A regional modelling study of the effects on air quality of electric power generation by fossil fuels

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Abstract

Using accurate regional chemical transport modelling, we compare the effects on air quality of electric power generation by coal and natural gas in southern Ontario. For the four operating coal generation facilities in Ontario, we show that without emission remediation, they contribute about 3-4% of the total SO_2 and about 1-2% of the total NO_X in southern Ontario. The contributions rise to about 10% and 8% respectively within 20 km of the largest facility. Use of currently existing remediation technology on the coal plants reduces both their SO_2 and NO_X contributions to about 0.3% when averaged across southern Ontario and about 1% within 20 km of the largest plant. The corresponding contributions from natural gas plants are roughly an order of magnitude lower than the coal plants for SO_2 and NO_X and about the same or slightly higher for particulate matter (PM). These results suggest that if currently existing remediation technology were used, the air quality effects from coal fired power plants are comparable to those from natural gas plants and neither could be distinguished from the regional background at distances more than a few km from the source.

1. Introduction

The majority of the population of southern Ontario is in a densely populated strip extending from Long Point in the south to the east end of the Greater Toronto Area. In 2006, the population of this region was about 8 million. This region is subject to significant air pollution, especially in the summer months, and there has been a long public debate about the contribution to this pollution of the four coal-burning power plants operated by Ontario Power Generation (OPG). During this debate, many alternative have been considered (Ontario Ministry of Energy, 2005), among which the following are cited frequently:

- **Status quo**: continue operating the coal-fired generation facilities within the current regulatory framework.
- **All Gas:** Replace the coal plants with natural gas facilities producing equivalent power.
- **Nuclear/Gas:** Create new gas generation facilities, and refurbish nuclear generation facilities to replace the coal plants.
- **Stringent Controls:** Continue operating the coal facilities, but install new state-of-the-art emission control technology.

The first option – status quo – is no longer considered seriously. In this study, we use regional atmospheric modelling to explore the air quality implications of the remaining three options. This implies a comparison of the two fossil fuel alternatives. Of the five fossil-fuelled OPG plants presently in operation, four use coal: Nanticoke (3,920 MW), Lambton (1,975 MW), Thunder Bay (325 MW) and Aticokan (230 MW) and one – Lennox (2,200 MW) - uses natural gas and fuel oil.

In order to focus on the comparison of coal with natural gas, we consider only the four OPG coal plants and assume that the operations of Lennox and all non-fossil OPG plants are unchanged. We did the comparison by modelling a series of scenarios in which an amount of electric power equal to that of the existing coal plants (6,450 MW) is generated either by natural gas or by coal. In the latter case, we also consider the effects of installing emissions remediation on all generating units. The results apply generally to the comparison of natural gas with coal for electric power generation. The remediation of coal plants *vs*. their replacement by natural gas generation involves economic as well as atmospheric consequences. This study helps to quantify the latter, thereby providing a context for the costs of the various alternatives.

2. Modelling

Eulerian regional chemical transport modeling (CTM) is used to compute the temporal and spatial distributions of atmospheric pollutants produced under scenarios that are designed to explore the effectiveness of different energy production strategies.

To increase accuracy in the target region (southern Ontario), we use nested domains centered on (40°N; 90°W) as follows:

- Domain (1): Eastern North America; 101x102 grid cells; 36 km resolution
- Domain (2): Great Lakes and north eastern US; 96x102 grid cells; 12 km resolution
- Domain (3): southern Ontario; 90x96 grid cells, 4 km resolution

2.1 Model Description

Although we will report results only for domain (3), it is important to note that full model simulations, including all emission sources, were done for the larger domains. This is essential to obtain accurate results for the target region.

Meteorological fields were obtained using the *MM5* mesoscale meteorology model, version 3.6 (Grell G., 1994). The air quality simulations were carried out using the *SMOKE v4.3/CMAQ* regional CTM system (Byun D.W., 1999; Carolina Environmental Programs, 2003) with the Carbon Bond IV (CB-IV) chemical mechanism.

The 1999 EPA national emissions inventory and the 1995 Canadian criteria emissions inventories were used. We chose to use the 1999 US inventory despite the availability of more recent US data because the 1995 inventories are the most recent Canadian data and we wanted to maintain temporal self consistency. Also, we wished to begin with a base case scenario that contained unremediated coal plants as much as possible and the 1995/99 data suited this purpose better than more recent ones. The calculations keep all criteria emissions constant except those altered in the scenarios. Identical meteorology files were used for all scenarios to ensure consistency. All simulations cover the summer of 2005, from May to September, inclusive.

2.2 Model Validation

The Ontario air quality monitoring network has 37 monitoring stations; To validate the basic calculation, we compared the values of O_3 and $PM_{2.5}$ produced by the model for the time period from June to September 2005 with the corresponding measurements from the 26 air quality stations in Domain 3. Despite the fact that the criteria emissions inventory is ten years old, the results are good. The average correlations between the measurements and the model for the daily maxima and daily average concentrations of O_3 are 0.71 and 0.76 respectively and for $PM_{2.5}$ these are 0.61 and 0.71 respectively. This indicates that the model results are reasonably accurate, although it overestimates the measured average $PM_{2.5}$ concentration by 7% and the average ozone concentration by 4%. It underestimates the ozone daily maximum concentration by about 8%. Overestimation of ozone and $PM_{2.5}$ would be expected to result from the use of older emissions datasets, while the underestimation of the ozone daily maximum reflects its high variability. Correlations calculated from the hourly ozone and $PM_{2.5}$ data over the lower resolution Domain 2 from June to September are slightly lower at 0.66 and 0.65 for O_3 and $PM_{2.5}$, respectively.

Although there is no generally accepted criterion to determine whether or not a model's performance is satisfactory, the US EPA (US EPA, 1991) has suggested that for regulatory applications, the model result (for concentrations above a prescribed threshold) should lie within the following ranges: Mean Normalized Bias Error (MNBE): ±10-15%; Unpaired Prediction Peak Accuracy (UPA): ±15-20%; Mean Normalized Gross Error (MNGE): ±30-35%. For the case of ozone, the commonly used threshold for this part of is North America 40 ppb and using this, we obtained MNBE = -14%; UPA = -13%, and MNGE = +22% for the time period from June to September 2005. Considering the discrepancy between the date of the emissions data and that of the measurements, we believe that this agreement is satisfactory. Moreover, the study's conclusions are obtained by subtracting the base case from scenarios in which certain emissions are modified, thereby reducing further the effects of errors in the absolute concentrations.

3. Calculations

3.1. Scenarios

We explore the effects of the four emission scenarios described below on the concentrations of O_3, NO_X, $PM_{2.5}$ and SO_2. The scenario calculations were done for the year 2005, but the results would not differ greatly for other years.

- **Scenario 1: Base case**. All emissions in the 1995/99 criteria inventories are used. At the time these data were released, the only emission remediation on the OPG plants was SO_2 scrubbers on two of the units in the Lambton plant, so the effects of these are included in the base case.
- **Scenario 2: OPG coal emissions removed.** All OPG coal plant emissions are removed from the 1995/99 inventories. This simulates the generation of electric power by nuclear or other means that do not have any significant affect on air quality.
- **Scenario 3: OPG coal emissions remediated.** This simulates the installation of state-of-the-art SO_2 scrubbers and Selective Catalytic Reduction (SCRs) on all power generation units of all OPG coal facilities.
- **Scenario 4: Equivalent power generation by CCGT plants.** This simulates the conversion of all coal stations to combined cycle gas turbine (CCGT) plants that produce the same amount of power. All CCGT units are fitted with SCRs.

3.2. Emission Data

It was necessary to create reasonable emission inventories for Scenarios 3 and 4. The emission factors (g/KWh) used to construct these are shown in Table 1 (White, 2006).

	Emission Factor (g/KWh)	
	Remediated coal (Scenario 3)	CC natural gas (Scenario 4)
NO_x (as NO_2)	0.1634	0.023
SO_2	0.0817	0.0041
H_2SO_4	0.0745	0.0009
PM_{10}	0.0078	0.017
NH_3	0	0.024
VOC	0	0.009

Table 1 – Factors used to construct emission inventories for Scenarios 3 and 4.

These data assume the coal plants would use a blend of 70% Powder River Basin (PRB) coal and 30% US low sulphur coal on a heat input basis. Low-NOX combustion systems would be installed, reducing NOX by 55%. The addition of SCRs would reduce NOx by an additional 82% for an overall NOX reduction of 92%. The use of wet flue gas desulfurization (FGD) systems would result in a net SO2 reduction of 97.7 %. The addition of a wet electrostatic precipitator (WESP) after the SO2 absorber vessel would reduce solid PM by 97% and SO3 emissions by about 56% from existing levels. The latter would be converted to H2SO4 mist. Ammonia emissions are zero for Scenario 3 because any ammonia slip would be removed by the wet FGD system. Ammonia

emissions remain in Scenario 4, however, because CCGT plants normally have SCRs but do not use wet FGD systems.

The emission of PM2.5 for Scenario 3 was determined as a fraction of the PM10 emission, in the 1995/99 emission inventories. The PM2.5 emission factor for Scenario 4 was assumed to be 1.35 times the emission factor for PM10 shown in Table 1, based on the ratio that had been measured for the Lennox natural gas plant and published in the 1995/99 emission inventory. All other emissions were taken directly from the 1995/99 inventories.

We used these emission factors to calculate the annual emissions for NO_X, PM_{10} , NH_3 and VOCs, assuming the annual power production (in KWh/yr) as follows. Lambton: 1.1×10^{10}; Nanticoke: 2.2×10^{10}; Atikokan: 9×10^{8}; and Thunder Bay: 1.5×10^{9}. The resulting total emissions in short tons per year for each of the four OPG plants are shown in Table 2.

		VOC	NOx	CO	SO_2	PM 10	PM 2.5	NH_3
LAMBTON								
	Scenario 1	59.64	12794.84	498.80	17636.20	507.97	132.75	1.12
	Scenario 2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Scenario 3	0.00	1981.26	496.04	1580.56	94.58	24.72	0.00
	Scenario 4	109.13	278.88	496.04	56.84	206.13	152.93	291.01
NANTICOKE								
	Scenario 1	103.28	25522.08	874.16	41224.88	660.80	172.72	4.96
	Scenario 2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Scenario 3	0.00	3962.52	854.32	3161.12	189.15	49.44	0.00
	Scenario 4	218.25	557.76	854.32	113.68	412.26	305.87	582.01
ATIKOKAN								
	Scenario 1	14.68	1419.78	126.37	2480.19	33.57	9.59	2.79
	Scenario 2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Scenario 3	0.00	162.10	125.66	129.32	7.73	5.73	0.00
	Scenario 4	8.92	22.82	125.66	4.65	16.86	4.82	23.80
THUNDER BAY								
	Scenario 1	28.44	3205.64	242.99	4716.19	39.54	10.32	4.77
	Scenario 2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Scenario 3	0.00	270.17	242.99	175.31	12.90	3.37	0.00
	Scenario 4	14.88	38.03	242.99	7.26	28.11	20.86	39.68

Table 2 – Emissions (short tons per year) from the OPG power plant at Lambton, Nanticoke, Atikokan, and Thunder Bay.

This table shows significant decreases in the emissions of VOCs, NOx, SO_2 and PM - the species commonly associated with reduced air quality - for the remediated coal and natural gas scenarios. It might be expected that these large reductions would lead to a significant improvement in air quality. The actual improvement is quantified in the next section.

4. Results

The chemistry of O_3 and other secondary pollutants is highly nonlinear and predictions of the changes in their concentrations under the above scenarios is only possible if all relevant trace species are considered, including reactive radicals such as OH, photochemical processing, cloud and secondary aerosol processes, etc. This can only be

achieved by the use of a comprehensive chemical transport model that can account for all relevant atmospheric chemistry in the target area.

We examined the concentration changes resulting from the scenarios both as averages across the smallest domain (Domain 3) and as changes within two 40 km x 40 km squares centered at the two OPG stations in domain 3 (Nanticoke and Lambton). All averages were calculated using the 4 km x 4 km resolution of domain 3 and all four coal plants were included in the nested calculations. These results are for the period from May to September, which is the time when the poorest air quality occurs.

4.1. Spatial Averages

The changes in the target species under the scenario conditions will be reported as averages of the hourly concentrations in Domain 3 over the period from May to September. The changes are obtained by subtracting the time average for scenario 2 from the time averages for each of scenarios 1, 3, and 4. The contributions from all four power generation facilities are included by the nesting procedure. The subtractions give the following information:

Scenario 1–Scenario 2 (“Base OPG”**):** Contributions from the four facilities assuming no remediation technology is used except the two SO_2 scrubbers installed in Lambton prior to 1995.

Scenario 3–Scenario 2 (“Remediated OPG”**):** Contributions from the four facilities assuming the clean-emissions technology described in Section 3.2 is installed.

Scenario 4–Scenario 2 (“All Gas”**):** Contributions from the four facilities assuming all four are converted to CCGT plants that produce the same electric power output.

	Species	Base OPG	Remediated OPG	All Gas
Domain 3[a]				
	O_3	-0.13	-0.01	0
	NO_X	1.7	0.25	0.03
	SO_2	3.14	0.28	0.01
	PM_{10}	0.51	0.07	0.06
	$PM_{2.5}$	0.61	0.08	0.07
At Lambton[b]				
	O_3	-0.5	-0.06	0
	NO_X	4.37	0.66	0.1
	SO_2	3.77	0.41	0.01
	PM_{10}	0.52	0.08	0.13
	$PM_{2.5}$	0.56	0.07	0.14
At Nanticoke[b]				
	O_3	-0.74	-0.1	0
	NO_X	8.5	1.32	0.17
	SO_2	10.68	0.97	0.02
	PM_{10}	0.80	0.12	0.17
	$PM_{2.5}$	0.89	0.12	0.19

[a]Total area: 360 x 384 km. [b]Inside a 44km x 44km square centered at the OPG location

Table 3 – The changes in the averaged concentrations of O_3, NO_x, SO_2, PM (expressed as percentages of the base case, (scenario 1) that would result from the indicated actions.

In Table 3, we summarize the numerical values of these results, both as domain-wide averages and as averages over the small regions around the two plants in domain 3. The concentration of ozone is reduced by the coal plants at all scales. Thus if the coal plants were simply turned off, the ozone levels in southern Ontario would increase. The ozone reduction is caused by the NO_X (principally NO) emissions, which react with ozone that is transported into the domain, converting it into NO_2. The resulting reductions are less than 1% of the total O_3 for the coal plants and even smaller for the CCGT plants, as would be expected.

The contributions to NO_x concentrations from unremediated coal plants are positive, ranging from 8.5% within 20 km of the Nanticoke plant to 1.7% if averaged across southern Ontario. If NO_X remediation on all coal generation units, however, reduces this to 1.3% at Nanticoke and 0.25% across the domain.

The unremediated OPG plants contribute about 3% of the total SO_2 concentration in southern Ontario and nearly 11% within 20 km of the Nanticoke plant. In this case as well, however, the very high efficiency of the SO_2 remediation technology removes most of this pollutant and the respective contributions drop to 0.3% across southern Ontario and about 1% near the Nanticoke plant.

The PM concentrations are reduced for Scenarios 3 and 4, as described in Section 3.2. The resulting emissions are all small and we will show in the next section that the spatial distributions of these are complicated by the presence of secondary particles.

4.2. Spatial distributions

These give a more detailed description of the way the scenarios affect the target populations. In this case as well, we will report the temporal averages for the period from May to September. This provides a good representation of long term exposure under a variety of meteorological conditions that are representative of the summer season.

4.2.1 Ozone

Figure 1 gives the spatially resolved hourly average ozone concentrations in domain 3 for May to September 2005. Total ozone levels in the 40-50 ppb range are typical of the summertime average in this part of Ontario, but during pollution episodes that occur occasionally during the summer months, the concentration approximately doubles. The average total concentrations are shown in part (a). The slightly higher total concentrations over the lakes reflect the relatively low solubility of ozone, combined with diurnal effects including lake breezes and the greater diurnal variation in mixing height over land. The significantly lower total ozone levels in the GTA, Detroit and Hamilton are due to titration by NO, emitted primarily by the large numbers of motor vehicles in

Part (b) shows the "Base OPG" result, which is the contribution to the O_3 concentration from the unremediated OPG coal plants. This is a very small reduction in ozone of about 0.1 to 0.2 ppb throughout most of southern Ontario, with higher reductions at the Nanticoke and Lambton plants of about 1.3 and 0.6 ppb respectively. As was the case in the three urban areas, these reductions are caused by titration of O_3 by NO_X. The reduction in background O_3 is roughly an order of magnitude smaller for the remediated coal plants and a further order of magnitude for "All Gas", reflecting the lower NO_X emissions for these cases. Such change would be extremely difficult to measure except perhaps in the immediate vicinity of the stacks.

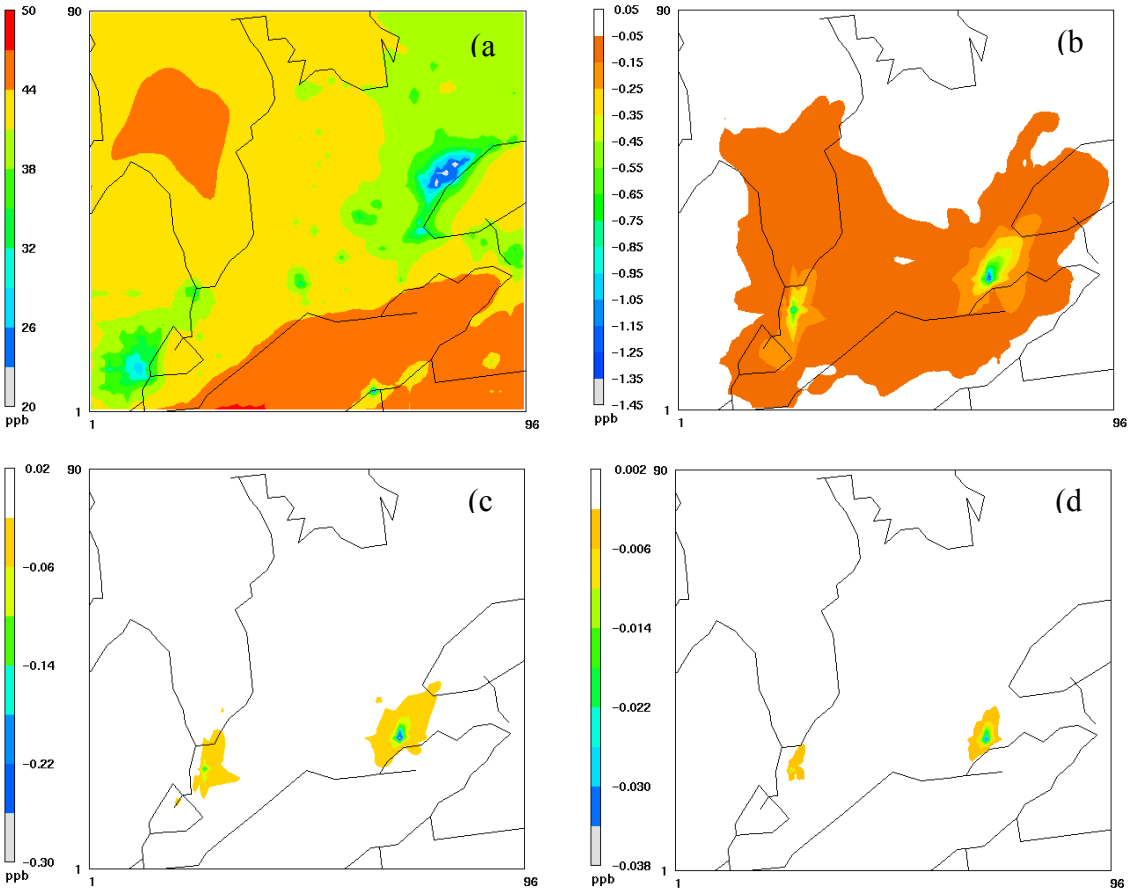

Figure 1 - Spatially resolved hourly average ozone concentrations in southern Ontario. (a) Total ozone concentrations. (b) Contribution from "Base OPG" scenario. (c) Contribution from "Remediated OPG" scenario. (d) Contribution from "All Gas" scenario. Note that colour scales differ for each panel.

4.2.2. Nitrogen oxides

The NO_X responsible for the O_3 titration that was discussed in the preceding section is shown in Figure 2. Part (a) shows that the largest contributions to the total NO_X concentrations come from the cities, with maximum hourly averages in the GTA at approximately 40-50 ppb. The maximum concentration of NO_X produced by the unremediated OPG coal plants is about 3 ppb at the Nanticoke plant. The NO_X contributions decrease rapidly from the point of emission, falling to about 0.5 ppb within about 50 km of the Nanticoke plant. Part (c) shows that the NO_X reduction technology described earlier would reduce the total concentration at the Nanticoke point of emission to about 0.4 ppb, which would decrease to less than 0.1 ppb within 50 km of the plant. Converting all of the plants to CCGT operation causes the NO_X emissions to fall to about 0.05 ppb at the maximum point of emission as shown in part (d).

These NO_X spatial distributions illustrate two important points: the peak contributions of the remediated plants are less than 1 % of those from vehicular traffic in the nearby cities and the areas over which the urban emissions occur are orders of magnitude larger than the point sources of the power plants. The effects of the point emission sources are

spatially limited because of the relatively short atmospheric lifetime of NO_X. Conversion of NO to NO_2 by reaction with O_3, followed by OH oxidation of NO_2 to HNO_3 limits the NO_X lifetime to about one day for typical OH concentrations.

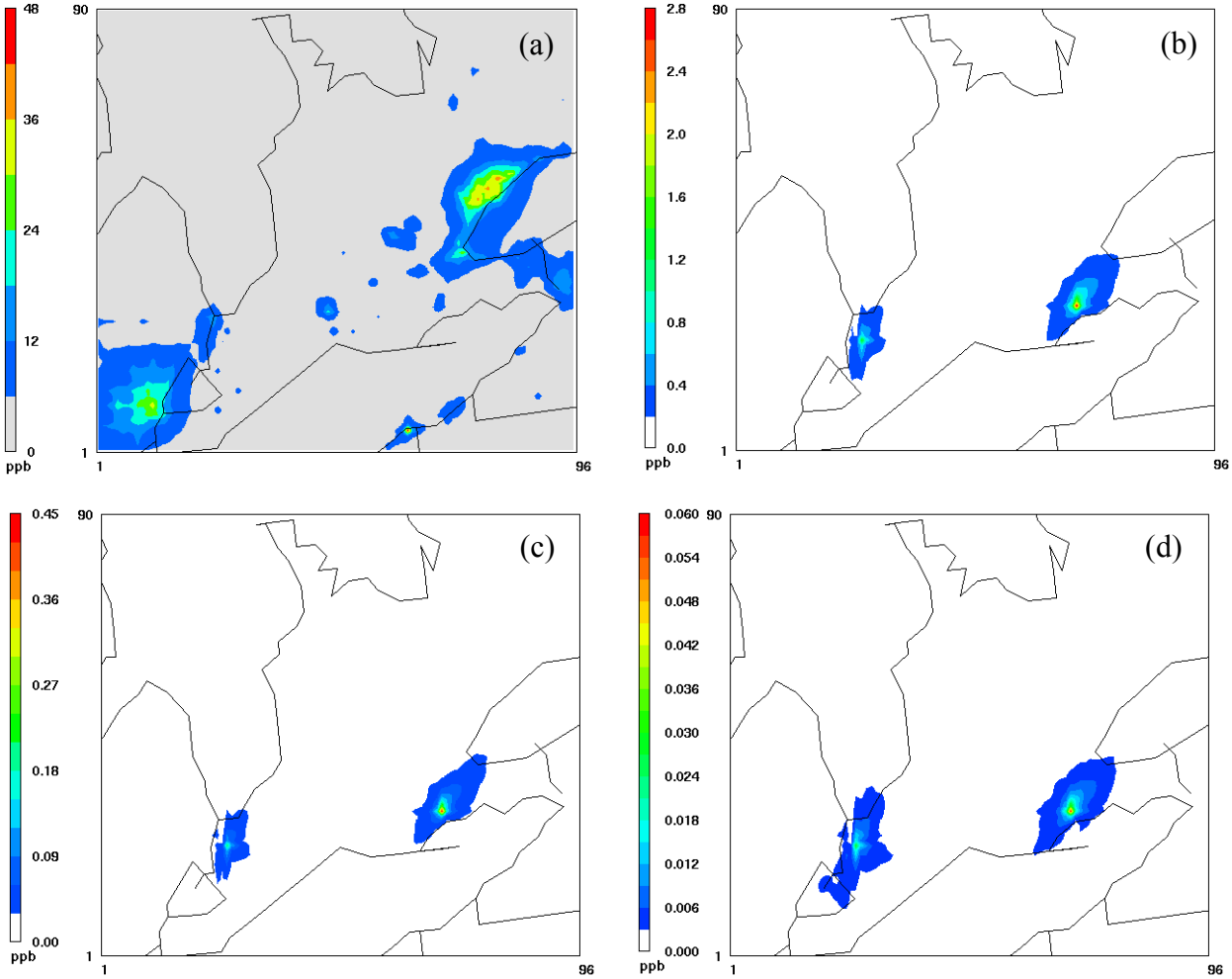

Figure 2 - Spatially resolved hourly average NOX concentrations in southern Ontario. (a) Total NOX concentrations. (b) Contribution from "Base OPG" scenario. (c) Contribution from "Remediated OPG" scenario. (d) "All Gas" scenario.

4.2.3. Sulfur Dioxide

Figure 3(a) shows that the largest point sources of SO_2 in the southern Ontario domain are on the Sainte-Claire river south of Sarnia and in the Hamilton area. The former is the location of several refineries and chemical manufacturing plants; the latter is the location of most of the steel industry in Ontario. In both cases, the maximum total hourly averaged SO_2 concentrations for the five month study period are about 20 ppb. The "Base OPG" case shown in part (b), indicates that the maximum hourly averaged SO_2 concentration at the point of emission from the unremediated Nanticoke plant is about 3.5 ppb. If SO_2 remediation were used, part (c) of the figure shows that the concentrations at the points of emission would decrease by about one order of magnitude, becoming about 0.27 ppb at the Nanticoke plant. The "All gas" scenario shown in part (d) shows that

peak SO_2 would decrease by approximately another factor of 40 to about 0.007 ppb if the power were generated by CCGT plants. As with the other primary gas phase pollutants, the spatial distributions of the affected areas are governed by the synoptic meteorology and thus are elongated in a south-west to north-east direction.

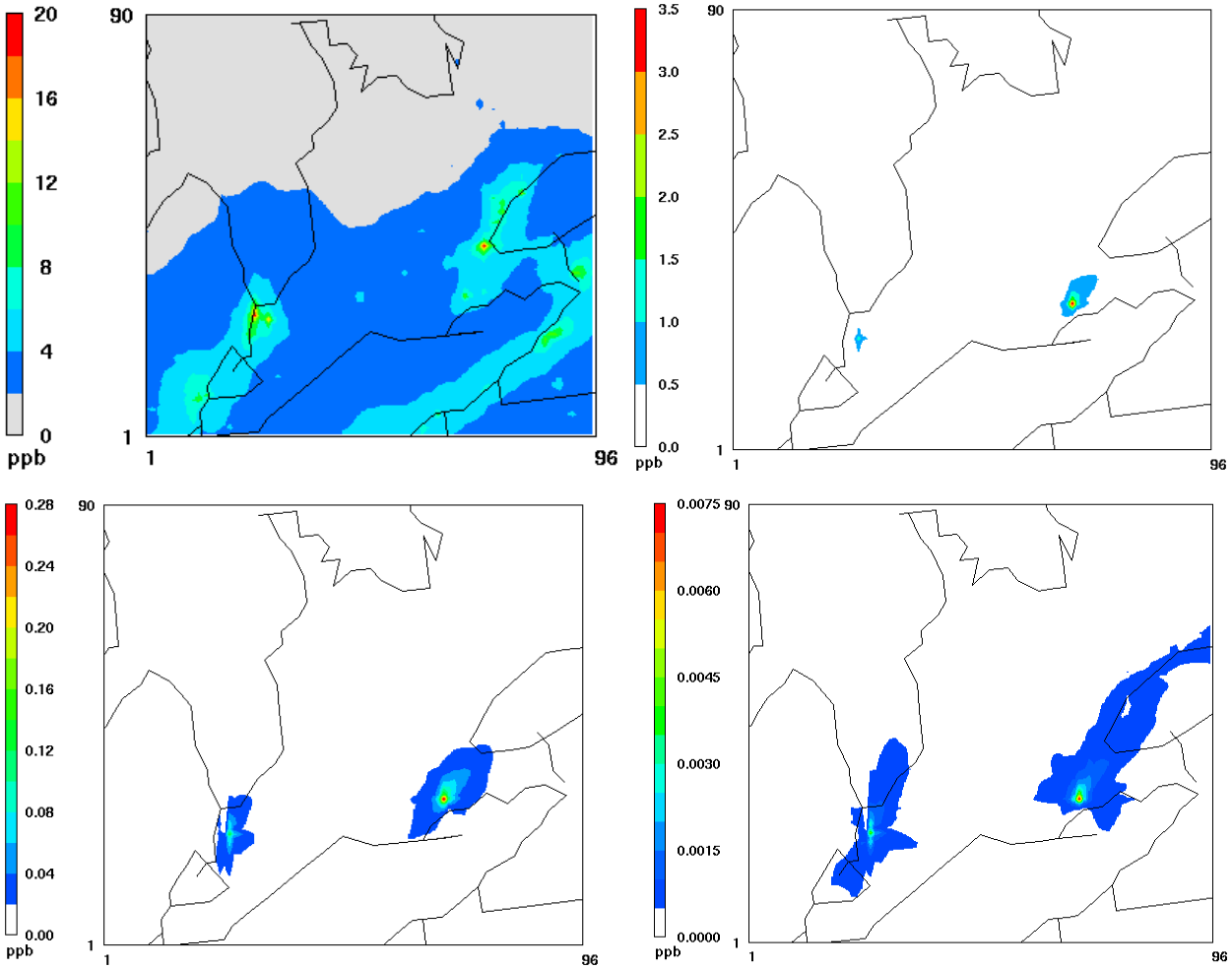

Figure 3 - Spatially resolved hourly average SO_2 concentrations in southern Ontario. (a) Base case total SO_2 concentrations. (b) Contribution from "Base OPG" scenario. (c) Contribution from "Remediated OPG" scenario. (d) contribution from "All Gas" scenario. Note that colour scales differ for each panel.

The SO_2 removal rate by oxidation and deposition is broadly similar to that of NO_X and both decrease by approximately one order of magnitude within a distance of about 50 km from the emission point. The mixing ratio of SO_2 in clean continental air (the continental background level) ranges from about 0.02 ppb to about 1 ppb. In view of this, it is unlikely that the concentrations indicated for either the "Remediated OPG" or the "All Gas" scenarios would be reached, because in both cases, the SO_2 would be below the typical continental background.

4.2.4 PM2.5

The situation with respect to PM is slightly different from that of the gas phase pollutants we have considered above because PM can have both primary and secondary sources. Primary PM is injected into the atmosphere as particles; secondary PM forms from gas phase pollutants as a result of chemical and photochemical processes. Larger primary particles having diameters of 10 μm or larger settle out fairly quickly due to gravitational sedimentation and are not important in long range transport. The major anthropogenic primary particles that are emitted by combustion sources such as those considered here are fine soot particles on the order of 100 nm in diameter and larger. Secondary particles form as very small nuclei and grow to sizes of a few μm in diameter with rates that depend on the concentrations of gases that condense on their surfaces.

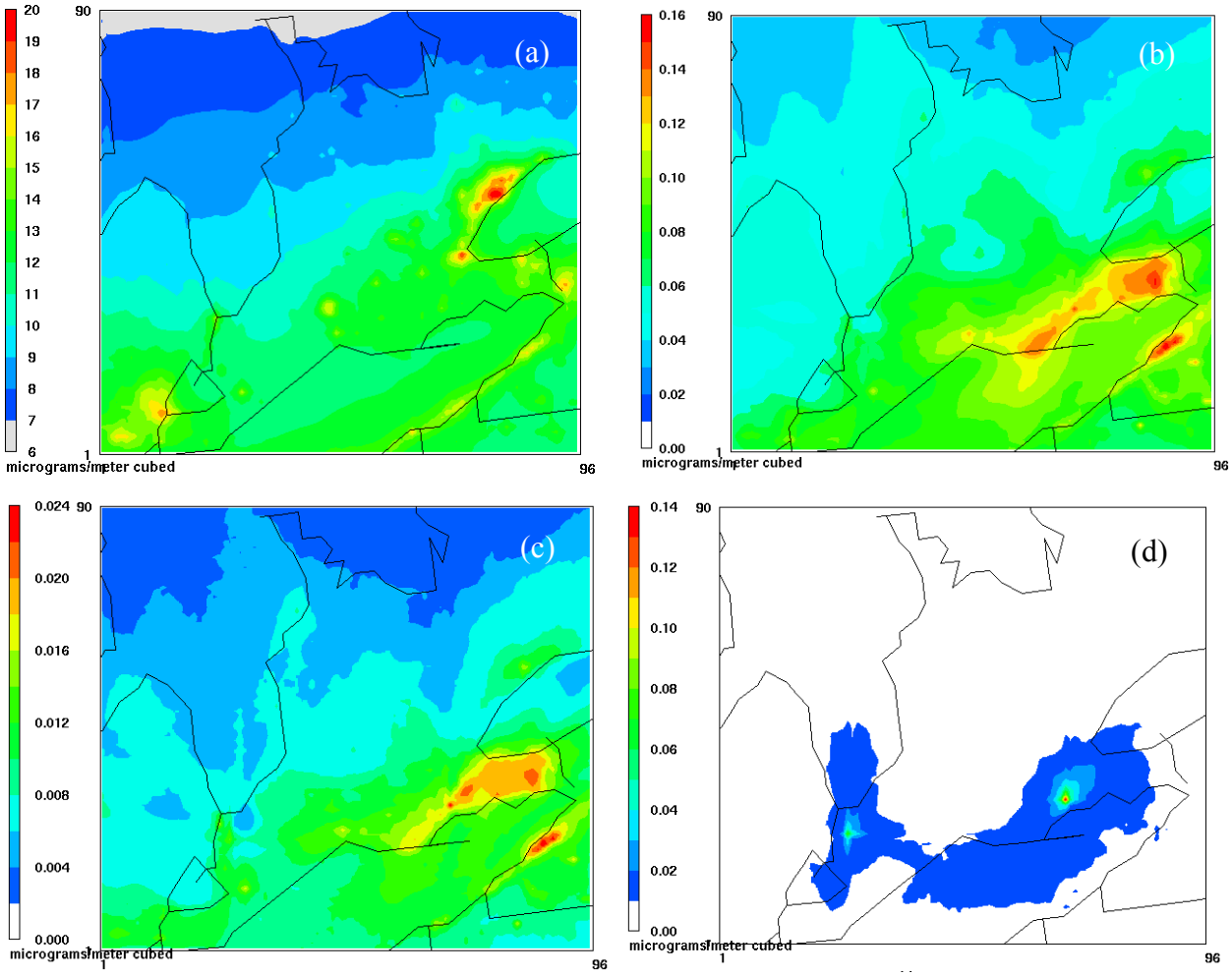

Figure 4 - Spatially resolved hourly average $PM_{2.5}$ concentrations in southern Ontario. (a) Total $PM_{2.5}$ concentrations. (b) Contribution from "Base OPG" scenario. (c) Contribution from "Remediated OPG" scenario. (d) Contribution from "All Gas" scenario. Note that colour scales differ for each panel.

Figure 4 gives information about the levels of $PM_{2.5}$ in the domain and the changes that result from the scenarios. Figure 4(a) shows that as in the cases of NO_X and SO_2, the

major sources of $PM_{2.5}$ are the urban areas – mostly the GTA (about 20 $\mu g/m^3$) and to a lesser extent, Detroit, Hamilton and Buffalo, which have average levels up to about 18 $\mu g/m^3$.

The contributions to these totals from the unremediated OPG coal plants, which are shown in part (b), are slightly less than 1%. The spatial distribution of these concentrations has the southwest-to-northeast direction of the gas phase distributions, but unlike the gas phase case, the maxima in the $PM_{2.5}$ concentrations occur at distances of more than 100 km from the source. These maxima are due to secondary particles that are formed by oxidation of SO_2 and SO_3 to $SO_4^=$ and the subsequent hygroscopic growth of sulfate nucleation mode particles as they move through regions of higher relative humidity such as that at the east end of lake Erie.

In figure 4(c), which shows the "Remediated OPG" scenario, the maximum values are decreased by nearly an order of magnitude, underscoring the effectiveness with which the remediation technology removes PM from coal fired power stations (Chow and Watson, 2002). The $PM_{2.5}$ contributed by the Nanticoke plant under these circumstances is reduced to about 0.1% of the total levels found in the GTA and the maximum occurs many km from the plant, suggesting that these are mostly secondary particles. The distributions of the $PM_{2.5}$ emissions from the "All Gas" scenario shown in figure 4(d) differ from those of the remediated coal plants inasmuch as they peak at values about a factor of five higher than the coal plants at the point of emission and decrease in all directions. This distribution indicates that these are primary particles and thus are probably composed mainly of organic and elemental carbon.

5. Conclusion

The chemistry of trace gas phase pollutants such as ozone, SO_2, NO_X and PM is highly non-linear, and conclusions about the effects of a single emission source must include consideration of the effects of all other emission sources and chemical processes that involve the target species. In this study, we have used a regional atmospheric modelling system composed of *MM5*, *SMOKE* and *CMAQ* to compute the air quality effects of several electric power production scenarios involving fossil fuelled power plants in the Province of Ontario. Four scenarios were considered for the time period from May to September 2005. A Base Case including all emissions as defined in the 1995/99 inventories; a case in which all coal fired generating plants were removed from the emissions inventories; a case where all coal plants were equipped with currently available emissions reduction technology and a scenario in which all coal plants were replaced by CCGT plants that generate the same amount of electric power.

Based on these scenarios, we derived the contributions of the various energy production methods to the air quality in Ontario. Expressed as percentages of current levels, the contributions of the coal plants are found to be small, but not negligible, especially in the vicinity of the plants, where the contributions to the concentrations of pollutants such as SO_2 and NO_X can reach about 10% of the totals. For ozone, the contributions of the coal plants are everywhere negative, due to titration by NO_X.

The use of currently existing emission reduction technologies including SO_2 scrubbers and catalytic NO_X reduction, diminishes the contributions of the coal plants to levels that are undetectable except in the immediate vicinity of the larger plants and below the background levels when averaged across southern Ontario. With the exception of PM,

the use of CCGT plants to produce electric power would cause a further reduction in air pollution that ranges from a few percent to more than an order of magnitude (for SO_2). Except in very unusual cases, it would not be possible in practice to measure the contributions from either the remediated coal plants or the natural gas plants in the natural fluctuations of the regional background.

6. Acknowledgements

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