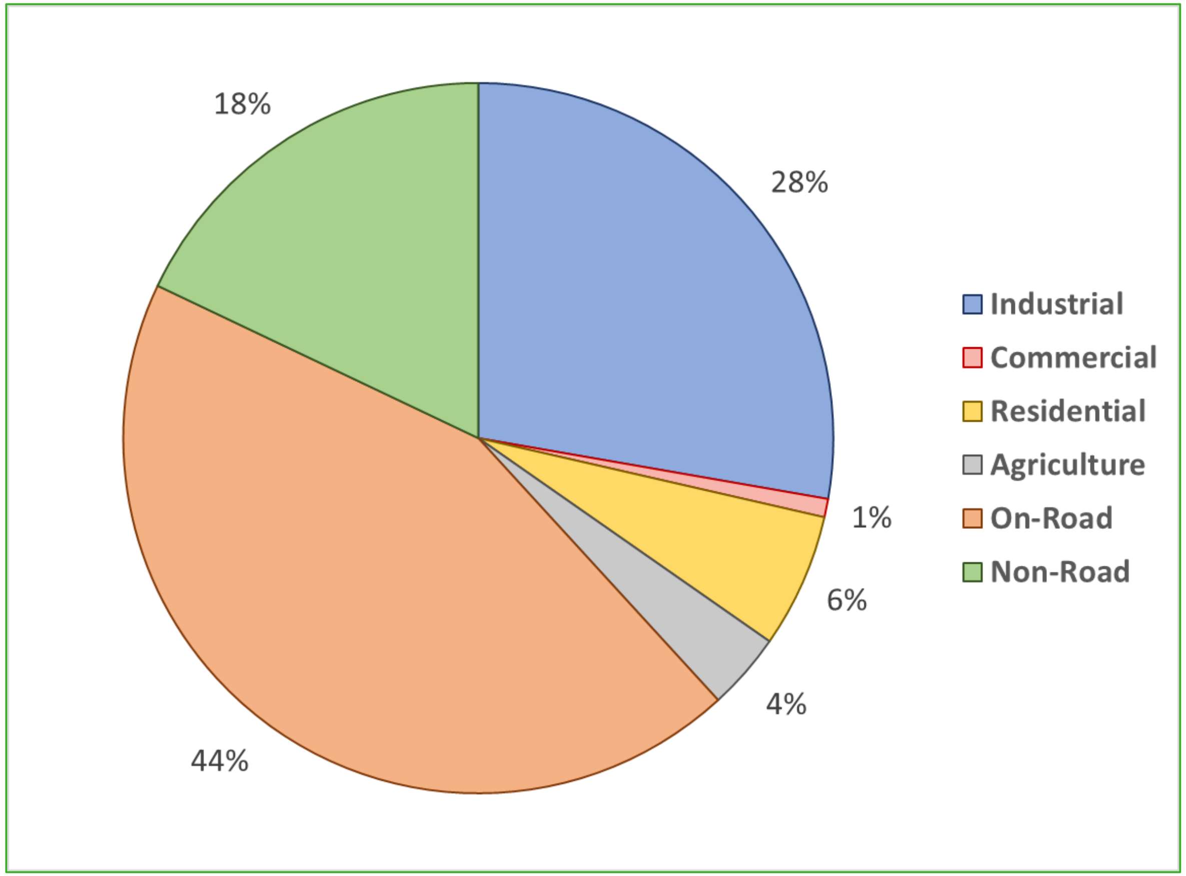
Hamilton & Transboundary Sector Profiles

HAMILTON EMISSIONS

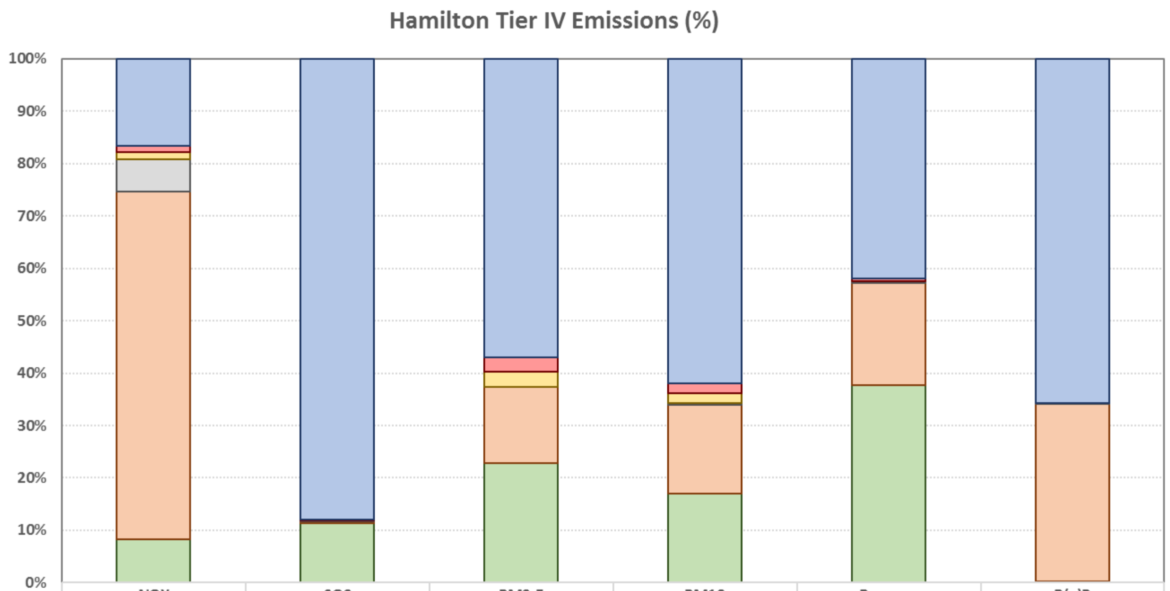


TRANSBOUNDARY EMISSIONS



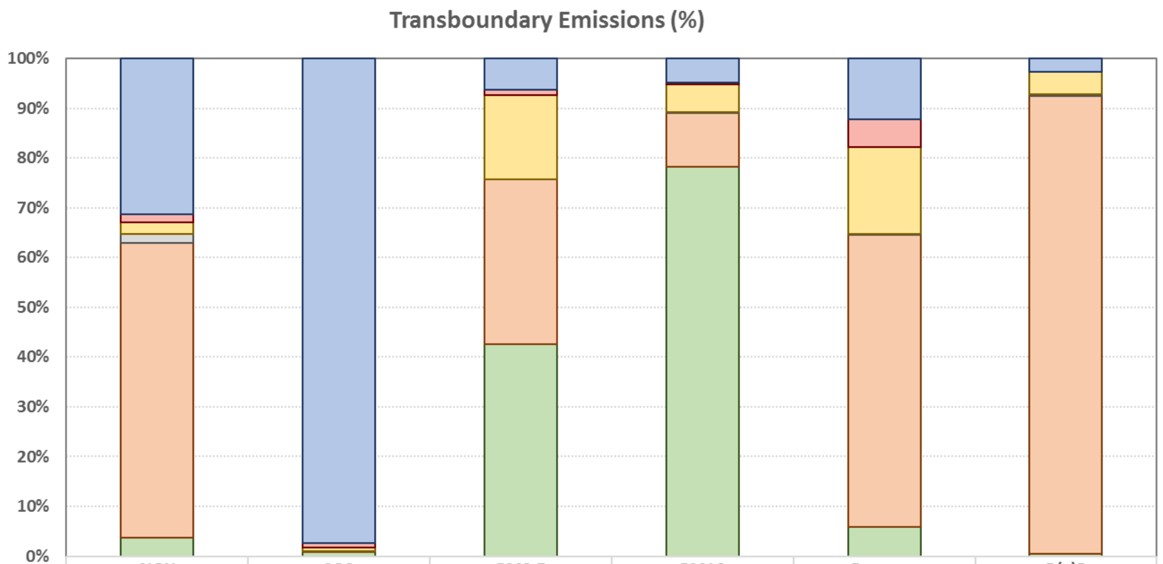
Hamilton & Transboundary Emissions Profiles

HAMILTON EMISSIONS (%)



	NOX	SO2	PM2.5	PM10	Benzene	B(a)P
Industrial	16.6%	88.0%	57.0%	61.9%	42.0%	65.7%
Commercial	1.2%	0.02%	2.7%	1.8%	0.5%	0.0%
Residential	1.3%	0.02%	2.9%	2.0%	0.0%	0.0%
Agriculture	6.2%	0.3%	0.0%	0.3%	0.4%	0.2%
On-Road	66.4%	0.4%	14.7%	17.0%	19.4%	33.8%
Non-Road	8.2%	11.3%	22.7%	17.0%	37.7%	0.3%

TRANSBOUNDARY EMISSIONS (%)



	NOX	SO2	PM2.5	PM10	Benzene	B(a)P
Industrial	31.3%	97.3%	6.4%	4.8%	12.2%	2.7%
Commercial	1.7%	1.0%	1.1%	0.5%	5.7%	0.0%
Residential	2.3%	0.7%	16.8%	5.6%	17.5%	4.4%
Agriculture	1.8%	0.0%	0.1%	0.1%	0.1%	0.5%
On-Road	59.1%	0.2%	33.1%	10.9%	58.7%	91.9%
Non-Road	3.7%	0.8%	42.5%	78.2%	5.9%	0.5%

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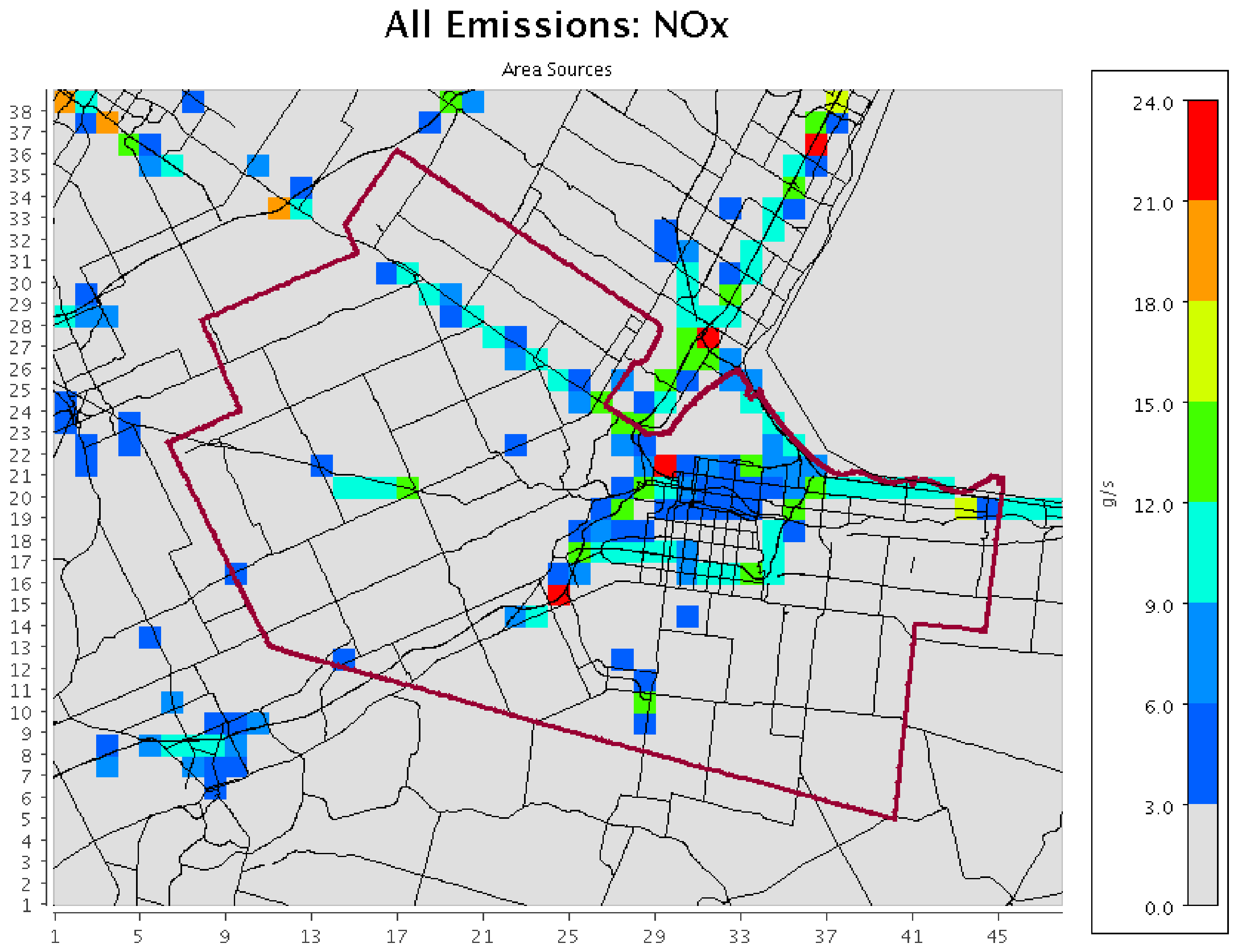
Tier IV: Geographical Distribution NO_x Emissions



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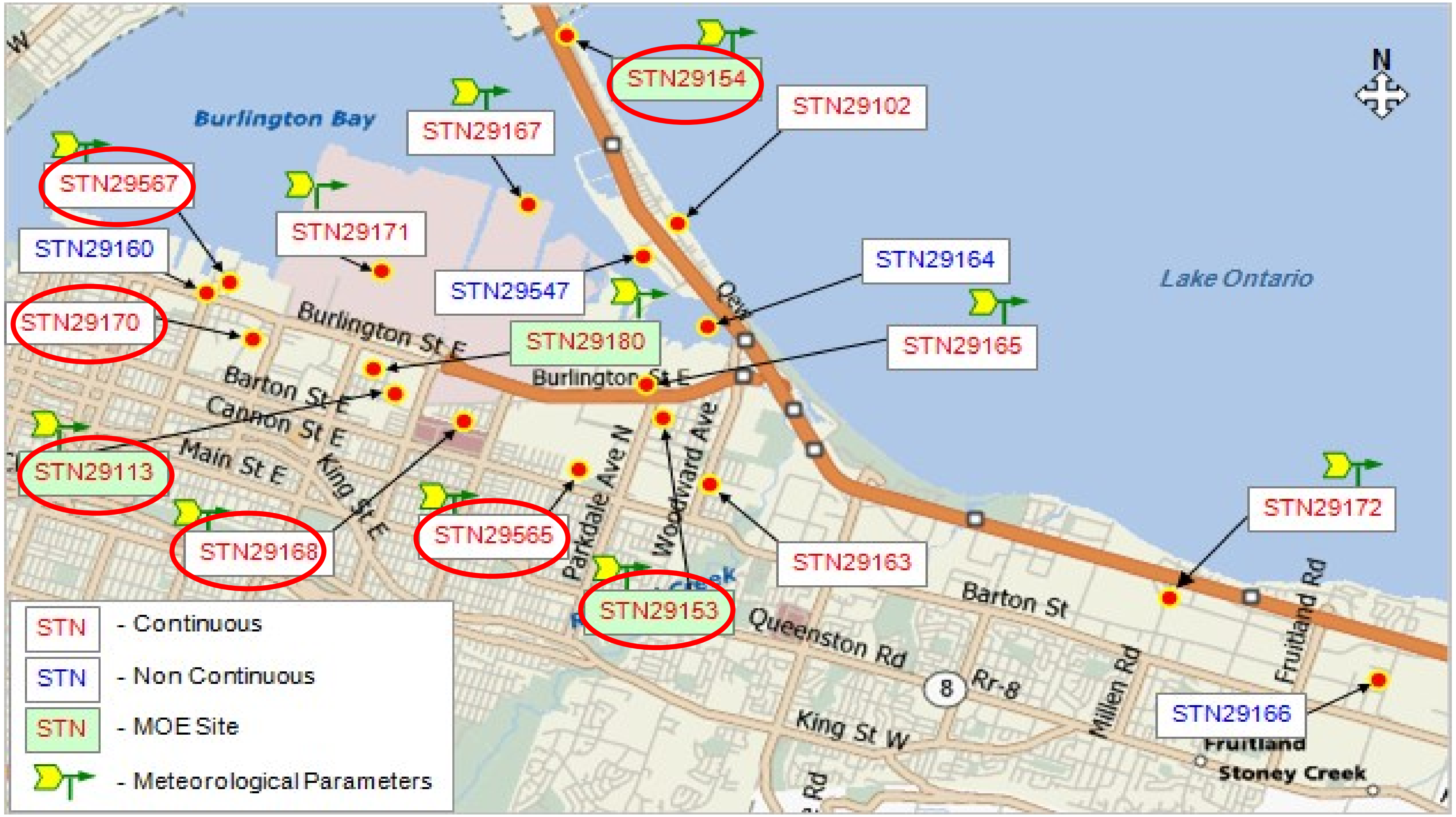
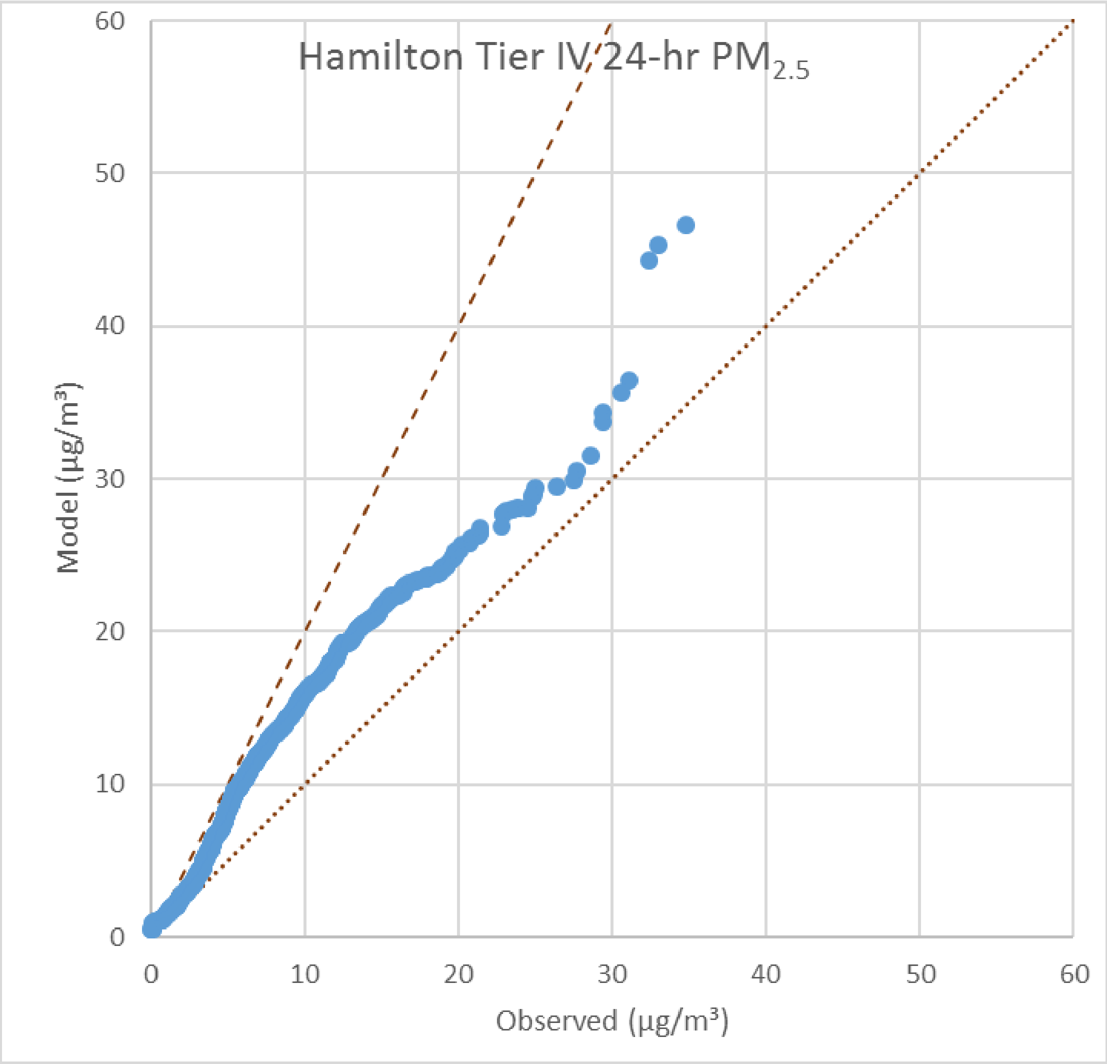
Air Quality Modelling Results: Model Performance

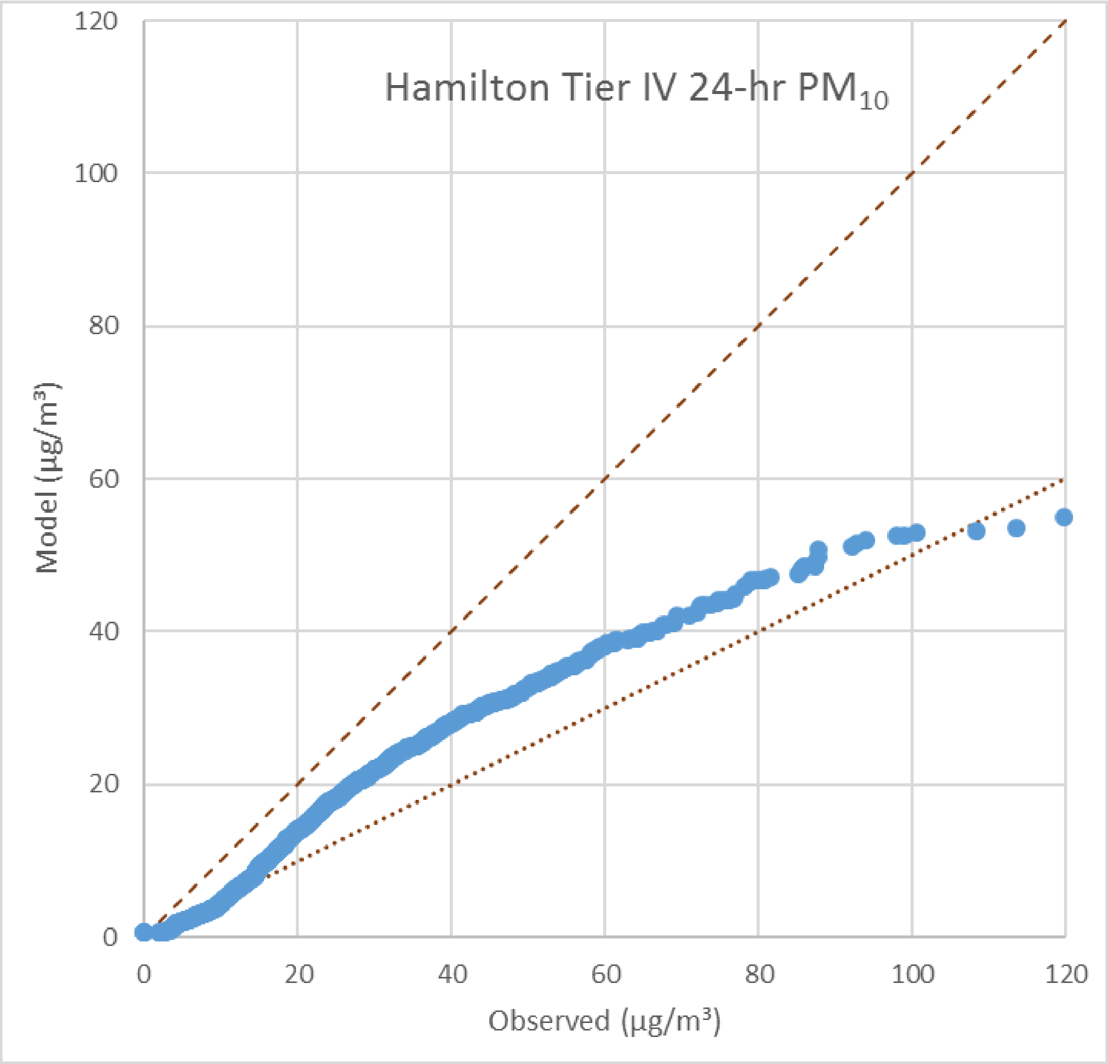
Source: https://en.wikipedia.org/wiki/File:HamiltonOntarioSkylineC.JPG, licensed under https://creativecommons.org/licenses/by-sa/3.0/

Air Quality Monitoring Station Map

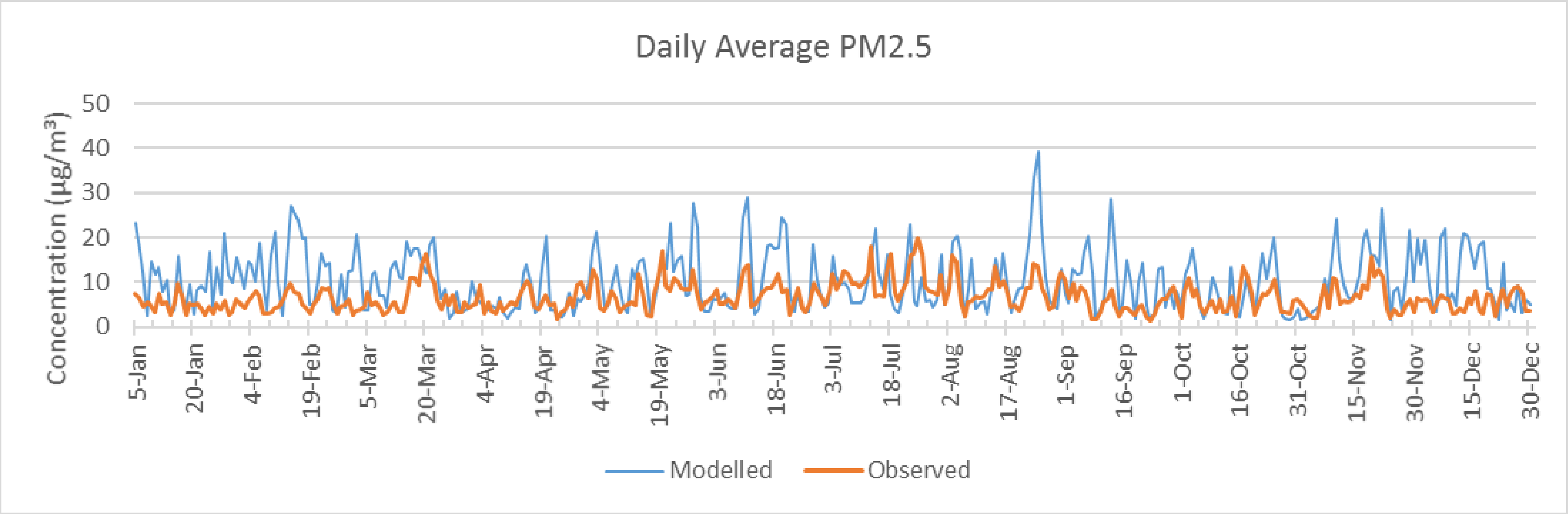


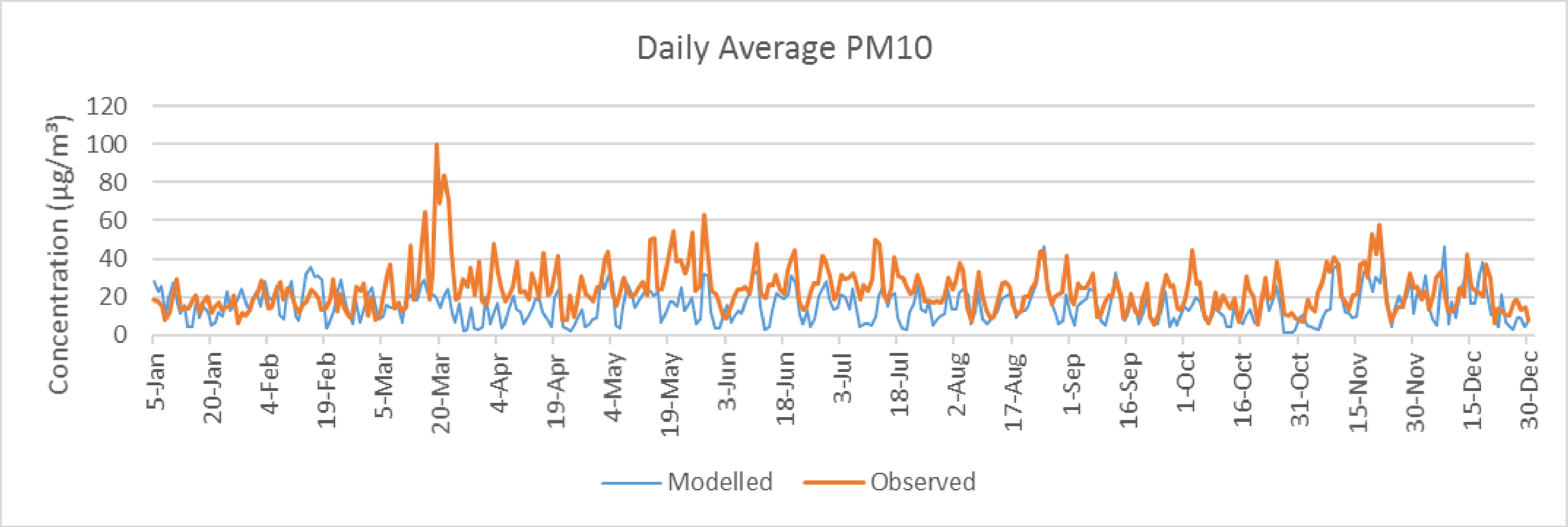
Q:Q Plots: $PM_{2.5}$ and PM_{10}





Time Series: $PM_{2.5}$ and PM_{10}





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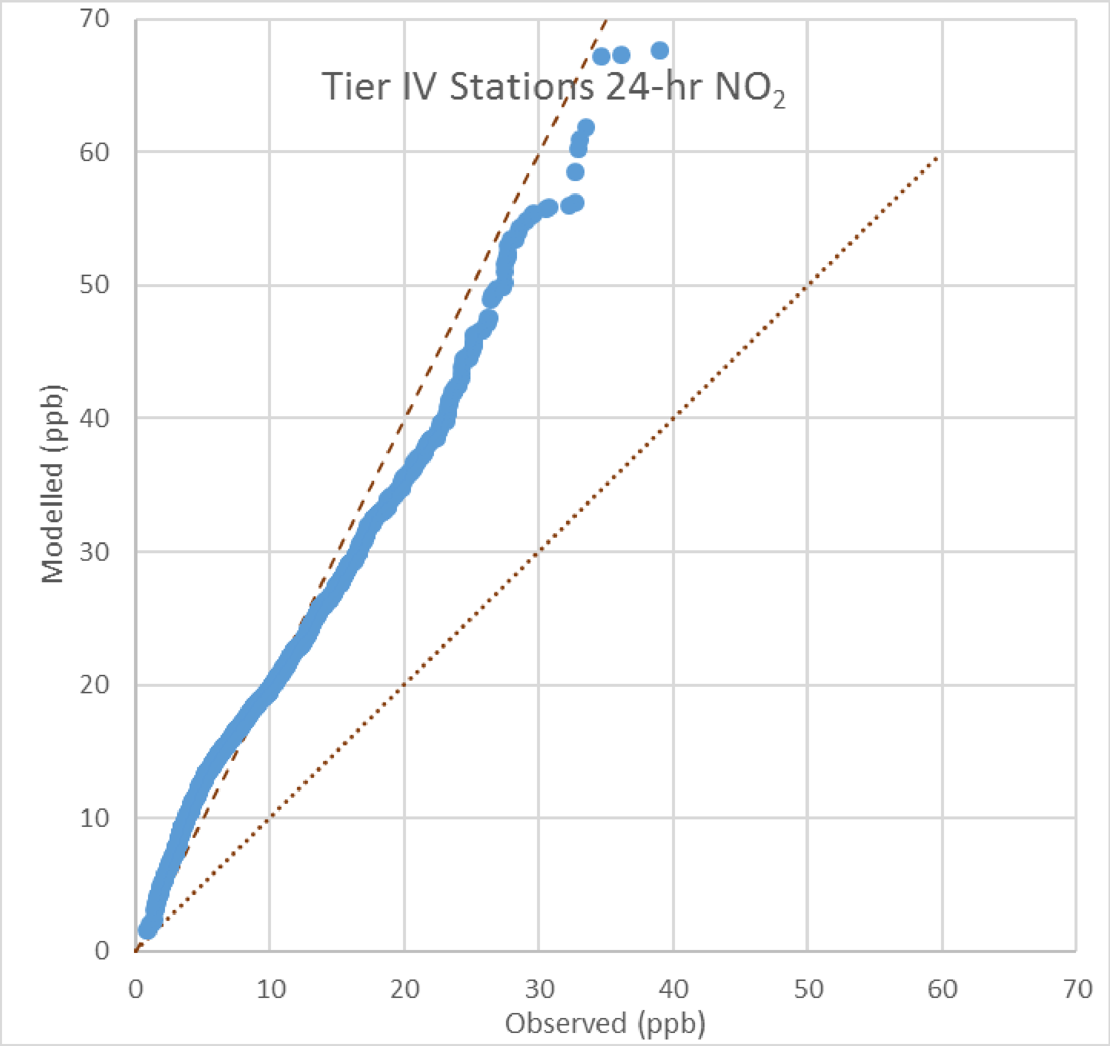
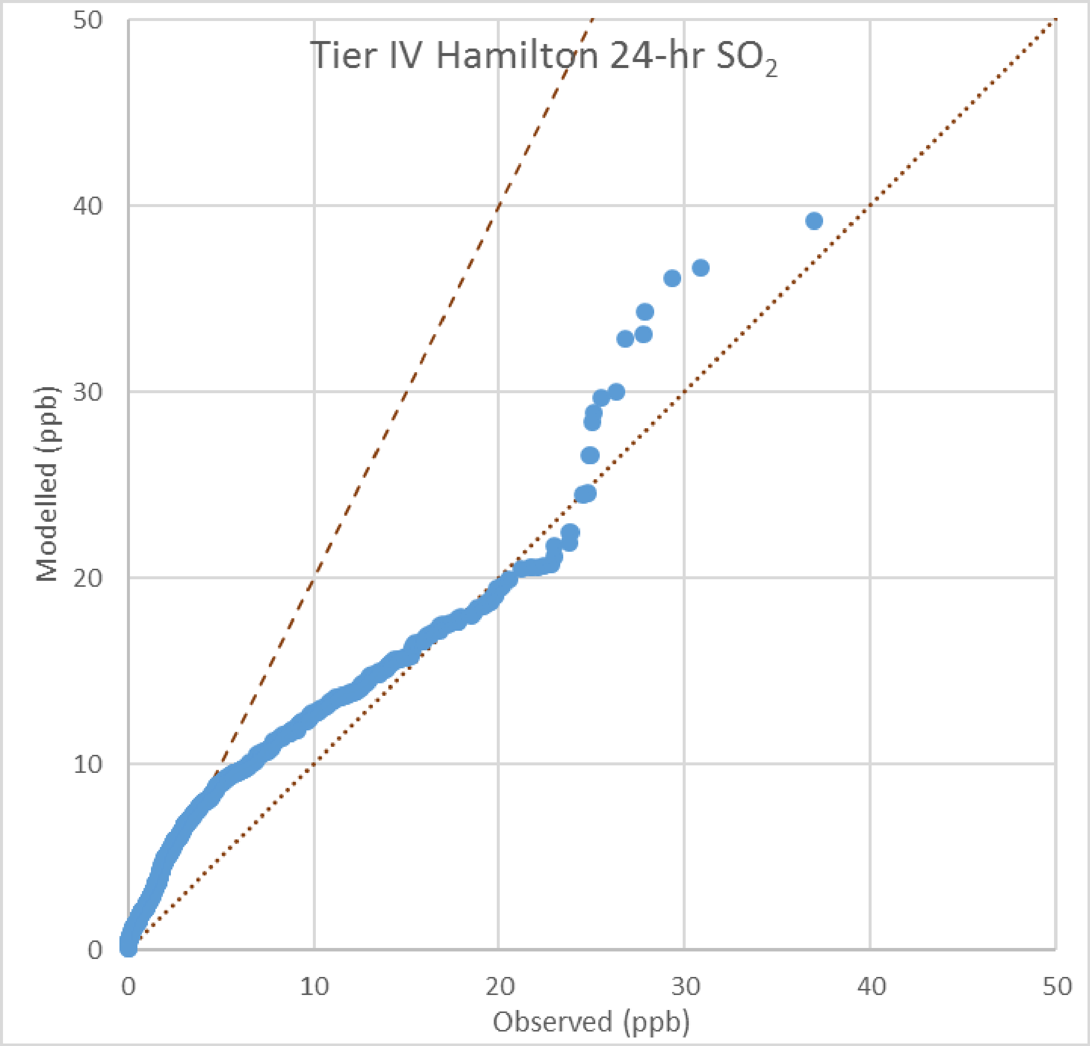
Q:Q Plots: NO_2 and SO_2





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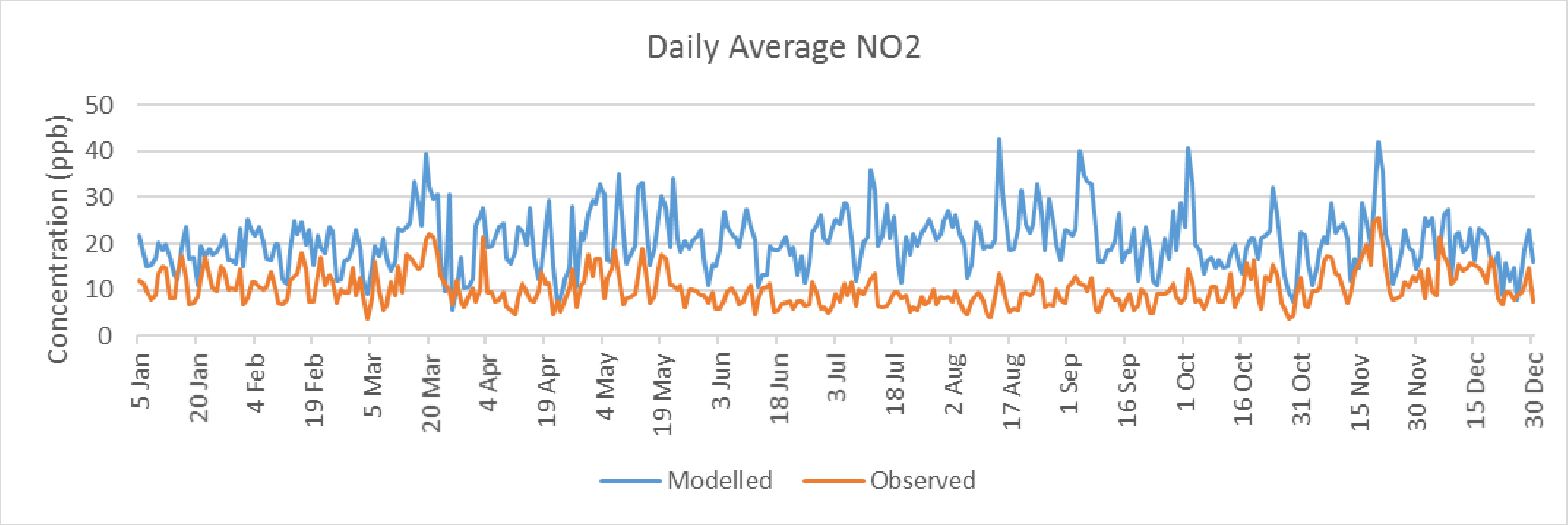
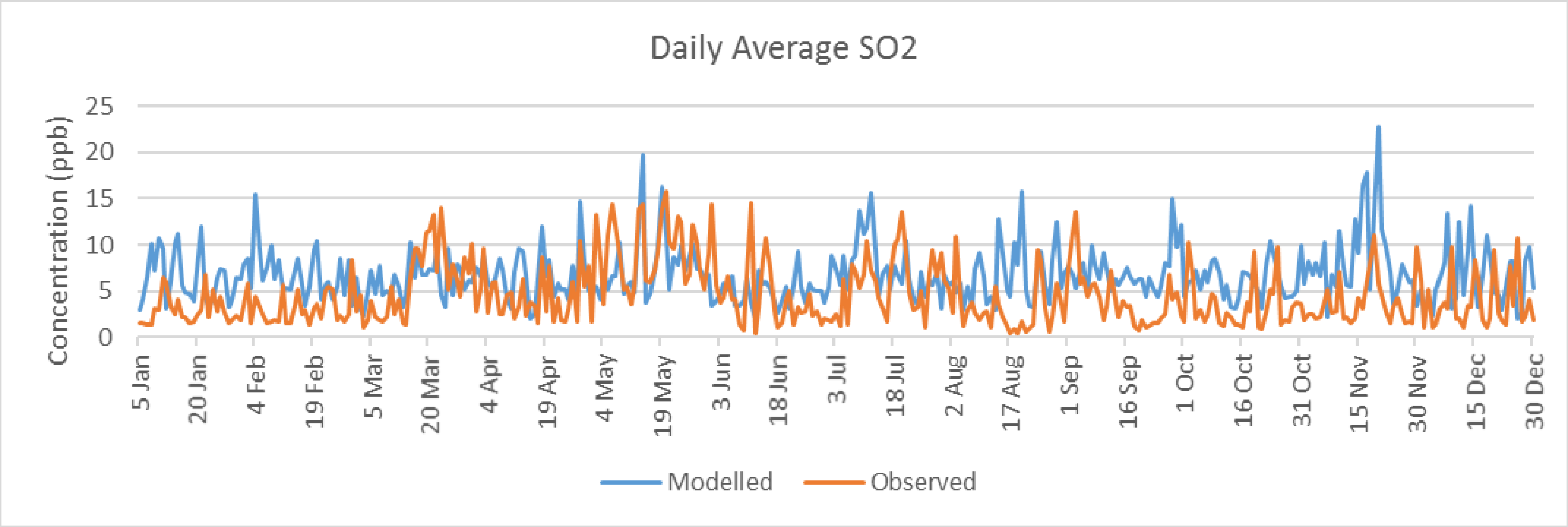
Time Series: NO_2 and SO_2





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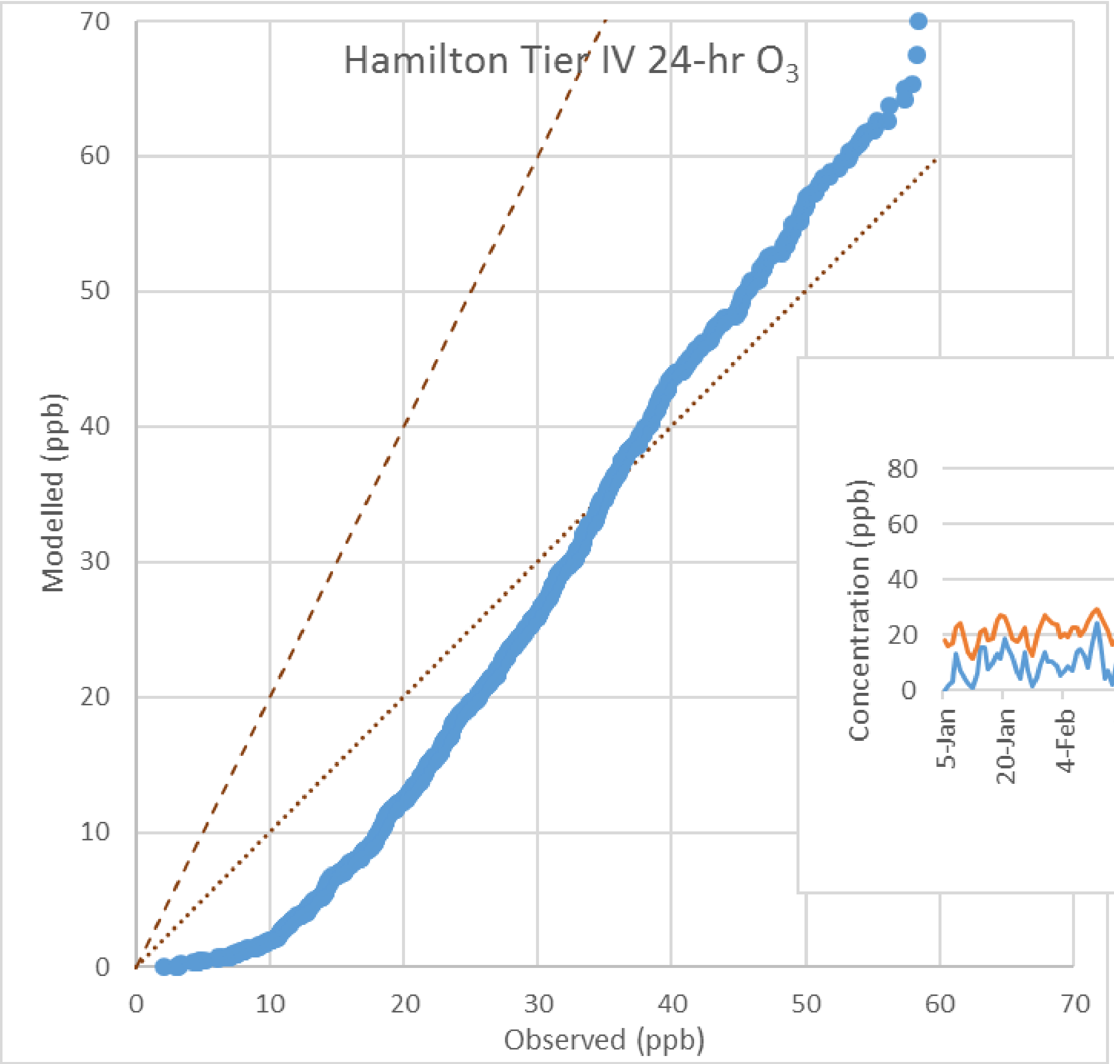
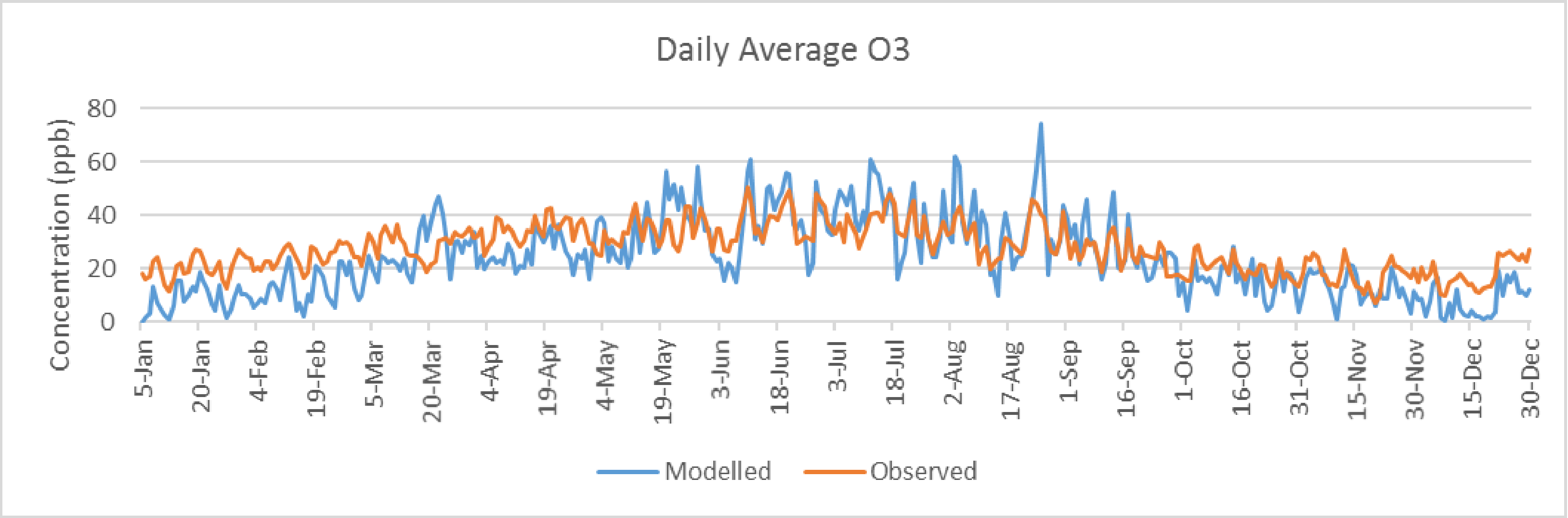
Q:Q and Time Series Plot: O_3





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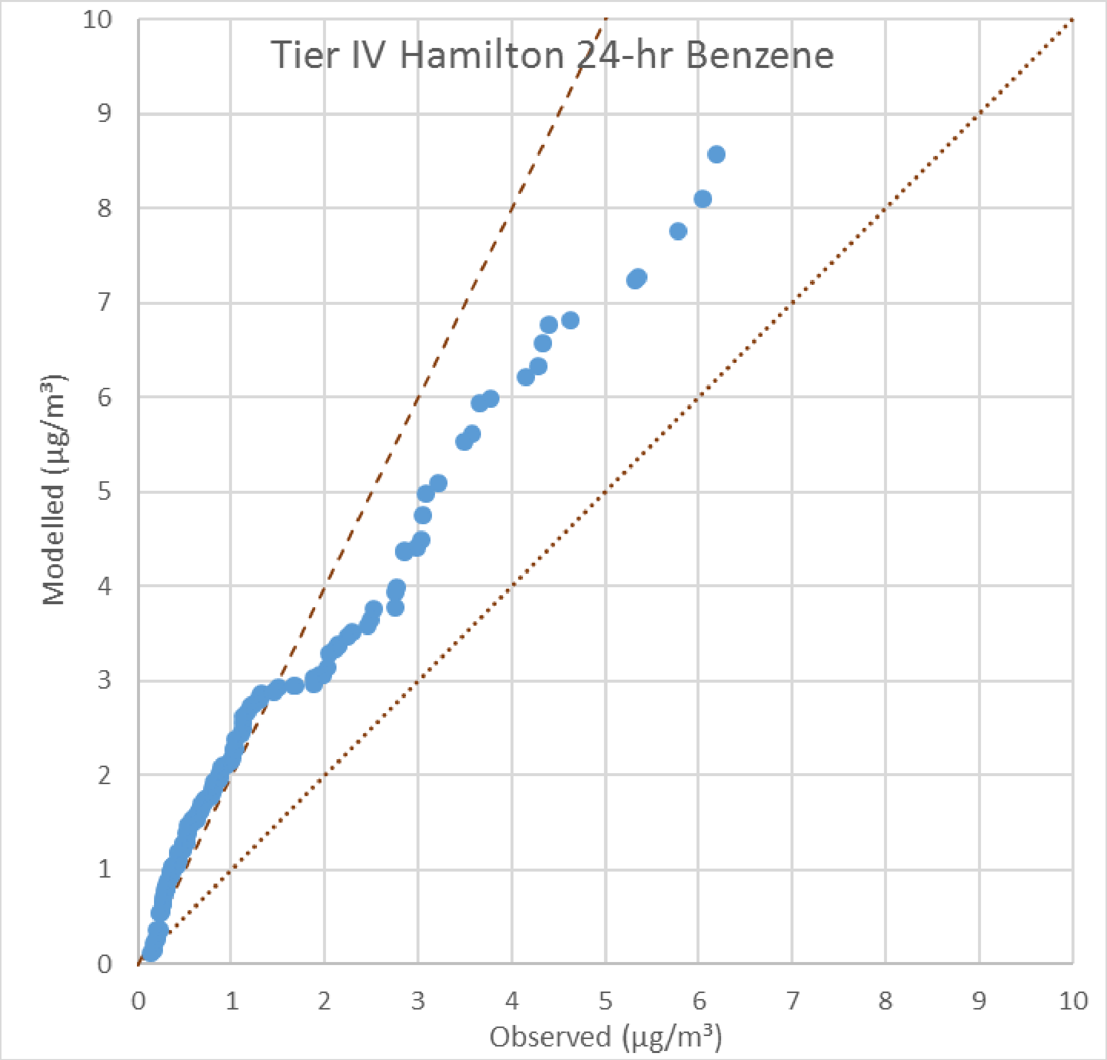
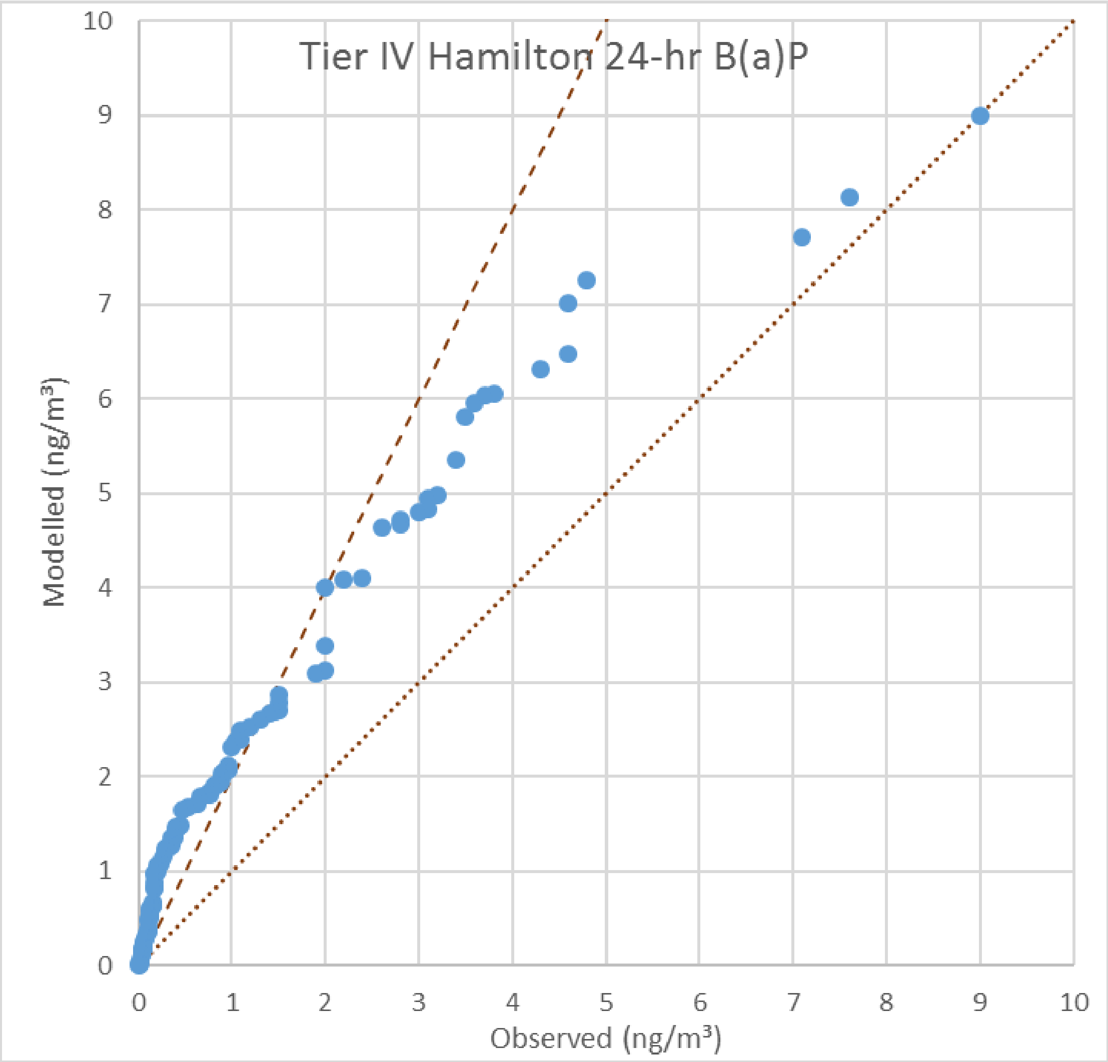
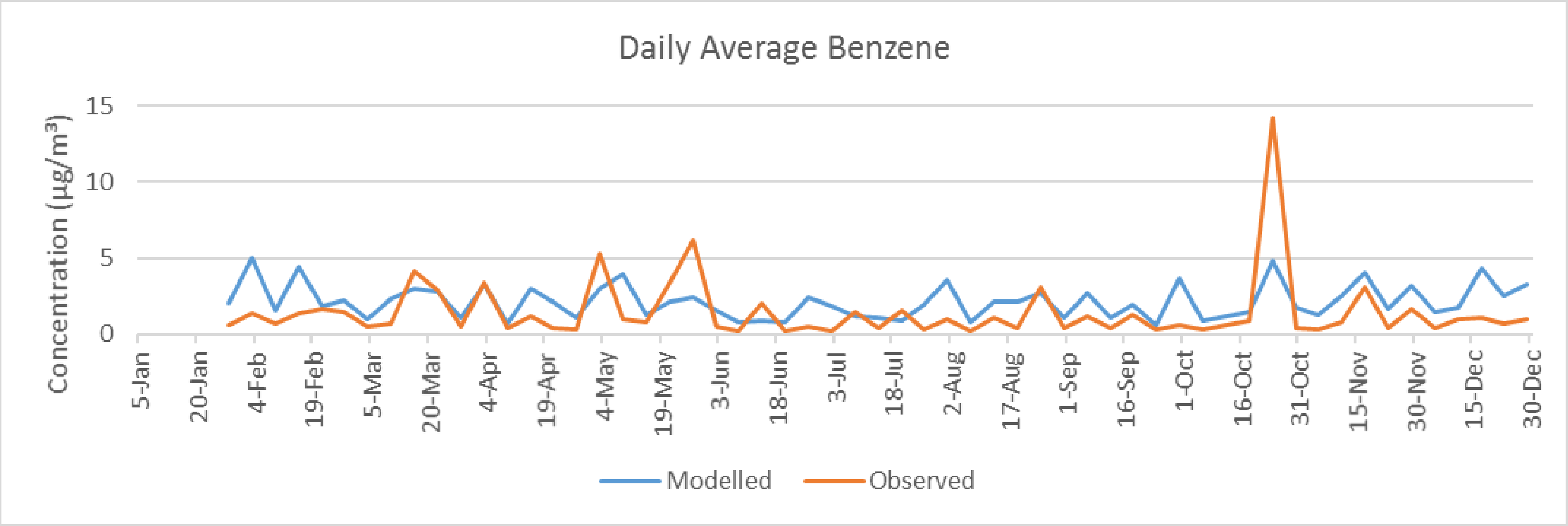
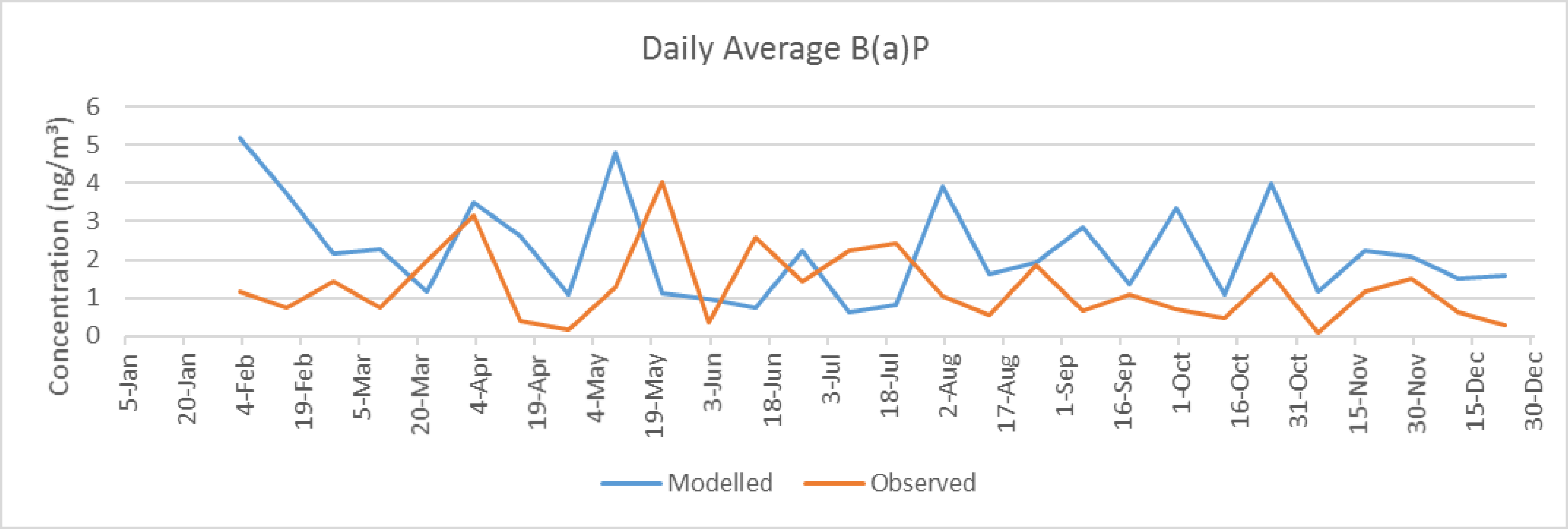
Q:Q Plots: Benzene and B(a)P





Time Series: Benzene and B(a)P





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Air Quality Modelling Results

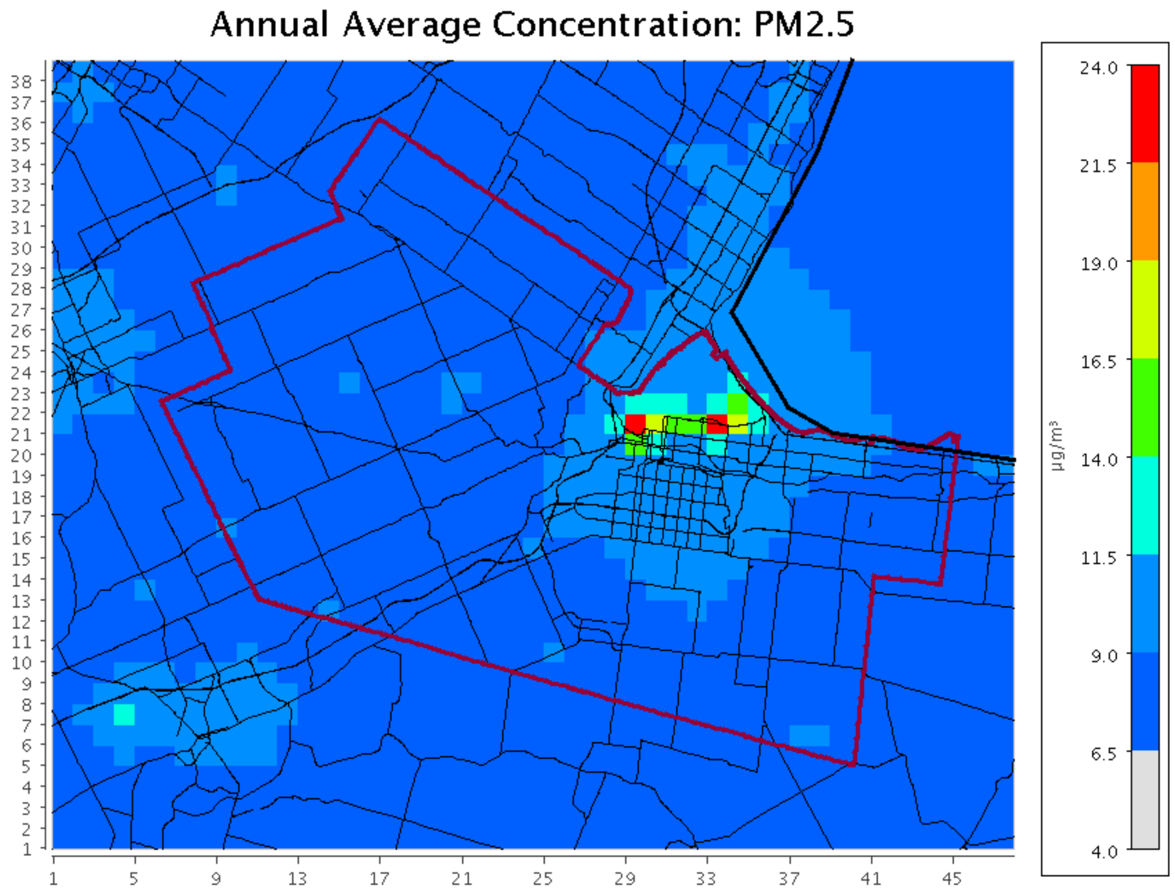
MODEL PERFORMANCE EVALUATION SUMMARY

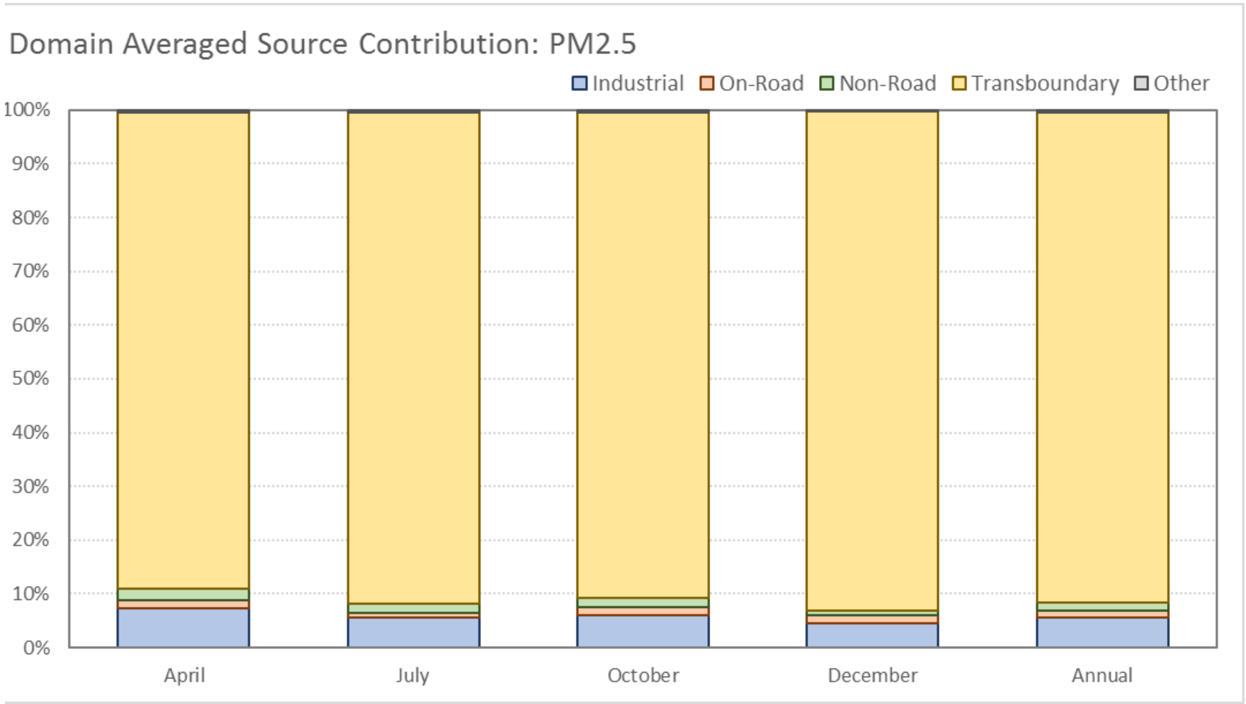
- **Model results are conservative and reliable!**
- Particulate matter met performance criteria
  - PM_{10} is under-predicted likely due to unaccounted for fugitive dust source
  - Over prediction seems to occur in the winter months
- All compounds are predicted within a factor of 2
  - Performing within expectations of the modelling community
- Transboundary NO_2 emissions are overstated leading to model over-prediction
- Metrics for benzene and B(a)P could be impacted by lack of observations (compared to other species)
- Seasonal terms are captured

Air Quality Modelling Results: Aerial and Source Apportionment across Tier IV

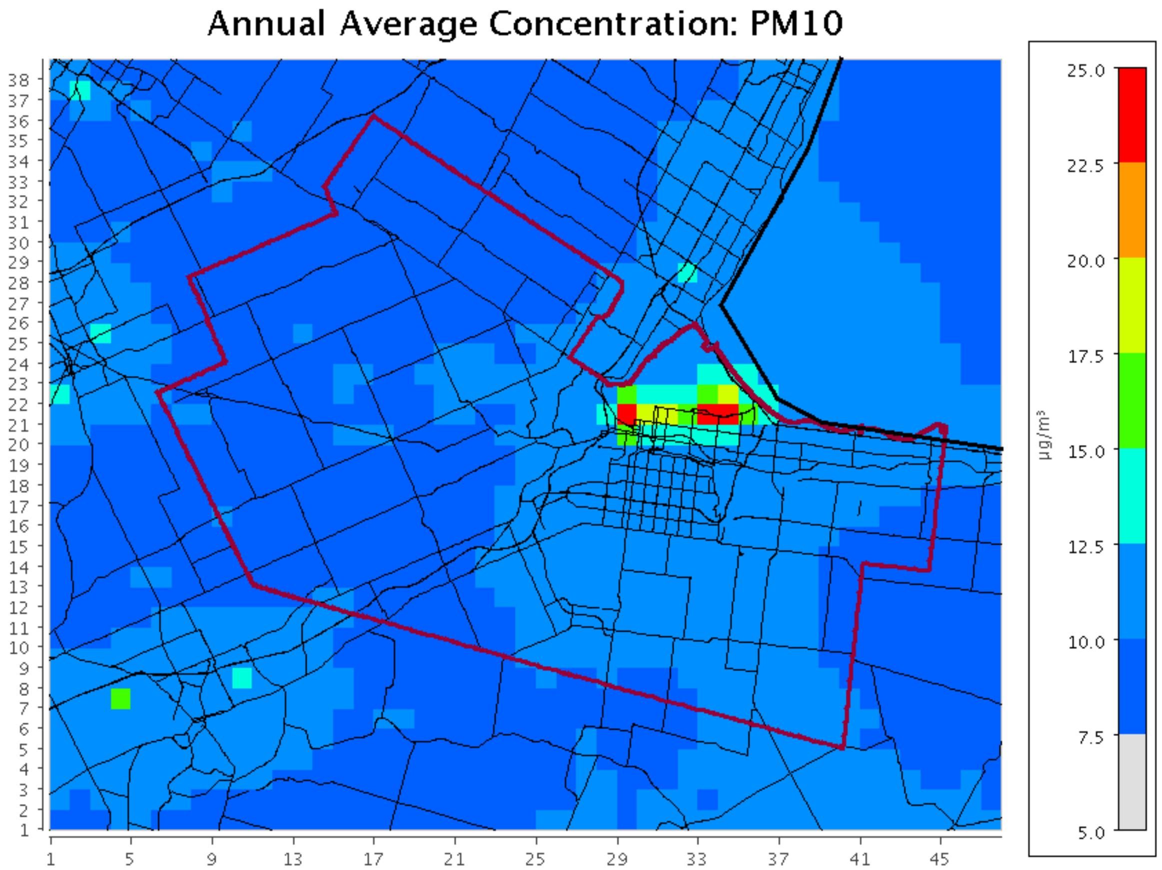
Source: https://en.wikipedia.org/wiki/File:HamiltonOntarioSkylineC.JPG, licensed under https://creativecommons.org/licenses/by-sa/3.0/

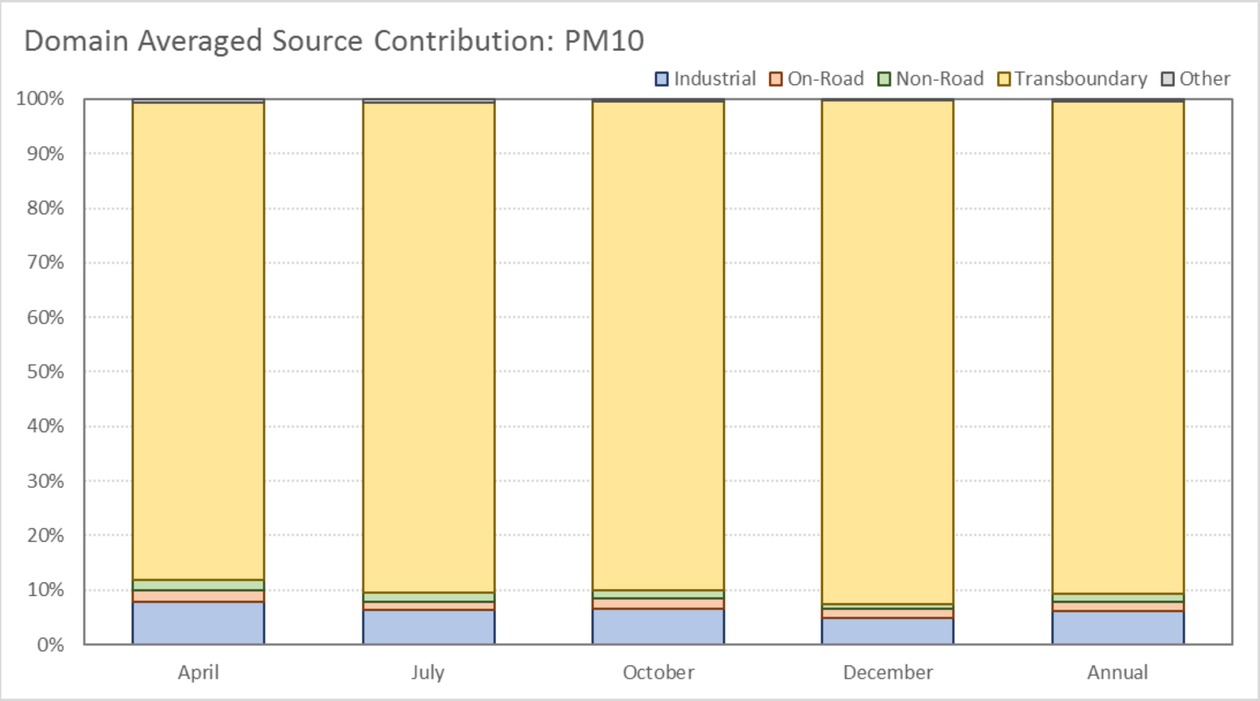
Air Quality Modelling Results: $PM_{2.5}$



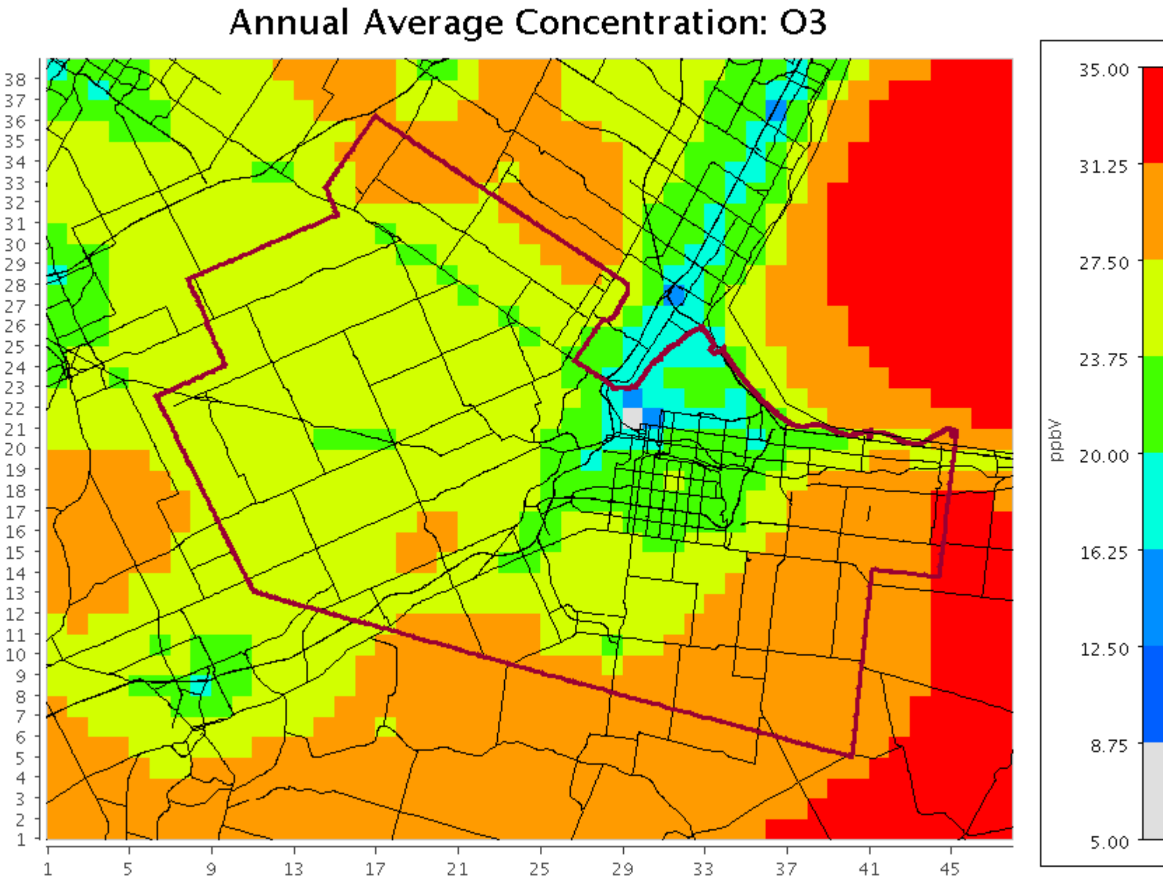


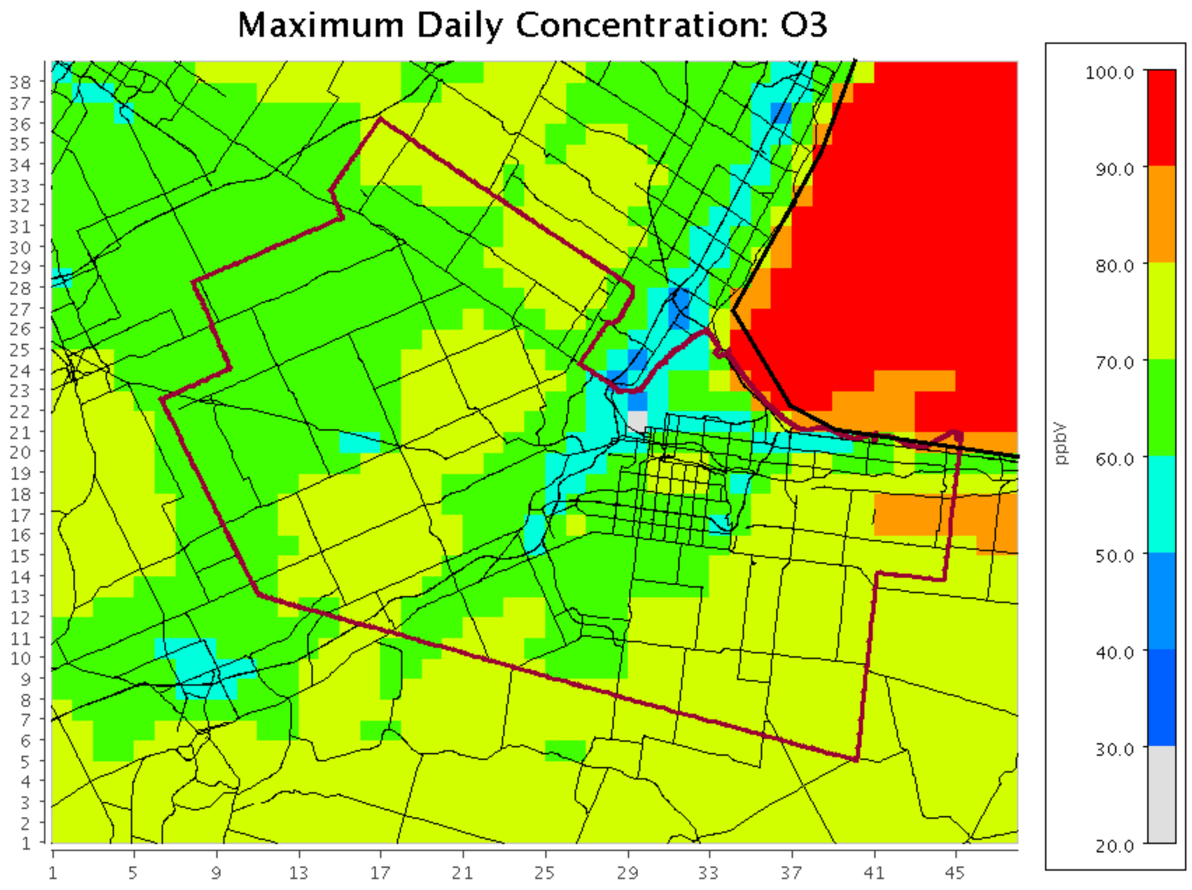
Air Quality Modelling Results: PM_{10}





Air Quality Modelling Results: O_3





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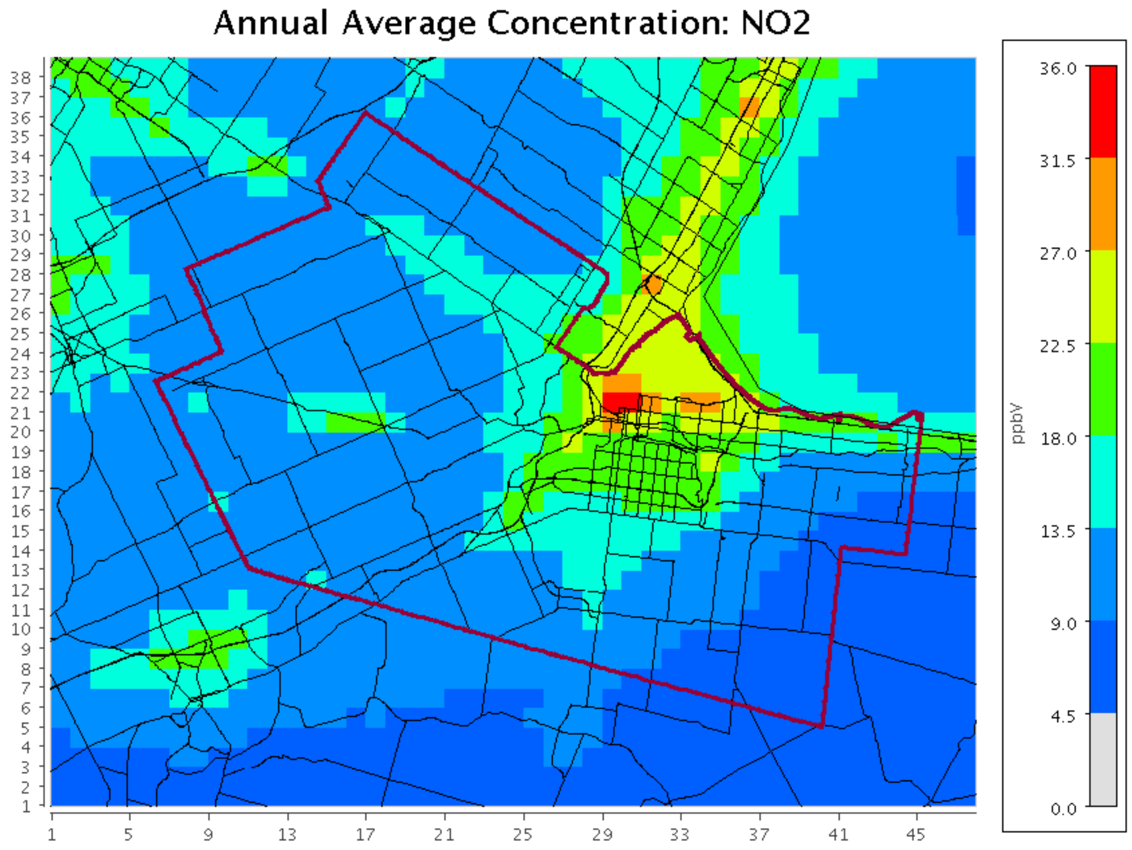
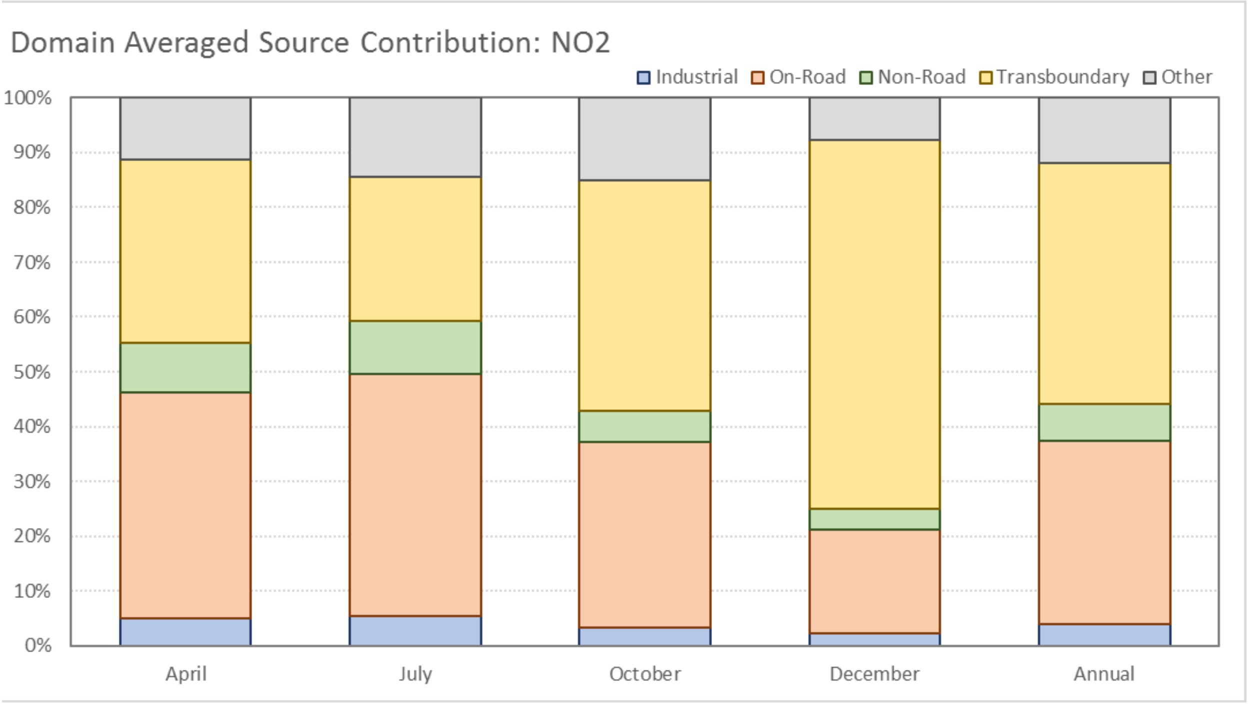
Air Quality Modelling Results: NO_2





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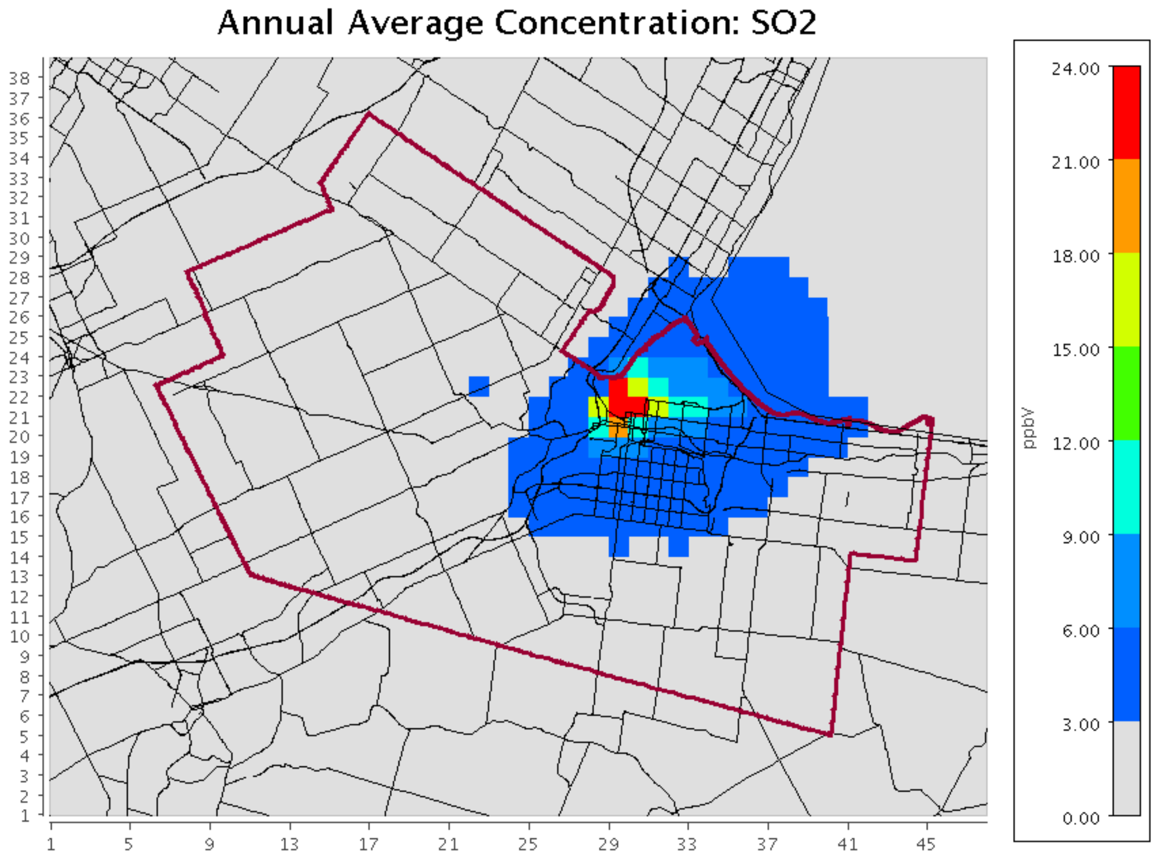
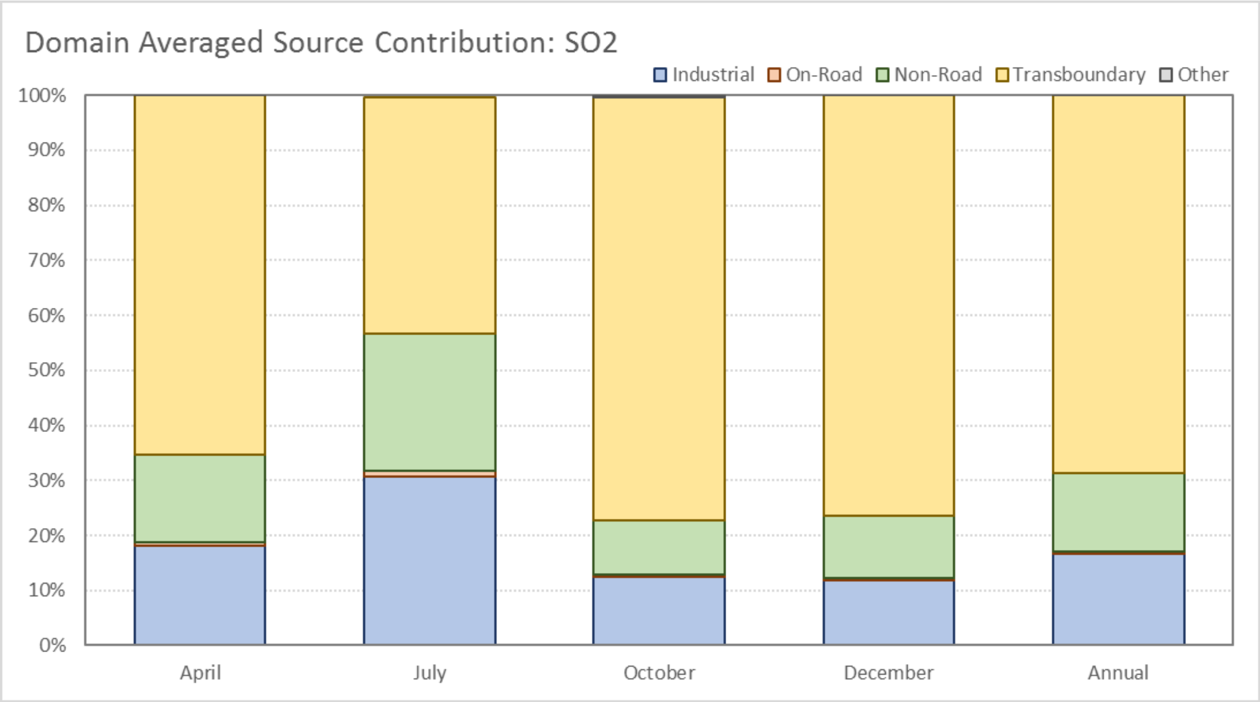
Air Quality Modelling Results: SO_2





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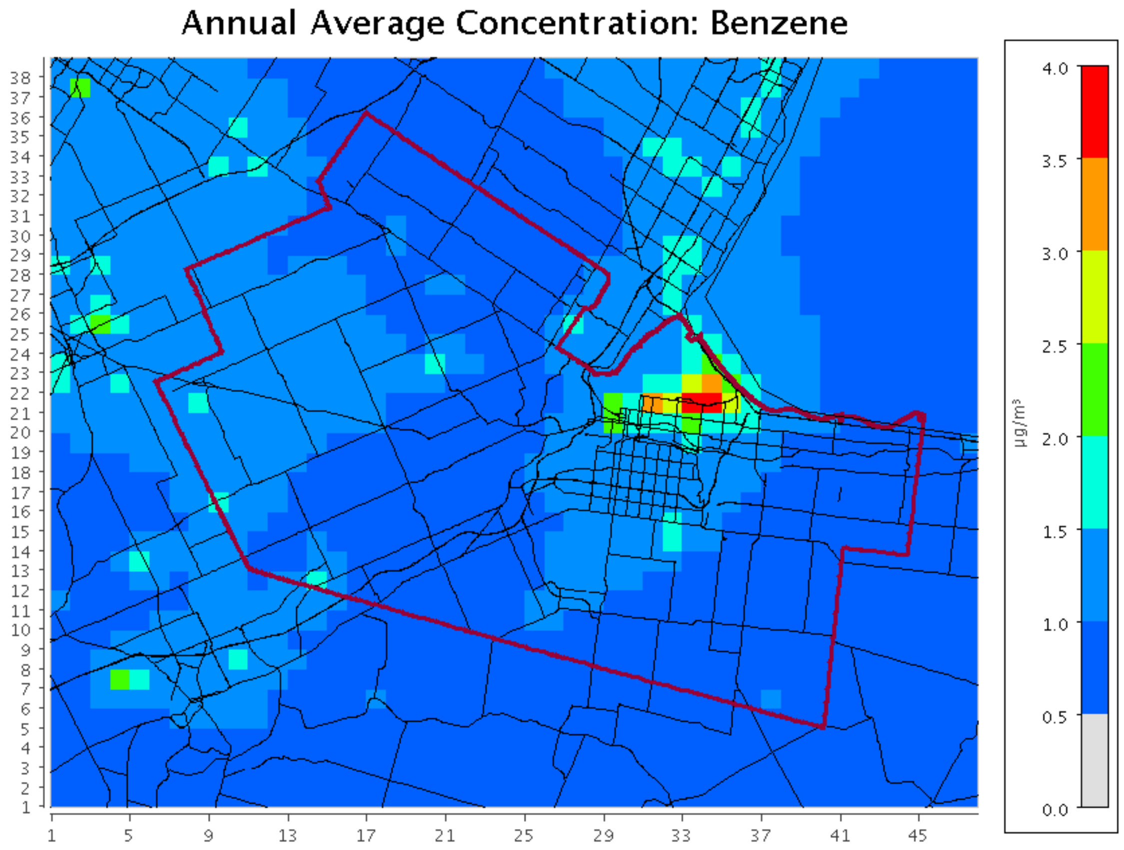
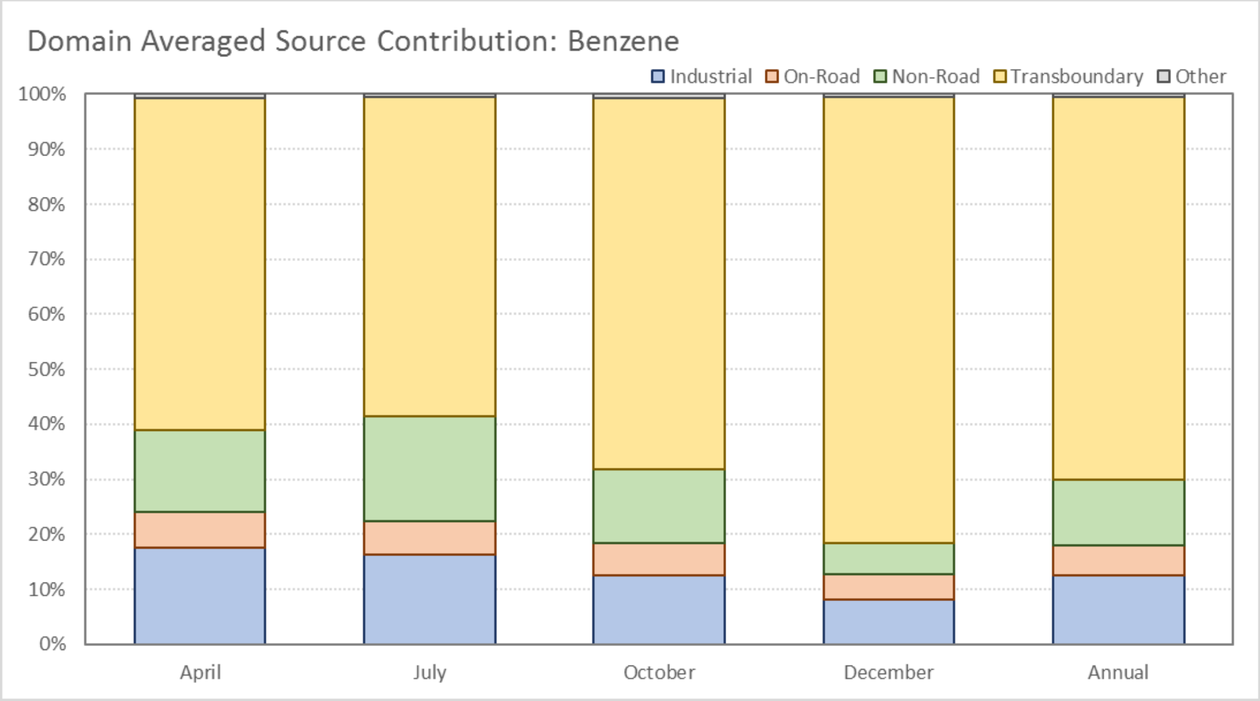
Air Quality Modelling Results: Benzene





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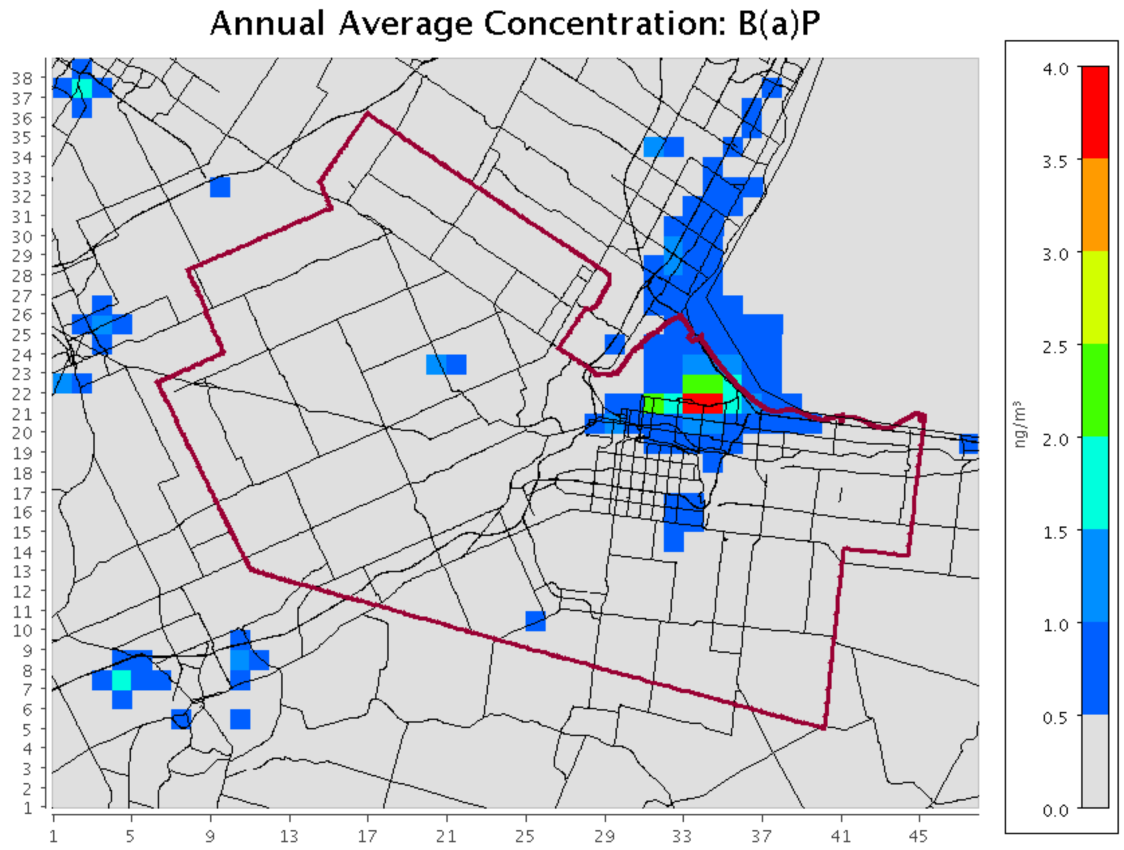
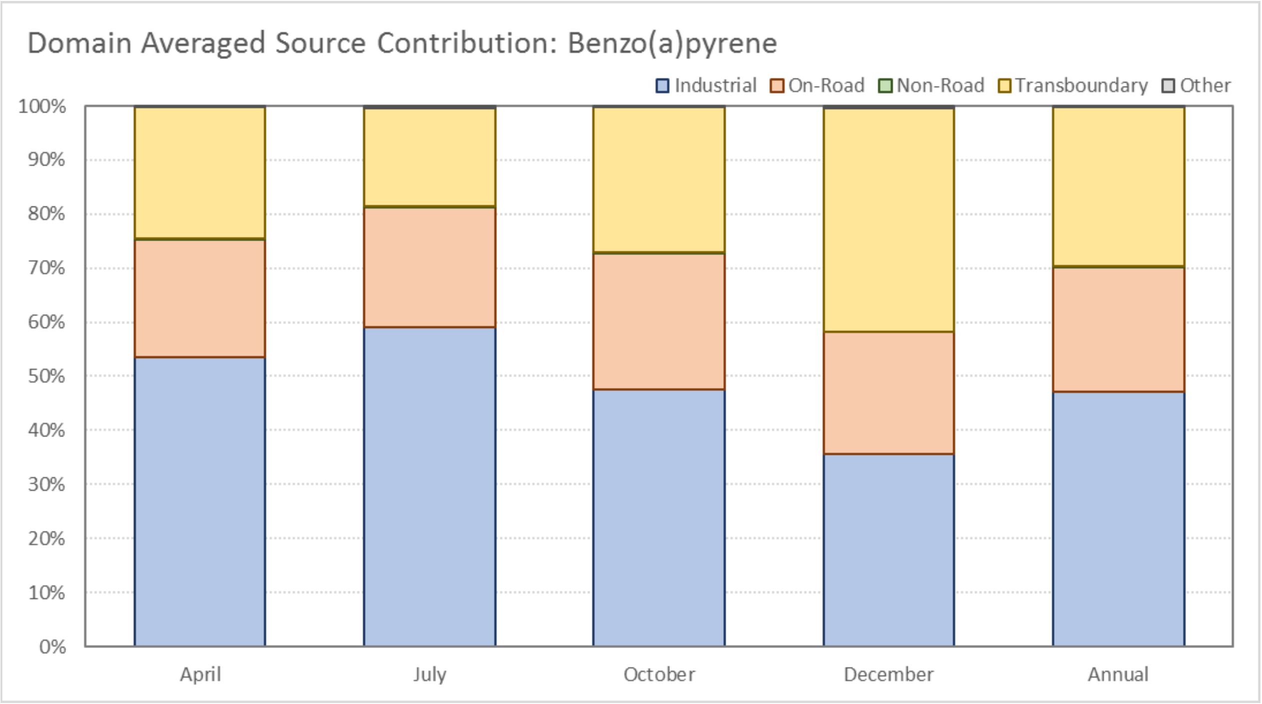
Air Quality Modelling Results: B(a)P





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Conclusions

Conclusions – Solving the Puzzle

WHAT HAVE WE LEARNED FROM THE HAMILTON AIRSHED MODELLING SYSTEM?

1. HAMS provides conservative and reliable results with a strong degree of confidence as results meet published benchmarks.
2. Source contribution profile varies according to geographic location (i.e. downtown vs mountain)
3. Transportation related activities are significant contributors to air quality levels (i.e., in and outside of the City)
4. Local industrial activities contribute less than 20% to air quality in the airshed except for B(a)P which is higher
5. Local industry and non-road sources contribute about ~15% to SO_2 levels

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Conclusions - Continued

WHAT HAVE WE LEARNED FROM THE HAMILTON AIRSHED MODELLING SYSTEM?

6. $PM_{2.5}$ contribution (~75%) are from transboundary sources outside of Hamilton

7. PM_{10} is under-predicted in the industrial area due to unaccounted fugitive sources

8. Transportation sources have the highest contribution to NO_2 levels (~40%)

9. NO_2 levels are likely over-predicted due to transboundary sources outside of Hamilton

10. Source contribution varies seasonally with higher transboundary contribution in winter and more local source contribution in the summer (e.g. on-road emissions)

Thank you.

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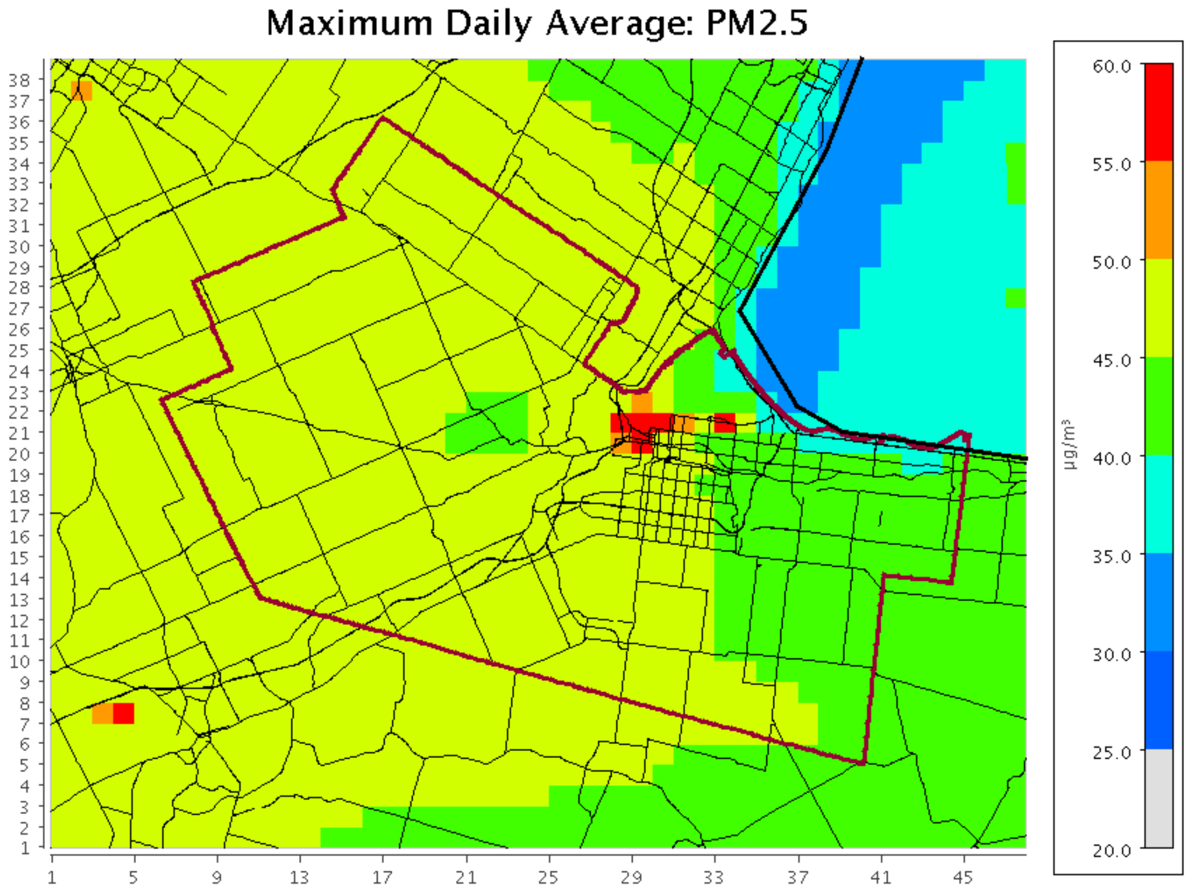
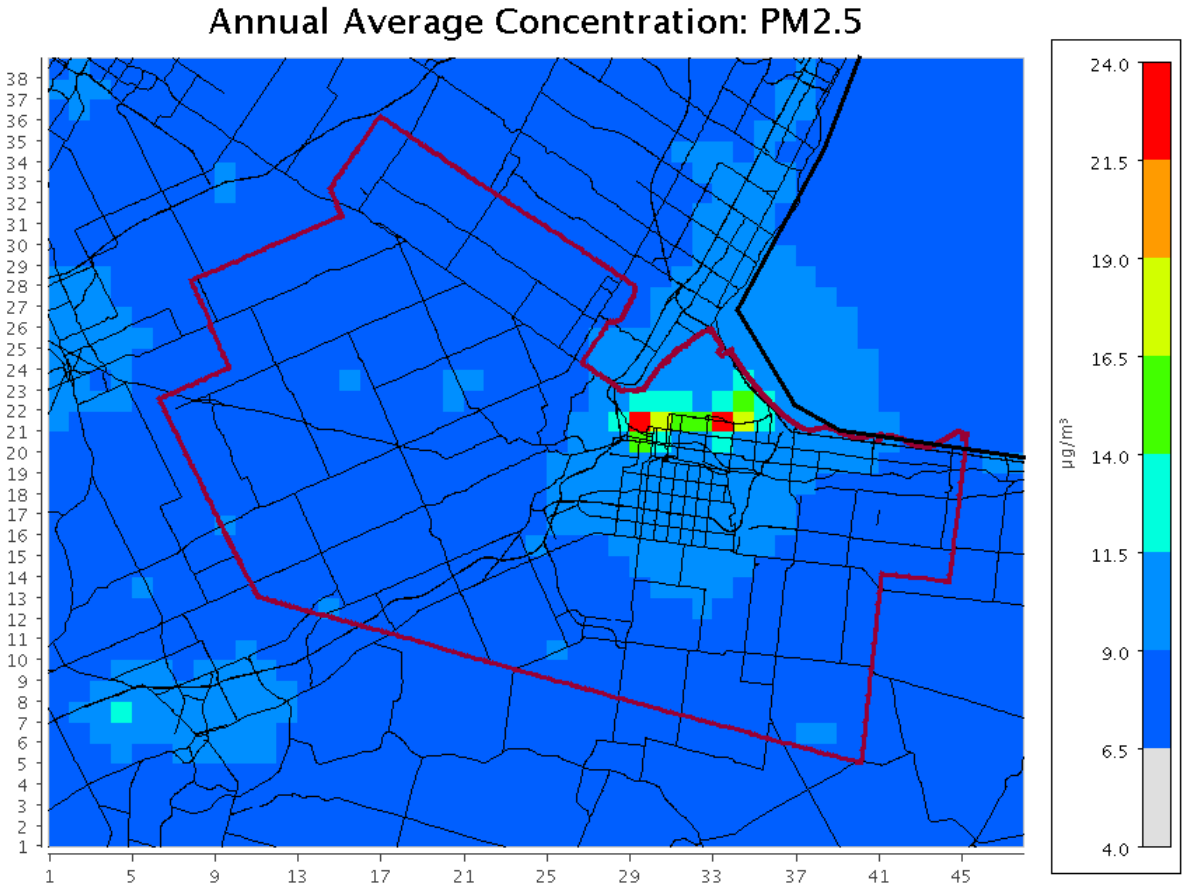
Janya_Kelly@Golder.com

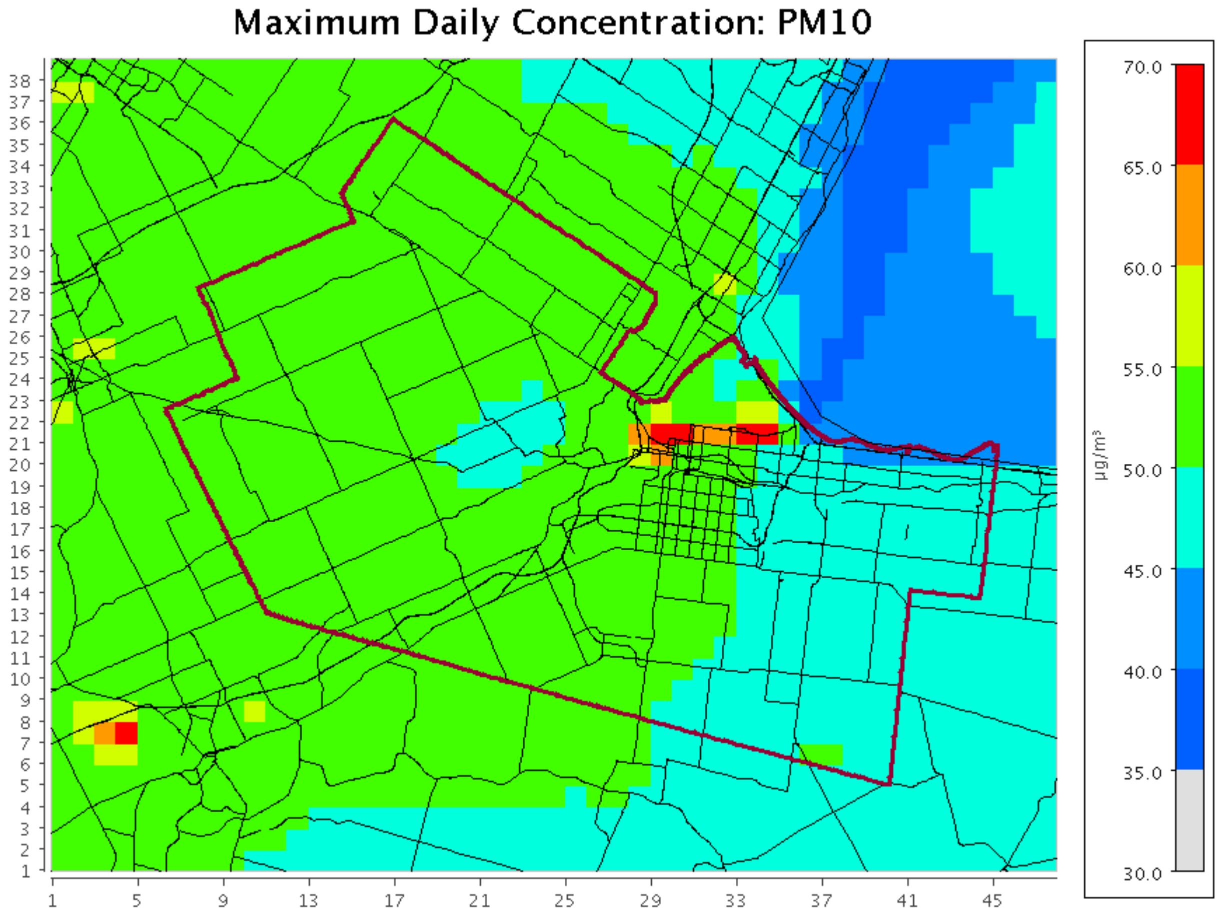
Additional Information: Maximum Daily and Annual Average Domain Plots

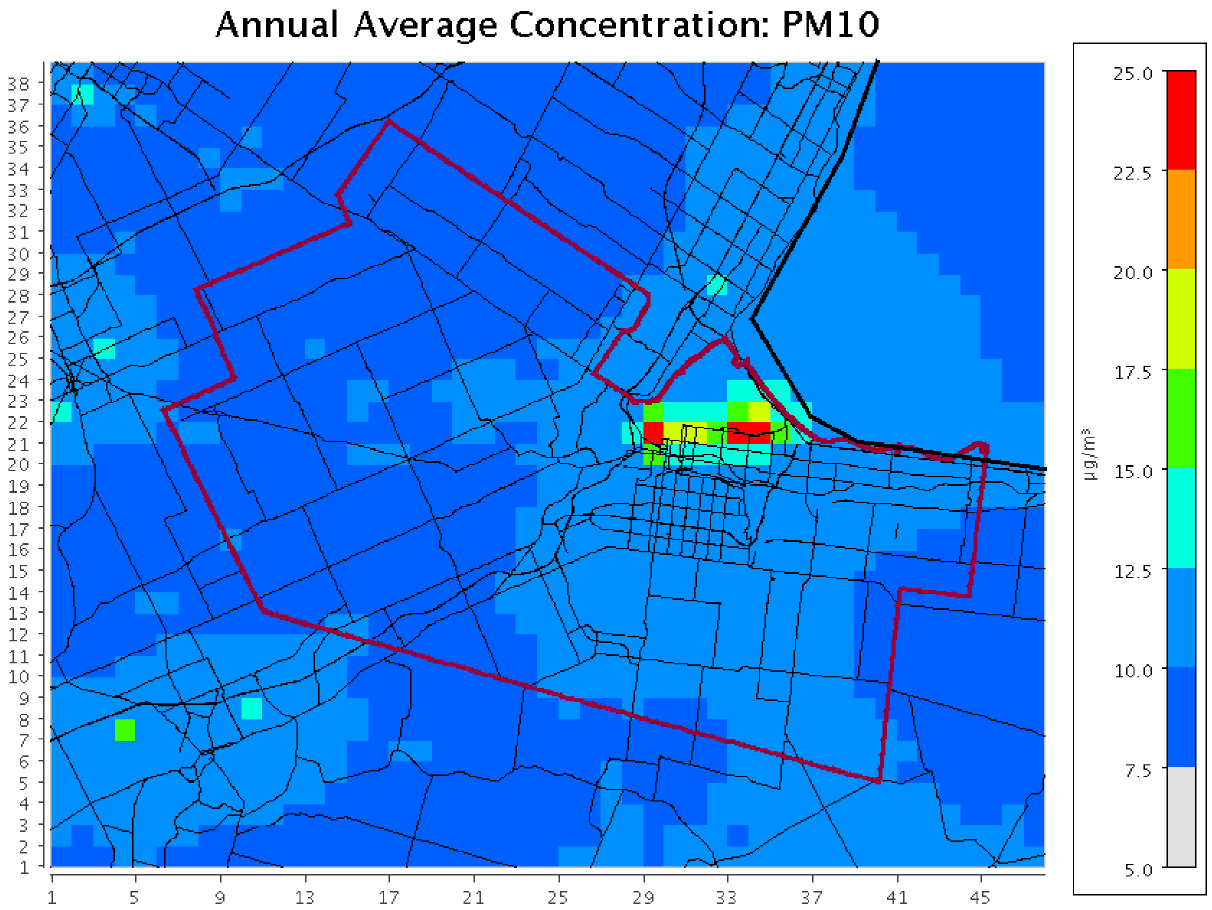
Air Quality Modelling Results: $PM_{2.5}$





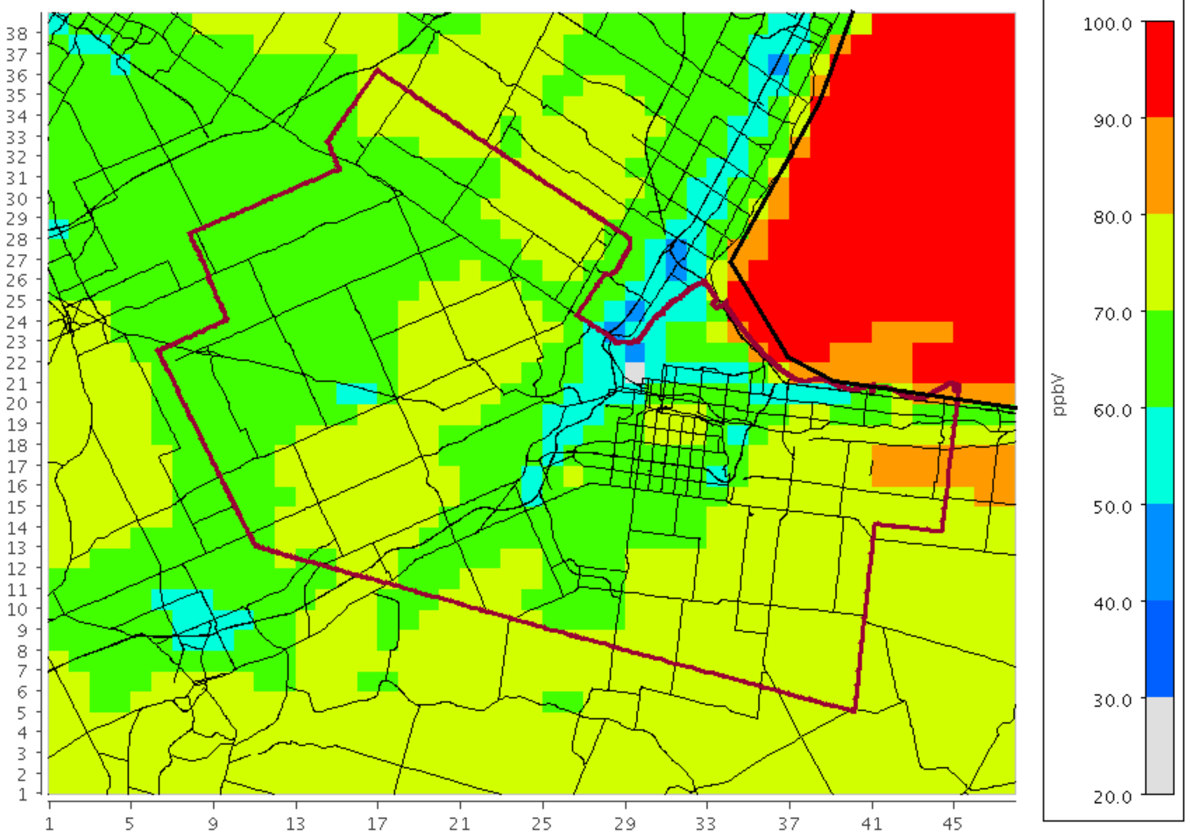
Air Quality Modelling Results: PM_{10}



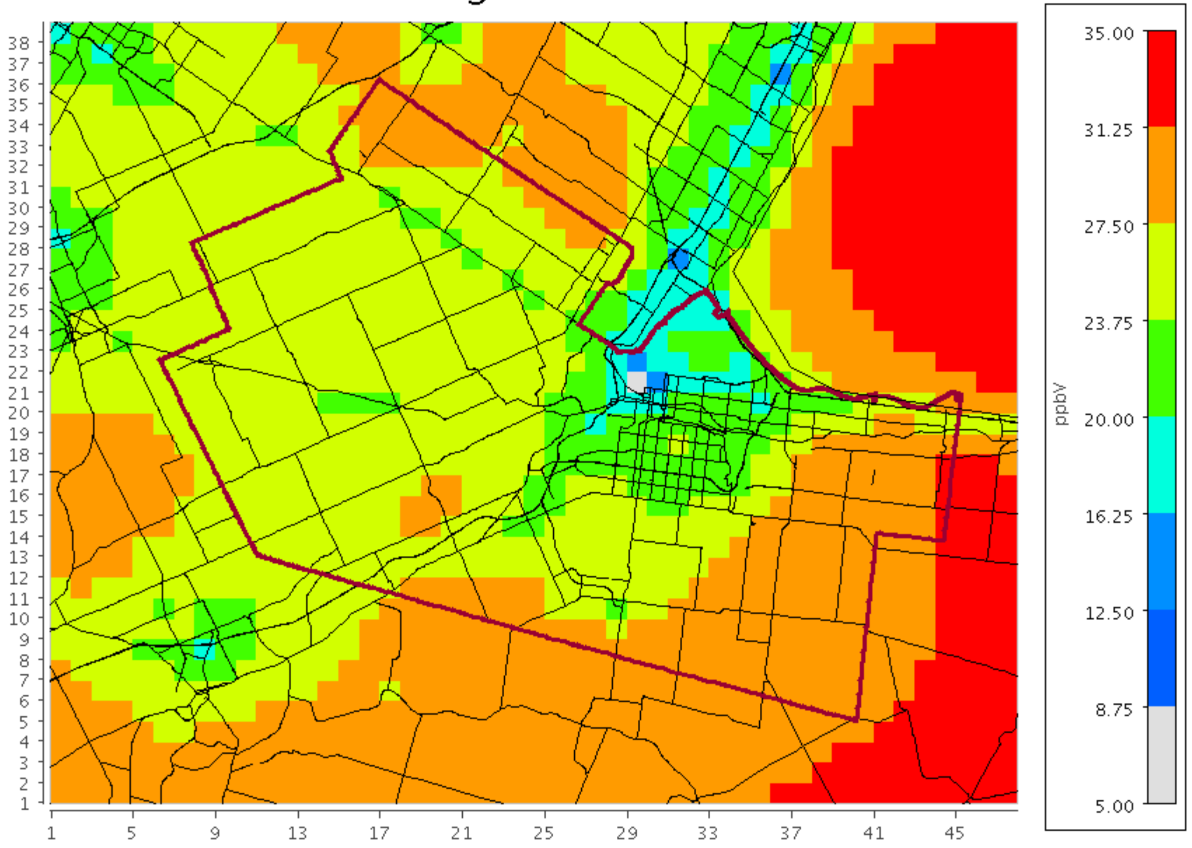


Air Quality Modelling Results: O_3

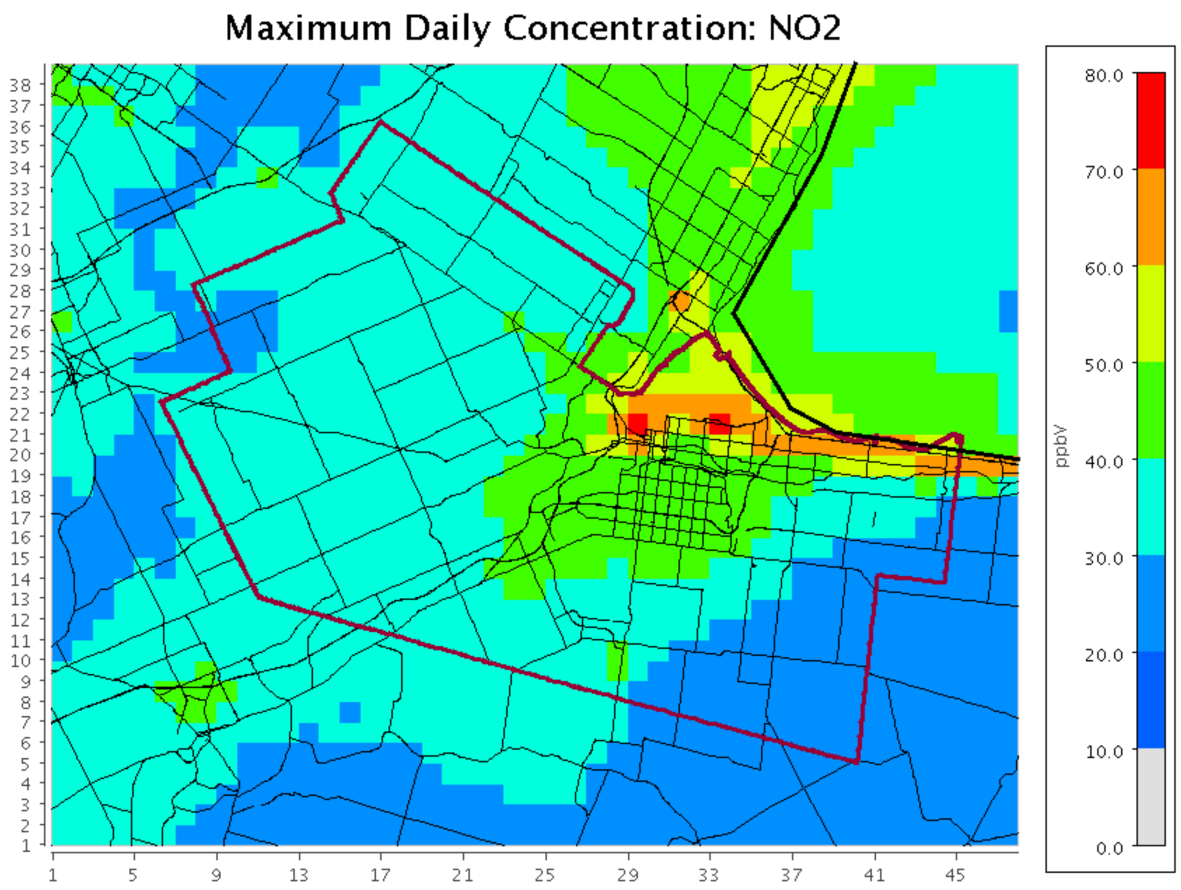
Maximum Daily Concentration: O3

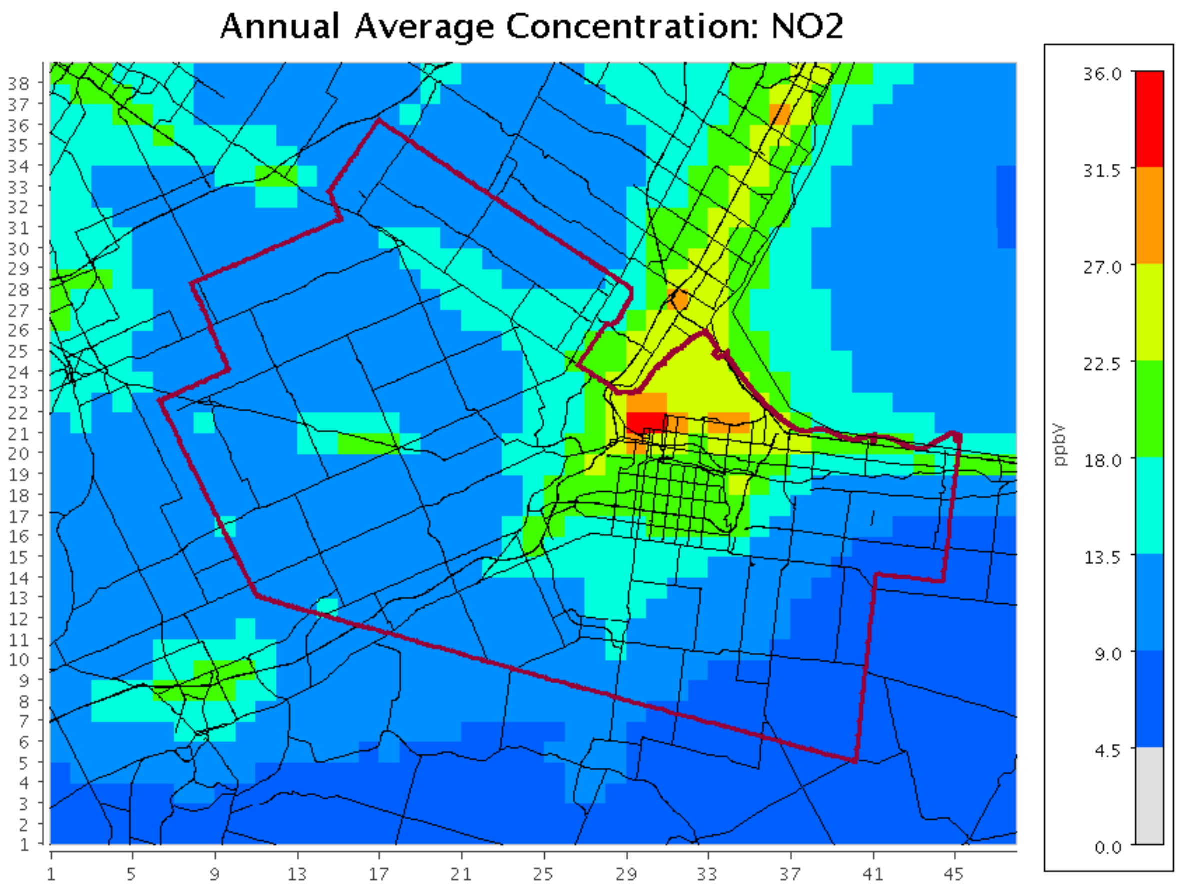


Annual Average Concentration: O3



Air Quality Modelling Results: NO_2





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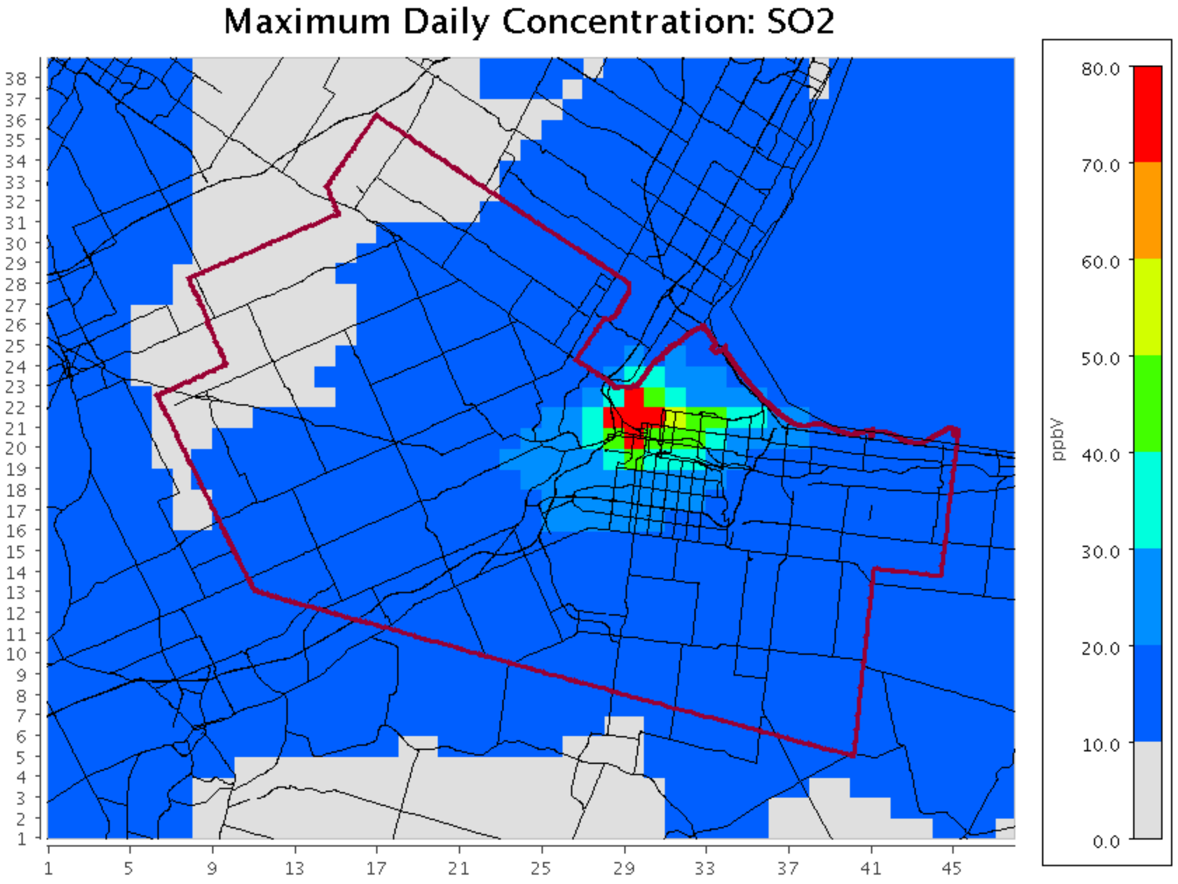
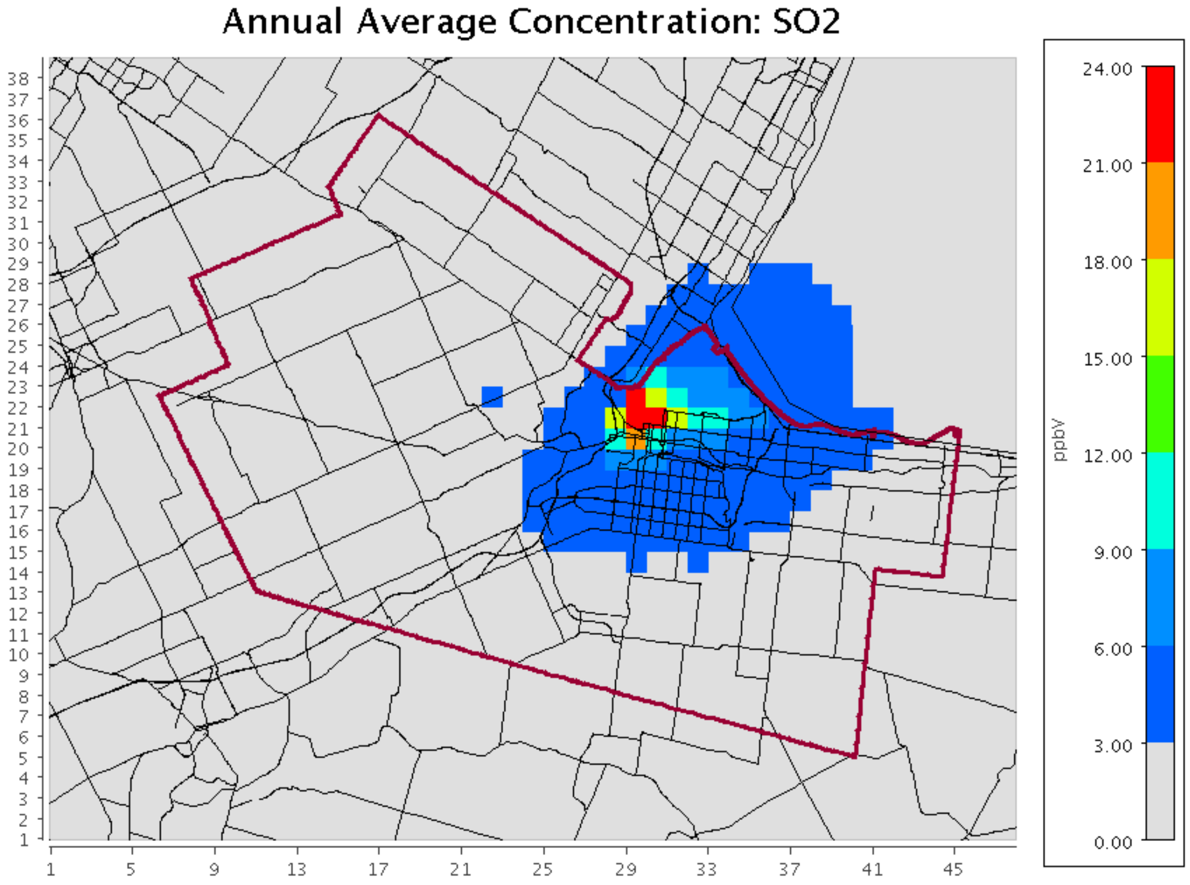
Air Quality Modelling Results: SO_2





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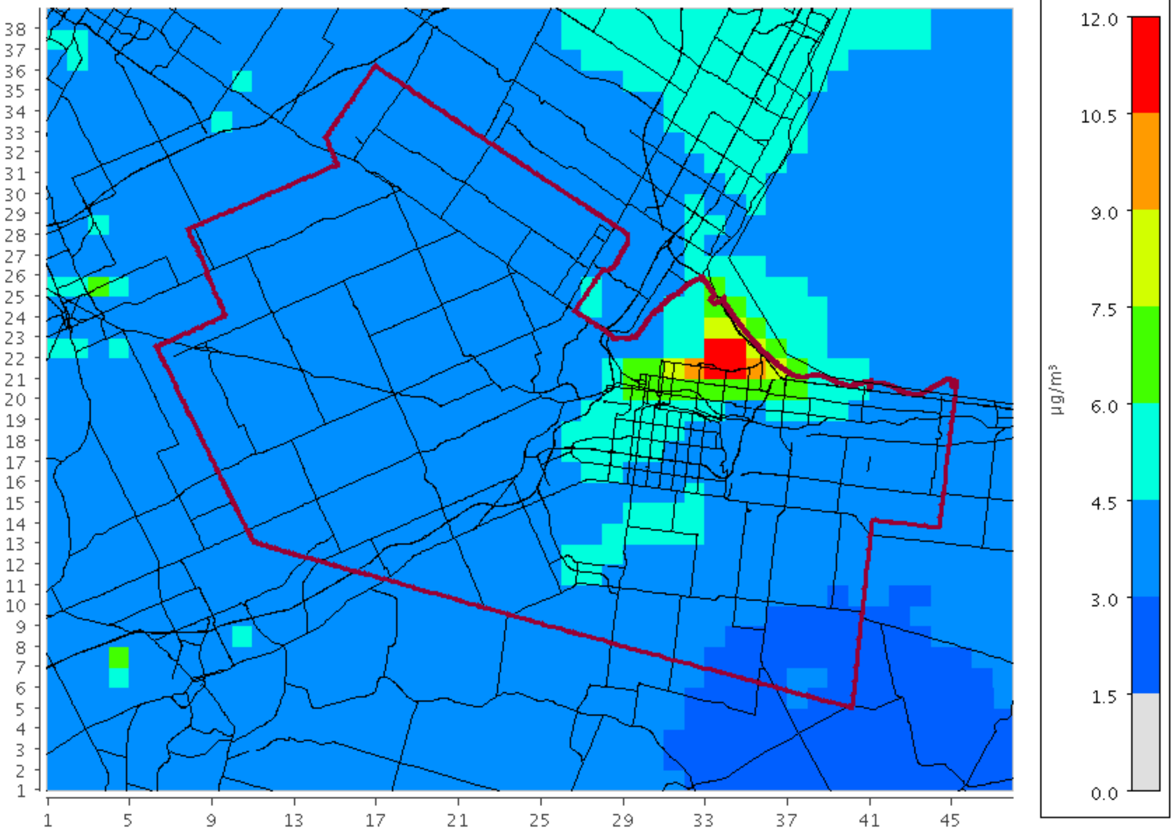
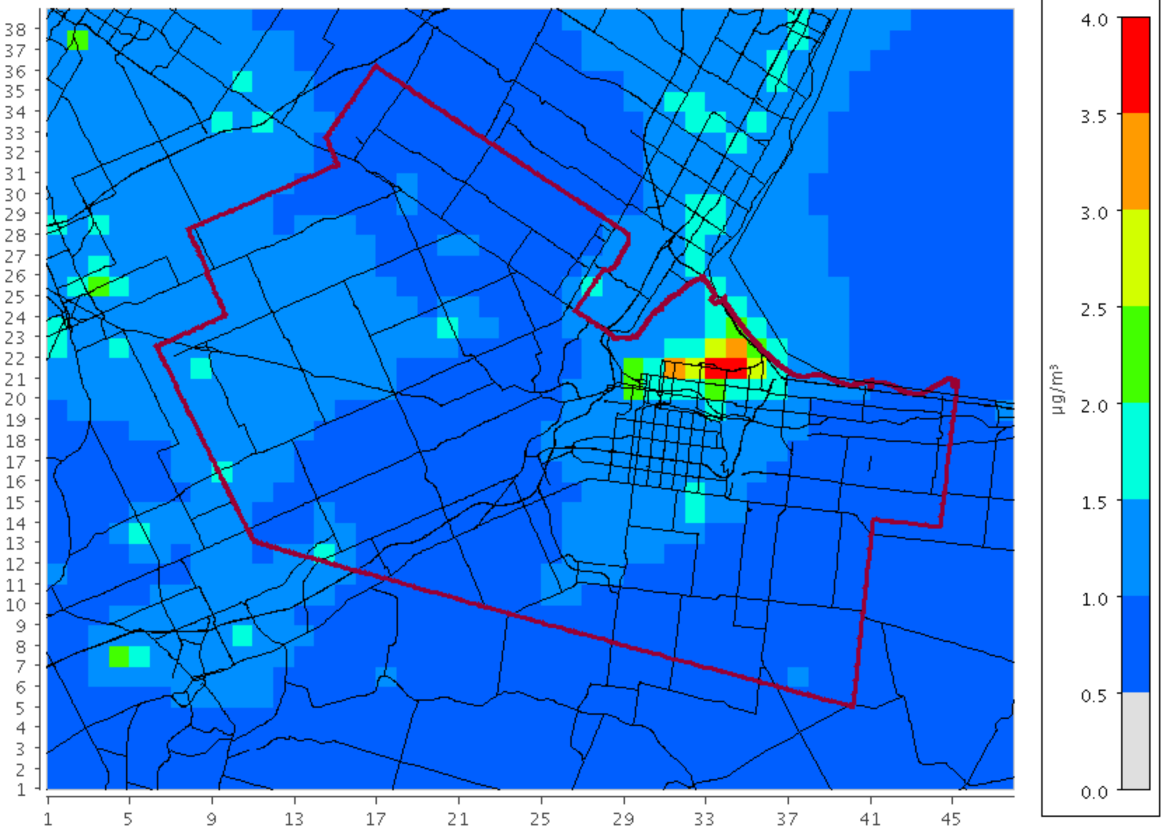
Air Quality Modelling Results: Benzene

Maximum Daily Concentration: Benzene

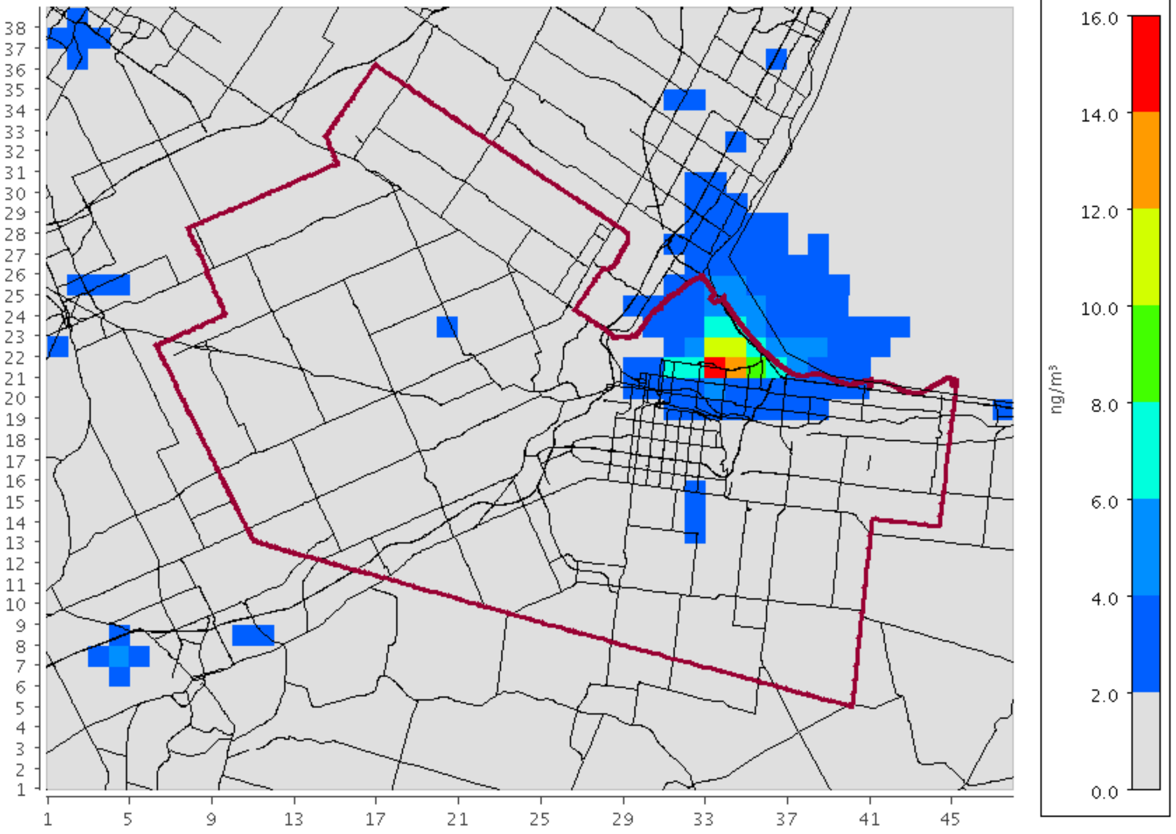


Annual Average Concentration: Benzene

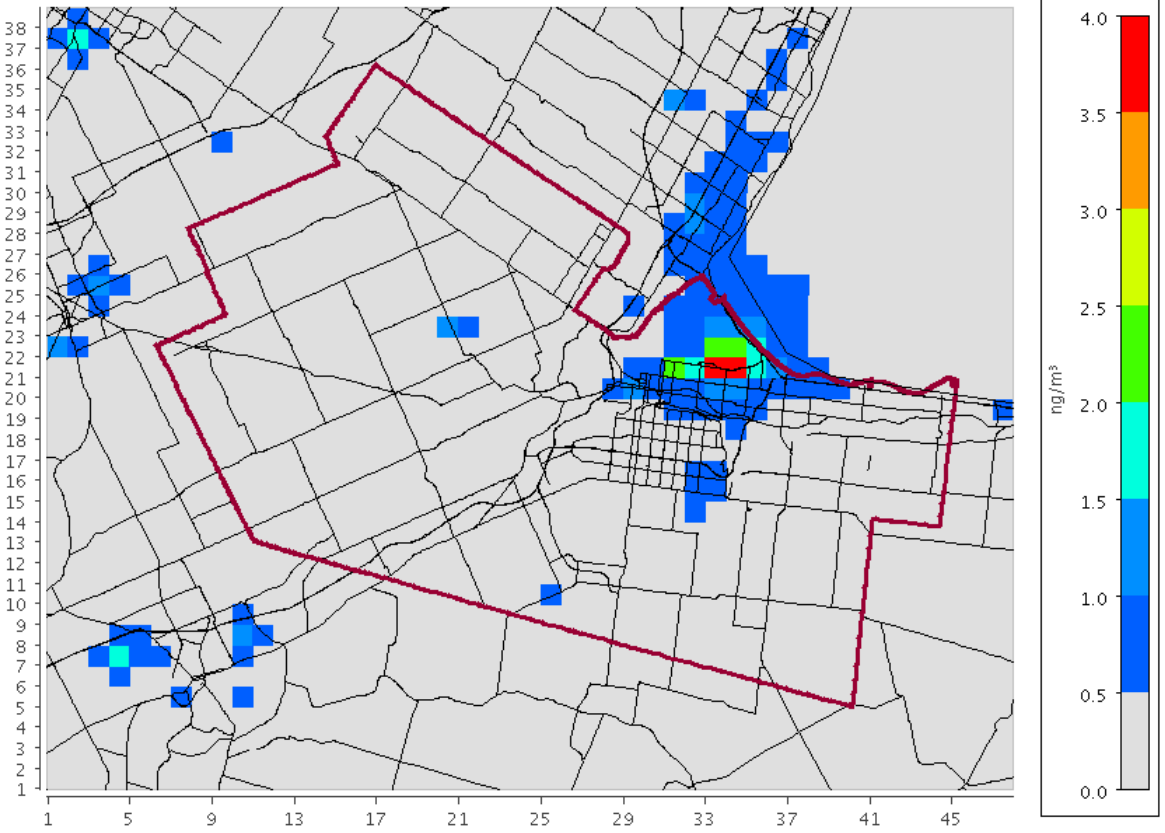


Air Quality Modelling Results: B(a)P

Maximum Daily Concentration: B(a)P



Annual Average Concentration: B(a)P



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Results Across Domain: Tier IV

Compounds	Symbol	Units	Annual Average	Maximum Daily
Acrolein	C_3H_4O	ppb	0.0069	0.64
Ammonia	NH_3	ppb	0.12	2.60
Benzene	C_6H_6	$\mu g/m^3$	1.00	18.00
1,3 Butadiene	C_4H_6	ppb	0.0088	0.57
Carbon Monoxide	CO	ppb	220	1100
Formaldehyde	CH_2O	ppb	1.40	16
Nitrogen Dioxide	NO_2	ppb	12	110
Particulate Matter less than 10 μm in diameter	PM_{10}	$\mu g/m^3$	10	100
Particulate Matter less than 2.5 μm in diameter	$PM_{2.5}$	$\mu g/m^3$	8.80	91
Sulphur Dioxide	SO_2	ppb	2.40	200
Volatile Organic Carbons (Anthropogenic/Biogenic)	VOCs	ppbC	130	1500
Ozone	O_3	ppb	27	100
Benzo (a) pyrene	B(a)P	ng/m3	0.27	17
Lead	Pb	$\mu g/m^3$	0.0024	0.10
Cadmium	Cd	$\mu g/m^3$	0.0031	0.10
Chromium (III)	Cr(III)	$\mu g/m^3$	0.00015	0.016
Chromium (VI)	Cr(VI)	$\mu g/m^3$	0.000039	0.0082
Nickel	Ni	$\mu g/m^3$	0.00028	0.012
Mercury	Hg	ppb	0.00026	0.0063
Manganese	Mn	$\mu g/m^3$	0.00093	0.080

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Hamilton Airshed Modelling System (HAMS)

Recommendations

1. That staff work with Golder Associates to undertake sub-region analyses using the Hamilton Airshed Modelling System, and in consultation with key stakeholders and affected residents;

2. That staff examine the feasibility of using HAMS to estimate morbidity and mortality outcomes associated with air pollution and report back to Board of Health, if necessary;

3. That the Board of Health direct Public Health Services' staff to work with City of Hamilton Planning staff to review the HAMS analysis and determine appropriate applications for planning directions and decisions and report back to Planning Committee in Q1 2019;

Hamilton Airshed Modelling System (HAMS)

Recommendations

4. That the Board of Health request the Ministry of Environment and Climate Change (MOECC) work with the City of Hamilton, other Ontario municipalities and levels of government regarding traffic-related air pollutants (TRAPs) to address transboundary transportation contributions impacting the City of Hamilton;

5. That the Board of Health advocate that the province of Ontario adopt the 24-hour Canadian Ambient Air Quality Standard for fine particulate matter (PM 2.5) of 28 micrograms per cubic metre of air (28 µg/m3) as air quality benchmarks for the maximum desirable concentration of particulate matter in the City of Hamilton; and

6. Support the Ministry of the Environment and Climate Change (MOECC) in their proposal for a new policy focusing on Cumulative Effects Assessment (CEA) in air approvals: "to more effectively consider cumulative impacts from multiple air pollution sources - both industrial and non-industrial" to address air quality issues in the City of Hamilton.