UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

OFFICE OF
AIR AND RADIATION

February 27, 2011

Memorandum

From: Jim DeMocker, US EPA/Office of Air and Radiation
To: 812 Second Prospective Study Files
Subject: Documentation of Second Prospective Study air quality modeling

The purpose of this memorandum to the files is to compile and describe the key elements of documentation for the Second Prospective Study air quality modeling and clarify which component of the documentation should be relied upon for each key aspect of the air quality modeling conducted for the study. This memorandum is necessary because certain elements of the air quality modeling work were revised following internal and external review. While the draft air quality modeling report produced in 2008 still provides the main documentation for the air quality modeling results obtained using the Community Multiscale Air Quality (CMAQ) model, adjustments were made subsequently to address two issues with the emissions inventories used as inputs to CMAQ. In addition, as part of the planned post-CMAQ processing of ambient concentration estimates, the grid cell data for fine particles were adjusted using the Modeled Attainment Test Software (MATS) procedure and information about the methods and results for this post-processing step are provided in documentation developed separately from, and subsequent to, the preparation of the 2008 draft report. Furthermore, a model performance evaluation for the CMAQ modeling was conducted following completion of the 2008 draft report, and the methods and results of this evaluation were documented in another separate technical memorandum. Consequently, there is no existing, single standalone report which provides integrated documentation of all aspects of the air quality modeling work and associated model evaluation and post-processing, and for practical reasons there are no plans to generate such an integrated report.

This memorandum is therefore intended to provide consolidated documentation of the input data, methods, and outputs from each major step in the air quality modeling conducted in support of the Second Prospective Study, including the post-CMAQ adjustments to emissions inventories and ambient concentration estimates. Implications of air quality modeling uncertainties, including those associated with the post-CMAQ adjustments, are described in the full integrated report for the overall study.

The remainder of this memorandum's main text lists each element of documentation and describes the specific aspects of the air quality modeling methods and results it documents. The elements of documentation themselves are provided as Attachments A, B, and C.

1. **Attachment A. Second Prospective Analysis of Air Quality in the U.S.: Air Quality Modeling.** This September 30, 2008 draft report can be relied upon as the final documentation for the following aspects of the Second Prospective Study air quality modeling analysis:
    a. Overall air quality modeling methodology.
    b. CMAQ model system, CMAQ model configuration, meteorological and other inputs, and post-processing and quality assurance procedures.
    c. Emissions inventory preparation conducted in support of the CMAQ model runs, including SMOKE processing.
    d. Final CMAQ modeling results for ozone.
    e. Final CMAQ modeling results for visibility.
    f. Final CMAQ modeling results for nitrogen and sulfur deposition.
    g. Initial, pre-adjustment CMAQ modeling results for fine particles. **NOTE: The fine particle results presented in Attachment A are superseded by the adjusted estimates described in Attachment C.**
    h. Air quality modeling system attributes and limitations which pertain for the CMAQ model runs.

2. **Attachment B. Evaluation of CMAQ Model Performance for the 812 Prospective II Study.** This November 24, 2009 memorandum documents the methodology and results of the CMAQ model performance evaluation using the Atmospheric Model Evaluation Tool (AMET).

3. **Attachment C. Description of the Adjustment to the Primary Particulate Matter Emissions Estimates and the Modeled Attainment Test Software Analysis (MATS) Procedure for the 812 Second Prospective Analysis.** This June 14, 2010 memorandum can be relied upon as the final documentation for the following aspects of the Second Prospective Study air quality modeling analysis:

    a. Methodologies and results of adjustments to the primary fine particle emissions inventories to reflect corrections to the area source and non-electric generating unit industrial point source inventories.
    b. Adjustments to the CMAQ ambient particle pollution estimates made subsequent to the emissions inventory adjustments.
    c. Methodology and results for the application of the MATS procedure to develop the final particulate matter concentration estimates used to estimate benefits.
    d. Stacked bar charts for select monitor locations which compare pre-adjustment CMAQ, post-adjustment CMAQ, MATS-adjusted, and monitored air quality. **NOTE: The fine particle results described in the set of technical memoranda included in Attachment C supersede the estimates described in Attachment A.**

# # #

3 attachments

Attachment A

Draft Report

SECOND PROSPECTIVE ANALYSIS OF AIR QUALITY IN THE U.S.: AIR QUALITY MODELING

08-099

30 September 2008

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Section I
Introduction

Section 812 of the Clean Air Act Amendments (CAAA) of 1990 requires the U.S. Environmental Protection Agency (EPA) to periodically assess the effects of the Clean Air Act (CAA) on air quality, the environment, public health, and the economy. This type of analysis requires the estimation of future-year emissions levels and associated air quality related values for scenarios reflecting compliance with the CAA, as well as scenarios that do not account for the effects of programs associated with the CAA in establishing the future-year estimates.

Prior retrospective and prospective analyses of the benefits and costs of the CAA conducted by EPA have used a variety of air quality modeling and analysis methods to estimate the effects of implementing the CAA measures on future-year ambient air quality. This report summarizes the methods and results of the emissions processing and air quality modeling that were conducted to support the development of the second prospective CAA Section 812 benefit-cost study.

This analysis is the first Section 812 prospective analysis to use an integrated modeling system, the Community Multiscale Air Quality (CMAQ) model, to simulate national and regional-scale pollutant concentrations and deposition. The CMAQ model (Byun and Ching, 1999) is a state-of-the-science, regional air quality modeling system that is designed to simulate the physical and chemical processes that govern the formation, transport, and deposition of gaseous and particulate species in the atmosphere.

The CMAQ model was applied for seven core CAAA scenarios that include four different years that span a 30-year period – 1990, 2000, 2010 and 2020. Scenarios that incorporate the emission reductions associated with the CAA are referred to as with-CAAA while those that do not are referred to as without-CAAA. The scenarios include:

<u>Retrospective Base-Year Scenario</u>
1990 without-CAAA

<u>Base- and Future-Year Scenarios without 1990 CAAA Controls</u>
2000 without-CAAA
2010 without-CAAA
2020 without-CAAA

<u>Base- and Future-Year Scenarios with 1990 CAAA Controls</u>
2000 with-CAAA
2010 with-CAAA
2020 with-CAAA

An integral component of the modeling analysis is the estimation of future-year emissions for the seven core scenarios. The emissions estimates were prepared by EPA and are discussed in some detail by Wilson et al. (2008). Emissions for the historical years (1990 and 2000) were based on the best available emission inventories for these years. Projection to the future years was based on economic growth projections, future-year control requirements (for attainment of National Ambient Air Quality Standards (NAAQS)), and control efficiencies. Different assumptions were applied for the with- and without-CAAA scenarios resulting in a different future-year emissions pathway for each scenario. The emissions data were processed for input to the CMAQ modeling using the Sparse-Matrix Operator Kernel Emissions (SMOKE) emissions processing system (CEP, 2004).

The model-ready emission inventories for each scenario and year were then used to obtain base- and future-year estimates of the key criteria pollutants, as well as many other species. The air quality modeling analysis was designed to make use of tools and databases that have recently been developed and evaluated by EPA for other national- and regional-scale air quality modeling studies. In particular, model-ready meteorological input files for 2002 were provided by EPA for use in this study. For fine particulate matter ($PM_{2.5}$) and related species, the CMAQ model was applied for an annual simulation period (January through December). A 36-km resolution modeling domain that encompasses the contiguous 48 states was used for the annual modeling. For ozone and related species, the CMAQ model was applied for a five-month simulation period that captures the key ozone-season months of May through September. Two 12-km resolution modeling domains (that when combined cover the contiguous 48 U.S. states) were used for the ozone-season modeling. Altogether, model-ready emission inventories were prepared and the CMAQ model was applied for a total of 21 simulations (comprising seven core scenarios and three modeling domains).

The outputs from the CMAQ model provide the basis for the calculation of health and ecological benefits of the CAA. The airborne criteria pollutants of interest include ozone and fine particulate matter ($PM_{2.5}$), where $PM_{2.5}$ consists of particles less 2.5 microns in diameter. Visibility is also an air quality parameter of interest and this was calculated using a variety of the CMAQ output species. In addition, deposition of nitrogen and sulfur was also extracted from the model outputs.

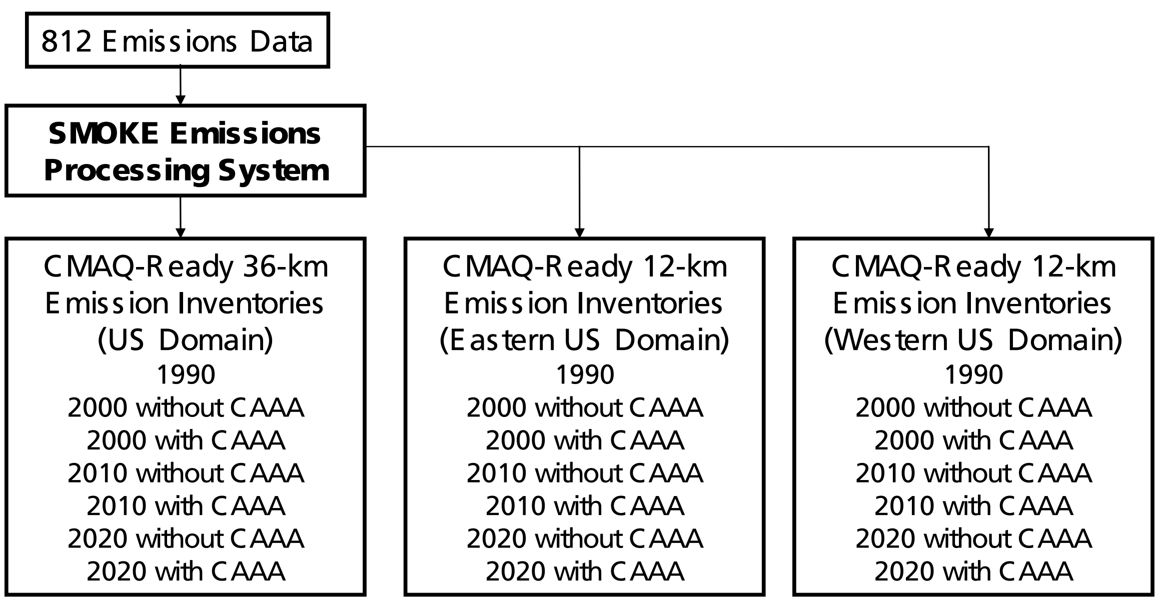
The remainder of this report summarizes the methods and results of the second Section 812 prospective air quality modeling analysis. An overview of the air quality modeling methodology is provided in Section 2. The emissions processing is summarized in Section 3. The air quality modeling methods and results are presented in Section 4. A discussion of the attributes and limitations of the modeling analysis methodologies is provided in Section 5. Finally, recommendations for further research are given in Section 6.

Section II
Overview of the Air Quality Modeling Methodology

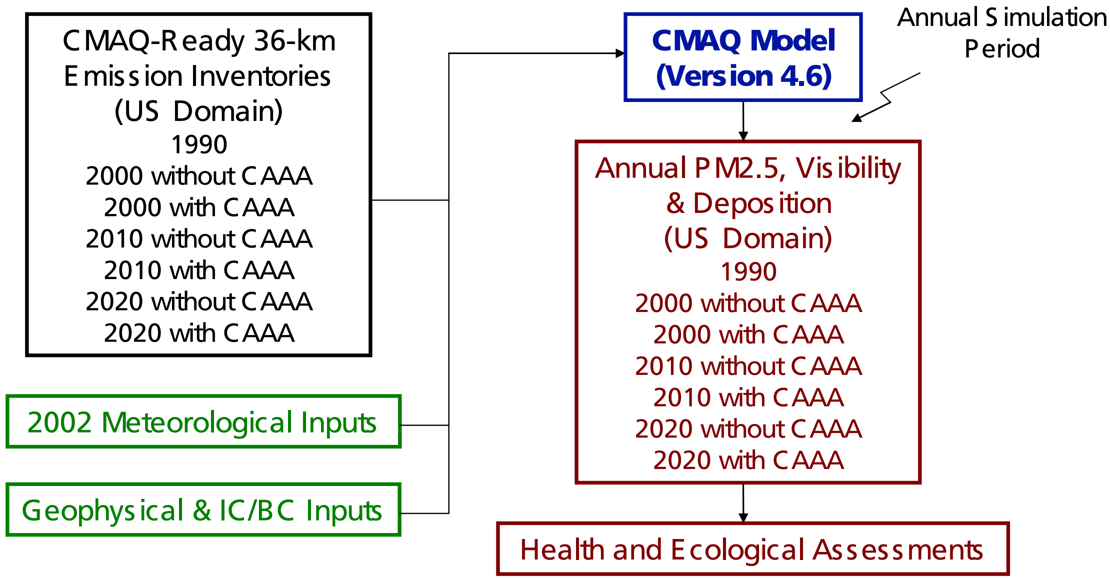
The air quality modeling component of the Section 812 prospective analysis included the application of the SMOKE emissions processing software, the CMAQ air quality model, and several post-processing and analysis tools. In addition, the modeling analysis included the use of detailed emissions data for each year and scenario and meteorological, geophysical and other inputs representative of 2002. Three separate modeling domains were employed. The input files, simulation period, and modeling domains are discussed in more detail in Sections III and IV. An overview of the modeling approach is provided in Figure II-1.

Figure II-1. Schematic Diagram of Section 812 Air Quality Modeling Analysis.

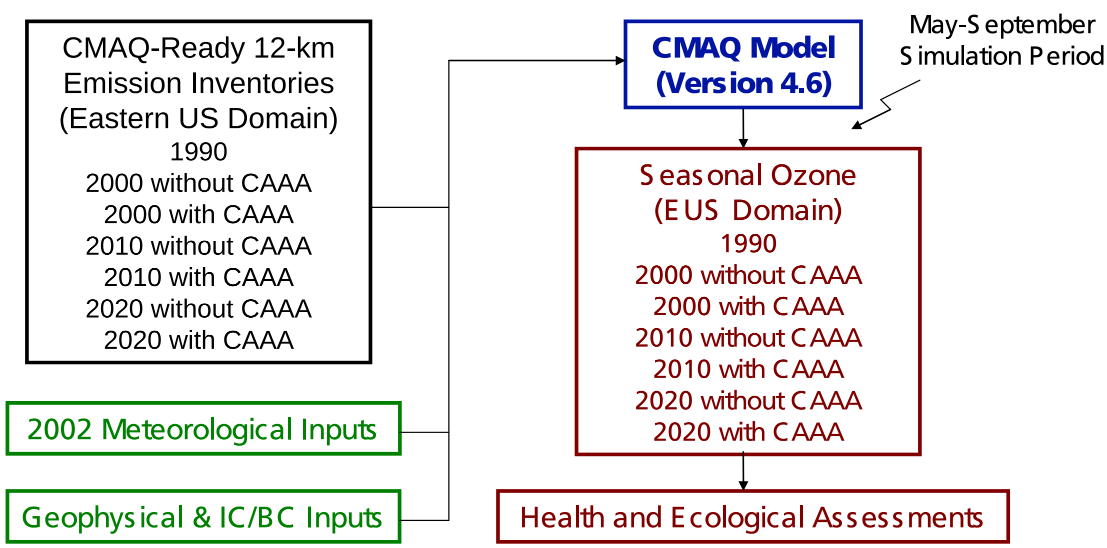
(a) SMOKE Emissions Processing Component



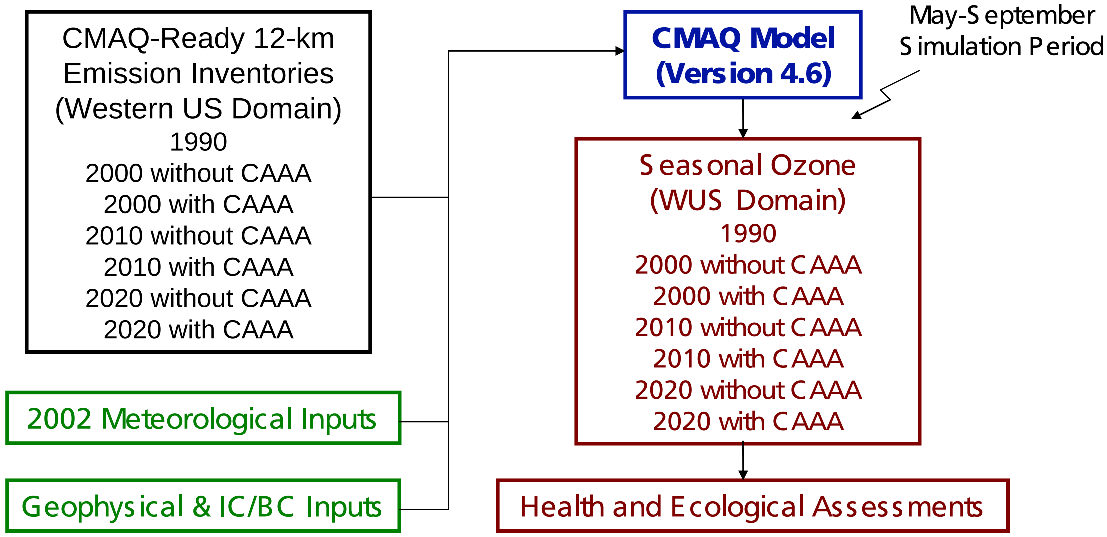
(b) *CMAQ Application for the 36-km Continental U.S. (CONUS) Domain.*



(c) *CMAQ Application for the 12-km Eastern U.S. (EUS) Domain.*



(d) *CMAQ Application for the 12-km Western U.S. (WUS) Domain.*



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Section III
Emission Inventory Preparation

Introduction

This section summarizes the data, methods, and procedures followed in preparing modeling emission inventories for the air quality modeling analysis conducted for the second 812 prospective study. The major objective of the 812 prospective study is to evaluate the costs and benefits of emission reductions mandated by the 1990 Clean Air Act Amendments (CAAA). The first part of the analysis involves the preparation of national criteria pollutant emission inventories that include: 1) a base year inventory for 1990 to establish the emissions baseline prior to any CAAA-mandated controls, 2) an interim year inventory for 2000 that includes some CAAA controls, and 3) two future-year inventories (2010 and 2020) that include expected future controls. The second part of the analysis, the results of which are summarized in the following sections of this report, includes a series of air quality modeling simulations that are performed to evaluate the expected changes in air quality for the years 2000, 2010, and 2020 using emission inventories that include and exclude (with and without) the CAAA controls. The results of these simulations provide estimates of the benefits to air quality throughout the US for ozone and particulate matter as a result of the emissions reductions realized (or expected to be realized) from controls and other air quality management programs as a result of the CAAA. To complete the overall Section 812 benefit-cost analysis, this third part of the analysis (to be conducted by others) also involves an evaluation of the incremental costs of control programs associated with the CAAA.

Emissions Data and Methods

For the 812 air quality modeling analysis, EPA's Community Multiscale Air Quality (CMAQ) model (Version 4.6), containing the Carbon Bond 2005 (CB-05) chemical mechanism, was utilized. The CMAQ model requires as input hourly, gridded emissions of both anthropogenic and biogenic sources that have been spatially allocated to the appropriate grid cells and chemically speciated for the applicable chemical mechanism used in the model. The emissions inventories prepared for the modeling analysis were based on information originally developed and provided by EPA and its emissions contractors, E. H. Pechan & Associates and Industrial Economics, Inc. The details of the development of the 1990 and 2000 base case and 2010 and 2020 future year inventories are contained in two recent publications (Wilson, et al., 2008 and E. H. Pechan & Industrial Economics, Inc., 2006). Input information was provided for the 48 states of the US and portions of Canada and Mexico. Using the emissions inputs provided, the modeling inventories were processed and prepared for CMAQ using EPA's Sparse-Matrix Operator Kernel Emissions (SMOKE) software (Version 2.3.2) for the following pollutants: volatile organic compounds (VOC), oxides of nitrogen (NO_x), carbon monoxide (CO), sulfur dioxide (SO_2), fine particulates ($PM_{2.5}$), coarse particulates (PM_{10}), and ammonia (NH_3). Information provided by EPA for preparation of the base and future-year modeling inventories included SMOKE input and output files for area, non-road, on-road, EGU and non-EGU sectors, and "identified" and "unidentified" local control information by county and source category code for each pollutant.

As noted, modeling inventories for the following emissions scenarios were developed for the 812 prospective analysis:

1990 Base Case	2000 with-CAAA (Base Case)
2000 without-CAAA	2010 with-CAAA
2010 without-CAAA	2020 with-CAAA
2020 without-CAAA	

The 1990 base case serves as the basis for the development of all subsequent inventories without CAAA controls, while the 2000 with-CAAA scenario serves as the basis for the development of the 2010 and 2010 with-CAAA inventories. The inventories that include controls represent provisions contained in the following sections of the 1990 CAAA:

- Title I VOC and NO_x reasonably available control technology (RACT) requirements in ozone nonattainment areas (NAAs);
- Title II on-road motor vehicle and non-road engine/vehicle provisions;
- Title III National Emissions Standards for Hazardous Air Pollutants (NESHAPS), and
- Title IV emissions programs for EGUs, as estimated by the Integrated Planning Model (IPM)

As presented in Wilson et al., (2008), Table III-1 summarizes the origin of the information by source category of the inventories that comprise the base case scenarios for 1990 and 2000, from which the other inventories were derived.

Table III-1. Base year Emission Data Sources for the With- and Without-CAAA Scenarios.

Sector	Without-CAAA Scenario 1990	With-CAAA Scenario 2000
EGU	1990 EPA point-source NEI	Estimated by EPA IPM for 2001
Non-EGU Point	1990 EPA point-source NEI	2002 EPA point-source NEI (final version 2.0)
Non-point	1990 EPA non-point-source NEI with adjustments for priority source categories.	2002 EPA point-source NEI (final version 1)
On-road	Mobile 6.2 emission factors and 1990 NEI VMT database	MOBILE 6.2 emission factors and 2000 NEI VMT database. CARB supplied estimates for California
Off-road/ non-road	NON-ROAD 2004 model simulation for calendar year 1990	NON-ROAD 2004 model simulation for calendar year 2000

Source: Wilson et al., 2008

As noted, the on-road and non-road inventories were developed using consistent emissions processors (MOBILE6.2 and NON-ROAD2004) along with year-specific VMT and equipment/activity databases corresponding to 1990 and 2000. The EGU inventories were developed for 1990 from the 1990 National Emission Inventory (NEI) and for 2000 using the Integrated Planning Model (IPM). The future-year inventories were developed for two scenarios: a) without-CAAA: includes expected growth in population and activity, but no controls beyond those in place in 1990, and b) with-CAAA: includes expected growth in population and activity and reflects controls mandated in the 1990 CAAA. In developing the future-year inventories, growth in emissions or activity was applied for the future year and then applicable controls were applied.

Table III-2 summarizes the approach followed in estimating the future year emissions for the Section 812 prospective analysis. In developing the future year inventories, the emissions for Mexico were left at base year levels. The controls on non-EGU point and non-point (area) sources were developed for their respective areas by the five Regional Planning Organizations (RPOs) that have been conducting modeling and analyses for regional haze, visibility, and $PM_{2.5}$ assessments in recent years throughout the US. These RPOs include the Visibility Improvement State and Tribal Association of the Southeast (VISTAS), the Mid-Atlantic and Northeast Visibility Union (MANE-VU), the Midwest Regional Planning Organization (MWRPO), the Central Regional Planning Association (CENRAP), and the Western Regional Air Partnership (WRAP).

Table III-2. Approach for Estimating Future-Year Emissions.

Sector	Growth Forecast	Estimation of Controls
EGU	DOE AEO 2005 forecasts	IPM
Non-EGU Point	DOE AEO 2005 forecasts	On the basis of control factors developed by the five RPOs and California from CARB
Non-point	DOE AEO 2005 forecasts	On the basis of control factors developed by the five RPOs and California from CARB
On-road	National VMT forecast from AEO 2005	MOBILE6.2 emission factors
Off-road/ non-road	EPA NON-ROAD 2004 model growth forecasts are largely based on historical trends in national engine populations by category/subcategory of engine	NON-ROAD2004 model

Source: Wilson et al., 2008

The without-CAAA inventories for 2000, 2010, and 2020 contain expected growth in various source sectors, with RACT controls held at 1990 levels for non-EGU point sources; RACT, New Source Review (NSR), Prevention of Significant Deterioration (PSD), and New Source Performance Standards (NSPS) held at 1990 levels for EGUs; engine standards held at 1990 levels for non-road engines/vehicles; engine standards, Phase I Reid Vapor Pressure (RVP) limits, and Inspection and Maintenance (I/M) programs set prior to/in place by 1990 assumed for on-road motor vehicles; and controls held at 1990 levels for area/non-point sources.

The with-CAAA inventories for 2000, 2010, and 2020 contain provisions mandated by the CAAA, including for non-EGU point sources such provisions as NO_x and VOC RACT for all nonattainment areas (NAAs), new control technique guidelines (CTGs), and applicable Maximum Achievable Control Technology (MACT) for VOCs; for EGUs, among other things, applicable RACT, NSR, PSD, and NSPS requirements, the Clean Air Interstate Rule (CAIR) and Clean Air Mercury Rule (CAMR) provisions, and other measures to meet PM and ozone NAAQS; for non-road engines such controls as the Federal locomotive, commercial/recreational marine vessel standards, Phase I and II engine standards, Non-road Diesel Rule, and gasoline sulfur limits; for on-road motor vehicles, Tier I & II tailpipe standards, a 49-state Low Emission Vehicle (LEV) program, I/M programs for ozone NAAs, Federal Reformulated Gas (RFG) for certain NAAs, Phase 2 RVP limits, California LEV and RFG, and diesel fuel sulfur limits, among other provisions; and for non-point/area sources such provisions as RACT, new CTGs, Stage II vapor recovery, and other measures to meet PM and ozone NAAQS, including those contained in various Early Action Compacts.

The national, regional, and local controls imposed in developing the with-CAAA inventories for 2010 and 2020 reflect those controls "on the books" as of September 2005. In addition to these controls, an analysis was conducted by Pechan to estimate additional local controls that reflect efforts and control requirements identified by state and local governments to achieve applicable NAAQS for ozone and $PM_{2.5,}$ and provisions included in EPA's recent Clean Air Visibility Rule (CAVR), also referred to as the BART rule. The assessment of potential control measures was conducted using EPA's AirControlNET model, which provides a linkage between identified control technologies/measures and EPA emission inventories. For certain NAAs that will require more rigorous controls, the local control measures assessment included reductions associated with unidentified measures, which were included in the future-year modeling inventories.

Emissions Processing Procedures

As noted above, the SMOKE emissions processor (Version 2.3.2) was utilized to process the emissions and prepare CMAQ-ready inputs for the various scenarios using source sector files provided by EPA and Pechan. The preparation of the various inventories included a) processing using various SMOKE programs, b) the application of control factors to emulate identified and unidentified controls at the local level for various nonattainment areas, and c) review and quality assurance checks. In addition, in processing the modeling emission inventories, a number of revisions were made to the original files provided by EPA and Pechan, as detailed below.

The general procedures followed in preparing the modeling inventories, using various programs included with SMOKE, are the following:

- Apply local control to emissions inventory data files (for with-CAAA inventories only)
- Perform chemical speciation to transform input criteria pollutants into the Carbon Bond 2005 (CB-05) chemical mechanism species, as required by CMAQ
- Perform temporal distribution to distribute the input annual/monthly emissions into hourly emissions
- Perform spatial distribution of input emissions to the various modeling grids
- Merge emissions from EGU, non-EGU, non-point, non-road, on-road, and biogenic sectors into the CMAQ model-ready files
- Conduct a review and quality assurance of the inventory processing

Development and Application of Local Control Factors for 2010 and 2020

The emission inventory files developed by EPA and Pechan for the second prospective analysis reflect federal, state, and local provisions of what was "on the books" as of September 2005, but do not include additional local controls that are expected to be identified and in place in various nonattainment areas by 2010 and 2020 to address both 8-hr ozone and $PM_{2.5}$ nonattainment issues. To estimate the expected reductions in emissions for the 2010 and 2020 inventories resulting from these local controls, Pechan conducted an analysis using EPA's AirControlNET model, which links control technologies and pollution prevention measures to EPA inventories.

From this analysis, a set of control factors for “identified” controls was developed. For certain areas with more severe control requirements (beyond what could be estimated by AirControlNET), additional “unidentified” controls were developed by examining available future-year air quality modeling results and making estimates of what other local reductions would be required to meet the 8-hr ozone standard. The “unidentified” controls were developed for 27 nonattainment areas.

The following summarizes how the local controls were incorporated into the 2010 and 2020 with-CAAA inventories:

Identified Local Controls: EPA provided an Access database file that contained the percentage reduction estimates for area, non-road, on-road, EGU and non-EGU sectors for the 2010/2020 identified local control measures, by county and source category code, for each pollutant. This information was incorporated into the inventories as follows:

- The control factors for the 2010/2020 identified local control measures were calculated using the EPA provided database.
- The on-road emissions were provided by detailed source category codes in the SMOKE IDA files, and the percentage reductions for on-road emissions were provided by aggregated source category codes in the EPA database. The control factors for each aggregated source category were applied to all corresponding detailed source categories.
- The on-road exhaust and evaporate VOC emissions were provided separately in the SMOKE IDA files, and the percentage reductions for on-road emissions were provided for overall VOC in the EPA database. The overall VOC control factors were applied to both exhaust and evaporate VOC emissions.

Unidentified Local Controls: EPA provided an Access database file that contained the 2010/2020 residual emissions (the emissions remaining after the identified controls have been applied, but before the unidentified controls) for all counties and source categories, and the county FIPS codes within the NAA that the unidentified controls will be applied to. EPA also provided the total unidentified NO_x and VOC emissions reduction for the NAA by county for area, on-road and non-road sectors.

The control factors for the unidentified control measures by county and source category code (SCC) were calculated as follows:

- Extract the residual emissions for the SCC in area, on-road and non-road sectors for the counties within the NAA from the EPA Access database.
- Calculate the residual emissions totals for area, on-road and non-road sectors for each county within the NAA.
- Compare the residual emissions and unidentified emissions reductions, and calculate the control factors for NO_x and VOC by sector for each county within the NAA.
- Assign the control factors for area, non-road and on-road sectors by county and SCC for each NAA.

Revisions Made to Emissions Input Files

After receiving the initial emission inventory files from EPA and Pechan, a number of revisions were made to various files prior to the development and processing of the modeling scenario inventories. These include the following, by source category:

On-road Sources

- Used older version of EPA PM2.5 speciation profiles and associated cross references to speciate PM2.5 emissions to accommodate the fact that the on-road PM2.5 emissions provided were not separated for tire dust, brake lining dust, gasoline exhaust, LDDV exhaust and HDDV exhaust.

Non-road Sources

- Used the older version of EPA VOC speciation profiles and associated cross reference files to speciated VOC emissions to accommodate the fact that the non-road emissions provided were not separated for exhaust, evaporative, and refueling emissions.

Area Sources

- Added 100 source category codes (SCC) to the SMOKE IDA file that are not included in the EPA's latest speciation profile cross reference file.

Non-EGU Sources

- Added 379 SCCs to the SMOKE IDA file that are not included in the EPA's latest speciation profile cross reference file.
- Added 35 SCCs to the SMOKE IDA file that are not included in the EPA latest temporal profile cross reference file.

Quality Assurance Procedures

The emissions inventory processing quality assurance (QA) procedures included the development and examination of tabular emissions summaries and graphical display products.

Tabular summaries were prepared to examine emissions totals for various steps of the emissions processing. Summaries for input emissions are based on the input inventory data: monthly emissions for the on-road sector, and annual emissions for other sectors for criteria pollutants. Summaries for output emissions are based on the SMKMERGE reports: daily emissions for CB-05 species for each sector. The output daily emissions are summed over all days in the year and the CB-05 species are summed for the criteria pollutants. The emissions summaries were made for each scenario by state and sector, and comparisons were made between the input emissions and output emissions for each sector to assure consistency. Comparisons were also made between the base and future years for both the with- and without-CAAA scenarios.

In addition to the tabular summaries, various graphical displays were prepared for one day of each month to examine the spatial distribution and temporal variation for each sector and the final merged emissions using the PAVE graphical plotting package. In addition, difference plots were prepared comparing the with- and without-CAAA scenarios for the future years for one day of each month to show the spatial emissions changes due to the controls.

Summary and Discussion of Modeling Emission Inventories

Using the inputs provided by EPA, the SMOKE emissions processing system was utilized to prepare the CMAQ model-ready hourly emission inventory inputs for each of the modeling scenarios for the 36-km resolution national grid (referred to as the CONUS grid), and the 12-km resolution Eastern U.S. (EUS) and Western U.S. (WUS) grids. Although the processed emission inventories were prepared for the full list of species listed above, most of the presentation and discussion that follows focuses on the VOC, NO_x, SO_2, and $PM_{2.5}$ emissions species.

Table III-3 presents national (48-state) emissions totals for each pollutant by sector for each of the 812 scenarios, and Table III-4 presents emission totals for all sectors combined. These estimates are very similar to those presented by Wilson (2008), with small differences attributed to changes/updates from the original inputs, differences due to processing with SMOKE, and potential differences due to the calculation involved in applying the local identified and unidentified controls.

Table III-3. National (48-State) Emission Inventory Totals (thousand tons/yr) by Sector for the 812 Modeling Scenarios.

Pollutant	Sector	1990	2000 Without-CAAA	2000 With-CAAA	2010 Without-CAAA	2010 With-CAAA	2020 Without-CAAA	2020 With-CAAA
VOC	EGU	36	40	41	43	43	48	47
	Non-EGU Point	2,609	3,078	1,402	3,463	1,434	3,999	1,646
	Non-point	11,280	12,427	8,544	13,601	8,277	15,703	9,009
	Non-road	2,666	3,218	2,565	4,077	1,831	4,753	1,427
	On-road Vehicle	9,328	5,857	5,232	5,734	2,533	6,767	1,573
NO_x	EGU	6,571	7,736	4,495	8,352	2,301	8,689	1,885
	Non-EGU Point	3,133	3,331	2,292	3,556	1,991	3,997	2,011
	Non-point	4,952	4,832	3,886	5,014	3,577	5,198	3,494
	Non-road	2,068	2,191	2,091	2,665	1,588	3,162	928
	On-road Vehicle	9,536	8,759	8,052	9,106	4,182	10,667	1,758
CO	EGU	312	497	504	602	618	751	772
	Non-EGU Point	5,667	6,467	3,113	6,808	3,291	7,382	3,677
	Non-point	17,318	16,269	14,614	15,365	14,605	15,089	15,451
	Non-road	22,176	25,459	22,330	31,542	26,214	37,199	28,995
	On-road Vehicle	109,566	78,786	66,931	80,491	41,976	95,242	35,624
SO_2	EGU	16,202	18,151	10,822	18,872	6,366	18,744	4,271
	Non-EGU Point	4,293	4,100	2,193	4,487	2,057	4,872	2,054
	Non-point	2,659	2,346	1,875	2,705	1,878	3,044	1,942
	Non-road	163	178	177	225	17	270	3
	On-road Vehicle	500	631	253	797	30	984	36

Pollutant	Sector	1990	2000 Without-CAAA	2000 With-CAAA	2010 Without-CAAA	2010 With-CAAA	2020 Without-CAAA	2020 With-CAAA
PM_{10}	EGU	542	752	729	835	641	897	623
	Non-EGU Point	1,735	2,014	598	2,202	608	2,491	704
	Non-point	22,499	23,124	19,332	22,822	18,841	24,256	19,008
	Non-road	309	287	266	323	200	367	131
	On-road Vehicle	385	246	220	229	151	268	134
$PM_{2.5}$	EGU	365	634	611	705	515	763	495
	Non-EGU Point	1,299	1,516	365	1,652	394	1,872	451
	Non-point	5,258	5,420	4,103	5,371	4,054	5,732	4,160
	Non-road	284	264	245	297	185	338	120
	On-road Vehicle	322	191	165	170	94	199	70
NH_3	EGU	0	3	3	1	1	0	0
	Non-EGU Point	244	236	154	237	174	256	202
	Non-point	3,260	3,624	3,552	3,830	3,713	4,131	3,987
	Non-road	2	2	2	2	2	3	2
	On-road Vehicle	154	272	272	336	334	397	394

Table III-4. National (48-State) Emission Inventory Totals (thousand tons/yr) for all Sectors Combined for the 812 Modeling Scenarios.

Pollutant	1990	2000 Without-CAAA	2000 With-CAAA	2010 Without-CAAA	2010 With-CAAA	2020 Without-CAAA	2020 With-CAAA
VOC	25,919	24,620	17,784	26,917	14,118	31,270	13,701
NO_x	26,261	26,848	20,817	28,692	13,639	31,714	10,077
CO	155,040	127,477	107,492	134,808	86,704	155,662	84,520
SO_2	23,818	25,406	15,320	27,086	10,348	27,914	8,306
PM_{10}	25,469	26,422	21,145	26,411	20,441	28,279	20,599
$PM_{2.5}$	7,529	8,025	5,489	8,194	5,242	8,903	5,297
NH_3	3,659	4,137	3,982	4,407	4,224	4,786	4,585

To illustrate and check the reasonableness of the spatial distribution of emissions throughout the modeling domain, daily emission density plots for a selected day were prepared and examined. Figure III-1 presents daily emissions for June 15, 2002 for VOC, NOx, SO2, and $PM_{2.5}$ for the 36-km CONUS grid. As noted above, the meteorological inputs for the modeling exercise are for 2002, while the emissions correspond to the selected study years (1990, 2000, 2010, and 2020). The plots show the spatial distribution of the 2000 emissions, with higher emissions in the more populated areas of the eastern US and California, and lower emissions in the less-populated areas of the interior western US and areas of Canada and Mexico. The VOC emission plots also include biogenic emissions, with higher emissions associated with the more forested regions of the southeast US and Canada. The $PM_{2.5}$ emissions are associated with various anthropogenic mobile and industrial sources, but the high values noted in southwestern Oregon are associated with wildfires.

Figure III-1a. Daily VOC Emissions (July 15, 2002) for the 2000 With-CAAA Scenario.

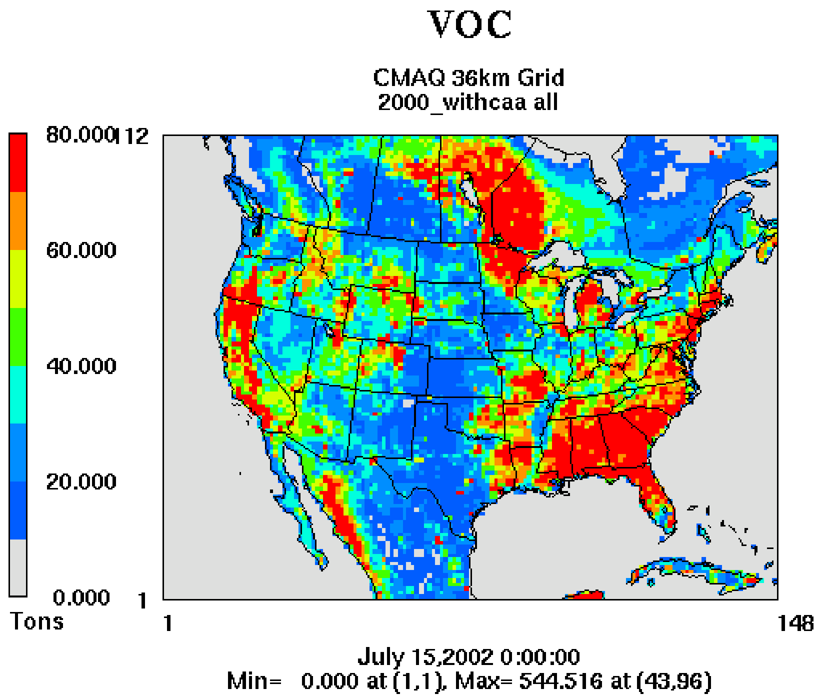


Figure III-1b. Daily NO_x Emissions (July 15, 2002) for the 2000 With-CAAA Scenario.

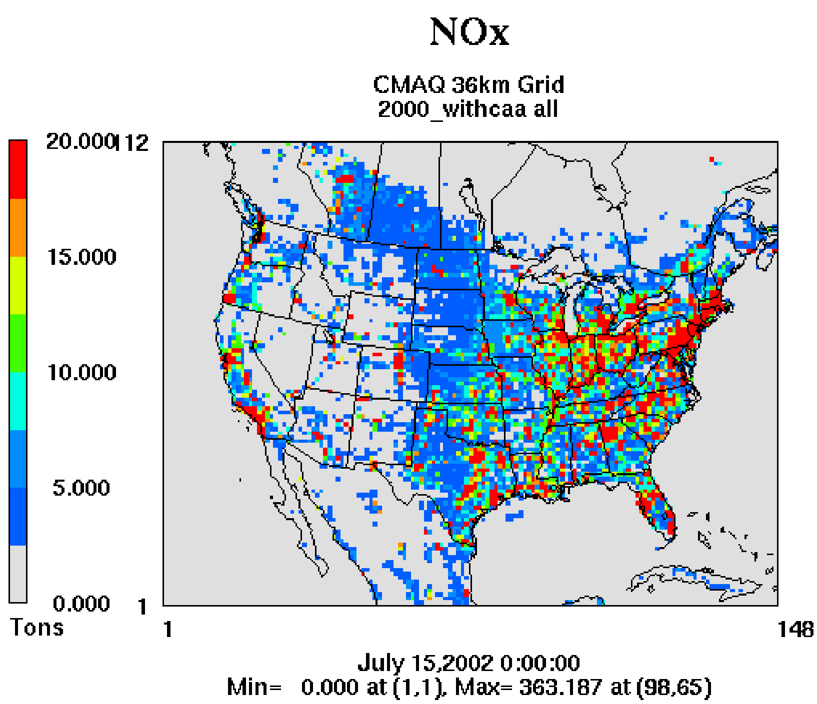


Figure III-1c. Daily SO_2 Emissions (July 15, 2002) for the 2000 With-CAAA Scenario.

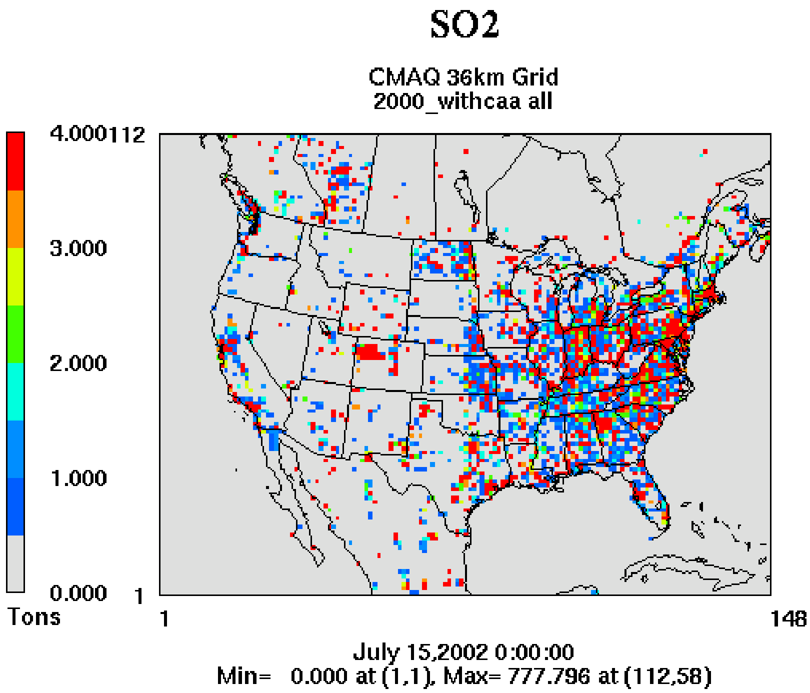
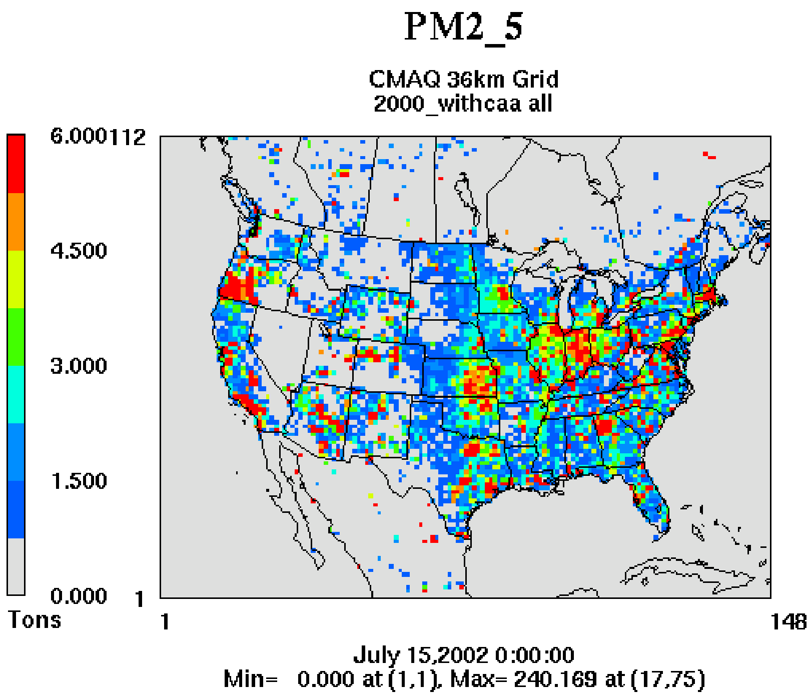


Figure III-1d. Daily $PM_{2.5}$ Emissions (July 15, 2002) for the 2000 With-CAAA Scenario.



To illustrate the spatial distribution of expected changes in the emissions for the various modeling scenarios, difference plots comparing the emissions from one scenario with another were prepared and examined. Figure III-2 presents example emissions difference plots for VOC, NOx, SO_2, and $PM_{2.5}$, comparing the 2000 with-CAAA scenario with the 2020 with-CAAA scenario. The figures illustrate where the reductions in emissions are expected to occur throughout the 36-km resolution CONUS modeling domain. For VOC emissions, there are expected decreases in 2020 throughout the eastern US, especially in the northeast urban corridor. Additional large reductions are found in Chicago, Houston, Dallas, and the Greater Las Angeles area. Emissions of NOx are expected to decrease substantially throughout the eastern US, Canada, and California. The decreases are more widespread than those for SO2, which are primarily associated with industrial point sources, such as EGUs. Some slight areas of increases in VOC, NOx, and SO_2 emissions are the result of new sources or inconsistencies in the origin of the datasets used to prepare the base and future year estimates. The majority of the emissions reductions for $PM_{2.5}$ are from area sources in population centers and from non-EGU industrial sources located throughout the US.

Figure III-2a. Differences in Daily VOC Emissions (July 15)
(2020 With-CAAA Minus 2000 With-CAAA).

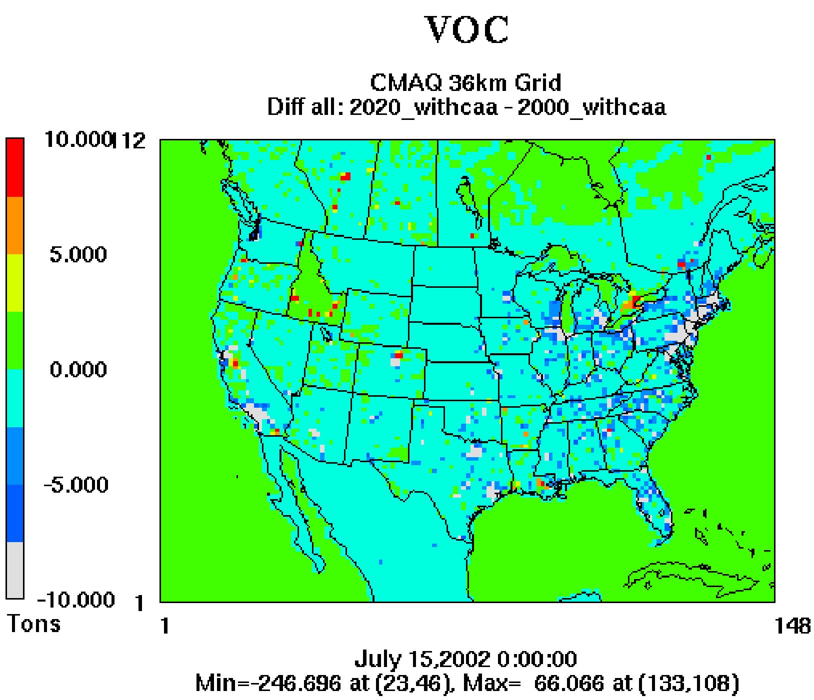


Figure III-2b. Differences in Daily NO_x Emissions (July 15) (2020 With-CAAA Minus 2000 With-CAAA).

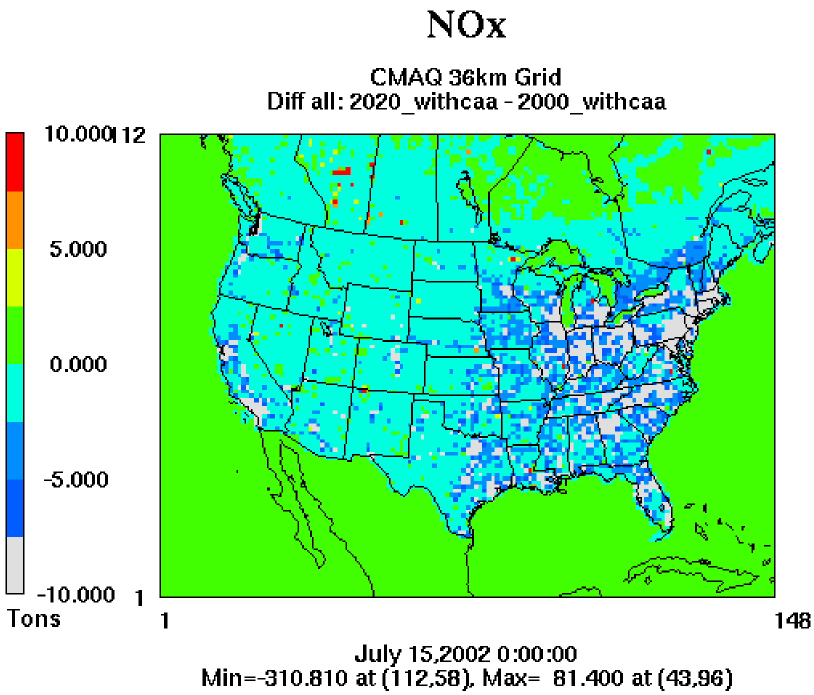


Figure III-2c. Differences in Daily SO_2 Emissions (July 15) (2020 With-CAAA Minus 2000 With-CAAA).

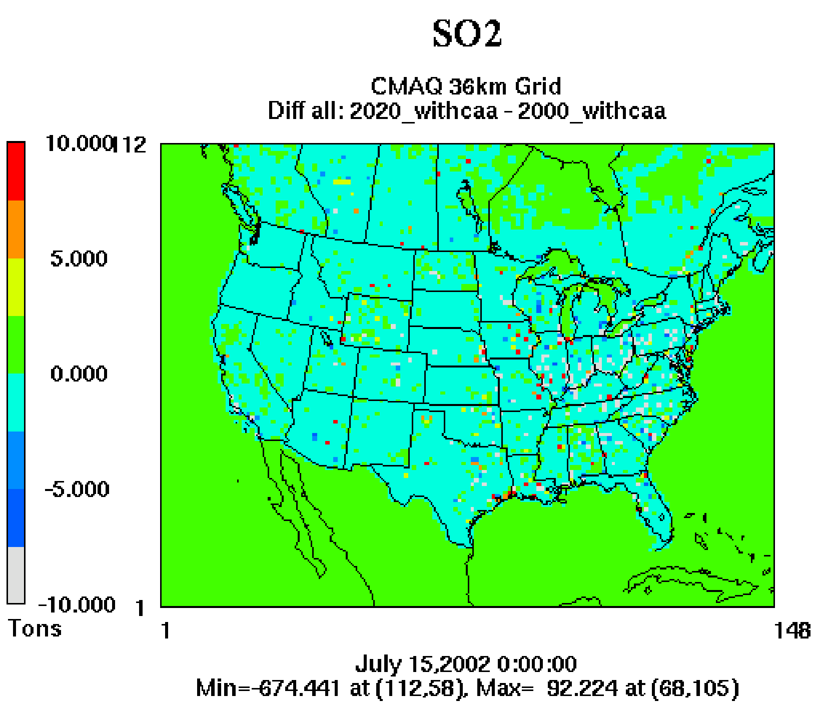
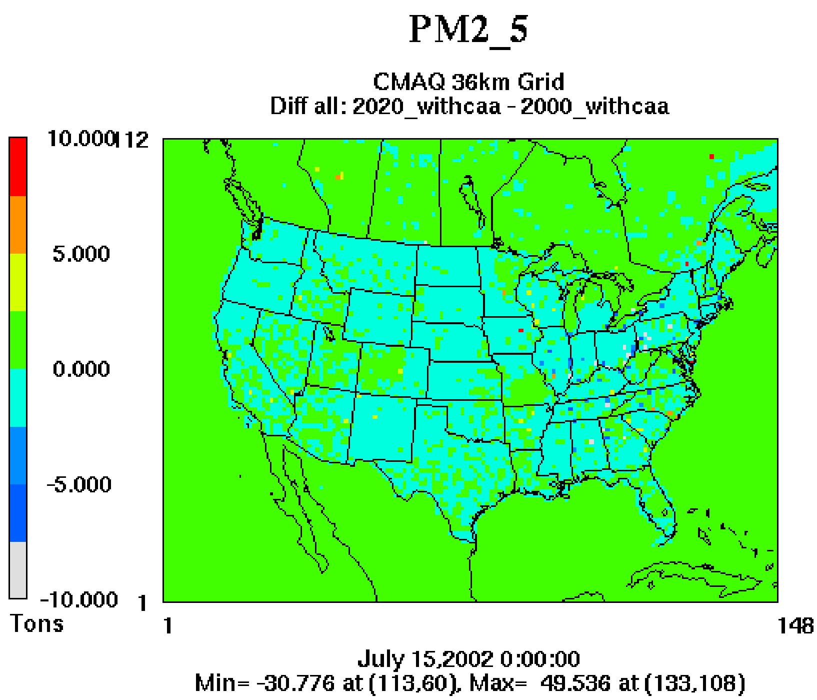


Figure III-2d. Differences in Daily $PM_{2.5}$ emissions (July 15) (2020 With-CAAA Minus 2000 With-CAAA).



In addition to spatial emission density figures, tabular summaries were also prepared for each of the scenario inventories. Figure III-3 presents national emissions estimates by source sector for all of the scenarios for VOC, NOx, SO_2, and $PM_{2.5}$.

Figure III-3a. National Emission Totals for VOC for the 812 Modeling Analysis Scenarios.

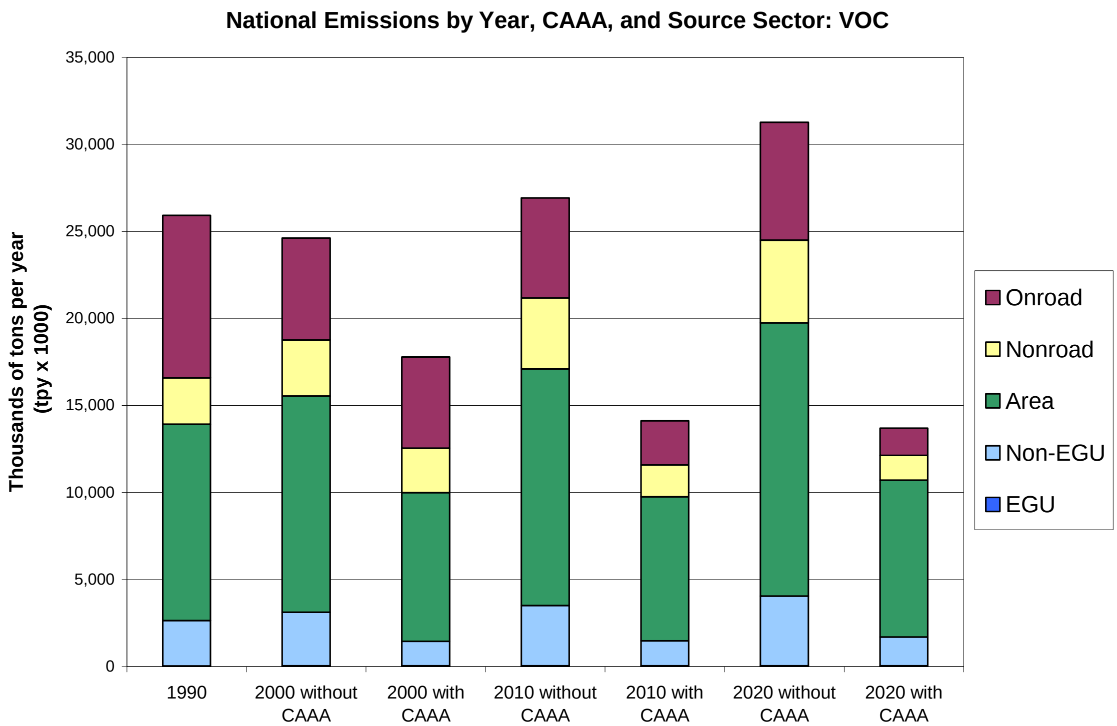


Figure III-3b. National Emission Totals for NO_x for the 812 Modeling Analysis Scenarios.

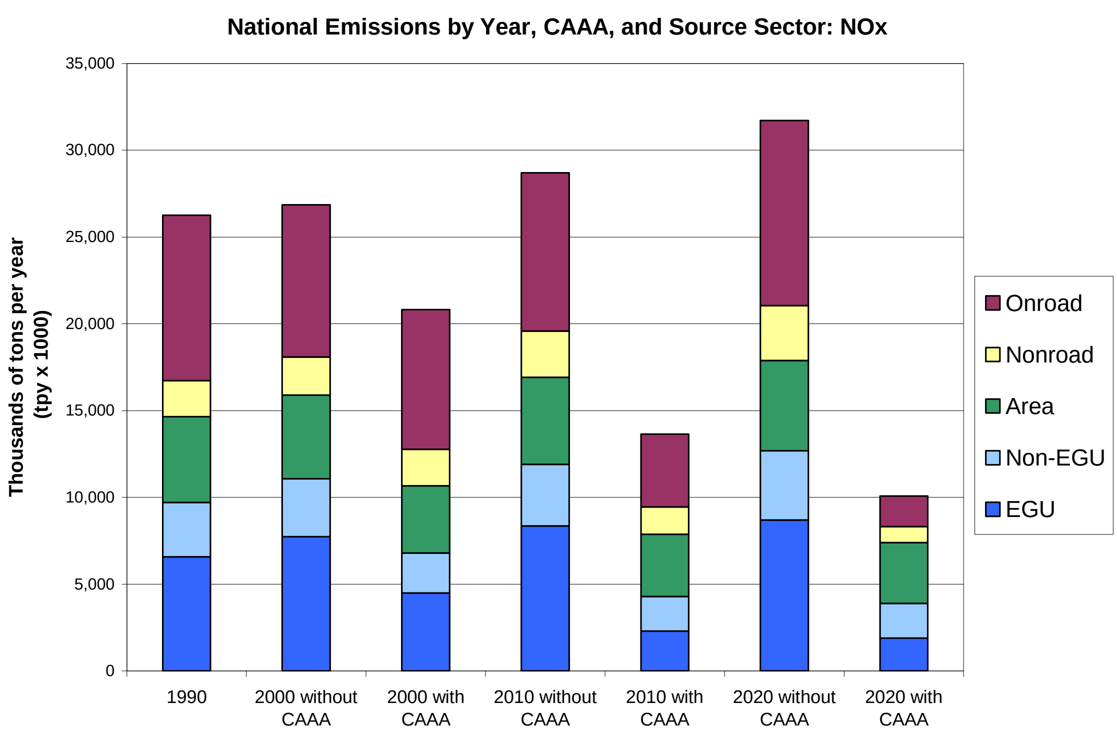


Figure III-3c. National Emission Totals for SO_2 for the 812 Modeling Analysis Scenarios.

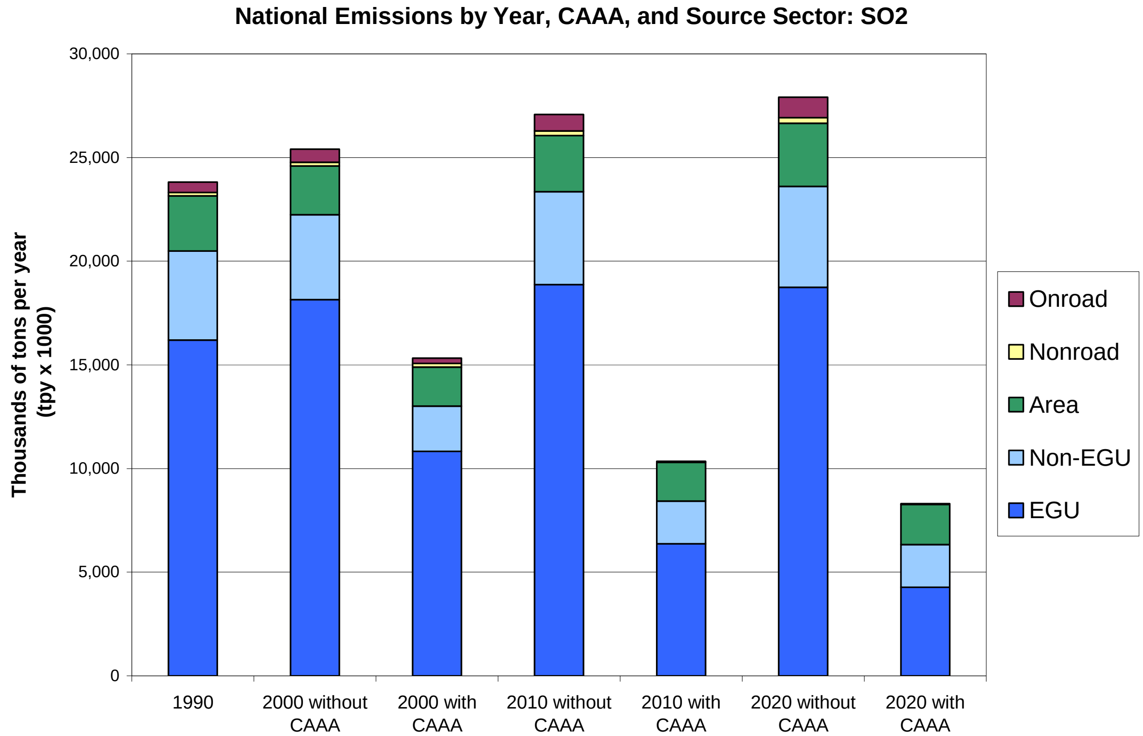
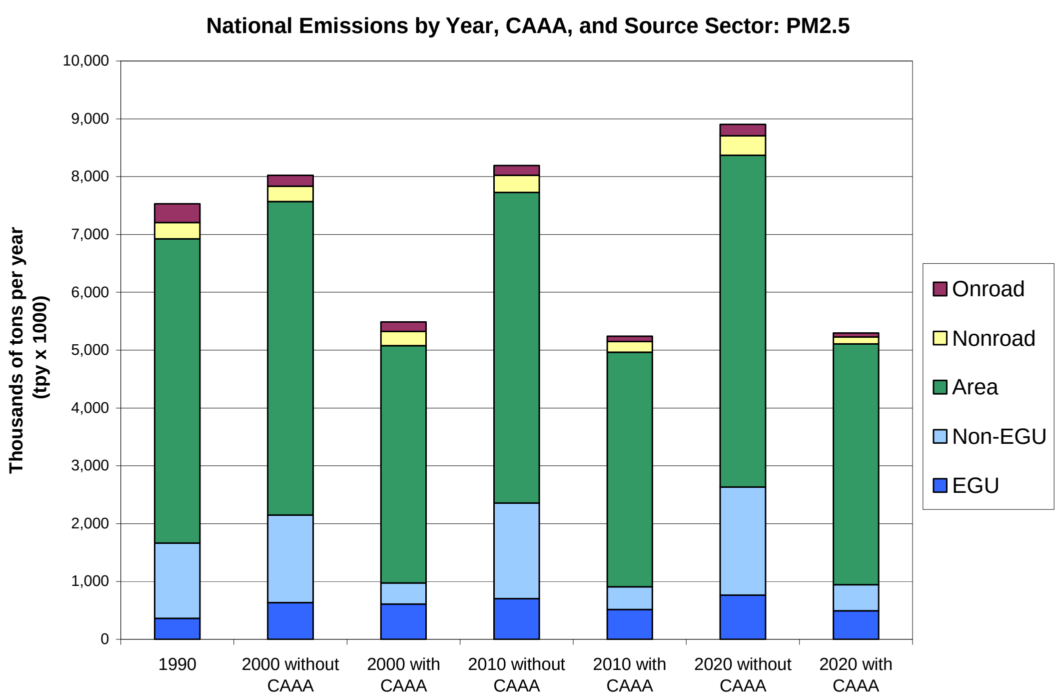


Figure III-3d. National Emission Totals for $PM_{2.5}$ for the 812 Modeling Analysis Scenarios.



As depicted in the figures, anthropogenic VOC emissions are primarily from on-road and area sources, NOx emissions are primarily from on-road and EGU sources, SO_2 emissions are primarily from EGU sources, and $PM_{2.5}$ emissions are primarily from area sources. Although the magnitude of emissions varies from region to region across the nation, the dominant source categories for each species are very consistent. An examination of the 48-state emission totals for the various emission scenarios that do not include CAAA controls shows an estimated increase in emissions in the future years (2010 & 2020) compared to the 2000 base year. This reflects the expected growth in population and the resulting increase in industrial, transportation, and energy-related activities/sources. Without CAAA controls, emissions for VOC, NOx, SO_2, and $PM_{2.5}$ are estimated to increase approximately 28, 18, 9, and 6 percent, respectively, by 2020, from the 2000 base year estimates that also do not include CAAA controls.

The future-year inventories that include CAAA controls show an estimated decrease in VOC, NOx, SO_2, and $PM_{2.5}$ emissions by 2020 of 22, 51, 47, and 4 percent, compared to the 2000 inventory with CAAA controls. Between 2000 and 2020, the largest percentage emission reductions are expected for VOC in the on-road mobile sector (from I/M programs, reformulated gasoline, RVP controls, oxygenated fuel, etc.), for NOx in the on-road mobile (same control programs as for VOC) and EGU sectors (from CAIR, CAMR, NOx SIP Call, RACT, etc.), for SO_2 in the EGU sector (from CAIR, RACT, etc.), and for $PM_{2.5}$ from all sectors (comparable small reductions due to various controls). On a percentage basis, $PM_{2.5}$ emissions are reduced by the largest amount for the non-EGU sources.

The overall magnitude and spatial differences within the 48 states in expected future increases/decreases in emissions depends on the specific source make-up of the geographic region. The more populated regions are dominated by mobile and area sources. To provide a comparison of the regional differences in the source characteristics and the magnitude of emissions, emissions totals are presented for six selected states, including Massachusetts, Pennsylvania, Georgia, Illinois, Colorado, and Washington. Figures III-4, III-5, III-6, and III-7 present emissions for each of the scenarios, respectively for VOC, NOx, SO_2, and $PM_{2.5}$, comparing component totals for each of these states for each of the 812 modeling scenarios. To facilitate the state-by-state comparisons, the species-specific scales of the plots are the same for each state.

Figure III-4a. Emission Totals for VOC for the 812 Modeling Analysis Scenarios for Massachusetts.

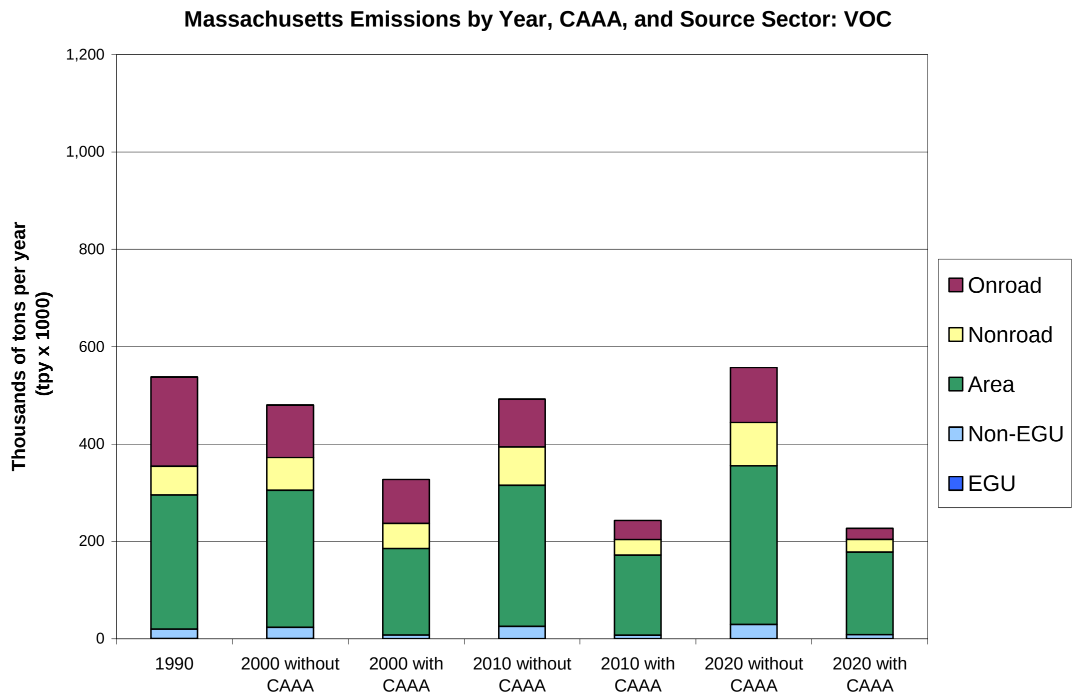


Figure III-4b. Emission Totals for VOC for the 812 Modeling Analysis Scenarios for Pennsylvania.

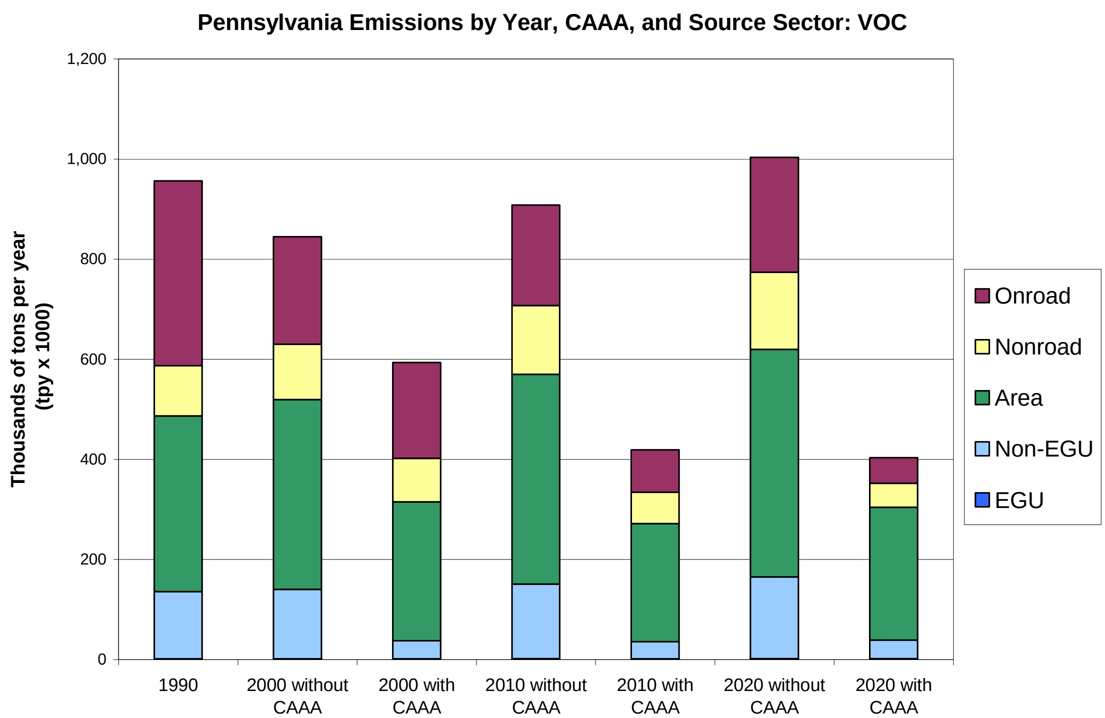


Figure III-4c. Emission totals for VOC for the 812 Modeling Analysis Scenarios for Georgia.

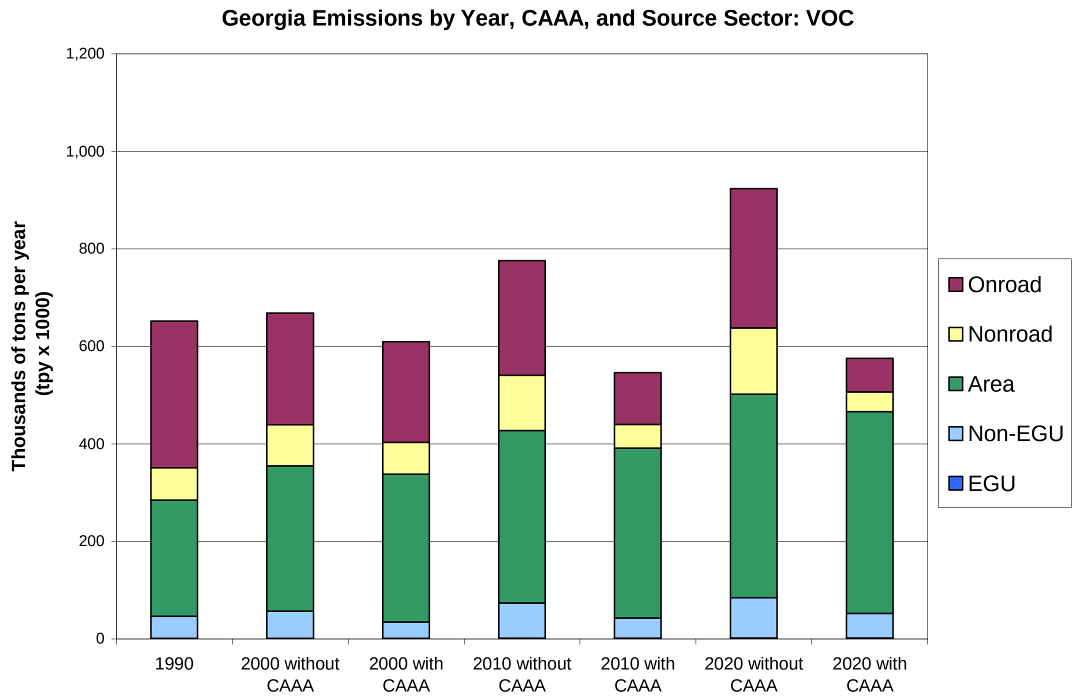


Figure III-4d. Emission Totals for VOC for the 812 Modeling Analysis Scenarios for Illinois.

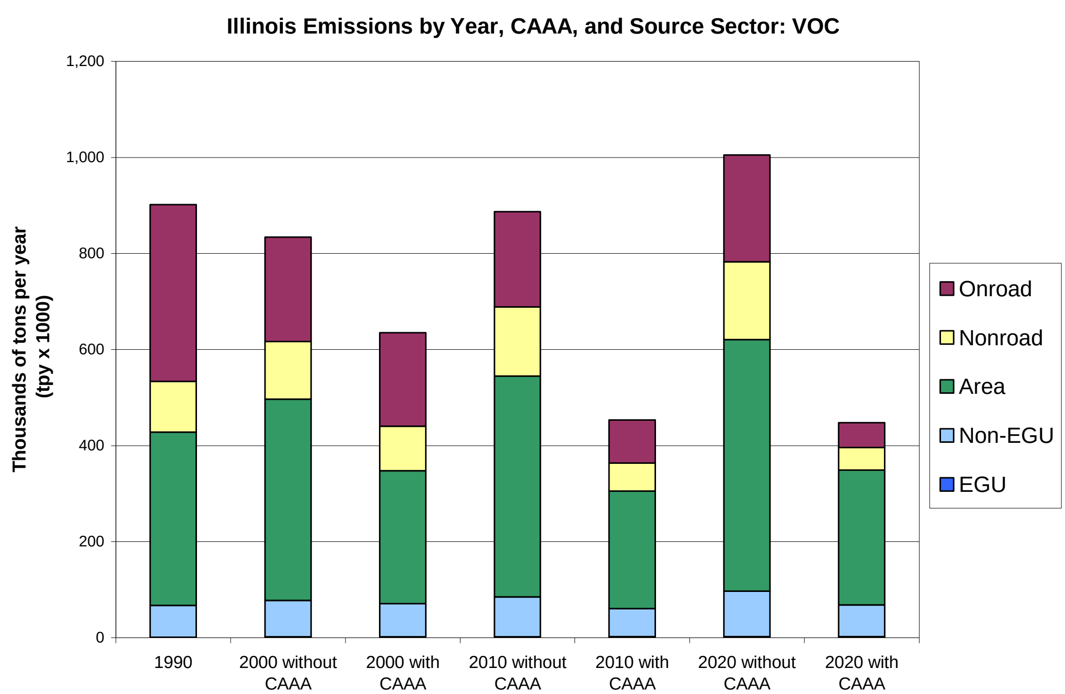


Figure III-4e. Emission Totals for VOC for the 812 Modeling Analysis Scenarios for Colorado.

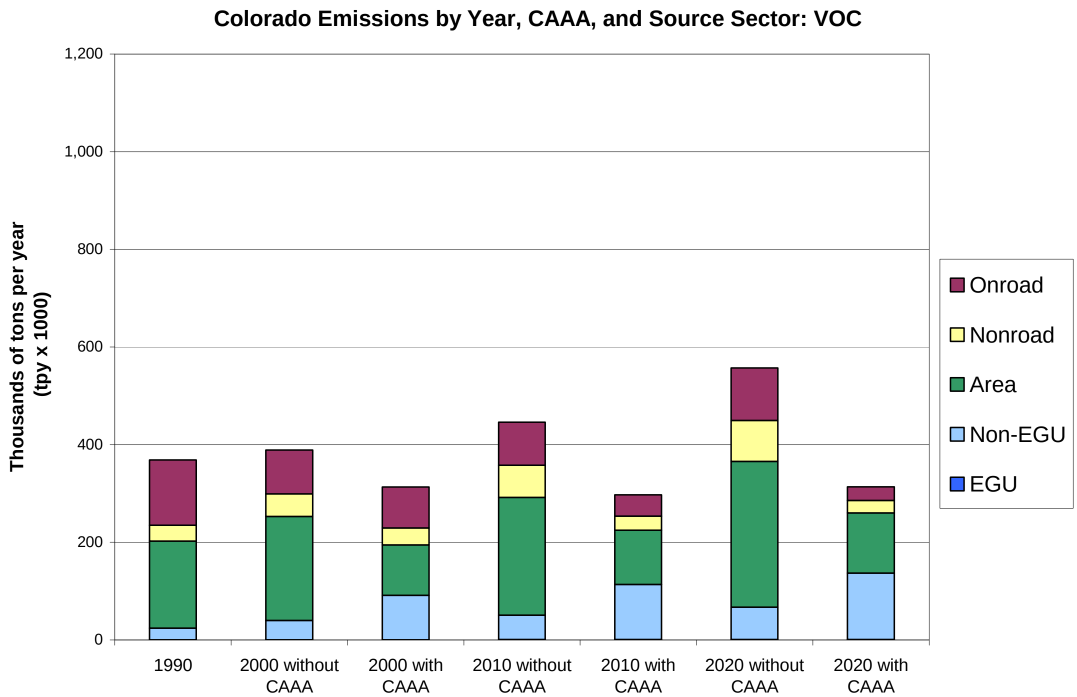


Figure III-4f. Emission Totals for VOC for the 812 Modeling Analysis Scenarios for Washington.

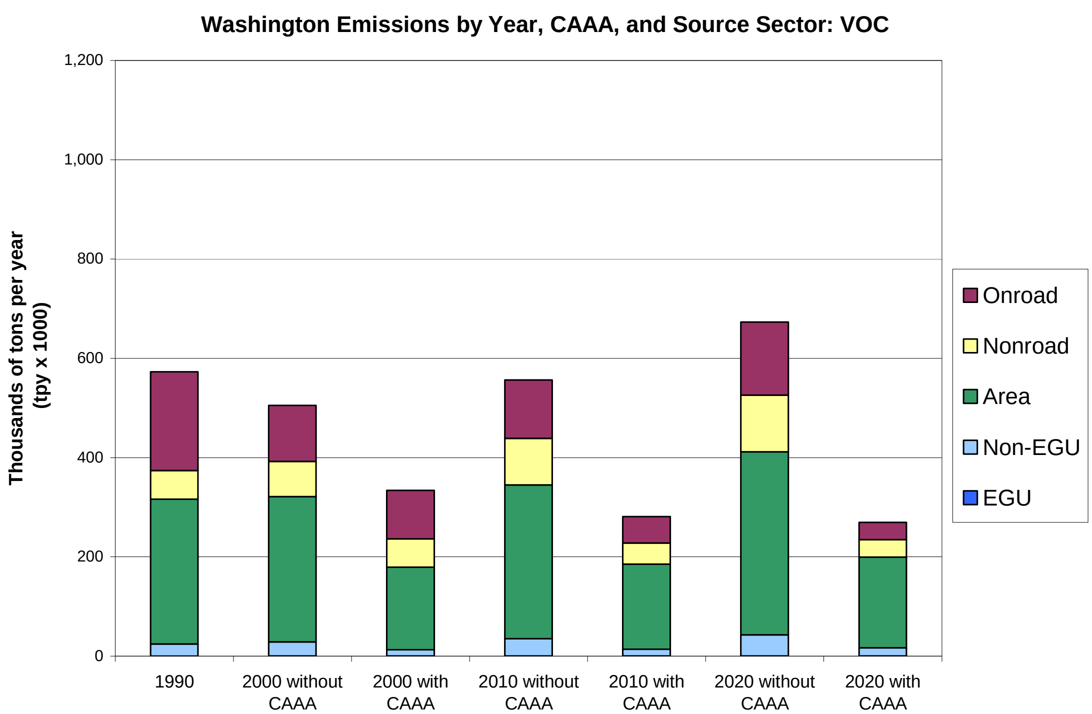


Figure III-5a. Emission Totals for NO_x for the 812 Modeling Analysis Scenarios for Massachusetts.

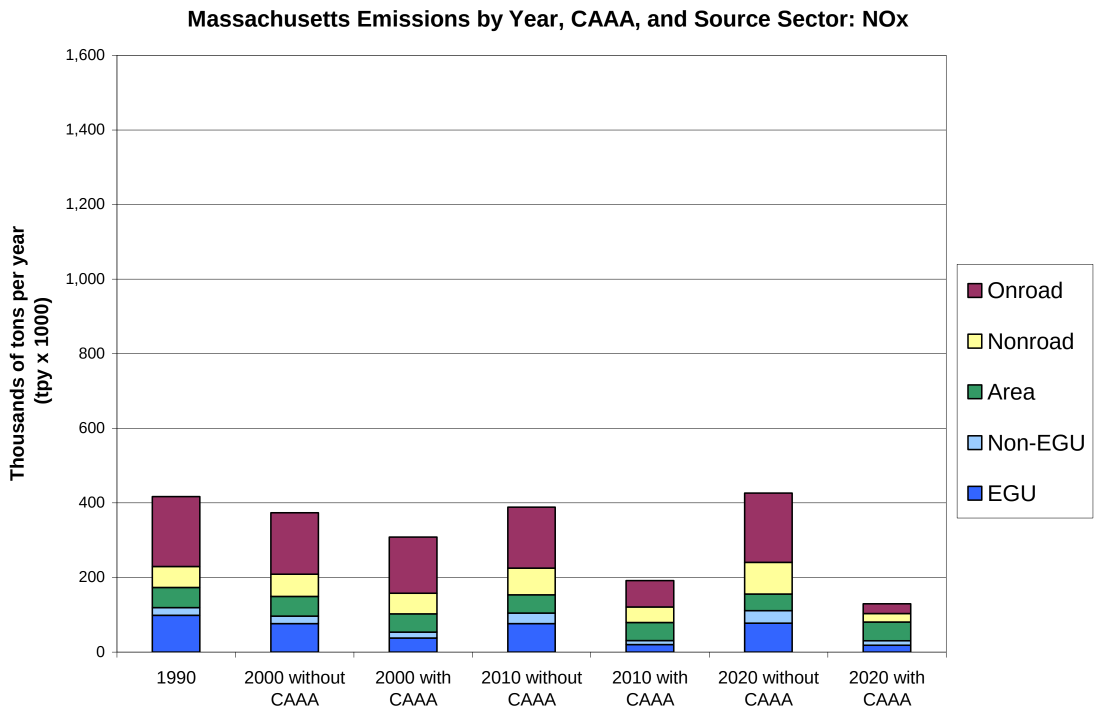


Figure III-5b. Emission Totals for NO_x for the 812 Modeling Analysis Scenarios for Pennsylvania.

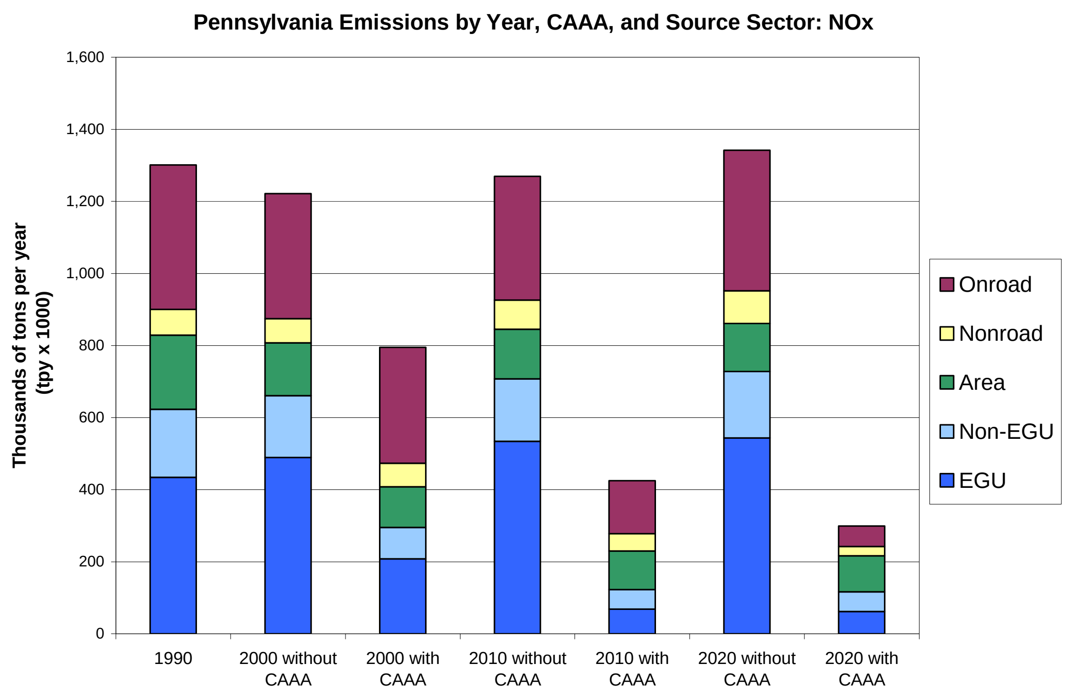


Figure III-5c. Emission Totals for NO_x for the 812 Modeling Analysis Scenarios for Georgia.

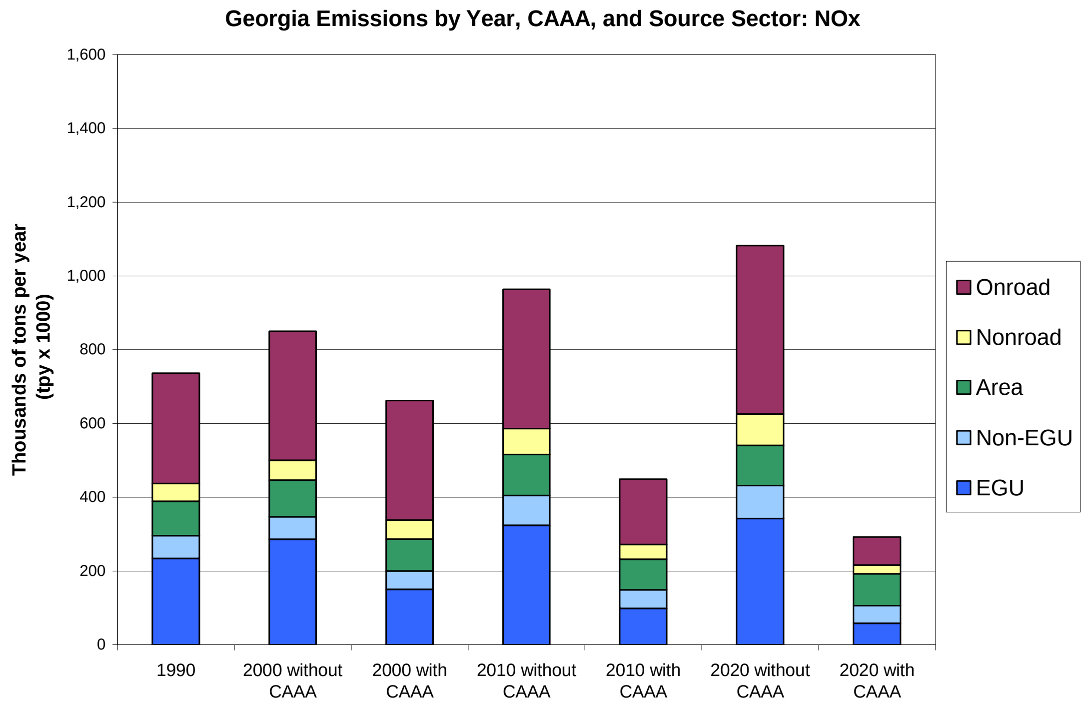


Figure III-5d. Emission Totals for NO_x for the 812 Modeling Analysis Scenarios for Illinois.

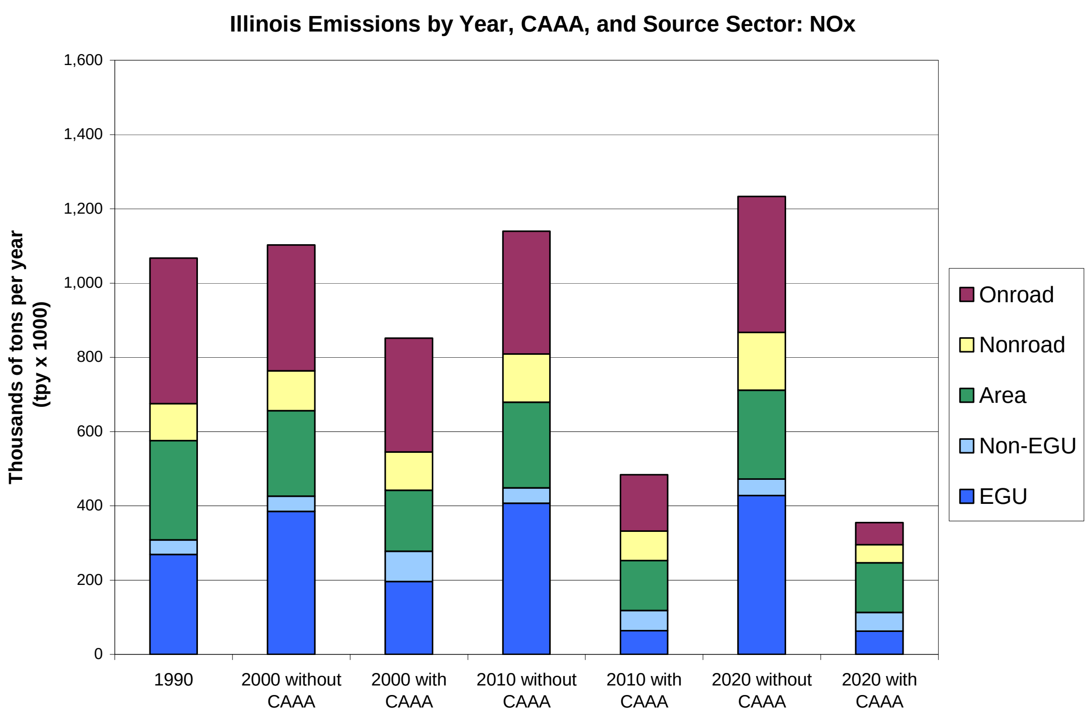


Figure III-5e. Emission Totals for NO_x for the 812 Modeling Analysis Scenarios for Colorado.

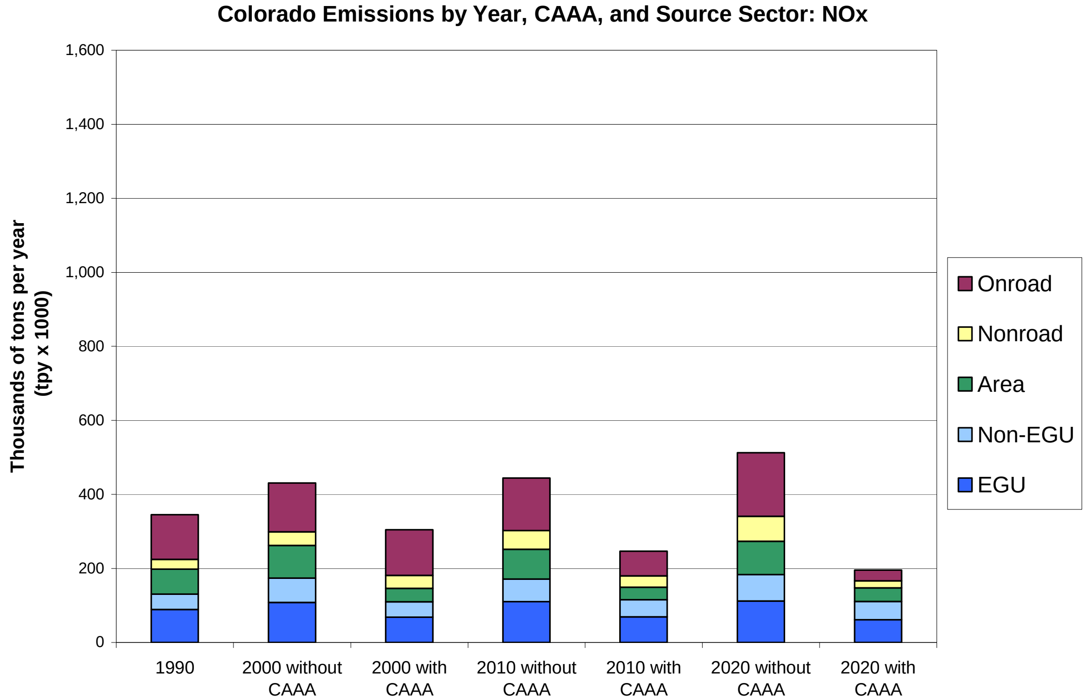


Figure III-5f. Emission Totals for NO_x for the 812 Modeling Analysis Scenarios for Washington.

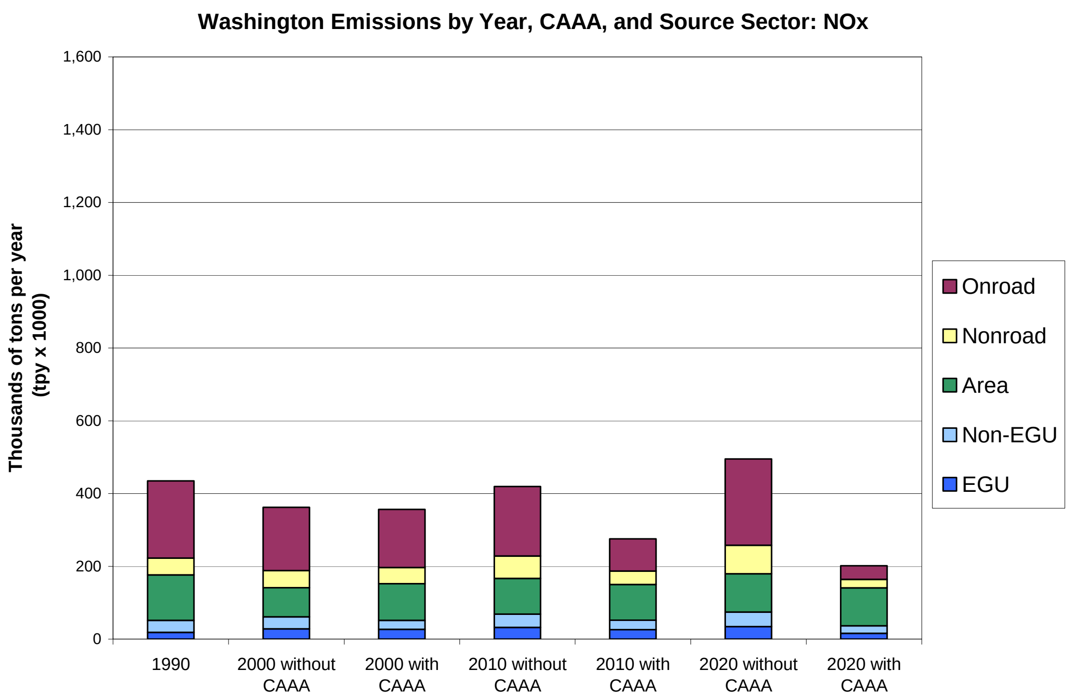


Figure III-6a. Emission Totals for SO_2 for the 812 Modeling Analysis Scenarios for Massachusetts.

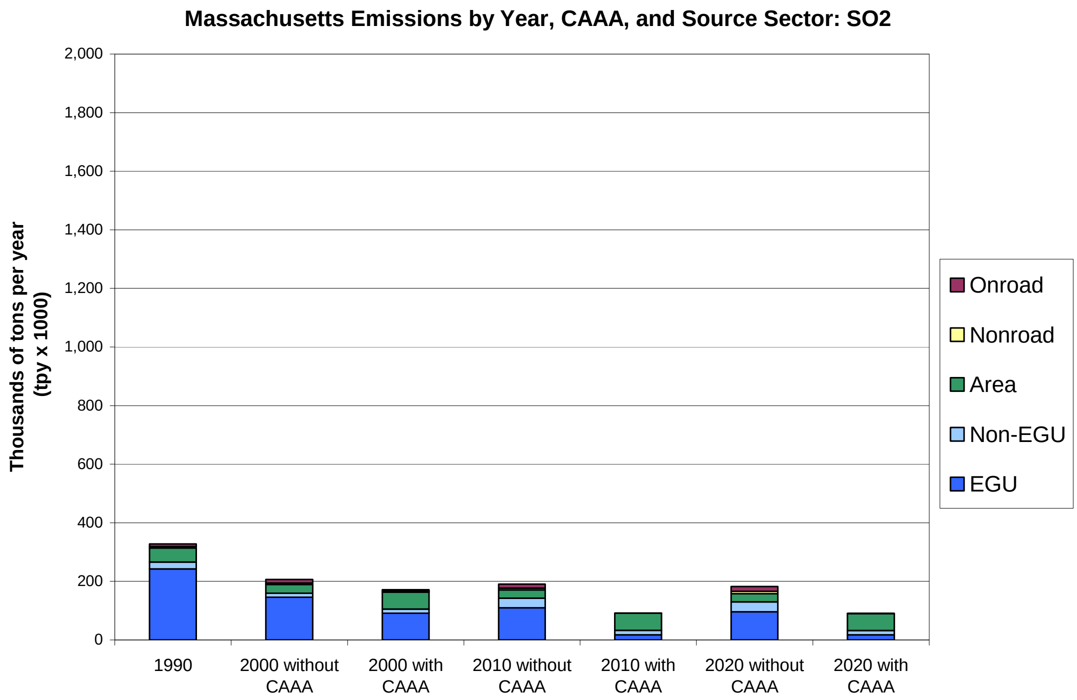


Figure III-6b. Emission Totals for SO_2 for the 812 Modeling Analysis Scenarios for Pennsylvania.

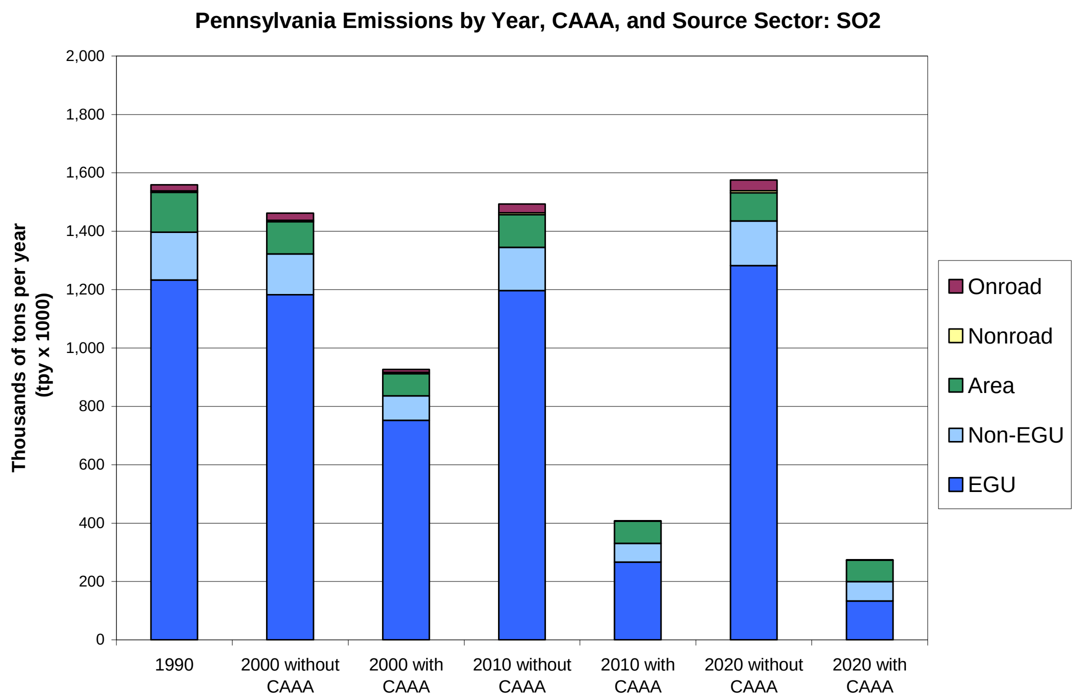


Figure III-6c. Emission Totals for SO_2 for the 812 Modeling Analysis Scenarios for Georgia.

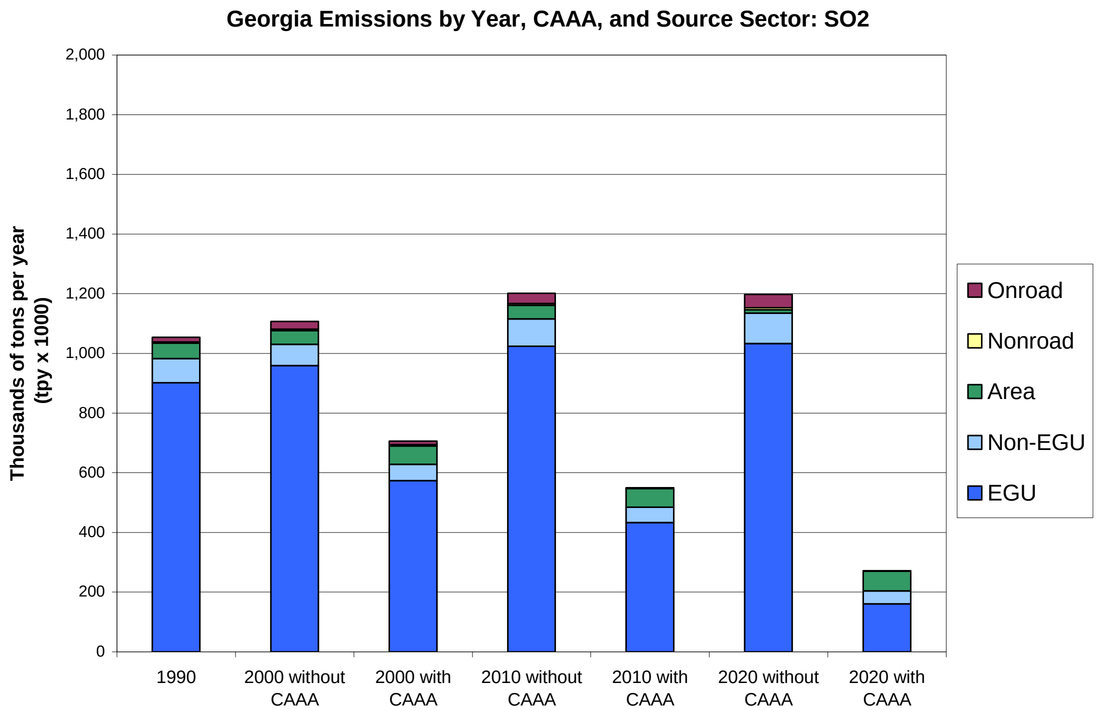


Figure III-6d. Emission Totals for SO_2 for the 812 Modeling Analysis Scenarios for Illinois.

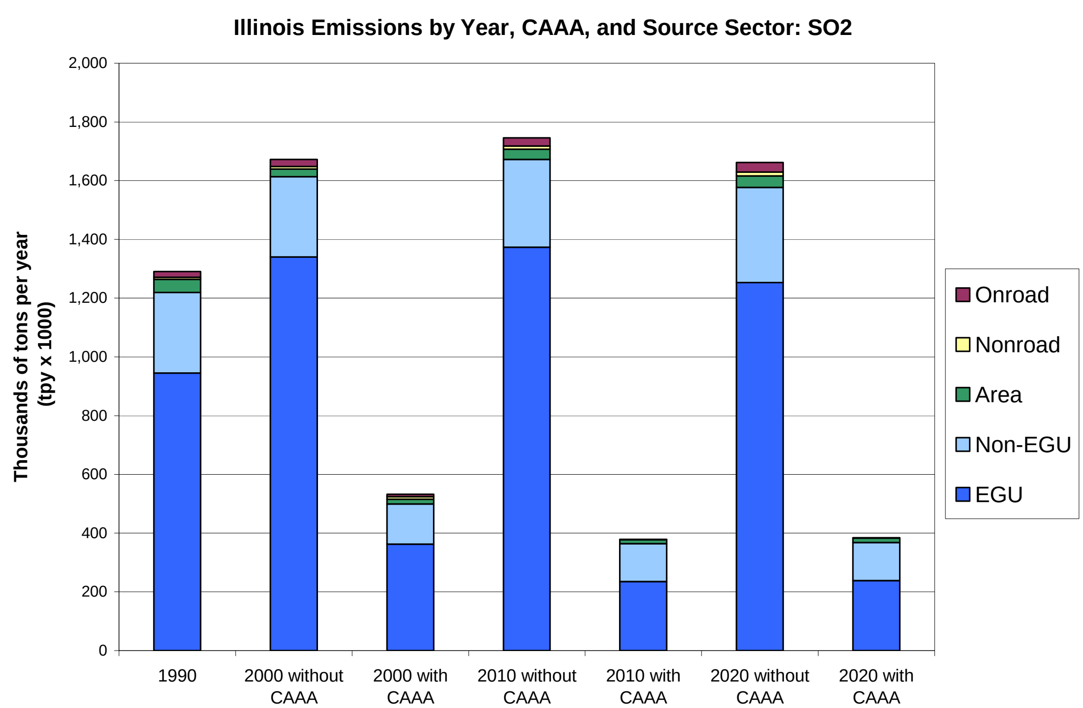


Figure III-6e. Emission Totals for SO_2 for the 812 Modeling Analysis Scenarios for Colorado.

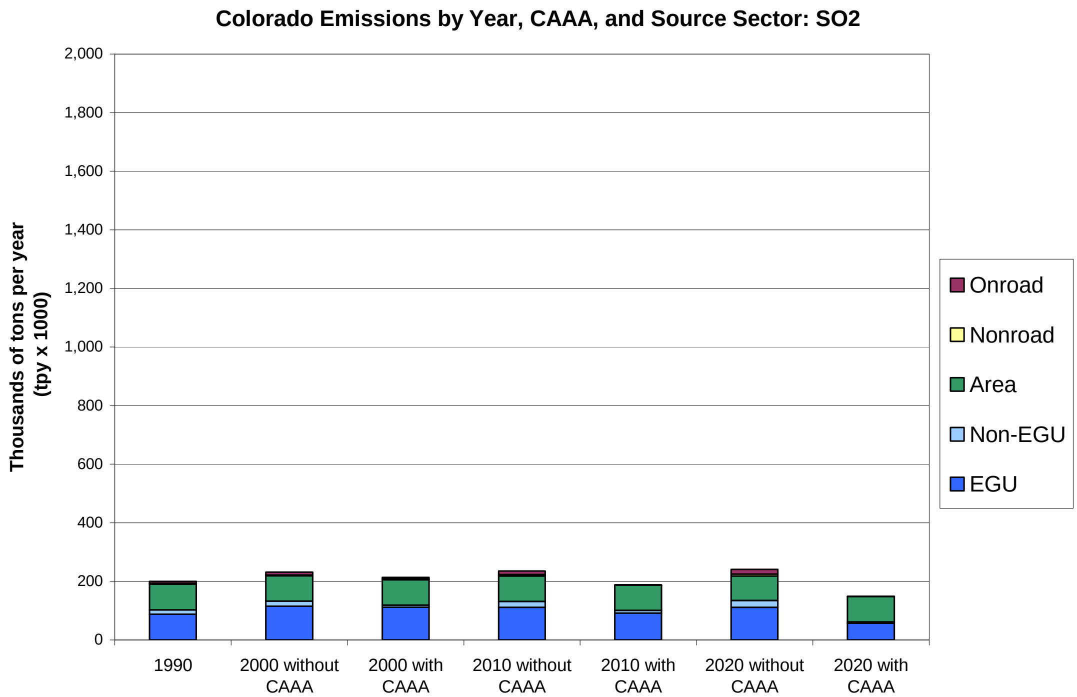


Figure III-6f. Emission Totals for SO_2 for the 812 Modeling Analysis Scenarios for Washington.

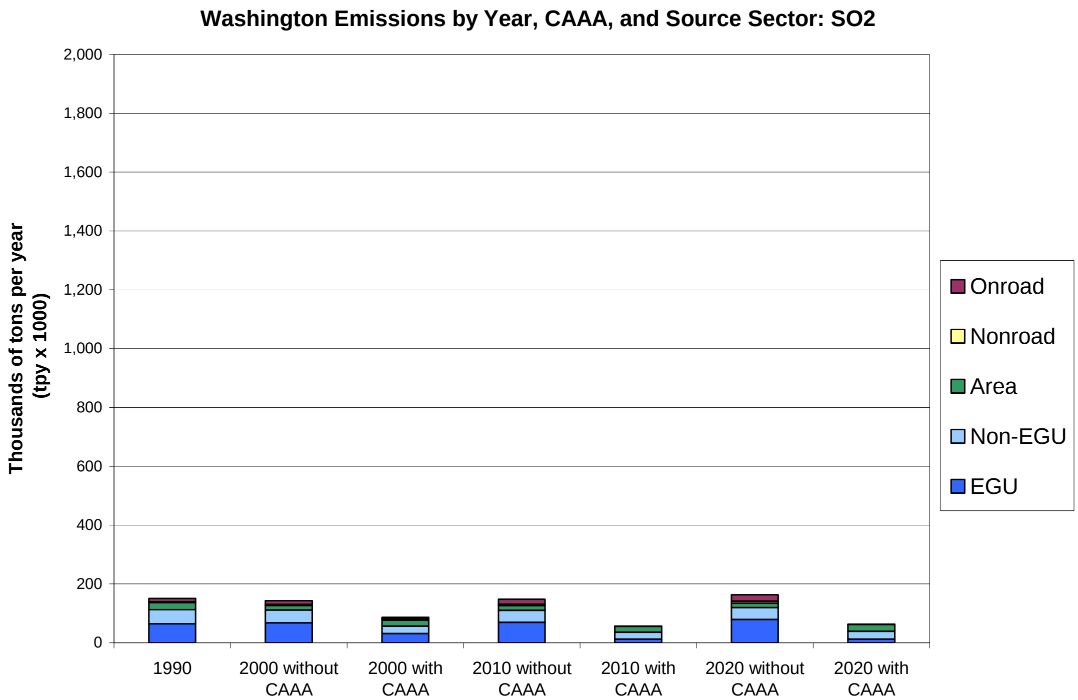


Figure III-7a. Emission Totals for $PM_{2.5}$ for the 812 Modeling Analysis Scenarios for Massachusetts.

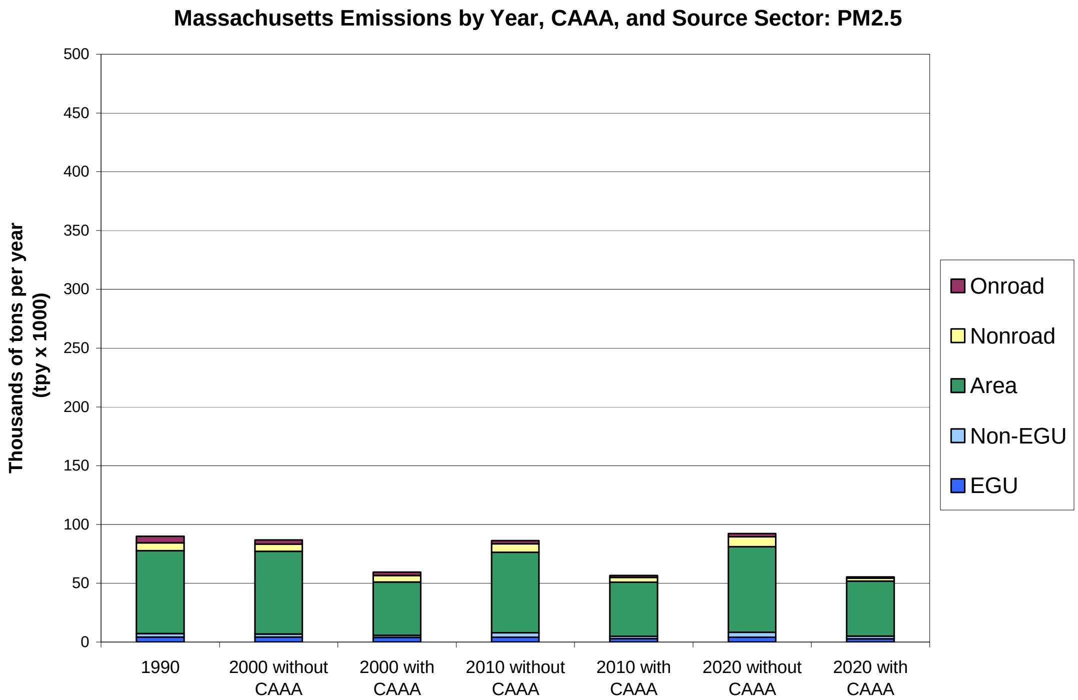


Figure III-7b. Emission Totals for $PM_{2.5}$ for the 812 Modeling Analysis Scenarios for Pennsylvania.

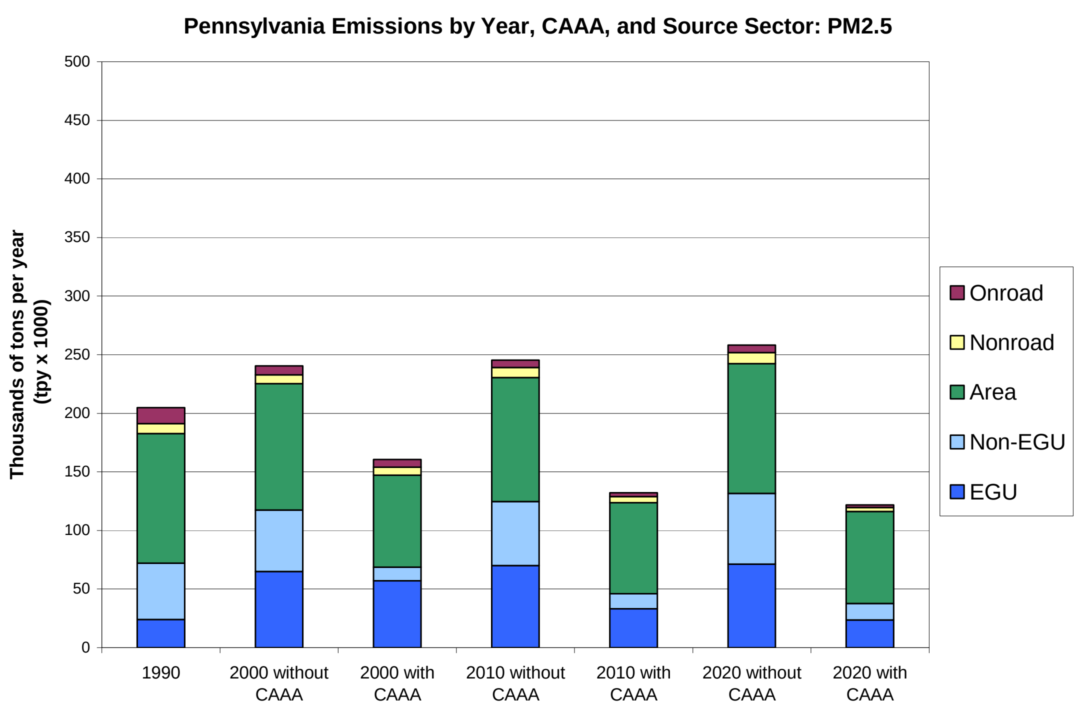


Figure III-7c. Emission Totals for $PM_{2.5}$ for the 812 Modeling Analysis Scenarios for Georgia.

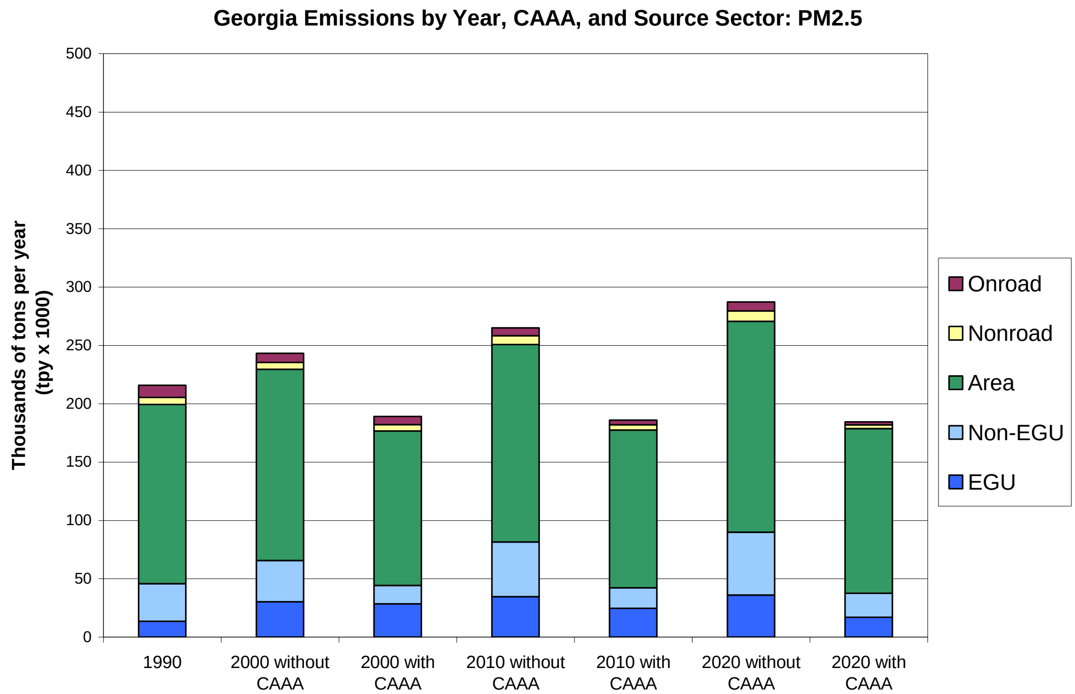


Figure III-7d. Emission Totals for $PM_{2.5}$ for the 812 Modeling Analysis Scenarios for Illinois.

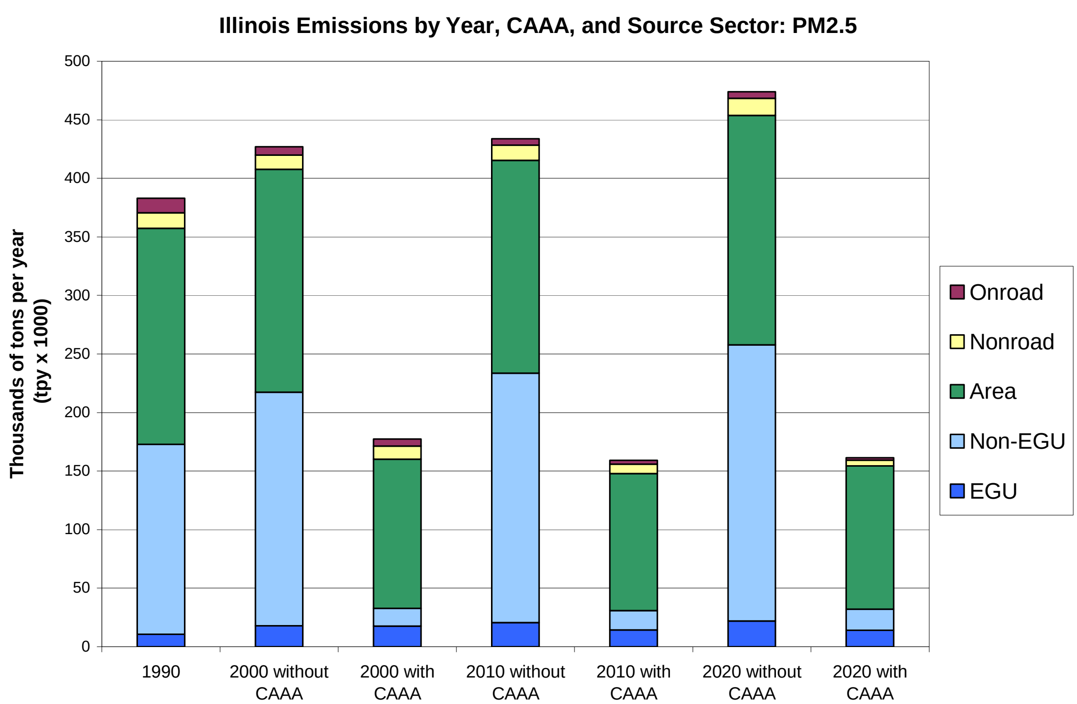


Figure III-7e. Emission Totals for $PM_{2.5}$ for the 812 Modeling Analysis Scenarios for Colorado.

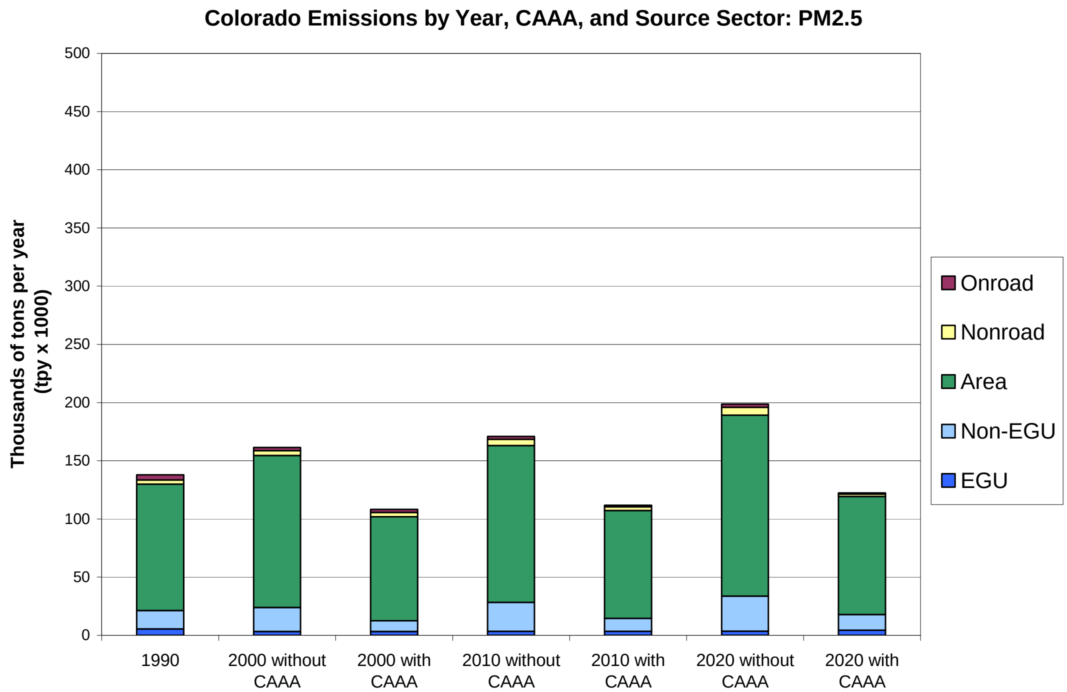
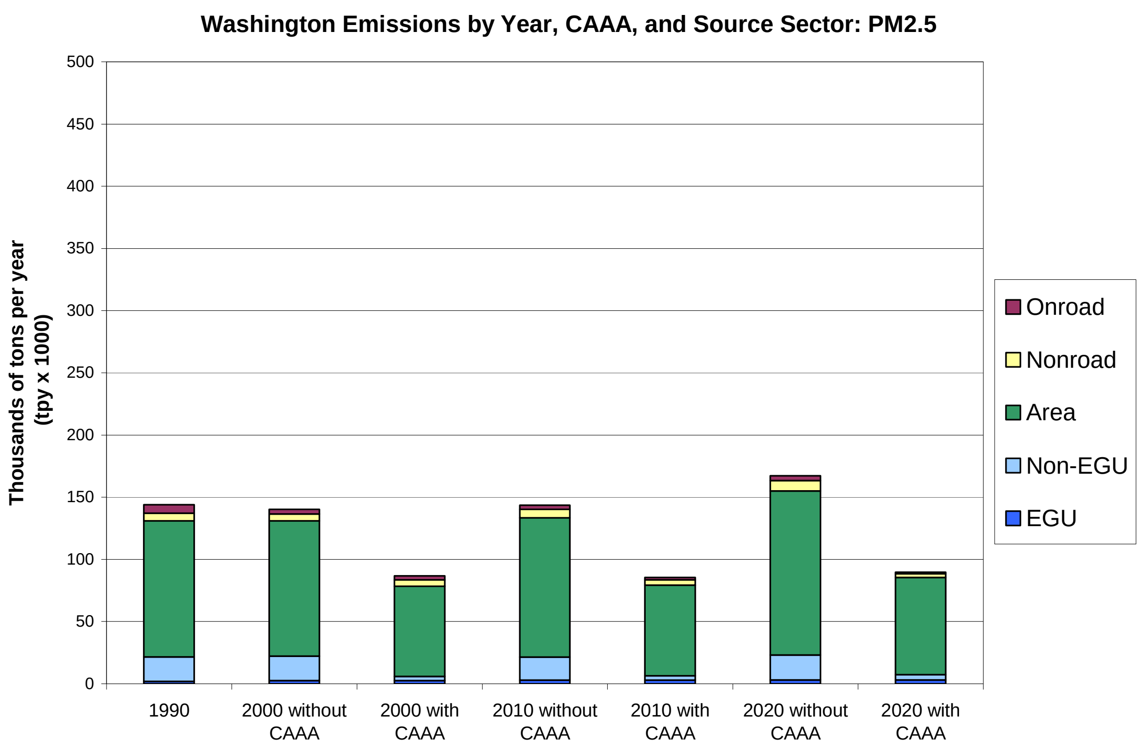


Figure III-7f. Emission Totals for $PM_{2.5}$ for the 812 Modeling Analysis Scenarios for Washington.



The state anthropogenic VOC emission totals presented in Figure III-4 are consistent with the national estimates and are dominated by on-road mobile and area sources. They reflect similar expected increases in emissions for the without-CAAA inventories (due to growth in population and activity) and similar decreases in emissions for the with-CAAA inventories, reflecting both growth and applicable control programs. The expected reductions in VOC emissions are derived from controls primarily from the on-road mobile sector, with additional reductions derived from all other sectors, with the exception of EGUs. The differences in magnitude of the VOC emissions reflect mainly state-by-state differences in population and accompanying motor vehicle activity, with Pennsylvania having the highest anthropogenic VOC emissions and Colorado having the lowest, of these states.

The state-specific NOx and SO_2 emissions totals presented in Figures III-5 and III-6, respectively, reflect differences in both population and the location of major EGU sources. Of the states presented, Pennsylvania and Illinois have the highest emissions and contribution of EGU sources while the states of Colorado and Washington have the lowest. The expected future-year reductions in NOx emissions are derived from both the on-road mobile and EGU sectors, while the expected future-year reductions in SO_2 are from the EGU sector.

For the state-specific $PM_{2.5}$ emissions, the source sector totals also reflect the types of sources operating in each of the states, with some states (e.g., Pennsylvania and Illinois) showing higher percentage contributions from non-EGU sources, reflecting industrial activity, compared to the State of Massachusetts, with a small number of non-EGU point sources. The expected future-year $PM_{2.5}$ emission reductions resulting from the CAAA are quite large for non-EGU sources (greater than 50 percent reduction) in Pennsylvania, Georgia, Colorado, and Washington, with an expected reduction of over 90 percent for the State of Illinois, likely the result of controls on metal processing and other industrial activity in the Greater Chicago area. This results in expected reductions in primary $PM_{2.5}$ emissions in these areas of 40-60 percent, which could greatly affect the locally simulated $PM_{2.5}$ concentrations for these areas. This will also depend on the local chemistry and resulting composition of total PM.

Section IV
Air Quality Modeling

Overview of the CMAQ Modeling System

The Community Multiscale Air Quality (CMAQ) model is a state-of-the-science, regional air quality modeling system that can be used to simulate the physical and chemical processes that govern the formation, transport, and deposition of gaseous and particulate species in the atmosphere (Byun and Ching, 1999). The CMAQ tool was designed to improve the understanding of air quality issues (including the physical and chemical processes that influence air quality) and to support the development of effective emissions control strategies on both the regional and local scale. The CMAQ model was designed as a "one-atmosphere" model and this concept refers to the ability of the model to dynamically simulate ozone, particulate matter, and other species (such as mercury) in a single simulation. In addition to addressing a variety of pollutants, CMAQ can be applied to a variety of regions (with varying geographical, land-use and emissions characteristics) and for a range of different space and time scales.

Numerous recent applications of the model, for both research and regulatory air quality planning purposes, have focused on the simulation of ozone and fine particulate matter ($PM_{2.5}$). The CMAQ model was used by EPA to support the development of the Clean Air Interstate Rule (CAIR) (EPA, 2005).

The CMAQ model numerically simulates the physical processes that determine the magnitude, temporal variation and spatial distribution of the concentrations of ozone and particulate species in the atmosphere and the amount, timing, and distribution of their deposition to the earth's surface. The simulation processes include advection, dispersion (or turbulent mixing), chemical transformation, cloud processes, and wet and dry deposition. The CMAQ science algorithms are described in detail by Byun and Chang (1999(.

The CMAQ model requires several different types of input files. Gridded, hourly emission inventories characterize the release of anthropogenic, biogenic and, in some cases, geogenic emissions from sources within the modeling domain. The emissions represent both low-level and elevated sources and a variety of source categories (including, for example, point, on-road mobile, non-road mobile, area, and biogenic). The amount and spatial and temporal distribution of each emitted pollutant or precursor species are key determinants to the resultant simulated air quality values.

The CMAQ model also requires hourly, gridded input fields of several meteorological parameters including wind, temperature, mixing ratio, pressure, solar radiation, fractional cloud cover, cloud depth, and precipitation. A full list of the meteorological input parameters is given in Byun and Chang (1999). The meteorological input fields are typically prepared using a data-assimilating prognostic meteorological model, the output of which is processed for input to the CMAQ model using the Meteorology-Chemistry Interface Processor (MCIP). The prescribed meteorological conditions influence the transport, vertical mixing, and resulting distribution of the simulation pollutant concentrations. Certain of the meteorological parameters, such as mixing ratio, can also influence the simulated chemical reaction rates. Rainfall and near-surface meteorological characteristics govern the wet and dry deposition, respectively, of the simulated atmospheric constituents.

Initial and boundary conditions (IC/BC) files provide information on pollutant concentrations throughout the domain for the first hour of the first day of the simulation, and along the lateral and top boundaries of the domain for each hour of the simulation. Photolysis rates and other chemistry related input files supply information needed by the gas-phase and particulate chemistry algorithms.

The latest available version of CMAQ, version 4.6, was used for this study. This version of the model supports several different gas-phase chemical mechanism, particle treatment, aerosol deposition, and cloud treatment options. All simulations conducted as part of this study used the CB05 chemical mechanism. For particles, the AERO4 particle treatment, which includes sea salt, was applied. For selected scenarios, the CMAQ Particle and Precursor Tagging Methodology (PPTM) (Douglas et al., 2007) was used to quantify the contribution of the emissions from selected source categories to the simulated $PM_{2.5}$ concentrations. Finally, the plume-in-grid feature of CMAQ was not used for this study.

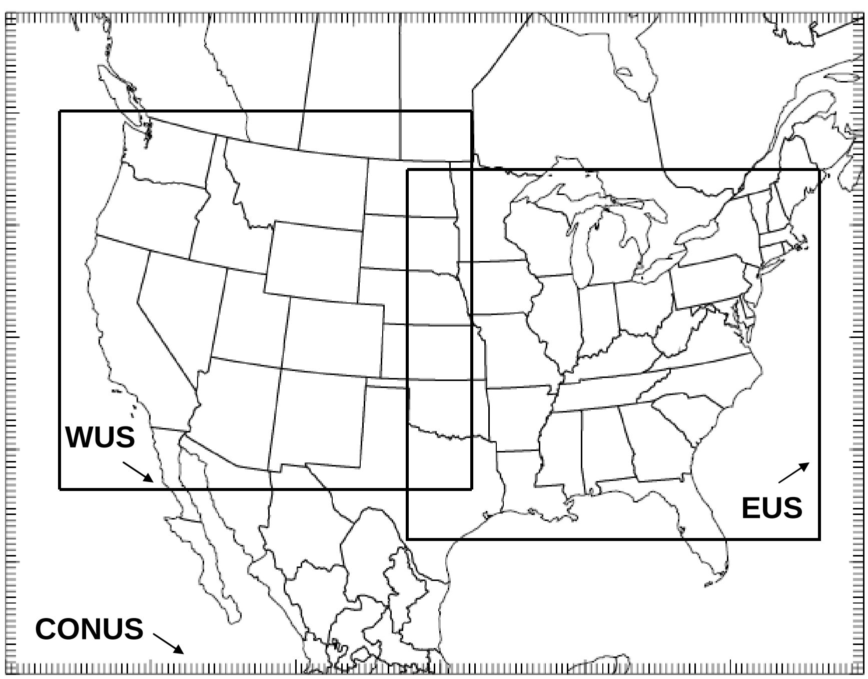
CMAQ Application Procedures for the §812 Prospective Analysis

The application of CMAQ, including the modeling domains, simulation periods, input files (with the exception of the emission inventories), and post-processing and quality assurance procedures are discussed in this section. Preparation of the emission inventories for the application of CMAQ was discussed in detail in the previous section.

Modeling Domains and Simulation Periods

The three modeling domains that were used for this analysis are shown in Figure IV-1.

Figure IV-1. CMAQ Modeling Domains for the 812 Modeling Study.



The 36-km resolution continental U.S. (CONUS) domain is the large area that is covered by the outer grid box. The CONUS domain includes 148 x 112 grid cells. The tick marks denote the 36-km grid cells. For this domain, the model was run for the entire 2002 calendar year. In running the model, the annual simulation period was divided into two parts covering January through June and July through December, respectively. Each part of the simulation also includes an additional five start-up simulation days, which are intended to reduce the influence of uncertainties in the initial conditions on the simulation results.

The Eastern U.S. (EUS) domain is comprised of 213 x 188 grid cells and the Western U.S. (WUS) domain includes 213 by 192 grid cells. Together these two domains cover most of the continental U.S. with 12-km horizontal resolution. There is some overlap in the central part of the country. For both the EUS and WUS domains, the CMAQ model was run for the months of May through September. This five-month period is intended to represent the ozone season. The seasonal simulation period was also divided into two parts covering May and June and July through September, respectively. Each part of the simulation also includes an additional ten start-up simulation days.

Meteorological and Other Input Files

All input files for the application of the CMAQ model, with the exception of the emission inventories, were provided by EPA.

The 36- and 12-km resolution meteorological input files were prepared using the Pennsylvania State University/National Center for Atmospheric Research (PSU/NCAR) Fifth Generation Mesoscale Model (MM5). The MM5 outputs were postprocessed by EPA for input to CMAQ using the Meteorology-Chemistry Interface Processor (MCIP) program. The meteorological input preparation methodology and some information on MM5 model performance are provided by Dolwick et al. (2007). Existing initial condition, boundary condition, land-use and photolysis rate input files prepared by EPA for use in CMAQ modeling for the selected modeling domains and simulation period were used.

Base- and Future-Year Simulations

For each modeling domain, the CMAQ model was applied for seven core CAAA scenarios that include four different years that span a 30-year period – 1990, 2000, 2010 and 2020. As noted earlier, scenarios that incorporate the emission reductions associated with CAA are referred to as with-CAAA while those that do not are referred to as without-CAAA. The scenarios include:

<u>Retrospective Base-Year Scenario</u>
1990 without-CAAA

<u>Base- and Future-Year Scenarios without 1990 CAAA Controls</u>
2000 without-CAAA
2010 without-CAAA
2020 without-CAAA

<u>Base- and Future-Year Scenarios with 1990 CAAA Controls</u>
2000 with-CAAA
2010 with-CAAA
2020 with-CAAA

To aid the analysis and quality assurance of the simulation results, two additional simulations were run using the CMAQ PPTM (source apportionment/contribution) methodology. PPTM was applied for the 2010 without-CAAA and with-CAAA scenarios and for the 36-km CONUS domain. Tags were applied for the following emission source categories: 1) electric generating unit (EGU) sources in the U.S., 2) non-EGU point sources in the U.S., 3) on-road mobile sources in the U.S., 4) non-road mobile sources in the U.S., 5) all other (non-point, non-mobile) sources in the U.S. (area sources), and 6) all other sources (including natural, offshore U.S., and non-U.S. sources). An additional tag was applied to the initial and boundary conditions.

Post-Processing and Quality Assurance Procedures

Quality assurance of the CMAQ runs included the following steps:

Scripts were routinely checked to ensure that the correct input files and output file names were used. Any error messages generated by CMAQ were check and reconciled.

Plots of ozone and selected particulate species were prepared for the 15^{th} day of each month, for each simulation (each grid and each scenario). These were examined and compared with the results for other runs. The concentration patterns and values were checked for reasonableness. For each scenario, month, and each selected species, the results for the 36- and 12-km grids were compared to ensure that the differences were commensurate with those expected from differences in grid resolution. Then for each modeling domain, the results for each month and each scenario were compared to ensure that the differences among the scenarios were consistent with the emissions changes.

The CMAQ modeling results were then incorporated into ACCESS database tools, one for $PM_{2.5}$ for the CONUS domain, one for ozone for the EUS domain, and one for ozone for the WUS domain. These tools are referred as ADVISOR tools, although their functionality, especially for $PM_{2.5}$ goes well beyond that indicated by the original acronym (ACCESS^{TM} Database for the Visualization and Investigation of Strategies for Ozone Reduction). The ADVISOR is an interactive database tool that contains information for review, comparison, and assessment of the CMAQ simulations. The database contains the simulation results (as represented by several different metrics) for the full domain, selected geographical subregions (EPA regions), and selected monitoring site locations. The ADVISOR database also supports application of EPA ozone and $PM_{2.5}$ attainment demonstration procedures (including the calculation of site-specific relative reduction factors and estimated design values).

For ozone, the ADVISOR metrics include daily maximum 1-hour ozone concentration (ppb), daily maximum 8-hour ozone concentration (ppb), and several ozone exposure metrics. For selected sites, relative reduction factors and estimated design values (EPA, 2007) can also be calculated and displayed.

For $PM_{2.5}$, the ADVISOR metrics include annual and quarterly average $PM_{2.5}$ concentration (μgm^{-3}), and several $PM_{2.5}$ exposure metrics. For selected sites, relative reduction factors and estimated design values (EPA, 2007) can also be calculated and displayed.

The results for all metrics can be displayed in an absolute or relative (as differences or percent differences). The ADVISOR tools were used extensive to review and compare the CMAQ results, primarily on a seasonal and annual basis.

Several examples of the types of displays that were used to review the modeling results follow.

Figure IV-2 gives two examples for $PM_{2.5}$. Figure IV-2a, presents annual $PM_{2.5}$ exceedance exposure for a threshold of 15 μgm^{-3} for all seven scenarios. $PM_{2.5}$ exceedance exposure is defined here as the amount by which the simulated $PM_{2.5}$ concentration exceeds 15 μgm^{-3}, summed over all grid cells for a selected area and for selected simulation days. In this plot the geographic area includes the EPA Region 3 states. All simulation days are included. The calculated $PM_{2.5}$ exceedance exposure value is highest for the 2020 without-CAAA scenario and lowest for the 2020 with-CAAA scenario. The order of the scenarios indicates that, without the CAAA measures, $PM_{2.5}$ concentrations would be expected to increase with time (due to growth), and that CAAA measures will result in a decrease in $PM_{2.5}$ with time (through 2020). Figure IV-2b displays simulated annual average $PM_{2.5}$ for Pittsburgh for all scenarios. There is a sharp jump to a lower value between the without-CAAA and with-CAAA scenarios, and a more gradual increase (without-CAAA scenarios) or decrease (with-CAAA scenarios) with time.

Figure IV-2a. Sample ADVISOR Display of Annual $PM_{2.5}$ Exceedance Exposure (μgm^{-3}) for EPA Region 3 States for the 812 Modeling Scenarios.

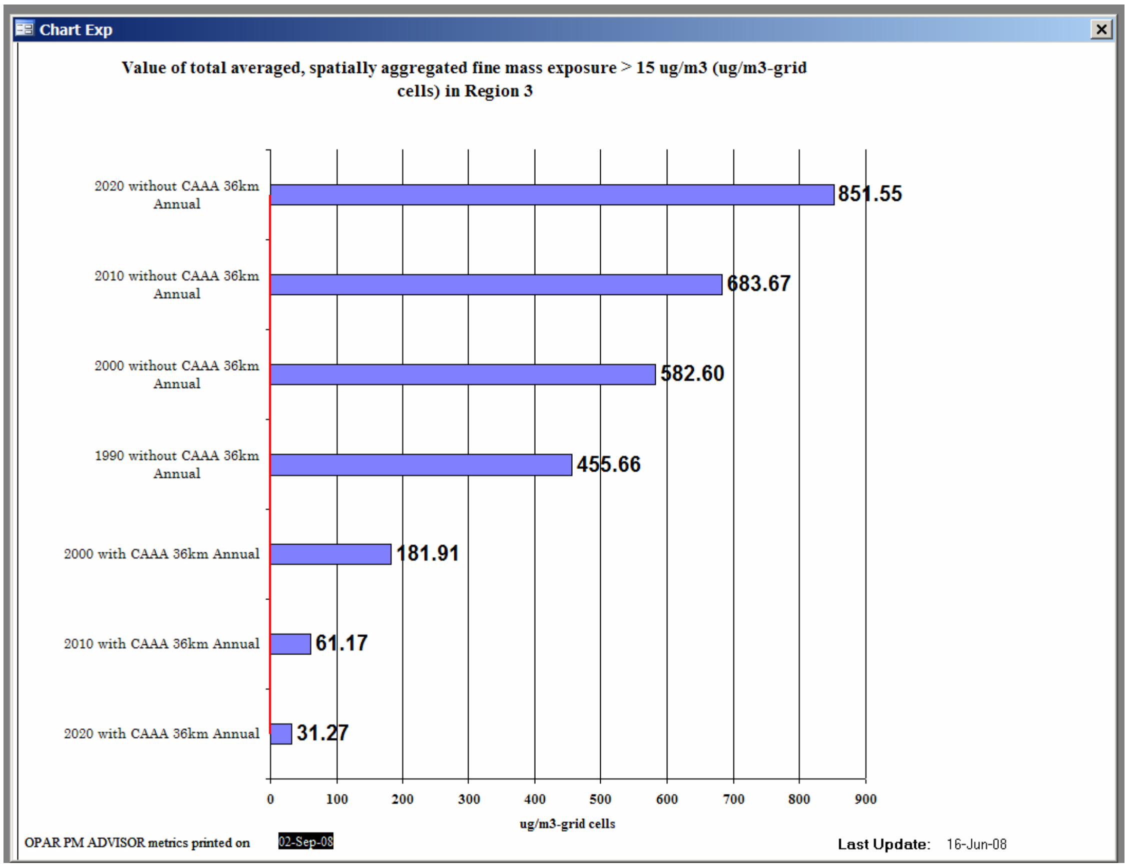


Figure IV-2b. Sample ADVISOR Display of Annual Average $PM_{2.5}$ Concentration (μgm^{-3}) for Pittsburgh for the 812 Modeling Scenarios.

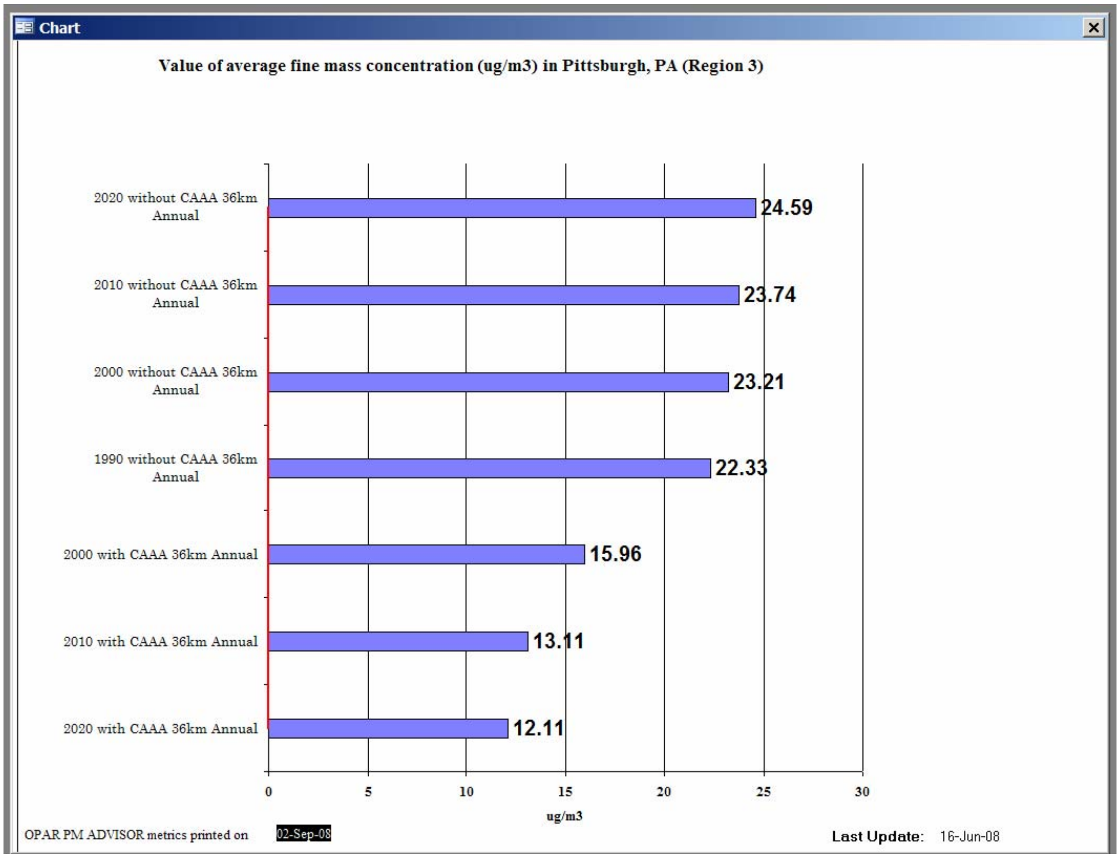


Figure IV-3 gives two examples for ozone. Figure IV-3a, presents 8-hour ozone exceedance exposure greater than 75 ppb for all scenarios and for the entire ozone season. Ozone exceedance exposure is defined here as the amount by which the simulated 8-hour ozone concentration exceeds 75 ppb, summed over all grid cells for a selected area and for selected simulation days. In this plot the geographic area includes the EPA Region 4 states. All simulation (ozone season) days are included. The calculated ozone exceedance exposure value is highest for the 2020 without-CAAA scenario and lowest for the 2020 with-CAAA scenario. The order of the scenarios indicates that without the CAAA measures ozone concentrations would be expected to increase with time (due to growth), and that CAAA measures will result in a decrease in ozone with time (through 2020). Figure IV-3b displays future-year estimated 8-hour ozone design values for Atlanta for the 2010 and 2020 scenarios. Without the CAAA measures, the design value is projected to increase (from a 2002 baseline value of 99 ppb) to 107 ppb by 2010 and to 111 ppb by 2020. When the CAAA measures are included in the modeling, the estimated design values are 86 ppb for 2010 and 74 ppb for 2020. Thus, attainment of the 8-hour ozone standard is expected by 2020.

Figure IV-3a. Sample ADVISOR Display of 8-Hour Ozone Exceedance Exposure (ppb) for EPA Region 4 States for the 812 Modeling Scenarios.

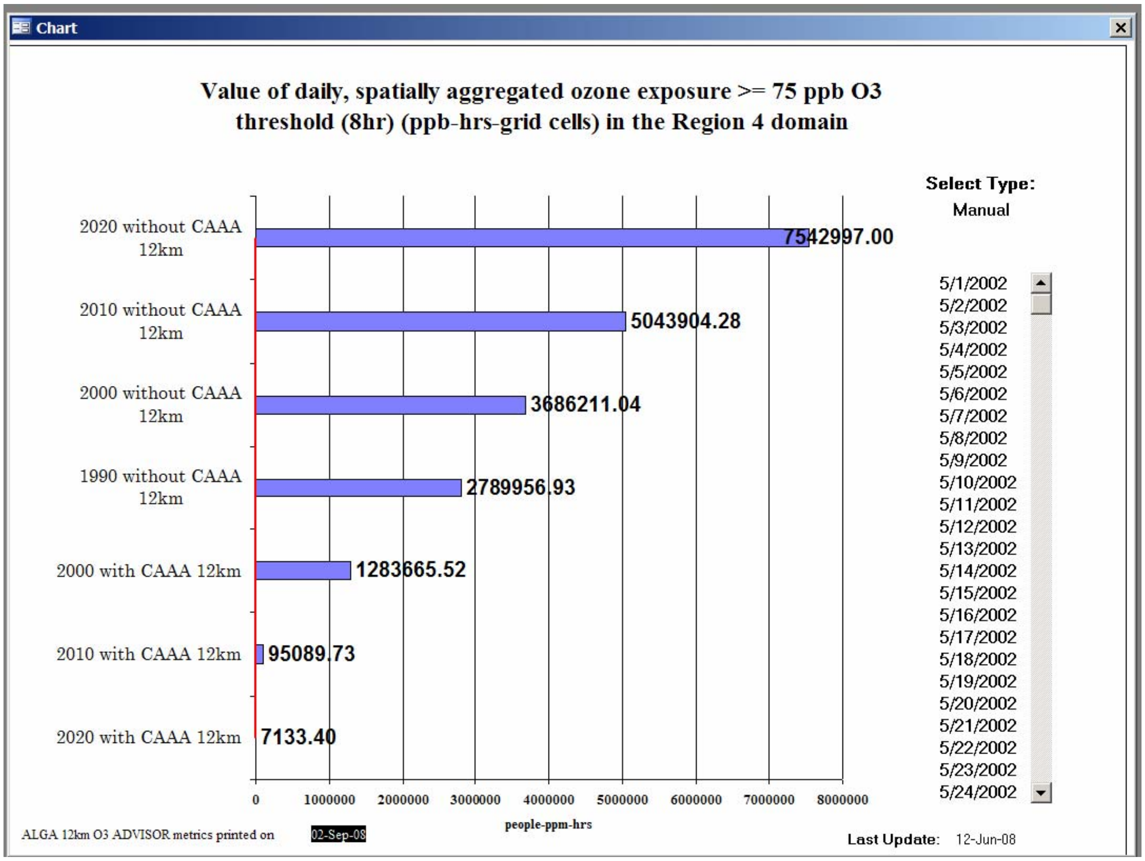
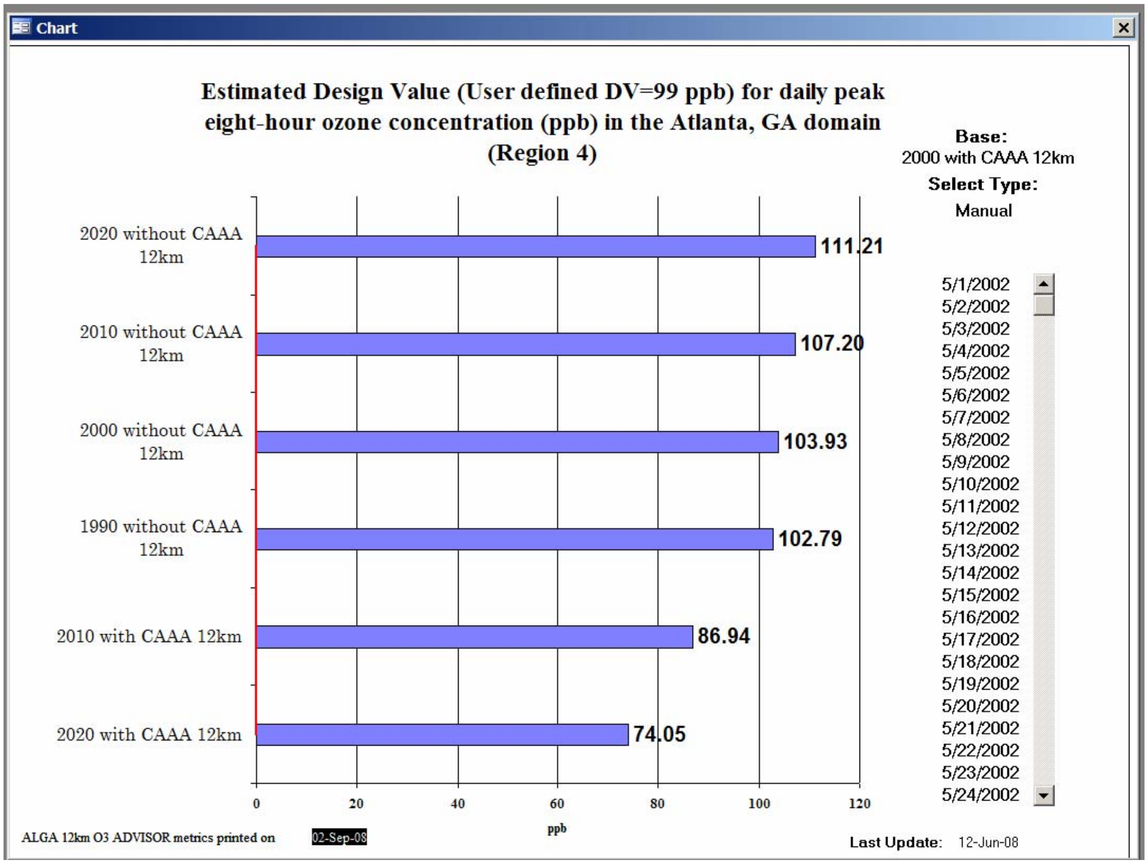


Figure IV-3b. Sample ADVISOR Display of Future-Year 8-Hour Ozone Design Value (ppb) for Atlanta for the 2010 and 2020 812 Modeling Scenarios.



Following the quality assurance of the modeling results, the CMAQ results were postprocessed for input to the health and ecological effects models.

$PM_{2.5}$ and Ozone Modeling Results for the Continental U.S. Modeling Domain

This section of the report provides an overview of the CMAQ modeling results for the 36-km continental U.S. (CONUS) modeling domain. The modeling results for $PM_{2.5}$ are used for the calculation of particulate matter related health effects and to calculate visibility.

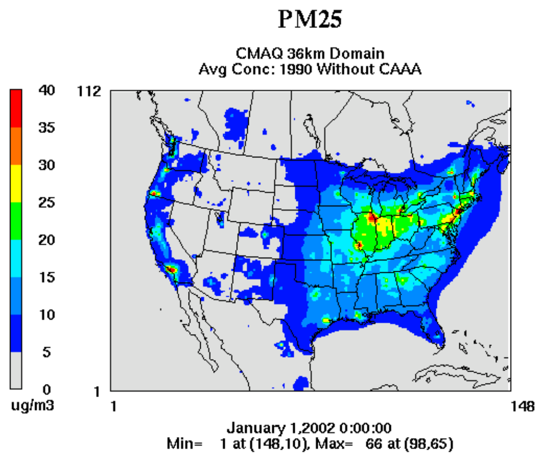
1990 Baseline Simulation

The 1990 scenario represents the base year for the CAAA and therefore this scenario does not include any CAAA measures.

$PM_{2.5}$

Figure IV-4 displays simulated annual average $PM_{2.5}$ concentration (μgm^{-3}) for the CONUS domain. This plot indicates high $PM_{2.5}$ concentrations along the west coast and in the eastern U.S., with localized peak concentrations in the Los Angeles, Chicago, St. Louis, Detroit and New York urban areas. There is also an area of high $PM_{2.5}$ in southwestern Oregon. About 50 percent of the U.S. is characterized by annual average concentrations greater than the current NAAQS of 15 μgm^{-3}.

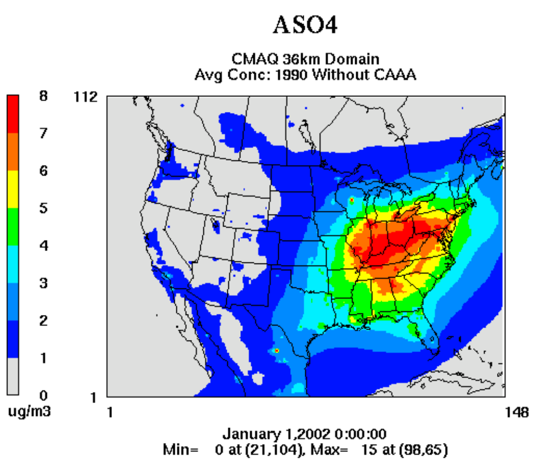
Figure IV-4. Simulated Annual Average $PM_{2.5}$ Concentration (μgm^{-3}) for the CONUS Domain: 1990 Baseline Simulation.



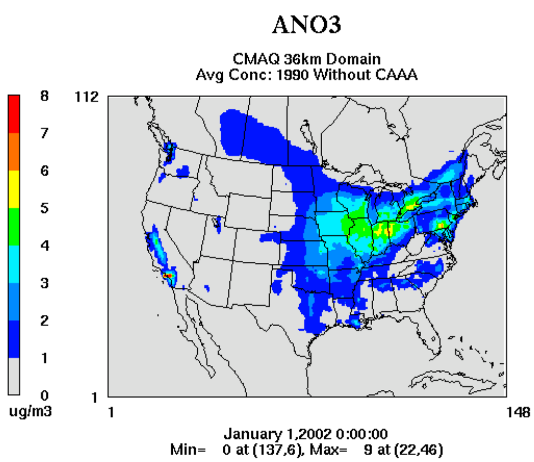
$PM_{2.5}$ is comprised of various components including sulfate, nitrate, organic carbon, and elemental carbon. These component species are plotted in Figure IV-5.

Figure IV-5. Simulated Annual Average $PM_{2.5}$ Species Concentration (μgm^{-3}) for the CONUS Domain: 1990 Baseline Simulation.

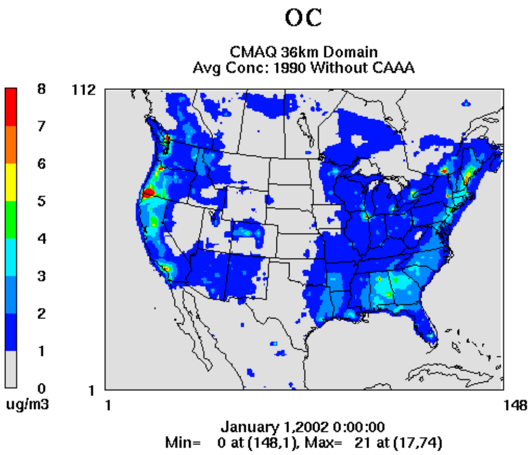
(a) Sulfate



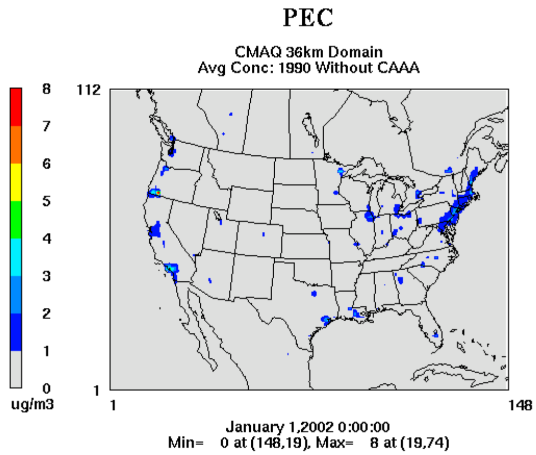
(b) Nitrate



(c) Organic Carbon



(d) Elemental Carbon



For many areas, especially in the eastern U.S., sulfate (Figure IV-5a) represents the highest concentration among the component species. The geographical distribution indicated in the figure occurs partly because humidity is essential to the formation of particulate sulfate (ASO4) and sulfate does not readily form in the dryer (or arid) parts of the western U.S. It is also related to the fact that the majority of SO_2 is emitted from coal-fired power plants of the EGU sector and that most of these plants are located in the eastern half of the country. Organic carbon (Figure IV-5c) is also among the highest of the $PM_{2.5}$ species, especially within the urban areas. Many of the sources contributing to the formation of secondary organic aerosols (such as wood burning for home heating and cooking) are anthropogenic and related to population. Nitrate (ANO3) values (Figure 5-IVb) tend to be highest in the agricultural areas. Nitrate concentrations may derive from a number of different NO_x sources including combustion, the use of nitrogen based fertilizers and livestock operations. Primary elemental carbon (PEC) comprises a relatively smaller portion of $PM_{2.5}$. PEC occurs in both urban and agricultural areas and is associated with road dust other particles caused by on-road and off-road motor vehicles.

Ozone

Figure IV-6 displays simulated daily maximum 8-hour ozone concentration (ppb) for the CONUS domain for the 15th of July. This day was selected as a representative ozone-season day for display of the ozone concentrations for the 36-km domain. The ozone modeling results for the Section 812 benefits analysis were derived using 12-km horizontal resolution grids, and those results are presented in the next two sections. Ozone is shown here only to highlight relative changes in both ozone and $PM_{2.5}$ for the 36-km grid, and the multi-pollutant analysis capabilities of CMAQ.

Figure IV-6. Simulated Daily Maximum 8-Hour Ozone Concentration (ppb) for the CONUS Domain for 15 July: 1990 Baseline Simulation.

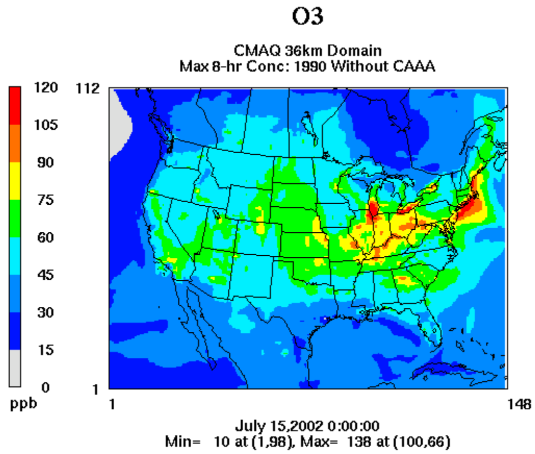


Figure IV-6 indicates that there are relative high ozone concentrations (in excess of the current 8-hour ozone NAAQS level of 75 ppb) in numerous areas throughout the U.S for this day. The highest values occur in the Midwest, along the Northeast Corridor, and in the Atlanta and Los Angeles areas. The ozone concentration pattern reflects a fairly typical summertime meteorological pattern, with an upper-level high pressure ridge over the continental U.S. and surface high pressure systems over northern Illinois and the Four Corners area. The eastern part of the nation had seasonal normal maximum temperatures around 90 degrees Fahrenheit (°F) , while the southwest, Great Basin, and upper plains experienced higher than normal temperatures, with maxima reaching from the mid-90's to over 100 °F in parts of Montana. The winds aloft over much of the U.S. were light and variable.

Without-CAAA2000 and with-CAAA2000 Scenarios

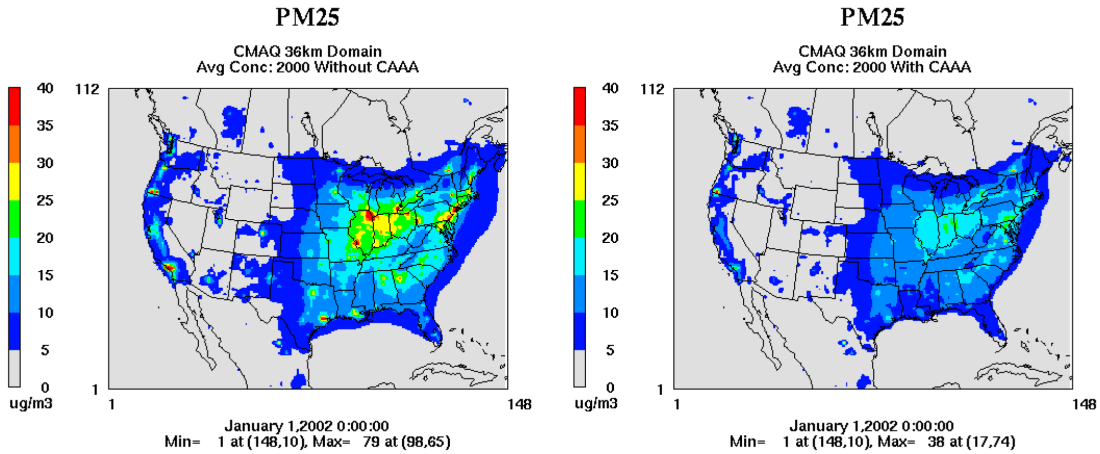
In this analysis, 2000 is the initial year for comparison of the without- and with-CAAA scenarios. The without-CAAA emissions for this year were projected from the 1990 base-year emissions. The with-CAAA emissions were based on emission inventory data for 2000. The emissions are summarized and compared in Section 2.

$PM_{2.5}$

Figure IV-7 displays simulated annual average $PM_{2.5}$ concentration (μgm^{-3}) for the CONUS domain for the 2000 without-CAAA (Figure IV-7a) and 2000 with-CAAA (Figure IV-7b) scenarios.

Figure IV-7. Simulated Annual Average $PM_{2.5}$ Concentration (μgm^{-3}) for the CONUS Domain: 2000 Scenarios.

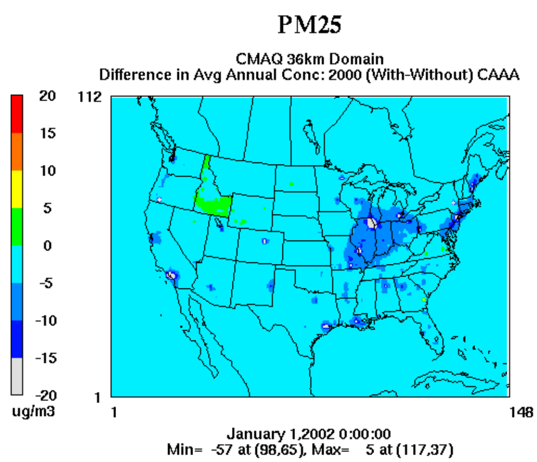
(a) Without CAAA *(b) With CAAA*



The areas of high concentration are reduced significantly with the CAAA measures. This is especially apparent over the Midwest, but reductions are also noticeable over the Northeast and for Los Angeles, Houston, Atlanta and several other urban areas. The domain-wide maximum simulated $PM_{2.5}$ concentration is reduced from 79 to 38 μgm^{-3} and the location of the maximum value moves from near Chicago to southwestern Oregon.

Figure IV-8 illustrates the differences in $PM_{2.5}$ between the two scenarios (with-CAAA minus without-CAAA).

Figure IV-8. Difference in Simulated Annual Average $PM_{2.5}$ Species Concentration (μgm^{-3}) for the CONUS Domain: 2000 With-CAAA Minus 2000 Without-CAAA Scenarios.

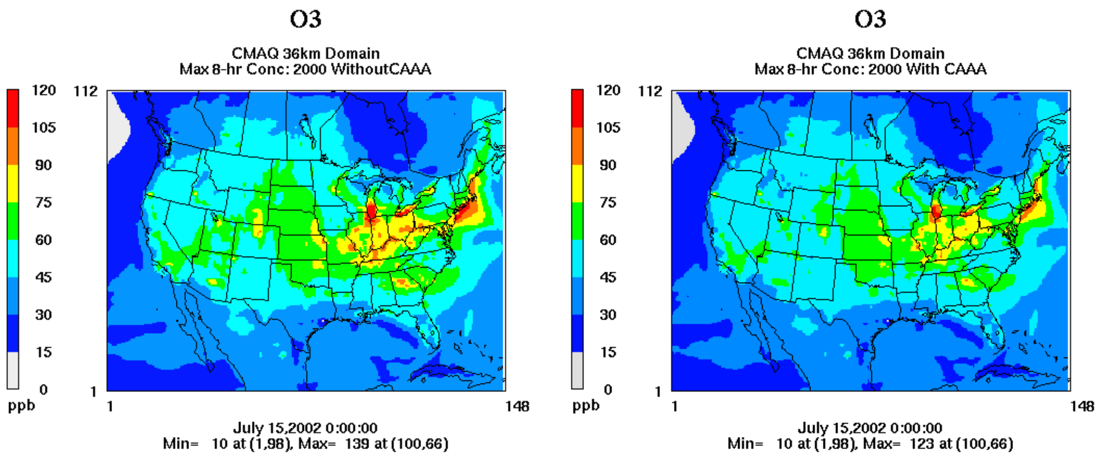


Ozone

This same set of figures is presented for ozone. Figure IV-9 displays simulated daily maximum 8-hour ozone concentration (ppb) for the CONUS domain for the 15th of July for the 2000 without-CAAA (Figure IV-9a) and 2000 with-CAAA (Figure IV-9b) scenarios.

Figure IV-9. Simulated Daily Maximum 8-Hour Ozone Concentration (ppb) for the CONUS Domain for 15 July: 2000 Scenarios.

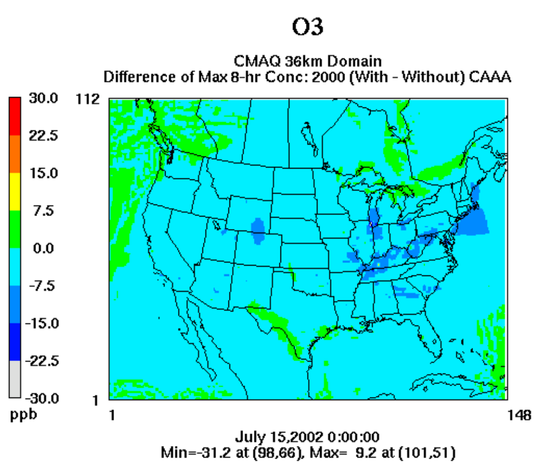
(a) Without CAAA *(b) With CAAA*



As with PM, there is a significant reduction in simulated ozone for 2000 with the inclusion of the CAAA measures. Reductions are notable in the Chicago and Atlanta metropolitan areas, and the Ohio River Valley and Northeast corridor areas. The peak simulated daily maximum concentration within the CONUS grid is reduced from 139 to 123 ppb in the Chicago area.

Figure IV-10 illustrates the differences in 8-hour ozone for this day between the two scenarios (with-CAAA minus without-CAAA).

Figure IV-10. Difference in Simulated Daily Maximum 8-Hour Ozone Concentration (ppb) for the CONUS Domain for 15 July: 2000 With-CAAA Minus 2000 Without-CAAA Scenarios.



In addition to the regions mentioned above, the difference plot indicates that simulated ozone for 2000 is also reduced along the Colorado/Wyoming border and in parts of the mid-South. The daily maximum simulated 8-hour ozone concentration is reduced in the Chicago area by 31 ppb.

Without-CAAA2010 and with-CAAA2010 Scenarios

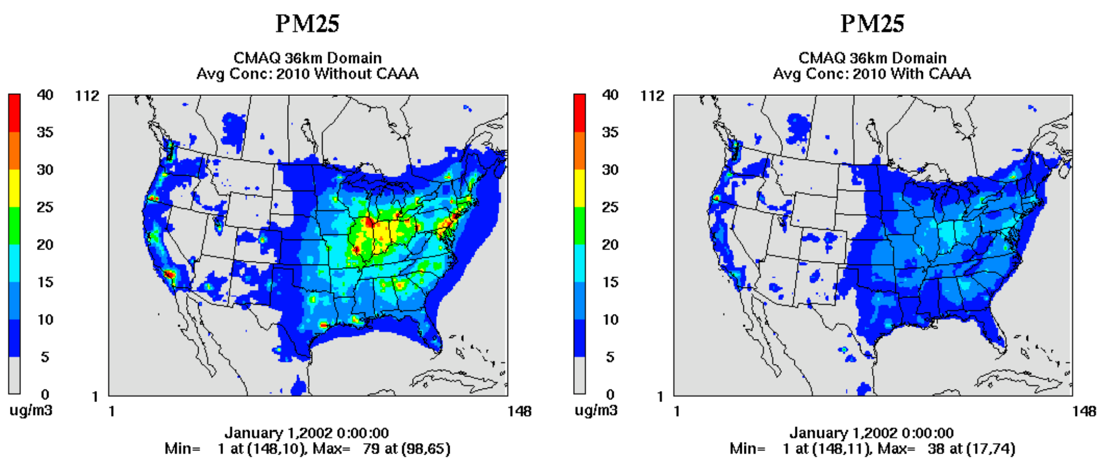
The 2010 without-CAAA emissions were projected from the 1990 base-year emissions. The 2010 with-CAAA emissions were projected from the 2000 base-year emissions. The emissions are summarized and compared in Section 2. The differences in emissions and simulated concentrations between the with- and without-CAAA scenarios are greater than for 2000.

$PM_{2.5}$

Figure IV-11 displays simulated annual average $PM_{2.5}$ concentration (μgm^{-3}) for the CONUS domain for the 2010 without-CAAA (Figure IV-11a) and 2010 with-CAAA (Figure IV-11b) scenarios.

Figure IV-11. Simulated Annual Average $PM_{2.5}$ Concentration (μgm^{-3}) for the CONUS Domain: 2010 Scenarios.

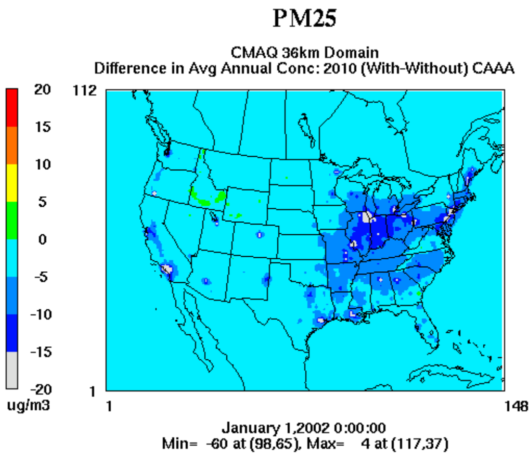
(a) Without CAAA *(b) With CAAA*



The reduction in annual $PM_{2.5}$ is greater than for 2000, due to increases in the without-CAAA concentrations and further decreases in the with-CAAA concentrations between 2000 and 2010. The domain-wide maximum values are unchanged compared to the 2000 scenarios.

Figure IV-12 illustrates the differences in $PM_{2.5}$ between the two scenarios (with-CAAA minus without-CAAA).

Figure IV-12. Difference in Simulated Annual Average $PM_{2.5}$ Species Concentration (μgm^{-3}) for the CONUS Domain: 2010 With-CAAA Minus 2010 Without-CAAA Scenarios.



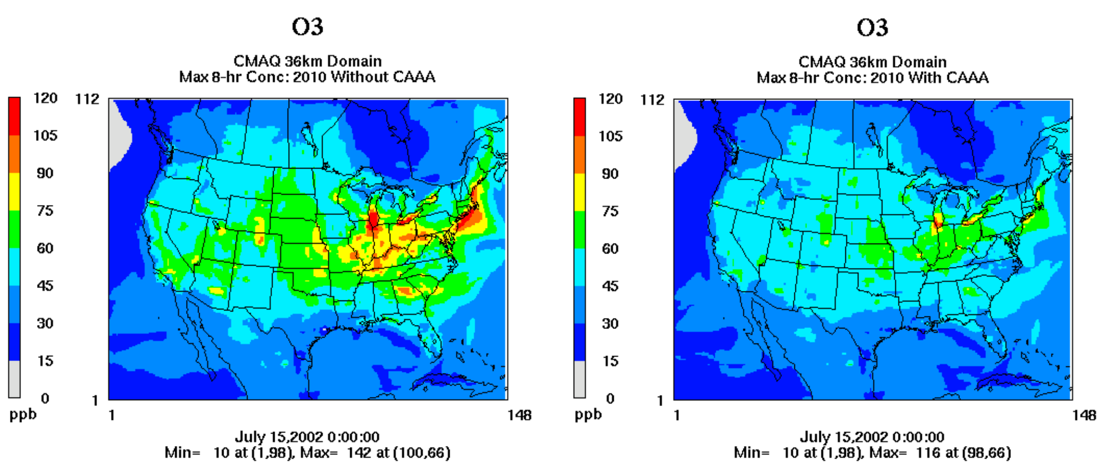
Compared to 2000, the with-CAAA reductions are greater in magnitude and cover a broader area, while the increases cover a smaller area.

Ozone

This same set of figures is presented for ozone. Figure IV-13 displays simulated daily maximum 8-hour ozone concentration (ppb) for the CONUS domain for the 15th of July for the 2010 without-CAAA (Figure IV-13a) and 2010 with-CAAA (Figure IV-13b) scenarios.

Figure IV-13 Simulated Daily Maximum 8-Hour Ozone Concentration (ppb) for the CONUS Domain for 15 July: 2010 Scenarios.

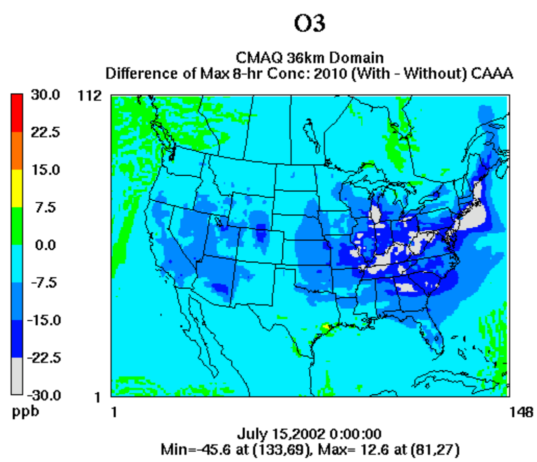
(a) Without CAAA *(b) With CAAA*



In the 2010 without-CAAA scenario, peak simulated ozone and the extent of high ozone are greater than in the 2000 without-CAAA scenario because of the expected increases in precursor emissions due to growth. The hourly peak value for the 2010 without-CAAA scenario increases from 139 ppb in 2000 to 142 ppb in 2010. With the inclusion of CAAA controls, precursor emissions are reduced throughout the domain and resulting simulated ozone concentrations are also reduced dramatically. The peak simulated value for the 2010 with-CAAA scenario is reduced to 116 ppb in the same vicinity of the peak in the 2010 without-CAAA scenario (Chicago area).

Figure IV-14 illustrates the differences in 8-hour ozone for this day between the two scenarios (with-CAAA minus without-CAAA).

Figure IV-14. Difference in Simulated Daily Maximum 8-Hour Ozone Concentration (ppb) for the CONUS Domain for 15 July: 2010 With-CAAA Minus 2010 Without-CAAA Scenarios.



The difference plot shows greater and more extensive reductions in simulated ozone concentrations between these scenarios compared to the year 2000 scenarios.

Without-CAAA2020 and with-CAAA2020 Scenarios

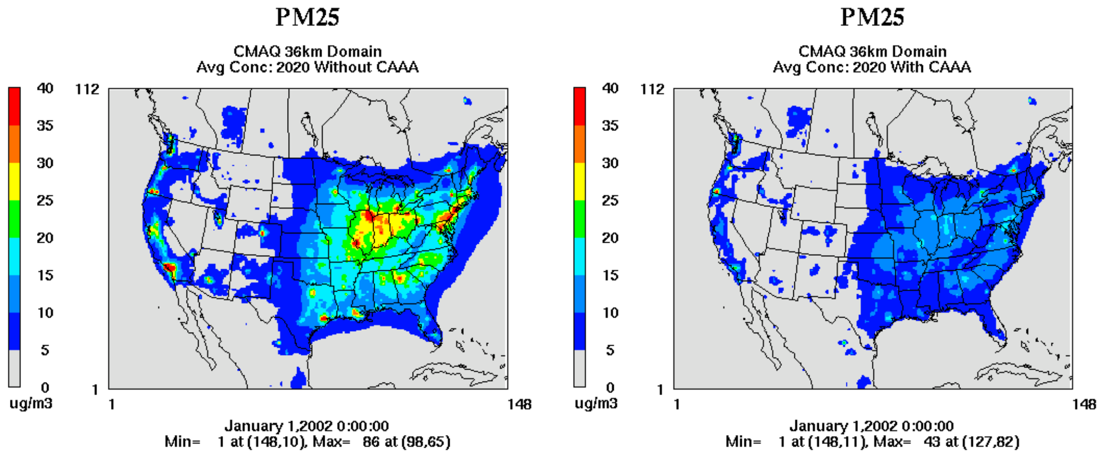
The 2020 without-CAAA emissions were projected from the 1990 base-year emissions. The 2020 with-CAAA emissions were projected from the 2000 base-year emissions. The emissions are summarized and compared in Section 2. The differences in emissions and simulated concentrations between the 2020 with- and without-CAAA scenarios are greater than for the other Section 812 scenario pairs.

$PM_{2.5}$

Figure IV-15 displays simulated annual average $PM_{2.5}$ concentration (μgm^{-3}) for the CONUS domain for the 2020 without-CAAA (Figure IV-15a) and 2020 with-CAAA (Figure IV-15b) scenarios.

Figure IV-15. Simulated Annual Average $PM_{2.5}$ Concentration (μgm^{-3}) for the CONUS Domain: 2020 Scenarios.

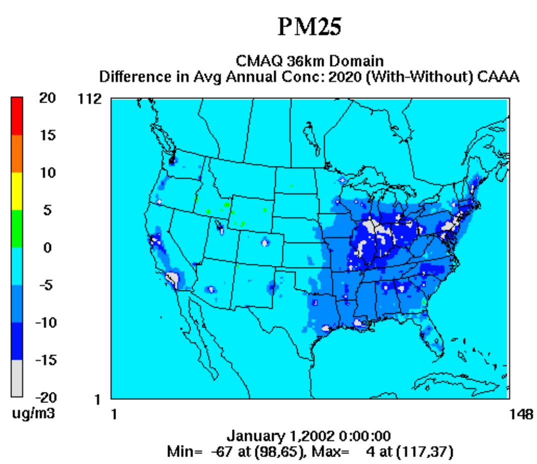
(a) Without CAAA *(b) With CAAA*



Compared to 2010 there are increases in the without-CAAA concentrations and further decreases in the with-CAAA concentrations. By 2020, only a few isolated areas with annual average $PM_{2.5}$ concentrations greater than 15 μgm^{-3} remain. Again, the domain-wide maximum values do not follow this pattern – both are higher than the corresponding 2010 values.

Figure IV-16 illustrates the differences in $PM_{2.5}$ between the two scenarios (with-CAAA minus without-CAAA).

Figure IV-16. Difference in Simulated Annual Average $PM_{2.5}$ Species Concentration (μgm^{-3}) for the CONUS Domain: 2020 With-CAAA Minus 2020 Without-CAAA Scenarios.



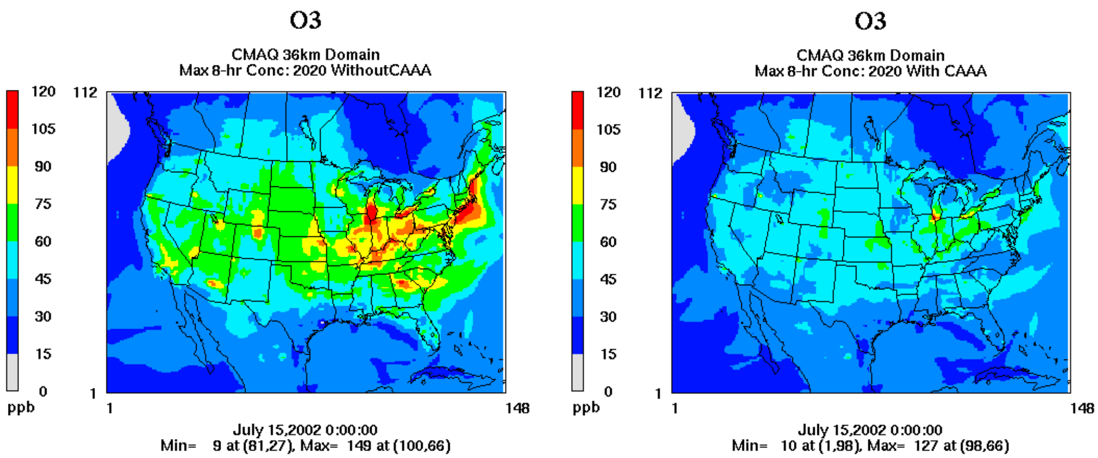
Compared to 2000 and 2010, the with-CAAA reductions are even greater in both magnitude and extent and the increases continue to shrink.

Ozone

This same set of figures is presented for ozone. Figure IV-17 displays simulated daily maximum 8-hour ozone concentration (ppb) for the CONUS domain for the 15th of July for the 2020 without-CAAA (Figure IV-17a) and 2020 with-CAAA (Figure IV-17b) scenarios.

Figure IV-17. Simulated Daily Maximum 8-Hour Ozone Concentration (ppb) for the CONUS Domain for 15 July: 2020 Scenarios.

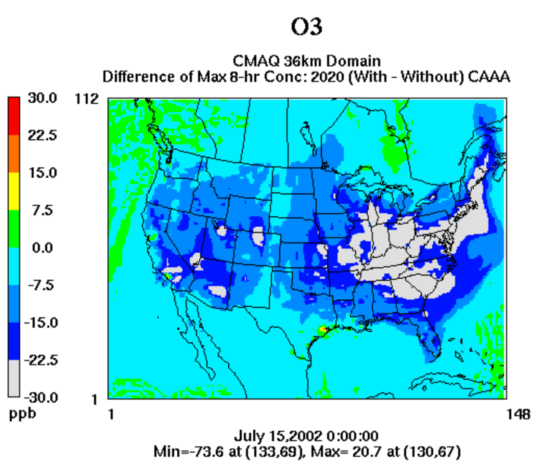
(a) Without CAAA *(b) With CAAA*



Compared to the 2000 and 2010 without-CAAA scenarios, the 2020 scenario shows further increases in simulated ozone, with the peak hourly simulated value increasing from 142 ppb to 149 ppb in the Chicago area. With the inclusion of CAAA controls in 2020, the magnitude and extent of high concentrations drop considerably.

Figure IV-18 illustrates the differences in 8-hour ozone for this day between the two scenarios (with-CAAA minus without-CAAA).

Figure IV-18. Difference in Simulated Daily Maximum 8-Hour Ozone Concentration (ppb) for the CONUS Domain for 15 July: 2020 With-CAAA Minus 2020 Without-CAAA Scenarios.



The ozone difference plot for the 2020 scenarios shows more extensive and larger simulated decreases in ozone throughout the modeling domain compared to the 2000 and 2010 scenarios, with a maximum reduction of 73.6 ppb for this day.

Summary of the Effects of the CAAA on $PM_{2.5}$ Quality

Tabular summaries of the 36-km CMAQ modeling results for selected subregions and monitoring sites are presented in this section. For the 36-km domain and annual simulation period, the focus is on $PM_{2.5}$.

The subregions follow the EPA region definitions and include states within specified geographical areas of the modeling domain. The regions definitions are as follows (states are listed alphabetically for each region):

- **Region 1:** Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont
- **Region 2:** New Jersey, New York
- **Region 3:** Delaware, District of Columbia, Maryland, Pennsylvania, Virginia, West Virginia
- **Region 4:** Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee
- **Region 5:** Illinois, Indiana, Michigan, Minnesota, Ohio, Wisconsin
- **Region 6:** Arkansas, Louisiana, New Mexico, Oklahoma, Texas
- **Region 7:** Iowa, Kansas, Missouri, Nebraska
- **Region 8:** Colorado, Montana, North Dakota, South Dakota, Utah, Wyoming
- **Region 9:** Arizona, California, Nevada
- **Region 10:** Idaho, Oregon, Washington

$PM_{2.5}$ monitoring sites within each region were selected for a more detailed examination of the modeling results for specific urban areas. The monitoring sites are listed in Table IV-1.

Table IV-1. $PM_{2.5}$ Monitoring Sites Used in the Analysis of CMAQ Results for the 812 Modeling Study.

Region	Site Location
Region 1	New Haven, CT
	Boston, MA
	Portsmouth, NH
Region 2	New Brunswick, NJ
	Bronx, NY (New York City)
Region 3	Fort Meade, MD (Baltimore)
	Philadelphia, PA
	Pittsburgh, PA
	Richmond, VA
Region 4	Pensacola, FL
	Atlanta, GA
	Charlotte, NC
	Knoxville, TN
	Memphis, TN

Region	Site Location
Region 5	Chicago, IL
	Minneapolis, MN
	Cleveland, OH
	Milwaukee, WI
Region 6	Baton Rouge, LA
	Albuquerque, NM
	Dallas, TX
	Houston, TX
Region 7	Kansas City, KS
	St Louis, MO
Region 8	Commerce City, CO (Denver)
	Missoula, MT
	Salt Lake City, UT
Region 9	Phoenix, AZ
	Sacramento, CA
	Fresno, CA
	Bakersfield, CA
	Los Angeles, CA
Region 10	Boise, ID
	Seattle, WA

Several metrics are used to summarize the modeling results for $PM_{2.5}$, including annual average $PM_{2.5}$, annual $PM_{2.5}$ exceedance exposure for a threshold of 15 μgm^{-3}, and estimated design value. These metrics were defined previously in this report.

Table IV-2 lists the annual $PM_{2.5}$ exceedance exposure for each subregion and scenario.

Table IV-2. $PM_{2.5}$ Exceedance Exposure Based on 15 μgm-3 for all Section 812 Scenarios.

Units are μgm-3 $*$ grid cell $*$ days.

Region	1990 Baseline	2000 w/o CAAA	2000 w/ CAAA	2010 w/o CAAA	2010 w/ CAAA	2020 w/o CAAA	2020 w/ CAAA
Region 1	239	239	23	253	9	289	3
Region 2	269	277	32	299	4	354	0
Region 3	456	583	182	684	61	852	31
Region 4	596	1125	102	1489	24	1979	9
Region 5	2498	3044	610	3272	78	3795	15
Region 6	205	390	15	501	5	905	6
Region 7	444	632	24	726	10	979	8
Region 8	7	34	0	49	0	93	0
Region 9	130	157	15	244	14	462	15
Region 10	85	99	30	114	35	171	39

For most regions, this metric is characterized by a steady increase with time for the without-CAAA scenarios, with the greatest increases between 2010 and 2020. Conversely, $PM_{2.5}$ exceedance exposure typically decreases with time for the with-CAAA scenarios. For all regions, the greatest decrease occurs between 1990 and 2000. For some regions, this relatively large reduction is followed by a small increase for 2010, 2020 or both years, presumably due to growth.

Table IV-3 lists the simulated annual $PM_{2.5}$ concentration for each monitoring site and scenario.

Table IV-3. Simulated Annual Average $PM_{2.5}$ Concentration (μgm^{-3}) for Selected Monitoring Sites and all Section 812 Scenarios.

	1990 Baseline	2000 w/o CAAA	2000 w/ CAAA	2010 w/o CAAA	2010 w/ CAAA	2020 w/o CAAA	2020 w/ CAAA
Region 1 Sites							
New Haven, CT	22.8	23.0	14.6	23.4	13.0	25.0	11.6
Boston, MA	21.8	21.8	15.9	22.3	14.5	23.6	13.3
Portsmouth, NH	19.5	19.8	11.4	20.3	10.5	20.9	9.7
Region 2 Sites							
New Brunswick, NJ	41.9	38.8	20.2	40.3	16.9	43.4	15.1
Bronx, NY (New York City)	50.8	50.5	22	51.8	18.3	55.8	16.1
Region 3 Sites							
Fort Meade, MD (Baltimore)	29.1	31.3	21.5	32.7	19.4	36	18.5
Philadelphia, PA	34.3	35.3	19.4	37	16.7	40.2	15.2
Pittsburgh, PA	22.3	23.2	16	23.7	13.1	24.6	12.1
Richmond, VA	16.1	17.6	16.8	18.8	15	20.3	14.2
Region 4 Sites							
Pensacola, FL	16.5	17.8	13.6	18.8	13.7	19.9	14
Atlanta, GA	21.7	24.7	18.2	26.6	16.5	29.2	15.2
Charlotte, NC	17.7	20	15.6	21.6	13.1	23.6	11.7
Knoxville, TN	15.5	16.8	13.4	17.7	11.5	18.7	10.1
Memphis, TN	15.6	16.8	12.6	17.2	10.9	18.2	10.2
Region 5 Sites							
Chicago, IL	66.5	78.6	21.2	79.3	18.9	85.5	18.4
Minneapolis, MN	23.7	26.4	16.3	27.7	15.5	30.5	15.4
Cleveland, OH	23.7	26	17.4	26.6	13.9	27.8	12.3
Milwaukee, WI	23.7	26	15.6	26.2	14.4	28.1	13.8
Region 6 Sites							
Baton Rouge, LA	15.6	17	10.7	17.7	9.8	20.5	9.6
Albuquerque, NM	13.8	14.9	10.4	14.8	10	15.8	10
Dallas, TX	23.8	29.3	18.5	30	17	33.3	16.9
Houston, TX	25.5	29.5	14.3	30.2	14.2	33.2	14.9
Region 7 Sites							
Kansas City, KS	20.2	21.7	15.1	22.5	13.8	24.1	13.3
St Louis, MO	52.5	62.8	20.9	65.3	18.7	71.9	18.3

	1990 Baseline	2000 w/o CAAA	2000 w/ CAAA	2010 w/o CAAA	2010 w/ CAAA	2020 w/o CAAA	2020 w/ CAAA
Region 8 Sites							
Commerce City, CO (Denver)	20.3	28.7	11.1	31.6	11.2	39.9	12
Missoula, MT	4.5	4.7	4	4.8	3.9	5.1	3.9
Salt Lake City, UT	13.4	18.3	8.9	20.5	8.9	25.7	9.4
Region 9 Sites							
Phoenix, AZ	16	23.7	10.2	27	9.9	34.7	10.7
Sacramento, CA	16.2	16.1	11.4	17.5	11	20.8	10.9
Fresno, CA	15	14.8	10.7	16.5	9.5	20	9.7
Bakersfield, CA	12.7	12.7	9.4	13.8	8.4	17.9	10.4
Los Angeles, CA	27.8	29.5	13.3	33.9	12.4	42.7	12.4
Region 10 Sites							
Boise, ID	5.9	6.6	6	7.4	6	8.6	6.2
Seattle, WA	16.7	17	11.8	18.6	12.6	21.9	13.6

Simulated annual average $PM_{2.5}$ concentrations generally increase with time for the without-CAAA scenarios, and decrease with time for the with-CAAA scenarios. As for the exposure metric, with the greatest increases for the without-CAAA scenarios occur between 2010 and 2020 and the greatest decreases for the with-CAAA scenarios occur between 1990 and 2000. There are some future-year increases in concentration at the site locations for the with-CAAA scenarios, especially for western sites for 2020.

Table IV-4 presents the estimated future-year $PM_{2.5}$ design values for each monitoring site and scenario. The future-year design values were estimated based on a 2002 baseline (observation based) design value. Quarterly and species-specific model-derived relative reduction factors were applied to observation-based average quantities in order to estimate the future-year design values. This procedure is described in detail in EPA's modeling guidance document (EPA, 2007). Note that a future-year design value less than or equal to 15 μgm^{-3} is an indicator of future-year attainment.

Table IV-4. Estimated Future-Year $PM_{2.5}$ Design Value (μgm^{-3}) for Selected Monitoring Sites and the Future-Year Section 812 Scenarios.

	2002 DV	2010 w/o CAAA	2010 w/CAAA	2020 w/o CAAA	2020 w/CAAA
Region 1 Sites					
New Haven, CT	16.5	24.1	13.6	25.0	12.4
Boston, MA	13.0	17.1	11.5	17.6	10.9
Portsmouth, NH	11.2	19.6	9.8	19.9	9.2
Region 2 Sites					
New Brunswick, NJ	12.7	22.0	10.6	23.0	9.9
Bronx, NY (New York City)	14.2	26.3	12.0	27.7	11.2

	2002 DV	2010 w/o CAAA	2010 w/CAAA	2020 w/o CAAA	2020 w/CAAA
Region 3 Sites					
Fort Meade, MD (Baltimore)	14	19.7	11.6	20.7	10.7
Philadelphia, PA	15.4	24.9	12.9	26.1	11.9
Pittsburgh, PA	15.8	23	12	23.5	10.8
Richmond, VA	14	17.3	11.3	17.8	10.1
Region 4 Sites					
Pensacola, FL	12.1	17.4	11.2	17.7	10.6
Atlanta, GA	16.5	23.3	14.2	24.2	12.2
Charlotte, NC	15.1	20.3	12.2	20.8	10.4
Knoxville, TN	17.3	23.8	14.3	24.1	12
Memphis, TN	14.9	21.6	12.6	22.4	11.6
Region 5 Sites					
Chicago, IL	16.3	64.8	14.6	67	14.5
Minneapolis, MN	10.9	16.6	10.7	18	10.8
Cleveland, OH	18.2	28.8	14.4	29.7	13.3
Milwaukee, WI	12.7	21.1	11.9	21.8	11.7
Region 6 Sites					
Baton Rouge, LA	13.6	21.9	12.1	25.6	11.6
Albuquerque, NM	6.4	8.8	6.2	9.7	6.3
Dallas, TX	12.6	18.9	11.3	20.6	11.1
Houston, TX	14.1	26.9	13.5	29.4	13.9
Region 7 Sites					
Kansas City, KS	13.5	18.8	12.4	19.6	12.1
St Louis, MO	15.7	32.6	14.1	34.6	13.9
Region 8 Sites					
Commerce City, CO (Denver)	10.3	21.8	10.2	26.6	10.5
Missoula, MT	11.4	12.8	11.1	13.6	11.1
Salt Lake City, UT	12	22.1	12.1	26.5	12.8
Region 9 Sites					
Phoenix, AZ	10.8	22.3	10.7	27.9	11.6
Sacramento, CA	11.1	13.8	10.8	15.8	10.9
Fresno, CA	21.9	26.2	19.5	30.5	20
Bakersfield, CA	22.1	27.6	20	35.1	25.6
Los Angeles, CA	22.2	43.1	20.4	52.7	22.8
Region 10 Sites					
Boise, ID	9.9	11.7	10	13.2	10.6
Seattle, WA	8.8	11.6	9.2	13.2	10.3

Estimated $PM_{2.5}$ design values increase with time for the without-CAAA scenarios. For a majority of the sites, the estimated design values for both 2010 and 2020 are greater than 15 μgm^{-3} for the without-CAAA scenarios.

For most sites the estimated design values decrease with time for the with-CAAA scenarios, but the results are mixed. There are several sites for which the estimated design values increase slightly between 2002 and 2010, and several more for which the design values increase between 2010 and 2020. The increases do not change the expectations for attainment at any of the sites. The estimated design values for both 2010 and 2020 are less than 15 μgm^{-3} for all but three sites (Fresno, Bakersfield and Los Angeles, CA). These three sites have very high base-year design values and the future-year design values for both Bakersfield and Los Angeles consistently increase rather than decrease with time, even with the CAAA measures.

The results are qualitatively similar for all three metrics. The CMAQ results for 2002 are characterized by relatively low $PM_{2.5}$ concentrations compared to the design values at several western sites. Thus, the estimated design value calculations which combine the modeling results and the observed data are an important tool for the overall assessment of the effects of the CAAA relative to attainment of the $PM_{2.5}$ NAAQS.

$PM_{2.5}$ Source Contribution Analysis for 2010

Within CMAQ, the Ozone and Precursor Tagging Methodology (OPTM) and the Particle and Precursor Tagging Methodology (PPTM) are designed to provide detailed, quantitative information about the *contribution* of selected sources, source categories, and/or source regions to simulated ozone and $PM_{2.5}$ concentrations, respectively. Emissions of precursor pollutants from selected sources, source categories, or source regions are (numerically) tagged and then tracked throughout a simulation. The contribution from each tag to the resulting simulated concentration of ozone, $PM_{2.5}$, or any of the $PM_{2.5}$ component species for any given location within the CMAQ modeling domain can be quantified. By tracking the emissions from selected sources or source locations, the methodology also provides information on the fate of the emissions from these sources.

The tagging methodology differs from the use of air quality model sensitivity simulations in which the emissions are modified or eliminated (zeroed-out). Sensitivity simulations typically provide information about the effects of changes in the emissions on the simulation results. In contrast, tagging provides information about the contribution of the emissions from the tagged sources, relative to the unmodified simulated conditions. Identifying and quantifying source contributions from certain sources or source sectors can inform air quality planning and aid the assessment of control measures.

CMAQ/PPTM was used in this study to examine the contributions of emissions from the major source categories to simulated $PM_{2.5}$ concentrations and to quantify the changes in these contributions between the with- and without-CAAA scenarios. The application of PPTM was limited to 2010 and was used primarily for quality assurance purposes – to assess whether the changes in concentrations were consistent with the changes in emissions. However, the PPTM results also provide some interesting information about which sources contribute to the simulated $PM_{2.5}$ concentrations, how the source contributions differ between the without- and with-CAAA scenarios, and, consequently, the relative effectiveness of the source-category specific CAAA measures in reducing $PM_{2.5}$ concentrations.

Technical Description of PPTM

The CMAQ model numerically simulates the physical processes that determine the magnitude, temporal variation, and spatial distribution of the concentrations of ozone and particulate species in the atmosphere and the amount, timing, and distribution of their deposition to the earth's surface. The simulation processes include advection, dispersion (or turbulent mixing), chemical transformation, cloud processes, and wet and dry deposition. Within the model, tagging is accomplished by the addition of duplicate model species variables for each source, source category, or source region that is to be tagged. For PPTM, the duplicated species include all PM-related sulfur, nitrogen, and secondary organic compounds, as well as primary organic carbon, elemental carbon, and other inorganic particulates.[1] The tagged species have the same properties and are subjected to the same processes (e.g., advection, chemical transformation, deposition) as the actual (or base) species. Because the tagged species are separate from the base species, tagging does not alter or affect the base simulation results.

PPTM was developed to utilize model algorithms as much as possible to track simulated tagged species concentrations. Processes that are linear, or not species-specific, utilize the model algorithms to calculate the changes in species concentrations. An example of this type of process is advection. Other processes that are potentially non-linear or involve interactions with other species, are given a special treatment and are calculated for the overall (or base) species and apportioned to the tagged species. An example of this type of process is aqueous-phase chemistry.

PPTM includes a species-specific approach for each reactive species (sulfur, nitrogen, and secondary organic compounds) and a more general approach for the non-reactive species (primary organic carbon, elemental carbon, and other inorganic particulates).

PPTM Application Procedures for the §812 Modeling Analysis

CMAQ/PPTM simulations were conducted using the 2010 without-CAAA and the 2010 with-CAAA emissions inventories. The simulations were run for the 36- km CONUS modeling domain.

For each scenario, PPTM was use to examine the contributions to simulated PM for the following major emissions source categories:

- EGU sources in the U.S.
- Non-EGU point sources in the U.S.
- On-road mobile sources in the U.S.
- Non-road mobile sources in the U.S.
- Area (non-point, non-mobile) sources in the U.S.
- Initial and boundary conditions (IC/BCs)
- All other sources (including natural emissions, U.S. offshore sources, and non-U.S. sources)

Source-Contribution Analysis Results

Selected plots of the PPTM results are shown in Figure IV-19. The contribution to annual average $PM_{2.5}$ from each of the seven tagged source category tags is displayed in Figure IV-19 for both the without- and with-CAAA scenarios.

[1] For OPTM, the duplicated modeled species are ozone, nitrogen oxides (NO_x), and volatile organic compounds (VOCs).

Figure IV-19a. Contribution to Simulated Annual Average $PM_{2.5}$ Species Concentration (μgm^{-3}) for the CONUS Domain from Emissions from EGU Sources in the U.S.

(a) Without CAAA *(b) With CAAA*

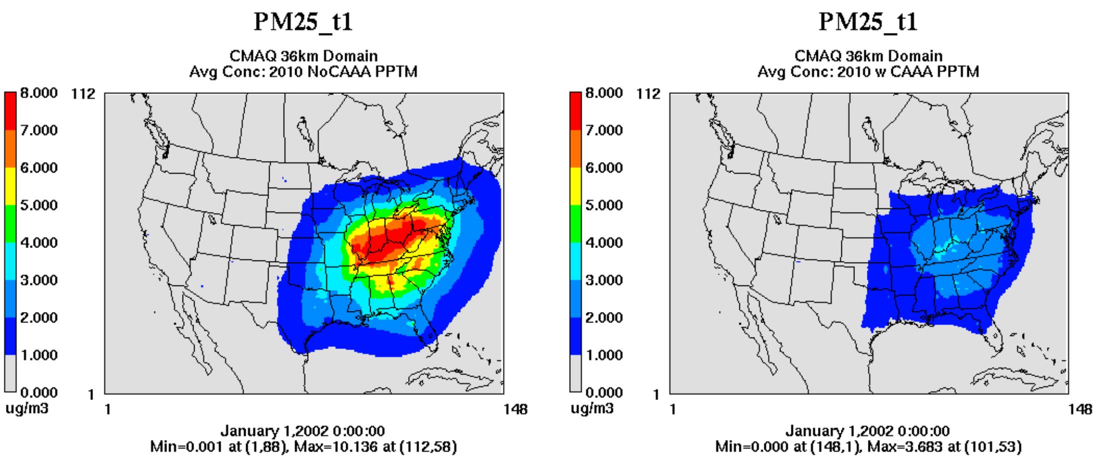


Figure IV-19b. Contribution to Simulated Annual Average $PM_{2.5}$ Species Concentration (μgm^{-3}) for the CONUS Domain from Emissions from Non-EGU Sources in the U.S.

(a) Without CAAA *(b) With CAAA*

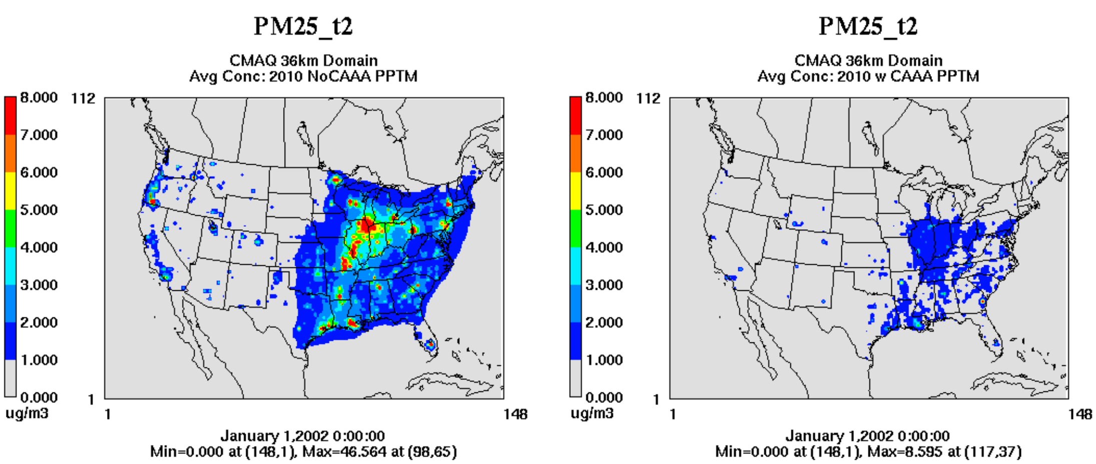


Figure IV-19c. Contribution to Simulated Annual Average $PM_{2.5}$ Species Concentration (μgm^{-3}) for the CONUS Domain from Emissions from On-Road Mobile Sources in the U.S.

(a) Without CAAA *(b) With CAAA*

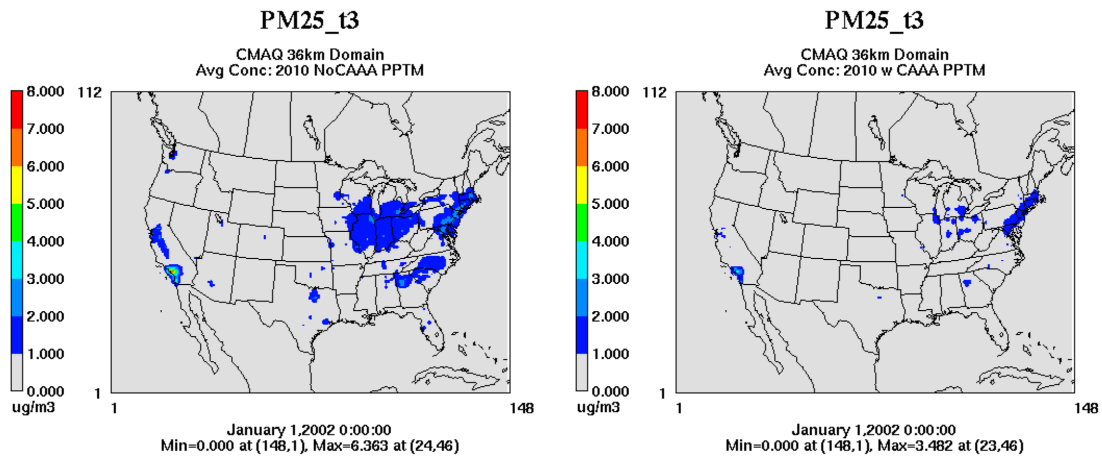


Figure IV-19d. Contribution to Simulated Annual Average $PM_{2.5}$ Species Concentration (μgm^{-3}) for the CONUS Domain from Emissions from Non-Road Sources in the U.S.

(a) Without CAAA *(b) With CAAA*

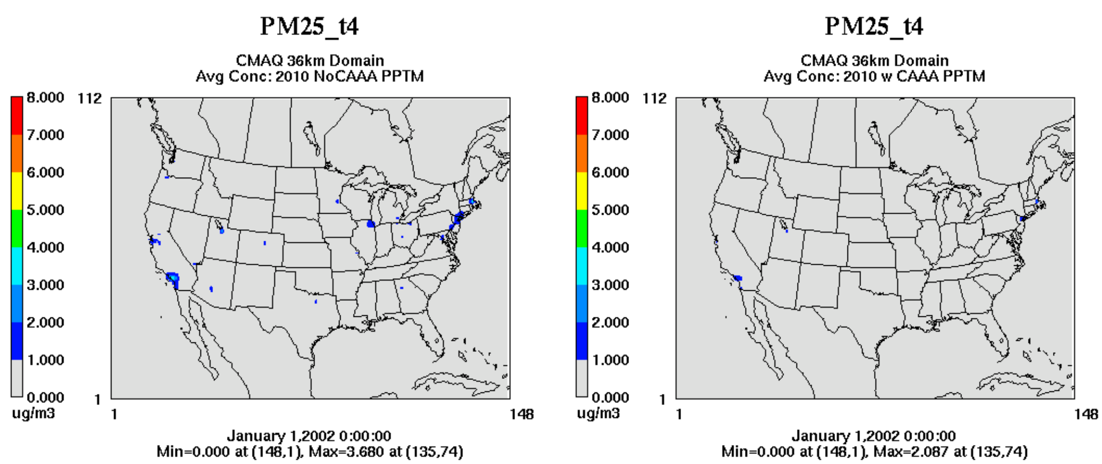


Figure IV-19e. Contribution to Simulated Annual Average $PM_{2.5}$ Species Concentration (μgm^{-3}) for the CONUS Domain from Emissions from Area Sources in the U.S.

(a) Without CAAA *(b) With CAAA*

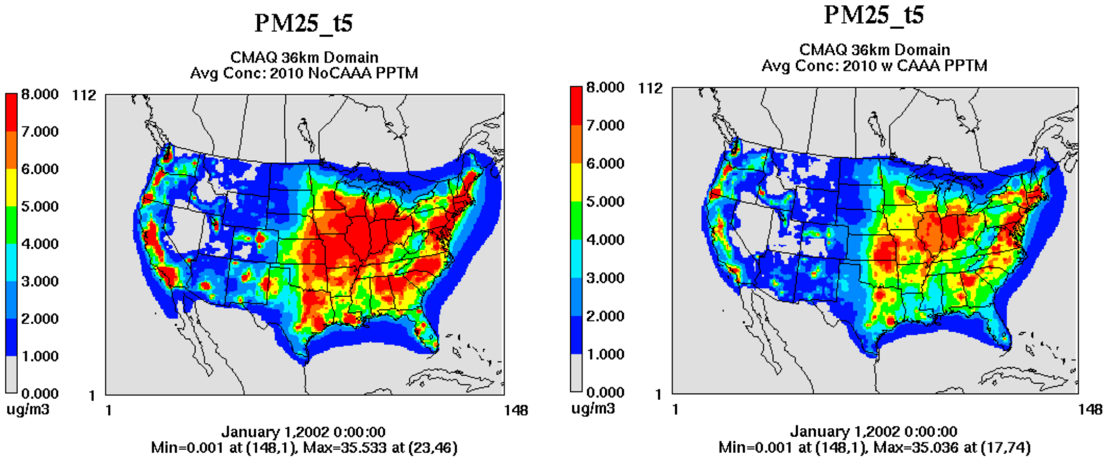


Figure IV-19f. Contribution to Simulated Annual Average $PM_{2.5}$ Species Concentration (μgm^{-3}) for the CONUS Domain from Initial and Boundary Conditions.

(a) Without CAAA *(b) With CAAA*

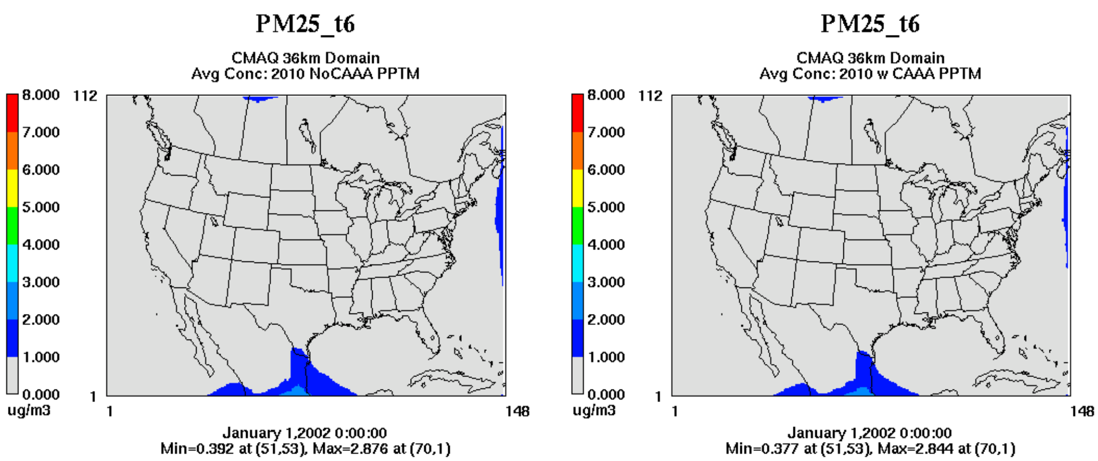
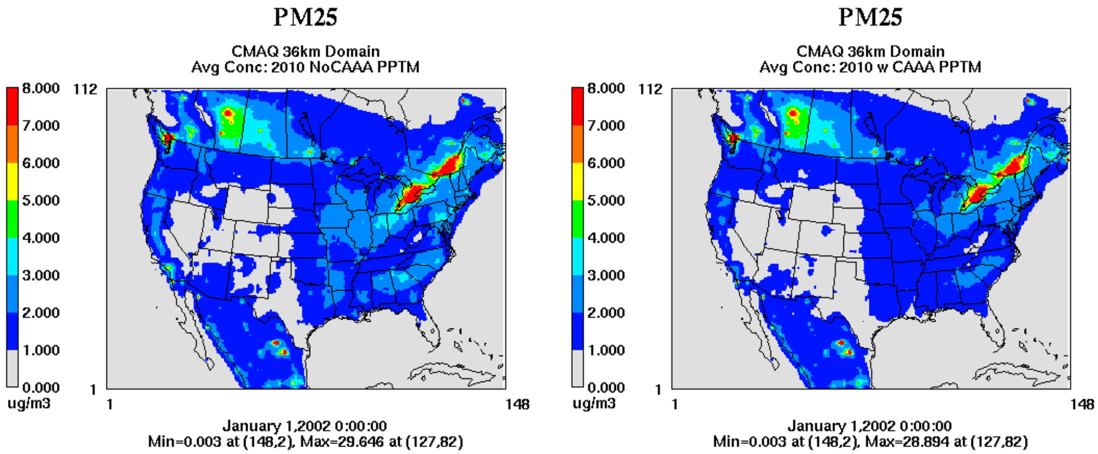


Figure IV-19g. Contribution to Simulated Annual Average $PM_{2.5}$ Species Concentration (μgm^{-3}) for the CONUS Domain from Emissions from All Other Sources.

(a) Without CAAA *(b) With CAAA*

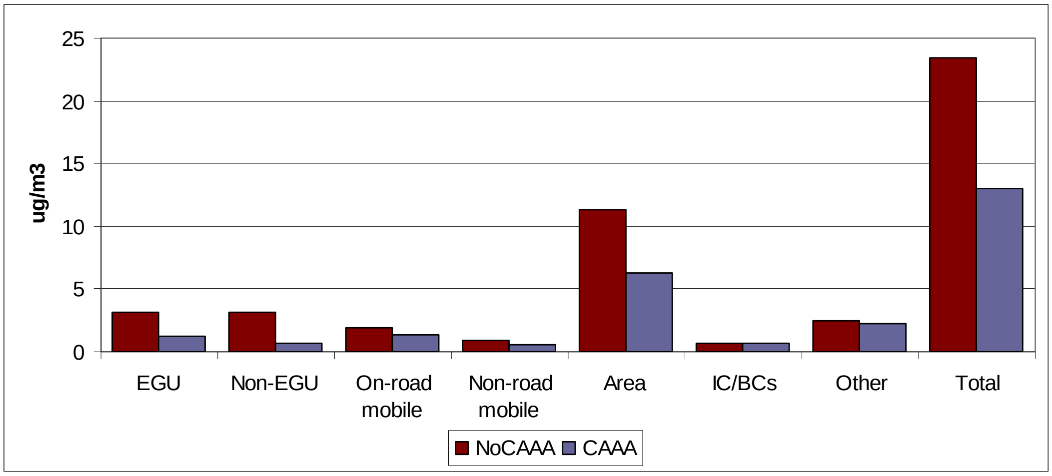


For most of the tagged source categories the contributions are much lower for the with-CAAA scenario. The overall effects of the CAAA measures on the simulated contributions vary by source category in accordance with the control measures for that category. For example, Figure IV-19a shows that the contribution from EGU emissions is substantially lower for 2010 for the with-CAAA scenario, particularly over the eastern U.S. This is due to lower NO_x, SO_2, and $PM_{2.5}$ emissions from coal-fired utility sources under the CAAA. The simulated contributions from emissions from non-EGU point sources (Figure IV-19b) and area sources (Figure IV-19e) are also substantially lower under the with-CAAA scenario. Emissions from these three categories comprise the largest contributions to the simulated annual average $PM_{2.5}$ concentrations.

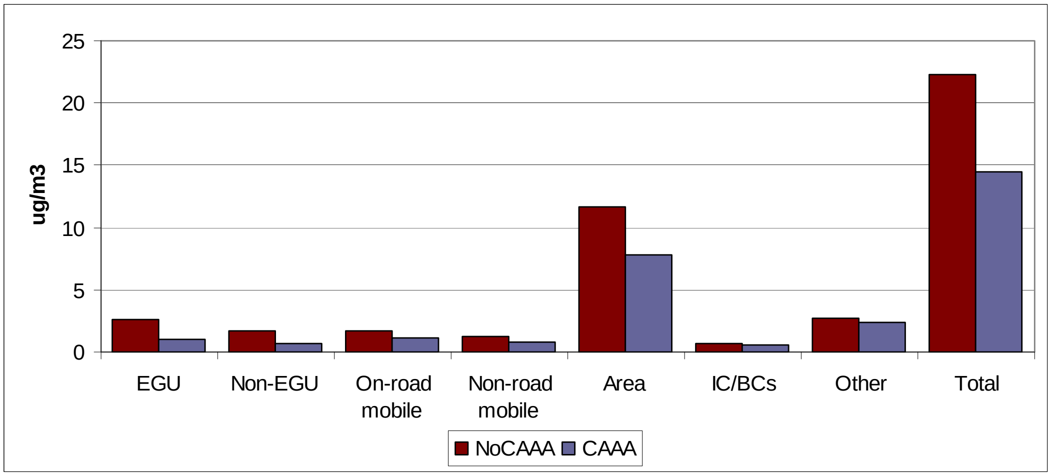
The effects of the CAAA measures on the simulated contributions also vary by location throughout the modeling domain. Figure IV-20 presents the PPTM results for both scenarios and each tagged source category for 34 locations throughout the modeling domain. These were selected to represent $PM_{2.5}$ monitoring sites for the subregions of the modeling domain defined by the EPA regions and are the same sites listed in Table IV-1.

Figure IV-20. CMAQ/PPTM Source Category Contributions to Annual Average PM2.5 for the 2010 Scenarios.

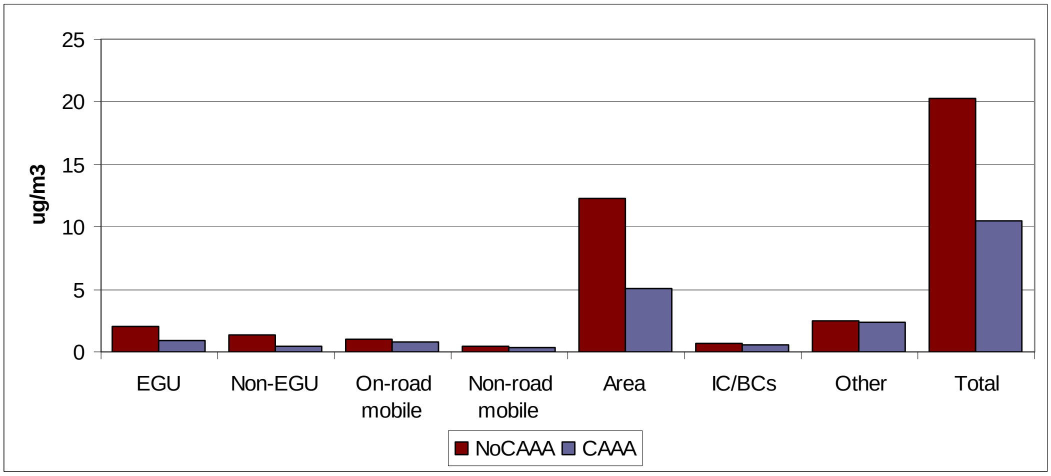
(a) New Haven, CT



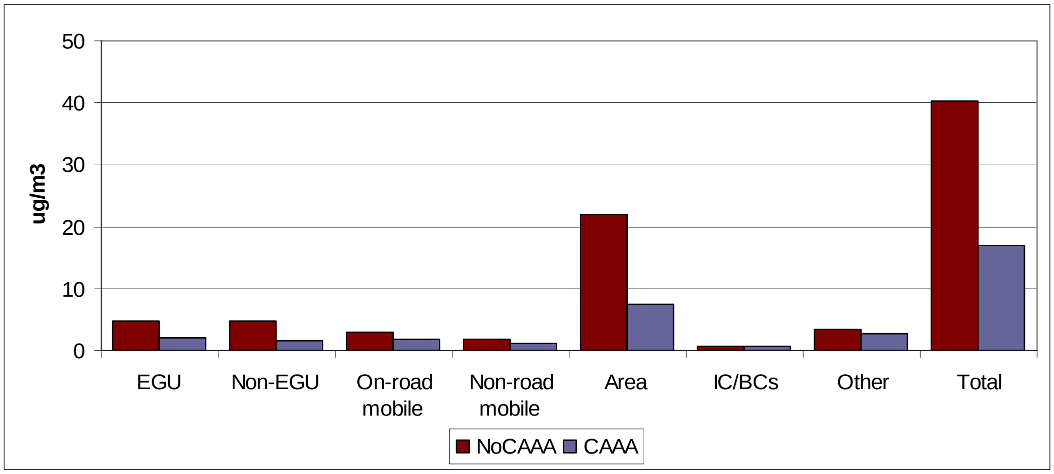
(b) Boston, MA



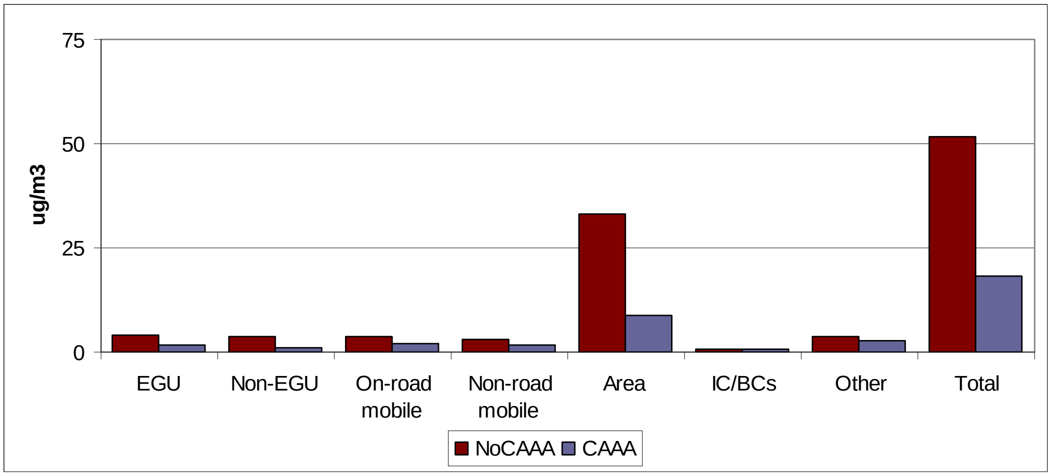
(c) Portsmouth, NH



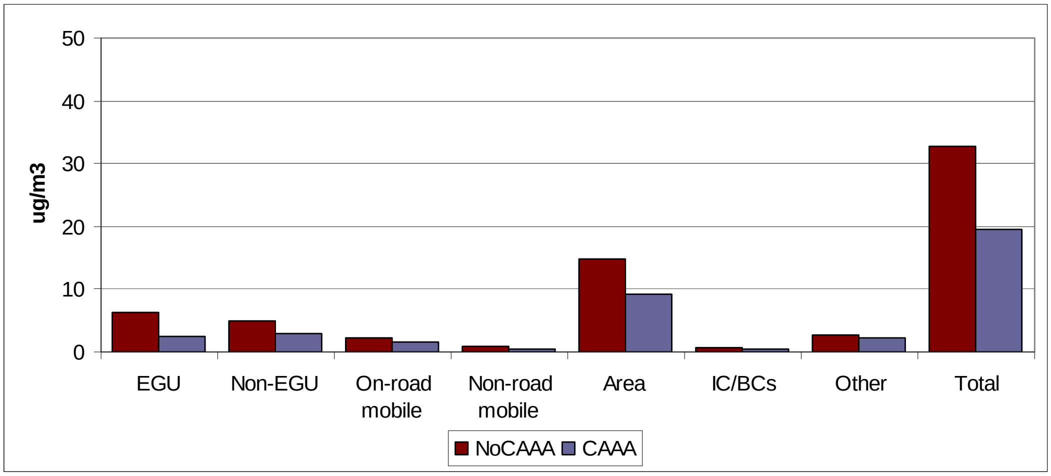
(d) New Brunswick, NJ



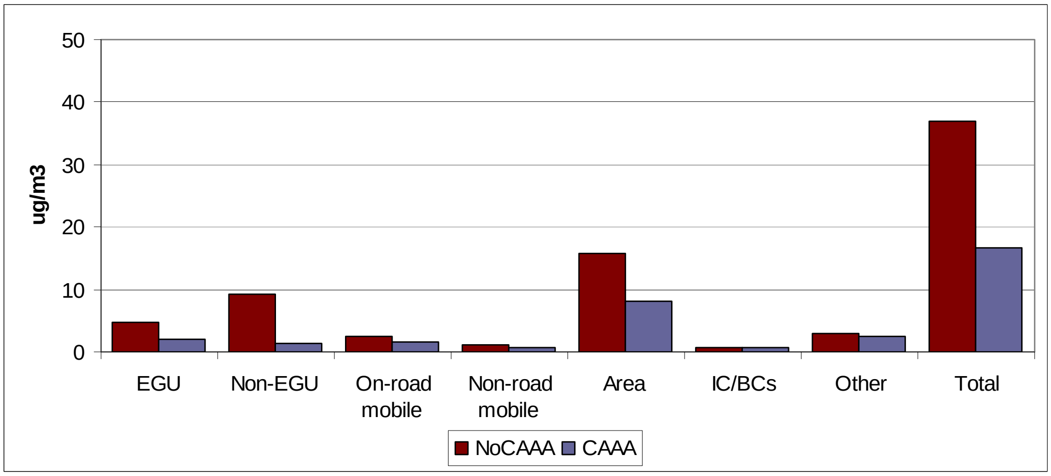
(e) Bronx, NY (New York City)



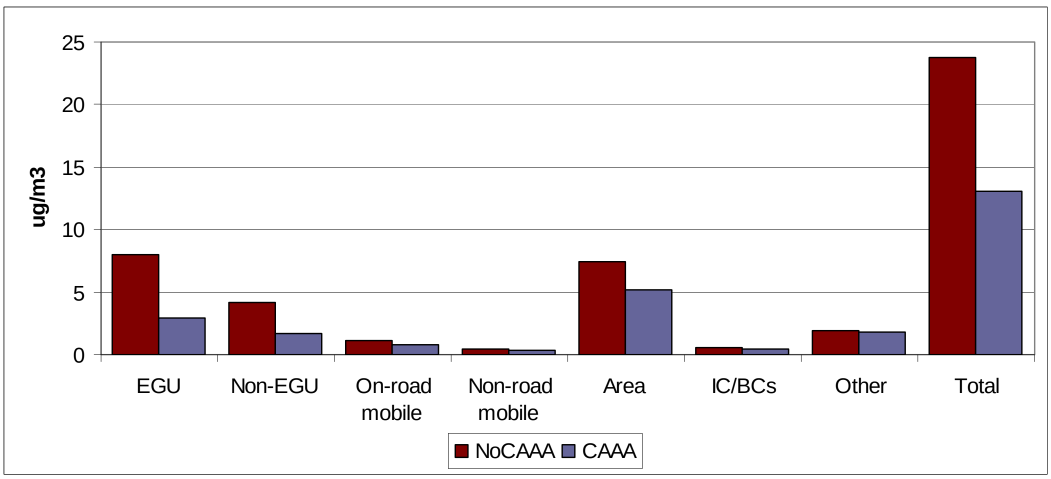
(f) Fort Meade, MD (Baltimore)



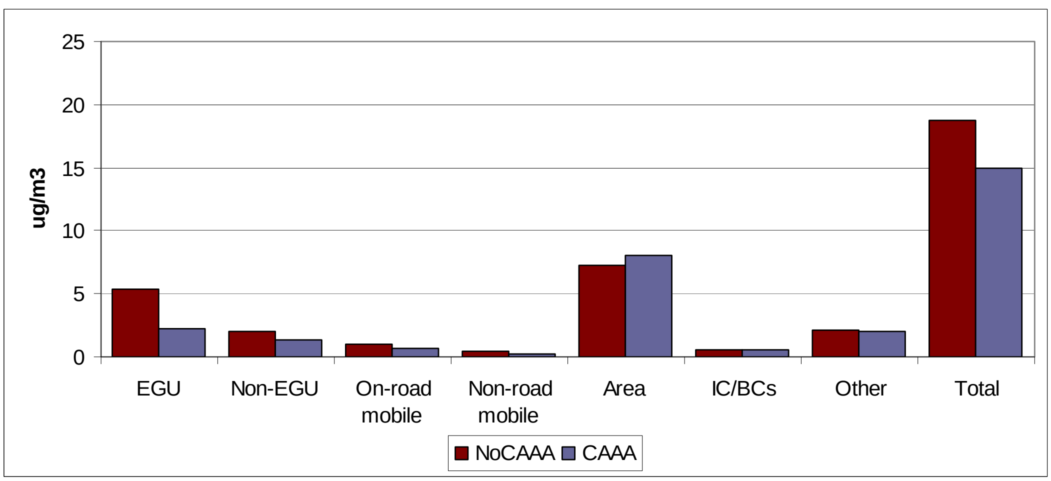
(g) Philadelphia, PA



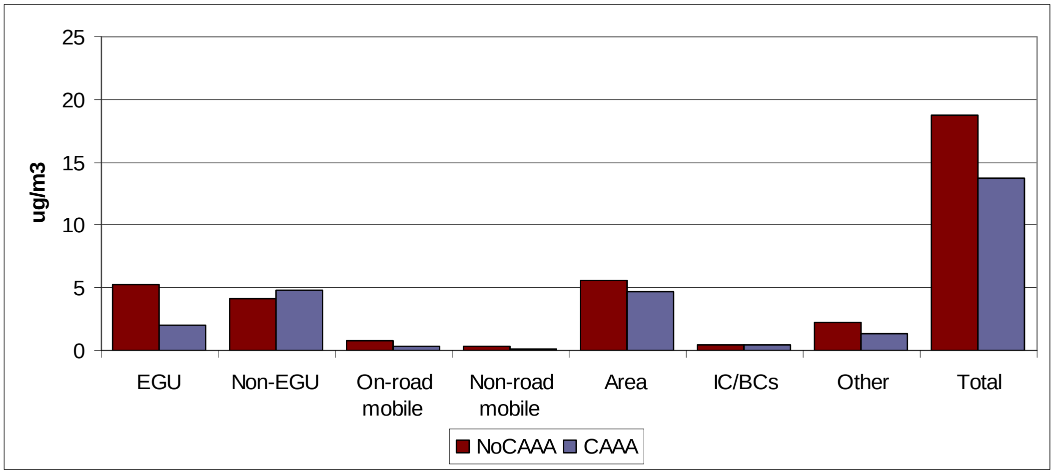
(h) Pittsburgh, PA



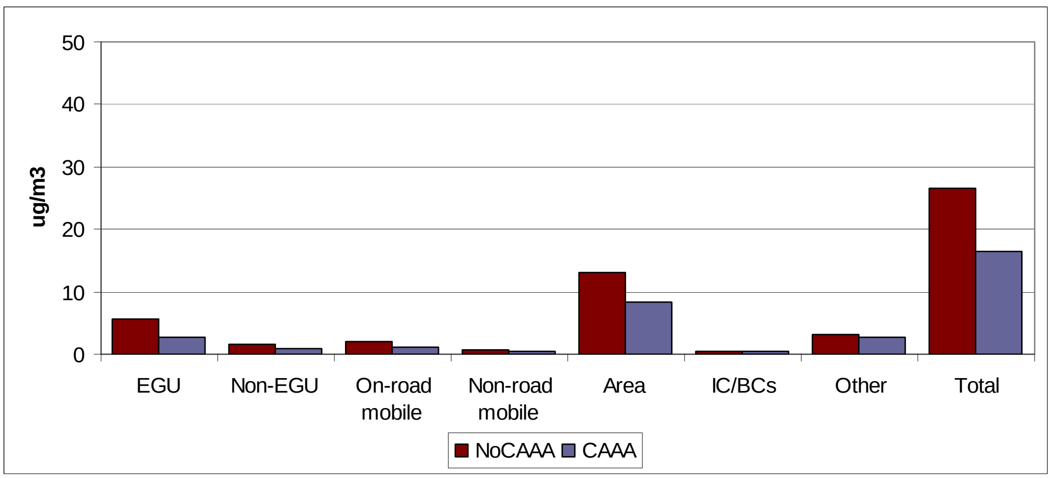
(i) Richmond, VA



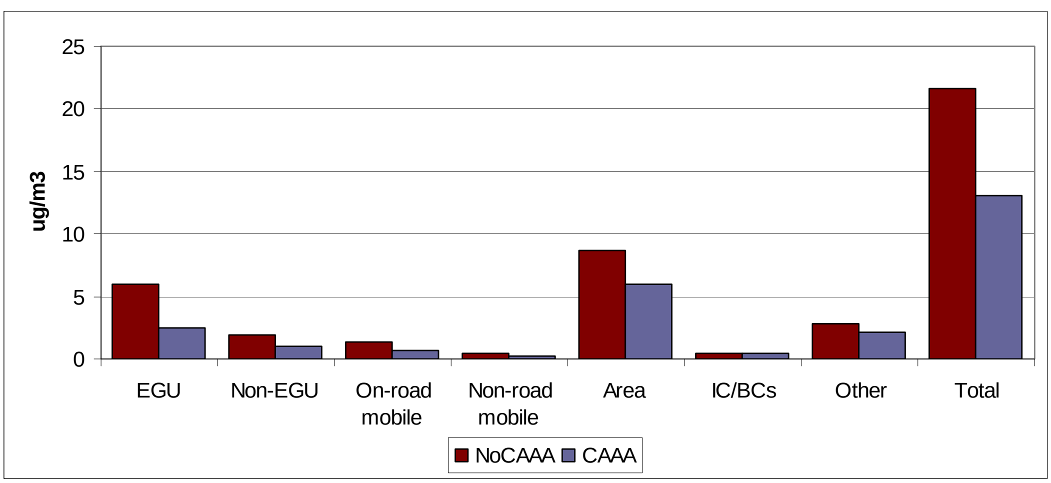
(j) Pensacola, FL



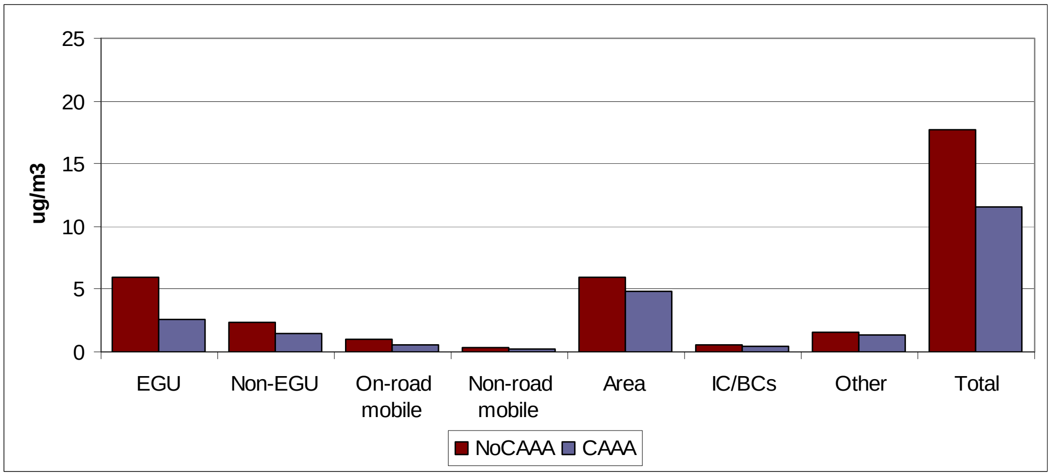
(k) Atlanta, GA



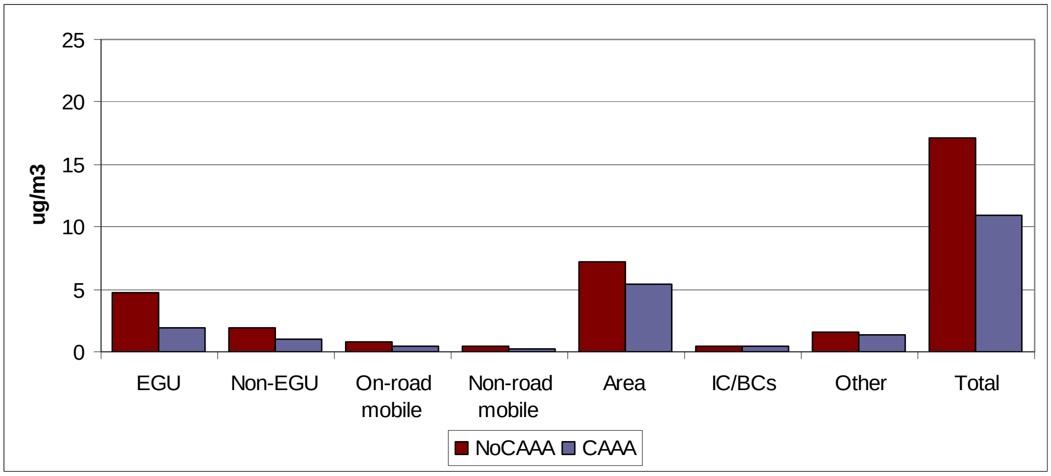
(l) Charlotte, NC



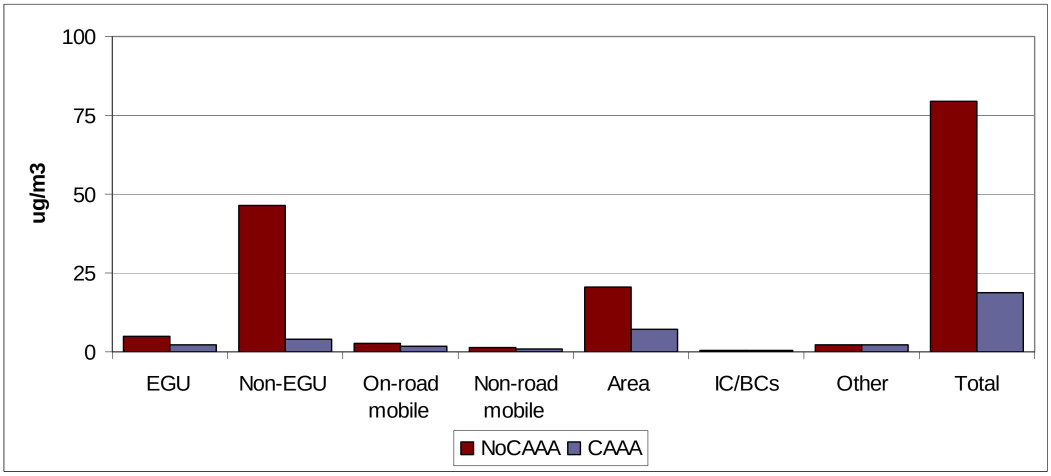
(m) Knoxville, TN



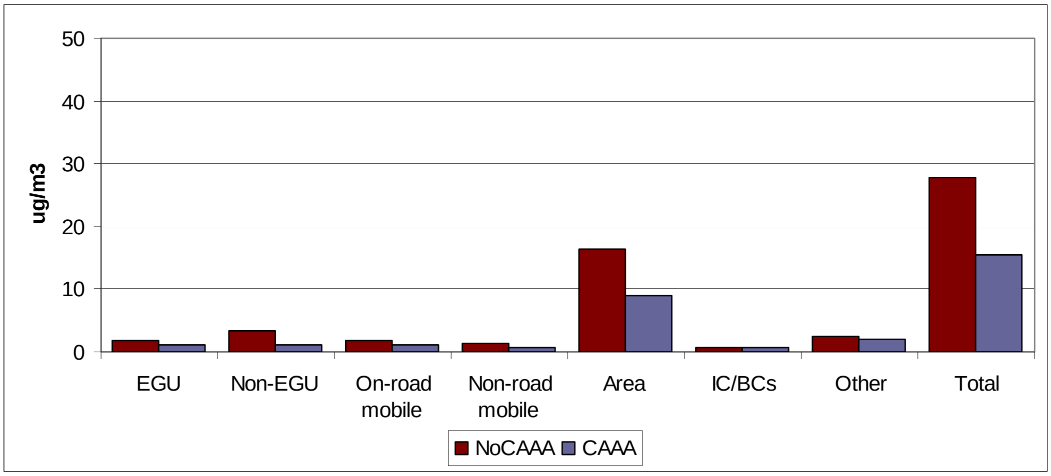
(n) Memphis, TN



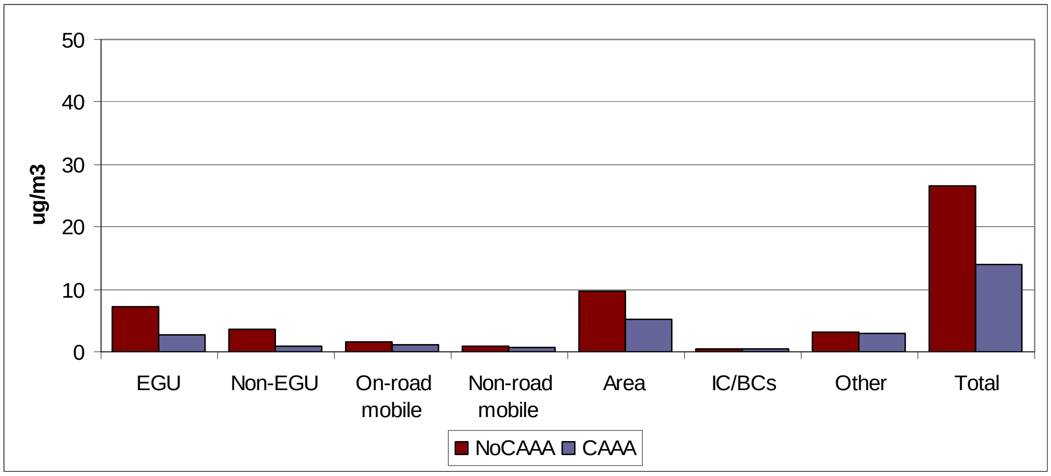
(o) Chicago, IL



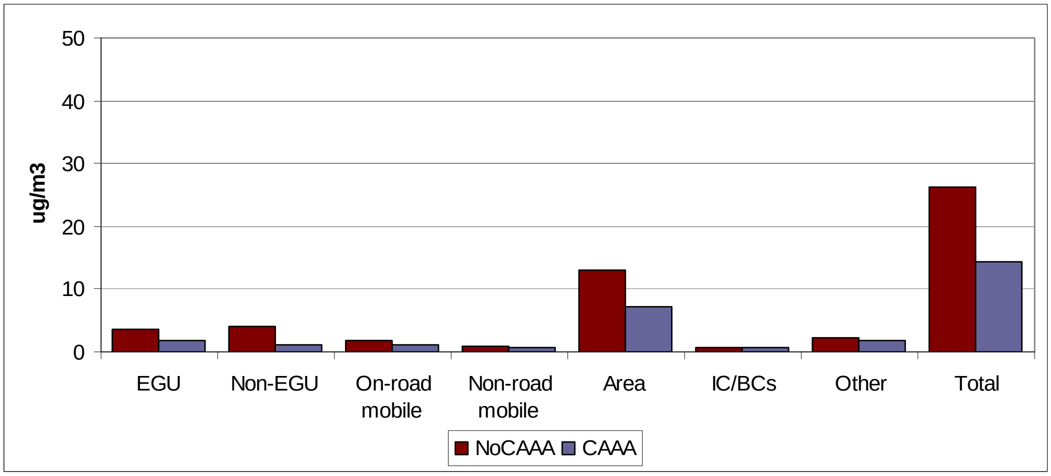
(p) Minneapolis, MN



(q) Cleveland, OH



(r) Milwaukee, WI



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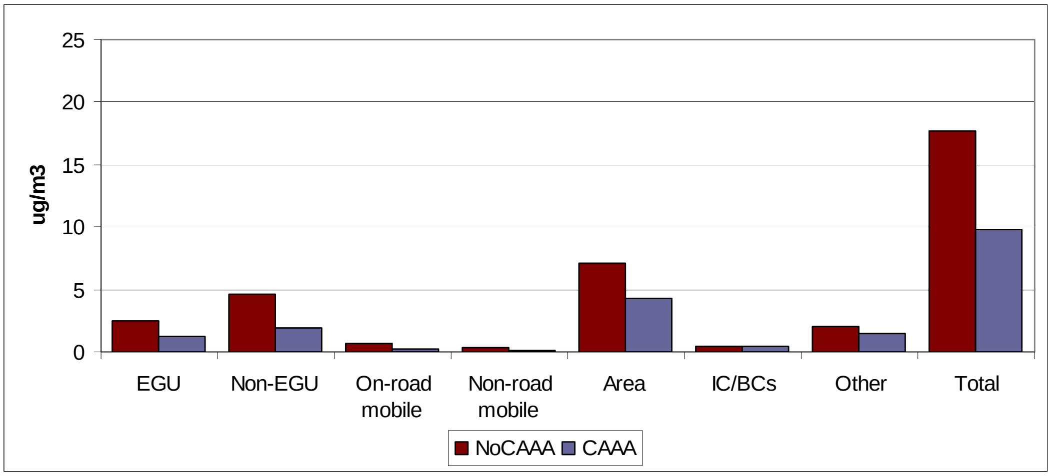

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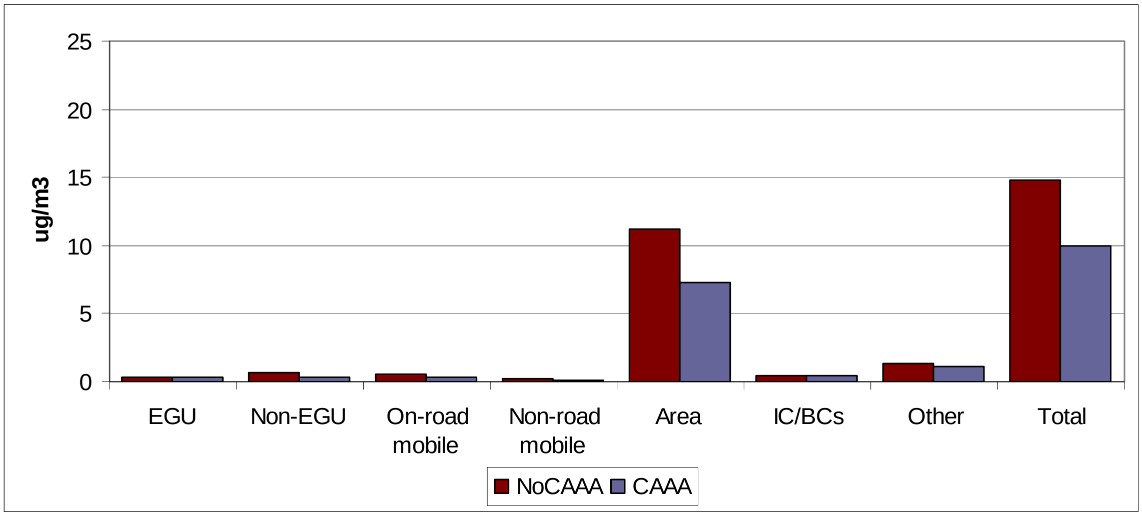
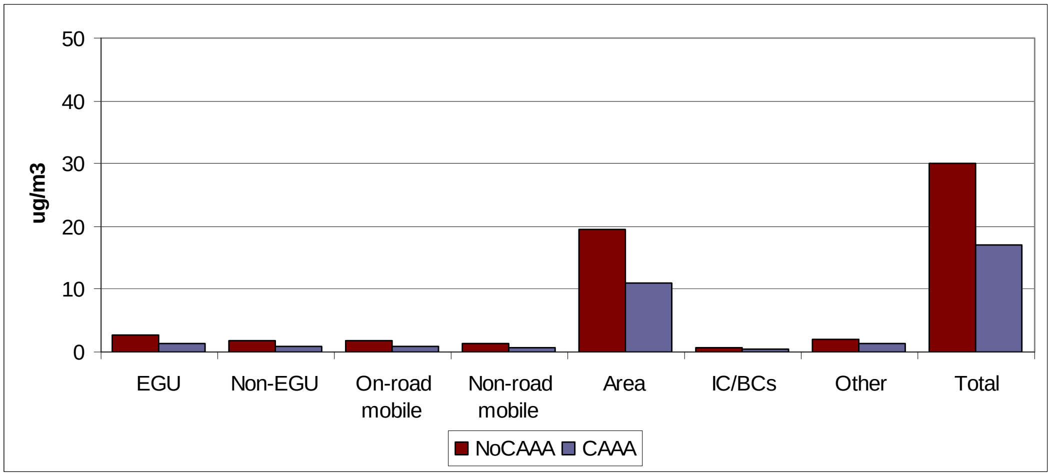
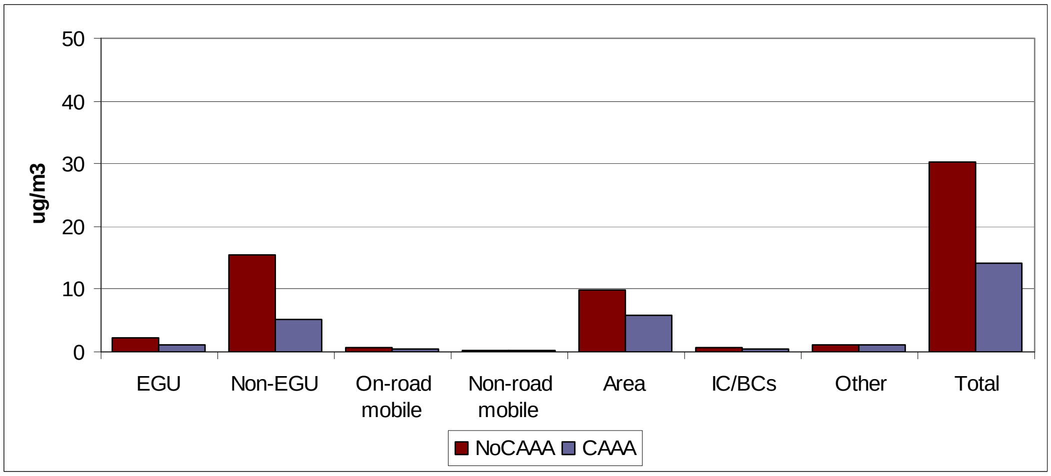


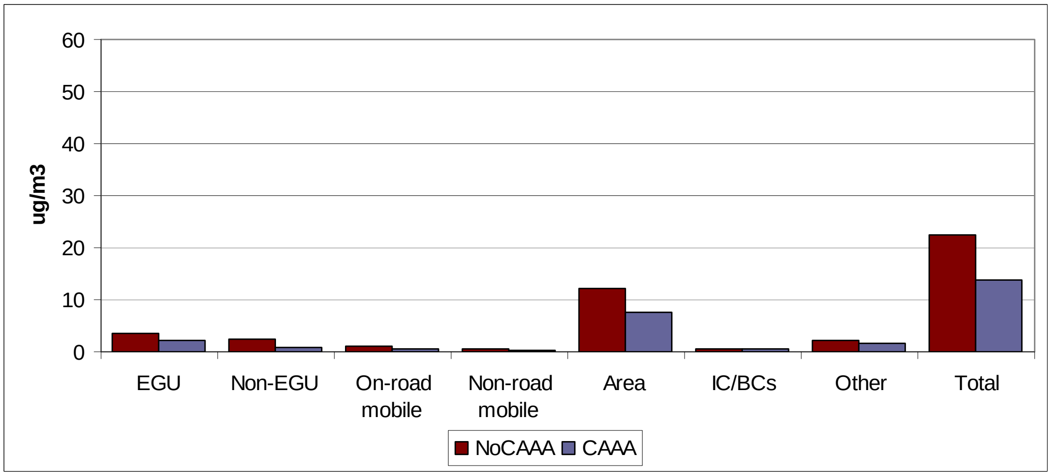
(u) Dallas, TX



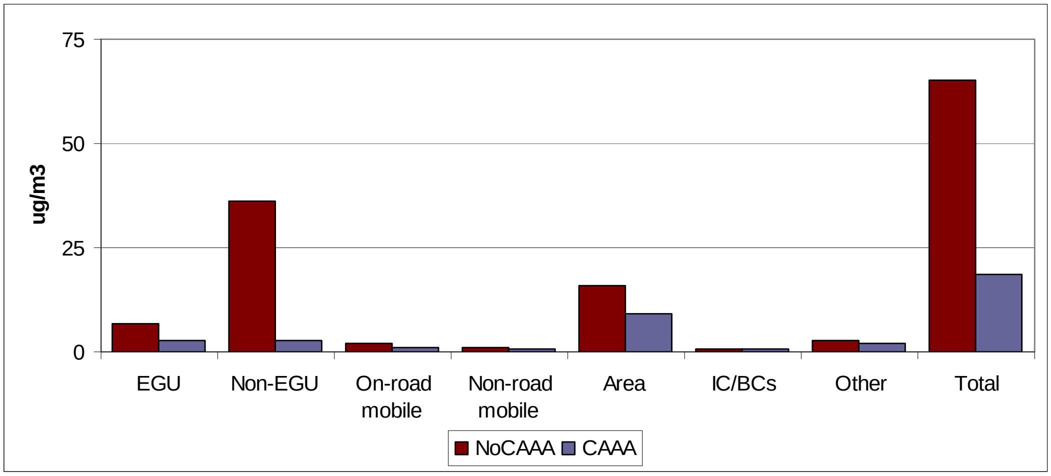
(v) Houston, TX



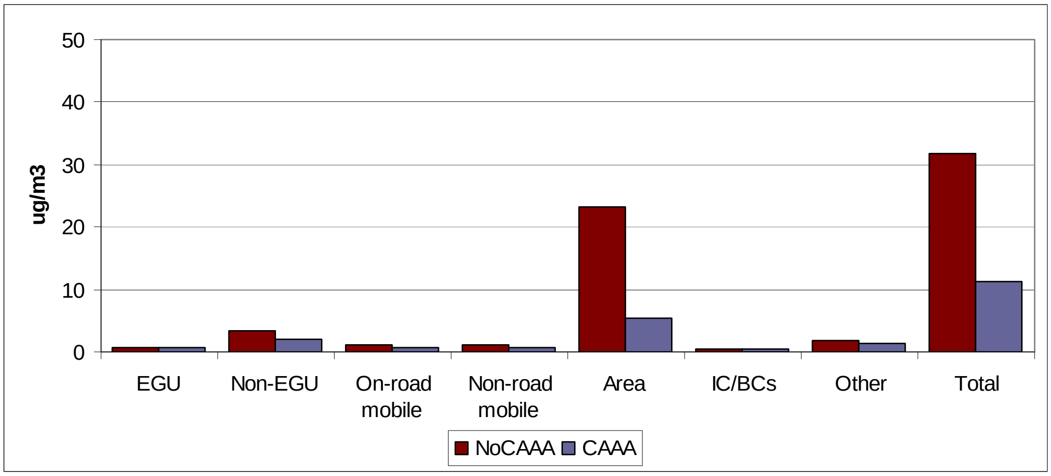
(w) Kansas City, KS



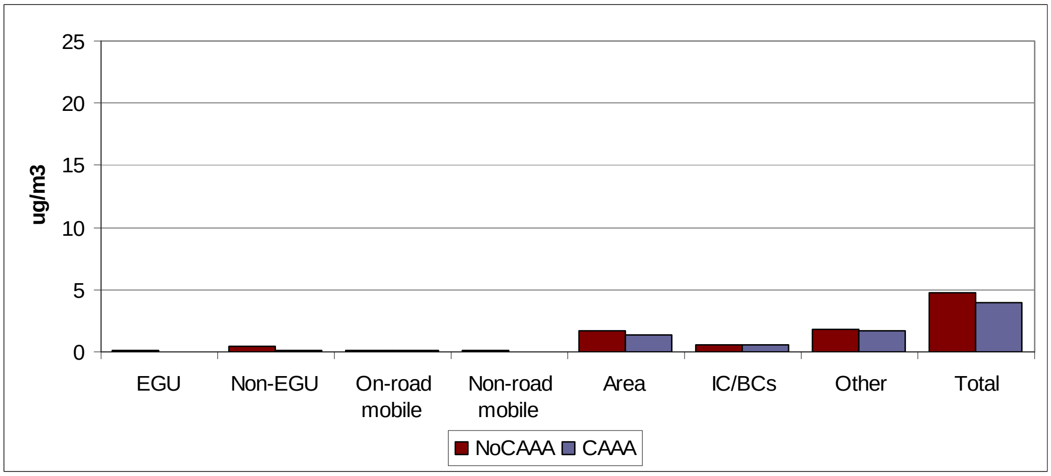
(x) St. Louis, MO



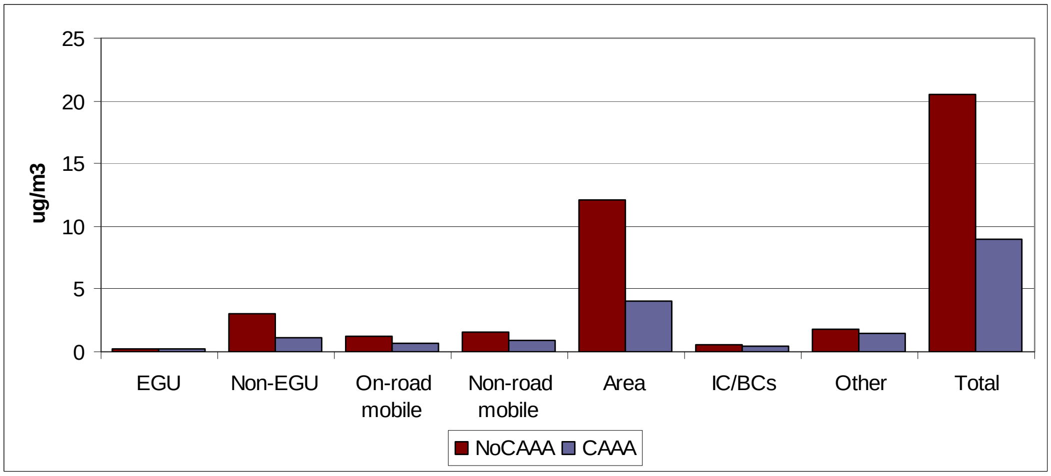
(y) Denver, CO



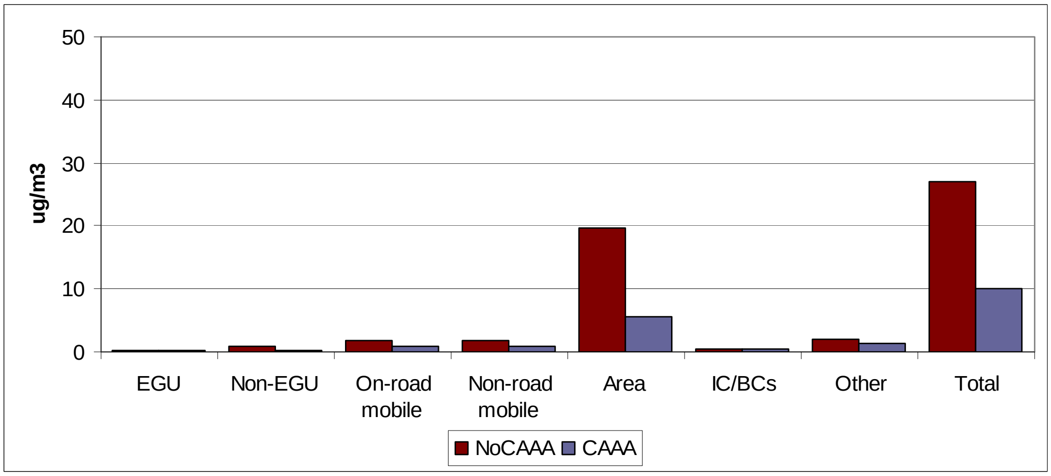
(z) Missoula, MT



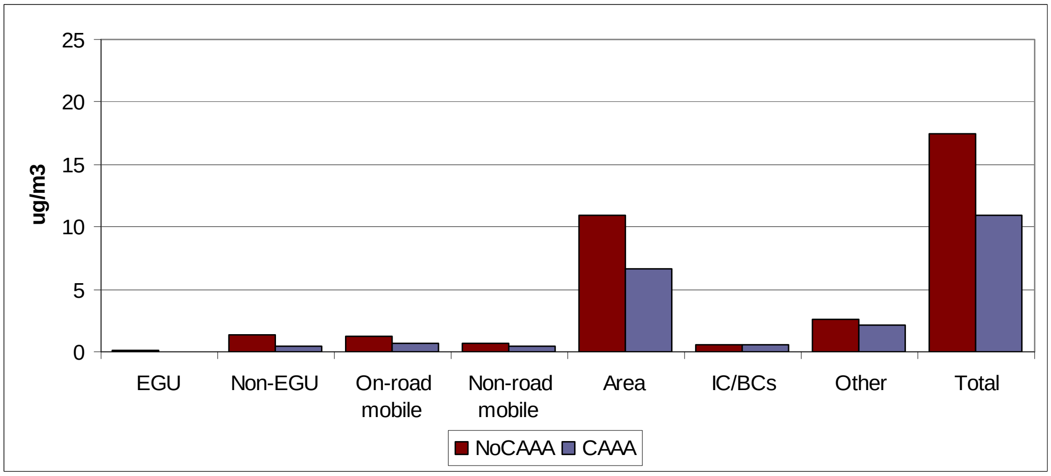
(aa) Salt Lake City, UT



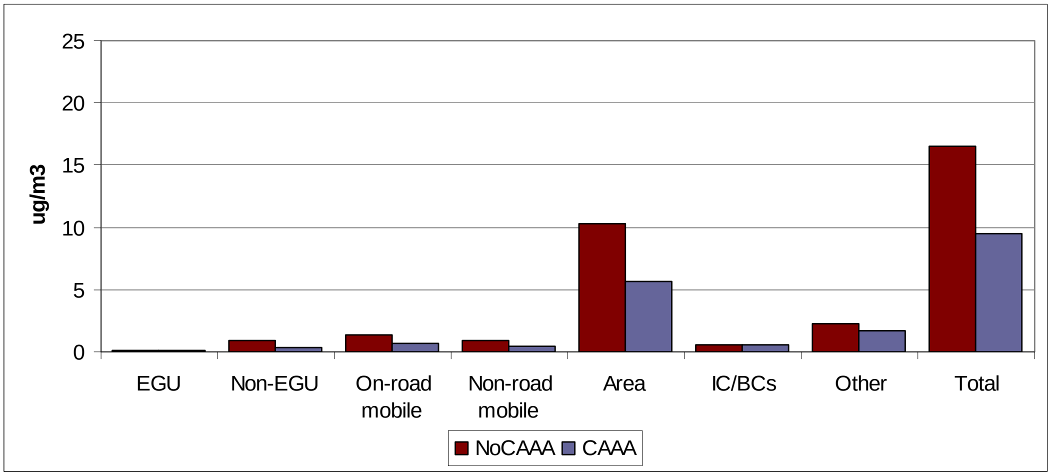
(ab) Phoenix, AZ



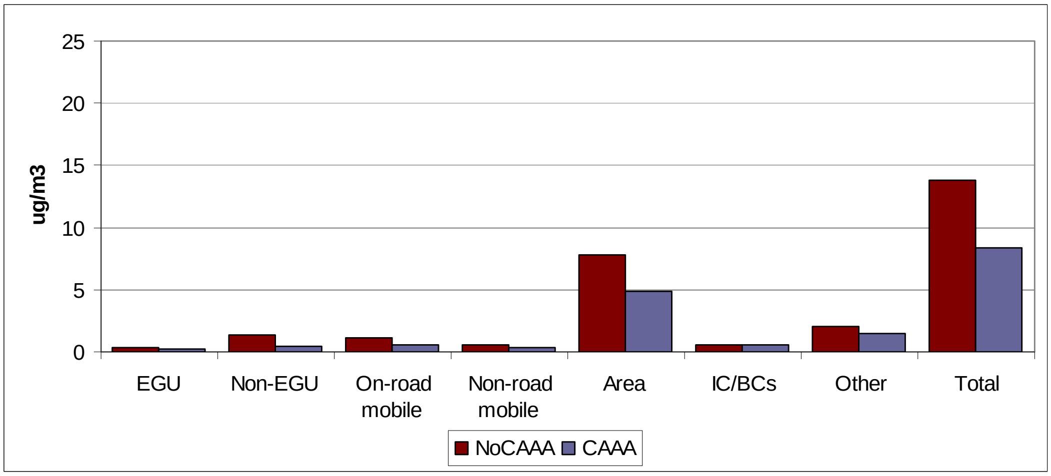
(ac) Sacramento, CA



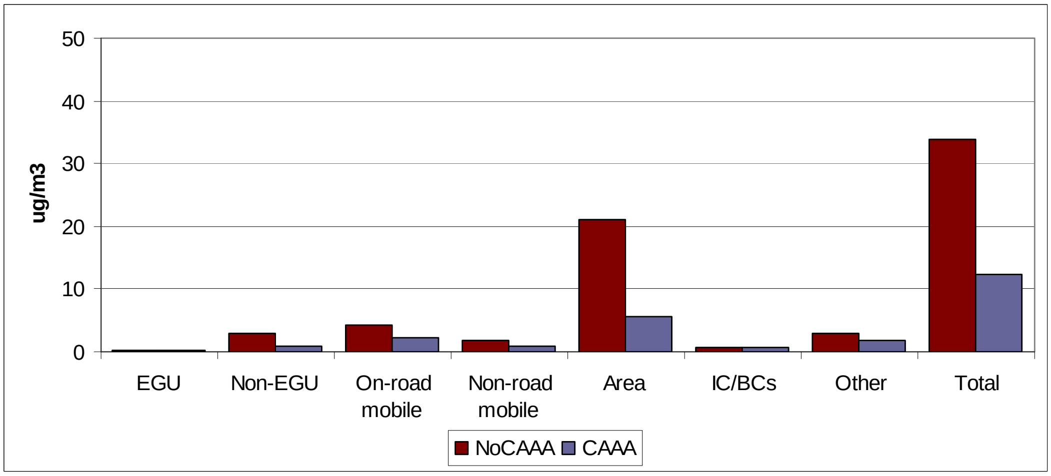
(ad) Fresno, CA



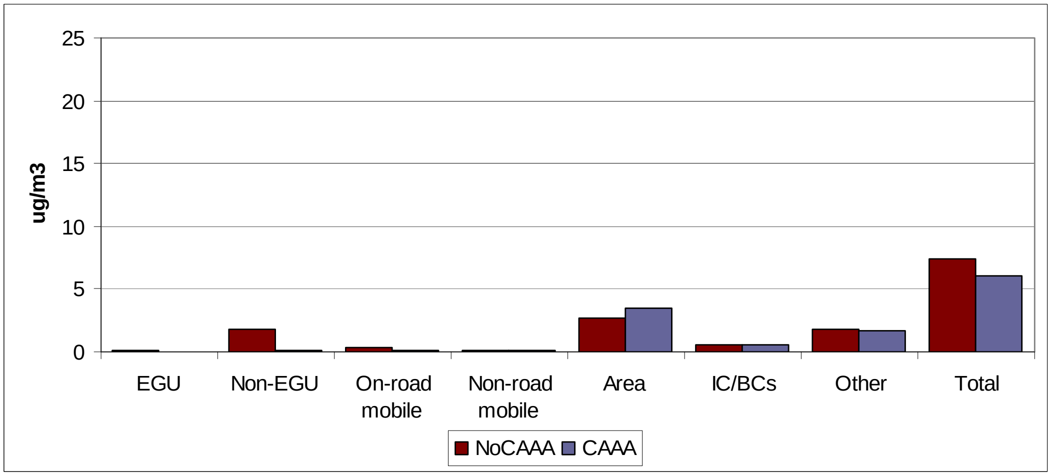
(ae) Bakersfield, CA



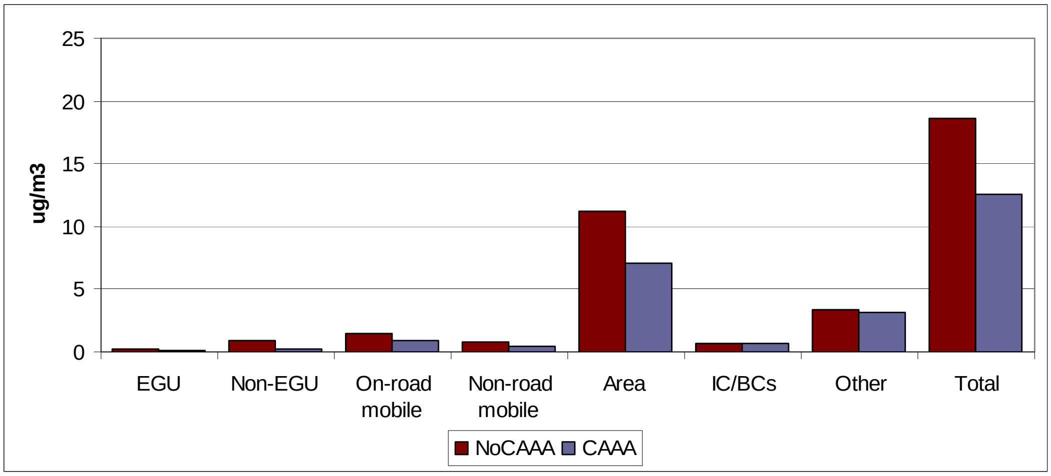
(af) Los Angeles, CA



(ag) Boise, ID



(ah) Seattle, WA



For all of the sites, the overall (total) simulated $PM_{2.5}$ concentration is lower under the CAAA scenario. The source category contributions to this reduction differ among the sites. For most sites, a reduction in the contribution from area (non-point, non-mobile) source emissions is a substantial part of the overall reduction. However, for some of the smaller urban areas such as Richmond (Figure IV-20i) and Boise (Figure IV-20ag), the contribution from these sources is greater with the CAAA. For many of the selected sites, reductions in the contributions from EGU and non-EGU point sources are important to the overall reduction. The plots reveal that, among the selected sites, a reduction in the contribution from EGU sources is an important component of the overall reduction in $PM_{2.5}$ concentrations for Pittsburgh (Figure IV-20h), Pensacola (Figure IV-20j), Charlotte (Figure IV-20l), Knoxville (Figure IV-20m), Memphis (Figure IV-20n), and Cleveland (Figure IV-20q). A reduction in the contribution from non-EGU sources is an important component of the overall reduction in $PM_{2.5}$ concentrations for Chicago (Figure IV-20o), Baton Rouge (Figure IV-20s), Houston (Figure IV-20v), and St. Louis (Figure IV-20x). For all sites, the contribution from on-road mobile, non-road, and all other sources is lower under the CAAA scenario.

Ozone Modeling Results for the Eastern U.S.

This section of the report provides an overview of the CMAQ modeling results for the 12-km eastern U.S. (EUS) modeling domain. These modeling results were generated for the assessment of ozone related health effects. Recall that the simulation period for the EUS domain is May through September.

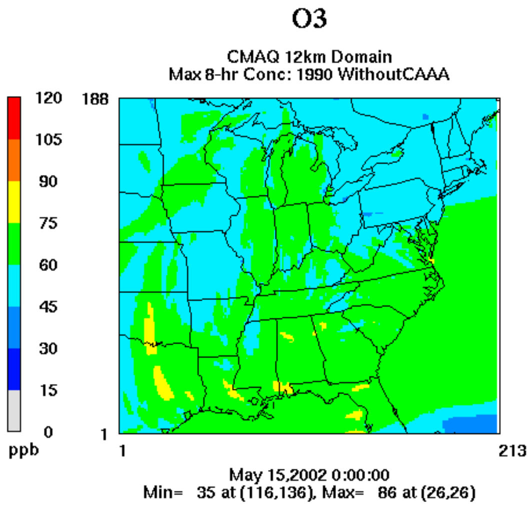
1990 Baseline Simulation

The 1990 scenario represents the base year for the CAAA and therefore this scenario does not include any CAAA measures.

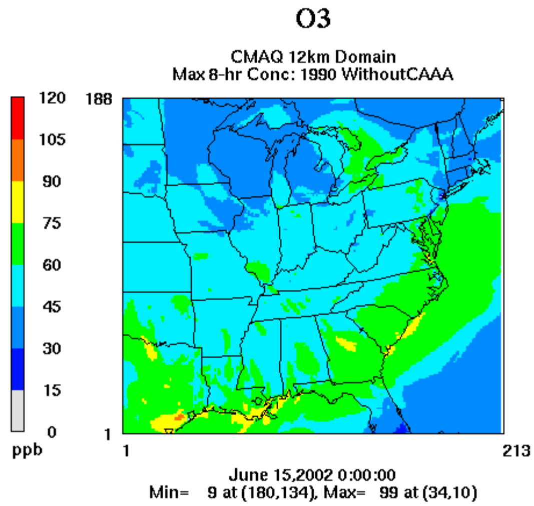
Figure IV-21 displays simulated daily maximum 8-hour ozone concentration (ppb) for the EUS domain for the 15th of May, June, July, August & September. The middle days of each month are used here to illustrate the month-to-month changes in ozone concentrations as well as a range of ozone concentration patterns.

Figure IV-21. Simulated Daily Maximum 8-Hour Ozone Concentration (ppb) for the EUS Domain for the 15th of May, June, July, August & September: 1990 Baseline Simulation.

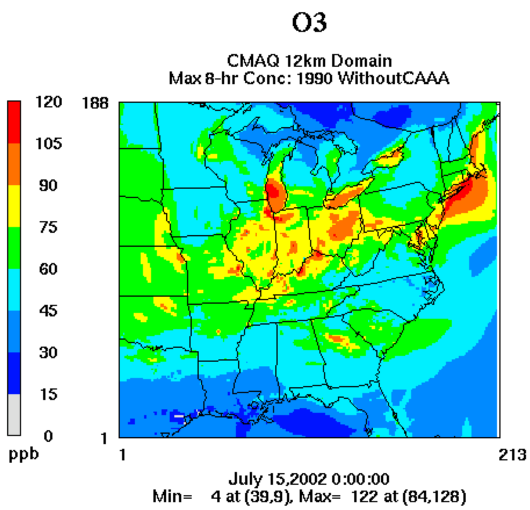
(a) May



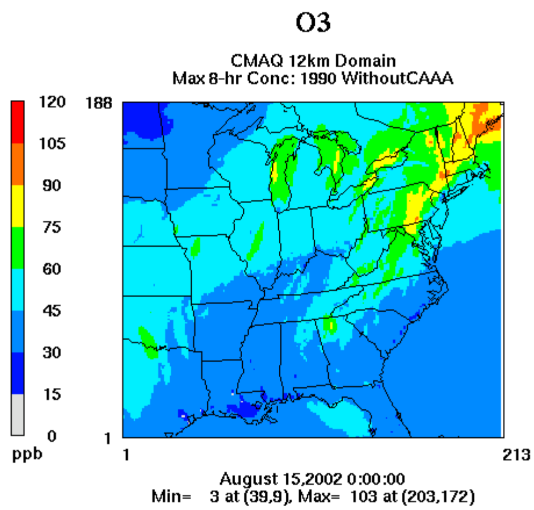
(b) June



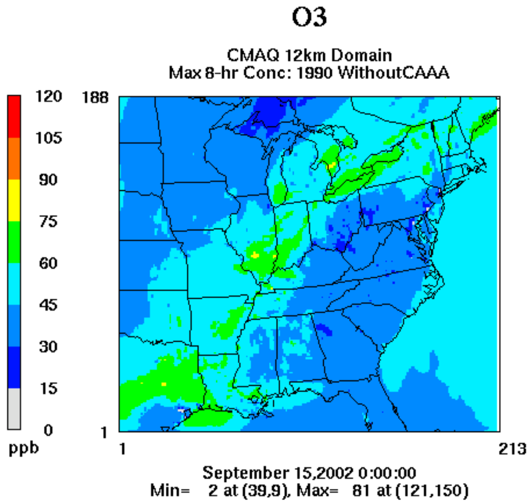
(c) July



(d) August



(e) September



Ozone gradually builds up in the South during the early part of the ozone season, while numerous areas of the South, Midwest, and Northeast are affected during the peak summer months. For this subset of days, July 15th has the most widespread high ozone as well as the highest overall concentrations.

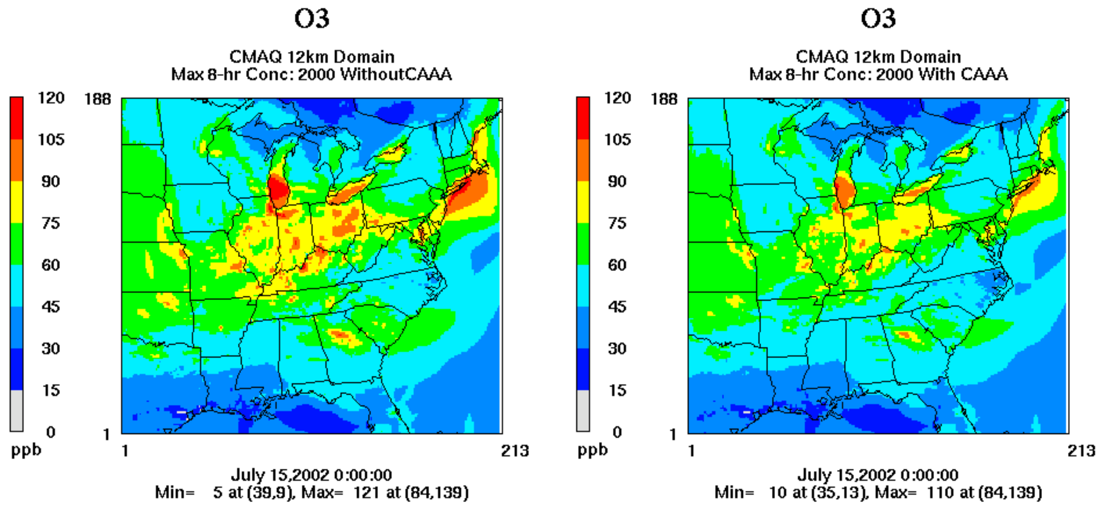
Without-CAAA2000 and with-CAAA2000 Scenarios

In this analysis, 2000 is the initial year for comparison of the without- and with-CAAA scenarios. The without-CAAA emissions for this year were projected from the 1990 base-year emissions. The with-CAAA emissions were based on emission inventory data for 2000. The emissions are summarized and compared in Section 2.

Figure IV-22 displays simulated daily maximum 8-hour ozone concentration (ppb) for the EUS domain for the 2000 without-CAAA (Figure IV-22a) and 2000 with-CAAA (Figure IV-22b) scenarios. The results for July 15th are shown. This day was selected as a representative ozone-season day for comparison of the without- and with-CAAA scenarios.

Figure IV-22. Simulated Daily Maximum 8-Hour Ozone Concentration (ppb) for the EUS Domain for 15 July: 2000 Scenarios.

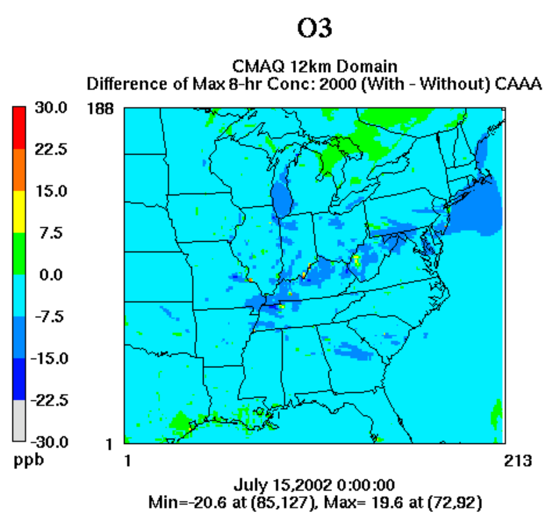
(a) Without CAAA *(b) With CAAA*



The results for the 12-km EUS domain for ozone for 15 July are very similar to those for the 36-km CONUS domain. For the year 2000 scenarios, high simulated ozone occurs downwind and in the vicinity of large metropolitan areas (Atlanta, Chicago, Cincinnati, New York, etc.). For the 2000 with-CAAA scenario, simulated ozone concentrations are reduced in these areas.

Figure IV-23 illustrates the differences in 8-hour ozone for this day between the two scenarios (with-CAAA minus without-CAAA).

Figure IV-23. Difference in Simulated Daily Maximum 8-Hour Ozone Concentration (ppb) for the EUS Domain for 15 July: 2000 With-CAAA Minus 2000 Without-CAAA Scenarios.



As shown in the results for the 36-km domain for these scenarios, simulated ozone is reduced in areas of high concentrations in the Ohio Valley area, over Lake Michigan, offshore of New Jersey/New York, and in the Atlanta area, when emission reductions due to CAAA controls are included for the year 2000.

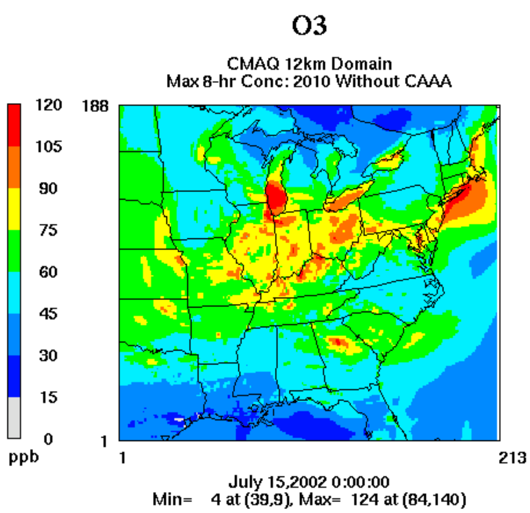
Without-CAAA2010 and with-CAAA2010 Scenarios

The 2010 without-CAAA emissions were projected from the 1990 base-year emissions. The 2010 with-CAAA emissions were projected from the 2000 base-year emissions. The emissions are summarized and compared in Section 2. The differences in emissions and simulated concentrations between the with- and without-CAAA scenarios are greater than for 2000.

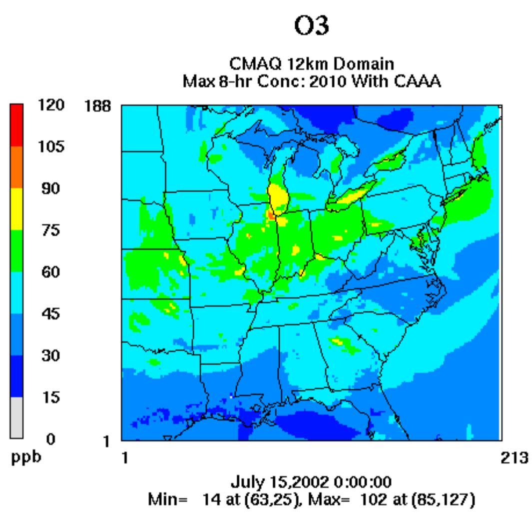
Figure IV-24 displays simulated daily maximum 8-hour ozone concentration (ppb) for the CONUS domain for July 15th for the 2010 without-CAAA (Figure IV-24a) and 2010 with-CAAA (Figure IV-24b) scenarios.

Figure IV-24 Simulated Daily Maximum 8-Hour Ozone Concentration (ppb) for the EUS Domain for 15 July: 2010 Scenarios.

(a) Without CAAA



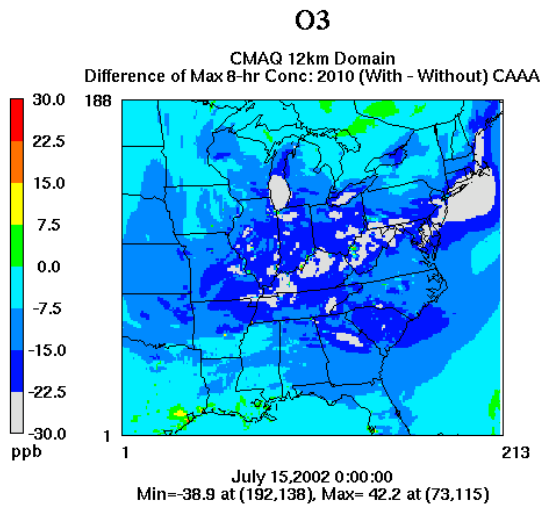
(b) With CAAA



For the 2010 scenarios, simulated ozone is increased compared to the year 2000 values in the same areas for the without-CAAA scenario in which precursor emissions are grown without controls. The maximum simulated 8-hr ozone concentration for this day is 124 ppb, compared to 121 ppb for the year 2000 without-CAAA scenario. Simulated ozone is substantially lower in the with-CAAA scenario.

Figure IV-25 illustrates the differences in 8-hour ozone for this day between the two scenarios (with-CAAA minus without-CAAA).

Figure IV-25. Difference in Simulated Daily Maximum 8-Hour Ozone Concentration (ppb) for the EUS Domain for 15 July: 2010 With-CAAA Minus 2010 Without-CAAA Scenarios.



The difference plot comparing the 2010 scenarios shows wide areas of simulated ozone reductions throughout the EUS domain, with a maximum decrease in simulated 8-hour maximum concentration of nearly 40 ppb, when CAAA controls are included.

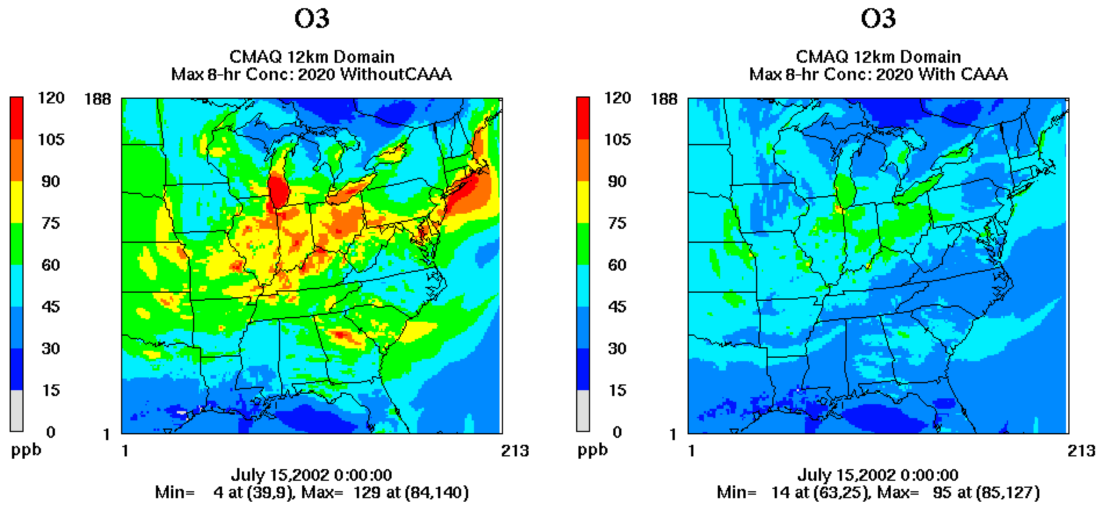
Without-CAAA2020 and with-CAAA2020 Scenarios

The 2020 without-CAAA emissions were projected from the 1990 base-year emissions. The 2020 with-CAAA emissions were projected from the 2000 base-year emissions. The emissions are summarized and compared in Section 2. The differences in emissions and simulated concentrations between the 2020 with- and without-CAAA scenarios are greater than for the other Section 812 scenario pairs.

Figure IV-26 displays simulated daily maximum 8-hour ozone concentration (ppb) for the CONUS domain for the 15th of July for the 2020 without-CAAA (Figure IV-26a) and 2020 with-CAAA (Figure IV-26b) scenarios.

Figure IV-26. Simulated Daily Maximum 8-Hour Ozone Concentration (ppb) for the EUS Domain for 15 July: 2020 Scenarios.

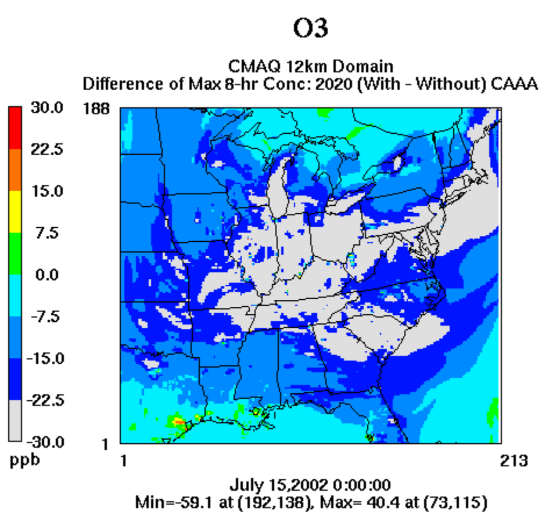
(a) Without CAAA *(b) With CAAA*



For the 2020 without CAAA scenario, simulated ozone concentrations increase beyond 2010 levels due to expected further increases in precursor emissions from growth during this period. In the absence of emission controls, the peak simulated concentration in the EUS domain for this day is 129 ppb, compared to 124 ppb for the 2010 without-CAAA scenario. When controls for 2020 are included, the maximum simulated 8-hr ozone concentration for this day is 95 ppb.

Figure IV-27 illustrates the differences in 8-hour ozone for this day between the two scenarios (with-CAAA minus without-CAAA).

Figure IV-27. Difference in Simulated Daily Maximum 8-Hour Ozone Concentration (ppb) for the EUS Domain for 15 July: 2020 With-CAAA Minus 2020 Without-CAAA Scenarios.



For 2020, the inclusion of CAAA controls and the resulting reduction in precursor emissions shows major reductions in simulated ozone in very large portions of the EUS domain. The gray area in the figure denotes an area with simulated 8-hr ozone reductions of greater than 22.5 ppb, with a maximum reduction of nearly 60 ppb in the New Jersey area.

Summary of the Effects of the CAAA on Ozone Quality

Tabular summaries of the 12-km CMAQ modeling results for selected subregions and monitoring sites are presented in this section. Again, for the 12-km domain and five-month simulation period, the focus is on ozone.

The subregions follow the EPA region definitions. The EPA region definitions for all regions were provided earlier in this section. Only Regions 1 through 7 are partly or fully contained within the EUS domain and the definitions used for this analysis are as follows:

- **Region 1:** Connecticut, Maine (partial), Massachusetts, New Hampshire, Rhode Island, Vermont
- **Region 2:** New Jersey, New York
- **Region 3:** Delaware, District of Columbia, Maryland, Pennsylvania, Virginia, West Virginia
- **Region 4:** Alabama, Florida (partial), Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee
- **Region 5:** Illinois, Indiana, Michigan, Minnesota, Ohio, Wisconsin
- **Region 6:** Arkansas, Louisiana, Oklahoma (partial), Texas (partial)
- **Region 7:** Iowa (partial), Kansas (partial), Missouri (partial), Nebraska (partial)

Ozone monitoring sites within each region were selected for a more detailed examination of the modeling results for specific urban areas. In some cases, these differ from the $PM_{2.5}$ monitoring sites but were selected to represent approximately the same areas. The EUS ozone monitoring sites are listed in Table IV-5.

Table IV-5. Ozone Monitoring Sites Used in the Analysis of CMAQ Results for the EUS Modeling Domain for the 812 Modeling Study.

Region	Site Location
Region 1	Groton, CT
	Truro, MA
	Bar Harbor, ME
	Portsmouth, NH
Region 2	East Brunswick, NJ
	Putnam Co., NY (New York City)
Region 3	Davidsonville, MD (Baltimore)
	Bristol, PA (Philadelphia)
	Pittsburgh, PA
	Richmond, VA
Region 4	Pensacola, FL
	Atlanta, GA
	Charlotte, NC
	Knoxville, TN

Region	Site Location
Region 5	Chicago, IL
	Stillwater, MN (Minneapolis)
	Cleveland, OH
	Sheboygan, WI
Region 6	Marion, AR (Memphis)
	Baton Rouge, LA
	Frisco, TX (Dallas)
	Houston, TX
Region 7	Kansas City, KS
	St Louis, MO

Several metrics are used to summarize the modeling results for ozone including peak simulated 8-hour ozone concentration, ozone exceedance exposure for a threshold of 75 ppb, and estimated design value. These metrics were defined previously in this report.

Table IV-6 lists the ozone exceedance exposure for each subregion and scenario. This metric is the amount by which the simulated ozone concentration exceeds 75 ppb, summed over all grid cells (within the selected area) and all days.

Table IV-6. Ozone Exceedance Exposure Based on 75 ppb for the EUS Domain and all Section 812 Scenarios. Units are ppb ∗ grid cell ∗ days.

Region	1990 Baseline	2000 w/o CAAA	2000 w/ CAAA	2010 w/o CAAA	2010 w/ CAAA	2020 w/o CAAA	2020 w/ CAAA
Region 1	489,338	388,979	143,159	460,610	5,956	633,378	541
Region 2	643,653	563,680	204,738	695,386	15,870	929,021	831
Region 3	1,521,879	1,471,197	454,546	1,899,539	24,129	2,659,081	3,389
Region 4	2,789,957	3,686,211	1,283,666	5,043,904	95,090	7,542,997	7,133
Region 5	3,030,564	3,225,655	1,093,113	3,936,466	89,895	5,347,470	24,168
Region 6	798,243	936,108	265,873	1,319,936	25,620	2,298,802	4,099
Region 7	441,020	516,665	147,570	671,918	16,940	1,037,752	3,263

For the without-CAAA scenarios, a mix of increases and decreases between 1990 and 2000 (depending on the region) is followed by a steady increase with time. The largest increases tend to occur between 2010 and 2020. Ozone exceedance exposure consistently decreases with time for the with-CAAA scenarios. For all regions, the greatest decrease occurs between 1990 and 2000. By 2020, the reduction is nearly 100 percent for most regions – indicating that only a small fraction of grid cells and days have simulated ozone concentrations greater than 75 ppb.

Table IV-7 lists the peak simulated 8-hour ozone concentration for each EUS monitoring site and scenario.

Table IV-7. Simulated Maximum 8-Hour Ozone Concentration (ppb) for Selected Monitoring Sites in the EUS Domain and all Section 812 Scenarios.

	1990 Baseline	2000 w/o CAAA	2000 w/ CAAA	2010 w/o CAAA	2010 w/ CAAA	2020 w/o CAAA	2020 w/ CAAA
Region 1 Sites							
Groton, CT	118.0	113.0	100.6	113.5	76.0	118.0	63.0
Truro, MA	123.0	122.0	115.2	125.7	96.1	134.0	81.0
Bar Harbor, ME	113.0	108.0	97.5	109.5	81.1	114.0	69.7
Nashua, NH	92.3	90.0	81.5	91.6	70.7	94.4	64.7
Region 2 Sites							
East Brunswick, NJ	106.0	106.0	93.7	108.1	81.3	111.0	66.7
Putnam Co., NY (New York City)	117.0	113.0	102.4	115.8	81.4	121.0	68.1
Region 3 Sites							
Davidsonville, MD	118.0	114.0	105.0	117.5	83.9	123.0	70.9
Bristol, PA (Philadelphia)	119.0	118.0	107.6	120.7	87.7	124.0	74.0
Pittsburgh, PA	111.0	110.0	97.4	111.9	86.7	115.0	82.6
Richmond, VA	98.4	100.0	91.8	103.4	80.0	108.0	74.9
Region 4 Sites							
Pensacola, FL	109.0	106.0	95.9	107.5	86.3	110.0	79.7
Atlanta, GA	137.0	133.0	128.9	136.8	118.9	140.0	93.1
Charlotte, NC	101.0	109.0	100.8	115.9	84.2	123.0	70.9
Knoxville, TN	114.0	113.0	104.4	115.7	75.8	119.0	63.5
Region 5 Sites							
Chicago, IL	129.0	120.0	104.4	123.5	102.0	129.0	102.8
Stillwater, MN (Minneapolis)	97.9	97.8	90.2	100.3	81.8	104.0	77.0
Cleveland, OH	108.0	107.0	99.3	109.3	82.7	113.0	72.6
Sheboygan, WI	143.0	140.0	126.9	142.9	109.0	149.0	97.7
Region 6 Sites							
Marion, AR (Memphis)	109.0	113.0	97.1	116.5	78.3	121.0	68.8
Baton Rouge, LA	87.7	87.5	81.2	88.8	76.8	92.6	71.9
Frisco, TX (Dallas)	95.0	94.9	86.8	96.7	77.7	100.0	71.4
Houston, TX	106.0	106.0	97.9	106.9	84.9	111.0	77.8
Region 7 Sites							
Kansas City, KS	97.6	97.4	90.3	99.9	82.6	104.0	75.9
St. Louis, MO	118.0	118.0	107.3	120.0	92.7	124.0	86.3

Simulated maximum 8-hour ozone concentrations generally increase with time for the without-CAAA scenarios, although there are some simulated decreases between 1990 and 2000. Conversely, the 8-hour ozone concentrations decrease with time for the with-CAAA scenarios (with one exception for Chicago between 2010 and 2020).

Table IV-8 presents the estimated future-year 8-hour ozone design values for each monitoring site and scenario. The future-year design values were estimated based on a 2002 baseline (observation-based) design value. Site-specific model-derived relative reduction factors were applied to the observation-based (baseline) design values in order to estimate the future-year design values. This procedure is described in detail in EPA's modeling guidance document (EPA, 2007). Note that a future-year design value less than or equal to 75 ppb is an indicator of future-year attainment.

Table IV-8. Estimated Future-Year 8-Hour Ozone Design Value (ppb) for Selected Monitoring Sites in the EUS Domain and the Future-Year Section 812 Scenarios.

	2002 DV	2010 w/o CAAA	2010 w/CAAA	2020 w/o CAAA	2020 w/CAAA
Region 1 Sites					
Groton, CT	90	100	72	104	60
Truro, MA	94	103	80	107	70
Bar Harbor, ME	93	101	79	104	70
Nashua, NH	85	92	72	94	62
Region 2 Sites					
East Brunswick, NJ	101	112	86	114	73
Putnam Co., NY (New York City)	92	103	74	106	61
Region 3 Sites					
Davidsonville, MD	102	114	84	119	73
Bristol, PA (Philadelphia)	105	116	89	119	77
Pittsburgh, PA	93	101	81	103	76
Richmond, VA	91	99	78	102	71
Region 4 Sites					
Pensacola, FL	84	91	78	93	73
Atlanta, GA	99	107	86	111	74
Charlotte, NC	102	115	85	120	73
Knoxville, TN	96	105	79	109	69
Region 5 Sites					
Chicago, IL	88	96	80	99	76
Stillwater, MN (Minneapolis)	73	78	66	81	61
Cleveland, OH	100	109	84	112	75
Sheboygan, WI	99	109	86	112	79
Region 6 Sites					
Marion, AR (Memphis)	94	103	79	106	71
Baton Rouge, LA	84	91	75	95	69
Frisco, TX (Dallas)	93	103	82	108	73
Houston, TX	108	117	95	123	87
Region 7 Sites					
Kansas City, KS	81	86	74	88	65
St. Louis, MO	91	98	78	101	71

Estimated 8-hour ozone design values increase with time for the without-CAAA scenario and decrease with time for the with-CAAA scenarios. For the with-CAAA scenarios, the number of sites for which attainment is not indicated is 19 for 2010 and 6 for 2020 (compared to 24 (all sites) for 2002). The results are qualitatively similar for all three metrics.

Ozone Modeling Results for the Western U.S.

This section of the report provides an overview of the CMAQ modeling results for the 12-km western U.S. (WUS) modeling domain. These modeling results were generated for the assessment of ozone related health effects. The simulation period for the WUS domain is May through September.

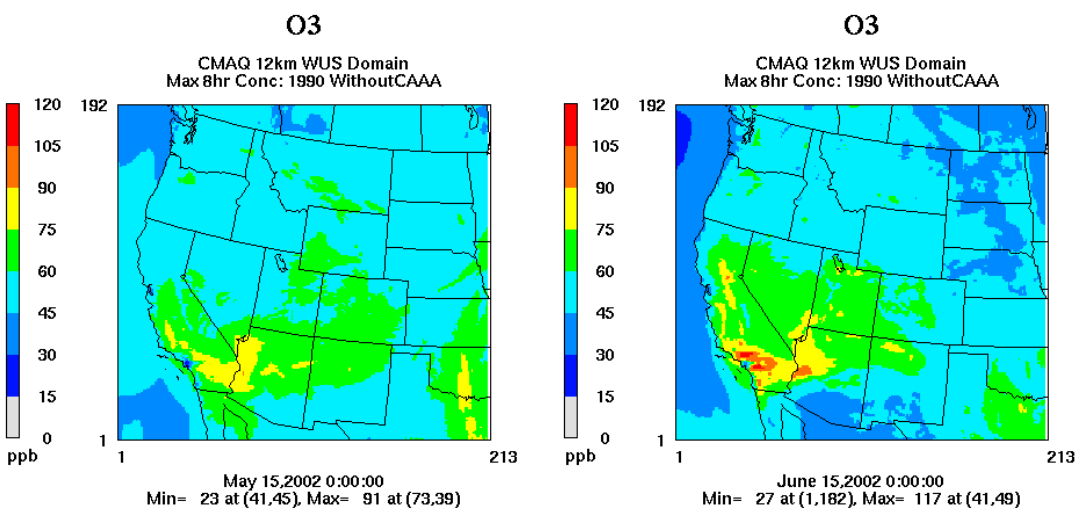
1990 Baseline Simulation

The 1990 scenario represents the base year for the CAAA and therefore this scenario does not include any CAAA measures.

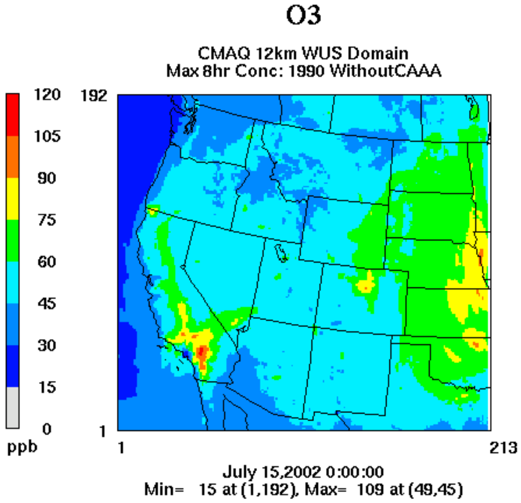
Figure IV-28 displays simulated daily maximum 8-hour ozone concentration (ppb) for the WUS domain for the 15th of May, June, July, August & September. The middle days of each month are used here to illustrate the month-to-month changes in ozone concentrations as well as a range of ozone concentration patterns.

Figure IV-28. Simulated Daily Maximum 8-Hour Ozone Concentration (ppb) for the WUS Domain for the 15th of May, June, July, August & September: 1990 Baseline Simulation.

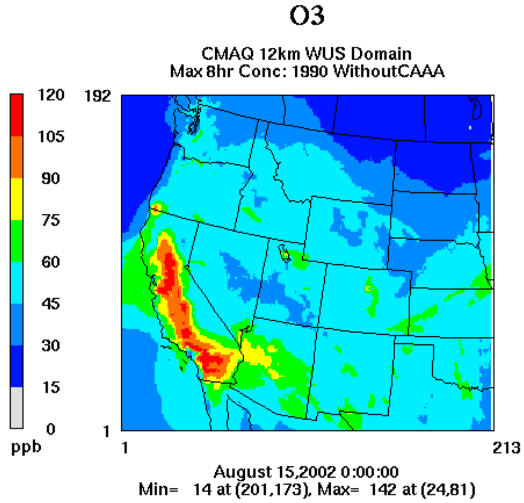
(a) May *(b) June*



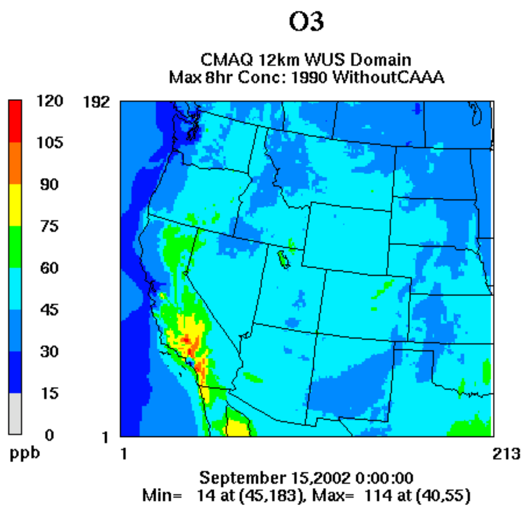
(c) July



(d) August



(e) September



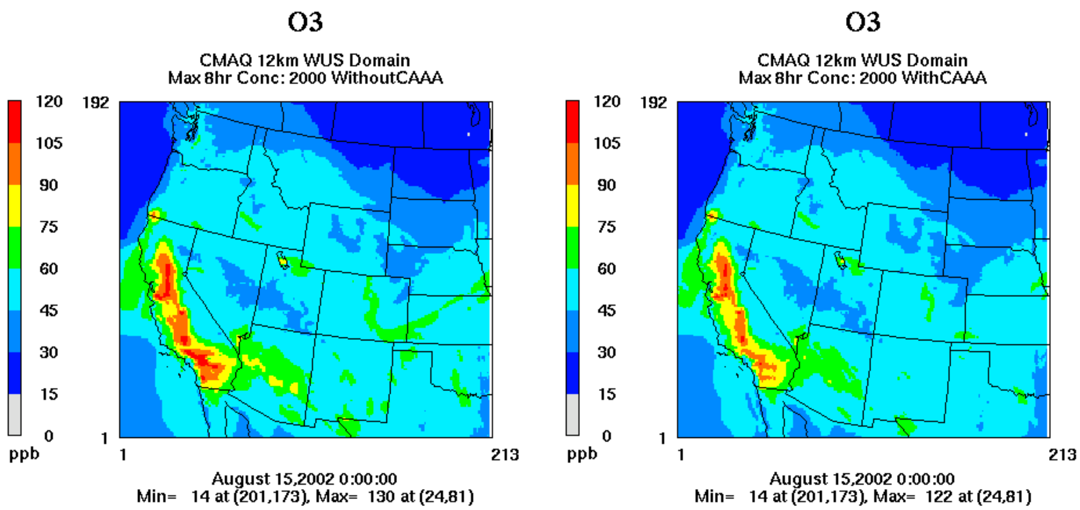
All of the selected days show moderate to highest ozone concentrations over southern California. The area of high ozone extends into Arizona on June 15th and high ozone encompasses California's Central Valley on August 15th. There are also high ozone concentrations in the easternmost part of the domain on July 15th – matching the concentrations for the EUS domain on this day. For this subset of days, August 15th has the most widespread high ozone as well as the highest overall concentrations.

Without-CAAA2000 and with-CAAA2000 Scenarios

Figure IV-29 displays simulated daily maximum 8-hour ozone concentration (ppb) for the WUS domain for the 2000 without-CAAA (Figure IV-29a) and 2000 with-CAAA (Figure IV-29b) scenarios. The results for August 15th are shown. This day was selected as a representative high ozone day for comparison of the without- and with-CAAA scenarios.

Figure IV-29. Simulated Daily Maximum 8-Hour Ozone Concentration (ppb) for the WUS Domain for 15 August: 2000 Scenarios.

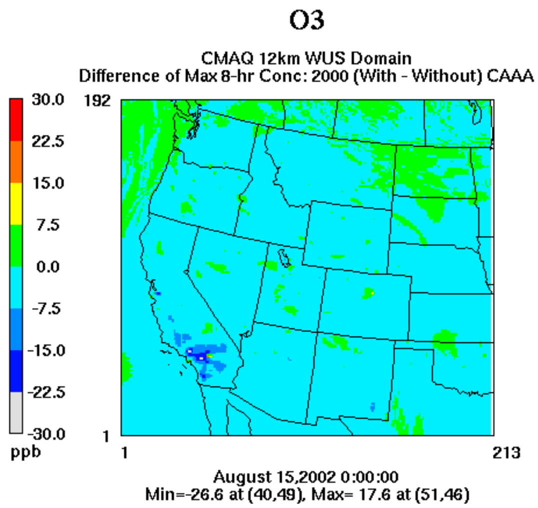
(a) Without CAAA *(b) With CAAA*



The 2000 without-CAAA scenario shows similar patterns throughout the WUS domain compared to 1990, but maximum simulated 8-hour ozone for 2000 is somewhat less in the Central Valley of California, the Los Angeles Basin, and parts of Arizona compared to 1990. This is due to estimated 7 percent reduction in total VOC emissions and 26 percent reduction in total NO_x emissions in California, despite assumed growth. The major reductions are from the on-road mobile source sector, reflecting fleet turnover during these ten years and California vehicle emission standards, which are not related to the 1990 CAAA. The peak simulated 8-hour concentration for 15 August in the 2000 without-CAAA scenario is 130 ppb, while the peak value for the 1990 base case at this same location (Central California) is 142 ppb. The inclusion of emission reductions from the CAAA results in modest decreases in simulated maximum 8-hour ozone for this day.

Figure IV-30 illustrates the differences in 8-hour ozone for this day between the two scenarios (with-CAAA minus without-CAAA).

Figure IV-30. Difference in Simulated Daily Maximum 8-Hour Ozone Concentration (ppb) for the WUS Domain for the 15 August: 2000 With-CAAA Minus 2000 Without-CAAA Scenarios.



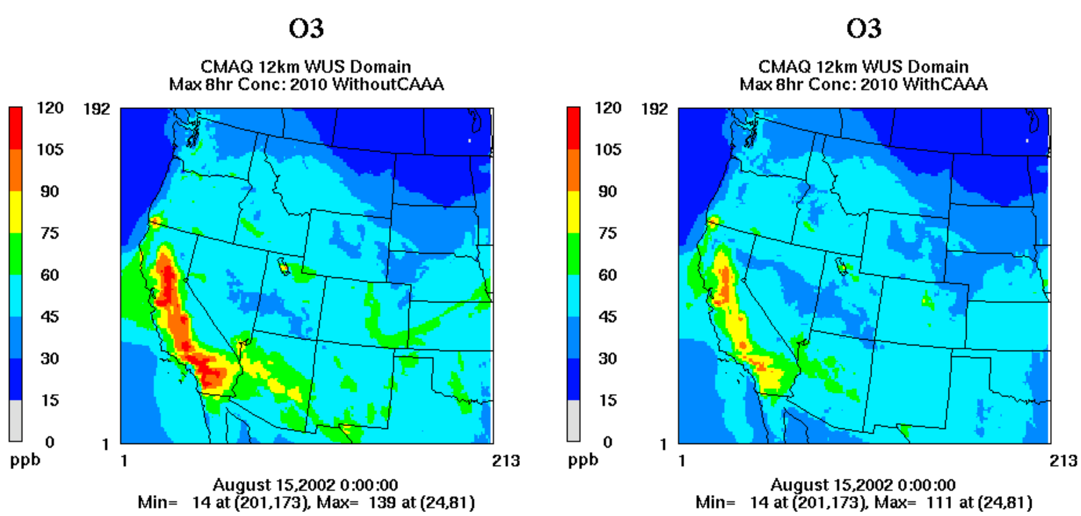
The inclusion of CAAA controls in 2000 results in modest reductions in simulated ozone concentrations throughout the WUS domain, with the largest reductions in 8-hour ozone occurring in the Los Angeles Basin.

Without-CAAA2010 and with-CAAA2010 Scenarios

Figure IV-31 displays simulated daily maximum 8-hour ozone concentration (ppb) for the WUS domain for August 15th for the 2010 without-CAAA (Figure IV-31a) and 2010 with-CAAA (Figure IV-31b) scenarios.

Figure IV-31. Simulated Daily Maximum 8-Hour Ozone Concentration (ppb) for the WUS Domain for 15 August: 2010 Scenarios.

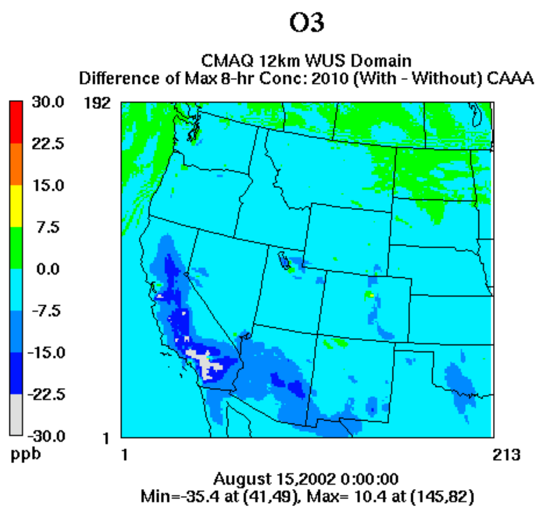
(a) Without CAAA *(b) With CAAA*



The results for the 2010 without-CAAA scenario for 15 August are quite similar in the extent and magnitude of simulated 8-hour ozone to the 1990 base case scenario, with high ozone confined to California's Central Valley, the Los Angeles Basin, and parts of central Arizona. The emissions reductions estimated in the 2000 without-CAAA case for California (from, for example, California vehicle emission standards) are somewhat outpaced by the assumed growth in population and motor vehicles, and the precursor emissions in 2010 are greater than 2000 levels for all source categories. The peak simulated 8-hour ozone concentration of 139 ppb, located in Central California, is comparable to the peak of 142 ppb in the 1990 base case.

Figure IV-32 illustrates the differences in 8-hour ozone for this day between the two scenarios (with-CAAA minus without-CAAA).

Figure IV-32. Difference in Simulated Daily Maximum 8-Hour Ozone Concentration (ppb) for the WUS Domain for 15 August: 2010 With-CAAA Minus 2010 Without-CAAA Scenarios.



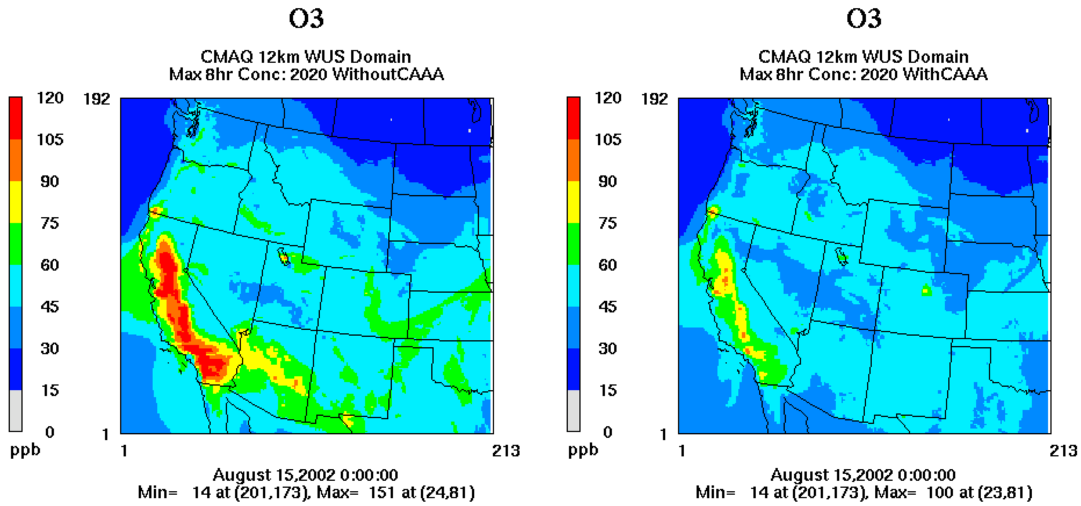
The inclusion of precursor emission reductions in the 2010 with-CAAA scenarios results in significant decreases in 8-hour ozone in the Los Angeles Basin, with smaller decreases shown in central Arizona and central California. The maximum decrease in 8-hour ozone is 35 ppb in the Los Angeles Basin when controls are included for 2010.

Without-CAAA2020 and with-CAAA2020 Scenarios

Figure IV-33 displays simulated daily maximum 8-hour ozone concentration (ppb) for the WUS domain for the 15th of August for the 2020 without-CAAA (Figure IV-33a) and 2020 with-CAAA (Figure IV-33b) scenarios.

Figure IV-33. Simulated Daily Maximum 8-Hour Ozone Concentration (ppb) for the WUS Domain for 15 August: 2020 Scenarios.

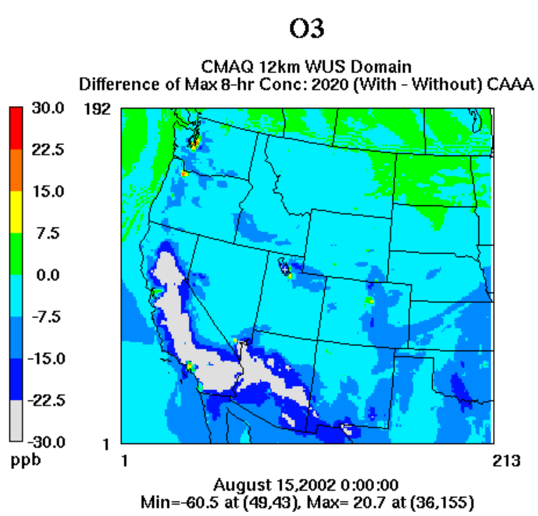
(a) Without CAAA *(b) With CAAA*



For the 2020 without-CAAA scenario, in which emissions are grown beyond 2010 levels, simulated 8-hour ozone increases substantially in California and Arizona. The peak simulated value for 2020 is 151 ppb, compared to a value of 139 ppb for 2010. The inclusion of controls in 2020 shows a large decrease in simulated 8-hour ozone in all areas, especially California and Arizona, resulting in no areas in Arizona showing concentrations over the current 8-hour ozone NAAQS of 75 ppb.

Figure IV-34 illustrates the differences in 8-hour ozone for this day between the two scenarios (with-CAAA minus without-CAAA).

Figure IV-34. Difference in Simulated Daily Maximum 8-Hour Ozone Concentration (ppb) for the WUS Domain for 15 August: 2020 With-CAAA Minus 2020 Without-CAAA Scenarios.



The difference plot comparing the with- and without-CAAA control scenarios for 2020 shows the extent and magnitude of the differences in simulated 8-hour ozone concentrations, with the largest decrease of over 60 ppb for this day in Central California. In addition to decreases in simulated 8-hour ozone in California and Arizona, modest decreases are also seen in the central states (Texas, Oklahoma, and Nebraska).

Summary of the Effects of the CAAA on Ozone Quality

Tabular summaries of the 12-km CMAQ ozone modeling results for selected subregions and monitoring sites are presented in this section.

The subregions follow the EPA region definitions. The EPA region definitions for all regions were provided earlier in this section. Only Regions 6 through 10 are partly or fully contained within the WUS domain and the definitions used for this analysis are as follows:

- **Region 6:** New Mexico, Oklahoma (partial), Texas (partial)
- **Region 7:** Iowa (partial), Kansas (partial), Nebraska
- **Region 8**: Colorado, Montana, North Dakota, South Dakota, Utah, Wyoming
- **Region 9:** Arizona, California, Nevada
- **Region 10**: Idaho, Oregon, Washington

Ozone monitoring sites within each region were selected for a more detailed examination of the modeling results for specific urban areas. These were selected to represent approximately the same areas as the $PM_{2.5}$ monitoring sites. Preference was given to sites with high ozone design values, where possible. The WUS ozone monitoring sites are listed in Table IV-9. Note that both Region 7 sites are in the EUS domain and not in the WUS domain and are therefore not listed here.

Table IV-9. Ozone Monitoring Sites Used in the Analysis of CMAQ Results for the WUS Modeling Domain for the 812 Modeling Study.

Region	Site Location
Region 6	Albuquerque, NM
	Frisco, TX (Dallas)
Region 8	Applewood, CO (Denver)
	Glacier National Park, MT
	Spanish Fork, UT (Provo-Orem)
Region 9	Phoenix, AR
	Cool, CA (Sacrament)
	Fresno, CA
	Bakersfield, CA
	Los Angeles, CA
Region 10	Boise, ID
	Seattle, WA

Metrics used to summarize the modeling results for ozone include: peak simulated 8-hour ozone concentration, ozone exceedance exposure for a threshold of 75 ppb, and estimated design value. These metrics were defined previously in this report.

Table IV-10 lists the ozone exceedance exposure for each subregion and scenario. This metric is the amount by which the simulated ozone concentration exceeds 75 ppb, summed over all grid cells (within the selected area) and all days.

Table IV-10. Ozone Exceedance Exposure Based on 75 ppb for the WUS Domain and all Section 812 Scenarios. Units are ppb ∗ grid cell ∗ days.

Region	1990 Baseline	2000 w/o CAAA	2000 w/ CAAA	2010 w/o CAAA	2010 w/ CAAA	2020 w/o CAAA	2020 w/ CAAA
Region 6	448,398	399,598	134,684	591,194	15,963	1,118,006	1,644
Region 7	133,126	138,395	28,456	210,848	2,032	409,052	75
Region 8	90,550	111,953	47,499	159,051	22,390	302,551	7,622
Region 9	5,757,786	3,533,353	1,628,242	5,339,838	597,833	8,932,696	189,229
Region 10	24,341	24,540	20,281	32,645	15,170	50,823	12,515

This is an interesting summary because it includes results for a variety of different geographic areas with a wide range of baseline ozone exceedance exposure values and corresponding ozone concentrations. For the without-CAAA scenarios, a mix of increases and decreases between 1990 and 2000 (depending on the region) is followed by a steady increase with time. The largest increases tend to occur between 2010 and 2020, where in some cases ozone exceedance exposure nearly doubles. Ozone exceedance exposure consistently decreases with time for the with-CAAA scenarios. There is a very large reduction in this metric for Region 9 (which includes California). For most areas, only a small fraction of grid cells and days have simulated 8-hour ozone concentrations greater than 75 ppb by 2020.

Table IV-11 lists the peak simulated 8-hour ozone concentration for each WUS monitoring site and scenario.

Table IV-11. Simulated Maximum 8-Hour Ozone Concentration (ppb) for Selected Monitoring Sites in the WUS Domain and all Section 812 Scenarios.

	1990 Baseline	2000 w/o CAAA	2000 w/ CAAA	2010 w/o CAAA	2010 w/ CAAA	2020 w/o CAAA	2020 w/ CAAA
Region 6 Sites							
Albuquerque, NM	80.8	79.6	74.8	82.9	68.8	88.0	64.6
Frisco, TX (Dallas)	102.9	104.1	97.1	107.9	84.7	113.9	73.8
Region 8 Sites							
Applewood, CO (Denver)	108.8	104.6	106.5	109.1	99.9	113.9	92.6
Glacier National Park, MT	58.9	58.8	58.5	58.8	58.2	58.5	57.7
Spanish Fork, UT (Provo-Orem)	82.9	77.8	77.3	80.3	75.3	83.7	70.5

	1990 Baseline	2000 w/o CAAA	2000 w/ CAAA	2010 w/o CAAA	2010 w/ CAAA	2020 w/o CAAA	2020 w/ CAAA
Region 9 Sites							
Phoenix, AZ	100.7	97.5	93.0	101.3	87.6	104.6	79.7
Cool, CA (Sacramento)	119.9	110.7	107.2	118.0	98.8	127.8	90.1
Fresno, CA	111.5	101.9	100.2	108.6	91.5	116.4	87.1
Bakersfield, CA	101.6	97.9	93.0	101.7	86.4	108.4	82.3
Glendora, CA (Los Angeles)	111.0	131.3	103.7	139.4	100.5	156.5	96.3
Region 10 Sites							
Boise, ID	77.5	79.6	79.0	82.2	76.5	84.6	76.2
Seattle, WA	70.2	66.9	62.6	69.2	60.3	71.7	60.3

Following a mix of increases and decreases in the simulated maximum 8-hour ozone concentrations between 1990 and 2000, the values generally increase with time for the without-CAAA scenarios and decrease with time for the with-CAAA scenarios.

Table IV-12 presents the estimated future-year 8-hour ozone design values for each monitoring site and scenario. The future-year design values were estimated based on a 2002 baseline (observation-based) design value. Site-specific model-derived relative reduction factors were applied to the baseline design values in order to estimate the future-year design values. This procedure is described in detail in EPA's modeling guidance document (EPA, 2007). Note that a future-year design value less than or equal to 75 ppb is an indicator of future-year attainment.

Table IV-12. Estimated Future-Year 8-Hour Ozone Design Value (ppb) for Selected Monitoring Sites in the WUS Domain and the Future-Year Section 812 Scenarios.

	2002 DV	2010 w/o CAAA	2010 w/CAAA	2020 w/o CAAA	2020 w/CAAA
Region 6 Sites					
Albuquerque, NM	70	75	65	77	60
Frisco, TX (Dallas)	93	102	81	107	73
Region 8 Sites					
Applewood, CO (Denver)	82	83	79	86	76
Glacier National Park, MT	52	52	51	52	51
Spanish Fork, UT (Provo-Orem)	75	78	71	79	66
Region 9 Sites					
Phoenix, AZ	86	93	82	95	75
Cool, CA (Sacramento)	106	116	98	122	91
Fresno, CA	115	124	106	132	102
Bakersfield, CA	101	109	94	116	90
Glendora, CA (Los Angeles)	111	109	94	116	90
Region 10 Sites					
Boise, ID	78	81	75	84	74
Seattle, WA	68	71	66	72	63

Estimated 8-hour ozone design values tend to increase with time for the without-CAAA scenario and decrease with time for the with-CAAA scenarios. Sites with low base design values show less of a response either way, compared to sites with high base design values. Glacier National Park shows little change, likely due to the isolated location of the monitoring site. For the with-CAAA scenarios, the number of sites for which attainment is not indicated is 8 for 2010 and 6 for 2020 (compared to 9 for 2002). The results are qualitatively similar for all three metrics.

The Frisco, TX (Dallas) monitoring site appears in both summary tables, for the EUS and WUS domain and it interesting to compare the results for the two modeling domains. The maximum 8-hour simulated concentrations for this site are show in Table IV-13a and the estimated design values are given in Table IV-13b.

Table IV-13a. Simulated Maximum 8-Hour Ozone Concentration (ppb) for the Frisco, TX (Dallas) Monitoring Site for all Section 812 Scenarios.

	1990 Baseline	2000 w/o CAAA	2000 w/ CAAA	2010 w/o CAAA	2010 w/ CAAA	2020 w/o CAAA	2020 w/ CAAA
EUS Simulation	95.0	94.9	86.8	96.7	77.7	100.0	71.4
WUS Simulation	102.9	104.1	97.1	107.9	84.7	113.9	73.8

Table IV-13b. Estimated Future-Year 8-Hour Ozone Design Value (ppb) for the Frisco, TX (Dallas) Monitoring Site for the Future-Year Section 812 Scenarios.

	2002 DV	2010 w/o CAAA	2010 w/CAAA	2020 w/o CAAA	2020 w/CAAA
EUS Simulation	93	103	82	108	73
WUS Simulation	93	102	81	107	73

The simulated concentrations are higher for the WUS domain, but the estimated design values are very similar for both grids. This indicates that model performance is different for the two grids in the overlap area, but that the response of the model to the emissions changes is about the same.

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Section V
Discussion of Attributes and Limitations

Unlike the air quality modeling conducted over a decade ago for the first Section 812 prospective analysis, which used two different models for ozone and particulate matter, the modeling conducted for the second prospective analysis utilized EPA's Community Multiscale Air Quality (CMAQ) model, a "one-atmosphere" model that simulates the chemical formation, transport, and deposition of ozone <u>and</u> particulate matter together in one comprehensive system. (The use of a model such as CMAQ was one of the recommendations that came out of the first prospective modeling analysis.) The use of a comprehensive air quality modeling system provides a consistent platform for evaluating the expected responses to changes in precursor emissions.

The CMAQ grid resolution and the annual and seasonal simulation periods used for this study are consistent with current EPA modeling guidance. A 36-km resolution continental-scale grid (CONUS) was used to simulate fine particulates ($PM_{2.5}$) and visibility. The 36-km simulations were run for an annual simulation period. In addition, two 12-km resolution grids (EUS – Eastern U.S. and WUS – Western U.S.) were used to simulate ozone concentrations (with higher resolution). The 12-km simulations were run for a five-month simulation period encompassing the ozone season.

The air quality modeling analysis conducted for the second Section 812 prospective study used national-scale modeling databases originally prepared by EPA for use in other recent modeling exercises conducted to support national rulemaking, including the latest available meteorological and other input databases (for 2002). Given that the modeling databases were originally prepared and utilized by EPA in other analyses, a comprehensive performance evaluation was not undertaken as part of this Section 812 prospective analysis. However, there still could exist various biases in the simulated concentration fields due to the inaccurate depiction of the meteorological fields or errors in the emission inventory inputs. In addition, biases or uncertainties could be manifested in the simulated concentration fields due to the use of the 36- and 12-km resolution grids, which might not be sufficiently detailed to resolve certain sub-grid scale processes in portions of the modeling domain. All air quality modeling exercises are affected by inherent uncertainties in model formulation, meteorological inputs, and emission inventory estimates. Nevertheless, the modeling was conducted following current EPA guidelines and consistent with EPA approaches/practice for similar national-scale modeling exercises.

For the future-year analysis for 2010 and 2020, the air quality forecasts provided by CMAQ are only as good as the future-year emission estimates. Although much effort was undertaken to provide accurate estimates of expected future growth in population and economic and industrial activity, such estimates still contain uncertainties due to potential unknown social, political, and/or economic factors that may affect growth/activity and resulting emissions in the future. In addition, the planned emission reductions by various source sectors due to the CAAA-mandated provisions may not occur with the expected degree of emission-reduction effectiveness or on the schedule assumed in this modeling analysis. Also, it is generally accepted that the farther out the forecast (e.g., 2020), the more uncertain are the future-year estimates.

It is also important to note that while this study was being conducted, two of EPA's major emission reduction rules affecting future controls on EGU SO_2 and NO_x emissions for 2010 and 2020, namely the Clean Air Interstate Rule (CAIR) and the Clean Air Mercury Rule (CAMR), were vacated by U.S. Court of Appeals for the District of Columbia. The CAIR was vacated on 11 July 2008 and the CAMR was vacated on 8 February 2008. The expected emissions reductions from the original CAIR and CAMR provisions were included in the modeling analysis presented in this report. Unless EPA quickly develops and adopts new rules that will be acceptable to the Court, the expected emissions reductions from CAIR and CAMR assumed in the second prospective modeling analysis will likely not be realized by 2010. This will reduce the accuracy of the future-year emissions projections and simulated ozone and PM concentrations for 2010 primarily in the eastern portion of the U.S. Depending on the final level of mandated reductions for EGUs and the schedule for such reductions contained in revised/updated rules, the results for 2020 presented herein are also somewhat uncertain.

Section VI
Summary and Recommendations for Further Research

For the second Section 812 prospective modeling analysis, the CMAQ air quality model was applied to estimate the effects of implementing the CAA measures on future-year ambient air quality. The CMAQ model was applied for seven core CAAA scenarios including the 1990 without-CAAA, 2000 without-CAAA, 2010 without-CAAA, 2020 without-CAAA, 2000 with-CAAA, 2010 with-CAAA and 2020 with-CAAA scenarios.

Emission inventories were developed for each of the scenario years. Emissions for the historical years (1990 and 2000) were based on the best available emission inventories for these years. Projection to the future years was based on economic growth projections, future-year control requirements (for attainment of National Ambient Air Quality Standards (NAAQS)), and control efficiencies. Different assumptions were applied for the with- and without-CAAA scenarios resulting in a different future-year emissions pathway for each scenario.

The model-ready emission inventories for each scenario and year were then used to obtain base- and future-year estimates of the key criteria pollutants, as well as many other species. For fine particulate matter ($PM_{2.5}$) and related species, the CMAQ model was applied for an annual simulation period (January through December). A 36-km resolution modeling domain that encompasses the contiguous 48 states was used for the annual modeling. For ozone and related species, the CMAQ model was applied for a five-month simulation period that captures the key ozone-season months of May through September. Two 12-km resolution modeling domains (that when combined cover the contiguous 48 U.S. states) were used for the ozone-season modeling. Altogether, model-ready emission inventories were prepared and the CMAQ model was applied for a total of 21 simulations (comprising seven core scenarios and three modeling domains). Simulated concentrations of ozone, $PM_{2.5}$, and $PM_{2.5}$ species and deposition of sulfur, nitrogen and other species provide the basis for the calculation of health and ecological benefits of the CAA.

Use of the CMAQ model provided the opportunity to simulate the interactions of gaseous and particulate precursors that lead to the formation, transport, and deposition of both ozone and particulate matter in the atmosphere. The inclusion of emission reductions for the future years due to CAAA controls resulted in substantial reductions in simulated ozone and PM throughout the U.S. Without such controls, many areas of the country would most likely fall into or continue to be in violation of the existing National Ambient Air Quality Standards (NAAQS) for ozone and $PM_{2.5}$. This would also affect progress towards improving regional haze and reaching the longer-term visibility improvement goals throughout the country. With the expected reductions due to CAA measures, the simulations indicate that most areas of the country (with a few exceptions) will be in compliance of the ozone and $PM_{2.5}$ NAAQS by 2020.

For this analysis, CMAQ's Particle and Precursor Tagging Methodology (PPTM) was also utilized as a quality-assurance tool to evaluate the contribution of source-category emissions on simulated

$PM_{2.5}$ for 2010. The use of PPTM provided additional information regarding which source categories were contributing most to the simulated and PM concentration fields throughout the US. This information can be used to refine the benefits analysis because contribution information (and resulting effectiveness) can now be evaluated and quantified by source category and control program, rather than just lumping all of the controls together and assuming equal effectiveness.

The following is a set of recommendations aimed at extending and improving the air quality modeling analysis to better support the overall Section 812 prospective analysis:

- Conduct additional modeling to evaluate any changes resulting from the re-issuance of the CAIR or CAMR legislation that would affect the expected magnitude and timing of future emission reductions on EGU sources throughout the U.S.
- Continue to utilize the most up-to-date national emission inventory estimates for all source sectors, taking advantage of updates in population & activity levels, revisions in emission factors, and new information submitted to EPA by states.
- Conduct additional modeling using meteorological inputs from a different base year (e.g., 2005) to test the robustness and sensitivity of the results and conclusions for another set of annual meteorological conditions.
- Extend the use of PPTM and OPTM techniques to further evaluate contributions to simulated PM and ozone in an effort to better quantify control effectiveness (and resulting benefits/costs) by source category, pollutant, and/or geographic area.
- Extend the analysis to include assessments of mercury deposition throughout the U.S. and the resulting effects and benefits of changes to watersheds from CAAA controls
- Use a modified set of meteorological inputs for 2020 that emulate/simulate the expected changes in meteorological conditions due to global warming/climate change to evaluate how emission reduction effectiveness changes in the future under these conditions.

Section VII
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Attachment B

ICF INTERNATIONAL

MEMORANDUM

To: Jim DeMocker, EPA Office of Policy Analysis and Review (OPAR)

From: Sharon Douglas & Tom Myers, ICF International

Date: 24 November 2009

Re: Evaluation of CMAQ Model Performance for the 812 Prospective II Study

Introduction

Section 812 of the Clean Air Act Amendments (CAAA) of 1990 requires EPA to periodically assess the effects of the Clean Air Act (CAA) on air quality, the environment, public health, and the economy. EPA is currently developing the second prospective analyses of the benefits and costs of the CAA. As part of this study, the Community Multiscale Air Quality (CMAQ) model was applied to simulate national and regional-scale pollutant concentrations and deposition. The air quality modeling relied on tools and databases that had recently been developed and evaluated by EPA for other national- and regional-scale air quality modeling studies and was used to estimate the differences in air quality for 2000, 2010 and 2020 with and without the emissions reductions expected from the 1990 CAAA.

The methods and results of the emissions processing and air quality modeling that were conducted to support the development of the second prospective CAA Section 812 benefit-cost study are summarized by Douglas et al. (2008). For fine particulate matter ($PM_{2.5}$) and related species, the CMAQ model was applied for an annual simulation period (January through December). A 36-km resolution modeling domain that encompasses the contiguous 48 states was used for the annual modeling. For ozone and related species, the CMAQ model was applied for a five-month simulation period that captures the key ozone-season months of May through September. Two 12-km resolution modeling domains (that when combined cover the contiguous 48 U.S. states) were used for the ozone-season modeling. Altogether, the CMAQ model was applied for a total of 21 simulations (comprising seven core scenarios and three modeling domains). Model-ready meteorological input files for 2002 were provided by EPA.

The outputs from the CMAQ model provide the basis for the calculation of health and ecological benefits of the CAA. Ozone, $PM_{2.5}$, speciated $PM_{2.5}$, and PM_{10} concentrations and nitrogen and sulfur deposition amounts were extracted from the model outputs. Visibility was calculated using a variety of the CMAQ output species.

An integral component of all modeling studies is the evaluation of model performance for the base-case simulation. For this study, the Atmospheric Model Evaluation Tool (AMET) (UNC, 2008) was used to evaluate the CMAQ modeling results. The modeling results for ozone, $PM_{2.5}$ and other pollutant species were compared with observed data. The evaluation was done for the 2000 with-CAAA90 scenario, which represents the base year for the modeling analysis. The modeling results were compared with data for calendar year 2002, since this is the year represented by the meteorological inputs. The results of this evaluation are summarized in this memorandum.

Definitions of Key Statistical Measures

The AMET tool generates a wide variety of statistical measures and graphical analysis products to facilitate the evaluation of CMAQ model performance. Table 1 summarizes the statistical measures discussed in this memorandum. Additional statistical summaries/other measures are available in the AMET output files (upon request).

Table 1. Definition and Description of Measures/Metrics Used for Model Performance Evaluation

Metric	Definition
# of data pairs	*The number of observation/simulation data pairs*
Mean observation value	*The average observed concentration*
Mean simulation value	*The average simulated concentration*
Mean bias	$\left(\frac{1}{N}\right)\sum_{l=1}^{N}(S_l - O_l)$ *where N is the number of data pairs, and S_l and O_l are the simulated and observed values at site l, respectively, over a given time interval.*
Normalized bias	$\left(\frac{1}{N}\right)\sum_{l=1}^{N}(S_l - O_l)/O_l \cdot 100\%$
Normalized mean bias	$\sum_{l=1}^{N}(S_l - O_l)/\sum_{l=1}^{N}O_l \cdot 100\%$
Fractional bias	$\left(\frac{1}{N}\right)\sum_{l=1}^{N}(S_l - O_l)/0.5(S_l + O_l) \cdot 100\%$
Mean error	$\left(\frac{1}{N}\right)\sum_{l=1}^{N}\lvert S_l - O_l\rvert$
Normalized error	$\left(\frac{1}{N}\right)\sum_{l=1}^{N}\lvert S_l - O_l\rvert/O_l \cdot 100\%$
Normalized mean error	$\sum_{l=1}^{N}\lvert S_l - O_l\rvert\Big/\sum_{l=1}^{N}O_l \cdot 100\%$
Fractional error	$\left(\frac{1}{N}\right)\sum_{l=1}^{N}\lvert S_l - O_l\rvert/0.5(S_l + O_l) \cdot 100\%$
Correlation	$\left(N\left(\sum SO\right)-\left(\sum S\right)\left(\sum O\right)\right)\Big/\sqrt{\left(N\sum S^2-\left(\sum S\right)^2\right)\left(N\sum O^2-\left(\sum O\right)^2\right)}$
Index of agreement	*A measure of how well the model represents the pattern of perturbation about the mean value; ranges from 0 to 1.*

In calculating the statistical measures, AMET pairs the CMAQ model output with the observed data for the appropriate locations and time intervals.

For this analysis, ozone data were extracted from the EPA Air Quality System (AQS) dataset. Statistics were calculated using hourly concentrations, daily maximum 1-hour concentrations, and daily maximum 8-hour average concentrations. This evaluation focuses on model performance for daily maximum 8-hour average ozone, since this is the primary ozone metric used in the cost-benefit analysis.

The $PM_{2.5}$ dataset used for this analysis consists of data from the Speciation Trends Network (STN), Interagency Monitoring of PROtected Visual Environments (IMPROVE), and Clean Air Status and Trends Network (CASTNet) monitoring networks. Statistical measures were calculated using paired daily average values of $PM_{2.5}$ and selected species for the STN and IMPROVE data, and weekly average values of selected species for the CASTNet data. This evaluation focuses on model performance for total $PM_{2.5}$, since this is the primary $PM_{2.5}$ metric used in the cost-benefit analysis.

Finally, deposition measurements from the National Acid Deposition Program (NADP) were used in the evaluation of deposition for selected species. In this case, the weekly measurements were matched with the appropriate time intervals from the model output.

For extraction of the model output and matching with the station values, concentration and deposition information were taken from the grid cell in which the monitoring site is located.

Summary of Model Performance for Ozone

CMAQ model performance for ozone was examined for the 12-km Eastern U.S. (EUS) and Western U.S. (WUS) modeling domains for each month and for the entire ozone-season simulation period.

Eastern U.S. (EUS)

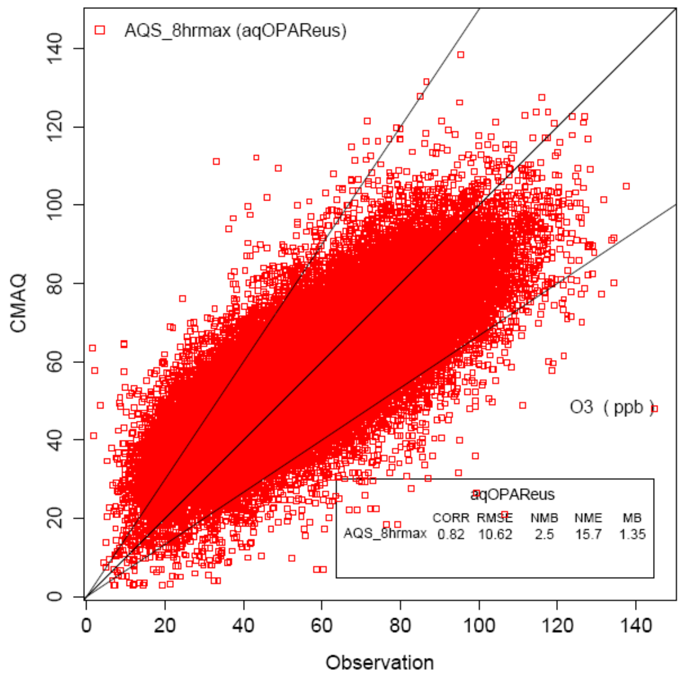
Summary metrics and statistical measures for 8-hour ozone for the EUS domain ozone are presented in Table 2. For certain of the measures, model performance goals and criteria used for prior studies are provided for comparison. For ozone, the recommended ranges for the normalized bias and normalized error are from prior EPA guidance but are still widely used for urban- and regional-scale model performance evaluation (EPA, 2007).

Table 2. Summary Model Performance Statistics for Ozone for the Eastern U.S. (EUS) Modeling Domain: Daily Maximum 8-Hour Average Ozone.

	May	Jun	Jul	Aug	Sep	O3 Season	Goal
No. of Observations	22431	21724	22626	22816	21312	110909	
Mean Observed (ppb)	48.4	56.2	56.6	54.4	48.2	52.8	
Mean Simulated (ppb)	52.9	56.3	57.8	54.2	49.2	54.1	
Normalized Bias (%)	13.4	6.0	7.5	5.7	10.2	8.6	± 15
Normalized Error (%)	19.2	17.2	18.1	17.8	21.6	18.8	≤ 35
Fractional Bias (%)	10.4	3.3	4.7	2.9	5.9	5.4	
Fractional Error (%)	16.8	15.6	16.4	16.4	18.7	16.8	
Correlation (unitless)	0.71	0.85	0.79	0.85	0.83	0.82	
Index of Agreement (unitless)	0.79	0.9	0.87	0.9	0.89	0.88	

Graphical summaries can also provide information about model performance. Simulated daily maximum 8-hour ozone concentrations for each site in the EUS domain are compared in the scatter plot in Figure 1. The scatter plot displays the values for the entire ozone season and visually depicts the range and frequency of agreement represented by the individual observation-simulation pairs included in the calculation of the cumulative statistical measures. Also included on the scatter plot is some statistical information further summarizing model performance.

Figure 1. Comparison of Simulated and Observed Daily Maximum 8-Hour Average Ozone (ppb) for the Eastern U.S. (EUS) Modeling Domain for the Ozone-Season Simulation Period.



The bar charts in Figure 2 summarize the month-to-month variations in the model performance for ozone for the EUS. The mean observed and simulated values for each month and the entire ozone season simulation period are graphically compared in Figure 2a. The normalized bias and error are graphically displayed in Figure 2b.

Figure 2a. Comparison of Mean Observed and Simulated Daily Maximum 8-Hour Average Ozone (ppb) for Each Month and the Entire Ozone Season: EUS Domain.

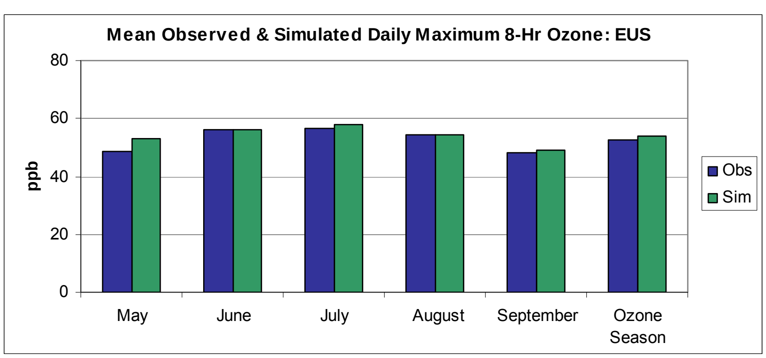


Figure 2b. Normalized Bias (%) and Error (%) for Simulated Daily Maximum 8-Hour Average Ozone for Each Month and the Entire Ozone Season: EUS Domain.

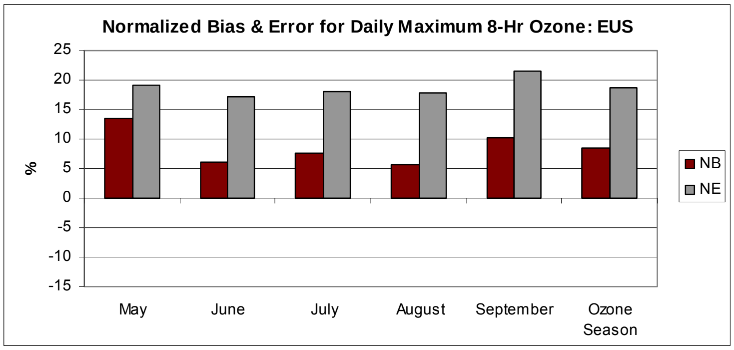
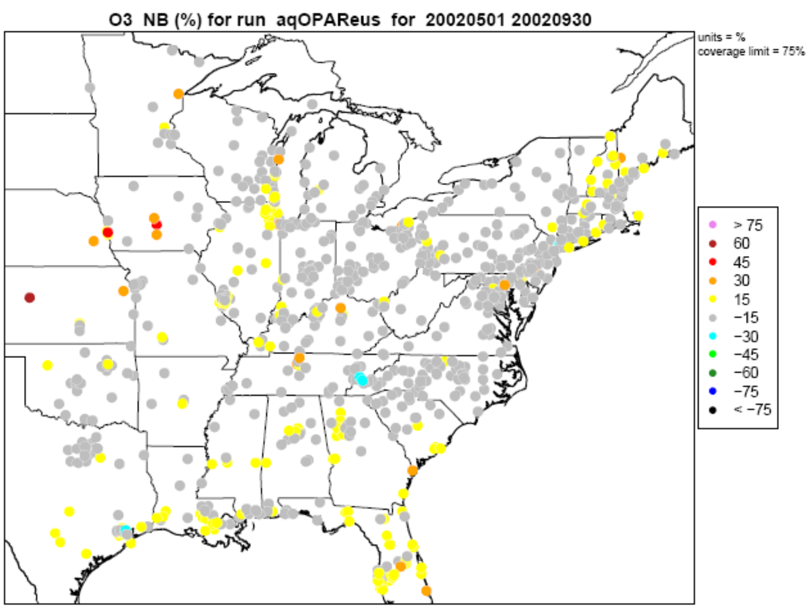


Figure 3 graphically displays spatial variations in model performance, based on the sign and magnitude of the normalized bias. Each dot represents a monitoring site location, and the color of the dot indicates the value of the normalized bias for that site for the entire ozone-season simulation period. Gray dots correspond to a normalized bias within ± 15 percent. Yellow dots indicate an overestimation of daily maximum 8-hour ozone by 15 to 30 percent, on average.

Figure 3. Normalized Bias (%) for Simulated Daily Maximum 8-Hour Average Ozone for the Entire Ozone Season: EUS Domain.



CIRCLE=AQS_8hrmax;

Western U.S. (WUS)

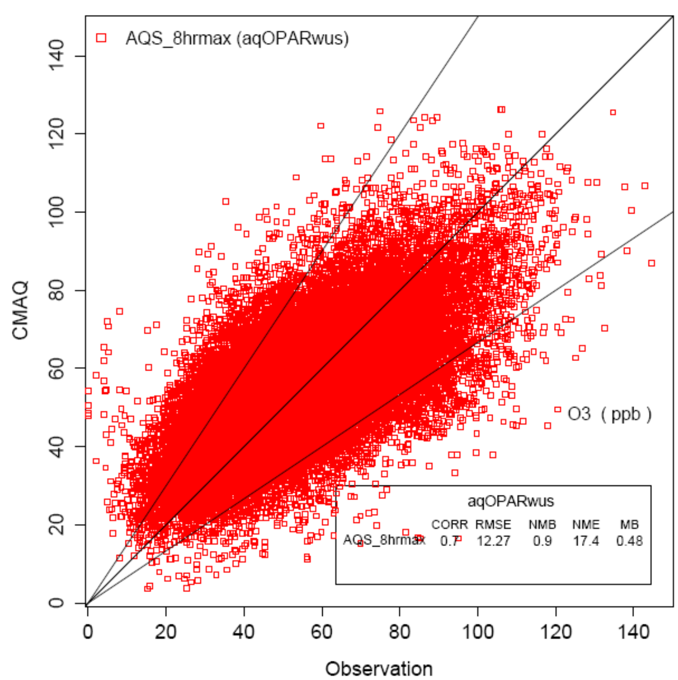
Summary metrics and statistical measures for the WUS domain ozone are presented in Table 3.

Table 3. Summary Model Performance Statistics for Ozone for the Western U.S. (WUS) Modeling Domain: Daily Maximum 8-Hour Average Ozone.

	May	Jun	Jul	Aug	Sep	O3 Season	Goal
No. of Observations	9490	9252	9564	9668	8987	46961	
Mean Observed (ppb)	52.1	56.0	55.5	56.8	50.7	54.3	
Mean Simulated (ppb)	54.2	55.5	53.7	57.2	50.2	54.2	
Normalized Bias (%)	7.7	4.4	2.5	7.6	5.0	5.5	± 15
Normalized Error (%)	17.0	18.1	21.0	23.1	21.4	20.1	≤ 35
Fractional Bias (%)	5.0	1.7	-1.4	2.4	0.9	1.7	
Fractional Error (%)	15.2	17.1	20.0	19.9	19.8	18.4	
Correlation (unitless)	0.69	0.75	0.69	0.67	0.66	0.69	
Index of Agreement (unitless)	0.81	0.84	0.82	0.81	0.8	0.82	

Simulated daily maximum 8-hour ozone concentrations for each site in the WUS domain are compared in the scatter plots in Figure 4.

Figure 4. Comparison of Simulated and Observed Daily Maximum 8-Hour Average Ozone (ppb) for the Western U.S. (WUS) Modeling Domain for the Ozone-Season Simulation Period.



The bar charts in Figure 5 summarize the month-to-month variations in the model performance for ozone for the WUS. The mean observed and simulated values for each month and the entire ozone season simulation period are graphically compared in Figure 5a. The normalized bias and error are displayed in Figure 5b.

Figure 5a. Comparison of Mean Observed and Simulated Daily Maximum 8-Hour Average Ozone (ppb) for Each Month and the Entire Ozone Season: WUS Domain.

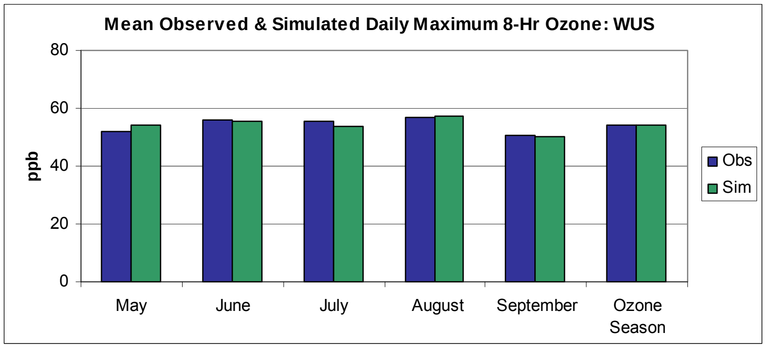


Figure 5b. Normalized Bias (%) and Error (%) for Simulated Daily Maximum 8-Hour Average Ozone for Each Month and the Entire Ozone Season: WUS Domain.

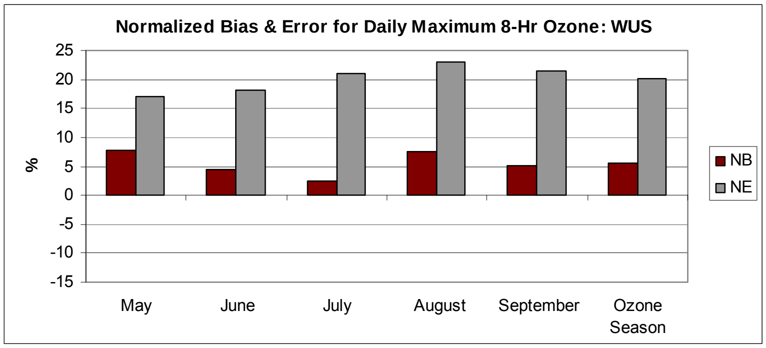
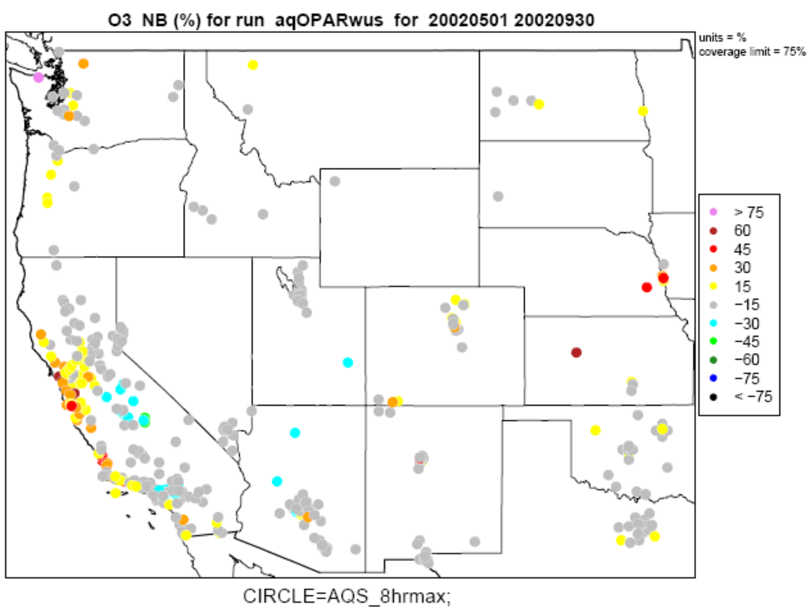


Figure 6 displays the regional distribution of the normalized bias for the WUS domain. Again gray dots correspond to a normalized bias within ± 15 percent and yellow dots indicate an overestimation of daily maximum 8-hour ozone by 15 to 30 percent, on average.

Figure 6. Normalized Bias (%) for Simulated Daily Maximum 8-Hour Average Ozone for the Entire Ozone Season: WUS Domain.



Summary of Model Performance for PM2.5

CMAQ model performance for $PM_{2.5}$ and selected species was examined for the full continental U.S. (CONUS) modeling domain and for two subregions representing the eastern and western U.S. Performance measures were calculated for each calendar quarter and for the entire annual simulation period. To accommodate differences in the measured species, measurement techniques and measurement frequency among the STN, IMPROVE and CASTNet datasets, statistics were calculated separately for each dataset.

STN

Summary metrics and statistical measures calculated using STN data for $PM_{2.5}$ and selected species for the full CONUS domain and the eastern and western portions of the domain are presented in Tables 4 and 5. Table 4 provides annual model performance results for $PM_{2.5}$ and selected species including sulfate (SO4), nitrate (NO3), ammonium (NH4), organic carbon (OC), and elemental carbon (EC). Table 5 provides quarterly and annual model performance results for $PM_{2.5}$ (the calendar quarters are defined as: January – March, April – June, July – September, and October – December). For certain of the measures, model performance goals and criteria used for prior studies are provided for comparison. The results of a number of different studies are listed in the EPA modeling guidance document (EPA, 2007). Few of the studies also list goals and/or criteria. For this analysis, we selected the goals presented by Boylan (2005) for comparison.

Table 4a. Summary Model Performance Statistics for $PM_{2.5}$ and Selected Species for the Continental U.S. (CONUS) Modeling Domain: 24-Hour Average $PM_{2.5}$ (STN).

	SO4	NO3	NH4	OC	EC	PM2.5	Goal
No. of Observations	12069	10682	12069	11653	11972	12257	
Mean Observed (µgm^{-3})	3.5	2.0	1.5	3.3	0.7	12.9	
Mean Simulated (µgm^{-3})	3.5	2.2	1.7	1.7	0.8	14.4	
Normalized Mean Bias (%)	-1.3	11.4	14.9	-47.5	22.2	11.3	
Normalized Mean Error (%)	36.9	78.3	51.4	61.0	66.2	48.5	
Fractional Bias (%)	-5.8	-21.6	19.8	-51.0	12.2	7.2	± 30
Fractional Error (%)	40.7	87.6	53.0	76.0	57.3	46.3	≤ 50
Correlation (unitless)	0.81	0.49	0.63	0.33	0.41	0.51	
Index of Agreement (unitless)	0.9	0.68	0.78	0.49	0.61	0.7	

Table 4b. Summary Model Performance Statistics for $PM_{2.5}$ and Selected Species for the Eastern Portion of the CONUS Modeling Domain: 24-Hour Average $PM_{2.5}$ (STN).

	SO4	NO3	NH4	OC	EC	PM2.5	Goal
No. of Observations	9900	8572	9900	9471	9775	10047	
Mean Observed (µgm^{-3})	3.9	1.7	1.6	2.9	0.6	12.8	
Mean Simulated (µgm^{-3})	4.0	2.4	1.9	1.6	0.8	15.2	
Normalized Mean Bias (%)	1.1	41.1	24.3	-46.3	28.2	18.9	
Normalized Mean Error (%)	35.9	81.3	48.8	59.7	66.7	47.8	
Fractional Bias (%)	-3.4	-10.1	23.5	-50.0	15.9	12.1	± 30
Fractional Error (%)	39.3	84.7	50.0	75.8	55.8	45.3	≤ 50
Correlation (unitless)	0.8	0.7	0.73	0.32	0.44	0.58	
Index of Agreement (unitless)	0.89	0.77	0.83	0.5	0.62	0.73	

Table 4c. Summary Model Performance Statistics for $PM_{2.5}$ and Selected Species for the Western Portion of the CONUS Modeling Domain: 24-Hour Average $PM_{2.5}$ (STN).

	SO4	NO3	NH4	OC	EC	PM2.5	Goal
No. of Observations	2169	2110	2169	2182	2197	2210	
Mean Observed (µgm^{-3})	1.5	3.2	1.3	4.7	0.9	13.6	
Mean Simulated ((µgm^{-3}))	1.1	1.5	0.8	2.3	0.9	10.7	
Normalized Mean Bias (%)	-29.4	-52.5	-36.0	-51.0	3.2	-21.0	
Normalized Mean Error (%)	48.0	71.8	65.8	64.6	64.8	51.6	
Fractional Bias (%)	-17.0	-68.3	3.2	-55.5	-4.4	-15.3	± 30
Fractional Error (%)	47.1	99.3	66.4	76.6	63.9	50.8	≤ 50
Correlation (unitless)	0.5	0.52	0.52	0.26	0.32	0.42	
Index of Agreement (unitless)	0.56	0.56	0.54	0.47	0.56	0.6	

Table 5a. Summary Model Performance Statistics for $PM_{2.5}$ by Quarter for the Continental U.S. (CONUS) Modeling Domain: 24-Hour Average $PM_{2.5}$ (STN).

	Q1	Q2	Q3	Q4	Annual	Goal
No. of Observations	2562	2988	3444	3263	12257	
Mean Observed (μgm^{-3})	12.1	11.8	14.9	12.6	12.9	
Mean Simulated (μgm^{-3})	17.4	12.4	13.0	15.3	14.4	
Normalized Mean Bias (%)	44.2	4.9	-12.5	21.9	11.3	
Normalized Mean Error (%)	69.0	42.5	34.5	55.8	48.5	
Fractional Bias (%)	32.8	0.0	-14.3	16.3	7.2	± 30
Fractional Error (%)	54.9	43.1	39.7	49.5	46.3	≤ 50
Correlation (unitless)	0.44	0.58	0.66	0.49	0.51	
Index of Agreement (unitless)	0.58	0.76	0.79	0.67	0.7	

Table 5b. Summary Model Performance Statistics for $PM_{2.5}$ by Quarter for the Eastern Portion of the CONUS Modeling Domain: 24-Hour Average $_{PM2.5}$ (STN).

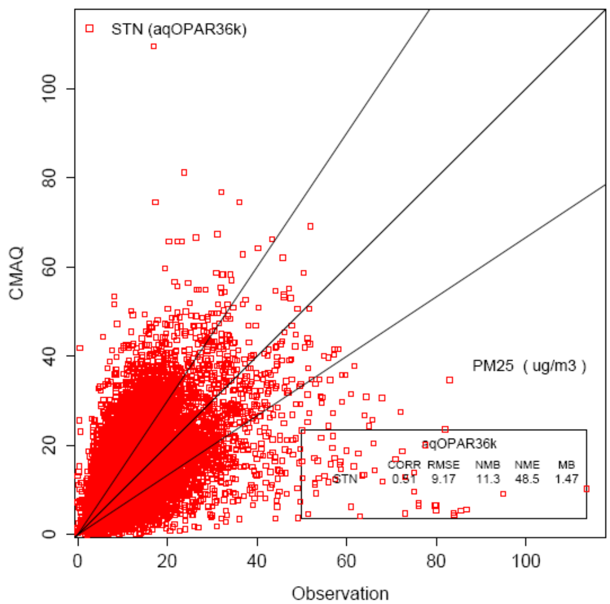
	Q1	Q2	Q3	Q4	Annual	Goal
No. of Observations	2089	2462	2815	2681	10047	
Mean Observed (μgm^{-3})	11.4	12.2	15.7	11.3	12.8	
Mean Simulated (μgm^{-3})	18.4	13.1	14.0	15.9	15.2	
Normalized Mean Bias (%)	62.5	7.3	-11.1	40.2	18.9	
Normalized Mean Error (%)	71.9	41.1	33.3	56.9	47.8	
Fractional Bias (%)	41.7	1.3	-12.7	25.2	12.1	± 30
Fractional Error (%)	54.2	42.1	38.7	48.3	45.3	≤ 50
Correlation (unitless)	0.67	0.62	0.66	0.7	0.58	
Index of Agreement (unitless)	0.62	0.77	0.8	0.74	0.73	

Table 5c. Summary Model Performance Statistics for $PM_{2.5}$ by Quarter for the Western Portion of the CONUS Modeling Domain: 24-Hour Average $PM_{2.5}$ (STN).

	Q1	Q2	Q3	Q4	Annual	Goal
No. of Observations	473	526	629	582	2210	
Mean Observed (μgm^{-3})	15.4	9.6	11.2	18.5	13.6	
Mean Simulated (μgm^{-3})	13.0	8.6	8.8	13.0	10.7	
Normalized Mean Bias (%)	-15.7	-9.9	-21.6	-29.6	-21.0	
Normalized Mean Error (%)	59.6	50.5	42.4	52.6	51.6	
Fractional Bias (%)	-6.5	-5.9	-21.2	-24.6	-15.3	± 30
Fractional Error (%)	58.2	47.6	44.2	54.9	50.8	≤ 50
Correlation (unitless)	0.34	0.35	0.42	0.39	0.42	
Index of Agreement (unitless)	0.55	0.57	0.61	0.58	0.6	

Graphical summaries for $PM_{2.5}$ using the STN data follow. Simulated annual average $PM_{2.5}$ concentrations for each site in the CONUS domain are compared in the scatter plot in Figure 7.

Figure 7. Comparison of Simulated and Observed 24-Hour Average $PM_{2.5}$ (μgm^{-3}) for the Continental U.S. (CONUS) Modeling Domain for the Annual Simulation Period (STN).



The bar charts in Figure 8 and 9 summarize the variations in the model performance by species. Observed and simulated annual average values for selected species and total $PM_{2.5}$ are graphically compared in Figure 8. Fractional bias and error and are graphically displayed in Figure 9.

Figure 8a. Comparison of Observed and Simulated Annual Average $PM_{2.5}$ and Selected Species (μgm^{-3}) for the CONUS Domain (STN).

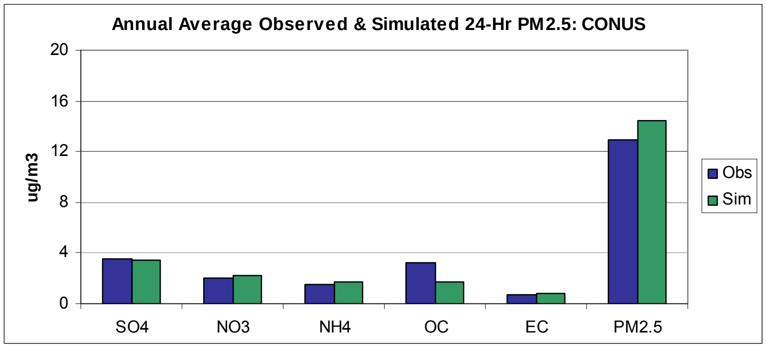


Figure 8b. Comparison of Observed and Simulated Annual Average $PM_{2.5}$ and Selected Species (μgm^{-3}) for the Eastern Portion of the CONUS Domain (STN).

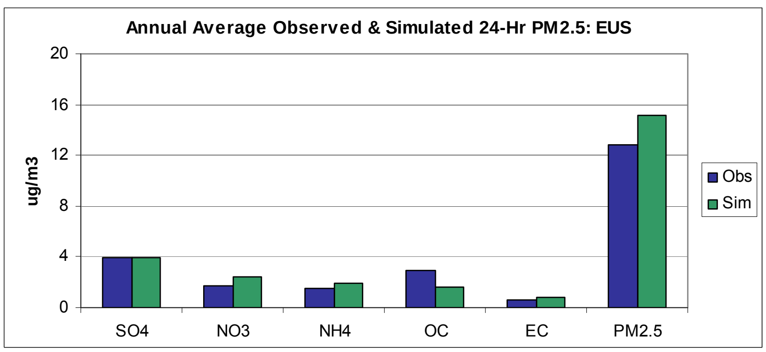


Figure 8c. Comparison of Observed and Simulated Annual Average $PM_{2.5}$ and Selected Species (μgm^{-3}) for the Western Portion of the CONUS Domain (STN).

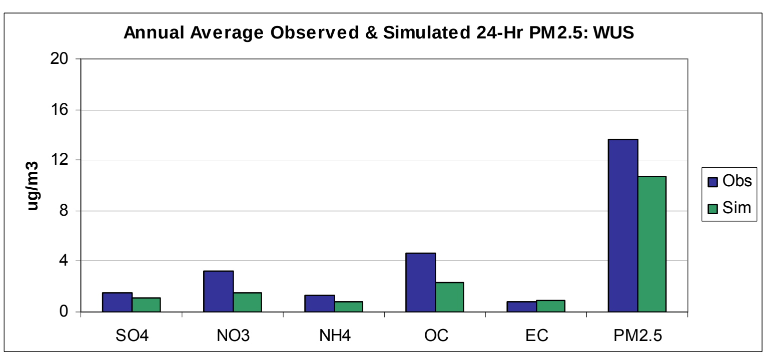


Figure 9a. Fractional Bias (%) and Error (%) for Simulated $PM_{2.5}$ and Selected Species for the CONUS Domain for the Annual Simulation Period (STN).

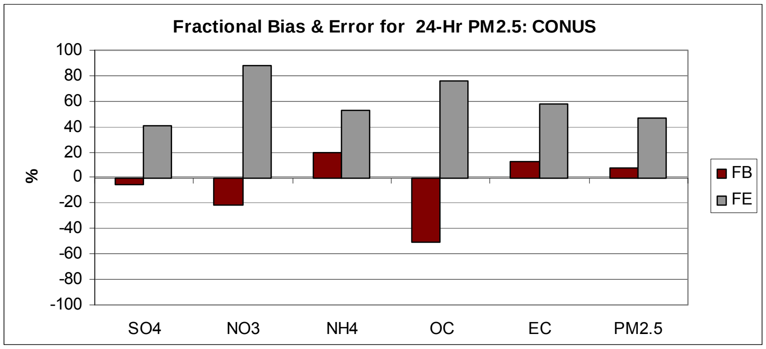


Figure 9b. Fractional Bias (%) and Error (%) for Simulated $PM_{2.5}$ and Selected Species for the Eastern Portion of CONUS Domain for the Annual Simulation Period (STN).

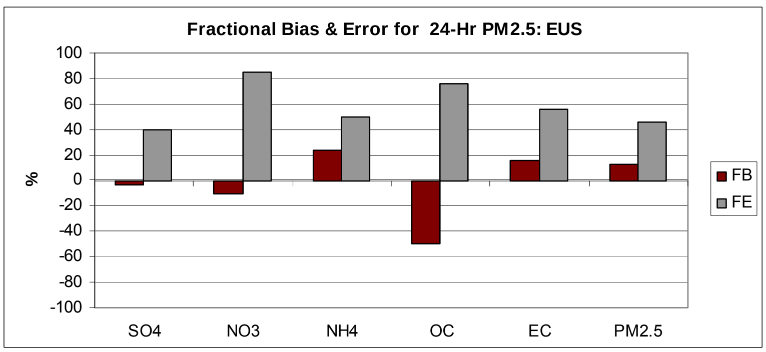
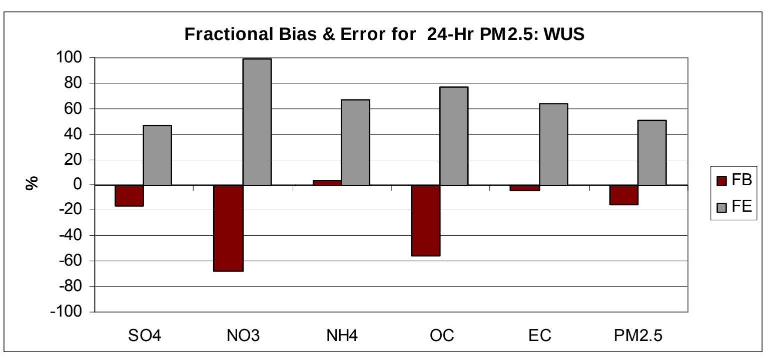


Figure 9c. Fractional Bias (%) and Error (%) for Simulated $PM_{2.5}$ and Selected Species for the Western Portion of CONUS Domain for the Annual Simulation Period (STN).



The bar charts in Figures 10 and 11 summarize the variations in $PM_{2.5}$ model performance by quarter. The mean observed and simulated values for each quarter and for the annual simulation period are graphically compared in Figure 10. Corresponding fractional bias and error values are graphically displayed in Figure 11.

Figure10a. Comparison of Observed and Simulated Average $PM_{2.5}$ (μgm^{-3}) for Each Quarter and the Annual Simulation Period for the CONUS Domain (STN).

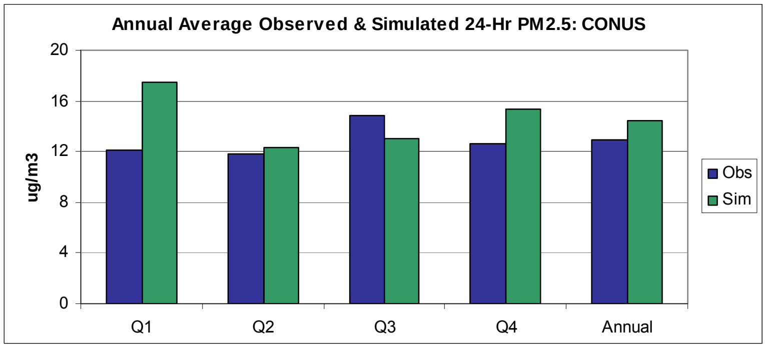


Figure 10b. Comparison of Observed and Simulated Average $PM_{2.5}$ (μgm^{-3}) for Each Quarter and the Annual Simulation Period for the Eastern Portion of the CONUS Domain (STN).

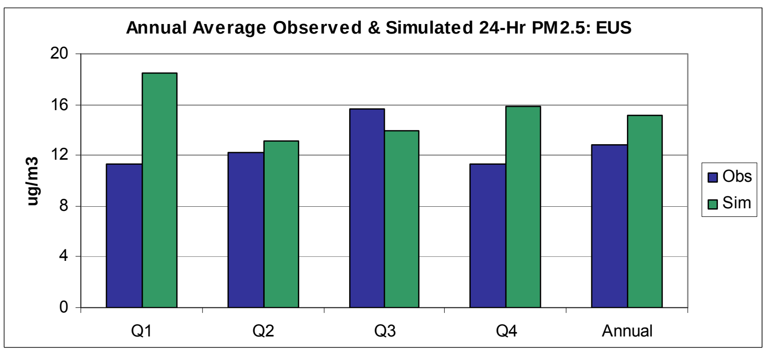


Figure 10c. Comparison of Observed and Simulated Average $PM_{2.5}$ (μgm^{-3}) for Each Quarter and the Annual Simulation Period for the Western Portion of the CONUS Domain (STN).

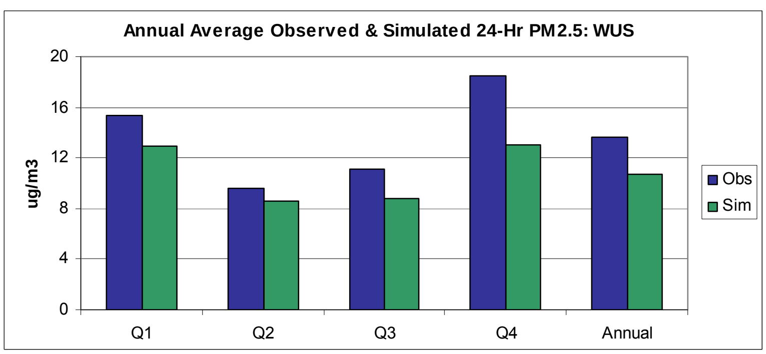


Figure 11a. Fractional Bias (%) and Error (%) for Simulated $PM_{2.5}$ (μgm^{-3}) for Each Quarter and the Annual Simulation Period for the CONUS Domain (STN).

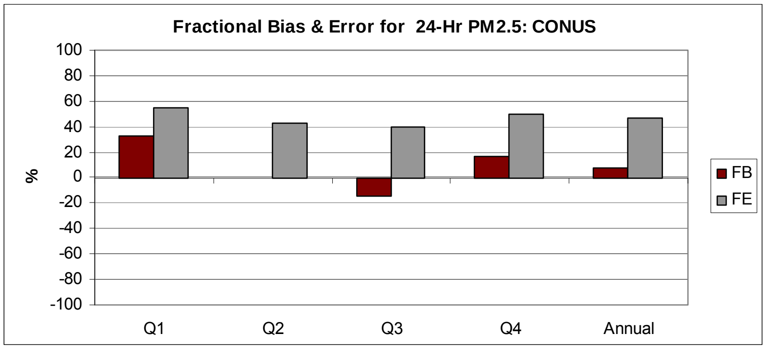


Figure 11b. Fractional Bias (%) and Error (%) for Simulated $PM_{2.5}$ (μgm^{-3}) for Each Quarter and the Annual Simulation Period for the Eastern Portion of the CONUS Domain (STN).

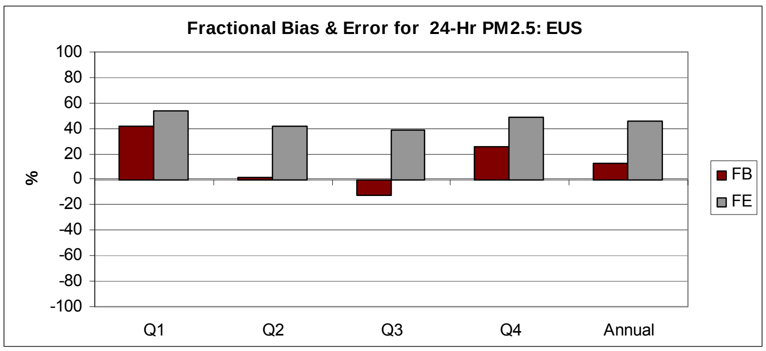


Figure 11c. Fractional Bias (%) and Error (%) for Simulated $PM_{2.5}$ (μgm^{-3}) for Each Quarter and the Annual Simulation Period for the Western Portion of the CONUS Domain (STN).

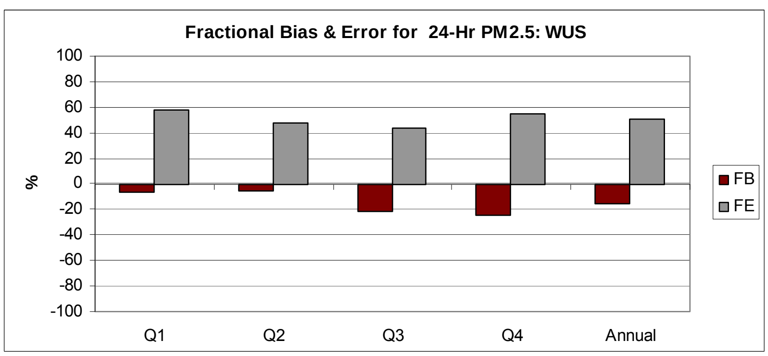
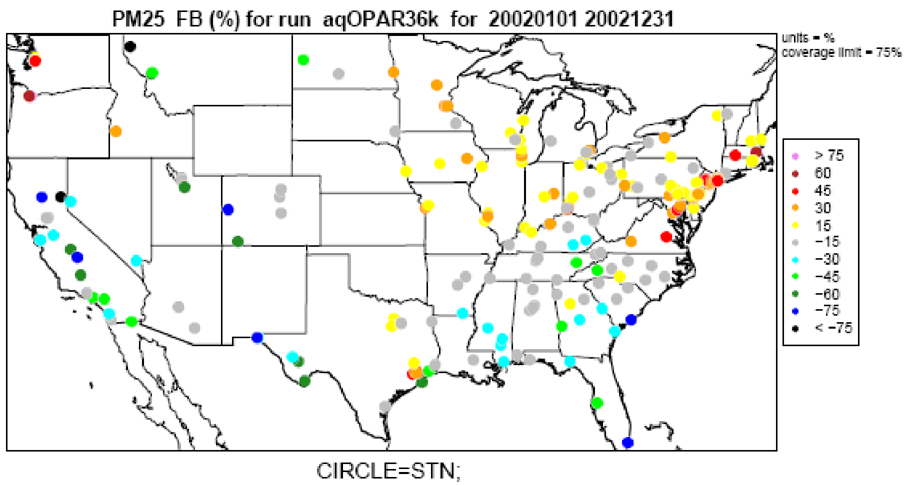


Figure 12 displays the regional distribution of the fractional bias for $PM_{2.5}$ for the CONUS domain. In this plot, gray dots correspond to a fractional bias within ± 15 percent, on average. Light blue dots correspond to a negative fractional bias within 15 to 30 percent. Yellow dots correspond to a positive fractional bias within 15 to 30 percent.

Figure 12. Fractional Bias (%) for Simulated $PM_{2.5}$ for the Annual Simulation Period for the CONUS Domain (STN).



IMPROVE

Summary metrics and statistical measures calculated using IMPROVE data for $PM_{2.5}$ and selected species for the full CONUS domain and the eastern and western portions of the domain are presented in Tables 6 and 7. Table 6 provides annual model performance results for SO4, NO3, NH4, OC, EC, and $PM_{2.5}$. Table 7 provides quarterly and annual model performance results for $PM_{2.5}$. Again, goals presented by Boylan (2005) are also listed for comparison.

Table 6a. Summary Model Performance Statistics for $PM_{2.5}$ and Selected Species for the Continental U.S. (CONUS) Modeling Domain: 24-Hour Average $PM_{2.5}$ (IMPROVE).

	SO4	NO3	NH4	OC	EC	PM2.5	Goal
No. of Observations	15788	15663	718	15494	15475	15622	
Mean Observed (μgm^{-3})	1.6	0.5	1.1	1.3	0.3	5.9	
Mean Simulated (μgm^{-3})	1.7	0.8	1.4	1.3	0.3	6.9	
Normalized Mean Bias (%)	1.5	51.4	27.9	-5.4	16.5	16.6	
Normalized Mean Error (%)	39.4	119.6	54.2	70.9	71.2	61.8	
Fractional Bias (%)	13.3	-43.1	21.6	1.8	6.9	12.7	± 30
Fractional Error (%)	47.2	114.9	52.0	65.6	58.9	55.6	≤ 50
Correlation (unitless)	0.87	0.59	0.67	0.42	0.44	0.54	
Index of Agreement (unitless)	0.93	0.68	0.78	0.58	0.62	0.7	

Table 6b. Summary Model Performance Statistics for $PM_{2.5}$ and Selected Species for the Eastern Portion of the CONUS Modeling Domain: 24-Hour Average $PM_{2.5}$ (IMPROVE).

	SO4	NO3	NH4	OC	EC	PM2.5	Goal
No. of Observations	6831	6826	718	6667	6663	6761	
Mean Observed (μgm^{-3})	2.9	0.7	1.1	1.5	0.3	8.1	
Mean Simulated (μgm^{-3})	2.9	1.3	1.4	1.1	0.3	9.8	
Normalized Mean Bias (%)	-0.9	88.1	27.9	-21.5	5.8	21.7	
Normalized Mean Error (%)	36.0	135.0	54.2	63.0	53.0	61.1	
Fractional Bias (%)	-0.7	-22.7	21.6	-26.3	-0.9	13.1	± 30
Fractional Error (%)	41.2	112.6	52.0	67.8	50.6	55.6	≤ 50
Correlation (unitless)	0.84	0.66	0.67	0.22	0.53	0.52	
Index of Agreement (unitless)	0.91	0.66	0.78	0.4	0.7	0.69	

Table 6c. Summary Model Performance Statistics for $PM_{2.5}$ and Selected Species for the Western Portion of the CONUS Modeling Domain: 24-Hour Average $PM_{2.5}$ (IMPROVE).

	SO4	NO3	NH4	OC	EC	PM2.5	Goal
No. of Observations	8957	8837	0	8827	8812	8861	
Mean Observed (μgm^{-3})	0.6	0.4	NA	1.2	0.2	4.2	
Mean Simulated (μgm^{-3})	0.7	0.4	NA	1.3	0.3	4.6	
Normalized Mean Bias (%)	9.7	2.5	NA	9.0	28.8	9.3	
Normalized Mean Error (%)	50.9	99.1	NA	78.0	91.9	62.8	
Fractional Bias (%)	24.0	-58.8	NA	23.0	12.8	12.3	± 30
Fractional Error (%)	51.7	116.6	NA	63.9	65.1	55.6	≤ 50
Correlation (unitless)	0.5	0.51	NA	0.47	0.41	0.36	
Index of Agreement (unitless)	0.68	0.68	NA	0.62	0.59	0.56	

Table 7a. Summary Model Performance Statistics for $PM_{2.5}$ by Quarter for the Continental U.S. (CONUS) Modeling Domain: 24-Hour Average $PM_{2.5}$ (IMPROVE).

	Q1	Q2	Q3	Q4	Annual	Goal
No. of Observations	3681	3746	4047	4148	15622	
Mean Observed (μgm^{-3})	4.2	6.4	8.2	4.7	5.9	
Mean Simulated (μgm^{-3})	7.4	6.1	6.7	7.3	6.9	
Normalized Mean Bias (%)	77.5	-5.3	-18.2	54.1	16.6	
Normalized Mean Error (%)	95.6	46.8	46.5	79.3	61.8	
Fractional Bias (%)	47.0	-8.4	-23.1	36.2	12.7	± 30
Fractional Error (%)	64.5	47.6	50.3	60.2	55.6	≤ 50
Correlation (unitless)	0.69	0.6	0.54	0.63	0.54	
Index of Agreement (unitless)	0.67	0.77	0.72	0.69	0.7	

Table 7b. Summary Model Performance Statistics for $PM_{2.5}$ by Quarter for the Eastern Portion of the CONUS Modeling Domain: 24-Hour Average $PM_{2.5}$ (IMPROVE).

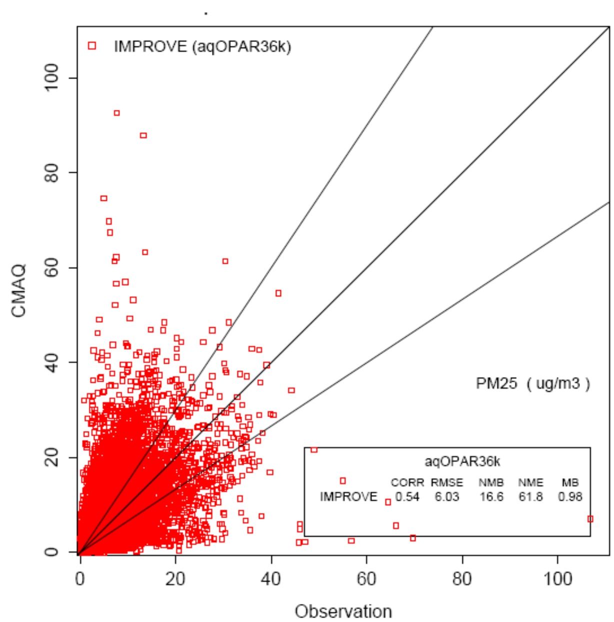
	Q1	Q2	Q3	Q4	Annual	Goal
No. of Observations	1573	1563	1767	1858	6761	
Mean Observed (μgm^{-3})	6.5	8.5	11.2	6.0	8.1	
Mean Simulated (μgm^{-3})	12.1	8.1	8.6	10.4	9.8	
Normalized Mean Bias (%)	87.1	-4.8	-23.1	72.5	21.7	
Normalized Mean Error (%)	100.2	43.4	38.7	86.1	61.1	
Fractional Bias (%)	49.3	-12.1	-30.3	45.0	13.1	± 30
Fractional Error (%)	64.3	47.1	48.9	61.6	55.6	≤ 50
Correlation (unitless)	0.6	0.64	0.7	0.65	0.52	
Index of Agreement (unitless)	0.55	0.79	0.8	0.65	0.69	

Table 7c. Summary Model Performance Statistics for $PM_{2.5}$ by Quarter for the Western Portion of the CONUS Modeling Domain: 24-Hour Average $PM_{2.5}$ (IMPROVE).

	Q1	Q2	Q3	Q4	Annual	Goal
No. of Observations	2108	2183	2280	2290	8861	
Mean Observed (μgm^{-3})	2.5	4.9	5.8	3.7	4.2	
Mean Simulated (μgm^{-3})	3.9	4.6	5.2	4.8	4.6	
Normalized Mean Bias (%)	58.8	-5.8	-11.0	29.6	9.3	
Normalized Mean Error (%)	86.7	51.0	58.0	70.3	62.8	
Fractional Bias (%)	45.3	-5.8	-17.5	29.0	12.3	± 30
Fractional Error (%)	64.5	47.9	51.4	59.0	55.6	≤ 50
Correlation (unitless)	0.53	0.35	0.18	0.53	0.36	
Index of Agreement (unitless)	0.64	0.58	0.38	0.68	0.56	

Graphical summaries for $PM_{2.5}$ using the IMPROVE data follow. Simulated annual average $PM_{2.5}$ concentrations for each site in the CONUS domain are compared in the scatter plots in Figure 13.

Figure 13. Comparison of Simulated and Observed 24-Hour Average $PM_{2.5}$ (µgm-3) for the Continental U.S. (CONUS) Modeling Domain for the Annual Simulation Period (IMPROVE).



The bar charts in Figures 14 and 15 summarize the variations in model performance by species. The mean observed and simulated values for selected species and total $PM_{2.5}$ are graphically compared in Figure 14. Fractional bias and error and are graphically displayed in Figure 15. In a few cases, values are slightly outside the scale used for plotting but can be found in the prior tables.

Figure 14a. Comparison of Mean Observed and Simulated Annual Average $PM_{2.5}$ and Selected Species (μgm^{-3}) for the CONUS Domain (IMPROVE).

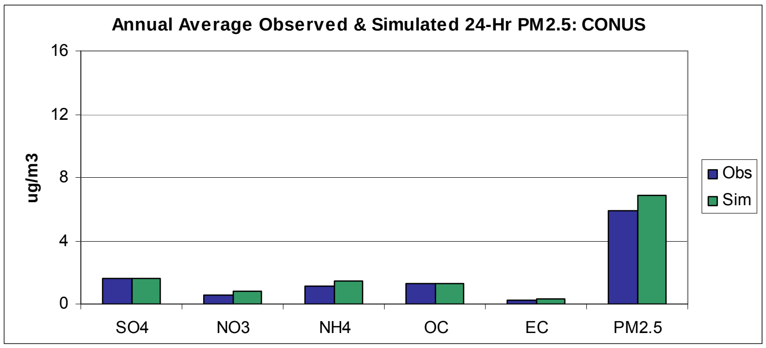


Figure 14b. Comparison of Mean Observed and Simulated Annual Average $PM_{2.5}$ and Selected Species (μgm^{-3}) for the Eastern Portion of the CONUS Domain (IMPROVE).

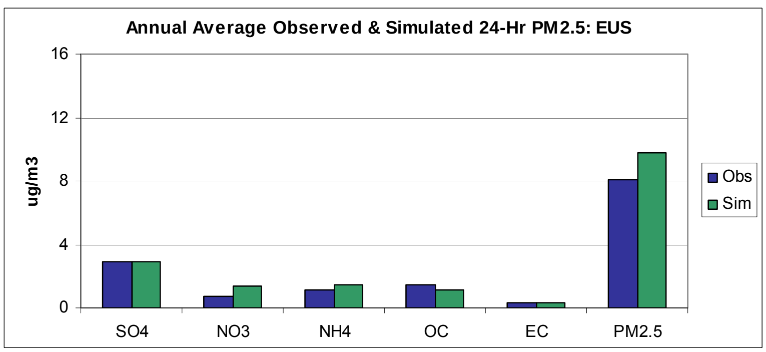


Figure 14c. Comparison of Mean Observed and Simulated Annual Average $PM_{2.5}$ and Selected Species (μgm^{-3}) for the Western Portion of the CONUS Domain (IMPROVE).

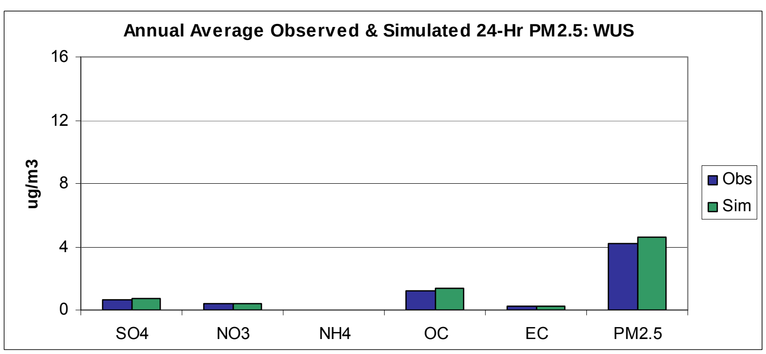


Figure 15a. Fractional Bias (%) and Error (%) for Simulated $PM_{2.5}$ and Selected Species for the CONUS Domain for the Annual Simulation Period (IMPROVE).

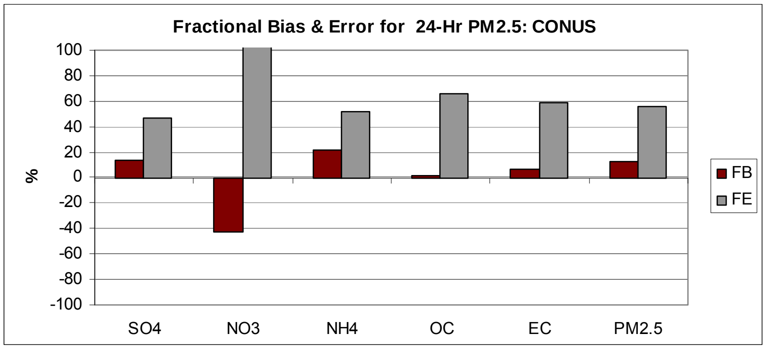


Figure 15b. Fractional Bias (%) and Error (%)Simulated $PM_{2.5}$ and Selected Species for the Eastern Portion of CONUS Domain for the Annual Simulation Period (MPROVE).

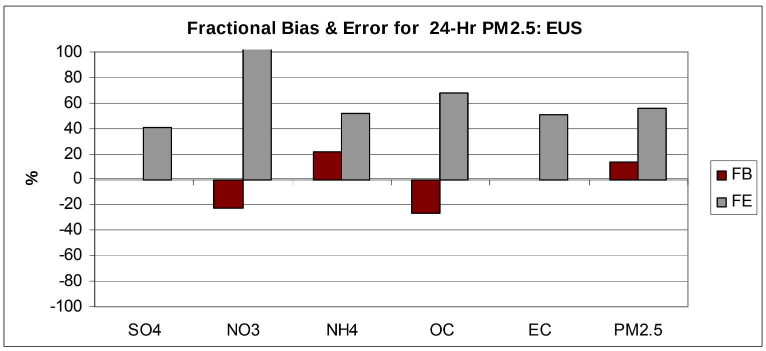
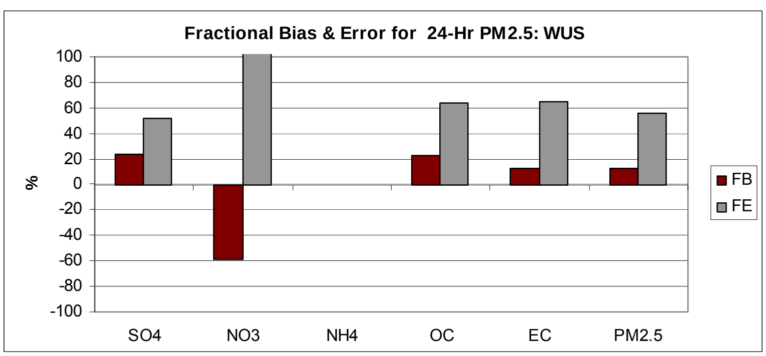


Figure 15c. Fractional Bias (%) and Error (%) for Simulated $PM_{2.5}$ and Selected Species for the Western Portion of CONUS Domain for the Annual Simulation Period (IMPROVE).



The bar charts in Figures 16 and 17 summarize the variations in the model performance by quarter. The mean observed and simulated values for each quarter and for the annual simulation period are graphically compared in Figure 16. Corresponding fractional bias and error values are graphically displayed in Figure 17.

Figure 16a. Comparison of Observed and Simulated Average $PM_{2.5}$ (μgm^{-3}) for Each Quarter and the Annual Simulation Period for the CONUS Domain (IMPROVE).

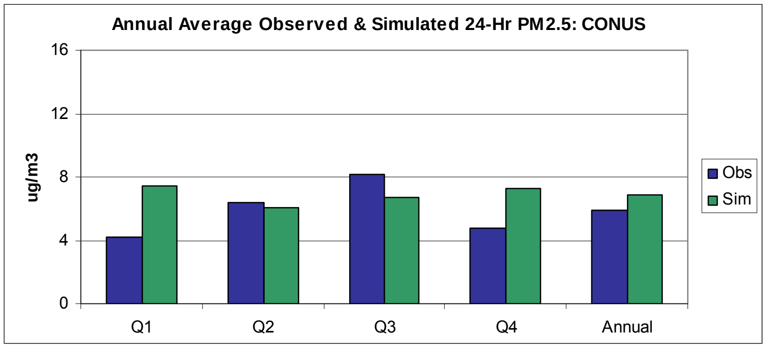


Figure 16b. Comparison of Observed and Simulated Average $PM_{2.5}$ (μgm^{-3}) for Each Quarter and the Annual Simulation Period for the Eastern Portion of the CONUS Domain (IMPROVE).

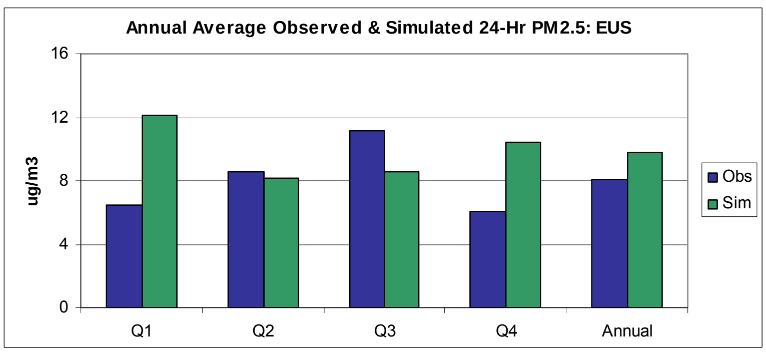


Figure 16c. Comparison of Observed and Simulated Average $PM_{2.5}$ (μgm^{-3}) for Each Quarter and the Annual Simulation Period for the Western Portion of the CONUS Domain (IMPROVE).

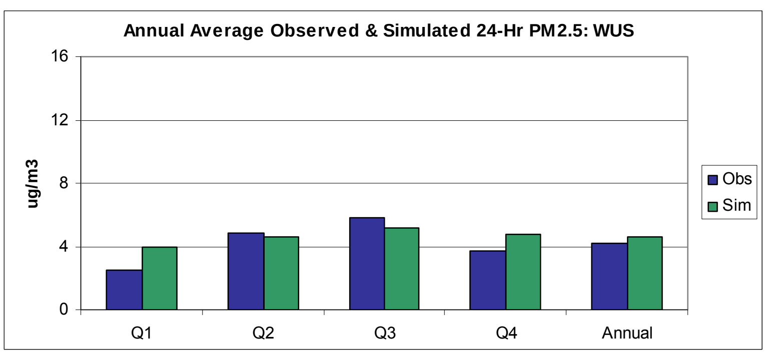


Figure 17a. Fractional Bias (%) and Error (%) for Simulated $PM_{2.5}$ for Each Quarter and the Annual Simulation Period for the CONUS Domain (IMPROVE).

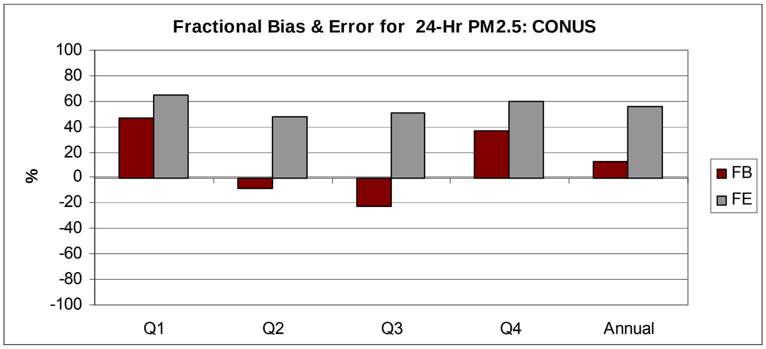


Figure 17b. Fractional Bias (%) and Error (%) for Simulated $PM_{2.5}$ for Each Quarter and the Annual Simulation Period for the Eastern Portion of the CONUS Domain (MPROVE).

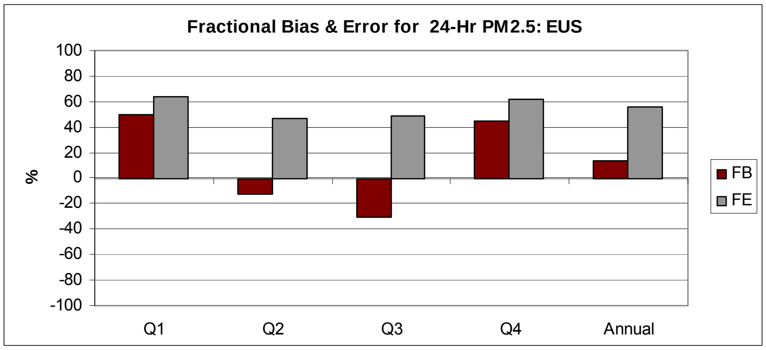


Figure 17c. Fractional Bias (%) and Error (%) for Simulated $PM_{2.5}$ for Each Quarter and the Annual Simulation Period for the Western Portion of the CONUS Domain (IMPROVE).

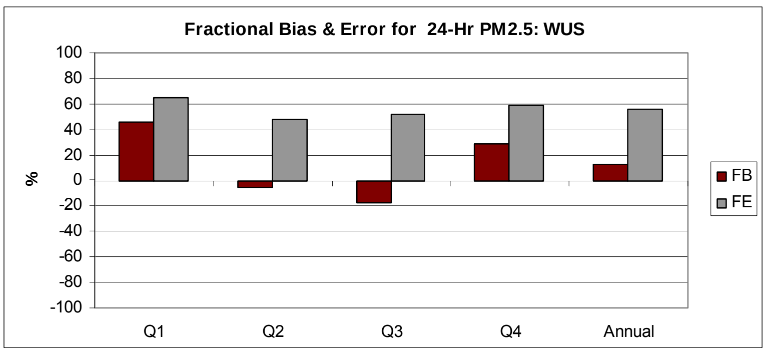
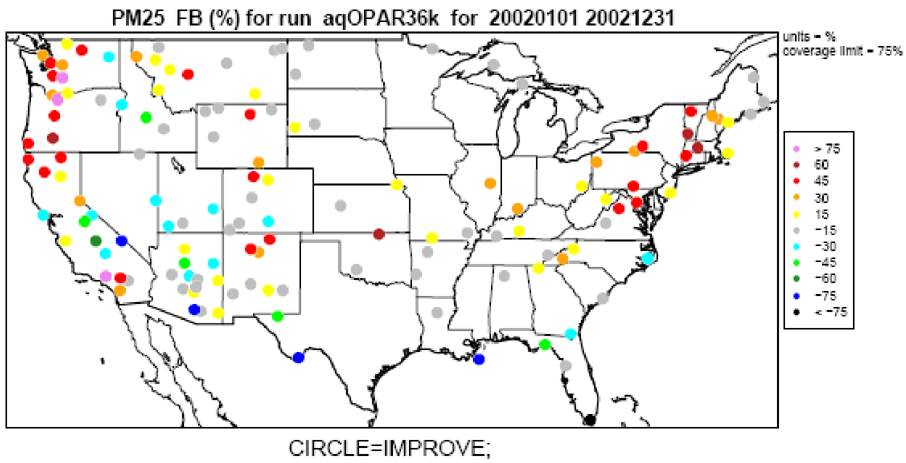


Figure 18 displays the regional distribution of the fractional bias for $PM_{2.5}$ from the IMPROVE dataset for the CONUS domain. In this plot, gray dots correspond to a fractional bias within ± 15 percent, on average. Light blue dots correspond to a negative fractional bias within 15 to 30 percent. Yellow dots correspond to a positive fractional bias within 15 to 30 percent.

Figure 18. Fractional Bias (%) for Simulated $PM_{2.5}$ for the Annual Simulation Period for the CONUS Domain (IMPROVE).



CASTNet

Summary metrics and statistical measures calculated using CASTNet data for $PM_{2.5}$ species for the full CONUS domain and the eastern and western portions of the domain are presented in Table 8. Table 8 provides annual model performance results for the CASTNet species (SO4, NO3, and NH4). Again, goals presented by Boylan (2005) are listed for comparison.

Table 8a. Summary Model Performance Statistics for $PM_{2.5}$ Species for the Continental U.S. (CONUS) Modeling Domain: Weekly Average Measurements (CASTNet).

	SO4	NO3	NH4	Goal
No. of Observations	4088	4088	4080	
Mean Observed (μgm^{-3})	3.0	1.0	1.1	
Mean Simulated (μgm^{-3})	2.9	1.5	1.3	
Normalized Mean Bias (%)	-2.8	52.9	18.7	
Normalized Mean Error (%)	24.6	101.2	41.5	
Fractional Bias (%)	-1.5	-1.9	17.6	± 30
Fractional Error (%)	29.9	96.0	40.0	≤ 50
Correlation (unitless)	0.66	0.35	0.4	
Index of Agreement (unitless)	0.77	0.52	0.51	

Table 8b. Summary Model Performance Statistics for $PM_{2.5}$ Species for the Eastern Portion of the CONUS Modeling Domain: Weekly Average Measurements (CASTNet).

	SO4	NO3	NH4	Goal
No. of Observations	2999	2999	2993	
Mean Observed (μgm^{-3})	3.8	1.1	1.4	
Mean Simulated (μgm^{-3})	3.7	1.9	1.7	
Normalized Mean Bias (%)	-2.6	64.7	19.6	
Normalized Mean Error (%)	23.4	104.0	40.4	
Fractional Bias (%)	-4.8	18.0	18.9	± 30
Fractional Error (%)	25.1	93.0	36.9	≤ 50
Correlation (unitless)	0.58	0.33	0.3	
Index of Agreement (unitless)	0.7	0.49	0.39	

Table 8c. Summary Model Performance Statistics for $PM_{2.5}$ Species for the Western Portion of the CONUS Modeling Domain: Weekly Average Measurements (CASTNet).

	SO4	NO3	NH4	Goal
No. of Observations	1089	1089	1087	
Mean Observed (μgm^{-3})	0.7	0.4	0.3	
Mean Simulated (μgm^{-3})	0.7	0.3	0.3	
Normalized Mean Bias (%)	-5.3	-31.3	6.9	
Normalized Mean Error (%)	43.2	81.4	55.9	
Fractional Bias (%)	7.6	-56.6	13.9	± 30
Fractional Error (%)	43.3	104.1	48.4	≤ 50
Correlation (unitless)	0.35	0.41	0.32	
Index of Agreement (unitless)	0.47	0.59	0.5	

The bar charts in Figures 19 and 20 summarize the variations in annual model performance by species. The mean observed and simulated values for the available CASTNet species are graphically compared in Figure 19. Fractional bias and error and are graphically displayed in Figure 20. In a few cases, values are slightly outside the scale used for plotting but can be found in the prior tables.

Figure 19a. Comparison of Mean Observed and Simulated Annual Average $PM_{2.5}$ Species (μgm^{-3}) for the CONUS Domain (CASTNet).

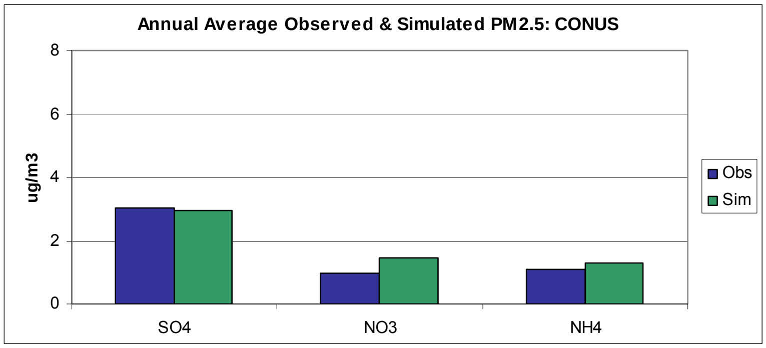


Figure 19b. Comparison of Mean Observed and Simulated Annual Average $PM_{2.5}$ Species (μgm^{-3}) for the Eastern Portion of the CONUS Domain (CASTNet).

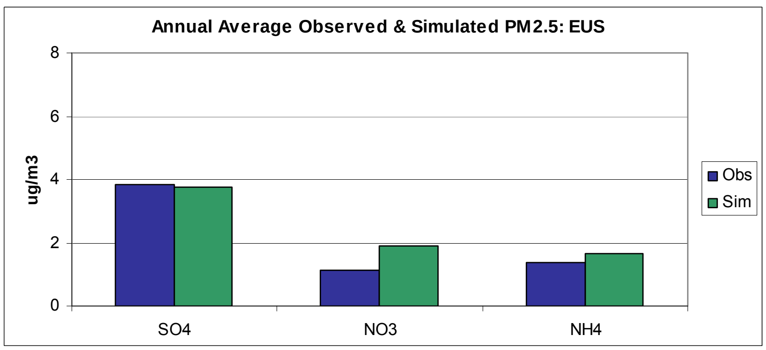


Figure 19c. Comparison of Mean Observed and Simulated Annual Average $PM_{2.5}$ Species (μgm^{-3}) for the Western Portion of the CONUS Domain (CASTNet).

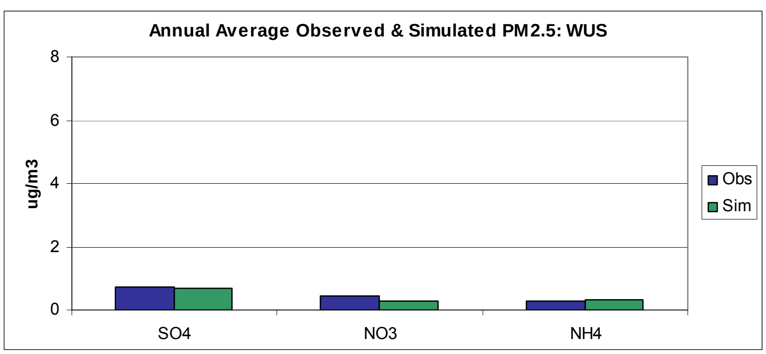


Figure 20a. Fractional Bias (%) and Error (%) for Annual Average $PM_{2.5}$ Species for the CONUS Domain (CASTNet).

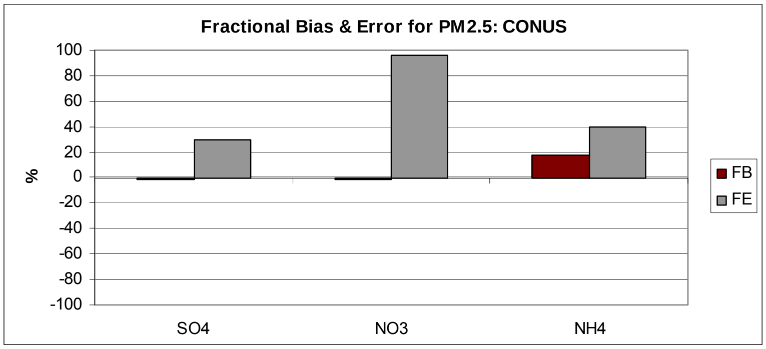


Figure 20b. Fractional Bias (%) and Error (%) for Annual Average $PM_{2.5}$ Species for the Eastern Portion of the CONUS Domain (CASTNet).

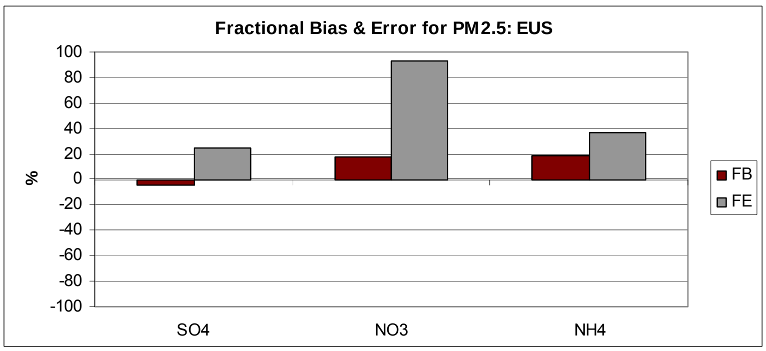
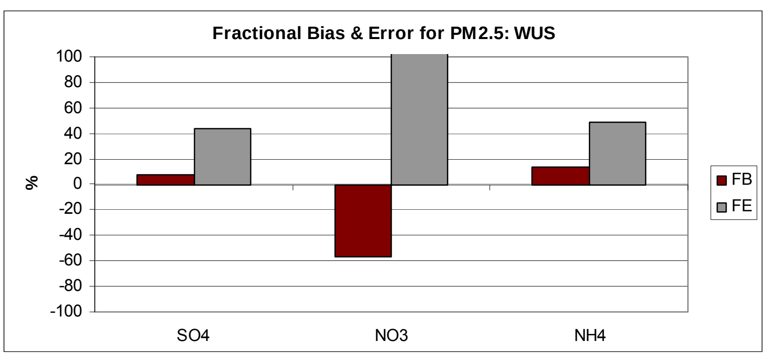


Figure 20c. Fractional Bias (%) and Error (%) for Annual Average $PM_{2.5}$ Species for the Western Portion of the CONUS Domain (CASTNet).



Summary of Model Performance for Selected Deposition Species

CMAQ model performance for selected deposition species was examined for the full CONUS domain and the eastern and western subregions. Performance measures were calculated for each calendar quarter and for the entire annual simulation period using NADP data. Table 9 provides annual model performance results for the NADP species (SO4, NO3, and NH4). No model performance goals for deposition were identified in the literature.

Table 9a. Summary Model Performance Statistics for Deposition Species for the Continental U.S. (CONUS) Modeling Domain: Weekly Average Measurements (NADP).

	SO4	NO3	NH4
No. of Observations	7978	7978	7978
Mean Observed (kg ha^{-1})	0.3	0.2	0.1
Mean Simulated (kg ha^{-1})	0.2	0.2	0.0
Normalized Mean Bias (%)	-2.2	-28.9	-20.2
Normalized Mean Error (%)	65.5	59.8	66.3
Fractional Bias (%)	-17.9	-43.2	-30.8
Fractional Error (%)	80.8	82.4	84.8
Correlation (unitless)	0.57	0.53	0.53
Index of Agreement (unitless)	0.74	0.69	0.69

Table 9b. Summary Model Performance Statistics for Deposition Species for the Eastern Portion of the Continental U.S. (CONUS) Modeling Domain: Weekly Average Measurements (NADP).

	SO4	NO3	NH4
No. of Observations	6172	6172	6172
Mean Observed (kg ha^{-1})	0.3	0.3	0.1
Mean Simulated (kg ha^{-1})	0.3	0.2	0.1
Normalized Mean Bias (%)	-0.8	-25.3	-17.0
Normalized Mean Error (%)	65.1	58.3	65.6
Fractional Bias (%)	-16.6	-35.4	-22.9
Fractional Error (%)	77.6	76.7	80.4
Correlation (unitless)	0.52	0.49	0.5
Index of Agreement (unitless)	0.71	0.67	0.67

Table 9c. Summary Model Performance Statistics for Deposition Species for the Western Portion of the Continental U.S. (CONUS) Modeling Domain: Weekly Average Measurements (NADP).

	SO4	NO3	NH4
No. of Observations	1806	1806	1806
Mean Observed (kg ha^{-1})	0.1	0.1	0.0
Mean Simulated (kg ha^{-1})	0.0	0.0	0.0
Normalized Mean Bias (%)	-25.3	-59.9	-48.8
Normalized Mean Error (%)	72.4	73.1	72.4
Fractional Bias (%)	-22.2	-69.9	-57.9
Fractional Error (%)	91.7	101.9	99.8
Correlation (unitless)	0.4	0.29	0.47
Index of Agreement (unitless)	0.57	0.44	0.57

The bar charts in Figures 21 and 22 summarize the variations in annual model performance by species. The mean observed and simulated values for the available NADP species are graphically compared in Figure 21. Fractional bias and error are graphically displayed in Figure 22. In a few cases, values are slightly outside the scale used for plotting but can be found in the prior tables.

Figure 21a. Comparison of Mean Observed and Simulated Deposition by Species (kg ha^{-1}) for the CONUS Domain (NADP).

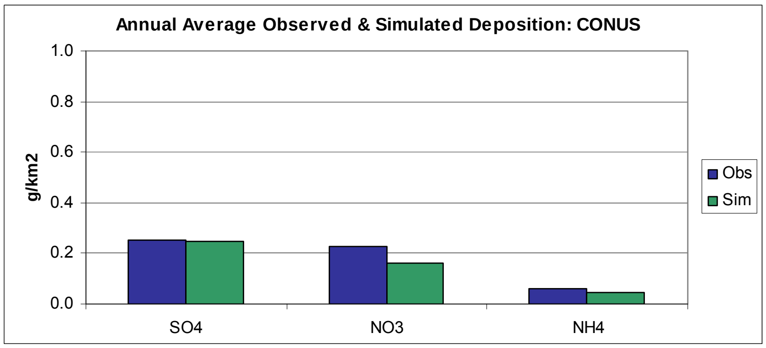


Figure 21b. Comparison of Mean Observed and Simulated Deposition by Species (kg ha^{-1}) for the Eastern Portion of the CONUS Domain (NADP).

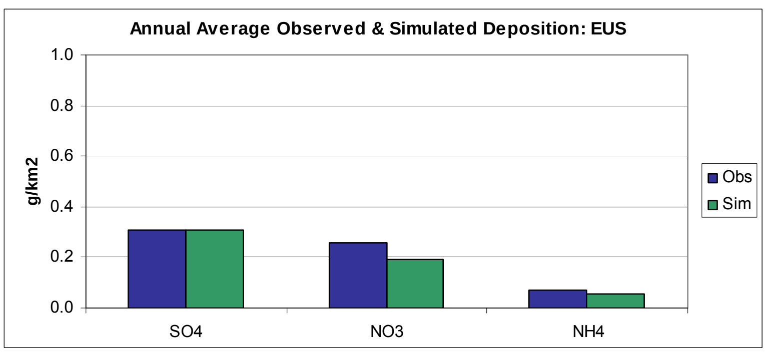


Figure 21c. Comparison of Mean Observed and Simulated Deposition by Species (kg ha^{-1}) for the Western Portion of the CONUS Domain (NADP).

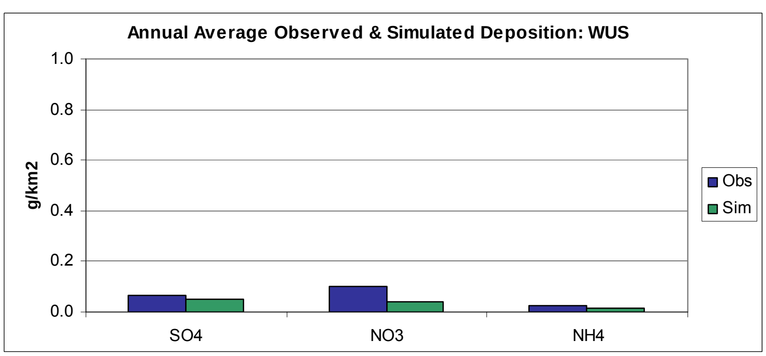


Figure 22a. Fractional Bias (%) and Error (%) for Annual Deposition by Species for the CONUS Domain (NADP).

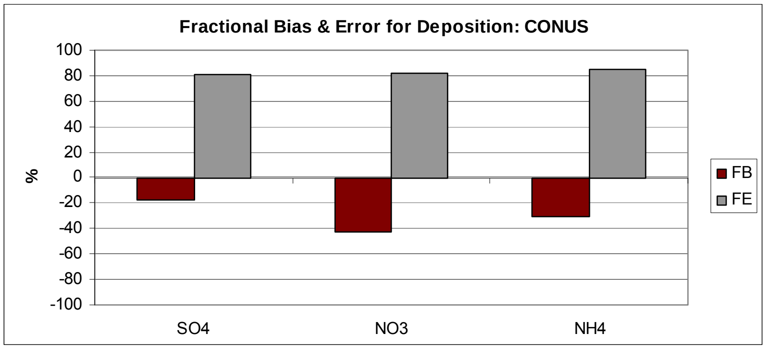


Figure 22b. Fractional Bias (%) and Error (%) for Annual Deposition by Species for the Eastern Portion of the CONUS Domain (NADP).

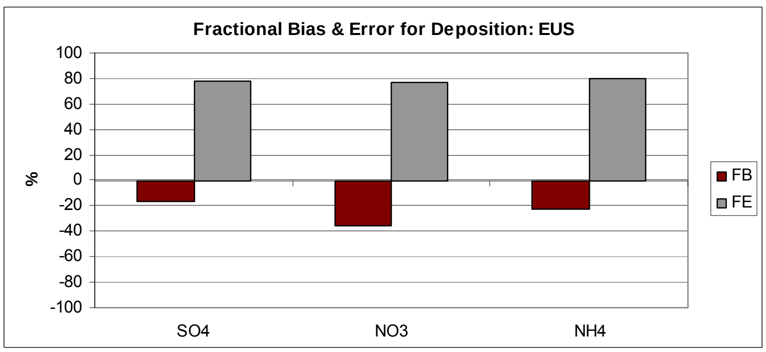
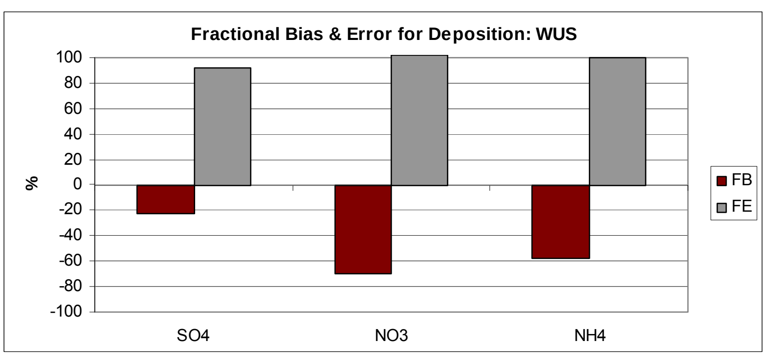


Figure 22c. Fractional Bias (%) and Error (%) for Annual Deposition by Species for the Western Portion of the CONUS Domain (NADP).



Discussion

By most measures, CMAQ model performance for 8-hour ozone for the five-month simulation period is reasonable. Bias and error statistics are well within the recommended ranges for acceptable model performance for both domains, all months, and the entire ozone season. For the EUS, the simulated values are highly correlated with the observations (the correlation ranges from 0.71 to 0.85 for the five months, with an overall value of 0.82). Comparison of the simulated and observed mean values shows that the simulated values are close to observed and the month-to-month variations are consistent. An overall index of agreement of 0.88 indicates that the variations about the mean are well represented. Model performance appears to be relatively consistent throughout the domain, with some overestimation of ozone at some sites scattered throughout the domain, especially in the Southeast, some portions of the Northeast, and the Chicago area.

Although the statistical measures are also good, model performance for ozone is slightly worse for the WUS domain, compared to the EUS domain. Here the correlation ranges from 0.66 to 0.75, with an overall value of 0.69. The corresponding overall index of agreement is 0.82. Spatially, model performance is characterized by a low bias (within ± 15 percent) for most sites throughout the domain, with some exceptions. Ozone is overestimated by more than 15 percent for several sites located in coastal California and underestimated by more than this amount for several sites in California's Central Valley.

CMAQ model performance is reasonable for total PM2.5, but the results for the individual $PM_{2.5}$ species are somewhat mixed. There are variations in performance when considering the different monitoring networks. For the comparison with the STN data, annual average $PM_{2.5}$ is overestimated in the eastern U.S. and overall, but underestimated in the western U.S. The fractional bias and error statistics are within (or in one case nearly within) the goals used for this analysis. Results for the full region and both subregions are characterized by underestimation of nitrate (NO3) and organic carbon (OC). The underestimation of nitrate is most pronounced in the western portion of the domain. The quarterly statistics for the full domain and the eastern portion of the domain show that $PM_{2.5}$ tends to be overestimated during Q1 and Q4 (October – December and January – March, respectively; colder months) and underestimated during Q3 (July – September; warmer months). For the western portion of the domain, there is a tendency for underestimation of $PM_{2.5}$ for all four quarterly periods. The correlation is 0.58 for the eastern portion of the domain, 0.42 for the western portion of the domain, and 0.51 for the full domain. The index of agreement is 0.73, 0.6 and 0.7 for these same three regions.

While the STN monitoring network is comprised mostly of urban and suburban sites, the IMPROVE network covers primarily Class I (i.e., national parks and wilderness) areas. On average, the observed concentrations for $PM_{2.5}$ and its constituent species are lower for the IMPROVE sites. Corresponding model performance errors are larger for the IMPROVE data. Annual average $PM_{2.5}$ is overestimated for the full domain and both subregions. For all three regions, the fractional bias is well within the goal of 30 percent but the fractional error statistics are slightly higher than the goal of 50 percent. Results for the full region based on the IMPROVE data are characterized by underestimation of nitrate. Organic carbon, on the other hand is underestimated in the east and overestimated in the western part of the domain. The quarterly statistics indicate that $PM_{2.5}$ is overestimated during Q1 and Q4 (colder months) and underestimated during Q3 (warmer months). The correlation for total $PM_{2.5}$ is 0.52 for the eastern portion of the domain, 0.36 for the western portion of the domain, and 0.54 for the full domain. The index of agreement is 0.69, 0.56 and 0.7 for these same three regions.

Comparison with the CASTNet data show that of the three PM2.5 species measured by CASTNet good performance is achieved for sulfate (SO4) and ammonium (NH4). NO3 is characterized by larger errors and is overestimated in the east and underestimated in the west.

Comparison of simulated deposition amounts with NADP data indicates that deposition for all three measured species (SO4, NO3, and NH4) is underestimated. For the full domain, the fractional bias ranges from -18 percent for SO4, to -31 percent for NH4, to -43 percent for NO3. The bias and error values are larger for the western, compared to the eastern, portion of the domain.

In summary, model performance is consistent with that for other national-scale and regional-scale CMAQ model applications, and the results can be used (with some uncertainty) to evaluate the effects of the CAAA, especially at the national scale. Model performance is reasonable to good for ozone, even with the relatively coarse 12-km grid resolution. Model performance is also reasonable for total $PM_{2.5}$. The larger errors associate with the simulation of NO3 and OC are typical for most national- and regional-scale PM2.5 applications (EPA, 2007).

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Attachment C

IEc

MEMORANDUM | June 14, 2010

TO Jim DeMocker, EPA

FROM Tyra Walsh, Henry Roman, and Jim Neumann, Industrial Economics, Inc. (IEc)

SUBJECT Description of the Adjustment to the Primary Particulate Matter Emissions Estimates and the Modeled Attainment Test Software Analysis (MATS) Procedure for the 812 Second Prospective Analysis

INTRODUCTION

The 812 Project Team recently revised its primary fine particulate matter ($PM_{2.5}$) emissions estimates generated for the Section 812 Second Prospective analysis of the 1990 Clean Air Act Amendments (CAAA) following the identification of analytical issues that resulted in biased estimates of the impact of the CAAA on emissions of primary particles (in some cases the impact was overestimated and in others it was underestimated).[1] The adjustments affected two major source categories of primary PM: area sources, including construction, paved and unpaved roads, residential wood combustion and fuel combustion; and non-electric generating unit (non-EGU) industrial point sources, including boilers, cement kilns, process heaters, and turbines.[2] These emissions changes affect subsequent steps in the 812 project analytical chain – namely, air quality modeling and health benefits estimates.

EPA tasked the 812 Project Team with developing an approach for estimating the effects of these changes that would approximate the magnitude of the adjustment without needing to re-run the Community Multi-scale Air Quality (CMAQ) model, which would have required substantial additional time and resources. This memo describes the adjustment process developed by the 812 Project Team and presents the results of this process in the form of speciated PM bar charts representing the output of EPA's Modeled Attainment Test Software (MATS) pre- and post-adjustment.

The 812 Project Team calculated adjustment factors that could be applied to the original CMAQ results based on a comparison of the adjusted emissions estimates to the original values. The Project Team then used EPA's MATS to adjust the CMAQ results using ambient monitoring data. The MATS output was then translated into revised air quality grids that were re-run through BenMAP to generate updated health benefits incidence and monetary valuation results.

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[1] "Primary" PM emissions refer to those that are essentially chemically unchanged from what is released at the source. "Secondary" PM has undergone transformations in the atmosphere causing the chemical and/or physical nature of what is measured to be different from what is emitted. USEPA (2007). *Guidance on the Use of Models and Other Analyses for Demonstrating Attainment of Air Quality Goals for ozone, $PM_{2.5}$ and Regional Haze*. EPA-454/B-07-002.

[2] Area sources are also commonly referred to as nonpoint sources.

The original primary PM emissions estimates generated for area and non-EGU point sources were found to be inaccurate due to two issues:

- The first issue relates to the differences in emissions estimation methods for primary PM emissions in the two emissions inventories from which EPA derives its *with-CAAA* and *without-CAAA* scenario estimates.[3] The *with-CAAA* area and non-EGU point source emission estimates are projected from EPA's 2002 National Emissions Inventory (NEI), while the *without-CAAA* scenario emissions are projected from EPA's 1990 NEI.[4] The 2002 NEI estimates were generated using improved emissions estimation methods for primary particles. For some emissions categories (e.g., construction) the 1990 estimates (and thus the *without-CAAA* estimates) were biased high, leading to overestimates of the CAAA impact; for some other sources (e.g., commercial cooking) the 1990 emissions estimates were biased low because emissions estimation methods did not exist in 1990 for those categories, leading to erroneous estimates of disbenefits in these source categories when compared to the *with-CAAA* scenario, and exerting a downward bias on the overall impact of the CAAA.
- The second issue, which only affected area sources, was that the original emissions estimates did not include application of transport factors (TFs). These are county-specific adjustment factors that are applied to specific types of emissions estimates to account for the fact that only a fraction of total fugitive dust emissions remain airborne and are available for transport away from the vicinity of the source after localized removal (i.e., some of the particles are captured by the local vegetation or other surface obstructions).[5] This issue affected both the *with-* and *without-CAAA* scenario estimates for area sources.[6]

This memo describes the methodology employed by the Project Team to adjust the primary $PM_{2.5}$ estimates and the CMAQ data. We then provide a general description of the MATS procedure and explain how it was applied in the Second Prospective analysis. Finally, we explore the effect of the emissions adjustments as well as the choice of monitoring data on the MATS output. We also include three appendices to the memo. Appendix A consists of a memo by E.H. Pechan and Associates that describes the specific adjustments made to the area source emissions to correct for overestimation bias in some Source Classification Codes (SCCs) in the 1990 NEI. Appendices B and C include stacked bar graphs that compare both the total and speciated $PM_{2.5}$ concentrations estimated by CMAQ and MATS to monitoring data.

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[3] EPA expected that the 1990 NEI would provide the best representation of 1990 base year emissions for important source categories under the *without-CAAA* scenario. EPA believes this remains a reasonable expectation for source categories other than those for which the adjustments described herein have been applied. EPA also believes the 2002 NEI provides the most reasonable emissions estimates for the *with-CAAA* scenario, the first target year of which is 2000.

[4] EPA conducts the NEI every three years. For further information, see: http://www.epa.gov/oar/data/neidb.html.

[5] Pace, T.J. (2005). "Methodology to Estimate the Transportable Fraction of Fugitive Dust Emissions for Regional and Urban Scale Air Quality Analyses." US EPA. Available at: http://www.epa.gov/ttn/chief/emch/dustfractions/.

[6] Note that TFs are only relevant for emission source categories that are associated with fugitive dust, such as unpaved and paved roads, commercial and residential construction and agricultural tilling. Therefore, the Project Team only applied TFs to specific Source Classification Codes (SCCs) within each county.

METHODOLOGY

This section outlines the methodology used by the Project Team to adjust the original primary $PM_{2.5}$ emissions estimates. We first made the necessary adjustments to the primary $PM_{2.5}$ emissions estimates for both area and non-EGU point sources, focusing on the $PM_{2.5}$ species that contribute most significantly to primary PM emissions: elemental carbon (EC), organic carbon (OC), and crustal material. We then calculated species-specific adjustment factors for the CMAQ data and applied them. Each of these procedures is discussed in further detail below.

ADJUSTMENTS TO PRIMARY PM EMISSIONS ESTIMATES

The process for adjusting the primary PM emissions estimates differed by source (area or non-EGU point) as well as by scenario (*with-CAAA* versus *without-CAAA*). Table 1 provides a summary of the various adjustments that the Project Team made to the original primary PM emissions estimates, indicating what bias each adjustment was intended to correct and the scenario and target year combination to which the adjustment corresponds. Below we describe in more detail the adjustments made for each source/scenario combination.

Area Sources

The available area source emissions data consisted of a total $PM_{2.5}$ emissions estimate as well as a set of allocation factors indicating the fraction of the total $PM_{2.5}$ that is comprised of each specific species.[7] These data were specific to a particular county and SCC. We generated revised emissions estimates in two steps: (1) we made the adjustments described below and in Table 1 to the total $PM_{2.5}$ emissions value for each county/SCC combination; and (2) we applied the SCC-specific allocation factors to the adjusted total $PM_{2.5}$ emissions values to generate revised emissions estimates for EC, OC and crustal $PM_{2.5}$.[8] These two steps are discussed in further detail below.

Adjustments to Total $PM_{2.5}$ Emissions Estimates

***With*-CAAA Scenario**

We decreased the primary $PM_{2.5}$ area source emissions estimates under the *with-CAAA* scenario by applying county-specific TFs to the emissions in each county that are associated with fugitive dust (e.g., commercial construction). This step provided adjusted values of emissions by county associated with transportable fugitive primary PM.

Without-CAAA Scenario

We made three types of adjustments to the primary $PM_{2.5}$ area source emissions estimates under the *without-CAAA* scenario.

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[7] ftp://ftp.epa.gov/EmisInventory/emch_latest_ancillary/smoke_format/.

[8] The speciation profile for area sources also included emissions estimates for sulfates and nitrates. However, these made up a very small portion of the total primary PM emissions. Therefore, we only made adjustments to EC, OC and crustal species.

TABLE 1. SUMMARY OF ADJUSTMENTS MADE TO THE PRIMARY PM EMISSIONS ESTIMATES FOR THE 812 SECOND PROSPECTIVE ANALYSIS

ADJUSTMENT	PURPOSE OF ADJUSTMENT	2000		2010		2020	
		WITH-CAAA	*WITH OUT-CAAA*	*WITH-CAAA*	*WITH OUT-CAAA*	*WITH-CAAA*	*WITH OUT-CAAA*
AREA SOURCES							
Applied Transport Factors (TFs)	Correct for overestimation of fugitive dust emissions	X	X	X	X	X	X
Adjusted year 2000 emissions estimates downward for some SCCs (specific adjustments differ by SCC – see Appendix A for details). Applied growth factors to revised 2000 estimates to generate adjusted 2010 and 2020 estimates.	Correct for overestimation of emissions in 1990 NEI for construction, paved and unpaved roads, residential wood burning and industrial combustion SCCs		X		X		X
Set *without-CAAA* emissions estimates equal to the *with-CAAA* values	Correct for underestimation of emissions in 1990 NEI due to omission of specific SCCs (e.g., commercial cooking)		X		X		X
NON-EGU POINT SOURCES							
Set *without-CAAA* emissions estimates equal to the *with-CAAA* values	Correct for errors in the 1990 NEI resulting in potential net overestimation of emissions reductions in this category.		X		X		X

1. **Adjust some of the area source emissions estimates to account for overestimation bias** – as noted above, the emissions estimation procedures in the 1990 NEI led to a substantial overestimation in estimates in the *without-CAAA* scenario for several emissions source categories (i.e., construction, paved roads, unpaved roads, residential wood burning, and industrial combustion).[9] The Project Team first decreased the year 2000 estimates, as described in Appendix A.[10] Then we applied growth factors based on the economic growth assumptions between target years to the revised 2000 estimates, to generate revised emissions estimates for target years 2010 and 2020 for these SCCs.[11]

2. **Adjust additional SCCs for underestimation bias as necessary** - the lack of emissions estimation methods for some SCCs in the 1990 NEI led to underestimation bias in those categories in the *without-CAAA* scenario. In these cases, the Project Team set the *without-CAAA* scenario values equal to the *with-CAAA* values for each target year. This approach implicitly assumes away the benefits of CAAA programs for these sources. While eliminating erroneous estimates of disbenefits in these categories resulting from emissions inventory methods changes, this approach likely still results in an underestimation bias because CAAA programs either directly or indirectly resulted in overall reductions in these emissions that cannot be estimated.

3. **Apply TFs where necessary –** as in the *with-CAAA* scenario, we applied TFs to emissions in each county that are associated with fugitive dust.

Speciating the Adjusted Total $PM_{2.5}$ Emissions Estimates

The second step in our adjustment process for area sources involved generating emissions estimates for the three main PM components that comprise primary PM: EC, OC, and crustal. We did this by multiplying the adjusted total $PM_{2.5}$ emissions estimate by SCC-specific allocation factors for these three species. The result was adjusted emissions estimates of EC, OC and crustal PM species.

Non-EGU Point Sources

The non-EGU point source emissions data consisted of estimates at the county level for total primary $PM_{2.5}$ as well as the PM species EC and OC. In order to generate emissions estimates for crustal material, we assumed that this species would be equal to the remaining portion of the total primary $PM_{2.5}$ after subtracting the EC and OC emissions estimates. Therefore, our adjustment procedure for non-EGU point sources consisted of first generating the crustal emissions estimates for both the *with-* and *without-CAAA* scenarios. We then made adjustments to the original emissions estimates for EC, OC, and crustal as described below.

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[9] See Appendix A for further detail about the specific adjustments made to these source categories.

[10] Though 1990 is the base year for the analysis, 2000 is the first of the target years for which differential outcomes under the *with-CAAA* and *without-CAAA* cases are estimated. This is why year 2000 is used as the foundation year for the *without-CAAA* adjustments.

[11] These growth factors are described in further detail in *Emission Projections for the Clean Air Act Second Section 812 Prospective Analysis* (March 2009), and are based on the Department of Energy's *Annual Energy Outlook* 2005 forecasts. The growth factors are the same as those applied to the original emissions estimates.

With-CAAA Scenario

No adjustments were needed for the non-EGU point emissions estimates for the *with-CAAA* scenario.

Without-CAAA Scenario

The emissions estimation procedure for this category applied in the 1990 NEI led to a likely net overestimate of emissions reductions from non-EGU point sources due to the CAAA. To address this, the Project Team opted to set the *without-CAAA* scenario values equal to *with-CAAA* values for each target year. The CAAA-related PM emissions changes for this source category, while likely overestimated, were minimal compared to other categories. Therefore, we opted to take a conservative approach of assuming no impact of the CAAA, rather than generating more precise corrections.

CALCULATING CMAQ ADJUSTMENT FACTORS

Once we updated all of the original emissions data for both area sources and non-EGU point sources, we then calculated a set of species-specific adjustment factors (AFs) to apply to the CMAQ results:

$$AF_{i,j,k,l}$$

Where: i = county

j = PM species (EC, OC, or crustal)

k = target year (2000, 2010, or 2020)

l = *with*-CAAA or *without*-CAAA scenario

We calculated AFs for each of the combinations of j, k and l, for a total of 18 factors for each county.

We performed the following calculations to derive the CMAQ adjustment factors:

1. Calculate the “old” area and non-EGU point emissions estimates for EC, OC, and crustal PM. For area sources, this required speciating the old primary PM estimates using the SCC-specific allocation factors and then summing across all of the SCCs in a particular county. For non-EGU point sources, we were able to use the existing county-level speciated data.
2. Calculate “new” adjusted emissions estimates for EC, OC, and crustal (as described in the previous section of this memo).
3. Calculate ratios of the “new” emissions estimates to the “old” estimates to derive adjustment factors to be applied to CMAQ data for EC, OC, and crustal species.

APPLYING ADJUSTMENT FACTORS TO CMAQ DATA

After calculating the adjustment factors, we then applied them to the CMAQ results. For each county, target year, and scenario, we employed the following procedure:

1. **Calculate the fraction of EC, OC, and crustal $PM_{2.5}$ that is primary** - the CMAQ data for each species includes both primary and secondary emissions. However, the adjustment factors are only applicable to primary PM. For EC and

crustal, we assumed that 100 percent of the emissions were primary. For OC, we estimated the primary fraction by applying quarterly EPA Region-level data generated by ICF International from the ADVISOR database.[12]

2. **Calculate the portion of primary EC, OC, and crustal $PM_{2.5}$ generated by area and non-EGU point sources –** since the adjustment factors are calculated using emissions from area and non-EGU point sources only, the Project Team estimated the portion of each PM species originating from these two sources by applying fractions produced by ICF International using 2010 CMAQ Particle and Precursor Tagging Methodology (PPTM) results.[13] We applied the 2010 fractions to all three target years.

3. **Apply corresponding adjustment factors to values from Step 2**.

4. **Recompile adjusted EC, OC, and crustal $PM_{2.5}$ values for input into MATS -** this included adding the "new" source-specific primary PM values to the "old" values for the remaining sources as well as the secondary PM fraction.

MATS

The Project Team applied EPA's MATS to the CMAQ model output. The advantage of this post-processing step is to generate air quality modeling projections for $PM_{2.5}$ species that are consistent with monitoring data. This helps to reduce uncertainty from known limitations and biases associated with CMAQ (e.g., underestimation of secondary aerosol formation) and to create more accurate air quality estimates. The MATS output formed the basis for the air quality grids that were used to estimate health benefits in BenMAP.

MATS OVERVIEW

MATS is a tool that was designed for use by entities required to submit State or Tribal Implementation Plans (SIPs or TIPs) to assess whether a particular emissions control strategy will lead to attainment of the National Ambient Air Quality Standards (NAAQS) for $PM_{2.5}$ and ozone.[14] MATS uses a combination of observed ambient monitoring data and air quality modeling estimates to generate predicted future-year pollutant concentrations using a three-step process:

1. Perform a spatial interpolation of ambient monitoring data;

2. Adjust the spatially interpolated monitor data using information derived from the air quality modeling output; and

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[12] These data were specific to scenario and target year. The ADVISOR database (Access™ Database for the Visualization and Investigation of Strategies for Ozone Reduction) is an interactive tool that contains information for review, comparison, and assessment of the CMAQ simulations. For further information, see the *Second Prospective Analysis of Air Quality in the U.S.: Air Quality Modeling*, Draft Report – September 20, 2008.

[13] The PPTM is designed to provide detailed, quantitative information about the contribution of selected source categories to simulated $PM_{2.5}$ concentrations. Emissions of precursor pollutants from specific source categories are numerically tagged and tracked throughout a CMAQ simulation. The contribution from each tag to the resulting simulated concentration of the $PM_{2.5}$ concentration or $PM_{2.5}$ component species can be quantified. For further information, see the *Second Prospective Analysis of Air Quality in the U.S.: Air Quality Modeling*, Draft Report – September 20, 2008.

[14] USEPA (2007). *Guidance on the Use of Models and Other Analyses for Demonstrating Attainment of Air Quality Goals for ozone, $PM_{2.5}$ and Regional Haze*. EPA-454/B-07-002.

3. Generate future year concentration estimates by extrapolating the values generated in step 2 based on a comparison of future year and base year air quality modeling data.

APPLICATION OF MATS TO $PM_{2.5}$ FOR THE 812 SECOND PROSPECTIVE ANALYSIS

The Project Team applied MATS to create $PM_{2.5}$ air quality concentration predictions for each target year of the 812 analysis, using 2002 ambient monitoring data adjusted by CMAQ modeling results. Below we provide additional detail on the MATS procedure and how it was applied in the Section 812 Second Prospective Analysis.

Because $PM_{2.5}$ is a mixture of different components that can behave independently of one another and relate to one another in a complex way, the MATS process for this pollutant is performed separately for each major PM species and is referred to as the Speciated Modeled Attainment Test (SMAT).[15] The total $PM_{2.5}$ mass is divided into the following categories: sulfates, nitrates, ammonium, OC, EC, crustal material, particle bound water and salt. In addition, MATS incorporates a blank mass component of 0.5 µg/m^3.

Step 1: Interpolate Ambient Monitor Data

The first step of the MATS process involves spatially interpolating ambient monitoring data for $PM_{2.5}$ from a time period that is representative of the base year of the analysis. This process allows for an estimation of pollutant concentrations at monitors as well as in areas between monitors. This creates a "spatial field" of air quality concentrations across a study area for the base year. The spatial field is comprised of air pollution estimates for the center of each grid cell in the air quality modeling domain. For example, CMAQ employs 36 km x 36 km grid cells. Therefore, the spatial field in the Second Prospective analysis consisted of a set of air pollution concentrations for each 36 km grid cell in the study area.

The Project Team used 2002 ambient monitoring data for the MATS analysis. This included quarterly $PM_{2.5}$ data from 1,232 Federal Reference Method (FRM) monitors, which provide concentrations of total $PM_{2.5}$. Most FRM monitors (about 75 percent) are not co-located with a speciation monitor.[16] Therefore, we also used data providing speciated PM mass from the Speciated Trends Network (STN) and the Interagency Monitoring of Protected Visual Environments (IMPROVE) monitors. The MATS analysis used speciated data from 273 STN or IMPROVE monitors with at least two valid quarters of speciated data in 2002.[17]

One thing to note is that the FRM monitors do not measure the same components and do not retain all of the $PM_{2.5}$ that is measured by the speciation monitors.[18] Therefore, it is necessary to reconstruct the measured species components so that they add up to the

[15] Ibid.

[16] Abt Associates (2009). *Modeled Attainment Test Software User's Manual*. Prepared for the US EPA's Office of Air Quality Planning and Standards, March.

[17] A "valid" quarter included speciated data from at least 11 days.

[18] FRM mass measurements do not retain all ammonium nitrate and other semi-volatile materials and includes particle bound water associated with sulfates, nitrates, and other hygroscopic species. This results in concentrations (and percent contributions to $PM_{2.5}$ mass) that may be different than the ambient levels of some $PM_{2.5}$ species. USEPA (2007). *Guidance on the Use of Models and Other Analyses for Demonstrating Attainment of Air Quality Goals for ozone, $PM_{2.5}$ and Regional Haze*. EPA-454/B-07-002.

measured FRM mass. The SMAT procedure achieves this by using an FRM mass construction methodology called "Sulfate, Adjusted Nitrate, Derived Water, Inferred Carbonaceous material balance approacH" (SANDWICH).[19] The result of applying this methodology is reduced nitrates (relative to the amount measured by the speciation monitors), higher mass associated with sulfates, and a measure of OC that is derived from the difference between measured $PM_{2.5}$ and its non-carbon components. This characterization of $PM_{2.5}$ mass also reflects crustal material and other minor constituents. See EPA's *Guidance on the Use of Models and Other Analyses for Demonstrating Attainment of Air Quality Goals for Ozone, $PM_{2.5}$ and Regional Haze* (2007) for information on the specific calculations performed in MATS for each species.

In order to create the "spatial field" of PM species concentrations for each 36 km CMAQ grid cell, the Project Team applied the Voronoi Neighborhood Averaging (VNA) technique in MATS to interpolate the PM monitoring data. This is an algorithm that identifies a set of monitors close to the grid cell (called "neighbors") and then estimates the PM species concentration in that grid cell by calculating an inverse-distance weighted average of the monitor values (i.e., the concentration values at monitors closer to the grid cell are weighted more heavily than monitors that are further away).[20] This process is performed for both the total $PM_{2.5}$ concentration, using the FRM data, and the speciation data from the STN or IMPROVE monitors. Concentrations for each $PM_{2.5}$ component are then generated by multiplying the interpolated $PM_{2.5}$ concentration in a grid cell by the fractional composition of each species, obtained from the interpolated speciated monitor data in that grid cell.

Step 2: Adjust the Monitoring Data with Modeling Data

The second step in the MATS procedure consists of adjusting the spatial field of concentrations generated in Step 1 by using "spatial gradients" generated by the CMAQ model. A spatial gradient is the ratio of the mean model values at an unmonitored location to the mean model values at a monitor. This process adjusts the monitor concentrations upwards in areas where the model predicts relatively high concentration levels and adjusts monitor concentration downwards in areas where the model predicts relatively low concentration levels, rather than using absolute model concentrations. The result is a prediction of more accurate concentrations in grid cells without monitors. For instance, rural areas may be overly influenced by high monitored concentrations near urban areas. Therefore, these areas would be adjusted downward based on the model predictions. In addition, the model can help identify unmonitored areas that could contain large sources of primary PM emissions and therefore should be adjusted upwards. The result of this step is referred to as a "gradient-adjusted spatial field."

Step 3: Generate Future Year Concentrations

The final step in the MATS process generates future year PM species concentrations for each target year by multiplying the gradient-adjusted spatial field for the base year (generated in step 2) by grid cell-level relative response factors (RRFs) derived from

[19] Frank, N. (2006). Retained Nitrate, Hydrated Sulfates, and Carbonaceous Mass in Federal Reference Method Fine Particulate Matter for Six Eastern U.S. Cities. *Journal of the Air and Waste Management Association* 56: 500-511.

[20] See the MATS user's manual for further information: Abt Associates (2009). *Modeled Attainment Test Software User's Manual*. Prepared for the US EPA's Office of Air Quality Planning and Standards, March.

comparing a future year model concentration to a base year model concentration for a given PM species. For each species and grid cell, the following calculation is performed:

$$C_{Target} = C_{Baseline} \text{ x RRF}$$

Where:

$C_{Baseline}$ = the grid cell-level baseline concentration of a particular PM species (generated in step 2);

RRF = the relative response factor. This is the ratio of the target year concentration predicted in a specific grid cell to the baseline concentration predicted in that grid cell for a particular PM species. The Project Team used the 2000 *with-CAAA* CMAQ results as the baseline.

C_{Target} = the predicted grid cell-level concentration of a particular PM species in the target year (2000, 2010, or 2020).

The Project Team used this process for each target year and scenario, with the exception of the 2000 *with-CAAA* scenario. In this case, Steps 1 and 2 were performed on the 2002 monitoring data. However, instead of calculating the 2000 values by temporally adjusting the monitoring data using the RRF, we assumed that the 2002 interpolated monitoring data provided an accurate representation of the 2000 *with-CAAA* scenario.

EFFECT OF PM ADJUSTMENT AND CHOICE OF MONITORING DATA ON MATS RESULTS

The Project Team generated stacked bar graphs to demonstrate the effect of MATS on the CMAQ output in terms of the total $PM_{2.5}$ concentration levels as well as the relative contributions of each PM species. Appendices B and C contain the graphs as well as additional detail on how the graphs were generated.

Each graph represents a specific monitoring location and includes two bars representing: 1) the total $PM_{2.5}$ concentrations measured at the FRM monitors; and 2) a stacked bar depicting the speciated $PM_{2.5}$ concentrations measured at the co-located STN monitor. The 23 graphs included in Appendix B also include an additional set of stacked bars representing the original CMAQ output based on the unadjusted PM emissions estimates, the CMAQ output derived from the adjusted emissions estimates, and the MATS output based on the adjusted CMAQ results for each target year and scenario. The second set of 10 graphs in Appendix C include bars for the original and adjusted CMAQ results as well as three sets of MATS results based on the following: 1) the original CMAQ data and monitoring data from 2002, 2003, and 2004 (MATS #1); 2) the original CMAQ data and 2002 monitoring data (MATS #2); and 3) the adjusted CMAQ data and 2002 monitoring data (MATS Final). This second set of graphs show the impact on the MATS results of restricting the monitoring data to a single year and of applying the adjustment factors to the CMAQ data for 2000 and 2010.

The following general observations emerge from analysis of the two sets of graphs:

- As seen in the graphs, applying the adjustment factors to the original CMAQ results corrects for the overestimation of the proportion of the total $PM_{2.5}$ concentration that is made up of crustal material. The adjustments made to the emissions data tend to reduce the crustal portion and therefore, the adjusted CMAQ results better reflect the proportion measured at the monitors.

- In general, it appears that the effect of applying MATS to the CMAQ output provides $PM_{2.5}$ concentrations that are more reflective of the relative proportions of the various PM species that were measured at the STN monitors. In addition, the 2000 *with-CAAA* scenario MATS output is a better match with the total $PM_{2.5}$ concentration measured at the FRM monitors than the CMAQ output.
- Comparing MATS #1 and MATS #2, it appears that using only 2002 monitoring data, as opposed to using data from 2002-2004, has only a modest effect on the MATS results.
- Comparing MATS #2 to MATS Final indicates that that the effect of applying the adjustment factors to the CMAQ data has a nominal effect on the total PM concentration, tending to result in slight decrease. However, the MATS Final estimates for both scenarios and target years do appear to have a smaller proportion of crustal material compared to MATS #2, which better reflects the composition measured at the monitors. This increases our confidence that the MATS results relying on the adjusted CMAQ data provide more realistic estimates of $PM_{2.5}$ composition than the MATS results based on the unadjusted CMAQ data.
- In the majority of locations evaluated, the MATS estimates for the 2000 *with-CAAA* scenario appear to correspond well to the 2002 monitor data. In the Bronx, Los Angeles, and Manhattan however, the MATS estimates for the 2000 *with-CAAA* scenario appear to be slightly lower than the total PM monitor concentrations. We note, however, that the Los Angeles and Manhattan results are based on only two quarters of monitoring data in 2002, compared to a full year in most other locations.

APPENDIX A

PECHAN

E.H. Pechan & Associates, Inc.

MEMORANDUM

Date: March 10, 2010

To: Jim Neumann, IEc

From: Jim Wilson, Andy Bollman, Maureen Mullen

Subject: Revised Section 812 Nonpoint Source $PM_{2.5}$ Emission Estimates
Work Assignment 0-1, TD #3

The Section 812 Project Team identified the need to refine the “without-CAAA” scenario emissions previously developed for the following nonpoint $PM_{2.5}$ emission source categories:

	2000 $PM_{2.5}$ Emissions (tons per year)		
Category	**Without CAAA**	**With CAAA**	**Difference**
1. Construction	1,134,719	237,780	896,939
2. Paved Roads	634,762	202,706	432,056
3. Unpaved Roads	1,103,413	835,152	268,261
4. Residential Wood Combustion	260,121	428,044	-167,924
5. Fuel Combustion Industrial/Coal/Other	3,584	154,045	-150,512

These are the nonpoint categories with the largest differences between the 2000 with- and without-CAAA scenario emission estimates. While the 2000 with-CAAA nonpoint source emission estimates are taken directly from the U.S. Environmental Protection Agency’s (EPA’s) 2002 nonpoint source National Emissions Inventory (NEI), the 2000 without-CAAA scenario nonpoint source emissions represent estimates projected from 1990 NEI emissions. Because of discrepancies in the emission estimation procedures for these categories, Pechan recalculated these categories’ 1990 and 2000 without-CAAA scenario emission estimates so that these categories’ estimates would rely on procedures comparable to those used in the 2002 NEI. In addition, Pechan developed revised 2010 and 2020 without-CAAA emission estimates for these categories by applying previously generated growth factors to the 2000 without-CAAA emissions. The balance of this memorandum describes how each category’s emissions were recalculated, and reports the updated with- and without-CAAA $PM_{2.5}$ emissions for each nonpoint source category.

A. METHODS FOR RECALCULATING WITHOUT-CAAA EMISSIONS

The following sections discuss the methods used for each of the five priority area source categories to recalculate the without-CAAA scenario emissions.

1. Construction

For the 2002 NEI, EPA developed emission estimates for three of the eight possible construction Source Classification Codes (SCCs). Emissions for other construction SCCs were supplied by local and/or state air quality agencies. Because of the minor contribution of these SCCs to total construction $PM_{2.5}$ emissions (~ 2.5 percent), Pechan calculated revised without-CAAA emission estimates for the state/local agency-supplied categories by applying year-specific uncontrolled/controlled emission ratios calculated from the emissions for the three categories for which EPA developed estimates.

Pechan computed revised without-CAAA emission estimates for the following specific SCCs, which are the three major components of construction emissions:

- 2311010000 – Residential Construction;
- 2311020000 – Nonresidential Construction; and
- 2311030000 – Road Construction.

First, Pechan recalculated the 2000 without-CAAA scenario emissions for each SCC by removing the 50 percent $PM_{2.5}$ emission reduction assumption that was applied to PM_{10} nonattainment area counties in the 2002 NEI. This control efficiency represents the Best Available Control Measure (BACM) controls on fugitive dust construction activity for these counties. Because state/local agencies also supplied emission estimates to the 2002 NEI for these SCCs, directly relying on the resulting emission estimates would have led to without-CAAA emission estimates that are not directly comparable to the with-CAAA scenario emissions. Therefore, Pechan computed values representing the ratio of EPA method-derived uncontrolled 2002 $PM_{2.5}$ emissions to EPA method-derived 2002 controlled $PM_{2.5}$ emissions. These ratios were computed as 1.206 (Residential Construction), 1.136 (Nonresidential Construction), and 1.128 (Road Construction), and each value multiplied by the 2000 with-CAAA scenario emissions to yield the without-CAAA scenario 2000 emission estimates.

An analogous procedure was used to estimate 1990 emissions. For Residential and Nonresidential Construction, Pechan utilized EPA's 2002 NEI estimation procedure for each SCC, but replaced the 2002 emissions activity values (e.g., number of housing starts) with 1990 values and removed the 50 percent emission reduction assumption for PM_{10} nonattainment area counties.[21] Pechan then computed values representing the ratio of EPA method-derived uncontrolled 1990 $PM_{2.5}$ emissions to EPA method-derived 2002 uncontrolled $PM_{2.5}$ emissions. These ratios were computed as 0.767 (Residential Construction) and 1.020 (Nonresidential Construction), and these values were applied to the 2000 without-CAAA emissions to yield 1990 emission estimates. For Road Construction, less detailed road construction expenditure data were available for 1990 than were used in developing emissions for EPA's 2002 NEI. Therefore, Pechan computed a ratio using more aggregate road construction expenditure data for each year, and this ratio was applied to the 2002 expenditures to estimate comparable 1990 expenditure data.[22] Using the same methods that were used to develop a 2002-specific

[21]The NEI methods were only replicated at the national level. To follow them exactly would have required obtaining 1990-specific data for allocating activity/emissions to counties. In the interest of time, we relied on the 2002 allocation data to also represent 1990 allocations.
[22]In the 2002 NEI, it was possible to exclude resurfacing and minor bridge rehabilitation expenditures from the emissions activity data. The ratio of 1990 to 2002 total outlays was used to estimate 1990 expenditure data consistent the expenditure data used by EPA to develop road construction emissions for the 2002 NEI.

conversion factor, Pechan computed a 1990-specific factor for converting the 1990 construction expenditures to number of acres disturbed. Pechan also removed the 50 percent emission reduction assumption for PM_{10} nonattainment area counties in calculating initial 1990 emission estimates for Road Construction. Pechan then computed the ratio of 1990 emissions to 2000 without-CAAA emissions (0.596) for application to the 2000 without-CAAA scenario emissions to yield estimates of 1990 emissions.

For 2010 and 2020, Pechan applied the growth factors that had previously been applied in preparing without-CAAA emission projections. These growth factors, which reflect regional output projections for the construction sector, were multiplied by the 2002 without-CAAA emission estimates that were computed in this effort, with the result representing estimates of national without-CAAA emissions in 2010 and 2020.

2. Paved Roads

The previous 2000 without-CAAA estimates were based on growing 1990 paved road emissions to 2000, while the 2000 with-CAAA estimates were taken from the 2002 NEI. Paved road emissions in the 2002 NEI reflect a combination of EPA emission estimates and emission estimates submitted by state/local agencies. To keep consistency with the previous emissions modeling, no changes were made to any of the previous Section 812 with-CAAA emission estimates. Because it was not possible to replicate the mix of EPA and state/local agency emission estimation methods that comprise the 2002 NEI, it was necessary for Pechan to estimate without-CAAA emission estimates by applying ratios to the with-CAAA emission estimates.

Paved road emissions were recalculated as part of this effort to be consistent with the calculation methodology and inputs that EPA used for the 2002 NEI. The without-CAAA emissions were re-estimated using the same general data inputs as the EPA used in developing estimates for the 2002 NEI (i.e., paved road vehicle miles traveled and AP-42 emission factor equation). Because the 2000 with-CAAA emission estimates include the effects of paved road controls in PM nonattainment areas, it was necessary to remove the effects of these controls in calculating without-CAAA emissions. In the 2002 NEI, EPA applied a control efficiency of 79 percent to urban and rural roads in serious PM nonattainment areas, and urban roads in moderate PM nonattainment areas (this corresponds to vacuum sweeping on paved roads twice per month). Rule penetration values varied by road type and nonattainment area classification (serious or moderate).

Between the time that the 1990 and 2002 NEI's were prepared, EPA made substantial changes to the paved road emission factor equation (the 2002 NEI uses the current AP-42 emission factor equation). Therefore, in recalculating the 1990 paved road dust emissions, Pechan multiplied the recomputed 2002 without-CAAA paved road $PM_{2.5}$ emissions by the ratio of 1990 paved road vehicle miles traveled (VMT) to 2002 paved road VMT. The paved road VMT ratios were developed at the state and roadway type level of detail.

The 2000 without-CAAA fugitive road dust emissions from paved roads were projected to 2010 and 2020 using the same county-level population-based growth factors that were applied in the previous Section 812 projections. These factors were applied to the 2000 without-CAAA emissions to provide revised estimates of 2010 and 2020 without-CAAA emissions.

3. Unpaved Roads

A review of the $PM_{2.5}$ emission estimates in the 2002 NEI indicates that EPA was responsible for developing estimates for only one of the three SCCs under which unpaved road emissions were reported. Emissions for other unpaved road SCCs were supplied by local and/or state air quality agencies. Because of the minor contribution of these SCCs to total unpaved road $PM_{2.5}$ emissions (~ 0.2 percent), Pechan calculated revised without-CAAA emission estimates for these two categories by applying year-specific uncontrolled/controlled emission ratios calculated from the emissions for the SCC for which EPA developed estimates (i.e., SCC 2294000000 – All Paved Roads/Total: Fugitives). The remainder of this section describes how Pechan recalculated the without-CAAA emissions for this SCC.

Because the 2002 NEI that forms the basis of the current 2000 with-CAAA unpaved road emissions represents a mixture of EPA and state/local agency data, it was not possible to replace the existing without-CAAA unpaved road emissions with updated values. Instead, Pechan calculated an updated without-CAAA emission value by first developing new with- and without-CAAA emission estimates for 2002, and then applying the resulting without- to with-CAAA emissions ratio to the 2002 NEI emissions that represent the 2000 with-CAAA scenario emissions.

Pechan used the same EPA data inputs, unpaved road VMT, and AP-42 emission factor equation that was used in the 2002 NEI in the updated emission calculations. However, without-CAAA emissions removed the unpaved road emission controls from the calculations. The EPA-developed unpaved road estimates in the 2002 NEI incorporated a control efficiency of 80 percent with a rule penetration rate of 75 percent for urban roads in serious PM nonattainment areas, a 50 percent control efficiency with 50 percent rule penetration rate for rural roads in serious PM nonattainment areas, and a 96 percent control efficiency with a 50 percent rule penetration for urban roads in moderate PM nonattainment areas. The ratio of newly calculated without- to with-CAAA emission estimates (1.01) was then applied to the existing national with-CAAA $PM_{2.5}$ emission estimate.

The 1990 NEI was the source for the original Section 812 1990 unpaved road emissions. To be consistent with the methods used to calculate unpaved road emissions in the 2002 NEI, the 1990 unpaved road dust emissions were recalculated by first computing 1990 unpaved road emissions using the same methods as the uncontrolled 2002 unpaved emissions, but with 1990 unpaved VMT data replacing 2002 unpaved VMT data (these data were developed at the state and roadway type level of detail). Next, Pechan summed the 1990 and 2002 emission estimates to the national level, and computed the ratio of 1990 to 2002 unpaved emissions. This ratio (1.007) was then applied to the newly calculated 2000 without-CAAA $PM_{2.5}$ emission estimate that was computed as described above.

The 2000 without-CAAA unpaved road emissions that were directly re-computed in this effort were projected to 2010 and 2020 using the same regional unpaved road VMT growth factors that were previously applied in calculating the 2010 and 2020 with-CAAA emission estimates.

4. Residential Wood Combustion

As part of the original Section 812 effort, Pechan performed a sector-specific analysis of emissions activity and controls for all but 2 of the 12 residential wood combustion (RWC) source category SCCs with emissions in the 2002 NEI.[23] Much of the information compiled from that work was applied in this effort. Because the two SCCs that were not previously analyzed accounted for a small percentage of total category 2002 with-CAAA $PM_{2.5}$ emissions (0.08 percent), and will not have any significant CAAA reductions, Pechan did not attempt to refine the without-CAAA emission estimates for these two SCCs.

The first step in recalculating the 2000-without CAAA RWC emissions for the remaining ten SCCs was to identify the emission reductions attributable to lower-emitting wood heating units resulting from EPA's wood heater New Source Performance Standard (NSPS). The 2002 NEI that forms the basis for the 2000 with-CAAA scenario emissions assumed the following proportions of total residential wood consumption: 92 percent in non-EPA certified units; 5.7 percent in EPA certified non-catalytic units; and 2.3 percent in EPA certified catalytic units. EPA's RWC forecast year proportions were calculated by adjusting the 2002 year proportions using an annual 2 percent RWC unit turnover rate computed from 1992-2005 data. This adjustment accounts for non-EPA certified units being replaced by NSPS compliant EPA-certified units. Therefore, by year 2020, it is assumed that 64.4 percent of residential wood consumption in woodstoves and fireplaces with inserts will occur in non-EPA certified units, 25.4 percent in EPA certified non-catalytic units, and 10.2 percent in EPA certified catalytic units.

For the four SCCs that represent heating units that meet EPA emission requirements, the ratio of non-CAAA to CAAA emissions was computed by dividing the 2002 NEI emission factor for conventional units by the 2002 NEI emission factor for EPA-certified units. Two SCCs are specific to non-EPA-certified units and therefore have no CAAA emission reductions (2104008001 and 2104008010). Two SCCs do not specify EPA certification status (2104008000-Total Fireplaces and Woodstoves and 2104008001-Total Fireplaces). For these SCCs, it was necessary to develop a 2002 weighted emission factor from the EPA-certified and non-EPA-certified unit emission factors. Each emission factor was weighted by the proportion of RWC that is estimated to have occurred in the particular type of unit (as noted above, the 2002 NEI provided this information). Each SCC's ratio of non-CAAA emissions to CAAA emissions was computed by dividing the emission factor for conventional units by the given weighted emission factor. The 2000 without-CAAA emissions were computed by multiplying the 2000 with-CAAA emissions by the appropriate adjustment ratio.

Pechan used the back-cast factors that were developed in the earlier Section 812 analysis to back-cast the 2000 with-CAAA emissions to 1990. These back-cast factors were computed based on SCC-level 2002 and 1990 residential wood consumption estimates. To calculate 1990 consumption, Pechan first calculated the ratio representing national 1990 residential wood consumption relative to 2002 consumption (1.85), and then multiplied this ratio by 2002 year regional residential renewable (wood) energy consumption. Next, Pechan applied values representing the estimated 1990 year proportions of total residential wood consumption attributable to each of the following unit types: woodstoves, fireplaces with inserts, and fireplaces without inserts. Next, we allocated the general unit-level consumption estimates to individual SCCs. For 1990, this step assumed that zero residential wood consumption would occur in EPA-certified units because 1992 was the first year of certification. Finally, we calculated the back-cast/forecast year growth factors by dividing estimated 1990 consumption by estimated 2002 year consumption.

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[23]These two SCCs were 2104009000-Residential/Firelog/Total: All Combustor Types, and 2199008000-Total Area Source Fuel Combustion/Wood/Total: All Boiler Types.

The final step was to apply the 2010 and 2020 growth factors from the previous Section 812 analysis to the 2000 without-CAAA emissions to yield estimates of 2010 and 2020 without-CAAA emissions.

5. Fuel Combustion Industrial/Coal/Other

Pechan did not identify any CAAA emission controls that affect $PM_{2.5}$ emissions for this category. Therefore, Pechan set the without-CAAA emissions for 2000, 2010, and 2020 equal to the with-CAAA emissions for each year. For 1990, Pechan was unable to replicate the 2001 emission calculations that underlie the EPA developed industrial coal combustion estimates for the 2002 NEI[24] because the NEI methods reflect the effects of point source subtractions that eliminate double counting of emissions reported in EPA's point source inventory. Therefore, 1990 emissions were estimated by applying the ratio of 1990 to 2001 emissions activity for this category to the NEI emissions. The emissions activity for this category is the volume of non-coke plant coal consumed by the industrial sector.[25] Pechan calculated the national ratio of 1990 coal consumption to 2001 coal consumption (1.170), and then multiplied this ratio by the national emissions in 2000 to estimate 1990 emissions.

B. SUMMARY OF REVISED EMISSION REDUCTIONS ATTRIBUTABLE TO CAAA

Table 1 displays the final with- and without-CAAA emissions for each of the source categories analyzed. Overall, the CAAA are estimated to reduce $PM_{2.5}$ emissions for these categories by approximately 4 percent, 9 percent, and 10 percent in 2000, 2010, and 2020, respectively.

[24]The 2002 NEI industrial coal emissions were based on the most recent data available at the time, which was 2001.
[25]Because Pechan only recalculated bituminous/sub-bituminous coal combustion, and not anthracite coal combustion, it was also necessary to estimate the portion of total consumption from bituminous/sub-bituminous coal. Pechan implemented this adjustment by applying the 2001 year state-specific bituminous to total coal consumption ratios that were compiled for the 2002 NEI. The 2001 ratios were used because analogous 1990 data were not available.

Table 1. Summary of Updated Section 812 Second Prospective $PM_{2.5}$ Emission Estimates for Five Nonpoint Source Categories (tons per year)

Category	1990	2000		2010		2020	
		Without CAAA	With CAAA	Without CAAA	With CAAA	Without CAAA	With CAAA
Construction	200,082	270,473	237,780	327,378	252,815	355,450	312,317
Paved Roads	162,436	210,409	202,706	226,196	217,706	245,903	236,673
Unpaved Roads	849,408	843,503	835,152	793,147	786,853	720,534	716,237
Residential Wood Combustion	786,697	460,003	428,043	529,172	438,225	573,504	431,195
Fuel Comb. Industrial/Coal/Other	180,361	154,095	154,095	153,289	153,289	147,870	147,870
Subtotal	2,178,984	1,938,484	1,857,776	2,029,183	1,848,888	2,043,261	1,844,291
% Reduction			4.2%		8.9%		9.7%

APPENDIX B

Memorandum

To:	Henry Roman and Jim Neumann, Industrial Economics Inc.
From:	Leland Deck, Stratus Consulting Inc.
Date:	May 27, 2010
Subject:	Stacked bar charts of estimated $PM_{2.5}$ at 23 Speciation Trend Network monitor locations for the §812 Second Prospective Project

This memorandum conveys a series of 23 stacked bar chart diagrams showing the estimated composition of fine particulate matter ($PM_{2.5}$) air quality estimates for the §812 second prospective project. The diagrams present observed 2002 monitor data, as well as estimates for each of the six §812 scenarios. The estimates were prepared directly by CMAQ ("Orig. CMAQ"), the results of the adjustments made in April and May, 2010 to the CMAQ estimates ("Adj. CMAQ"), and the estimates prepared using EPA's Monitor Attainment Test Software (MATS, ver. 2.1.1), using the adjusted CMAQ files as modeled input. The principal adjustment to the CMAQ estimates involved revising the crustal component, although adjustments were also made to a portion of the EC and OC estimates.

Each diagram presents a stacked bar for each of 21 different estimates of annual mean $PM_{2.5}$ levels. There is a diagram for 23 Speciation Trend Network (STN) monitor locations. The 23 monitors were selected to present a range of locations throughout the contiguous United States, including monitors in densely populated areas, coastal and inland areas, and more rural locations with STN monitors.

The first three stacked bars shown on each diagram are:

1) The Federal Reference Method (FRM) measure of 2002 annual mean $PM_{2.5}$ at the STN monitor location.
2) A Reconstructed Fine Mass (RCFM) estimate prepared by EPA for the STN monitor.
3) The bar labeled "2002 STN" presents 8 components derived from the STN monitor data: sulfate (SO_4) retained nitrate (NO_3), ammonium (NH_4), blank-adjusted organic carbon (OC), elemental carbon (EC), crustal material, salt, and particular bound water (H2O) estimated using the Aerosol Inorganic Model (AIM).

The data for each of these three stacked bars comes from the MATS input file ("Species-for-fractions-0205-v2.csv") supplied with MATS.

The other 18 stacked bars on each diagram include three stacked bars for each of the six §812 scenarios. Each scenario has a stacked bar for original CMAQ estimates, the adjusted CMAQ estimates, and the MATS estimate. Each stacked bar is designated by the scenario's year, whether the scenario includes the Clean Air Act Amendments of 1990, or not (for example "2010 No ____" is the No CAAA scenario for 2010), and which model was used to prepare that estimate. The original and adjusted CMAQ estimates have six species components (SO4, NO3, NH4, EC, OC and Crustal). The MATS estimates have 9 components: SO4, NO3, NH4, EC, OC, Crustal, water, salt (a very small component on many diagrams), and a blank mass component (set as a constant 0.5 μg/m^3 throughout the CMAQ domain).

Note that the MATS estimates were made using the Gradient Adjustment (GA) option, which estimates the $PM_{2.5}$ levels at the center of each CMAQ grid cell rather than at the exact location of the STN monitor. These MATS GA estimates are presented in the stacked bar diagrams, and are also used in the §812 health analyses. In some locations, especially where the FRM monitor is near an edge of a CMAQ cell and there are other FRM monitors relatively nearby, there is a modest difference between the MATS estimate and either the STN or FRM monitor level.

Also note while most of the STN locations presented in the diagrams have complete data for 2002, four of the STN monitors have fewer than 4 quarters of STN data. Los Angeles, Manhattan and Lawrence County, TN have STN data for only the third and fourth quarters of 2002, and Tucson, AZ has data for three quarters. MATS prepares a separate estimate for each quarter, using available monitor data in that quarter. Thus the estimated annual mean species concentrations at these three STN locations are MATS estimates using less than 4 quarters of available STN data from that grid cell, and interpolated quarterly data from other STN monitors for the missing quarters. All other locations presented in a diagram have complete STN data (defined as at least 11 valid days of data in each quarter).

Figure 1 Atlanta, GA

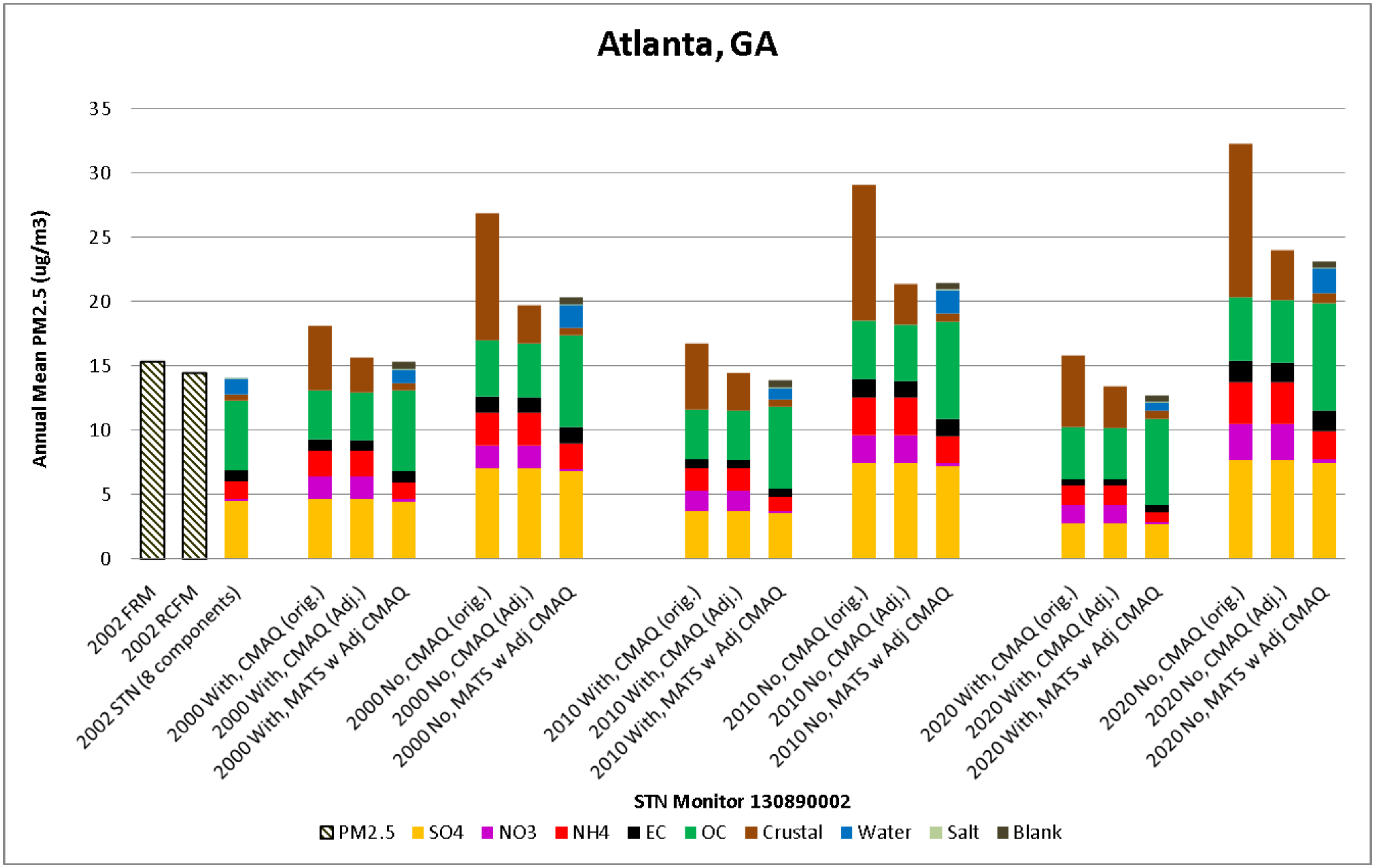


Figure 2 Baltimore County, MD

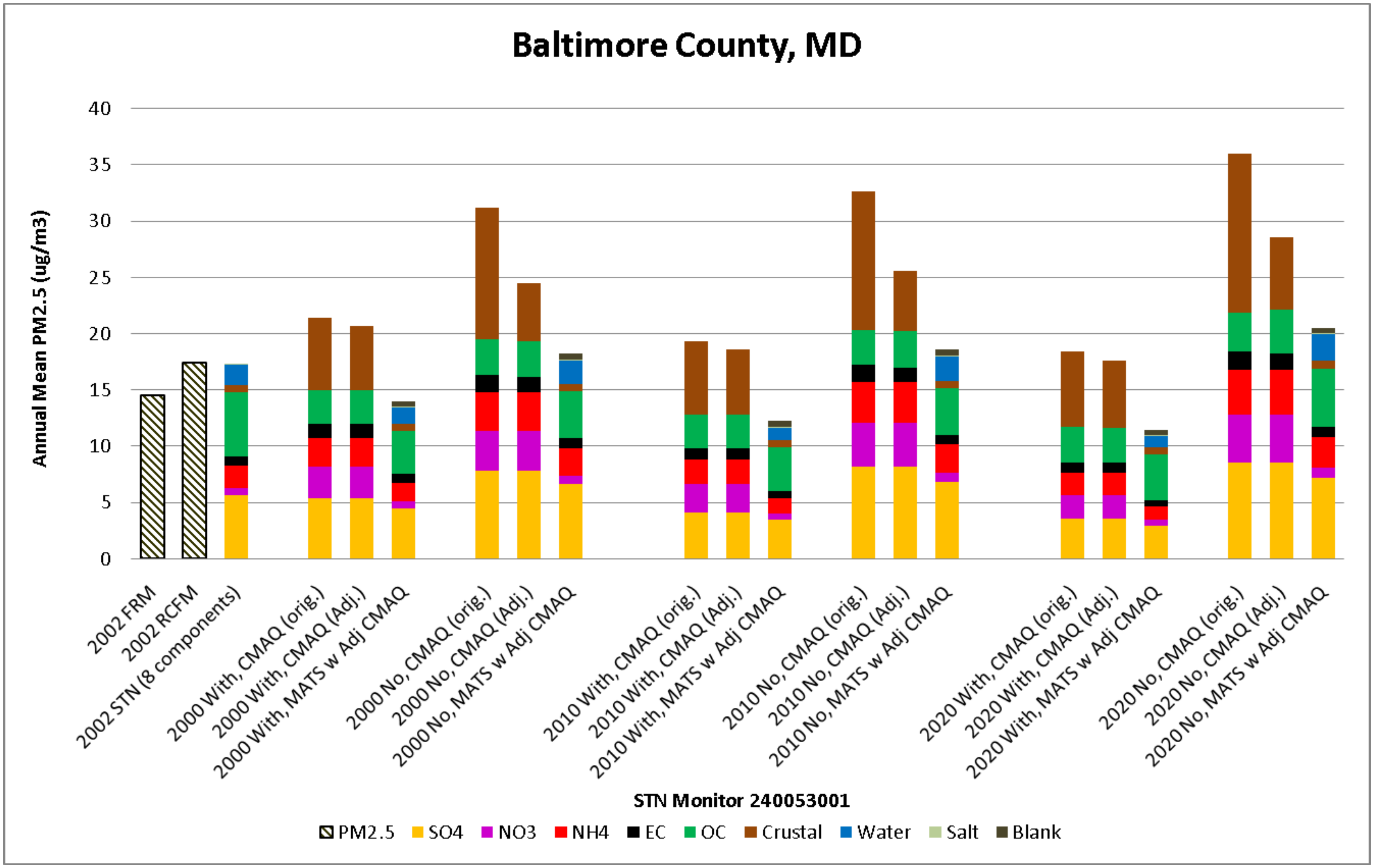


Figure 3 East Baton Rouge, LA

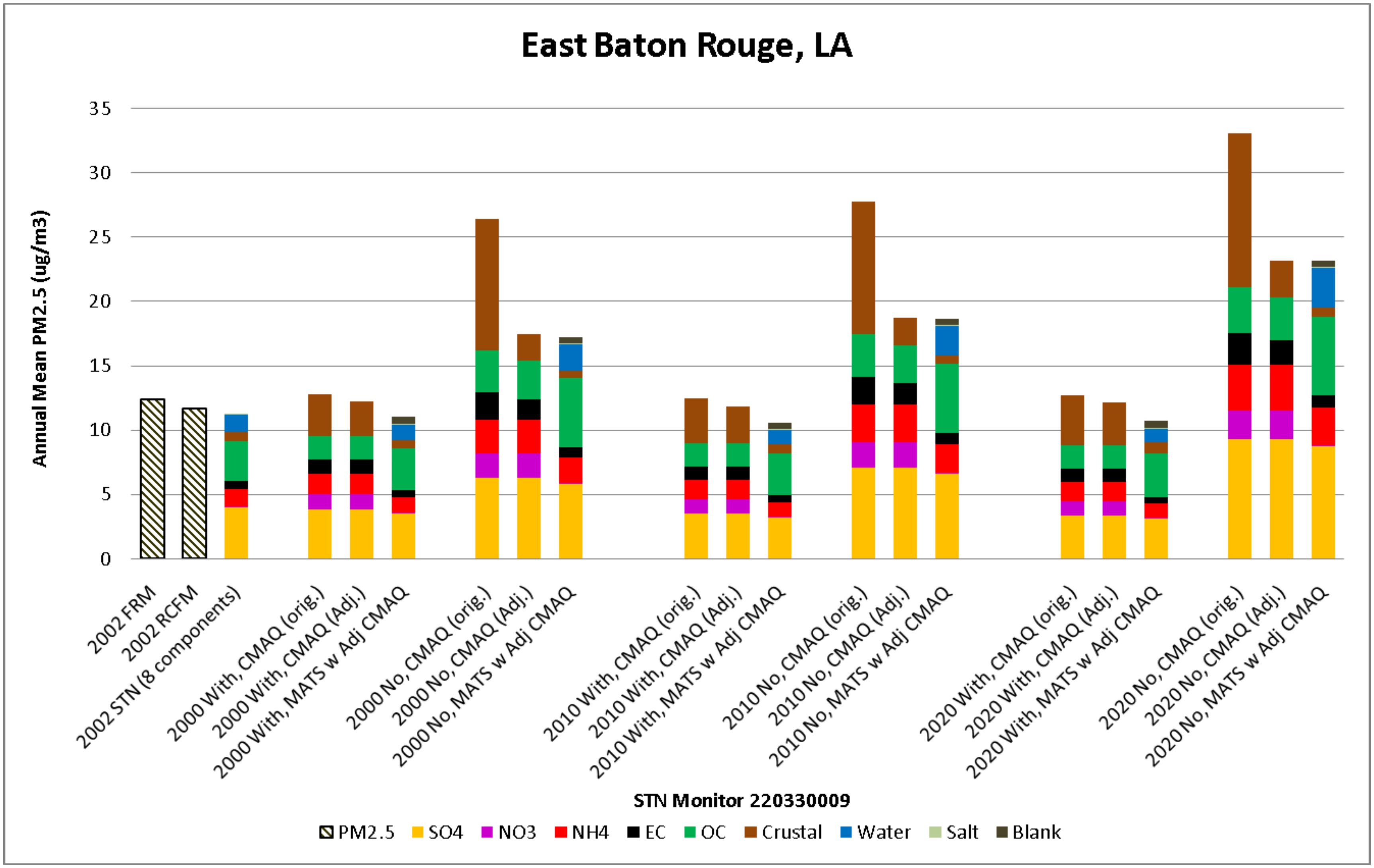


Figure 4 Boston, MA

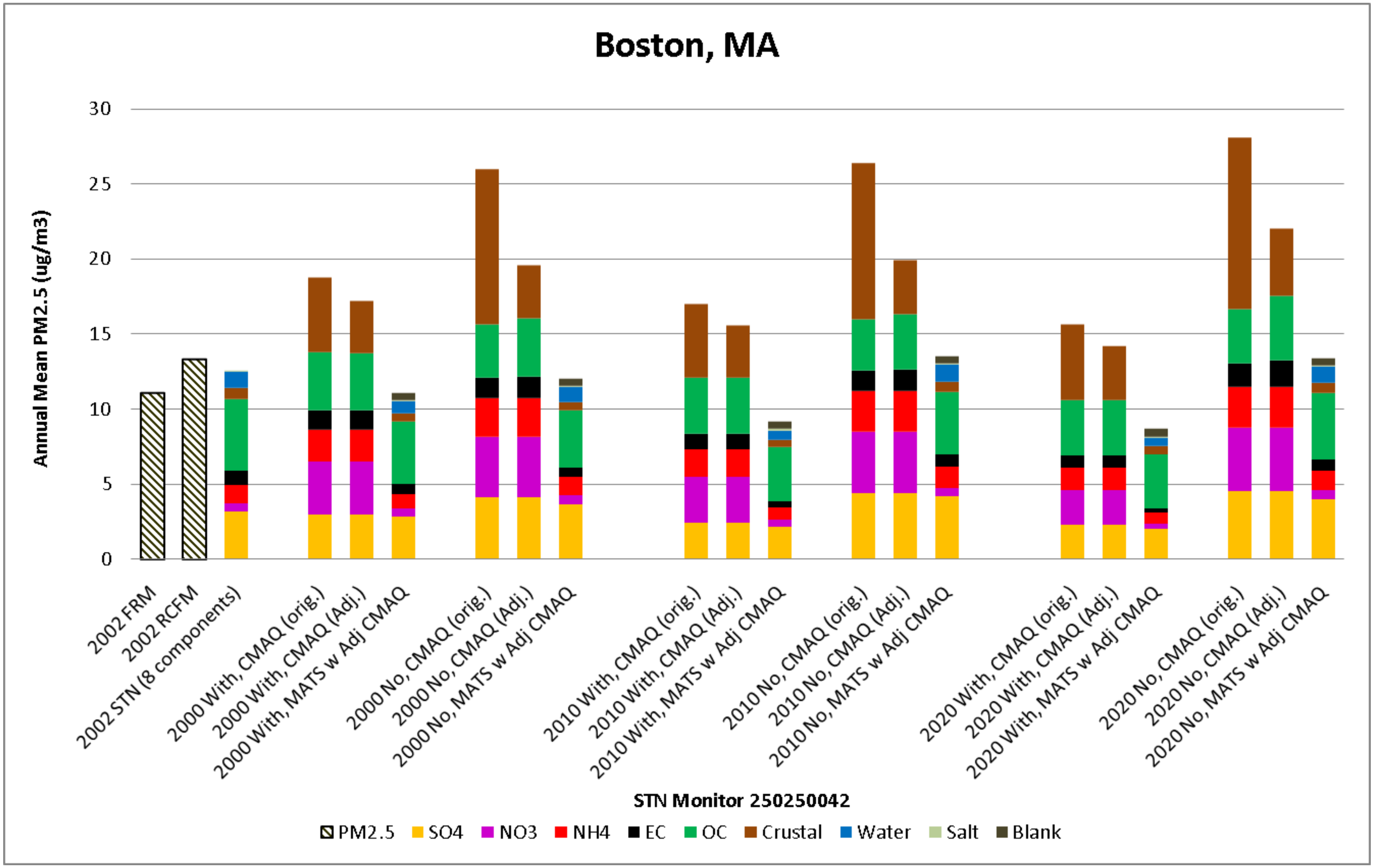


Figure 5 The Bronx, NY

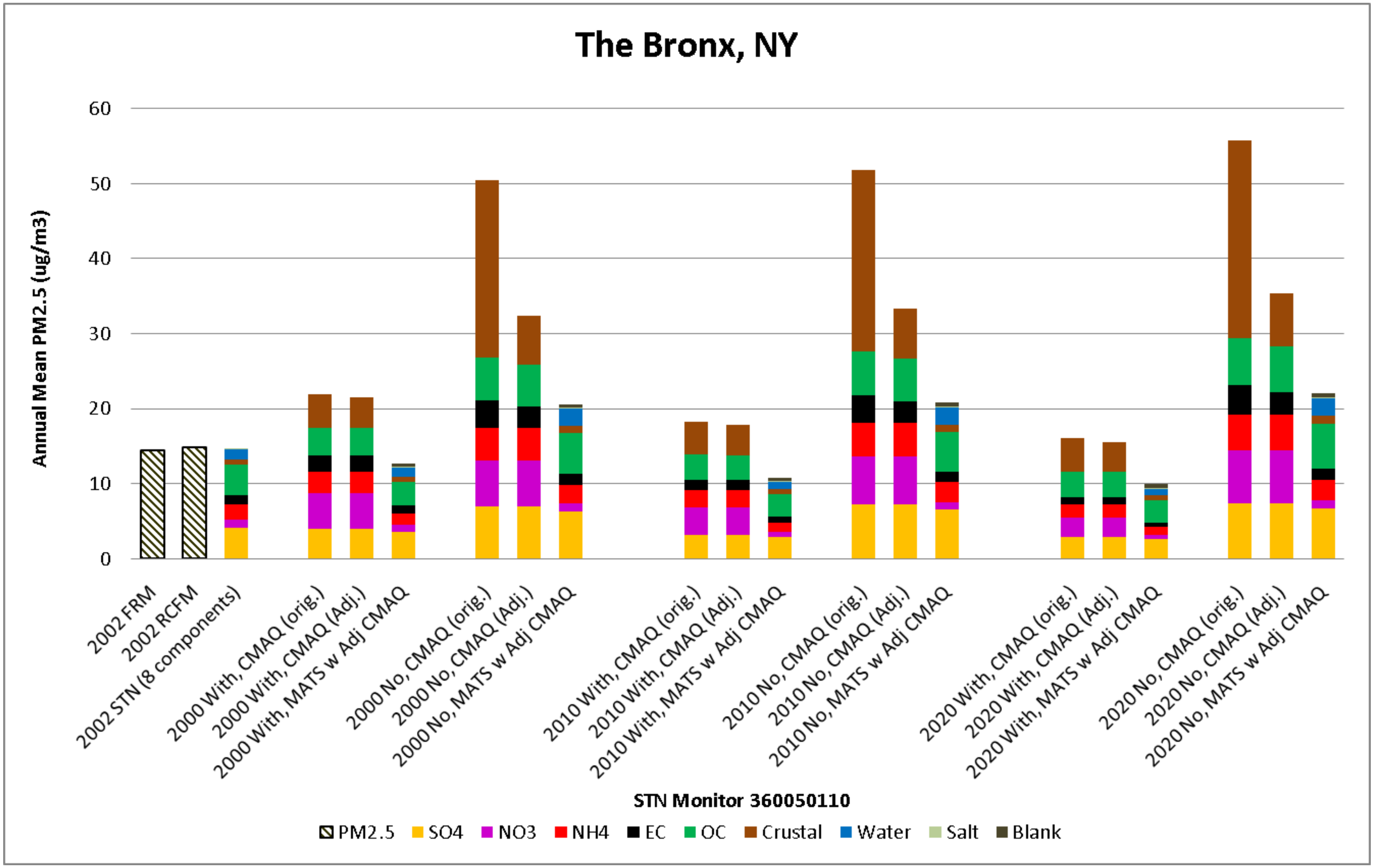


Figure 6 Chicago, IL

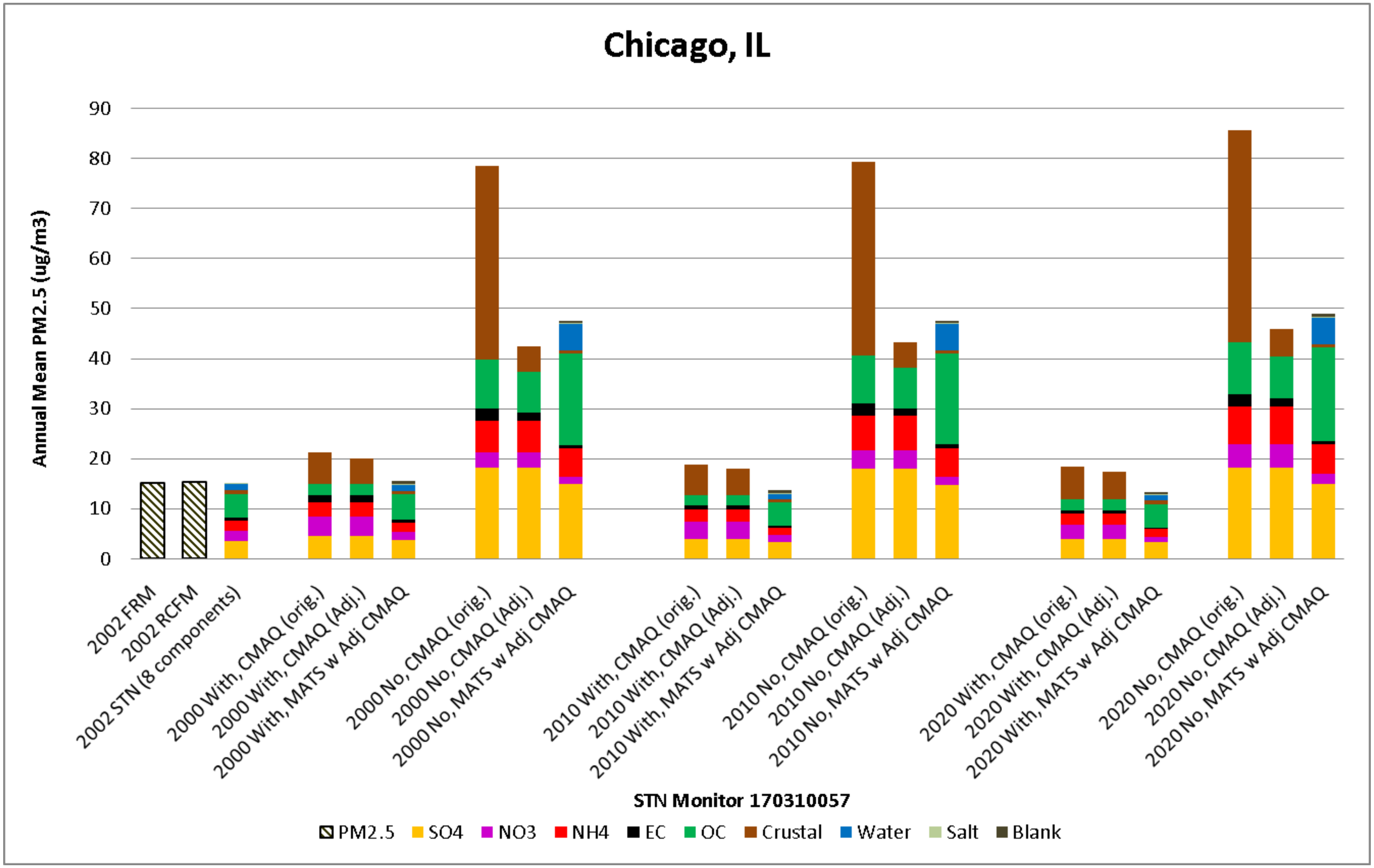


Figure 7 Dallas, TX

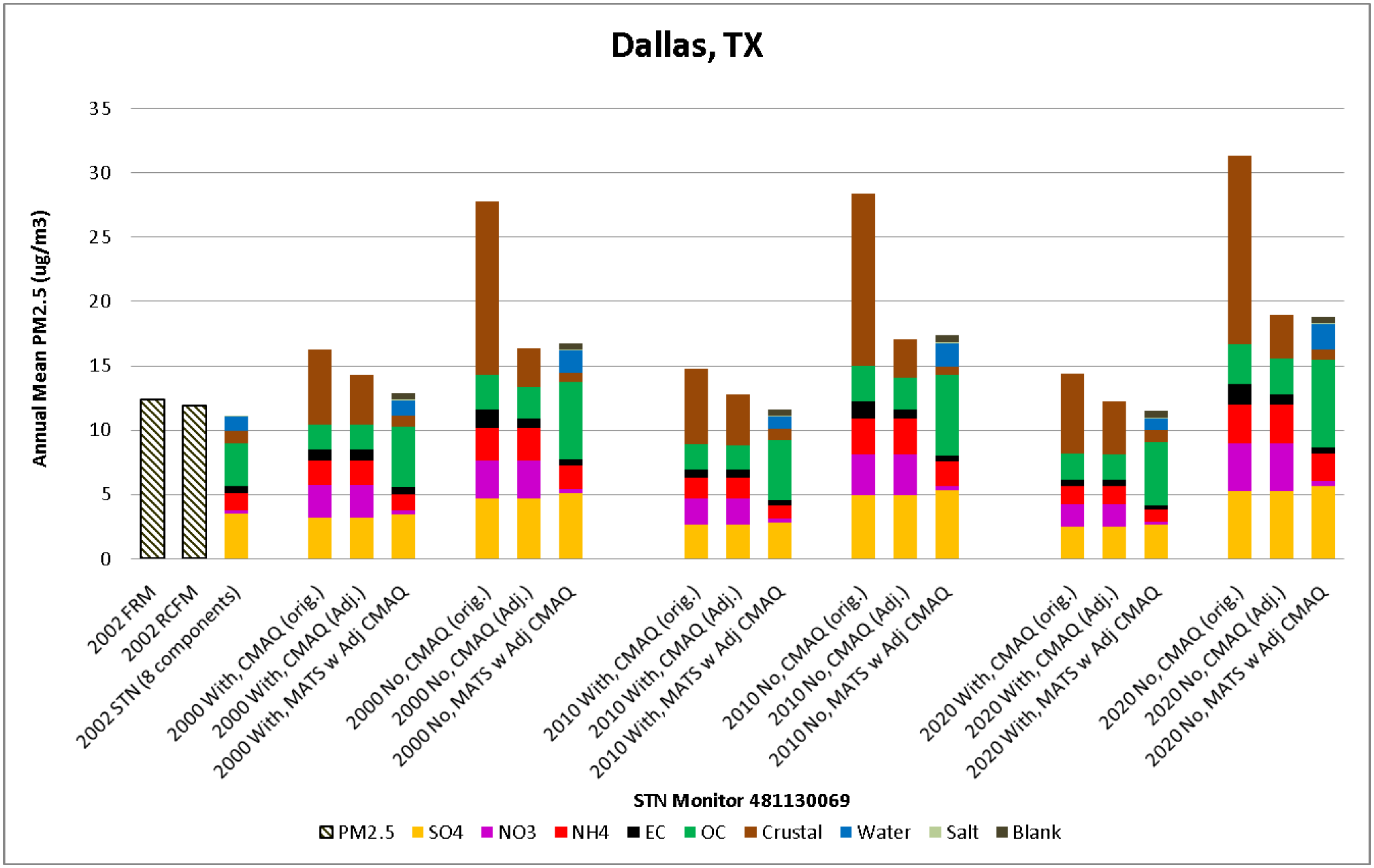


Figure 8 Denver, CO

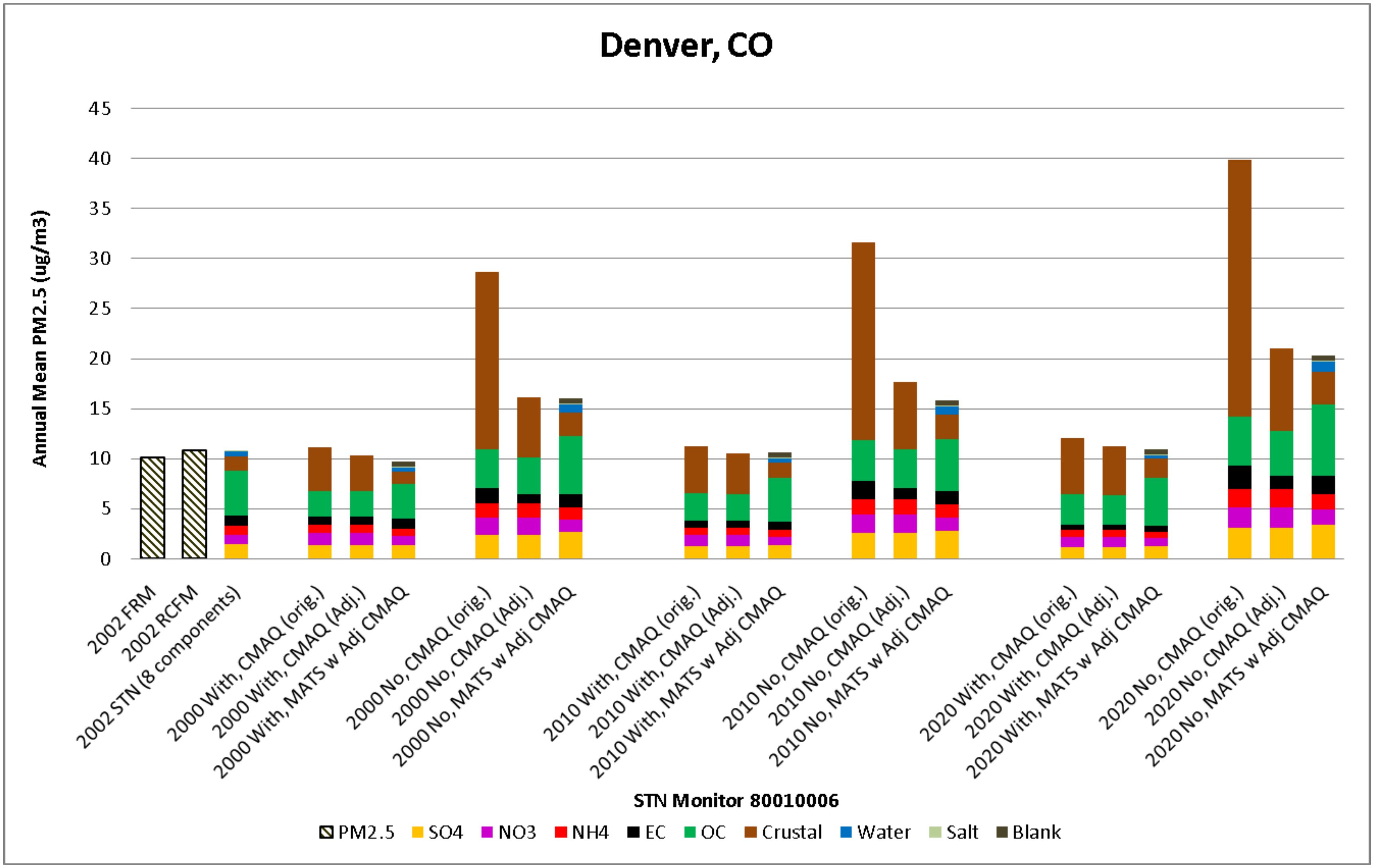


Figure 9 Detroit, MI

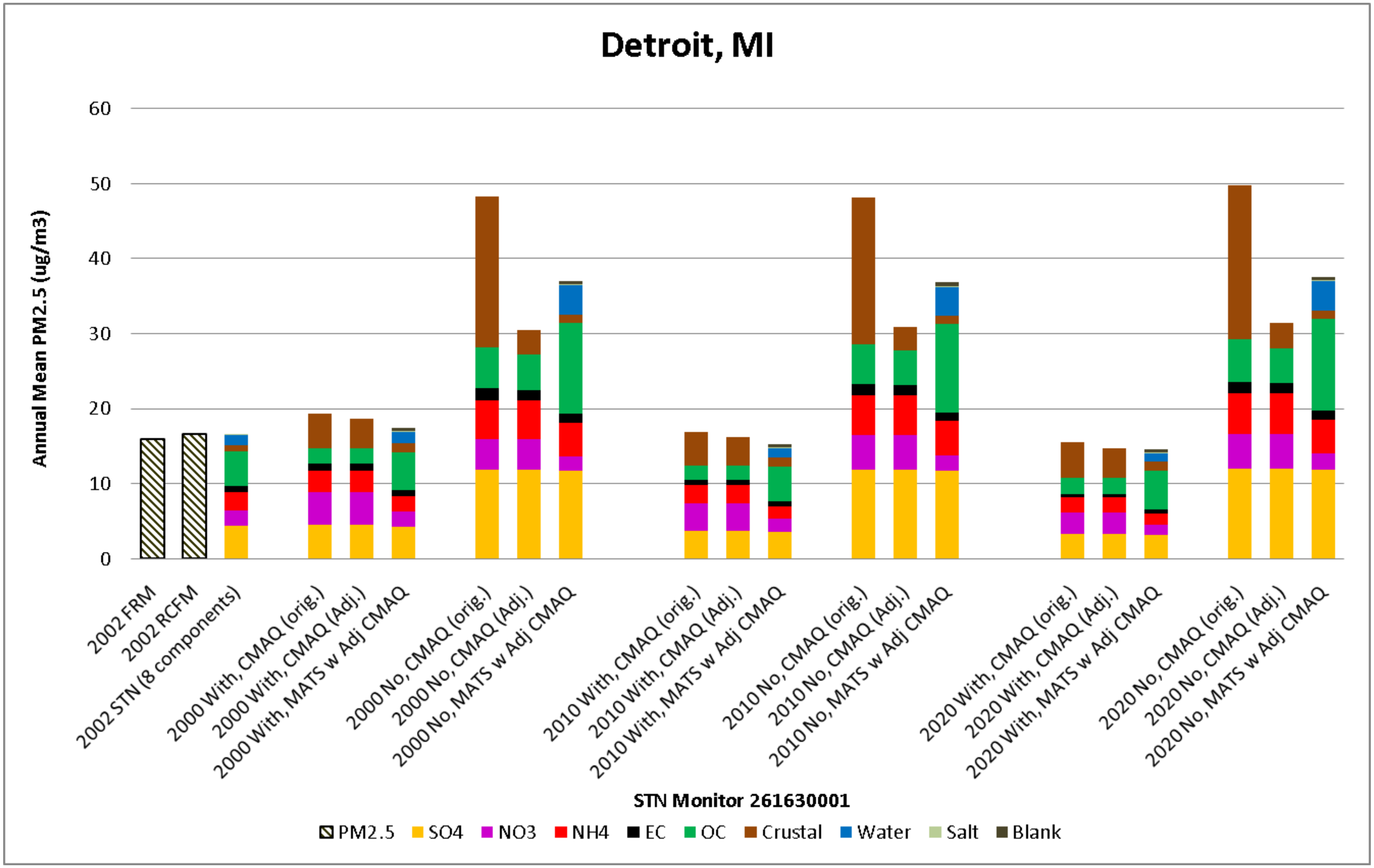


Figure 10 Kern County, CA

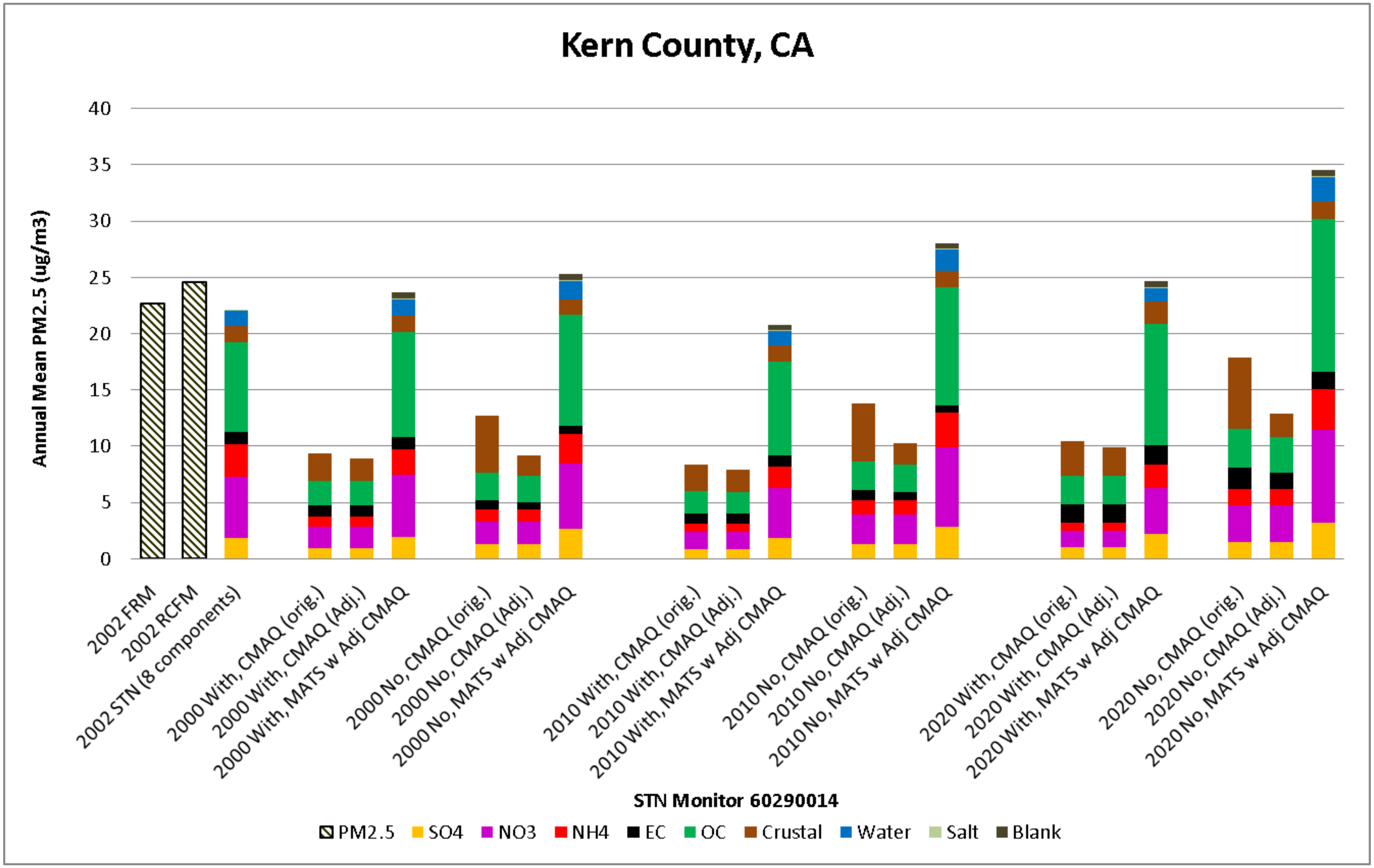


Figure 11 Lawrence County, TN

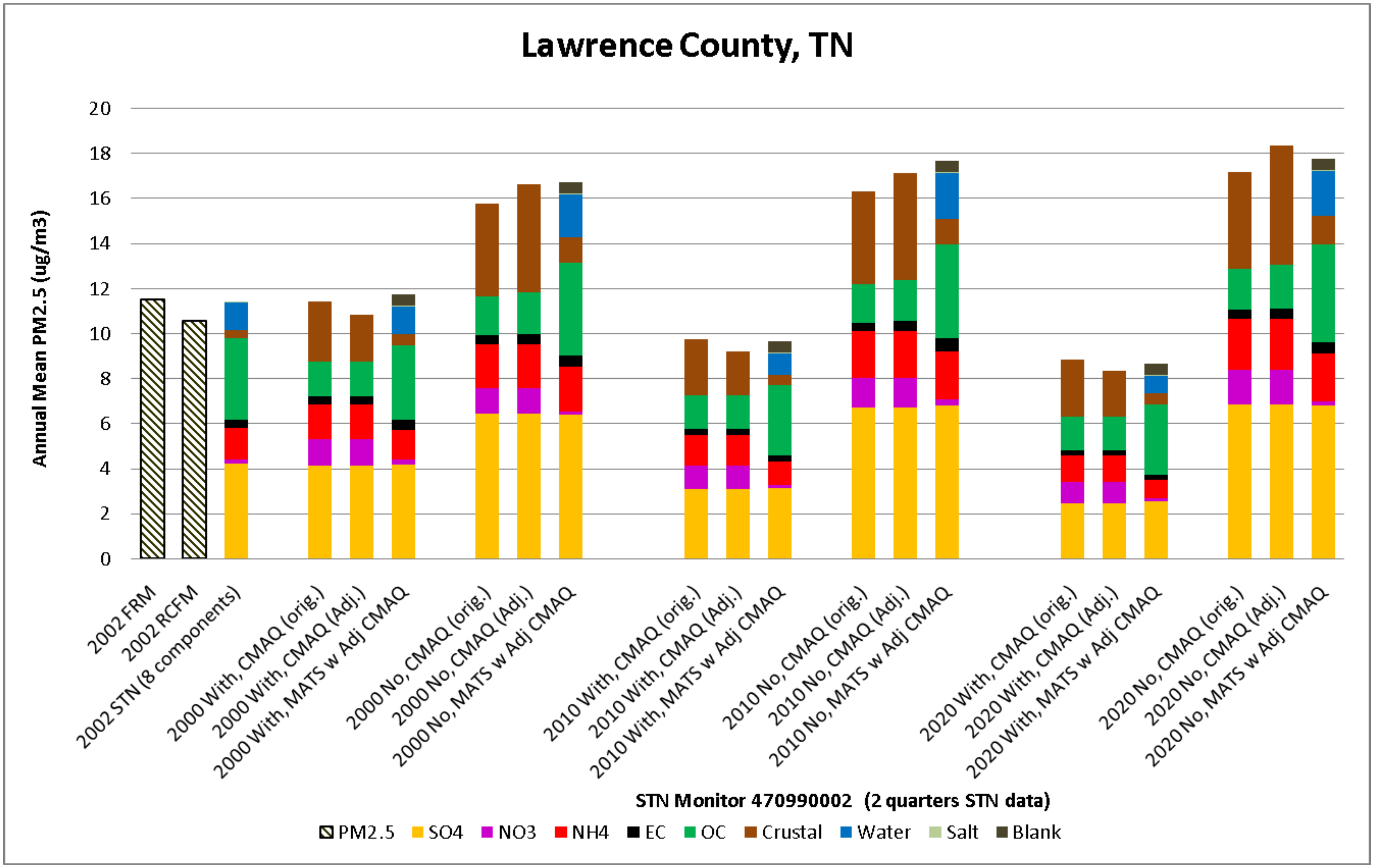


Figure 12 Los Angeles, CA

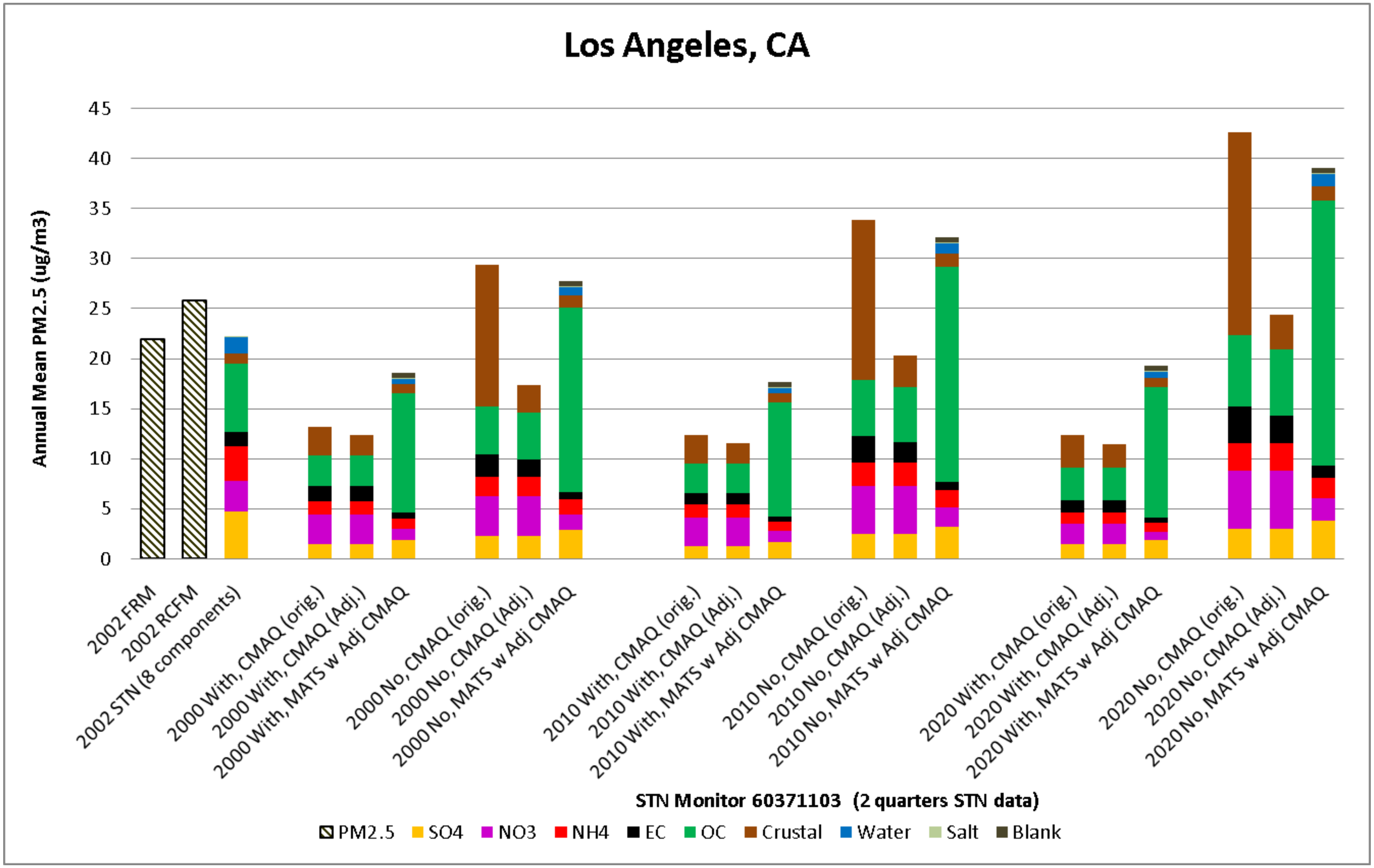


Figure 13 Manhattan, NY

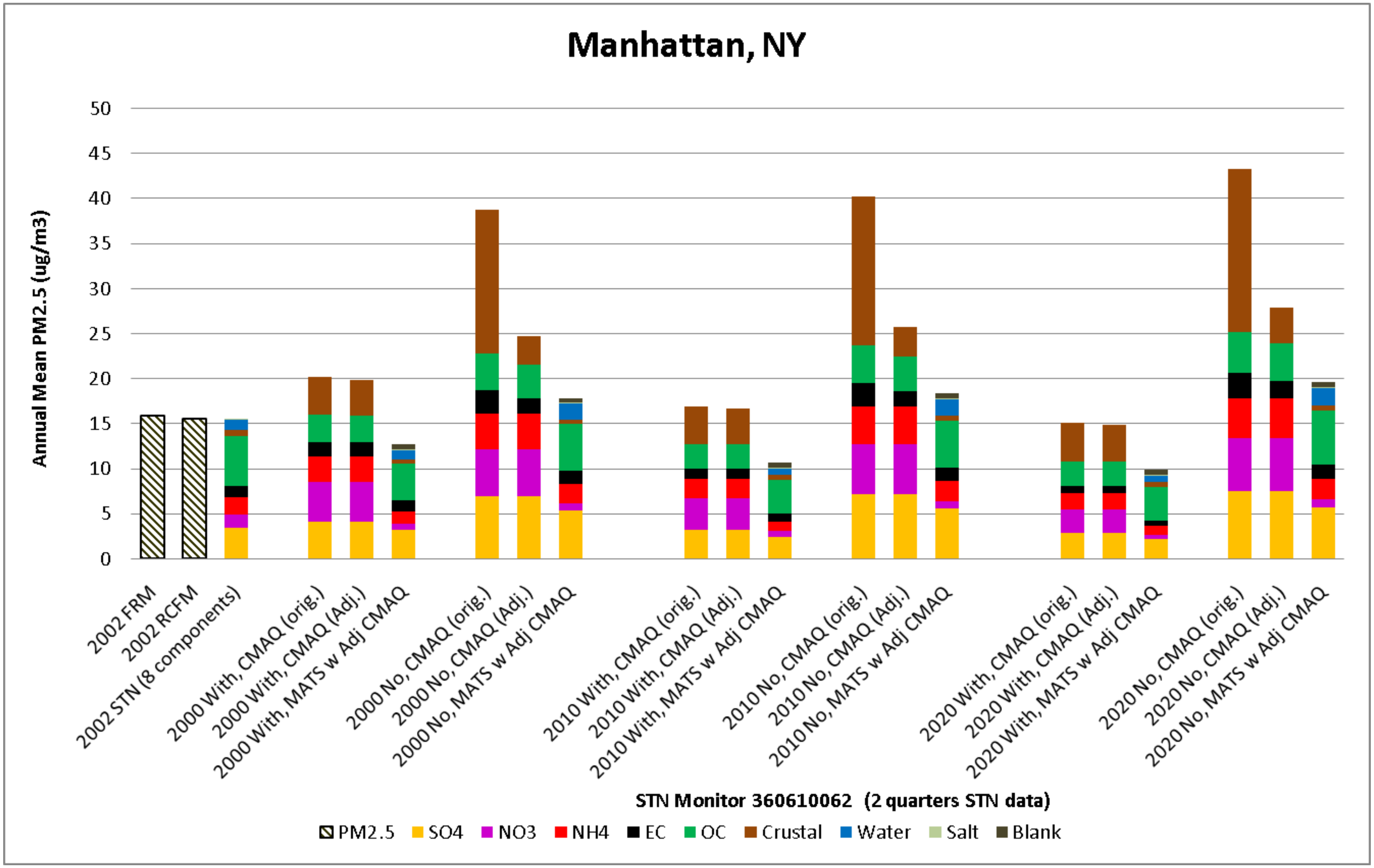


Figure 14 Miami, FL

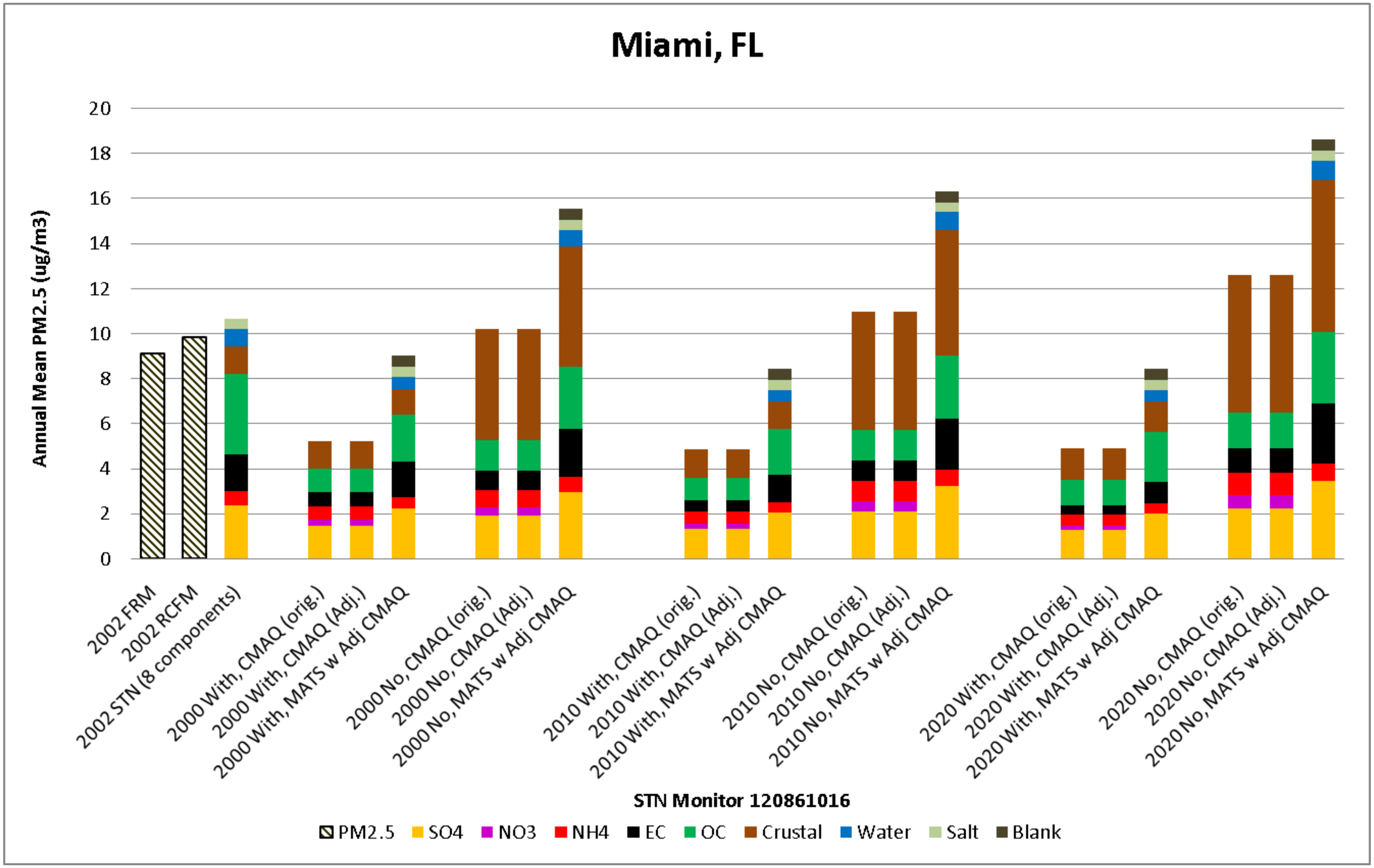


Figure 15 Minneapolis, MN

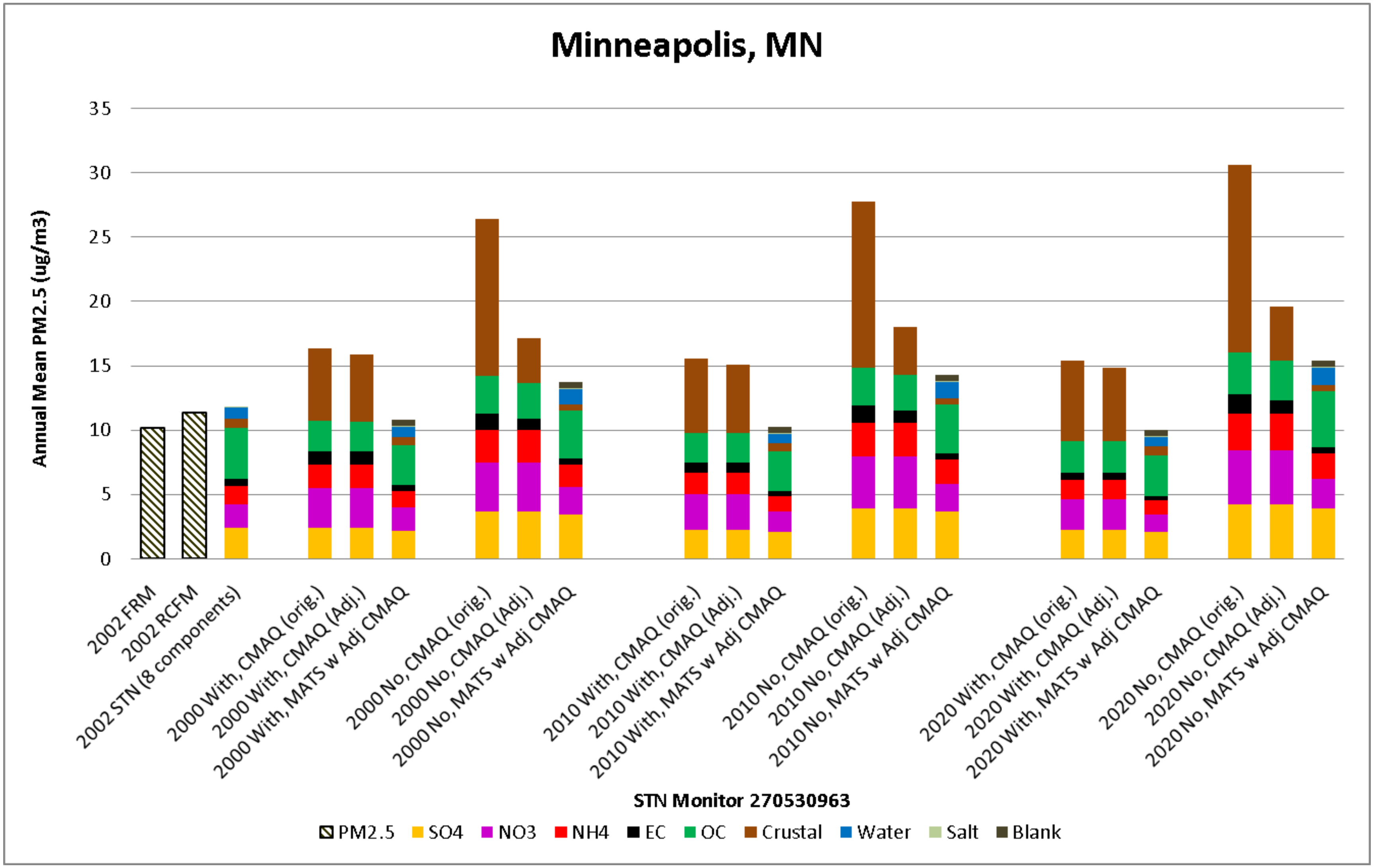


Figure 16 Morris County, NJ

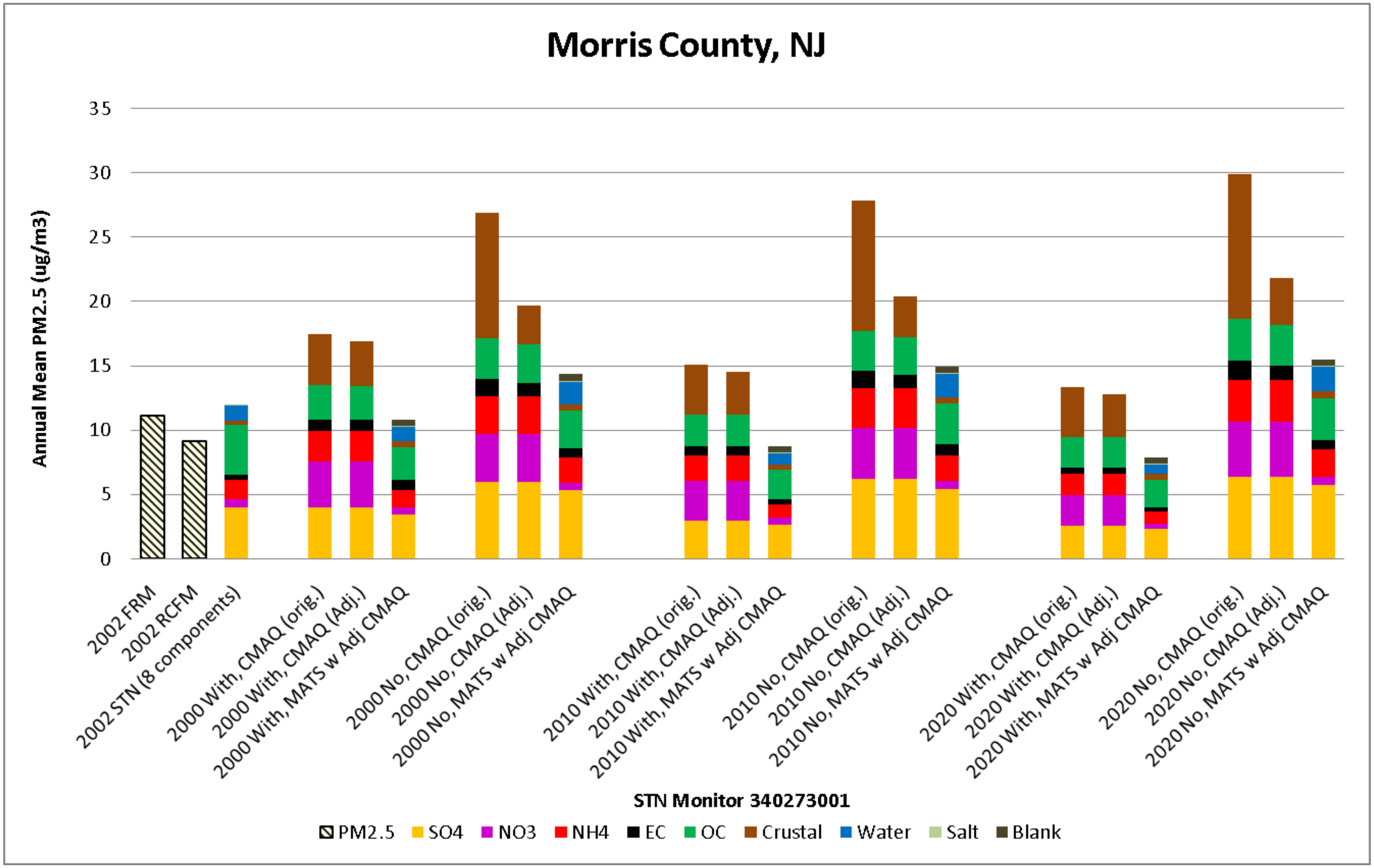


Figure 17 Philadelphia, PA

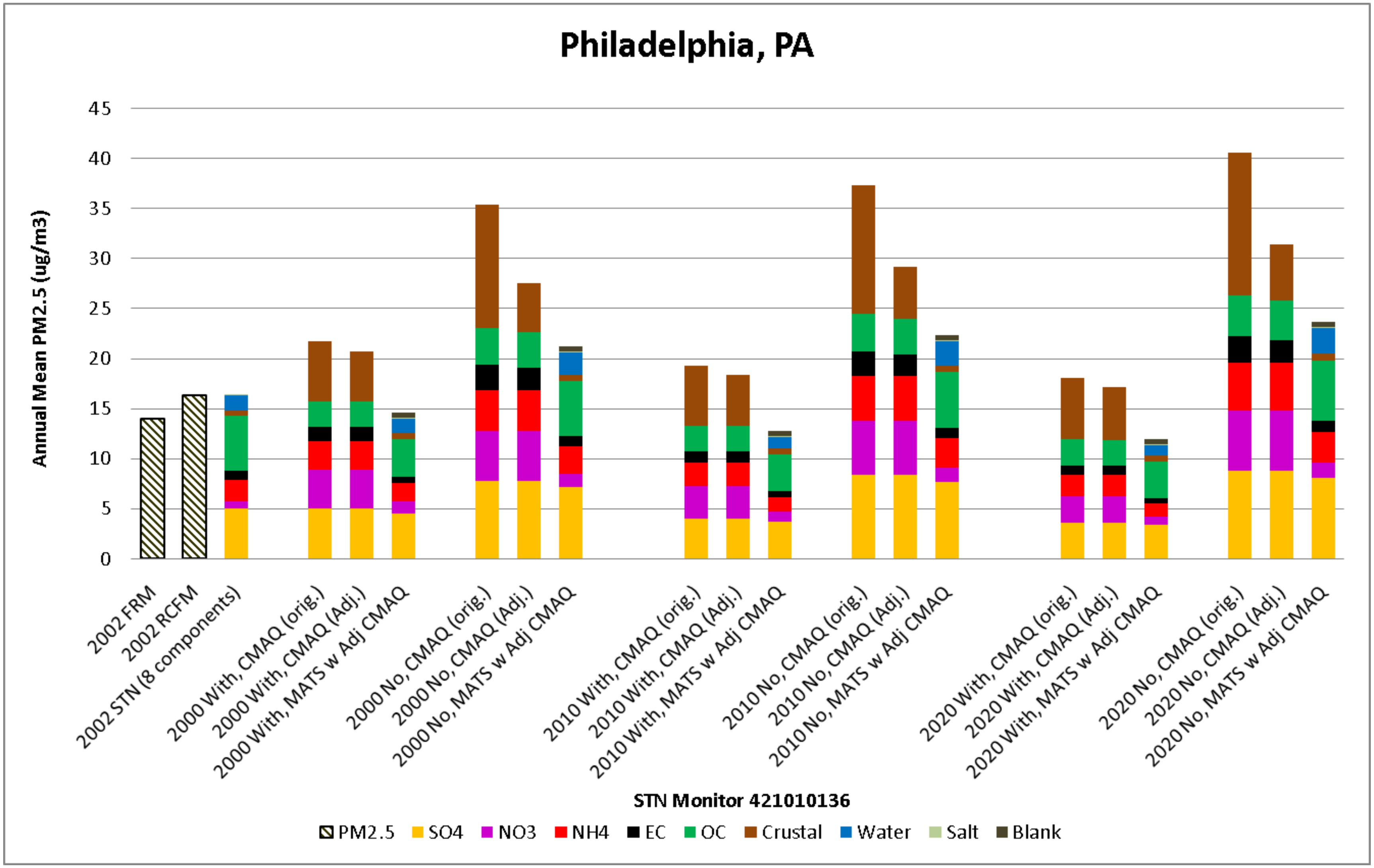


Figure 18 Pittsburgh, PA

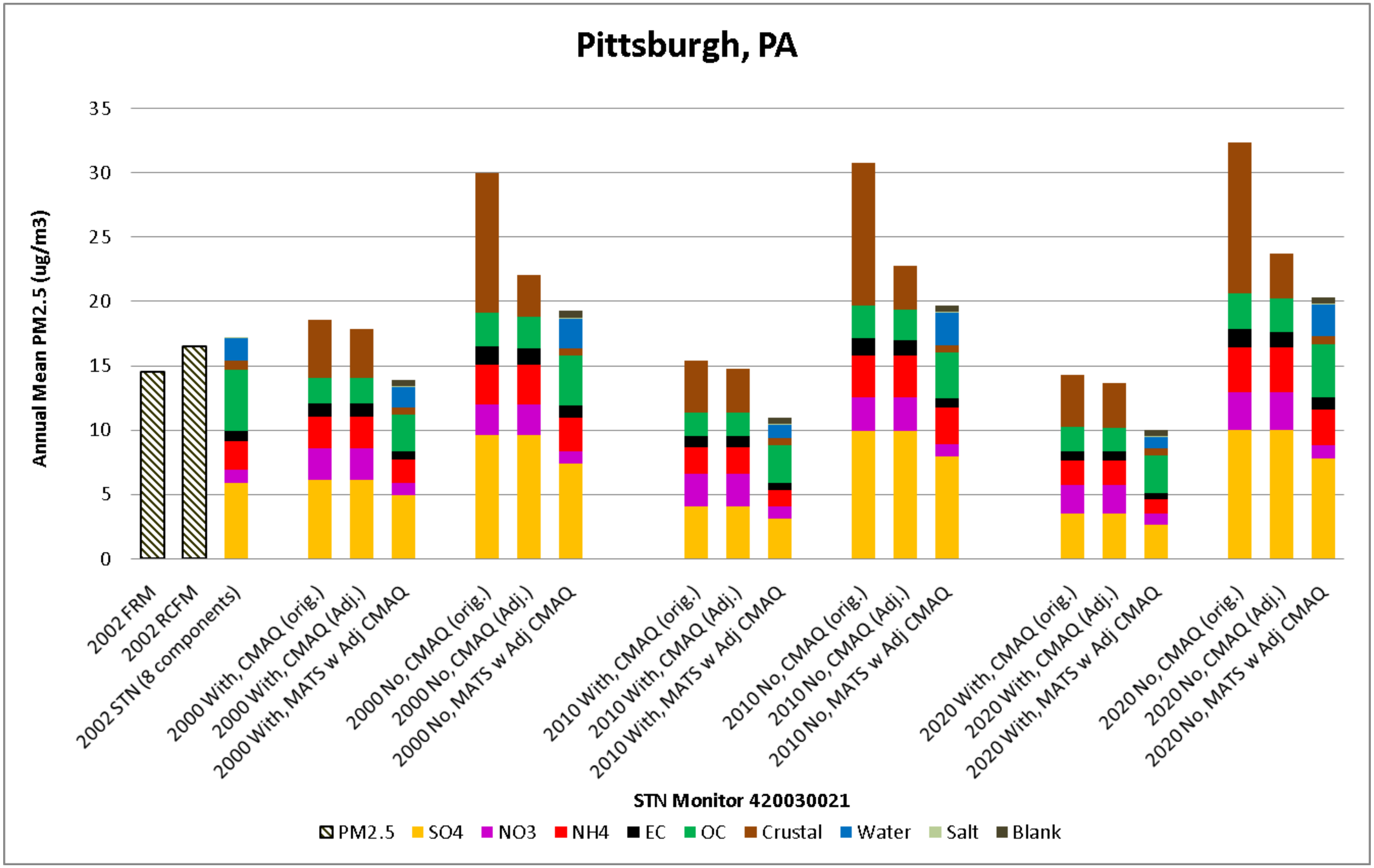


Figure 19 Riverside, CA

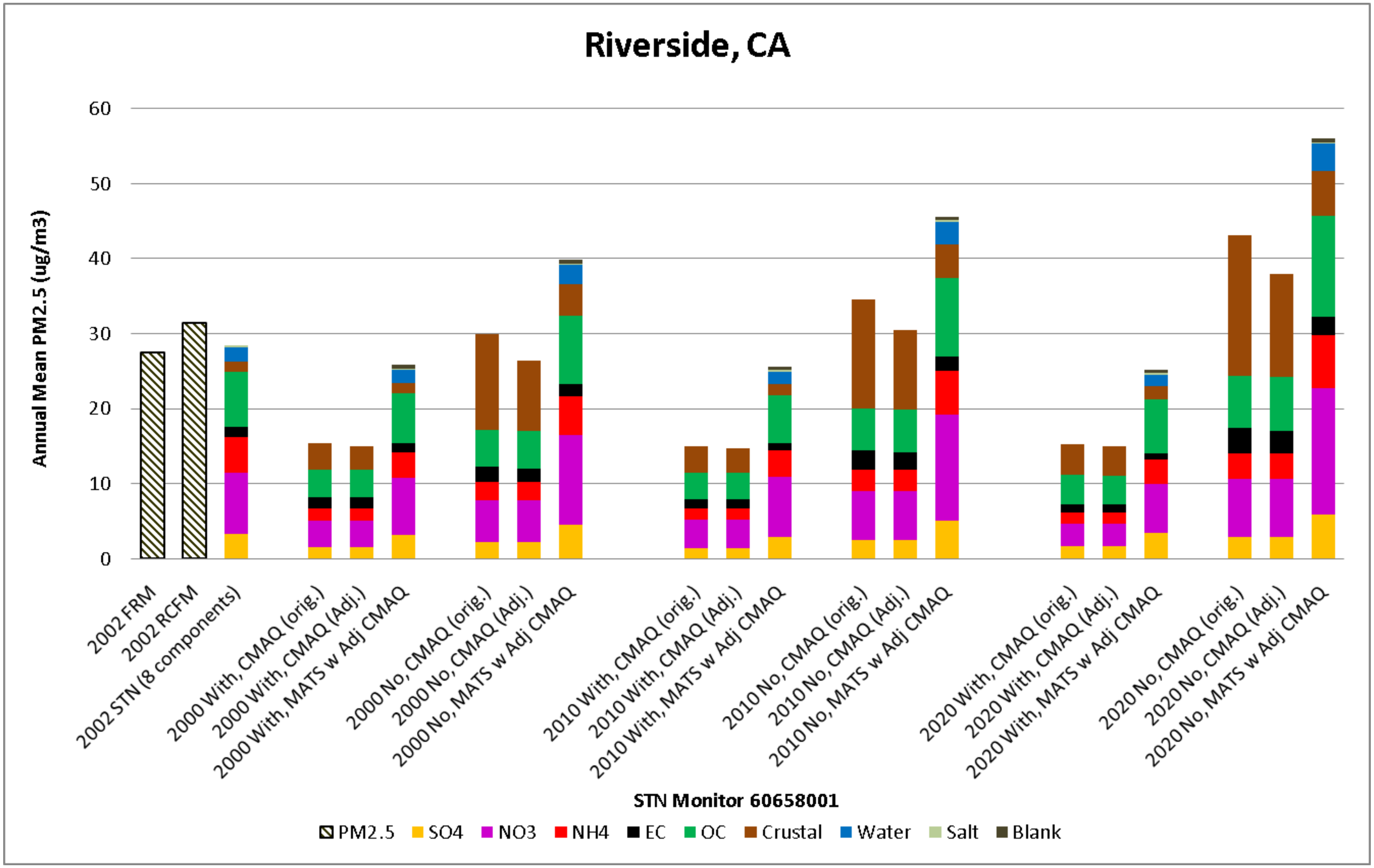


Figure 20 Salt Lake City, UT

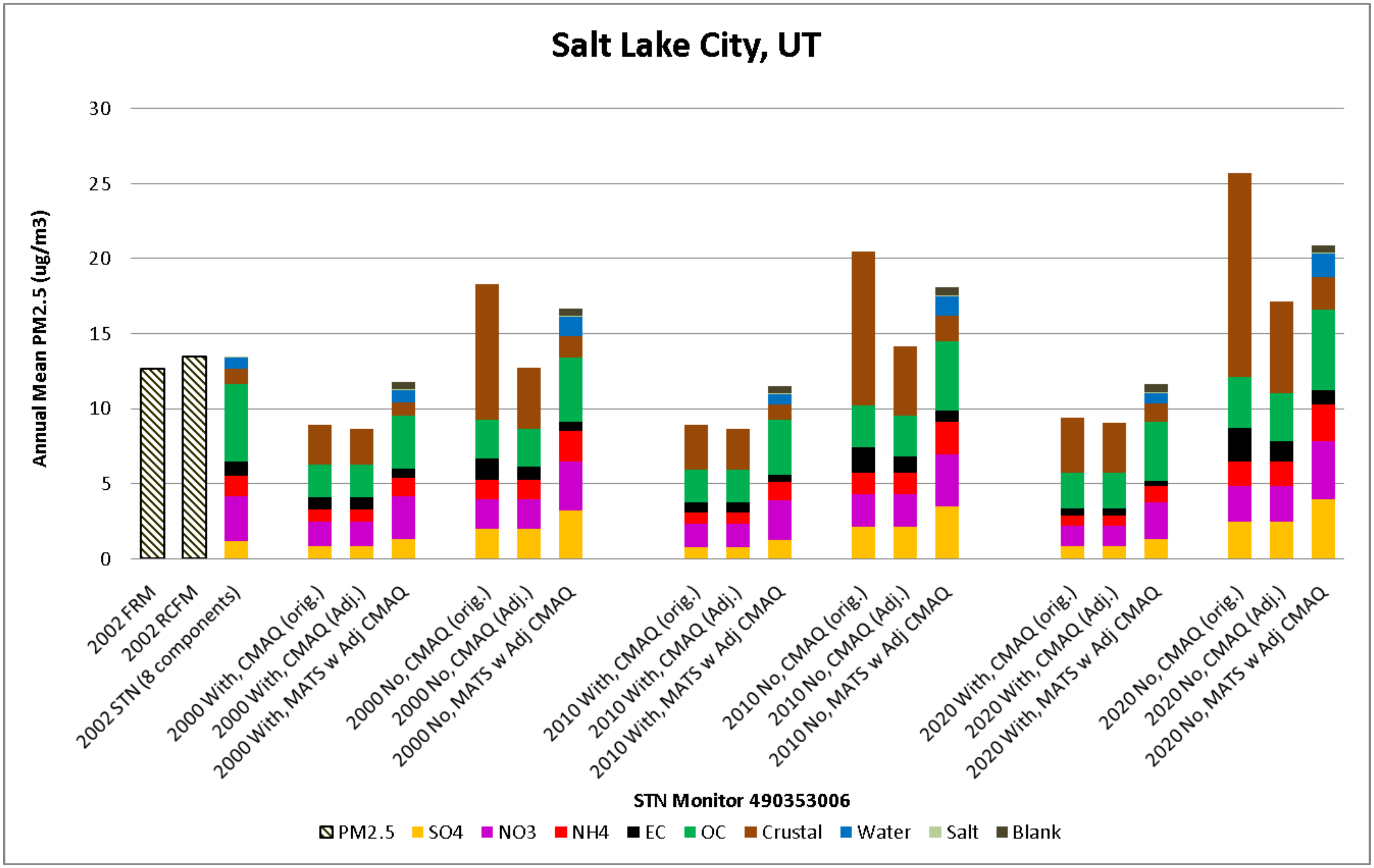


Figure 21 Tulare County, CA

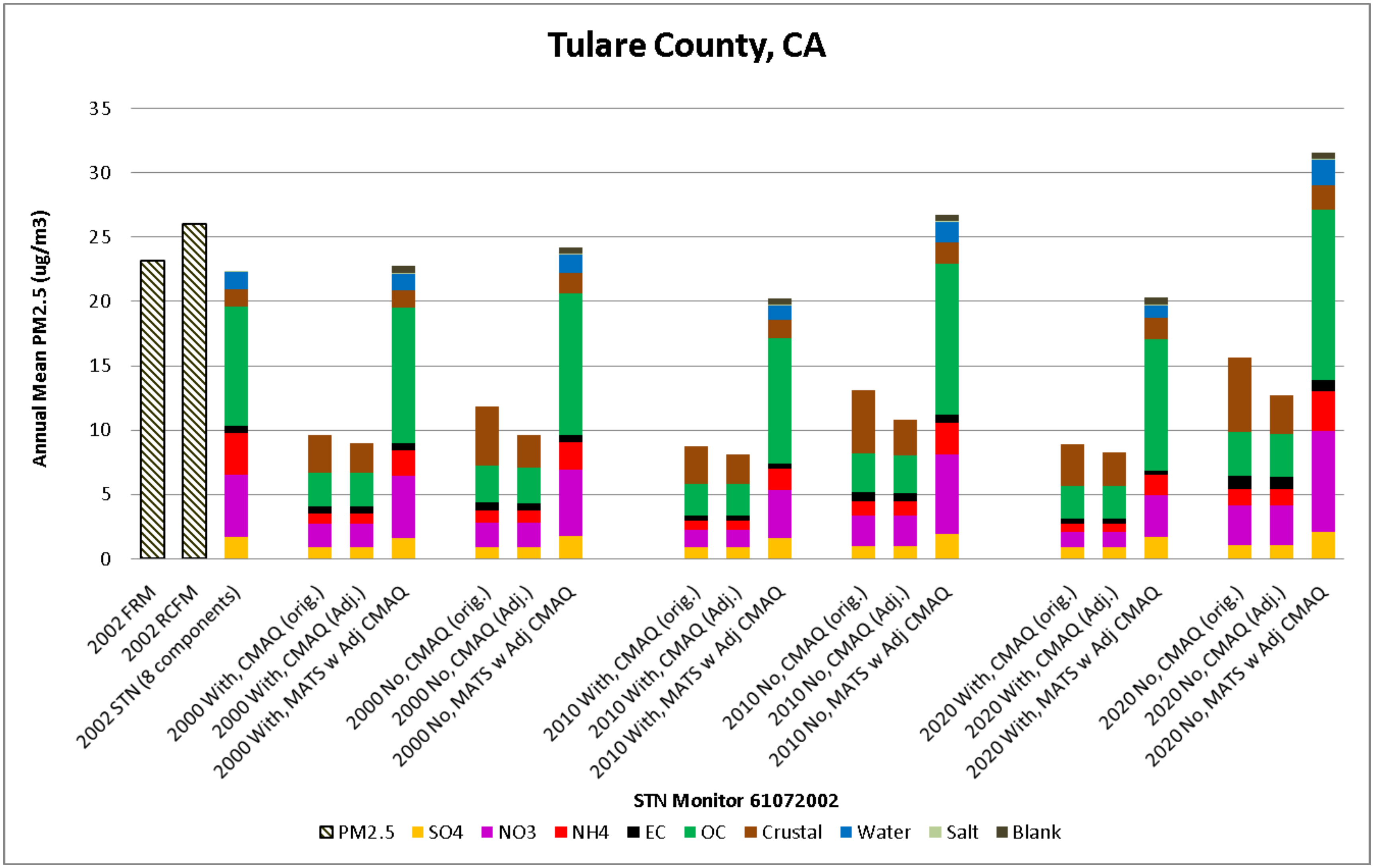


Figure 22 Tucson, AZ

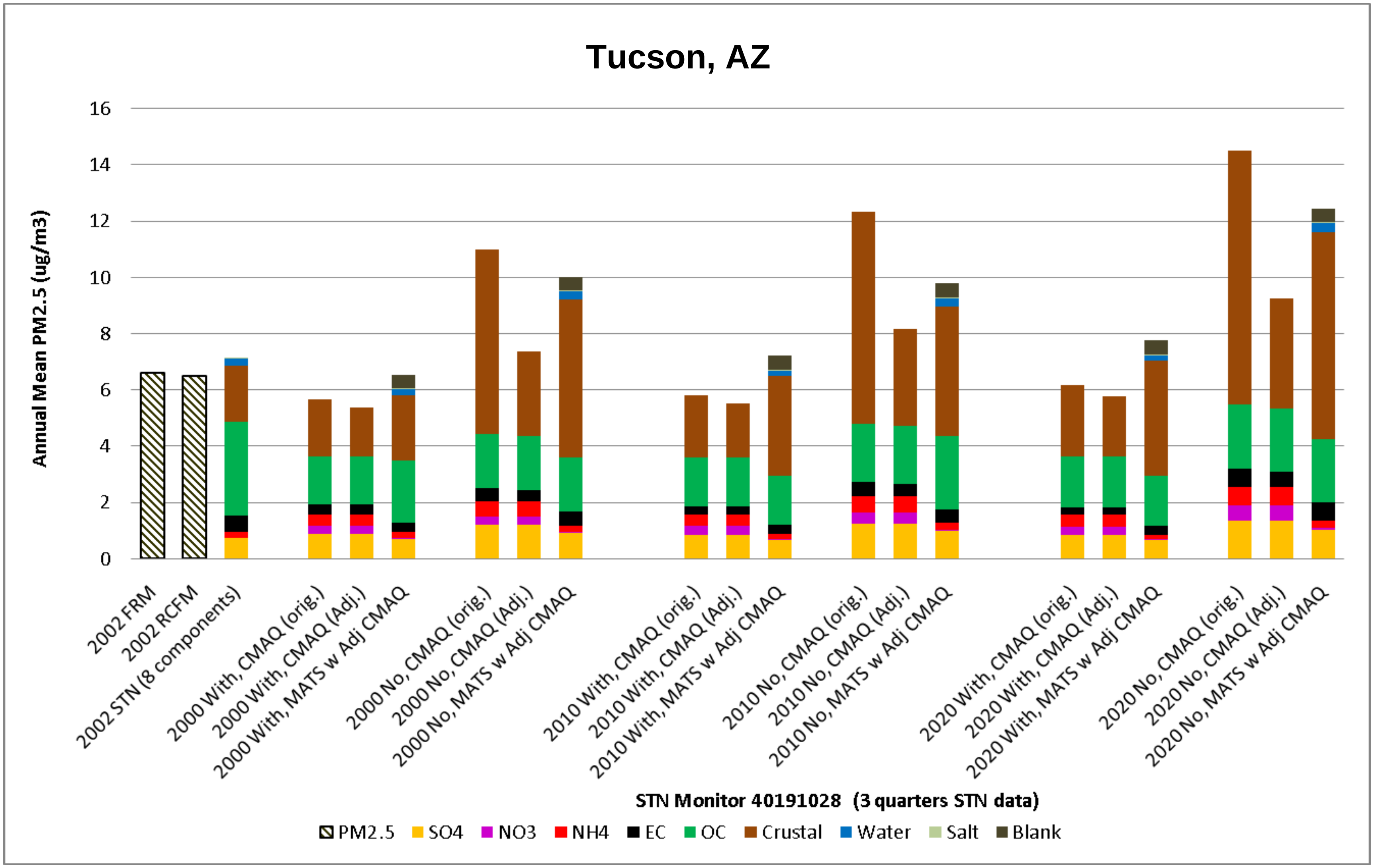
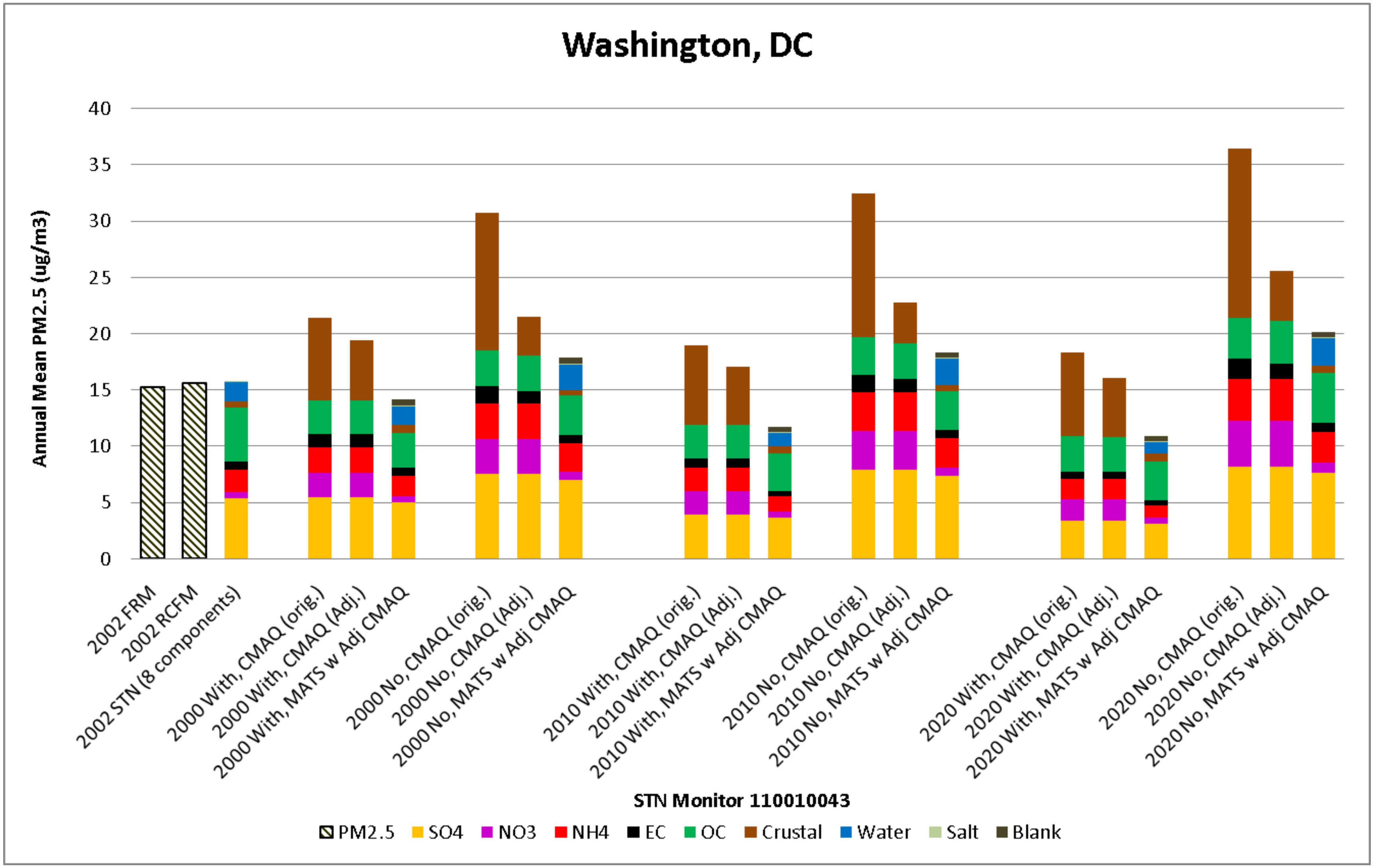


Figure 23 Washington, DC



APPENDIX C

Memorandum

To:	Henry Roman and Jim Neumann, Industrial Economics Inc.
From:	Leland Deck, Stratus Consulting Inc.
Date:	May 27, 2010
Subject:	Impact of using only 2002 monitors in MATS for the §812 second prospective project

This memorandum conveys a series of 10 stacked bar chart diagrams showing the impact of the project team's decision to use only 2002 monitors when preparing estimates of $PM_{2.5}$ using EPA's Monitor Attainment Test Software (MATS, ver. 2.1.1).

In the preliminary results previously prepared for the §812 project, we used multiple years of monitor data in MATS. The preliminary MATS analysis used Federal Reference Method (FRM) monitor data of quarterly average $PM_{2.5}$ for 2001 thorough 2003, and quarterly species-specific Speciation Trend Network (STN) and IMPROVE monitor data from 2002-2004.

The final $PM_{2.5}$ estimates for the §812 project revised the selection of years; only 2002 data from FRM, STN and IMPROVE monitors were used in the MATS.

In addition to the change in monitor years, the final MATS analysis also used certain adjustments to the species-specific air quality modeling (CMAQ) estimates. Therefore the methods used to prepare the final $PM_{2.5}$ estimates differed from the preliminary estimates in two (unrelated) ways.

The decision to change to using only 2002 monitor data in MATS was motivated by two considerations.

1) The CMAQ analysis used for the "2000 with Clean Air Act Amendments" scenario was conducted using the 2002 estimated emissions inventory and 2002 meteorological data.
2) Because more STN monitors were becoming operational throughout the period 2002 to 2004, the preliminary MATS analysis using the multiple years of STN data was effectively weighted towards 2004. In the first quarter of 2002, the MATS monitor input dataset had 259 STN or IMPROVES monitors with sufficient species data. By the second quarter of 2004 there were 365 STN or IMPROVE monitors.

The combination of these two factors lead the 812 project team to decide to use only the 2002 monitors, concluding 2002 was a better basis than using multiple (and mis-matched) year monitors for conducting the MATS analysis because it is most representative of the 2000 With Clean Air Act Amendments scenario. The "2000 With" scenario was the baseline scenario used for the "Without" and future MATS analyses.

A series of stacked bar diagrams for a sample of 10 STN monitors present the impact of changing from multiple monitor years in MATS to using only 2002 monitors. The ten monitors were selected to present a range of locations throughout the contiguous United States, including monitors in densely populated areas, coastal and inland areas, and more rural locations with STN monitors.

Each diagram presents a stacked bar for each of 23 estimates of annual mean $PM_{2.5}$ levels. The first three stacked bars shown on each diagram are:

4) The Federal Reference Method (FRM) measure of 2002 annual mean $PM_{2.5}$ at the STN monitor location.

5) A Reconstructed Fine Mass (RCFM) estimate prepared by EPA for the STN monitor in 2002.

6) The bar labeled "2002 STN" presents 8 components derived from the STN monitor data fro 2002: sulfate (SO_4) retained nitrate (NO_3), ammonium (NH_4), blank-adjusted organic carbon (OC), elemental carbon (EC), crustal material, salt, and particular bound water (H2O) estimated using the Aerosol Inorganic Model (AIM).

The data for each of these three stacked bars comes from the MATS input file ("Species-for-fractions-0205-v2.csv") supplied with MATS.

The diagram also presents a set of stacked bars for each of four scenarios:

1) The "2000 With Clean Air Act Amendments" scenario
2) The "2000 Without (No) Clean Air Act Amendments" scenario
3) The "2020 With Clean Air Act Amendments" scenario
4) The "2020 Without (No) Clean Air Act Amendments" scenario

Within each scenario there are 5 stacked bars:

1) The original CMAQ estimate
2) The adjusted CMAQ estimate
3) The MATS estimate using the original CMAQ estimate and multiple monitor years (labeled "MATS # 1")
4) The MATS estimate using the adjusted CMAQ estimate and multiple monitor years (labeled "MATS # 2")
5) The final MATS estimate using the adjusted CMAQ estimate and 2002 monitor data.

The original and adjusted CMAQ estimates have six species components: SO4, NO3, NH4, EC, OC and crustal. The MATS estimates have 9 components: SO4, NO3, NH4, EC, OC, crustal, water, salt (a very small component on many diagrams), and a blank mass component (set as a constant 0.5 $\mu g/m^3$ throughout the CMAQ domain).

Note that the MATS estimates were made using the Gradient Adjustment (GA) option, which estimates the $PM_{2.5}$ levels at the center of each CMAQ grid cell rather than at the exact location of the STN monitor. These MATS GA estimates are presented in the stacked bar diagrams, and are also used in the §812 health analyses. In some locations, especially where the FRM monitor is near an edge of a CMAQ cell and there are other FRM monitors relatively nearby, there is a modest difference between the MATS estimate and either the STN or FRM monitor level.

Also note while most of the STN locations presented in the diagrams have complete data for

2002, three of the STN monitors have fewer than 4 quarters of STN data in 2002 (all had complete STN data in 2003 and 2004). Los Angeles and Manhattan have STN data for only the third and fourth quarters of 2002, and Tucson, AZ has data for three quarters of 2002. MATS prepares a separate estimate for each quarter, using available monitor data in that quarter. Thus the estimated annual mean species concentrations at these three STN locations are MATS estimates using less than 4 quarters of available STN data from that grid cell, and interpolated quarterly data from other STN monitors for the missing quarters. All other locations presented in a diagram have complete STN data (defined as at least 11 valid days of data in each quarter).

As can be seen from the diagrams, in most locations the decision to use only 2002 monitors had relatively little impact compared with using multiple-year monitor data. The adjustment process used on the CMAQ data had a larger impact than the change to single monitor year data. The largest impacts occur for the "2020 Without (No) Clean Air Act Amendments" scenario, where the significantly larger emissions estimates make the impacts more visible.

Figure 1 Atlanta, GA

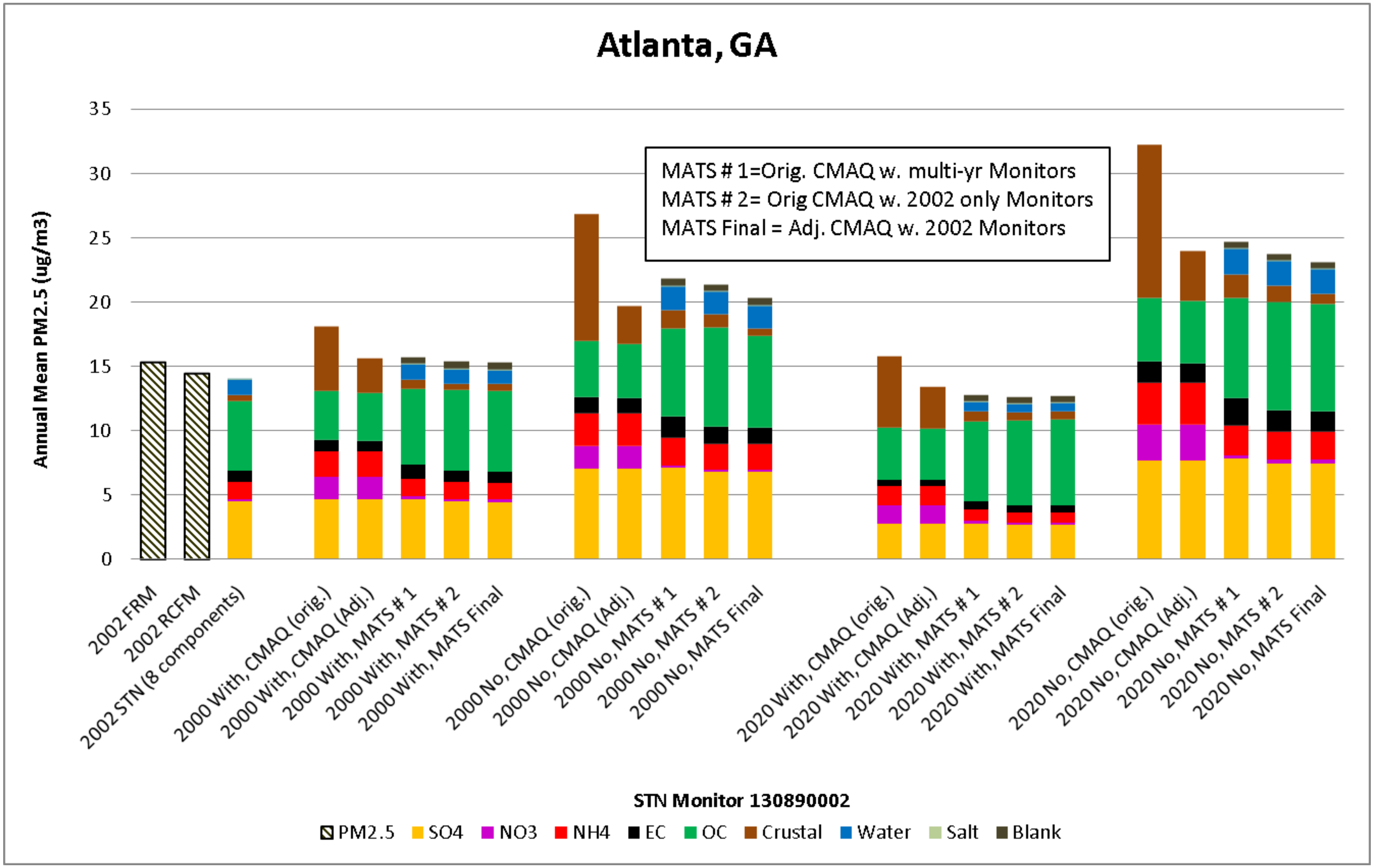


Figure 2 East Baton Rouge, LA

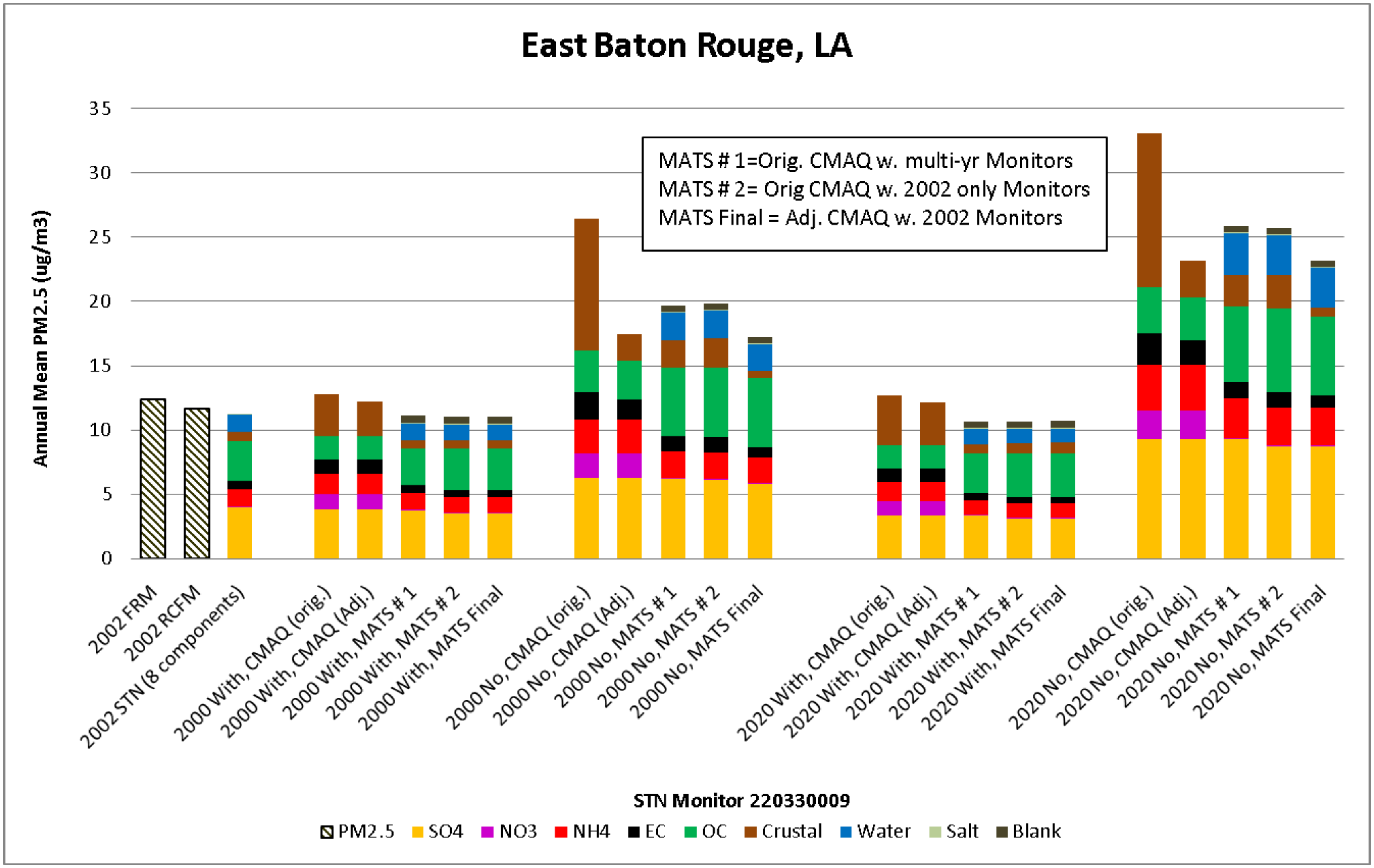


Figure 3 The Bronx, NY

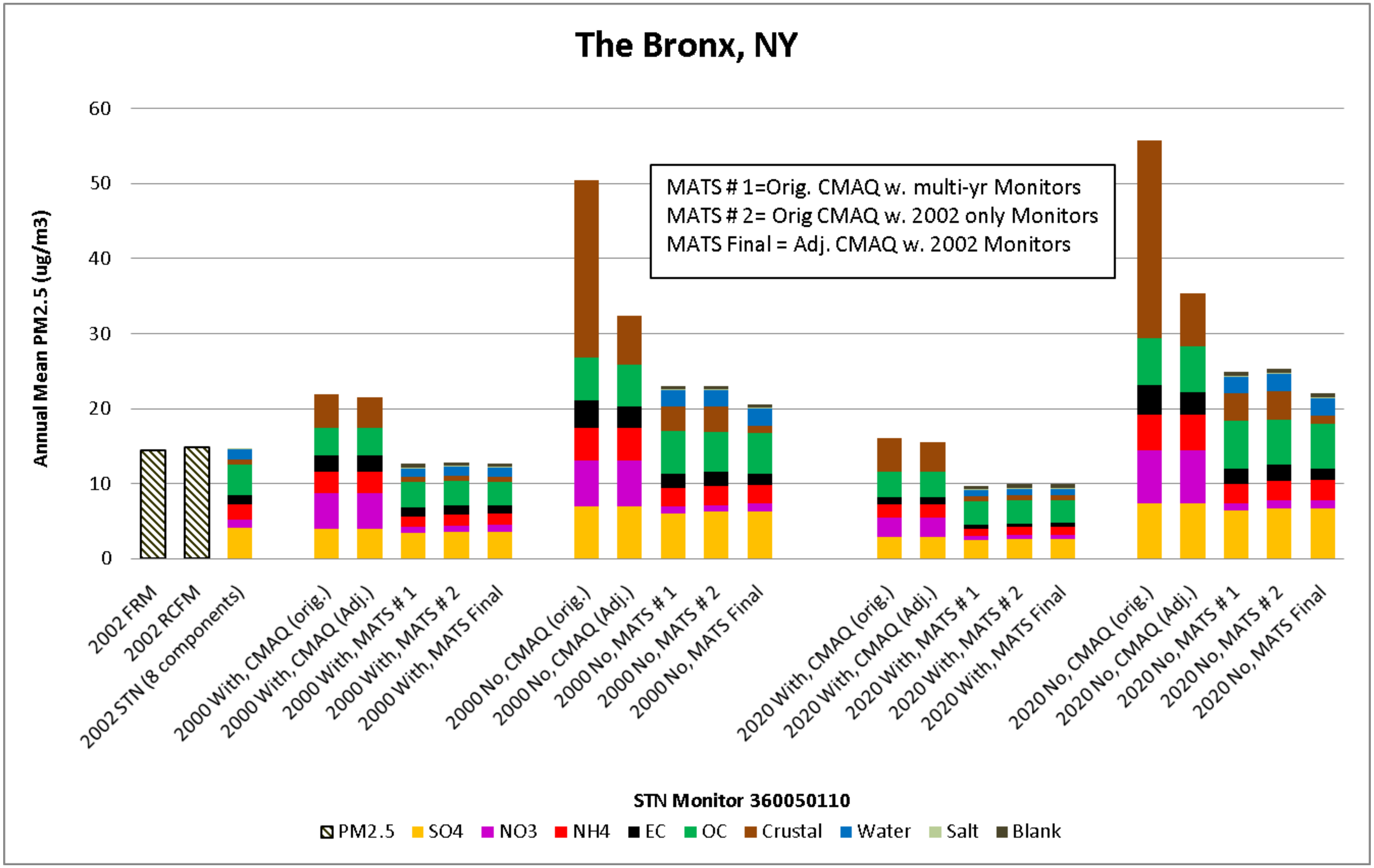


Figure 4 Chicago, IL

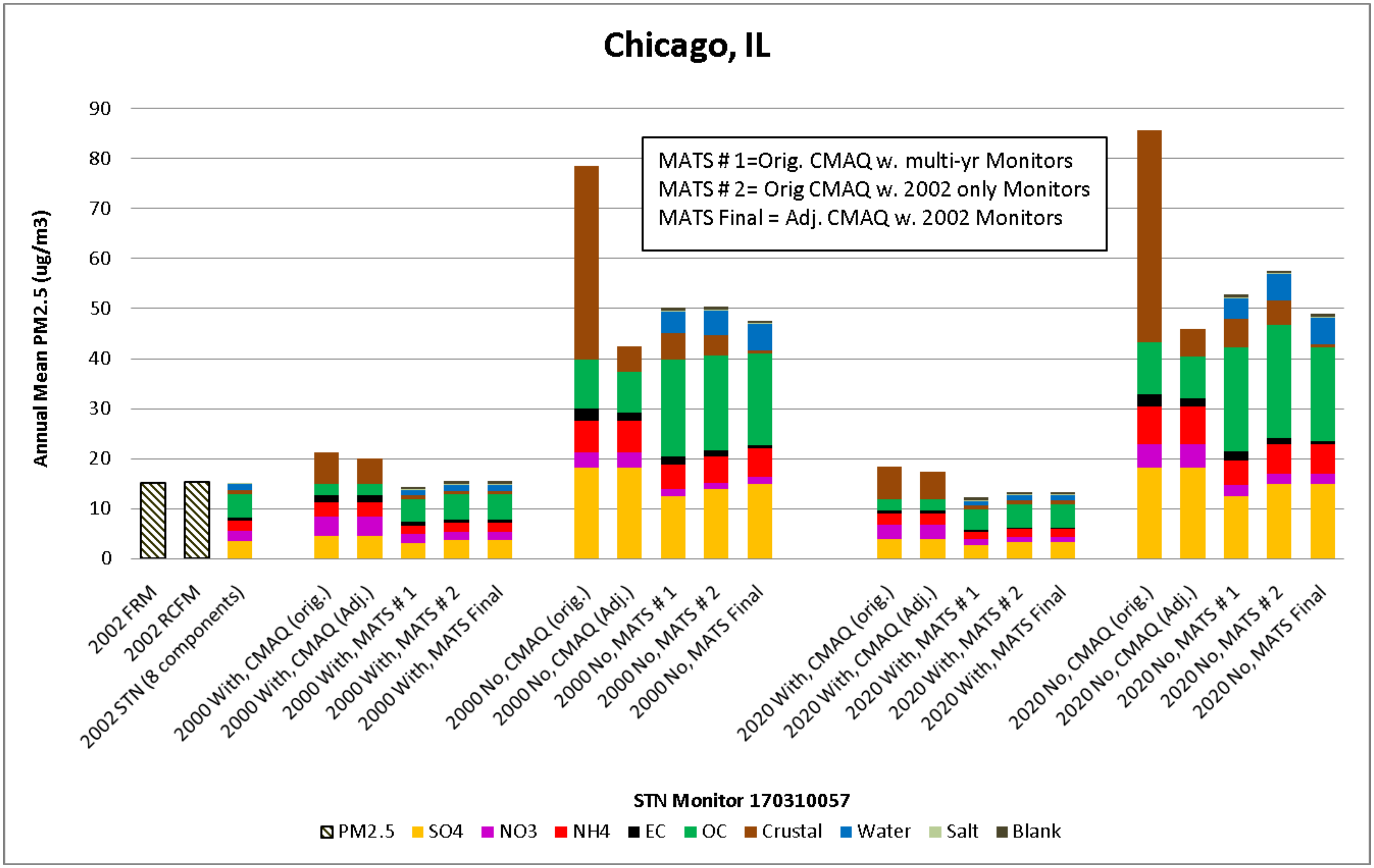


Figure 5 Los Angeles, CA (only 2 quarters of 2002 STN data)

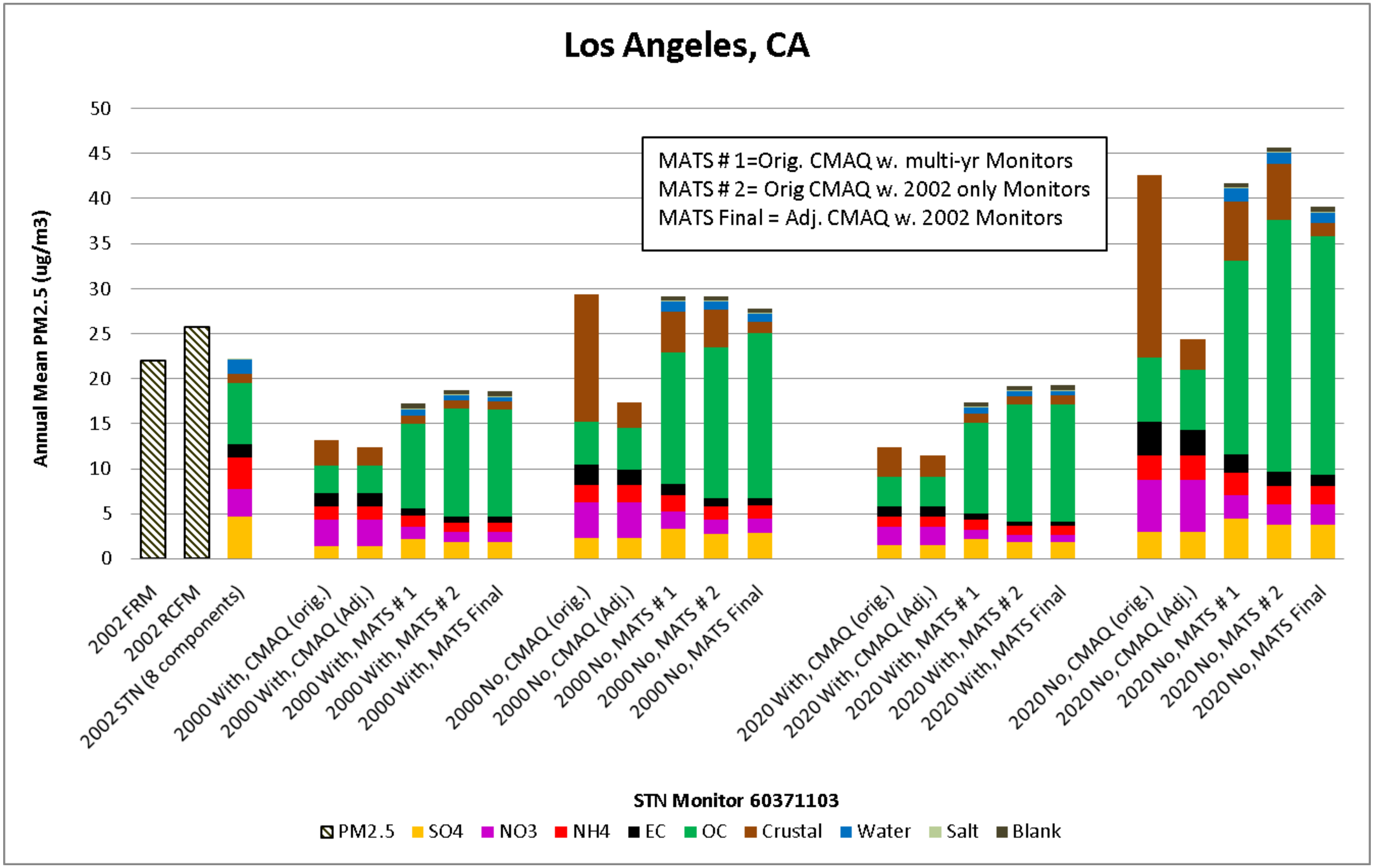


Figure 6 Manhattan, NY (only 2 quarters of 2002 STN data)

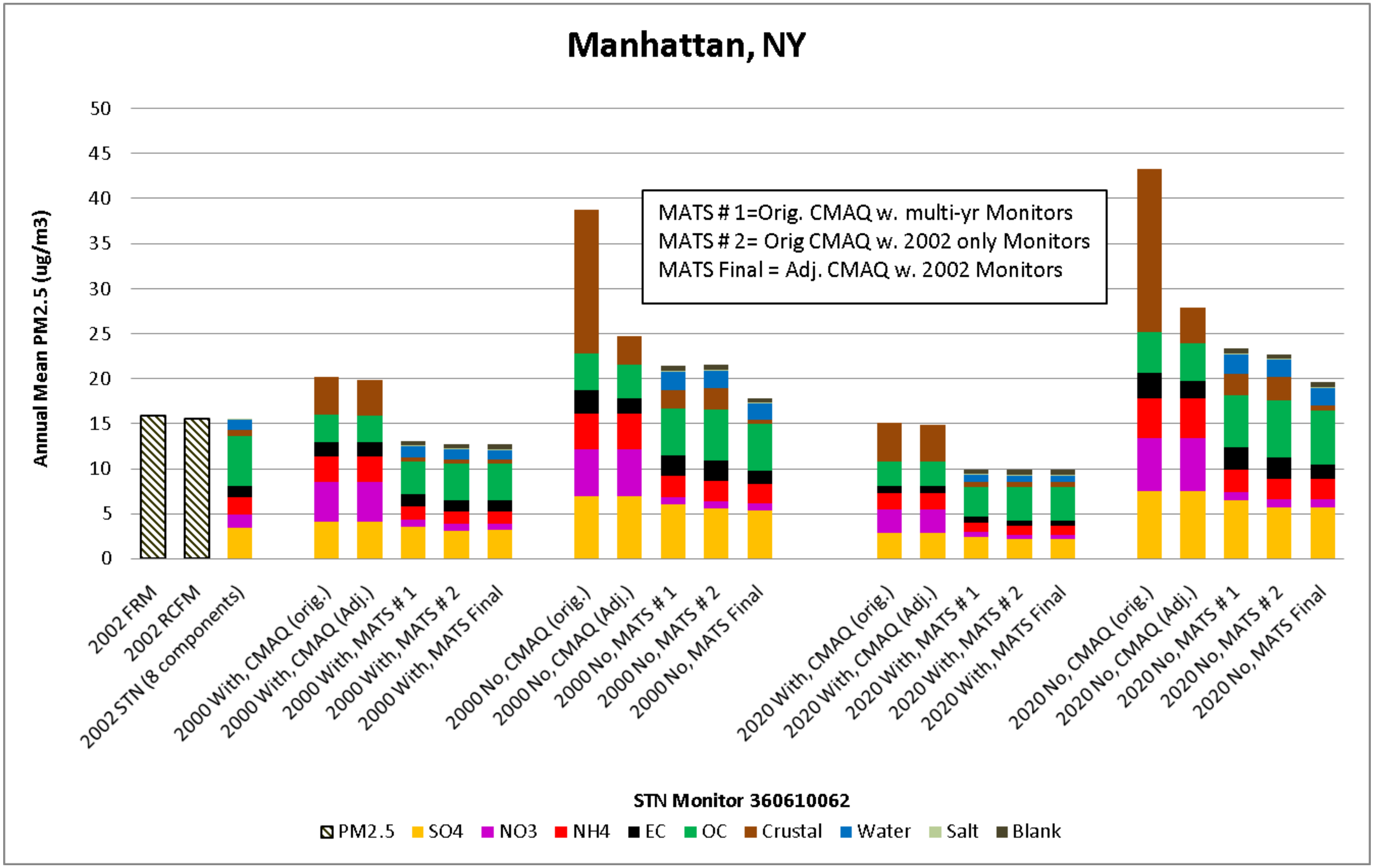


Figure 7 Miami, FL

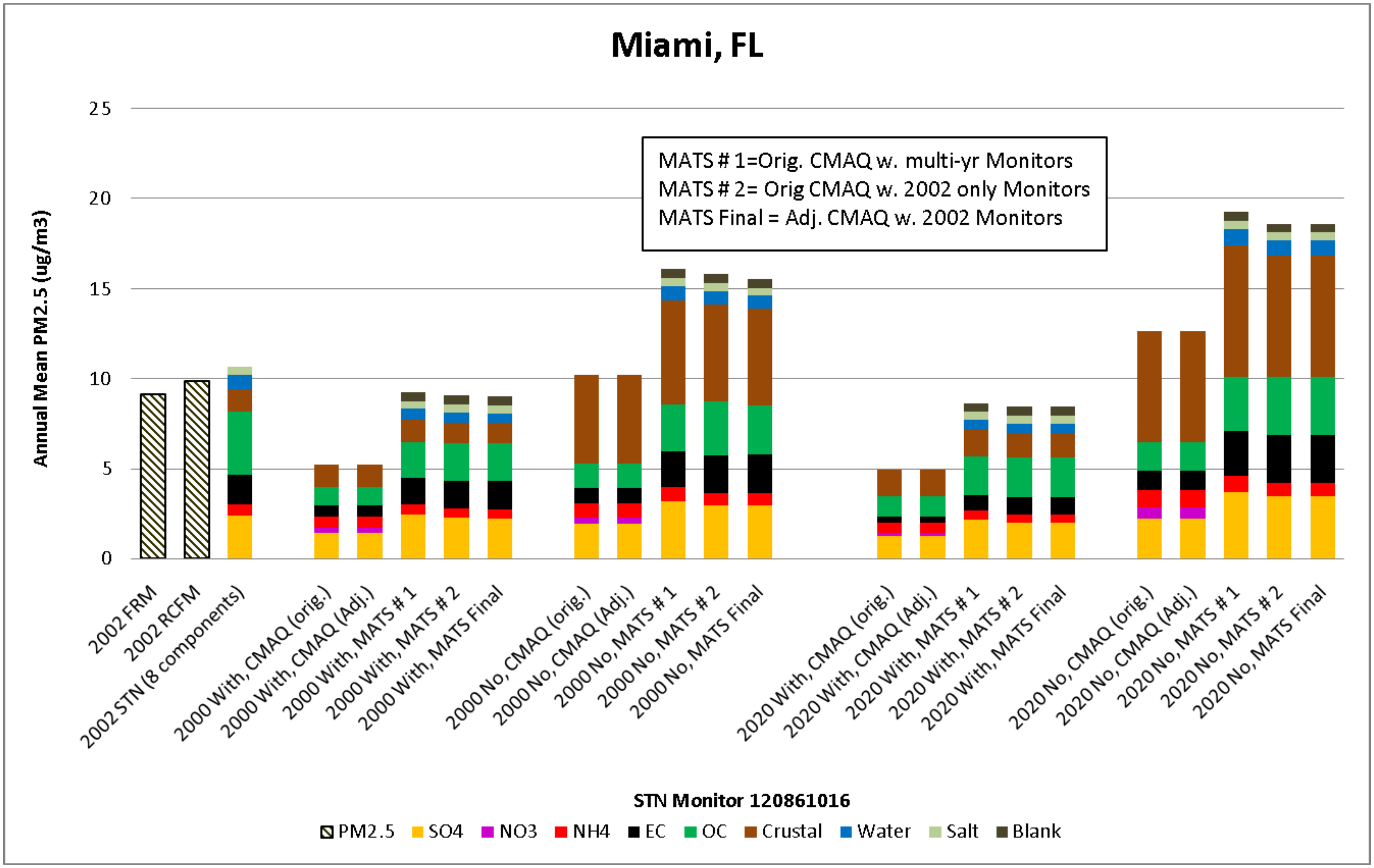


Figure 8 Philadelphia, PA

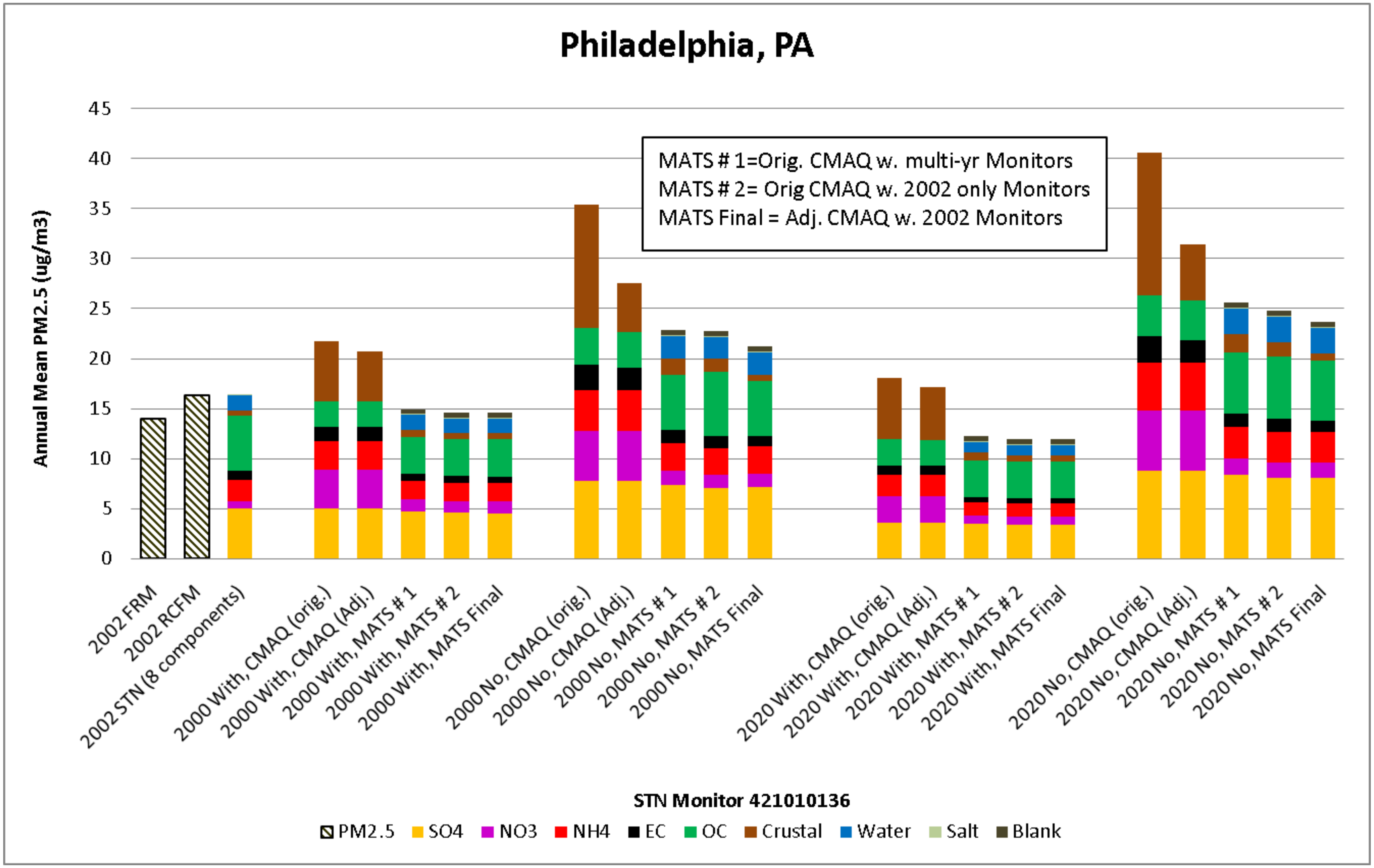


Figure 9 Tulare County, CA

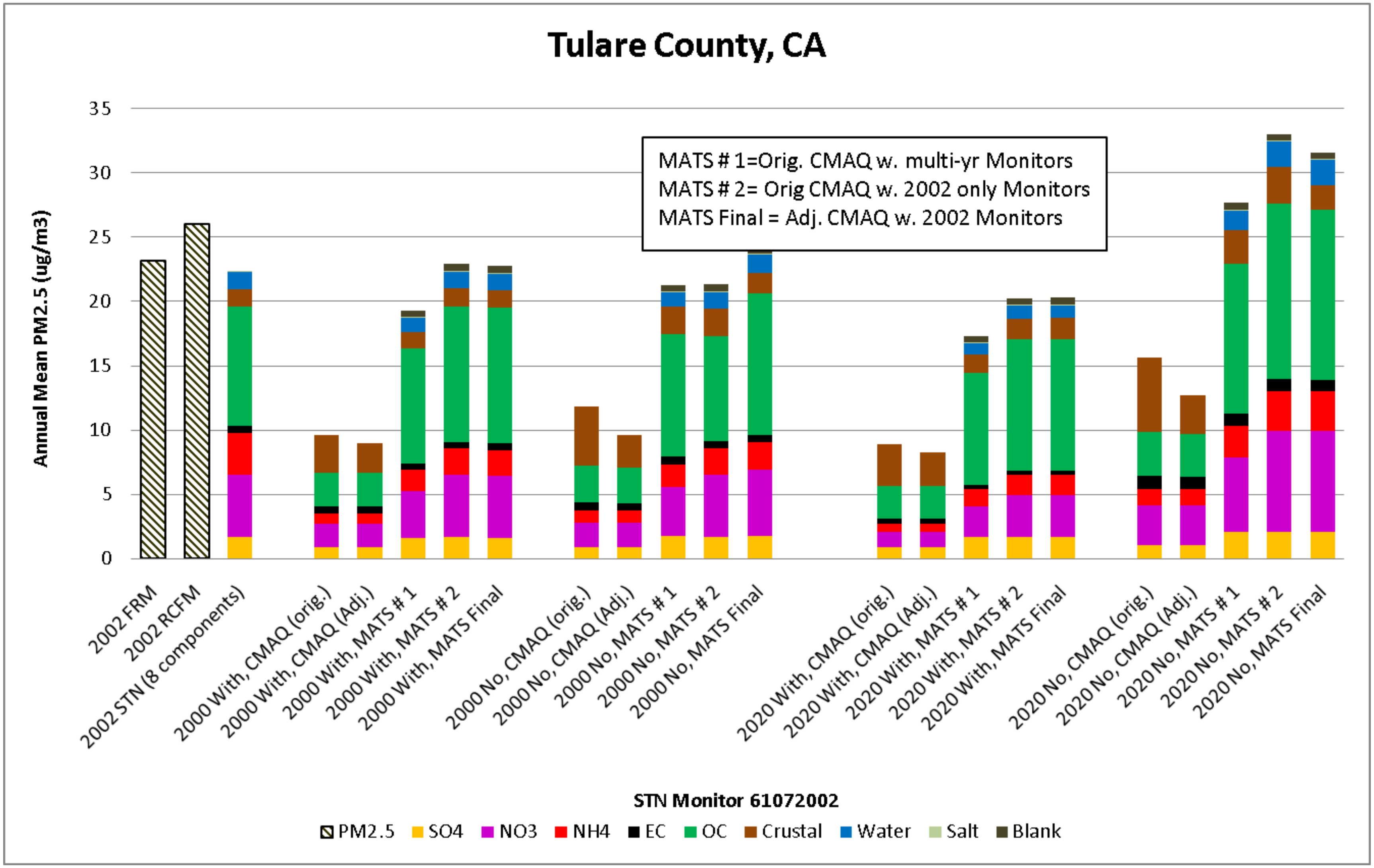


Figure 10 Tucson, AZ (only 3 quarters of 2002 STN data)