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Air Quality Modeling Technical Support Document: Changes to the Renewable Fuel Standard Program

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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 final revisions to the National Renewable Fuel Standard rule (commonly known as RFS2). A national scale air quality modeling analysis was performed to estimate the effect of the rule on future year: annual and 24-hour $PM_{2.5}$ concentrations, daily maximum 8-hour ozone concentrations, annual nitrogen and sulfur deposition levels, and select annual and seasonal air toxic concentrations (formaldehyde, acetaldehyde, ethanol, benzene, 1,3-butadiene, acrolein). 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.

It is critical to note that a key limitation of the air quality modeling analysis is that it employed interim emission inventories, which were somewhat enhanced compared to what was described in the proposal, but due to the timing of the analysis did not include some of the later enhancements and corrections of the final emission inventories presented in the FRM (see Section 3.3 of the RIA). Most significantly, our modeling of the air quality impacts of the renewable fuel volumes required by RFS2 relied upon interim inventories that assumed that ethanol will make up 34 of the 36 billion gallon renewable fuel mandate, that approximately 20 billion gallons of this ethanol will be in the form of E85, and that the use of E85 results in fewer emissions of direct $PM_{2.5}$ from vehicles. The emission impacts and air quality results would be different if, instead of E85, more non-ethanol biofuels are used or mid-level ethanol blends are approved. There are additional, important limitations and uncertainties associated with the interim inventories that must be kept in mind when considering the results. These limitations and uncertainties are described in more detail in Section 3.4.1.3 of the RIA.

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 two future baselines and the RFS2 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.

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

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 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.[3,4,5,6] This 2005 multi-pollutant modeling platform used the latest publicly-released CMAQ version 4.7[7] 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.[8] This version reflects updates in a number of areas to improve the underlying science, including:

1) an enhanced secondary organic aerosol (SOA) mechanism to include chemistry of isoprene, sesquiterpene, and aged in-cloud biogenic SOA in addition to terpene,

2) an improved vertical convective mixing algorithm;

3) an improved heterogeneous reaction involving nitrate formation, and

4) an updated gas-phase chemistry mechanism, Carbon Bond 05 (CB05), with extensions to model explicit concentrations of air toxic species as well as chlorine and mercury.

This mechanism, CB05-toxics, also computes concentrations of species that are involved in aqueous chemistry and that are precursors to aerosols. Chapter 3 of the RIA discusses in detail

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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

[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.

[6] 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] 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.

[7] 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.
[8] 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.

the chemical mechanism, SOA formation, and details about the improvements made to the SOA mechanism within this recent release of CMAQ.

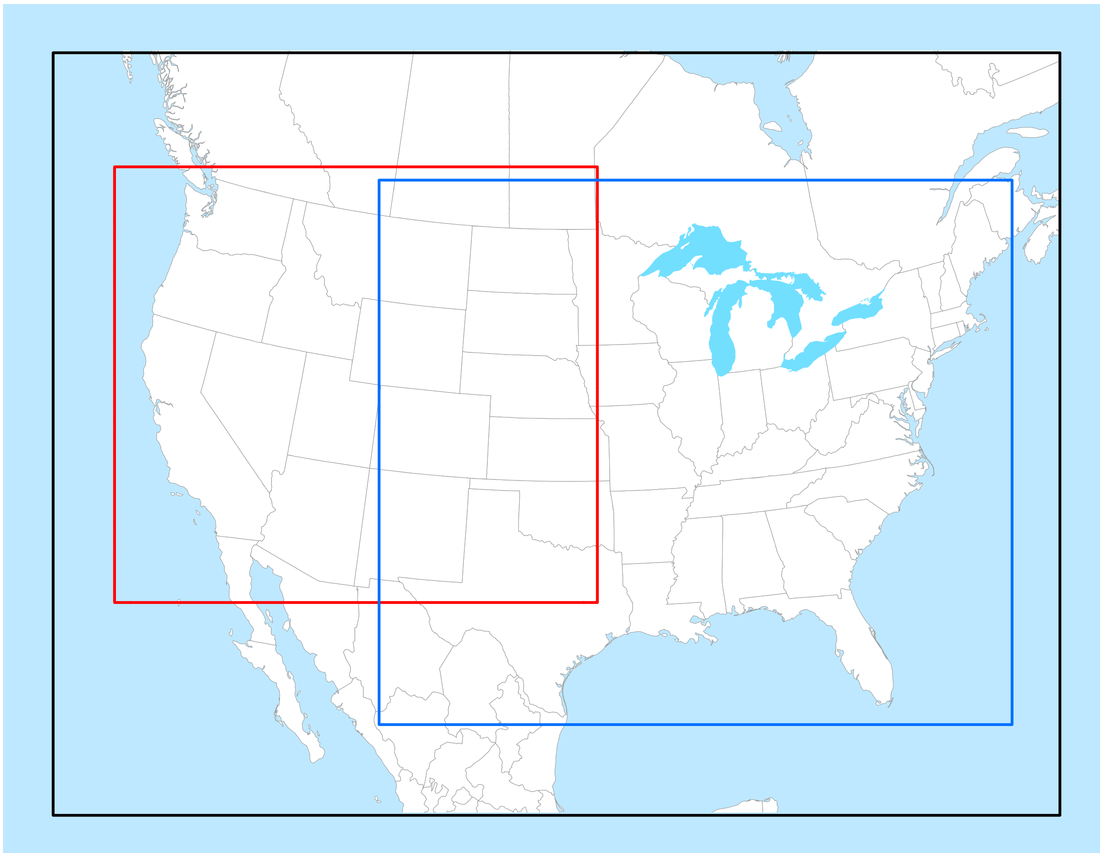
B. Model domain and grid resolution

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 RFS2 program changes. Table II-1 provides some basic geographic information regarding the CMAQ domains.

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. Valid Modeling Days

The 36 km and both 12 km CMAQ modeling domains were modeled for the entire year of 2005.[9] 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 toxics impacts from the regulation.

Normally, all 365 model days would also have been used in the estimation of $PM_{2.5}$ and visibility impacts; however during the RFS2 modeling, an error was discovered in the aqueous

[9] 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.

phase chemistry routines of CMAQ v4.7. This error[10] caused simulated hourly sulfate concentrations to increase sporadically and in an unrealistic manner over a very limited number of grid-cell hours over the RFS2 simulations. While this artifact has subsequently been removed from CMAQ v4.7, the RFS2 modeling schedule did not allow for the simulations to be redone. Instead, we simply invalidated any day that contained evidence of the aqueous phase problem and used the remaining data to determine the "true" model signal from the RFS2 scenarios. The following invalidation criteria were used. Any day in which there were five or more grid cell-hours that had greater than 50 ug/m^3 difference in sulfate concentrations between the future base and control cases was invalidated. Additionally any day with a single grid cell-hour difference exceeding 250 ug/m^3 was invalidated. Based on these invalidation criteria, nine days were removed from the EUS12 analysis and two days were removed from the WUS12 analysis[11].

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-HQ-OAR-2005-0161), contains a detailed discussion of the emissions inputs used in our air quality modeling as well as Section 3.1 in the final RFS2 RIA. 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 each of the future base cases are based on the 2005 v4 platform. The RFS2 cases use some different emissions data than the official v4 platform for two reasons: (1) the RFS2 modeling was done prior to the completion of the platform and (2) the RFS2 modeling used data intended only for the rule development and not for general application. The US EGU point source emissions estimates for all 2022 future year base cases are based on an Integrated Planning Model (IPM) run for criteria pollutants, hydrochloric acid, and mercury in 2020. The year 2020 was used since it was the year closest to the 2022 modeling year supported by the IPM model. Both control and growth factors were applied to a subset of the 2005 non-EGU point and nonpoint to create each of the 2022 future base cases. The 2002 v3.1 platform 2020 projection factors were the starting point for most of the RFS2 year 2022 SMOKE-based projections. Ethanol plant replacements and additions were included in the 2005 base and 2022 future baselines 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 were enhanced compared to what was described in the proposal, but did not include

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[10] This model artifact is discussed in more detail in an August 5th, 2009 document prepared by Shawn Roselle and Ann Marie Carlton. This document has been placed in the rule docket (EPA-HQ-OAR-2005-0161-DRAFT-2902).

[11] The days to be removed for the EUS12 are: 1/25, 2/25, 3/04, 3/05, 3/13, 3/14. 12/08, 12/09, 12/12. The days to be removed for the WUS12 are: 1/04 and 1/27.

some of the later enhancements and corrections of the final emission inventories presented in this FRM.

2. RFS2 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, and total nitrogen and sulfur deposition levels for each of the following emissions scenarios:

2005 base year

2022 baseline projection (RFS1 Mandate) of 7.5 billion gallons of renewable fuels

2022 baseline projection (Annual Energy Outlook (AEO) 2007) volume of roughly 14 billion gallons of renewable fuels

2022 control case projection (implementation of RFS2; also referred to as EISA (Energy Independence and Security Act of 2007)

Model predictions are used in a relative sense to estimate scenario-specific, future-year design values of $PM_{2.5}$ and ozone. 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[12] 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. Model predictions for air toxics as well as nitrogen and sulfur deposition were analyzed for an absolute change and percent change between the control case and two future baselines.

3. *Sensitivity analyses looking at impacts of chosen speciation profiles:* During the course of the RFS2 modeling, two issues arose concerning the approaches used to speciate certain classes of mobile source emissions into the chemical mechanism used by CMAQ. In order to determine what effect, if any, these particular RFS2 speciation assumptions may have had on the modeling results, a limited set of sensitivity modeling runs were performed and are summarized below.

The first analysis considered the impacts of an error in the emissions processing of nonroad gasoline emissions. Inadvertently, the speciation profiles for highway sources, which reflect a mix of pre-/post-Tier 2 vehicles and a mix of E0, E10, and E85 gasoline, had also been applied to nonroad gasoline engines which do not have similar advanced Tier-2 emissions controls, nor do they use E85 gasoline. The concern was that this error would result in potential overestimates of ethanol and potential underestimates of acetaldehyde in the control case. The corrected RFS2 emissions contained 9.1% less ethanol and 1.1% more acetaldehyde than what was modeled in the original scenario. The RFS2 control case was remodeled with the appropriate speciation profiles for four months in 2005 (January, April, July, and October). The

[12] 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.

sensitivity modeling showed that the original simulations (i.e., the ones summarized herein) do overestimate the expected ethanol changes between the baselines (i.e., AEO and RFS1) and the control case (RFS2). However, the CMAQ modeling indicated that the impacts of the speciation fixes were very small for ozone, $PM_{2.5}$, and key toxics species. Outside of ethanol, the impacts of the fix were generally at least one order of magnitude smaller than the differences between the RFS1 base and the control scenario. As a result, it was determined that the original modeling was sufficient for isolating the impacts of RFS2.

The second analysis evolved out of initial comparisons of the RFS1 mandate reference case with the RFS2 control case, where the modeling showed decreases in acetaldehyde concentrations in the summer and winter in urban areas. Decreases are less pronounced in winter when there is less secondary formation of acetaldehyde. The main reason for the decrease in urban areas is determined to be due to reductions in emissions of certain acetaldehyde precursors. In particular, reductions in alkenes (olefins) were noted, driven by differences in the E0 gasoline headspace speciation profiles used for the control case and the reference cases, as discussed in Section 3.4.1.3 of the RFS2 RIA. Headspace profiles are used to speciate hydrocarbon emissions from gasoline storage, gasoline distribution, and gas cans. After the initial modeling was completed, EPA noticed that the headspace profiles used in the reference case scenarios exhibited a reduction in alkene levels going from E0 to E10 that was inconsistent with what one would expect as a result of increased ethanol use. In these cases, the E0 gasoline headspace profile has 13% of the VOC as alkenes and the E10 profile has an alkene content of 4%. To address this issue, EPA conducted a sensitivity analysis by adjusting the E0 headspace profile in the RFS1 mandate reference case for the Eastern U.S. modeling domain[13] (based on the assumption that the emissions have an alkene content of 4%, consistent with the percent alkene content of the E10 headspace profile[14]). A sensitivity analysis was conducted for the month of July and EPA compared results with the control case for the following two cases:

1) RFS1 case with no change in alkene levels between headspace profiles for E0 and E10 (i.e., adjusted E0 profile)

2) RFS1 case with higher alkene levels for E0 headspace profile

Because of these uncharacteristic differences, EPA reran the control case using the adjusted E0 gasoline headspace profile. Due to time constraints, we were not able to make this improvement for the reference cases. Thus, alkene levels associated with the E0 use are lower in the control case than the reference cases, leading to a reduction in secondarily formed acetaldehyde.

The results of the sensitivity analysis showed that acetaldehyde levels were significantly higher for the comparison between Case 1 and the control case than for the comparison between Case 2 and the control case. The sensitivity analysis thus confirmed that the decrease in these

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[13] Details of the sensitivity run are discussed in the emissions modeling TSD, found in the docket for this rule (EPA-HQ-OAR-2005-0161).

[14] U.S. Environmental Protection Agency. 2010. Hydrocarbon Composition of Gasoline Vapor Emissions from Enclosed Fuel Tanks. Draft Report EPA-420-D-10-001, January 2010.

acetaldehyde precursors between the reference cases and the control case E0 headspace profile is driving the decrease in ambient concentrations of acetaldehyde in urban areas. Thus, while the air quality modeling results presented in the RFS2 RIA and in Section III.C.1 below suggest impacts of increased renewable fuel use on ambient acetaldehyde are not substantial and there may be decreases in urban areas, there is considerable uncertainty associated with these results. In fact, if the reference cases were rerun with revised E0 headspace profiles, some of the observed decreases could become increases.

4. 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.[15] Meteorological model input 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

[15] 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.

	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.[16]

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

[16] 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).

evaluation, five meteorological parameters were investigated: temperature, humidity, shortwave downward radiation, wind speed, and wind direction. The three individual MM5 evaluations are described elsewhere.[17,18,19] 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.

5. Initial and Boundary Conditions: The lateral boundary and initial species concentrations are provided by a three-dimensional global atmospheric chemistry model, the GEOS-CHEM[20] model (standard version 7-04-11[21]). 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[22]. The "acceptability" of model performance was judged by

[17] 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.

[18] 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.

[19] 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.

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

[21] 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.

[22] 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).

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[23]. 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 RFS2 assessment. A detailed summary of the 2005 CMAQ model performance evaluation is available in Appendix B[24].

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

CMAQ 2005 Annual			No. of Obs.	NMB (%)	NME (%)	FB (%)	FE (%)
$PM_{2.5}$ Total Mass	STN	12-km EUS	11797	-0.8	37.6	-2.4	38.7
		12-km WUS	3440	-10.0	45.0	-9.5	44.4
		Midwest	2318	8.5	35.2	9.2	33.5
		Northeast	2977	10.8	41.6	9.9	38.8
		Southeast	2960	-13.7	34.0	-14.5	37.1
		Central U.S.	2523	-6.3	39.8	-9.8	44.3
		West	2826	-10.9	46.1	-10.6	45.0
	IMPROVE	12-km EUS	9321	-6.4	41.6	-7.2	43.6
		12-km WUS	10411	-19.9	44.6	-21.9	48.4
		Midwest	571	1.3	36.8	1.3	37.2
		Northeast	2339	12.1	47.7	8.1	44.3
		Southeast	1694	-17.6	37.5	-16.9	43.1
		Central U.S.	2376	-13.3	41.7	-11.9	46.2
		West	9258	-22.9	44.8	-23.5	48.6
Sulfate	STN	12-km EUS	13897	-12.3	33.2	-9.2	35.9
		12-km WUS	3920	-17.0	42.3	-7.8	42.8
		Midwest	2495	-5.2	34.0	0.7	34.8
		Northeast	3441	-7.7	32.1	-4.0	33.9
		Southeast	3499	-14.5	30.9	-12.2	33.4
		Central U.S.	2944	-22.5	37.2	-19.5	41.6
		West	3157	-15.5	45.8	-6.7	44.0
	IMPROVE	12-km EUS	9034	-15.2	34.5	-6.2	38.9
		12-km WUS	10002	-14.4	41.0	2.7	44.5
		Midwest	531	-12.7	32.5	-5.0	34.6
		Northeast	2253	-7.7	34.3	-0.2	37.3
		Southeast	1685	-17.8	32.7	-12.2	36.2
		Central U.S.	2350	-23.5	36.6	-16.1	40.7
		West	8896	-10.5	42.3	5.0	45.1
	CASTNet	12-km EUS	3170	-19.3	24.8	-18.5	27.8

[23] 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.

[24] 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).

		12-km WUS	1142	-24.6	33.6	-16.6	35.2
		Midwest	615	-16.7	23.4	-14.8	24.8
		Northeast	786	-14.2	22.6	-12.3	24.8
		Southeast	1099	-21.5	24.7	-23.6	27.7
		Central U.S.	300	-32.2	34.3	-33.6	38.4
		West	1091	-23.7	33.8	-15.8	35.2
Nitrate	STN	12-km EUS	12741	25.5	70.4	-8.1	78.1
		12-km WUS	3655	-41.7	65.3	-70.8	97.5
		Midwest	2495	29.8	64.7	17.1	63.9
		Northeast	3442	37.0	73.9	3.2	73.6
		Southeast	3499	13.1	78.2	-27.5	86.0
		Central U.S.	1812	5.2	58.8	-6.2	71.6
		West	31339	-47.3	65.4	-79.1	99.9
	IMPROVE	12-km EUS	9027	34.2	86.9	-31.6	101.6
		12-km WUS	9987	-29.7	72.5	-93.8	124.0
		Midwest	531	20.7	69.8	-7.3	82.1
		Northeast	2248	66.4	106.9	-1.0	95.4
		Southeast	1685	42.5	106.6	-37.5	105.2
		Central U.S.	2350	22.8	72.7	-20.5	95.0
		West	8881	-45.7	75.6	-102.3	128.4
Total Nitrate (NO3 + HNO3)	CASTNet	12-km EUS	3170	27.3	40.3	21.9	38.1
		12-km WUS	1142	-3.3	34.5	6.4	39.9
		Midwest	615	26.1	37.4	26.9	34.1
		Northeast	786	40.6	46.0	34.4	42.4
		Southeast	1099	25.7	41.4	17.2	39.2
		Central U.S.	300	10.4	33.9	7.3	33.3
		West	1091	-4.7	35.7	6.4	40.5
Ammonium	STN	12-km EUS	13897	6.7	42.3	12.6	45.4
		12-km WUS	3893	-14.9	55.3	7.1	55.0
		Midwest	2495	14.3	42.0	22.3	42.2
		Northeast	3498	14.7	44.3	25.0	46.3
		Southeast	3882	0.8	39.1	6.5	42.0
		Central U.S.	3059	-4.3	43.6	-0.2	50.4
		West	3130	-20.5	59.0	5.8	57.2
	CASTNet	12-km EUS	3170	-1.3	34.6	0.4	35.8
		12-km WUS	1142	-14.5	38.8	-12.1	40.1
		Midwest	615	8.1	34.6	12.8	33.3
		Northeast	786	6.2	37.2	11.3	35.9
		Southeast	1099	-13.6	32.6	-13.7	36.5
		Central U.S.	300	-4.2	35.4	-1.1	39.6
		West	1091	-20.8	39.1	-13.9	40.2
Elemental Carbon	STN	12-km EUS	14038	25.9	66.0	18.2	54.3
		12-km WUS	3814	31.1	77.7	19.5	62.5
		Midwest	2502	18.7	51.7	20.1	47.1
		Northeast	3479	37.7	70.5	26.7	54.7
		Southeast	3877	10.7	59.1	8.1	49.4
		Central U.S.	3221	48.1	86.3	26.5	64.3
		West	3015	38.7	82.8	21.0	65.1
	IMPROVE	12-km EUS	8668	-25.9	49.1	-28.3	56.0
		12-km WUS	9495	-10.2	57.2	-17.8	60.4
		Midwest	602	-16.8	41.8	-28.3	50.4

		Northeast	2117	-4.8	48.8	-15.5	54.1
		Southeast	1584	-46.1	51.4	-51.5	62.8
		Central U.S.	2123	-31.3	49.5	-30.1	56.5
		West	8518	-9.6	58.2	-18.2	61.5
Organic Carbon	STN	12-km EUS	12619	-35.1	52.6	-32.5	63.9
		12-km WUS	3582	-32.1	56.7	-28.2	61.3
		Midwest	2380	-37.3	51.9	-31.0	62.5
		Northeast	3323	-17.4	52.7	-13.7	60.3
		Southeast	3802	-45.7	52.9	-48.7	66.7
		Central U.S.	2259	-38.8	53.4	-37.3	66.9
		West	3060	-31.7	57.6	-27.8	61.4
	IMPROVE	12-km EUS	8662	-29.9	50.6	-34.3	59.1
		12-km WUS	9495	-24.0	57.1	-29.4	62.8
		Midwest	601	-33.1	43.6	-39.3	53.2
		Northeast	2116	-7.7	52.4	-14.4	53.5
		Southeast	1587	-37.8	46.7	-48.0	60.2
		Central U.S.	2123	-42.5	54.2	-46.8	65.2
		West	8518	-22.3	57.3	-28.1	62.7

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 RFS2 final rule. Appendix B 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 Proposal to Designate an Emissions Control Area for Nitrogen Oxides [25] and the Clean Air Interstate Rule[26]). Overall, 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

[25] 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)

[26] 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.

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 RFS2 emissions 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
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. 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 B 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.[27,28,29] 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-7 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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[27] 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.

[28] 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.

[29] 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 II-7. 2005 CMAQ annual toxics model performance statistics

CMAQ 2005 Annual		No. of Obs.	NMB (%)	NME (%)	FB (%)	FE (%)
Formaldehyde	12-km EUS	6365	-55.5	65.3	-39.2	65.6
	12-km WUS	1928	-28.4	52.1	-30.1	60.7
	Midwest	771	-77.1	85.4	-25.8	74.0
	Northeast	1982	-30.5	51.3	-28.5	61.6
	Southeast	1246	-66.2	72.2	-51.3	70.4
	Central U.S.	1815	-43.5	51.0	-41.4	61.5
	West	1746	-25.5	52.3	-26.0	59.8
Acetaldehyde	12-km EUS	6094	-4.2	62.0	-8.2	60.3
	12-km WUS	1892	-19.2	53.7	-19.5	59.6
	Midwest	703	-12.6	58.0	-12.1	60.0
	Northeast	1969	-9.5	62.8	-9.0	63.7
	Southeast	1231	0.4	63.5	-6.2	62.2
	Central U.S.	1640	1.8	57.0	-4.3	51.1
	West	1709	-20.4	54.1	-20.1	60.6
Benzene	12-km EUS	11615	-32.6	66.8	-13.5	62.8
	12-km WUS	3369	-38.4	60.8	-30.4	63.9
	Midwest	1425	-8.3	72.7	25.2	62.4
	Northeast	2589	21.6	53.3	18.1	46.8
	Southeast	2426	-41.1	68.6	-17.2	59.8
	Central U.S.	4737	-47.0	68.3	-32.7	69.4
	West	2333	-30.5	61.2	-19.2	63.4
1,3-Butadiene	12-km EUS	8102	-74.7	85.6	-49.4	91.6
	12-km WUS	1976	-51.9	82.1	-34.5	91.7
	Midwest	516	-78.7	86.2	-48.3	81.9
	Northeast	1902	-41.6	55.5	-54.8	71.3
	Southeast	1226	-85.4	86.4	-106.2	111.5
	Central U.S.	4142	-66.5	85.9	-20.0	89.2
	West	1082	-40.8	77.5	-41.9	85.3
Acrolein	12-km EUS	1660	-94.4	95.0	-131.3	142.2
	12-km WUS	783	-95.7	95.7	-168.1	170.4
	Midwest	n/a	n/a	n/a	n/a	n/a
	Northeast	850	-90.4	91.5	-120.5	134.2
	Southeast	278	-97.0	97.0	-156.4	157.0
	Central U.S.	n/a	n/a	n/a	n/a	n/a
	West	592	-95.9	95.9	-177.6	177.6

III. CMAQ Model Results

A. Impacts of RFS2 Changes on Future $PM_{2.5}$ Levels

It is important to remember that there are uncertainties and limitations related to the air quality modeling (see Section 3.4.1.3 in RFS2 RIA), including the projected amount of E85 in use. The modeled projected usage of E85 is higher than what was included in the final rule inventory, which could overestimate the decreases in $PM_{2.5}$. These differences in the air quality modeling inventories and the final rule inventories are discussed in detail in Section 3.3 of the RFS2 RIA.

After the air quality modeling was complete an error was found in the PM inventory for locomotives, therefore only design value changes over all 577 modeled counties are reported. A large majority of the modeled counties will have relatively minor annual average $PM_{2.5}$ design value changes of between -0.05 $\mu g/m^3$ and +0.05 $\mu g/m^3$. On a population-weighted basis, the average modeled future-year annual $PM_{2.5}$ design values are projected to decrease by 0.002 $\mu g/m^3$ when compared with the RFS1 mandate or AEO reference case.[30] Likewise, daily $PM_{2.5}$ design values show the majority of the modeled counties will experience changes of between -0.25 $\mu g/m^3$ and +0.25 $\mu g/m^3$. On a population-weighted basis, the average modeled future-year daily $PM_{2.5}$ design value is projected to decrease by 0.06 $\mu g/m^3$ when compared with the RFS1 mandate scenario or 0.05 $\mu g/m^3$ when compared with the AEO scenario.

The changes in ambient $PM_{2.5}$ described above are likely due to both increased emissions at biofuel production plants and from biofuel transport, and reductions in SOA formation and reduced emissions from gasoline refineries. In addition, decreases in ambient PM are predicted because our modeling inventory assumed large volumes of E85 use and also that E85 usage reduces PM tailpipe emissions. As mentioned previously and in more detail in Section 3.4 of the RIA, these direct PM emission reductions would not occur with final rule inventory assumptions.

B. Impacts of RFS2 Changes on Future 8-Hour Ozone Levels

This section summarizes the results of our modeling of ozone air quality impacts in the future due to the required renewable fuel volumes. Our modeling indicates that the renewable fuel standards will result in increases in ozone design value concentrations in many areas of the country as well as decreases in ozone design value concentrations in a small number of areas. Figures III-1 and III-2 display the projected county-level, 8-hour ozone design value changes expected when the RFS2 control scenario is compared to the RFS1 mandate reference case and the AEO 2007 reference case respectively.[31] The air quality modeling of the expected impacts of the final rule shows that in 2022, most counties with modeled data, especially those in the southeast U.S., will see increases in their ozone design values. The bulk of these design value increases are less than 0.5 ppb. On a population-weighted basis, the average modeled future-year 8-hour ozone design values are projected to increase by 0.15 ppb in 2022 when compared with the RFS1 mandate reference case and increase by 0.27 ppb when comparing with the AEO reference case. On a population-weighted basis those counties that are projected to be above the

[30] Note that the change in annual average $PM_{2.5}$ for design values differs from the change in national population-weighted annual average $PM_{2.5}$ discussed in Sections I and VIII of the preamble and Chapter 5 of the RIA. The discussion of national population-weighted annual average $PM_{2.5}$ with respect to health impacts in Sections I and VIII of the preamble and Chapter 5 of this RIA is based on modeling data from all grid cells rather than just those counties with monitors. It finds that there is a small increase in annual average $PM_{2.5}$.

[31] The air quality modeling used a different speciation profile for E10 gasoline headspace emissions in the RFS2 control case than was used for the RFS1 and AEO reference cases. This inconsistency is described in Section 3.4.1.3 in the RFS2 RIA.

2008 ozone standard in 2022 will see decreases of 0.18 when compared with the AEO reference case and 0.17 ppb when compared with the RFS1 mandate reference case.

When comparing the changes in projected ozone it is important to note the differences in the inventories used for the air quality modeling and the inventories presented in the RFS2 final rule. The most important difference and uncertainty has to do with the fact that the modeled inventory assumes increases in NOx for vehicles using E10 fuel. The air quality modeling indicates that the NOx increases required from the renewable fuel volumes contribute to the ozone increases in NOx-limited areas as well as the ozone decreases in VOC-limited areas.

Figure III-1. Model-projected change in annual 8-hour Ozone design values between the RFS2 Control Scenario and the RFS1 Mandate Scenario in 2022. Units are ppb.

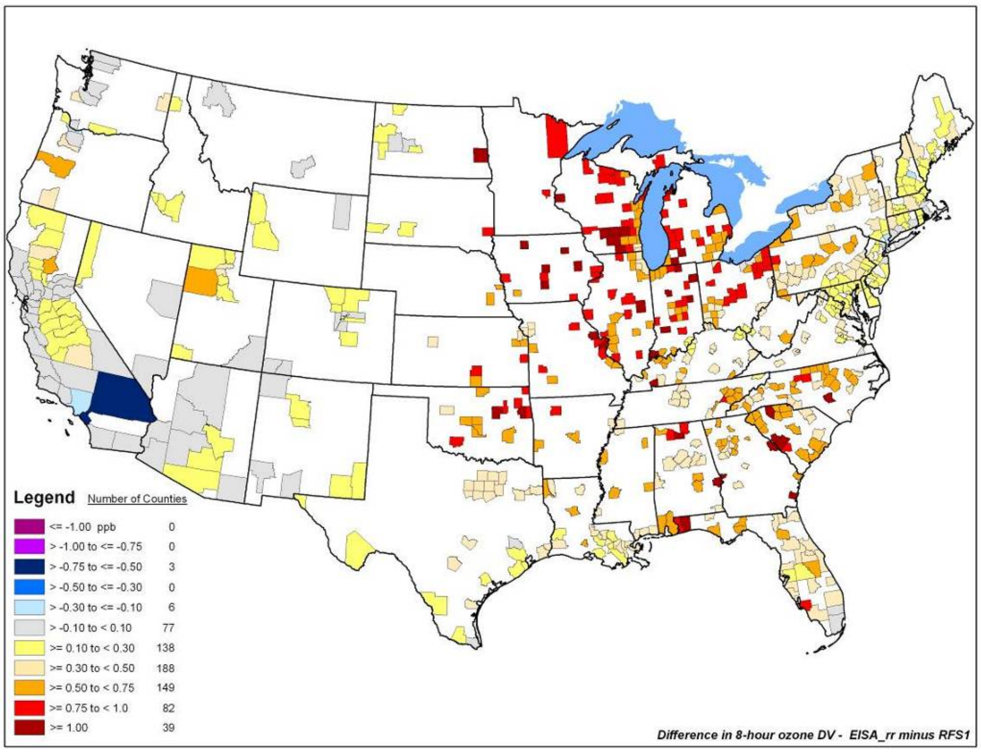
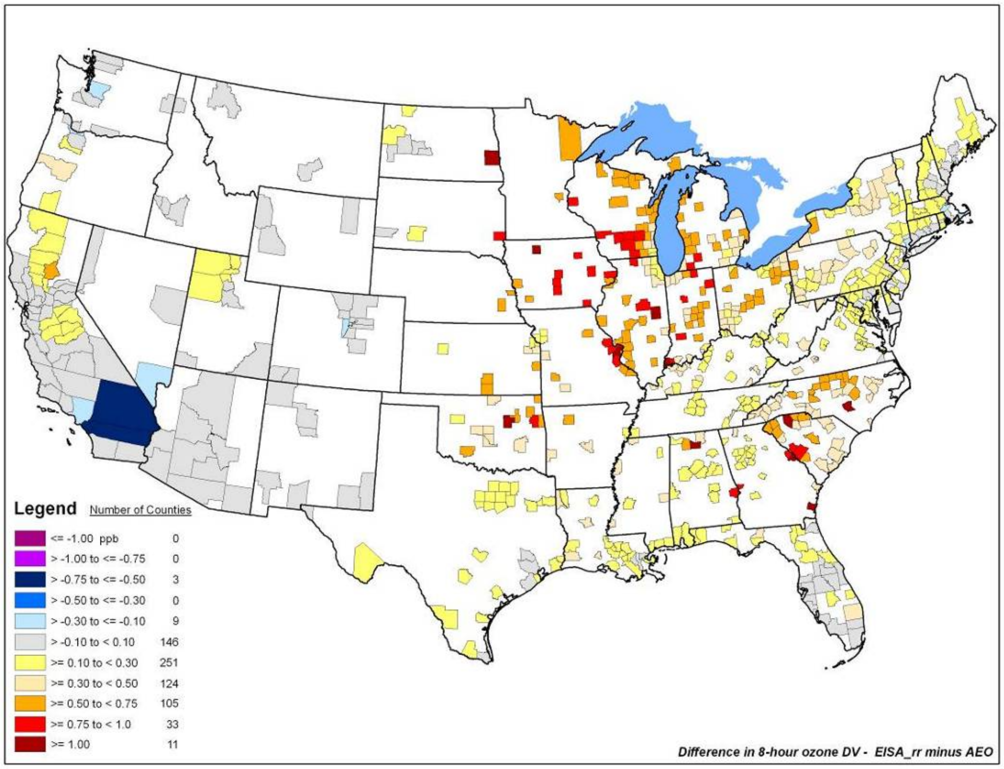


Figure III-2. Model-projected change in annual 8-hour Ozone design values between the RFS2 Control Scenario and AEO Scenario in 2022. Units are ppb.



C. Impacts of RFS2 Changes on Toxic Air Pollutant Levels

This section summarizes the results of our modeling of ambient air toxics impacts in the future from the renewable fuel volumes required by RFS2. Specifically, we compare the RFS1 mandate and AEO reference scenarios to the RFS2 control scenario for 2022 (see Section 3.3 of the RIA for more information on the scenarios).[32] Our modeling indicates that, while there are some localized impacts, the renewable fuel volumes required by RFS2 have relatively little impact on national average ambient concentrations of the modeled air toxics. An exception is increased ambient concentrations of ethanol. Since the overall impacts are relatively small, we concluded that assessing exposure to ambient concentrations and conducting a quantitative risk assessment of air toxic impacts was not warranted. Although, we developed 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.

[32] We used a different speciation profile for E10 gasoline headspace emissions in the RFS2 control case than was used for the RFS1 and AEO reference cases. This inconsistency is described in Section 3.4.1.3 of the RIA.

1. Acetaldehyde

Overall, the air quality modeling does not show substantial nationwide impacts on ambient concentrations of acetaldehyde due to the renewable fuel volumes required by this rule. Figure III-3 shows the annual percent changes in ambient concentrations of acetaldehyde are less than 1% for most of the country. Several urban areas show decreases in ambient acetaldehyde concentrations ranging from 1 to 10%, and some rural areas associated with new ethanol plants show increases in ambient acetaldehyde concentrations ranging from 1 to 10% with RFS2. In Figure III-4, the annual absolute changes in ambient concentrations of acetaldehyde are generally less than 0.1 µg/m³. As noted above, the results show that the largest increases in ambient acetaldehyde concentrations with RFS2 volumes occur in areas associated with new ethanol plants. This result is due to an increase in emissions of primary acetaldehyde and precursor emissions from ethanol plants not included in the RFS1 mandate reference scenario.

Figure III-3. Acetaldehyde Annual Percent Change in Concentration Between the RFS2 Mandate Reference Case and the RFS2 Control Case in 2022

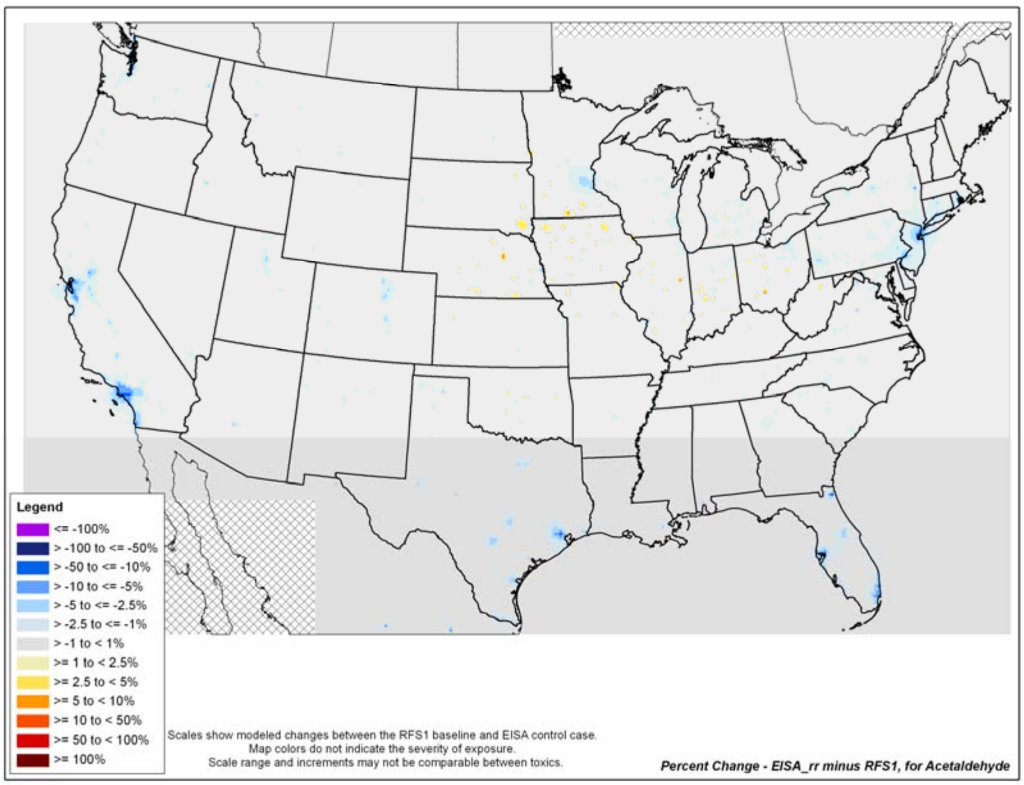
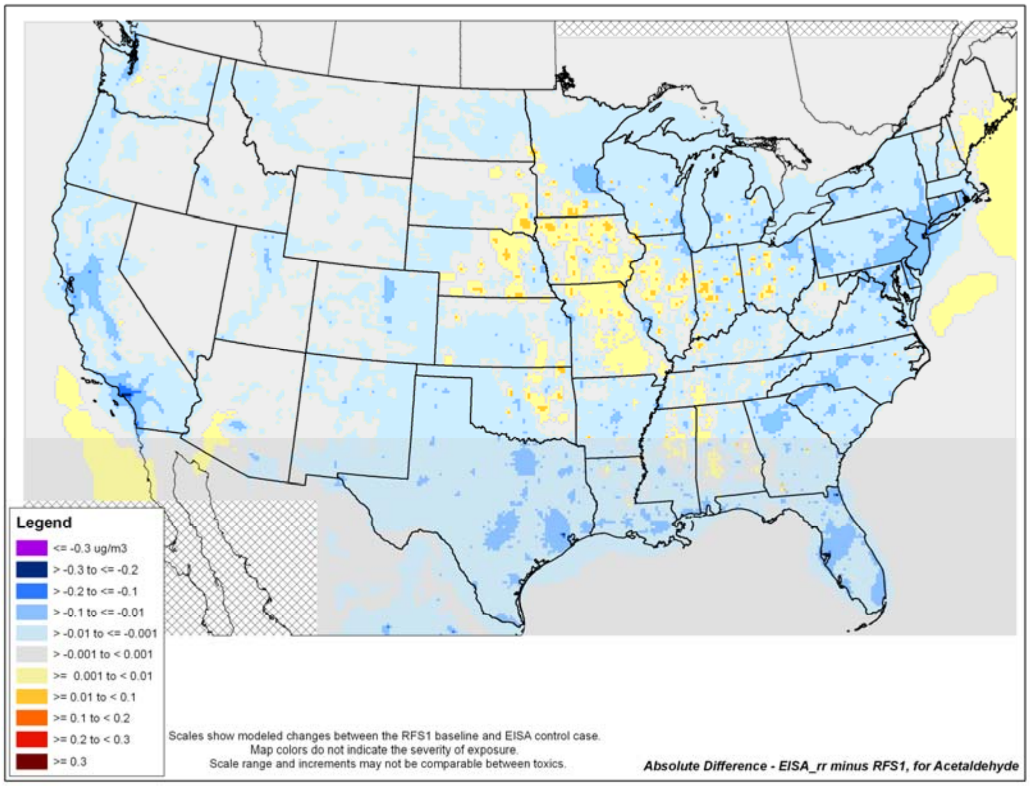


Figure III-4. Acetaldehyde Annual Absolute Changes in Ambient Concentrations Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022 (µg/m³)



Figures III-5 and III-6 show the comparison of the RFS1 mandate reference case with the RFS2 control case for summer and winter shows decreases in ambient acetaldehyde concentrations in urban areas. Decreases are less pronounced in winter when there is less secondary formation of acetaldehyde (Figures III-6). As stated above, the main reason for the decrease in urban areas is reductions in certain acetaldehyde precursors, primarily alkenes (olefins) that are related to the differences in the E0 gasoline headspace speciation profiles used for the control case and the reference cases. While the air quality modeling results presented here and in the RFS2 RIA suggest impacts of increased renewable fuel use on ambient acetaldehyde are not substantial and there may be decreases in urban areas, there is considerable uncertainty associated with these results. Thus, if the reference cases were rerun with revised E0 headspace profiles, some of the observed decreases could become increases. Additional research is underway to address these uncertainties, e.g., measurement of representative fuels to create better headspace speciation profiles (Section 3.4.1.3 in the RFS2 RIA) and improvements in other speciation profiles based on additional results from the EPAct emissions test program.[33]

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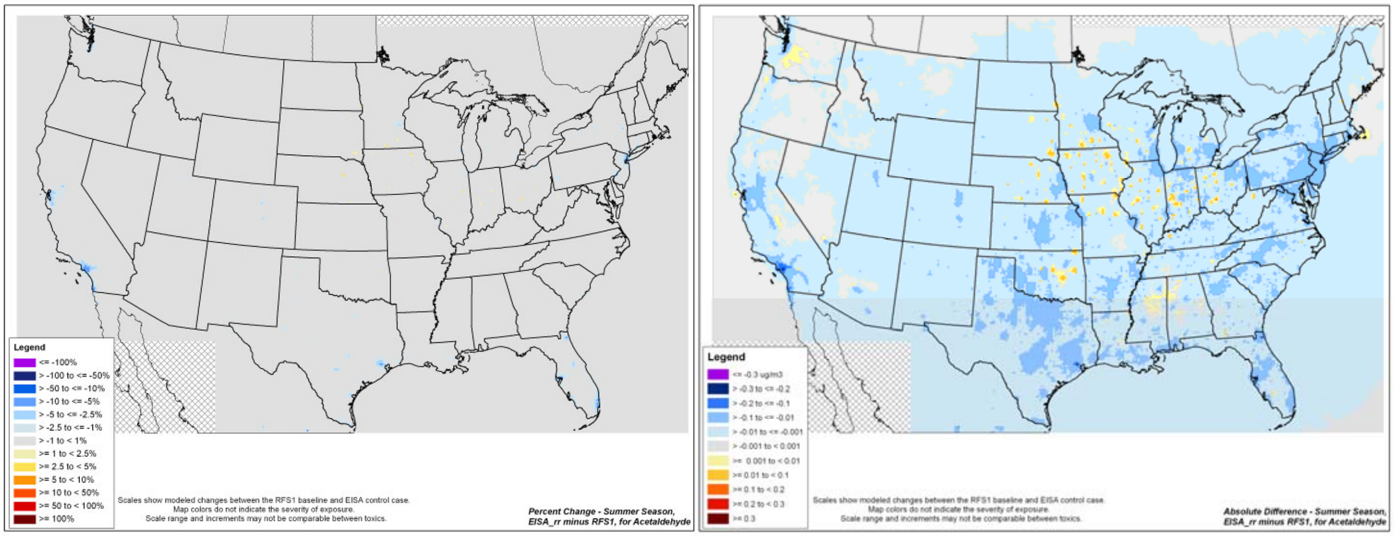
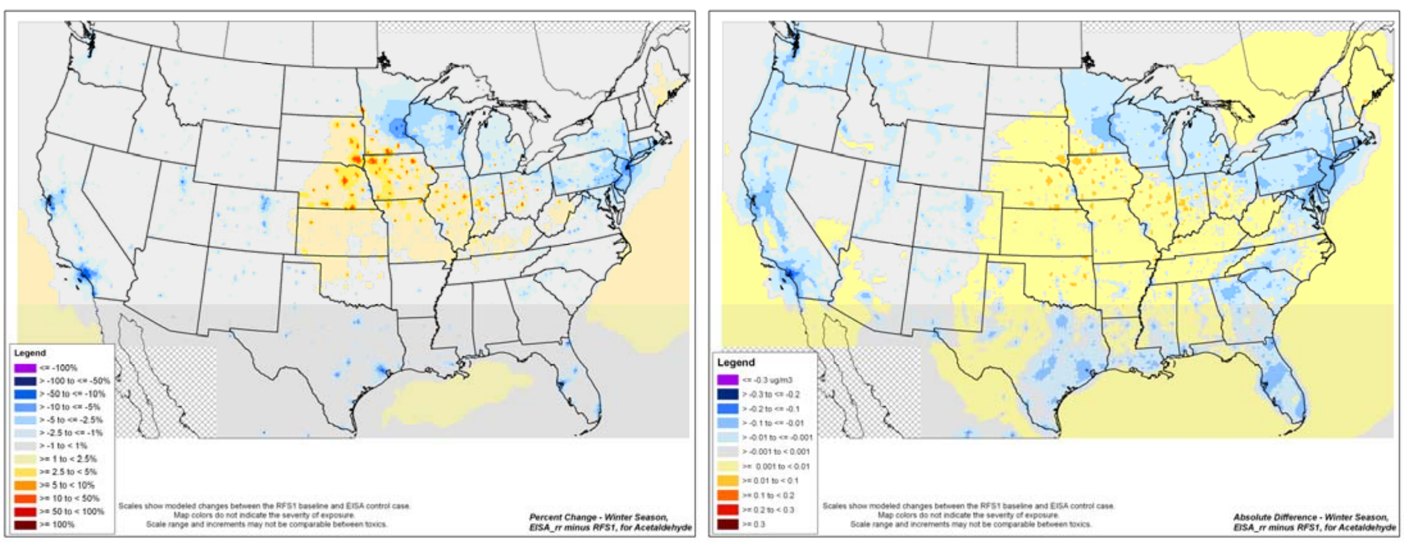
[33]. EPAct Phase I II, and III Testing: Comprehensive Gasoline Light-Duty Exhaust Fuel Effects Test Program to Cover Multiple Fuel Properties. EPA Contract: EPC-07-028EPA. Southwest Research Institute, San Antonio, TX. Phase III of the EPAct emission test program is scheduled for completion in 2010.

Figure III-5. Summer Changes in Acetaldehyde Ambient Concentrations Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022: (a) Percent Changes and (b) Absolute Changes (μg/m³)



a **b**

Figure III-6. Winter Changes in Acetaldehyde Ambient Concentrations Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022: (a) Percent Changes and (b) Absolute Changes (μg/m³)



a **b**

2. Formaldehyde

Our air quality modeling results do not show substantial impacts on ambient concentrations of formaldehyde from the renewable fuel volumes required by this rule. As shown in Figure III-7, most of the U.S. experiences a 1% or less change in ambient formaldehyde concentrations. Decreases in ambient formaldehyde concentrations range between 1 and 5% in a few urban areas. Increases range between 1 and 2.5% in some rural areas associated with new ethanol plants; this result is due to increases in emissions of primary formaldehyde and formaldehyde precursors from the new ethanol plants. Figure III-8 shows that absolute changes in ambient concentrations of formaldehyde are generally less than 0.1 μg/m³.

Figure III-7. Formaldehyde Annual Percent Change in Concentration Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022

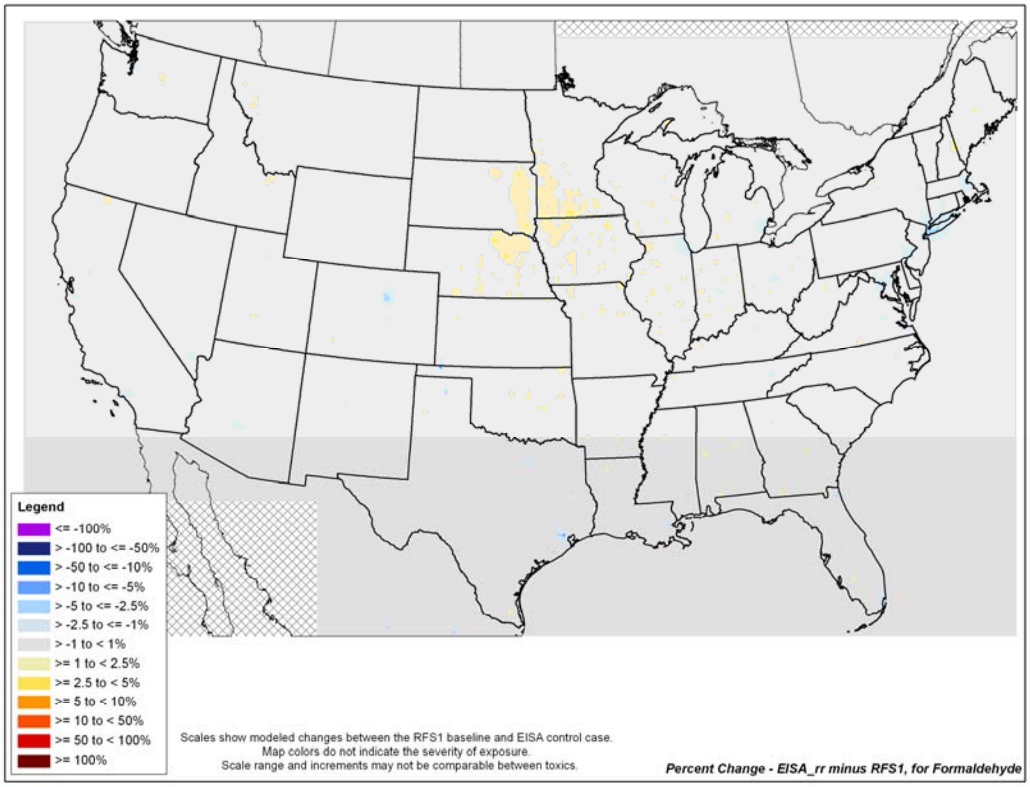
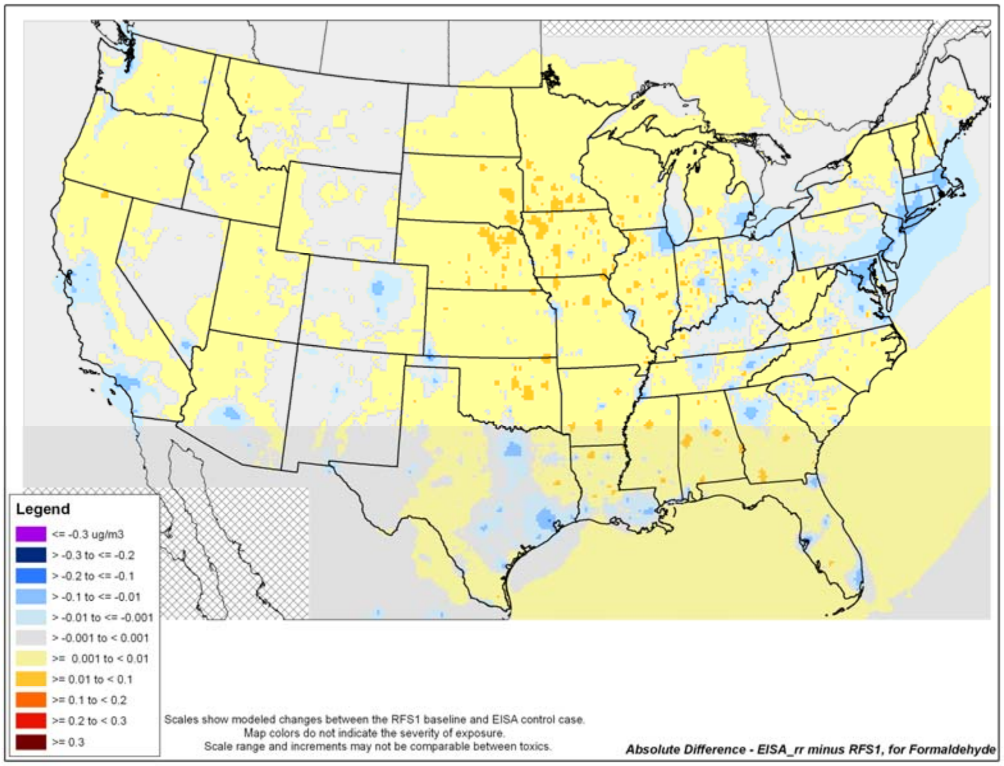


Figure III-8. Formaldehyde Annual Percent Changes in Ambient Concentrations Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022 (μg/m³)



3. Ethanol

Our modeling projects that the renewable fuel volumes required by this rule will lead to significant nationwide increases in ambient ethanol concentrations. Figure III-9 shows increases ranging between 10 to 50% that are seen across most of the country. The largest increases (more than 100%) occur in urban areas with high amounts of onroad emissions and in rural areas associated with new ethanol plants. Absolute increases in ambient ethanol concentrations are above 1.0 ppb in some urban areas (Figure III-10). The location of these localized increases is limited by uncertainties in the placement of the new ethanol plants, as discussed in Section 3.4.1.3 of the RFS2 RIA. It should be noted here that these increases are overestimated because the speciated profile combination used for modeling nonroad emissions was misapplied. While sensitivity analyses suggest that the impact of this error was negligible for other pollutants, it resulted in overestimates of ethanol impacts by more than 10% across much of the modeling domain. Details on the ethanol impacts are discussed in the emissions modeling TSD, found in the docket for this rule (EPA-HQ-OAR-2005-0161).

Figure III-9. Ethanol Annual Percent Changes Change in Concentration Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022

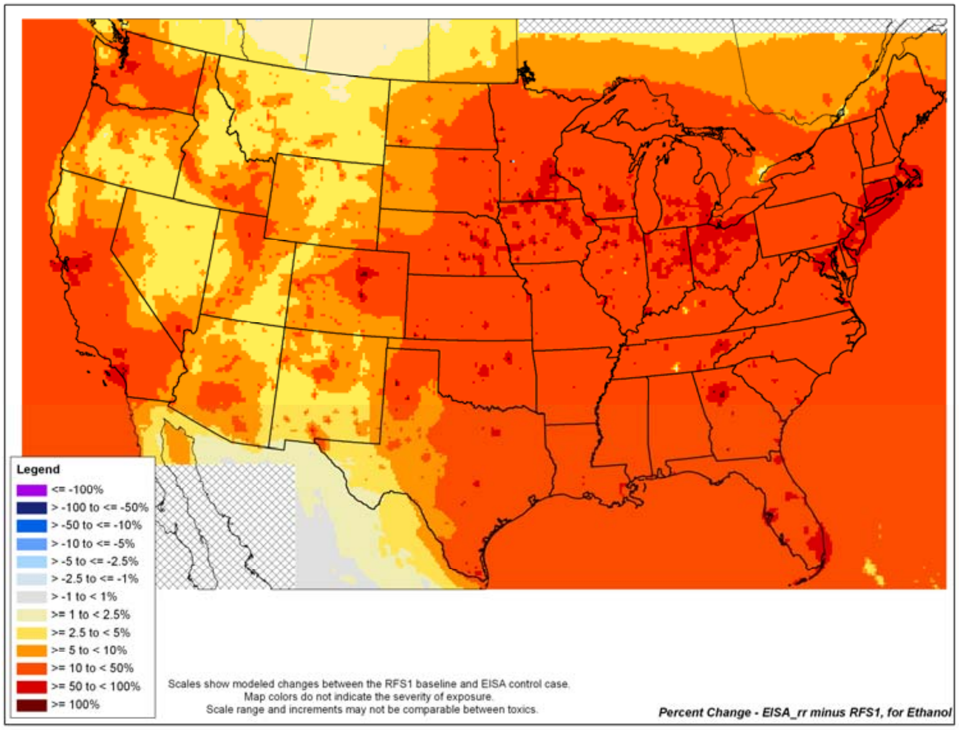
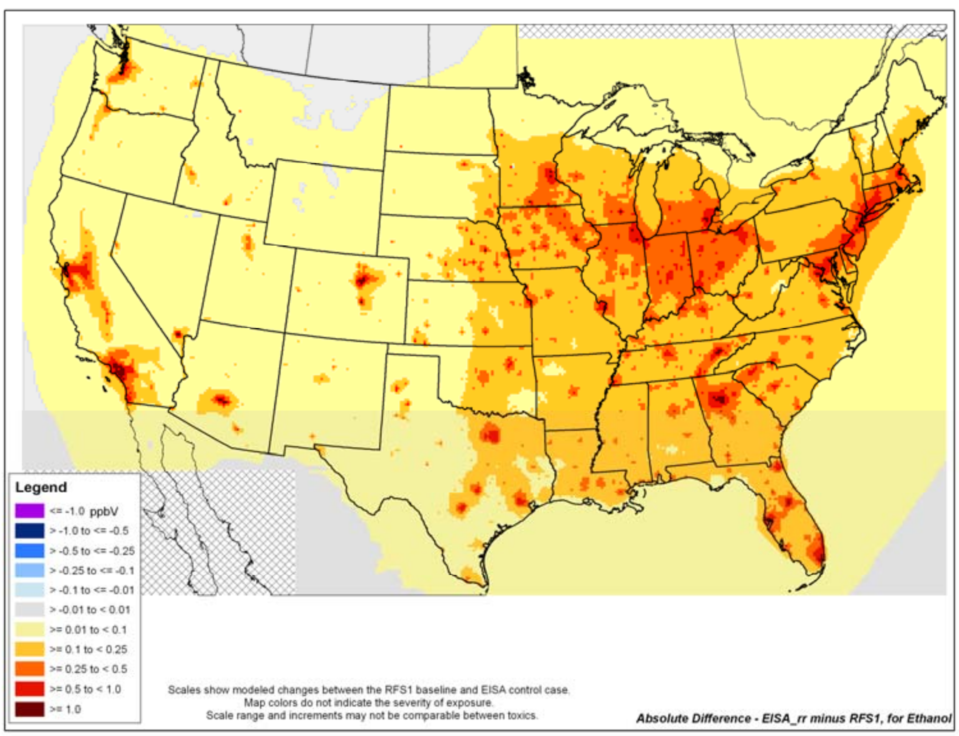


Figure III-10. Ethanol Annual Absolute Changes in Ambient Concentrations Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022 (ppb)



4. Benzene

Our modeling projects that the renewable fuel volumes required by this rule will lead to small nationwide decreases in ambient benzene concentrations. Figure III-11, show decreases in ambient benzene concentrations that range between 1 and 10% across most of the country and can be higher in a few urban areas. Figure III-12 indicates absolute changes in ambient concentrations of benzene show reductions up to 0.2 µg/m³.

Figure III-11. Benzene Annual Percent Change in Concentration Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022

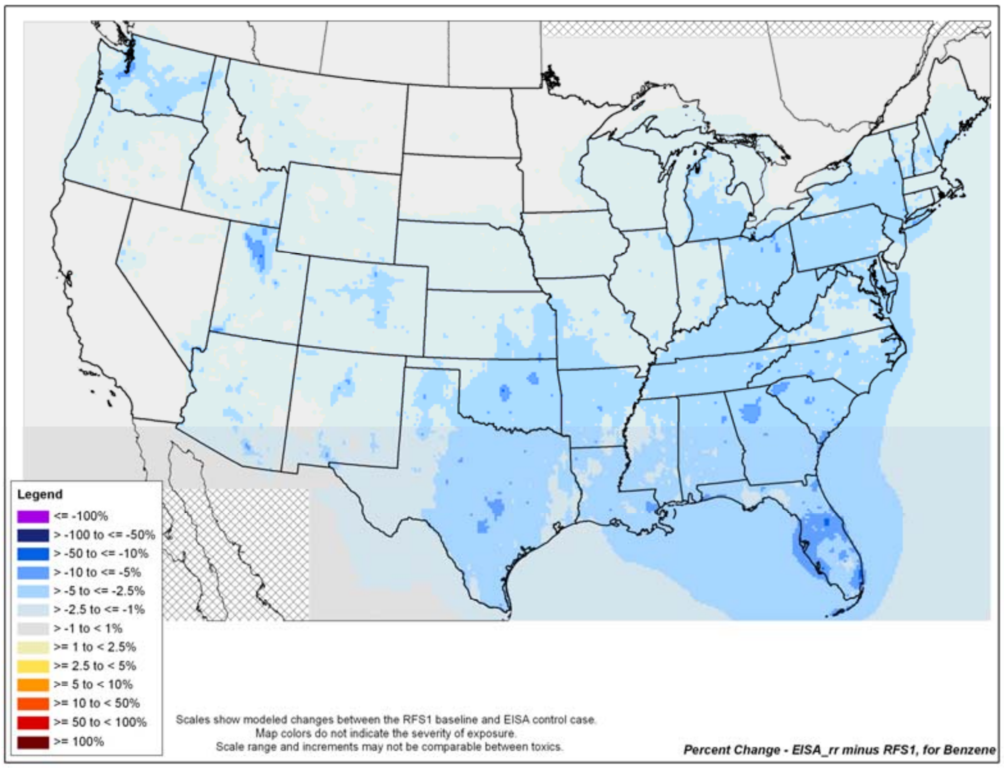
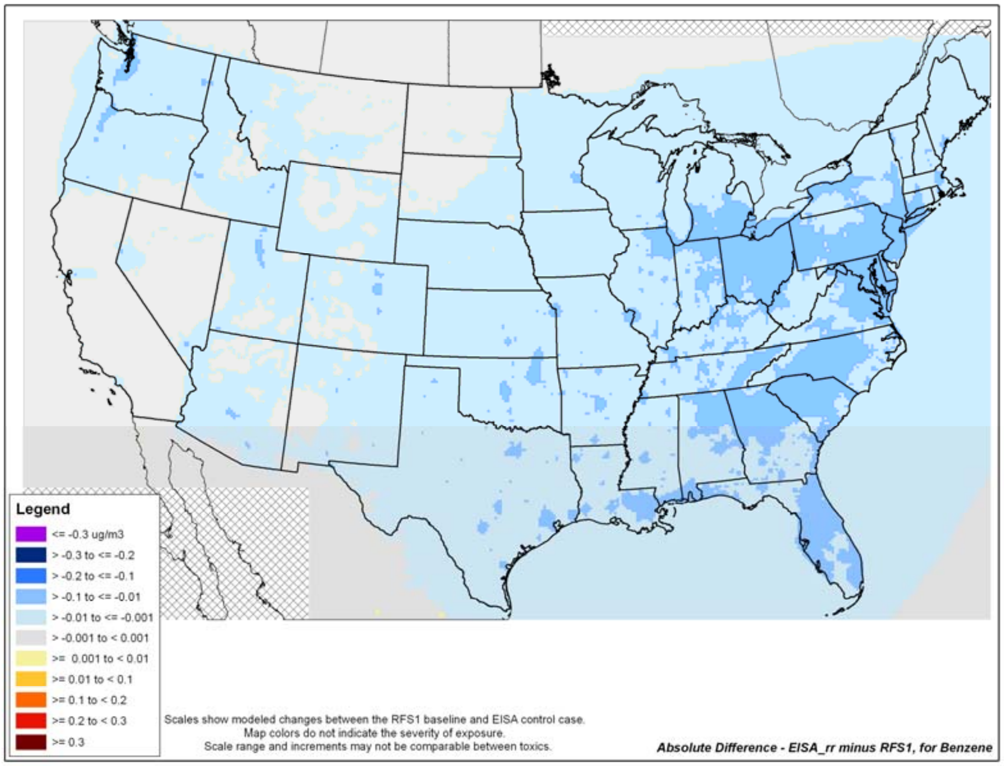


Figure III-12. Benzene Annual Absolute Changes in Ambient Concentrations Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022 (µg/m³)



5. 1,3-Butadiene

The results of our air quality modeling show small increases and decreases in ambient concentrations of 1,3-butadiene in parts of the U.S. as a result of the renewable fuel volumes required this rule. Overall, as seen in Figure III-13, decreases occur in some southern areas of the country and increases occur in some northern areas and areas with high altitudes. Percent changes in 1,3-butadiene concentrations are over 50% in several areas; but the changes in absolute concentrations of ambient 1,3-butadiene are generally less than 0.005 µg/m³ (Figure III-14). Annual increases in ambient concentrations of 1,3-butadiene are driven by wintertime rather than summertime changes (Figures III-15 and III-16). 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.

Figure III-13. 1,3-Butadiene Annual Percent Change in Concentration Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022

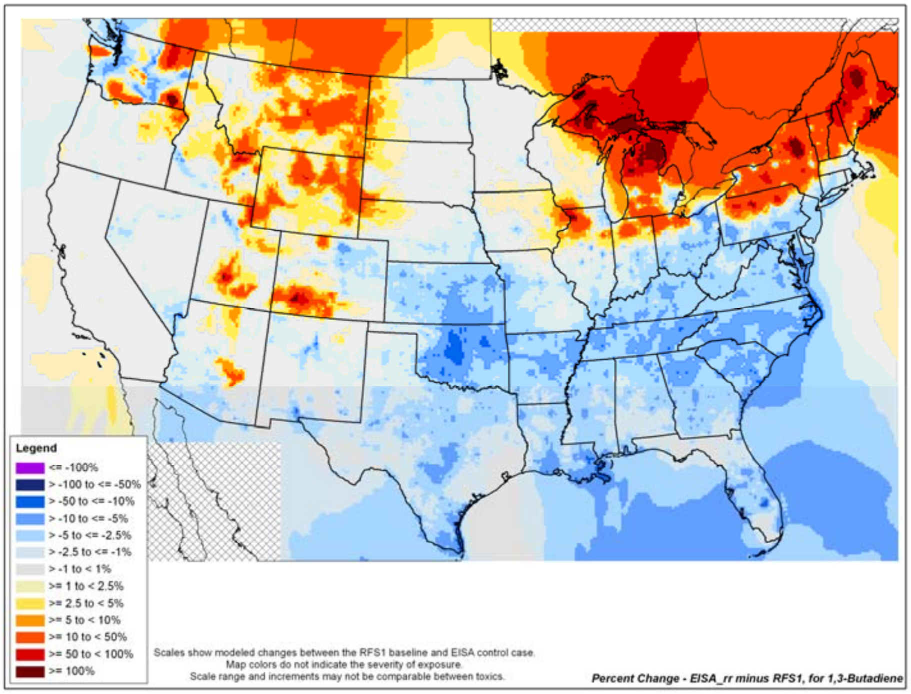


Figure III-14. 1,3-Butadiene Annual Absolute Changes in Ambient Concentrations Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022 (µg/m³)

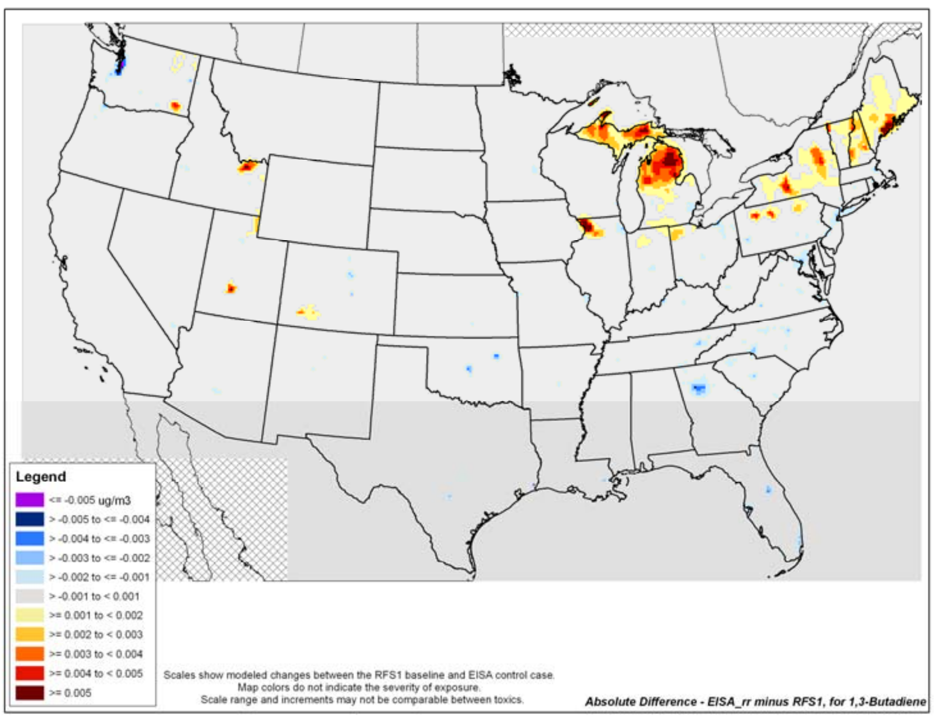
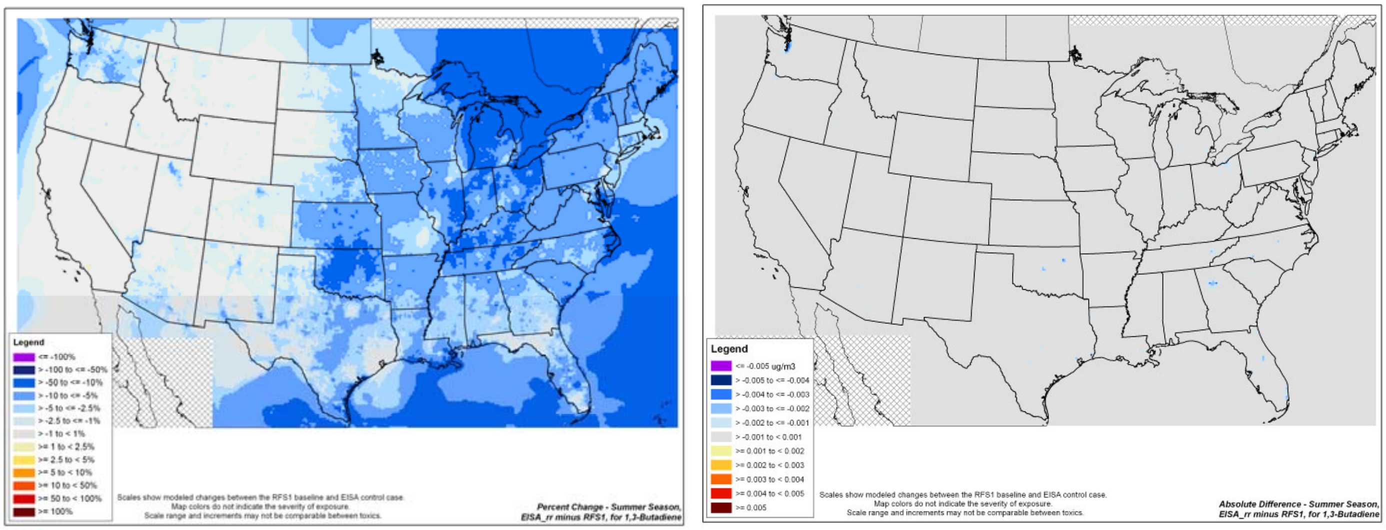
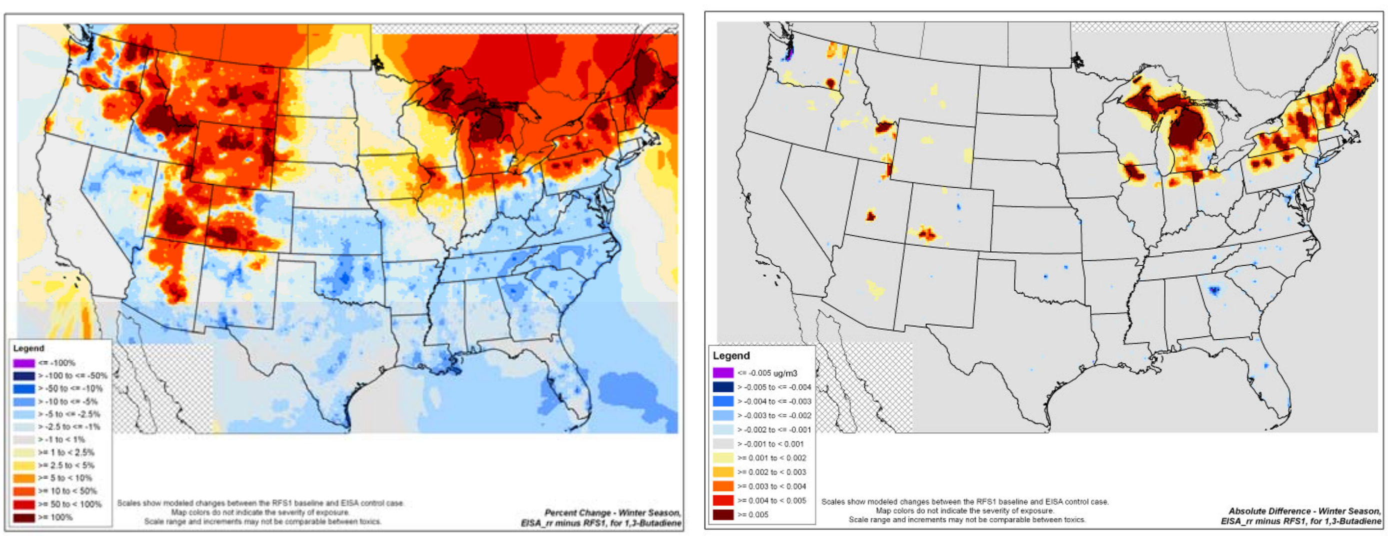


Figure III-15. Summer Changes in 1,3-Butadiene Ambient Concentrations Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022: (a) Percent Changes and (b) Absolute Changes (µg/m³)



a b

Figure III-16. Winter Changes in 1,3-Butadiene Ambient Concentrations Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022: (a) Percent Changes and (b) Absolute Changes (µg/m³)



a b

6. Acrolein

Our air quality modeling shows small regional increases and decreases in ambient concentrations of acrolein as a result of the renewable fuel volumes required by this rule. As shown in Figure III-17, decreases in acrolein concentrations occur in some eastern and southern parts of the U.S. and increases occur in some northern areas and areas associated with new ethanol plants. Figure III-18 indicates that changes in absolute ambient concentrations of acrolein are between ± 0.001 µg/m³ with the exception of the increases associated with new ethanol plants. These increases can be up to and above 0.005 µg/m³ with percent changes above 50% and are due to increases in emissions of acrolein from the new plants. As discussed in Section 3.4.1.3 of the RFS RIA, uncertainties in the placement of new ethanol plants limit the model's projected location of associated emission increases. Ambient acrolein increases in upper Michigan, Canada, the Northeast, and the Rocky Mountain region are driven by wintertime changes (Figures III-19 and III-20), 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 issues in areas of high snowmobile usage seen for 1,3-butadiene, as described above.

Figure III-17. Acrolein Annual Percent Changes Change in Concentration Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022

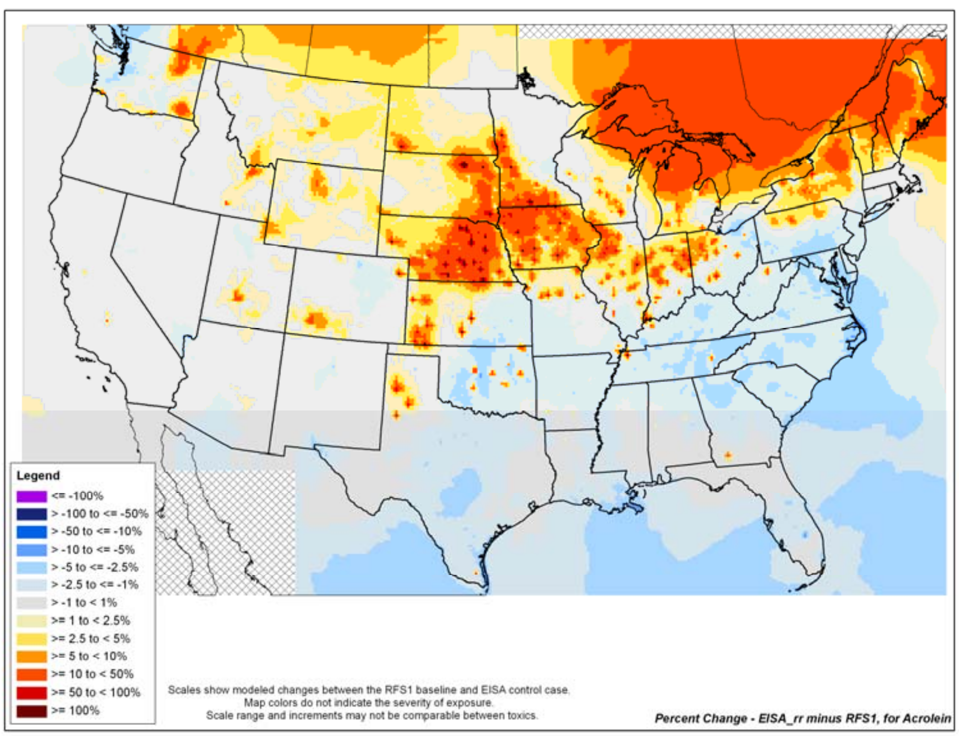


Figure III-18. Acrolein Annual Absolute Changes in Ambient Concentrations Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022 (μg/m³)

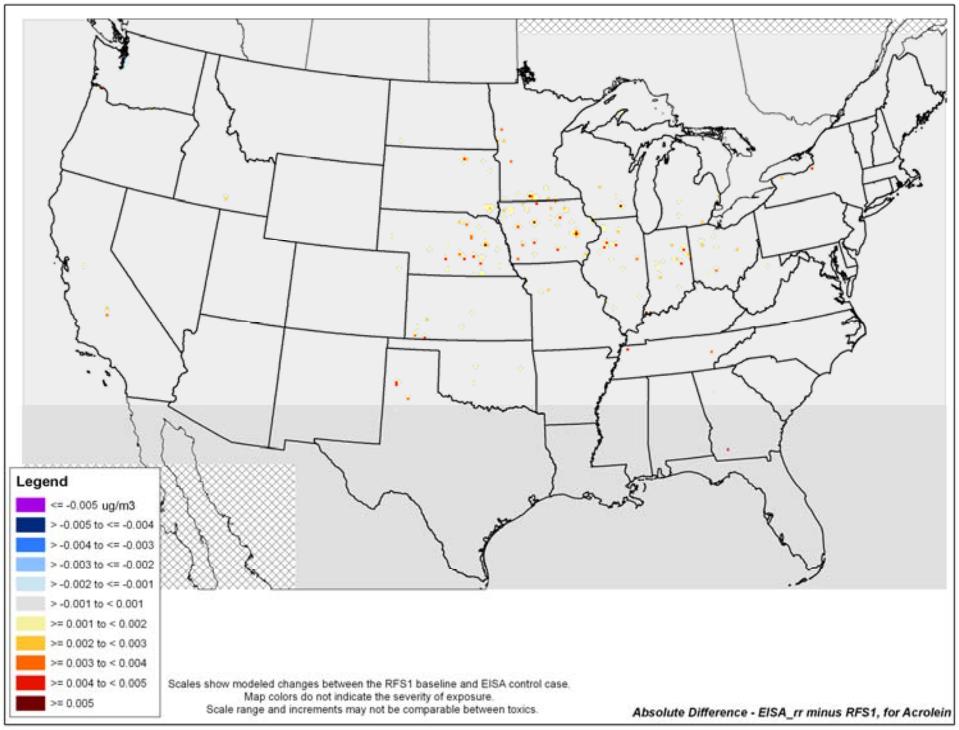
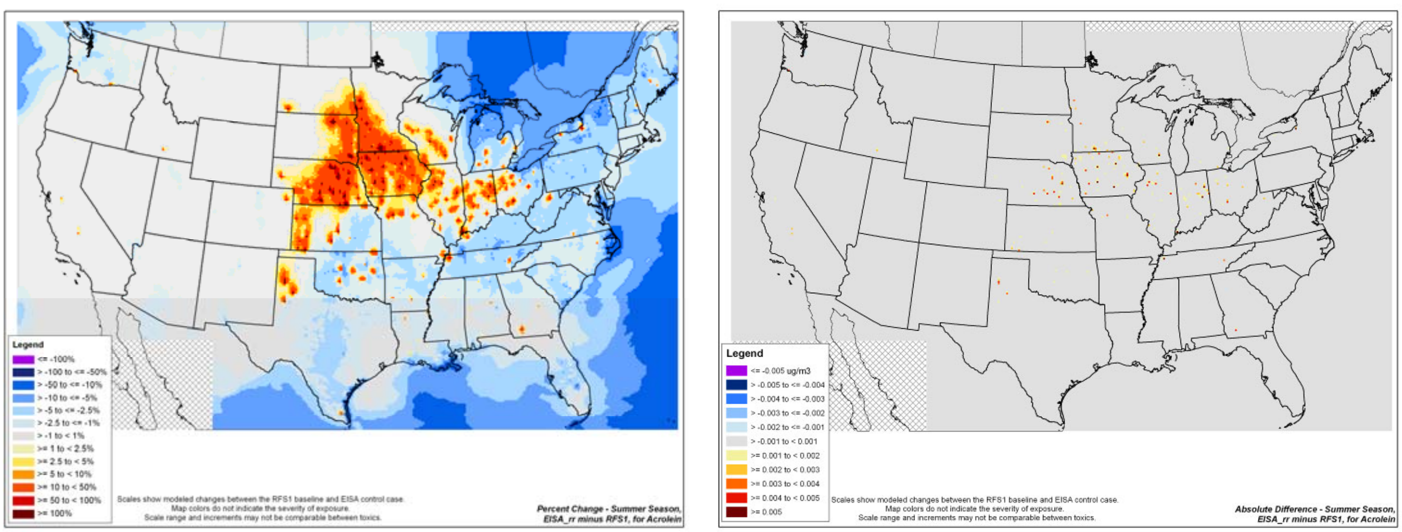
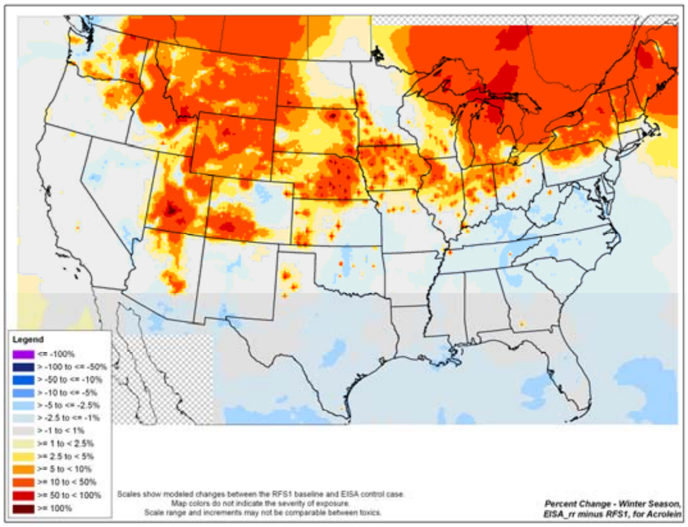


Figure III-19. Summer Changes in Acrolein Ambient Concentrations Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022: (a) Percent Changes and (b) Absolute Changes (μg/m³)

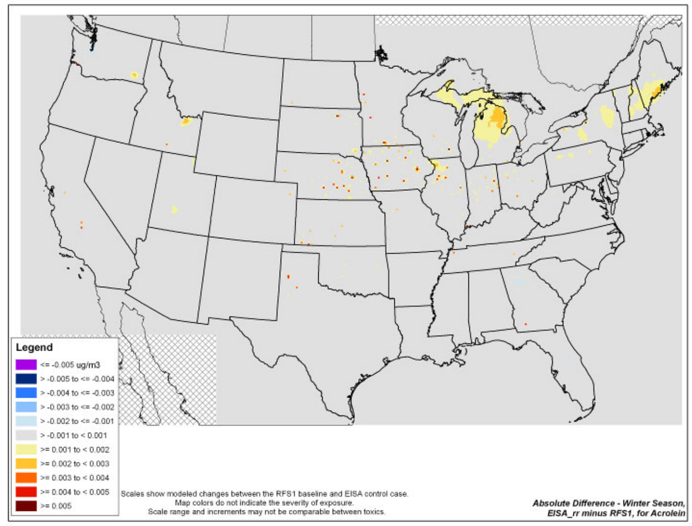


a **b**

Figure III-20. Winter Changes in Acrolein Ambient Concentrations Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022: (a) Percent Changes and (b) Absolute Changes (μg/m³)



a



b

Appendix A: 8-Hour Ozone Design Values for RFS-2 Scenarios (units are ppb)

State Name	County Name	Baseline DV	2022 RFS1 DV	2022 AEO DV	2022 RFS2 DV
Alabama	Baldwin	77.30	63.76	64.20	64.40
Alabama	Clay	74.00	56.43	56.65	56.88
Alabama	Colbert	72.00	50.47	50.77	51.00
Alabama	Elmore	70.70	52.07	52.38	52.63
Alabama	Etowah	71.70	54.66	54.92	55.14
Alabama	Houston	71.00	57.36	57.55	57.82
Alabama	Jefferson	83.70	62.27	62.55	62.73
Alabama	Lawrence	72.00	55.16	55.40	56.02
Alabama	Madison	77.30	59.03	59.39	59.81
Alabama	Mobile	76.70	63.66	64.07	64.24
Alabama	Montgomery	69.30	49.96	50.26	50.51
Alabama	Morgan	77.30	62.50	62.80	64.07
Alabama	Russell	71.30	55.24	55.47	56.26
Alabama	Shelby	85.70	63.20	63.50	63.65
Alabama	Sumter	64.00	53.65	53.78	54.02
Alabama	Talladega	72.00	52.98	53.18	53.40
Alabama	Tuscaloosa	73.30	53.52	53.74	53.93
Arizona	Cochise	71.30	62.66	62.74	62.74
Arizona	Coconino	73.00	64.74	64.77	64.80
Arizona	Gila	80.30	62.93	63.10	63.10
Arizona	La Paz	72.00	62.13	62.17	62.20
Arizona	Maricopa	83.00	68.91	69.06	68.99
Arizona	Pima	76.00	63.54	63.67	63.67
Arizona	Pinal	79.30	62.93	63.10	63.08
Arizona	Yavapai	72.00	62.68	62.74	62.77
Arizona	Yuma	75.00	63.11	63.18	63.19
Arkansas	Crittenden	87.30	66.66	66.84	67.01
Arkansas	Newton	72.70	58.70	58.90	59.46
Arkansas	Polk	75.00	62.86	63.01	63.44
Arkansas	Pulaski	79.70	59.98	60.21	60.65
California	Alameda	78.30	70.90	70.90	70.89
California	Amador	83.00	71.11	71.11	71.21
California	Butte	83.70	69.84	69.85	70.39
California	Calaveras	91.30	80.22	80.23	80.36
California	Colusa	67.00	57.77	57.77	57.96
California	Contra Costa	73.30	69.50	69.50	69.49
California	El Dorado	96.00	79.46	79.47	79.51
California	Fresno	98.30	86.26	86.29	86.37
California	Glenn	65.50	56.24	56.24	56.44
California	Imperial	85.00	74.04	74.05	74.04
California	Inyo	82.30	71.67	71.72	71.76
California	Kern	110.00	98.45	98.49	98.47
California	Kings	85.70	73.42	73.46	73.55
California	Lake	60.70	53.07	53.08	53.16
California	Los Angeles	114.00	103.39	103.39	103.23
California	Madera	79.30	68.48	68.51	68.61

California	Marin	49.70	45.74	45.74	45.69
California	Mariposa	86.30	75.74	75.77	75.88
California	Mendocino	56.70	48.97	48.99	49.03
California	Merced	89.30	76.57	76.63	76.82
California	Monterey	61.00	54.77	54.77	54.80
California	Napa	59.30	52.18	52.20	52.23
California	Nevada	96.30	80.00	80.01	80.06
California	Orange	84.30	81.40	81.35	80.83
California	Placer	94.00	78.00	78.01	78.05
California	Riverside	112.30	108.72	108.66	108.06
California	Sacramento	97.30	81.05	81.05	81.09
California	San Benito	75.00	65.39	65.40	65.46
California	San Bernardino	123.30	121.22	121.17	120.64
California	San Diego	87.70	76.76	76.75	76.66
California	San Francisco	46.00	45.37	45.37	45.34
California	San Joaquin	75.30	67.86	67.91	68.00
California	San Luis Obispo	70.70	62.46	62.48	62.56
California	San Mateo	53.70	51.43	51.42	51.39
California	Santa Barbara	76.00	68.26	68.27	68.27
California	Santa Clara	75.30	65.26	65.26	65.25
California	Santa Cruz	61.30	55.65	55.64	55.60
California	Shasta	79.30	67.23	67.25	67.45
California	Siskiyou	63.50	54.67	54.72	54.93
California	Solano	72.70	63.93	63.94	63.98
California	Sonoma	47.70	41.27	41.28	41.32
California	Stanislaus	84.70	74.98	75.05	75.21
California	Sutter	82.00	70.06	70.06	70.20
California	Tehama	82.70	70.26	70.28	70.58
California	Tulare	103.70	89.07	89.34	89.41
California	Tuolumne	80.00	70.43	70.44	70.56
California	Ventura	89.70	78.66	78.68	78.65
California	Yolo	78.70	67.63	67.64	67.67
Colorado	Adams	69.00	62.90	62.99	62.91
Colorado	Arapahoe	78.70	69.39	69.52	69.51
Colorado	Boulder	77.00	67.41	67.52	67.51
Colorado	Denver	73.00	66.55	66.64	66.56
Colorado	Douglas	83.00	73.88	73.99	73.93
Colorado	El Paso	73.30	64.60	64.71	64.74
Colorado	Jefferson	81.70	74.36	74.44	74.33
Colorado	La Plata	63.70	59.00	59.04	59.06
Colorado	Larimer	76.00	66.07	66.19	66.20
Colorado	Montezuma	72.00	66.07	66.12	66.15
Colorado	Weld	76.70	67.37	67.49	67.52
Connecticut	Fairfield	92.30	78.29	78.30	78.22
Connecticut	Hartford	84.30	67.41	67.50	67.67
Connecticut	Litchfield	87.70	70.05	70.15	70.35
Connecticut	Middlesex	90.30	75.10	75.15	75.24
Connecticut	New Haven	90.30	76.14	76.17	76.16
Connecticut	New London	85.30	70.51	70.54	70.50
Connecticut	Tolland	88.70	71.08	71.16	71.33
Delaware	Kent	80.30	64.51	64.59	64.71
Delaware	New Castle	82.30	68.12	68.18	68.27
Delaware	Sussex	82.70	69.10	69.16	69.25

D.C.	Washington	84.70	68.78	68.87	69.00
Florida	Alachua	72.00	54.16	54.45	54.67
Florida	Baker	68.70	53.65	53.90	54.11
Florida	Bay	78.70	61.49	61.98	62.23
Florida	Brevard	71.30	57.01	57.34	57.38
Florida	Broward	65.00	58.55	58.56	58.63
Florida	Collier	68.30	53.82	54.19	54.28
Florida	Columbia	72.00	56.97	57.20	57.41
Florida	Duval	77.70	62.74	63.05	63.06
Florida	Escambia	82.70	67.06	67.72	67.86
Florida	Highlands	72.30	60.69	60.89	61.15
Florida	Hillsborough	80.70	64.92	65.19	65.16
Florida	Holmes	70.30	56.17	56.39	56.67
Florida	Lake	76.70	59.32	59.76	59.80
Florida	Lee	70.30	55.56	56.30	56.37
Florida	Leon	71.00	53.22	53.59	53.90
Florida	Manatee	77.30	60.49	60.76	60.80
Florida	Marion	73.00	55.13	55.46	55.60
Florida	Miami-Dade	71.30	65.33	65.38	65.39
Florida	Orange	79.30	62.40	62.87	62.89
Florida	Osceola	72.00	53.73	54.18	54.24
Florida	Palm Beach	65.00	57.86	57.97	58.28
Florida	Pasco	76.30	59.87	60.19	60.23
Florida	Pinellas	72.70	56.09	56.39	56.44
Florida	Polk	74.70	57.85	58.14	58.13
Florida	St Lucie	66.50	54.79	55.10	55.25
Florida	Santa Rosa	80.00	65.21	66.25	66.45
Florida	Sarasota	77.30	58.88	59.19	59.24
Florida	Seminole	76.00	59.45	59.90	59.91
Florida	Volusia	68.30	51.74	52.04	52.18
Florida	Wakulla	71.30	57.05	57.40	57.69
Georgia	Bibb	81.00	65.09	65.36	65.55
Georgia	Chatham	68.30	57.09	57.38	57.71
Georgia	Chattooga	75.00	55.41	55.70	55.92
Georgia	Clarke	80.70	56.49	56.90	57.15
Georgia	Cobb	82.70	59.53	59.97	60.18
Georgia	Columbia	73.00	56.28	56.50	57.48
Georgia	Coweta	82.00	64.12	64.36	64.57
Georgia	Dawson	76.30	52.93	53.38	53.62
Georgia	De Kalb	88.70	70.62	70.88	71.01
Georgia	Douglas	87.30	63.96	64.29	64.51
Georgia	Fayette	85.70	66.46	66.73	66.90
Georgia	Fulton	91.70	73.01	73.28	73.42
Georgia	Glynn	67.00	52.25	52.53	53.63
Georgia	Gwinnett	88.70	65.80	66.20	66.38
Georgia	Henry	89.70	66.91	67.26	67.45
Georgia	Murray	78.00	60.28	60.54	60.88
Georgia	Muscogee	75.70	56.81	57.09	58.02
Georgia	Paulding	80.30	56.54	56.86	57.06
Georgia	Richmond	80.30	60.76	61.00	62.18
Georgia	Rockdale	90.00	65.63	65.99	66.18
Georgia	Sumter	72.30	57.41	57.61	57.88
Idaho	Ada	76.00	69.69	69.81	69.80

Idaho	Canyon	66.00	59.37	59.53	59.54
Idaho	Elmore	63.00	57.30	57.42	57.44
Idaho	Kootenai	67.00	57.90	58.14	58.20
Illinois	Adams	70.00	58.60	58.74	59.40
Illinois	Champaign	68.30	56.65	56.79	57.92
Illinois	Clark	66.00	54.50	54.65	55.15
Illinois	Cook	77.70	69.45	69.59	69.84
Illinois	Du Page	69.00	62.49	62.60	62.89
Illinois	Effingham	70.00	57.72	57.88	58.43
Illinois	Hamilton	73.00	58.96	59.13	59.74
Illinois	Jersey	78.70	60.58	60.69	61.37
Illinois	Kane	74.30	63.36	63.48	63.87
Illinois	Lake	78.00	69.37	69.50	69.76
Illinois	McHenry	73.30	60.54	60.68	61.07
Illinois	McLean	73.00	59.13	59.32	60.09
Illinois	Macon	71.30	58.95	59.09	59.82
Illinois	Macoupin	73.00	55.79	55.89	56.46
Illinois	Madison	83.00	67.06	67.18	67.76
Illinois	Peoria	72.70	61.99	62.11	62.76
Illinois	Randolph	72.00	60.39	60.54	61.28
Illinois	Rock Island	65.30	55.10	55.22	55.90
Illinois	St Clair	81.70	66.77	66.90	67.49
Illinois	Sangamon	70.00	55.21	55.34	55.91
Illinois	Will	71.70	60.94	61.07	61.47
Illinois	Winnebago	69.00	57.39	57.55	58.31
Indiana	Allen	79.30	63.96	64.25	65.09
Indiana	Boone	79.70	63.90	64.06	64.52
Indiana	Carroll	74.00	60.27	60.47	61.28
Indiana	Clark	80.30	63.04	63.19	63.33
Indiana	Delaware	76.30	60.84	61.15	61.86
Indiana	Elkhart	79.00	64.27	64.54	65.34
Indiana	Floyd	77.70	63.61	63.75	63.84
Indiana	Greene	78.30	62.41	62.58	63.52
Indiana	Hamilton	82.70	65.75	65.95	66.52
Indiana	Hancock	78.00	62.44	62.63	63.17
Indiana	Hendricks	75.30	61.36	61.51	61.85
Indiana	Huntington	75.00	61.28	61.55	62.17
Indiana	Jackson	74.70	60.27	60.42	61.17
Indiana	Johnson	76.70	63.38	63.53	63.98
Indiana	Lake	81.00	72.55	72.76	73.17
Indiana	La Porte	78.50	67.43	67.61	68.08
Indiana	Madison	76.70	60.45	60.66	61.36
Indiana	Marion	78.70	64.00	64.16	64.66
Indiana	Morgan	77.00	63.02	63.21	63.81
Indiana	Perry	81.00	63.99	64.18	64.53
Indiana	Porter	78.30	69.47	69.70	70.09
Indiana	Posey	71.70	57.31	57.46	58.66
Indiana	St Joseph	79.30	64.84	65.09	65.83
Indiana	Shelby	77.30	64.89	65.06	65.69
Indiana	Vanderburgh	77.30	62.01	62.16	63.11
Indiana	Vigo	74.00	61.42	61.67	62.23
Indiana	Warrick	77.70	63.17	63.32	63.80
Iowa	Bremer	66.30	56.49	56.71	57.58

Iowa	Clinton	71.30	60.46	60.61	61.37
Iowa	Harrison	74.70	63.57	63.71	64.42
Iowa	Linn	68.30	58.14	58.60	59.40
Iowa	Montgomery	65.70	55.56	55.71	56.26
Iowa	Palo Alto	61.00	52.63	52.80	53.94
Iowa	Polk	63.00	51.30	51.45	52.21
Iowa	Scott	72.00	60.00	60.15	60.88
Iowa	Story	61.00	49.97	50.12	50.99
Iowa	Van Buren	69.00	58.37	58.53	59.31
Iowa	Warren	64.50	52.00	52.19	53.03
Kansas	Douglas	73.00	59.93	60.12	60.58
Kansas	Johnson	75.30	62.36	62.53	62.96
Kansas	Leavenworth	75.00	63.88	64.02	64.28
Kansas	Linn	73.30	59.50	59.72	60.28
Kansas	Sedgwick	71.30	59.33	59.51	60.09
Kansas	Sumner	71.70	59.82	60.01	60.51
Kansas	Trego	70.70	63.18	63.33	63.58
Kansas	Wyandotte	75.30	64.35	64.48	64.68
Kentucky	Bell	71.70	53.68	53.94	54.25
Kentucky	Boone	75.70	60.67	60.79	60.97
Kentucky	Boyd	77.30	63.49	63.61	63.74
Kentucky	Bullitt	74.00	59.93	60.07	60.21
Kentucky	Campbell	75.00	62.36	62.52	62.78
Kentucky	Carter	71.00	56.67	56.80	56.96
Kentucky	Christian	78.00	60.18	60.35	60.57
Kentucky	Daviess	75.70	61.46	61.63	61.98
Kentucky	Edmonson	73.70	59.28	59.44	59.79
Kentucky	Fayette	70.30	57.37	57.53	57.72
Kentucky	Greenup	76.70	63.26	63.38	63.53
Kentucky	Hancock	74.00	58.82	58.98	59.29
Kentucky	Hardin	74.70	60.02	60.16	60.39
Kentucky	Henderson	75.30	61.35	61.49	61.94
Kentucky	Jefferson	78.30	64.51	64.65	64.77
Kentucky	Jessamine	73.30	59.35	59.50	59.75
Kentucky	Kenton	78.70	63.53	63.72	64.01
Kentucky	Livingston	73.70	61.16	61.38	61.66
Kentucky	McCracken	73.30	61.71	61.89	62.20
Kentucky	McLean	73.00	58.86	59.01	59.46
Kentucky	Oldham	83.00	63.73	63.89	64.08
Kentucky	Perry	72.30	58.50	58.66	58.97
Kentucky	Pike	66.70	53.76	53.91	54.13
Kentucky	Pulaski	70.30	58.12	58.26	58.48
Kentucky	Simpson	75.70	58.21	58.36	58.76
Kentucky	Trigg	70.00	55.17	56.03	56.36
Kentucky	Warren	72.00	58.85	58.98	59.24
Louisiana	Ascension	82.00	72.39	72.47	72.71
Louisiana	Beauregard	75.00	67.63	67.70	67.92
Louisiana	Bossier	78.00	62.91	63.20	63.40
Louisiana	Caddo	79.00	63.73	63.99	64.31
Louisiana	Calcasieu	82.00	72.48	72.63	72.96
Louisiana	East Baton Rouge	92.00	81.32	81.44	81.71
Louisiana	Grant	73.00	61.93	62.09	62.47
Louisiana	Iberville	85.00	75.62	75.70	75.87

Louisiana	Jefferson	83.00	72.83	73.15	73.25
Louisiana	Lafayette	82.00	70.27	70.41	70.81
Louisiana	Lafourche	79.30	70.35	70.47	70.58
Louisiana	Livingston	78.30	69.46	69.54	69.76
Louisiana	Orleans	70.00	61.82	62.06	62.13
Louisiana	Ouachita	75.30	62.20	62.44	62.68
Louisiana	Pointe Coupee	83.70	74.74	74.80	75.10
Louisiana	St Bernard	78.00	67.71	67.96	68.09
Louisiana	St Charles	77.30	67.58	67.93	68.01
Louisiana	St James	76.30	67.78	67.88	68.00
Louisiana	St John The Baptis	79.00	69.83	70.00	70.13
Louisiana	St Mary	76.00	66.29	66.42	66.59
Louisiana	West Baton Rouge	84.30	74.24	74.34	74.60
Maine	Cumberland	72.00	58.25	58.28	58.36
Maine	Hancock	82.00	67.38	67.53	67.68
Maine	Kennebec	69.70	56.68	56.75	56.85
Maine	Knox	75.30	61.11	61.18	61.29
Maine	Oxford	61.00	51.06	51.18	51.48
Maine	Penobscot	67.00	56.74	56.83	56.96
Maine	Sagadahoc	68.50	55.72	55.77	55.85
Maine	York	74.00	60.68	60.74	60.80
Maryland	Anne Arundel	89.70	69.53	69.64	69.80
Maryland	Baltimore	85.30	73.83	74.01	74.01
Maryland	Calvert	81.00	63.80	64.07	64.20
Maryland	Carroll	83.30	64.12	64.22	64.37
Maryland	Cecil	90.70	70.33	70.46	70.61
Maryland	Charles	86.00	65.14	65.28	65.49
Maryland	Frederick	80.30	62.78	62.85	62.99
Maryland	Garrett	75.50	60.08	60.25	60.57
Maryland	Harford	92.70	78.87	79.07	79.10
Maryland	Kent	82.00	63.70	63.79	63.91
Maryland	Montgomery	83.00	66.14	66.23	66.33
Maryland	Prince Georges	91.00	71.16	71.27	71.44
Maryland	Washington	78.30	62.37	62.48	62.67
Massachusetts	Barnstable	84.70	69.99	70.07	69.91
Massachusetts	Berkshire	79.70	64.49	64.64	64.92
Massachusetts	Bristol	82.70	69.53	69.58	69.63
Massachusetts	Dukes	83.00	71.26	71.30	71.34
Massachusetts	Essex	83.30	71.29	71.39	71.40
Massachusetts	Hampden	87.30	70.03	70.12	70.29
Massachusetts	Hampshire	85.00	67.67	67.77	67.96
Massachusetts	Middlesex	79.00	63.92	64.01	64.13
Massachusetts	Norfolk	84.70	68.40	68.56	68.42
Massachusetts	Suffolk	80.30	65.30	65.40	65.40
Massachusetts	Worcester	80.00	62.82	62.92	63.15
Michigan	Allegan	90.00	75.26	75.49	76.18
Michigan	Benzie	81.70	68.76	68.99	69.68
Michigan	Berrien	82.30	69.63	69.83	70.33
Michigan	Cass	80.70	66.37	66.63	67.42
Michigan	Clinton	75.70	60.43	60.67	61.16
Michigan	Genesee	79.30	64.31	64.56	65.07
Michigan	Huron	75.70	63.63	63.84	64.30
Michigan	Ingham	76.00	61.87	62.12	62.72

Michigan	Kalamazoo	75.30	61.55	61.83	62.79
Michigan	Kent	81.00	65.22	65.50	66.13
Michigan	Leelanau	75.70	63.85	64.33	65.03
Michigan	Lenawee	78.70	64.93	65.19	65.64
Michigan	Macomb	86.00	70.95	71.30	71.69
Michigan	Mason	79.70	65.67	65.86	66.57
Michigan	Missaukee	73.70	60.43	60.67	61.32
Michigan	Muskegon	85.00	71.44	71.61	72.28
Michigan	Oakland	78.00	66.14	66.41	66.84
Michigan	Ottawa	81.70	67.25	67.45	68.07
Michigan	St Clair	82.30	67.67	67.93	68.51
Michigan	Schoolcraft	79.30	65.40	65.53	66.22
Michigan	Washtenaw	78.30	66.16	66.38	66.68
Michigan	Wayne	82.00	69.27	69.51	69.86
Minnesota	Anoka	67.70	63.38	63.50	64.14
Minnesota	St Louis	65.00	55.52	55.67	56.34
Mississippi	Adams	74.70	64.38	64.50	64.82
Mississippi	Bolivar	74.30	60.09	60.28	60.72
Mississippi	De Soto	82.70	65.16	65.32	65.66
Mississippi	Hancock	79.00	66.94	67.23	67.38
Mississippi	Harrison	83.00	68.47	68.70	68.87
Mississippi	Hinds	71.30	51.08	51.42	51.61
Mississippi	Jackson	80.30	67.43	67.67	67.81
Mississippi	Lauderdale	74.30	58.34	58.56	58.91
Mississippi	Lee	73.70	54.53	54.83	55.11
Missouri	Cass	74.70	61.11	61.28	61.72
Missouri	Cedar	75.70	62.38	62.56	63.26
Missouri	Clay	84.30	70.48	70.64	70.89
Missouri	Clinton	83.00	68.47	68.64	68.90
Missouri	Greene	73.00	59.73	59.85	60.34
Missouri	Jefferson	82.30	69.75	69.91	70.74
Missouri	Lincoln	87.00	71.24	71.40	72.26
Missouri	Monroe	71.70	58.85	59.00	59.62
Missouri	Perry	77.50	63.18	63.34	63.85
Missouri	Platte	77.00	65.23	65.37	65.57
Missouri	St Charles	87.00	68.85	68.98	69.82
Missouri	Ste Genevieve	79.70	66.50	66.63	67.22
Missouri	St Louis	88.00	73.02	73.18	74.19
Missouri	St Louis City	84.00	69.19	69.32	69.98
Montana	Yellowstone	59.00	54.67	54.70	54.76
Nebraska	Douglas	68.70	59.73	59.84	60.48
Nebraska	Lancaster	56.00	46.74	46.85	47.41
Nevada	Clark	83.70	74.23	74.33	74.20
Nevada	Washoe	70.70	60.56	60.62	60.67
Nevada	White Pine	72.30	64.93	64.97	65.01
Nevada	Carson City	65.00	55.81	55.82	55.87
New Hampshire	Belknap	71.30	56.01	55.64	55.73
New Hampshire	Cheshire	70.70	56.59	56.65	56.78
New Hampshire	Coos	77.00	63.97	64.14	64.43
New Hampshire	Grafton	67.00	55.17	55.27	55.44
New Hampshire	Hillsborough	78.70	63.46	63.53	63.64
New Hampshire	Merrimack	71.70	56.02	56.07	56.16
New Hampshire	Rockingham	75.00	61.50	61.56	61.62

New Hampshire	Sullivan	70.00	57.34	57.43	57.60
New Jersey	Atlantic	79.30	65.49	65.53	65.60
New Jersey	Bergen	86.00	74.46	74.48	74.46
New Jersey	Camden	89.30	72.65	72.73	72.88
New Jersey	Cumberland	83.30	66.32	66.39	66.54
New Jersey	Gloucester	87.00	71.61	71.68	71.78
New Jersey	Hudson	85.70	73.50	73.49	73.47
New Jersey	Hunterdon	89.00	70.25	70.37	70.59
New Jersey	Mercer	88.00	72.37	72.46	72.61
New Jersey	Middlesex	88.30	71.71	71.78	71.91
New Jersey	Monmouth	87.30	74.07	74.07	74.07
New Jersey	Morris	83.30	67.01	67.10	67.26
New Jersey	Ocean	93.00	75.75	75.80	75.92
New Jersey	Passaic	81.00	67.07	67.13	67.24
New Mexico	Bernalillo	73.70	61.89	62.02	62.04
New Mexico	Dona Ana	75.30	68.52	68.58	68.60
New Mexico	Eddy	69.00	64.38	64.44	64.52
New Mexico	Grant	66.00	59.96	60.01	60.03
New Mexico	Lea	69.50	65.30	65.34	65.40
New Mexico	Sandoval	73.30	61.55	61.68	61.70
New Mexico	San Juan	71.30	67.01	67.05	67.06
New York	Albany	73.70	59.59	59.72	59.97
New York	Bronx	74.70	67.68	67.65	67.53
New York	Chautauqua	86.70	73.83	74.02	74.51
New York	Chemung	68.70	57.63	57.75	58.04
New York	Dutchess	75.70	61.25	61.34	61.48
New York	Erie	85.00	70.86	71.07	71.58
New York	Essex	77.00	64.66	64.81	65.23
New York	Hamilton	71.70	60.64	60.77	61.12
New York	Herkimer	68.30	58.08	58.21	58.54
New York	Jefferson	78.00	64.47	64.72	64.90
New York	Madison	72.00	59.75	59.87	60.21
New York	Monroe	75.00	62.57	62.81	63.03
New York	Niagara	82.70	71.53	71.75	71.96
New York	Oneida	68.30	57.13	57.30	57.68
New York	Onondaga	73.70	62.92	63.10	63.43
New York	Orange	82.00	66.60	66.67	66.78
New York	Oswego	78.00	66.62	66.83	67.11
New York	Putnam	84.30	69.71	69.76	69.84
New York	Queens	80.00	69.57	69.56	69.54
New York	Rensselaer	77.30	62.29	62.46	62.73
New York	Richmond	88.30	75.53	75.54	75.54
New York	Saratoga	79.70	64.39	64.56	64.85
New York	Schenectady	70.00	56.91	57.05	57.34
New York	Suffolk	90.30	81.86	81.83	81.77
New York	Ulster	77.30	62.86	62.98	63.25
New York	Wayne	68.00	57.22	57.42	57.64
New York	Westchester	87.70	76.61	76.60	76.49
North Carolina	Alexander	77.00	57.64	57.72	58.15
North Carolina	Avery	70.00	56.78	56.89	57.23
North Carolina	Buncombe	74.00	59.31	59.43	59.81
North Carolina	Caldwell	74.30	54.93	55.00	55.52
North Carolina	Caswell	76.30	58.13	58.22	58.74

North Carolina	Chatham	73.30	56.71	56.79	57.21
North Carolina	Cumberland	81.70	61.89	61.96	63.08
North Carolina	Davie	81.30	61.84	61.93	62.45
North Carolina	Durham	77.00	57.26	57.33	57.88
North Carolina	Edgecombe	77.00	58.76	58.84	59.31
North Carolina	Forsyth	80.00	62.34	62.43	63.18
North Carolina	Franklin	78.70	60.04	60.12	60.63
North Carolina	Graham	78.30	61.41	61.64	61.97
North Carolina	Granville	82.00	62.59	62.69	63.34
North Carolina	Guilford	82.00	61.78	61.88	62.55
North Carolina	Haywood	78.30	63.42	63.59	63.90
North Carolina	Jackson	76.00	60.49	60.65	61.01
North Carolina	Johnston	77.30	57.23	57.29	57.82
North Carolina	Lenoir	75.30	60.34	60.41	60.80
North Carolina	Lincoln	81.00	60.65	60.73	61.21
North Carolina	Martin	75.00	62.23	62.32	62.66
North Carolina	Mecklenburg	89.30	68.17	68.22	68.54
North Carolina	New Hanover	72.30	61.79	61.85	62.20
North Carolina	Person	77.30	59.81	59.90	60.55
North Carolina	Pitt	76.30	57.93	58.02	58.46
North Carolina	Rockingham	77.00	57.75	57.83	58.42
North Carolina	Rowan	86.70	65.70	65.78	66.31
North Carolina	Swain	66.30	52.49	52.64	52.96
North Carolina	Union	79.30	58.52	58.58	58.98
North Carolina	Wake	80.30	60.77	60.84	61.34
North Carolina	Yancey	76.00	61.17	61.33	61.67
North Dakota	Billings	61.50	56.57	56.73	56.83
North Dakota	Burke	57.50	52.72	52.78	52.96
North Dakota	Cass	60.00	51.18	51.52	52.66
North Dakota	McKenzie	61.30	56.46	56.59	56.71
North Dakota	Oliver	57.70	52.93	52.97	53.04
Ohio	Allen	78.70	65.15	65.43	66.13
Ohio	Ashtabula	89.00	75.07	75.37	75.86
Ohio	Butler	83.30	67.28	67.44	67.76
Ohio	Clark	81.00	64.18	64.37	64.80
Ohio	Clermont	81.00	65.88	66.04	66.39
Ohio	Clinton	82.30	63.54	63.71	63.93
Ohio	Cuyahoga	79.70	67.43	67.31	67.51
Ohio	Delaware	78.30	63.38	63.60	64.21
Ohio	Franklin	86.30	69.39	69.66	70.35
Ohio	Geauga	79.30	63.42	63.72	64.17
Ohio	Greene	80.30	63.77	63.94	64.26
Ohio	Hamilton	84.70	67.74	67.91	68.23
Ohio	Jefferson	78.00	62.64	62.84	63.09
Ohio	Knox	77.70	61.44	61.69	62.32
Ohio	Lake	86.30	71.72	71.46	71.55
Ohio	Lawrence	70.70	58.31	58.42	58.56
Ohio	Licking	78.00	61.92	62.15	62.73
Ohio	Lorain	76.70	64.21	64.00	64.13
Ohio	Lucas	81.30	67.70	67.98	68.17
Ohio	Madison	79.70	62.16	62.40	62.94
Ohio	Mahoning	78.70	61.66	61.93	62.54
Ohio	Medina	80.30	65.36	65.66	65.89

Ohio	Miami	76.70	60.06	60.25	60.64
Ohio	Montgomery	74.00	58.37	58.52	58.79
Ohio	Portage	83.70	66.80	67.14	67.70
Ohio	Preble	73.00	57.60	57.77	58.14
Ohio	Stark	81.00	64.54	64.81	65.35
Ohio	Summit	83.70	67.28	67.64	68.15
Ohio	Trumbull	84.30	66.18	66.47	66.97
Ohio	Warren	87.70	69.70	69.89	70.27
Ohio	Washington	82.70	68.43	68.63	68.89
Ohio	Wood	80.00	65.36	65.66	66.26
Oklahoma	Adair	75.70	63.78	63.97	64.62
Oklahoma	Canadian	76.00	61.58	61.92	62.27
Oklahoma	Cherokee	75.70	66.40	66.54	67.53
Oklahoma	Cleveland	74.70	62.14	62.38	62.84
Oklahoma	Comanche	77.50	64.22	64.39	65.02
Oklahoma	Creek	76.70	62.92	63.18	64.18
Oklahoma	Dewey	72.70	61.02	61.16	61.45
Oklahoma	Kay	78.00	64.01	64.21	64.64
Oklahoma	Mc Clain	72.00	59.90	60.12	60.44
Oklahoma	Mayes	78.50	69.61	69.75	70.39
Oklahoma	Oklahoma	80.00	65.50	65.85	66.18
Oklahoma	Ottawa	78.00	65.99	66.20	66.89
Oklahoma	Pittsburg	72.00	61.32	61.51	61.91
Oklahoma	Tulsa	79.30	67.89	68.12	68.78
Oregon	Clackamas	66.30	62.18	62.22	62.26
Oregon	Columbia	58.70	54.33	54.45	54.47
Oregon	Jackson	68.00	56.05	56.26	56.39
Oregon	Lane	69.30	59.58	59.79	60.21
Oregon	Marion	65.70	57.84	58.00	58.20
Oregon	Multnomah	56.30	57.83	57.67	57.54
Pennsylvania	Adams	76.30	60.02	60.12	60.29
Pennsylvania	Allegheny	83.70	67.83	67.98	68.28
Pennsylvania	Armstrong	83.00	65.65	65.83	66.13
Pennsylvania	Beaver	83.00	68.78	68.95	69.26
Pennsylvania	Berks	76.00	60.39	60.56	60.80
Pennsylvania	Blair	74.30	58.94	59.11	59.40
Pennsylvania	Bucks	88.00	73.97	74.03	74.13
Pennsylvania	Cambria	74.70	60.00	60.15	60.46
Pennsylvania	Centre	78.30	62.20	62.42	62.86
Pennsylvania	Chester	86.00	66.77	66.91	67.07
Pennsylvania	Clearfield	78.30	62.17	62.36	62.71
Pennsylvania	Dauphin	79.30	64.44	64.57	64.79
Pennsylvania	Delaware	83.30	68.12	68.18	68.24
Pennsylvania	Erie	81.30	68.93	69.15	69.65
Pennsylvania	Franklin	72.30	56.99	57.07	57.23
Pennsylvania	Greene	80.00	63.42	63.58	63.93
Pennsylvania	Indiana	80.00	63.12	63.28	63.58
Pennsylvania	Lackawanna	75.30	59.63	59.87	60.26
Pennsylvania	Lancaster	83.30	66.27	66.45	66.67
Pennsylvania	Lawrence	72.30	57.98	58.17	58.56
Pennsylvania	Lehigh	83.30	66.03	66.20	66.47
Pennsylvania	Luzerne	76.30	60.42	60.64	60.96
Pennsylvania	Lycoming	77.30	62.99	63.16	63.52

Pennsylvania	Mercer	82.00	64.94	65.20	65.75
Pennsylvania	Montgomery	85.70	71.24	71.32	71.45
Pennsylvania	Northampton	84.30	66.73	66.89	67.16
Pennsylvania	Perry	77.00	60.90	61.12	61.35
Pennsylvania	Philadelphia	90.30	76.12	76.20	76.31
Pennsylvania	Tioga	77.70	64.53	64.68	65.00
Pennsylvania	Washington	78.30	63.45	63.62	63.93
Pennsylvania	Westmoreland	79.00	63.69	63.81	64.08
Pennsylvania	York	82.00	65.36	65.46	65.63
Rhode Island	Kent	84.30	69.67	69.72	69.80
Rhode Island	Providence	82.30	67.79	67.85	67.98
Rhode Island	Washington	86.00	71.10	71.15	71.25
South Carolina	Abbeville	79.00	60.78	60.90	61.39
South Carolina	Aiken	76.00	56.79	57.03	57.94
South Carolina	Anderson	76.50	57.05	57.14	57.65
South Carolina	Barnwell	73.00	54.00	54.21	54.90
South Carolina	Berkeley	67.30	52.82	52.90	53.37
South Carolina	Charleston	74.00	62.55	62.65	63.11
South Carolina	Cherokee	74.00	57.67	57.76	58.27
South Carolina	Chester	75.70	56.52	56.58	57.06
South Carolina	Chesterfield	75.00	59.34	59.43	59.77
South Carolina	Colleton	72.30	56.81	56.99	57.46
South Carolina	Darlington	76.30	59.45	59.54	59.95
South Carolina	Edgefield	70.00	52.89	53.12	54.04
South Carolina	Oconee	73.00	55.09	55.19	55.71
South Carolina	Pickens	78.70	59.16	59.23	59.81
South Carolina	Richland	82.30	60.63	60.70	61.25
South Carolina	Spartanburg	82.30	60.61	60.72	61.90
South Carolina	Union	76.00	60.12	60.19	60.62
South Carolina	Williamsburg	69.30	55.09	55.20	55.56
South Carolina	York	76.70	57.92	57.98	58.48
South Dakota	Custer	70.00	64.60	64.67	64.73
South Dakota	Jackson	67.00	61.35	61.43	61.53
South Dakota	Minnehaha	66.00	56.41	56.64	57.41
Tennessee	Anderson	77.30	55.86	56.17	56.44
Tennessee	Blount	85.30	62.23	62.52	62.76
Tennessee	Davidson	77.70	58.48	58.66	58.83
Tennessee	Hamilton	81.00	61.14	61.38	61.55
Tennessee	Jefferson	82.30	60.37	60.65	60.88
Tennessee	Knox	85.00	61.89	62.17	62.41
Tennessee	Loudon	83.00	60.51	61.02	61.29
Tennessee	Meigs	80.00	59.26	59.56	59.96
Tennessee	Rutherford	76.30	57.32	57.51	57.77
Tennessee	Sevier	80.70	59.07	59.34	59.63
Tennessee	Shelby	80.70	61.50	61.70	61.91
Tennessee	Sullivan	80.30	67.64	67.75	67.90
Tennessee	Sumner	83.00	62.79	62.97	63.12
Tennessee	Williamson	75.30	56.51	56.66	56.84
Tennessee	Wilson	78.70	60.64	60.82	61.02
Texas	Bexar	85.00	73.28	73.42	73.59
Texas	Brazoria	94.70	82.10	82.18	82.28
Texas	Brewster	64.00	56.38	56.47	56.61
Texas	Collin	90.30	72.47	72.63	72.85

Texas	Dallas	88.30	74.61	74.73	74.94
Texas	Denton	94.00	72.51	72.69	72.94
Texas	Ellis	81.70	64.91	65.04	65.25
Texas	El Paso	77.70	70.26	70.36	70.39
Texas	Galveston	80.30	71.73	71.82	71.98
Texas	Gregg	84.30	73.47	73.59	73.80
Texas	Harris	100.70	89.17	89.24	89.29
Texas	Harrison	79.00	65.63	65.84	66.13
Texas	Hidalgo	65.70	57.30	57.43	57.59
Texas	Hood	83.00	62.70	62.87	63.15
Texas	Hunt	78.00	65.38	65.54	65.81
Texas	Jefferson	84.70	74.98	75.10	75.36
Texas	Johnson	87.00	67.73	67.89	68.13
Texas	Kaufman	74.70	63.61	63.76	63.99
Texas	Montgomery	85.00	72.76	72.80	72.80
Texas	Nueces	72.30	64.40	64.65	64.84
Texas	Orange	78.00	67.62	67.76	68.01
Texas	Parker	88.70	66.46	66.64	66.91
Texas	Rockwall	79.70	68.23	68.36	68.57
Texas	Smith	81.00	69.03	69.18	69.45
Texas	Tarrant	95.30	73.84	73.99	74.24
Texas	Travis	81.30	66.57	66.78	67.01
Texas	Victoria	72.30	63.52	63.62	63.80
Texas	Webb	61.30	54.61	54.69	54.84
Utah	Box Elder	76.00	68.29	68.41	68.51
Utah	Cache	68.70	60.96	61.09	61.19
Utah	Davis	81.30	71.92	72.27	72.37
Utah	Salt Lake	81.00	71.69	71.82	71.91
Utah	San Juan	70.30	64.99	65.03	65.08
Utah	Tooele	78.00	67.86	68.25	68.41
Utah	Utah	76.70	71.42	71.47	71.52
Utah	Washington	78.50	68.96	69.04	69.10
Utah	Weber	80.30	70.51	70.78	70.90
Vermont	Bennington	72.00	57.74	57.90	58.18
Vermont	Chittenden	69.70	58.20	58.37	58.63
Virginia	Arlington	86.70	71.91	71.99	72.12
Virginia	Caroline	80.00	61.41	61.50	61.75
Virginia	Charles City	80.30	65.69	65.75	66.03
Virginia	Chesterfield	76.70	62.43	62.48	62.71
Virginia	Fairfax	90.00	71.76	71.85	72.04
Virginia	Fauquier	72.70	57.67	57.76	57.96
Virginia	Frederick	72.30	57.62	57.72	57.93
Virginia	Hanover	81.30	64.59	64.66	64.93
Virginia	Henrico	82.00	66.09	66.14	66.37
Virginia	Loudoun	80.70	62.34	62.41	62.59
Virginia	Madison	77.70	63.21	63.29	63.50
Virginia	Page	74.00	60.13	60.23	60.48
Virginia	Prince William	78.70	61.91	61.98	62.13
Virginia	Roanoke	74.70	60.78	60.88	61.22
Virginia	Rockbridge	69.70	58.20	58.30	58.59
Virginia	Stafford	81.70	63.01	63.07	63.32
Virginia	Wythe	72.70	59.33	59.45	59.79
Virginia	Alexandria City	81.70	65.14	65.22	65.39

Virginia	Hampton City	76.70	67.57	67.60	67.76
Virginia	Suffolk City	76.70	70.76	70.77	70.70
Washington	Clark	59.50	59.23	59.22	59.23
Washington	King	72.30	66.42	66.48	66.37
Washington	Klickitat	64.50	59.53	59.67	59.73
Washington	Pierce	68.70	62.11	62.13	62.06
Washington	Skagit	46.00	45.83	45.79	45.78
Washington	Spokane	68.30	58.43	58.72	58.75
Washington	Thurston	65.00	56.82	57.17	57.24
Washington	Whatcom	57.00	55.54	55.52	55.50
West Virginia	Berkeley	75.00	60.18	60.29	60.48
West Virginia	Cabell	78.70	64.75	64.86	65.00
West Virginia	Greenbrier	69.70	59.86	59.98	60.36
West Virginia	Hancock	75.70	61.88	62.05	62.35
West Virginia	Kanawha	77.30	60.83	61.01	61.25
West Virginia	Monongalia	75.30	58.16	58.31	58.70
West Virginia	Ohio	78.30	62.93	63.12	63.42
West Virginia	Wood	79.00	64.31	64.50	64.75
Wisconsin	Ashland	61.50	53.14	53.27	53.94
Wisconsin	Brown	73.70	62.25	62.40	62.97
Wisconsin	Columbia	72.70	59.48	59.69	60.62
Wisconsin	Dane	72.00	59.65	59.86	60.83
Wisconsin	Dodge	74.70	61.74	62.02	62.90
Wisconsin	Door	88.70	72.97	73.11	73.75
Wisconsin	Florence	66.30	57.03	57.19	57.74
Wisconsin	Fond Du Lac	73.70	61.94	62.17	62.88
Wisconsin	Forest	69.50	59.77	59.94	60.53
Wisconsin	Jefferson	74.30	61.37	61.46	62.05
Wisconsin	Kenosha	84.70	76.27	76.39	76.62
Wisconsin	Kewaunee	82.70	68.76	68.87	69.40
Wisconsin	Manitowoc	85.00	71.47	71.59	72.11
Wisconsin	Marathon	70.00	60.32	60.55	61.30
Wisconsin	Milwaukee	82.70	71.63	71.75	72.16
Wisconsin	Oneida	69.00	59.60	59.76	60.42
Wisconsin	Outagamie	74.00	61.98	62.20	62.89
Wisconsin	Ozaukee	83.30	71.67	71.78	72.19
Wisconsin	Racine	80.30	71.56	71.68	71.91
Wisconsin	Rock	74.00	61.24	61.41	62.34
Wisconsin	St Croix	69.00	58.71	58.85	59.84
Wisconsin	Sauk	69.70	57.88	58.14	58.97
Wisconsin	Sheboygan	88.00	74.71	74.84	75.33
Wisconsin	Vernon	69.70	59.00	59.21	59.99
Wisconsin	Vilas	68.70	59.51	59.67	60.31
Wisconsin	Walworth	75.70	62.74	62.91	63.50
Wisconsin	Washington	72.30	61.14	61.32	61.93
Wisconsin	Waukesha	75.00	63.24	63.38	63.88
Wyoming	Campbell	67.30	64.63	64.68	64.70
Wyoming	Sublette	70.00	65.10	65.15	65.21
Wyoming	Teton	62.70	57.02	57.12	57.18

Appendix B: 2002 CMAQ Model Performance Evaluation for Ozone, Particulate Matter and Air Toxics

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Office of Air Quality Planning and Standards
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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, acrolein, and naphthalene) 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 Final National Renewable Fuel Standard Rule (commonly known as RFS2): 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

[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/)

following networks for model evaluation: **S**peciation **T**rends **N**etwork (STN- total of 260 sites), **I**nteragency **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	
	PM2.5 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 RFS2 final rule, i.e., formaldehyde, acetaldehyde, benzene, 1,3-butadiene, acrolein, and naphthalene. Similar to the PM2.5 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., Clean Air Interstate Rule[7], Final PM NAAQS Rule[8], and EPA's

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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.

Proposal to Designate an Emissions Control Area for Nitrogen Oxides[9]). 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 RFS2 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.

[7] 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).

[8] 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.

[9] 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

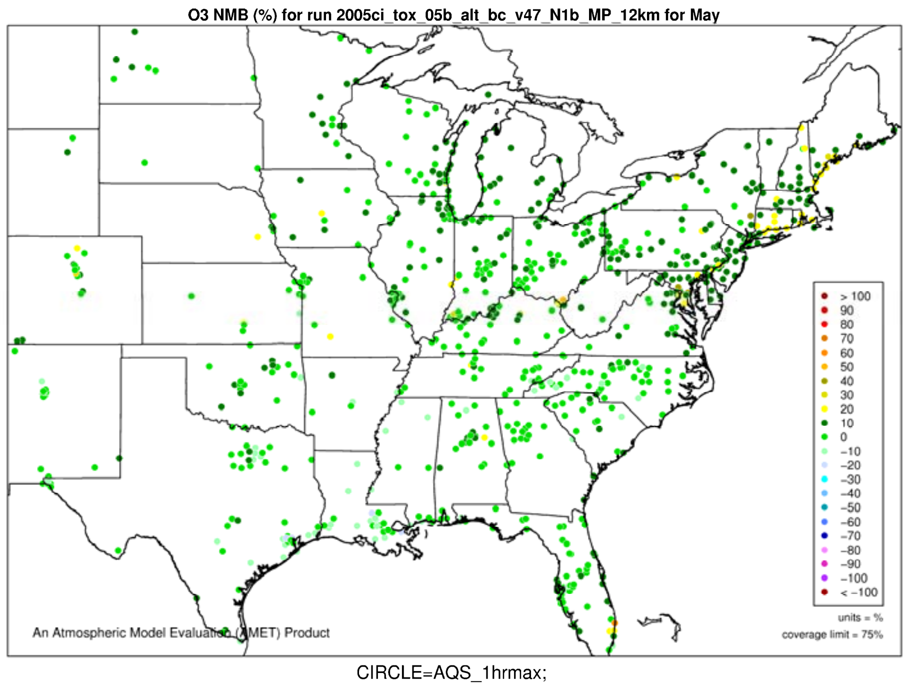


Figure B-1. Normalized Mean Bias (%) of one-hour daily maximum ozone (40 ppb threshold) by monitor for Eastern U.S., May 2005.

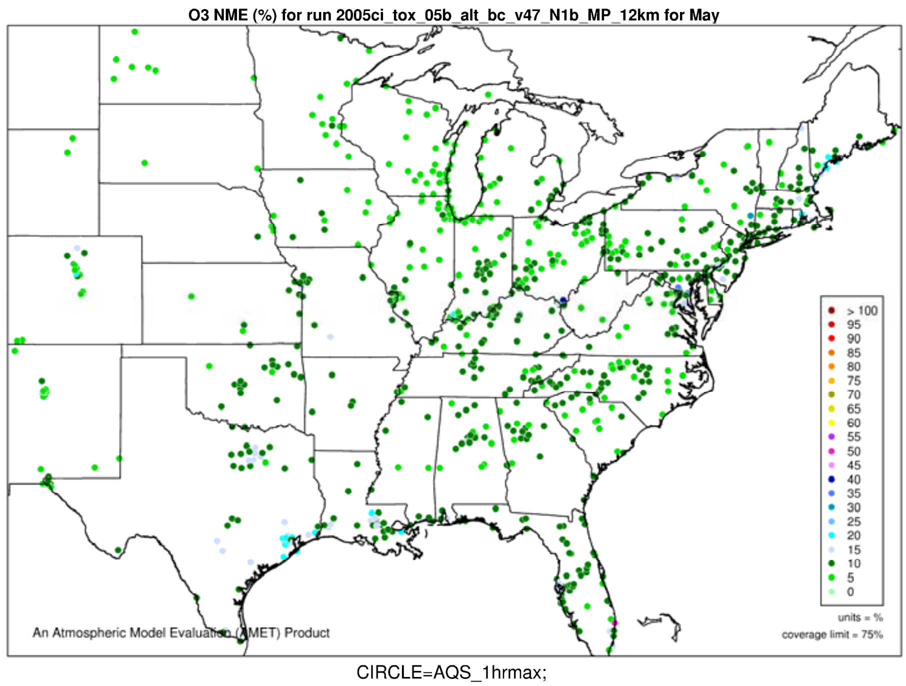


Figure B-2. Normalized Mean Error (%) of one-hour daily maximum ozone (40 ppb threshold) by monitor for Eastern U.S., May 2005.

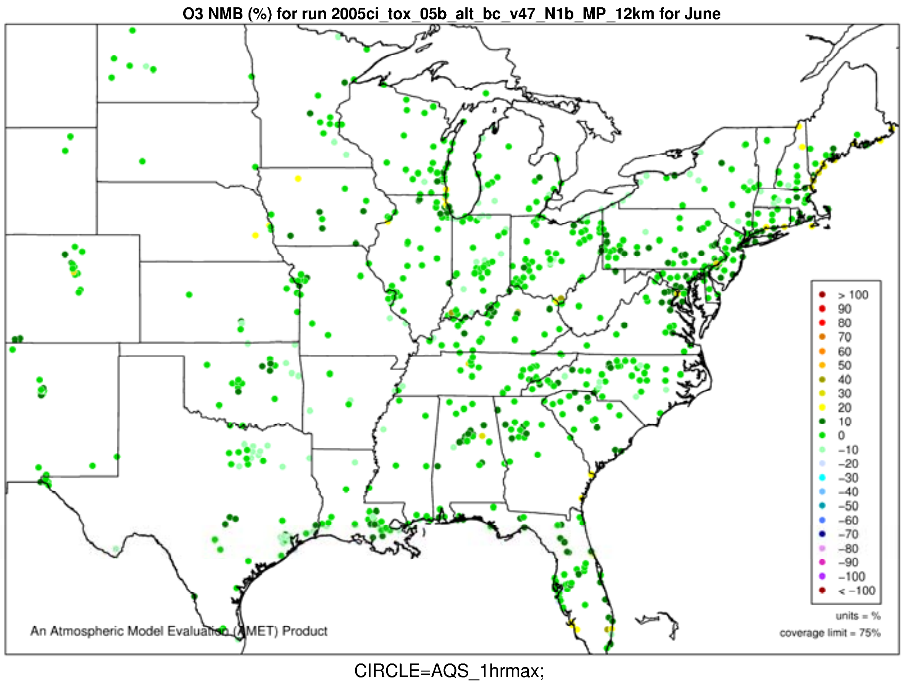


Figure B-3. Normalized Mean Bias (%) of one-hour daily maximum ozone (40 ppb threshold) by monitor for Eastern U.S., June 2005.

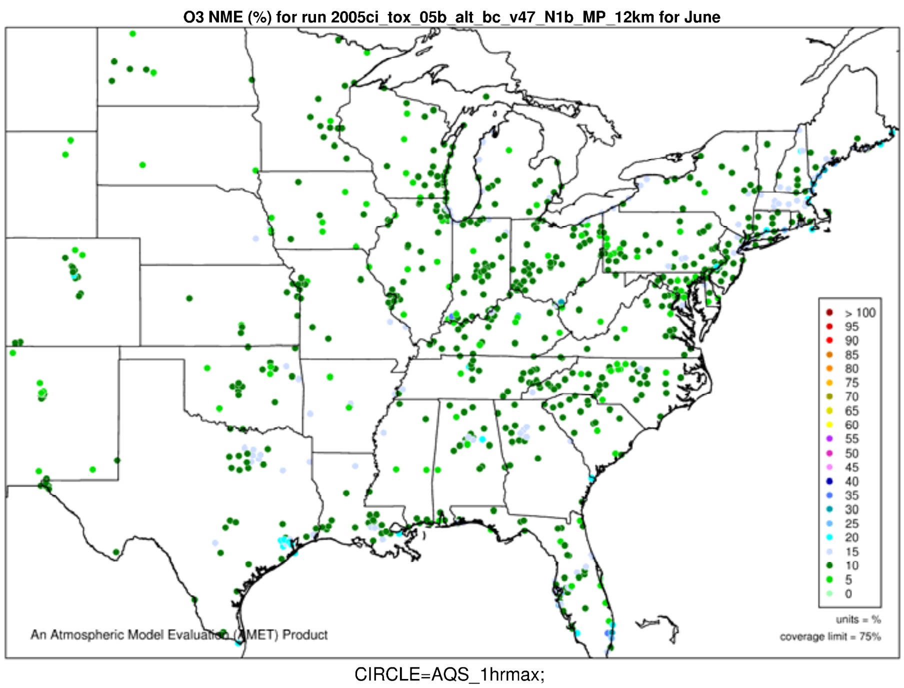


Figure B-4. Normalized Mean Error (%) of one-hour daily maximum ozone (40 ppb threshold) by monitor for Eastern U.S., June 2005.

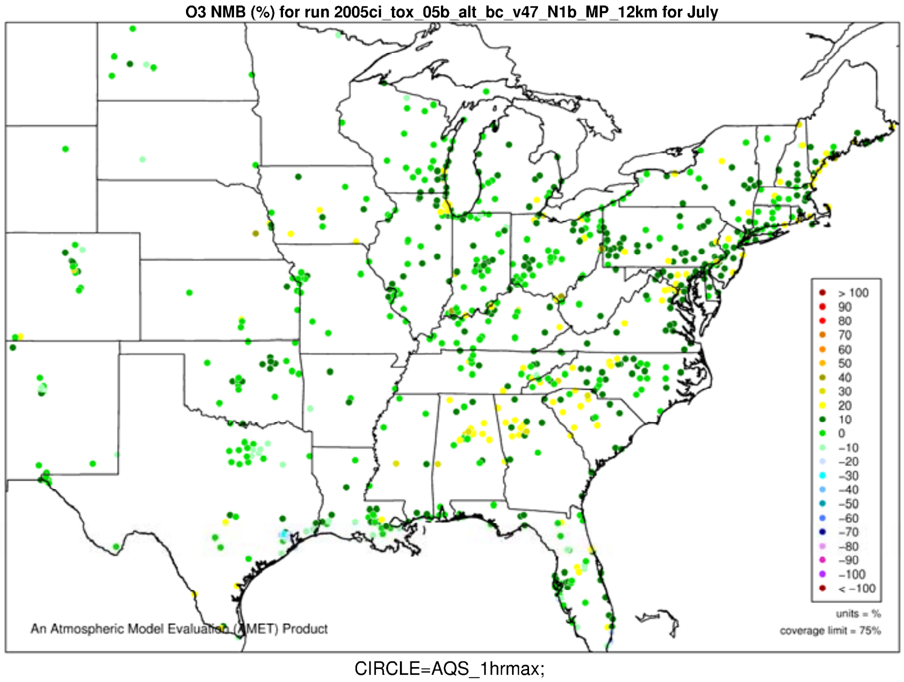


Figure B-5. Normalized Mean Bias (%) of one-hour daily maximum ozone (40 ppb threshold) by monitor for Eastern U.S., July 2005.

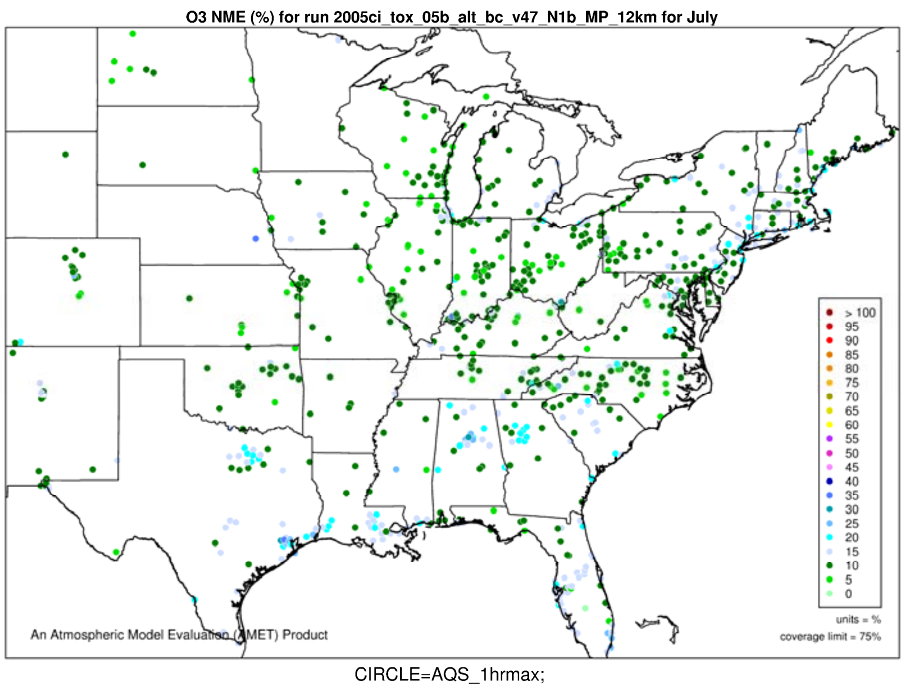


Figure B-6. Normalized Mean Error (%) of one-hour daily maximum ozone (40 ppb threshold) by monitor for Eastern U.S., July 2005.

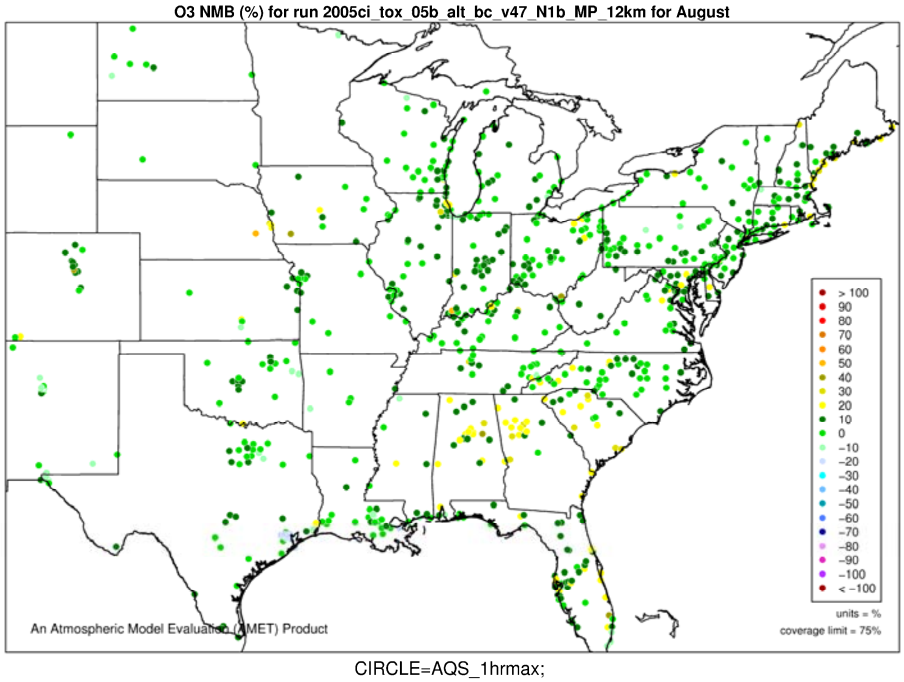


Figure B-7. Normalized Mean Bias (%) of one-hour daily maximum ozone (40 ppb threshold) by monitor for Eastern U.S., August 2005.

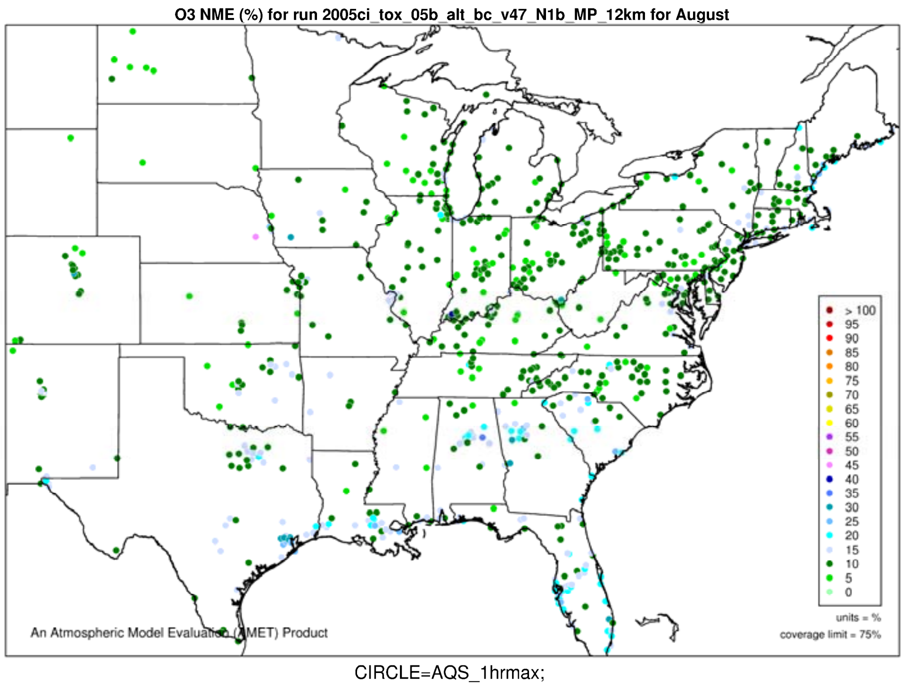


Figure B-8. Normalized Mean Error (%) of one-hour daily maximum ozone (40 ppb threshold) by monitor for Eastern U.S., August 2005.

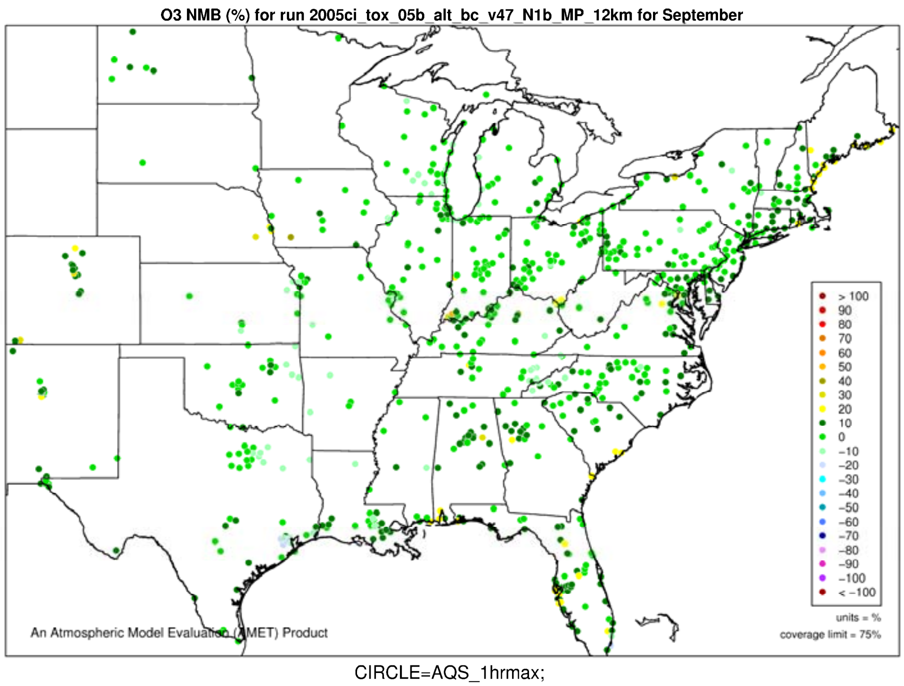


Figure B-9. Normalized Mean Bias (%) of one-hour daily maximum ozone (40 ppb threshold) by monitor for Eastern U.S., September 2005.

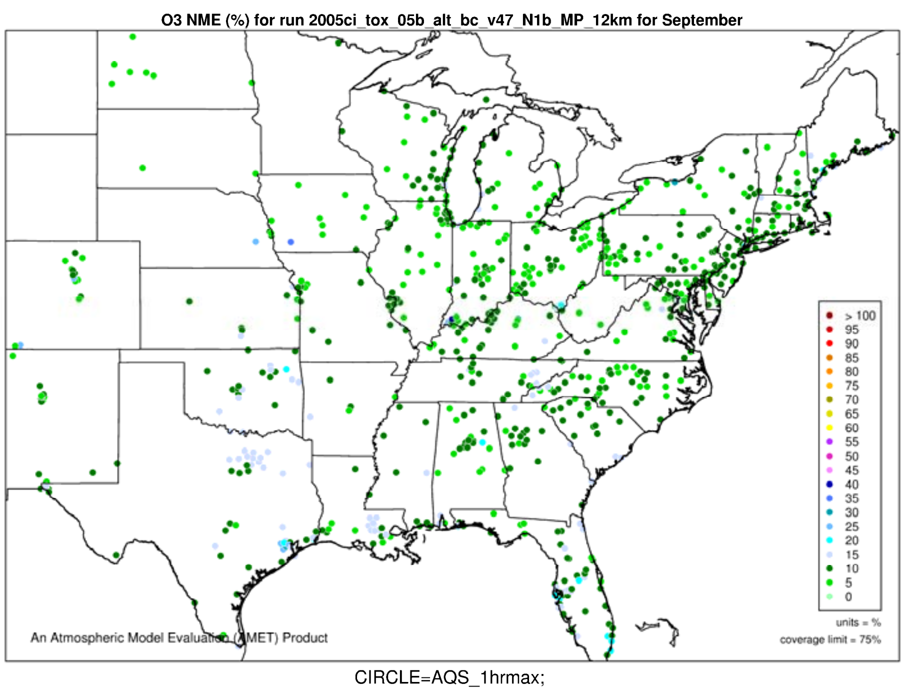


Figure B-10. Normalized Mean Error (%) of one-hour daily maximum ozone (40 ppb threshold) by monitor for Eastern U.S., September 2005.

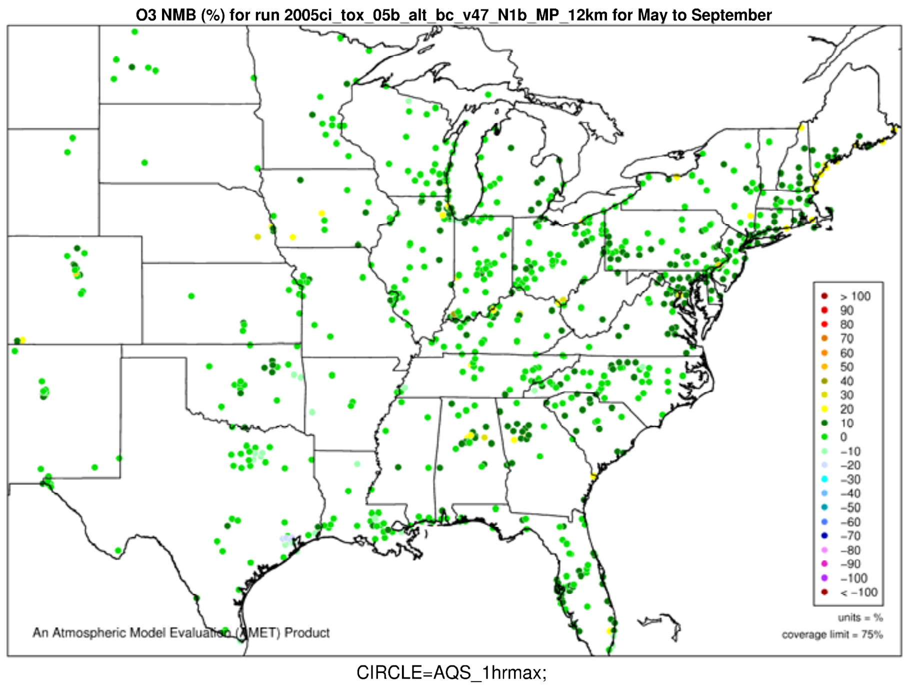


Figure B-11. Normalized Mean Bias (%) of one-hour daily maximum ozone (40 ppb threshold) by monitor for Eastern U.S., seasonal aggregate 2005.

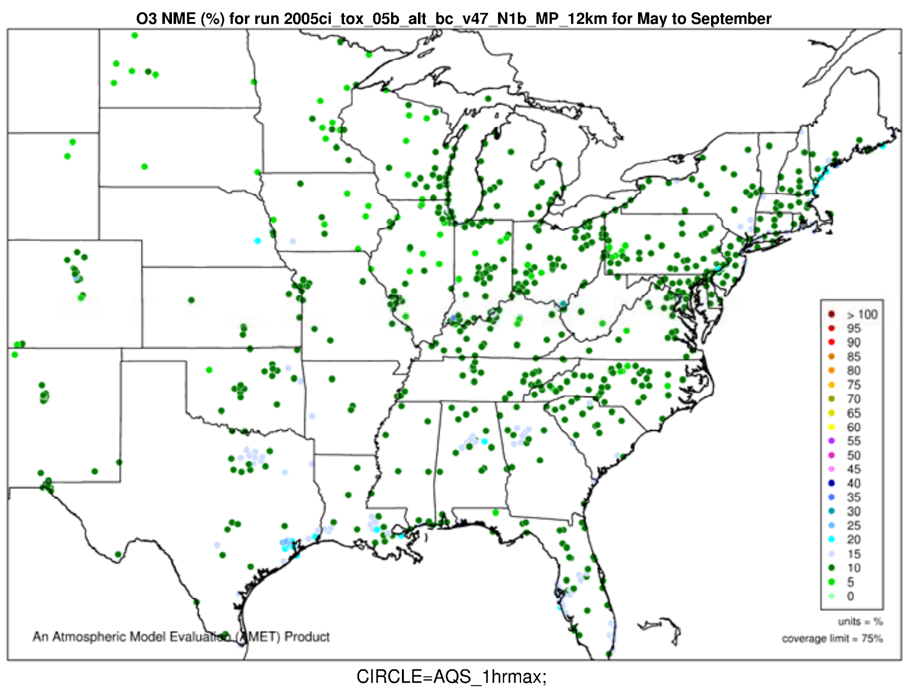


Figure B-12. Normalized Mean Error (%) of one-hour daily maximum ozone (40 ppb threshold) by monitor for Eastern U.S., seasonal aggregate 2005.

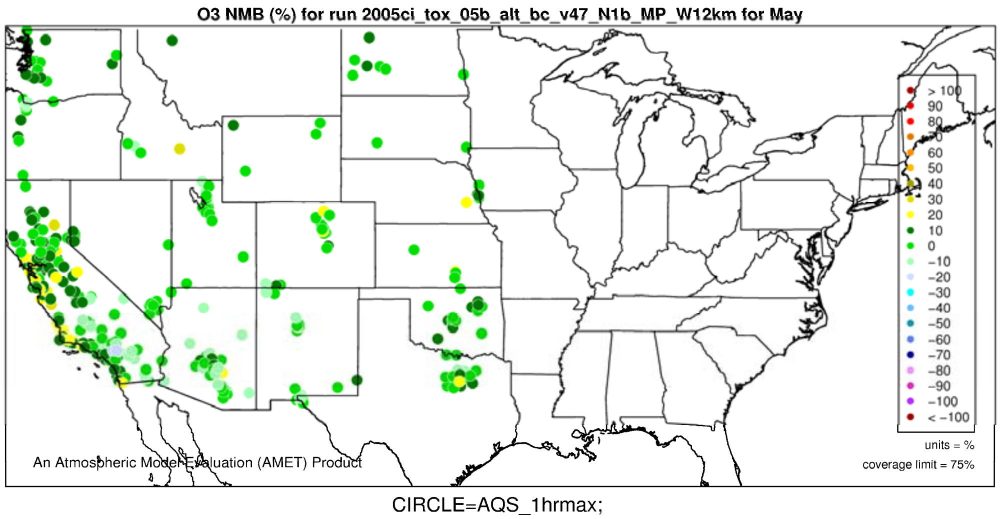


Figure B-13. Normalized Mean Bias (%) of one-hour daily maximum ozone (40 ppb threshold) by monitor for Western U.S., May 2005.

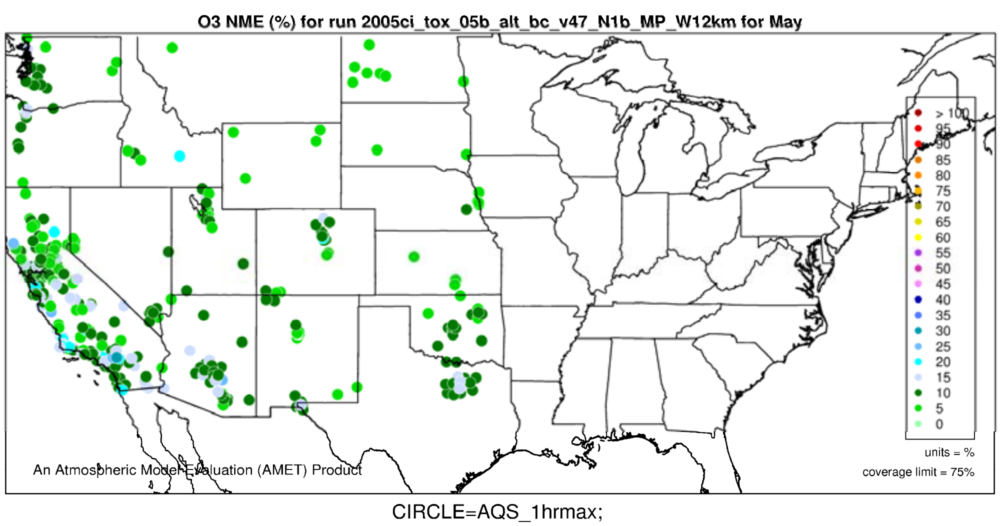


Figure B-14. Normalized Mean Error (%) of one-hour daily maximum ozone (40 ppb threshold) by monitor for Western U.S., May 2005.

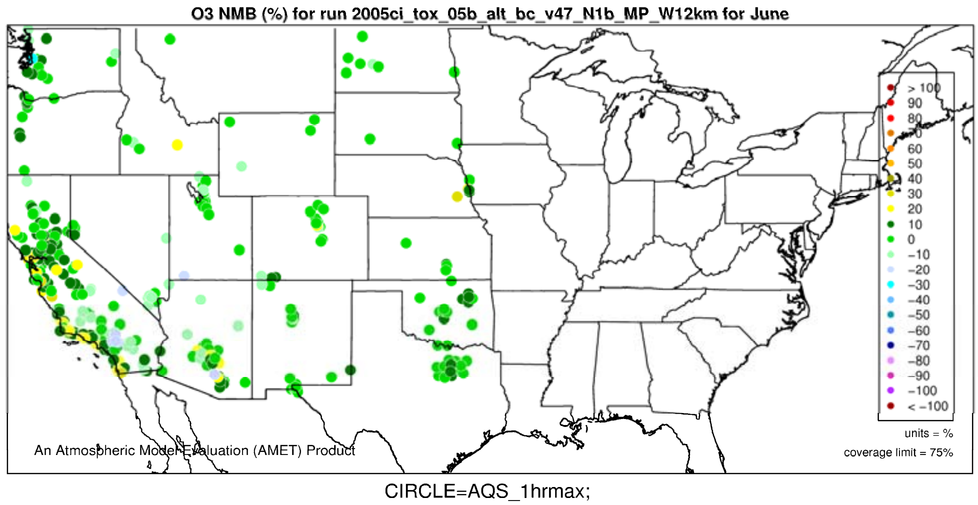


Figure B-15. Normalized Mean Bias (%) of one-hour daily maximum ozone (40 ppb threshold) by monitor for Western U.S., June 2005.

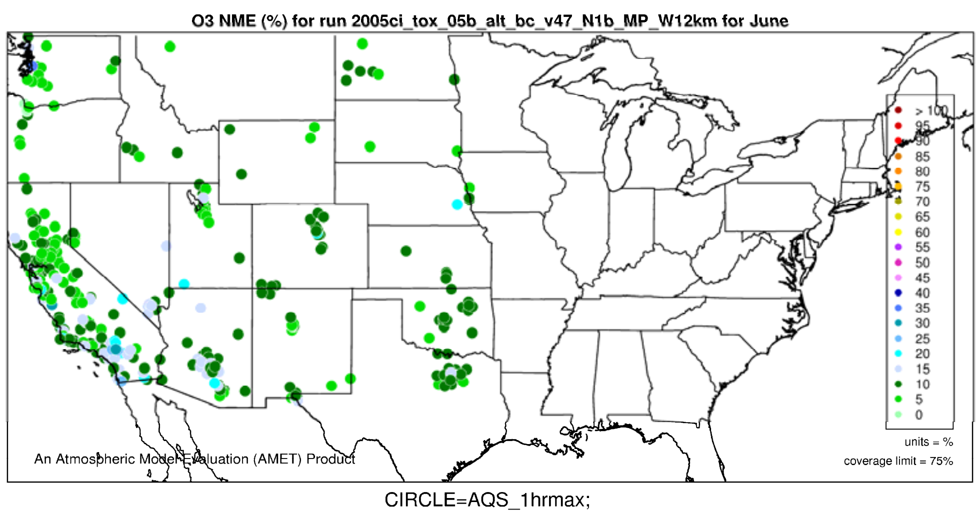


Figure B-16. Normalized Mean Error (%) of one-hour daily maximum ozone (40 ppb threshold) by monitor for Western U.S., June 2005.

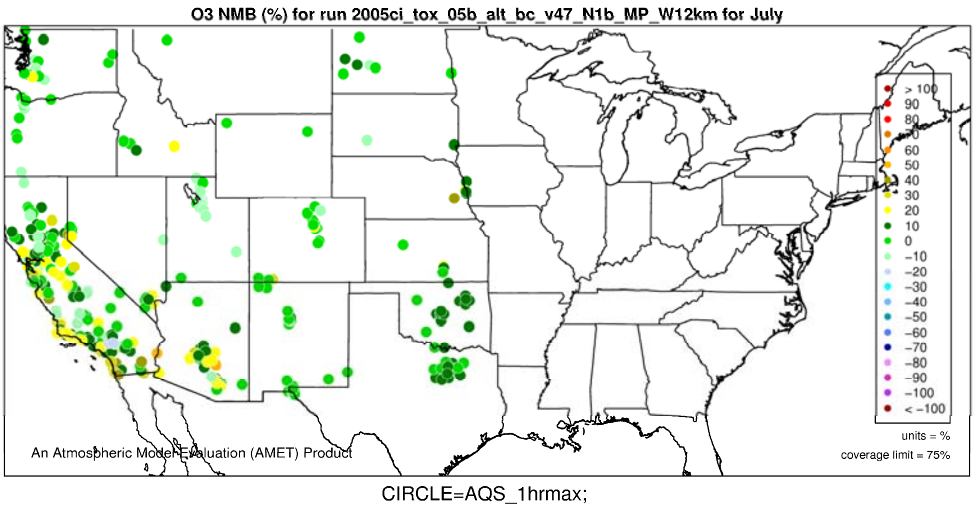


Figure B-17. Normalized Mean Bias (%) of one-hour daily maximum ozone (40 ppb threshold) by monitor for Western U.S., July 2005.

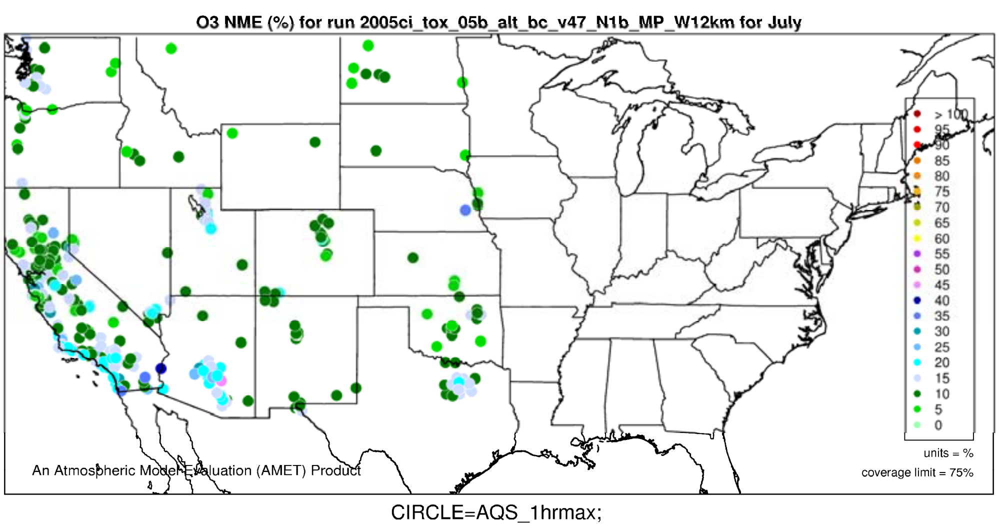


Figure B-18. Normalized Mean Error (%) of one-hour daily maximum ozone (40 ppb threshold) by monitor for Western U.S., July 2005.

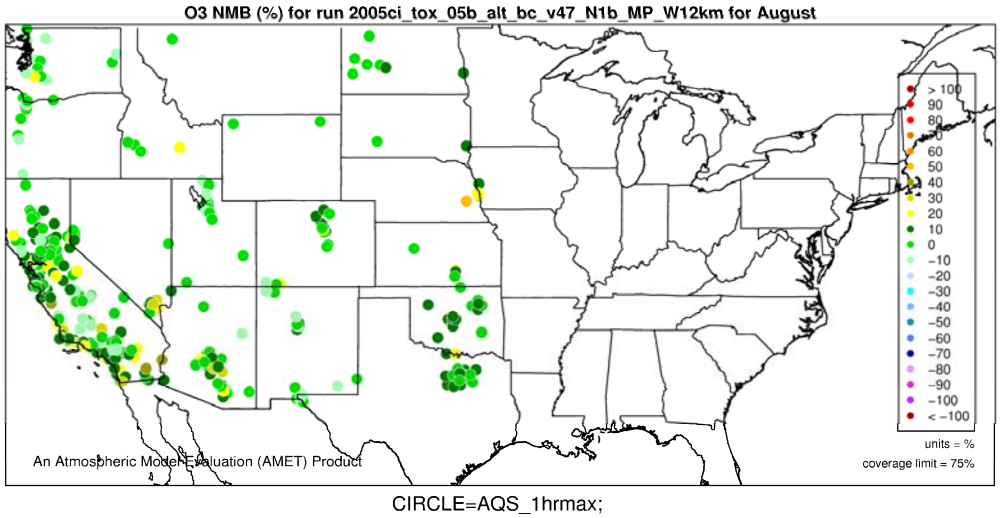


Figure B-19. Normalized Mean Bias (%) of one-hour daily maximum ozone (40 ppb threshold) by monitor for Western U.S., August 2005.

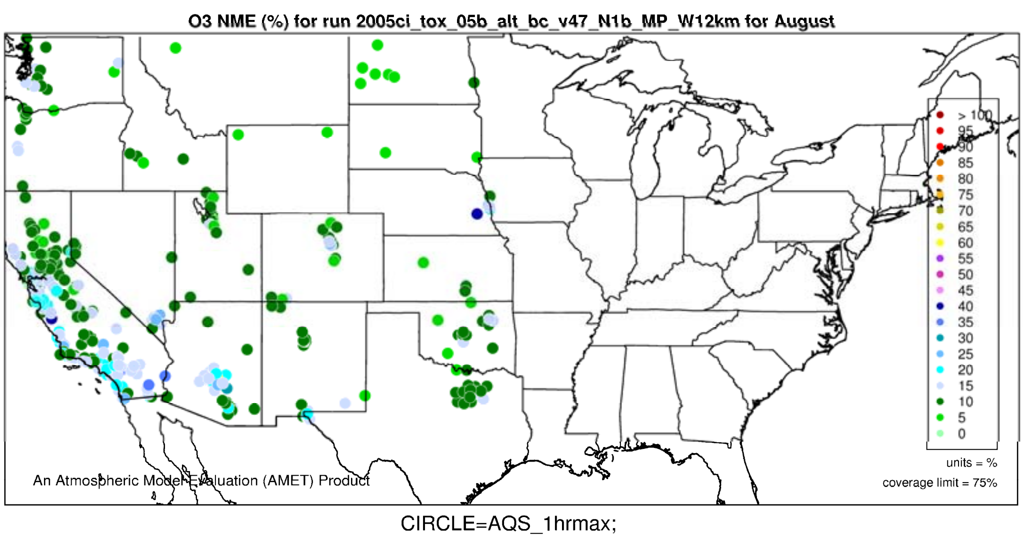


Figure B-20. Normalized Mean Error (%) of one-hour daily maximum ozone (40 ppb threshold) by monitor for Western U.S., August 2005.

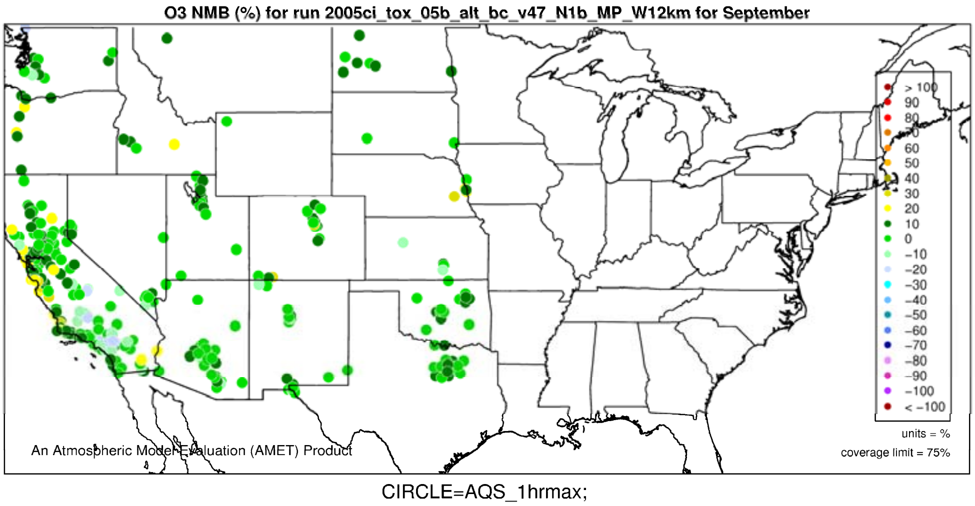


Figure B-21. Normalized Mean Bias (%) of one-hour daily maximum ozone (40 ppb threshold) by monitor for Western U.S., September 2005.

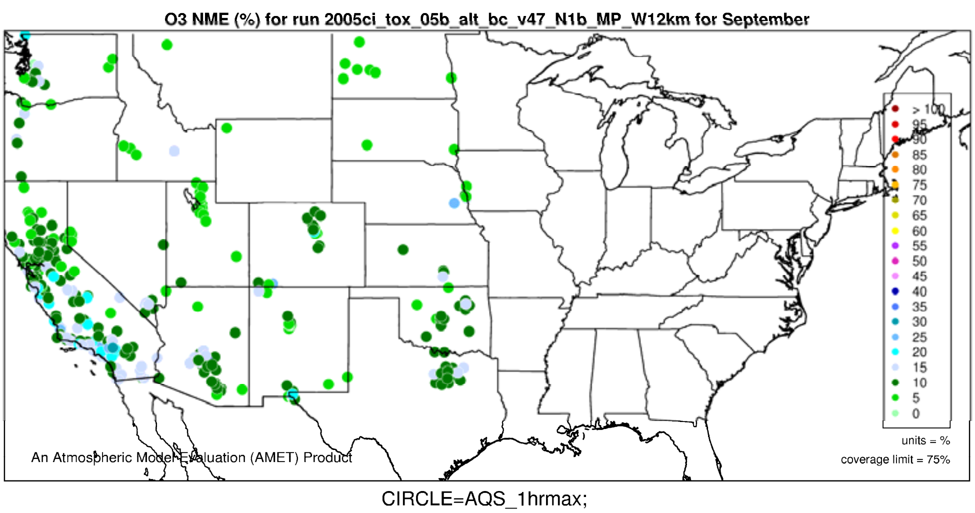


Figure B-22. Normalized Mean Error (%) of one-hour daily maximum ozone (40 ppb threshold) by monitor for Western U.S., September 2005.

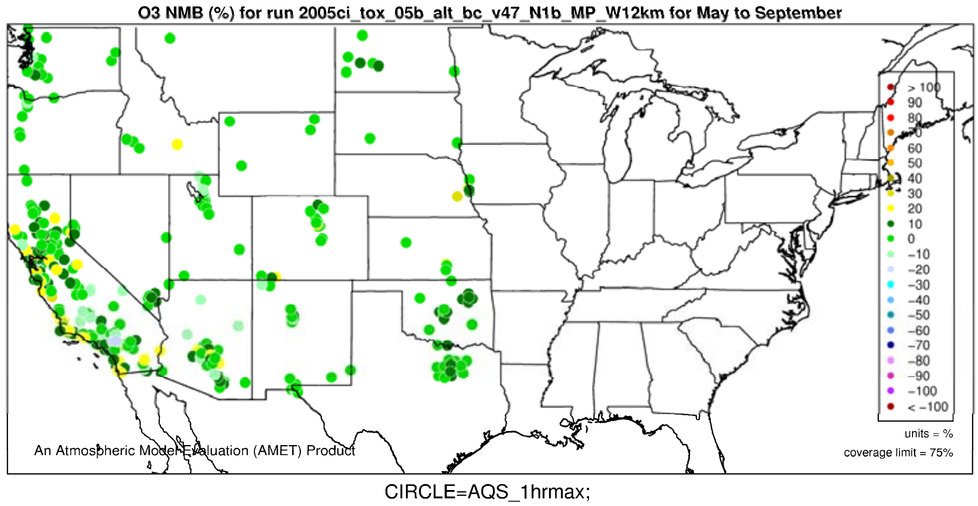


Figure B-23. Normalized Mean Bias (%) of one-hour daily maximum ozone (40 ppb threshold) by monitor for Western U.S., seasonal aggregate 2005.

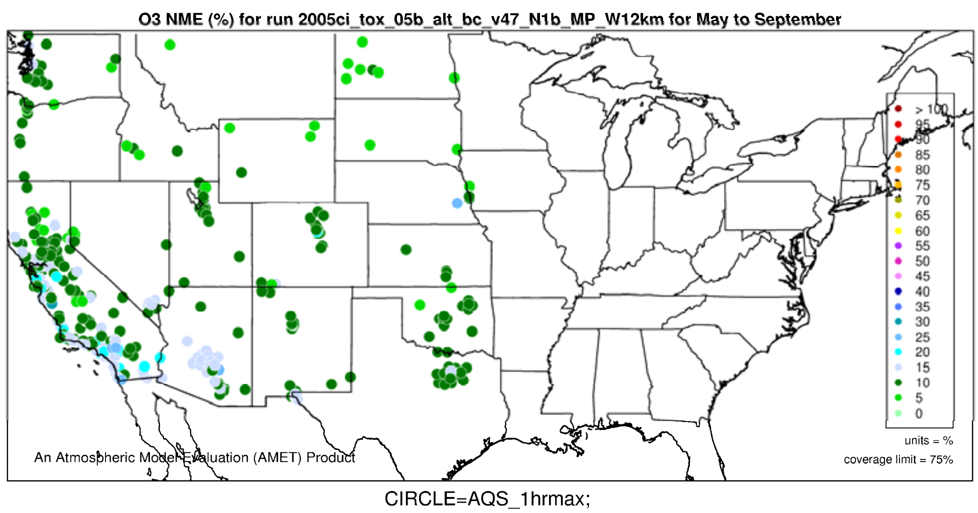


Figure B-24. Normalized Mean Error (%) of one-hour daily maximum ozone (40 ppb threshold) by monitor for Western U.S., seasonal aggregate 2005.

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

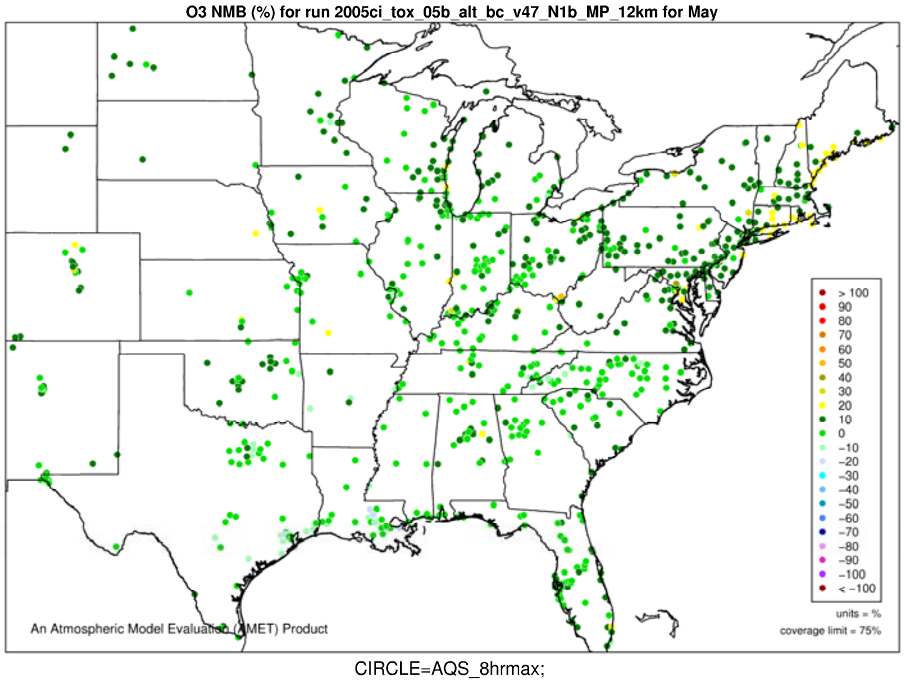


Figure C-1. Normalized Mean Bias (%) of eight-hour daily maximum ozone (40 ppb threshold) by monitor for Eastern U.S., May 2005.

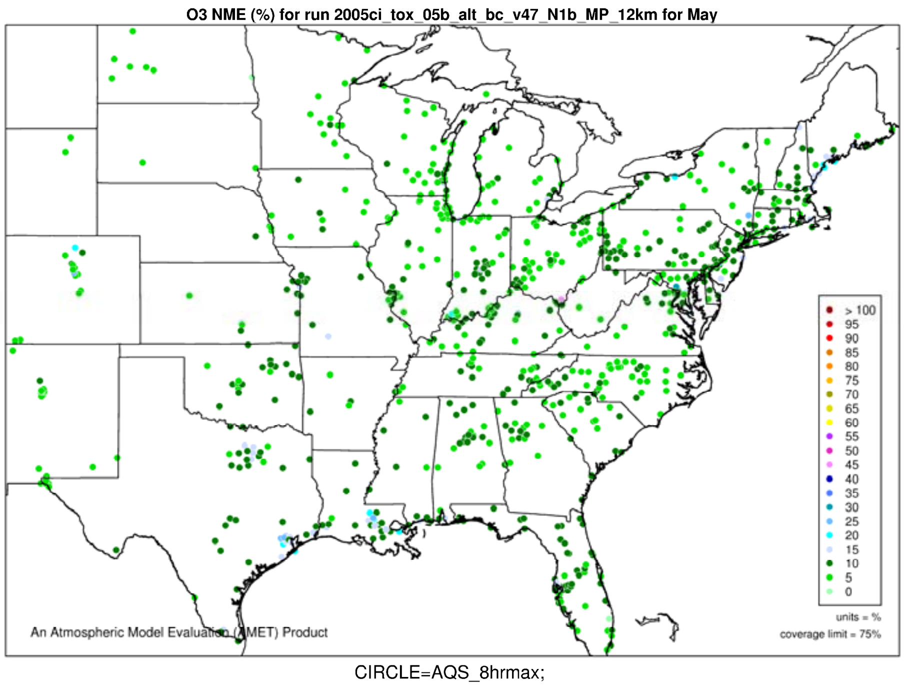


Figure C-2. Normalized Mean Error (%) of eight-hour daily maximum ozone (40 ppb threshold) by monitor for Eastern U.S., May 2005.

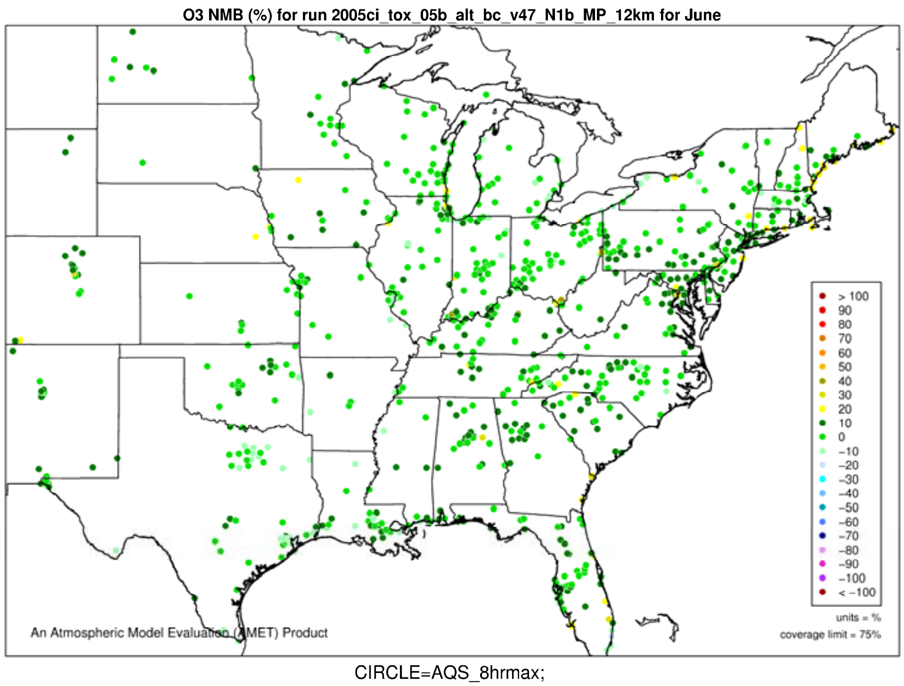


Figure C-3. Normalized Mean Bias (%) of eight-hour daily maximum ozone (40 ppb threshold) by monitor for Eastern U.S., June 2005.

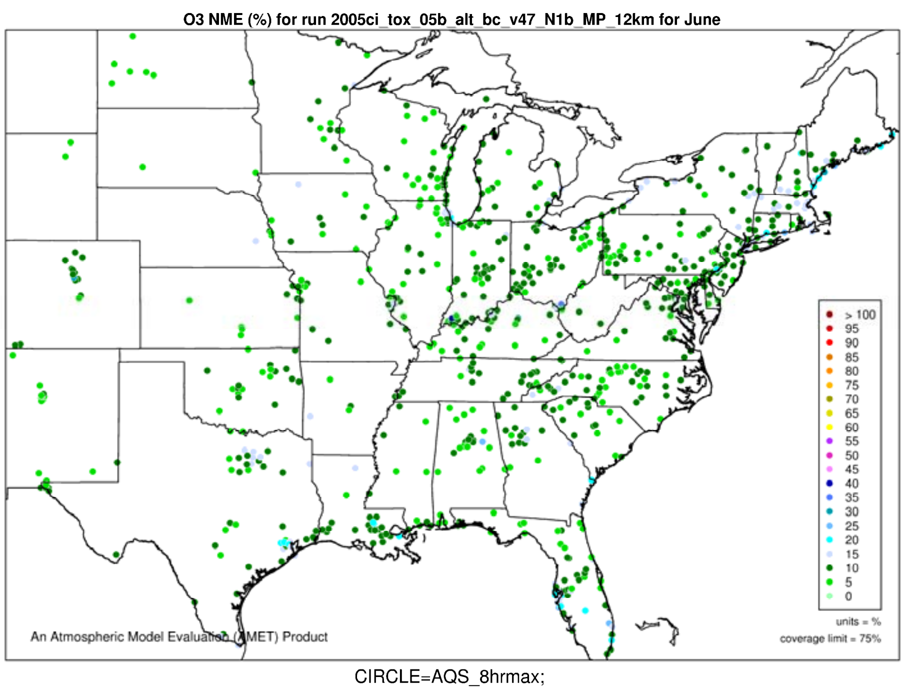


Figure C-4. Normalized Mean Error (%) of eight-hour daily maximum ozone (40 ppb threshold) by monitor for Eastern U.S., June 2005.

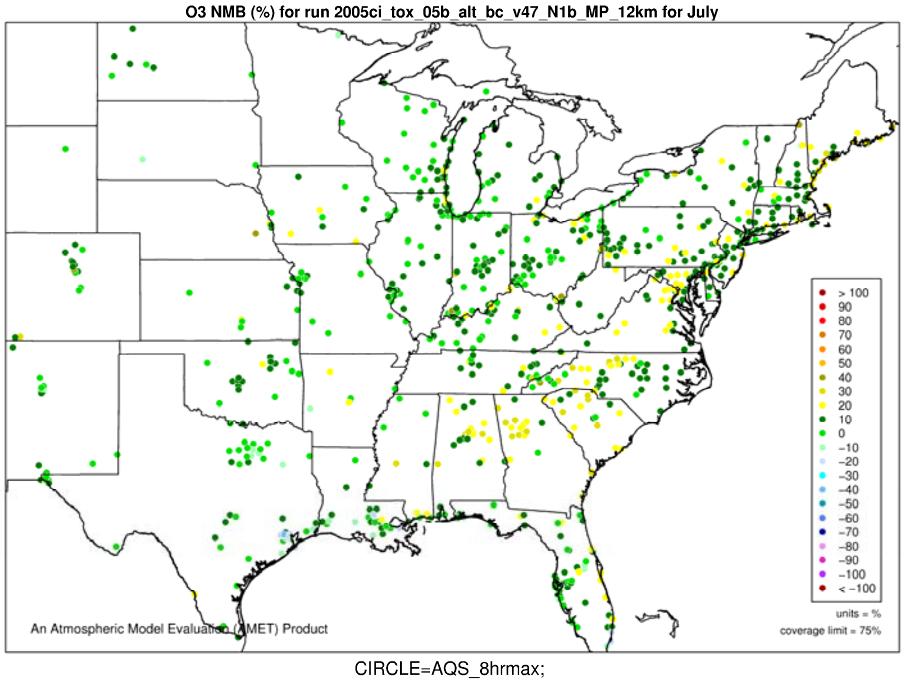


Figure C-5. Normalized Mean Bias (%) of eight-hour daily maximum ozone (40 ppb threshold) by monitor for Eastern U.S., July 2005.

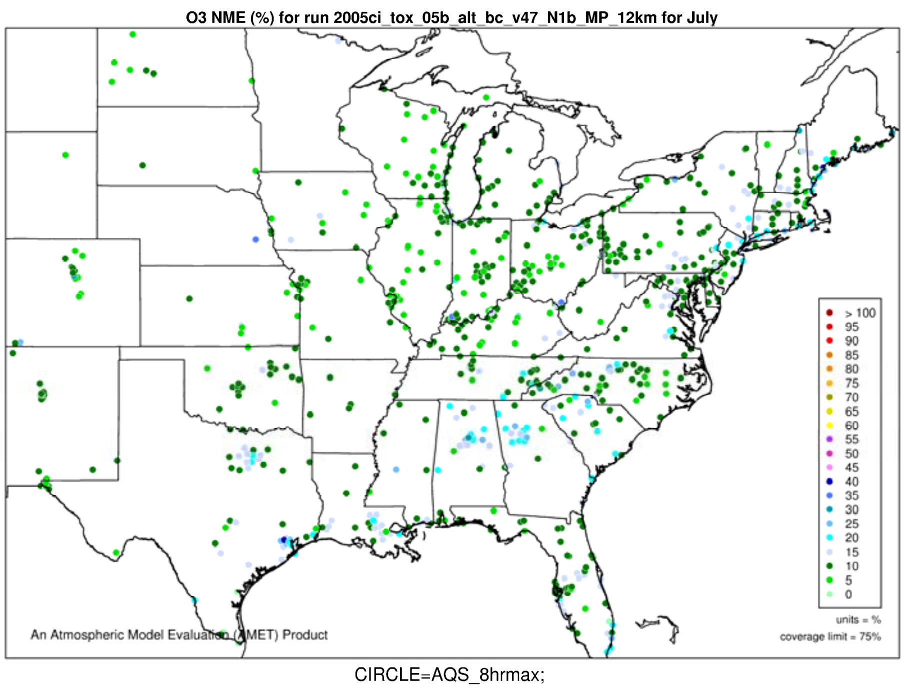


Figure C-6. Normalized Mean Error (%) of eight-hour daily maximum ozone (40 ppb threshold) by monitor for Eastern U.S., July 2005.

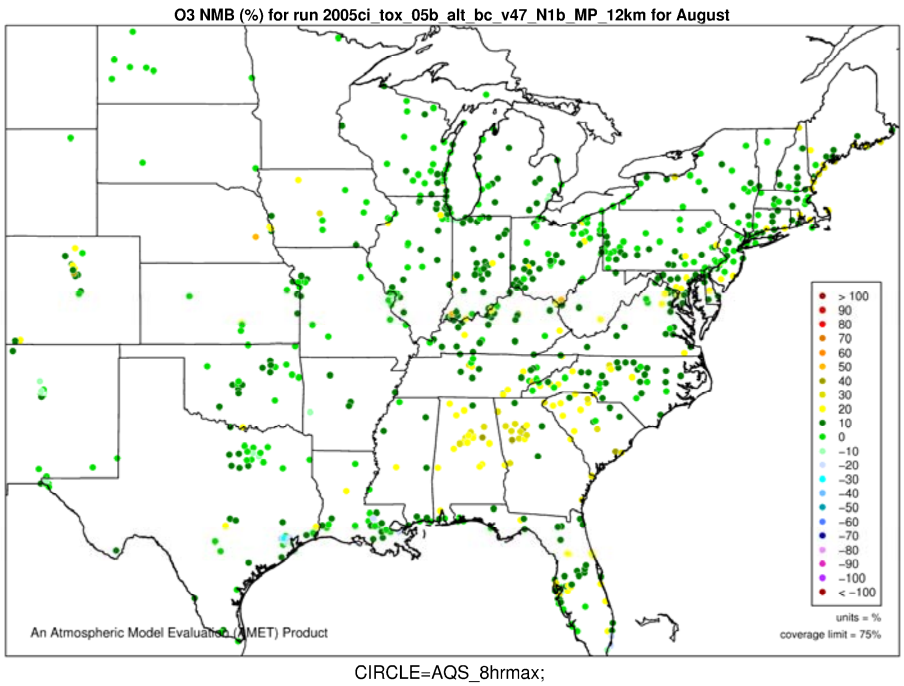


Figure C-7. Normalized Mean Bias (%) of eight-hour daily maximum ozone (40 ppb threshold) by monitor for Eastern U.S., August 2005.

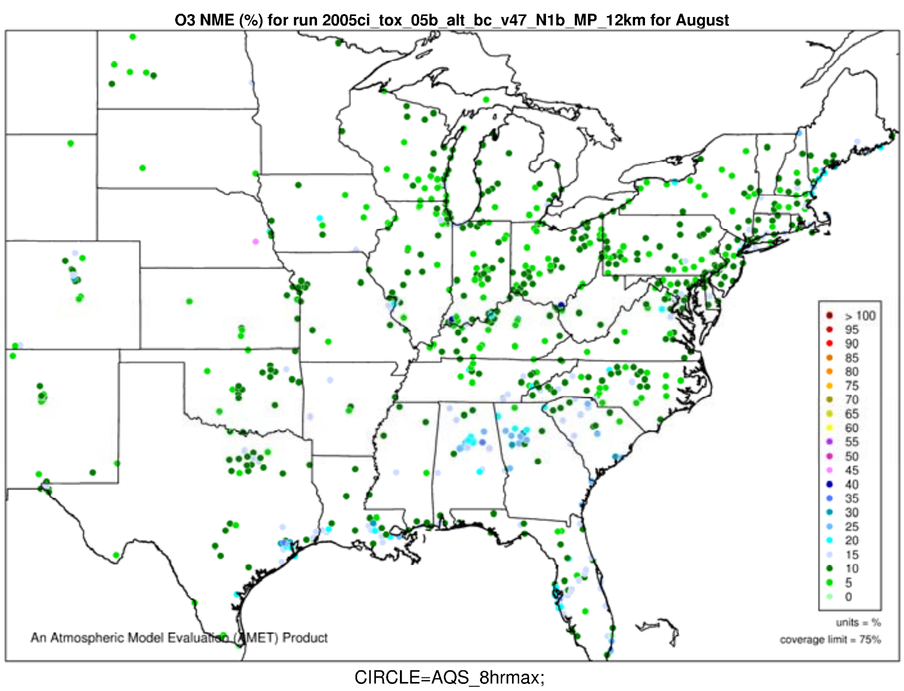


Figure C-8. Normalized Mean Error (%) of eight-hour daily maximum ozone (40 ppb threshold) by monitor for Eastern U.S., August 2005.

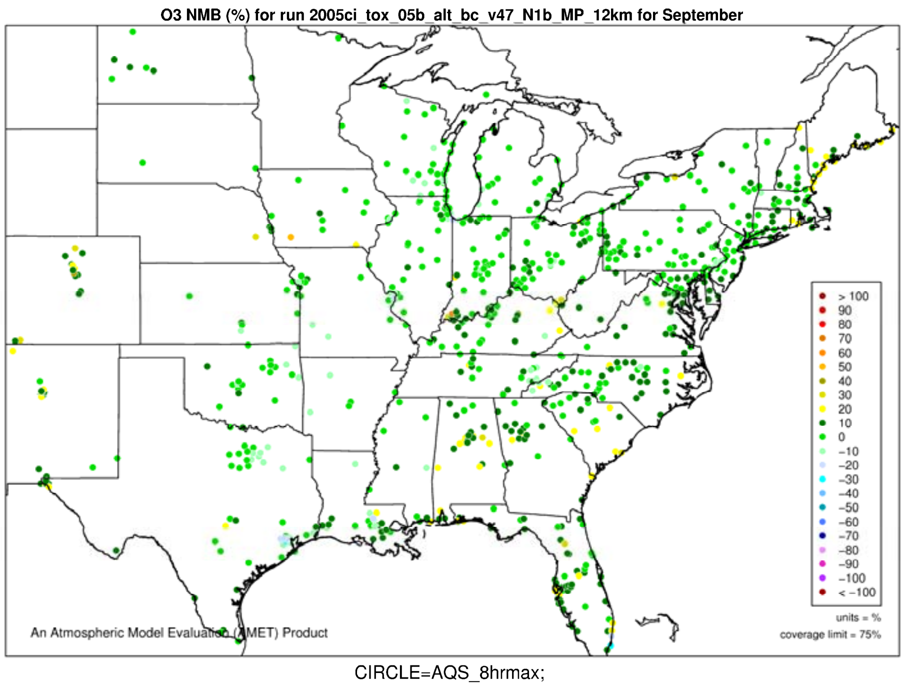


Figure C-9. Normalized Mean Bias (%) of eight-hour daily maximum ozone (40 ppb threshold) by monitor for Eastern U.S., September 2005.

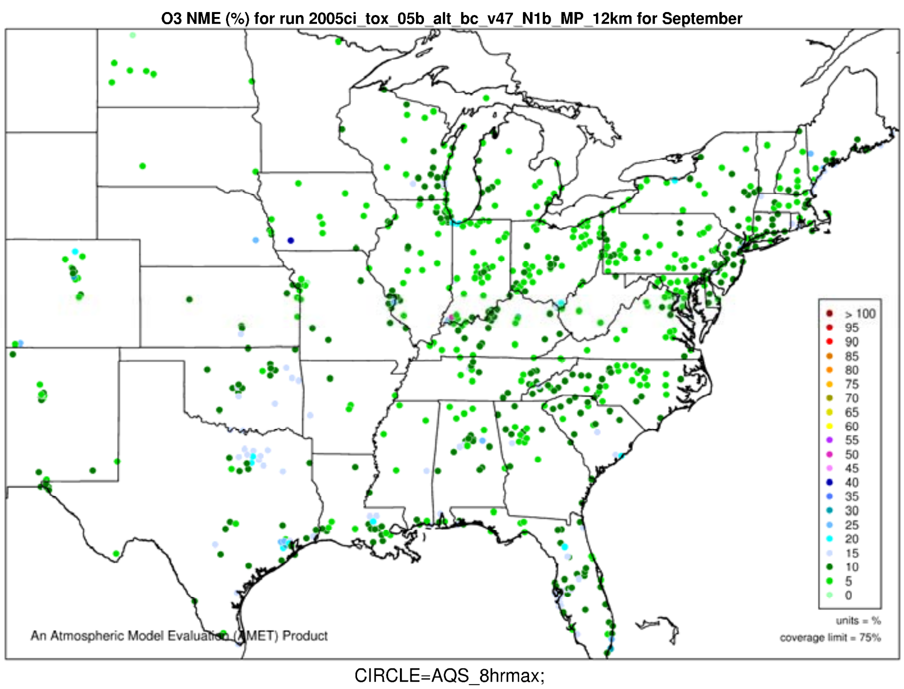


Figure C-10. Normalized Mean Error (%) of eight-hour daily maximum ozone (40 ppb threshold) by monitor for Eastern U.S., September 2005.

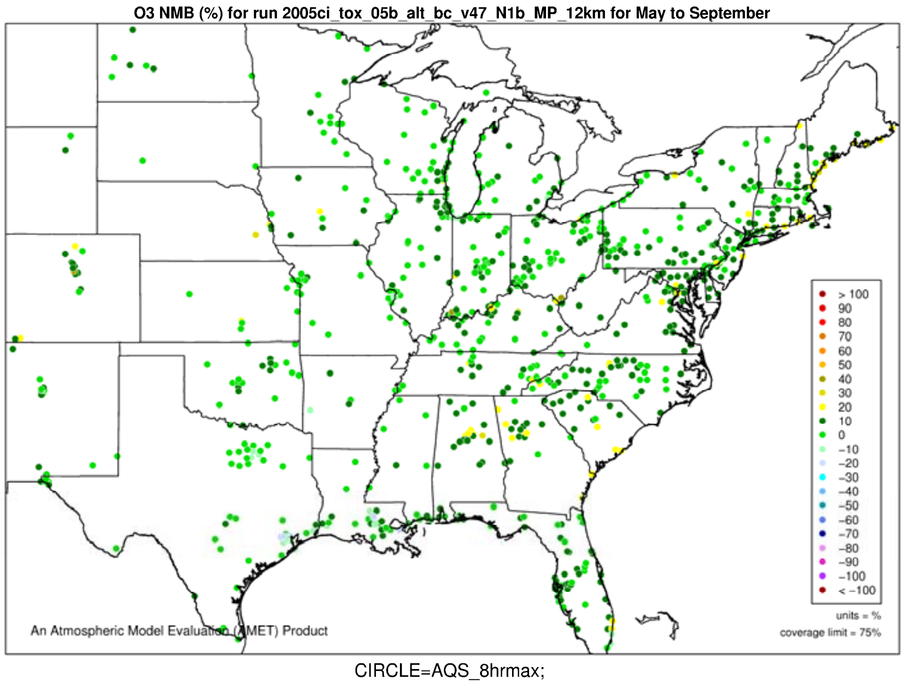


Figure C-11. Normalized Mean Bias (%) of eight-hour daily maximum ozone (40 ppb threshold) by monitor for Eastern U.S., seasonal aggregate 2005.

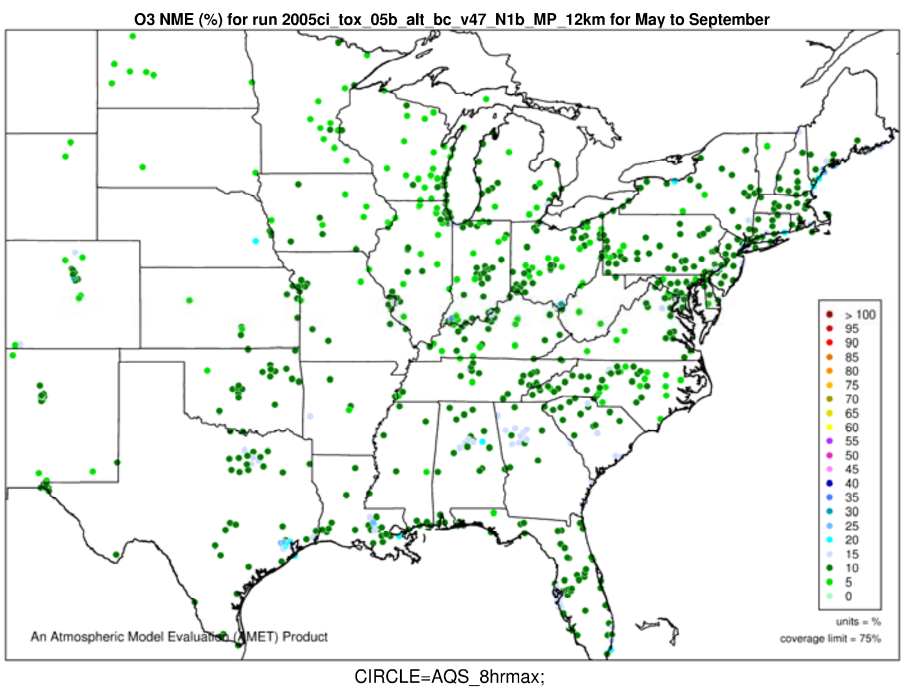


Figure C-12. Normalized Mean Error (%) of eight-hour daily maximum ozone (40 ppb threshold) by monitor for Eastern U.S., seasonal aggregate 2005.

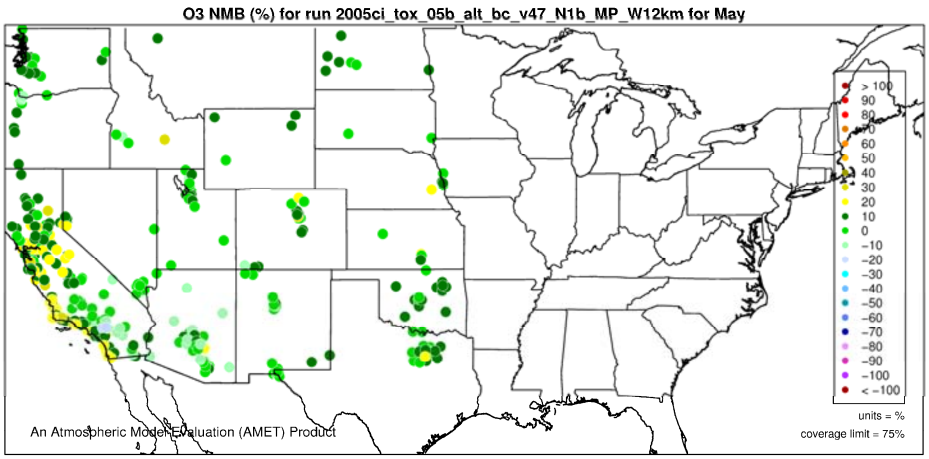


Figure C-13. Normalized Mean Bias (%) of eight-hour daily maximum ozone (40 ppb threshold) by monitor for Western U.S., May 2005.

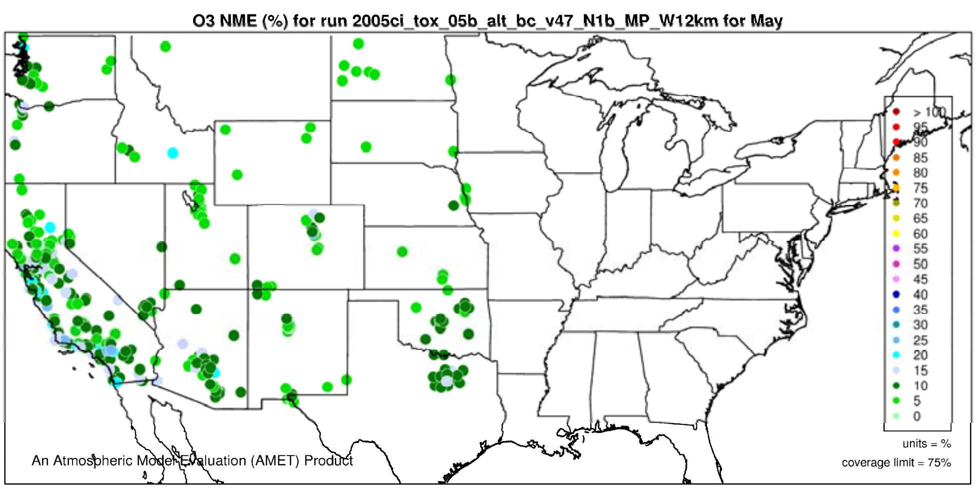


Figure C-14. Normalized Mean Error (%) of eight-hour daily maximum ozone (40 ppb threshold) by monitor for Western U.S., May 2005.

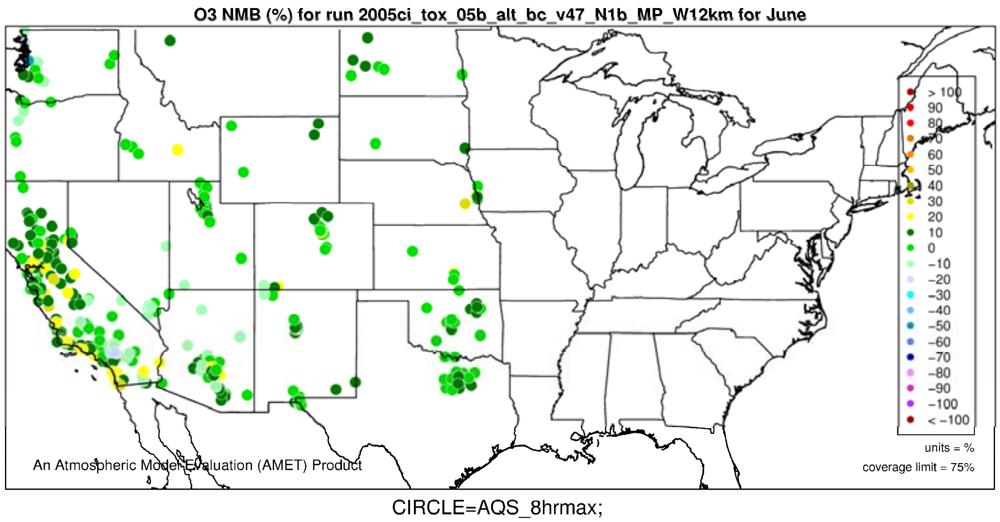


Figure C-15. Normalized Mean Bias (%) of eight-hour daily maximum ozone (40 ppb threshold) by monitor for Western U.S., June 2005.

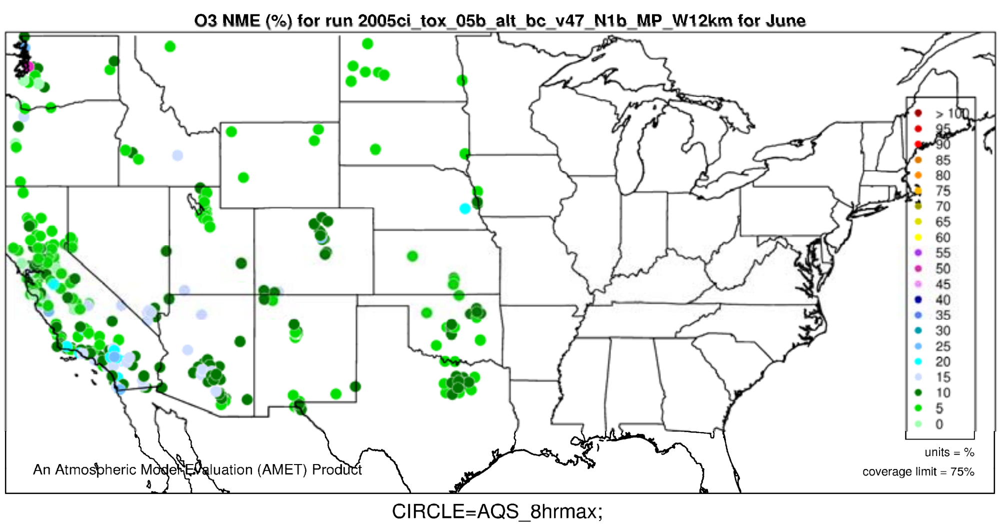


Figure C-16. Normalized Mean Error (%) of eight-hour daily maximum ozone (40 ppb threshold) by monitor for Western U.S., June 2005.

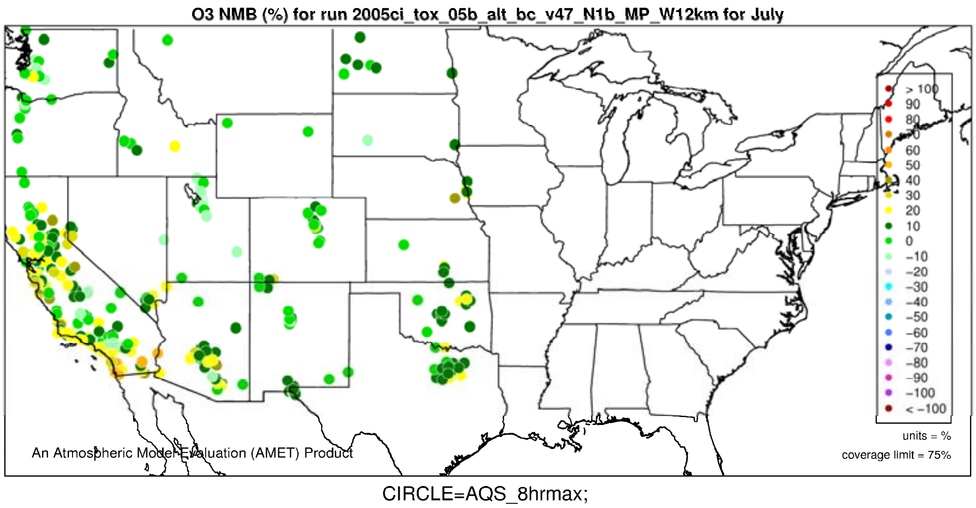


Figure C-17. Normalized Mean Bias (%) of eight-hour daily maximum ozone (40 ppb threshold) by monitor for Western U.S., July 2005.

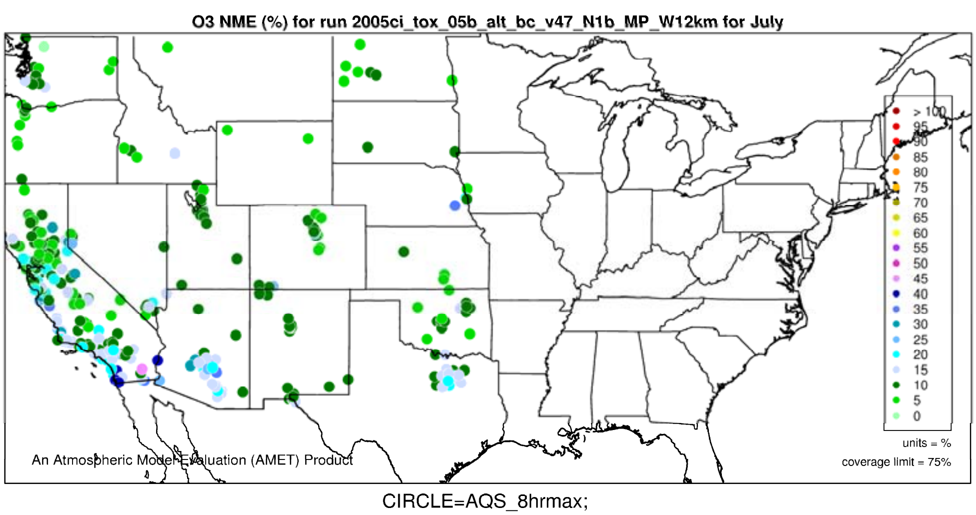


Figure C-18. Normalized Mean Error (%) of eight-hour daily maximum ozone (40 ppb threshold) by monitor for Western U.S., July 2005.

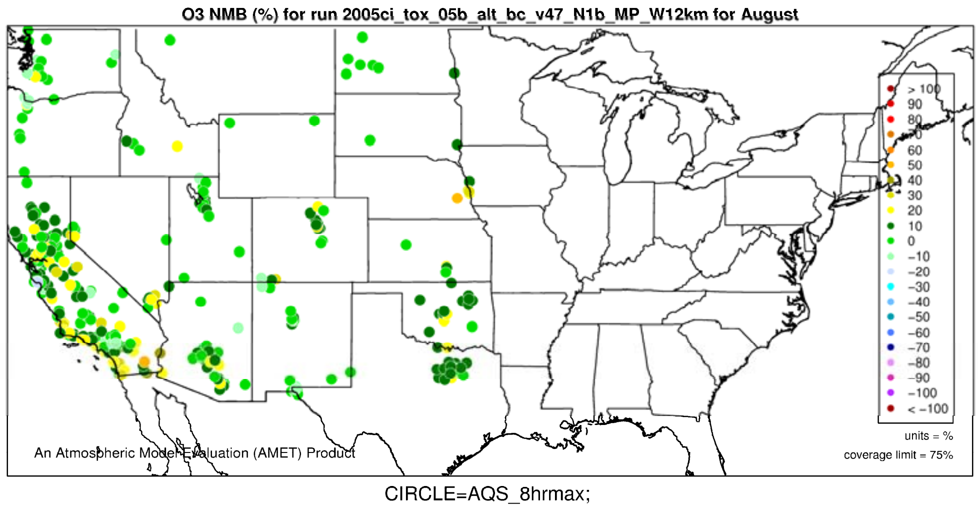


Figure C-19. Normalized Mean Bias (%) of eight-hour daily maximum ozone (40 ppb threshold) by monitor for Western U.S., August 2005.

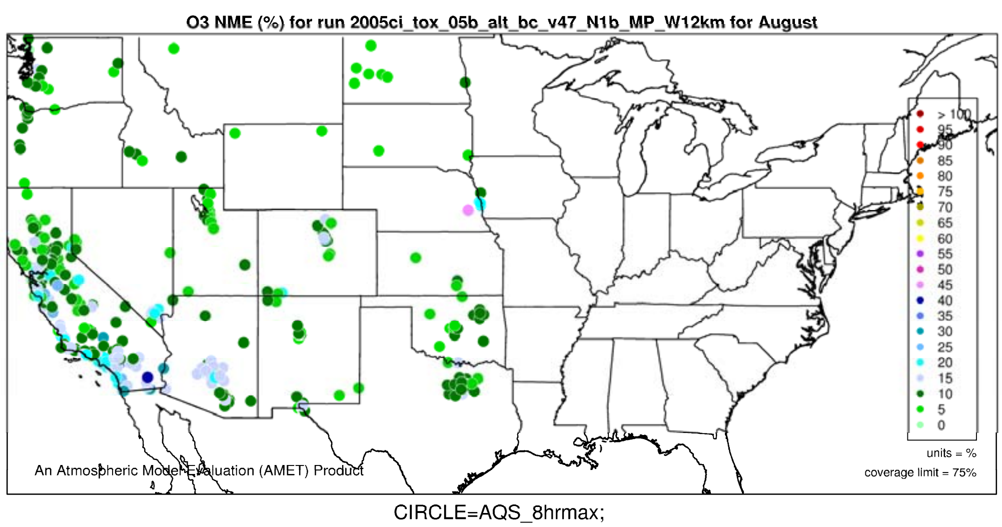


Figure C-20. Normalized Mean Error (%) of eight-hour daily maximum ozone (40 ppb threshold) by monitor for Western U.S., August 2005.

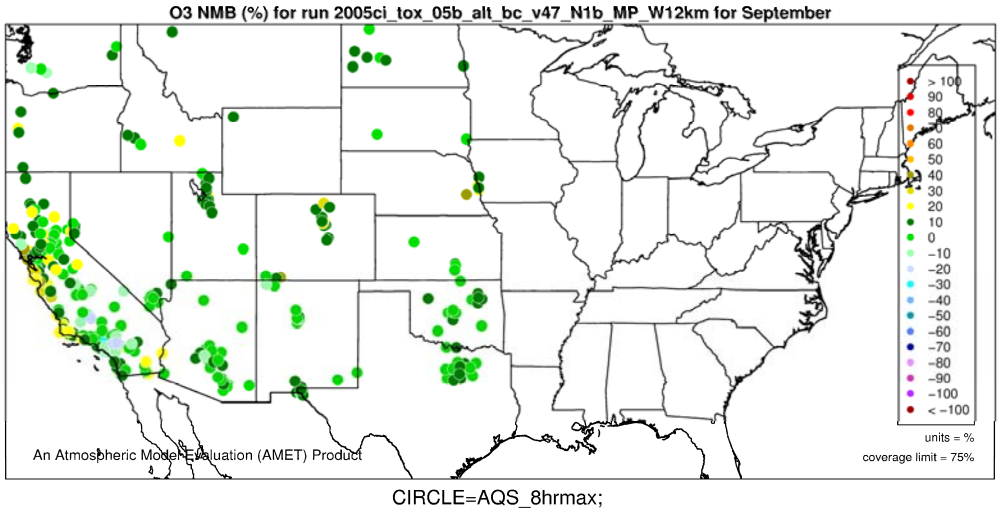


Figure C-21. Normalized Mean Bias (%) of eight-hour daily maximum ozone (40 ppb threshold) by monitor for Western U.S., September 2005.

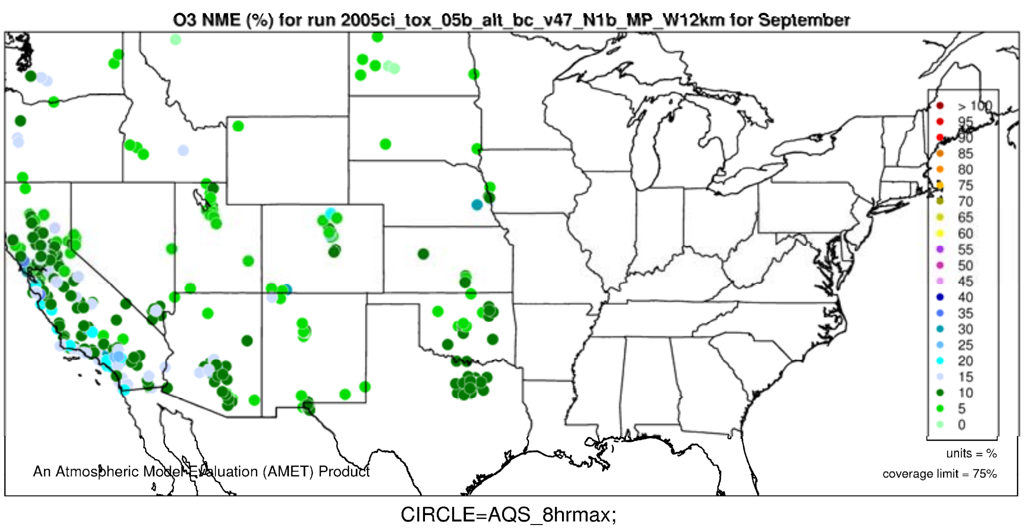


Figure C-22. Normalized Mean Error (%) of eight-hour daily maximum ozone (40 ppb threshold) by monitor for Western U.S., September 2005.

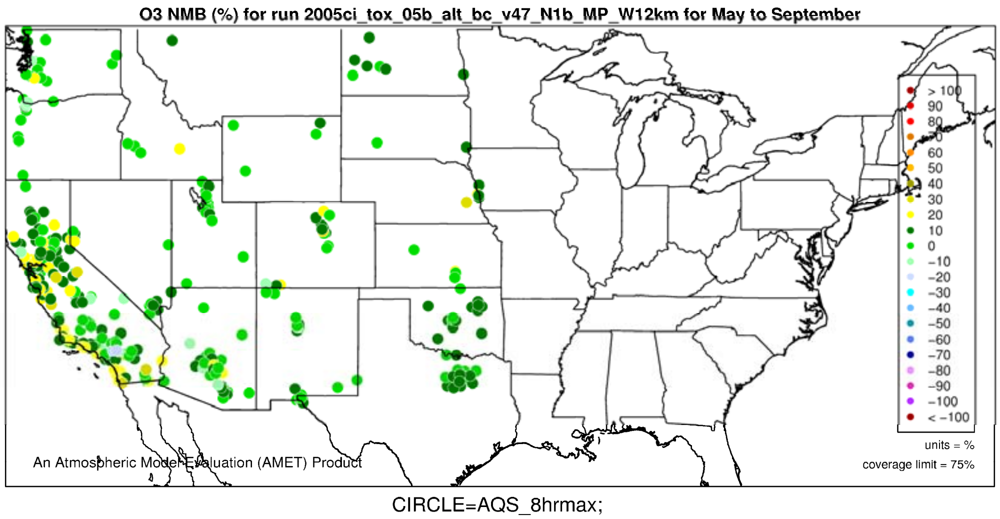


Figure C-23. Normalized Mean Bias (%) of eight-hour daily maximum ozone (40 ppb threshold) by monitor for Western U.S., seasonal aggregate 2005.

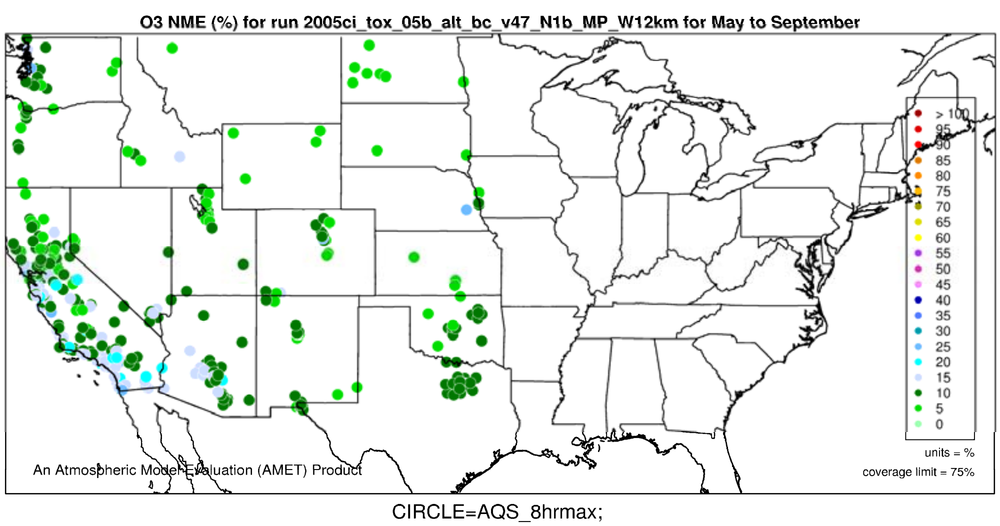


Figure C-24. Normalized Mean Error (%) of eight-hour daily maximum ozone (40 ppb threshold) by monitor for Western U.S., seasonal aggregate 2005.

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 above (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 better performance at 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 -32% to -5%. 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 5% to 66%), while nitrate is under-predicted in the 12-km Western domain (NMB in the range of -29% to -47%). Likewise, model performance of total nitrate at CASTNet sites shows an over-prediction in the East (NMB = 27%) and an under-prediction in the West (NMB = -3%). 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 ~60%. Although, EC is under-predicted at IMPROVE sites in the East and West with a NMB of ~ -20% and error of ~45%. Organic carbon is moderately under-predicted for all domains in the STN and IMPROVE networks (bias ~ -35% and error ~ 60%. 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	-0.8	37.6	-2.4	38.7
		12-km WUS	3440	-10.0	45.0	-9.5	44.4
		Midwest	2318	8.5	35.2	9.2	33.5
		Northeast	2977	10.8	41.6	9.9	38.8
		Southeast	2960	-13.7	34.0	-14.5	37.1
		Central U.S.	2523	-6.3	39.8	-9.8	44.3
		West	2826	-10.9	46.1	-10.6	45.0
	IMPROVE	12-km EUS	9321	-6.4	41.6	-7.2	43.6
		12-km WUS	10411	-19.9	44.6	-21.9	48.4
		Midwest	571	1.3	36.8	1.3	37.2
		Northeast	2339	12.1	47.7	8.1	44.3

		Southeast	1694	-17.6	37.5	-16.9	43.1
		Central U.S.	2376	-13.3	41.7	-11.9	46.2
		West	9258	-22.9	44.8	-23.5	48.6
Sulfate	STN	12-km EUS	13897	-12.3	33.2	-9.2	35.9
		12-km WUS	3920	-17.0	42.3	-7.8	42.8
		Midwest	2495	-5.2	34.0	0.7	34.8
		Northeast	3441	-7.7	32.1	-4.0	33.9
		Southeast	3499	-14.5	30.9	-12.2	33.4
		Central U.S.	2944	-22.5	37.2	-19.5	41.6
		West	3157	-15.5	45.8	-6.7	44.0
	IMPROVE	12-km EUS	9034	-15.2	34.5	-6.2	38.9
		12-km WUS	10002	-14.4	41.0	2.7	44.5
		Midwest	531	-12.7	32.5	-5.0	34.6
		Northeast	2253	-7.7	34.3	-0.2	37.3
		Southeast	1685	-17.8	32.7	-12.2	36.2
		Central U.S.	2350	-23.5	36.6	-16.1	40.7
		West	8896	-10.5	42.3	5.0	45.1
	CASTNet	12-km EUS	3170	-19.3	24.8	-18.5	27.8
		12-km WUS	1142	-24.6	33.6	-16.6	35.2
		Midwest	615	-16.7	23.4	-14.8	24.8
		Northeast	786	-14.2	22.6	-12.3	24.8
		Southeast	1099	-21.5	24.7	-23.6	27.7
		Central U.S.	300	-32.2	34.3	-33.6	38.4
		West	1091	-23.7	33.8	-15.8	35.2
Nitrate	STN	12-km EUS	12741	25.5	70.4	-8.1	78.1
		12-km WUS	3655	-41.7	65.3	-70.8	97.5
		Midwest	2495	29.8	64.7	17.1	63.9
		Northeast	3442	37.0	73.9	3.2	73.6
		Southeast	3499	13.1	78.2	-27.5	86.0
		Central U.S.	1812	5.2	58.8	-6.2	71.6
		West	31339	-47.3	65.4	-79.1	99.9
	IMPROVE	12-km EUS	9027	34.2	86.9	-31.6	101.6
		12-km WUS	9987	-29.7	72.5	-93.8	124.0
		Midwest	531	20.7	69.8	-7.3	82.1
		Northeast	2248	66.4	106.9	-1.0	95.4
		Southeast	1685	42.5	106.6	-37.5	105.2
		Central U.S.	2350	22.8	72.7	-20.5	95.0
		West	8881	-45.7	75.6	-102.3	128.4
Total Nitrate (NO_3 + HNO_3)	CASTNet	12-km EUS	3170	27.3	40.3	21.9	38.1
		12-km WUS	1142	-3.3	34.5	6.4	39.9
		Midwest	615	26.1	37.4	26.9	34.1
		Northeast	786	40.6	46.0	34.4	42.4
		Southeast	1099	25.7	41.4	17.2	39.2
		Central U.S.	300	10.4	33.9	7.3	33.3

		West	1091	-4.7	35.7	6.4	40.5
Ammonium	STN	12-km EUS	13897	6.7	42.3	12.6	45.4
		12-km WUS	3893	-14.9	55.3	7.1	55.0
		Midwest	2495	14.3	42.0	22.3	42.2
		Northeast	3498	14.7	44.3	25.0	46.3
		Southeast	3882	0.8	39.1	6.5	42.0
		Central U.S.	3059	-4.3	43.6	-0.2	50.4
		West	3130	-20.5	59.0	5.8	57.2
	CASTNet	12-km EUS	3170	-1.3	34.6	0.4	35.8
		12-km WUS	1142	-14.5	38.8	-12.1	40.1
		Midwest	615	8.1	34.6	12.8	33.3
		Northeast	786	6.2	37.2	11.3	35.9
		Southeast	1099	-13.6	32.6	-13.7	36.5
		Central U.S.	300	-4.2	35.4	-1.1	39.6
		West	1091	-20.8	39.1	-13.9	40.2
Elemental Carbon	STN	12-km EUS	14038	25.9	66.0	18.2	54.3
		12-km WUS	3814	31.1	77.7	19.5	62.5
		Midwest	2502	18.7	51.7	20.1	47.1
		Northeast	3479	37.7	70.5	26.7	54.7
		Southeast	3877	10.7	59.1	8.1	49.4
		Central U.S.	3221	48.1	86.3	26.5	64.3
		West	3015	38.7	82.8	21.0	65.1
	IMPROVE	12-km EUS	8668	-25.9	49.1	-28.3	56.0
		12-km WUS	9495	-10.2	57.2	-17.8	60.4
		Midwest	602	-16.8	41.8	-28.3	50.4
		Northeast	2117	-4.8	48.8	-15.5	54.1
		Southeast	1584	-46.1	51.4	-51.5	62.8
		Central U.S.	2123	-31.3	49.5	-30.1	56.5
		West	8518	-9.6	58.2	-18.2	61.5
Organic Carbon	STN	12-km EUS	12619	-35.1	52.6	-32.5	63.9
		12-km WUS	3582	-32.1	56.7	-28.2	61.3
		Midwest	2380	-37.3	51.9	-31.0	62.5
		Northeast	3323	-17.4	52.7	-13.7	60.3
		Southeast	3802	-45.7	52.9	-48.7	66.7
		Central U.S.	2259	-38.8	53.4	-37.3	66.9
		West	3060	-31.7	57.6	-27.8	61.4
	IMPROVE	12-km EUS	8662	-29.9	50.6	-34.3	59.1
		12-km WUS	9495	-24.0	57.1	-29.4	62.8
		Midwest	601	-33.1	43.6	-39.3	53.2
		Northeast	2116	-7.7	52.4	-14.4	53.5
		Southeast	1587	-37.8	46.7	-48.0	60.2
		Central U.S.	2123	-42.5	54.2	-46.8	65.2
		West	8518	-22.3	57.3	-28.1	62.7

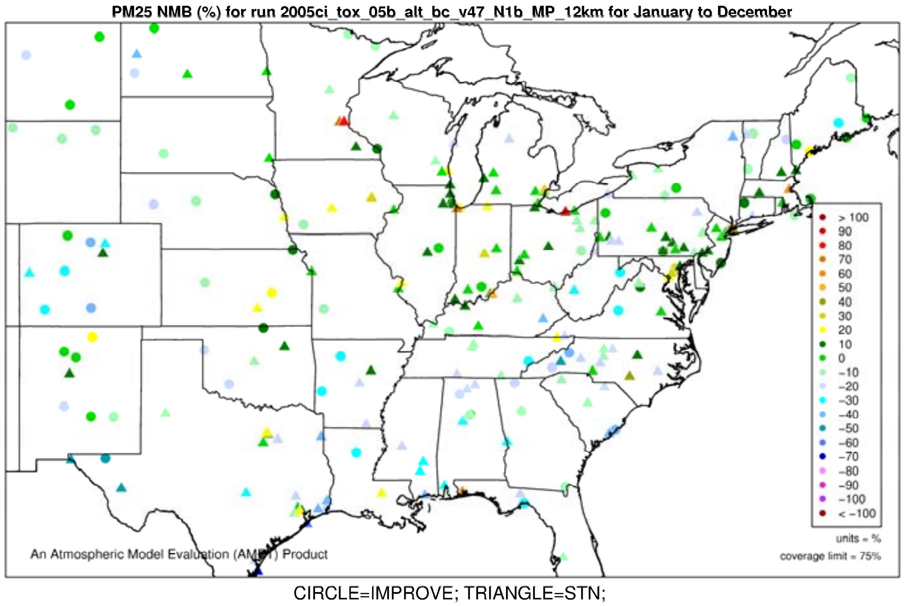


Figure D-1. Normalized Mean Bias (%) of annual $PM_{2.5}$ by monitor for Eastern U.S., 2005.

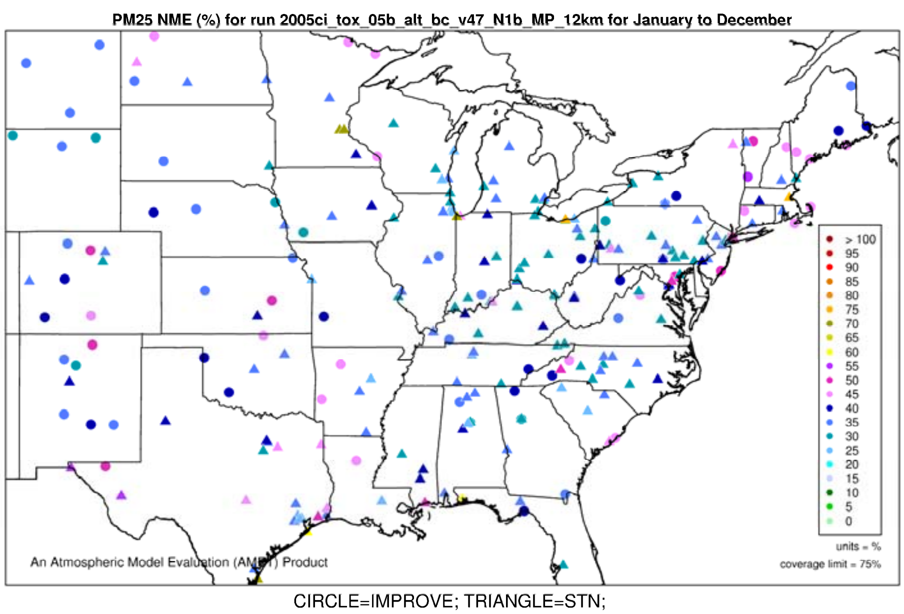


Figure D-2. Normalized Mean Error (%) of annual $PM_{2.5}$ by monitor for Eastern U.S., 2005.

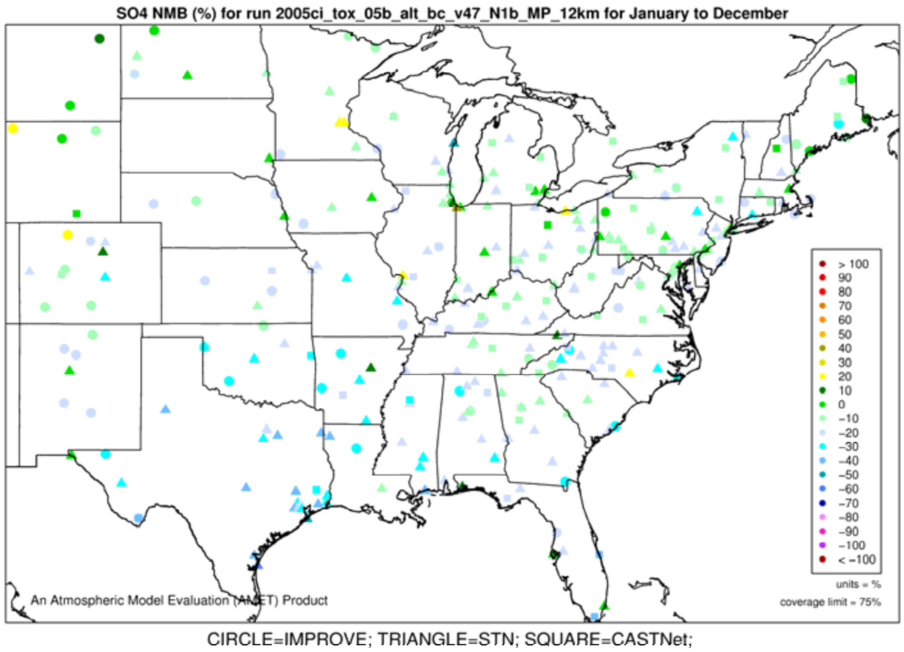


Figure D-3. Normalized Mean Bias (%) of annual sulfate by monitor for Eastern U.S., 2005.

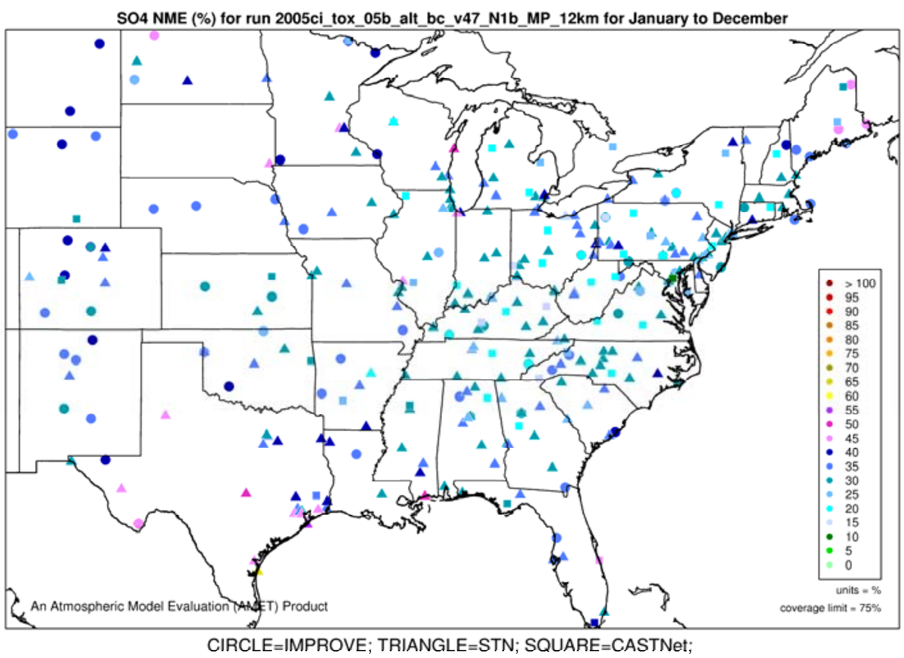


Figure D-4. Normalized Mean Error (%) of annual sulfate by monitor for Eastern U.S., 2005.

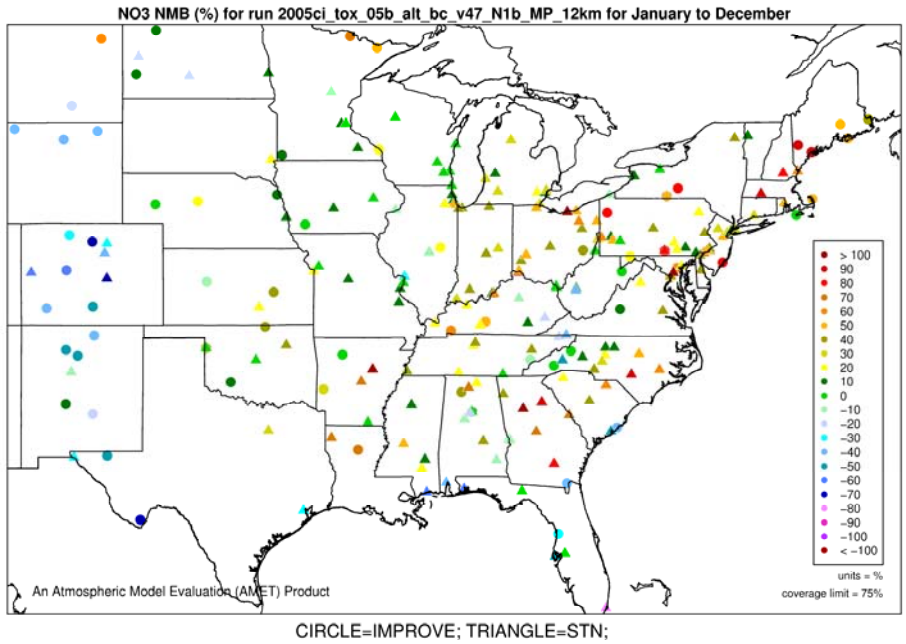


Figure D-5. Normalized Mean Bias (%) of annual nitrate by monitor for Eastern U.S., 2005.

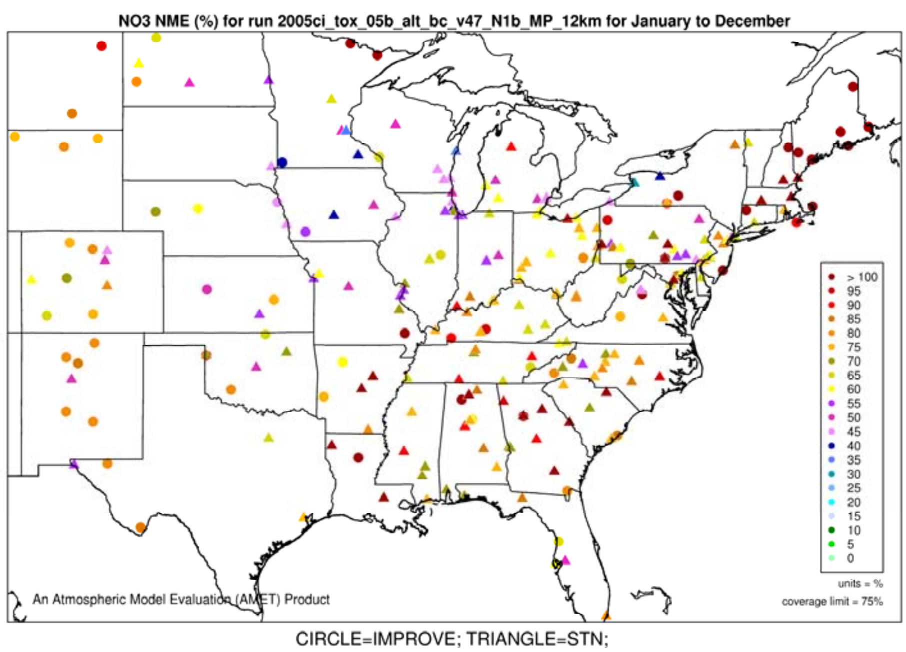


Figure D-6. Normalized Mean Error (%) of annual nitrate by monitor for Eastern U.S., 2005.

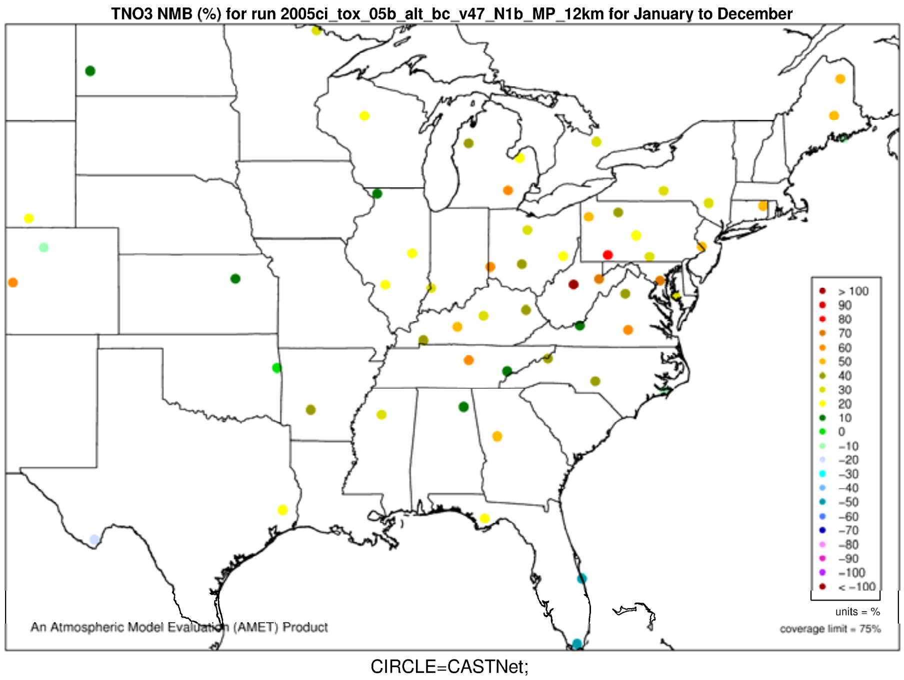


Figure D-7. Normalized Mean Bias (%) of annual total nitrate by monitor for Eastern U.S., 2005.

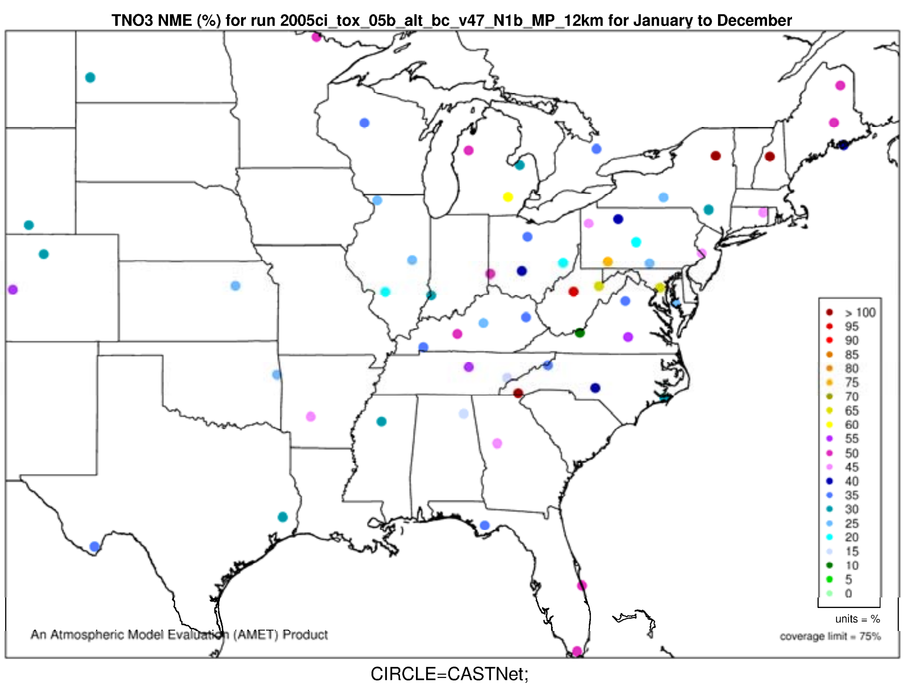


Figure D-8. Normalized Mean Error (%) of annual total nitrate by monitor for Eastern U.S., 2005.

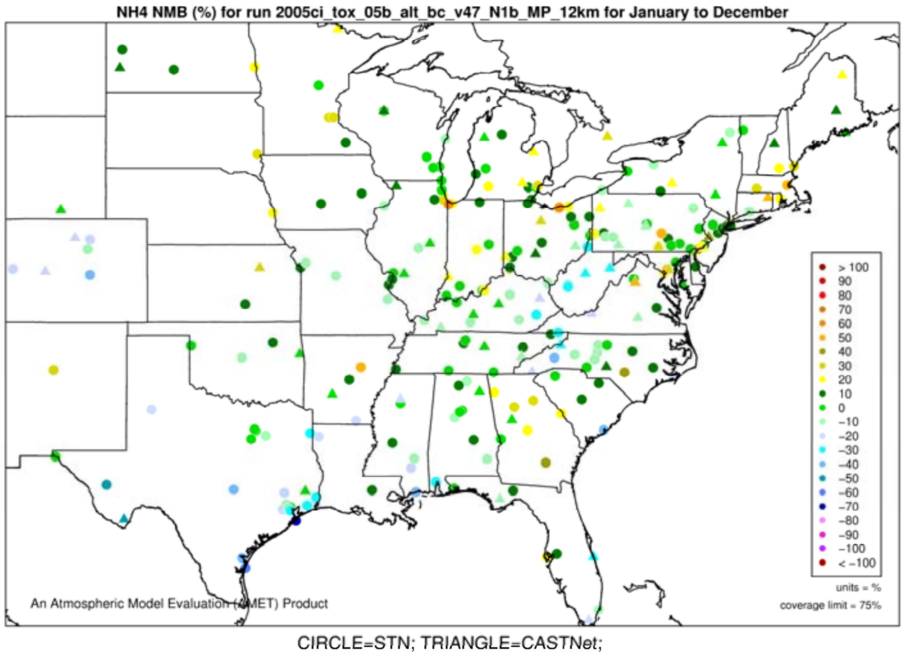


Figure D-9. Normalized Mean Bias (%) of annual ammonium by monitor for Eastern U.S., 2005.

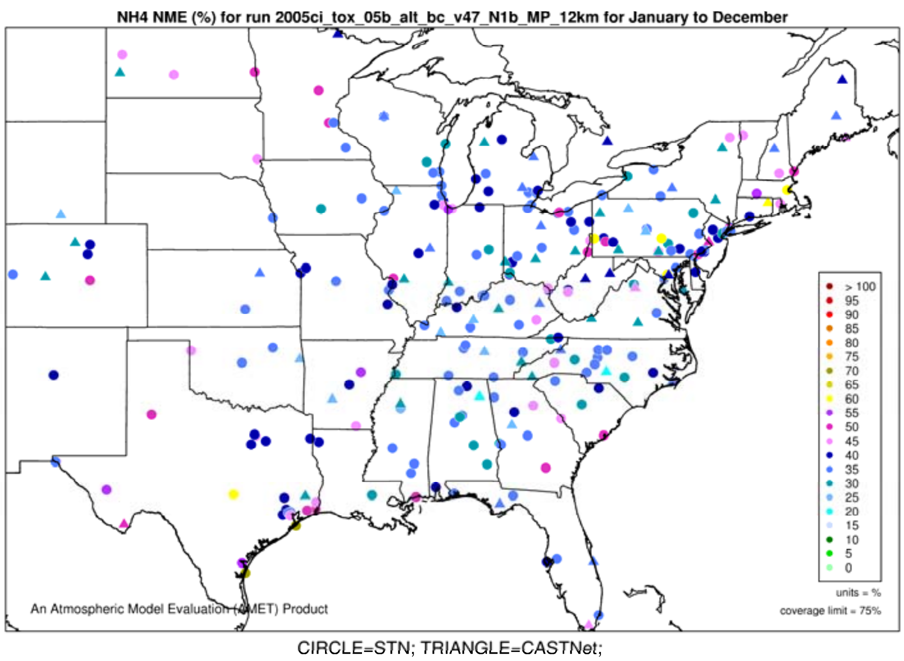


Figure D-10. Normalized Mean Error (%) of annual ammonium by monitor for Eastern U.S., 2005.

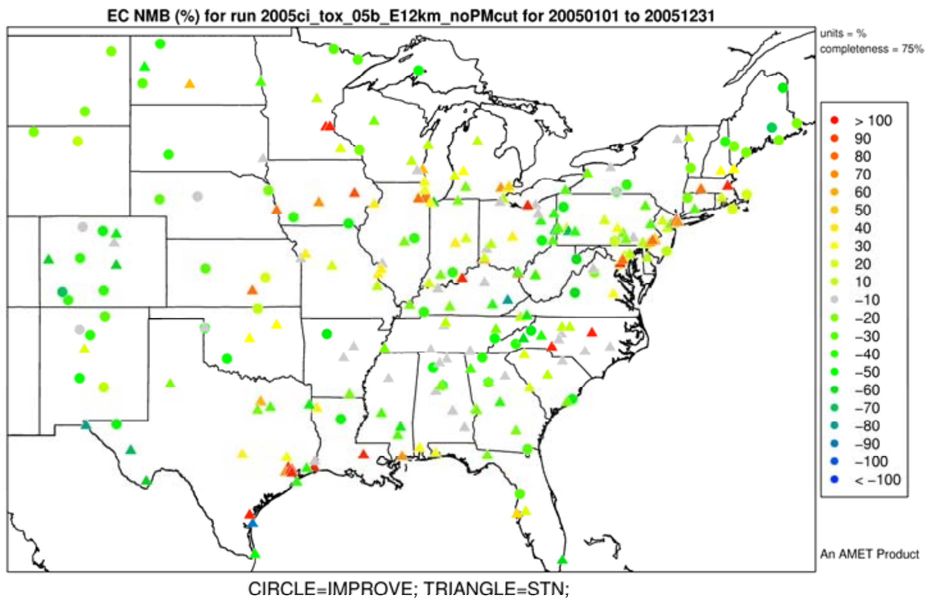


Figure D-11. Normalized Mean Bias (%) of annual elemental carbon by monitor for Eastern U.S., 2005.

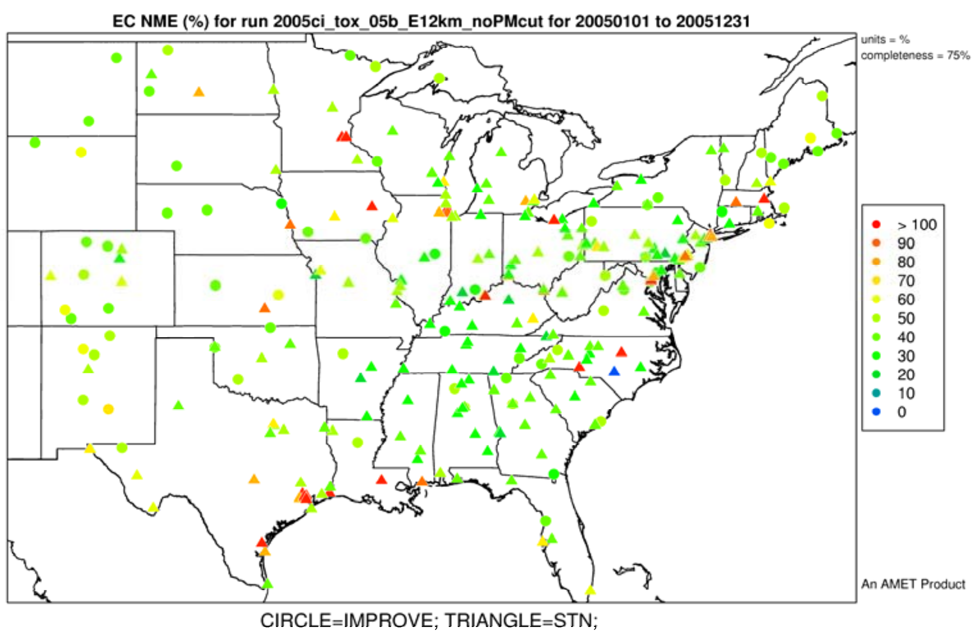


Figure D-12. Normalized Mean Error (%) of annual elemental carbon by monitor for Eastern U.S., 2005.

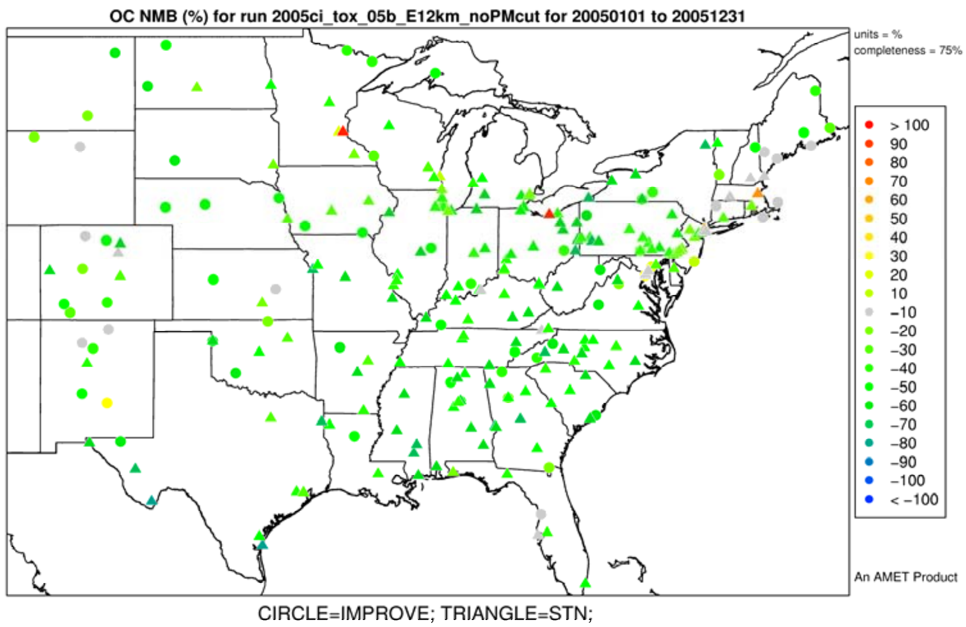


Figure D-13. Normalized Mean Bias (%) of annual organic carbon by monitor for Eastern U.S., 2005.

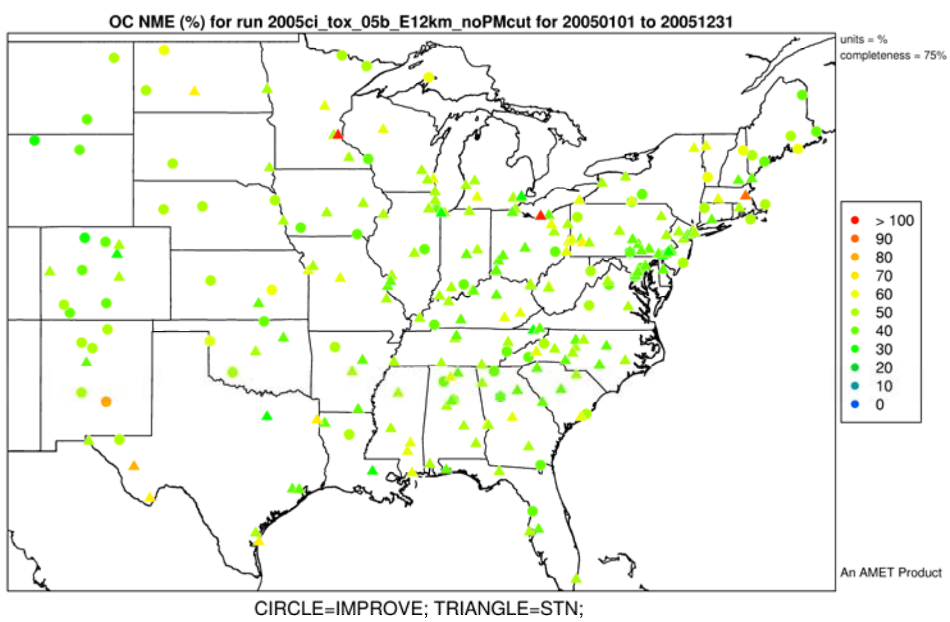


Figure D-14. Normalized Mean Error (%) of annual organic carbon by monitor for Eastern U.S., 2005.

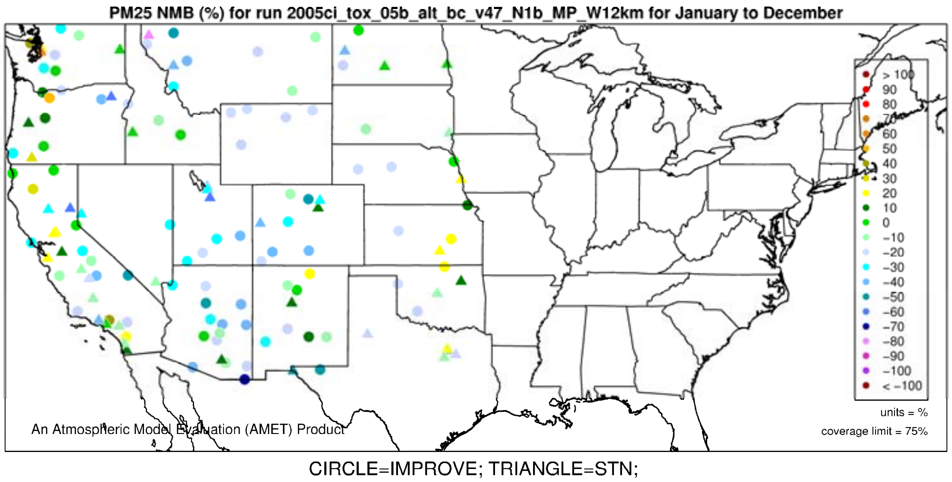


Figure D-15. Normalized Mean Bias (%) of annual $PM_{2.5}$ by monitor for Western U.S., 2005.

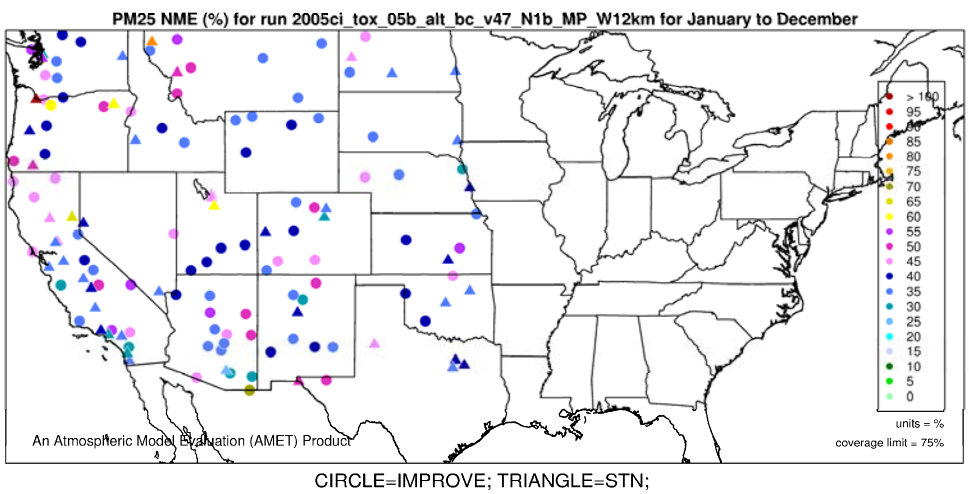


Figure D-16. Normalized Mean Error (%) of annual $PM_{2.5}$ by monitor for Western U.S., 2005.

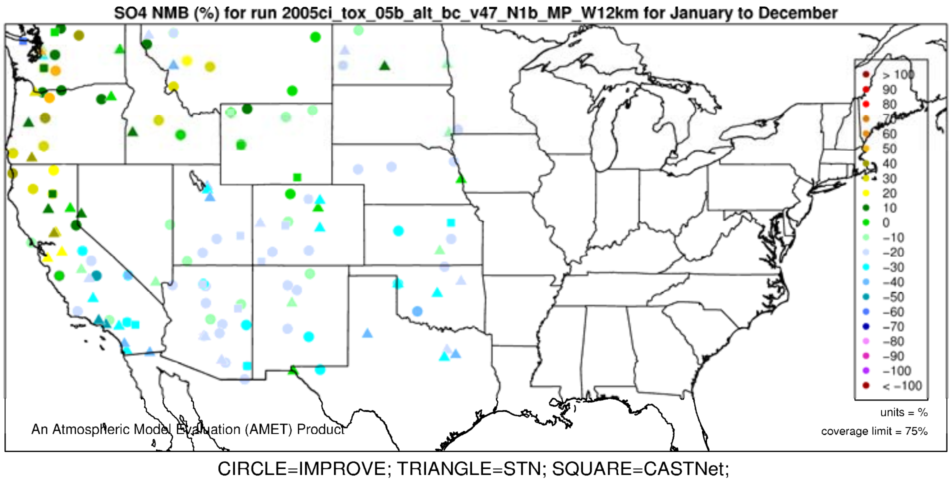


Figure D-17. Normalized Mean Bias (%) of annual sulfate by monitor for Western U.S., 2005.

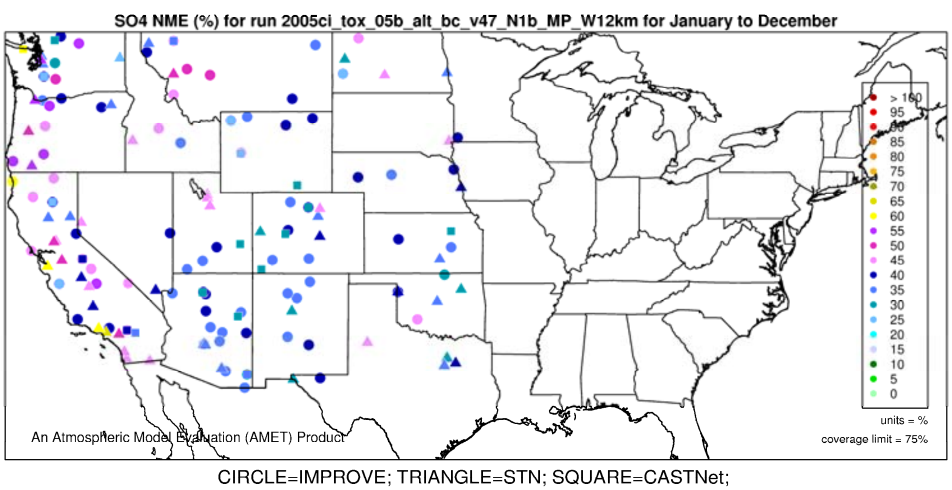


Figure D-18. Normalized Mean Error (%) of annual sulfate by monitor for Western U.S., 2005.

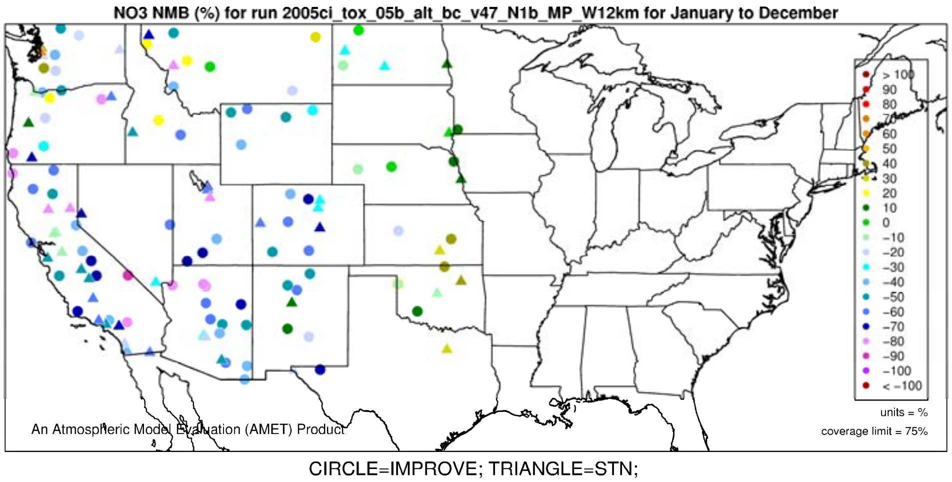


Figure D-19. Normalized Mean Bias (%) of annual nitrate by monitor for Western U.S., 2005.

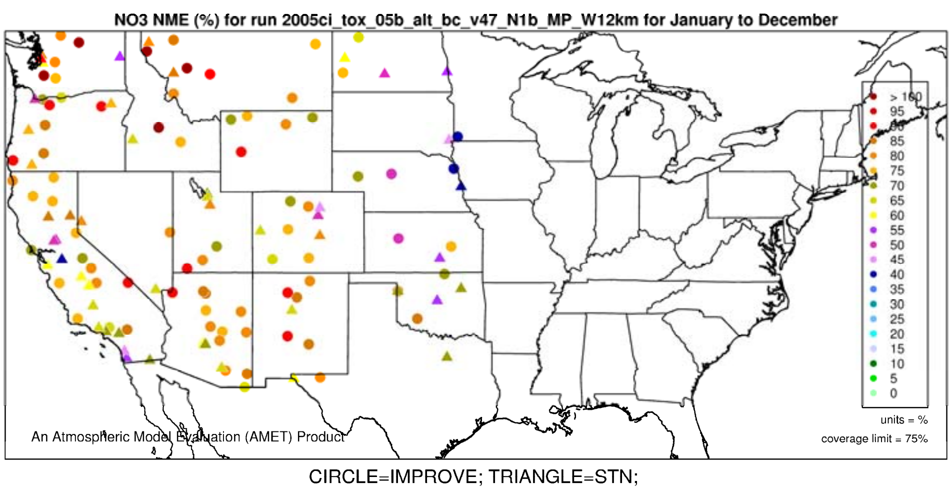


Figure D-20. Normalized Mean Error (%) of annual nitrate by monitor for Western U.S., 2005.

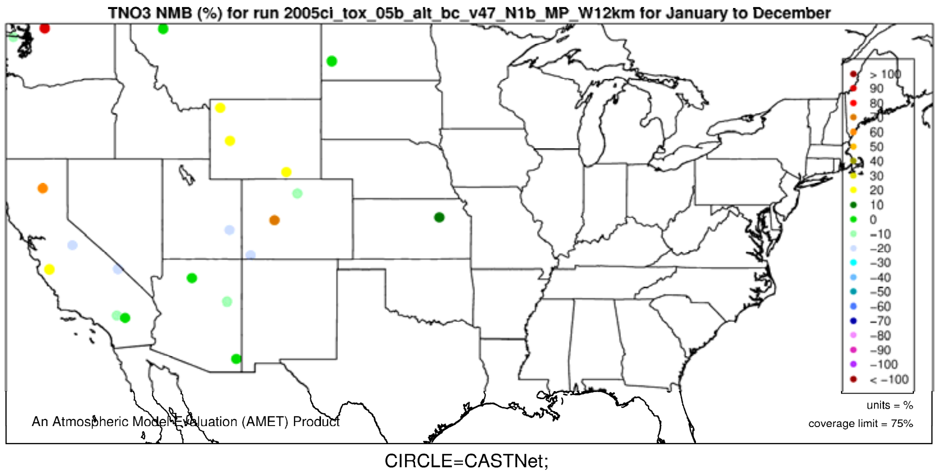


Figure D-21. Normalized Mean Bias (%) of annual total nitrate by monitor for Western U.S., 2005.

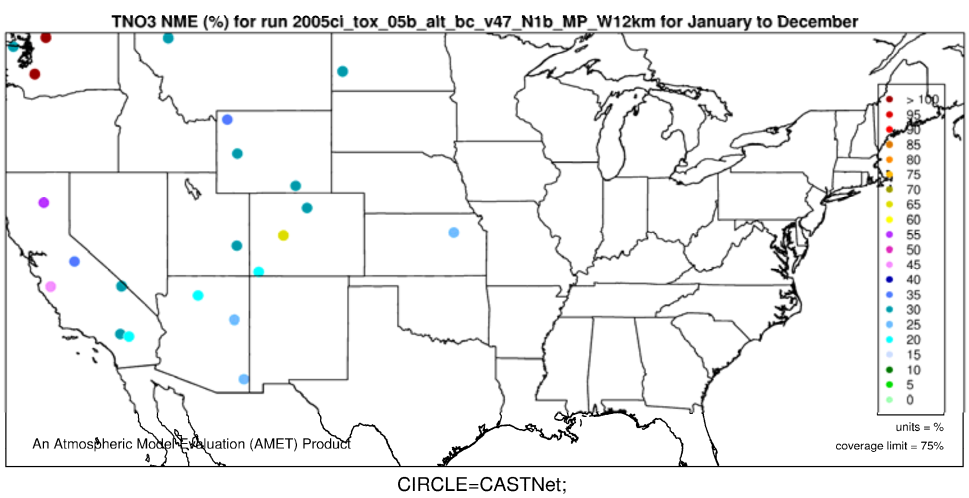


Figure D-22. Normalized Mean Error (%) of annual total nitrate by monitor for Western U.S., 2005.

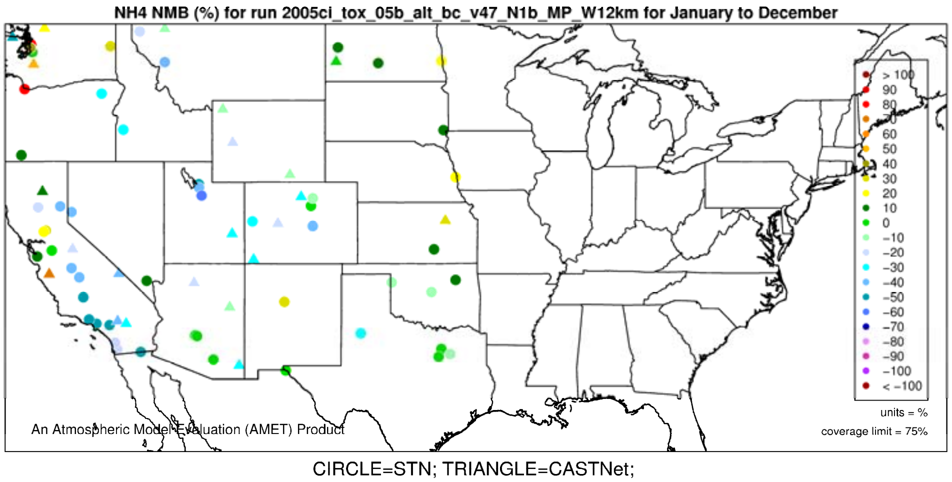


Figure D-23. Normalized Mean Bias (%) of annual ammonium by monitor for Western U.S., 2005.

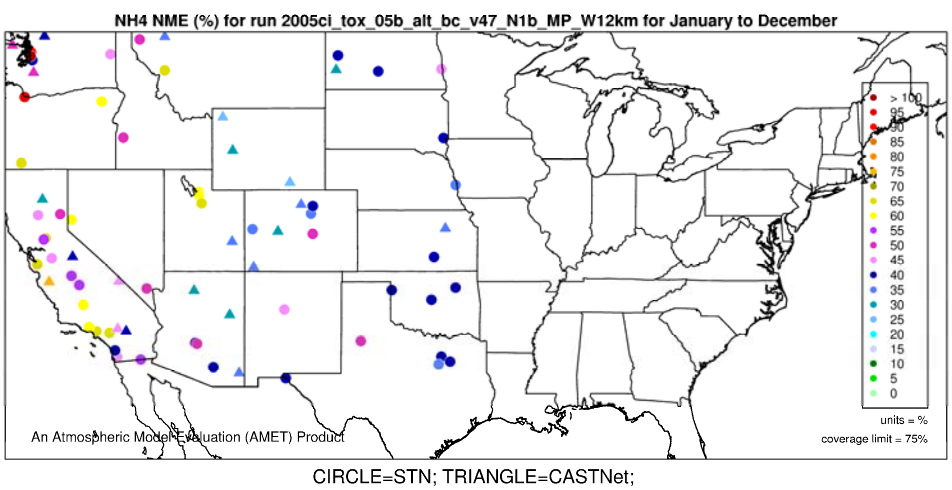


Figure D-24. Normalized Mean Error (%) of annual ammonium by monitor for Western U.S., 2005.

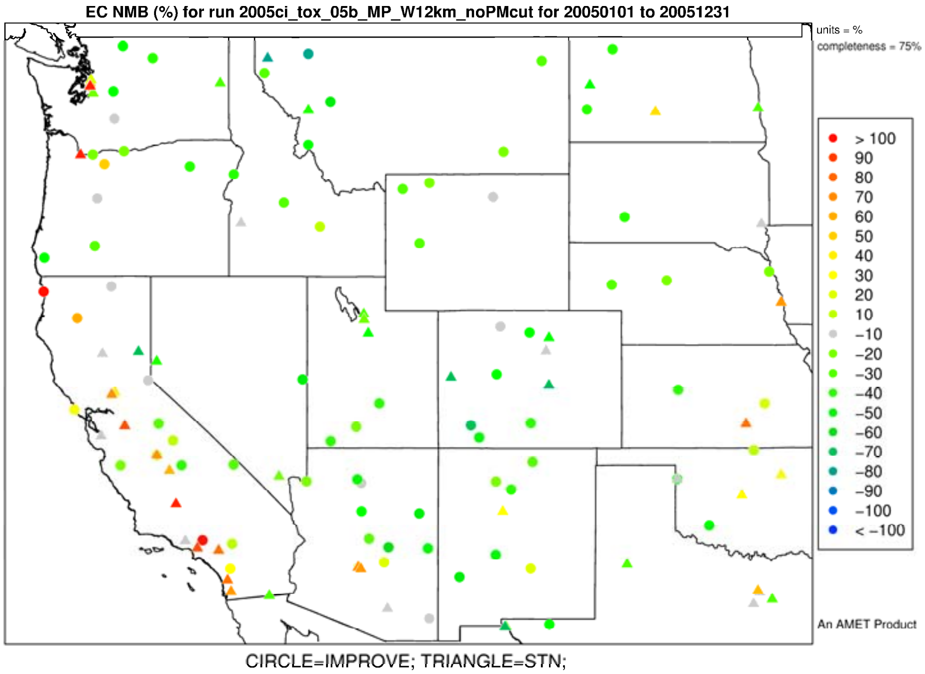


Figure D-25. Normalized Mean Bias (%) of annual elemental carbon by monitor for Western U.S., 2005.

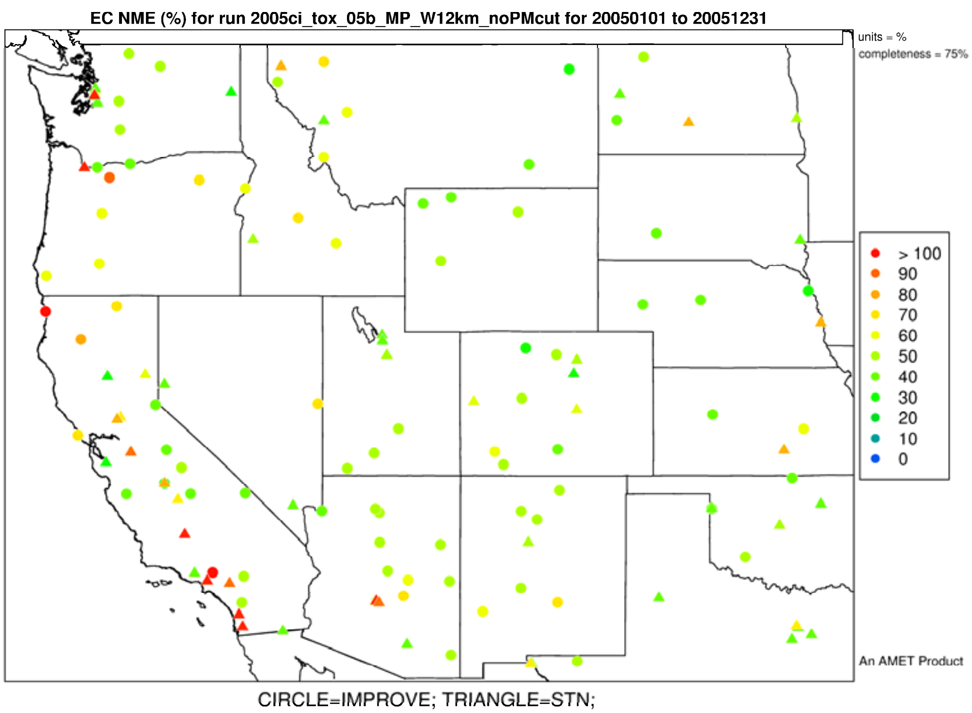


Figure D-26. Normalized Mean Error (%) of annual elemental carbon by monitor for Western U.S., 2005.

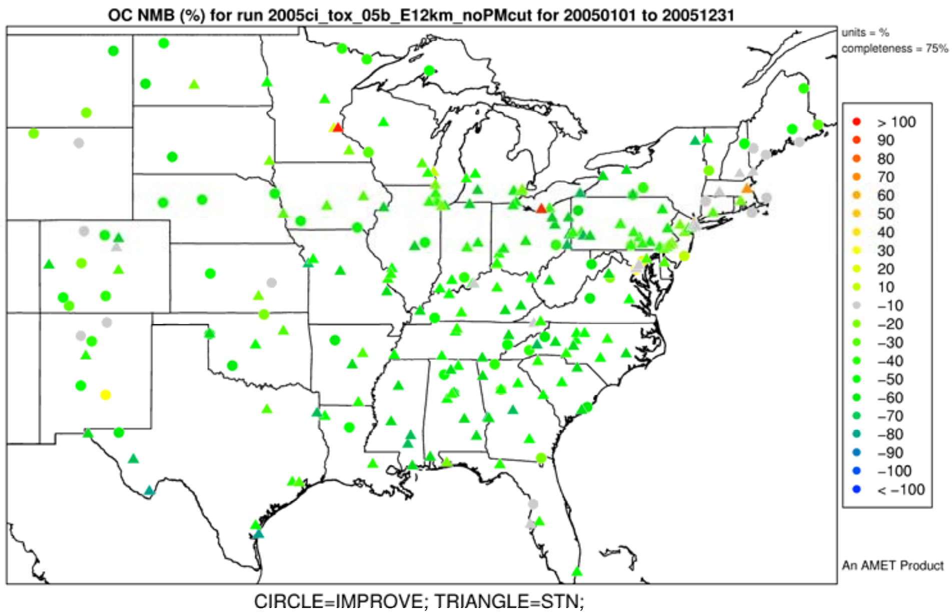


Figure D-27. Normalized Mean Bias (%) of annual organic carbon by monitor for Western U.S., 2005.

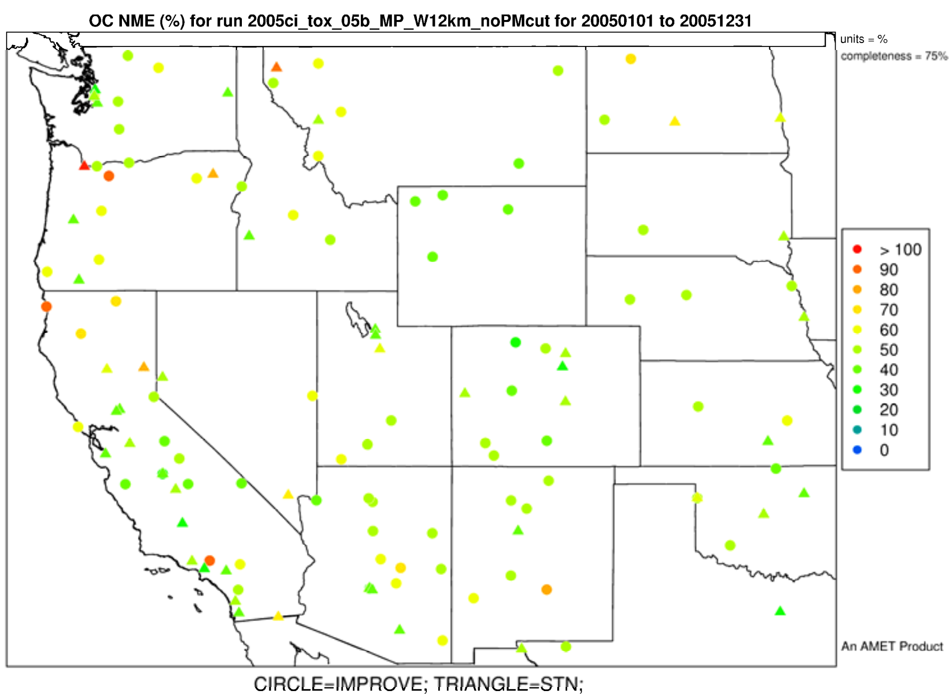


Figure D-28. Normalized Mean Error (%) of annual organic carbon by monitor for Western U.S., 2005.

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 cooler seasons (winter and fall) in the 12-km Eastern domain for both STN and IMPROVE networks. In the fall season, $PM_{2.5}$ is over-predicted for Eastern STN sites with NMB values ranging from 0% to 15% whereas $PM_{2.5}$ is under-predicted at Eastern IMPROVE sites. In the winter season, $PM_{2.5}$ is over-predicted for Eastern STN and IMPROVE networks with NMB values ranging from 3% to 39% and FB values ranging from 60% to 72%. However, in the 12-km Western domain, $PM_{2.5}$ is under-predicted in the winter (NMB in the range of -2% to -11%) and the fall (NMB in the range of -7% to -26%). 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, CMAQ generally over-predicts $PM_{2.5}$ in the East and West at urban STN and rural IMPROVE sites. In the summer season, $PM_{2.5}$ is under-predicted in the East and West for STN and IMPROVE (NMB = ~ 30% and NME = ~40%).

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	2861	8.8	37.8	5.5	36.9
		12-km WUS	895	-6.2	54.7	-3.2	53.0
		Northeast	716	22.8	40.9	18.1	35.7
		Midwest	542	7.3	32.3	8.5	31.1
		Southeast	762	-2.6	35.7	-5.0	36.6
		Central	635	10.0	43.0	4.5	43.0
		West	739	-10.9	55.0	-8.7	54.6
	IMPROVE	12-km EUS	2213	16.3	44.7	13.4	43.3
		12-km WUS	2493	-1.9	49.3	-2.2	49.0
		Northeast	573	39.4	54.3	28.7	44.0
		Midwest	143	7.1	34.3	4.7	34.3
		Southeast	406	3.6	38.6	-0.9	41.0
		Central	546	5.6	43.1	5.5	44.6
		West	2217	-8.8	49.3	-4.3	49.4
Spring	STN	12-km EUS	3159	10.5	41.2	6.5	39.1
		12-km WUS	964	0.5	43.2	-1.1	41.2
		Northeast	795	31.1	51.4	24.6	43.3
		Midwest	612	31.2	46.2	25.1	39.5
		Southeast	798	-7.3	33.1	-7.8	34.2
		Central	752	-6.6	37.1	-9.4	40.8
		West	773	3.2	45.5	-0.2	41.9
	IMPROVE	12-km EUS	2385	3.4	42.5	0.2	41.5

		12-km WUS	2692	-24.3	43.0	-26.6	47.0
		Northeast	630	33.9	55.7	20.2	45.5
		Midwest	153	20.6	44.4	16.7	41.5
		Southeast	429	-8.6	34.5	-7.0	36.3
		Central	601	-14.6	39.4	-12.5	43.5
		West	2389	-27.1	44.4	-28.2	47.5
Summer	STN	12-km EUS	2950	-29.9	37.8	-36.2	46.5
		12-km WUS	935	-20.9	35.9	-21.0	40.3
		Northeast	754	-27.7	36.1	-30.5	41.6
		Midwest	558	-21.1	30.8	-21.6	33.8
		Southeast	722	-39.1	42.7	-49.9	54.8
		Central	701	-29.5	40.4	-38.8	53.1
		West	758	-18.2	36.2	-19.0	40.3
	IMPROVE	12-km EUS	2277	-38.1	43.7	-45.2	53.4
		12-km WUS	2433	-27.7	43.5	-31.1	48.5
		Northeast	580	-32.6	41.2	-41.3	50.5
		Midwest	156	-31.1	63.6	-33.8	41.9
		Southeast	421	-46.6	48.4	-63.1	67.7
		Central	568	-40.7	45.9	-49.1	57.7
		West	2155	-26.0	43.7	-29.7	48.0
Fall	STN	12-km EUS	2802	-0.9	36.8	1.3	37.0
		12-km WUS	962	-6.9	46.2	-4.9	45.3
		Northeast	755	15.1	44.8	10.9	39.2
		Midwest	606	0.1	32.2	4.4	31.6
		Southeast	785	-17.0	32.5	-16.0	36.0
		Central	435	6.9	42.4	11.1	42.9
		West	812	-9.1	47.2	-7.8	45.8
	IMPROVE	12-km EUS	2256	-7.4	41.8	-8.2	43.3
		12-km WUS	2600	-21.6	46.9	-27.2	51.1
		Northeast	556	14.55	48.2	7.1	43.1
		Midwest	119	-5.3	37.1	-2.7	39.2
		Southeast	438	-23.6	36.5	-22.8	42.4
		Central	549	-8.01	44.3	-5.4	47.4
		West	2304	-26.5	46.0	-30.3	51.1

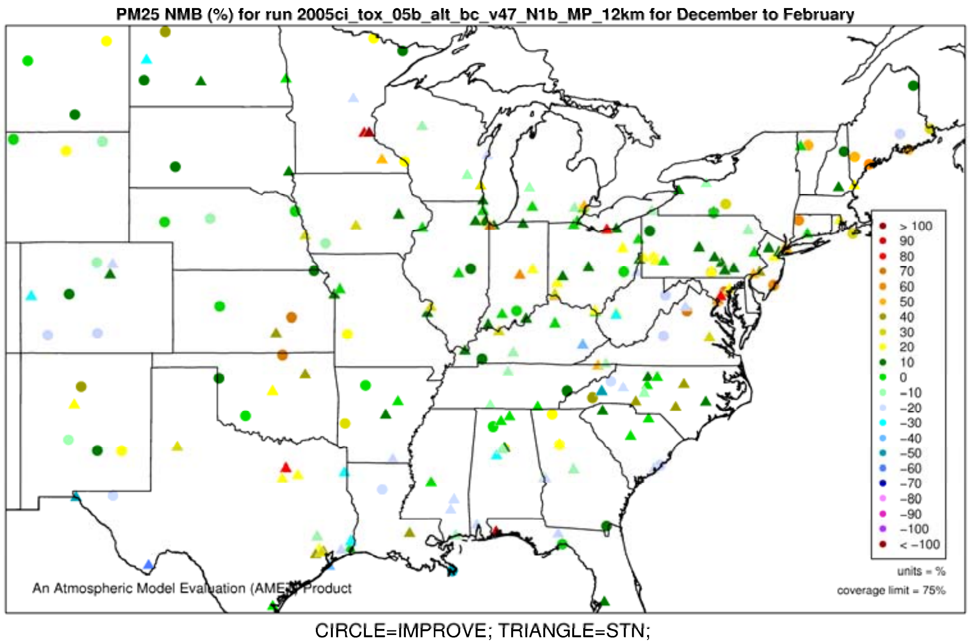


Figure E-1. Normalized Mean Bias (%) of $PM_{2.5}$ by monitor for 12-km Eastern U.S. domain, Winter 2005.

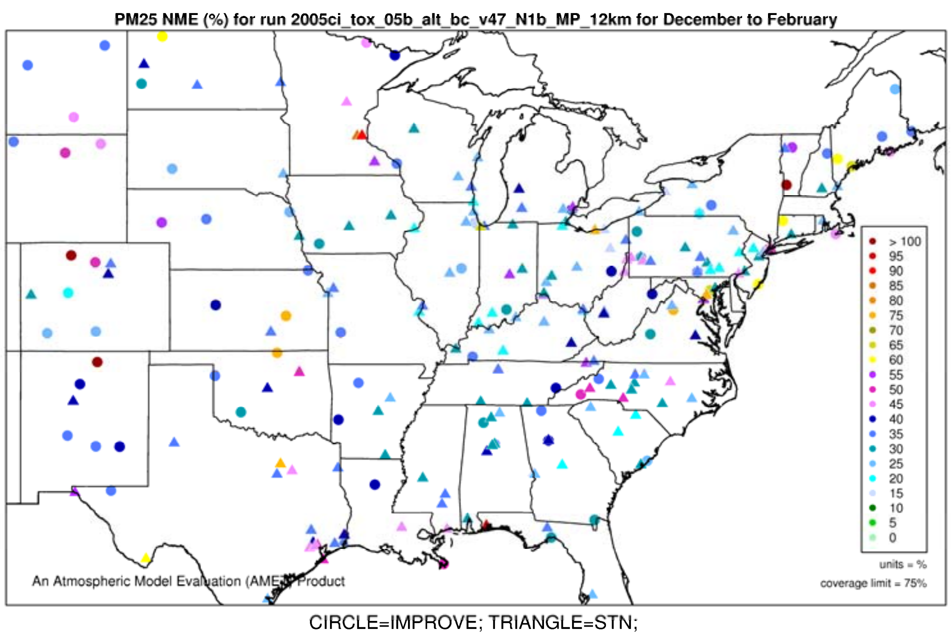


Figure E-2. Normalized Mean Error (%) of $PM_{2.5}$ by monitor for 12-km Eastern U.S. domain, Winter 2005.

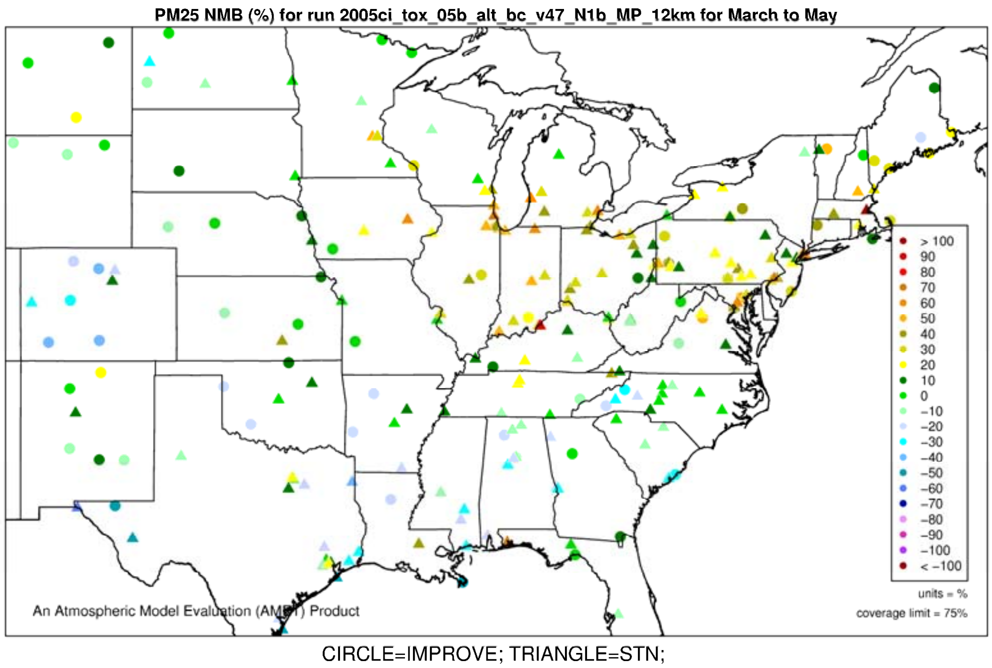


Figure E-3. Normalized Mean Bias (%) of $PM_{2.5}$ by monitor for 12-km Eastern U.S. domain, Spring 2005.

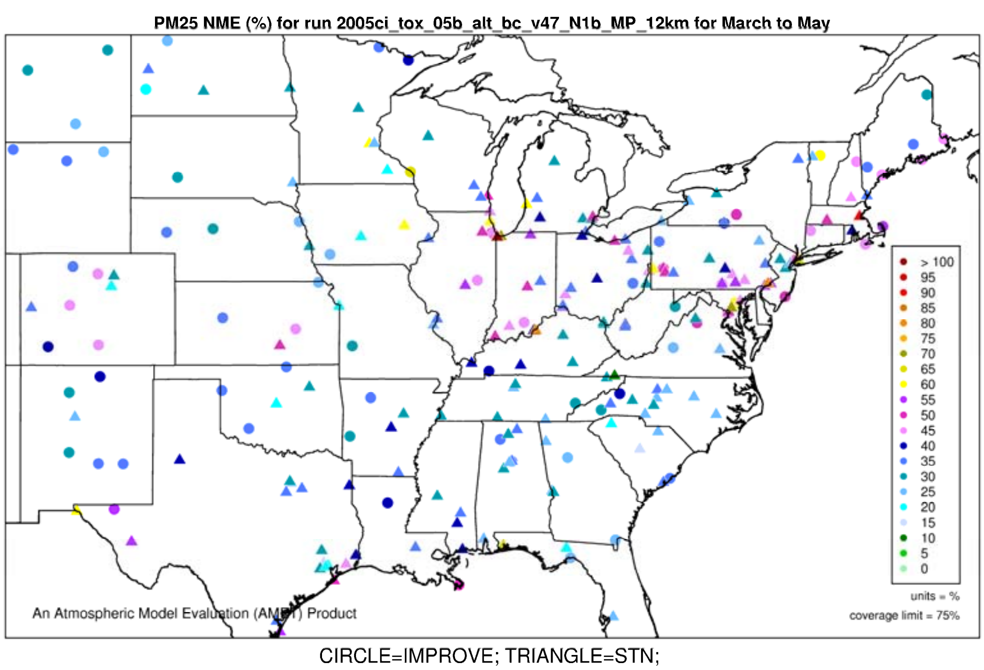


Figure E-4. Normalized Mean Error (%) of $PM_{2.5}$ by monitor for 12-km Eastern U.S. domain, Spring 2005.

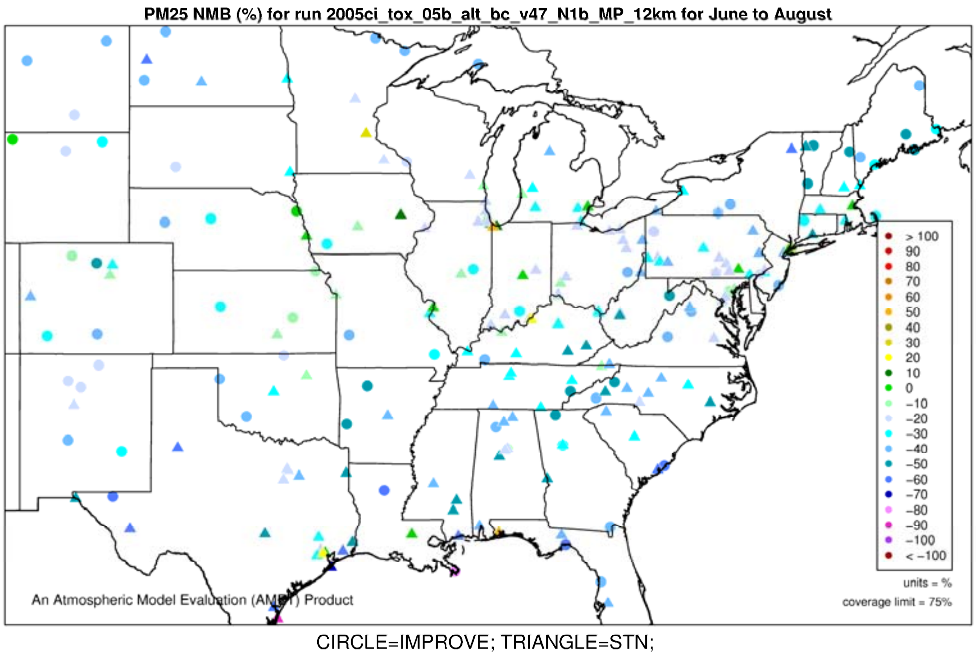


Figure E-5. Normalized Mean Bias (%) of $PM_{2.5}$ by monitor for 12-km Eastern U.S. domain, Summer 2005.

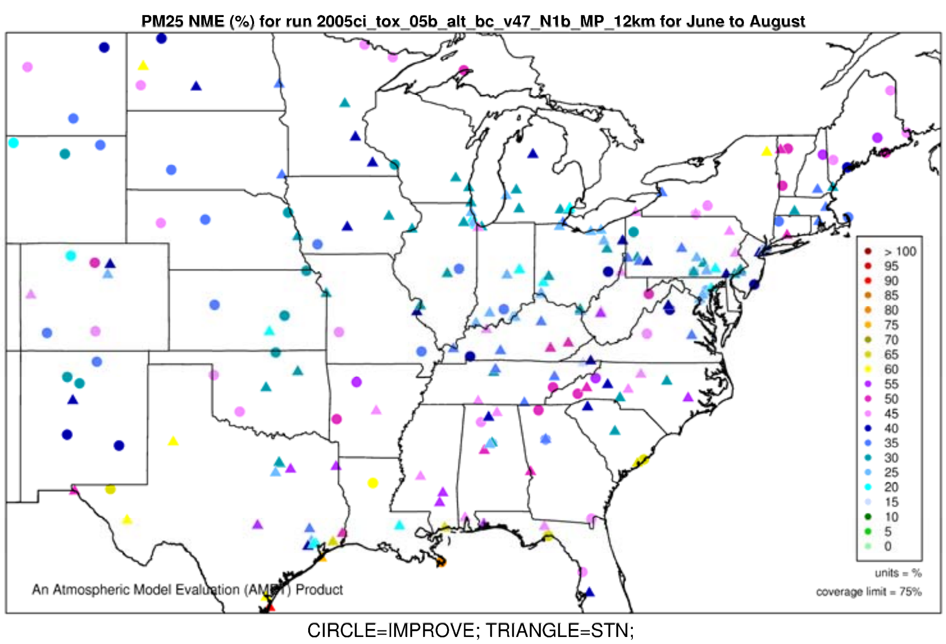


Figure E-6. Normalized Mean Error (%) of $PM_{2.5}$ by monitor for 12-km Eastern U.S. domain., Summer 2005.

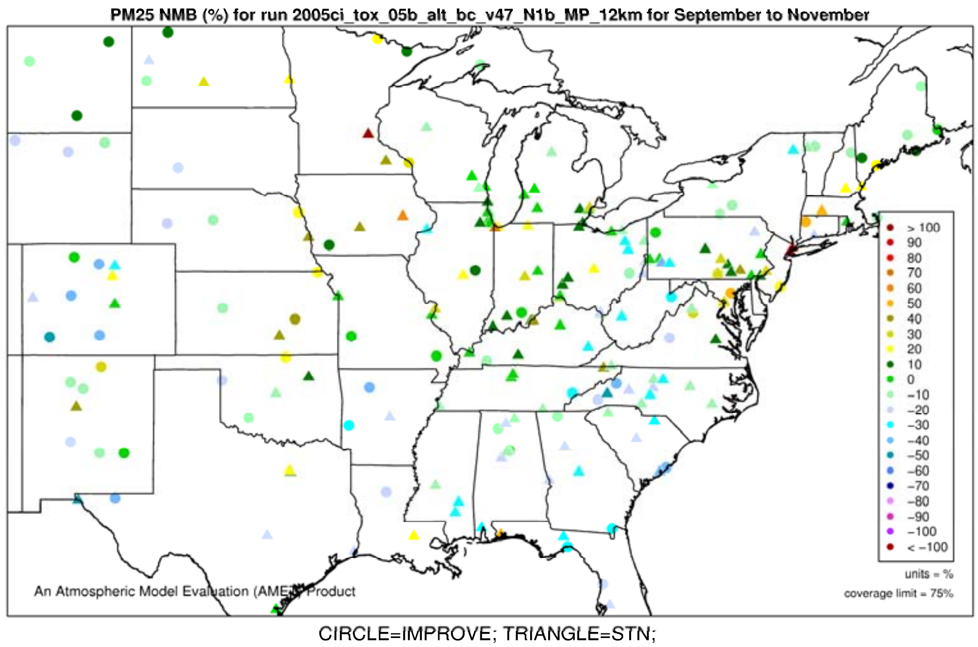


Figure E-7. Normalized Mean Bias (%) of $PM_{2.5}$ by monitor for 12-km Eastern U.S. domain, Fall 2005.

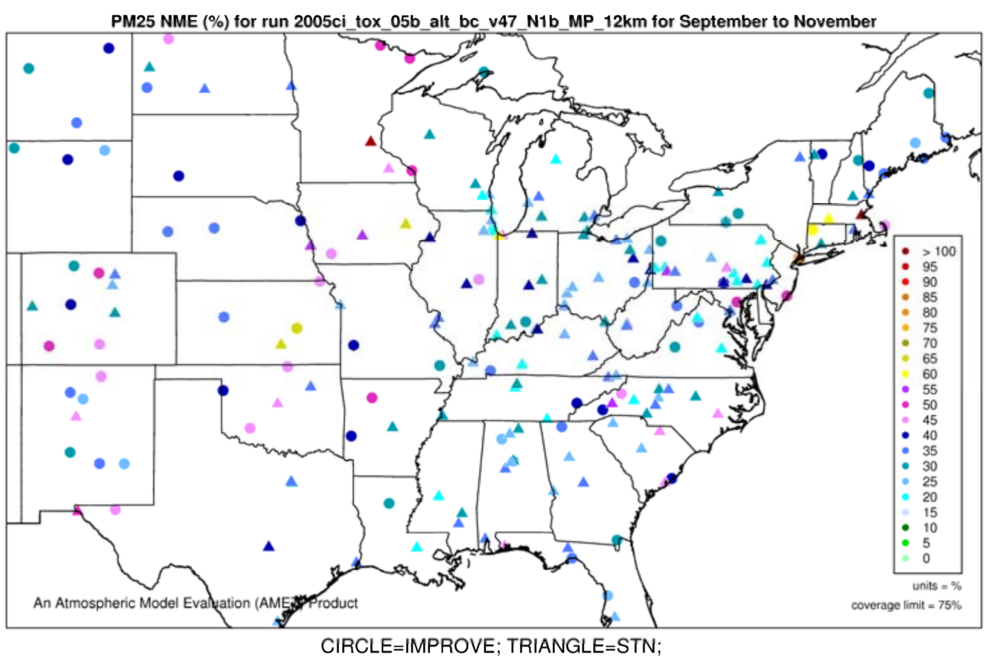


Figure E-8. Normalized Mean Error (%) of $PM_{2.5}$ by monitor for 12-km Eastern U.S. domain, Fall 2005.

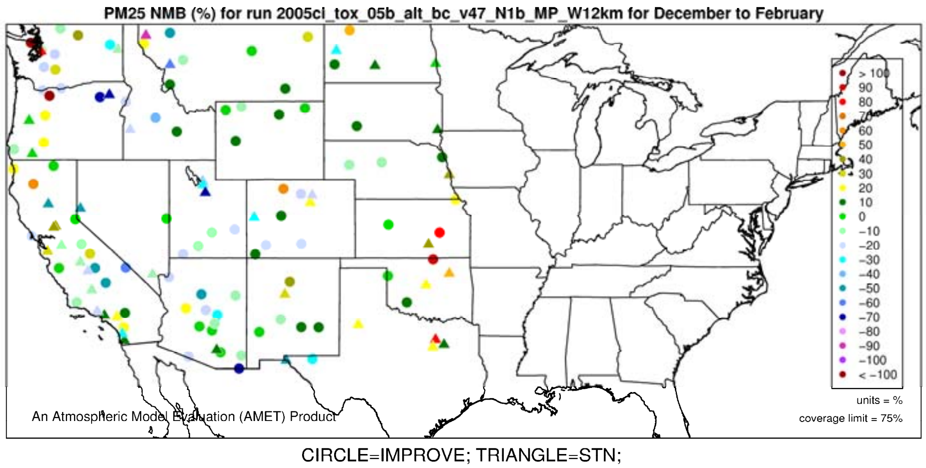


Figure E-9. Normalized Mean Bias (%) of $PM_{2.5}$ by monitor for 12-km Western U.S. domain, Winter 2005.

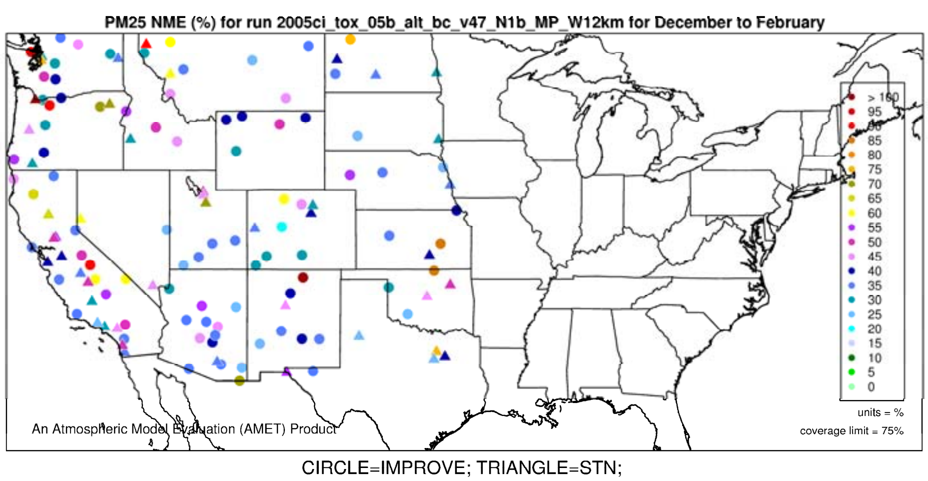


Figure E-10. Normalized Mean Error (%) of $PM_{2.5}$ by monitor for 12-km Western U.S. domain, Winter 2005.

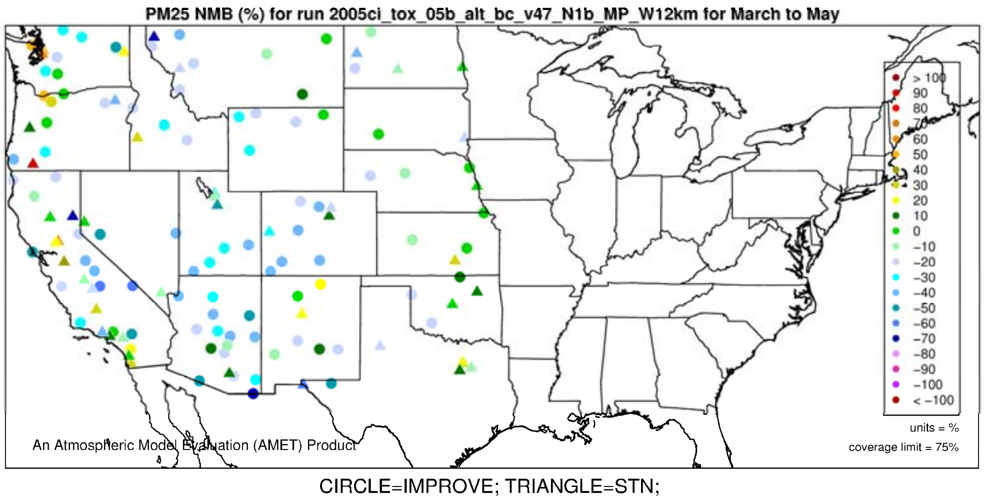


Figure E-11. Normalized Mean Bias (%) of $PM_{2.5}$ by monitor for 12-km Western U.S. domain, Spring 2005.

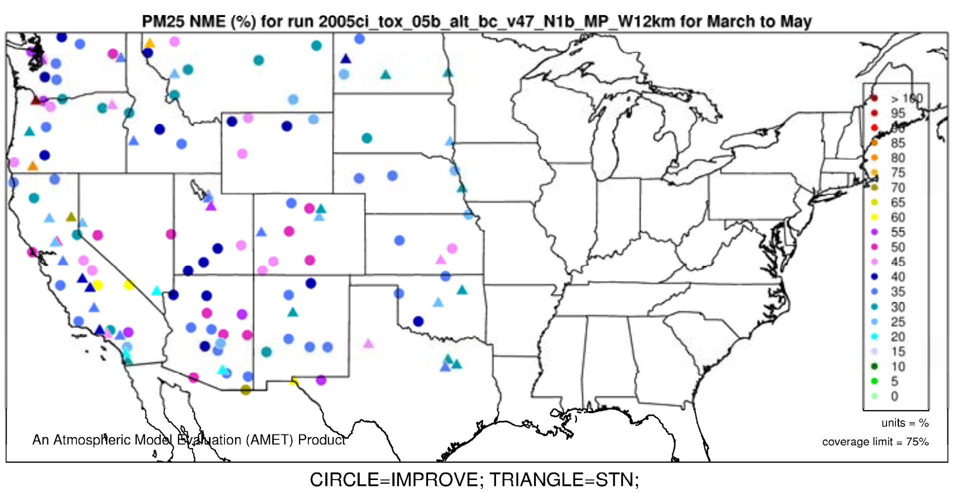


Figure E-12. Normalized Mean Error (%) of $PM_{2.5}$ by monitor for 12-km Western U.S. domain, Spring 2005.

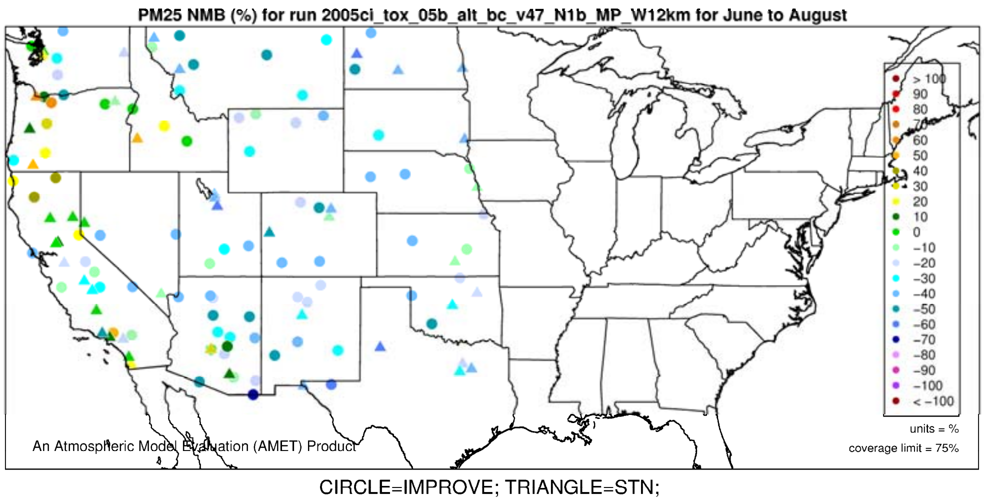


Figure E-13. Normalized Mean Bias (%) of $PM_{2.5}$ by monitor for 12-km Western U.S. domain, Summer 2005.

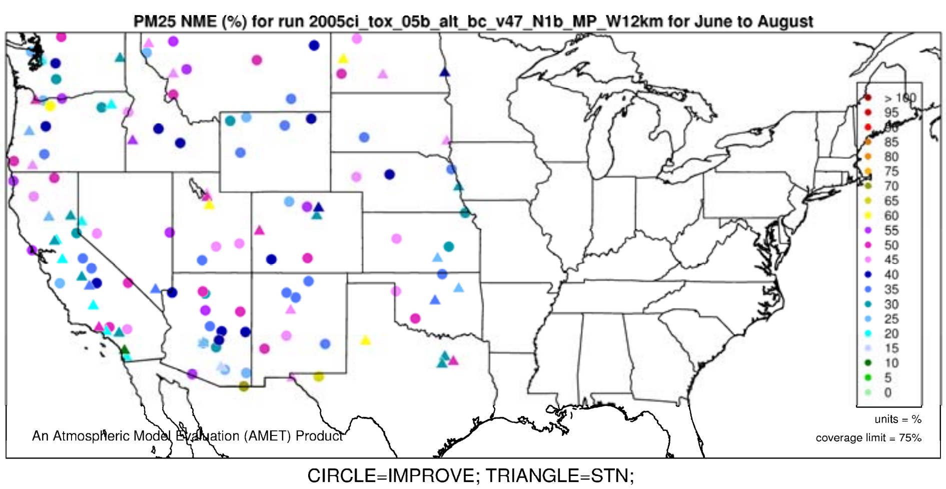
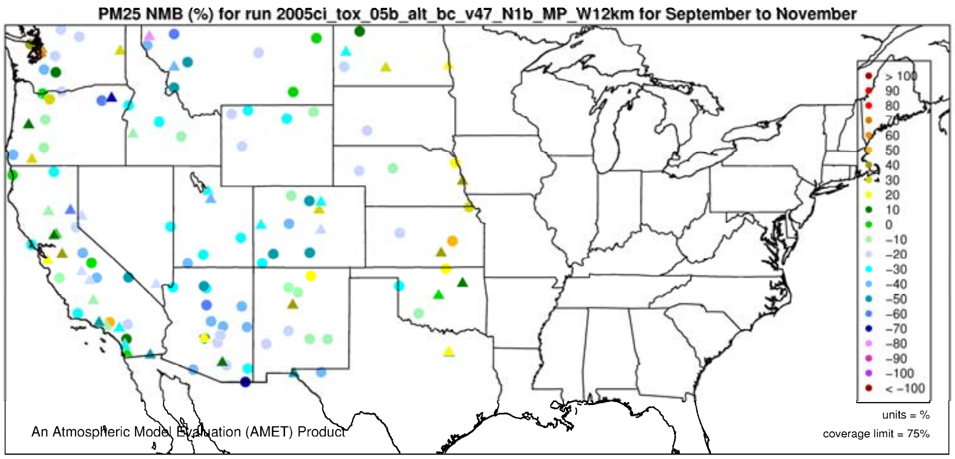
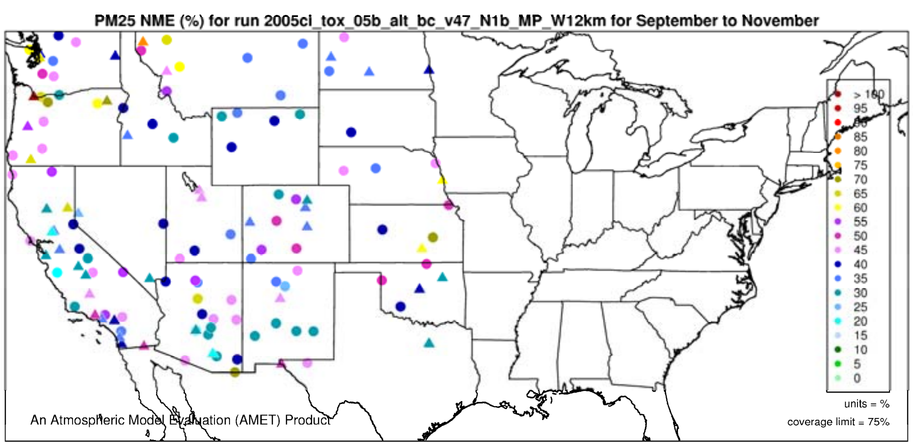


Figure E-14. Normalized Mean Error (%) of $PM_{2.5}$ by monitor for 12-km Western U.S. domain, Summer 2005.



CIRCLE=IMPROVE; TRIANGLE=STN;

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



CIRCLE=IMPROVE; TRIANGLE=STN;

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. Sulfate predictions during the winter season show NMB values ranging from -7% to -35% and in the East and with NMB values range from -1% to -10% in the West. In the fall season, sulfate predictions show NMB values ranging from -14% to -29%, across STN, IMPROVE, and CASTNet networks in the East and West. In the spring, sulfate predictions for the most part are under-predicted in the East and West, with NMB values ranging from -2% to -31%. Sulfate predictions during the summer season are moderately under-predicted in the East and West across the available monitoring data (NMB values rage from -17% to -38%.

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	3385	-15.1	38.0	-16.7	40.7
		12-km WUS	1033	-7.3	55.4	-2.6	53.7
		Northeast	828	-17.3	35.9	-21.5	37.7
		Midwest	598	-7.4	39.4	-12.7	42.2
		Southeast	963	-13.1	36.7	-12.4	37.9
		Central	766	-22.0	39.3	-21.2	44.1
		West	830	-10.3	58.1	-3.5	54.9
	IMPROVE	12-km EUS	2018	-16.2	37.1	-6.5	42.8
		12-km WUS	2370	-1.3	50.6	22.1	53.1
		Northeast	502	-16.3	31.8	-18.9	34.7
		Midwest	129	-7.1	35.6	-12.0	36.8
		Southeast	386	-13.7	35.7	-9.5	37.3
		Central	511	-27.1	42.6	-21.6	47.2
		West	2120	8.5	51.9	26.6	53.4
	CASTNet	12-km EUS	760	-20.4	25.4	-20.2	30.2
		12-km WUS	267	-5.4	33.2	9.4	35.5
		Northeast	193	-19.7	24.4	-24.3	28.7
		Midwest	142	-16.9	23.4	-20.2	29.1
		Southeast	264	-21.2	3-23.9	-21.5	25.3
		Central	72	-35.7	36.6	-40.2	41.7
		West	255	-1.6	34.1	11.3	35.5
Spring	STN	12-km EUS	3626	-7.3	32.9	-6.2	33.6
		12-km WUS	1085	-12.3	35.0	-3.4	35.8
		Northeast	894	4.2	34.8	2.9	34.0
		Midwest	637	11.3	39.2	10.8	36.1
		Southeast	988	-13.7	28.0	-13.7	30.4
		Central	875	-23.0	33.9	-19.2	35.9
		West	867	-6.2	37.5	0.3	36.7
	IMPROVE	12-km EUS	2378	-10.3	34.0	-4.6	35.4

		12-km WUS	2642	-9.2	34.8	2.2	36.8
		Northeast	630	4.3	37.2	4.2	38.3
		Midwest	147	-2.3	36.2	2.2	36.0
		Southeast	436	-14.7	29.7	-11.9	31.2
		Central	605	-25.8	35.4	-18.9	36.5
		West	2352	-5.1	35.3	4.6	37.1
	CASTNet	12-km EUS	832	-10.9	23.6	-9.6	24.6
		12-km WUS	287	-18.1	26.3	-14.8	26.3
		Northeast	206	0.4	24.4	1.1	26.2
		Midwest	155	-4.9	22.2	-2.9	21.6
		Southeast	292	-15.8	21.9	-17.1	23.8
		Central	78	-31.2	34.3	-27.9	34.1
		West	274	-16.9	25.9	-14.2	26.1
Summer	STN	12-km EUS	3512	-28.1	36.2	-27.3	42.7
		12-km WUS	1075	-35.3	43.4	-28.8	45.1
		Northeast	874	-22.9	32.1	-16.5	35.3
		Midwest	621	-22.8	33.1	-12.9	34.0
		Southeast	941	-31.3	37.5	-34.2	44.8
		Central	847	-37.9	44.4	-43.8	56.4
		West	853	-35.4	45.8	-27.3	45.6
	IMPROVE	12-km EUS	2269	-32.8	40.3	-28.4	46.7
		12-km WUS	2340	-32.2	43.8	-23.9	47.2
		Northeast	590	-26.3	37.2	-15.4	42.6
		Midwest	158	-31.3	37.0	-20.5	40.5
		Southeast	427	-37.8	42.3	-42.3	52.4
		Central	572	-37.7	43.9	-34.8	50.9
		West	2066	-30.1	44.2	-22.3	47.2
	CASTNet	12-km EUS	792	-22.4	25.7	-25.3	31.7
		12-km WUS	295	-38.1	41.2	-40.2	45.8
		Northeast	192	-17.9	21.9	-14.5	24.1
		Midwest	161	-18.6	23.0	-16.8	25.1
		Southeast	270	-24.6	27.0	-31.9	35.0
		Central	75	-36.2	38.9	-42.5	48.3
		West	282	-38.2	41.6	-40.1	45.9
Fall	STN	12-km EUS	3349	-21.0	32.3	-12.6	33.6
		12-km WUS	1095	-17.2	44.2	-7.9	44.5
		Northeast	902	-17.0	35.8	-0.2	38.3
		Midwest	639	-21.4	32.0	-13.3	32.0
		Southeast	990	-22.2	30.9	-17.7	31.9
		Central	571	-21.0	35.0	-12.3	36.7
		West	900	-14.6	48.8	-6.9	46.4
	IMPROVE	12-km EUS	2147	-23.7	35.1	-11.7	39.1
		12-km WUS	2427	-19.3	41.4	-4.0	44.0
		Northeast	531	-17.0	35.8	-0.2	38.3

		Midwest	97	-29.3	33.8	-27.1	36.5
		Southeast	436	-26.6	34.2	-20.8	38.3
		Central	548	-26.0	35.0	-17.7	40.2
		West	2135	-14.9	43.3	-1.5	44.6
	CASTNet	12-km EUS	786	-21.8	24.1	-19.4	24.9
		12-km WUS	293	-22.4	30.6	-18.2	32.9
		Northeast	195	-17.2	20.8	-12.5	20.3
		Midwest	157	-23.0	24.9	-19.6	23.8
		Southeast	273	-22.9	24.5	-24.3	26.8
		Central	75	-25.2	26.7	-24.5	29.9
		West	280	-21.5	31.1	-17.6	33.0

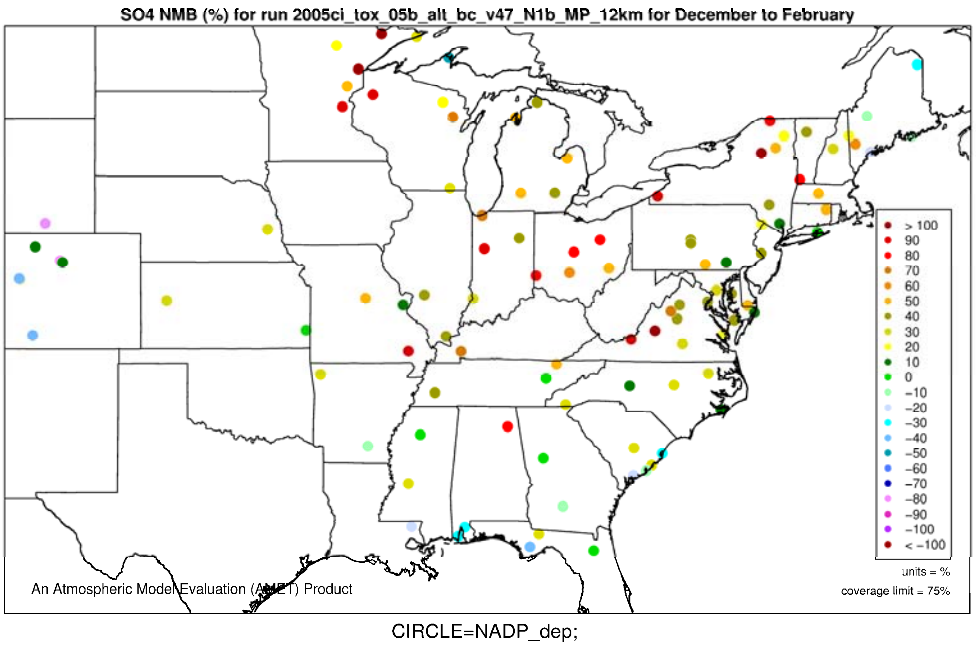


Figure F-1. Normalized Mean Bias (%) of sulfate by monitor for 12-km Eastern U.S. domain, Winter 2005.

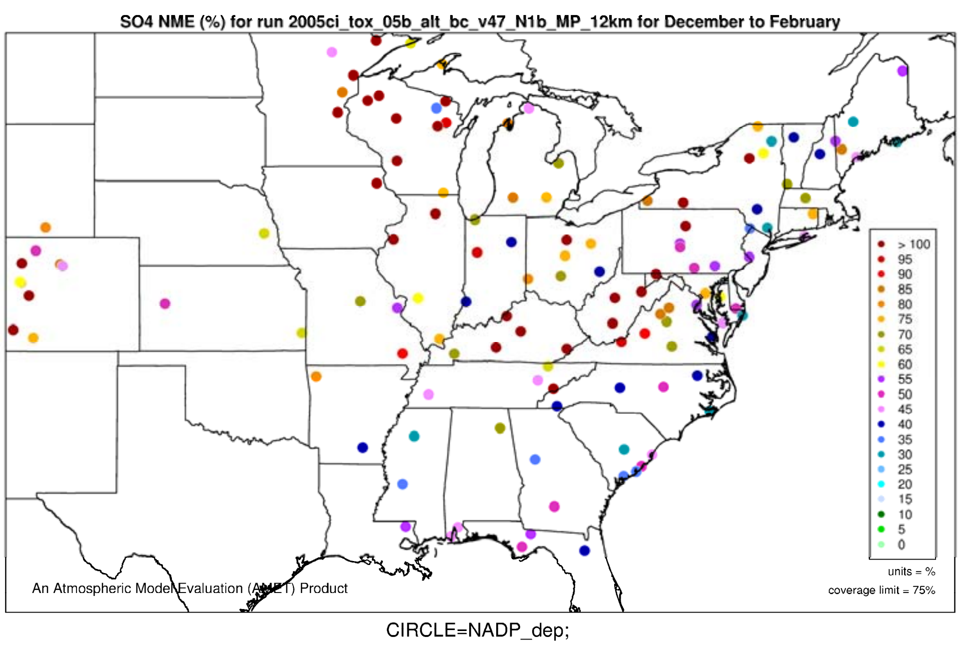


Figure F-2. Normalized Mean Error (%) of sulfate by monitor for 12-km Eastern U.S. domain, Winter 2005.

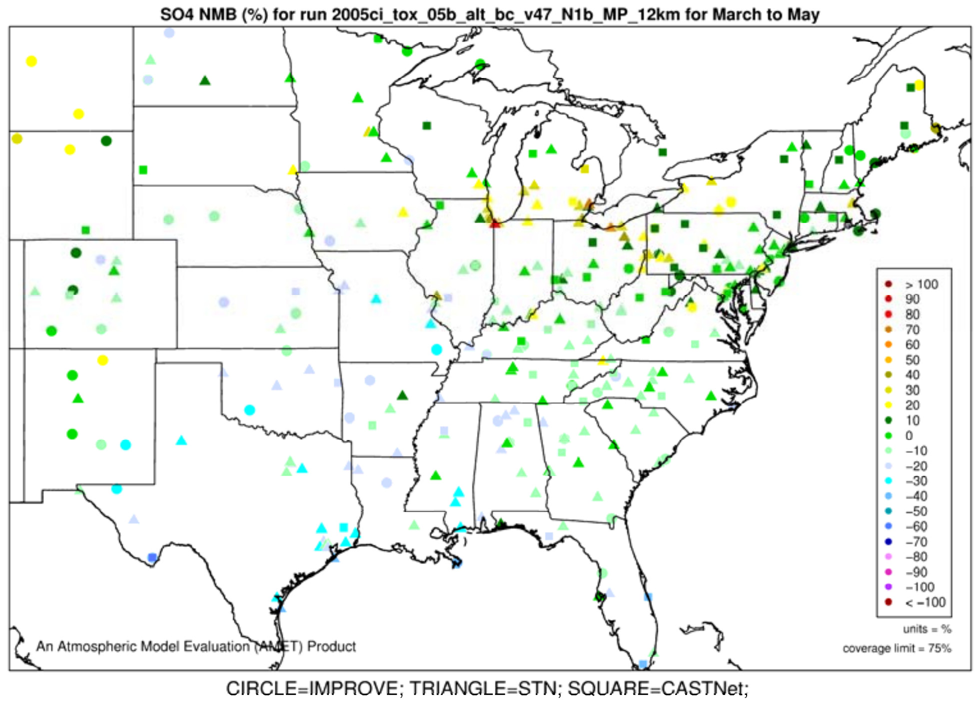


Figure F-3. Normalized Mean Bias (%) of sulfate by monitor for 12-km Eastern U.S. domain, Spring 2005.

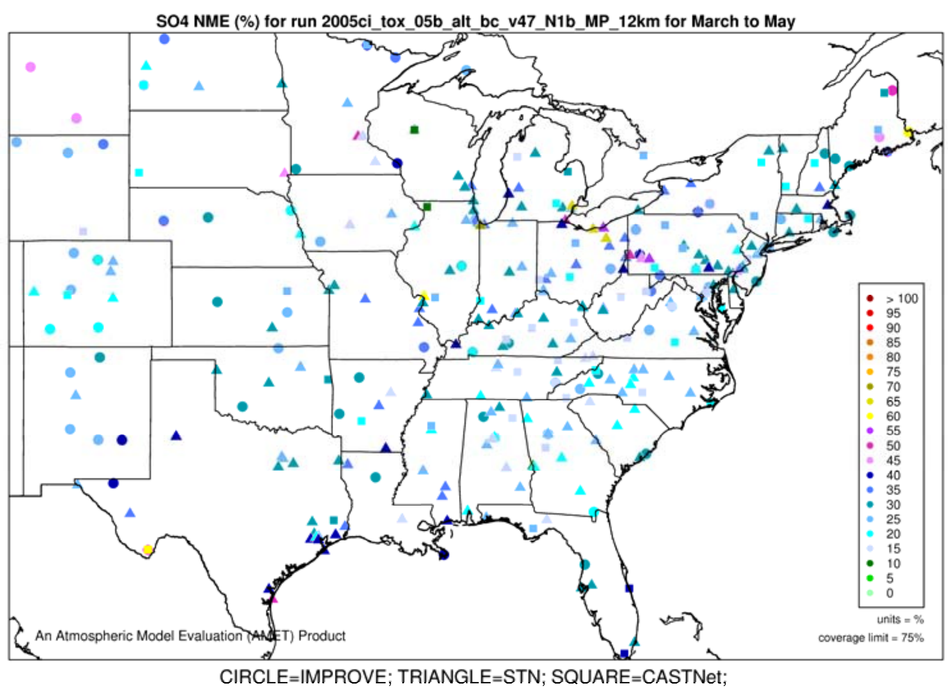


Figure F-4. Normalized Mean Error (%) of sulfate by monitor for 12-km Eastern U.S. domain, Spring 2005.

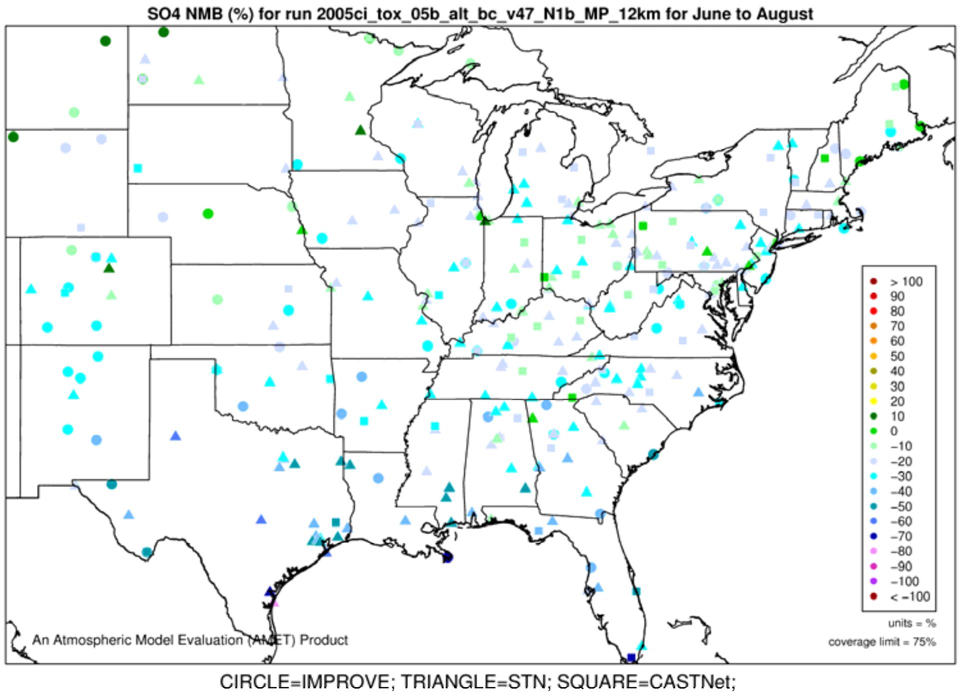


Figure F-5. Normalized Mean Bias (%) of sulfate by monitor for 12-km Eastern U.S. domain, Summer 2005.

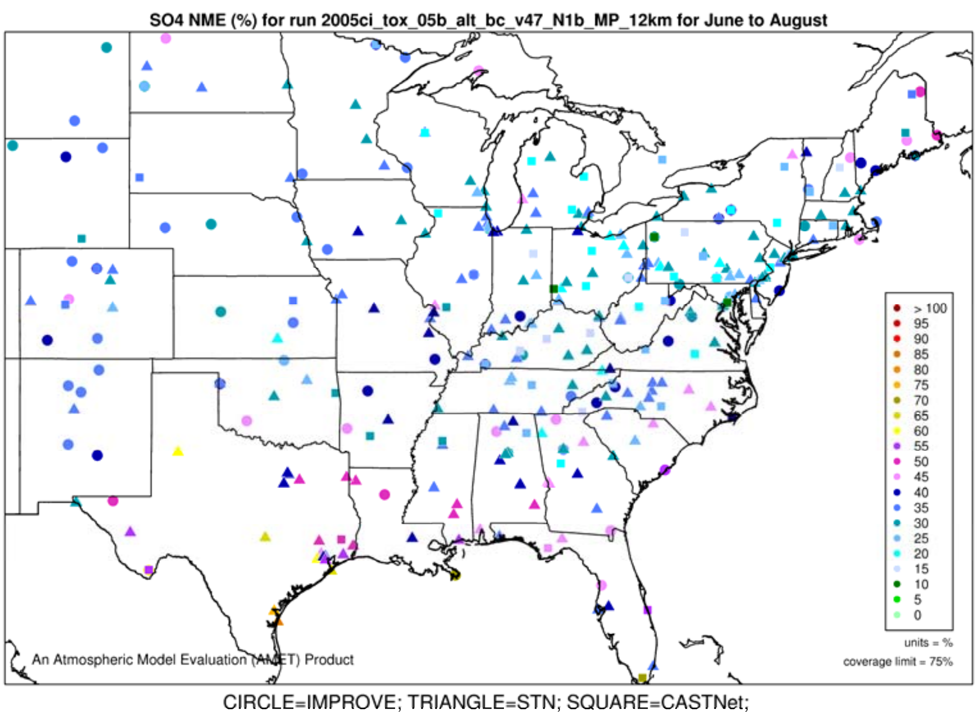


Figure F-6. Normalized Mean Error (%) of sulfate by monitor for 12-km Eastern U.S. domain, Summer 2005.

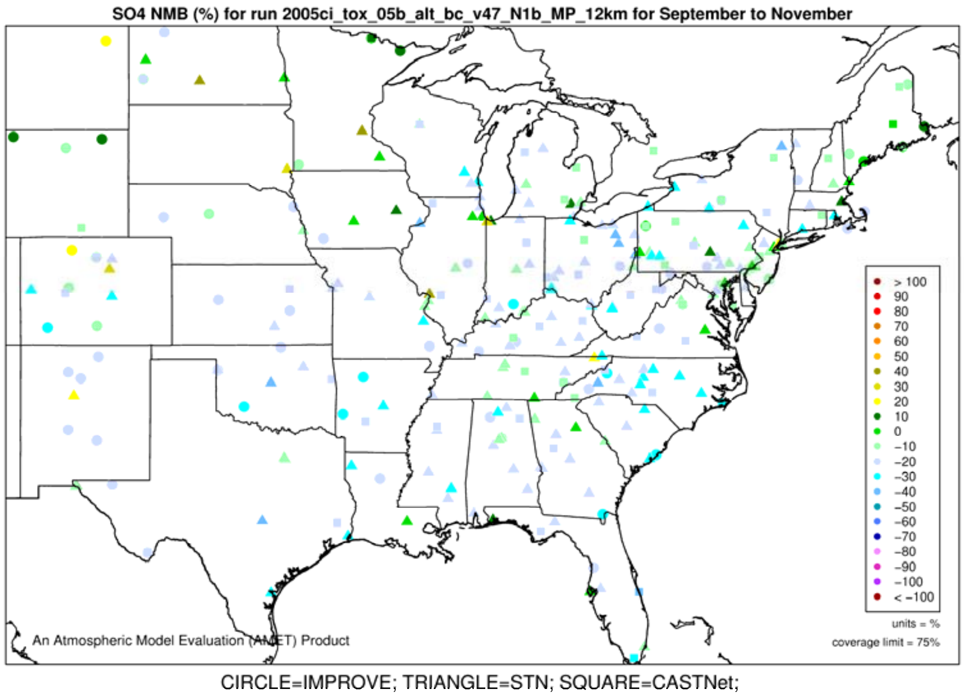


Figure F-7. Normalized Mean Bias (%) of sulfate by monitor for 12-km Eastern U.S. domain, Fall 2005.

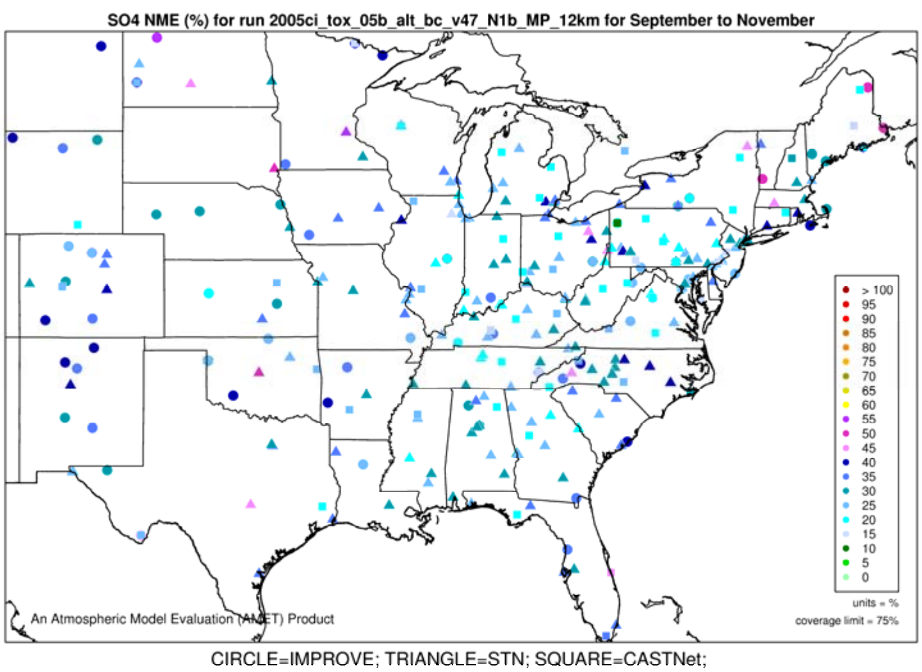


Figure F-8. Normalized Mean Error (%) of sulfate by monitor for 12-km Eastern U.S. domain, Fall 2005.

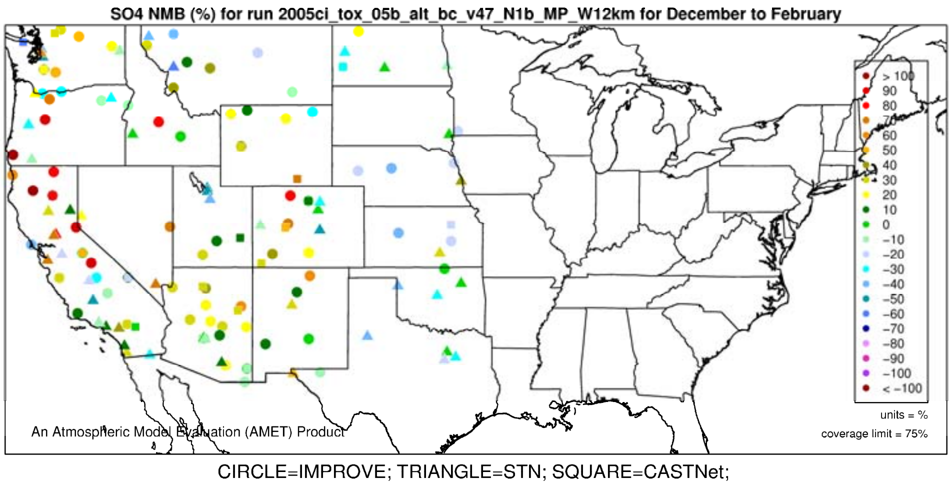


Figure F-9. Normalized Mean Bias (%) of sulfate by monitor for 12-km Western U.S. domain, Winter 2005.

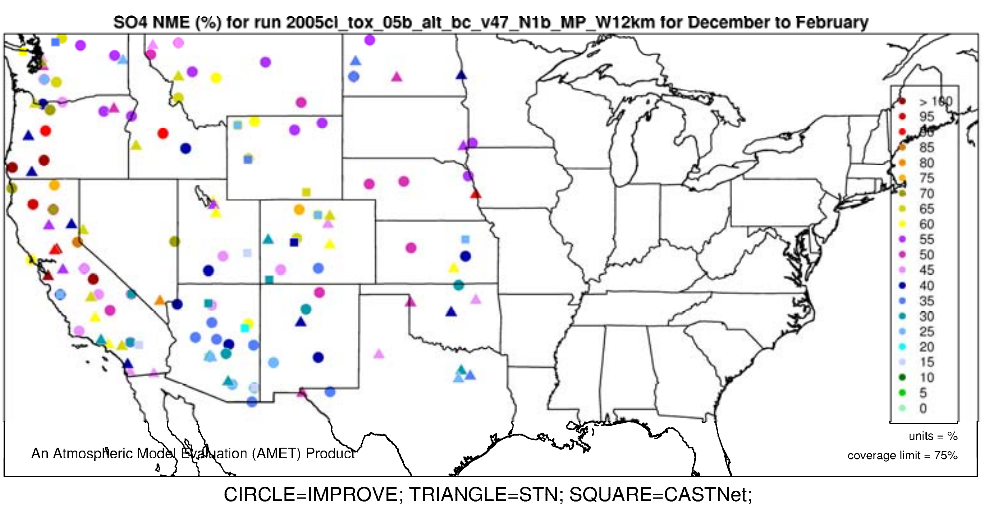


Figure F-10. Normalized Mean Error (%) of sulfate by monitor for 12-km Western U.S. domain, Winter 2005.

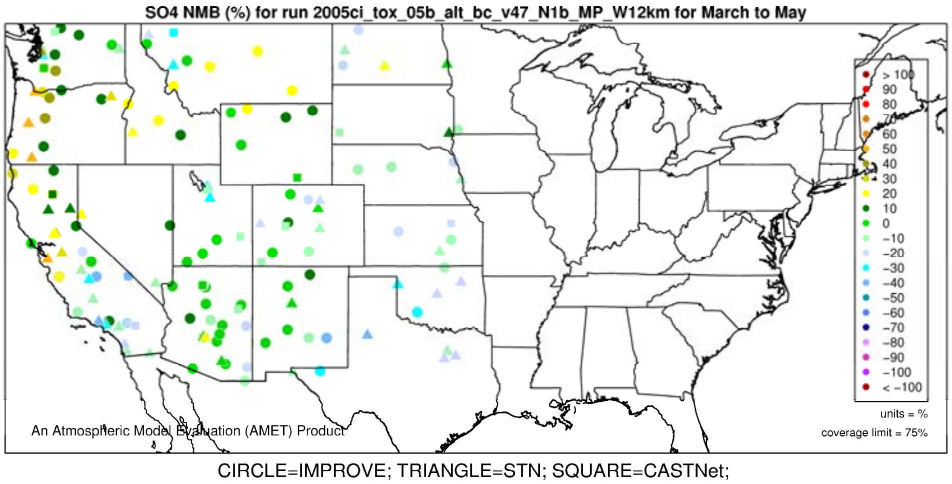


Figure F-11. Normalized Mean Bias (%) of sulfate by monitor for 12-km Western U.S. domain, Spring 2005.

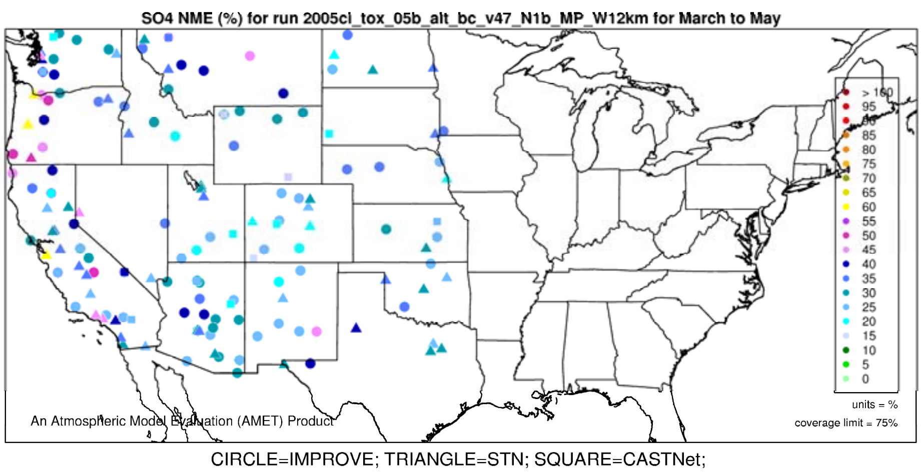


Figure F-12. Normalized Mean Error (%) of sulfate by monitor for 12-km Western U.S. domain, Spring 2005.

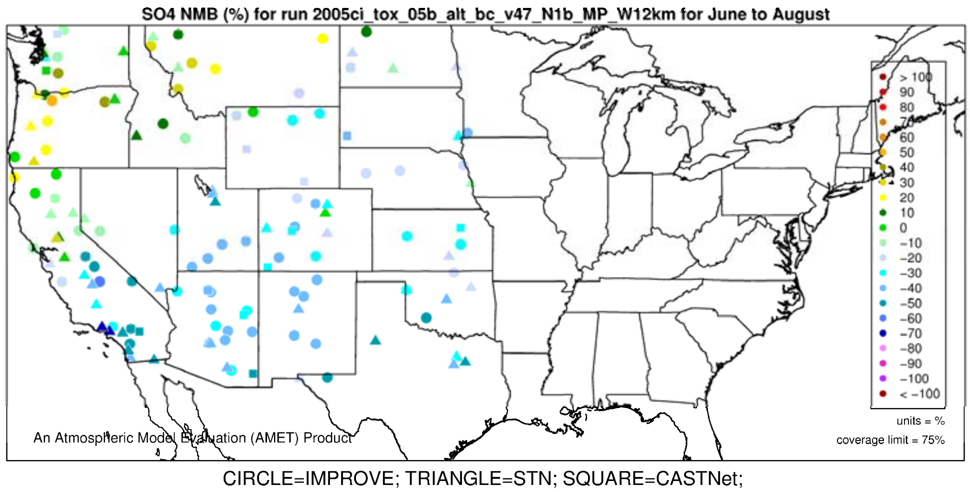


Figure F-13. Normalized Mean Bias (%) of sulfate by monitor for 12-km Western U.S. domain, Summer 2005.

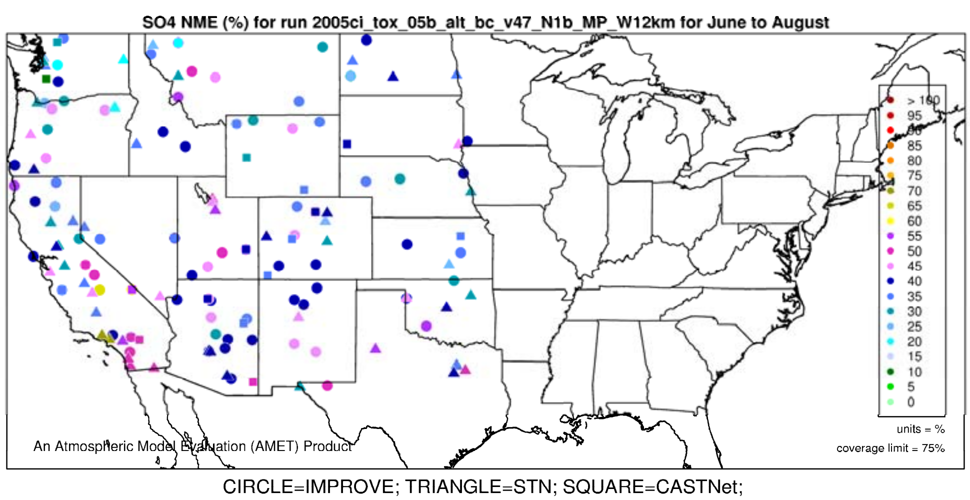


Figure F-14. Normalized Mean Error (%) of sulfate by monitor for 12-km Western U.S. domain, Summer 2005.

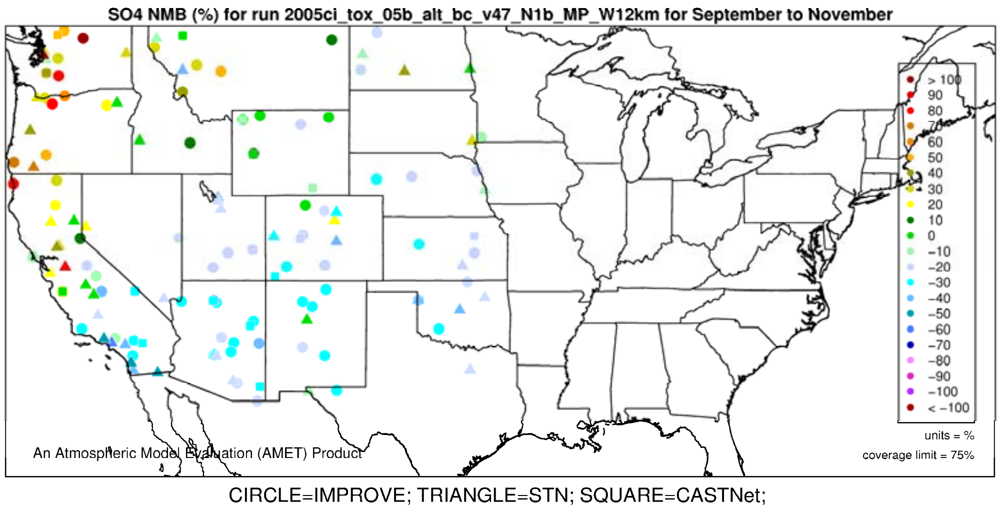


Figure F-15. Normalized Mean Bias (%) of sulfate by monitor for 12-km Western U.S. domain, Fall 2005.

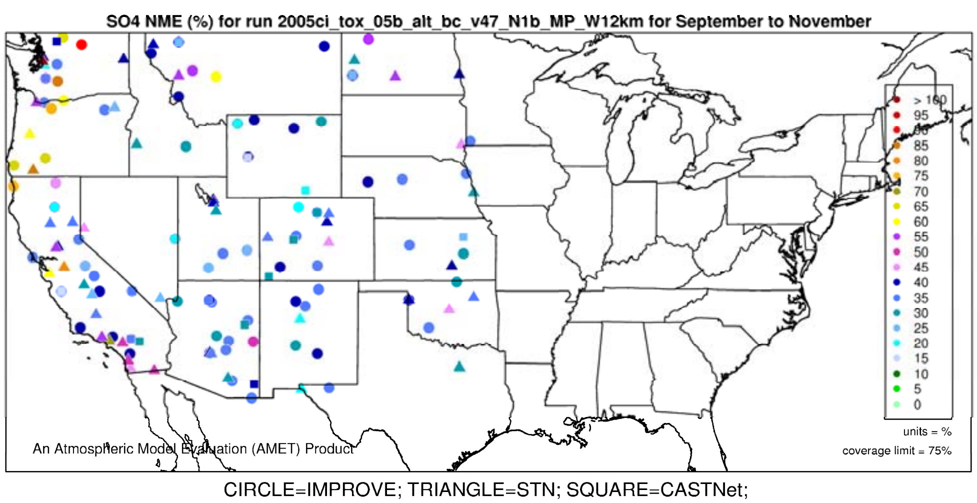


Figure F-16. Normalized Mean Error (%) of sulfate by monitor for 12-km Western U.S. domain, Fall 2005.

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 under-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 0.4% to 70%). In the East and West, nitrate and total nitrate are moderately under-predicted during the winter season when nitrate is most abundant (NMB values ranging from -2% to -46%).

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	-10.9	45.7	-16.1	57.8
		12-km WUS	973	-42.8	61.8	-53.1	82.1
		Northeast	829	9.1	44.7	9.1	47.5
		Midwest	598	-18.7	38.0	-15.9	44.2
		Southeast	963	-14.7	57.2	-34.6	72.8
		Central	479	-16.3	46.8	-10.8	56.7
		West	831	-46.9	64.1	-60.5	86.1
	IMPROVE	12-km EUS	2018	-2.0	59.2	-25.0	81.6
		12-km WUS	2368	-33.6	62.1	-78.4	108.5
		Northeast	502	40.0	71.7	29.3	72.2
		Midwest	129	-29.5	43.2	-35.7	64.8
		Southeast	386	3.4	75.5	-36.2	82.1
		Central	511	-12.6	50.9	-20.1	71.9
		West	2118	-46.3	74.2	-84.5	113.9
Total Nitrate (Winter)	CASTNet	12-km EUS	760	10.5	27.9	16.9	31.9
		12-km WUS	267	13.1	40.4	26.4	49.7
		Northeast	193	24.5	30.9	30.0	34.2
		Midwest	142	-6.0	19.9	0.3	20.4
		Southeast	264	17.7	31.4	14.5	32.1
		Central	72	11.4	30.3	13.3	31.1
		West	255	14.4	47.4	27.2	51.4
Nitrate (Spring)	STN	12-km EUS	3254	38.8	72.6	16.8	70.4
		12-km WUS	987	-33.5	55.5	-56.9	81.4
		Northeast	894	48.8	81.3	39.0	70.5
		Midwest	637	47.2	69.3	36.4	60.4
		Southeast	988	37.2	86.8	-3.0	81.2
		Central	503	11.6	52.3	7.9	60.3

		West	859	-38.4	56.8	-63.8	84.3
	IMPROVE	12-km EUS	2378	41.5	84.1	-6.8	91.3
		12-km WUS	2636	-26.8	67.0	-81.2	112.3
		Northeast	630	68.9	107.3	29.9	91.3
		Midwest	147	42.3	74.5	11.1	79.3
		Southeast	436	54.7	97.9	-9.6	89.7
		Central	605	21.1	62.6	-14.0	86.3
		West	2346	-39.6	76.5	-88.7	116.9
Total Nitrate (Spring)	CASTNet	12-km EUS	832	12.0	35.2	15.7	32.9
		12-km WUS	287	-12.2	31.1	-3.6	32.3
		Northeast	206	36.9	40.0	31.6	36.9
		Midwest	155	27.9	33.5	24.3	30.0
		Southeast	292	16.5	34.5	9.7	33.7
		Central	78	-1.4	31.0	-1.1	31.3
		West	274	-11.8	31.9	-3.0	32.6
Nitrate (Summer)	STN	12-km EUS	3150	0.4	79.9	-51.1	92.7
		12-km WUS	992	-68.2	74.6	-120.1	127.1
		Northeast	874	-8.6	78.9	-49.3	91.2
		Midwest	621	30.3	79.8	-9.3	74.3
		Southeast	941	-28.4	75.3	-73.0	100.4
		Central	485	11.1	88.1	-41.5	89.7
		West	846	-70.6	74.1	-126.0	130.0
	IMPROVE	12-km EUS	2269	-3.6	94.2	-78.4	115.2
		12-km WUS	2339	-65.9	82.3	-135.3	144.1
		Northeast	590	7.1	102.3	-55.8	104.7
		Midwest	158	16.2	86.7	-34.0	91.2
		Southeast	427	-4.9	96.3	-68.8	112.3
		Central	572	0.1	92.0	-64.2	106.9
		West	2065	-72.2	82.2	-142.3	148.6
Total Nitrate (Summer)	CASTNet	12-km EUS	792	27.0	41.9	14.4	37.6
		12-km WUS	295	-13.3	30.9	-13.0	34.1
		Northeast	192	40.3	49.6	26.3	43.3
		Midwest	161	40.6	45.1	33.1	37.3
		Southeast	270	16.8	39.6	8.2	39.0
		Central	75	-6.3	26.5	-12.0	29.4
		West	282	-14.5	31.5	-13.6	34.6
Nitrate (Fall)	STN	12-km EUS	3238	72.2	104.6	4.1	83.0
		12-km WUS	1048	-42.0	72.4	-52.3	91.6
		Northeast	902	82.7	109.2	2.3	81.3
		Midwest	639	63.1	88.4	28.5	69.7
		Southeast	990	76.6	126.2	-12.3	94.1
		Central	460	78.8	107.8	16.1	81.5
		West	896	-48.9	69.1	-63.2	92.5
	IMPROVE	12-km EUS	2140	102.3	144.2	-12.7	100.2

		12-km WUS	2421	-5.4	98.3	-65.0	112.1
		Northeast	526	112.6	147.0	-4.3	95.0
		Midwest	97	85.9	123.8	16.8	92.8
		Southeast	436	98.4	161.4	-25.5	107.4
		Central	548	119.5	150.5	6.0	98.9
		West	2129	-38.1	83.3	-75.4	114.1
Total Nitrate (Fall)	CASTNet	12-km EUS	786	60.9	66.6	40.8	50.1
		12-km WUS	293	6.0	38.2	17.6	44.1
		Northeast	195	73.9	76.7	49.7	55.6
		Midwest	157	65.6	66.2	47.0	0.5
		Southeast	273	57.6	67.6	36.9	52.3
		Central	75	40.7	51.1	29.7	41.3
		West	280	2.2	37.0	16.9	44.4

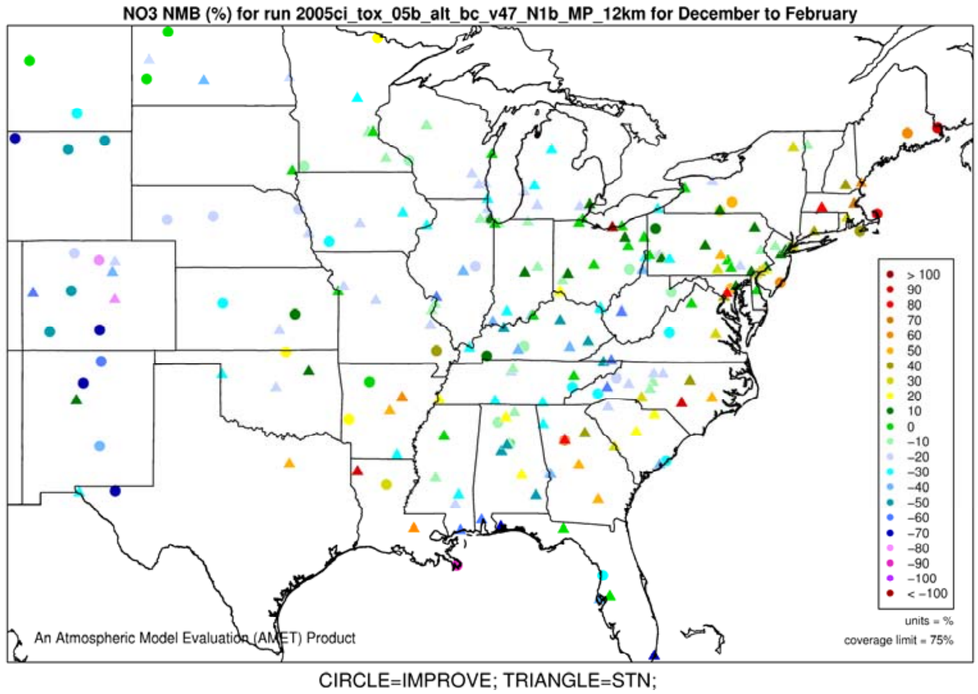


Figure G-1. Normalized Mean Bias (%) of nitrate by monitor for 12-km Eastern U.S. domain, Winter 2005.

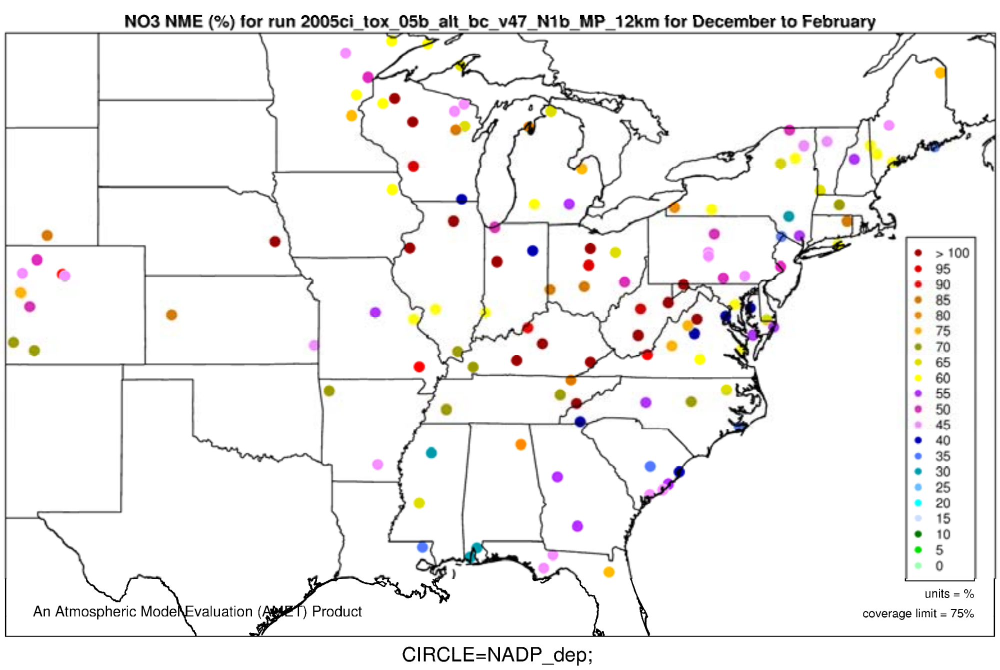


Figure G-2. Normalized Mean Error (%) of nitrate by monitor for 12-km Eastern U.S. domain, Winter 2005.

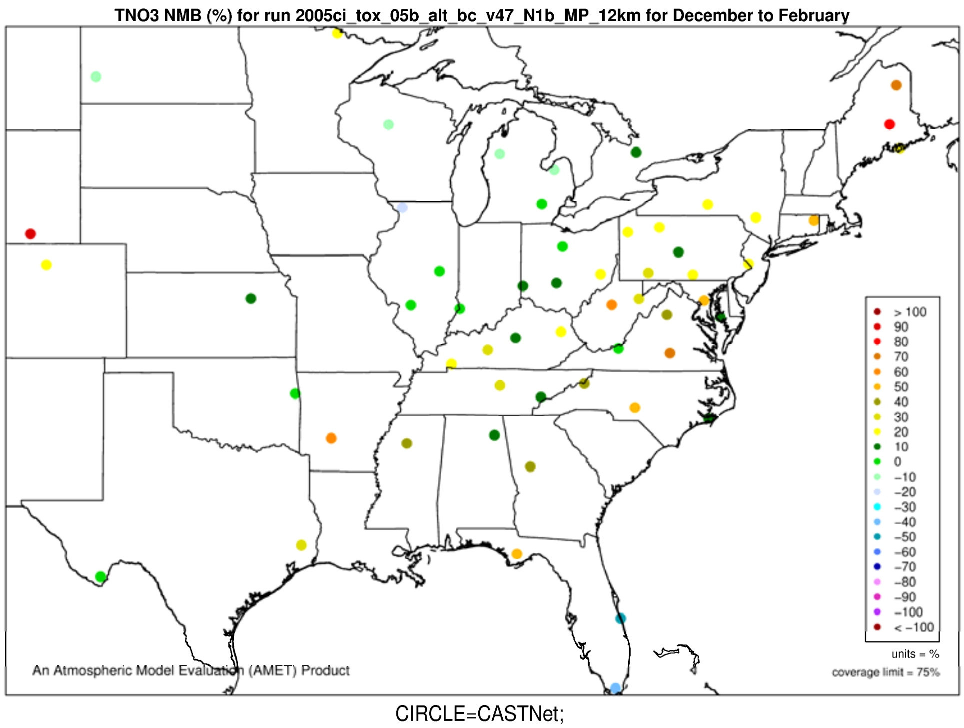


Figure G-3. Normalized Mean Bias (%) of total nitrate by monitor for 12-km Eastern U.S. domain, Winter 2005.

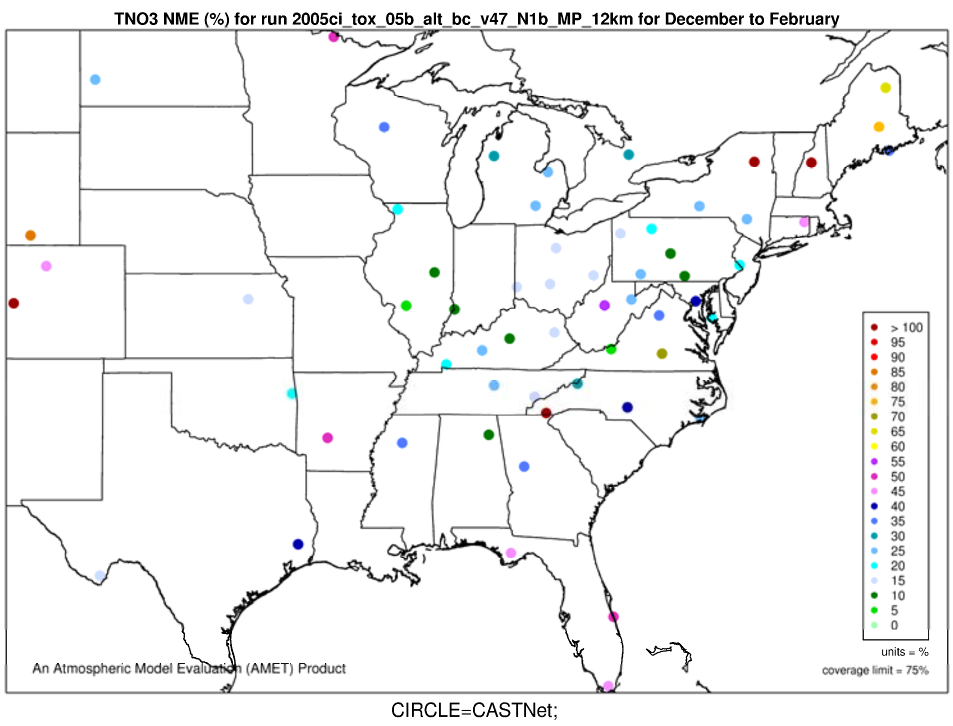


Figure G-4. Normalized Mean Error (%) of total nitrate by monitor for 12-km Eastern U.S. domain, Winter 2005.

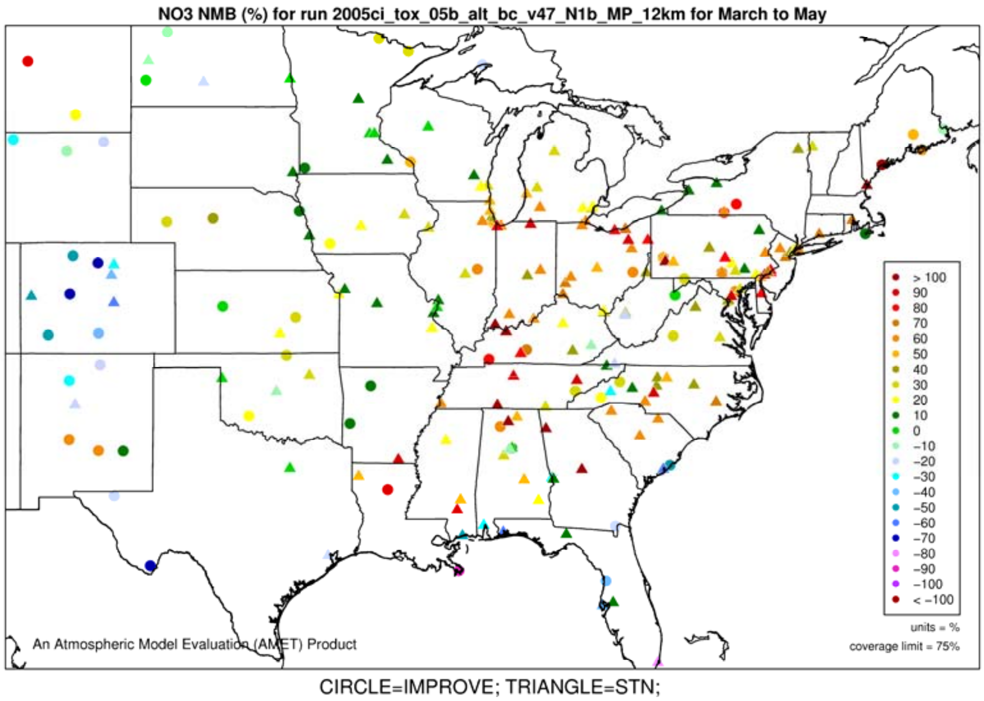


Figure G-5. Normalized Mean Bias (%) of nitrate by monitor for 12-km Eastern U.S. domain, Spring 2005.

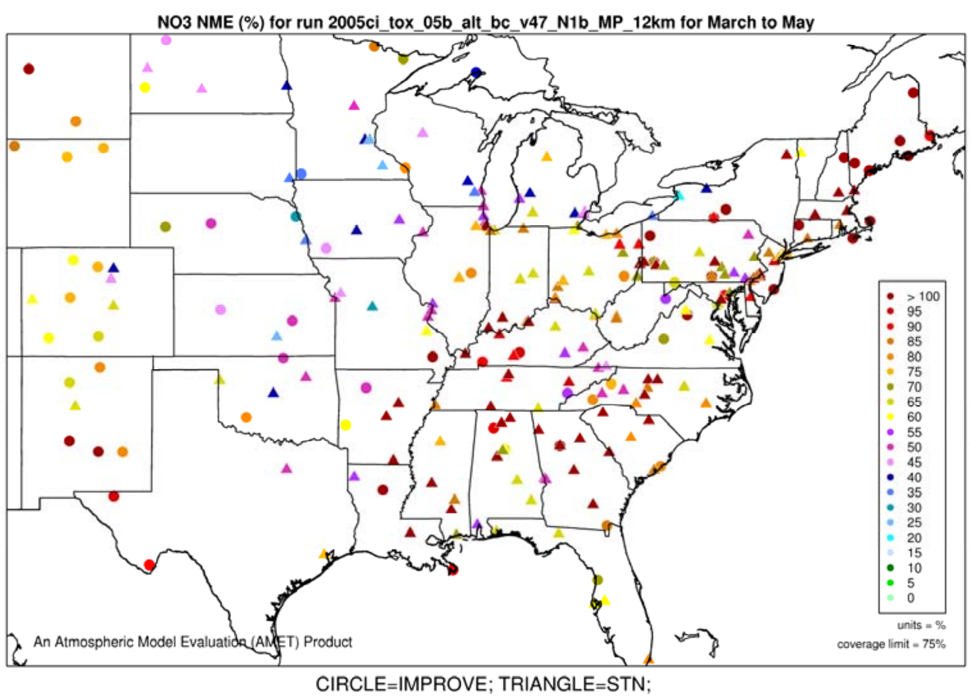


Figure G-6. Normalized Mean Error (%) of nitrate by monitor for 12-km Eastern U.S. domain, Spring 2005.

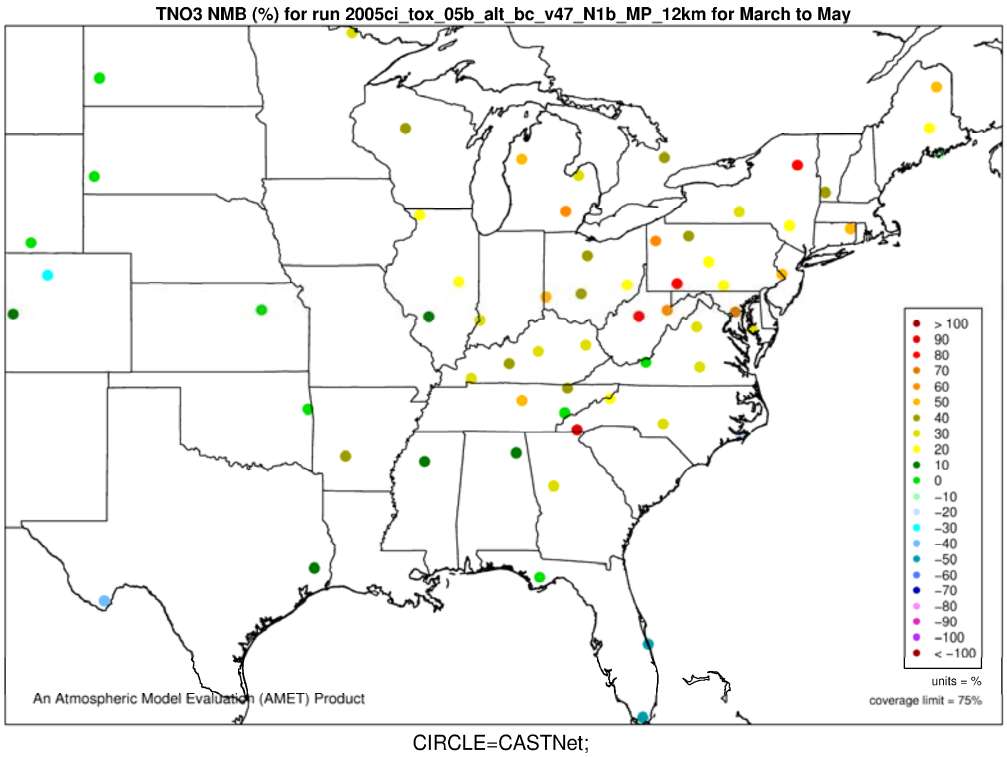


Figure G-7. Normalized Mean Bias (%) of total nitrate by monitor for 12-km Eastern U.S. domain, Spring 2005.

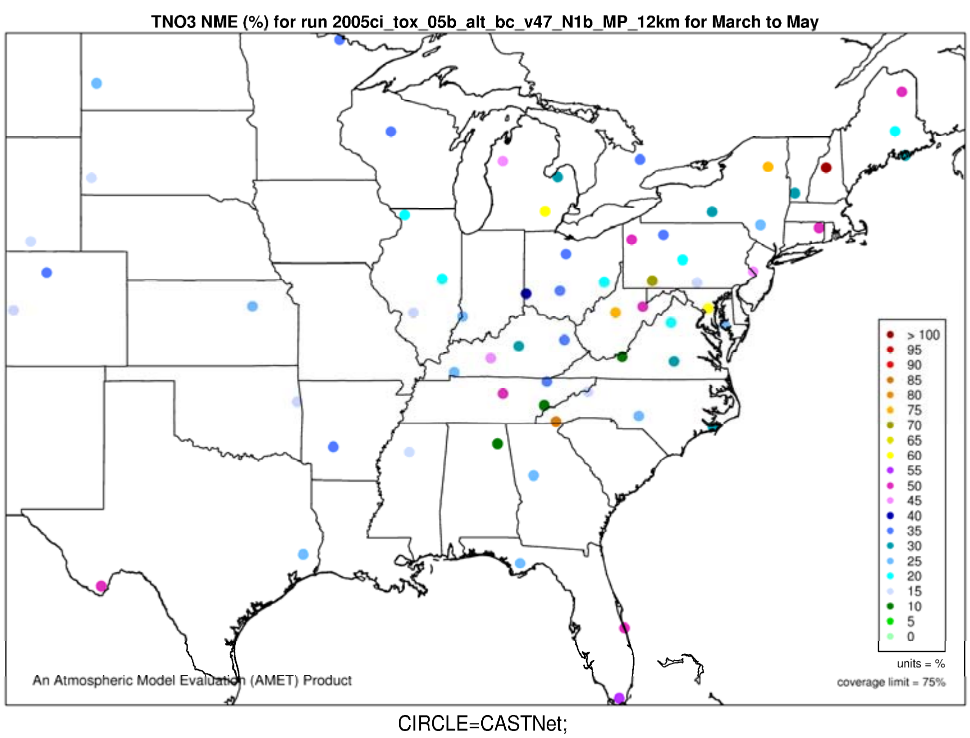


Figure G-8 Normalized Mean Error (%) of total nitrate by monitor for 12-km Eastern U.S. domain, Spring 2005.

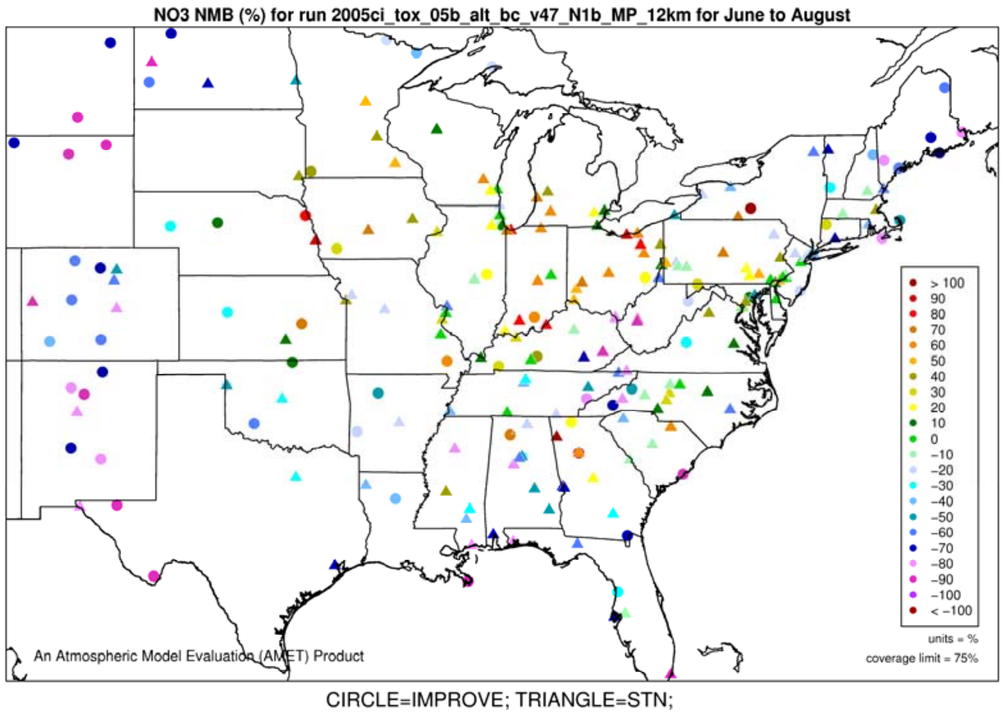


Figure G-9. Normalized Mean Bias (%) of nitrate by monitor for 12-km Eastern U.S. domain, Summer 2005.

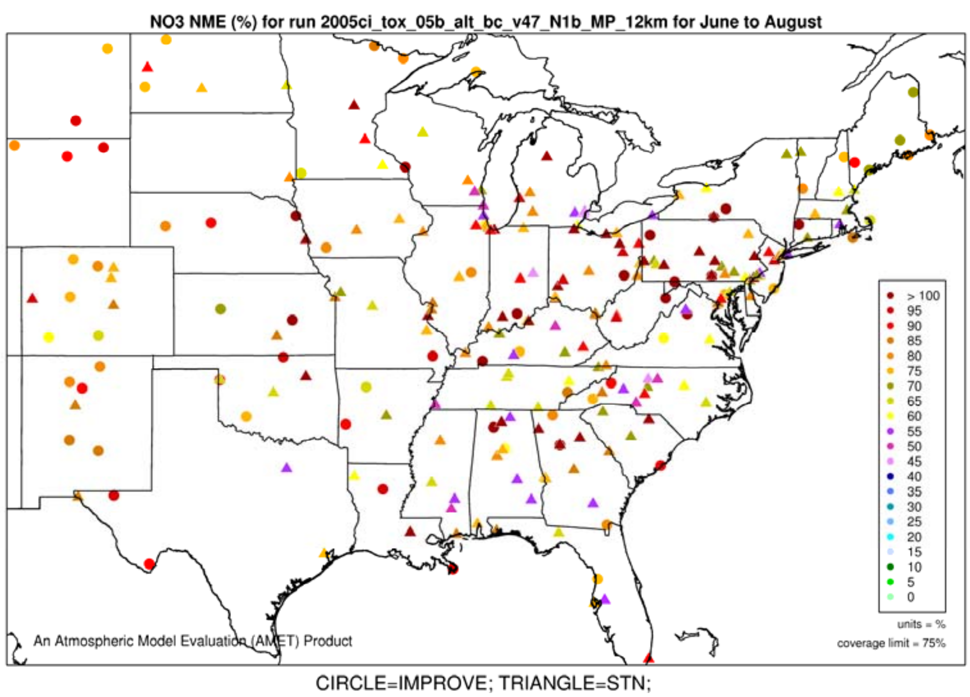


Figure G-10. Normalized Mean Error (%) of nitrate by monitor for 12-km Eastern U.S. domain, Summer 2005.

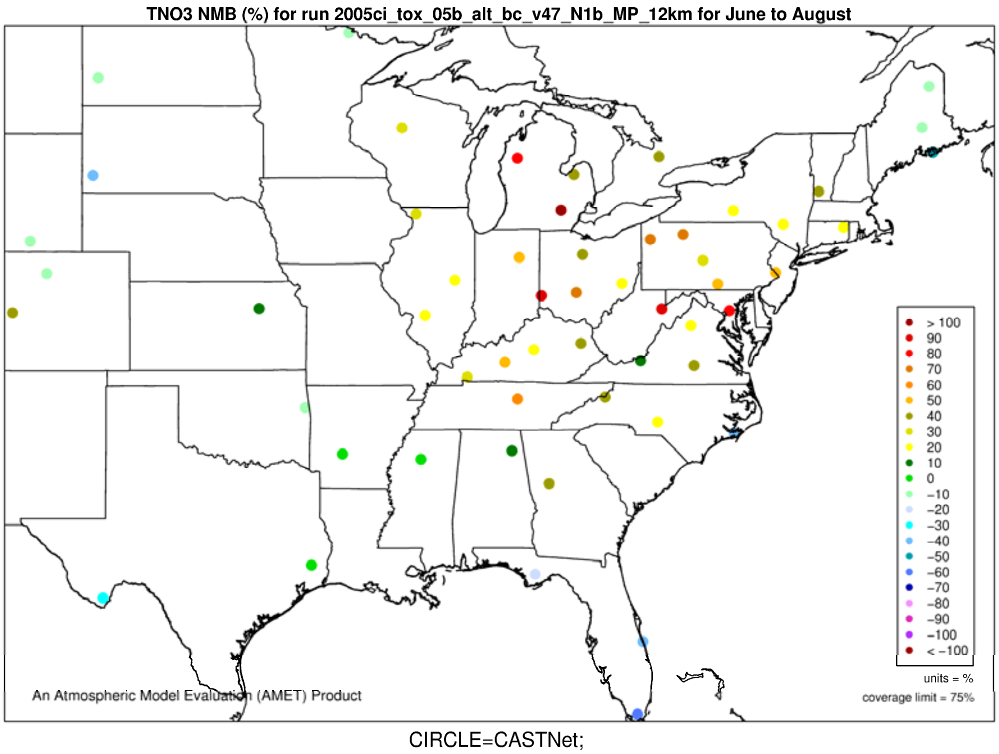


Figure G-11. Normalized Mean Bias (%) of total nitrate by monitor for 12-km Eastern U.S. domain, Summer 2005.

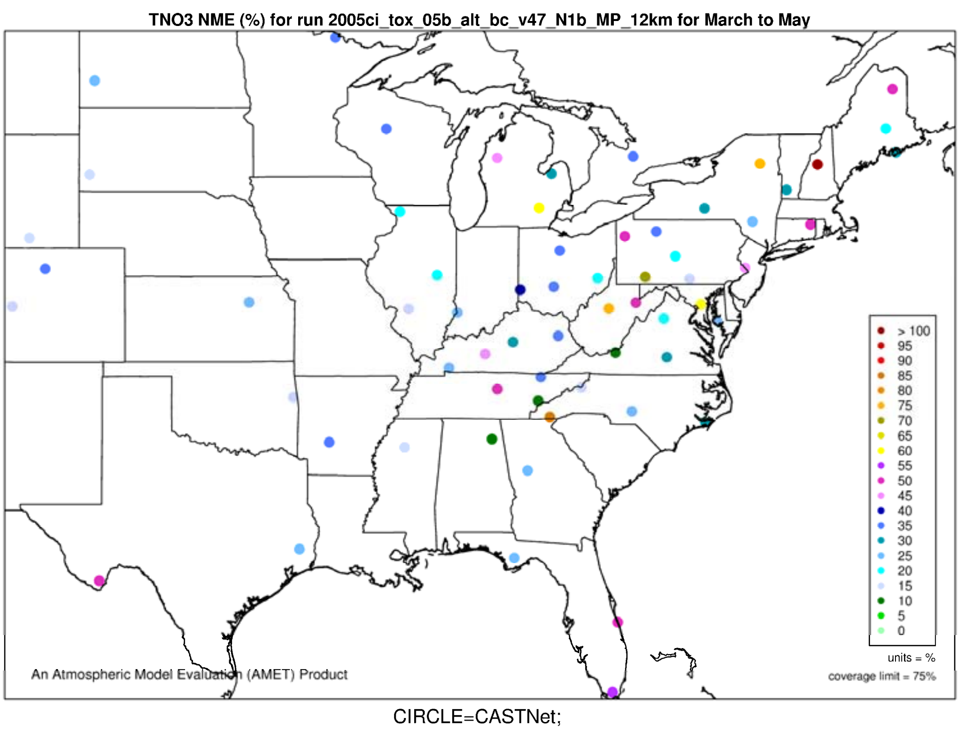


Figure G-12. Normalized Mean Error (%) of total nitrate by monitor for 12-km Eastern U.S. domain, Summer 2005.

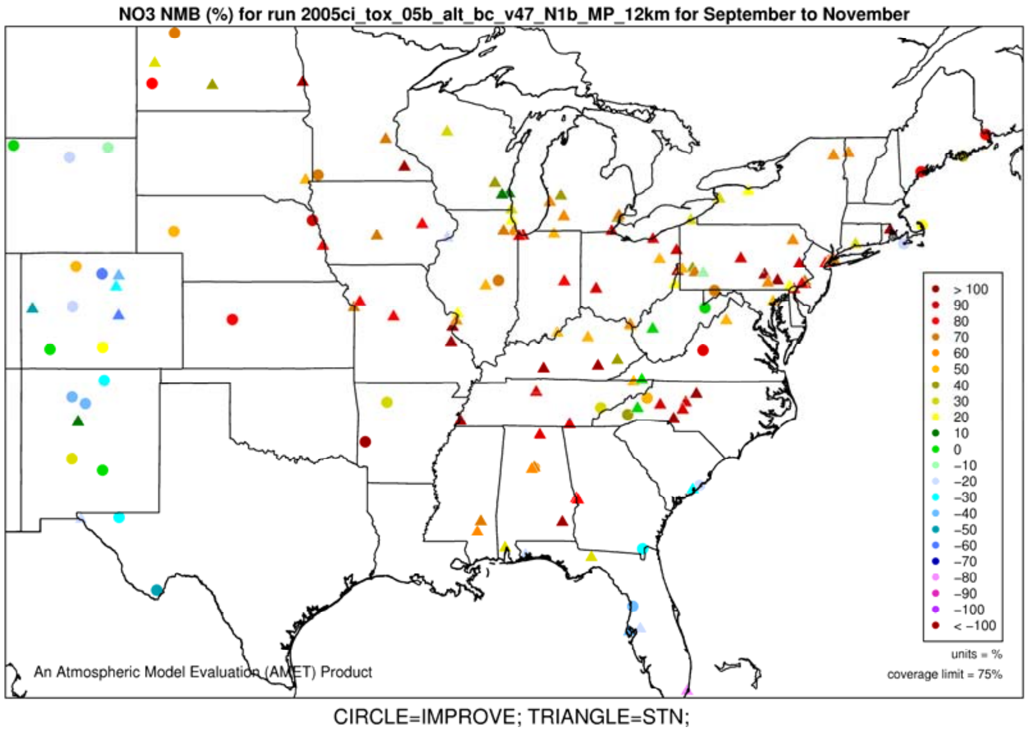


Figure G-13. Normalized Mean Bias (%) of nitrate by monitor for 12-km Eastern U.S. domain, Fall 2005.

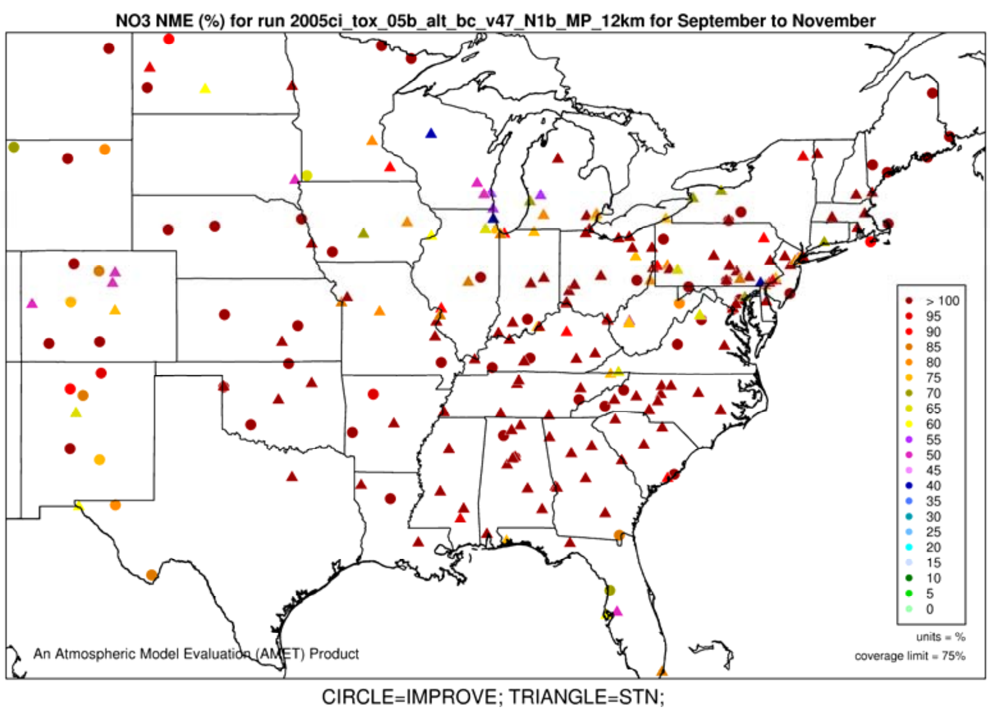


Figure G-14. Normalized Mean Error (%) of nitrate by monitor for 12-km Eastern U.S. domain, Fall 2005.

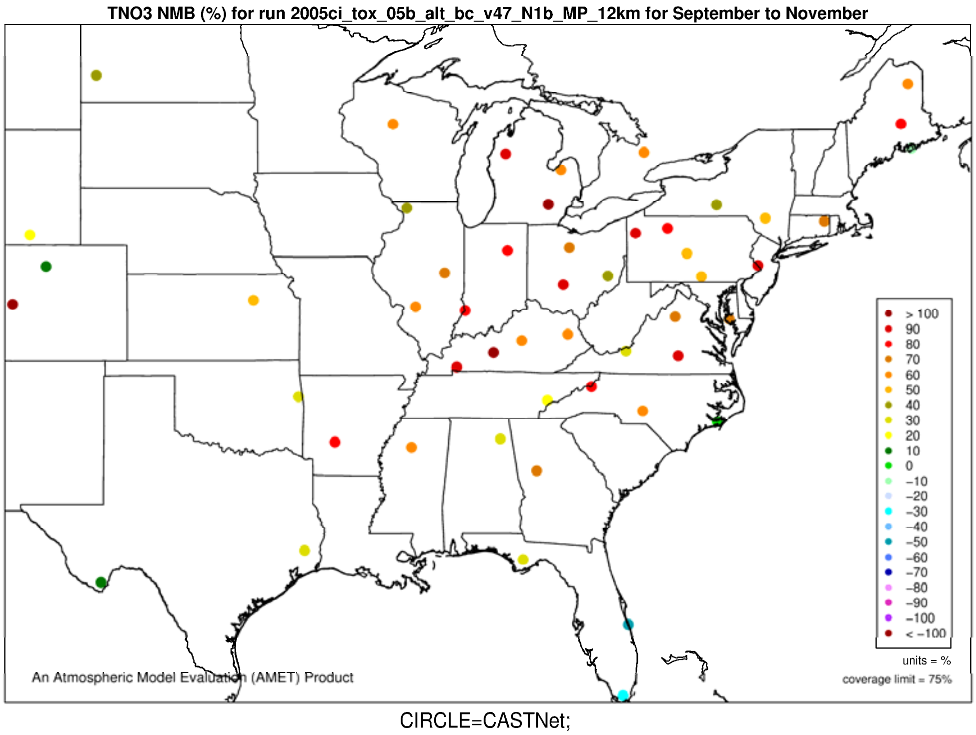


Figure G-15. Normalized Mean Bias (%) of total nitrate by monitor for 12-km Eastern U.S. domain, Fall 2005.

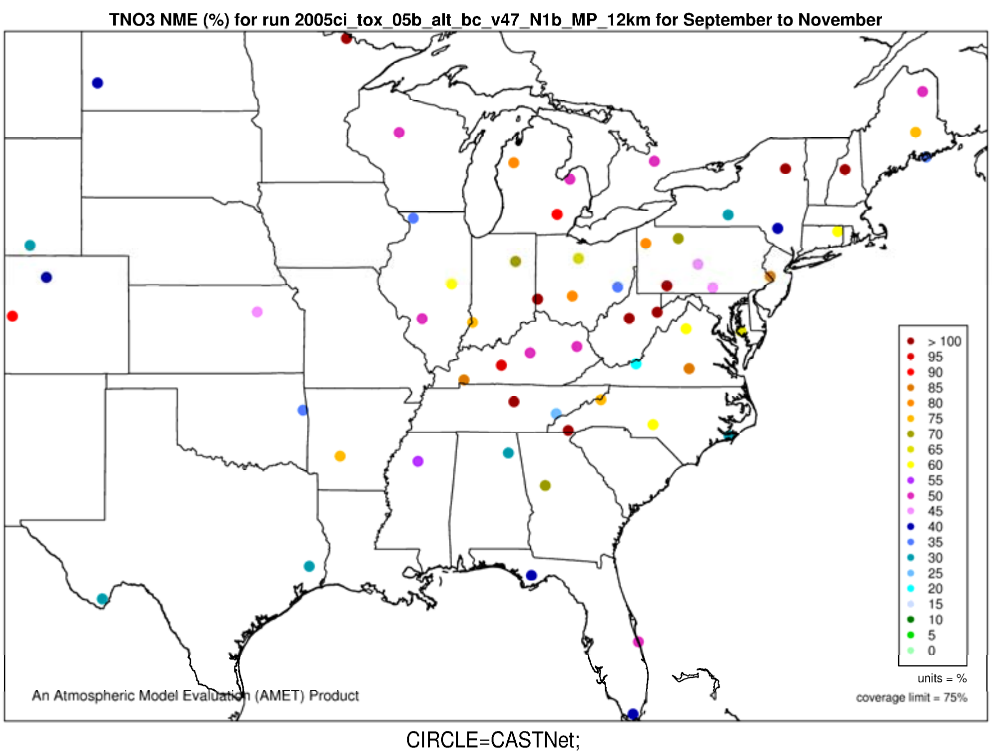


Figure G-16. Normalized Mean Error (%) of total nitrate by monitor for 12-km Eastern U.S. domain, Fall 2005.

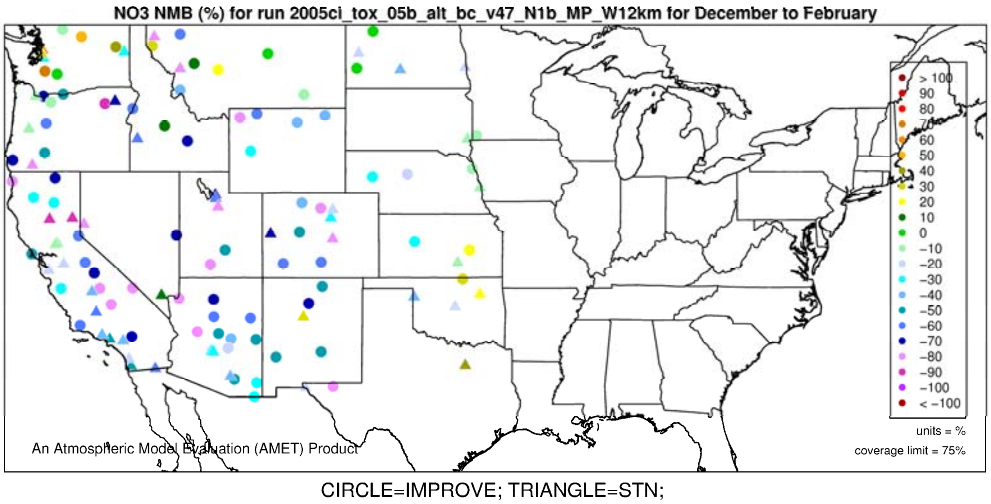


Figure G-17. Normalized Mean Bias (%) of nitrate by monitor for 12-km Western U.S. domain, Winter 2005.

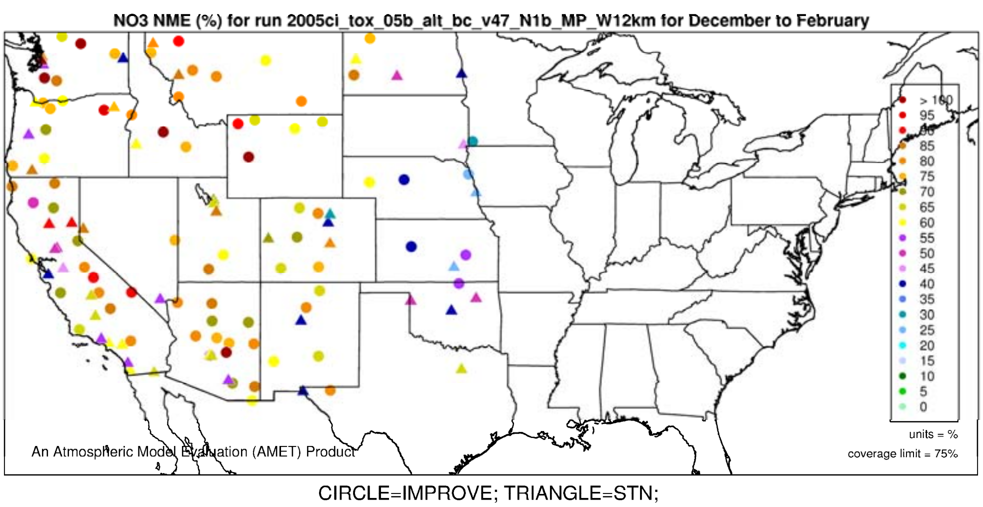


Figure G-18. Normalized Mean Error (%) of nitrate by monitor for 12-km Western U.S. domain, Winter 2005.

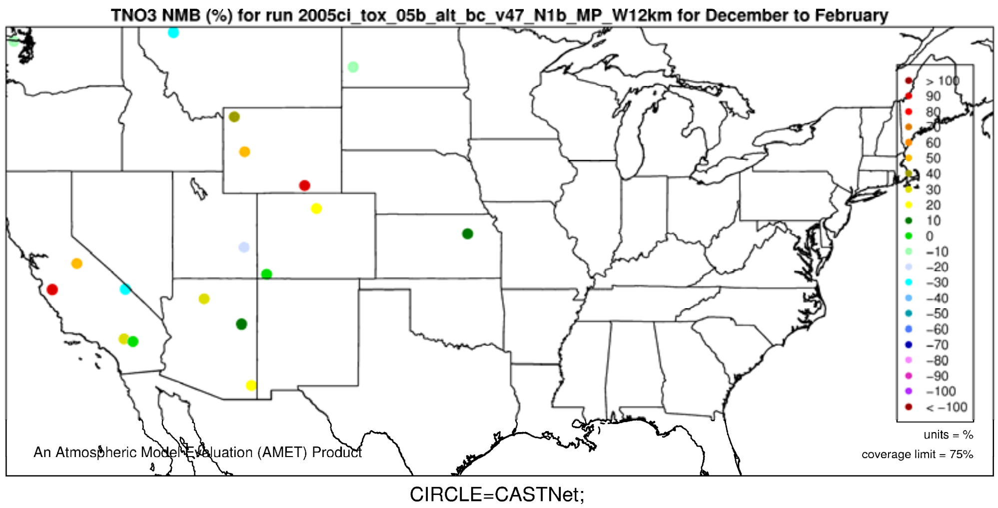


Figure G-19. Normalized Mean Bias (%) of total nitrate by monitor for 12-km Western U.S. domain, Winter 2005.

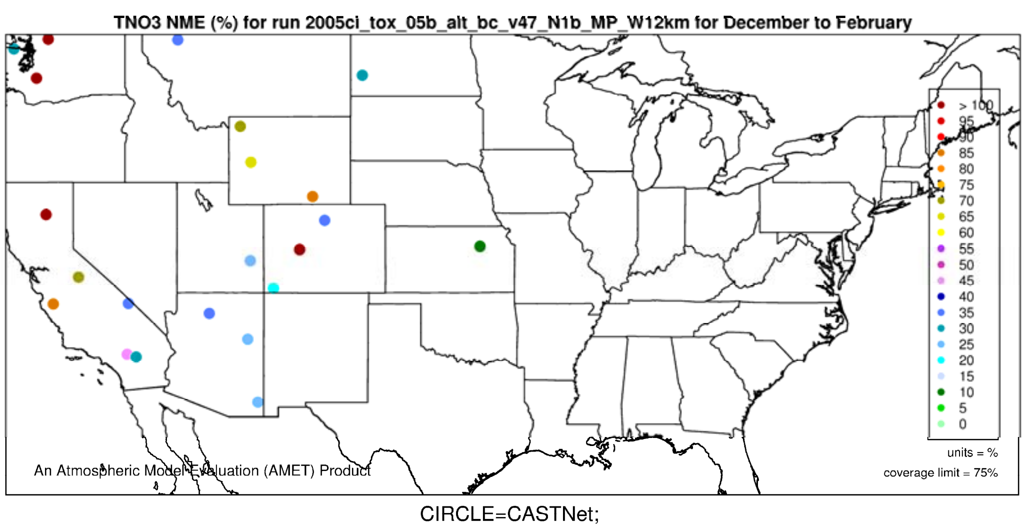


Figure G-20. Normalized Mean Error (%) of total nitrate by monitor for 12-km Western U.S. domain, Winter 2005.

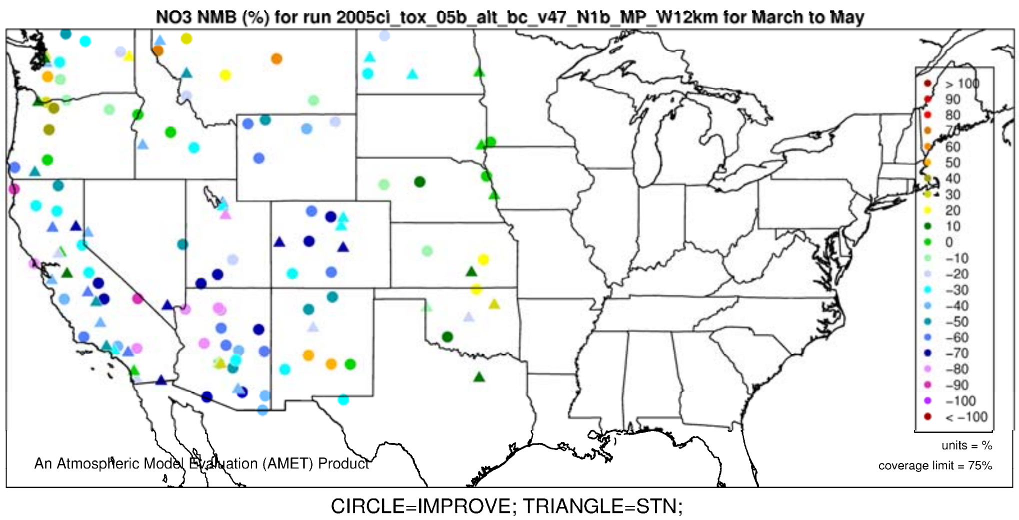


Figure G-21. Normalized Mean Bias (%) of nitrate by monitor for 12-km Western U.S. domain, Spring 2005.

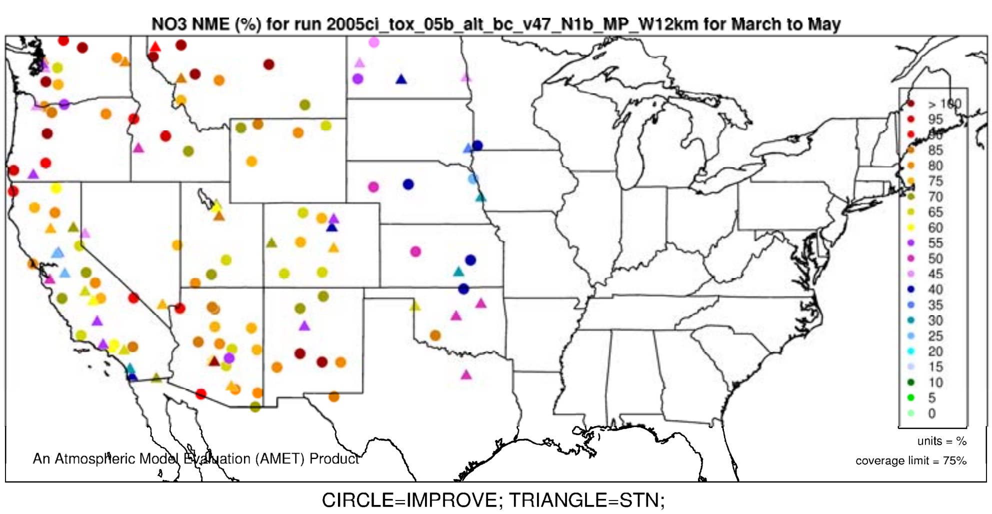


Figure G-22. Normalized Mean Error (%) of nitrate by monitor for 12-km Western U.S. domain, Spring 2005.

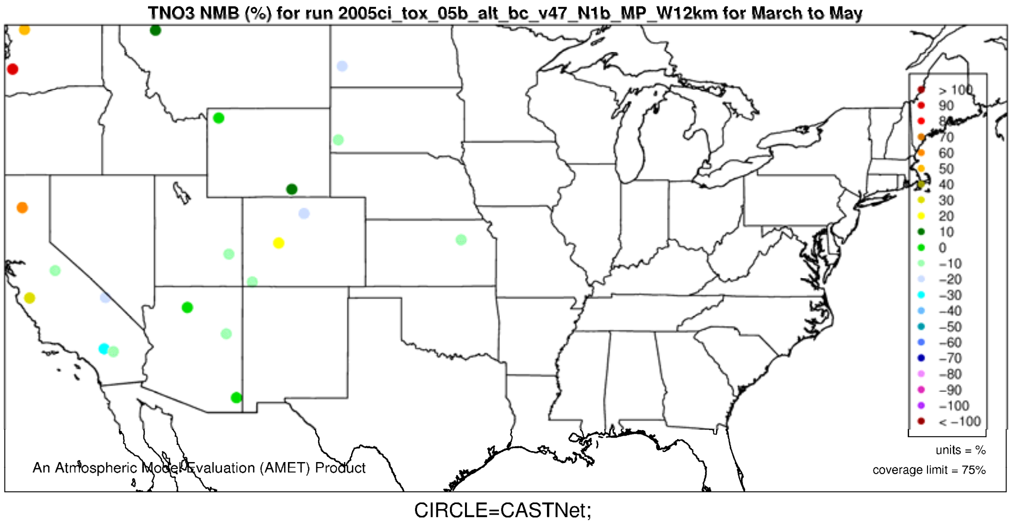


Figure G-23. Normalized Mean Bias (%) of total nitrate by monitor for 12-km Western U.S. domain, Spring 2005.

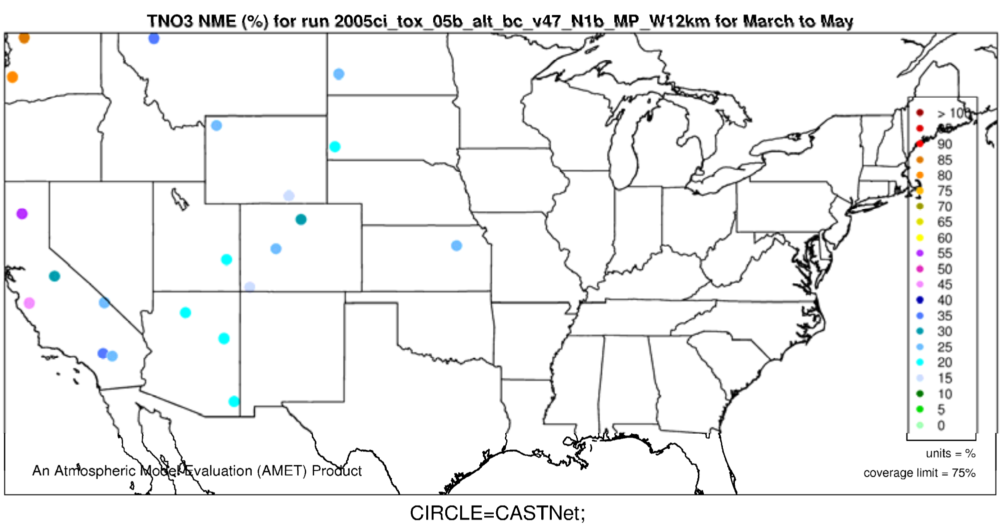


Figure G-24. Normalized Mean Error (%) of total nitrate by monitor for 12-km Western U.S. domain, Spring 2005.

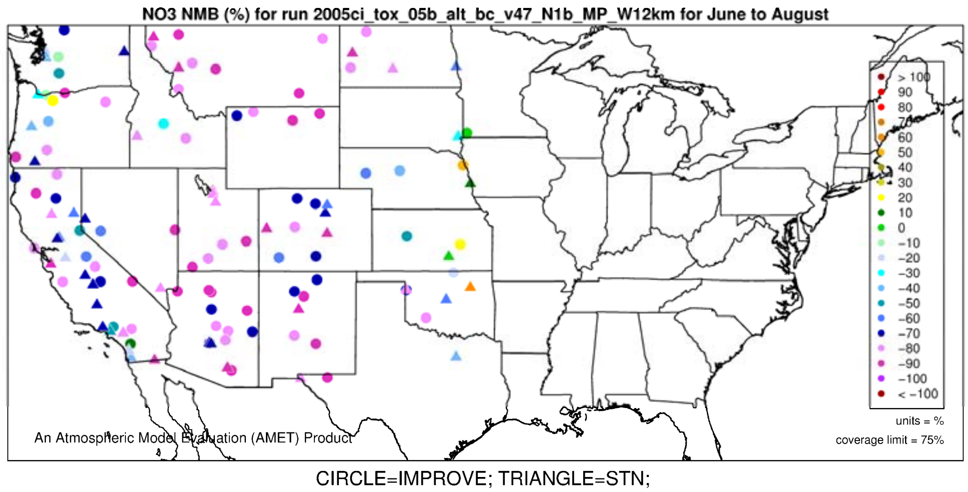


Figure G-25. Normalized Mean Bias (%) of nitrate by monitor for 12-km Western U.S. domain, Summer 2005.

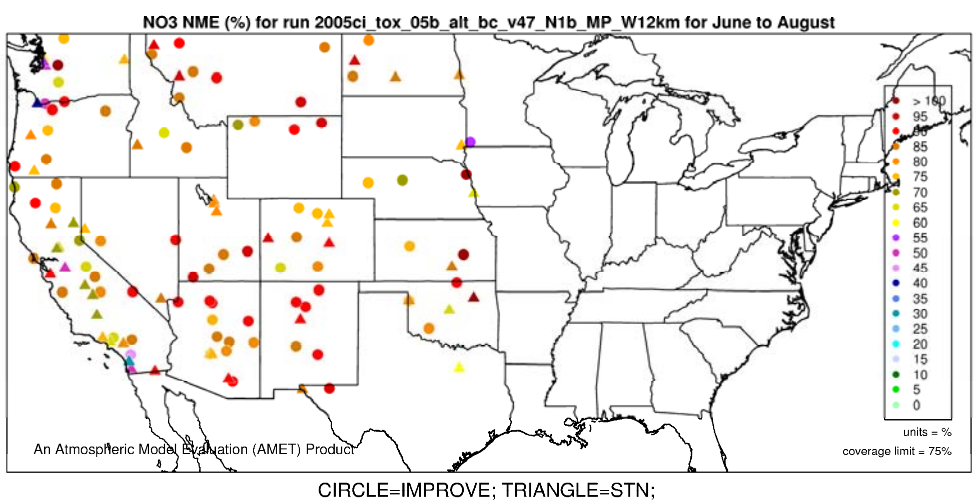


Figure G-26. Normalized Mean Error (%) of nitrate by monitor for 12-km Western U.S. domain, Summer 2005.

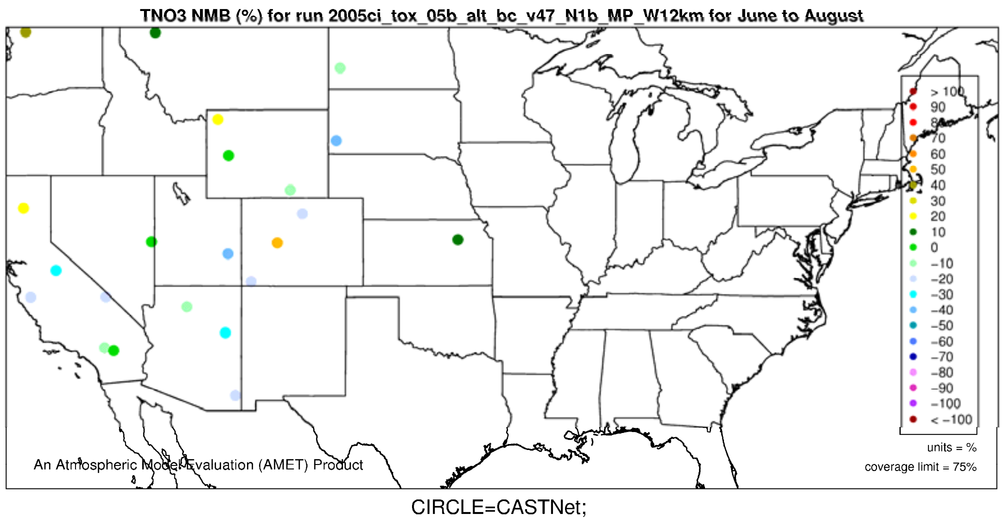


Figure G-27. Normalized Mean Bias (%) of total nitrate by monitor for 12-km Western U.S. domain, Summer 2005.

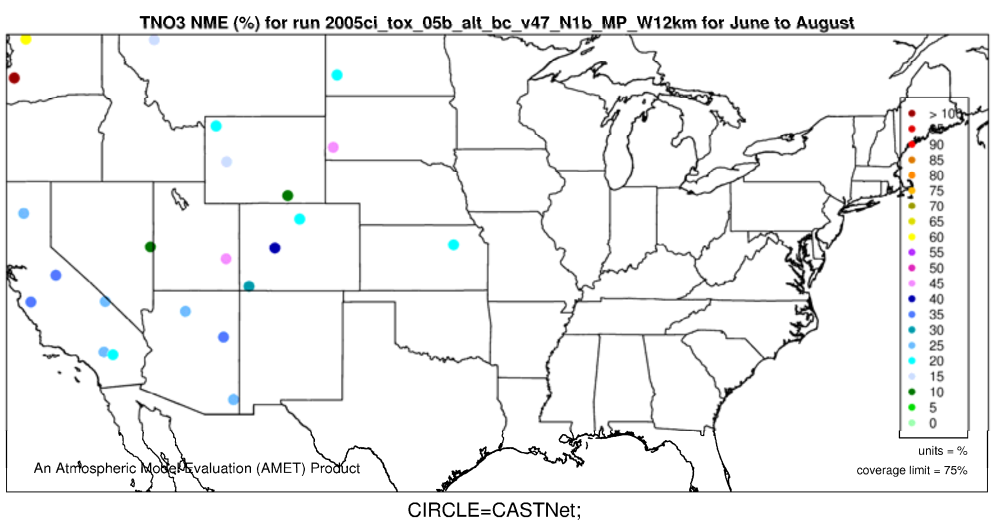


Figure G-28. Normalized Mean Error (%) of total nitrate by monitor for 12-km Western U.S. domain, Summer 2005.

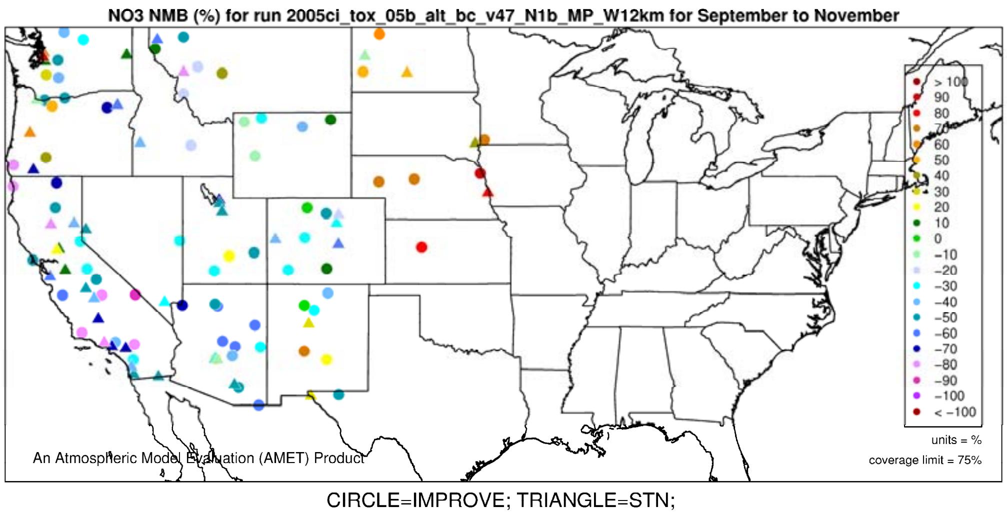


Figure G-29. Normalized Mean Bias (%) of nitrate by monitor for 12-km Western U.S. domain, Fall 2005.

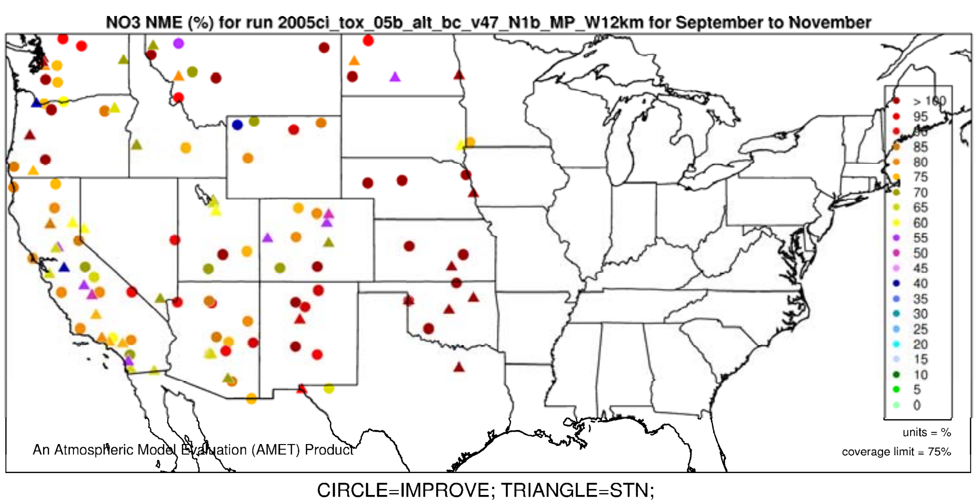


Figure G-30. Normalized Mean Error (%) of nitrate by monitor for 12-km Western U.S. domain, Fall 2005.

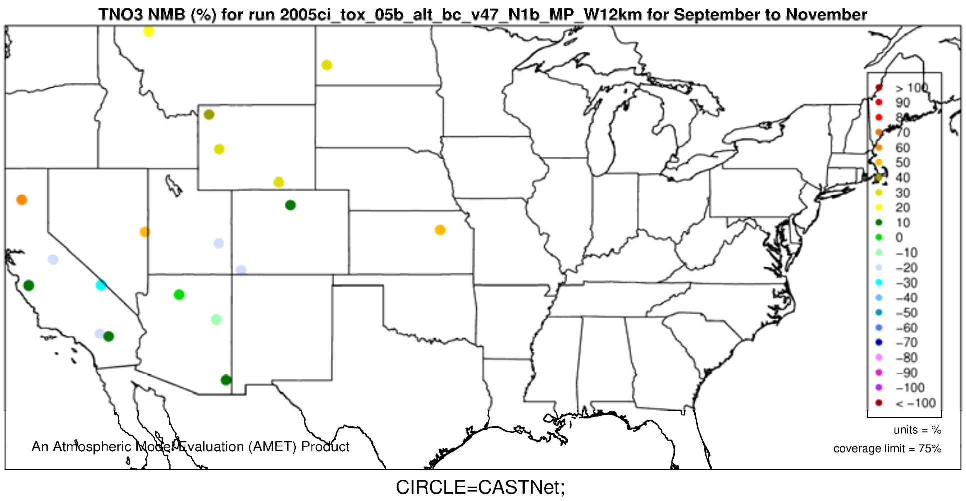


Figure G-31. Normalized Mean Bias (%) of total nitrate by monitor for 12-km Western U.S. domain, Fall 2005.

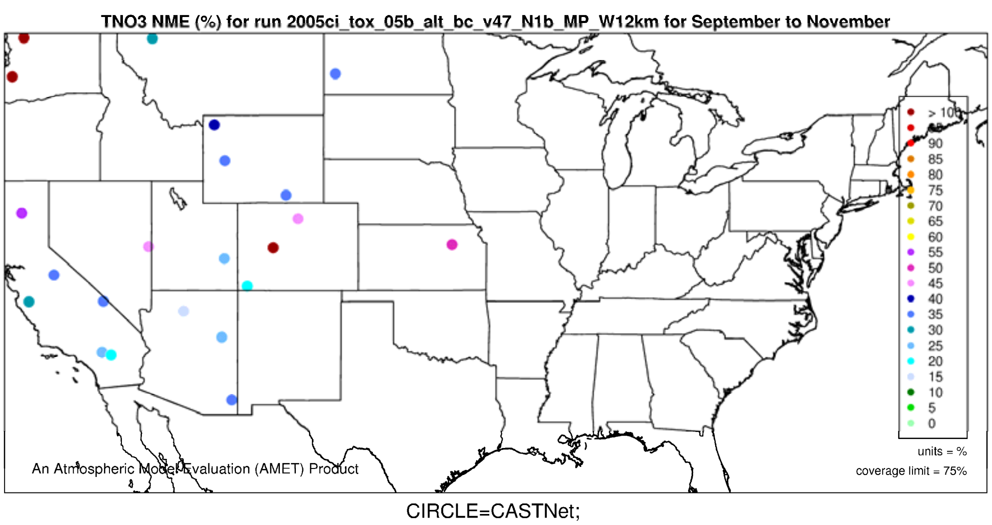


Figure G-32. Normalized Mean Error (%) of total nitrate by monitor for 12-km Western U.S. domain, Fall 2005.

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, ammonium performance at STN and CASTNet networks shows an under-prediction in the EUS and WUS (NMB values range from -1% to -31%), except in the Northeast (NMB values range from 5% to 20%). Likewise, 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. Ammonium predictions in the summer are moderately under-predicted for the East and West in both the rural and urban sites (NMB values ranging from -6% to - 37%).

Table H-1. CMAQ 2002 seasonal model performance statistics for ammonium.

CMAQ 2002 Ammonium			No. of Obs.	NMB (%)	NME (%)	FB (%)	FE (%)
Winter	STN	12-km EUS	3385	-5.3	37.5	-1.8	41.6
		12-km WUS	1032	-24.0	58.9	-8.0	63.4
		Northeast	828	4.7	34.0	8.7	34.0
		Midwest	598	-9.2	32.5	-3.7	33.6
		Southeast	963	-6.7	41.5	-4.7	44.3
		Central	766	-8.9	41.9	-5.5	50.2
		West	829	-31.0	61.1	-14.5	66.0
	CASTNet	12-km EUS	760	-1.4	29.8	2.7	31.9
		12-km WUS	267	-6.8	37.0	1.2	40.7
		Northeast	193	20.5	37.3	22.9	34.8
		Midwest	142	-12.7	24.7	-7.8	25.1
		Southeast	264	-7.4	27.7	-7.3	29.3
		Central	72	-5.8	35.4	-4.9	42.5
		West	255	-12.1	42.1	0.7	41.4
Spring	STN	12-km EUS	3626	18.8	46.4	18.5	44.4
		12-km WUS	1077	-2.0	47.4	17.5	48.7
		Northeast	894	34.7	54.9	38.0	51.7
		Midwest	637	39.0	55.0	35.7	48.6
		Southeast	988	5.9	37.1	7.1	37.8
		Central	875	-4.3	39.3	0.5	42.6
		West	859	-2.5	52.2	20.4	51.4
	CASTNet	12-km EUS	832	24.1	39.8	18.8	34.3
		12-km WUS	287	-5.3	33.1	-3.3	32.0
		Northeast	206	42.6	48.3	33.9	38.6
		Midwest	155	42.2	49.6	35.7	40.3
		Southeast	292	5.3	29.1	4.7	29.4
		Central	78	3.7	34.1	4.9	32.9
		West	274	-10.4	32.7	-4.7	32.1
Summer	STN	12-km EUS	3512	-18.2	38.5	-9.0	48.0

		12-km WUS	1071	-31.6	49.6	-8.9	51.7
		Northeast	874	-17.5	36.9	-1.4	45.2
		Midwest	621	-8.5	35.8	9.1	40.7
		Southeast	941	-21.4	37.3	-14.3	44.6
		Central	847	-27.7	45.7	-27.8	60.3
		West	849	-34.7	54.6	-7.2	54.2
	CASTNet	12-km EUS	792	-22.6	31.3	-28.0	38.5
		12-km WUS	295	-32.9	41.6	-37.3	47.8
		Northeast	192	-23.4	29.7	-25.9	34.5
		Midwest	161	-6.8	25.2	-3.6	27.0
		Southeast	270	-32.8	35.6	-44.8	48.1
		Central	75	-20.7	31.4	-24.5	38.1
		West	282	-36.9	43.5	-39.1	49.0
Fall	STN	12-km EUS	3349	4.4	43.2	18.6	46.8
		12-km WUS	1081	-18.3	62.5	8.6	59.8
		Northeast	902	15.5	49.9	29.5	51.3
		Midwest	639	1.9	37.6	17.8	41.1
		Southeast	990	-2.8	40.1	9.7	43.2
		Central U.S.	571	6.9	48.5	18.6	51.0
		West	886	-24.9	64.7	5.5	61.2
	CASTNet	12-km EUS	786	3.0	38.7	7.2	38.5
		12-km WUS	293	-3.8	43.4	-7.3	39.9
		Northeast	195	7.4	38.8	12.3	35.5
		Midwest	157	18.7	44.3	25.5	40.2
		Southeast	273	-11.3	35.6	-9.0	39.7
		Central	75	10.9	42.0	19.5	45.3
		West	280	-14.5	37.9	-10.8	38.3

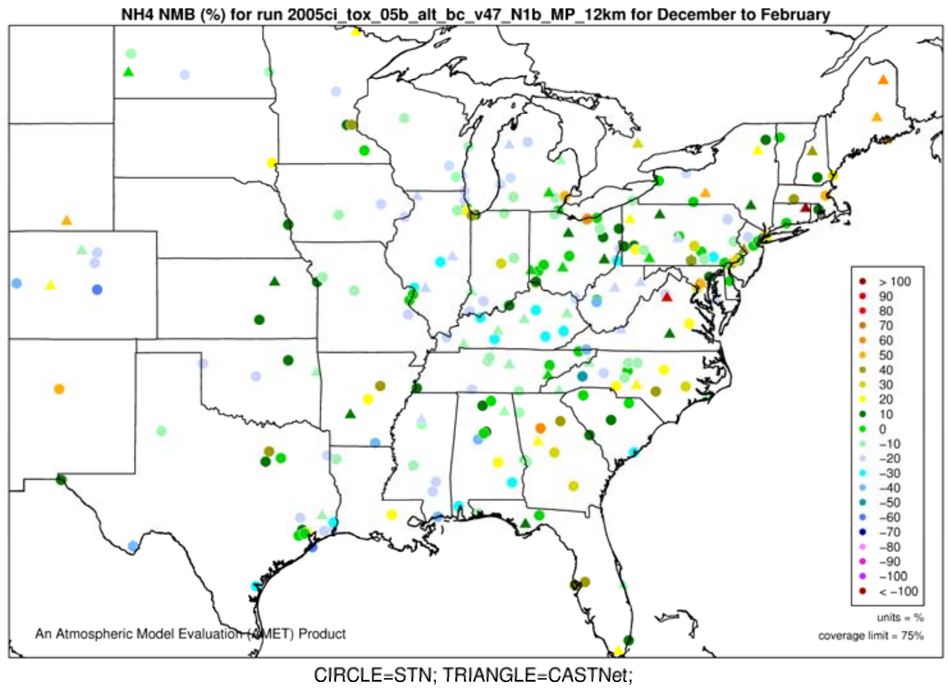


Figure H-1. Normalized Mean Bias (%) of ammonium by monitor for 12-km Eastern U.S. domain, Winter 2005.

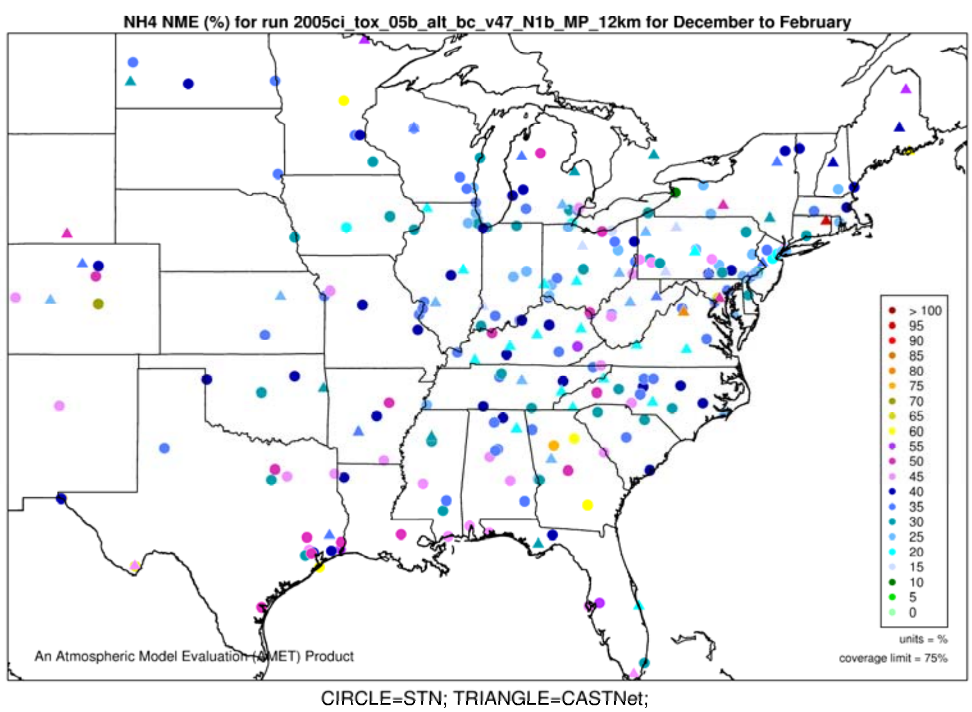


Figure H-2. Normalized Mean Error (%) of ammonium by monitor for 12-km Eastern U.S. domain, Winter 2005.

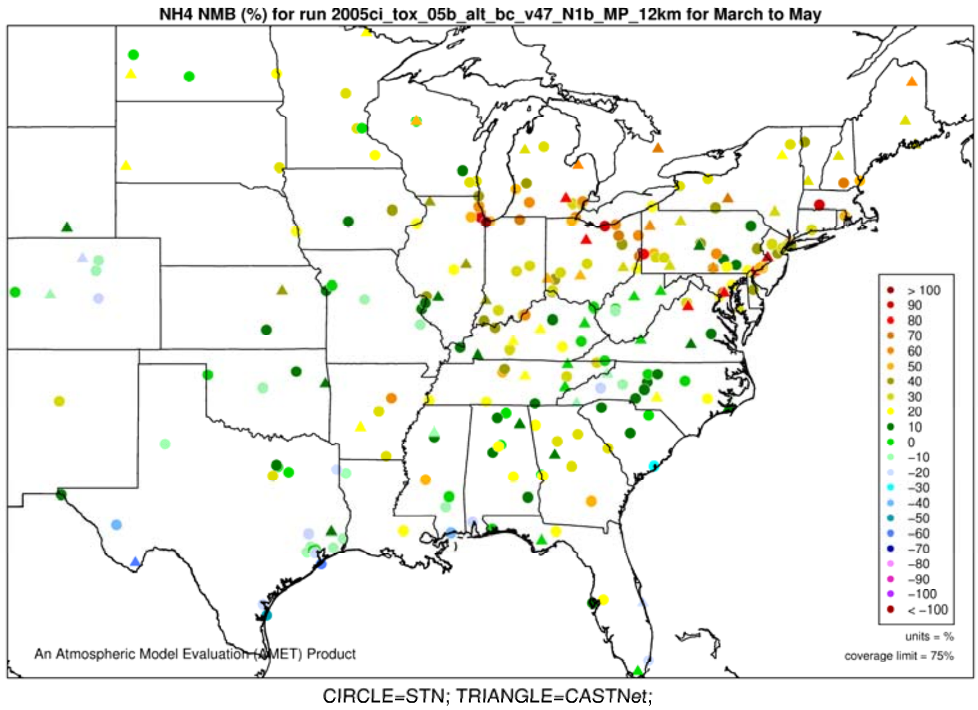


Figure H-3. Normalized Mean Bias (%) of ammonium by monitor for 12-km Eastern U.S. domain, Spring 2005.

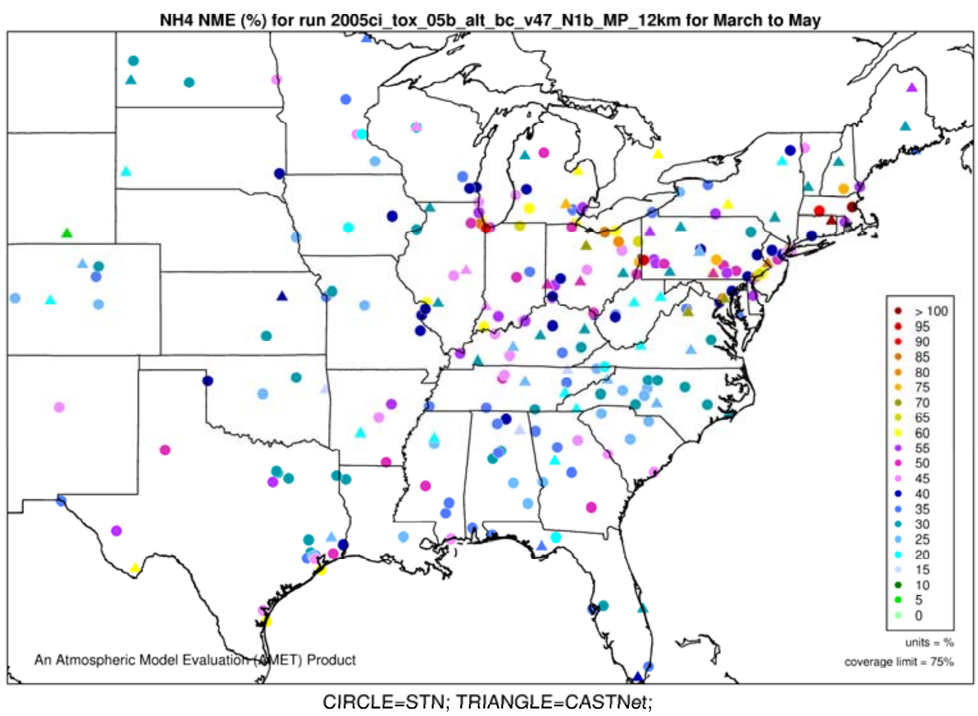


Figure H-4. Normalized Mean Error (%) of ammonium by monitor for 12-km Eastern U.S. domain, Spring 2005.

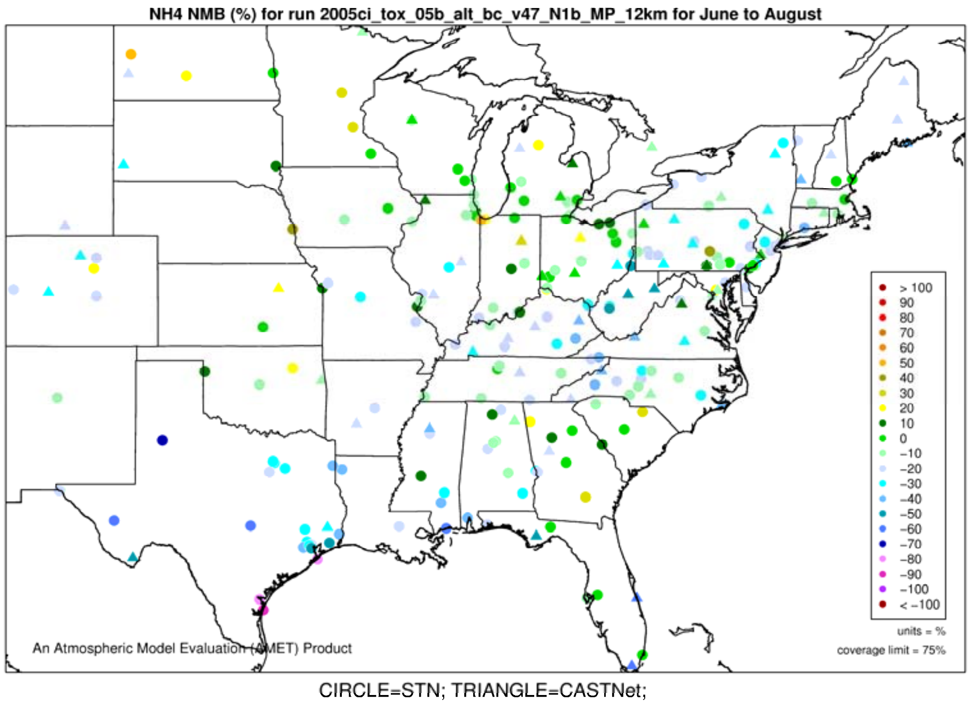


Figure H-5. Normalized Mean Bias (%) of ammonium by monitor for 12-km Eastern U.S. domain, Summer 2005.

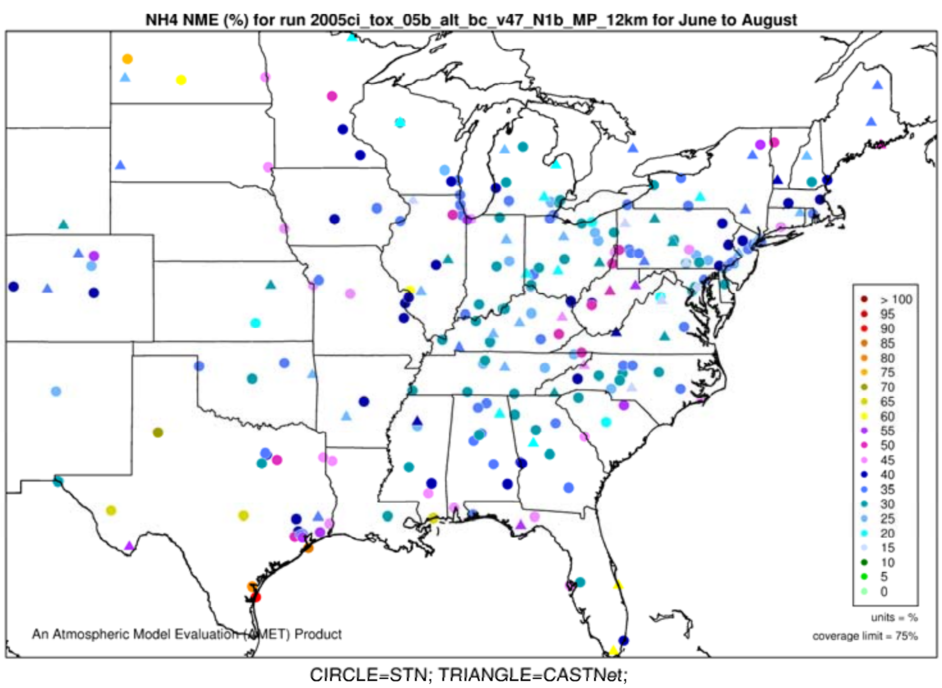


Figure H-6. Normalized Mean Error (%) of ammonium by monitor for 12-km Eastern U.S. domain, Summer 2005.

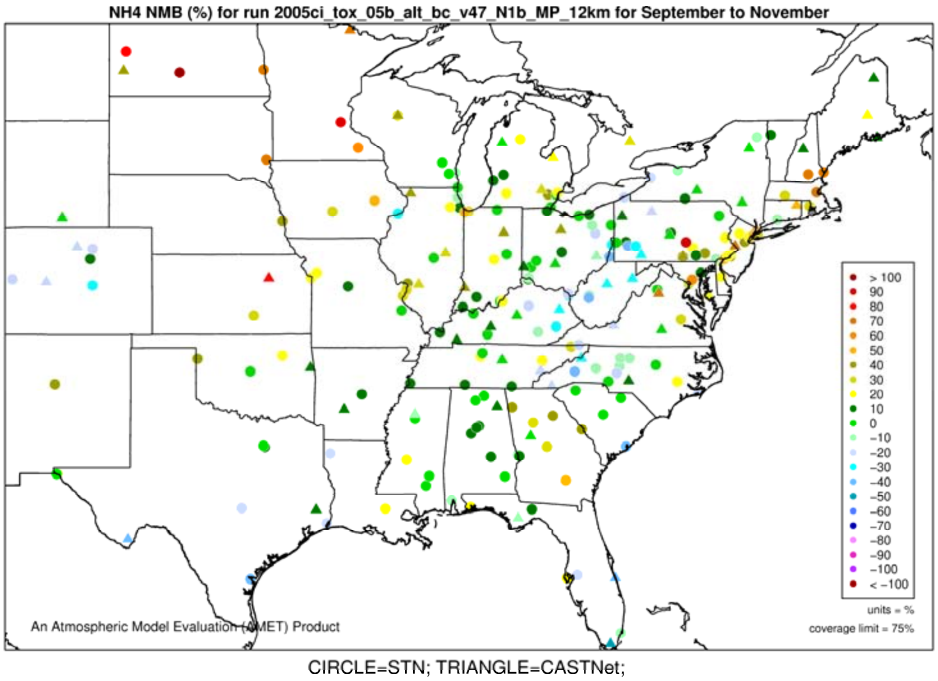


Figure H-7. Normalized Mean Bias (%) of ammonium by monitor for 12-km Eastern U.S. domain, Fall 2005.

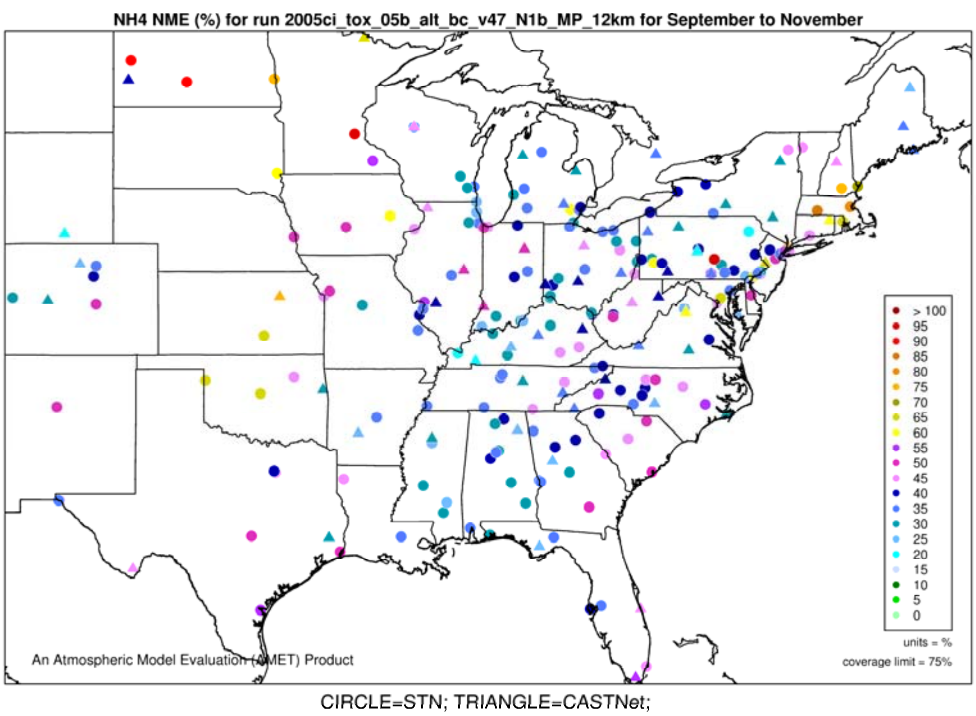


Figure H-8. Normalized Mean Error (%) of ammonium by monitor for 12-km Eastern U.S. domain, Fall 2005.

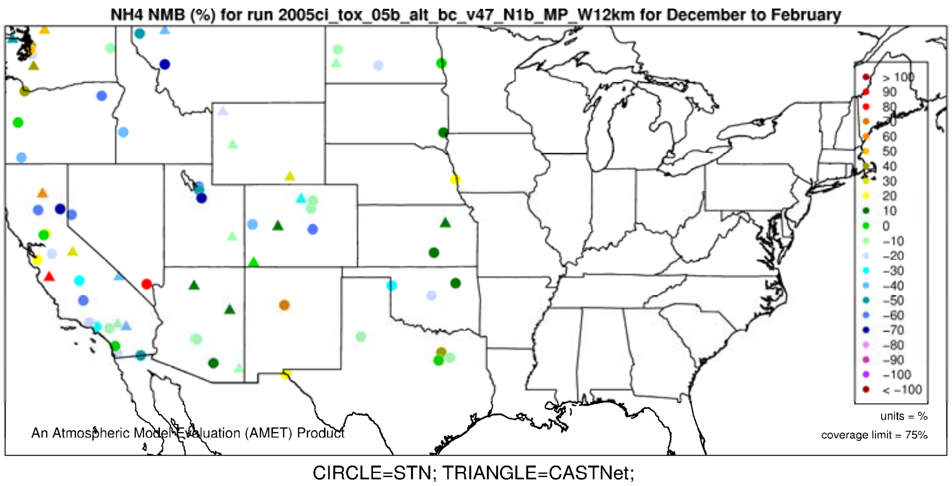


Figure H-9. Normalized Mean Bias (%) of ammonium by monitor for 12-km Western U.S. domain, Winter 2005.

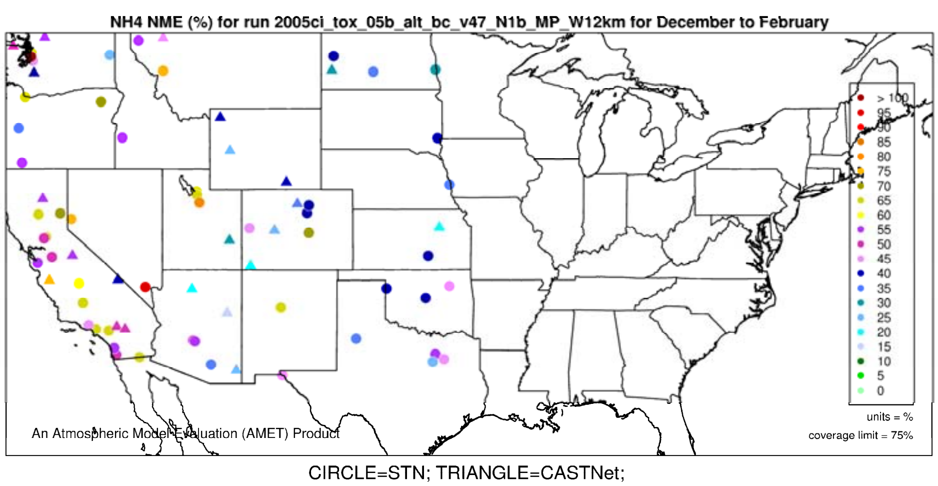


Figure H-10. Normalized Mean Error (%) of ammonium by monitor for 12-km Western U.S. domain, Winter 2005.

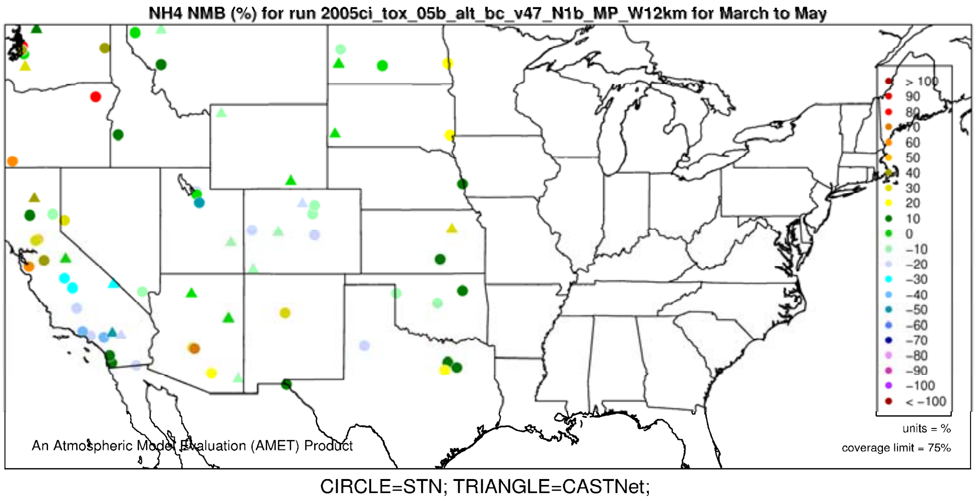


Figure H-11. Normalized Mean Bias (%) of ammonium by monitor for 12-km Western U.S. domain, Spring 2005.

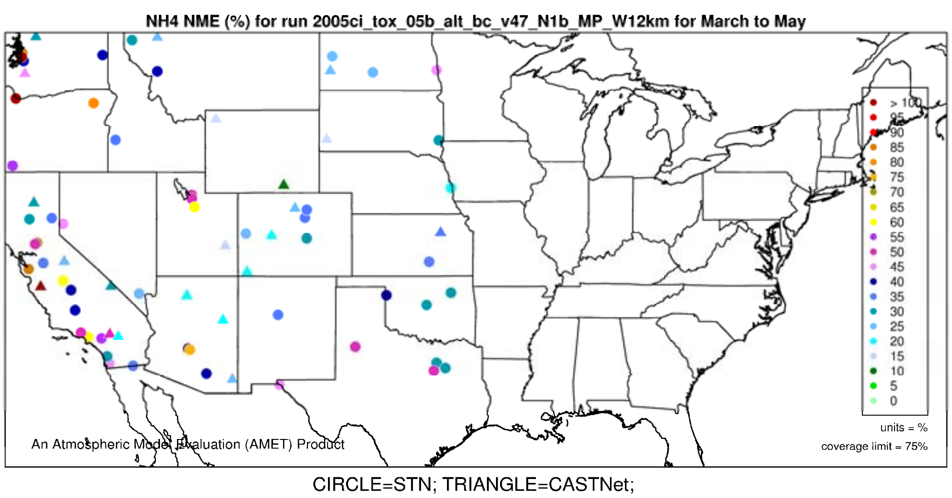


Figure H-12. Normalized Mean Error (%) of ammonium by monitor for 12-km Western U.S. domain, Spring 2005.

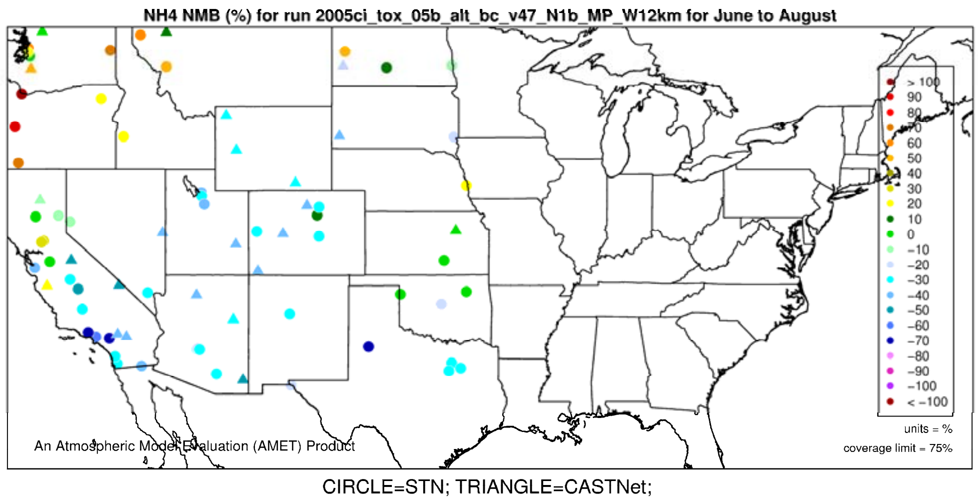


Figure H-13. Normalized Mean Bias (%) of ammonium by monitor for 12-km Western U.S. domain, Summer 2005.

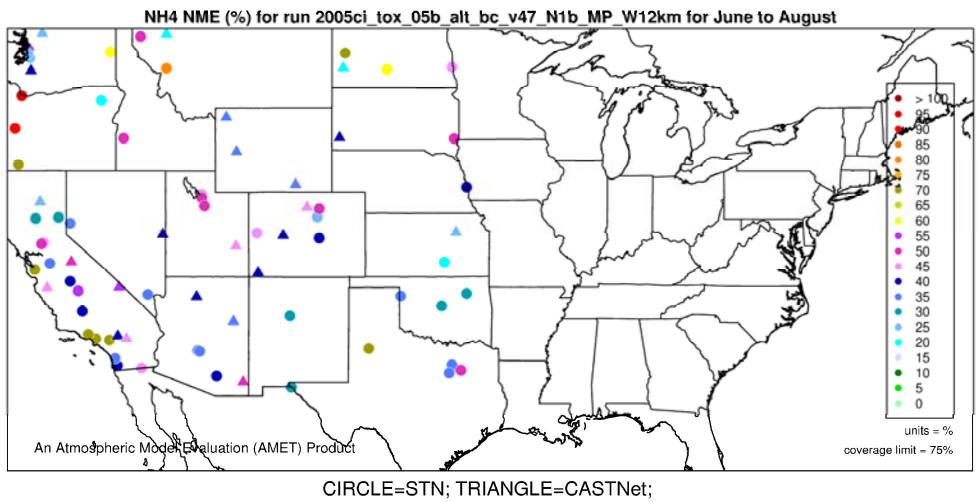


Figure H-14. Normalized Mean Error (%) of ammonium by monitor for 12-km Western U.S. domain, Summer 2005.

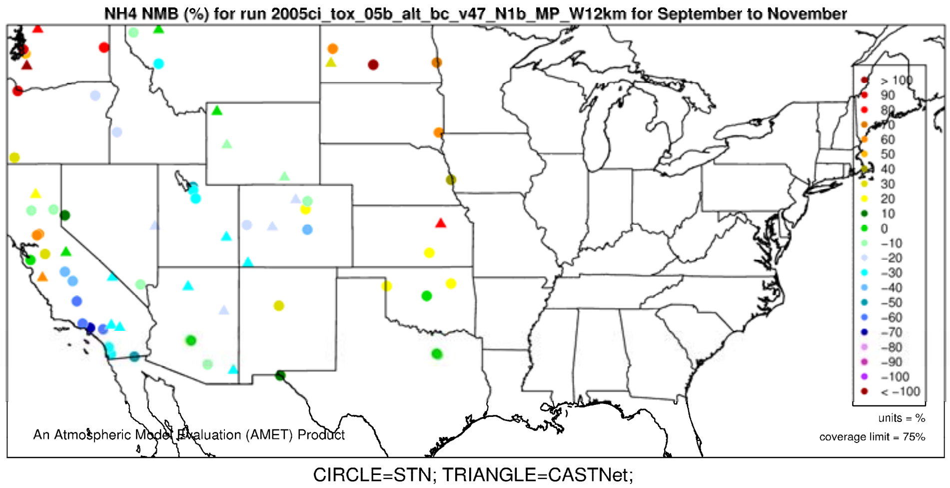


Figure H-15. Normalized Mean Bias (%) of ammonium by monitor for 12-km Western U.S. domain, Fall 2005.

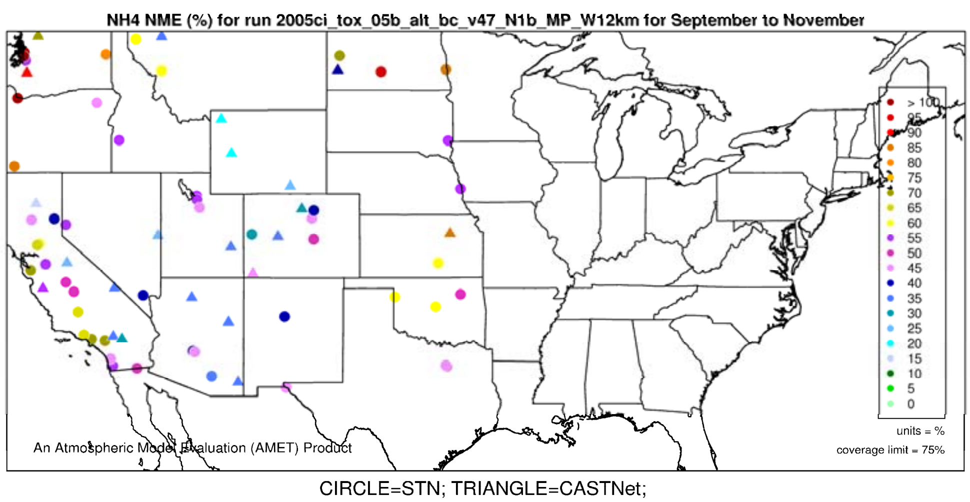


Figure H-16. Normalized Mean Error (%) of ammonium by monitor for 12-km Western U.S. domain, Fall 2005.

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 moderate under-prediction at the IMPROVE sites (except during the summer season in the WUS). 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	36.3	73.2	24.7	55.5
		12-km WUS	657	8.1	71.3	5.4	65.2
		Northeast	831	53.3	74.7	36.3	53.8
		Midwest	602	53.5	78.1	41.2	56.9
		Southeast	964	17.5	60.1	7.9	46.0
		Central	811	43.7	90.5	31.0	65.6
		West	520	10.4	71.0	0.4	66.1
	IMPROVE	12-km EUS	2072	-10.1	49.2	-16.4	53.3
		12-km WUS	2279	-19.4	57.1	-31.7	68.2
		Northeast	522	13.3	51.3	6.1	47.2
		Midwest	166	11.3	46.1	-1.9	42.4
		Southeast	386	-33.4	45.0	-34.2	52.8
		Central	474	-17.3	51.4	-13.6	52.5
		West	2066	-23.6	56.7	-35.7	70.0
Spring	STN	12-km EUS	3672	31.7	68.1	22.1	54.1
		12-km WUS	1064	49.5	86.4	24.2	63.8
		Northeast	881	52.1	80.4	36.6	58.5
		Midwest	637	14.7	49.7	19.5	45.6
		Southeast	985	18.9	61.2	15.5	49.1
		Central	937	44.9	81.9	22.5	60.9
		West	822	65.2	97.3	28.5	67.2
	IMPROVE	12-km EUS	2296	-23.9	48.5	-17.7	52.3
		12-km WUS	2563	-7.6	54.7	-11.4	54.0
		Northeast	565	1.9	48.2	-3.1	52.5
		Midwest	160	-15.3	42.0	-29.4	50.0
		Southeast	408	-43.9	49.7	-42.2	52.2
		Central	578	44.9	81.9	22.5	60.9
		West	2289	-3.6	55.1	-11.4	54.2
Summer	STN	12-km EUS	3529	27.4	66.9	17.2	58.0
		12-km WUS	1030	62.1	91.3	34.6	62.5

		Northeast	866	30.4	66.1	24.1	55.7
		Midwest	621	3.8	40.1	8.7	44.2
		Southeast	940	18.6	66.9	15.5	55.9
		Central	571	62.5	98.4	21.2	72.0
		West	806	78.9	10.7	41.0	65.8
	IMPROVE	12-km EUS	2182	-42.2	51.1	-46.8	64.1
		12-km WUS	2301	1.4	60.8	0.8	56.6
		Northeast	512	-38.1	47.8	-54.2	66.6
		Midwest	160	-35.5	40.6	-52.9	58.6
		Southeast	384	-58.7	59.8	-81.2	87.0
		Central	561	-42.7	51.7	-51.9	65.5
		West	2055	5.1	63.0	4.7	57.1
Fall	STN	12-km EUS	3396	10.8	56.9	8.3	49.4
		12-km WUS	1063	21.4	70.3	9.0	59.6
		Northeast	901	18.8	63.1	10.6	50.9
		Midwest	642	8.8	43.6	11.9	42.3
		Southeast	988	-5.6	52.2	-6.2	46.9
		Central	602	42.4	73.7	34.1	56.4
		West	867	26.4	74.3	7.6	61.8
	IMPROVE	12-km EUS	2118	-25.0	47.4	-32.2	54.5
		12-km WUS	2352	-16.0	55.6	-29.2	63.7
		Northeast	518	3.6	47.7	-12.5	50.4
		Midwest	116	36.6	-25.4	-30.5	51.1
		Southeast	406	-47.8	60.9	-49.4	60.3
		Central	510	-28.4	44.1	-29.3	50.6
		West	2108	-16.8	56.8	-30.7	65.5

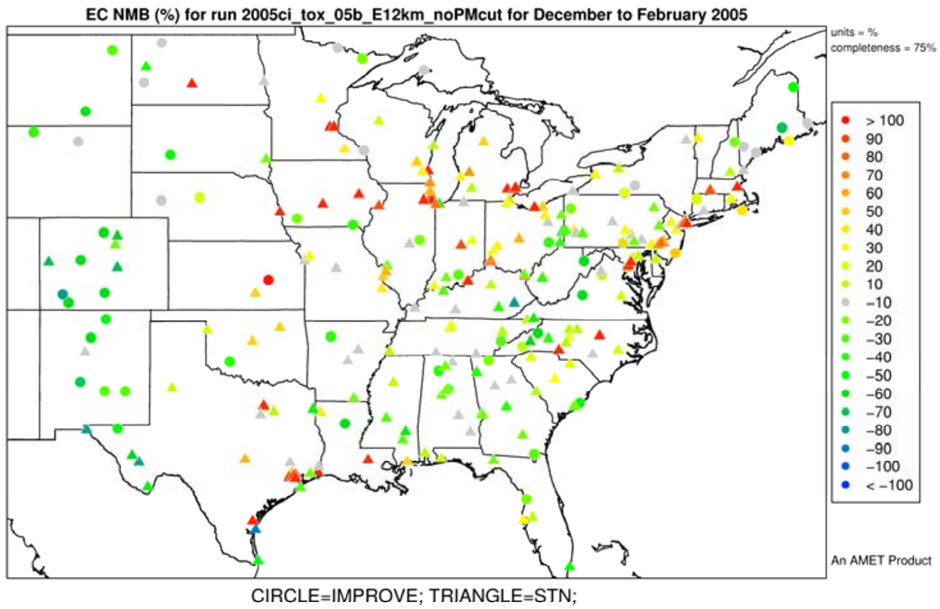


Figure I-1. Normalized Mean Bias (%) of elemental carbon by monitor for 12-km Eastern U.S. domain, Winter 2005.

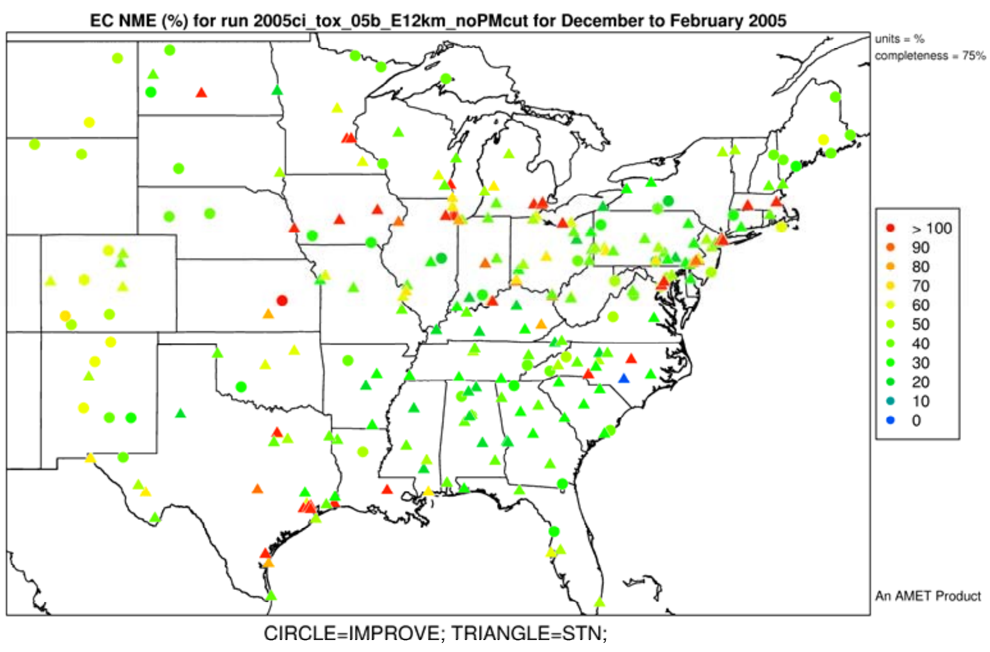


Figure I-2. Normalized Mean Error (%) of elemental carbon by monitor for 12-km Eastern U.S. domain, Winter 2005.

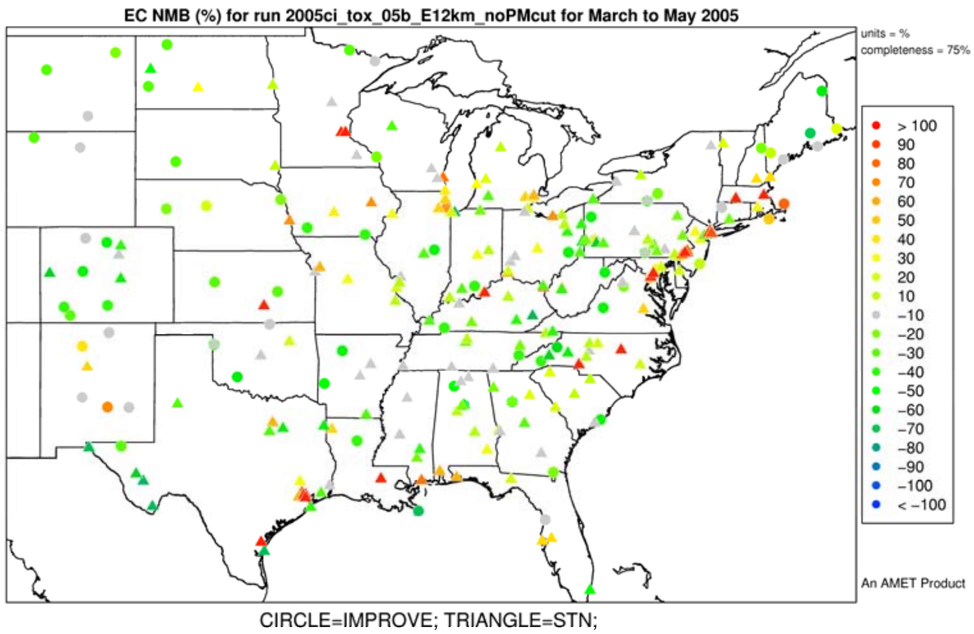


Figure I-3. Normalized Mean Bias (%) of elemental carbon by monitor for 12-km Eastern U.S. domain, Spring 2005.

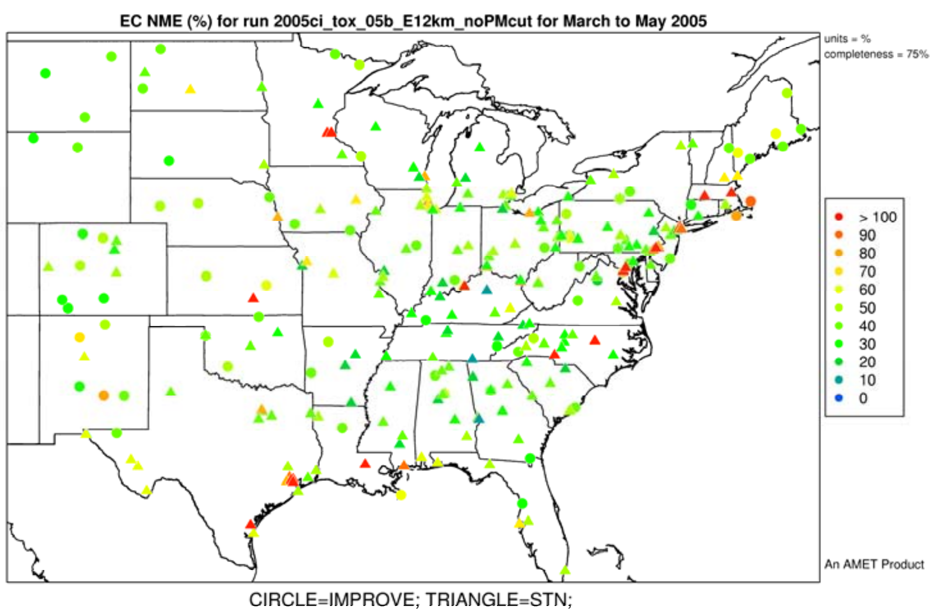


Figure I-4. Normalized Mean Error (%) of elemental carbon by monitor for 12-km Eastern U.S. domain, Spring 2005.

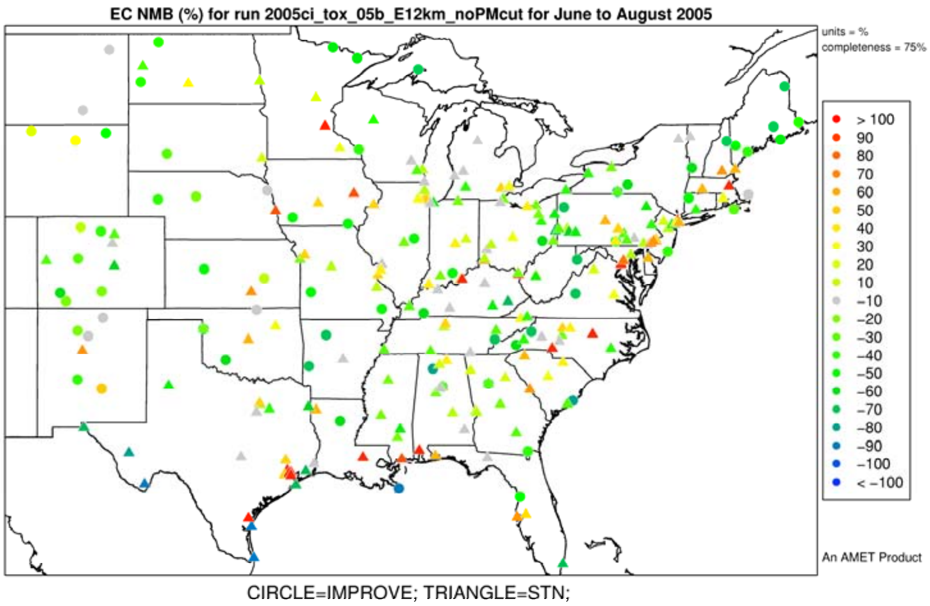


Figure I-5. Normalized Mean Bias (%) of elemental carbon by monitor for 12-km Eastern U.S. domain, Summer 2005.

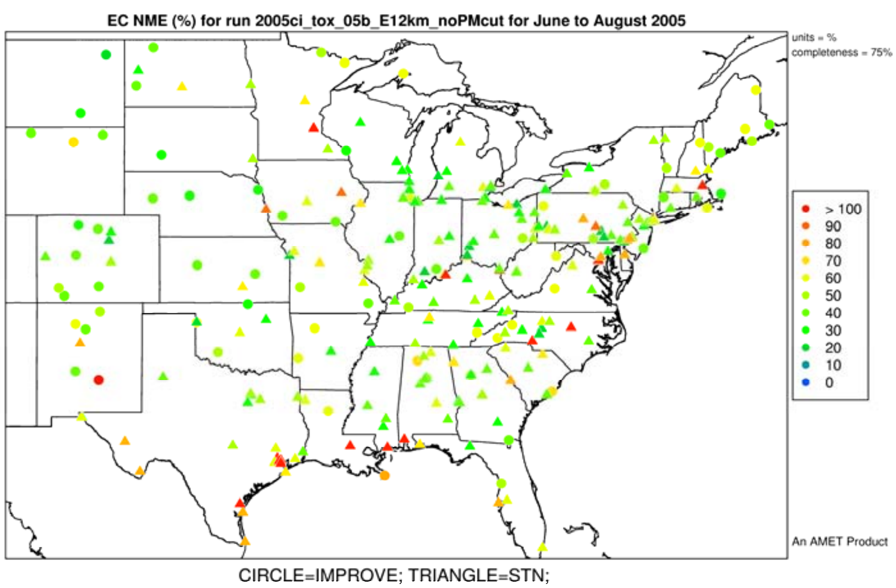


Figure I-6. Normalized Mean Error (%) of elemental carbon by monitor for 12-km Eastern U.S. domain, Summer 2005.

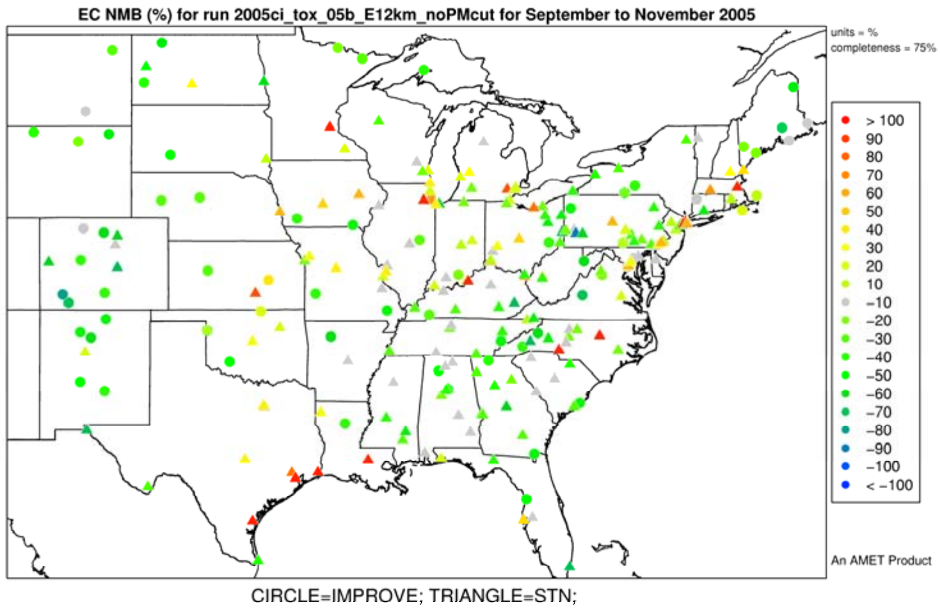


Figure I-7. Normalized Mean Bias (%) of elemental carbon by monitor for 12-km Eastern U.S. domain, Fall 2005.

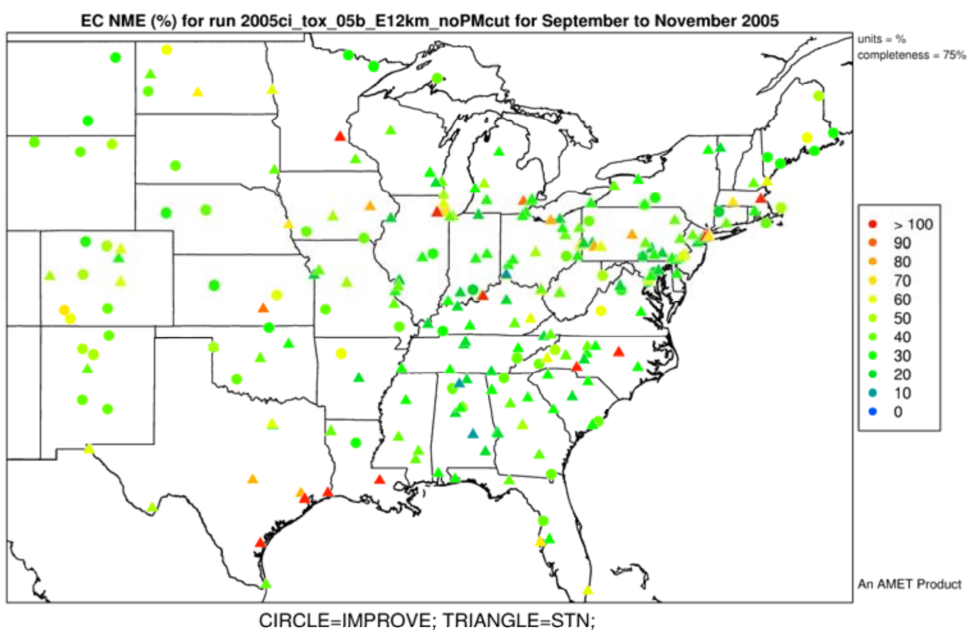


Figure I-8. Normalized Mean Error (%) of elemental carbon by monitor for 12-km Eastern U.S. domain, Fall 2005.

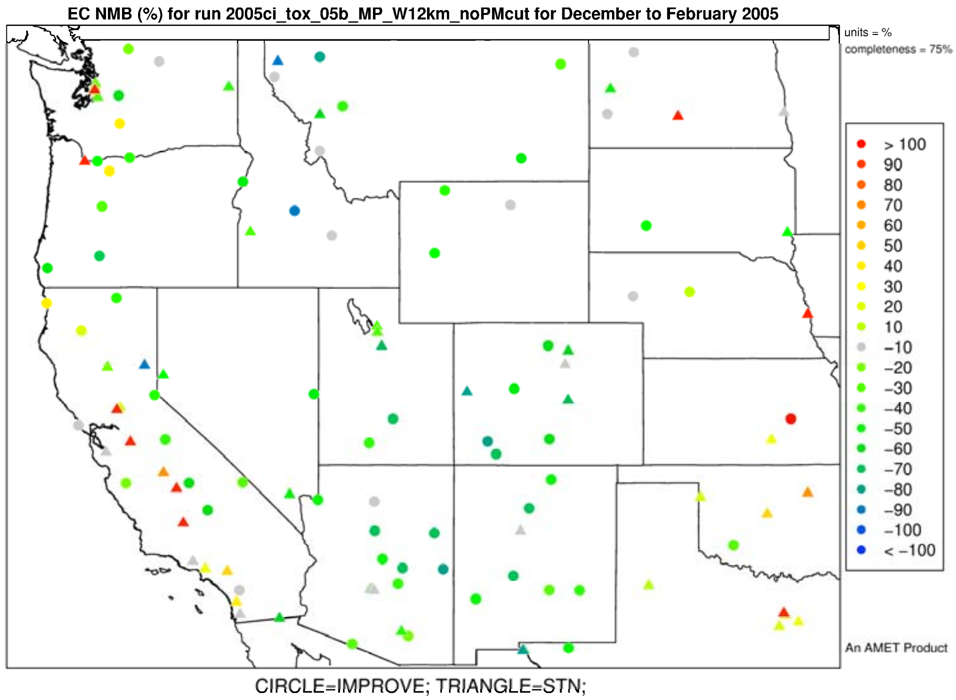


Figure I-9. Normalized Mean Bias (%) of elemental carbon by monitor for 12-km Eastern U.S. domain, Winter 2005.

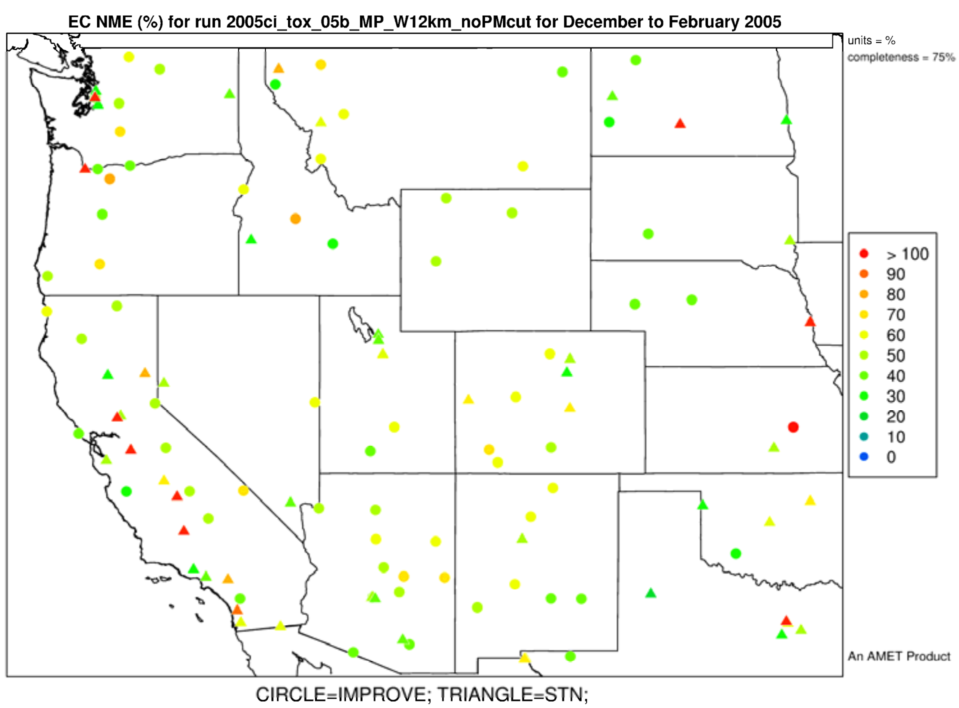


Figure I-10. Normalized Mean Error (%) of elemental carbon by monitor for 12-km Western U.S. domain, Winter 2005.

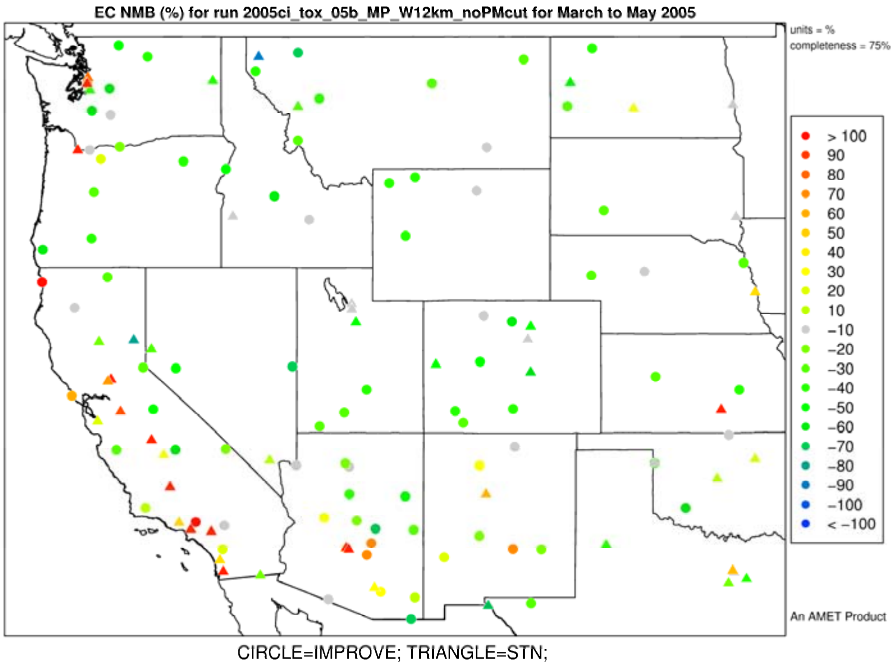


Figure I-11. Normalized Mean Bias (%) of elemental carbon by monitor for 12-km Western U.S. domain, Spring 2005.

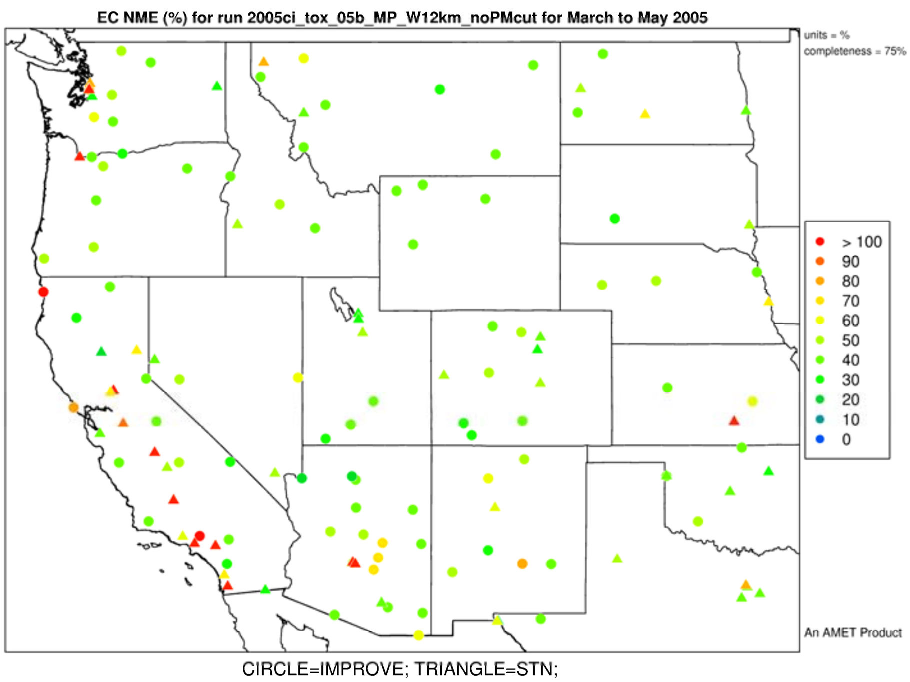


Figure I-12. Normalized Mean Error (%) of elemental carbon by monitor for 12-km Western U.S. domain, Spring 2005.

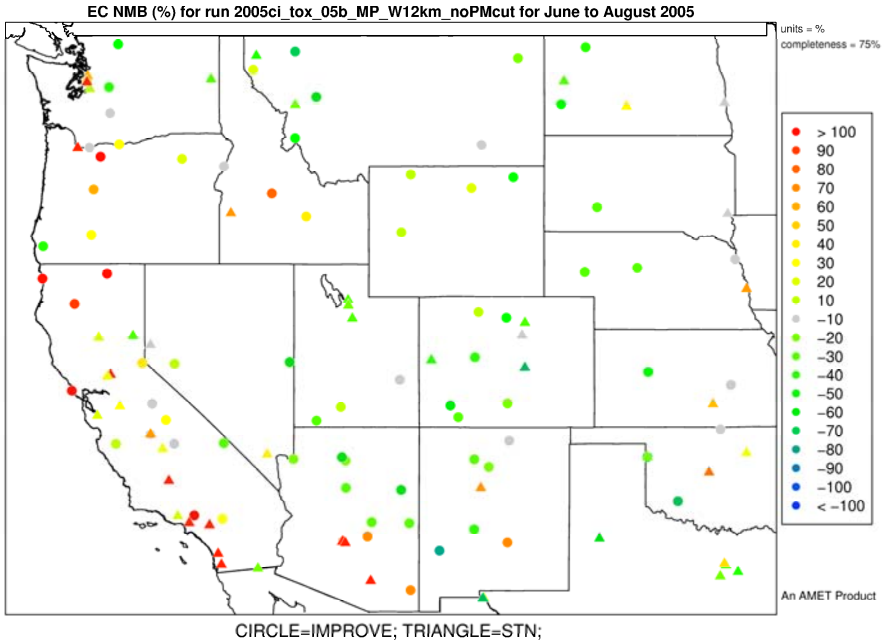


Figure I-13. Normalized Mean Bias (%) of elemental carbon by monitor for 12-km Western U.S. domain, Summer 2005.

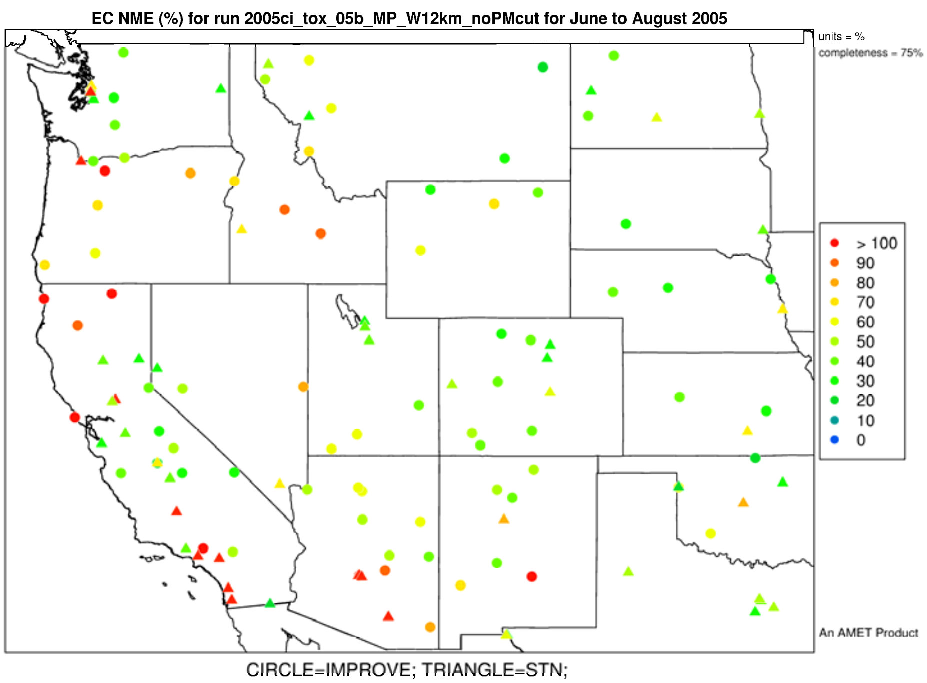


Figure I-14. Normalized Mean Error (%) of elemental carbon by monitor for 12-km Western U.S. domain, Summer 2005.

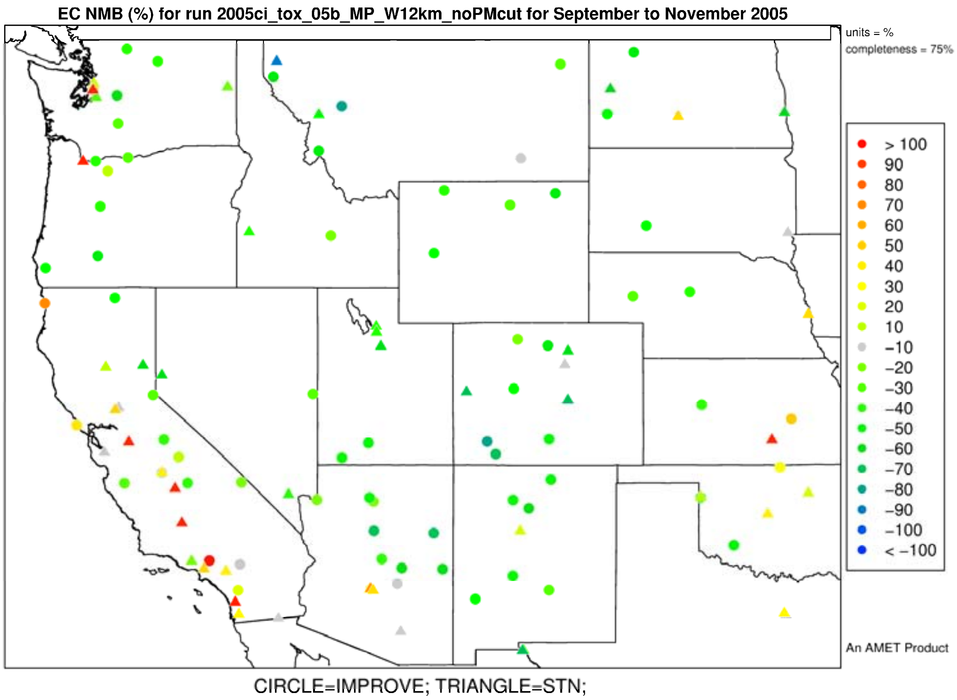


Figure I-15. Normalized Mean Bias (%) of elemental carbon by monitor for 12-km Western U.S. domain, Fall 2005.

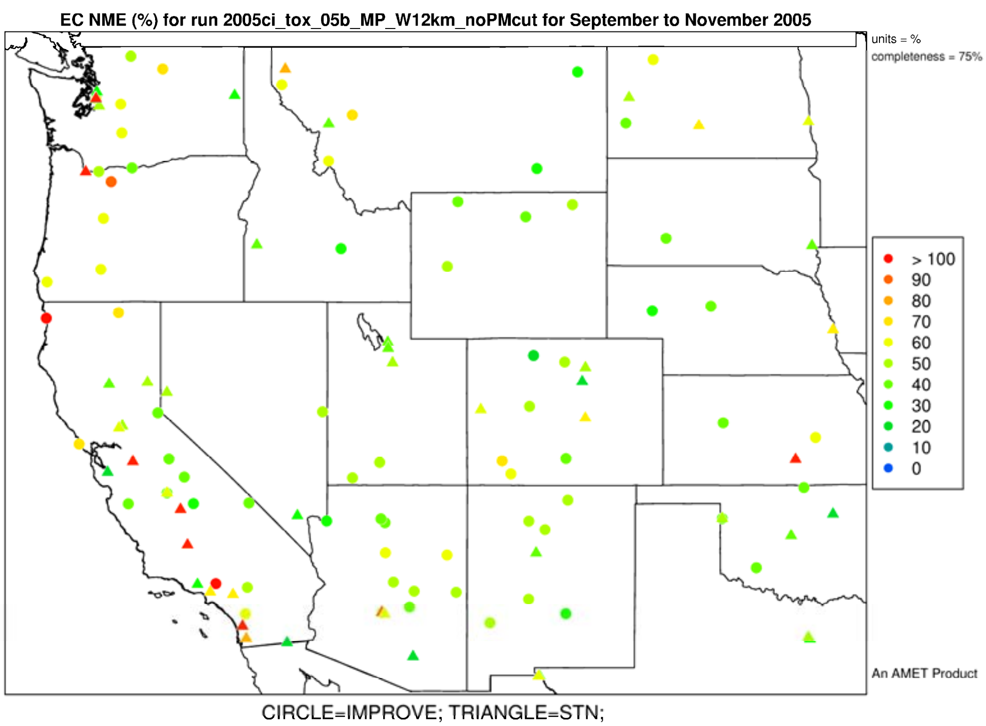


Figure I-16. Normalized Mean Error (%) of elemental carbon by monitor for 12-km Western U.S. domain, Fall 2005.

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 (NMB values range from -12% to -67%) and rural IMPROVE sites (NMB values range from -3% to -50%). Organic carbon performance in the EUS and WUS shows the largest under estimations during the summer season. For IMPROVE, organic carbon performance shows a negative bias in the West (NMB= -3%) and a positive bias in the East (NMB=24%). For STN, organic carbon is under-predicted in the East (NMB= -12%) and West (NMB= -26%). 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	2063	-12.4	51.2	-2.5	55.2
		12-km WUS	606	-25.6	62.0	-22.4	62.6
		Northeast	284	-18.1	58.7	-0.7	62.7
		Midwest	552	24.4	61.6	34.0	60.4
		Southeast	520	-32.4	44.0	-27.8	51.5
		Central	568	-22.9	45.4	-13.2	48.5
		West	507	-24.2	63.0	-22.0	64.3
	IMPROVE	12-km EUS	2032	24.5	65.4	14.1	55.4
		12-km WUS	2432	-2.9	59.9	-4.3	58.9
		Northeast	149	4.6	43.1	16.6	45.0
		Midwest	512	89.2	104.2	63.5	71.9
		Southeast	439	-12.9	42.9	-22.1	49.9
		Central	366	-5.1	52.9	-4.5	51.4
		West	2307	-4.8	59.3	-5.1	59.4
Spring	STN	12-km EUS	2241	-19.1	53.6	-15.7	60.8
		12-km WUS	656	-19.8	63.4	-13.7	64.5
		Northeast	337	-19.9	57.1	-6.6	63.8
		Midwest	583	8.5	55.3	9.8	55.8
		Southeast	590	-25.9	47.5	-22.7	54.0
		Central	579	-38.7	53.2	-45.7	68.3
		West	560	-15.9	65.9	-7.1	65.5
	IMPROVE	12-km EUS	1917	-27.2	53.0	-32.0	58.5
		12-km WUS	2369	-23.7	54.5	-26.4	56.3
		Northeast	147	-29.7	43.9	-28.6	52.1
		Midwest	508	15.6	46.4	8.5	45.0

		Southeast	442	-42.8	58.3	-60.6	73.0
		Central	293	-53.9	59.6	-71.6	81.0
		West	2307	-21.5	53.6	-24.4	55.1
Summer	STN	12-km EUS	2690	-67.5	69.4	-95.0	100.3
		12-km WUS	832	-55.4	60.0	-76.2	83.6
		Northeast	408	-69.2	69.8	-98.4	101.2
		Midwest	754	-68.1	71.5	-88.4	97.7
		Southeast	683	-68.7	69.5	-100.9	104.5
		Central	659	-63.3	64.9	-91.1	95.7
		West	684	-54.0	59.3	-73.3	81.8
	IMPROVE	12-km EUS	2133	-66.7	69.0	-95.5	99.0
		12-km WUS	2595	-50.4	63.7	-61.9	76.0
		Northeast	153	-70.4	70.7	-103.1	104.0
		Midwest	523	-66.2	68.5	-73.8	80.0
		Southeast	460	-73.8	74.8	-122.3	123.2
		Central	411	-74.2	74.5	-120.0	120.7
		West	2435	-49.4	63.2	-58.1	73.0
Fall	STN	12-km EUS	2732	-37.6	50.2	-37.8	60.6
		12-km WUS	809	-40.4	57.9	-38.7	63.4
		Northeast	418	-44.1	51.3	-42.0	60.1
		Midwest	752	-14.6	45.4	-13.2	51.9
		Southeast	681	-47.6	52.3	-53.1	65.9
		Central	698	-43.7	50.7	-49.2	63.5
		West	657	-41.0	59.9	-39.6	66.8
	IMPROVE	12-km EUS	2205	-25.5	47.2	-32.4	57.6
		12-km WUS	2686	-29.4	56.5	-30.0	59.9
		Northeast	149	-41.0	44.6	-44.0	53.0
		Midwest	514	4.1	43.9	0.5	45.9
		Southeast	459	-43.6	50.8	-71.3	77.4
		Central	461	-37.8	51.8	-47.2	64.6
		West	2459	-29.9	56.4	-29.5	59.5

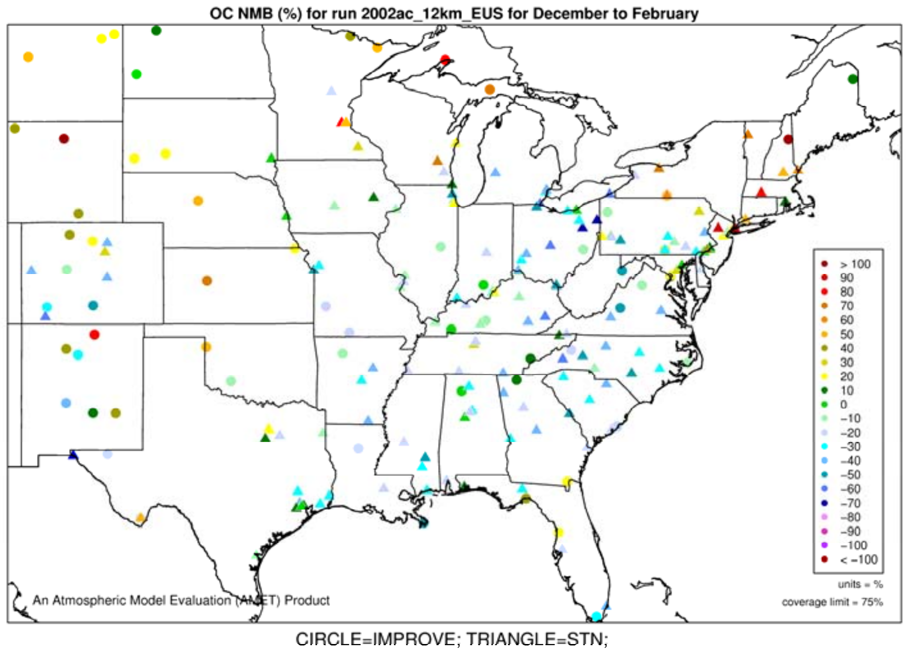


Figure J-1. Normalized Mean Bias (%) of organic carbon by monitor for 12-km Eastern U.S. domain, Winter 2005.

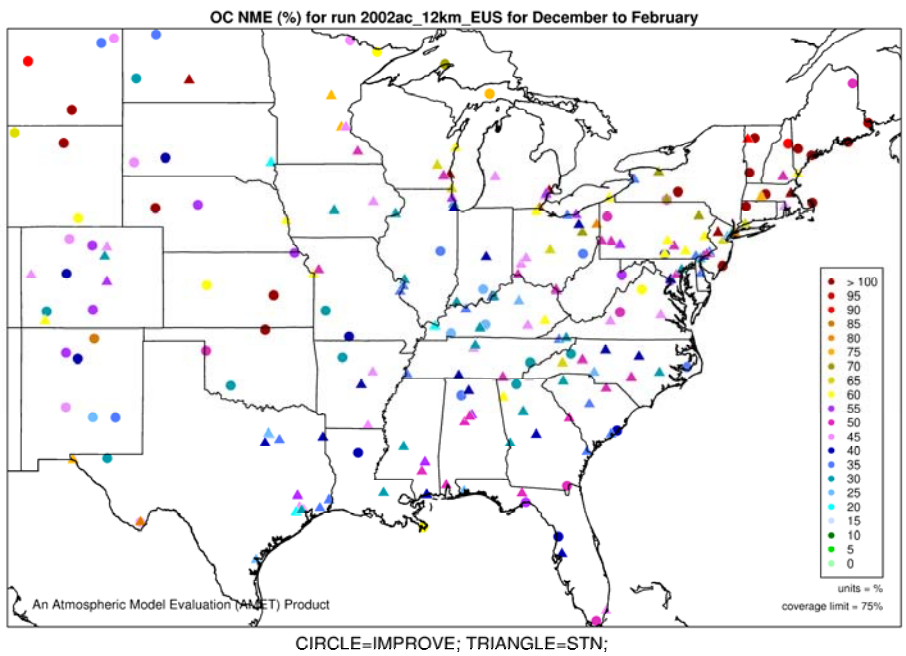


Figure J-2. Normalized Mean Error (%) of organic carbon by monitor for 12-km Eastern U.S. domain, Winter 2005.

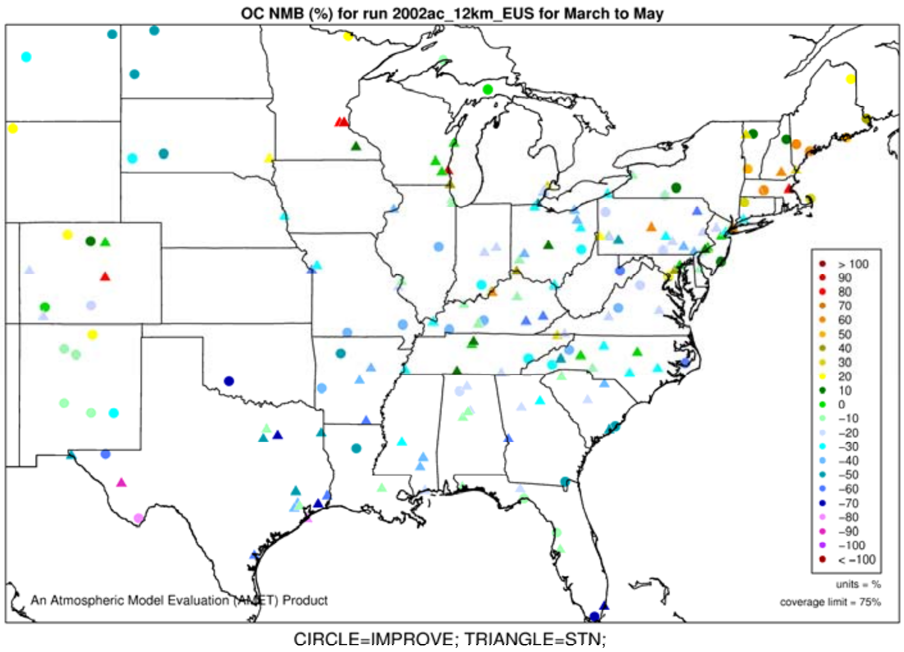


Figure J-3. Normalized Mean Bias (%) of organic carbon by monitor for 12-km Eastern U.S. domain, Spring 2005.

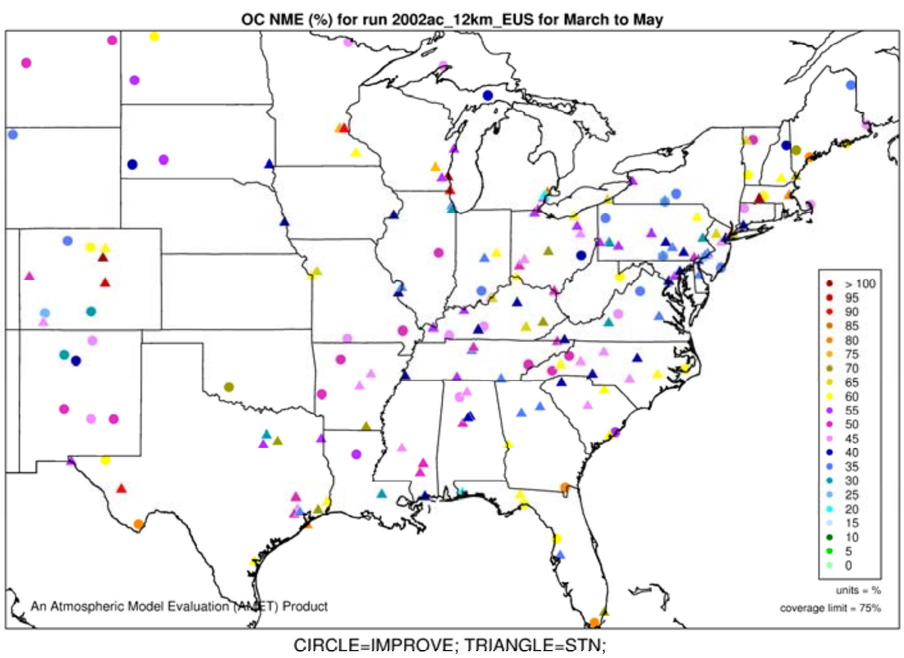


Figure J-4. Normalized Mean Error (%) of organic carbon by monitor for 12-km Eastern U.S. domain, Spring 2005.

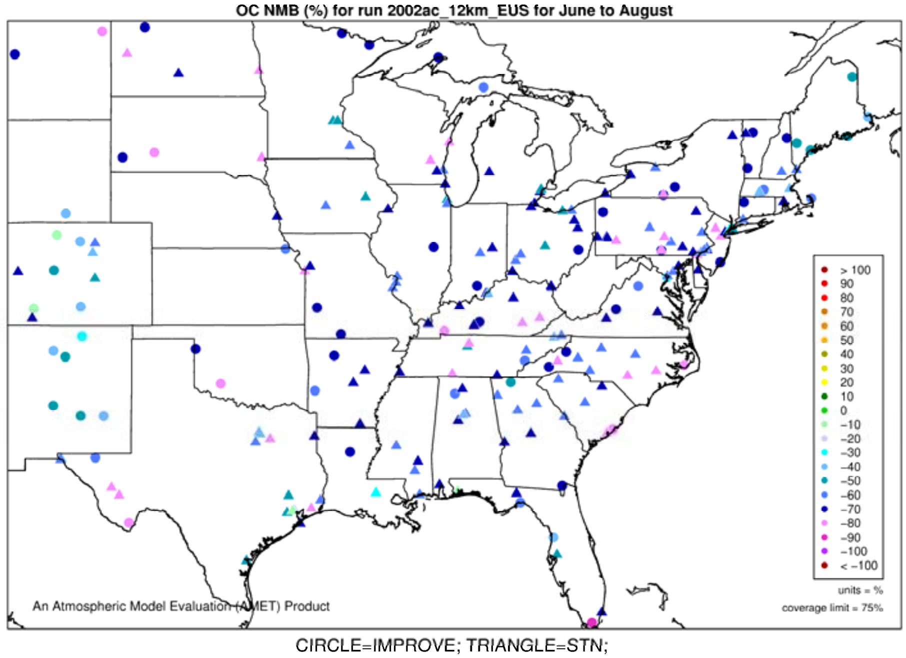


Figure J-5. Normalized Mean Bias (%) of organic carbon by monitor for 12-km Eastern U.S. domain, Summer 2005.

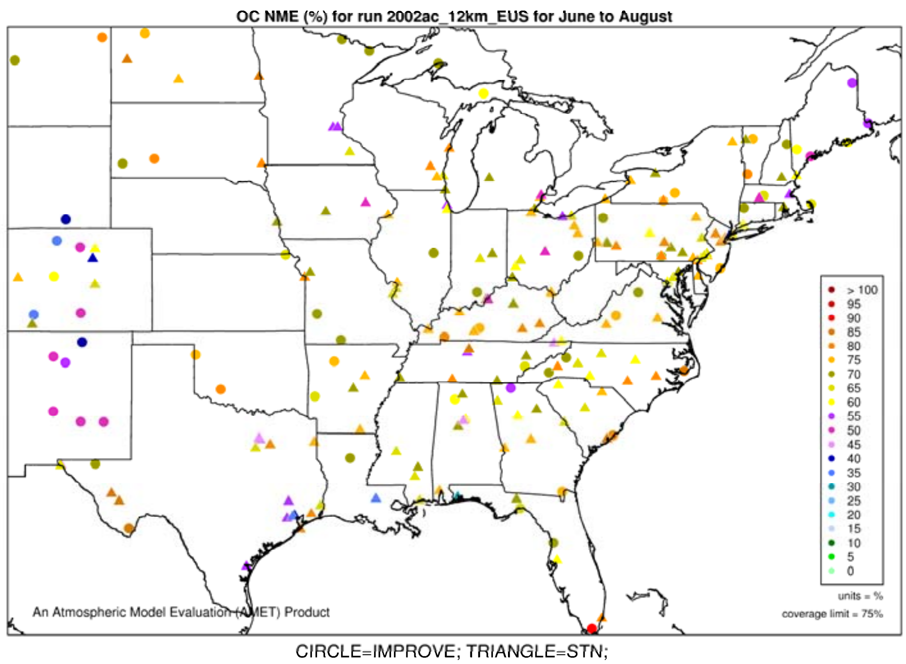


Figure J-6. Normalized Mean Error (%) of organic carbon by monitor for 12-km Eastern U.S. domain, Summer 2005.

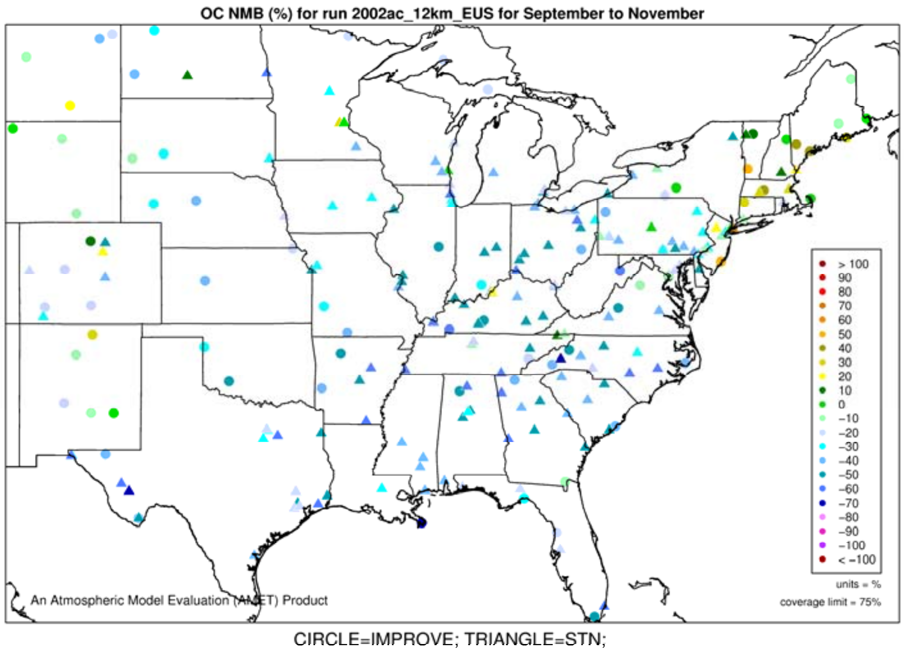


Figure J-7. Normalized Mean Bias (%) of organic carbon by monitor for 12-km Eastern U.S. domain, Fall 2005.

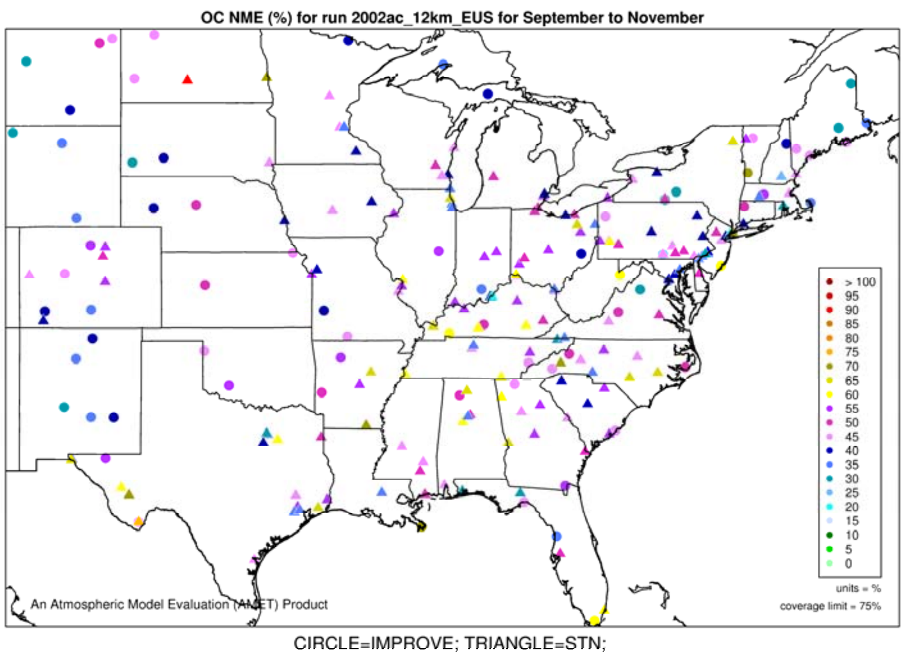


Figure J-8. Normalized Mean Error (%) of organic carbon by monitor for 12-km Eastern U.S. domain, Fall 2005.

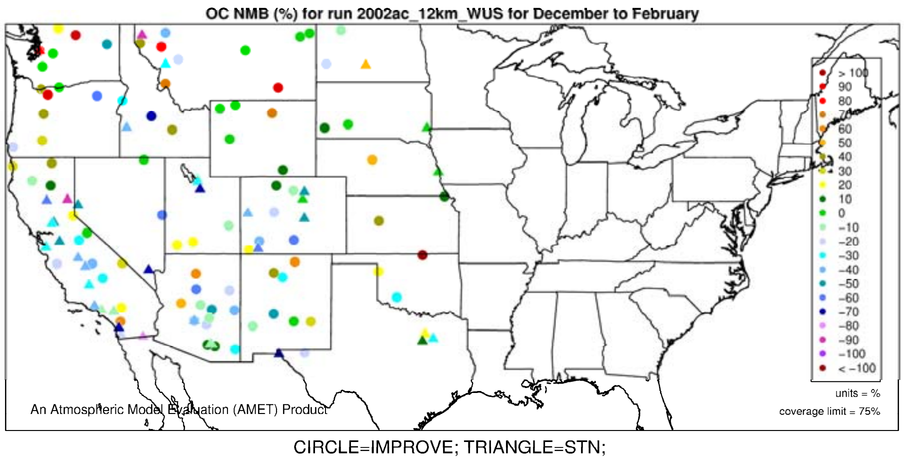


Figure J-9. Normalized Mean Bias (%) of organic carbon by monitor for 12-km Western U.S. domain, Winter 2005.

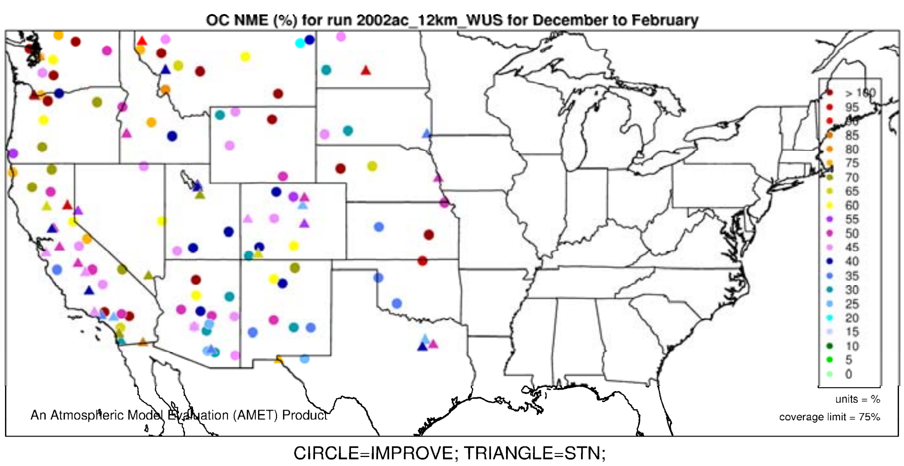


Figure J-10. Normalized Mean Error (%) of organic carbon by monitor for 12-km Western U.S. domain, Winter 2005.

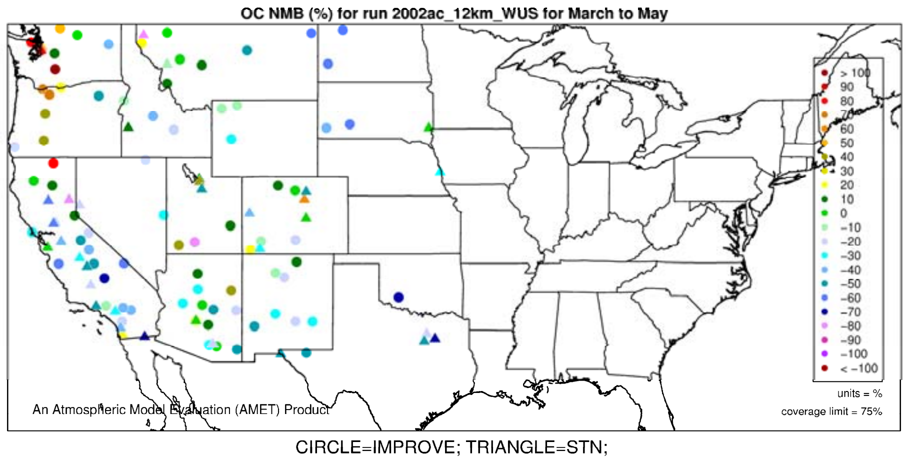


Figure J-11. Normalized Mean Bias (%) of organic carbon by monitor for 12-km Western U.S. domain, Spring 2005.

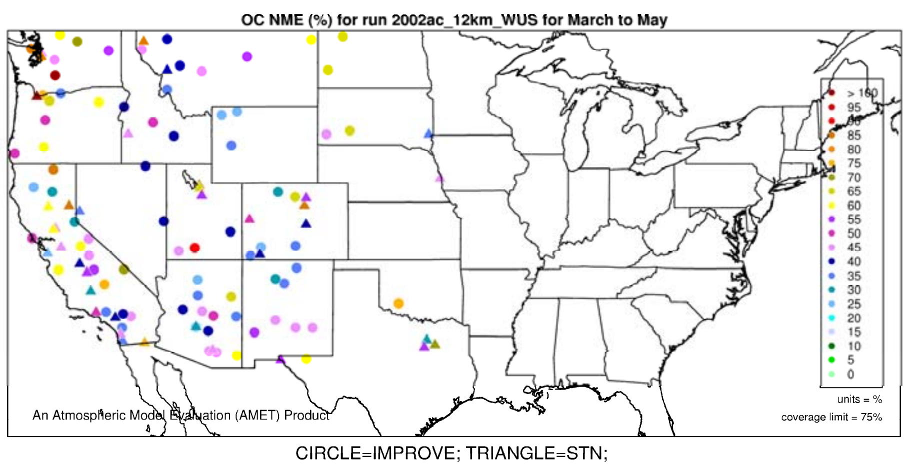


Figure J-12. Normalized Mean Error (%) of organic carbon by monitor for 12-km Western U.S. domain, Spring 2005.

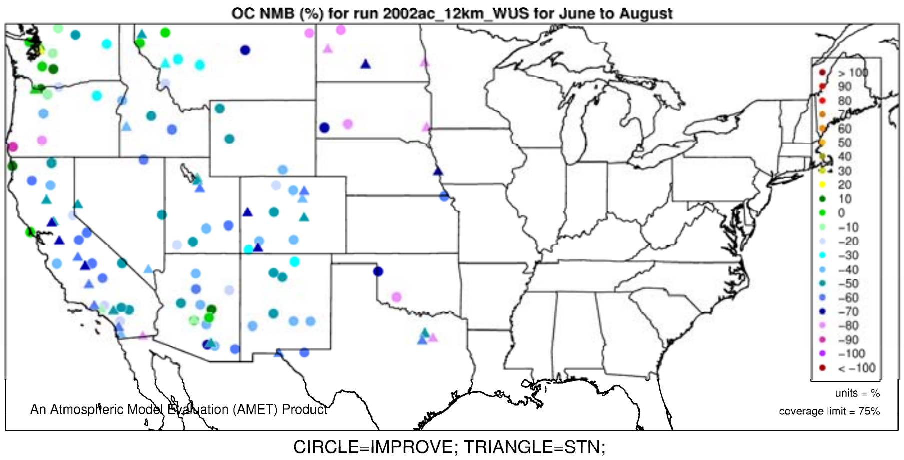


Figure J-13. Normalized Mean Bias (%) of organic carbon by monitor for 12-km Western U.S. domain, Summer 2005.

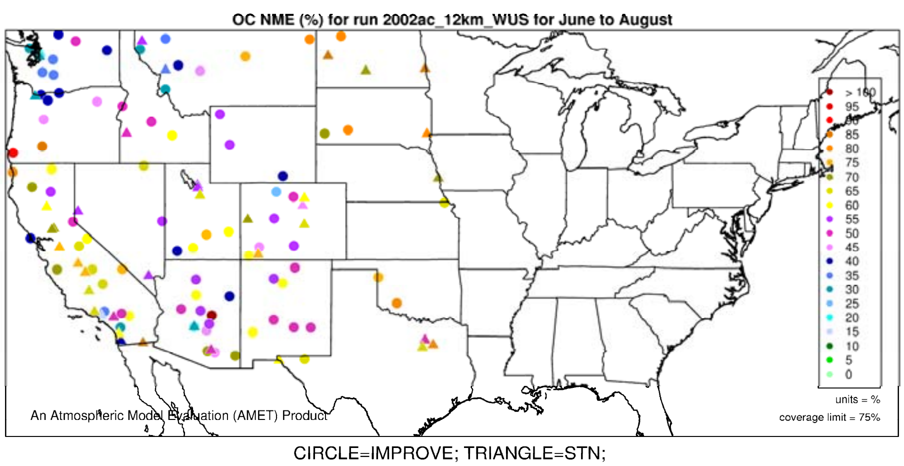


Figure J-14. Normalized Mean Error (%) of organic carbon by monitor for 12-km Western U.S. domain, Summer 2005.

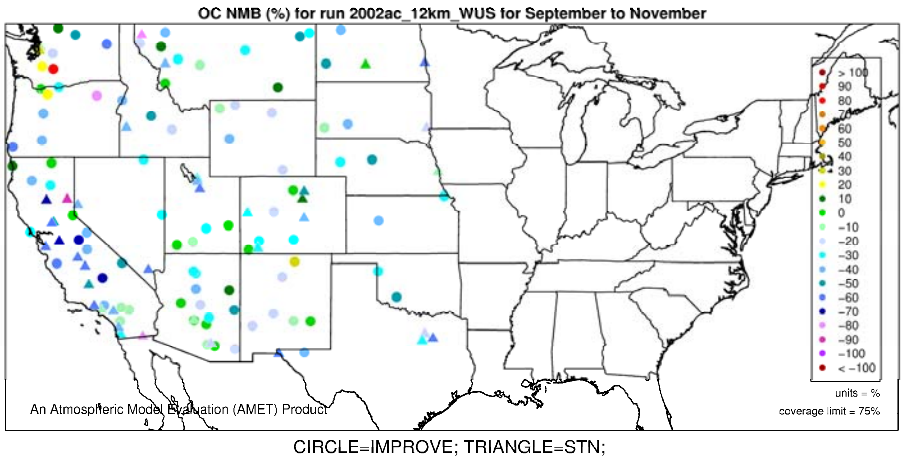


Figure J-15. Normalized Mean Bias (%) of organic carbon by monitor for 12-km Western U.S. domain, Fall 2005.

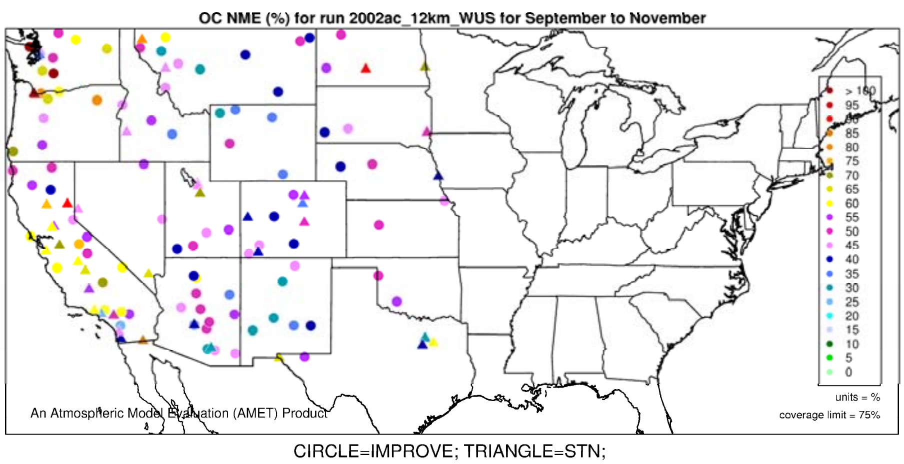


Figure J-16. Normalized Mean Error (%) of organic carbon by monitor for 12-km Western U.S. domain, Fall 2005.

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.[10,11,12] 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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[10] 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.

[11] 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.

[12] 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. CMAQ 2005 annual model performance statistics for air toxics.

CMAQ 2005 Annual		No. of Obs.	NMB (%)	NME (%)	FB (%)	FE (%)
Formaldehyde	12-km EUS	6365	-55.5	65.3	-39.2	65.6
	12-km WUS	1928	-28.4	52.1	-30.1	60.7
	Midwest	771	-77.1	85.4	-25.8	74.0
	Northeast	1982	-30.5	51.3	-28.5	61.6
	Southeast	1246	-66.2	72.2	-51.3	70.4
	Central U.S.	1815	-43.5	51.0	-41.4	61.5
	West	1746	-25.5	52.3	-26.0	59.8
Acetaldehyde	12-km EUS	6094	-4.2	62.0	-8.2	60.3
	12-km WUS	1892	-19.2	53.7	-19.5	59.6
	Midwest	703	-12.6	58.0	-12.1	60.0
	Northeast	1969	-9.5	62.8	-9.0	63.7
	Southeast	1231	0.4	63.5	-6.2	62.2
	Central U.S.	1640	1.8	57.0	-4.3	51.1
	West	1709	-20.4	54.1	-20.1	60.6
Benzene	12-km EUS	11615	-32.6	66.8	-13.5	62.8
	12-km WUS	3369	-38.4	60.8	-30.4	63.9
	Midwest	1425	-8.3	72.7	25.2	62.4
	Northeast	2589	21.6	53.3	18.1	46.8
	Southeast	2426	-41.1	68.6	-17.2	59.8
	Central U.S.	4737	-47.0	68.3	-32.7	69.4
	West	2333	-30.5	61.2	-19.2	63.4
1,3-Butadiene	12-km EUS	8102	-74.7	85.6	-49.4	91.6
	12-km WUS	1976	-51.9	82.1	-34.5	91.7
	Midwest	516	-78.7	86.2	-48.3	81.9
	Northeast	1902	-41.6	55.5	-54.8	71.3
	Southeast	1226	-85.4	86.4	-106.2	111.5
	Central U.S.	4142	-66.5	85.9	-20.0	89.2
	West	1082	-40.8	77.5	-41.9	85.3
Acrolein	12-km EUS	1660	-94.4	95.0	-131.3	142.2
	12-km WUS	783	-95.7	95.7	-168.1	170.4
	Midwest	n/a	n/a	n/a	n/a	n/a
	Northeast	850	-90.4	91.5	-120.5	134.2
	Southeast	278	-97.0	97.0	-156.4	157.0
	Central U.S.	n/a	n/a	n/a	n/a	n/a
	West	592	-95.9	95.9	-177.6	177.6

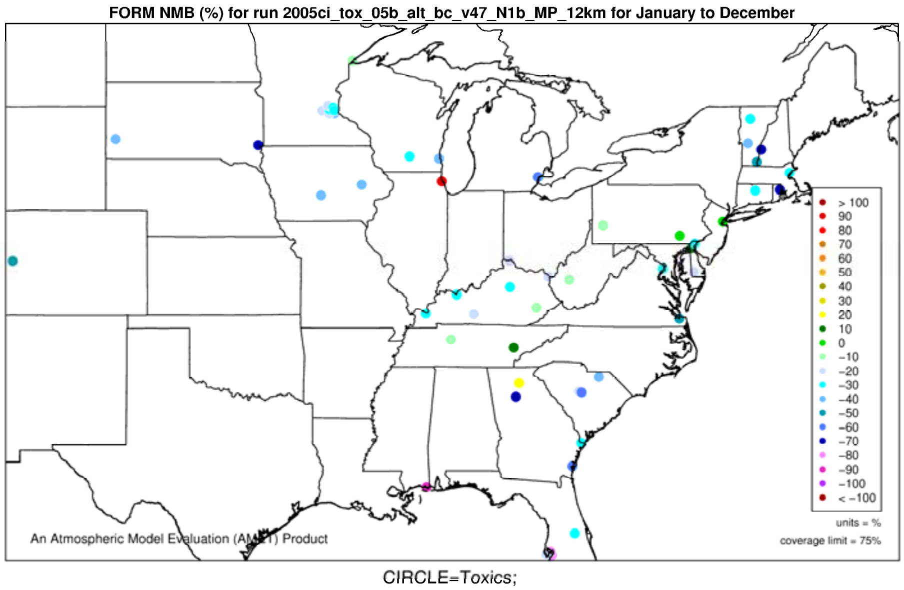


Figure K-1. Normalized Mean Bias (%) of annual formaldehyde by monitor for Eastern U.S., 2005.

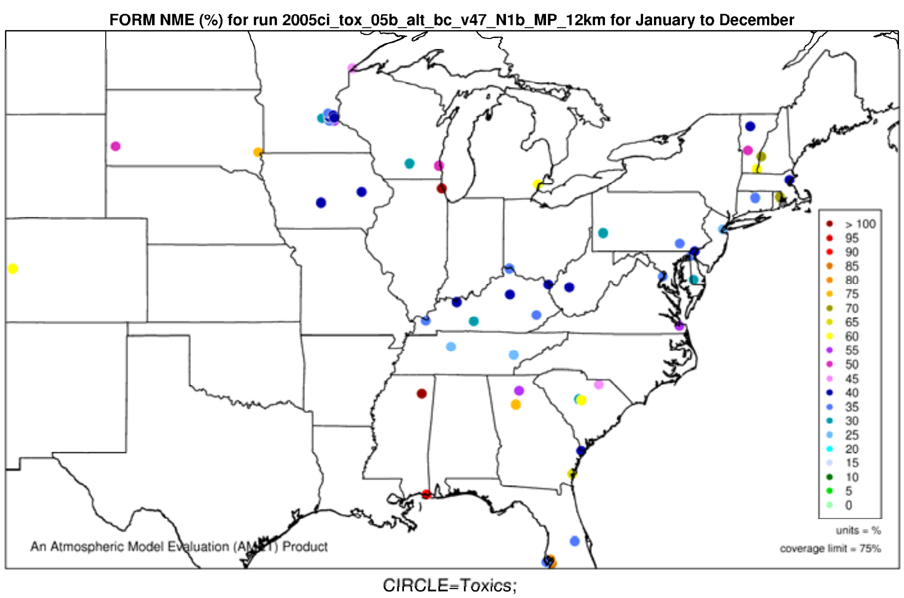


Figure K-2. Normalized Mean Error (%) of annual formaldehyde by monitor for Eastern U.S., 2005.

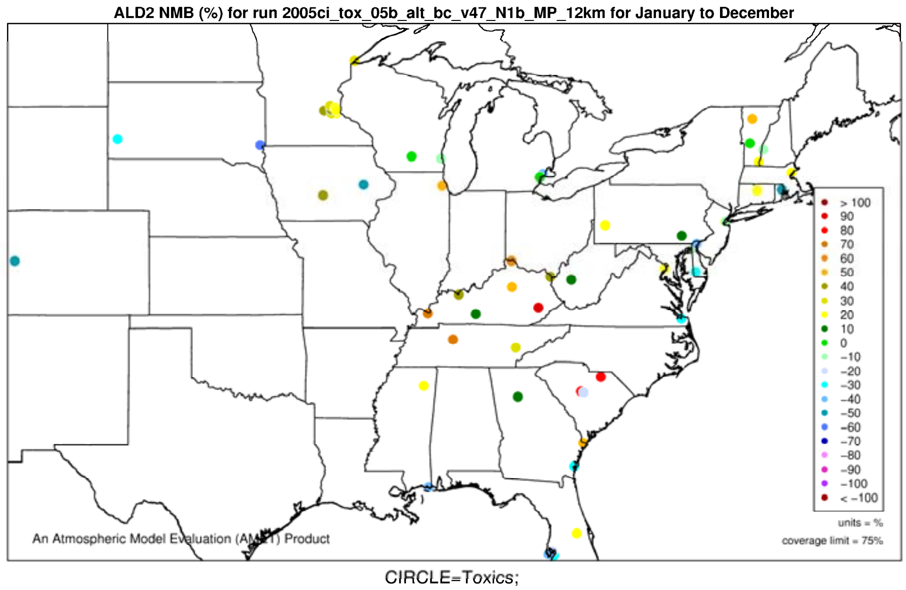


Figure K-3. Normalized Mean Bias (%) of annual acetaldehyde by monitor for Eastern U.S., 2005.

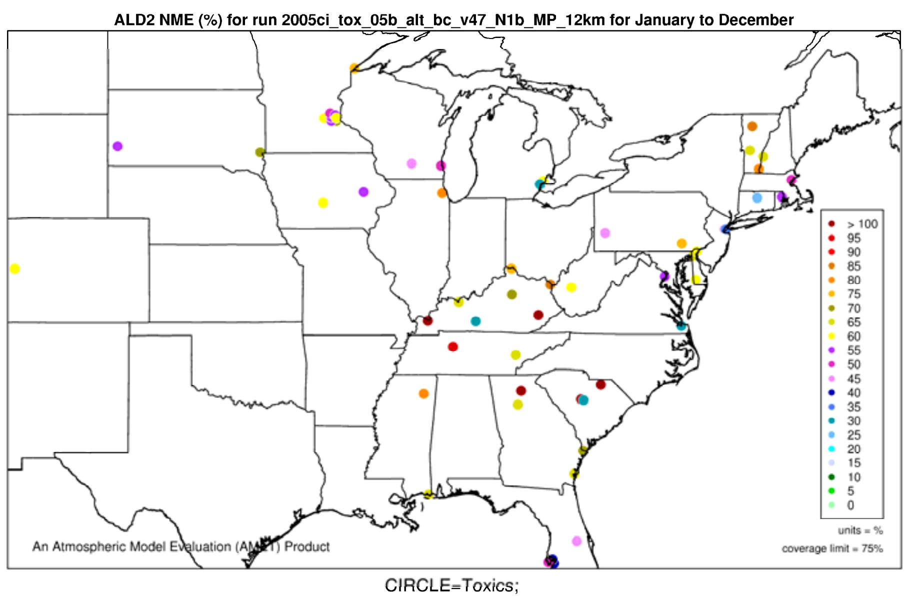


Figure K-4. Normalized Mean Error (%) of annual acetaldehyde by monitor for Eastern U.S., 2005.

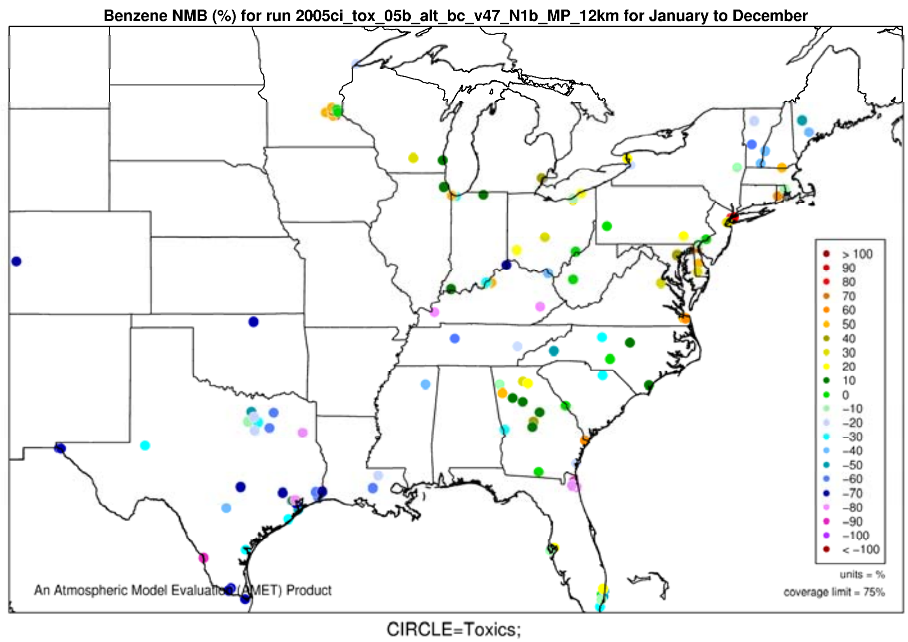


Figure K-5. Normalized Mean Bias (%) of annual benzene by monitor for Eastern U.S., 2005.

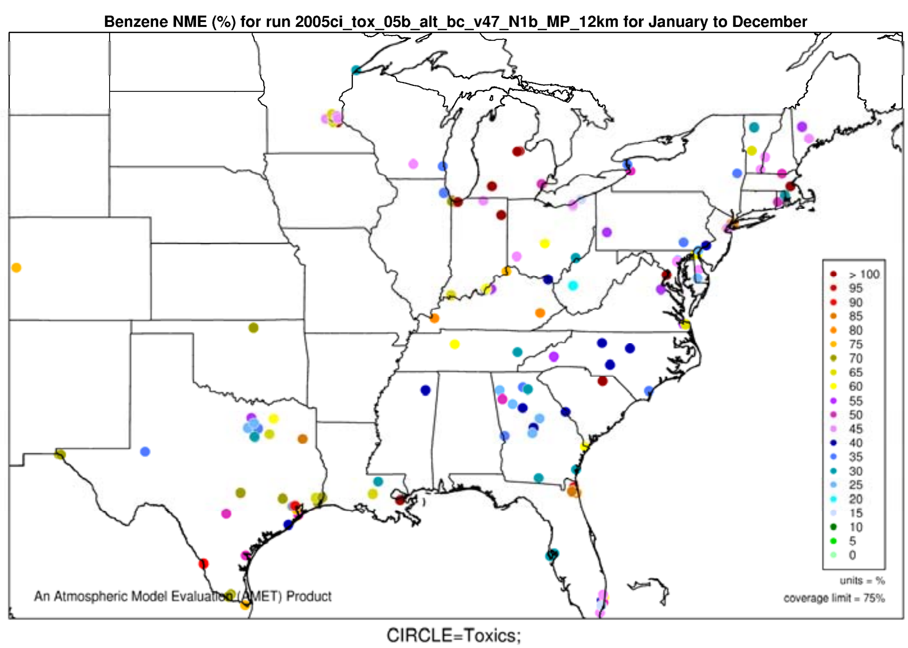


Figure K-6. Normalized Mean Error (%) of annual benzene by monitor for Eastern U.S., 2005.

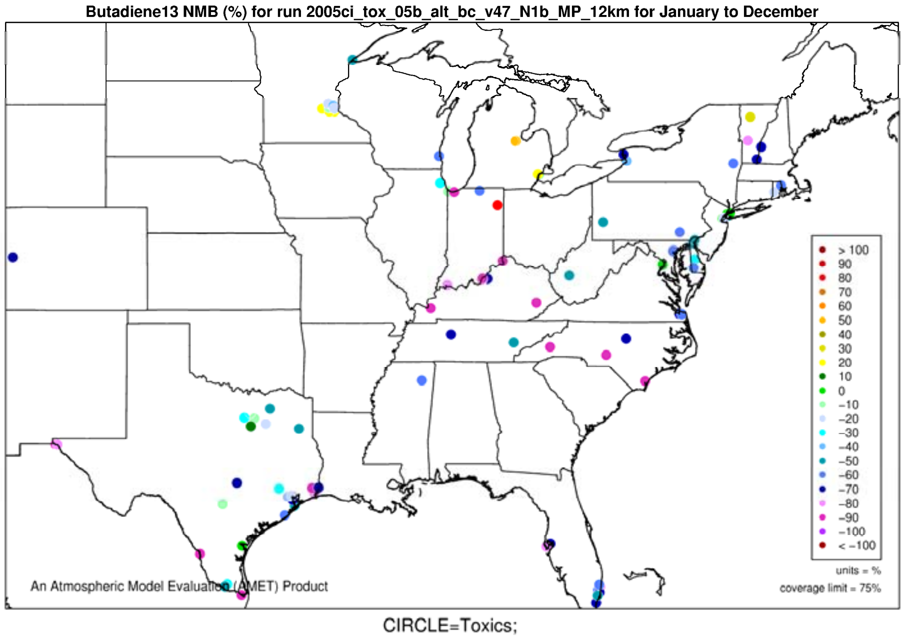


Figure K-7. Normalized Mean Bias (%) of annual 1,3-butadiene by monitor for Eastern U.S., 2005.

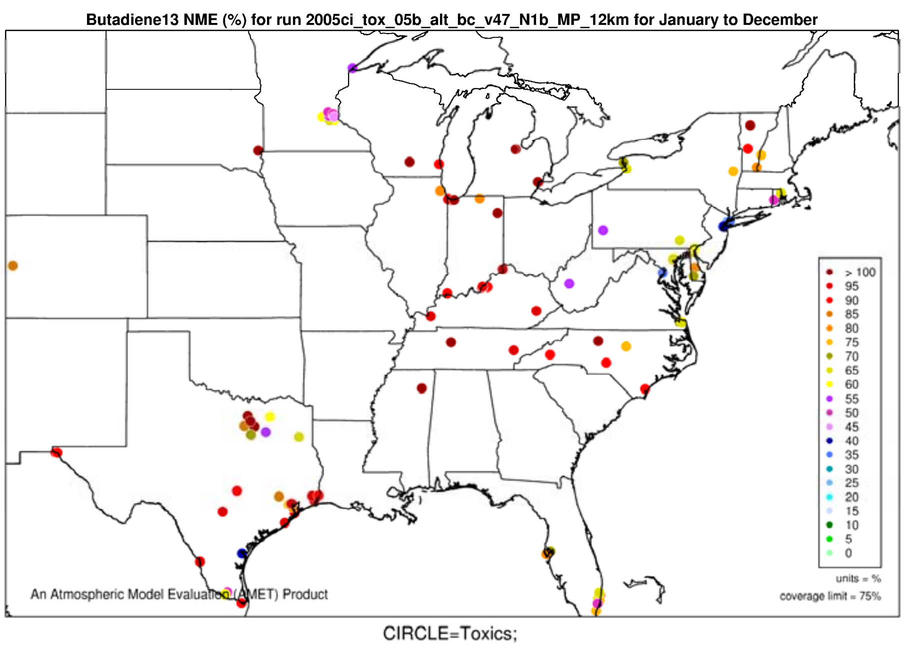


Figure K-8. Normalized Mean Error (%) of annual 1,3-butadiene by monitor for Eastern U.S., 2005.

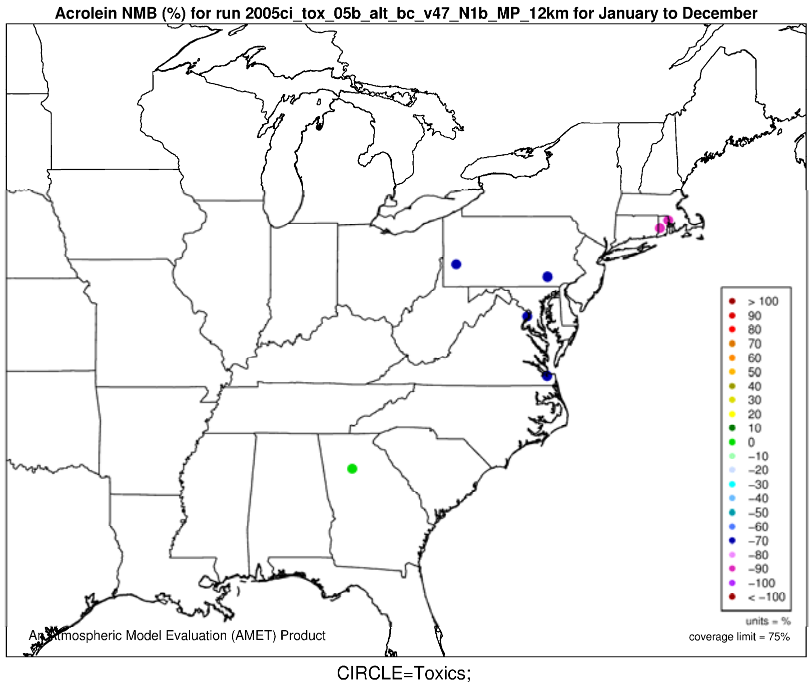


Figure K-9. Normalized Mean Bias (%) of annual acrolein by monitor for Eastern U.S., 2005.

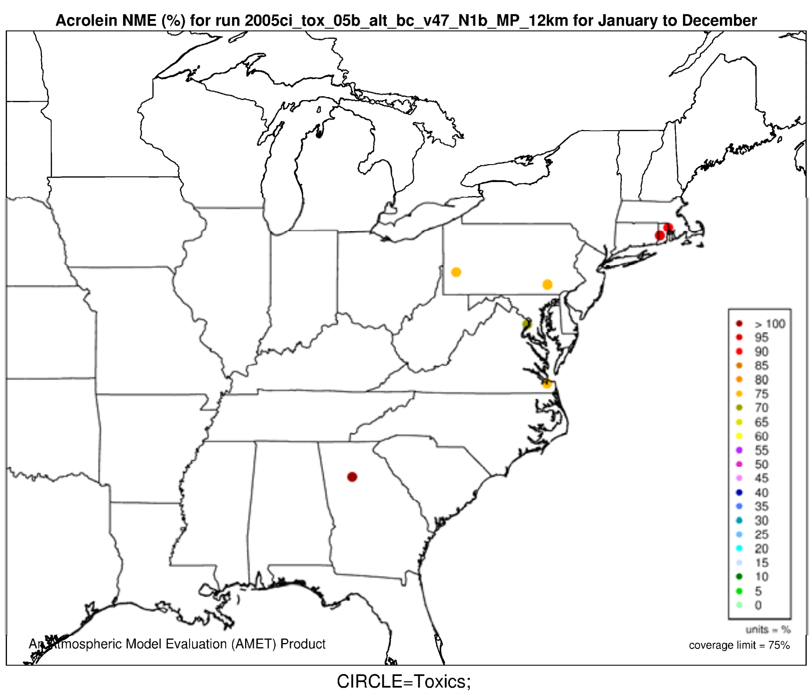


Figure K-10. Normalized Mean Error (%) of annual acrolein by monitor for Eastern U.S., 2005.

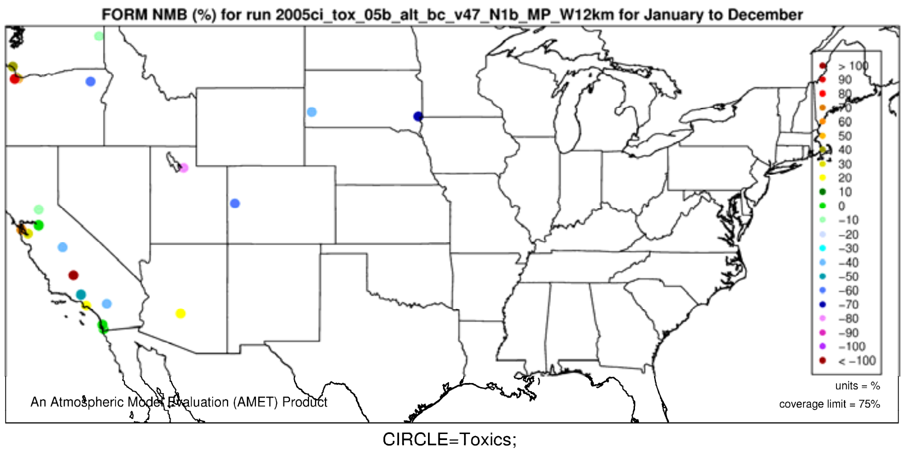


Figure K-15. Normalized Mean Bias (%) of annual formaldehyde by monitor for Western U.S., 2005.

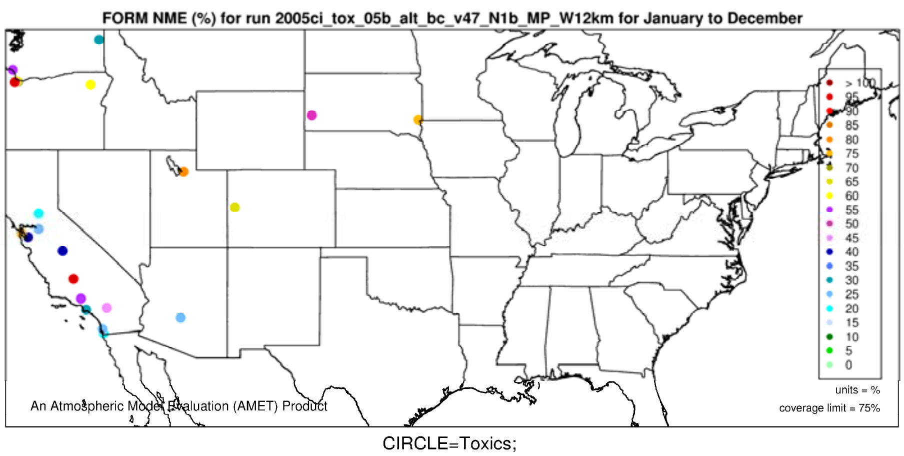


Figure K-16. Normalized Mean Error (%) of annual formaldehyde by monitor for Western U.S., 2005.

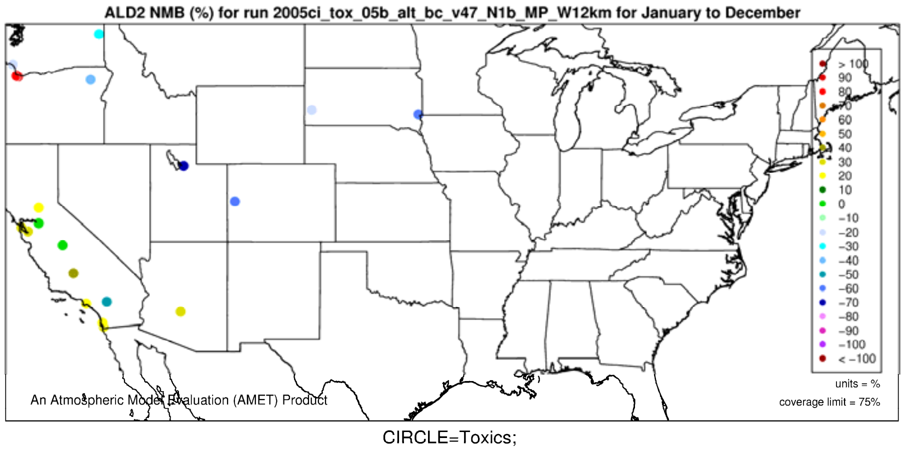


Figure K-17. Normalized Mean Bias (%) of annual acetaldehyde by monitor for Western U.S., 2005.

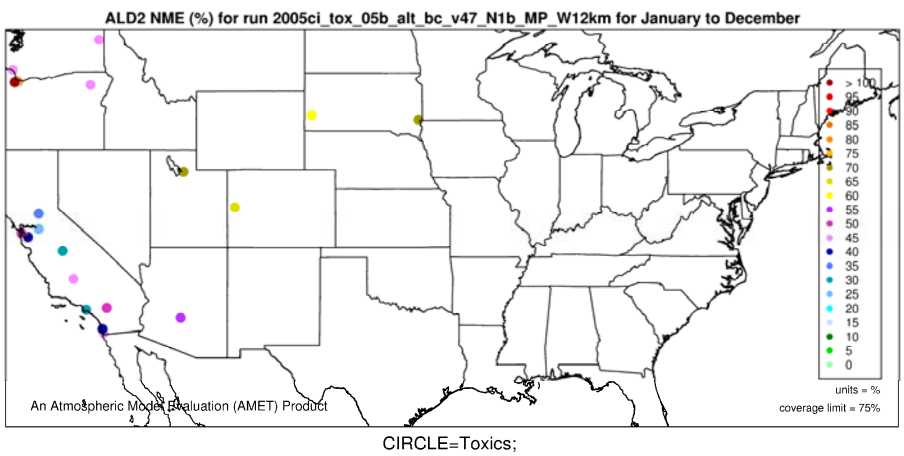


Figure K-18. Normalized Mean Error (%) of annual acetaldehyde by monitor for Western U.S., 2005.

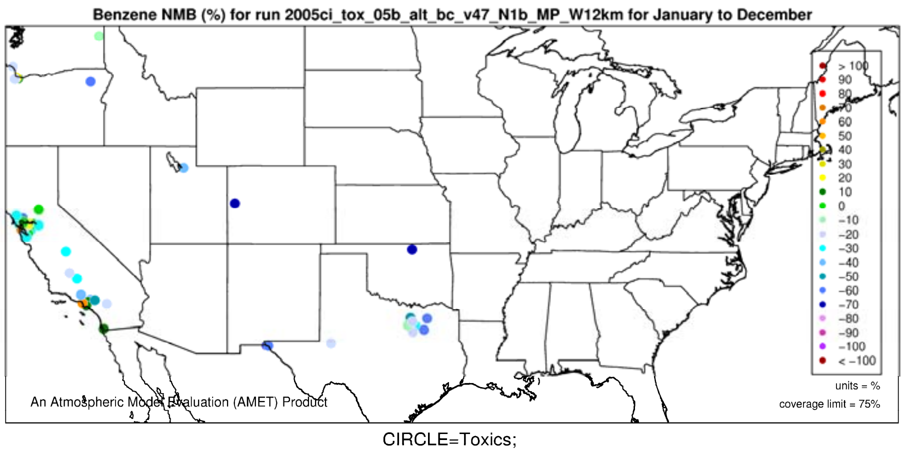


Figure K-19. Normalized Mean Bias (%) of annual benzene by monitor for Western U.S., 2005.

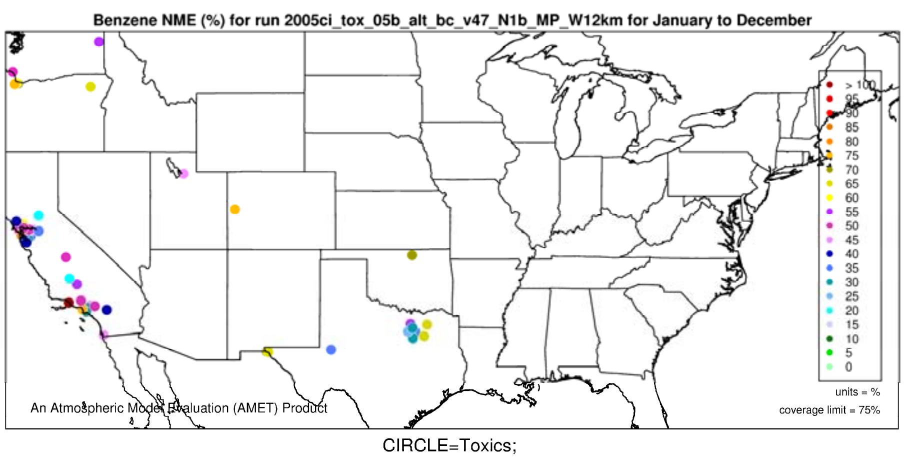


Figure K-20. Normalized Mean Error (%) of annual benzene by monitor for Western U.S., 2005.

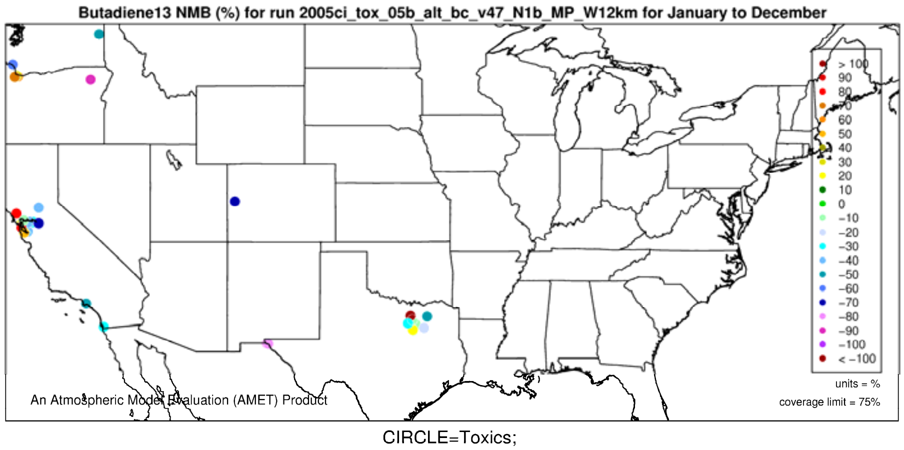


Figure K-21. Normalized Mean Bias (%) of annual 1,3-butadiene by monitor for Western U.S., 2005.

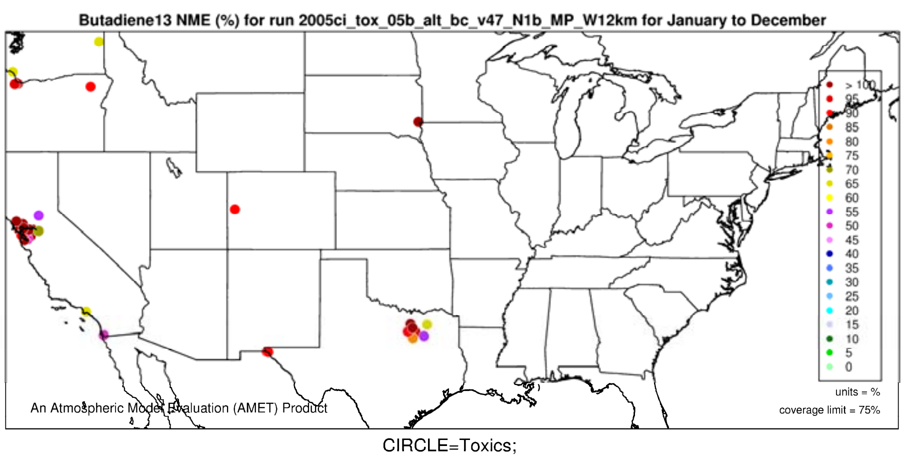


Figure K-22. Normalized Mean Error (%) of annual 1,3-butadiene by monitor for Western U.S., 2005.

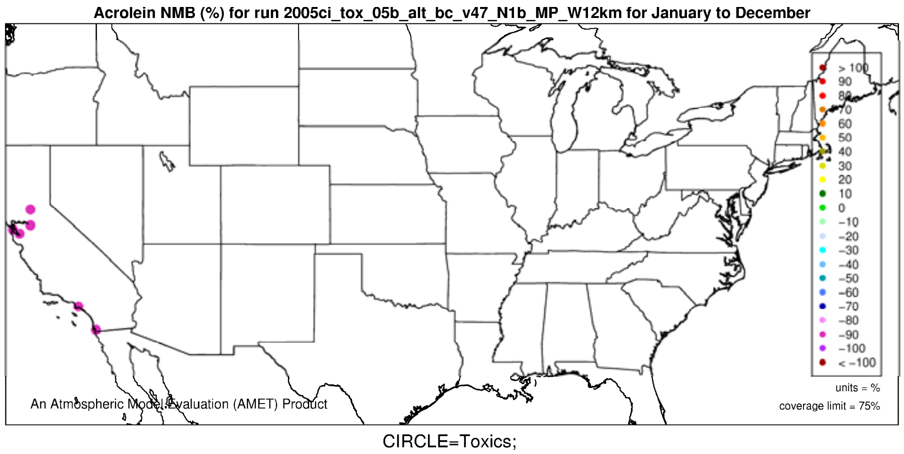


Figure K-23. Normalized Mean Bias (%) of annual acrolein by monitor for Western U.S., 2005.

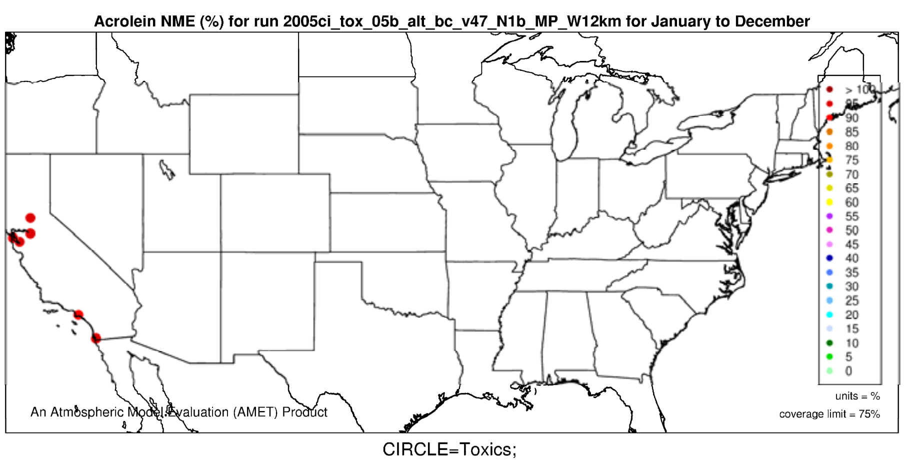


Figure K-24. Normalized Mean Error (%) of annual acrolein by monitor for Western U.S., 2005.

L. Seasonal Formaldehyde Performance

Seasonal formaldehyde 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-16). The model predictions generally show moderate under-predictions (bias and error results) for all seasons in the Eastern and Western sites (NMB values range from -19% to -84%; NME values range from 44% to 90%). Formaldehyde performance in the EUS and WUS shows the largest under estimations during the Midwest and Southeast areas. These biases and errors reflect sampling artifacts mentioned previously among the NATTS monitoring network.

Table L-1. CMAQ 2005 seasonal model performance statistics for formaldehyde.

CMAQ 2005 Formaldehyde		No. of Obs.	NMB (%)	NME (%)	FB (%)	FE (%)
Winter	12-km EUS	1532	-54.2	63.0	-46.9	70.1
	12-km WUS	389	-25.1	70.9	-40.1	79.9
	Northeast	468	-35.9	48.9	-35.5	57.0
	Midwest	171	-64.2	74.1	-39.7	75.9
	Southeast	306	-66.2	68.9	-68.5	77.9
	Central	456	-49.0	62.0	-31.5	65.9
	West	347	-19.7	72.5	-35.1	79.8
Spring	12-km EUS	1480	-55.4	66.3	-37.5	69.3
	12-km WUS	440	-34.4	60.3	-26.4	65.9
	Northeast	472	-36.7	57.9	-26.9	66.3
	Midwest	181	-59.9	71.9	-26.7	67.9
	Southeast	249	-70.6	79.1	-41.0	77.8
	Central	435	-48.8	57.1	-42.2	69.0
	West	396	-29.4	60.2	-19.6	63.5
Summer	12-km EUS	1693	-55.8	65.6	-32.0	60.8
	12-km WUS	585	-26.7	44.3	-23.6	47.8
	Northeast	608	-27.5	50.6	-20.3	60.7
	Midwest	244	-84.0	90.6	-16.9	76.4
	Southeast	283	-50.6	58.3	-39.1	56.9
	Central	425	-43.2	47.2	-51.3	57.9
	West	538	-25.1	44.3	-20.8	47.1
Fall	12-km EUS	1660	-55.8	65.3	-41.0	63.1
	12-km WUS	514	-28.9	48.2	-33.2	56.3
	Northeast	434	-26.3	49.0	-34.3	62.8
	Midwest	175	-67.4	79.4	-23.5	75.0
	Southeast	408	-72.8	77.6	-53.2	69.6
	Central	499	-36.0	44.4	-41.3	54.1
	West	465	-27.0	48.8	-30.7	56.2

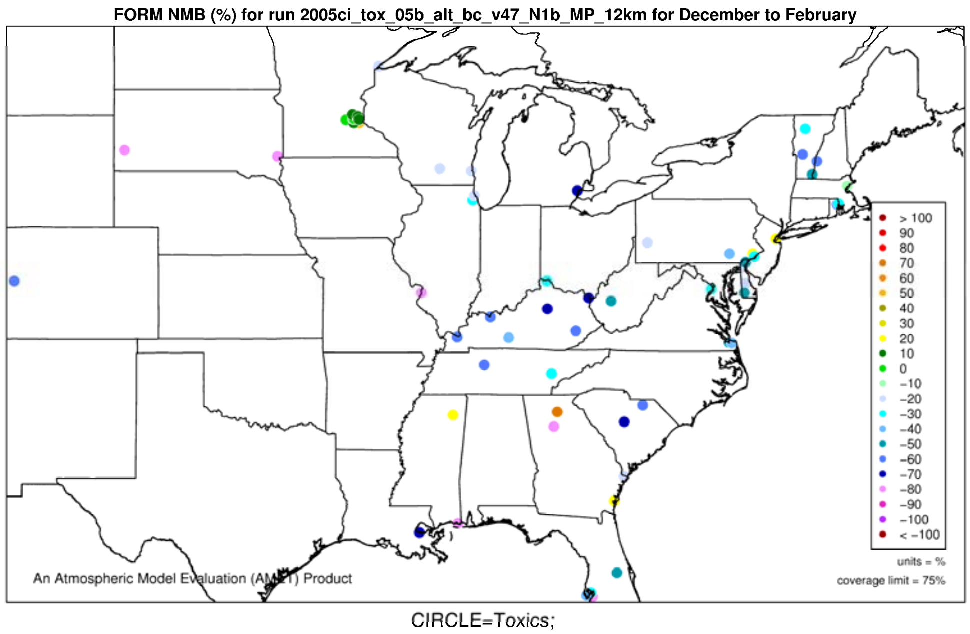


Figure L-1. Normalized Mean Bias (%) of formaldehyde by monitor for 12-km Eastern U.S. domain, Winter 2005.

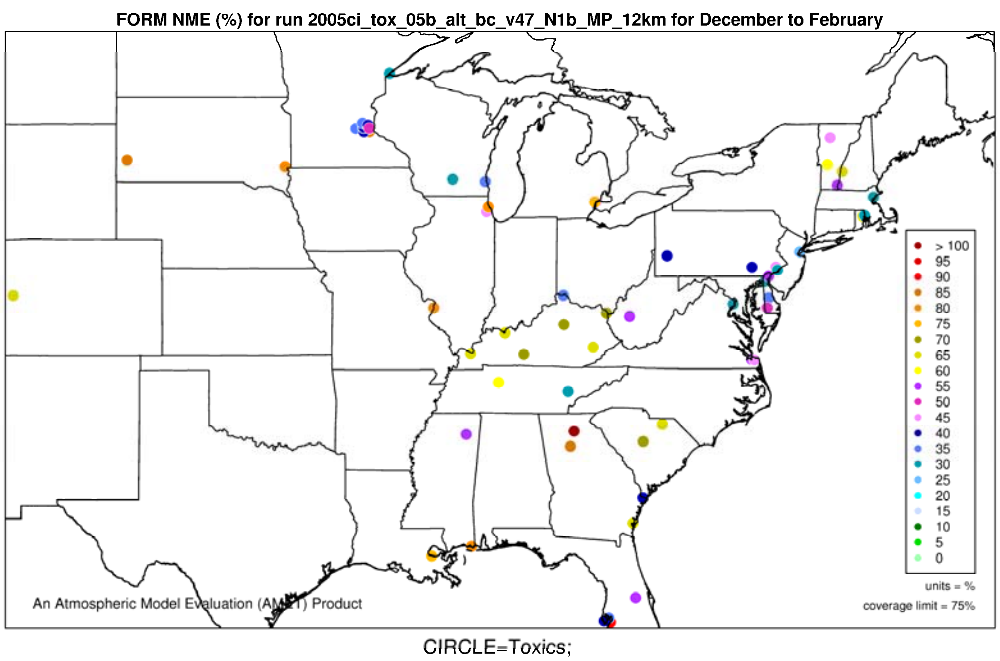


Figure L-2. Normalized Mean Error (%) of formaldehyde by monitor for 12-km Eastern U.S. domain, Winter 2005.

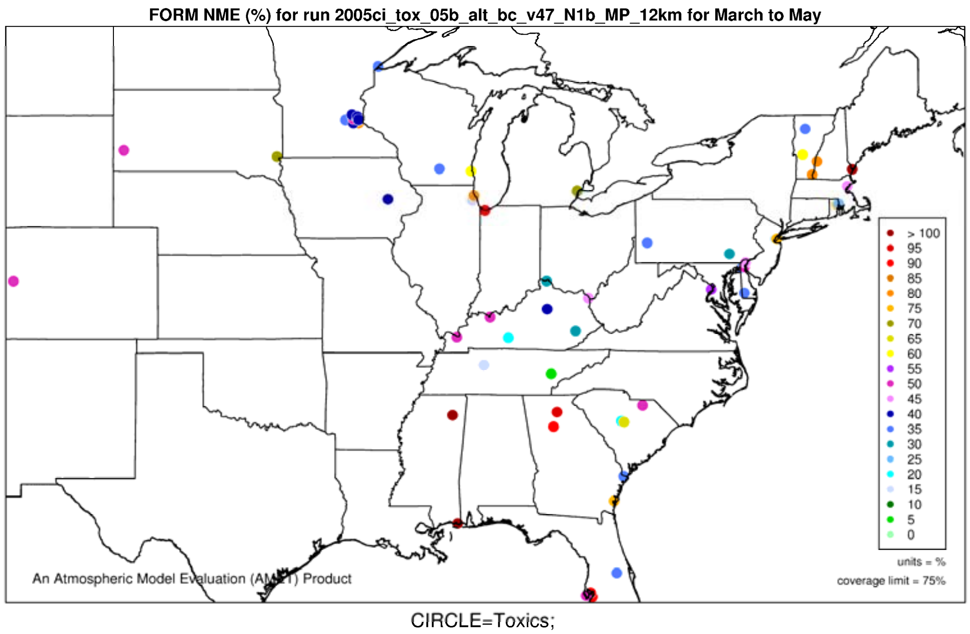


Figure L-3. Normalized Mean Bias (%) of formaldehyde by monitor for 12-km Eastern U.S. domain, Spring 2005.

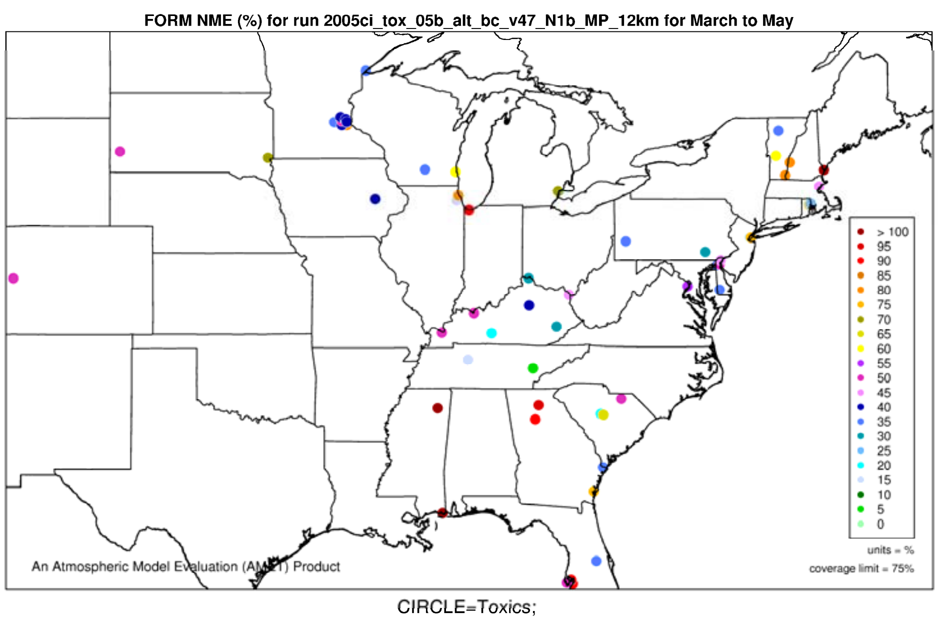


Figure L-4. Normalized Mean Error (%) of formaldehyde by monitor for 12-km Eastern U.S. domain, Spring 2005.

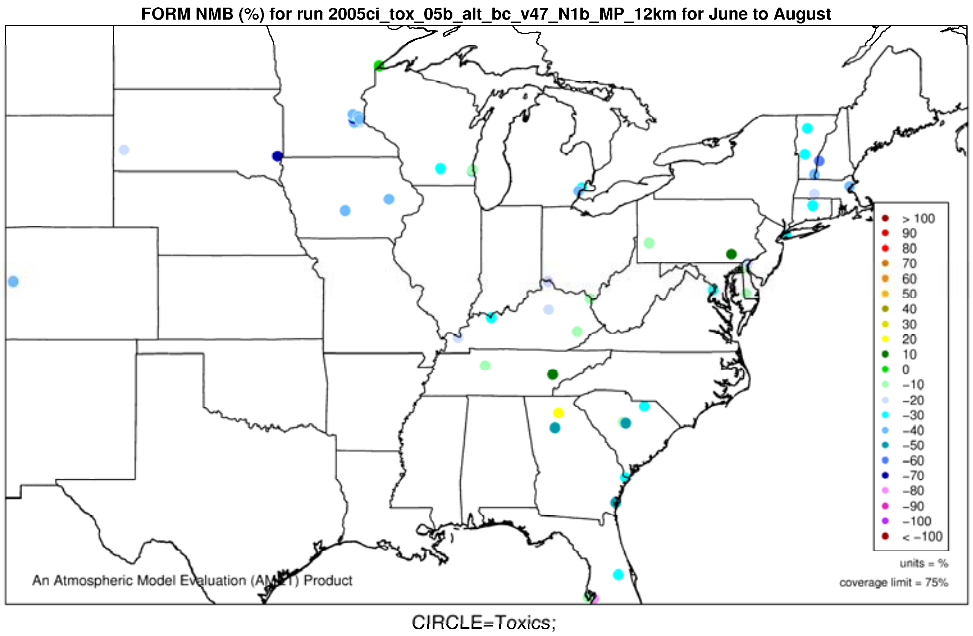


Figure L-5. Normalized Mean Bias (%) of formaldehyde by monitor for 12-km Eastern U.S. domain, Summer 2005.

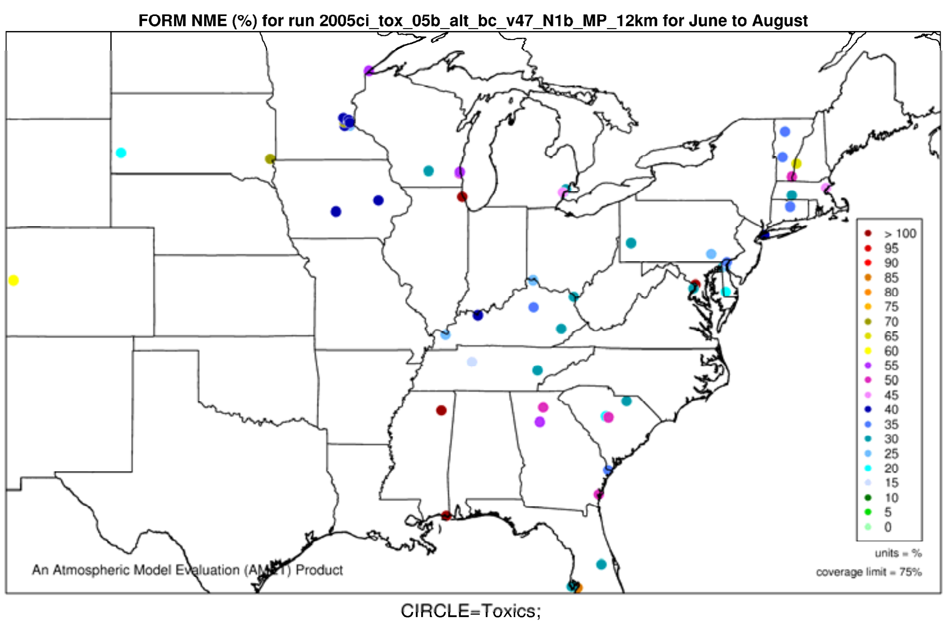


Figure L-6. Normalized Mean Error (%) of formaldehyde by monitor for 12-km Eastern U.S. domain, Summer 2005.

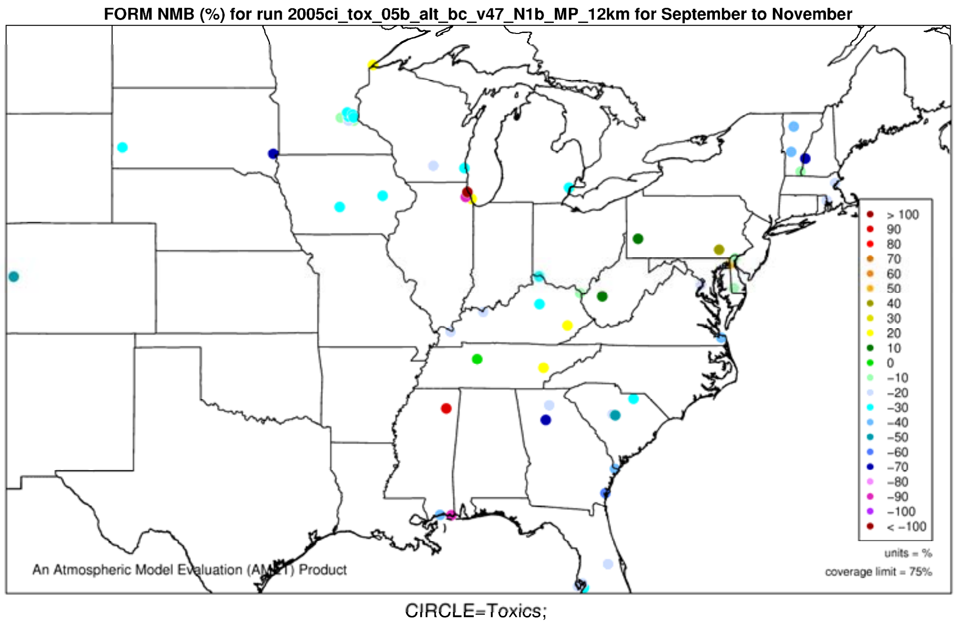


Figure L-7. Normalized Mean Bias (%) of formaldehyde by monitor for 12-km Eastern U.S. domain, Fall 2005.

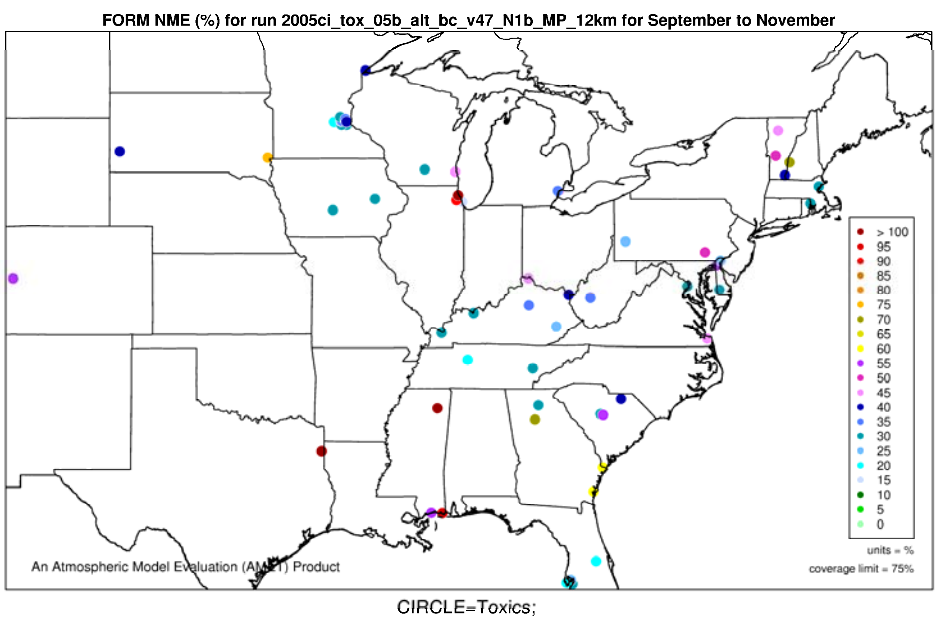


Figure L-8. Normalized Mean Error (%) of formaldehyde by monitor for 12-km Eastern U.S. domain, Fall 2005.

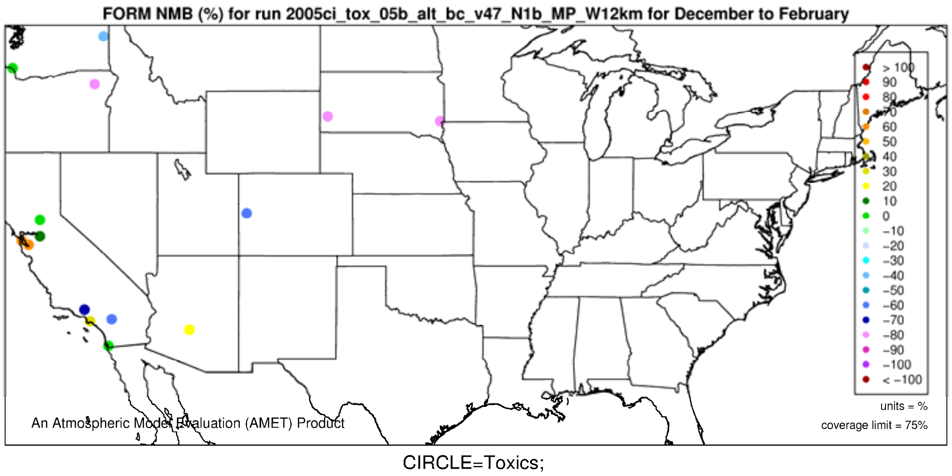


Figure L-9. Normalized Mean Bias (%) of formaldehyde by monitor for 12-km Eastern U.S. domain, Winter 2005.

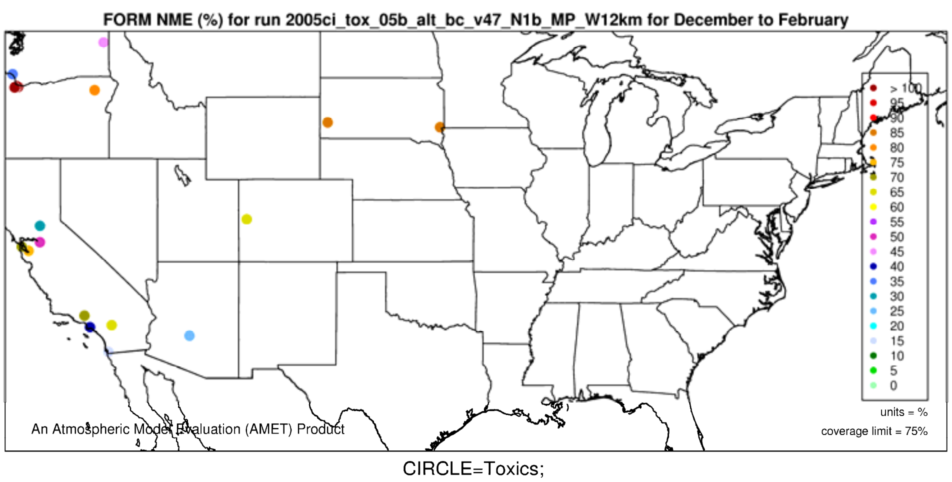


Figure L-10. Normalized Mean Error (%) of formaldehyde by monitor for 12-km Western U.S. domain, Winter 2005.

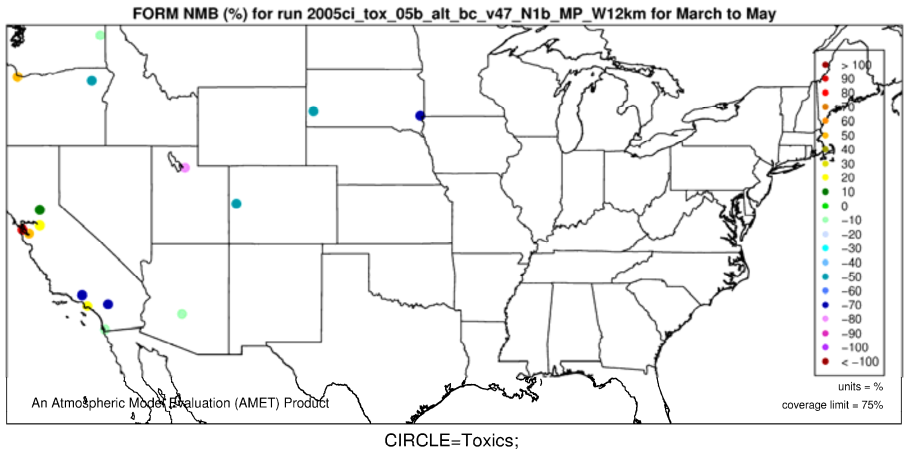


Figure L-11. Normalized Mean Bias (%) of formaldehyde by monitor for 12-km Western U.S. domain, Spring 2005.

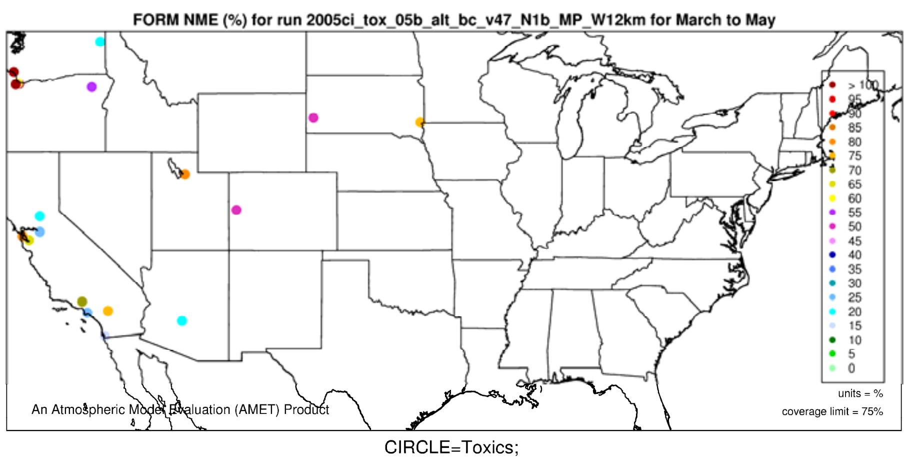


Figure L-12. Normalized Mean Error (%) of formaldehyde by monitor for 12-km Western U.S. domain, Spring 2005.

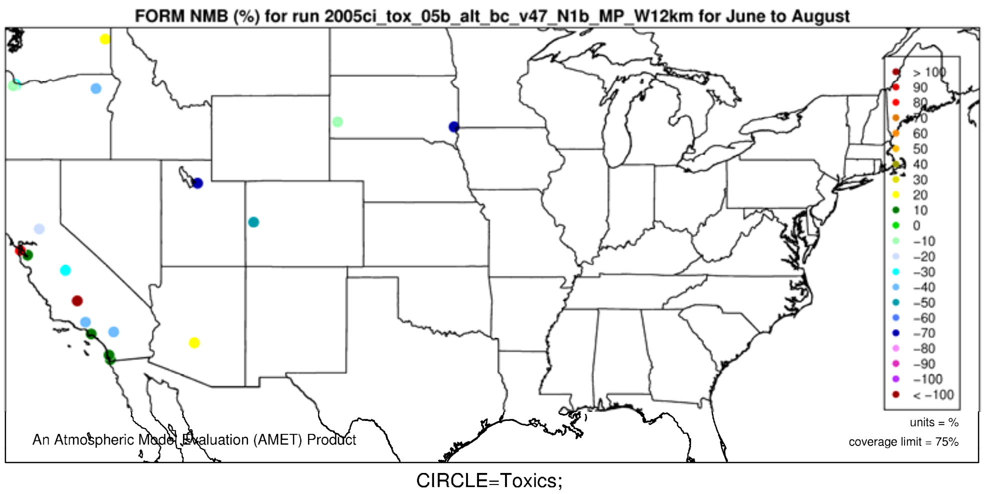


Figure L-13. Normalized Mean Bias (%) of formaldehyde by monitor for 12-km Western U.S. domain, Summer 2005.

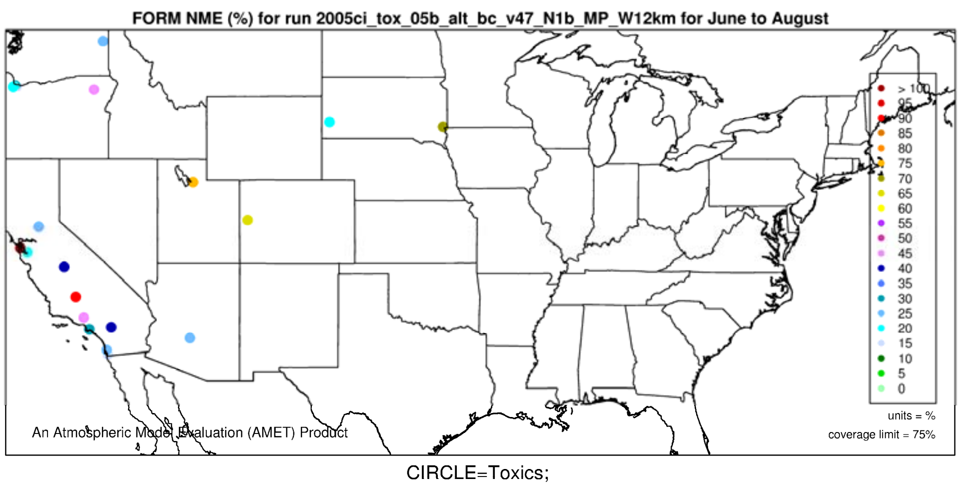


Figure L-14. Normalized Mean Error (%) of formaldehyde by monitor for 12-km Western U.S. domain, Summer 2005.

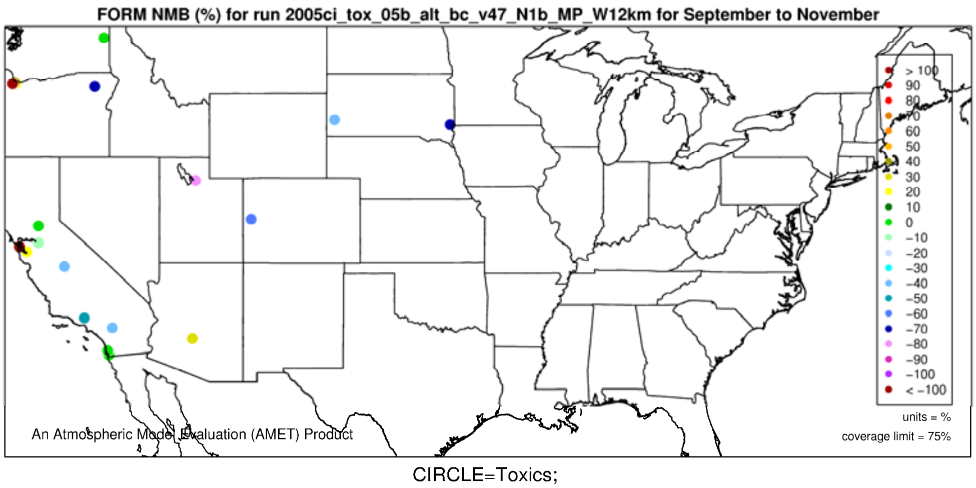


Figure L-15. Normalized Mean Bias (%) of formaldehyde by monitor for 12-km Western U.S. domain, Fall 2005.

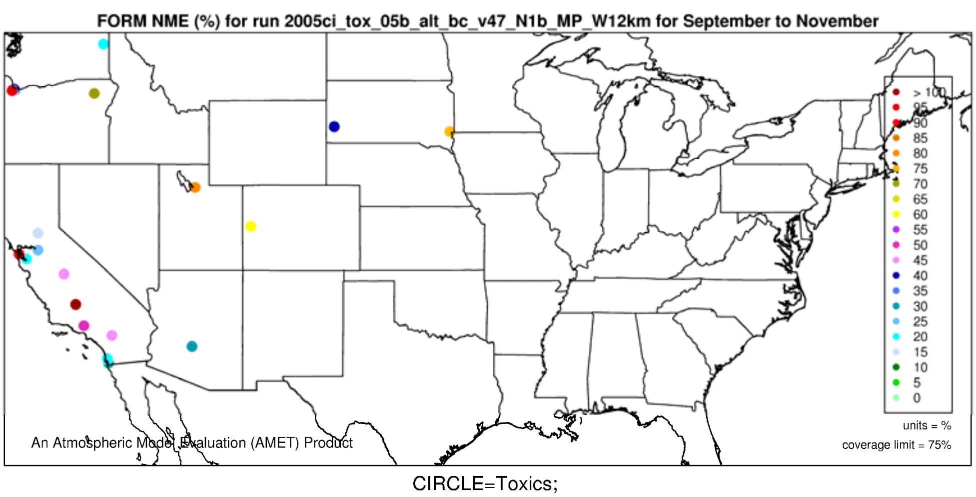


Figure L-16. Normalized Mean Error (%) of formaldehyde by monitor for 12-km Western U.S. domain, Fall 2005.

M. Seasonal Acetaldehyde Performance

Seasonal acetaldehyde performance statistics are provided in Table M-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 M-1 – M-16). Overall, the model predictions show moderate under-predictions for all Eastern and Western sites (NMB values range from -3% to -47%). Although, in the summer, acetaldehyde performance in the EUS and WUS shows a positive bias with over-predictions ranging from 15% in the Midwest to 84% in the Southeast. Similar to formaldehyde results the biases and errors reflect technical issues with observational data (uncertainties in monitoring methods and limited measurements in time and space).

Table M-1. CMAQ 2005 seasonal model performance statistics for acetaldehyde.

CMAQ 2005 Acetaldehyde		No. of Obs.	NMB (%)	NME (%)	FB (%)	FE (%)
Winter	12-km EUS	1454	-44.8	52.0	-46.5	60.5
	12-km WUS	388	-30.2	69.9	-44.4	79.7
	Northeast	470	-47.8	54.4	-48.7	62.2
	Midwest	141	-46.1	51.8	-52.7	66.6
	Southeast	304	-41.6	52.6	-44.0	63.9
	Central	408	-34.8	40.8	-34.4	44.3
	West	346	-27.9	72.1	-42.1	81.7
Spring	12-km EUS	1417	-29.9	50.8	-25.6	56.5
	12-km WUS	429	-29.1	54.8	-26.3	60.8
	Northeast	473	-33.1	57.4	-23.0	66.3
	Midwest	164	-44.9	50.7	-45.5	55.9
	Southeast	245	-12.9	52.2	-4.1	57.0
	Central	392	-30.5	43.4	-29.4	44.6
	West	383	-29.7	58.3	-25.7	63.8
Summer	12-km EUS	1622	47.8	83.6	44.9	66.9
	12-km WUS	572	-5.6	47.0	5.9	45.4
	Northeast	576	37.6	76.1	40.9	65.6
	Midwest	238	15.0	63.5	32.0	56.9
	Southeast	278	84.8	103.7	51.9	70.0
	Central	397	54.0	87.9	49.2	69.4
	West	525	-8.9	46.1	2.6	45.0
Fall	12-km EUS	1601	-8.7	55.3	-11.9	56.9
	12-km WUS	503	-24.4	52.2	-23.3	59.3
	Northeast	450	-16.0	57.6	-16.9	59.8
	Midwest	160	-3.5	60.4	-7.6	63.1
	Southeast	404	-16.0	52.9	-19.0	58.8
	Central	443	2.2	47.8	-2.3	46.6
	West	455	-26.0	51.9	-25.0	59.9

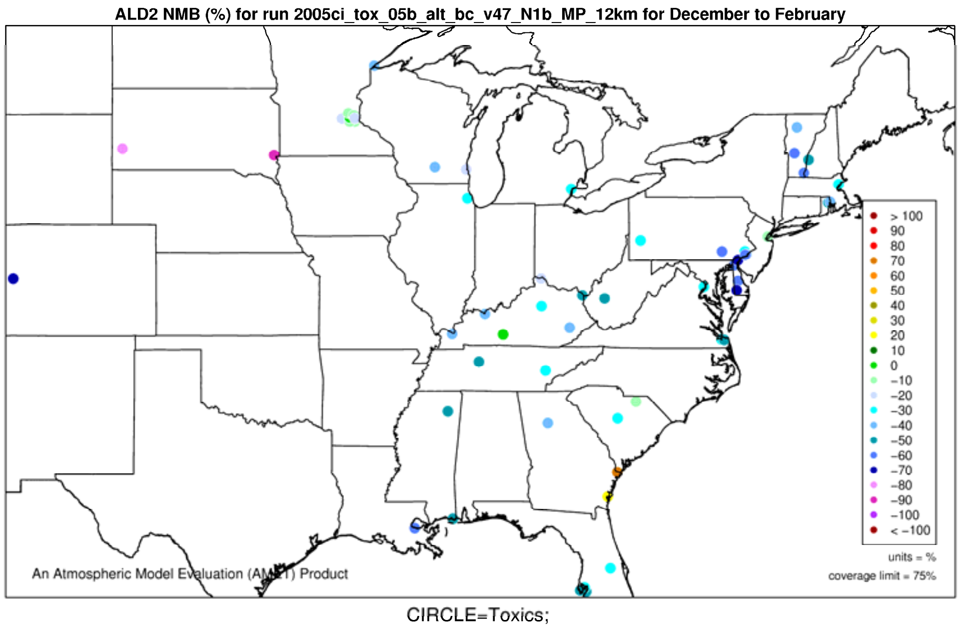


Figure M-1. Normalized Mean Bias (%) of acetaldehyde by monitor for 12-km Eastern U.S. domain, Winter 2005.

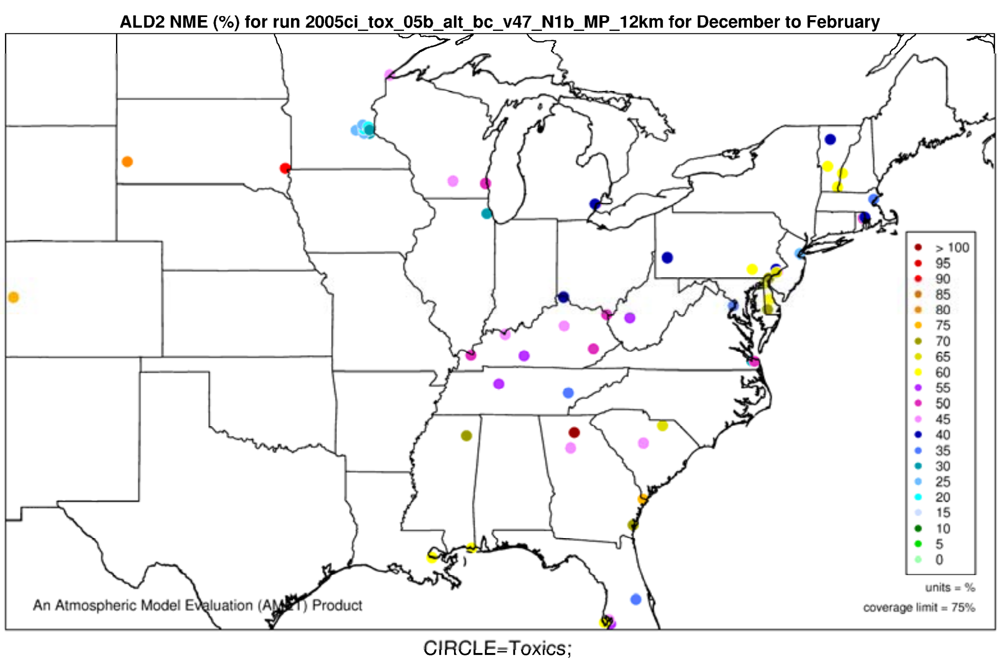


Figure M-2. Normalized Mean Error (%) of acetaldehyde by monitor for 12-km Eastern U.S. domain, Winter 2005.

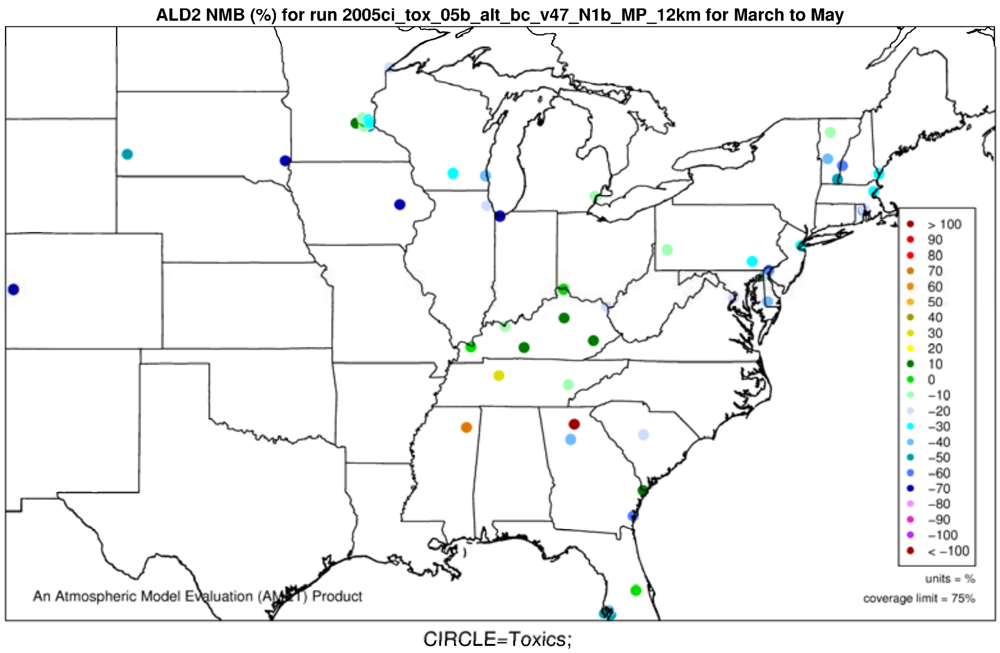


Figure M-3. Normalized Mean Bias (%) of acetaldehyde by monitor for 12-km Eastern U.S. domain, Spring 2005.

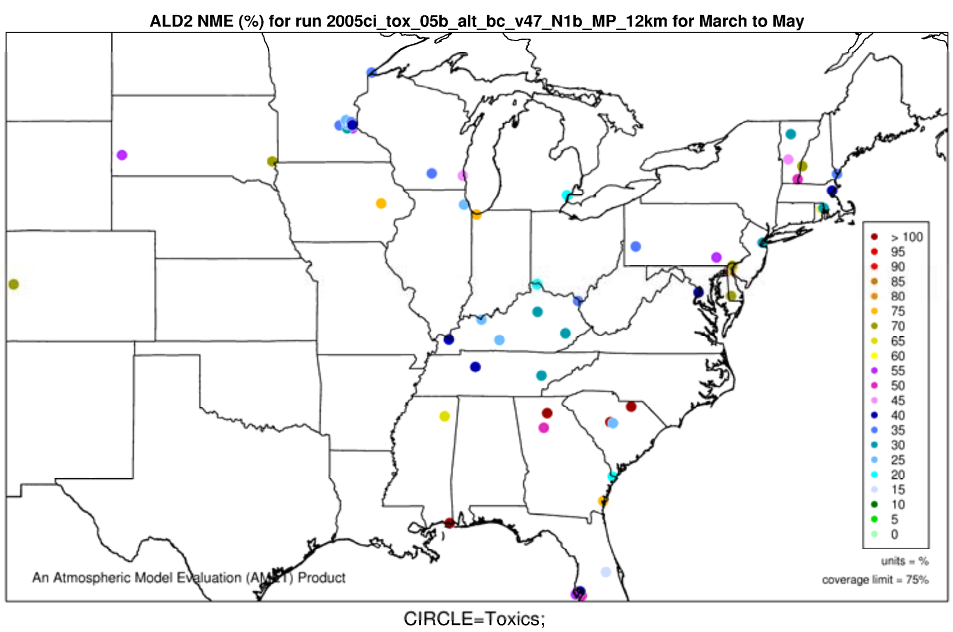


Figure M-4. Normalized Mean Error (%) of acetaldehyde by monitor for 12-km Eastern U.S. domain, Spring 2005.

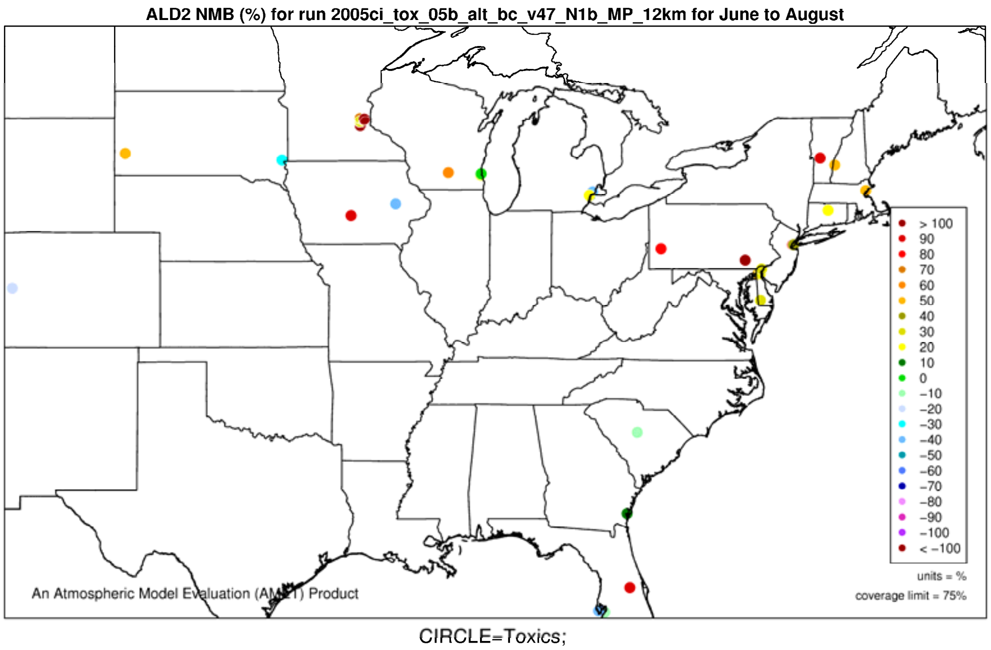


Figure M-5. Normalized Mean Bias (%) of acetaldehyde by monitor for 12-km Eastern U.S. domain, Summer 2005.

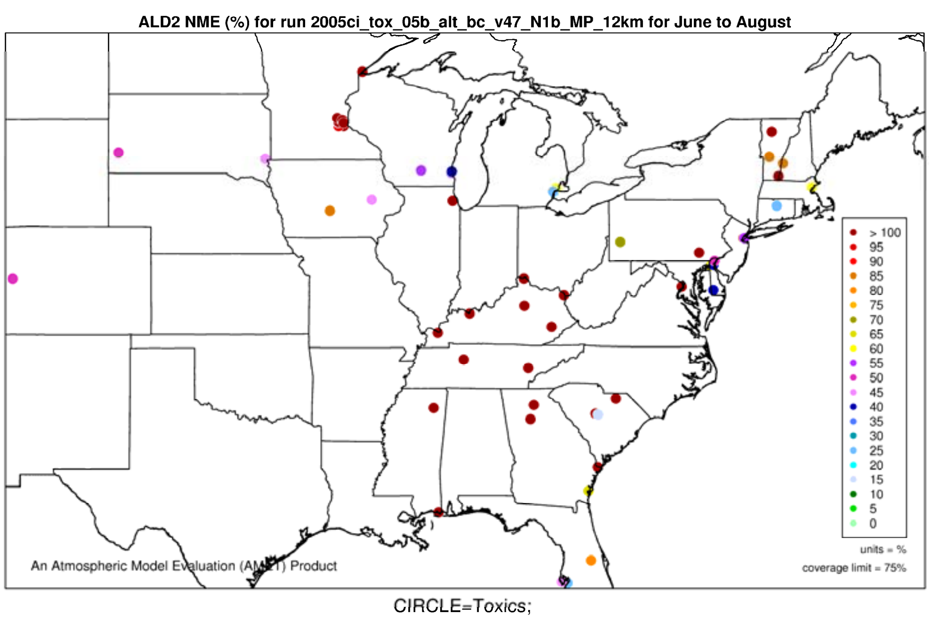


Figure M-6. Normalized Mean Error (%) of acetaldehyde by monitor for 12-km Eastern U.S. domain, Summer 2005.

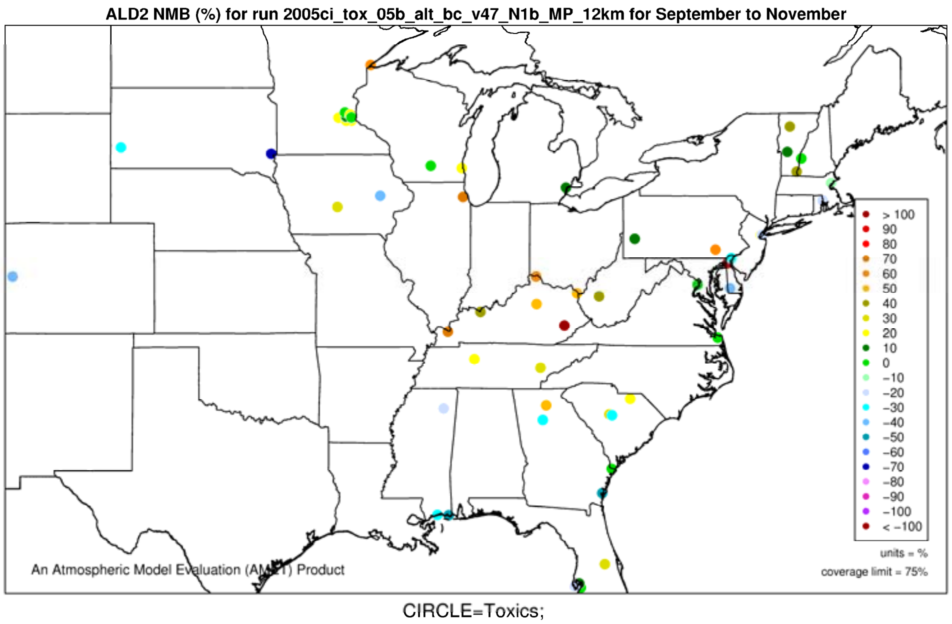


Figure M-7. Normalized Mean Bias (%) of acetaldehyde by monitor for 12-km Eastern U.S. domain, Fall 2005.

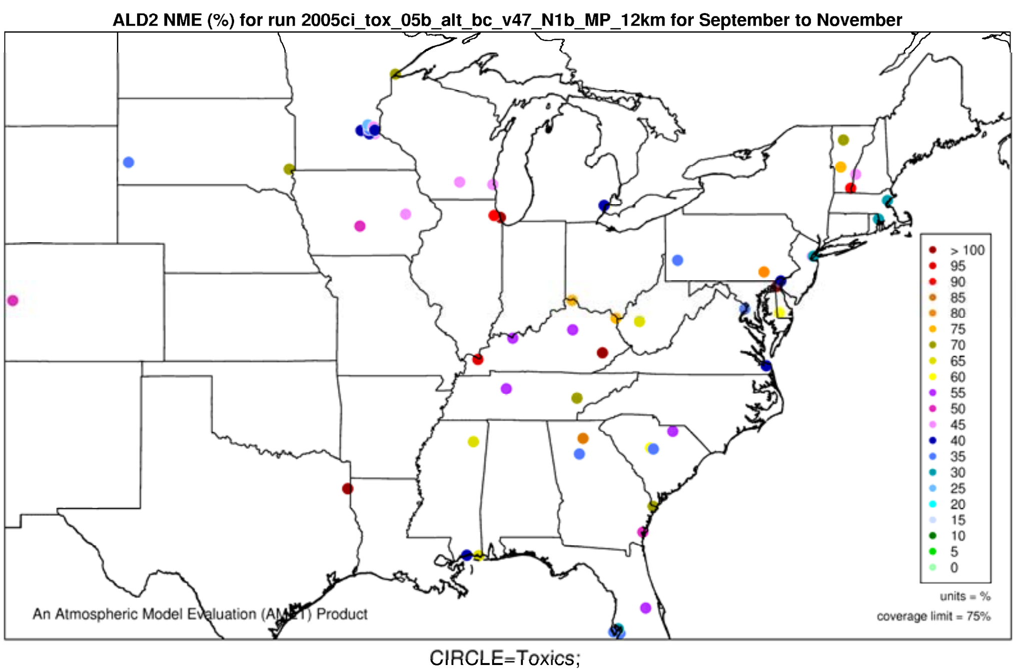


Figure M-8. Normalized Mean Error (%) of acetaldehyde by monitor for 12-km Eastern U.S. domain, Fall 2005.

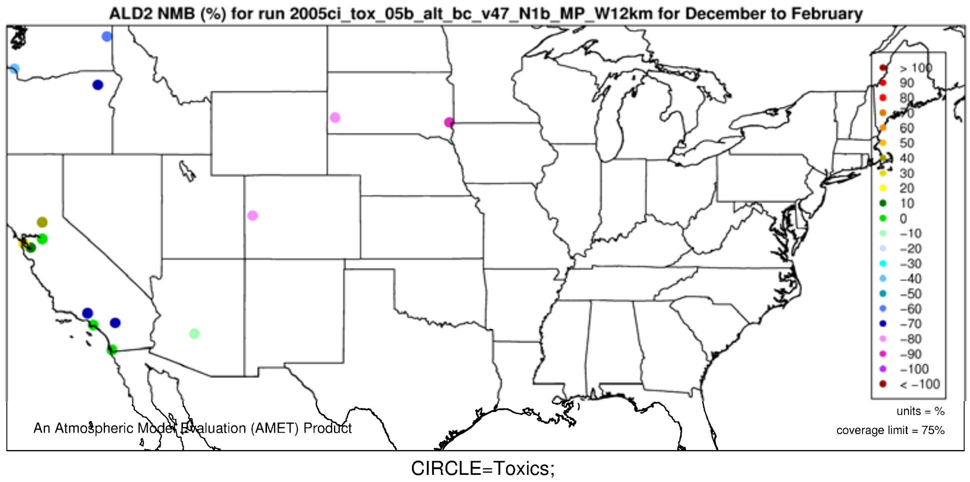


Figure M-9. Normalized Mean Bias (%) of acetaldehyde by monitor for 12-km Eastern U.S. domain, Winter 2005.

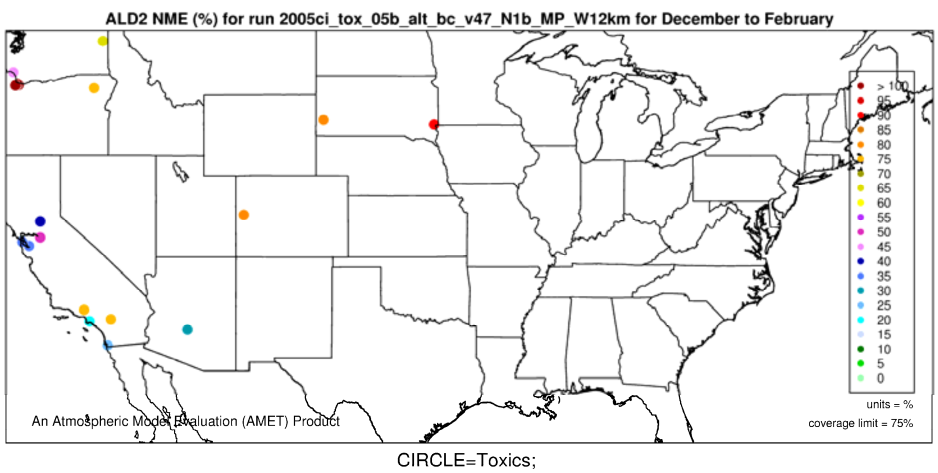


Figure M-10. Normalized Mean Error (%) of acetaldehyde by monitor for 12-km Western U.S. domain, Winter 2005.

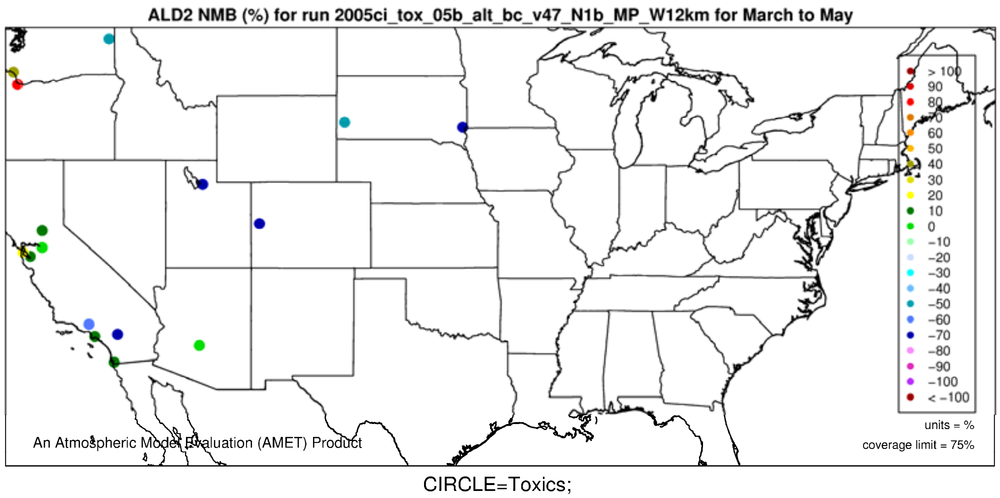


Figure M-11. Normalized Mean Bias (%) of acetaldehyde by monitor for 12-km Western U.S. domain, Spring 2005.

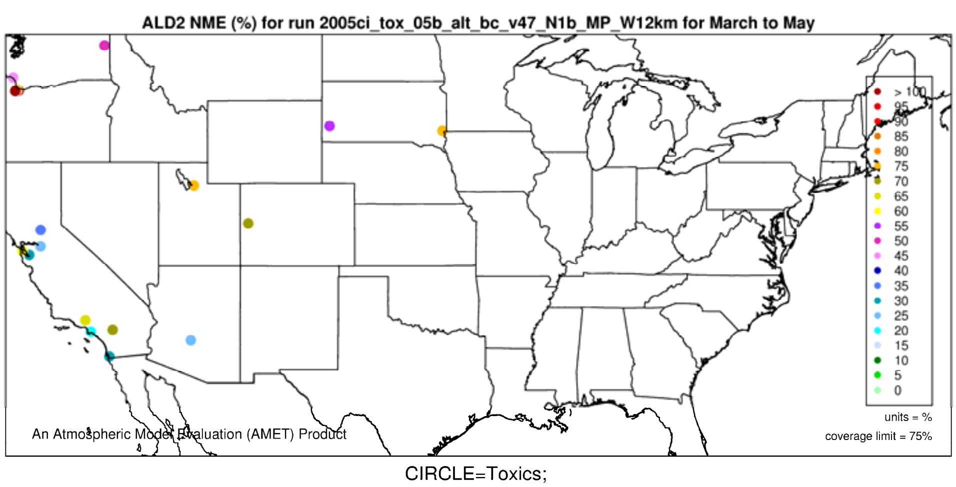


Figure M-12. Normalized Mean Error (%) of acetaldehyde by monitor for 12-km Western U.S. domain, Spring 2005.

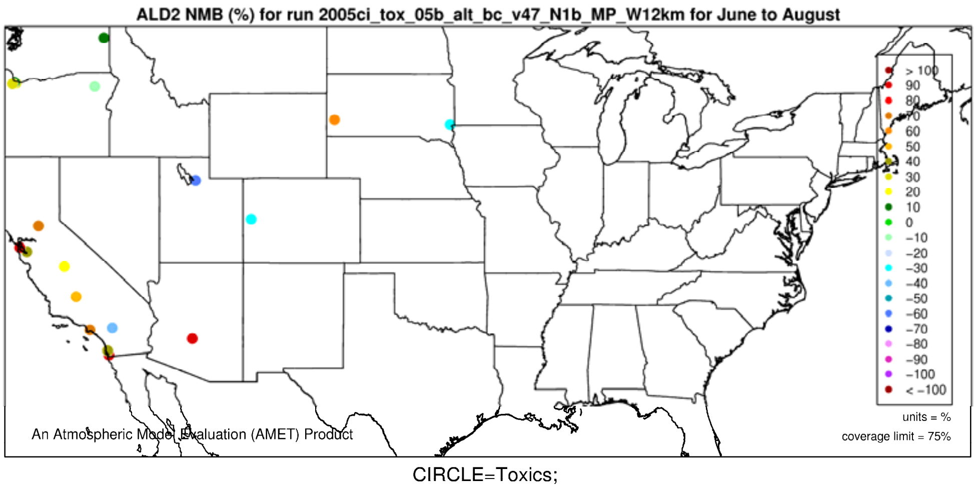


Figure M-13. Normalized Mean Bias (%) of acetaldehyde by monitor for 12-km Western U.S. domain, Summer 2005.

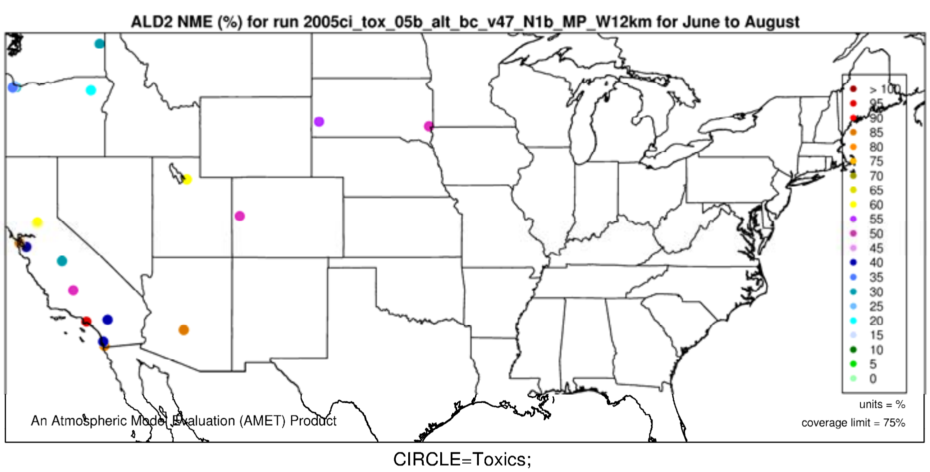


Figure M-14. Normalized Mean Error (%) of acetaldehyde by monitor for 12-km Western U.S. domain, Summer 2005.

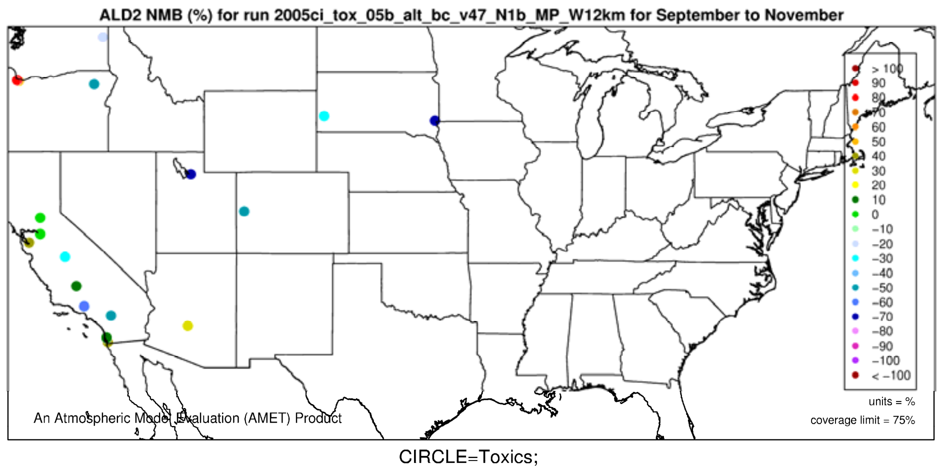


Figure M-15. Normalized Mean Bias (%) of acetaldehyde by monitor for 12-km Western U.S. domain, Fall 2005.

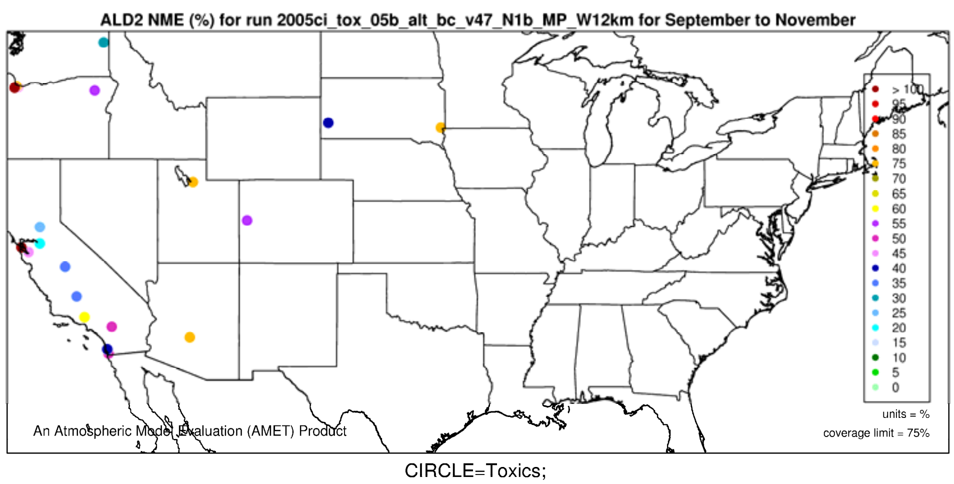


Figure M-16. Normalized Mean Error (%) of acetaldehyde by monitor for 12-km Western U.S. domain, Fall 2005.

N. Seasonal Benzene Performance

Seasonal benzene performance statistics are provided in Table N-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 N-1 – N-16). The model predictions typically show moderate bias (under-predictions) and error results for all Eastern and Western NATTS sites (NMB values range from -3% to -52%; NME values range from 50% to 75%). However, benzene performance in the Northeast shows over-predictions during all the seasons (NMB values range from 11% in the Summer and Fall to 30% in the Spring and Winter). Similar to the other HAPs modeled, these biases and errors reflect sampling artifacts among the NATTS monitoring network.

Table N-1. CMAQ 2005 seasonal model performance statistics for benzene.

CMAQ 2005 Benzene		No. of Obs.	NMB (%)	NME (%)	FB (%)	FE (%)
Winter	12-km EUS	2846	-28.6	69.7	-6.0	60.0
	12-km WUS	781	-39.2	59.1	-39.4	64.9
	Northeast	592	31.1	56.7	25.2	46.2
	Midwest	322	27.2	72.0	35.0	55.0
	Southeast	591	-30.2	67.3	-6.4	55.8
	Central	1217	-50.3	74.1	-23.4	66.4
	West	523	-31.4	58.9	-33.8	67.4
Spring	12-km EUS	2888	-35.8	65.3	-19.9	63.2
	12-km WUS	769	-29.8	56.8	-30.6	62.1
	Northeast	632	28.8	52.1	19.5	45.2
	Midwest	331	-20.6	67.7	13.1	54.4
	Southeast	618	-51.9	70.9	-22.2	61.0
	Central	1169	-42.0	62.3	-37.4	69.6
	West	516	-17.0	57.0	-16.1	60.2
Summer	12-km EUS	2955	-36.8	67.2	-15.8	67.0
	12-km WUS	943	-28.9	58.7	-19.2	61.8
	Northeast	751	11.4	52.9	17.2	51.0
	Midwest	396	-3.2	76.8	31.4	75.3
	Southeast	563	-48.4	69.2	-26.3	62.3
	Central	1167	-51.7	68.0	-41.7	73.8
	West	675	-16.9	57.6	-3.0	58.2
Fall	12-km EUS	2926	-30.9	64.0	-12.3	60.9
	12-km WUS	876	-47.9	65.8	-34.2	67.0
	Northeast	614	11.7	49.8	10.9	44.1
	Midwest	376	-29.2	74.9	20.8	62.2
	Southeast	654	-34.8	66.8	-14.3	60.2
	Central	1184	-41.8	64.9	-28.6	67.9
	West	619	-44.0	67.5	-27.1	68.3

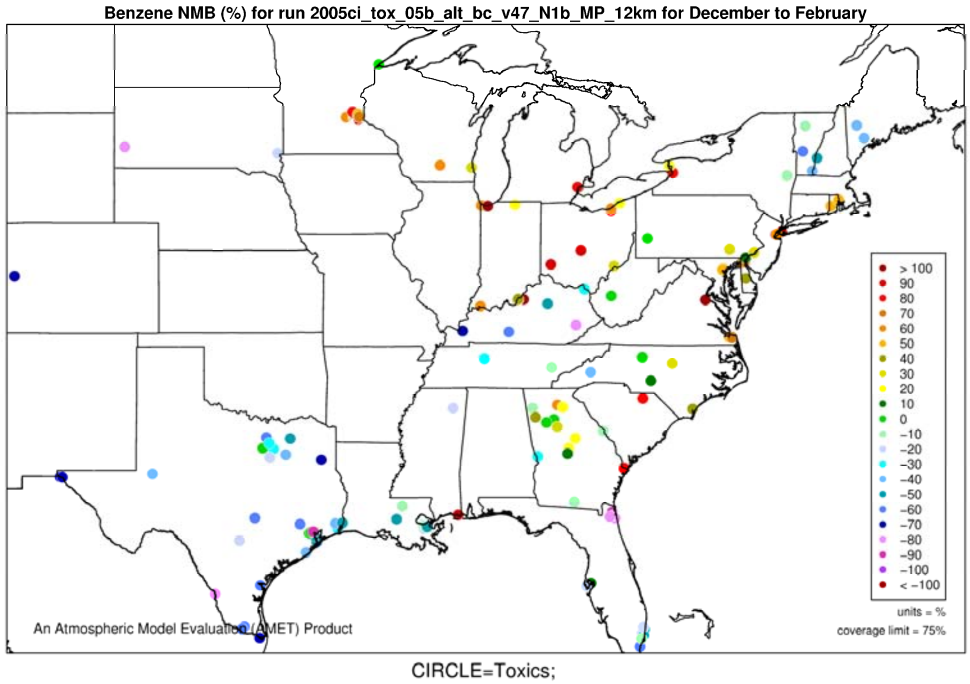


Figure N-1. Normalized Mean Bias (%) of benzene by monitor for 12-km Eastern U.S. domain, Winter 2005.

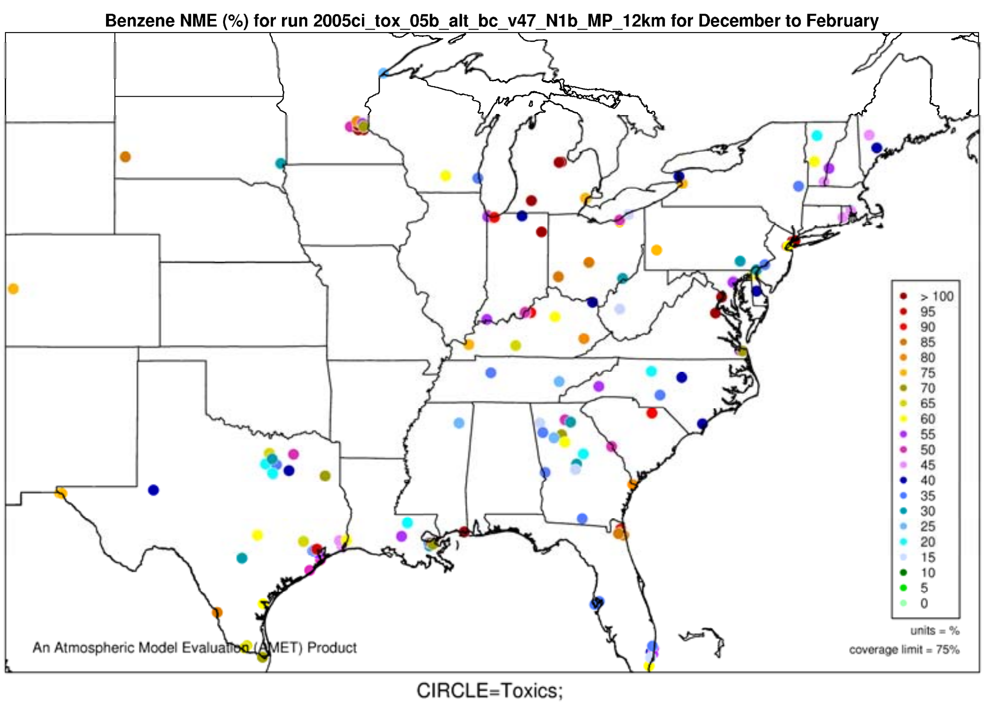


Figure N-2. Normalized Mean Error (%) of benzene by monitor for 12-km Eastern U.S. domain, Winter 2005.

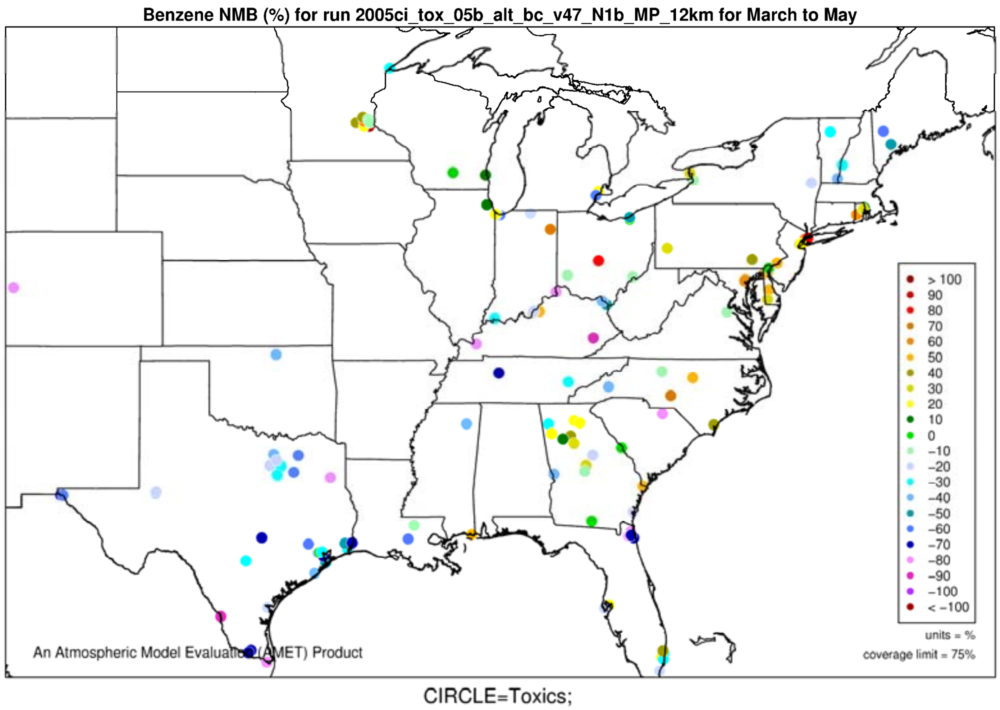


Figure N-3. Normalized Mean Bias (%) of benzene by monitor for 12-km Eastern U.S. domain, Spring 2005.

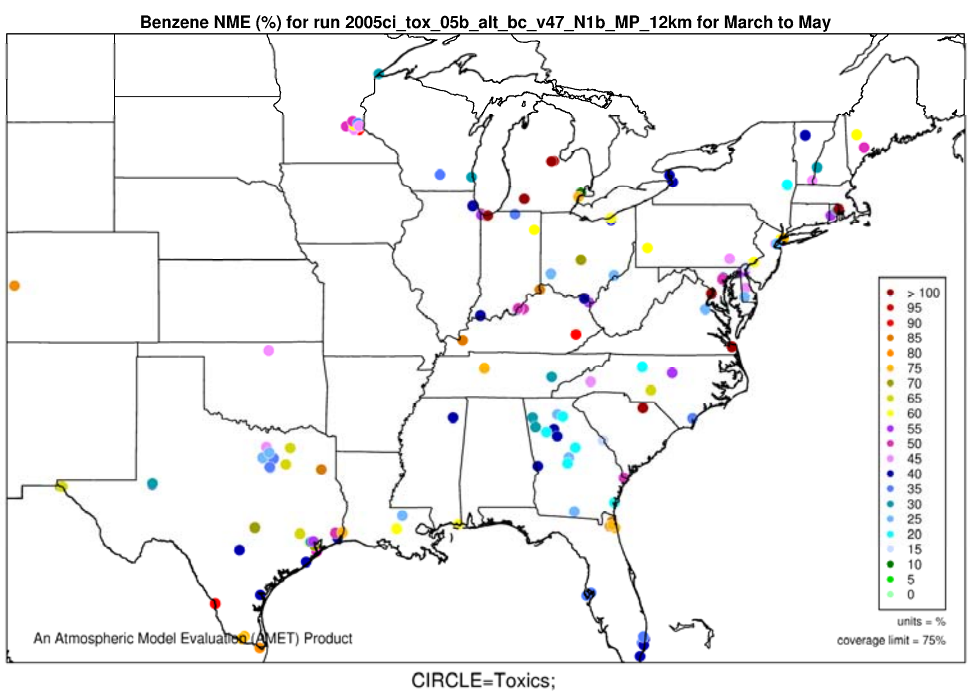


Figure N-4. Normalized Mean Error (%) of benzene by monitor for 12-km Eastern U.S. domain, Spring 2005.

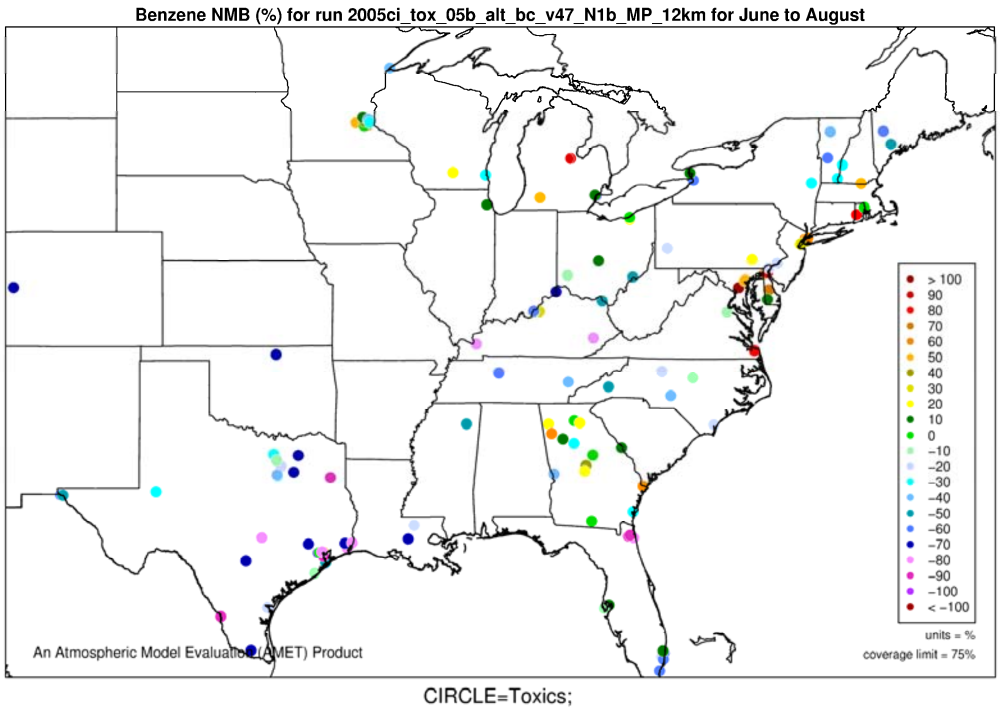


Figure N-5. Normalized Mean Bias (%) of benzene by monitor for 12-km Eastern U.S. domain, Summer 2005.

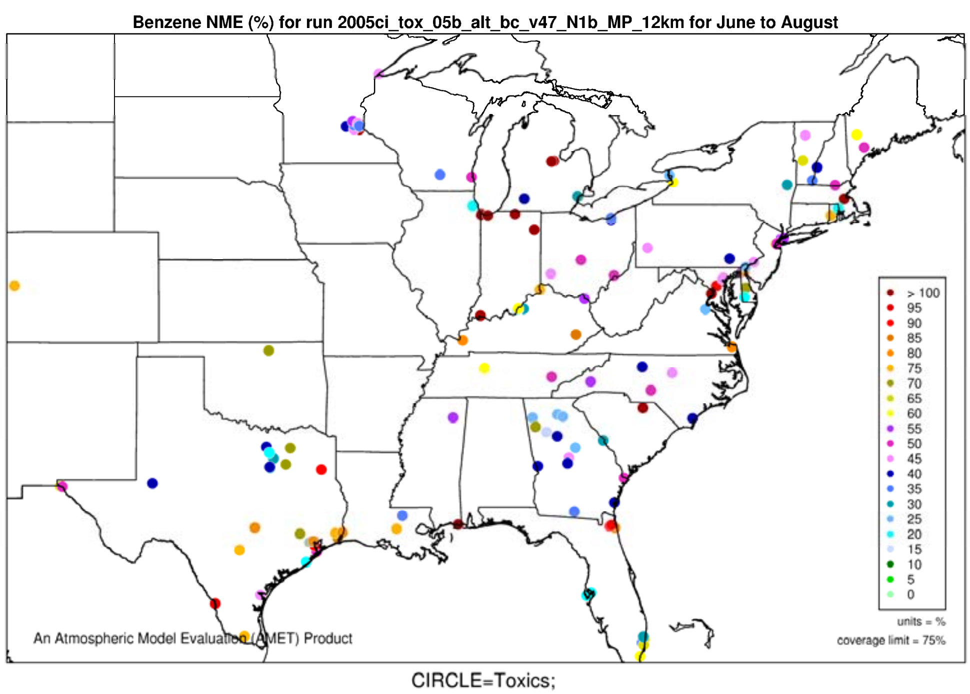


Figure N-6. Normalized Mean Error (%) of benzene by monitor for 12-km Eastern U.S. domain, Summer 2005.

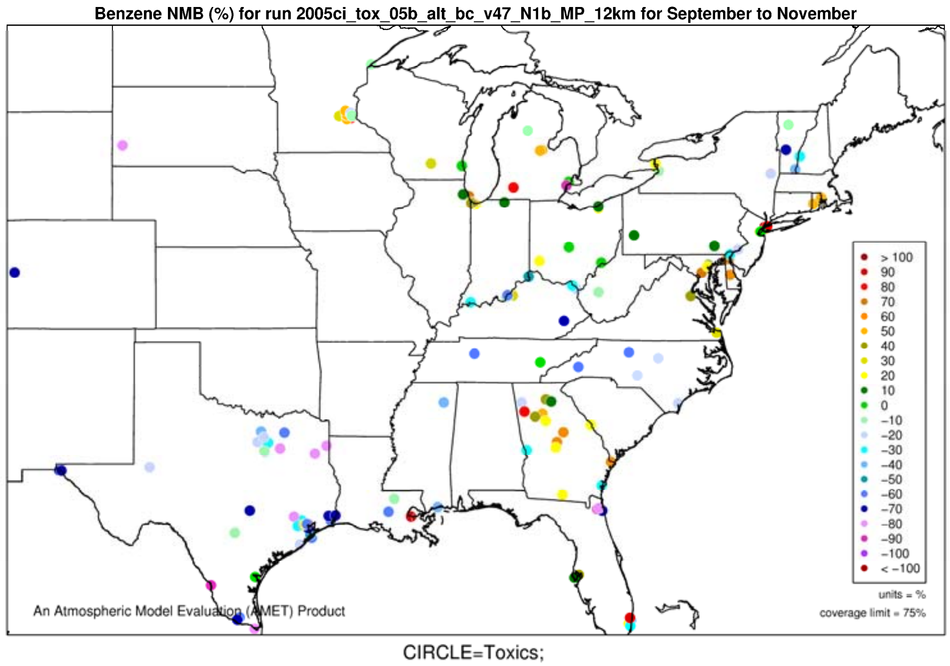


Figure N-7. Normalized Mean Bias (%) of benzene by monitor for 12-km Eastern U.S. domain, Fall 2005.

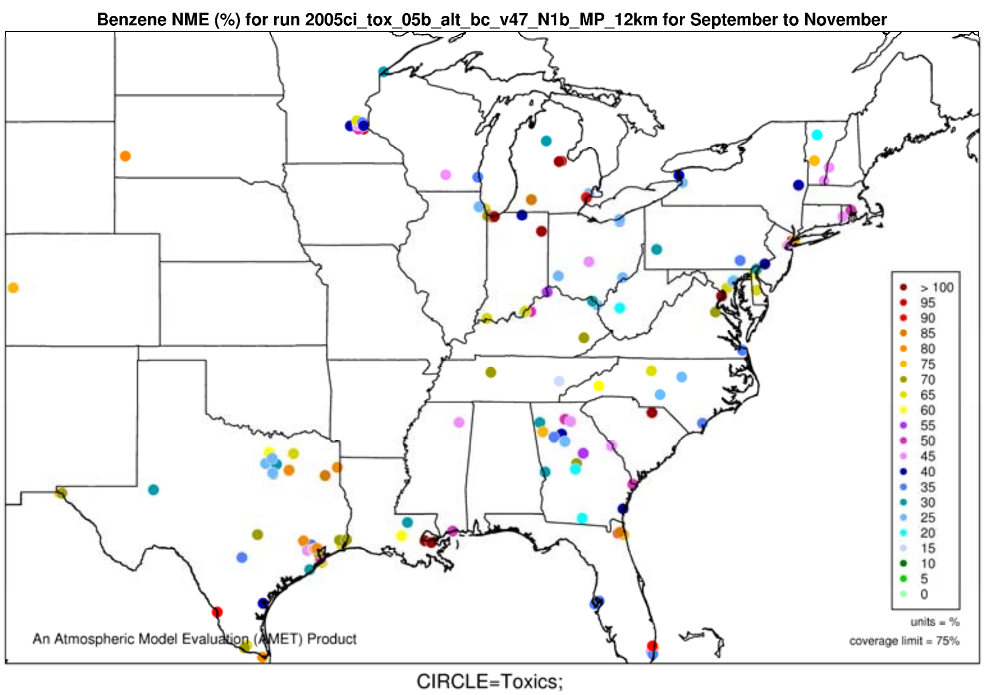


Figure N-8. Normalized Mean Error (%) of benzene by monitor for 12-km Eastern U.S. domain, Fall 2005.

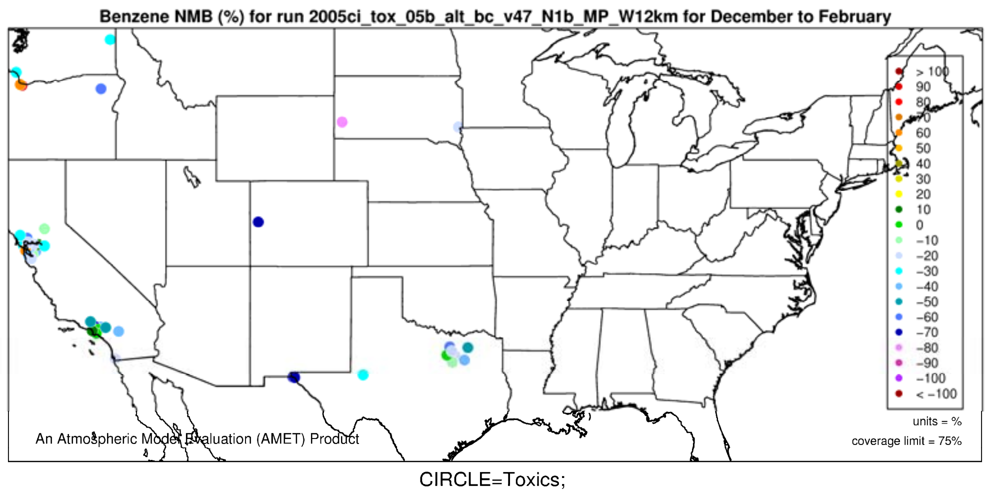


Figure N-9. Normalized Mean Bias (%) of benzene by monitor for 12-km Eastern U.S. domain, Winter 2005.

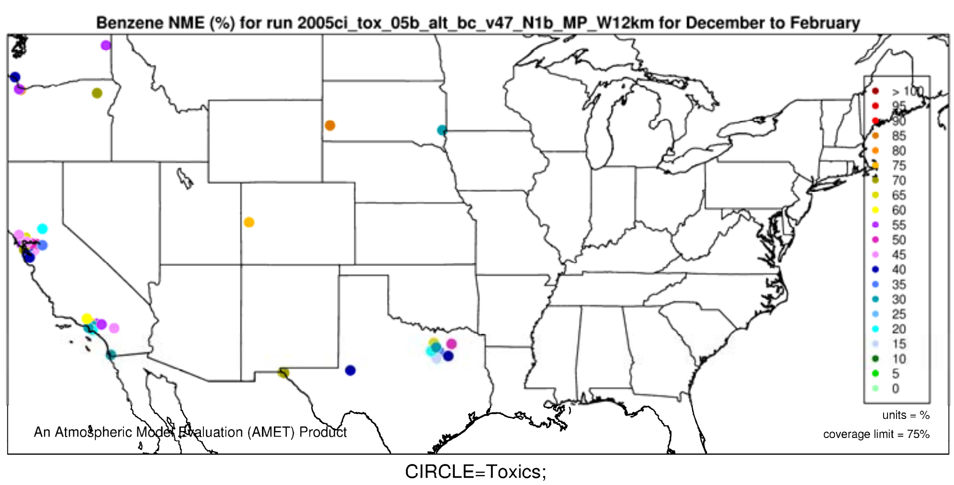


Figure N-10. Normalized Mean Error (%) of benzene by monitor for 12-km Western U.S. domain, Winter 2005.

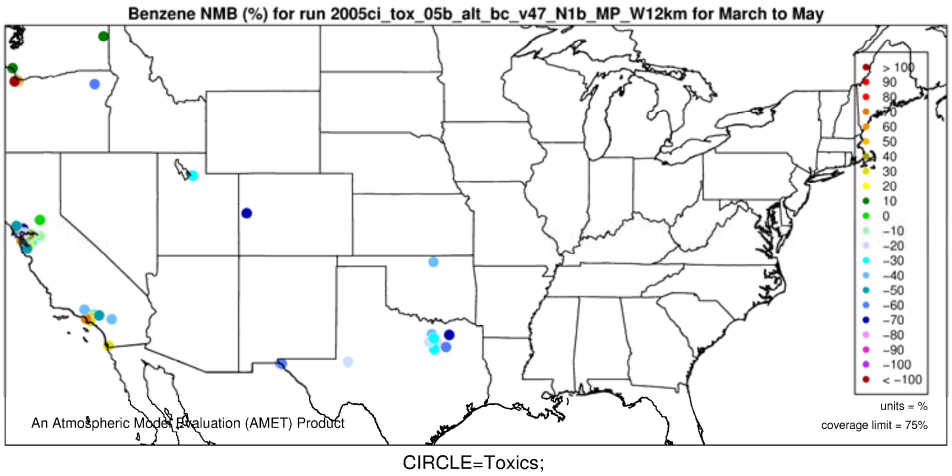


Figure N-11. Normalized Mean Bias (%) of benzene by monitor for 12-km Western U.S. domain, Spring 2005.

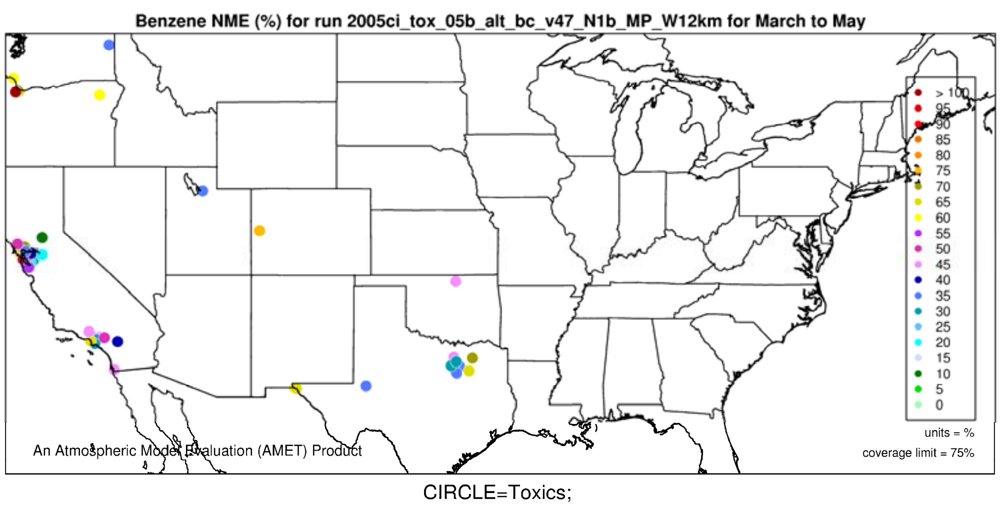


Figure N-12. Normalized Mean Error (%) of benzene by monitor for 12-km Western U.S. domain, Spring 2005.

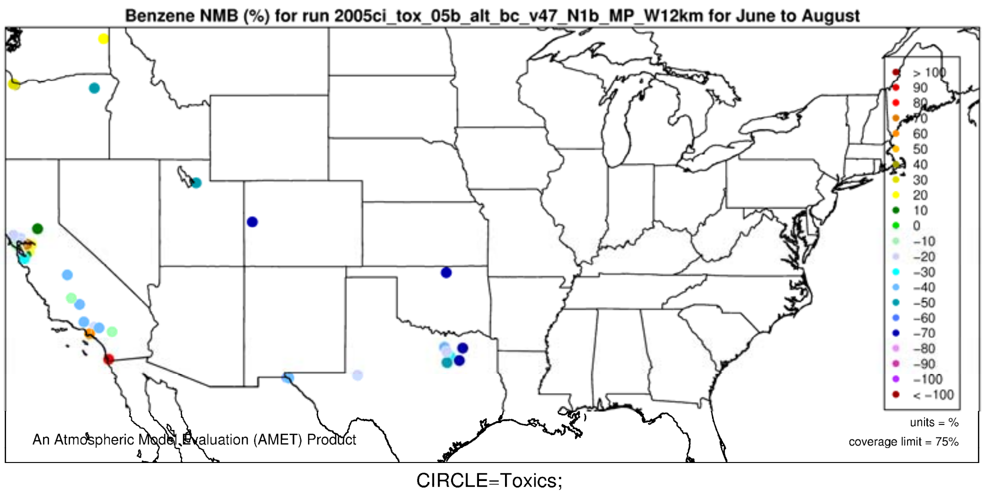


Figure N-13. Normalized Mean Bias (%) of benzene by monitor for 12-km Western U.S. domain, Summer 2005.

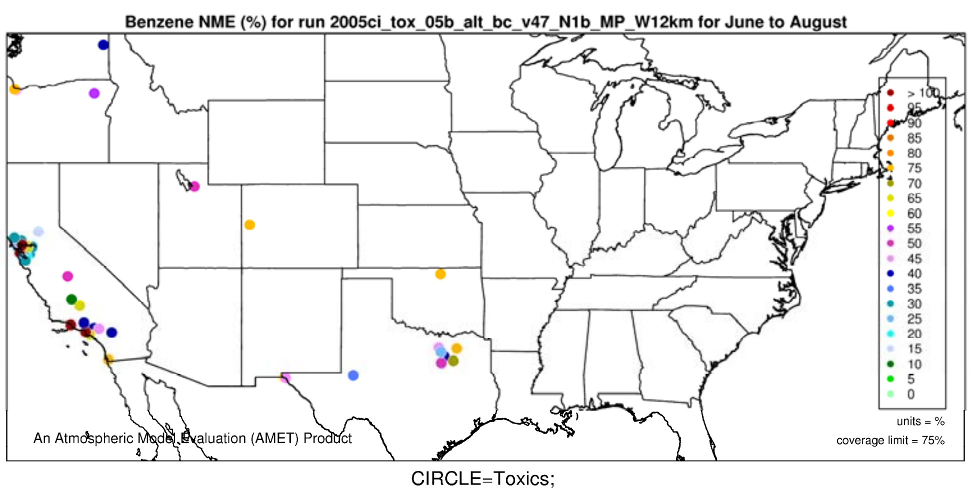


Figure N-14. Normalized Mean Error (%) of benzene by monitor for 12-km Western U.S. domain, Summer 2005.

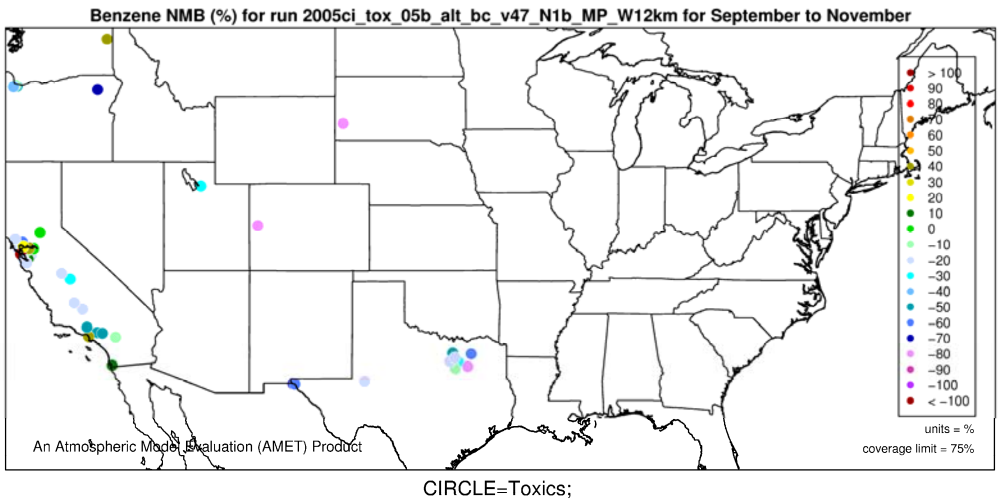


Figure N-15. Normalized Mean Bias (%) of benzene by monitor for 12-km Western U.S. domain, Fall 2005.

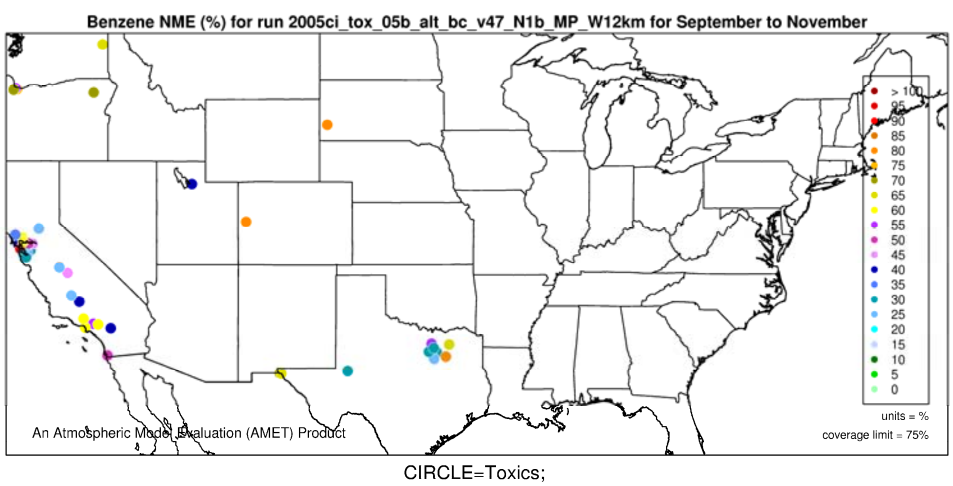


Figure N-16. Normalized Mean Error (%) of benzene by monitor for 12-km Western U.S. domain, Fall 2005.

O. Seasonal 1,3-Butadiene Performance

Table O-1 presents the seasonal 1.3-butadiene performance statistics. 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 O-1 – O-16). In general, the model predictions show moderate to large under-predictions for all Eastern and Western sites during all the seasons (NMB values range from -29% to -90%). Performance of 1,3-butadiene shows the largest under estimations in the areas of the Southeast and Central U.S. Likewise, the error results are large ranging from approximately 50% to 100%. These biases and errors reveal the underlying issues in the HAPs data (i.e., uncertainties in monitoring methods; limited measurements in time/space, proportionality issues between measurements and model predictions, emissions and science uncertainty issues, as well as boundary condition estimates).

Table O-1. CMAQ 2005 seasonal model performance statistics for 1,3-butadiene.

CMAQ 2005 1,3-Butadiene		No. of Obs.	NMB (%)	NME (%)	FB (%)	FE (%)
Winter	12-km EUS	2028	-69.8	84.9	-26.0	88.3
	12-km WUS	501	-55.3	87.6	-30.7	100.7
	Northeast	453	-32.0	53.1	-32.5	60.0
	Midwest	133	-34.9	70.5	-2.6	64.5
	Southeast	313	-78.4	80.4	-92.9	100.1
	Central	1045	-65.2	89.0	6.7	92.4
	West	280	-39.9	83.2	-42.7	95.2
Spring	12-km EUS	1963	-80.3	88.8	-52.1	93.6
	12-km WUS	491	-36.5	79.4	-26.5	85.6
	Northeast	446	-42.7	52.6	-56.0	69.9
	Midwest	105	-66.6	75.3	-65.3	93.2
	Southeast	294	-83.8	84.4	-108.1	111.0
	Central	1011	-67.8	88.1	-17.8	88.4
	West	281	-29.4	75.3	-33.8	81.0
Summer	12-km EUS	2003	-79.1	86.7	-63.1	93.8
	12-km WUS	482	-47.9	72.6	-40.2	86.0
	Northeast	489	-47.8	55.7	-66.4	77.0
	Midwest	122	-94.5	95.3	-73.6	89.9
	Southeast	279	-90.6	91.0	-122.1	125.3
	Central	1059	-71.8	85.0	-39.5	90.0
	West	246	-42.1	65.5	-46.7	78.0
Fall	12-km EUS	2108	-69.3	81.1	-56.2	90.6
	12-km WUS	502	-57.0	80.3	-40.6	94.3
	Northeast	514	-49.1	60.7	-62.4	77.1
	Midwest	156	-62.0	70.3	-56.1	82.9
	Southeast	340	-87.7	88.8	-103.7	111.1
	Central	1027	-60.3	80.5	-29.2	86.0
	West	275	-47.9	76.7	-45.0	86.3

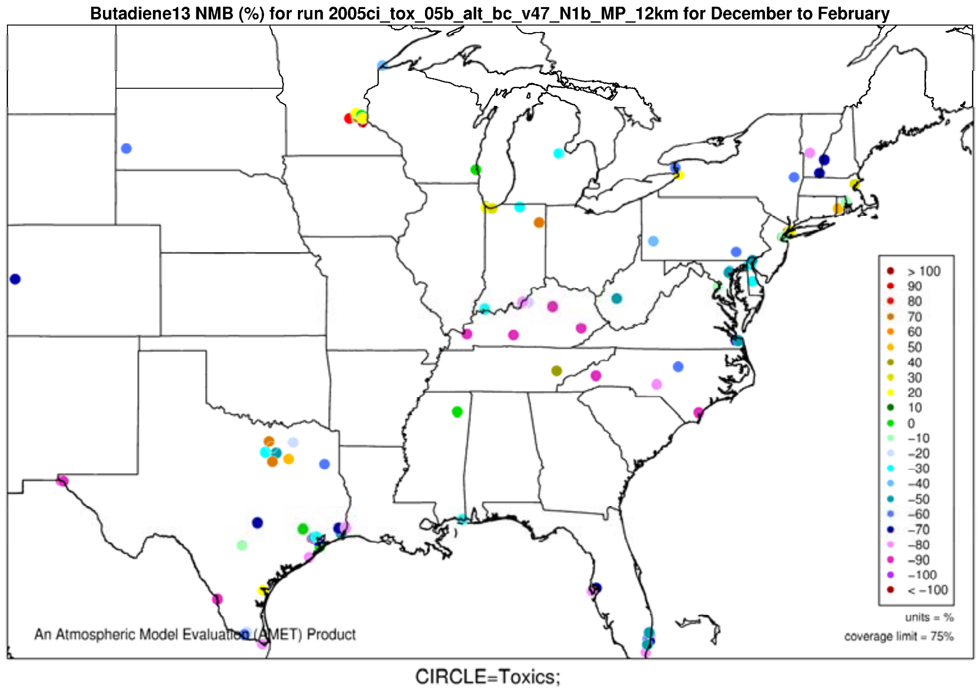


Figure O-1. Normalized Mean Bias (%) of 1,3-butadiene by monitor for 12-km Eastern U.S. domain, Winter 2005.

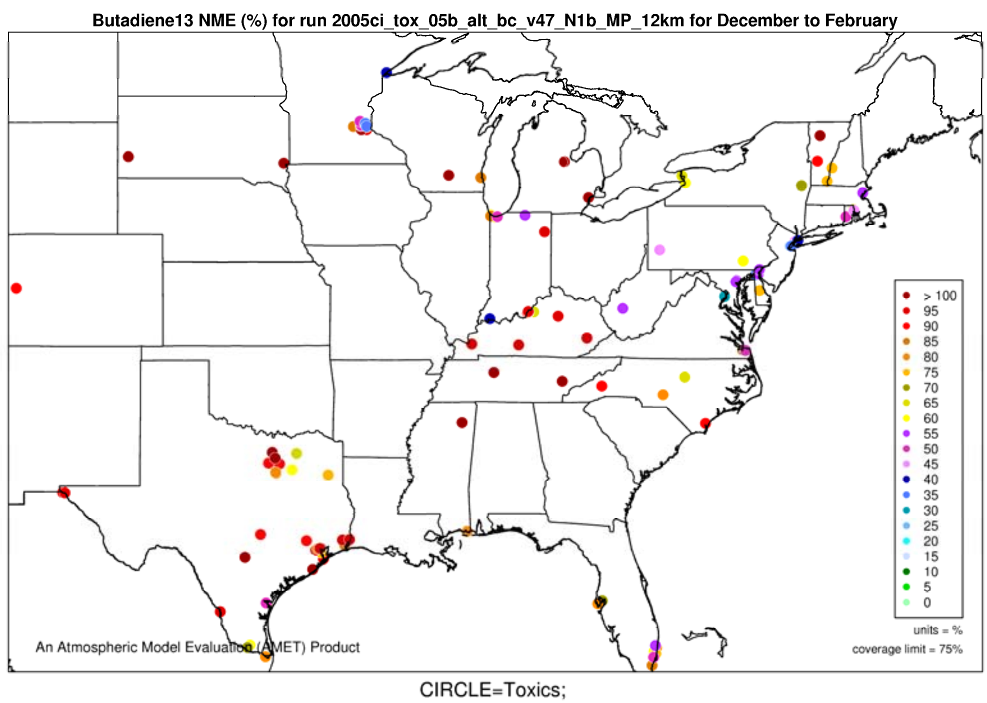


Figure O-2. Normalized Mean Error (%) of 1,3-butadiene by monitor for 12-km Eastern U.S. domain, Winter 2005.

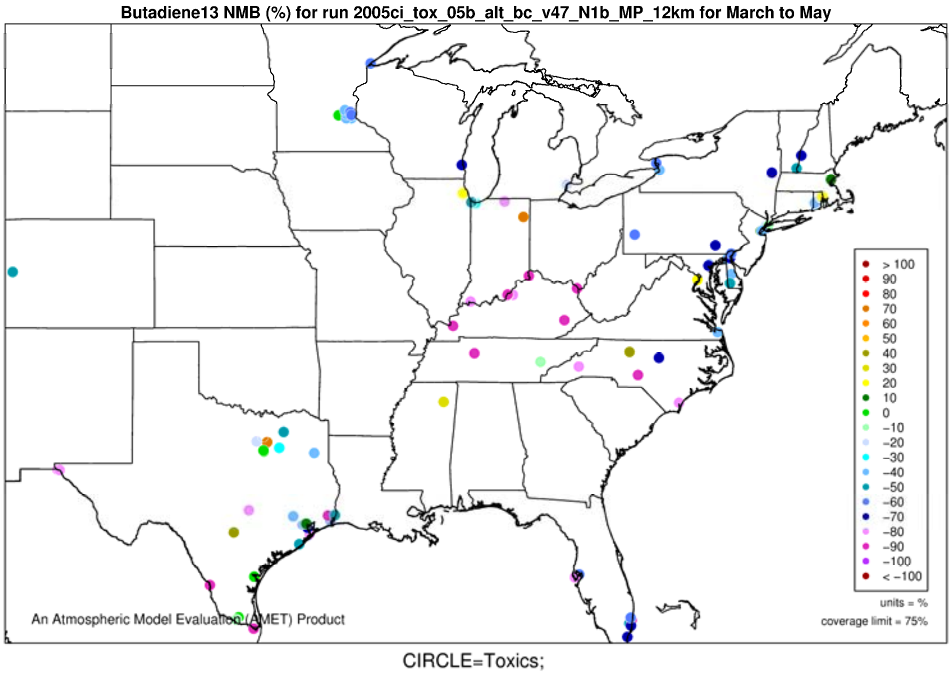


Figure O-3. Normalized Mean Bias (%) of 1,3-butadiene by monitor for 12-km Eastern U.S. domain, Spring 2005.

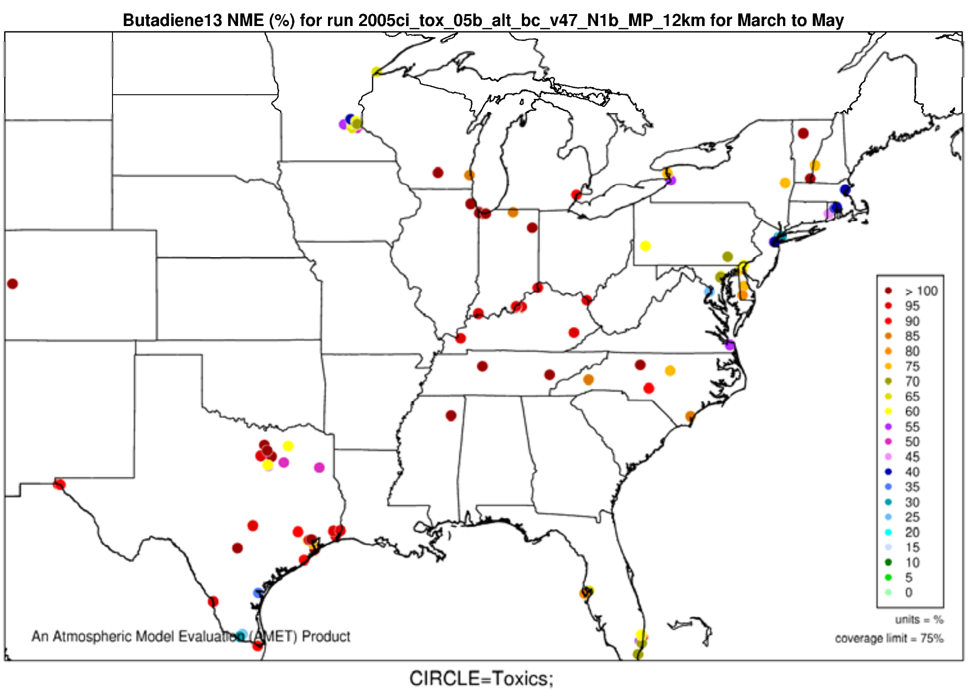


Figure O-4. Normalized Mean Error (%) of 1,3-butadiene by monitor for 12-km Eastern U.S. domain, Spring 2005.

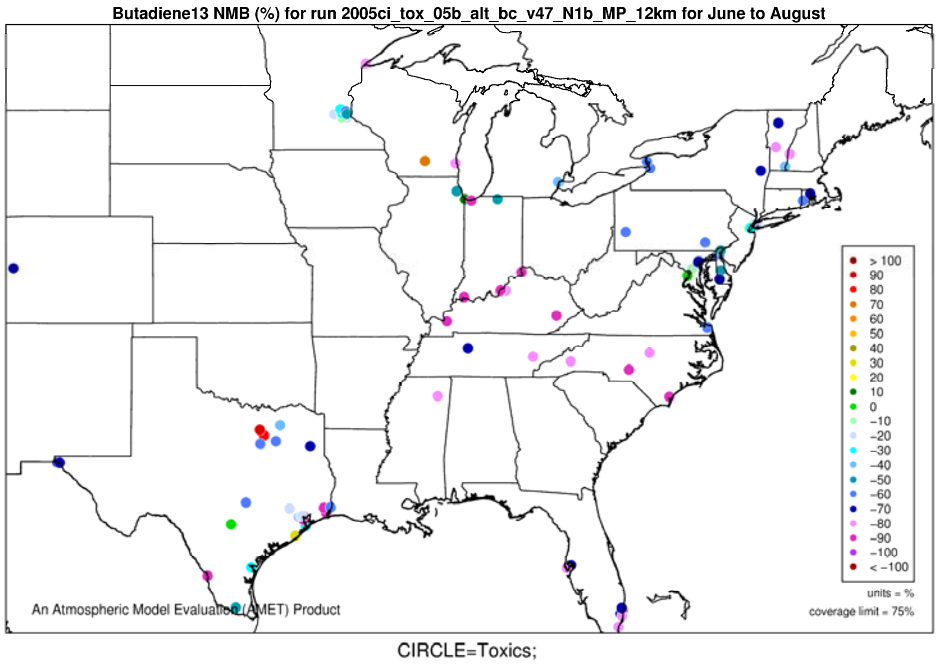


Figure O-5. Normalized Mean Bias (%) of 1,3-butadiene by monitor for 12-km Eastern U.S. domain, Summer 2005.

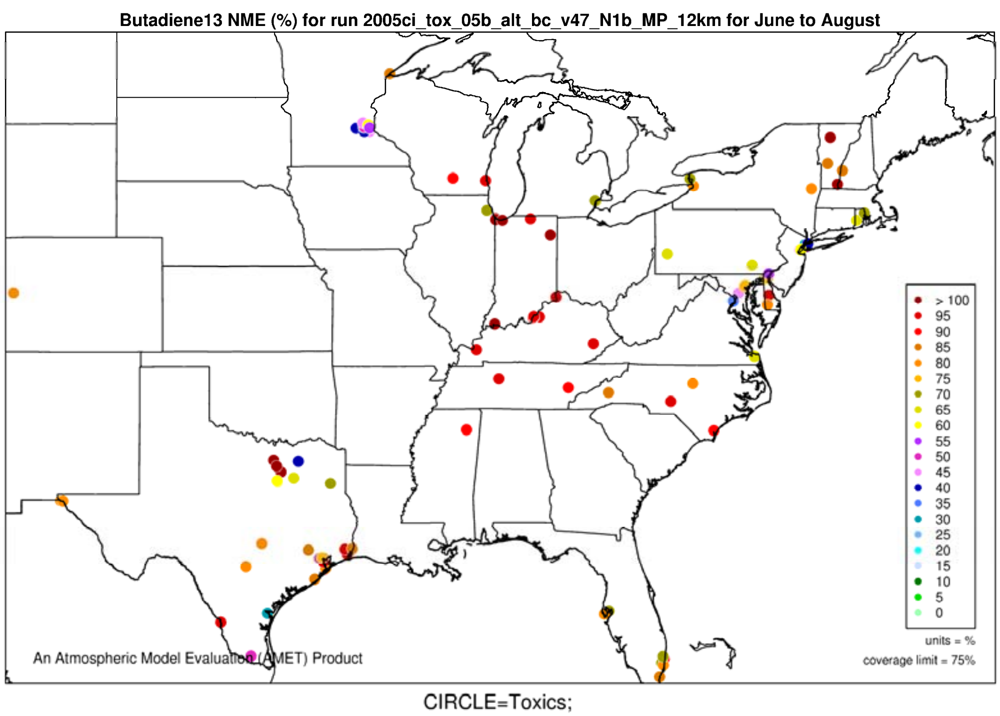


Figure O-6. Normalized Mean Error (%) of 1,3-butadiene by monitor for 12-km Eastern U.S. domain, Summer 2005.

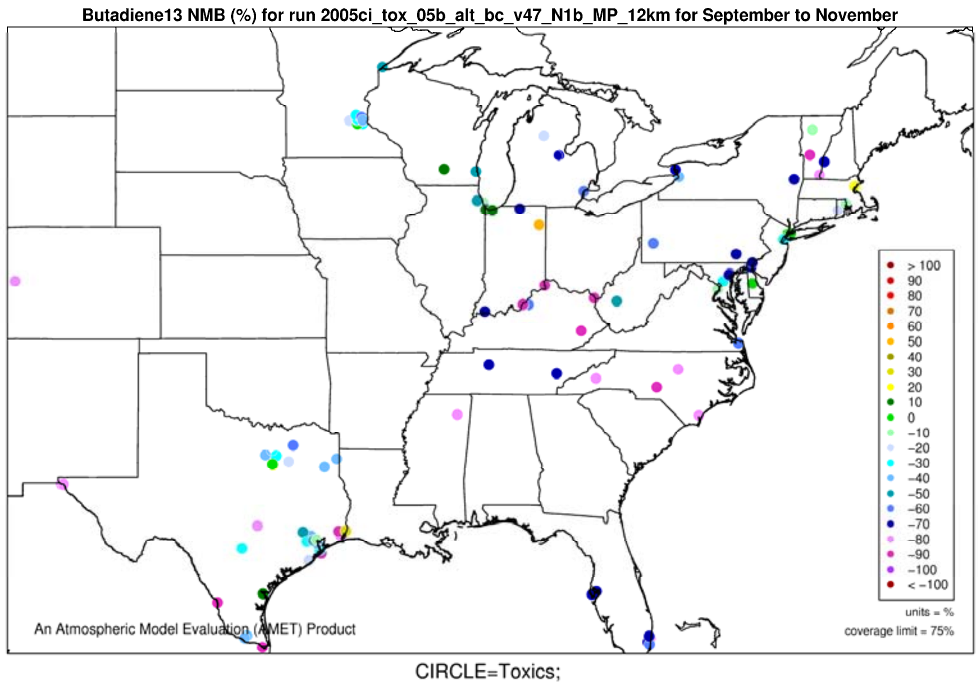


Figure O-7. Normalized Mean Bias (%) of 1,3-butadiene by monitor for 12-km Eastern U.S. domain, Fall 2005.

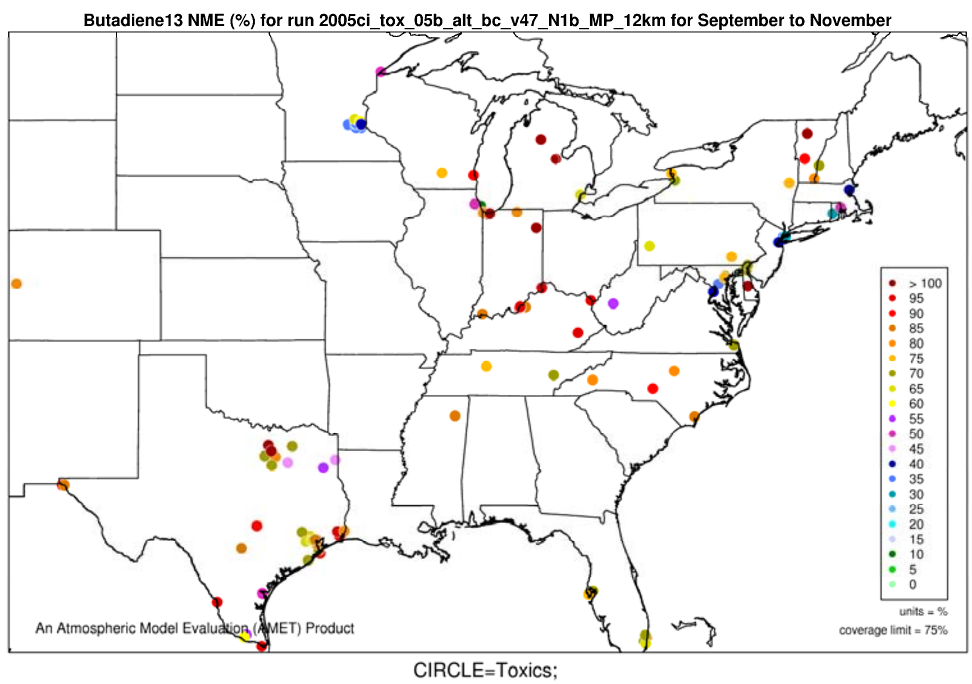


Figure O-8. Normalized Mean Error (%) of 1,3-butadiene by monitor for 12-km Eastern U.S. domain, Fall 2005.

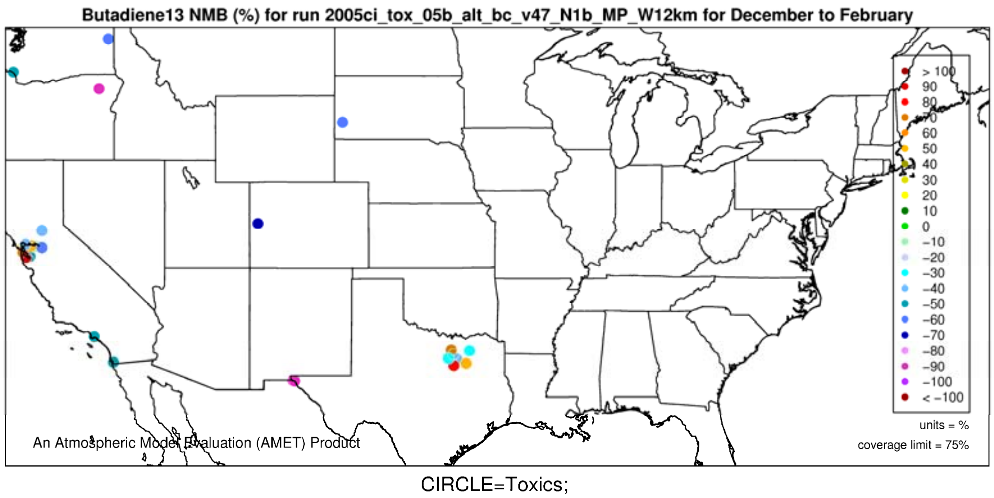


Figure O-9. Normalized Mean Bias (%) of 1,3-butadiene by monitor for 12-km Eastern U.S. domain, Winter 2005.

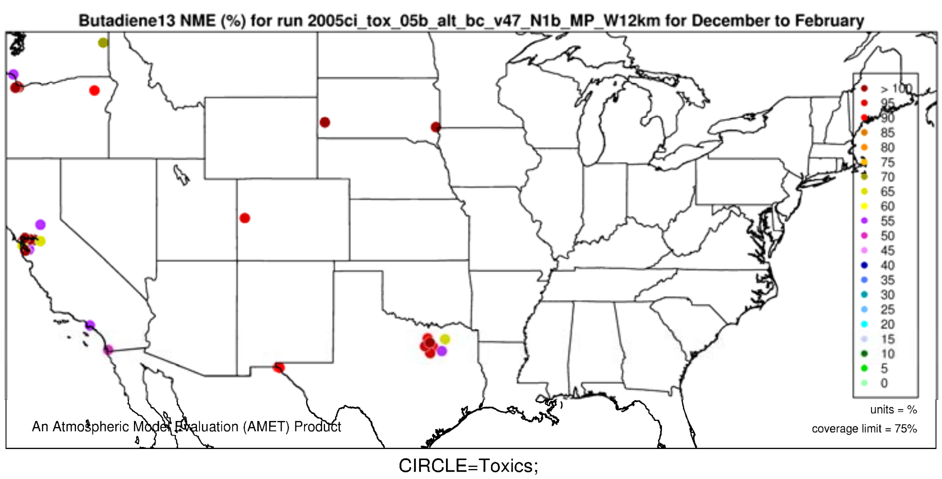


Figure O-10. Normalized Mean Error (%) of 1,3-butadiene by monitor for 12-km Western U.S. domain, Winter 2005.

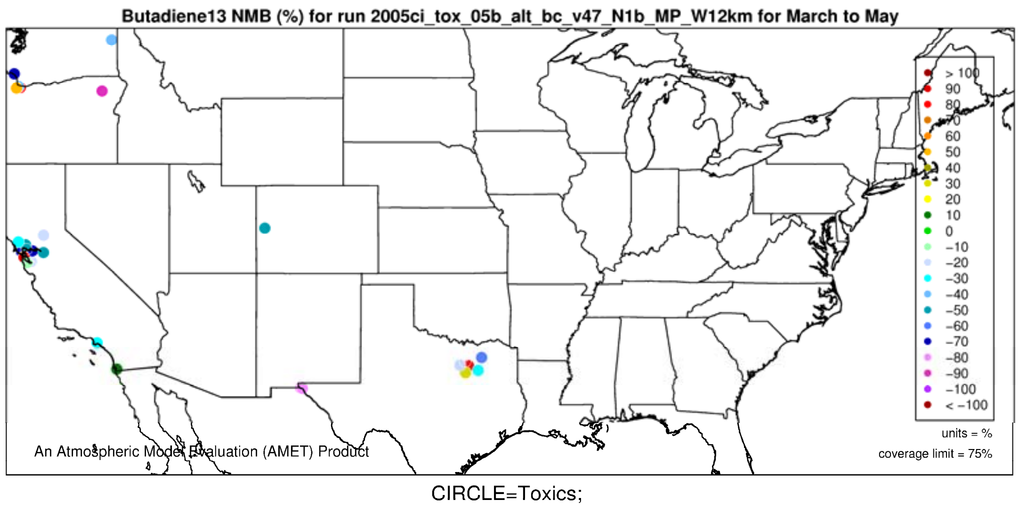


Figure O-11. Normalized Mean Bias (%) of 1,3-butadiene by monitor for 12-km Western U.S. domain, Spring 2005.

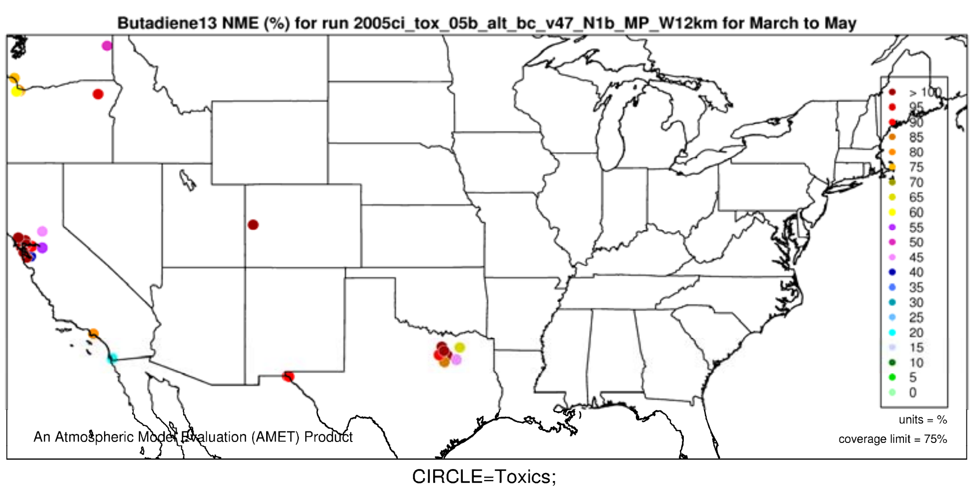
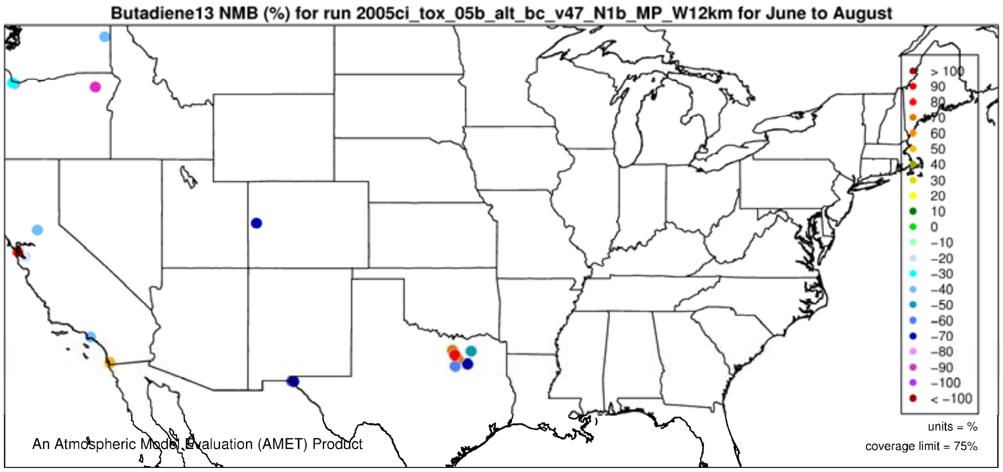
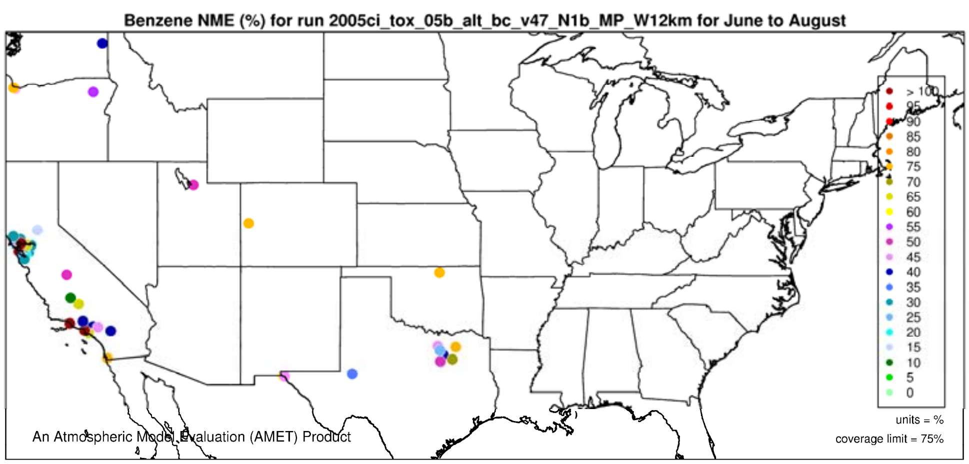


Figure O-12. Normalized Mean Error (%) of 1,3-butadiene by monitor for 12-km Western U.S. domain, Spring 2005.



CIRCLE=Toxics;

Figure O-13. Normalized Mean Bias (%) of 1,3-butadiene by monitor for 12-km Western U.S. domain, Summer 2005.



CIRCLE=Toxics;

Figure O-14. Normalized Mean Error (%) of 1,3-butadiene by monitor for 12-km Western U.S. domain, Summer 2005.

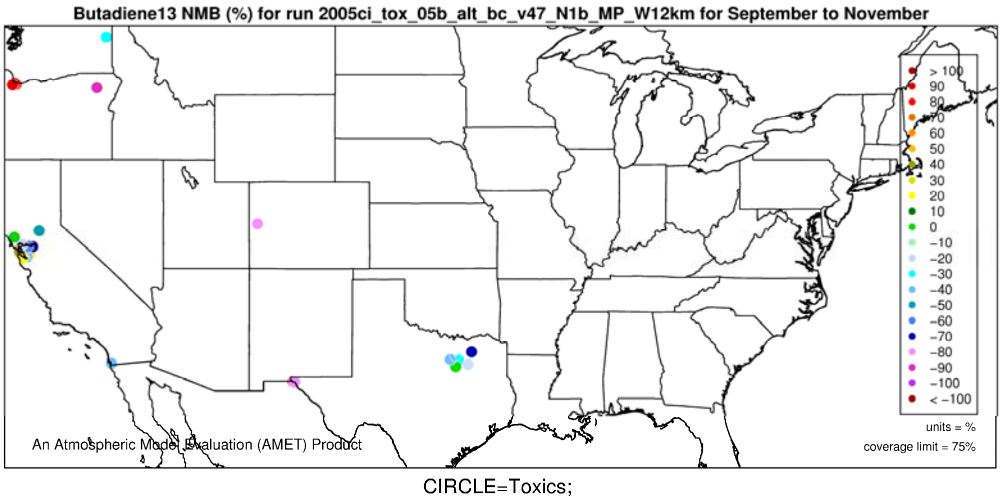


Figure O-15. Normalized Mean Bias (%) of 1,3-butadiene by monitor for 12-km Western U.S. domain, Fall 2005.

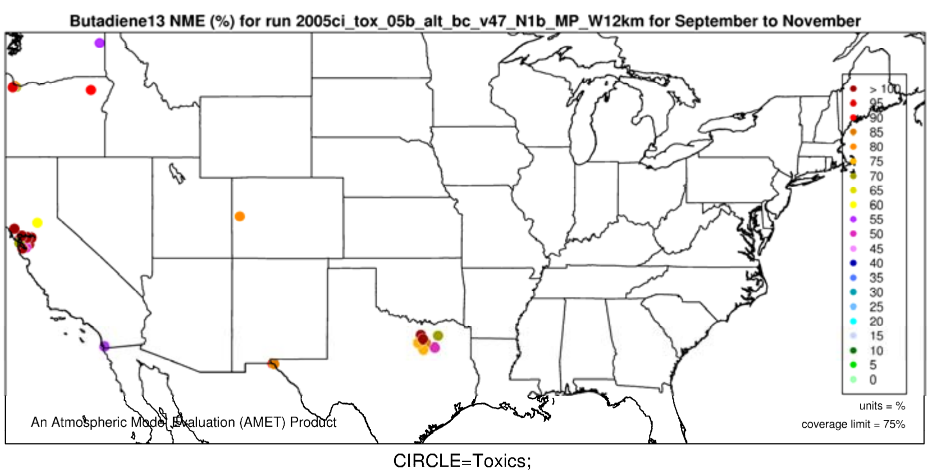


Figure O-16. Normalized Mean Error (%) of 1,3-butadiene by monitor for 12-km Western U.S. domain, Fall 2005.

P. Seasonal Acrolein Performance

Seasonal acrolein performance statistics are provided in Table P-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 P-1 – P-16). The model predictions generally show large under-predictions for all Eastern and Western sites (NMB values range from -85% to -97%). Acrolein performance in the EUS and WUS shows the similar under estimations during each season. These biases and errors reflect sampling artifacts among each monitoring network mentioned above.

Table P-1. CMAQ 2005 seasonal model performance statistics for acrolein.

CMAQ 2005 Acrolein		No. of Obs.	NMB (%)	NME (%)	FB (%)	FE (%)
Winter	12-km EUS	423	-91.9	92.7	-123.1	133.8
	12-km WUS	195	-93.7	93.7	-160.5	162.1
	Northeast	216	-85.6	87.2	-108.4	119.7
	Midwest	n/a	n/a	n/a	n/a	n/a
	Southeast	80	-96.6	96.6	-165.9	165.9
	Central	n/a	n/a	n/a	n/a	n/a
	West	153	-94.0	94.0	-169.1	169.1
Spring	12-km EUS	298	-86.3	87.3	-118.2	128.0
	12-km WUS	190	-94.7	94.7	-167.1	167.9
	Northeast	180	-87.7	88.7	-121.3	129.2
	Midwest	n/a	n/a	n/a	n/a	n/a
	Southeast	25	-76.7	76.9	-107.4	108.1
	Central	n/a	n/a	n/a	n/a	n/a
	West	143	-95.1	95.1	-177.3	177.3
Summer	12-km EUS	447	-95.8	96.5	-132.9	151.5
	12-km WUS	187	-96.4	96.4	-171.7	177.3
	Northeast	251	-93.0	94.8	-119.1	147.9
	Midwest	n/a	n/a	n/a	n/a	n/a
	Southeast	52	-93.9	93.9	-142.1	142.2
	Central	n/a	n/a	n/a	n/a	n/a
	West	n/a	n/a	n/a	n/a	n/a
Fall	12-km EUS	492	-96.3	96.4	-144.8	149.5
	12-km WUS	211	-96.8	96.8	-172.8	174.3
	Northeast	203	-92.9	93.1	-134.5	137.3
	Midwest	29	-98.3	98.5	-145.4	153.5
	Southeast	121	-98.1	98.2	-166.5	167.5
	Central	n/a	n/a	n/a	n/a	n/a
	West	160	-97.0	97.0	-180.9	180.9

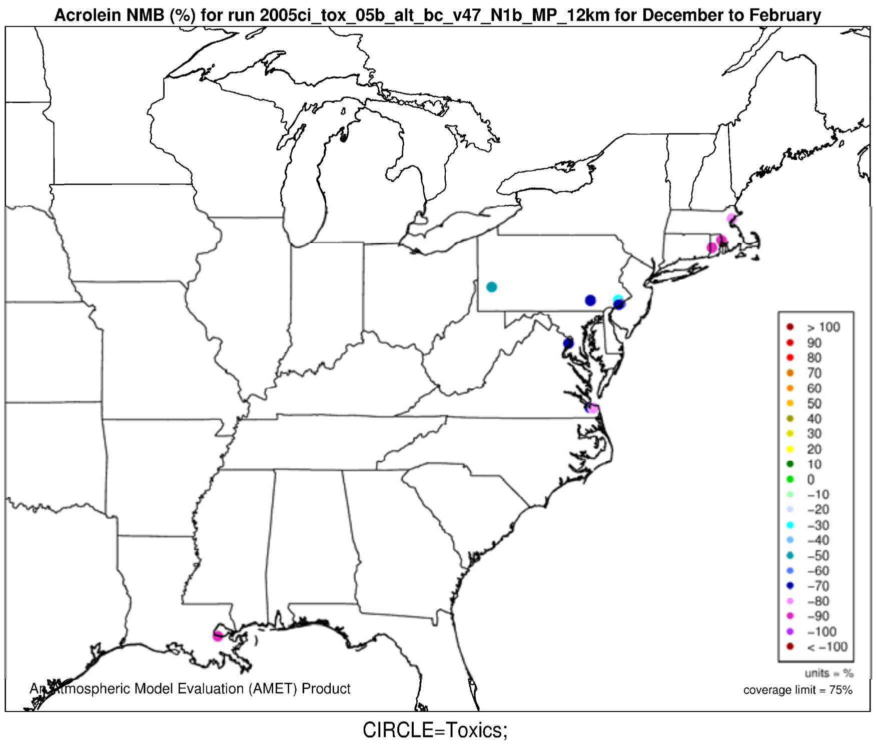


Figure P-1. Normalized Mean Bias (%) of acrolein by monitor for 12-km Eastern U.S. domain, Winter 2005.

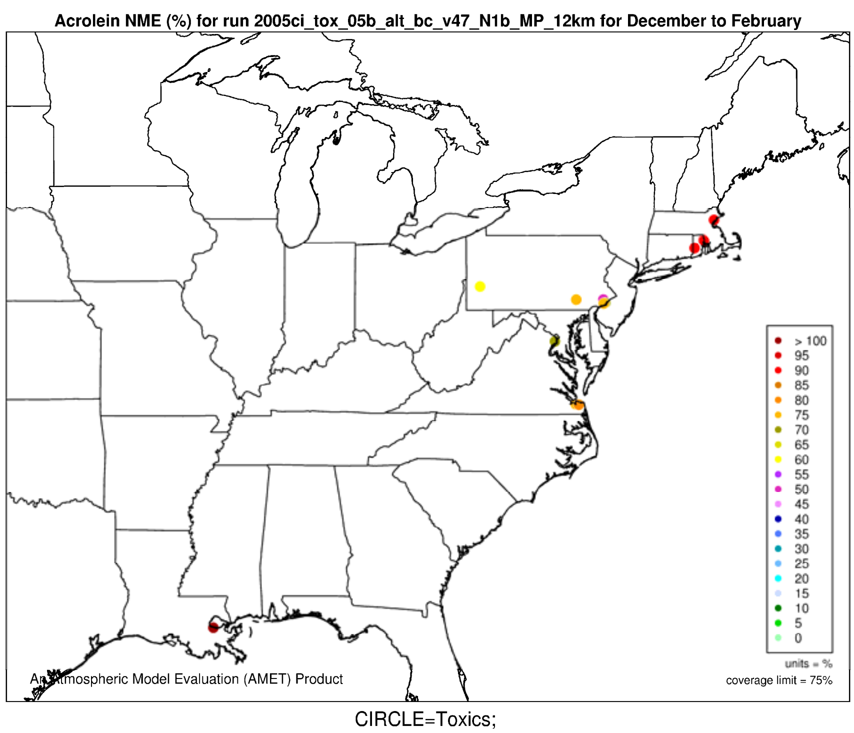


Figure P-2. Normalized Mean Error (%) of acrolein by monitor for 12-km Eastern U.S. domain, Winter 2005.

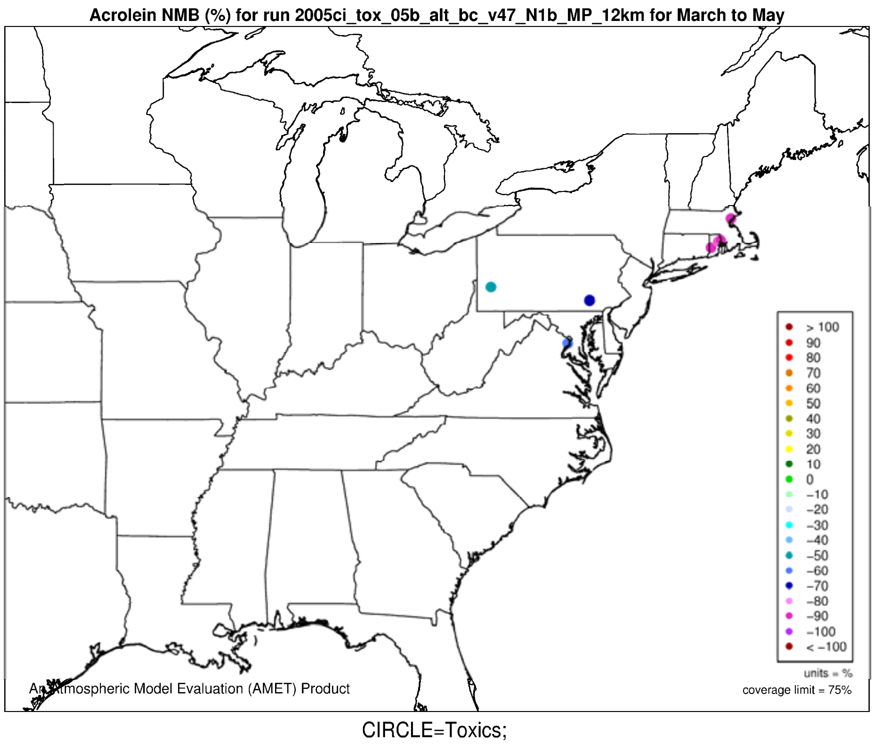


Figure P-3. Normalized Mean Bias (%) of acrolein by monitor for 12-km Eastern U.S. domain, Spring 2005.

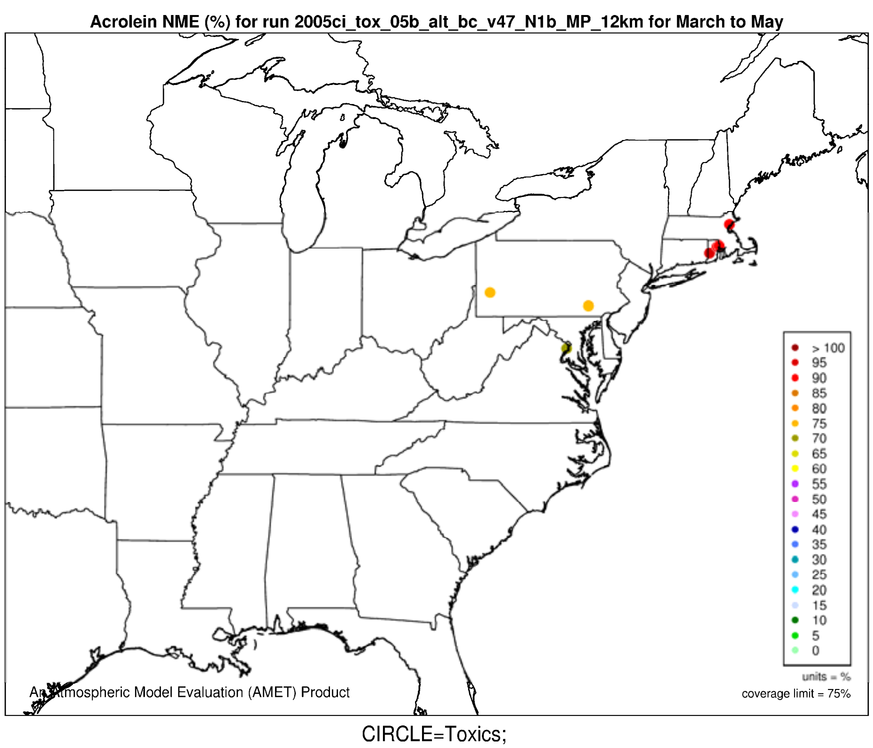


Figure P-4. Normalized Mean Error (%) of acrolein by monitor for 12-km Eastern U.S. domain, Spring 2005.

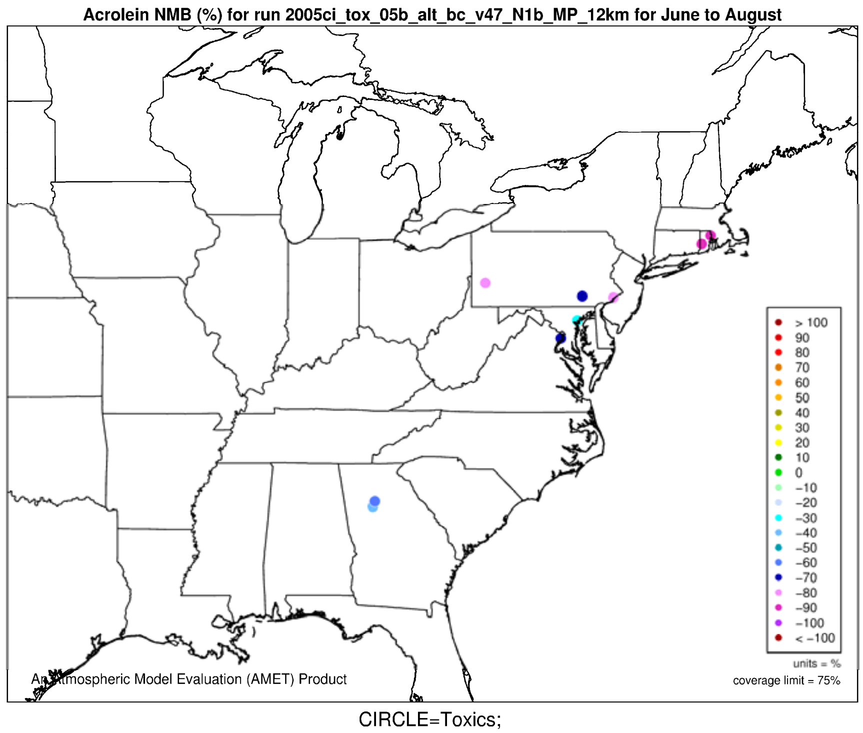


Figure P-5. Normalized Mean Bias (%) of acrolein by monitor for 12-km Eastern U.S. domain, Summer 2005.

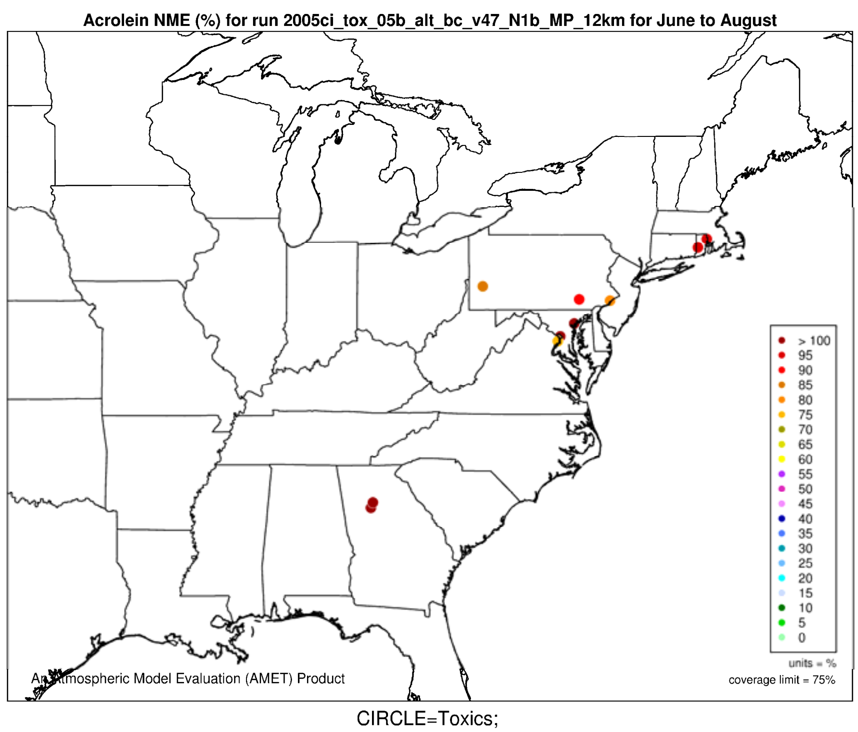


Figure P-6. Normalized Mean Error (%) of acrolein by monitor for 12-km Eastern U.S. domain, Summer 2005.

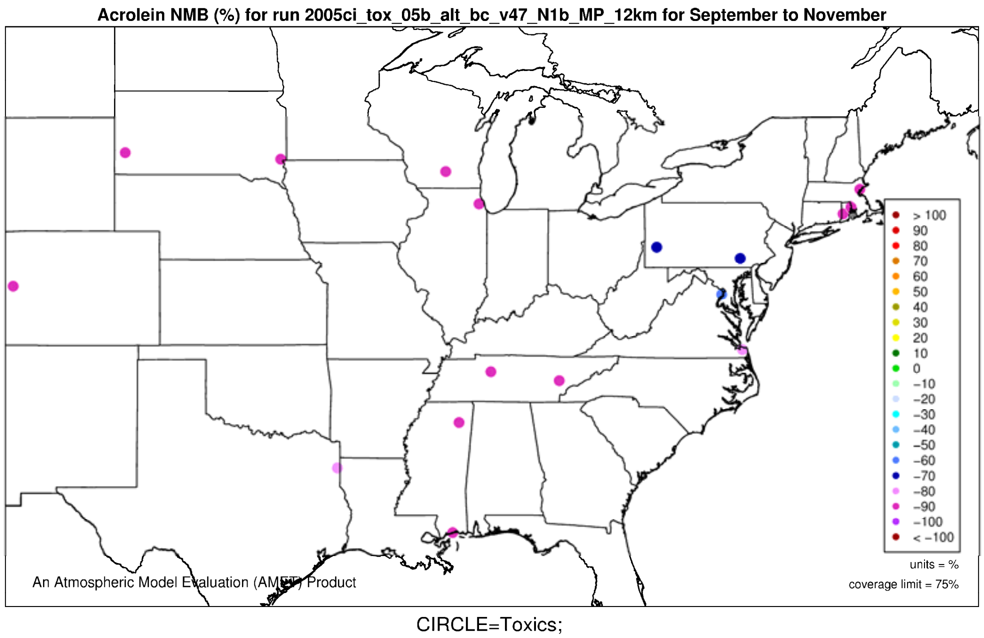


Figure P-7. Normalized Mean Bias (%) of acrolein by monitor for 12-km Eastern U.S. domain, Fall 2005.

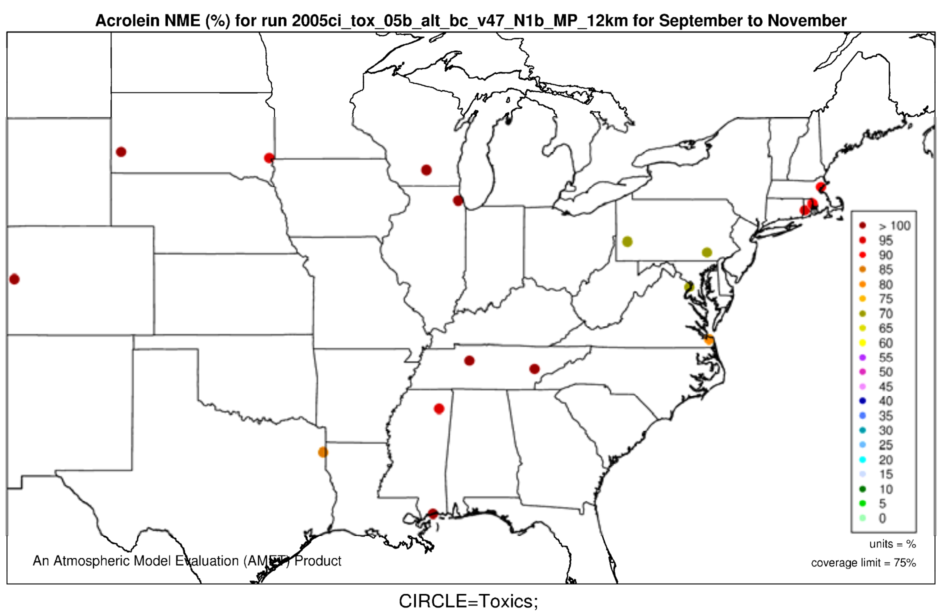


Figure P-8. Normalized Mean Error (%) of acrolein by monitor for 12-km Eastern U.S. domain, Fall 2005.

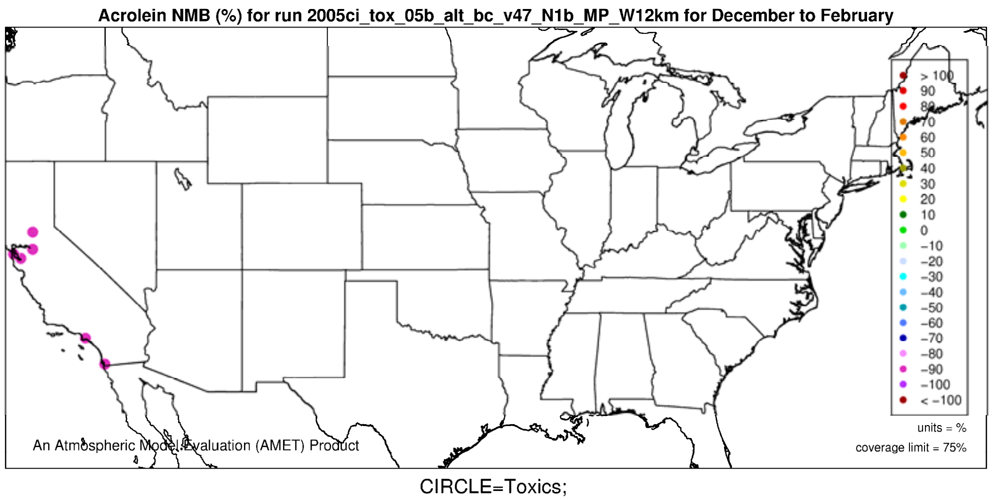


Figure P-9. Normalized Mean Bias (%) of acrolein by monitor for 12-km Eastern U.S. domain, Winter 2005.

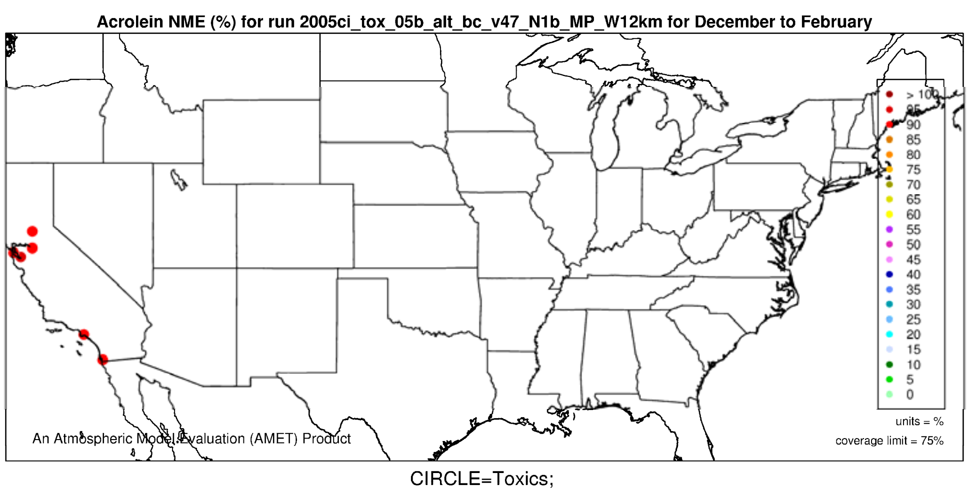


Figure P-10. Normalized Mean Error (%) of acrolein by monitor for 12-km Western U.S. domain, Winter 2005.

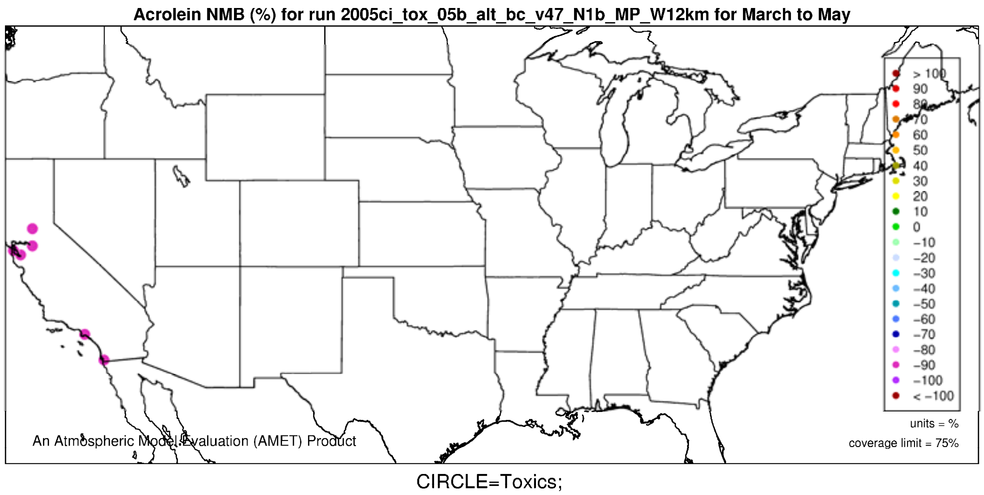


Figure P-11. Normalized Mean Bias (%) of acrolein by monitor for 12-km Western U.S. domain, Spring 2005.

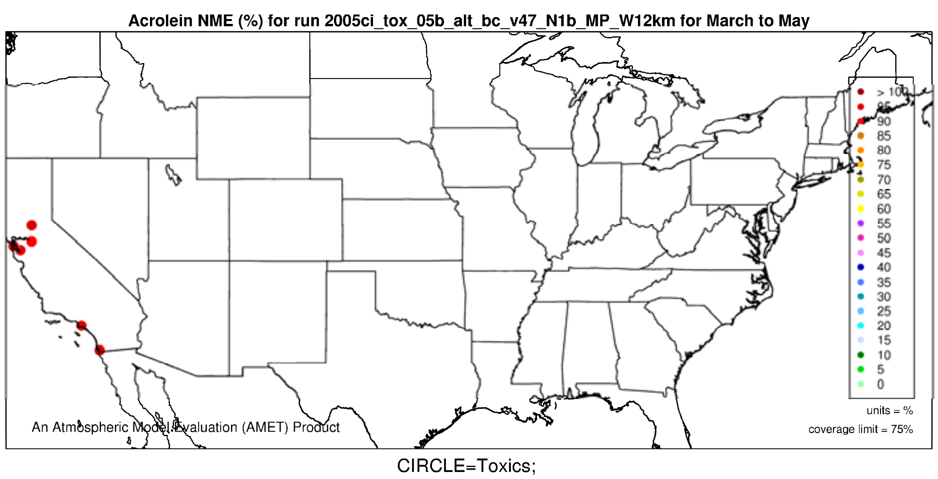


Figure P-12. Normalized Mean Error (%) of acrolein by monitor for 12-km Western U.S. domain, Spring 2005.

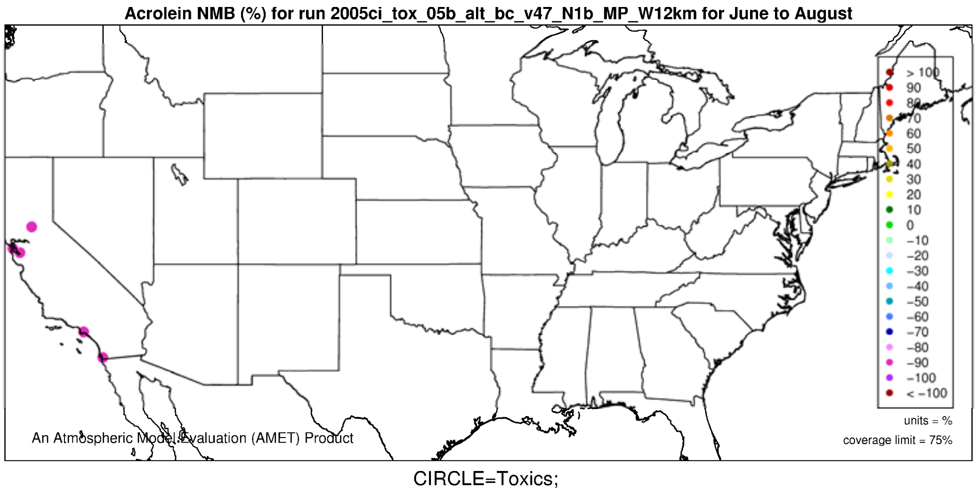


Figure P-13. Normalized Mean Bias (%) of acrolein by monitor for 12-km Western U.S. domain, Summer 2005.

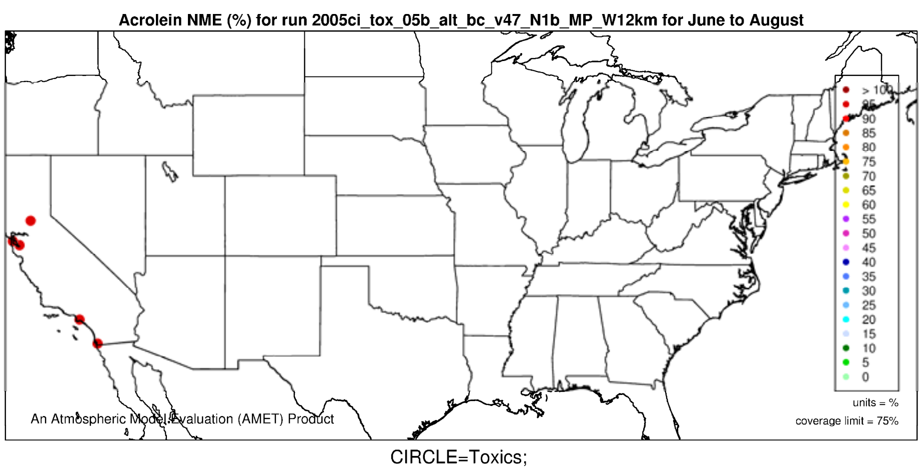


Figure P-14. Normalized Mean Error (%) of acrolein by monitor for 12-km Western U.S. domain, Summer 2005.

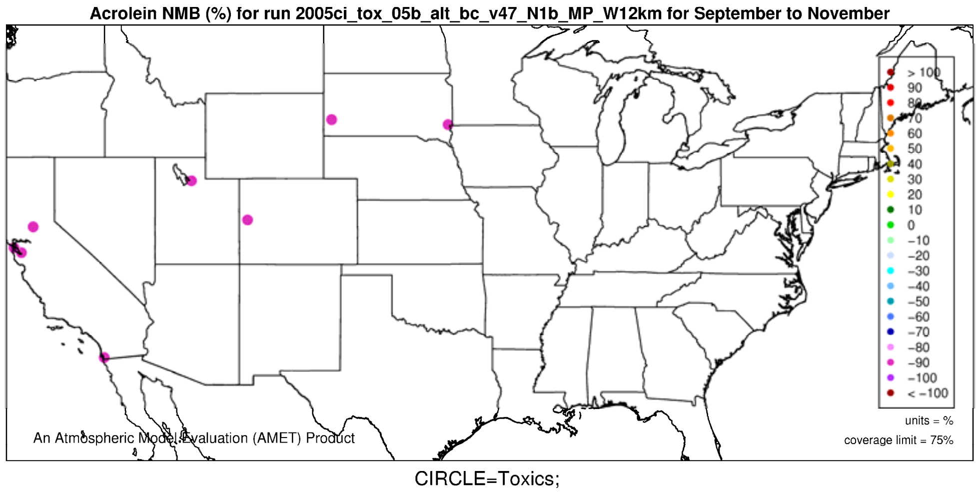


Figure P-15. Normalized Mean Bias (%) of acrolein by monitor for 12-km Western U.S. domain, Fall 2005.

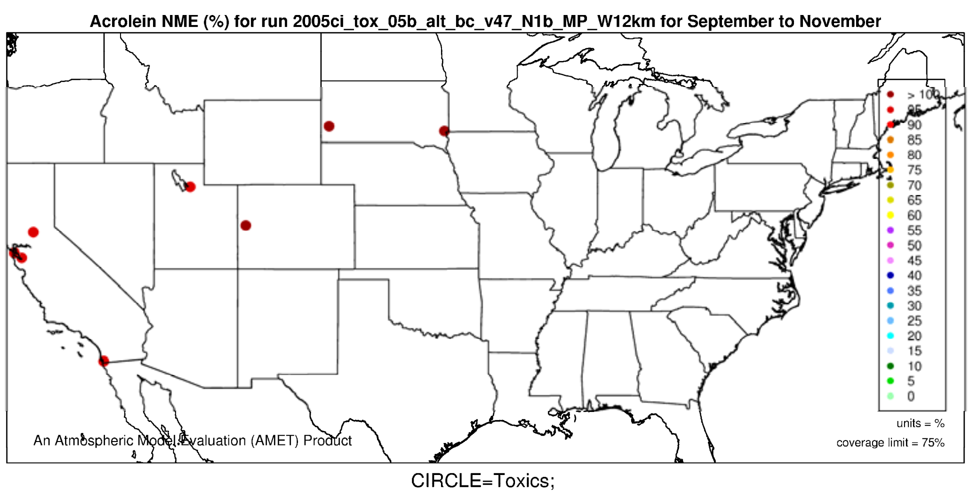


Figure P-16. Normalized Mean Error (%) of acrolein by monitor for 12-km Western U.S. domain, Fall 2005.

Q. Annual Nitrate and Sulfate Deposition Performance

Annual nitrate and sulfate deposition performance statistics are provided in Table Q-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 Q-1 – Q-8). 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 o observation comparison.

Table Q-1. CMAQ 2005 seasonal model performance statistics for acrolein.

CMAQ 2005 Total Deposition		No. of Obs.	NMB (%)	NME (%)	FB (%)	FE (%)
Nitrate	12-km EUS	7381	-8.6	61.3	-5.1	54.2
	12-km WUS	2732	-16.3	68.4	-16.1	83.3
	Northeast	1658	1.0	57.4	-3.1	65.7
	Midwest	1391	-3.3	59.7	-2.0	67.5
	Southeast	1980	-3.7	63.8	-6.5	70.7
	Central	1229	-18.5	61.4	-17.6	78.6
	West	2400	-13.4	71.8	-15.4	84.1
Sulfate	12-km EUS	7381	6.2	66.5	4.7	75.3
	12-km WUS	2732	3.7	75.9	3.2	86.5
	Northeast	1658	11.3	63.7	16.0	67.2
	Midwest	1391	13.9	61.7	21.4	69.9
	Southeast	1980	7.4	71.0	6.0	73.8
	Central	1229	-9.9	64.4	-3.5	80.3
	West	2400	11.6	80.99	5.4	87.1

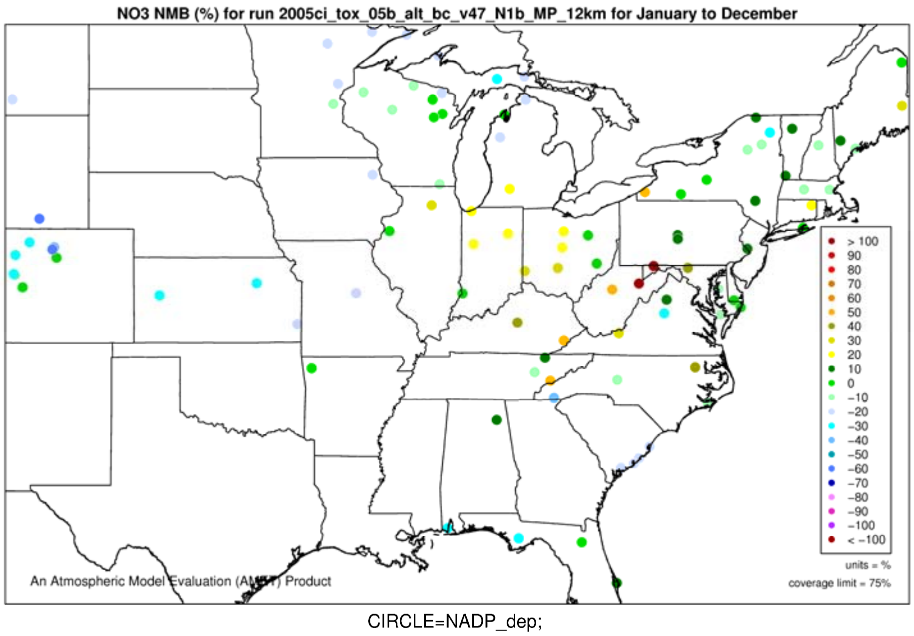


Figure Q-1. Normalized Mean Bias (%) of annual nitrate deposition by monitor for Eastern U.S., 2005.

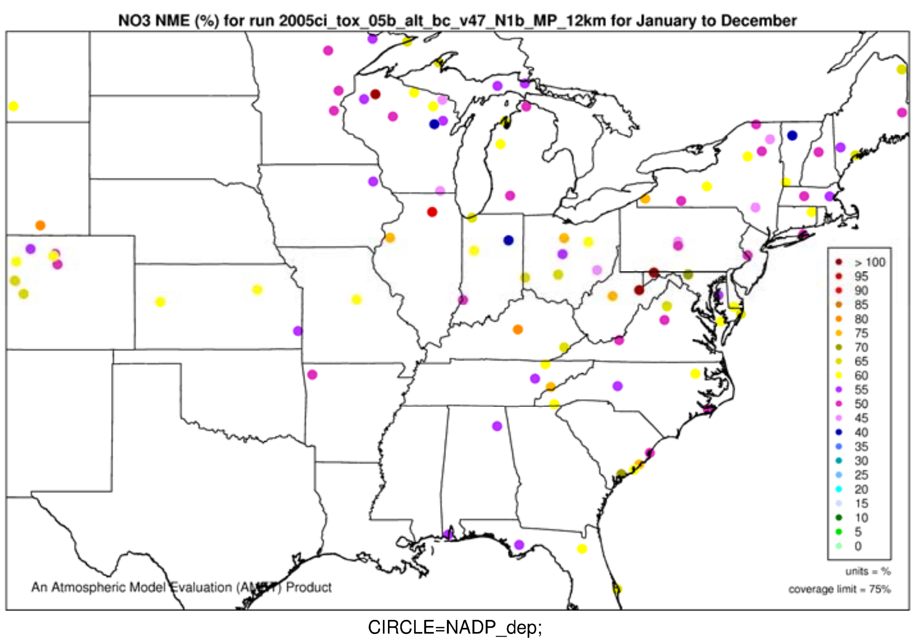


Figure Q-2. Normalized Mean Error (%) of annual nitrate by monitor for Eastern U.S., 2005.

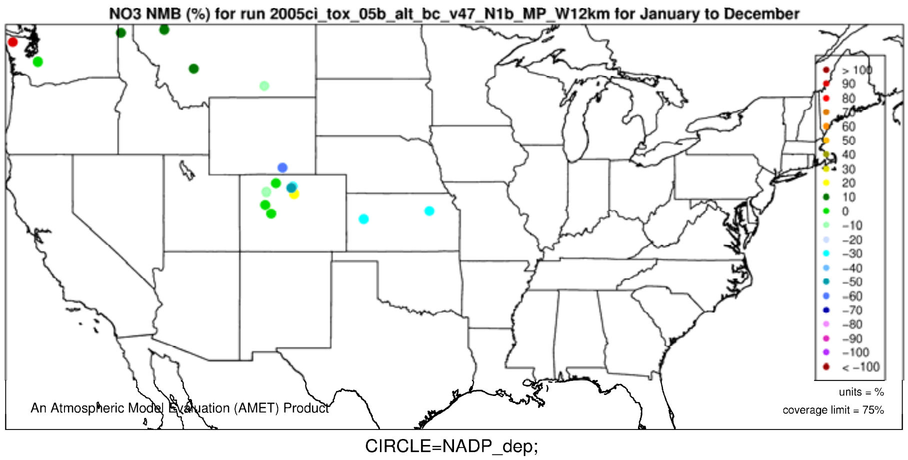


Figure Q-3. Normalized Mean Bias (%) of annual nitrate deposition by monitor for Western U.S., 2005.

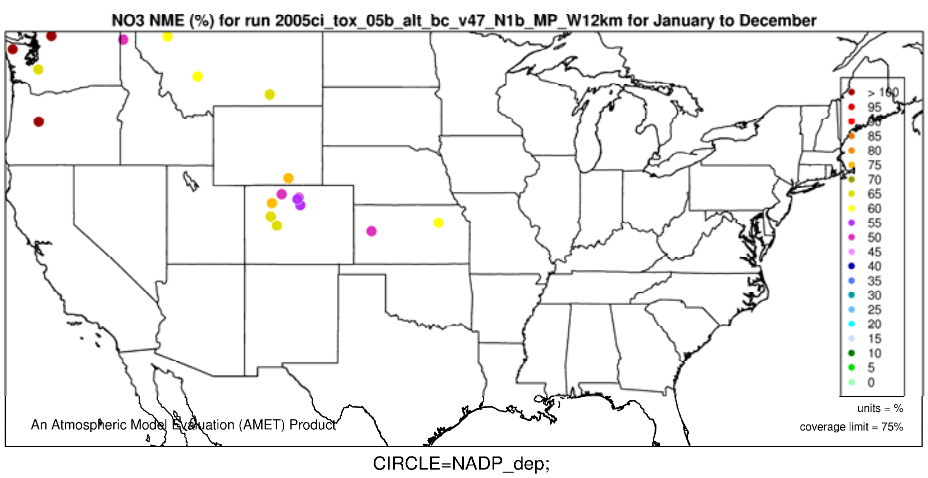


Figure Q-4. Normalized Mean Error (%) of annual nitrate deposition by monitor for Western U.S., 2005.

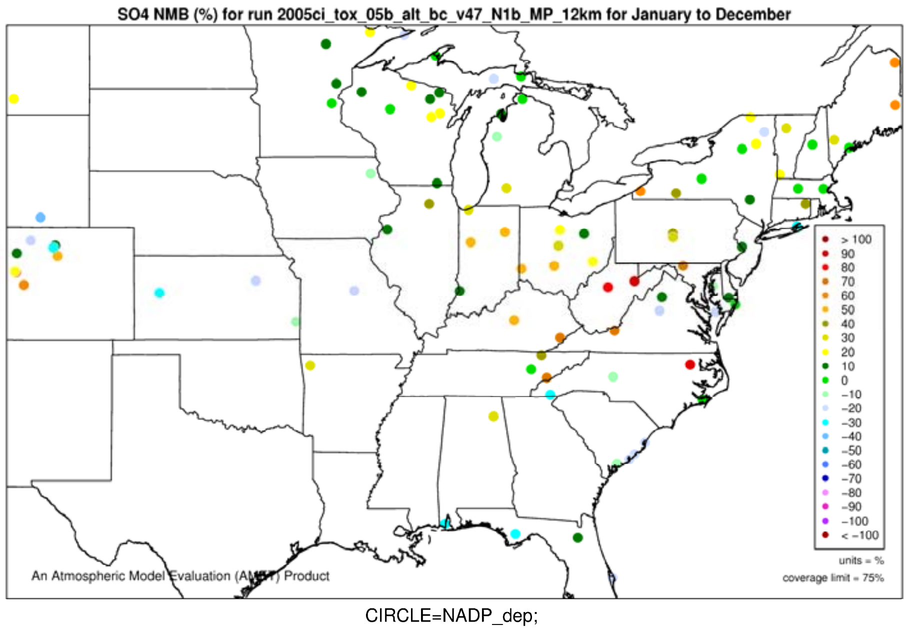


Figure Q-5. Normalized Mean Bias (%) of annual sulfate deposition by monitor for Eastern U.S., 2005.

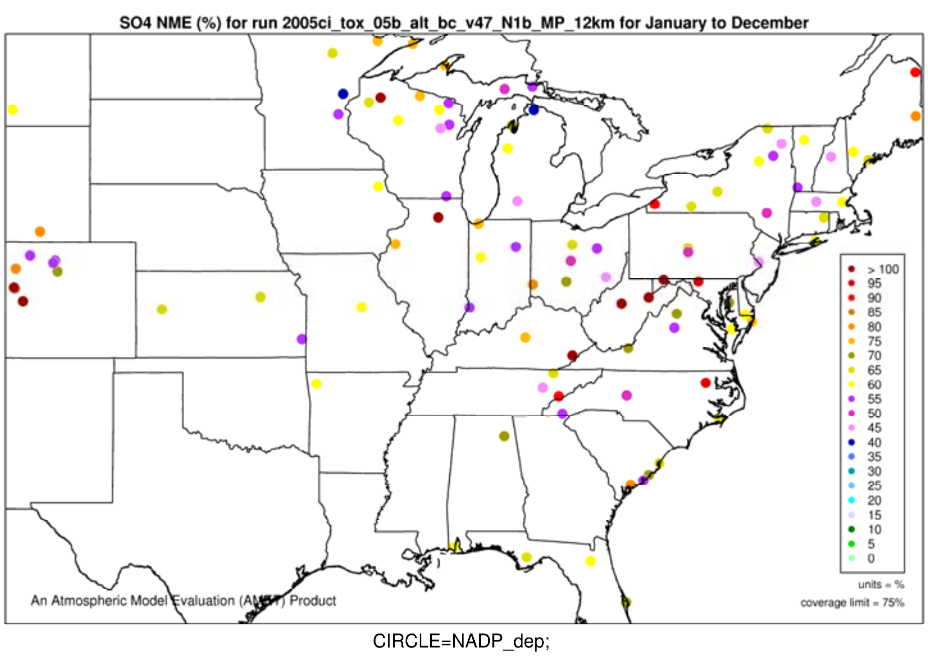


Figure Q-6. Normalized Mean Error (%) of annual sulfate deposition by monitor for Eastern U.S., 2005.

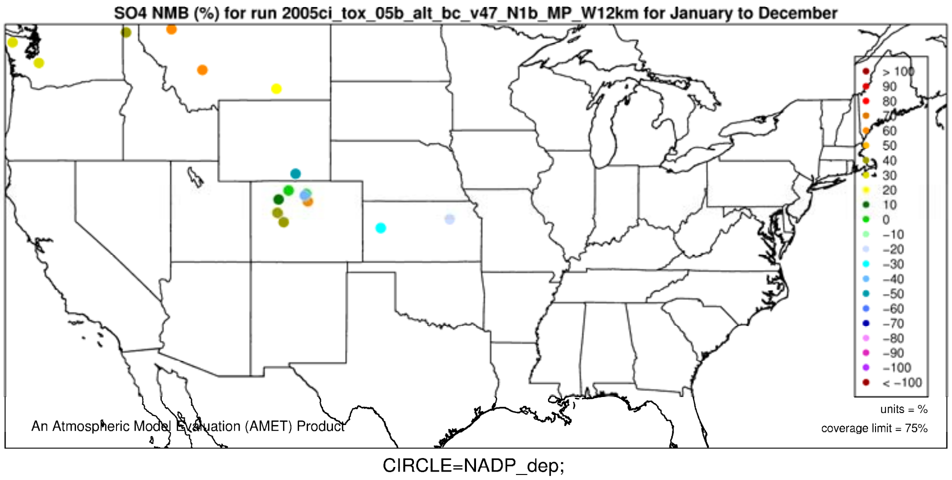


Figure Q-7. Normalized Mean Bias (%) of annual sulfate deposition by monitor for Western U.S., 2005.

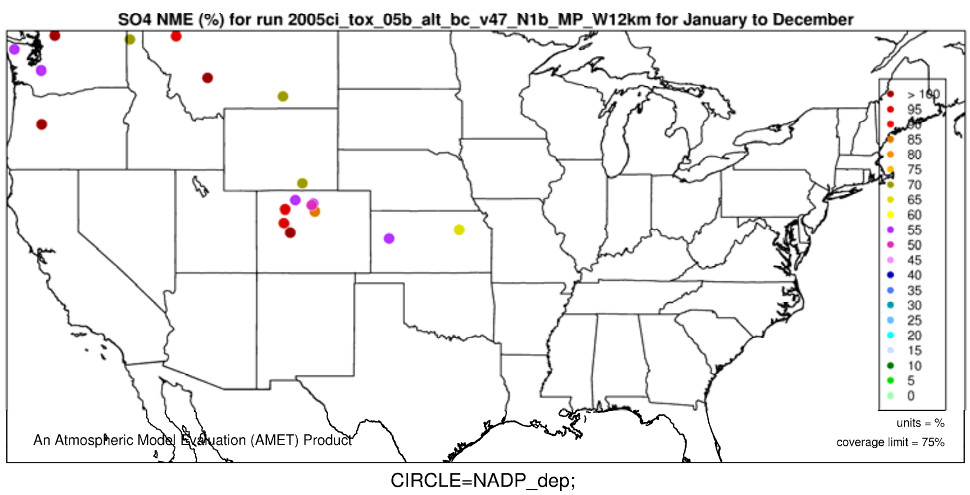


Figure Q-8. Normalized Mean Error (%) of annual sulfate deposition by monitor for Western U.S., 2005.

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