Atmospheric Mercury Model Testing and Application in North America

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Major Atmospheric Mercury Model Testing and Application Studies

- North American Mercury Model Inter-comparison Study (NAMMIS)
- CMAQ-Hg modeling to support the development of the Clean Air Mercury Rule (CAMR)

North American Mercury Model Intercomparison Study (NAMMIS)

Motivation

- Various modeling studies have been conducted to estimate the sources of atmospheric mercury (Hg) responsible for observed Hg deposition in the United States and other nations. These studies have sometimes come to rather different conclusions.
- A Hg model inter-comparison study was previously conducted by the Meteorological Synthesizing Centre – East (MSC-E). This original model inter-comparison study provided valuable information about variations between models in their input data and science process treatments and about mercury transports within Europe.
- The NAMMIS is a follow-on effort to apply atmospheric Hg models in a more tightly constrained testing environment where all models use the same input data and the focus of the study is on North America.

North American Mercury Model Intercomparison Study (NAMMIS)

Technique

- Each regional-scale model uses the same inputs for initial and boundary conditions, meteorology and emissions.
- Three sets of initial condition / boundary condition (IC/BC) data are used which are based on simulations of three separate global-scale models.
- Each regional-scale model uses the same horizontal modeling domain.

Desired Outcome

- The separate effects of input data and scientific process treatments within each model can be better understood.
- Better guidance can be provided to the research community regarding which scientific process uncertainties are contributing most to observed discrepancies in model simulations of Hg deposition.

North American Mercury Model Intercomparison Study (NAMMIS)

Global Models for IC/BC development

- Chemical Transport Model (CTM) developed and applied by Atmospheric and Environmental Research, Inc.
- GEOS-Chem model developed and applied by Harvard University.
- Global/Regional Atmospheric Heavy Metals (GRAHM) model developed and applied by Environment Canada.

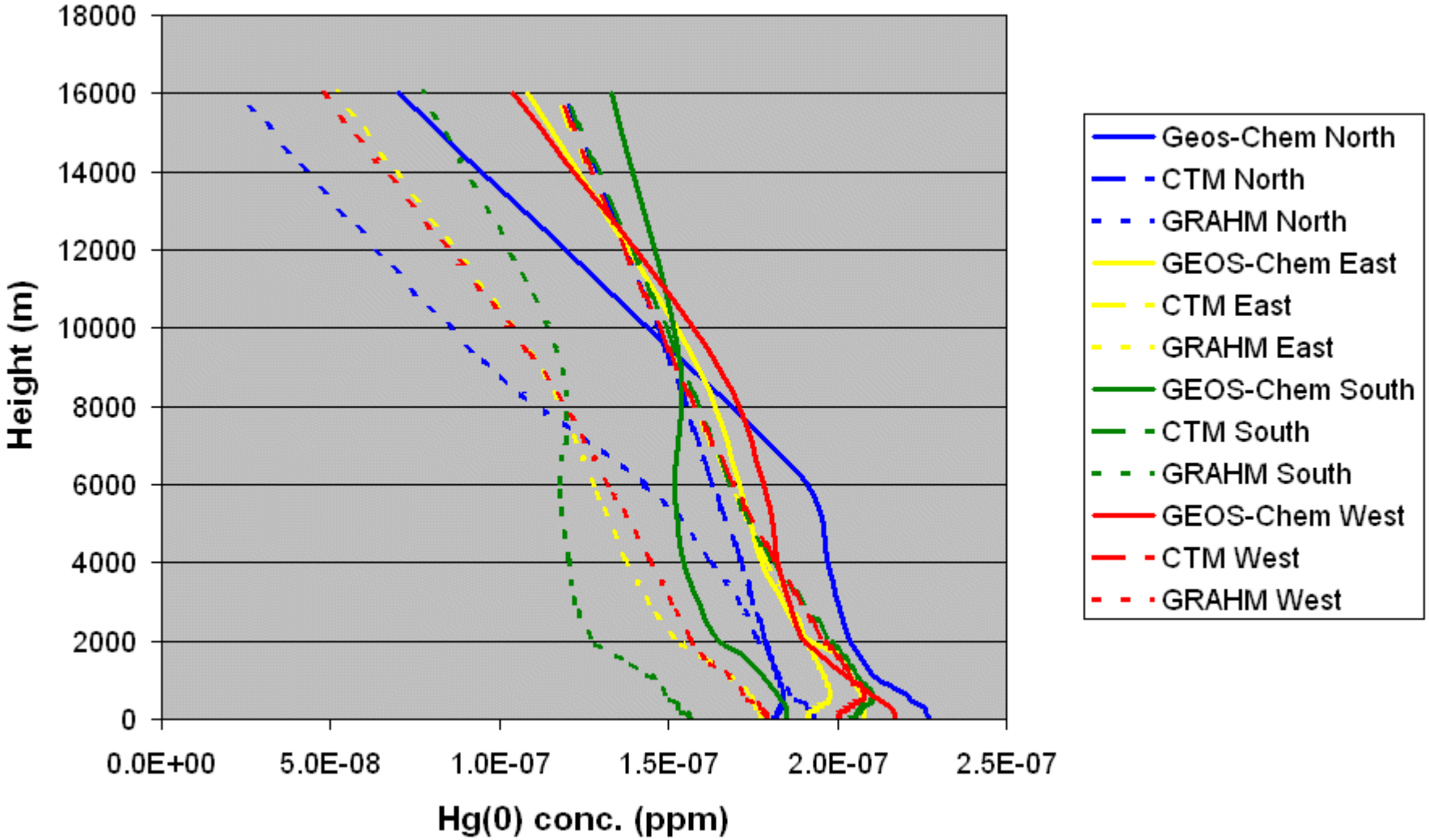
Regional Models that are the focus of the study

- Community Multi-scale Air Quality (CMAQ) model developed and applied by NOAA and U.S. EPA.
- Regional Modeling System for Aerosols and Deposition (REMSAD) developed and applied by ICF International.
- Trace Element Analysis Model (TEAM) developed and applied by Atmospheric and Environmental Research, Inc.

NAMMIS Regional Modeling Domain

Our first bit of insight was gained from looking at the boundary conditions provided from the three global models.

February 2001 Average Lateral Boundary Values



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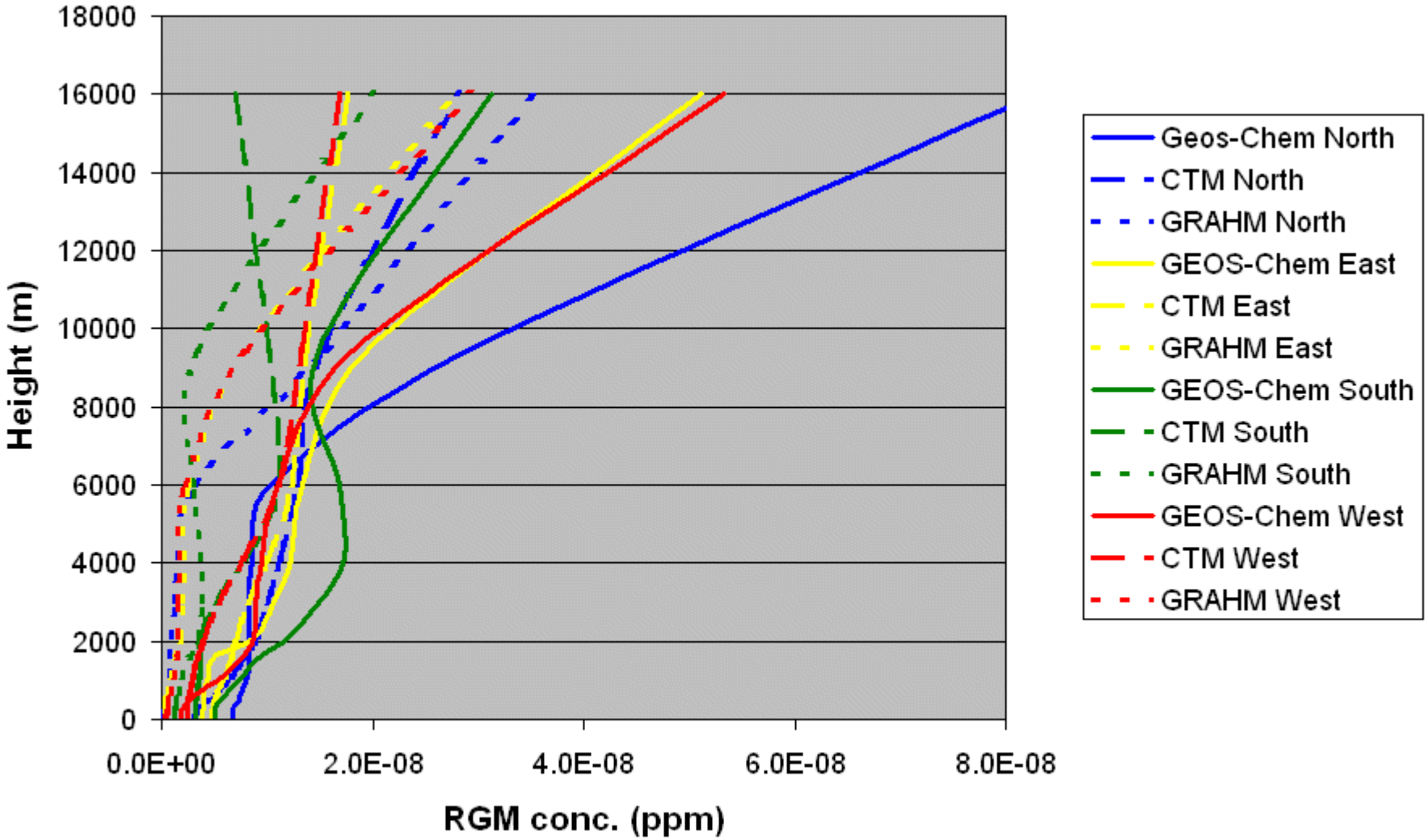

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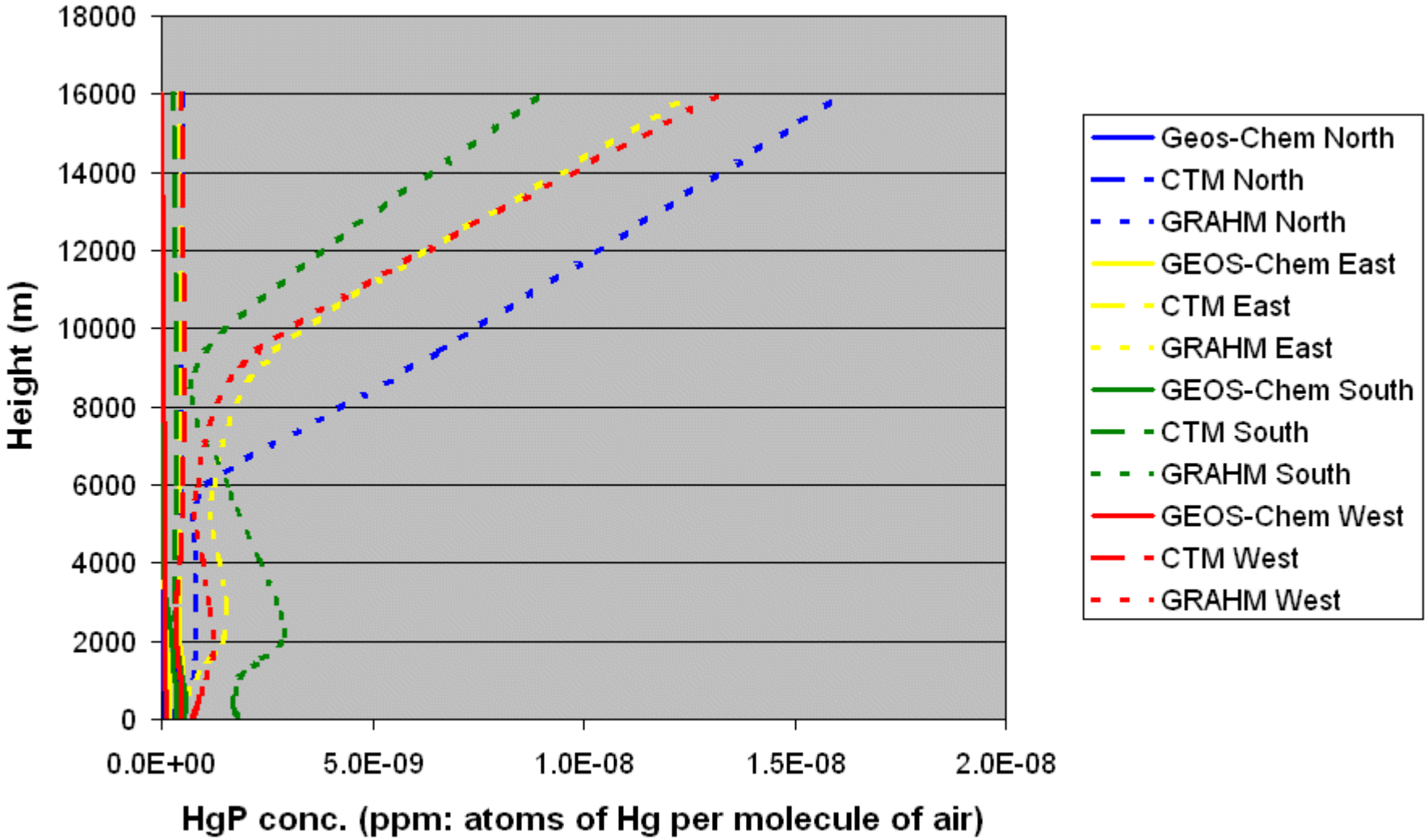
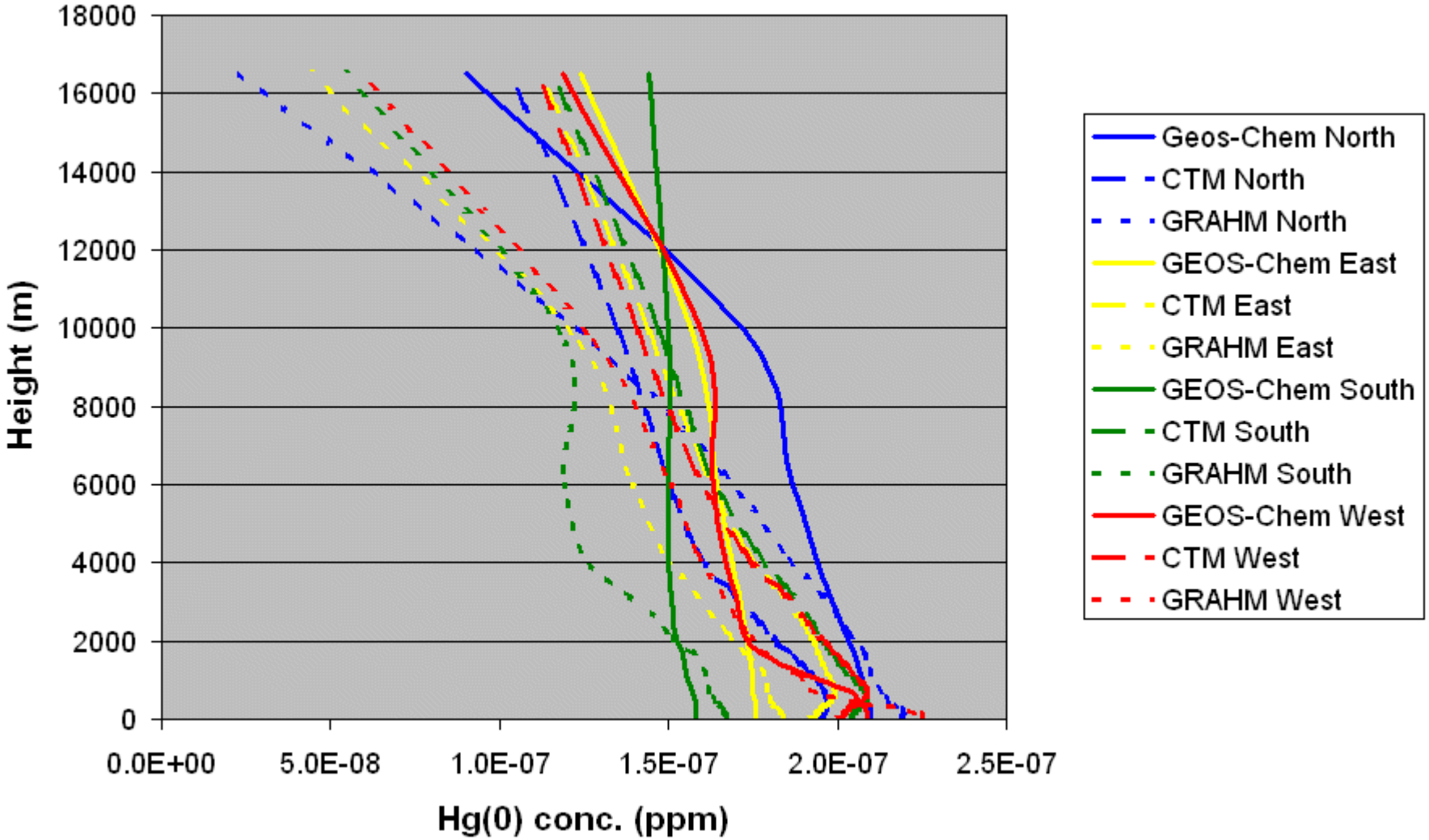
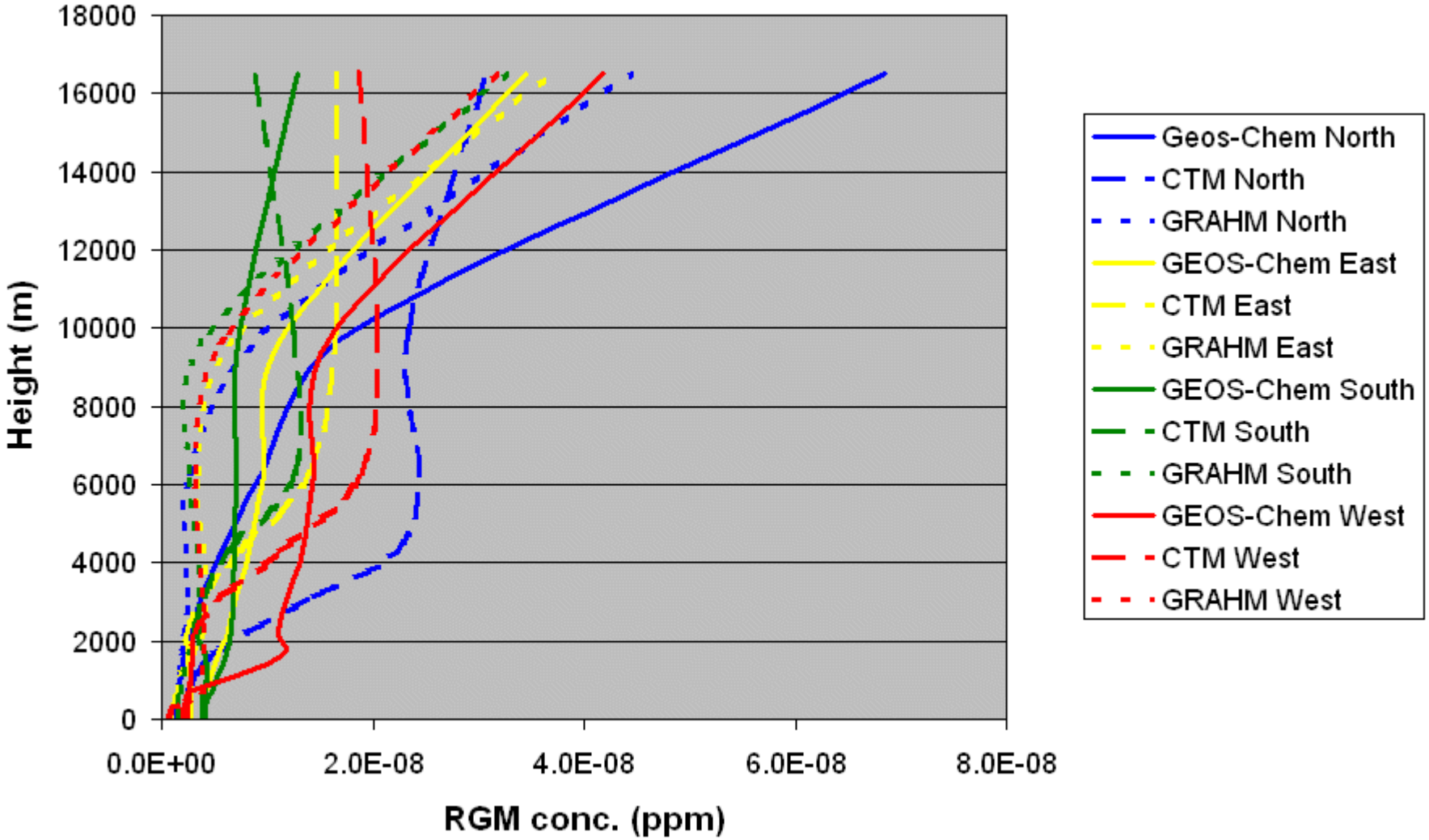


July 2001 Average Lateral Boundary Values



July 2001 Average Lateral Boundary Values



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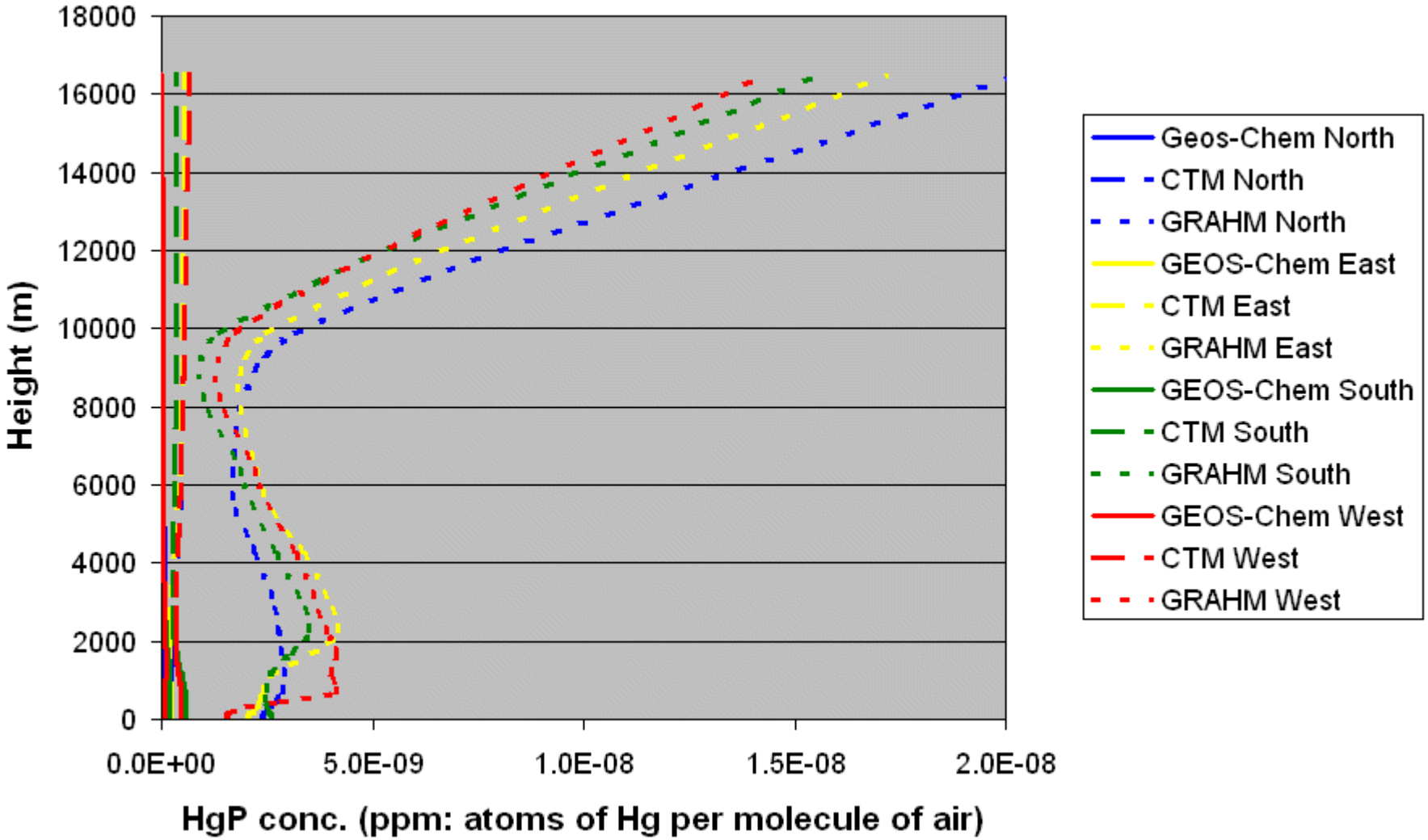
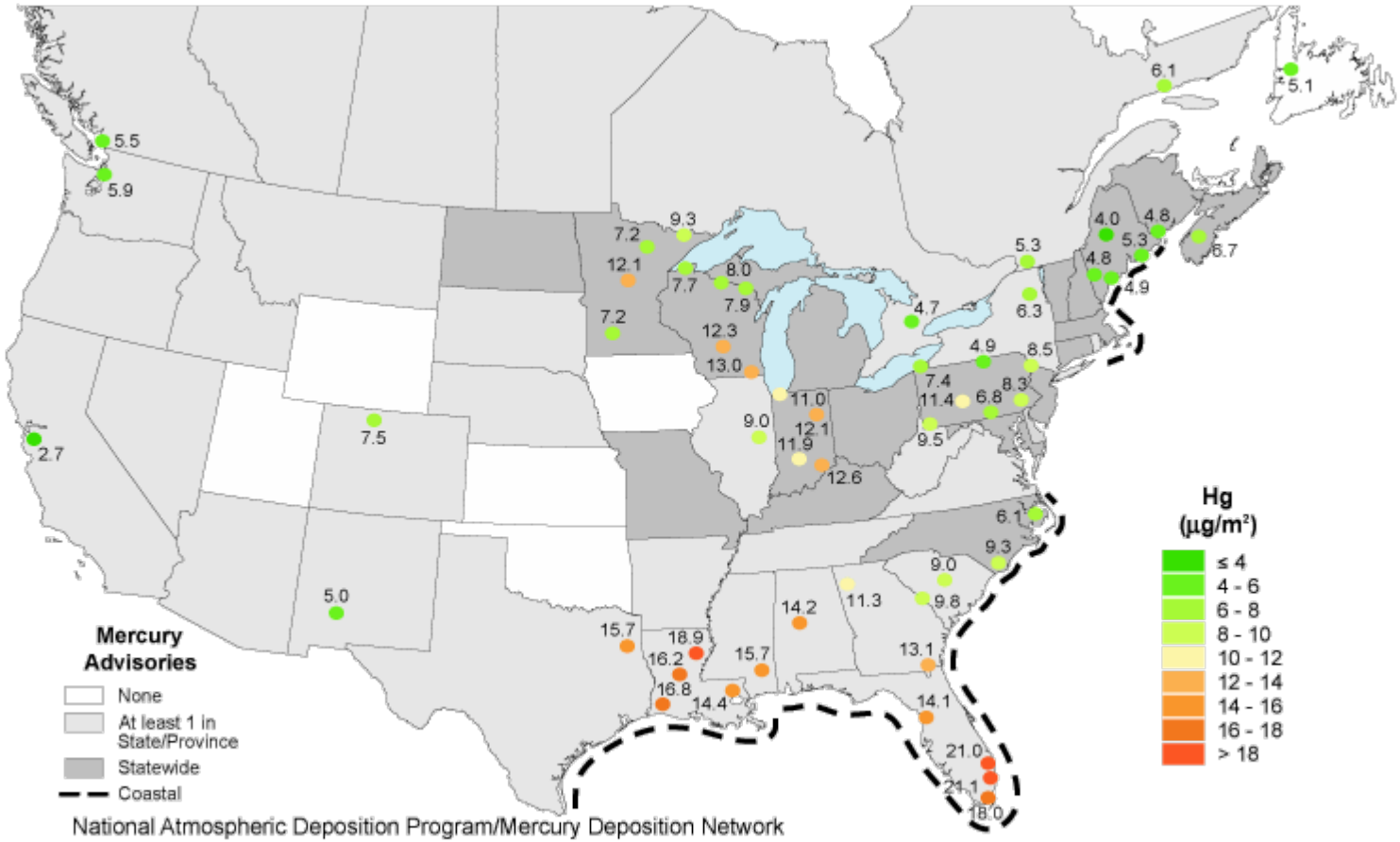


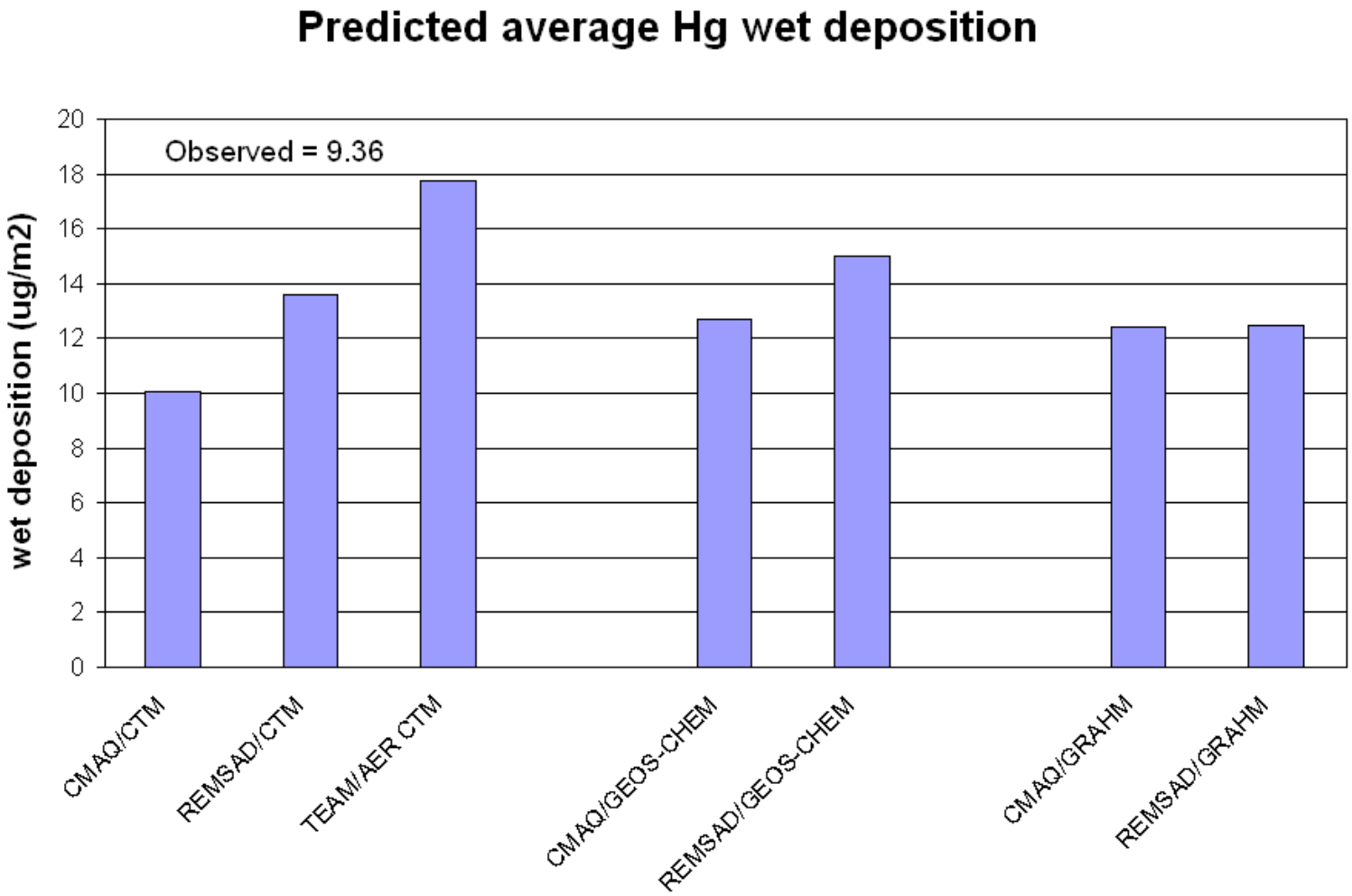
Status of the Regional Model Simulations and Results Analysis

- CMAQ and REMSAD have been applied for all of 2001 using all three IC/BC data sets.
- TEAM has been applied for all of 2001 for only the IC/BC data set derived from the CTM global model. The other two cases are pending.
- These regional modeling results have been compared against 2001 observations from the Mercury Deposition Network (wet deposition only).

Observed Hg Wet Deposition in 2001 from the Mercury Deposition Network (MDN)



Regional Modeling Results Comparison to Observed Total Hg Wet Deposition for 2001



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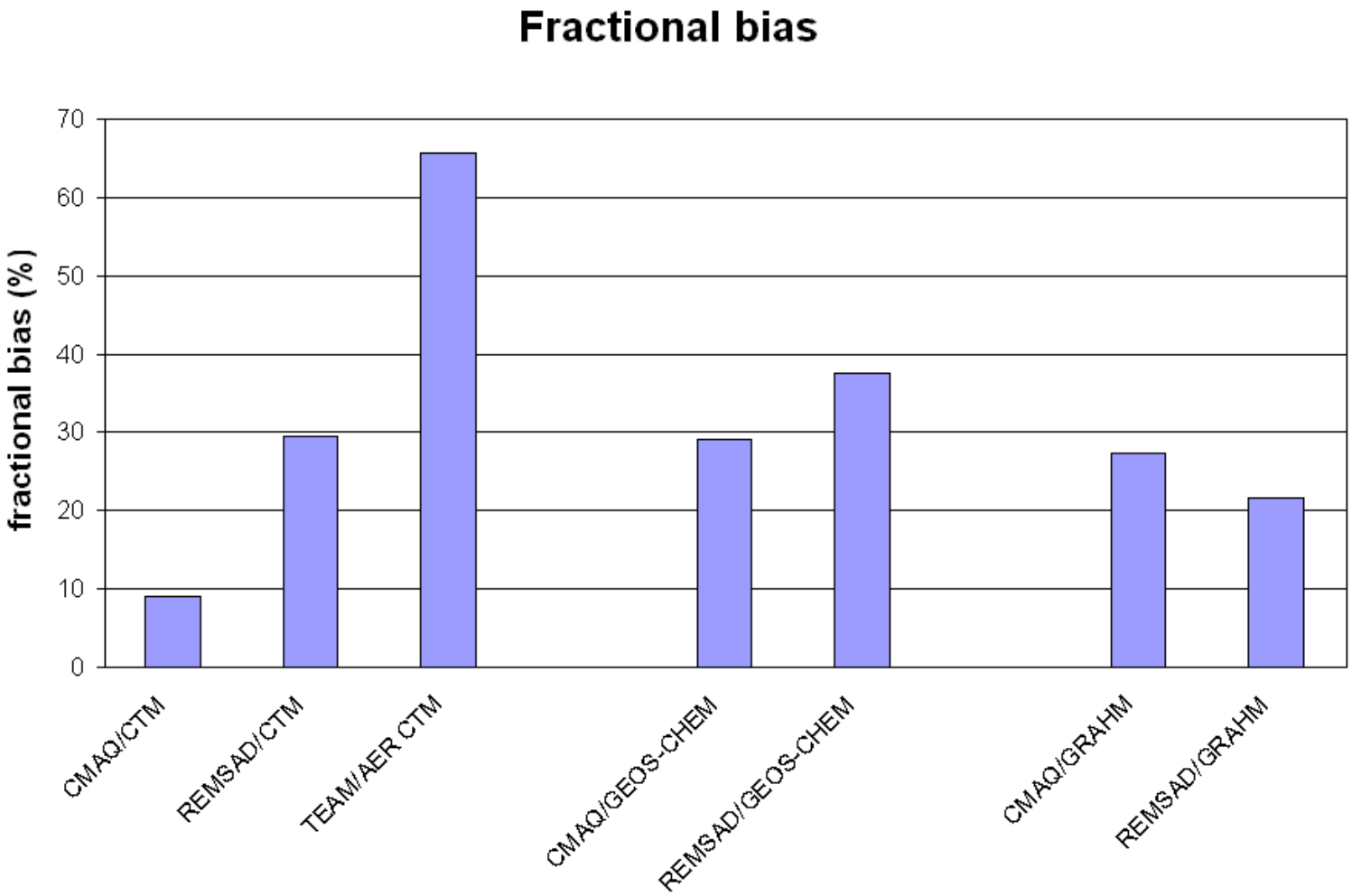

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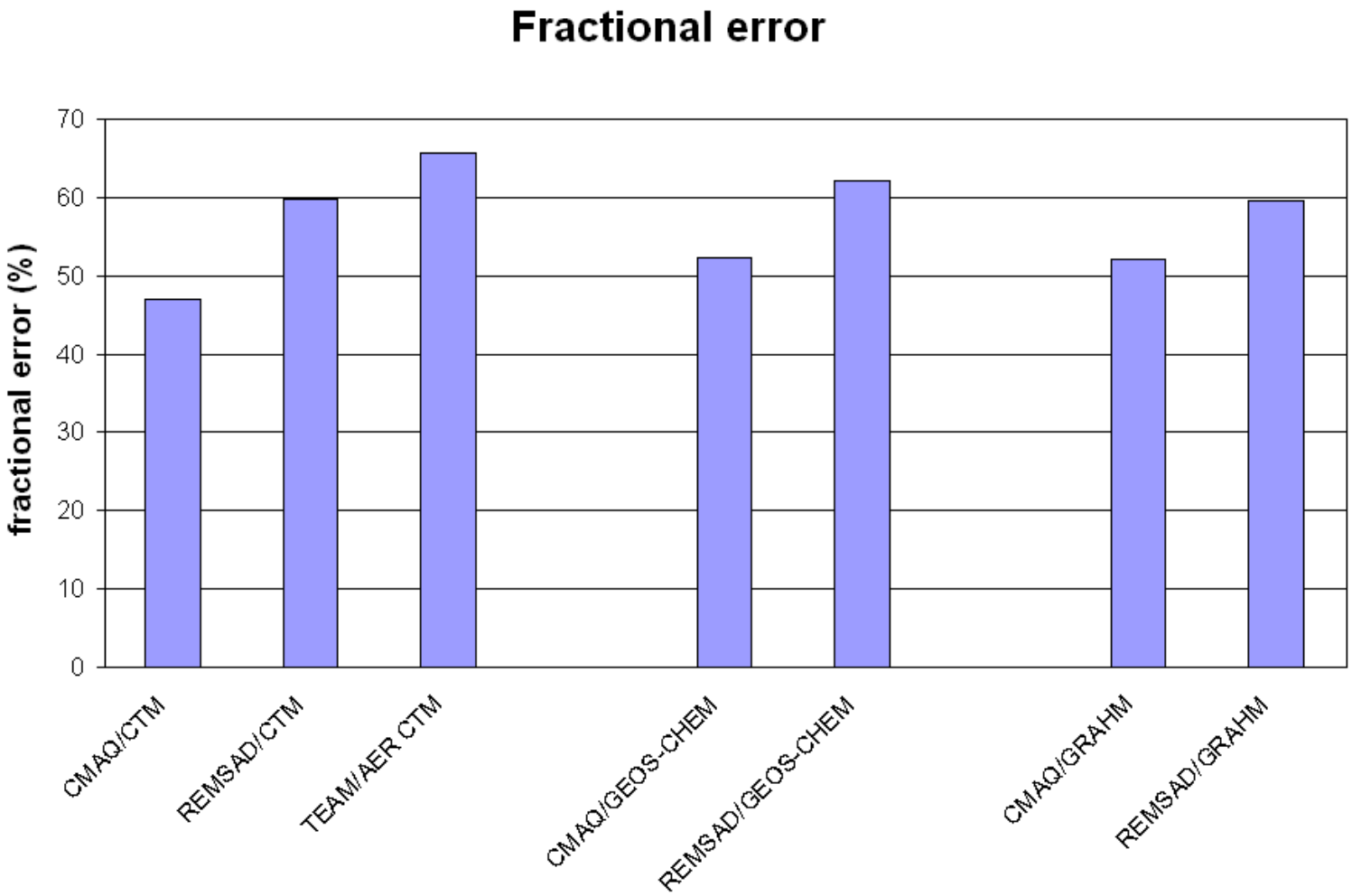


General Conclusions About Modeling Accuracy

- CMAQ appears have superior statistical agreement with observations of annual total Hg wet deposition in 2001.
  - However, this advantage is very slight in the context of the mean fractional error which is the best indication of model realism.
- The relatively high fractional error versus fractional bias against a continental-scale observation set suggests that modeling skill may be adequate for national-scale assessments of average impact, but the uncertainty remains quite large for any particular location.

Note: These conclusions are based on comparisons to wet deposition measurements only.

General Conclusions About Modeling Accuracy

- The regional-scale model sensitivity to changes in the boundary values demonstrates that hemispheric- and global-scale transport of mercury is important to smaller-scale assessments.
- Based on other analyses performed for this study, it appears that the gaseous elemental mercury concentrations at the boundary are most important.

North American Mercury Model Intercomparison Study (NAMMIS)

- Regional-scale modeling and results analysis are continuing.
- Air concentration data for the various mercury species will be compared to model simulations.
- Look for more complete NAMMIS results at the 8th International Conference on Mercury as a Global Pollutant in Madison, WI. (6-11 August 2006)

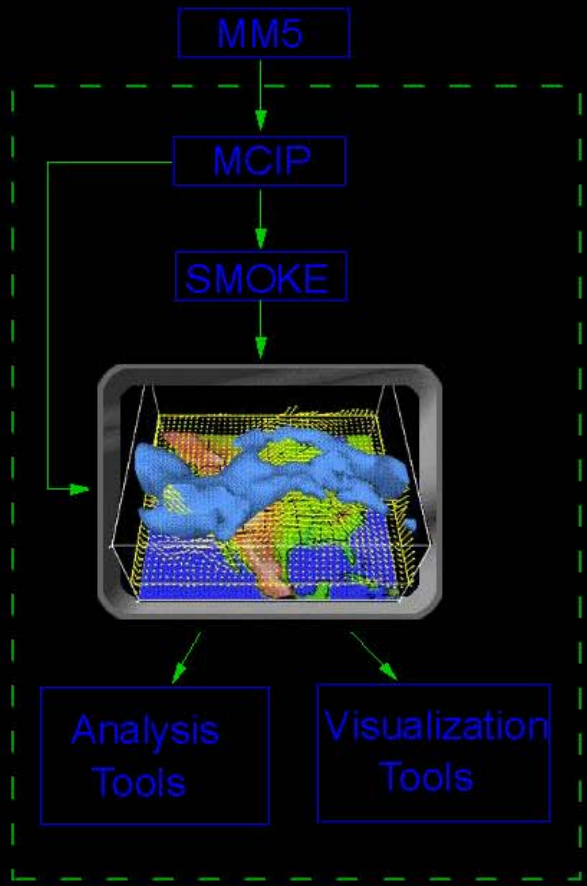
The U.S. EPA's Clean Air Mercury Rule

- On March 15, 2005, the U.S. EPA issued the Clean Air Mercury Rule (CAMR) to permanently cap and reduce mercury emissions from coal-fired electric generating units (EGUs).
- The CAMR builds on the U.S. EPA's Clean Air Interstate Rule (CAIR) targeting SO_2 and NO_X. When fully implemented, these rules will reduce EGU emissions of mercury from 48 tons per year to 15 tons per year.
- The Community Multiscale Air Quality (CMAQ) model was used to support the development of the CAIR and the CAMR.

CMAQ Mercury Model Description

- 3-D Eulerian-type model
- Multi-scale (urban to continental)
- Configuration for CAMR simulations:
  - 36-km horizontal grid (112 x 148)
  - 14 vertical layers (hi-res in PBL)
- Initial condition and boundary condition (IC/BC) data provided by GEOS-Chem global-scale model simulation (3-hr resolution vs. monthly average used in the NAMMIS)

Models-3 / CMAQ Air Quality Modeling System



Mesoscale Model - Ver. 5 (Meteorology)

Meteorology-Chemistry Interface Processor

Sparse Matrix Operator Kernel Emissions System

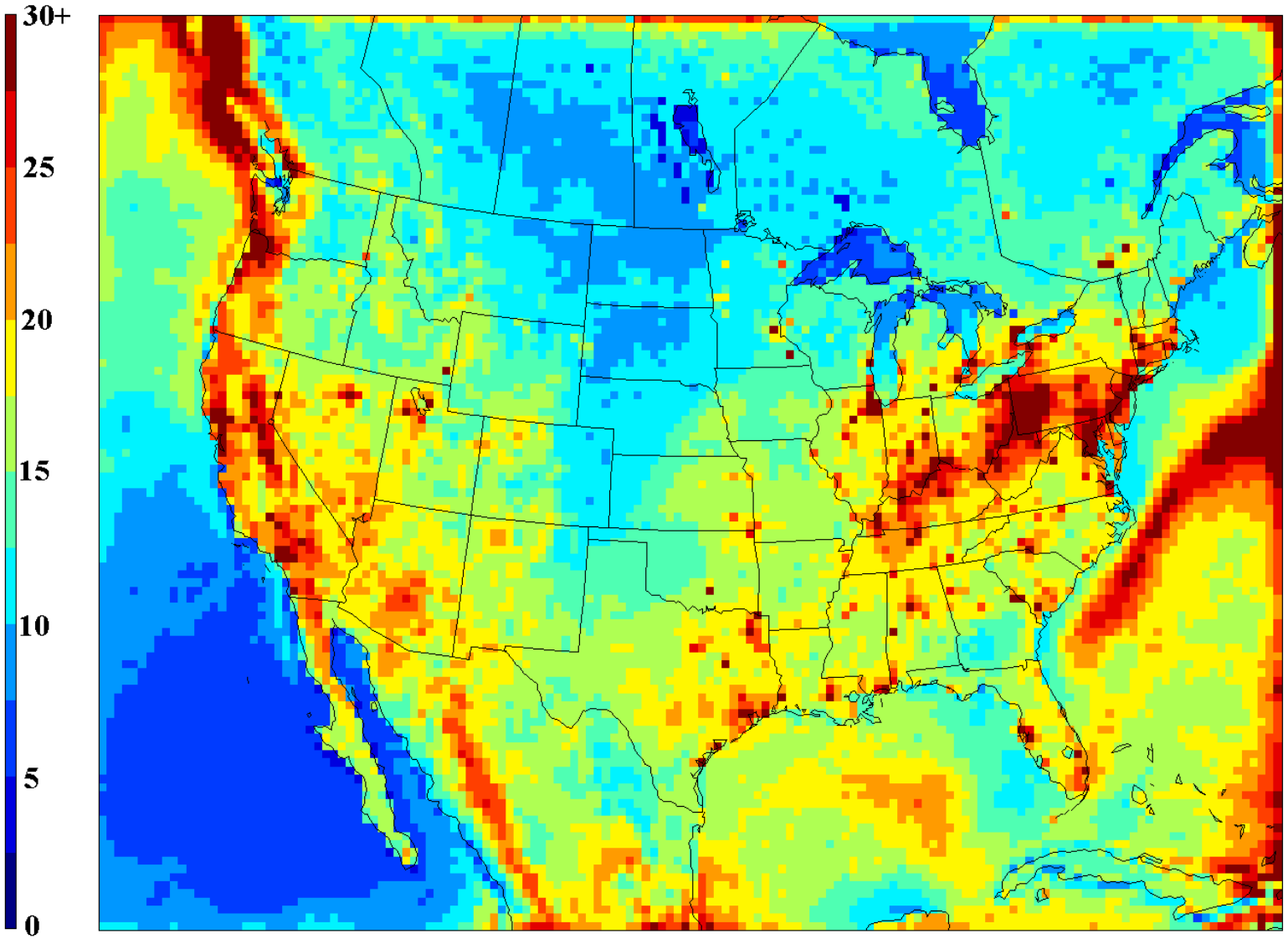
Community Multiscale Air Quality (CMAQ) Model

Summary of Hg Emissions by Species: 2001 and 2020

Emissions Source	Mercury Emissions Species (tons)			Total Mercury (tons)
	Elemental	Reactive Gaseous	Particulate	
2001 Base Year				
EGUs	26.26	20.58	1.73	48.57
Non-EGU Point	37.85	13.33	7.60	58.78
Non-point	5.05	1.53	0.96	7.54
Total, All Sources	69.16	35.44	10.29	114.89
2020 (with CAIR and CAMR)				
EGUs	-32.8%	-68.1%	-52.0%	-48.4%
Non-EGU Point	-25.9%	-22.2%	-13.0%	-23.4%
Non-point	+12.7%	-15.0%	-19.8%	+2.9%
Total, All Sources	-25.7%	-48.5%	-20.2%	-32.3%

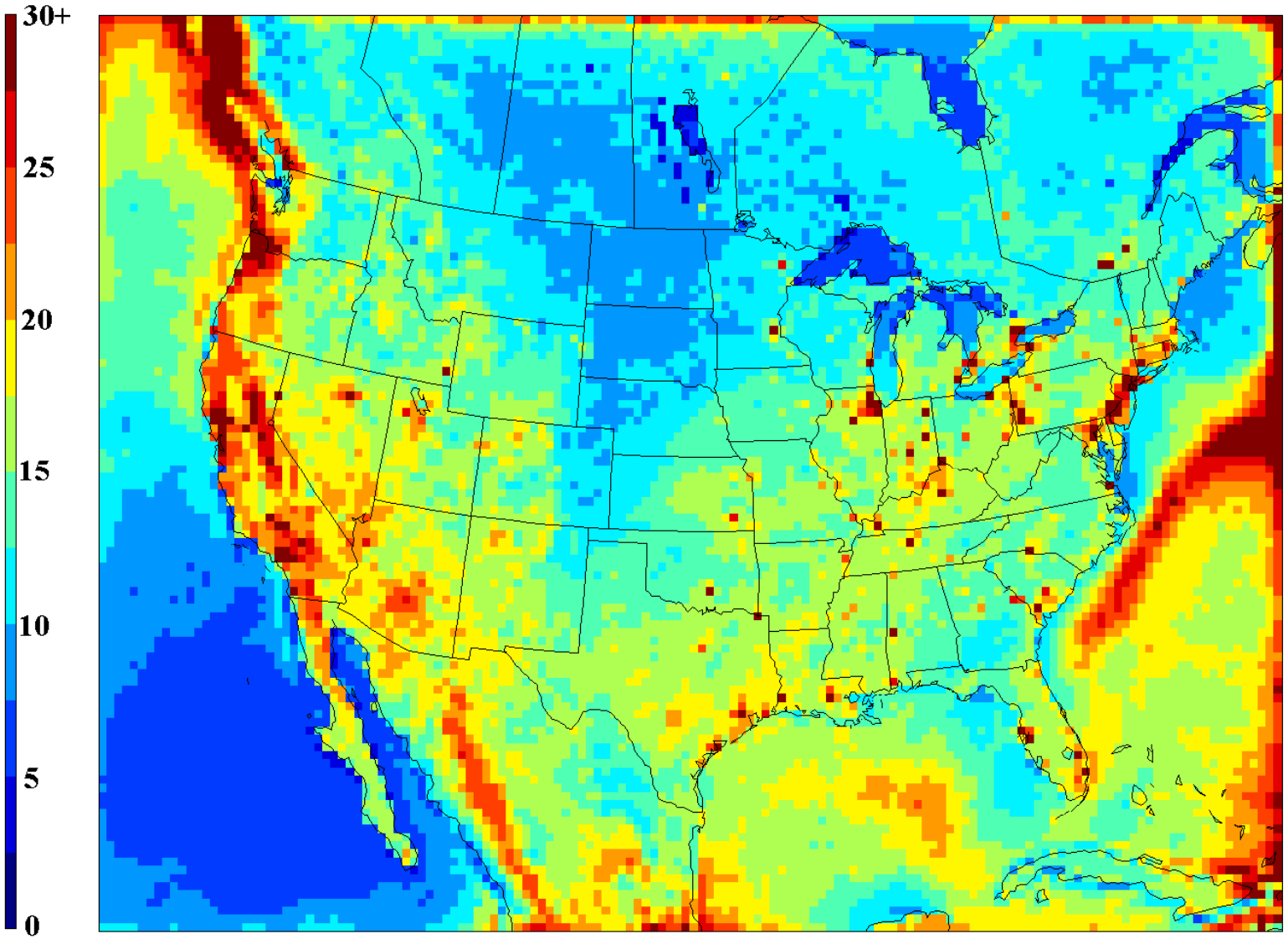
CMAQ-Simulated Total Hg Deposition for the 2001 Base Case

(in micrograms per square meter)

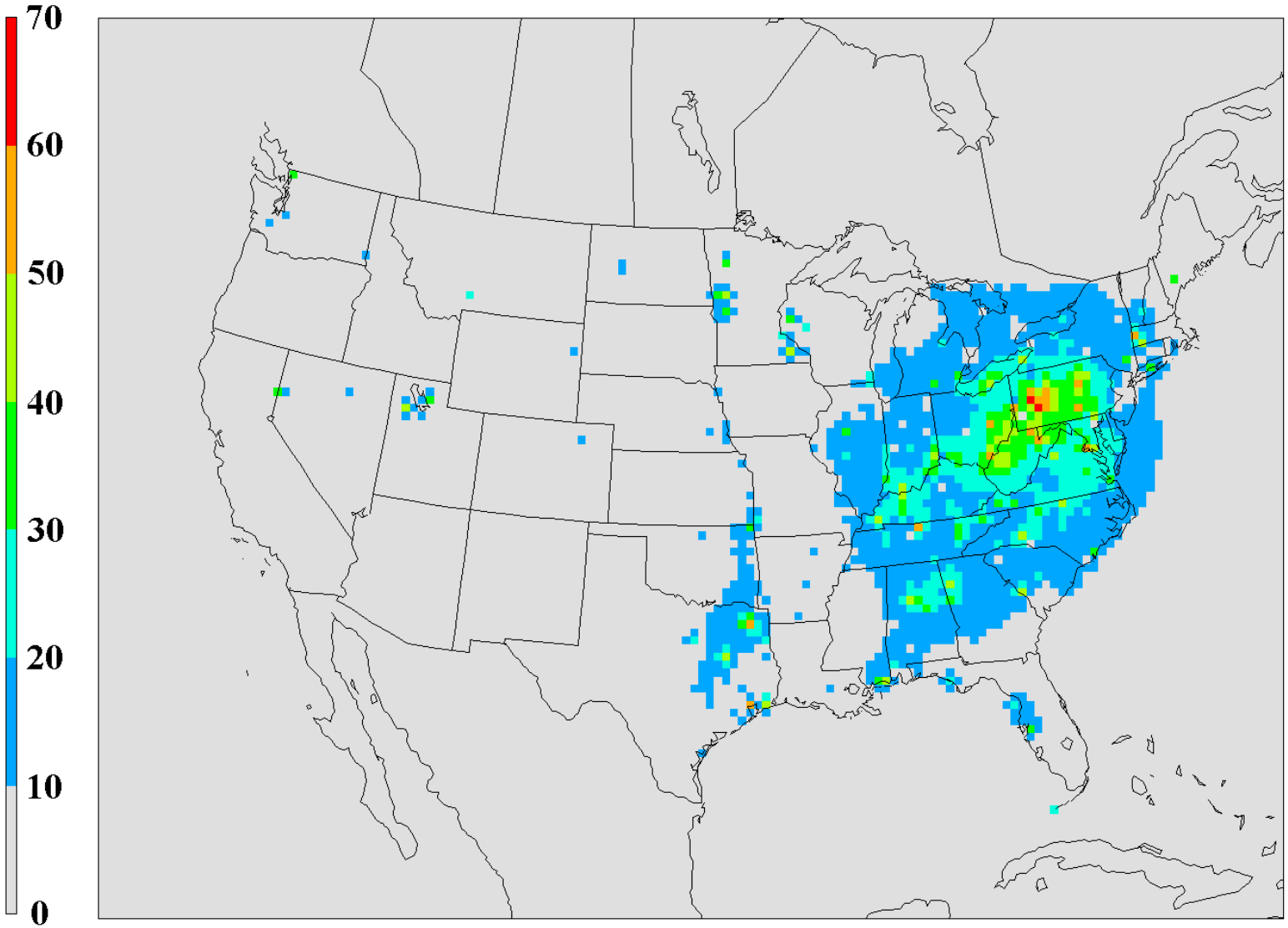


CMAQ-Simulated Total Hg Deposition in 2020 with CAIR and CAMR

(in micrograms per square meter)

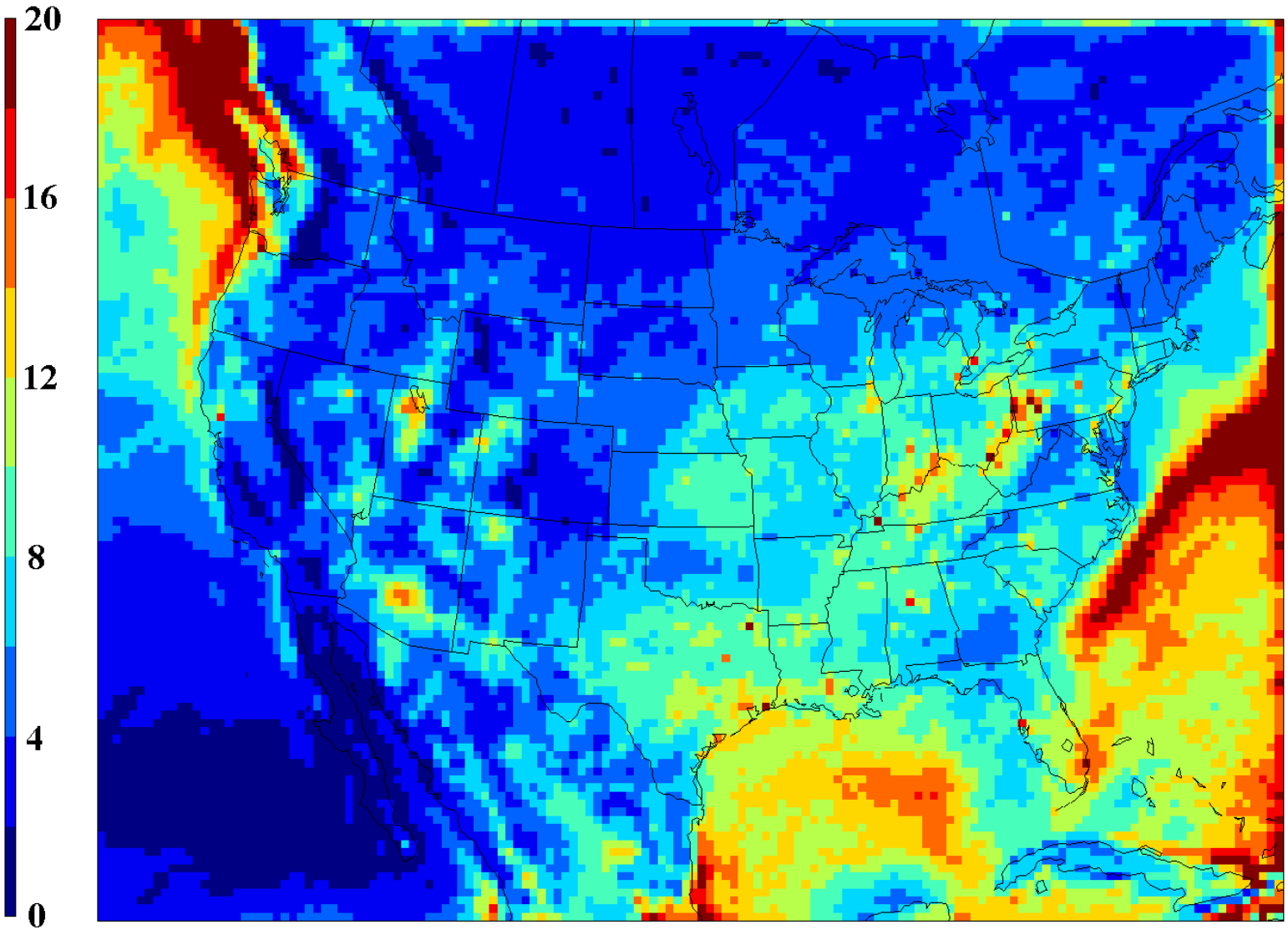


Percent Reduction in Hg Deposition from the 2001 Base Case 2020 with CAIR and CAMR

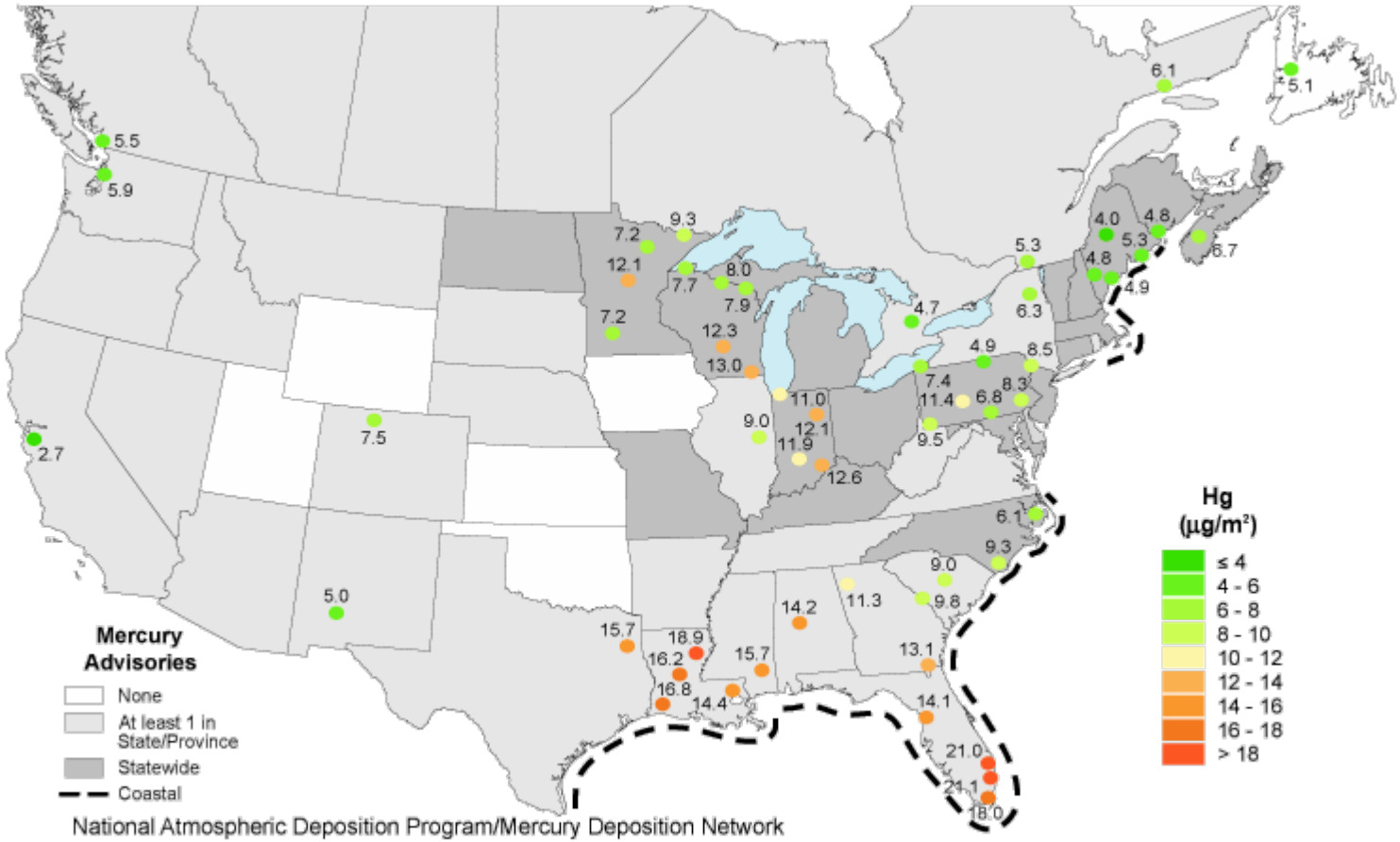


CMAQ-Simulated Hg Wet Deposition for the 2001 Base Case

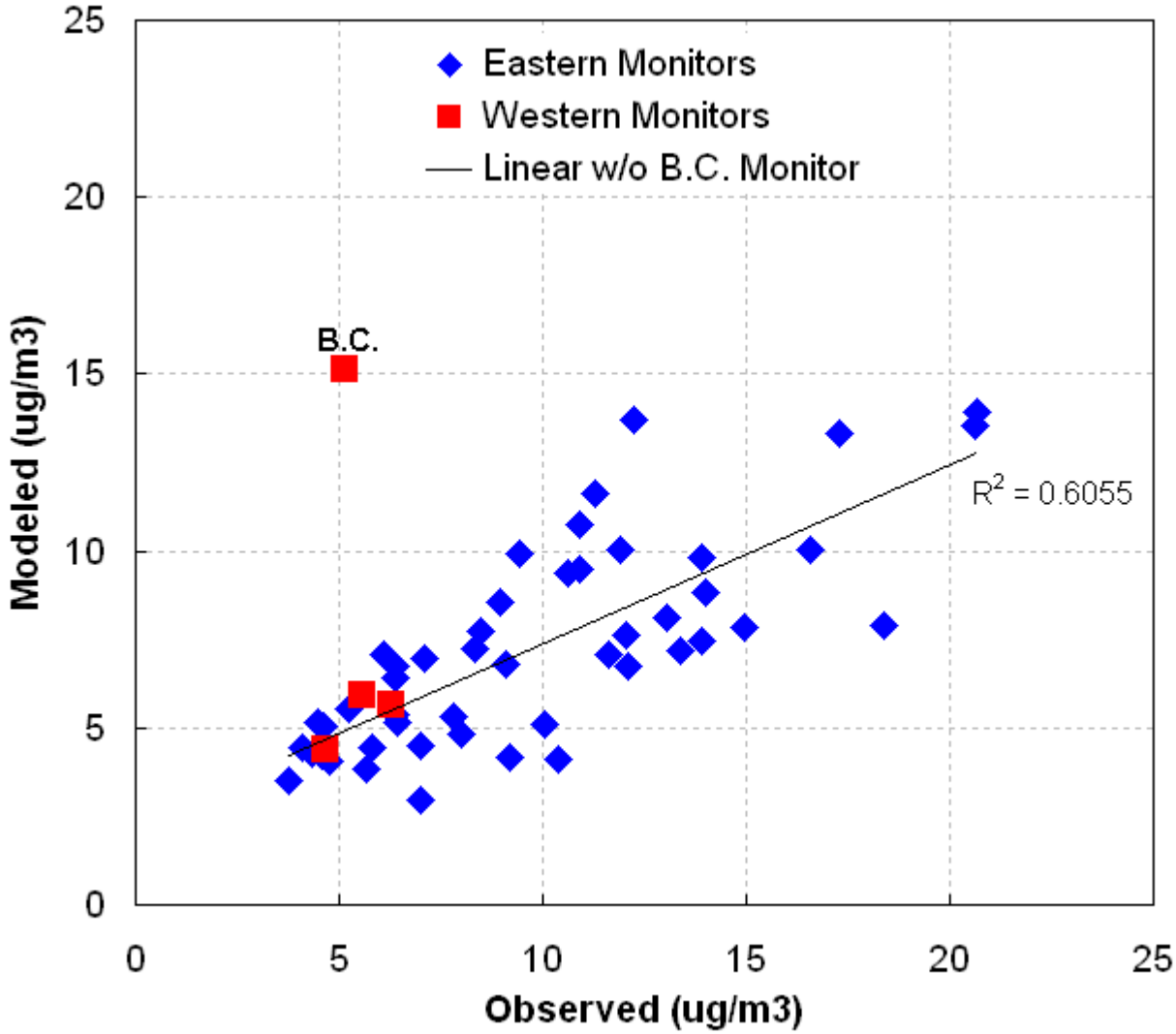
(in micrograms per square meter)



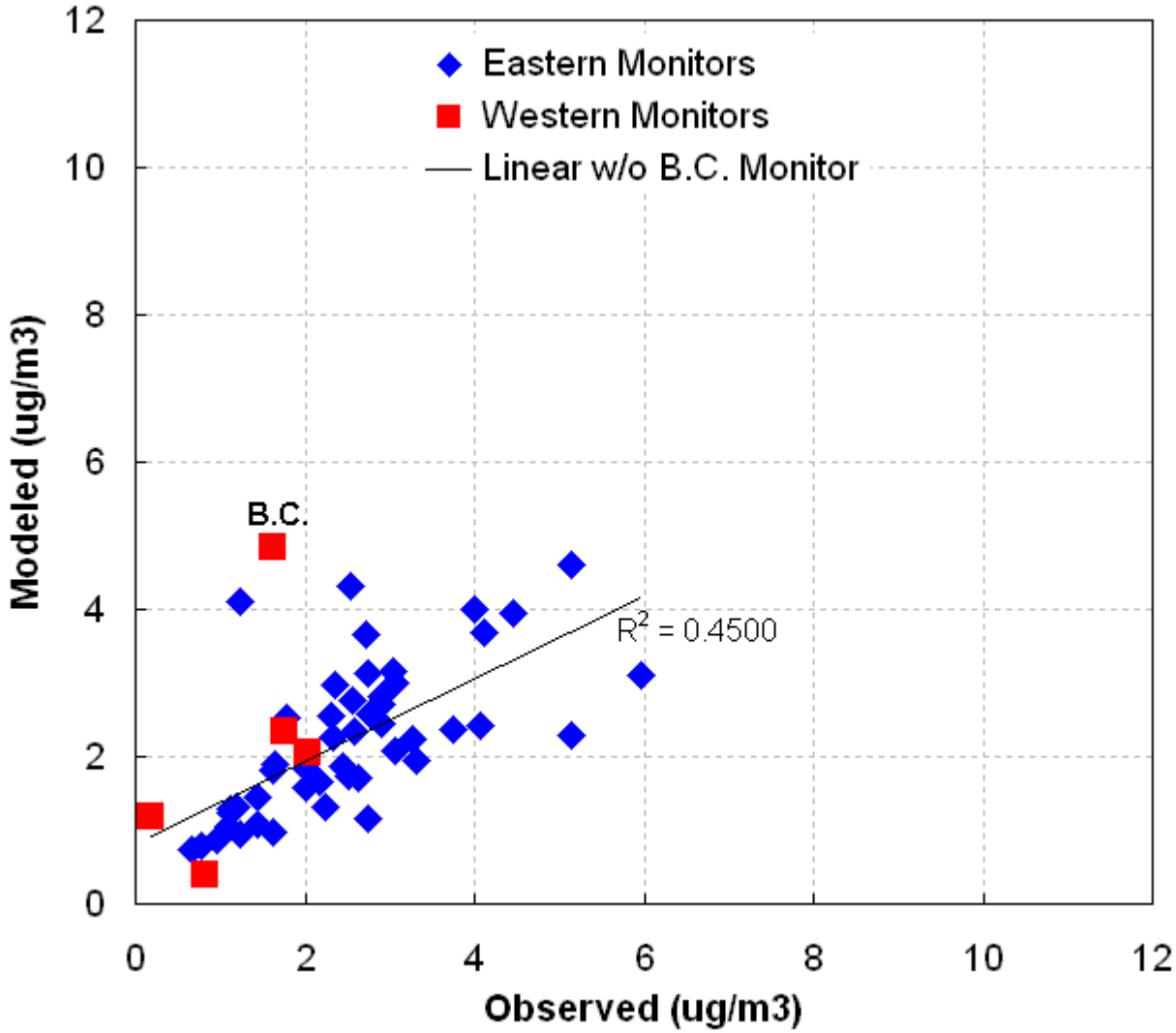
Observed Hg Wet Deposition in 2001 from the Mercury Deposition Network (MDN)



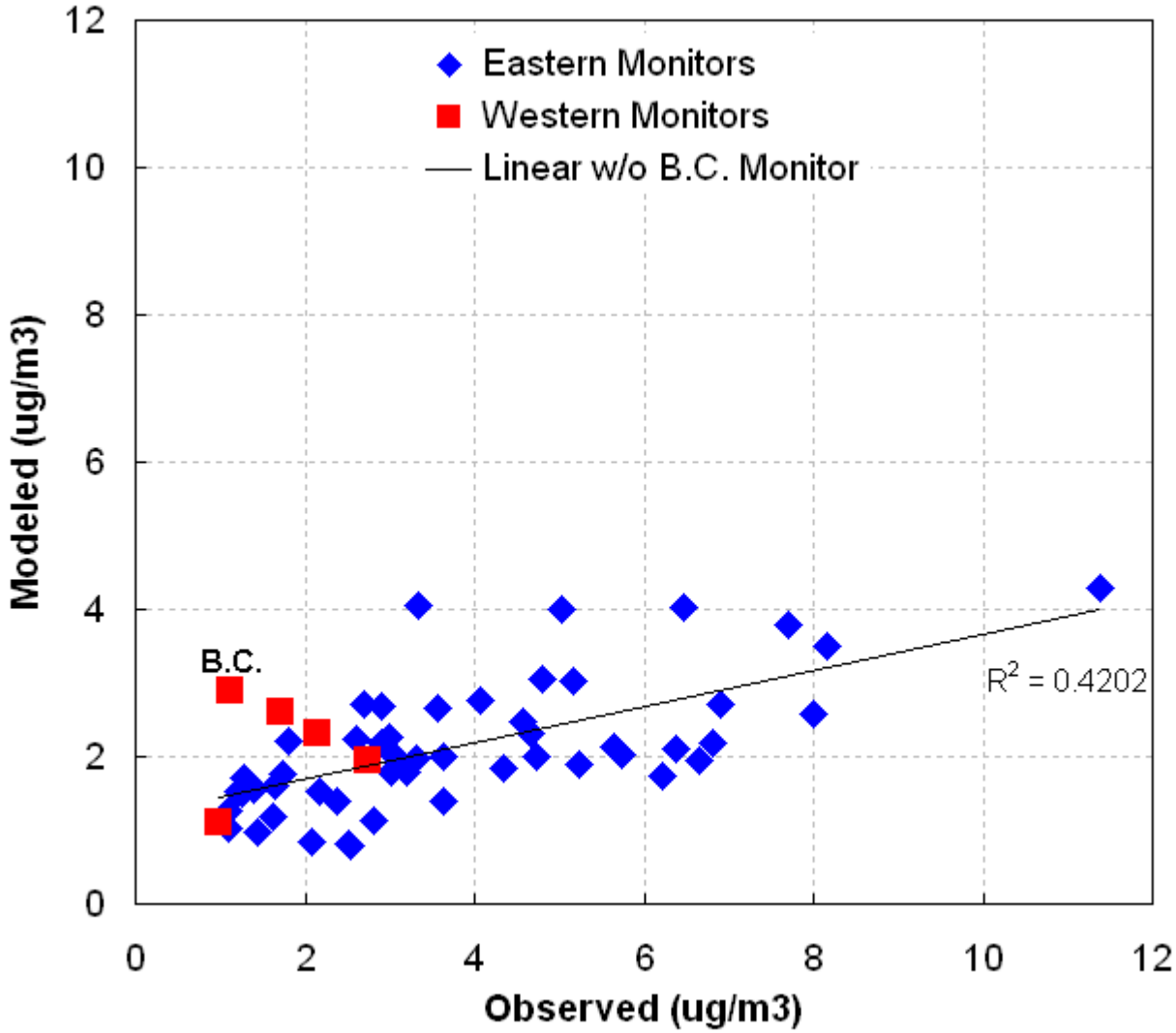
Comparison of CMAQ to MDN Observations
(annual)



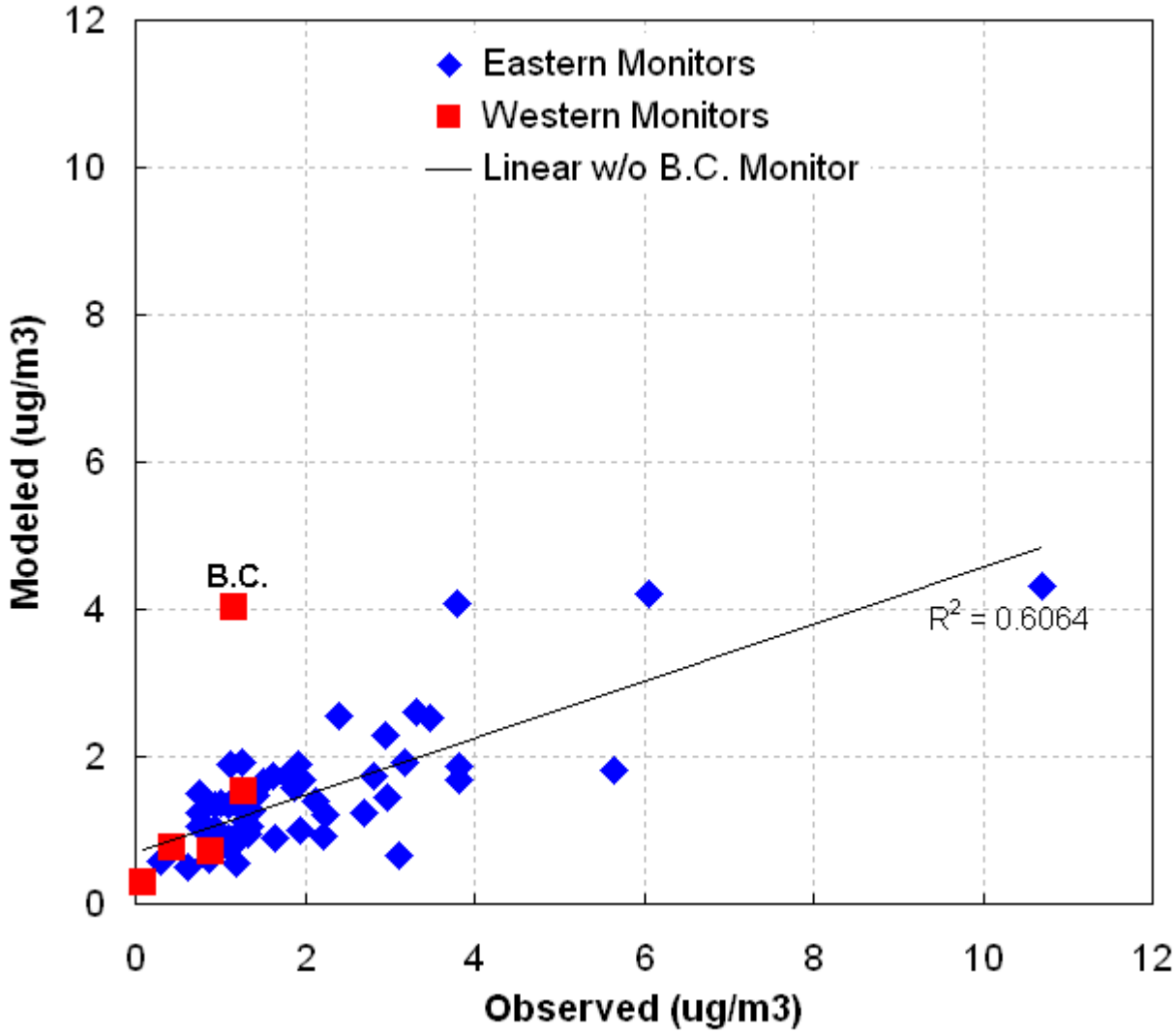
Comparison of CMAQ to MDN Observations
(spring)



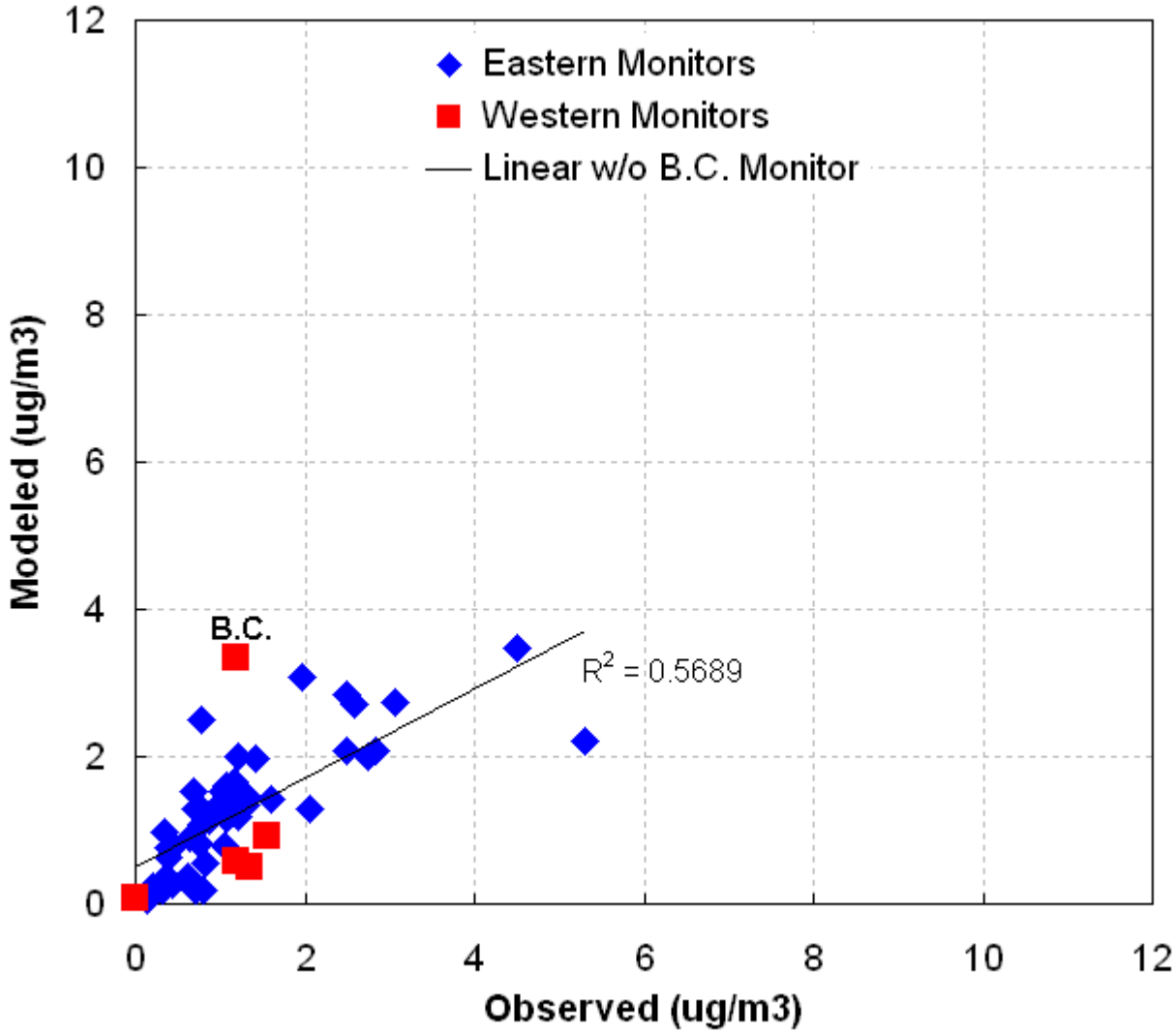
Comparison of CMAQ to MDN Observations (summer)



Comparison of CMAQ to MDN Observations
(fall)

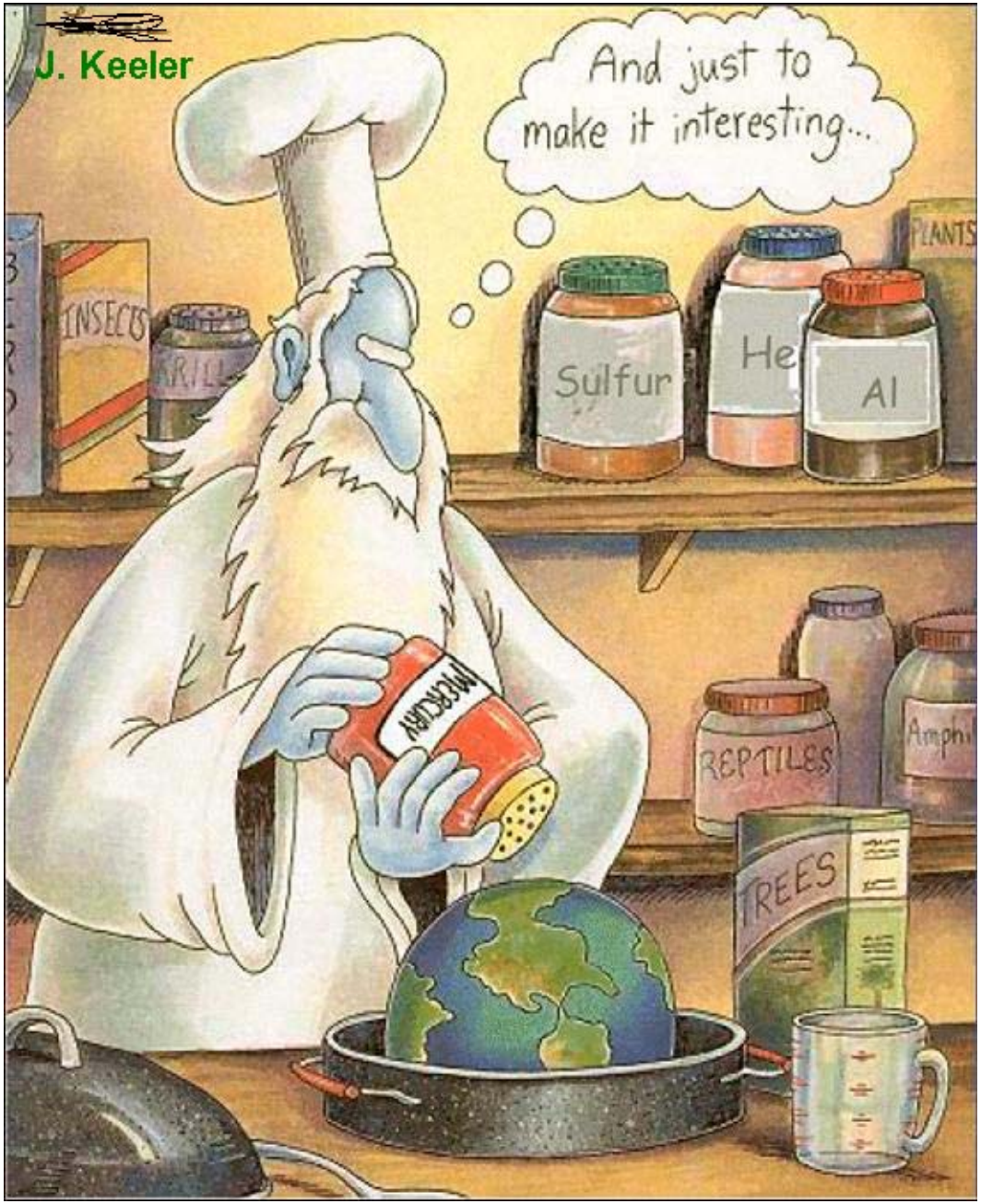


Comparison of CMAQ to MDN Observations
(winter)



General Findings from CAMR Modeling

- The importance of global emissions of Hg^0 was greater than previously indicated from EPA's Mercury Study Report to Congress (in 1997).
  - New gas-phase oxidation reactions were identified
  - Higher kinetic rate constants for some existing reactions
- Coal-fired utility boilers contribute less than 10% to the total mercury deposition over most of the contiguous U.S., but the simulated range is 0% to 68%
- 144 tons of mercury were deposited to the contiguous U.S. in 2001: 23 tons from all U.S. anthropogenic sources, 11 tons from coal-fired electric utility boilers.



Disclaimer

The research presented here was performed under the Memorandum of Understanding between the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Commerce's National Oceanic and Atmospheric Administration (NOAA) and under agreement number DW13921548. This work constitutes a contribution to the NOAA Air Quality Program. Although it has been reviewed by EPA and NOAA and approved for publication, it does not necessarily reflect their policies or views.