United States Environmental Protection Agency

Air Quality Modeling Technical Support Document: Light-Duty Vehicle Greenhouse Gas Emission Standards Final Rule

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U.S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Air Quality Assessment Division
Research Triangle Park, NC 27711
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I. Introduction

This document describes the air quality modeling performed by EPA in support of the Light-Duty Vehicle Greenhouse Gas Final Rule (hereafter referred to as LDGHG). A national scale air quality modeling analysis was performed to estimate the impact of the vehicle standards on future year: annual and 24-hour $PM_{2.5}$ concentrations, daily maximum 8-hour ozone concentrations, annual nitrogen and sulfur deposition levels, annual and seasonal ethanol levels and select annual and seasonal air toxic concentrations (formaldehyde, acetaldehyde, benzene, 1,3-butadiene and acrolein) as well as visibility impairment. To model the air quality benefits of this rule we used the Community Multiscale Air Quality (CMAQ)[1] model. 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. For this reason, it is important to note that the inventories used in the air quality modeling and the benefits modeling, which are presented in Section 5.8 of the RIA, are slightly different than the final vehicle standard inventories presented in Section 5.5 of the RIA. However, the air quality inventories and the final rule inventories are generally consistent, so the air quality modeling adequately reflects the effects of the rule.

II. CMAQ Model Version, Inputs and Configuration

The 2005-based CMAQ modeling platform was used as the basis for the air quality modeling of the LDGHG future baseline and the future control scenario for this 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 2005. 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. Model version

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 4.7 was most recently peer-reviewed in February of

[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.

2009 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 2005 multi-pollutant modeling platform used CMAQ version 4.7.1[6] with a minor internal change made by the U.S. EPA CMAQ model developers intended to speed model runtimes when only a small subset of toxics species are of interest. CMAQ v4.7.1 reflects updates to version 4.7 to improve the underlying science which include aqueous chemistry mass conservation improvements, improved vertical convective mixing and lowered Carbon Bond Mechanism-05 (CB-05) mechanism unit yields for acrolein (from 1,3-butadiene tracer reactions which were updated to be consistent with laboratory measurements).

B. Model domain and grid resolution

The CMAQ modeling analyses were performed for a domain covering the continental United States, as shown in Figure II-1. This domain has a parent horizontal grid of 36 km with two finer-scale 12 km grids over portions of the eastern and western U.S. The model extends vertically from the surface to 100 millibars (approximately 15 km) using a sigma-pressure coordinate system. Air quality conditions at the outer boundary of the 36 km domain were taken from a global model and did not change over the simulations. In turn, the 36 km grid was only used to establish the incoming air quality concentrations along the boundaries of the 12 km grids. Only the finer grid data were used in determining the impacts of the LDGHG emission standard program changes. Table II-1 provides some basic geographic information regarding the CMAQ domains.

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[2] Allen, D., Burns, D., Chock, D., Kumar, N., Lamb, B., Moran, M. (February 2009 Draft Version). Report on the Peer Review of the Atmospheric Modeling and Analysis Division, NERL/ORD/EPA. U.S. EPA, Research Triangle Park, NC. CMAQ version 4.7 was released on December, 2008. 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.

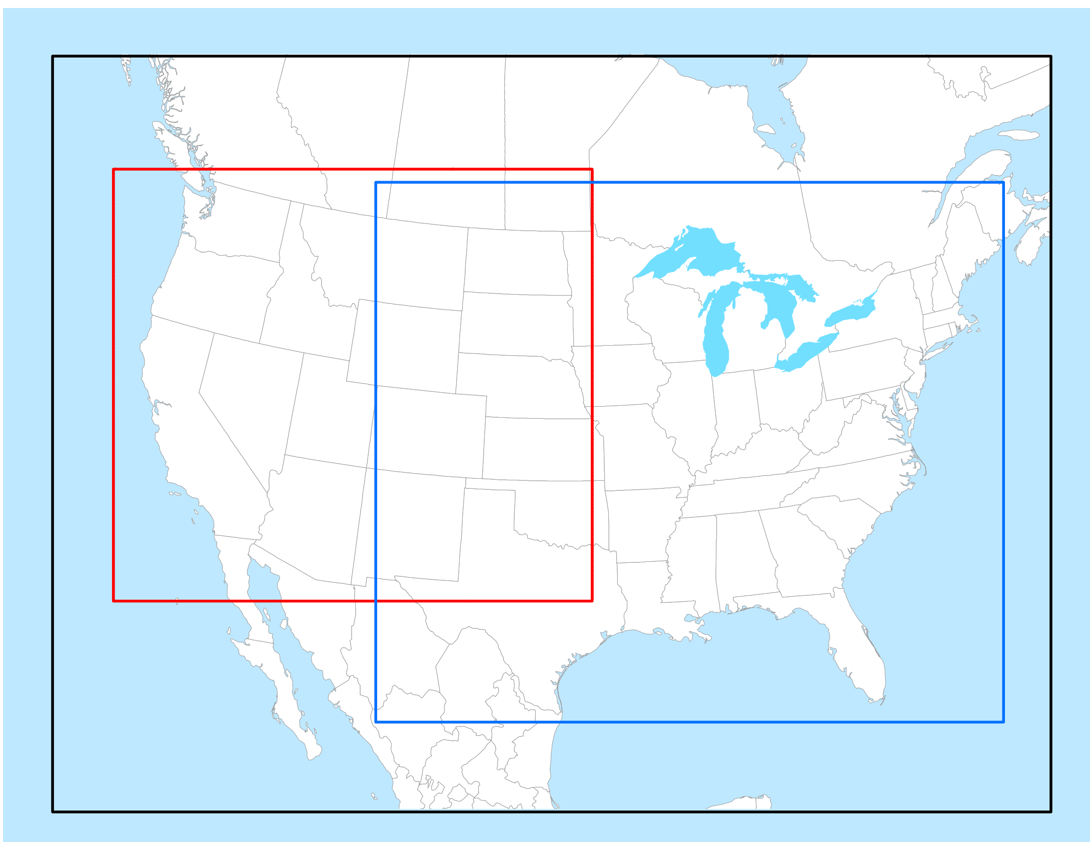
[5] Lin, M., Oki, T., Holloway, T., Streets, D.G., Bengtsson, M., Kanae, S., (2008). Long range transport of acidifying substances in East Asia Part I: Model evaluation and sensitivity studies. Atmospheric Environment, 42(24), 5939-5955.

[6] CMAQ version 4.7.1 model code is available from the Community Modeling and Analysis System (CMAS) at: http://www.cmascenter.org as well as at EPA-HQ-OAR-0472-DRAFT-11662.

Table II-1. Geographic elements of domains used in RFS2 modeling.

	CMAQ Modeling Configuration		
	National Grid	**Western U.S. Fine Grid**	**Eastern U.S. Fine Grid**
Map Projection	Lambert Conformal Projection		
Grid Resolution	36 km	12 km	12 km
Coordinate Center	97 deg W, 40 deg N		
True Latitudes	33 deg N and 45 deg N		
Dimensions	148 x 112 x 14	213 x 192 x 14	279 x 240 x 14
Vertical extent	14 Layers: Surface to 100 millibar level (see Table II-3)		

Figure II-1. Map of the CMAQ modeling domain. The black outer box denotes the 36 km national modeling domain; the red inner box is the 12 km western U.S. fine grid; and the blue inner box is the 12 km eastern U.S. fine grid.



C. Modeling Time-period

The 36 km and both 12 km CMAQ modeling domains were modeled for the entire year of 2005.[7] For the 8-hour ozone results, we are only using modeling results from the period between May 1 and September 30, 2005. 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 2005. Data from the entire year were utilized when looking at the estimation of $PM_{2.5}$, total nitrogen and sulfate deposition, visibility and toxics impacts from the regulation.

D. Model Inputs: Emissions, Meteorology and Boundary Conditions

The 2005-based CMAQ modeling platform was used for the air quality modeling of future baseline emissions and control scenarios. As noted in the introduction, in addition to the CMAQ model, the modeling platform also consists of the base- and future-year emissions estimates (both anthropogenic and biogenic), meteorological fields, as well as initial and boundary condition data which are all inputs to the air quality model.

1. Base Year and Future Baseline Emissions: The emissions modeling TSD, found in the docket for this rule (EPA-420-R-10-011) contains a detailed discussion of the emissions inputs used in our air quality modeling. We have provided a brief summary of the base year and future baseline emissions used for the air quality modeling. The emissions data used in the base year and future reference and control case are based on the 2005 v4 platform. The LDGHG cases use some different emissions data than the official v4 platform for two reasons: (1) the LDGHG Standard was evaluated in comparison to the modeling performed for the Revised annual Renewable Fuel Standard (RFS2)[8]; therefore, RFS2-specific inputs were retained for LDGHG and (2) the LDGHG modeling used data intended only for the rule development and not for general use. Unlike the 2005 v4 platform, the configuration for LDGHG modeling included additional hazardous air pollutants (HAPs) and used slightly older ancillary data. Both of these differences are described in Section 2.1 of the emissions modeling TSD.

The 2030 reference case (projection without vehicle standards) is intended to represent the emissions associated with use of the most likely volume of ethanol in the absence of the LDGHG CO_2 reductions and RFS2 rule and Energy Independence and Security Act of 2007 (EISA) renewable fuel requirements. For this case, the ethanol volume was projected for 2030 using the Department of Energy, Energy Information Administration in the 2007 Annual Energy Outlook (AEO) report. The US EGU point source emissions estimates for the future year reference and control case are based on an Integrated Planning Model (IPM) run for criteria pollutants, hydrochloric acid, and mercury in 2020 (though mercury was not modeled). The year 2020 was used since it was the closest readily year to the 2030 year used for LDGHG air quality modeling. Both control and growth factors were applied to a subset of the 2005 non-EGU point

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[7] We also modeled 10 days at the end of December 2004 as a modeled "ramp up" period. These days are used to minimize the effects of initial conditions and are not considered as part of the output analyses.

[8] EPA 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.

and nonpoint to create the 2030 reference case. The 2002 v3.1 platform 2020 projection factors were the starting point for most of the LDGHG year of 2030 SMOKE-based projections. Ethanol plant replacements and additions were included in the 2005 base and 2030 reference case as well as biodiesel additions and portable fuel containers.

It should be noted that the emission inventories used in the air quality and benefits modeling are different from the final rule inventories due to the length of time required to conduct the modeling. However, the air quality modeling inventories are generally consistent with the final emission inventories, so the air quality modeling adequately reflects the effects of the rule.

2. LDGHG 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 and seasonal air toxics concentrations, annual total nitrogen and sulfur deposition levels and visibility impairment for each of the following emissions scenarios:

2005 base year

2030 reference case projection without the vehicle standards

2030 control case projection with the vehicle standards

Model predictions are used in a relative sense to estimate scenario-specific, future-year design values of $PM_{2.5}$ and ozone. Specifically, we compare a 2030 reference scenario, a scenario without the vehicle standards, to a 2030 control scenario which includes the vehicle standards. This is done by calculating the simulated air quality ratios between any particular future year simulation and the 2005 base. These predicted change ratios are then applied to ambient base year design values. The design value projection methodology used here followed EPA guidance[9] for such analyses. Additionally, the raw model outputs are also used in a relative sense as inputs to the health and welfare impact functions of the benefits analysis. Only model predictions for air toxics as well as nitrogen and sulfur deposition were analyzed using absolute model changes, although these parameters also considered percent changes between the control case and two future baselines.

3. Meteorological Input Data: The gridded meteorological input data for the entire year of 2005 were derived from simulations of the Pennsylvania State University / National Center for Atmospheric Research Mesoscale Model. This model, commonly referred to as MM5, is a limited-area, nonhydrostatic, terrain-following system that solves for the full set of physical and thermodynamic equations which govern atmospheric motions.[10] Meteorological model input

[9] U.S. EPA, Guidance on the Use of Models and Other Analyses in Attainment Demonstrations for the 8-hour Ozone NAAQS; EPA-454/R-05-002; Research Triangle Park, NC; October 2005.
[10] Grell, G., J. Dudhia, and D. Stauffer, 1994: A Description of the Fifth-Generation Penn State/NCAR Mesoscale Model (MM5), NCAR/TN-398+STR., 138 pp, National Center for Atmospheric Research, Boulder CO.

fields were prepared separately for each of the three domains shown in Figure II-1 using MM5 version 3.7.4. The MM5 simulations were run on the same map projection as CMAQ.

All three meteorological model runs configured similarly. The selections for key MM5 physics options are shown below:

- Pleim-Xiu PBL and land surface schemes
- Kain-Fritsh 2 cumulus parameterization
- Reisner 2 mixed phase moisture scheme
- RRTM longwave radiation scheme
- Dudhia shortwave radiation scheme

Three dimensional analysis nudging for temperature and moisture was applied above the boundary layer only. Analysis nudging for the wind field was applied above and below the boundary layer. The 36 km domain nudging weighting factors were 3.0×10^4 for wind fields and temperatures and 1.0×10^5 for moisture fields. The 12 km domain nudging weighting factors were 1.0×10^4 for wind fields and temperatures and 1.0×10^5 for moisture fields.

All three sets of model runs were conducted in 5.5 day segments with 12 hours of overlap for spin-up purposes. All three domains contained 34 vertical layers with an approximately 38 m deep surface layer and a 100 millibar top. The MM5 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 MM5 and CMAQ (heights are layer top).

CMAQ Layers	MM5 Layers	Sigma P	Approximate Height (m)	Approximate Pressure (mb)
0	0	1.000	0	1000
1	1	0.995	38	995
2	2	0.990	77	991
3	3	0.985	115	987
	4	0.980	154	982
4	5	0.970	232	973
	6	0.960	310	964
5	7	0.950	389	955
	8	0.940	469	946
6	9	0.930	550	937
	10	0.920	631	928
	11	0.910	712	919
7	12	0.900	794	910
	13	0.880	961	892
	14	0.860	1,130	874
8	15	0.840	1,303	856
	16	0.820	1,478	838
	17	0.800	1,657	820
9	18	0.770	1,930	793
	19	0.740	2,212	766
10	20	0.700	2,600	730
	21	0.650	3,108	685
11	22	0.600	3,644	640

	23	0.550	4,212	595
12	24	0.500	4,816	550
	25	0.450	5,461	505
	26	0.400	6,153	460
13	27	0.350	6,903	415
	28	0.300	7,720	370
	29	0.250	8,621	325
	30	0.200	9,625	280
14	31	0.150	10,764	235
	32	0.100	12,085	190
	33	0.050	13,670	145
	34	0.000	15,674	100

The meteorological outputs from all three MM5 sets were processed to create model-ready inputs for CMAQ using the Meteorology-Chemistry Interface Processor (MCIP), version 3.4 to derive the specific inputs to CMAQ.[11]

Before initiating the air quality simulations, it is important to identify the biases and errors associated with the meteorological modeling inputs. The 2005 MM5 model performance evaluations used an approach which included a combination of qualitative and quantitative analyses to assess the adequacy of the MM5 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. Qualitatively, the model fields closely matched the observed synoptic patterns, which is not unexpected given the use of nudging. The operational evaluation included statistical comparisons of model/observed pairs (e.g., mean normalized bias, mean normalized error, index of agreement, root mean square errors, etc.) 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 three individual MM5 evaluations are described elsewhere.[12,13,14] It was ultimately determined that the bias and error values associated with all three sets of 2005 meteorological data were generally within the range of past meteorological modeling results that have been used for air quality applications.

4. Initial and Boundary Conditions: The lateral boundary and initial species concentrations are provided by a three-dimensional global atmospheric chemistry model, the

[11] 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).

[12] Baker K. and P. Dolwick. Meteorological Modeling Performance Evaluation for the Annual 2005 Eastern U.S. 12-km Domain Simulation, USEPA/OAQPS, February 2, 2009.

[13] Baker K. and P. Dolwick. Meteorological Modeling Performance Evaluation for the Annual 2005 Western U.S. 12-km Domain Simulation, USEPA/OAQPS, February 2, 2009.

[14] Baker K. and P. Dolwick. Meteorological Modeling Performance Evaluation for the Annual 2005 Continental U.S. 36-km Domain Simulation, USEPA/OAQPS, February 2, 2009.

GEOS-CHEM[15] model (standard version 7-04-11[16]). 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). This model was run for 2005 with a grid resolution of 2.0 degree x 2.5 degree (latitude-longitude) and 30 vertical layers up to 100 mb. The predictions were used to provide one-way dynamic boundary conditions at three-hour intervals and an initial concentration field for the 36-km CMAQ simulations. The future base conditions from the 36 km coarse grid modeling were used as the initial/boundary state for all subsequent 12 km finer grid modeling.

E. CMAQ Base Case Model Performance Evaluation

1. $PM_{2.5}$: An operational model performance evaluation for $PM_{2.5}$ and its related speciated components (e.g., sulfate, nitrate, elemental carbon, organic carbon, etc.) was conducted using 2005 state/local monitoring data in order to estimate the ability of the CMAQ modeling system to replicate base year concentrations. In summary, model performance statistics were calculated for observed/predicted pairs of daily/monthly/seasonal/annual concentrations. Statistics were generated for the following geographic groupings: domain wide, Eastern vs. Western (divided along the 100th meridian), and each Regional Planning Organization (RPO) region[17]. The "acceptability" of model performance was judged by comparing our CMAQ 2005 performance results to the range of performance found in recent regional $PM_{2.5}$ model applications for other, non-EPA studies[18]. Overall, the fractional bias, fractional error, normalized mean bias, and normalized mean error statistics shown in Table II-4 are within the range or close to that found by other groups in recent applications. The model performance results give us confidence that our application of CMAQ using this modeling platform provides a scientifically credible approach for assessing $PM_{2.5}$ concentrations for the purposes of the LDGHG vehicle standards assessment. A detailed summary of the 2005 CMAQ model performance evaluation is available in Appendix D[19].

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[15] Yantosca, B., 2004. GEOS-CHEMv7-01-02 User's Guide, Atmospheric Chemistry Modeling Group, Harvard University, Cambridge, MA, October 15, 2004.

[16] Henze, D.K., J.H. Seinfeld, N.L. Ng, J.H. Kroll, T-M. Fu, D.J. Jacob, C.L. Heald, 2008. Global modeling of secondary organic aerosol formation from aromatic hydrocarbons: high-vs.low-yield pathways. *Atmos. Chem. Phys.*, 8, 2405-2420.

[17] Regional Planning Organization regions include: Mid-Atlantic/Northeast Visibility Union (MANEVU), Midwest Regional Planning Organization – Lake Michigan Air Directors Consortium (MWRPO-LADCO), Visibility Improvement State and Tribal Association of the Southeast (VISTAS), Central States Regional Air Partnership (CENRAP), and the Western Regional Air Partnership (WRAP).

[18] These other modeling studies represent a wide range of modeling analyses which cover various models, model configurations, domains, years and/or episodes, chemical mechanisms, and aerosol modules.

[19] U.S. Environmental Protection Agency, Air Quality Modeling Technical Support Document: Light-Duty Vehicle Greenhouse Gas Emission Standards Final Rule, Appendix D: CMAQ Model Performance Evaluation for Ozone, Particulate Matter and Toxics. April, 2010 (EPA-454/R-10-003).

Table II-4. 2005 CMAQ annual $PM_{2.5}$ species model performance statistics.

CMAQ 2005 Annual $PM_{2.5}$ species			No. of Obs.	NMB (%)	NME (%)	FB (%)	FE (%)
$PM_{2.5}$ Total Mass	STN	12-km EUS	11797	6.6	39.5	4.0	39.2
		12-km WUS	3440	-10.0	45.0	-9.5	44.4
		Northeast	2318	16.6	38.1	15.8	35.1
		Midwest	3020	19.5	45.6	16.5	40.7
		Southeast	3067	-7.2	34.1	-7.6	29.1
		Central U.S.	2523	0.6	41.7	-3.6	44.7
		West	2826	-10.9	46.1	-10.6	45.0
	IMPROVE	12-km EUS	9321	1.6	43.4	0.0	44.0
		12-km WUS	10411	-10.9	44.8	-13.6	46.8
		Northeast	571	9.1	39.4	8	38.5
		Midwest	2339	21.5	52.9	14.9	46.8
		Southeast	1694	-10.5	37.2	-9.7	42.3
		Central U.S.	2376	-5.5	42.4	-4.7	46.0
		West	8820	-13.3	45.0	-14.5	47.2
Sulfate	STN	12-km EUS	13897	-8.7	32.6	-5.8	35.2
		12-km WUS	3920	-17.0	42.3	-7.8	42.8
		Northeast	2495	-1.2	33.4	4.1	34.1
		Midwest	3498	-3.9	31.7	-0.7	33.3
		Southeast	3882	-10.9	30.3	-8.6	32.9
		Central U.S.	3059	-19.8	36.5	-16.6	40.8
		West	3157	-15.5	45.8	-6.7	44.0
	IMPROVE	12-km EUS	9034	-11.4	33.8	-2.6	38.4
		12-km WUS	10002	-9.0	39.9	6.8	43.5
		Northeast	531	-9.5	31.8	-1.9	34.1
		Midwest	2253	-3.8	34.2	3.0	37.1
		Southeast	1685	-13.8	31.5	-8.1	35.4
		Central U.S.	2350	-19.7	35.8	-12.2	39.8
		West	8496	-4.7	41.7	9.6	44.4
	CASTNet	12-km EUS	3170	-15.7	23.1	-14.2	25.8
		12-km WUS	1142	-19.8	31.1	-10.5	32.6
		Northeast	615	-13.4	21.7	-11.0	22.9
		Midwest	786	-10.3	21.3	-7.7	23.0
		Southeast	1099	-17.9	22.7	-19.5	25.6
		Central U.S.	300	-29.1	32.0	-29.3	35.2
		West	1041	-18.4	31.6	-9.3	32.8
Nitrate	STN	12-km EUS	12741	37.8	78.6	0.4	79.4
		12-km WUS	3655	-41.7	65.3	-70.8	97.5
		Northeast	2495	41.0	73.3	24.0	66.8
		Midwest	3499	48.9	83.1	11.5	75.6

		Southeast	3882	34.5	93.7	-19.4	91.4
		Central U.S.	1927	25.0	67.2	4.8	75.0
		West	3139	-47.3	65.4	-79.1	99.9
	IMPROVE	12-km EUS	9027	52.8	98.5	-21.0	101.4
		12-km WUS	9987	-18.3	75.4	-84.2	120.6
		Northeast	531	32.8	77.1	2.0	83.8
		Midwest	2248	86.2	122.5	8.9	97.3
		Southeast	1685	67.2	126.4	-24.5	104.4
		Central U.S.	2350	40.89	82.1	-10.1	95.8
		West	8480	-35.7	77.0	-91.7	124.2
Total Nitrate (NO3 + HNO3)	CASTNet	12-km EUS	3170	41.0	51.0	31.7	44.0
		12-km WUS	1142	5.4	36.3	13.1	40.6
		Northeast	615	37.4	47.0	35.1	40.6
		Midwest	786	55.8	59.4	44.4	50.2
		Southeast	1099	41.8	53.4	29.0	45.6
		Central U.S.	300	23.6	40.3	16.8	36.2
		West	1041	4.8	37.6	14.7	41.6
Ammonium	STN	12-km EUS	13897	13.0	44.8	17.2	46.8
		12-km WUS	3893	-14.9	55.3	7.1	55.0
		Northeast	2495	21.0	44.8	27.0	43.8
		Midwest	3498	21.2	47.6	29.5	48.2
		Southeast	3882	7.0	41.4	11.4	43.4
		Central U.S.	3059	1.3	45.1	4.22	51.1
		West	3130	-20.5	59.0	5.8	57.2
	CASTNet	12-km EUS	3170	5.7	36.5	7.1	36.8
		12-km WUS	1142	-6.4	37.8	-4.0	37.6
		Northeast	615	15.4	37.2	18.9	35.2
		Midwest	786	14.5	40.8	18.4	38.7
		Southeast	1099	-7.5	32.9	-7.4	36.2
		Central U.S.	300	3.3	36.9	5.5	40.1
		West	1041	-12.6	37.1	-4.9	37.5
Elemental Carbon	STN	12-km EUS	14038	45.5	77.1	30.6	58.3
		12-km WUS	3814	31.1	77.7	19.5	62.5
		Northeast	2502	40.4	65.9	33.8	53.4
		Midwest	3479	57.3	83.7	38.5	59.6
		Southeast	3877	27.2	64.4	20.6	51.0
		Central U.S.	3221	72.1	102.0	39.0	69.5
		West	3015	38.7	82.8	21.0	65.1
	IMPROVE	12-km EUS	8668	-14.6	49.3	-18.2	53.3
		12-km WUS	12851	43.4	75.6	29.6	57.8
		Northeast	602	-1.3	45.1	-15.7	48.1
		Midwest	2117	10.6	54.5	-3.7	54.1
		Southeast	1584	-36.7	46.9	-39.3	56.3
		Central U.S.	2123	-23.8	47.7	-21.5	53.4

		West	8169	5.8	64.9	-8.6	61.0
Organic Carbon	STN	12-km EUS	12619	-27.2	50.5	-22.8	60.1
		12-km WUS	3582	-32.1	56.7	-28.2	61.3
		Northeast	2380	-28.3	49.0	-19.7	58.1
		Midwest	3323	-7.6	53.3	-4.2	58.6
		Southeast	3802	-39.3	49.2	-39.4	61.0
		Central U.S.	2259	-31.4	51.2	-28.3	63.2
		West	3060	-31.7	57.6	-27.8	61.4
	IMPROVE	12-km EUS	8662	-21.7	49.4	-25.6	55.8
		12-km WUS	11586	-29.9	50.4	-26.7	60.6
		Northeast	601	-22.7	41.3	-27.7	48.3
		Midwest	2116	3.5	55.7	-5.1	53.1
		Southeast	1587	-30.1	42.8	-37.8	54.1
		Central U.S.	2123	-36.9	51.7	-39.1	61.0
		West	8165	-11.7	59.2	-19.3	61.0

2. Ozone: An operational model performance evaluation for hourly and eight-hour daily maximum ozone was conducted in order to estimate the ability of the CMAQ modeling system to replicate the base year concentrations for the 12-km Eastern and Western United States domain shown in Figure II-1. Ozone measurements from 1194 sites (817 in the East and 377 in the West) were included in the evaluation and were taken from the 2005 State/local monitoring site data in the Air Quality System (AQS) Aerometric Information Retrieval System (AIRS). The ozone metrics covered in this evaluation include one-hour daily maximum ozone concentrations and eight-hour daily maximum ozone concentrations. The evaluation principally consists of statistical assessments of model versus observed pairs that were paired in time and space on an hourly and/or daily basis, depending on the sampling frequency of each measurement site (measured data). This ozone model performance was limited to the ozone season (May through September) that was modeled for the LDGHG final rule. Appendix D contains a more detailed summary of ozone model performance over the 12km Eastern and Western U.S. grid. A summary of the evaluation is presented here.

As with the national, annual $PM_{2.5}$ CMAQ modeling, the "acceptability" of model performance was judged by comparing our CMAQ 2005 performance results to the range of performance found in recent regional ozone model applications (e.g., EPA's Renewable Fuel Standards-2 Final Rule[20], EPA's Proposal to Designate an Emissions Control Area for Nitrogen Oxides, Sulfur Oxides, and Particulate Matter [21] and the Clean Air Interstate Rule[22]). Overall,

[20] U.S. Environmental Protection Agency, Air Quality Modeling Technical Support Document: Changes to Renewable Fuel Standard Program, Appendix B: CMAQ Model Performance Evaluation for Ozone, Particulate Matter and Toxics. January, 2010 (EPA-454/R-10-001A).

[21] 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)

the normalized mean bias and error (NMB and NME), as well as the fractional bias and error (FB and FE) statistics shown in Tables II-5 and II-6 indicate that CMAQ-predicted 2005 hourly and eight-hour daily maximum ozone residuals (i.e., observation vs. model predictions) are within the range of other recent regional modeling applications. The CMAQ model performance results give us confidence that our applications of CMAQ using this modeling platform provide a scientifically credible approach for assessing ozone concentration changes resulting from the final LDGHG emission standard reductions.

Table II-5. 2005 CMAQ one-hour daily maximum ozone model performance statistics calculated for a threshold of 40 ppb.

CMAQ 2005 One-Hour Maximum Ozone: Threshold of 40 ppb		**No. of Obs.**	**NMB (%)**	**NME (%)**	**FB (%)**	**FE (%)**
May	12-km EUS	21394	-1.6	11.5	-0.8	11.6
	12-km WUS	9631	-3.4	12.8	-2.8	12.7
	Midwest	4418	0.8	10.0	1.0	10.2
	Northeast	4102	5.4	11.8	5.9	11.7
	Southeast	6424	-3.6	11.3	-3.0	11.5
	Central U.S.	4328	-6.4	13.4	-5.5	13.4
	West	8294	-3.5	12.9	-3.0	12.8
June	12-km EUS	19517	-3.5	12.8	-2.8	12.9
	12-km WUS	9056	-3.7	13.0	-3.2	13.0
	Midwest	4639	-4.6	12.3	-4.0	12.4
	Northeast	4148	-1.0	14.1	-0.1	14.2
	Southeast	4644	-2.7	12.5	-2.2	12.6
	Central U.S.	4062	-6.2	13.2	-5.4	13.3
	West	7737	-4.0	13.1	-3.6	13.1
July	12-km EUS	19692	1.2	14.2	1.8	14.1
	12-km WUS	9443	0.4	16.0	1.0	15.8
	Midwest	4923	0.4	12.7	0.9	12.6
	Northeast	4445	4.2	15.2	4.8	14.9
	Southeast	4733	4.2	15.1	4.6	14.8
	Central U.S.	3521	-3.8	14.8	-3.1	14.9
	West	8168	0.2	16.2	0.7	16.0
August	12-km EUS	19643	0.1	13.9	0.8	13.8
	12-km WUS	9562	-0.8	15.5	-0.6	15.5
	Midwest	4549	0.2	12.2	1.0	12.3
	Northeast	4139	0.2	13.2	1.2	13.1
	Southeast	5303	3.6	14.9	3.9	14.5
	Central U.S.	3589	-4.1	16.2	-2.9	16.1
	West	8357	-1.0	15.7	-1.0	15.7
September	12-km EUS	18085	-2.2	12.0	-1.3	12.0
	12-km WUS	8725	-3.6	14.1	-3.2	14.3
	Midwest	4002	-3.6	10.7	-3.0	10.8
	Northeast	3667	-1.8	11.3	-0.7	11.3
	Southeast	5259	-0.1	12.1	0.8	12.1
	Central U.S.	3286	-6.1	14.5	-5.1	14.5
	West	7530	-4.1	14.3	-3.8	14.4

[22] 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; Research Triangle Park, NC; March 2005.

Seasonal Aggregate (May – September)	12-km EUS	98331	-1.2	12.9	-0.5	12.8
	12-km WUS	46417	-2.1	14.3	-1.7	14.2
	Midwest	22531	-1.4	11.7	-0.8	11.7
	Northeast	20501	1.4	13.3	2.3	13.1
	Southeast	26363	0.1	13.1	0.7	13.0
	Central U.S.	18786	-5.4	14.4	-4.4	14.4
	West	40086	-2.3	14.5	-2.1	14.4

Table II-6. 2005 CMAQ eight-hour daily maximum ozone model performance statistics calculated for a threshold of 40 ppb.

CMAQ 2005 Eight-Hour Maximum Ozone: Threshold of 40 ppb		No. of Obs.	NMB (%)	NME (%)	FB (%)	FE (%)
May	12-km EUS	19310	-1.0	10.9	-0.4	11.0
	12-km WUS	8445	-1.6	12.0	-1.2	12.0
	Midwest	3858	0.2	10.0	0.7	10.2
	Northeast	3528	5.2	11.4	5.4	11.2
	Southeast	6019	-2.1	10.5	-1.6	10.6
	Central U.S.	3927	-5.8	12.8	-5.2	13.0
	West	7234	-1.8	12.1	-1.5	12.0
June	12-km EUS	17404	-2.1	11.9	-1.5	12.0
	12-km WUS	8102	-1.9	11.9	-1.6	11.9
	Midwest	4324	-3.8	11.6	-3.4	11.8
	Northeast	3590	0.3	13.1	1.0	13.2
	Southeast	3924	-0.3	11.4	0.1	11.5
	Central U.S.	3663	-5.5	12.1	-5.0	12.3
	West	6889	-2.2	12.1	-2.0	12.1
July	12-km EUS	17045	3.3	13.4	3.6	13.3
	12-km WUS	8556	3.7	15.0	3.9	14.7
	Midwest	4429	1.8	11.8	2.3	11.8
	Northeast	3856	6.6	14.6	6.8	14.3
	Southeast	3806	7.4	15.0	7.3	14.5
	Central U.S.	3057	-2.3	13.2	-2.1	13.5
	West	7407	3.5	15.1	3.6	14.9
August	12-km EUS	16953	1.9	12.9	2.2	12.9
	12-km WUS	8523	1.6	13.9	1.5	13.9
	Midwest	4027	0.9	11.3	1.4	11.4
	Northeast	3530	1.4	12.3	2.0	12.2
	Southeast	4447	7.4	14.7	7.2	14.1
	Central U.S.	3096	-3.4	14.4	-3.1	14.8
	West	7469	1.4	14.1	1.2	14.0
September	12-km EUS	15190	-1.8	11.2	-1.3	11.3
	12-km WUS	7465	-2.4	13.4	-2.6	13.9
	Midwest	3265	-4.2	10.2	-4.0	10.4
	Northeast	2856	-2.3	10.6	-1.8	10.7
	Southeast	4647	1.5	11.2	2.1	11.2
	Central U.S.	2798	-6.5	13.6	-6.1	14.0
	West	6446	-2.9	13.7	-3.1	14.1
Seasonal Aggregate (May – September)	12-km EUS	85902	0.1	12.1	0.5	12.1
	12-km WUS	41091	0.0	13.3	0.1	13.3
	Midwest	19903	-0.9	11.1	-0.5	11.2

	Northeast	17360	2.4	12.6	2.9	12.4
	Southeast	22843	2.3	12.3	2.6	12.2
	Central U.S.	16541	-4.8	13.2	-4.4	13.4
	West	35445	-0.2	13.5	-0.3	13.5

3. Nitrate and Sulfate Deposition

Annual nitrate and sulfate deposition performance statistics are provided in Table II-7. The model predictions for annual nitrate deposition generally show small under-predictions for the Eastern and Western NADP sites (NMB values range from -3% to -18%). Sulfate deposition performance in the EUS and WUS shows the similar over predictions (NMB values range from 3% to 14%), except for predicted under-prediction in the Central US (NMB = -9.9%). The errors for both annual nitrate and sulfate are relatively moderate with values ranging from 54% to 87% which reflect scatter in the model predictions to observation comparison. Similar to the national, annual $PM_{2.5}$ and ozone CMAQ modeling, the "acceptability" of model performance was judged by comparing our CMAQ 2005 performance results to the model performance results found in recent regional multi-pollutant model applications.

Table II-7. CMAQ 2005 annual model performance statistics for total nitrate and sulfate deposition.

CMAQ 2005 Total Deposition		No. of Obs.	NMB (%)	NME (%)	FB (%)	FE (%)
Nitrate	12-km EUS	7381	-0.6	63.9	-7.8	74.0
	12-km WUS	2732	-11.6	69.5	-12.7	83.4
	Northeast	1391	4.9	62.0	5.0	67.8
	Midwest	1658	10.1	60.9	3.9	66.5
	Southeast	1980	4.9	67.3	0.1	71.3
	Central	1229	-11.0	62.7	-11.0	78.3
	West	2257	-9.8	73.8	-12.7	85.0
Sulfate	12-km EUS	7381	7.8	67.0	6.0	75.3
	12-km WUS	2732	5.6	76.3	4.8	86.5
	Northeast	1391	16.4	62.6	23.2	70.4
	Midwest	1658	12.6	64.3	16.5	67.3
	Southeast	1980	8.6	71.4	6.4	73.8
	Central	1229	-7.3	65.1	-1.2	80.3
	West	2257	13.2	81.8	6.5	87.9

4. Hazardous air pollutants

An operational model performance evaluation for daily, monthly, seasonal, and annual specific air toxics (formaldehyde, acetaldehyde, benzene, acrolein, and 1,3-butadiene) was conducted in order to estimate the ability of the CMAQ modeling system to replicate the base year concentrations for the 12-km Eastern and Western United States domains. Toxic measurements from 471 sites in the East and 135 sites in the West were included in the evaluation and were taken from the 2005 State/local monitoring site data in the National Air Toxics Trends Stations (NATTS). 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. Appendix D contains a more detailed summary of air toxics model performance over the 12km Eastern and Western U.S. grid. A summary of the evaluation is presented here.

Model predictions of annual formaldehyde, acetaldehyde and benzene showed relatively small bias and error percentages when compared to observations. The model yielded larger bias and error results for 1,3 butadiene and acrolein based on limited monitoring sites. As with the national, annual $PM_{2.5}$ and ozone CMAQ modeling, the “acceptability” of model performance was judged by comparing our CMAQ 2005 performance results to the limited performance found in recent regional multi-pollutant model applications.[23,24,25] Overall, the normalized mean bias and error (NMB and NME), as well as the fractional bias and error (FB and FE) statistics shown in Table II-8 indicate that CMAQ-predicted 2005 toxics (i.e., observation vs. model predictions) are within the range of recent regional modeling applications.

Table II-8. 2005 CMAQ annual toxics model performance statistics

CMAQ 2005 Annual		No. of Obs.	NMB (%)	NME (%)	FB (%)	FE (%)
Formaldehyde	12-km EUS	6365	-53.8	64.5	-36.6	64.2
	12-km WUS	1928	-24.5	50.9	-25.8	58.6
	Northeast	1982	-28.2	50.7	-26.3	60.7
	Midwest	771	-75.9	85.0	-22.6	72.7
	Southeast	1246	-65.0	71.4	-48.8	69.1
	Central U.S.	1815	-41.4	49.4	-38.7	59.6
	West	1746	-21.7	51.5	-22.0	58.2
Acetaldehyde	12-km EUS	6094	-0.9	63.0	-5.2	59.8
	12-km WUS	1892	-14.4	53.6	-14.7	58.2
	Northeast	1969	-6.6	64.0	-6.4	63.4
	Midwest	703	-8.9	58.8	-8.7	59.3
	Southeast	1231	3.2	64.1	-3.7	61.5
	Central U.S.	1640	5.6	57.9	-0.9	50.5
	West	1709	-15.6	53.9	-15.4	59.3
Benzene	12-km EUS	11615	-30.6	66.9	-10.4	62.4
	12-km WUS	3369	-34.9	60.5	-25.4	62.3
	Northeast	2589	26.5	55.1	22.7	47.7
	Midwest	1425	-5.8	73.5	27.9	62.7

[23] 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.

[24] Strum, M., Wesson, K., Phillips, S., Cook, R., Michaels, H., Brzezinski, D., Pollack, A., Jimenez, M., Shepard, S. Impact of using link-level 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.

[25] 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.

	Southeast	2426	-38.3	69.4	-12.9	60.1
	Central U.S.	4737	-46.4	67.6	-30.9	68.0
	West	2333	-26.1	61.2	-13.6	62.1
1,3-Butadiene	12-km EUS	8102	-71.9	84.9	-37.5	88.2
	12-km WUS	1976	-46.5	83.1	-22.7	91.5
	Northeast	1902	-34.1	53.0	-42.5	64.5
	Midwest	516	-74.8	85.5	-34.8	77.7
	Southeast	1226	-82.4	84.0	-93.4	100.7
	Central U.S.	4142	-63.8	86.1	-8.0	89.6
	West	1082	-36.7	78.4	-36.6	84.2
Acrolein	12-km EUS	1660	-93.8	94.5	-126.2	138.4
	12-km WUS	783	-95.4	95.5	-164.5	167.2
	Northeast	850	-89.5	90.9	-116.0	131.1
	Midwest	n/a	n/a	n/a	n/a	n/a
	Southeast	278	-96.7	96.7	-152.8	153.6
	Central U.S.	n/a	n/a	n/a	n/a	n/a
	West	592	-95.8	95.8	-176.9	176.9

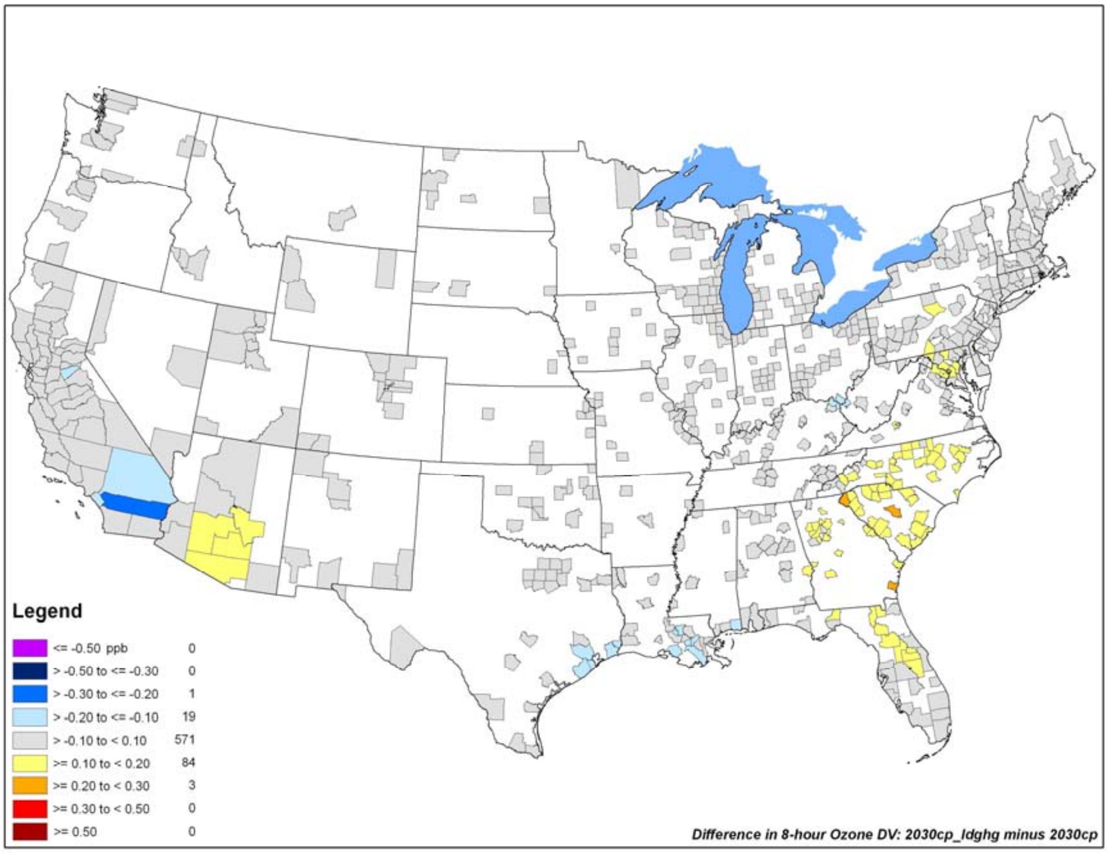
III. CMAQ Model Results

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 light-duty vehicle greenhouse gas rule. We looked at impacts on future ambient $PM_{2.5}$, ozone, ethanol and air toxics levels, as well as nitrogen and sulfur deposition levels and visibility impairment. In this section, we present information on current levels of pollution as well as model projected levels of pollution for 2030.

A. Impacts of LDGHG 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 vehicle standards. Specifically, we compare a 2030 reference scenario, a scenario without the vehicle standards, to a 2030 control scenario which includes the vehicle standards. Our modeling indicates ozone design value concentrations will increase in many areas of the country and decrease in a few areas. The increases in ozone design values are related to our assumptions about changes in fuel consumption and production that are not directly due to the standards finalized in this rule. As discussed in Sections 5.3.2 and 5.3.3.5 of the RIA, the decreased fuel consumption and production from this program is attributed to gasoline only, while assuming constant ethanol volumes in our reference and control cases. Holding ethanol volumes constant while decreasing gasoline volumes increases the market share of 10% ethanol (E10) in the control case. However, the increased E10 market share is projected to occur regardless of this rule, and the air quality impacts of this effect are included in our analyses for the recent RFS2 rule. As the RFS2 analyses indicate, increasing usage of E10 fuels (when compared with E0 fuels) can increase NO_X emissions and thereby increase ozone concentrations, especially in NO_X-limited areas where relatively small amounts of NO_X enable ozone to form rapidly.[26] Figure III-1 presents the changes in 8-hour ozone design value concentration in 2030 between the reference case and the control case.[27] Appendix A details the state and county 8-hour maximum ozone design values for the ambient baseline and the future reference and control cases.

Figure III-1. Projected Change in 2030 8-hour Ozone Design Values Between the Reference Case and Control Case



As can be seen in Figure III-1, the majority of the design value increases are less than 0.1 ppb. However, there are some counties that will see 8-hour ozone design value increases above 0.1 ppb; these counties are along the mid-Atlantic coast and in southern Arizona. The maximum projected increase in an 8-hour ozone design value is 0.25 ppb in Richland County, South Carolina. There are also some counties that are projected to see 8-hour ozone design value decreases. The decreases in ambient ozone concentration are likely due to projected upstream emissions decreases in NO_X and VOCs from reduced gasoline production. The counties with ozone design value decreases greater than 0.1 ppb are in California, Texas, Louisiana,

[26] EPA 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.

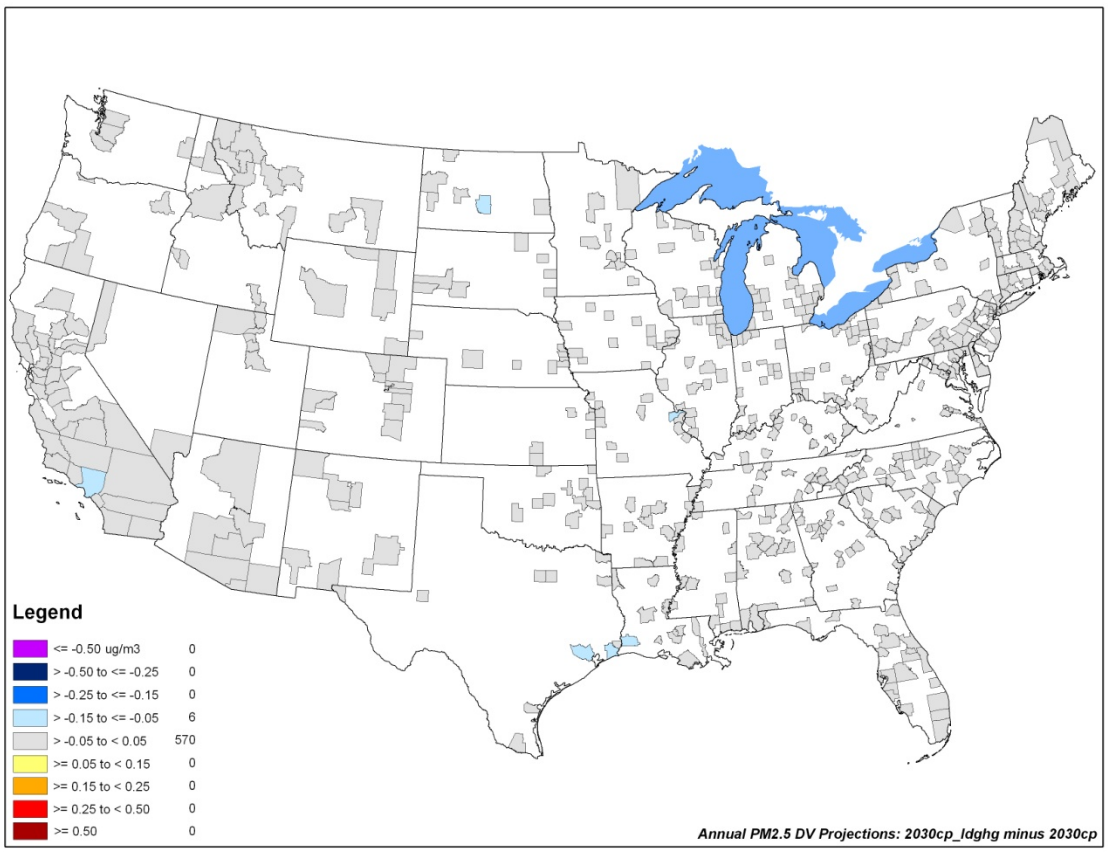
[27] An 8-hour ozone design value is the concentration that determines whether a monitoring site meets the 8-hour ozone NAAQS. The full details involved in calculating an 8-hour ozone design value are given in appendix I of 40 CFR part 50.

Mississippi, Kentucky, Ohio and West Virginia. The maximum decrease projected in an 8-hour ozone design value is 0.22 ppb in Riverside, CA.

B. Impacts of LDGHG 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 vehicle standards. Specifically, we compare a 2030 reference scenario, a scenario without the vehicle standards, to a 2030 control scenario which includes the vehicle standards. Our modeling indicates that the majority of the modeled counties will see decreases of less than 0.05 µg/m^3 in their annual $PM_{2.5}$ design values due to the vehicle standards. **Error! Reference source not found.** presents the changes in annual $PM_{2.5}$ design values in 2030.[28]

Figure III-2. Projected Change in 2030 Annual $PM_{2.5}$ Design Values Between the Reference Case and Control Case



As shown in Figure III-2, six counties will see decreases of more than 0.05 µg/m^3. These counties are in southern California, central North Dakota, eastern Missouri, southwest Louisiana and the Houston area in Texas. The maximum projected decrease in an annual $PM_{2.5}$ design

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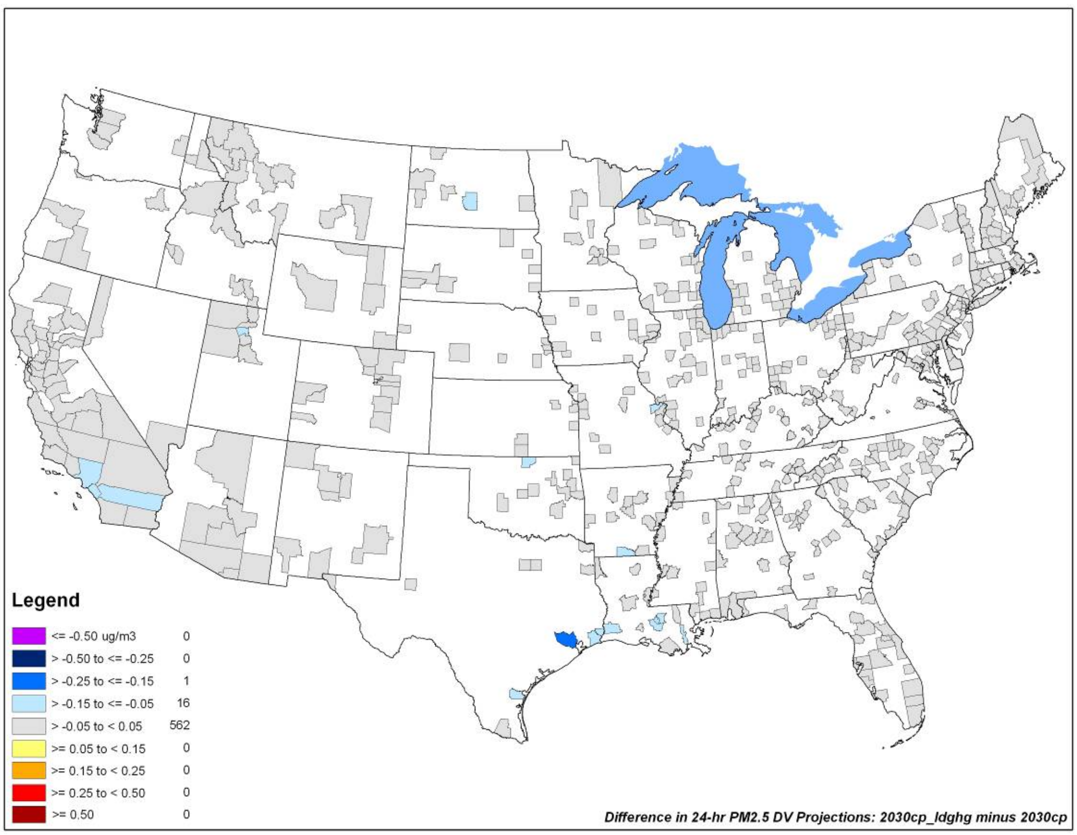
[28] An annual $PM_{2.5}$ design value is the concentration that determines whether a monitoring site meets the annual NAAQS for $PM_{2.5}$. The full details involved in calculating an annual $PM_{2.5}$ design value are given in appendix N of 40 CFR part 50.

value is 0.07 µg/m^3 in Harris County, Texas. The decreases in annual $PM_{2.5}$ design values that are modeled in some counties are likely due to emission reductions related to lower gasoline production at existing oil refineries; reductions in direct $PM_{2.5}$ emissions and $PM_{2.5}$ precursor emissions (NO_X and SO_X) contribute to reductions in ambient concentrations of both direct $PM_{2.5}$ and secondarily-formed $PM_{2.5}$. Additional information on the upstream emissions reductions that are projected with this final rule is available in Section 5.5 of the RIA.

C. Impacts of LDGHG 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 vehicle standards. Specifically, we compare a 2030 reference scenario, a scenario without the vehicle standards, to a 2030 control scenario which includes the vehicle standards. Our modeling indicates that the majority of the modeled counties will see changes of between -0.05 µg/m^3 and +0.05 µg/m^3 in their 24-hour $PM_{2.5}$ design values. Figure III-3 presents the changes in 24-hour $PM_{2.5}$ design values in 2030.[29]

Figure III-3. Projected Change in 2030 24-hour $PM_{2.5}$ Design Values Between the Reference Case and the Control Case



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

As shown in Figure III-3, 17 counties will see decreases of more than 0.05 μg/m^3. These counties are in southern California, northern Utah, central North Dakota, eastern Missouri, southern Arkansas, northern Oklahoma, southwest Louisiana and the Houston area in Texas. The maximum projected decrease in a 24-hour $PM_{2.5}$ design value is 0.21 μg/m^3 in Harris County, Texas. The decreases in 24-hour $PM_{2.5}$ design values that we see in some counties are likely due to emission reductions related to lower gasoline production at existing oil refineries; reductions in direct $PM_{2.5}$ emissions and $PM_{2.5}$ precursor emissions (NO_X and SO_X) contribute to reductions in ambient concentrations of both direct $PM_{2.5}$ and secondarily-formed $PM_{2.5}$. There are also some counties that will see small, less than 0.05 μg/m^{3,} design value increases. These small increases in 24-hour $PM_{2.5}$ design values are likely related to the same factors responsible for the increases in annual $PM_{2.5}$ design values (see Section III-B above). Appendix C details the state and county annual $PM_{2.5}$ design values for the ambient baseline and the future reference and control cases.

D. Impacts of LDGHG Standards on Future Toxic Air Pollutant Levels

The following sections summarize the results of our modeling of air toxics impacts in the future from this vehicle emission standards required by LDGHG. We focus on air toxics which were identified as national and regional-scale cancer and noncancer risk drivers in past NATA assessments and were also likely to be significantly impacted by the standards. These compounds include benzene, 1,3-butadiene, formaldehyde, acetaldehyde, and acrolein. Ethanol impacts were also included in our analyses. Our modeling indicates that the GHG standards have relatively little impact on national average ambient concentrations of the modeled air toxics. Because overall impacts are small, we concluded that assessing exposure to ambient concentrations and conducting a quantitative risk assessment of air toxic impacts was not warranted. However, we did develop population metrics, including the population living in areas with increases or decreases in concentrations of various magnitudes. We also estimated aggregated populations above and below reference concentrations for noncancer effects.

1. Acetaldehyde

Overall, the air quality modeling does not show substantial nationwide impacts on ambient concentrations of acetaldehyde as a result of the standards finalized in this rule. Annual and seasonal percent changes in ambient concentrations of acetaldehyde are less than 1% across the country (Figure III-4 through III-6). Decreases in ambient concentrations of acetaldehyde seen in the much of the eastern half of the U.S. and parts of the West are generally less than 0.01 μg/m^3. Small increases of less than 0.01 μg/m^3 are noted in the in New York, Pennsylvania, and Utah during the winter season (Figure III-5).

Figure III-4. Changes in Annual Acetaldehyde Ambient Concentrations Between the Reference Case and the Control Case in 2030: Percent Changes (left) and Absolute Changes in µg/m³ (right)

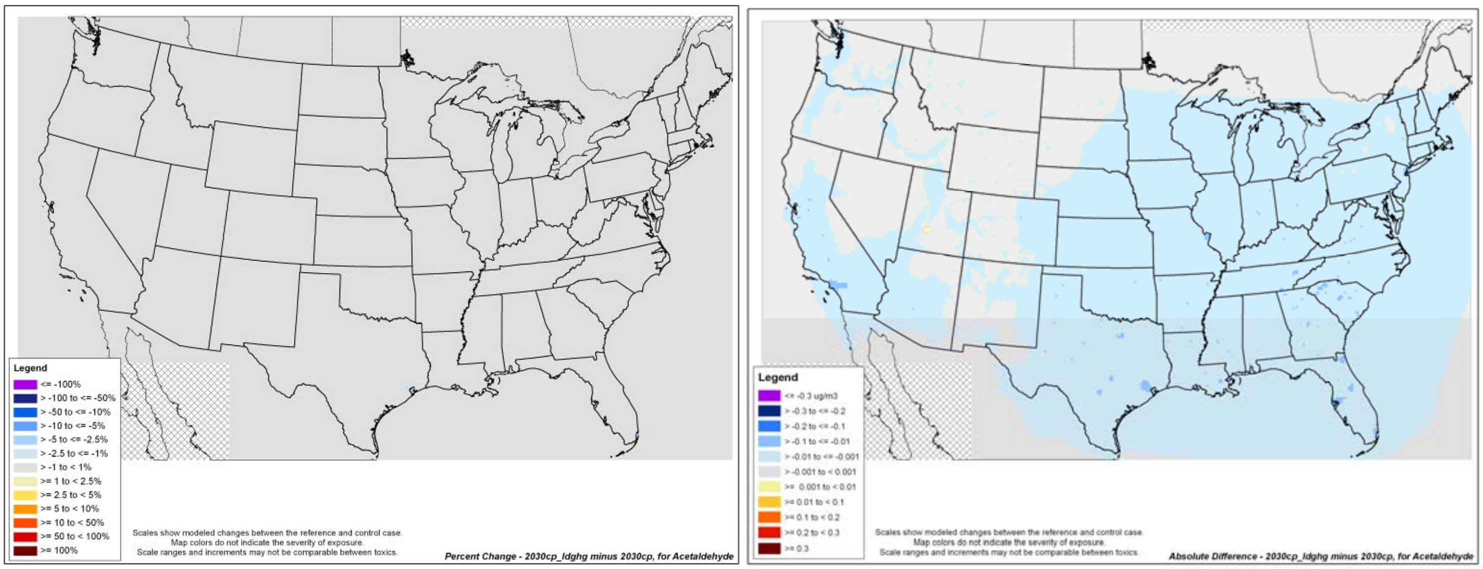


Figure III-5. Changes in Winter Acetaldehyde Ambient Concentrations Between the Reference Case and the Control Case in 2030: Percent Changes (left) and Absolute Changes in µg/m³ (right)

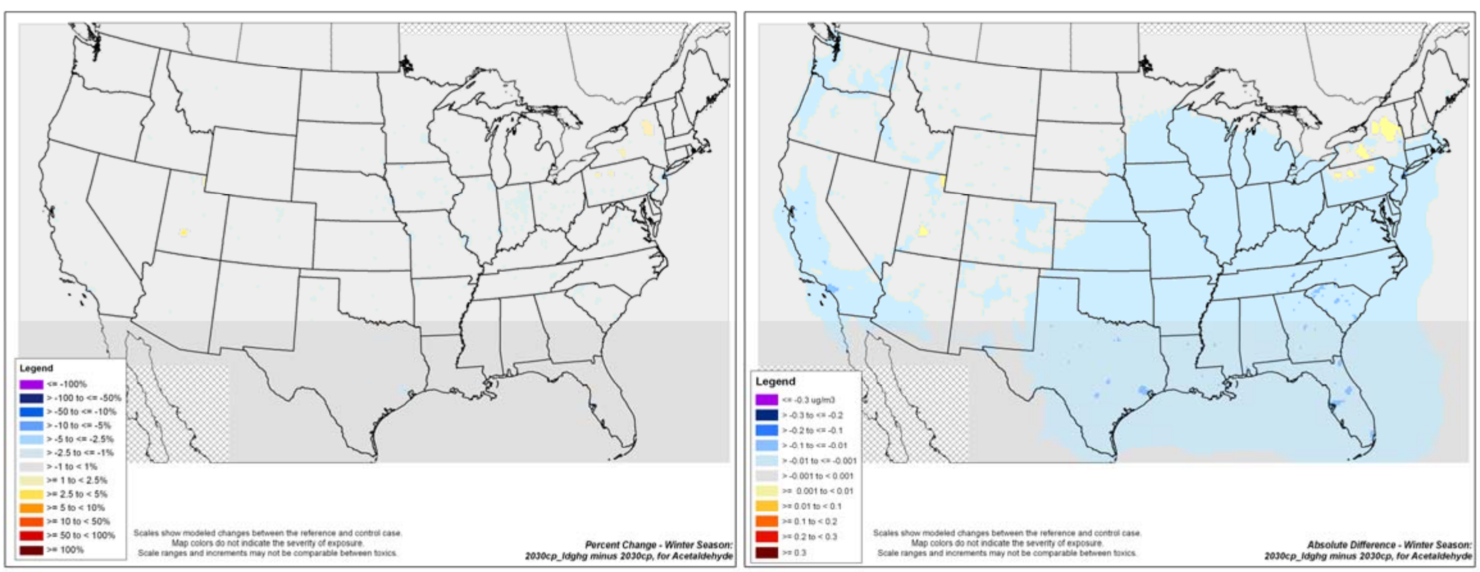
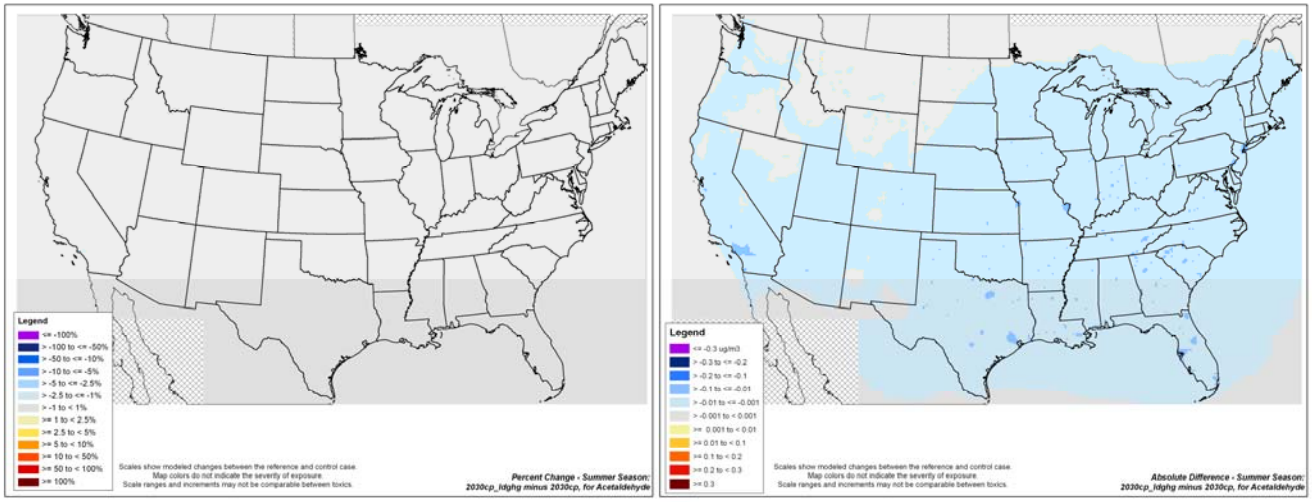


Figure III-6. Changes in Summer Acetaldehyde Ambient Concentrations Between the Reference Case and the Control Case in 2030: Percent Changes (left) and Absolute Changes in µg/m³ (right)



2. Formaldehyde

Our modeling projects that the standards finalized in this rule will not have a significant impact on ambient formaldehyde concentrations. As shown in Figure III-7, annual percent changes in ambient concentrations of formaldehyde are less than 1% across the country, with the exception of a 1 to 5% decrease in a small area of southern Kansas and northern Oklahoma. Figure III-7 also shows that absolute changes in ambient concentrations of formaldehyde are generally less than 0.1 µg/m³. Also, increases in annual and seasonal ambient formaldehyde (Figures III-7 through III-9), which range from 0.001 to 0.1 µg/m³, are a reflection of our ethanol volume assumptions as discussed above in Section III-A and are not due to the standards finalized in this rule.

Figure III-7. **Changes in Annual Formaldehyde Ambient Concentrations Between the Reference Case and the Control Case in 2030: Percent Changes (left) and Absolute Changes in µg/m³ (right)**

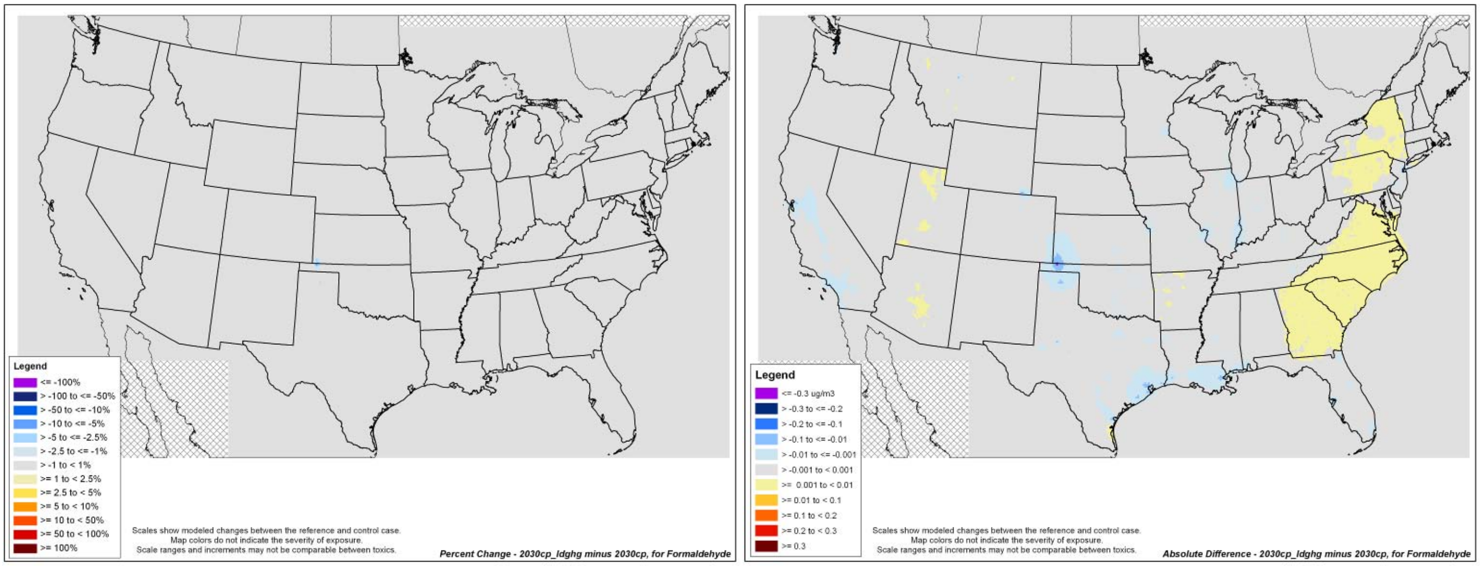


Figure III-8. **Changes in Winter Formaldehyde Ambient Concentrations Between the Reference Case and the Control Case in 2030: Percent Changes (left) and Absolute Changes in µg/m³ (right)**

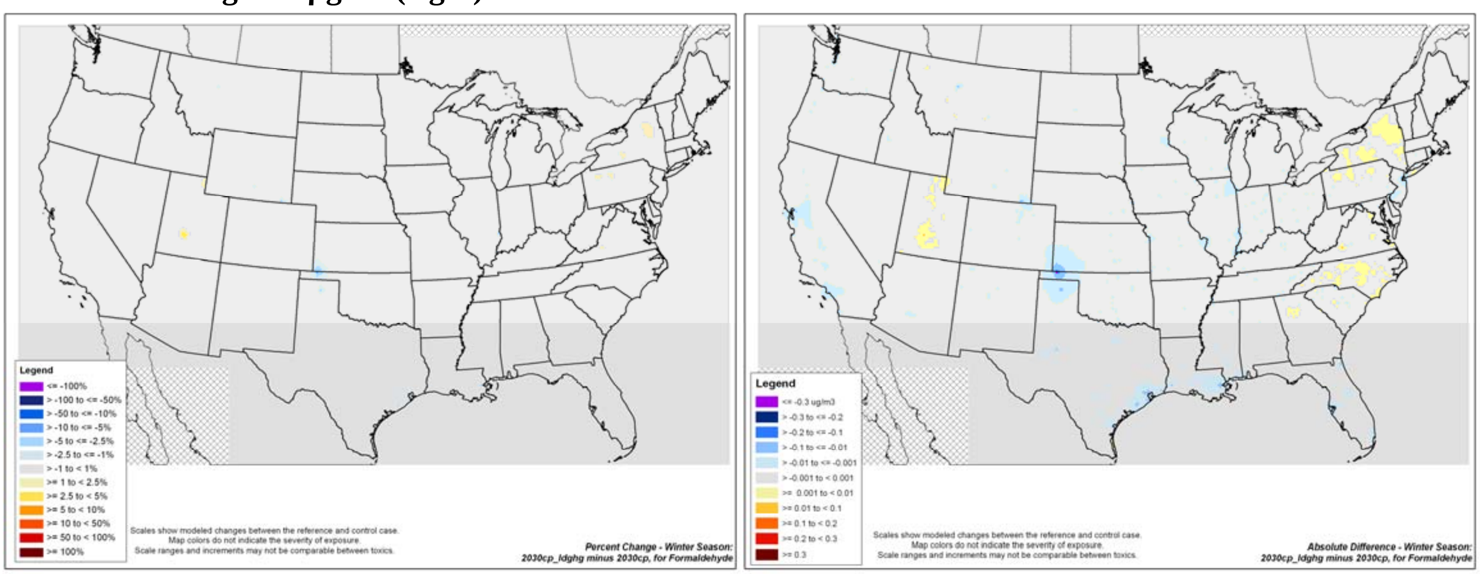
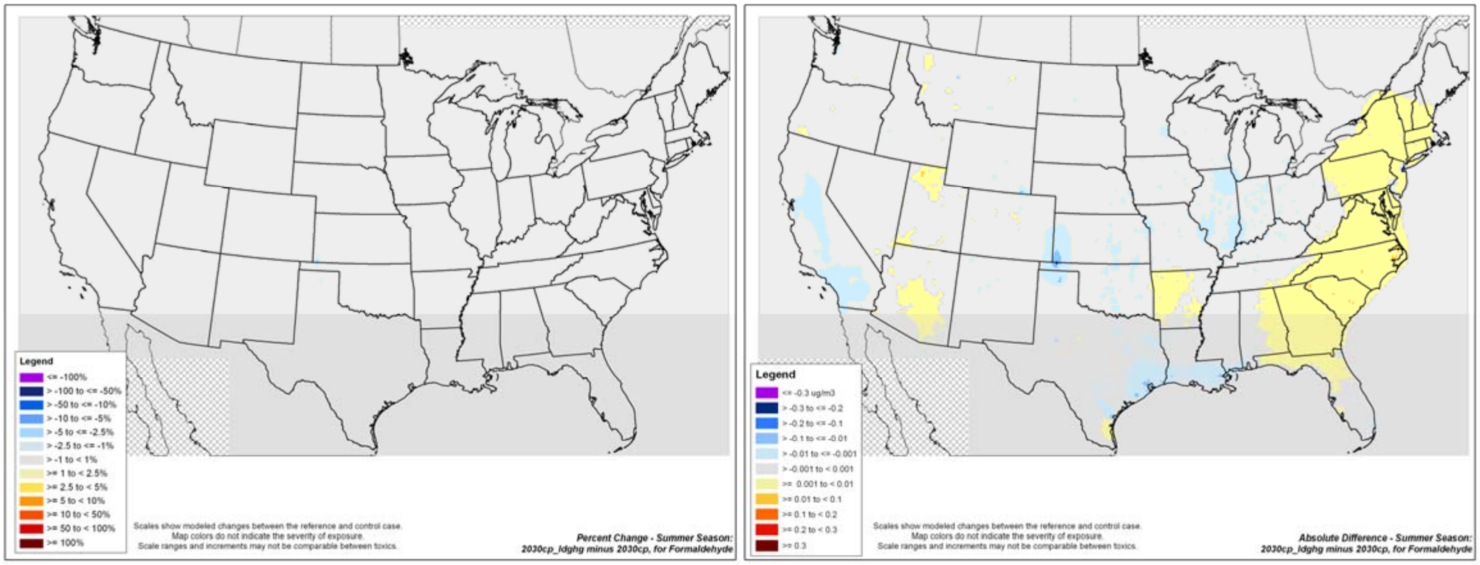


Figure III-9. Changes in Summer Formaldehyde Ambient Concentrations Between the Reference Case and the Control Case in 2030: Percent Changes (left) and Absolute Changes in μg/m³ (right)



3. Ethanol

Our modeling results do not show substantial impacts on ambient concentrations of ethanol from the vehicle GHG standards. While Figure III-10 through III-12 show increases in ambient ethanol concentrations ranging between 1 and 50% in some areas of the country, these increases are a reflection of our ethanol volume assumptions as discussed above in Section III-A and are not due to the standards finalized in this rule.

Figure III-10. Changes in Annual Ethanol Ambient Concentrations Between the Reference Case and the Control Case in 2030: Percent Changes (left) and Absolute Changes in µg/m³ (right)

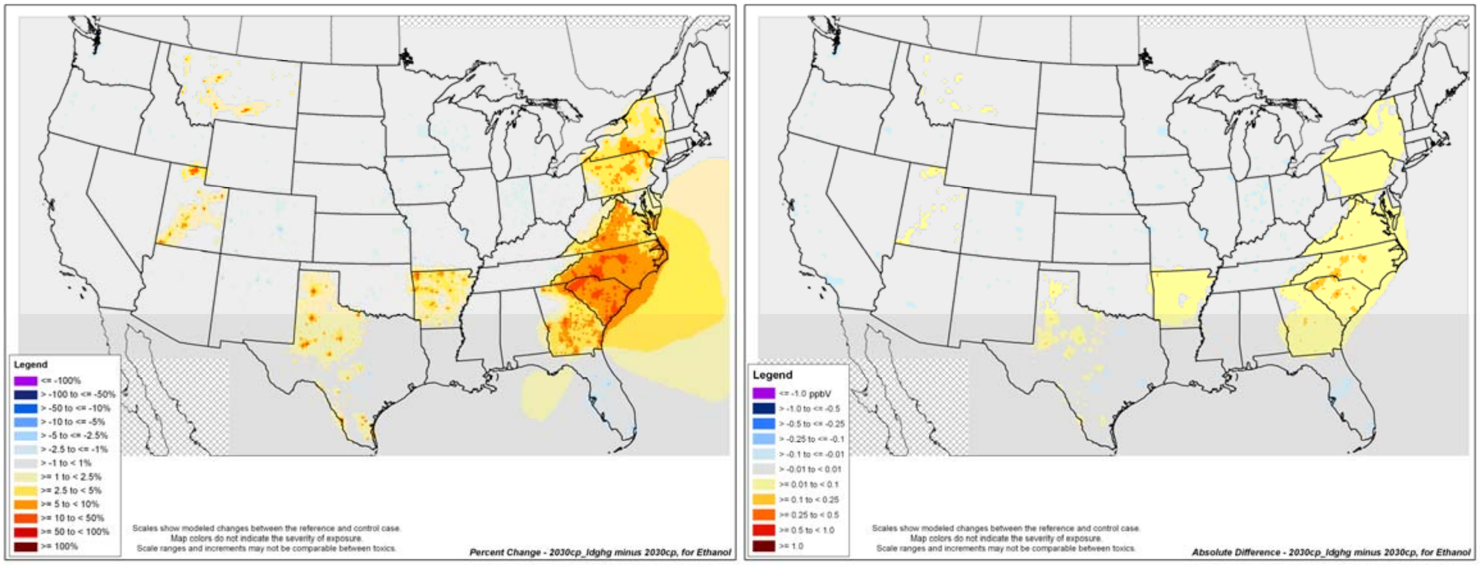


Figure III-11. Changes in Winter Ethanol Ambient Concentrations Between the Reference Case and the Control Case in 2030: Percent Changes (left) and Absolute Changes in µg/m³ (right)

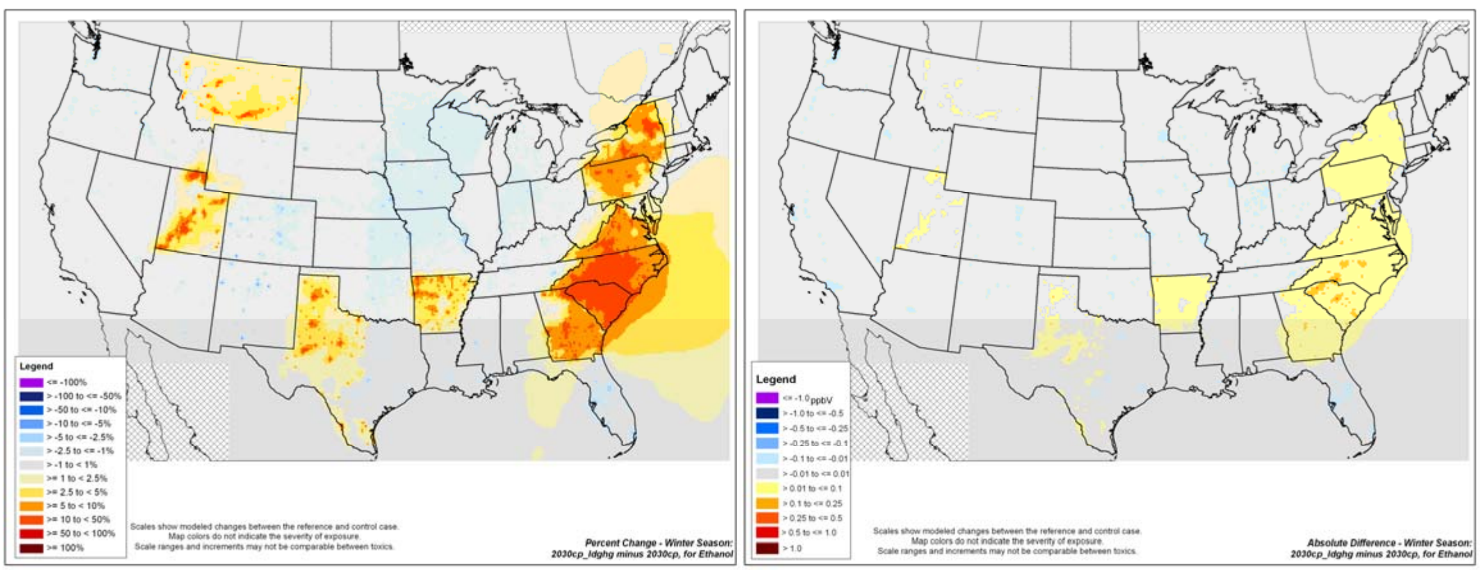
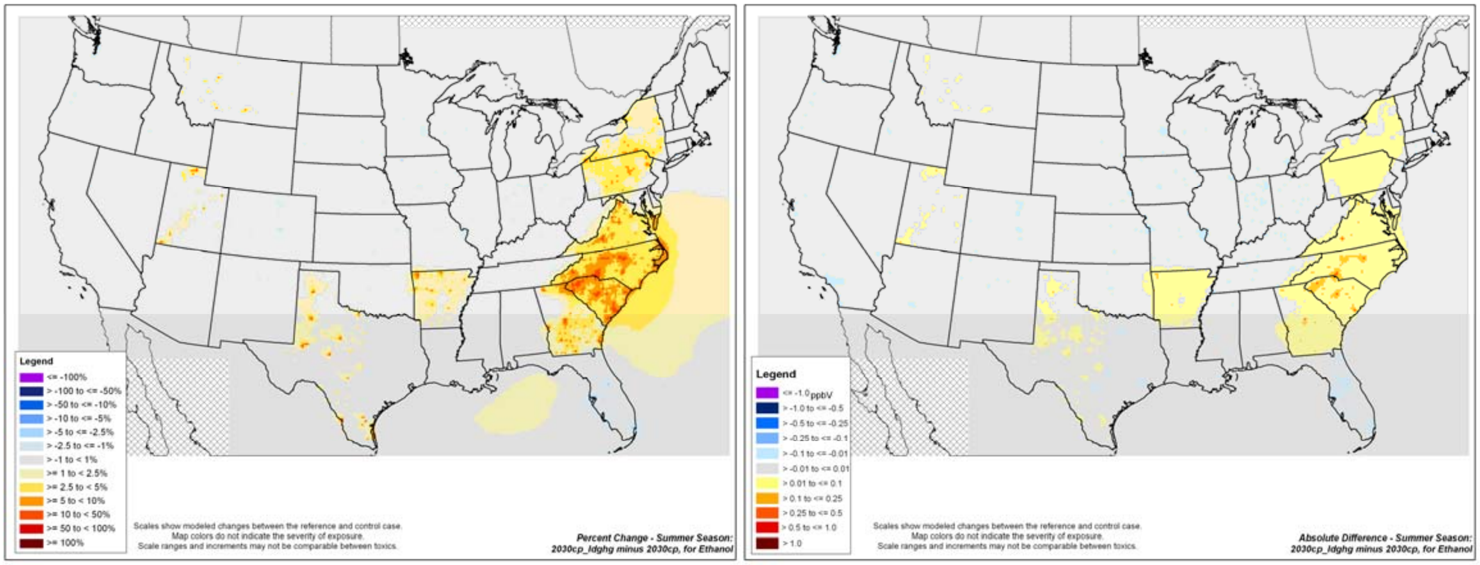


Figure III-12. Changes in Summer Ethanol Ambient Concentrations Between the Reference Case and the Control Case in 2030: Percent Changes (left) and Absolute Changes in µg/m³ (right)



4. Benzene

Our air quality modeling projects that the standards finalized in this rule will not have a significant impact on ambient benzene concentrations. Figure III-13, III-14, and III-15 show decreases in annual and seasonal ambient benzene concentrations ranging between 1 and 10% and between 0.001 and 0.1 µg/m³. Because this rule will reduce consumption and production of gasoline, some of these decreases in benzene concentrations are likely due to the vehicle GHG standards. However, decreases in benzene concentrations may also be a reflection of our ethanol volume assumptions as discussed above for ozone, ethanol and formaldehyde, and are not due to the standards finalized in this rule. For example, the percent change map in Figure III-13 below shows benzene decreases occurring in the same areas of the country as ozone, ethanol, and formaldehyde increases.

Figure III-13. Changes in Annual Benzene Ambient Concentrations Between the Reference Case and the Control Case in 2030: Percent Changes (left) and Absolute Changes in μg/m³ (right)

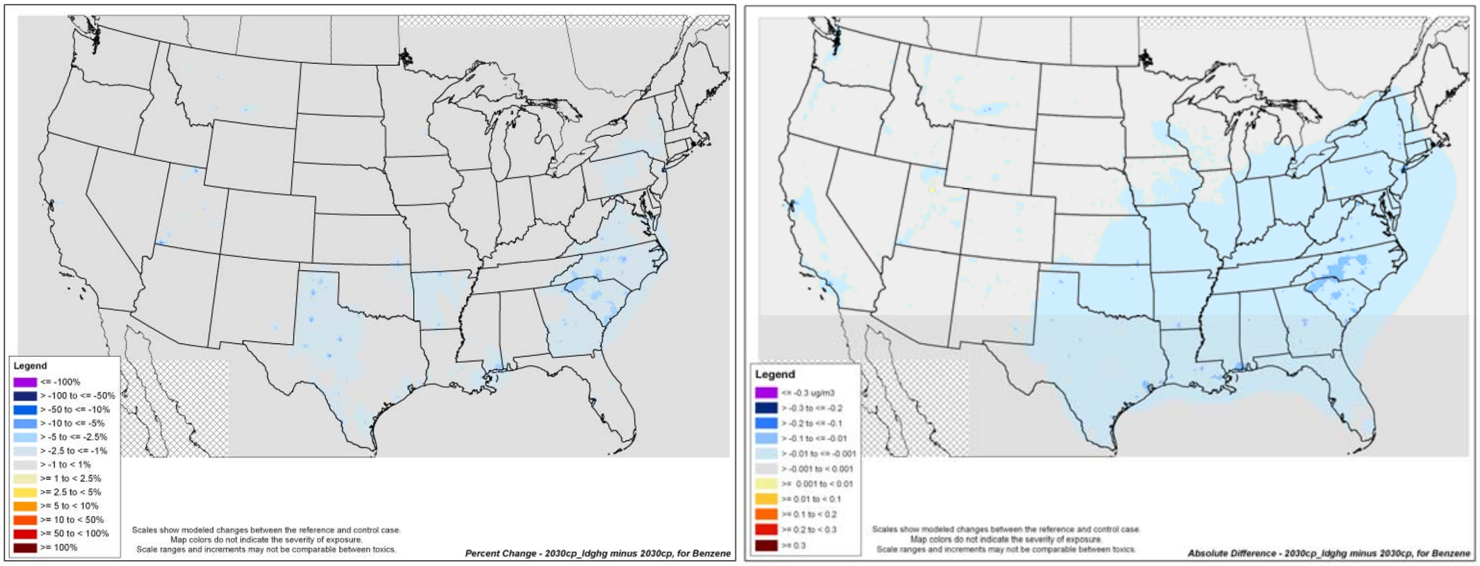


Figure III-14. Changes in Winter Benzene Ambient Concentrations Between the Reference Case and the Control Case in 2030: Percent Changes (left) and Absolute Changes in μg/m³ (right)

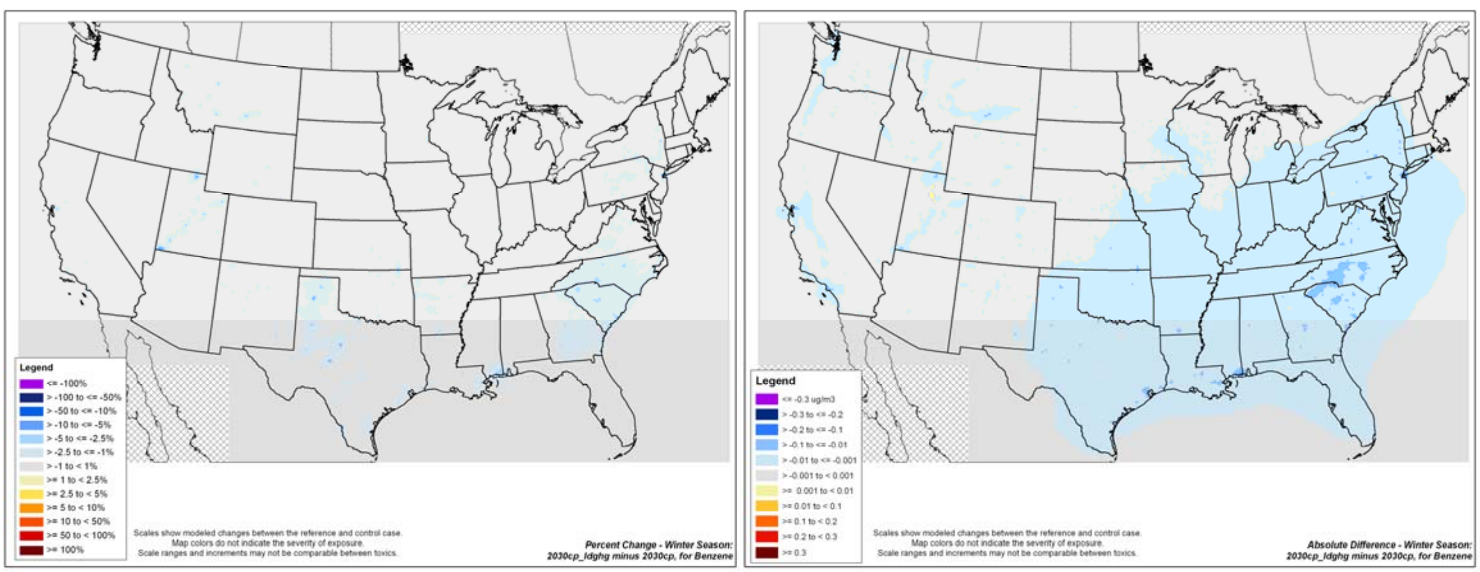
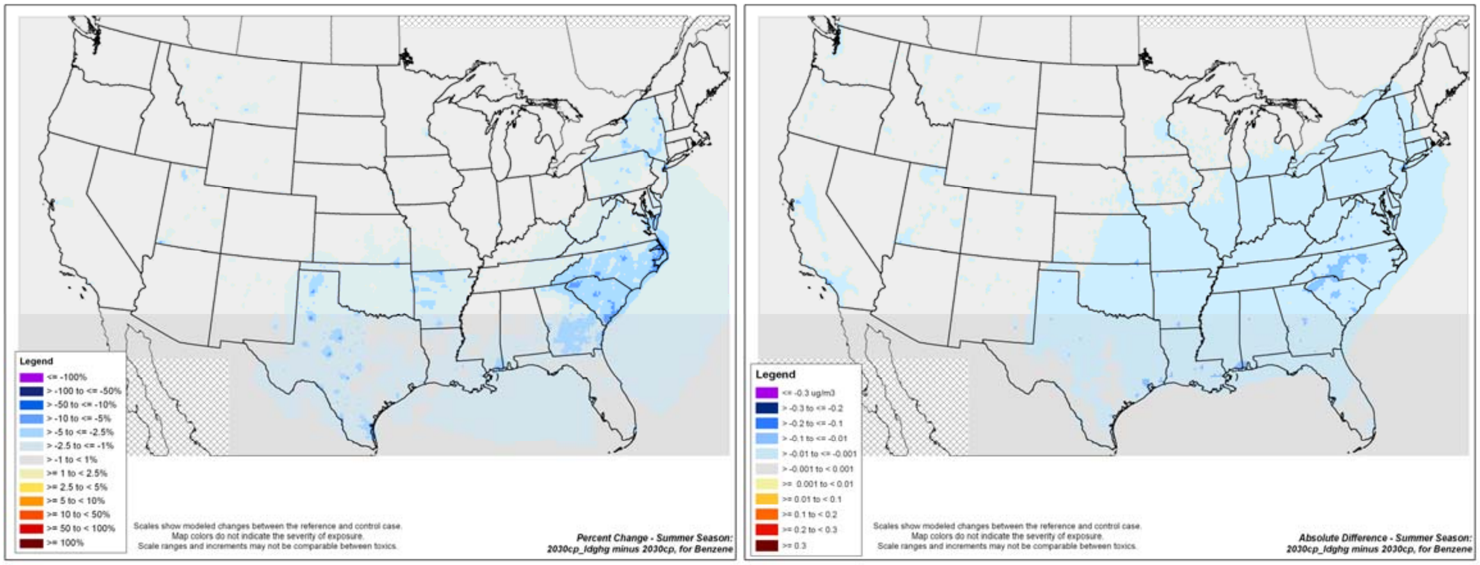


Figure III-15. Changes in Summer Benzene Ambient Concentrations Between the Reference Case and the Control Case in 2030: Percent Changes (left) and Absolute Changes in µg/m³ (right)



5. 1,3-Butadiene

Our air quality modeling results do not show substantial impacts on ambient concentrations of 1,3-butadiene from the GHG standards. In the annual and winter, small decreases ranging from 1 to 10% occur in some southern areas of the country and increases ranging from 1 to over 100% occur in some northern areas and areas with high altitudes (Figure III-16). Changes in absolute concentrations of ambient 1,3-butadiene are less than 0.001 µg/m³ except in some areas of the Northeast and Utah (Figure III-16 and III-17). Annual increases in ambient concentrations of 1,3-butadiene are driven by wintertime rather than summertime changes (Figures III-17 and III-18). These increases appear in rural areas with cold winters and low ambient levels but high contributions of emissions from snowmobiles, and a major reason for this modeled increase may be deficiencies in available emissions test data used to estimate snowmobile 1,3-butadiene emission inventories. These data were based on tests using only three engines, which showed significantly higher 1,3-butadiene emissions with 10% ethanol. However, they may not have been representative of real-world response of snowmobile engines to ethanol. Regardless, these increases are a reflection of our ethanol volume assumptions and are not due to the standards finalized in this rule.

Figure III-16. Changes in Annual 1,3-Butadiene Ambient Concentrations Between the Reference Case and the Control Case in 2030: Percent Changes (left) and Absolute Changes in μg/m³ (right)

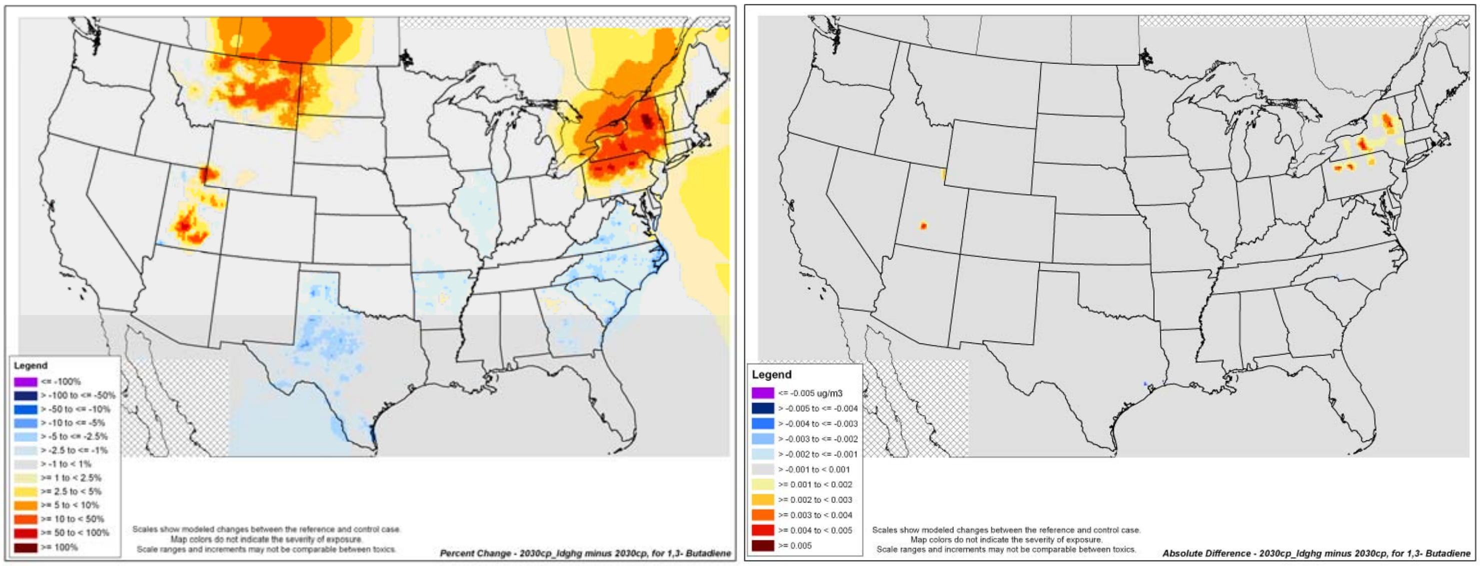


Figure III-17. Changes in Winter 1,3-Butadiene Ambient Concentrations Between the Reference Case and the Control Case in 2030: Percent Changes (left) and Absolute Changes in μg/m³ (right)

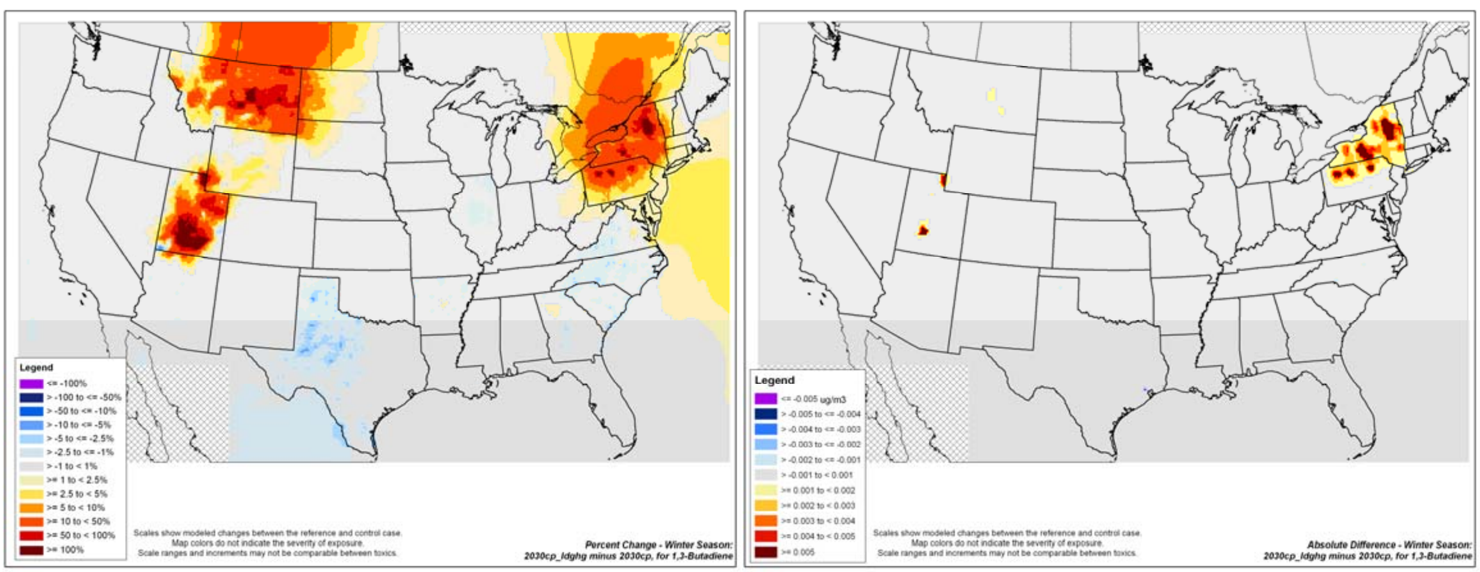
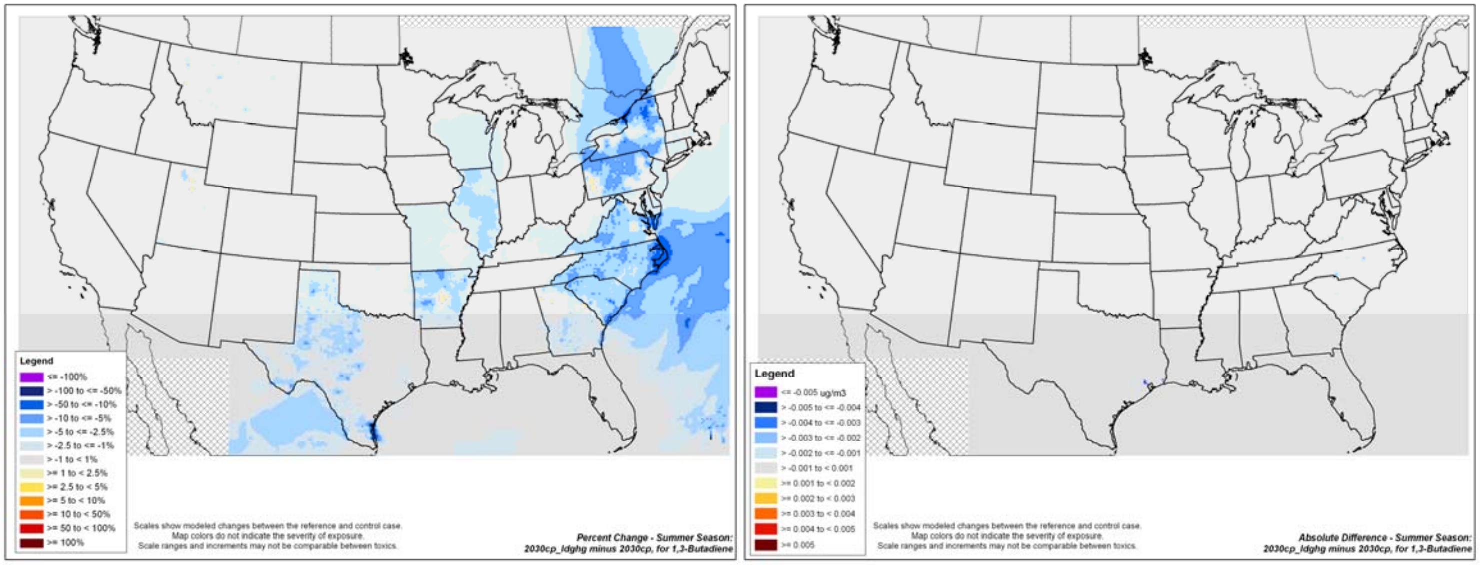


Figure III-18. Changes in Summer 1,3-Butadiene Ambient Concentrations Between the Reference Case and the Control Case in 2030: Percent Changes (left) and Absolute Changes in µg/m³ (right)



6. Acrolein

Our air quality modeling results do not show substantial impacts on ambient concentrations of acrolein from the standards finalized in this rule. Small decreases ranging from 1.0 to 2.5% occur in a few areas of the country and increases ranging from 1 to 100% occur in some northern areas and areas with high altitudes in the annual and winter (Figure III-19 and III-20). Changes in annual absolute concentrations of acrolein are less than 0.001 µg/m³ across the country (Figure III-19). Ambient acrolein increases are driven by wintertime changes rather than summertime changes (Figures III-20 and III-21), and occur in the same areas of the country that have wintertime rather than summertime increases in ambient 1,3-butadiene. 1,3-butadiene is a precursor to acrolein, and these increases are likely associated with the same emission inventory uncertainties in areas of high snowmobile usage seen for 1,3-butadiene. As described above, these increases are a reflection of our ethanol volume assumptions and are not due to the standards finalized in this rule.

Figure III-19. Changes in Annual Acrolein Ambient Concentrations Between the Reference Case and the Control Case in 2030: Percent Changes (left) and Absolute Changes in µg/m³ (right)

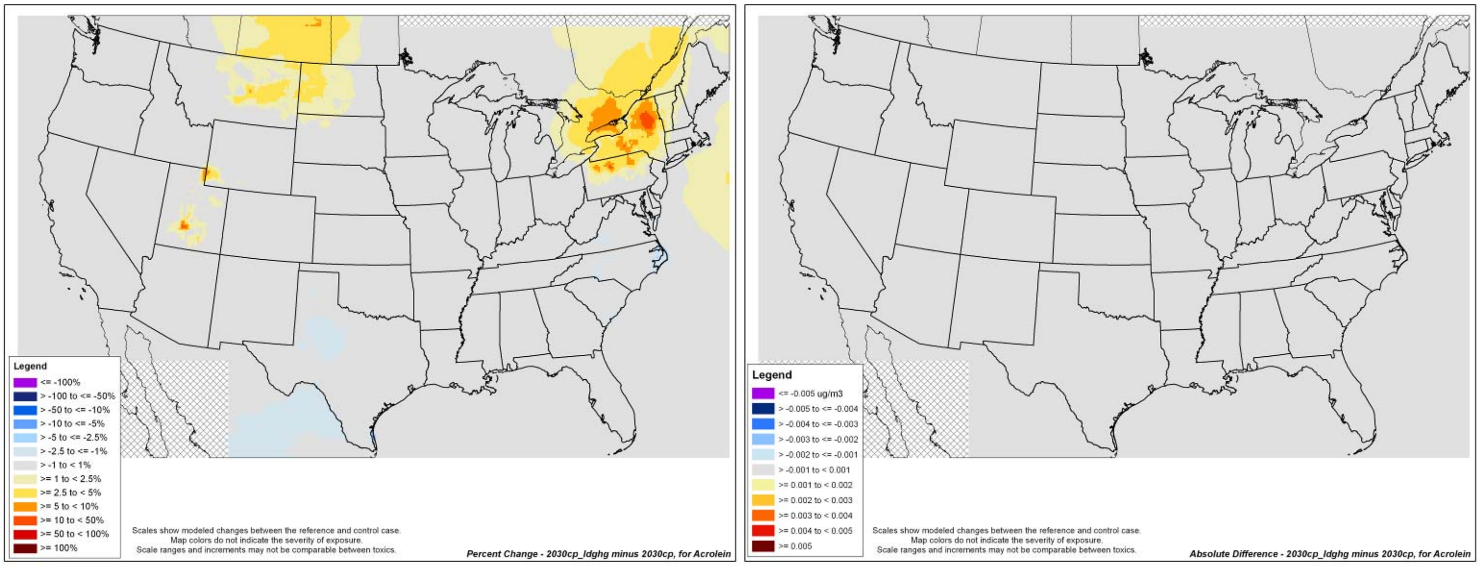


Figure III-20. Changes in Winter Acrolein Ambient Concentrations Between the Reference Case and the Control Case in 2030: Percent Changes (left) and Absolute Changes in µg/m³ (right)

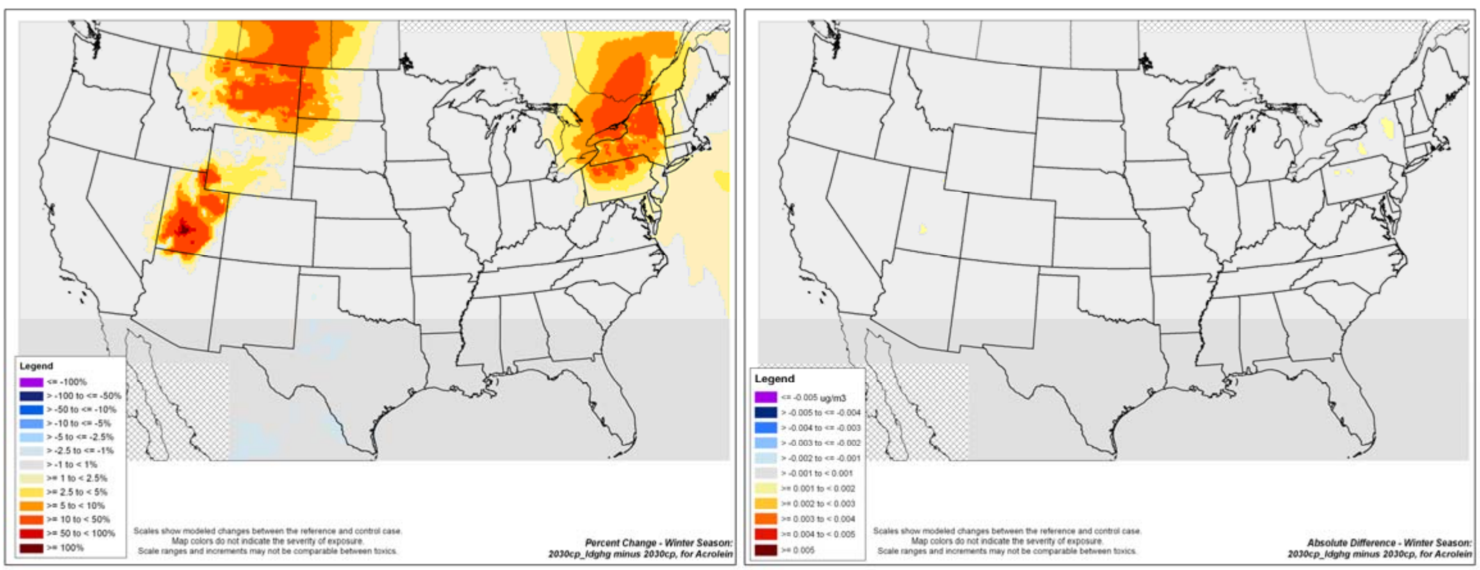
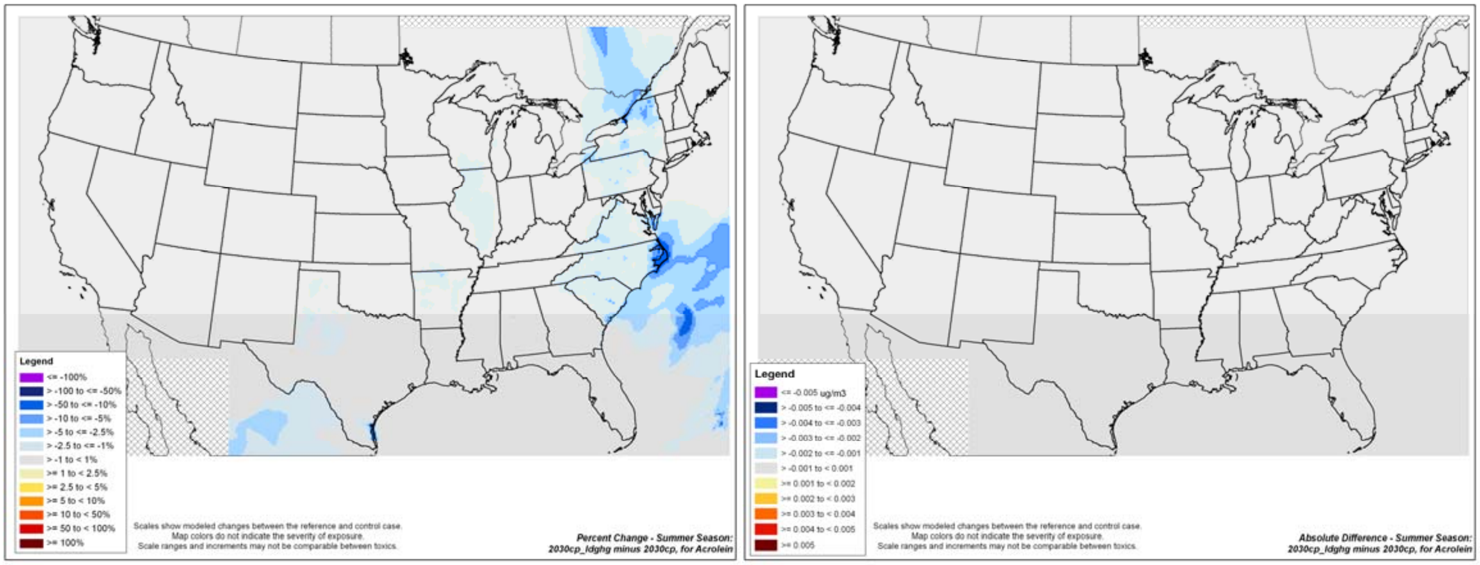


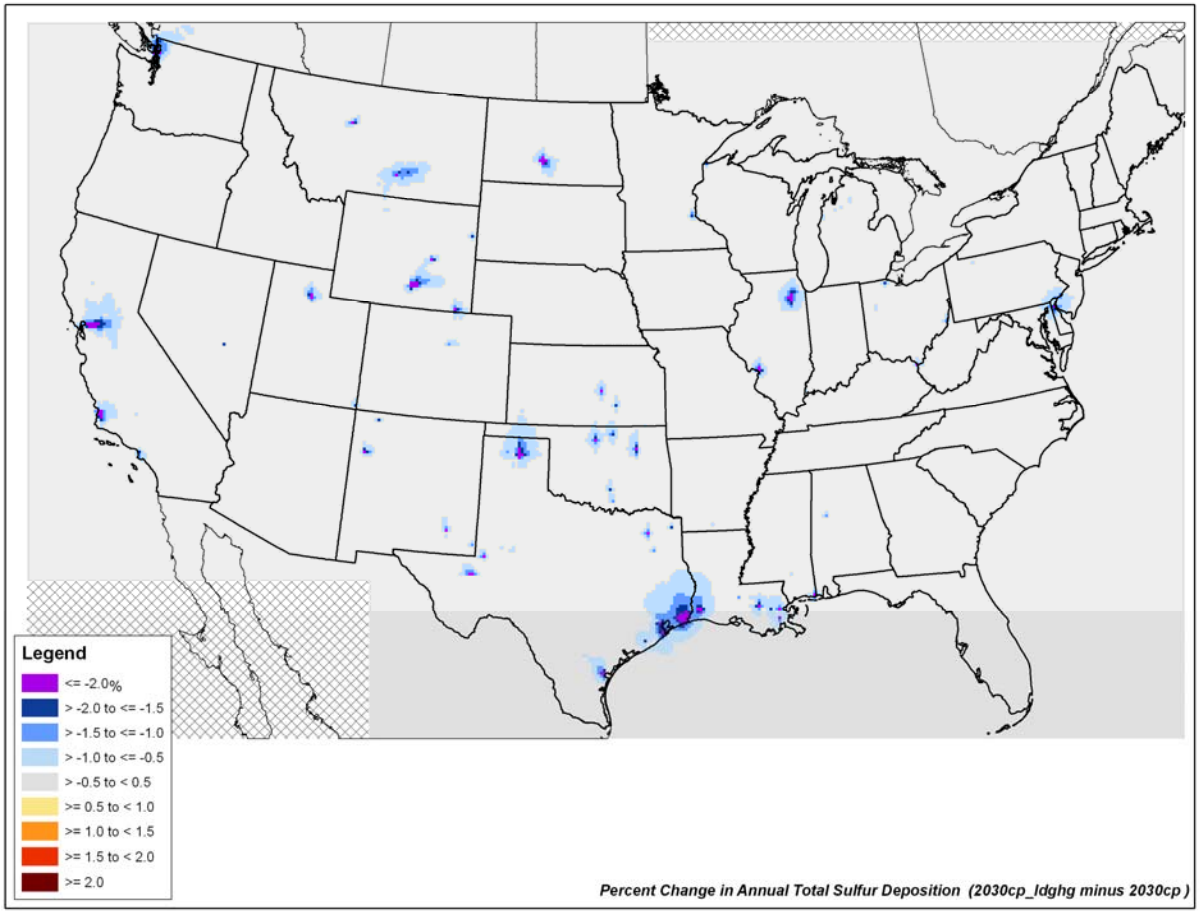
Figure III-21. Changes in Summer Acrolein Ambient Concentrations Between the Reference Case and the Control Case in 2030: Percent Changes (left) and Absolute Changes in μg/m³ (right)



E. Impacts of LDGHG Standards on Future Annual Nitrogen and Sulfur Deposition Levels

Our air quality modeling does not show substantial overall nationwide impacts on the annual total sulfur and nitrogen deposition occurring across the U.S. as a result of the vehicle standards required by this rule. Figure III-22 shows that for sulfur deposition the vehicle standards will result in annual percent decreases of 0.5% to more than 2% in locations with refineries as a result of the lower output from refineries due to less gasoline usage. These locations include the Texas and Louisiana portions of the Gulf Coast; the Washington D.C. area; Chicago, IL; portions of Oklahoma and northern Texas; Bismarck, North Dakota; Billings, Montana; Casper, Wyoming; Salt Lake City, Utah; Seattle, Washington; and San Francisco, Los Angeles, and San Luis Obispo, California. The remainder of the country will see only minimal changes in sulfur deposition, ranging from decreases of less than 0.5% to increases of less than 0.5%. The impacts of the vehicle standards on nitrogen deposition are minimal, ranging from decreases of up to 0.5% to increases of up to 0.5%.

Figure III-22. Percent Change in Annual Total Sulfur over the U.S. Modeling Domain as a Result of the Required Vehicle Standards



F. Impacts of LDGHG Standards on Future Visibility Levels

Air quality modeling conducted for this final rule was used to project visibility conditions in 138 mandatory class I federal areas across the U.S. in 2030. As expected, the results show that all the modeled areas will continue to have annual average deciview levels above background in 2030.[30] The results also indicate that the majority of the modeled mandatory class I federal areas will see no change in their visibility, but some mandatory class I federal areas will see improvements in visibility due to the vehicle standards and a few mandatory class I federal areas will see visibility decreases. The average visibility at all modeled mandatory class I federal areas on the 20% worst days is projected to improve by 0.002 deciviews, or 0.01%, in 2030. The greatest improvement in visibilities will be seen in Bosque de Apache (New Mexico) and the San

[30] 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.

Gorgonio Wilderness (near Los Angeles, California). Bosque de Apache will see a 0.15% improvement (0.02 DV) and the San Gorgonio Wilderness will see a 0.10% improvement (0.02 DV) in 2030 due to the vehicle standards. The following six areas will see a degradation of 0.01 DV in 2030 as a result of the vehicle standards: Hells Canyon Wilderness (Oregon), 0.06% degradation; Kalmiopsis Wilderness (Oregon), 0.06% degradation; Strawberry Mountain Wilderness (Oregon), 0.06% degradation; Petrified Forest National Park (Arizona), 0.08% degradation; Rocky Mountain National Park (Colorado), 0.08% degradation; and Three Sisters Wilderness (Oregon), 0.06% degradation. Section 7.2.2.6.2 of this RIA contains more detail on the visibility portion of the air quality modeling. Table III-1 contains the full visibility results from 2030 for the 138 analyzed areas.

Table III-1. Visibility Levels in Deciviews for Individual U.S. Class I Areas on the 20% Worst Days for Several Scenarios

CLASS 1 AREA (20% WORST DAYS)	STATE	2005 BASELINE VISIBILITY	2030 BASE	2030 CONT-ROL	NATURAL BACKGROUND
Sipsey Wilderness	AL	29.62	23.41	23.41	11.39
Caney Creek Wilderness	AR	26.78	22.52	22.51	11.33
Upper Buffalo Wilderness	AR	27.09	23.06	23.05	11.28
Chiricahua NM	AZ	13.33	13.28	13.28	6.92
Chiricahua Wilderness	AZ	13.33	13.27	13.27	6.91
Galiuro Wilderness	AZ	13.33	13.20	13.20	6.88
Grand Canyon NP	AZ	11.85	11.58	11.58	6.95
Mazatzal Wilderness	AZ	13.80	13.10	13.10	6.91
Mount Baldy Wilderness	AZ	11.27	11.10	11.10	6.95
Petrified Forest NP	AZ	13.73	13.31	13.32	6.97
Pine Mountain Wilderness	AZ	13.80	13.12	13.12	6.92
Saguaro NM	AZ	14.53	14.04	14.04	6.84
Sierra Ancha Wilderness	AZ	14.37	13.82	13.82	6.92
Superstition Wilderness	AZ	14.01	13.46	13.46	6.88
Sycamore Canyon Wilderness	AZ	15.34	15.04	15.04	6.96
Agua Tibia Wilderness	CA	23.09	24.56	24.55	7.17
Ansel Adams Wilderness (Minarets)	CA	14.90	14.78	14.77	7.12

Caribou Wilderness	CA	14.19	13.98	13.97	7.29
Cucamonga Wilderness	CA	19.35	18.23	18.22	7.17
Desolation Wilderness	CA	12.52	12.54	12.54	7.13
Emigrant Wilderness	CA	17.37	17.21	17.20	7.14
Hoover Wilderness	CA	11.92	11.85	11.85	7.12
John Muir Wilderness	CA	14.90	14.81	14.80	7.14
Joshua Tree NM	CA	19.40	18.68	18.68	7.08
Kaiser Wilderness	CA	14.90	14.71	14.71	7.13
Kings Canyon NP	CA	23.41	22.81	22.80	7.13
Lassen Volcanic NP	CA	14.19	14.00	14.00	7.31
Lava Beds NM	CA	14.77	14.31	14.31	7.49
Mokelumne Wilderness	CA	12.52	12.50	12.49	7.14
Pinnacles NM	CA	18.22	18.10	18.09	7.34
Point Reyes NS	CA	22.89	22.98	22.98	7.39
Redwood NP	CA	18.66	19.22	19.22	7.81
San Gabriel Wilderness	CA	19.35	18.06	18.05	7.17
San Gorgonio Wilderness	CA	21.80	20.23	20.21	7.10
San Jacinto Wilderness	CA	21.80	20.12	20.11	7.12
San Rafael Wilderness	CA	19.04	18.94	18.93	7.28
Sequoia NP	CA	23.41	22.64	22.64	7.13
South Warner Wilderness	CA	14.77	14.58	14.58	7.32
Thousand Lakes Wilderness	CA	14.19	14.00	14.00	7.32
Ventana Wilderness	CA	18.22	18.58	18.58	7.32
Yosemite NP	CA	17.37	17.24	17.24	7.14
Black Canyon of the Gunnison NM	CO	10.18	9.82	9.82	7.06
Eagles Nest Wilderness	CO	9.38	9.19	9.19	7.08
Flat Tops Wilderness	CO	9.38	9.27	9.27	7.07
Great Sand Dunes NM	CO	12.49	12.29	12.28	7.10

La Garita Wilderness	CO	10.18	10.00	10.00	7.06
Maroon Bells-Snowmass Wilderness	CO	9.38	9.23	9.23	7.07
Mesa Verde NP	CO	12.78	12.44	12.44	7.09
Mount Zirkel Wilderness	CO	10.19	10.08	10.08	7.08
Rawah Wilderness	CO	10.19	9.99	9.99	7.08
Rocky Mountain NP	CO	13.54	13.33	13.34	7.05
Weminuche Wilderness	CO	10.18	9.99	9.99	7.06
West Elk Wilderness	CO	9.38	9.20	9.20	7.07
Everglades NP	FL	22.48	21.34	21.34	11.15
Okefenokee	GA	27.24	23.44	23.44	11.45
Wolf Island	GA	27.24	23.44	23.44	11.42
Craters of the Moon NM	ID	14.19	13.56	13.56	7.13
Sawtooth Wilderness	ID	14.33	14.24	14.24	7.15
Mammoth Cave NP	KY	31.76	25.48	25.48	11.53
Acadia NP	ME	23.19	22.20	22.20	11.45
Moosehorn	ME	21.94	21.03	21.03	11.36
Roosevelt Campobello International Park	ME	21.94	21.03	21.03	11.36
Isle Royale NP	MI	21.33	19.42	19.42	11.22
Seney	MI	24.71	22.45	22.45	11.37
Voyageurs NP	MN	19.82	17.79	17.79	11.09
Hercules-Glades Wilderness	MO	27.15	23.60	23.60	11.27
Anaconda-Pintler Wilderness	MT	13.91	13.72	13.72	7.28
Bob Marshall Wilderness	MT	14.54	14.32	14.32	7.36
Cabinet Mountains Wilderness	MT	14.15	13.81	13.81	7.43
Gates of the Mountains Wilderness	MT	11.67	11.47	11.47	7.22
Glacier NP	MT	19.13	18.55	18.55	7.56

Medicine Lake	MT	17.78	16.81	16.81	7.30
Mission Mountains Wilderness	MT	14.54	14.25	14.25	7.39
Scapegoat Wilderness	MT	14.54	14.30	14.29	7.29
Selway-Bitterroot Wilderness	MT	13.91	13.79	13.79	7.32
UL Bend	MT	14.92	14.63	14.63	7.18
Linville Gorge Wilderness	NC	29.40	23.36	23.36	11.43
Shining Rock Wilderness	NC	28.72	23.04	23.04	11.45
Lostwood	ND	19.50	17.95	17.95	7.33
Theodore Roosevelt NP	ND	17.69	16.29	16.29	7.31
Great Gulf Wilderness	NH	22.13	20.19	20.18	11.31
Presidential Range-Dry River Wilderness	NH	22.13	20.19	20.18	11.33
Brigantine	NJ	29.28	25.88	25.87	11.28
Bandelier NM	NM	11.87	11.29	11.28	7.02
Bosque del Apache	NM	13.89	13.18	13.16	6.97
Gila Wilderness	NM	13.32	13.03	13.03	6.95
Pecos Wilderness	NM	10.10	9.82	9.82	7.04
Salt Creek	NM	18.20	17.21	17.20	6.99
San Pedro Parks Wilderness	NM	10.39	10.06	10.06	7.03
Wheeler Peak Wilderness	NM	10.10	9.70	9.70	7.07
White Mountain Wilderness	NM	13.52	12.94	12.94	6.98
Jarbidge Wilderness	NV	12.13	12.09	12.09	7.10
Wichita Mountains	OK	23.79	20.50	20.49	11.07
Crater Lake NP	OR	14.04	13.76	13.76	7.71
Diamond Peak Wilderness	OR	14.04	13.71	13.71	7.77
Eagle Cap Wilderness	OR	18.25	17.64	17.63	7.34
Gearhart Mountain Wilderness	OR	14.04	13.88	13.88	7.46
Hells Canyon Wilderness	OR	18.73	17.90	17.91	7.32

Kalmiopsis Wilderness	OR	16.31	16.38	16.39	7.71
Mount Hood Wilderness	OR	14.79	14.49	14.49	7.77
Mount Jefferson Wilderness	OR	15.93	15.75	15.75	7.81
Mount Washington Wilderness	OR	15.93	15.72	15.72	7.89
Mountain Lakes Wilderness	OR	14.04	13.75	13.74	7.57
Strawberry Mountain Wilderness	OR	18.25	17.65	17.66	7.49
Three Sisters Wilderness	OR	15.93	15.72	15.73	7.87
Cape Romain	SC	27.14	24.09	24.09	11.36
Badlands NP	SD	16.73	15.52	15.51	7.30
Wind Cave NP	SD	15.96	14.93	14.93	7.24
Great Smoky Mountains NP	TN	30.43	24.30	24.30	11.44
Joyce-Kilmer-Slickrock Wilderness	TN	30.43	24.30	24.30	11.45
Big Bend NP	TX	17.39	16.43	16.42	6.93
Carlsbad Caverns NP	TX	16.98	15.89	15.88	7.02
Guadalupe Mountains NP	TX	16.98	15.89	15.88	7.03
Arches NP	UT	11.04	10.82	10.81	6.99
Bryce Canyon NP	UT	11.73	11.52	11.52	6.99
Canyonlands NP	UT	11.04	10.88	10.88	7.01
Capitol Reef NP	UT	10.63	10.74	10.74	7.03
James River Face Wilderness	VA	29.32	23.18	23.17	11.24
Shenandoah NP	VA	29.66	23.73	23.72	11.25
Lye Brook Wilderness	VT	24.17	20.72	20.72	11.25
Alpine Lake Wilderness	WA	17.35	17.29	17.28	7.86
Glacier Peak Wilderness	WA	13.78	14.06	14.05	7.80
Goat Rocks Wilderness	WA	12.88	12.32	12.32	7.82
Mount Adams Wilderness	WA	12.88	12.33	12.33	7.78
Mount Rainier NP	WA	17.56	17.23	17.22	7.90

North Cascades NP	WA	13.78	14.20	14.19	7.78
Olympic NP	WA	16.14	16.35	16.35	7.88
Pasayten Wilderness	WA	15.39	14.99	14.99	7.77
Dolly Sods Wilderness	WV	29.73	23.14	23.14	11.32
Otter Creek Wilderness	WV	29.73	23.14	23.14	11.33
Bridger Wilderness	WY	10.93	10.80	10.80	7.08
Fitzpatrick Wilderness	WY	10.93	10.80	10.80	7.09
Grand Teton NP	WY	10.94	10.61	10.61	7.09
North Absaroka Wilderness	WY	11.12	10.98	10.98	7.09
Red Rock Lakes	WY	10.94	10.68	10.68	7.14
Teton Wilderness	WY	10.94	10.70	10.70	7.09
Washakie Wilderness	WY	11.12	10.98	10.98	7.09
Yellowstone NP	WY	10.94	10.66	10.66	7.12

Appendix A: 8-Hour Ozone Design Values for LDGHG Scenarios (units are ppb)

State Name	County Name	Baseline DV	2030 Reference Case DV	2030 Control Case DV
Alabama	Baldwin	77.30	62.12	62.13
Alabama	Clay	74.00	54.56	54.66
Alabama	Colbert	72.00	49.56	49.60
Alabama	Elmore	70.70	50.66	50.70
Alabama	Etowah	71.70	53.50	53.57
Alabama	Houston	71.00	54.06	54.12
Alabama	Jefferson	83.70	60.25	60.28
Alabama	Lawrence	72.00	54.59	54.65
Alabama	Madison	77.30	57.70	57.77
Alabama	Mobile	76.70	62.00	61.99
Alabama	Montgomery	69.30	49.81	49.85
Alabama	Morgan	77.30	61.83	61.88
Alabama	Russell	71.30	53.80	53.91
Alabama	Shelby	85.70	61.15	61.19
Alabama	Sumter	64.00	50.66	50.72
Alabama	Talladega	72.00	52.05	52.10
Alabama	Tuscaloosa	73.30	51.92	51.97
Arizona	Cochise	71.30	60.19	60.26
Arizona	Coconino	73.00	61.38	61.37
Arizona	Gila	80.30	60.96	61.14
Arizona	La Paz	72.00	58.91	58.90
Arizona	Maricopa	83.00	68.25	68.40
Arizona	Pima	76.00	60.34	60.46
Arizona	Pinal	79.30	61.31	61.48
Arizona	Yavapai	72.00	59.01	59.03
Arizona	Yuma	75.00	59.62	59.66
Arkansas	Crittenden	87.30	64.30	64.31
Arkansas	Newton	72.70	56.17	56.20
Arkansas	Polk	75.00	61.52	61.55
Arkansas	Pulaski	79.70	57.57	57.61
California	Alameda	78.30	68.54	68.50
California	Amador	83.00	67.88	67.80
California	Butte	83.70	64.96	64.93
California	Calaveras	91.30	77.10	77.00
California	Colusa	67.00	54.40	54.38
California	Contra Costa	73.30	67.60	67.55
California	El Dorado	96.00	74.21	74.16
California	Fresno	98.30	82.26	82.22
California	Glenn	65.50	52.97	52.96
California	Imperial	85.00	71.17	71.15
California	Inyo	82.30	67.61	67.59
California	Kern	110.00	94.06	94.00
California	Kings	85.70	69.61	69.58
California	Lake	60.70	50.74	50.73
California	Los Angeles	114.00	99.78	99.73
California	Madera	79.30	65.08	65.04
California	Marin	49.70	45.02	44.99
California	Mariposa	86.30	71.56	71.51

California	Mendocino	56.70	47.18	47.17
California	Merced	89.30	72.83	72.79
California	Monterey	61.00	52.97	52.96
California	Napa	59.30	50.01	49.97
California	Nevada	96.30	75.01	74.96
California	Orange	84.30	80.34	80.21
California	Placer	94.00	72.94	72.89
California	Riverside	112.30	108.99	108.78
California	Sacramento	97.30	75.82	75.78
California	San Benito	75.00	63.10	63.08
California	San Bernardino	123.30	119.23	119.05
California	San Diego	87.70	74.73	74.68
California	San Francisco	46.00	45.94	45.94
California	San Joaquin	75.30	65.35	65.29
California	San Luis Obispo	70.70	59.82	59.78
California	San Mateo	53.70	51.04	51.02
California	Santa Barbara	76.00	65.76	65.75
California	Santa Clara	75.30	63.59	63.55
California	Santa Cruz	61.30	53.31	53.28
California	Shasta	79.30	63.16	63.15
California	Siskiyou	63.50	51.30	51.31
California	Solano	72.70	61.24	61.20
California	Sonoma	47.70	40.16	40.15
California	Stanislaus	84.70	71.72	71.66
California	Sutter	82.00	66.24	66.21
California	Tehama	82.70	65.63	65.61
California	Tulare	103.70	84.91	84.89
California	Tuolumne	80.00	67.55	67.46
California	Ventura	89.70	76.08	76.06
California	Yolo	78.70	64.49	64.46
Colorado	Adams	69.00	61.53	61.56
Colorado	Arapahoe	78.70	67.53	67.60
Colorado	Boulder	77.00	65.65	65.71
Colorado	Denver	73.00	65.09	65.13
Colorado	Douglas	83.00	71.56	71.63
Colorado	El Paso	73.30	62.29	62.34
Colorado	Jefferson	81.70	73.11	73.15
Colorado	La Plata	63.70	56.79	56.81
Colorado	Larimer	76.00	64.19	64.26
Colorado	Montezuma	72.00	63.35	63.35
Colorado	Weld	76.70	65.92	65.95
Connecticut	Fairfield	92.30	78.57	78.57
Connecticut	Hartford	84.30	65.93	66.02
Connecticut	Litchfield	87.70	68.49	68.59
Connecticut	Middlesex	90.30	74.32	74.38
Connecticut	New Haven	90.30	76.01	76.04
Connecticut	New London	85.30	69.67	69.72
Connecticut	Tolland	88.70	68.80	68.88
D.C.	Washington	84.70	68.15	68.25
Delaware	Kent	80.30	63.66	63.69
Delaware	New Castle	82.30	65.94	65.97
Delaware	Sussex	82.70	68.73	68.76
Florida	Alachua	72.00	52.50	52.60
Florida	Baker	68.70	51.57	51.70

Florida	Bay	78.70	60.32	60.40
Florida	Brevard	71.30	56.10	56.17
Florida	Broward	65.00	53.85	53.86
Florida	Collier	68.30	51.32	51.40
Florida	Columbia	72.00	55.63	55.74
Florida	Duval	77.70	62.06	62.10
Florida	Escambia	82.70	65.40	65.44
Florida	Highlands	72.30	59.63	59.69
Florida	Hillsborough	80.70	63.51	63.53
Florida	Holmes	70.30	54.06	54.14
Florida	Lake	76.70	58.47	58.61
Florida	Lee	70.30	55.42	55.49
Florida	Leon	71.00	51.79	51.91
Florida	Manatee	77.30	59.10	59.15
Florida	Marion	73.00	51.54	51.65
Florida	Miami-Dade	71.30	66.00	65.98
Florida	Orange	79.30	62.64	62.78
Florida	Osceola	72.00	53.23	53.37
Florida	Palm Beach	65.00	58.40	58.42
Florida	Pasco	76.30	58.77	58.84
Florida	Pinellas	72.70	54.92	54.99
Florida	Polk	74.70	54.96	55.04
Florida	St Lucie	66.50	55.23	55.29
Florida	Santa Rosa	80.00	63.28	63.34
Florida	Sarasota	77.30	57.58	57.64
Florida	Seminole	76.00	57.58	57.71
Florida	Volusia	68.30	51.29	51.38
Florida	Wakulla	71.30	54.29	54.37
Georgia	Bibb	81.00	63.22	63.33
Georgia	Chatham	68.30	56.28	56.41
Georgia	Chattooga	75.00	55.13	55.23
Georgia	Clarke	80.70	54.77	54.88
Georgia	Cobb	82.70	58.69	58.82
Georgia	Columbia	73.00	55.80	55.91
Georgia	Coweta	82.00	62.93	63.01
Georgia	Dawson	76.30	51.47	51.58
Georgia	De Kalb	88.70	69.21	69.31
Georgia	Douglas	87.30	63.01	63.14
Georgia	Fayette	85.70	65.17	65.27
Georgia	Fulton	91.70	71.55	71.65
Georgia	Glynn	67.00	51.68	51.90
Georgia	Gwinnett	88.70	65.14	65.26
Georgia	Henry	89.70	65.47	65.58
Georgia	Murray	78.00	59.29	59.37
Georgia	Muscogee	75.70	55.33	55.47
Georgia	Paulding	80.30	55.75	55.86
Georgia	Richmond	80.30	60.26	60.38
Georgia	Rockdale	90.00	64.04	64.16
Georgia	Sumter	72.30	54.58	54.68
Idaho	Ada	76.00	68.16	68.19
Idaho	Canyon	66.00	57.50	57.53
Idaho	Elmore	63.00	56.42	56.44
Idaho	Kootenai	67.00	56.09	56.13
Illinois	Adams	70.00	57.37	57.37

Illinois	Champaign	68.30	55.36	55.37
Illinois	Clark	66.00	53.83	53.80
Illinois	Cook	77.70	69.26	69.23
Illinois	Du Page	69.00	62.42	62.39
Illinois	Effingham	70.00	56.86	56.85
Illinois	Hamilton	73.00	57.28	57.29
Illinois	Jersey	78.70	58.17	58.18
Illinois	Kane	74.30	62.39	62.35
Illinois	Lake	78.00	68.34	68.30
Illinois	McHenry	73.30	59.25	59.23
Illinois	McLean	73.00	58.06	58.05
Illinois	Macon	71.30	58.34	58.35
Illinois	Macoupin	73.00	53.17	53.12
Illinois	Madison	83.00	64.79	64.77
Illinois	Peoria	72.70	61.04	61.02
Illinois	Randolph	72.00	57.77	57.77
Illinois	Rock Island	65.30	53.40	53.38
Illinois	St Clair	81.70	65.01	65.01
Illinois	Sangamon	70.00	53.38	53.37
Illinois	Will	71.70	60.19	60.17
Illinois	Winnebago	69.00	55.39	55.36
Indiana	Allen	79.30	63.25	63.26
Indiana	Boone	79.70	62.92	62.92
Indiana	Carroll	74.00	58.00	58.02
Indiana	Clark	80.30	61.29	61.30
Indiana	Delaware	76.30	58.66	58.69
Indiana	Elkhart	79.00	62.48	62.48
Indiana	Floyd	77.70	63.36	63.36
Indiana	Greene	78.30	61.19	61.21
Indiana	Hamilton	82.70	64.80	64.81
Indiana	Hancock	78.00	61.82	61.84
Indiana	Hendricks	75.30	60.42	60.42
Indiana	Huntington	75.00	59.55	59.57
Indiana	Jackson	74.70	58.89	58.91
Indiana	Johnson	76.70	62.15	62.16
Indiana	Lake	81.00	70.86	70.85
Indiana	La Porte	78.50	66.03	66.03
Indiana	Madison	76.70	59.43	59.44
Indiana	Marion	78.70	62.96	62.97
Indiana	Morgan	77.00	62.18	62.19
Indiana	Perry	81.00	61.98	62.00
Indiana	Porter	78.30	68.89	68.87
Indiana	Posey	71.70	55.40	55.41
Indiana	St Joseph	79.30	63.08	63.07
Indiana	Shelby	77.30	63.40	63.40
Indiana	Vanderburgh	77.30	60.50	60.51
Indiana	Vigo	74.00	60.27	60.28
Indiana	Warrick	77.70	61.55	61.56
Iowa	Bremer	66.30	53.55	53.55
Iowa	Clinton	71.30	58.82	58.82
Iowa	Harrison	74.70	61.19	61.19
Iowa	Linn	68.30	56.98	56.98
Iowa	Montgomery	65.70	52.99	53.00
Iowa	Palo Alto	61.00	50.64	50.64

Iowa	Polk	63.00	49.82	49.83
Iowa	Scott	72.00	58.08	58.08
Iowa	Story	61.00	48.15	48.16
Iowa	Van Buren	69.00	56.48	56.48
Iowa	Warren	64.50	50.26	50.27
Kansas	Douglas	73.00	57.98	57.99
Kansas	Johnson	75.30	59.77	59.79
Kansas	Leavenworth	75.00	62.21	62.21
Kansas	Linn	73.30	59.10	59.12
Kansas	Sedgwick	71.30	56.85	56.85
Kansas	Sumner	71.70	57.13	57.14
Kansas	Trego	70.70	61.71	61.72
Kansas	Wyandotte	75.30	62.79	62.78
Kentucky	Bell	71.70	53.22	53.27
Kentucky	Boone	75.70	59.43	59.45
Kentucky	Boyd	77.30	63.21	63.07
Kentucky	Bullitt	74.00	58.62	58.62
Kentucky	Campbell	75.00	61.20	61.20
Kentucky	Carter	71.00	56.12	56.03
Kentucky	Christian	78.00	58.91	58.94
Kentucky	Daviess	75.70	59.81	59.82
Kentucky	Edmonson	73.70	57.55	57.57
Kentucky	Fayette	70.30	55.38	55.38
Kentucky	Greenup	76.70	62.96	62.84
Kentucky	Hancock	74.00	56.96	56.97
Kentucky	Hardin	74.70	59.20	59.21
Kentucky	Henderson	75.30	59.99	60.01
Kentucky	Jefferson	78.30	64.65	64.64
Kentucky	Jessamine	73.30	57.33	57.34
Kentucky	Kenton	78.70	62.06	62.08
Kentucky	Livingston	73.70	59.14	59.17
Kentucky	McCracken	73.30	60.47	60.49
Kentucky	McLean	73.00	57.79	57.80
Kentucky	Oldham	83.00	62.16	62.17
Kentucky	Perry	72.30	57.12	57.15
Kentucky	Pike	66.70	52.53	52.55
Kentucky	Pulaski	70.30	56.82	56.84
Kentucky	Simpson	75.70	57.29	57.32
Kentucky	Trigg	70.00	53.84	53.87
Kentucky	Warren	72.00	56.36	56.38
Louisiana	Ascension	82.00	69.22	69.13
Louisiana	Beauregard	75.00	64.45	64.38
Louisiana	Bossier	78.00	60.36	60.36
Louisiana	Caddo	79.00	61.30	61.32
Louisiana	Calcasieu	82.00	70.59	70.52
Louisiana	East Baton Rouge	92.00	77.68	77.57
Louisiana	Grant	73.00	60.23	60.22
Louisiana	Iberville	85.00	72.73	72.64
Louisiana	Jefferson	83.00	70.23	70.18
Louisiana	Lafayette	82.00	67.35	67.30
Louisiana	Lafourche	79.30	67.93	67.79
Louisiana	Livingston	78.30	66.09	66.01
Louisiana	Orleans	70.00	60.37	60.33
Louisiana	Ouachita	75.30	59.90	59.94

Louisiana	Pointe Coupee	83.70	72.55	72.46
Louisiana	St Bernard	78.00	65.84	65.79
Louisiana	St Charles	77.30	65.95	65.90
Louisiana	St James	76.30	65.50	65.37
Louisiana	St John The Baptis	79.00	68.56	68.44
Louisiana	St Mary	76.00	63.79	63.68
Louisiana	West Baton Rouge	84.30	71.70	71.60
Maine	Cumberland	72.00	58.52	58.60
Maine	Hancock	82.00	66.90	66.99
Maine	Kennebec	69.70	56.26	56.34
Maine	Knox	75.30	60.91	60.99
Maine	Oxford	61.00	50.62	50.67
Maine	Penobscot	67.00	56.68	56.75
Maine	Sagadahoc	68.50	55.64	55.70
Maine	York	74.00	60.50	60.57
Maryland	Anne Arundel	89.70	68.30	68.41
Maryland	Baltimore	85.30	74.70	74.75
Maryland	Calvert	81.00	63.53	63.63
Maryland	Carroll	83.30	62.87	62.99
Maryland	Cecil	90.70	69.07	69.16
Maryland	Charles	86.00	64.72	64.81
Maryland	Frederick	80.30	61.49	61.59
Maryland	Garrett	75.50	59.59	59.64
Maryland	Harford	92.70	79.90	79.96
Maryland	Kent	82.00	62.52	62.58
Maryland	Montgomery	83.00	64.86	64.98
Maryland	Prince Georges	91.00	70.29	70.40
Maryland	Washington	78.30	60.78	60.89
Massachusetts	Barnstable	84.70	70.72	70.76
Massachusetts	Berkshire	79.70	62.69	62.78
Massachusetts	Bristol	82.70	70.01	70.05
Massachusetts	Dukes	83.00	71.02	71.04
Massachusetts	Essex	83.30	70.86	70.91
Massachusetts	Hampden	87.30	68.12	68.22
Massachusetts	Hampshire	85.00	65.66	65.76
Massachusetts	Middlesex	79.00	63.28	63.34
Massachusetts	Norfolk	84.70	67.57	67.62
Massachusetts	Suffolk	80.30	65.84	65.89
Massachusetts	Worcester	80.00	60.98	61.06
Michigan	Allegan	90.00	74.82	74.76
Michigan	Benzie	81.70	66.95	66.91
Michigan	Berrien	82.30	68.23	68.20
Michigan	Cass	80.70	64.33	64.33
Michigan	Clinton	75.70	58.96	58.96
Michigan	Genesee	79.30	63.07	63.08
Michigan	Huron	75.70	62.68	62.68
Michigan	Ingham	76.00	60.47	60.47
Michigan	Kalamazoo	75.30	59.39	59.39
Michigan	Kent	81.00	63.46	63.44
Michigan	Leelanau	75.70	62.73	62.71
Michigan	Lenawee	78.70	63.47	63.47
Michigan	Macomb	86.00	70.72	70.71
Michigan	Mason	79.70	64.06	64.03
Michigan	Missaukee	73.70	60.01	59.98

Michigan	Muskegon	85.00	70.50	70.45
Michigan	Oakland	78.00	66.05	66.04
Michigan	Ottawa	81.70	65.82	65.79
Michigan	St Clair	82.30	65.96	65.97
Michigan	Schoolcraft	79.30	64.42	64.40
Michigan	Washtenaw	78.30	64.01	64.02
Michigan	Wayne	82.00	67.60	67.59
Minnesota	Anoka	67.70	62.22	62.19
Minnesota	St Louis	65.00	54.11	54.11
Mississippi	Adams	74.70	60.66	60.65
Mississippi	Bolivar	74.30	58.09	58.13
Mississippi	De Soto	82.70	61.60	61.60
Mississippi	Hancock	79.00	64.72	64.66
Mississippi	Harrison	83.00	67.11	67.01
Mississippi	Hinds	71.30	48.15	48.17
Mississippi	Jackson	80.30	66.23	66.11
Mississippi	Lauderdale	74.30	55.73	55.82
Mississippi	Lee	73.70	53.00	53.08
Missouri	Cass	74.70	58.86	58.86
Missouri	Cedar	75.70	59.98	60.00
Missouri	Clay	84.30	67.18	67.18
Missouri	Clinton	83.00	65.61	65.62
Missouri	Greene	73.00	57.62	57.63
Missouri	Jefferson	82.30	67.04	67.01
Missouri	Lincoln	87.00	68.52	68.50
Missouri	Monroe	71.70	56.96	56.96
Missouri	Perry	77.50	60.83	60.85
Missouri	Platte	77.00	63.46	63.46
Missouri	St Charles	87.00	66.95	66.93
Missouri	Ste Genevieve	79.70	64.64	64.60
Missouri	St Louis	88.00	71.39	71.35
Missouri	St Louis City	84.00	67.73	67.72
Montana	Yellowstone	59.00	53.77	53.73
Nebraska	Douglas	68.70	57.84	57.83
Nebraska	Lancaster	56.00	45.40	45.41
Nevada	Clark	83.70	72.85	72.88
Nevada	Washoe	70.70	57.13	57.12
Nevada	White Pine	72.30	61.46	61.47
Nevada	Carson City	65.00	52.27	52.23
New Hampshire	Belknap	71.30	53.91	53.98
New Hampshire	Cheshire	70.70	55.40	55.46
New Hampshire	Coos	77.00	61.95	62.03
New Hampshire	Grafton	67.00	53.73	53.80
New Hampshire	Hillsborough	78.70	62.91	62.98
New Hampshire	Merrimack	71.70	55.55	55.62
New Hampshire	Rockingham	75.00	61.31	61.39
New Hampshire	Sullivan	70.00	55.05	55.13
New Jersey	Atlantic	79.30	65.33	65.35
New Jersey	Bergen	86.00	74.04	74.04
New Jersey	Camden	89.30	72.01	71.99
New Jersey	Cumberland	83.30	65.99	66.01
New Jersey	Gloucester	87.00	70.30	70.30
New Jersey	Hudson	85.70	74.89	74.84
New Jersey	Hunterdon	89.00	68.12	68.19

New Jersey	Mercer	88.00	70.81	70.85
New Jersey	Middlesex	88.30	70.53	70.55
New Jersey	Monmouth	87.30	73.06	73.06
New Jersey	Morris	83.30	65.36	65.44
New Jersey	Ocean	93.00	74.05	74.07
New Jersey	Passaic	81.00	65.90	65.96
New Mexico	Bernalillo	73.70	60.10	60.11
New Mexico	Dona Ana	75.30	64.16	64.19
New Mexico	Eddy	69.00	63.01	63.01
New Mexico	Grant	66.00	58.00	58.03
New Mexico	Lea	69.50	64.11	64.11
New Mexico	Sandoval	73.30	59.78	59.78
New Mexico	San Juan	71.30	65.82	65.82
New York	Albany	73.70	58.31	58.40
New York	Bronx	74.70	67.12	67.11
New York	Chautauqua	86.70	73.47	73.50
New York	Chemung	68.70	55.85	55.89
New York	Dutchess	75.70	59.06	59.14
New York	Erie	85.00	71.88	71.88
New York	Essex	77.00	64.30	64.33
New York	Hamilton	71.70	59.84	59.88
New York	Herkimer	68.30	58.12	58.14
New York	Jefferson	78.00	64.85	64.81
New York	Madison	72.00	56.92	57.00
New York	Monroe	75.00	63.07	63.10
New York	Niagara	82.70	72.43	72.45
New York	Oneida	68.30	56.98	57.02
New York	Onondaga	73.70	61.50	61.54
New York	Orange	82.00	64.50	64.59
New York	Oswego	78.00	67.43	67.46
New York	Putnam	84.30	66.58	66.66
New York	Queens	80.00	69.37	69.34
New York	Rensselaer	77.30	61.18	61.26
New York	Richmond	88.30	74.46	74.45
New York	Saratoga	79.70	63.14	63.23
New York	Schenectady	70.00	56.13	56.22
New York	Suffolk	90.30	83.36	83.34
New York	Ulster	77.30	60.44	60.53
New York	Wayne	68.00	58.07	58.10
New York	Westchester	87.70	75.32	75.32
North Carolina	Alexander	77.00	56.20	56.35
North Carolina	Avery	70.00	56.72	56.78
North Carolina	Buncombe	74.00	57.37	57.48
North Carolina	Caldwell	74.30	54.80	54.94
North Carolina	Caswell	76.30	57.06	57.19
North Carolina	Chatham	73.30	55.22	55.36
North Carolina	Cumberland	81.70	59.46	59.66
North Carolina	Davie	81.30	60.28	60.44
North Carolina	Durham	77.00	55.71	55.87
North Carolina	Edgecombe	77.00	58.27	58.40
North Carolina	Forsyth	80.00	61.01	61.12
North Carolina	Franklin	78.70	58.29	58.46
North Carolina	Graham	78.30	58.90	58.97
North Carolina	Granville	82.00	60.30	60.47

North Carolina	Guilford	82.00	60.11	60.30
North Carolina	Haywood	78.30	61.08	61.18
North Carolina	Jackson	76.00	57.67	57.74
North Carolina	Johnston	77.30	55.60	55.80
North Carolina	Lenoir	75.30	58.61	58.72
North Carolina	Lincoln	81.00	59.12	59.29
North Carolina	Martin	75.00	61.07	61.20
North Carolina	Mecklenburg	89.30	67.24	67.36
North Carolina	New Hanover	72.30	62.14	62.24
North Carolina	Person	77.30	58.86	58.92
North Carolina	Pitt	76.30	57.55	57.68
North Carolina	Rockingham	77.00	57.60	57.70
North Carolina	Rowan	86.70	63.62	63.79
North Carolina	Swain	66.30	48.49	48.54
North Carolina	Union	79.30	56.19	56.39
North Carolina	Wake	80.30	58.70	58.89
North Carolina	Yancey	76.00	59.00	59.06
North Dakota	Billings	61.50	55.15	55.15
North Dakota	Burke	57.50	51.48	51.48
North Dakota	Cass	60.00	49.25	49.26
North Dakota	McKenzie	61.30	54.96	54.97
North Dakota	Oliver	57.70	52.43	52.43
Ohio	Allen	78.70	63.23	63.21
Ohio	Ashtabula	89.00	74.40	74.41
Ohio	Butler	83.30	65.42	65.44
Ohio	Clark	81.00	62.17	62.19
Ohio	Clermont	81.00	65.24	65.24
Ohio	Clinton	82.30	61.79	61.81
Ohio	Cuyahoga	79.70	66.25	66.23
Ohio	Delaware	78.30	61.86	61.89
Ohio	Franklin	86.30	67.88	67.90
Ohio	Geauga	79.30	61.14	61.16
Ohio	Greene	80.30	62.22	62.24
Ohio	Hamilton	84.70	67.23	67.23
Ohio	Jefferson	78.00	60.93	60.95
Ohio	Knox	77.70	59.90	59.92
Ohio	Lake	86.30	70.00	69.98
Ohio	Lawrence	70.70	58.04	57.92
Ohio	Licking	78.00	60.04	60.07
Ohio	Lorain	76.70	63.35	63.35
Ohio	Lucas	81.30	66.46	66.44
Ohio	Madison	79.70	60.41	60.44
Ohio	Mahoning	78.70	60.02	60.06
Ohio	Medina	80.30	63.53	63.53
Ohio	Miami	76.70	58.74	58.76
Ohio	Montgomery	74.00	57.59	57.61
Ohio	Portage	83.70	65.22	65.24
Ohio	Preble	73.00	56.44	56.47
Ohio	Stark	81.00	62.34	62.35
Ohio	Summit	83.70	66.01	66.02
Ohio	Trumbull	84.30	64.41	64.45
Ohio	Warren	87.70	67.73	67.74
Ohio	Washington	82.70	67.24	67.27
Ohio	Wood	80.00	64.12	64.12

Oklahoma	Adair	75.70	63.64	63.64
Oklahoma	Canadian	76.00	59.87	59.90
Oklahoma	Cherokee	75.70	64.95	64.94
Oklahoma	Cleveland	74.70	60.04	60.04
Oklahoma	Comanche	77.50	62.08	62.09
Oklahoma	Creek	76.70	61.61	61.59
Oklahoma	Dewey	72.70	58.90	58.91
Oklahoma	Kay	78.00	62.49	62.48
Oklahoma	Mc Clain	72.00	58.00	58.01
Oklahoma	Mayes	78.50	68.29	68.28
Oklahoma	Oklahoma	80.00	62.86	62.89
Oklahoma	Ottawa	78.00	64.01	64.01
Oklahoma	Pittsburg	72.00	59.61	59.60
Oklahoma	Tulsa	79.30	66.10	66.11
Oregon	Clackamas	66.30	61.35	61.36
Oregon	Jackson	68.00	52.47	52.52
Oregon	Lane	69.30	56.38	56.43
Oregon	Marion	65.70	56.16	56.21
Oregon	Multnomah	56.30	68.82	68.81
Pennsylvania	Adams	76.30	58.87	58.96
Pennsylvania	Allegheny	83.70	65.49	65.54
Pennsylvania	Armstrong	83.00	63.64	63.70
Pennsylvania	Beaver	83.00	66.42	66.43
Pennsylvania	Berks	76.00	58.57	58.63
Pennsylvania	Blair	74.30	57.20	57.28
Pennsylvania	Bucks	88.00	73.37	73.37
Pennsylvania	Cambria	74.70	58.80	58.84
Pennsylvania	Centre	78.30	61.29	61.37
Pennsylvania	Chester	86.00	65.39	65.48
Pennsylvania	Clearfield	78.30	61.50	61.54
Pennsylvania	Dauphin	79.30	63.45	63.50
Pennsylvania	Delaware	83.30	66.79	66.81
Pennsylvania	Erie	81.30	68.63	68.65
Pennsylvania	Franklin	72.30	55.39	55.49
Pennsylvania	Greene	80.00	62.27	62.30
Pennsylvania	Indiana	80.00	61.30	61.34
Pennsylvania	Lackawanna	75.30	57.70	57.79
Pennsylvania	Lancaster	83.30	64.64	64.72
Pennsylvania	Lawrence	72.30	55.73	55.76
Pennsylvania	Lehigh	83.30	64.77	64.82
Pennsylvania	Luzerne	76.30	58.61	58.71
Pennsylvania	Lycoming	77.30	61.59	61.74
Pennsylvania	Mercer	82.00	62.29	62.32
Pennsylvania	Montgomery	85.70	69.23	69.25
Pennsylvania	Northampton	84.30	65.16	65.21
Pennsylvania	Perry	77.00	59.69	59.78
Pennsylvania	Philadelphia	90.30	75.25	75.26
Pennsylvania	Tioga	77.70	62.11	62.21
Pennsylvania	Washington	78.30	61.80	61.84
Pennsylvania	Westmoreland	79.00	61.36	61.40
Pennsylvania	York	82.00	64.36	64.44
Rhode Island	Kent	84.30	69.16	69.20
Rhode Island	Providence	82.30	66.90	66.97
Rhode Island	Washington	86.00	72.74	72.78

South Carolina	Abbeville	79.00	59.15	59.29
South Carolina	Aiken	76.00	55.83	55.95
South Carolina	Anderson	76.50	55.10	55.28
South Carolina	Barnwell	73.00	53.26	53.37
South Carolina	Berkeley	67.30	52.12	52.27
South Carolina	Charleston	74.00	63.01	63.17
South Carolina	Cherokee	74.00	56.01	56.11
South Carolina	Chester	75.70	55.03	55.23
South Carolina	Chesterfield	75.00	57.05	57.17
South Carolina	Colleton	72.30	55.94	56.04
South Carolina	Darlington	76.30	58.42	58.55
South Carolina	Edgefield	70.00	52.25	52.36
South Carolina	Oconee	73.00	52.92	53.13
South Carolina	Pickens	78.70	57.21	57.39
South Carolina	Richland	82.30	58.61	58.86
South Carolina	Spartanburg	82.30	60.75	60.90
South Carolina	Union	76.00	58.78	58.90
South Carolina	Williamsburg	69.30	52.71	52.82
South Carolina	York	76.70	56.33	56.52
South Dakota	Custer	70.00	62.69	62.69
South Dakota	Jackson	67.00	59.43	59.44
South Dakota	Minnehaha	66.00	54.41	54.42
Tennessee	Anderson	77.30	55.86	55.90
Tennessee	Blount	85.30	60.51	60.57
Tennessee	Davidson	77.70	57.38	57.40
Tennessee	Hamilton	81.00	58.97	59.02
Tennessee	Jefferson	82.30	59.67	59.72
Tennessee	Knox	85.00	60.95	61.00
Tennessee	Loudon	83.00	60.13	60.18
Tennessee	Meigs	80.00	57.90	57.95
Tennessee	Rutherford	76.30	55.68	55.71
Tennessee	Sevier	80.70	60.36	60.43
Tennessee	Shelby	80.70	58.94	58.97
Tennessee	Sullivan	80.30	69.16	69.16
Tennessee	Sumner	83.00	61.82	61.86
Tennessee	Williamson	75.30	55.01	55.04
Tennessee	Wilson	78.70	58.47	58.50
Texas	Bexar	85.00	71.27	71.31
Texas	Brazoria	94.70	80.54	80.39
Texas	Brewster	64.00	54.87	54.89
Texas	Cameron	66.00	59.57	59.57
Texas	Collin	90.30	71.15	71.18
Texas	Dallas	88.30	73.63	73.66
Texas	Denton	94.00	71.00	71.05
Texas	Ellis	81.70	64.35	64.39
Texas	Galveston	80.30	70.17	70.05
Texas	Gregg	84.30	71.97	71.96
Texas	Harris	100.70	88.23	88.06
Texas	Harrison	79.00	63.31	63.32
Texas	Hidalgo	65.70	57.13	57.13
Texas	Hood	83.00	60.03	60.11
Texas	Hunt	78.00	62.83	62.84
Texas	Jefferson	84.70	73.06	72.95
Texas	Johnson	87.00	65.96	66.02

Texas	Kaufman	74.70	59.69	59.72
Texas	Montgomery	85.00	70.30	70.24
Texas	Nueces	72.30	63.26	63.25
Texas	Orange	78.00	65.65	65.54
Texas	Parker	88.70	64.23	64.30
Texas	Rockwall	79.70	64.29	64.32
Texas	Smith	81.00	67.68	67.68
Texas	Tarrant	95.30	72.45	72.50
Texas	Travis	81.30	65.57	65.63
Texas	Victoria	72.30	62.12	62.07
Texas	Webb	61.30	53.70	53.68
Texas	El Paso	77.70	64.98	65.02
Utah	Box Elder	76.00	65.44	65.48
Utah	Cache	68.70	58.73	58.79
Utah	Davis	81.30	69.94	69.98
Utah	Salt Lake	81.00	69.42	69.46
Utah	San Juan	70.30	62.60	62.62
Utah	Tooele	78.00	65.58	65.63
Utah	Utah	76.70	69.40	69.43
Utah	Washington	78.50	64.53	64.54
Utah	Weber	80.30	68.68	68.73
Vermont	Bennington	72.00	56.33	56.39
Vermont	Chittenden	69.70	57.57	57.66
Virginia	Arlington	86.70	70.80	70.90
Virginia	Caroline	80.00	59.66	59.76
Virginia	Charles City	80.30	65.43	65.48
Virginia	Chesterfield	76.70	61.41	61.49
Virginia	Fairfax	90.00	71.19	71.30
Virginia	Fauquier	72.70	56.47	56.55
Virginia	Frederick	72.30	56.38	56.47
Virginia	Hanover	81.30	63.37	63.47
Virginia	Henrico	82.00	65.02	65.08
Virginia	Loudoun	80.70	60.81	60.92
Virginia	Madison	77.70	61.03	61.11
Virginia	Page	74.00	57.96	58.04
Virginia	Prince William	78.70	60.78	60.87
Virginia	Roanoke	74.70	58.05	58.16
Virginia	Rockbridge	69.70	56.44	56.50
Virginia	Stafford	81.70	62.52	62.61
Virginia	Wythe	72.70	57.76	57.83
Virginia	Alexandria City	81.70	64.62	64.72
Virginia	Hampton City	76.70	67.99	68.02
Virginia	Suffolk City	76.70	71.64	71.66
Washington	Clark	59.50	60.99	60.99
Washington	King	72.30	66.81	66.78
Washington	Klickitat	64.50	58.02	58.04
Washington	Pierce	68.70	61.53	61.51
Washington	Skagit	46.00	45.94	45.93
Washington	Spokane	68.30	55.77	55.81
Washington	Thurston	65.00	56.03	56.05
Washington	Whatcom	57.00	55.79	55.81
West Virginia	Berkeley	75.00	58.60	58.69
West Virginia	Cabell	78.70	64.31	64.21
West Virginia	Greenbrier	69.70	57.31	57.31

West Virginia	Hancock	75.70	60.17	60.19
West Virginia	Kanawha	77.30	61.53	61.55
West Virginia	Monongalia	75.30	57.03	57.08
West Virginia	Ohio	78.30	62.29	62.30
West Virginia	Wood	79.00	63.28	63.30
Wisconsin	Ashland	61.50	51.68	51.68
Wisconsin	Brown	73.70	61.42	61.40
Wisconsin	Columbia	72.70	57.64	57.64
Wisconsin	Dane	72.00	57.79	57.79
Wisconsin	Dodge	74.70	60.55	60.54
Wisconsin	Door	88.70	72.01	71.96
Wisconsin	Florence	66.30	55.01	55.02
Wisconsin	Fond Du Lac	73.70	60.79	60.77
Wisconsin	Forest	69.50	57.69	57.69
Wisconsin	Jefferson	74.30	59.34	59.34
Wisconsin	Kenosha	84.70	75.11	75.06
Wisconsin	Kewaunee	82.70	68.15	68.10
Wisconsin	Manitowoc	85.00	70.80	70.75
Wisconsin	Marathon	70.00	58.52	58.52
Wisconsin	Milwaukee	82.70	70.97	70.92
Wisconsin	Oneida	69.00	57.89	57.90
Wisconsin	Outagamie	74.00	60.72	60.71
Wisconsin	Ozaukee	83.30	71.82	71.76
Wisconsin	Racine	80.30	70.19	70.15
Wisconsin	Rock	74.00	59.40	59.39
Wisconsin	St Croix	69.00	56.81	56.80
Wisconsin	Sauk	69.70	56.22	56.22
Wisconsin	Sheboygan	88.00	73.81	73.75
Wisconsin	Vernon	69.70	55.62	55.62
Wisconsin	Vilas	68.70	57.33	57.34
Wisconsin	Walworth	75.70	60.32	60.30
Wisconsin	Washington	72.30	59.91	59.89
Wisconsin	Waukesha	75.00	62.21	62.18
Wyoming	Campbell	67.30	63.38	63.39
Wyoming	Sublette	70.00	63.41	63.42
Wyoming	Teton	62.70	55.86	55.87

Appendix B: Annual $PM_{2.5}$ Design Values for LDGHG Scenarios (units are ug/m^3)

State Name	County Name	Baseline DV	2030 Reference Case DV	2030 Control Case DV
Alabama	Clay	13.21	10.25	10.25
Alabama	Colbert	12.67	9.88	9.88
Alabama	DeKalb	14.09	10.67	10.67
Alabama	Etowah	14.80	11.26	11.26
Alabama	Houston	12.86	10.78	10.78
Alabama	Jefferson	18.48	14.62	14.62
Alabama	Madison	13.73	10.58	10.58
Alabama	Montgomery	14.14	11.78	11.78
Alabama	Morgan	13.23	10.44	10.44
Alabama	Russell	15.63	12.46	12.46
Alabama	Shelby	14.28	11.10	11.10
Alabama	Sumter	11.92	9.64	9.64
Alabama	Talladega	14.51	11.00	11.00
Alabama	Walker	13.77	10.71	10.71
Alabama	Baldwin	11.44	9.47	9.46
Alabama	Escambia	13.12	11.15	11.14
Alabama	Mobile	12.90	10.59	10.58
Alabama	Tuscaloosa	13.44	10.61	10.60
Arizona	Maricopa	12.59	11.01	11.02
Arizona	Cochise	7.00	6.91	6.91
Arizona	Coconino	6.49	6.27	6.27
Arizona	Gila	8.94	8.58	8.58
Arizona	Pima	6.04	5.50	5.50
Arizona	Pinal	7.77	7.42	7.42
Arizona	Santa Cruz	12.94	12.56	12.56
Arkansas	Arkansas	12.45	10.46	10.46
Arkansas	Ashley	12.83	11.14	11.14
Arkansas	Garland	12.40	10.44	10.44
Arkansas	Mississippi	12.61	10.06	10.06
Arkansas	Phillips	12.08	9.81	9.81
Arkansas	Polk	11.65	9.88	9.88
Arkansas	Pope	12.79	10.90	10.90
Arkansas	Pulaski	14.05	11.57	11.57
Arkansas	Crittenden	13.27	10.39	10.38
Arkansas	White	12.57	10.60	10.59
Arkansas	Faulkner	12.79	10.71	10.70
Arkansas	Union	12.86	11.12	11.10
California	Alameda	9.34	10.24	10.24
California	Colusa	7.39	7.24	7.24
California	Fresno	17.17	15.90	15.90
California	Imperial	12.71	12.74	12.74
California	Inyo	5.25	5.21	5.21
California	Kings	17.28	16.12	16.12
California	Lake	4.62	4.66	4.66
California	Mendocino	6.46	6.28	6.28
California	Monterey	6.96	7.25	7.25

California	Nevada	6.71	6.32	6.32
California	Placer	9.80	9.11	9.11
California	San Diego	13.38	15.73	15.73
California	San Francisco	9.62	10.80	10.80
California	San Luis Obispo	7.94	8.07	8.07
California	San Mateo	9.03	10.15	10.15
California	Santa Barbara	10.37	10.33	10.33
California	Santa Clara	11.38	12.30	12.30
California	Shasta	7.41	6.63	6.63
California	Sonoma	8.21	8.42	8.42
California	Sutter	9.85	9.10	9.10
California	Yolo	9.03	8.66	8.66
California	Kern	19.17	17.33	17.32
California	Butte	12.73	11.45	11.44
California	Merced	14.78	14.00	13.99
California	Plumas	11.46	10.62	10.61
California	Sacramento	11.88	11.34	11.33
California	San Joaquin	12.94	12.65	12.64
California	Ventura	11.68	12.60	12.59
California	Calaveras	7.77	7.40	7.39
California	Stanislaus	14.21	13.30	13.29
California	Tulare	18.51	17.28	17.27
California	Contra Costa	9.47	9.87	9.85
California	Riverside	20.95	20.77	20.75
California	Solano	9.99	10.41	10.39
California	Orange	15.75	16.50	16.47
California	San Bernardino	19.67	19.82	19.79
California	Los Angeles	17.66	18.69	18.63
Colorado	Mesa	9.28	8.49	8.50
Colorado	Arapahoe	7.96	6.94	6.94
Colorado	Boulder	8.32	7.41	7.41
Colorado	Delta	7.44	6.67	6.67
Colorado	Denver	9.76	8.34	8.34
Colorado	Elbert	4.40	4.05	4.05
Colorado	El Paso	7.94	7.09	7.09
Colorado	Larimer	7.33	6.74	6.74
Colorado	Pueblo	7.45	6.76	6.76
Colorado	San Miguel	4.65	4.44	4.44
Colorado	Weld	8.78	7.77	7.77
Colorado	Adams	10.06	8.61	8.60
Connecticut	Fairfield	13.18	11.64	11.64
Connecticut	Hartford	11.03	9.59	9.59
Connecticut	Litchfield	8.01	7.05	7.05
Connecticut	New Haven	13.12	11.35	11.35
Connecticut	New London	10.96	9.58	9.58
Delaware	Sussex	13.39	11.01	11.01
Delaware	Kent	12.61	10.34	10.33
Delaware	New Castle	14.87	12.20	12.19
District Of Columbia	District of Columbia	14.41	11.11	11.11
Florida	Hillsborough	10.74	8.67	8.68
Florida	Alachua	9.59	8.00	8.00
Florida	Bay	11.46	9.65	9.65
Florida	Brevard	8.32	7.37	7.37
Florida	Broward	8.21	8.20	8.20

Florida	Citrus	9.00	7.30	7.30
Florida	Duval	10.44	8.92	8.92
Florida	Escambia	11.72	9.83	9.83
Florida	Lee	8.36	7.39	7.39
Florida	Leon	12.56	10.54	10.54
Florida	Manatee	8.81	7.16	7.16
Florida	Marion	10.11	8.43	8.43
Florida	Miami-Dade	9.45	9.39	9.39
Florida	Orange	9.61	8.07	8.07
Florida	Palm Beach	7.70	7.41	7.41
Florida	Pinellas	9.82	8.02	8.02
Florida	Polk	9.55	7.91	7.91
Florida	St. Lucie	8.34	7.57	7.57
Florida	Sarasota	8.77	7.34	7.34
Florida	Seminole	9.51	7.99	7.99
Florida	Volusia	9.27	7.93	7.93
Georgia	Clarke	14.90	11.67	11.68
Georgia	Cobb	16.09	12.06	12.07
Georgia	Bibb	16.47	13.10	13.10
Georgia	Chatham	13.88	12.37	12.37
Georgia	Clayton	16.47	12.01	12.01
Georgia	DeKalb	15.33	11.15	11.15
Georgia	Dougherty	14.35	11.94	11.94
Georgia	Floyd	16.10	12.38	12.38
Georgia	Fulton	17.43	12.81	12.81
Georgia	Glynn	12.18	10.59	10.59
Georgia	Gwinnett	16.07	12.04	12.04
Georgia	Hall	14.12	10.88	10.88
Georgia	Houston	13.99	11.09	11.09
Georgia	Lowndes	12.49	10.68	10.68
Georgia	Muscogee	15.16	12.07	12.07
Georgia	Paulding	14.08	10.25	10.25
Georgia	Richmond	15.68	12.93	12.93
Georgia	Walker	15.49	11.89	11.89
Georgia	Washington	15.14	12.37	12.37
Georgia	Wilkinson	15.23	12.16	12.16
Idaho	Idaho	9.58	9.18	9.19
Idaho	Ada	8.41	7.76	7.76
Idaho	Bannock	7.66	7.14	7.14
Idaho	Benewah	9.59	9.11	9.11
Idaho	Canyon	8.46	7.62	7.62
Idaho	Franklin	7.70	6.97	6.97
Idaho	Shoshone	12.08	11.38	11.38
Illinois	Adams	12.50	10.30	10.30
Illinois	Cook	15.75	12.52	12.52
Illinois	Kane	14.34	11.66	11.66
Illinois	Lake	11.81	9.82	9.82
Illinois	McLean	12.39	10.08	10.08
Illinois	Macon	13.24	10.76	10.76
Illinois	Winnebago	13.57	11.15	11.15
Illinois	Champaign	12.53	10.08	10.07
Illinois	DuPage	13.82	11.25	11.24
Illinois	McHenry	12.40	10.15	10.14
Illinois	Madison	16.72	13.31	13.30

Illinois	Peoria	13.34	10.93	10.92
Illinois	Randolph	13.11	10.48	10.47
Illinois	Rock Island	12.01	9.86	9.85
Illinois	Sangamon	13.13	10.96	10.95
Illinois	Jersey	12.89	10.51	10.49
Illinois	Saint Clair	15.58	12.40	12.38
Illinois	Will	13.63	11.10	11.08
Indiana	Allen	13.67	11.14	11.14
Indiana	Clark	16.40	12.58	12.58
Indiana	Dubois	15.18	11.46	11.46
Indiana	Floyd	14.80	11.28	11.28
Indiana	Henry	13.64	10.72	10.72
Indiana	Howard	13.93	11.15	11.15
Indiana	Knox	14.03	10.60	10.60
Indiana	LaPorte	12.69	10.24	10.24
Indiana	Madison	13.96	10.93	10.93
Indiana	Marion	16.05	12.40	12.40
Indiana	St. Joseph	13.69	11.33	11.33
Indiana	Spencer	14.32	10.59	10.59
Indiana	Tippecanoe	13.69	10.91	10.91
Indiana	Vanderburgh	14.99	11.71	11.71
Indiana	Delaware	13.66	10.79	10.78
Indiana	Lake	14.27	11.50	11.49
Indiana	Porter	13.21	10.53	10.52
Indiana	Vigo	13.99	10.82	10.81
Iowa	Black Hawk	11.16	9.35	9.35
Iowa	Clinton	12.52	10.30	10.30
Iowa	Johnson	12.08	10.13	10.13
Iowa	Linn	10.79	9.06	9.06
Iowa	Montgomery	10.02	8.37	8.37
Iowa	Muscatine	12.92	10.79	10.79
Iowa	Palo Alto	9.53	8.00	8.00
Iowa	Polk	10.64	8.74	8.74
Iowa	Pottawattamie	11.13	9.18	9.18
Iowa	Scott	14.42	11.93	11.93
Iowa	Van Buren	10.84	9.06	9.06
Iowa	Woodbury	10.32	8.67	8.67
Iowa	Wright	10.37	8.68	8.68
Kansas	Johnson	11.10	9.21	9.21
Kansas	Shawnee	10.93	9.37	9.37
Kansas	Wyandotte	12.73	10.54	10.54
Kansas	Linn	10.47	8.93	8.92
Kansas	Sedgwick	10.36	8.77	8.76
Kansas	Sumner	9.89	8.48	8.47
Kentucky	Bell	14.28	10.82	10.82
Kentucky	Bullitt	14.90	11.22	11.22
Kentucky	Campbell	13.67	9.81	9.81
Kentucky	Carter	12.22	8.77	8.77
Kentucky	Fayette	14.85	11.09	11.09
Kentucky	Franklin	13.37	9.76	9.76
Kentucky	Hardin	13.58	10.03	10.03
Kentucky	Henderson	13.93	10.54	10.54
Kentucky	Jefferson	15.53	11.85	11.85
Kentucky	Kenton	14.36	10.45	10.45

Kentucky	Laurel	12.55	9.26	9.26
Kentucky	McCracken	13.38	10.36	10.36
Kentucky	Madison	13.61	9.94	9.94
Kentucky	Warren	13.83	10.32	10.32
Kentucky	Boyd	14.49	10.77	10.76
Kentucky	Christian	13.20	9.98	9.97
Kentucky	Perry	13.06	9.79	9.78
Kentucky	Pike	13.46	9.90	9.89
Kentucky	Daviess	14.10	10.38	10.37
Louisiana	Caddo	12.53	10.62	10.61
Louisiana	Concordia	11.42	9.58	9.57
Louisiana	Ouachita	11.97	10.31	10.30
Louisiana	Rapides	11.03	9.50	9.49
Louisiana	Terrebonne	10.74	9.33	9.32
Louisiana	Lafayette	11.08	9.55	9.54
Louisiana	West Baton Rouge	13.51	11.34	11.32
Louisiana	Tangipahoa	12.03	10.14	10.12
Louisiana	Iberville	12.90	11.08	11.05
Louisiana	East Baton Rouge	13.38	11.23	11.20
Louisiana	Jefferson	11.52	9.85	9.81
Louisiana	Calcasieu	11.07	9.81	9.75
Maine	Androscoggin	9.90	8.85	8.86
Maine	Aroostook	9.74	9.44	9.44
Maine	Cumberland	11.13	9.87	9.87
Maine	Hancock	5.76	5.35	5.35
Maine	Kennebec	9.99	8.91	8.91
Maine	Oxford	10.13	9.25	9.25
Maine	Penobscot	9.12	8.23	8.23
Maryland	Anne Arundel	14.82	11.87	11.87
Maryland	Baltimore	14.76	11.68	11.68
Maryland	Harford	12.51	9.72	9.72
Maryland	Montgomery	12.47	9.59	9.59
Maryland	Washington	13.70	10.41	10.41
Maryland	Baltimore (City)	15.76	12.51	12.51
Maryland	Cecil	12.68	10.06	10.05
Maryland	Prince George's	13.03	10.13	10.12
Massachusetts	Suffolk	13.07	11.22	11.23
Massachusetts	Berkshire	10.65	9.88	9.88
Massachusetts	Bristol	9.58	8.26	8.26
Massachusetts	Essex	9.58	8.24	8.24
Massachusetts	Hampden	12.17	10.69	10.69
Massachusetts	Plymouth	9.87	8.51	8.51
Massachusetts	Worcester	11.29	9.72	9.72
Michigan	Allegan	11.84	9.64	9.64
Michigan	Bay	10.93	8.94	8.94
Michigan	Berrien	11.72	9.57	9.57
Michigan	Genesee	11.61	9.33	9.33
Michigan	Ingham	12.23	9.82	9.82
Michigan	Kalamazoo	12.84	10.40	10.40
Michigan	Kent	12.89	10.25	10.25
Michigan	Macomb	12.70	10.34	10.34
Michigan	Missaukee	8.26	7.10	7.10
Michigan	Monroe	13.92	11.02	11.02
Michigan	Muskegon	11.61	9.55	9.55

Michigan	Oakland	13.78	11.02	11.02
Michigan	Ottawa	12.55	10.02	10.02
Michigan	Saginaw	10.61	8.68	8.68
Michigan	St. Clair	13.34	11.35	11.35
Michigan	Washtenaw	13.88	10.99	10.99
Michigan	Wayne	17.50	14.18	14.18
Minnesota	Cass	5.70	5.13	5.13
Minnesota	Dakota	9.30	7.84	7.84
Minnesota	Hennepin	9.76	8.15	8.15
Minnesota	Mille Lacs	6.54	5.73	5.73
Minnesota	Olmsted	10.13	8.56	8.56
Minnesota	Ramsey	11.32	9.56	9.56
Minnesota	Saint Louis	7.51	6.55	6.55
Minnesota	Scott	9.00	7.61	7.61
Minnesota	Stearns	8.58	7.40	7.40
Mississippi	Bolivar	12.36	10.43	10.43
Mississippi	DeSoto	12.43	9.76	9.76
Mississippi	Warren	12.32	10.11	10.11
Mississippi	Adams	11.29	9.44	9.43
Mississippi	Forrest	13.62	11.32	11.31
Mississippi	Harrison	12.20	10.42	10.41
Mississippi	Hinds	12.56	10.39	10.38
Mississippi	Jones	14.39	11.90	11.89
Mississippi	Lauderdale	13.07	10.58	10.57
Mississippi	Lowndes	12.79	10.24	10.23
Mississippi	Pearl River	12.14	10.28	10.27
Mississippi	Lee	12.57	9.88	9.87
Mississippi	Jackson	12.04	10.01	9.98
Missouri	Boone	11.84	10.03	10.03
Missouri	Buchanan	12.80	10.84	10.84
Missouri	Cass	10.67	8.87	8.87
Missouri	Cedar	11.12	9.46	9.46
Missouri	Clay	11.03	9.27	9.27
Missouri	Greene	11.75	9.83	9.83
Missouri	Jackson	12.78	10.52	10.52
Missouri	Monroe	10.87	8.95	8.95
Missouri	Sainte Genevieve	13.34	10.84	10.84
Missouri	Saint Louis	13.46	10.67	10.67
Missouri	Jefferson	13.79	11.10	11.09
Missouri	St. Louis City	14.56	11.58	11.56
Missouri	Saint Charles	13.29	10.80	10.75
Montana	Cascade	5.57	5.15	5.15
Montana	Flathead	9.87	8.97	8.97
Montana	Gallatin	4.25	4.15	4.15
Montana	Lake	9.06	8.35	8.35
Montana	Lewis and Clark	7.96	7.41	7.41
Montana	Lincoln	14.93	13.47	13.47
Montana	Missoula	10.20	9.34	9.34
Montana	Ravalli	8.56	7.92	7.92
Montana	Sanders	6.69	6.33	6.33
Montana	Silver Bow	9.86	9.06	9.06
Montana	Rosebud	6.58	6.38	6.37
Montana	Yellowstone	8.14	7.45	7.44
Nebraska	Cass	9.99	8.31	8.31

Nebraska	Douglas	9.88	8.12	8.12
Nebraska	Hall	7.95	6.85	6.85
Nebraska	Lancaster	8.90	7.29	7.29
Nebraska	Lincoln	7.57	6.73	6.73
Nebraska	Sarpy	9.79	8.04	8.04
Nebraska	Scotts Bluff	6.04	5.49	5.49
Nebraska	Washington	9.29	7.73	7.73
Nevada	Clark	9.44	8.90	8.91
Nevada	Washoe	8.11	7.33	7.34
New Hampshire	Hillsborough	10.18	8.64	8.65
New Hampshire	Rockingham	9.00	7.78	7.79
New Hampshire	Belknap	7.28	6.36	6.36
New Hampshire	Cheshire	11.53	10.08	10.08
New Hampshire	Coos	10.24	9.53	9.53
New Hampshire	Grafton	8.43	7.45	7.45
New Hampshire	Merrimack	9.72	8.26	8.26
New Hampshire	Sullivan	9.86	8.69	8.69
New Jersey	Atlantic	11.47	9.92	9.92
New Jersey	Bergen	13.09	10.83	10.83
New Jersey	Essex	13.27	11.04	11.04
New Jersey	Hudson	14.24	12.10	12.10
New Jersey	Morris	11.50	9.48	9.48
New Jersey	Ocean	10.92	9.20	9.20
New Jersey	Passaic	12.88	10.57	10.57
New Jersey	Union	14.94	12.35	12.35
New Jersey	Warren	12.72	10.32	10.32
New Jersey	Camden	13.51	11.03	11.02
New Jersey	Mercer	12.71	10.39	10.38
New Jersey	Middlesex	12.15	10.03	10.02
New Jersey	Gloucester	13.46	11.11	11.09
New Mexico	Bernalillo	7.03	6.06	6.06
New Mexico	Grant	5.93	5.73	5.73
New Mexico	Sandoval	7.99	7.49	7.49
New Mexico	San Juan	5.92	5.65	5.65
New Mexico	Santa Fe	4.76	4.46	4.46
New Mexico	Chaves	6.54	6.16	6.15
New Mexico	Dona Ana	9.95	8.89	8.88
New York	Kings	14.20	12.29	12.30
New York	New York	16.18	13.71	13.72
New York	Queens	12.18	10.31	10.32
New York	Albany	11.83	10.55	10.55
New York	Bronx	15.43	12.98	12.98
New York	Chautauqua	9.80	7.59	7.59
New York	Erie	12.62	10.23	10.23
New York	Monroe	10.64	8.93	8.93
New York	Nassau	11.66	10.15	10.15
New York	Niagara	11.96	10.01	10.01
New York	Onondaga	10.08	9.66	9.66
New York	Orange	10.99	9.37	9.37
New York	Richmond	13.31	11.14	11.14
New York	St. Lawrence	7.29	6.57	6.57
New York	Steuben	9.00	7.13	7.13
New York	Suffolk	11.52	9.94	9.94
New York	Westchester	11.73	10.05	10.05

New York	Essex	5.94	5.24	5.23
North Carolina	Alamance	13.94	10.60	10.60
North Carolina	Buncombe	12.60	9.63	9.63
North Carolina	Caswell	13.19	9.85	9.85
North Carolina	Catawba	15.31	11.34	11.34
North Carolina	Cumberland	13.73	11.12	11.12
North Carolina	Davidson	15.17	11.53	11.53
North Carolina	Duplin	11.30	9.42	9.42
North Carolina	Durham	13.57	11.12	11.12
North Carolina	Edgecombe	12.37	10.12	10.12
North Carolina	Forsyth	14.28	10.52	10.52
North Carolina	Gaston	14.26	10.83	10.83
North Carolina	Guilford	13.79	10.47	10.47
North Carolina	Haywood	12.98	10.29	10.29
North Carolina	Jackson	12.09	9.24	9.24
North Carolina	Lenoir	11.12	9.21	9.21
North Carolina	McDowell	14.24	10.92	10.92
North Carolina	Martin	10.86	8.85	8.85
North Carolina	Mecklenburg	15.31	12.37	12.37
North Carolina	Mitchell	12.75	9.63	9.63
North Carolina	New Hanover	9.96	8.35	8.35
North Carolina	Onslow	10.98	9.10	9.10
North Carolina	Orange	13.12	10.20	10.20
North Carolina	Pitt	11.59	9.56	9.56
North Carolina	Robeson	12.78	10.67	10.67
North Carolina	Rowan	14.02	10.75	10.75
North Carolina	Swain	12.65	9.66	9.66
North Carolina	Wake	13.54	11.24	11.24
North Carolina	Watauga	12.05	8.85	8.85
North Carolina	Chatham	11.99	9.23	9.22
North Carolina	Montgomery	12.24	9.44	9.43
North Carolina	Wayne	12.96	10.87	10.86
North Dakota	Billings	4.61	4.31	4.31
North Dakota	Burke	5.90	5.70	5.70
North Dakota	Cass	7.72	6.76	6.76
North Dakota	McKenzie	5.01	4.72	4.72
North Dakota	Mercer	6.04	5.30	5.30
North Dakota	Burleigh	6.61	5.92	5.87
Ohio	Cuyahoga	17.37	13.38	13.39
Ohio	Butler	15.36	11.86	11.86
Ohio	Clark	14.64	11.38	11.38
Ohio	Clermont	14.15	10.31	10.31
Ohio	Franklin	15.27	11.52	11.52
Ohio	Greene	13.36	10.12	10.12
Ohio	Hamilton	17.54	12.97	12.97
Ohio	Lake	13.02	10.23	10.23
Ohio	Lorain	13.87	10.68	10.68
Ohio	Mahoning	15.12	11.50	11.50
Ohio	Montgomery	15.54	11.95	11.95
Ohio	Portage	13.37	10.26	10.26
Ohio	Preble	13.70	10.66	10.66
Ohio	Stark	16.15	12.34	12.34
Ohio	Summit	15.17	11.80	11.80
Ohio	Trumbull	14.53	11.17	11.17

Ohio	Athens	12.39	8.83	8.82
Ohio	Jefferson	16.51	12.02	12.01
Ohio	Lawrence	15.14	11.44	11.43
Ohio	Lucas	14.38	11.40	11.39
Ohio	Scioto	14.65	10.69	10.68
Oklahoma	Caddo	9.22	7.95	7.95
Oklahoma	Cherokee	11.79	10.01	10.01
Oklahoma	Muskogee	11.89	10.17	10.17
Oklahoma	Pittsburg	11.06	9.41	9.41
Oklahoma	Sequoyah	12.99	11.13	11.13
Oklahoma	Tulsa	11.52	9.80	9.80
Oklahoma	Lincoln	10.28	8.79	8.78
Oklahoma	Mayes	11.70	10.11	10.10
Oklahoma	Oklahoma	10.07	8.35	8.34
Oklahoma	Ottawa	11.69	10.02	10.01
Oklahoma	Kay	10.26	9.08	9.06
Oregon	Multnomah	9.13	8.59	8.60
Oregon	Jackson	10.32	9.88	9.88
Oregon	Klamath	11.20	10.55	10.55
Oregon	Lane	11.93	11.38	11.38
Oregon	Union	8.35	7.80	7.80
Pennsylvania	Adams	13.05	9.84	9.84
Pennsylvania	Allegheny	20.31	15.00	15.00
Pennsylvania	Beaver	16.38	12.42	12.42
Pennsylvania	Berks	15.82	12.67	12.67
Pennsylvania	Bucks	13.42	10.88	10.88
Pennsylvania	Cambria	15.40	10.92	10.92
Pennsylvania	Cumberland	14.45	11.05	11.05
Pennsylvania	Dauphin	15.13	11.32	11.32
Pennsylvania	Erie	12.54	9.86	9.86
Pennsylvania	Lackawanna	11.73	9.27	9.27
Pennsylvania	Lancaster	16.55	12.87	12.87
Pennsylvania	Lehigh	14.50	11.76	11.76
Pennsylvania	Luzerne	12.76	10.16	10.16
Pennsylvania	Mercer	13.28	9.98	9.98
Pennsylvania	Northampton	13.68	11.05	11.05
Pennsylvania	Washington	15.17	10.69	10.69
Pennsylvania	Westmoreland	15.49	10.80	10.80
Pennsylvania	York	16.52	12.64	12.64
Pennsylvania	Centre	12.78	9.60	9.59
Pennsylvania	Perry	12.81	9.83	9.82
Pennsylvania	Chester	15.22	12.13	12.12
Pennsylvania	Delaware	15.23	12.60	12.58
Pennsylvania	Philadelphia	15.19	12.42	12.40
Rhode Island	Providence	12.14	10.51	10.51
South Carolina	Beaufort	11.52	10.03	10.03
South Carolina	Charleston	12.21	10.11	10.11
South Carolina	Edgefield	13.14	10.55	10.55
South Carolina	Florence	12.62	10.21	10.21
South Carolina	Georgetown	12.85	10.91	10.91
South Carolina	Greenville	15.65	11.98	11.98
South Carolina	Greenwood	13.53	10.57	10.57
South Carolina	Horry	12.00	9.93	9.93
South Carolina	Lexington	14.64	11.52	11.52

South Carolina	Richland	14.24	11.13	11.13
South Carolina	Spartanburg	14.17	10.70	10.70
South Carolina	Chesterfield	12.53	10.04	10.03
South Carolina	Oconee	10.95	8.13	8.12
South Dakota	Brookings	9.37	8.07	8.07
South Dakota	Brown	8.42	7.45	7.45
South Dakota	Codington	10.14	8.89	8.89
South Dakota	Custer	5.64	5.40	5.40
South Dakota	Jackson	5.39	5.08	5.08
South Dakota	Minnehaha	10.18	8.60	8.60
South Dakota	Pennington	8.77	8.26	8.26
Tennessee	Blount	14.30	10.87	10.87
Tennessee	Davidson	14.18	10.73	10.73
Tennessee	Hamilton	15.48	11.84	11.84
Tennessee	Knox	15.64	11.72	11.72
Tennessee	Lawrence	11.69	9.13	9.13
Tennessee	Loudon	15.49	11.81	11.81
Tennessee	McMinn	14.29	10.84	10.84
Tennessee	Montgomery	13.79	10.68	10.68
Tennessee	Putnam	13.37	10.00	10.00
Tennessee	Roane	14.49	10.79	10.79
Tennessee	Shelby	13.71	10.65	10.65
Tennessee	Sullivan	14.16	11.09	11.09
Tennessee	Sumner	13.68	10.11	10.11
Tennessee	Dyer	12.28	9.65	9.64
Tennessee	Maury	13.21	10.46	10.45
Texas	Dallas	11.80	9.49	9.49
Texas	El Paso	9.09	8.03	8.03
Texas	Hidalgo	10.98	10.08	10.08
Texas	Tarrant	12.23	9.84	9.84
Texas	Bowie	12.85	10.82	10.81
Texas	Harrison	11.69	9.89	9.88
Texas	Ector	7.78	6.90	6.89
Texas	Nueces	10.42	9.06	9.04
Texas	Orange	11.51	10.29	10.26
Texas	Jefferson	11.51	10.16	10.11
Texas	Harris	15.42	13.44	13.37
Utah	Box Elder	8.40	7.51	7.52
Utah	Weber	11.16	9.91	9.92
Utah	Cache	11.56	10.21	10.21
Utah	Salt Lake	11.98	10.61	10.61
Utah	Utah	10.51	9.41	9.41
Utah	Davis	10.31	9.56	9.55
Vermont	Chittenden	10.02	9.00	9.01
Vermont	Addison	8.94	8.10	8.10
Vermont	Bennington	8.52	7.70	7.70
Vermont	Rutland	11.08	9.96	9.96
Virginia	Arlington	14.27	11.02	11.02
Virginia	Charles	12.37	9.36	9.36
Virginia	Fairfax	13.88	10.75	10.75
Virginia	Henrico	13.51	10.09	10.09
Virginia	Loudoun	13.57	10.39	10.39
Virginia	Page	12.79	9.39	9.39
Virginia	Bristol City	13.93	10.52	10.52

Virginia	Hampton City	12.17	9.71	9.71
Virginia	Lynchburg City	12.84	9.55	9.55
Virginia	Norfolk City	12.78	10.24	10.24
Virginia	Roanoke City	14.27	10.58	10.58
Virginia	Salem City	14.69	11.04	11.04
Virginia	Virginia Beach City	12.40	10.04	10.04
Virginia	Chesterfield	13.44	10.13	10.12
Washington	King	11.24	10.72	10.73
Washington	Pierce	10.55	9.93	9.93
Washington	Snohomish	9.91	9.63	9.63
Washington	Spokane	9.97	8.51	8.51
West Virginia	Berkeley	15.93	12.30	12.30
West Virginia	Brooke	16.52	12.04	12.04
West Virginia	Hancock	15.76	11.56	11.56
West Virginia	Harrison	13.99	10.19	10.19
West Virginia	Marion	15.03	10.87	10.87
West Virginia	Monongalia	14.35	9.85	9.85
West Virginia	Ohio	14.58	10.14	10.14
West Virginia	Raleigh	12.90	9.52	9.52
West Virginia	Wood	15.40	11.45	11.45
West Virginia	Cabell	16.30	12.37	12.36
West Virginia	Kanawha	16.52	12.18	12.17
West Virginia	Marshall	15.19	10.72	10.71
Wisconsin	Dane	12.20	10.47	10.48
Wisconsin	Milwaukee	14.08	11.89	11.90
Wisconsin	Outagamie	10.96	9.53	9.54
Wisconsin	Ashland	6.07	5.40	5.40
Wisconsin	Brown	11.39	9.94	9.94
Wisconsin	Dodge	11.04	9.33	9.33
Wisconsin	Forest	7.41	6.53	6.53
Wisconsin	Grant	11.79	9.99	9.99
Wisconsin	Kenosha	11.98	10.00	10.00
Wisconsin	Manitowoc	10.20	8.86	8.86
Wisconsin	Ozaukee	11.60	9.85	9.85
Wisconsin	St. Croix	10.09	8.60	8.60
Wisconsin	Sauk	10.22	8.58	8.58
Wisconsin	Taylor	8.24	7.19	7.19
Wisconsin	Vilas	6.78	5.99	5.99
Wisconsin	Waukesha	13.91	11.87	11.87
Wyoming	Campbell	6.29	6.10	6.10
Wyoming	Converse	3.52	3.40	3.40
Wyoming	Fremont	8.17	7.61	7.61
Wyoming	Laramie	4.48	4.10	4.10
Wyoming	Sheridan	9.70	9.05	9.05

Appendix C: 24-hour $PM_{2.5}$ Design Values for LDGHG Scenarios (units are ug/m^3)

State Name	County Name	Baseline DV	2030 Reference Case DV	2030 Control Case DV
Alabama	Baldwin	26.20	20.80	20.80
Alabama	Clay	31.80	22.07	22.07
Alabama	Colbert	30.40	20.24	20.24
Alabama	DeKalb	32.00	21.30	21.29
Alabama	Escambia	29.00	22.35	22.35
Alabama	Etowah	35.10	22.06	22.06
Alabama	Houston	28.60	22.02	22.02
Alabama	Jefferson	44.00	33.06	33.06
Alabama	Madison	33.50	21.80	21.80
Alabama	Mobile	30.00	22.16	22.15
Alabama	Montgomery	32.00	23.97	23.97
Alabama	Morgan	31.50	18.97	18.97
Alabama	Russell	35.50	28.05	28.05
Alabama	Shelby	32.00	22.02	22.02
Alabama	Sumter	28.90	20.26	20.26
Alabama	Talladega	33.40	22.41	22.41
Alabama	Tuscaloosa	29.80	21.54	21.53
Alabama	Walker	32.80	21.70	21.70
Arizona	Cochise	16.60	16.38	16.37
Arizona	Coconino	17.10	16.59	16.59
Arizona	Gila	22.10	21.09	21.09
Arizona	Maricopa	31.40	27.23	27.25
Arizona	Pima	12.20	10.88	10.88
Arizona	Pinal	17.50	15.42	15.43
Arizona	Santa Cruz	36.00	34.33	34.34
Arkansas	Arkansas	29.10	21.93	21.93
Arkansas	Ashley	28.90	23.21	23.20
Arkansas	Crittenden	35.00	22.79	22.79
Arkansas	Faulkner	29.80	23.33	23.33
Arkansas	Garland	29.20	22.41	22.40
Arkansas	Mississippi	30.30	22.92	22.92
Arkansas	Phillips	29.10	21.79	21.78
Arkansas	Polk	26.10	19.02	19.02
Arkansas	Pope	28.30	24.34	24.34
Arkansas	Pulaski	31.90	25.84	25.84
Arkansas	Union	28.70	23.38	23.26
Arkansas	White	29.90	22.79	22.79
California	Alameda	32.50	28.25	28.24
California	Butte	52.50	41.83	41.83
California	Calaveras	20.50	16.97	16.96
California	Colusa	26.10	23.63	23.63
California	Contra Costa	34.70	31.22	31.22
California	Fresno	60.20	49.22	49.21
California	Imperial	40.20	36.78	36.78
California	Inyo	16.60	15.81	15.84
California	Kern	64.50	53.63	53.60
California	Kings	58.00	48.18	48.16

California	Lake	12.90	13.97	13.96
California	Los Angeles	50.90	49.25	49.15
California	Mendocino	15.30	12.22	12.22
California	Merced	46.10	37.03	37.02
California	Monterey	14.30	14.81	14.80
California	Nevada	16.50	14.58	14.57
California	Orange	43.70	42.89	42.79
California	Placer	29.80	24.96	24.96
California	Plumas	32.40	28.84	28.83
California	Riverside	59.10	54.76	54.70
California	Sacramento	49.20	45.65	45.64
California	San Bernardino	55.50	49.20	49.18
California	San Diego	33.20	36.00	35.97
California	San Francisco	30.90	30.35	30.33
California	San Joaquin	41.80	35.21	35.21
California	San Luis Obispo	22.50	19.78	19.77
California	San Mateo	29.40	27.48	27.47
California	Santa Barbara	24.00	24.03	24.02
California	Santa Clara	38.60	37.27	37.25
California	Shasta	20.40	18.01	18.01
California	Solano	34.70	32.00	31.97
California	Sonoma	29.10	26.03	26.02
California	Stanislaus	51.40	41.63	41.62
California	Sutter	38.50	31.65	31.64
California	Tulare	56.60	47.58	47.58
California	Ventura	30.30	31.98	31.94
California	Yolo	30.30	25.83	25.82
Colorado	Adams	25.30	20.48	20.45
Colorado	Arapahoe	21.20	18.72	18.72
Colorado	Boulder	21.10	18.10	18.11
Colorado	Delta	20.70	17.34	17.35
Colorado	Denver	26.40	22.60	22.56
Colorado	Elbert	13.10	12.26	12.27
Colorado	El Paso	16.50	15.09	15.09
Colorado	Larimer	18.30	16.35	16.36
Colorado	Mesa	23.50	21.03	21.04
Colorado	Pueblo	15.40	13.47	13.47
Colorado	San Miguel	10.10	9.89	9.89
Colorado	Weld	22.90	20.09	20.10
Connecticut	Fairfield	34.90	29.79	29.79
Connecticut	Hartford	31.80	25.18	25.19
Connecticut	Litchfield	27.10	19.32	19.30
Connecticut	New Haven	38.30	31.64	31.65
Connecticut	New London	32.00	25.27	25.27
Delaware	Kent	32.10	26.18	26.18
Delaware	New Castle	36.60	30.74	30.74
Delaware	Sussex	33.70	27.75	27.75
District Of Co	District of Columbia	36.30	29.61	29.62
Florida	Alachua	23.40	18.36	18.35
Florida	Bay	28.40	22.37	22.37
Florida	Brevard	20.70	16.83	16.82
Florida	Broward	19.10	17.80	17.80
Florida	Citrus	21.70	16.67	16.67
Florida	Duval	25.20	22.23	22.23

Florida	Escambia	28.80	23.34	23.34
Florida	Hillsborough	23.60	19.71	19.70
Florida	Lee	17.80	14.88	14.88
Florida	Leon	29.00	23.41	23.41
Florida	Manatee	19.90	14.32	14.32
Florida	Marion	23.20	18.60	18.60
Florida	Miami-Dade	19.40	21.14	21.14
Florida	Orange	21.70	17.64	17.65
Florida	Palm Beach	18.90	17.88	17.88
Florida	Pinellas	21.90	17.97	17.98
Florida	Polk	19.50	15.89	15.89
Florida	St. Lucie	18.70	15.59	15.58
Florida	Sarasota	19.80	15.24	15.24
Florida	Seminole	22.80	16.66	16.66
Florida	Volusia	22.60	16.00	16.00
Georgia	Bibb	33.50	25.08	25.09
Georgia	Chatham	28.40	23.58	23.59
Georgia	Clayton	35.80	24.31	24.33
Georgia	Cobb	35.00	24.86	24.87
Georgia	DeKalb	33.90	25.98	26.00
Georgia	Dougherty	34.10	27.21	27.21
Georgia	Floyd	35.10	25.52	25.52
Georgia	Fulton	37.60	26.06	26.08
Georgia	Glynn	26.10	21.55	21.55
Georgia	Gwinnett	32.80	23.72	23.73
Georgia	Hall	30.60	23.87	23.87
Georgia	Houston	29.60	21.70	21.70
Georgia	Lowndes	25.90	20.97	20.97
Georgia	Muscogee	31.30	25.78	25.78
Georgia	Paulding	33.00	22.48	22.48
Georgia	Richmond	32.70	26.34	26.34
Georgia	Walker	30.90	21.92	21.93
Georgia	Washington	30.80	21.99	21.99
Georgia	Wilkinson	33.10	25.54	25.55
Idaho	Ada	28.30	24.94	24.95
Idaho	Bannock	27.00	24.40	24.41
Idaho	Benewah	32.90	30.33	30.34
Idaho	Canyon	31.80	27.31	27.32
Idaho	Franklin	36.70	31.82	31.85
Idaho	Idaho	28.40	27.20	27.20
Idaho	Lemhi	36.50	34.20	34.20
Idaho	Power	33.30	30.05	30.06
Idaho	Shoshone	38.10	34.99	34.99
Illinois	Adams	31.40	23.38	23.38
Illinois	Champaign	30.00	22.77	22.77
Illinois	Cook	43.00	34.31	34.32
Illinois	DuPage	34.60	30.70	30.72
Illinois	Hamilton	31.60	20.93	20.92
Illinois	Jersey	32.10	23.92	23.89
Illinois	Kane	34.80	29.09	29.09
Illinois	Lake	33.00	26.29	26.28
Illinois	La Salle	28.90	23.73	23.73
Illinois	McHenry	31.50	27.75	27.75
Illinois	McLean	33.40	24.71	24.68

Illinois	Macon	33.20	22.79	22.79
Illinois	Madison	39.10	31.89	31.87
Illinois	Peoria	32.70	26.23	26.23
Illinois	Randolph	28.90	23.92	23.91
Illinois	Rock Island	30.90	25.32	25.32
Illinois	Saint Clair	33.70	27.30	27.29
Illinois	Sangamon	33.40	27.56	27.55
Illinois	Will	36.40	28.28	28.26
Illinois	Winnebago	34.70	28.20	28.21
Indiana	Allen	33.10	28.81	28.82
Indiana	Clark	37.50	27.96	27.96
Indiana	Delaware	32.00	25.33	25.32
Indiana	Dubois	35.30	26.58	26.57
Indiana	Elkhart	34.40	27.61	27.61
Indiana	Floyd	33.20	22.89	22.89
Indiana	Henry	31.80	25.51	25.50
Indiana	Howard	32.20	23.62	23.62
Indiana	Knox	35.90	26.50	26.49
Indiana	Lake	38.90	32.04	32.03
Indiana	LaPorte	33.60	25.54	25.55
Indiana	Madison	32.80	25.67	25.66
Indiana	Marion	38.40	30.34	30.35
Indiana	Porter	31.80	25.06	25.06
Indiana	St. Joseph	33.10	27.90	27.91
Indiana	Spencer	32.30	24.09	24.09
Indiana	Tippecanoe	35.60	28.11	28.11
Indiana	Vanderburgh	32.60	27.09	27.09
Indiana	Vigo	35.10	30.86	30.86
Iowa	Black Hawk	30.10	24.71	24.72
Iowa	Clinton	33.90	27.22	27.22
Iowa	Johnson	34.60	29.55	29.56
Iowa	Linn	30.60	25.81	25.83
Iowa	Montgomery	27.50	21.16	21.16
Iowa	Muscatine	36.00	30.34	30.34
Iowa	Palo Alto	25.70	20.39	20.39
Iowa	Polk	31.40	24.86	24.87
Iowa	Pottawattamie	28.60	22.80	22.80
Iowa	Scott	37.10	29.19	29.19
Iowa	Van Buren	28.30	21.81	21.82
Iowa	Woodbury	26.40	21.49	21.50
Iowa	Wright	28.60	23.78	23.78
Kansas	Johnson	29.30	25.37	25.37
Kansas	Linn	25.30	20.85	20.84
Kansas	Sedgwick	25.30	21.62	21.62
Kansas	Shawnee	29.10	23.75	23.74
Kansas	Sumner	22.80	18.83	18.82
Kansas	Wyandotte	29.50	23.58	23.58
Kentucky	Bell	29.50	21.15	21.15
Kentucky	Boyd	33.10	21.23	21.19
Kentucky	Bullitt	34.60	24.18	24.18
Kentucky	Campbell	31.20	24.64	24.65
Kentucky	Carter	29.90	17.83	17.82
Kentucky	Christian	33.60	21.10	21.09
Kentucky	Daviess	33.80	22.82	22.82

Kentucky	Fayette	32.70	22.92	22.90
Kentucky	Franklin	32.10	21.14	21.15
Kentucky	Hardin	32.80	21.35	21.34
Kentucky	Henderson	31.80	22.88	22.88
Kentucky	Jefferson	36.10	28.25	28.25
Kentucky	Kenton	34.70	23.80	23.80
Kentucky	Laurel	25.10	16.76	16.75
Kentucky	McCracken	33.60	23.32	23.31
Kentucky	Madison	30.10	19.76	19.76
Kentucky	Perry	28.50	17.31	17.31
Kentucky	Pike	30.50	19.00	19.00
Kentucky	Warren	33.10	23.36	23.35
Louisiana	Caddo	27.50	21.80	21.79
Louisiana	Calcasieu	26.30	21.57	21.49
Louisiana	Concordia	26.10	20.50	20.48
Louisiana	East Baton Rouge	29.30	22.27	22.15
Louisiana	Iberville	28.60	23.38	23.32
Louisiana	Jefferson	27.00	21.42	21.35
Louisiana	Lafayette	24.20	18.98	18.96
Louisiana	Ouachita	28.90	22.70	22.69
Louisiana	Rapides	30.20	23.15	23.13
Louisiana	Tangipahoa	29.60	23.21	23.18
Louisiana	Terrebonne	26.20	20.03	20.00
Louisiana	West Baton Rouge	29.00	22.48	22.36
Maine	Androscoggin	26.50	23.08	23.08
Maine	Aroostook	24.20	23.48	23.48
Maine	Cumberland	29.20	24.85	24.86
Maine	Hancock	19.40	16.30	16.30
Maine	Kennebec	26.20	22.69	22.70
Maine	Oxford	28.30	24.77	24.77
Maine	Penobscot	22.00	19.43	19.43
Maryland	Anne Arundel	35.50	31.41	31.42
Maryland	Baltimore	35.80	29.17	29.19
Maryland	Cecil	30.80	24.67	24.68
Maryland	Harford	31.20	23.22	23.22
Maryland	Montgomery	30.90	23.91	23.90
Maryland	Prince George's	33.40	25.22	25.22
Maryland	Washington	33.40	27.22	27.22
Maryland	Baltimore (City)	39.00	32.91	32.93
Massachusetts	Berkshire	31.00	28.40	28.40
Massachusetts	Bristol	25.00	19.63	19.63
Massachusetts	Essex	28.70	23.09	23.09
Massachusetts	Hampden	33.10	28.00	28.01
Massachusetts	Plymouth	28.40	21.18	21.18
Massachusetts	Suffolk	32.10	27.22	27.23
Massachusetts	Worcester	30.50	24.62	24.63
Michigan	Allegan	33.80	28.27	28.28
Michigan	Bay	31.60	24.94	24.95
Michigan	Berrien	31.30	25.21	25.21
Michigan	Genesee	30.40	25.63	25.63
Michigan	Ingham	31.90	26.72	26.73
Michigan	Kalamazoo	31.10	24.49	24.50
Michigan	Kent	36.50	28.61	28.64
Michigan	Macomb	35.30	29.76	29.77

Michigan	Missaukee	24.80	19.08	19.09
Michigan	Monroe	38.80	30.01	30.02
Michigan	Muskegon	34.70	25.56	25.58
Michigan	Oakland	39.90	33.37	33.38
Michigan	Ottawa	34.20	29.52	29.54
Michigan	Saginaw	30.60	23.61	23.62
Michigan	St. Clair	39.60	34.43	34.44
Michigan	Washtenaw	39.40	31.31	31.34
Michigan	Wayne	43.80	36.62	36.61
Minnesota	Cass	18.00	15.11	15.11
Minnesota	Dakota	25.40	20.59	20.60
Minnesota	Hennepin	26.70	21.44	21.46
Minnesota	Mille Lacs	22.00	18.64	18.64
Minnesota	Ramsey	28.00	24.00	23.99
Minnesota	Saint Louis	23.50	19.25	19.25
Minnesota	Scott	24.90	20.53	20.53
Minnesota	Stearns	20.90	17.44	17.44
Mississippi	Adams	27.40	20.04	20.03
Mississippi	Bolivar	28.90	22.97	22.97
Mississippi	DeSoto	30.80	21.24	21.23
Mississippi	Forrest	30.40	24.69	24.69
Mississippi	Harrison	30.50	23.80	23.78
Mississippi	Hinds	28.80	21.27	21.27
Mississippi	Jackson	28.20	21.89	21.86
Mississippi	Jones	31.20	25.45	25.45
Mississippi	Lauderdale	29.80	22.48	22.48
Mississippi	Lee	32.10	22.24	22.24
Mississippi	Lowndes	32.40	21.44	21.44
Mississippi	Pearl River	28.50	22.33	22.32
Mississippi	Warren	30.20	22.40	22.39
Missouri	Boone	30.20	24.29	24.28
Missouri	Buchanan	30.10	24.06	24.05
Missouri	Cass	25.60	20.74	20.73
Missouri	Cedar	28.70	22.05	22.04
Missouri	Clay	28.00	23.04	23.04
Missouri	Greene	28.20	21.38	21.38
Missouri	Jackson	28.90	23.77	23.78
Missouri	Jefferson	33.40	27.46	27.45
Missouri	Monroe	27.80	21.52	21.52
Missouri	Saint Charles	33.10	26.61	26.54
Missouri	Sainte Genevieve	31.40	24.69	24.69
Missouri	Saint Louis	33.20	28.48	28.48
Missouri	St. Louis City	34.30	28.29	28.27
Montana	Cascade	17.30	14.86	14.85
Montana	Flathead	24.50	21.90	21.91
Montana	Gallatin	29.50	27.64	27.65
Montana	Lake	30.60	27.94	27.94
Montana	Lewis and Clark	30.70	27.49	27.50
Montana	Lincoln	42.70	38.28	38.28
Montana	Missoula	38.50	33.40	33.40
Montana	Ravalli	37.80	32.63	32.64
Montana	Rosebud	19.70	18.99	18.99
Montana	Sanders	19.50	18.38	18.38
Montana	Silver Bow	33.80	29.19	29.20

Montana	Yellowstone	19.30	17.32	17.30
Nebraska	Douglas	25.70	20.97	20.97
Nebraska	Hall	19.10	15.56	15.56
Nebraska	Lancaster	24.70	19.67	19.67
Nebraska	Lincoln	23.70	20.41	20.41
Nebraska	Sarpy	24.10	19.57	19.58
Nebraska	Scotts Bluff	16.60	14.87	14.86
Nebraska	Washington	24.10	20.35	20.34
Nevada	Clark	25.20	22.39	22.40
Nevada	Washoe	30.70	25.77	25.78
New Hampshire	Belknap	20.50	15.09	15.09
New Hampshire	Cheshire	30.20	26.11	26.12
New Hampshire	Coos	26.50	23.28	23.28
New Hampshire	Grafton	23.00	18.65	18.65
New Hampshire	Hillsborough	28.60	24.52	24.53
New Hampshire	Merrimack	25.60	20.84	20.84
New Hampshire	Rockingham	26.30	21.27	21.28
New Hampshire	Sullivan	28.90	21.67	21.67
New Jersey	Bergen	37.00	30.67	30.68
New Jersey	Camden	37.30	29.15	29.14
New Jersey	Essex	38.30	28.66	28.66
New Jersey	Gloucester	32.10	25.43	25.41
New Jersey	Hudson	41.40	35.23	35.25
New Jersey	Mercer	34.70	25.81	25.81
New Jersey	Middlesex	34.80	25.95	25.95
New Jersey	Morris	32.30	24.94	24.93
New Jersey	Ocean	31.50	21.55	21.55
New Jersey	Passaic	36.30	26.88	26.88
New Jersey	Union	40.40	31.97	31.96
New Jersey	Warren	34.00	28.03	28.03
New Mexico	Bernalillo	18.60	16.04	16.04
New Mexico	Chaves	15.60	14.21	14.21
New Mexico	Dona Ana	32.90	27.19	27.19
New Mexico	Grant	13.00	12.46	12.45
New Mexico	Sandoval	15.60	14.41	14.41
New Mexico	San Juan	12.40	11.80	11.79
New Mexico	Santa Fe	9.70	8.90	8.91
New York	Albany	34.20	30.26	30.28
New York	Bronx	38.80	31.95	31.97
New York	Chautauqua	29.10	21.47	21.47
New York	Erie	35.30	30.93	30.94
New York	Essex	22.40	18.74	18.73
New York	Kings	36.90	29.62	29.64
New York	Monroe	32.20	26.79	26.80
New York	Nassau	34.00	24.95	24.96
New York	New York	39.70	33.54	33.55
New York	Niagara	33.60	28.45	28.45
New York	Onondaga	27.30	24.07	24.07
New York	Orange	28.90	23.41	23.41
New York	Queens	35.50	30.29	30.31
New York	Richmond	34.90	29.98	29.98
New York	St. Lawrence	22.10	19.75	19.75
New York	Steuben	27.80	21.12	21.11
New York	Suffolk	34.60	24.27	24.27

New York	Westchester	33.50	26.06	26.05
North Carolina	Alamance	31.70	22.16	22.16
North Carolina	Buncombe	30.00	20.91	20.91
North Carolina	Caswell	29.40	20.15	20.15
North Carolina	Catawba	34.50	23.59	23.59
North Carolina	Chatham	26.90	20.36	20.36
North Carolina	Cumberland	30.70	23.62	23.62
North Carolina	Davidson	31.30	23.16	23.16
North Carolina	Duplin	28.30	21.91	21.91
North Carolina	Durham	31.00	22.87	22.88
North Carolina	Edgecombe	26.70	22.10	22.09
North Carolina	Forsyth	31.90	24.85	24.86
North Carolina	Gaston	30.80	21.30	21.30
North Carolina	Guilford	30.60	23.44	23.44
North Carolina	Haywood	27.70	21.09	21.09
North Carolina	Jackson	25.50	18.04	18.03
North Carolina	Lenoir	25.20	20.43	20.43
North Carolina	McDowell	31.50	22.14	22.13
North Carolina	Martin	24.80	20.95	20.95
North Carolina	Mecklenburg	32.30	28.92	28.92
North Carolina	Mitchell	30.20	21.55	21.54
North Carolina	Montgomery	28.20	19.95	19.95
North Carolina	New Hanover	24.00	17.88	17.87
North Carolina	Onslow	24.60	19.37	19.37
North Carolina	Orange	29.30	20.67	20.67
North Carolina	Pitt	26.20	22.98	22.97
North Carolina	Robeson	29.90	21.38	21.38
North Carolina	Rowan	30.20	22.09	22.08
North Carolina	Swain	27.30	20.42	20.42
North Carolina	Wake	31.60	24.74	24.75
North Carolina	Watauga	30.40	20.12	20.12
North Carolina	Wayne	29.70	22.89	22.88
North Dakota	Billings	13.00	11.97	11.97
North Dakota	Burke	16.70	15.92	15.91
North Dakota	Burleigh	17.60	15.61	15.47
North Dakota	Cass	21.20	17.74	17.74
North Dakota	McKenzie	11.90	11.21	11.21
North Dakota	Mercer	16.90	13.68	13.67
Ohio	Athens	32.30	20.73	20.72
Ohio	Butler	39.20	29.27	29.27
Ohio	Clark	35.30	25.99	25.99
Ohio	Clermont	34.40	23.60	23.61
Ohio	Cuyahoga	42.10	33.04	33.05
Ohio	Franklin	38.50	31.07	31.10
Ohio	Greene	33.00	24.73	24.74
Ohio	Hamilton	40.60	28.83	28.84
Ohio	Jefferson	41.90	28.87	28.87
Ohio	Lake	37.10	29.71	29.72
Ohio	Lawrence	33.70	22.01	22.00
Ohio	Lorain	31.50	22.97	22.97
Ohio	Lucas	36.30	29.22	29.23
Ohio	Mahoning	36.80	28.03	28.04
Ohio	Montgomery	37.80	28.90	28.93
Ohio	Portage	34.30	25.96	25.96

Ohio	Preble	32.80	25.89	25.89
Ohio	Scioto	34.50	22.57	22.57
Ohio	Stark	36.90	27.46	27.47
Ohio	Summit	38.00	31.04	31.05
Ohio	Trumbull	36.20	28.29	28.30
Oklahoma	Caddo	23.90	19.09	19.08
Oklahoma	Cherokee	27.50	22.73	22.73
Oklahoma	Kay	31.80	27.68	27.59
Oklahoma	Lincoln	27.80	22.20	22.19
Oklahoma	Mayes	28.70	24.98	24.96
Oklahoma	Muskogee	29.50	24.86	24.85
Oklahoma	Oklahoma	27.10	21.64	21.64
Oklahoma	Ottawa	29.10	23.48	23.47
Oklahoma	Pittsburg	26.30	21.28	21.27
Oklahoma	Sequoyah	31.40	25.67	25.66
Oklahoma	Tulsa	30.30	25.65	25.63
Oregon	Jackson	33.70	32.10	32.10
Oregon	Klamath	44.00	40.83	40.83
Oregon	Lane	48.90	45.99	45.99
Oregon	Multnomah	29.80	27.26	27.26
Oregon	Union	27.30	25.15	25.15
Pennsylvania	Adams	34.90	26.74	26.75
Pennsylvania	Allegheny	64.20	50.29	50.33
Pennsylvania	Beaver	43.40	28.51	28.51
Pennsylvania	Berks	37.70	32.22	32.23
Pennsylvania	Bucks	34.00	27.86	27.86
Pennsylvania	Cambria	39.00	23.83	23.84
Pennsylvania	Centre	36.20	29.34	29.34
Pennsylvania	Chester	36.70	28.24	28.26
Pennsylvania	Cumberland	38.00	31.65	31.65
Pennsylvania	Dauphin	38.00	32.61	32.62
Pennsylvania	Delaware	35.20	27.93	27.90
Pennsylvania	Erie	34.40	29.92	29.92
Pennsylvania	Lackawanna	31.50	25.05	25.06
Pennsylvania	Lancaster	40.80	33.71	33.73
Pennsylvania	Lehigh	36.40	31.47	31.48
Pennsylvania	Luzerne	32.40	26.19	26.20
Pennsylvania	Mercer	36.30	28.27	28.29
Pennsylvania	Northampton	36.70	30.01	30.02
Pennsylvania	Perry	30.40	25.54	25.55
Pennsylvania	Philadelphia	36.50	30.06	30.06
Pennsylvania	Washington	38.10	25.26	25.26
Pennsylvania	Westmoreland	37.10	22.48	22.49
Pennsylvania	York	38.20	32.46	32.47
Rhode Island	Providence	30.60	25.59	25.60
South Carolina	Beaufort	30.20	22.52	22.52
South Carolina	Charleston	27.90	23.12	23.12
South Carolina	Chesterfield	28.70	21.07	21.08
South Carolina	Edgefield	32.20	22.23	22.24
South Carolina	Florence	28.80	22.15	22.15
South Carolina	Georgetown	29.20	22.88	22.88
South Carolina	Greenville	32.10	25.86	25.86
South Carolina	Greenwood	30.00	21.42	21.42
South Carolina	Horry	28.60	21.85	21.85

South Carolina	Lexington	32.80	24.88	24.88
South Carolina	Oconee	28.40	20.06	20.06
South Carolina	Richland	33.20	25.18	25.18
South Carolina	Spartanburg	32.40	23.04	23.04
South Dakota	Brookings	23.50	19.38	19.38
South Dakota	Brown	18.70	15.79	15.78
South Dakota	Codington	23.60	20.06	20.05
South Dakota	Custer	14.30	13.77	13.77
South Dakota	Jackson	12.70	11.75	11.74
South Dakota	Minnehaha	24.10	19.55	19.56
South Dakota	Pennington	18.50	17.28	17.28
Tennessee	Blount	32.50	22.50	22.50
Tennessee	Davidson	33.50	24.02	24.03
Tennessee	Dyer	31.90	22.99	22.99
Tennessee	Hamilton	33.20	24.77	24.77
Tennessee	Knox	36.60	24.42	24.42
Tennessee	Lawrence	28.40	18.97	18.96
Tennessee	Loudon	32.20	23.08	23.08
Tennessee	McMinn	32.40	21.10	21.10
Tennessee	Maury	30.80	21.20	21.20
Tennessee	Montgomery	36.30	26.38	26.38
Tennessee	Putnam	32.60	20.47	20.46
Tennessee	Roane	30.20	21.08	21.08
Tennessee	Shelby	32.20	23.10	23.10
Tennessee	Sullivan	31.10	22.45	22.45
Tennessee	Sumner	33.60	21.01	21.01
Texas	Bowie	29.40	22.41	22.41
Texas	Dallas	25.70	21.59	21.59
Texas	Ector	17.80	14.68	14.67
Texas	El Paso	22.90	19.25	19.21
Texas	Harris	30.80	26.81	26.59
Texas	Harrison	25.90	20.54	20.53
Texas	Hidalgo	26.40	25.22	25.22
Texas	Jefferson	26.00	19.95	19.90
Texas	Nueces	27.50	22.72	22.66
Texas	Orange	27.70	22.02	21.96
Texas	Tarrant	25.70	21.92	21.93
Utah	Box Elder	33.20	29.56	29.58
Utah	Cache	56.90	45.29	45.30
Utah	Davis	38.90	33.75	33.70
Utah	Salt Lake	50.10	44.48	44.46
Utah	Tooele	30.50	26.77	26.81
Utah	Utah	44.00	39.59	39.64
Utah	Weber	38.50	33.37	33.36
Vermont	Addison	31.70	27.42	27.42
Vermont	Bennington	26.40	23.22	23.22
Vermont	Chittenden	30.10	26.14	26.16
Vermont	Rutland	30.60	28.43	28.43
Virginia	Arlington	34.10	26.65	26.65
Virginia	Charles	31.70	22.32	22.32
Virginia	Chesterfield	31.20	20.44	20.45
Virginia	Fairfax	33.30	26.75	26.76
Virginia	Henrico	31.90	21.73	21.73
Virginia	Loudoun	34.40	24.50	24.50

Virginia	Page	30.00	20.65	20.66
Virginia	Bristol City	30.20	20.45	20.45
Virginia	Hampton City	29.00	22.52	22.52
Virginia	Lynchburg City	30.70	19.39	19.38
Virginia	Norfolk City	29.60	23.58	23.59
Virginia	Roanoke City	32.70	22.41	22.41
Virginia	Salem City	34.00	24.22	24.22
Virginia	Virginia Beach City	30.00	25.13	25.13
Washington	King	29.10	27.47	27.49
Washington	Pierce	41.80	38.07	38.10
Washington	Snohomish	34.30	32.87	32.87
Washington	Spokane	29.70	24.34	24.35
West Virginia	Berkeley	34.50	29.43	29.44
West Virginia	Brooke	43.90	35.53	35.53
West Virginia	Cabell	35.10	22.48	22.47
West Virginia	Hancock	40.60	25.52	25.52
West Virginia	Harrison	33.50	20.55	20.54
West Virginia	Kanawha	36.90	24.17	24.16
West Virginia	Marion	33.60	20.36	20.36
West Virginia	Marshall	33.90	22.66	22.66
West Virginia	Monongalia	35.60	18.86	18.86
West Virginia	Ohio	32.00	23.26	23.26
West Virginia	Raleigh	30.60	19.27	19.26
West Virginia	Summers	31.20	18.84	18.83
West Virginia	Wood	35.40	22.22	22.22
Wisconsin	Ashland	18.60	14.96	14.96
Wisconsin	Brown	36.50	32.31	32.27
Wisconsin	Dane	35.50	29.68	29.70
Wisconsin	Dodge	31.80	27.06	27.07
Wisconsin	Forest	25.20	20.80	20.81
Wisconsin	Grant	34.30	29.04	29.05
Wisconsin	Kenosha	32.70	28.96	28.95
Wisconsin	Manitowoc	29.70	26.17	26.18
Wisconsin	Milwaukee	38.60	35.73	35.73
Wisconsin	Outagamie	32.80	28.94	28.96
Wisconsin	Ozaukee	32.50	28.11	28.11
Wisconsin	St. Croix	26.60	21.85	21.85
Wisconsin	Sauk	28.60	24.38	24.39
Wisconsin	Taylor	25.30	21.72	21.73
Wisconsin	Vilas	22.60	19.03	19.03
Wisconsin	Waukesha	35.40	30.20	30.21
Wyoming	Campbell	18.60	17.71	17.71
Wyoming	Converse	10.00	9.72	9.72
Wyoming	Fremont	29.80	25.89	25.90
Wyoming	Laramie	11.90	10.91	10.88
Wyoming	Sheridan	30.80	28.42	28.43

Appendix D: 2005 CMAQ Model Performance Evaluation for Ozone, Particulate Matter and Air Toxics

U.S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Air Quality Assessment Division
Research Triangle Park, NC 27711
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A. Introduction

An operational model performance evaluation for ozone, $PM_{2.5}$ and its related speciated components, and specific air toxics (i.e., formaldehyde, acetaldehyde, benzene, 1,3-butadiene, and acrolein) was conducted using 2005 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 Eastern and Western United States domain[1]. This evaluation principally comprises statistical assessments 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_{25} and air toxic observations 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. In conjunction with the model performance statistics, we also provide spatial plots for individual monitors of the calculated bias and error statistics (defined below). Statistics were generated for the 12-km Eastern US domain (EUS), 12-km Western US domain (WUS), and five large subregions[2]: Midwest, Northeast, Southeast, Central, and West U.S. The Atmospheric Model Evaluation Tool (AMET) was used to conduct the evaluation described in this document.[3]

The ozone evaluation primarily focuses on observed and predicted one-hour daily maximum ozone concentrations and eight-hour daily maximum ozone concentrations at a threshold of 40ppb. This ozone model performance was limited to the ozone season modeled for the Light-Duty Vehicle Greenhouse Gas Final Rule (hereafter referred to as LDGHG): May, June, July, August, and September. Ozone ambient measurements for 2005 were obtained from the Air Quality System (AQS) Aerometric Information Retrieval System (AIRS). A total of 1194 ozone measurement sites were included for evaluation. The ozone data were measured and reported on an hourly basis.

The $PM_{2.5}$ evaluation focuses on $PM_{2.5}$ total mass and its components including sulfate (SO_4), nitrate (NO_3), total nitrate (TNO_3=NO_3+HNO_3), ammonium (NH_4), elemental carbon (EC), and organic carbon (OC). The $PM_{2.5}$ performance statistics were calculated for each month and season individually and for the entire year, as a whole. Seasons were defined as: winter (December-January-February), spring (March-April-May), summer (June-July-August), and fall (September-October-November). $PM_{2.5}$ ambient measurements for 2002 were obtained from the following networks for model evaluation: **S**peciation **T**rends **N**etwork (STN- total of 260 sites),

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[1]See Air Quality Modeling Technical Support Document, 2010 (EPA 454/R-10-001): Changes to the Renewable Fuel Standard Program (Figure II-1) for the map of the CMAQ modeling domain.

[2] The subregions are defined by States where: Midwest is IL, IN, MI, OH, and WI; Northeast is CT, DE, MA, MD, ME, NH, NJ, NY, PA, RI, and VT; Southeast is AL, FL, GA, KY, MS, NC, SC, TN, VA, and WV; Central is AR, IA, KS, LA, MN, MO, NE, OK, and TX; West is AK, CA, OR, WA, AZ, NM, CO, UT, WY, SD, ND, MT, ID, and NV.

[3] Gilliam, R. C., W. Appel, and S. Phillips. The Atmospheric Model Evaluation Tool (AMET): Meteorology Module. Presented at 4th Annual CMAS Models-3 Users Conference, Chapel Hill, NC, September 26 - 28, 2005. (http://www.cmascenter.org/)

Interagency **M**onitoring of **PRO**tected **V**isual **E**nvironments (IMPROVE- total of 204), **C**lean **A**ir **S**tatus and **T**rends **Net**work (CASTNet- total of 93), and **N**ational **A**cid **D**eposition **P**rogram**/N**ational **T**rends **(**NADP/NTN- toal of 297). The pollutant species included in the evaluation for each 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.

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	NH_4	OC	SO_4	NO_3
IMPROVE	X	X	X		X	X	X		
CASTNet		X		X		X			
STN	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 LDGHG final rule, i.e., formaldehyde, acetaldehyde, benzene, 1,3-butadiene, acrolein, and naphthalene. Similar to the $PM_{2.5}$ evaluation, the air toxics performance statistics were calculated for each month and season individually and for the entire year, as a whole to estimate the ability of the CMAQ modeling system to replicate the base year concentrations for the 12-km Eastern and Western United States domains. As mentioned above, seasons were defined as: winter (December-January-February), spring (March-April-May), summer (June-July-August), and fall (September-October-November). Toxic measurements for 2005 were obtained from the National Air Toxics Trends Stations (NATTS). Toxic measurements from 471 sites in the East and 135 sites in the West were included in the evaluation for the 12km Eastern and Western U.S. grids, respectively.

There are various statistical metrics available and used by the science community for model performance evaluation. For a robust evaluation, the principal evaluation statistics used to evaluate CMAQ performance were two bias metrics, normalized mean bias and fractional bias; and two error metrics, normalized mean error and fractional error.

Normalized mean bias (NMB) is used as a normalization to facilitate a range of concentration magnitudes. This statistic averages the difference (model - 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 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 (model - observed) over the sum of observed values. Normalized mean error is defined as:

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

Fractional bias is defined as:

$$\text{FB} = \frac{1}{n}\left(\frac{\sum_{1}^{n}(P-O)}{\sum_{1}^{n}\left(\frac{(P+O)}{2}\right)}\right) * 100$$

, where P = predicted concentrations and O = observed concentrations. FB is a useful model performance indicator because it has the advantage of equally weighting positive and negative bias estimates. The single largest disadvantage in this estimate of model performance is that the estimated concentration (i.e., prediction, P) is found in both the numerator and denominator. Fractional error (FE) is similar to fractional bias except the absolute value of the difference is used so that the error is always positive. Fractional error is defined as:

$$\text{FE} = \frac{1}{n}\left(\frac{\sum_{1}^{n}|P-O|}{\sum_{1}^{n}\left(\frac{(P+O)}{2}\right)}\right) * 100$$

The "acceptability" of model performance was judged by comparing our CMAQ 2005 performance results to the range of performance found in recent regional ozone, $PM_{2.5}$, and air toxic[4,5,6] model applications (e.g., Revised Renewable Fuel Standards Final Rule,[7] Clean Air

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[4] 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.

[5] Strum, M., Wesson, K., Phillips, S., Cook, R., Michaels, H., Brzezinski, D., Pollack, A., Jimenez, M., Shepard, S. Impact of using lin-level 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.

[6] 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.

Interstate Rule[8], Final PM NAAQS Rule[9], and EPA's Proposal to Designate an Emissions Control Area for Nitrogen Oxides[10]). These other modeling studies represent a wide range of modeling analyses which cover various models, model configurations, domains, years and/or episodes, chemical mechanisms, and aerosol modules. Overall, the NMB, NME, FB, and FE statistics shown in Sections B through P below for CMAQ predicted 2005 ozone, $PM_{2.5}$, and air toxics concentrations are within the range or close to that found in recent OAQPS applications. The CMAQ model performance results give us confidence that our applications of CMAQ using this 2005 modeling platform provide a scientifically credible approach for assessing ozone and $PM_{2.5}$ concentrations for the purposes of the LDGHG Final Rule. We discuss in the following sections the bias and error results for the one-hour maximum ozone concentrations and eight-hour daily maximum ozone concentrations evaluated at a threshold of 40 ppb, the annual and seasonal $PM_{2.5}$ and its related speciated components as well as specific air toxic concentrations.

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[7] EPA 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.

[8] See: 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).

[9] U.S. Environmental Protection Agency, 2006. Technical Support Document for the Final PM NAAQS Rule: Office of Air Quality Planning and Standards, Research Triangle Park, NC.

[10] 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)

B. One-Hour Daily Maximum Ozone Performance

Ozone Performance: Threshold of 40 ppb

Table B-1 provides one-hour daily maximum ozone model performance statistics calculated for a threshold of 40 ppb of observed and modeled concentrations, restricted to the ozone season modeled for the 12-km Eastern and Western U.S. domain and the five subregions (Midwest, Northeast, Southeast, Central and Western U.S.). Spatial plots of the NMB and NME statistics (units of percent) for individual monitors are also provided as a complement to the tabular statistical data (Figures B-1 – B-24). Overall, one-hour daily maximum ozone model performance is slightly under-predicted or near negligible in both the 12-km EUS and WUS when applying a threshold of 40 ppb for the modeled ozone season (May-September). For the 12-km Eastern domain, the bias and error statistics are comparable for the aggregate of the ozone season and for each individual ozone month modeled, with a NMB range of -1% to -5% and a FB range of -0.5% to -4%, and a NME and FE range of 11% to 14%. Likewise, for the 12-km Western domain, the bias and error statistics are similar between the ozone seasonal aggregate and the individual months, with a NMB and FB approximately -2%, and a NME and FE approximately 14%. Hourly ozone model performance when compared across the five subregions shows slightly better performance in the Southeast. In general, the Northeast, Midwest, Central and West U.S. exhibit similar bias and error statistics for the episodes modeled. The month of August shows a slightly better bias and error model performance results, although the results are spatially and temporally comparable across the months modeled.

Table B-1. 2005 CMAQ one-hour daily maximum ozone model performance statistics calculated for a threshold of 40 ppb.

CMAQ 2005 One-Hour Maximum Ozone: Threshold of 40 ppb		No. of Obs.	NMB (%)	NME (%)	FB (%)	FE (%)
May	12-km EUS	21394	-1.6	11.5	-0.8	11.6
	12-km WUS	9631	-3.4	12.8	-2.8	12.7
	Midwest	4418	0.8	10.0	1.0	10.2
	Northeast	4102	5.4	11.8	5.9	11.7
	Southeast	6424	-3.6	11.3	-3.0	11.5
	Central U.S.	4328	-6.4	13.4	-5.5	13.4
	West	8294	-3.5	12.9	-3.0	12.8
June	12-km EUS	19517	-3.5	12.8	-2.8	12.9
	12-km WUS	9056	-3.7	13.0	-3.2	13.0
	Midwest	4639	-4.6	12.3	-4.0	12.4
	Northeast	4148	-1.0	14.1	-0.1	14.2
	Southeast	4644	-2.7	12.5	-2.2	12.6
	Central U.S.	4062	-6.2	13.2	-5.4	13.3
	West	7737	-4.0	13.1	-3.6	13.1
July	12-km EUS	19692	1.2	14.2	1.8	14.1
	12-km WUS	9443	0.4	16.0	1.0	15.8
	Midwest	4923	0.4	12.7	0.9	12.6
	Northeast	4445	4.2	15.2	4.8	14.9
	Southeast	4733	4.2	15.1	4.6	14.8

	Central U.S.	3521	-3.8	14.8	-3.1	14.9
	West	8168	0.2	16.2	0.7	16.0
August	12-km EUS	19643	0.1	13.9	0.8	13.8
	12-km WUS	9562	-0.8	15.5	-0.6	15.5
	Midwest	4549	0.2	12.2	1.0	12.3
	Northeast	4139	0.2	13.2	1.2	13.1
	Southeast	5303	3.6	14.9	3.9	14.5
	Central U.S.	3589	-4.1	16.2	-2.9	16.1
	West	8357	-1.0	15.7	-1.0	15.7
September	12-km EUS	18085	-2.2	12.0	-1.3	12.0
	12-km WUS	8725	-3.6	14.1	-3.2	14.3
	Midwest	4002	-3.6	10.7	-3.0	10.8
	Northeast	3667	-1.8	11.3	-0.7	11.3
	Southeast	5259	-0.1	12.1	0.8	12.1
	Central U.S.	3286	-6.1	14.5	-5.1	14.5
	West	7530	-4.1	14.3	-3.8	14.4
Seasonal Aggregate (May – September)	12-km EUS	98331	-1.2	12.9	-0.5	12.8
	12-km WUS	46417	-2.1	14.3	-1.7	14.2
	Midwest	22531	-1.4	11.7	-0.8	11.7
	Northeast	20501	1.4	13.3	2.3	13.1
	Southeast	26363	0.1	13.1	0.7	13.0
	Central U.S.	18786	-5.4	14.4	-4.4	14.4
	West	40086	-2.3	14.5	-2.1	14.4

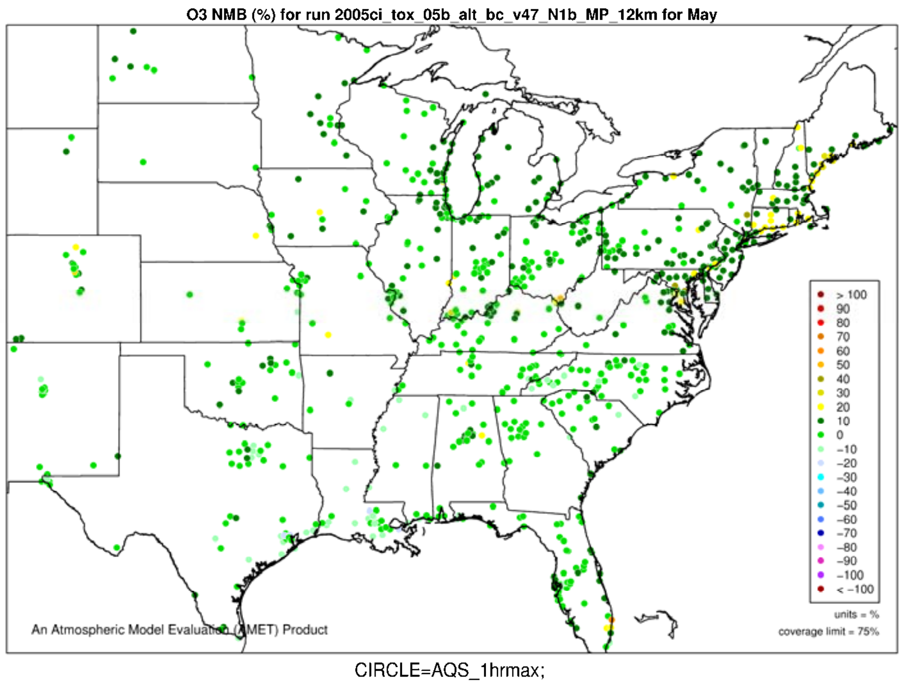


Figure B-1. Normalized Mean Bias (%) of one-hour daily maximum ozone (40 ppb threshold) by monitor for Eastern U.S., May 2005.

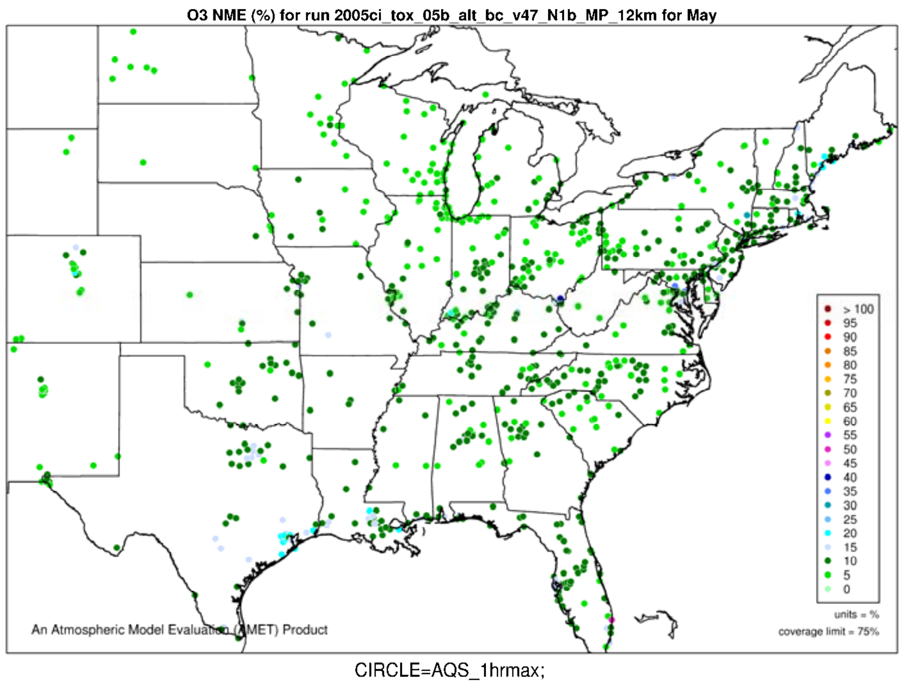


Figure B-2. Normalized Mean Error (%) of one-hour daily maximum ozone (40 ppb threshold) by monitor for Eastern U.S., May 2005.

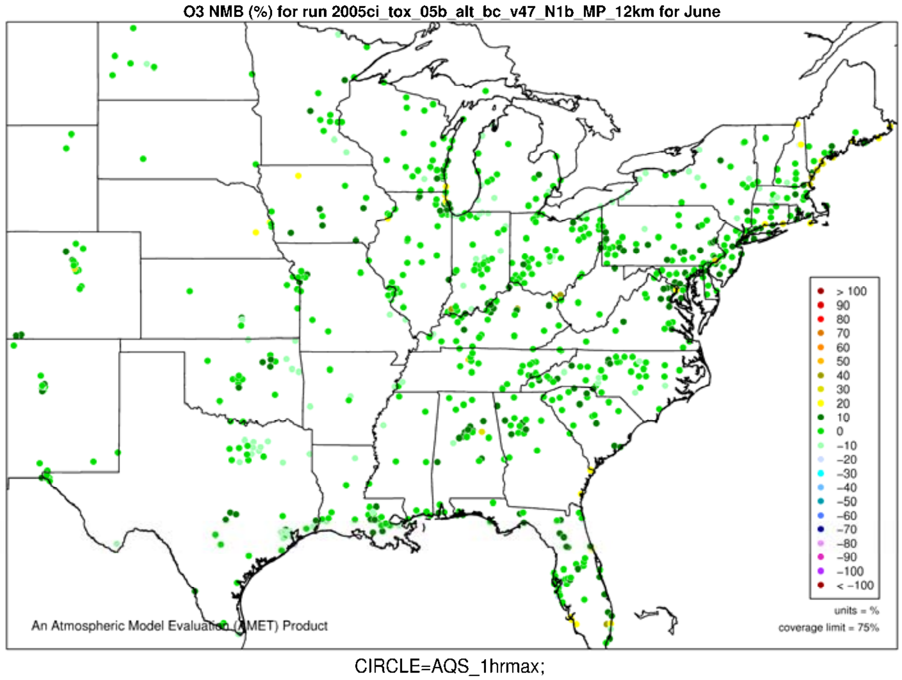


Figure B-3. Normalized Mean Bias (%) of one-hour daily maximum ozone (40 ppb threshold) by monitor for Eastern U.S., June 2005.

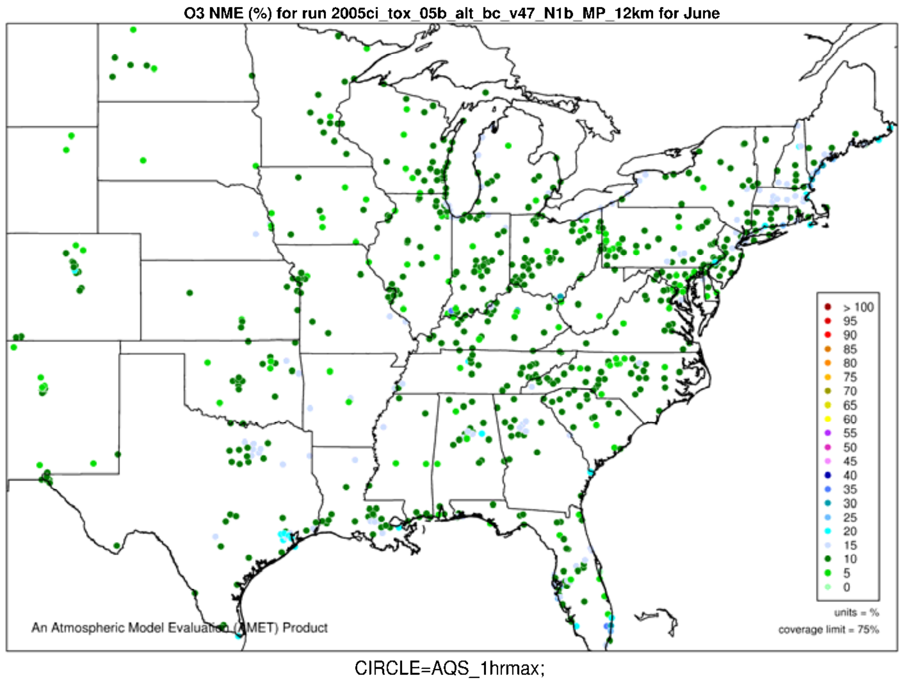


Figure B-4. Normalized Mean Error (%) of one-hour daily maximum ozone (40 ppb threshold) by monitor for Eastern U.S., June 2005.

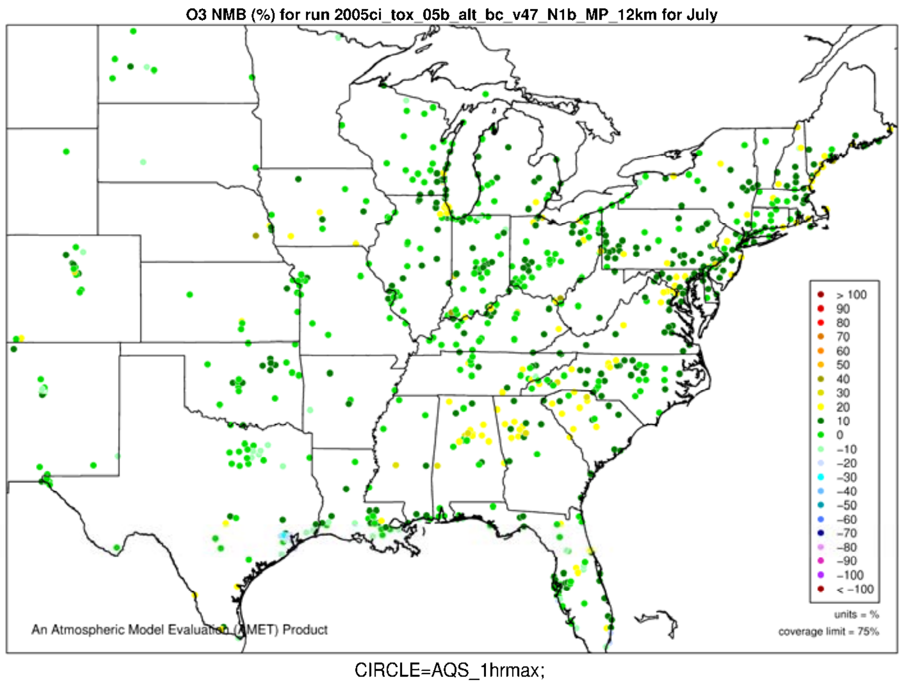


Figure B-5. Normalized Mean Bias (%) of one-hour daily maximum ozone (40 ppb threshold) by monitor for Eastern U.S., July 2005.

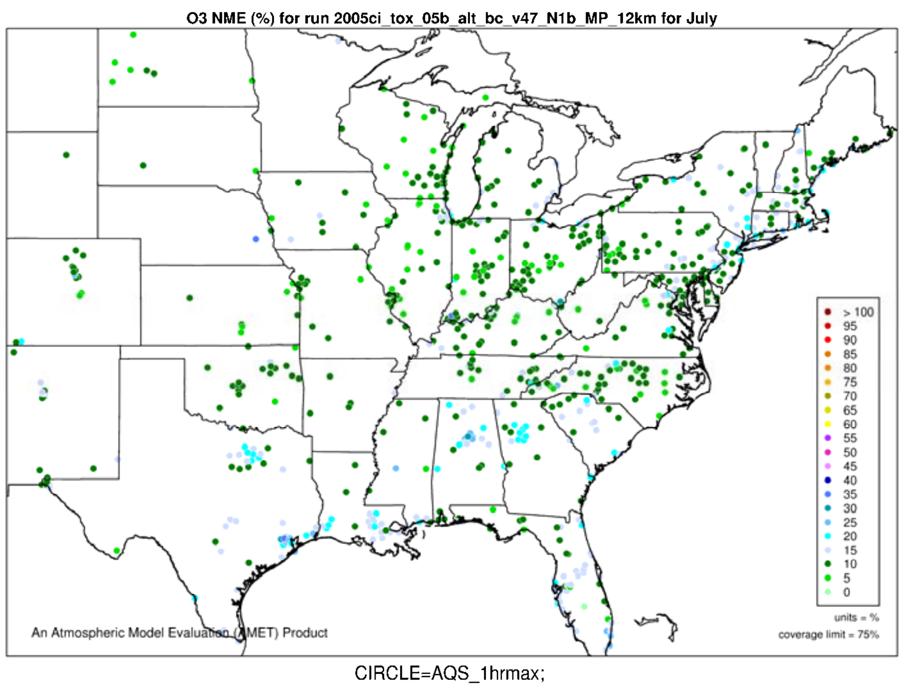


Figure B-6. Normalized Mean Error (%) of one-hour daily maximum ozone (40 ppb threshold) by monitor for Eastern U.S., July 2005.

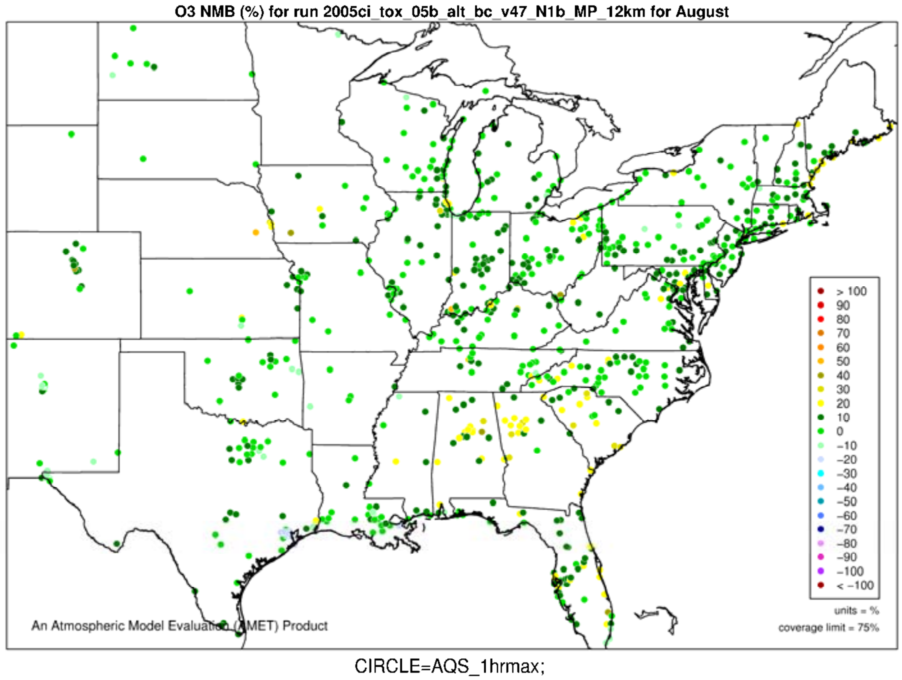


Figure B-7. Normalized Mean Bias (%) of one-hour daily maximum ozone (40 ppb threshold) by monitor for Eastern U.S., August 2005.

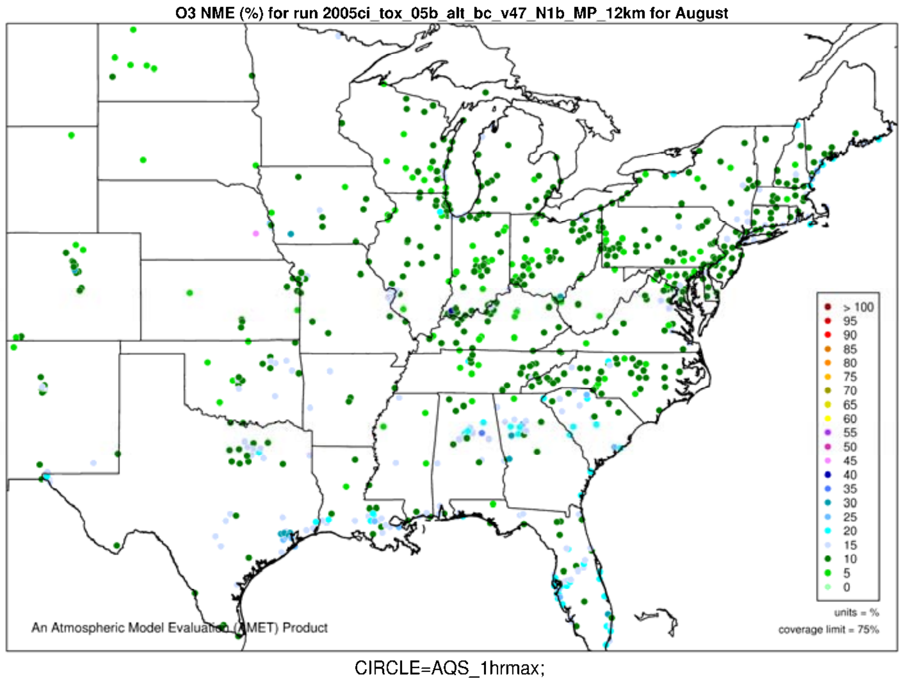


Figure B-8. Normalized Mean Error (%) of one-hour daily maximum ozone (40 ppb threshold) by monitor for Eastern U.S., August 2005.

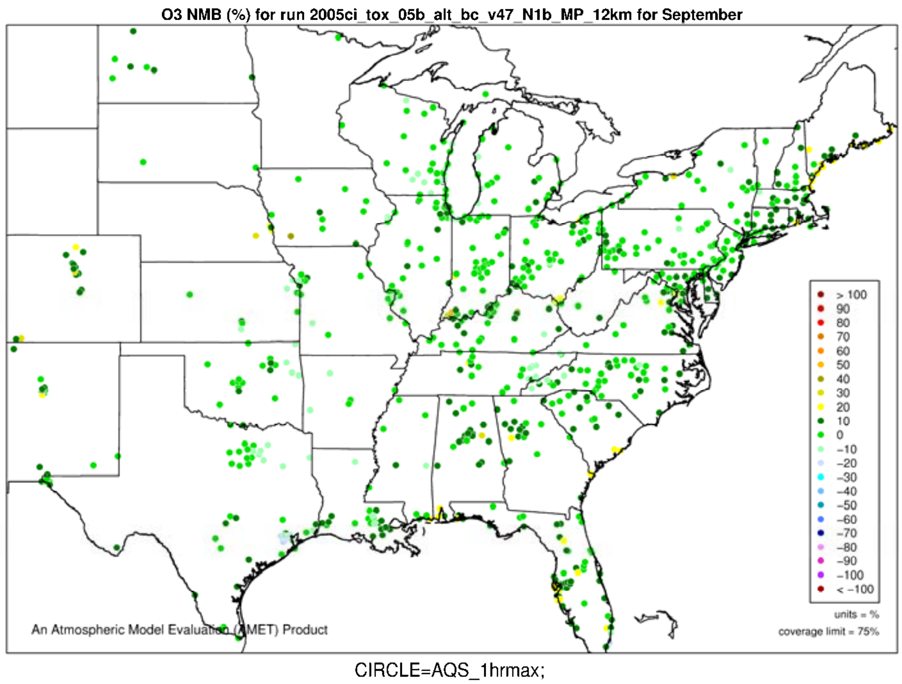


Figure B-9. Normalized Mean Bias (%) of one-hour daily maximum ozone (40 ppb threshold) by monitor for Eastern U.S., September 2005.

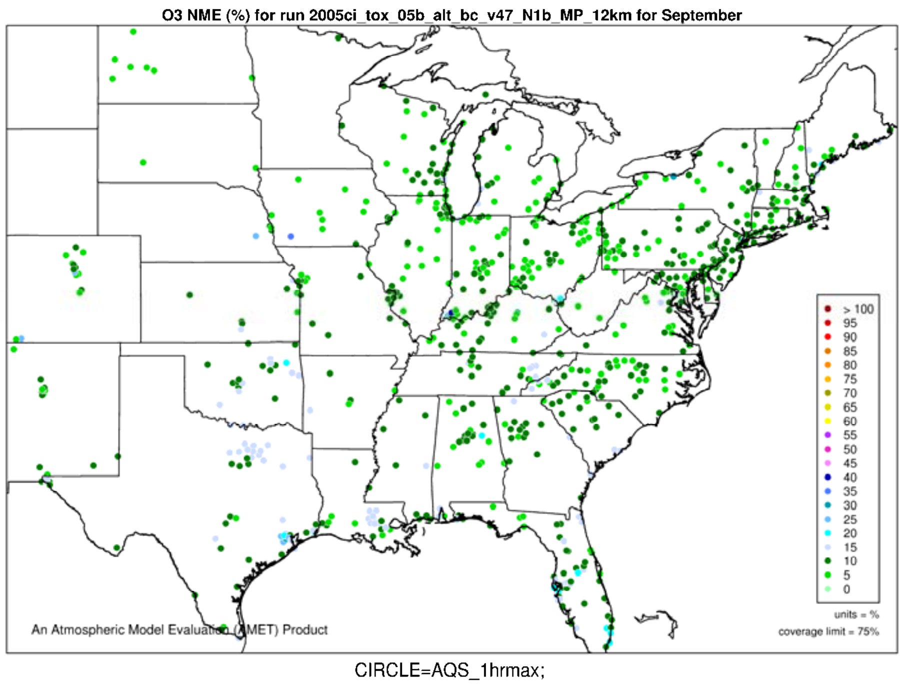


Figure B-10. Normalized Mean Error (%) of one-hour daily maximum ozone (40 ppb threshold) by monitor for Eastern U.S., September 2005.

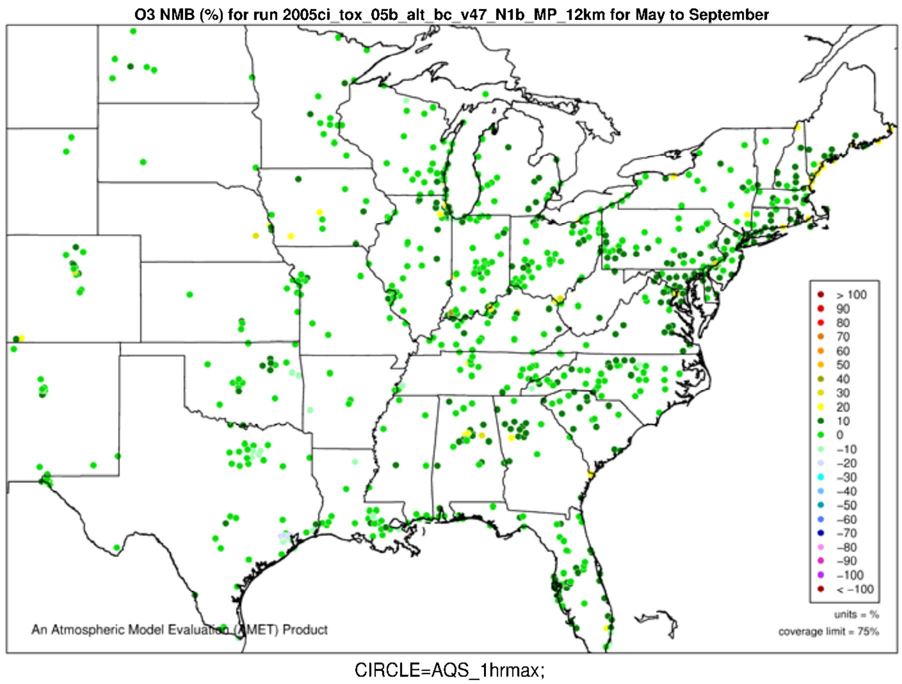


Figure B-11. Normalized Mean Bias (%) of one-hour daily maximum ozone (40 ppb threshold) by monitor for Eastern U.S., seasonal aggregate 2005.

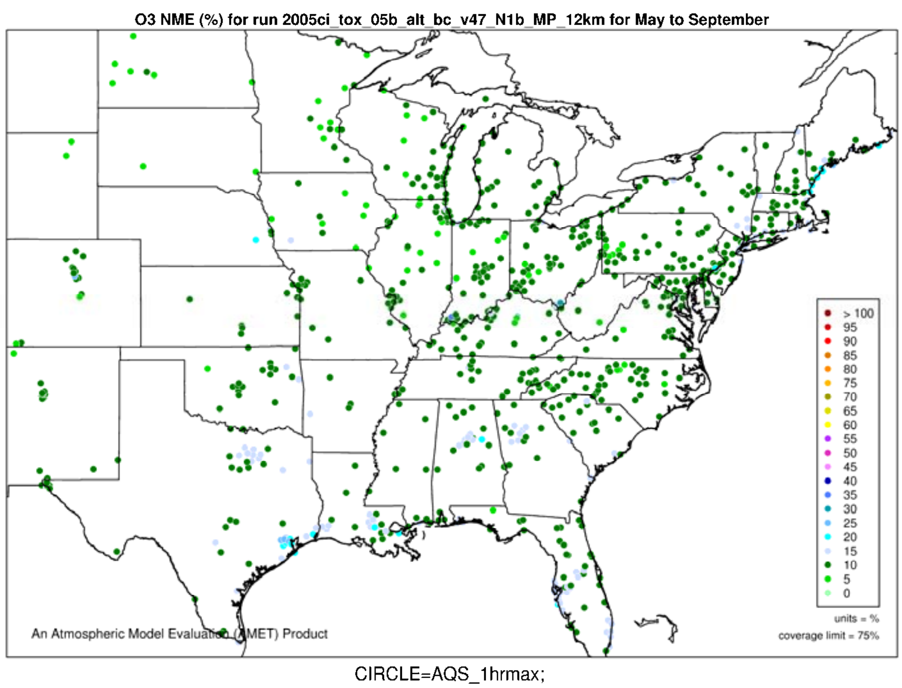


Figure B-12. Normalized Mean Error (%) of one-hour daily maximum ozone (40 ppb threshold) by monitor for Eastern U.S., seasonal aggregate 2005.

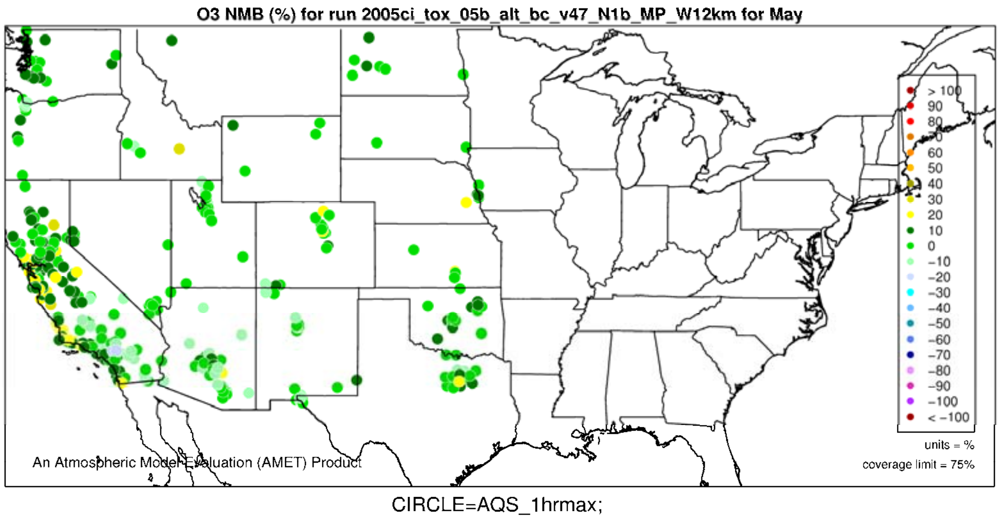


Figure B-13. Normalized Mean Bias (%) of one-hour daily maximum ozone (40 ppb threshold) by monitor for Western U.S., May 2005.

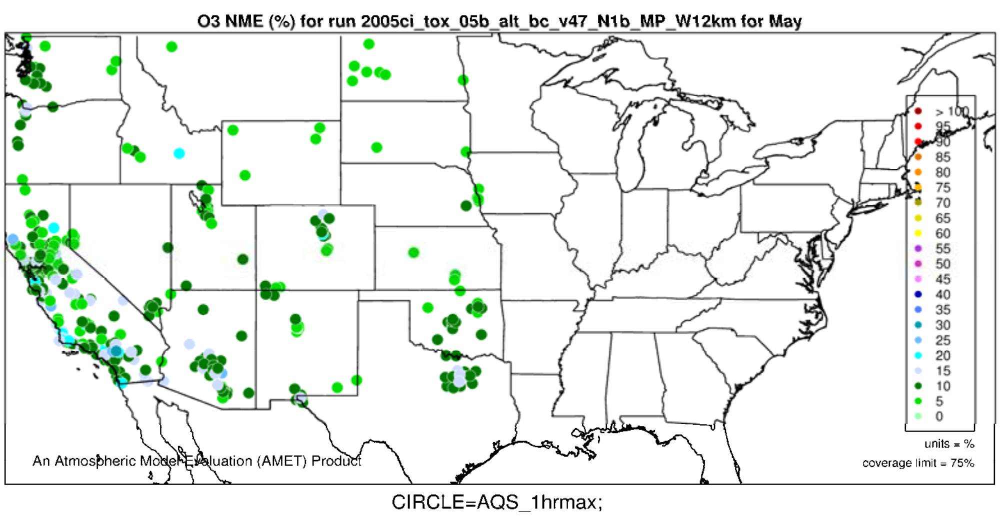


Figure B-14. Normalized Mean Error (%) of one-hour daily maximum ozone (40 ppb threshold) by monitor for Western U.S., May 2005.

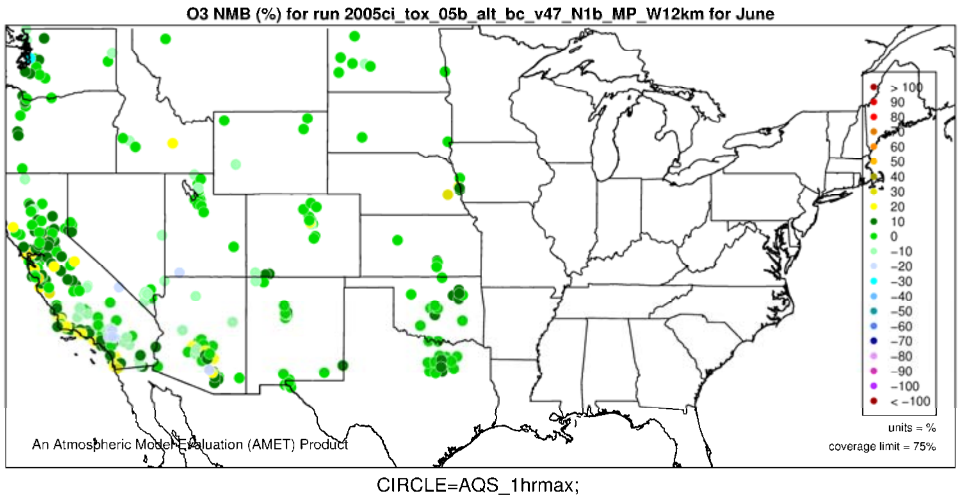


Figure B-15. Normalized Mean Bias (%) of one-hour daily maximum ozone (40 ppb threshold) by monitor for Western U.S., June 2005.

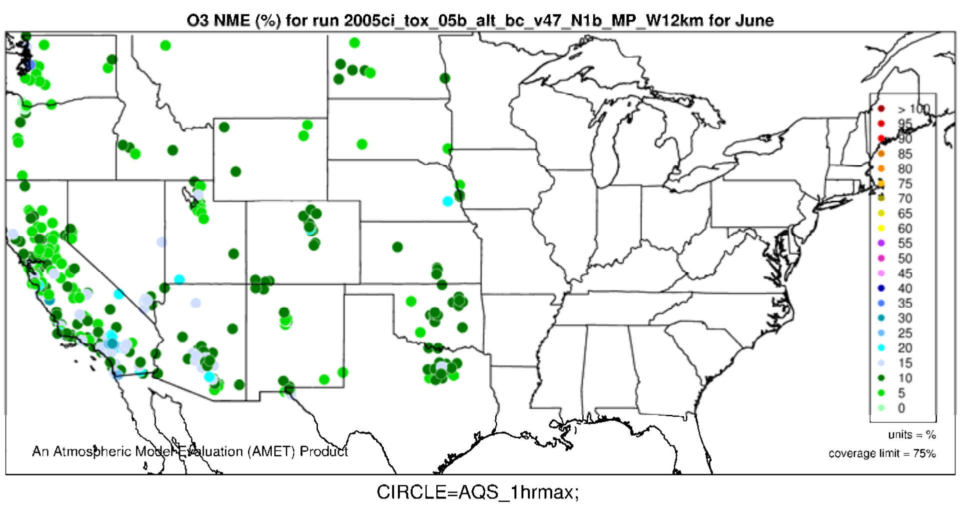


Figure B-16. Normalized Mean Error (%) of one-hour daily maximum ozone (40 ppb threshold) by monitor for Western U.S., June 2005.

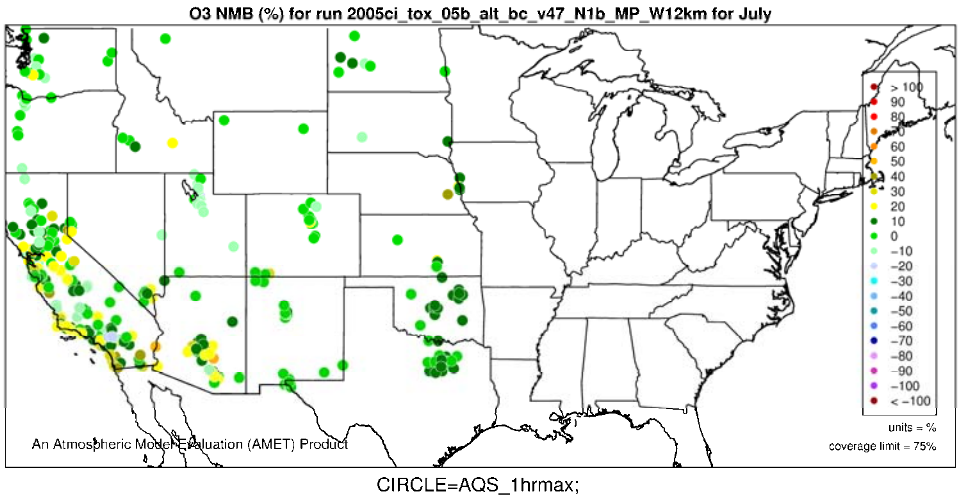


Figure B-17. Normalized Mean Bias (%) of one-hour daily maximum ozone (40 ppb threshold) by monitor for Western U.S., July 2005.

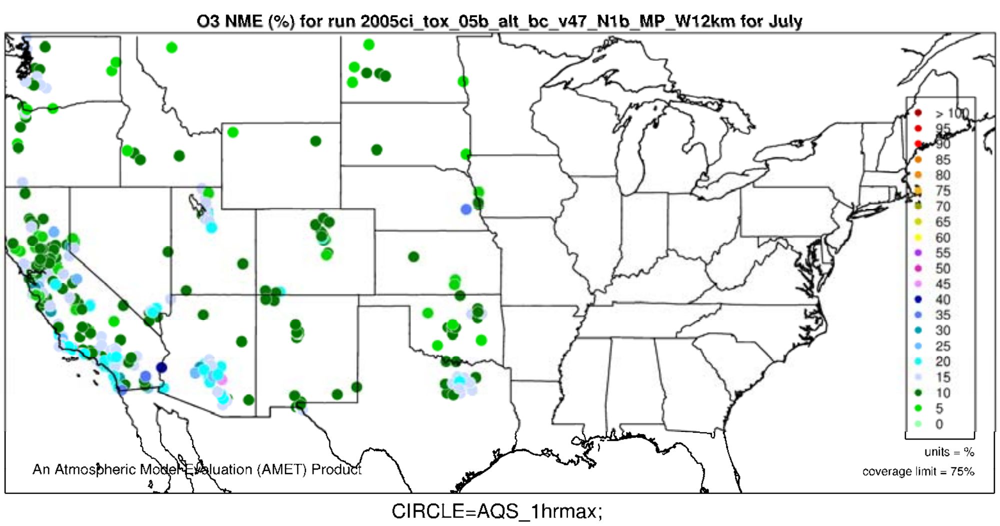


Figure B-18. Normalized Mean Error (%) of one-hour daily maximum ozone (40 ppb threshold) by monitor for Western U.S., July 2005.

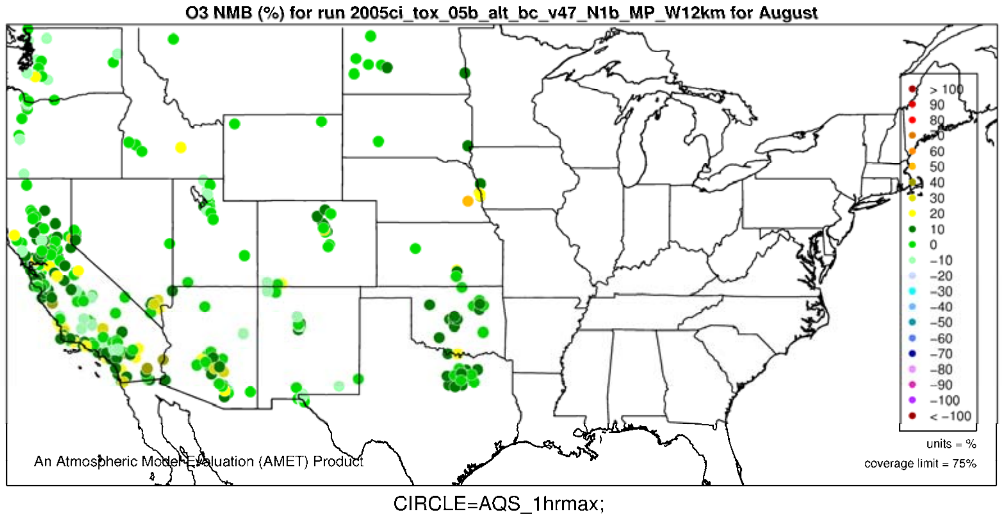


Figure B-19. Normalized Mean Bias (%) of one-hour daily maximum ozone (40 ppb threshold) by monitor for Western U.S., August 2005.

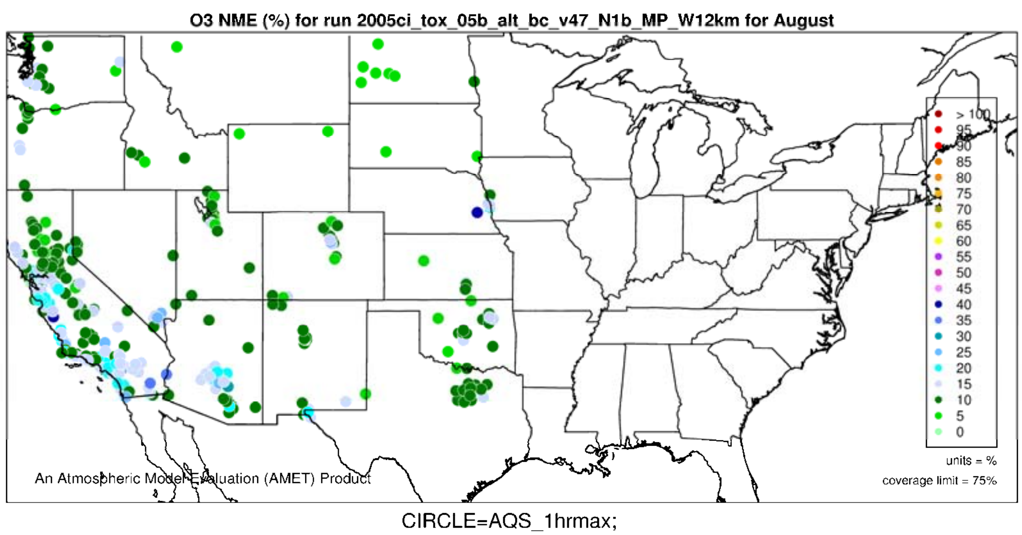


Figure B-20. Normalized Mean Error (%) of one-hour daily maximum ozone (40 ppb threshold) by monitor for Western U.S., August 2005.

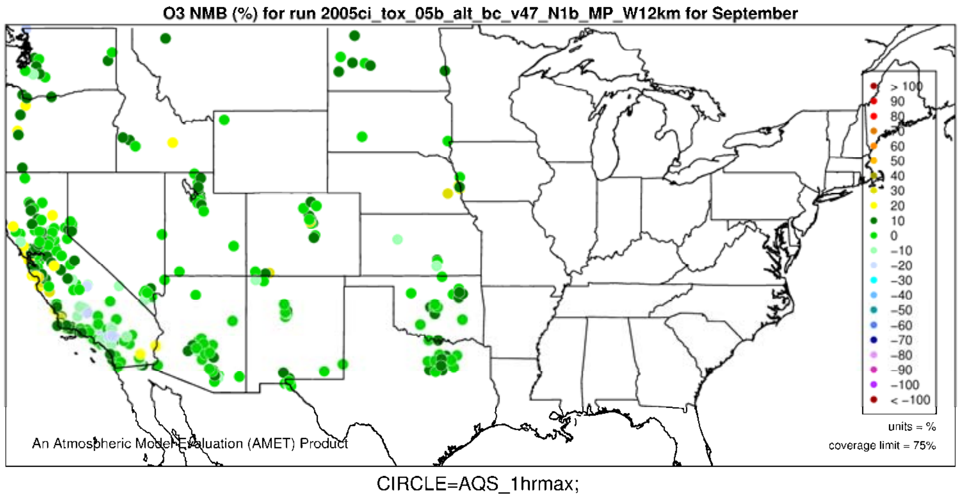


Figure B-21. Normalized Mean Bias (%) of one-hour daily maximum ozone (40 ppb threshold) by monitor for Western U.S., September 2005.

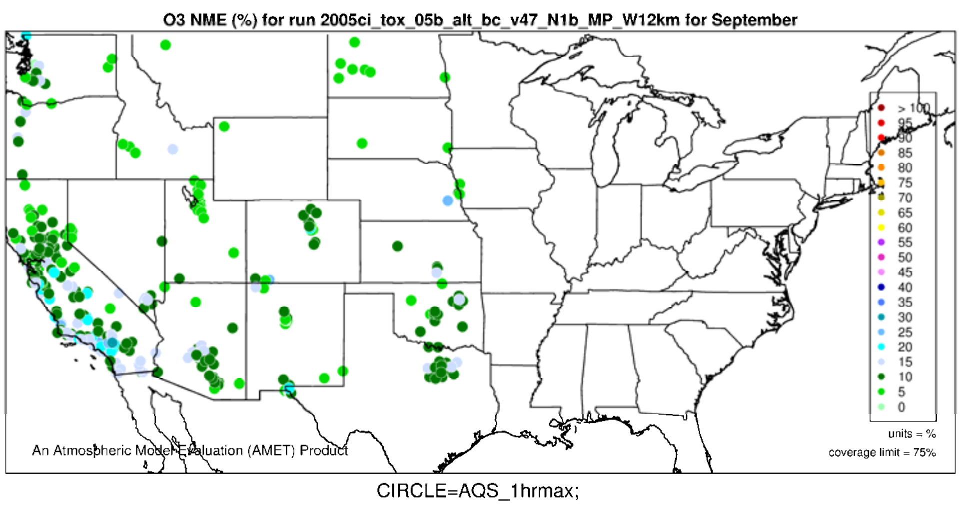


Figure B-22. Normalized Mean Error (%) of one-hour daily maximum ozone (40 ppb threshold) by monitor for Western U.S., September 2005.

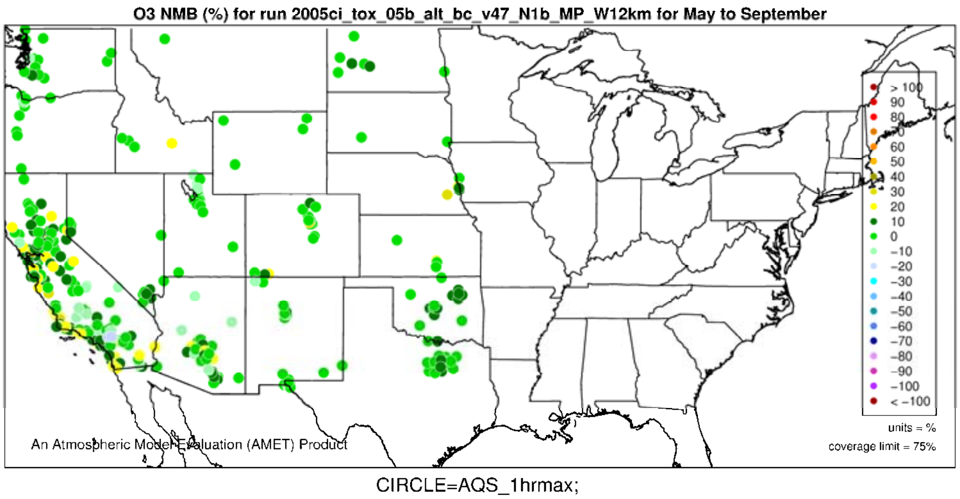


Figure B-23. Normalized Mean Bias (%) of one-hour daily maximum ozone (40 ppb threshold) by monitor for Western U.S., seasonal aggregate 2005.

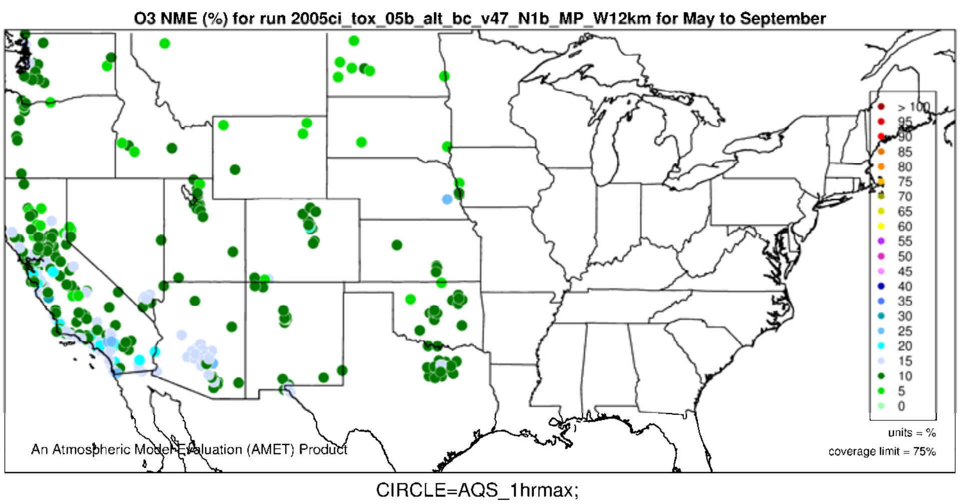


Figure B-24. Normalized Mean Error (%) of one-hour daily maximum ozone (40 ppb threshold) by monitor for Western U.S., seasonal aggregate 2005.

C. Eight-hour Daily Maximum Ozone Performance

Ozone Performance: Threshold of 40 ppb

Table C-1 presents eight-hour daily maximum ozone model performance bias and error statistics for the entire range of observed and modeled concentrations at a threshold of 40 ppb for the ozone season modeled for the 12-km Eastern and Western U.S. domain and the corresponding subregions defined above. Spatial plots of the NMB and NME statistics (units of percent) for individual monitors based on the aggregate and the individual ozone months modeled respectively are shown in Figures C-1 through C-24. In general, CMAQ slightly under-predicts eight-hour daily maximum ozone with a threshold of 40 ppb in the months of May, June and August. Likewise, model predictions in the EUS and WUS are slightly over-predicted in the months of July and August. For the 12-km Eastern domain, the bias statistics are within the range of approximately -4% to 7%, while the error statistics range from 11% to 14% for the aggregate of the ozone season and for most of the months modeled. For the 12-km Western domain, the bias statistics are within the range of approximately 3% to -3%, while the error statistics range from 11% to 13% for the aggregate of the ozone season and for the individual months modeled. The five subregions show relatively similar eight-hour daily maximum ozone performance.

Table C-1. 2005 CMAQ eight-hour daily maximum ozone model performance statistics calculated for a threshold of 40 pbb.

CMAQ 2005 Eight-Hour Maximum Ozone: Threshold of 40 ppb		No. of Obs.	NMB (%)	NME (%)	FB (%)	FE (%)
May	12-km EUS	19310	-1.0	10.9	-0.4	11.0
	12-km WUS	8445	-1.6	12.0	-1.2	12.0
	Midwest	3858	0.2	10.0	0.7	10.2
	Northeast	3528	5.2	11.4	5.4	11.2
	Southeast	6019	-2.1	10.5	-1.6	10.6
	Central U.S.	3927	-5.8	12.8	-5.2	13.0
	West	7234	-1.8	12.1	-1.5	12.0
June	12-km EUS	17404	-2.1	11.9	-1.5	12.0
	12-km WUS	8102	-1.9	11.9	-1.6	11.9
	Midwest	4324	-3.8	11.6	-3.4	11.8
	Northeast	3590	0.3	13.1	1.0	13.2
	Southeast	3924	-0.3	11.4	0.1	11.5
	Central U.S.	3663	-5.5	12.1	-5.0	12.3
	West	6889	-2.2	12.1	-2.0	12.1
July	12-km EUS	17045	3.3	13.4	3.6	13.3
	12-km WUS	8556	3.7	15.0	3.9	14.7
	Midwest	4429	1.8	11.8	2.3	11.8
	Northeast	3856	6.6	14.6	6.8	14.3
	Southeast	3806	7.4	15.0	7.3	14.5
	Central U.S.	3057	-2.3	13.2	-2.1	13.5
	West	7407	3.5	15.1	3.6	14.9

August	12-km EUS	16953	1.9	12.9	2.2	12.9
	12-km WUS	8523	1.6	13.9	1.5	13.9
	Midwest	4027	0.9	11.3	1.4	11.4
	Northeast	3530	1.4	12.3	2.0	12.2
	Southeast	4447	7.4	14.7	7.2	14.1
	Central U.S.	3096	-3.4	14.4	-3.1	14.8
	West	7469	1.4	14.1	1.2	14.0
September	12-km EUS	15190	-1.8	11.2	-1.3	11.3
	12-km WUS	7465	-2.4	13.4	-2.6	13.9
	Midwest	3265	-4.2	10.2	-4.0	10.4
	Northeast	2856	-2.3	10.6	-1.8	10.7
	Southeast	4647	1.5	11.2	2.1	11.2
	Central U.S.	2798	-6.5	13.6	-6.1	14.0
	West	6446	-2.9	13.7	-3.1	14.1
Seasonal Aggregate (May – September)	12-km EUS	85902	0.1	12.1	0.5	12.1
	12-km WUS	41091	0.0	13.3	0.1	13.3
	Midwest	19903	-0.9	11.1	-0.5	11.2
	Northeast	17360	2.4	12.6	2.9	12.4
	Southeast	22843	2.3	12.3	2.6	12.2
	Central U.S.	16541	-4.8	13.2	-4.4	13.4
	West	35445	-0.2	13.5	-0.3	13.5

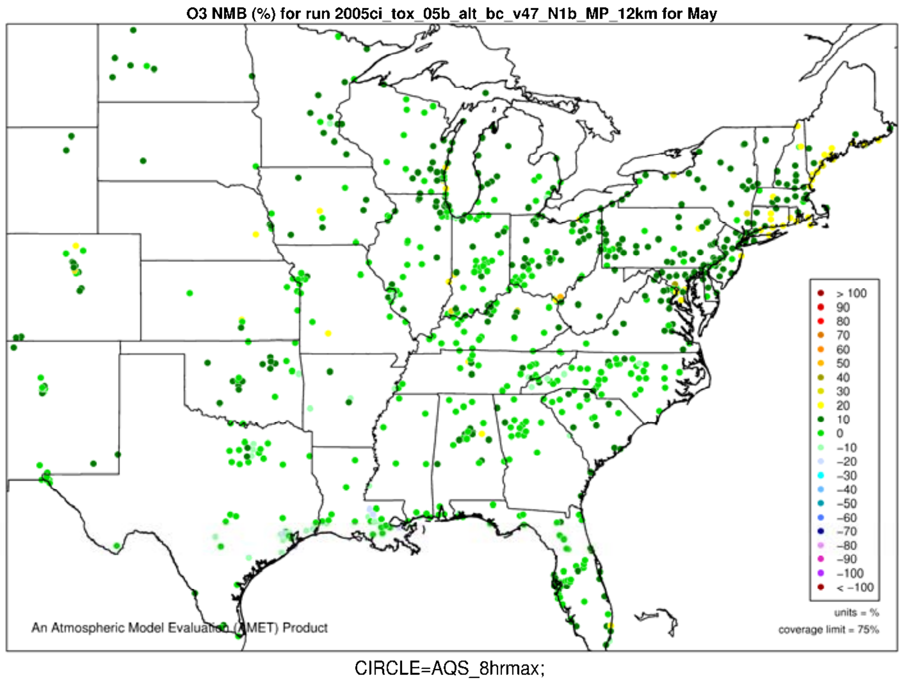


Figure C-1. Normalized Mean Bias (%) of eight-hour daily maximum ozone (40 ppb threshold) by monitor for Eastern U.S., May 2005.

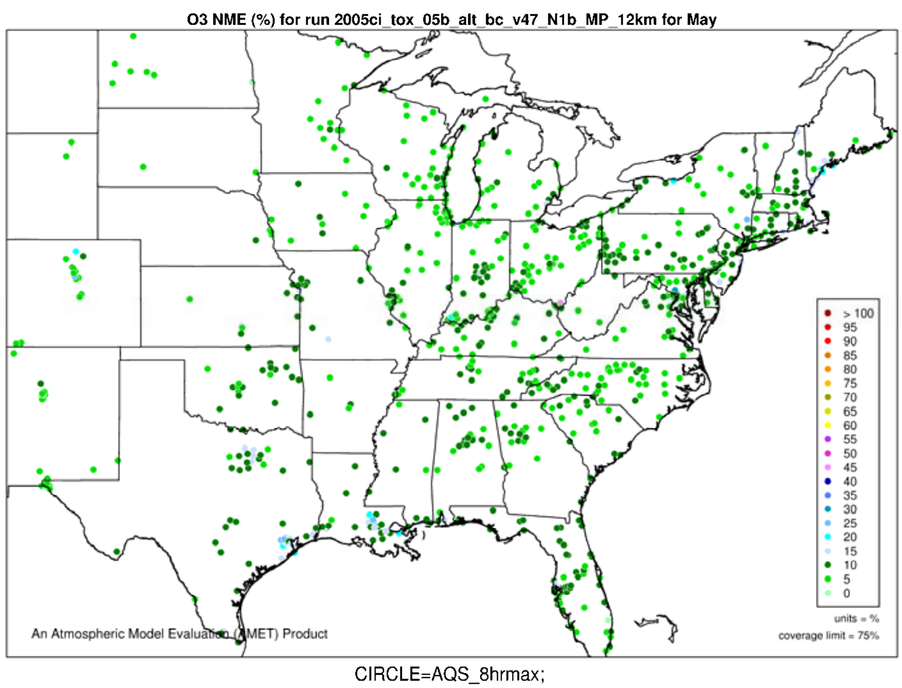


Figure C-2. Normalized Mean Error (%) of eight-hour daily maximum ozone (40 ppb threshold) by monitor for Eastern U.S., May 2005.

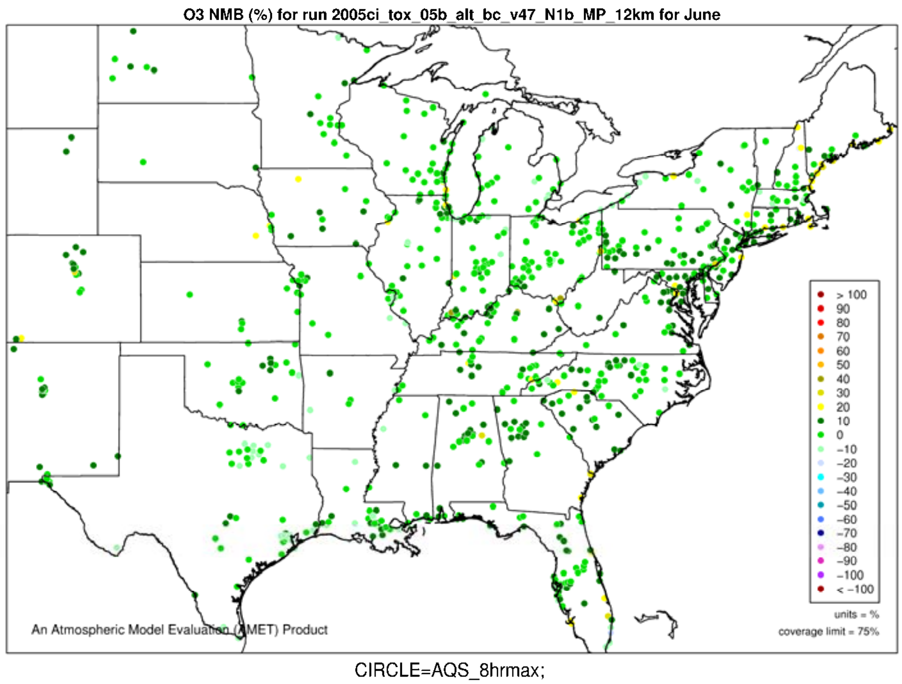


Figure C-3. Normalized Mean Bias (%) of eight-hour daily maximum ozone (40 ppb threshold) by monitor for Eastern U.S., June 2005.

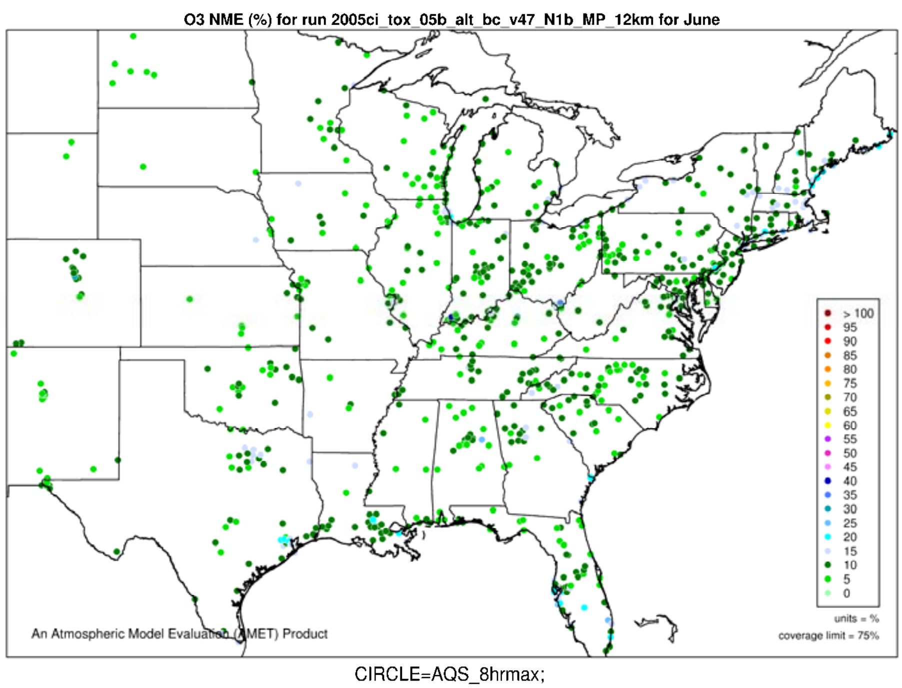


Figure C-4. Normalized Mean Error (%) of eight-hour daily maximum ozone (40 ppb threshold) by monitor for Eastern U.S., June 2005.

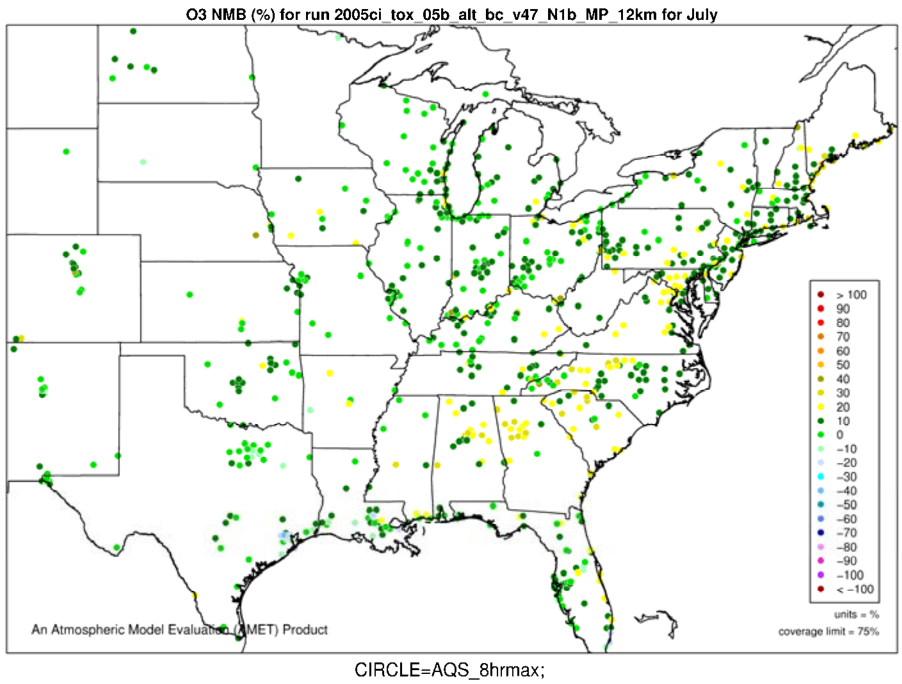


Figure C-5. Normalized Mean Bias (%) of eight-hour daily maximum ozone (40 ppb threshold) by monitor for Eastern U.S., July 2005.

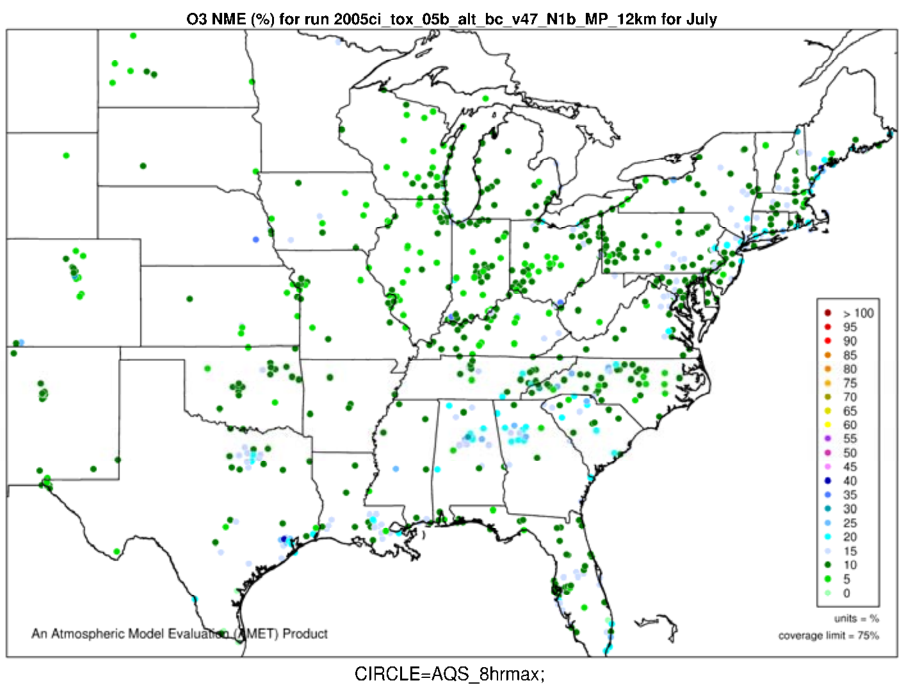


Figure C-6. Normalized Mean Error (%) of eight-hour daily maximum ozone (40 ppb threshold) by monitor for Eastern U.S., July 2005.

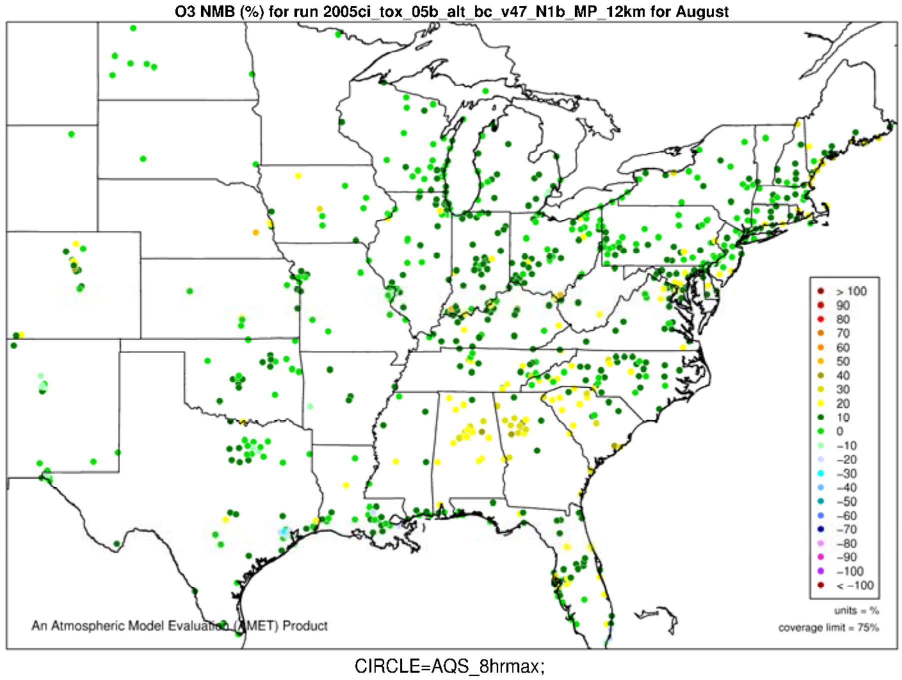


Figure C-7. Normalized Mean Bias (%) of eight-hour daily maximum ozone (40 ppb threshold) by monitor for Eastern U.S., August 2005.

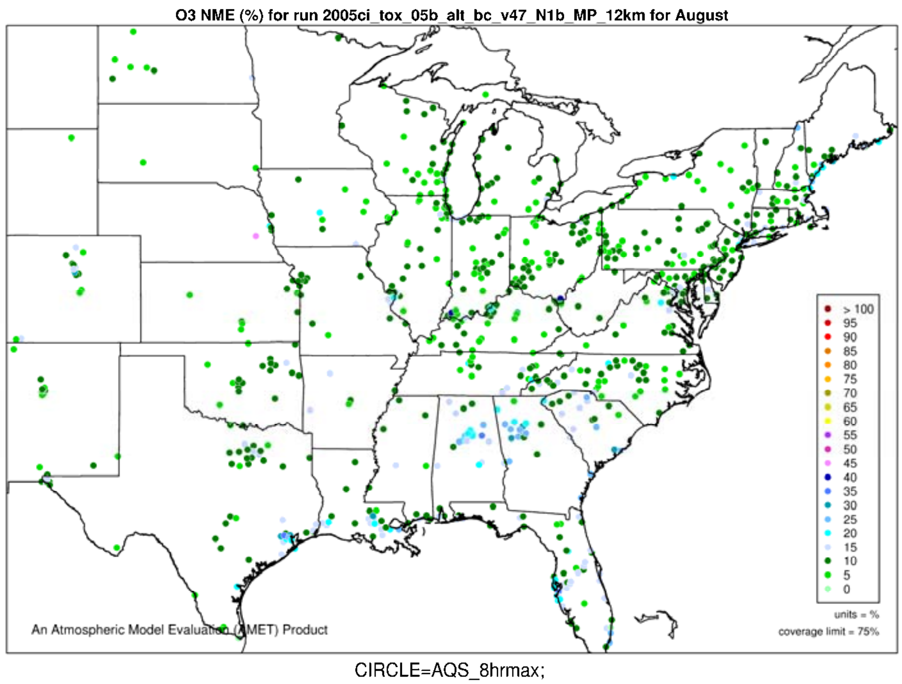


Figure C-8. Normalized Mean Error (%) of eight-hour daily maximum ozone (40 ppb threshold) by monitor for Eastern U.S., August 2005.

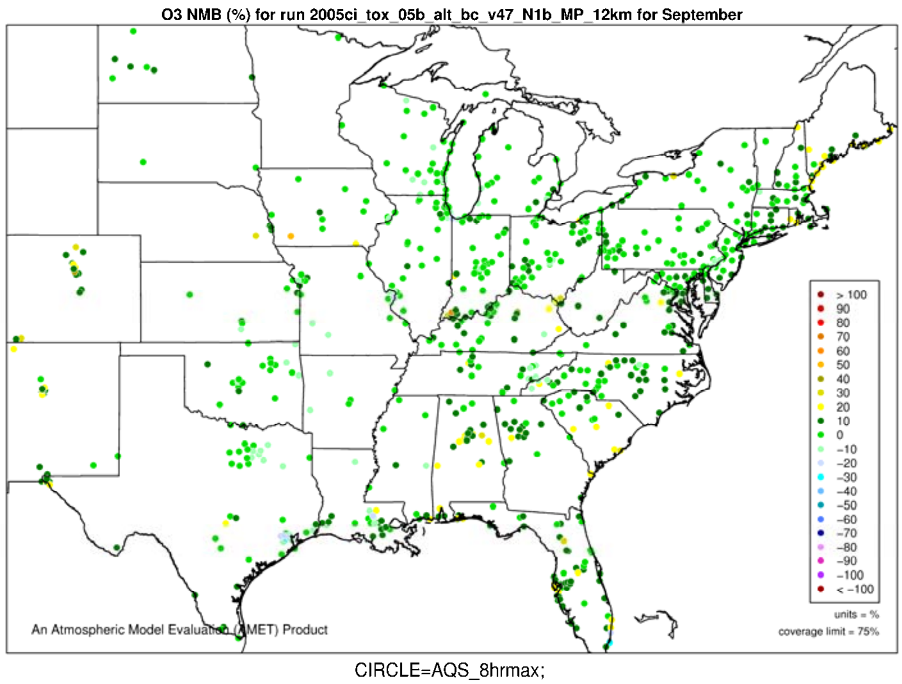


Figure C-9. Normalized Mean Bias (%) of eight-hour daily maximum ozone (40 ppb threshold) by monitor for Eastern U.S., September 2005.

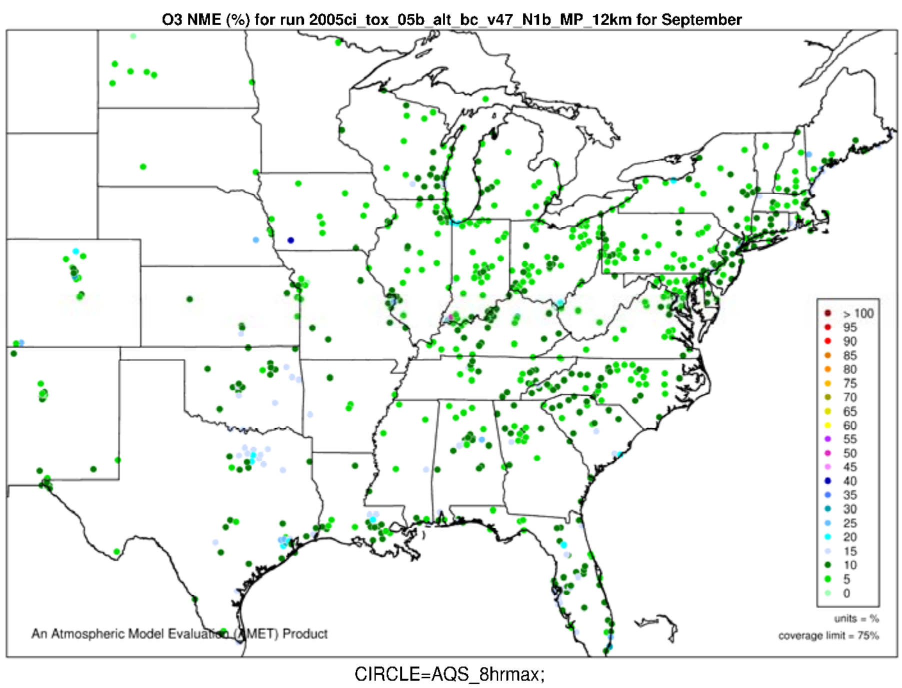


Figure C-10. Normalized Mean Error (%) of eight-hour daily maximum ozone (40 ppb threshold) by monitor for Eastern U.S., September 2005.

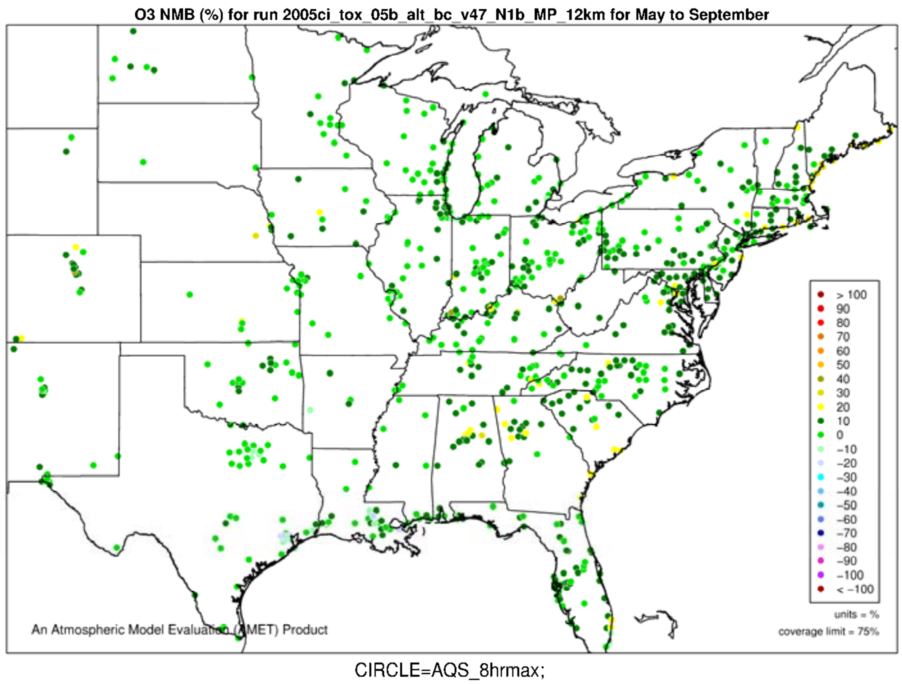


Figure C-11. Normalized Mean Bias (%) of eight-hour daily maximum ozone (40 ppb threshold) by monitor for Eastern U.S., seasonal aggregate 2005.

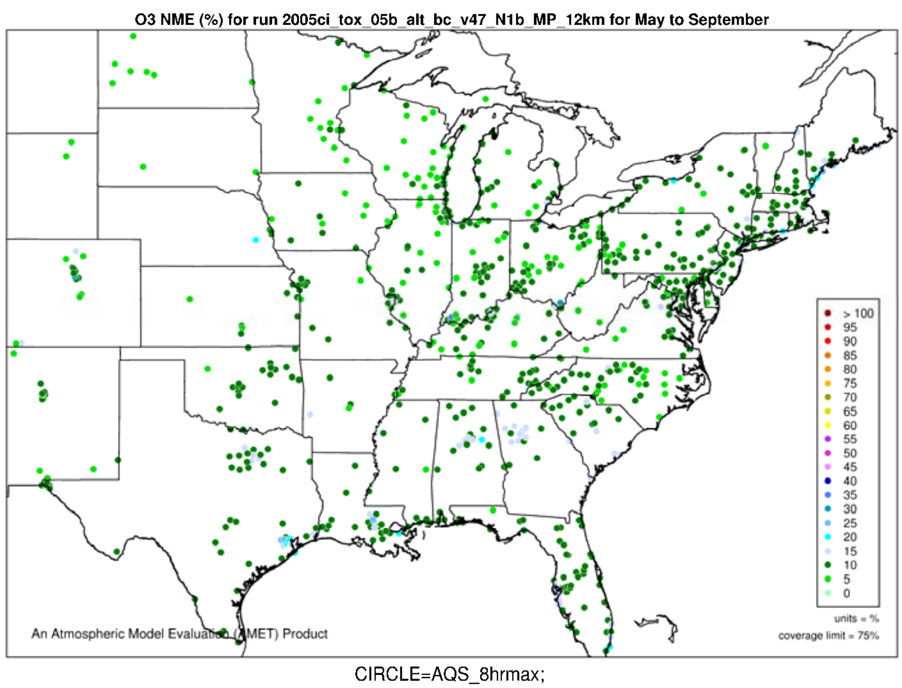


Figure C-12. Normalized Mean Error (%) of eight-hour daily maximum ozone (40 ppb threshold) by monitor for Eastern U.S., seasonal aggregate 2005.

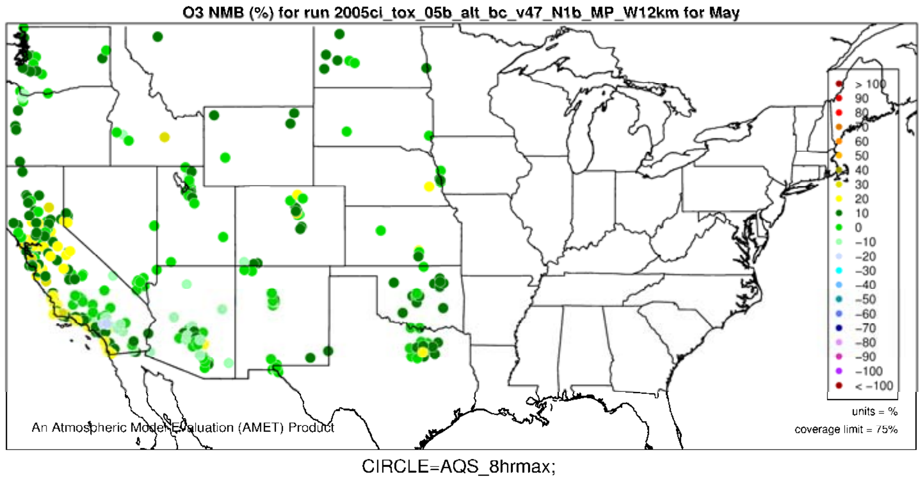


Figure C-13. Normalized Mean Bias (%) of eight-hour daily maximum ozone (40 ppb threshold) by monitor for Western U.S., May 2005.

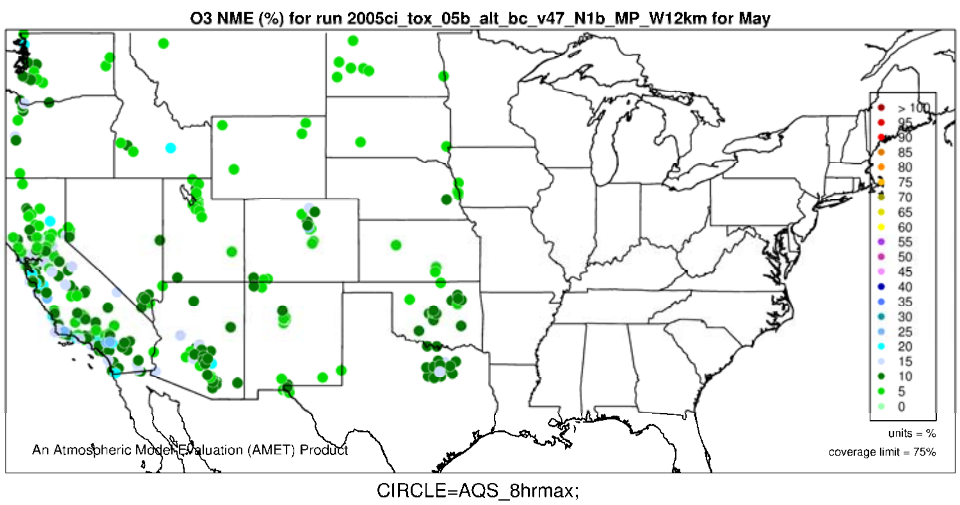


Figure C-14. Normalized Mean Error (%) of eight-hour daily maximum ozone (40 ppb threshold) by monitor for Western U.S., May 2005.

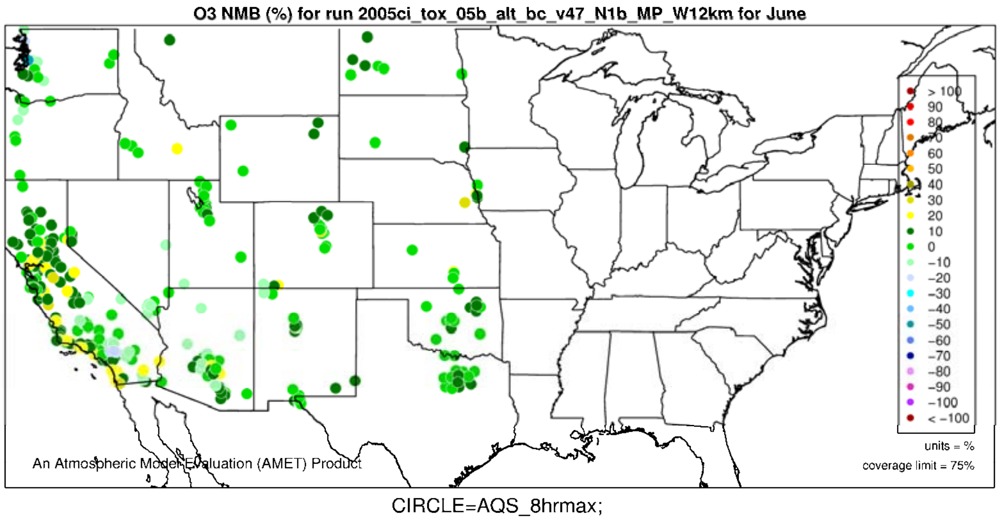


Figure C-15. Normalized Mean Bias (%) of eight-hour daily maximum ozone (40 ppb threshold) by monitor for Western U.S., June 2005.

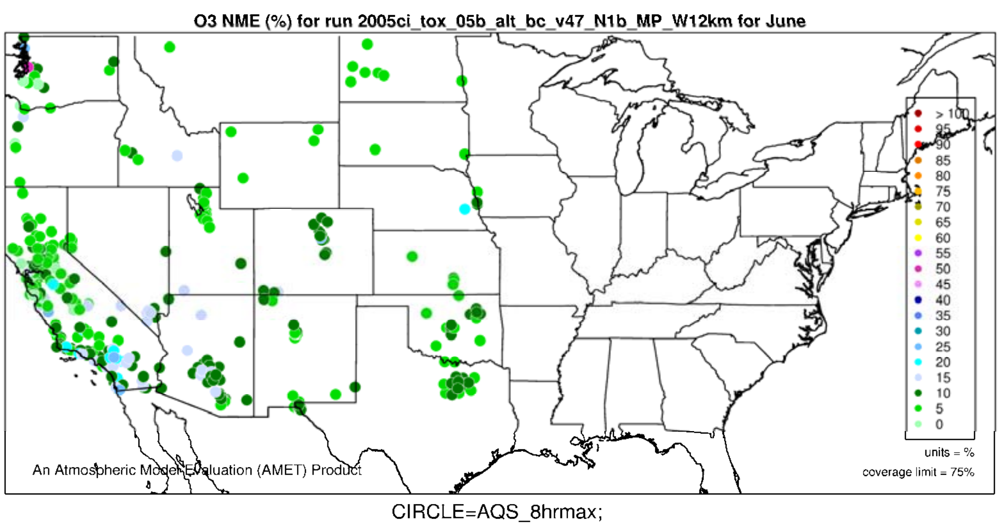


Figure C-16. Normalized Mean Error (%) of eight-hour daily maximum ozone (40 ppb threshold) by monitor for Western U.S., June 2005.

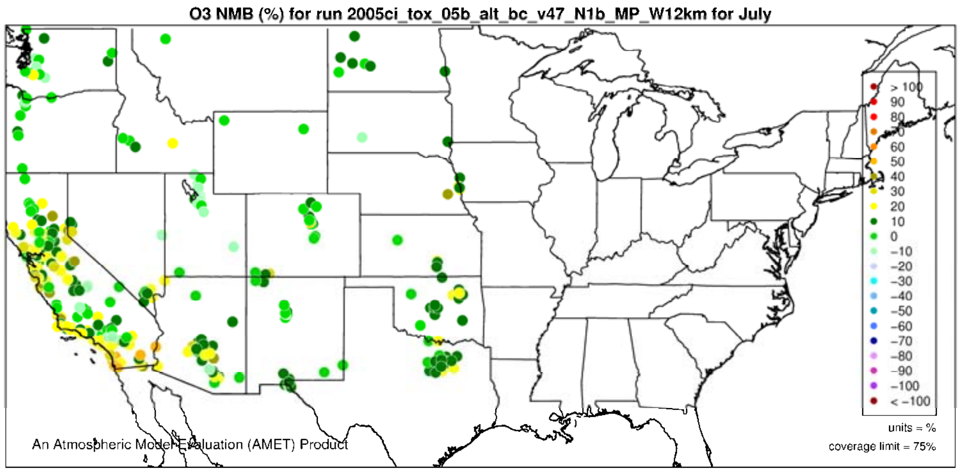


Figure C-17. Normalized Mean Bias (%) of eight-hour daily maximum ozone (40 ppb threshold) by monitor for Western U.S., July 2005.

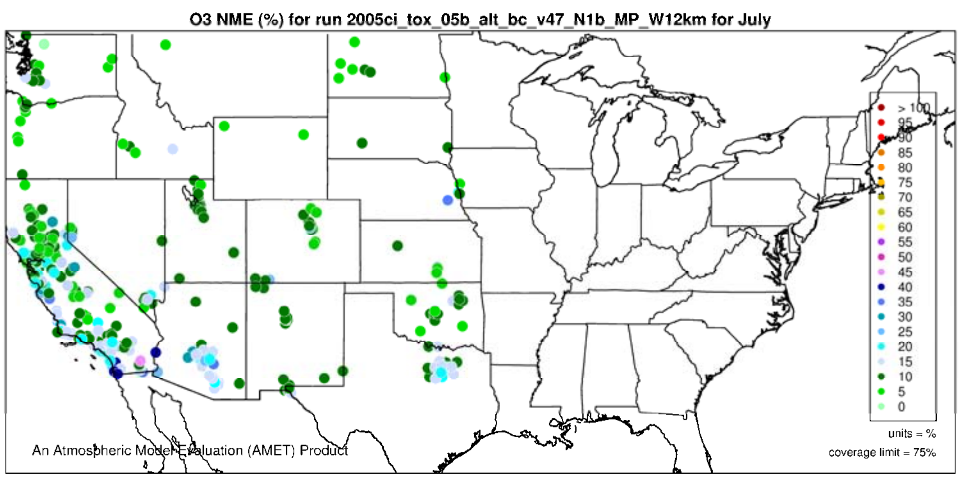


Figure C-18. Normalized Mean Error (%) of eight-hour daily maximum ozone (40 ppb threshold) by monitor for Western U.S., July 2005.

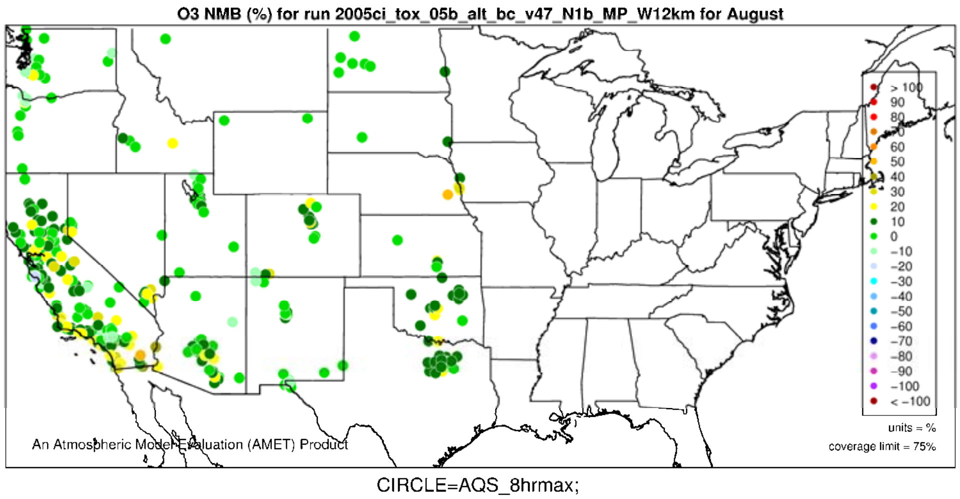


Figure C-19. Normalized Mean Bias (%) of eight-hour daily maximum ozone (40 ppb threshold) by monitor for Western U.S., August 2005.

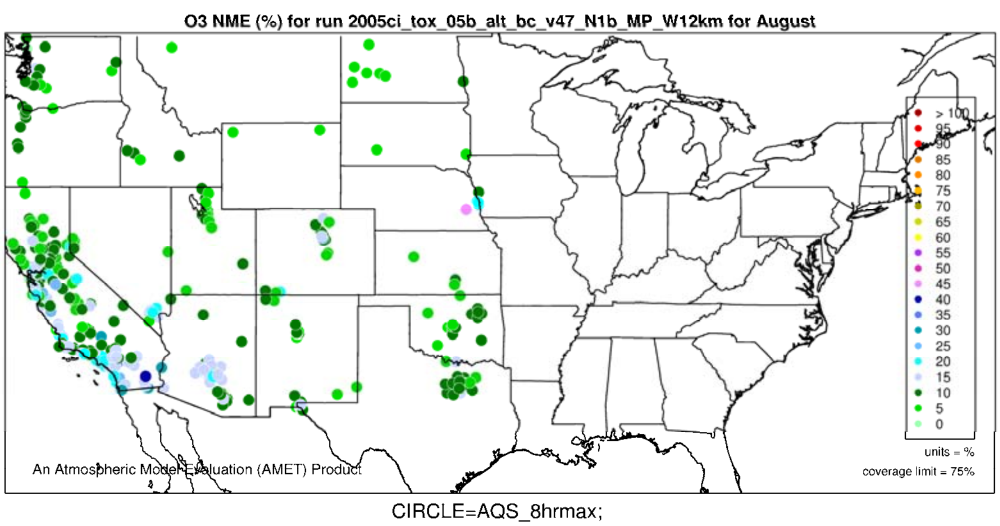


Figure C-20. Normalized Mean Error (%) of eight-hour daily maximum ozone (40 ppb threshold) by monitor for Western U.S., August 2005.

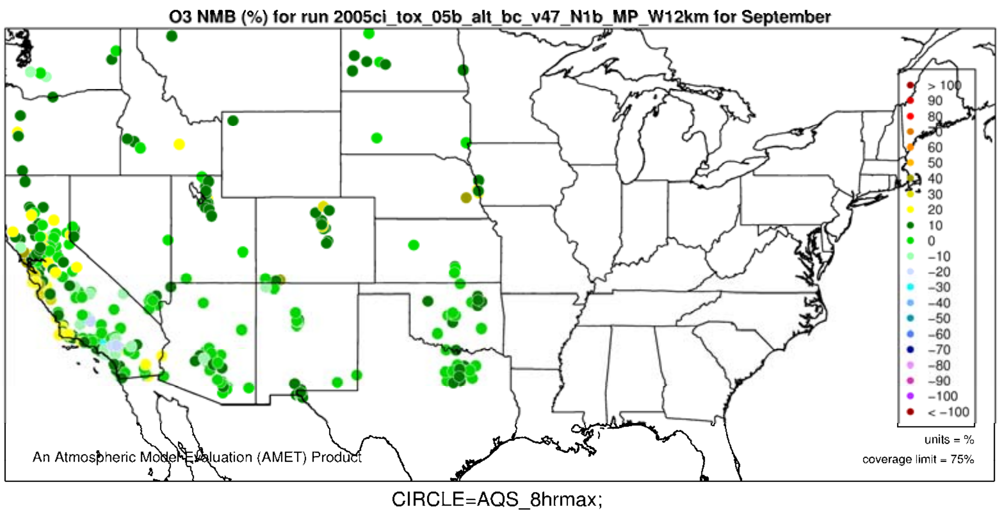


Figure C-21. Normalized Mean Bias (%) of eight-hour daily maximum ozone (40 ppb threshold) by monitor for Western U.S., September 2005.

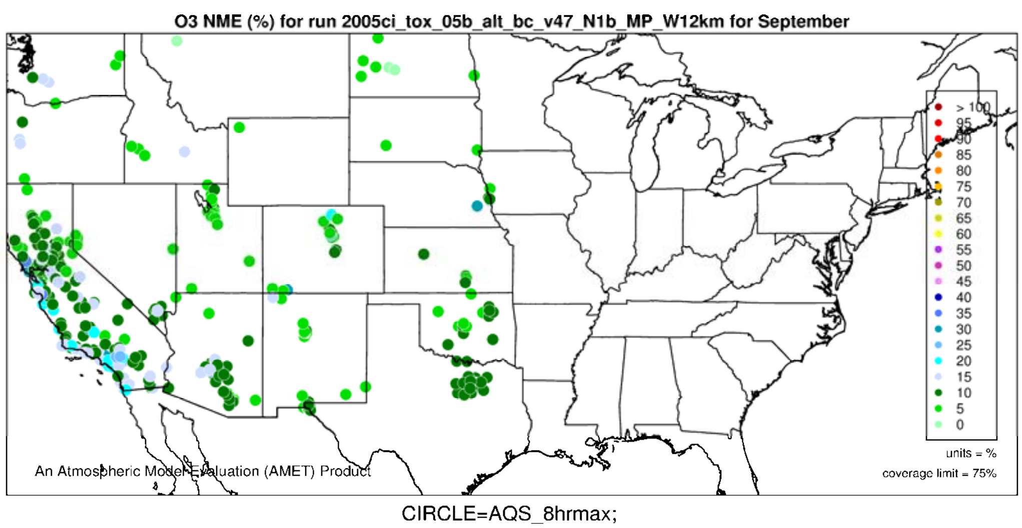


Figure C-22. Normalized Mean Error (%) of eight-hour daily maximum ozone (40 ppb threshold) by monitor for Western U.S., September 2005.

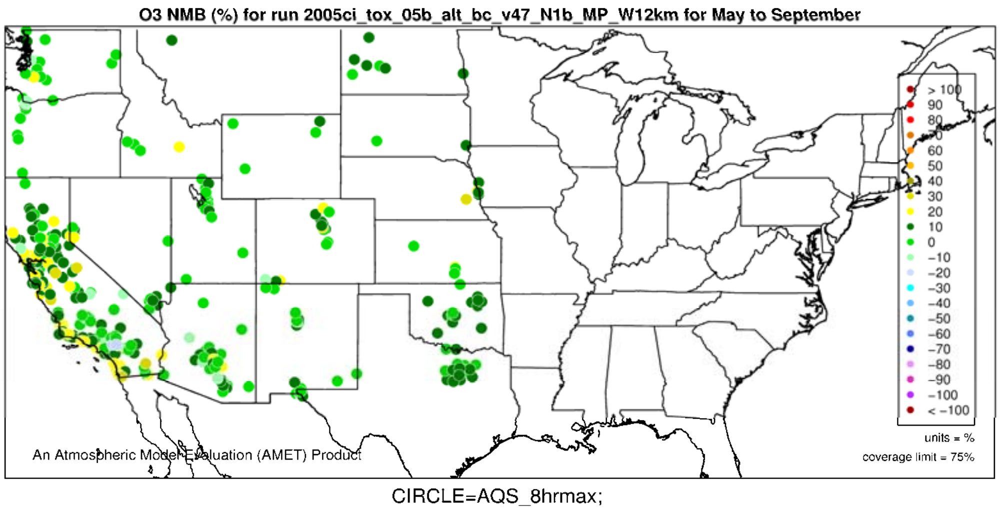


Figure C-23. Normalized Mean Bias (%) of eight-hour daily maximum ozone (40 ppb threshold) by monitor for Western U.S., seasonal aggregate 2005.

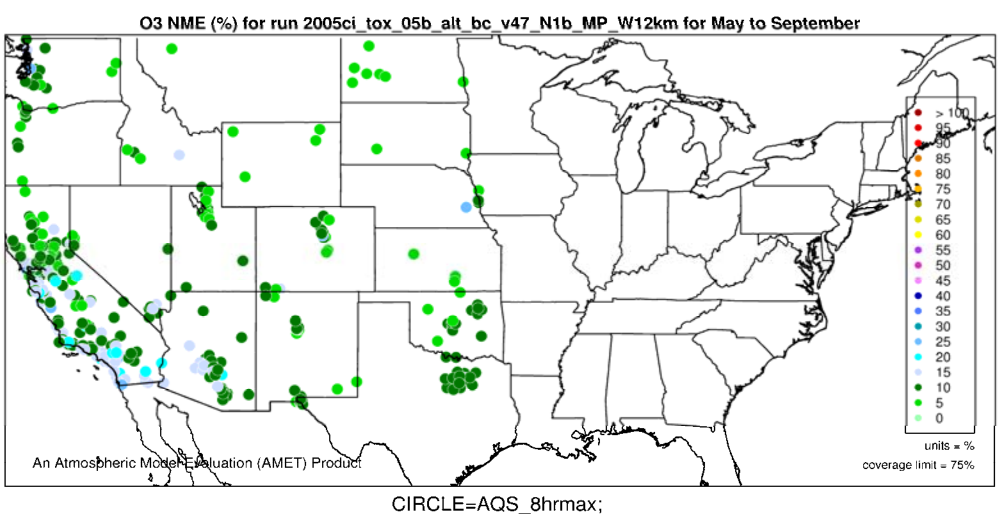


Figure C-24. Normalized Mean Error (%) of eight-hour daily maximum ozone (40 ppb threshold) by monitor for Western U.S., seasonal aggregate 2005.

D. Annual $PM_{2.5}$ Species Evaluation

Table D-1 provides annual model performance statistics for $PM_{2.5}$ and its component species for the 12-km Eastern domain, 12-km Western domain, and five subregions defined in Section A (Midwest, Northeast, Southeast, Central, and West U.S.). Spatial plots of the NMB and NME statistics (units of percent) for individual monitors are also provided as a complement to the tabular statistical data (Figures D-1 – D-28). In the East, annual total $PM_{2.5}$ mass is under-predicted when compared at STN and IMPROVE sites in the Southeast and Central U.S. In the West, annual total $PM_{2.5}$ mass is under-predicted when evaluated at STN sites and IMPROVE sites, with slightly better performance at the STN network (bias ~ -10). Although not shown here, the mean observed concentrations of $PM_{2.5}$ are approximately twice as high at the STN sites (EUS = ~13µg m^{-3}; WUS = ~11µg m^{-3}) as the IMPROVE sites (EUS = ~7µg m^{-3}; WUS = ~4µg m^{-3}), thus illustrating the statistical differences between the urban STN and rural IMPROVE networks. Sulfate is consistently under-predicted at STN, IMPROVE, and CASTNet sites, with NMB values ranging from -29% to -1%. Overall, sulfate performance is best in the East at urban STN sites. Nitrate is over-predicted in the 12-km Eastern domain (NMB in the range of 25% to 86%), while nitrate is under-predicted in the 12-km Western domain (NMB in the range of -18% to -47%). Likewise, model performance of total nitrate at CASTNet sites shows an over-prediction in the East (NMB ~ 40%) and in the West (NMB ~ 5%). Ammonium model performance varies across the STN and CASTNet in the East and West, with a mix of over and under-predictions in the Eastern domain and also an under-prediction in the West. Elemental carbon is over-predicted at STN sites in the East and West with a bias of ~30% and error of ~70%. Although, EC is under-predicted at IMPROVE sites in the East and over-predicted in the West. Organic carbon is moderately under-predicted for all domains in the STN and IMPROVE networks (bias ~ -30% and error ~ 50%. Differences in model predictions between IMPROVE and STN networks could be attributed to both the rural versus urban characteristics as well as differences in the measurement methodology between the two networks (e.g. blank correction factors, and filter technology used).

Table D-1. 2005 CMAQ annual $PM_{2.5}$ species model performance statistics.

CMAQ 2005 Annual $PM_{2.5}$ species			No. of Obs.	NMB (%)	NME (%)	FB (%)	FE (%)
$PM_{2.5}$ Total Mass	STN	12-km EUS	11797	6.6	39.5	4.0	39.2
		12-km WUS	3440	-10.0	45.0	-9.5	44.4
		Northeast	2318	16.6	38.1	15.8	35.1
		Midwest	3020	19.5	45.6	16.5	40.7
		Southeast	3067	-7.2	34.1	-7.6	29.1
		Central U.S.	2523	0.6	41.7	-3.6	44.7
		West	2826	-10.9	46.1	-10.6	45.0
	IMPROVE	12-km EUS	9321	1.6	43.4	0.0	44.0
		12-km WUS	10411	-10.9	44.8	-13.6	46.8
		Northeast	571	9.1	39.4	8	38.5
		Midwest	2339	21.5	52.9	14.9	46.8

		Southeast	1694	-10.5	37.2	-9.7	42.3
		Central U.S.	2376	-5.5	42.4	-4.7	46.0
		West	8820	-13.3	45.0	-14.5	47.2
Sulfate	STN	12-km EUS	13897	-8.7	32.6	-5.8	35.2
		12-km WUS	3920	-17.0	42.3	-7.8	42.8
		Northeast	2495	-1.2	33.4	4.1	34.1
		Midwest	3498	-3.9	31.7	-0.7	33.3
		Southeast	3882	-10.9	30.3	-8.6	32.9
		Central U.S.	3059	-19.8	36.5	-16.6	40.8
		West	3157	-15.5	45.8	-6.7	44.0
	IMPROVE	12-km EUS	9034	-11.4	33.8	-2.6	38.4
		12-km WUS	10002	-9.0	39.9	6.8	43.5
		Northeast	531	-9.5	31.8	-1.9	34.1
		Midwest	2253	-3.8	34.2	3.0	37.1
		Southeast	1685	-13.8	31.5	-8.1	35.4
		Central U.S.	2350	-19.7	35.8	-12.2	39.8
		West	8496	-4.7	41.7	9.6	44.4
	CASTNet	12-km EUS	3170	-15.7	23.1	-14.2	25.8
		12-km WUS	1142	-19.8	31.1	-10.5	32.6
		Northeast	615	-13.4	21.7	-11.0	22.9
		Midwest	786	-10.3	21.3	-7.7	23.0
		Southeast	1099	-17.9	22.7	-19.5	25.6
		Central U.S.	300	-29.1	32.0	-29.3	35.2
		West	1041	-18.4	31.6	-9.3	32.8
Nitrate	STN	12-km EUS	12741	37.8	78.6	0.4	79.4
		12-km WUS	3655	-41.7	65.3	-70.8	97.5
		Northeast	2495	41.0	73.3	24.0	66.8
		Midwest	3499	48.9	83.1	11.5	75.6
		Southeast	3882	34.5	93.7	-19.4	91.4
		Central U.S.	1927	25.0	67.2	4.8	75.0
		West	3139	-47.3	65.4	-79.1	99.9
	IMPROVE	12-km EUS	9027	52.8	98.5	-21.0	101.4
		12-km WUS	9987	-18.3	75.4	-84.2	120.6
		Northeast	531	32.8	77.1	2.0	83.8
		Midwest	2248	86.2	122.5	8.9	97.3
		Southeast	1685	67.2	126.4	-24.5	104.4
		Central U.S.	2350	40.89	82.1	-10.1	95.8
		West	8480	-35.7	77.0	-91.7	124.2
Total Nitrate (NO3 + HNO3)	CASTNet	12-km EUS	3170	41.0	51.0	31.7	44.0
		12-km WUS	1142	5.4	36.3	13.1	40.6
		Northeast	615	37.4	47.0	35.1	40.6
		Midwest	786	55.8	59.4	44.4	50.2
		Southeast	1099	41.8	53.4	29.0	45.6
		Central U.S.	300	23.6	40.3	16.8	36.2

		West	1041	4.8	37.6	14.7	41.6
Ammonium	STN	12-km EUS	13897	13.0	44.8	17.2	46.8
		12-km WUS	3893	-14.9	55.3	7.1	55.0
		Northeast	2495	21.0	44.8	27.0	43.8
		Midwest	3498	21.2	47.6	29.5	48.2
		Southeast	3882	7.0	41.4	11.4	43.4
		Central U.S.	3059	1.3	45.1	4.22	51.1
		West	3130	-20.5	59.0	5.8	57.2
	CASTNet	12-km EUS	3170	5.7	36.5	7.1	36.8
		12-km WUS	1142	-6.4	37.8	-4.0	37.6
		Northeast	615	15.4	37.2	18.9	35.2
		Midwest	786	14.5	40.8	18.4	38.7
		Southeast	1099	-7.5	32.9	-7.4	36.2
		Central U.S.	300	3.3	36.9	5.5	40.1
		West	1041	-12.6	37.1	-4.9	37.5
Elemental Carbon	STN	12-km EUS	14038	45.5	77.1	30.6	58.3
		12-km WUS	3814	31.1	77.7	19.5	62.5
		Northeast	2502	40.4	65.9	33.8	53.4
		Midwest	3479	57.3	83.7	38.5	59.6
		Southeast	3877	27.2	64.4	20.6	51.0
		Central U.S.	3221	72.1	102.0	39.0	69.5
		West	3015	38.7	82.8	21.0	65.1
	IMPROVE	12-km EUS	8668	-14.6	49.3	-18.2	53.3
		12-km WUS	12851	43.4	75.6	29.6	57.8
		Northeast	602	-1.3	45.1	-15.7	48.1
		Midwest	2117	10.6	54.5	-3.7	54.1
		Southeast	1584	-36.7	46.9	-39.3	56.3
		Central U.S.	2123	-23.8	47.7	-21.5	53.4
		West	8169	5.8	64.9	-8.6	61.0
Organic Carbon	STN	12-km EUS	12619	-27.2	50.5	-22.8	60.1
		12-km WUS	3582	-32.1	56.7	-28.2	61.3
		Northeast	2380	-28.3	49.0	-19.7	58.1
		Midwest	3323	-7.6	53.3	-4.2	58.6
		Southeast	3802	-39.3	49.2	-39.4	61.0
		Central U.S.	2259	-31.4	51.2	-28.3	63.2
		West	3060	-31.7	57.6	-27.8	61.4
	IMPROVE	12-km EUS	8662	-21.7	49.4	-25.6	55.8
		12-km WUS	11586	-29.9	50.4	-26.7	60.6
		Northeast	601	-22.7	41.3	-27.7	48.3
		Midwest	2116	3.5	55.7	-5.1	53.1
		Southeast	1587	-30.1	42.8	-37.8	54.1
		Central U.S.	2123	-36.9	51.7	-39.1	61.0
		West	8165	-11.7	59.2	-19.3	61.0

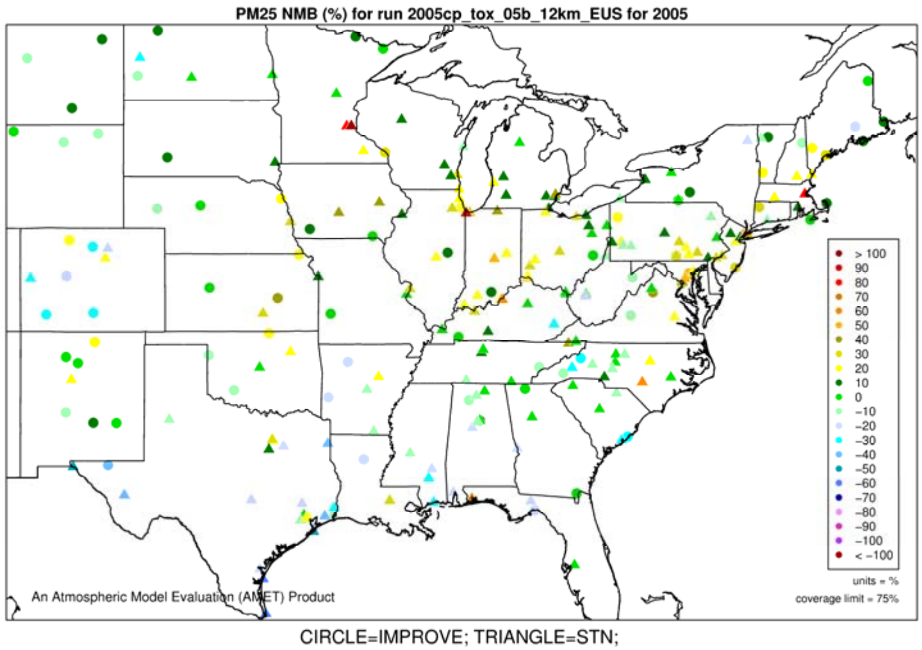


Figure D-1. Normalized Mean Bias (%) of annual $PM_{2.5}$ by monitor for Eastern U.S., 2005.

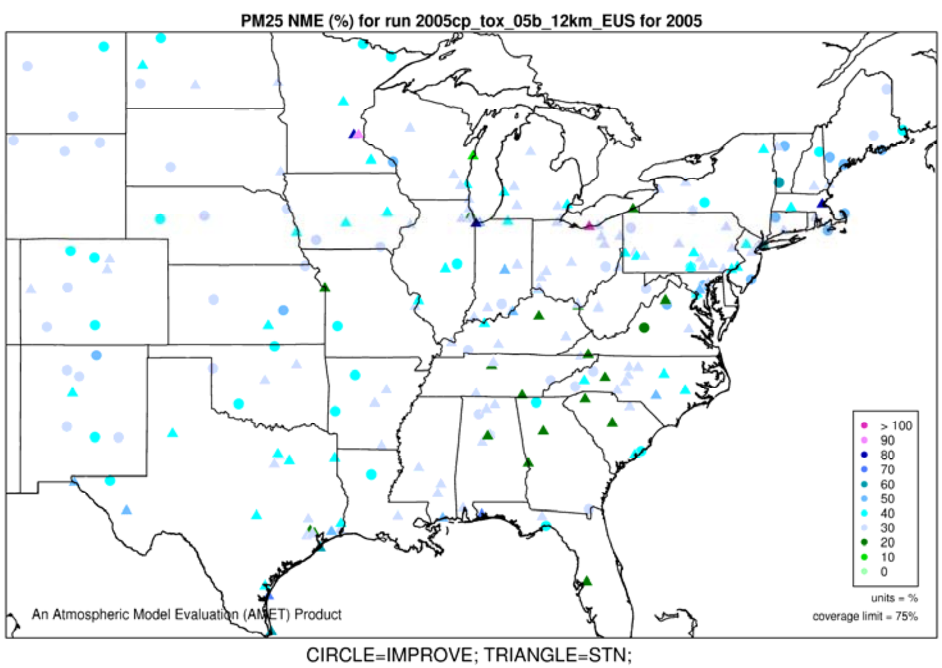


Figure D-2. Normalized Mean Error (%) of annual $PM_{2.5}$ by monitor for Eastern U.S., 2005.

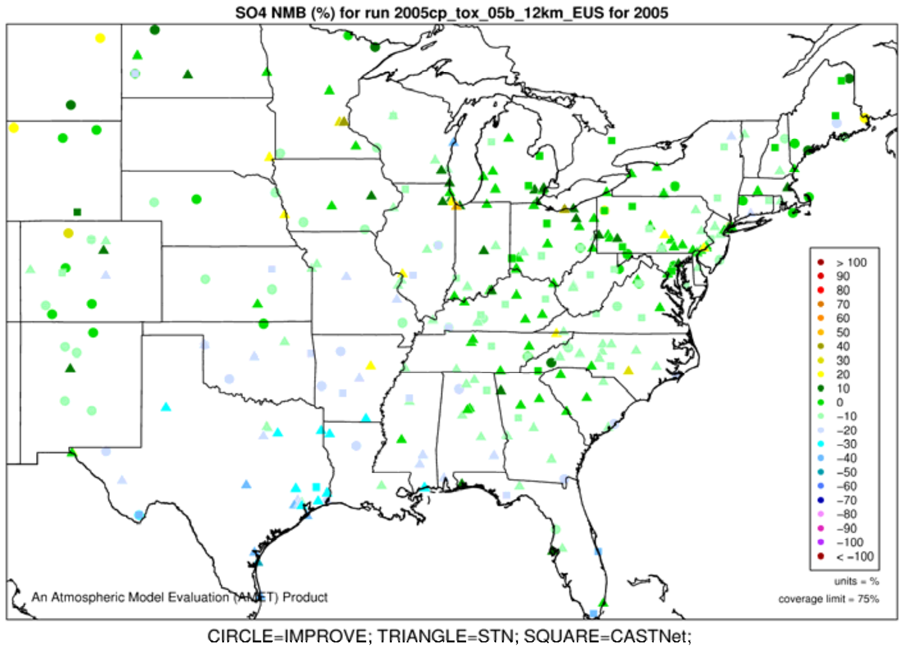


Figure D-3. Normalized Mean Bias (%) of annual sulfate by monitor for Eastern U.S., 2005.

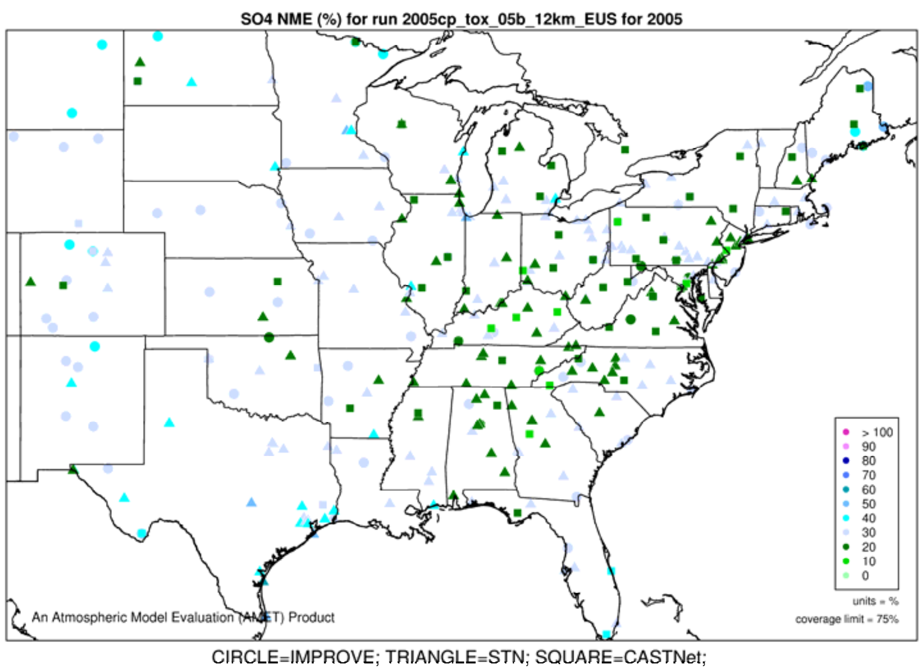


Figure D-4. Normalized Mean Error (%) of annual sulfate by monitor for Eastern U.S., 2005.

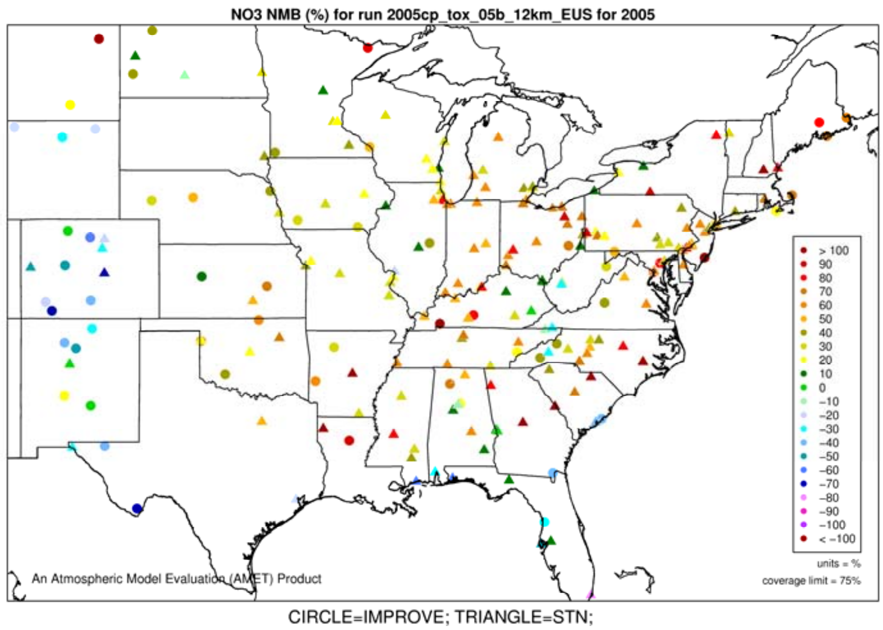


Figure D-5. Normalized Mean Bias (%) of annual nitrate by monitor for Eastern U.S., 2005.

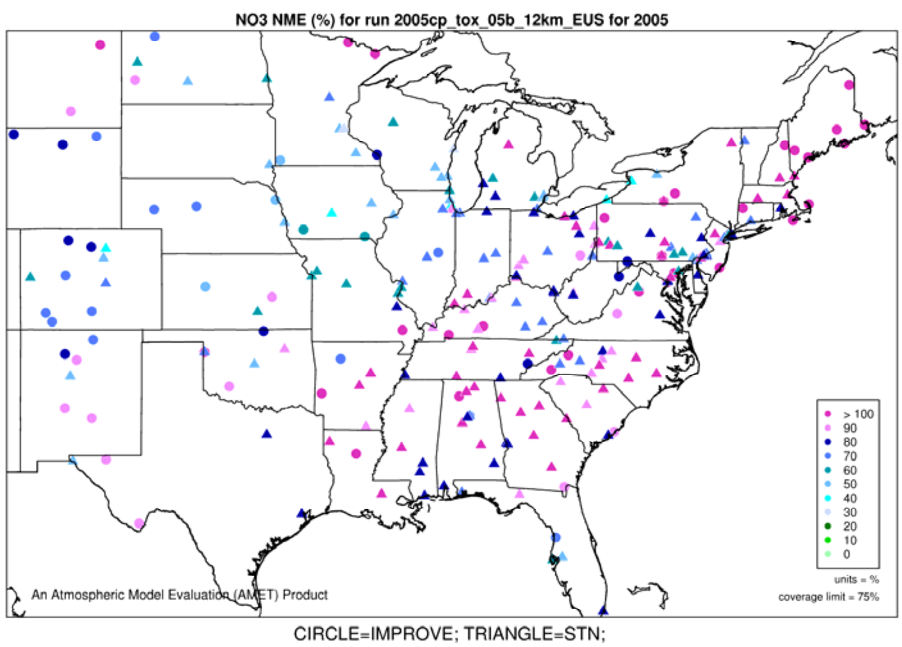
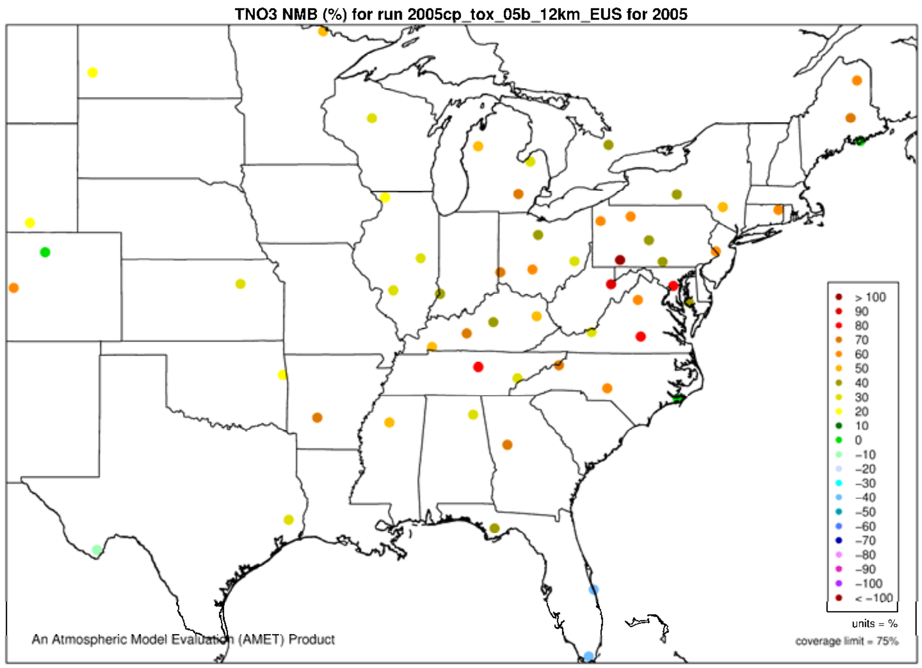
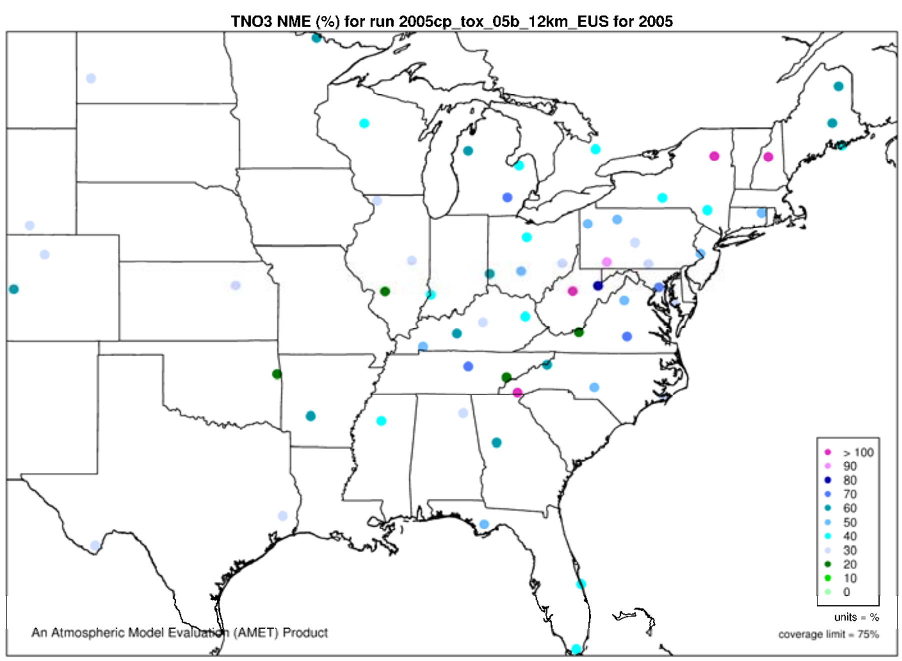


Figure D-6. Normalized Mean Error (%) of annual nitrate by monitor for Eastern U.S., 2005.



CIRCLE=CASTNet;

Figure D-7. Normalized Mean Bias (%) of annual total nitrate by monitor for Eastern U.S., 2005.



CIRCLE=CASTNet;

Figure D-8. Normalized Mean Error (%) of annual total nitrate by monitor for Eastern U.S., 2005.

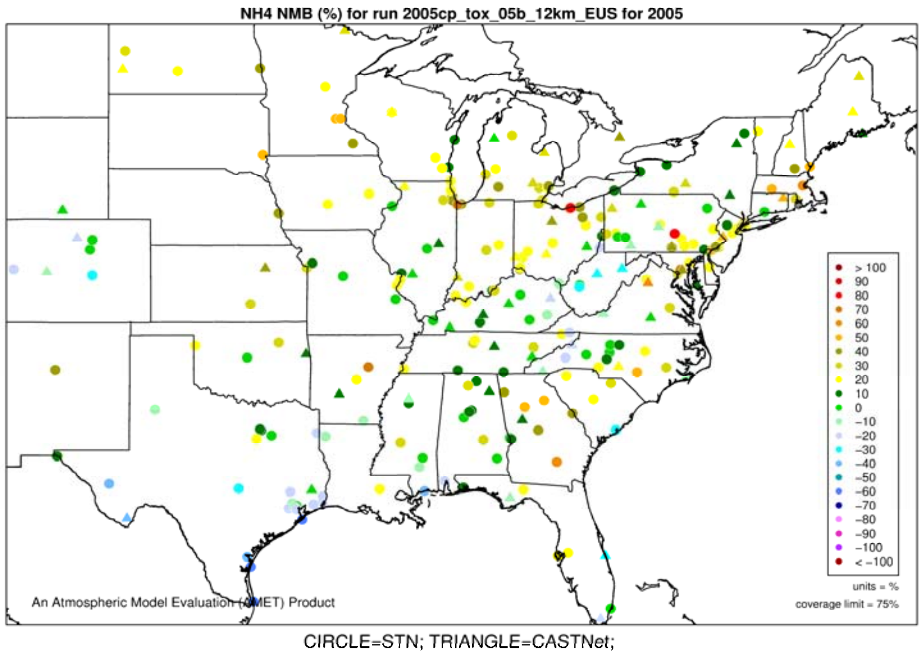


Figure D-9. Normalized Mean Bias (%) of annual ammonium by monitor for Eastern U.S., 2005.

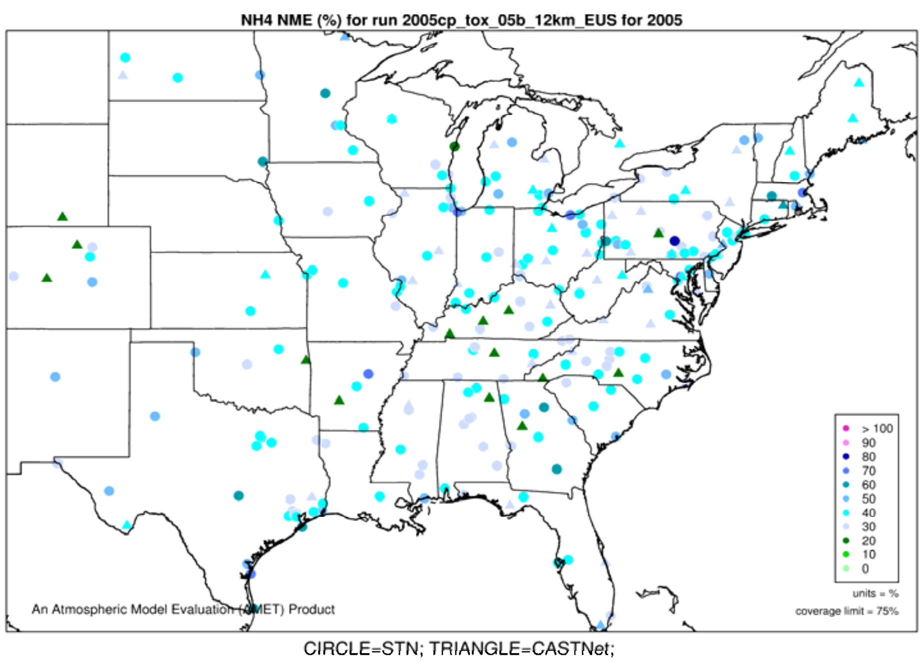


Figure D-10. Normalized Mean Error (%) of annual ammonium by monitor for Eastern U.S., 2005.

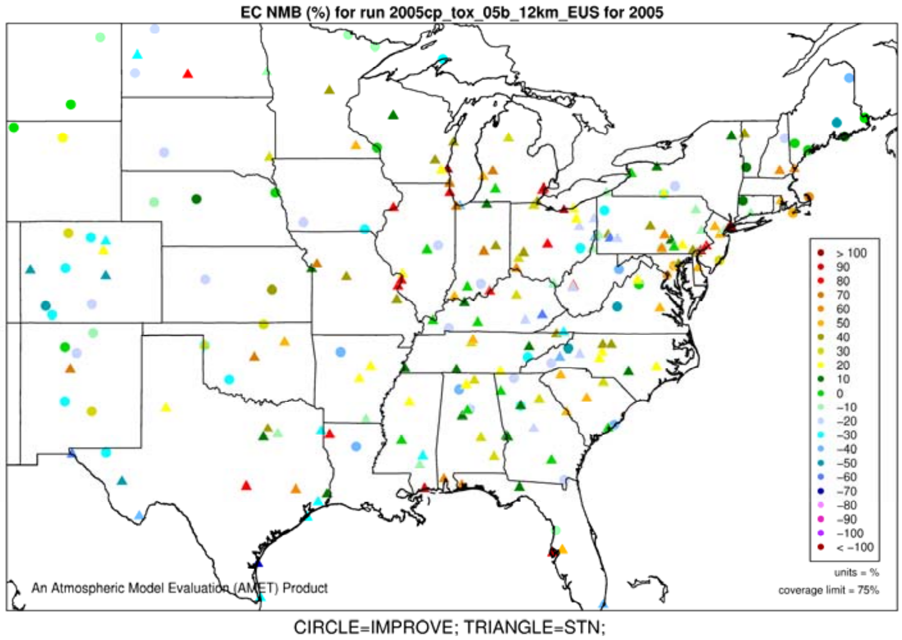


Figure D-11. Normalized Mean Bias (%) of annual elemental carbon by monitor for Eastern U.S., 2005.

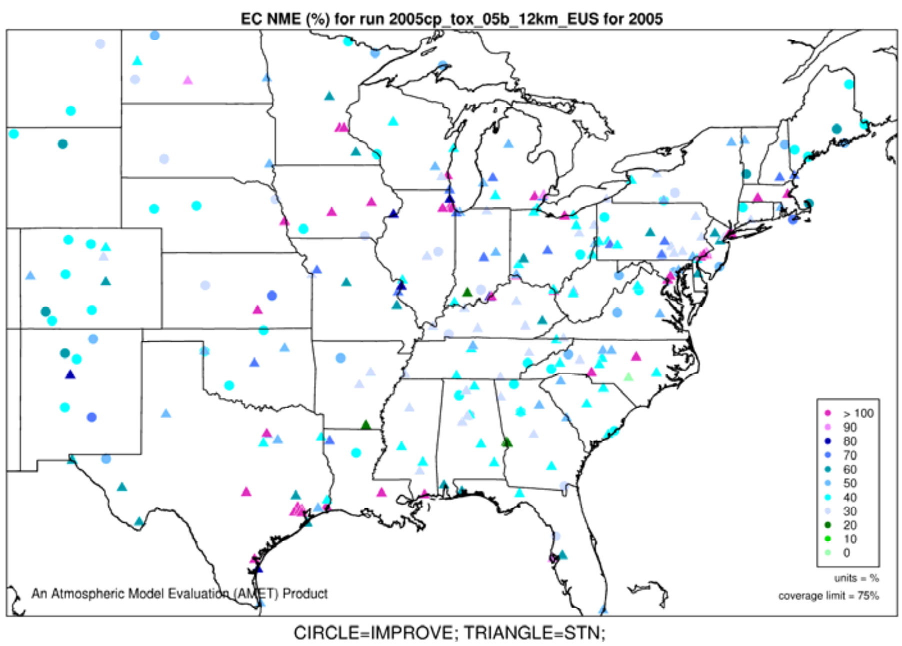


Figure D-12. Normalized Mean Error (%) of annual elemental carbon by monitor for Eastern U.S., 2005.

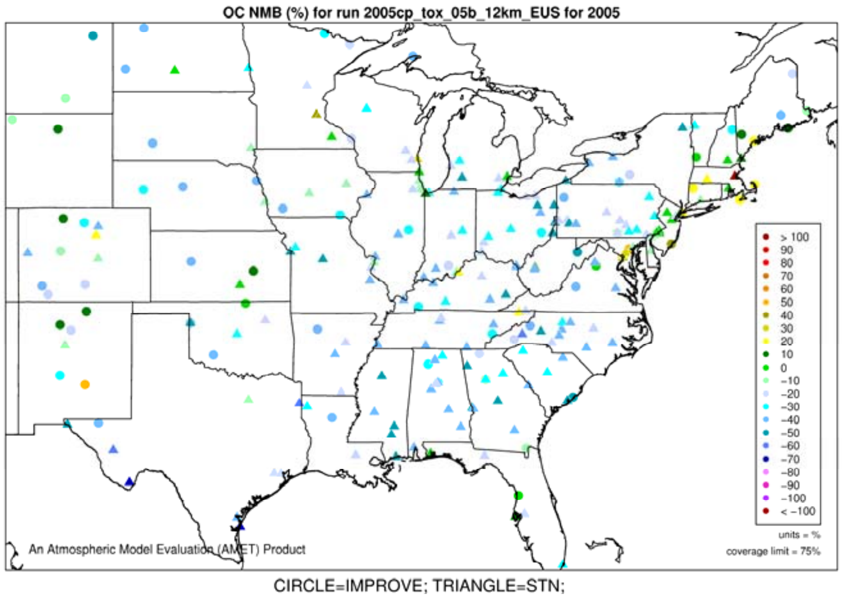


Figure D-13. Normalized Mean Bias (%) of annual organic carbon by monitor for Eastern U.S., 2005.

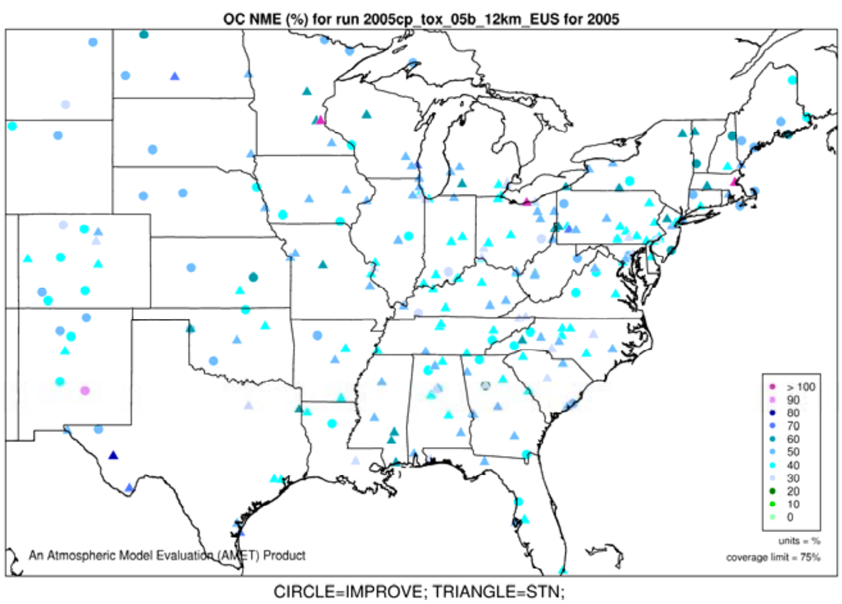


Figure D-14. Normalized Mean Error (%) of annual organic carbon by monitor for Eastern U.S., 2005.

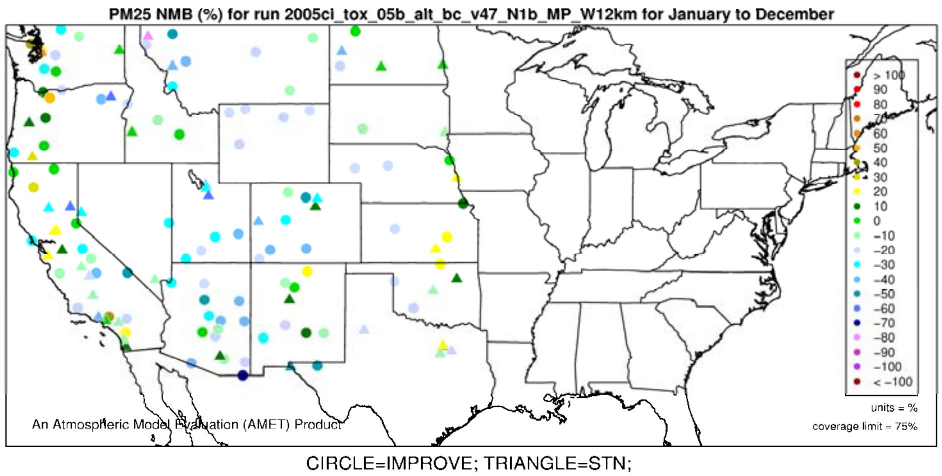


Figure D-15. Normalized Mean Bias (%) of annual $PM_{2.5}$ by monitor for Western U.S., 2005.

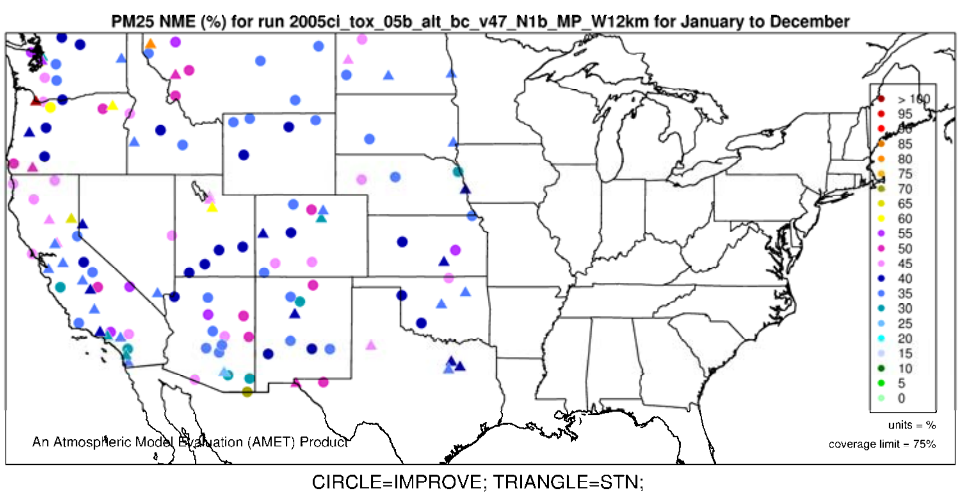


Figure D-16. Normalized Mean Error (%) of annual $PM_{2.5}$ by monitor for Western U.S., 2005.

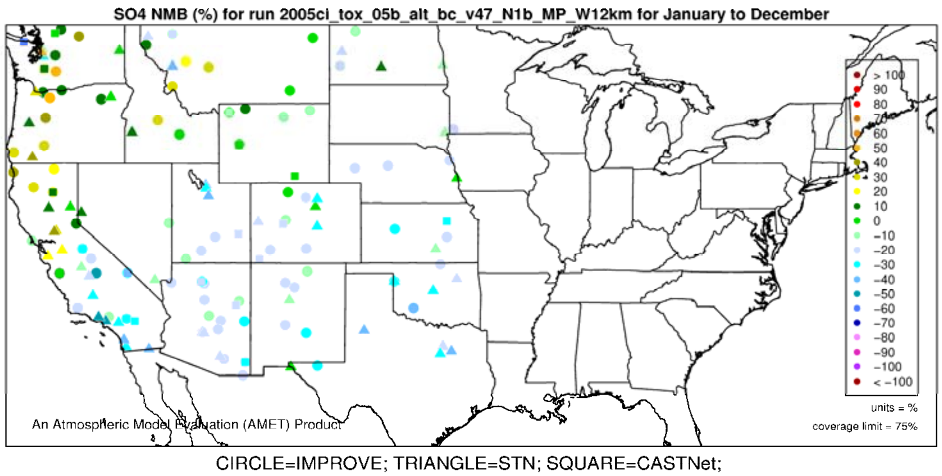


Figure D-17. Normalized Mean Bias (%) of annual sulfate by monitor for Western U.S., 2005.

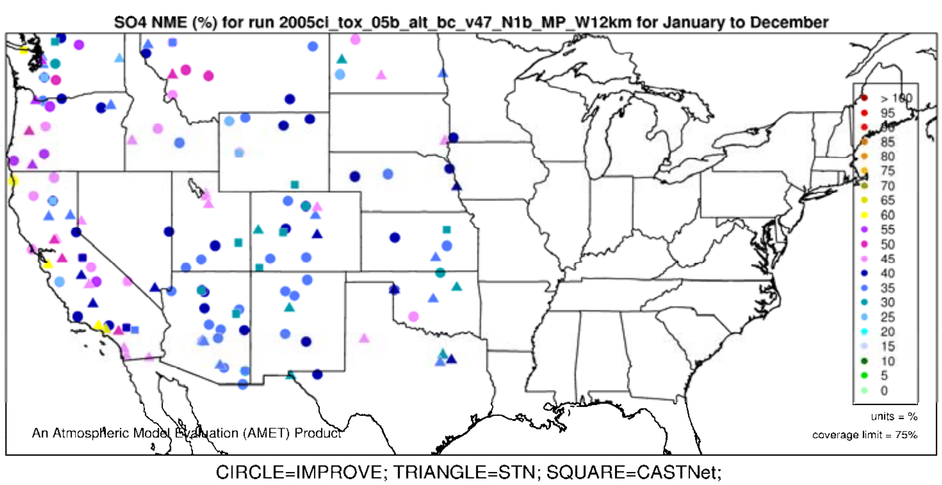


Figure D-18. Normalized Mean Error (%) of annual sulfate by monitor for Western U.S., 2005.

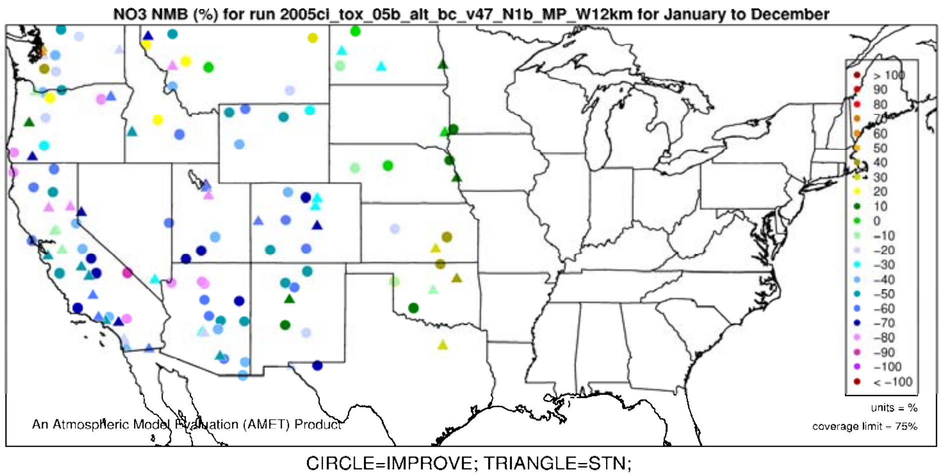


Figure D-19. Normalized Mean Bias (%) of annual nitrate by monitor for Western U.S., 2005.

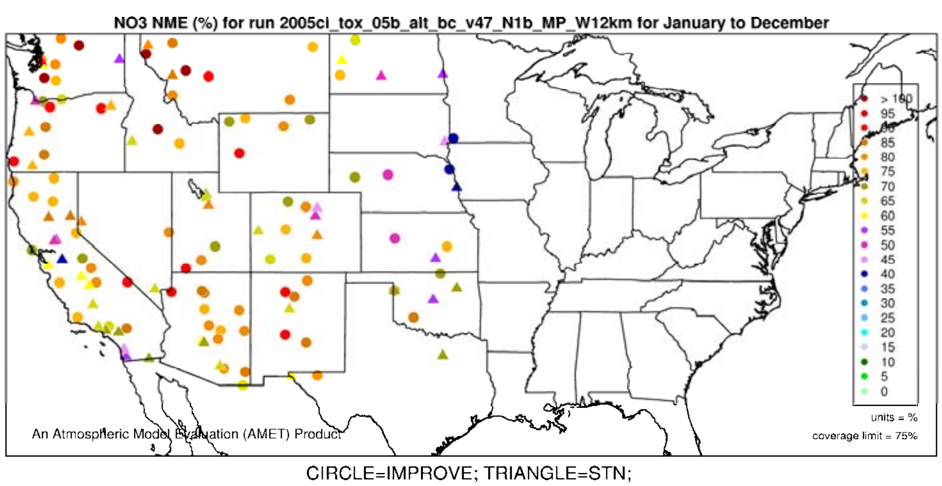


Figure D-20. Normalized Mean Error (%) of annual nitrate by monitor for Western U.S., 2005.

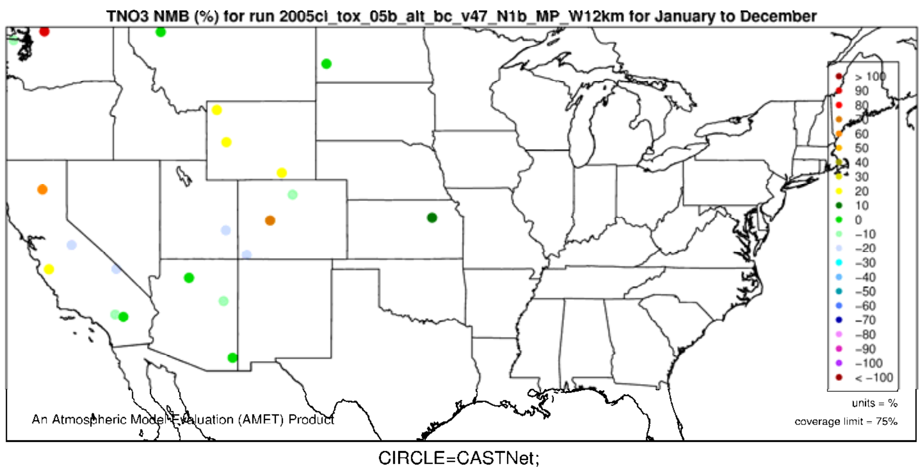


Figure D-21. Normalized Mean Bias (%) of annual total nitrate by monitor for Western U.S., 2005.

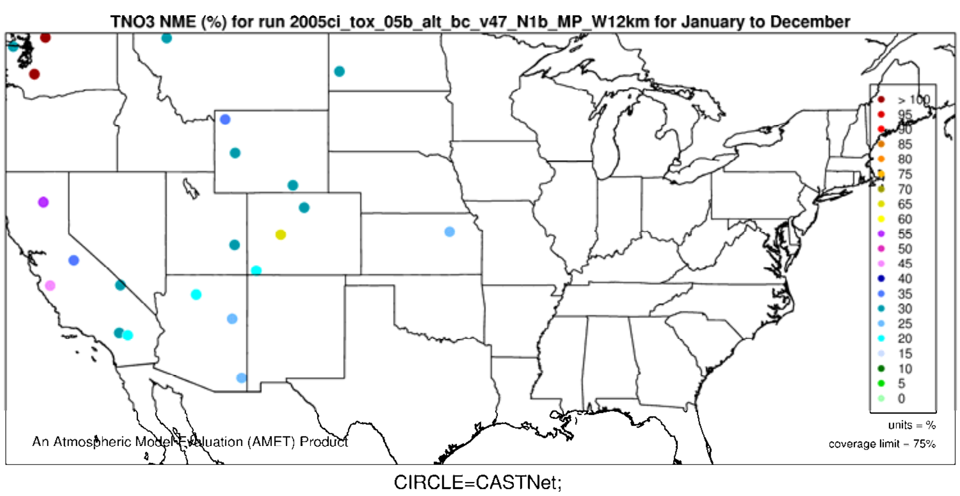


Figure D-22. Normalized Mean Error (%) of annual total nitrate by monitor for Western U.S., 2005.

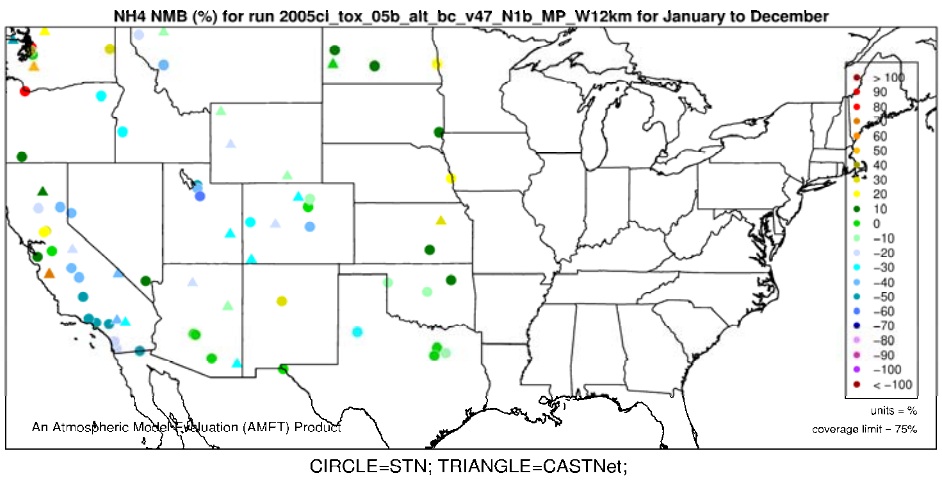


Figure D-23. Normalized Mean Bias (%) of annual ammonium by monitor for Western U.S., 2005.

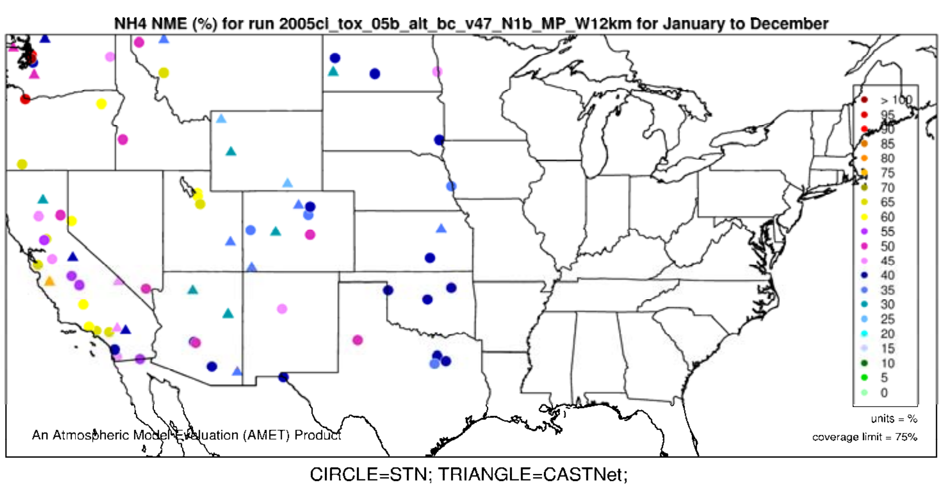


Figure D-24. Normalized Mean Error (%) of annual ammonium by monitor for Western U.S., 2005.

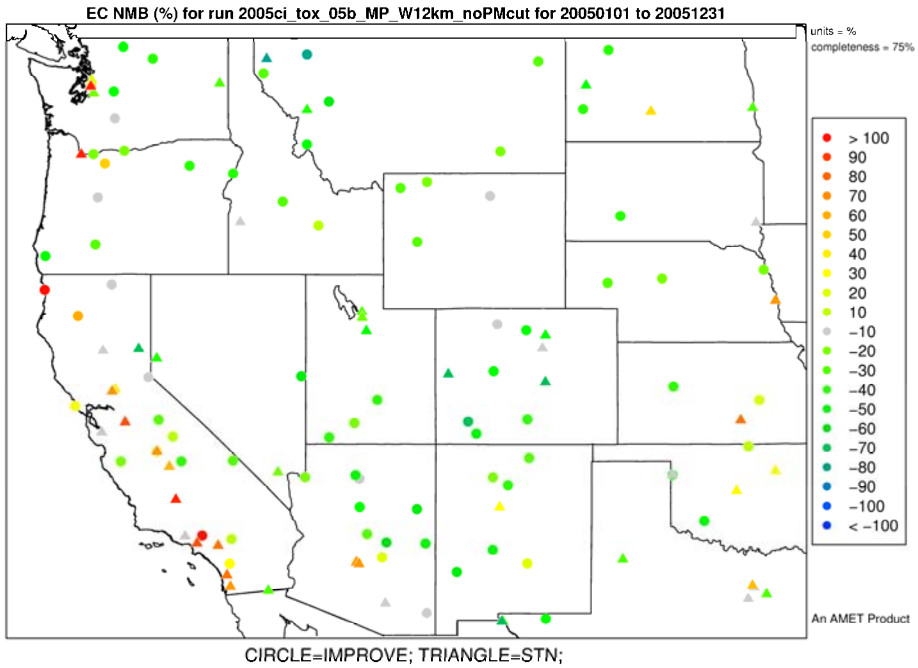


Figure D-25. Normalized Mean Bias (%) of annual elemental carbon by monitor for Western U.S., 2005.

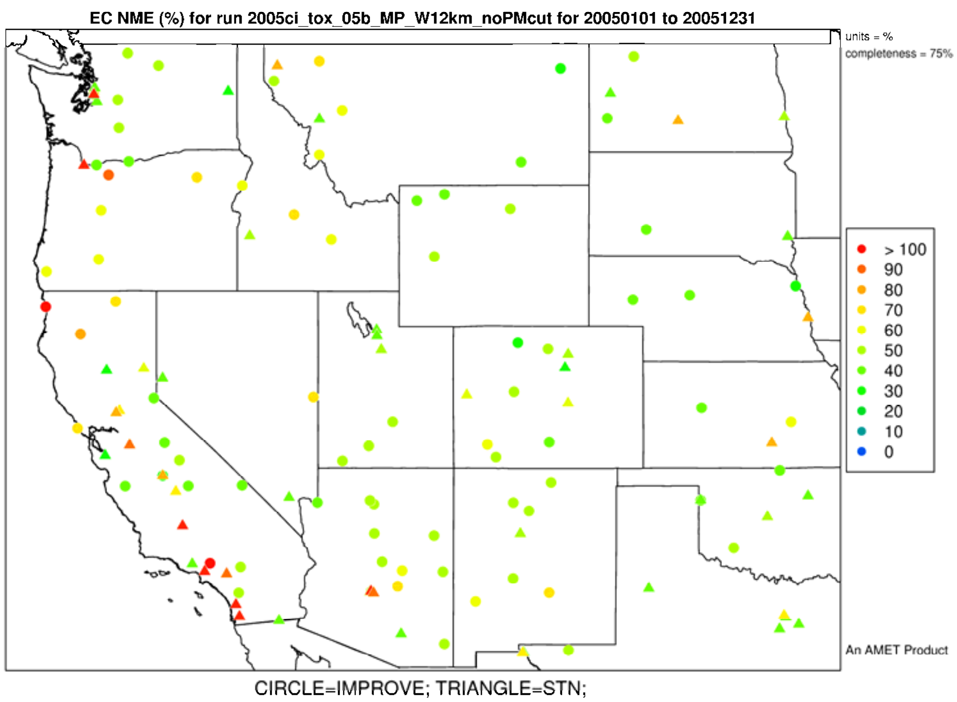


Figure D-26. Normalized Mean Error (%) of annual elemental carbon by monitor for Western U.S., 2005.

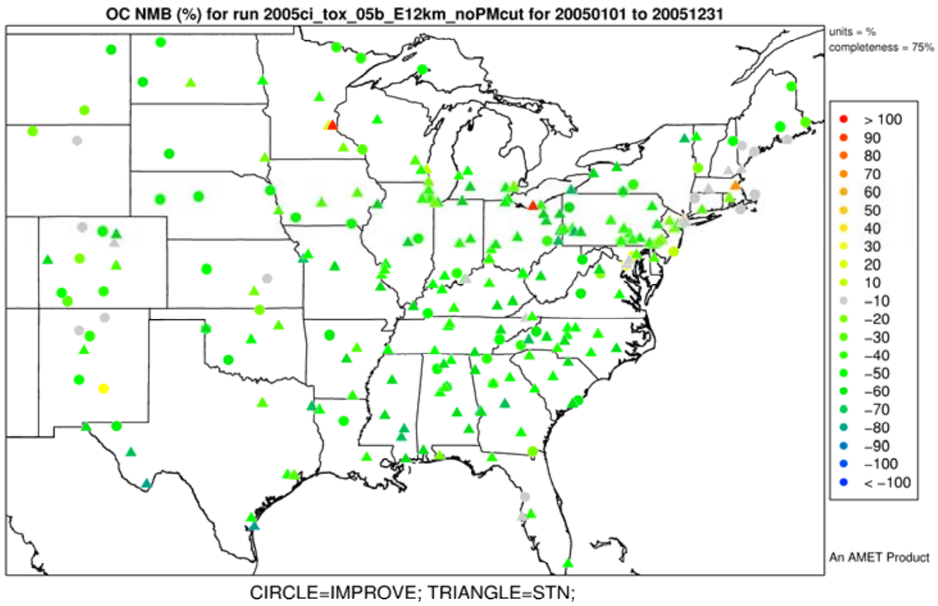


Figure D-27. Normalized Mean Bias (%) of annual organic carbon by monitor for Western U.S., 2005.

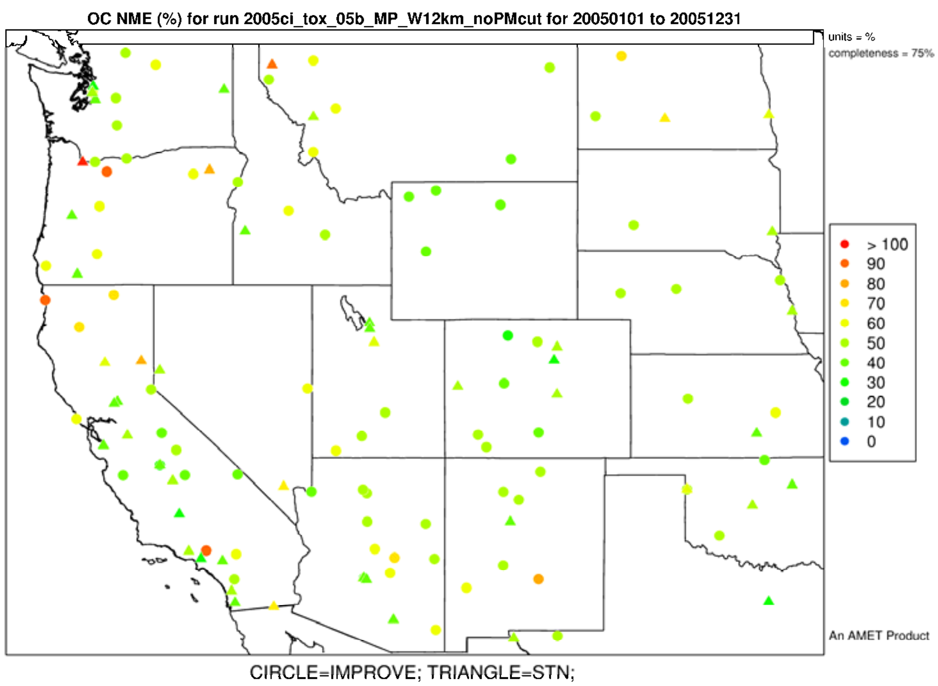


Figure D-28. Normalized Mean Error (%) of annual organic carbon by monitor for Western U.S., 2005.

E. Seasonal $PM_{2.5}$ Total Mass Performance

Seasonal model performance statistics for $PM_{2.5}$ total mass are shown in Table E-1. Spatial plots of the NMB and NME statistics (units of percent) for individual monitors are also provided as a complement to the tabular statistical data (Figures E-1 – E-16). Total $PM_{2.5}$ mass is generally over-predicted in the winter, fall, and spring seasons for both STN and IMPROVE networks. In the fall season, $PM_{2.5}$ is over-predicted for Eastern STN and IMPROVE sites with NMB values ranging from 6% to 30% whereas $PM_{2.5}$ is under-predicted at Western STN and IMPROVE sites. In the winter season, $PM_{2.5}$ is over-predicted for EUS and WUS STN and IMPROVE networks with NMB values ranging from 5% to 58%. However, in the 12-km Western domain, $PM_{2.5}$ is under-predicted at STN in the winter (NMB in the range of -6% to -11%) and the fall (NMB in the range of -7% to -9%). Note that for comparison of West versus East STN sites, the total number of Western sites is usually less than a third of the Eastern sites. In the spring, $PM_{2.5}$ is over-predicted in the East and West, although $PM_{2.5}$ at urban STN sites is over-predicted in the East but under-predicted in the West. In the summer season, $PM_{2.5}$ is under-predicted in the East and West for STN and IMPROVE (NMB = ~ 25% and NME = ~35%).

Table E-1. CMAQ 2005 seasonal model performance statistics for $PM_{2.5}$ total mass.

CMAQ 2005 PM2.5 total mass			No. of Obs.	NMB (%)	NME (%)	FB (%)	FE (%)
Winter	STN	12-km EUS	2866	20.5	42.4	14.8	38.5
		12-km WUS	895	-6.2	54.7	-3.2	53.0
		Northeast	716	36.7	48.7	28.1	39.4
		Midwest	542	20.1	36.7	19.0	33.3
		Southeast	762	7.9	38.1	4.7	36.5
		Central	635	20.2	47.1	12.8	44.2
		West	739	-10.9	55.0	-8.7	54.6
	IMPROVE	12-km EUS	2252	31.5	51.8	23.9	45.8
		12-km WUS	2532	11.8	51.6	7.1	49.5
		Northeast	573	58.6	68.4	40.8	50.7
		Midwest	143	21.5	39.2	16.8	35.9
		Southeast	406	17.5	43.7	11.4	42.3
		Central	574	19.6	46.3	17.7	45.0
		West	2145	5.4	51.1	5.5	50.7
Spring	STN	12-km EUS	3159	22.6	46.9	15.2	41.0
		12-km WUS	964	0.5	43.2	-1.1	41.2
		Northeast	795	44.2	60.1	33.0	47.4
		Midwest	612	49.7	59.8	36.0	45.8
		Southeast	798	3.1	34.2	2.0	33.5
		Central	752	1.0	38.3	-2.6	40.2
		West	773	3.2	45.5	-0.2	41.9
	IMPROVE	12-km EUS	2424	14.7	46.2	7.6	42.4

		12-km WUS	2735	-18.0	43.2	-22.8	46.4
		Northeast	630	47.9	65.6	28.4	49.3
		Midwest	153	36.8	53.4	27.3	44.8
		Southeast	429	2.7	35.7	4.1	36.1
		Central	628	-3.7	39.1	-3.1	42.1
		West	2308	-20.5	44.7	-23.9	47.0
Summer	STN	12-km EUS	2954	-19.3	32.6	-24.7	39.8
		12-km WUS	935	-20.9	35.9	-21.0	40.3
		Northeast	754	-15.0	30.5	-16.3	33.9
		Midwest	558	-8.2	26.7	-7.9	28.4
		Southeast	722	-28.2	34.7	-34.9	43.1
		Central	701	-24.1	38.2	-33.3	50.3
		West	758	-18.2	36.2	-19.0	40.3
	IMPROVE	12-km EUS	2334	-27.6	37.2	-33.8	45.6
		12-km WUS	2492	-20.1	41.9	-23.0	45.3
		Northeast	580	-20.5	35.2	-27.7	42.1
		Midwest	156	-18.8	30.1	-19.7	34.2
		Southeast	421	-34.1	39.1	-45.5	53.6
		Central	596	-32.2	39.8	-38.8	50.2
		West	2114	-18.1	42.6	-21.5	45.1
Fall	STN	12-km EUS	2818	10.6	38.4	10.6	37.4
		12-km WUS	962	-6.9	46.2	-4.9	45.3
		Northeast	755	28.6	51.2	20.8	41.7
		Midwest	606	12.4	33.1	14.6	31.9
		Southeast	785	-5.5	30.08	-4.1	32.8
		Central	435	16.5	45.6	18.4	44.2
		West	812	-9.1	47.2	-7.8	45.8
	IMPROVE	12-km EUS	2311	6.0	42.6	2.8	42.2
		12-km WUS	2652	-9.6	44.9	-14.9	46.1
		Northeast	556	29.8	54.5	17.1	45.0
		Midwest	119	7.9	38.5	8.9	39.2
		Southeast	438	-9.7	31.7	-8.2	37.4
		Central	578	5.6	45.9	6.6	46.7
		West	2253	-13.9	43.8	-17.3	46.0

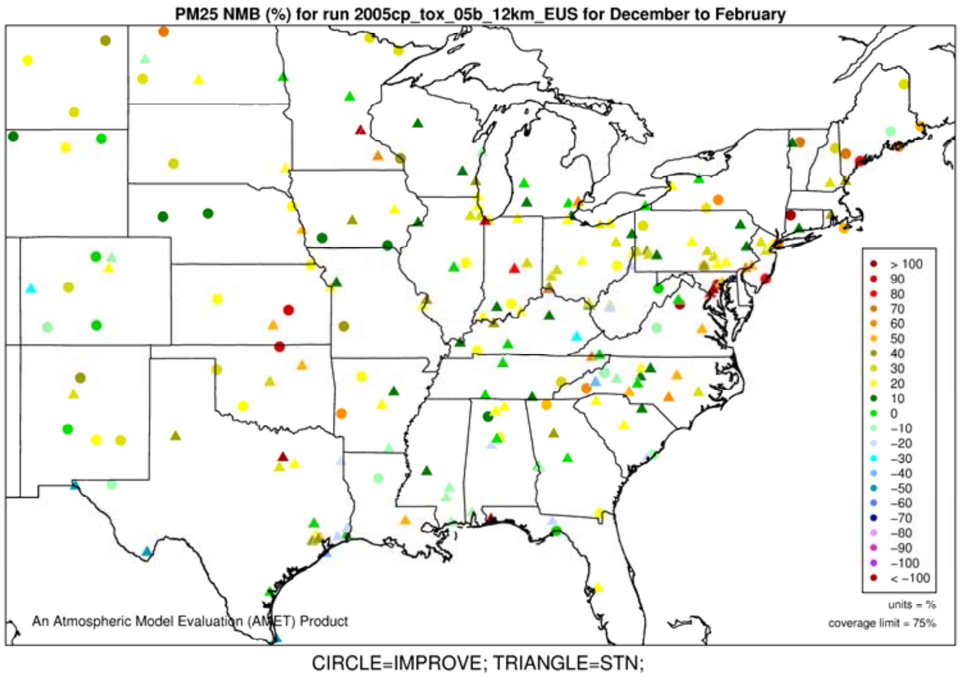


Figure E-1. Normalized Mean Bias (%) of $PM_{2.5}$ by monitor for 12-km Eastern U.S. domain, Winter 2005.

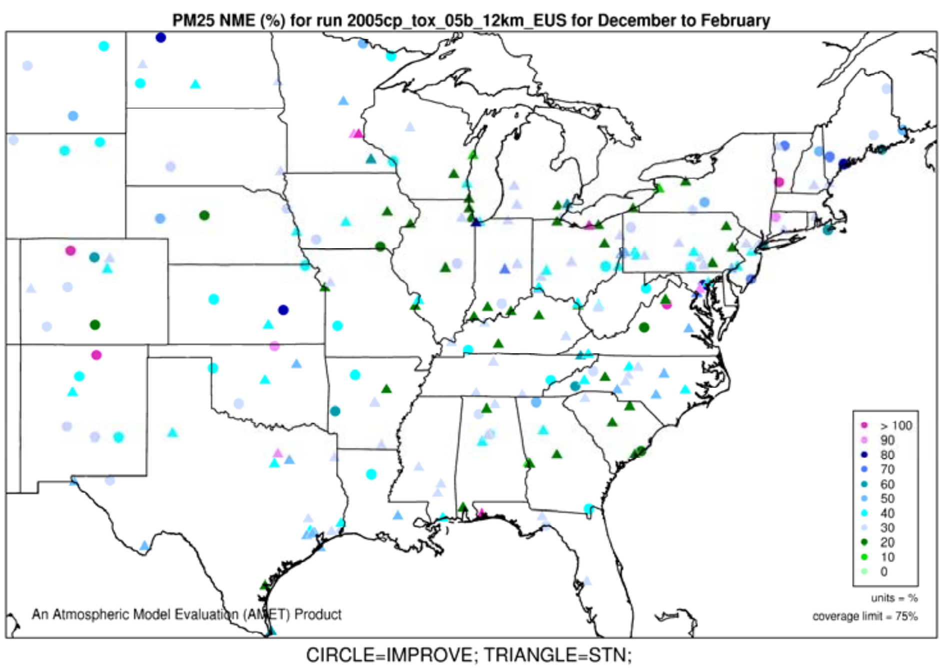


Figure E-2. Normalized Mean Error (%) of $PM_{2.5}$ by monitor for 12-km Eastern U.S. domain, Winter 2005.

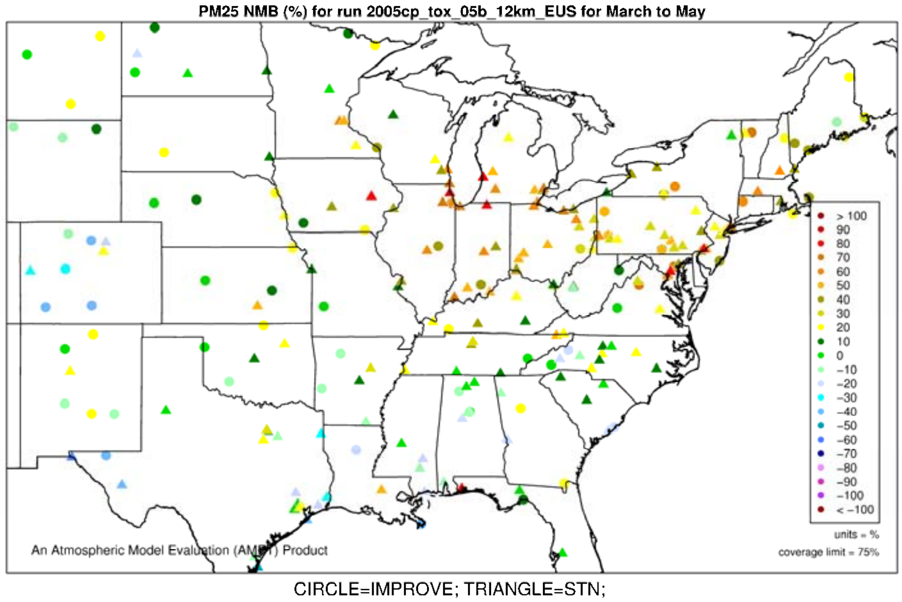


Figure E-3. Normalized Mean Bias (%) of $PM_{2.5}$ by monitor for 12-km Eastern U.S. domain, Spring 2005.

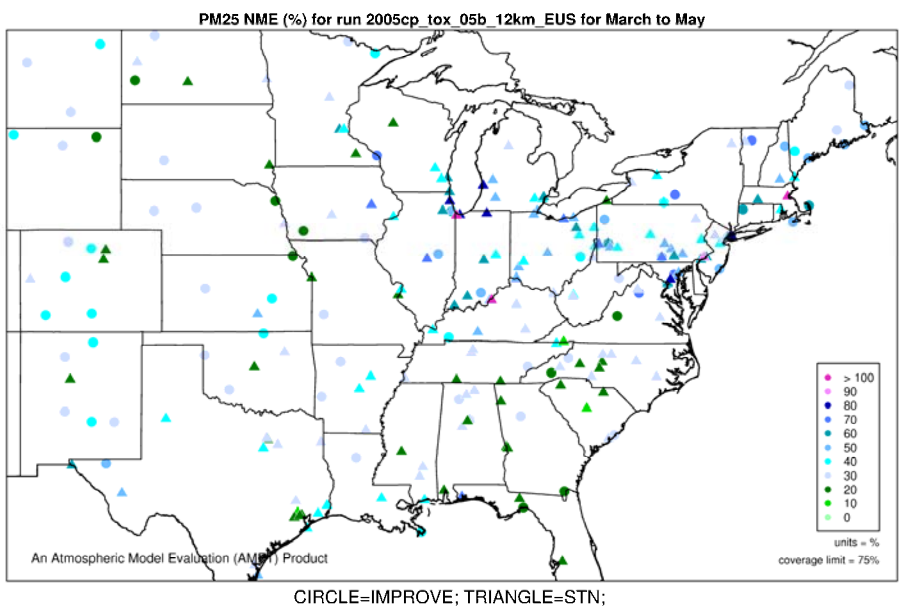


Figure E-4. Normalized Mean Error (%) of $PM_{2.5}$ by monitor for 12-km Eastern U.S. domain, Spring 2005.

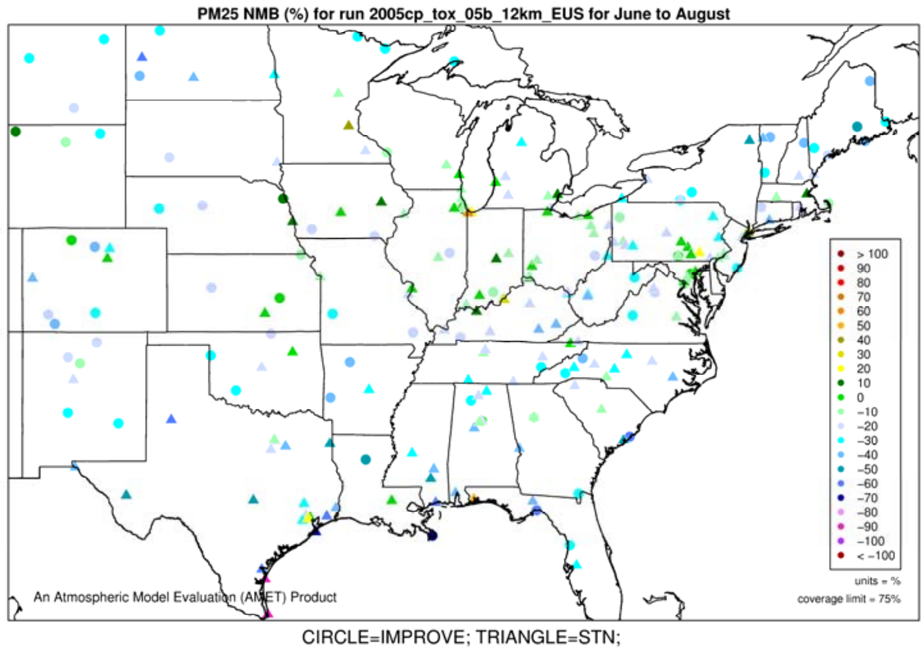


Figure E-5. Normalized Mean Bias (%) of $PM_{2.5}$ by monitor for 12-km Eastern U.S. domain, Summer 2005.

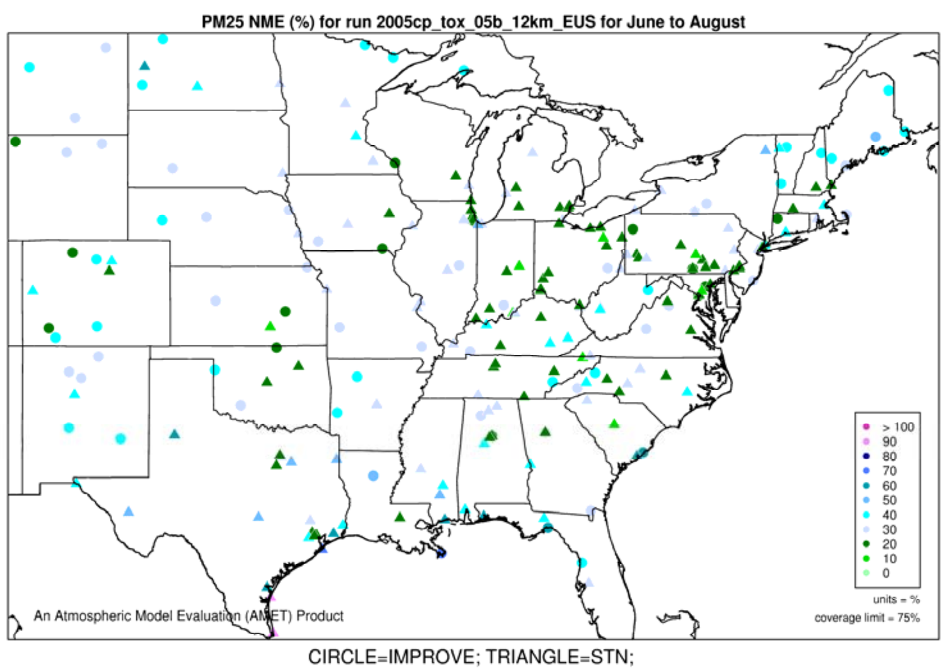


Figure E-6. Normalized Mean Error (%) of $PM_{2.5}$ by monitor for 12-km Eastern U.S. domain., Summer 2005.

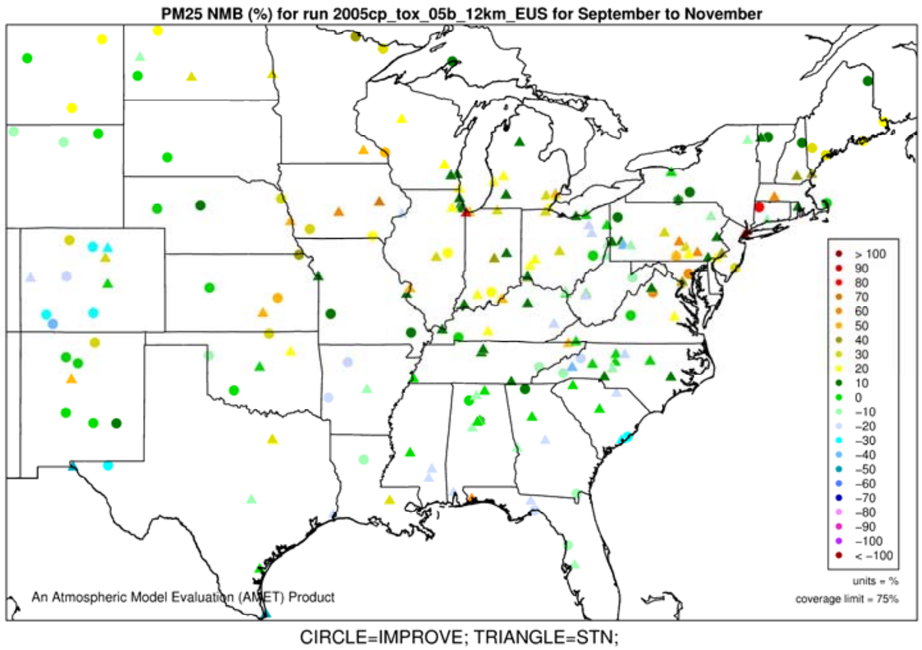


Figure E-7. Normalized Mean Bias (%) of $PM_{2.5}$ by monitor for 12-km Eastern U.S. domain, Fall 2005.

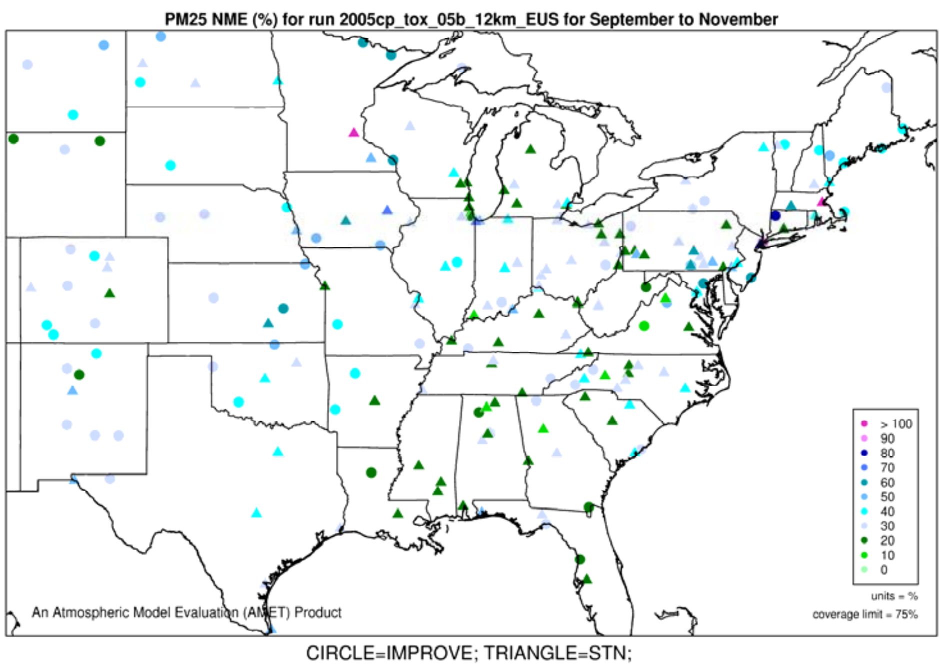


Figure E-8. Normalized Mean Error (%) of $PM_{2.5}$ by monitor for 12-km Eastern U.S. domain, Fall 2005.

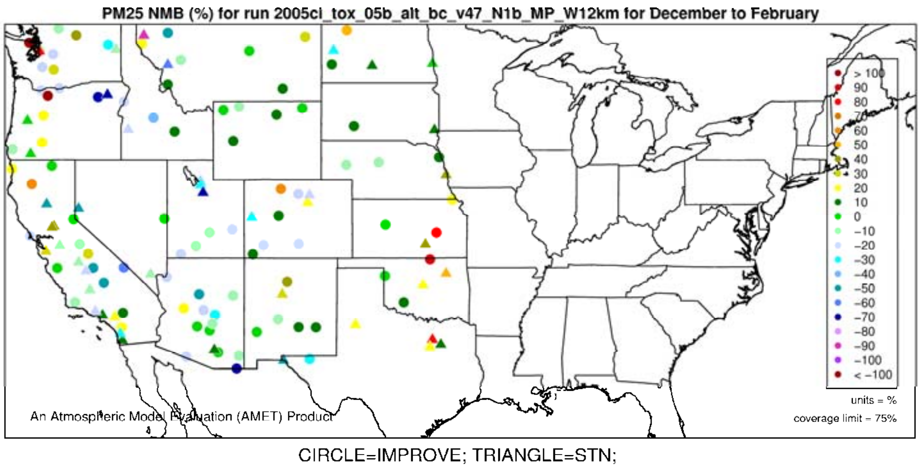


Figure E-9. Normalized Mean Bias (%) of $PM_{2.5}$ by monitor for 12-km Western U.S. domain, Winter 2005.

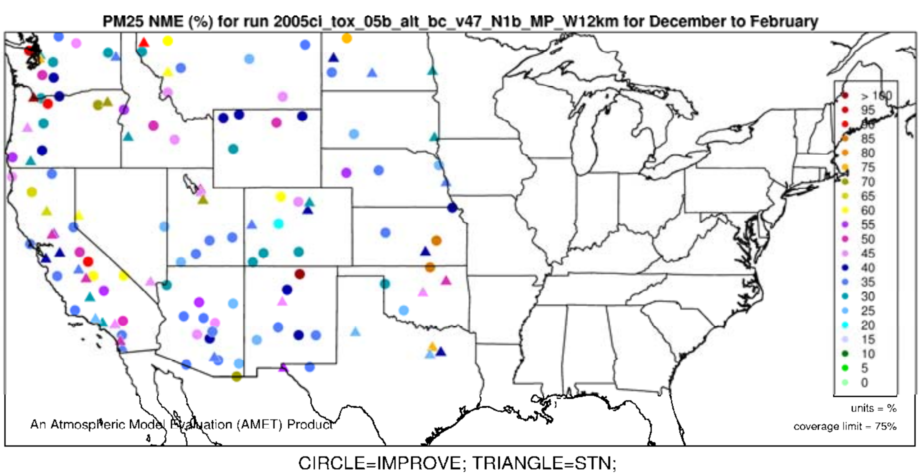


Figure E-10. Normalized Mean Error (%) of $PM_{2.5}$ by monitor for 12-km Western U.S. domain, Winter 2005.

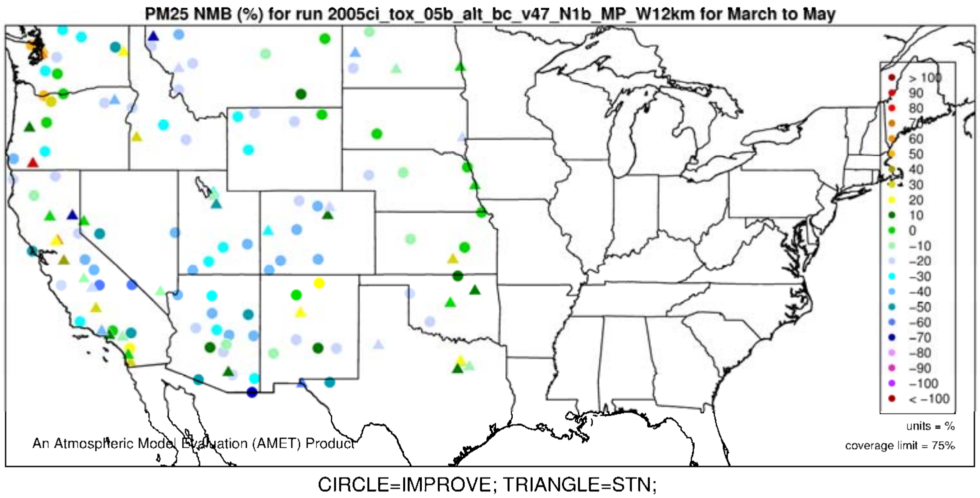


Figure E-11. Normalized Mean Bias (%) of $PM_{2.5}$ by monitor for 12-km Western U.S. domain, Spring 2005.

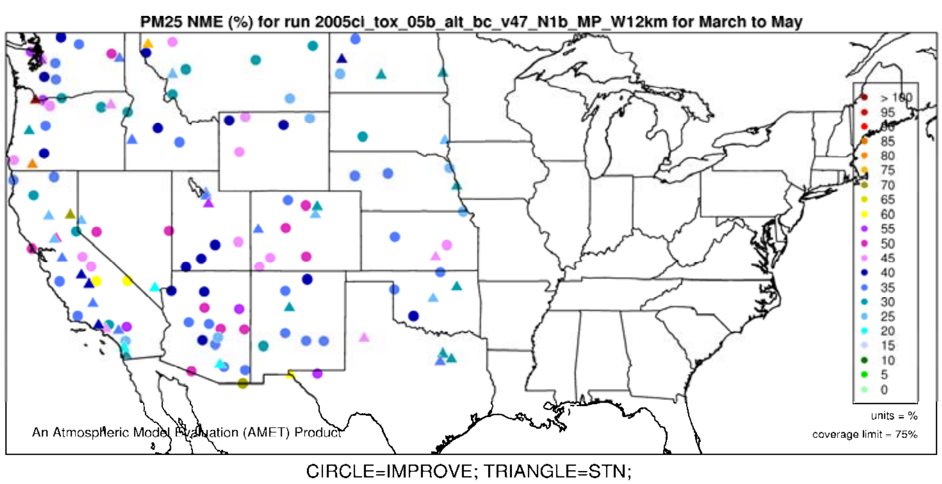


Figure E-12. Normalized Mean Error (%) of $PM_{2.5}$ by monitor for 12-km Western U.S. domain, Spring 2005.

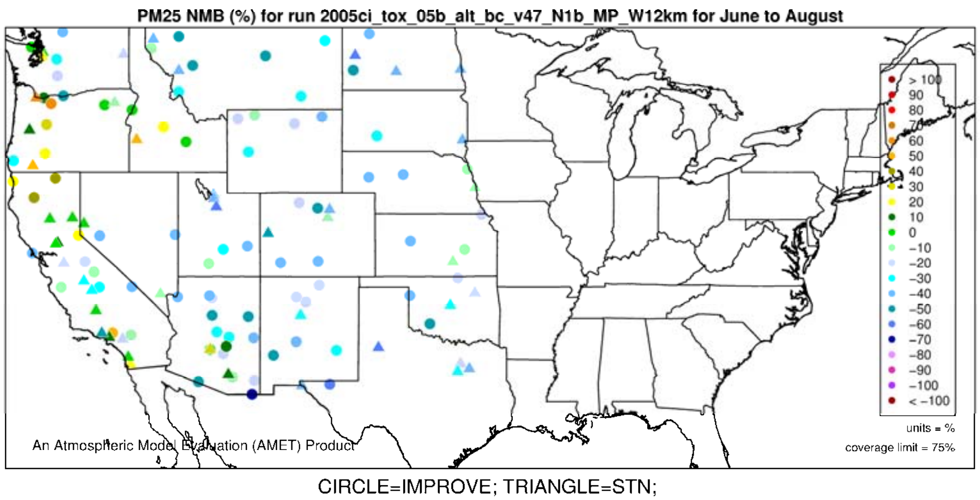


Figure E-13. Normalized Mean Bias (%) of $PM_{2.5}$ by monitor for 12-km Western U.S. domain, Summer 2005.

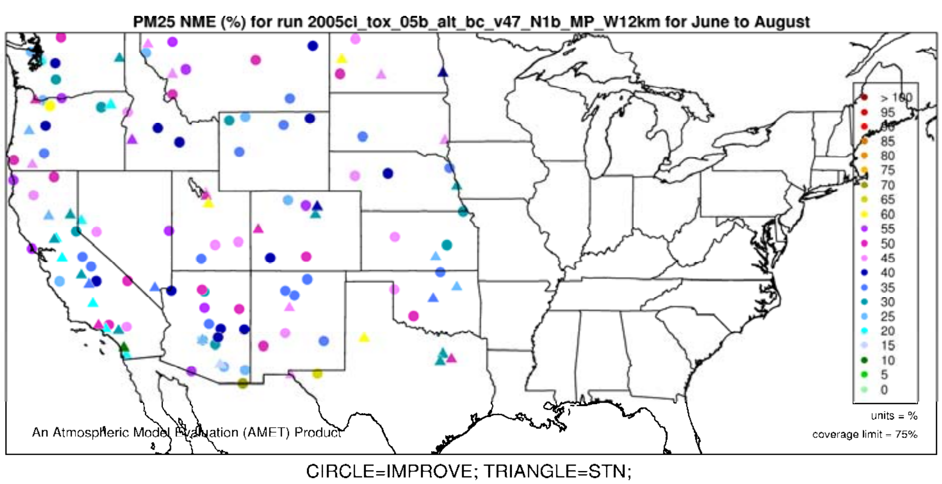


Figure E-14. Normalized Mean Error (%) of $PM_{2.5}$ by monitor for 12-km Western U.S. domain, Summer 2005.

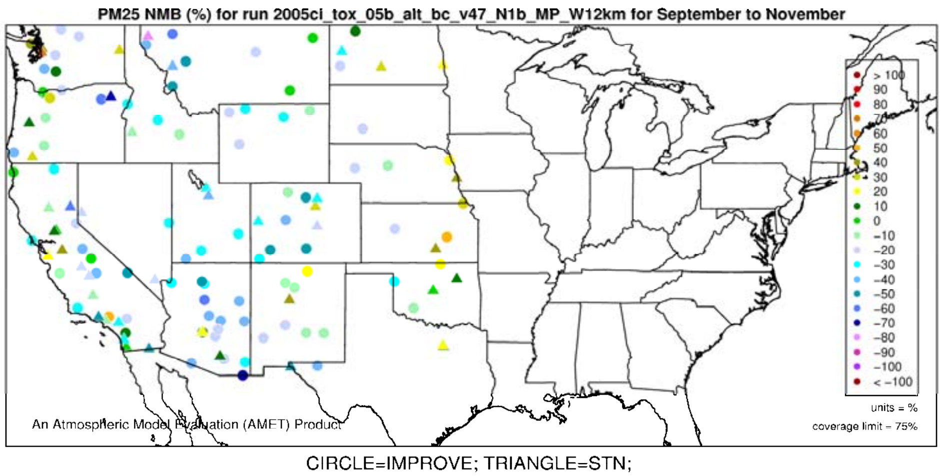


Figure E-15. Normalized Mean Bias (%) of $PM_{2.5}$ by monitor for 12-km Western U.S. domain, Fall 2005.

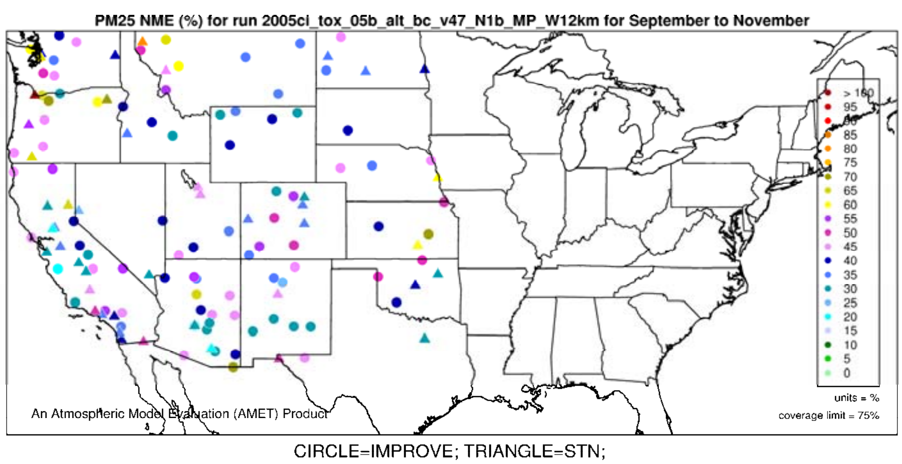


Figure E-16. Normalized Mean Error (%) of $PM_{2.5}$ by monitor for 12-km Western U.S. domain, Fall 2005.

F. Seasonal Sulfate Performance

As seen in Table F-1, CMAQ generally under-predicts sulfate in the 12-km Eastern and Western domains throughout the entire year. Spatial plots of the NMB and NME statistics (units of percent) for individual monitors are also provided in Figures F-1 – F-16. In the fall season, sulfate predictions show NMB values ranging from -5% to -20%, across STN, IMPROVE, and CASTNet networks in the East and West. In the spring and winter seasons, sulfate predictions for the most part are under-predicted in the East and West, with NMB values ranging from -2% to -32%. Sulfate predictions during the summer season are moderately under-predicted in the East and West across the available monitoring data (NMB values range from -8% to -35%.

Table F-1. CMAQ 2005 seasonal model performance statistics for sulfate.

CMAQ 2005 Sulfate			No. of Obs.	NMB (%)	NME (%)	FB (%)	FE (%)
Winter	STN	12-km EUS	3390	-4.7	38.3	-6.8	38.4
		12-km WUS	1033	-7.3	55.4	-2.6	53.7
		Northeast	828	-5.0	36.3	-10.7	34.5
		Midwest	598	6.9	41.3	-0.1	39.2
		Southeast	963	-5.1	36.6	-4.1	36.7
		Central	766	-14.2	38.4	-12.3	41.6
		West	830	-10.3	58.1	-3.5	54.9
	IMPROVE	12-km EUS	2076	-4.4	37.4	4.7	42.4
		12-km WUS	2428	13.9	56.0	30.9	56.0
		Northeast	502	-3.5	31.6	-7.6	32.7
		Midwest	129	6.6	37.7	0.1	35.2
		Southeast	386	-3.9	35.8	1.4	36.7
		Central	539	-15.5	41.1	-9.7	44.1
		West	2086	23.8	59.3	34.7	57.2
	CASTNet	12-km EUS	760	-15.3	23.6	-14.0	27.7
		12-km WUS	267	1.5	34.3	16.0	37.3
		Northeast	193	-12.4	21.6	-16.3	24.4
		Midwest	142	-11.2	21.0	-13.9	25.5
		Southeast	264	-17.9	22.6	-17.1	23.6
		Central	72	-32.9	34.1	-34.8	37.0
		West	243	5.7	36.5	18.1	38.4
Spring	STN	12-km EUS	3626	1.5	34.1	1.1	33.4
		12-km WUS	1085	-12.3	35.0	-3.4	35.8
		Northeast	894	11.8	38.4	8.2	35.6
		Midwest	637	24.0	45.6	19.2	38.9
		Southeast	988	-4.9	27.7	-5.4	29.2
		Central	875	-15.4	31.1	-11.2	32.8
		West	867	-6.2	37.5	0.3	36.7
	IMPROVE	12-km EUS	2435	-1.7	33.8	1.4	34.2
		12-km WUS	2703	-5.2	32.9	3.1	35.0
		Northeast	630	12.5	40.7	9.8	39.3

		Midwest	147	7.9	37.5	10.2	36.5
		Southeast	436	-4.7	28.5	-2.4	29.9
		Central	632	-16.6	31.9	-10.4	33.2
		West	2305	-2.4	34.4	5.0	36.1
	CASTNet	12-km EUS	832	-8.2	23.6	-7.6	24.6
		12-km WUS	287	-18.5	26.6	-16.4	27.3
		Northeast	206	2.7	25.8	2.9	26.8
		Midwest	155	-2.7	22.9	-1.1	22.1
		Southeast	292	-12.6	21.3	-14.0	23.0
		Central	78	-28.7	32.3	-24.5	31.6
		West	262	-17.6	26.8	-15.9	27.4
Summer	STN	12-km EUS	3516	-15.8	31.7	-15.0	38.1
		12-km WUS	1075	-35.3	43.4	-28.8	45.1
		Northeast	874	-8.6	27.5	-2.5	31.3
		Midwest	621	-9.9	28.7	0.1	30.9
		Southeast	941	-18.1	31.8	-19.0	37.3
		Central	847	-30.5	41.5	-35.7	52.2
		West	853	-35.4	45.8	-27.3	45.6
	IMPROVE	12-km EUS	2324	-19.5	34.3	-16.2	41.1
		12-km WUS	2394	-25.0	40.0	-16.4	42.9
		Northeast	590	-11.2	32.7	-1.0	39.0
		Midwest	158	-18.2	29.8	-6.6	33.9
		Southeast	427	-22.7	34.0	-23.9	41.5
		Central	601	-27.0	38.4	-23.3	45.1
		West	2021	-22.9	40.8	-14.0	42.7
	CASTNet	12-km EUS	792	-19.2	23.9	-21.7	29.5
		12-km WUS	295	-34.1	37.7	-34.4	40.6
		Northeast	192	-14.9	20.6	-11.2	22.4
		Midwest	161	-15.7	21.3	-13.2	23.2
		Southeast	270	-21.1	24.8	-28.1	32.6
		Central	75	-33.3	36.9	-38.9	46.2
		West	269	-33.6	37.9	-33.5	40.2
Fall	STN	12-km EUS	3365	-10.5	28.4	-2.5	30.9
		12-km WUS	1095	-17.2	44.2	-7.9	44.5
		Northeast	902	-8.3	29.7	1.6	31.9
		Midwest	639	-10.9	26.8	-3.1	27.7
		Southeast	990	-10.9	26.7	-6.1	28.5
		Central	571	-10.9	32.6	-2.4	35.1
		West	900	-14.6	48.8	-6.9	46.4
	IMPROVE	12-km EUS	2199	-11.3	30.8	0.6	36.5
		12-km WUS	2476	-4.8	38.2	9.5	41.0
		Northeast	531	-5.6	32.6	9.2	36.5
		Midwest	97	-19.1	26.6	-15.3	29.3
		Southeast	436	-13.1	28.6	-6.7	33.9

		Central	578	-14.3	32.0	-5.1	37.5
		West	2084	0.5	41.2	12.6	42.5
	CASTNet	12-km EUS	786	-17.5	21.0	-14.0	21.7
		12-km WUS	293	-11.4	24.3	-4.9	25.3
		Northeast	195	-12.3	18.4	-7.2	18.2
		Midwest	157	-19.7	21.9	-15.8	20.9
		Southeast	273	-18.6	21.3	-19.4	23.4
		Central	75	-21.0	23.6	-19.3	26.3
		West	267	-9.2	24.9	-3.5	25.7

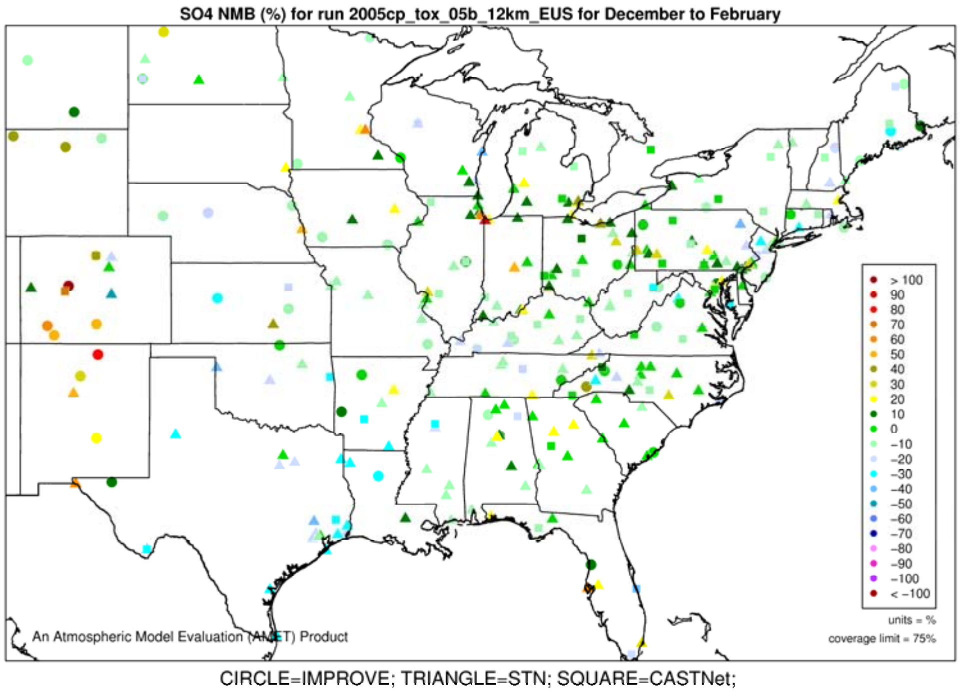


Figure F-1. Normalized Mean Bias (%) of sulfate by monitor for 12-km Eastern U.S. domain, Winter 2005.

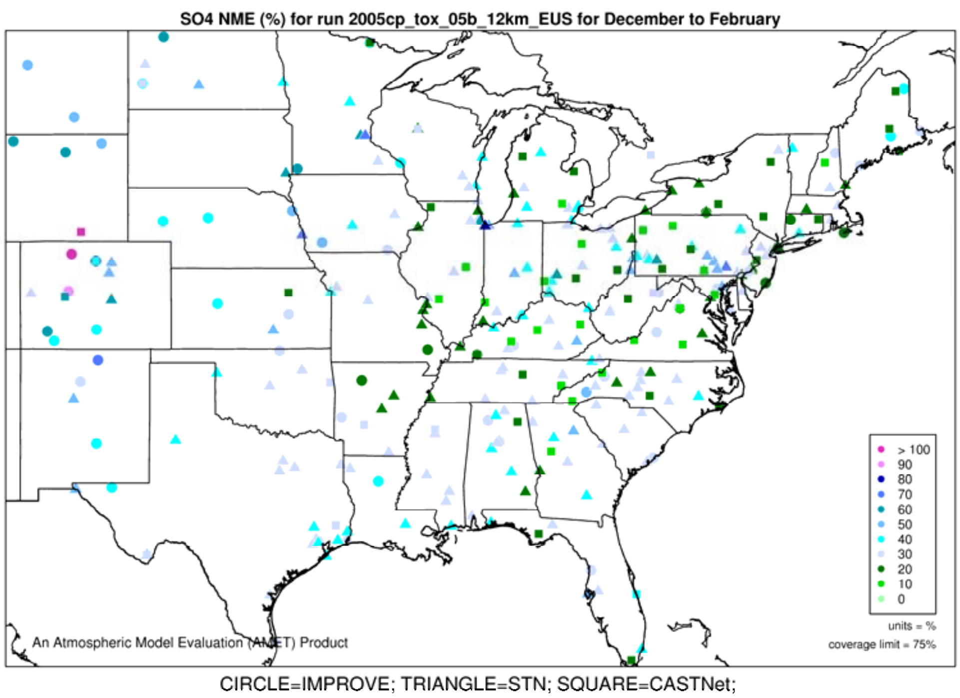


Figure F-2. Normalized Mean Error (%) of sulfate by monitor for 12-km Eastern U.S. domain, Winter 2005.

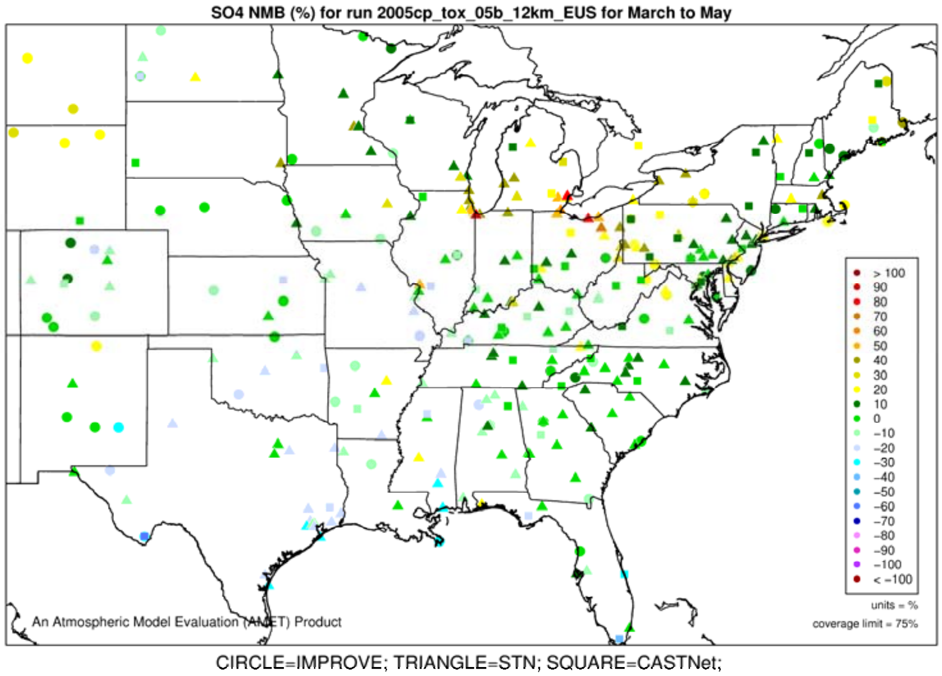


Figure F-3. Normalized Mean Bias (%) of sulfate by monitor for 12-km Eastern U.S. domain, Spring 2005.

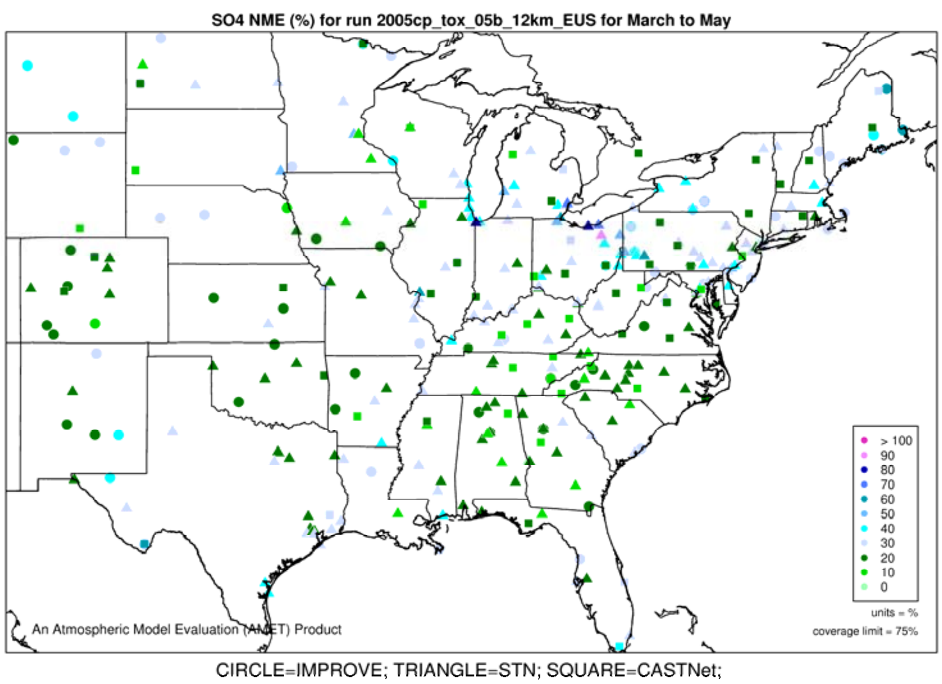


Figure F-4. Normalized Mean Error (%) of sulfate by monitor for 12-km Eastern U.S. domain, Spring 2005.

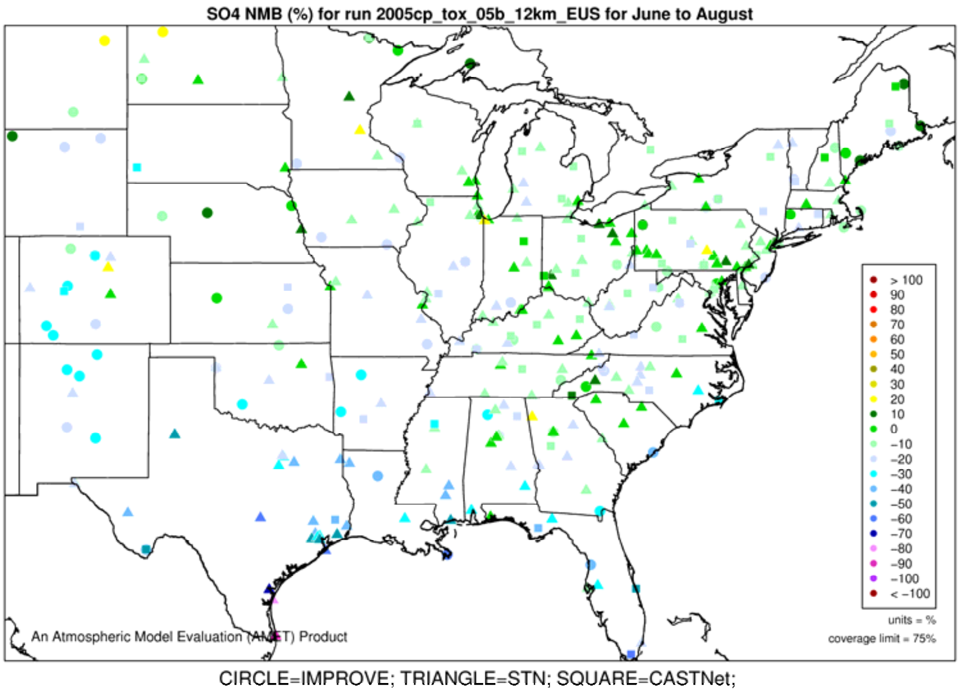


Figure F-5. Normalized Mean Bias (%) of sulfate by monitor for 12-km Eastern U.S. domain, Summer 2005.

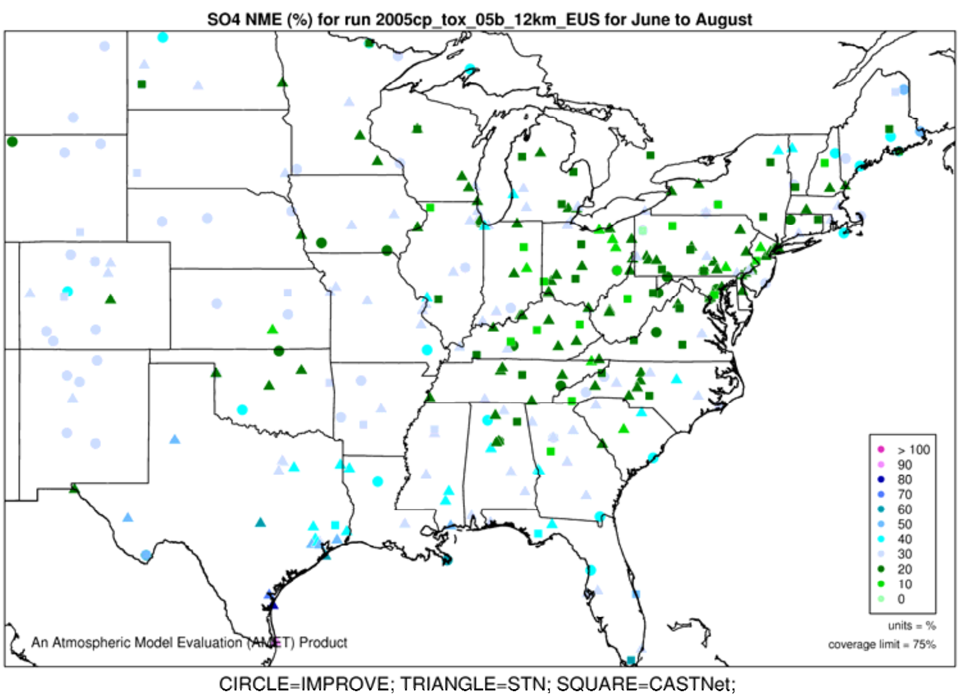


Figure F-6. Normalized Mean Error (%) of sulfate by monitor for 12-km Eastern U.S. domain, Summer 2005.

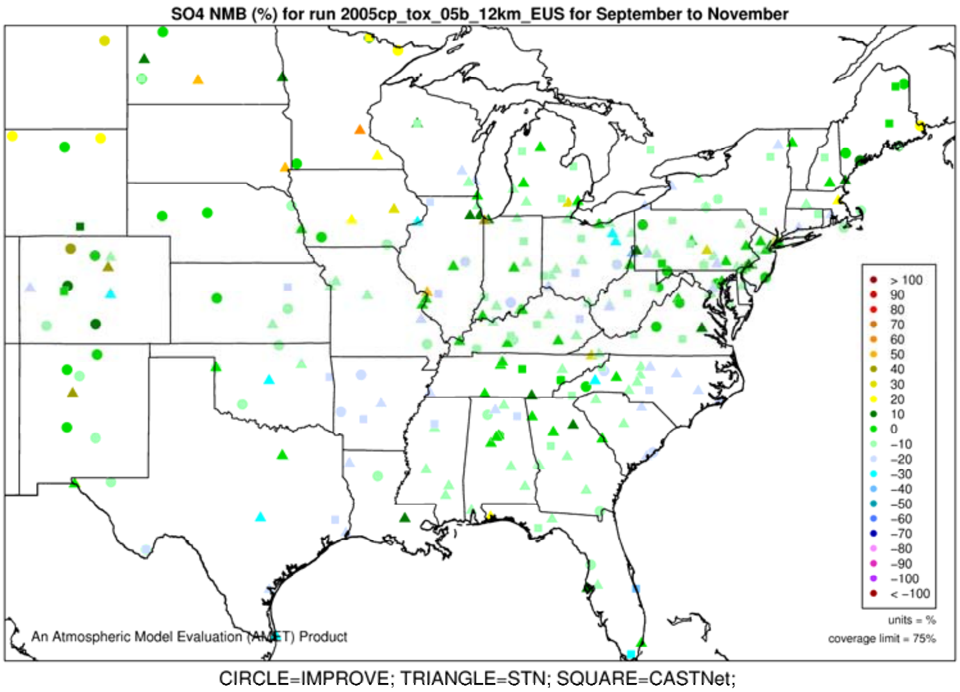


Figure F-7. Normalized Mean Bias (%) of sulfate by monitor for 12-km Eastern U.S. domain, Fall 2005.

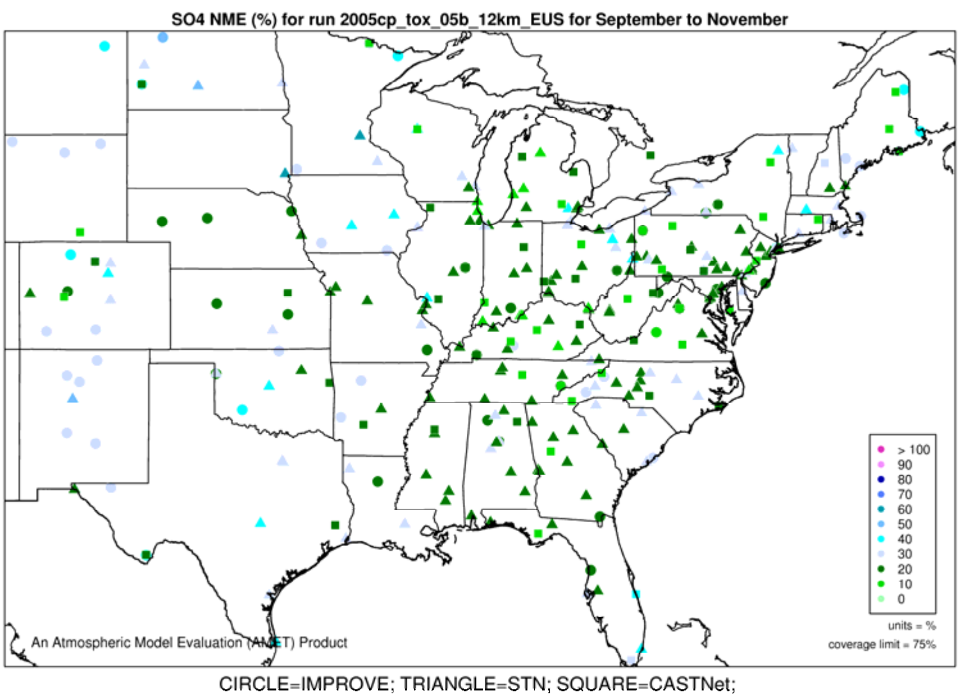


Figure F-8. Normalized Mean Error (%) of sulfate by monitor for 12-km Eastern U.S. domain, Fall 2005.

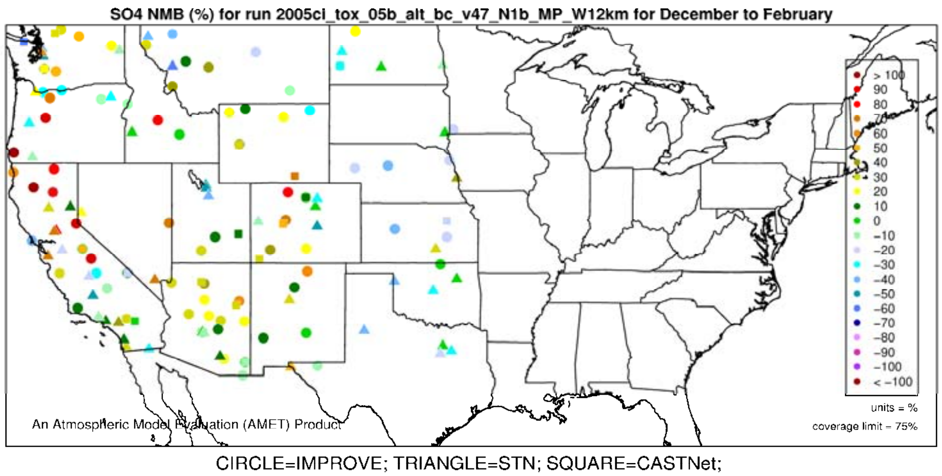


Figure F-9. Normalized Mean Bias (%) of sulfate by monitor for 12-km Western U.S. domain, Winter 2005.

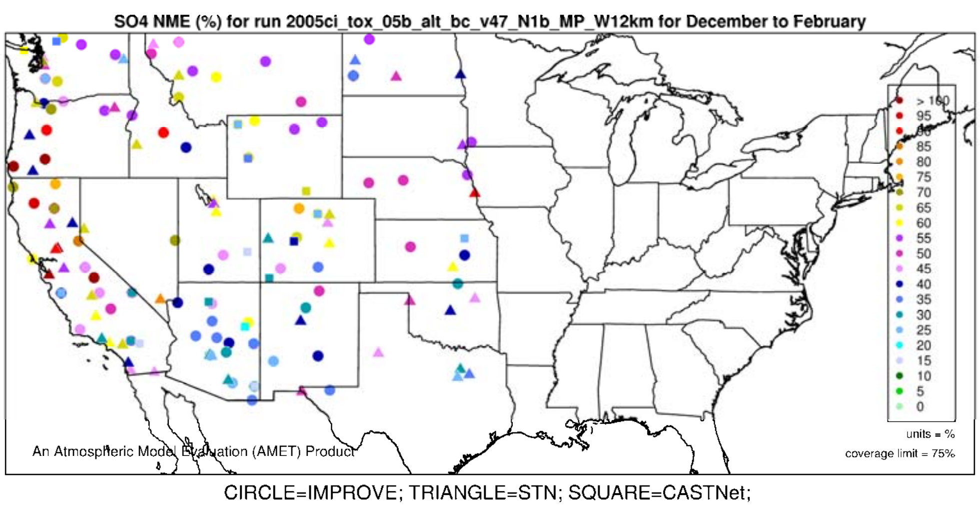


Figure F-10. Normalized Mean Error (%) of sulfate by monitor for 12-km Western U.S. domain, Winter 2005.

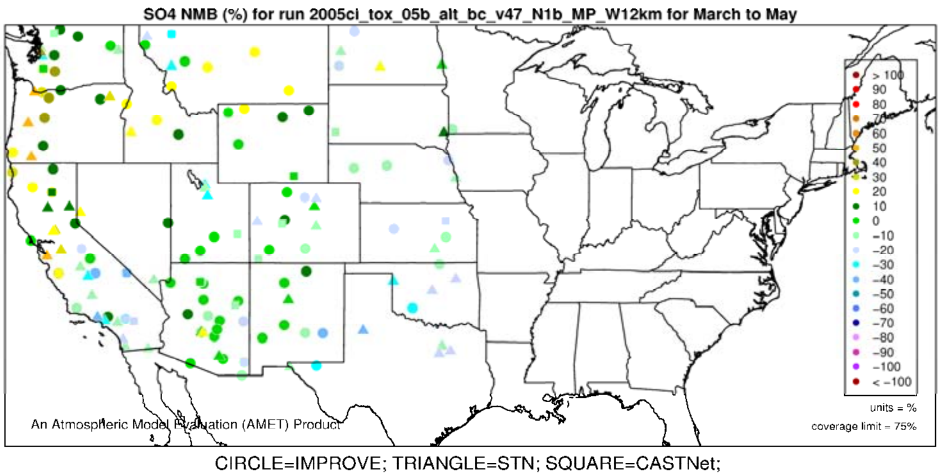


Figure F-11. Normalized Mean Bias (%) of sulfate by monitor for 12-km Western U.S. domain, Spring 2005.

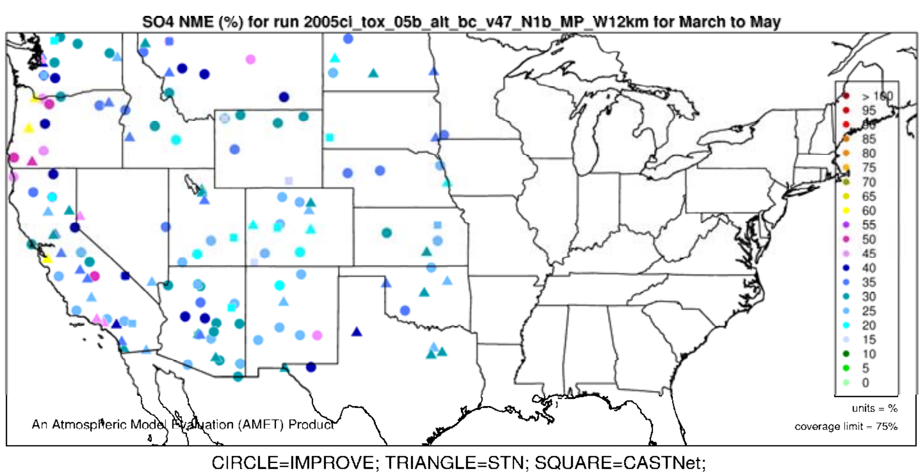


Figure F-12. Normalized Mean Error (%) of sulfate by monitor for 12-km Western U.S. domain, Spring 2005.

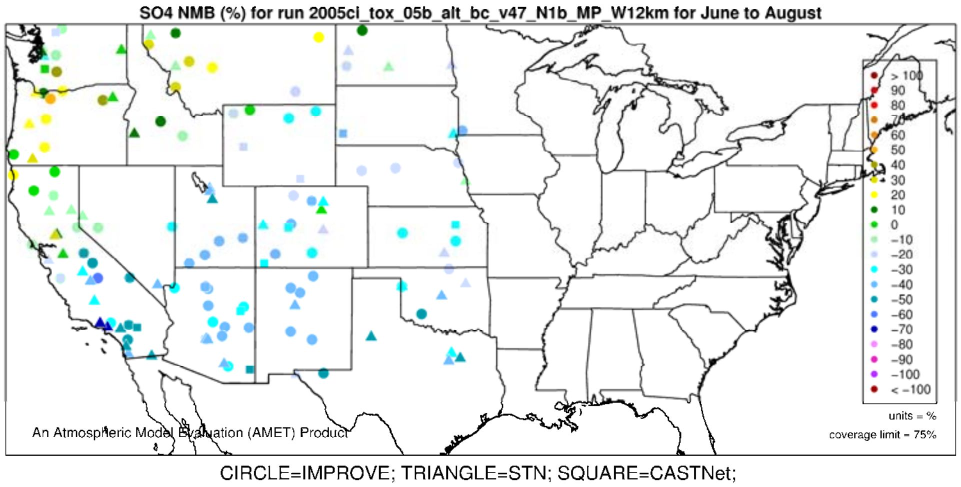


Figure F-13. Normalized Mean Bias (%) of sulfate by monitor for 12-km Western U.S. domain, Summer 2005.

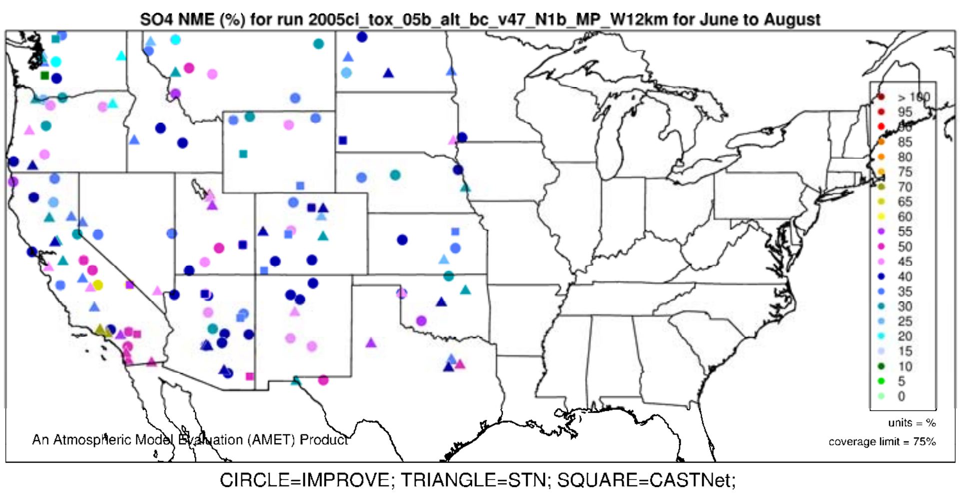


Figure F-14. Normalized Mean Error (%) of sulfate by monitor for 12-km Western U.S. domain, Summer 2005.

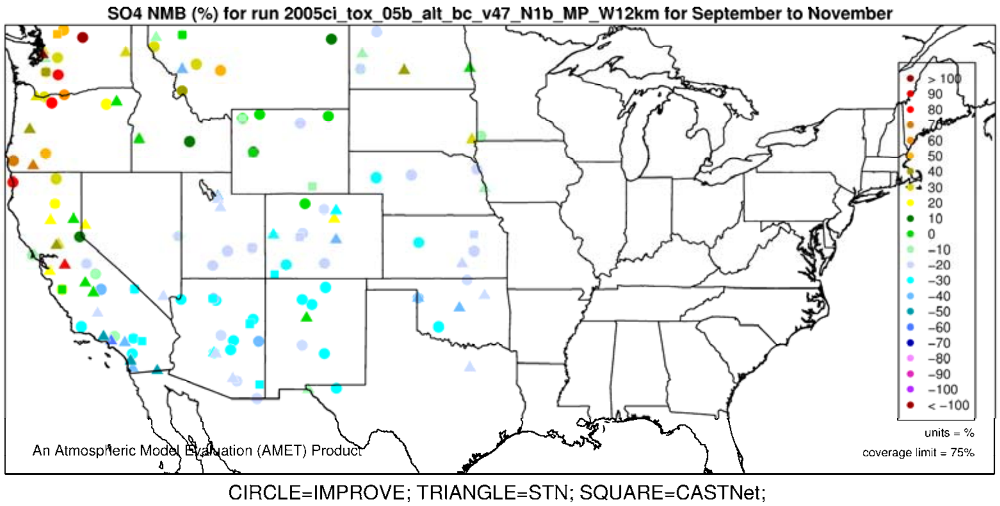


Figure F-15. Normalized Mean Bias (%) of sulfate by monitor for 12-km Western U.S. domain, Fall 2005.

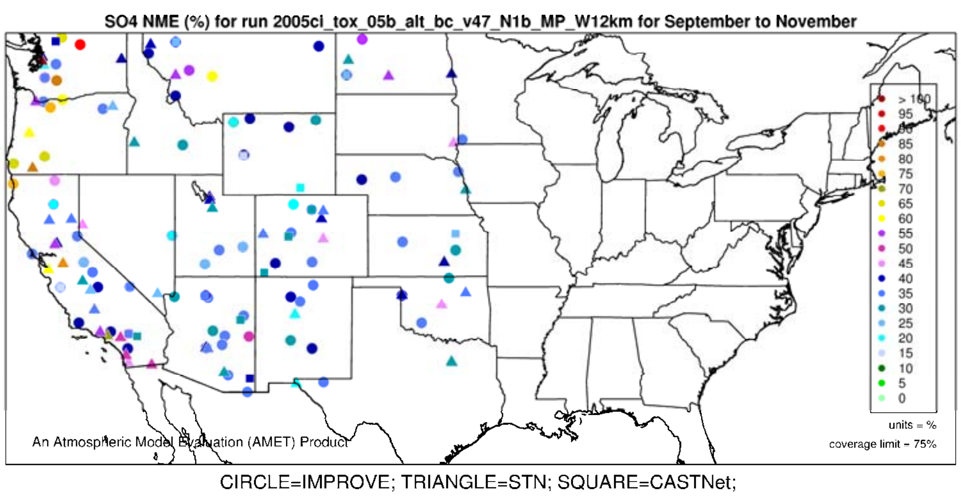


Figure F-16. Normalized Mean Error (%) of sulfate by monitor for 12-km Western U.S. domain, Fall 2005.

G. Seasonal Nitrate Performance

Table G-1 provides the seasonal model performance statistics for nitrate and total nitrate for the 12-km Eastern and Western domains. Spatial plots of the NMB and NME statistics (units of percent) for individual monitors are also provided as a complement to the tabular statistical data (Figures G-1 – G-32). Overall, nitrate and total nitrate performance is over-predicted in the EUS and under-predicted in the WUS for all of the seasonal assessments except in the winter and fall season, where total nitrate is over-predicted in the EUS and WUS and in the spring where nitrate is over-predicted in the EUS. Likewise, in the East, nitrate and total nitrate are moderately over-predicted during the spring and summer seasons (NMB values ranging from 10% to 100%). In the winter season when nitrate is most abundant, nitrate is under-predicted in the East and West, however total nitrate is over-predicted.

Table G-1. CMAQ 2005 seasonal model performance statistics for nitrate.

CMAQ 2005 Nitrate			No. of Obs.	NMB (%)	NME (%)	FB (%)	FE (%)
Nitrate (Winter)	STN	12-km EUS	3099	-0.4	47.9	-6.9	58.1
		12-km WUS	973	-42.8	61.8	-53.1	82.1
		Northeast	829	17.2	48.7	16.0	49.5
		Midwest	598	-10.1	38.1	-7.3	43.5
		Southeast	963	-2.1	61.8	-25.5	73.1
		Central	479	-1.4	48.1	2.1	56.9
		West	831	-46.9	64.1	-60.5	86.1
	IMPROVE	12-km EUS	2076	15.8	64.1	-13.6	82.5
		12-km WUS	2426	-18.6	63.1	-71.4	110.2
		Northeast	502	59.0	84.2	40.6	75.8
		Midwest	129	-18.5	41.9	-19.9	63.5
		Southeast	386	24.5	84.8	-24.6	81.9
		Central	539	6.9	53.7	-3.0	71.2
		West	2084	-31.2	71.6	-77.7	115.9
Total Nitrate (Winter)	CASTNet	12-km EUS	760	16.8	31.6	24.1	35.4
		12-km WUS	267	25.6	44.5	35.2	51.5
		Northeast	193	29.7	34.3	35.9	38.4
		Midwest	142	-4.0	20.9	3.1	21.4
		Southeast	264	26.9	37.6	22.5	36.2
		Central	72	26.3	36.8	26.1	35.5
		West	243	29.8	53.1	37.9	54.6
Nitrate (Spring)	STN	12-km EUS	3254	65.7	91.7	29.9	76.3
		12-km WUS	987	-33.5	55.5	-56.9	81.4
		Northeast	894	71.9	98.1	51.8	75.9
		Midwest	637	78.3	93.1	51.0	68.9
		Southeast	988	68.5	111.6	9.8	87.9
		Central	503	33.4	62.5	21.2	64.6

		West	859	-38.4	56.8	-63.8	84.3
	IMPROVE	12-km EUS	2435	70.7	103.4	4.1	95.3
		12-km WUS	2697	-14.6	71.1	-74.2	112.0
		Northeast	630	100.6	133.2	41.1	98.6
		Midwest	147	70.9	93.2	23.9	83.2
		Southeast	436	93.3	130.1	4.4	96.7
		Central	632	48.4	76.1	-1.2	90.4
		West	2299	-29.5	78.9	-80.7	115.8
Total Nitrate (Spring)	CASTNet	12-km EUS	832	39.9	48.1	27.6	40.0
		12-km WUS	287	-4.8	31.1	2.2	32.1
		Northeast	206	56.5	58.0	44.2	47.3
		Midwest	155	43.0	45.8	35.0	38.0
		Southeast	292	35.2	47.7	24.2	41.1
		Central	78	10.4	35.7	7.7	34.1
		West	262	-4.5	33.0	3.4	33.0
Nitrate (Summer)	STN	12-km EUS	3150	31.1	100.0	-36.9	94.3
		12-km WUS	992	-68.2	74.6	-120.1	127.1
		Northeast	874	19.6	96.2	-33.5	90.4
		Midwest	621	71.6	109.2	10.1	78.8
		Southeast	941	-4.1	89.3	-60.9	102.8
		Central	485	36.5	105.6	-31.2	91.8
		West	846	-70.6	74.1	-126.0	130.0
	IMPROVE	12-km EUS	2324	27.6	118.1	-69.6	119
		12-km WUS	2394	-59.8	83.9	-132.8	145.2
		Northeast	590	40.6	129.7	-47.4	110.9
		Midwest	158	51.5	111.3	-17.9	92.8
		Southeast	427	29.8	124.8	-58.9	118.5
		Central	601	36.5	118.7	-51.8	111.6
		West	2020	-67.2	82.3	-139.2	148.6
Total Nitrate (Summer)	CASTNet	12-km EUS	792	44.3	55.2	25.2	43.3
		12-km WUS	295	-7.4	31.1	-8.3	33.4
		Northeast	192	61.1	67.8	38.3	51.5
		Midwest	161	59.7	61.8	44.6	46.4
		Southeast	270	34.5	51.3	20.8	44.3
		Central	75	2.1	28.6	-4.8	29.5
		West	269	-7.5	31.0	-6.7	32.7
Nitrate (Fall)	STN	12-km EUS	3238	102.6	130.8	14.0	88.4
		12-km WUS	1048	-42.0	72.4	-52.3	91.6
		Northeast	902	110.6	133.7	10.9	84.9
		Midwest	639	91.8	111.8	40.0	74.8
		Southeast	990	112.9	159.0	-3.1	101.8
		Central	460	114.3	137.9	27.7	87.3
		West	896	-48.9	69.1	-63.2	92.5
	IMPROVE	12-km EUS	2192	147.0	185.11	-4.4	107.3

		12-km WUS	2470	3.6	99.6	-60.7	116.5
		Northeast	526	147.8	179.7	3.0	101.0
		Midwest	97	126.1	157.1	30.5	97.2
		Southeast	436	151.0	212.3	-19.8	118.5
		Central	578	171.5	199.3	16.8	108.4
		West	2078	-29.0	79.9	-71.7	118.1
Total Nitrate (Fall)	CASTNet	12-km EUS	786	72.7	82.7	50.1	57.3
		12-km WUS	293	17.2	42.2	25.1	46.1
		Northeast	195	93.5	95.6	58.9	63.5
		Midwest	157	79.3	79.6	54.5	54.7
		Southeast	273	79.1	86.6	48.5	60.9
		Central	75	57.3	63.8	38.7	45.9
		West	267	14.2	40.8	26.4	47.0

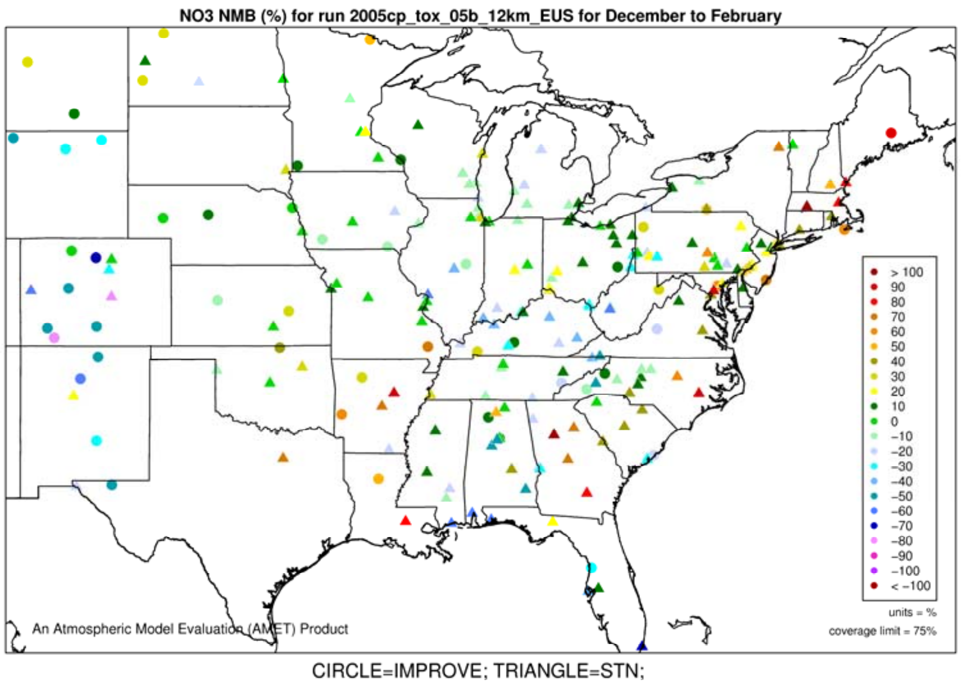


Figure G-1. Normalized Mean Bias (%) of nitrate by monitor for 12-km Eastern U.S. domain, Winter 2005.

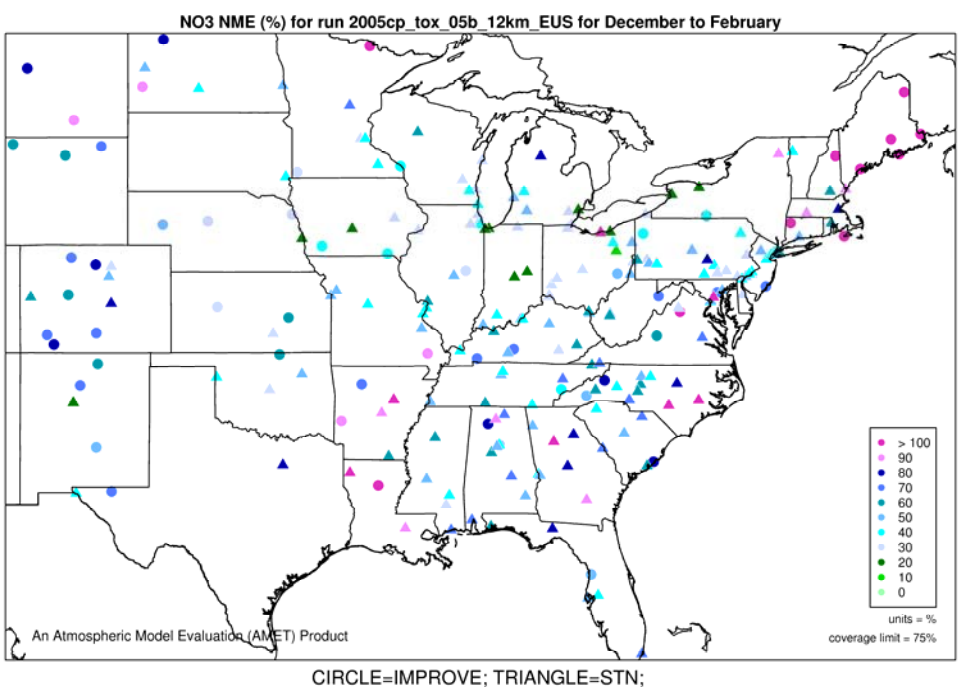


Figure G-2. Normalized Mean Error (%) of nitrate by monitor for 12-km Eastern U.S. domain, Winter 2005.

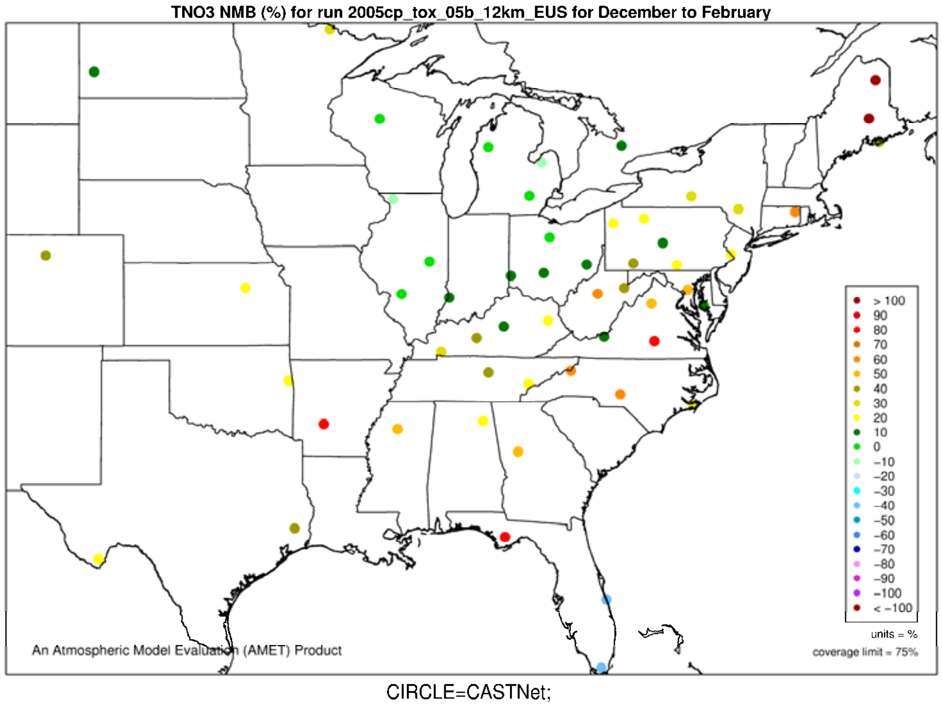


Figure G-3. Normalized Mean Bias (%) of total nitrate by monitor for 12-km Eastern U.S. domain, Winter 2005.

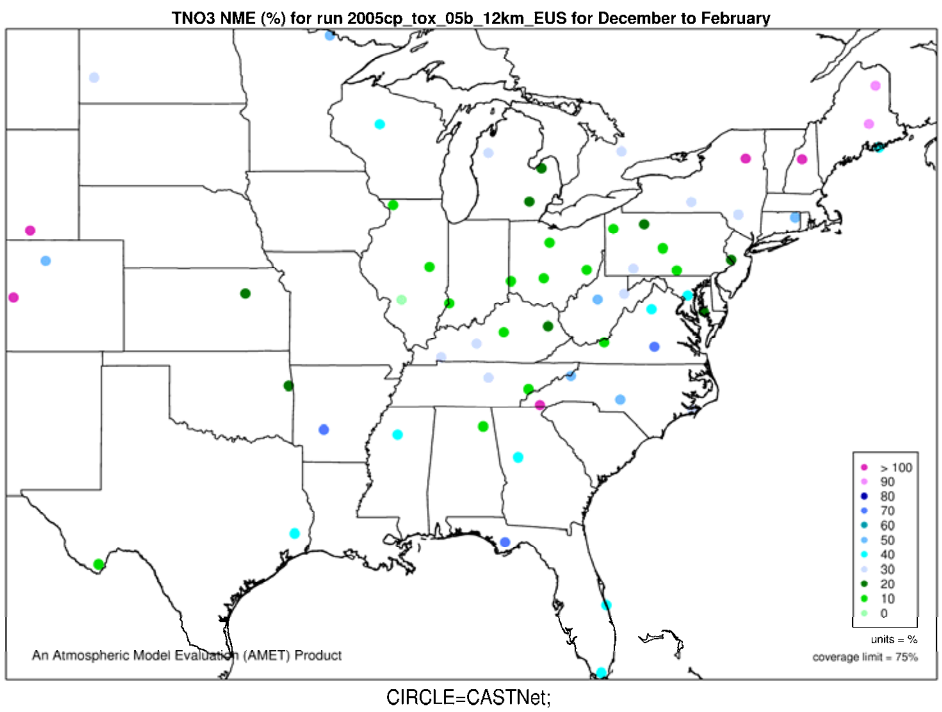


Figure G-4. Normalized Mean Error (%) of total nitrate by monitor for 12-km Eastern U.S. domain, Winter 2005.

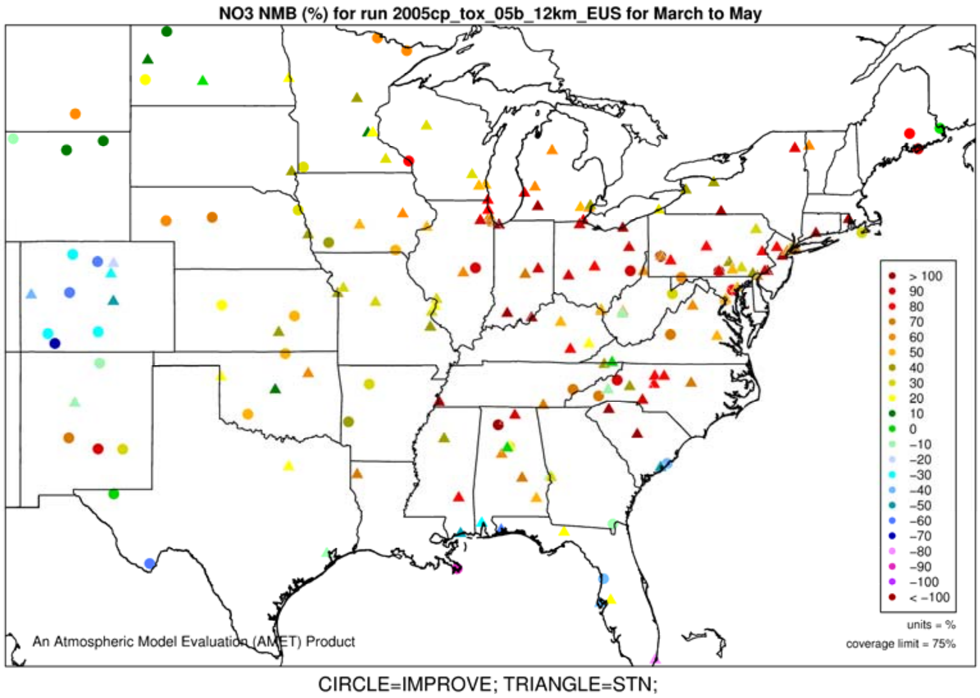


Figure G-5. Normalized Mean Bias (%) of nitrate by monitor for 12-km Eastern U.S. domain, Spring 2005.

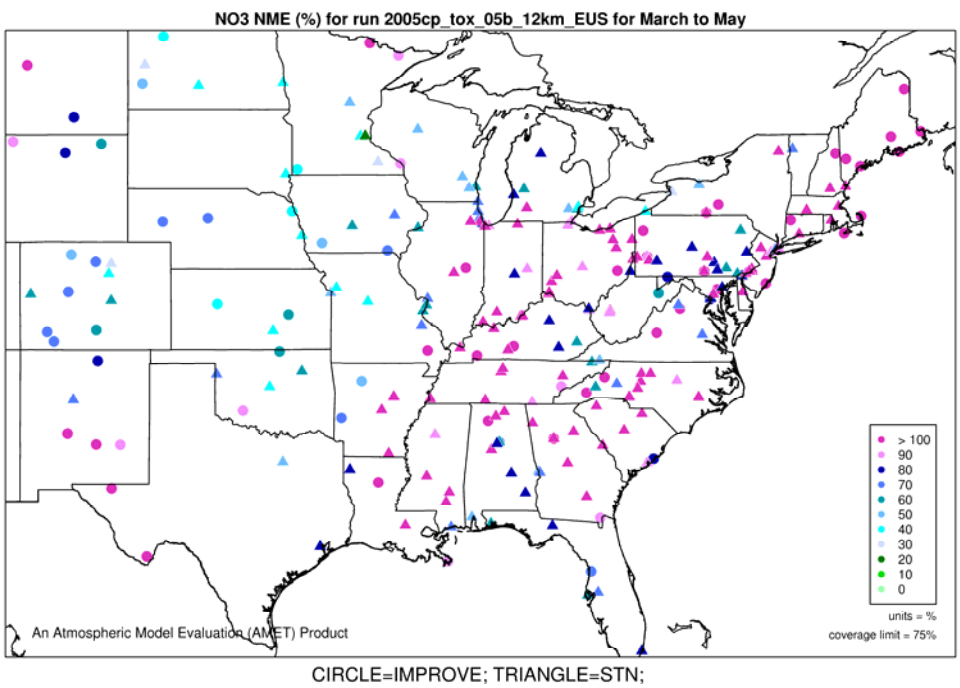


Figure G-6. Normalized Mean Error (%) of nitrate by monitor for 12-km Eastern U.S. domain, Spring 2005.

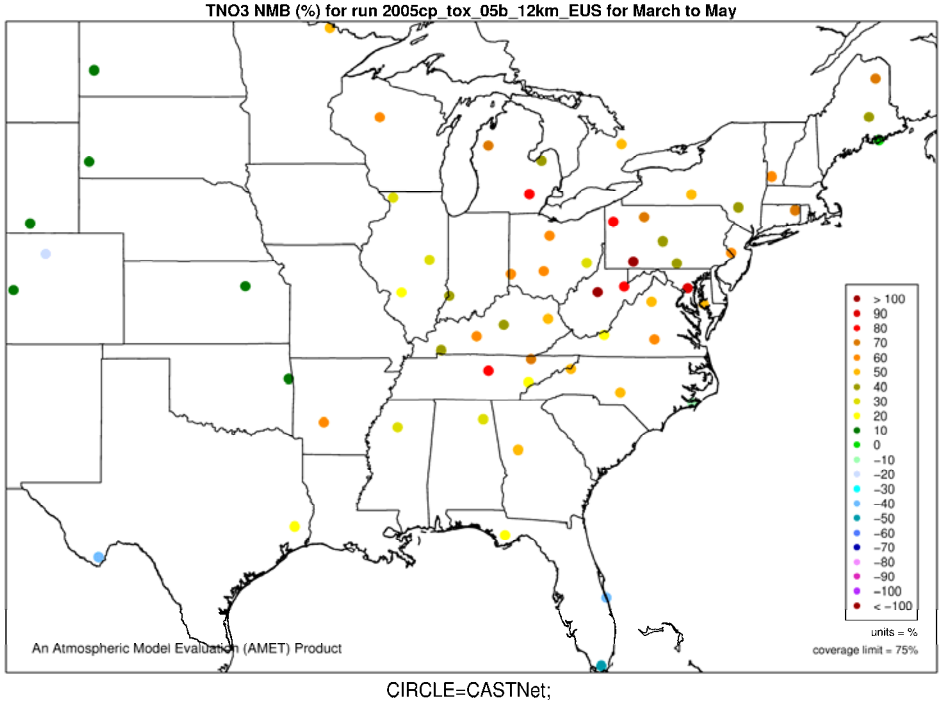


Figure G-7. Normalized Mean Bias (%) of total nitrate by monitor for 12-km Eastern U.S. domain, Spring 2005.

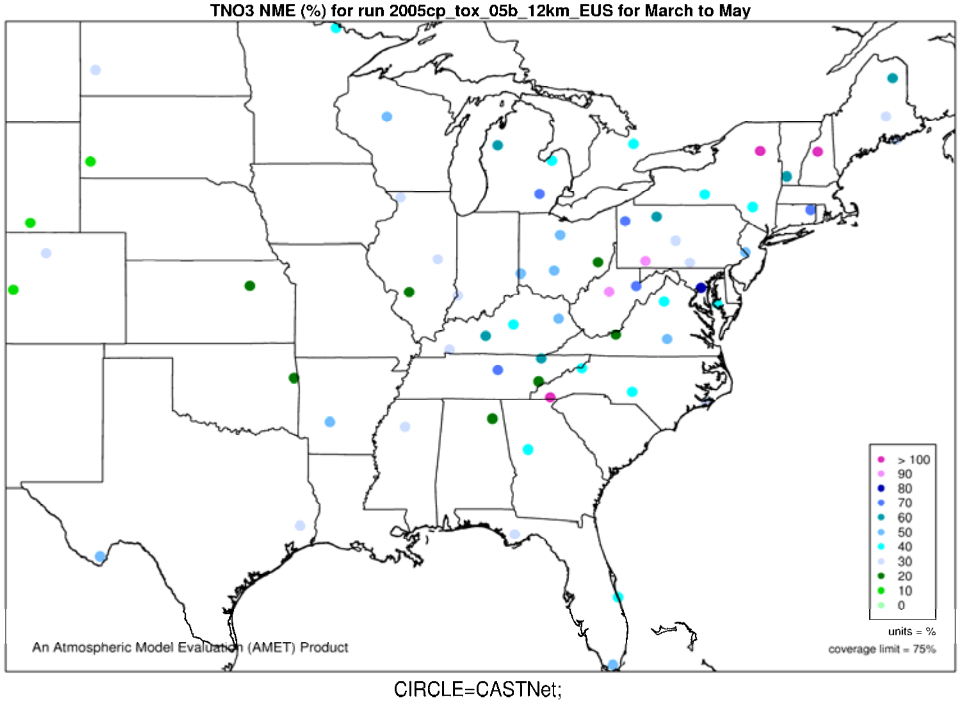


Figure G-8 Normalized Mean Error (%) of total nitrate by monitor for 12-km Eastern U.S. domain, Spring 2005.

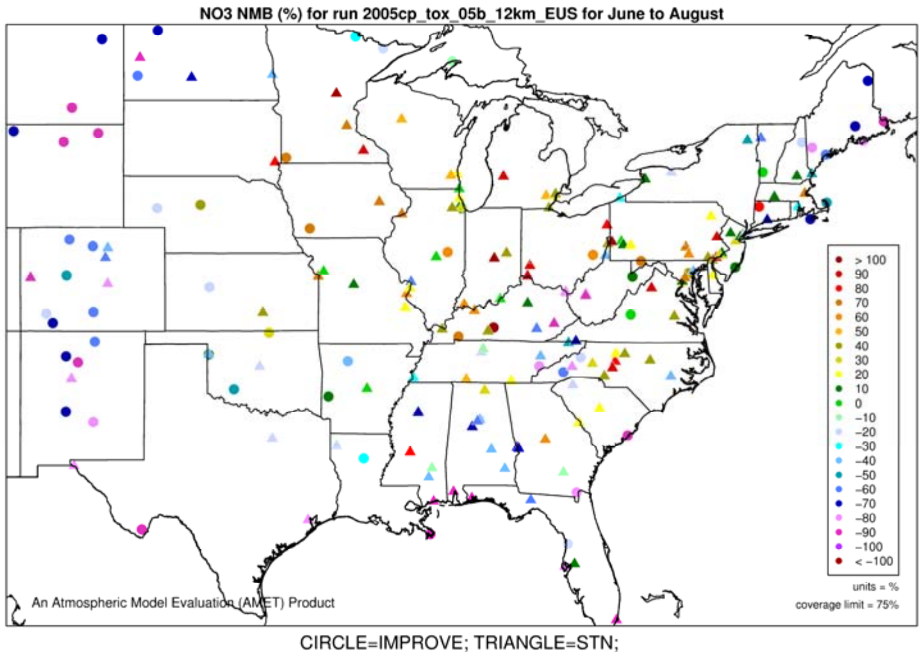


Figure G-9. Normalized Mean Bias (%) of nitrate by monitor for 12-km Eastern U.S. domain, Summer 2005.

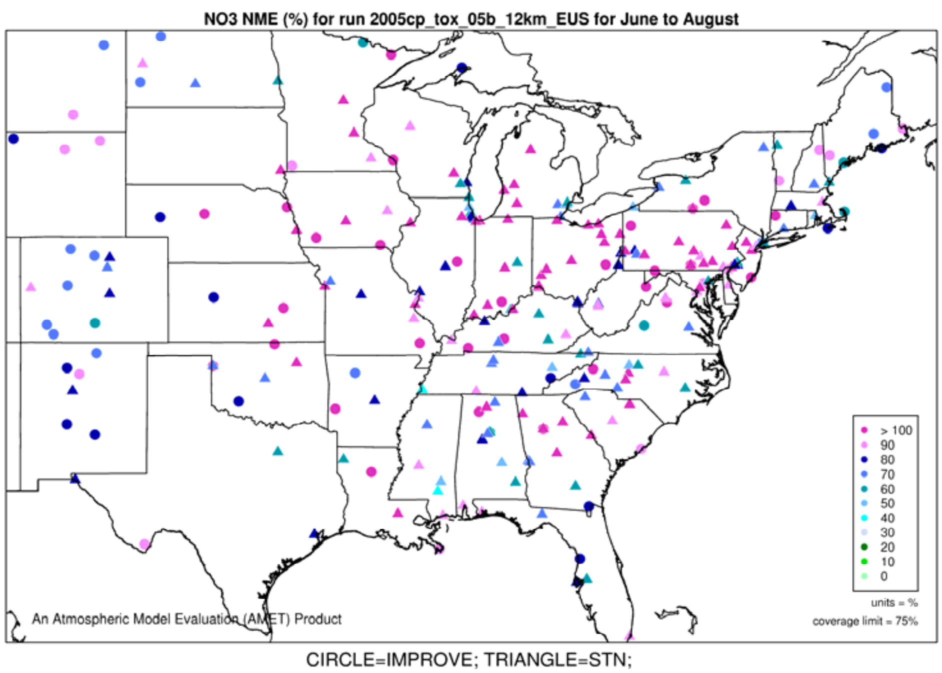


Figure G-10. Normalized Mean Error (%) of nitrate by monitor for 12-km Eastern U.S. domain, Summer 2005.

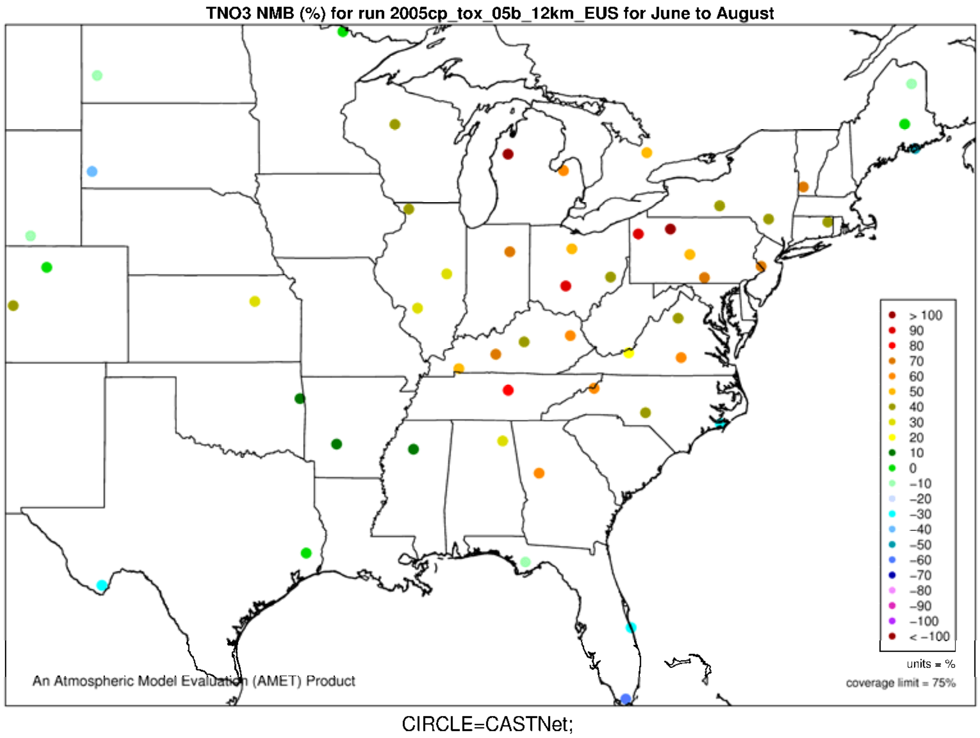


Figure G-11. Normalized Mean Bias (%) of total nitrate by monitor for 12-km Eastern U.S. domain, Summer 2005.

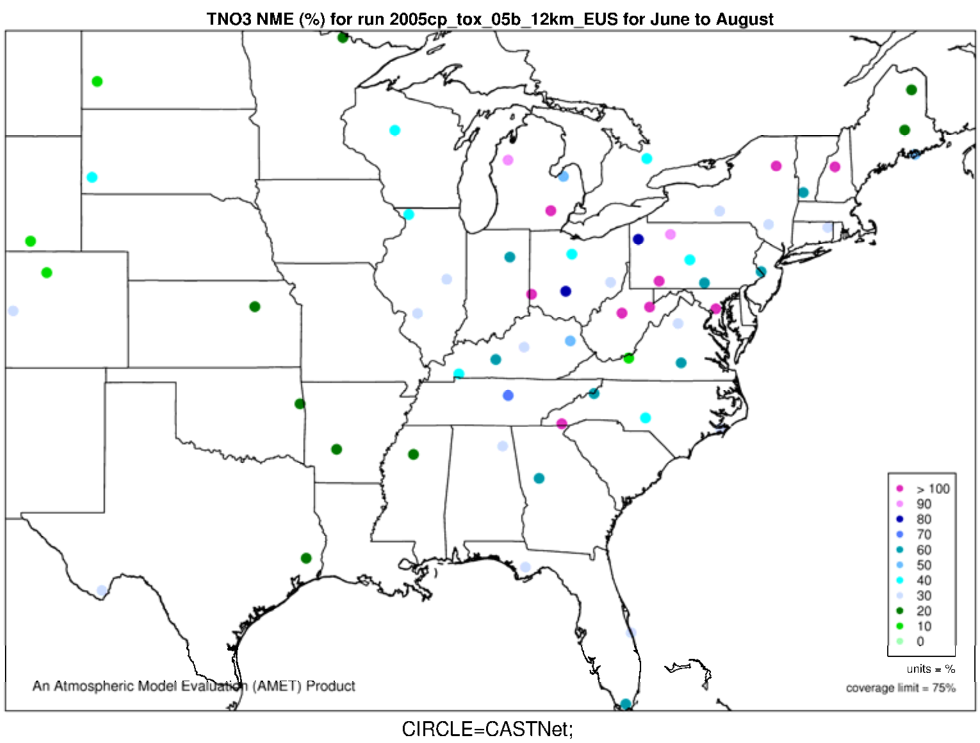


Figure G-12. Normalized Mean Error (%) of total nitrate by monitor for 12-km Eastern U.S. domain, Summer 2005.

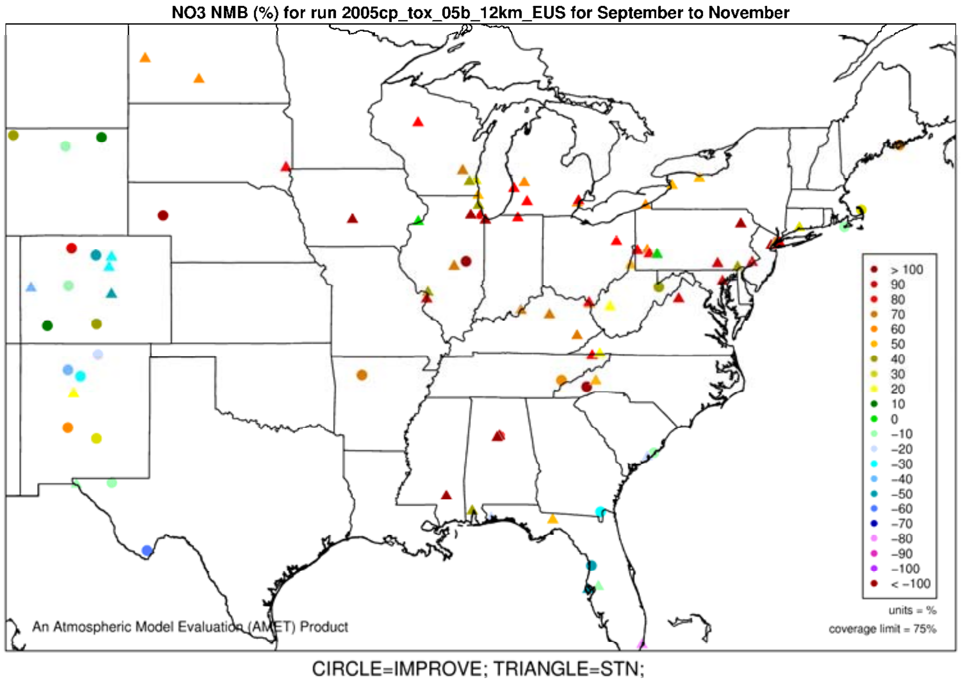


Figure G-13. Normalized Mean Bias (%) of nitrate by monitor for 12-km Eastern U.S. domain, Fall 2005.

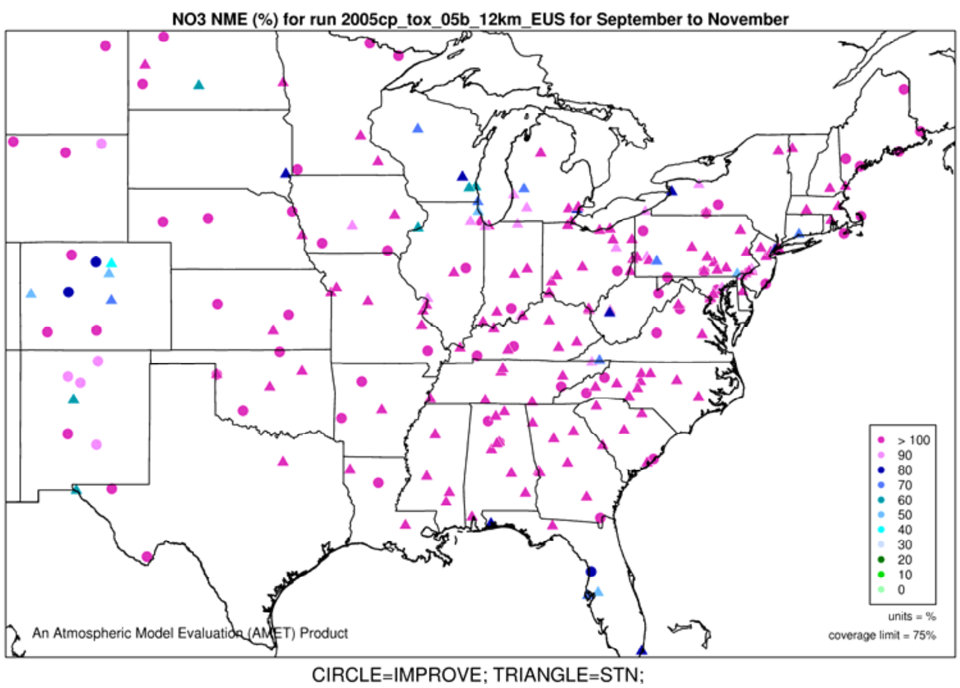


Figure G-14. Normalized Mean Error (%) of nitrate by monitor for 12-km Eastern U.S. domain, Fall 2005.

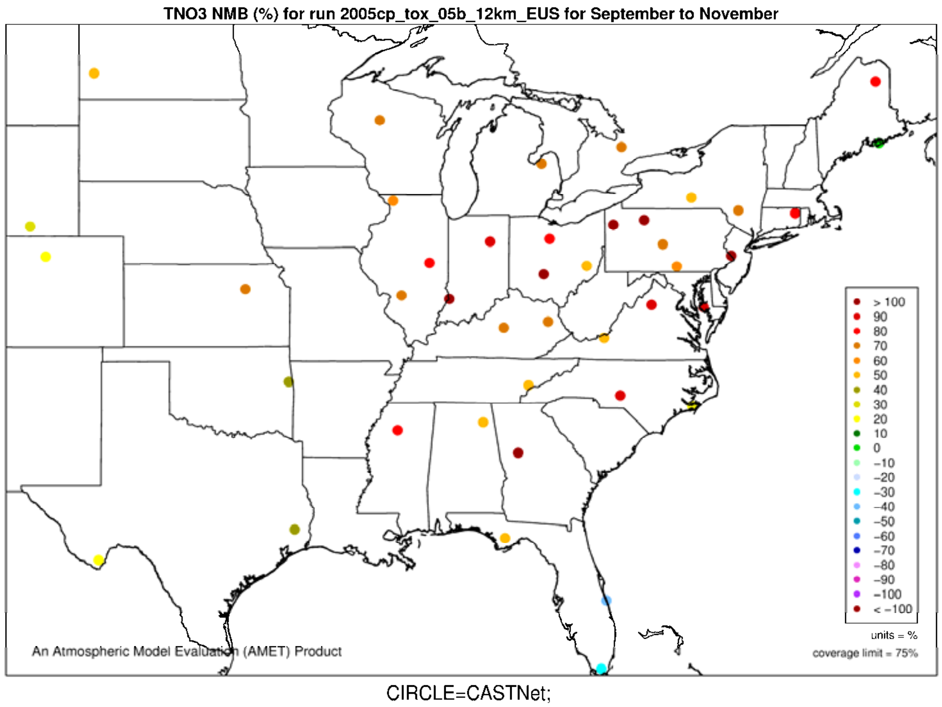


Figure G-15. Normalized Mean Bias (%) of total nitrate by monitor for 12-km Eastern U.S. domain, Fall 2005.

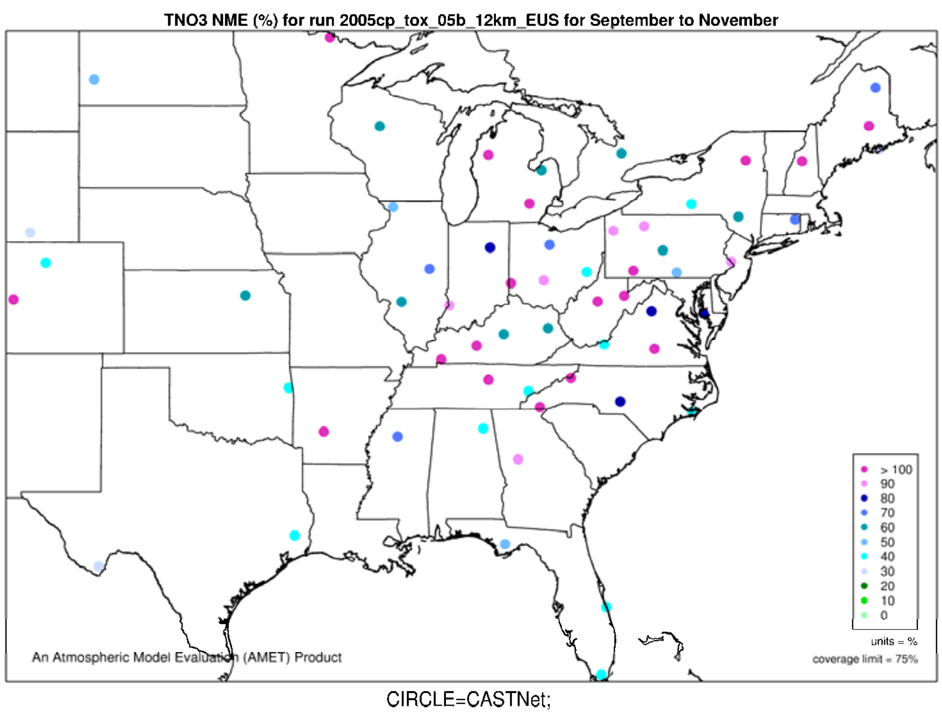


Figure G-16. Normalized Mean Error (%) of total nitrate by monitor for 12-km Eastern U.S. domain, Fall 2005.

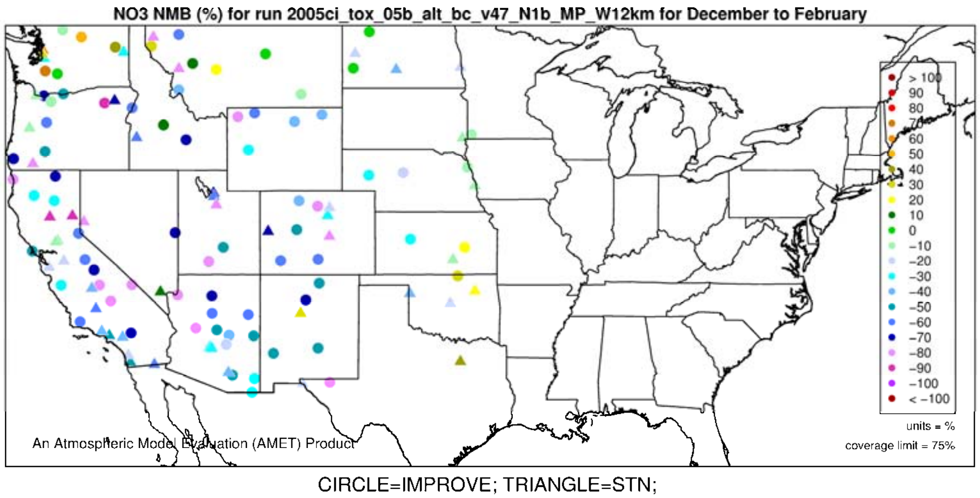


Figure G-17. Normalized Mean Bias (%) of nitrate by monitor for 12-km Western U.S. domain, Winter 2005.

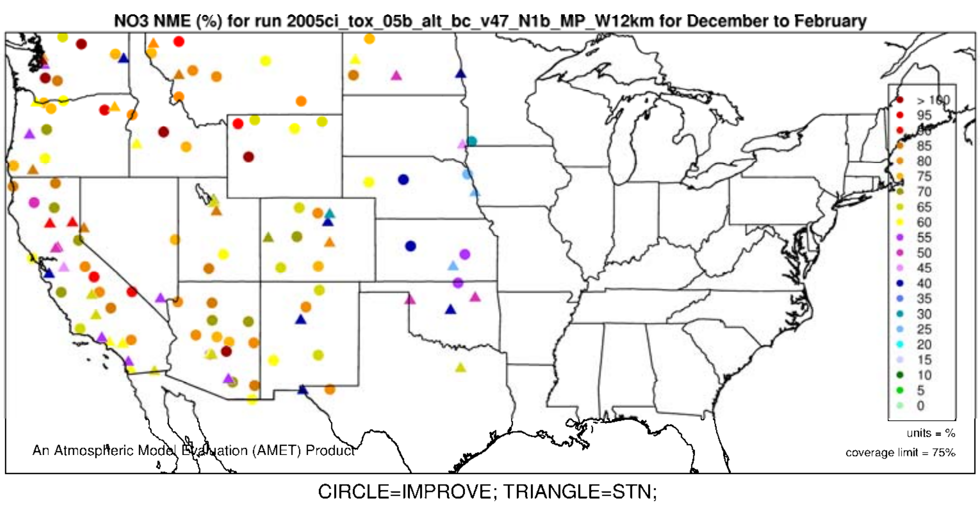


Figure G-18. Normalized Mean Error (%) of nitrate by monitor for 12-km Western U.S. domain, Winter 2005.

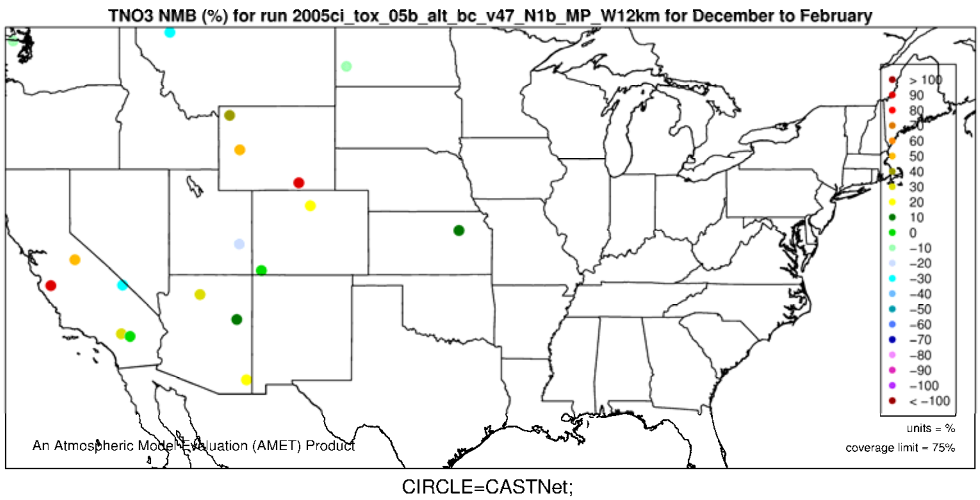


Figure G-19. Normalized Mean Bias (%) of total nitrate by monitor for 12-km Western U.S. domain, Winter 2005.

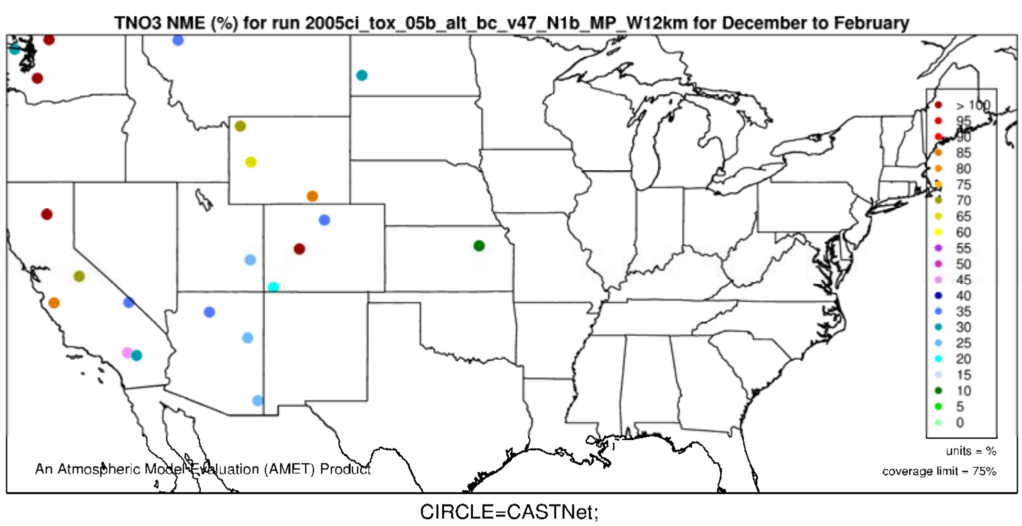


Figure G-20. Normalized Mean Error (%) of total nitrate by monitor for 12-km Western U.S. domain, Winter 2005.

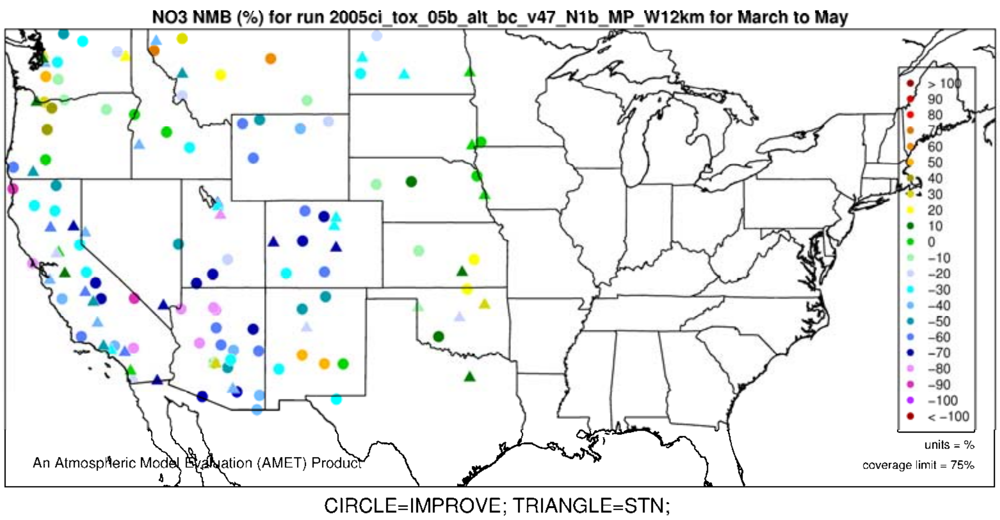


Figure G-21. Normalized Mean Bias (%) of nitrate by monitor for 12-km Western U.S. domain, Spring 2005.

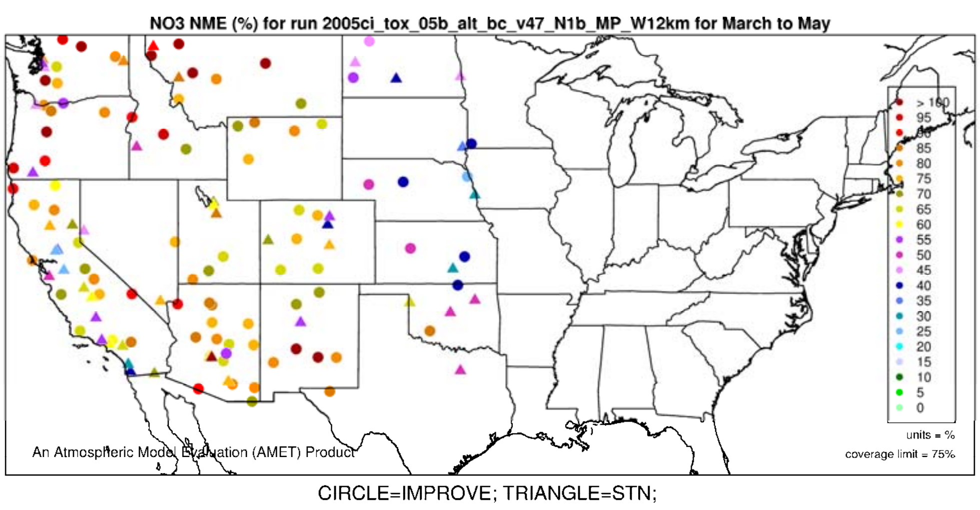


Figure G-22. Normalized Mean Error (%) of nitrate by monitor for 12-km Western U.S. domain, Spring 2005.

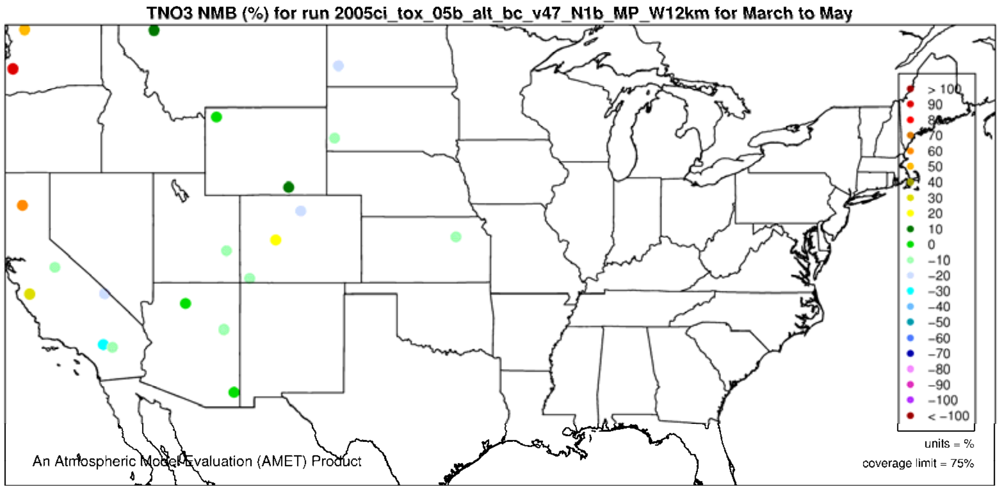


Figure G-23. Normalized Mean Bias (%) of total nitrate by monitor for 12-km Western U.S. domain, Spring 2005.

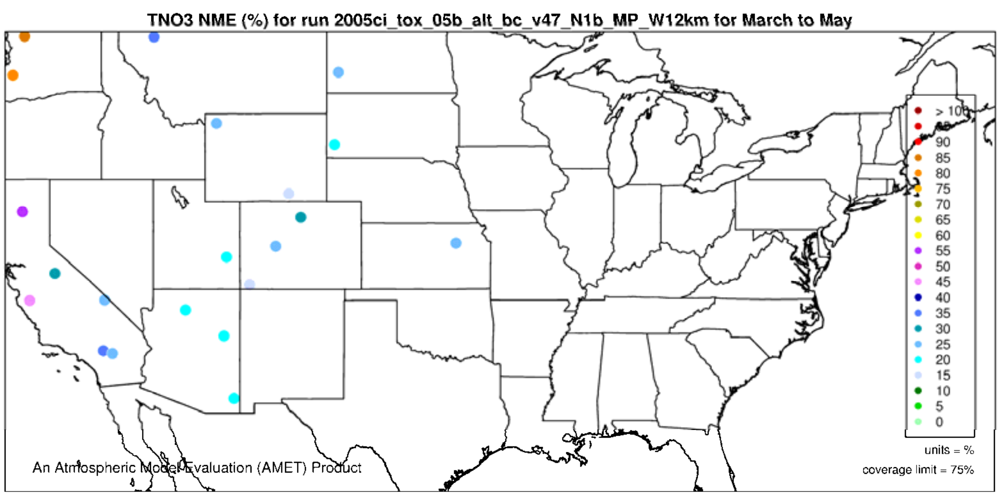


Figure G-24. Normalized Mean Error (%) of total nitrate by monitor for 12-km Western U.S. domain, Spring 2005.

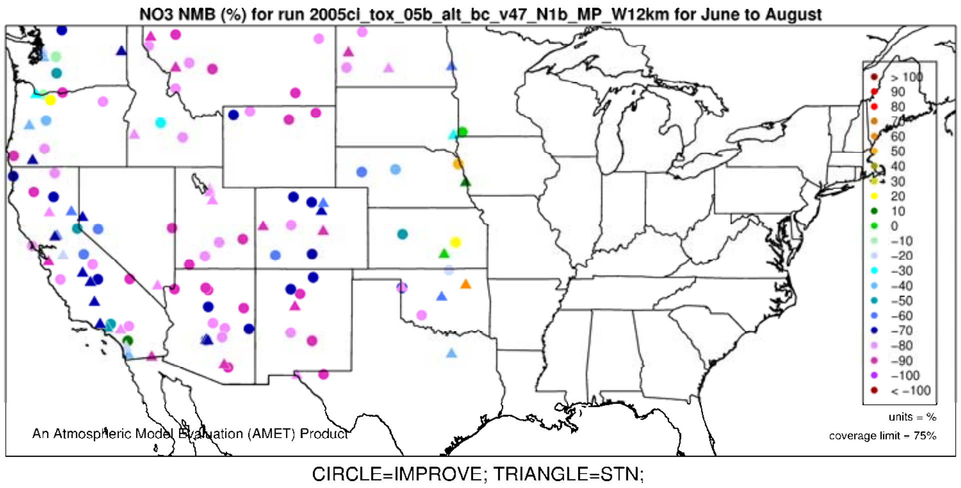


Figure G-25. Normalized Mean Bias (%) of nitrate by monitor for 12-km Western U.S. domain, Summer 2005.

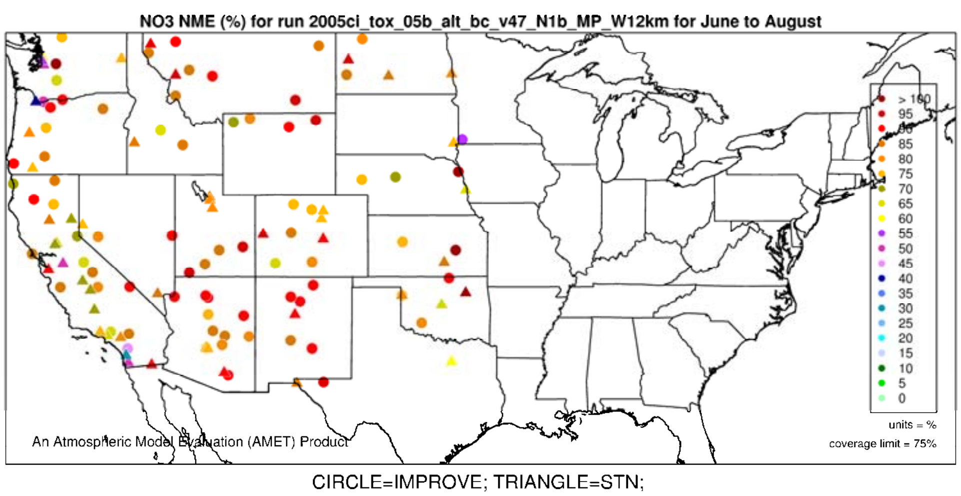


Figure G-26. Normalized Mean Error (%) of nitrate by monitor for 12-km Western U.S. domain, Summer 2005.

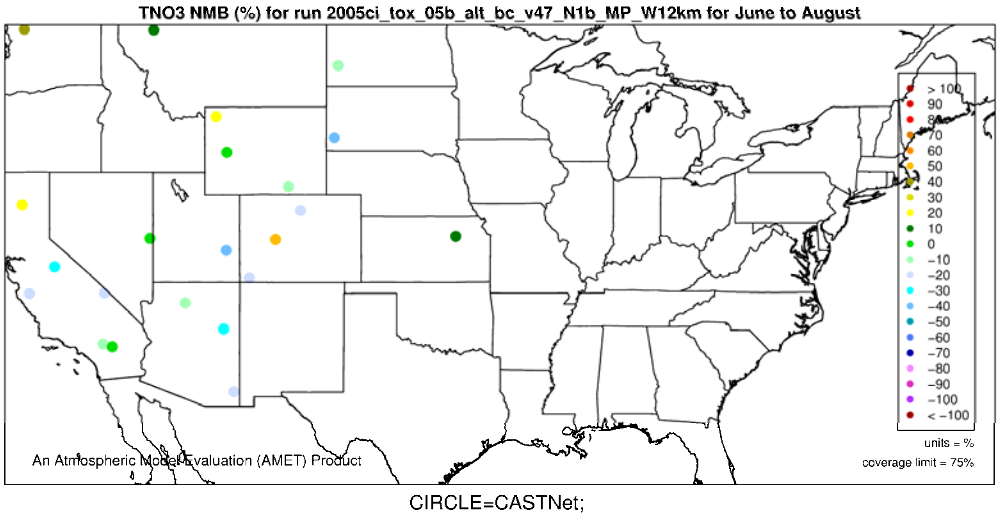


Figure G-27. Normalized Mean Bias (%) of total nitrate by monitor for 12-km Western U.S. domain, Summer 2005.

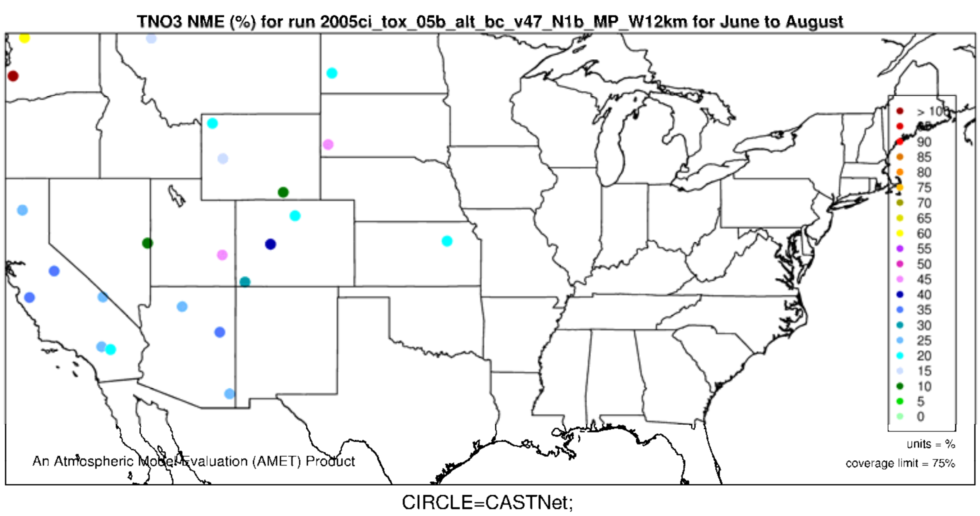


Figure G-28. Normalized Mean Error (%) of total nitrate by monitor for 12-km Western U.S. domain, Summer 2005.

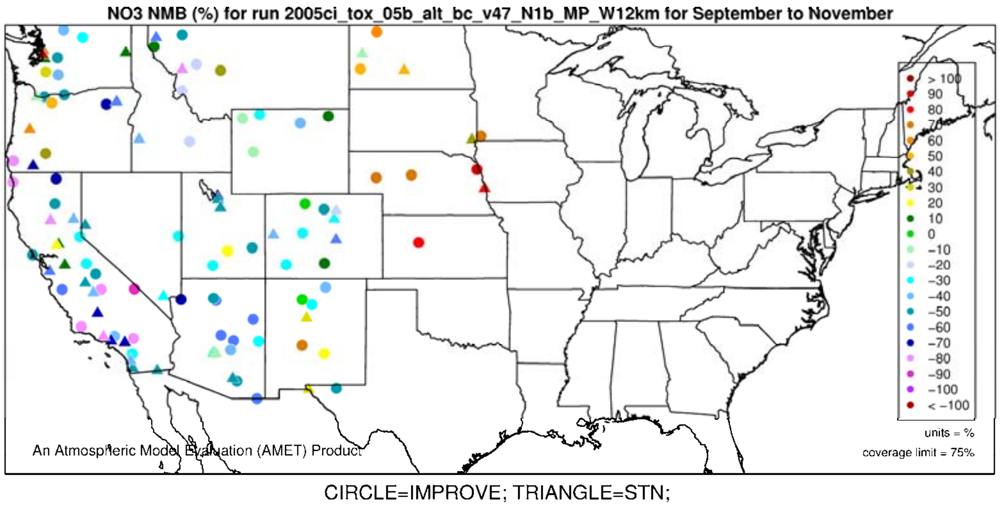


Figure G-29. Normalized Mean Bias (%) of nitrate by monitor for 12-km Western U.S. domain, Fall 2005.

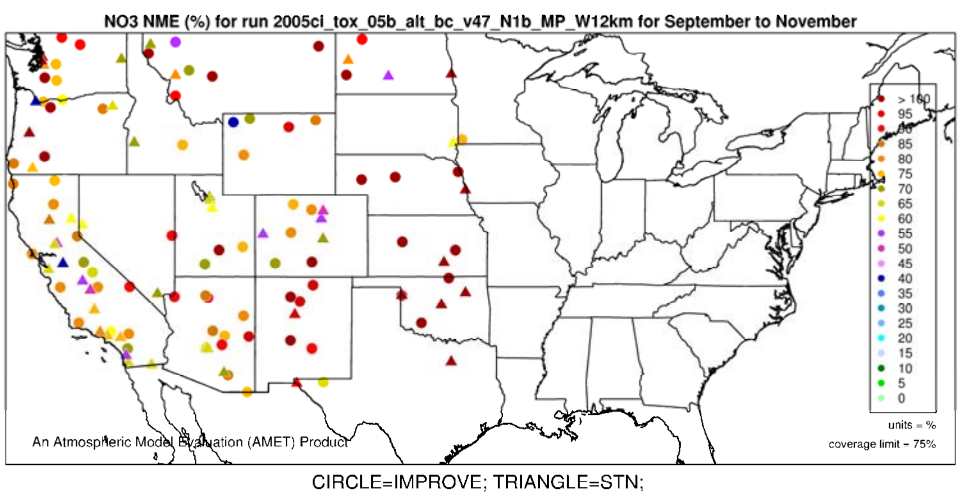


Figure G-30. Normalized Mean Error (%) of nitrate by monitor for 12-km Western U.S. domain, Fall 2005.

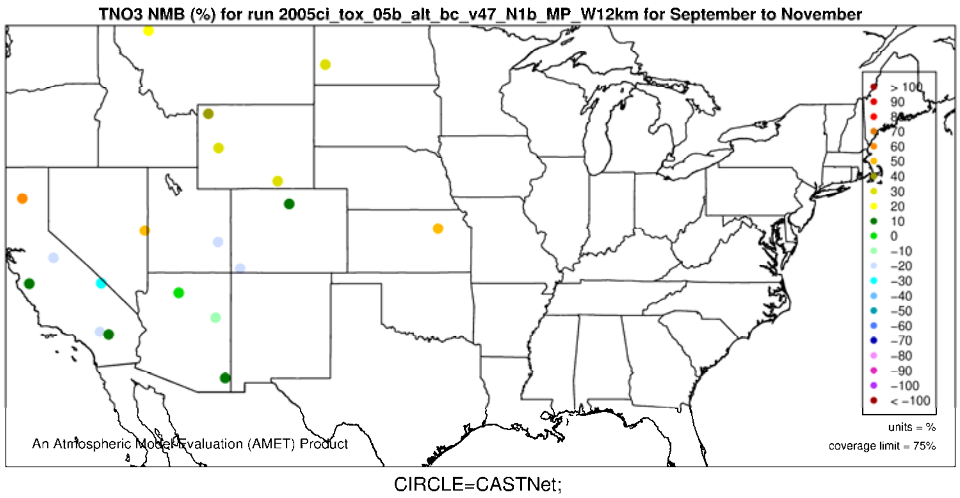


Figure G-31. Normalized Mean Bias (%) of total nitrate by monitor for 12-km Western U.S. domain, Fall 2005.

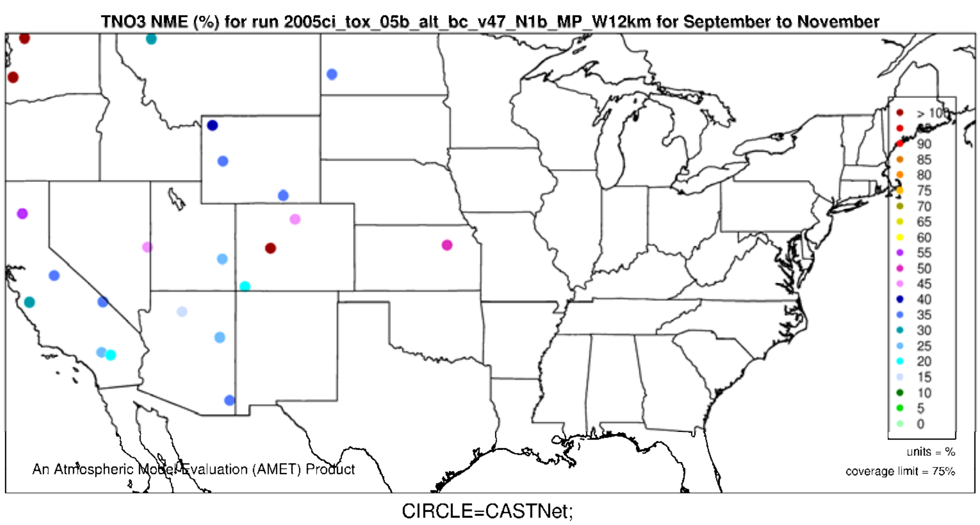


Figure G-32. Normalized Mean Error (%) of total nitrate by monitor for 12-km Western U.S. domain, Fall 2005.

H. Seasonal Ammonium Performance

Table H-1 lists the performance statistics for ammonium PM at the STN and CASTNet sites. Spatial plots of the NMB and NME statistics (units of percent) for individual monitors are also provided in Figures H-1 – H-16. In the winter and spring, ammonium performance at STN sites shows an over-prediction in the EUS and under-prediction in the WUS. Model performance at CASTNet sites show over-predictions at both EUS and WUS. Ammonium performance for the summer season shows an under-prediction in the East and West. However, in the spring, model predictions in the East are over-predicted, whereas ammonia predictions are under-predicted in the West.

Table H-1. CMAQ 2005 seasonal model performance statistics for ammonium.

CMAQ 2005 Ammonium			No. of Obs.	NMB (%)	NME (%)	FB (%)	FE (%)
Winter	STN	12-km EUS	3390	6.6	39.5	8.4	42.0
		12-km WUS	1032	-24.0	58.9	-8.0	63.4
		Northeast	828	16.9	38.4	18.4	36.0
		Midwest	598	2.9	32.4	7.8	32.8
		Southeast	963	4.3	43.8	5.0	44.4
		Central	766	3.5	43.0	5.4	50.0
		West	829	-31.0	61.1	-14.5	66.0
	CASTNet	12-km EUS	760	7.7	31.4	12.2	33.3
		12-km WUS	267	4.4	38.8	10.2	40.8
		Northeast	193	33.4	44.7	33.6	40.8
		Midwest	142	-5.3	23.3	0.3	24.1
		Southeast	264	0.9	27.9	1.3	28.7
		Central	72	4.6	36.8	5.7	41.7
		West	243	-0.5	43.6	10.6	42.1
Spring	STN	12-km EUS	3626	34.3	55.8	28.1	48.3
		12-km WUS	1077	-2.0	47.4	17.5	48.7
		Northeast	894	49.1	66.3	46.2	57.3
		Midwest	637	61.1	72.1	47.0	56.1
		Southeast	988	19.4	43.7	17.3	41.4
		Central	875	7.7	41.8	10.1	42.9
		West	859	-2.5	52.2	20.4	51.4
	CASTNet	12-km EUS	832	33.1	45.8	24.6	37.6
		12-km WUS	287	-1.4	33.6	-1.4	32.1
		Northeast	206	53.2	57.4	40.1	43.5
		Midwest	155	52.6	58.5	41.9	45.4
		Southeast	292	13.0	32.1	11.1	31.0
		Central	78	10.7	37.3	10.3	34.6
		West	262	-7.1	32.9	-2.5	32.5
Summer	STN	12-km EUS	3516	-4.0	37.9	3.4	46.8
		12-km WUS	1071	-31.6	49.6	-8.9	51.7
		Northeast	874	-1.9	35.3	12.9	43.1

		Midwest	621	8.1	37.8	23.3	42.6
		Southeast	941	-6.5	35.3	0.7	41.8
		Central	847	-18.9	45.0	-19.9	58.7
		West	849	-34.7	54.6	-7.2	54.2
	CASTNet	12-km EUS	792	-18.5	30.0	-23.5	36.5
		12-km WUS	295	-27.6	38.5	-30.6	43.1
		Northeast	192	-19.5	27.9	-21.5	32.1
		Midwest	161	-1.5	25.9	1.6	27.3
		Southeast	270	-29.3	33.6	-40.8	45.5
		Central	75	-16.5	30.1	-20.5	37.2
		West	269	-31.0	39.5	-31.1	43.3
Fall	STN	12-km EUS	3365	19.2	47.8	28.9	50.0
		12-km WUS	1081	-18.3	62.5	8.6	59.8
		Northeast	902	31.2	57.4	39.1	55.3
		Midwest	639	16.5	39.7	28.7	42.9
		Southeast	990	12.0	43.4	21.8	46.0
		Central	571	22.5	54.3	29.5	54.1
		West	886	-24.9	64.7	5.5	61.2
	CASTNet	12-km EUS	786	10.5	41.0	14.5	39.6
		12-km WUS	293	11.0	41.3	7.1	34.4
		Northeast	195	16.2	42.6	19.8	38.2
		Midwest	157	25.5	47.6	30.9	43.1
		Southeast	273	-4.5	36.2	-2.4	39.8
		Central	75	19.9	45.8	26.4	47.4
		West	267	0.9	34.1	4.9	32.5

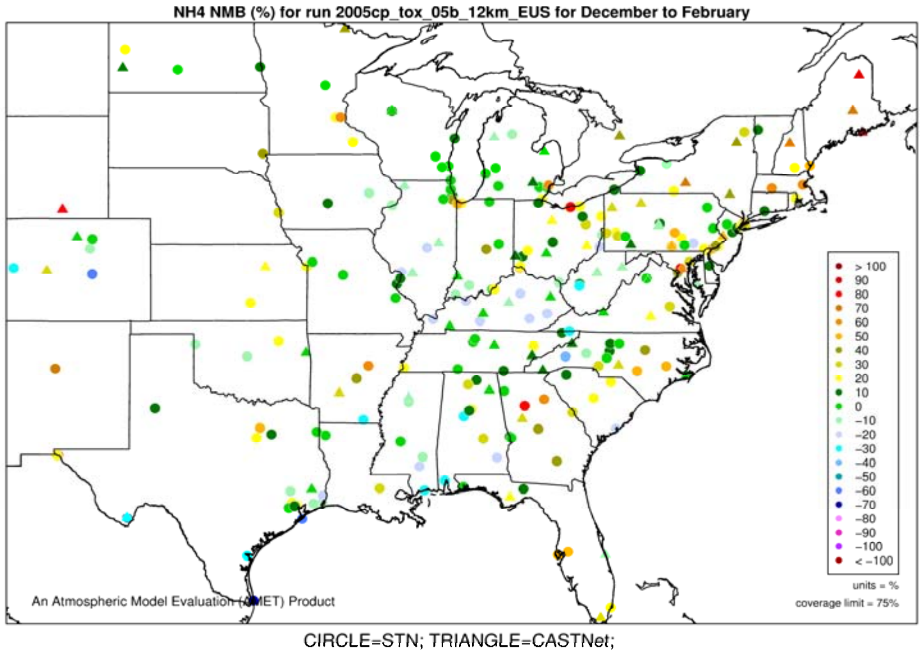


Figure H-1. Normalized Mean Bias (%) of ammonium by monitor for 12-km Eastern U.S. domain, Winter 2005.

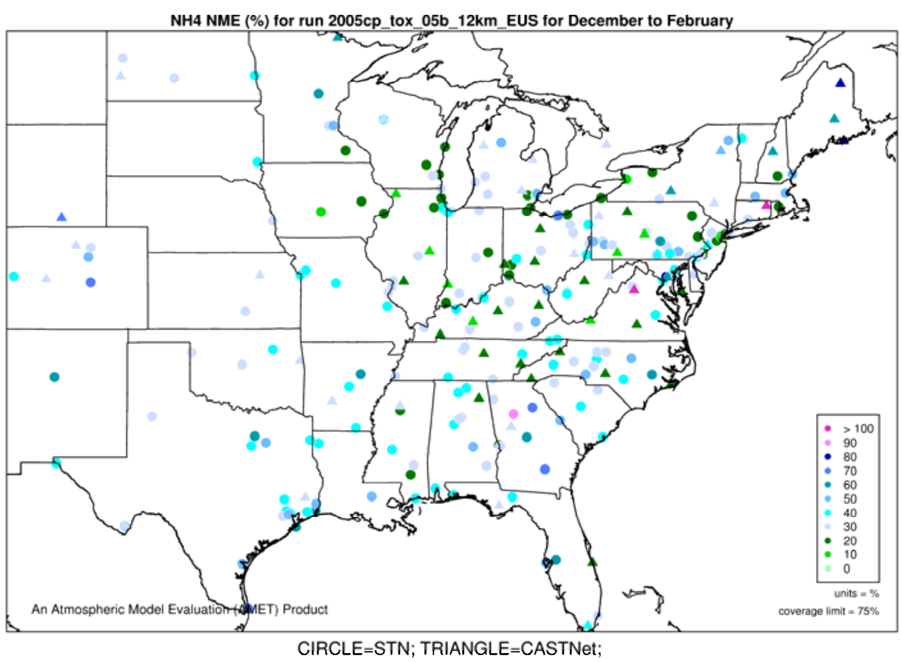


Figure H-2. Normalized Mean Error (%) of ammonium by monitor for 12-km Eastern U.S. domain, Winter 2005.

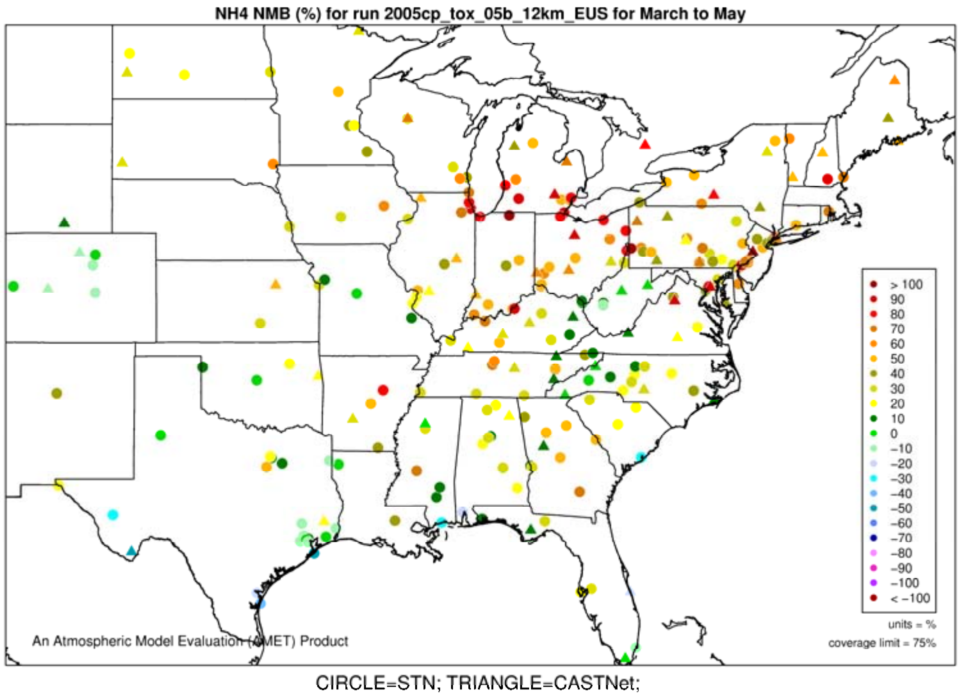


Figure H-3. Normalized Mean Bias (%) of ammonium by monitor for 12-km Eastern U.S. domain, Spring 2005.

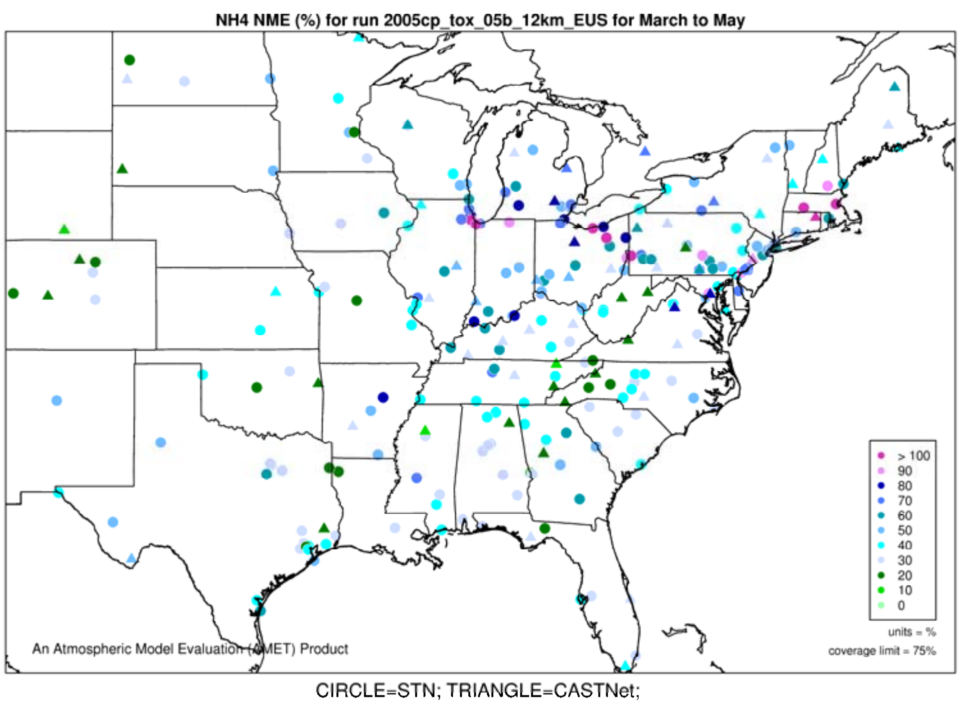


Figure H-4. Normalized Mean Error (%) of ammonium by monitor for 12-km Eastern U.S. domain, Spring 2005.

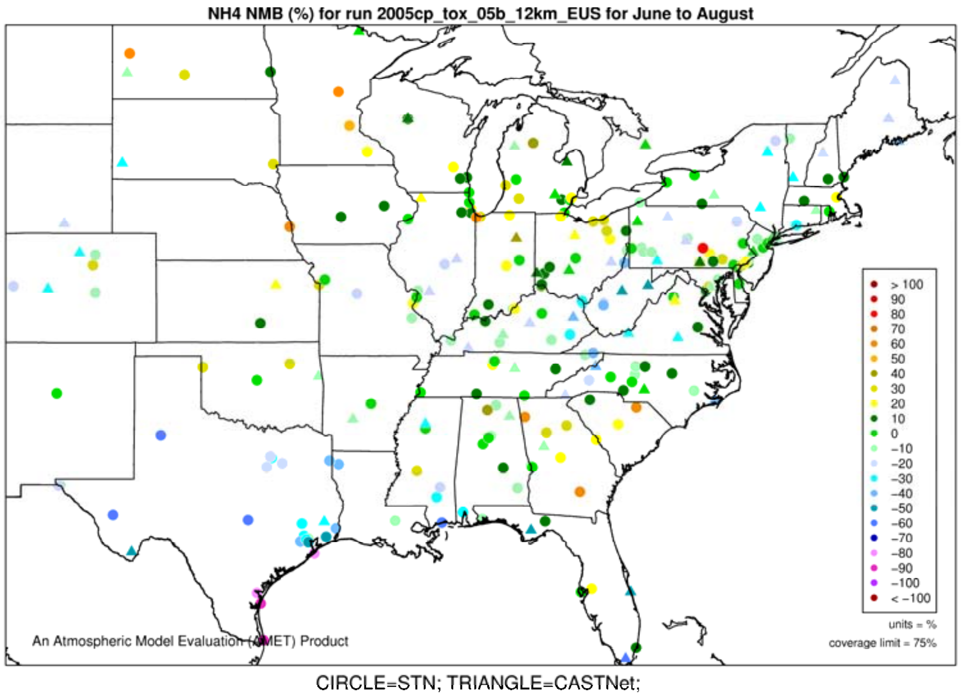


Figure H-5. Normalized Mean Bias (%) of ammonium by monitor for 12-km Eastern U.S. domain, Summer 2005.

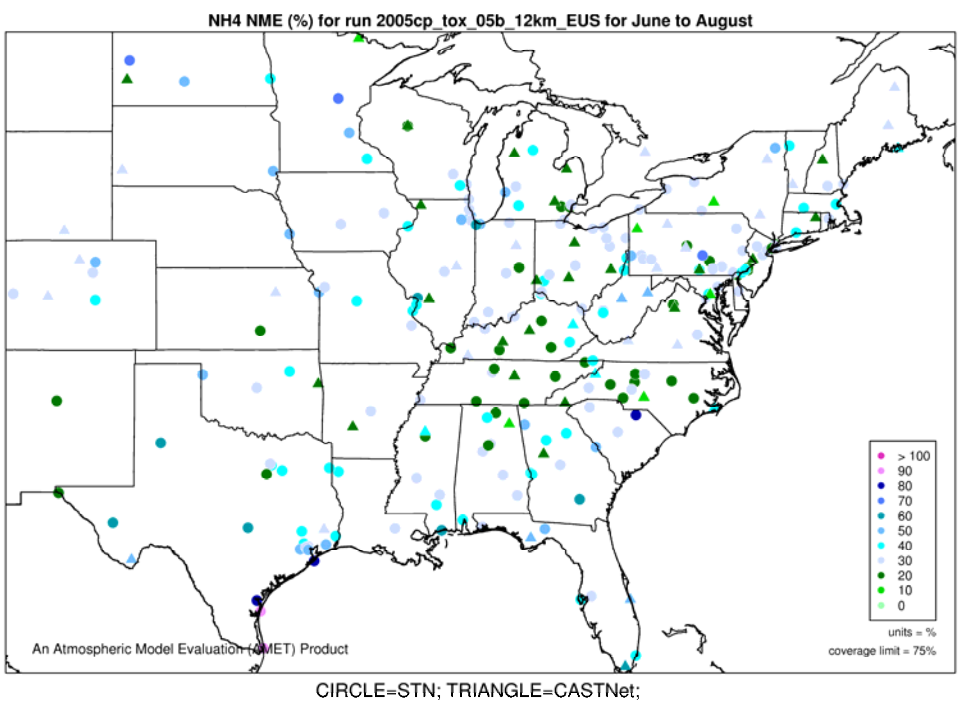


Figure H-6. Normalized Mean Error (%) of ammonium by monitor for 12-km Eastern U.S. domain, Summer 2005.

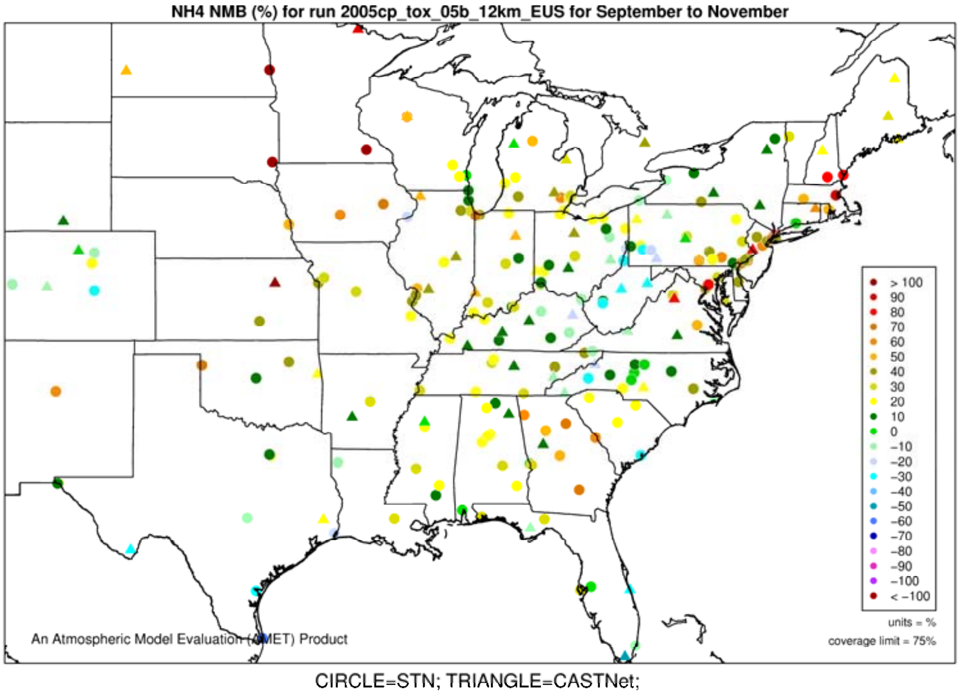


Figure H-7. Normalized Mean Bias (%) of ammonium by monitor for 12-km Eastern U.S. domain, Fall 2005.

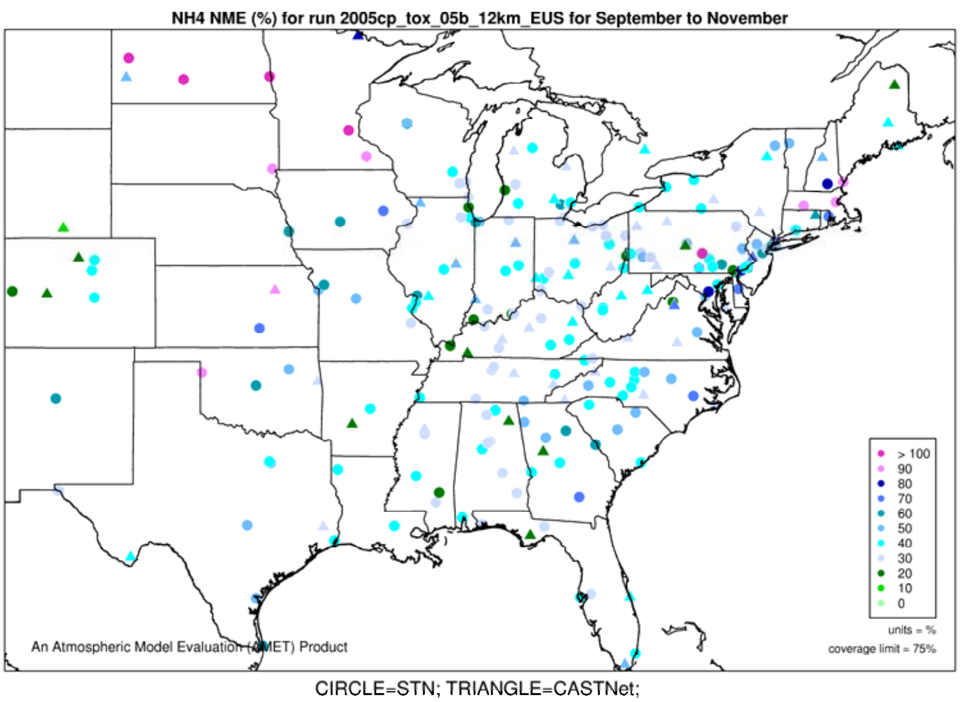


Figure H-8. Normalized Mean Error (%) of ammonium by monitor for 12-km Eastern U.S. domain, Fall 2005.

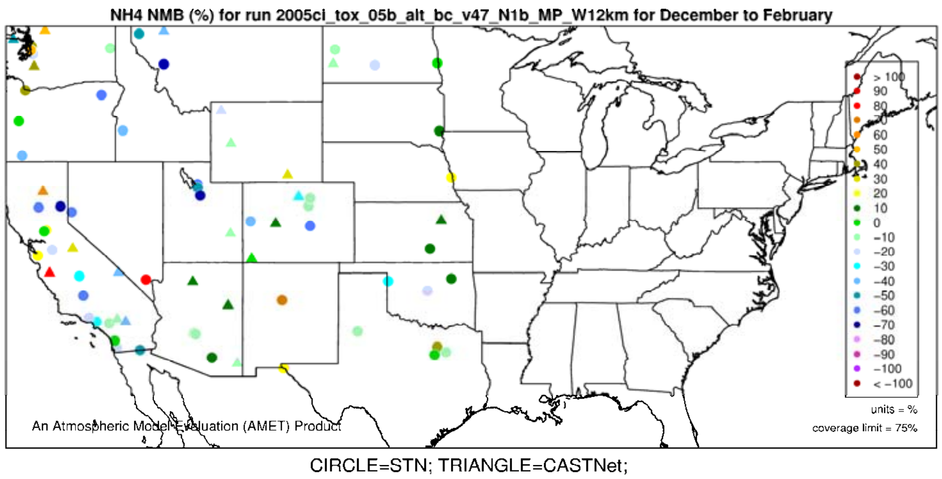


Figure H-9. Normalized Mean Bias (%) of ammonium by monitor for 12-km Western U.S. domain, Winter 2005.

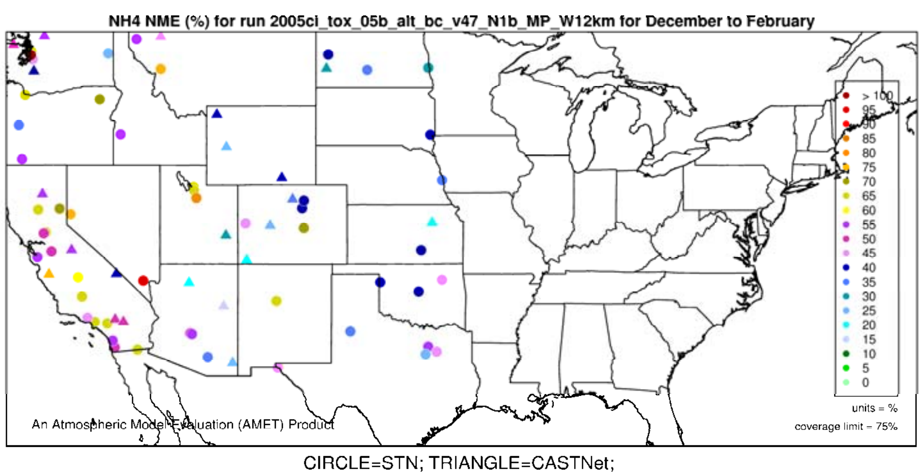


Figure H-10. Normalized Mean Error (%) of ammonium by monitor for 12-km Western U.S. domain, Winter 2005.

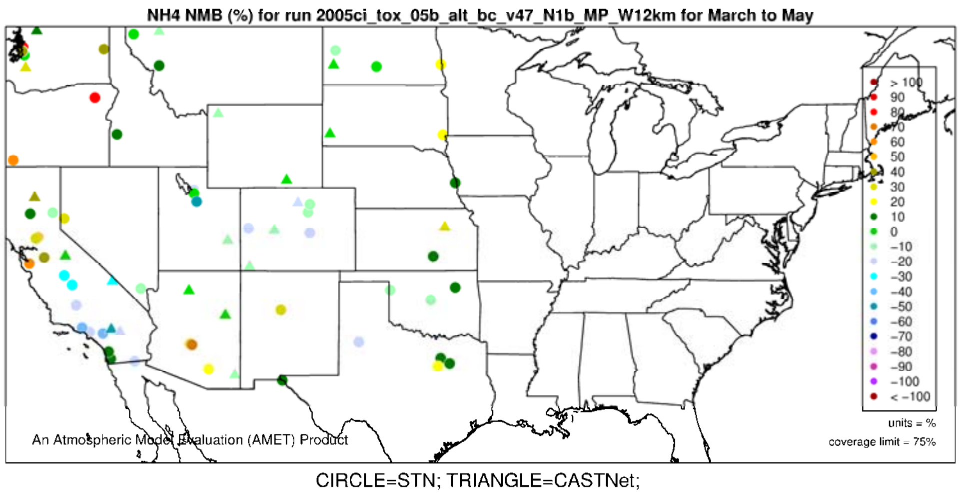


Figure H-11. Normalized Mean Bias (%) of ammonium by monitor for 12-km Western U.S. domain, Spring 2005.

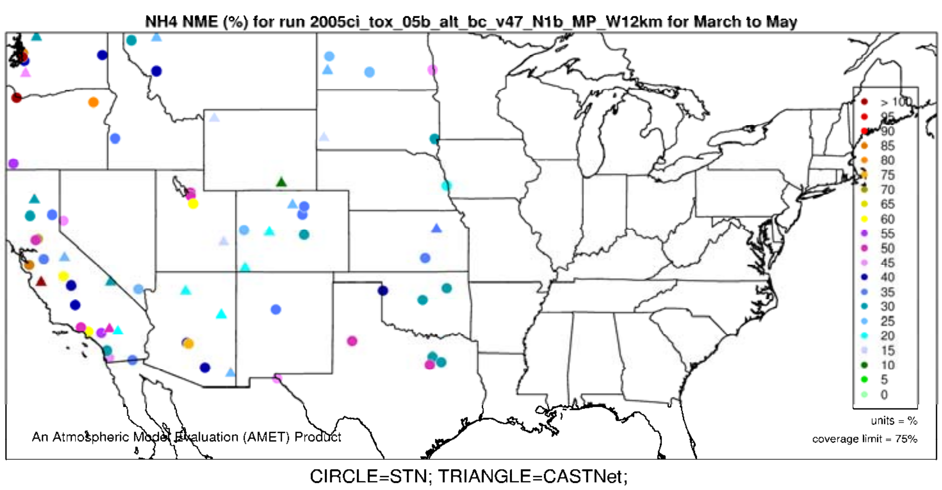


Figure H-12. Normalized Mean Error (%) of ammonium by monitor for 12-km Western U.S. domain, Spring 2005.

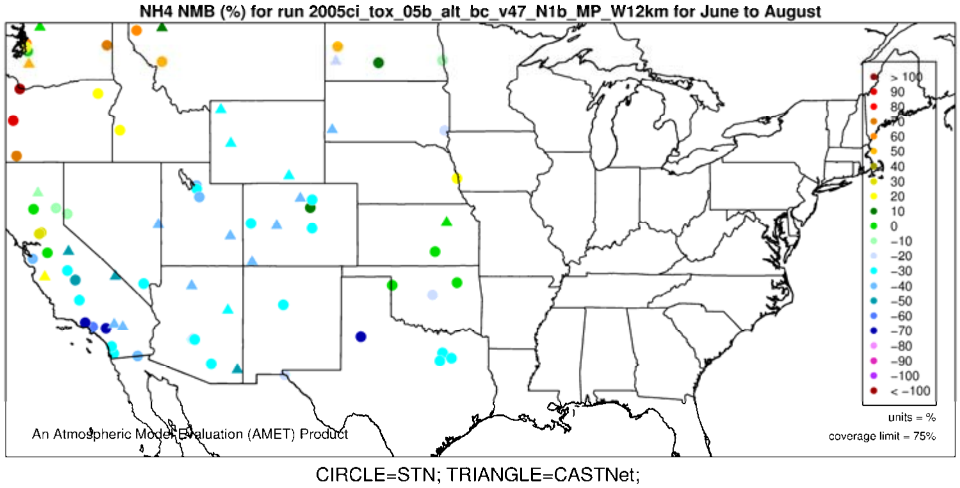


Figure H-13. Normalized Mean Bias (%) of ammonium by monitor for 12-km Western U.S. domain, Summer 2005.

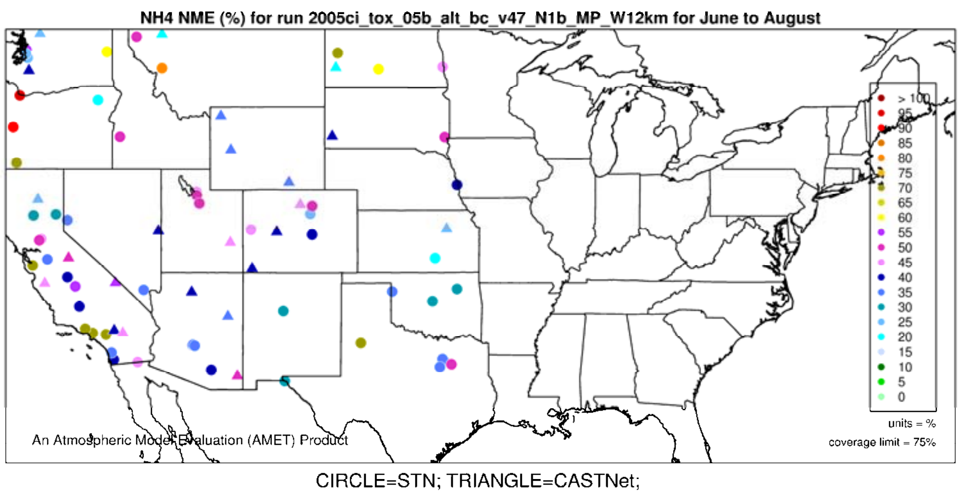


Figure H-14. Normalized Mean Error (%) of ammonium by monitor for 12-km Western U.S. domain, Summer 2005.

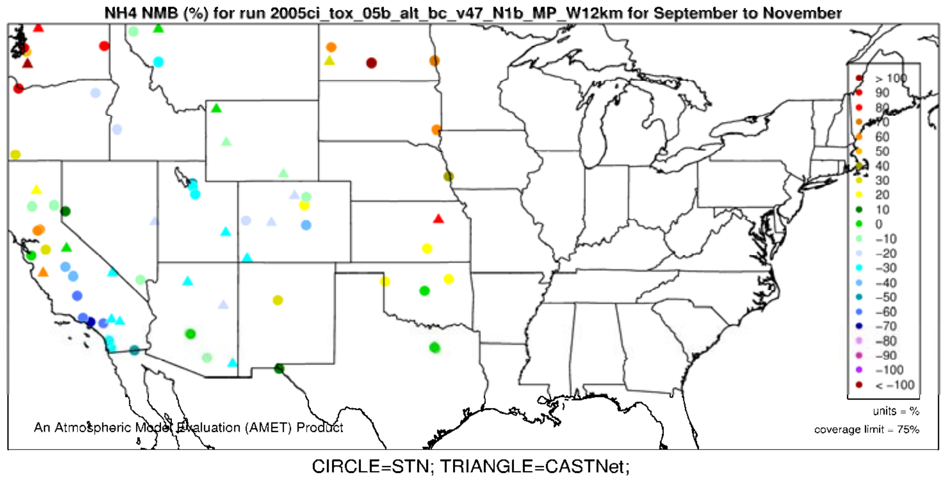


Figure H-15. Normalized Mean Bias (%) of ammonium by monitor for 12-km Western U.S. domain, Fall 2005.

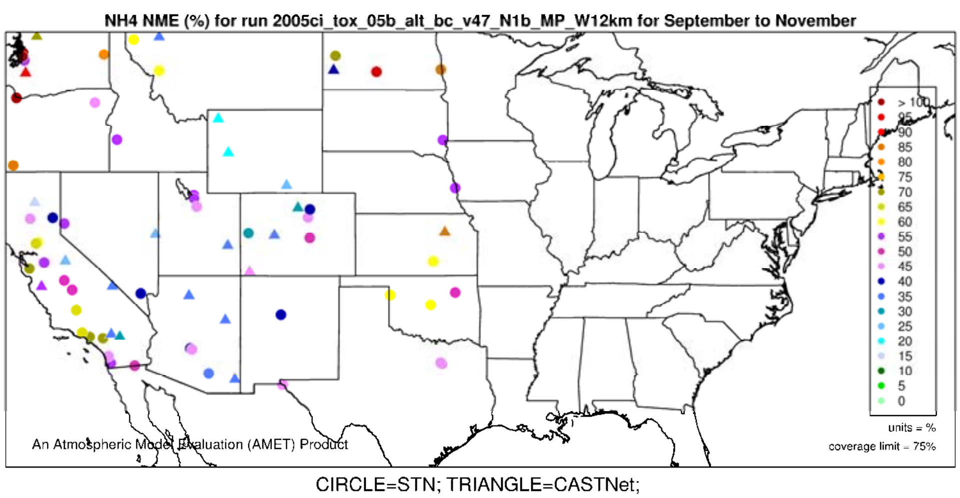


Figure H-16. Normalized Mean Error (%) of ammonium by monitor for 12-km Western U.S. domain, Fall 2005.

I. Seasonal Elemental Carbon Performance

Table I-1 presents the seasonal performance statistics of elemental carbon for the urban and rural 2005 monitoring data. Spatial plots of the NMB and NME statistics (units of percent) for individual monitors are also provided as a complement to the tabular statistical data (Figures I1 – I16). In the winter, elemental carbon performance is mixed across the STN and IMPROVE networks in the EUS and WUS, with a moderate over-prediction at STN sites and a slight under-prediction at the IMPROVE sites. In general, model performance at urban STN sites is over-predicted, whereas model performance at rural IMPROVE sites show an under-prediction. These biases and errors are not unexpected since there are known uncertainties among the scientific community in carbonaceous emissions/measurements, transport, and deposition processes.

Table I-1. CMAQ 2005 seasonal model performance statistics for elemental carbon.

CMAQ 2005 Elemental Carbon			No. of Obs.	NMB (%)	NME (%)	FB (%)	FE (%)
Winter	STN	12-km EUS	3441	60.2	89.1	38.6	61.3
		12-km WUS	657	8.1	71.3	5.4	65.2
		Northeast	831	78.2	93.8	49.7	61.6
		Midwest	602	85.2	104.6	56.1	66.8
		Southeast	964	36.3	68.5	21.7	48.7
		Central	811	71.6	109.3	45.4	71.5
		West	520	10.4	71.0	0.4	66.1
	IMPROVE	12-km EUS	2072	6.7	54.5	-2.7	52.3
		12-km WUS	2279	-2.8	61.4	-20.6	66.0
		Northeast	522	34.7	63.6	21.0	51.0
		Midwest	166	36.2	59.6	14.2	44.1
		Southeast	386	-20.6	43.3	-19.1	48.9
		Central	474	-4.4	52.2	-0.3	50.8
		West	1994	-6.3	61.0	-23.4	67.5
Spring	STN	12-km EUS	3672	49.9	79.0	33.3	58.3
		12-km WUS	1064	49.5	86.4	24.2	63.8
		Northeast	881	71.2	93.6	47.1	63.6
		Midwest	637	35.0	62.9	33.1	52.1
		Southeast	985	34.0	67.6	26.3	51.6
		Central	937	65.2	94.7	33.5	65.1
		West	822	65.2	97.3	28.5	67.2
	IMPROVE	12-km EUS	2296	-13.9	49.6	-10.4	51.3
		12-km WUS	2563	3.9	61.1	-6.7	54.7
		Northeast	565	17.0	56.0	6.9	54.2
		Midwest	160	0.6	47.0	-17.3	48.4
		Southeast	408	-35.4	46.0	-31.5	46.8
		Central	578	-27.3	49.9	-17.6	54.4
		West	2191	10.1	63.8	-6.2	55.7

Summer	STN	12-km EUS	3529	45.5	76.7	28.6	61.3
		12-km WUS	1030	62.1	91.3	34.6	62.5
		Northeast	866	47.0	76.7	34.6	59.5
		Midwest	621	21.2	47.9	21.6	47.6
		Southeast	940	35.7	73.5	27.3	58.0
		Central	871	85.3	113.8	32.3	76.5
		West	806	78.9	10.7	41.0	65.8
	IMPROVE	12-km EUS	2182	-34.7	47.8	-38.8	59.8
		12-km WUS	2301	14.0	67.7	8.9	57.8
		Northeast	512	-29.0	46.1	-44.5	61.5
		Midwest	160	-25.0	36.4	-42.1	52.0
		Southeast	384	-51.3	53.3	-71.0	78.4
		Central	561	-38.1	49.1	-45.5	61.5
		West	1961	19.8	71.6	12.9	59.1
Fall	STN	12-km EUS	3396	28.5	64.8	21.6	52.1
		12-km WUS	1063	21.4	70.3	9.0	59.6
		Northeast	901	36.0	72.7	23.4	53.8
		Midwest	642	28.0	55.2	25.2	47.9
		Southeast	988	9.4	53.2	7.6	45.8
		Central	602	67.2	89.4	48.4	63.4
		West	867	26.4	74.3	7.6	61.8
	IMPROVE	12-km EUS	2118	-13.7	45.9	-20.5	49.9
		12-km WUS	2352	-0.9	60.1	-16.7	60.3
		Northeast	518	19.7	52.2	0.0	49.6
		Midwest	116	-18.4	35.4	-20.0	48.0
		Southeast	406	-38.7	44.8	-36.2	51.9
		Central	510	-19.6	41.0	-19.0	46.0
		West	2023	-0.4	62.3	-17.6	62.4

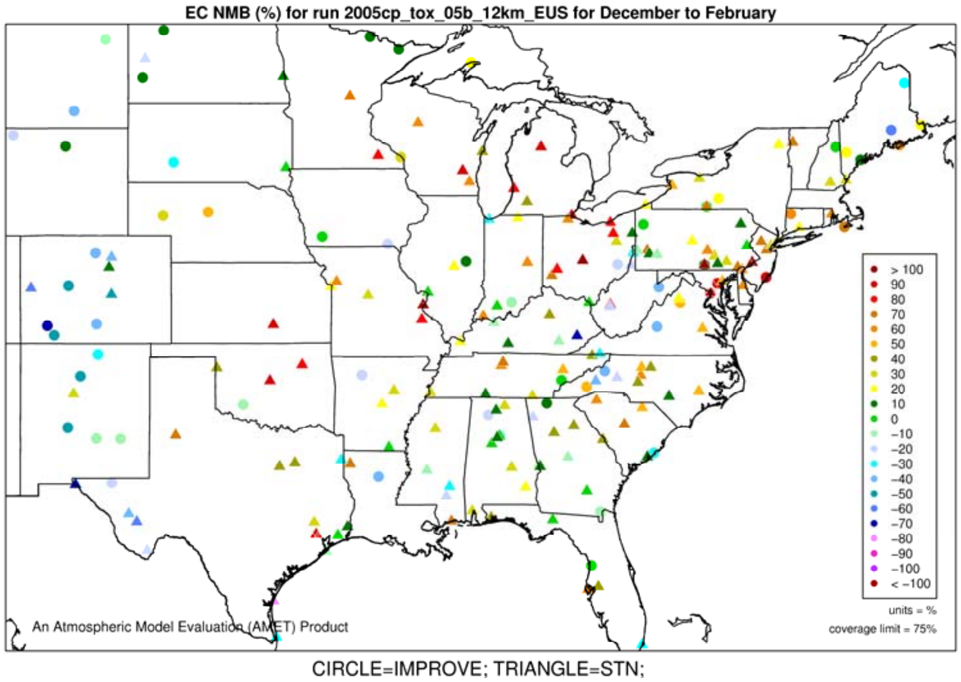


Figure I-1. Normalized Mean Bias (%) of elemental carbon by monitor for 12-km Eastern U.S. domain, Winter 2005.

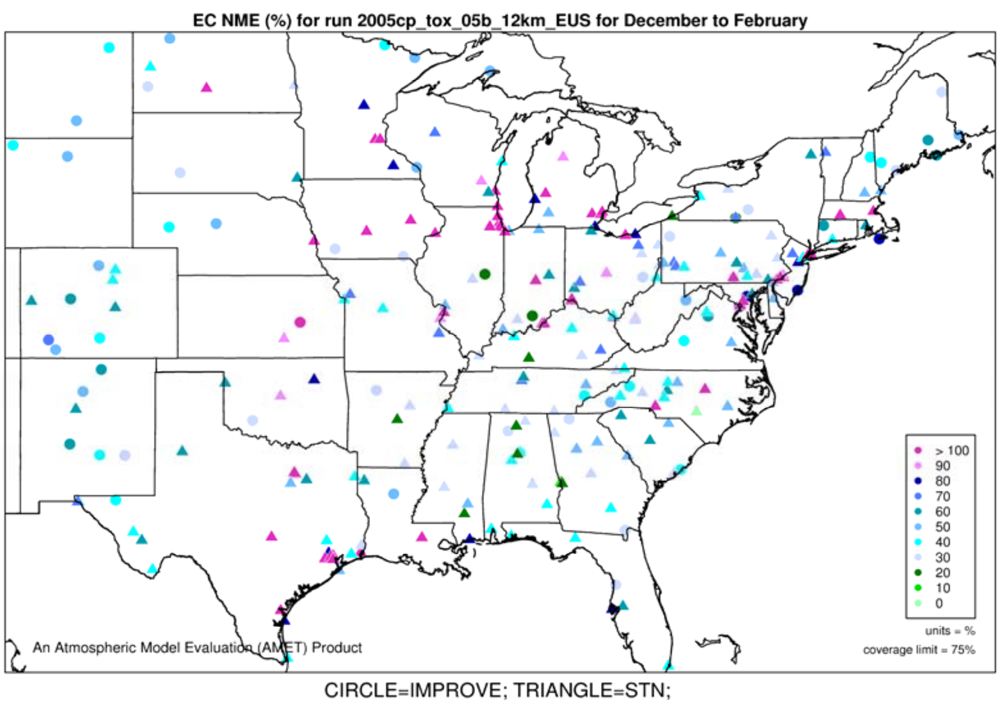


Figure I-2. Normalized Mean Error (%) of elemental carbon by monitor for 12-km Eastern U.S. domain, Winter 2005.

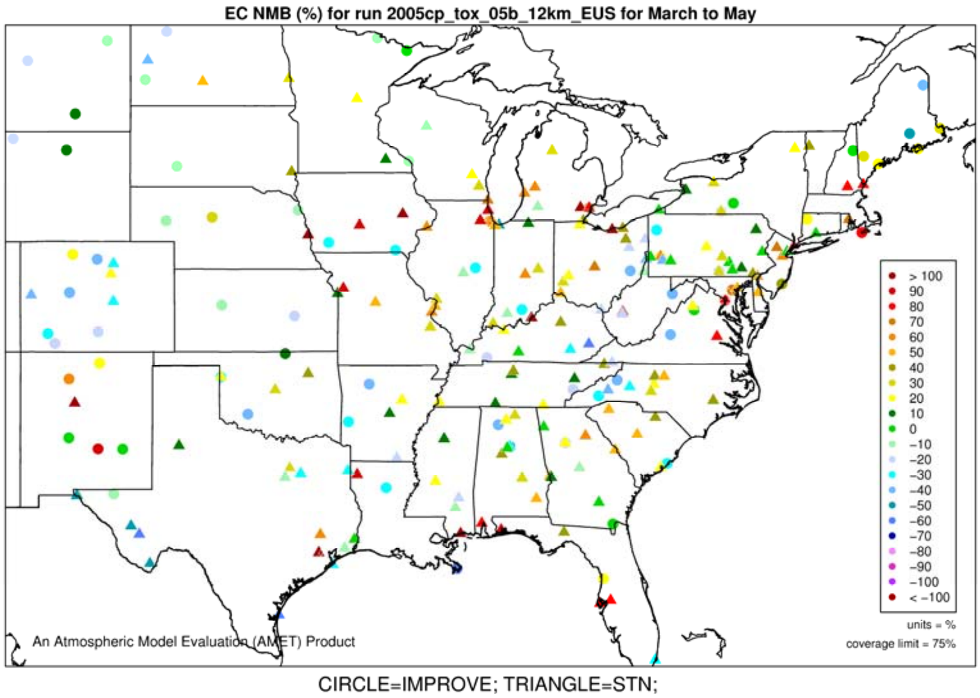


Figure I-3. Normalized Mean Bias (%) of elemental carbon by monitor for 12-km Eastern U.S. domain, Spring 2005.

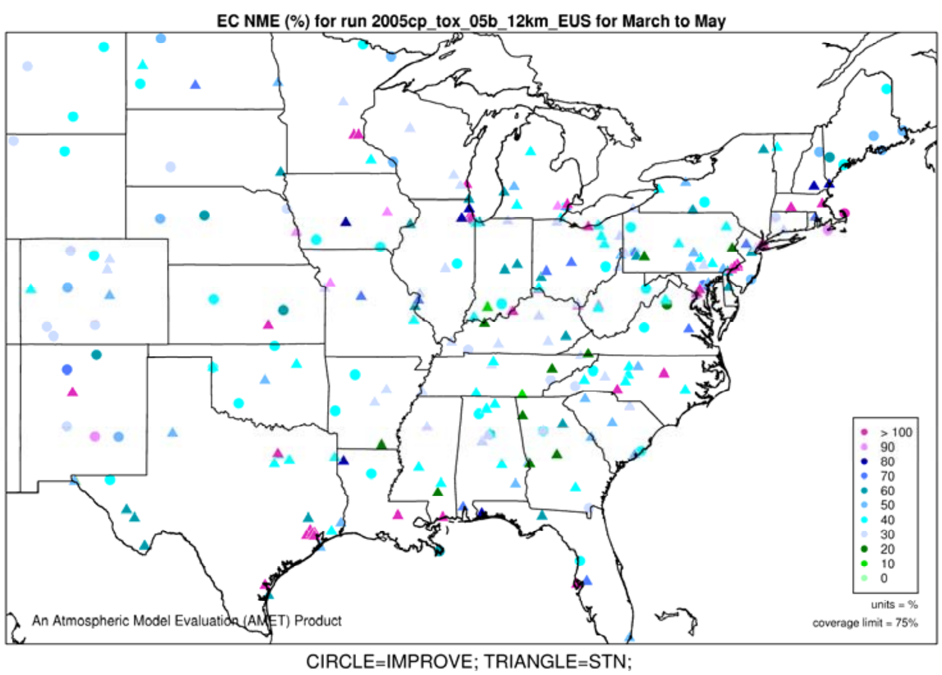


Figure I-4. Normalized Mean Error (%) of elemental carbon by monitor for 12-km Eastern U.S. domain, Spring 2005.

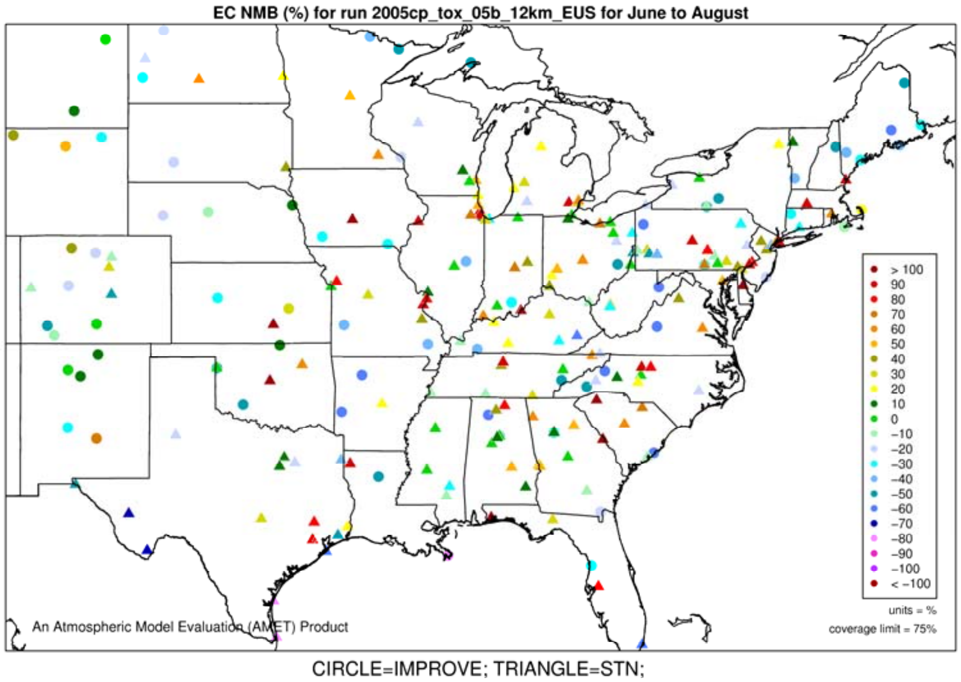


Figure I-5. Normalized Mean Bias (%) of elemental carbon by monitor for 12-km Eastern U.S. domain, Summer 2005.

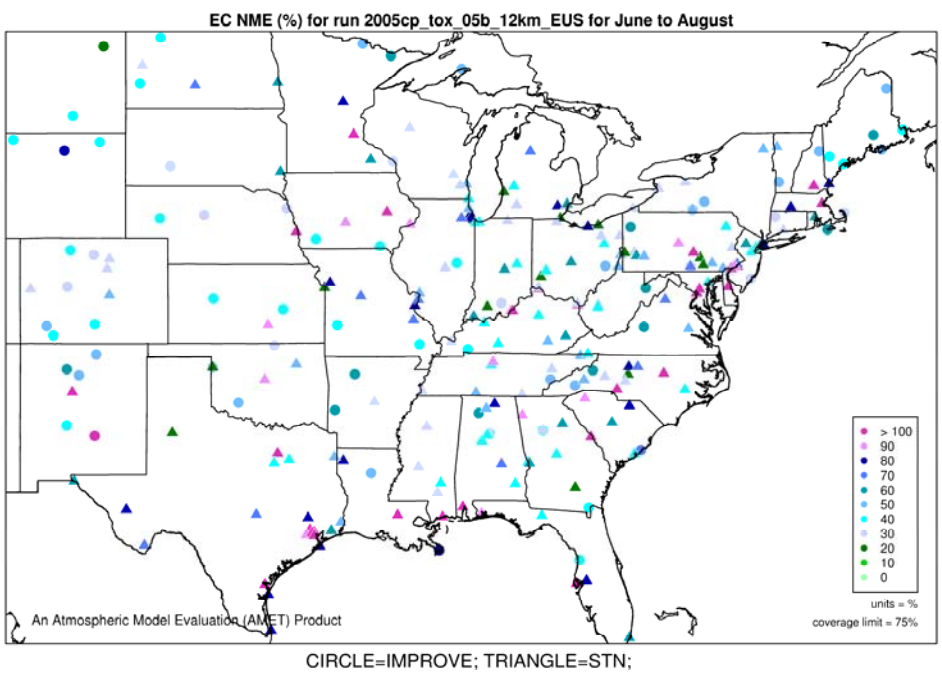


Figure I-6. Normalized Mean Error (%) of elemental carbon by monitor for 12-km Eastern U.S. domain, Summer 2005.

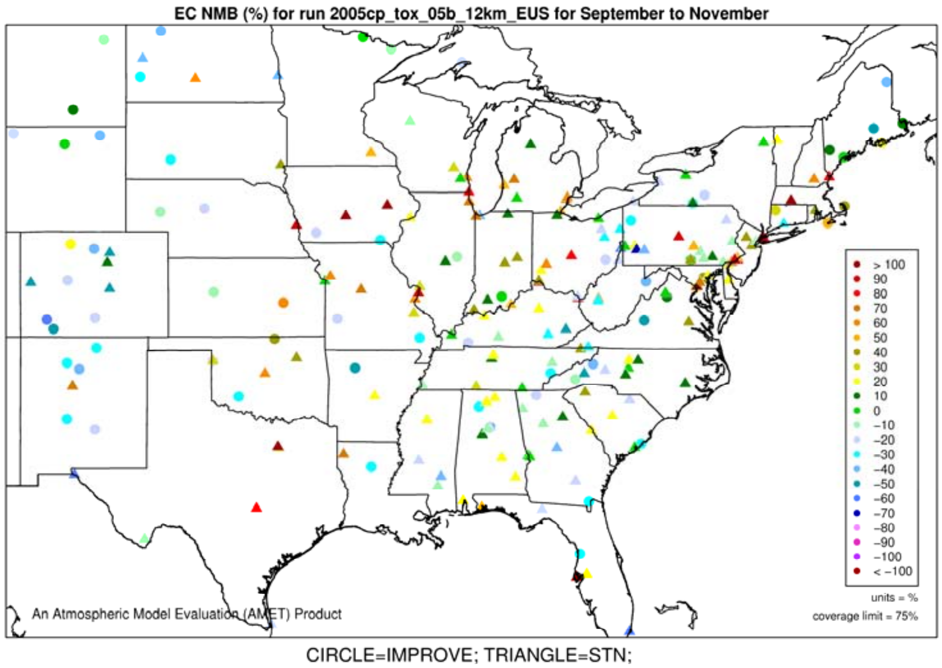


Figure I-7. Normalized Mean Bias (%) of elemental carbon by monitor for 12-km Eastern U.S. domain, Fall 2005.

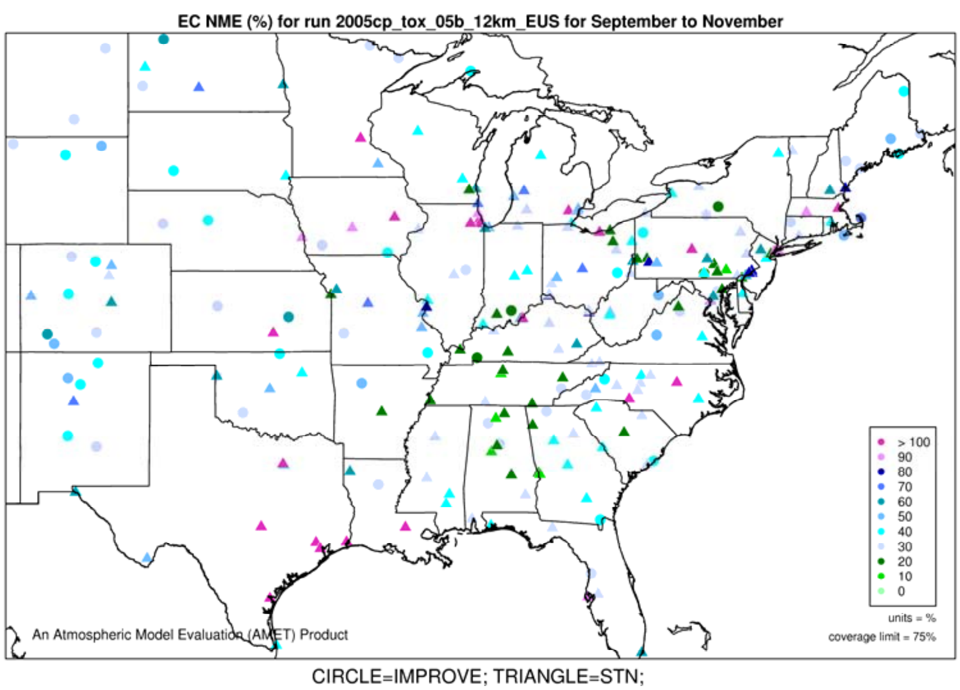


Figure I-8. Normalized Mean Error (%) of elemental carbon by monitor for 12-km Eastern U.S. domain, Fall 2005.

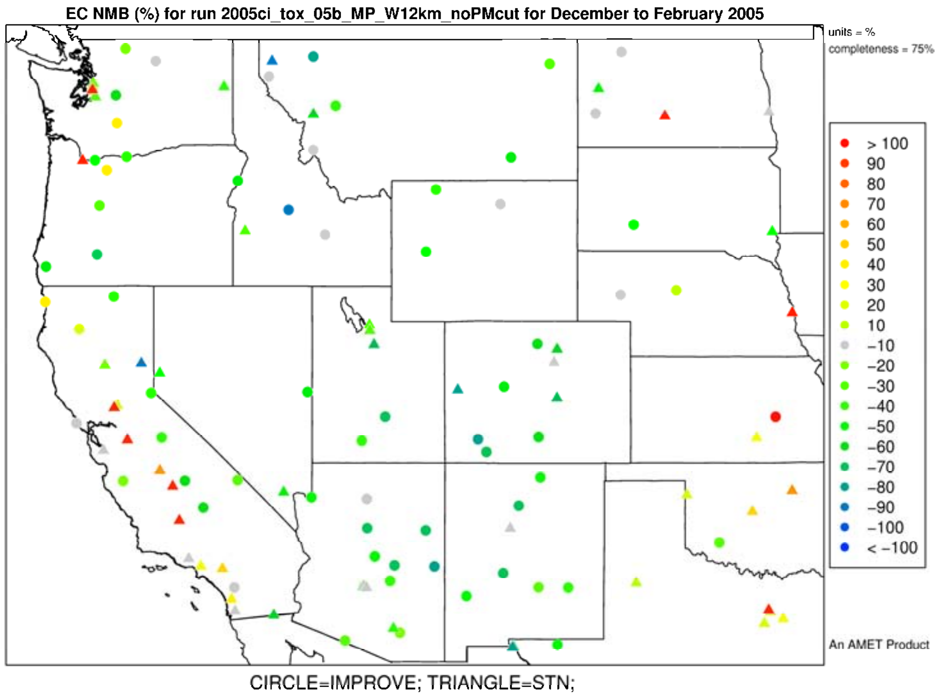


Figure I-9. Normalized Mean Bias (%) of elemental carbon by monitor for 12-km Eastern U.S. domain, Winter 2005.

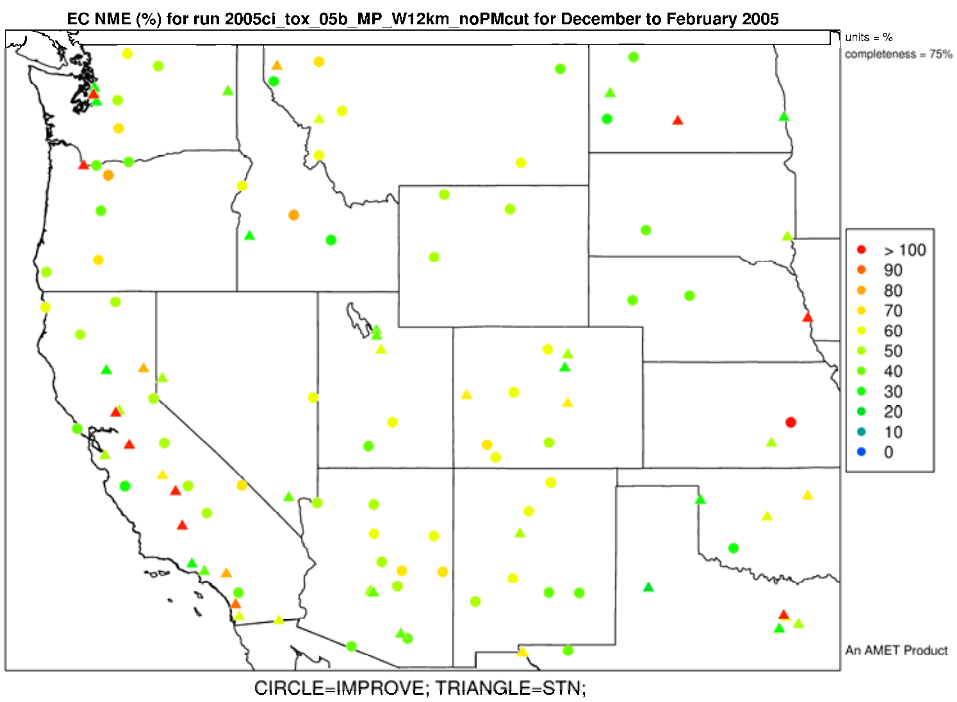


Figure I-10. Normalized Mean Error (%) of elemental carbon by monitor for 12-km Western U.S. domain, Winter 2005.

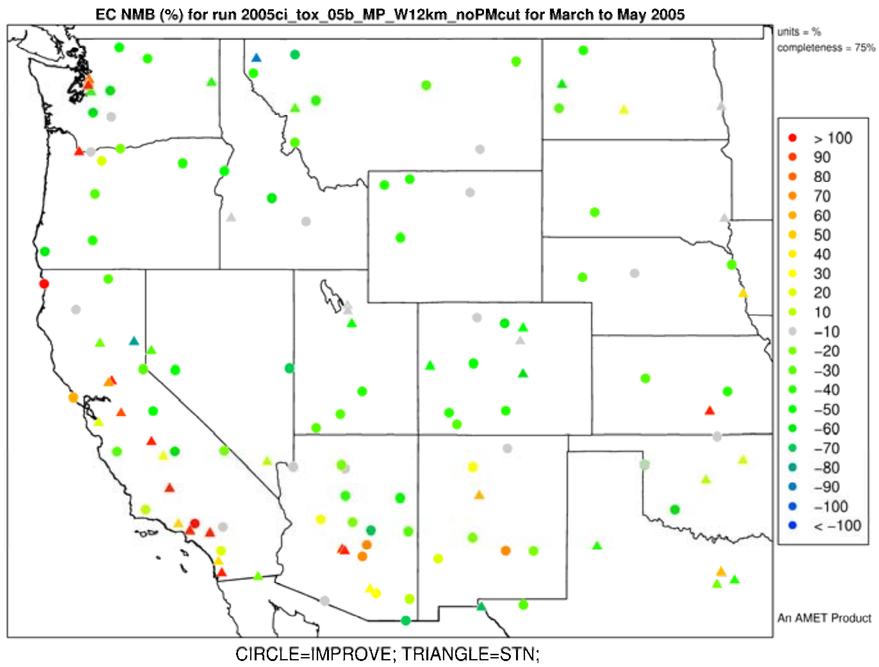


Figure I-11. Normalized Mean Bias (%) of elemental carbon by monitor for 12-km Western U.S. domain, Spring 2005.

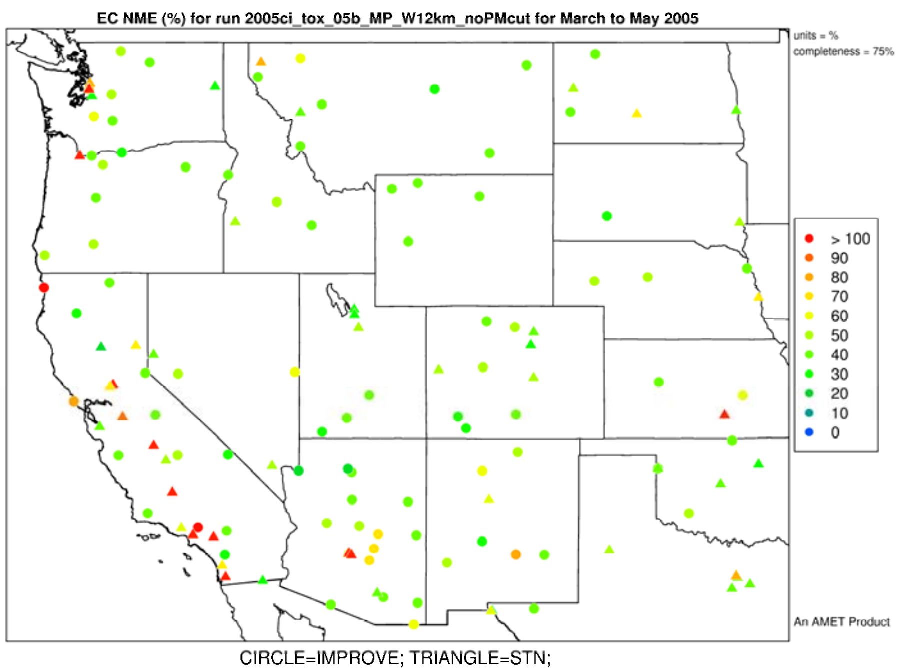


Figure I-12. Normalized Mean Error (%) of elemental carbon by monitor for 12-km Western U.S. domain, Spring 2005.

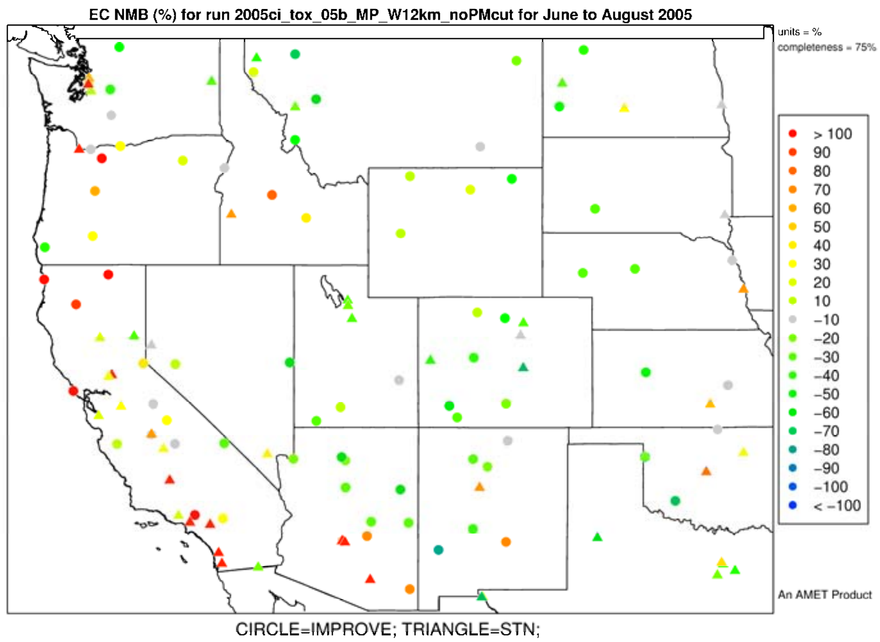


Figure I-13. Normalized Mean Bias (%) of elemental carbon by monitor for 12-km Western U.S. domain, Summer 2005.

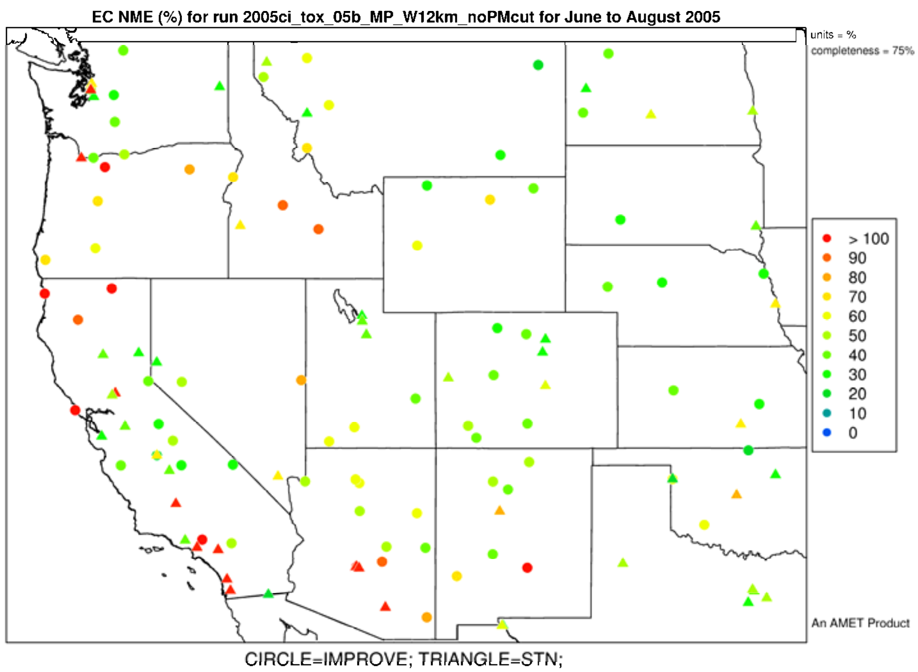


Figure I-14. Normalized Mean Error (%) of elemental carbon by monitor for 12-km Western U.S. domain, Summer 2005.

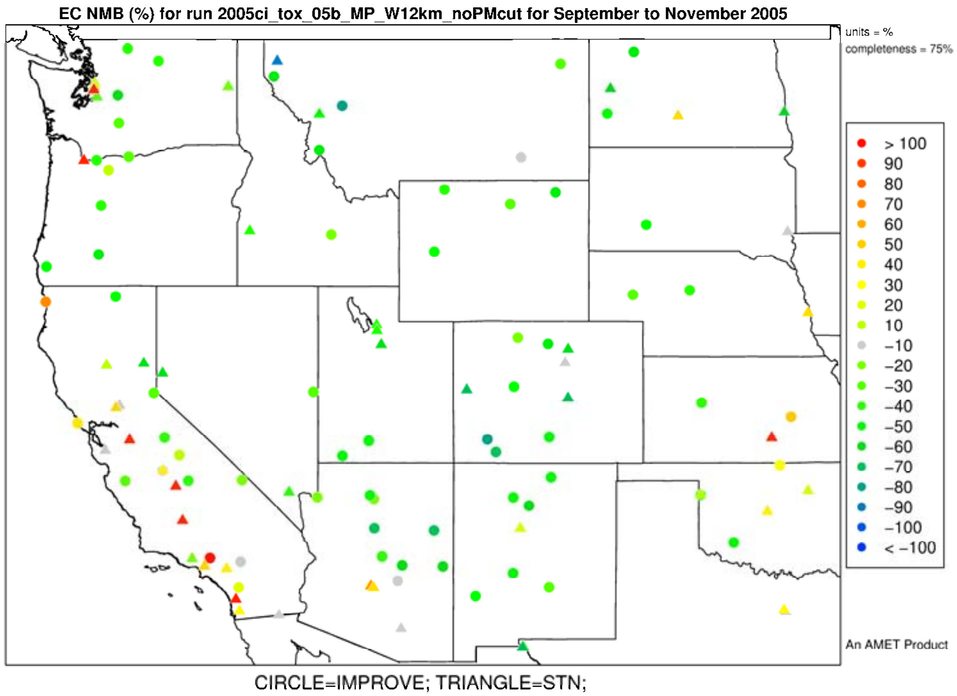


Figure I-15. Normalized Mean Bias (%) of elemental carbon by monitor for 12-km Western U.S. domain, Fall 2005.

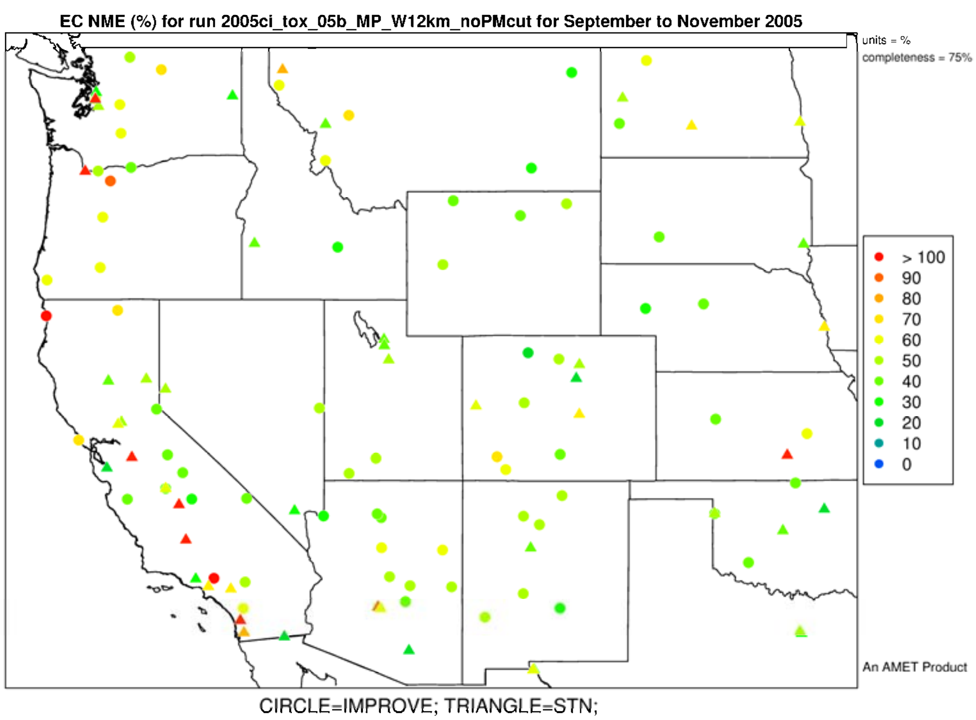


Figure I-16. Normalized Mean Error (%) of elemental carbon by monitor for 12-km Western U.S. domain, Fall 2005.

J. Seasonal Organic Carbon Performance

Seasonal organic carbon performance statistics are provided in Table J-1. Spatial plots of the NMB and NME statistics (units of percent) for individual monitors are also provided as a complement to the tabular statistical data (Figures J-1 – J-16). The model predictions generally show moderate under-predictions for all Eastern sites located in the urban STN sites and rural IMPROVE sites. Organic carbon performance in the EUS and WUS shows the largest under estimations during the summer season. 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.

Table J-1. CMAQ 2002 seasonal model performance statistics for organic carbon.

CMAQ 2002 Organic Carbon			No. of Obs.	NMB (%)	NME (%)	FB (%)	FE (%)
Winter	STN	12-km EUS	3051	1.9	53.2	13.1	54.9
		12-km WUS	606	-25.6	62.0	-22.4	62.6
		Northeast	804	31.7	61.1	34.4	56.1
		Midwest	565	9.0	54.5	25.7	55.3
		Southeast	943	-23.1	44.9	-11.9	50.3
		Central	544	2.4	56.3	17.7	58.9
		West	507	-24.2	63.0	-22.0	64.3
	IMPROVE	12-km EUS	2071	11.1	54.0	1.2	50.9
		12-km WUS	2269	-12.1	59.0	-21.7	63.6
		Northeast	522	53.9	72.7	37.0	54.2
		Midwest	166	10.7	40.4	7.1	37.2
		Southeast	386	-16.8	40.5	-19.1	47.8
		Central	474	-2.6	51.9	-2.8	48.6
		West	1981	-16.3	58.4	-23.7	65.0
Spring	STN	12-km EUS	3243	-24.8	48.9	-15.0	56.1
		12-km WUS	656	-19.8	63.4	-13.7	64.5
		Northeast	831	3.8	51.5	10.0	53.7
		Midwest	605	-27.7	45.5	-15.5	52.2
		Southeast	972	-35.7	48.1	-29.0	56.7
		Central	627	-36.6	50.8	-32.9	61.7
		West	560	-15.9	65.9	-7.1	65.5
	IMPROVE	12-km EUS	2290	-20.5	47.1	-18.3	50.8
		12-km WUS	2554	-26.3	53.0	-25.3	56.5
		Northeast	565	8.1	48.0	1.5	46.7
		Midwest	160	-21.2	35.0	-26.2	41.8
		Southeast	409	-22.1	41.0	-24.9	45.6
		Central	577	-41.6	54.8	-35.9	58.7
		West	2183	-22.1	52.2	-23.5	56.6

Summer	STN	12-km EUS	3228	-51.7	54.3	-68.2	74.2
		12-km WUS	832	-55.4	60.0	-76.2	83.6
		Northeast	859	-47.6	52.1	-62.1	70.2
		Midwest	619	-53.1	54.3	-69.5	72.8
		Southeast	931	-55.9	57.1	-76.0	79.8
		Central	595	-50.3	53.2	-68.0	74.7
		West	684	-54.0	59.3	-73.3	81.8
	IMPROVE	12-km EUS	2183	-41.6	50.7	-53.0	66.7
		12-km WUS	2311	-1.5	63.3	-7.1	61.0
		Northeast	513	-47.5	52.2	-60.2	67.6
		Midwest	160	-43.9	46.8	-58.0	62.2
		Southeast	384	-43.6	48.2	-66.3	71.3
		Central	562	-46.4	51.6	-65.8	73.5
		West	1970	4.0	65.2	-2.3	60.2
Fall	STN	12-km EUS	3097	-26.1	45.0	-19.2	54.7
		12-km WUS	809	-40.4	57.9	-38.7	63.4
		Northeast	829	-3.9	47.6	4.1	53.7
		Midwest	591	-27.6	40.7	-15.1	51.6
		Southeast	956	-39.2	45.7	-41.3	57.5
		Central	493	-29.4	45.2	-25.3	56.1
		West	657	-41.0	59.9	-39.6	66.8
	IMPROVE	12-km EUS	2118	-23.5	46.1	-31.3	54.7
		12-km WUS	2361	-22.7	56.0	-29.0	62.7
		Northeast	516	16.3	48.4	32.6	-0.3
		Midwest	115	-30.2	40.3	-37.7	53.7
		Southeast	408	-35.1	41.3	-41.6	52.6
		Central	510	-39.2	48.9	-47.1	61.5
		West	2031	-21.3	57.0	-27.1	62.7

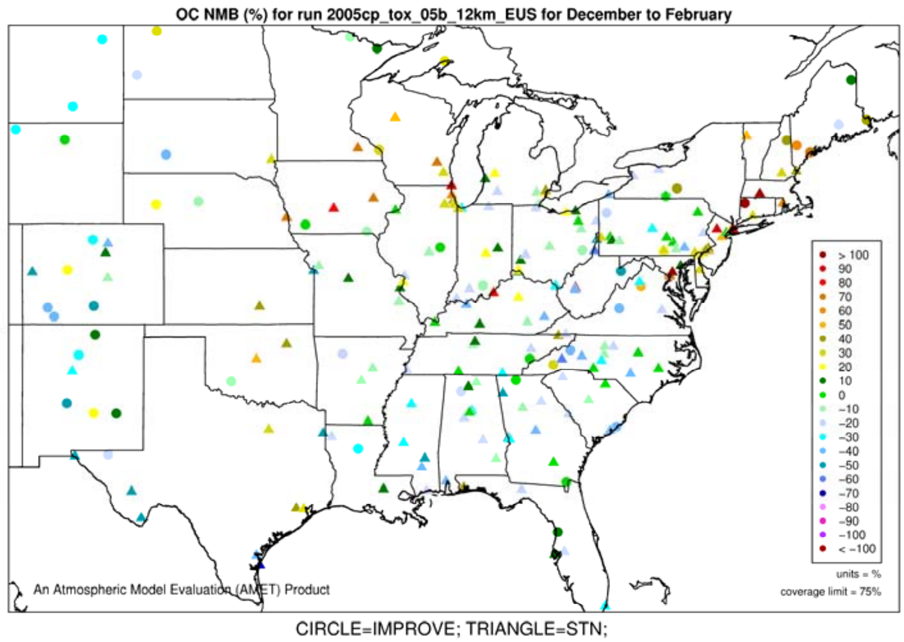


Figure J-1. Normalized Mean Bias (%) of organic carbon by monitor for 12-km Eastern U.S. domain, Winter 2005.

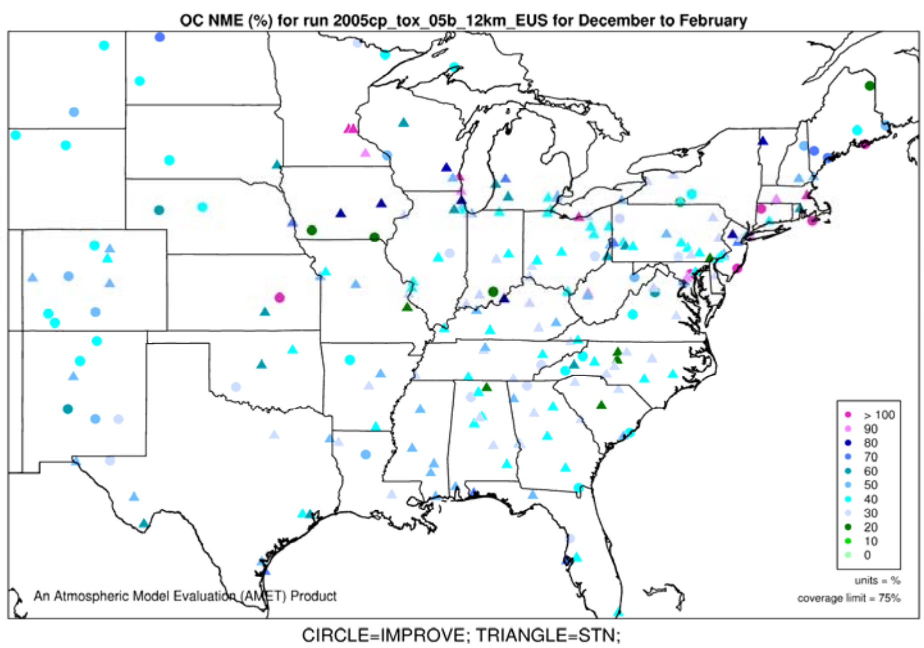


Figure J-2. Normalized Mean Error (%) of organic carbon by monitor for 12-km Eastern U.S. domain, Winter 2005.

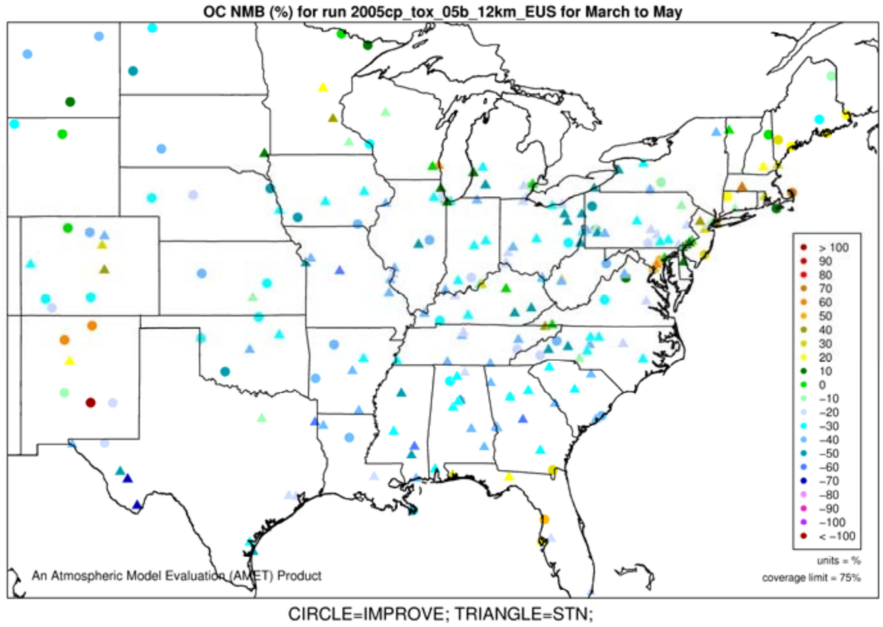


Figure J-3. Normalized Mean Bias (%) of organic carbon by monitor for 12-km Eastern U.S. domain, Spring 2005.

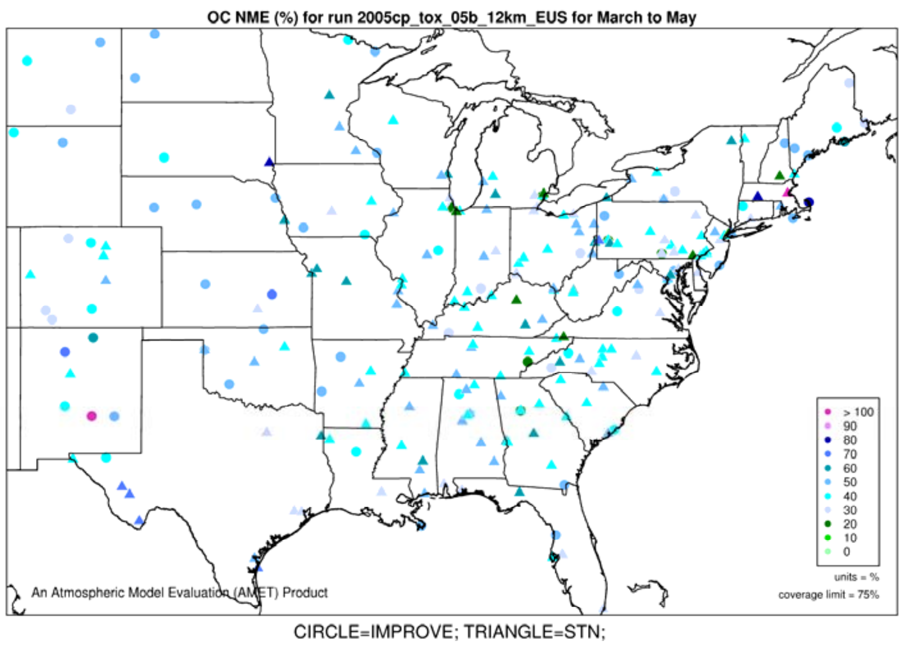


Figure J-4. Normalized Mean Error (%) of organic carbon by monitor for 12-km Eastern U.S. domain, Spring 2005.

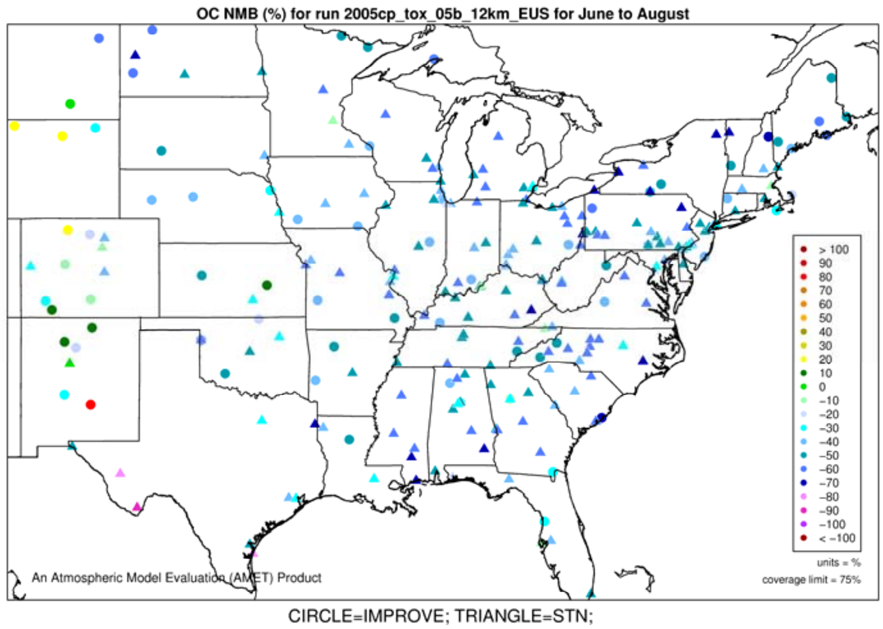


Figure J-5. Normalized Mean Bias (%) of organic carbon by monitor for 12-km Eastern U.S. domain, Summer 2005.

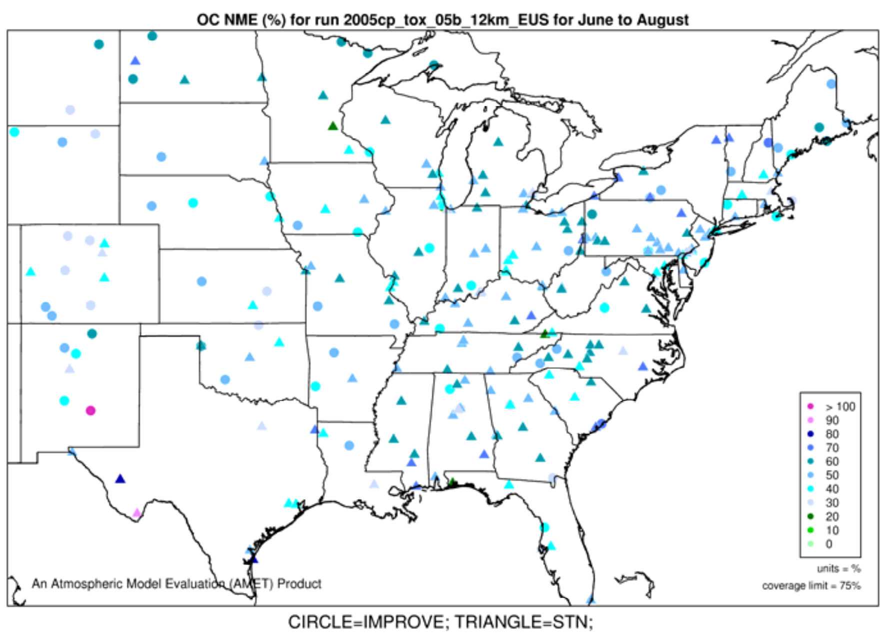


Figure J-6. Normalized Mean Error (%) of organic carbon by monitor for 12-km Eastern U.S. domain, Summer 2005.

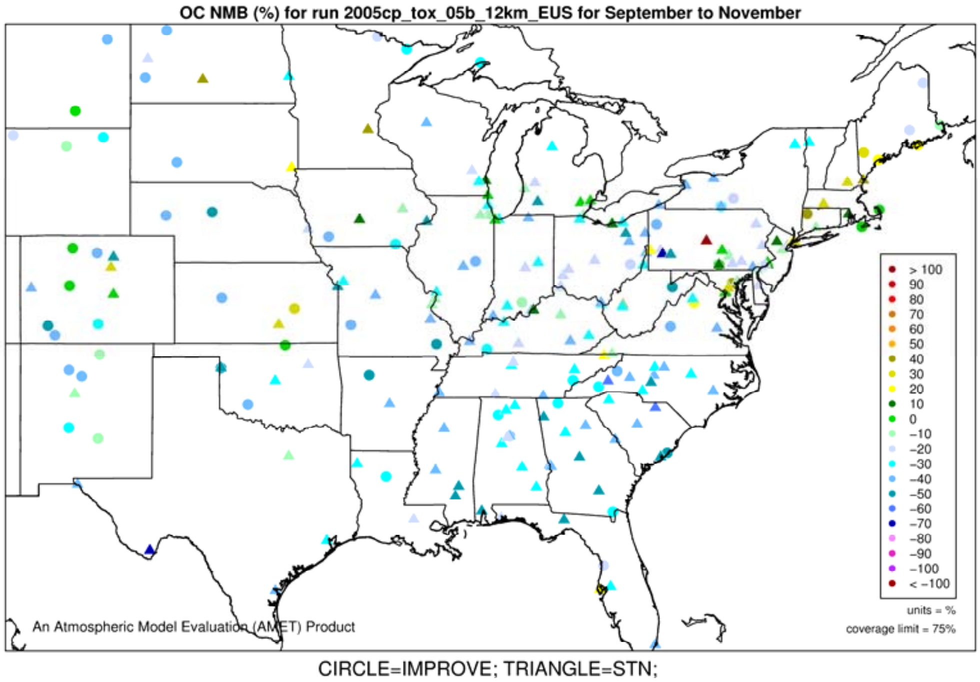


Figure J-7. Normalized Mean Bias (%) of organic carbon by monitor for 12-km Eastern U.S. domain, Fall 2005.

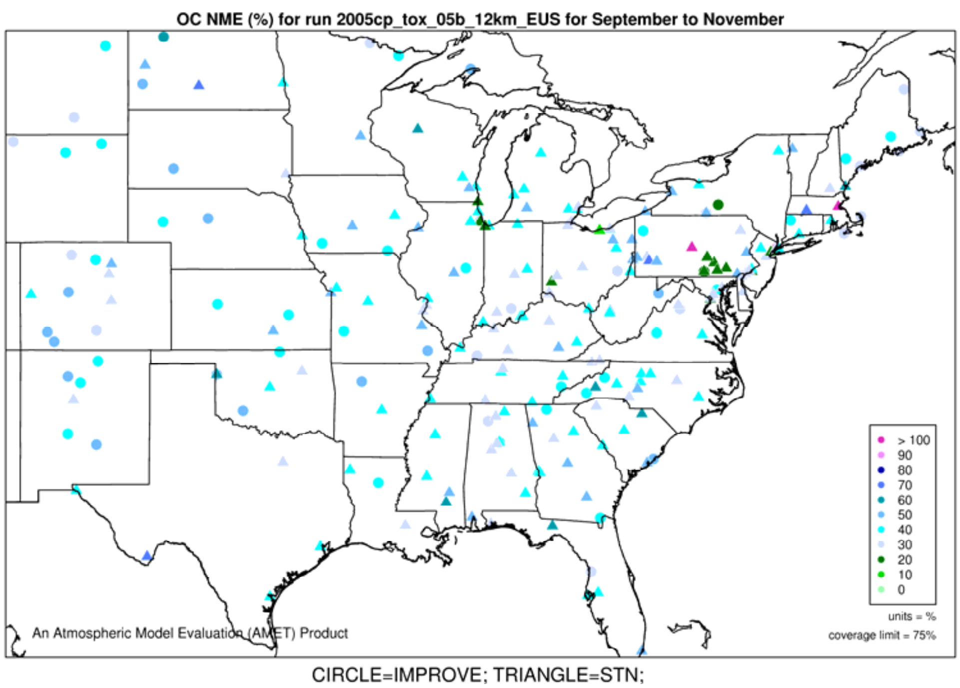


Figure J-8. Normalized Mean Error (%) of organic carbon by monitor for 12-km Eastern U.S. domain, Fall 2005.

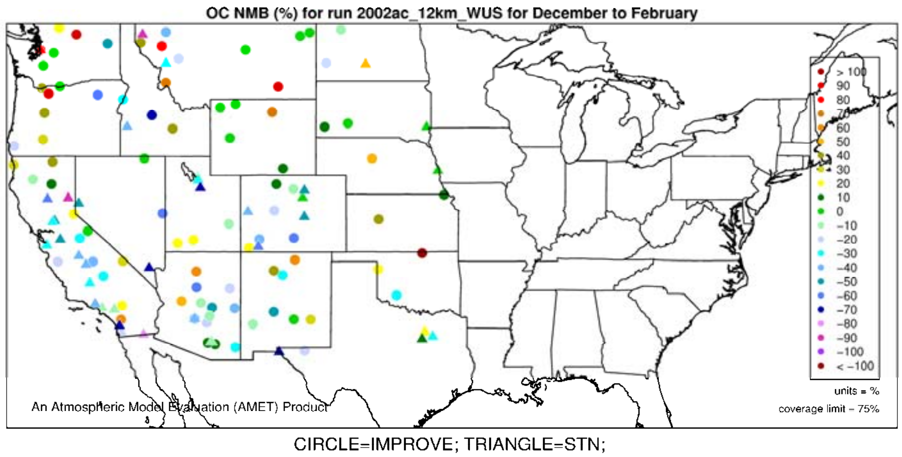


Figure J-9. Normalized Mean Bias (%) of organic carbon by monitor for 12-km Western U.S. domain, Winter 2005.

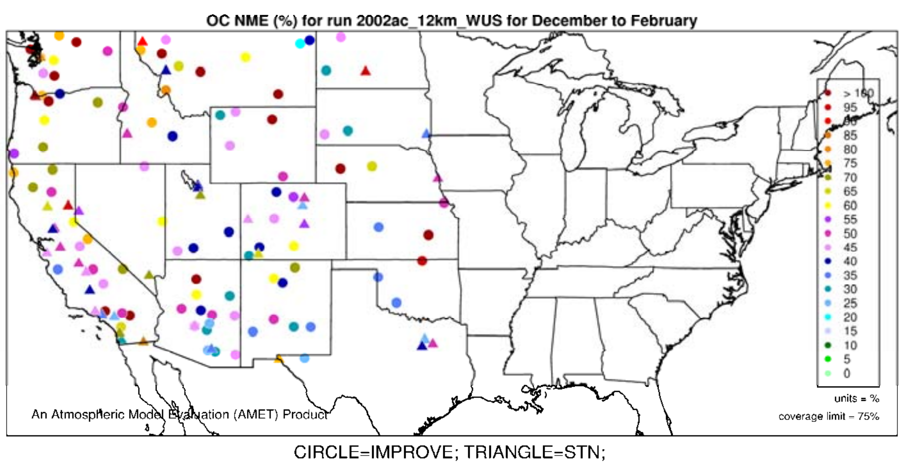


Figure J-10. Normalized Mean Error (%) of organic carbon by monitor for 12-km Western U.S. domain, Winter 2005.

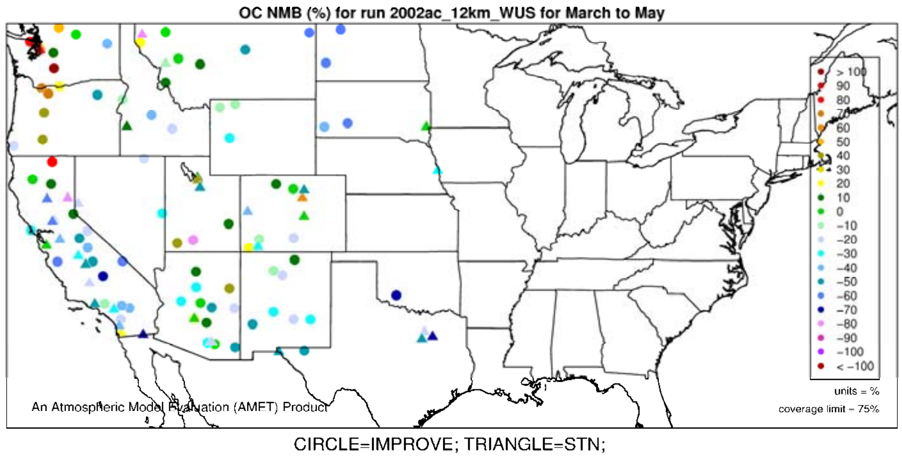


Figure J-11. Normalized Mean Bias (%) of organic carbon by monitor for 12-km Western U.S. domain, Spring 2005.

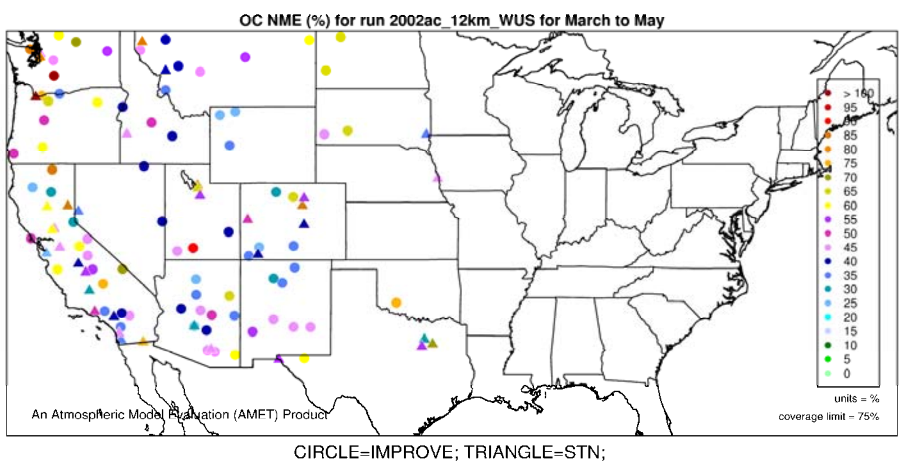


Figure J-12. Normalized Mean Error (%) of organic carbon by monitor for 12-km Western U.S. domain, Spring 2005.

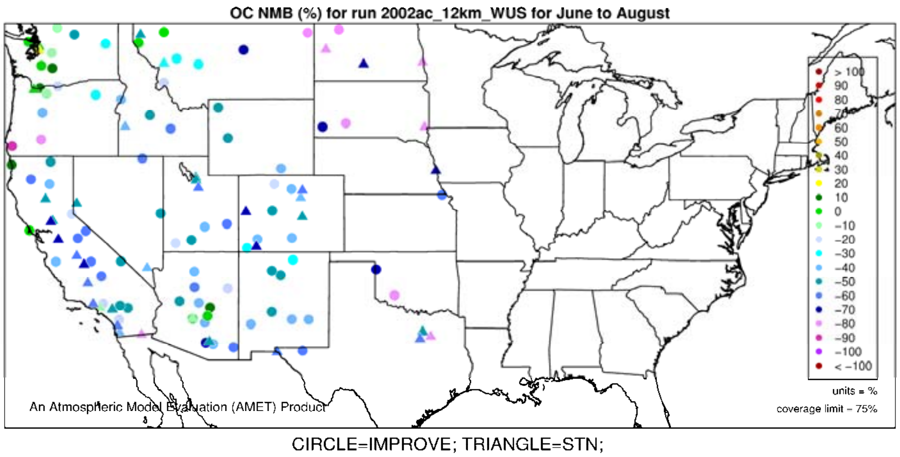


Figure J-13. Normalized Mean Bias (%) of organic carbon by monitor for 12-km Western U.S. domain, Summer 2005.

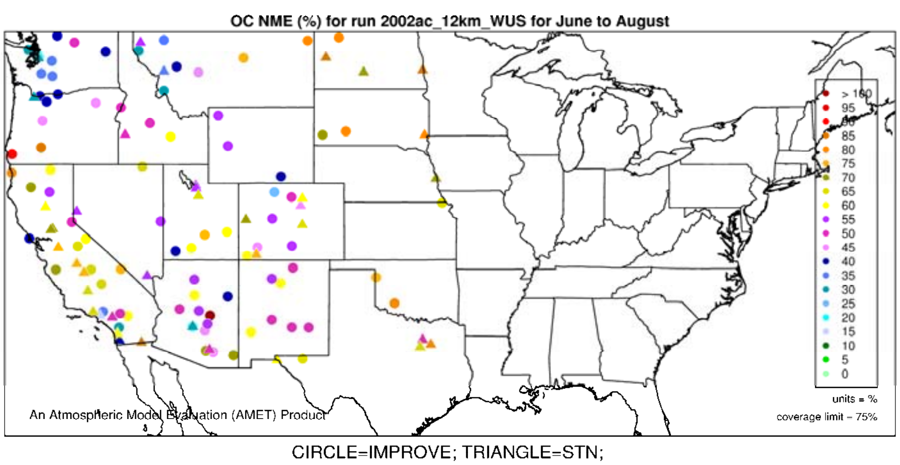


Figure J-14. Normalized Mean Error (%) of organic carbon by monitor for 12-km Western U.S. domain, Summer 2005.

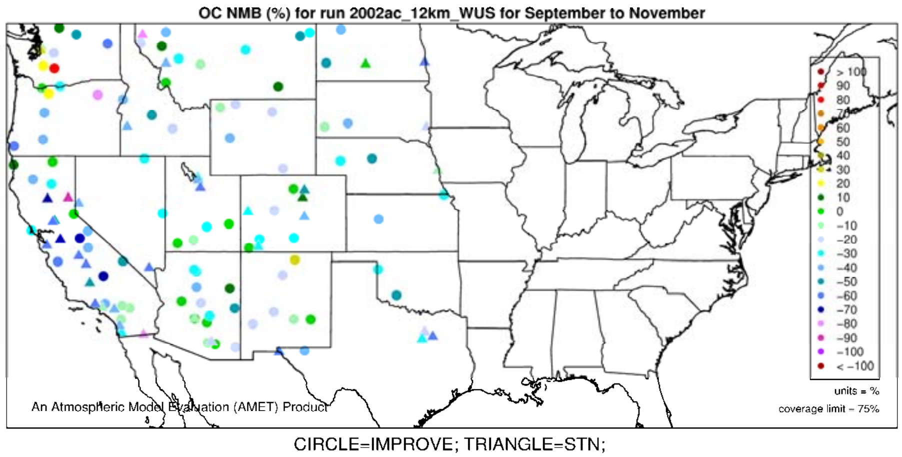


Figure J-15. Normalized Mean Bias (%) of organic carbon by monitor for 12-km Western U.S. domain, Fall 2005.

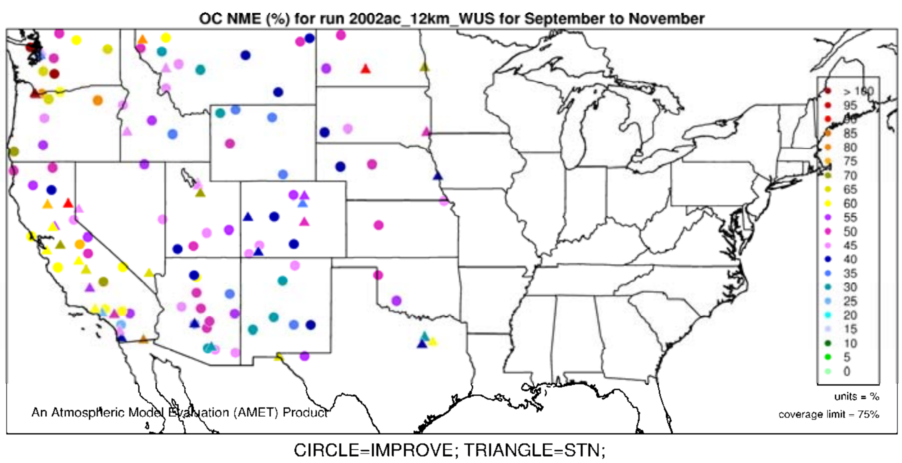


Figure J-16. Normalized Mean Error (%) of organic carbon by monitor for 12-km Western U.S. domain, Fall 2005.

K. Annual Hazardous Air Pollutants Performance

An annual and seasonal operational model performance evaluation for specific hazardous air pollutants (formaldehyde, acetaldehyde, benzene, acrolein, and 1,3-butadiene) was conducted in order to estimate the ability of the CMAQ modeling system to replicate the base year concentrations for the 12-km Eastern and Western United States domains. The annual model performance results are presented in Table K-1 below. Spatial plots of the NMB and NME statistics (units of percent) for individual monitors are also provided as a complement to the tabular statistical data (Figures K-1 – K-24). The seasonal results follow in Sections L-P. Toxic measurements from 471 sites in the East and 135 sites in the West were included in the evaluation and were taken from the 2005 State/local monitoring site data in the National Air Toxics Trends Stations (NATTS). 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 and benzene showed relatively small bias and error percentages when compared to observations. The model yielded larger bias and error results for 1,3 butadiene and 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) commensurability issues between measurements and model predictions; (4) emissions and science uncertainty issues may also affect model performance; and (5) 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 2005 performance results to the limited performance found in recent regional multi-pollutant model applications.[1,2,3] Overall, the normalized mean bias and error (NMB and NME), as well as the fractional bias and error (FB and FE) statistics shown in Table J-1 indicate that CMAQ-predicted 2005 toxics (i.e., observation vs. model predictions) are within the range of recent regional modeling applications.

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[1] 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.

[2] Strum, M., Wesson, K., Phillips, S., Cook, R., Michaels, H., Brzezinski, D., Pollack, A., Jimenez, M., Shepard, S. Impact of using lin-level 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.

[3] 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 K-1. 2005 CMAQ annual toxics model performance statistics

CMAQ 2005 Annual		No. of Obs.	NMB (%)	NME (%)	FB (%)	FE (%)
Formaldehyde	12-km EUS	6365	-53.8	64.5	-36.6	64.2
	12-km WUS	1928	-24.5	50.9	-25.8	58.6
	Northeast	1982	-28.2	50.7	-26.3	60.7
	Midwest	771	-75.9	85.0	-22.6	72.7
	Southeast	1246	-65.0	71.4	-48.8	69.1
	Central U.S.	1815	-41.4	49.4	-38.7	59.6
	West	1746	-21.7	51.5	-22.0	58.2
Acetaldehyde	12-km EUS	6094	-0.9	63.0	-5.2	59.8
	12-km WUS	1892	-14.4	53.6	-14.7	58.2
	Northeast	1969	-6.6	64.0	-6.4	63.4
	Midwest	703	-8.9	58.8	-8.7	59.3
	Southeast	1231	3.2	64.1	-3.7	61.5
	Central U.S.	1640	5.6	57.9	-0.9	50.5
	West	1709	-15.6	53.9	-15.4	59.3
Benzene	12-km EUS	11615	-30.6	66.9	-10.4	62.4
	12-km WUS	3369	-34.9	60.5	-25.4	62.3
	Northeast	2589	26.5	55.1	22.7	47.7
	Midwest	1425	-5.8	73.5	27.9	62.7
	Southeast	2426	-38.3	69.4	-12.9	60.1
	Central U.S.	4737	-46.4	67.6	-30.9	68.0
	West	2333	-26.1	61.2	-13.6	62.1
1,3-Butadiene	12-km EUS	8102	-71.9	84.9	-37.5	88.2
	12-km WUS	1976	-46.5	83.1	-22.7	91.5
	Northeast	1902	-34.1	53.0	-42.5	64.5
	Midwest	516	-74.8	85.5	-34.8	77.7
	Southeast	1226	-82.4	84.0	-93.4	100.7
	Central U.S.	4142	-63.8	86.1	-8.0	89.6
	West	1082	-36.7	78.4	-36.6	84.2
Acrolein	12-km EUS	1660	-93.8	94.5	-126.2	138.4
	12-km WUS	783	-95.4	95.5	-164.5	167.2
	Northeast	850	-89.5	90.9	-116.0	131.1
	Midwest	n/a	n/a	n/a	n/a	n/a
	Southeast	278	-96.7	96.7	-152.8	153.6
	Central U.S.	n/a	n/a	n/a	n/a	n/a
	West	592	-95.8	95.8	-176.9	176.9

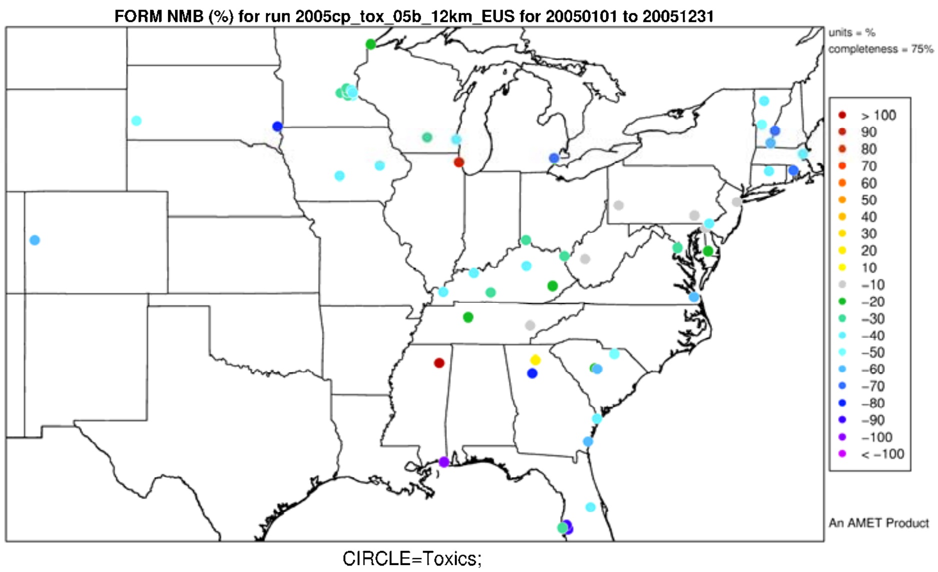

Figure K-1. Normalized Mean Bias (%) of annual formaldehyde by monitor for Eastern U.S., 2005.

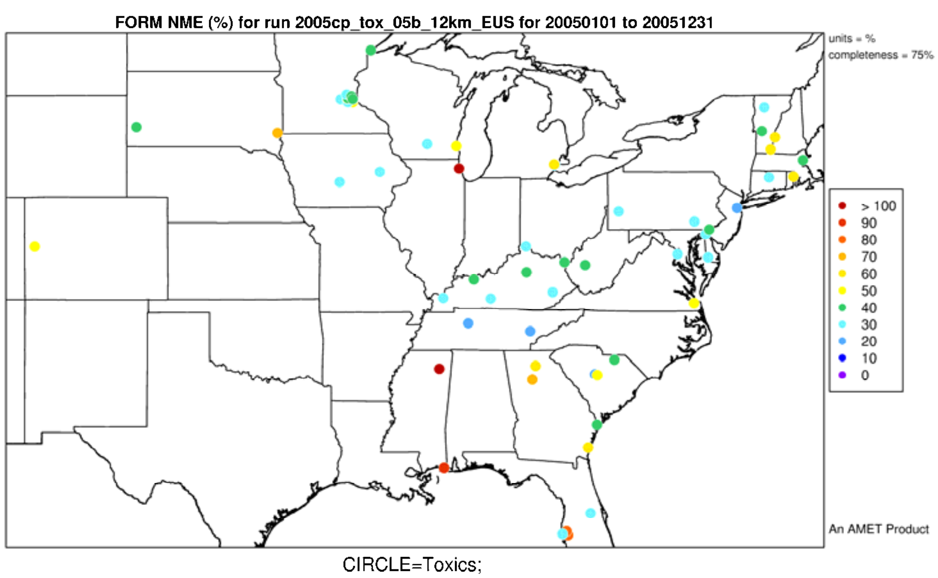

Figure K-2. Normalized Mean Error (%) of annual formaldehyde by monitor for Eastern U.S., 2005.

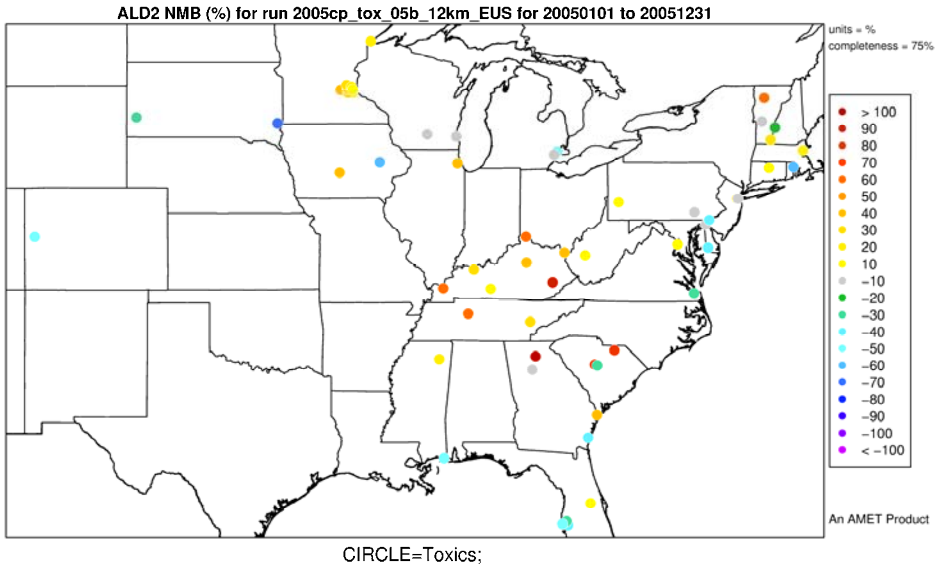

Figure K-3. Normalized Mean Bias (%) of annual acetaldehyde by monitor for Eastern U.S., 2005.

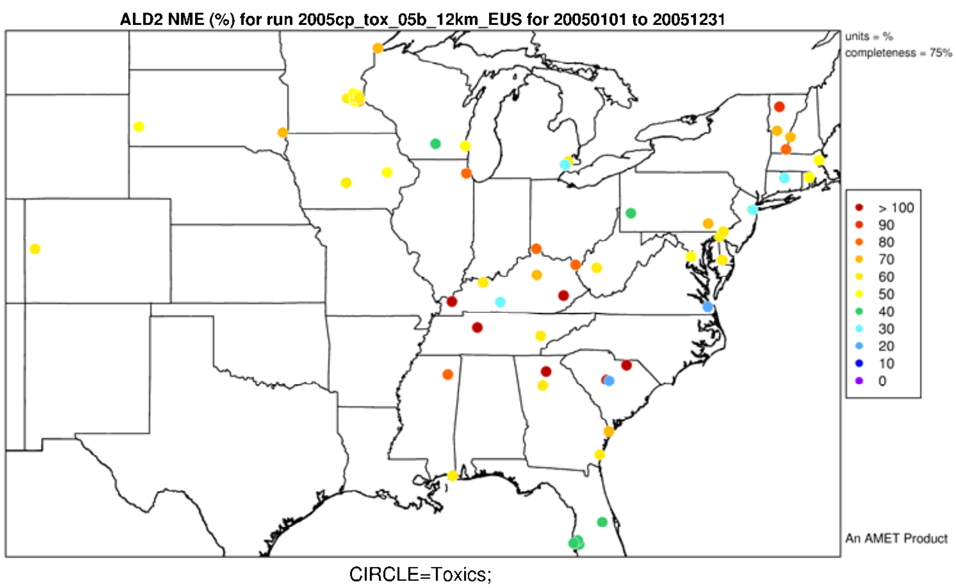

Figure K-4. Normalized Mean Error (%) of annual acetaldehyde by monitor for Eastern U.S., 2005.

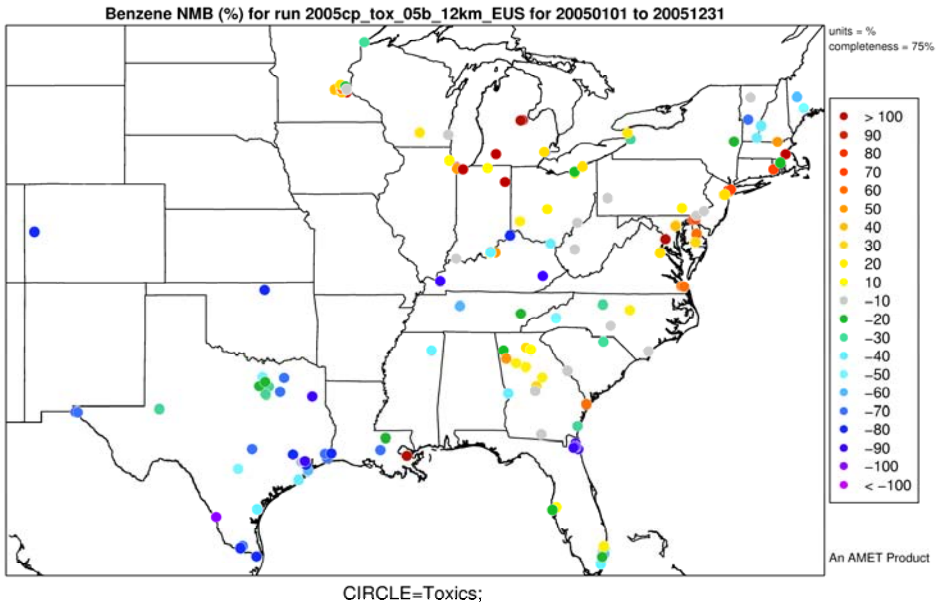

Figure K-5. Normalized Mean Bias (%) of annual benzene by monitor for Eastern U.S., 2005.

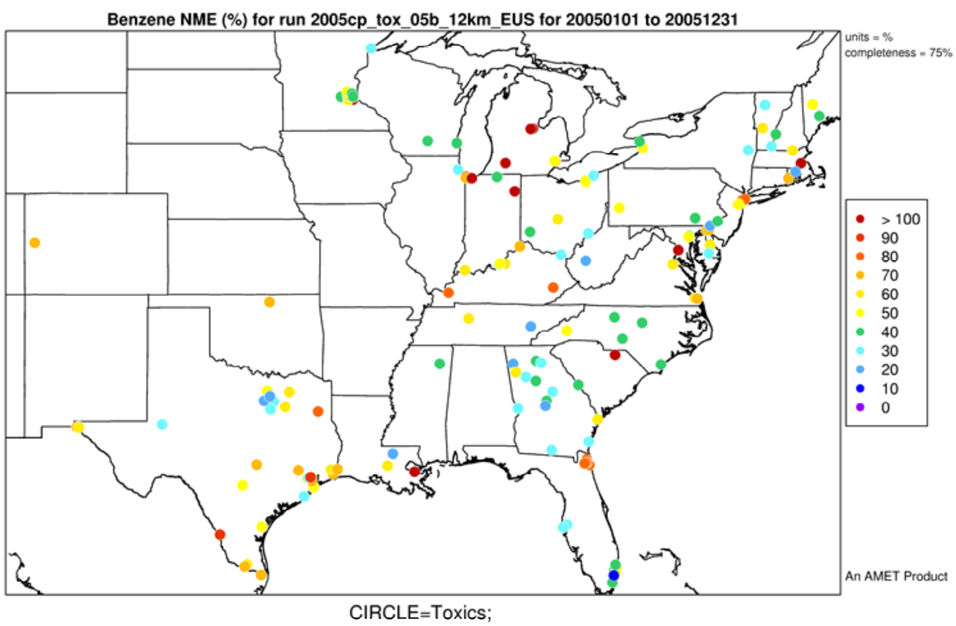

Figure K-6. Normalized Mean Error (%) of annual benzene by monitor for Eastern U.S., 2005.

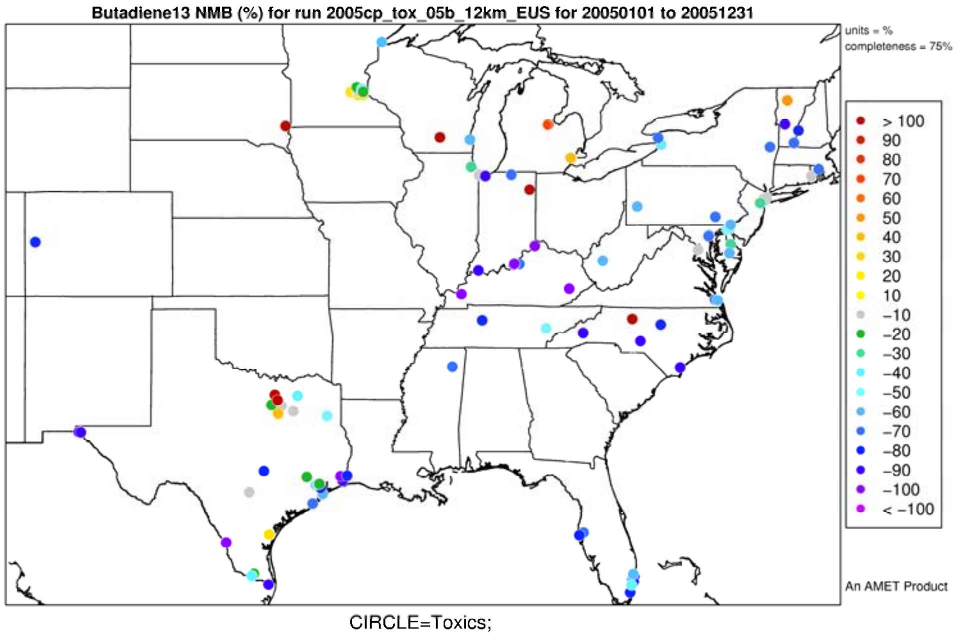

Figure K-7. Normalized Mean Bias (%) of annual 1,3-butadiene by monitor for Eastern U.S., 2005.

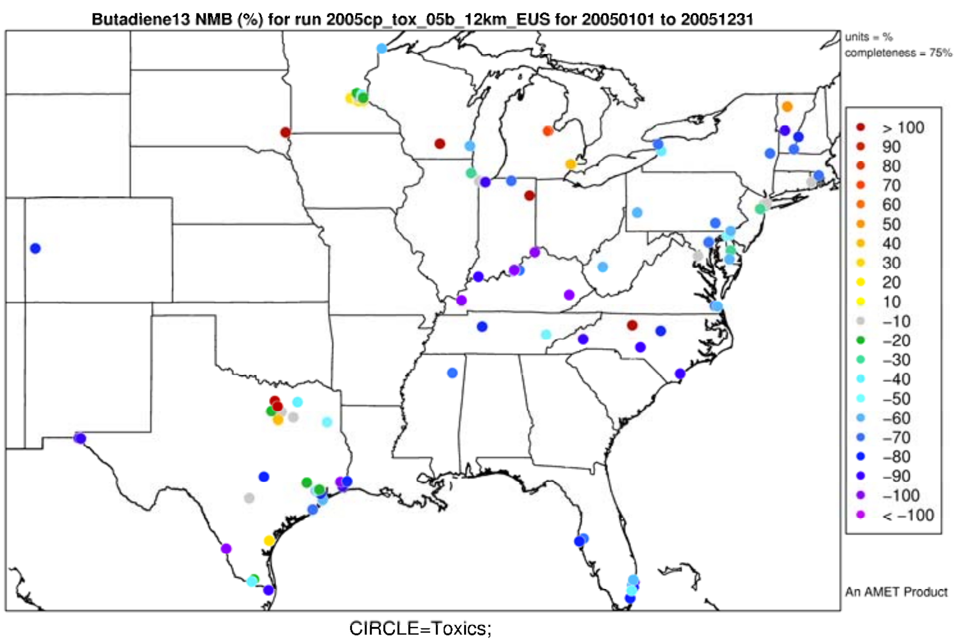

Figure K-8. Normalized Mean Error (%) of annual 1,3-butadiene by monitor for Eastern U.S., 2005.

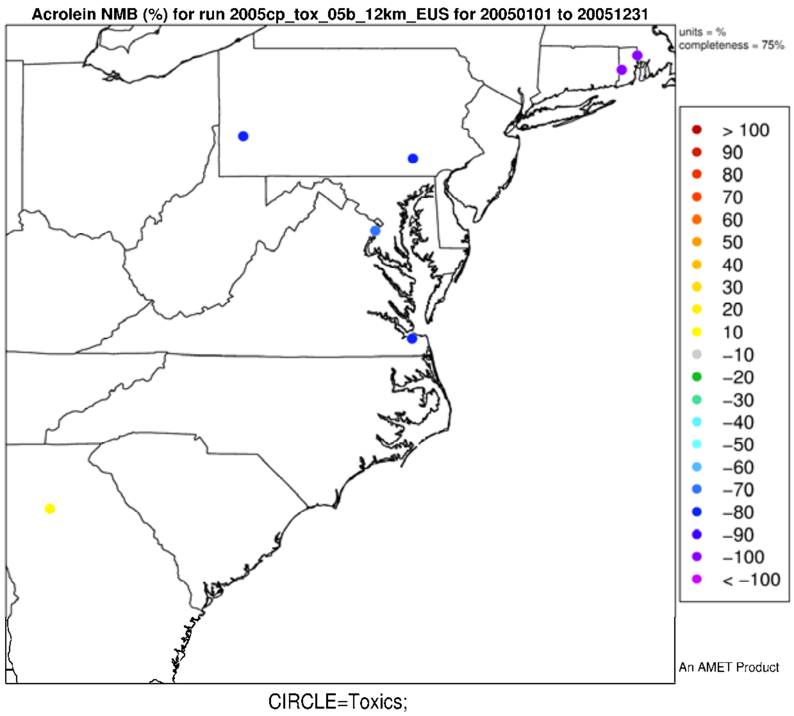

Figure K-9. Normalized Mean Bias (%) of annual acrolein by monitor for Eastern U.S., 2005.

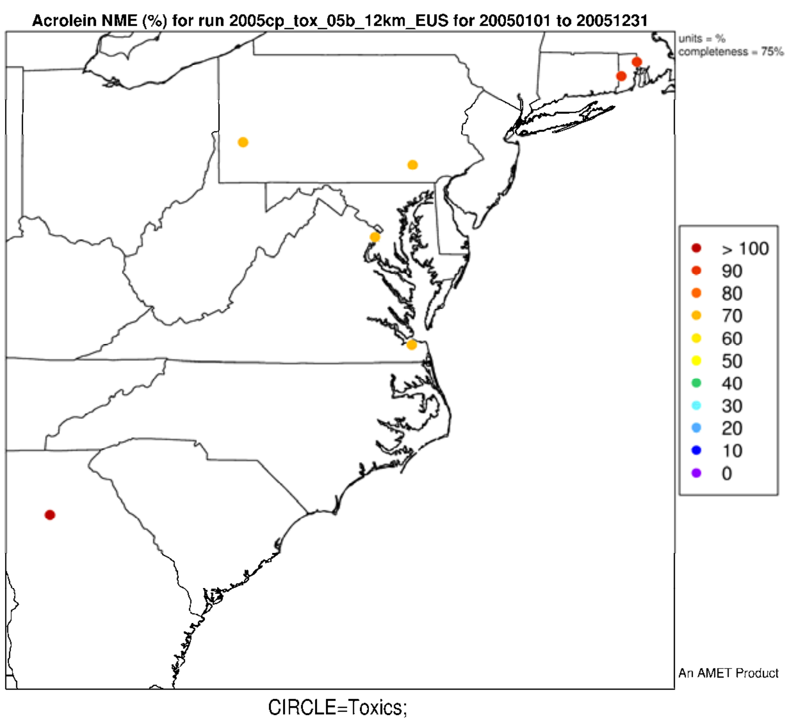

Figure K-10. Normalized Mean Error (%) of annual acrolein by monitor for Eastern U.S., 2005.

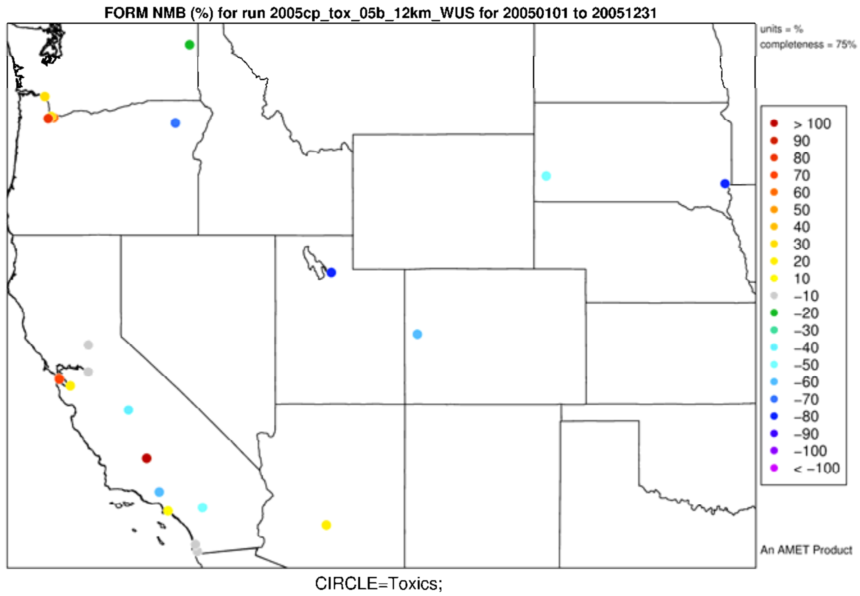

Figure K-15. Normalized Mean Bias (%) of annual formaldehyde by monitor for Western U.S., 2005.

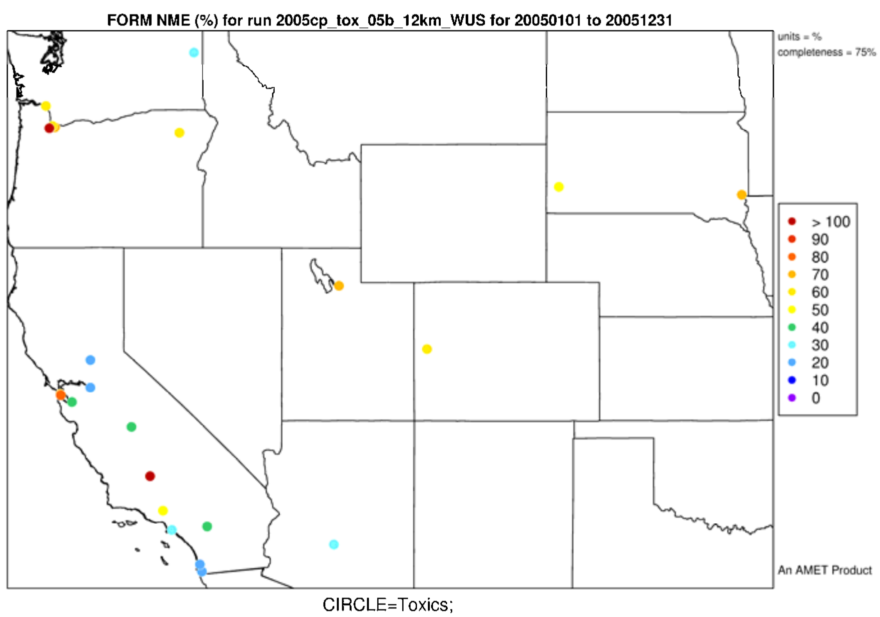

Figure K-16. Normalized Mean Error (%) of annual formaldehyde by monitor for Western U.S., 2005.

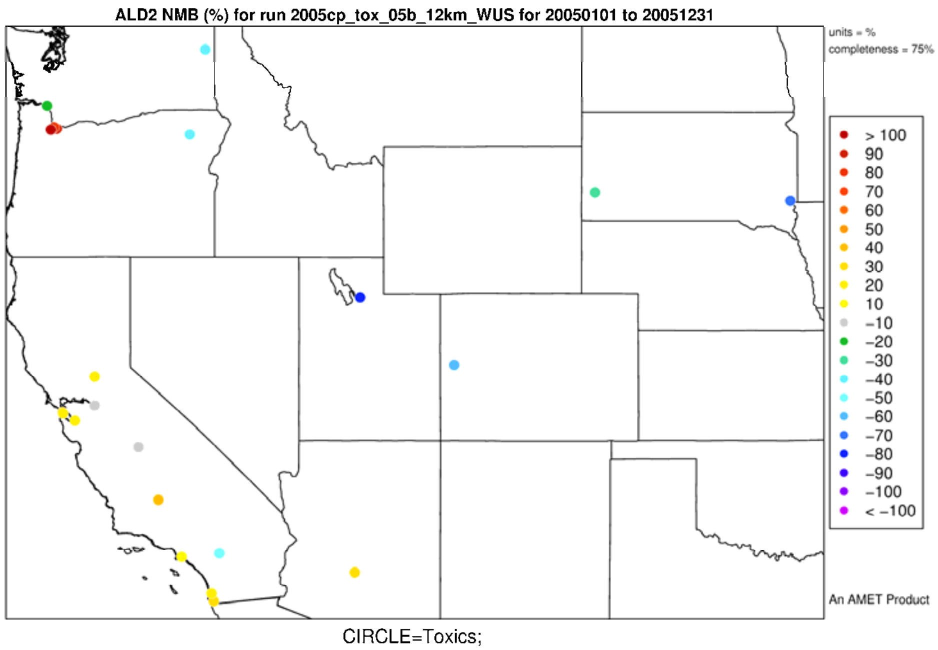

Figure K-17. Normalized Mean Bias (%) of annual acetaldehyde by monitor for Western U.S., 2005.

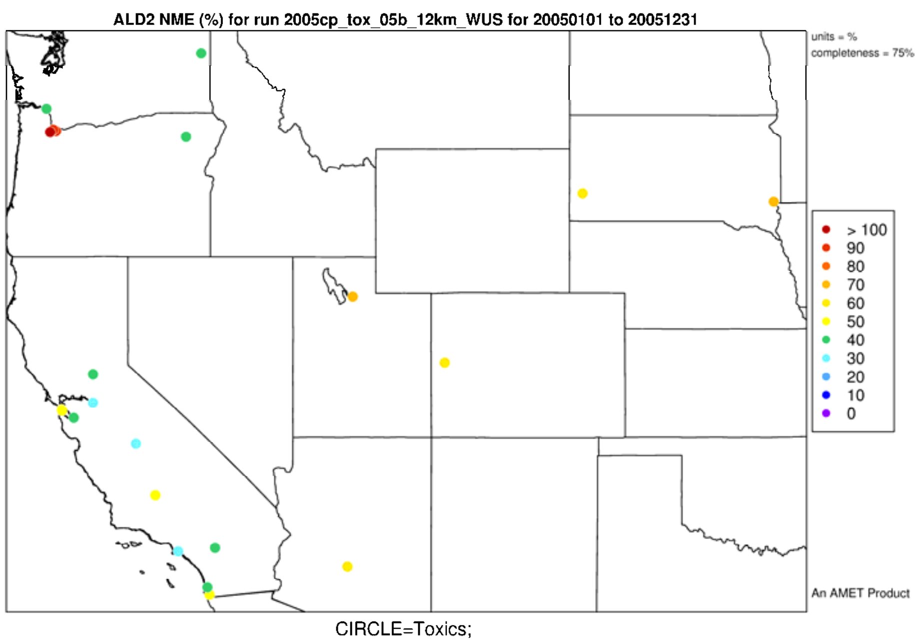

Figure K-18. Normalized Mean Error (%) of annual acetaldehyde by monitor for Western U.S., 2005.

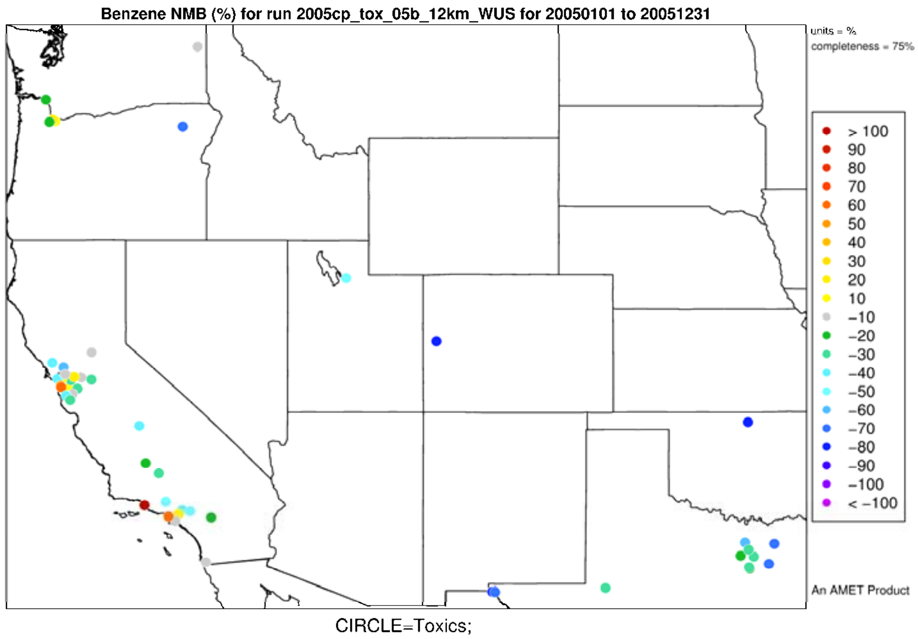

Figure K-19. Normalized Mean Bias (%) of annual benzene by monitor for Western U.S., 2005.

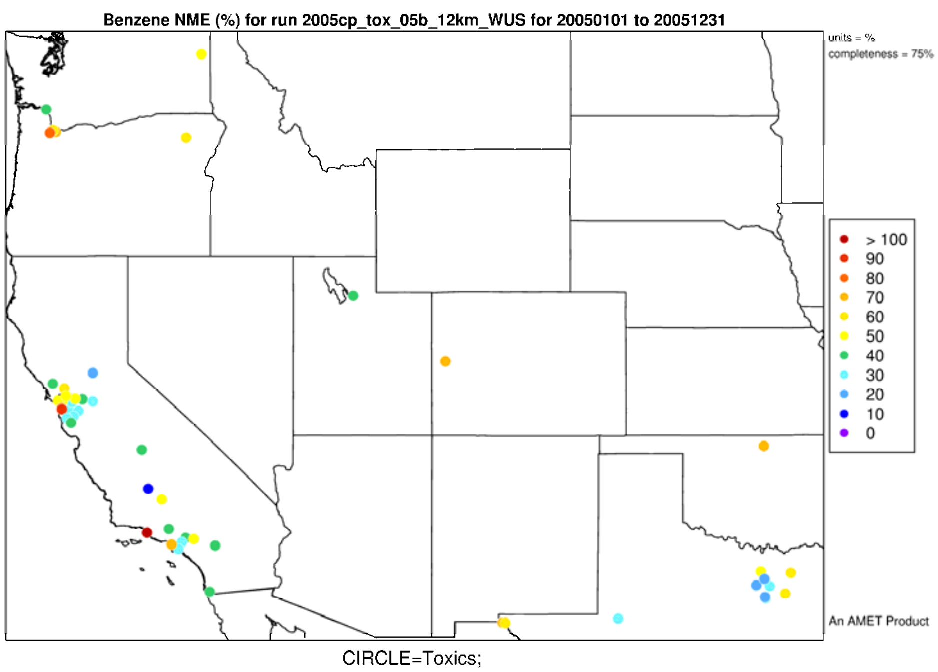

Figure K-20. Normalized Mean Error (%) of annual benzene by monitor for Western U.S., 2005.

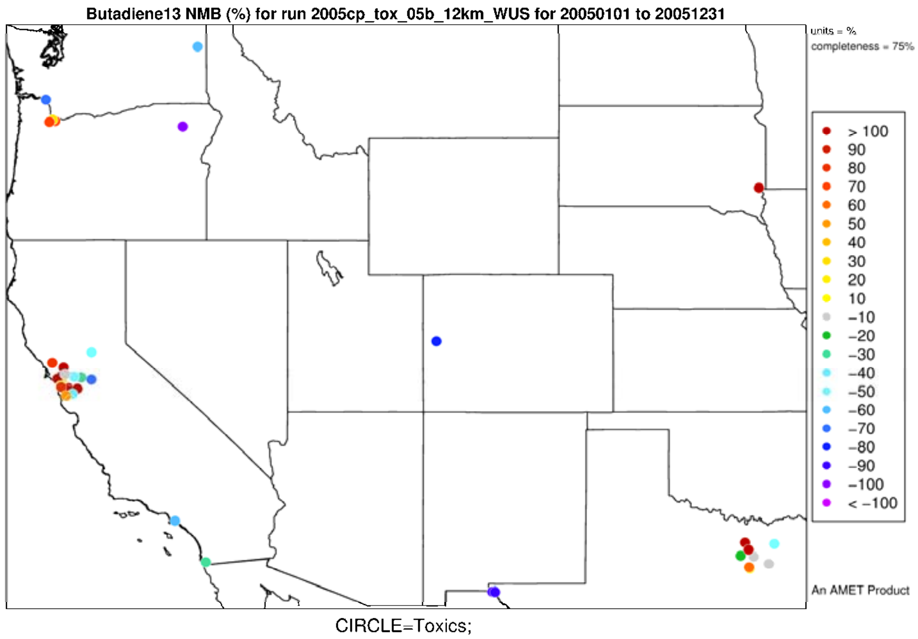

Figure K-21. Normalized Mean Bias (%) of annual 1,3-butadiene by monitor for Western U.S., 2005.

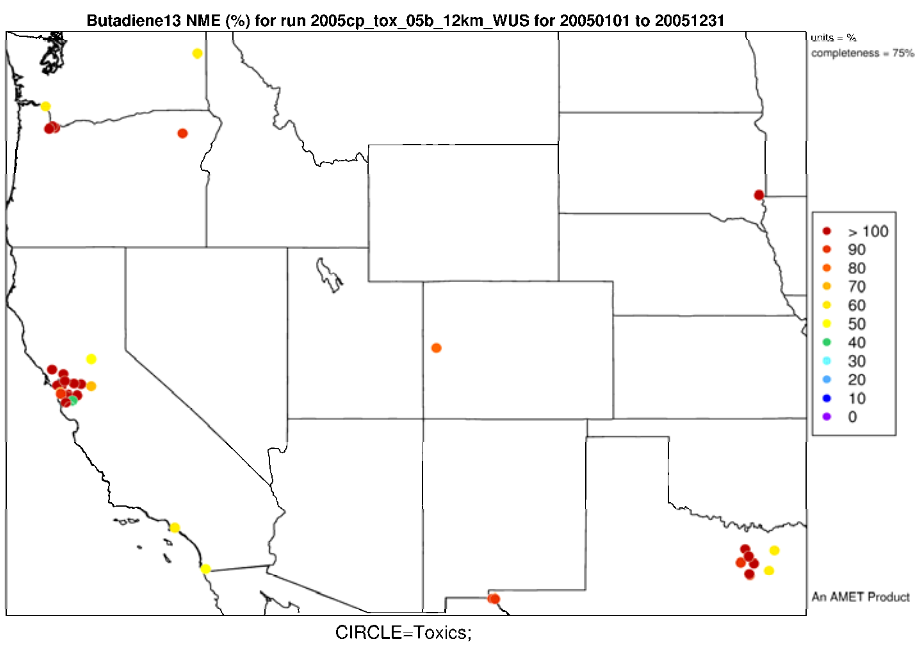

Figure K-22. Normalized Mean Error (%) of annual 1,3-butadiene by monitor for Western U.S., 2005.

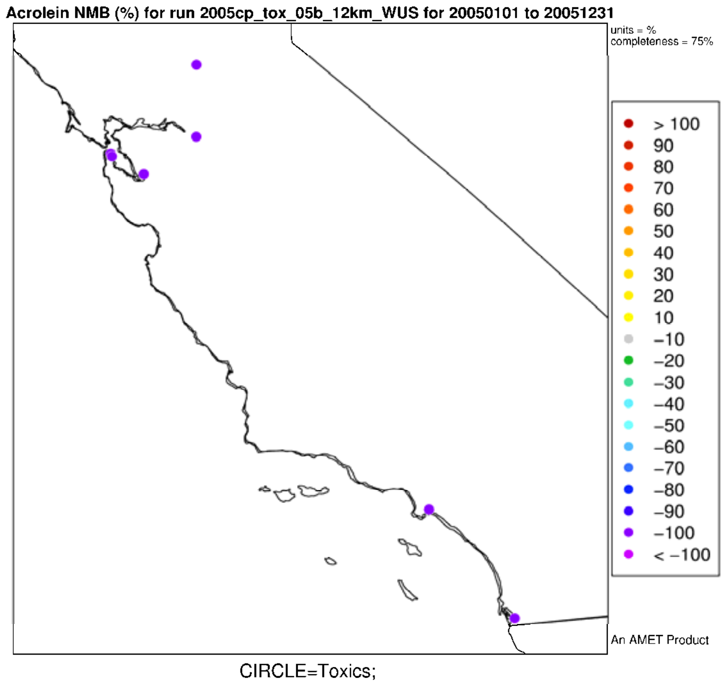

Figure K-23. Normalized Mean Bias (%) of annual acrolein by monitor for Western U.S., 2005.

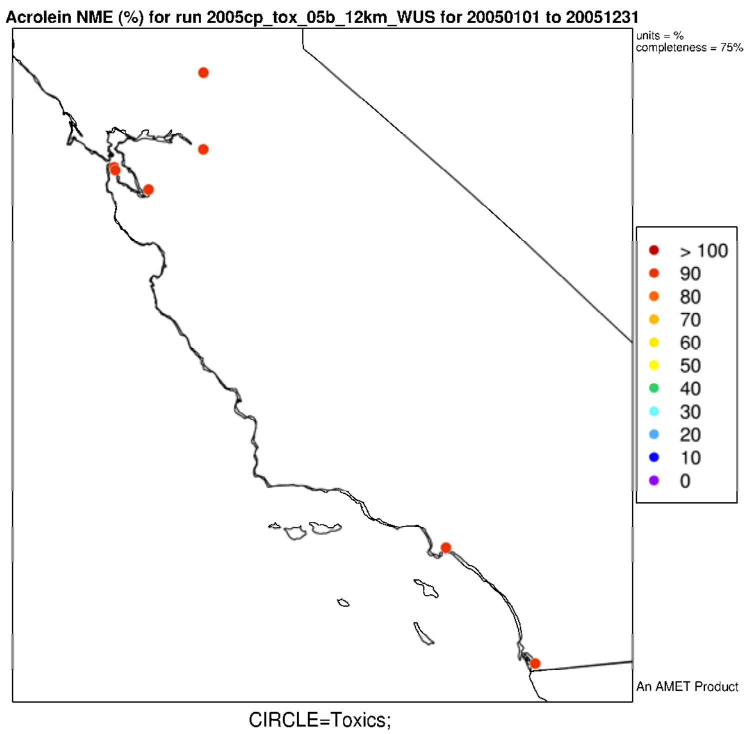

Figure K-24. Normalized Mean Error (%) of annual acrolein by monitor for Western U.S., 2005.

L. Annual Nitrate and Sulfate Deposition Performance

Annual nitrate and sulfate deposition performance statistics are provided in Table L-1. Spatial plots of the NMB and NME statistics (units of percent) for individual monitors are also provided as a complement to the tabular statistical data (Figures L-1 – L-8). The model predictions for annual nitrate deposition generally show small under-predictions for the Eastern and Western NADP sites (NMB values range from 0% to -11%). Sulfate deposition performance in the EUS and WUS shows the similar over predictions (NMB values range from 5% to 16%). The errors for both annual nitrate and sulfate are relatively moderate with values ranging from 60% to 81% which reflect scatter in the model predictions o observation comparison.

Table L-1. CMAQ 2005 annual model performance statistics for total nitrate and sulfate deposition.

CMAQ 2005 Total Deposition		No. of Obs.	NMB (%)	NME (%)	FB (%)	FE (%)
Nitrate	12-km EUS	7381	-0.6	63.9	-7.8	74.0
	12-km WUS	2732	-11.6	69.5	-12.7	83.4
	Northeast	1391	4.9	62.0	5.0	67.8
	Midwest	1658	10.1	60.9	3.9	66.5
	Southeast	1980	4.9	67.3	0.1	71.3
	Central	1229	-11.0	62.7	-11.0	78.3
	West	2257	-9.8	73.8	-12.7	85.0
Sulfate	12-km EUS	7381	7.8	67.0	6.0	75.3
	12-km WUS	2732	5.6	76.3	4.8	86.5
	Northeast	1391	16.4	62.6	23.2	70.4
	Midwest	1658	12.6	64.3	16.5	67.3
	Southeast	1980	8.6	71.4	6.4	73.8
	Central	1229	-7.3	65.1	-1.2	80.3
	West	2257	13.2	81.8	6.5	87.9

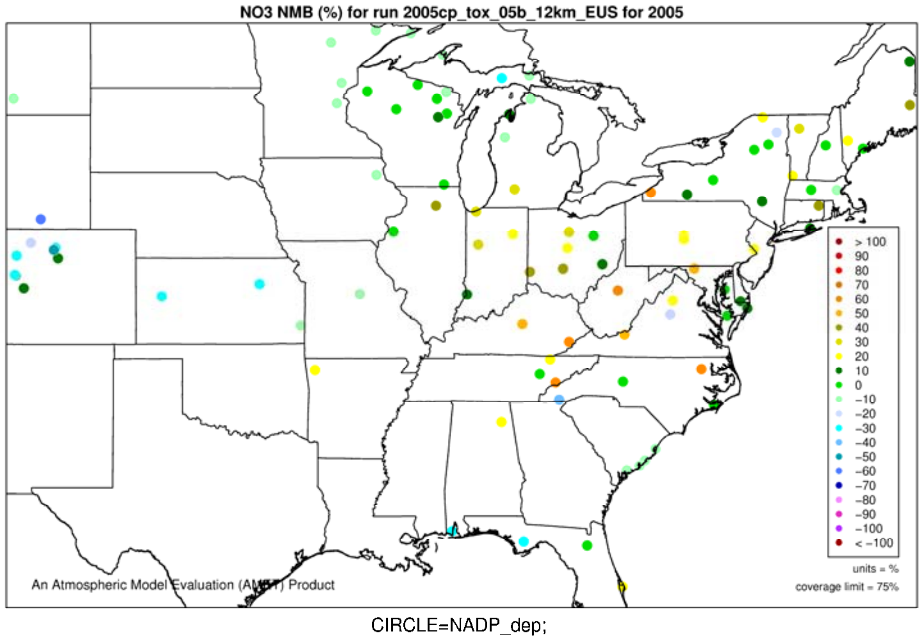

Figure L-1. Normalized Mean Bias (%) of annual nitrate deposition by monitor for Eastern U.S., 2005.

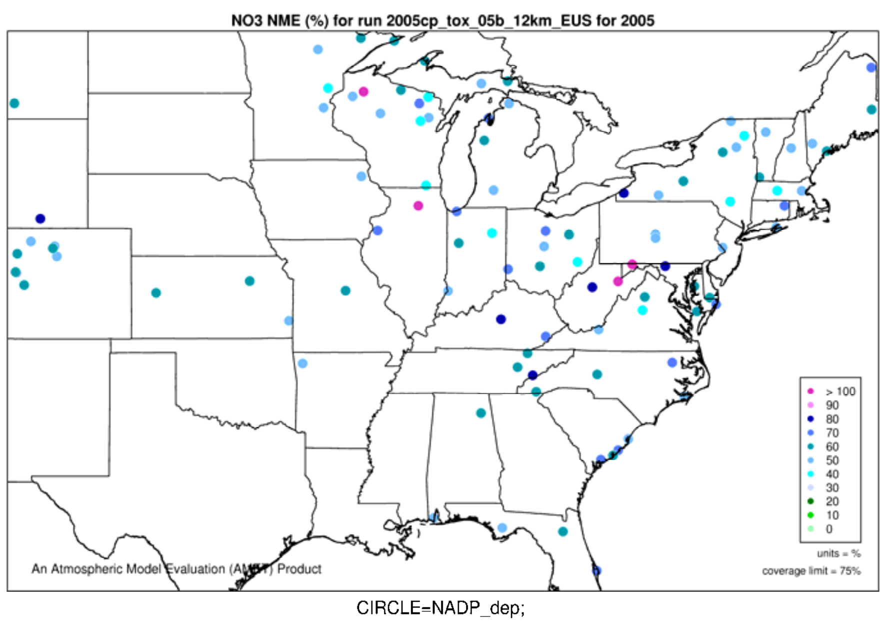

Figure L-2. Normalized Mean Error (%) of annual nitrate by monitor for Eastern U.S., 2005.

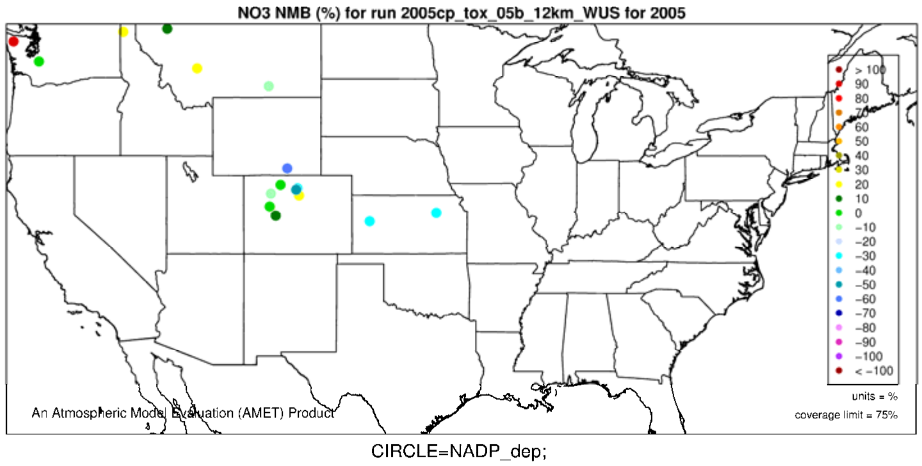

Figure L-3. Normalized Mean Bias (%) of annual nitrate deposition by monitor for Western U.S., 2005.

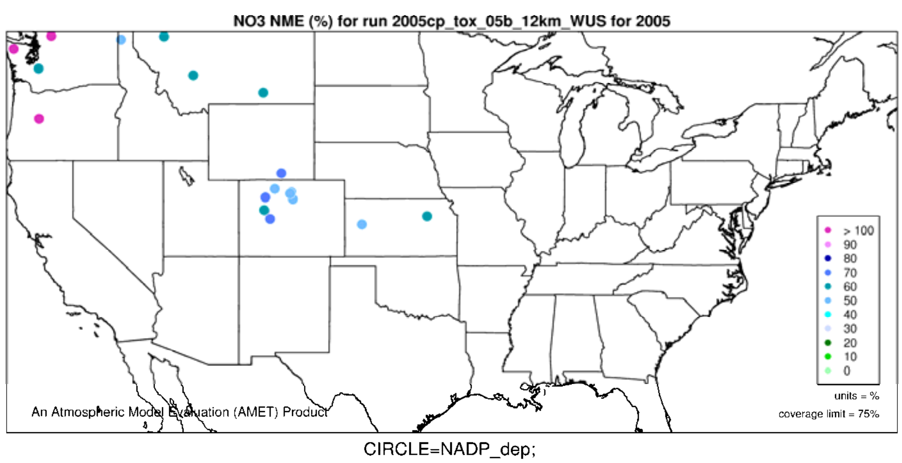

Figure L-4. Normalized Mean Error (%) of annual nitrate deposition by monitor for Western U.S., 2005.

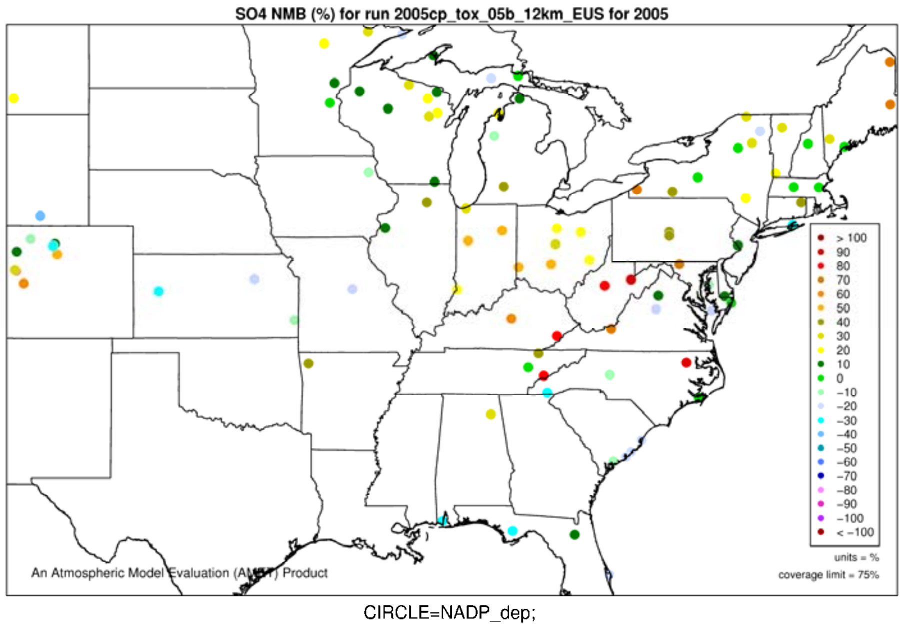

Figure L-5. Normalized Mean Bias (%) of annual sulfate deposition by monitor for Eastern U.S., 2005.

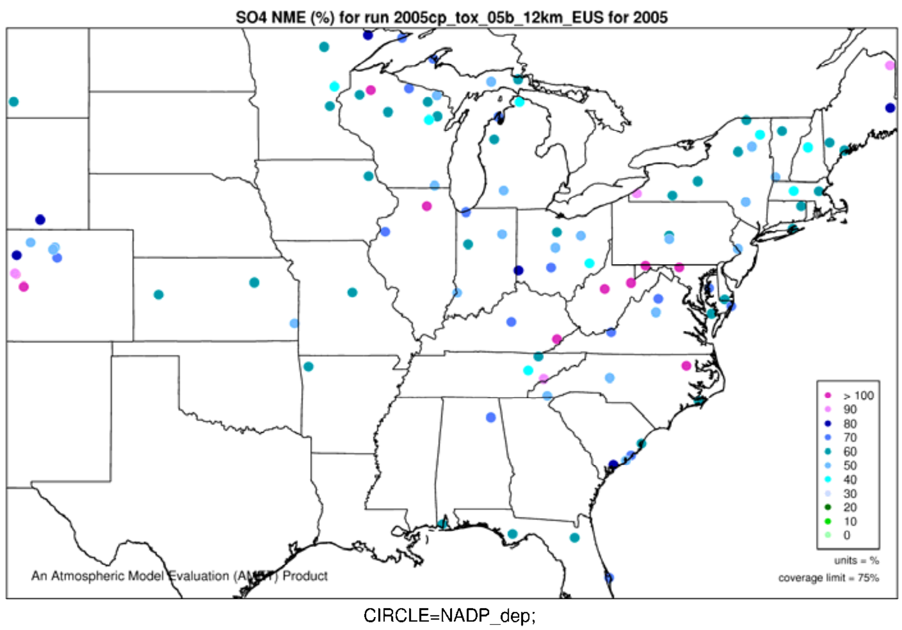

Figure L-6. Normalized Mean Error (%) of annual sulfate deposition by monitor for Eastern U.S., 2005.

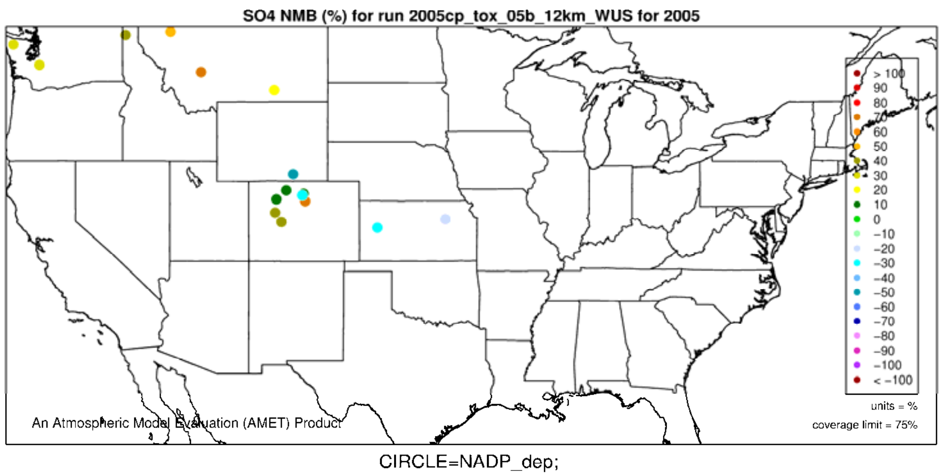

Figure L-7. Normalized Mean Bias (%) of annual sulfate deposition by monitor for Western U.S., 2005.

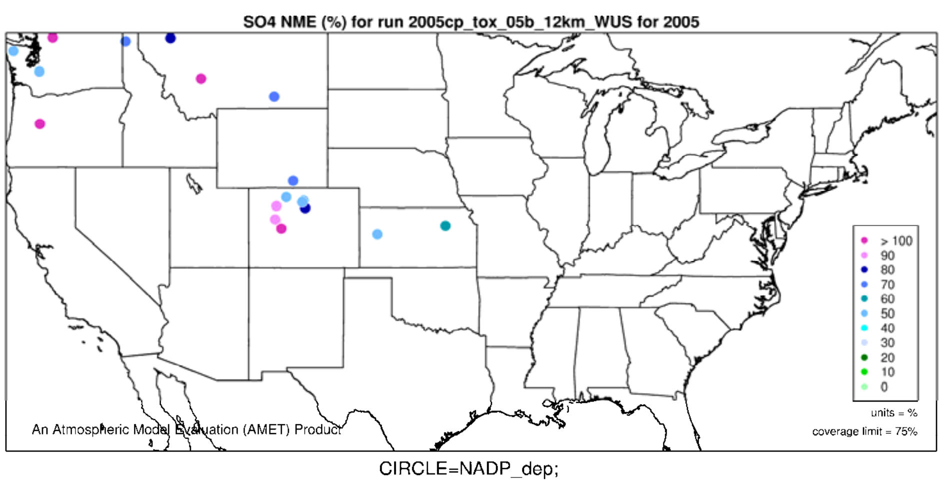

Figure L-8. Normalized Mean Error (%) of annual sulfate deposition by monitor for Western U.S., 2005.

United States Environmental Protection Agency	Office of Air Quality Planning and Standards Air Quality Assessment Division Research Triangle Park, NC	Publication No. EPA-454/R-10-003 April, 2010