ASSESSMENT OF THE AIR QUALITY EFFECTS OF NITROGEN DIOXIDE IN THE NATIONAL CAPITAL REGION OF CANADA BY COMBINING REGIONAL CHEMICAL TRANSPORT MODELING WITH SATELLITE AND SURFACE MEASUREMENTS

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1. INTRODUCTION

Pollutants such as NO_2, which have high spatial and temporal variability in urban areas, yet can also be transported for hundreds of kilometers, are difficult to quantify on all relevant time scales. Their adverse health effects, however, increase the value of a forecasting capability. To obtain a more accurate description of the air quality effects of NO_2, we have developed a system that synthesizes a variety of measured and modelled information to allow the prediction of its spatial and temporal behaviour on a time scale that includes synoptic effects, while still being useful for local applications.

The geographical focus of this study is Shown in Figure 1. The three model domains having 36, 12 and 4 km grid intervals are shown in Figure 1a.The Regional Municipality of Ottawa-Carleton (RMOC) is inside the pink circle in Figure 1b. The RMOC has very little heavy industry and most local NO_2 emissions come from commuter traffic. On occasion, the area is also affected significantly by NO_X transported from Montreal, to the east, and the heavily populated region of southern Ontario to the south west. To obtain a good description of both the local and long range effects, we combine space remote sensing with local surface measurements, line source modelling from a traffic model and a regional chemical transport model (CTM), the MM5-WRF/SMOKE/CMAQ system, which used a two-way nesting scheme among the domains shown in Figure 1a.

In this presentation, we will report our first attempts to develop such a system. It combines two different modelling techniques with a small

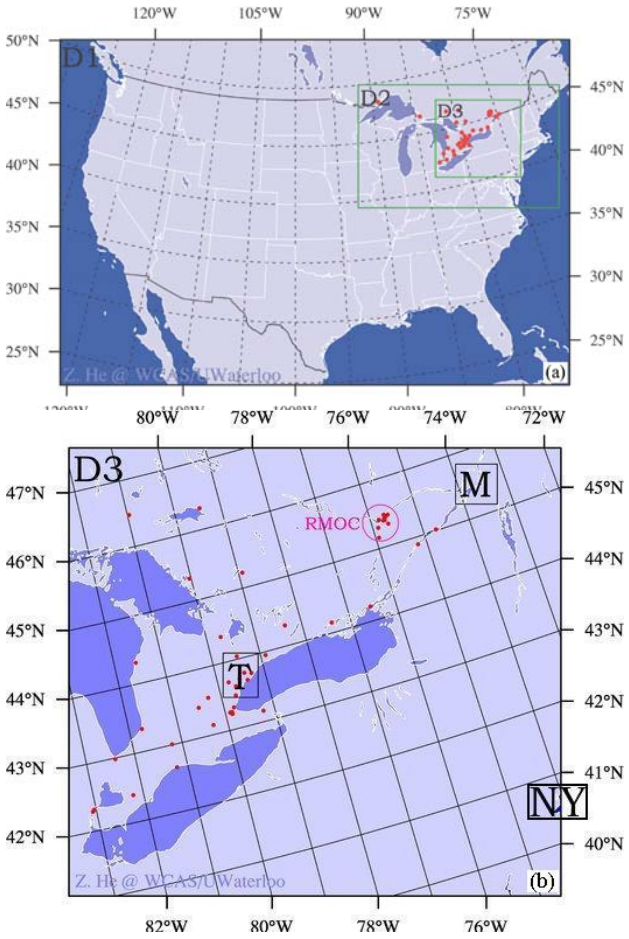

Figure 1. (a): Three domains used by SMOKE-CMAQ. (b): The high resolution domain D3. Locations of RMOC (pink circle), Toronto (T), Montreal (M) and New York (NY) are also displayed. The red dots are air quality sampling sites of the Ontario Ministry of the Environment (MOE). The corresponding domains used by MM5 are a little larger for appropriate boundary configuration of mcip3.3

number of surface measurements and retrievals of total column NO_2 by the Ozone Monitoring Instrument (OMI; Levelt et al. (2006)). The two models used are the Community Multi-Scale Air Quality (CMAQ) CTM, driven by either MM5 or WRF, and a proprietary spatial interpolation model developed by A-Maps Environmental Inc. The A-

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Maps modelling system combines statistical information and real-time surface measurements with estimates based on the OMI measurements. OMI, a nadir viewing imaging spectrograph, achieves a single-pixel resolution across the swath that increases from 13 x 24 km^2 (exact nadir) to approximately 13 x 128 km^2 at the outermost edges (Suraiya etc., 2003). The A-Maps model re-grids the OMI pixels and the surface measurements to higher resolution using Kriging and land use regression (Beelen et. 2009). The CTM emission inputs were created using SMOKE to combine emission surrogates from U.S. Environmental Protection Agency (EPA), Environment Canada (EA) and the Ontario Ministry of the Environment (MOE).

The initial CTM results were obtained using the CMAQ CB4_ae3_aq chemical mechanism with emissions inventories dating from 1999 (US) and 2001 (Canada). The results were evaluated at selected "city", "residential", "rural" and "clean" locations and it was found that the description provided by the combined system is better than that from any of the individual components.

The overall goal of this project is to assess whether it is possible to determine the local NO_X concentrations with sufficient accuracy to assess the effect of this pollutant on such sensitive facilities as schools, hospitals and geriatric homes. During later stages of the project, the SAPRC99 and CB5 chemical mechanisms will be tested with newer (2005/2006) emission inventories before making a decision on the final form of the modelling system.

2. METHODS

The largest SMOKE/CMAQ domain (see Figure 1a) includes the North American continent from about 20°N to 60°N; the second domain covers the Eastern North America from the 95°W to the Atlantic Ocean and the third domain with highest resolution covers the "lower" three Great Lakes region. The locations of the target areas, RMOC, Toronto and Montreal are indicated in Figure 2.

The SMOKE/CMAQ CTM uses emission files produced by Environment Canada with additions by the Ontario Ministry of the Environment to predict temporal and spatial distributions of common pollutants in three nested domains having 36, 12 and 4 km resolution. Meteorology inputs created by MM5 and WRF for SMOKE/CMAQ are pre-processed by mcip3.3.

The A-Maps model was calibrated using daily Aura/OMI data, hourly surface measurements and a road traffic model developed by the City of Ottawa. The OMI pixels were used with the surface measurements to provide a coarse spatial field, which was then interpolated to 1 km through Kriging and land use regression (Beelen et. 2008).

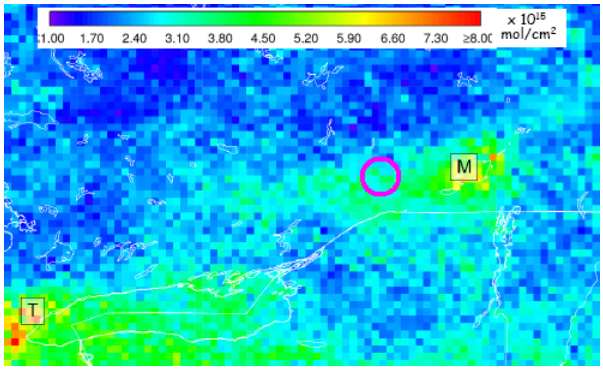

Figure 2. Example of 4x4km NO_2 distribution in July 2007, retrieved from OMI measurements. The red cycle is our project target region. Symbols T and M are locations of Toronto and Montreal, respectively.

3. RESULTS AND DISCUSSION

A 4x4km^2 OMI measurement of NO_2 in July 2007 covering the target area is shown in Figure 2, which also includes the locations of Toronto and Montreal.

Preliminary results for the region are shown in Figure 3. This is the central part of the RMOC, consisting of the cities of Ottawa, Vanier and Hull/Gatineau. This area contains the road network that is the focus of the NO_2 study.

Two surface air quality measurement stations (Symbols A and B.), with which the simulation results will be compared, are also shown in Figure 3. For reference, a double-headed arrow indicating the size of the 4 km grid interval used in the part of the simulation is shown in green. The yellow arrow indicates the 8-month average surface wind direction. The upper station (A) is located in a residential part of the city, and the lower one (B) is located in a large open area. In addition to, the lower one (B) is used as the "upwind" station for local high resolution traffic emission measurements. In this study, the results from the two stations will be averaged.

Figure 4 shows an example of an A-Maps plot of the NO_2 concentrations for a typical afternoon in July and December, 2007, in the region shown in Figure 3. The colour scale on the right of the figure ranges from 0 to 100 ppb. The road network is outlined in red and some known NO_2 point sources (heating plants, etc.) are also shown. This plot contains all of the surface information presently available for the region shown in Figure 3, including thirteen NO_2 monitoring stations from a network deployed for the purposes of this study.

The CMAQ regional simulations for the high resolution (4 km) domain on typical morning in summer 2007 are shown in Figure 5. The surface layer concentrations of NO_2 at local time 6:00a.m. and 10:00a.m. on 4 July 2007 are shown at the left and right hand sides, respectively. These spatial distributions of NO_2 may be compared with the OMI measurements shown in Figure 2. (Note that Figure 2 extends only to the end of Lake Ontario in the West, whereas the domains in Figure 5 include Detroit and the west end of Lake Erie.) Both figures display clearly that RMOC, Toronto and Montreal all had high NO_2 concentrations. These plots also illustrate the meteorology effects on the air quality patterns.

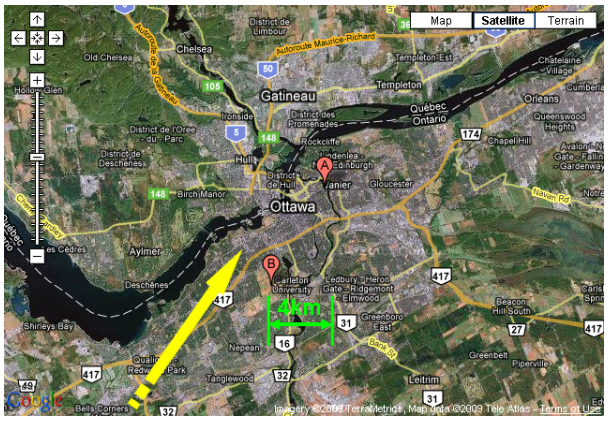

Figure 3. Two AQ stationsare located in the central part of RMOC (A: Ottawa Downtown; B: Ottawa Center).

The curved arrow indicates the wind vectors, suggesting highly polluted air masses carried away from the urban areas. The seasonal as well as the spatial variabilities of NO_2 in this area were also investigated. The summertime values are reduced somewhat by photochemistry, while the winter surface concentrations in the urban areas are somewhat higher due to the lower boundary layer.

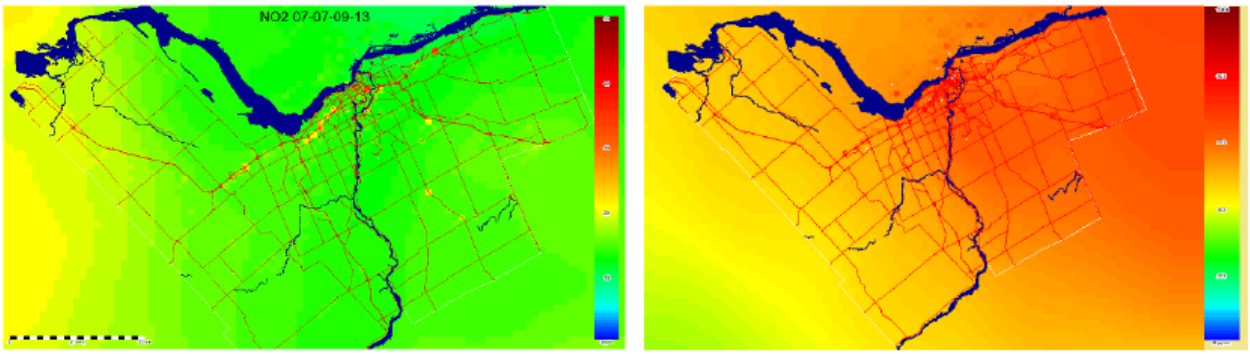

Figure 4. A-Maps plots of NO_2 for daytime in July (left) and December (right) 2007. The maximum colour scale of the left side is 50ppb and that of the right side is 100ppb.

Figure 6 shows another example of similar high concentrations of NO_2 patterns near Ottawa downtown in a winter morning. Evaluation of NO_2 simulations in urban areas is particularly difficult because of the high spatial and temporal variability of this pollutant. For this reason, we chose to compare the measured and simulated values of Ox ($=NO_2+O_3$), which is more stable under typical urban conditions. A scatter plot of this comparison is displayed in Figure 7 for the month of July 2007.

The figure shows the average of the hourly data for the two air quality stations shown in Figure 3. A regression plot of these data gives an adjusted R^2 value of 0.426 and standard error of estimate equal to 7.944 (note there are 55 missing observations for these statistics). These values are only qualitative, however, since the emission data used in this preliminary simulation are from 1999/2001, whereas the measurements were from 2007. It would be expected that improvements in vehicle technology during this seven-year period would reduce NO_2 levels in urban areas like this as well as overall regional O_3 levels and this is likely at least partly responsible for the lower measured Ox. (Note that

meteorology for 2007, when the measurements were done, was used in the simulations so this is not a factor.) Further tests will also be done to ascertain the effects of emission reductions and technology improvements**.**

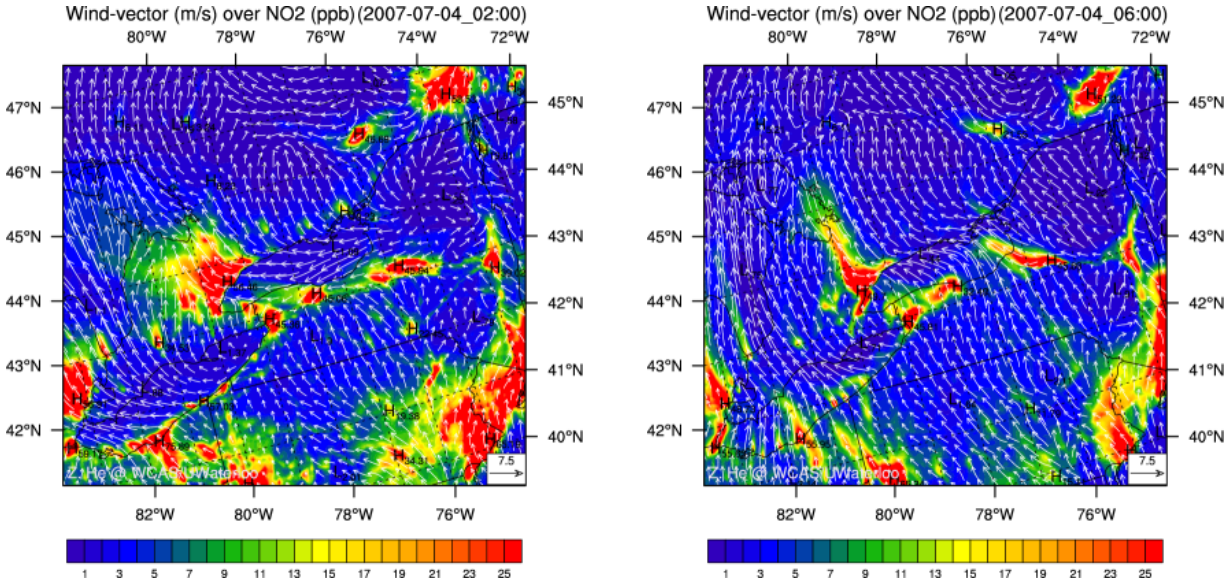

Figure 5. CMAQ regional simulations of NO_2 at 6:00am (left side) and 10:00am (right side) (Local time) on 4 July 2007. The times shown on the main title of the pictures are UTC time, which are four hours earlier than Canadian East Local time in summer. The white curved arrow on the pictures indicted the wind vector (direction and speed).

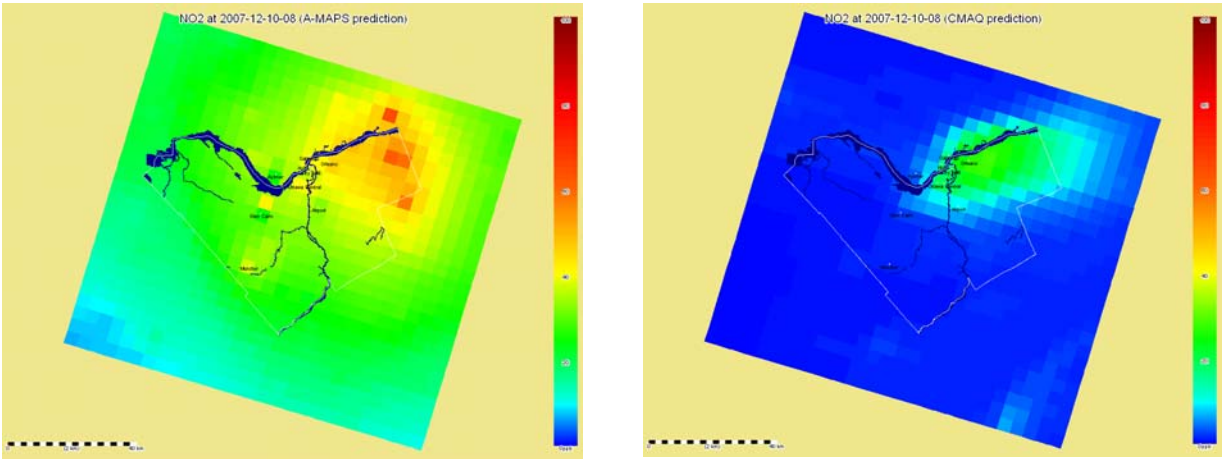

Figure 6. Comparison of A-Maps (left) and CMAQ (right) modeling results over RMOC area in winter time. Both of these pictures exhibited the high concentrations of NO_2 near Ottawa downtown at 08:00a.m. on 10 Dec. 2007. MTM9 projection & datum NAD1983 were used for creating these plots.

4. CONCLUSIONS

We have examined whether a combination of statistical modelling, regional chemical transport modelling and both low- and high-resolution measurements can improve the temporal and spatial representation of the short-lived pollutant, NO_2, affected by both local and regional sources in an urban area. Presently the (high resolution) statistical modelling and surface measurements have been combined with the (low resolution) satellite remote sensing measurements, with promising initial results. Regional CTM results at intermediate resolution (4km) have been obtained and evaluated. Further tests will be continued to ascertain whether weighted combinations of these methods can further improve the results.

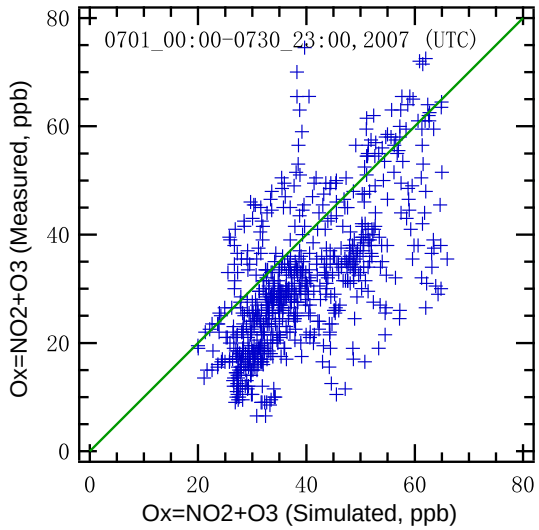

Figure 7. Comparison of simulated and measured O_X concentrations in July 2007 for model evaluation

5. REFERENCES

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6. ACKNOWLEDGEMENTS

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