HAMILTON AIRSHED MODELLING SYSTEM (HAMS)

April 16, 2018
Hamilton Board of Health
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

- 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

Chemistry
- \( \text{NO}_2 + h\nu (+ \text{O}_2) \rightarrow \text{O}_3 \)
- \( \text{O}_3 + \text{NO} \rightarrow \text{NO}_2 + \text{O}_2 \)
- \( \text{HO} + \text{NO}_2 \rightarrow \text{HNO}_3 \)

Emissions
- \( \text{NO}_x \)

Meteorology
- Ozone
- Aerosols

Cloud Processes

Deposition

Environment
Hamilton Airshed Modelling System

Boundary Conditions (GEOS-CHEM)

Initial Conditions (GEOS-CHEM)

Meteorological Modelling (WRF)

Emissions Modelling (SMOKE, MEGAN, MOVES)

Chemical Transport Model (CMAQ)

Concentration of Compounds
<table>
<thead>
<tr>
<th>Tier</th>
<th>Area (km²)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tier I (36 km)</td>
<td>1,390,608</td>
<td>100%</td>
</tr>
<tr>
<td>Tier II (12 km)</td>
<td>243,648</td>
<td>17.5%</td>
</tr>
<tr>
<td>Tier III (4 km)</td>
<td>46,020</td>
<td>3.3%</td>
</tr>
<tr>
<td>Tier IV (1.33 km)</td>
<td>3,159</td>
<td>0.2%</td>
</tr>
</tbody>
</table>
### Compounds of Interest

<table>
<thead>
<tr>
<th>Studied Compounds*</th>
<th>Presented Compounds*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acrolein</td>
<td>PM$_{2.5}$</td>
</tr>
<tr>
<td>Ammonia</td>
<td>PM$_{10}$</td>
</tr>
<tr>
<td>Benzene</td>
<td>Nitrogen Oxides</td>
</tr>
<tr>
<td>Butadiene 1,3</td>
<td>Sulphur Dioxide</td>
</tr>
<tr>
<td>Carbon Monoxide</td>
<td>Ozone</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>Benzene</td>
</tr>
<tr>
<td>Nitrogen Oxides (NO$_2$ and NO)</td>
<td>Benzo(a)pyrene</td>
</tr>
<tr>
<td>Sulphur Dioxide</td>
<td></td>
</tr>
<tr>
<td>PM$_{10}$</td>
<td></td>
</tr>
<tr>
<td>PM$_{2.5}$</td>
<td></td>
</tr>
</tbody>
</table>

*Selected by the Stakeholder Advisory Committee

*Please note additional species, including precursors, are available but were not studied
WRF – Meteorological Modelling Results

Source: https://en.wikipedia.org/wiki/File:HamiltonOntarioSkylineC.JPG, licensed under https://creativecommons.org/licenses/by-sa/3.0/
Tier IV Temperature: Winter and Spring
Tier IV Temperature: Summer and Fall

Observed and Predicted Temperature

ObsTemp  PredTemp

Temperature (K)

Date (Month/Day)

Observed and Predicted Temperature

ObsTemp  PredTemp

Temperature (K)

Date (Month/Day)
Tier IV Wind Rose Comparison

Tier 4 Observations (Jan 1, 2012 – Dec 31, 2012)

- 12% N
- 10% NNE
- 8% NE
- 6% ENE
- 4% E
- 2% ESE
- 0% SE
- 0% SSE
- 0% S
- 0% SSW
- 0% SW
- 0% WSW
- 0% W
- 0% WNW
- 12% NNW

Tier 4 Predictions (Jan 1, 2012 – Dec 31, 2012)

- 12% N
- 10% NNE
- 8% NE
- 6% ENE
- 4% E
- 2% ESE
- 0% SE
- 0% SSE
- 0% S
- 0% SSW
- 0% SW
- 0% WSW
- 0% W
- 0% WNW
- 12% NNW

calms (i.e., <0.2 m/s) = 0.0%
model calms (i.e., <1 m/s) = 1.5%
Emissions Inventory Results

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

**GRIDDED, HOURLY EMISSION ESTIMATES BY TIER**

<table>
<thead>
<tr>
<th>Emission Classification</th>
<th>Type</th>
<th>Definition</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industrial</td>
<td>Point (all tiers)</td>
<td>Elevated stacks from industrial activities</td>
<td>2012 NPRI, 2011 US NEI</td>
</tr>
<tr>
<td></td>
<td>Area</td>
<td>Industrial activities</td>
<td>2012 NPRI, 2011 US NEI</td>
</tr>
<tr>
<td></td>
<td>Area</td>
<td>Natural gas usage, auto-body shops, dry cleaners, commercial solvents</td>
<td>2012, ChemTRAC (scaled by population), 2012 Stats Can population data, 2011 US NEI</td>
</tr>
<tr>
<td>Residential</td>
<td>Area</td>
<td>Natural gas usage, other residential heating sources</td>
<td>2006 Canadian National Emissions Inventory (NEI), 2011 US NEI</td>
</tr>
<tr>
<td>On-Road</td>
<td>Area</td>
<td>On-road vehicles (trucks, cars, motorcycles)</td>
<td>2012 MOVES, 2012 MTO traffic data, 2011 US NEI</td>
</tr>
<tr>
<td></td>
<td>Area</td>
<td>Airport, marine, rail and lawn mowers,</td>
<td>2006 Canadian NEI, 2012 NRCAN data, 2011 US NEI</td>
</tr>
<tr>
<td>Biogenic / Agricultural</td>
<td>Area</td>
<td>Natural, farmland etc activities</td>
<td>2012 MEGAN, 2006 Canadian NEI, 2011 US NEI</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2012 MEGAN, 2012 NONROAD</td>
</tr>
</tbody>
</table>
Total Emissions per Tier over the Computational Domain

<table>
<thead>
<tr>
<th>Tier</th>
<th>%</th>
<th>Tonne/km²/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tier I (36 km)</td>
<td>87.2%</td>
<td>21.91</td>
</tr>
<tr>
<td>Tier II (12 km)</td>
<td>8.7%</td>
<td>12.43</td>
</tr>
<tr>
<td>Tier III (4 km)</td>
<td>3.7%</td>
<td>27.87</td>
</tr>
<tr>
<td>Tier IV (1.33 km)</td>
<td>0.5%</td>
<td>53.02</td>
</tr>
</tbody>
</table>
Hamilton & Transboundary Sector Profiles

**Hamilton Emissions**
- Industrial: 34.2%
- Commercial: 21.4%
- Residential: 4.5%
- Agriculture: 2.9%
- On-Road: 0.5%
- Non-Road: 0.5%

**Transboundary Emissions**
- Industrial: 28%
- Commercial: 18%
- Residential: 6%
- Agriculture: 4%
- On-Road: 1%
- Non-Road: 4%
Hamilton & Transboundary Emissions Profiles

**HAMILTON EMISSIONS (%)**

<table>
<thead>
<tr>
<th></th>
<th>NOx</th>
<th>SO2</th>
<th>PM2.5</th>
<th>PM10</th>
<th>Benzene</th>
<th>B(e)P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industrial</td>
<td>16.6%</td>
<td>88.0%</td>
<td>57.0%</td>
<td>61.0%</td>
<td>42.0%</td>
<td>65.7%</td>
</tr>
<tr>
<td>Commercial</td>
<td>1.2%</td>
<td>0.02%</td>
<td>2.7%</td>
<td>1.8%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Residential</td>
<td>1.5%</td>
<td>0.02%</td>
<td>2.9%</td>
<td>2.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Agriculture</td>
<td>0.2%</td>
<td>0.3%</td>
<td>0.0%</td>
<td>0.3%</td>
<td>0.4%</td>
<td>0.2%</td>
</tr>
<tr>
<td>On-Road</td>
<td>66.4%</td>
<td>0.4%</td>
<td>14.7%</td>
<td>17.0%</td>
<td>19.4%</td>
<td>33.8%</td>
</tr>
<tr>
<td>Non-Road</td>
<td>8.2%</td>
<td>11.3%</td>
<td>22.7%</td>
<td>17.0%</td>
<td>97.7%</td>
<td>0.3%</td>
</tr>
</tbody>
</table>

**TRANSBOUNDARY EMISSIONS (%)**

<table>
<thead>
<tr>
<th></th>
<th>NOx</th>
<th>SO2</th>
<th>PM2.5</th>
<th>PM10</th>
<th>Benzene</th>
<th>B(e)P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industrial</td>
<td>31.3%</td>
<td>97.3%</td>
<td>6.4%</td>
<td>4.8%</td>
<td>12.2%</td>
<td>2.7%</td>
</tr>
<tr>
<td>Commercial</td>
<td>1.7%</td>
<td>1.0%</td>
<td>1.1%</td>
<td>0.5%</td>
<td>5.7%</td>
<td>6.0%</td>
</tr>
<tr>
<td>Residential</td>
<td>2.3%</td>
<td>0.7%</td>
<td>16.8%</td>
<td>5.6%</td>
<td>17.5%</td>
<td>4.4%</td>
</tr>
<tr>
<td>Agriculture</td>
<td>1.4%</td>
<td>0.0%</td>
<td>0.1%</td>
<td>0.1%</td>
<td>0.1%</td>
<td>0.5%</td>
</tr>
<tr>
<td>On-Road</td>
<td>59.1%</td>
<td>0.2%</td>
<td>33.1%</td>
<td>10.9%</td>
<td>58.7%</td>
<td>91.9%</td>
</tr>
<tr>
<td>Non-Road</td>
<td>3.7%</td>
<td>0.8%</td>
<td>42.5%</td>
<td>78.2%</td>
<td>5.9%</td>
<td>0.5%</td>
</tr>
</tbody>
</table>
Tier IV: Geographical Distribution NO$_x$ Emissions

All Emissions: NOx
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$_{10}$
Q:Q Plots: NO₂ and SO₂

Tier IV Stations 24-hr NO₂

Tier IV Hamilton 24-hr SO₂
Time Series: NO\textsubscript{2} and SO\textsubscript{2}
Q:Q and Time Series Plot: O₃

Hamilton Tier IV 24-hr O₃

Daily Average O₃

Modelled

Observed (ppb)

Concentration (ppb)
Q-Q Plots: Benzene and B(a)P

Tier IV Hamilton 24-hr Benzene

Tier IV Hamilton 24-hr B(a)P
Time Series: Benzene and B(a)P
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$_{10}$

**Annual Average Concentration: PM10**

**Domain Averaged Source Contribution: PM10**
Air Quality Modelling Results: O₃
Air Quality Modelling Results: NO₂

Annual Average Concentration: NO₂

Domain Averaged Source Contribution: NO₂
Air Quality Modelling Results: $\text{SO}_2$

**Annual Average Concentration: SO2**

**Domain Averaged Source Contribution: SO2**
- Industrial
- On-Road
- Non-Road
- Transboundary
- Other

Legend:
- Industrial
- On-Road
- Non-Road
- Transboundary
- Other

Annual Averages:
- April
- July
- October
- December
- Annual

Map and chart showing annual average concentrations and domain averaged source contributions for $\text{SO}_2$. The map highlights areas with varying concentrations, and the chart provides a breakdown of contributions by source category for different months and the annual average.
Air Quality Modelling Results: Benzene

Annual Average Concentration: Benzene

Domain Averaged Source Contribution: Benzene
Air Quality Modelling Results: B(a)P
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 SO₂ levels
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.

Anthony_Ciccone@Golder.com
Janya_Kelly@Golder.com
Additional Information:
Maximum Daily and Annual Average Domain Plots

Source: https://en.wikipedia.org/wiki/File:HamiltonOntarioSkylineC.JPG, licensed under https://creativecommons.org/licenses/by-sa/3.0/
Air Quality Modelling Results: PM$_{2.5}$

Maximum Daily Average: PM2.5

Annual Average Concentration: PM2.5
Air Quality Modelling Results: PM$_{10}$
Air Quality Modelling Results: $O_3$
Air Quality Modelling Results: NO₂

Maximum Daily Concentration: NO₂

Annual Average Concentration: NO₂
Air Quality Modelling Results: \( \text{SO}_2 \)
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
## Results Across Domain: Tier IV

<table>
<thead>
<tr>
<th>Compounds</th>
<th>Symbol</th>
<th>Units</th>
<th>Annual Average</th>
<th>Maximum Daily</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acrolein</td>
<td>C₃H₄O</td>
<td>ppb</td>
<td>0.0069</td>
<td>0.64</td>
</tr>
<tr>
<td>Ammonia</td>
<td>NH₃</td>
<td>ppb</td>
<td>0.12</td>
<td>2.60</td>
</tr>
<tr>
<td>Benzene</td>
<td>C₆H₆</td>
<td>µg/m³</td>
<td>1.00</td>
<td>18.00</td>
</tr>
<tr>
<td>1,3 Butadiene</td>
<td>C₄H₆</td>
<td>ppb</td>
<td>0.0088</td>
<td>0.57</td>
</tr>
<tr>
<td>Carbon Monoxide</td>
<td>CO</td>
<td>ppb</td>
<td>220</td>
<td>1100</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>CH₂O</td>
<td>ppb</td>
<td>1.40</td>
<td>16</td>
</tr>
<tr>
<td>Nitrogen Dioxide</td>
<td>NO₂</td>
<td>ppb</td>
<td>12</td>
<td>110</td>
</tr>
<tr>
<td>Particulate Matter less than 10 µm in diameter</td>
<td>PM₁₀</td>
<td>µg/m³</td>
<td>10</td>
<td>100</td>
</tr>
<tr>
<td>Particulate Matter less than 2.5 µm in diameter</td>
<td>PM₂·₅</td>
<td>µg/m³</td>
<td>8.80</td>
<td>91</td>
</tr>
<tr>
<td>Sulphur Dioxide</td>
<td>SO₂</td>
<td>ppb</td>
<td>2.40</td>
<td>200</td>
</tr>
<tr>
<td>Volatile Organic Carbons (Anthropogenic/Biogenic)</td>
<td>VOCs</td>
<td>ppb</td>
<td>130</td>
<td>1500</td>
</tr>
<tr>
<td>Ozone</td>
<td>O₃</td>
<td>ppb</td>
<td>27</td>
<td>100</td>
</tr>
<tr>
<td>Benzo (a) pyrene</td>
<td>B(a)P</td>
<td>ng/m³</td>
<td>0.27</td>
<td>17</td>
</tr>
<tr>
<td>Lead</td>
<td>Pb</td>
<td>µg/m³</td>
<td>0.0024</td>
<td>0.10</td>
</tr>
<tr>
<td>Cadmium</td>
<td>Cd</td>
<td>µg/m³</td>
<td>0.0031</td>
<td>0.10</td>
</tr>
<tr>
<td>Chromium (III)</td>
<td>Cr(III)</td>
<td>µg/m³</td>
<td>0.00015</td>
<td>0.016</td>
</tr>
<tr>
<td>Chromium (VI)</td>
<td>Cr(VI)</td>
<td>µg/m³</td>
<td>0.000039</td>
<td>0.0082</td>
</tr>
<tr>
<td>Nickel</td>
<td>Ni</td>
<td>µg/m³</td>
<td>0.00028</td>
<td>0.012</td>
</tr>
<tr>
<td>Mercury</td>
<td>Hg</td>
<td>ppb</td>
<td>0.00026</td>
<td>0.0063</td>
</tr>
<tr>
<td>Manganese</td>
<td>Mn</td>
<td>µg/m³</td>
<td>0.00093</td>
<td>0.080</td>
</tr>
</tbody>
</table>
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;
**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.