Air Quality Modeling Technical Support Document: Heavy-Duty Vehicle Greenhouse Gas Phase 2 Final Rule

United States
Environmental Protection
Agency

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Air Quality Assessment Division
Office of Air Quality Planning and Standards
U.S. Environmental Protection Agency

and

Assessment and Standards Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

United States Environmental Protection Agency

EPA-420-R-16-007
August 2016

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I. Introduction

This document describes the air quality modeling performed by EPA in support of the Heavy-Duty Greenhouse Gas (HDGHG) Phase 2 motor vehicle emission and fuel standards. A national scale air quality modeling analysis was performed to estimate the impact of the Phase 2 standards on future year annual and 24-hour $PM_{2.5}$ concentrations, daily maximum 8-hour ozone concentrations, annual nitrogen dioxide concentrations, annual nitrogen and sulfur deposition levels, specific annual and seasonal air toxic concentrations (formaldehyde, acetaldehyde, benzene, 1,3-butadiene, acrolein and naphthalene) as well as visibility impairment. To model the air quality benefits of this rule we used the Community Multiscale Air Quality (CMAQ) model.[1] CMAQ simulates the numerous physical and chemical processes involved in the formation, transport, and destruction of ozone, particulate matter and air toxics. In addition to the CMAQ model, the modeling platform includes the emissions, meteorology, and initial and boundary condition data which are inputs to this model.

Emissions and air quality modeling decisions are made early in the analytical process to allow for sufficient time required to conduct emissions and air quality modeling. For this reason, it is important to note that the inventories used in the air quality modeling and the benefits modeling are slightly different than the final emissions inventories. The standards in the air quality modeling inventory are based on the Phase 2 proposal. As mentioned in Chapter 5.5.2.3 and 6.2.2.3 of the RIA, the air quality inventories and the final rule inventories are generally consistent, however there are some important differences. For example, the air quality modeling inventory predicted increases in downstream $PM_{2.5}$ emissions that are not expected to occur. The air quality modeling inventory also predicts larger reductions in NOx emissions than the final inventory. The implications of these differences are noted in the following discussion of the air quality modeling results.

Air quality modeling was performed for three emissions cases: a 2011 base year, a 2040 reference case projection without the HDGHG Phase 2 rule standards and a 2040 control case projection with HDGHG Phase 2 standards in place. The year 2011 was selected for the HDGHG Phase 2 base year because this is the most recent year for which EPA had a complete national emissions inventory at the time of emissions and air quality modeling.

The remaining sections of the Air Quality Modeling TSD are as follows. Section II describes the air quality modeling platform and the evaluation of model predictions of $PM_{2.5}$ and ozone using corresponding ambient measurements. In Section III we present the results of modeling performed for 2040 to assess the impacts on air quality of the Phase 2 vehicle standards. Information on the development of emissions inventories for the HDGHG Phase 2 Rule and the steps and data used in creating emissions inputs for air quality modeling can be found in the Emissions Inventory for Air Quality Modeling TSD (EITSD; EPA-HQ-OAR-2014-0827; EPA-420-R-16-008). The docket for this rulemaking also contains state/sector/pollutant emissions summaries for each of the emissions scenarios modeled.

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[1] Byun, D.W., and K. L. Schere, 2006: Review of the Governing Equations, Computational Algorithms, and Other Components of the Models-3 Community Multiscale Air Quality (CMAQ) Modeling System. Applied Mechanics Reviews, Volume 59, Number 2 (March 2006), pp. 51-77.

II. Air Quality Modeling Platform

The 2011-based CMAQ modeling platform was used as the basis for the air quality modeling of the HDGHG Phase 2 final rule. This platform represents a structured system of connected modeling-related tools and data that provide a consistent and transparent basis for assessing the air quality response to projected changes in emissions. The base year of data used to construct this platform includes emissions and meteorology for 2011. The platform was developed by the U.S. EPA's Office of Air Quality Planning and Standards in collaboration with the Office of Research and Development and is intended to support a variety of regulatory and research model applications and analyses. This modeling platform and analysis is fully described below.

A. Air Quality Model

CMAQ is a non-proprietary computer model that simulates the formation and fate of photochemical oxidants, primary and secondary PM concentrations, acid deposition, and air toxics, over regional and urban spatial scales for given input sets of meteorological conditions and emissions. The CMAQ model version 5.1, which was an upcoming new community version in late 2015, was most recently peer-reviewed in September of 2015 for the U.S. EPA.[2] The CMAQ model is a well-known and well-respected tool and has been used in numerous national and international applications.[3,4,5] CMAQ includes numerous science modules that simulate the emission, production, decay, deposition and transport of organic and inorganic gas-phase and particle-phase pollutants in the atmosphere. This 2011 multi-pollutant modeling platform used the most recent multi-pollutant CMAQ code available at the time of air quality modeling (CMAQ version 5.0.2; multipollutant version[6]). CMAQ v5.0.2 reflects updates to version 5.0 to improve the underlying science algorithms which are detailed at http://www.cmascenter.org.[7,8,9]

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[2] Moran, M., Astitha, M., Barsanti, K.C., Brown, N.J., Kaduwela, A., McKeen, S.A., Pickering, K.E. (28 September 2015). Final Report: Fifth Peer Review of the CMAQ Model, NERL/ORD/EPA. U.S. EPA, Research Triangle Park, NC. https://www.cmascenter.org/PDF/CMAQ_5th_peer_review_report.pdf. It is available from the Community Modeling and Analysis System (CMAS) as well as previous peer-review reports at: http://www.cmascenter.org.

[3] Hogrefe, C., Biswas, J., Lynn, B., Civerolo, K., Ku, J.Y., Rosenthal, J., et al. (2004). Simulating regional-scale ozone climatology over the eastern United States: model evaluation results. *Atmospheric Environment, 38(17),* 2627-2638.

[4] United States Environmental Protection Agency. (2008). Technical support document for the final locomotive/marine rule: Air quality modeling analyses. Research Triangle Park, N.C.: U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Air Quality Assessment Division.

[5] Lin, M., Oki, T., Holloway, T., Streets, D.G., Bengtsson, M., Kanae, S., (2008). Long range transport of acidifying substances in East Asia Part I: Model evaluation and sensitivity studies. Atmospheric Environment, 42(24), 5939-5955.

[6] CMAQ version 5.0.2 was released on April 2014. It is available from the Community Modeling and Analysis System (CMAS) website: http://www.cmascenter.org.

[7] Community Modeling and Analysis System (CMAS) website: http://www.cmascenter.org., RELEASE_NOTES for CMAQv5.0 - February 2012.

[8] Community Modeling and Analysis System (CMAS) website: http://www.cmascenter.org., RELEASE_NOTES for CMAQv5.0.1 - July 2012.

[9] Community Modeling and Analysis System (CMAS) website: http://www.cmascenter.org., CMAQ version 5.0.2 (April 2014 release) Technical Documentation. - May 2014.

B. Model Domains and Grid Resolution

The CMAQ modeling analyses were performed for a 12 kilometer (km) domain covering the continental United States, as shown in Figure II-1. The model extends vertically from the surface to 50 millibars (approximately 17,600 meters) using a sigma-pressure coordinate system with 25 vertical layers. Table II-1 provides some basic geographic information regarding the CMAQ domains.

In addition to the CMAQ model, the HDGHG Phase 2 modeling platform includes (1) emissions for the 2011 base year, 2040 reference and control case projections, (2) meteorology for the year 2011, and (3) estimates of intercontinental transport (i.e., boundary concentrations) for the year 2011 from a global photochemical model. Using these input data, CMAQ was run to generate hourly predictions of ozone, $PM_{2.5}$ component species, nitrogen and sulfate deposition, nitrogen dioxide, and a subset of air toxics (formaldehyde, acetaldehyde, acrolein, benzene, 1,3-butadiene, and naphthalene) concentrations for each grid cell in the modeling domains. The development of 2011 meteorological inputs and initial and boundary concentrations are described below. The emissions inventories used in the HDGHG Phase 2 air quality modeling are described in the EITSD found in the docket for this rule (EPA-420-R-16-008).

Table II-1. Geographic elements of domains used in HDGHG Phase 2 modeling.

	CMAQ Modeling Configuration
Grid Resolution	12 km National Grid
Map Projection	Lambert Conformal Projection
Coordinate Center	97 deg W, 40 deg N
True Latitudes	33 deg N and 45 deg N
Dimensions	396 x 246 x 25
Vertical extent	25 Layers: Surface to 50 millibar level (see Table II-3)

Figure II-1. Map of the CMAQ 12 km modeling domain (noted by the purple box).

C. Modeling Simulation Periods

The 12 km CMAQ modeling domain was modeled for the entire year of the 2011 base year and 2040 reference and control scenarios. These annual simulations were performed in two half-year segments (i.e., January through June, July through December) for each emissions scenario. With this approach to segmenting an annual simulation we were able to reduce the overall throughput time for an annual simulation. The 12 km domain simulations included a "ramp-up" period, comprised of 10 days before the beginning of each half-year segment, to mitigate the effects of initial concentrations. The ramp-up period is not considered as part of the output analyses.

For the 8-hour ozone results, we are only using modeling results from the period between May 1 and September 30, 2011. This 153-day period generally conforms to the ozone season across most parts of the U.S. and contains the majority of days with observed high ozone concentrations in 2011. Data from the entire year were utilized when looking at the estimation of $PM_{2.5}$, total nitrogen and sulfate deposition, nitrogen dioxide, toxics and visibility impacts from this rulemaking.

D. Modeling Scenarios

As part of our analysis for this rulemaking, the CMAQ modeling system was used to calculate daily and annual $PM_{2.5}$ concentrations, 8-hour ozone concentrations, annual NO_2 concentrations, annual and seasonal air toxics concentrations, annual total nitrogen and sulfur deposition levels and visibility impairment for each of the following emissions scenarios:

2011 base year

2040 reference case projection without the HDGHG Phase 2 standards

2040 control case projection with the HDGHG Phase 2 standards

Model predictions are used in a relative sense to estimate scenario-specific, future-year design values of $PM_{2.5}$ and ozone. For example, we compare a 2040 reference scenario (a scenario without the vehicle standards) to a 2040 control scenario which includes the vehicle standards. This is done by calculating the simulated air quality ratios between the 2040 future year simulation and the 2011 base. These predicted change ratios are then applied to ambient base year design values. The ambient air quality observations are average conditions, on a site-by-site basis, for a period centered around the model base year (i.e., 2009-2013). The raw model outputs are also used in a relative sense as inputs to the health and welfare impact functions of the benefits analysis. The difference between the 2040 reference case and 2040 control case was used to quantify the air quality benefits of the rule. Additionally, the differences in projected annual average $PM_{2.5}$ and seasonal average ozone were used to calculate monetized benefits by the BenMAP model (see Section 8.6 of the RIA).

The design value projection methodology used here followed EPA guidance[10] for such analyses. For each monitoring site, all valid design values (up to 3) from the 2009-2013 period were averaged together. Since 2011 is included in all three design value periods, this has the effect of creating a 5-year weighted average, where the middle year is weighted 3 times, the 2nd and 4th years are weighted twice, and the 1st and 5th years are weighted once. We refer to this as the 5-year weighted average value. The 5-year weighted average values were then projected to the future years that were analyzed.

Concentrations of $PM_{2.5}$ in 2040 were estimated by applying the modeled 2011-to-2040 relative change in $PM_{2.5}$ species to the 5 year weighted average (2009-2013) design values. Monitoring sites were included in the analysis if they had at least one complete design value in the 2009-2013 period. EPA followed the procedures recommended in the modeling guidance for projecting $PM_{2.5}$ by projecting individual $PM_{2.5}$ component species and then summing these to calculate the concentration of total $PM_{2.5}$. The $PM_{2.5}$ species are defined as sulfates, nitrates, ammonium, organic carbon mass, elemental carbon, crustal mass, water, and blank mass (a fixed value of 0.5 $\mu g/m^3$). EPA's Modeled Attainment Test Software (MATS) was used to calculate

[10] U.S. EPA, 2014: Draft Modeling Guidance for Demonstrating Attainment of Air Quality Goals for Ozone, $PM_{2.5}$, and Regional Haze (Draft version of the updated Ozone, $PM_{2.5}$, and Regional Haze modeling guidance document). Office of Air Quality Planning and Standards, Research Triangle Park, NC. https://www3.epa.gov/ttn/scram/guidance/guide/Draft_O3-PM-RH_Modeling_Guidance-2014.pdf

the future year design values. The software (including documentation) is available at: http://www.epa.gov/scram001/modelingapps_mats.htm.

To calculate 24-hour $PM_{2.5}$ design values, the measured 98th percentile concentrations from the 2009-2013 period at each monitor are projected to the future. The procedures for calculating the future year 24-hour $PM_{2.5}$ design values have been updated. The updates are intended to make the projection methodology more consistent with the procedures for calculating ambient design values.

A basic assumption of the old projection methodology is that the distribution of high measured days in the base period will be the same in the future. In other words, EPA assumed that the 98th-percentile day could only be displaced "from below" in the instance that a different day's future concentration exceeded the original 98th-percentile day's future concentration. This sometimes resulted in overstatement of future-year design values for 24-hour $PM_{2.5}$ at receptors whose seasonal distribution of highest-concentration 24-hour $PM_{2.5}$ days changed between the 2009-2013 period and the future year modeling.

In the revised methodology, we do not assume that the seasonal distribution of high days in the base period years and future years will remain the same. We project a larger set of ambient days from the base period to the future and then re-rank the entire set of days to find the new future 98th percentile value (for each year). More specifically, we project the highest 8 days per quarter (32 days per year) to the future and then re-rank the 32 days to derive the future year 98th percentile concentrations. More details on the methodology can be found in a guidance memo titled "Update to the 24 Hour $PM_{2.5}$ NAAQS Modeled Attainment Test" which can be found here: http://www.epa.gov/ttn/scram/guidance/guide/Update_to_the_24-hour_PM25_Modeled_Attainment_Test.pdf.

The future year 8-hour average ozone design values were calculated in a similar manner as the $PM_{2.5}$ design values. The May-to-September daily maximum 8-hour average concentrations from the 2011 base case and the 2040 cases were used to project ambient design values to 2040. The calculations used the base period 2009-2013 ambient ozone design value data for projecting future year design values. Relative response factors (RRF) for each monitoring site were calculated as the percent change in ozone on days with modeled ozone greater than 70 ppb[11].

We also conducted an analysis to compare the absolute and percent differences between the 2040 control case and the 2040 reference case for annual and seasonal nitrogen dioxide, formaldehyde, acetaldehyde, benzene, 1,3-butadiene, acrolein, and naphthalene as well as annual nitrate and sulfate deposition. These data were not compared in a relative sense due to the limited observational data available.

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[11] If there are less than 5 days > 70 ppb for a site, then the threshold is lowered in 1 ppb increments to as low as 60 ppb. If there are not 5 days > 60 ppb, then the site is excluded. If a county has no sites that meet the 70 ppb threshold, then the county design value is calculated from the sites that meet the 60 ppb threshold.

E. Meteorological Input Data

The gridded meteorological input data for the entire year of 2011 were derived from simulations of the Weather Research and Forecasting Model (WRF) version 3.4, Advanced Research WRF (ARW) core[12] for the entire year of 2011 over a model domain slightly larger than that shown in Figure II-1. Meteorological model input fields were prepared for the 12 km domain shown in Figure II-1. The WRF simulation was run on the same map projection as CMAQ.

The selections for key WRF physics options are shown below[13]:

- Pleim-Xiu PBL and land surface schemes
- Asymmetric Convective Model version 2 planetary boundary layer scheme
- Kain-Fritsh cumulus parameterization utilizing the moisture-advection trigger
- Morrison double moment microphysics
- RRTMG longwave and shortwave radiation schemes

The WRF model was initialized using the 12km North American Model (12NAM) analysis product provided by National Climatic Data Center (NCDC). Where 12NAM data was unavailable, the 40km Eta Data Assimilation System (EDAS) analysis (ds609.2) from the National Center for Atmospheric Research (NCAR) was used. Three dimensional analysis nudging for temperature, wind, and moisture was applied above the boundary layer only. The meteorological simulations were conducted in 5.5 day blocks with soil moisture and temperature carried from one block to the next via the ipxwrf program.[14] Landuse and land cover data are based on the U.S. Geological Survey (USGS) data. The 36km and 12km meteorological modeling domains contained 35 vertical layers with an approximately 19 m deep surface layer and a 50 millibar top. The WRF and CMAQ vertical structures are shown in Table II-3 and do not vary by horizontal grid resolution.

Table II-3. Vertical layer structure for WRF and CMAQ (heights are layer top).

CMAQ Layers	WRF Layers	Sigma P	Approximate Height (m)
25	35	0.0000	17,556
	34	0.0500	14,780
24	33	0.1000	12,822
	32	0.1500	11,282

[12] Skamarock, W.C., Klemp, J.B., Dudhia, J., Gill, D.O., Barker, D.M., Duda, M.G., Huang, X., Wang, W., Powers, J.G., 2008. A Description of the Advanced Research WRF Version 3.
[13] Gilliam, R.C., Pleim, J.E., 2010. Performance Assessment of New Land Surface and Planetary Boundary Layer Physics in the WRF-ARW. Journal of Applied Meteorology and Climatology 49, 760-774.
[14] Gilliam, R.C., Pleim, J.E., 2010. Performance Assessment of New Land Surface and Planetary Boundary Layer Physics in the WRF-ARW. Journal of Applied Meteorology and Climatology 49, 760-774.

23	31	0.2000	10,002
	30	0.2500	8,901
22	29	0.3000	7,932
	28	0.3500	7,064
21	27	0.4000	6,275
	26	0.4500	5,553
20	25	0.5000	4,885
	24	0.5500	4,264
19	23	0.6000	3,683
18	22	0.6500	3,136
17	21	0.7000	2,619
16	20	0.7400	2,226
15	19	0.7700	1,941
14	18	0.8000	1,665
13	17	0.8200	1,485
12	16	0.8400	1,308
11	15	0.8600	1,134
10	14	0.8800	964
9	13	0.9000	797
	12	0.9100	714
8	11	0.9200	632
	10	0.9300	551
7	9	0.9400	470
	8	0.9500	390
6	7	0.9600	311
5	6	0.9700	232
4	5	0.9800	154
	4	0.9850	115
3	3	0.9900	77
2	2	0.9950	38
1	1	0.9975	19
Surface		1.0000	0

The 2011 meteorological outputs from the 12km WRF simulation were processed to create model-ready inputs for CMAQ using the Meteorology-Chemistry Interface Processor (MCIP), version 4.1.3.[15,16]

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[15] Byun, D.W., and Ching, J.K.S., Eds, 1999. Science algorithms of EPA Models-3 Community Multiscale Air Quality (CMAQ modeling system, EPA/600/R-99/030, Office of Research and Development).

[16] Otte, T.L., Pleim, J.E., 2010. The Meteorology-Chemistry Interface Processor (MCIP) for the CMAQ modeling system: updates through MCIPv3.4.1. Geoscientific Model Development 3, 243-256.

Before initiating the air quality simulations, it is important to identify the biases and errors associated with the meteorological modeling inputs. The 2011 WRF model performance evaluations used an approach which included a combination of qualitative and quantitative analyses to assess the adequacy of the WRF simulated fields. The qualitative aspects involved comparisons of the model-estimated synoptic patterns against observed patterns from historical weather chart archives. Additionally, the evaluations compared spatial patterns of monthly average rainfall and monthly maximum planetary boundary layer (PBL) heights. The operational evaluation included statistical comparisons of model/observed pairs (e.g., mean bias, mean (gross) error, fractional bias, and fractional error[17]) for multiple meteorological parameters. For this portion of the evaluation, five meteorological parameters were investigated: temperature, humidity, shortwave downward radiation, wind speed, and wind direction. The 36 km and 12 km WRF evaluations are described elsewhere.[18] The results of these analyses indicate that the bias and error values associated with all three sets of 2011meteorological data were generally within the range of past meteorological modeling results that have been used for air quality applications.

F. Initial and Boundary Conditions

The lateral boundary concentrations are provided by a three-dimensional global atmospheric chemistry model, the GEOS-CHEM[19] model (standard version 8-03-02 with version 8-02-03 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 degree x 2.5 degree (latitude-longitude) and 46 vertical layers up to 0.01 hPa. The predictions were processed using the GEOS-2-CMAQ tool[20,21] and used to provide one-way dynamic boundary conditions at one-hour intervals and an initial concentration field for the CMAQ simulations.

A GEOS-Chem model evaluation was conducted for the purpose of validating the 2011 GEOS-Chem simulation outputs for their use as inputs to the CMAQ modeling system. This evaluation included using satellite retrievals paired with GEOS-Chem grid cell concentrations.[22]

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[17] Boylan, J.W., Russell, A.G., 2006. PM and light extinction model performance metrics, goals, and criteria for three-dimensional air quality models. Atmospheric Environment 40, 4946-4959.

[18] Misenis, Chris, Meteorological Model Performance Evaluation for Annual 2011 WRF v3.4 Simulation, USEPA/OAQPS, November, 2014.

[19] Yantosca, B. and Carouge, C., 2010, GEOS-Chem v8-03-01 User's Guide, Atmospheric Chemistry Modeling Group, Harvard University, Cambridge, MA, http://acmg.seas.harvard.edu/geos/doc/archive/man.v8-03-02/index.html

[20] Akhtar, F., Henderson, B., Appel, W., Napelenok, S., Hutzell, B., Pye, H., Foley, K., 2012. Multiyear Boundary Conditions for CMAQ 5.0 from GEOS-Chem with Secondary Organic Aerosol Extensions, 11th annual Community Modeling and Analysis System conference, Chapel Hill, NC, October 2012.

[21] Henderson, B.H., Akhtar, F., Pye, H.O.T., Napelenok, S.L., Hutzell, W.T., 2013. A database and tool for boundary conditions for regional air quality modeling: description and evaluation, Geoscientific Model Development Discussions, 6, 4665-4704.

[22] Lam, Y.F., Fu, J.S., Jacob, D.J., Jang, C., Dolwick, P., 2010 2006-2008 GEOS-Chem for CMAQ Initial and Boundary Conditions. 9th Annual CMAS Conference, October 11-13, 2010, Chapel Hill, NC.

More information is available about the GEOS-Chem model and other applications using this tool at: http://www-as.harvard.edu/chemistry/trop/geos.

G. CMAQ Base Case Model Performance Evaluation

The CMAQ predictions for ozone, fine particulate matter, sulfate, nitrate, ammonium, organic carbon, elemental carbon, nitrogen and sulfur deposition, and specific air toxics (formaldehyde, acetaldehyde, benzene, 1,3-butadiene, and acrolein) from the 2011 base year evaluation case were compared to measured concentrations in order to evaluate the performance of the modeling platform for replicating observed concentrations. This evaluation was comprised of statistical and graphical comparisons of paired modeled and observed data. Details on the model performance evaluation including a description of the methodology, the model performance statistics, and results are provided in Appendix A.

III. CMAQ Model Results

As described above, we performed a series of air quality modeling simulations for the continental U.S in order to assess the impacts of the HDGHG Phase 2 standards. We looked at impacts on future ambient levels of daily and annual $PM_{2.5}$ concentrations, 8-hour maximum ozone concentrations and annual NO_2 concentrations, as well as changes in annual and seasonal (summer and winter) ambient concentrations of the following air toxics: formaldehyde, acetaldehyde, acrolein, benzene, 1,3-butadiene, and naphthalene . The air quality modeling results also include impacts on deposition of nitrogen and sulfur and on visibility levels due to this rule. In this section, we present the air quality modeling results for the 2040 HDGHG Phase 2 control case relative to the 2040 reference case.

A. Impacts of HDGHG Phase 2 Standards on Future 8-Hour Ozone Levels

This section summarizes the results of our modeling of ozone air quality impacts in the future with the HDGHG Phase 2 fuel and vehicle standards. Specifically, for the year 2040 we compare a reference scenario (a scenario without the proposed HDGHG Phase 2 standards) to a control scenario which includes the Phase 2 standards. Our modeling indicates that there will be reductions in 8-hour maximum ozone across most of the country as a result of the HDGHG Phase 2 standards. The decreases in 8-hour ozone design values (DV), max reduction of 1.7 ppb, are likely due to the projected reductions in both upstream and downstream NO_X and VOC emissions. As described in the RIA Section 5.5.2.3, assumptions about the usage of diesel-powered APUs differs between the air quality inventories and the final rule inventories. The air quality inventories assumed more widespread usage of diesel-powered APUs than was assumed for the final rule. The APU assumptions mean that the NO_X reductions assumed in the air quality inventories are larger than we expect to occur and reductions in 8-hour ozone are over-estimated in the air quality modeling. The magnitude of the reductions in 8-hour ozone DV from the final rule inventories is difficult to estimate due to the complex, non-linear chemistry governing ozone formation. However, EPA does expect reductions in ambient ozone concentrations due to these final standards.

Figure III-1 presents the changes in 8-hour ozone design value concentrations between the projected air quality modeling inventories for the 2040 reference case and the 2040 control case.[23] Appendix B details the state and county 8-hour maximum ozone design values for the 2011 ambient baseline and the 2040 future reference and control cases.

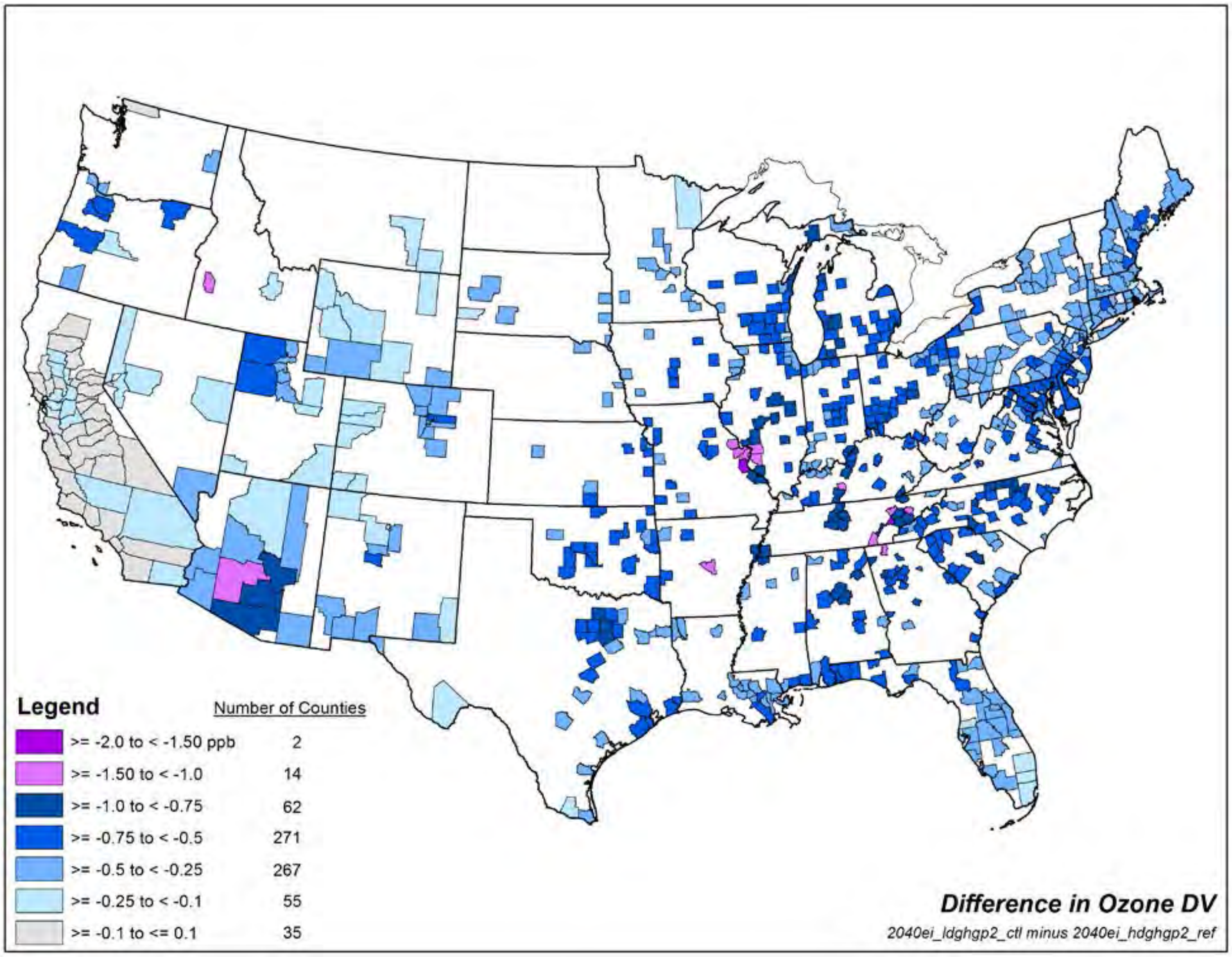

Figure III-1. Projected Change in 2040 8-hour Ozone Design Values Between the Reference Case and Control Case Using Air Quality Modeling Inventories

B. Impacts of HDGHG Phase 2 Standards on Future Annual $PM_{2.5}$ Levels

This section summarizes the results of our modeling of annual average $PM_{2.5}$ air quality impacts in the future due to the HDGHG Phase 2 fuel and vehicle standards. Specifically, for the year of 2040 we compare a reference scenario (a scenario without the standards) to a control scenario that includes the standards. Our modeling indicates that by 2040 annual $PM_{2.5}$ design values in the majority of the modeled counties would decrease due to the standards. The

[23] An 8-hour ozone design value is the concentration that determines whether a monitoring site meets the 8-hour ozone NAAQS. The full details involved in calculating an 8-hour ozone design value are given in Appendix I of 40 CFR part 50.

decreases in annual $PM_{2.5}$ DV, less than 0.05 $\mu g/m^3$, are likely due to the projected reductions in upstream primary $PM_{2.5}$ emissions, and reductions in both upstream and downstream NO_X, SO_X and VOCs. As described in the RIA Section 5.5.3.2 and 6A2.1, the air quality modeling used inventories that do not reflect the new requirements for controlling $PM_{2.5}$ emissions from APUs installed in new tractors and therefore show increases in downstream $PM_{2.5}$ emissions that we now do not expect to occur. Although in most areas this direct $PM_{2.5}$ increase is outweighed by reductions in secondary $PM_{2.5}$, the air quality modeling does predict ambient $PM_{2.5}$ increases in a few places. We do not expect to actually see increases in $PM_{2.5}$ DV from the HDGHG Phase 2 program. In addition, assumptions about the usage of diesel-powered APUs also differs between the air quality inventories and the final rule inventories. The air quality inventories assumed more widespread usage of diesel-powered APUs than was assumed for the final rule. The APU assumptions mean that the NO_X reductions assumed in the air quality inventories are larger than we expect to occur and reductions in ambient $PM_{2.5}$ due to secondary nitrate formation are over-estimated in the air quality modeling.

The magnitude of the reductions in $PM_{2.5}$ DV from the HDGHG Phase 2 final rule inventories is difficult to estimate due to the differences in the air quality inventories, namely overestimation of nitrate reductions and underestimation of direct $PM_{2.5}$ reductions. However, EPA does expect reductions in ambient concentrations of $PM_{2.5}$ due to these final standards. Figure III-2 presents the projected impacts of the air quality modeling inventories on annual $PM_{2.5}$ design values in 2040.[24] Appendix C details the state and county annual $PM_{2.5}$ design values for the ambient 2011 baseline and the 2040 future reference and control cases.

[24] An annual $PM_{2.5}$ design value is the concentration that determines whether a monitoring site meets the annual NAAQS for $PM_{2.5}$. The full details involved in calculating an annual $PM_{2.5}$ design value are given in appendix N of 40 CFR part 50.

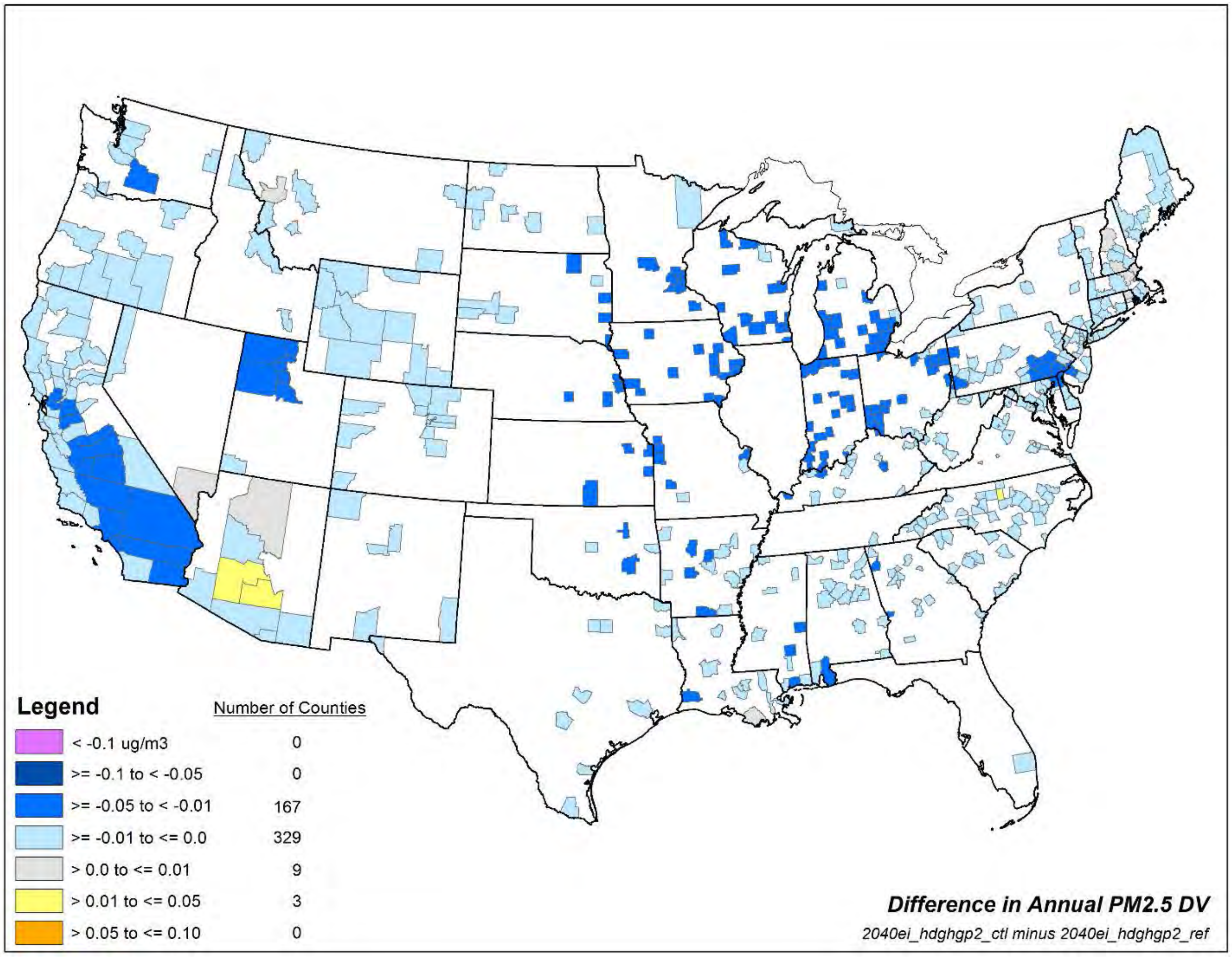

Figure III-2. Projected Change in 2040 Annual $PM_{2.5}$ Design Values Between the Reference Case and Control Case Using Air Quality Modeling Inventories

C. Impacts of HDGHG Phase 2 Standards on Future 24-hour $PM_{2.5}$ Levels

This section summarizes the results of our modeling of 24-hour $PM_{2.5}$ air quality impacts in the future due to the HDGHG Phase 2 final rule. Specifically, for the year 2040 we compare a reference scenario (a scenario without the proposed standards) to a 2040 control scenario that includes the standards. Our modeling indicates that 24-hour $PM_{2.5}$ design values in the majority of the modeled counties would decrease due to the standards. The daily $PM_{2.5}$ decreases, less than 0.6 $\mu g/m^3$, are likely due to the projected reductions in upstream primary $PM_{2.5}$ emissions, and reductions in both upstream and downstream NO_X, SO_X and VOCs. As described in Section 5.5.2.3 of the RIA, the air quality modeling used inventories that do not reflect the new requirements for controlling $PM_{2.5}$ emissions from APUs installed in new tractors and therefore show increases in downstream $PM_{2.5}$ emissions. Although in most areas this direct $PM_{2.5}$ increase is outweighed by reductions in secondary $PM_{2.5}$, the air quality modeling does predict ambient $PM_{2.5}$ increases in a few places. We do not expect to actually see increases in $PM_{2.5}$ DV from the Phase 2 program. In addition, assumptions about the usage of diesel-powered APUs also differs between the air quality inventories and the final rule inventories. The air quality inventories assumed more widespread usage of diesel-powered APUs than was assumed for the final rule. The APU assumptions mean that the NO_X reductions assumed in the air quality inventories are larger than we expect to occur and reductions in ambient $PM_{2.5}$ due to secondary nitrate formation are over-estimated in the air quality modeling.

The magnitude of the reductions in $PM_{2.5}$ DV from the final rule inventories is difficult to estimate due to the differences in the air quality inventories, namely overestimation of nitrate reductions and underestimation of direct $PM_{2.5}$ reductions. However, EPA does expect reductions in ambient concentrations of $PM_{2.5}$ due to these final standards. Figure III-3 shows the projected impacts of the air quality inventories on 24-hour $PM_{2.5}$ DVs.

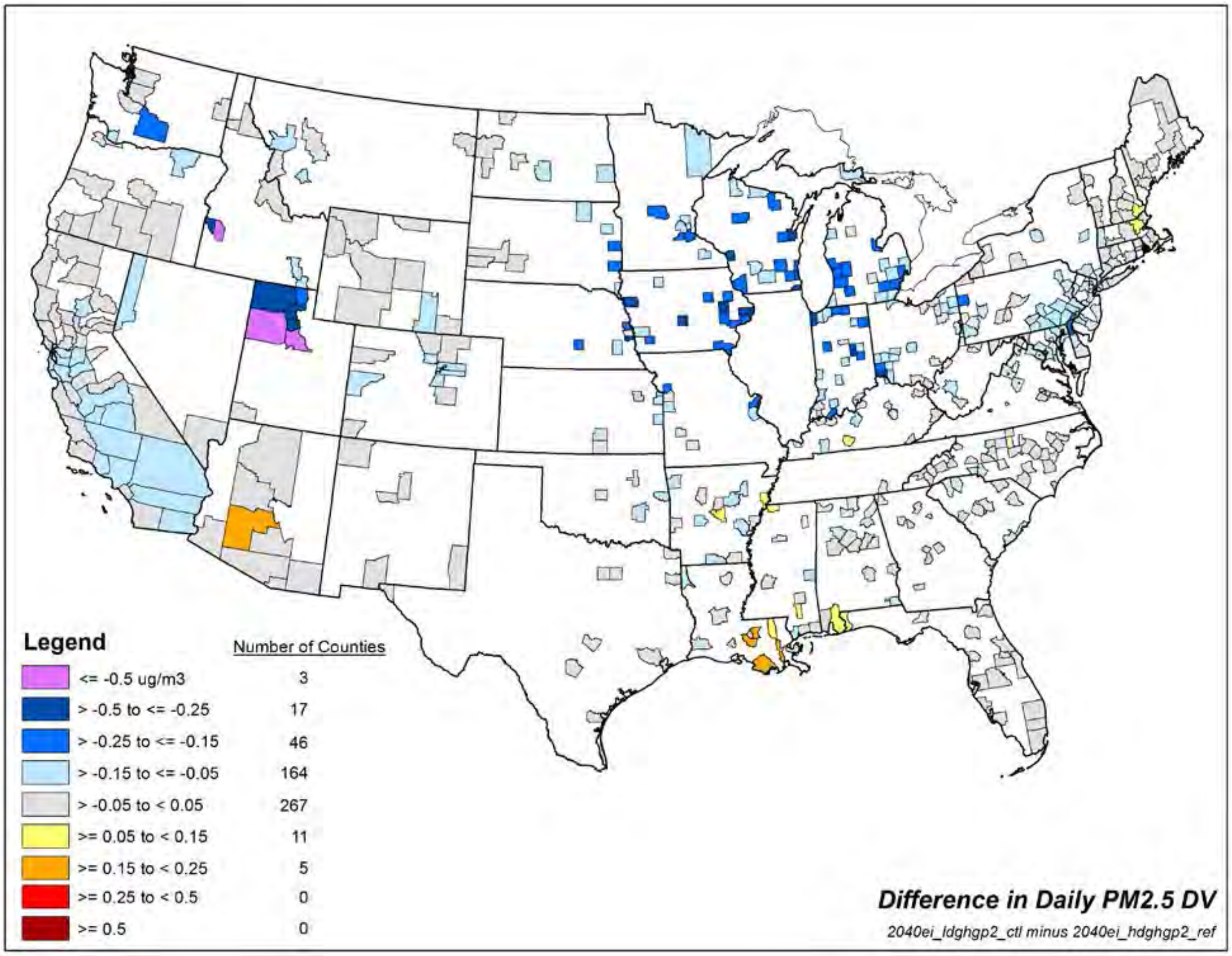

Figure III-3. Projected Change in 2040 24-hour $PM_{2.5}$ Design Values Between the Reference Case and the Control Case Using Air Quality Modeling Inventories

D. Impacts of HDGHG Phase 2 Standards on Future Nitrogen Dioxide Levels

This section summarizes the results of our modeling of annual average nitrogen dioxide (NO_2) air quality impacts in the future due to the final HDGHG Phase 2 standards. Specifically, we compare a 2040 reference scenario (a scenario without the HDGHG Phase 2 standards) to a

2040 control scenario that includes the HDGHG Phase 2 standards. Figure III-4 presents the changes in annual NO_2 concentrations in 2040 based on percent changes and absolute changes. Air quality modeling results indicate that annual average NO_2 concentrations will be reduced across the country. However, the magnitude of the reductions that will actually result from the final standards is difficult to estimate because the air quality modeling inventories included larger NOx emission reductions than we now expect to occur. As described in Section 5.5.2.3, the air quality inventories and the final rule inventories make different assumptions about the usage of diesel-powered APUs. The air quality inventories assumed more widespread usage of diesel-powered APUs than was assumed for the final rule, and as a result the reductions in ambient NO_2 concentrations are overestimated in the air quality modeling.

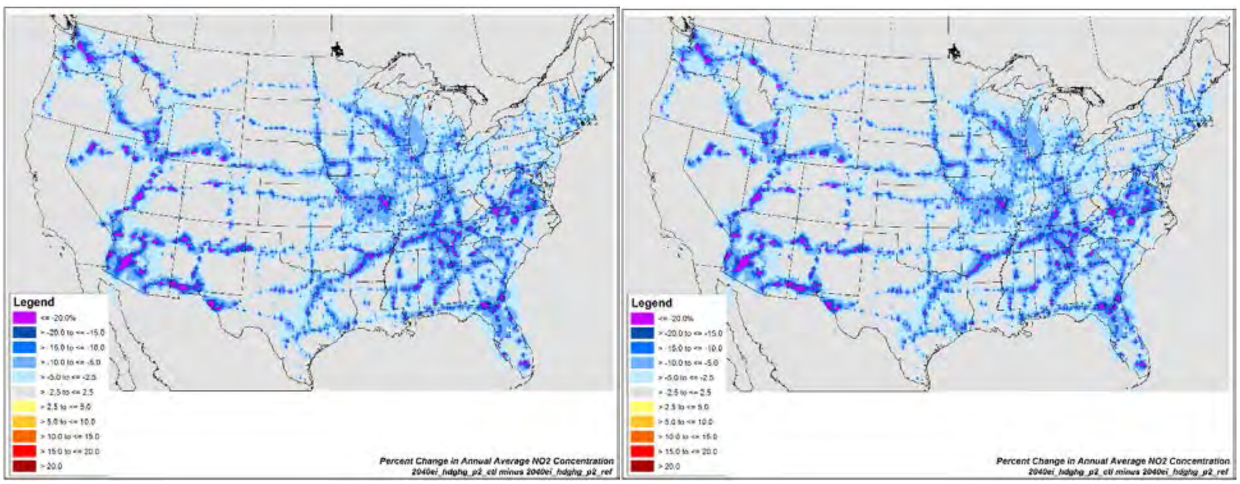

Figure III-4. Projected Change in 2040 Annual NO_2 Concentrations Between the Reference Case and Control Case Using Air Quality Modeling Inventories: Percent Changes (left) and Absolute Changes in ppb (right)

E. Impacts of HDGHG Phase 2 Standards on Future Ambient Air Toxic Concentrations

This section summarize the results of our modeling of air toxics impacts in the future from the HDGHG Phase 2 fuel and vehicle emission standards. Our modeling indicates that the standards have relatively little impact on national average ambient concentrations of the modeled air toxics. Annual absolute changes in ambient concentrations are generally less than 0.2 $\mu g/m^3$ for benzene, formaldehyde, and acetaldehyde and less than 0.005 $\mu g/m^3$ for acrolein and 1,3-butadiene. Naphthalene changes are in the range of 0.005 $\mu g/m^3$ along major roadways and in urban areas. Air toxics concentration maps are presented below in Figures III-5 through III-22 along with Table III-1 showing the percent of the population experiencing changes in ambient toxic concentrations.

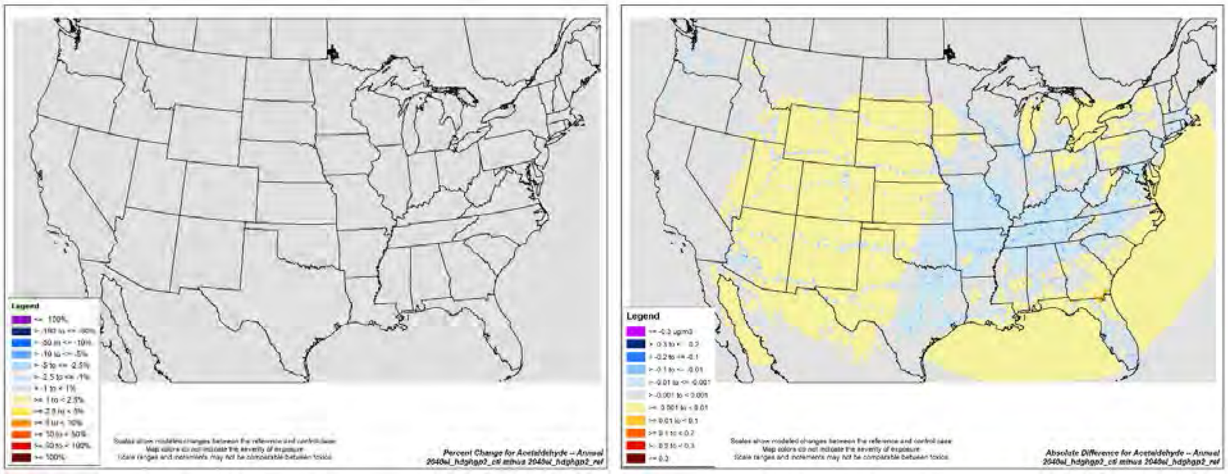

Figure III-5. Annual Changes in Acetaldehyde Ambient Concentrations between the Reference Case and the Control Case in 2040 Using Air Quality Modeling Inventories: Percent Changes (left) and Absolute Changes in µg/m³ (right)

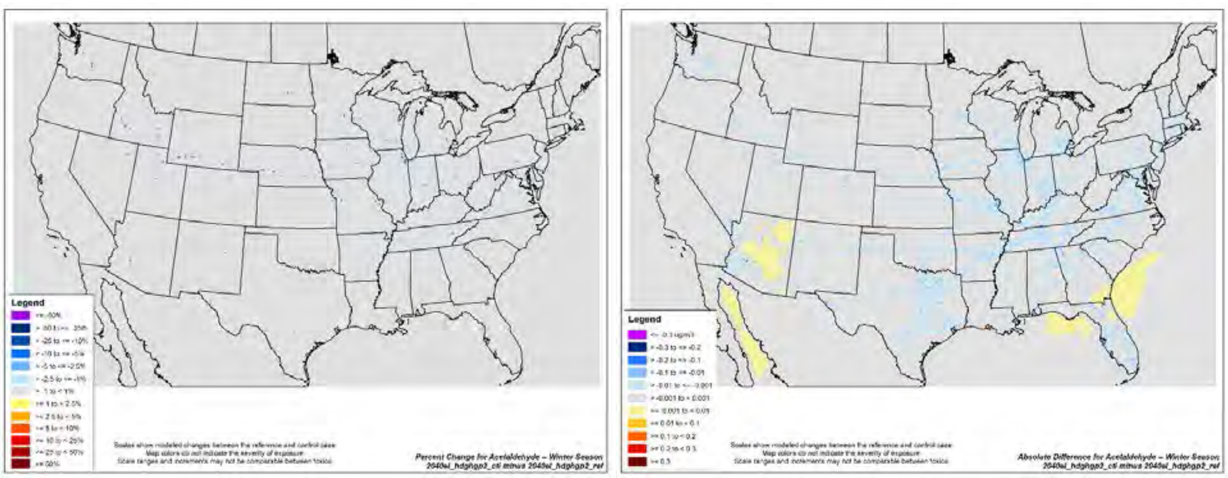

Figure III-6. Winter Changes in Acetaldehyde Ambient Concentrations between the Reference Case and the Control Case in 2040 Using Air Quality Modeling Inventories: Percent Changes (left) and Absolute Changes in µg/m³ (right)

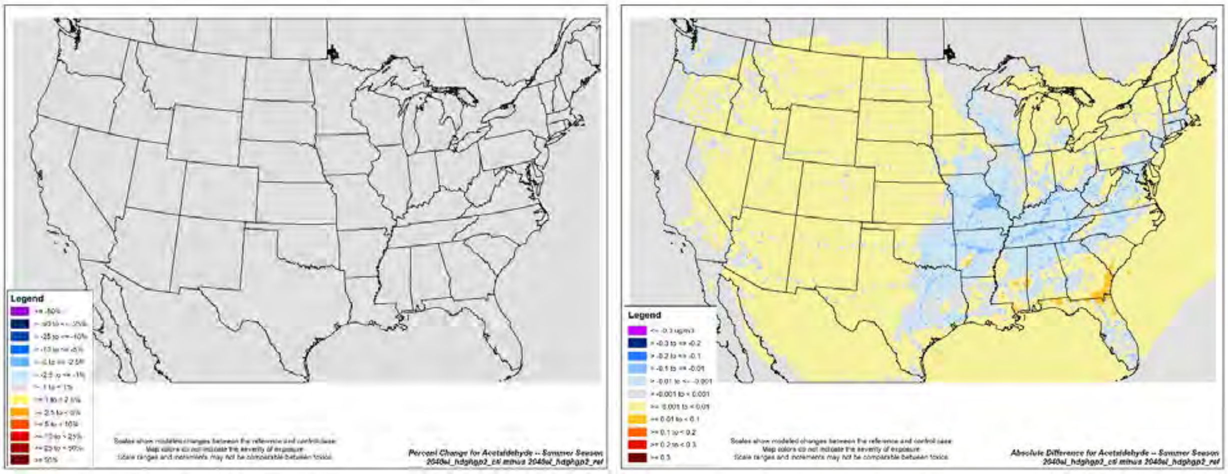

Figure III-7. Summer Changes in Acetaldehyde Ambient Concentrations between the Reference Case and the Control Case in 2040 Using Air Quality Modeling Inventories: Percent Changes (left) and Absolute Changes in µg/m³ (right)

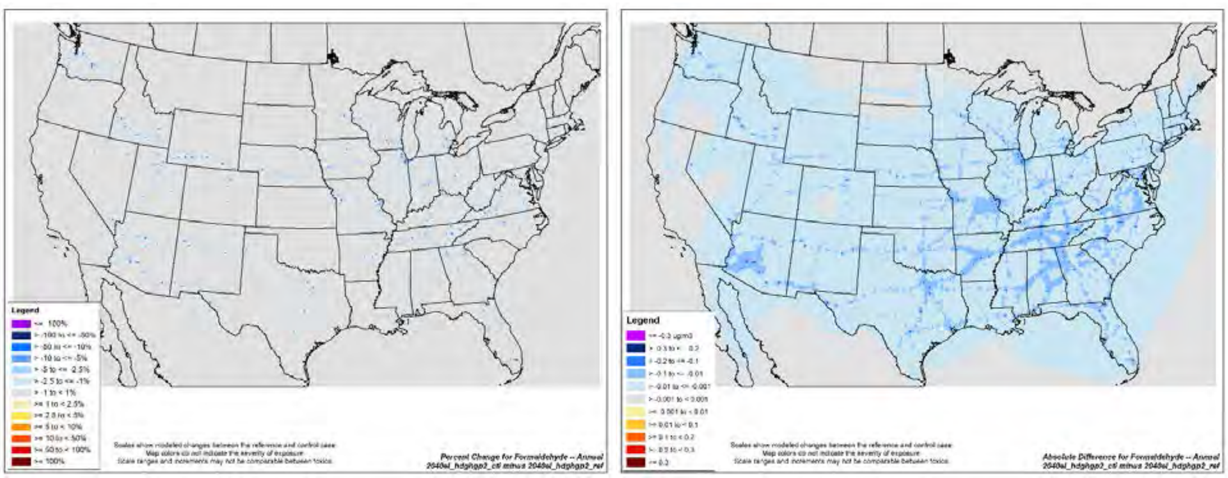

Figure III-8. Changes in Formaldehyde Ambient Concentrations between the Reference Case and the Control Case in 2040 Using Air Quality Modeling Inventories: Percent Changes (left) and Absolute Changes in µg/m³ (right)

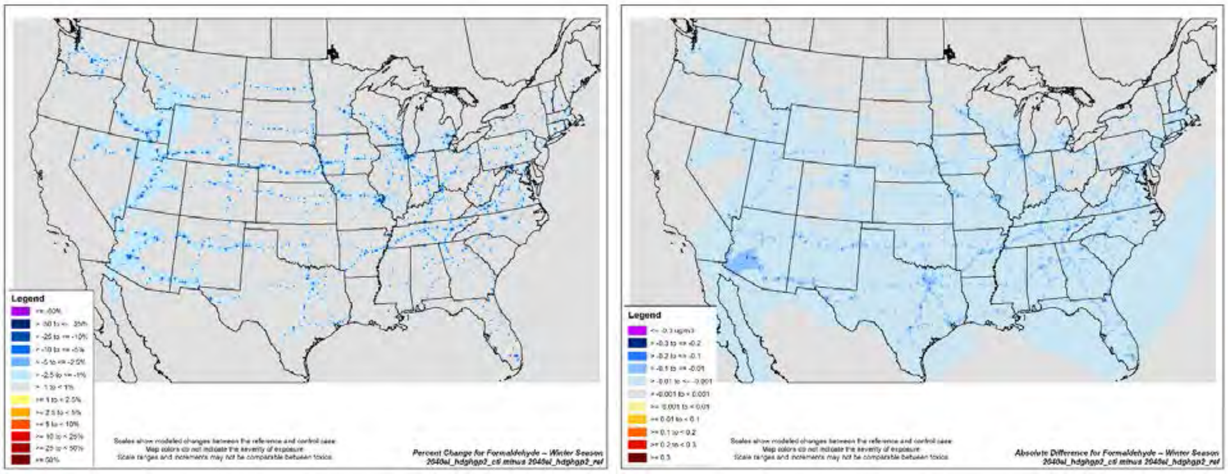

Figure III-9. Winter Changes in Formaldehyde Ambient Concentrations between the Reference Case and the Control Case in 2040 Using Air Quality Modeling Inventories: Percent Changes (left) and Absolute Changes in µg/m³ (right)

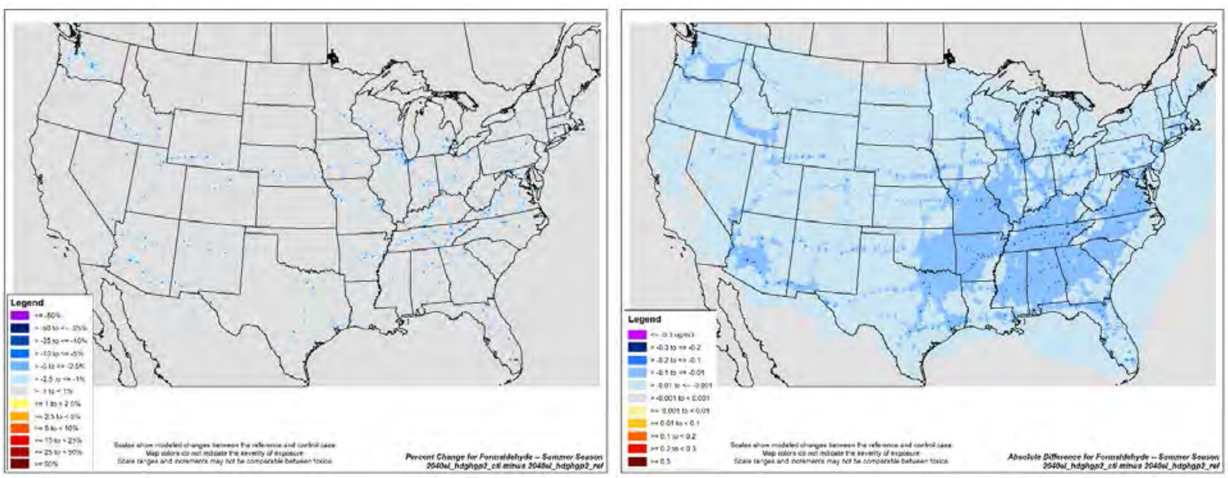

Figure III-10. Summer Changes in Formaldehyde Ambient Concentrations between the Reference Case and the Control Case in 2040 Using Air Quality Modeling Inventories: Percent Changes (left) and Absolute Changes in µg/m³ (right)

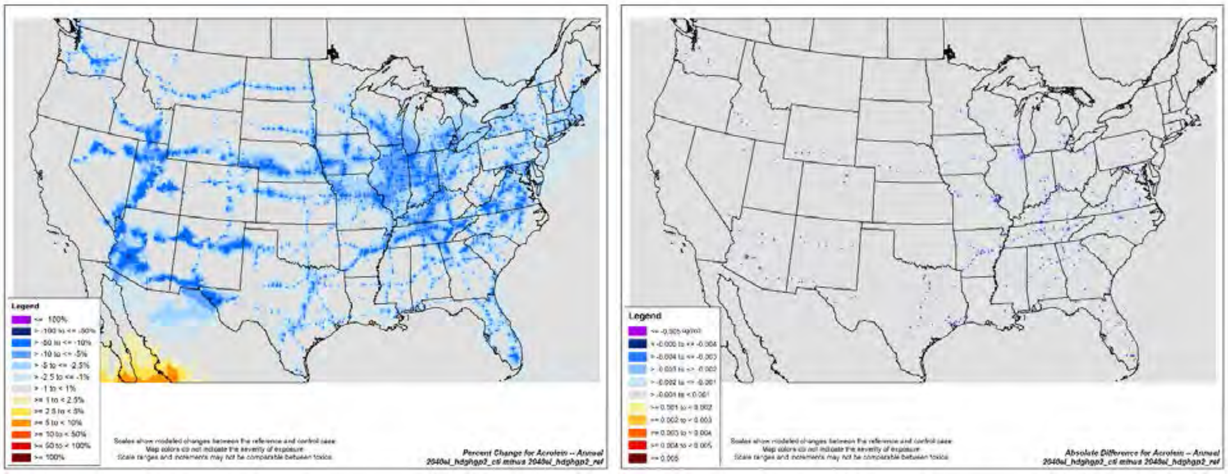

Figure III-11. Annual Changes in Acrolein Ambient Concentrations between the Reference Case and the Control Case in 2040 Using Air Quality Modeling Inventories: Percent Changes (left) and Absolute Changes in µg/m³ (right)

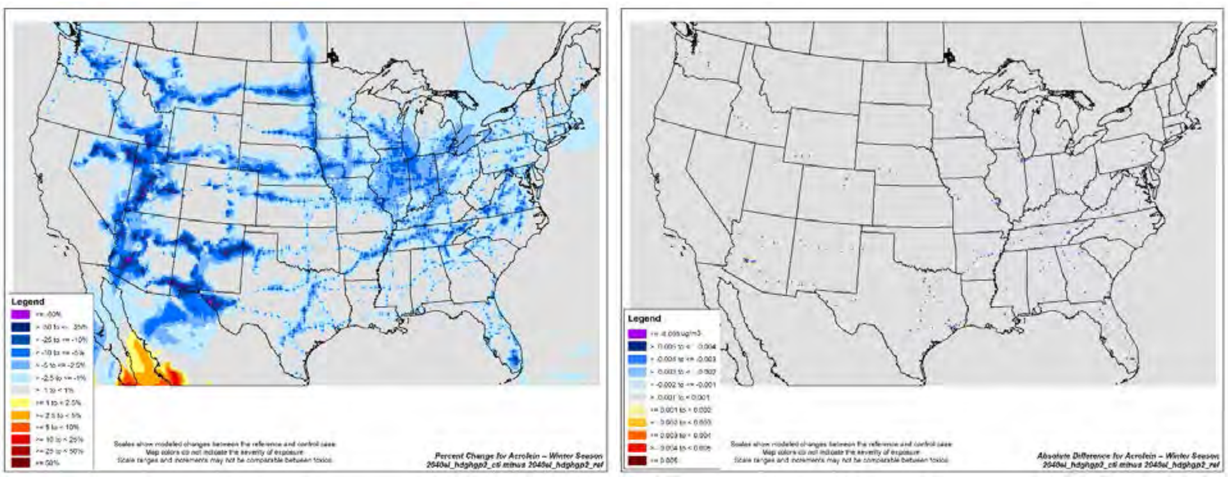

Figure III-12. Winter Changes in Acrolein Ambient Concentrations between the Reference Case and the Control Case in 2040 Using Air Quality Modeling Inventories: Percent Changes (left) and Absolute Changes in µg/m³ (right)

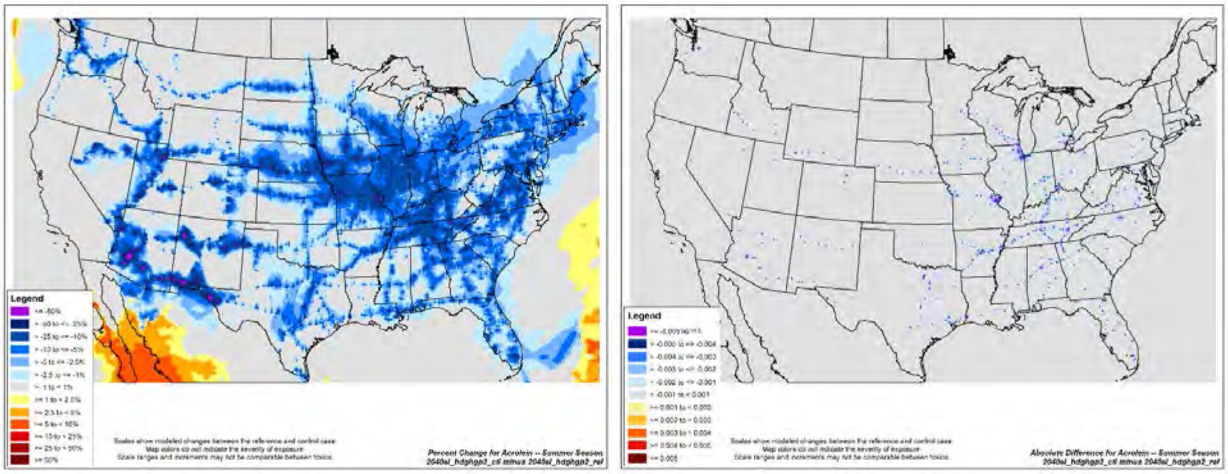

Figure III-13. Summer Changes in Acrolein Ambient Concentrations between the Reference Case and the Control Case in 2040 Using Air Quality Modeling Inventories: Percent Changes (left) and Absolute Changes in µg/m³ (right)

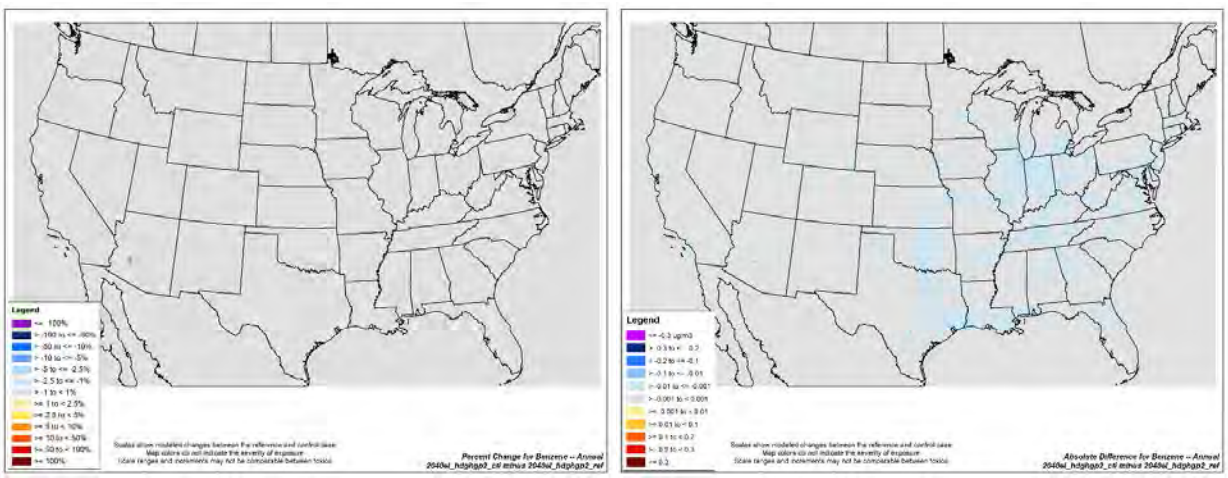

Figure III-14. Annual Changes in Benzene Ambient Concentrations between the Reference Case and the Control Case in 2040 Using Air Quality Modeling Inventories: Percent Changes (left) and Absolute Changes in µg/m³ (right)

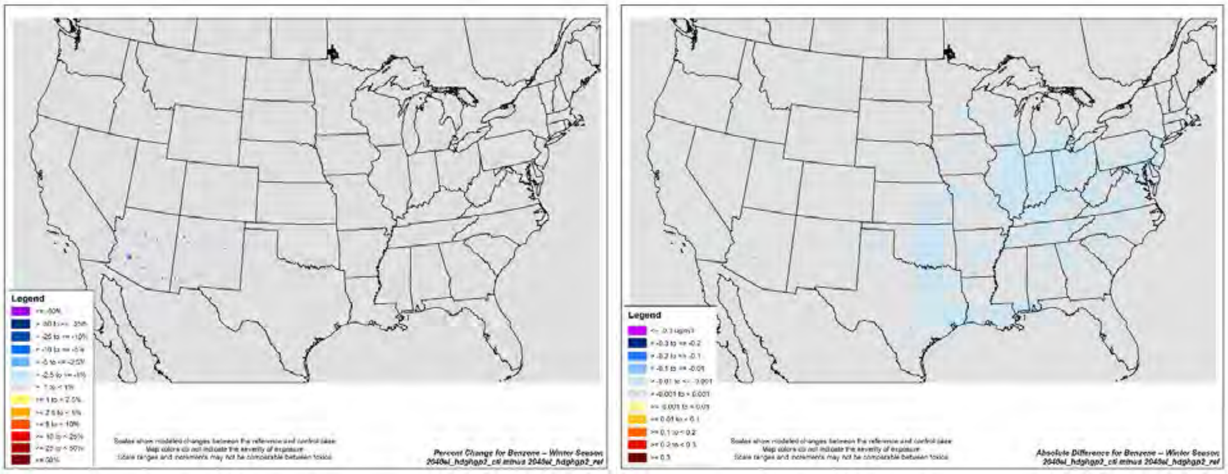

Figure III-15. Winter Changes in Benzene Ambient Concentrations between the Reference Case and the Control Case in 2040 Using Air Quality Modeling Inventories: Percent Changes (left) and Absolute Changes in µg/m³ (right)

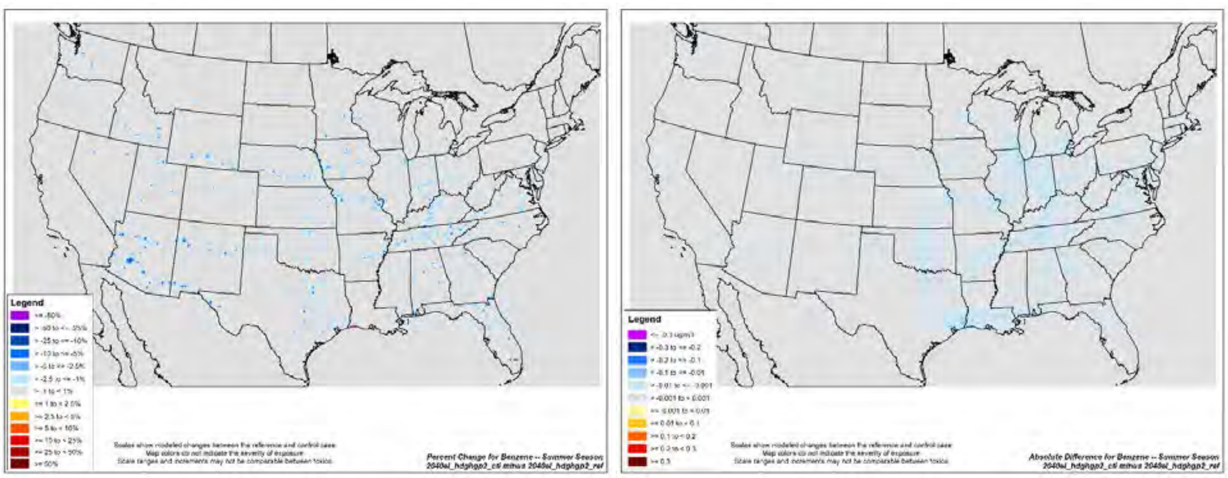

Figure III-16. Summer Changes in Benzene Ambient Concentrations between the Reference Case and the Control Case in 2040 Using Air Quality Modeling Inventories: Percent Changes (left) and Absolute Changes in µg/m³ (right)

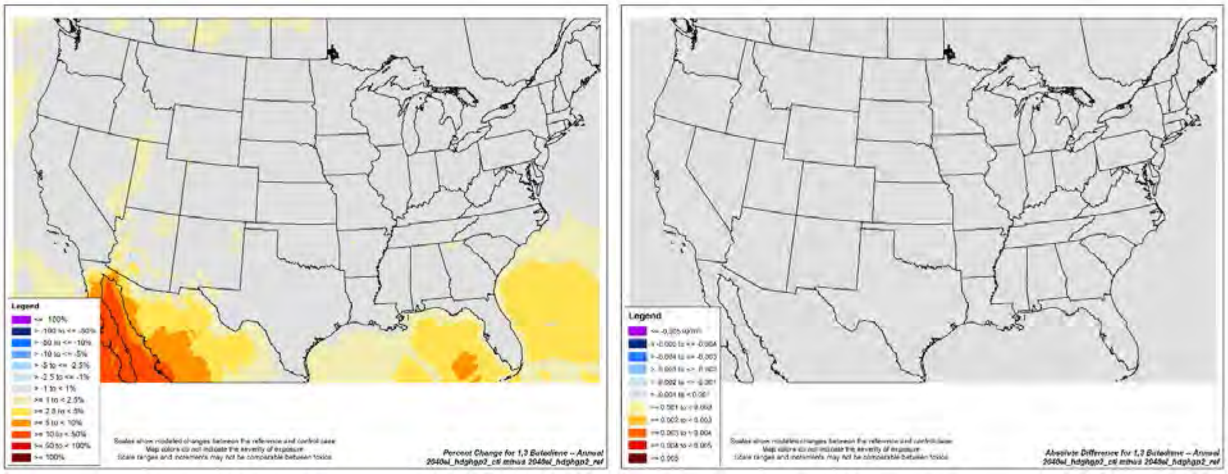

Figure III-17. Changes in 1,3-Butadiene Ambient Concentrations between the Reference Case and the Control Case in 2040 Using Air Quality Modeling Inventories: Percent Changes (left) and Absolute Changes in µg/m³ (right)

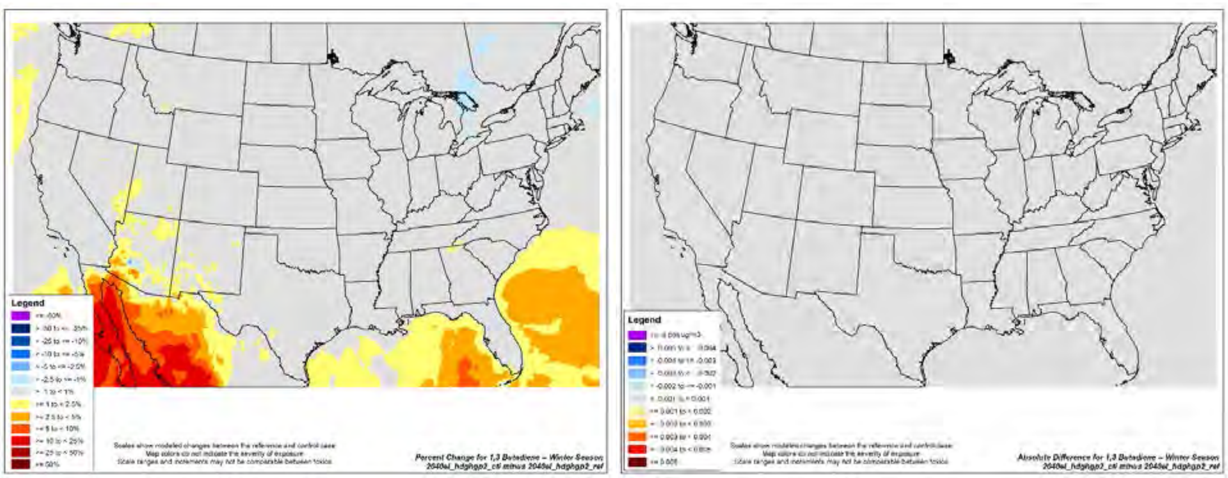

Figure III-18. Winter Changes in 1,3-Butadiene Ambient Concentrations between the Reference Case and the Control Case in 2040 Using Air Quality Modeling Inventories: Percent Changes (left) and Absolute Changes in µg/m³ (right)

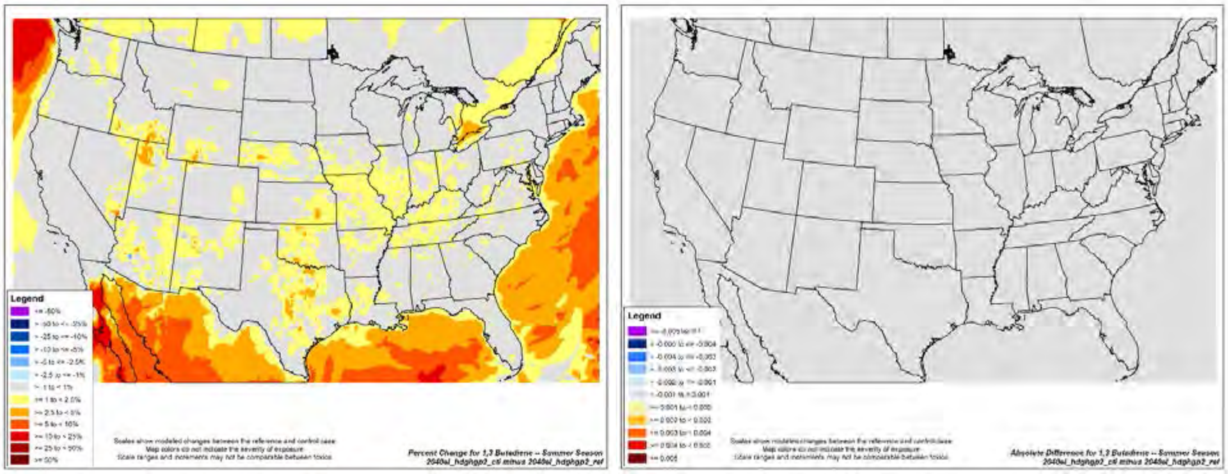

Figure III-19. Summer Changes in 1,3-Butadiene Ambient Concentrations between the Reference Case and the Control Case in 2040 Using Air Quality Modeling Inventories: Percent Changes (left) and Absolute Changes in µg/m³ (right)

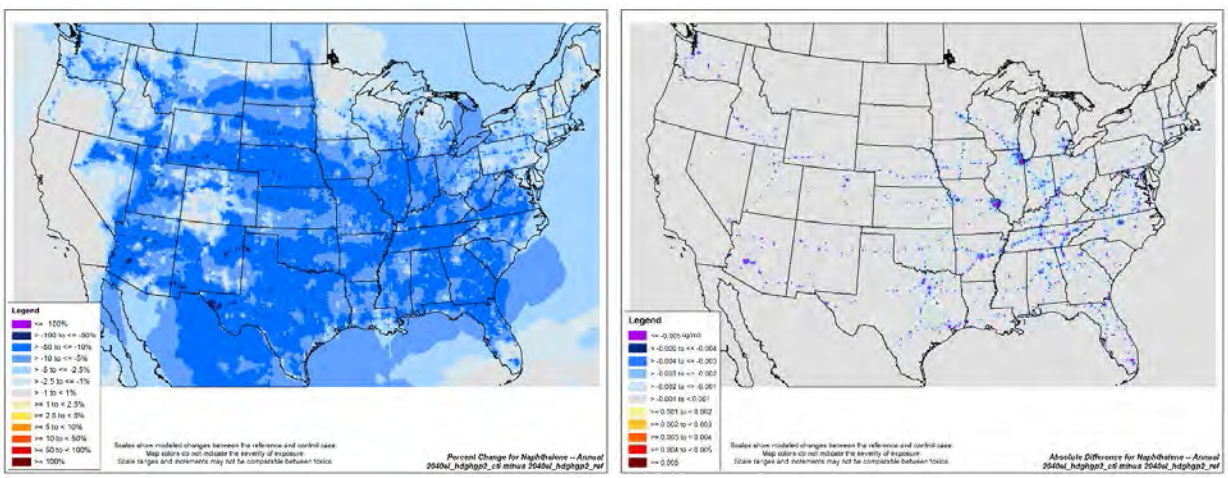

Figure III-20. Changes in Naphthalene Ambient Concentrations between the Reference Case and the Control Case in 2040 Using Air Quality Modeling Inventories: Percent Changes (left) and Absolute Changes in µg/m³ (right)

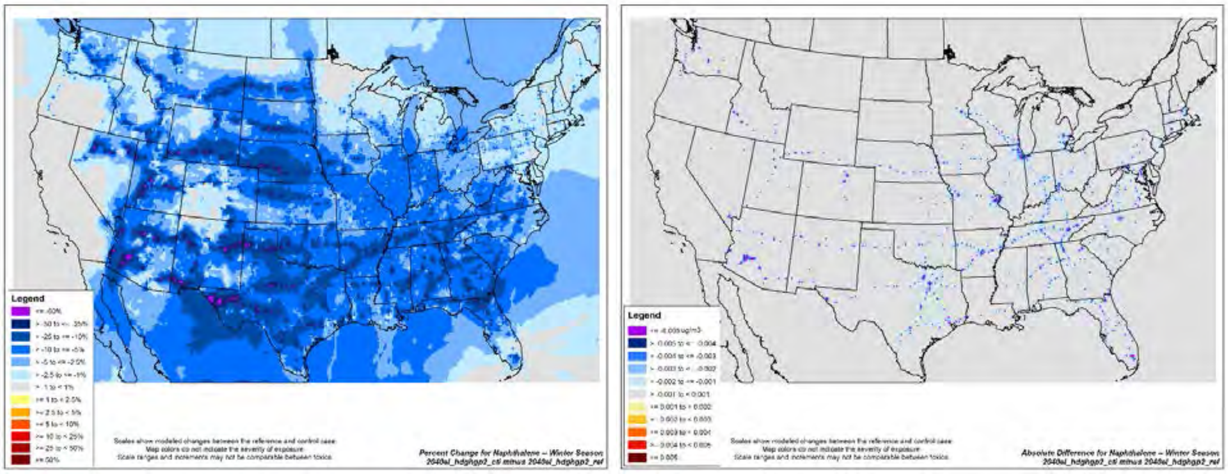

Figure III-21. Winter Changes in Naphthalene Ambient Concentrations between the Reference Case and the Control Case in 2040 Using Air Quality Modeling Inventories: Percent Changes (left) and Absolute Changes in μg/m³ (right)

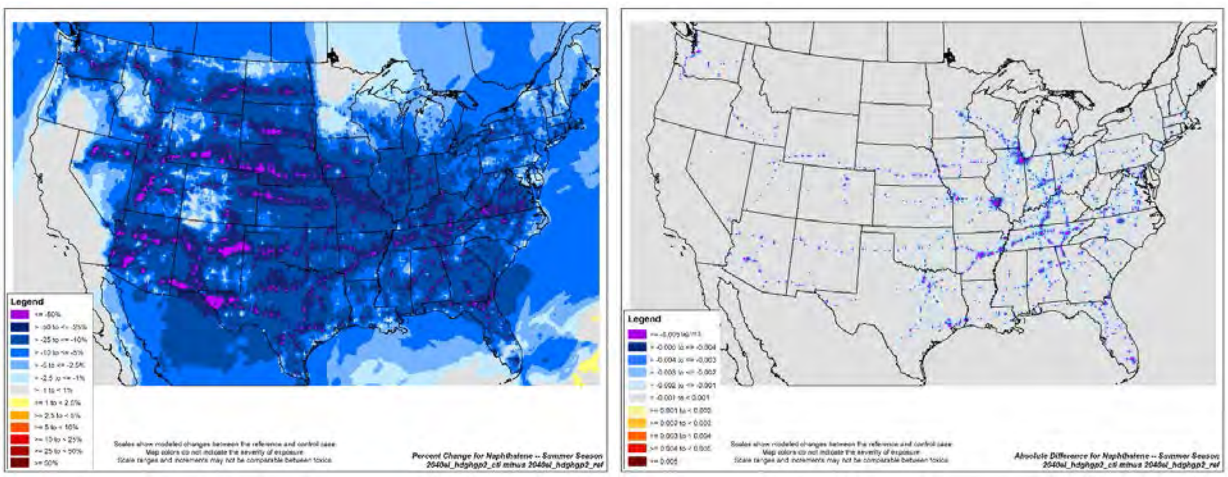

Figure III-22. Summer Changes in Naphthalene Ambient Concentrations between the Reference Case and the Control Case in 2040 Using Air Quality Modeling Inventories: Percent Changes (left) and Absolute Changes in μg/m³ (right)

Table III-1. Percent of Total Population Experiencing Changes in Annual Ambient Concentrations of Toxic Pollutants in 2040 as a Result of the HDGHG Phase 2 Standards

Percent Change	Acetaldehyde	Acrolein	Benzene	1,3-Butadiene	Formaldehyde	Naphthalene
≤ -50		0%				0%
> -50 to ≤ -25		1%				4%
> -25 to ≤ -10		8%			1%	20%
> -10 to ≤ -5	0%	15%	0%		2%	24%
> -5 to ≤ -2.5	0%	25%	1%		5%	21%
> -2.5 to ≤ -1	3%	28%	5%	1%	18%	15%
> -1 to < 1	97%	23%	94%	99%	74%	15%
≥ 1 to < 2.5				0%		
≥ 2.5 to < 5						
≥ 5 to < 10						
≥ 10 to < 25						
≥ 25 to < 50						
≥ 50						

F. Impacts of HDGHG Phase 2 Standards on Future Annual Nitrogen and Sulfur Deposition Levels

Our air quality modeling projects decreases in both nitrogen and sulfur deposition due to this rule (Figures III-23 and III-24). However, the magnitude of the reductions that will actually result from the final standards is difficult to estimate because the air quality modeling inventories included larger NOx emission reductions than we now expect to occur. As described in the RIA Section 5.5.2.3, the air quality inventories and the final rule inventories make different assumptions about the usage of diesel-powered APUs. The air quality inventories assumed more widespread usage of diesel-powered APUs than was assumed for the final rule, and as a result the reductions in ambient NOx deposition are overestimated in the air quality modeling.

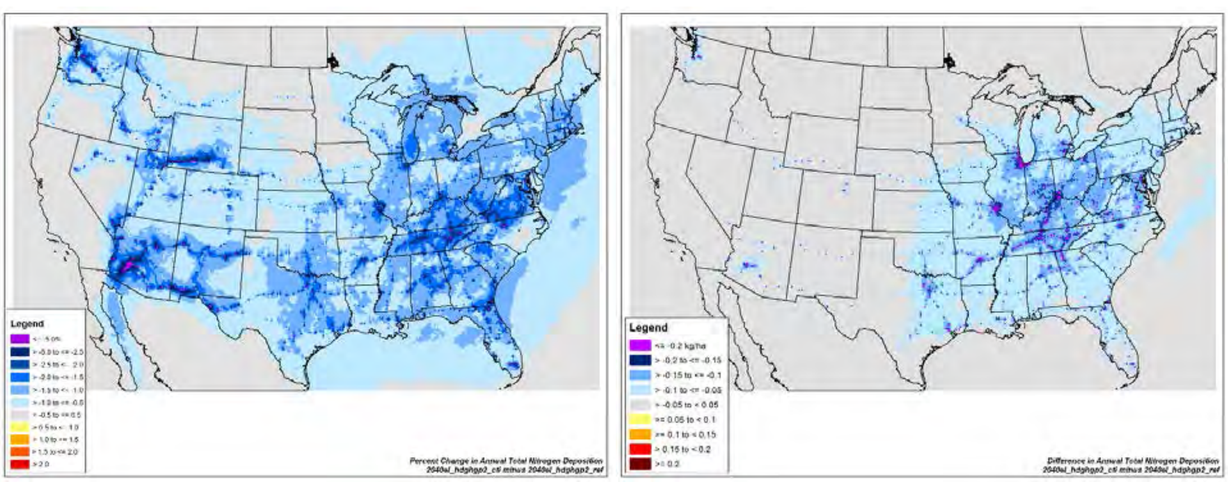

Figure III-23. Changes in Nitrogen Deposition between the Reference Case and the Control Case in 2040 using Air Quality Modeling Inventories: Percent Changes (left) and Absolute Changes in kg/ha (right)

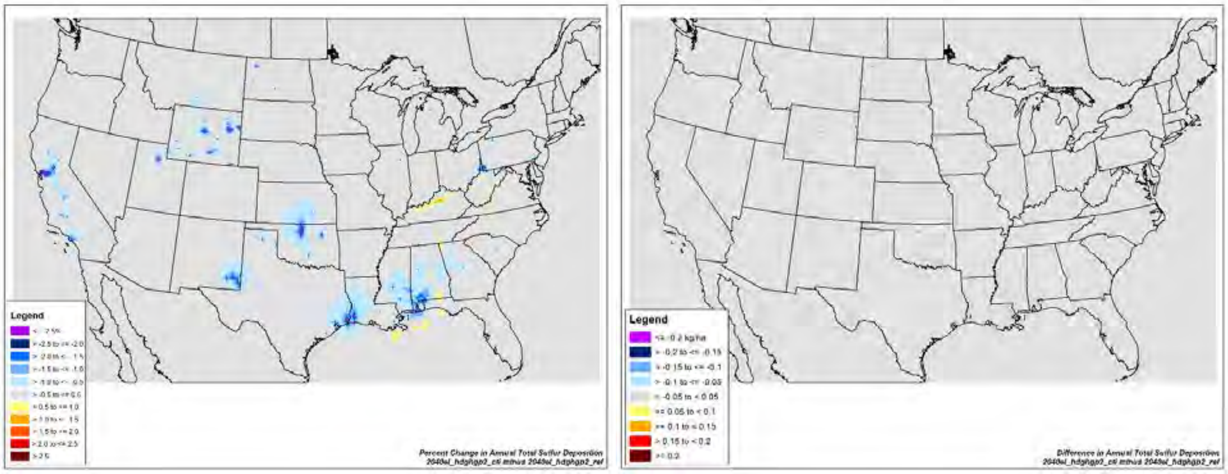

Figure III-24. Changes in Sulfur Deposition between the Reference Case and the Control Case in 2040 using Air Quality Modeling Inventories: Percent Changes (left) and Absolute Changes in kg/ha (right)

G. Impacts of HDGHG Phase 2 Standards on Future Visibility Levels

Air quality modeling conducted for the HDGHG Phase 2 final rule was used to project visibility conditions in 135 Mandatory Class I Federal areas across the U.S. in 2040. The impacts of this action were examined in terms of the projected improvements in visibility on the 20 percent worst visibility days at Class I areas. We quantified visibility impacts at the Class I areas which have complete IMPROVE ambient data for 2011 or are represented by IMPROVE monitors with complete data. Sites were used in this analysis if they had at least 3 years of complete data for the 2009-2013 period[25].

Visibility for the 2040 reference and control cases were calculated using the regional haze methodology outlined in section 6 of the photochemical modeling guidance, which applies modeling results in a relative sense, using base year ambient data. The $PM_{2.5}$ and regional haze modeling guidance recommends the calculation of future year changes in visibility in a similar manner to the calculation of changes in $PM_{2.5}$ design values https://www3.epa.gov/scram001/guidance/guide/Draft_O3-PM-RH_Modeling_Guidance-2014.pdf). The regional haze methodology for calculating future year visibility impairment is included in MATS (http://www.epa.gov/scram001/modelingapps_mats.htm)

In calculating visibility impairment, the extinction coefficient values[26] are made up of individual component species (sulfate, nitrate, organics, etc). The predicted change in visibility (on the 20 percent worst days) is calculated as the modeled percent change in the mass for each of the $PM_{2.5}$ species (on the 20% worst observed days) multiplied by the observed concentrations. The future mass is converted to extinction and then daily species extinction

[25] Since the base case modeling used meteorology for 2011, one of the complete years must be 2011.

[26] Extinction coefficient is in units of inverse megameters (Mm^{-1}). It is a measure of how much light is absorbed or scattered as it passes through a medium. Light extinction is commonly used as a measure of visibility impairment in the regional haze program.

coefficients are summed to get a daily total extinction value (including Rayleigh scattering). The daily extinction coefficients are converted to deciviews and averaged across all 20 percent worst days. In this way, we calculate an average change in deciviews from the base case to a future case at each IMPROVE site. For example, subtracting the 2040 reference case from the corresponding 2040 reference case deciview values gives an estimate of the visibility benefits in Class I areas that are expected to occur from the rule.

The following options were chosen in MATS for calculating the future year visibility values for the rule:

New IMPROVE algorithm
Use model grid cells at (IMPROVE) monitor
Temporal adjustment at monitor- 3x3 for 12km grid, (1x1 for 36km grid)
Start monitor year- 2009
End monitor year- 2013
Base model year 2011
Minimum years required for a valid monitor- 3

The “base model year” was chosen as 2011 because it is the base case meteorological year for the HDGHG Phase 2 final rule modeling. The start and end years were chosen as 2009 and 2013 because that is the 5 year period which is centered on the base model year of 2011. These choices are consistent with using a 5 year base period for regional haze calculations.

The results show that in 2040 all the modeled areas would continue to have annual average deciview levels above background and the rule would improve visibility in the majority of these areas.[27] Table III-2 contains the full visibility results from 2040 for the 135 analyzed areas.

Table III-2. Visibility Levels (in Deciviews) for Mandatory Class I Federal Areas on the 20 Percent Worst Days Using Air Quality Inventories (with and without HDGHG Phase 2 Rule)

Class 1 Area (20% worst days)	State	2011 Baseline Visibility	2040 Reference	2040 HDGHGP2 Control	Natural Background
Sipsey Wilderness	Alabama	22.93	18.16	18.07	10.99
Mazatzal Wilderness	Arizona	12.03	11.40	11.38	6.68
Pine Mountain Wilderness	Arizona	12.03	11.40	11.38	6.68
Superstition Wilderness	Arizona	12.72	11.82	11.80	6.54
Chiricahua NM	Arizona	12.08	11.54	11.53	7.20
Chiricahua Wilderness	Arizona	12.08	11.54	11.53	7.20

[27] The level of visibility impairment in an area is based on the light-extinction coefficient and a unitless visibility index, called a “deciview”, which is used in the valuation of visibility. The deciview metric provides a scale for perceived visual changes over the entire range of conditions, from clear to hazy. Under many scenic conditions, the average person can generally perceive a change of one deciview. The higher the deciview value, the worse the visibility. Thus, an improvement in visibility is a decrease in deciview value.

Class 1 Area (20% worst days)	State	2011 Baseline Visibility	2040 Reference	2040 HDGHGP2 Control	Natural Background
Galiuro Wilderness	Arizona	12.08	11.54	11.53	7.20
Grand Canyon NP	Arizona	10.92	10.53	10.52	7.04
Petrified Forest NP	Arizona	11.92	11.64	11.63	6.49
Sycamore Canyon Wilderness	Arizona	14.62	14.00	14.01	6.65
Caney Creek Wilderness	Arkansas	22.23	19.01	18.96	11.58
Upper Buffalo Wilderness	Arkansas	22.12	19.00	18.95	11.57
Joshua Tree NM	California	15.07	13.49	13.47	7.19
Kings Canyon NP	California	20.82	17.93	17.91	7.70
San Rafael Wilderness	California	16.46	14.51	14.49	7.57
San Gorgonio Wilderness	California	16.85	14.11	14.09	7.30
San Jacinto Wilderness	California	16.85	14.11	14.09	7.30
Sequoia NP	California	20.82	17.93	17.91	7.70
Agua Tibia Wilderness	California	18.44	15.66	15.65	7.64
Ansel Adams Wilderness (Minarets)	California	14.27	13.01	13.00	7.12
Desolation Wilderness	California	11.82	11.02	11.01	6.05
Dome Land Wilderness	California	17.23	15.93	15.92	7.46
Emigrant Wilderness	California	14.75	14.16	14.15	7.64
Hoover Wilderness	California	10.78	10.31	10.30	7.71
John Muir Wilderness	California	14.27	13.01	13.00	7.12
Kaiser Wilderness	California	14.27	13.01	13.00	7.12
Marble Mountain Wilderness	California	14.10	13.34	13.33	7.90
Mokelumne Wilderness	California	11.82	11.02	11.01	6.05
Pinnacles NM	California	16.15	14.42	14.41	7.99
Ventana Wilderness	California	16.15	14.42	14.41	7.99
Yolla Bolly Middle Eel Wilderness	California	14.10	13.34	13.33	7.90
Yosemite NP	California	14.75	14.16	14.15	7.64
Caribou Wilderness	California	13.49	12.83	12.83	7.31
Lava Beds NM	California	13.38	12.93	12.93	7.85
Lassen Volcanic NP	California	13.49	12.83	12.83	7.31
Point Reyes NS	California	20.98	19.93	19.93	15.77
Redwood NP	California	17.38	16.82	16.82	13.91
South Warner Wilderness	California	13.38	12.93	12.93	7.85
Thousand Lakes Wilderness	California	13.49	12.83	12.83	7.31
Rocky Mountain NP	Colorado	11.84	10.93	10.91	7.15
Black Canyon of the Gunnison NM	Colorado	9.88	9.71	9.70	6.21
La Garita Wilderness	Colorado	9.88	9.71	9.70	6.21
Weminuche Wilderness	Colorado	9.88	9.71	9.70	6.21
Eagles Nest Wilderness	Colorado	8.48	8.04	8.03	6.06
Flat Tops Wilderness	Colorado	8.48	8.04	8.03	6.06
Great Sand Dunes NM	Colorado	11.57	11.50	11.49	6.66

Class 1 Area (20% worst days)	State	2011 Baseline Visibility	2040 Reference	2040 HDGHGP2 Control	Natural Background
Maroon Bells-Snowmass Wilderness	Colorado	8.48	8.04	8.03	6.06
Mount Zirkel Wilderness	Colorado	9.11	8.70	8.69	6.08
Rawah Wilderness	Colorado	9.11	8.70	8.69	6.08
West Elk Wilderness	Colorado	8.48	8.04	8.03	6.06
Mesa Verde NP	Colorado	11.22	11.37	11.37	6.81
Chassahowitzka	Florida	21.34	18.21	18.17	11.03
St. Marks	Florida	22.23	18.74	18.70	11.67
Everglades NP	Florida	18.15	17.65	17.62	12.15
Cohutta Wilderness	Georgia	22.71	17.47	17.43	10.78
Okefenokee	Georgia	22.68	18.82	18.78	11.44
Wolf Island	Georgia	22.68	18.82	18.78	11.44
Craters of the Moon NM	Idaho	14.05	12.93	12.80	7.53
Sawtooth Wilderness	Idaho	15.64	15.44	15.44	6.42
Selway-Bitterroot Wilderness	Idaho	14.89	14.77	14.77	7.43
Mammoth Cave NP	Kentucky	25.09	19.83	19.75	11.08
Acadia NP	Maine	17.93	15.81	15.80	12.43
Moosehorn	Maine	16.83	15.27	15.26	12.01
Roosevelt Campobello International Park	Maine	16.83	15.27	15.26	12.01
Seney	Michigan	20.56	17.15	17.08	12.65
Isle Royale NP	Michigan	18.92	16.06	16.01	12.37
Boundary Waters Canoe Area	Minnesota	18.82	16.66	16.60	11.61
Hercules-Glades Wilderness	Missouri	22.89	19.57	19.51	11.30
Mingo	Missouri	24.31	20.91	20.86	11.62
Medicine Lake	Montana	17.98	17.07	17.06	7.89
Bob Marshall Wilderness	Montana	14.43	14.33	14.32	7.73
Cabinet Mountains Wilderness	Montana	12.73	12.24	12.23	7.52
Glacier NP	Montana	16.03	15.82	15.81	9.18
Mission Mountains Wilderness	Montana	14.43	14.33	14.32	7.73
Red Rock Lakes	Montana	11.98	11.73	11.72	6.44
Scapegoat Wilderness	Montana	14.43	14.33	14.32	7.73
UL Bend	Montana	14.11	13.77	13.76	8.16
Anaconda-Pintler Wilderness	Montana	14.89	14.77	14.77	7.43
Jarbidge Wilderness	Nevada	11.97	11.90	11.90	7.87
Great Gulf Wilderness	New Hampshire	16.66	13.61	13.60	11.99
Presidential Range-Dry River Wilderness	New Hampshire	16.66	13.61	13.60	11.99
Brigantine	New Jersey	23.75	19.64	19.61	12.24
Bosque del Apache	New Mexico	14.02	14.37	14.34	6.73
Salt Creek	New Mexico	17.42	18.32	18.30	6.81
Bandelier NM	New Mexico	11.92	12.22	12.21	6.26
Carlsbad Caverns NP	New Mexico	15.32	15.09	15.08	6.65

Class 1 Area (20% worst days)	State	2011 Baseline Visibility	2040 Reference	2040 HDGHGP2 Control	Natural Background
Pecos Wilderness	New Mexico	9.93	9.84	9.83	6.08
San Pedro Parks Wilderness	New Mexico	10.02	10.02	10.01	5.72
Wheeler Peak Wilderness	New Mexico	9.93	9.84	9.83	6.08
White Mountain Wilderness	New Mexico	14.19	14.56	14.56	6.80
Linville Gorge Wilderness	North Carolina	21.60	15.94	15.91	11.22
Swanquarter	North Carolina	21.77	16.75	16.73	11.55
Theodore Roosevelt NP	North Dakota	16.96	15.96	15.95	7.80
Wichita Mountains	Oklahoma	21.24	18.83	18.76	7.53
Hells Canyon Wilderness	Oregon	16.58	15.10	14.94	8.32
Eagle Cap Wilderness	Oregon	14.87	14.20	14.17	8.92
Strawberry Mountain Wilderness	Oregon	14.87	14.20	14.17	8.92
Kalmiopsis Wilderness	Oregon	15.01	14.52	14.51	9.44
Mount Hood Wilderness	Oregon	13.35	12.72	12.71	8.43
Mount Jefferson Wilderness	Oregon	15.77	15.52	15.51	8.79
Mount Washington Wilderness	Oregon	15.77	15.52	15.51	8.79
Three Sisters Wilderness	Oregon	15.77	15.52	15.51	8.79
Crater Lake NP	Oregon	11.64	11.33	11.33	7.62
Diamond Peak Wilderness	Oregon	11.64	11.33	11.33	7.62
Gearhart Mountain Wilderness	Oregon	11.64	11.33	11.33	7.62
Mountain Lakes Wilderness	Oregon	11.64	11.33	11.33	7.62
Cape Romain	South Carolina	23.17	19.02	18.99	12.12
Wind Cave NP	South Dakota	14.04	12.85	12.82	7.71
Badlands NP	South Dakota	15.67	14.32	14.30	8.06
Great Smoky Mountains NP	Tennessee	22.50	16.99	16.95	11.24
Joyce-Kilmer-Slickrock Wilderness	Tennessee	22.50	16.99	16.95	11.24
Guadalupe Mountains NP	Texas	15.32	15.09	15.08	6.65
Big Bend NP	Texas	16.30	16.54	16.54	7.16
Arches NP	Utah	10.83	10.53	10.50	6.43
Canyonlands NP	Utah	10.83	10.53	10.50	6.43
Capitol Reef NP	Utah	10.18	9.69	9.66	6.03
Bryce Canyon NP	Utah	10.61	10.21	10.19	6.80
Lye Brook Wilderness	Vermont	19.26	14.94	14.92	11.73
James River Face Wilderness	Virginia	22.55	17.28	17.24	11.13
Shenandoah NP	Virginia	21.82	15.20	15.16	11.35
Alpine Lake Wilderness	Washington	16.14	14.86	14.80	8.43
Mount Rainier NP	Washington	15.50	14.43	14.41	8.54
Olympic NP	Washington	14.10	13.50	13.48	8.44
Pasayten Wilderness	Washington	12.44	11.83	11.81	8.25
Glacier Peak Wilderness	Washington	13.51	12.82	12.81	8.39
Goat Rocks Wilderness	Washington	12.37	11.77	11.76	8.35

Class 1 Area (20% worst days)	State	2011 Baseline Visibility	2040 Reference	2040 HDGHGP2 Control	Natural Background
North Cascades NP	Washington	13.51	12.82	12.81	8.01
Mount Adams Wilderness	Washington	12.37	11.77	11.76	8.35
Dolly Sods Wilderness	West Virginia	22.40	16.06	16.03	10.39
Otter Creek Wilderness	West Virginia	22.40	16.06	16.03	10.39
Bridger Wilderness	Wyoming	10.25	9.91	9.90	6.45
Fitzpatrick Wilderness	Wyoming	10.25	9.91	9.90	6.45
Grand Teton NP	Wyoming	11.98	11.73	11.72	6.44
Teton Wilderness	Wyoming	11.98	11.73	11.72	6.44
Yellowstone NP	Wyoming	11.98	11.73	11.72	6.44

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Appendix A

Model Performance Evaluation for the 2011-Based Air Quality Modeling Platform

A.1. Introduction

An operational model performance evaluation for ozone, $PM_{2.5}$ and its related speciated components, specific air toxics (i.e., formaldehyde, acetaldehyde, benzene, 1,3-butadiene, and acrolein), as well as nitrate and sulfate deposition was conducted using 2011 State/local monitoring sites data in order to estimate the ability of the CMAQ modeling system to replicate the base year concentrations for the 12 km Continental United States domain (Figure A-1) [1]. Included in this evaluation are statistical measures of model versus observed pairs that were paired in space and time on a daily or weekly basis, depending on the sampling frequency of each network (measured data). For certain time periods with missing ozone, $PM_{2.5}$, air toxic observations and nitrate and sulfate deposition we excluded the CMAQ predictions from those time periods in our calculations. It should be noted when pairing model and observed data that each CMAQ concentration represents a grid-cell volume-averaged value, while the ambient network measurements are made at specific locations.

Model performance statistics were calculated for several spatial scales and temporal periods (statistics are defined in Section A.1.2). Statistics were calculated for individual monitoring sites and for each of the nine National Oceanic and Atmospheric Administration (NOAA) climate regions of the 12-km U.S. modeling domain (Figure A-2)[2]. The regions include the Northeast, Ohio Valley, Upper Midwest, Southeast, South, Southwest, Northern Rockies, Northwest and West[3,4] as were originally identified in Karl and Koss (1984)[5]. The statistics for each site and climate region were calculated by season ("winter" is defined as average of December, January, and February; "spring" is defined as average of March, April, and May; "summer" is defined as average of June, July, and August; and "fall" is defined as average of September, October, and December). For 8-hour daily maximum ozone, we also calculated performance statistics by region for the May through September ozone season[6]. In addition to the performance statistics, we prepared several graphical presentations of model performance. These graphical presentations include regional maps which show the mean bias, mean error, normalized mean bias and normalized mean error calculated for each season at individual monitoring sites.

[1]See section 6A.1. of the RIA document (Figure 6A-1 for the description and map of the CMAQ modeling domain.
[2] NOAA, National Centers for Environmental Information scientists have identified nine climatically consistent regions within the contiguous U.S., http://www.ncdc.noaa.gov/monitoring-references/maps/us-climate-regions.php.
[3] The nine climate regions are defined by States where: Northeast includes CT, DE, ME, MA, MD, NH, NJ, NY, PA, RI, and VT; Ohio Valley includes IL, IN, KY, MO, OH, TN, and WV; Upper Midwest includes IA, MI, MN, and WI; Southeast includes AL, FL, GA, NC, SC, and VA; South includes AR, KS, LA, MS, OK, and TX; Southwest includes AZ, CO, NM, and UT; Northern Rockies includes MT, NE, ND, SD, WY; Northwest includes ID, OR, and WA; and West includes CA and NV.
[4] Note most monitoring sites in the West region are located in California (see Figure A-2), therefore statistics for the West will be mostly representative of California ozone air quality.
[5] Karl, T. R. and Koss, W. J., 1984: "Regional and National Monthly, Seasonal, and Annual Temperature Weighted by Area, 1895-1983." Historical Climatology Series 4-3, National Climatic Data Center, Asheville, NC, 38 pp.
[6] In calculating the ozone season statistics we limited the data to those observed and predicted pairs with observations that exceeded 60 ppb in order to focus on concentrations at the upper portion of the distribution of values.

Figure A-1. Map of the CMAQ 12 km Modeling Domain Used for HDGHG Phase 2 rule (noted by the purple box).

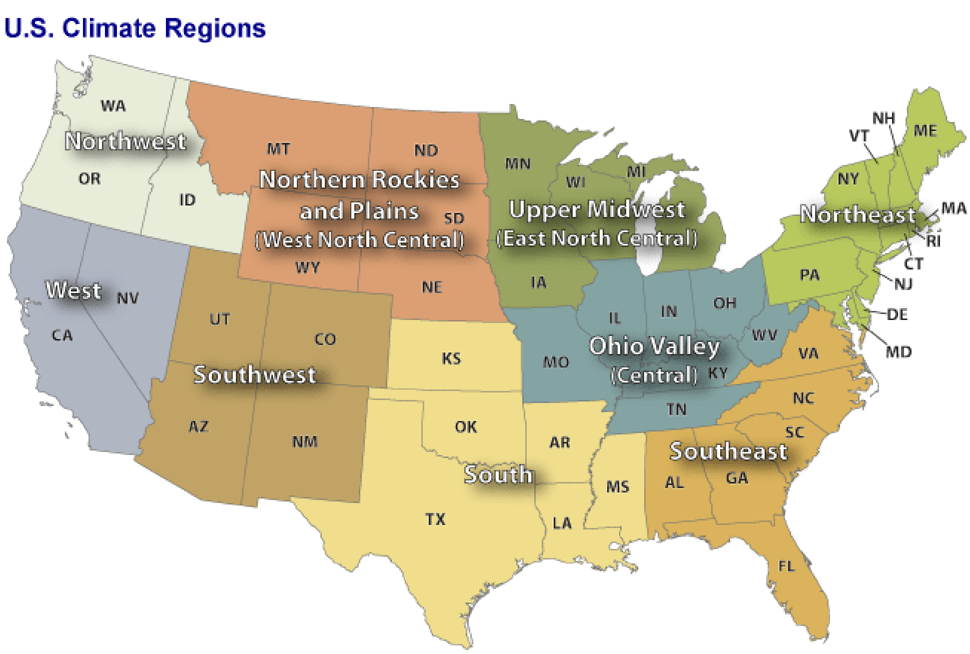

Figure A-2. NOAA Nine Climate Regions **(source: http://www.ncdc.noaa.gov/monitoring-references/maps/us-climate-regions.php#references)**

A.1.1 Monitoring Networks

The model evaluation for ozone was based upon comparisons of model predicted 8-hour daily maximum concentrations to the corresponding ambient measurements for 2011 at monitoring sites in the EPA Air Quality System (AQS) and the Clean Air Status and Trends Network (CASTNet). The observed ozone data were measured and reported on an hourly basis. The $PM_{2.5}$ evaluation focuses on concentrations of $PM_{2.5}$ total mass and its components including sulfate (SO_4), nitrate (NO_3), total nitrate (TNO_3), ammonium (NH_4), elemental carbon (EC), and organic carbon (OC) as well as wet deposition for nitrate and sulfate. The $PM_{2.5}$ performance statistics were calculated for each season (e.g., "winter" is defined as December, January, and February). $PM_{2.5}$ ambient measurements for 2011 were obtained from the following networks: Chemical Speciation Network (CSN), Interagency Monitoring of PROtected Visual Environments (IMPROVE), Clean Air Status and Trends Network (CASTNet), and National Acid Deposition Program/National Trends (NADP/NTN). NADP/NTN collects and reports wet deposition measurements as weekly average data. The pollutant species included in the evaluation for each monitoring network are listed in Table A-1. For $PM_{2.5}$ species that are measured by more than one network, we calculated separate sets of statistics for each network. The CSN and IMPROVE networks provide 24-hour average concentrations on a 1 in every 3 day, or 1 in every 6 day sampling cycle. The $PM_{2.5}$ species data at CASTNet sites are weekly integrated samples. In this analysis we use the term "urban sites" to refer to CSN sites; "suburban/rural sites" to refer to CASTNet sites; and "rural sites" to refer to IMPROVE sites.

Table A-1. $PM_{2.5}$ monitoring networks and pollutants species included in the CMAQ performance evaluation.

Ambient Monitoring Networks	Particulate Species							Wet Deposition Species	
	$PM_{2.5}$ Mass	SO_4	NO_3	TNO_3[a]	EC	OC	NH_4	SO_4	NO_3
IMPROVE	X	X	X		X	X			
CASTNet		X		X			X		
CSN	X	X	X		X	X	X		
NADP								X	X

[a] $TNO_3 = (NO_3 + HNO_3)$

The air toxics evaluation focuses on specific species relevant to the HDGHG Phase 2 standards and rulemaking, i.e., formaldehyde, acetaldehyde, benzene, 1,3-butadiene, and acrolein. Similar to the $PM_{2.5}$ evaluation, the air toxics performance statistics were calculated for each season to estimate the ability of the CMAQ modeling system to replicate the base year concentrations for the 12 km continental U.S. domain. Toxic measurements for 2011 were obtained from the air toxics archive, http://www.epa.gov/ttn/amtic/toxdat.html#data. While most of the data in the archive are from the AQS database including the National Air Toxics Trends Stations (NATTS) (downloaded in July 2014), additional data (e.g., special studies) are included in the archive but not reported in the AQS.

A.1.2 Model Performance Statistics

The Atmospheric Model Evaluation Tool (AMET) was used to conduct the evaluation described in this document.[7] There are various statistical metrics available and used by the science community for model performance evaluation. For this evaluation of the 2011 CMAQ modeling platform, 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)[8] and the draft photochemical modeling guidance[9].

Mean bias (MB) is used as average of the difference (predicted – observed) divided by the total number of replicates (*n*). Mean bias is given in units of ppb and is defined as:

MB = $\frac{1}{n}\sum_1^n(P-O)$, where P = predicted and O = observed concentrations.

Mean error (ME) calculates the absolute value of the difference (predicted – observed) divided by the total number of replicates (*n*). Mean error is given in units of ppb and is defined as:

ME = $\frac{1}{n}\sum_1^n|P-O|$

Normalized mean bias (NMB) is used as a normalization to facilitate a range of concentration magnitudes. This statistic averages the difference (predicted – observed) over the sum of observed values. NMB is a useful model performance indicator because it avoids over inflating the observed range of values, especially at low concentrations. Normalized mean bias is given in percentage units and is defined as:

$$\text{NMB} = \frac{\sum_1^n (P-O)}{\sum_1^n (O)} * 100$$

Normalized mean error (NME) is also similar to NMB, where the performance statistic is used as a normalization of the mean error. NME calculates the absolute value of the difference (predicted – observed) over the sum of observed values. Normalized mean error is given in percentage units and is defined as:

[7] Appel, K.W., Gilliam, R.C., Davis, N., Zubrow, A., and Howard, S.C.: Overview of the Atmospheric Model Evaluation Tool (AMET) v1.1 for evaluating meteorological and air quality models, *Environ. Modell. Softw.*,26, 4, 434-443, 2011. (http://www.cmascenter.org/)
[8] Simon, H., Baker, K., Phillips, S., 2012: Compilation and interpretation of photochemical model performance statistics published between 2006 and 2012. Atmospheric Environment 61, 124-139.
[9] U.S. Environmental Protection Agency (US EPA), Draft Modeling Guidance for Demonstrating Attainment of Air Quality Goals for Ozone, $PM_{2.5}$, and Regional Haze. December 2014, U.S. EPA, Research Triangle Park, NC, 27711.

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

The "acceptability" of model performance was judged by comparing our CMAQ 2011 performance results in light of the range of performance found in recent regional ozone model applications.[10,11,12,13,14,15,16,17,18,19,20] 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 CMAQ 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 that our applications of CMAQ using this 2011 modeling platform provide a scientifically credible approach for assessing ozone and $PM_{2.5}$ concentrations for the purposes of the HDGHG Phase 2 final rule.

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[10] National Research Council (NRC), 2002. Estimating the Public Health Benefits of Proposed Air Pollution Regulations, Washington, DC: National Academies Press.

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[13] Hogrefe, G., Civeroio, K.L., Hao, W., Ku, J-Y., Zalewsky, E.E., and Sistla, G., Rethinking the Assessment of Photochemical Modeling Systems in Air Quality Planning Applications. Air & Waste Management Assoc., 58:1086-1099, 2008.

[14] Phillips, S., K. Wang, C. Jang, N. Possiel, M. Strum, T. Fox, 2007. Evaluation of 2002 Multi-pollutant Platform: Air Toxics, Ozone, and Particulate Matter, 7th Annual CMAS Conference, Chapel Hill, NC, October 6-8, 2008. (http://www.cmascenter.org/conference/2008/agenda.cfm).

[15] Simon, H., Baker, K.R., and Phillips, S., 2012. Compilation and interpretation of photochemical model performance statistics published between 2006 and 2012. Atmospheric Environment 61, 124-139. http://dx.doi.org/10.1016/j.atmosenv.2012.07.012

[16] Strum, M., Wesson, K., Phillips, S., Pollack, A., Shepard, S., Jimenez, M., M., Beidler, A., Wilson, M., Ensley, D., Cook, R., Michaels H., and Brzezinski, D. Link Based vs NEI Onroad Emissions Impact on Air Quality Model Predictions. 17th Annual International Emission Inventory Conference, Portland, Oregon, June 2-5, 2008. (http://www.epa.gov/ttn/chief/conference/ei17/session11/strum_pres.pdf)

[17] Tesche, T.W., Morris, R., Tonnesen, G., McNally, D., Boylan, J., Brewer, P., 2006. CMAQ/CAMx annual 2002 performance evaluation over the eastern United States. Atmospheric Environment 40, 4906-4919.

[18] U.S. Environmental Protection Agency; Technical Support Document for the Final Clean Air Interstate Rule: Air Quality Modeling; Office of Air Quality Planning and Standards; RTP, NC; March 2005 (CAIR Docket OAR-2005-0053-2149).

[19] U.S. Environmental Protection Agency, Proposal to Designate an Emissions Control Area for Nitrogen Oxides, Sulfur Oxides, and Particulate Matter: Technical Support Document. EPA-420-R-007, 329pp., 2009. (http://www.epa.gov/otaq/regs/nonroad/marine/ci/420r09007.pdf)

[20] U.S. Environmental Protection Agency, 2010, Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis. EPA-420-R-10-006. February 2010. Sections 3.4.2.1.2 and 3.4.3.3. Docket EPA-HQ-OAR-2009-0472-11332. (http://www.epa.gov/oms/renewablefuels/420r10006.pdf)

A.2. Evaluation for 8-hour Daily Maximum Ozone

The 8-hour ozone model performance bias and error statistics for each climate region, for each season defined above and for each monitor network (AQS and CASTNet) are provided in Table A-2. Spatial plots of the mean bias and error as well as the normalized mean bias and error for individual monitors are shown in Figures A-1a through A-1h. The statistics shown in these two figures were calculated over the ozone season using data pairs on days with observed 8-hour ozone of $\geq$ 60 ppb.

As indicated by the statistics in Table A-2, bias and error for 8-hour daily maximum ozone are relatively low in each climate region. In general the winter shows under prediction except at AQS sites in the Southeast and West and also at rural CASTNet sites in the Northeast. Likewise, the model tends to under predict in the spring with the exception of slight over predictions at AQS sites in the Ohio Valley, South and Southeast in addition to CASTNet sites in the Southeast and Northwest. Model predictions for the summer season typically show slight over predictions apart from rural CASTNet sites in the Upper Midwest, Southwest, Northern Rockies, and West and at AQS sites in the Northwest and Southwest. Figures A-1a and A-1e show MB for 8-hour ozone $\geq$ 60 ppb during the ozone season in the range of ±10 ppb at the majority of ozone AQS and CASTNet measurement sites. At both AQS and CASTNet sites, NMB is within the range of ±20 percent (Figures A-1c and A-1g). Model error for 8-hour maximum ozone $\geq$ 60 ppb, as seen from Figure A-1b and A-1f, is 10 ppb or less at most of the sites across the modeling domain.

Table A-2. Daily Maximum 8-hour Ozone Performance Statistics by Climate Region, by Season, and by Monitoring Network for the 2011 CMAQ Model Simulation.

Climate Region	Monitor Network	Season	No. of Obs	MB (ppb)	ME (ppb)	NMB (%)	NME (%)
Northeast	AQS	Winter	8,109	-2.5	5.1	-8.3	16.7
		Spring	15,432	-0.2	5.3	-0.4	12.4
		Summer	17,223	1.4	7.1	3.0	14.8
		Fall	14,105	3.2	5.1	9.9	19.9
	CASTNet	Winter	1,188	-3.2	4.7	-9.3	13.8
		Spring	1,160	-1.2	5.0	-2.8	11.3
		Summer	1,217	0.7	6.0	1.6	13.1
		Fall	1,295	2.8	5.5	8.3	16.6
Ohio Valley	AQS	Winter	3,293	-1.4	5.0	-4.9	17.7
		Spring	15,995	0.1	5.8	0.2	13.0
		Summer	19,865	1.4	7.3	2.7	13.9
		Fall	13,574	1.5	6.2	4.1	16.6
	CASTNet	Winter	1,485	-1.1	4.8	-3.2	14.5
		Spring	1,461	-0.7	5.3	-1.5	11.4
		Summer	1,393	0.7	6.1	1.4	11.7
		Fall	1,501	1.2	5.4	3.1	13.8
Upper Midwest	AQS	Winter	1,048	-3.3	5.3	-10.7	17.0
		Spring	5,416	-0.3	4.9	-0.7	11.1
		Summer	8,149	1.4	6.4	3.2	14.5
		Fall	4,727	2.8	5.7	7.9	16.3
	CASTNet	Winter	442	-4.4	5.6	-12.6	15.9
		Spring	432	-3.0	5.4	-6.6	11.9

Climate Region	Monitor Network	Season	No. of Obs	MB (ppb)	ME (ppb)	NMB (%)	NME (%)
		Summer	403	-1.7	5.5	-3.8	12.8
		Fall	393	1.7	4.5	5.0	13.1
Southeast	AQS	Winter	6,117	0.5	5.0	1.3	13.6
		Spring	15,428	3.5	6.5	7.5	13.9
		Summer	17,342	6.6	9.8	13.9	20.5
		Fall	898	2.8	5.4	6.8	13.4
	CASTNet	Winter	851	-1.4	4.5	-3.8	11.8
		Spring	910	1.2	5.4	2.4	11.2
		Summer	892	5.1	8.0	10.6	16.6
		Fall	14,169	4.1	6.6	10.6	16.9
South	AQS	Winter	11,863	-0.2	5.4	-0.8	16.7
		Spring	13,954	2.7	6.5	6.0	14.4
		Summer	14,054	7.4	11.7	15.3	24.2
		Fall	13,407	1.6	6.4	3.5	14.1
	CASTNet	Winter	566	-1.1	4.8	-3.0	13.1
		Spring	549	-0.1	5.9	-0.3	12.3
		Summer	547	1.1	6.9	2.0	13.1
		Fall	551	-0.3	5.0	-0.5	10.9
Southwest	AQS	Winter	9,010	-1.0	6.30	-2.7	15.8
		Spring	10,867	-2.7	5.6	-5.0	10.4
		Summer	11,989	-1.6	7.3	-2.8	12.7
		Fall	10,711	2.9	5.8	6.6	13.1
	CASTNet	Winter	640	-3.2	4.9	-7.1	10.7
		Spring	687	-4.8	6.2	-8.5	10.9
		Summer	702	-3.0	6.8	-5.2	11.7
		Fall	688	0.1	3.8	0.2	7.8
Northern Rockies	AQS	Winter	3,293	-6.2	7.5	-16.0	19.3
		Spring	3,673	-2.0	6.3	-4.2	13.1
		Summer	4,148	2.4	6.0	5.1	12.7
		Fall	4,062	3.1	4.7	8.2	12.4
	CASTNet	Winter	423	-5.8	6.8	-13.9	16.2
		Spring	403	-4.6	6.8	-8.9	13.1
		Summer	421	-1.3	4.9	-2.6	9.5
		Fall	386	1.9	4.3	4.4	10.3
Northwest	AQS	Winter	654	-0.3	6.7	-0.9	23
		Spring	1,522	-1.3	5.7	-3.2	13.5
		Summer	2,784	-0.1	5.5	-0.3	15.1
		Fall	1,266	3.0	6.7	8.5	19.1
	CASTNet	Winter	87	10.6	11.1	44.4	46.7
		Spring	92	2.4	4.0	6.0	10.2
		Summer	84	5.4	6.3	18.3	21.1
		Fall	78	13.1	13.6	51.4	53.1
West	AQS	Winter	15,225	3.6	6.4	11.3	19.9
		Spring	16,907	-1.7	6.0	-3.7	12.6
		Summer	18,073	1.1	8.2	2.1	16.0
		Fall	17,064	2.8	7.5	6.6	17.4
	CASTNet	Winter	551	-0.8	5.1	-1.9	11.7
		Spring	535	-5.2	6.9	-9.7	12.9
		Summer	539	-6.7	8.9	-10.8	14.3
		Fall	532	-1.7	6.6	-3.5	13.1

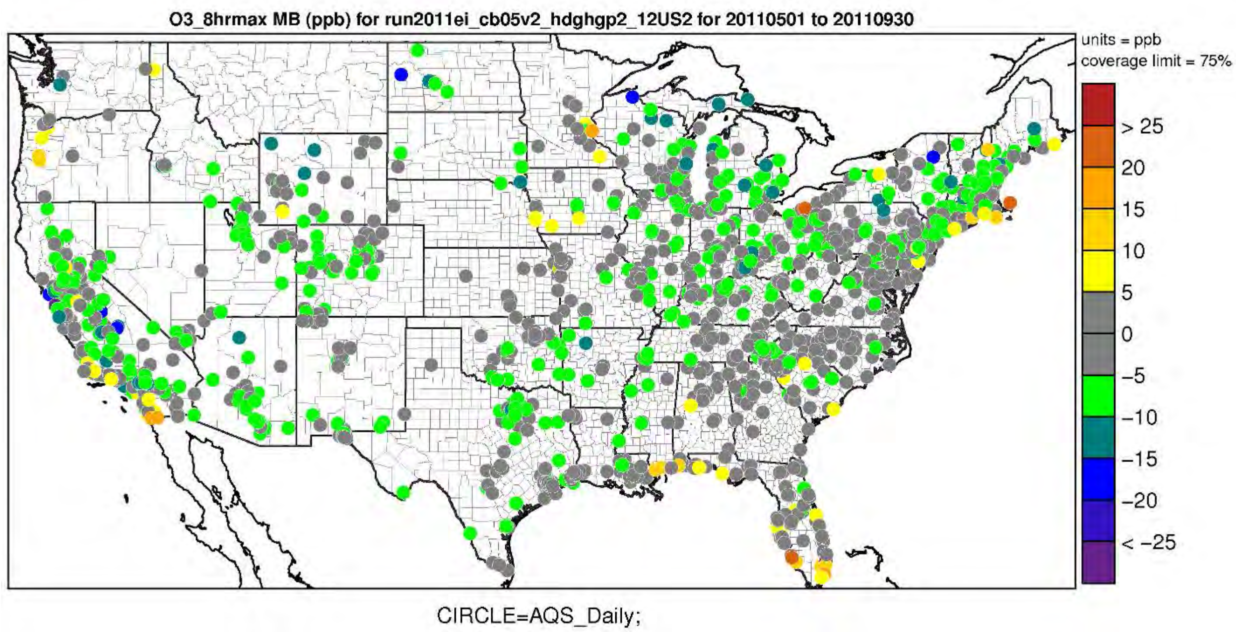

Figure A-1a. Mean Bias (ppb) of 8-hour daily maximum ozone greater than 60 ppb over the period May-September 2011 at AQS monitoring sites in the modeling domain.

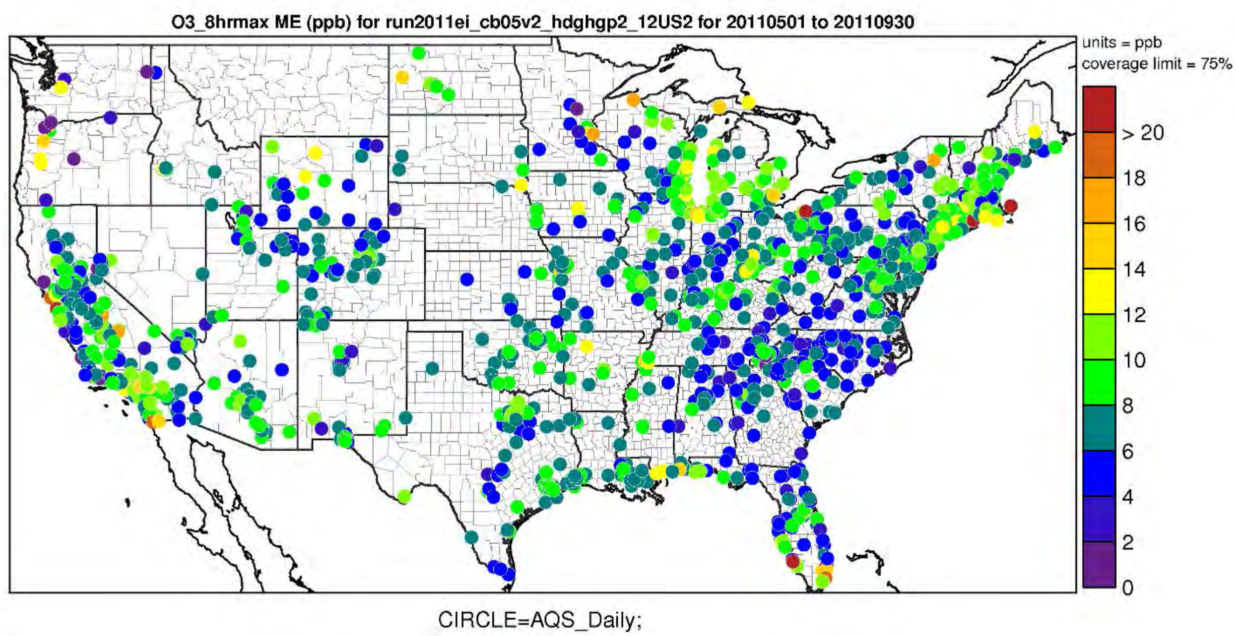

Figure A-1b. Mean Error (ppb) of 8-hour daily maximum ozone greater than 60 ppb over the period May-September 2011 at AQS monitoring sites in the modeling domain.

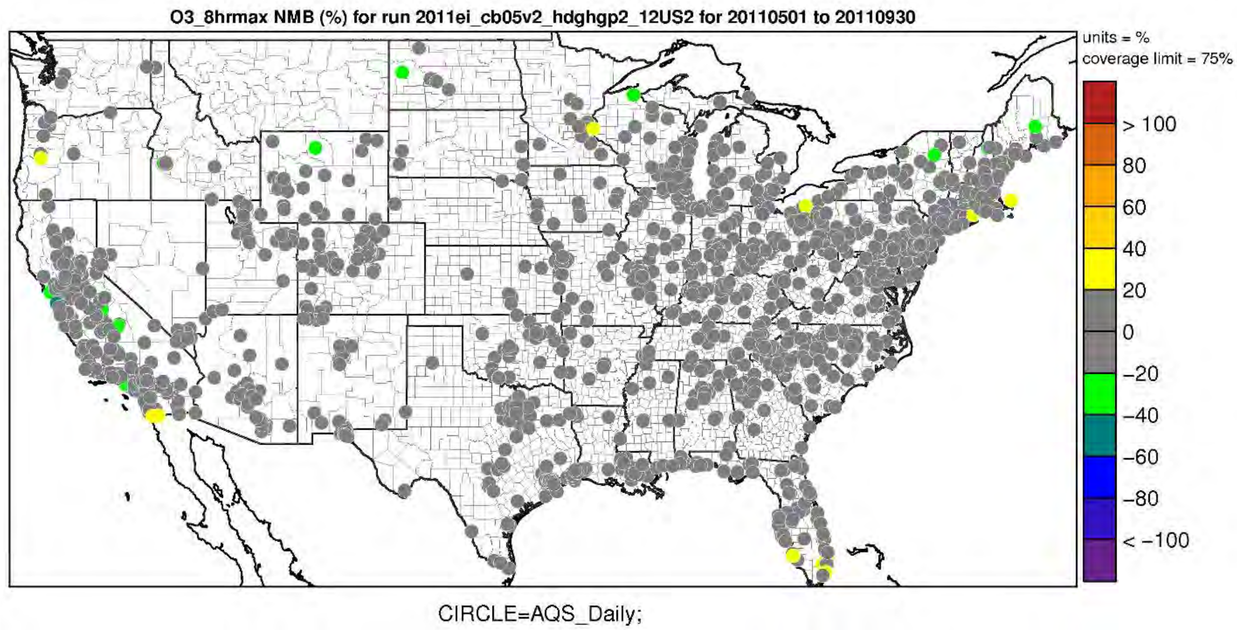

Figure A-1c. Normalized Mean Bias (%) of 8-hour daily maximum ozone greater than 60 ppb over the period May-September AQS 2011 at monitoring sites in the modeling domain.

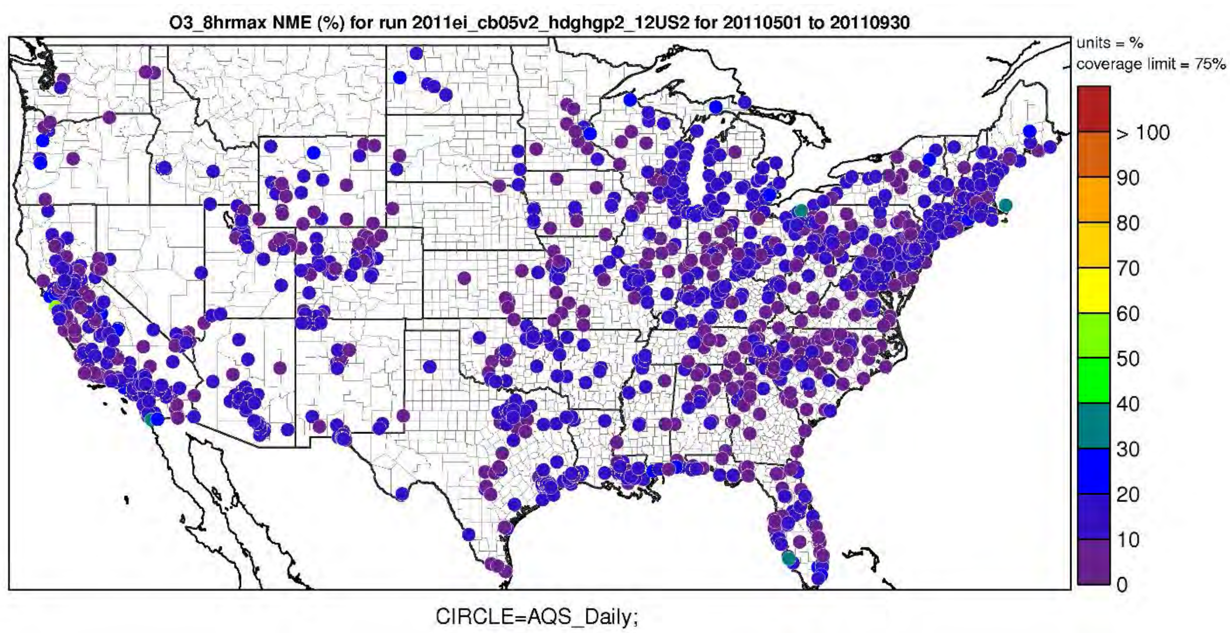

Figure A-1d. Normalized Mean Error (%) of 8-hour daily maximum ozone greater than 60 ppb over the period May-September AQS 2011 at monitoring sites in the modeling domain.

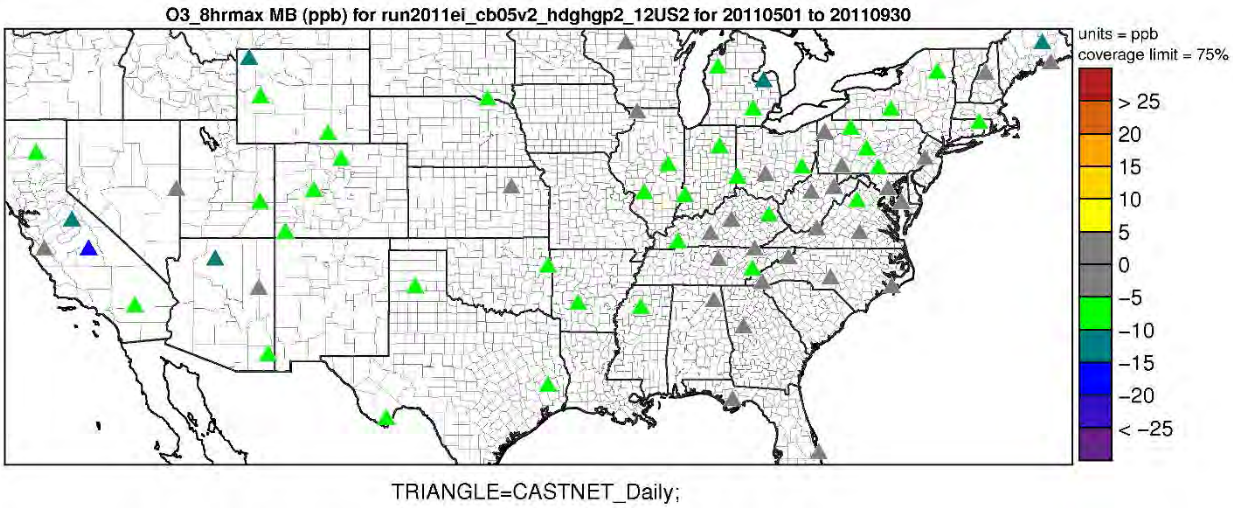

Figure A-1e. Mean Bias (ppb) of 8-hour daily maximum ozone greater than 60 ppb over the period May-September 2011 at CASTNet monitoring sites in the modeling domain.

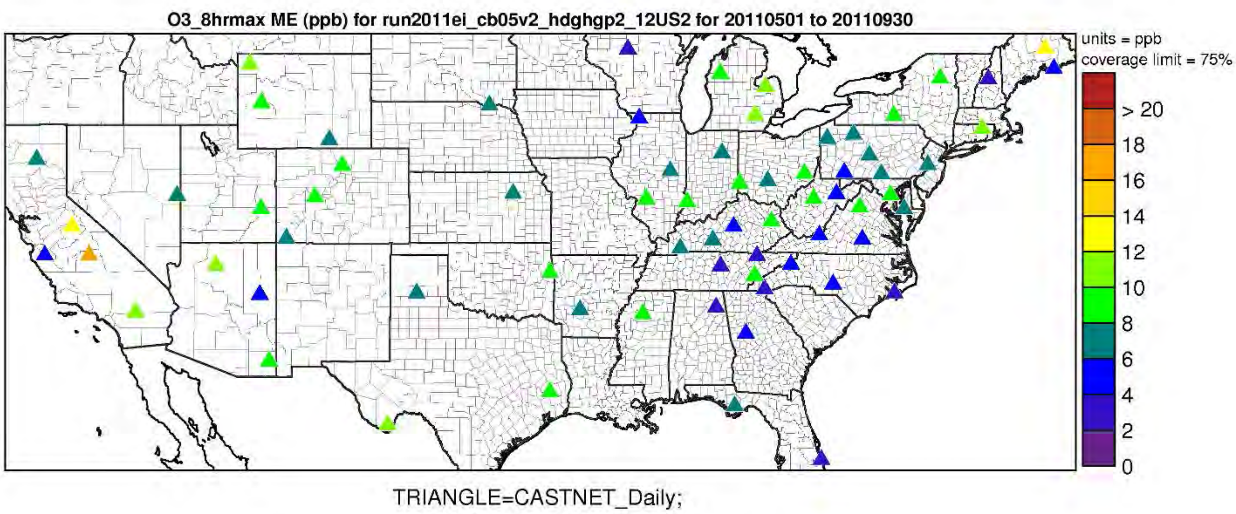

Figure A-1f. Mean Error (ppb) of 8-hour daily maximum ozone greater than 60 ppb over the period May-September 2011 at CASTNet monitoring sites in the modeling domain.

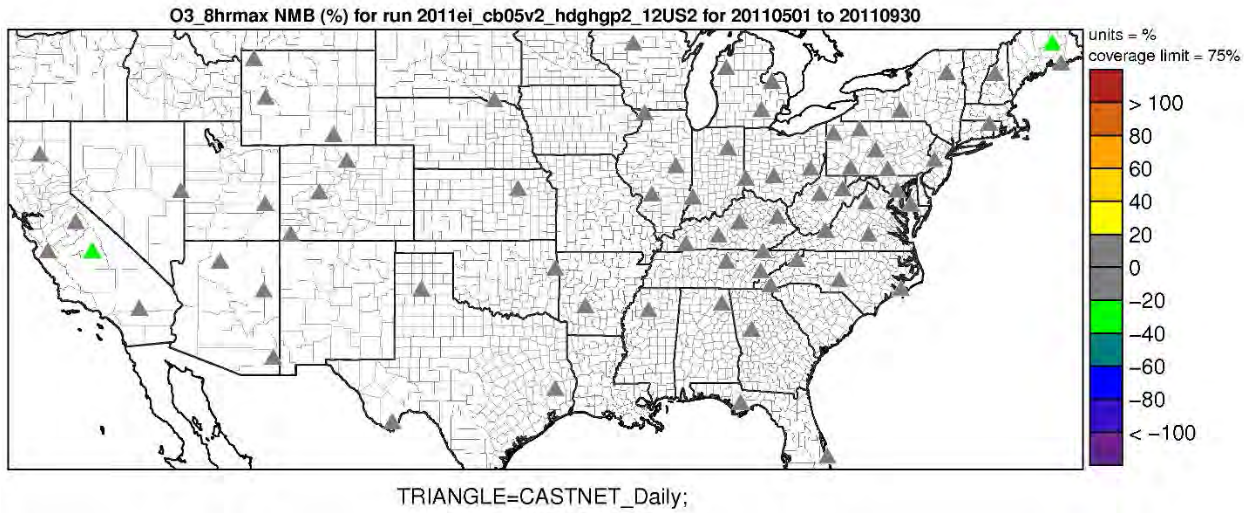

Figure A-1g. Normalized Mean Bias (%) of 8-hour daily maximum ozone greater than 60 ppb over the period May-September CASTNet 2011 at monitoring sites in the modeling domain.

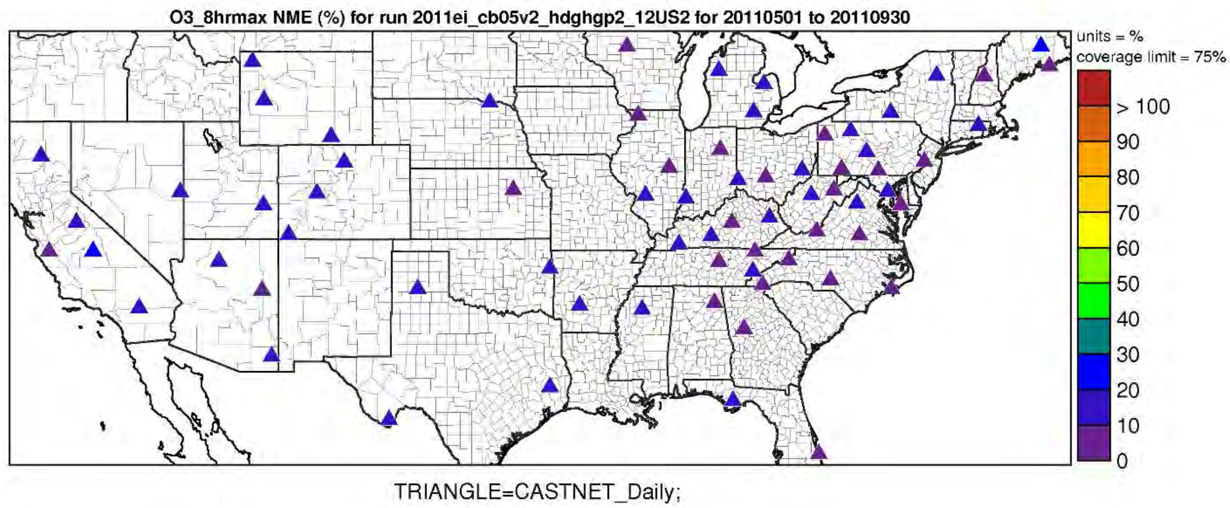

Figure A-1h. Normalized Mean Error (%) of 8-hour daily maximum ozone greater than 60 ppb over the period May-September CASTNet 2011 at monitoring sites in the modeling domain.

A.3. Seasonal Evaluation of $PM_{2.5}$ Component Species

The evaluation of 2011 model predictions for $PM_{2.5}$ covers the performance for the individual $PM_{2.5}$ component species (i.e., sulfate, nitrate, organic carbon, elemental carbon, and ammonium). Performance results are provided for each $PM_{2.5}$ species. As indicated above, for each species we present tabular summaries of bias and error statistics by climate region for each season. These statistics are based on the set of observed-predicted pairs of data for the particular quarter at monitoring sites within the nine NOAA climate regions. Separate statistics are provided for each monitoring network, as applicable for the particular species measured. For sulfate and nitrate we also provide a more refined temporal and spatial analysis of model performance that includes spatial maps which show the mean bias and error and the normalized mean bias and error by site, aggregated by season.

A.3.1. Seasonal Evaluation for Sulfate

The model performance bias and error statistics for sulfate for each climate region and each season by monitor network are provided in Table A-3. Spatial plots of the normalized mean bias and error by season for individual monitors are shown in Figures A-3 through A-6. As seen in Table A-3, CMAQ generally under predicts sulfate in the NOAA climate regions throughout the entire year except for the following: (1) at Southeast IMPROVE sites during the spring season, (2) at Northeast, Northern Rockies and Upper Midwest IMPROVE sites, as well as Northeast, Northern Rockies, and South CSN sites during the fall season, (3) at Southwest and West IMPROVE and CASTNet ozone sites in addition to CSN in the West, and (4) at Northwest IMPROVE, CASTNet and CSN during all seasons except for the summer at CASTNet sites.

Table A-3. Sulfate Performance Statistics by Climate Region, by Season, and by Monitoring Network for the 2011 CMAQ Model Simulation.

Climate Region	Monitor Network	Season	No. of Obs	MB (ug/m^3)	ME (ug/m^3)	NMB (%)	NME (%)
Northeast	IMPROVE	Winter	425	-0.2	0.3	-12.4	26.2
		Spring	475	0.2	0.5	18.2	40.6
		Summer	422	-0.2	0.7	-9.7	41.7
		Fall	418	0.1	0.4	5.9	34.7
	CSN	Winter	679	-0.4	0.7	-19.0	35.2
		Spring	717	-0.2	0.5	-8.1	29.7
		Summer	721	-0.4	0.9	-13.6	28.8
		Fall	685	0.1	0.6	5.3	33.1
	CASTNet	Winter	170	-0.6	0.6	-32.6	33.2
		Spring	193	-0.3	0.4	-13.9	23.8
		Summer	187	-0.7	0.7	-23.1	26.2
		Fall	196	-0.2	0.3	-9.7	18.9
Ohio Valley	IMPROVE	Winter	207	-0.5	0.7	-27.6	37.0
		Spring	235	-0.4	0.7	-19.1	31.5
		Summer	211	-0.9	1.2	-24.5	33.3
		Fall	226	-0.1	0.6	-7.3	34.1
	CSN	Winter	588	-0.7	0.9	-31.5	39.0
		Spring	624	-0.5	0.8	-18.8	31.0
		Summer	645	-0.7	1.2	17.0	30.3
		Fall	611	-0.2	0.6	-12.1	31.6

Climate Region	Monitor Network	Season	No. of Obs	MB (ug/m^3)	ME (ug/m^3)	NMB (%)	NME (%)
	CASTNet	Winter	201	-0.9	1.0	-39.7	40.3
		Spring	214	-0.7	0.7	-26.5	27.7
		Summer	207	-1.2	1.3	-28.6	30.2
		Fall	214	-0.4	0.5	-20.0	23.5
Upper Midwest	IMPROVE	Winter	210	-0.3	0.4	-23.5	37.2
		Spring	205	0.0	0.4	-1.3	27.2
		Summer	221	-0.2	0.5	-16.9	33.8
		Fall	223	0.0	0.4	1.9	36.7
	CSN	Winter	334	-0.4	0.6	-24.6	38.4
		Spring	337	0.0	0.6	-0.1	30.5
		Summer	335	-0.4	0.8	-17.6	33.1
		Fall	340	0.0	0.5	-1.2	31.3
	CASTNet	Winter	56	-0.5	0.5	-33.4	33.8
		Spring	62	-0.2	0.3	-12.5	18.3
		Summer	65	-0.5	0.5	-24.7	25.7
		Fall	62	-0.2	0.3	-12.4	19.0
Southeast	IMPROVE	Winter	329	-0.2	0.6	-11.0	34.7
		Spring	346	-0.4	0.7	-16.3	31.0
		Summer	331	-0.7	0.9	-22.4	31.0
		Fall	319	-0.1	0.5	-4.9	30.2
	CSN	Winter	435	-0.2	0.6	-8.9	35.6
		Spring	454	-0.4	0.8	-16.4	32.6
		Summer	471	-0.6	1.0	-17.5	29.0
		Fall	442	0.0	0.5	-0.3	29.7
	CASTNet	Winter	138	-0.6	0.6	-30.0	30.3
		Spring	146	-0.8	0.9	-31.0	32.1
		Summer	147	-1.2	1.2	-34.2	34.6
		Fall	150	-0.4	0.5	-23.4	26.6
South	IMPROVE	Winter	247	-0.2	0.5	-18.7	39.7
		Spring	269	-0.5	0.7	-28.0	37.1
		Summer	279	-0.7	0.8	-33.4	36.8
		Fall	252	-0.1	0.3	-8.7	27.3
	CSN	Winter	222	-0.2	0.7	-10.1	38.1
		Spring	248	-0.6	0.8	-23.9	33.0
		Summer	253	-0.7	0.8	-26.4	33.7
		Fall	238	0.0	0.5	1.9	30.1
	CASTNet	Winter	70	-0.6	0.6	-35.7	36.5
		Spring	85	-1.0	1.0	-39.9	40.0
		Summer	88	-1.0	1.0	-40.6	42.0
		Fall	76	-0.4	0.5	-22.3	27.2
Southwest	IMPROVE	Winter	904	0.1	0.2	39.5	60.6
		Spring	920	-0.1	0.3	-14.8	42.7
		Summer	922	-0.4	0.4	-43.1	44.9
		Fall	916	-0.1	0.2	-21.3	34.9
	CSN	Winter	185	0.0	0.3	-4.0	48.0
		Spring	190	0.0	0.3	-3.5	37.5
		Summer	192	-0.4	0.4	-39.8	43.9
		Fall	186	-0.1	0.2	-14.8	32.6
	CASTNet	Winter	94	0.1	0.1	23.0	33.4
		Spring	102	-0.1	0.2	-18.3	31.9
		Summer	102	-0.4	0.5	-39.0	45.9

Climate Region	Monitor Network	Season	No. of Obs	MB (ug/m^3)	ME (ug/m^3)	NMB (%)	NME (%)
		Fall	101	-0.2	0.2	-27.5	32.0
Northern Rockies	IMPROVE	Winter	522	0.0	0.2	-5.4	49.1
		Spring	590	0.0	0.3	-5.5	38.5
		Summer	580	-0.1	0.2	-14.8	31.8
		Fall	551	0.1	0.2	22.5	40.1
	CSN	Winter	66	-0.2	0.3	-24.0	31.9
		Spring	70	-0.3	0.4	-17.2	29.7
		Summer	72	-0.2	0.4	-12.0	29.3
		Fall	69	0.0	0.2	4.8	28.1
	CASTNet	Winter	77	-0.1	0.2	-17.2	32.9
		Spring	76	-0.2	0.2	-20.8	26.6
		Summer	88	-0.3	0.3	33.1	33.9
		Fall	89	-0.1	0.1	-9.1	20.6
Northwest	IMPROVE	Winter	422	0.2	0.2	65.0	90.
		Spring	500	0.2	0.2	45.2	58.3
		Summer	438	0.0	0.3	6.9	39.3
		Fall	450	0.2	0.3	41.5	62.4
	CSN	Winter	166	0.3	0.5	44.4	70.3
		Spring	167	0.3	0.4	54.6	63.0
		Summer	172	0.2	0.4	15.9	39.9
		Fall	164	0.4	0.5	48.4	65.6
	CASTNet	Winter	12	0.1	0.1	48.6	54.2
		Spring	13	0.1	0.2	26.0	32.4
		Summer	13	-0.1	0.2	-14.1	21.6
		Fall	13	0.1	0.1	17.1	30.0
West	IMPROVE	Winter	471	0.1	0.2	51.1	82.7
		Spring	513	0.0	0.3	-1.4	47.3
		Summer	526	-0.4	0.5	-46.5	53.7
		Fall	525	-0.1	0.3	-20.6	44.3
	CSN	Winter	226	0.0	0.4	4.6	55.8
		Spring	242	-0.1	0.4	-9.9	39.2
		Summer	246	-0.9	0.9	-49.5	52.3
		Fall	229	-0.5	0.7	-36.1	46.8
	CASTNet	Winter	69	0.0	0.2	5.1	40.8
		Spring	73	-0.2	0.3	-24.9	37.9
		Summer	77	-0.6	0.6	-57.4	57.8
		Fall	77	-0.3	0.4	-40.7	46.8

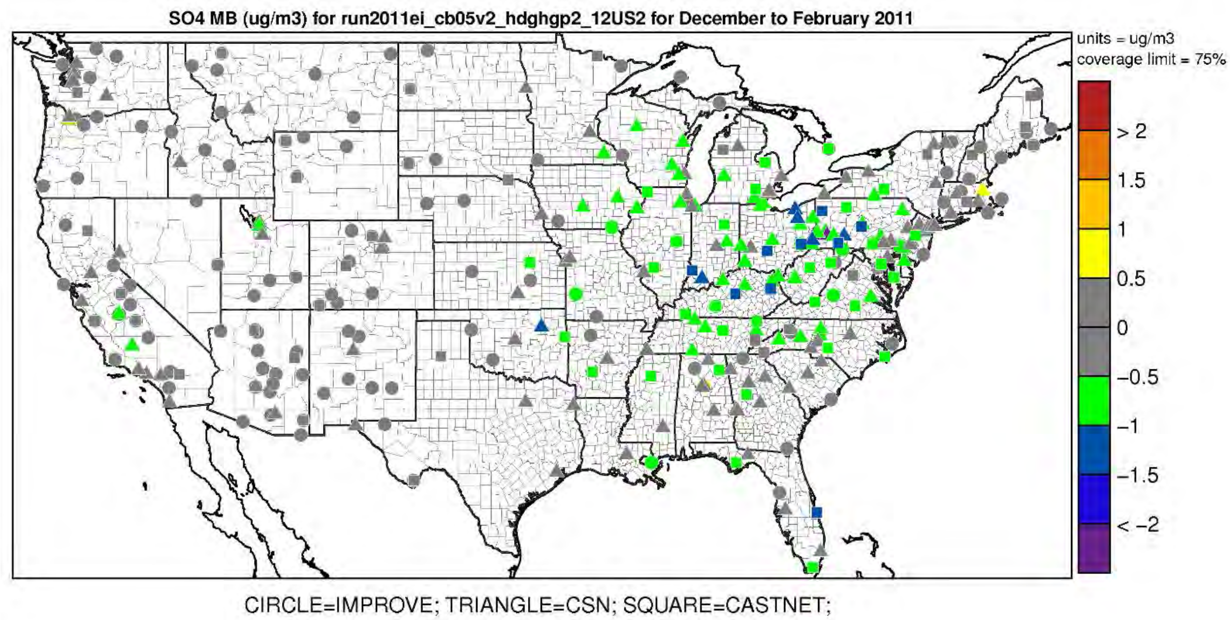

Figure A-3a. Mean Bias (ug/m³) of sulfate during winter 2011 at monitoring sites in the modeling domain.

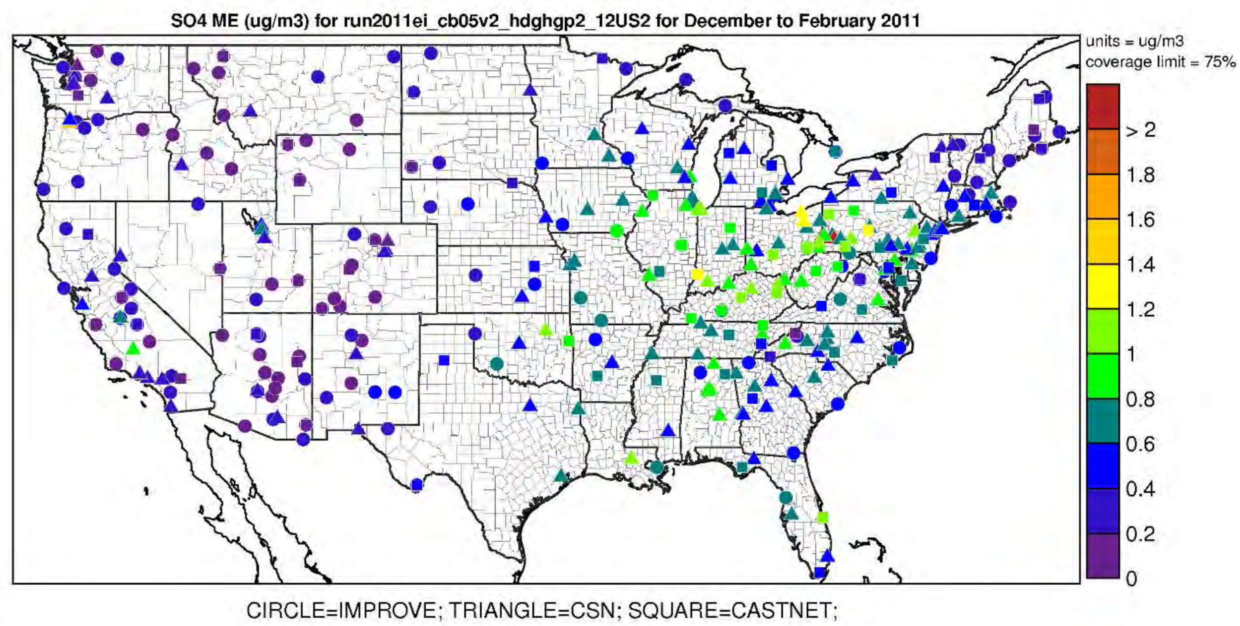

Figure A-3b. Mean Error (ug/m³) of sulfate during winter 2011 at monitoring sites in the modeling domain.

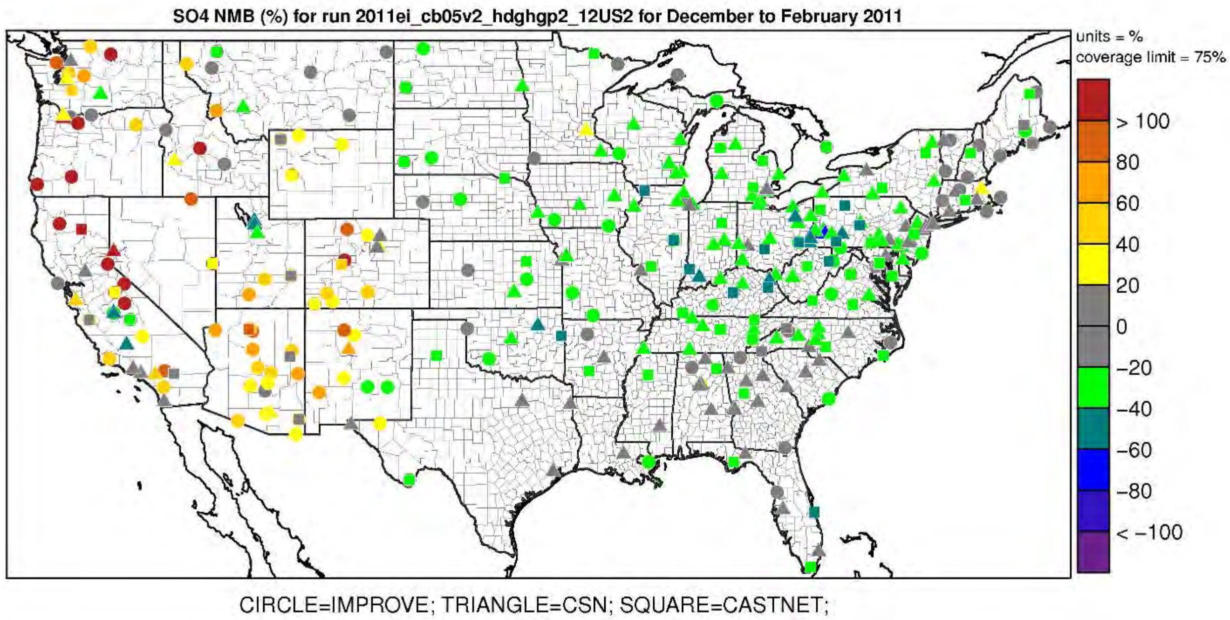

Figure A-3c. Normalized Mean Bias (%) of sulfate during winter 2011 at monitoring sites in the modeling domain.

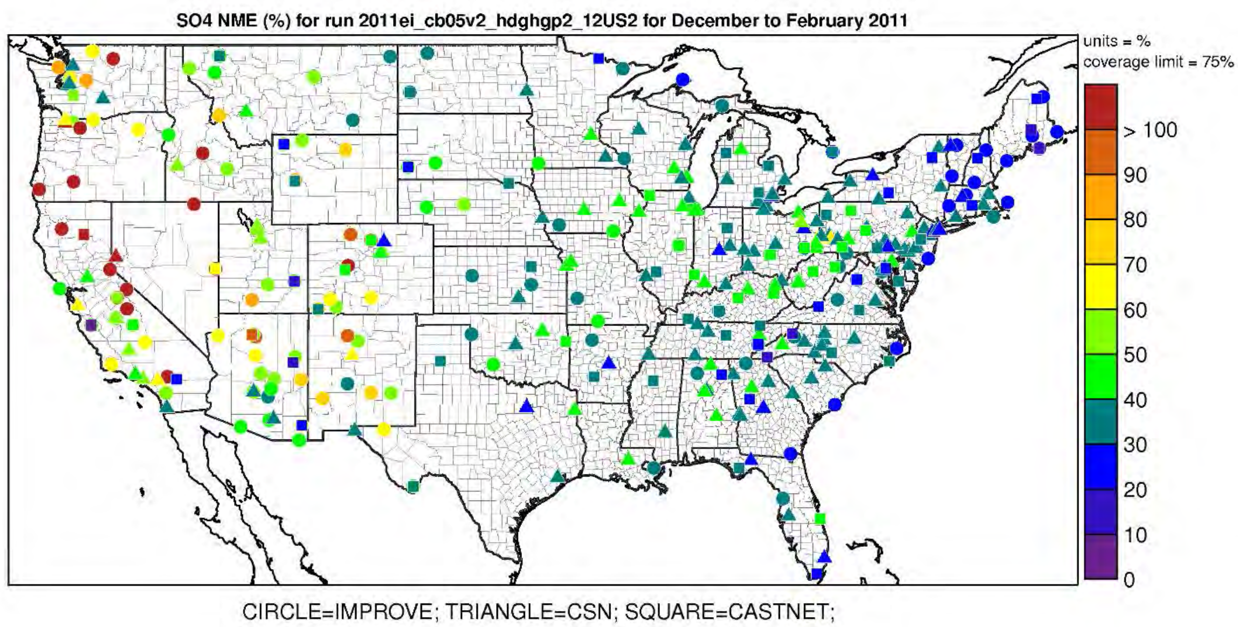

Figure A-3d. Normalized Mean Error (%) of sulfate during winter 2011 at monitoring sites in the modeling domain.

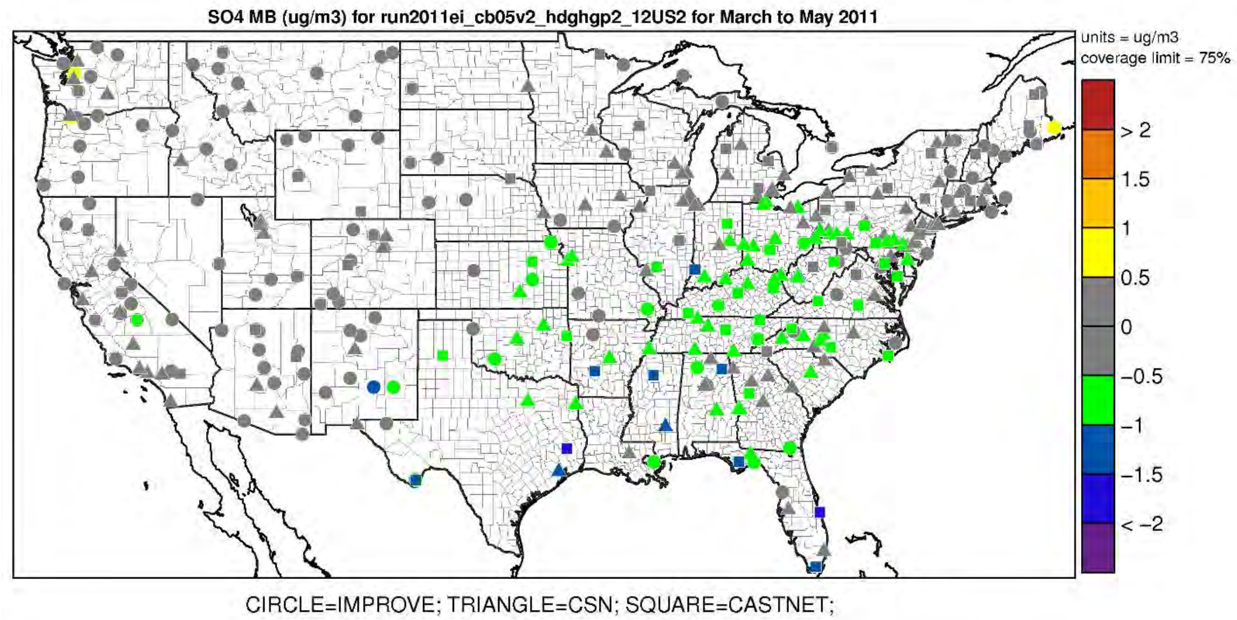

Figure A-4a. Mean Bias (ug/m³) of sulfate during spring 2011 at monitoring sites in the modeling domain.

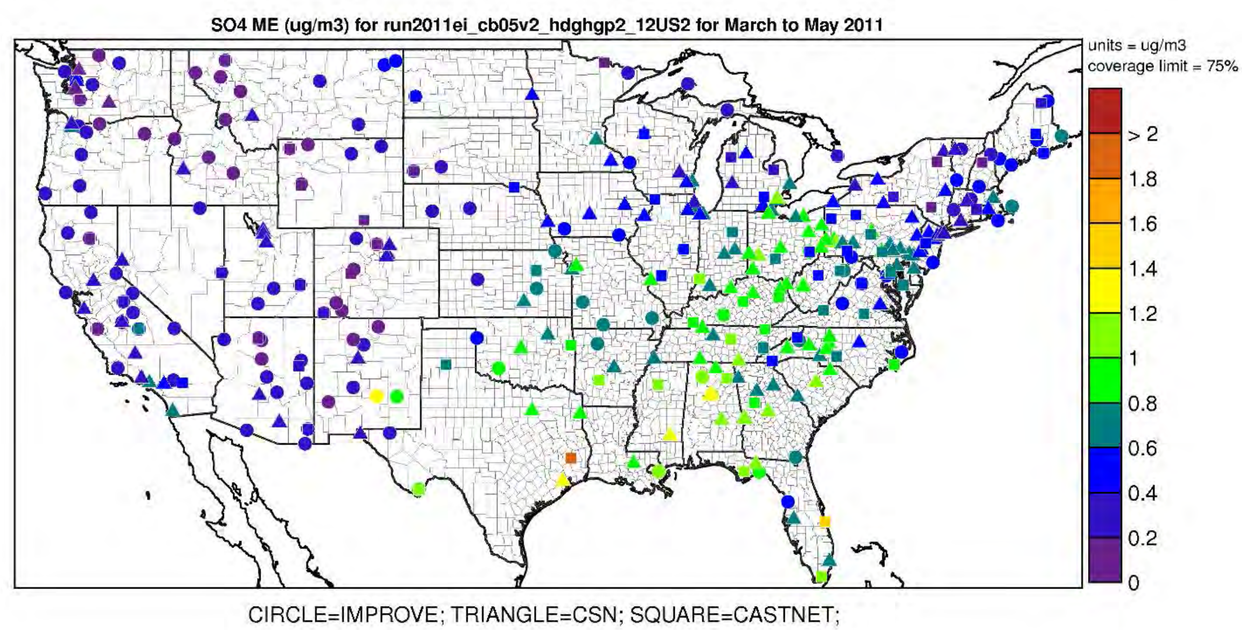

Figure A-4b. Mean Error (ug/m³) of sulfate during spring 2011 at monitoring sites in the modeling domain.

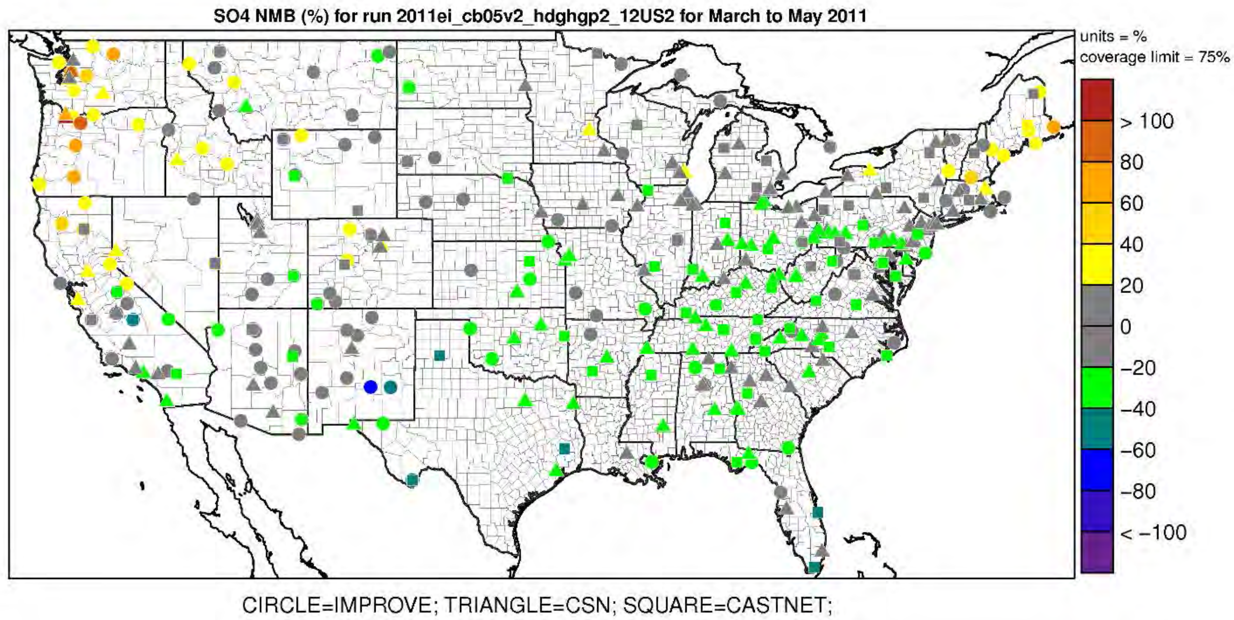

Figure A-4c. Normalized Mean Bias (%) of sulfate during spring 2011 at monitoring sites in the modeling domain.

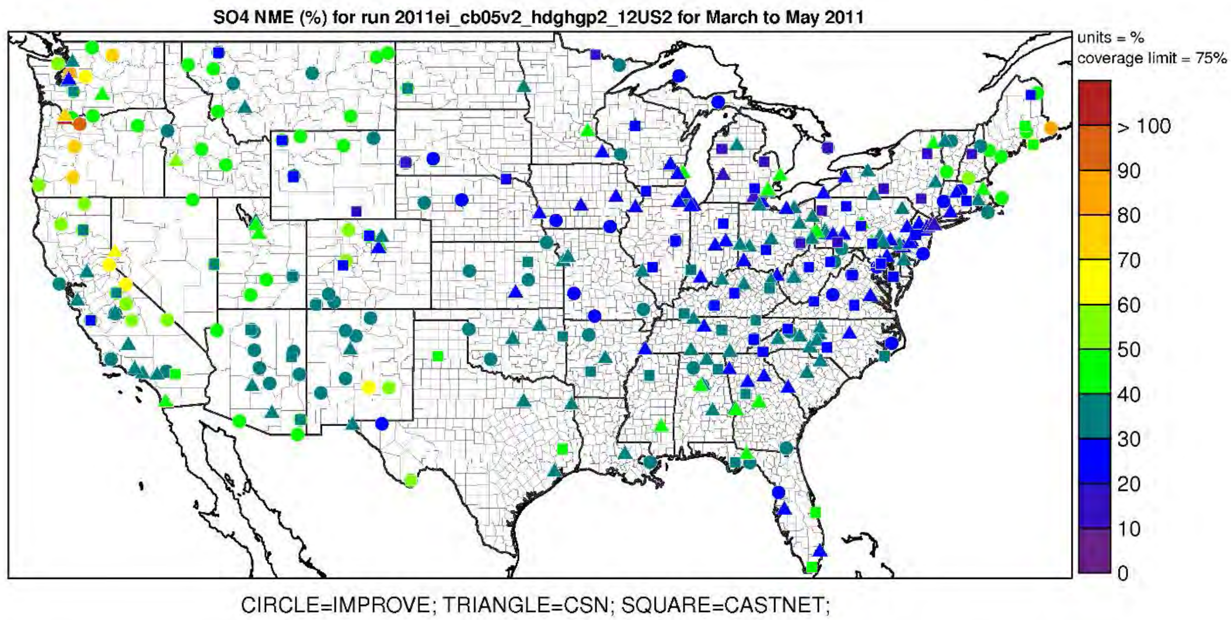

Figure A-4d. Normalized Mean Error (%) of sulfate during spring 2011 at monitoring sites in the modeling domain.

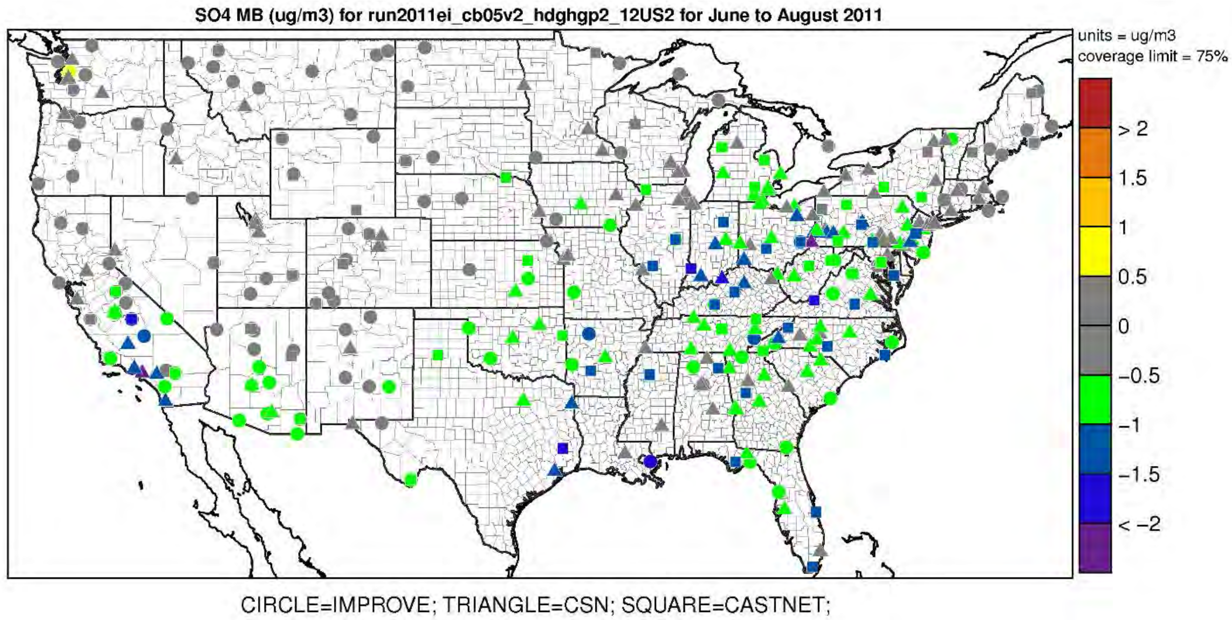

Figure A-5a. Mean Bias (ug/m³) of sulfate during summer 2011 at monitoring sites in the modeling domain.

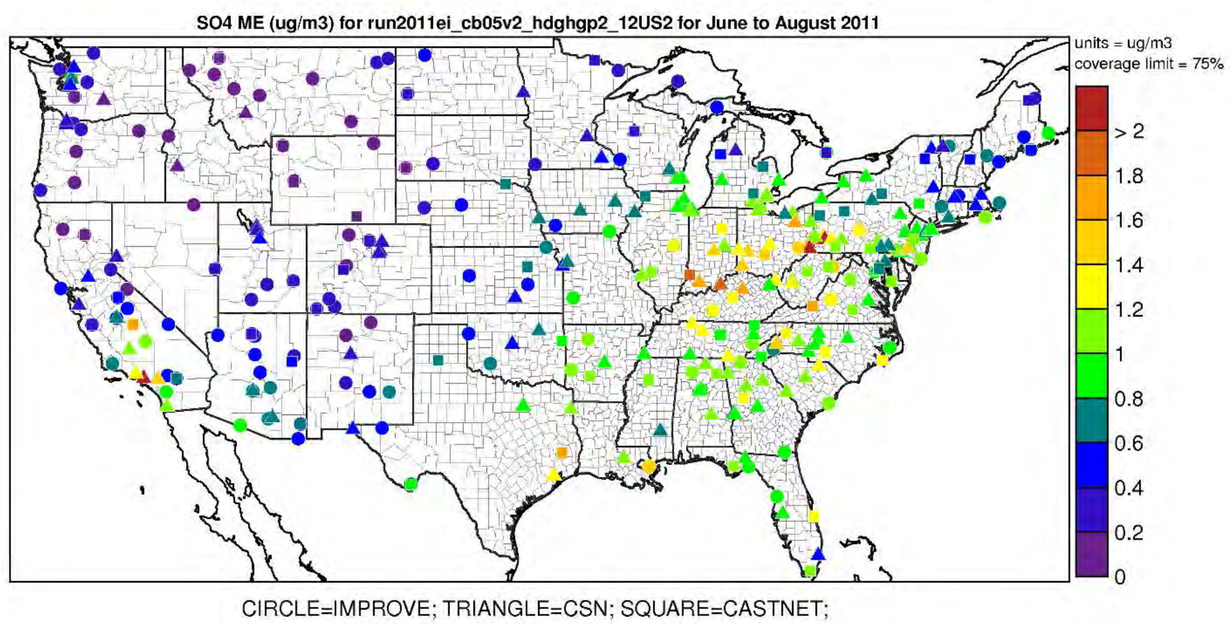

Figure A-5b. Mean Error (ug/m³) of sulfate during summer 2011 at monitoring sites in the modeling domain.

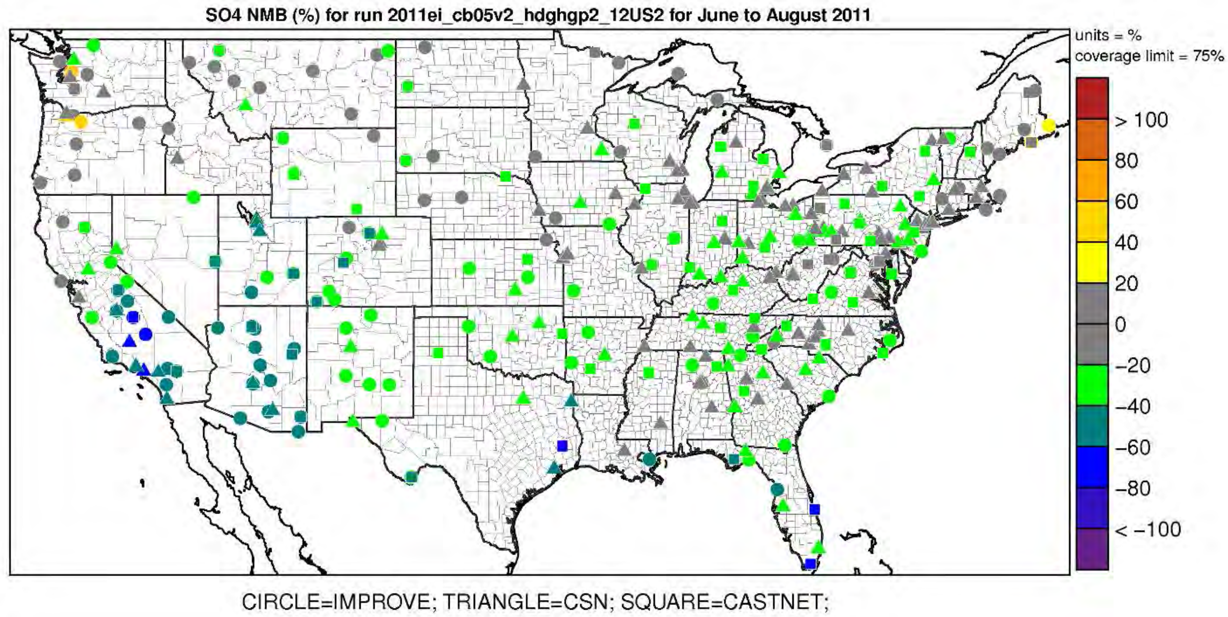

Figure A-5c. Normalized Mean Bias (%) of sulfate during summer 2011 at monitoring sites in the modeling domain.

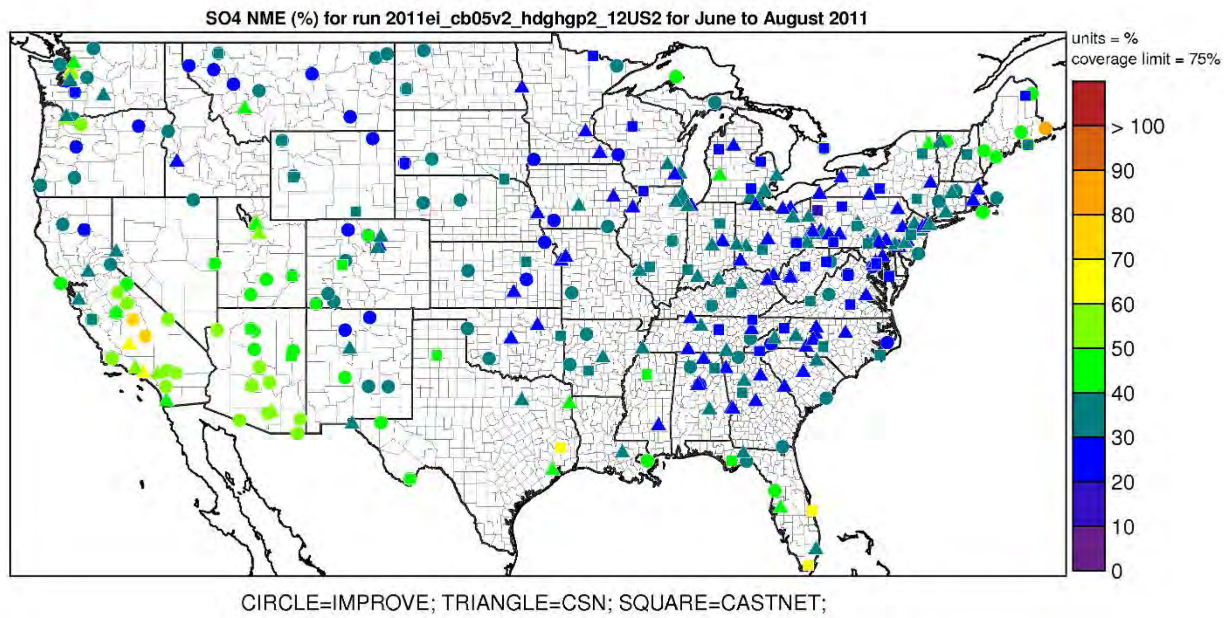

Figure A-5d. Normalized Mean Error (%) of sulfate during summer 2011 at monitoring sites in the modeling domain.

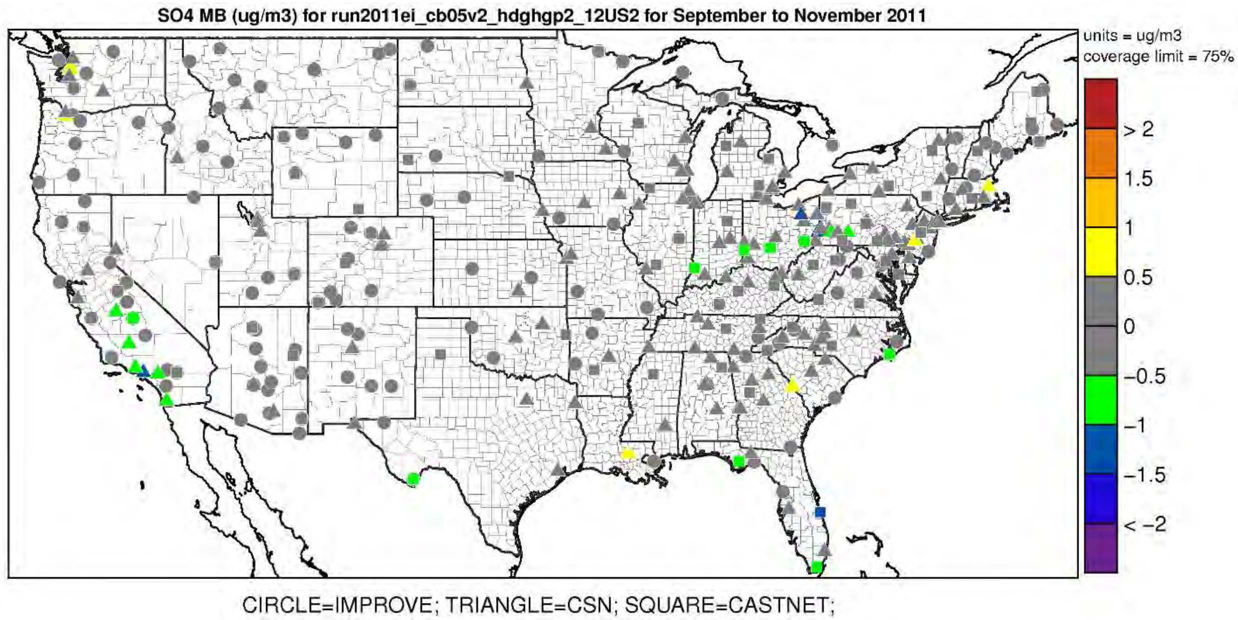

Figure A-6a. Mean Bias (ug/m³) of sulfate during fall 2011 at monitoring sites in the modeling domain.

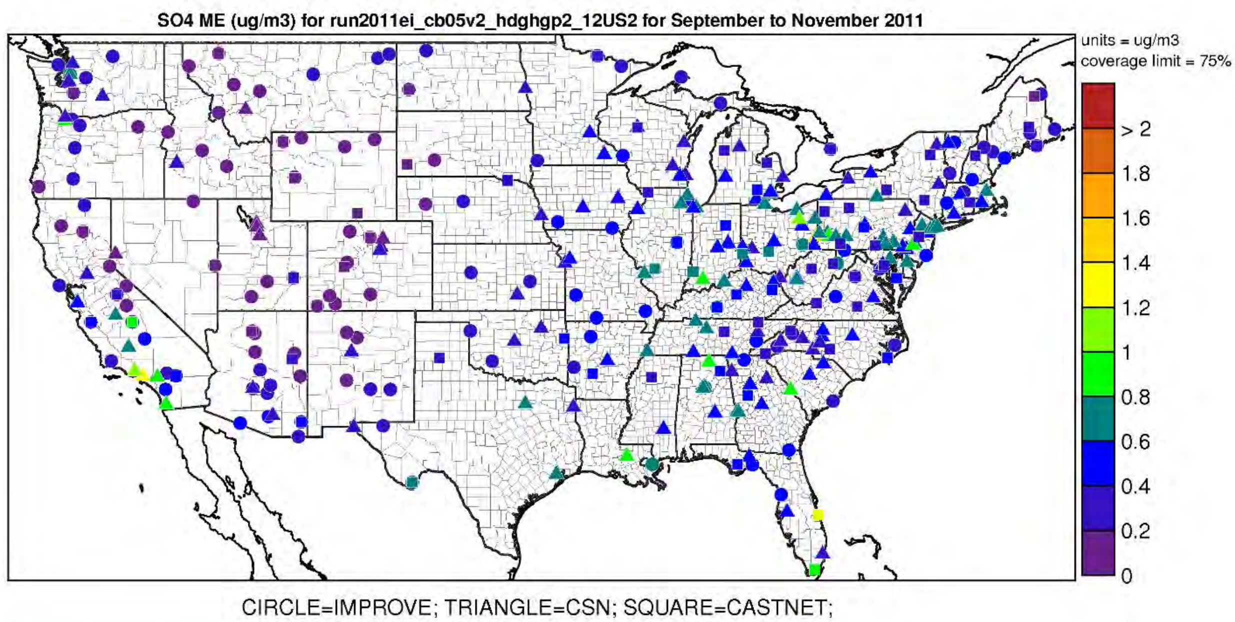

Figure A-6b. Mean Error (ug/m³) of sulfate during fall 2011 at monitoring sites in the modeling domain.

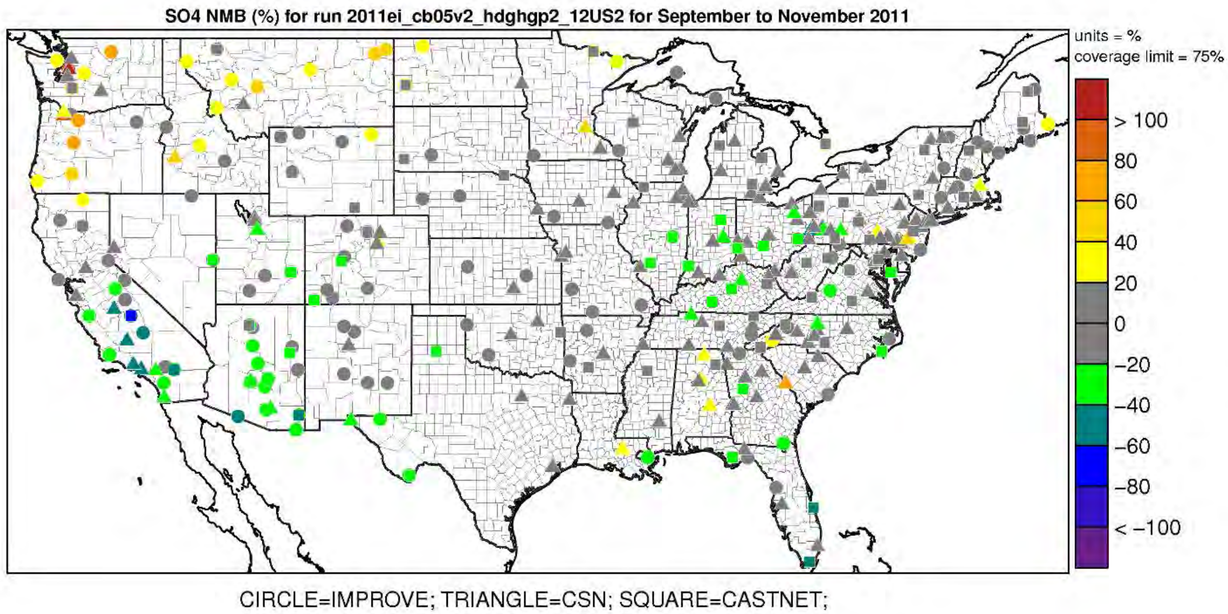

Figure A-6c. Normalized Mean Bias (%) of sulfate during fall 2011 at monitoring sites in the modeling domain.

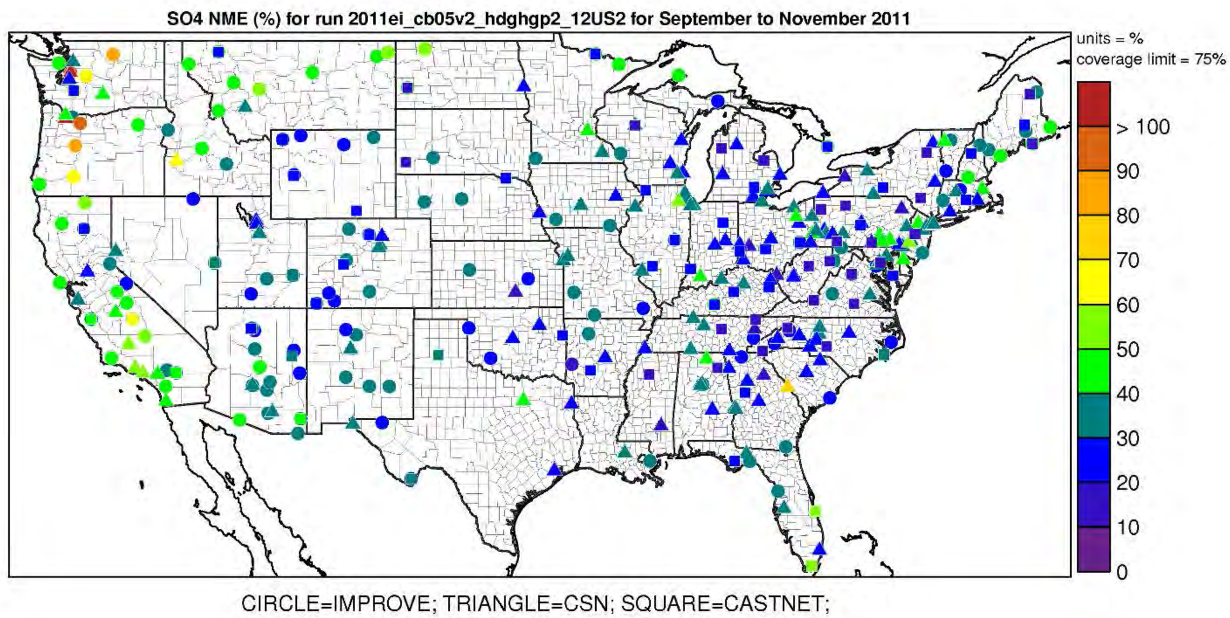

Figure A-6d. Normalized Mean Error (%) of sulfate during fall 2011 at monitoring sites in the modeling domain.

A.3.1. Seasonal Evaluation for Nitrate

The model performance bias and error statistics for nitrate for each climate region and each season are provided in Table A-4. This table includes statistics for particulate nitrate as measured at CSN and IMPROVE sites and total nitrate (NO_3+HNO_3) as measured at CASTNet sites. Spatial plots of the mean bias and error as well as normalized mean bias and error by season for individual monitors are shown in Figures A-7 through A-10. Overall, nitrate and total nitrate performance are over predicted in the Northeast, Ohio Valley, Upper Midwest, Southeast, South, Northern Rockies and Northwest U.S.; with the exception at the IMPROVE and CSN sites in the Southwest where nitrate is under predicted in the winter. Likewise, the model tends to over predict nitrate during the fall season except in the South and Southwest at CSN and CASTNet and in the Southwest at all three monitoring networks. During the spring, nitrate and total nitrate is also over predicted except in the South, Southeast and Southwest. Nitrate and total nitrate performance during the summer season typically shows an under prediction in most areas of the U.S. with the exception of the Northwest at urban CSN sites and the Ohio Valley region at rural CASTNet sites. Model performance shows an under prediction in the West for all of the seasonal assessments of nitrate.

Table A-4. Nitrate and Total Nitrate Performance Statistics by Climate Region, by Season, and by Monitoring Network for the 2011 CMAQ Model Simulation.

Climate Region	Monitor Network	Season	No. of Obs	MB (ug/m^3)	ME (ug/m^3)	NMB (%)	NME (%)
Northeast	IMPROVE	Winter	425	0.9	1.0	154.0	163.0
		Spring	474	0.1	0.3	42.6	111.0
		Summer	422	-0.1	0.2	-55.5	97.1
		Fall	418	0.1	0.3	26.2	106.0
	CSN	Winter	679	1.1	1.4	52.9	66.7
		Spring	717	0.1	0.6	6.5	58.8
		Summer	721	-0.3	0.4	-54.1	72.5
		Fall	685	0.1	0.5	16.0	63.8
	CASTNet	Winter	170	0.8	0.9	38.7	40.9
		Spring	193	0.2	0.4	11.0	30.3
		Summer	187	0.0	0.3	-1.7	27.5
		Fall	196	0.4	0.6	35.4	46.1
Ohio Valley	IMPROVE	Winter	207	0.6	1.2	29.5	57.7
		Spring	235	0.6	0.9	70.5	110.0
		Summer	211	-0.1	0.2	-62.5	81.3
		Fall	226	0.2	0.4	38.9	83.0
	CSN	Winter	588	1.0	1.4	35.0	49.0
		Spring	624	0.7	1.1	43.0	68.5
		Summer	645	-0.2	0.4	-33.0	69.4
		Fall	611	0.3	0.1	38.0	67.0
	CASTNet	Winter	201	0.6	0.9	16.1	25.4
		Spring	214	0.3	0.7	14.7	33.1
		Summer	207	0.0	0.5	0.7	28.4
		Fall	214	0.5	0.6	33.6	38.1
Upper Midwest	IMPROVE	Winter	210	0.6	1.0	30.2	49.9
		Spring	205	0.4	0.7	35.7	59.3
		Summer	221	-0.1	0.1	-33.2	69.0
		Fall	222	0.5	0.6	74.9	88.7

Climate Region	Monitor Network	Season	No. of Obs	MB (ug/m^3)	ME (ug/m^3)	NMB (%)	NME (%)
	CSN	Winter	334	0.8	1.3	22.7	36.8
		Spring	337	0.7	1.1	30.5	50.8
		Summer	335	-0.2	0.4	-38.1	72.1
		Fall	340	0.6	0.8	47.5	62.9
	CASTNet	Winter	56	0.5	0.7	18.6	23.4
		Spring	62	0.4	0.6	24.1	38.6
		Summer	65	-0.1	0.4	-10.7	29.6
		Fall	62	0.7	0.7	43.1	47.3
Southeast	IMPROVE	Winter	329	0.4	0.7	70.9	119.0
		Spring	346	-0.1	0.4	-17.5	97.5
		Summer	331	-0.2	0.2	-60.7	87.2
		Fall	319	0.1	0.3	24.7	111.0
	CSN	Winter	435	0.9	1.0	97.3	115.0
		Spring	454	0.0	0.4	-8.1	83.4
		Summer	471	-0.1	0.2	-47.9	70.8
		Fall	442	0.3	0.5	88.1	131.0
	CASTNet	Winter	138	0.4	0.9	22.1	50.8
		Spring	146	-0.4	0.6	-25.8	39.2
		Summer	147	-0.3	0.4	-21.0	34.5
		Fall	150	0.1	0.5	11.2	41.7
South	IMPROVE	Winter	247	0.1	0.7	3.9	51.8
		Spring	269	0.0	0.5	-1.4	61.1
		Summer	279	-0.2	0.3	-91.6	93.6
		Fall	252	0.0	0.3	0.1	78.3
	CSN	Winter	222	0.3	1.0	15.9	52.7
		Spring	248	-0.1	0.6	-13.2	70.6
		Summer	253	-0.3	0.3	-79.7	87.0
		Fall	238	0.0	0.4	-1.0	65.2
	CASTNet	Winter	70	0.3	0.7	11.7	27.7
		Spring	85	-0.5	0.8	-27.0	40.0
		Summer	88	-0.7	0.7	-39.4	40.3
		Fall	76	-0.2	0.4	-12.3	31.0
Southwest	IMPROVE	Winter	903	-0.1	0.3	-37.5	74.2
		Spring	920	-0.1	0.2	-59.5	75.0
		Summer	922	-0.1	0.2	-87.1	92.0
		Fall	916	-0. 1	0.1	-49.6	93.0
	CSN	Winter	185	-1.8	2.1	-51.9	62.6
		Spring	190	-0.2	0.4	-26.2	58.2
		Summer	192	-0.1	0.3	-44.2	96.8
		Fall	186	-0.2	0.6	-21.5	73.0
	CASTNet	Winter	94	0.0	0.3	1.7	47.2
		Spring	102	-0.2	0.2	-26.6	36.2
		Summer	102	-0.4	0.4	-40.2	45.4
		Fall	101	-0.1	0.2	-15.7	38.6
Northern Rockies	IMPROVE	Winter	520	0.5	0.6	130.0	166.0
		Spring	588	0.3	0.4	67.1	101.0
		Summer	578	-0.1	0.1	-59.9	90.0
		Fall	551	0.2	0.3	152	193
	CSN	Winter	66.0	0.1	1.1	4.4	46.7
		Spring	70.0	0.2	0.8	12.6	48.4
		Summer	72.0	-0.2	0.2	-64.2	83.2

Climate Region	Monitor Network	Season	No. of Obs	MB (ug/m^3)	ME (ug/m^3)	NMB (%)	NME (%)
		Fall	69.0	0.5	0.7	66.0	94.3
	CASTNet	Winter	77	0.3	0.3	36.8	45.1
		Spring	76	0.1	0.3	13.4	33.6
		Summer	88	-0.2	0.2	-19.5	23.8
		Fall	89	0.1	0.2	23.9	35.9
Northwest	IMPROVE	Winter	416	0.1	0.4	16.5	109.0
		Spring	498	0.1	0.1	37.3	103.0
		Summer	436	0.0	0.1	-21.3	103.0
		Fall	447	0.1	0.2	40.8	119.0
	CSN	Winter	166	0.5	1.5	28.7	84.9
		Spring	167	0.2	0.4	49.6	84.6
		Summer	172	0.1	0.3	40.5	113.0
		Fall	164	0.4	0.6	61.1	99.6
	CASTNet	Winter	-	-	-	-	-
		Spring	-	-	-	-	-
		Summer	-	-	-	-	-
		Fall	-	-	-	-	-
West	IMPROVE	Winter	460	-0.4	0.6	-44.3	74.1
		Spring	513	-0.2	0.3	-46.6	72.8
		Summer	526	-0.3	0.3	-78.9	90.6
		Fall	522	-0.1	0.4	-33.0	85.4
	CSN	Winter	226	-2.5	2.9	-52.9	61.2
		Spring	242	-0.7	1.0	-38.8	55.5
		Summer	246	-1.5	1.5	-71.4	72.8
		Fall	229	-2.0	2.3	-55.8	64.3
	CASTNet	Winter	69	-0.2	0.6	-21.4	55.1
		Spring	73	-0.3	0.4	-31.8	41.7
		Summer	77	-0.6	0.6	-34.3	38.9
		Fall	77	-0.4	0.6	-29.1	40.1

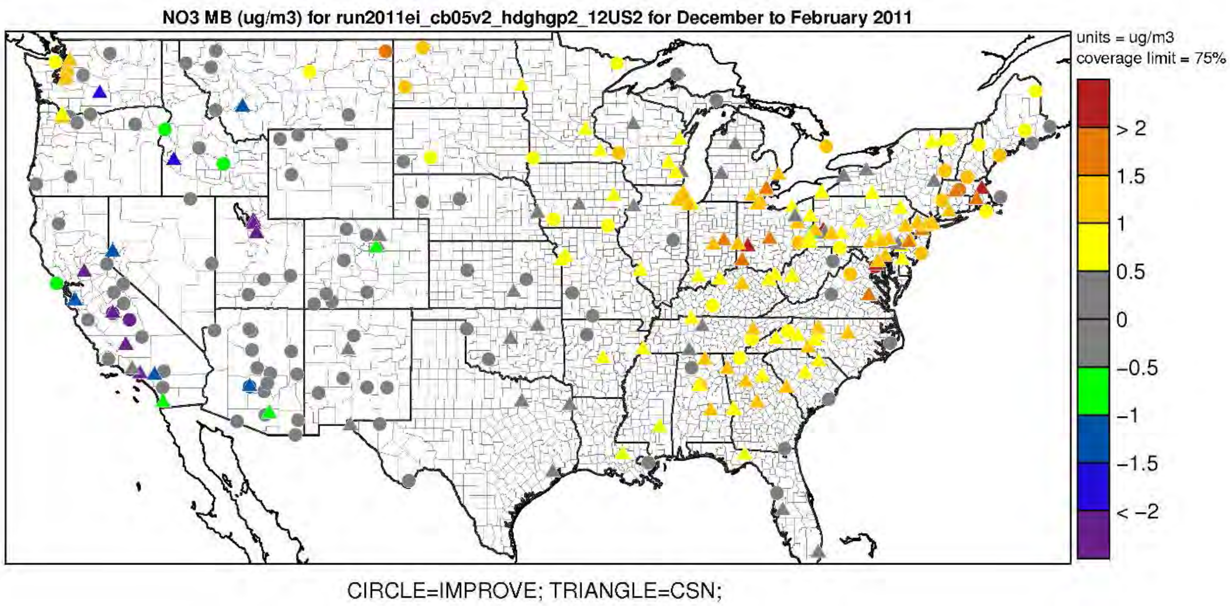

Figure A-7a. Mean Bias (ug/m³) for nitrate during winter 2011 at monitoring sites in the modeling domain.

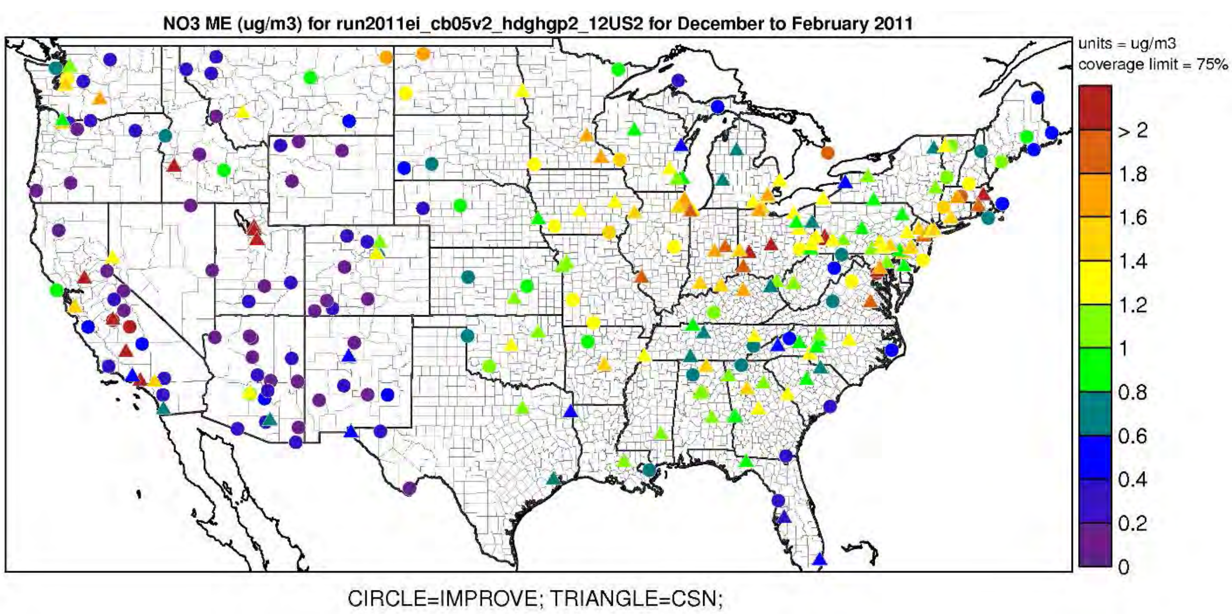

Figure A-7b. Mean Error (ug/m³) for nitrate during winter 2011 at monitoring sites in the modeling domain.

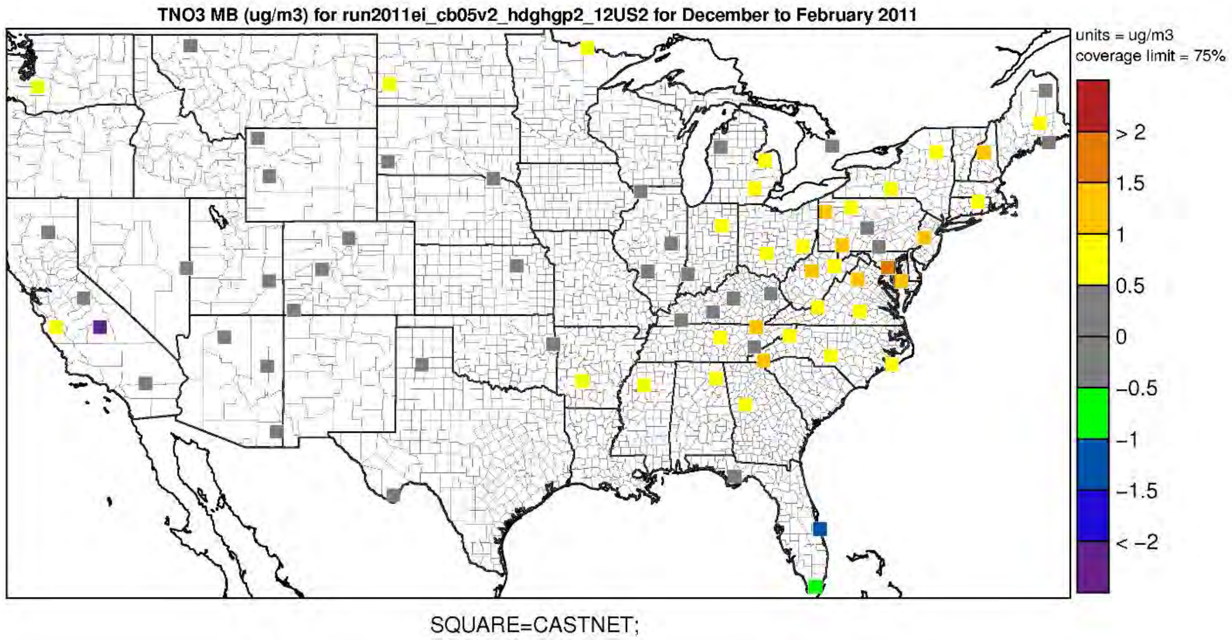

Figure A-7c. Mean Bias (ug/m³) for total nitrate during winter 2011 at monitoring sites in the modeling domain.

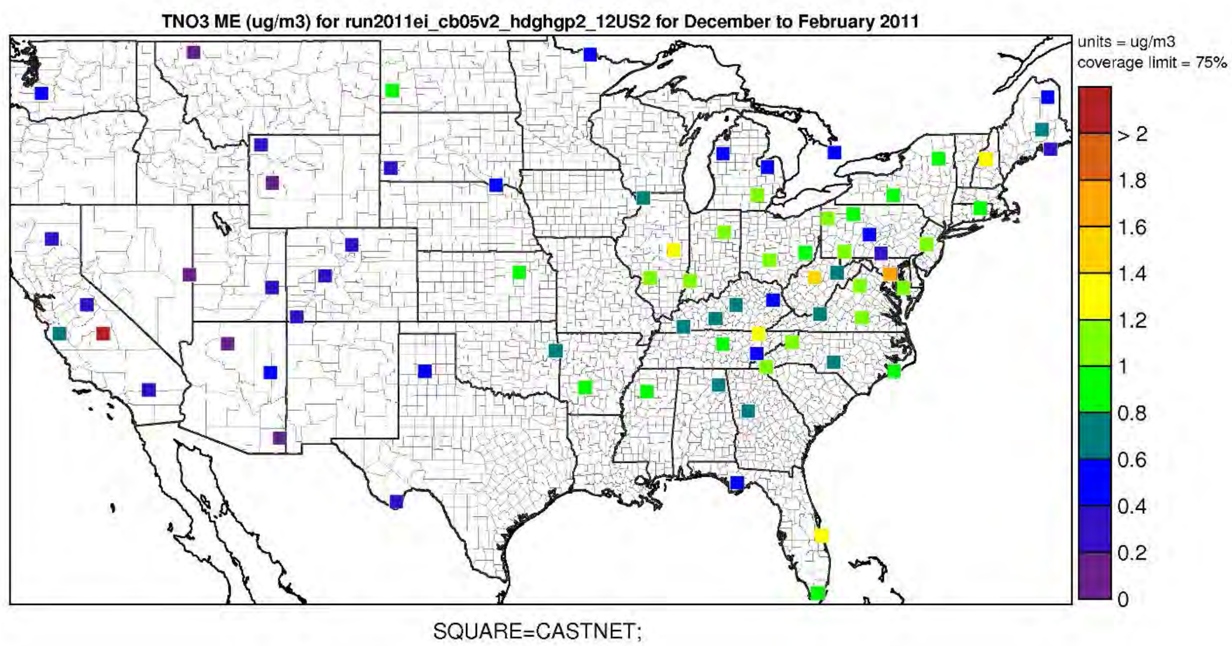

Figure A-7d. Mean Error (ug/m³) for total nitrate during winter 2011 at monitoring sites in the modeling domain.

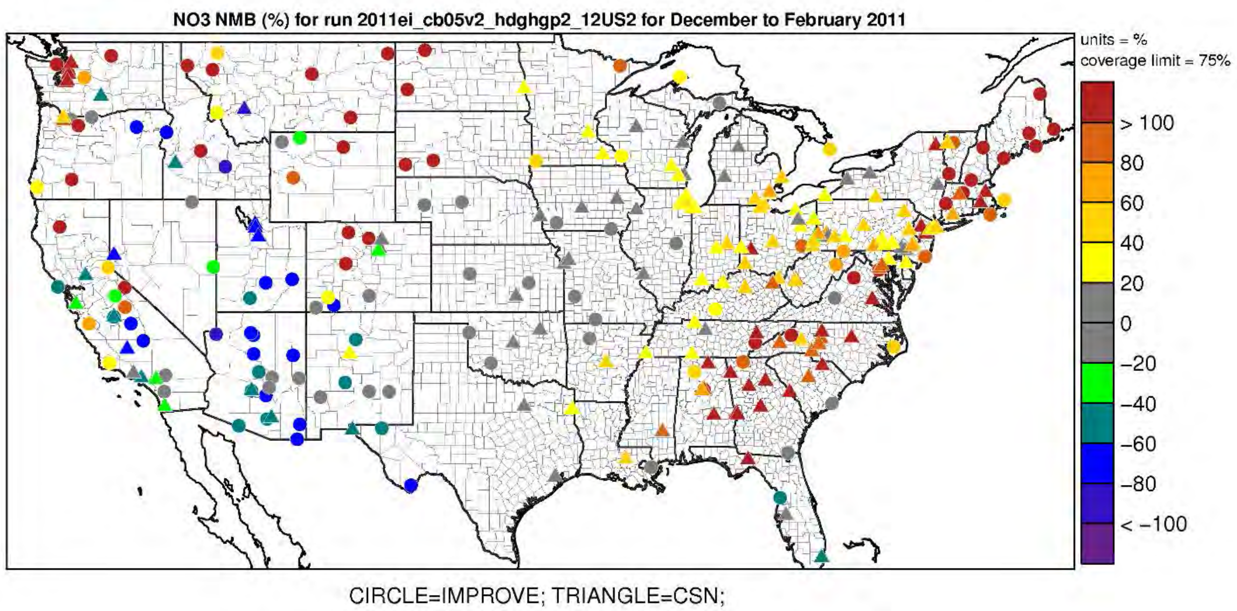

Figure A-7e. Normalized Mean Bias (%) for nitrate during winter 2011 at monitoring sites in the modeling domain.

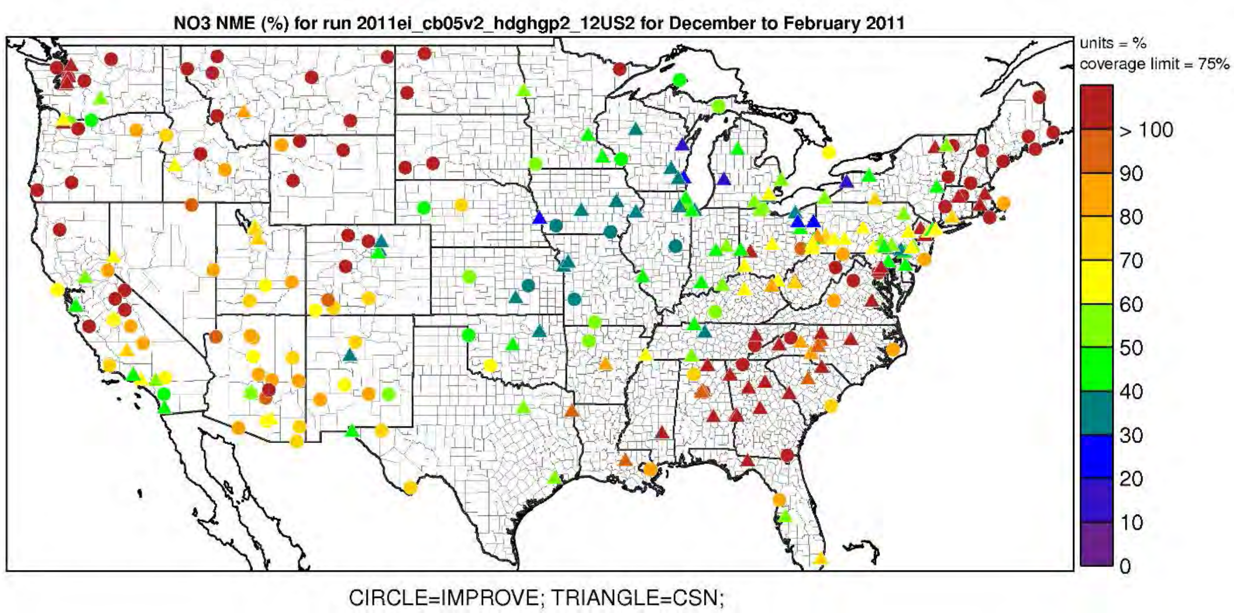

Figure A-7f. Normalized Mean Error (%) for nitrate during winter 2011 at monitoring sites in the modeling domain.

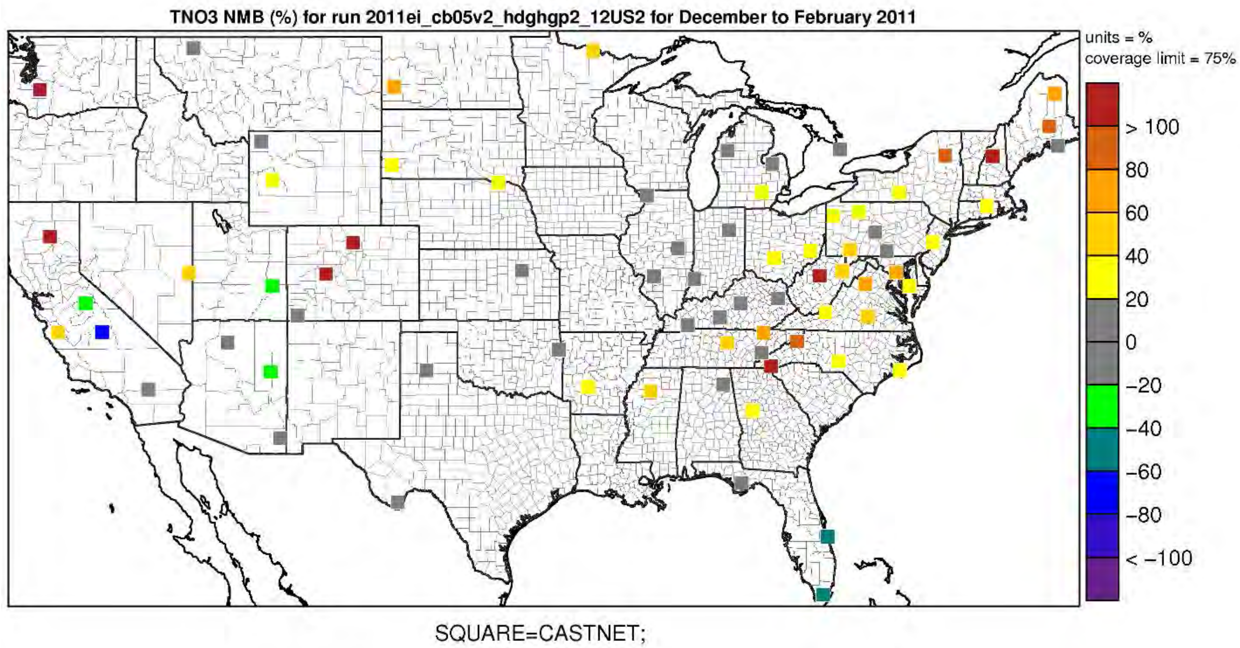

Figure A-7g. Normalized Mean Bias (%) for total nitrate during winter 2011 at monitoring sites in the modeling domain.

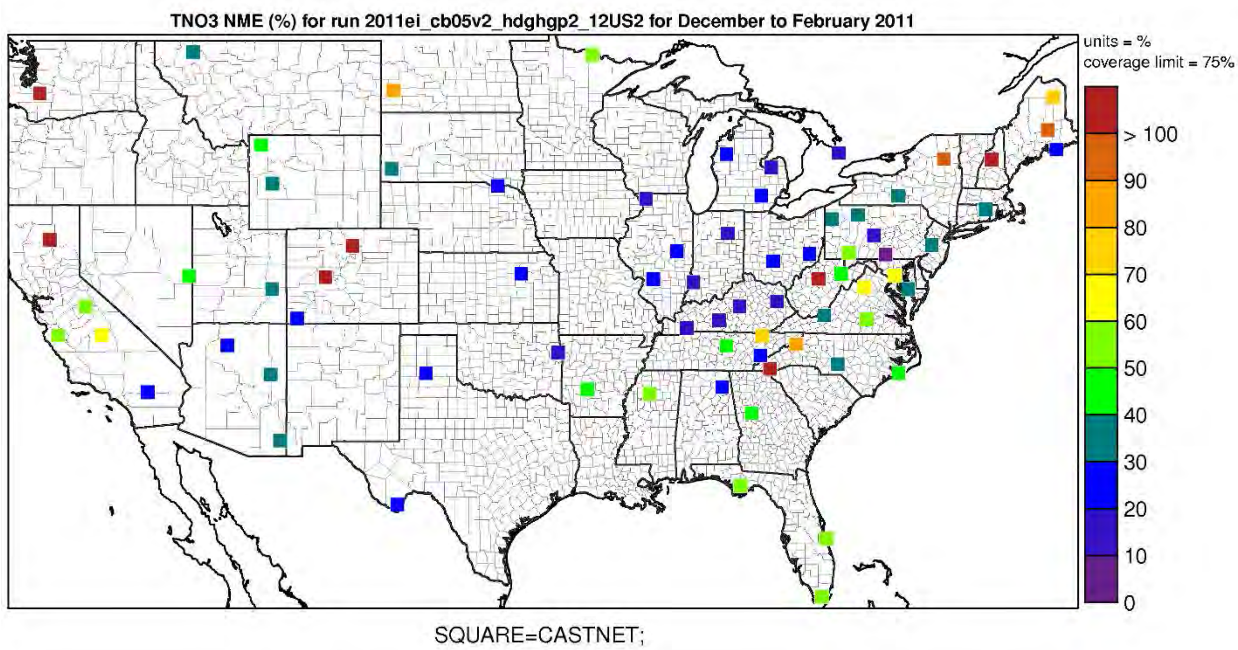

Figure A-7h. Normalized Mean Error (%) for total nitrate during winter 2011 at monitoring sites in the modeling domain.

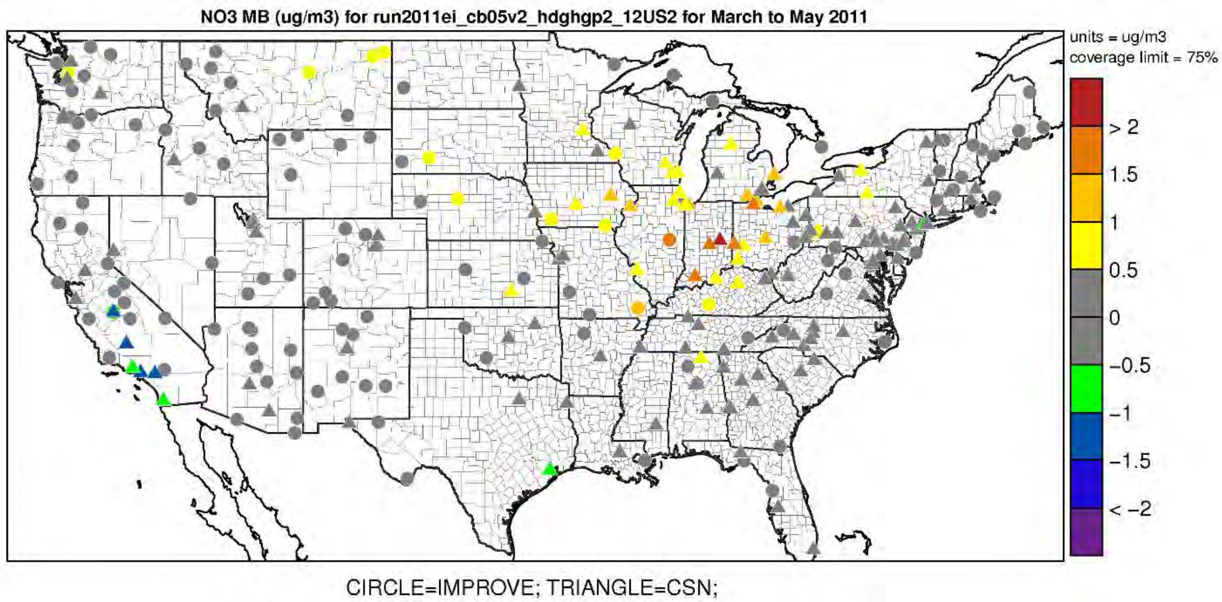

Figure A-8a. Mean Bias (ug/m³) for nitrate during spring 2011 at monitoring sites in the modeling domain.

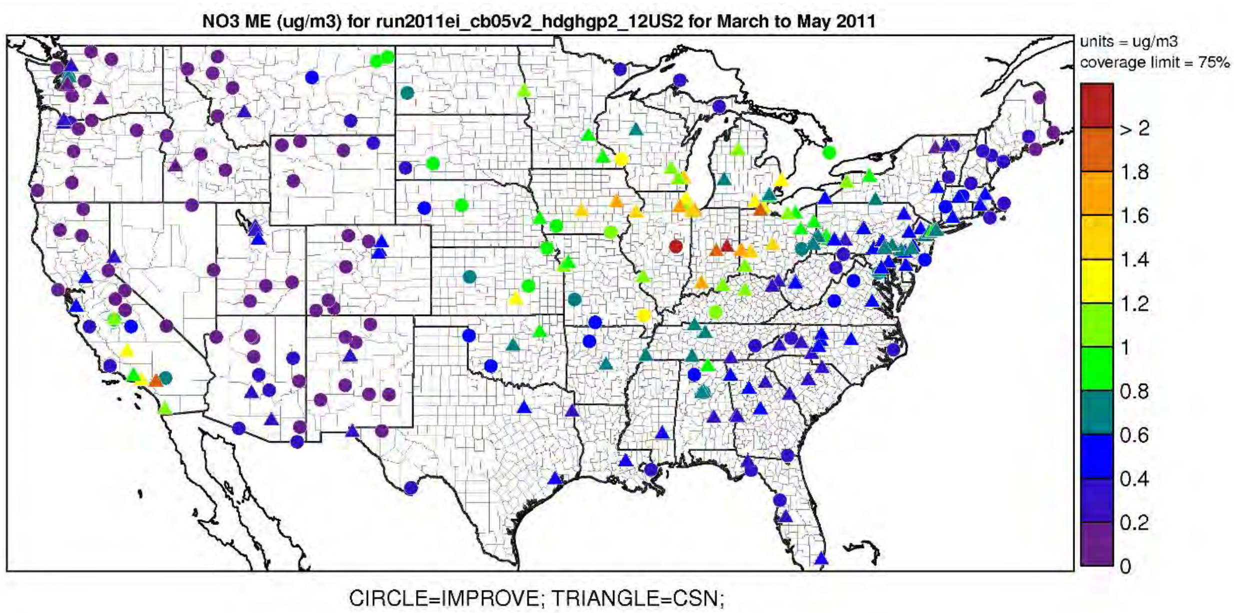

Figure A-8b. Mean Error (ug/m³) for nitrate during spring 2011 at monitoring sites in the modeling domain.

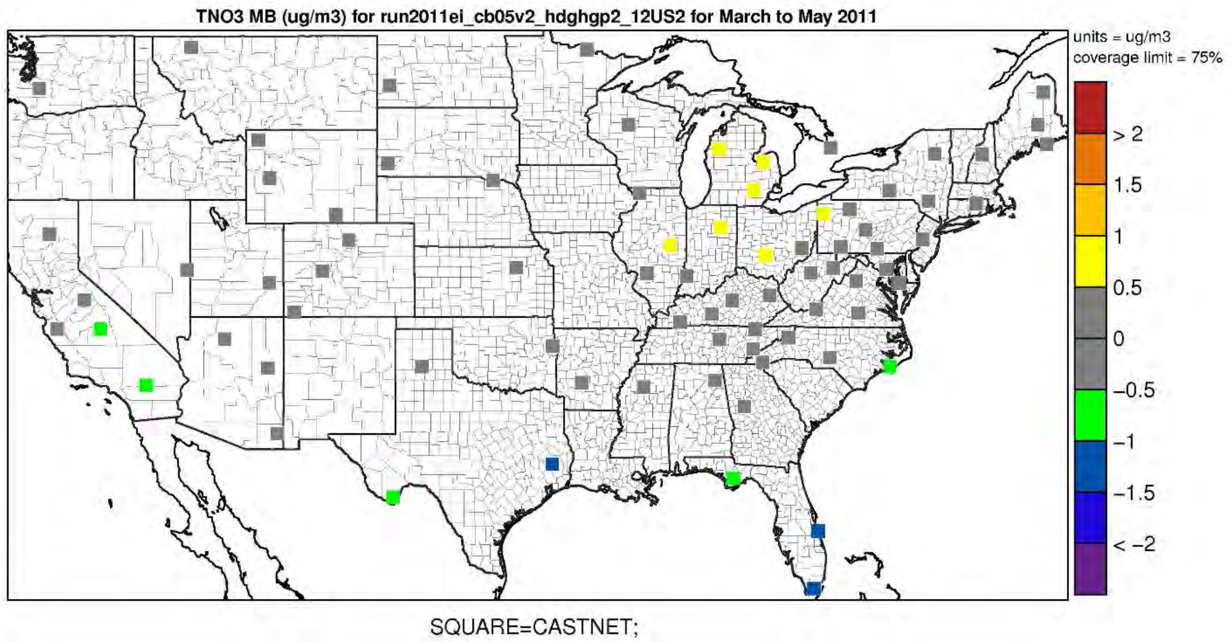

Figure A-8c. Mean Bias (ug/m³) for total nitrate during spring 2011 at monitoring sites in the modeling domain.

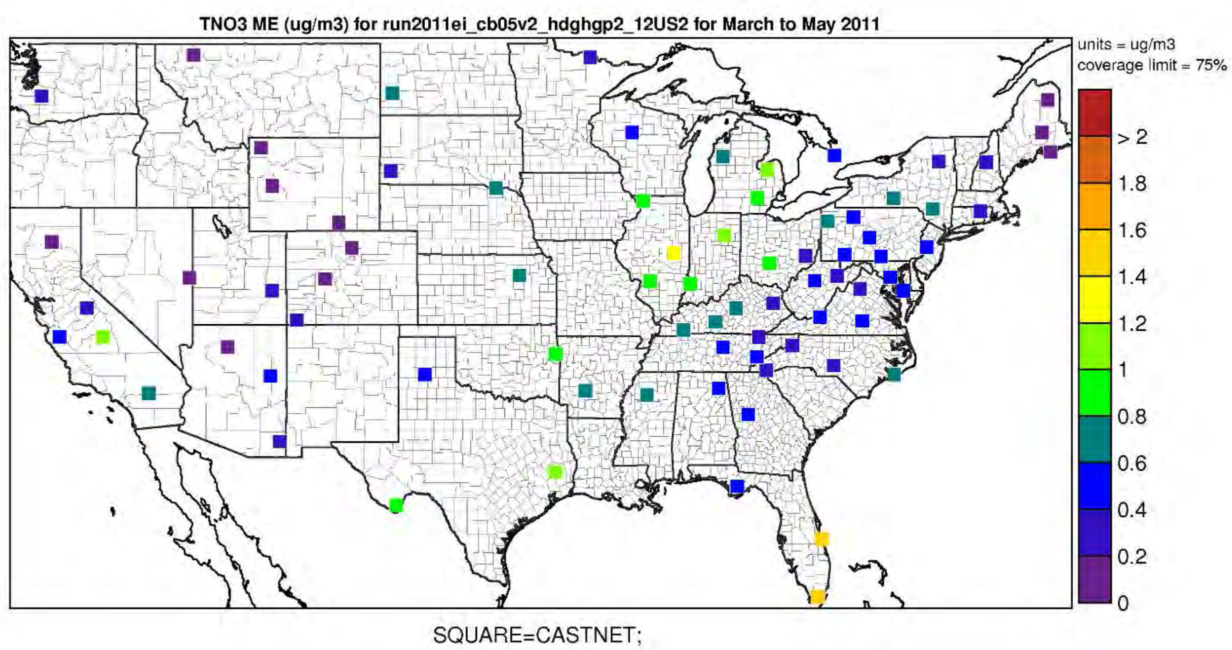

Figure A-8d. Mean Error (ug/m³) for total nitrate during spring 2011 at monitoring sites in the modeling domain.

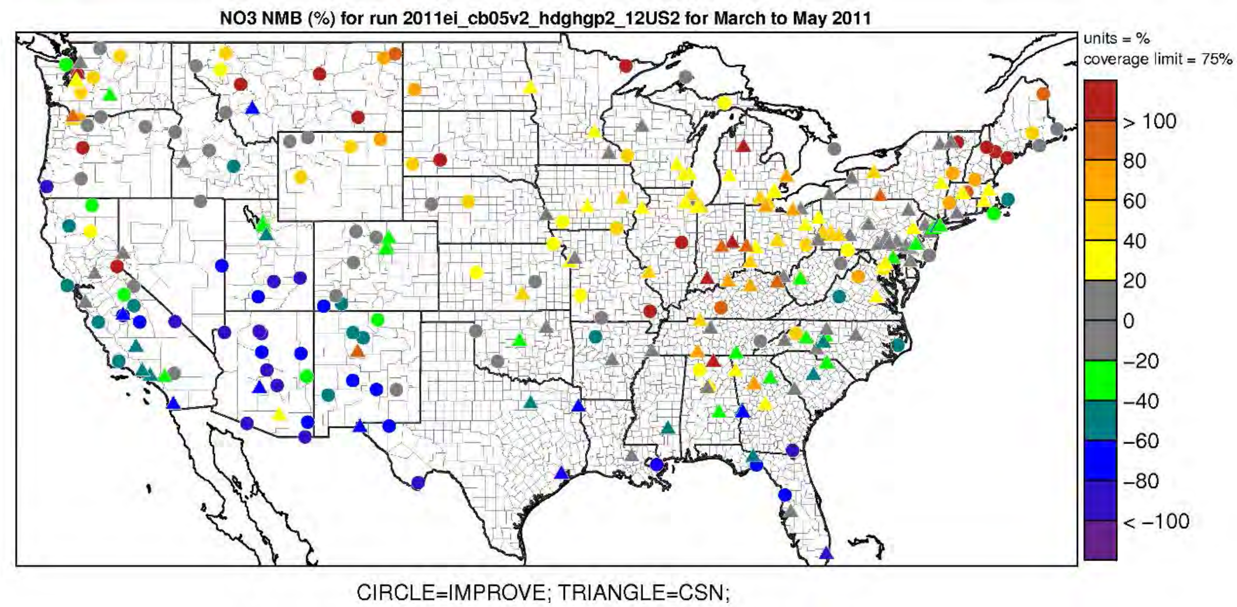

Figure A-8e. Normalized Mean Bias (%) for nitrate during spring 2011 at monitoring sites in the modeling domain.

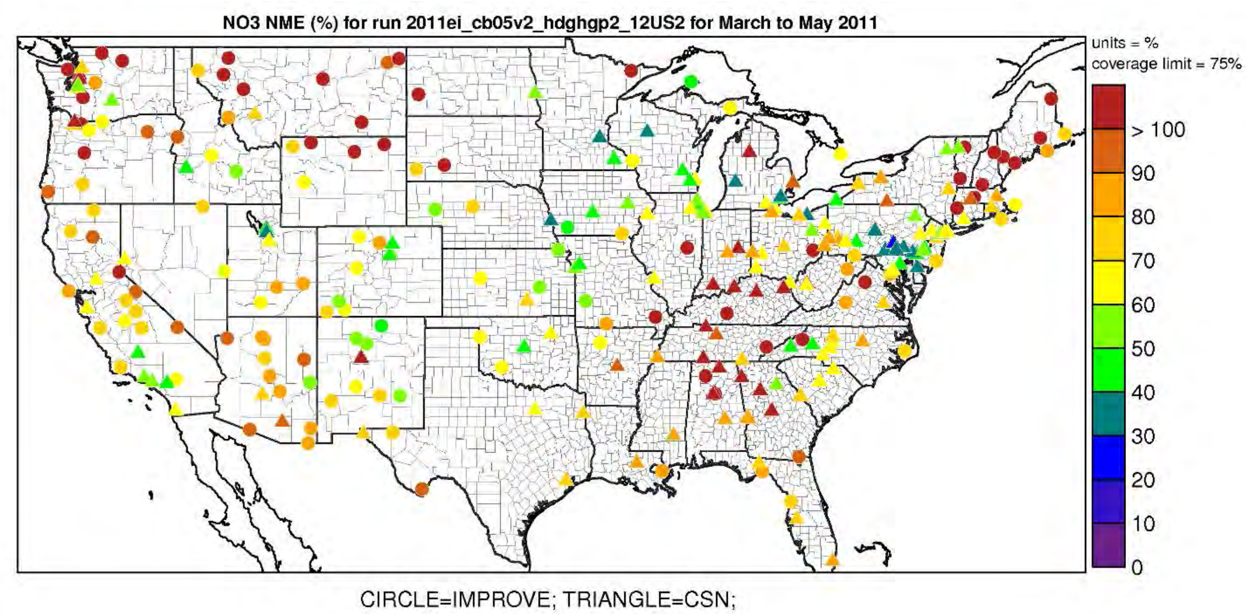

Figure A-8f. Normalized Mean Error (%) for nitrate during spring 2011 at monitoring sites in the modeling domain.

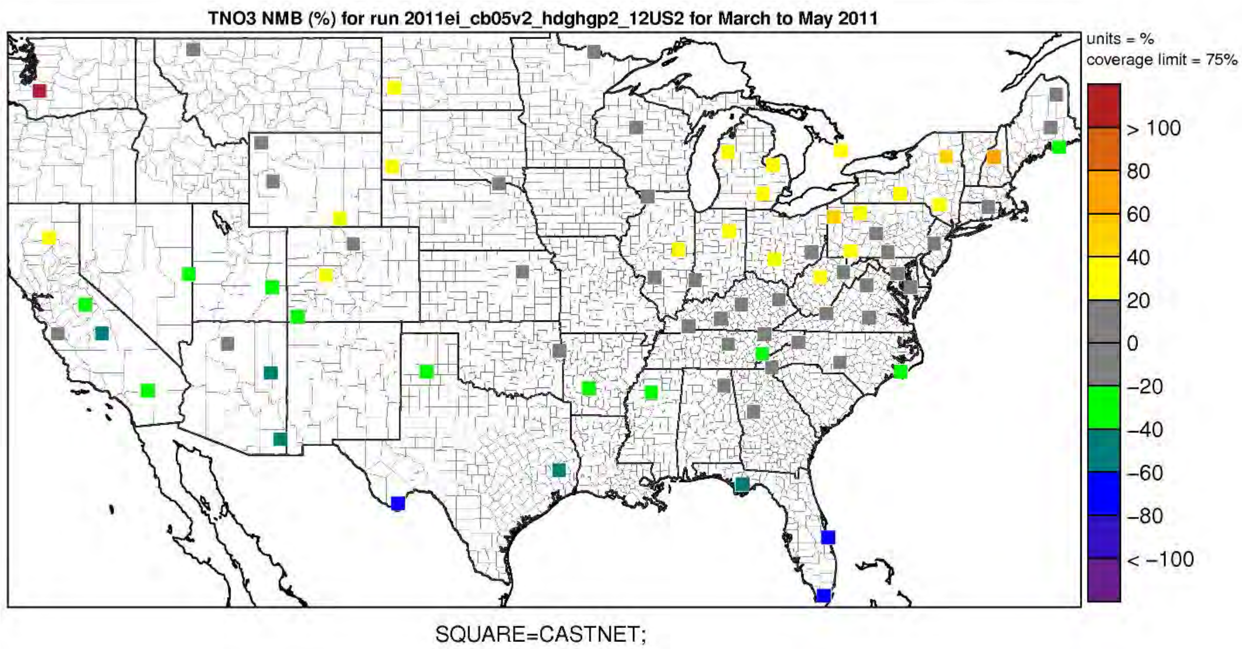

Figure A-8g. Normalized Mean Bias (%) for total nitrate during spring 2011 at monitoring sites in the modeling domain.

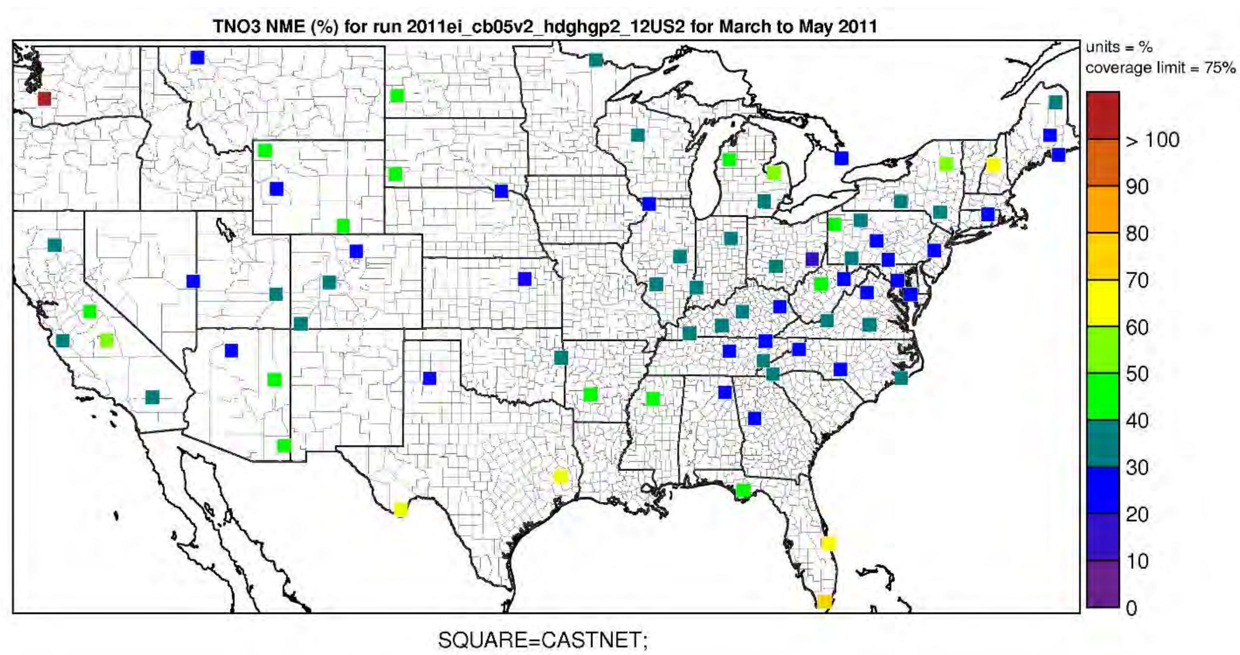

Figure A-8h. Normalized Mean Error (%) for total nitrate during spring 2011 at monitoring sites in the modeling domain.

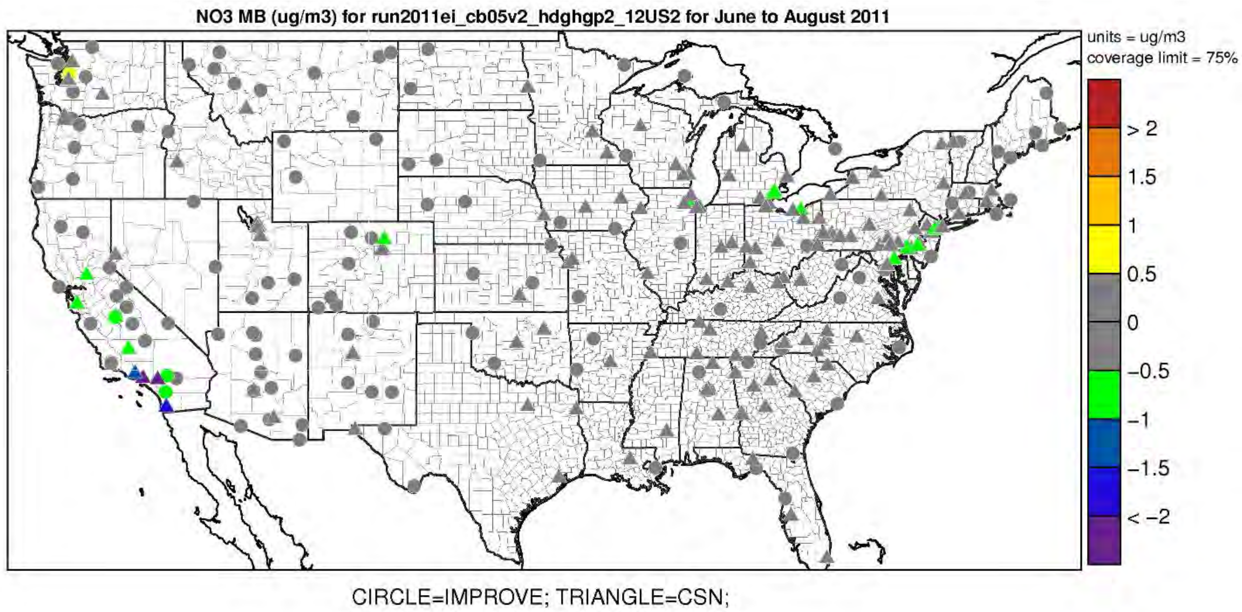

Figure A-9a. Mean Bias (ug/m³) for nitrate during summer 2011 at monitoring sites in the modeling domain.

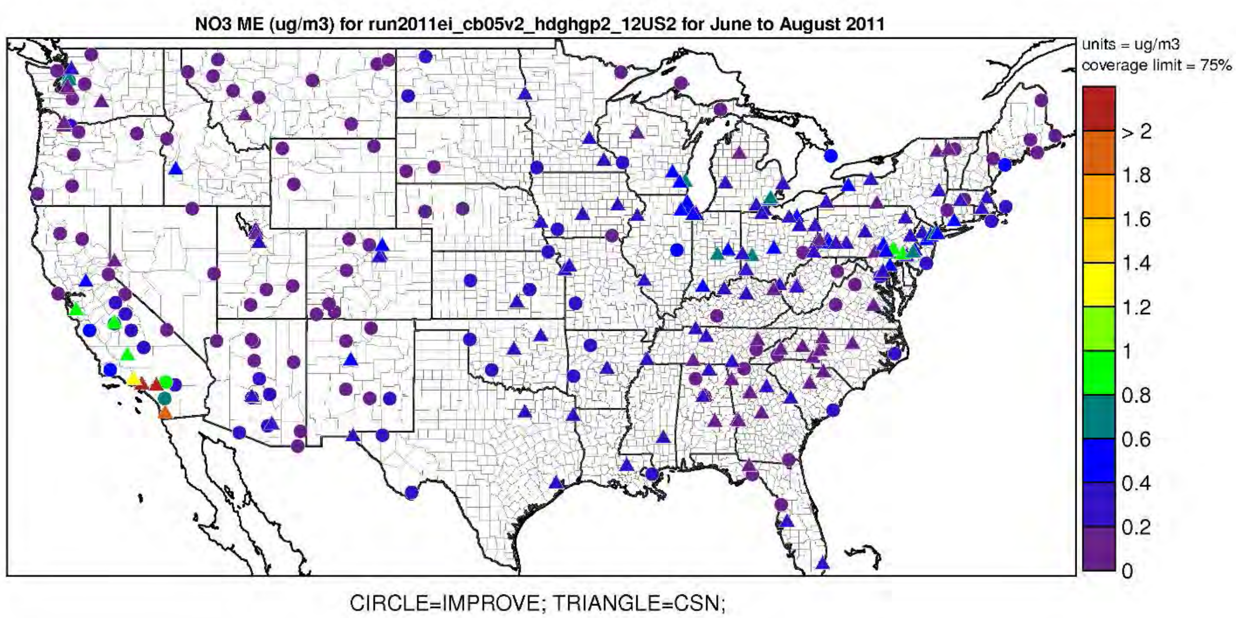

Figure A-9b. Mean Error (ug/m³) for nitrate during summer 2011 at monitoring sites in the modeling domain.

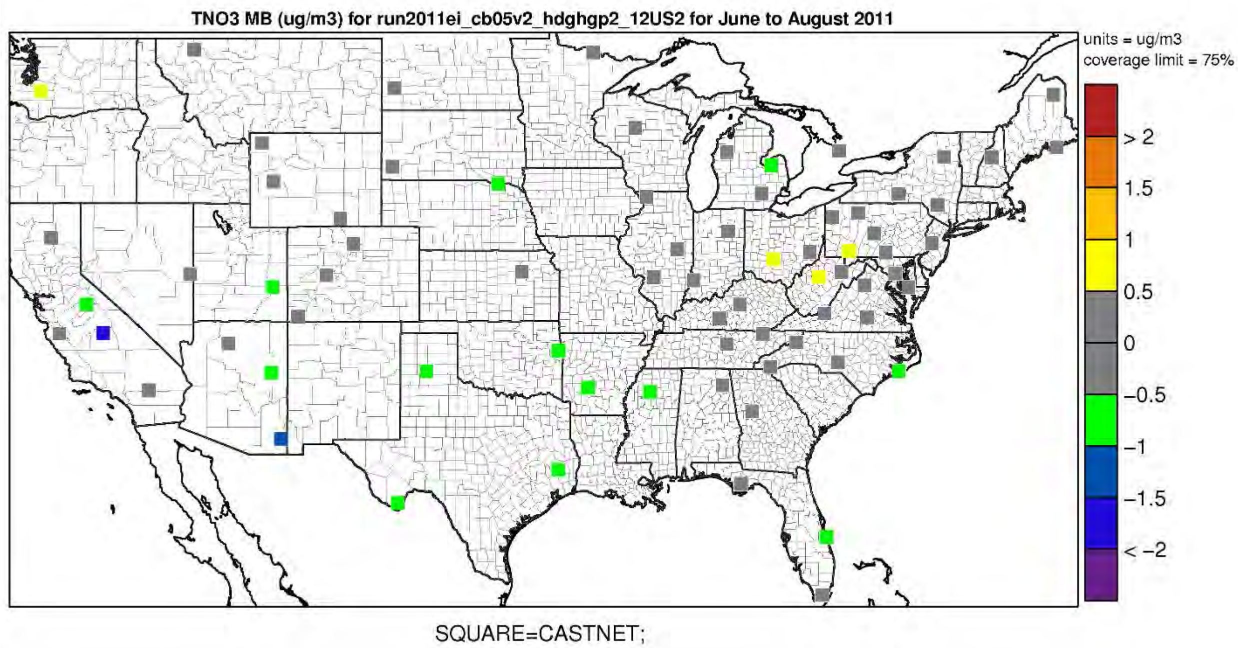

Figure A-9c. Mean Bias (ug/m³) for total nitrate during summer 2011 at monitoring sites in the modeling domain.

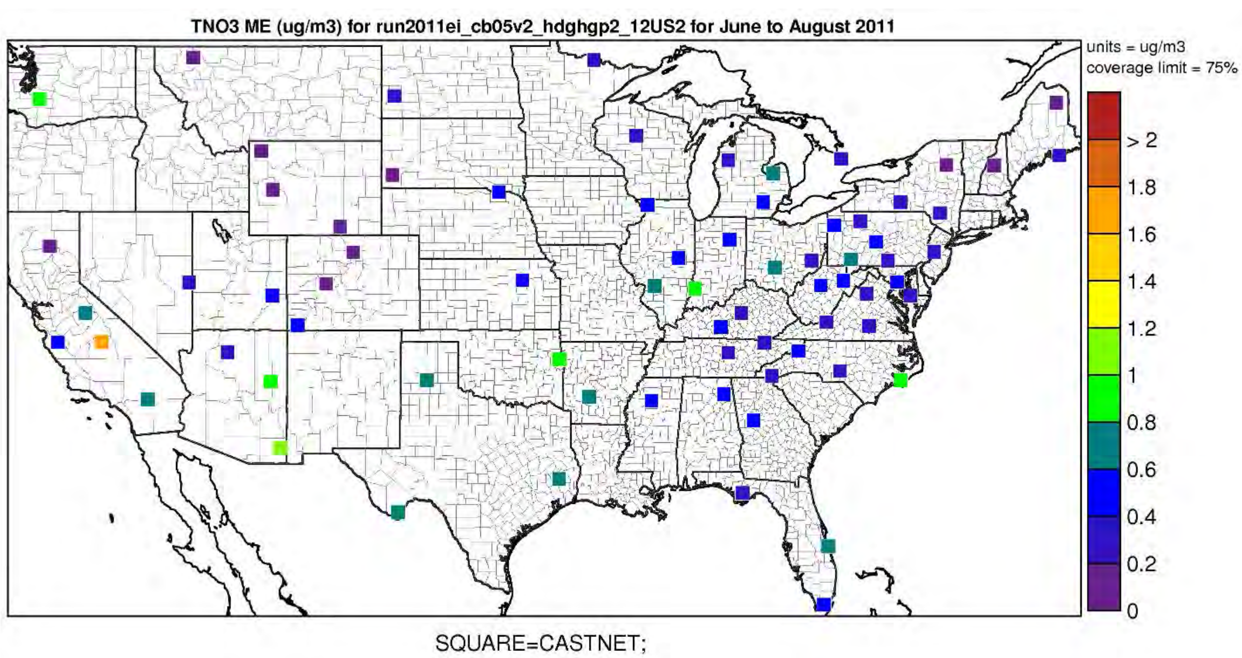

Figure A-9d. Mean Error (ug/m³) for total nitrate during summer 2011 at monitoring sites in the modeling domain.

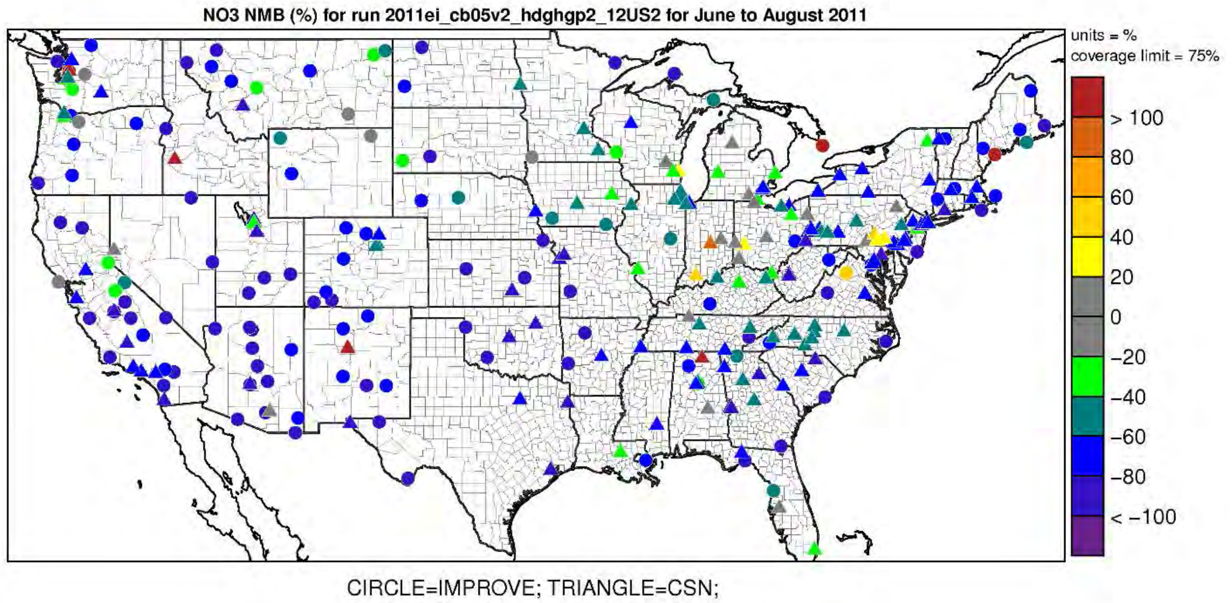

Figure A-9e. Normalized Mean Bias (%) for nitrate during summer 2011 at monitoring sites in the modeling domain.

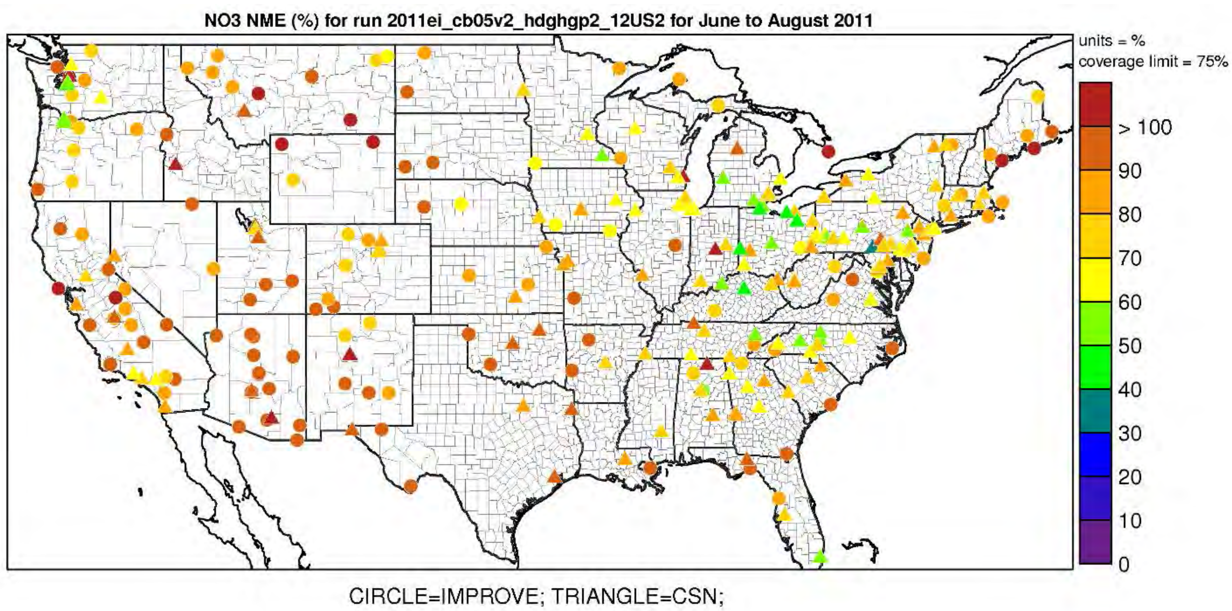

Figure A-9f. Normalized Mean Error (%) for nitrate during summer 2011 at monitoring sites in the modeling domain.

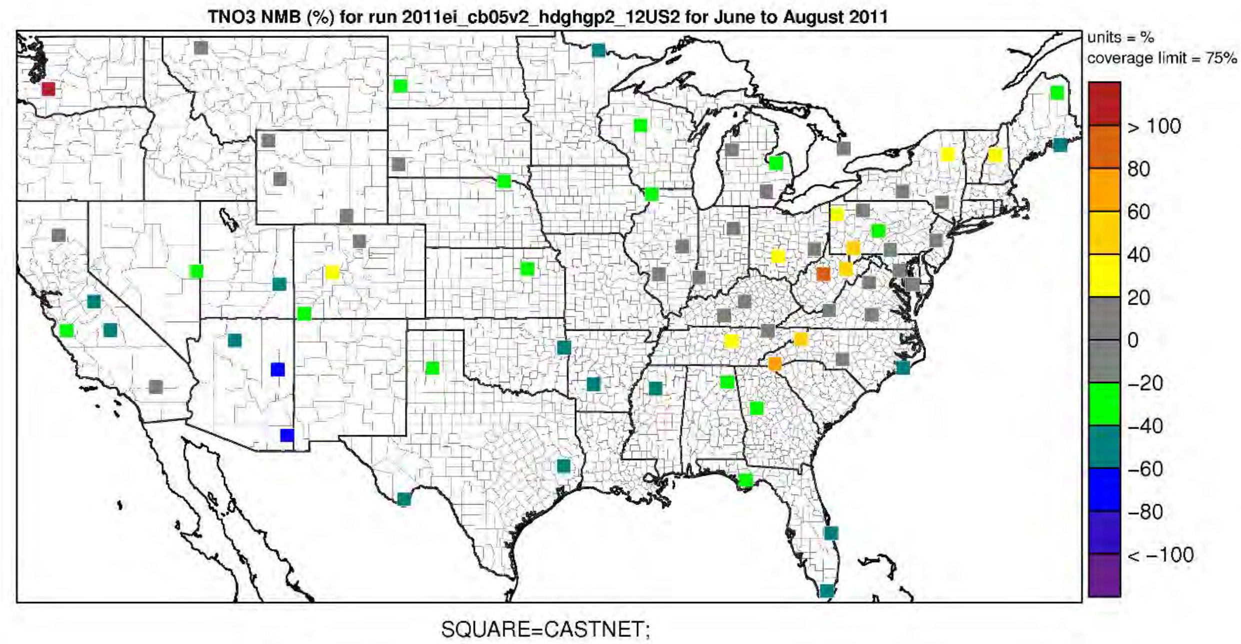

Figure A-9g. Normalized Mean Bias (%) for total nitrate during summer 2011 at monitoring sites in the modeling domain.

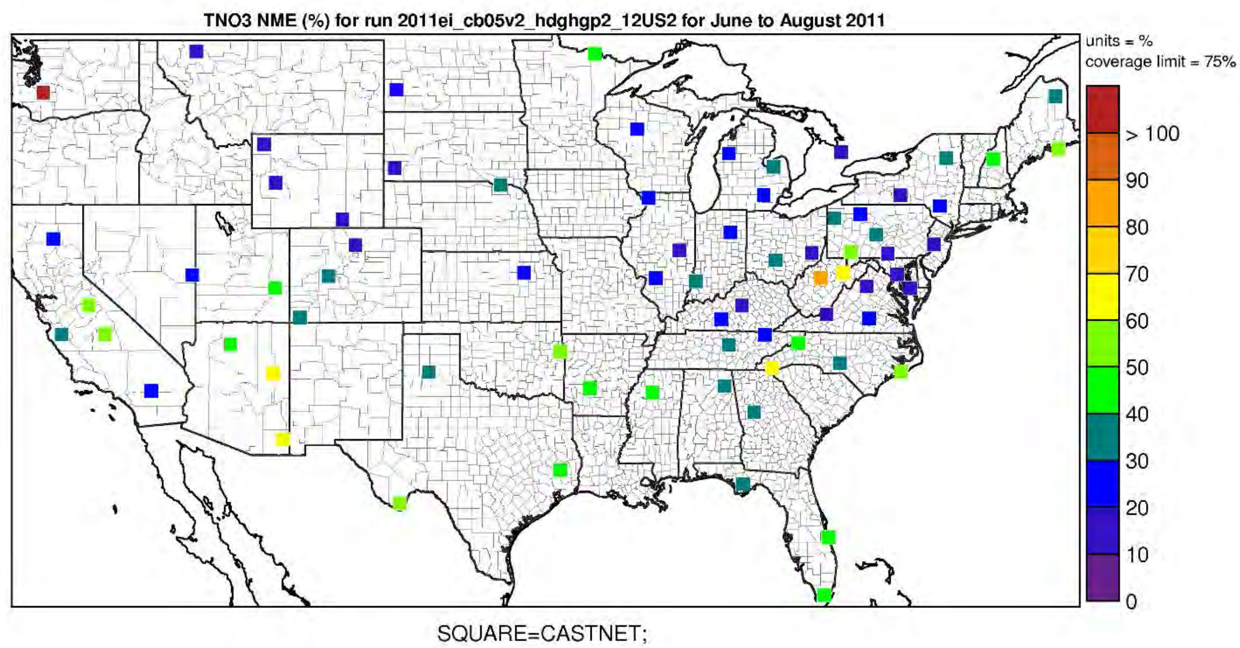

Figure A-9h. Normalized Mean Error (%) for total nitrate during summer 2011 at monitoring sites in the modeling domain.

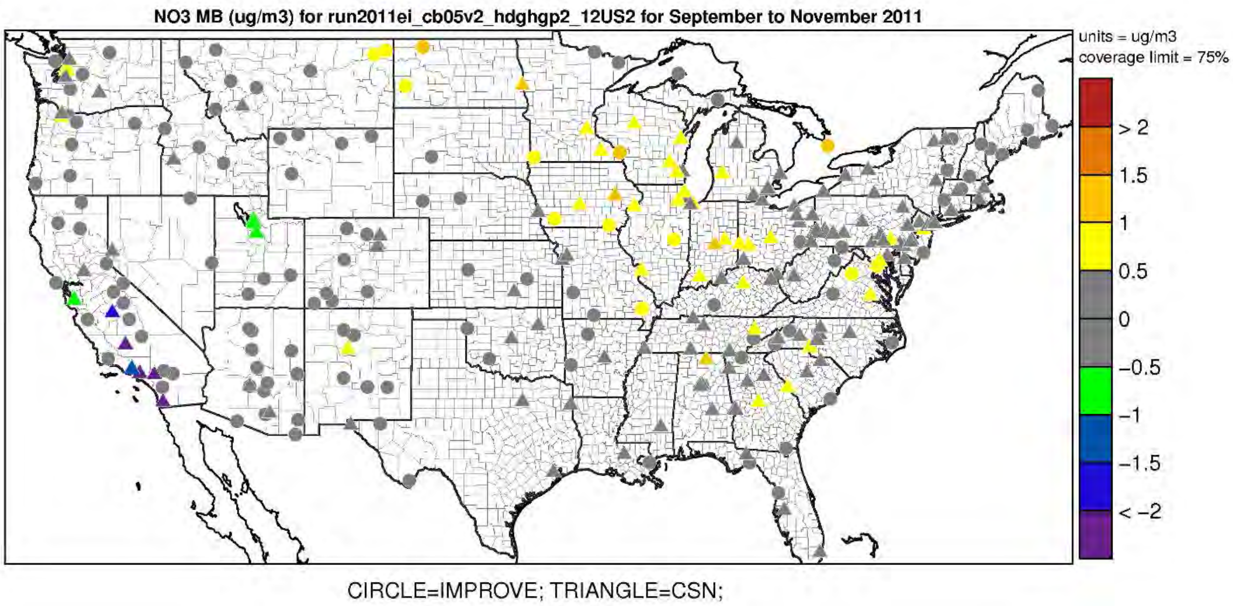

Figure A-10a. Mean Bias (ug/m³) for nitrate during fall 2011 at monitoring sites in the modeling domain.

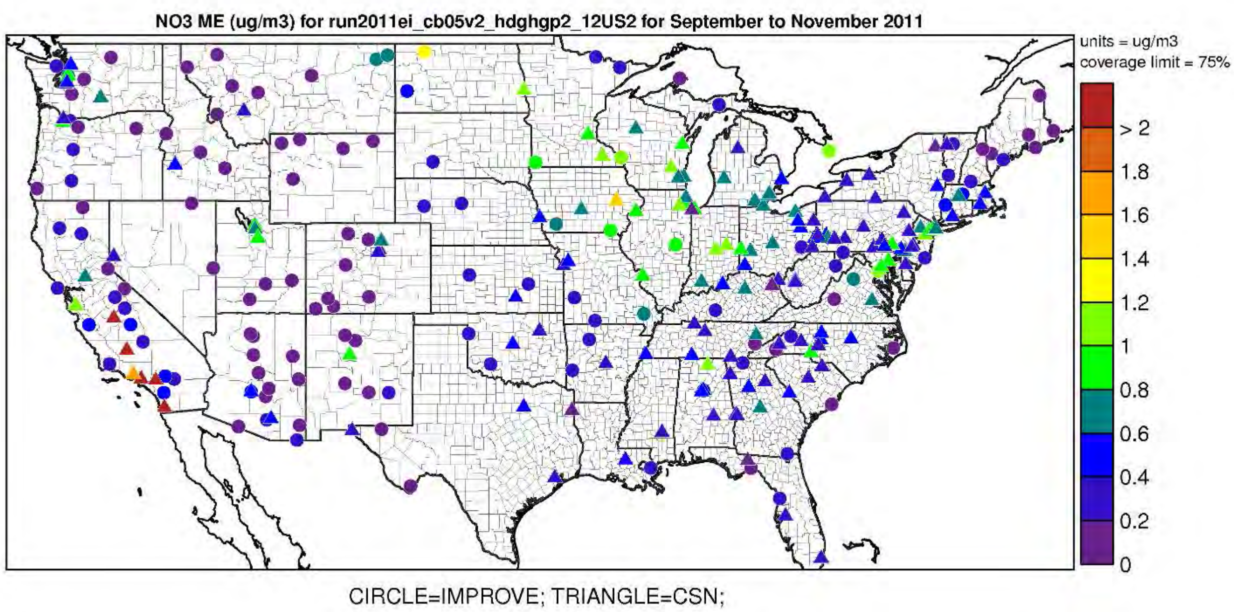

Figure A-10b. Mean Error (ug/m³) for nitrate during fall 2011 at monitoring sites in the modeling domain.

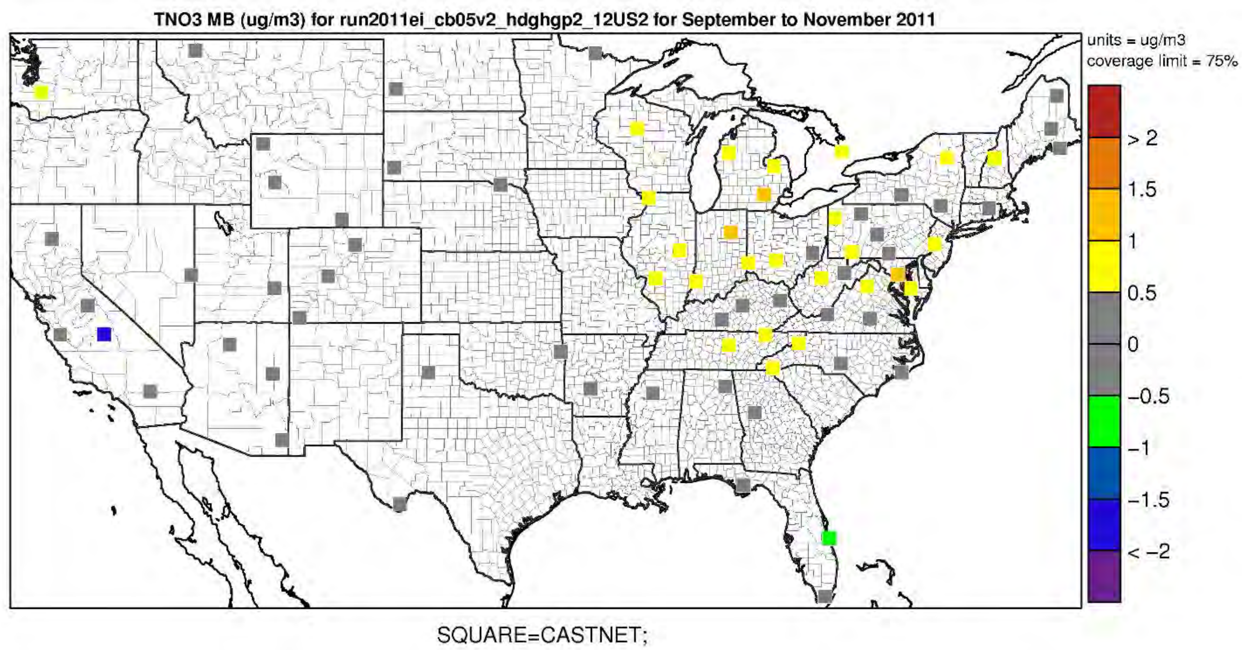

Figure A-10c. Mean Bias (ug/m³) for total nitrate during fall 2011 at monitoring sites in the modeling domain.

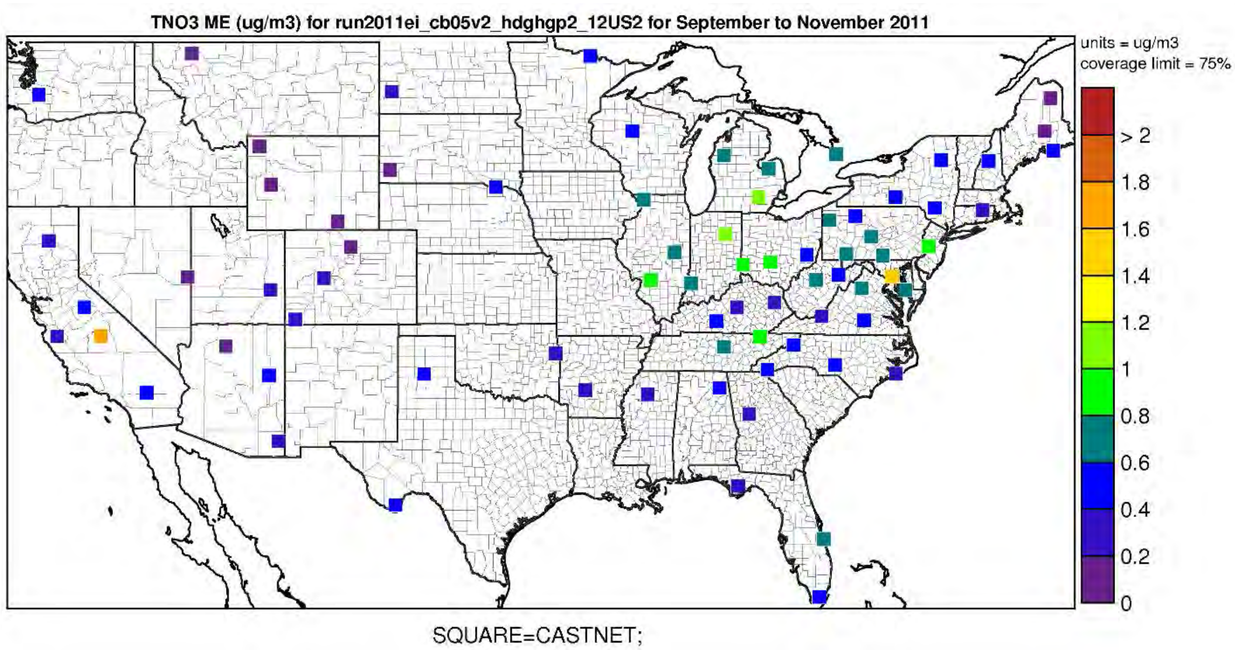

Figure A-10d. Mean Error (ug/m³) for total nitrate during fall 2011 at monitoring sites in the modeling domain.

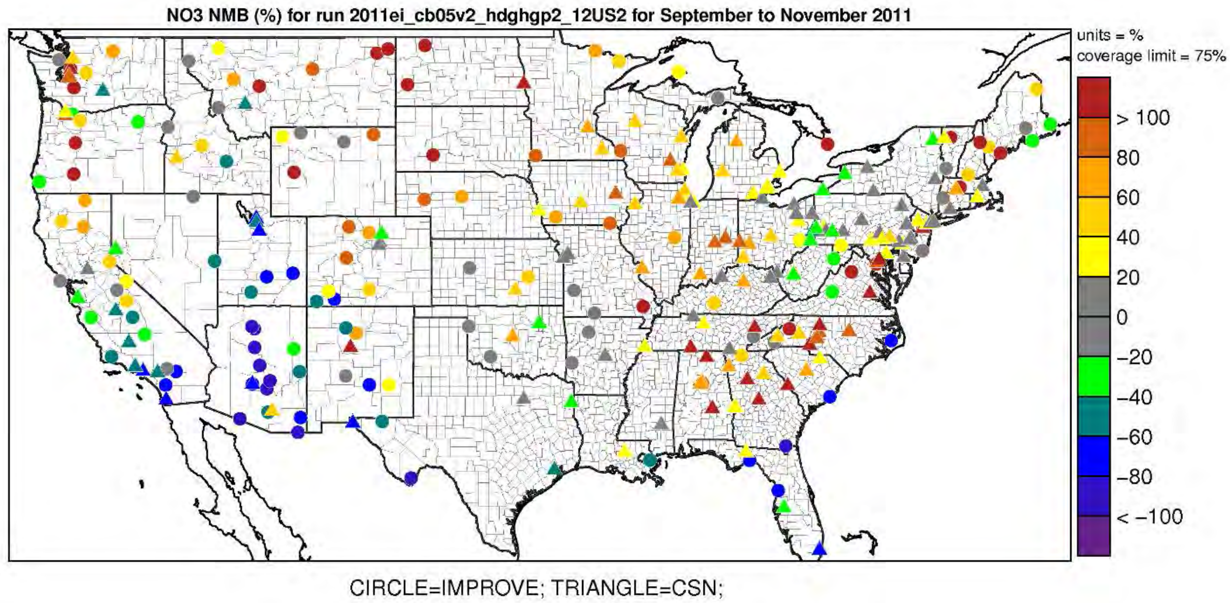

Figure A-10e. Normalized Mean Bias (%) for nitrate during fall 2011 at monitoring sites in the modeling domain.

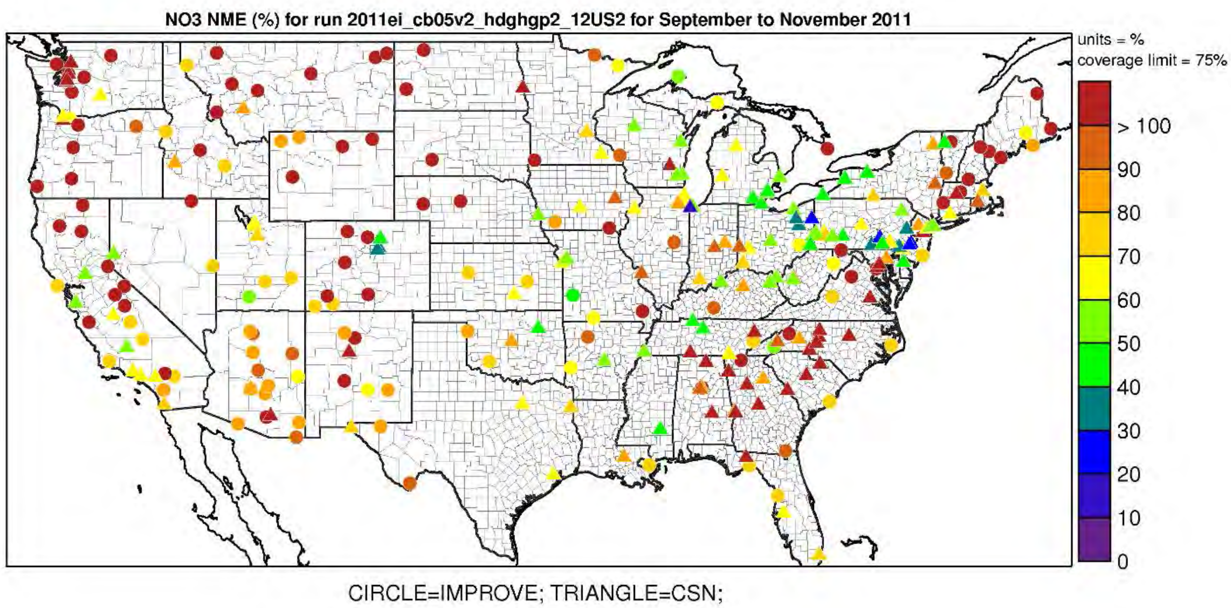

Figure A-10f. Normalized Mean Error (%) for nitrate during fall 2011 at monitoring sites in the modeling domain.

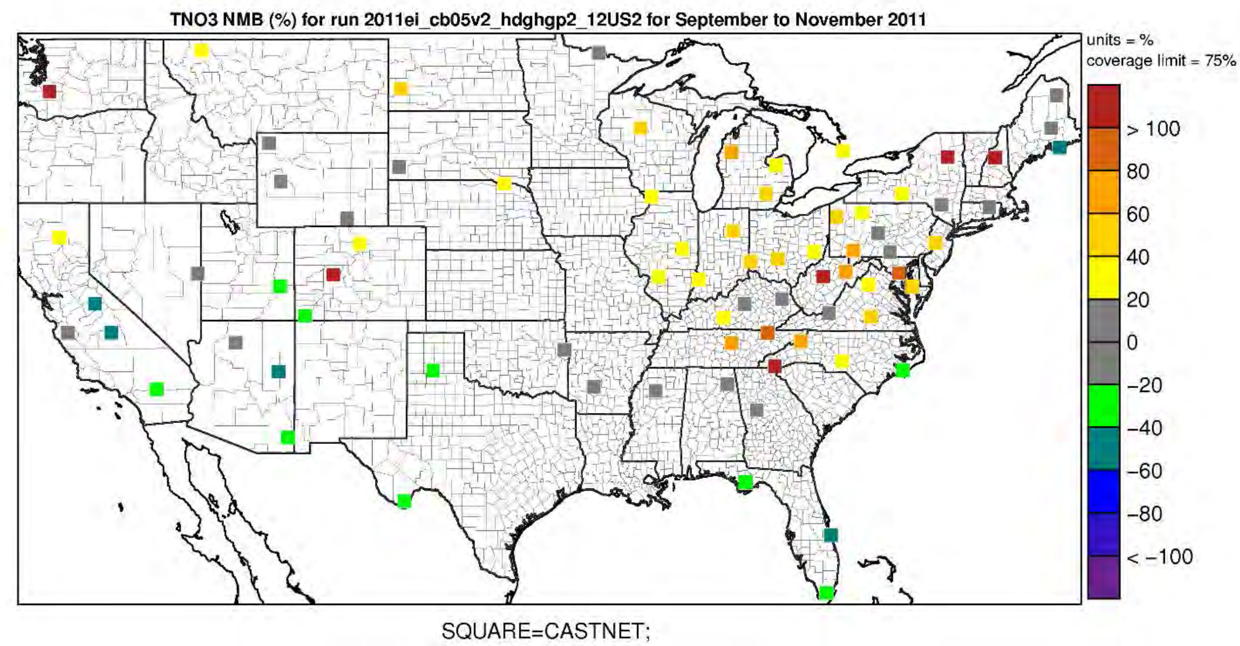

Figure A-10g. Normalized Mean Bias (%) for total nitrate during fall 2011 at monitoring sites in the modeling domain.

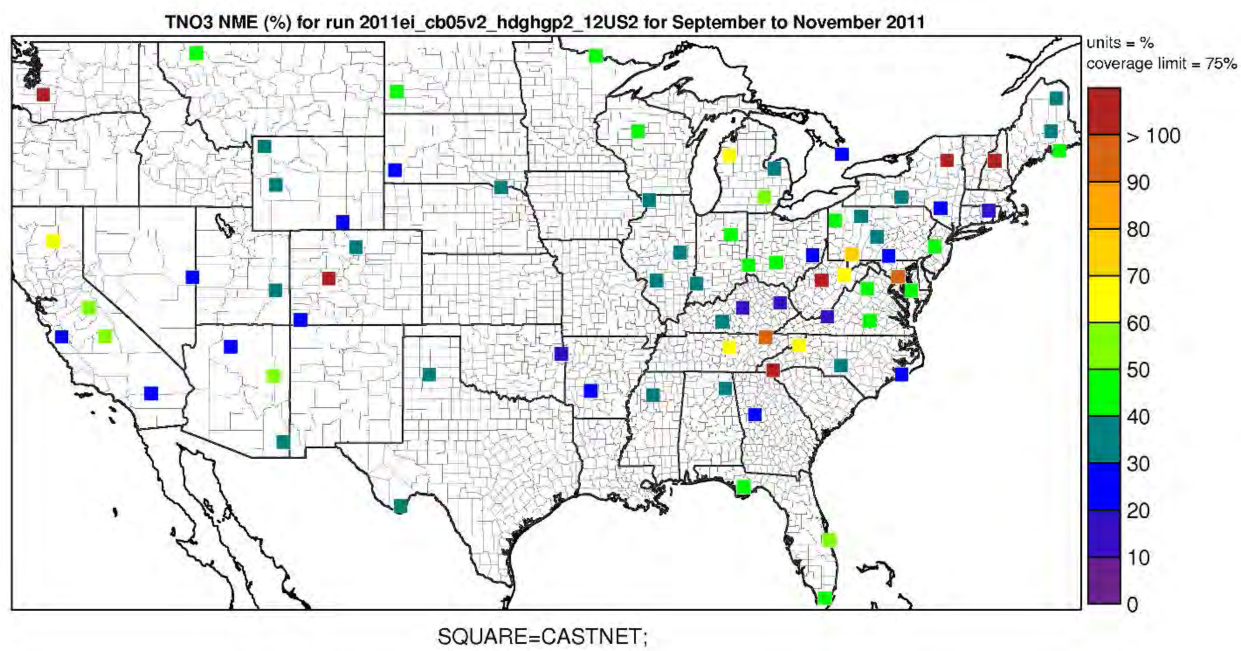

Figure A-10h. Normalized Mean Error (%) for total nitrate during fall 2011 at monitoring sites in the modeling domain.

H. Seasonal Ammonium Performance

The model performance bias and error statistics for ammonium for each climate region and season are provided in Table A-5. These statistics indicate model bias for ammonium is generally over predicted in the spring, fall and winter seasons except for the following exclusions: (1) the spring shows under predictions in the South, Southeast, and Southwest at both CSN and CASTNet sites; (2) the fall has under predictions at rural CASTNet sites in the Ohio Valley, Southeast, South, Southwest, and Northern Rockies as well as at the urban CSN sites in the Southwest; and (3) the winter performance shows under predictions in the Ohio Valley, Southeast, South, Southwest and Northern Rockies at CASTNet monitors in addition to CSN sites at the Northern Rockies. Generally, the West (California and Nevada) show under predictions of ammonia.

Table A-5. Ammonium Performance Statistics by Climate Region, by Season, and by Monitoring Network for the 2011 CMAQ Model Simulation.

Climate Region	Monitor Network	Season	No. of Obs	MB (ug/m^3)	ME (ug/m^3)	NMB (%)	NME (%)
Northeast	CSN	Winter	679	0.2	0.5	20.9	39.3
		Spring	717	0.0	0.3	2.3	37.2
		Summer	721	-0.1	0.3	-11.8	36.6
		Fall	685	0.2	0.3	36.2	56.3
	CASTNet	Winter	170	0.1	0.2	6.7	25.3
		Spring	193	0.0	0.2	-0.1	24.3
		Summer	187	-0.3	0.3	-33.0	34.2
		Fall	196	0.0	0.2	36.2	56.3
Ohio Valley	CSN	Winter	588	0.1	0.5	5.0	34.9
		Spring	624	0.1	0.4	4.4	33.7
		Summer	645	-0.1	0.4	-11.5	34.7
		Fall	611	0.1	0.3	18.6	47.3
	CASTNet	Winter	201	-0.2	0.3	-13.5	21.6
		Spring	214	0.0	0.3	-2.9	28.6
		Summer	207	-0.5	0.5	-34.1	35.2
		Fall	214	-0.1	0.3	-6.6	32.9
Upper Midwest	CSN	Winter	334	0.1	0.6	8.8	38.5
		Spring	337	0.2	0.4	17.8	35.2
		Summer	335	-0.1	0.3	-11.0	43.2
		Fall	340	0.3	0.4	38.8	53.1
	CASTNet	Winter	56	0.0	0.2	2.6	16.2
		Spring	62	0.1	0.2	12.3	29.0
		Summer	65	-0.2	0.2	-30.6	32.1
		Fall	62	0.0	0.2	6.9	28.0
Southeast	CSN	Winter	435	0.2	0.3	23.0	47.3
		Spring	454	-0.1	0.3	-14.6	39.5
		Summer	471	0.0	0.3	-4.0	35.9
		Fall	442	0.2	0.3	56.5	71.6
	CASTNet	Winter	138	-0.1	0.2	-8.0	23.4
		Spring	146	-0.2	0.2	-22.5	30.3
		Summer	147	-0.3	0.4	-32.8	35.2
		Fall	150	-0.1	0.2	-15.3	30.1
South	CSN	Winter	222	0.0	0.4	2.4	44.8

Climate Region	Monitor Network	Season	No. of Obs	MB (ug/m^3)	ME (ug/m^3)	NMB (%)	NME (%)
		Spring	248	-0.2	0.4	-23.2	40.9
		Summer	253	-0.1	0.3	-24.3	45.0
		Fall	238	0.0	0.3	8.4	50.9
	CASTNet	Winter	70	-0.1	0.3	-13.0	32.1
		Spring	85	-0.2	0.3	-24.0	38.5
		Summer	88	-0.3	0.3	-38.6	41.2
		Fall	76	-0.1	0.2	-22.4	32.6
Southwest	CSN	Winter	185	-0.6	0.8	-53.9	65.2
		Spring	190	-0.1	0.2	-44.5	68.9
		Summer	471	0.0	0.3	-4.0	35.9
		Fall	186	-0.2	0.2	-45.6	60.5
	CASTNet	Winter	94	0.0	0.1	13.0	44.9
		Spring	102	-0.1	0.1	-52.8	61.7
		Summer	147	-0.3	.4	-32.8	35.2
		Fall	101	-0.1	0.1	-40.7	45.0
Northern Rockies	CSN	Winter	70	0.0	0.3	-1.5	33.1
		Spring	66	0.1	0.4	5.9	40.5
		Summer	72	0.0	0.1	1.8	39.8
		Fall	69	0.2	0.3	57.9	86.4
	CASTNet	Winter	76	0.0	0.1	-1.7	28.7
		Spring	77	0.1	0.1	23.4	37.6
		Summer	88	-0.1	0.1	-49.4	51.0
		Fall	89	0.0	0.1	-4.4	42.1
Northwest	CSN	Winter	166	0.3	0.6	48.6	108.0
		Spring	167	0.2	0.2	111.0	135.0
		Summer	172	0.0	0.1	11.7	58.8
		Fall	164	0.2	0.3	109.0	152.0
	CASTNet	Winter	12	0.0	0.1	71.5	79.3
		Spring	13	0.0	0.1	33.4	47.1
		Summer	13	0.0	0.1	-18.3	25.0
		Fall	13	0.0	0.1	27.3	50.6
West	CSN	Winter	226	-0.8	1.0	-49.9	62.9
		Spring	242	-0.2	0.4	-32.0	60.0
		Summer	246	-0.6	0.6	-66.8	68.6
		Fall	229	-0.8	0.9	-56.0	66.0
	CASTNet	Winter	69	-0.1	0.2	-19.0	64.9
		Spring	73	-0.1	0.2	-44.2	63.9
		Summer	77	-0.3	0.3	-74.9	74.9
		Fall	77	-0.2	0.2	-52.9	64.1

I. Seasonal Elemental Carbon Performance

The model performance bias and error statistics for elemental carbon for each of the nine climate regions and each season are provided in Table A-6. The statistics show clear over prediction at urban and rural sites in all climate regions with the exception of a slight under prediction during the winter in the Northern Rockies urban sites. In the Northwest, issues in the ambient data when compared to model predictions were found and thus removed from the performance analysis.

Table A-6. Elemental Carbon Performance Statistics by Climate Region, by Season, and by Monitoring Network for the 2011 CMAQ Model Simulation.

Climate Region	Monitor Network	Season	No. of Obs	MB (ug/m^3)	ME (ug/m^3)	NMB (%)	NME (%)
Northeast	IMPROVE	Winter	441	0.2	0.3	94.0	108.0
		Spring	480	0.1	0.1	52.4	79.3
		Summer	446	0.0	0.1	6.0	39.8
		Fall	449	0.1	0.1	34.9	58.1
	CSN	Winter	645	0.7	0.8	94.3	108.0
		Spring	687	0.3	0.4	58.7	81.8
		Summer	699	0.1	0.4	17.5	48.9
		Fall	625	0.3	0.5	48.1	68.8
Ohio Valley	IMPROVE	Winter	222	0.2	0.2	62.4	71.8
		Spring	238	0.0	0.1	15.8	44.0
		Summer	225	0.0	0.1	6.0	31.9
		Fall	236	0.1	0.1	28.3	47.8
	CSN	Winter	575	0.6	0.7	109.0	117.0
		Spring	604	0.3	0.4	50.2	67.8
		Summer	662	0.3	0.4	33.9	52.8
		Fall	611	0.4	0.5	55.4	70.3
Upper Midwest	IMPROVE	Winter	222	0.1	0.2	88.5	102.0
		Spring	232	0.1	0.1	65.8	22.2
		Summer	231	0.0	0.1	0.6	41.6
		Fall	228	0.2	0.2	80.3	99.2
	CSN	Winter	326	0.6	0.6	153.0	155.0
		Spring	330	0.4	0.4	96.3	103.0
		Summer	333	0.2	0.3	37.7	53.4
		Fall	340	0.4	0.4	78.1	82.3
Southeast	IMPROVE	Winter	345	0.2	0.3	51.0	66.8
		Spring	374	0.0	0.2	5.1	50.4
		Summer	359	0.0	0.2	9.5	53.0
		Fall	350	0.1	0.2	26.0	49.6
	CSN	Winter	417	0.4	0.5	52.8	74.5
		Spring	430	0.3	0.4	44.0	68.2
		Summer	460	0.3	0.5	53.4	80.6
		Fall	423	0.4	0.5	61.2	81.5
South	IMPROVE	Winter	267	0.2	0.2	54.5	76.2
		Spring	299	0.0	0.2	6.5	56.0
		Summer	279	0.0	0.1	1.2	47.1
		Fall	251	0.1	0.1	26.2	52.0
	CSN	Winter	222	0.5	0.6	68.9	95.6
		Spring	250	0.3	0.4	53.5	81.6

Climate Region	Monitor Network	Season	No. of Obs	MB (ug/m^3)	ME (ug/m^3)	NMB (%)	NME (%)
		Summer	257	0.4	0.5	94.1	111.0
		Fall	240	0.4	0.5	67.7	85.5
Southwest	IMPROVE	Winter	946	0.1	0.1	36.5	68.3
		Spring	965	0.1	0.1	68.0	101.0
		Summer	987	0.1	0.1	37.7	96.7
		Fall	948	0.1	0.1	40.2	78.9
	CSN	Winter	181	0.6	0.8	57.2	72.4
		Spring	187	0.5	0.5	153.0	155.0
		Summer	195	0.4	0.5	88.4	103.0
		Fall	189	0.6	0.6	76.8	86.6
Northern Rockies	IMPROVE	Winter	541	0.0	0.1	52.6	91.0
		Spring	594	0.0	0.0	18.3	59.2
		Summer	583	0.0	0.1	32.1	69.6
		Fall	568	0.1	0.1	52.5	82.8
	CSN	Winter	63	-0.1	0.9	-13.1	117.0
		Spring	60	0.1	0.3	35.6	91.3
		Summer	70	0.1	0.3	34.3	76.5
		Fall	69	0.2	0.5	41.4	96.2
Northwest	IMPROVE	Winter	-	-	-	-	-
		Spring	-	-	-	-	-
		Summer	-	-	-	-	-
		Fall	-	-	-	-	-
	CSN	Winter	-	-	-	-	-
		Spring	-	-	-	-	-
		Summer	-	-	-	-	-
		Fall	-	-	-	-	-
West	IMPROVE	Winter	552	0.0	0.1	11.6	50.9
		Spring	555	0.0	0.1	25.2	67.0
		Summer	566	0.0	0.1	32.6	69.8
		Fall	588	0.1	0.1	26.0	72.0
	CSN	Winter	226	0.1	0.6	9.5	41.2
		Spring	237	0.5	0.5	100.0	105.0
		Summer	244	0.4	0.4	77.0	80.3
		Fall	226	0.4	0.5	39.0	52.7

J. Seasonal Organic Carbon Performance

The model performance bias and error statistics for organic carbon for each climate region and season are provided in Table A-7. The statistics in this table indicate a tendency for the modeling platform to under predict observed organic carbon concentrations during the spring and summer although over predict organic carbon during the fall and winter at urban and rural locations with the exceptions of the following: (1) the spring shows over predictions in the Northeast and Upper Midwest at MPROVE and CSN sites as well as in the Ohio Valley and Southeast at CSN sites; (2) the summer has over predictions at urban CSN sites in the South, Southeast and Southwest; (3) the fall under predicts at rural IMPROVE sites in the Ohio Valley, South and Southeast; and (4) the winter under predicts in the Northern Rockies at urban sites. In the West, organic carbon performance shows over predictions at urban sites during all seasons. However, in the West performance shows under predictions at rural sites during the entire year. These biases and errors reflect sampling artifacts among each monitoring network. In addition, uncertainties exist for primary organic mass emissions and secondary organic aerosol formation. Research efforts are ongoing to improve fire emission estimates and understand the formation of semi-volatile compounds, and the partitioning of SOA between the gas and particulate phases. Similar to the elemental carbon performance, issues in the ambient data when compared to model predictions were found in the Northwest as well as in the Southwest at urban sites and thus removed from the performance analysis.

Table A-7. Organic Carbon Performance Statistics by Climate Region, by Season, and by Monitoring Network for the 2011 CMAQ Model Simulation.

Climate Region	Monitor Network	Season	No. of Obs	MB (ug/m^3)	ME (ug/m^3)	NMB (%)	NME (%)
Northeast	IMPROVE	Winter	440	1.3	1.4	133.0	140.0
		Spring	478	0.2	0.5	32.8	78.0
		Summer	445	-0.7	0.8	-44.4	50.2
		Fall	448	0.1	0.5	12.1	51.5
	CSN	Winter	639	3.4	3.4	211.0	213.0
		Spring	682	0.9	1.2	84.0	106.0
		Summer	698	-0.2	0.7	-10.9	36.1
		Fall	622	1.1	1.2	74.3	84.3
Ohio Valley	IMPROVE	Winter	222	0.6	0.9	45.7	65.9
		Spring	238	-0.3	0.6	-18.7	45.9
		Summer	225	-0.6	0.6	-29.4	36.3
		Fall	236	0.0	0.5	-0.9	42.6
	CSN	Winter	570	1.9	2.0	121.0	126.0
		Spring	600	0.4	0.8	26.9	52.0
		Summer	662	-0.1	0.7	-4.4	29.0
		Fall	610	0.6	0.8	39.3	54.2
Upper Midwest	IMPROVE	Winter	221	0.6	0.7	95.5	106.0
		Spring	232	0.2	0.5	19.9	64.3
		Summer	231	-0.7	0.7	-45.4	48.2
		Fall	228	0.2	1.2	12.1	73.3
	CSN	Winter	324	2.4	2.4	186.0	190.0
		Spring	330	1.1	1.2	98.3	110.0
		Summer	332	-0.1	0.7	-3.3	37.3
		Fall	333	1.0	1.1	72.1	80.1

Climate Region	Monitor Network	Season	No. of Obs	MB (ug/m^3)	ME (ug/m^3)	NMB (%)	NME (%)
Southeast	IMPROVE	Winter	345	0.5	1.0	33.5	63.9
		Spring	374	-0.5	1.1	-26.4	56.8
		Summer	361	-0.7	1.4	-31.9	61.6
		Fall	349	-0.1	0.9	-6.1	61.1
	CSN	Winter	415	1.3	1.7	62.3	80.5
		Spring	429	0.4	1.0	19.9	52.6
		Summer	458	0.4	1.6	16.4	60.0
		Fall	421	0.8	1.2	47.0	68.4
South	IMPROVE	Winter	266	0.3	0.5	33.5	67.9
		Spring	299	-0.5	0.9	-29.7	57.4
		Summer	281	-0.4	0.6	-28.5	41.6
		Fall	251	0.0	0.4	-1.7	45.7
	CSN	Winter	220	1.2	1.7	61.7	89.3
		Spring	250	-0.1	1.2	-7.0	57.6
		Summer	257	0.5	1.0	27.6	55.8
		Fall	239	0.7	1.1	42.5	64.1
Southwest	IMPROVE	Winter	930	0.1	0.4	18.3	67.8
		Spring	962	0.0	0.2	-6.6	55.5
		Summer	991	-0.3	0.6	-33.3	59.3
		Fall	948	0.0	0.4	8.0	61.8
	CSN	Winter	-	-	-	-	-
		Spring	-	-	-	-	-
		Summer	-	-	-	-	-
		Fall	-	-	-	-	-
Northern Rockies	IMPROVE	Winter	527	0.1	0.2	20.6	73.1
		Spring	584	-0.1	0.2	-25.3	51.2
		Summer	583	-0.3	0.7	-31.4	64.5
		Fall	568	0.1	0.6	7.5	62.3
	CSN	Winter	63	-1.2	3.2	-38.8	107.0
		Spring	58	0.0	0.7	4.4	67.6
		Summer	70	-0.4	0.6	-30.2	39.3
		Fall	68	0.1	1.1	4.1	61.2
Northwest	IMPROVE	Winter	-	-	-	-	-
		Spring	-	-	-	-	-
		Summer	-	-	-	-	-
		Fall	-	-	-	-	-
	CSN	Winter	-	-	-	-	-
		Spring	-	-	-	-	-
		Summer	-	-	-	-	-
		Fall	-	-	-	-	-
West	IMPROVE	Winter	538	0.0	0.3	-2.1	48.1
		Spring	551	-0.1	0.3	-21.0	55.5
		Summer	242	-0.3	0.6	-26.5	56.3
		Fall	585	-0.2	0.8	-14.3	62.6
	CSN	Winter	224	1.3	2.1	34.1	56.5
		Spring	237	1.2	1.3	87.9	96.5
		Summer	242	0.1	0.6	7.1	38.8
		Fall	225	0.7	1.3	27.2	45.7

K. Seasonal Hazardous Air Pollutants Performance

A seasonal operational model performance evaluation for specific hazardous air pollutants (i.e., formaldehyde, acetaldehyde, benzene, 1,3-butadiene and acrolein) was conducted in order to estimate the ability of the CMAQ modeling system to replicate the base year concentrations for the 12 km Continental United States domain. The seasonal model performance results for the 12 km modeling domain are presented below in Table A-8. Toxic measurements included in the evaluation were taken from the 2011 air toxics archive, http://www.epa.gov/ttn/amtic/toxdat.html#data. While most of the data in the archive are from the AQS database including the National Air Toxics Trends Stations (NATTS) (downloaded in July 2014), additional data (e.g., special studies) are included in the archive but not reported in the AQS. Similar to $PM_{2.5}$ and ozone, the evaluation principally consists of statistical assessments of model versus observed pairs that were paired in time and space on daily basis.

Model predictions of annual formaldehyde, acetaldehyde, benzene and 1,3 butadiene showed relatively small to moderate bias and error percentages when compared to observations. The model yielded larger bias and error results for acrolein based on limited monitoring sites. Model performance for HAPs is not as good as model performance for ozone and $PM_{2.5}$. Technical issues in the HAPs data consist of (1) uncertainties in monitoring methods; (2) limited measurements in time/space to characterize ambient concentrations (“local in nature”); (3) ambient data below method detection limit (MDL); (4) commensurability issues between measurements and model predictions; (5) emissions and science uncertainty issues may also affect model performance; and (6) limited data for estimating intercontinental transport that effects the estimation of boundary conditions (i.e., boundary estimates for some species are much higher than predicted values inside the domain).

As with the national, annual $PM_{2.5}$ and ozone CMAQ modeling, the “acceptability” of model performance was judged by comparing our CMAQ 2011 performance results to the limited performance found in recent regional multi-pollutant model applications.[21,22,23] Overall, the mean bias and error (MB and ME), as well as the normalized mean bias and error (NMB and NME) statistics shown below in Table A-8 indicate that CMAQ-predicted 2011 toxics (i.e., observation vs. model predictions) are within the range of recent regional modeling applications.

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[21] Phillips, S., K. Wang, C. Jang, N. Possiel, M. Strum, T. Fox, 2007: Evaluation of 2002 Multi-pollutant Platform: Air Toxics, Ozone, and Particulate Matter, 7th Annual CMAS Conference, Chapel Hill, NC, October 6-8, 2008.

[22] Strum, M., Wesson, K., Phillips, S., Cook, R., Michaels, H., Brzezinski, D., Pollack, A., Jimenez, M., Shepard, S. Impact of using in-line emissions on multi-pollutant air quality model predictions at regional and local scales. 17th Annual International Emission Inventory Conference, Portland, Oregon, June 2-5, 2008.

[23] Wesson, K., N. Fann, and B. Timin, 2010: Draft Manuscript: Air Quality and Benefits Model Responsiveness to Varying Horizontal Resolution in the Detroit Urban Area, Atmospheric Pollution Research, Special Issue: Air Quality Modeling and Analysis.

Table A-8. Hazardous Air Toxics Performance Statistics by Season for the 2011 CMAQ Model Simulation.

Air Toxic Species	Season	No. of Obs.	MB (ug/m^3)	ME (ug/m^3)	NMB (%)	NME (%)
Formaldehyde	Winter	1,070	-0.9	1.1	-50.8	59.9
	Spring	1,067	-1.3	1.3	-59.1	62.4
	Summer	1,044	-1.2	1.6	-32.8	41.8
	Fall	1,055	-0.8	1.1	-41.3	42.9
Acetaldehyde	Winter	1,056	-0.4	0.7	-30.0	52.9
	Spring	1,069	-0.2	0.7	-12.0	55.0
	Summer	1,063	1.6	1.9	88.5	106.0
	Fall	1,095	0.0	0.8	2.6	55.9
Benzene	Winter	2,498	0.2	0.7	25.5	76.4
	Spring	2,386	-0.1	0.5	-11.0	64.7
	Summer	2,504	-0.1	0.6	-14.0	79.0
	Fall	2,448	0.0	0.6	-5.6	67.9
1,3-Butadiene	Winter	2,373	0.0	0.1	-8.2	114.0
	Spring	2,254	0.0	0.1	-24.7	115.0
	Summer	2,330	0.0	0.1	-15.3	116.0
	Fall	2,327	0.0	0.1	-38.3	100.0
Acrolein	Winter	172	-0.4	0.4	-93.2	93.5
	Spring	140	-0.3	0.3	-94.9	94.9
	Summer	211	-0.5	0.5	-97.5	97.6
	Fall	198	-0.4	0.4	-93.7	94.5

L. Seasonal Nitrate and Sulfate Deposition Performance

Seasonal nitrate and sulfate wet deposition performance statistics for the 12 km Continental U.S. domain are provided in Table A-9. The model predictions for seasonal nitrate deposition generally show under predictions for the continental U.S. NADP sites (NMB values range from -8% to -41%). Sulfate deposition performance shows the similar under predictions (NMB values range from -15% to 25%). The errors for both annual nitrate and sulfate are relatively moderate with values ranging from 51% to 69% which reflect scatter in the model predictions versus observation comparison.

Table A-9. Nitrate and Sulfate Wet Deposition Performance Statistics by Season for the 2011 CMAQ Model Simulation.

Wet Deposition Species	Season	No. of Obs.	MB (kg/ha)	ME (kg/ha)	NMB (%)	NME (%)
Nitrate	Winter	1,772	0.0	0.1	-15.4	58.4
	Spring	2,006	-0.1	0.1	-26.7	50.9
	Summer	1,892	-0.1	0.2	-40.8	64.1
	Fall	1,934	0.0	0.1	-7.6	55.5
Sulfate	Winter	1,772	0.0	0.1	-24.7	53.0
	Spring	2,006	-0.1	0.1	-22.8	53.5
	Summer	1,892	0.0	0.2	-19.1	68.7
	Fall	1,934	0.0	0.1	-15.0	56.1

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Appendix B

8-Hour Ozone Design Values for Air Quality Modeling Scenarios

Table B-1. 8-Hour Ozone Design Values for HDGHG Phase 2 Scenarios
(units are ppb)

State	County	2011 Baseline DV	2040 Reference DV	2040 HDGHGP2 Control DV
Alabama	Baldwin	70.0	48.94	48.42
Alabama	Colbert	65.0	42.70	42.29
Alabama	De Kalb	66.0	49.11	48.40
Alabama	Elmore	66.3	46.73	46.05
Alabama	Etowah	61.7	43.59	42.74
Alabama	Houston	63.7	47.11	46.60
Alabama	Jefferson	76.7	55.69	54.88
Alabama	Madison	70.7	50.92	50.31
Alabama	Mobile	73.0	50.79	50.33
Alabama	Montgomery	67.3	47.97	47.23
Alabama	Morgan	68.7	51.73	51.09
Alabama	Russell	66.0	48.06	47.58
Alabama	Shelby	73.3	50.70	49.93
Alabama	Sumter	61.0	47.57	47.01
Alabama	Tuscaloosa	58.7	43.54	42.93
Arizona	Cochise	72.0	66.64	66.38
Arizona	Coconino	71.0	62.68	62.48
Arizona	Gila	73.7	59.06	58.11
Arizona	La Paz	71.3	61.74	61.34
Arizona	Maricopa	79.7	63.29	62.15
Arizona	Navajo	68.7	61.14	60.83
Arizona	Pima	71.3	55.84	54.87
Arizona	Pinal	75.0	60.30	59.53
Arizona	Yavapai	68.0	61.76	61.46
Arizona	Yuma	75.3	60.91	60.55
Arkansas	Crittenden	77.3	57.18	56.39
Arkansas	Newton	68.0	53.10	52.55
Arkansas	Polk	72.3	57.34	56.68
Arkansas	Pulaski	75.7	52.21	50.93
Arkansas	Washington	71.0	56.87	56.37
California	Alameda	73.3	61.69	61.59
California	Amador	72.0	54.63	54.55
California	Butte	76.3	56.58	56.49
California	Calaveras	75.0	56.50	56.41
California	Colusa	61.0	49.03	48.89
California	Contra Costa	71.7	59.24	59.13
California	El Dorado	82.7	59.99	59.89

State	County	2011 Baseline DV	2040 Reference DV	2040 HDGHGP2 Control DV
California	Fresno	97.0	75.88	75.80
California	Glenn	64.3	51.51	51.40
California	Imperial	81.0	72.19	72.06
California	Inyo	71.7	64.98	64.94
California	Kern	91.7	73.89	73.76
California	Kings	87.0	68.38	68.30
California	Lake	58.3	46.68	46.64
California	Los Angeles	97.3	79.22	79.14
California	Madera	85.0	68.04	67.95
California	Marin	52.3	47.87	47.81
California	Mariposa	77.3	64.73	64.67
California	Merced	82.7	65.69	65.60
California	Monterey	58.0	46.87	46.81
California	Napa	62.3	48.11	48.03
California	Nevada	77.7	56.30	56.20
California	Orange	72.0	62.51	62.45
California	Placer	84.0	60.93	60.84
California	Riverside	100.7	79.14	79.04
California	Sacramento	93.3	66.68	66.57
California	San Benito	70.0	56.83	56.75
California	San Bernardino	105.0	87.81	87.70
California	San Diego	81.0	60.49	60.45
California	San Joaquin	79.0	64.19	64.07
California	San Luis Obispo	78.0	62.78	62.70
California	Santa Barbara	68.3	58.74	58.69
California	Santa Clara	71.3	58.57	58.51
California	Santa Cruz	53.0	44.46	44.40
California	Shasta	68.0	54.14	54.08
California	Solano	68.0	53.93	53.82
California	Sonoma	48.0	36.06	36.02
California	Stanislaus	87.0	69.89	69.78
California	Sutter	65.0	49.49	49.38
California	Tehama	75.3	58.90	58.80
California	Tulare	94.7	74.01	73.94
California	Tuolumne	73.3	55.65	55.56
California	Ventura	81.0	63.90	63.81
California	Yolo	69.0	55.97	55.87
Colorado	Adams	76.0	64.84	64.32
Colorado	Arapahoe	76.7	64.64	64.21
Colorado	Boulder	74.7	65.21	64.85

State	County	2011 Baseline DV	2040 Reference DV	2040 HDGHGP2 Control DV
Colorado	Denver	71.0	60.57	60.09
Colorado	Douglas	80.7	66.77	66.33
Colorado	El Paso	72.7	61.40	61.10
Colorado	Garfield	65.0	63.21	63.06
Colorado	Jefferson	80.3	69.89	69.46
Colorado	La Plata	73.0	64.05	63.81
Colorado	Larimer	78.0	71.33	70.94
Colorado	Mesa	67.0	60.82	60.65
Colorado	Montezuma	68.3	59.24	59.02
Colorado	Rio Blanco	77.0	71.10	70.90
Colorado	Weld	74.7	68.41	68.07
Connecticut	Fairfield	84.3	77.78	77.32
Connecticut	Hartford	73.7	55.79	55.28
Connecticut	Litchfield	70.3	54.48	54.13
Connecticut	Middlesex	79.3	59.52	59.06
Connecticut	New Haven	85.7	67.33	66.86
Connecticut	New London	80.3	62.78	62.45
Connecticut	Tolland	75.3	56.94	56.45
Delaware	Kent	74.3	55.93	55.36
Delaware	New Castle	78.0	56.34	55.70
Delaware	Sussex	77.7	60.20	59.69
D.C.	Washington	80.7	56.67	56.19
Florida	Alachua	63.7	49.36	48.72
Florida	Baker	61.7	49.17	48.69
Florida	Bay	68.0	49.31	48.80
Florida	Brevard	64.0	50.68	50.25
Florida	Broward	59.3	48.20	48.05
Florida	Collier	59.5	45.95	45.64
Florida	Columbia	62.7	50.26	49.75
Florida	Duval	64.3	49.67	49.20
Florida	Escambia	72.0	50.77	50.17
Florida	Highlands	63.3	52.16	51.86
Florida	Hillsborough	71.7	55.26	55.00
Florida	Holmes	62.3	45.97	45.46
Florida	Indian River	65.0	51.03	50.64
Florida	Lake	65.7	51.28	51.00
Florida	Lee	63.7	48.17	47.80
Florida	Leon	64.3	46.19	45.72
Florida	Manatee	67.0	51.20	50.89
Florida	Marion	65.0	49.23	48.85

State	County	2011 Baseline DV	2040 Reference DV	2040 HDGHGP2 Control DV
Florida	Miami-Dade	64.0	52.53	52.32
Florida	Okaloosa	66.0	47.21	46.68
Florida	Orange	71.7	54.13	53.82
Florida	Osceola	66.0	48.71	48.31
Florida	Palm Beach	62.7	51.92	51.73
Florida	Pasco	66.7	51.56	51.31
Florida	Pinellas	66.7	56.12	55.91
Florida	Polk	68.3	51.87	51.61
Florida	Santa Rosa	71.7	50.44	49.81
Florida	Sarasota	71.3	53.31	52.91
Florida	Seminole	67.3	50.42	50.07
Florida	Volusia	63.3	48.91	48.41
Florida	Wakulla	63.7	48.30	47.78
Georgia	Bibb	72.3	48.55	47.79
Georgia	Chatham	63.3	48.07	47.53
Georgia	Chattooga	66.3	47.19	46.43
Georgia	Clarke	70.7	45.68	45.05
Georgia	Cobb	76.0	50.41	49.75
Georgia	Columbia	68.7	48.53	47.87
Georgia	Coweta	65.0	43.36	42.84
Georgia	Dawson	66.3	45.22	44.56
Georgia	De Kalb	77.3	50.19	49.47
Georgia	Douglas	73.3	48.53	47.85
Georgia	Fulton	81.0	54.12	53.44
Georgia	Glynn	60.0	45.73	45.04
Georgia	Gwinnett	76.7	49.02	48.42
Georgia	Henry	80.0	53.99	53.26
Georgia	Murray	70.3	49.42	48.33
Georgia	Muscogee	66.0	47.98	47.46
Georgia	Paulding	70.7	45.48	44.62
Georgia	Richmond	70.0	49.94	49.26
Georgia	Rockdale	77.0	49.96	49.22
Georgia	Sumter	64.7	49.50	49.00
Idaho	Ada	67.5	57.33	56.32
Idaho	Butte	62.3	58.82	58.65
Illinois	Adams	67.0	53.67	53.14
Illinois	Champaign	71.0	54.89	54.04
Illinois	Clark	66.0	52.80	52.19
Illinois	Cook	77.7	59.44	58.96
Illinois	Du Page	66.3	52.60	52.18

State	County	2011 Baseline DV	2040 Reference DV	2040 HDGHGP2 Control DV
Illinois	Effingham	68.3	53.12	52.16
Illinois	Hamilton	74.3	59.35	58.71
Illinois	Jersey	76.0	56.37	55.44
Illinois	Jo Daviess	68.0	54.59	54.18
Illinois	Kane	69.7	57.70	57.14
Illinois	Lake	79.3	51.44	51.14
Illinois	McHenry	69.7	57.84	57.26
Illinois	McLean	70.3	53.67	52.89
Illinois	Macon	71.3	54.33	53.57
Illinois	Macoupin	71.3	52.56	51.59
Illinois	Madison	78.3	57.18	56.10
Illinois	Peoria	70.7	53.98	53.39
Illinois	Randolph	67.7	53.90	53.01
Illinois	Rock Island	58.3	46.76	46.40
Illinois	St Clair	74.7	56.45	55.14
Illinois	Sangamon	72.0	54.39	53.50
Illinois	Will	64.0	52.23	51.62
Illinois	Winnebago	67.3	54.64	54.02
Indiana	Allen	69.3	54.26	53.73
Indiana	Boone	72.3	56.74	56.19
Indiana	Carroll	69.0	55.04	54.42
Indiana	Clark	78.0	60.20	59.31
Indiana	Delaware	68.7	52.08	51.47
Indiana	Elkhart	67.7	52.05	51.37
Indiana	Floyd	76.0	57.91	57.32
Indiana	Greene	77.0	65.65	65.24
Indiana	Hamilton	71.0	54.71	54.20
Indiana	Hancock	66.7	50.84	50.33
Indiana	Hendricks	67.0	52.23	51.77
Indiana	Huntington	65.0	51.86	51.34
Indiana	Jackson	66.0	54.92	54.41
Indiana	Johnson	69.0	54.93	54.29
Indiana	Knox	73.0	61.01	60.63
Indiana	Lake	69.7	54.06	53.55
Indiana	La Porte	79.3	64.26	64.00
Indiana	Madison	68.3	51.45	50.84
Indiana	Marion	72.7	55.62	55.08
Indiana	Morgan	69.0	53.98	53.40
Indiana	Perry	72.7	58.26	58.13
Indiana	Porter	70.3	55.09	54.75

State	County	2011 Baseline DV	2040 Reference DV	2040 HDGHGP2 Control DV
Indiana	Posey	70.3	57.59	57.22
Indiana	St Joseph	69.3	53.69	52.95
Indiana	Shelby	74.0	56.94	56.28
Indiana	Vanderburgh	74.0	61.24	60.87
Indiana	Vigo	65.7	52.03	51.52
Indiana	Warrick	71.0	59.41	59.04
Iowa	Bremer	64.0	50.54	50.02
Iowa	Clinton	66.7	53.05	52.63
Iowa	Harrison	67.7	54.06	53.60
Iowa	Linn	64.3	50.92	50.37
Iowa	Montgomery	65.3	53.56	53.08
Iowa	Palo Alto	66.7	54.62	54.14
Iowa	Polk	59.7	46.00	45.48
Iowa	Scott	66.0	52.93	52.52
Iowa	Story	61.3	47.85	47.32
Iowa	Van Buren	65.7	51.23	50.58
Iowa	Warren	63.7	49.72	49.16
Kansas	Johnson	72.7	56.24	55.72
Kansas	Leavenworth	72.0	54.95	54.33
Kansas	Linn	70.0	55.80	55.25
Kansas	Sedgwick	75.7	58.67	58.22
Kansas	Shawnee	71.7	54.64	54.08
Kansas	Sumner	76.0	61.85	61.31
Kansas	Trego	72.3	63.91	63.60
Kansas	Wyandotte	65.7	50.15	49.70
Kentucky	Bell	63.3	48.37	47.58
Kentucky	Boone	68.0	56.50	55.93
Kentucky	Boyd	70.0	56.02	55.53
Kentucky	Bullitt	72.3	57.48	56.53
Kentucky	Campbell	76.7	60.10	59.45
Kentucky	Carter	67.0	54.06	53.55
Kentucky	Christian	70.7	49.97	49.32
Kentucky	Daviess	76.3	60.56	60.14
Kentucky	Edmonson	72.0	53.82	52.61
Kentucky	Fayette	71.3	54.79	54.14
Kentucky	Greenup	69.7	56.82	56.31
Kentucky	Hancock	73.7	59.24	58.84
Kentucky	Hardin	70.3	53.80	52.97
Kentucky	Henderson	76.3	62.77	62.39
Kentucky	Jefferson	82.0	67.22	66.68

State	County	2011 Baseline DV	2040 Reference DV	2040 HDGHGP2 Control DV
Kentucky	Jessamine	70.0	51.87	51.23
Kentucky	Livingston	72.3	54.78	54.22
Kentucky	McCracken	73.7	55.29	54.79
Kentucky	Oldham	82.0	63.12	62.32
Kentucky	Perry	65.3	54.27	53.86
Kentucky	Pike	65.7	53.81	53.40
Kentucky	Pulaski	66.7	47.03	46.40
Kentucky	Simpson	69.3	49.79	48.95
Kentucky	Trigg	69.0	52.39	51.64
Kentucky	Warren	64.0	46.97	46.02
Kentucky	Washington	69.0	53.44	52.82
Louisiana	Ascension	74.7	59.74	59.26
Louisiana	Bossier	77.3	62.52	62.11
Louisiana	Caddo	74.7	59.76	59.34
Louisiana	Calcasieu	73.3	59.86	59.39
Louisiana	East Baton Rouge	78.7	63.68	63.21
Louisiana	Iberville	76.0	61.76	61.30
Louisiana	Jefferson	73.7	58.99	58.53
Louisiana	Lafayette	71.0	56.01	55.53
Louisiana	Lafourche	72.3	57.83	57.30
Louisiana	Livingston	74.0	58.43	57.94
Louisiana	Orleans	69.3	56.68	56.26
Louisiana	Ouachita	63.3	52.36	52.07
Louisiana	Pointe Coupee	75.3	58.17	57.73
Louisiana	St Bernard	69.0	55.24	54.85
Louisiana	St Charles	70.0	55.72	55.28
Louisiana	St James	68.0	54.75	54.28
Louisiana	St John the Baptist	74.0	57.79	57.24
Louisiana	St Tammany	73.3	60.17	59.75
Louisiana	West Baton Rouge	70.3	55.57	55.08
Maine	Androscoggin	61.0	47.87	47.36
Maine	Cumberland	69.3	53.82	53.38
Maine	Hancock	71.7	57.50	57.12
Maine	Kennebec	62.7	47.18	46.63
Maine	Knox	67.7	52.92	52.31
Maine	Oxford	54.3	44.20	43.79
Maine	Sagadahoc	61.0	47.78	47.28
Maine	Washington	58.3	46.94	46.64

State	County	2011 Baseline DV	2040 Reference DV	2040 HDGHGP2 Control DV
Maine	York	73.7	56.74	56.20
Maryland	Anne Arundel	83.0	57.66	57.07
Maryland	Baltimore	80.7	63.14	62.63
Maryland	Calvert	79.7	62.26	61.90
Maryland	Carroll	76.3	57.04	56.40
Maryland	Cecil	83.0	60.36	59.61
Maryland	Charles	79.0	55.03	54.58
Maryland	Dorchester	75.0	58.20	57.62
Maryland	Frederick	76.3	57.88	57.17
Maryland	Garrett	72.0	54.68	54.28
Maryland	Harford	90.0	68.70	68.06
Maryland	Kent	78.7	55.75	55.05
Maryland	Montgomery	75.7	55.07	54.45
Maryland	Prince Georges	82.3	56.71	56.17
Maryland	Washington	72.7	55.55	54.87
Maryland	Baltimore City	73.7	57.84	57.38
Massachusetts	Barnstable	73.0	58.28	57.83
Massachusetts	Berkshire	69.0	54.77	54.37
Massachusetts	Bristol	74.0	58.34	57.86
Massachusetts	Dukes	77.0	62.53	62.03
Massachusetts	Essex	71.0	55.74	55.28
Massachusetts	Hampden	73.7	55.62	55.12
Massachusetts	Hampshire	71.3	53.44	52.97
Massachusetts	Middlesex	67.3	51.31	50.83
Massachusetts	Norfolk	72.3	54.65	54.54
Massachusetts	Suffolk	68.3	49.82	49.61
Massachusetts	Worcester	69.0	51.55	51.09
Michigan	Allegan	82.7	65.91	65.20
Michigan	Benzie	73.0	58.45	57.66
Michigan	Berrien	79.7	61.82	61.07
Michigan	Cass	76.7	58.75	57.93
Michigan	Chippewa	63.5	56.16	55.84
Michigan	Clinton	69.3	53.41	52.70
Michigan	Genesee	73.0	57.23	56.58
Michigan	Huron	71.3	57.28	56.62
Michigan	Ingham	70.3	53.37	52.66
Michigan	Kalamazoo	73.7	57.25	56.46
Michigan	Kent	73.0	55.67	54.85
Michigan	Lenawee	75.5	58.06	57.38
Michigan	Macomb	77.3	63.92	63.36

State	County	2011 Baseline DV	2040 Reference DV	2040 HDGHGP2 Control DV
Michigan	Manistee	72.3	58.23	57.53
Michigan	Mason	73.3	58.53	57.87
Michigan	Missaukee	68.3	54.51	53.88
Michigan	Muskegon	79.7	63.98	63.42
Michigan	Oakland	76.3	61.56	60.94
Michigan	Ottawa	76.0	58.42	57.53
Michigan	St Clair	75.3	61.23	60.57
Michigan	Schoolcraft	71.7	56.74	55.90
Michigan	Washtenaw	73.3	57.32	56.71
Michigan	Wayne	78.7	64.84	64.25
Minnesota	Anoka	67.0	52.98	52.52
Minnesota	Crow Wing	62.0	49.64	49.20
Minnesota	Goodhue	62.5	50.51	50.10
Minnesota	Lyon	64.5	53.62	53.23
Minnesota	Mille Lacs	59.7	45.61	45.35
Minnesota	Olmsted	63.5	50.36	49.93
Minnesota	St Louis	61.3	42.83	42.71
Minnesota	Scott	63.5	51.03	50.67
Minnesota	Stearns	61.5	51.18	50.73
Minnesota	Wright	63.5	52.22	51.88
Mississippi	Bolivar	71.7	58.68	58.28
Mississippi	De Soto	72.3	53.58	52.75
Mississippi	Hancock	66.3	50.28	49.82
Mississippi	Harrison	72.3	51.65	51.07
Mississippi	Hinds	67.0	44.87	44.17
Mississippi	Jackson	71.7	54.60	53.99
Mississippi	Lauderdale	62.7	47.51	46.78
Mississippi	Lee	65.0	48.56	48.08
Mississippi	Yalobusha	63.0	50.49	50.08
Missouri	Andrew	73.3	56.14	55.53
Missouri	Boone	69.0	53.72	53.01
Missouri	Callaway	67.7	52.88	52.27
Missouri	Cass	70.0	53.85	53.36
Missouri	Cedar	71.7	57.05	56.50
Missouri	Clay	77.7	59.25	58.65
Missouri	Clinton	78.0	58.64	57.93
Missouri	Greene	71.7	54.92	54.44
Missouri	Jasper	76.7	60.36	59.77
Missouri	Jefferson	76.3	57.29	55.57
Missouri	Lincoln	77.0	58.68	57.65

State	County	2011 Baseline DV	2040 Reference DV	2040 HDGHGP2 Control DV
Missouri	Monroe	68.7	54.83	54.19
Missouri	Perry	74.3	57.73	56.91
Missouri	St Charles	82.3	60.36	59.24
Missouri	Ste Genevieve	72.3	57.18	56.30
Missouri	St Louis	79.0	59.55	58.23
Missouri	Taney	69.0	54.17	53.59
Missouri	St Louis City	75.7	56.93	55.57
Montana	Powder River	55.0	50.47	50.25
Montana	Rosebud	55.5	52.08	51.93
Nebraska	Douglas	67.0	54.55	54.08
Nebraska	Knox	68.0	59.37	59.03
Nebraska	Lancaster	53.3	45.22	44.92
Nevada	Churchill	56.7	50.48	50.36
Nevada	Clark	76.0	64.62	64.28
Nevada	Lyon	68.5	58.89	58.71
Nevada	Washoe	67.3	56.90	56.65
Nevada	White Pine	72.0	63.30	63.10
Nevada	Carson City	66.0	57.09	56.99
New Hampshire	Belknap	62.3	49.20	48.88
New Hampshire	Cheshire	62.3	47.79	47.39
New Hampshire	Coos	69.3	56.84	56.38
New Hampshire	Grafton	59.7	47.04	46.58
New Hampshire	Hillsborough	69.0	52.95	52.52
New Hampshire	Merrimack	64.7	49.83	49.34
New Hampshire	Rockingham	68.0	52.76	52.22
New Jersey	Atlantic	74.3	56.05	55.56
New Jersey	Bergen	77.0	58.86	58.37
New Jersey	Camden	82.7	62.81	62.25
New Jersey	Cumberland	72.0	53.98	53.45
New Jersey	Essex	78.0	60.44	59.93
New Jersey	Gloucester	84.3	62.41	61.75
New Jersey	Hudson	77.0	62.20	61.73
New Jersey	Hunterdon	78.0	57.77	57.27
New Jersey	Mercer	78.3	59.37	58.87
New Jersey	Middlesex	81.3	61.60	61.08
New Jersey	Monmouth	80.0	63.08	62.62
New Jersey	Morris	76.3	55.94	55.47
New Jersey	Ocean	82.0	60.92	60.40
New Jersey	Passaic	73.3	57.14	56.66
New Jersey	Warren	66.0	47.90	47.48

State	County	2011 Baseline DV	2040 Reference DV	2040 HDGHGP2 Control DV
New Mexico	Bernalillo	72.0	59.63	59.25
New Mexico	Dona Ana	71.0	59.08	58.70
New Mexico	Eddy	70.3	66.47	66.21
New Mexico	Grant	65.0	58.53	58.16
New Mexico	Lea	62.7	60.51	60.34
New Mexico	Luna	63.0	54.72	54.31
New Mexico	Sandoval	63.0	56.56	56.37
New Mexico	San Juan	71.0	60.79	60.61
New Mexico	Santa Fe	64.3	58.04	57.72
New Mexico	Valencia	68.5	56.21	55.70
New York	Albany	68.0	53.85	53.46
New York	Bronx	74.0	73.23	73.06
New York	Chautauqua	74.0	58.29	57.80
New York	Chemung	66.5	53.89	53.46
New York	Dutchess	72.0	54.42	54.05
New York	Erie	71.3	58.34	57.79
New York	Essex	70.3	58.12	57.70
New York	Hamilton	66.0	51.96	51.46
New York	Herkimer	62.0	49.79	49.32
New York	Jefferson	71.7	57.89	57.58
New York	Madison	67.0	53.93	53.45
New York	New York	73.3	70.61	70.39
New York	Niagara	72.3	62.56	62.24
New York	Oneida	61.5	49.39	48.98
New York	Onondaga	69.3	55.75	55.34
New York	Orange	67.0	52.41	52.01
New York	Oswego	68.0	54.68	54.37
New York	Putnam	70.0	52.36	51.93
New York	Queens	78.0	76.00	75.80
New York	Rensselaer	67.0	52.68	52.31
New York	Richmond	81.3	73.85	73.47
New York	Rockland	75.0	57.67	57.18
New York	Saratoga	67.0	52.18	51.77
New York	Steuben	65.3	53.43	53.01
New York	Suffolk	83.3	72.82	72.49
New York	Ulster	69.0	55.74	55.37
New York	Wayne	65.0	53.78	53.45
New York	Westchester	75.3	74.17	73.94
North Carolina	Alexander	66.7	47.39	46.95
North Carolina	Avery	63.3	48.76	48.19

State	County	2011 Baseline DV	2040 Reference DV	2040 HDGHGP2 Control DV
North Carolina	Buncombe	66.7	48.11	47.55
North Carolina	Caldwell	66.0	47.68	47.24
North Carolina	Caswell	70.7	49.49	48.60
North Carolina	Chatham	64.0	45.06	44.37
North Carolina	Cumberland	70.7	50.75	50.11
North Carolina	Davie	71.0	47.93	47.17
North Carolina	Durham	70.0	47.10	46.27
North Carolina	Edgecombe	70.0	49.85	49.25
North Carolina	Forsyth	75.3	52.22	51.53
North Carolina	Franklin	69.3	48.12	47.36
North Carolina	Graham	70.3	52.47	51.83
North Carolina	Granville	70.7	49.49	48.62
North Carolina	Guilford	74.0	51.87	51.22
North Carolina	Haywood	67.7	52.83	52.27
North Carolina	Jackson	67.0	51.93	51.39
North Carolina	Johnston	71.7	49.65	49.08
North Carolina	Lenoir	67.7	51.44	50.84
North Carolina	Lincoln	72.7	49.35	48.76
North Carolina	Martin	66.3	48.67	48.16
North Carolina	Mecklenburg	80.0	54.96	54.15
North Carolina	Montgomery	66.0	46.25	45.50
North Carolina	New Hanover	63.0	45.18	44.79
North Carolina	Person	71.0	48.37	47.59
North Carolina	Pitt	69.7	51.59	50.94
North Carolina	Rockingham	71.0	50.07	49.30
North Carolina	Rowan	75.3	50.83	50.08
North Carolina	Swain	60.7	46.52	46.02
North Carolina	Union	71.0	47.47	46.81
North Carolina	Wake	73.0	51.61	51.06
North Carolina	Yancey	69.7	53.01	52.50
Ohio	Allen	73.0	56.88	56.34
Ohio	Ashtabula	77.3	58.00	57.44
Ohio	Athens	69.0	54.72	54.22
Ohio	Butler	79.7	62.26	61.56
Ohio	Clark	75.0	56.06	55.40
Ohio	Clermont	78.7	58.58	57.86
Ohio	Clinton	78.7	57.77	56.98
Ohio	Cuyahoga	77.7	57.10	56.83
Ohio	Delaware	73.0	54.45	53.80
Ohio	Fayette	72.0	52.14	51.55

State	County	2011 Baseline DV	2040 Reference DV	2040 HDGHGP2 Control DV
Ohio	Franklin	80.3	60.19	59.51
Ohio	Geauga	74.7	57.09	56.53
Ohio	Greene	73.0	53.98	53.28
Ohio	Hamilton	82.0	64.25	63.48
Ohio	Jefferson	70.3	58.34	57.96
Ohio	Knox	73.7	54.68	54.02
Ohio	Lake	80.0	56.20	55.83
Ohio	Lawrence	70.0	57.07	56.55
Ohio	Licking	74.3	54.27	53.48
Ohio	Lorain	71.7	52.72	52.39
Ohio	Lucas	74.3	55.56	55.13
Ohio	Madison	74.3	54.46	53.76
Ohio	Mahoning	70.7	54.12	53.63
Ohio	Medina	69.0	52.97	52.40
Ohio	Miami	73.3	56.85	56.33
Ohio	Montgomery	76.7	57.30	56.64
Ohio	Portage	68.3	51.55	51.05
Ohio	Preble	72.3	55.49	54.89
Ohio	Stark	76.7	57.34	56.72
Ohio	Summit	72.0	55.29	54.69
Ohio	Trumbull	76.3	57.53	57.01
Ohio	Warren	77.7	58.18	57.44
Ohio	Washington	71.3	55.56	55.07
Ohio	Wood	71.3	55.79	55.25
Oklahoma	Adair	73.7	58.39	57.81
Oklahoma	Caddo	74.7	59.54	59.02
Oklahoma	Canadian	75.7	56.27	55.68
Oklahoma	Cherokee	73.7	58.51	58.02
Oklahoma	Cleveland	75.0	59.25	58.71
Oklahoma	Comanche	74.7	62.71	62.19
Oklahoma	Creek	77.0	58.51	57.99
Oklahoma	Dewey	72.3	64.28	63.92
Oklahoma	Kay	73.0	59.16	58.61
Oklahoma	Mc Clain	74.0	59.15	58.60
Oklahoma	Mc Curtain	68.0	56.84	56.27
Oklahoma	Mayes	76.3	61.60	61.06
Oklahoma	Oklahoma	78.3	62.06	61.52
Oklahoma	Ottawa	74.0	57.69	57.13
Oklahoma	Pittsburg	73.3	62.38	61.79
Oklahoma	Sequoyah	72.0	58.49	57.90

State	County	2011 Baseline DV	2040 Reference DV	2040 HDGHGP2 Control DV
Oklahoma	Tulsa	79.0	60.94	60.42
Oregon	Clackamas	64.0	51.19	50.51
Oregon	Columbia	51.3	42.33	41.83
Oregon	Deschutes	58.5	52.28	52.14
Oregon	Jackson	61.7	53.21	52.87
Oregon	Lane	60.0	47.17	46.60
Oregon	Marion	59.3	47.20	46.68
Oregon	Multnomah	56.7	49.10	48.69
Oregon	Umatilla	61.3	50.07	49.52
Pennsylvania	Allegheny	80.7	67.30	66.98
Pennsylvania	Armstrong	74.3	62.54	62.26
Pennsylvania	Beaver	74.7	64.12	63.78
Pennsylvania	Berks	76.3	57.11	56.61
Pennsylvania	Blair	72.7	61.24	60.99
Pennsylvania	Bucks	80.3	60.12	59.58
Pennsylvania	Cambria	70.3	58.15	57.89
Pennsylvania	Centre	72.0	59.88	59.60
Pennsylvania	Chester	76.3	54.53	53.86
Pennsylvania	Clearfield	72.3	59.26	58.90
Pennsylvania	Dauphin	74.7	56.94	56.42
Pennsylvania	Delaware	75.7	55.55	54.96
Pennsylvania	Erie	74.0	57.49	56.98
Pennsylvania	Franklin	67.0	52.35	51.89
Pennsylvania	Greene	69.0	54.24	53.78
Pennsylvania	Indiana	75.7	63.39	63.10
Pennsylvania	Lackawanna	71.0	56.37	55.86
Pennsylvania	Lancaster	78.0	57.50	57.01
Pennsylvania	Lawrence	71.0	57.22	56.84
Pennsylvania	Lebanon	76.0	57.19	56.65
Pennsylvania	Lehigh	76.0	57.34	56.84
Pennsylvania	Luzerne	65.0	49.80	49.36
Pennsylvania	Lycoming	67.0	54.25	53.78
Pennsylvania	Mercer	76.3	58.40	57.89
Pennsylvania	Monroe	66.7	50.23	49.77
Pennsylvania	Montgomery	76.3	57.76	57.21
Pennsylvania	Northampton	76.0	57.19	56.73
Pennsylvania	Perry	68.3	56.16	55.87
Pennsylvania	Philadelphia	83.3	63.33	62.77
Pennsylvania	Somerset	65.0	49.75	49.44
Pennsylvania	Tioga	69.7	56.88	56.48

State	County	2011 Baseline DV	2040 Reference DV	2040 HDGHGP2 Control DV
Pennsylvania	Washington	70.7	59.40	59.02
Pennsylvania	Westmoreland	71.7	58.88	58.59
Pennsylvania	York	74.3	53.02	52.52
Rhode Island	Kent	73.7	57.09	56.61
Rhode Island	Providence	74.0	57.94	57.66
Rhode Island	Washington	76.3	60.16	59.75
South Carolina	Abbeville	62.0	43.88	43.22
South Carolina	Aiken	64.3	45.53	44.89
South Carolina	Anderson	70.0	49.12	48.50
South Carolina	Berkeley	62.3	46.89	46.45
South Carolina	Charleston	64.7	48.73	48.17
South Carolina	Chesterfield	64.3	46.32	45.82
South Carolina	Colleton	61.0	46.36	45.90
South Carolina	Darlington	68.0	49.75	49.27
South Carolina	Edgefield	61.3	43.48	42.91
South Carolina	Greenville	68.0	47.73	47.22
South Carolina	Pickens	69.7	49.75	49.10
South Carolina	Richland	71.7	51.14	50.34
South Carolina	Spartanburg	73.7	51.25	50.60
South Carolina	York	64.0	43.46	42.82
South Dakota	Brookings	63.3	53.08	52.66
South Dakota	Custer	61.7	56.23	56.00
South Dakota	Jackson	57.0	51.10	50.79
South Dakota	Meade	58.5	51.25	50.96
South Dakota	Minnehaha	66.0	54.45	53.97
South Dakota	Union	62.5	52.34	51.96
Tennessee	Anderson	70.7	51.11	50.06
Tennessee	Blount	76.7	56.35	55.53
Tennessee	Claiborne	62.0	46.70	45.83
Tennessee	Davidson	70.3	51.22	50.27
Tennessee	Hamilton	73.3	52.69	51.68
Tennessee	Jefferson	74.7	53.65	52.53
Tennessee	Knox	71.7	50.85	49.96
Tennessee	Loudon	72.3	53.18	51.65
Tennessee	Meigs	71.3	51.94	51.02
Tennessee	Rutherford	68.5	48.73	47.79
Tennessee	Sevier	74.3	55.42	54.52
Tennessee	Shelby	78.0	57.73	56.95
Tennessee	Sullivan	71.7	57.80	57.38
Tennessee	Sumner	76.7	54.48	53.51

State	County	2011 Baseline DV	2040 Reference DV	2040 HDGHGP2 Control DV
Tennessee	Williamson	70.3	50.51	49.63
Tennessee	Wilson	71.7	50.33	49.46
Texas	Bell	74.5	59.64	59.11
Texas	Bexar	78.7	61.17	60.68
Texas	Brazoria	88.0	68.78	68.15
Texas	Brewster	70.0	67.21	67.10
Texas	Cameron	62.7	55.55	55.29
Texas	Collin	82.7	62.63	61.92
Texas	Dallas	82.0	63.53	62.77
Texas	Denton	84.3	65.28	64.46
Texas	Ellis	75.7	61.15	60.37
Texas	El Paso	71.0	57.85	57.43
Texas	Galveston	77.3	64.97	64.41
Texas	Gregg	77.7	66.39	65.96
Texas	Harris	83.0	69.77	69.19
Texas	Harrison	72.7	60.39	59.91
Texas	Hidalgo	61.0	53.42	53.17
Texas	Hood	76.7	61.73	61.07
Texas	Hunt	71.7	56.31	55.81
Texas	Jefferson	78.0	63.33	62.71
Texas	Johnson	79.0	64.01	63.31
Texas	Kaufman	70.7	58.45	57.91
Texas	Mc Lennan	72.7	60.22	59.63
Texas	Montgomery	77.3	59.06	58.57
Texas	Navarro	71.0	61.12	60.64
Texas	Nueces	71.0	62.97	62.66
Texas	Orange	72.7	59.46	58.87
Texas	Parker	78.7	64.28	63.62
Texas	Rockwall	77.0	60.08	59.48
Texas	Smith	75.0	62.19	61.69
Texas	Tarrant	87.3	68.61	67.91
Texas	Travis	73.7	59.17	58.76
Texas	Victoria	68.7	59.23	58.82
Utah	Box Elder	67.7	58.53	57.96
Utah	Cache	64.3	55.98	55.61
Utah	Carbon	69.0	62.53	62.36
Utah	Davis	69.3	60.81	60.36
Utah	Duchesne	68.0	61.45	61.27
Utah	Salt Lake	76.0	65.58	65.10
Utah	San Juan	68.7	61.83	61.67

State	County	2011 Baseline DV	2040 Reference DV	2040 HDGHGP2 Control DV
Utah	Tooele	72.0	62.45	61.76
Utah	Utah	70.0	61.80	61.35
Utah	Washington	71.7	63.79	63.61
Utah	Weber	72.7	62.96	62.59
Vermont	Bennington	63.7	50.24	49.85
Virginia	Albemarle	66.7	50.83	50.17
Virginia	Arlington	81.7	58.02	57.43
Virginia	Caroline	71.7	51.54	50.97
Virginia	Charles City	75.7	56.19	55.53
Virginia	Chesterfield	72.0	53.39	52.90
Virginia	Fairfax	82.3	56.61	56.07
Virginia	Fauquier	62.7	47.85	47.35
Virginia	Frederick	66.7	51.57	51.05
Virginia	Giles	63.0	46.56	46.09
Virginia	Hanover	73.7	54.82	54.16
Virginia	Henrico	75.0	55.26	54.63
Virginia	Loudoun	73.0	56.88	56.30
Virginia	Madison	70.7	57.08	56.65
Virginia	Page	66.3	53.68	53.28
Virginia	Prince Edward	62.0	47.64	47.06
Virginia	Prince William	70.0	55.13	54.59
Virginia	Roanoke	67.3	51.97	51.27
Virginia	Rockbridge	62.3	51.41	50.99
Virginia	Rockingham	66.0	52.40	51.96
Virginia	Stafford	73.0	48.99	48.42
Virginia	Wythe	64.3	51.01	50.39
Virginia	Alexandria City	80.0	56.13	55.68
Virginia	Hampton City	74.0	57.97	57.49
Virginia	Suffolk City	71.3	58.23	57.78
Washington	Clark	56.0	47.54	47.14
Washington	Spokane	59.0	48.55	48.13
Washington	Whatcom	45.0	41.77	41.74
West Virginia	Berkeley	68.0	52.55	51.97
West Virginia	Cabell	69.3	55.39	54.85
West Virginia	Gilmer	60.0	50.28	49.92
West Virginia	Greenbrier	64.7	51.72	51.17
West Virginia	Hancock	73.0	60.87	60.48
West Virginia	Kanawha	72.3	61.84	61.35
West Virginia	Monongalia	69.7	57.92	57.55
West Virginia	Ohio	72.3	55.98	55.47

State	County	2011 Baseline DV	2040 Reference DV	2040 HDGHGP2 Control DV
West Virginia	Wood	68.3	52.89	52.44
Wisconsin	Brown	68.3	53.20	52.70
Wisconsin	Columbia	67.0	53.51	52.88
Wisconsin	Dane	66.3	53.03	52.44
Wisconsin	Dodge	71.5	57.72	57.01
Wisconsin	Door	75.7	59.18	58.36
Wisconsin	Eau Claire	62.0	48.34	47.74
Wisconsin	Fond Du Lac	70.0	56.32	55.65
Wisconsin	Jefferson	68.5	54.83	54.28
Wisconsin	Kenosha	81.0	53.84	53.54
Wisconsin	Kewaunee	75.0	59.25	58.44
Wisconsin	La Crosse	63.3	50.41	49.91
Wisconsin	Manitowoc	78.7	62.03	61.33
Wisconsin	Marathon	63.3	50.06	49.44
Wisconsin	Milwaukee	80.0	61.95	61.48
Wisconsin	Outagamie	69.3	55.64	55.07
Wisconsin	Ozaukee	76.3	64.23	63.87
Wisconsin	Racine	77.7	55.40	55.15
Wisconsin	Rock	69.5	56.14	55.54
Wisconsin	Sauk	65.0	52.44	51.75
Wisconsin	Sheboygan	84.3	68.51	67.97
Wisconsin	Walworth	69.3	56.53	55.93
Wisconsin	Waukesha	66.7	54.29	53.77
Wyoming	Campbell	63.7	58.62	58.40
Wyoming	Carbon	63.0	58.18	58.02
Wyoming	Fremont	68.0	62.77	62.58
Wyoming	Laramie	68.0	61.36	61.06
Wyoming	Sublette	77.3	72.16	71.99
Wyoming	Sweetwater	66.0	59.28	59.00
Wyoming	Teton	65.3	61.61	61.44
Wyoming	Uinta	64.3	56.49	56.18

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Appendix C

Annual $PM_{2.5}$ Design Values for Air Quality Modeling Scenarios

Table C-1. Annual $PM_{2.5}$ Design Values for HDGHG Phase 2 Scenarios (units are ug/m^3)

State	County	2011 Baseline DV	2040 Reference DV	2040 HDGHGP2 Control DV
Alabama	Baldwin	9.49	7.94	7.92
Alabama	Clay	9.74	7.74	7.73
Alabama	Colbert	9.70	8.28	8.27
Alabama	DeKalb	10.41	8.38	8.37
Alabama	Etowah	10.70	8.74	8.73
Alabama	Houston	9.62	8.19	8.18
Alabama	Jefferson	12.59	11.03	11.03
Alabama	Madison	10.48	9.18	9.17
Alabama	Mobile	9.45	8.06	8.05
Alabama	Montgomery	10.88	9.49	9.49
Alabama	Morgan	10.02	8.74	8.73
Alabama	Russell	11.87	9.95	9.94
Alabama	Shelby	9.75	8.22	8.21
Alabama	Talladega	11.05	9.05	9.04
Alabama	Tuscaloosa	10.21	8.81	8.80
Alabama	Walker	10.84	9.03	9.02
Arizona	Cochise	6.77	7.21	7.21
Arizona	Coconino	5.47	5.34	5.35
Arizona	Maricopa	11.48	10.18	10.22
Arizona	Pima	5.52	4.89	4.89
Arizona	Pinal	9.36	8.61	8.64
Arizona	Santa Cruz	10.07	10.02	10.02
Arizona	Yavapai	4.14	4.10	4.10
Arizona	Yuma	7.70	7.29	7.28
Arkansas	Arkansas	10.51	8.71	8.70
Arkansas	Ashley	10.48	9.10	9.09
Arkansas	Crittenden	10.94	8.56	8.56
Arkansas	Faulkner	10.76	9.02	9.00
Arkansas	Garland	10.75	9.04	9.02
Arkansas	Jackson	10.00	8.11	8.10
Arkansas	Phillips	10.67	8.75	8.74
Arkansas	Polk	10.67	9.22	9.21
Arkansas	Pope	11.34	9.70	9.68
Arkansas	Pulaski	12.01	9.89	9.89
Arkansas	Union	11.07	9.59	9.57
Arkansas	Washington	10.67	9.11	9.10
Arkansas	White	11.26	9.52	9.51

State	County	2011 Baseline DV	2040 Reference DV	2040 HDGHGP2 Control DV
California	Alameda	9.37	8.20	8.19
California	Butte	10.09	9.19	9.19
California	Calaveras	7.76	6.56	6.55
California	Colusa	6.56	5.95	5.95
California	Contra Costa	7.43	6.53	6.51
California	Fresno	16.44	13.86	13.84
California	Humboldt	6.21	6.01	6.01
California	Imperial	13.64	14.88	14.86
California	Inyo	7.38	7.06	7.05
California	Kern	17.02	13.75	13.73
California	Kings	16.33	13.87	13.85
California	Lake	3.51	3.25	3.25
California	Los Angeles	12.92	10.57	10.55
California	Madera	18.75	16.25	16.22
California	Marin	9.53	8.59	8.58
California	Mendocino	8.55	7.91	7.91
California	Merced	14.54	12.81	12.80
California	Monterey	6.15	5.43	5.42
California	Nevada	6.39	5.84	5.84
California	Orange	10.77	8.75	8.73
California	Placer	7.54	6.57	6.56
California	Plumas	9.59	8.92	8.91
California	Riverside	15.31	12.43	12.41
California	Sacramento	9.94	8.82	8.81
California	San Benito	5.51	4.74	4.74
California	San Bernardino	13.03	10.64	10.62
California	San Diego	10.79	9.48	9.48
California	San Francisco	9.51	8.36	8.34
California	San Joaquin	12.09	10.47	10.45
California	San Luis Obispo	11.33	9.91	9.90
California	San Mateo	8.80	7.73	7.72
California	Santa Barbara	9.59	8.61	8.61
California	Santa Clara	9.79	8.56	8.55
California	Santa Cruz	6.25	5.53	5.53
California	Shasta	5.42	5.10	5.09
California	Siskiyou	5.54	5.29	5.28
California	Solano	9.15	8.09	8.07
California	Sonoma	8.15	7.54	7.54
California	Stanislaus	15.27	13.12	13.10
California	Sutter	7.30	6.45	6.44

State	County	2011 Baseline DV	2040 Reference DV	2040 HDGHGP2 Control DV
California	Tulare	15.54	13.06	13.04
California	Ventura	8.98	8.02	8.02
California	Yolo	6.87	5.99	5.98
Colorado	Adams	8.06	6.88	6.87
Colorado	Arapahoe	6.29	5.33	5.32
Colorado	Boulder	6.92	6.22	6.21
Colorado	Denver	7.63	6.51	6.50
Colorado	Douglas	5.68	4.85	4.84
Colorado	El Paso	5.87	5.08	5.08
Colorado	Larimer	6.32	5.66	5.66
Colorado	Mesa	8.60	7.79	7.79
Colorado	Montezuma	6.05	5.77	5.77
Colorado	Rio Blanco	9.55	9.50	9.50
Colorado	Weld	7.49	6.89	6.88
Connecticut	Fairfield	9.35	7.26	7.26
Connecticut	Hartford	8.78	7.23	7.23
Connecticut	Litchfield	5.63	4.48	4.48
Connecticut	New Haven	9.45	7.37	7.37
Connecticut	New London	8.19	6.51	6.51
Delaware	Kent	8.93	6.63	6.62
Delaware	New Castle	10.35	7.83	7.81
Delaware	Sussex	8.97	6.68	6.67
District Of Co	District of Columbia	10.29	7.91	7.90
Florida	Palm Beach	7.37	6.79	6.79
Georgia	Bibb	12.78	10.61	10.60
Georgia	Chatham	10.70	8.57	8.57
Georgia	Clarke	10.35	7.87	7.86
Georgia	Clayton	11.97	9.02	9.02
Georgia	Cobb	11.10	8.26	8.25
Georgia	DeKalb	11.31	8.34	8.34
Georgia	Dougherty	12.05	10.29	10.28
Georgia	Floyd	11.72	9.22	9.20
Georgia	Fulton	13.08	9.87	9.87
Georgia	Hall	10.22	7.80	7.79
Georgia	Houston	10.45	8.57	8.57
Georgia	Muscogee	12.58	10.55	10.53
Georgia	Richmond	12.05	9.85	9.84
Georgia	Walker	10.16	7.73	7.73
Georgia	Wilkinson	12.27	10.19	10.18

State	County	2011 Baseline DV	2040 Reference DV	2040 HDGHGP2 Control DV
Idaho	Bannock	6.45	6.02	6.01
Idaho	Lemhi	11.59	11.09	11.09
Idaho	Shoshone	12.34	11.69	11.69
Indiana	Allen	10.51	7.78	7.75
Indiana	Clark	12.91	9.88	9.87
Indiana	Delaware	10.74	8.02	8.00
Indiana	Dubois	12.23	8.99	8.97
Indiana	Elkhart	11.10	8.39	8.35
Indiana	Floyd	11.60	8.71	8.69
Indiana	Gibson	11.43	8.51	8.49
Indiana	Greene	9.89	7.02	7.00
Indiana	Henry	10.43	7.66	7.63
Indiana	Howard	11.61	8.76	8.72
Indiana	Knox	11.70	8.68	8.66
Indiana	Lake	12.04	9.24	9.21
Indiana	LaPorte	9.96	7.41	7.38
Indiana	Madison	10.08	7.42	7.39
Indiana	Marion	12.57	9.34	9.32
Indiana	Monroe	10.14	7.32	7.29
Indiana	Porter	10.73	8.09	8.06
Indiana	St. Joseph	10.54	7.94	7.90
Indiana	Spencer	11.82	8.70	8.68
Indiana	Tippecanoe	10.51	7.80	7.77
Indiana	Vanderburgh	12.06	9.21	9.19
Indiana	Vigo	11.80	8.69	8.67
Indiana	Whitley	9.61	7.11	7.08
Iowa	Black Hawk	10.63	8.39	8.37
Iowa	Clinton	11.34	8.81	8.78
Iowa	Delaware	9.49	7.40	7.37
Iowa	Johnson	10.29	8.09	8.07
Iowa	Lee	11.14	8.90	8.87
Iowa	Linn	10.19	8.03	8.01
Iowa	Montgomery	9.10	7.38	7.34
Iowa	Muscatine	12.10	9.53	9.50
Iowa	Palo Alto	8.82	7.11	7.08
Iowa	Polk	9.52	7.29	7.24
Iowa	Pottawattamie	10.70	8.55	8.52
Iowa	Scott	11.42	8.81	8.77
Iowa	Van Buren	9.40	7.50	7.46
Iowa	Woodbury	9.65	7.88	7.85

State	County	2011 Baseline DV	2040 Reference DV	2040 HDGHGP2 Control DV
Kansas	Johnson	8.32	6.64	6.62
Kansas	Linn	9.08	7.47	7.44
Kansas	Sedgwick	9.24	7.79	7.77
Kansas	Shawnee	9.10	7.57	7.55
Kansas	Sumner	8.56	7.22	7.19
Kansas	Wyandotte	10.09	8.19	8.17
Kentucky	Bell	10.83	8.50	8.50
Kentucky	Boyd	10.44	7.82	7.81
Kentucky	Bullitt	12.18	9.67	9.66
Kentucky	Campbell	10.53	7.14	7.11
Kentucky	Carter	8.71	6.40	6.39
Kentucky	Christian	10.51	7.99	7.98
Kentucky	Daviess	11.73	8.78	8.76
Kentucky	Fayette	10.59	7.59	7.58
Kentucky	Hardin	11.08	8.07	8.06
Kentucky	Henderson	11.22	8.44	8.43
Kentucky	Jefferson	12.38	9.39	9.38
Kentucky	McCracken	10.84	8.19	8.17
Kentucky	Madison	9.37	6.58	6.56
Kentucky	Pike	9.42	7.08	7.07
Kentucky	Warren	11.03	8.45	8.45
Louisiana	Caddo	11.50	10.27	10.26
Louisiana	Calcasieu	8.80	7.61	7.58
Louisiana	East Baton Rouge	9.95	8.71	8.70
Louisiana	Iberville	9.78	8.74	8.74
Louisiana	Jefferson	9.03	7.40	7.39
Louisiana	Lafayette	8.89	7.87	7.87
Louisiana	Ouachita	9.14	7.91	7.91
Louisiana	Rapides	8.56	7.34	7.33
Louisiana	St. Bernard	10.23	8.42	8.41
Louisiana	Tangipahoa	8.80	7.26	7.25
Louisiana	Terrebonne	8.26	7.18	7.19
Louisiana	West Baton Rouge	10.50	9.26	9.25
Maine	Androscoggin	7.50	6.24	6.24
Maine	Aroostook	6.53	6.00	6.00
Maine	Cumberland	8.37	7.01	7.01
Maine	Hancock	4.59	4.06	4.06
Maine	Kennebec	7.16	5.99	5.99
Maine	Oxford	8.20	7.11	7.11
Maine	Penobscot	7.21	6.19	6.19

State	County	2011 Baseline DV	2040 Reference DV	2040 HDGHGP2 Control DV
Maryland	Anne Arundel	10.53	8.20	8.20
Maryland	Baltimore	10.79	8.27	8.27
Maryland	Cecil	10.27	7.72	7.70
Maryland	Garrett	8.93	6.90	6.90
Maryland	Harford	10.11	7.59	7.58
Maryland	Kent	10.16	7.75	7.74
Maryland	Montgomery	10.14	8.04	8.03
Maryland	Prince George's	10.53	8.44	8.44
Maryland	Washington	10.89	8.45	8.45
Maryland	Baltimore (City)	10.97	8.51	8.51
Massachusetts	Berkshire	8.68	7.12	7.11
Massachusetts	Bristol	7.58	6.00	6.00
Massachusetts	Essex	7.91	6.67	6.68
Massachusetts	Hampden	9.22	7.75	7.75
Massachusetts	Middlesex	7.49	6.28	6.29
Massachusetts	Plymouth	7.85	6.35	6.35
Massachusetts	Suffolk	9.87	8.10	8.10
Massachusetts	Worcester	8.71	7.29	7.29
Michigan	Allegan	8.42	6.40	6.38
Michigan	Bay	7.81	6.19	6.17
Michigan	Berrien	8.66	6.52	6.48
Michigan	Chippewa	6.23	5.62	5.62
Michigan	Genesee	8.35	6.48	6.45
Michigan	Ingham	8.65	6.76	6.74
Michigan	Kalamazoo	9.16	6.95	6.92
Michigan	Kent	9.53	7.44	7.41
Michigan	Lenawee	9.13	6.99	6.97
Michigan	Macomb	8.73	6.84	6.82
Michigan	Manistee	6.58	5.28	5.26
Michigan	Missaukee	5.96	4.86	4.85
Michigan	Monroe	9.72	7.27	7.24
Michigan	Muskegon	8.48	6.59	6.56
Michigan	Oakland	9.23	7.12	7.10
Michigan	Ottawa	8.99	6.89	6.87
Michigan	St. Clair	9.13	7.52	7.51
Michigan	Washtenaw	9.35	7.25	7.23
Michigan	Wayne	11.47	9.33	9.31
Minnesota	Anoka	8.44	7.28	7.25
Minnesota	Dakota	8.89	7.65	7.62
Minnesota	Hennepin	8.94	7.76	7.74

State	County	2011 Baseline DV	2040 Reference DV	2040 HDGHGP2 Control DV
Minnesota	Olmsted	8.96	7.20	7.17
Minnesota	Ramsey	9.86	8.57	8.54
Minnesota	Saint Louis	6.59	5.80	5.79
Minnesota	Scott	8.62	7.37	7.34
Minnesota	Stearns	8.34	7.09	7.07
Minnesota	Washington	9.21	7.84	7.81
Mississippi	DeSoto	9.76	7.78	7.78
Mississippi	Forrest	11.36	9.40	9.39
Mississippi	Grenada	9.41	7.56	7.56
Mississippi	Hancock	9.44	7.84	7.83
Mississippi	Harrison	9.66	7.93	7.91
Mississippi	Hinds	10.83	8.97	8.97
Mississippi	Jackson	9.38	7.64	7.63
Mississippi	Jones	11.67	9.68	9.66
Mississippi	Lauderdale	10.86	8.92	8.90
Mississippi	Lee	10.77	8.86	8.86
Missouri	Cass	10.65	8.81	8.79
Missouri	Cedar	10.48	8.87	8.85
Missouri	Clay	9.38	7.47	7.44
Missouri	Greene	10.15	8.46	8.45
Missouri	Jackson	10.25	8.28	8.26
Missouri	Jefferson	10.05	7.63	7.62
Missouri	Saint Louis	10.89	8.10	8.07
Missouri	St. Louis City	11.61	8.68	8.66
Montana	Lewis and Clark	8.45	8.10	8.10
Montana	Lincoln	11.43	10.97	10.97
Montana	Missoula	10.83	10.40	10.41
Montana	Powder River	5.83	5.72	5.72
Montana	Ravalli	10.00	9.76	9.76
Montana	Richland	6.81	6.53	6.53
Montana	Silver Bow	10.07	9.24	9.24
Nebraska	Douglas	10.34	8.32	8.29
Nebraska	Hall	7.24	5.98	5.96
Nebraska	Lancaster	8.57	6.97	6.94
Nebraska	Sarpy	11.26	9.06	9.03
Nebraska	Washington	9.09	7.34	7.30
Nevada	Clark	8.16	7.13	7.14
Nevada	Washoe	6.90	6.14	6.14
New Hampshire	Belknap	5.91	4.99	4.99
New Hampshire	Cheshire	9.27	7.75	7.75

State	County	2011 Baseline DV	2040 Reference DV	2040 HDGHGP2 Control DV
New Hampshire	Grafton	6.75	5.52	5.53
New Hampshire	Hillsborough	7.78	6.59	6.60
New Hampshire	Merrimack	8.48	7.22	7.22
New Hampshire	Rockingham	7.49	6.35	6.35
New Jersey	Atlantic	8.91	6.83	6.82
New Jersey	Bergen	9.17	6.84	6.84
New Jersey	Camden	9.51	7.23	7.21
New Jersey	Essex	9.45	7.25	7.24
New Jersey	Gloucester	9.30	6.77	6.74
New Jersey	Hudson	11.10	8.53	8.53
New Jersey	Mercer	9.54	7.48	7.48
New Jersey	Middlesex	8.01	6.16	6.15
New Jersey	Morris	8.39	6.43	6.43
New Jersey	Ocean	8.48	6.48	6.47
New Jersey	Passaic	9.32	7.08	7.08
New Jersey	Union	11.24	8.45	8.44
New Jersey	Warren	9.24	7.18	7.17
New Mexico	Bernalillo	6.36	6.00	6.00
New Mexico	Dona Ana	5.78	5.98	5.98
New Mexico	Lea	8.02	8.30	8.30
New Mexico	San Juan	4.60	4.97	4.97
New Mexico	Santa Fe	4.55	4.63	4.63
New York	Albany	8.05	6.37	6.37
New York	Bronx	11.91	9.08	9.08
New York	Chautauqua	7.43	5.69	5.68
New York	Erie	9.43	7.42	7.41
New York	Essex	4.33	3.61	3.61
New York	Kings	9.98	7.57	7.56
New York	Nassau	8.88	6.73	6.72
New York	New York	11.75	9.08	9.08
New York	Onondaga	7.52	5.87	5.86
New York	Orange	8.04	6.20	6.19
New York	Queens	9.08	6.91	6.91
New York	Richmond	9.47	7.01	7.01
New York	Steuben	6.85	5.28	5.28
New York	Suffolk	8.31	6.14	6.14
New York	Westchester	9.09	6.83	6.83
North Carolina	Alamance	9.53	7.09	7.11
North Carolina	Buncombe	9.07	6.77	6.77
North Carolina	Caswell	8.66	6.30	6.30

State	County	2011 Baseline DV	2040 Reference DV	2040 HDGHGP2 Control DV
North Carolina	Catawba	10.14	7.74	7.73
North Carolina	Chatham	8.08	5.93	5.93
North Carolina	Cumberland	9.78	7.58	7.57
North Carolina	Davidson	10.77	8.23	8.23
North Carolina	Duplin	8.57	6.52	6.51
North Carolina	Durham	9.12	6.76	6.75
North Carolina	Edgecombe	8.73	6.51	6.50
North Carolina	Forsyth	9.53	6.99	6.99
North Carolina	Gaston	10.00	7.54	7.53
North Carolina	Guilford	9.29	6.82	6.82
North Carolina	Haywood	9.65	7.82	7.82
North Carolina	Jackson	8.96	7.02	7.02
North Carolina	Johnston	8.76	6.55	6.55
North Carolina	Lenoir	8.88	6.74	6.73
North Carolina	McDowell	9.48	7.42	7.42
North Carolina	Martin	8.30	6.12	6.12
North Carolina	Mecklenburg	10.65	8.21	8.21
North Carolina	Mitchell	8.94	7.07	7.07
North Carolina	Montgomery	8.88	6.74	6.73
North Carolina	New Hanover	7.77	5.76	5.75
North Carolina	Pitt	8.27	6.13	6.12
North Carolina	Robeson	9.56	7.83	7.83
North Carolina	Rowan	9.97	7.66	7.66
North Carolina	Swain	9.36	7.37	7.36
North Carolina	Wake	9.97	7.64	7.63
North Carolina	Watauga	7.99	6.07	6.07
North Carolina	Wayne	9.51	7.40	7.40
North Dakota	Billings	4.38	4.11	4.10
North Dakota	Burke	6.76	6.43	6.43
North Dakota	Burleigh	6.60	5.98	5.97
North Dakota	Cass	7.70	6.80	6.79
North Dakota	McKenzie	6.46	6.18	6.17
North Dakota	Mercer	6.14	5.76	5.75
Ohio	Athens	8.80	6.21	6.20
Ohio	Butler	12.39	9.02	8.99
Ohio	Clark	11.83	8.49	8.46
Ohio	Clermont	11.34	7.87	7.84
Ohio	Cuyahoga	12.82	9.92	9.91
Ohio	Franklin	11.63	8.31	8.28
Ohio	Greene	11.18	7.90	7.87

State	County	2011 Baseline DV	2040 Reference DV	2040 HDGHGP2 Control DV
Ohio	Hamilton	13.17	9.52	9.50
Ohio	Jefferson	12.07	8.72	8.70
Ohio	Lake	9.54	7.01	7.00
Ohio	Lawrence	10.97	8.34	8.33
Ohio	Lorain	9.64	7.31	7.29
Ohio	Lucas	10.89	8.28	8.25
Ohio	Mahoning	11.14	8.45	8.43
Ohio	Montgomery	12.06	8.63	8.59
Ohio	Portage	10.26	7.45	7.43
Ohio	Preble	10.66	7.76	7.74
Ohio	Scioto	10.37	7.62	7.61
Ohio	Stark	12.85	9.89	9.87
Ohio	Summit	11.85	8.70	8.68
Ohio	Trumbull	10.57	7.92	7.90
Ohio	Warren	11.54	8.23	8.19
Oklahoma	Oklahoma	9.61	8.48	8.47
Oklahoma	Pittsburg	10.25	9.15	9.13
Oklahoma	Sequoyah	10.68	9.26	9.25
Oklahoma	Tulsa	10.46	9.10	9.08
Oregon	Crook	9.02	8.93	8.92
Oregon	Harney	9.05	8.72	8.71
Oregon	Jackson	9.43	9.19	9.19
Oregon	Josephine	7.76	7.59	7.59
Oregon	Klamath	10.67	10.20	10.20
Oregon	Lake	9.66	9.37	9.37
Oregon	Lane	9.32	8.94	8.93
Oregon	Multnomah	7.61	7.24	7.23
Oregon	Umatilla	7.41	7.02	7.02
Oregon	Washington	7.82	7.49	7.49
Pennsylvania	Adams	11.49	8.93	8.92
Pennsylvania	Allegheny	14.40	10.57	10.56
Pennsylvania	Armstrong	11.60	9.05	9.04
Pennsylvania	Beaver	12.00	9.36	9.35
Pennsylvania	Berks	10.88	8.31	8.29
Pennsylvania	Blair	11.89	8.66	8.65
Pennsylvania	Bucks	10.88	8.61	8.61
Pennsylvania	Cambria	12.34	9.35	9.34
Pennsylvania	Centre	9.36	6.94	6.93
Pennsylvania	Chester	12.33	9.56	9.54
Pennsylvania	Cumberland	11.00	8.32	8.31

State	County	2011 Baseline DV	2040 Reference DV	2040 HDGHGP2 Control DV
Pennsylvania	Dauphin	11.97	9.18	9.16
Pennsylvania	Delaware	12.81	10.00	9.98
Pennsylvania	Erie	11.60	9.49	9.48
Pennsylvania	Lackawanna	9.16	7.13	7.13
Pennsylvania	Lancaster	12.01	9.05	9.03
Pennsylvania	Lebanon	12.56	9.59	9.57
Pennsylvania	Mercer	10.44	7.90	7.88
Pennsylvania	Monroe	7.90	5.99	5.98
Pennsylvania	Montgomery	9.90	7.68	7.67
Pennsylvania	Northampton	12.90	10.44	10.44
Pennsylvania	Philadelphia	11.15	8.40	8.37
Pennsylvania	Washington	11.81	8.70	8.68
Pennsylvania	Westmoreland	12.63	9.91	9.90
Pennsylvania	York	11.48	8.78	8.75
Rhode Island	Kent	6.15	4.75	4.75
Rhode Island	Providence	9.38	7.59	7.60
South Carolina	Charleston	8.89	7.02	7.02
South Carolina	Chesterfield	9.15	7.10	7.09
South Carolina	Edgefield	9.75	7.81	7.81
South Carolina	Florence	10.26	8.25	8.24
South Carolina	Greenville	10.74	8.44	8.44
South Carolina	Lexington	10.89	8.75	8.75
South Carolina	Richland	10.41	8.36	8.36
South Carolina	Spartanburg	10.53	8.28	8.27
South Dakota	Brookings	8.34	6.99	6.97
South Dakota	Brown	7.67	6.73	6.71
South Dakota	Codington	9.11	7.87	7.86
South Dakota	Custer	4.20	4.00	3.99
South Dakota	Jackson	3.96	3.66	3.66
South Dakota	Minnehaha	8.83	7.19	7.17
South Dakota	Pennington	5.89	5.58	5.58
South Dakota	Union	9.22	7.62	7.59
Tennessee	Hamilton	10.79	8.26	8.25
Texas	Bexar	9.03	8.74	8.73
Texas	Bowie	10.94	9.56	9.55
Texas	Dallas	10.07	8.89	8.89
Texas	El Paso	10.39	10.80	10.79
Texas	Harris	12.05	11.24	11.23
Texas	Harrison	10.65	9.32	9.31
Texas	Hidalgo	10.37	10.74	10.74

State	County	2011 Baseline DV	2040 Reference DV	2040 HDGHGP2 Control DV
Texas	Nueces	10.28	9.79	9.78
Texas	Tarrant	10.59	9.70	9.69
Texas	Travis	10.01	9.51	9.50
Utah	Box Elder	8.03	6.86	6.82
Utah	Cache	9.40	8.03	8.00
Utah	Davis	8.65	7.24	7.19
Utah	Salt Lake	9.60	7.88	7.83
Utah	Tooele	6.48	5.55	5.50
Utah	Utah	8.71	7.19	7.14
Utah	Washington	4.63	4.51	4.51
Utah	Weber	9.38	7.80	7.75
Vermont	Bennington	6.83	5.62	5.61
Vermont	Chittenden	7.12	6.03	6.02
Vermont	Rutland	9.49	7.85	7.85
Virginia	Albemarle	8.40	6.40	6.40
Virginia	Charles	8.61	6.37	6.36
Virginia	Chesterfield	9.54	7.19	7.19
Virginia	Fairfax	9.23	7.03	7.02
Virginia	Frederick	10.04	7.81	7.80
Virginia	Henrico	9.22	6.97	6.96
Virginia	Loudoun	9.27	7.25	7.24
Virginia	Page	8.79	6.84	6.84
Virginia	Rockingham	9.66	7.67	7.67
Virginia	Alexandria City	10.74	8.34	8.34
Virginia	Bristol City	9.58	7.54	7.54
Virginia	Hampton City	7.85	5.78	5.78
Virginia	Lynchburg City	8.40	6.37	6.36
Virginia	Norfolk City	9.20	6.98	6.98
Virginia	Roanoke City	9.85	7.53	7.53
Virginia	Salem City	9.59	7.29	7.29
Virginia	Virginia Beach City	9.11	6.85	6.85
Washington	Clark	7.34	6.87	6.87
Washington	King	10.13	8.88	8.88
Washington	Pierce	7.88	7.00	7.00
Washington	Snohomish	7.62	6.88	6.88
Washington	Spokane	7.69	7.19	7.19
Washington	Yakima	8.91	7.77	7.74
West Virginia	Berkeley	11.38	8.90	8.90
West Virginia	Brooke	12.41	8.98	8.97
West Virginia	Cabell	11.36	8.54	8.53

State	County	2011 Baseline DV	2040 Reference DV	2040 HDGHGP2 Control DV
West Virginia	Hancock	11.17	8.16	8.15
West Virginia	Kanawha	11.76	8.80	8.80
West Virginia	Marion	11.34	8.71	8.70
West Virginia	Marshall	12.46	9.65	9.64
West Virginia	Monongalia	10.20	7.56	7.56
West Virginia	Ohio	11.35	8.23	8.21
West Virginia	Raleigh	9.06	6.60	6.60
West Virginia	Wood	11.51	8.69	8.68
Wisconsin	Ashland	5.32	4.58	4.56
Wisconsin	Brown	9.57	7.86	7.84
Wisconsin	Dane	10.07	7.97	7.94
Wisconsin	Dodge	8.99	7.08	7.05
Wisconsin	Forest	5.57	4.55	4.54
Wisconsin	Grant	10.04	7.83	7.80
Wisconsin	Kenosha	9.33	7.25	7.22
Wisconsin	La Crosse	8.98	7.32	7.29
Wisconsin	Milwaukee	10.82	8.52	8.50
Wisconsin	Outagamie	9.22	7.49	7.46
Wisconsin	Ozaukee	9.02	7.08	7.05
Wisconsin	Sauk	8.36	6.43	6.40
Wisconsin	Taylor	7.62	6.34	6.31
Wisconsin	Vilas	5.76	4.82	4.80
Wisconsin	Waukesha	11.26	8.84	8.81
Wyoming	Albany	4.97	4.64	4.64
Wyoming	Fremont	8.19	8.03	8.02
Wyoming	Laramie	4.54	4.21	4.21
Wyoming	Natrona	4.79	4.64	4.64
Wyoming	Park	4.55	4.53	4.52
Wyoming	Sheridan	8.04	7.80	7.80
Wyoming	Sublette	3.82	3.68	3.68
Wyoming	Sweetwater	5.77	5.17	5.16
Wyoming	Teton	4.94	4.71	4.71

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Appendix D

24-Hour $PM_{2.5}$ Design Values for Air Quality Modeling Scenarios

Table D-1. 24-hour $PM_{2.5}$ Design Values for HDGHG Phase 2 Scenarios
(units are ug/m^3)

State	County	2011 Baseline DV	2040 Reference DV	2040 HDGHGP2 Control DV
Alabama	Baldwin	19.0	15.4	15.5
Alabama	Clay	20.7	16.8	16.8
Alabama	Colbert	19.5	16.7	16.7
Alabama	DeKalb	20.7	17.0	17.0
Alabama	Etowah	21.6	18.0	17.9
Alabama	Houston	19.3	17.0	16.9
Alabama	Jefferson	25.6	23.1	23.1
Alabama	Madison	21.0	19.4	19.4
Alabama	Mobile	20.0	16.3	16.3
Alabama	Montgomery	23.1	20.2	20.2
Alabama	Morgan	20.1	17.3	17.2
Alabama	Russell	26.2	22.9	22.9
Alabama	Shelby	20.1	16.4	16.4
Alabama	Talladega	21.4	18.3	18.3
Alabama	Tuscaloosa	22.9	19.4	19.4
Alabama	Walker	22.0	17.8	17.7
Arizona	Cochise	12.8	14.1	14.1
Arizona	Coconino	12.6	12.5	12.5
Arizona	Maricopa	27.2	23.0	23.2
Arizona	Pima	12.2	10.6	10.6
Arizona	Pinal	28.9	26.6	26.6
Arizona	Santa Cruz	28.1	27.9	27.9
Arizona	Yavapai	9.7	9.7	9.7
Arizona	Yuma	15.5	14.9	14.9
Arkansas	Arkansas	21.5	17.4	17.3
Arkansas	Ashley	22.5	18.6	18.6
Arkansas	Crittenden	22.7	16.9	17.0
Arkansas	Faulkner	20.1	16.4	16.4
Arkansas	Garland	21.4	17.7	17.6
Arkansas	Jackson	21.4	17.0	16.9
Arkansas	Phillips	20.6	16.7	16.7
Arkansas	Polk	22.0	18.8	18.8
Arkansas	Pope	22.8	19.3	19.3
Arkansas	Pulaski	25.2	20.0	20.1
Arkansas	Union	22.5	18.7	18.6
Arkansas	Washington	22.3	19.0	18.9
Arkansas	White	21.7	18.5	18.4

State	County	2011 Baseline DV	2040 Reference DV	2040 HDGHGP2 Control DV
California	Alameda	27.5	22.0	21.9
California	Butte	34.6	30.5	30.4
California	Calaveras	19.0	14.1	14.1
California	Colusa	22.3	19.5	19.5
California	Contra Costa	27.0	21.6	21.6
California	Fresno	58.9	49.8	49.7
California	Humboldt	22.7	22.1	22.1
California	Imperial	30.8	30.8	30.7
California	Inyo	35.3	33.7	33.7
California	Kern	61.6	41.2	41.1
California	Kings	60.1	44.3	44.2
California	Lake	8.7	7.9	7.9
California	Los Angeles	31.1	26.3	26.2
California	Madera	52.3	41.0	41.0
California	Marin	24.3	21.3	21.2
California	Mendocino	19.2	16.7	16.7
California	Merced	41.7	35.7	35.7
California	Monterey	13.9	11.9	11.9
California	Nevada	17.5	15.3	15.3
California	Orange	26.6	21.0	21.0
California	Placer	19.9	16.4	16.4
California	Plumas	32.1	30.1	30.1
California	Riverside	36.7	26.0	25.9
California	Sacramento	34.0	29.5	29.5
California	San Benito	14.3	11.2	11.2
California	San Bernardino	29.5	26.8	26.7
California	San Diego	23.2	19.5	19.5
California	San Francisco	25.3	21.6	21.5
California	San Joaquin	39.8	34.3	34.2
California	San Luis Obispo	30.2	27.8	27.8
California	San Mateo	24.5	20.1	20.0
California	Santa Barbara	18.9	17.1	17.1
California	Santa Clara	32.1	26.6	26.5
California	Santa Cruz	13.0	11.5	11.5
California	Shasta	15.3	14.3	14.3
California	Siskiyou	18.4	17.8	17.8
California	Solano	28.5	24.8	24.8
California	Sonoma	22.4	19.6	19.6
California	Stanislaus	50.9	40.5	40.4
California	Sutter	27.2	23.1	23.0

State	County	2011 Baseline DV	2040 Reference DV	2040 HDGHGP2 Control DV
California	Tulare	49.8	36.7	36.6
California	Ventura	20.2	17.0	16.9
California	Yolo	21.3	18.4	18.4
Colorado	Adams	21.1	17.6	17.5
Colorado	Arapahoe	14.5	12.4	12.3
Colorado	Boulder	20.2	17.6	17.5
Colorado	Denver	18.8	15.7	15.7
Colorado	Douglas	15.5	13.1	13.0
Colorado	El Paso	13.7	11.9	11.9
Colorado	Larimer	17.7	15.2	15.2
Colorado	Mesa	33.5	28.0	27.9
Colorado	Montezuma	13.6	13.3	13.3
Colorado	Rio Blanco	20.6	21.3	21.3
Colorado	Weld	22.8	19.6	19.6
Connecticut	Fairfield	24.8	19.9	19.9
Connecticut	Hartford	22.9	18.2	18.2
Connecticut	Litchfield	16.4	11.4	11.4
Connecticut	New Haven	25.5	19.3	19.3
Connecticut	New London	21.4	16.8	16.8
Delaware	Kent	22.9	17.5	17.4
Delaware	New Castle	25.7	20.5	20.3
Delaware	Sussex	23.6	16.2	16.2
District Of Co	District of Columbia	25.9	20.0	19.9
Florida	Alachua	20.1	19.3	19.3
Florida	Brevard	14.8	12.8	12.8
Florida	Broward	14.5	13.8	13.8
Florida	Citrus	17.0	14.3	14.3
Florida	Duval	20.9	18.3	18.3
Florida	Escambia	19.5	15.8	15.9
Florida	Hillsborough	16.1	14.1	14.1
Florida	Lee	14.0	12.3	12.3
Florida	Leon	23.8	21.3	21.3
Florida	Miami-Dade	15.2	13.9	13.9
Florida	Orange	15.6	13.9	13.9
Florida	Palm Beach	15.1	13.8	13.8
Florida	Pinellas	16.7	15.2	15.2
Florida	Polk	15.2	13.4	13.4
Florida	Sarasota	15.5	13.3	13.3
Florida	Seminole	17.4	14.9	14.9
Florida	Volusia	16.2	13.8	13.8

State	County	2011 Baseline DV	2040 Reference DV	2040 HDGHGP2 Control DV
Georgia	Bibb	26.7	22.3	22.2
Georgia	Chatham	29.6	23.4	23.4
Georgia	Clarke	21.7	16.7	16.6
Georgia	Cobb	21.4	16.3	16.3
Georgia	DeKalb	22.0	16.5	16.5
Georgia	Dougherty	26.4	24.3	24.3
Georgia	Hall	21.1	15.9	15.9
Georgia	Houston	22.4	19.3	19.2
Georgia	Walker	22.0	17.1	17.1
Georgia	Wilkinson	22.8	20.0	20.0
Idaho	Ada	33.1	31.5	31.0
Idaho	Bannock	23.5	21.1	21.0
Idaho	Benewah	28.4	27.8	27.8
Idaho	Canyon	24.2	22.1	21.8
Idaho	Franklin	42.2	35.5	35.4
Idaho	Lemhi	37.0	35.3	35.3
Idaho	Shoshone	38.1	36.3	36.3
Indiana	Allen	24.9	18.0	17.8
Indiana	Clark	26.8	20.7	20.7
Indiana	Delaware	25.4	18.5	18.4
Indiana	Dubois	25.3	17.8	17.7
Indiana	Elkhart	29.2	21.9	21.7
Indiana	Floyd	24.5	17.9	17.8
Indiana	Gibson	25.3	17.3	17.3
Indiana	Henry	24.2	18.0	17.8
Indiana	Howard	26.0	18.9	18.8
Indiana	Knox	25.8	18.1	18.0
Indiana	Lake	30.0	23.9	23.6
Indiana	LaPorte	24.1	18.1	18.0
Indiana	Madison	22.6	17.2	16.8
Indiana	Marion	28.1	20.8	20.7
Indiana	Monroe	21.9	15.1	15.0
Indiana	Porter	26.6	20.8	20.7
Indiana	St. Joseph	26.9	20.3	20.1
Indiana	Spencer	25.7	17.5	17.3
Indiana	Tippecanoe	23.8	17.7	17.5
Indiana	Vanderburgh	25.5	19.9	19.8
Indiana	Vigo	26.0	17.8	17.7
Indiana	Whitley	22.2	16.0	15.9
Iowa	Black Hawk	29.2	22.1	21.9

State	County	2011 Baseline DV	2040 Reference DV	2040 HDGHGP2 Control DV
Iowa	Clinton	27.6	20.6	20.3
Iowa	Delaware	21.9	15.7	15.5
Iowa	Johnson	26.1	19.7	19.5
Iowa	Lee	25.2	18.9	18.7
Iowa	Linn	30.4	22.2	21.9
Iowa	Montgomery	22.1	16.4	16.2
Iowa	Muscatine	31.5	24.6	24.4
Iowa	Palo Alto	22.0	15.9	15.8
Iowa	Polk	24.3	17.8	17.5
Iowa	Pottawattamie	25.2	19.0	18.9
Iowa	Scott	28.7	20.8	20.6
Iowa	Van Buren	23.8	18.2	18.0
Iowa	Woodbury	25.9	19.4	19.1
Kansas	Johnson	18.2	14.2	14.1
Kansas	Linn	20.4	16.4	16.3
Kansas	Sedgwick	22.1	17.6	17.5
Kansas	Shawnee	20.0	18.3	18.2
Kansas	Sumner	20.8	17.5	17.5
Kansas	Wyandotte	22.4	18.1	18.0
Kentucky	Bell	23.7	20.1	20.0
Kentucky	Boyd	23.0	16.7	16.7
Kentucky	Campbell	23.7	15.4	15.3
Kentucky	Carter	18.3	14.1	14.1
Kentucky	Christian	21.5	14.8	14.7
Kentucky	Daviess	25.5	18.8	18.8
Kentucky	Fayette	21.9	15.5	15.5
Kentucky	Hardin	22.7	16.3	16.2
Kentucky	Henderson	23.9	17.2	17.2
Kentucky	Jefferson	26.0	20.5	20.5
Kentucky	McCracken	23.4	15.9	15.8
Kentucky	Madison	19.6	13.8	13.8
Kentucky	Pike	21.5	16.3	16.3
Kentucky	Warren	21.9	15.3	15.4
Louisiana	Caddo	22.0	19.2	19.1
Louisiana	Calcasieu	19.8	17.0	16.9
Louisiana	East Baton Rouge	21.2	18.5	18.7
Louisiana	Iberville	20.6	19.9	20.1
Louisiana	Jefferson	18.7	16.1	16.3
Louisiana	Lafayette	19.9	17.8	17.8
Louisiana	Ouachita	19.9	16.9	16.9

State	County	2011 Baseline DV	2040 Reference DV	2040 HDGHGP2 Control DV
Louisiana	Rapides	19.8	16.8	16.8
Louisiana	St. Bernard	20.2	16.2	16.2
Louisiana	Tangipahoa	18.3	15.2	15.3
Louisiana	Terrebonne	17.5	14.4	14.6
Louisiana	West Baton Rouge	21.9	18.9	18.9
Maine	Androscoggin	20.9	16.0	16.0
Maine	Aroostook	18.6	16.3	16.3
Maine	Cumberland	20.4	16.1	16.1
Maine	Hancock	14.8	12.7	12.7
Maine	Kennebec	19.7	14.6	14.6
Maine	Oxford	26.4	21.6	21.6
Maine	Penobscot	19.5	15.4	15.4
Maryland	Anne Arundel	24.5	18.9	18.9
Maryland	Baltimore	27.0	21.6	21.6
Maryland	Cecil	26.7	19.9	19.8
Maryland	Garrett	19.5	14.2	14.2
Maryland	Harford	23.6	17.9	17.8
Maryland	Kent	24.1	18.9	18.8
Maryland	Montgomery	24.5	19.8	19.7
Maryland	Prince George's	24.4	19.9	19.8
Maryland	Washington	27.4	21.8	21.8
Maryland	Baltimore (City)	27.1	21.9	21.9
Massachusetts	Berkshire	24.1	18.6	18.5
Massachusetts	Bristol	19.5	13.9	13.9
Massachusetts	Essex	18.8	15.4	15.4
Massachusetts	Hampden	24.6	20.0	20.0
Massachusetts	Middlesex	19.3	15.0	15.1
Massachusetts	Plymouth	19.4	15.0	15.0
Massachusetts	Suffolk	22.5	17.8	17.8
Massachusetts	Worcester	21.6	17.1	17.1
Michigan	Allegan	23.9	17.5	17.3
Michigan	Bay	23.1	17.6	17.4
Michigan	Berrien	21.2	16.2	16.1
Michigan	Chippewa	16.2	13.6	13.5
Michigan	Genesee	21.8	16.1	16.0
Michigan	Ingham	22.4	17.1	17.1
Michigan	Kalamazoo	22.6	17.0	16.8
Michigan	Kent	24.2	18.5	18.3
Michigan	Lenawee	24.0	18.6	18.5
Michigan	Macomb	23.5	17.9	17.7

State	County	2011 Baseline DV	2040 Reference DV	2040 HDGHGP2 Control DV
Michigan	Manistee	18.6	13.4	13.3
Michigan	Missaukee	17.1	13.4	13.4
Michigan	Monroe	24.4	18.0	17.9
Michigan	Muskegon	23.7	17.5	17.3
Michigan	Oakland	24.8	18.7	18.6
Michigan	Ottawa	23.8	18.1	17.9
Michigan	St. Clair	23.8	19.3	19.2
Michigan	Washtenaw	23.3	17.8	17.6
Michigan	Wayne	28.4	22.7	22.5
Minnesota	Anoka	22.6	17.7	17.6
Minnesota	Dakota	25.9	20.6	20.4
Minnesota	Hennepin	25.7	21.1	21.0
Minnesota	Olmsted	25.7	19.1	19.0
Minnesota	Ramsey	28.5	23.0	22.9
Minnesota	Saint Louis	21.2	17.7	17.6
Minnesota	Scott	24.8	19.4	19.2
Minnesota	Stearns	24.4	18.4	18.2
Mississippi	DeSoto	18.9	14.6	14.7
Mississippi	Forrest	21.7	18.3	18.4
Mississippi	Grenada	19.5	15.3	15.3
Mississippi	Hancock	19.2	16.4	16.3
Mississippi	Harrison	18.3	14.5	14.5
Mississippi	Hinds	21.2	17.5	17.5
Mississippi	Jackson	20.4	16.2	16.2
Mississippi	Jones	22.6	19.5	19.5
Mississippi	Lauderdale	21.0	17.4	17.3
Mississippi	Lee	21.1	16.3	16.3
Missouri	Cass	23.4	19.6	19.5
Missouri	Cedar	22.4	18.7	18.7
Missouri	Clay	21.6	17.6	17.4
Missouri	Greene	22.0	18.6	18.6
Missouri	Jackson	23.0	19.1	19.1
Missouri	Jefferson	22.9	17.6	17.5
Missouri	Saint Louis	25.4	20.2	20.0
Missouri	St. Louis City	25.3	20.0	19.7
Montana	Lewis and Clark	33.3	31.9	31.9
Montana	Missoula	31.5	31.2	31.1
Montana	Ravalli	51.3	50.3	50.3
Montana	Richland	15.7	15.2	15.2
Montana	Silver Bow	39.7	36.1	36.0

State	County	2011 Baseline DV	2040 Reference DV	2040 HDGHGP2 Control DV
Nebraska	Douglas	22.7	17.3	17.3
Nebraska	Hall	18.9	14.4	14.2
Nebraska	Lancaster	21.3	16.3	16.2
Nebraska	Sarpy	25.7	19.8	19.5
Nebraska	Washington	22.7	17.1	16.9
Nevada	Clark	21.3	18.4	18.4
Nevada	Washoe	22.8	19.0	18.9
New Hampshire	Belknap	16.3	13.0	13.0
New Hampshire	Cheshire	28.4	23.0	23.0
New Hampshire	Grafton	19.0	14.4	14.4
New Hampshire	Hillsborough	20.5	16.5	16.5
New Hampshire	Merrimack	21.8	17.4	17.4
New Hampshire	Rockingham	22.8	18.2	18.3
New Jersey	Atlantic	23.2	17.0	17.0
New Jersey	Bergen	23.5	17.3	17.3
New Jersey	Camden	22.6	16.5	16.4
New Jersey	Essex	22.8	18.0	18.0
New Jersey	Gloucester	22.2	15.9	15.8
New Jersey	Hudson	26.8	20.1	20.1
New Jersey	Mercer	25.0	19.9	19.9
New Jersey	Middlesex	19.3	14.7	14.7
New Jersey	Morris	21.1	15.4	15.4
New Jersey	Ocean	22.7	16.3	16.3
New Jersey	Passaic	24.3	18.9	18.8
New Jersey	Union	29.4	22.3	22.2
New Jersey	Warren	25.3	19.1	19.0
New Mexico	Bernalillo	19.1	16.2	16.2
New Mexico	Dona Ana	12.7	14.3	14.3
New Mexico	Lea	19.4	20.3	20.3
New Mexico	San Juan	13.4	15.3	15.3
New Mexico	Santa Fe	9.9	10.1	10.1
New York	Albany	21.8	16.5	16.4
New York	Bronx	28.0	21.9	21.9
New York	Chautauqua	21.1	14.3	14.3
New York	Erie	24.5	18.5	18.5
New York	Essex	14.2	9.9	9.9
New York	Kings	24.1	18.1	18.1
New York	Nassau	23.0	17.2	17.1
New York	New York	25.7	20.3	20.3
New York	Onondaga	20.7	14.4	14.3

State	County	2011 Baseline DV	2040 Reference DV	2040 HDGHGP2 Control DV
New York	Orange	21.7	16.5	16.4
New York	Queens	24.2	18.5	18.4
New York	Richmond	23.0	17.8	17.8
New York	Steuben	19.3	13.5	13.5
New York	Suffolk	21.9	16.6	16.6
New York	Westchester	25.4	18.4	18.4
North Carolina	Alamance	19.8	14.6	14.7
North Carolina	Buncombe	17.8	13.1	13.1
North Carolina	Caswell	17.8	12.3	12.2
North Carolina	Catawba	20.6	16.0	16.0
North Carolina	Chatham	18.1	12.7	12.7
North Carolina	Cumberland	21.0	16.8	16.8
North Carolina	Davidson	20.8	15.6	15.6
North Carolina	Duplin	19.3	14.5	14.5
North Carolina	Durham	18.7	13.4	13.3
North Carolina	Edgecombe	19.6	14.4	14.4
North Carolina	Forsyth	19.9	14.7	14.6
North Carolina	Gaston	21.6	16.2	16.1
North Carolina	Guilford	20.4	15.4	15.4
North Carolina	Haywood	21.1	18.6	18.6
North Carolina	Jackson	17.4	13.8	13.8
North Carolina	Johnston	18.9	13.8	13.8
North Carolina	Lenoir	21.4	15.4	15.4
North Carolina	McDowell	18.4	15.1	15.1
North Carolina	Martin	22.9	16.5	16.5
North Carolina	Mecklenburg	22.6	17.6	17.5
North Carolina	Mitchell	18.0	13.8	13.8
North Carolina	Montgomery	19.6	14.6	14.6
North Carolina	New Hanover	22.0	15.8	15.8
North Carolina	Pitt	20.6	15.0	15.0
North Carolina	Robeson	20.5	17.5	17.5
North Carolina	Rowan	19.3	14.8	14.8
North Carolina	Swain	19.4	15.4	15.4
North Carolina	Wake	21.9	16.9	16.9
North Carolina	Watauga	16.9	12.5	12.5
North Carolina	Wayne	20.3	15.6	15.6
North Dakota	Billings	10.9	9.7	9.7
North Dakota	Burke	14.7	13.9	13.9
North Dakota	Burleigh	15.7	14.1	14.0
North Dakota	Cass	20.2	17.1	17.0

State	County	2011 Baseline DV	2040 Reference DV	2040 HDGHGP2 Control DV
North Dakota	McKenzie	15.2	14.5	14.5
North Dakota	Mercer	14.9	13.9	13.9
Ohio	Athens	17.1	12.1	12.1
Ohio	Butler	27.0	20.2	20.0
Ohio	Clark	26.4	18.7	18.6
Ohio	Clermont	26.6	18.1	18.0
Ohio	Cuyahoga	29.4	22.7	22.7
Ohio	Franklin	24.8	18.0	17.9
Ohio	Greene	21.8	15.5	15.4
Ohio	Hamilton	28.9	21.0	20.7
Ohio	Jefferson	27.2	19.6	19.5
Ohio	Lake	22.3	15.7	15.6
Ohio	Lawrence	22.3	17.7	17.7
Ohio	Lorain	22.7	16.2	16.2
Ohio	Lucas	25.6	19.8	19.7
Ohio	Mahoning	24.8	18.8	18.7
Ohio	Montgomery	26.6	19.7	19.6
Ohio	Portage	24.1	17.0	16.9
Ohio	Preble	24.0	17.6	17.5
Ohio	Scioto	21.1	14.8	14.8
Ohio	Stark	27.9	21.9	21.9
Ohio	Summit	26.5	18.5	18.5
Ohio	Trumbull	23.9	17.4	17.3
Ohio	Warren	26.3	18.8	18.7
Oklahoma	Oklahoma	19.6	17.1	17.1
Oklahoma	Pittsburg	20.2	18.1	18.0
Oklahoma	Sequoyah	22.2	18.8	18.7
Oklahoma	Tulsa	22.3	19.3	19.2
Oregon	Crook	33.5	33.2	33.2
Oregon	Harney	32.6	31.3	31.3
Oregon	Jackson	32.2	31.4	31.4
Oregon	Josephine	26.2	25.9	25.9
Oregon	Klamath	35.8	33.7	33.7
Oregon	Lake	41.8	40.4	40.4
Oregon	Lane	24.6	23.9	23.9
Oregon	Multnomah	27.2	26.2	26.2
Oregon	Umatilla	23.4	22.1	22.0
Oregon	Washington	28.9	27.9	27.9
Pennsylvania	Adams	28.8	21.2	21.1
Pennsylvania	Allegheny	41.4	33.7	33.6

State	County	2011 Baseline DV	2040 Reference DV	2040 HDGHGP2 Control DV
Pennsylvania	Armstrong	25.5	18.9	18.8
Pennsylvania	Beaver	27.4	21.6	21.6
Pennsylvania	Berks	27.4	22.2	22.1
Pennsylvania	Blair	29.8	22.5	22.5
Pennsylvania	Bucks	28.8	24.0	23.9
Pennsylvania	Cambria	30.2	23.0	23.0
Pennsylvania	Centre	25.0	18.2	18.2
Pennsylvania	Chester	29.6	23.1	23.0
Pennsylvania	Cumberland	30.9	24.1	24.1
Pennsylvania	Dauphin	31.5	25.3	25.2
Pennsylvania	Delaware	29.7	24.1	23.9
Pennsylvania	Erie	26.6	20.6	20.6
Pennsylvania	Lackawanna	23.6	17.6	17.5
Pennsylvania	Lancaster	30.9	24.6	24.5
Pennsylvania	Mercer	24.8	18.7	18.5
Pennsylvania	Monroe	20.4	14.7	14.6
Pennsylvania	Montgomery	25.8	19.9	19.8
Pennsylvania	Northampton	32.1	25.3	25.2
Pennsylvania	Philadelphia	30.4	22.5	22.5
Pennsylvania	Washington	26.4	19.0	18.9
Pennsylvania	York	28.6	22.6	22.5
Rhode Island	Kent	16.0	11.4	11.4
Rhode Island	Providence	23.3	17.6	17.6
South Carolina	Charleston	21.0	16.8	16.7
South Carolina	Chesterfield	19.5	17.3	17.3
South Carolina	Edgefield	20.3	16.4	16.3
South Carolina	Florence	21.9	17.4	17.4
South Carolina	Greenville	22.4	18.7	18.7
South Carolina	Lexington	22.8	19.4	19.4
South Carolina	Richland	22.8	18.9	18.9
South Carolina	Spartanburg	21.3	17.1	17.0
South Dakota	Brookings	21.8	16.2	16.0
South Dakota	Brown	20.9	15.2	15.1
South Dakota	Codington	21.1	15.8	15.7
South Dakota	Custer	12.6	11.7	11.7
South Dakota	Jackson	11.9	11.0	11.0
South Dakota	Minnehaha	22.8	16.5	16.3
South Dakota	Pennington	14.9	14.2	14.2
South Dakota	Union	23.1	17.6	17.5
Tennessee	Hamilton	22.5	18.0	18.0

State	County	2011 Baseline DV	2040 Reference DV	2040 HDGHGP2 Control DV
Texas	Bexar	22.6	22.2	22.2
Texas	Bowie	21.8	18.5	18.5
Texas	Dallas	20.9	18.8	18.8
Texas	El Paso	29.2	32.0	32.0
Texas	Harris	23.7	21.4	21.4
Texas	Harrison	21.1	17.5	17.5
Texas	Nueces	27.8	26.4	26.3
Texas	Tarrant	22.3	21.0	21.0
Texas	Travis	22.3	21.1	21.1
Utah	Box Elder	38.1	31.1	30.7
Utah	Cache	41.7	32.7	32.5
Utah	Davis	36.5	29.0	28.6
Utah	Salt Lake	41.2	32.4	32.0
Utah	Tooele	26.4	20.4	19.9
Utah	Utah	42.5	32.7	32.1
Utah	Washington	10.8	10.6	10.6
Utah	Weber	39.4	31.7	31.3
Vermont	Bennington	18.2	13.2	13.2
Vermont	Chittenden	20.4	16.1	16.1
Vermont	Rutland	28.1	22.4	22.4
Virginia	Albemarle	18.6	12.7	12.7
Virginia	Charles	20.3	13.2	13.2
Virginia	Chesterfield	21.0	14.8	14.8
Virginia	Fairfax	23.0	17.7	17.6
Virginia	Frederick	23.4	18.2	18.2
Virginia	Henrico	21.4	15.6	15.5
Virginia	Loudoun	20.2	16.0	15.9
Virginia	Page	20.8	15.5	15.4
Virginia	Rockingham	21.8	17.4	17.4
Virginia	Bristol City	19.5	15.7	15.6
Virginia	Hampton City	20.6	14.7	14.7
Virginia	Lynchburg City	18.2	13.5	13.4
Virginia	Norfolk City	21.6	16.0	15.9
Virginia	Roanoke City	21.5	16.6	16.6
Virginia	Salem City	19.8	14.6	14.6
Virginia	Virginia Beach City	23.1	16.6	16.5
Washington	Clark	27.9	25.8	25.7
Washington	King	23.8	21.7	21.7
Washington	Pierce	31.8	28.5	28.5
Washington	Snohomish	28.4	26.7	26.7

State	County	2011 Baseline DV	2040 Reference DV	2040 HDGHGP2 Control DV
Washington	Spokane	26.0	24.3	24.3
Washington	Yakima	32.7	27.3	27.1
West Virginia	Berkeley	29.1	22.4	22.4
West Virginia	Brooke	26.2	18.1	18.1
West Virginia	Cabell	23.3	17.3	17.3
West Virginia	Hancock	27.0	19.0	19.0
West Virginia	Kanawha	24.1	17.8	17.7
West Virginia	Marion	24.2	18.5	18.5
West Virginia	Marshall	27.6	22.4	22.4
West Virginia	Monongalia	23.6	16.4	16.4
West Virginia	Ohio	25.2	16.8	16.7
West Virginia	Raleigh	19.4	13.6	13.6
West Virginia	Wood	24.2	17.7	17.7
Wisconsin	Ashland	17.2	13.6	13.5
Wisconsin	Brown	28.5	21.7	21.4
Wisconsin	Dane	27.4	20.8	20.7
Wisconsin	Dodge	25.0	18.4	18.2
Wisconsin	Forest	19.5	14.2	14.0
Wisconsin	Grant	25.1	18.9	18.7
Wisconsin	Kenosha	25.5	19.3	19.0
Wisconsin	La Crosse	24.6	18.1	17.8
Wisconsin	Milwaukee	29.6	22.5	22.3
Wisconsin	Outagamie	27.2	19.9	19.7
Wisconsin	Ozaukee	23.6	17.6	17.4
Wisconsin	Sauk	24.3	18.1	18.0
Wisconsin	Taylor	23.8	17.6	17.4
Wisconsin	Vilas	17.5	12.3	12.2
Wisconsin	Waukesha	27.3	21.0	20.8
Wyoming	Albany	13.0	12.2	12.1
Wyoming	Fremont	29.6	30.0	30.0
Wyoming	Laramie	11.3	10.9	10.9
Wyoming	Natrona	14.1	14.1	14.1
Wyoming	Park	12.6	12.8	12.8
Wyoming	Sheridan	22.0	21.9	21.9
Wyoming	Sweetwater	15.6	14.0	14.0
Wyoming	Teton	14.1	13.6	13.6