

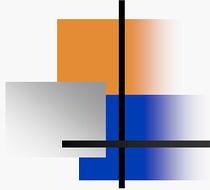


# Second Prospective Analysis of Air Quality in the U.S. – Air Quality Modeling

February 19, 2010

Prepared for the EPA Science Advisory Board  
Air Quality Modeling Subcommittee

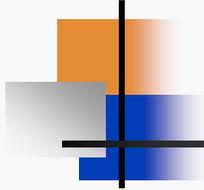
Presented by Sharon Douglas  
ICF International, San Rafael, CA



# ICF AQM Team Contributors

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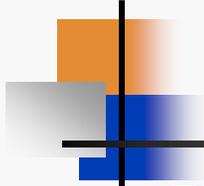
- Yihua Wei
- Tom Myers
- Belle Hudischewskyj
- Cara Henning
- Jay Haney



# Briefing Outline

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- Overview/Air Quality Modeling Methodology
- Emission Inventory Preparation
- PM2.5 Modeling Results for the Continental U.S.
- Ozone Modeling Results for the Eastern U.S.
- Ozone Modeling Results for the Western U.S.
- Attributes & Limitations
- Model Performance Evaluation
- Summary & Recommendations for Further Work

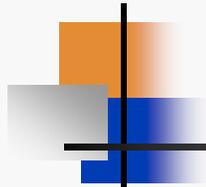


# Overview

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- Retrospective & prospective analyses are routinely conducted by EPA to assess the benefits and costs of the CAAA
- In this study, emissions processing & air quality modeling were conducted to support the second prospective CAAA Section 812 study
- This is the first prospective analysis to use an integrated modeling system, the Community Multiscale Air Quality (CMAQ) model, to simulate national & regional-scale pollutant concentrations & deposition

# Modeling Domains



Continental U.S.  
(CONUS)

36 km

PM<sub>2.5</sub>, (Ozone),  
Deposition

Eastern U.S.  
(EUS)

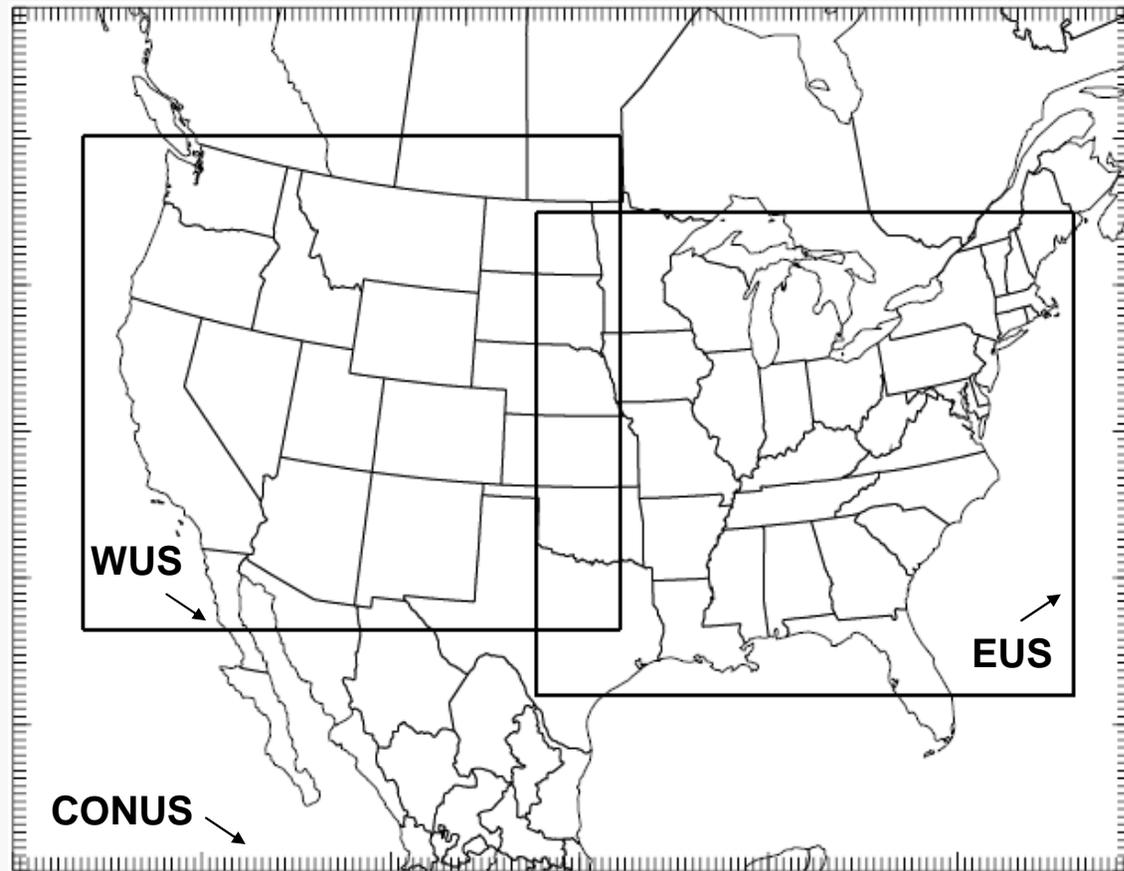
12 km

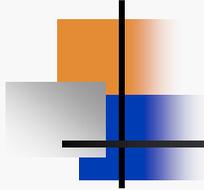
Ozone

Western U.S.  
(WUS)

12 km

Ozone

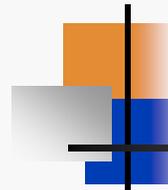




## Pollutants of Interest & Simulation Periods

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- PM<sub>2.5</sub>, visibility & deposition analyses:
  - 2002 annual period
  - CONUS domain
- Ozone analyses:
  - May – September 2002
  - EUS & WUS domains

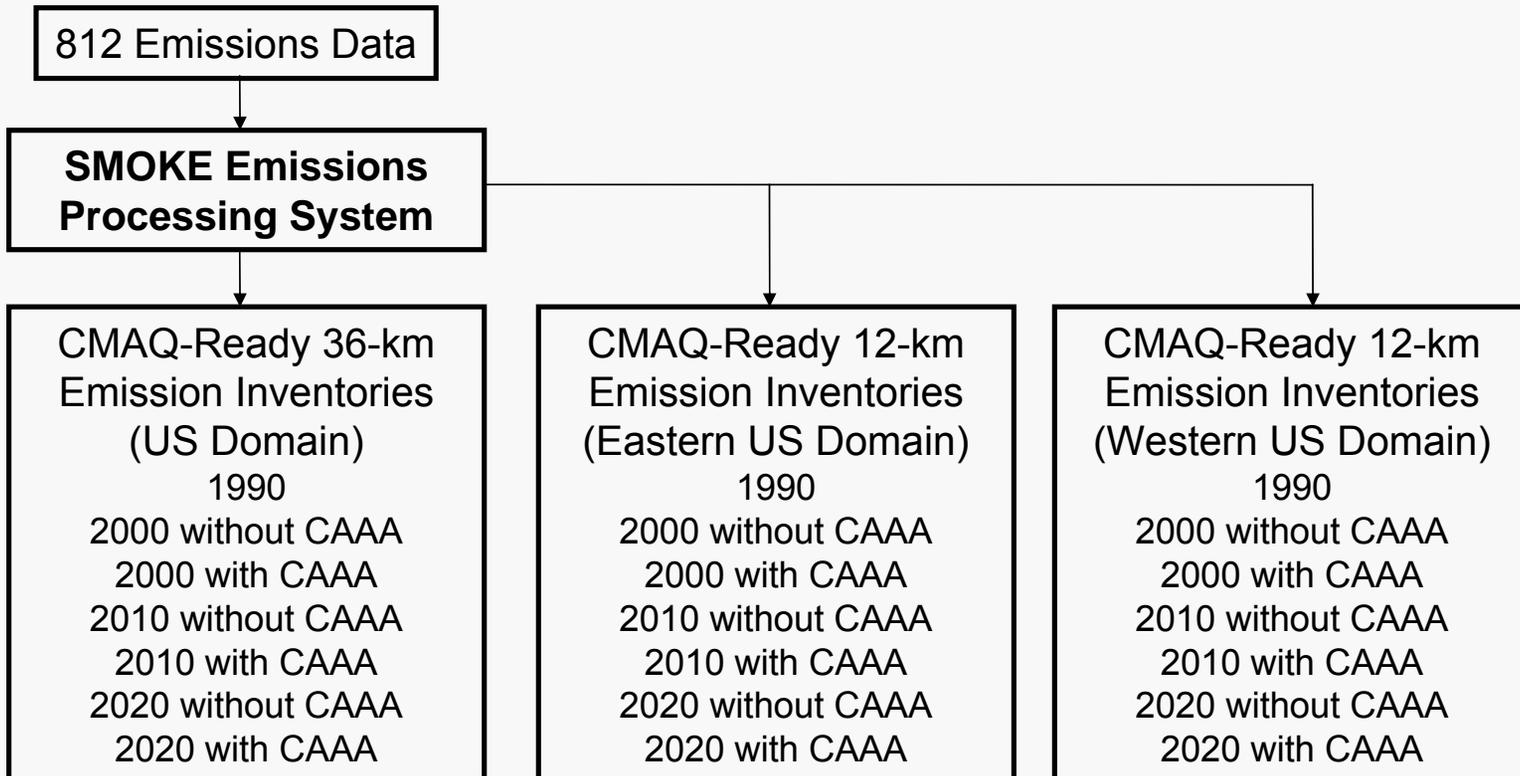
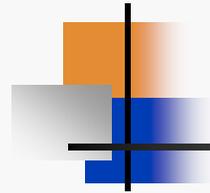


# Emissions & Modeling Scenarios

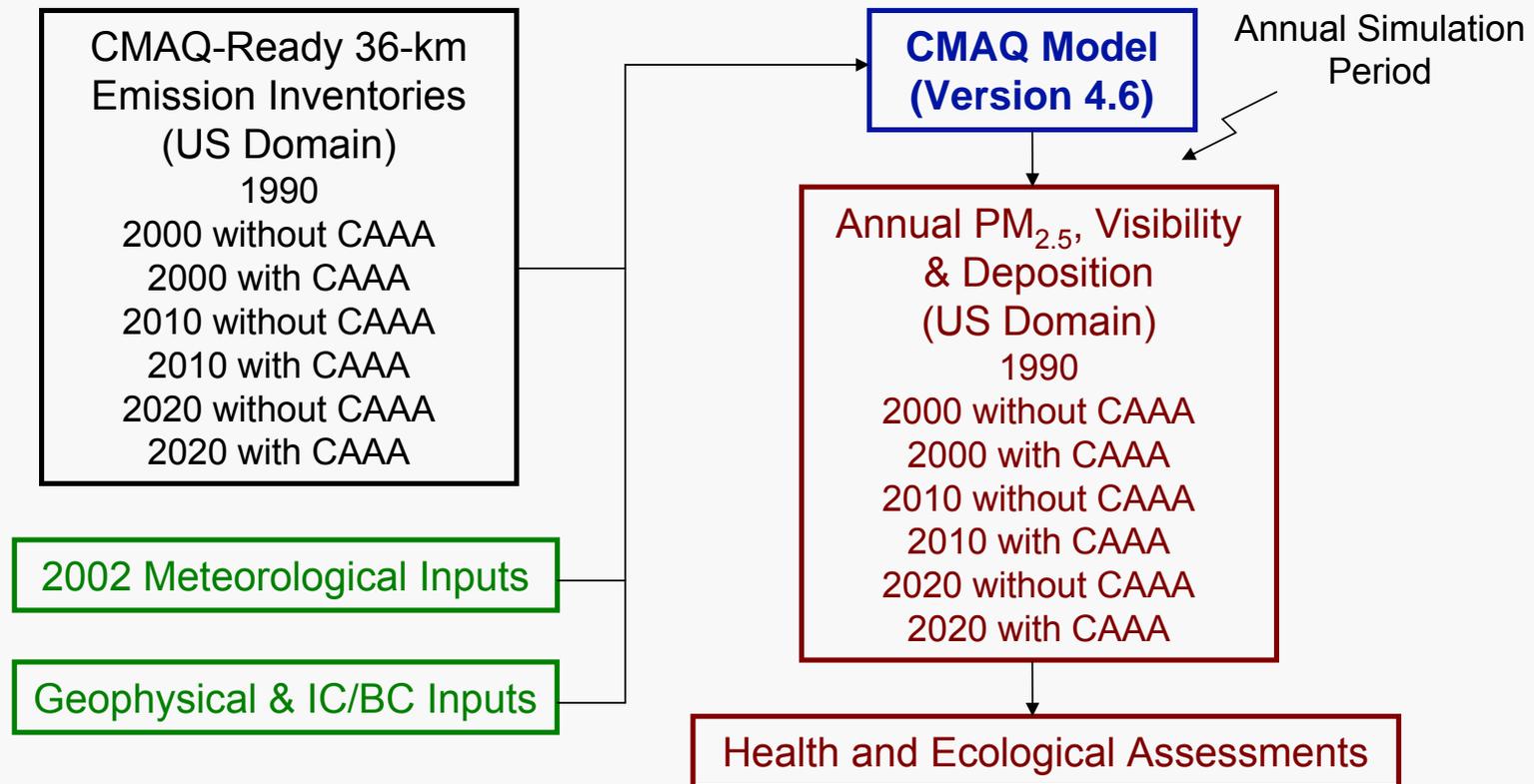
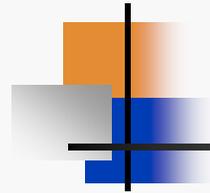
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- Retrospective base year scenario
  - 1990
  
- Base- & future-year scenarios without CAAA
  - 2000 without CAAA
  - 2010 without CAAA
  - 2020 without CAAA
  
- Base & future-year scenarios with CAAA
  - 2000 with CAAA
  - 2010 with CAAA
  - 2020 with CAAA

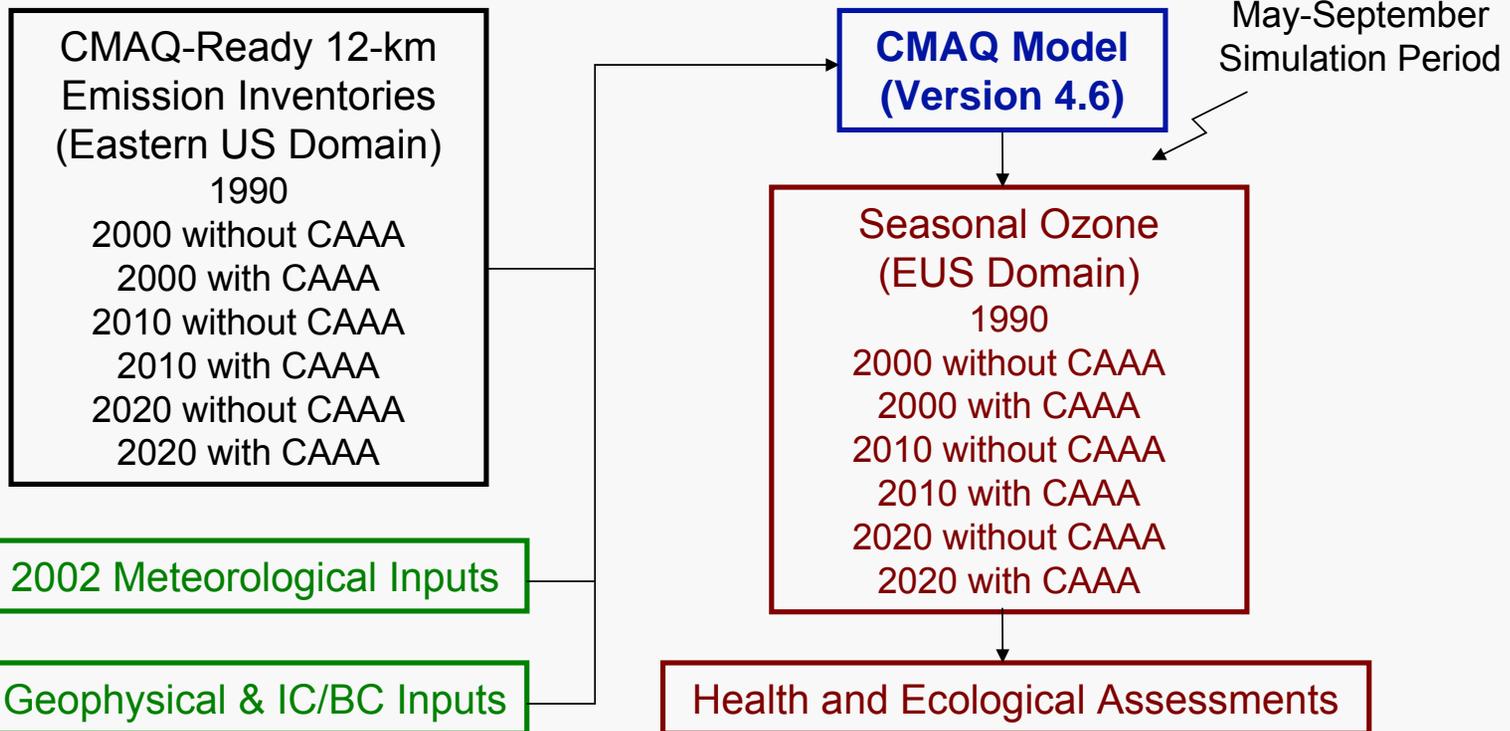
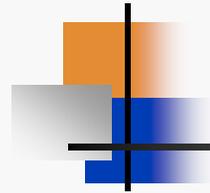
# Emissions Processing & Modeling Methodology (1)



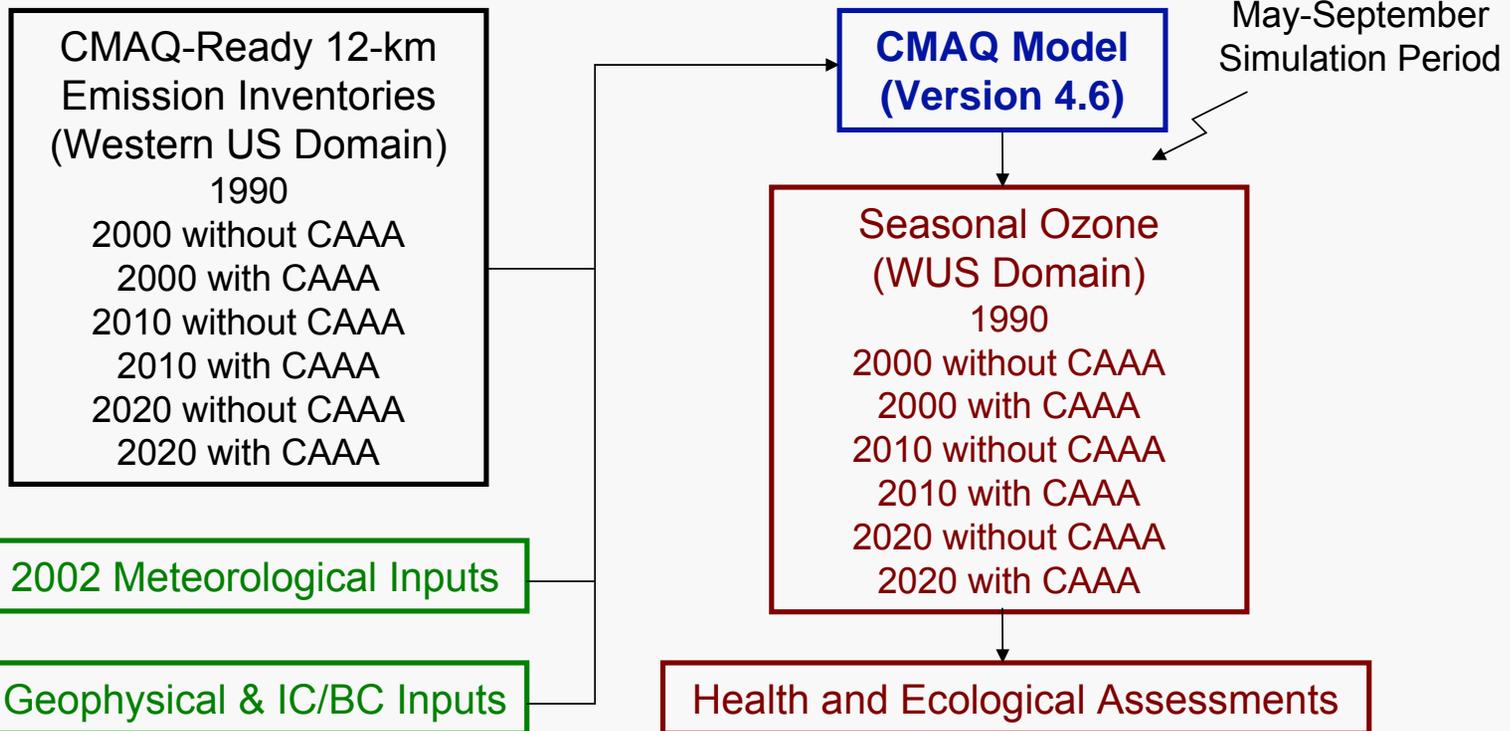
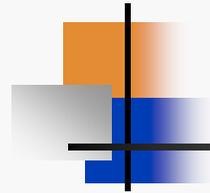
# Emissions Processing & Modeling Methodology (2)

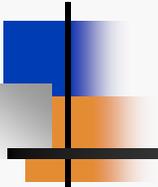


# Emissions Processing & Modeling Methodology (3)



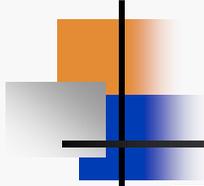
# Emissions Processing & Modeling Methodology (4)





# Emission Inventory Preparation

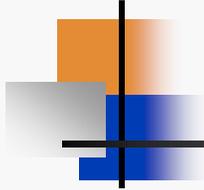
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# Emissions Data

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- Emissions data provided by EPA, Pechan & IEC (Wilson et al., 2008)
  - Geographical coverage: 48 U.S. states; portions of Canada & Mexico
  - Species: Volatile organic compounds (VOC), oxides of nitrogen ( $\text{NO}_x$ ), carbon monoxide (CO), sulfur dioxide ( $\text{SO}_2$ ), fine particulates ( $\text{PM}_{2.5}$ ), coarse particulates ( $\text{PM}_{10}$ ), and ammonia ( $\text{NH}_3$ )
  - Categories/sectors: Area, non-road, on-road mobile, EGU and non-EGU
  - Scenarios: Base and future-year (w- & w/o-CAAA)
  - Additional control information: “Identified” and “unidentified” local control information



# Base-Year Emission Data Sources

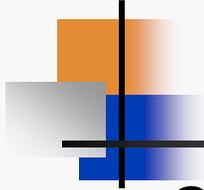
Sector	Without-CAAA 1990	With-CAAA 2000
EGU	1990 EPA point-source NEI	Estimated by EPA IPM for 2001
Non-EGU Point	1990 EPA point-source NEI	2002 EPA point-source NEI (final version 2.0)
Non-point (Area)	1990 EPA non-point-source NEI with adjustments for priority source categories	2002 EPA point-source 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 estimates for CA
Off-road/ Non-road	NON-ROAD 2004 model simulation for 1990	NON-ROAD 2004 model simulation for 2000

Source: Wilson et al., 2008

# Future-Year Emissions Projections

<b>Sector</b>	<b>Growth Forecast</b>	<b>Estimation of Controls</b>
EGU	DOE AEO 2005 forecasts	IPM
Non-EGU Point	DOE AEO 2005 forecasts	Control factors developed by RPOs and CARB
Non-point	DOE AEO 2005 forecasts	Control factors developed by RPOs and CARB
On-road	National VMT forecast from AEO 2005	MOBILE6.2 emission factors
Off-road/ Non-road	EPA NON-ROAD 2004 model growth forecasts largely based on historical trends in engine populations	NON-ROAD2004 model

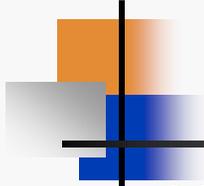
*Source: Wilson et al., 2008*



## CAAA Controls

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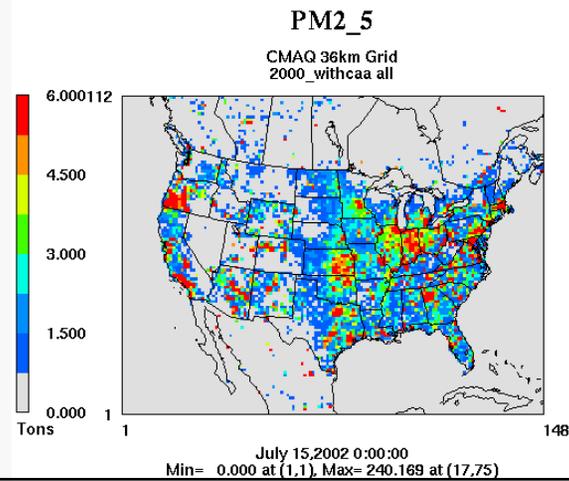
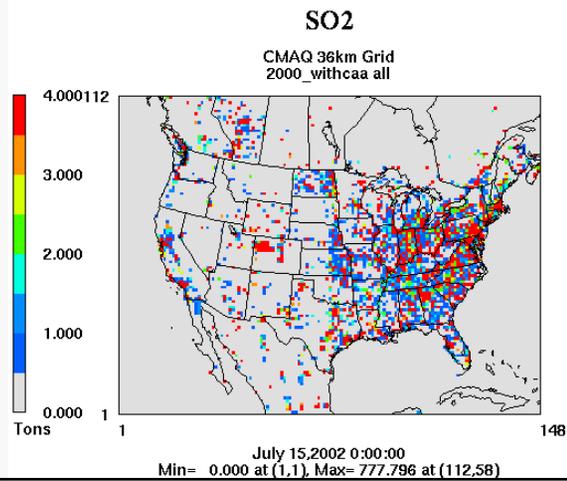
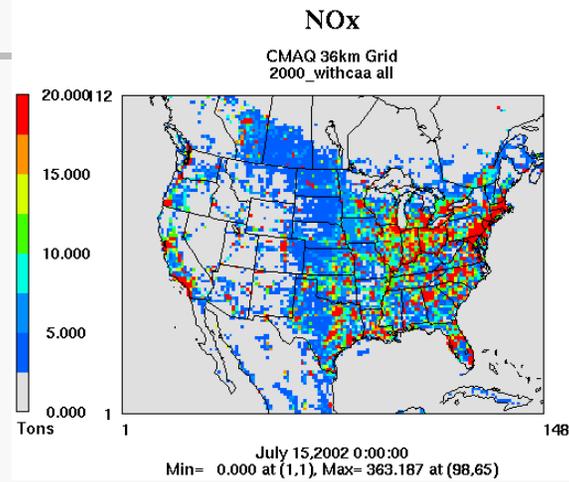
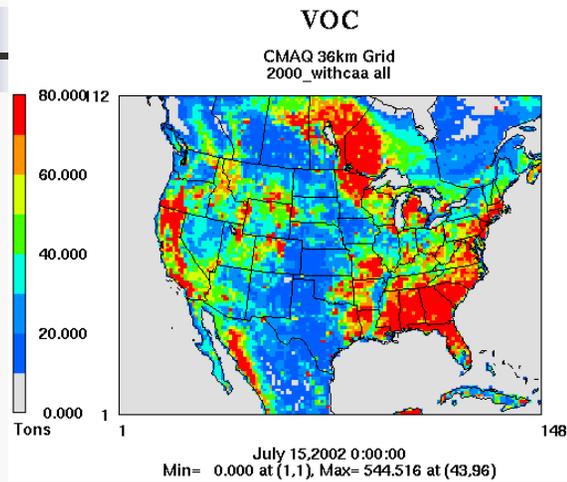
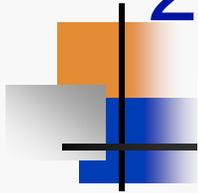
- CAAA inventories include controls that represent provisions contained in the following sections of the 1990 CAAA:
  - Title I VOC and NO<sub>x</sub> reasonably available control technology (RACT) requirements in ozone nonattainment areas (NAAs)
  - Title II on-road motor vehicle and non-road engine/vehicle provisions
  - Title III National Emissions Standards for Hazardous Air Pollutants (NESHAPS)
  - Title IV emissions programs for EGUs, as estimated by the Integrated Planning Model (IPM)



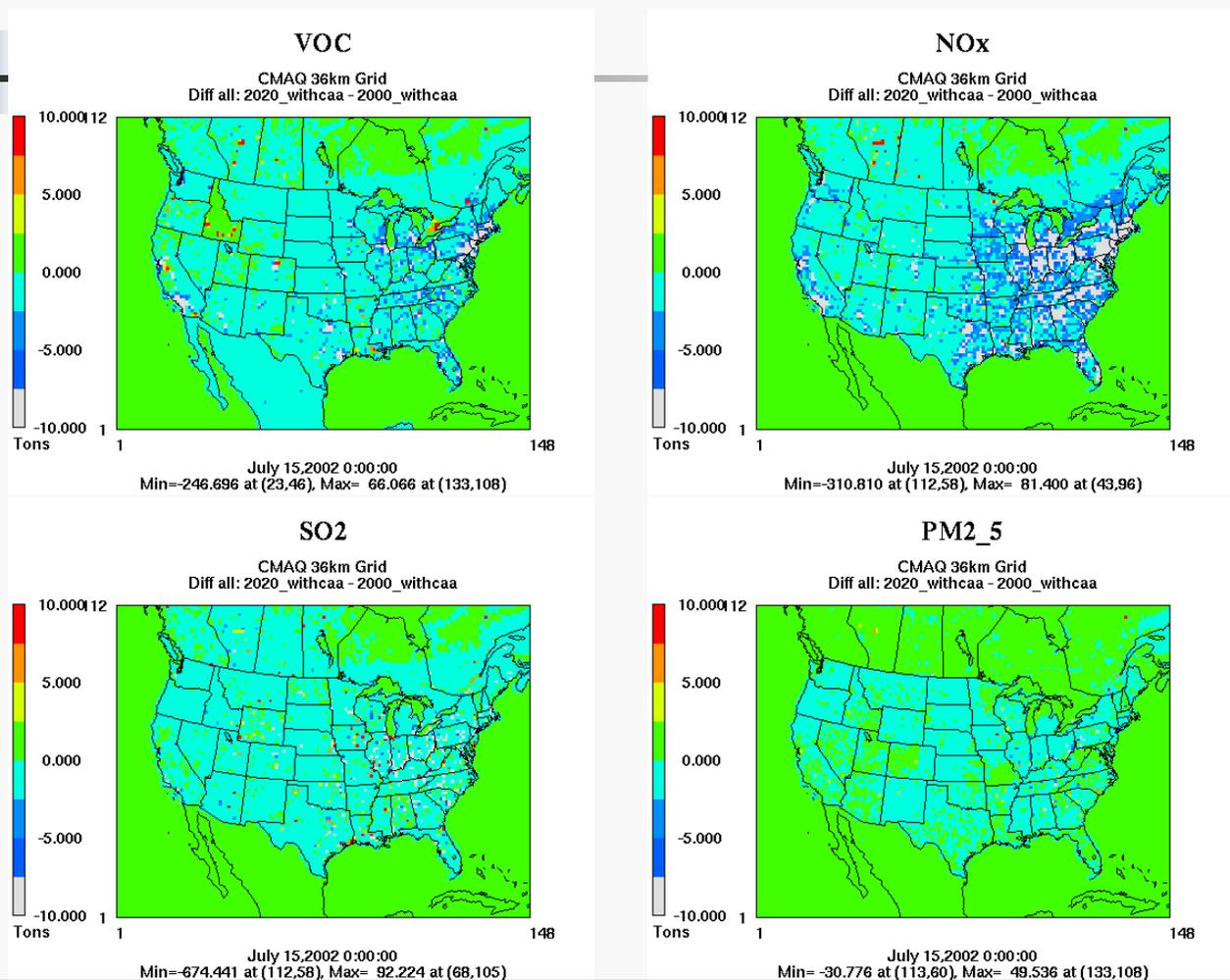
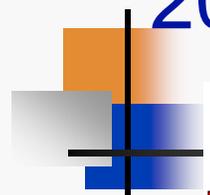
# Emissions Processing Procedures

- Used SMOKE and associated tools to:
  - Apply local controls to emissions inventory data files (with-CAAA inventories only)
  - Chemically speciate emissions for the Carbon Bond 2005 (CB-05) chemical mechanism
  - Temporally allocate annual/monthly emissions to each hour (of the simulation period)
  - Spatially allocate the emissions to each grid cell
  - Merge emissions from EGU, non-EGU, non-point, non-road, on-road, and biogenic sectors into CMAQ model-ready files
  - Review & quality assure the inventory processing

# 2000 With-CAAA Base Emissions

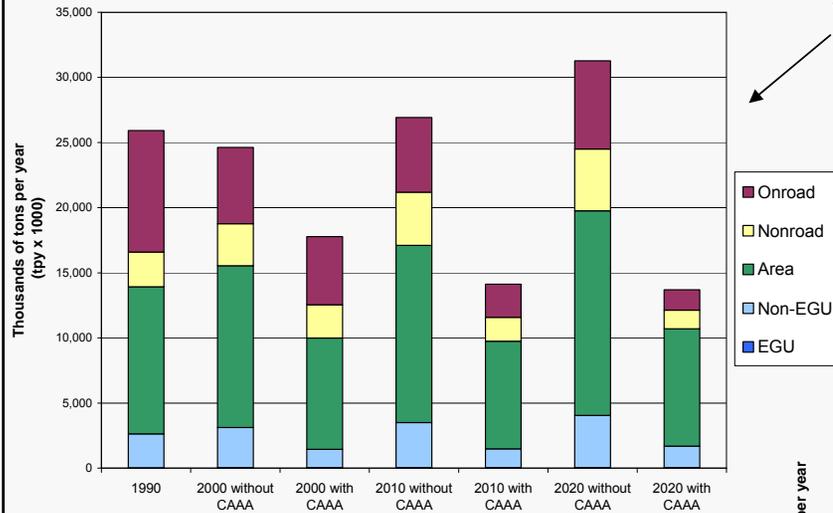


# 2020 & 2000 With-CAAA Differences



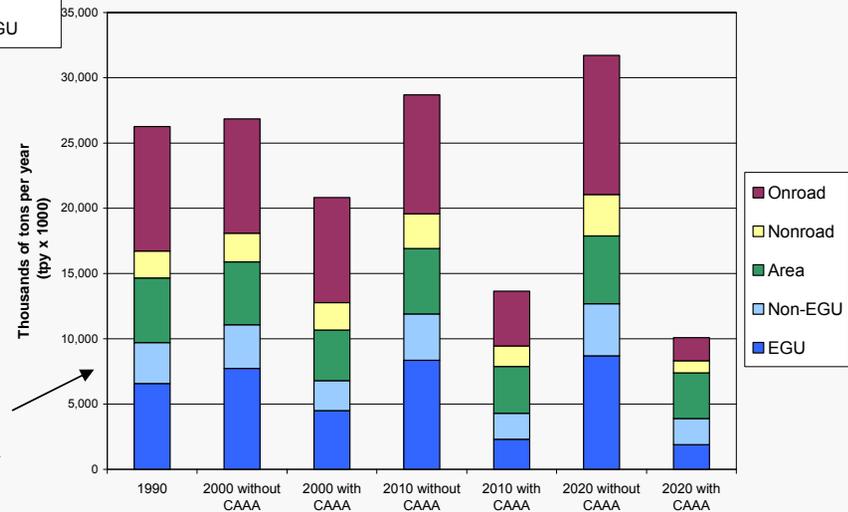
# Emissions Summaries: All Scenarios

National Emissions by Year, CAAA, and Source Sector: VOC



VOC

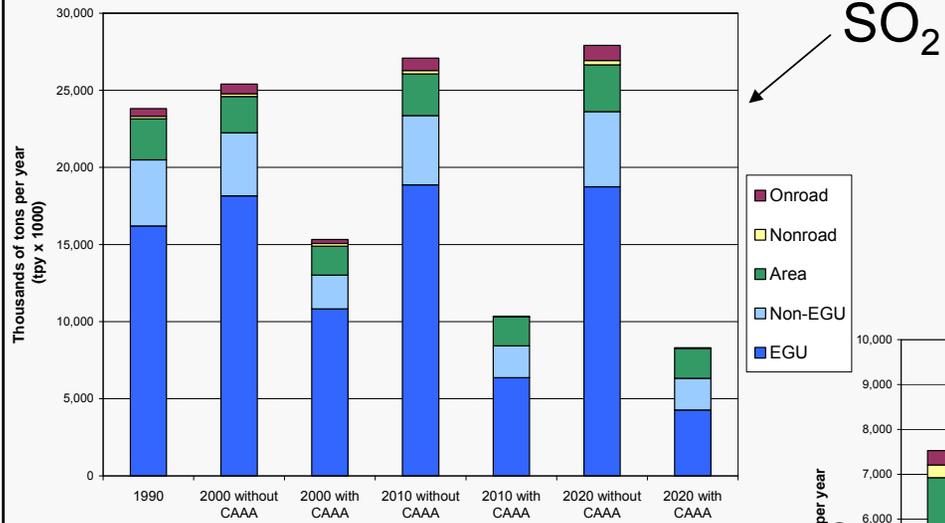
National Emissions by Year, CAAA, and Source Sector: NO<sub>x</sub>



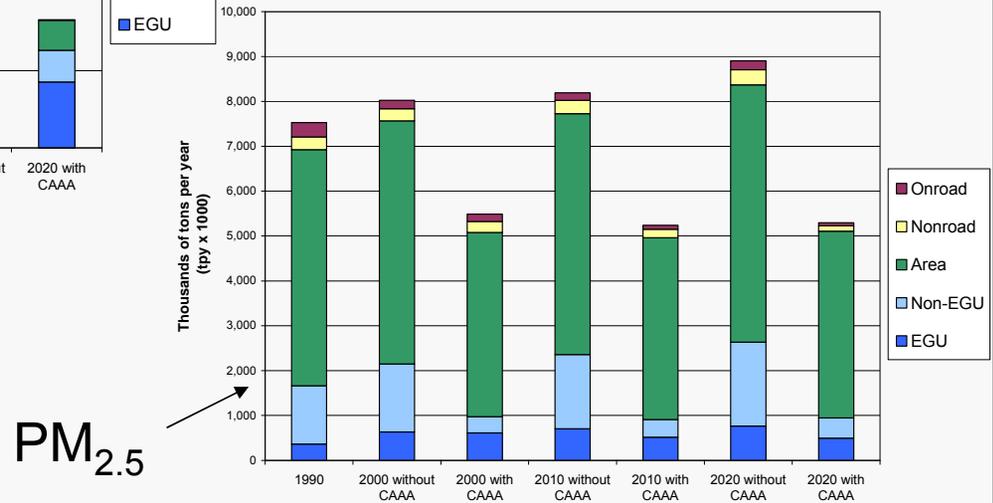
NO<sub>x</sub>

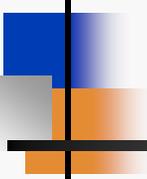
# Emissions Summaries: All Scenarios

National Emissions by Year, CAAA, and Source Sector: SO<sub>2</sub>



National Emissions by Year, CAAA, and Source Sector: PM<sub>2.5</sub>

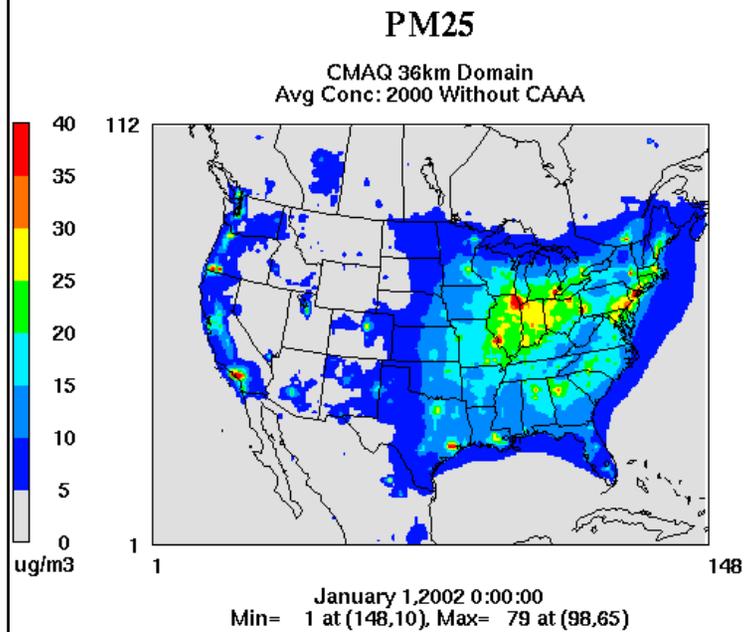




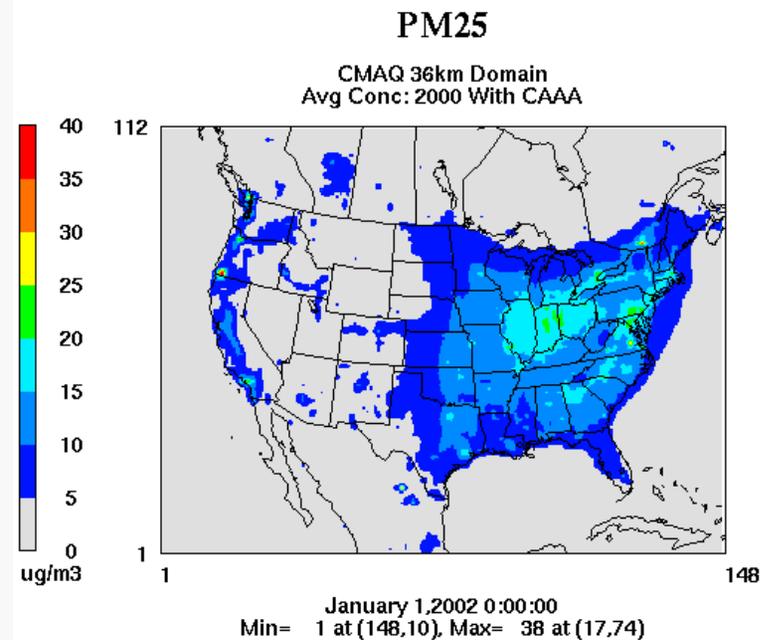
# PM<sub>2.5</sub> Modeling Results

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# PM<sub>2.5</sub> Modeling Results: 2000



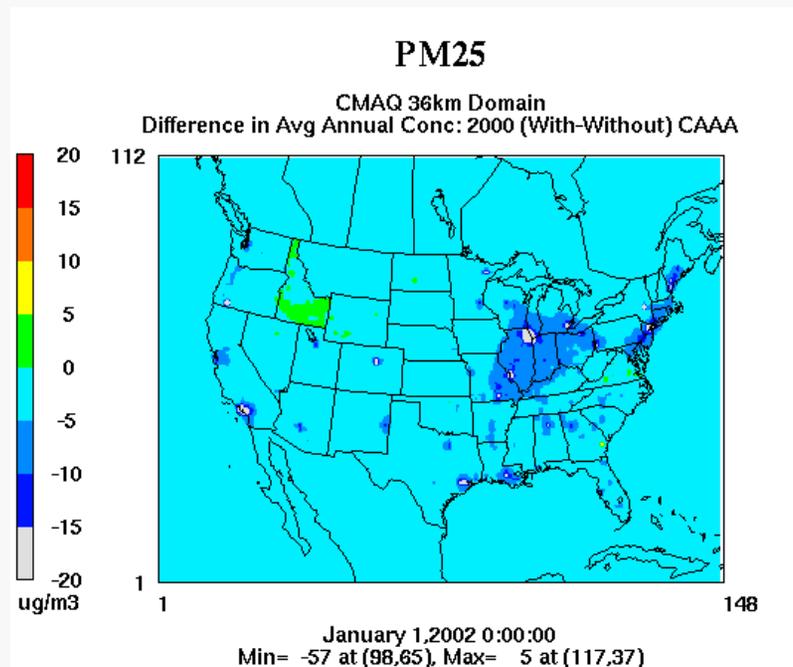
**Without CAAA**



**With CAAA**

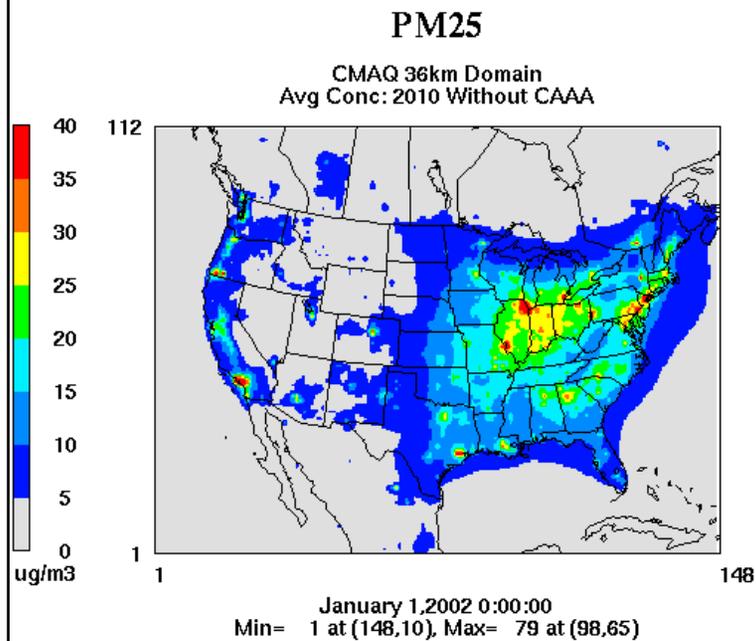
*Annual Average PM<sub>2.5</sub>; Units are  $\mu\text{g}\text{m}^{-3}$*

# Difference in Simulated $PM_{2.5}$ With CAAA – Without CAAA: 2000

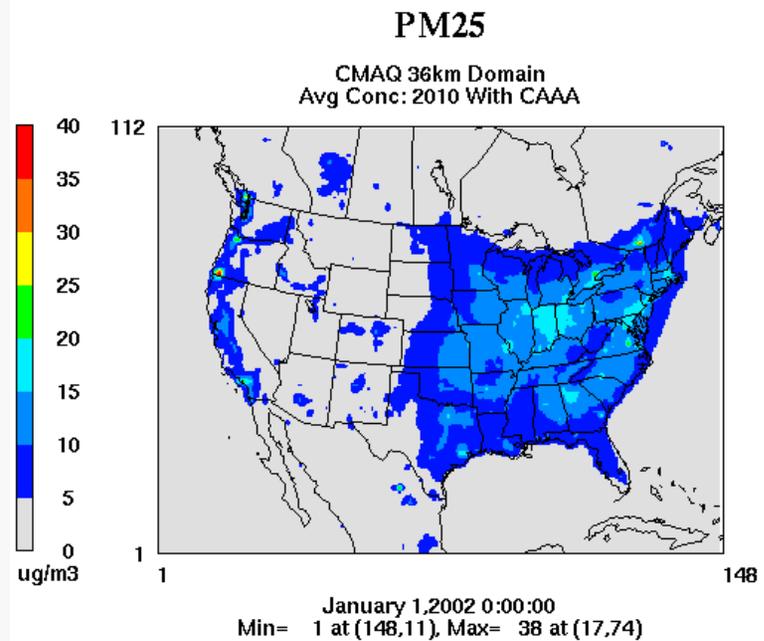


*Annual Average  $PM_{2.5}$ ; Units are  $\mu g m^{-3}$*

# PM<sub>2.5</sub> Modeling Results: 2010



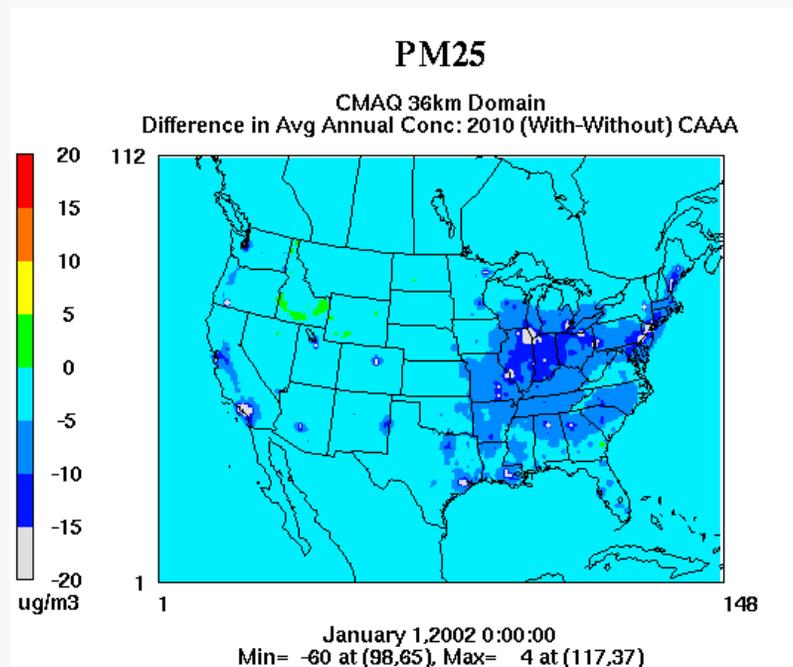
**Without CAAA**



**With CAAA**

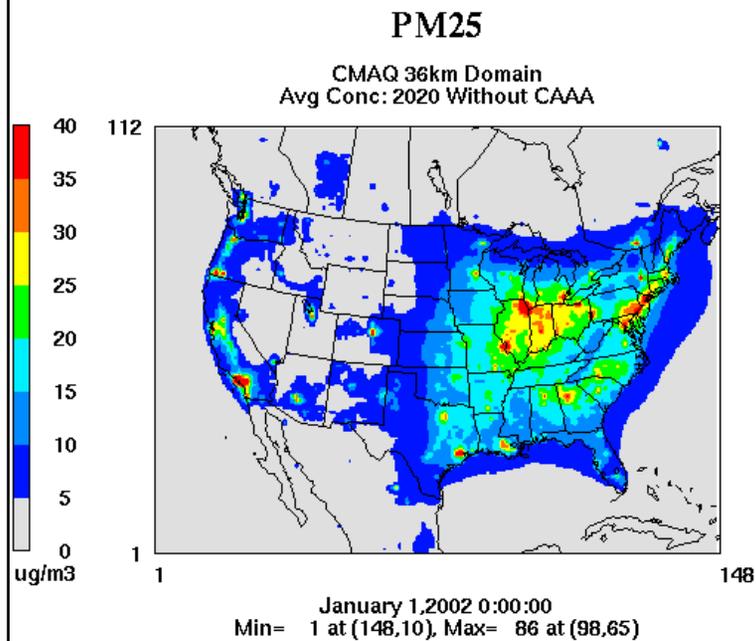
*Annual Average PM<sub>2.5</sub>; Units are  $\mu\text{g}\text{m}^{-3}$*

# Difference in Simulated $PM_{2.5}$ With CAAA – Without CAAA: 2010

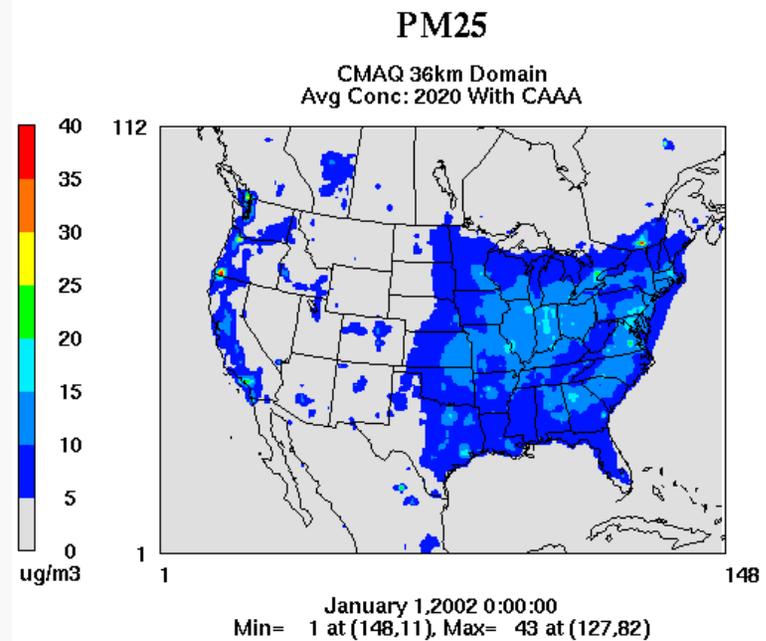


*Annual Average  $PM_{2.5}$ ; Units are  $\mu g m^{-3}$*

# PM<sub>2.5</sub> Modeling Results: 2020



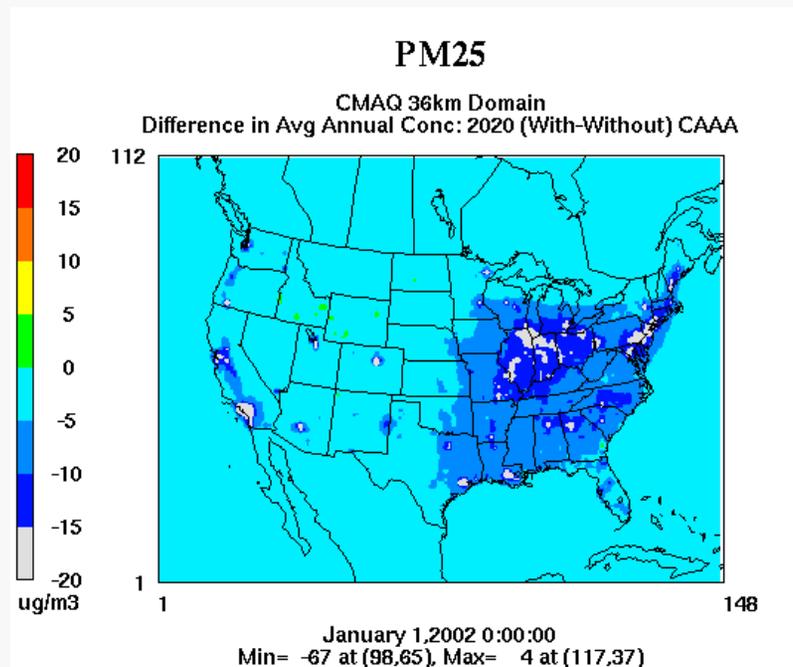
**Without CAAA**



**With CAAA**

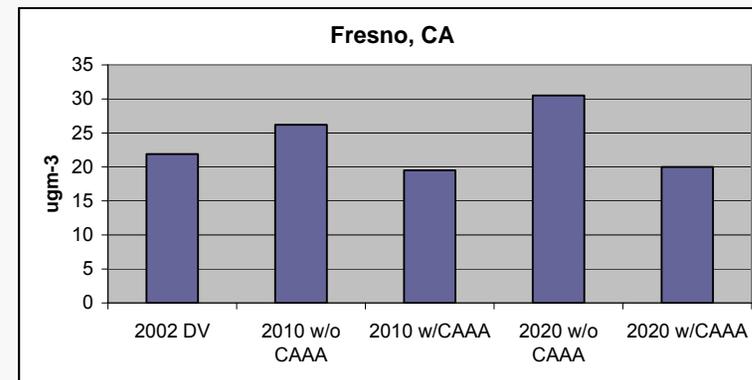
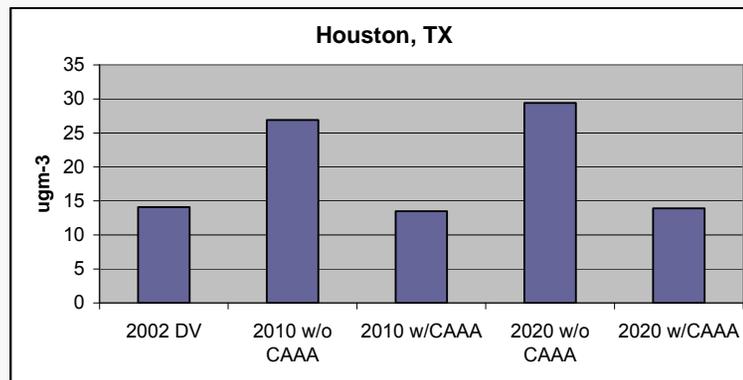
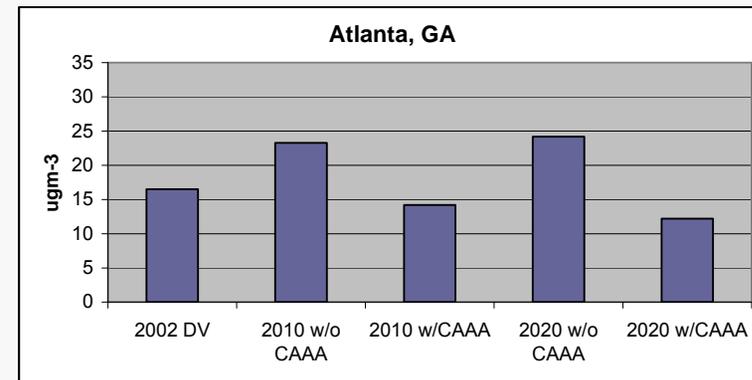
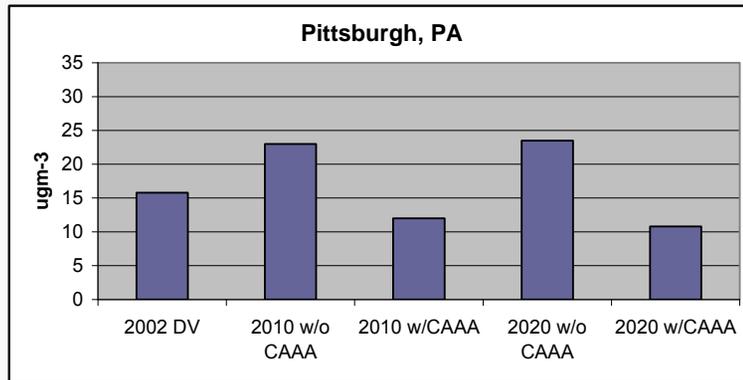
*Annual Average PM<sub>2.5</sub>; Units are  $\mu\text{g}\text{m}^{-3}$*

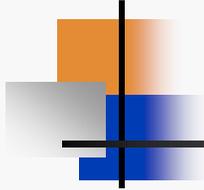
# Difference in Simulated $PM_{2.5}$ With CAAA – Without CAAA: 2020



*Annual Average  $PM_{2.5}$ ; Units are  $\mu g m^{-3}$*

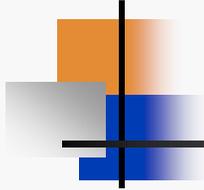
# Actual & Estimated Annual PM<sub>2.5</sub> Design Values





# PM<sub>2.5</sub> Source Contribution Analysis

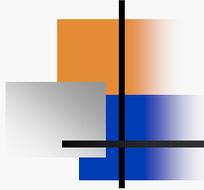
- Objectives:
  - Examine the contributions of emissions from the major source categories to simulated PM<sub>2.5</sub> concentrations
  - Quantify the changes in these contributions between the with- and without-CAAA scenarios
- Applied CMAQ Particle & Precursor Tagging Methodology (PPTM)



## Overview of CMAQ/PPTM

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- Emissions (or IC/BC) species are tagged in the input files and continuously tracked throughout the simulation
- Tags can be applied to source regions, source categories, individual sources, and/or IC/BCs
- Tagged species have the same properties and are subjected to the same processes (e.g., advection, chemical transformation, deposition) as the actual species

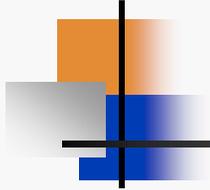


## Overview of PPTM (Concluded)

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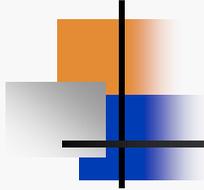
- PPTM species include PM-related S, N, SOA, POC, EC & other inorganic particulates\*
- Base simulation results not affected by tagging
- PPTM quantifies the contribution of tagged sources to simulated species concentrations & deposition

\*PPTM has also been implemented for mercury



## Application of CMAQ/PPTM

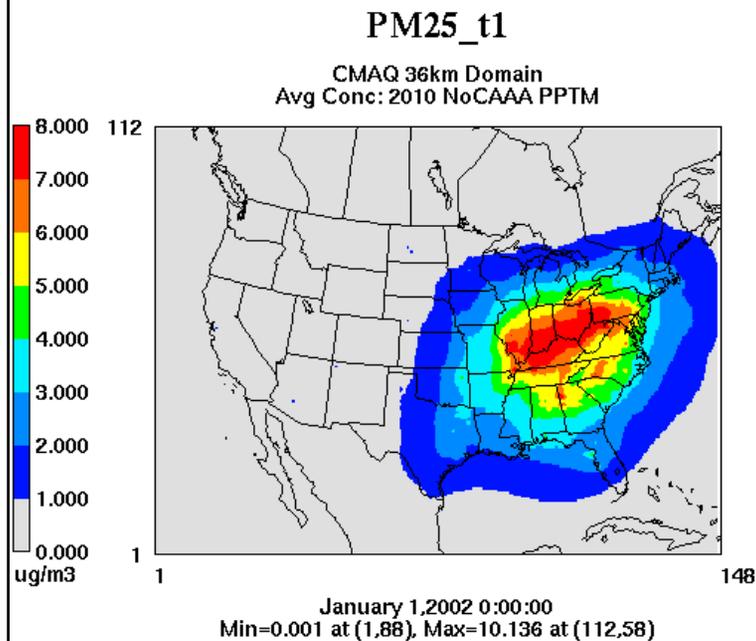
- All PM species
- CONUS regional-scale modeling domain
- 2010 without-CAAA & 2010 with-CAAA emissions inventories
- 7 tagged source categories/regions (see next slide)



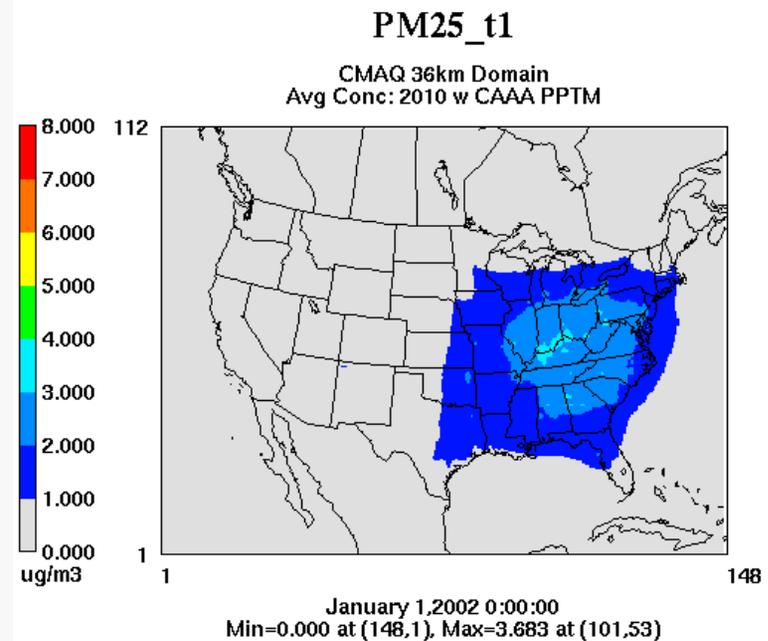
## CMAQ/PPTM Source Categories/Regions

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

# PPTM Contributions to PM<sub>2.5</sub>: EGU Sources



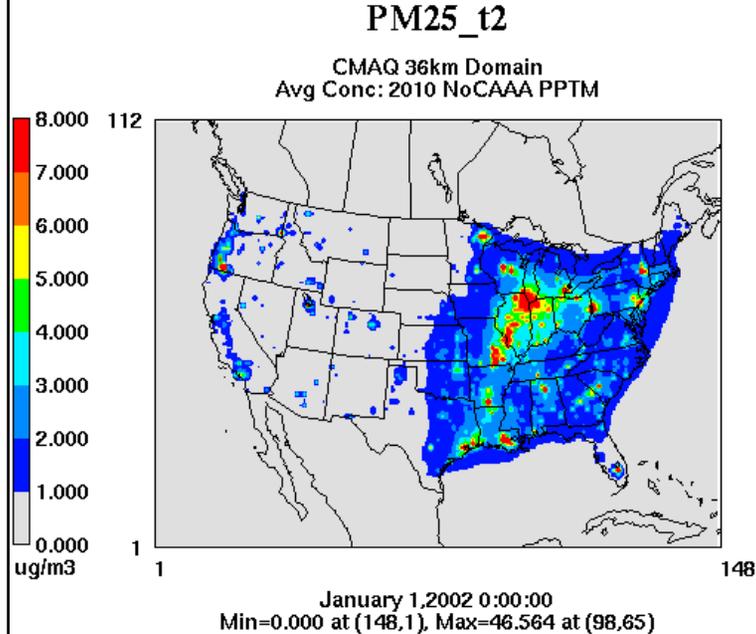
**2010 without CAAA**



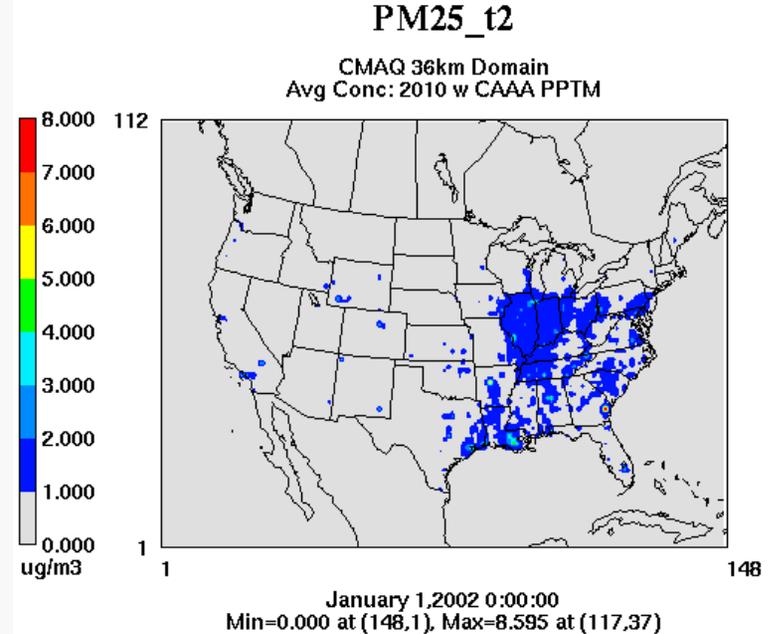
**2010 with CAAA**

*Annual Average PM<sub>2.5</sub>; Units are  $\mu\text{g}\text{m}^{-3}$*

# PPTM Contributions to PM<sub>2.5</sub>: Non-EGU Point Sources



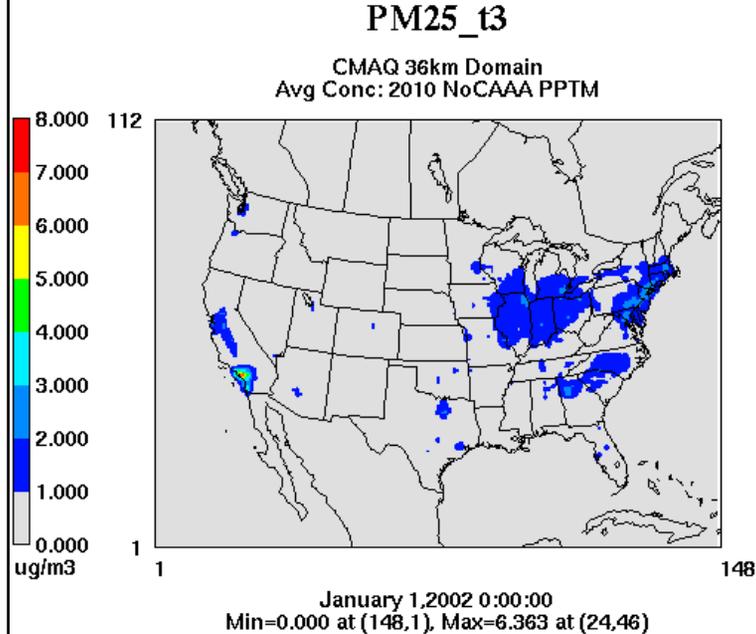
**2010 without CAAA**



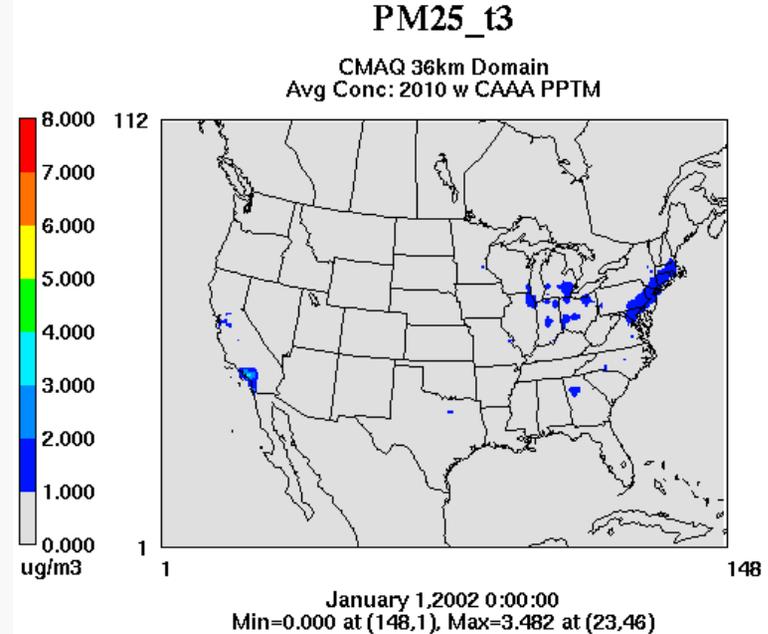
**2010 with CAAA**

*Annual Average PM<sub>2.5</sub>; Units are  $\mu\text{g}\text{m}^{-3}$*

# PPTM Contributions to $PM_{2.5}$ : On-Road Mobile Sources



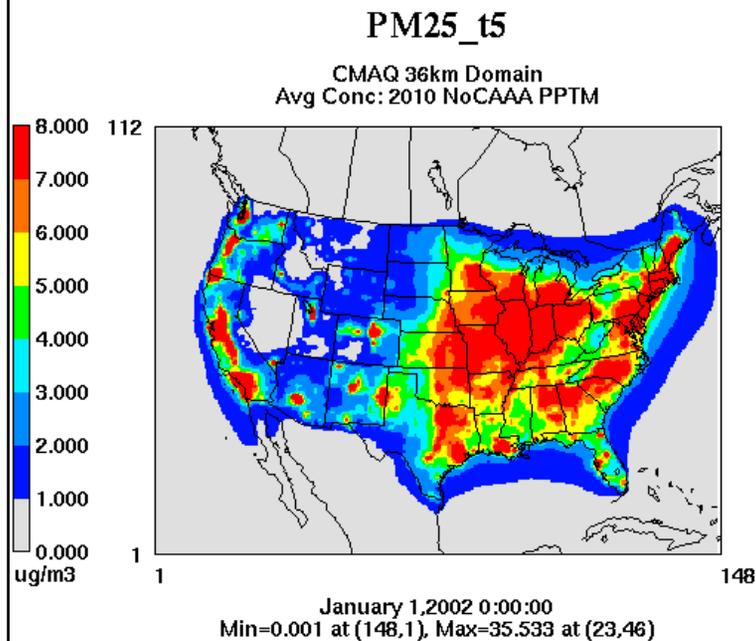
**2010 without CAAA**



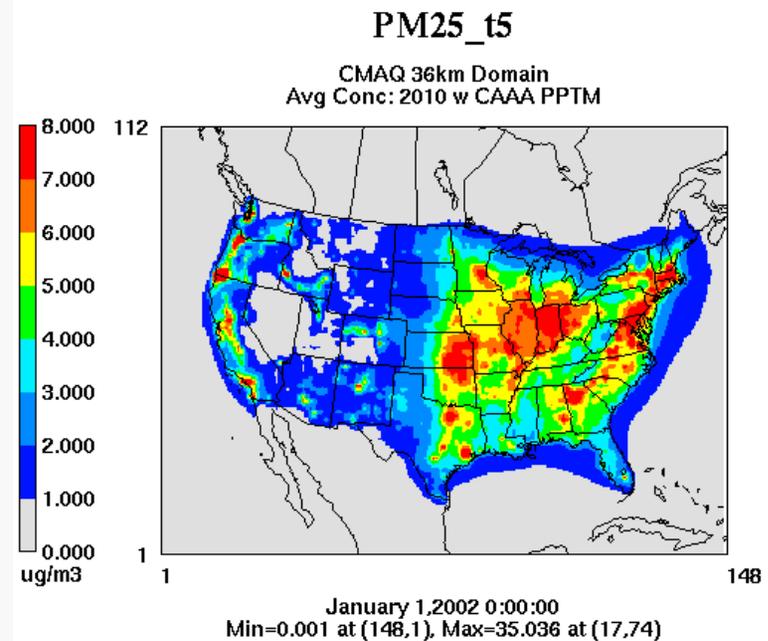
**2010 with CAAA**

*Annual Average  $PM_{2.5}$ ; Units are  $\mu g m^{-3}$*

# PPTM Contributions to PM<sub>2.5</sub>: Area Sources



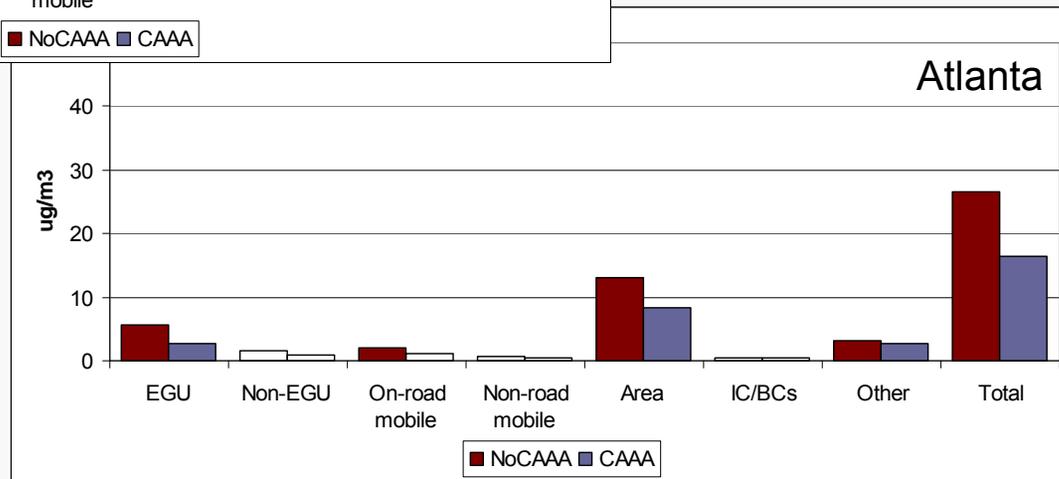
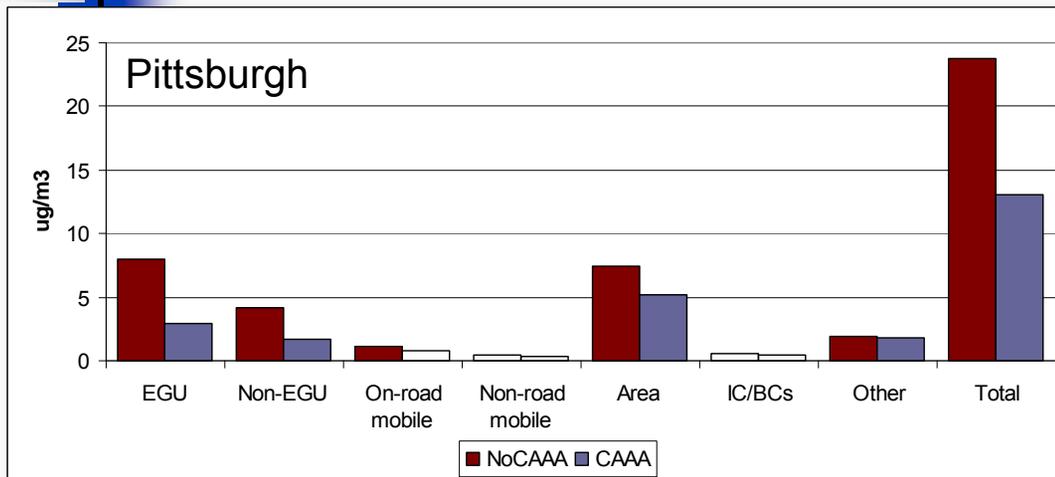
**2010 without CAAA**



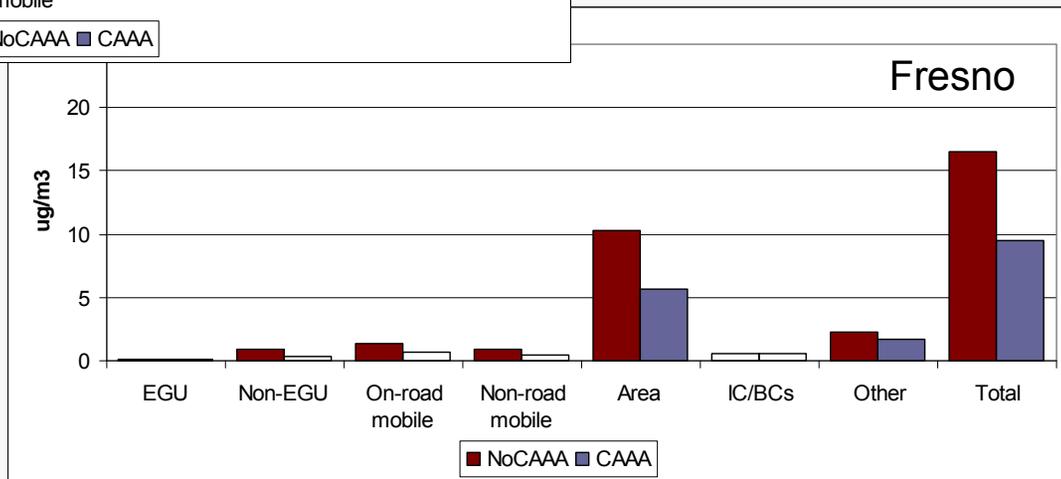
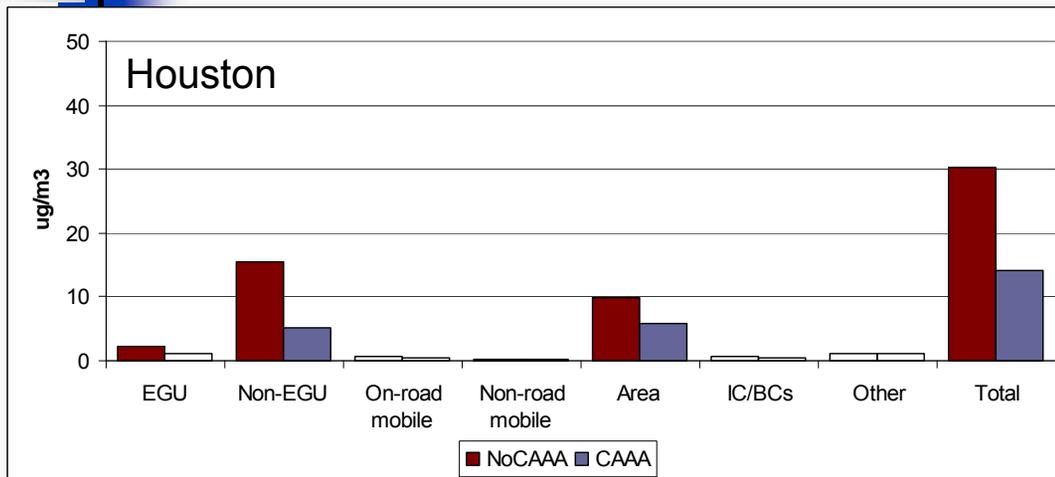
**2010 with CAAA**

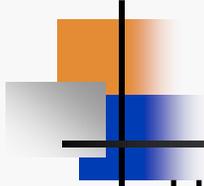
*Annual Average PM<sub>2.5</sub>; Units are  $\mu\text{g}\text{m}^{-3}$*

# PPTM Contributions to PM<sub>2.5</sub>



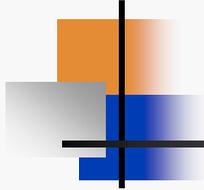
# PPTM Contributions to PM<sub>2.5</sub>





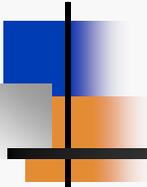
# Summary of CMAQ Modeling Results for PM<sub>2.5</sub>

- Used to calculate particulate matter related health effects & visibility
- For 2000, areas of high concentrations are reduced significantly with CAAA measures, especially over the Midwest
- For 2010, reduction in annual PM<sub>2.5</sub> is even greater than for 2000, due to increases in the without-CAAA concentrations and further decreases in the with-CAAA concentrations
- For 2020, there are increases in the without-CAAA concentrations (compared to 2010) and further decreases in the with-CAAA concentrations
- By 2020, only a few isolated areas with annual average PM<sub>2.5</sub> concentrations greater than 15 µgm<sup>-3</sup> remain



## Summary of CMAQ/PPTM Modeling Results for PM<sub>2.5</sub>

- Overall effects of the CAAA measures on the simulated contributions vary by source category in accordance with the control measures for that category
- Source category contributions to reductions in PM<sub>2.5</sub> differ among the sites
- For most sites, a reduction from area source emissions is a substantial part of the overall reduction in PM<sub>2.5</sub>
- For many areas, reductions in contributions from EGU and non-EGU point sources are also important to the overall reduction

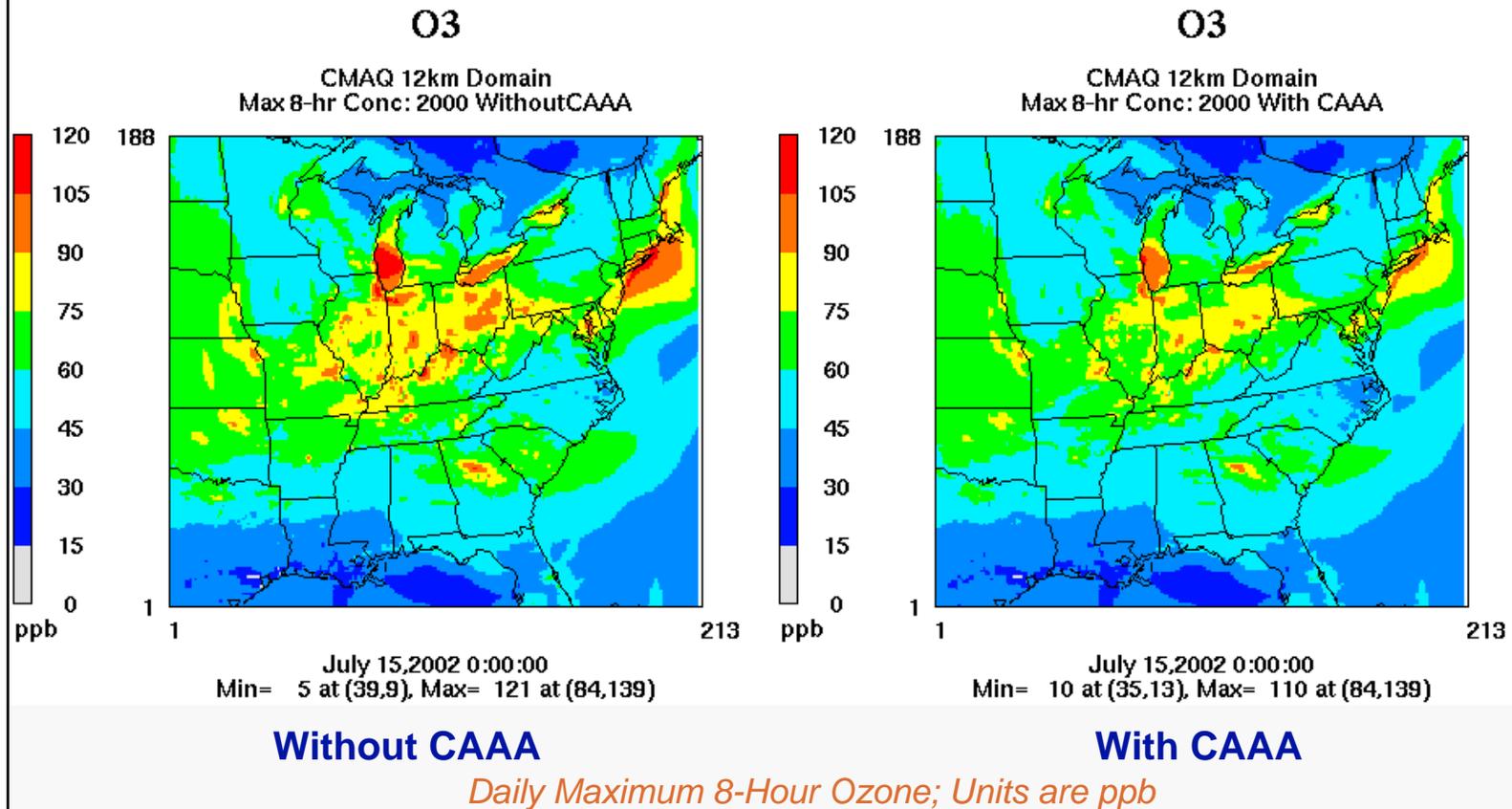


# Ozone Modeling Results

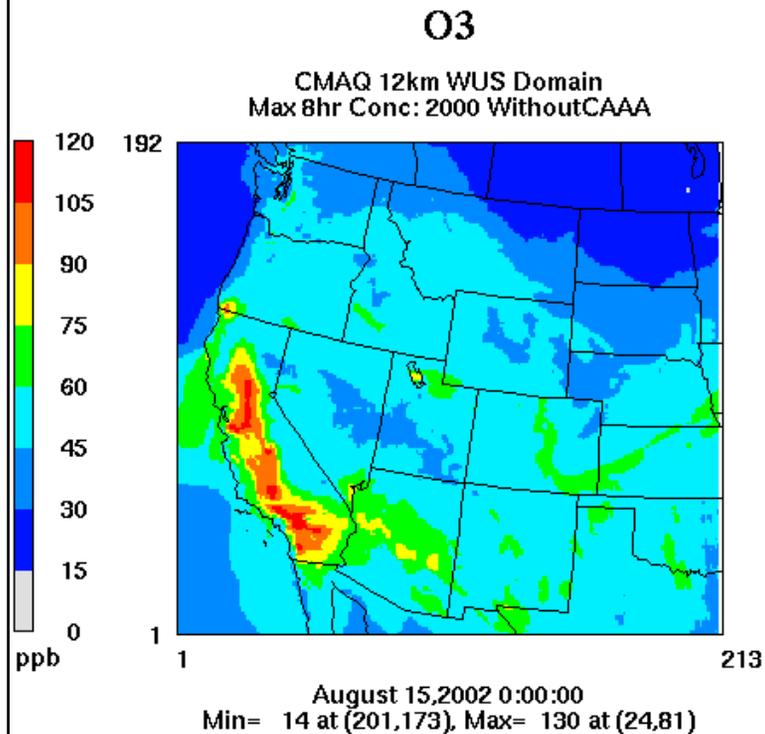
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Eastern & Western U.S.

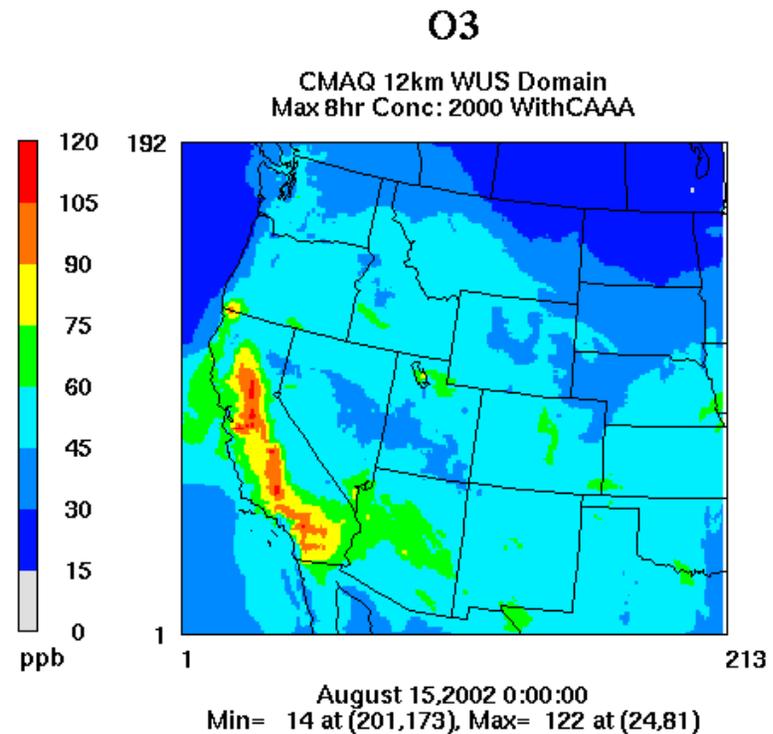
# Ozone Modeling Results (EUS): 2000



# Ozone Modeling Results (WUS): 2000



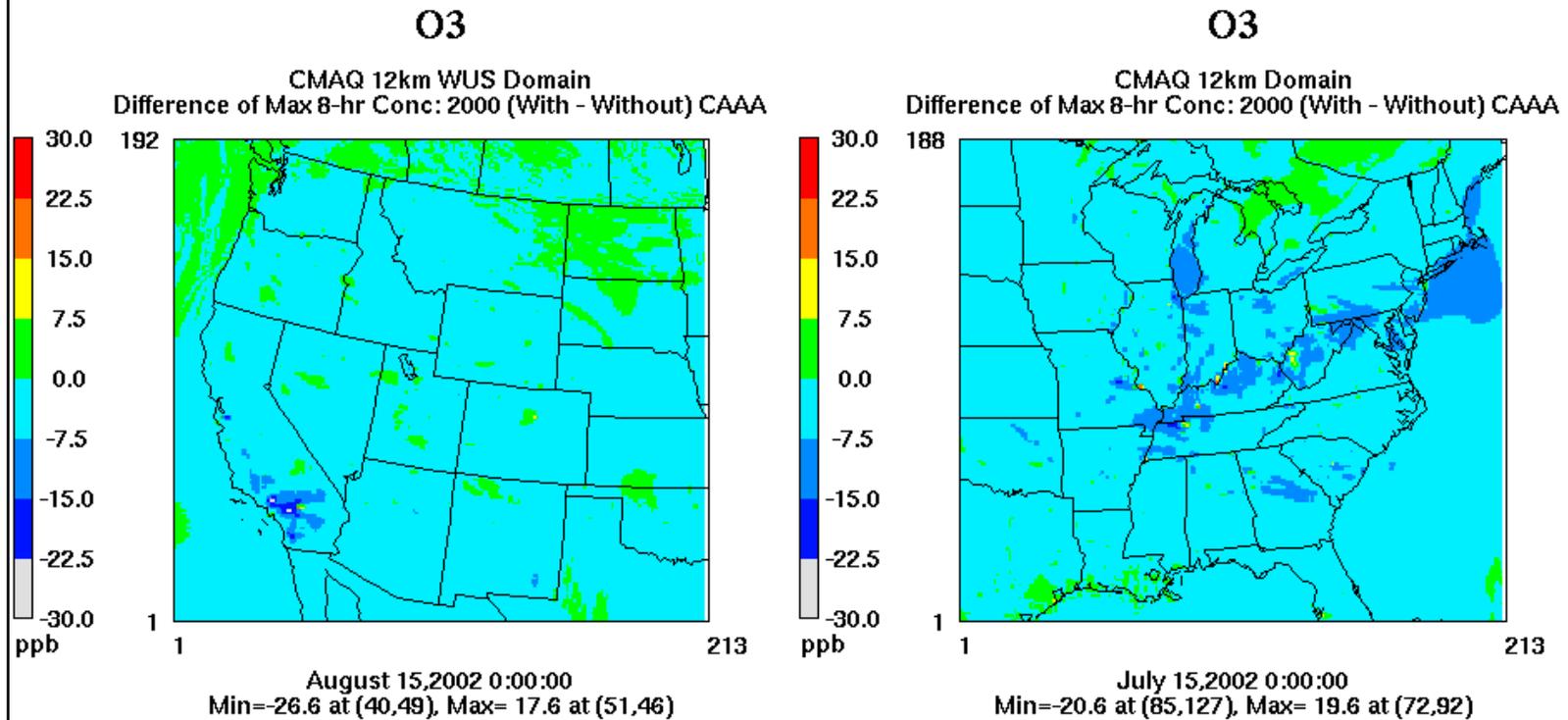
**Without CAAA**



**With CAAA**

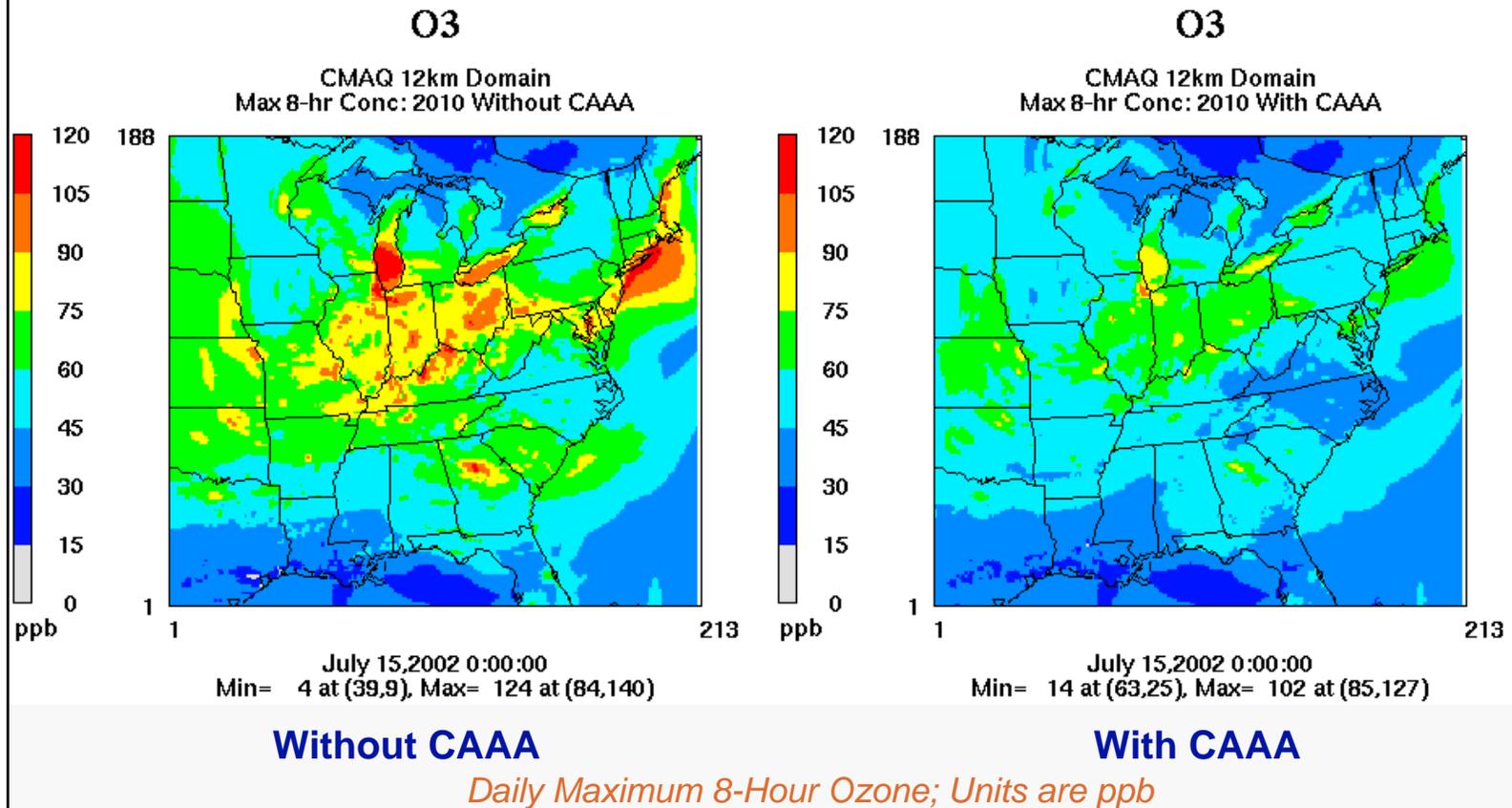
*Daily Maximum 8-Hour Ozone; Units are ppb*

# Difference in Simulated 8-Hr Ozone With CAAA – Without CAAA: 2000

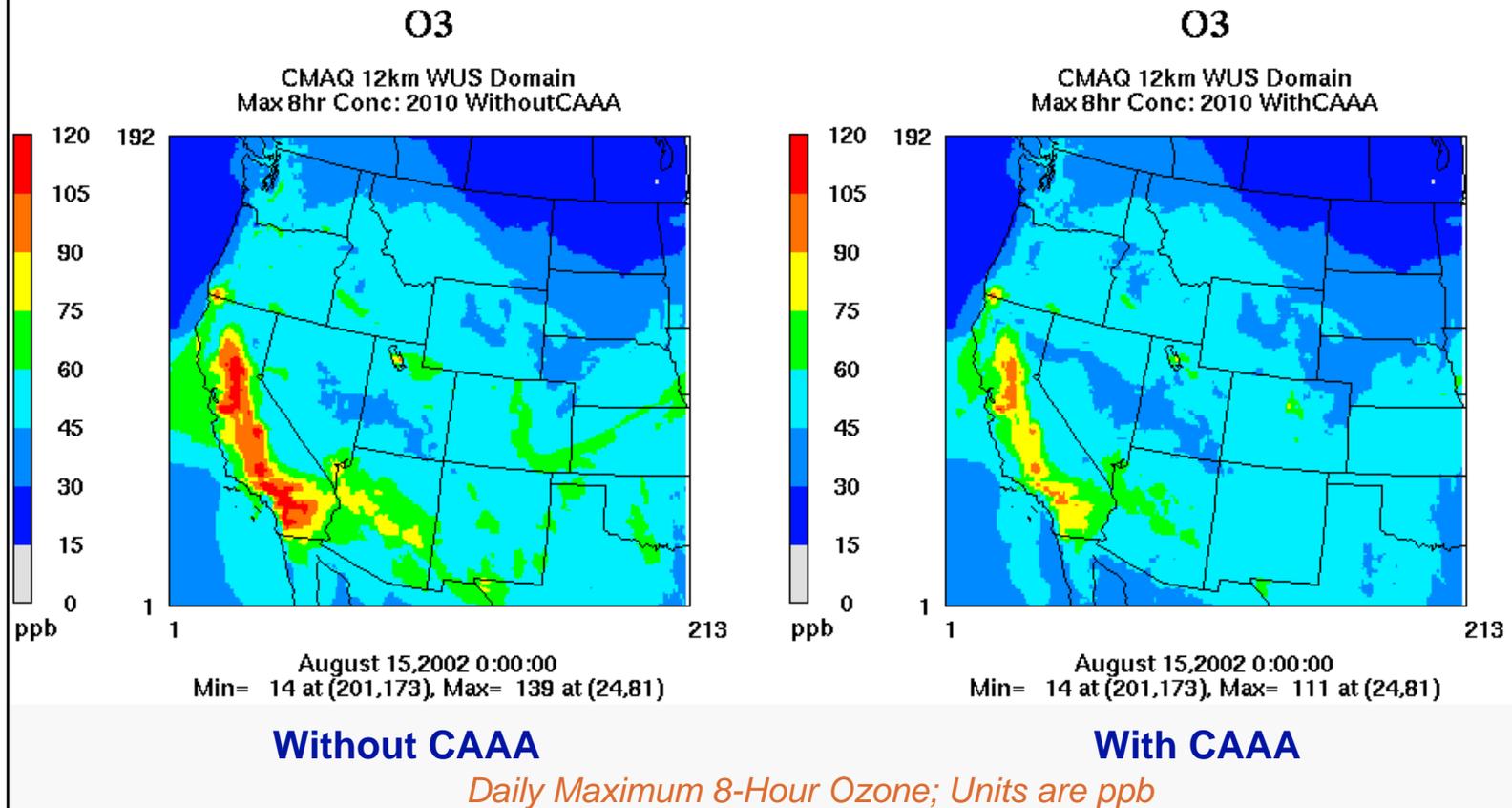


*Daily Maximum 8-Hour Ozone; Units are ppb*

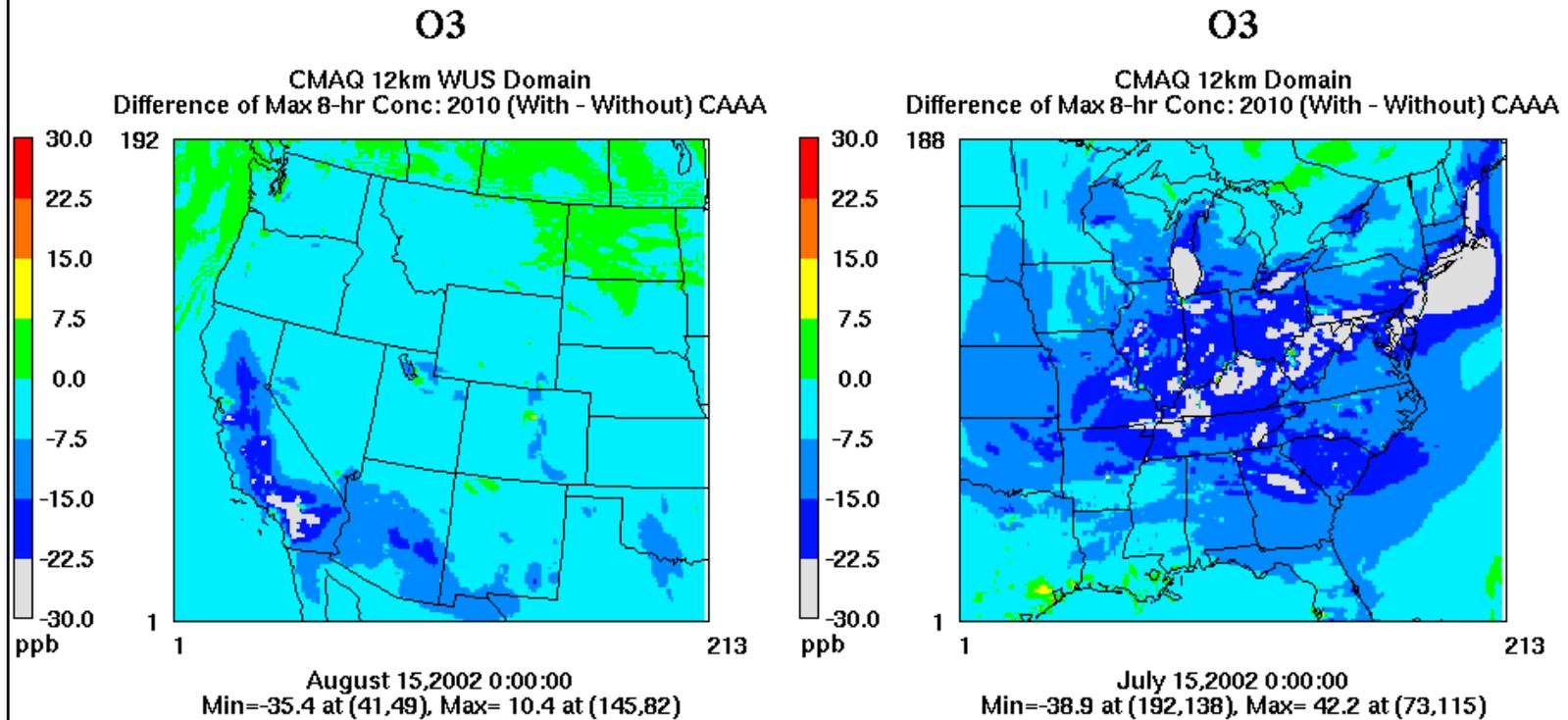
# Ozone Modeling Results (EUS): 2010



# Ozone Modeling Results (WUS): 2010

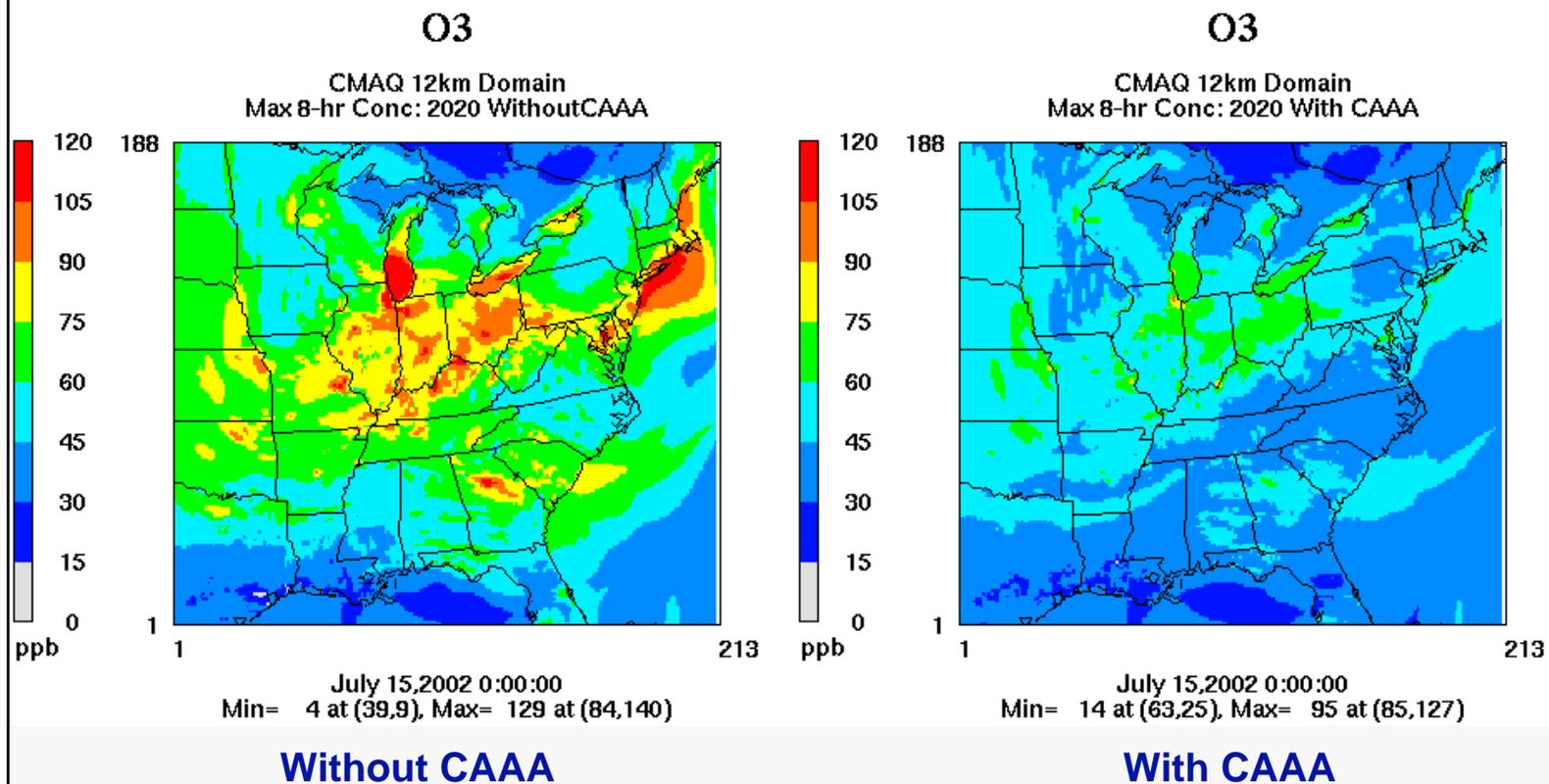


# Difference in Simulated 8-Hr Ozone With CAAA – Without CAAA: 2010



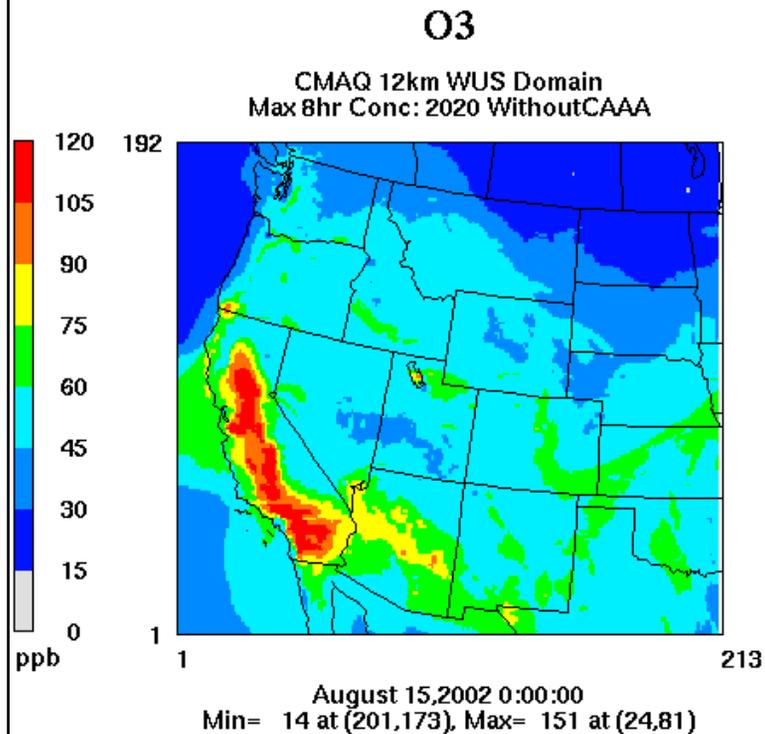
*Daily Maximum 8-Hour Ozone; Units are ppb*

# Ozone Modeling Results (EUS): 2020

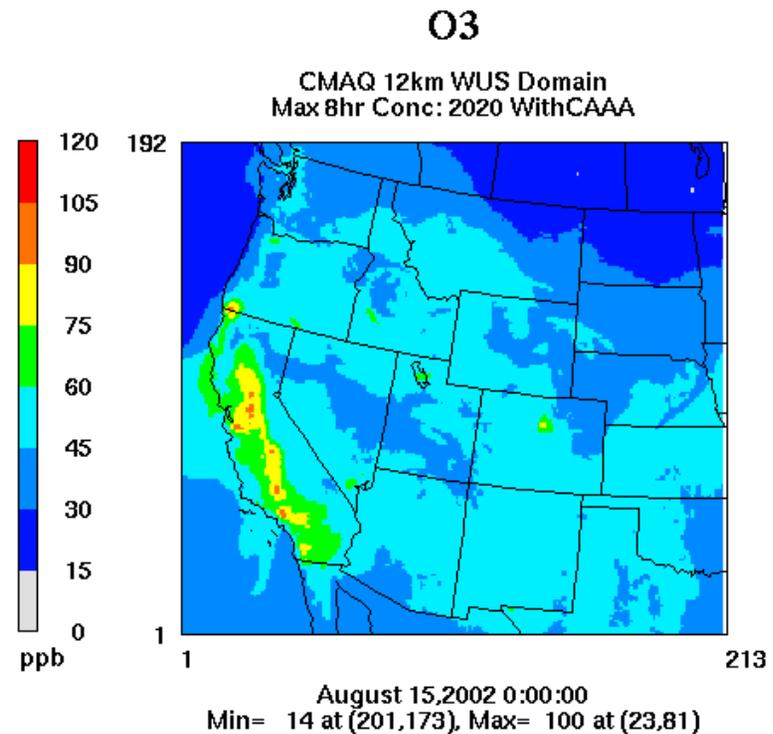


*Daily Maximum 8-Hour Ozone; Units are ppb*

# Ozone Modeling Results (WUS): 2020



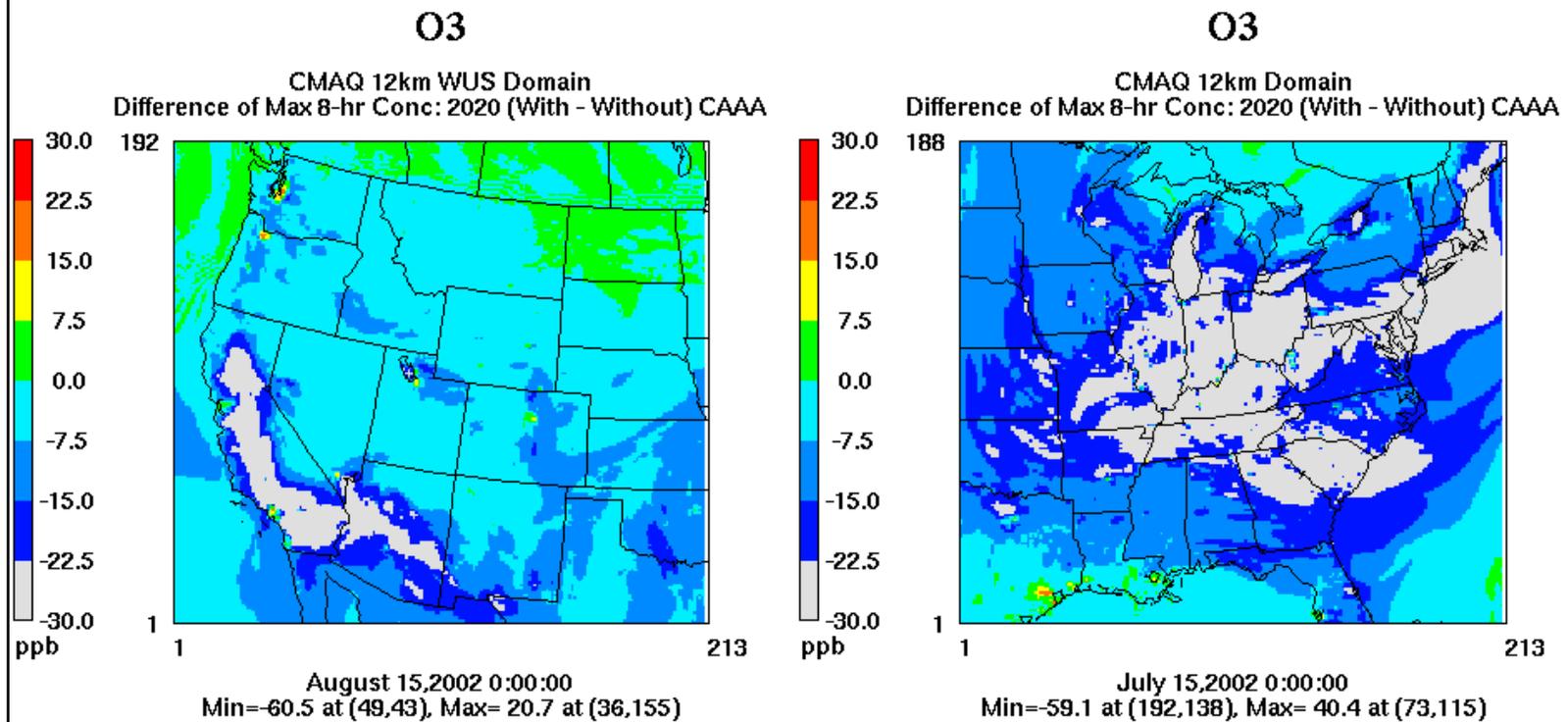
**Without CAAA**



**With CAAA**

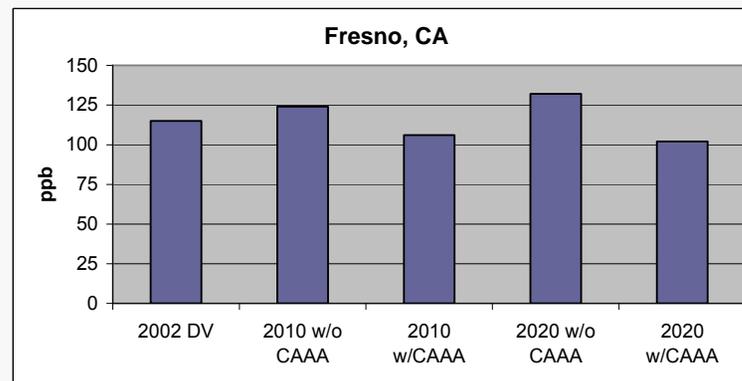
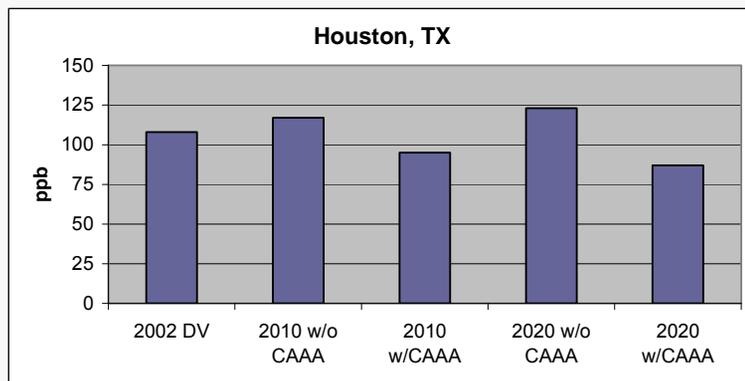
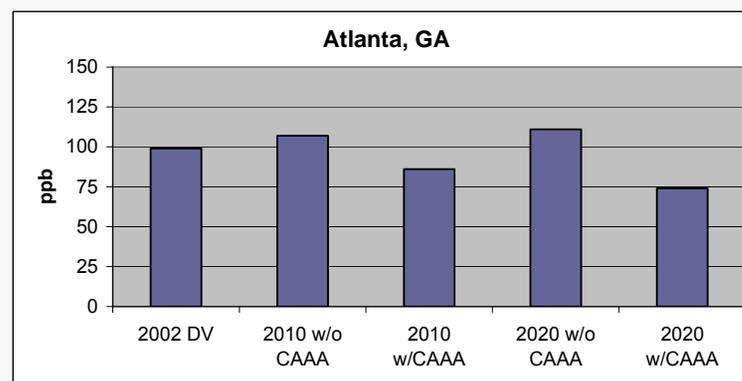
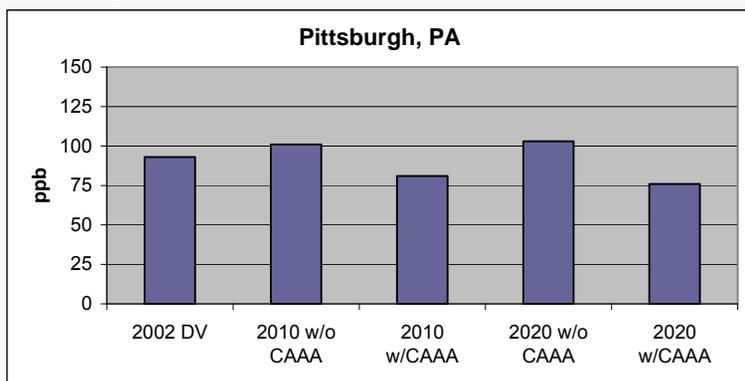
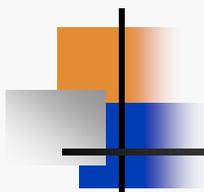
*Daily Maximum 8-Hour Ozone; Units are ppb*

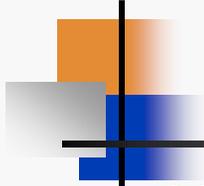
# Difference in Simulated 8-Hr Ozone With CAAA – Without CAAA: 2020



*Daily Maximum 8-Hour Ozone; Units are ppb*

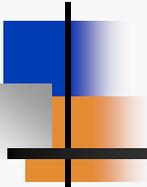
# Actual & Estimated 8-Hour Ozone Design Values





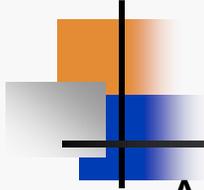
## Summary of CMAQ Modeling Results for Ozone

- Used to calculate ozone-related health effects & visibility
- For 2000, 2010 & 2020, there is a significant reduction in simulated daily maximum ozone concentrations with CAAA (compared to without CAAA)
- The extent and magnitude of the decreases due to CAAA measures increases with projection year



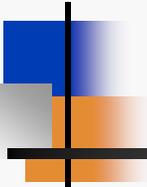
# Attributes & Limitations

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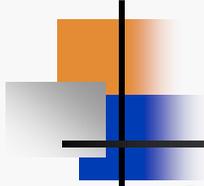
# Attributes & Limitations of the §812 Modeling Analysis

- Attributes
  - Use of CMAQ for both ozone & particulate modeling provides a consistent platform for evaluating the responses to changes in precursor emissions
  - CMAQ grid resolution & annual/seasonal simulation periods consistent with EPA modeling guidance
- Limitations
  - Pre-existing national-scale databases used; Biases & uncertainties due to use of the 36- and 12-km grid resolutions are expected
  - Air quality forecasts provided by CMAQ for future years are only as good as the future-year emission estimates



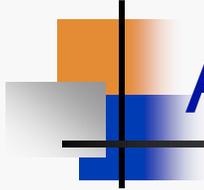
# Uncertainty Factors

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## Key Sources of Uncertainty: Emissions Processing

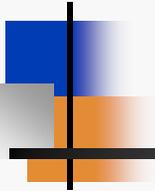
- Speciation of emissions
- Spatial & temporal allocation of emissions
- Biogenic emission estimates
- Base-year emissions data & projection assumptions
- Future-year control assumptions and measures

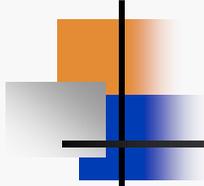


## Key Sources of Uncertainty: Air Quality Modeling Application

- Quality & representativeness of the meteorological inputs
- Boundary conditions
- Grid resolution
- Model performance
- Attribution of changes in air quality to specific measures or source categories

# Base-Year Model Performance Evaluation

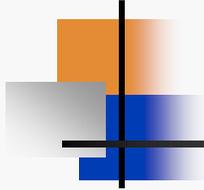




## AMET-Based MPE

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- Atmospheric Model Evaluation Tool (AMET) used to compare CMAQ results with observed data
  - Ozone, PM<sub>2.5</sub>, PM<sub>2.5</sub> component species, deposition
  - AQS, STN, IMPROVE, CASTNet, NADP datasets
  - 2000 with-CAAA scenario model output (2002 meteorological base year) paired with 2002 observed air quality data



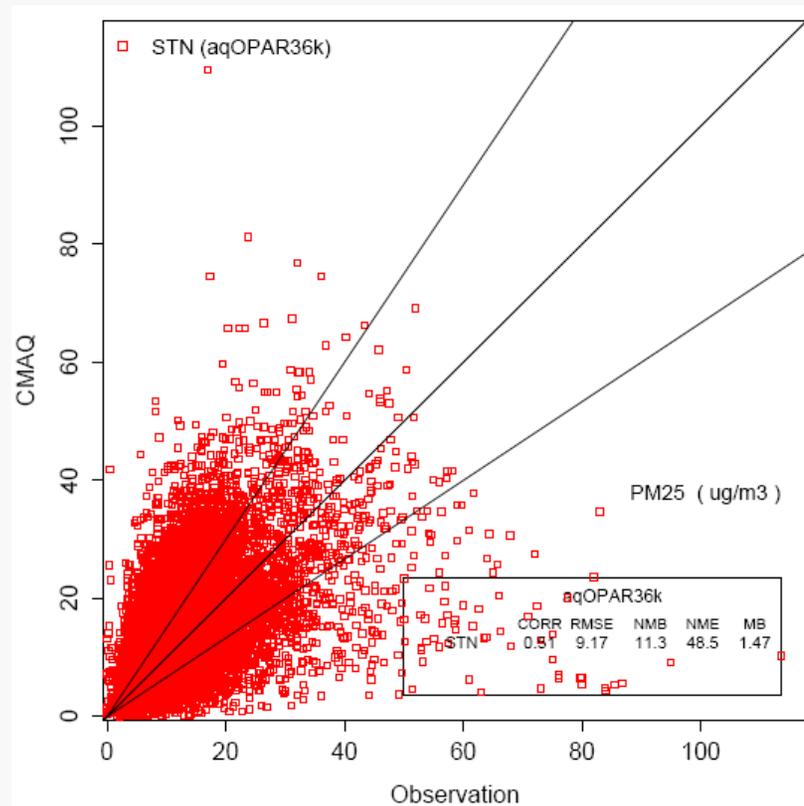
## Summary Model Performance: PM<sub>2.5</sub>

- STN, IMPROVE & CASTNet statistics separate due to measurement differences (techniques, species & frequency)
- Metric: 24-hr average PM<sub>2.5</sub>
- Key statistical measures:

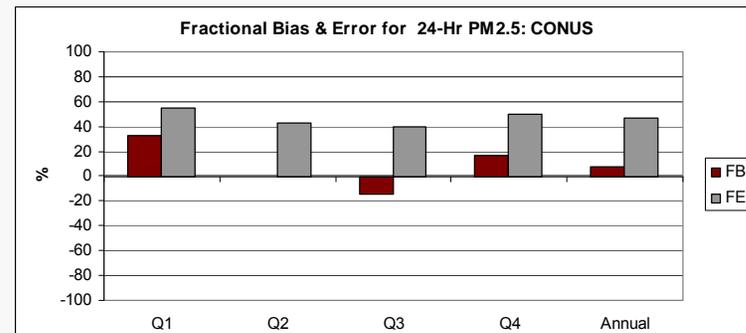
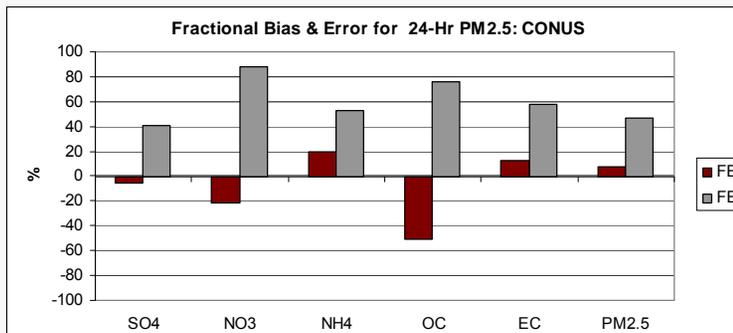
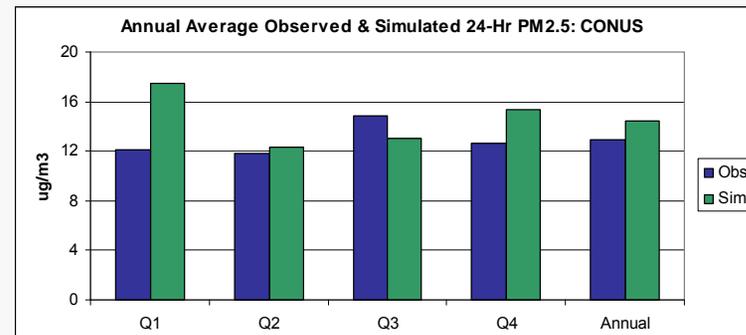
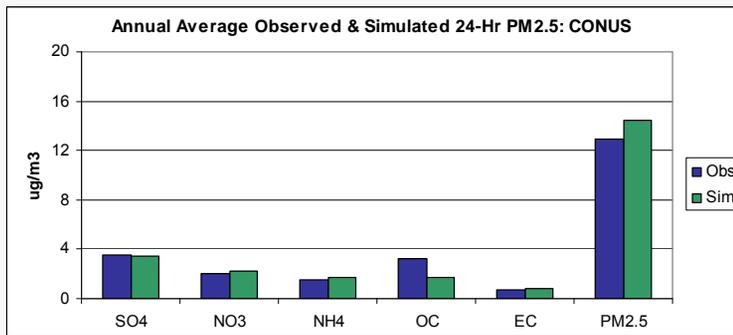
Fractional Bias: 
$$\left(\frac{1}{N}\right)\sum_{l=1}^N (S_l - O_l)/0.5(S_l + O_l) \cdot 100\%$$

Fractional Error: 
$$\left(\frac{1}{N}\right)\sum_{l=1}^N |S_l - O_l|/0.5(S_l + O_l) \cdot 100\%$$

# Summary Model Performance: PM<sub>2.5</sub> (STN; CONUS)

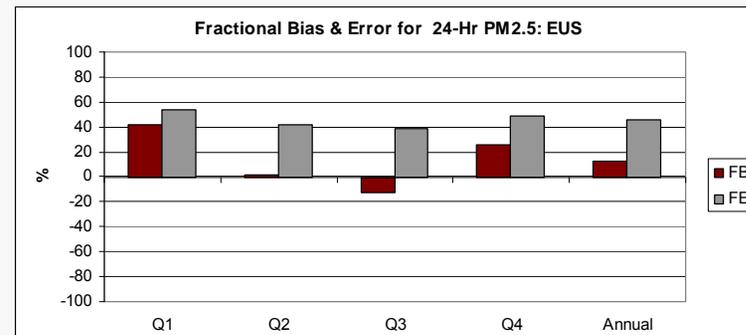
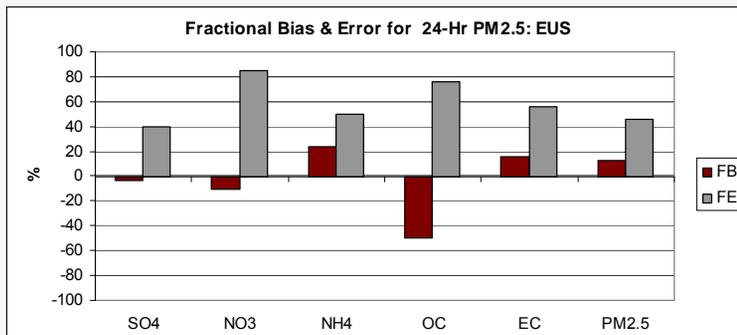
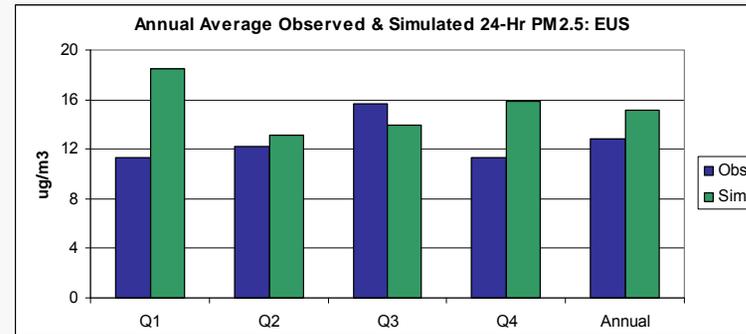
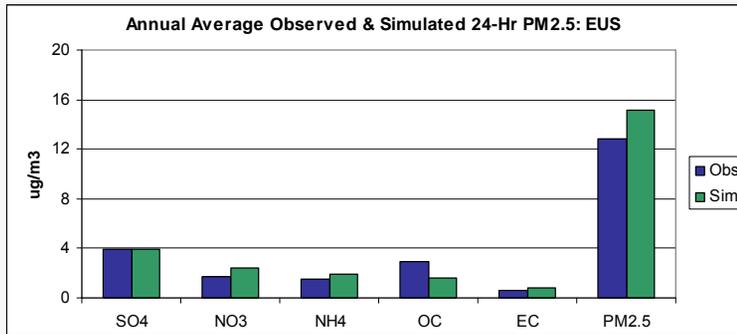


# Summary Model Performance: PM<sub>2.5</sub> (STN; CONUS)



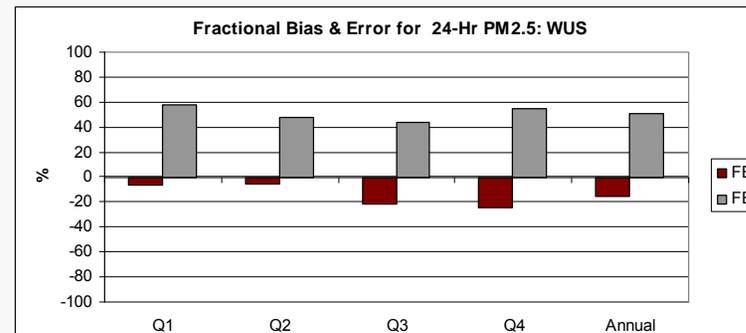
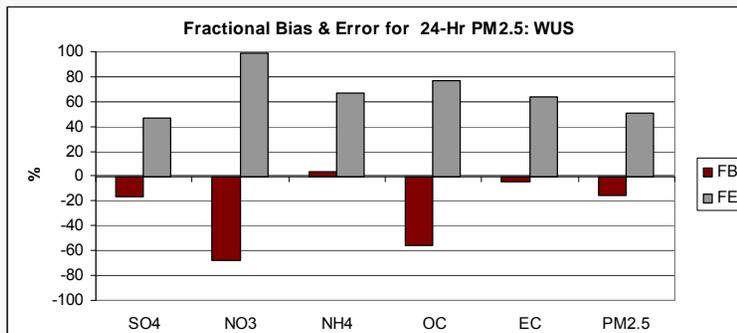
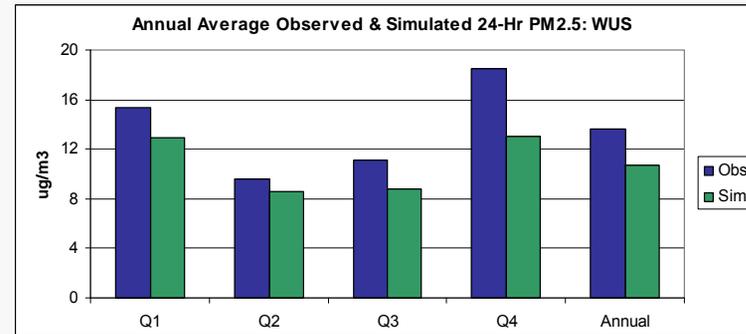
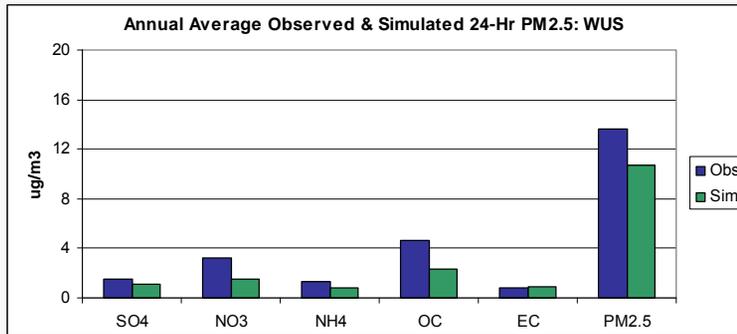
Goals: Fractional Bias  $\pm$  30%  
Fractional Error:  $\leq$  50%

# Summary Model Performance: PM<sub>2.5</sub> (STN; EUS\*)



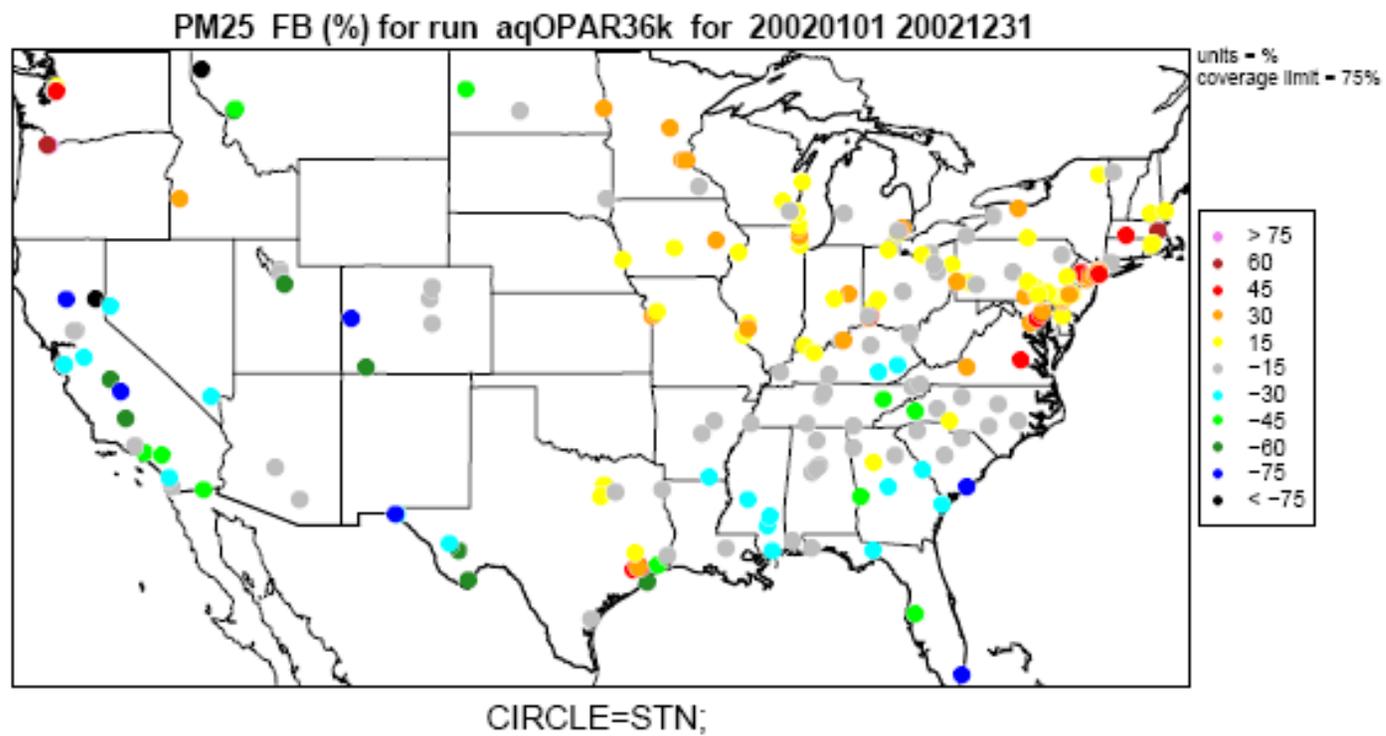
Goals: Fractional Bias  $\pm$  30%  
Fractional Error:  $\leq$  50%

# Summary Model Performance: PM<sub>2.5</sub> (STN; WUS\*)

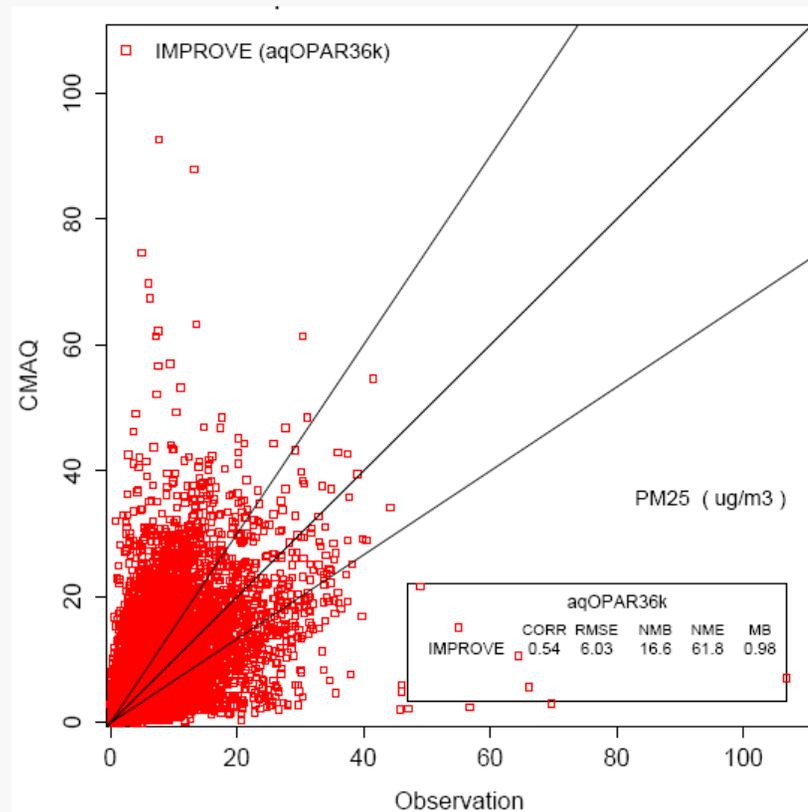


Goals: Fractional Bias  $\pm$  30%  
Fractional Error:  $\leq$  50%

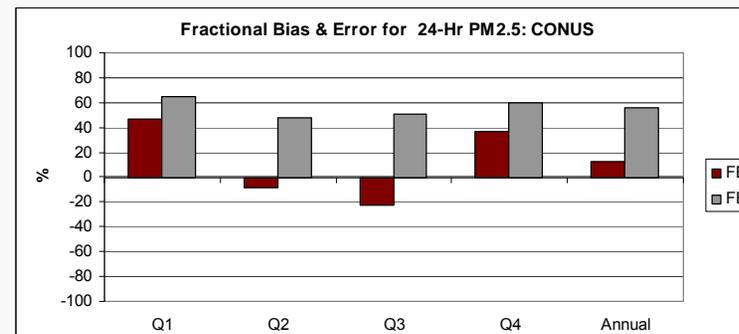
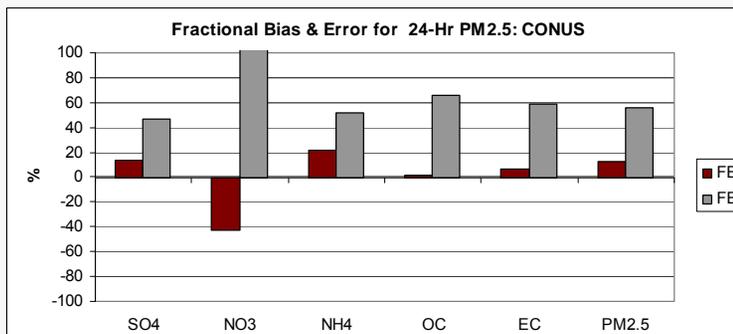
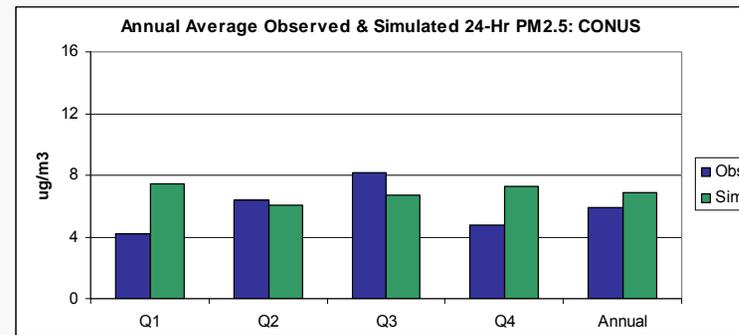
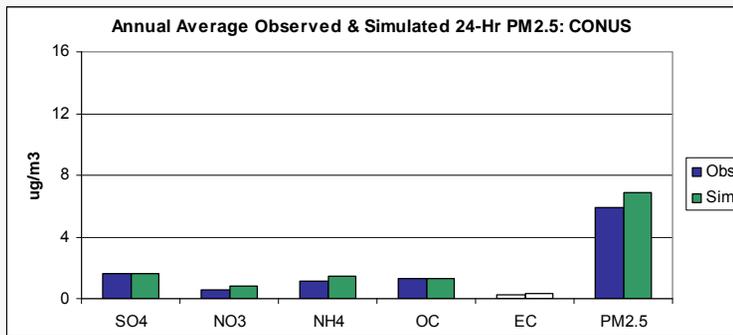
# Summary Model Performance: PM<sub>2.5</sub> (STN; CONUS)



# Summary Model Performance: PM<sub>2.5</sub> (IMPROVE; CONUS)

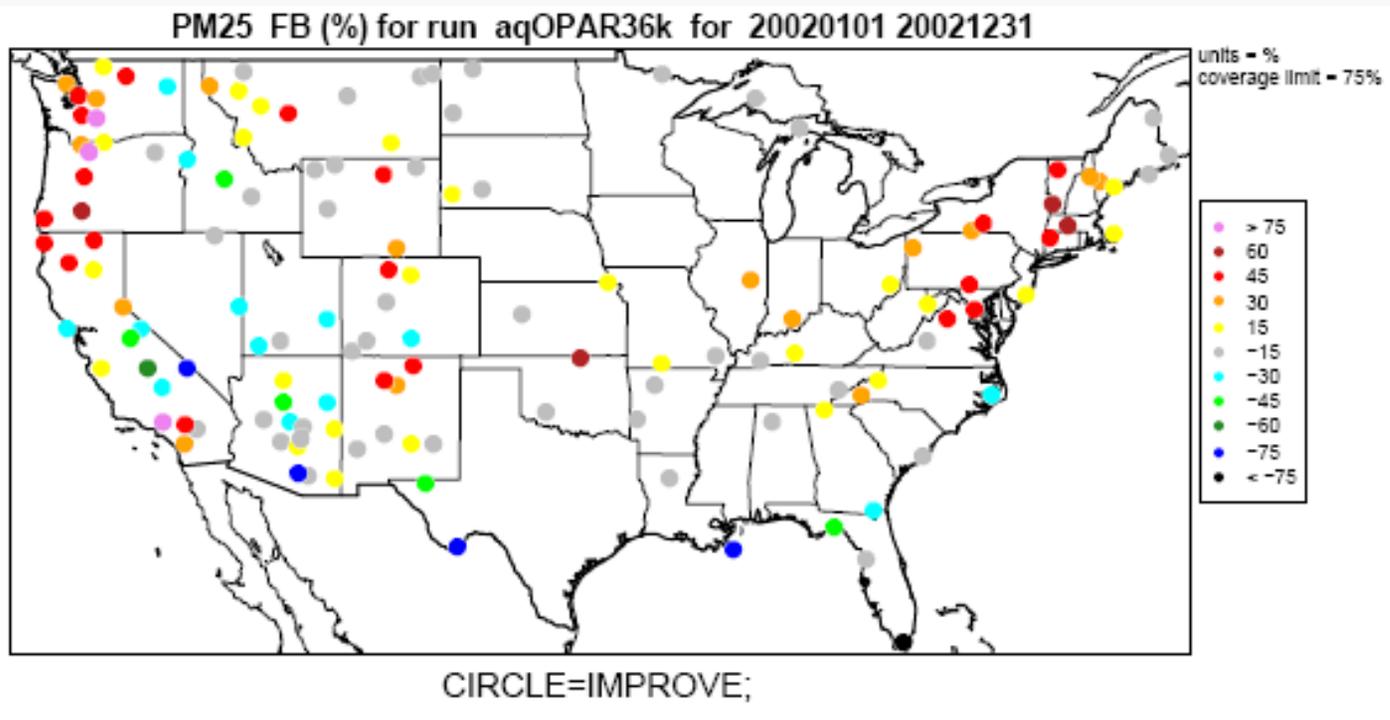


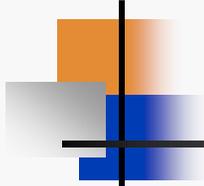
# Summary Model Performance: PM<sub>2.5</sub> (IMPROVE; CONUS)



Goals: Fractional Bias  $\pm$  30%  
Fractional Error:  $\leq$  50%

# Summary Model Performance: PM<sub>2.5</sub> (IMPROVE; CONUS)





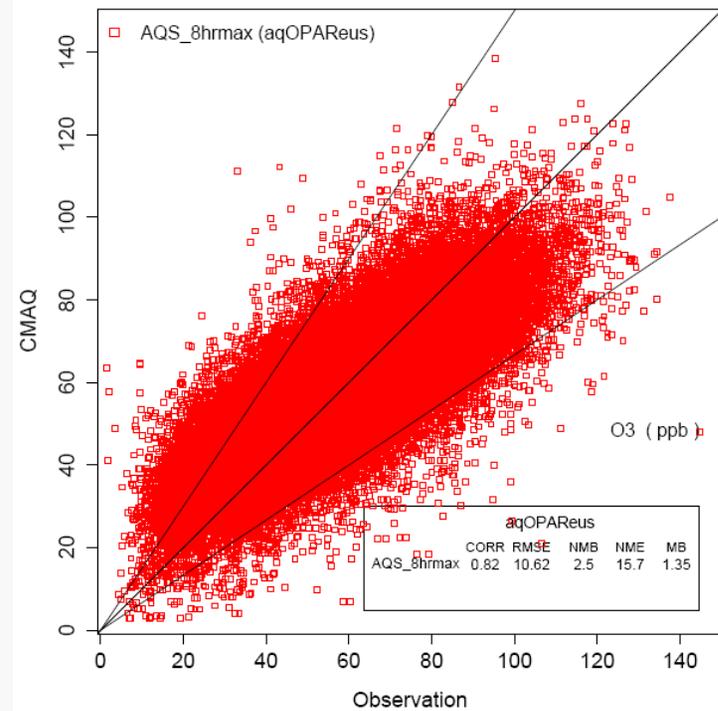
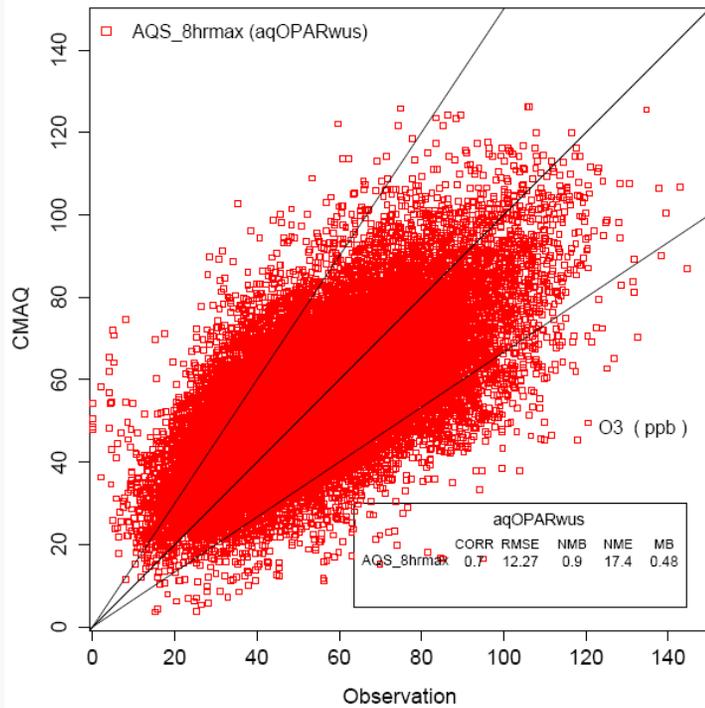
## Summary Model Performance: Ozone

- AQS ozone data
- Metric: Daily maximum 8-hr average ozone
- Key statistical measures:

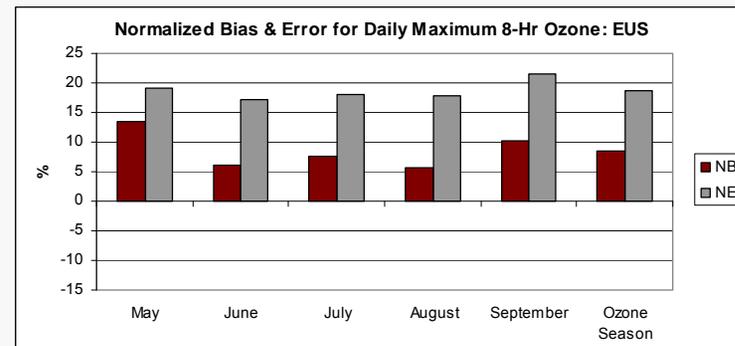
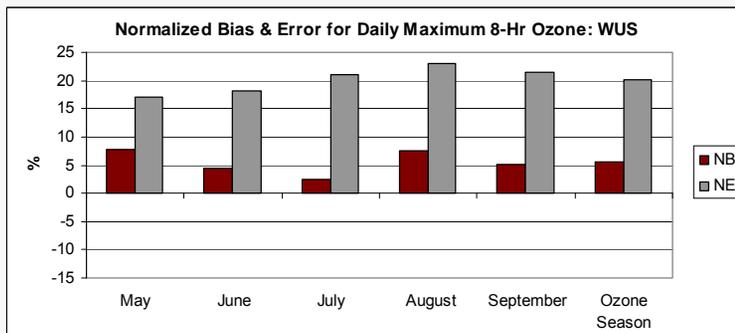
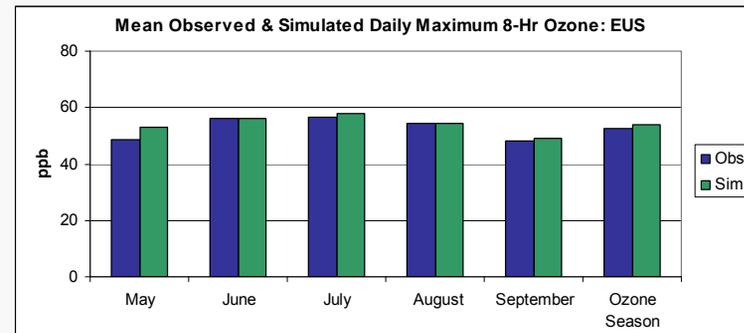
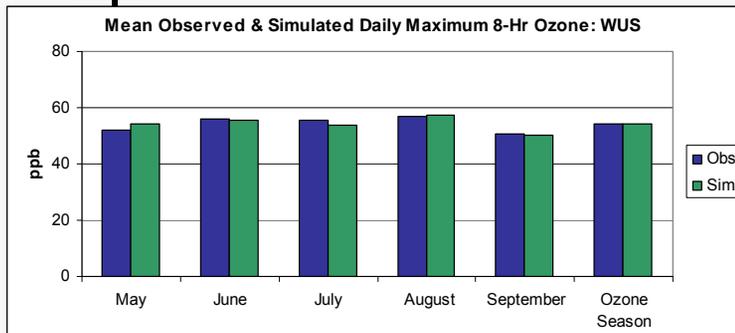
Normalized Bias: 
$$\left(\frac{1}{N}\right)\sum_{l=1}^N (S_l - O_l)/O_l \cdot 100\%$$

Normalized Error: 
$$\left(\frac{1}{N}\right)\sum_{l=1}^N |S_l - O_l|/O_l \cdot 100\%$$

# Summary Model Performance: Ozone (AQS; WUS & EUS)

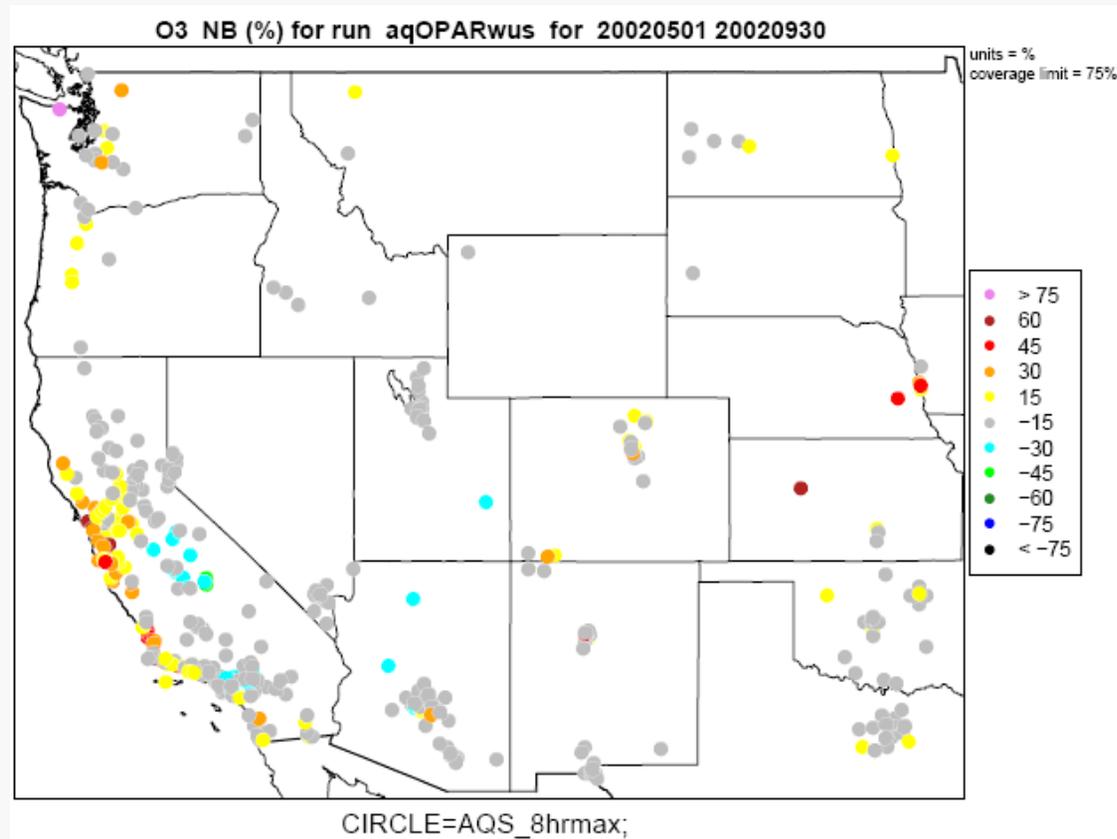


# Summary Model Performance: Ozone (AQS; WUS & EUS)

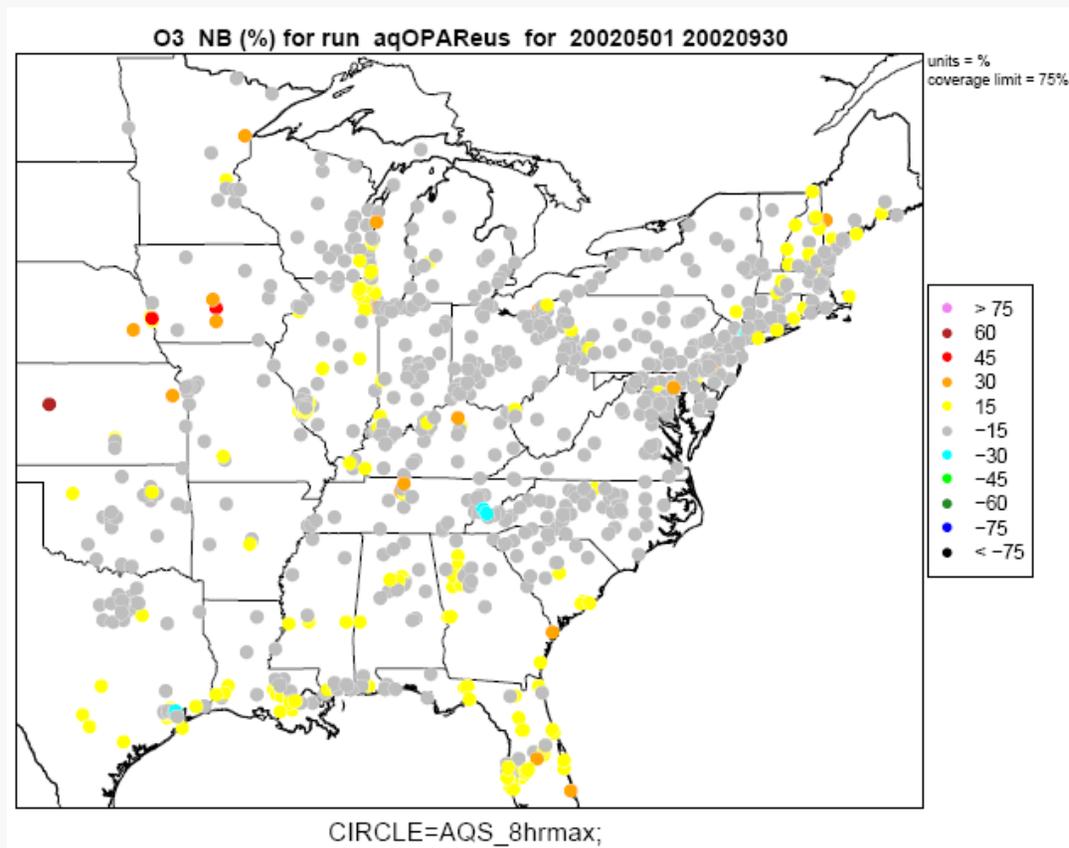


Goals: Normalized Bias  $\pm 15\%$   
Normalized Error:  $\leq 35\%$

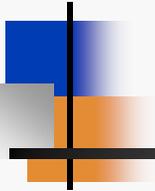
# Summary Model Performance: Ozone (AQS; WUS)

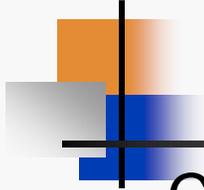


# Summary Model Performance: Ozone (AQS; EUS)



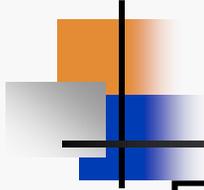
# Recommendations for Future §812 Air Quality Modeling Studies





## Recommendations for Future §812 Modeling (1)

- Conduct modeling to evaluate any changes in the expected magnitude & timing of future emission reductions for EGU sources due to revisions to CAIR or CAMR
- Continue to utilize the most up-to-date NEI estimates, taking advantage of
  - updates in population & activity levels
  - revisions in emission factors
  - new information submitted to EPA by states
- Use meteorological inputs from a different base year (e.g., 2005) to test the robustness of the results for another set of annual conditions



## Recommendations for Future §812 Modeling (2)

- Extend the use of PPTM (and OPTM) to further evaluate contributions to simulated PM & ozone and better quantify control effectiveness (& resulting benefits/costs) by source category, pollutant & geographic area
- Examine the effects & benefits of CAAA controls on mercury deposition to watersheds
- Modify future-year meteorological inputs to reflect expected changes in meteorology due to climate change, and evaluate how emission reduction effectiveness changes under these conditions