PECULIARITIES OF OZONE AND PM2.5 CONCENTRATIONS OVER ONTARIO IN THE SUMMER OF 2010

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1. INTRODUCTION

There were a number of time periods with mostly clear skies and temperatures above 30ºC during the 2010 ozone season (May to September) however there were not many days where the Ontario Ministry of the Environment's Air Quality Index (AQI) reached poor levels due to ozone concentrations as compared to 2005 when there were many more cases when the AQI reached poor levels.

Since meteorological conditions in both 2005 and 2010 appeared to be conducive to periods of high ozone concentrations, an assessment of ozone based on regional air quality modelling with CMAQv4.6 and analysis of observed ozone concentrations was performed. The purpose of this study was to assess the relative impacts of emissions and meteorological conditions on ozone formation in 2010. To separate these two factors, the assessment was performed in several stages.

In the first scenario, emissions were kept exactly the same as for the 2005 base case except for biogenic emissions which were recalculated using 2010 meteorological input data. Plume rise for major point sources was also recalculated to reflect the 2010 meteorological conditions. This scenario assesses only the meteorological differences between the 2005 and 2010 ozone concentrations.

In the second scenario emissions from major point sources were updated to 2010 or 2009 values (depending on the availability of the data- NPRI data from 2009 for Canada and 2010 EGU sources from the US).
Modelled CMAQ results showed the combined effect of changed emissions and meteorological conditions on ozone concentrations and were compared with the monitoring data. Emissions from on road mobile sources were recalculated to represent meteorological conditions and fleet distribution in 2010.

2. COMPONENTS OF THE OZONE/PM2.5 MODELLING SYSTEM

Meteorological conditions were simulated using the Weather Research Forecast (WRF) regional model for each hour of the ozone season in 2010. Modelling domain has a 36 km horizontal resolution with 136 x 97 grid cells. The model has 22 vertical levels extending to 100 mb. Physical and numerical parameters were set mostly to default values.

For grid cells representing Toronto and Montreal modifications were made to a number of turbulence parameters to simulate additional impact on vertical mixing due to the urban heat island effect. This was done as a post processing step and it resulted in increased overnight vertical mixing which was underestimated in the regular WRF modelling. Results from the simulations verified against synoptic analysis data showed overall good agreement.

Biogenic emissions for Canada and the US were calculated using the Biogenic Emission Inventory System (BIES) model.
The 2005 anthropogenic emissions for the US were taken from data published on an EPA website.

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Mobile emissions were derived using input data from this website in the MOBILE6.2 model. The 2010 emissions had updated data for EGUs based on published Clean Air Markets data and mobile emissions were updated to 2010.

Inventory files for 2005 in Canada were obtained from Environment Canada. The area and transportation emissions were then spatially allocated to the Census Division level based on a 2002 emission distribution. Mobile emissions were calculated with the Mobile6.2C model. For 2010 mobile emissions were recalculated and about 35-50 top point sources for each precursor pollutant were updated with 2009 data from NPRI.

For the EGUs in the US states closest to Ontario, NOx emissions were lower by about 40 to 60% in 2010 compared to 2005. In Ontario NOx emissions were about 35% lower for major point sources in 2009 while VOC emissions dropped by about 30%. For both the US and Canada, mobile emissions of NOx decreased by 35 to 40% with VOC reductions of 30 to 35% by 2010. SO2 emissions from EGUs in nearby US states were lower by about 40 to 60% in 2010. Reductions in SO2 emissions from major point sources in Ontario averaged about 50%.

The chemical transport model used was the US EPA Community Multi-scale Air Quality (CMAQ) model. The chemical mechanism used was SAPRC99 along with default physical settings. Boundary and initial conditions used the default profiles for all compounds.

The post processing for ozone started by calculating 8 hour maximum concentrations for each day and each grid cell. Days with high concentrations (ozone > 70 ppb) were selected and averaged for each grid cell. The grid cell data were then integrated for the 16 sub-domains (fig. 1). In addition, a time series for sub-domains located in Ontario was produced for comparison with observed results.

3. MODELLING RESULTS

Table 1 gives the median number of high ozone concentration days and averaged 8-hour max O3 concentrations across each sub domain. Compared to 2005, the meteorological conditions in 2010 resulted in fewer modelled high concentration days (i.e., with anthropogenic emissions kept constant). The summer of 2010 did have time periods that were conducive to high ozone but not to the extent as in 2005. When 2010 emissions changes were taken into account, modelled results showed significant drops in the number of high concentration days in all sub domains. In the Greater Toronto Area (GTA, # 5), the changes were not as large as in the other locations. One of the largest changes occurred in domain # 2; the Chatham/London area. One reason for the differences in the response to emission reductions in these two domains is that reductions in low level mobile NOx emissions (which can increase ozone concentrations locally due to less ozone titration) is a much more significant factor in the GTA.

Changing meteorological conditions from the summer of 2005 to the summer of 2010 resulted in mean higher ozone concentrations in some sub domains, while other domains were lower and some were nearly the same. Emission reductions from 2005 to 2010 levels with meteorological conditions staying the same ended up with decreases of mean concentrations by about 1 – 3 ppb in all of the sub domains. The decreases in mean values with lower emission rates went along with decreases in the number of high concentration days.

Time series of ozone concentrations for all sub domains (especially in domains # 2, 7 and 8) showed good to very good correlations between modelled and observed data for most episodes. This indicates that the 2010 model input meteorological data is reasonably good. Modelled concentrations are biased higher for some sub domains, such as the GTA, especially during ozone episodes (early July for example). That can in part be explained by titration of ozone due to NOx emitted near ground level. The observed data is usually collected at heights about 3 m above ground, while the modelled ozone concentrations are averaged over the whole grid cell with a thickness of about 20 m resulting in higher average concentrations.

Higher modelled and observed concentrations only occurred when meteorological conditions were consistent with regional ozone formation. Modelling results show sensitivity to emission reductions mainly on high concentration days. There were noticeable reductions in ozone concentrations between the emission scenarios during high concentration days in most sub domains.

In highly urbanized areas (GTA), ozone concentrations were not as significantly affected by emission reductions from 2005 to 2010 levels as in rural areas. Even on high concentration days differences were less then 4 -5 ppb. That can be explained by the fact that less regional ozone production due to reductions of elevated emitted ozone precursor pollutants upwind of the GTA is compensated by less ozone titration by local low level NOx emissions because of the mobile emission changes from 2005 to 2010 levels.

Downwind from the GTA the correspondence between modelled and observed ozone is the best among all domains even for low ozone concentrations. The good agreement for lower ozone concentrations is in part due to the smaller size of these urban areas resulting in less NOx titration of ozone.

The Barrie and London/Chatham areas represent a mix of urban and rural environments with relatively lower titration rates due to NOx emissions. Consequently regional ozone formation which is affected by reductions in NOx emissions from stacks is more important in these sub domains. That can result in more significant differences in ozone concentrations between emission scenarios in these sub domains.

Frequency distributions for the 2010 emission scenario had a larger fraction of lower ozone concentrations compared with distributions for the 2005 scenario. The highest probability was in the range 40 – 50 ppb for the GTA and Peterborough and 50 – 60 ppb for Windsor/Sarnia. Reduction in emissions for 2010 leads to increases in occurrences by 4-6 % in these highest probability bins.

Concentrations at the high end of the distributions were less frequent when modelled with the reduced emissions for 2010. Typically emission reductions end up in shifting the probability of concentrations from higher values to lower concentrations.

Table 2 has the same structure as Table 1 except it is for high PM2.5 concentration days. The number of high concentration days for PM2.5 showed similar trends to those as for ozone however there were differences. Meteorological conditions in 2010 compared to 2005 resulted in fewer high concentrations in the majority of the sub domains (especially in Ontario) however there were either no changes or small increases in some of the sub domains. Overall 2010 meteorology was not as conducive to high PM2.5 as was found in the 2005 model run.

Comparing the columns where 2005 emissions were replaced with 2010 emissions with the same 2010 meteorology used, resulted in very significant decreases in the number of high concentration days for all sub domains. The reductions were more dramatic than those found for ozone. Percentage decreases in the number of high concentration days in sub domains #1 through 6 ranged from about 40% for the GTA to 75% or more for sub domains #1, 2 and 4.

A comparison with meteorology for 2005 and 2010 resulted in some sub domains with higher averages and some with lower values. The impacts of emission reductions were lower averages in all sub domains which is the same as was found for ozone. Emission reductions resulted in both a significant decrease in the number of high concentration days and lower averages for those days.

As was found for ozone, the modelling for PM2.5 concentrations showed good to very good correlations with observed concentrations in all 4 sub domains. There were however a couple of days where the model results were correlated with observed concentrations but underestimated peaks by 5 to 10 $\mu g/m^3$ (June 26-27th and August 10th).

When the predicted concentrations were low, the change in PM2.5 concentrations between the run with 2005 emissions and the 2010 emissions was small. Model results generally agreed well with observed concentrations for these lower values. Higher predicted concentrations were generally reduced by 3 to 7 $\mu g/m^3$ when 2010 emissions were used. Compared to observed concentrations, the predicted peak concentrations using 2010 emissions were sometimes lower and sometimes higher with a tendency to under predict.

CONCLUSIONS

1). Modelled ozone concentrations over southern Ontario demonstrated good correspondence with actual meteorological conditions and observed ozone concentrations in locations across Ontario with very high positive correlations between observed and modelled data.

2). The lower number of smog episodes with high ozone concentrations over southern Ontario in the summer of 2010 (compared to 2005) was the result of a combination of factors – specific meteorological conditions and emission reductions. Comparisons of modelled 2010 and 2005 ozone with only meteorology changed showed fewer days with 8 hour maximum concentrations in 2010. The summer of 2010 did have time periods that were conducive to high ozone but not to the same extent as in 2005.

3). Emission reductions from 2005 to 2010 levels resulted in a smaller number of days with high concentrations of ozone and shifted the ozone frequency distribution from high end to lower concentrations.

4). Emission reductions from 2005 to 2010 levels showed reductions in ozone concentrations on high days that generally ranged from about 2 to 10 ppb. Although these ozone reductions are not extremely large, they are large enough to shift an AQI reading from a poor level to a moderate level. For a number of days in 2010, the observed ozone concentrations fell just short of reaching a poor air quality level.

5). For PM2.5, the impact of meteorology was similar to that for ozone. Overall the 2010 meteorology was less conducive to high PM2.5 concentrations than 2005 meteorology.
When the emissions were changed to 2010 the reductions in the number of high PM2.5 concentration days were significantly larger than was found for ozone.

Table 1

Median number of days and concentrations in subdomains on ozone high concentration days (O3>70ppb)

Domain	Emission scenario: 2005 emissions with 2005 meteorology		2005 emissions with 2010 meteorology		2010 emissions with 2010 meteorology	
	# days	O3	# days	O3	# days	O3
1	37	80.9	24	82.0	14	79.1
2	30	76.5	22	77.6	12	75.7
3	30	76.9	23	77.7	14	74.9
4	32	76.9	27	79.0	18	75.2
5	27	79.6	20	80.0	16	78.2
6	25	81.6	22	80.0	17	79.6
7	27	78.7	20	80.2	12	78.9
8	23	79.3	21	80.4	15	77.6
9	12	74.7	10	74.2	1	73.2
10	15	76.8	6	75.5	2	73.0
11	3	73.9	3	76.3	1	72.5
12	4	75.1	3	73.4	1	71.6
13	22	75.3	19	78.7	10	77.2
14	9	75.7	3	76.2	2	72.8
15	14	74.2	14	77.2	8	74.0
16	6	76.2	4	74.3	1	71.6

Table 2

Median number of days and concentrations in subdomains on PM25 high concentration days (PM25> 20 ug/m**3)

Domain	Emission scenario: 2005 emissions with 2005 meteorology		2005 emissions with 2010 meteorology		2010 emissions with 2010 meteorology	
	# days	PM2.5	# days	PM2.5	# days	PM2.5
1	14	24.0	12	24.0	1	21.2
2	22	25.4	18	25.0	4	22.5
3	29	27.4	25	26.0	9	22.7
4	17	25.4	15	25.8	3	21.1
5	33	26.8	24	26.6	15	23.9
6	15	24.4	13	25.3	4	21.9
7	5	25.6	9	24.7	2	23.2
8	4	25.1	6	26.2	2	21.6
9	6	23.2	4	24.0	0	20.0
10	2	28.3	2	21.3	0	N/A
11	0	21.6	1	20.7	0	N/A
12	1	21.4	1	20.8	0	N/A
13	4	24.3	7	24.8	1	22.0
14	3	24.8	4	21.8	0	21.8
15	1	22.2	4	23.1	0	21.2
16	0	20.4	0	20.1	0	N/A

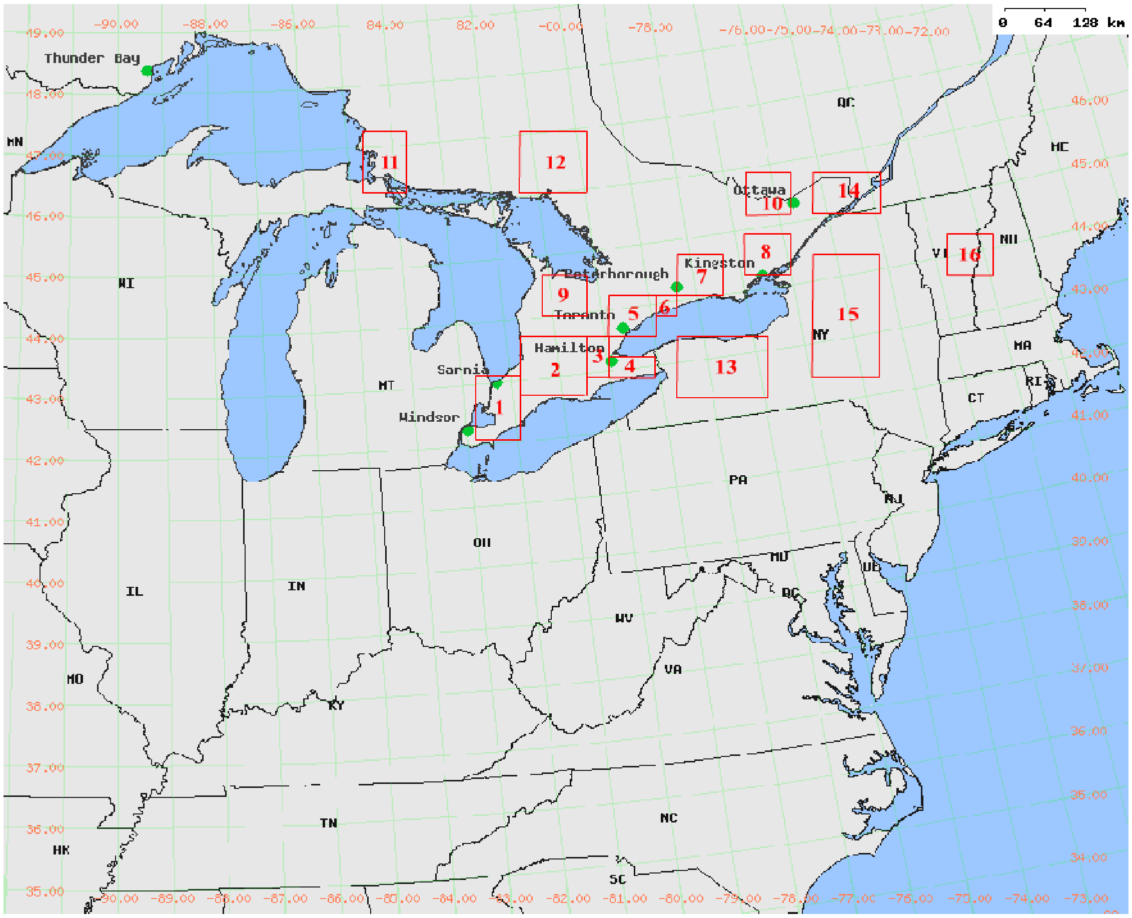

Fig 1 . Modelling domain and subdomains used for analysis.