Presented at the 13th Annual CMAS Conference, Chapel Hill, NC, October 27-29, 2014

HIGH-RESOLUTION AIR QUALITY MODELING OF NEW YORK CITY TO ASSESS THE EFFECTS OF CHANGES IN FUELS FOR BOILERS AND POWER GENERATION

Sharon Douglas*, Jay Haney, Tom Myers, Yihua Wei and Belle Hudischewskyj
ICF International, San Rafael, CA, USA

Iyad Kheirbek
New York City Department of Health and Mental Hygiene, New York, NY, USA

1. INTRODUCTION

This air quality modeling study was designed to examine and quantify the effects of changes in heating oil and fuel use in the power sector on air quality in New York City (NYC). Key components of the assessment included the preparation of meteorological inputs for a base year of 2008, preparation of emission inputs for the base year and the various alternative emission scenarios, application of the Community Multiscale Air Quality (CMAQ) model, model performance evaluation and assessment of the air quality impacts/benefits.

The air quality assessment focused on ozone, fine particulate matter ($PM_{2.5}$), nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) and was specifically designed to examine the benefits of emission reductions at the local scale for New York City neighborhoods. To achieve this, the modeling was conducted using a high-resolution modeling grid with 1-kilometer (1-km) spacing.

Meteorological input fields for the CMAQ model for the New York City air quality assessment were prepared using the WRF meteorological model. Both the WRF and CMAQ models were applied for an annual simulation and for a modeling domain that includes four nested grids with approximately 45-, 15-, 5- and 1-kilometer (km) horizontal resolution. Good model performance was achieved for both WRF and the CMAQ models

CMAQ was applied for a variety of scenarios reflecting changes in fuel-related emissions. The modeling results indicate that full implementation of heating oil emission control programs will result in improved air quality in New York City, with large reductions (on the order of 20 and 65 percent, respectively) in peak, NAAQS-relevant $PM_{2.5}$ and SO_2 concentrations. Regional-scale changes in fuel use in the electric power generation sector since 2005 have also resulted in reductions of 2 to 4 percent in NAAQS-relevant ozone, $PM_{2.5}$ and SO_2 concentrations.

This study was sponsored by the New York City Department of Health and Mental Hygiene (DOHMH) and the Mayor's Office of Long Term Planning and Sustainability (OLTPS). The modeling results are being used to quantify the air quality and public health benefits attributable to recent changes in fuel use in the heating and power sectors. The changes in boiler fuels were mandated in recent years within the New York City area to phase out the use of high-sulfur residual oil and to institute the use of low-sulfur (15 ppm) distillate oil or natural gas for all heating units.

2. APPLICATION AND EVALUATION OF WRF

Meteorological input fields for the CMAQ model for the New York City air quality assessment were prepared using the WRF meteorological model. Specifically, version 3.4 of the Advanced Research WRF (ARW) model was used. The ARW version of the WRF model contains data assimilation capabilities that are integral to the use of the model for air quality modeling of historical simulation periods.

The WRF model was applied for the calendar year 2008. The modeling domain includes four nested grids with approximately 45-, 15-, 5- and 1-kilometer (km) horizontal resolution. The 15-, 5- and 1-km grids encompass the corresponding CMAQ grids with "buffer" regions around the CMAQ grids to minimize WRF boundary influences. The 1-km grid is centered over New York City. In the vertical dimension, the modeling domain includes 34 layers.

For this application, surface temperature and moisture were characterized using the Noah Land Surface Model (LSM).

For the coarser grids, the Grell-Devenyi ensemble cumulus parameterization scheme was used to parameterize the effects of convection on the simulated environment. This feature was not

---

**Corresponding author:* Sharon G. Douglas, ICF International, 101 Lucas Valley Road, Suite 260, San Rafael, CA 94903; e-mail: sharon.douglas@icfi.com

employed for the 5- and 1-km grids where the model can explicitly resolve convection.

Analysis nudging, in which the simulation variables are "nudged" toward an objective analysis that incorporates observed data, was used for all parameters for the outer modeling grids. Analysis nudging of temperature and moisture was applied only above the planetary boundary layer. Observational nudging, in which the simulation parameters are nudged directly toward selected observations, was used for surface winds within the high-resolution grids. Figures 1 through 3 illustrate WRF model performance for the 1-km grid. Results shown are for wind speed, wind direction and temperature for the month of April (2008).

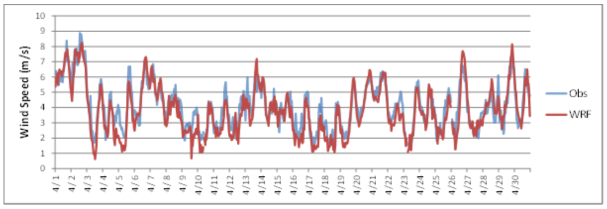

Fig. 1. Average observed (Obs) and simulated (WRF) surface wind speed (m/s) for the NYC 1-km grid: April.

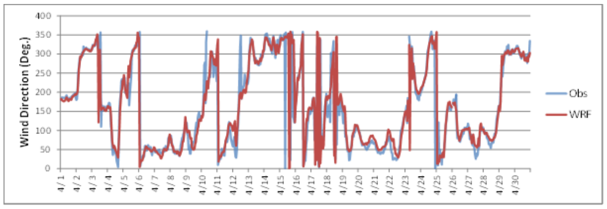

Fig. 2. Average observed (Obs) and simulated (WRF) surface wind direction (degrees) for the NYC 1-km grid: April.

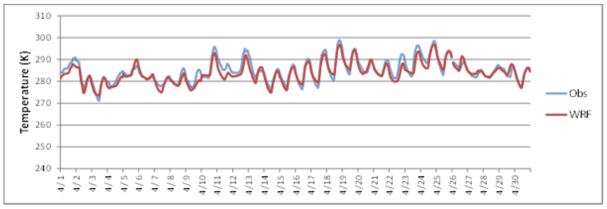

Fig. 3. Average observed (Obs) and simulated (WRF) surface temperature (K) for the NYC 1-km grid: April.

Overall good model agreement between the simulated and observed values was achieved and the WRF meteorological fields were processed for input to the CMAQ model.

3. APPLICATION AND EVALUATION OF CMAQ

Version 5.0 of the CMAQ model was used for the New York City high-resolution modeling analysis. The CMAQ modeling domain (Figure 4) includes a 15-km resolution outer grid encompassing the northeastern U.S.; a 5-km resolution intermediate grid over the greater New York area; and a 1-km resolution inner grid over the City.

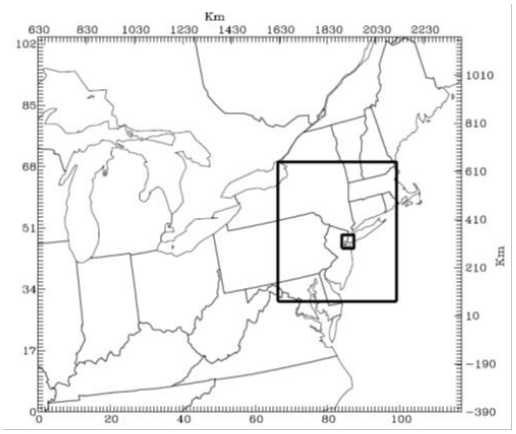

Fig. 4. CMAQ modeling domain for the NYC modeling analysis: 15-, 5- and 1-km grids.

The CMAQ modeling results were compared with observed data, using a variety of graphical and statistical analysis products. Figure 5 compares simulated and observed daily maximum 8-hour ozone concentrations for the 1-km grid for April through October.

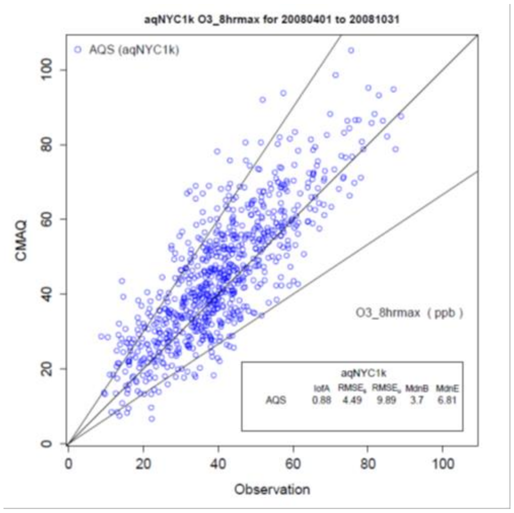

Fig. 5. Comparison of simulated and observed daily maximum 8-hour average ozone concentration (ppb) for the 1-km grid (April through October).

There is a general tendency for CMAQ to overestimate the 8-hour average ozone concentrations and good correlation overall as indicated by an index of agreement of 0.88.

Figure 6 compares simulated and observed 24-hour $PM_{2.5}$ concentrations for the 1-km grid for the full annual simulation period.

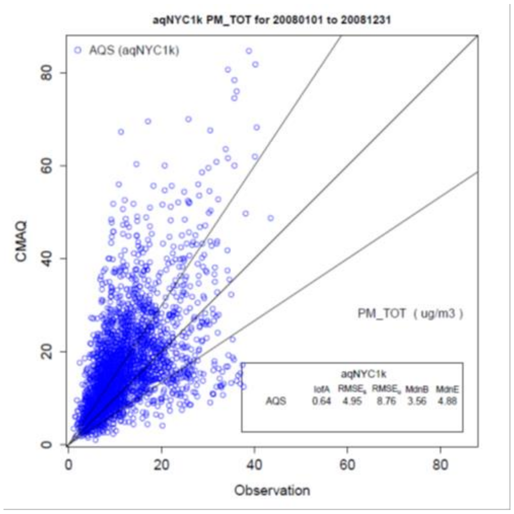

Fig. 6. Comparison of simulated and observed 24-hour average $PM_{2.5}$ concentration (μg/m3) for the 1-km grid (all months).

The scatter plot reveals a tendency for overestimation of the observed $PM_{2.5}$ concentrations, especially concentrations greater than approximately 40 μg/m^3.

4. MODELING RESULTS FOR THE HEATING OIL SCENARIOS

Two CMAQ scenarios examined the effects of local changes in heating fuels:

- Scenario #1: Partial implementation of the rule on heating oil, reflecting the reduction in emissions achieved by the end of the 2012-2013 winter heating season.
- Scenario #2: Full implementation of the rule on heating oil (complete phase out of No. 4 and No. 6 heating oil).

Both heating oil scenarios also included implementation of a 15 ppm sulfur limit to No. 2 heating oil.

The base emission inventory was developed using emission estimates from the National Emission Inventory (NEI) supplemented by local permit data. The permit data provided the emissions and locations of all boilers from heating systems in commercial, residential, institutional and industrial buildings in New York City that use residual oil (No. 6 or No. 4) as their primary fuel, and emissions and locations of all No. 2 oil burning boilers over 350,000 BTUs in New York City subject to Department of Environmental Protection (DEP) permitting. Emissions for primary $PM_{2.5}$, oxides of nitrogen (NO_x), SO_2 and carbon monoxide (CO) were generated using information of heat throughput of each boiler combined with source- and fuel- specific emissions factors. This refinement of the emission inventory facilitated the adjustment of the boiler emissions for the two scenarios and the accurate accounting of the reductions from boiler fuel switching and reductions in fuel sulfur content at the neighborhood scale.

For both scenarios, the reduction in emissions leads to simulated increases in ozone and decreases in $PM_{2.5}$, NO_2 and SO_2 concentrations over New York City and beyond. As expected, the decreases are greatest for the winter months when heating fuel consumption is greatest. The decrease in SO_2 is especially large. Full implementation of the heating oil rule results in greater and more widespread decreases in $PM_{2.5}$ compared to partial implementation, as illustrated in Figures 7 and 8.

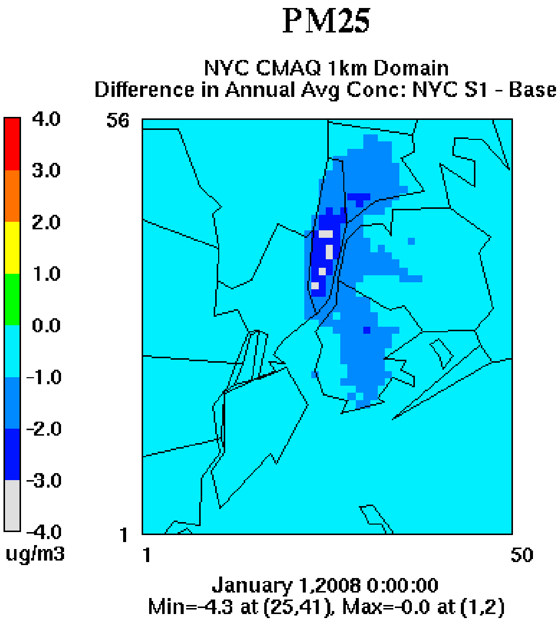

Fig. 7. Difference in Simulated Annual Average $PM_{2.5}$ Concentration: Scenario #1 Minus Base.

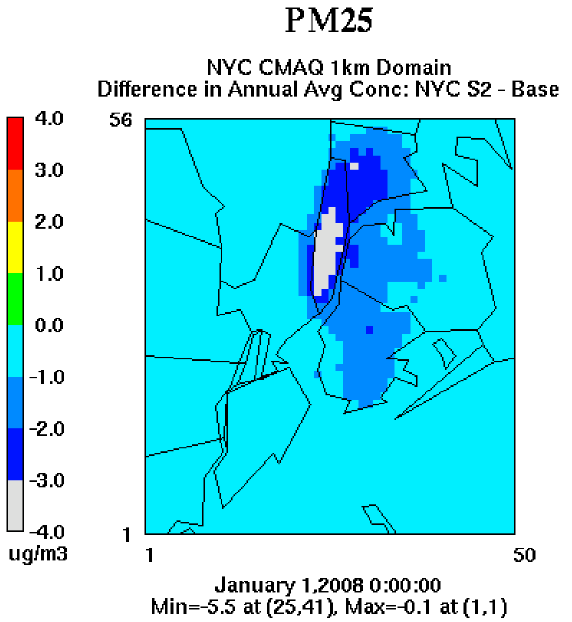

Fig. 8. Difference in Simulated Annual Average $PM_{2.5}$ Concentration: Scenario #2 Minus Base.

Annual average $PM_{2.5}$ concentrations within the 1-km grid are reduced by as much as 4.3 $\mu g/m^3$ with partial implementation of the rule (Scenario #1) and by as much as 5.5 $\mu g/m^3$ with full implementation of the rule (Scenario #2). Decreases occur over Manhattan, Brooklyn, Queens and the Bronx, with the greatest decreases over Manhattan.

5. MODELING RESULTS FOR THE EGU SCENARIOS

Two additional scenarios examined the effects of changes in electric generating unit (EGU) fuel between 2005 and the present:

- Scenario #3: Adjustment of EGU emissions to reflect changes in fuel use at Title V EGUs outside of the five boroughs of New York City.
- Scenario #4: Adjustment of EGU emissions to reflect changes in fuel use at EGUs located within the five boroughs.

For Scenario #3, the reduction in NO_x emissions outside of New York City but within the 1-km grid leads to simulated increases in ozone concentration throughout the 1-km grid, including over New York City. The reduction in NO_x and SO_2 emissions leads to simulated decreases in $PM_{2.5}$ concentration. Annual average $PM_{2.5}$ concentrations within the 1-km grid are reduced by as much as 2.6 $\mu g/m^3$, with fairly uniform decreases on the order of 1 to 2 $\mu g/m^3$ over New York City.

For Scenario #4, the reduction in EGU NO_x emissions in the five-borough area leads to increases in ozone concentration over New York City. The influence of the local emission reductions is largely confined to the five-borough area. The reduction in NO_x and SO_2 emissions leads to small simulated decreases in $PM_{2.5}$ concentration over New York City. Annual average $PM_{2.5}$ concentrations within the 1-km grid are reduced by as much as 0.4 $\mu g/m^3$.

6. AUTHORS' NOTES

This air quality modeling exercise demonstrates that grid-based meteorological and air quality models can be reliably applied at 1-km grid resolution to examine the effects of both regional and local emission changes on air quality at the local scale for New York City neighborhoods. The modeling results are being used to quantify the air quality and public health benefits attributable to recent changes in fuel use in the heating and power sectors. In one such study (Kheirbek et. al., 2014), the local emission data and high-resolution modeling results for the heating oil scenarios have been used to support local-scale air quality health impact analyses and to estimate the city-wide and neighborhood-level public health benefits of the programs developed to reduce emissions from the heating sector. The authors found that, based on the modeling results, the air quality improvements from full implementation of heating oil strategies are expected to result in hundreds of avoided deaths, emergency department visits and hospitalizations for respiratory or cardiovascular causes each year. The benefits of the program were found to be uneven across New York City, with the greatest health benefits expected to occur in high poverty neighborhoods. The modeling platform is expected to be used in the future to examine the air quality and health effects benefits of emission reduction programs for motor vehicles.

7. REFERENCES

Kheirbek, I., J. Haney, S. Douglas, K. Ito, S. Caputo Jr. and T. Matte, 2014: The public health benefits of reducing fine particulate matter through conversion to cleaner heating fuels in New York City. Submitted to *Env. Sci. & Technol.*