Air Quality Modeling Technical Support Document for Midwest Ozone Group's Updated 4km Modeling

Final Technical Support Document

Prepared by:

Alpine Geophysics, LLC
387 Pollard Mine Road
Burnsville, NC 28174

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1.0 INTRODUCTION

1.1 OVERVIEW

Sections 110(a)(1) and (2) of the Clean Air Act (CAA) require all states to adopt and submit to the U. S. Environmental Protection Agency (EPA) any revisions to their infrastructure State Implementation Plans (SIP) which provide for the implementation, maintenance and enforcement of a new or revised national ambient air quality standard (NAAQS). CAA section 110(a)(2)(D)(i)(I) requires each state to prohibit emissions that will significantly contribute to nonattainment of a NAAQS, or interfere with maintenance of a NAAQS, in a downwind state. The EPA revised the ozone NAAQS in March 2008 and completed the designation process to identify nonattainment areas in July 2012. Under this revision, the 8-hour ozone NAAQS form is the three year average of the fourth highest daily maximum 8-hour ozone concentrations with a threshold not to be exceeded of 0.075 ppm (75 ppb).

On October 1, 2015, EPA promulgated a revision to the ozone NAAQS, lowering the level of both the primary and secondary standards to 70 parts per billion (ppb) (80 FR 65292). Pursuant to CAA section 110(a), good neighbor SIPs are, therefore, due by October 1, 2018. This promulgated revision changed the threshold as to not exceed a value of 0.070 ppm (70 ppb). This document serves to provide a technical support document for recently updated 4km air quality modeling and results recently conducted by Alpine Geophysics, LLC (Alpine) under contract to the Midwest Ozone Group (MOG) for purposes of individual state review and preparation of 8-hour ozone modeling analysis in support of revisions of the 2008 and 2015 8-hour ozone Good Neighbor State Implementation Plans (GNS).

This document describes our initial modeling effort was developed using EPA's national 12km modeling domain (12US2) and further refined with two 4km modeling domains over a Mid-Atlantic region and Lake Michigan. It uses the 2011/2023en modeling platform which represents EPA's estimation of a projected "base case" that demonstrates compliance with final CSAPR update seasonal EGU NOx budgets.

Our 4km modeling exercise largely utilized the same platform configuration with new meteorological and emissions data prepared for the 4km domains to support both attainment demonstration and source apportionment simulations.

1.2 STUDY BACKGROUND

Section 110(a)(2)(D)(i)(I) of the CAA requires that states address the interstate transport of pollutants and ensure that emissions within the state do not contribute significantly to nonattainment in, or interfere with maintenance by, any other state.

On October 26, 2016, EPA published in the Federal Register (81 FR 74504) a final update to the Cross-State Air Pollution Rule (CSAPR) for the 2008 ozone NAAQS. In this final update, EPA outlines its four-tiered approach to addressing the interstate transport of pollution related to the ozone NAAQS, or states' Good Neighbor responsibilities. EPA's approach determines which states contribute significantly to nonattainment areas or significantly interfere with air quality in maintenance areas in downwind states. EPA has determined that if a state's contribution to downwind air quality problems is below one percent of the applicable NAAQS, then it does not consider that state to be significantly contributing to the downwind area's nonattainment or maintenance concerns. EPA's approach to addressing interstate transport has been shaped by public notice and comment and refined in response to court decisions.

As part of the final CSAPR update, EPA released regional air quality modeling to support the 2008 ozone NAAQS attainment date of 2017, indicating which states significantly contribute to nonattainment or maintenance area air quality problems in other states. To make these determinations, the EPA projected future ozone nonattainment and maintenance receptors, then conducted state-level ozone source apportionment modeling to determine which states contributed pollution over a pre-identified "contribution threshold."

A follow-up technical memorandum was issued by EPA on October 27, 2017 (Page, 2017) that provided supplemental information on interstate SIP submissions for the 2008 ozone NAAQS. In this memorandum, EPA provided future year 2023 design value calculations and source contribution results with updated modeling and included background on the four-step process interstate transport framework that the EPA uses to address the good neighbor provision for regional pollutants. This document also explains EPA's choice of 2023 as the new analytic year for the 2008 ozone NAAQS, introduced the "no water" approach to calculating relative response factors (RRFs) at coastal sites, and confirmed that there are no monitoring sites, outside of California, that were projected to have nonattainment or maintenance problems with respect to the 2008 ozone NAAQS of 75 ppb in 2023.

Concurrent with EPA's modeling documented in the October 2017 memo, Alpine was conducting good neighbor SIP modeling for the Commonwealth of Kentucky (Alpine, 2017) using EPA's 2023en modeling platform. This analysis confirmed EPA's "3x3 grid cell" findings and specifically noted that none of the problem monitors identified in EPA's final rule were predicted to be in nonattainment or have issues with maintenance in 2023 and therefore Kentucky (and by extension, any other upwind state) was not required to estimate its contribution to these monitors.

On March 27, 2018, EPA released a technical memorandum (Tsirigotis, 2018) providing additional information on interstate SIP submissions for the 2015 ozone NAAQS. In this memo, EPA provided incremental results of their 12km modeling using a projection year of 2023, including updated source apportionment results, a "no water" grid cell RRF methodology, and a discussion of potential flexibilities in analytical approaches that an upwind state may consider in developing GNS. As discussed in greater detail in Section 1.3.3, the year of 2023 was selected as the analytic year in EPA's modeling primarily because it aligned with the anticipated attainment year for Moderate ozone nonattainment areas and because it reflected the timeframe for implementing further emission reductions.

EPA's goal in providing these new ozone air quality projections for 2023 was to assist states' efforts to develop GNS for the 2015 ozone NAAQS.

A number of monitors in the eastern U.S. were found to be in nonattainment of the 2015 ozone NAAQS with multiple states demonstrating contribution to projected downwind nonattainment area air quality over the one-percent threshold at EPA-identified nonattainment or maintenance monitors. These EPA-identified monitors are provided in Table 1-1 along with their 3-yr design value for the period 2014-2016.

As EPA found that multiple state contributions to projected downwind maintenance problems at these monitors is above the one percent threshold and thus significant, additional analyses are required to identify these upwind state responsibilities under the Good Neighbor Provisions for the various ozone NAAQS.

Table 1-1. EPA-identified eastern U.S. nonattainment and maintenance monitors.

Monitor	State	County	2009-2013 Avg	2009-2013 Max	2023en "3x3" Avg	2023en "3x3" Max	2023en "No Water" Avg	2023en "No Water" Max	2014-2016
90010017	CT	Fairfield	80.3	83	69.8	72.1	68.9	71.2	80
90013007	CT	Fairfield	84.3	89	71.2	75.2	71.0	75.0	81
90019003	CT	Fairfield	83.7	87	72.7	75.6	73.0	75.9	85
90099002	CT	New Haven	85.7	89	71.2	73.9	69.9	72.6	76
240251001	MD	Harford	90.0	93	71.4	73.8	70.9	73.3	73
260050003	MI	Allegan	82.7	86	69.0	71.8	69.0	71.7	75
261630019	MI	Wayne	78.7	81	69.0	71.0	69.0	71.0	72
360810124	NY	Queens	78.0	80	70.1	71.9	70.2	72.0	69
360850067	NY	Richmond	81.3	83	71.9	73.4	67.1	68.5	76
361030002	NY	Suffolk	83.3	85	72.5	74.0	74.0	75.5	72
480391004	TX	Brazoria	88.0	89	74.0	74.9	74.0	74.9	75
481210034	TX	Denton	84.3	87	69.7	72.0	69.7	72.0	80
482011024	TX	Harris	80.3	83	70.4	72.8	70.4	72.8	79
482011034	TX	Harris	81.0	82	70.8	71.6	70.8	71.6	73
482011039	TX	Harris	82.0	84	71.8	73.6	71.8	73.5	67
484392003	TX	Tarrant	87.3	90	72.5	74.8	72.5	74.8	73
550790085	WI	Milwaukee	80.0	82	65.4	67.0	71.2	73.0	71
551170006	WI	Sheboygan	84.3	87	70.8	73.1	72.8	75.1	79

1.2.2 Purpose

This document primarily serves to provide the air quality modeling approach and results for two 4km grid domains in support of revisions that states may make to their 2008 or 2015 8-hour ozone Good Neighbor State Implementation Plan (GNS). This document demonstrates that many of the eastern state receptors demonstrate modeled attainment using a finer grid 4km modeling domain (compared to 12km results).

1.3 OVERVIEW OF MODELING APPROACH

The GNS 8-Hour ozone SIP modeling documented here includes an ozone simulation study using the 12 km grid based on EPA's 2011/2023en modeling platform supplemented with two additional 4km modeling domains over the Mid-Atlantic region and Lake Michigan.

1.3.1 Episode Selection

Episode selection is an important component of an 8-hour ozone attainment demonstration. EPA guidance recommends that 10 days be used to project 8-hour ozone Design Values at each critical monitor. The May 1 through August 31 2011 ozone season period was selected for the ozone SIP modeling primarily due to the following reasons:

- It is aligned with the 2011 NEI year, which is the latest NEI modeled in a regulatory platform.
- It is not an unusually low ozone year.
- Ambient meteorological and air quality data are available.
- A 2011 12 km CAMx modeling platform was available from the EPA that was leveraged for the GNS ozone SIP modeling.

More details of the summer 2011 episode selection and justification using criteria in EPA's modeling guidance are contained in Section 3.

1.3.2 Model Selection

Details on the rationale for model selection are provided in Section 2. The Weather Research Forecast (WRF) prognostic meteorological model was selected for the GNS ozone modeling using both the EPA 12US2 grid and two additional 4km modeling grids. Additional emission modeling was not required for the 12km simulation as the 2023en platform was provided to Alpine in pre-merged CAMx ready format. For both the base and future years, 4km subgrids were created using the EPA-provided SMOKE emissions input files and the CONUS 4km spatial surrogates developed by EPA for the 2014 platform modelling

Emissions processing was completed by EPA for the 12km domain and Alpine for the two 4km domains using the SMOKE emissions model for most source categories. The exceptions are that BEIS model was used for biogenic emissions and there are special processors for fires, windblown dust, lightning and sea salt emissions. The MOVES2014 on-road mobile source emissions model was used with SMOKE-MOVES to generate on-road mobile source emissions with EPA generated vehicle activity data provided in the NAAQS NODA. The same version of the CAMx photochemical grid model was also used. The setup is based on the same WRF/SMOKE/BEIS/CAMx modeling system used in the EPA 2023en platform modeling.

1.3.3 Base and Future Year Emissions Data

The 2023 future year was selected for the attainment demonstration modeling based on OAQPS Director Steven Page's October 27, 2017 memo (Page, 2017, page 4) to Regional Air Directors. In this memo, Director Page identified the two primary reasons the EPA selected 2023 for their 2008 NAAQS modeling; (1) the D.C. Circuit Court's response to *North Carolina v. EPA* in considering downwind attainment dates for the 2008 NAAQS, and (2) EPA's consideration of the timeframes that may be required for implementing further emission reductions as expeditiously as possible. The 2011 base case and 2023 future year emissions were based on EPA's "en" inventories with no adjustment. This platform has been identified by EPA as the base case for compliance with the final CSAPR update seasonal EGU NOx emission budgets.

1.3.4 Input Preparation and QA/QC

Quality assurance (QA) and quality control (QC) of the emissions datasets are some of the most critical steps in performing air quality modeling studies. Because emissions processing is tedious, time consuming and involves complex manipulation of many different types of large databases, rigorous QA measures are a necessity to prevent errors in emissions processing from occurring. The GNS 8-Hour ozone modeling study utilized EPA's pre-QA/QC'd emissions platform that followed a multistep emissions QA/QC approach for the 12km domain. Additional tabular and graphical review of the 4km emissions was conducted to ensure consistency with the 12km modeling results on spatial, temporal, and speciated levels.

1.3.5 Meteorology Input Preparation and QA/QC

The CAMx 2011 12 km meteorological inputs are based on WRF meteorological modeling conducted by EPA. Details on the EPA 2011 WRF application and evaluation are provided by EPA (EPA 2014d). Additional WRF simulations were conducted to generate meteorological data fields to support the 4km modeling domains. A performance evaluation of this incremental modeling was prepared (Alpine, 2018a) and confirmed adequacy of the files for SIP attainment and contribution analyses.

1.3.6 Initial and Boundary Conditions Development

Initial concentrations (IC) and Boundary Conditions (BC) are important inputs to the CAMx model. We ran 15 days of model spin-up before the first of each month so the ICs are washed out of the modeling domain. The lateral boundary and initial species concentrations are provided by a three dimensional global atmospheric chemistry model, GEOS-Chem (Yantosca, 2004) standard version 8-03-02 with 8-02-01 chemistry and were unchanged from the files EPA used in the "en" modeling platform.

The 4km domains were run as two-way interactive nests within the 12km simulation and therefore were provided with updated boundary conditions at each integration time step and provided up-scale feedback from the 4km domains to the 12km domain.

1.3.7 Air Quality Modeling Input Preparation and QA/QC

Each step of the air quality modeling was subjected to QA/QC procedures. These procedures included verification of model configurations, confirmation that the correct data were used and processed correctly, and other procedures.

1.3.8 Model Performance Evaluation

The Model Performance Evaluation (MPE) relied on the 12km CAMx MPE from EPA's associated modeling platforms. EPA's MPE recommendations in their ozone modeling guidance (EPA, 2007; 2014e) were followed in this evaluation. Many of EPA's MPE procedures have already been performed by EPA in their CAMx 2011 modeling database being used in the GNS ozone SIP modeling. An additional MPE was prepared by Alpine (Alpine, 2018b) to support the 4km domains and confirmed the adequacy of the analysis for SIP and contribution analyses.

1.3.9 Diagnostic Sensitivity Analyses

Since no issues were identified in confirming Alpine's 12km CAMx runs compared to EPA's using the same modeling platform and configuration, additional diagnostic sensitivity analyses were not required.

2.0 MODEL SELECTION

This section documents the models used in this 8-hour ozone GNS SIP modeling study. The selection methodology presented in this chapter mirrors EPA's and other's regulatory modeling in support of the 2008 Ozone NAAQS Preliminary Interstate Transport Assessment (Page, 2017; Alpine, 2017; EPA, 2016b) and technical memorandum providing additional information on the Interstate SIP submissions for the 2015 Ozone NAAQS (Tsirigotis, 2018).

Unlike previous ozone modeling guidance that specified a particular ozone model (e.g., EPA, 1991 that specified the Urban Airshed Model; Morris and Myers, 1990), the EPA now recommends that models be selected for ozone SIP studies on a "case-by-case" basis. The latest EPA ozone guidance (EPA, 2014) explicitly mentions the CMAQ and CAMx PGMs as the most commonly used PGMs that would satisfy EPA's selection criteria but notes that this is not an exhaustive list and does not imply that they are "preferred" over other PGMs that could also be considered and used with appropriate justification. EPA's current modeling guidelines lists the following criteria for model selection (EPA, 2014e):

- It should not be proprietary;
- It should have received a scientific peer review;
- It should be appropriate for the specific application on a theoretical basis;
- It should be used with data bases which are available and adequate to support its application;
- It should be shown to have performed well in past modeling applications;
- It should be applied consistently with an established protocol on methods and procedures;
- It should have a user's guide and technical description;
- The availability of advanced features (e.g., probing tools or science algorithms) is desirable; and
- When other criteria are satisfied, resource considerations may be important and are a legitimate concern.

For the GNS 8-hour ozone modeling, we used the WRF/SMOKE/MOVES2014/BEIS/CAMx modeling system as the primary tool for demonstrating attainment of the ozone NAAQS at downwind monitors at downwind problem monitors. The utilized modeling system satisfies all of EPA's selection criteria. A description of the key models to be used in the GNS ozone SIP modeling follows.

<u>WRF/ARW:</u> The Weather Research and Forecasting (WRF)[1] Model is a mesoscale numerical weather prediction system designed to serve both operational forecasting and atmospheric research needs (Skamarock, 2004; 2006; Skamarock et al., 2005). The Advanced Research WRF (ARW) version of WRF was used in this ozone modeling study. It features multiple dynamical cores, a 3-dimensional variational (3DVAR) data assimilation system, and a software architecture allowing for computational parallelism and system extensibility. WRF is suitable

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[1] http://www.wrf-model.org/index.php

for a broad spectrum of applications across scales ranging from meters to thousands of kilometers. The effort to develop WRF has been a collaborative partnership, principally among the National Center for Atmospheric Research (NCAR), the National Oceanic and Atmospheric Administration (NOAA), the National Centers for Environmental Prediction (NCEP) and the Forecast Systems Laboratory (FSL), the Air Force Weather Agency (AFWA), the Naval Research Laboratory, the University of Oklahoma, and the Federal Aviation Administration (FAA). WRF allows researchers the ability to conduct simulations reflecting either real data or idealized configurations. WRF provides operational forecasting a model that is flexible and efficient computationally, while offering the advances in physics, numerics, and data assimilation contributed by the research community.

<u>SMOKE:</u> The Sparse Matrix Operator Kernel Emissions (SMOKE)[2] modeling system is an emissions modeling system that generates hourly gridded speciated emission inputs of mobile, non-road, area, point, fire and biogenic emission sources for photochemical grid models (Coats, 1995; Houyoux and Vukovich, 1999). As with most ‘emissions models’, SMOKE is principally an emission processing system and not a true emissions modeling system in which emissions estimates are simulated from ‘first principles’. This means that, with the exception of mobile and biogenic sources, its purpose is to provide an efficient, modern tool for converting an existing base emissions inventory data into the hourly gridded speciated formatted emission files required by a photochemical grid model. SMOKE was used by EPA to prepare 2023en emission inputs for non-road mobile, area and point sources. These files were adopted and used as-is for this analysis.

<u>SMOKE-MOVES</u>: SMOKE-MOVES uses an Emissions Factor (EF) Look-Up Table from MOVES, gridded vehicle miles travelled (VMT) and other activity data and hourly gridded meteorological data (typically from WRF) and generates hourly gridded speciated on-road mobile source emissions inputs.

<u>MOVES2014:</u> MOVES2014[3] is EPA’s latest on-road mobile source emissions model that was first released in July 2014 (EPA, 2014a,b,c). MOVES2014 includes the latest on-road mobile source emissions factor information. Emission factors developed by EPA were used in this analysis.

<u>BEIS:</u> Biogenic emissions were modeled by EPA using version 3.61 of the Biogenic Emission Inventory System (BEIS). First developed in 1988, BEIS estimates volatile organic compound (VOC) emissions from vegetation and nitric oxide (NO) emissions from soils. Because of resource limitations, recent BEIS development has been restricted to versions that are built within the Sparse Matrix Operational Kernel Emissions (SMOKE) system.

<u>CAMx:</u> The Comprehensive Air quality Model with Extensions (CAMx[4]) is a state-of-science “One-Atmosphere” photochemical grid model capable of addressing ozone, particulate matter (PM), visibility and acid deposition at regional scale for periods up to one year (ENVIRON,

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[2] http://www.smoke-model.org/index.cfm
[3] http://www.epa.gov/otaq/models/moves/
[4] http://www.camx.com

2015[5]). CAMx is a publicly available open-source computer modeling system for the integrated assessment of gaseous and particulate air pollution. Built on today's understanding that air quality issues are complex, interrelated, and reach beyond the urban scale, CAMx is designed to (a) simulate air quality over many geographic scales, (b) treat a wide variety of inert and chemically active pollutants including ozone, inorganic and organic $PM_{2.5}$ and PM_{10} and mercury and toxics, (c) provide source-receptor, sensitivity, and process analyses and (d) be computationally efficient and easy to use. The U.S. EPA has approved the use of CAMx for numerous ozone and PM State Implementation Plans throughout the U.S., and has used this model to evaluate regional mitigation strategies including those for most recent regional rules (e.g., Transport Rule, CAIR, NO_X SIP Call, etc.). CAMx Version 6.40 was used in this study.

<u>SMAT-CE:</u> The Software for the Modeled Attainment Test - Community Edition (SMAT-CE)[6] is a PC-based software tool that can perform the modeled attainment tests for particulate matter and ozone, and calculate changes in visibility at Class I areas as part of the reasonable progress analysis for regional haze. Version 1.2 (Beta) was used in this analysis.

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[5] http://www.camx.com/files/camxusersguide_v6-20.pdf

[6] https://www.epa.gov/scram/photochemical-modeling-tools

3.0 EPISODE SELECTION

EPA's most recent 8-hour ozone modeling guidance (EPA, 2014e) contains recommended procedures for selecting modeling episodes The GNS ozone SIP revision modeling used the May through end of August 2011 modeling period because it satisfies the most criteria in EPA's modeling guidance episode selection discussion.

EPA guidance recommends that 10 days be used to project 8-hour ozone Design Values at each critical monitor. The May through August 2011 period has been selected for the ozone SIP modeling primarily due to being aligned with the 2011 NEI year, not being an unusually low ozone year and availability of a 2011 12 km CAMx modeling platform from the EPA NAAQS NODA.

4.0 MODELING DOMAIN SELECTION

This section summarizes the modeling domain definitions for the GNS 8-hour ozone modeling, including the domain coverage, resolution, and map projection. It also discusses emissions, aerometric, and other data available for use in model input preparation and performance testing.

4.1 HORIZONTAL DOMAINS

The GNS ozone SIP modeling used a 12 km continental U.S. (12US2) domain and two 4 km subnested domains; one over the Mid-Atlantic region and another over Lake Michigan and surrounding states.

The 12 km nested grid modeling domain configuration is shown in Figure 4-1 with the two 4km domains represented in Figure 4-2. The 12km domain shown in Figure 4-1 represents the CAMx 12km air quality and SMOKE/BEIS emissions modeling domain. The WRF meteorological modeling was run on larger 12 km modeling domains than used for CAMx as demonstrated in EPA's meteorological model performance evaluation document (EPA, 2014d). The WRF meteorological modeling domains are defined larger than the air quality modeling domains because meteorological models can sometimes produce artifacts in the meteorological variables near the boundaries as the prescribed boundary conditions come into dynamic balance with the coupled equations and numerical methods in the meteorological model.

Figure 4-1. Map of 12km CAMx modeling domains. Source: EPA NAAQS NODA.

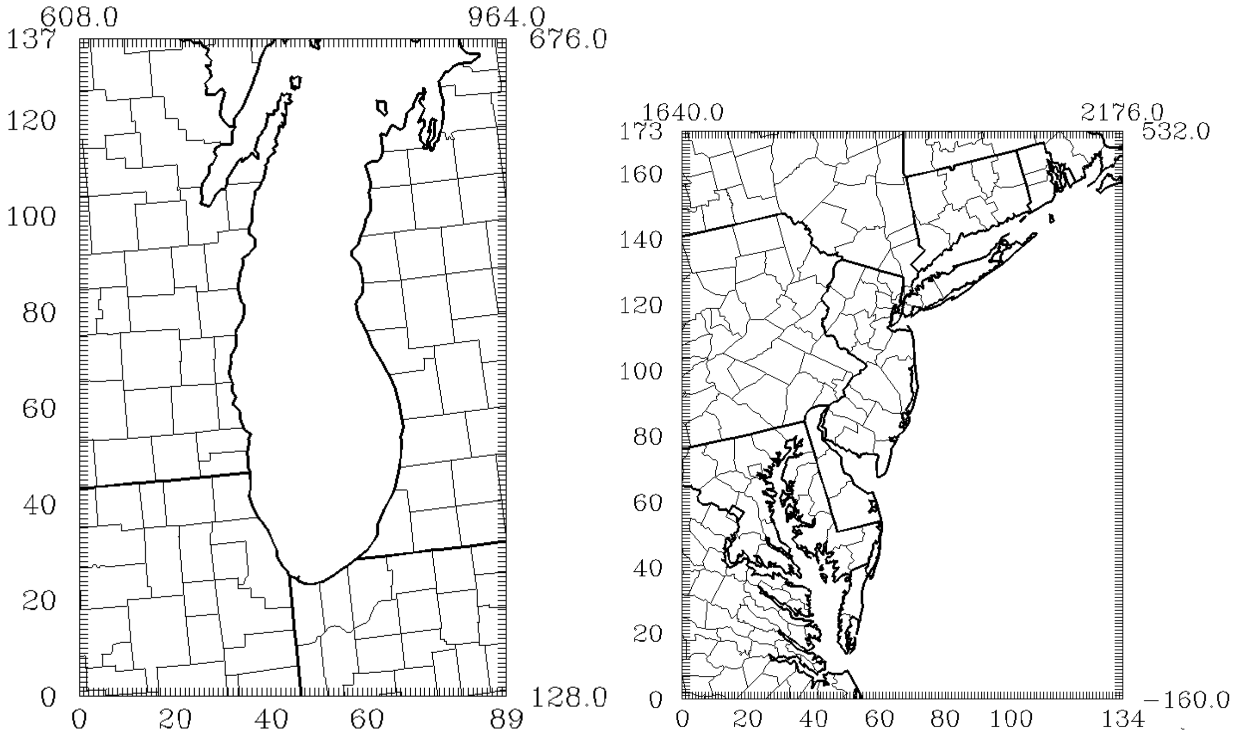

Figure 4-2. Maps of 4km CAMx modeling domains. Lake Michigan (left) and Mid-Atlantic (right).

4.2 VERTICAL MODELING DOMAIN

The CAMx vertical structure is primarily defined by the vertical layers used in the WRF meteorological modeling. The WRF model employs a terrain following coordinate system defined by pressure, using multiple layer interfaces that extend from the surface to 50 mb (approximately 19 km above sea level). EPA ran WRF using 35 vertical layers. A layer averaging scheme is adopted for CAMx simulations whereby multiple WRF layers are combined into one CAMx layer to reduce the air quality model computational time. Table 4-1 displays the approach for collapsing the WRF 35 vertical layers to 25 vertical layers in CAMx for the 12km and 4km grid domains.

Table 4-1. WRF and CAMx layers and their approximate height above ground level.

CAMx Layer	WRF Layers	Sigma P	Pressure (mb)	Approx. Height (m AGL)
25	35	0.00	50.00	17,556
	34	0.05	97.50	14,780
24	33	0.10	145.00	12,822
	32	0.15	192.50	11,282
23	31	0.20	240.00	10,002
	30	0.25	287.50	8,901
22	29	0.30	335.00	7,932
	28	0.35	382.50	7,064
21	27	0.40	430.00	6,275
	26	0.45	477.50	5,553
20	25	0.50	525.00	4,885
	24	0.55	572.50	4,264
19	23	0.60	620.00	3,683
18	22	0.65	667.50	3,136
17	21	0.70	715.00	2,619
16	20	0.74	753.00	2,226
15	19	0.77	781.50	1,941
14	18	0.80	810.00	1,665
13	17	0.82	829.00	1,485
12	16	0.84	848.00	1,308
11	15	0.86	867.00	1,134
10	14	0.88	886.00	964
9	13	0.90	905.00	797
	12	0.91	914.50	714
8	11	0.92	924.00	632
	10	0.93	933.50	551
7	9	0.94	943.00	470
	8	0.95	952.50	390
6	7	0.96	962.00	311
5	6	0.97	971.50	232
4	5	0.98	981.00	154
	4	0.99	985.75	115
3	3	0.99	990.50	77
2	2	1.00	995.25	38
1	1	1.00	997.63	19

4.3 DATA AVAILABILITY

The CAMx modeling systems requires emissions, meteorology, surface characteristics, initial and boundary conditions (IC/BC), and ozone column data for defining the inputs.

4.3.1 Emissions Data

Without exception, the 2011 base year and 2023 base case emissions inventories for ozone modeling for this analysis were based on emissions obtained from the EPA's "en" modeling platform. This platform was obtained from EPA, via LADCO, in late September of 2017 and represents EPA's best estimate of all promulgated national, regional, and local control strategies, including final implementation of the seasonal EGU NOx emission budgets outlined in CSAPR.

4.3.2 Air Quality

Data from ambient monitoring networks for gas species are used in the model performance evaluation. Table 4-2 summarizes routine ambient gaseous and PM monitoring networks available in the U.S.

4.3.4 Meteorological Data

The 12km meteorological data were generated by EPA using the WRF prognostic meteorological model (EPA, 2014d). Alpine ran WRF with identical physics options (with the exception that no cumulus-parameterization was used on the 4km grid) and configuration for the 4km domains as was run by EPA for the 12km domain. WRF was run on a continental U.S. 12 km grid for the NAAQS NODA platform and for two subnested 4km domains as described in earlier sections.

4.3.5 Initial and Boundary Conditions Data

The lateral boundary and initial species concentrations are provided by a three dimensional global atmospheric chemistry model, GEOS-Chem (Yantosca, 2004) standard version 8-03-02 with 8-02-01 chemistry. The global GEOS-Chem model simulates atmospheric chemical and physical processes driven by assimilated meteorological observations from the NASA's Goddard Earth Observing System (GEOS-5; additional information available at: http://gmao.gsfc.nasa.gov/GEOS/ and http://wiki.seas.harvard.edu/geos-chem/index.php/GEOS-5). This model was run for 2011 with a grid resolution of 2.0 degrees x 2.5 degrees (latitude-longitude). The predictions were used to provide one-way dynamic boundary concentrations at one-hour intervals and an initial concentration field for the CAMx simulations. The 2011 boundary concentrations from GEOS-Chem will be used for the 2011 and 2023 model simulations.

The 4km domains were run as two-way interactive nests within the 12km simulation and therefore provided with updated boundary conditions at each integration time step and provided up-scale feedback from the 4km domains to the 12km domain.

Table 4-2. Overview of routine ambient data monitoring networks.

Monitoring Network	Chemical Species Measured	Sampling Period	Data Availability/Source
The Interagency Monitoring of Protected Visual Environments (IMPROVE)	Speciated PM25 and PM10 (see species mappings)	1 in 3 days; 24 hr average	
Clean Air Status and Trends Network (CASTNET)	Speciated PM25, Ozone (see species mappings)	Approximately 1-week average	http://www.epa.gov/castnet/data.html
National Atmospheric Deposition Program (NADP)	Wet deposition (hydrogen (acidity as pH), sulfate, nitrate, ammonium, chloride, and base cations (such as calcium, magnesium, potassium and sodium)), Mercury	1-week average	http://nadp.sws.uiuc.edu/
Air Quality System (AQS) or Aerometric Information Retrieval System (AIRS)	CO, NO2, O3, SO2, PM25, PM10, Pb	Typically hourly average	http://www.epa.gov/air/data/
Chemical Speciation Network (CSN)	Speciated PM	24-hour average	http://www.epa.gov/ttn/amtic/amticpm.html
Photochemical Assessment Monitoring Stations (PAMS)	Varies for each of 4 station types.		http://www.epa.gov/ttn/amtic/pamsmain.html
National Park Service Gaseous Pollutant Monitoring Network	Acid deposition (Dry; SO4, NO3, HNO3, NH4, SO2), O3, meteorological data	Hourly	http://www2.nature.nps.gov/ard/gas/netdata1.htm

5.0 MODEL INPUT PREPARATION PROCEDURES

This section summarizes the procedures used in developing the meteorological, emissions, and air quality inputs to the CAMx model for the GNS 8-hour ozone modeling on the 12km and 4km grids for the May through August 2011 period. Both the 12km and 4km CAMx modeling databases are based on the EPA “en” platform (EPA, 2017a; Page, 2017) databases. While some of the data prepared by EPA for this platform are new, many of the files are largely based on the NAAQS NODA platform. More details on the NAAQS NODA 2011 CAMx database development are provided in EPA documentation as follows:

- Technical Support Document (TSD) Preparation of Emissions Inventories for the Version 6.3, 2011 Emissions Modeling Platform (EPA, 2016a).
- Meteorological Model Performance for Annual 2011 WRF v3.4 Simulation (EPA, 2014d).
- Air Quality Modeling Technical Support Document for the 2015 Ozone NAAQS Preliminary Interstate Transport Assessment (EPA, 2016b).

The modeling procedures used in the modeling are consistent with over 20 years of EPA ozone modeling guidance documents (e.g., EPA, 1991; 1999; 2005a; 2007; 2014), other recent 8-hour ozone modeling studies conducted for various State and local agencies using these or other state-of-science modeling tools (see, for example, Morris et al., 2004a,b, 2005a,b; 2007; 2008a,b,c; Tesche et al., 2005a,b; Stoeckenius et al., 2009; ENVIRON, Alpine and UNC, 2013; Adelman, Shanker, Yang and Morris, 2014; 2015), as well as the methods used by EPA in support of the recent Transport analysis (EPA, 2010; 2015b, 2016b, 2018).

5.1 METEOROLOGICAL INPUTS

5.1.1 WRF Model Science Configuration

For the 12km domain, Version 3.4 of the WRF model, Advanced Research WRF (ARW) core (Skamarock, 2008) was used for generating the 2011 simulations. Selected physics options include Pleim-Xiu land surface model, Asymmetric Convective Model version 2 planetary boundary layer scheme, Kain Fritsch cumulus parameterization utilizing the moisture-advection trigger (Ma and Tan, 2009), Morrison double moment microphysics, and RRTMG longwave and shortwave radiation schemes (Gilliam and Pleim, 2010). The WRF model configuration was prepared by EPA (EPA, 2014d).

The 4km domains were prepared using a nested WRF 3.9 simulation with domains shown in Figure 5-1. This domain, a 36km continental domain and a 12km domain that extends from the western border of the Dakotas off the eastern seaboard has two focused 4km domains over Lake Michigan and the Mid-Atlantic states. The WRF configuration options used in the 4km simulation were the same as those used by EPA, with the exception that no cumulus parameterization was used on the 4km domains. A summary of the 4km WRF application and evaluation are presented elsewhere (Alpine, 2018a).

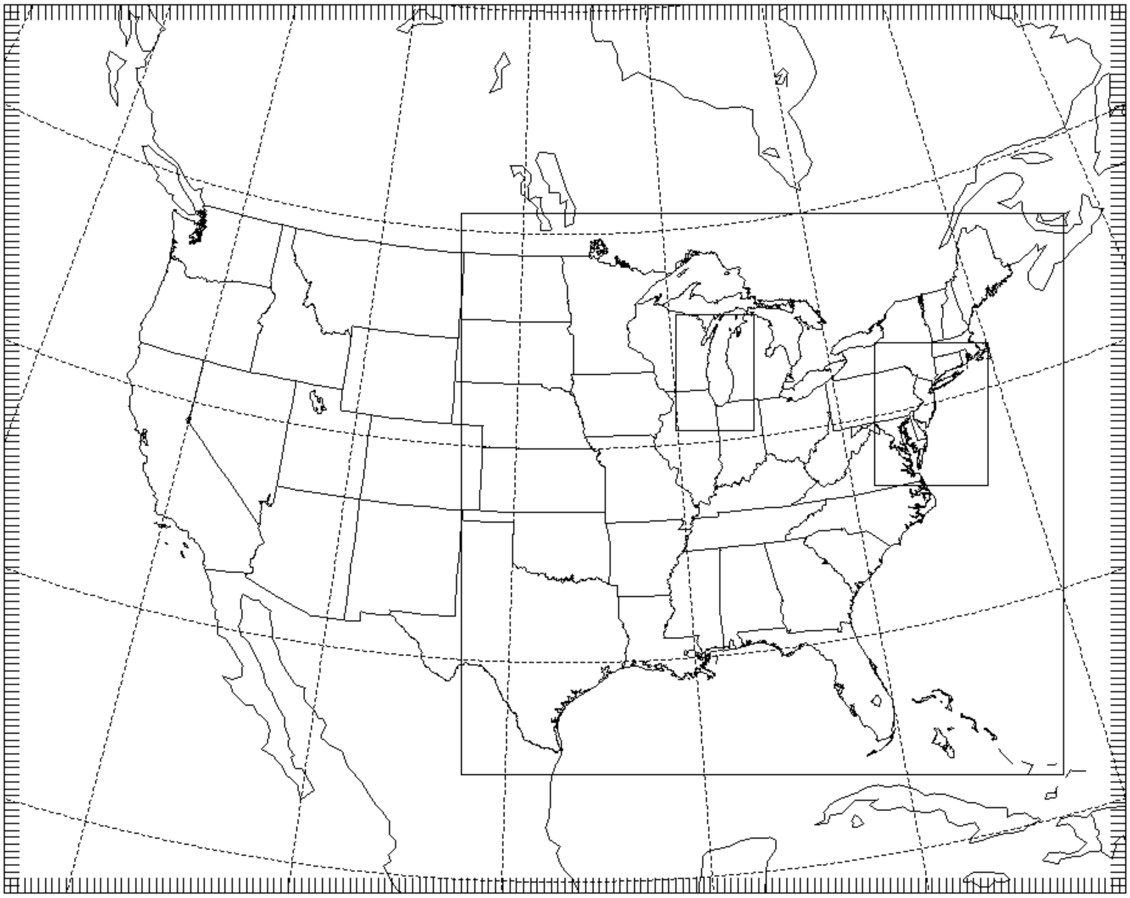

Figure 5-1. Map of WRF domains. The outer domain is the 36km CONUS domain, the large domain is the 12km domain and the inner are the Lake Michigan (left) and Mid-Atlantic (right) 4km domains.

5.1.2 WRF Input Data Preparation Procedures

For the 4km domain a summary of the WRF input data preparation procedures that were used are listed in EPA's documentation (EPA, 2014d). A summary of the 4km WRF application and evaluation are presented elsewhere (Alpine, 2018a).

5.1.3 WRF Model Performance Evaluation

The WRF model evaluation approach was based on a combination of qualitative and quantitative analyses. The quantitative analysis was divided into monthly summaries of 2-m temperature, 2-m mixing ratio, and 10-m wind speed using the boreal seasons to help generalize the model bias and error relative to a set of standard model performance benchmarks. The qualitative approach was to compare spatial plots of model estimated monthly total precipitation with the monthly PRISM precipitation. The WRF model performance evaluation for the 12km domain is provided in EPA's documentation (EPA, 2014d). A separate MPE for the 4km WRF simulations was prepared by Alpine (Alpine, 2018a). This evaluation is comprised of a quantitative and qualitative evaluation of WRF generated fields. The quantitative model performance evaluation of WRF using surface meteorological measurements was performed using the publicly available METSTAT[7] evaluation tool. METSTAT calculates statistical performance metrics for bias, error and correlation for surface winds, temperature and mixing ratio and can produce time series of predicted and observed meteorological variables and performance statistics. Alpine also conducted a qualitative comparison of WRF estimated precipitation with the Climate Prediction Center (CPC) retrospective analysis data.

5.1.4 WRFCAMx/MCIP Reformatting Methodology

The WRF meteorological model output data was processed to provide inputs for the CAMx photochemical grid model. The WRFCAMx processor maps WRF meteorological fields to the format required by CAMx. It also calculates turbulent vertical exchange coefficients (Kv) that define the rate and depth of vertical mixing in CAMx. The methodology used by EPA to reform the meteorological data into CAMx format is provided in documentation provided with the wrfcamx conversion utility.

The meteorological data generated by the WRF simulations were processed by EPA using WRFCAMx v4.3 (Ramboll Environ, 2014) meteorological data processing program to create model-ready meteorological inputs to CAMx. The 4km domains were processed using WRFCAMx v4.6[8]. In running WRFCAMx, vertical eddy diffusivities (Kv) were calculated using the Yonsei University (YSU) (Hong and Dudhia, 2006) mixing scheme with a minimum Kv of 0.1 m^2/sec except for urban grid cells where the minimum Kv was reset to 1.0 m^2/sec within the lowest 200 m of the surface in order to enhance mixing associated with the night time “urban heat island” effect. In addition, all domains used the subgrid convection and subgrid stratoform stratiform cloud options in our wrfcamx.

5.2 EMISSION INPUTS

5.2.1 Available Emissions Inventory Datasets

EPA’s 2011 base year and 2023 future year emission inventories from the “en” modeling platform (EPA, 2017a) were used for all categories without exception.

5.2.2 Development of CAMx-Ready Emission Inventories

CAMx-ready emission inputs were generated by EPA mainly by the SMOKE and BEIS emissions models. CAMx requires two emission input files for each day: (1) low level gridded emissions that are emitted directly into the first layer of the model from sources at the surface with little or no plume rise; and (2) elevated point sources (stacks) with plume rise calculated from stack parameters and meteorological conditions. For this analysis, CAMx was operated using version 6 revision 4 of the Carbon Bond chemical mechanism (CB6r4).

Additional emission modeling was not required for the 12km simulation as the 2023en platform was provided to Alpine in pre-merged near CAMx ready format. For the base and future years, 4km subgrids were created using the EPA-provided SMOKE emissions input files and the CONUS 4km spatial surrogates developed by EPA for the 2014 platform modeling.

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[7] http://www.camx.com/download/support-software.aspx

[8] http://www.camx.com/getmedia/7f3ee9dc-d430-42d6-90d5-dedb3481313f/wrfcamx-11jul17.tgz

5.2.2.1 Episodic Biogenic Source Emissions

Biogenic emissions were generated by EPA using the BEIS biogenic emissions model within SMOKE. BEIS uses high resolution GIS data on plant types and biomass loadings and the WRF surface temperature fields, and solar radiation (modeled or satellite-derived) to develop hourly emissions for biogenic species on the 12 km grids. Alpine ran BEIS using the same underlying data sets as EPA to generate emissions for the 4km domains. BEIS generates gridded, speciated, temporally allocated emission files.

5.2.2.2 Point Source Emissions

2011 point source emissions were from the 2011 “en” modeling platform. Point sources were developed in two categories: (1) major point sources with Continuous Emissions Monitoring (CEM) devices; and (2) point sources without CEMs. For point sources with continuous emissions monitoring (CEM) data, day-specific hourly NO_x and SO_2 emissions were used for the 2011 base case emissions scenario. The VOC, CO and PM emissions for point sources with CEM data were based on the annual emissions temporally allocated to each hour of the year using the CEM hourly heat input. The locations of the point sources were converted to the LCP coordinate system used in the modeling. They were processed by EPA using SMOKE to generate the temporally varying (i.e., day-of-week and hour-of-day) speciated emissions needed by CAMx, using profiles by source category from the EPA “en” modeling platform. Since the elevated point source locations are allocated directly to the grid, rather than by spatial surrogate, rerunning the elevated emissions for the 4km grids was not required.

5.2.2.3 Area and Non-Road Source Emissions

2011 area and non-road emissions were from the 2011 “en” modeling platform. The area and non-road sources were spatially allocated to the grid using an appropriate surrogate distribution (e.g., population for home heating, etc.). The area sources were temporally allocated by month and by hour of day using the EPA source-specific temporal allocation factors. The SMOKE source-specific CB6 speciation allocation profiles were also used.

5.2.2.4 Wildfires, Prescribed Burns, Agricultural Burns

Fire emissions in 2011NEIv2 were developed based on Version 2 of the Satellite Mapping Automated Reanalysis Tool for Fire Incident Reconciliation (SMARTFIRE) system (Sullivan, et al., 2008). SMARTFIRE2 was the first version of SMARTFIRE to assign all fires as either prescribed burning or wildfire categories. In past inventories, a significant number of fires were published as unclassified, which impacted the emissions values and diurnal emissions pattern. Recent updates to SMARTFIRE include improved emission factors for prescribed burning.

5.2.2.5 On-Road Motor Vehicle Emissions

On-road motor vehicle emissions were processed using the SMOKE-MOVES module. The MOVES emissions factors table for the 2011 on-road segments were combined with the 2011 4km meteorology and 4km spatial surrogates to create actual 4km resolution for the on-road emissions.

5.2.2.6 QA/QC and Emissions Merging

EPA processed the emissions by major source category in several different "streams", including area sources, on-road mobile sources, non-road mobile sources, biogenic sources, non-CEM point sources, CEM point sources using day-specific hourly emissions, and emissions from fires. Separate Quality Assurance (QA) and Quality Control (QC) were performed for each stream of emissions processing and in each step following the procedures utilized by EPA. SMOKE includes advanced quality assurance features that include error logs when emissions are dropped or added. In addition, we generated visual displays that included spatial plots of the hourly emissions for each major species (e.g., NOX, VOC, some speciated VOC, SO2, NH3, PM and CO). Emissions for the 4km subgrids were reprocessed using the same emissions streams, lookup and cross reference tables, and adjustment factors as used by the EPA.

Scripts to perform the emissions merging of the appropriate biogenic, on-road, non-road, area, low-level, fire, and point emission files were written to generate the CAMx-ready two-dimensional day and domain-specific hourly speciated gridded emission inputs. The point source and, as available elevated fire, emissions were processed into the day-specific hourly speciated emissions in the CAMx-ready point source format.

The resultant CAMx model-ready emissions were subjected to a final QA using spatial maps to assure that: (1) the emissions were merged properly; (2) CAMx inputs contain the same total emissions; and (3) to provide additional QA/QC information.

In addition, the 4km subgrid nest results were compared with the results from original EPA files that had been windowed from the 12km to the 4km domains. This provided assurance that all of the segments were being represented properly in the new subgrids.

5.2.3 Use of the Plume-in-Grid (PiG) Subgrid-Scale Plume Treatment

Consistent with the EPA 2011 modeling platform, no PiG subgrid-scale plume treatment will be used.

5.2.4 Future-Year Emissions Modeling

Future-year emission inputs were generated by processing the 2023 emissions data provided with EPA's "en" modeling platform without exception.

5.3 PHOTOCHEMICAL MODELING INPUTS

5.3.1 CAMx Science Configuration and Input Configuration

Version of CAMx (Version 6.40) was used in the GNS ozone modeling. The CAMx model setup used is defined by EPA in its air quality modeling technical support documents (EPA, 2016b, 2017, 2018).

6.0 MODEL PERFORMANCE EVALUATION

The CAMx 2011 base case model estimates are compared against the observed ambient ozone and other concentrations to establish that the model is capable of reproducing the current year observed concentrations so it is likely a reliable tool for estimating future year ozone levels.

6.1 MODEL PERFORMACE EVALUATION

6.1.1 Overview of EPA Model Performance Evaluation Recommendations

EPA current (EPA, 2007) and draft (EPA, 2014e) ozone modeling guidance recommendations for model performance evaluation (MPE) describes a MPE framework that has four components:

- Operation evaluation that includes statistical and graphical analysis aimed at determining how well the model simulates observed concentrations (i.e., does the model get the right answer).
- Diagnostic evaluation that focuses on process-oriented evaluation and whether the model simulates the important processes for the air quality problem being studied (i.e., does the model get the right answer for the right reason).
- Dynamic evaluation that assess the ability of the model air quality predictions to correctly respond to changes in emissions and meteorology.
- Probabilistic evaluation that assess the level of confidence in the model predictions through techniques such as ensemble model simulations.

EPA's guidance recommends that "At a minimum, a model used in an attainment demonstration should include a complete operational MPE using all available ambient monitoring data for the base case model simulations period" (EPA, 2014, pg. 63). And goes on to say "*Where practical, the MPE should also include some level of diagnostic evaluation*." EPA notes that there is no single definite test for evaluation model performance, but instead there are a series of statistical and graphical MPE elements to examine model performance in as many ways as possible while building a "weight of evidence" (WOE) that the model is performing sufficiently well for the air quality problem being studied.

6.1.2 MPE Results

Because this 2011 ozone modeling is using a CAMx 2011 modeling database developed by EPA, we include by reference the air quality modeling performance evaluation as conducted by EPA (EPA, 2016b) on the national 12km domain. Alpine additionally conducted an MPE (Appendix B) on the 4km domains (Alpine, 2018b) that generated results consistent with the 12km simulation and configuration.

In summary, EPA conducted an operational model performance evaluation for ozone to examine the ability of the CAMx v6.32 and v.6.40 modeling systems to simulate 2011 measured concentrations. This evaluation focused on graphical analyses and statistical metrics of model predictions versus observations. Details on the evaluation methodology, the calculation of performance statistics, and results are provided in Appendix A of that report.

Overall, the ozone model performance statistics for the CAMx v6.32 2011 simulation are similar to those from the CAMx v6.20 2011 simulation performed by EPA for the final CSAPR Update. The 2011 CAMx model performance statistics are within or close to the ranges found in other recent peer-reviewed applications (Simon et al, 2012). As described in Appendix A of the EPA AQ TSD, the predictions from the 2011 modeling platform correspond closely to observed concentrations in terms of the magnitude, temporal fluctuations, and geographic differences for 8-hour daily maximum ozone.

Alpine conducted a separate operational model performance evaluation for the two 4km modeling domains (Alpine, 2018b) and found that 4km domains for the 2011en platform performed similarly to EPA’s 12km MPE that fell within or close to the ranges found in other recent peer-reviewed applications (Simon et al, 2012). Thus, the model performance results demonstrate the scientific credibility of the two 4km domains using the 2011 modeling platform chosen and used for this analysis. These results provide confidence in the ability of the modeling platform to provide a reasonable projection of expected future year ozone concentrations and contributions over the two 4km grids.

7.0 FUTURE YEAR MODELING

This chapter discusses the future year modeling used in the GNS 8-hour ozone modeling effort.

7.1 FUTURE YEAR TO BE SIMULATED

As discussed in Section 1, to support the 2008 and 2015 ozone NAAQS preliminary interstate transport assessment, EPA conducted air quality modeling to project ozone concentrations at individual monitoring sites to 2023 and to estimate state-by-state contributions to those 2023 concentrations. The projected 2023 ozone concentrations were used to identify ozone monitoring sites that are projected to be nonattainment or have maintenance problems for the two ozone NAAQS in 2023 and for which upwind states have been identified as significant contributors.

7.2 FUTURE YEAR GROWTH AND CONTROLS

In September 2017, EPA released the revised “en” modeling platform that was the source for the 2023 future year emissions in this analysis. This platform has been identified by EPA as the base case for compliance with the final CSAPR update seasonal EGU NOx emission budgets. Additionally, there were several emission categories and model inputs/options that were held constant at 2011 levels as follows:

- Biogenic emissions.
- Wildfires, Prescribed Burns and Agricultural Burning (open land fires).
- Windblown dust emissions.
- Sea Salt.
- 36 km CONUS domain Boundary Conditions (BCs).
- 2011 12 km meteorological conditions.
- All model options and inputs other than emissions.

The effects of climate change on the future year meteorological conditions were not accounted. It has been argued that global warming could increase ozone due to higher temperatures producing more biogenic VOC and faster photochemical reactions (the so called climate penalty). However, the effects of inter-annual variability in meteorological conditions will be more important than climate change given the 12 year difference between the base (2011) and future (2023) years. It has also been noted that the level of ozone being transported into the U.S. from Asia has also increased.

7.3 FUTURE YEAR BASELINE AIR QUALITY SIMULATIONS

A 2023 future year base case CAMx simulation was conducted and 2023 ozone design value projection calculations were made based on EPA’s latest ozone modeling guidance (EPA, 2014e) for the 12US2 and two 4km modeling domains in this analysis.

7.3.1 Identification of Future Nonattainment and Maintenance Receptors

The ozone predictions from the 2011 and 2023 CAMx model simulations were used to project 2009-2013 average and maximum ozone design values to 2023 following the approach described in the EPA's draft guidance for attainment demonstration modeling (US EPA, 2014b). Using the approach in the final CSAPR Update, we evaluated the 2023 projected average and maximum design values in conjunction with the most recent measured ozone design values (i.e., 2014-2016) to identify sites that may warrant further consideration as potential nonattainment or maintenance sites in 2023.

If the approach in the CSAPR Update is applied to evaluate the projected design values, those sites with 2023 average design values that exceed the NAAQS (i.e., 2023 average design values of 71 ppb or greater) and that are currently measuring nonattainment would be considered to be nonattainment receptors in 2023. Similarly, with the CSAPR Update approach, monitoring sites with a projected 2023 maximum design value that exceeds the NAAQS would be projected to be maintenance receptors in 2023. In the CSAPR Update approach, maintenance-only receptors include both those monitoring sites where the projected 2023 average design value is below the NAAQS, but the maximum design value is above the NAAQS, and monitoring sites with projected 2023 average design values that exceed the NAAQS, but for which current design values based on measured data do not exceed the NAAQS.

As documented in EPA's March 2018 technical memorandum (Tsirigotis, 2018), EPA used results of CAMx v6.40 to model emissions in 2011 and 2023 to project base period 2009-2013 average and maximum ozone design values to 2023 at monitoring sites nationwide. In projecting these future year design values, EPA applied its own modeling guidance, which recommends using model predictions from the "3x3" array of grid cells surrounding the location of the monitoring site. In response to comments submitted on the January 2017 NODA and other analyses, EPA also projected 2023 design values based on a modified version of the "3x3" approach for those monitoring sites located in coastal areas (Tsirigotis, 2018). This modeling was intended as an alternate approach to addressing complex meteorological monitor locations without having to rerun the simulations on finer grid scales.

Alpine's applied approach in developing and using 4km grid domains further followed EPA's guidance recommendation that "grid resolution finer than 12 km would generally be more appropriate for areas with a combination of complex meteorology, strong gradients in emissions sources, and/or land-water interfaces in or near the nonattainment area(s)." (EPA, 2014e)

We used the finer grid resolution and the Software for the Modeled Attainment Test - Community Edition[9] (SMAT-CE) tool consistent with EPA's 12km attainment demonstration modeling methods calculating relative response factors and "3x3" neighborhoods (EPA, 2014e). Alpine also prepared 2023 projected average and maximum design values in conjunction with the most recent measured ozone design values (2015-2017) to identify sites in these 4km

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[9] https://www.epa.gov/scram/photochemical-modeling-tools

domains that may warrant further consideration as potential nonattainment or maintenance sites in 2023.

After applying the approach outlined in the final CSAPR update (and described above) to evaluate the projected design values from the 4km analysis, we developed a list of nonattainment and maintenance monitors located within these two eastern 4km domains resulting from the approach. Modeled nonattainment monitors defined using Alpine's 4km simulation are provided in Table 7-1 along with their calculated 2023 average and maximum design values from both EPA's "no water" calculation approach and Alpine's 4km simulation and most current 2015-2017 design values. Similarly, Table 7-2 presents the modeled maintenance monitors with their calculated average and maximum design values from both simulations and the most current 2015-2017 design value data. Monitors originally designated as nonattainment or maintenance by EPA using their "no water" calculation and found to be neither nonattainment or maintenance using Alpine's 4km modeling are presented in Table 7-3. A full list of monitor locations and modeled average and maximum ozone design values for the 4km domain modeling is provided in Appendix A of this report.

Table 7-1. Alpine 4km Modeling-identified nonattainment monitors in the 4km domains.

			Ozone Design Value (ppb)					
				EPA "No Water" 12km Modeling		Alpine Updated 4km Modeling		
Monitor	State	County	DVb (2011)	DVf (2023) Ave	DVf (2023) Max	DVf (2023) Ave	DVf (2023) Max	2015-2017 DV
551170006	WI	Sheboygan	84.3	72.8	75.1	71.5	73.8	80

Table 7-2. Alpine 4km Modeling-identified maintenance monitors in the 4km domains.

			Ozone Design Value (ppb)					
				EPA "No Water" 12km Modeling		Alpine Updated 4km Modeling		
Monitor	State	County	DVb (2011)	DVf (2023) Ave	DVf (2023) Max	DVf (2023) Ave	DVf (2023) Max	2015-2017 DV
90013007	CT	Fairfield	84.3	71.0	75.0	69.2	73.1	83
90019003	CT	Fairfield	83.7	73.0	75.9	68.3	71.0	83
90099002	CT	New Haven	85.7	69.9	72.6	68.9	71.5	82
240251001	MD	Harford	90.0	70.9	73.3	70.9	73.3	75
260050003	MI	Allegan	82.7	69.0	71.7	70.0	72.8	73
340150002	NJ	Gloucester	84.3	68.2	70.4	68.8	71.0	74
360850067	NY	Richmond	81.3	67.1	68.5	69.6	71.0	76
361030002	NY	Suffolk	83.3	74.0	75.5	70.6	72.0	76

Table 7-3. Alpine 4km modeling-identified attainment monitors in the 4km domains previously identified by EPA as nonattainment or maintenance.

			Ozone Design Value (ppb)					
				EPA "No Water" 12km Modeling		Alpine Updated 4km Modeling		2015-2017 DV
Monitor	**State**	**County**	**DVb (2011)**	**DVf (2023) Ave**	**DVf (2023) Max**	**DVf (2023) Ave**	**DVf (2023) Max**	
90010017	CT	Fairfield	80.3	68.9	71.2	66.8	69.0	79
90110124	CT	New London	80.3	67.3	70.4	66.0	69.1	76
360810124	NY	Queens	78.0	70.2	72.0	68.5	70.2	74
421010024	PA	Philadelphia	83.3	67.3	70.3	67.5	70.5	78
550790085	WI	Milwaukee	80.0	71.2	73.0	67.1	68.8	71

The procedures for calculating projected 2023 average and maximum design values are described in Section 3.2 of EPA's air quality technical support document (EPA, 2016b). The only noted differences are that Alpine used 4km modeling results, compared to EPA's 12km, compared modeled design values with 3yr design values from 2015-2017, and did not remove "no water" cells from the calculation as further described in the March 2018 memorandum.

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Appendix A

Updated 4km Modeling Results for Mid-Atlantic and Lake Michigan Domains Compared To EPA 12km “No Water” Design Value Calculations from March 2018 Memorandum

Table A-1. 4km and EPA "No Water" 12km Design Value Results for Monitors Located in 4km Mid-Atlantic Modeling Domain.

			Ozone Design Value (ppb)					
				EPA "No Water" 12km Modeling		Updated 4km Modeling		
Monitor	State	County	DVb (2011)	DVf (2023) Ave	DVf (2023) Max	DVf (2023) Ave	DVf (2023) Max	2015-2017 DV
90010017	Connecticut	Fairfield	80.3	68.9	71.2	66.8	69.0	79
90011123	Connecticut	Fairfield	81.3	66.4	67.8	65.2	66.6	77
90013007	Connecticut	Fairfield	84.3	71.0	75.0	69.2	73.1	83
90019003	Connecticut	Fairfield	83.7	73.0	75.9	68.3	71.0	83
90031003	Connecticut	Hartford	73.7	60.7	61.7	60.3	61.3	72
90050005	Connecticut	Litchfield	70.3	57.2	57.8	56.8	57.3	72
90070007	Connecticut	Middlesex	79.3	64.7	66.1	63.8	65.2	79
90090027	Connecticut	New Haven	74.3	61.9	65.0	61.8	64.9	77
90099002	Connecticut	New Haven	85.7	69.9	72.6	68.9	71.5	82
90110124	Connecticut	New London	80.3	67.3	70.4	66.0	69.1	76
90131001	Connecticut	Tolland	75.3	61.4	62.8	61.3	62.7	71
100010002	Delaware	Kent	74.3	57.6	60.5	58.4	61.4	66
100031007	Delaware	New Castle	76.3	59.2	62.0	59.8	62.7	67
100031010	Delaware	New Castle	78.0	61.2	61.2	61.7	61.7	74
100031013	Delaware	New Castle	77.7	60.8	62.6	61.6	63.5	71
100032004	Delaware	New Castle	75.0			59.0	59.0	72
100051002	Delaware	Sussex	77.3	59.7	62.6	60.5	63.4	65
100051003	Delaware	Sussex	77.7	61.1	63.7	61.7	64.3	67
110010041	District Of Columbia	District of Columbia	76.0	58.7	61.7	60.5	63.6	
110010043	District Of Columbia	District of Columbia	80.7	62.3	64.8	65.2	67.9	71
240030014	Maryland	Anne Arundel	83.0	63.4	66.4	64.9	68.0	
240051007	Maryland	Baltimore	79.0	63.9	66.3	61.6	64.0	
240053001	Maryland	Baltimore	80.7	65.3	67.9	63.9	66.5	73

Table A-1. 4km and EPA “No Water” 12km Design Value Results for Monitors Located in 4km Mid-Atlantic Modeling Domain.

			Ozone Design Value (ppb)					
				EPA "No Water" 12km Modeling		Updated 4km Modeling		
Monitor	**State**	**County**	**DVb (2011)**	**DVf (2023) Ave**	**DVf (2023) Max**	**DVf (2023) Ave**	**DVf (2023) Max**	**2015-2017 DV**
240090011	Maryland	Calvert	79.7	63.2	65.9	64.0	66.7	67
240130001	Maryland	Carroll	76.3	58.8	60.9	59.4	61.5	69
240150003	Maryland	Cecil	83.0	64.5	66.8	65.2	67.5	74
240170010	Maryland	Charles	79.0	61.6	64.7	63.2	66.4	69
240199991	Maryland	Dorchester	75.0	59.4	59.4	59.7	59.7	65
240210037	Maryland	Frederick	76.3	59.6	61.8	60.4	62.5	69
240251001	Maryland	Harford	90.0	70.9	73.3	70.9	73.3	75
240259001	Maryland	Harford	79.3	62.2	64.3	62.4	64.5	73
240290002	Maryland	Kent	78.7	61.2	63.7	61.2	63.8	70
240313001	Maryland	Montgomery	75.7	60.0	61.0	60.0	61.1	68
240330030	Maryland	Prince George's	79.0	60.5	62.8	61.0	63.3	70
240338003	Maryland	Prince George's	82.3	63.2	66.8	64.0	67.7	71
240339991	Maryland	Prince George's	80.0	61.0	61.0	61.9	61.9	69
240430009	Maryland	Washington	72.7			56.6	58.4	67
245100054	Maryland	Baltimore (City)	73.7	59.4	60.4	59.2	60.2	69
250034002	Massachusetts	Berkshire	69.0			56.2	57.9	
250051002	Massachusetts	Bristol	74.0	61.2	61.2	60.8	60.8	
250070001	Massachusetts	Dukes	77.0	64.1	66.6	64.8	67.4	
250130008	Massachusetts	Hampden	73.7	59.3	59.5	60.4	60.7	71
250150103	Massachusetts	Hampshire	64.7			52.4	53.5	
250154002	Massachusetts	Hampshire	71.3			57.3	57.9	70
250213003	Massachusetts	Norfolk	72.3			57.6	58.1	70
250270015	Massachusetts	Worcester	68.3			55.4	56.8	65
250270024	Massachusetts	Worcester	69.0			55.3	56.1	66
340010006	New Jersey	Atlantic	74.3	58.6	60.0	60.2	61.5	64

Table A-1. 4km and EPA “No Water” 12km Design Value Results for Monitors Located in 4km Mid-Atlantic Modeling Domain.

			Ozone Design Value (ppb)					
				EPA "No Water" 12km Modeling		Updated 4km Modeling		2015-2017 DV
Monitor	**State**	**County**	**DVb (2011)**	**DVf (2023) Ave**	**DVf (2023) Max**	**DVf (2023) Ave**	**DVf (2023) Max**	
340030006	New Jersey	Bergen	77.0	64.1	65.0	65.5	66.4	74
340071001	New Jersey	Camden	82.7	66.3	69.8	65.9	69.3	68
340110007	New Jersey	Cumberland	72.0	57.0	59.4	57.1	59.5	66
340130003	New Jersey	Essex	78.0	64.3	67.6	63.4	66.7	68
340150002	New Jersey	Gloucester	84.3	68.2	70.4	68.8	71.0	74
340170006	New Jersey	Hudson	77.0	64.6	65.4	65.3	66.2	70
340190001	New Jersey	Hunterdon	78.0	62.0	63.6	60.8	62.4	72
340210005	New Jersey	Mercer	78.3	63.2	65.4	62.7	64.9	71
340219991	New Jersey	Mercer	76.0	60.4	60.4	58.5	58.5	73
340230011	New Jersey	Middlesex	81.3	65.0	68.0	64.5	67.4	75
340250005	New Jersey	Monmouth	80.0	64.1	66.5	65.4	67.9	68
340273001	New Jersey	Morris	76.3	62.4	63.8	62.6	64.0	69
340290006	New Jersey	Ocean	82.0	65.8	68.2	64.8	67.2	73
340315001	New Jersey	Passaic	73.3	61.3	62.7	59.9	61.3	68
340410007	New Jersey	Warren	66.0	54.0	54.0	50.9	50.9	65
360010012	New York	Albany	68.0			56.8	58.4	64
360050133	New York	Bronx	74.0	63.3	65.0	63.8	65.6	70
360150003	New York	Chemung	66.5			55.3	55.7	
360270007	New York	Dutchess	72.0	58.6	60.2	57.0	58.6	67
360530006	New York	Madison	67.0			54.4	54.4	
360610135	New York	New York	73.3	64.2	66.5	62.9	65.2	70
360671015	New York	Onondaga	69.3			57.7	59.9	64
360715001	New York	Orange	67.0	55.3	56.9	54.2	55.8	65
360750003	New York	Oswego	68.0			55.9	57.6	61
360790005	New York	Putnam	70.0	58.4	59.2	56.7	57.5	70

Table A-1. 4km and EPA “No Water” 12km Design Value Results for Monitors Located in 4km Mid-Atlantic Modeling Domain.

			Ozone Design Value (ppb)					
				EPA "No Water" 12km Modeling		Updated 4km Modeling		2015-2017 DV
Monitor	State	County	DVb (2011)	DVf (2023) Ave	DVf (2023) Max	DVf (2023) Ave	DVf (2023) Max	
360810124	New York	Queens	78.0	70.2	72.0	68.5	70.2	74
360850067	New York	Richmond	81.3	67.1	68.5	69.6	71.0	76
360870005	New York	Rockland	75.0	62.0	62.8	63.7	64.5	72
361030002	New York	Suffolk	83.3	74.0	75.5	70.6	72.0	76
361030004	New York	Suffolk	78.0	65.2	66.9	63.8	65.4	76
361030009	New York	Suffolk	78.7	67.6	68.7	66.5	67.5	69
361111005	New York	Ulster	69.0			56.3	56.3	
361192004	New York	Westchester	75.3	63.8	64.4	64.6	65.2	73
420110006	Pennsylvania	Berks	71.7	56.2	58.8	55.8	58.4	66
420110011	Pennsylvania	Berks	76.3	58.9	61.0	59.9	62.1	70
420170012	Pennsylvania	Bucks	80.3	64.6	66.8	64.4	66.6	80
420290100	Pennsylvania	Chester	76.3	58.7	60.8	59.9	62.0	73
420430401	Pennsylvania	Dauphin	69.0	54.7	54.7	54.9	54.9	65
420431100	Pennsylvania	Dauphin	74.7	58.3	60.1	59.1	61.0	66
420450002	Pennsylvania	Delaware	75.7	60.3	62.1	60.7	62.6	71
420550001	Pennsylvania	Franklin	67.0			52.6	53.4	59
420690101	Pennsylvania	Lackawanna	71.0			55.7	56.4	67
420692006	Pennsylvania	Lackawanna	68.7			53.5	55.3	64
420710007	Pennsylvania	Lancaster	77.0	60.1	62.4	60.6	63.0	70
420710012	Pennsylvania	Lancaster	78.0	60.2	63.3	60.6	63.7	66
420750100	Pennsylvania	Lebanon	76.0	58.6	58.6	59.0	59.0	69
420770004	Pennsylvania	Lehigh	76.0	59.5	61.1	59.4	61.0	70
420791100	Pennsylvania	Luzerne	65.0			49.5	50.3	
420791101	Pennsylvania	Luzerne	64.3			49.7	51.0	64
420810100	Pennsylvania	Lycoming	67.0			52.6	54.2	64

Table A-1. 4km and EPA "No Water" 12km Design Value Results for Monitors Located in 4km Mid-Atlantic Modeling Domain.

			Ozone Design Value (ppb)					
				EPA "No Water" 12km Modeling		Updated 4km Modeling		
Monitor	State	County	DVb (2011)	DVf (2023) Ave	DVf (2023) Max	DVf (2023) Ave	DVf (2023) Max	2015-2017 DV
420890002	Pennsylvania	Monroe	66.7	52.9	55.6	52.6	55.2	67
420910013	Pennsylvania	Montgomery	76.3	61.0	62.4	62.0	63.4	72
420950025	Pennsylvania	Northampton	76.0	58.5	60.6	58.8	59.6	70
420958000	Pennsylvania	Northampton	69.7	54.8	55.9	54.7	55.7	69
420990301	Pennsylvania	Perry	68.3			54.7	56.1	
421010004	Pennsylvania	Philadelphia	66.0	53.9	57.1	54.2	57.5	
421010024	Pennsylvania	Philadelphia	83.3	67.3	70.3	67.5	70.5	78
421011002	Pennsylvania	Philadelphia	80.0	64.7	64.7	65.3	65.3	
421174000	Pennsylvania	Tioga	69.7			57.4	58.5	64
421330008	Pennsylvania	York	72.3	56.9	58.3	58.3	59.7	66
421330011	Pennsylvania	York	74.3	58.0	60.1	58.8	61.0	70
440030002	Rhode Island	Kent	73.7	60.4	60.7	59.5	59.7	72
440071010	Rhode Island	Providence	74.0	59.5	61.1	59.9	61.6	70
440090007	Rhode Island	Washington	76.3	62.6	64.0	62.3	63.7	71
510130020	Virginia	Arlington	81.7	64.9	68.3	66.1	69.6	71
510330001	Virginia	Caroline	71.7	56.0	57.6	55.2	57.0	61
510360002	Virginia	Charles	75.7	59.4	62.0	61.1	63.7	61
510410004	Virginia	Chesterfield	72.0	56.8	59.2	55.6	58.0	62
510590030	Virginia	Fairfax	82.3	65.1	68.1	66.2	69.1	71
510610002	Virginia	Fauquier	62.7			49.8	50.9	58
510850003	Virginia	Hanover	73.7	56.9	58.6	55.3	57.1	63
510870014	Virginia	Henrico	75.0	58.8	61.2	57.7	60.0	65
511071005	Virginia	Loudoun	73.0	57.8	59.4	58.7	60.3	68
511479991	Virginia	Prince Edward	62.0			50.2	50.2	58
511530009	Virginia	Prince William	70.0	56.2	57.8	54.8	56.3	66

Table A-1. 4km and EPA "No Water" 12km Design Value Results for Monitors Located in 4km Mid-Atlantic Modeling Domain.

			Ozone Design Value (ppb)					
				EPA "No Water" 12km Modeling		Updated 4km Modeling		
Monitor	State	County	DVb (2011)	DVf (2023) Ave	DVf (2023) Max	DVf (2023) Ave	DVf (2023) Max	2015-2017 DV
511790001	Virginia	Stafford	73.0	57.1	59.4	57.0	59.4	62
515100009	Virginia	Alexandria City	80.0	63.4	65.8	64.7	67.1	
516500008	Virginia	Hampton City	74.0	56.9	58.4	54.8	56.3	65
518000004	Virginia	Suffolk City	71.3	56.2	57.5	56.5	57.9	61
518000005	Virginia	Suffolk City	69.7			54.9	56.0	59

Table A-2. 4km and EPA “No Water” 12km Design Value Results for Monitors Located in 4km Lake Michigan Modeling Domain.

			Ozone Design Value (ppb)					
				EPA "No Water" 12km Modeling		Updated 4km Modeling		
Monitor	State	County	DVb (2011)	DVf (2023) Ave	DVf (2023) Max	DVf (2023) Ave	DVf (2023) Max	2015-2017 DV
170310001	Illinois	Cook	72.0	63.2	64.9	60.3	62.0	73
170310032	Illinois	Cook	77.7	66.6	69.5	57.7	60.1	72
170310064	Illinois	Cook	71.3	61.1	64.3	55.1	58.0	
170310076	Illinois	Cook	71.7	62.7	64.7	61.1	63.0	72
170311003	Illinois	Cook	69.7	62.4	64.4	59.7	61.7	67
170311601	Illinois	Cook	71.3	61.5	63.9	62.2	64.5	69
170314002	Illinois	Cook	71.7	62.3	64.3	62.3	64.3	68
170314007	Illinois	Cook	65.7	58.0	60.0	55.7	57.6	71
170314201	Illinois	Cook	75.7	66.8	68.8	62.6	64.5	72
170317002	Illinois	Cook	76.0	66.8	70.3	59.7	62.8	73
170436001	Illinois	DuPage	66.3	57.9	59.4	58.6	60.1	70
170890005	Illinois	Kane	69.7	62.8	63.9	60.5	61.6	69
170971007	Illinois	Lake	79.3	63.4	65.6	60.2	62.2	73
171110001	Illinois	McHenry	69.7	61.8	62.9	59.8	60.9	69
171971011	Illinois	Will	64.0	55.6	56.5	54.7	55.5	65
172012001	Illinois	Winnebago	67.3	57.5	58.0	57.5	58.1	66
180150002	Indiana	Carroll	69.0			56.5	58.2	63
180390007	Indiana	Elkhart	67.7	54.6	56.5	55.0	56.9	64
180690002	Indiana	Huntington	65.0			53.5	54.4	60
180890022	Indiana	Lake	66.7	58.3	60.3	55.2	57.1	68
180890030	Indiana	Lake	69.7	61.9	64.8	55.6	58.2	
180892008	Indiana	Lake	68.0	60.4	60.4	56.8	56.8	
180910005	Indiana	LaPorte	79.3	67.2	70.4	65.4	68.4	
180910010	Indiana	LaPorte	69.7	58.9	60.9	57.7	59.6	67
181270024	Indiana	Porter	70.3	61.8	63.3	59.3	60.8	69

Table A-2. 4km and EPA “No Water” 12km Design Value Results for Monitors Located in 4km Lake Michigan Modeling Domain.

			Ozone Design Value (ppb)					
				EPA "No Water" 12km Modeling		Updated 4km Modeling		2015-2017 DV
Monitor	**State**	**County**	**DVb (2011)**	**DVf (2023) Ave**	**DVf (2023) Max**	**DVf (2023) Ave**	**DVf (2023) Max**	
181270026	Indiana	Porter	63.0	54.4	55.3	53.2	54.0	69
181410010	Indiana	St. Joseph	62.7			51.4	52.5	65
181410015	Indiana	St. Joseph	69.3	56.9	59.9	57.6	60.7	70
181411007	Indiana	St. Joseph	64.0	52.5	52.5	52.5	52.5	
260050003	Michigan	Allegan	82.7	69.0	71.7	70.0	72.8	73
260190003	Michigan	Benzie	73.0	60.6	62.3	60.3	61.9	68
260210014	Michigan	Berrien	79.7	66.9	68.8	66.3	68.2	73
260270003	Michigan	Cass	76.7	62.0	63.1	61.5	62.6	72
260770008	Michigan	Kalamazoo	73.7			60.7	61.8	69
260810020	Michigan	Kent	73.0	59.8	61.4	60.0	61.7	68
260810022	Michigan	Kent	72.7			57.5	58.5	67
261010922	Michigan	Manistee	72.3	60.5	61.9	59.6	61.0	67
261050007	Michigan	Mason	73.3	60.7	62.1	60.6	62.0	68
261130001	Michigan	Missaukee	68.3			56.3	57.7	66
261210039	Michigan	Muskegon	79.7	65.8	67.7	66.7	68.6	74
261390005	Michigan	Ottawa	76.0	62.3	64.0	63.0	64.7	68
550090026	Wisconsin	Brown	68.3			57.8	59.3	65
550210015	Wisconsin	Columbia	67.0			55.6	57.2	65
550250041	Wisconsin	Dane	66.3			56.0	58.2	65
550270001	Wisconsin	Dodge	71.5			60.2	60.7	65
550290004	Wisconsin	Door	75.7	63.3	65.2	63.8	65.7	73
550390006	Wisconsin	Fond du Lac	70.0			58.9	60.6	64
550410007	Wisconsin	Forest	64.7			53.0	54.9	62
550550002	Wisconsin	Jefferson	68.5			57.0	58.2	
550590019	Wisconsin	Kenosha	81.0	64.8	67.2	59.6	61.8	78

Table A-2. 4km and EPA “No Water” 12km Design Value Results for Monitors Located in 4km Lake Michigan Modeling Domain.

			Ozone Design Value (ppb)					
				EPA "No Water" 12km Modeling		Updated 4km Modeling		
Monitor	**State**	**County**	**DVb (2011)**	**DVf (2023) Ave**	**DVf (2023) Max**	**DVf (2023) Ave**	**DVf (2023) Max**	**2015-2017 DV**
550610002	Wisconsin	Kewaunee	75.0	64.5	67.1	64.6	67.2	69
550710007	Wisconsin	Manitowoc	78.7	67.6	68.7	66.6	67.7	74
550790010	Wisconsin	Milwaukee	69.7	60.6	62.6	60.2	62.2	65
550790026	Wisconsin	Milwaukee	74.7	66.5	69.4	65.2	68.1	67
550790085	Wisconsin	Milwaukee	80.0	71.2	73.0	67.1	68.8	71
550870009	Wisconsin	Outagamie	69.3			58.6	60.8	65
550890008	Wisconsin	Ozaukee	76.3	67.2	70.5	65.0	68.2	71
550890009	Wisconsin	Ozaukee	74.7	63.6	65.5	63.3	65.2	73
551010017	Wisconsin	Racine	77.7	62.2	64.8	58.2	60.7	
551050024	Wisconsin	Rock	69.5			59.4	61.5	
551170006	Wisconsin	Sheboygan	84.3	72.8	75.1	71.5	73.8	80
551270005	Wisconsin	Walworth	69.3			58.4	59.8	68
551330027	Wisconsin	Waukesha	66.7	58.1	60.1	57.8	59.8	65

Appendix B

Ozone Model Performance Evaluation Of Midwest Ozone Group Updated 4km Modeling Domains

Ozone Model Performance Evaluation
Of Midwest Ozone Group
Updated 4km Modeling Domains

Final Report

Prepared by:

Alpine Geophysics, LLC
387 Pollard Mine Road
Burnsville, NC 28174

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Project Number: TS-533

Contents

TABLES

FIGURES

1.0 INTRODUCTION

An operational model evaluation was conducted for the 2011 base year CAMx v6.40 simulation performed for the EPA continental 12km and two 4km modeling domains defined by the Midwest Ozone Group (MOG) and shown in Figure 1-2. The purpose of this evaluation is to examine the ability of this 2011 air quality modeling platform to represent the magnitude and spatial and temporal variability of measured (i.e., observed) ozone concentrations within the two modeling domains. The evaluation presented here is based on model simulations using the 2011 emissions platform (i.e., scenario name 2011en_cb6r4_v6_11g). This model evaluation for ozone focuses on comparisons of model predicted 8-hour daily maximum concentrations to the corresponding observed data at monitoring sites in the EPA Air Quality System (AQS).

The model simulations are identical to the EPA CSAPR Closeout modeling simulation (EPA, 2018) with the exception that meteorology was developed at 4km resolution using the Weather, Research and Forecasting (WRF) model and spatially resolved emissions source coverage files were applied to the CAMx simulation for the Lake Michigan and Mid-Atlantic regions (Alpine, 2018a, 2018b). All other CAMx model inputs were taken from the EPA simulation.

Figure 1. Maps of 12km CAMx modeling domain.

Included in the evaluation are statistical measures of model performance based upon model-predicted versus observed concentrations that were paired in space and time. Model performance statistics were calculated for several spatial scales and temporal periods. Statistics were calculated for individual monitoring sites, and in aggregate for monitoring sites within states and regions of the 12km and 4 km modeling domains.

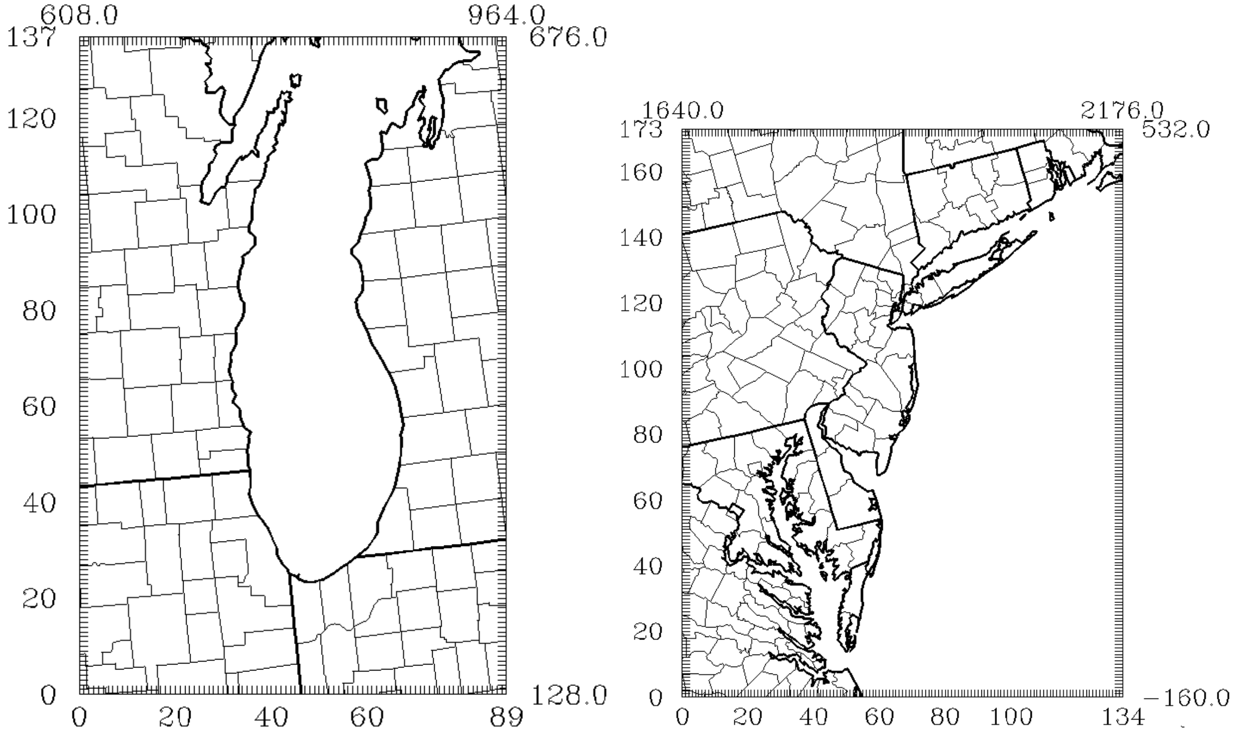

Figure 2. Maps of 4km CAMx modeling domains. Lake Michigan (left) and Mid-Atlantic (right).

For maximum daily average 8-hour (MDA8) ozone, model performance statistics were created for the periods May through September. The aggregate statistics by state and by climate region are presented in this document. Model performance statistics for MDA8 ozone at individual monitoring sites based on days with observed values > 60 ppb can be found as Appendix A to this document.

In addition to the above performance statistics, we prepared several graphical presentations of model performance for MDA8 ozone. These graphical presentations include:

1. spatial maps that show the mean bias and error as well as normalized mean bias and error calculated for MDA8 ≥ 60 ppb for May through September at individual AQS monitoring sites;
2. time series plots (May through September) of observed and predicted MDA8 ozone concentrations for the 2023 nonattainment and maintenance-only sites for which EPA’s 12km modeling indicates that upwind states contribute at or above the 1 percent of the NAAQS screening threshold and are located within one of the two 4km modeling domains; and
3. scatter plots that show the correlation of the predicted and observed MDA8 ozone concentrations by monitor for May through September.

The Model Performance Evaluation, Analysis, and Plotting Software (MAPS) tool was used to calculate the model performance statistics used in this document (McNally and Tesche, 1993). For this evaluation we have selected the mean bias, mean error, normalized mean bias, and normalized mean error to characterize model performance, statistics which are consistent with the recommendations in Simon et al. (2012), the draft photochemical modeling guidance (U.S. EPA, 2014a), and EPA's recent performance evaluation of the 2011en platform (EPA, 2018).

Mean bias (MB) is the average difference between predicted (P) and observed (O) concentrations for a given number of samples (n):

$$MB(ppb) = \frac{1}{n}\sum_{i=1}^{n}(P_i - O_i)$$

Mean error (ME) is the average absolute value of the difference between predicted and observed concentrations for a given number of samples:

$$ME(ppb) = \frac{1}{n}\sum_{i=1}^{n}|P_i - O_i|$$

Normalized mean bias (NMB) is the sum of the difference between predicted and observed values divided by the sum of the observed values:

$$NMB(\%) = \frac{\sum_{1}^{n}(P - O)}{\sum_{1}^{n}(O)} * 100$$

Normalized mean error (NME) is the sum of the absolute value of the difference between predicted and observed values divided by the sum of the observed values:

$$NME(\%) = \frac{\sum_{1}^{n}|P - O|}{\sum_{1}^{n}(O)} * 100$$

As described in more detail below, the model performance statistics indicate that the 4km 8-hour daily maximum ozone concentrations predicted by the 2011en CAMx modeling platform closely reflect the corresponding 8-hour observed ozone concentrations in each region of the 12 km U.S. modeling domain. The acceptability of model performance was judged by considering the 2011 CAMx performance results in light of the range of performance found in recent regional ozone model applications (NRC, 2002; Phillips et al., 2007; Simon et al., 2012; EPA, 2005; EPA, 2009; EPA, 2010, EPA, 2016, EPA, 2018). These other modeling studies represent a wide range of modeling analyses that cover various models, model configurations, domains, years and/or episodes, chemical mechanisms, and aerosol modules.

Overall, the ozone model performance results for the 2011 CAMx simulations are within the range found in other recent peer-reviewed and regulatory applications. The model performance results, as described in this document, demonstrate that the predictions from the 4km domains using the 2011en modeling platform correspond closely to observed concentrations in terms of the magnitude, temporal fluctuations, and geographic differences for 8-hour daily maximum ozone.

2.0 RESULTS

The 8-hour ozone model performance bias and error statistics for the months May through September for each region and select states in the 12km modeling domain are provided in Tables 1 through 3, respectively. The 8-hour ozone model performance bias and error statistics by the months May through September across all monitors in each 4km modeling domain are provided in Table 4. The statistics shown were calculated using data pairs on days with observed 8-hour ozone of ≥ 60 ppb. Spatial plots of the mean bias and error as well as the normalized mean bias and error for individual monitors are shown in Figures 3 through 6. Time series plots of observed and predicted MDA 8-hour ozone during the period May through September at select sites listed in Table 5 are provided in Figure7 through 17. The correlations of observed and predicted 8-hour ozone by month in the period May through September for each region are shown in Figures 18 through 28.

Overall, model performance for MDA8 ozone concentrations for this 2011 CAMx v6.40 simulation is similar to what was found in EPA's model performance evaluation conducted for the 2011en CAMx v6.40 simulation performed in support of the 2008 and 2015 ozone NAAQS reviews (EPA, 2018). In general, the 4km simulations tend to under predict MDA8 ozone in the Lake Michigan domain and over predict MDA8 concentrations in the Mid-Atlantic domain.

2.1 PERFORMANCE STATISTICS BY REGION AND MONTH

As indicated by the statistics in Table 1, bias and error for 8-hour daily maximum ozone are relatively low in each region. Generally, mean bias for 8-hour ozone ≥ 60 ppb during each month of the May through September period, demonstrating within ± 5 ppb at AQS sites in the two eastern RPO regions (MANE-VU and LADCO) with the exception of September in the LADCO domain (-6.99 ppb). The mean error is 10 ppb or less in all regions. Normalized mean bias is within ± 5 percent for AQS sites in May, June, and July in the MANE-VU region, with somewhat larger values in MANE-VU in August (6.30%) and September (6.24%) and in the LADCO domain during September (-9.63%) of the ozone season. The mean bias and normalized mean bias statistics indicate a tendency for the model to over predict MDA8 ozone concentrations in the Mid-Atlantic domain and under predict MDA8 ozone concentrations in the Lake Michigan regions for AQS sites. The normalized mean error is less than 15 percent for both regions across all months.

We note that for regions outside those covered by the 4km domains, this simulation differs from the EPA simulation only in the feedback from the 4km domains on the 12km domains. Additionally, for the 12km metrics presented in this report and for portions of states that are included in the 4km domain, results from the 4km simulation are aggregated in CAMx to 12km grid resolution.

Table 1. Performance statistics for MDA8 ozone ≥60 ppb by month and region for MANE-VU and LADCO states in 12km domain based on data at AQS network sites.

Region	Month	# of Obs	MB (ppb)	ME (ppb)	NMB (%)	NME (%)
MANE-VU	05	332	2.72	7.65	4.15	11.67
MANE-VU	06	982	1.72	8.73	2.46	12.50
MANE-VU	07	1606	2.74	9.32	3.94	13.40
MANE-VU	08	420	4.12	7.03	6.30	10.73
MANE-VU	09	164	4.08	7.88	6.24	12.05
MANE-VU	All		2.68	8.65	3.94	12.60
LADCO	05	245	-3.02	7.68	-4.78	12.13
LADCO	06	1232	-1.30	6.91	-1.90	10.12
LADCO	07	1493	0.79	8.69	1.16	12.84
LADCO	08	576	-1.61	7.53	-2.43	11.38
LADCO	09	415	-6.99	9.54	-9.63	13.15
LADCO	All		-1.26	7.99	-1.81	11.77

Looking at 12km model performance for individual states located within the Lake Michigan 4km domain (Table 2) indicates that mean bias is within ± 5 ppb for a majority of the months and states and within ± 10 ppb for all but September in Wisconsin. The mean error is less than 10 ppb for nearly all months and states, again with the exceptions occurring in May (Wisconsin), July (Illinois, Wisconsin) and September (Michigan, Wisconsin). The normalized mean bias is within ± 10 percent except May in Illinois (-11.92 %) and September in Wisconsin (-26.05 %). The normalized mean error is within 15 percent for all but May and September in Wisconsin.

Table 2. Performance statistics for MDA8 ozone ≥60 ppb by month and state within Lake Michigan 4km domain based on data at AQS network sites.

State	Month	# of Obs	MB (ppb)	ME (ppb)	NMB (%)	NME (%)
IL	05	27	-7.52	8.39	-11.92	13.30
IL	06	197	1.58	6.32	2.38	9.53
IL	07	257	-1.59	10.09	-2.35	14.92
IL	08	100	-2.56	7.15	-3.83	10.68
IL	09	81	-5.34	7.17	-7.52	10.10
MI	05	53	-4.82	8.93	-7.63	14.14
MI	06	199	-6.29	8.55	-9.02	12.26
MI	07	263	-1.52	8.29	-2.20	11.99
MI	08	52	-4.49	6.24	-6.97	9.69
MI	09	56	-6.45	10.44	-9.01	14.60
OH	05	103	0.14	6.35	0.23	10.04
OH	06	355	-1.18	6.98	-1.70	10.08
OH	07	501	4.01	8.05	5.92	11.89
OH	08	231	-1.10	8.81	-1.65	13.23

State	Month	# of Obs	MB (ppb)	ME (ppb)	NMB (%)	NME (%)
OH	09	119	-4.37	8.16	-5.97	11.15
WI	05	22	-4.26	12.02	-6.69	18.90
WI	06	158	-3.61	6.82	-5.31	10.03
WI	07	143	-3.50	10.72	-5.11	15.68
WI	08	24	-4.34	7.21	-6.52	10.82
WI	09	35	-21.49	22.59	-26.05	27.39

Even better model performance for individual states is seen in the 12km modeling for states in the Mid-Atlantic 4km domain (Table 3). Mean bias is within ± 5 ppb for most months and states with the exception of July, August, and September in Connecticut (6.73 ppb, 6.19 ppb, and 6.98 ppb, respectively), August and September in Maryland (6.18 ppb and 6.17 ppb, respectively), July and September in New Jersey (6.00 ppb and 5.70 ppb, respectively), July in Rhode Island and Virginia (5.02 ppb and 5.06, respectively). The mean error is less than 10 ppb for nearly all months and states, with the exceptions occurring in June and July in Connecticut. The normalized mean bias is within ± 10 percent in all months and states except September in Connecticut. The normalized mean error is within 15 percent in most months and states with the exceptions of June and July in Connecticut (15.02 and 15.95 percent, respectively) and September in Maryland (15.01 percent).

Table 3. Performance statistics for MDA8 ozone ≥60 ppb by month and select states within Mid-Atlantic 4km domain based on data at AQS network sites.

State	Month	# of Obs	MB (ppb)	ME (ppb)	NMB (%)	NME (%)
CT	05	8	1.62	4.81	2.57	7.63
CT	06	69	4.60	11.12	6.21	15.02
CT	07	98	6.73	11.67	9.20	15.95
CT	08	28	6.19	7.93	9.55	12.24
CT	09	19	6.98	7.90	10.88	12.30
MD	05	70	6.24	8.01	9.17	11.77
MD	06	196	2.47	7.72	3.47	10.86
MD	07	286	4.53	9.89	6.36	13.89
MD	08	88	6.18	7.31	9.19	10.88
MD	09	22	6.17	9.58	9.68	15.01
NJ	05	33	2.59	7.71	3.86	11.51
NJ	06	101	1.53	8.67	2.10	11.91
NJ	07	149	6.00	9.02	8.49	12.76
NJ	08	41	4.22	6.61	6.42	10.07
NJ	09	6	5.70	5.86	8.86	9.12
NY	05	34	0.45	8.33	0.70	12.97
NY	06	129	1.10	8.67	1.59	12.59

State	Month	# of Obs	MB (ppb)	ME (ppb)	NMB (%)	NME (%)
NY	07	220	0.35	8.02	0.51	11.54
NY	08	52	0.86	6.34	1.32	9.76
NY	09	25	2.10	7.83	3.29	12.25
RI	05	5	-4.70	4.70	-7.47	7.47
RI	06	21	-1.76	7.43	-2.57	10.87
RI	07	38	5.02	9.72	7.25	14.04
RI	08	11	-3.24	6.75	-5.02	10.46
RI	09	4	3.85	3.91	5.98	6.07
VA	05	41	1.96	8.56	2.81	12.32
VA	06	199	2.49	6.86	3.71	10.19
VA	07	224	5.06	9.05	7.38	13.20
VA	08	87	3.83	8.59	5.88	13.17
VA	09	16	1.10	7.52	1.72	11.77

While we make general comparisons below in both the Lake Michigan and Mid-Atlantic 4km results to the 12km results from Table 1, we note that there is a spatial mismatch preventing direct comparison as the 4km results only includes the portions of states that are included in the 4km domain while the 12km results capture each state in its entirety and contain averaged 4km results for regions covered by the 4km domains.

Table 4 presents model performance statistics for all monitors across the two 4km modeling domains.

Table 4. Performance statistics for MDA8 ozone ≥60 ppb by month and region for 4km domains based on data at AQS network sites.

Region	Month	# of Obs	MB (ppb)	ME (ppb)	NMB (%)	NME (%)
Mid-Atlantic	05	239	4.46	7.65	6.65	11.41
Mid-Atlantic	06	820	3.39	8.75	4.78	12.34
Mid-Atlantic	07	1247	5.09	9.84	7.24	13.99
Mid-Atlantic	08	339	5.41	8.04	8.19	12.18
Mid-Atlantic	09	93	5.99	8.03	9.40	12.61
Mid-Atlantic	All		4.60	9.04	6.64	13.00
Lake Michigan	05	50	-2.79	9.35	-4.43	14.88
Lake Michigan	06	381	-2.29	6.92	-3.38	10.21
Lake Michigan	07	487	-3.72	10.75	-5.46	15.75
Lake Michigan	08	101	-3.18	7.13	-4.86	10.90
Lake Michigan	09	112	-12.28	13.89	-16.04	18.14
Lake Michigan	All		-4.00	9.39	-5.71	13.65

Compared to the 12km results (Table 1), bias and error for 8-hour daily maximum ozone are slightly higher in each 4km region. Generally, mean bias for 8-hour ozone ≥ 60 ppb during each month of the May through September period is demonstrated to be within ± 5 ppb at AQS sites for all months in the Lake Michigan domain, with the exception of September. June, July, and August in the Mid-Atlantic domain demonstrate mean bias just outside of ± 5 ppb (5.09 ppb, 5.41 ppb, and 5.99 ppb, respectively). September in the Lake Michigan is the only month within the two 4km domains that exceeds ± 10 ppb (-12.28 ppb). The mean error is 10 ppb or less for most months, except July and September in the Lake Michigan domain. Normalized mean bias is within ± 10 percent for AQS sites in all months except September in the Lake Michigan domain, with somewhat larger values in the Mid-Atlantic domain (ranging from 4.78 percent in June to 9.40 percent in September).

Consistent with the 12km results, the mean bias and normalized mean bias statistics again indicate a tendency for the model to over predict MDA8 ozone concentrations in the Mid-Atlantic domain and under predict MDA8 ozone concentrations in the Lake Michigan regions for AQS sites. The normalized mean error is less than 15 percent for months other than July and September in the Lake Michigan 4km domain.

When performing higher grid resolution (e.g., 4km) simulations, we often see poorer performance than in using coarser grid resolution (e.g., 12km). This is likely a result of the 12km results smoothing the results and not capturing the steep concentration gradients that are often present in higher resolution simulations. In this analysis and averaged over the modeling period, the model statistically performs better at 12km for the Mid-Atlantic domain and better at 4km for the Lake Michigan domain.

Monitor specific performance metrics for the two 4km modeling domains are provided as Appendix A to this document.

2.2 GRAPHICAL DISTRIBUTION OF STATISTICS

Figures 3 through 6 show the spatial variability in bias and error at monitor locations. Mean bias, as seen from Figure 3, is within ± 5 ppb at most sites across the Lake Michigan domain with a maximum under-prediction of 9.16 ppb at one site (171971011) southwest of Joliet, IL. In the Mid-Atlantic, a positive mean bias is generally seen in the range of 5 to 10 ppb with spots of 10 to 15 ppb over-prediction seen scattered throughout the domain. The maximum mean bias in the Mid-Atlantic domain (340110007 at 13.78 ppb) is located near Atlantic City, NJ.

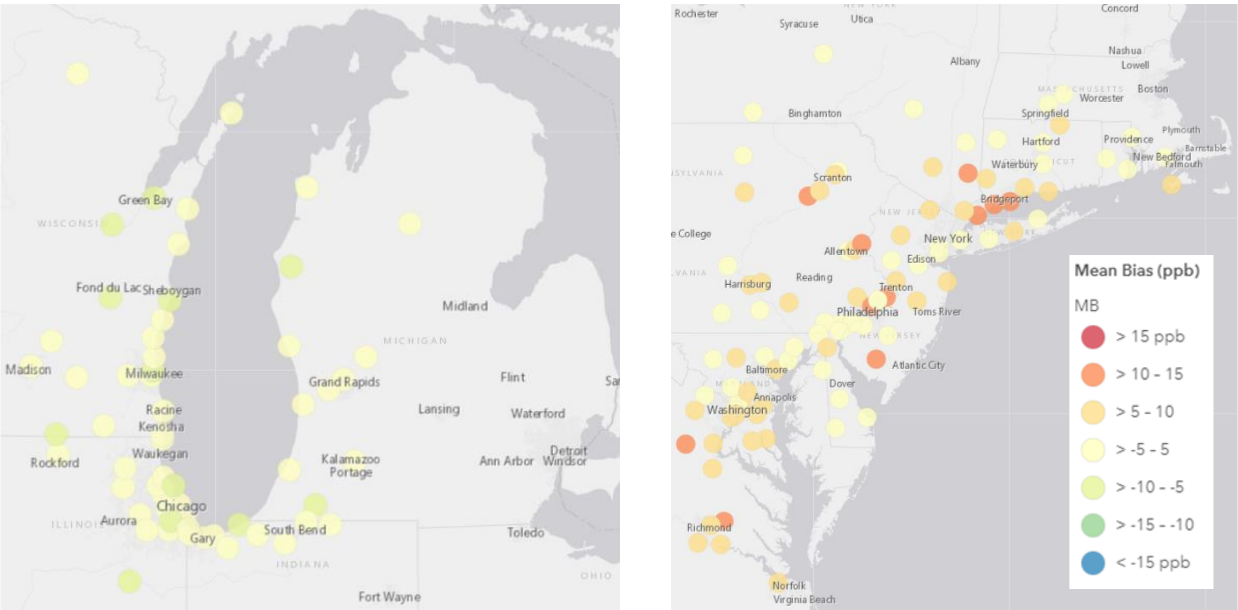

Figure 3. Mean Bias (ppb) of MDA8 ozone > 60 ppb over the period May-September 2011 at AQS monitoring sites in Lake Michigan (left) and Mid-Atlantic (right) 4km domains.

Figure 4 indicates that the normalized mean bias for days with observed 8-hour daily maximum ozone > 60 ppb is within ± 10 percent at the vast majority of monitoring sites across the Lake Michigan 4km modeling domain. Monitor (171971011) exceeds -10 percent with a NMB of -13.5 percent. There are clear regional differences in model performance, as the model tends to over predict at most sites in the 4km Mid-Atlantic domain and generally under predict at sites in and around the 4km Lake Michigan domain. Model performance in the Mid-Atlantic domain shows that about two thirds of sites are within + 10 percent normalized mean bias.

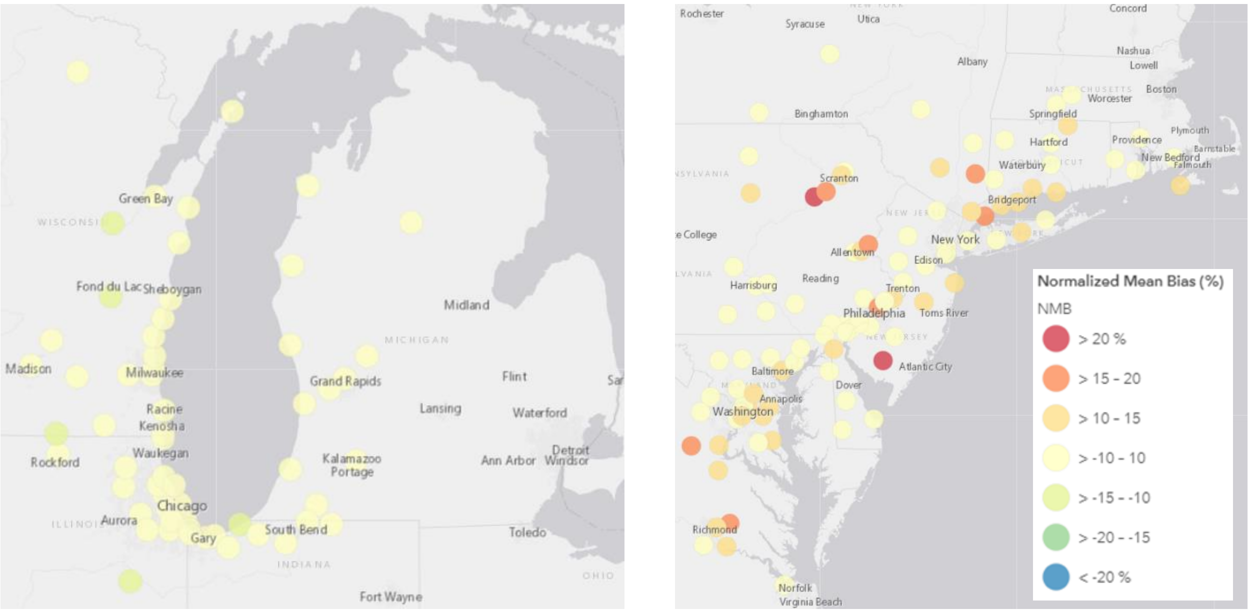

Figure 4. Normalized Mean Bias (%) of MDA8 ozone > 60 ppb over the period May-September 2011 at AQS monitoring sites in Lake Michigan (left) and Mid-Atlantic (right) 4km domains.

Mean error (ME), as seen from Figure 5, is generally 10 ppb or less at most of the sites across the Lake Michigan 4km modeling domain although monitor (170317002) outside of Evanston, IL shows a much higher ME of 16.13 ppb. The Mid-Atlantic 4km domain shows approximately one third of its monitors above 10 ppb model error, with the majority of those exceeding this value being located along the I-95 interstate corridor or along coastal waterways. Figure 6 indicates that the normalized mean error (NME) for days with observed 8-hour daily maximum ozone > 60 ppb is less than 15 percent at the vast majority of monitoring sites across the Lake Michigan 4km modeling domain. The noted exception seen is monitor (170317002) outside of Evanston, IL with a NME of 23.1%. Somewhat greater error (i.e., 15 to 20 percent) is again seen at several sites in the 4km Mid-Atlantic domain, most notably along the I-95 interstate corridor.

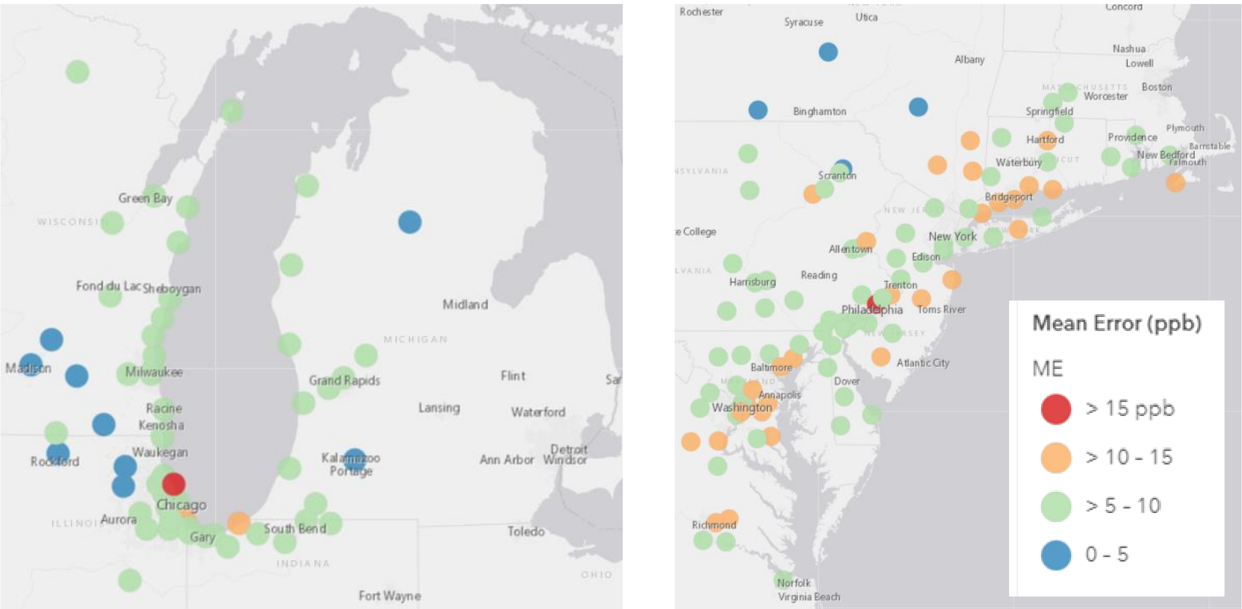

Figure 5. Mean Error (ppb) of MDA8 ozone > 60 ppb over the period May-September 2011 at AQS monitoring sites in Lake Michigan (left) and Mid-Atlantic (right) 4km domains.

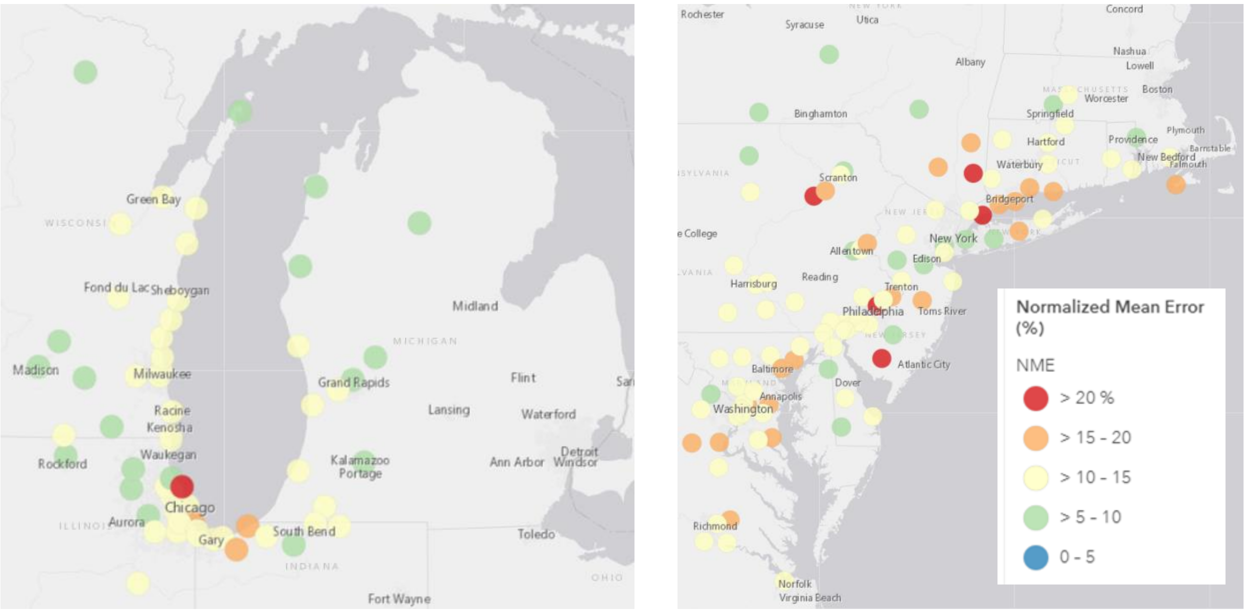

Figure 6. Normalized Mean Error (%) of MDA8 ozone > 60 ppb over the period May-September 2011 at AQS monitoring sites in Lake Michigan (left) and Mid-Atlantic (right) 4km domains.

2.3 TIME SERIES PLOTS BY MONITOR

In addition to the above analysis of overall model performance, we also examined how well the modeling platform replicates day to day fluctuations in observed 8-hour daily maximum concentrations using data for select nonattainment and maintenance sites identified in the 4km modeling or via EPA's March 2018 technical memorandum (Tsirigotis, 2018) as presented in Table 5.

Table 5. Monitoring sites included in the ozone time series analysis.

AIRS Monitor ID	State	County
90013007	Connecticut	Fairfield
90019003	Connecticut	Fairfield
90099002	Connecticut	New Haven
240251001	Maryland	Harford
260050003	Michigan	Allegan
340150002	New Jersey	Gloucester
360810124	New York	Queens
360850067	New York	Richmond
361030002	New York	Suffolk
421010024	Pennsylvania	Philadelphia
551170006	Wisconsin	Sheboygan

For this site-specific analysis we present the time series of observed and predicted 8-hour daily maximum concentrations by site in the 4km simulation over the period May through September. The results, as shown in Figures 7 through 17, indicate that the modeling platform generally replicates the day-to-day variability in ozone during this time period at these sites. That is, days with high modeled concentrations are generally also days with high measured concentrations and, conversely, days with low modeled concentrations are also days with low measured concentrations in most cases.

For example, model predictions at several sites not only accurately capture the day-to-day variability in the observations, but also appear to have relatively low bias on individual days: Harford Co., MD; Allegan Co., MI; Gloucester Co., NJ; Queens, Richmond, and Suffolk Co., NY; Philadelphia Co., PA; and Sheboygan Co., WI each track closely with the observations, but there is a tendency to over predict on several of the observed high ozone days at locations in the Mid-Atlantic 4km domain and under predict on several of the observed high ozone days at locations in the Lake Michigan 4km domain. Of particular note are the over predictions at Connecticut monitors during a mid-July episode and the under prediction of MDA8 at the Sheboygan, WI receptor during an early September episode.

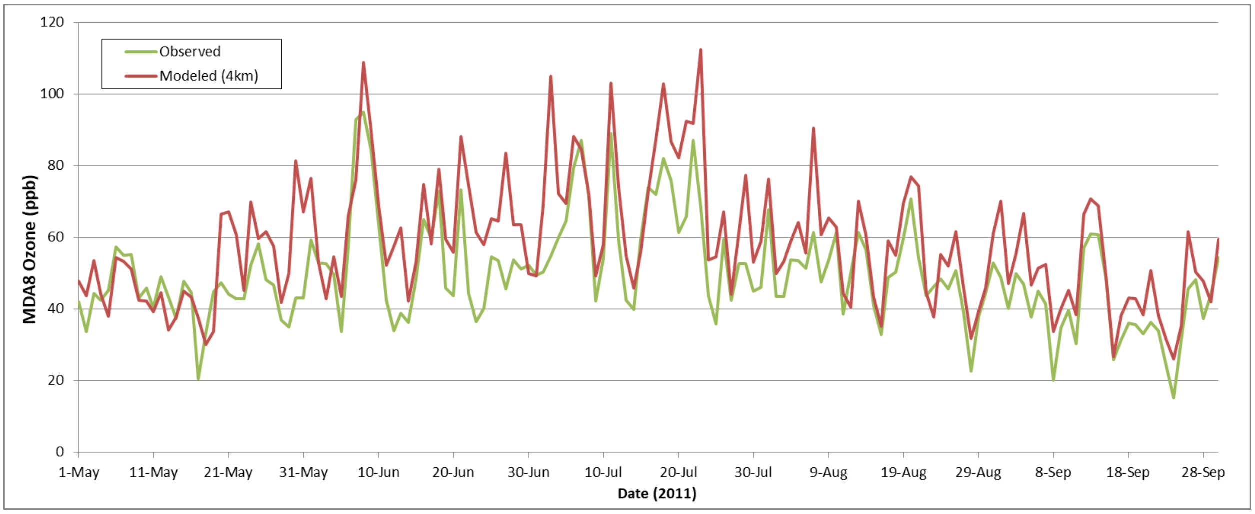

Figure 7. Time series of observed (green) and predicted 4km (red) MDA8 ozone for May through September 2011 at site 90013007 in Fairfield Co., Connecticut.

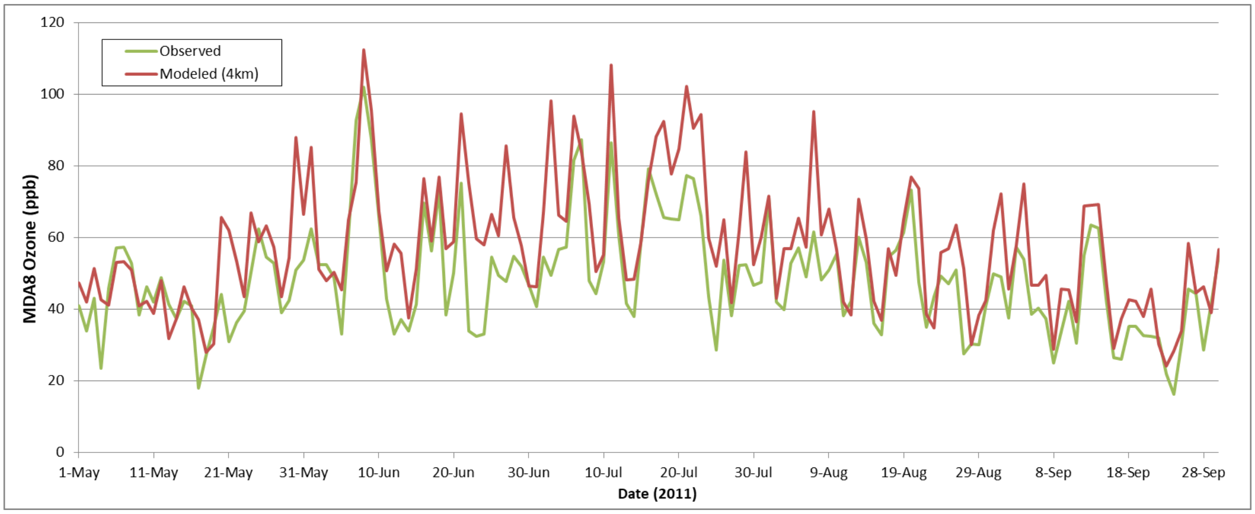

Figure 8. Time series of observed (green) and predicted 4km (red) MDA8 ozone for May through September 2011 at site 90019003 in Fairfield Co., Connecticut.

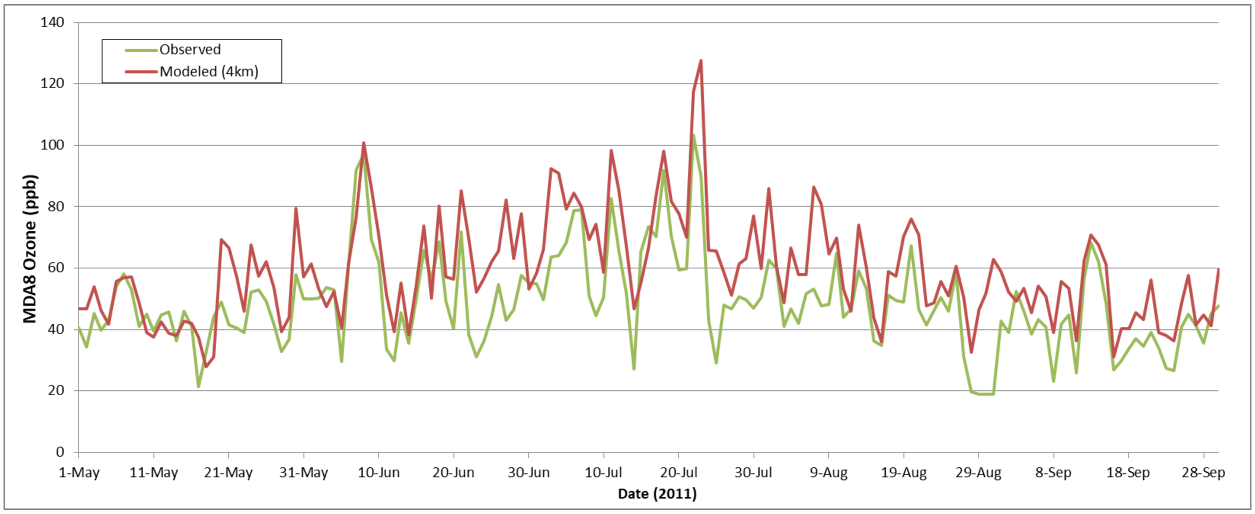

Figure 9. Time series of observed (green) and predicted 4km (red) MDA8 ozone for May through September 2011 at site 90099002 in New Haven Co., Connecticut.

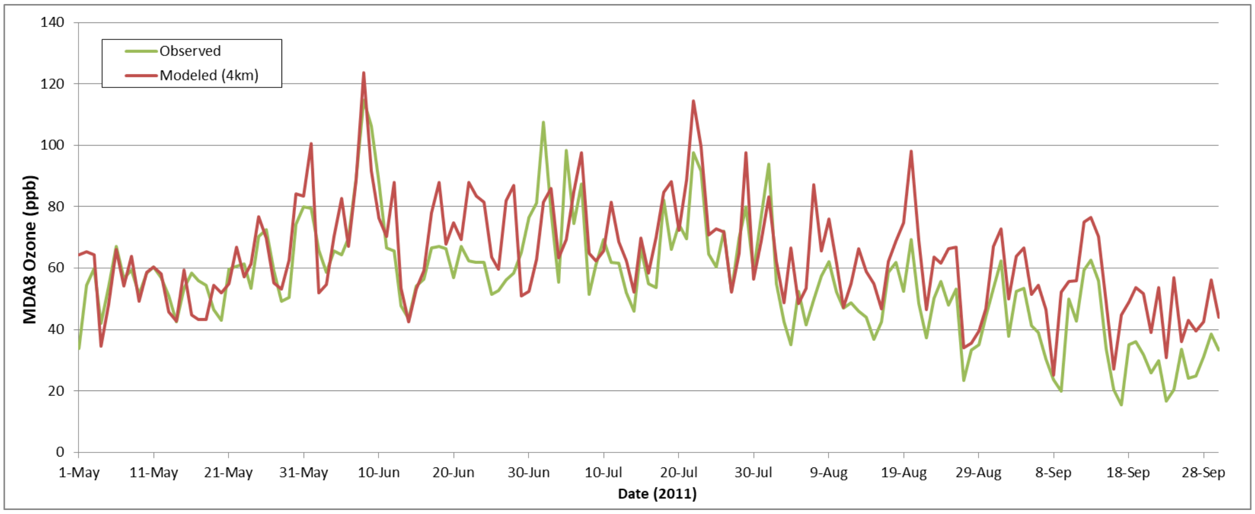

Figure 10. Time series of observed (green) and predicted 4km (red) MDA8 ozone for May through September 2011 at site 240251001 in Harford Co., Maryland.

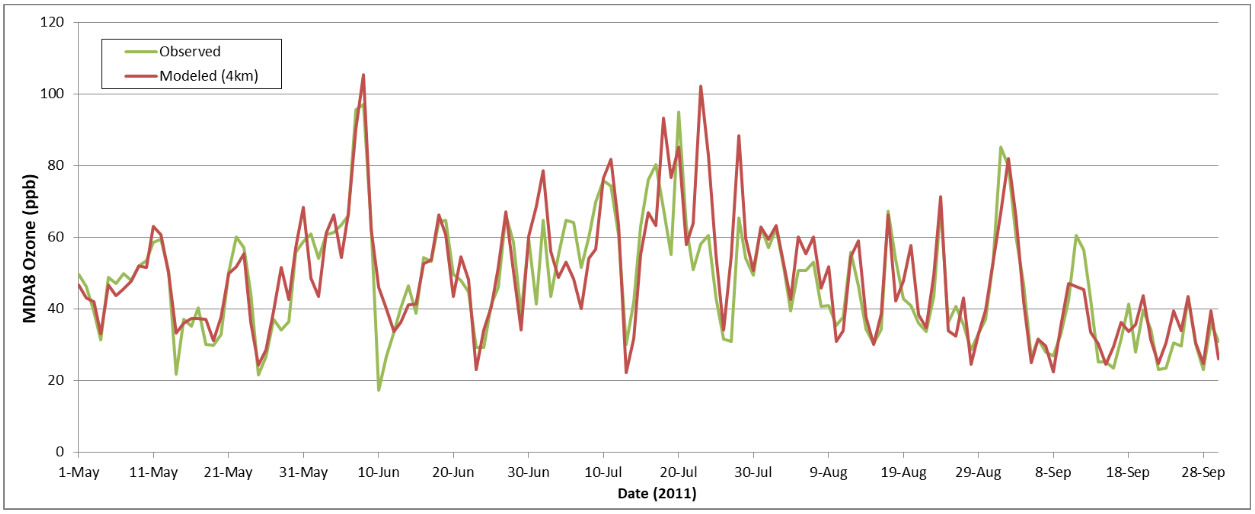

Figure 11. Time series of observed (green) and predicted 4km (red) MDA8 ozone for May through September 2011 at site 260050003 in Allegan Co., Michigan.

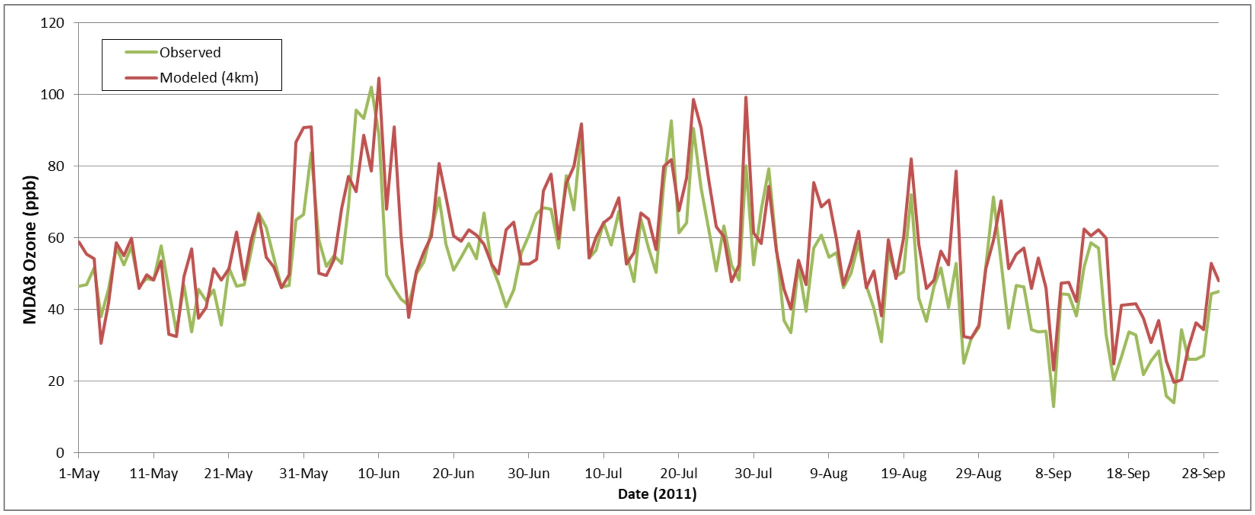

Figure 12. Time series of observed (green) and predicted 4km (red) MDA8 ozone for May through September 2011 at site 340150002 in Gloucester Co., New Jersey.

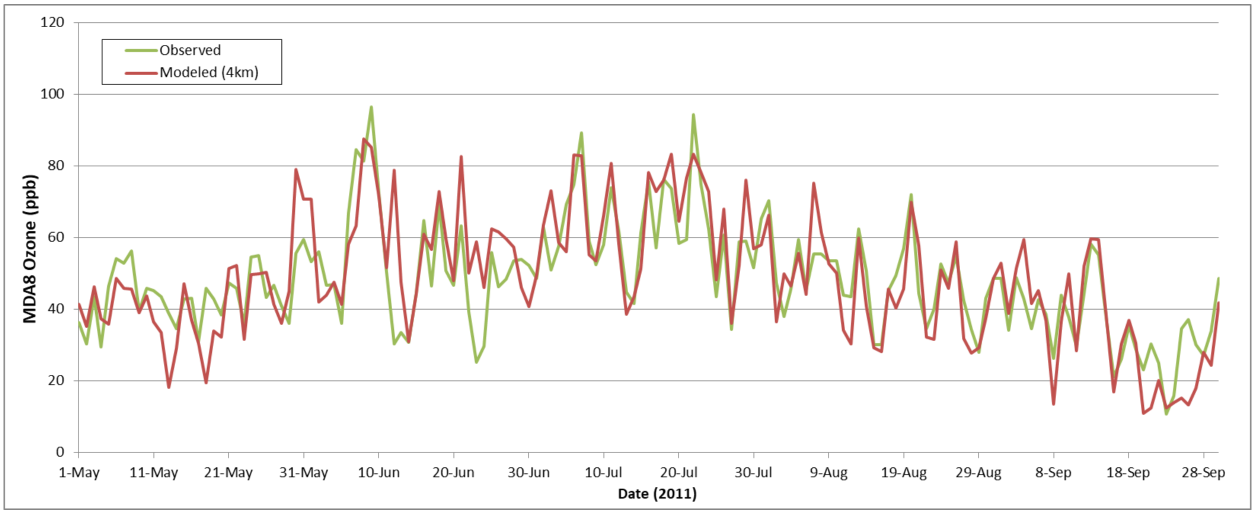

Figure 13. Time series of observed (green) and predicted 4km (red) MDA8 ozone for May through September 2011 at site 360810124 in Queens Co., New York.

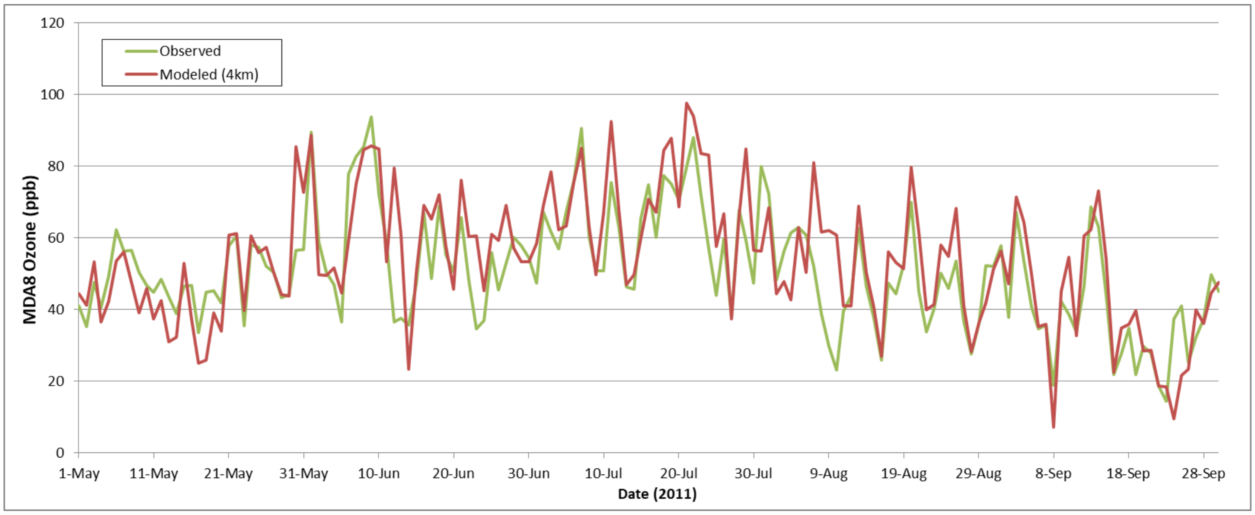

Figure 14. Time series of observed (green) and predicted 4km (red) MDA8 ozone for May through September 2011 at site 360850067 in Richmond Co., New York.

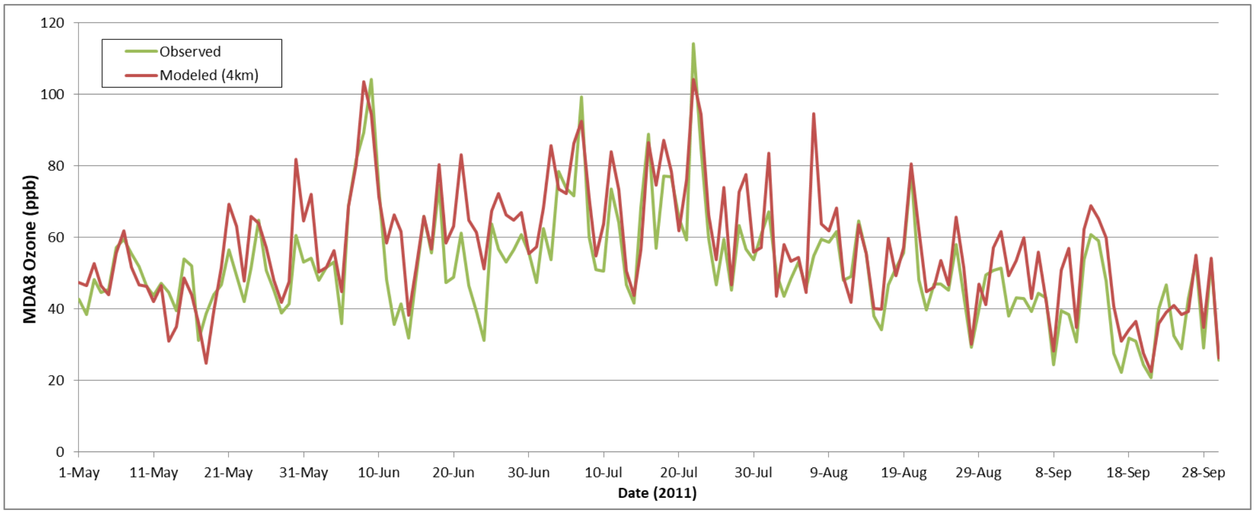

Figure 15. Time series of observed (green) and predicted 4km (red) MDA8 ozone for May through September 2011 at site 361030002 in Suffolk Co., New York.

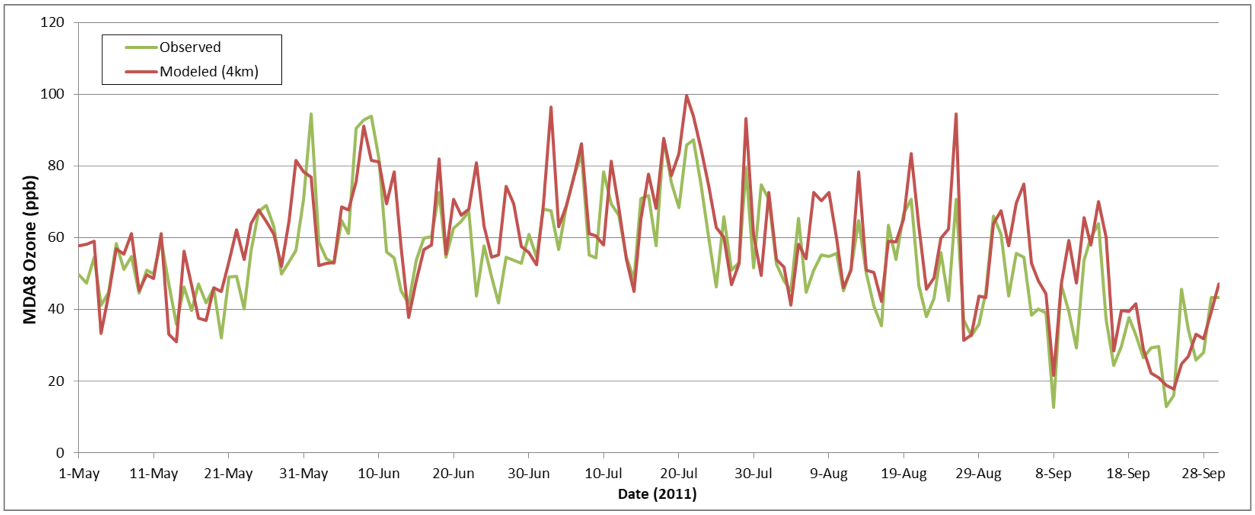

Figure16. Time series of observed (green) and predicted 4km (red) MDA8 ozone for May through September 2011 at site 421010024 in Philadelphia Co., Pennsylvania.

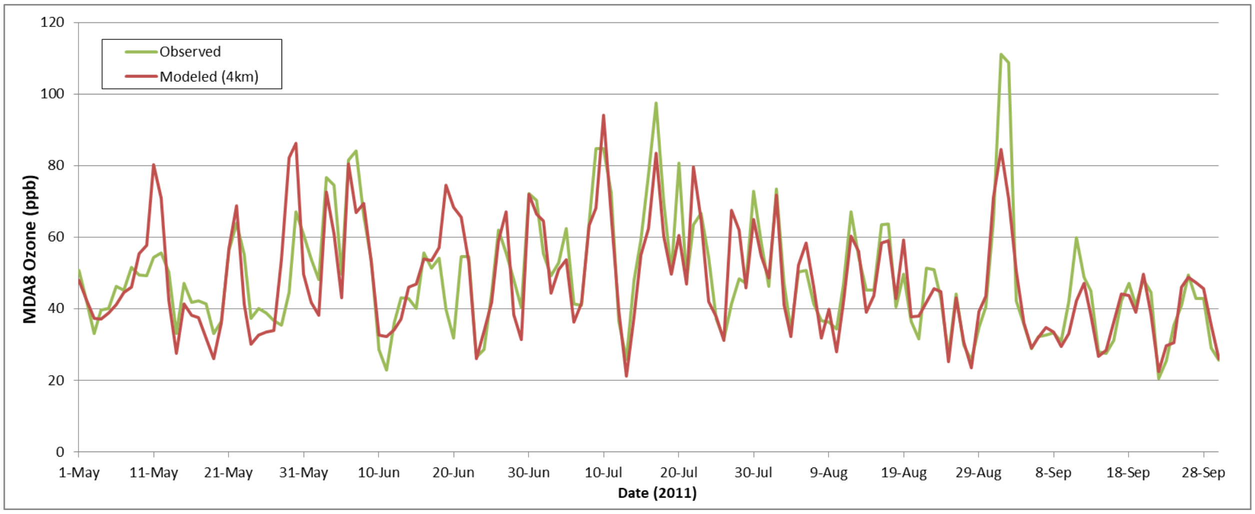

Figure 17. Time series of observed (green) and predicted 4km (red) MDA8 ozone for May through September 2011 at site 551170006 in Sheboygan Co., Wisconsin.

2.4 CONCENTRATION CORRELATION PLOTS

Under and over predictions can also be reviewed through examination of correlation plots of observed vs. modeled MDA8 concentrations by location during the May through September episode (Figures 18 through 28). On these graphics each daily MDA8 concentration at a monitor is plotted as a single ordered pair with the observed ozone on and horizontal axis and the corresponding model estimate on the vertical axis. A perfect model would show all points in a single line with a unit slope. In the figures the fourth highest observation is plotted with a red square and the fourth highest model estimate has a yellow square.

While many of the sites generally track well and capture day-to-day variability, the following sites do demonstrate the underestimation of ozone on some of the days with measured high ozone concentrations, specifically at locations in Connecticut in the Mid-Atlantic 4km domain. At the monitors in Richmond Co., NY; Suffolk Co., NY; and Sheboygan Co., WI, the model has over predicted the 4th high observed values where at all other represented monitors, the model has under predicted this value.

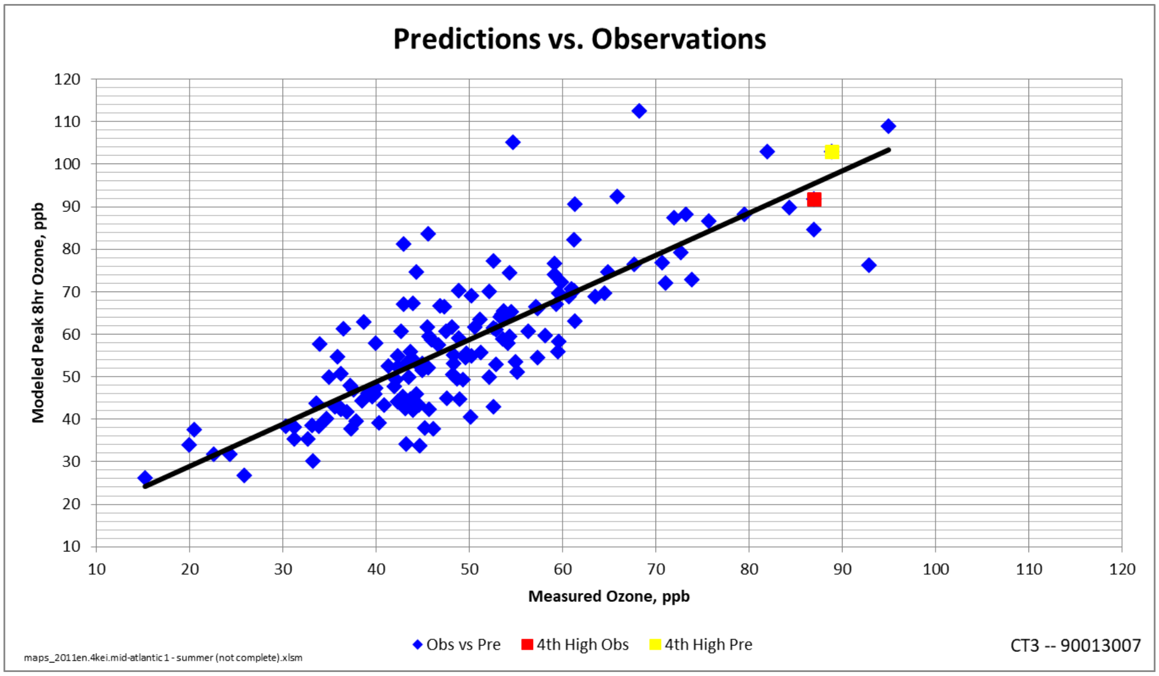

Figure 18. Correlation of observed and predicted MDA8 ozone for May through September 2011 at site 90013007 in Fairfield Co., Connecticut. Red square indicates 4th high observed value and yellow diamond indicates 4th high modeled value.

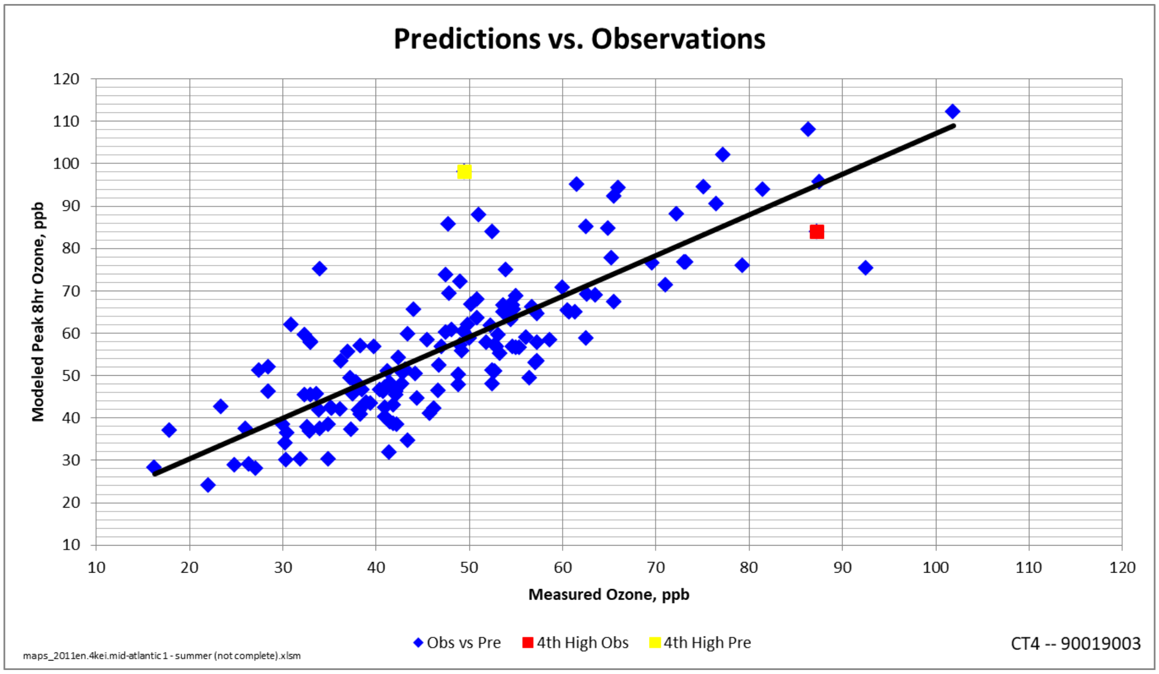

Figure 19. Correlation of observed and predicted MDA8 ozone for May through September 2011 at site 90019003 in Fairfield Co., Connecticut. Red square indicates 4th high observed value and yellow diamond indicates 4th high modeled value.

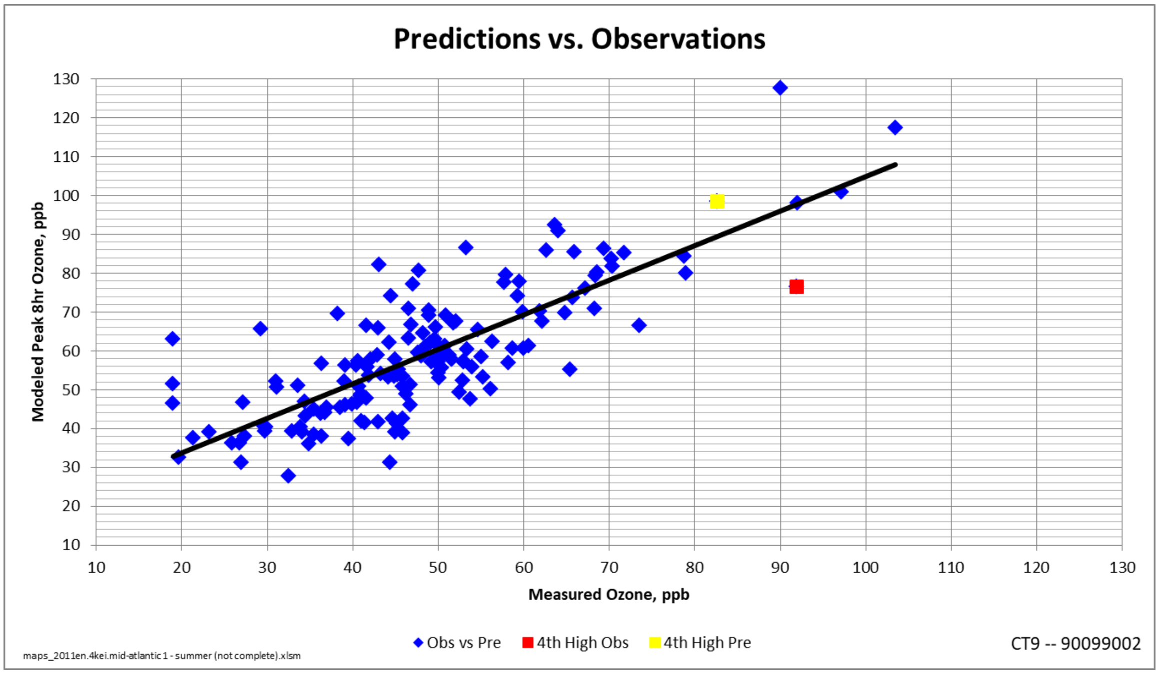

Figure 20. Correlation of observed and predicted MDA8 ozone for May through September 2011 at site 90099002 in New Haven Co., Connecticut. Red square indicates 4th high observed value and yellow diamond indicates 4th high modeled value.

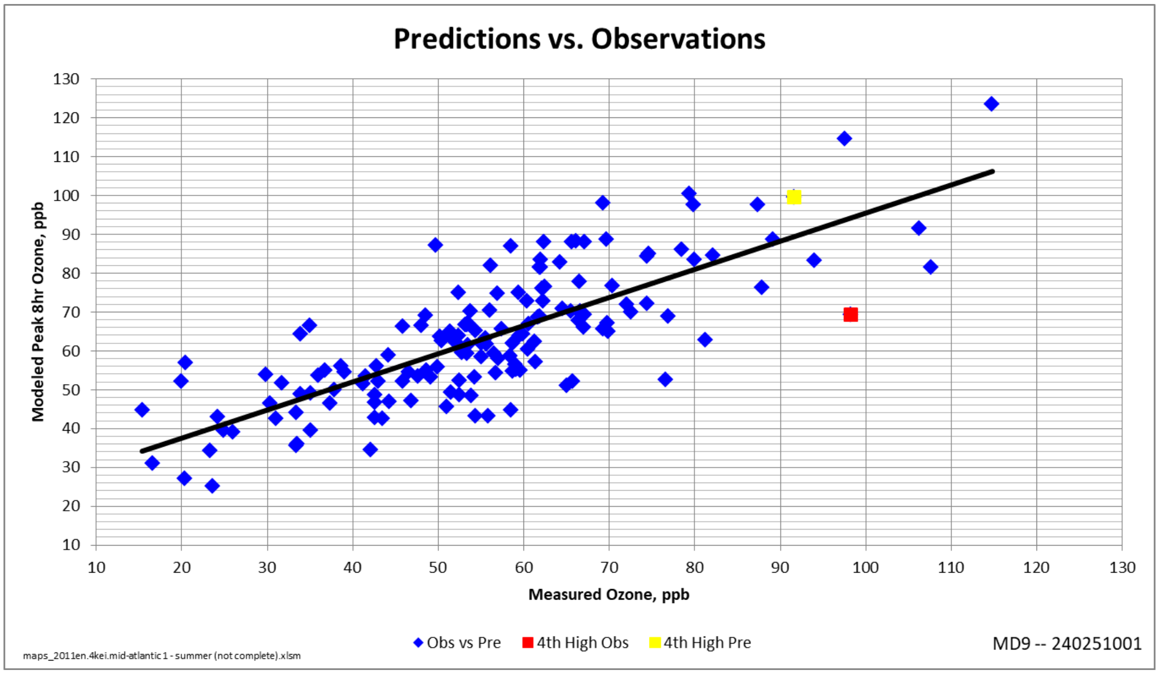

Figure 21. Correlation of observed and predicted MDA8 ozone for May through September 2011 at site 240251001 in Harford Co., Maryland. Red square indicates 4th high observed value and yellow diamond indicates 4th high modeled value.

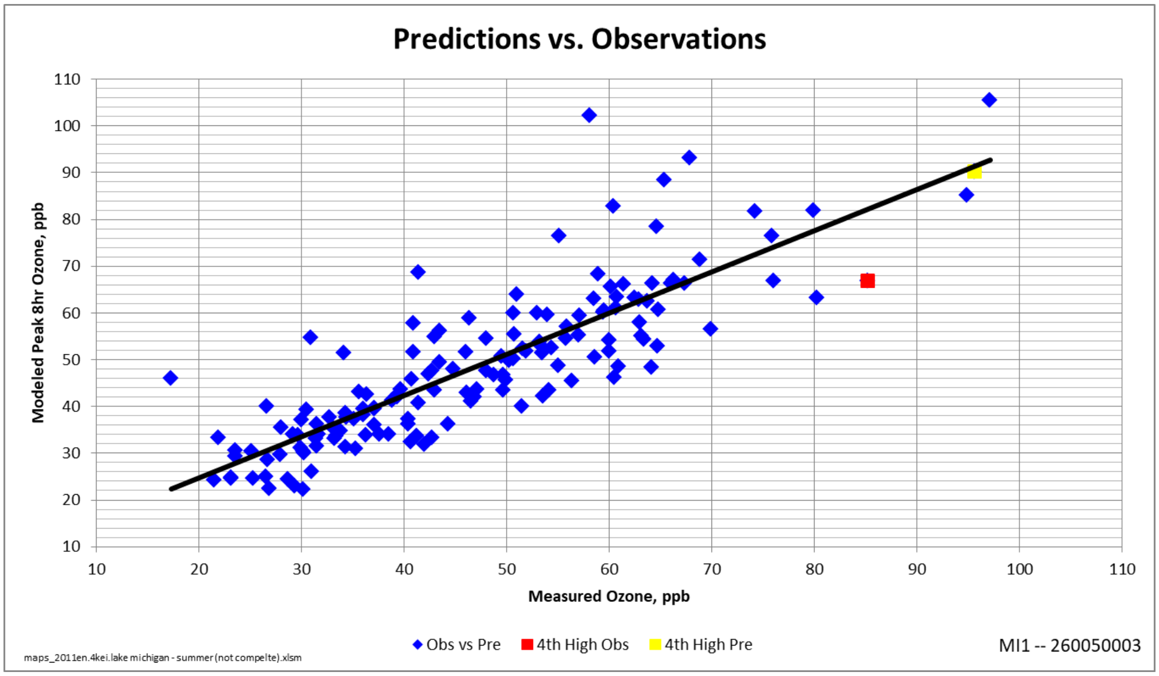

Figure 22. Correlation of observed and predicted MDA8 ozone for May through September 2011 at site 260050003 in Allegan Co., Michigan. Red square indicates 4th high observed value and yellow diamond indicates 4th high modeled value.

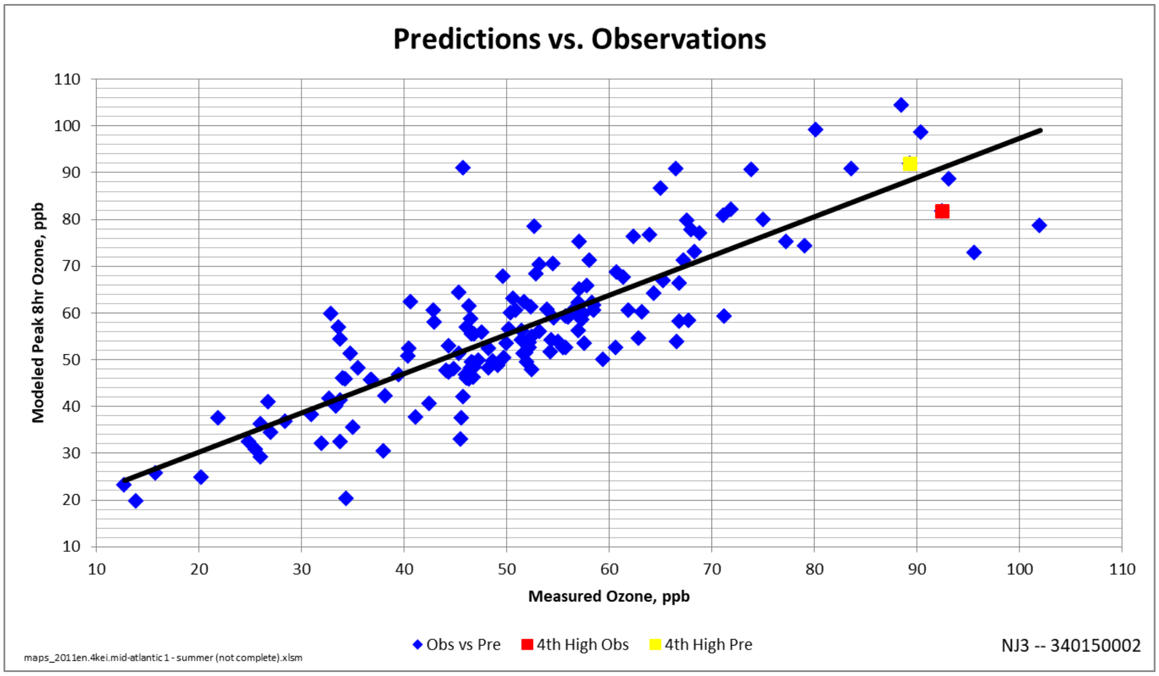

Figure 23. Correlation of observed and predicted MDA8 ozone for May through September 2011 at site 340150002 in Gloucester Co., New Jersey. Red square indicates 4th high observed value and yellow diamond indicates 4th high modeled value.

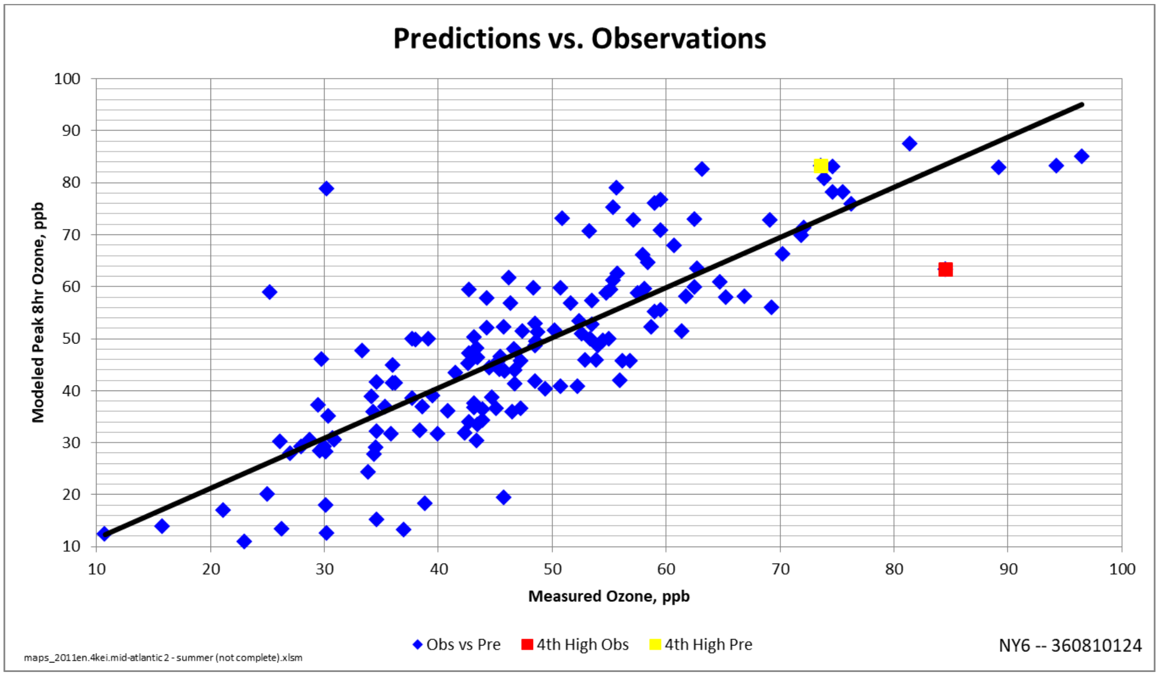

Figure 24. Correlation of observed and predicted MDA8 ozone for May through September 2011 at site 360810124 in Queens Co., New York. Red square indicates 4th high observed value and yellow diamond indicates 4th high modeled value.

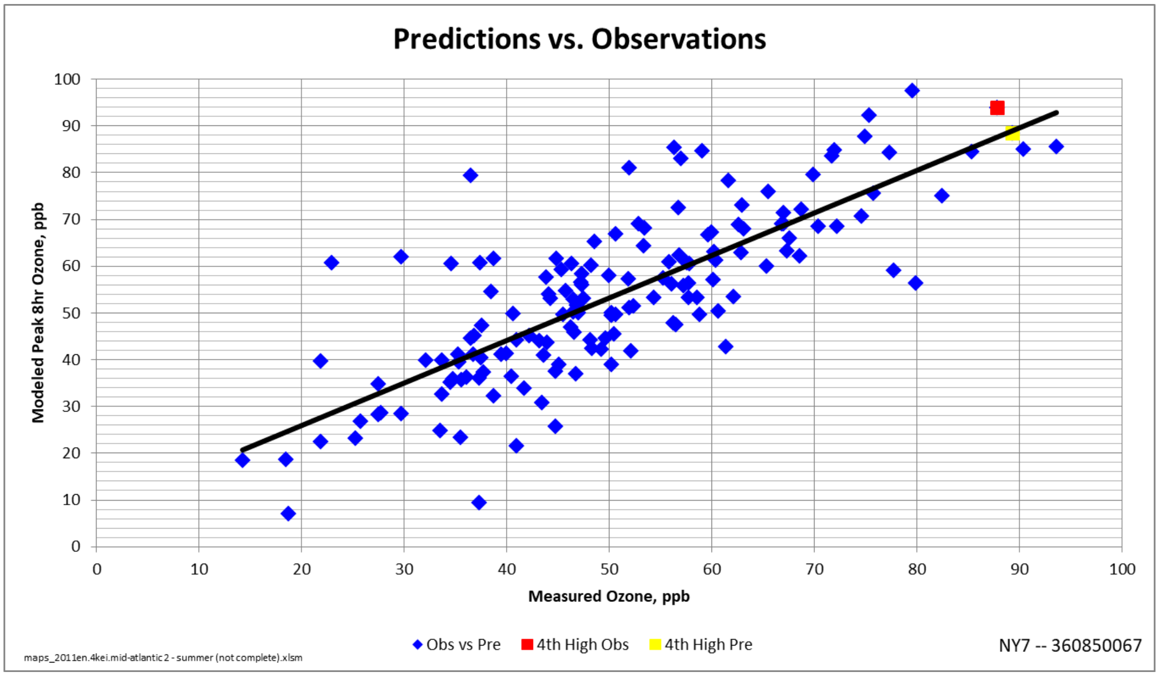

Figure 25. Correlation of observed and predicted MDA8 ozone for May through September 2011 at site 360850067 in Richmond Co., New York. Red square indicates 4th high observed value and yellow diamond indicates 4th high modeled value.

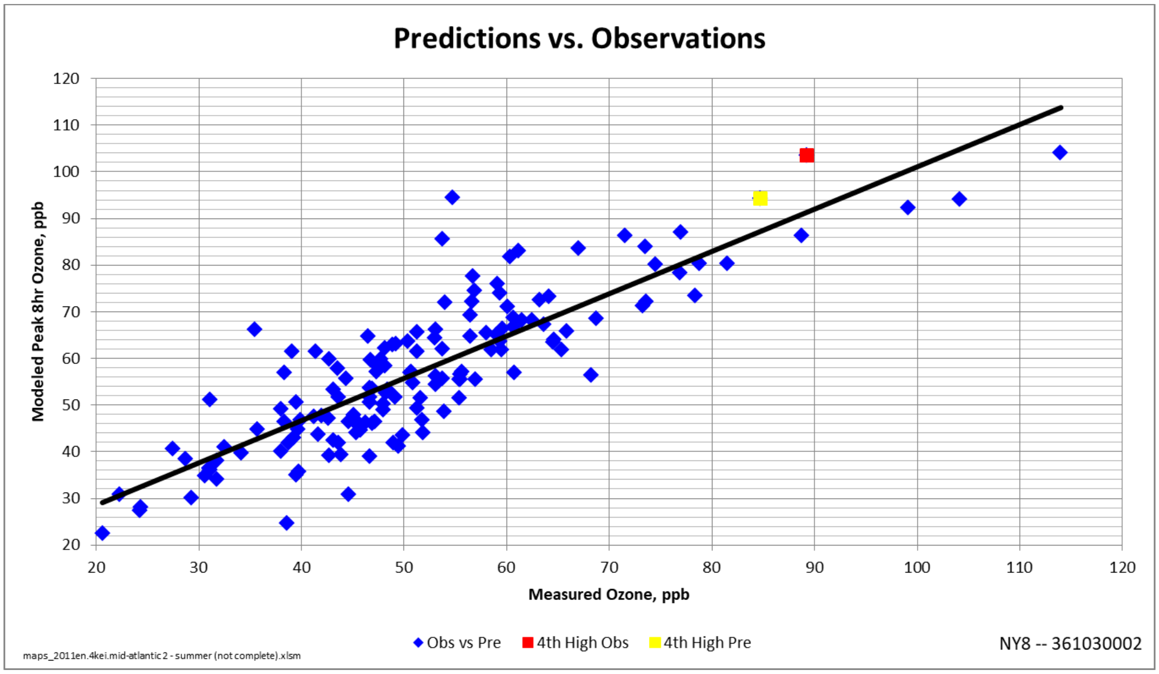

Figure 26. Correlation of observed and predicted MDA8 ozone for May through September 2011 at site 361030002 in Suffolk Co., New York. Red square indicates 4th high observed value and yellow diamond indicates 4th high modeled value.

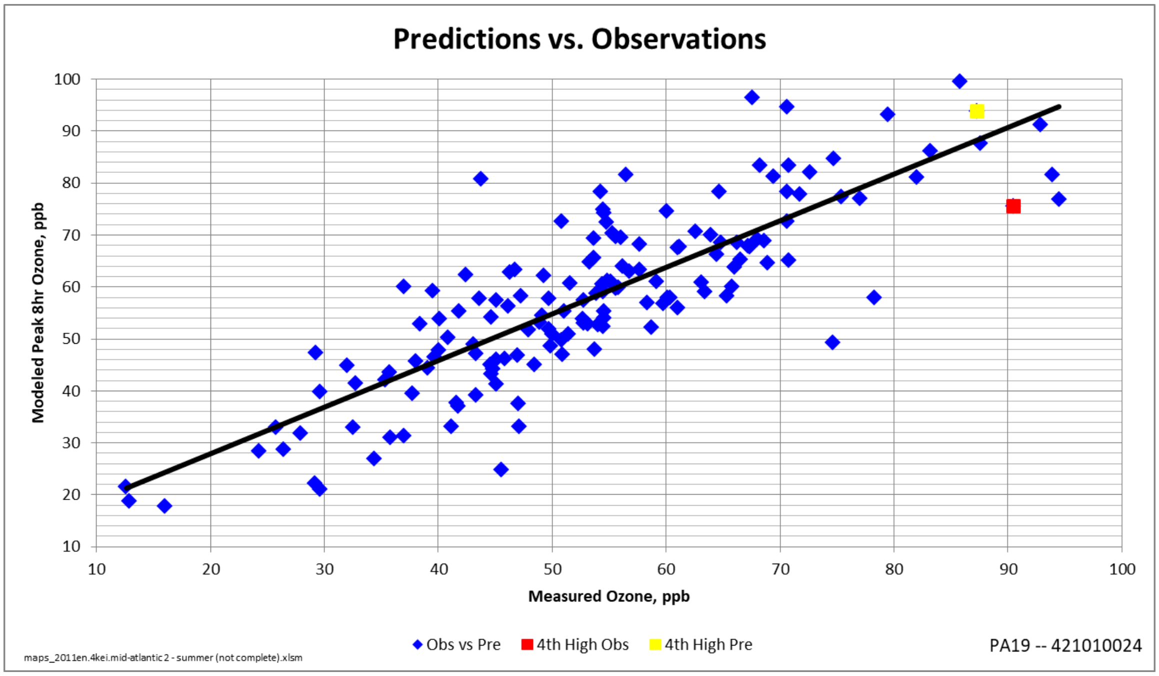

Figure 27. Correlation of observed and predicted MDA8 ozone for May through September 2011 at site 421010024 in Philadelphia Co., Pennsylvania. Red square indicates 4th high observed value and yellow diamond indicates 4th high modeled value.

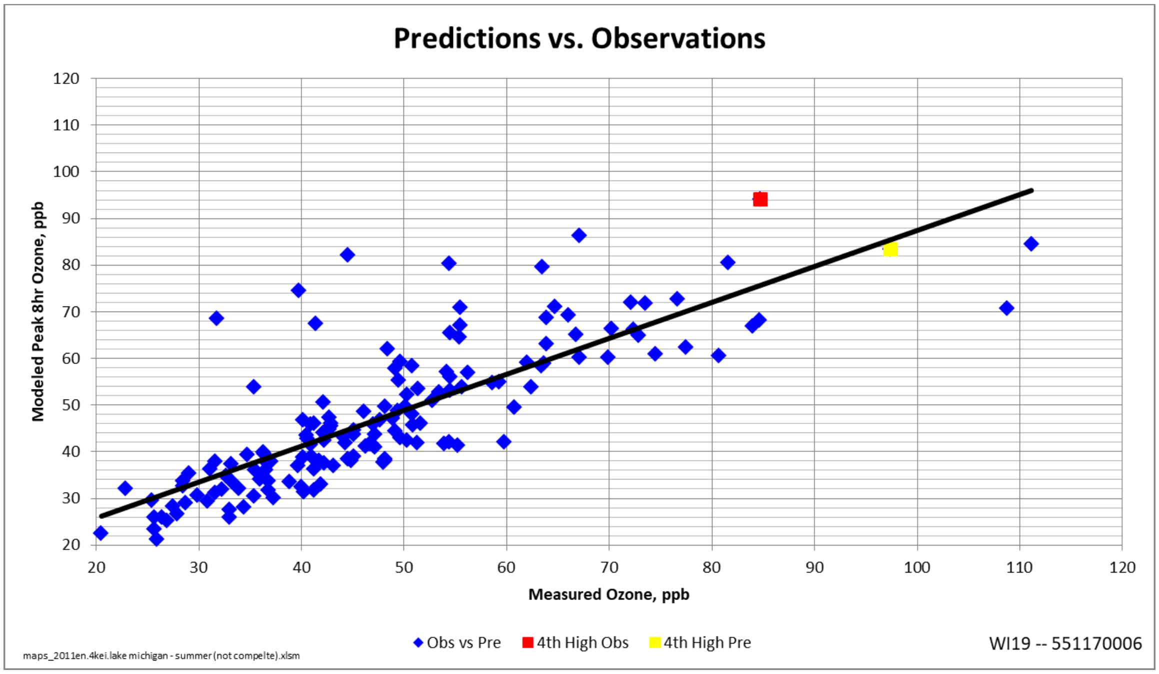

Figure 28. Correlation of observed and predicted MDA8 ozone for May through September 2011 at site 551170006 in Sheboygan Co., Wisconsin. Red square indicates 4th high observed value and yellow diamond indicates 4th high modeled value.

3.0 SUMMARY

As was seen with the 12km evaluation conducted by EPA on the 2011en platform (EPA, 2018), this 4km CAMx modeling configuration has better skill at predicting ozone concentrations in the mid-range of 40 to 60 ppb than it does at the tail ends of the concentration curves. Additionally, as noted above and demonstrated with the statistics and figures of this analysis, both low-end observed concentrations (less than 40 ppb) and high-end (greater than 60 ppb) concentrations tend to be under predicted by this platform configuration on both 4km domains.

Over the entire concentration range, the model tends to under predict MDA8 ozone in the Lake Michigan 4km domain and over predict MDA8 ozone concentrations in the 4km Mid-Atlantic domain. However, looking across all represented monitors in the two 4km domains, we note that the model is able to capture site-to-site differences in the short-term (i.e., day-to-day) variability and the general magnitude of the observed ozone concentrations for the May through September 2011 episode.

As a result, and compared to similar results from comparable studies, we find that the predictions from the 4km domains using this configuration of the 2011en modeling platform correspond closely to observed concentrations in terms of the magnitude, temporal fluctuations, and geographic differences for 8-hour daily maximum ozone.

Thus, the model performance results demonstrate the scientific credibility of the 2011 modeling platform for these two 4km domains. These results provide confidence in the ability of the modeling platform to be used for future year ozone concentration projections and contribution analyses.

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Appendix A

Model performance statistics for MDA8 ozone at individual monitoring sites based on days with observed values > 60 ppb.

MOG 4km Monitor-Level Model Performance Statistics
Mid-Atlantic Domain

AIRS Station Id	Thresh (ppb)	N	Avg Obs (ppb)	Peak Obs (ppb)	Peak Obs Day	Avg Pre (ppb)	Peak Pre (ppb)	Peak Pre Day	AU (%)	Variance (ppb^2)	MB (ppb)	MNB (%)	NMB (%)	MFB (%)	NMBF	MEr (ppb)	NME (%)	MNGE (%)	MFE (%)	NMEF	RMSE (ppb)	RSQR
90010017	60	31	69.76	93.63	2011060824	82.89	111.49	2011060824	19.08	144.65	13.13	19.38	18.82	16.46	0.19	14.13	20.26	20.66	17.80	0.20	17.81	0.25
90011123	60	26	70.00	89.38	2011072124	75.48	94.88	2011060924	6.15	68.76	5.48	7.97	7.83	6.99	0.08	8.26	11.79	12.05	11.31	0.12	9.94	0.48
90013007	60	27	72.89	95.00	2011060824	83.20	112.46	2011072324	18.38	126.27	10.31	15.05	14.15	13.00	0.14	11.82	16.22	16.71	14.80	0.16	15.25	0.30
90019003	60	29	71.95	101.88	2011060824	82.12	112.27	2011060824	10.20	124.29	10.17	14.87	14.13	12.82	0.14	12.06	16.76	17.10	15.20	0.17	15.09	0.37
90031003	60	15	72.08	95.00	2011060924	73.12	96.06	2011072124	1.12	234.23	1.04	3.90	1.45	1.89	0.01	10.45	14.50	14.24	14.25	0.14	15.34	0.03
90050005	60	19	67.53	85.50	2011072124	70.90	89.40	2011072124	4.56	53.79	3.37	5.22	5.00	4.48	0.05	7.04	10.43	10.62	10.34	0.10	8.07	0.32
90070007	60	22	71.42	92.00	2011060924	73.84	103.37	2011072124	12.36	82.14	2.42	3.86	3.39	3.05	0.03	7.27	10.18	10.29	9.98	0.10	9.38	0.44
90090027	60	17	72.80	98.25	2011071124	80.66	101.76	2011060824	3.57	137.88	7.86	11.88	10.79	10.01	0.11	11.95	16.42	17.06	15.55	0.16	14.13	0.19
90099002	60	28	72.84	103.43	2011072224	82.37	127.57	2011072324	23.34	127.37	9.53	13.50	13.09	11.66	0.13	11.85	16.27	16.48	14.87	0.16	14.77	0.50
90131001	60	14	66.34	87.88	2011071124	73.17	96.32	2011072124	9.60	114.52	6.83	11.10	10.29	9.36	0.10	7.60	11.46	12.11	10.38	0.11	12.69	0.08
100010002	60	32	67.86	94.25	2011060824	71.63	102.66	2011060824	8.92	89.03	3.77	5.55	5.56	4.51	0.06	7.97	11.75	11.78	11.17	0.12	10.16	0.40
100031007	60	26	69.42	82.75	2011061024	78.36	98.03	2011060124	18.47	66.02	8.94	12.89	12.88	11.53	0.13	9.89	14.25	14.39	13.10	0.14	12.08	0.44
100031010	60	27	69.31	86.00	2011072224	72.70	94.57	2011072224	9.97	103.44	3.39	5.12	4.89	3.89	0.05	8.63	12.45	12.69	12.30	0.12	10.72	0.28
100031013	60	34	70.66	100.75	2011060724	73.91	91.02	2011072224	-9.66	139.48	3.25	5.62	4.60	4.20	0.05	9.84	13.92	14.04	13.47	0.14	12.25	0.20
100032004	60	31	68.23	82.38	2011072224	69.49	87.81	2011072224	6.59	89.05	1.26	1.89	1.84	0.90	0.02	8.07	11.82	11.88	11.77	0.12	9.52	0.29
100051002	60	42	68.63	94.50	2011060824	68.17	96.66	2011072924	2.29	58.09	-0.47	-0.51	-0.68	-1.11	-0.01	6.27	9.14	9.11	9.08	0.09	7.64	0.35
100051003	60	42	68.03	85.00	2011060824	70.85	89.60	2011072924	5.41	64.92	2.82	4.44	4.14	3.67	0.04	7.04	10.35	10.51	10.12	0.10	8.54	0.23
110010041	60	37	69.10	85.50	2011061024	78.91	105.69	2011061024	23.61	106.33	9.81	14.58	14.20	12.59	0.14	11.57	16.75	17.21	15.37	0.17	14.23	0.24
110010043	60	51	69.71	92.38	2011061024	72.67	104.94	2011061024	13.60	70.56	2.96	4.45	4.25	3.65	0.04	7.33	10.51	10.66	10.29	0.11	8.91	0.43
240030014	60	42	71.02	94.13	2011061024	80.91	119.50	2011060824	26.95	108.05	9.89	14.30	13.93	12.48	0.14	11.65	16.40	16.52	14.85	0.16	14.35	0.36
240051007	60	50	69.84	92.63	2011070224	72.64	93.84	2011072124	1.31	100.26	2.80	4.73	4.00	3.62	0.04	8.86	12.69	12.88	12.61	0.13	10.40	0.17
240053001	60	46	70.88	101.13	2011060824	78.00	124.57	2011060824	23.18	168.25	7.11	10.48	10.03	8.53	0.10	11.59	16.35	16.55	15.07	0.16	14.79	0.30
240090011	60	37	69.46	93.75	2011060924	79.31	104.23	2011072924	11.18	112.21	9.85	14.88	14.19	12.87	0.14	11.08	15.96	16.37	14.42	0.16	14.47	0.19
240130001	60	45	66.70	85.13	2011070224	72.66	94.79	2011060824	11.35	80.86	5.96	9.32	8.94	8.09	0.09	8.52	12.78	12.93	12.02	0.13	10.79	0.14
240150003	60	38	71.16	94.63	2011060824	74.33	95.15	2011060824	0.55	93.40	3.18	5.08	4.47	4.06	0.04	8.05	11.31	11.64	11.19	0.11	10.17	0.30
240170010	60	41	69.25	98.38	2011061024	75.42	110.42	2011053124	12.24	93.19	6.16	9.47	8.90	8.20	0.09	8.14	11.76	12.21	11.01	0.12	11.45	0.25
240210037	60	47	66.73	85.50	2011070224	71.39	88.30	2011053124	3.27	56.46	4.65	7.23	6.97	6.39	0.07	7.10	10.64	10.80	10.15	0.11	8.84	0.26
240251001	60	57	73.37	114.75	2011060824	77.83	123.54	2011060824	7.66	171.52	4.46	7.36	6.08	5.64	0.06	11.20	15.27	15.46	14.66	0.15	13.84	0.30
240259001	60	46	72.01	98.25	2011070224	72.15	96.25	2011072124	-2.04	102.71	0.14	0.88	0.20	-0.10	0.00	7.79	10.81	10.77	10.84	0.11	10.14	0.21
240290002	60	42	70.89	100.75	2011060924	73.25	106.16	2011072224	5.37	57.31	2.36	3.24	3.33	2.62	0.03	6.88	9.70	9.76	9.53	0.10	7.93	0.63
240313001	60	42	68.72	88.63	2011070224	73.11	98.75	2011072024	11.42	84.75	4.39	6.76	6.39	5.71	0.06	8.26	12.02	12.18	11.58	0.12	10.20	0.22
240330030	60	37	70.25	94.00	2011070724	77.53	101.27	2011072524	7.73	118.82	7.28	11.11	10.36	9.41	0.10	10.34	14.72	15.27	13.93	0.15	13.11	0.20
240338003	60	38	73.68	95.63	2011060824	82.74	120.97	2011060824	26.50	91.82	9.06	12.47	12.30	11.06	0.12	10.25	13.92	14.02	12.70	0.14	13.19	0.47
250051002	60	20	67.92	85.50	2011060724	72.50	94.18	2011072324	10.15	140.15	4.58	7.45	6.74	5.73	0.07	9.87	14.53	14.96	13.99	0.15	12.69	0.08
250070001	60	20	73.28	113.43	2011072224	82.11	118.06	2011072324	4.08	184.14	8.83	12.96	12.05	10.93	0.12	13.01	17.76	17.80	16.14	0.18	16.19	0.25
250130008	60	15	69.09	81.00	2011072124	71.58	94.58	2011060124	16.77	71.65	2.49	3.85	3.61	3.13	0.04	6.31	9.13	9.00	8.66	0.09	8.82	0.19
250154002	60	12	66.50	84.00	2011072124	71.25	89.95	2011060124	7.08	125.06	4.75	8.12	7.14	6.50	0.07	8.47	12.74	13.26	11.96	0.13	12.15	0.02
340071001	60	40	69.81	97.75	2011060824	72.60	99.28	2011060824	1.57	64.50	2.79	3.96	4.00	3.28	0.04	6.94	9.94	9.86	9.56	0.10	8.50	0.57
340110007	60	20	64.57	77.88	2011060924	78.34	94.45	2011072224	21.28	83.32	13.78	21.55	21.34	18.68	0.21	14.13	21.89	22.11	19.25	0.22	16.53	0.14
340150002	60	37	73.01	102.00	2011060924	75.41	104.41	2011061024	2.36	128.14	2.40	3.90	3.28	2.73	0.03	9.56	13.10	13.05	12.68	0.13	11.57	0.34
340170006	60	25	69.90	88.75	2011072124	72.86	99.35	2011072124	11.94	58.11	2.96	4.20	4.24	3.54	0.04	6.60	9.44	9.46	9.13	0.09	8.18	0.54
340190001	60	35	70.12	88.25	2011072224	73.12	96.89	2011072224	9.79	47.12	3.00	4.51	4.28	3.93	0.04	5.69	8.11	8.31	7.91	0.08	7.49	0.49
340210005	60	29	69.85	89.75	2011060924	74.99	97.37	2011072124	8.49	43.52	5.14	7.53	7.36	6.85	0.07	7.12	10.19	10.28	9.69	0.10	8.36	0.58
340230011	60	42	70.18	92.88	2011072124	72.66	98.19	2011072124	5.72	66.99	2.47	3.74	3.52	2.93	0.04	6.90	9.83	10.17	9.96	0.10	8.55	0.49
340250005	60	29	70.51	97.50	2011060924	77.77	103.25	2011072224	5.90	91.12	7.26	10.98	10.29	9.68	0.10	10.11	14.35	14.24	13.26	0.14	11.99	0.33
340273001	60	29	68.92	84.63	2011060724	75.07	97.33	2011072224	15.01	51.85	6.15	9.09	8.92	8.21	0.09	7.55	10.95	11.03	10.25	0.11	9.47	0.50
340290006	60	27	73.22	101.13	2011060924	81.84	113.04	2011072224	11.78	111.92	8.62	12.53	11.77	10.94	0.12	11.23	15.34	15.60	14.18	0.15	13.65	0.34
340315001	60	19	69.09	81.88	2011072024	75.36	90.27	2011070824	10.25	70.45	6.27	9.69	9.07	8.55	0.09	8.48	12.28	12.75	11.73	0.12	10.47	0.10
360150003	60	18	64.00	72.13	2011060824	62.05	71.07	2011060724	-1.47	21.04	-1.95	-2.94	-3.05	-3.25	-0.03	4.21	6.58	6.60	6.71	0.07	4.98	0.07
360270007	60	16	69.79	96.38	2011072024	74.02	91.34	2011072124	-5.23	125.13	4.23	6.70	6.06	5.29	0.06	10.53	15.08	15.12	14.50	0.15	11.96	0.16
360530006	60	12	63.45	70.25	2011060824	66.46	72.73	2011060924	3.53	8.48	3.01	4.76	4.75	4.55	0.05	3.33	5.24	5.26	5.06	0.05	4.19	0.46
360715001	60	11	68.43	92.00	2011072024	76.88	89.14	2011062824	-3.11	151.55	8.44	13.85	12.34	11.64	0.12	12.59	18.40	18.65	16.93	0.18	14.93	0.01
360790005	60	10	66.53	75.00	2011072024	78.62	94.88	2011072024	26.51	74.91	12.09	18.10	18.18	15.93	0.18	13.64	20.50	20.40	18.38	0.21	14.87	0.32
360810124	60	26	72.26	96.50	2011060924	71.16	87.45	2011060824	-9.38	76.51	-1.10	-1.05	-1.52	-1.80	-0.02	7.13	9.87	9.88	9.98	0.10	8.82	0.40
360850067	60	40	71.08	93.63	2011060924	71.87	97.41	2011072124	4.04	89.73	0.79	1.29	1.12	0.37	0.01	7.47	10.51	10.58	10.62	0.11	9.51	0.43
361030002	60	34	73.00	114.00	2011072224	76.74	104.00	2011072224	-8.77	71.43	3.74	6.07	5.13	5.23	0.05	7.27	9.97	10.34	9.70	0.10	9.24	0.61
361030004	60	25	70.32	89.00	2011072224	75.27	107.72	2011072324	21.03	123.46	4.95	7.02	7.03	5.68	0.07	9.62	13.67	13.68	12.87	0.14	12.16	0.41
361030009	60	20	69.84	94.25	2011072224	79.43	102.45	2011072224	8.70	78.58	9.59	14.65	13.73	12.94	0.14	10.50	15.03	15.74	14.06	0.15	13.06	0.42
361111005	60	16	67.04	77.63	2011052624	65.20	75.20	2011072124	-3.13	25.05	-1.84	-2.63	-2.74	-2.97	-0.03	4.37	6.52	6.60	6.76	0.07	5.33	0.35
361192004	60	21	69.37	98.75	2011060924	78.25	101.52	2011062124	2.81	89.94	8.88	13.70	12.79	12.00	0.13	9.96	14.36	14.96	13.29	0.14	12.99	0.25
420010002	60	17	65.97	82.75	2011070224	65.52	81.81	2011060824	-1.14	85.68	-0.45	-0.34	-0.68	-1.29	-0.01	7.48	11.33	11.21	11.50	0.11	9.27	0.02
420170012	60	27	69.91	85.50	2011060124	79.92	97.50	2011072224	14.04	140.96	10.01	14.99	14.32	12.66	0.14	12.96	18.54	19.02	17.08	0.19	15.53	0.09
420290100	60	32	69.64	90.88	2011060824	72.82	92.50	2011072224	1.78	121.39	3.18	5.03	4.57	3.65	0.05	8.96	12.87	13.32	12.67	0.13	11.47	0.16
420430401	60	26	65.49	82.13	2011070224	71.88	89.60	2011060824	9.10	65.59	6.40	10.24	9.77	9.09	0.10	8.10	12.37	12.50	11.55	0.12	10.32	0.07
420431100	60	30	68.18	85.50	2011070224	73.63	99.90	2011060824	16.84	68.32	5.45	8.40	8.00	7.41	0.08	7.89	11.57	11.75	11.02	0.12	9.90	0.21
420450002	60	29	69.69	84.75	2011060724	72.70	89.99	2011072924	6.18	120.81	3.02	4.75	4.33	3.44	0.04	9.73	13.97	14.09	13.65	0.14	11.40	0.14

MOG 4km Monitor-Level Model Performance Statistics
Mid-Atlantic Domain

AIRS Station Id	Thresh (ppb)	N	Avg Obs (ppb)	Peak Obs (ppb)	Peak Obs Day	Avg Pre (ppb)	Peak Pre (ppb)	Peak Pre Day	AU (%)	Variance (ppb^2)	MB (ppb)	MNB (%)	NMB (%)	MFB (%)	NMBF	MEr (ppb)	NME (%)	MNGE (%)	MFE (%)	NMEF	RMSE (ppb)	RSQR
420690101	60	16	67.03	73.88	2011060924	71.00	82.91	2011072124	12.22	11.94	3.98	5.90	5.93	5.61	0.06	4.04	6.03	6.01	5.72	0.06	5.27	0.69
420692006	60	14	64.67	70.50	2011071724	71.89	82.28	2011072124	16.71	17.08	7.21	11.07	11.15	10.33	0.11	7.21	11.15	11.07	10.33	0.11	8.31	0.59
420710007	60	36	68.41	87.50	2011070224	74.20	100.51	2011060824	14.87	97.67	5.79	8.79	8.46	7.48	0.08	9.25	13.52	13.58	12.73	0.14	11.45	0.26
420770004	60	34	68.04	84.75	2011072024	69.97	90.22	2011072024	6.45	64.74	1.93	3.02	2.84	2.25	0.03	6.57	9.65	9.83	9.73	0.10	8.27	0.32
420791100	60	5	64.25	70.13	2011071724	77.48	83.02	2011060724	18.38	20.36	13.23	20.61	20.59	18.49	0.21	13.23	20.59	20.61	18.49	0.21	13.98	0.39
420791101	60	10	64.12	69.50	2011071724	73.88	80.64	2011060724	16.03	17.97	9.76	15.18	15.22	13.93	0.15	9.76	15.22	15.18	13.93	0.15	10.64	0.48
420810100	60	10	63.13	71.88	2011072124	71.66	79.71	2011090124	10.89	25.53	8.53	13.73	13.51	12.56	0.14	8.53	13.51	13.73	12.56	0.14	9.91	0.08
420910013	60	34	69.38	86.63	2011060824	74.45	96.32	2011082624	11.19	97.89	5.07	7.65	7.31	6.35	0.07	8.61	12.41	12.90	12.10	0.12	11.12	0.23
420950025	60	26	66.09	79.25	2011060924	73.56	90.09	2011072024	13.68	35.36	7.48	11.51	11.31	10.52	0.11	8.45	12.79	12.98	12.04	0.13	9.55	0.43
420958000	60	17	65.72	74.25	2011060724	77.46	90.48	2011072024	21.86	39.99	11.73	18.28	17.85	16.33	0.18	11.75	17.87	18.31	16.36	0.18	13.33	0.15
420990301	60	21	63.53	74.00	2011070224	67.46	81.77	2011060824	10.50	57.37	3.94	6.47	6.20	5.61	0.06	7.07	11.13	11.16	10.68	0.11	8.54	0.01
421010004	60	13	66.04	73.26	2011060724	77.78	90.14	2011072124	23.04	137.55	11.74	17.94	17.78	15.08	0.18	15.00	22.72	23.02	20.47	0.23	16.60	0.07
421010024	60	48	71.68	94.50	2011060124	73.67	99.51	2011072124	5.30	104.81	1.99	3.25	2.78	2.25	0.03	7.67	10.70	10.64	10.38	0.11	10.43	0.32
421174000	60	25	65.65	74.13	2011060824	61.36	72.88	2011090124	-1.69	27.37	-4.30	-6.45	-6.54	-7.03	-0.07	5.85	8.91	8.92	9.39	0.10	6.77	0.19
421330008	60	31	67.52	84.25	2011070224	71.76	89.29	2011060824	5.98	73.18	4.23	6.60	6.27	5.68	0.06	7.43	11.00	10.98	10.39	0.11	9.55	0.06
440030002	60	26	67.51	84.88	2011070624	70.63	89.68	2011072324	5.66	60.17	3.13	4.62	4.63	3.90	0.05	6.82	10.10	10.12	9.75	0.10	8.36	0.44
440071010	60	23	67.01	78.50	2011070624	66.87	79.74	2011072124	1.58	51.52	-0.15	-0.24	-0.22	-0.92	0.00	5.19	7.74	7.91	8.20	0.08	7.18	0.36
440090007	60	31	68.18	84.38	2011071624	70.73	102.97	2011072324	22.03	112.25	2.55	3.71	3.73	2.54	0.04	8.65	12.69	12.63	12.23	0.13	10.90	0.28
510130020	60	54	70.35	100.25	2011061024	74.41	101.82	2011060524	1.57	70.80	4.06	5.97	5.77	5.13	0.06	7.31	10.39	10.48	9.94	0.10	9.34	0.45
510330001	60	18	67.30	82.63	2011053124	74.42	93.45	2011053124	13.09	31.40	7.12	10.58	10.58	9.75	0.11	7.82	11.62	11.59	10.78	0.12	9.06	0.59
510360002	60	26	70.41	104.50	2011060824	77.83	113.54	2011060824	8.65	51.52	7.42	11.34	10.54	10.22	0.11	8.25	11.72	12.36	11.27	0.12	10.33	0.57
510410004	60	15	67.71	78.63	2011070124	74.01	98.46	2011053124	25.22	92.65	6.30	9.59	9.30	8.33	0.09	9.02	13.32	13.13	12.10	0.13	11.50	0.08
510590030	60	48	70.03	99.50	2011061024	76.74	102.51	2011060524	3.03	71.66	6.71	9.99	9.59	8.84	0.10	8.09	11.55	11.98	10.91	0.12	10.80	0.48
510610002	60	8	62.83	67.25	2011070224	73.34	84.86	2011080424	26.19	45.18	10.51	16.72	16.72	14.98	0.17	10.59	16.85	16.85	15.10	0.17	12.47	0.11
510850003	60	28	68.51	80.75	2011060824	81.13	107.01	2011060924	32.52	92.41	12.63	18.52	18.43	16.22	0.18	12.95	18.91	18.97	16.68	0.19	15.87	0.26
510870014	60	37	69.19	86.63	2011060824	76.69	102.65	2011072524	18.49	104.41	7.50	11.09	10.84	9.54	0.11	10.28	14.86	14.99	13.76	0.15	12.68	0.21
511071005	60	37	66.85	86.63	2011072024	68.31	94.08	2011072024	8.60	52.48	1.46	2.11	2.18	1.50	0.02	5.94	8.88	8.93	8.79	0.09	7.39	0.47
511530009	60	28	65.40	79.13	2011070224	71.12	85.81	2011070724	8.44	73.60	5.72	8.80	8.75	7.64	0.09	9.05	13.84	13.87	13.11	0.14	10.31	0.19
511790001	60	21	68.19	86.38	2011053124	77.24	109.53	2011080424	26.80	155.48	9.05	14.20	13.27	11.79	0.13	10.97	16.08	16.99	14.72	0.16	15.41	0.01
515100009	60	42	69.85	100.63	2011061024	78.62	105.66	2011061024	5.00	88.01	8.76	13.12	12.55	11.49	0.13	10.40	14.88	15.41	13.90	0.15	12.84	0.38
518000004	60	22	67.61	79.88	2011072924	73.40	90.60	2011053124	13.42	68.73	5.78	9.21	8.55	8.12	0.09	7.86	11.62	11.92	11.02	0.12	10.11	0.03

MOG 4km Monitor-Level Model Performance Statistics
Lake Michigan Domain

AIRS Station Id	Thresh (ppb)	N	Avg Obs (ppb)	Peak Obs (ppb)	Peak Obs Day	Avg Pre (ppb)	Peak Pre (ppb)	Peak Pre Day	AU (%)	Variance (ppb^2)	MB (ppb)	MNB (%)	NMB (%)	MFB (%)	NMBF	MEr (ppb)	NME (%)	MNGE (%)	MFE (%)	NMEF	RMSE (ppb)	RSQR
170310001	60	18	65.93	80.00	2011090224	68.50	77.82	2011060424	-2.73	63.27	2.57	4.46	3.89	3.67	0.04	7.31	11.09	11.17	10.71	0.11	8.36	0.02
170310032	60	33	67.47	89.63	2011090224	63.97	89.25	2011070224	-0.42	227.29	-3.50	-4.20	-5.19	-7.13	-0.05	11.74	17.40	17.36	18.69	0.18	15.48	0.01
170310064	60	23	67.46	89.00	2011072124	64.80	84.31	2011072124	-5.27	167.64	-2.66	-2.95	-3.95	-4.97	-0.04	9.31	13.80	13.64	14.84	0.14	13.22	0.00
170310072	60	29	66.56	85.50	2011080124	61.64	85.78	2011072124	0.33	82.17	-4.92	-7.24	-7.39	-8.58	-0.08	8.47	12.72	12.69	13.67	0.14	10.31	0.22
170310076	60	29	67.11	82.13	2011090124	61.90	81.14	2011072124	-1.21	99.86	-5.21	-7.69	-7.76	-9.32	-0.08	9.39	14.00	14.08	15.26	0.15	11.27	0.17
170311003	60	13	64.71	76.13	2011090124	65.94	81.15	2011072124	6.59	166.78	1.22	2.50	1.89	0.32	0.02	9.19	14.20	14.07	14.96	0.14	12.97	0.02
170311601	60	25	66.06	82.00	2011090124	67.24	99.68	2011071924	21.56	87.27	1.18	1.97	1.79	1.09	0.02	6.72	10.17	10.00	9.63	0.10	9.42	0.08
170314002	60	19	67.16	89.25	2011090124	63.79	78.57	2011072124	-11.97	125.92	-3.37	-4.05	-5.02	-5.59	-0.05	8.55	12.73	12.21	13.28	0.13	11.72	0.00
170314007	60	10	65.37	76.00	2011090124	66.41	79.23	2011090124	4.25	135.84	1.04	2.10	1.60	0.41	0.02	9.14	13.99	14.09	14.61	0.14	11.70	0.01
170314201	60	23	68.43	86.50	2011090124	70.16	81.46	2011090124	-5.83	78.71	1.73	2.90	2.53	1.93	0.03	6.00	8.76	8.87	9.12	0.09	9.04	0.19
170317002	60	20	69.82	88.38	2011073124	63.25	132.10	2011072324	49.47	453.09	-6.57	-8.12	-9.41	-13.10	-0.10	16.13	23.10	23.35	23.96	0.25	22.28	0.01
170436001	60	16	65.50	76.63	2011073024	68.31	92.08	2011071924	20.16	56.77	2.81	4.44	4.28	3.79	0.04	6.54	9.99	9.77	9.39	0.10	8.04	0.19
170890005	60	21	66.27	78.88	2011073024	66.55	80.86	2011061824	2.51	41.72	0.28	0.66	0.43	0.20	0.00	5.00	7.54	7.51	7.37	0.08	6.47	0.19
170971007	60	25	69.19	95.63	2011090124	73.00	102.04	2011071024	6.70	135.62	3.81	5.76	5.51	4.33	0.06	8.69	12.56	12.63	11.70	0.13	12.25	0.30
171110001	60	21	66.09	79.75	2011073024	63.51	72.13	2011071924	-9.55	34.21	-2.57	-3.62	-3.89	-4.06	-0.04	4.82	7.30	7.08	7.42	0.08	6.39	0.16
171971011	60	7	67.77	91.75	2011071924	58.61	71.21	2011071924	-22.39	39.71	-9.16	-12.71	-13.52	-13.89	-0.16	9.16	13.52	12.71	13.89	0.16	11.12	0.75
172012001	60	15	64.79	75.25	2011061724	64.62	74.93	2011061824	-0.43	30.93	-0.17	0.04	-0.26	-0.32	0.00	4.51	6.96	6.82	6.90	0.07	5.56	0.03
180390007	60	22	67.43	85.16	2011090224	62.63	83.68	2011072124	-1.74	49.86	-4.80	-6.71	-7.12	-7.46	-0.08	6.80	10.08	9.75	10.35	0.11	8.54	0.19
180890022	60	13	66.00	84.22	2011090224	66.68	90.22	2011072124	7.12	156.92	0.68	1.67	1.03	-0.04	0.01	8.88	13.46	13.24	13.20	0.13	12.55	0.00
180890030	60	17	65.98	75.76	2011090224	62.71	83.19	2011060424	9.81	155.78	-3.26	-4.83	-4.94	-7.19	-0.05	8.91	13.50	13.75	15.14	0.14	12.90	0.05
180892008	60	27	67.67	77.53	2011090124	64.69	81.42	2011070224	5.02	99.45	-2.98	-4.10	-4.40	-5.40	-0.05	7.44	10.99	10.87	11.67	0.11	10.41	0.04
180910005	60	38	71.09	96.43	2011090224	63.94	102.71	2011071124	6.51	192.55	-7.15	-9.49	-10.06	-12.08	-0.11	12.43	17.48	17.18	18.90	0.19	15.61	0.10
180910010	60	18	67.10	82.56	2011090224	64.41	82.09	2011060424	-0.57	110.47	-2.69	-3.42	-4.01	-4.62	-0.04	8.71	12.98	12.48	13.02	0.14	10.85	0.00
181270024	60	11	67.32	82.55	2011090224	69.06	91.94	2011072124	11.37	144.95	1.74	3.13	2.59	1.56	0.03	9.82	14.58	14.35	14.37	0.15	12.16	0.07
181270026	60	11	63.91	77.70	2011090224	66.12	84.37	2011080124	8.58	145.89	2.21	4.11	3.45	2.38	0.03	9.63	15.07	15.08	14.46	0.15	12.28	0.03
181410010	60	13	65.40	83.57	2011090224	63.60	76.93	2011060424	-7.95	52.62	-1.81	-2.24	-2.77	-2.81	-0.03	5.85	8.95	8.64	8.75	0.09	7.48	0.03
181411007	60	17	68.58	85.70	2011090224	65.76	86.90	2011072124	1.40	79.22	-2.83	-3.66	-4.12	-4.61	-0.04	7.81	11.38	11.45	11.69	0.12	9.34	0.12
260050003	60	36	68.79	97.13	2011060824	67.50	105.44	2011060824	8.56	112.62	-1.29	-1.65	-1.88	-2.87	-0.02	8.13	11.82	11.94	12.01	0.12	10.69	0.41
260190003	60	18	68.44	84.00	2011060724	64.07	85.63	2011060724	1.94	23.98	-4.37	-6.29	-6.38	-6.78	-0.07	5.40	7.90	7.91	8.37	0.08	6.56	0.58
260210014	60	38	69.69	96.50	2011090124	70.21	101.51	2011072324	5.19	136.05	0.52	1.48	0.75	0.20	0.01	9.34	13.40	13.26	12.94	0.13	11.68	0.17
260270003	60	32	70.02	87.13	2011090224	64.84	81.93	2011070224	-5.97	63.08	-5.18	-6.97	-7.40	-7.88	-0.08	8.10	11.57	11.36	11.95	0.12	9.48	0.25
260770008	60	26	68.05	77.00	2011071724	65.83	79.50	2011070224	3.25	33.63	-2.22	-3.26	-3.26	-3.70	-0.03	4.77	7.01	7.06	7.31	0.07	6.21	0.37
260810020	60	16	68.05	82.00	2011060824	68.78	86.85	2011060824	5.91	58.62	0.73	1.35	1.07	0.67	0.01	6.04	8.88	9.13	8.95	0.09	7.69	0.34
260810022	60	18	67.50	81.38	2011060824	64.71	88.10	2011060724	8.26	41.67	-2.79	-4.33	-4.13	-4.95	-0.04	5.85	8.67	8.88	9.21	0.09	7.03	0.64
261050007	60	14	70.73	94.25	2011060724	65.50	89.07	2011060724	-5.50	23.13	-5.22	-7.24	-7.38	-7.77	-0.08	5.68	8.03	7.97	8.49	0.09	7.10	0.76
261130001	60	12	66.12	77.63	2011060724	62.16	80.22	2011060724	3.34	30.70	-3.95	-6.16	-5.98	-6.78	-0.06	4.81	7.28	7.36	7.97	0.08	6.81	0.58
261210039	60	28	69.14	104.50	2011060724	73.51	100.92	2011060724	-3.43	90.22	4.36	7.04	6.31	5.86	0.06	7.64	11.05	11.64	10.77	0.11	10.45	0.43
261390005	60	26	68.95	88.38	2011060824	66.96	95.26	2011060824	7.78	91.19	-1.99	-2.37	-2.88	-3.40	-0.03	7.62	11.05	11.04	11.26	0.11	9.75	0.28
550090026	60	13	68.61	84.00	2011090124	63.35	72.23	2011060724	-14.01	58.12	-5.25	-6.97	-7.66	-7.83	-0.08	7.44	10.85	10.48	11.17	0.12	9.26	0.05
550210015	60	12	65.42	69.50	2011060624	62.09	69.17	2011060624	-0.47	3.55	-3.33	-5.11	-5.09	-5.29	-0.05	3.36	5.14	5.16	5.35	0.05	3.83	0.75
550250041	60	15	64.61	70.63	2011060624	61.20	67.51	2011061824	-4.42	17.65	-3.41	-5.21	-5.28	-5.58	-0.06	4.12	6.38	6.33	6.67	0.07	5.41	0.09
550290004	60	17	71.59	90.50	2011060724	73.68	88.94	2011060724	-1.72	73.88	2.09	3.14	2.92	2.38	0.03	6.55	9.15	9.36	9.08	0.09	8.85	0.33
550390006	60	14	68.65	82.25	2011063024	61.45	72.91	2011090124	-11.36	26.68	-7.19	-10.19	-10.48	-11.01	-0.12	7.41	10.79	10.55	11.36	0.12	8.85	0.47
550410007	60	6	65.86	75.13	2011060324	63.34	69.71	2011060724	-7.21	35.04	-2.52	-3.41	-3.82	-3.89	-0.04	5.17	7.85	7.77	8.05	0.08	6.43	0.12
550550002	60	15	65.19	71.75	2011090124	61.07	68.30	2011061824	-4.81	16.06	-4.12	-6.41	-6.32	-6.86	-0.07	4.32	6.63	6.73	7.17	0.07	5.75	0.55
550590019	60	31	71.00	96.00	2011090124	74.40	105.94	2011071024	10.35	131.10	3.39	4.86	4.78	3.58	0.05	8.96	12.62	12.71	11.97	0.13	11.94	0.36
550610002	60	15	71.32	103.71	2011090224	69.84	81.17	2011053024	-21.73	139.80	-1.48	-0.23	-2.07	-1.31	-0.02	8.91	12.50	11.76	11.86	0.13	11.92	0.15
550710007	60	19	73.22	100.13	2011090224	71.40	87.66	2011071024	-12.45	107.61	-1.82	-1.41	-2.48	-2.28	-0.03	8.35	11.40	10.93	10.98	0.12	10.53	0.26
550790010	60	13	68.36	89.13	2011090124	65.06	79.80	2011071024	-10.47	100.10	-3.30	-4.61	-4.83	-5.96	-0.05	8.04	11.77	11.86	12.73	0.12	10.54	0.18
550790026	60	15	69.37	96.50	2011090124	62.64	80.75	2011071024	-16.32	101.58	-6.73	-9.23	-9.71	-10.85	-0.11	9.20	13.26	12.92	14.32	0.15	12.12	0.16
550790085	60	15	70.81	103.25	2011090124	69.49	89.72	2011072324	-13.10	138.26	-1.32	-0.61	-1.87	-1.96	-0.02	9.06	12.80	12.58	12.65	0.13	11.83	0.11
550870009	60	11	70.16	76.88	2011063024	61.34	73.11	2011060324	-4.90	21.95	-8.82	-12.83	-12.57	-14.04	-0.14	8.82	12.57	12.83	14.04	0.14	9.99	0.73
550890008	60	23	69.58	98.38	2011090124	64.95	93.62	2011071024	-4.84	100.46	-4.63	-6.01	-6.65	-7.23	-0.07	8.54	12.27	11.89	12.59	0.13	11.04	0.15
550890009	60	15	71.45	96.00	2011090124	72.60	96.17	2011071024	0.18	127.77	1.15	2.58	1.60	1.35	0.02	8.60	12.03	12.23	11.71	0.12	11.36	0.10
551010017	60	21	70.37	101.63	2011090124	71.09	100.32	2011071024	-1.29	113.77	0.72	1.49	1.03	0.35	0.01	8.46	12.03	12.05	11.91	0.12	10.69	0.32
551050024	60	20	66.50	73.75	2011071524	58.54	66.36	2011060624	-10.02	23.14	-7.96	-11.94	-11.98	-13.00	-0.14	7.96	11.98	11.94	13.00	0.14	9.30	0.30
551170006	60	30	74.26	111.13	2011090124	68.32	94.06	2011071024	-15.36	133.13	-5.94	-6.75	-8.00	-8.01	-0.09	9.88	13.30	12.56	13.31	0.14	12.98	0.26
551270005	60	18	65.67	72.38	2011060324	63.07	74.46	2011071524	2.87	27.52	-2.60	-3.93	-3.95	-4.35	-0.04	4.93	7.51	7.50	7.81	0.08	5.85	0.17
551330027	60	13	67.01	75.88	2011070924	63.06	75.41	2011090124	-0.62	78.50	-3.95	-5.33	-5.90	-6.45	-0.06	7.04	10.50	10.27	11.16	0.11	9.70	0.03