

# Atmospheric Mercury Modeling at the NOAA Air Resources Laboratory using the HYSPLIT-Hg Model



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*<http://www.arl.noaa.gov/ss/transport/cohen.html>*



**Presentation at the**  
**Gulf Coast Mercury Research Collaboration Meeting**  
**Gulf Power Building, Pensacola FL, May 18-19, 2006**

# Outline of Presentation

- ❑ **modeling methodology**
- ❑ **some preliminary results for Mobile Bay**  
*(based on this methodology)*
- ❑ **model intercomparisons**
- ❑ **summary of previous work; current goals; challenges**

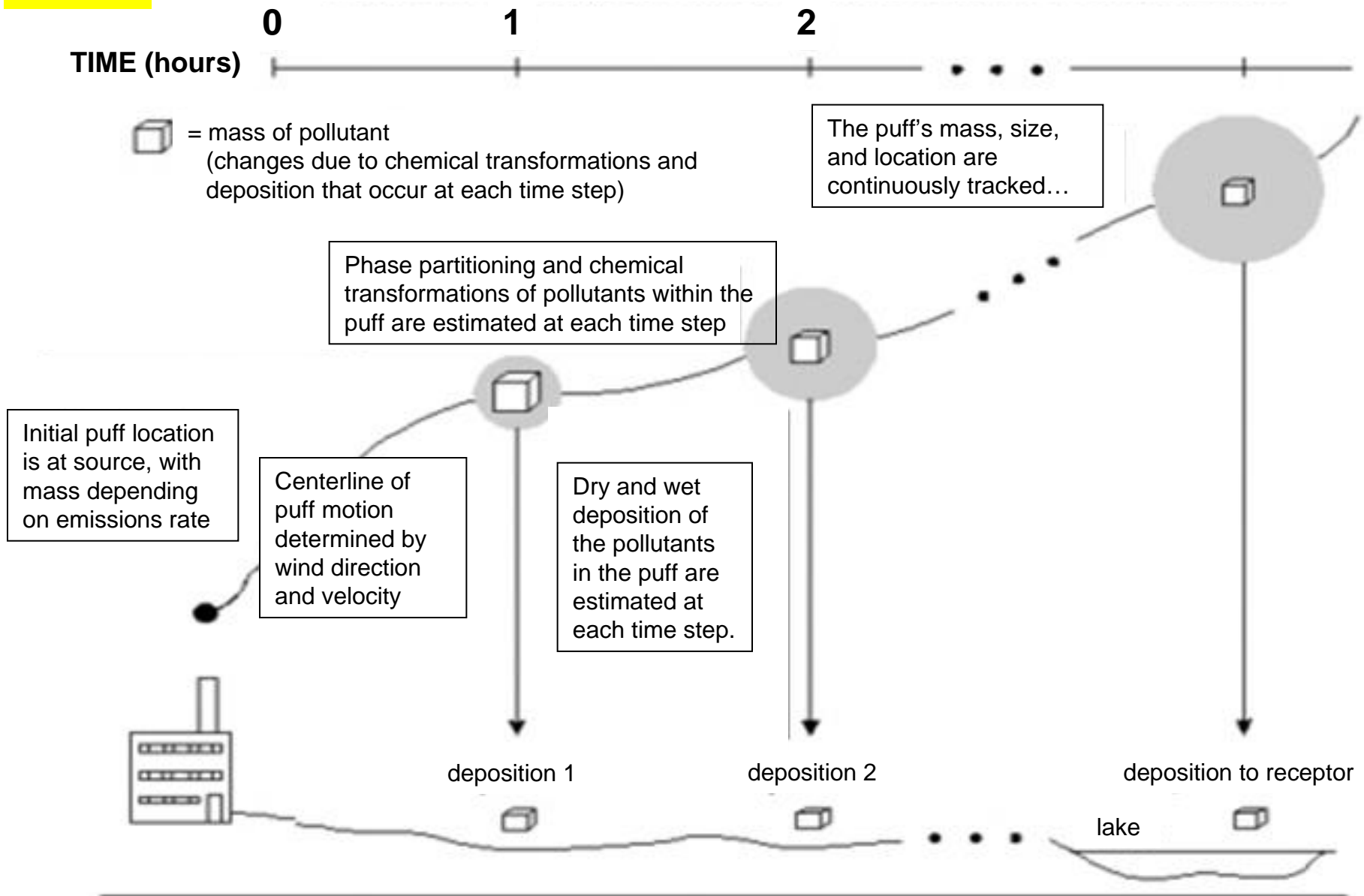
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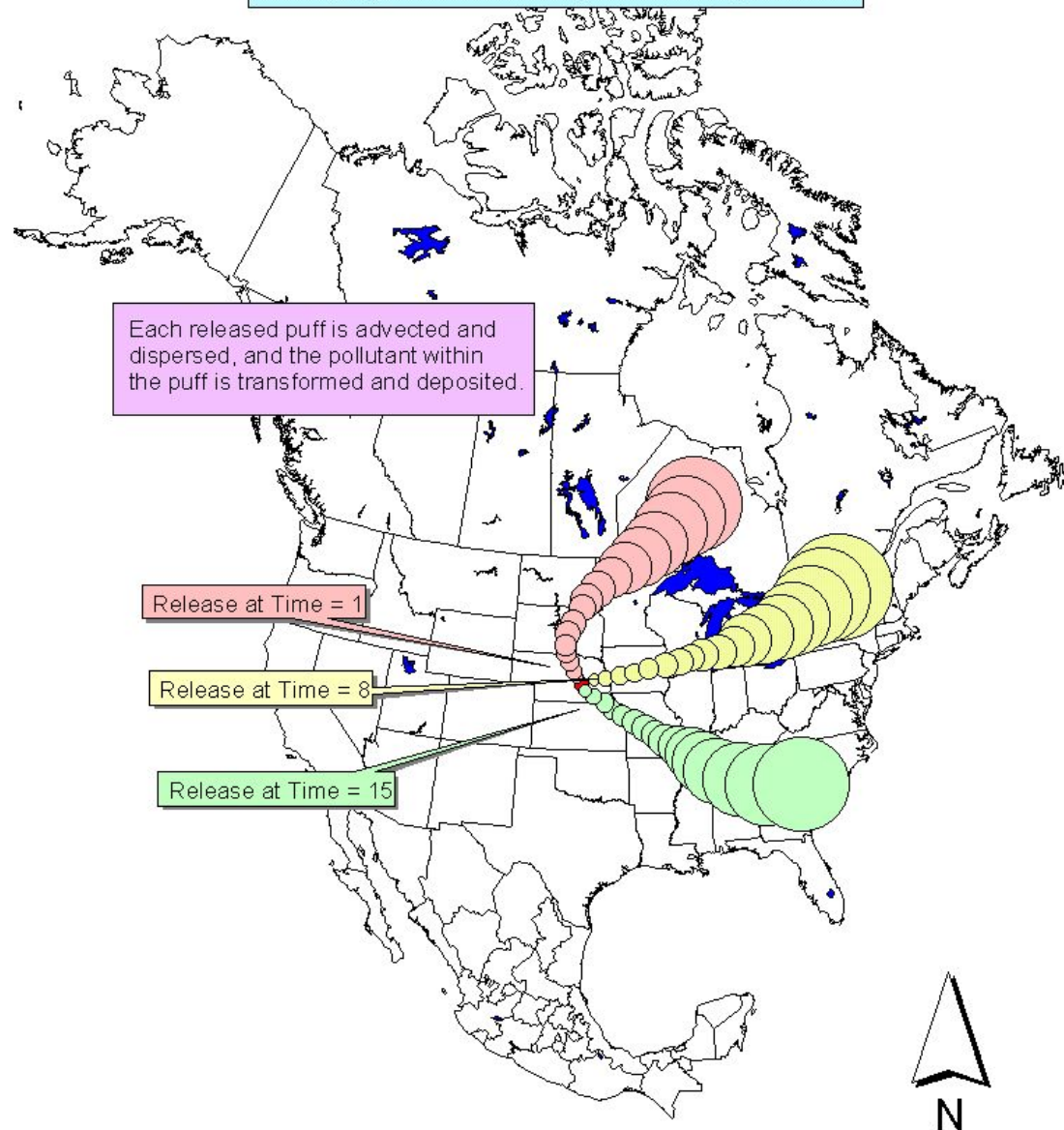
# Modeling Methodology

- ❑ NOAA HYSPLIT model → HYSPLIT-Hg

# Lagrangian Puff Atmospheric Fate and Transport Model



Over the entire modeling period (e.g., one year), puffs are released at periodic intervals (e.g., once every 7 hours).

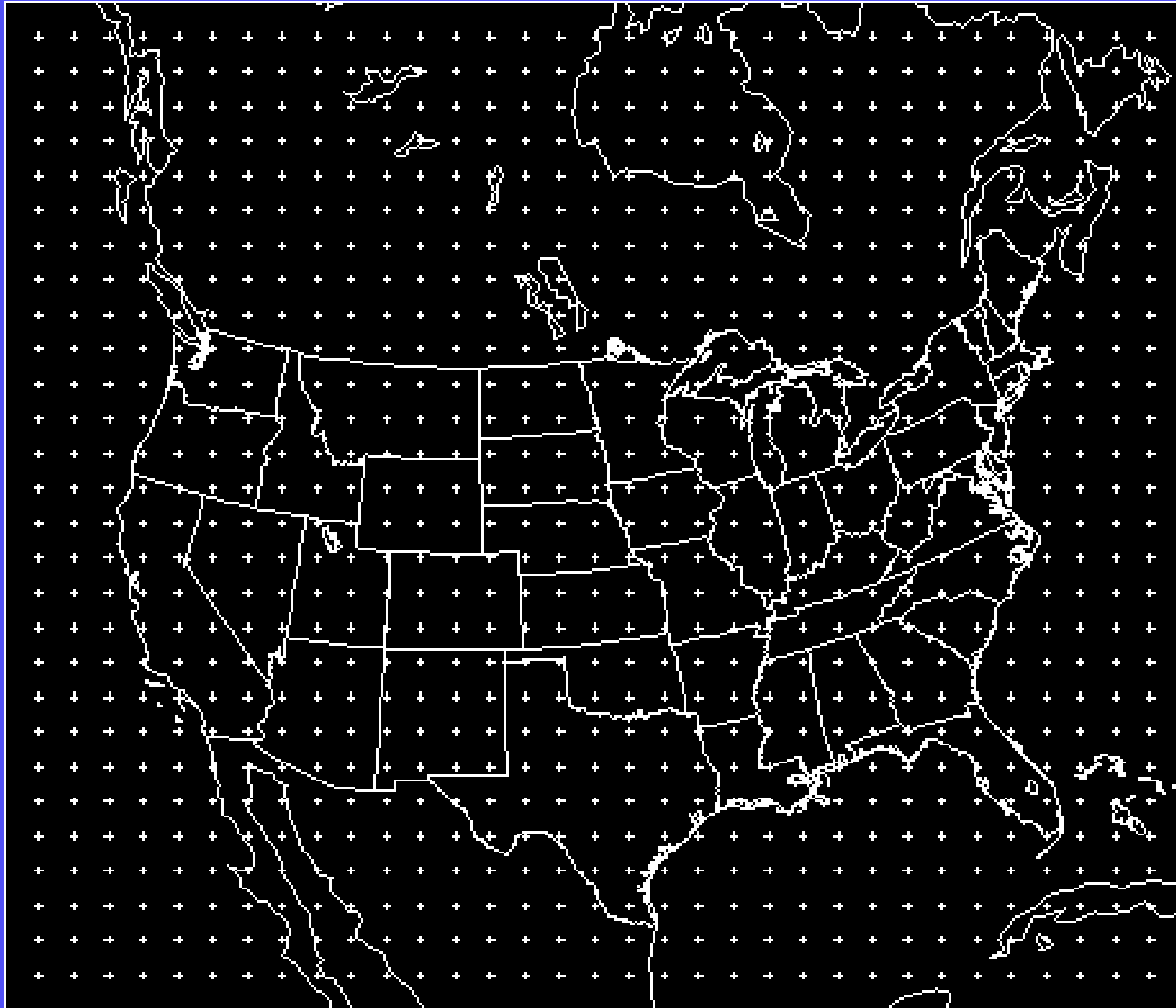


# Modeling Methodology

- ❑ NOAA HYSPLIT model → HYSPLIT-Hg
- ❑ **Modeling domain: North America**  
*(northern half of Mexico; continental U.S.; southern half of Canada)*
- ❑ **1996 meteorology (180 km horizontal resolution)**



# NGM Archive Grid



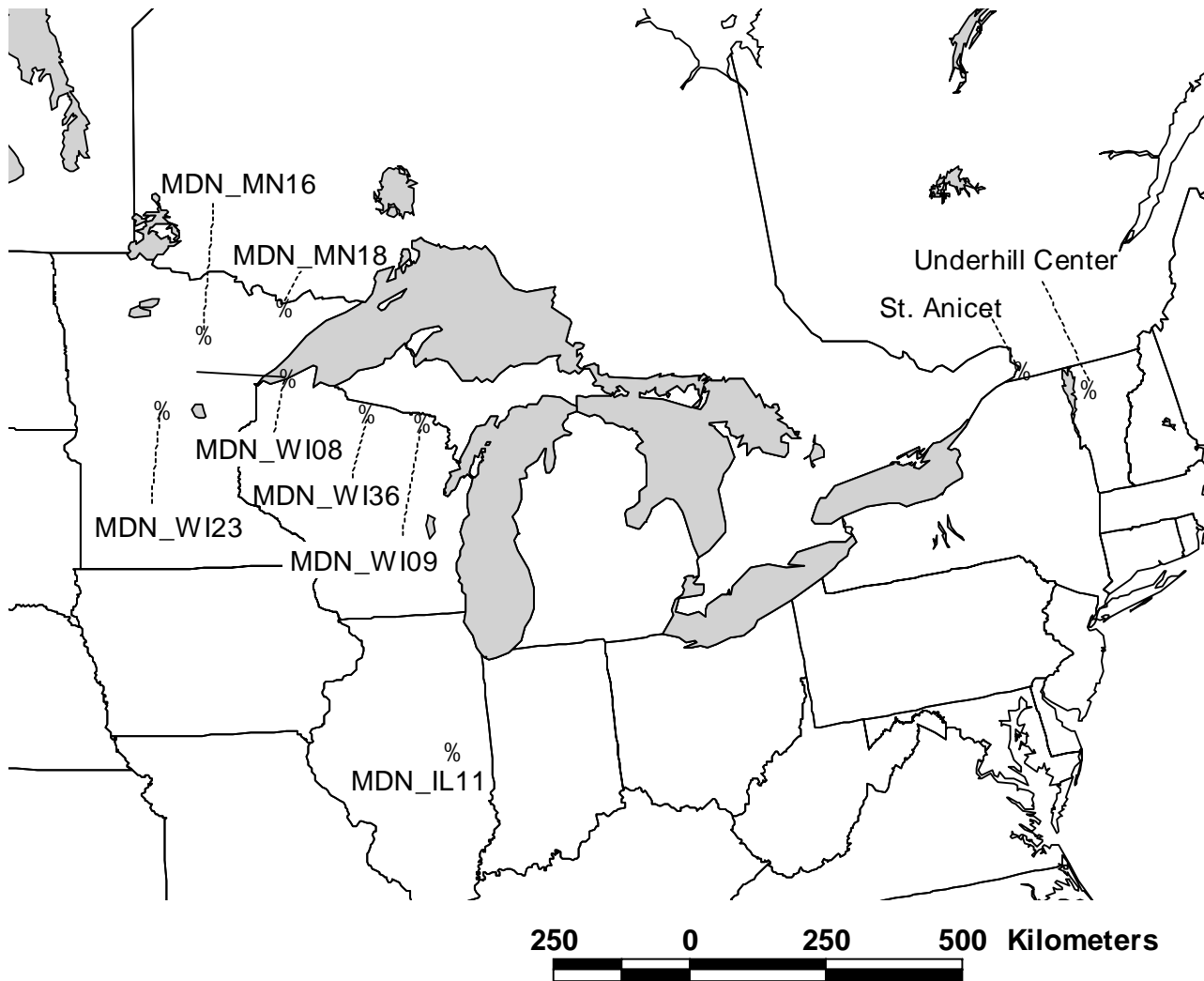


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- ❑ **only U.S. and Canadian anthropogenic sources;**  
*(natural emissions, re-emissions, & global sources not included)*
- ❑ **Model evaluation: 1996 emissions and 1996 monitoring data**  
*(also evaluated in EMEP Hg model intercomparison project)*

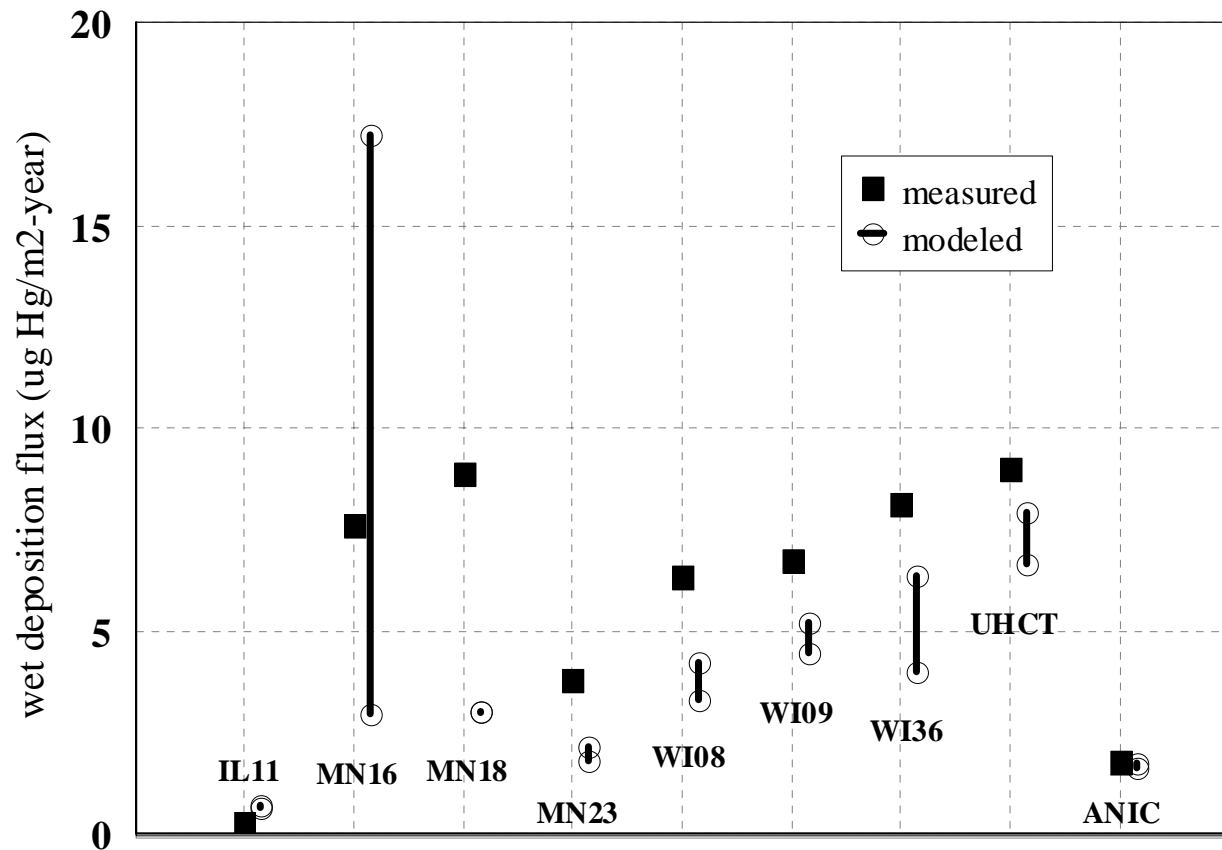
Figure 7. Model evaluation sites for wet deposition fluxes within 250 km of any Great Lake with available data for 1996.

(Cohen et al., 2004, Environmental Research 95: 247-265)

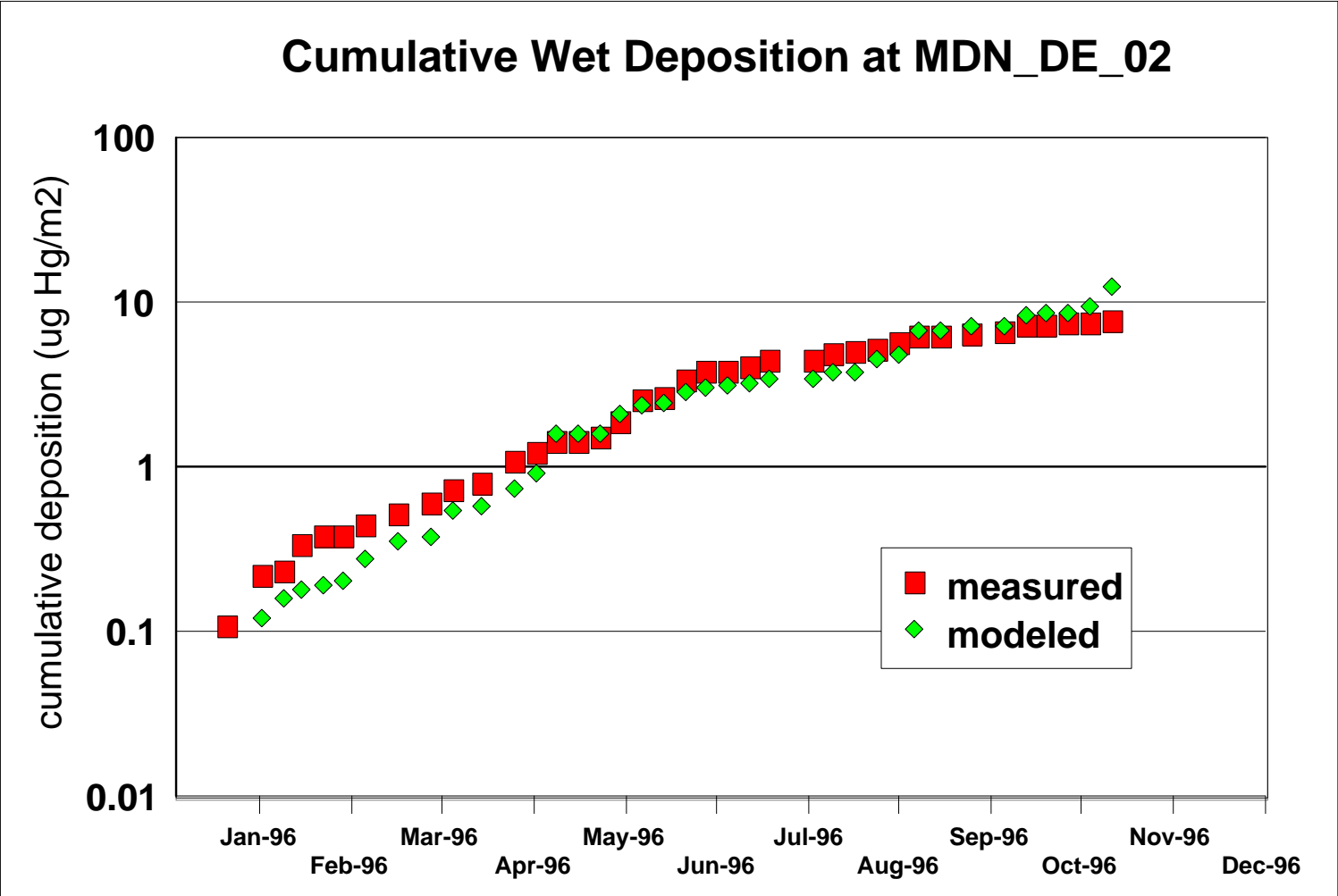


(Cohen et al., 2004, Environmental Research 95: 247-265)

Figure 8. Comparison of annual model-estimated wet deposition fluxes with measured values at sites within 250 km of the Great Lakes during 1996. The range of modeled estimates shown for each site represents the difference in estimated deposition in using the NGM-forecast *model* precipitation and the *actual* precipitation at the site. (Cohen et al., 2004, Environmental Research 95: 247-265)



# Modeled vs. Measured Wet Deposition at Mercury Deposition Network Site DE\_02 during 1996



# Modeling Methodology

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- ❑ **1<sup>st</sup> set of results – Cohen et al. 2004**



## Modeling the atmospheric transport and deposition of mercury to the Great Lakes<sup>☆</sup>

Mark Cohen,<sup>a,\*</sup> Richard Artz,<sup>a</sup> Roland Draxler,<sup>a</sup> Paul Miller,<sup>b</sup> Laurier Poissant,<sup>c</sup> David Niemi,<sup>d</sup> Dominique Ratté,<sup>d</sup> Marc Deslauriers,<sup>d</sup> Roch Duval,<sup>e</sup> Rachele Laurin,<sup>e,1</sup> Jennifer Slotnick,<sup>f</sup> Todd Nettesheim,<sup>g</sup> and John McDonald<sup>h</sup>

<sup>a</sup>NOAA Air Resources Laboratory, 1315 East West Highway RIARL, Room 3316, Silver Spring, MD 20910, USA

<sup>b</sup>Commission for Environmental Cooperation, Montreal, Que., Canada

<sup>c</sup>Atmospheric Toxic Processes Service, Meteorological Service of Canada, Environment Canada Quebec region, Montreal, Que., Canada

<sup>d</sup>Pollutant Data Branch, Environment Canada, Hull, Que., Canada

<sup>e</sup>Environmental Monitoring and Reporting Branch, Ontario Ministry of the Environment, Toronto, Ont., Canada

<sup>f</sup>University of California, Berkeley, CA, USA

<sup>g</sup>US EPA Great Lakes

<sup>h</sup>Internat

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### Abstract

A special version of the NOAA HYSPLIT, 4 n mercury in a North American modeling domain results and provide estimates of the contributi atmospheric mercury deposition to the Great I suitable for model evaluation are scarce, model the Great Lakes region and with independent m from the Great Lakes contributed significant an significant contributions from incineration an contributor to atmospheric mercury deposition Published by Elsevier Inc.

**Keywords:** Mercury; Atmospheric deposition; Great Lakes

Mercury contamination in the Great Lak other ecosystems is increasingly being rec serious environmental concern. The domin human exposure to mercury is through fi tion, and significant portions of the gener are believed to be consuming toxicological levels of mercury (e.g., National Resea 2000). Historical discharges e.g., from production using the mercury-cell process to have caused large accumulations of

<sup>☆</sup>Supplementary data associated with this article can be found in the online version, at [doi:10.1016/j.envres.2003.11.007](http://doi.org/10.1016/j.envres.2003.11.007).

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0013-9351/\$ - see front matter. Published by Elsevier Inc. doi:10.1016/j.envres.2003.11.007

Shannon and Voldner, 1995; Xu et al., 2000a-c), none has developed detailed source-receptor relationships for the Great Lakes, as advocated in Annex 15 of the Great

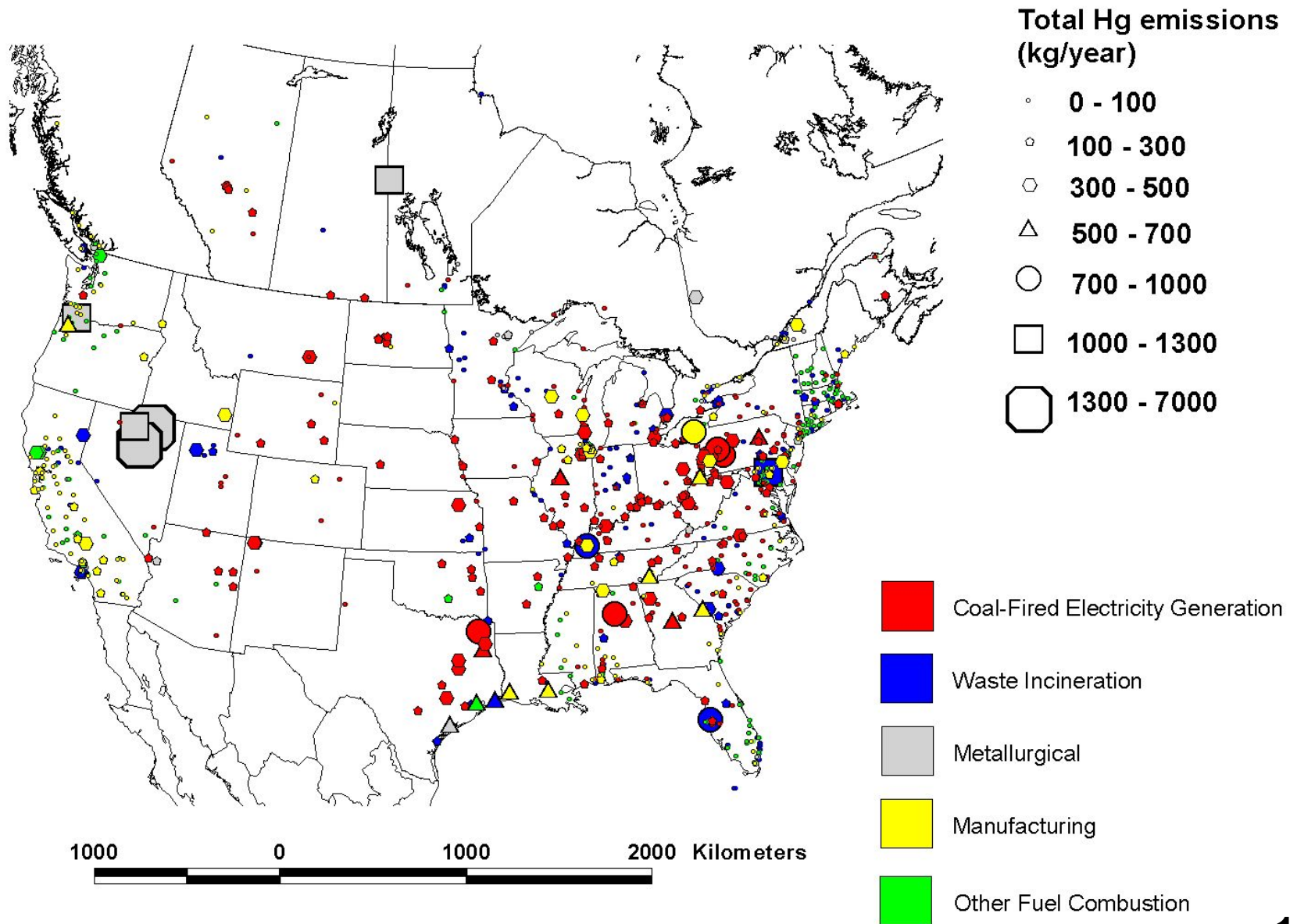
**Cohen, M., Artz, R., Draxler, R., Miller, P., Poissant, L., Niemi, D., Ratté, D., Deslauriers, M., Duval, R., Laurin, R., Slotnick, J., Nettesheim, T., McDonald, J. "Modeling the Atmospheric Transport and Deposition of Mercury to the Great Lakes." *Environmental Research* 95(3), 247-265, 2004.**

**Note: Volume 95(3) is a Special Issue: "An Ecosystem Approach to Health Effects of Mercury in the St. Lawrence Great Lakes", edited by David O. Carpenter.**

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- ❑ Model evaluation: 1996 emissions and 1996 monitoring data  
*(also evaluated in EMEP Hg model intercomparison project)*
- ❑ 1<sup>st</sup> set of results – Cohen et al. 2004
- ❑ **2<sup>nd</sup> set of results (examples shown today) –**
  - *1996 meteorology*
  - *1999 U.S. EPA National Emissions Inventory*
  - *2000 emissions data from Environment Canada*

# Geographic Distribution of Largest Anthropogenic Mercury Emissions Sources in the U.S. (1999) and Canada (2000)





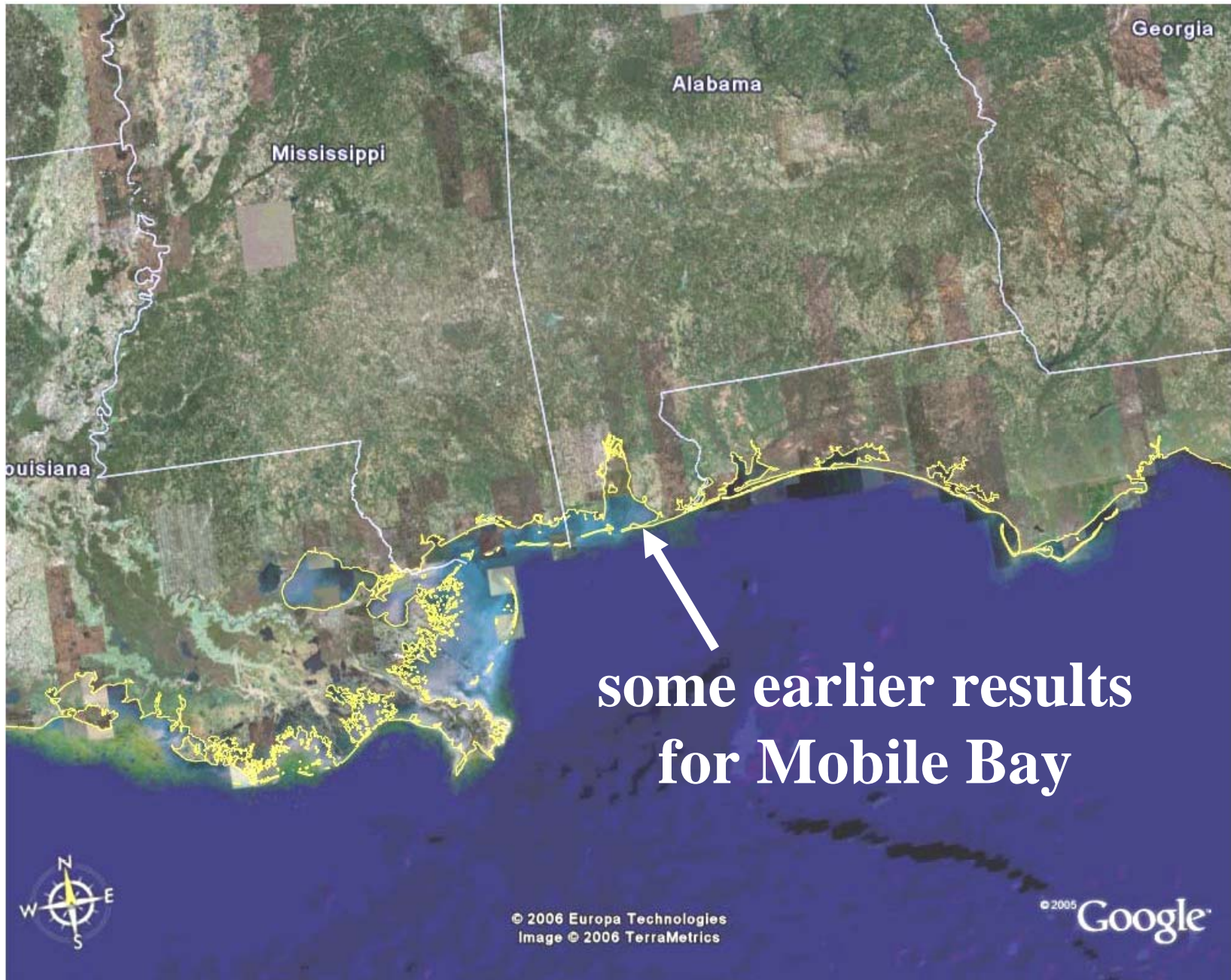
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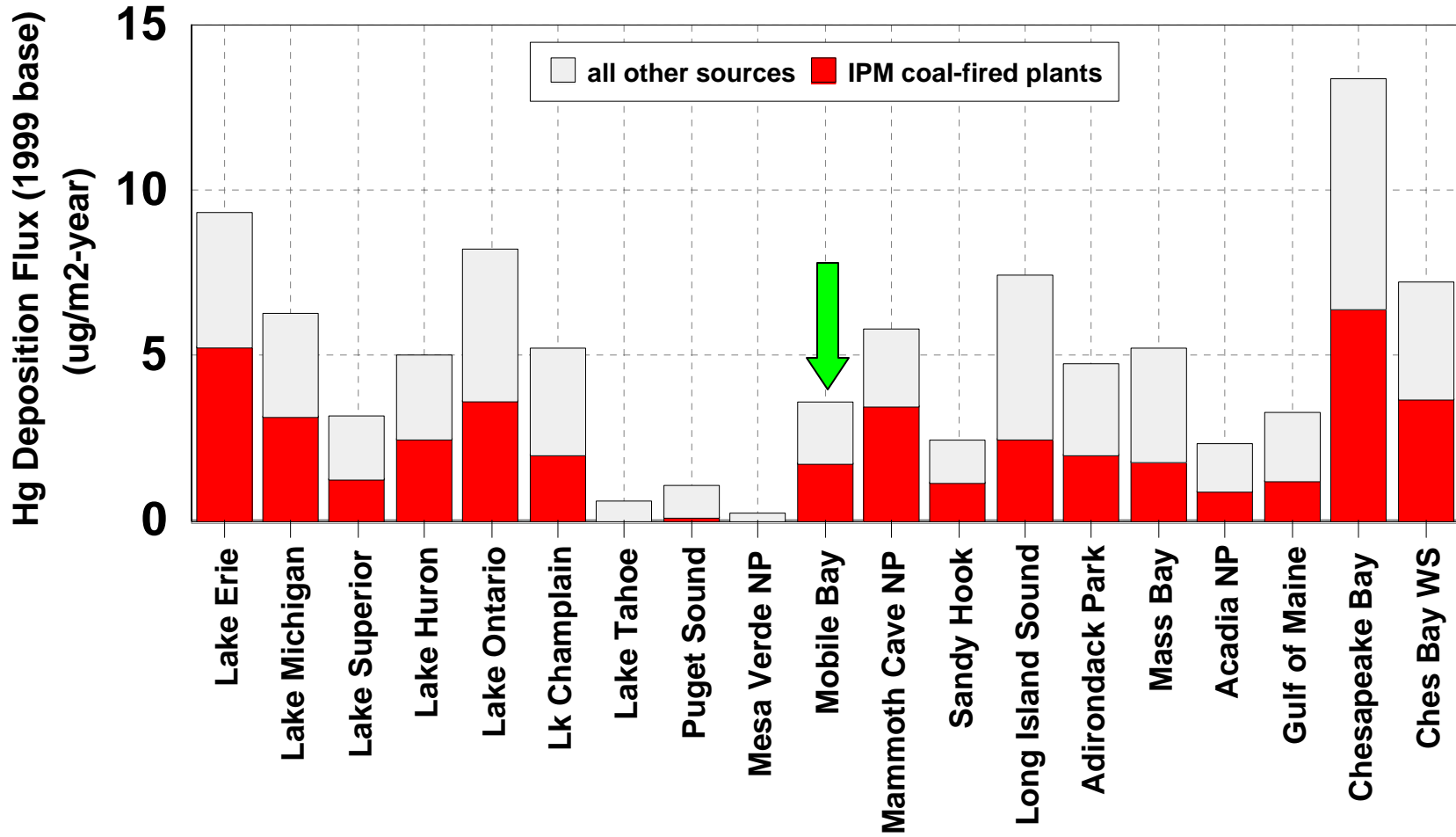
- **model intercomparisons**

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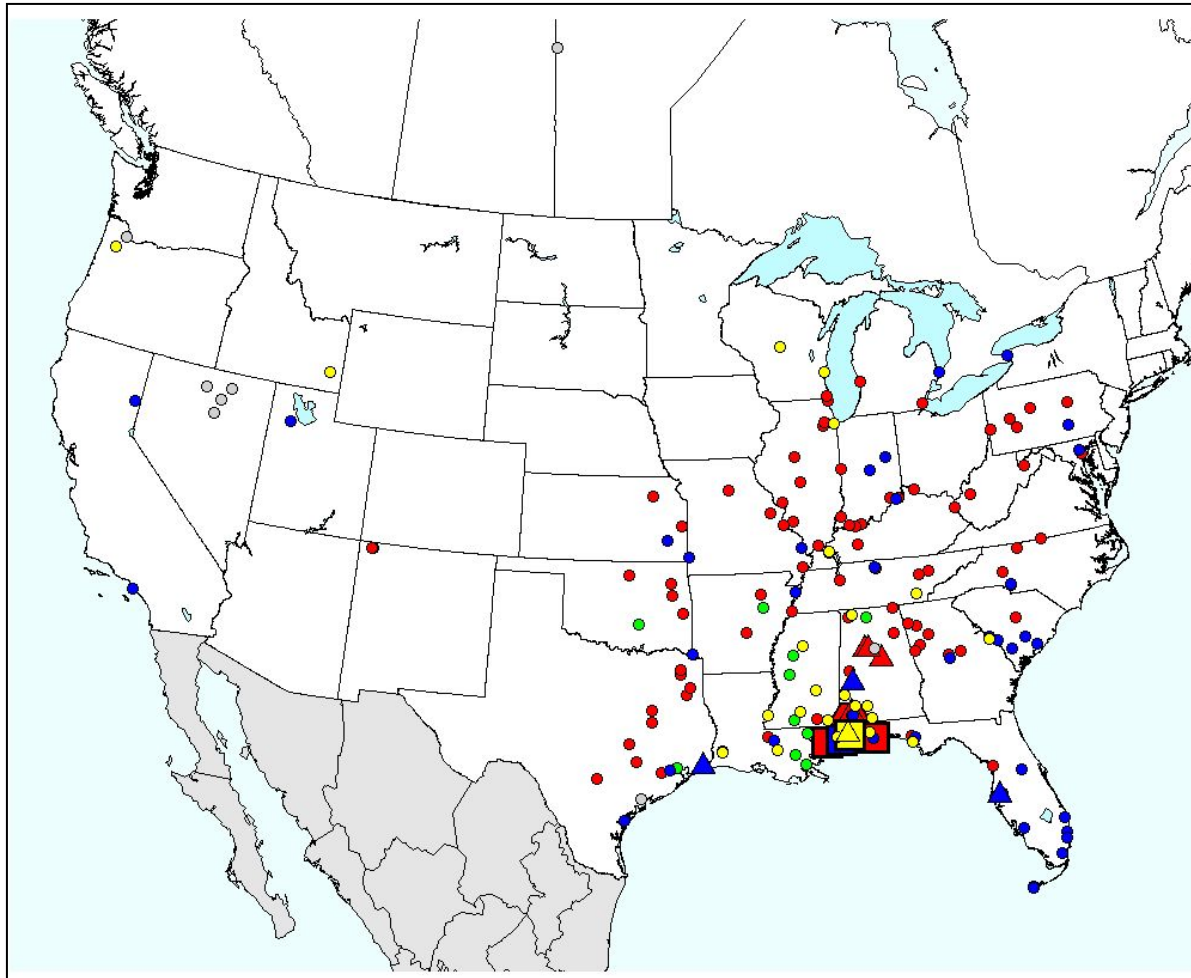
**some earlier results  
for Mobile Bay**

**Total modeled mercury deposition at selected receptors arising from from 1999 direct anthropogenic emissions sources in the United States and Canada (IPM coal fired plants are large coal-fired plants in the U.S. only)**



# Largest Modeled Individual Sources Contributing Mercury Deposition Directly to Mobile Bay (national view)

- 1996 meteorology (NGM)
- 1999 U.S. emissions (EPA NEI)
- 2000 Canadian emissions (Envr. Canada)
- no sources other than U.S. & Can. anthropogenic emissions
- total modeled deposition to Mobile Bay ~ 3.5 g Hg/km<sup>2</sup>-year



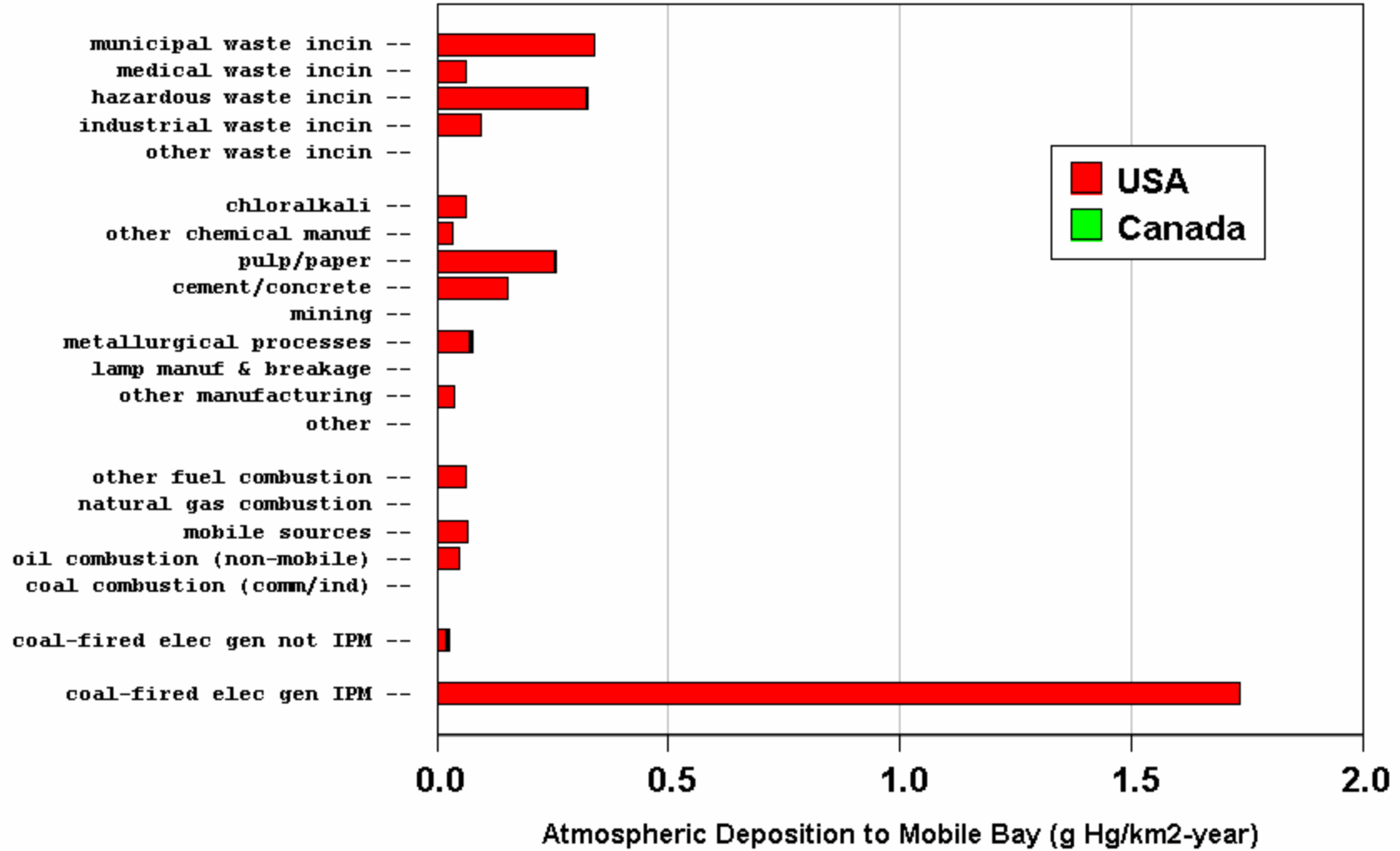
**Color of symbol indicates broad source category**

- coal-fired electricity generation
- waste incineration
- metallurgical processes
- manufacturing
- other fuel combustion

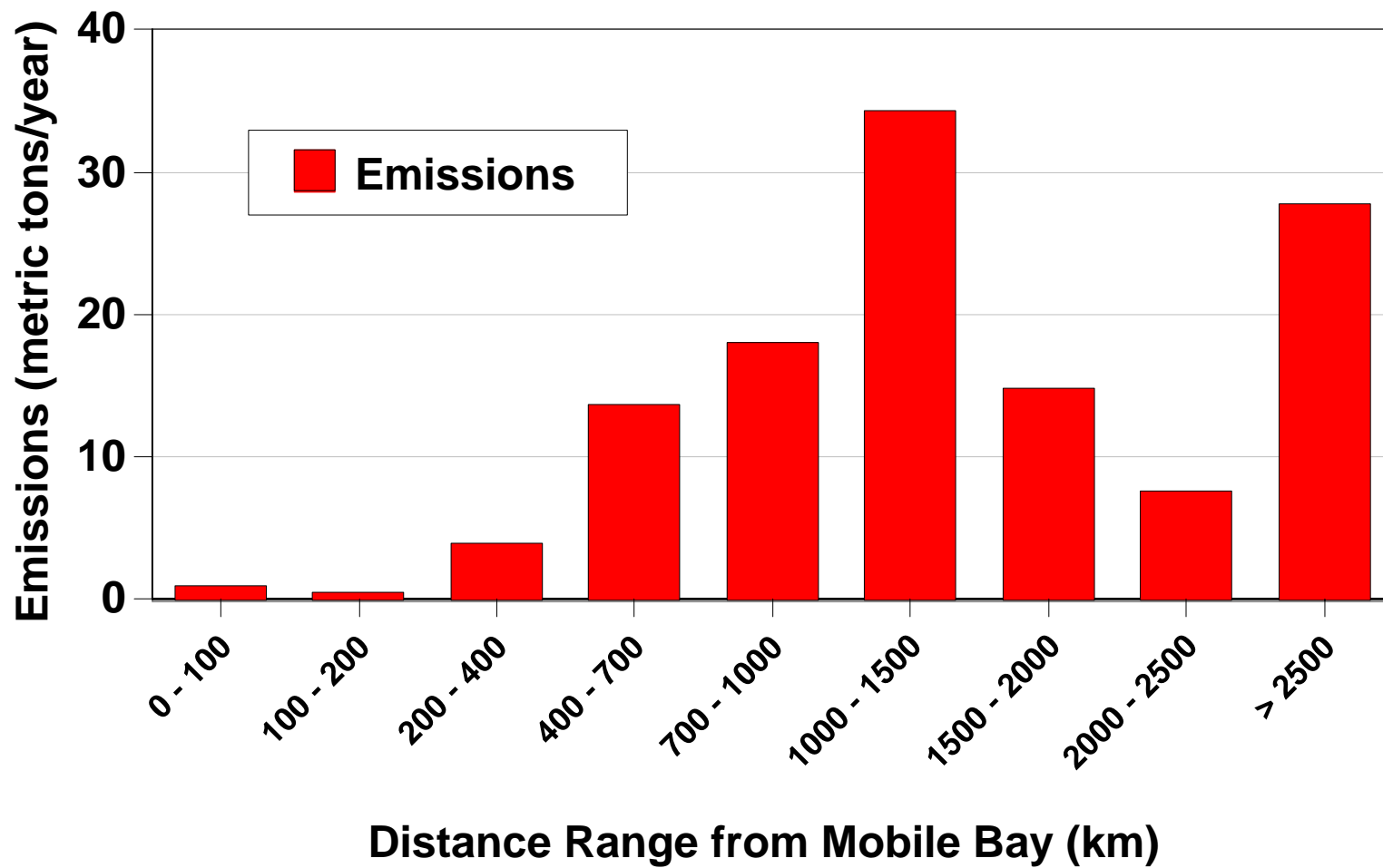
**Size and shape of symbol indicates percent of total modeled deposition from 1999 emissions from U.S. and Canadian direct anthropogenic mercury sources**

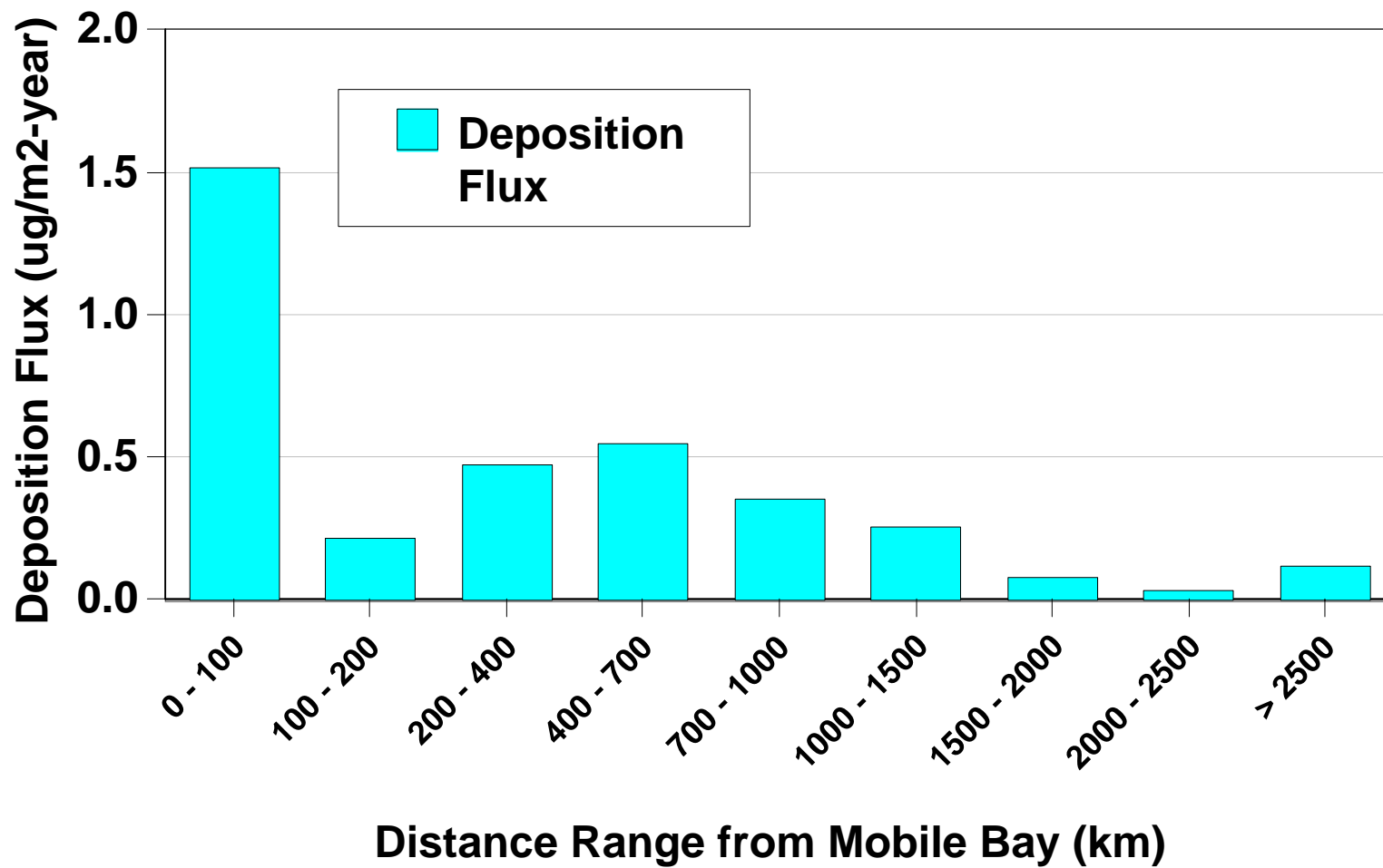
- 0.1 - 1%
- △ 1 - 3%
- 3 - 10%
- ⬡ 10 - 30%
- > 30%

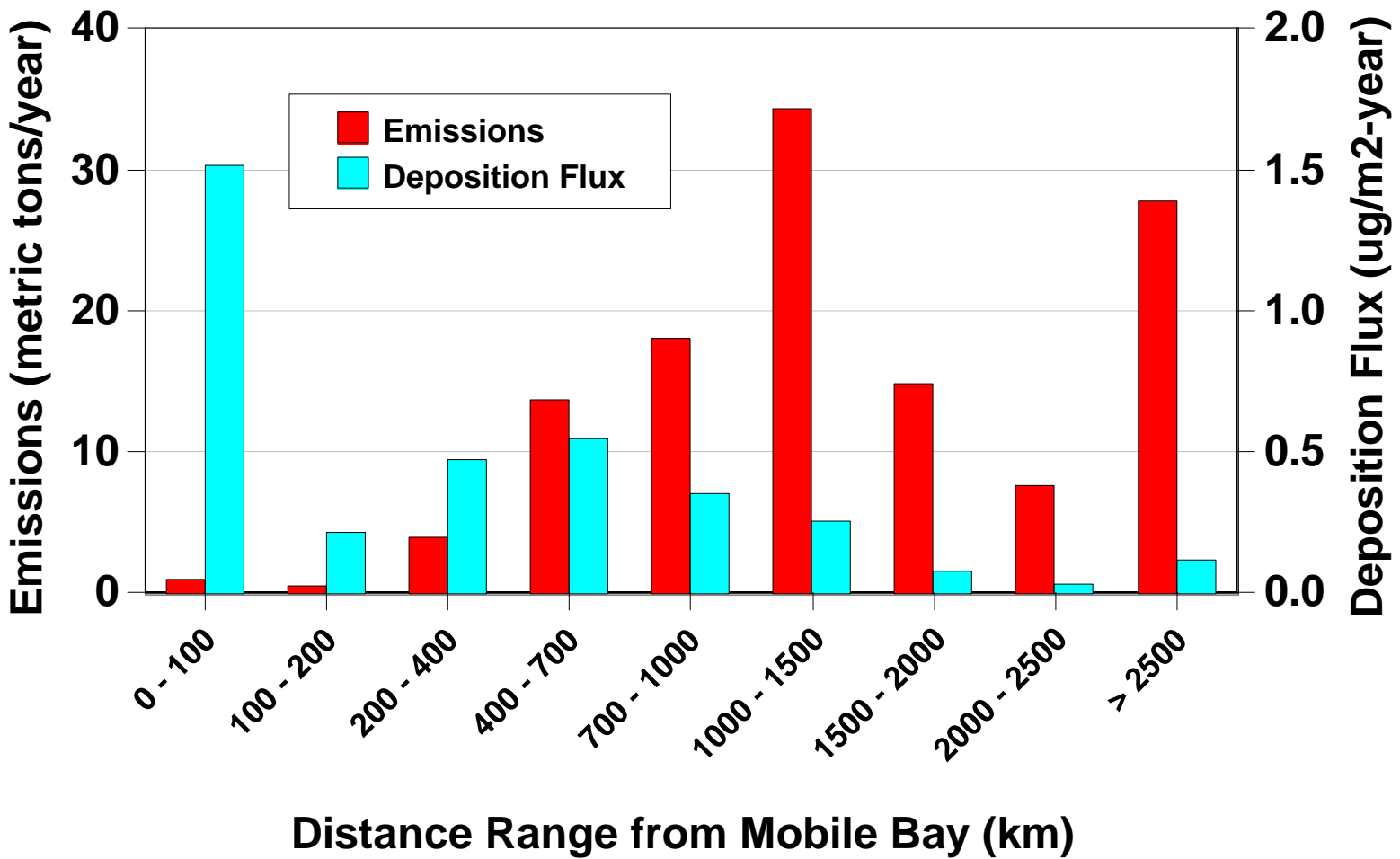




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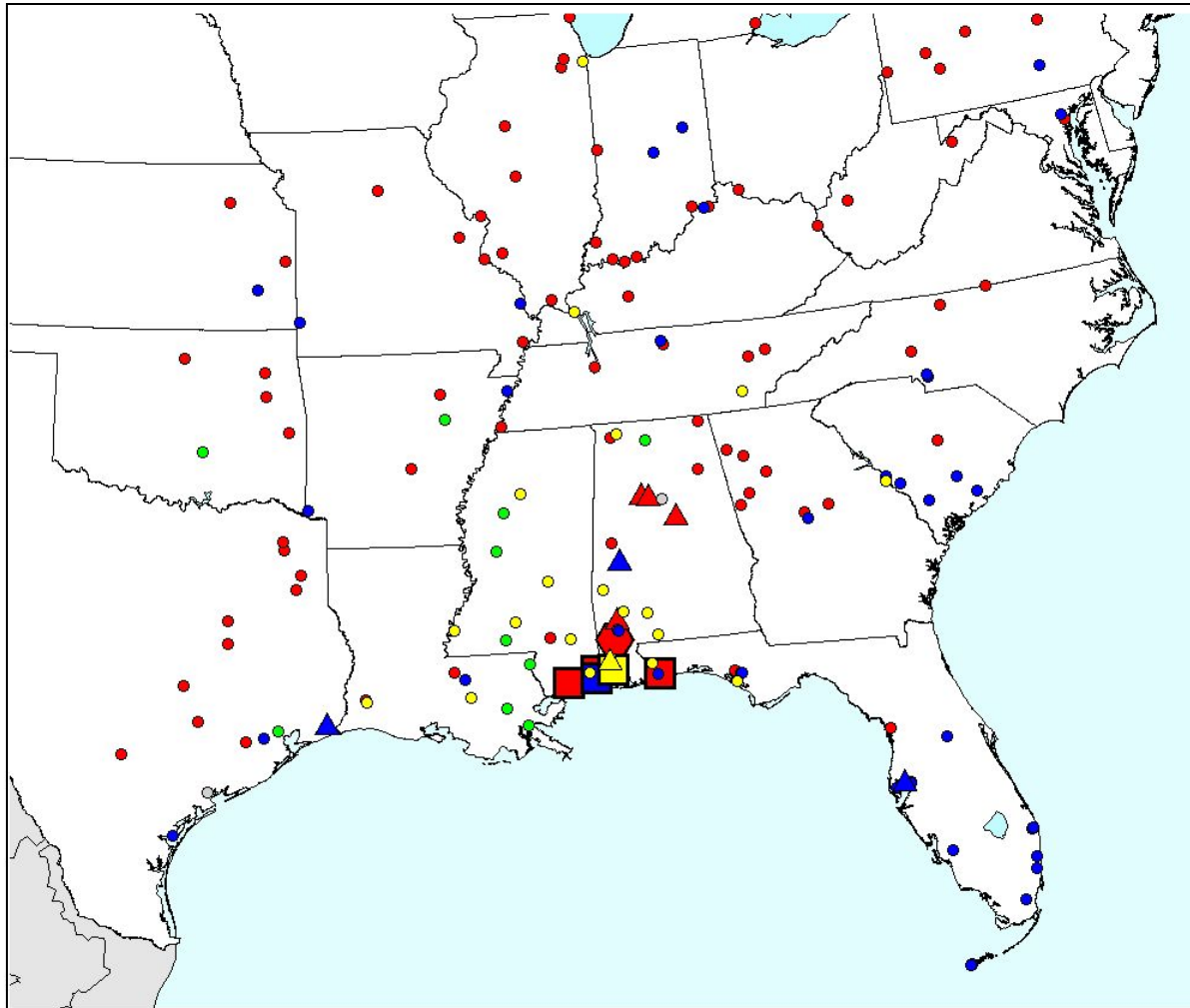






# Largest Modeled Individual Sources Contributing Mercury Deposition Directly to Mobile Bay (large regional view)

- 1996 meteorology (NGM)
- 1999 U.S. emissions (EPA NEI)
- 2000 Canadian emissions (Envr. Canada)
- no sources other than U.S. & Can. anthropogenic emissions
- total modeled deposition to Mobile Bay ~ 3.5 g Hg/km<sup>2</sup>-year

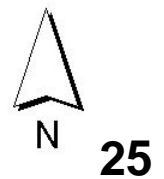
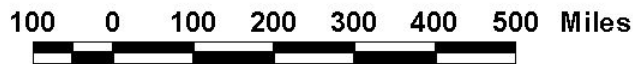


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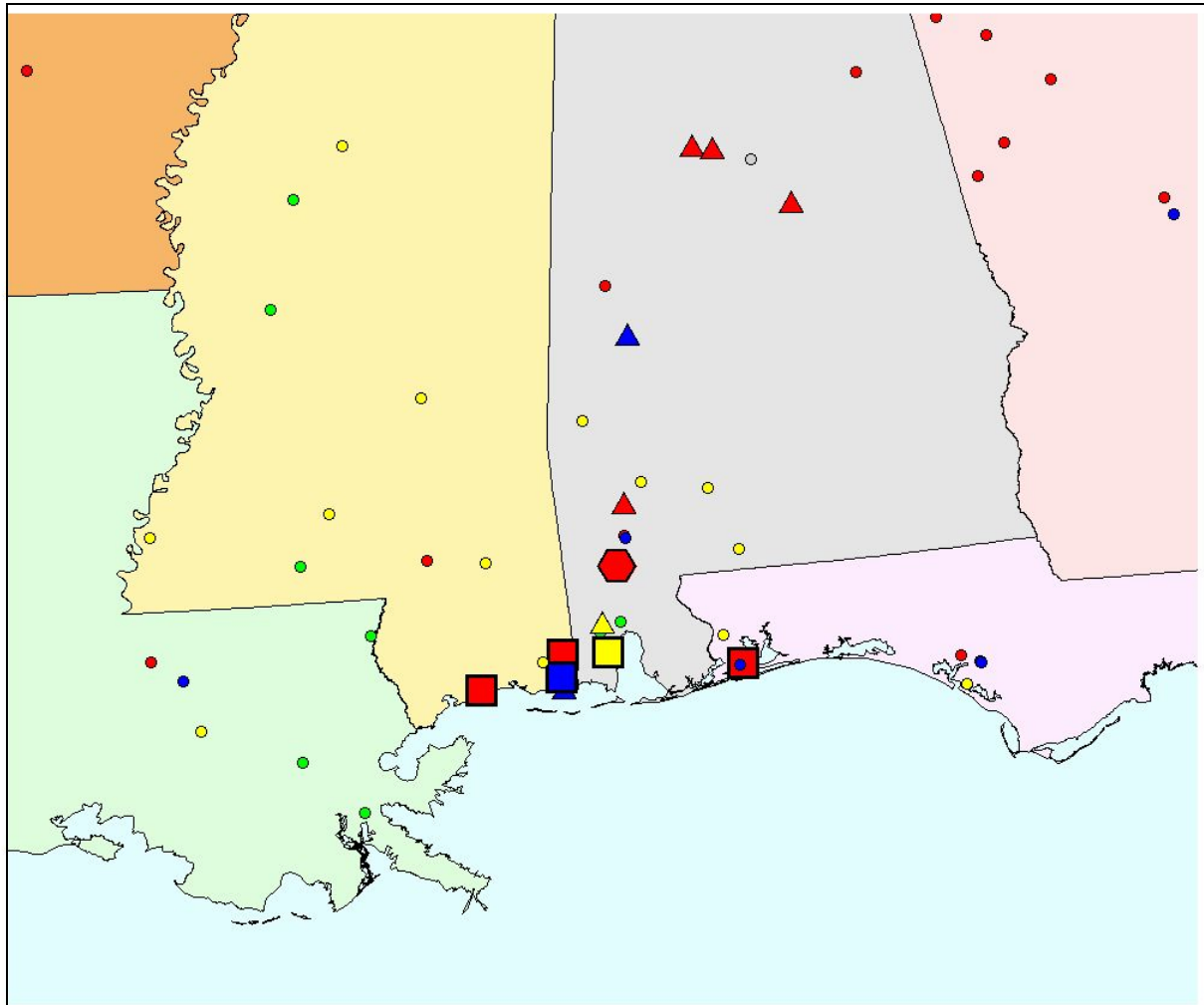
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# Largest Modeled Individual Sources Contributing Mercury Deposition Directly to Mobile Bay (regional view)

- 1996 meteorology (NGM)
- 1999 U.S. emissions (EPA NEI)
- 2000 Canadian emissions (Envr. Canada)
- no sources other than U.S. & Can. anthropogenic emissions
- total modeled deposition to Mobile Bay ~ 3.5 g Hg/km<sup>2</sup>-year



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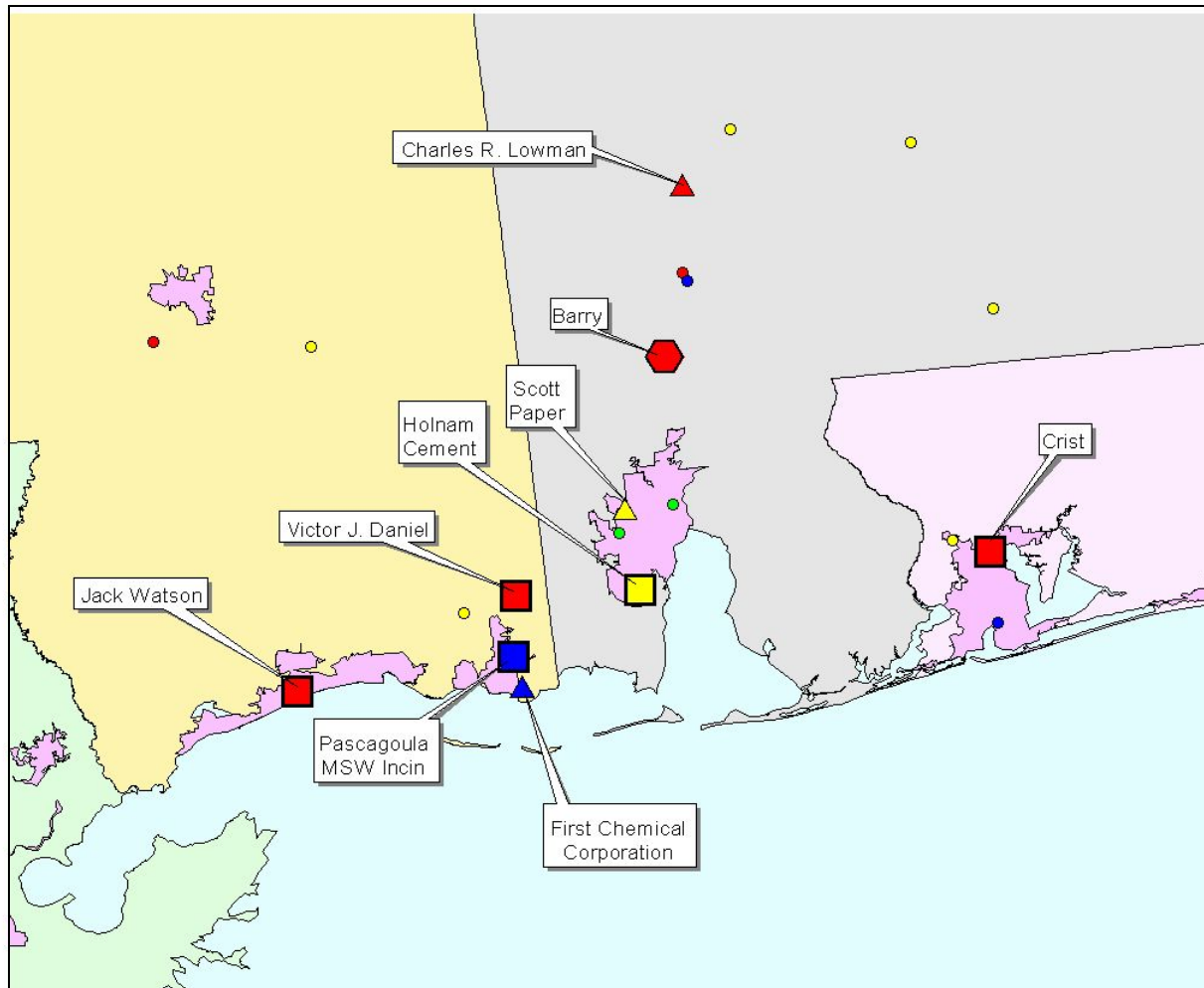
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- > 30%

100 0 100 200 Kilometers



# Largest Modeled Individual Sources Contributing Mercury Deposition Directly to Mobile Bay (local view)

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- 2000 Canadian emissions (Envr. Canada)
- no sources other than U.S. & Can. anthropogenic emissions
- total modeled deposition to Mobile Bay ~ 3.5 g Hg/km<sup>2</sup>-year

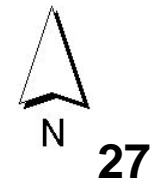
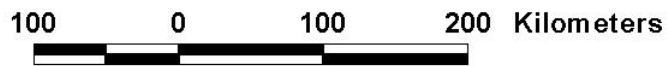


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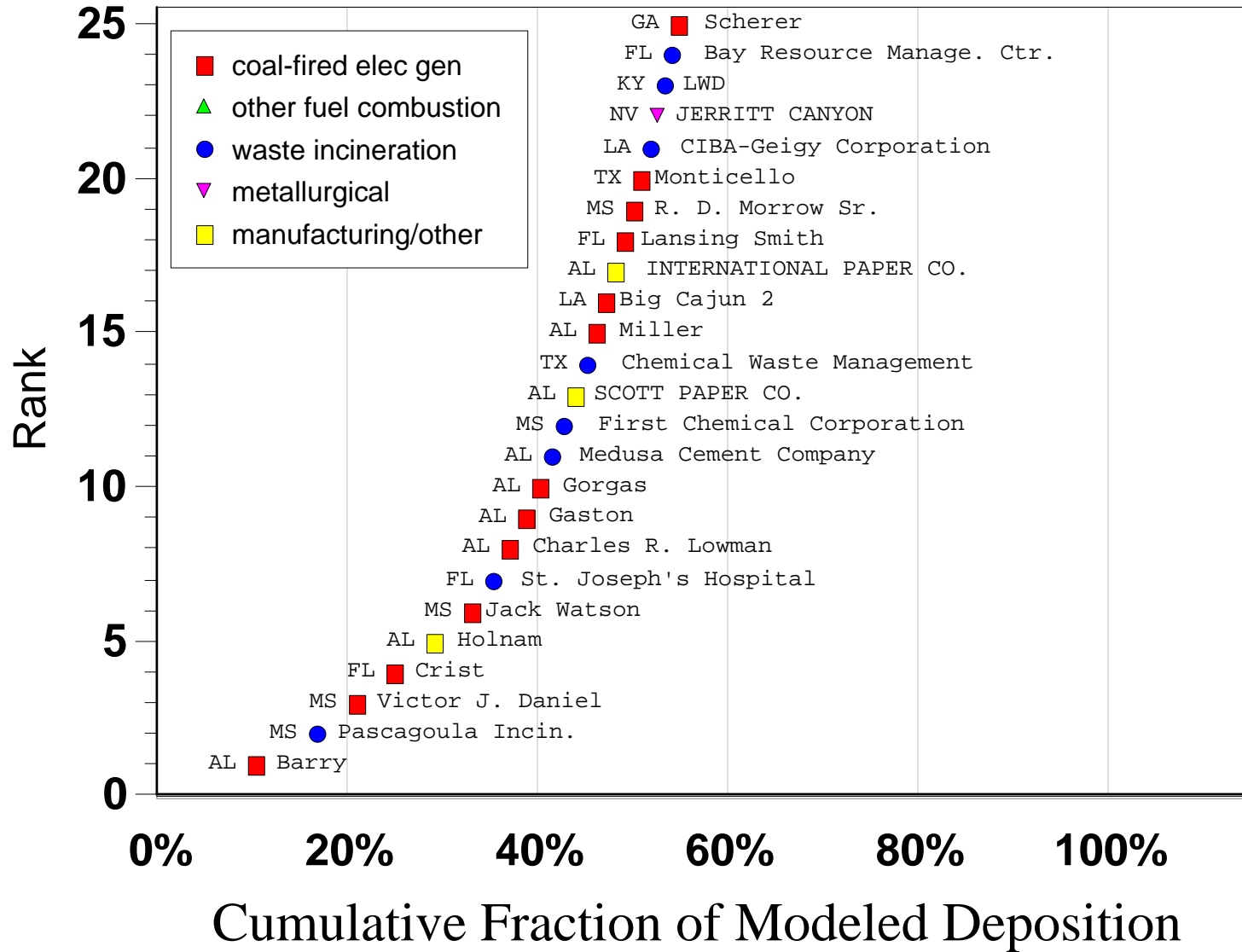
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## Top 25 Modeled Contributors to 1999 Hg Deposition Directly to Mobile Bay, considering anthropogenic direct emission sources in the United States and Canada



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- ❑ modeling methodology
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*(based on this methodology)*
- ❑ **model intercomparisons**
- ❑ **summary of previous work; current goals; challenges**

# Model Intercomparisons

- ❑ **EMEP MSC-East (~7 models)**
- ❑ **HYSPLIT-Hg vs. ISC**
- ❑ **HYSPLIT-Hg vs. CMAQ-Hg**

# Model Intercomparisons

**EMEP MSC-East (~7 models)**

**HYSPLIT-Hg vs. ISC**

**HYSPLIT-Hg vs. CMAQ-Hg**

Intro- duction	Stage I	Stage II			Stage III			Conclu- sions
	Chemistry	Hg <sup>0</sup>	Hg(p)	RGM	Wet Dep	Dry Dep	Budgets	

## Participants

- D. Syrakov ..... **Bulgaria...NIMH**
- A. Dastoor, D. Davignon ..... **Canada..... MSC-Can**
- J. Christensen ..... **Denmark...NERI**
- G. Petersen, R. Ebinghaus ..... **Germany...GKSS**
- J. Pacyna ..... **Norway.....NILU**
- J. Munthe, I. Wängberg ..... **Sweden..... IVL**
- R. Bullock ..... **USA.....EPA**
- M. Cohen, R. Artz, R. Draxler ..... **USA.....NOAA**
- C. Seigneur, K. Lohman ..... **USA..... AER/EPRI**
- A. Ryaboshapko, I. Ilyin, O.Travnikov...**EMEP..... MSC-E**



Intro- duction	Stage I	Stage II			Stage III			Conclu- sions
	Chemistry	Hg <sup>0</sup>	Hg(p)	RGM	Wet Dep	Dry Dep	Budgets	

## Intercomparison Conducted in 3 Stages

- I. Comparison of chemical schemes for a cloud environment**
- II. Air Concentrations in Short Term Episodes**
- III. Long-Term Deposition and Source-Receptor Budgets**

*EMEP Intercomparison Study of Numerical Models for Long-Range Atmospheric Transport of Mercury*

Intro- duction	Stage I	Stage II			Stage III			Conclu- sions
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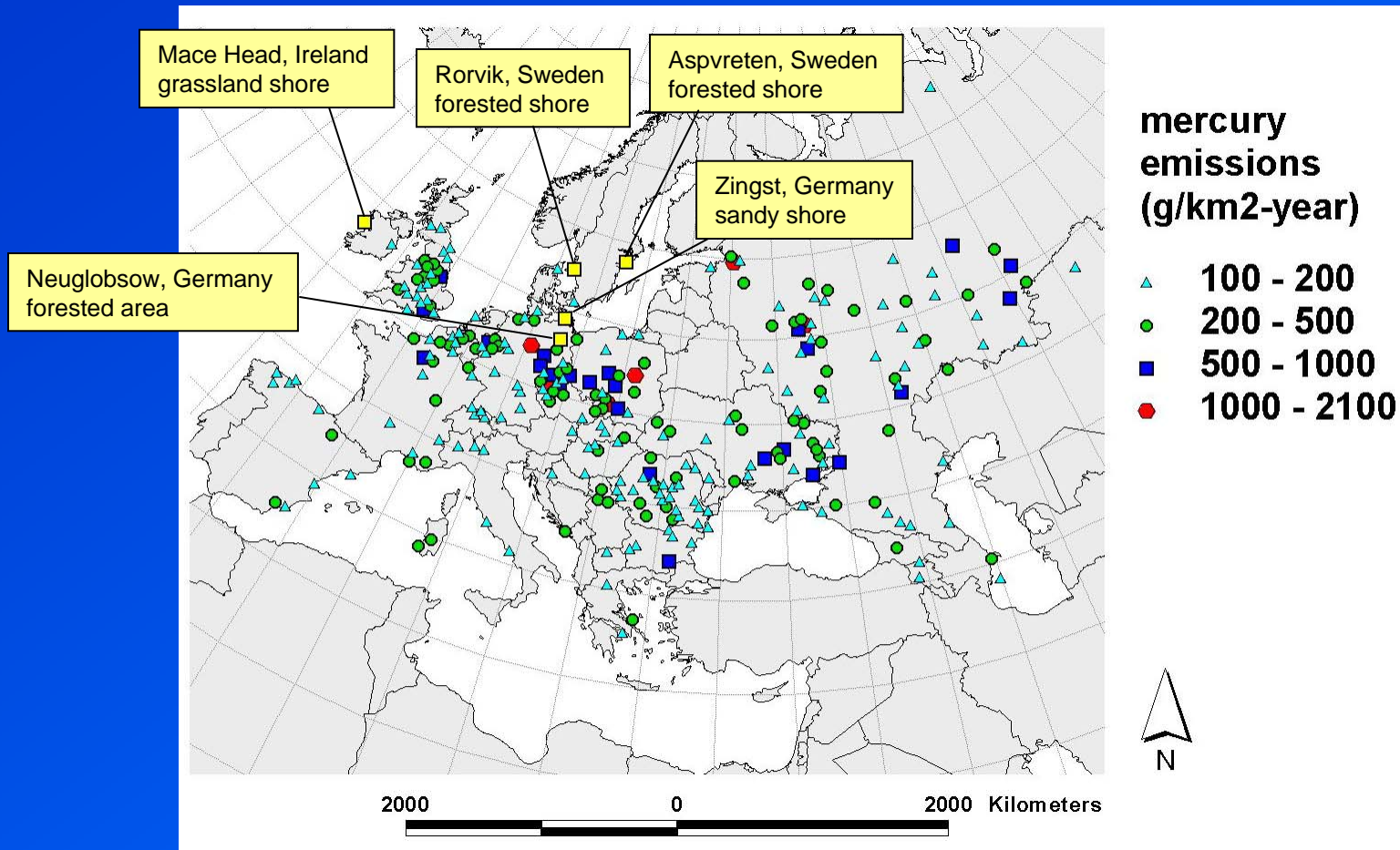
## Participating Models

Model Acronym	Model Name and Institution	Stage		
		I	II	III
CAM	<i>Chemistry of Atmos. Mercury model</i> , Environmental Institute, Sweden			
MCM	<i>Mercury Chemistry Model</i> , Atmos. & Environmental Research, USA			
CMAQ	<i>Community Multi-Scale Air Quality model</i> , US EPA			
ADOM	<i>Acid Deposition and Oxidants Model</i> , GKSS Research Center, Germany			
MSCE-HM	<i>MSC-E heavy metal regional model</i> , EMEP MSC-E			
GRAHM	<i>Global/Regional Atmospheric Heavy Metal model</i> , Environment Canada			
EMAP	<i>Eulerian Model for Air Pollution</i> , Bulgarian Meteo-service			
DEHM	<i>Danish Eulerian Hemispheric Model</i> , National Environmental Institute			
HYSPLIT	<i>Hybrid Single Particle Lagrangian Integrated Trajectory model</i> , US NOAA			
MSCE-HM-Hem	<i>MSC-E heavy metal hemispheric model</i> , EMEP MSC-E			

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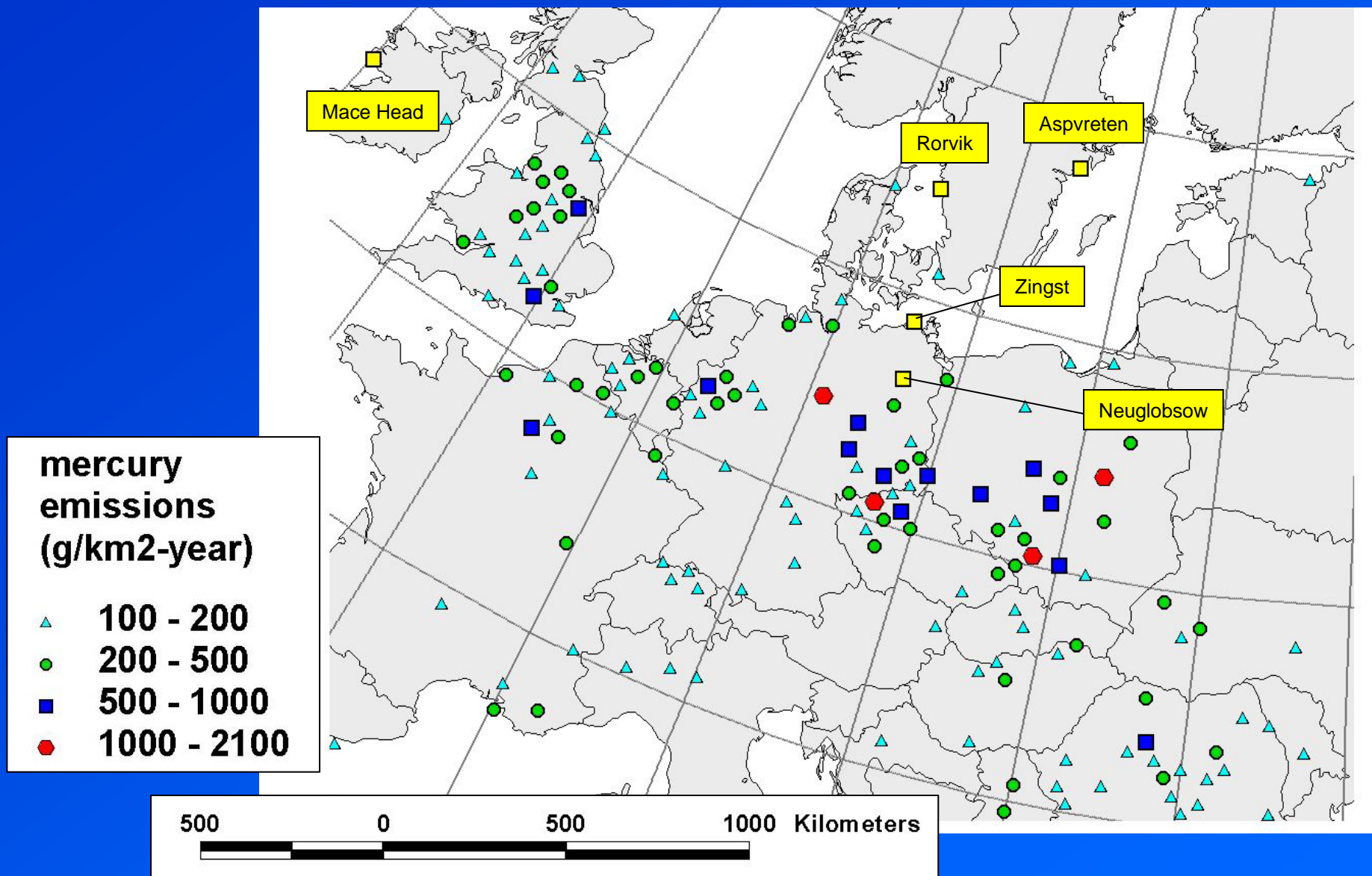
## Anthropogenic Mercury Emissions Inventory and Monitoring Sites for Phase II

(note: only showing largest emitting grid cells)



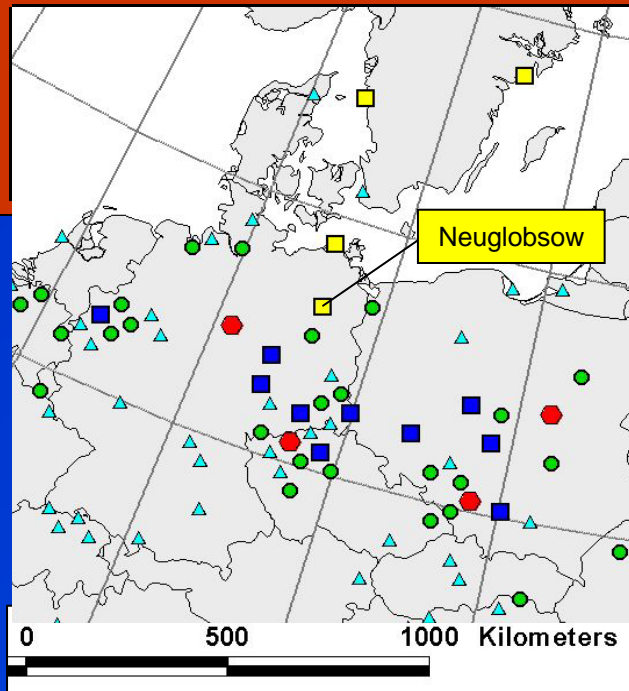
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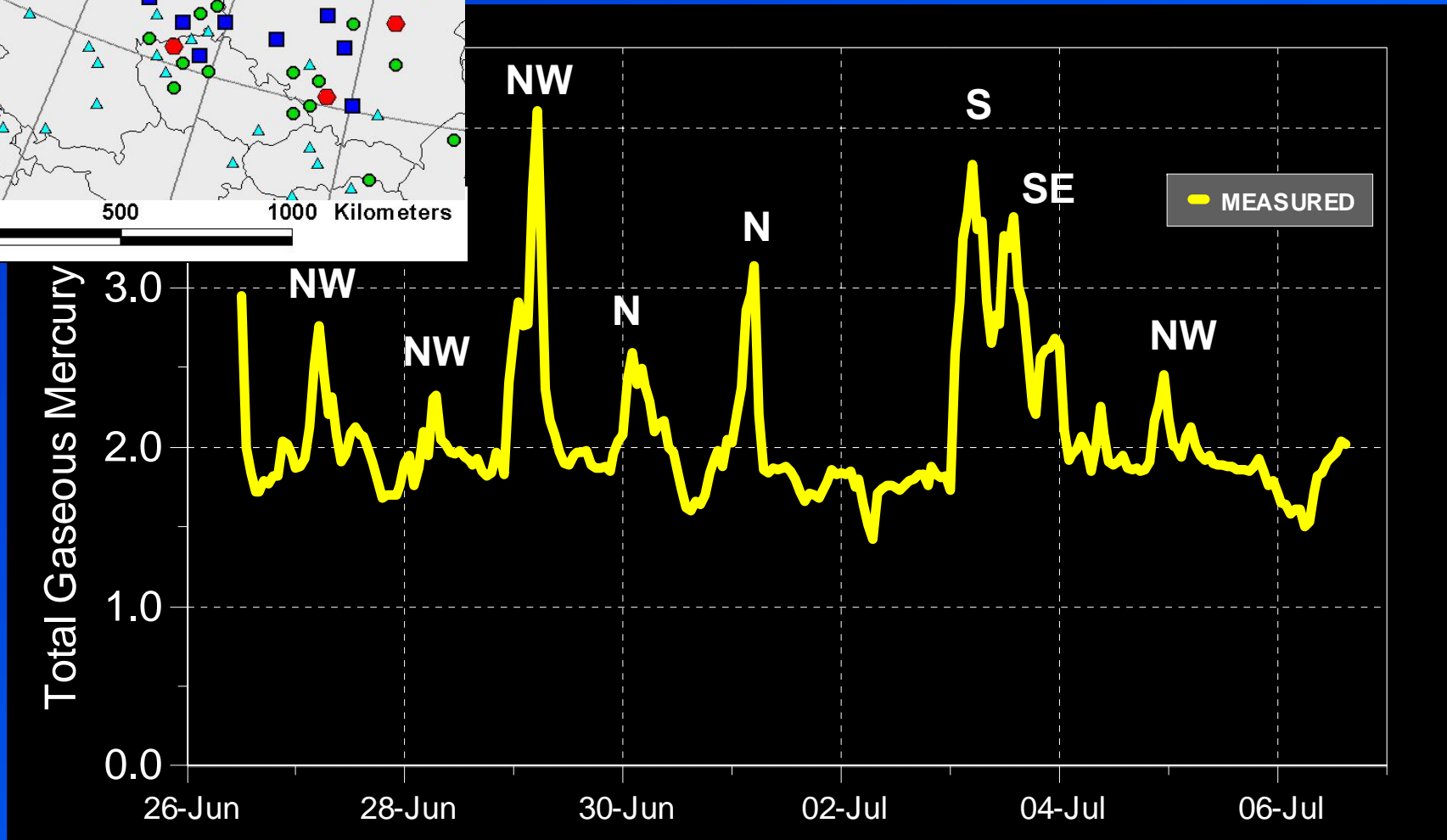


of Numerical Models for Long-Range Atmospheric Transport of Mercury

Stage II		Stage III			Conclu- sions
Hg(p)	RGM	Wet Dep	Dry Dep	Budgets	



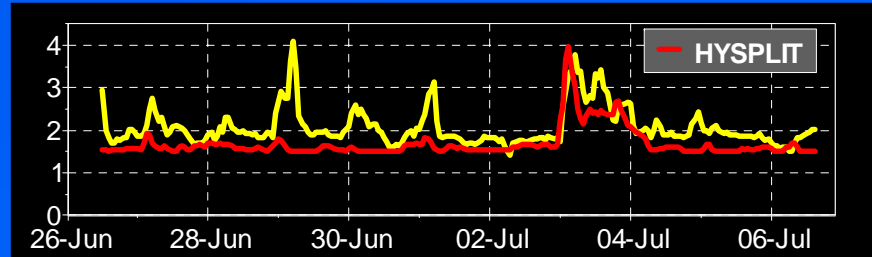
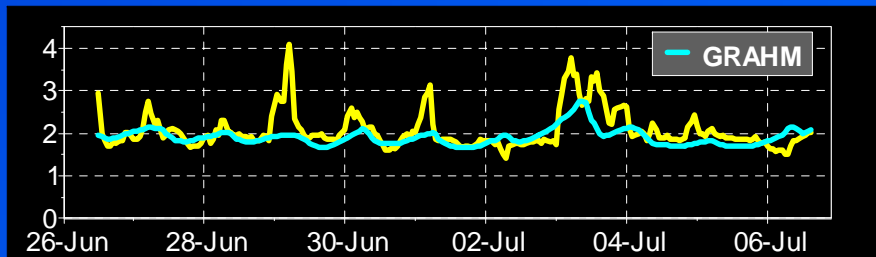
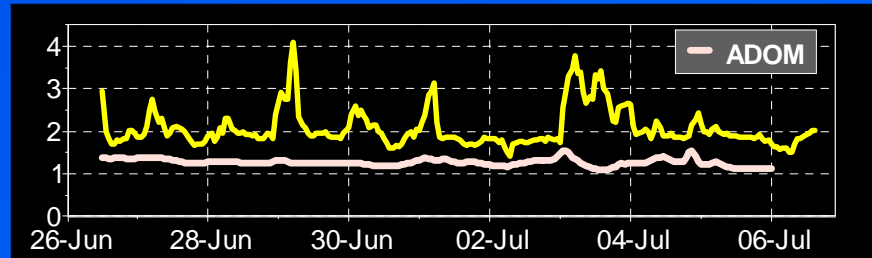
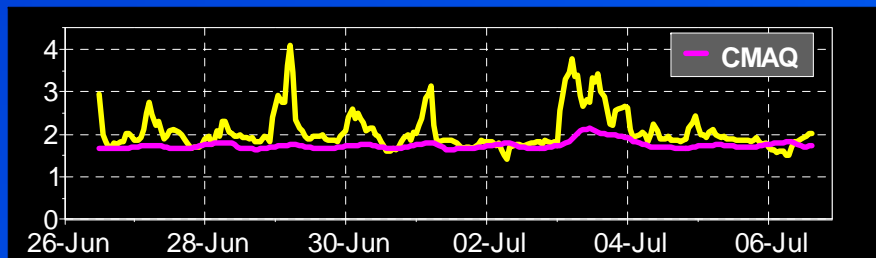
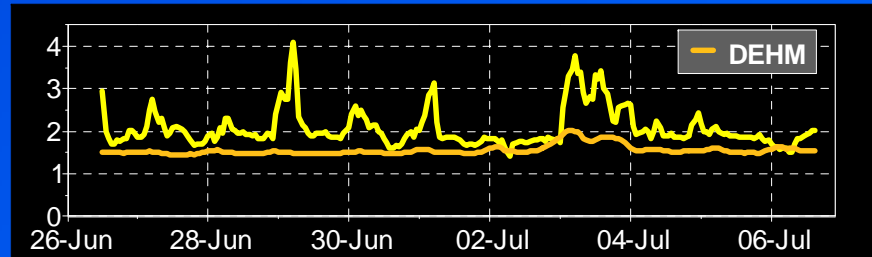
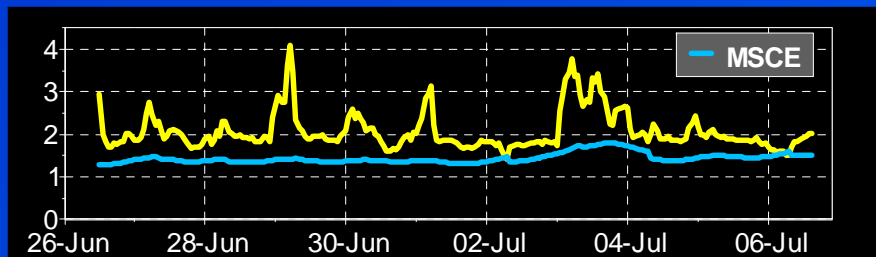
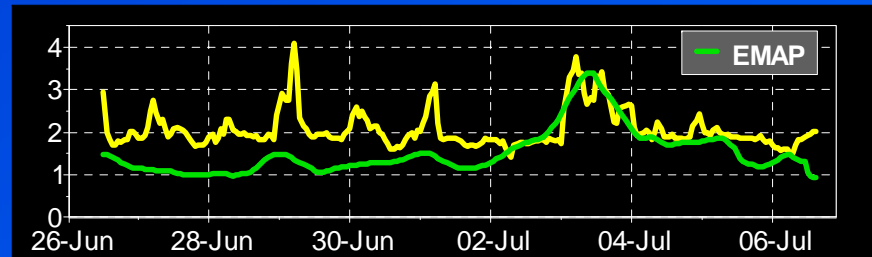
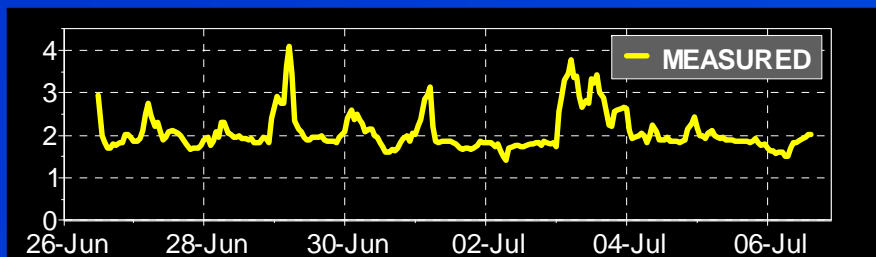
Mercury at Neuglobsow: June 26 – July 6, 1995



*EMEP Intercomparison Study of Numerical Models for Long-Range Atmospheric Transport of Mercury*

Intro- duction	Stage I	Stage II			Stage III			Conclu- sions
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**Total Gaseous Mercury (ng/m<sup>3</sup>) at Neuglobsow: June 26 – July 6, 1995**

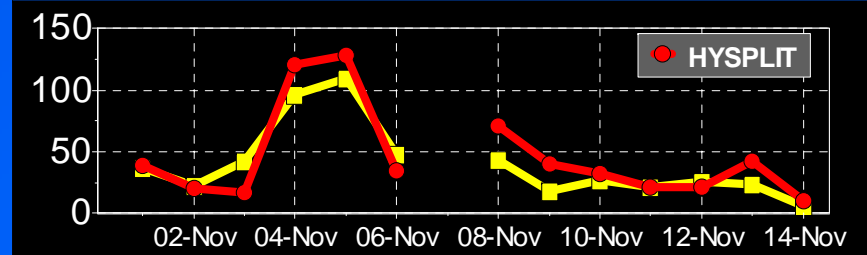
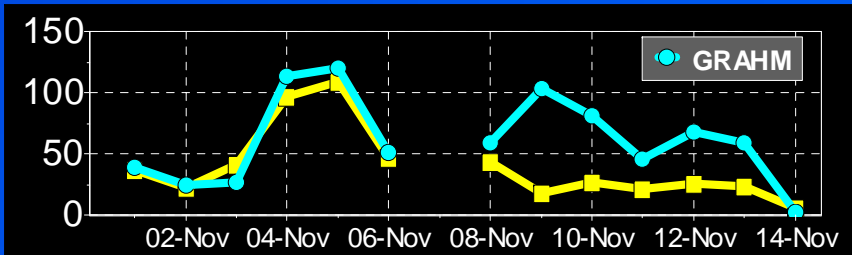
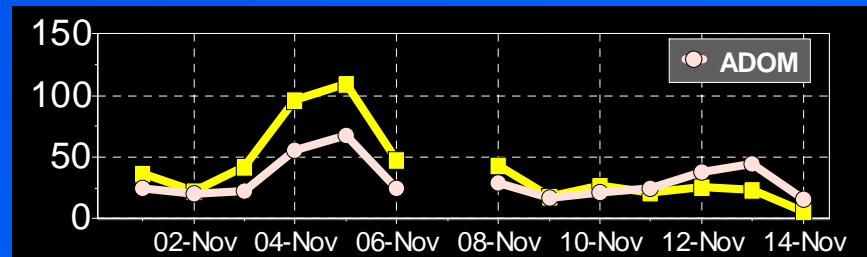
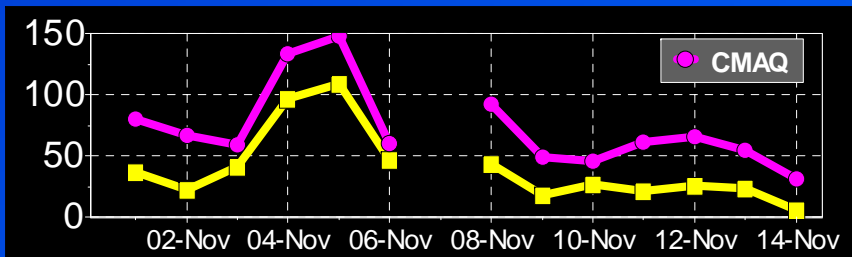
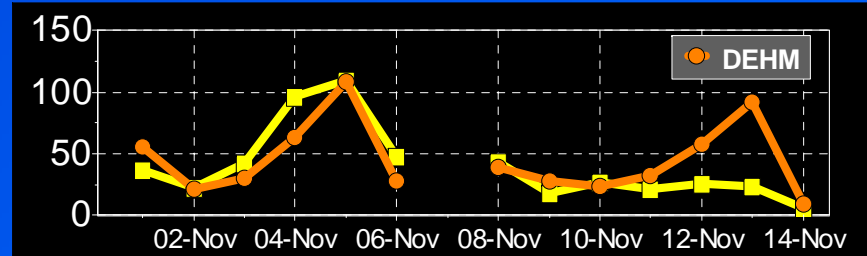
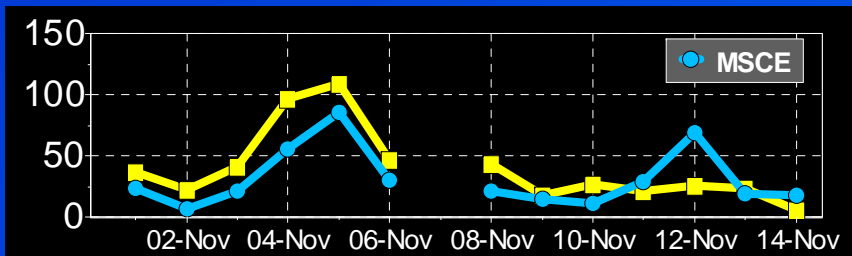
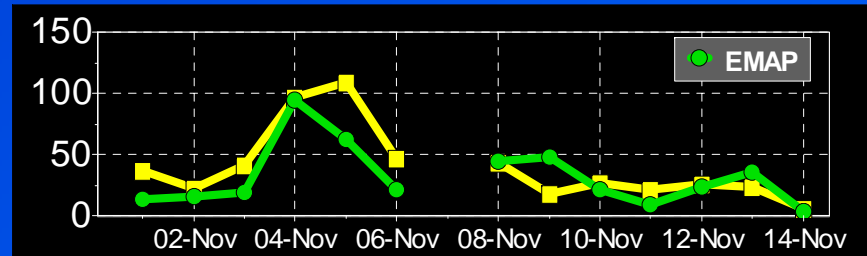
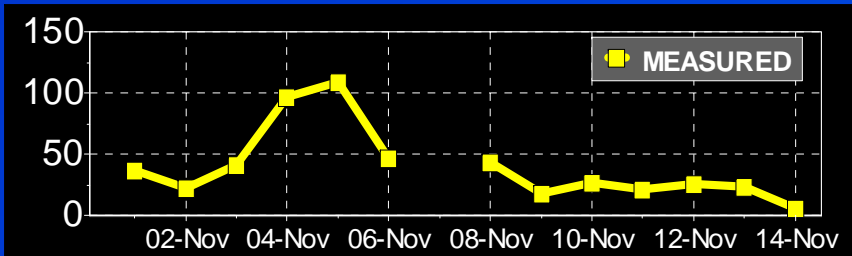




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Intro- duction	Stage I	Stage II			Stage III			Conclu- sions
	Chemistry	Hg <sup>0</sup>	Hg(p)	RGM	Wet Dep	Dry Dep	Budgets	

**Total *Particulate* Mercury (pg/m<sup>3</sup>) at Neuglobsow, Nov 1-14, 1999**



# Model Intercomparisons

□ EMEP MSC-East (~7 models)

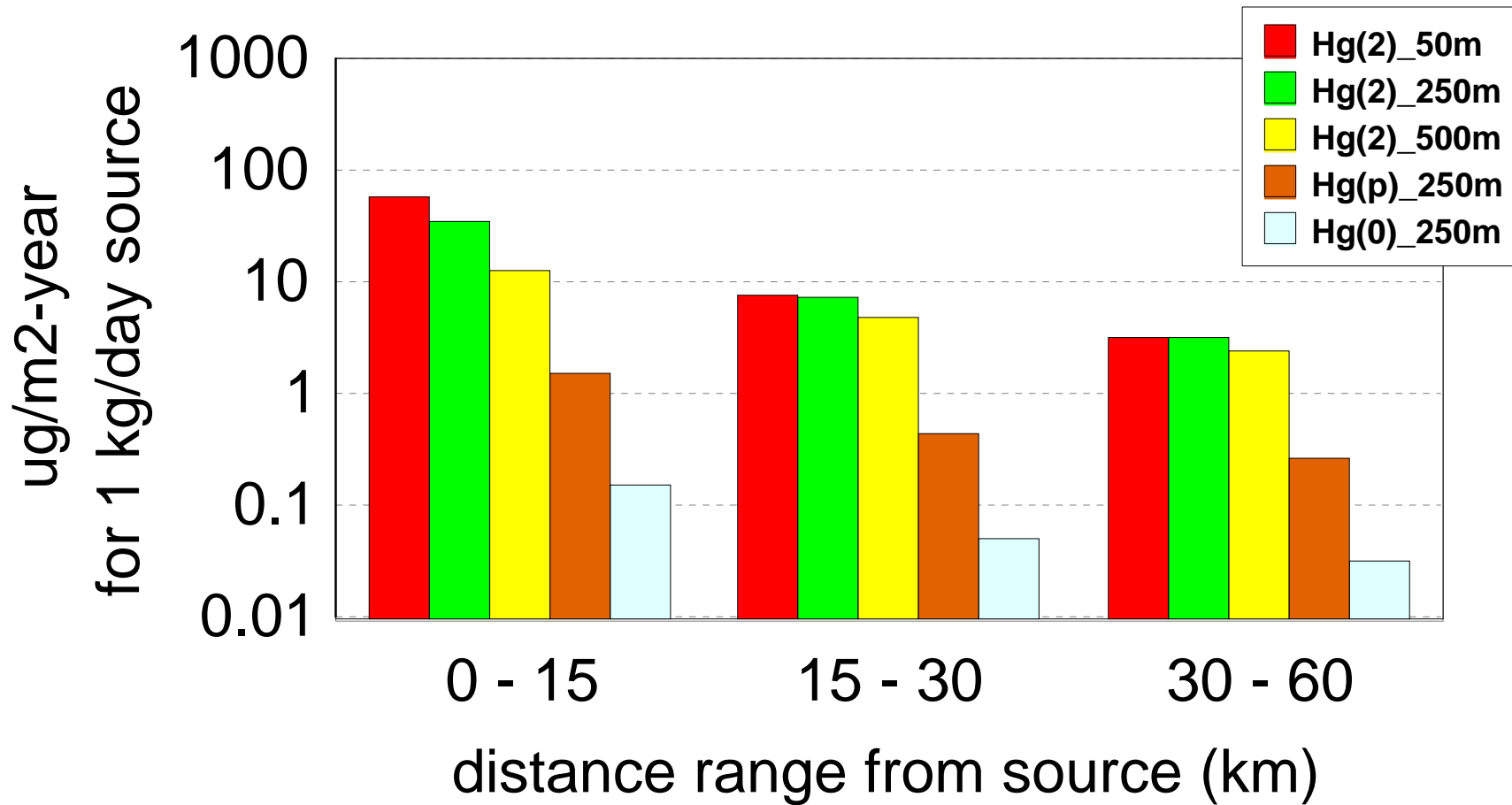
□ HYSPLIT-Hg vs. ISC

□ HYSPLIT-Hg vs. CMAQ-Hg



# Wet + Dry Deposition: HYSPLIT (Nebraska)

for emissions of different mercury forms from different stack heights



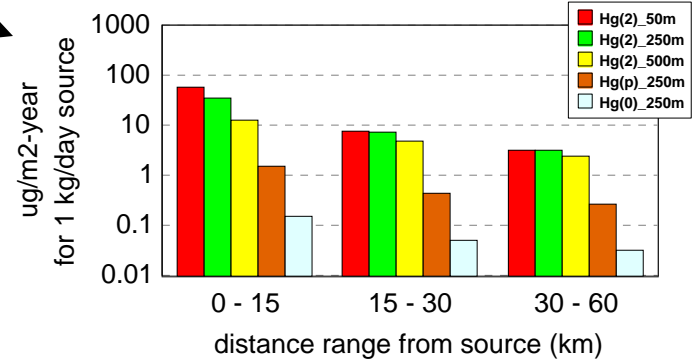
# HYSPLIT 1996



# ISC: 1990-1994

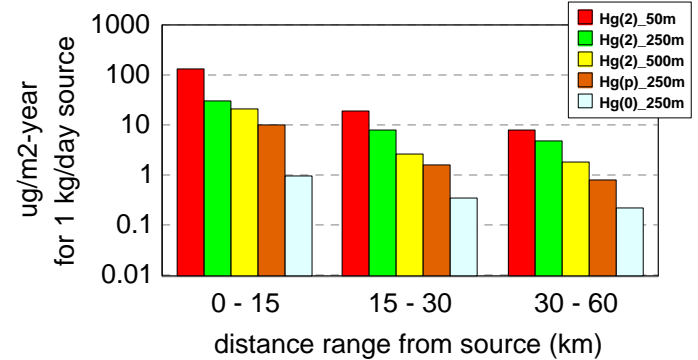


Wet + Dry Deposition: HYSPLIT (Nebraska)  
for emissions of different mercury forms from different stack heights

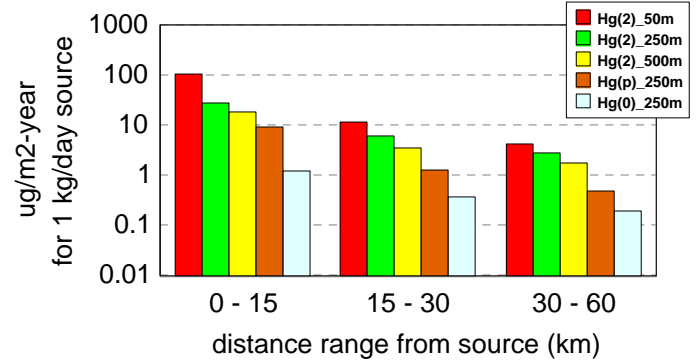


**Different Time Periods and Locations, but Similar Results**

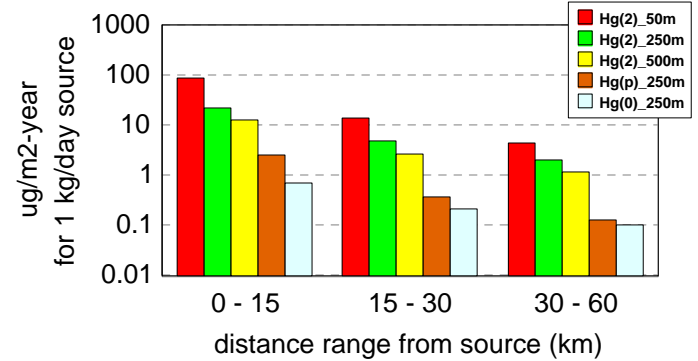
Wet + Dry Deposition: ISC (Kansas City)  
for emissions of different mercury forms from different stack heights



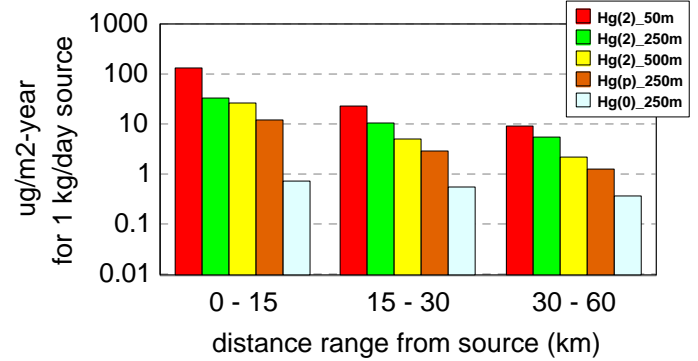
Wet + Dry Deposition: ISC (Tampa)  
for emissions of different mercury forms from different stack heights



Wet + Dry Deposition: ISC (Phoenix)  
for emissions of different mercury forms from different stack heights



Wet + Dry Deposition: ISC (Indianapolis)  
for emissions of different mercury forms from different stack heights



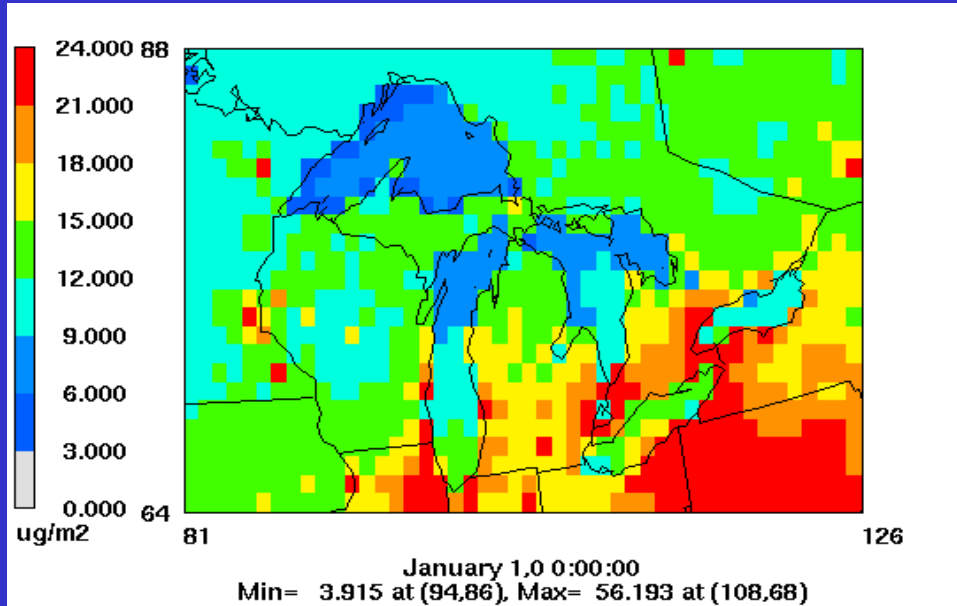
# Model Intercomparisons

□ EMEP MSC-East (~7 models)

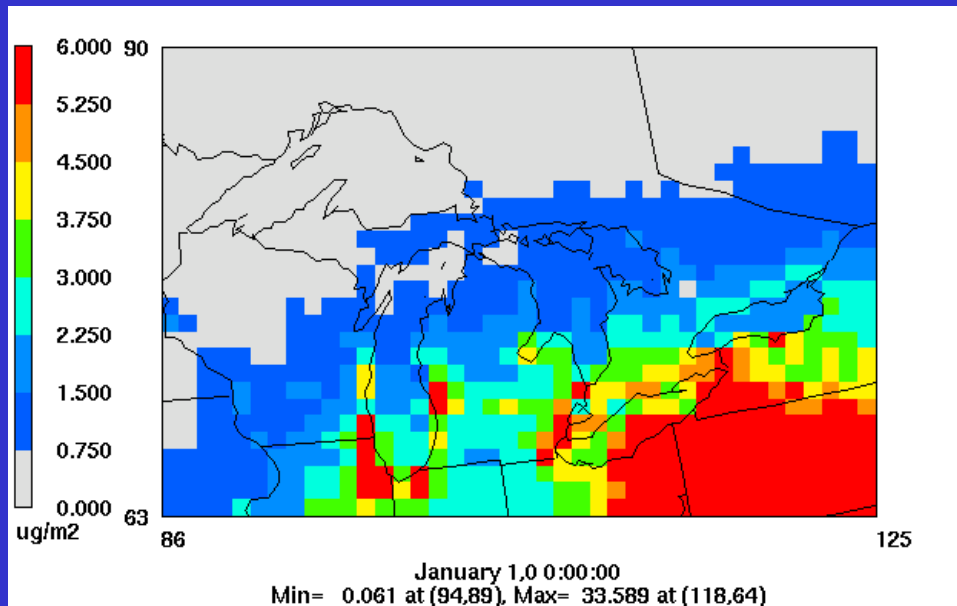
□ HYSPLIT-Hg vs. ISC

□ HYSPLIT-Hg vs. CMAQ-Hg

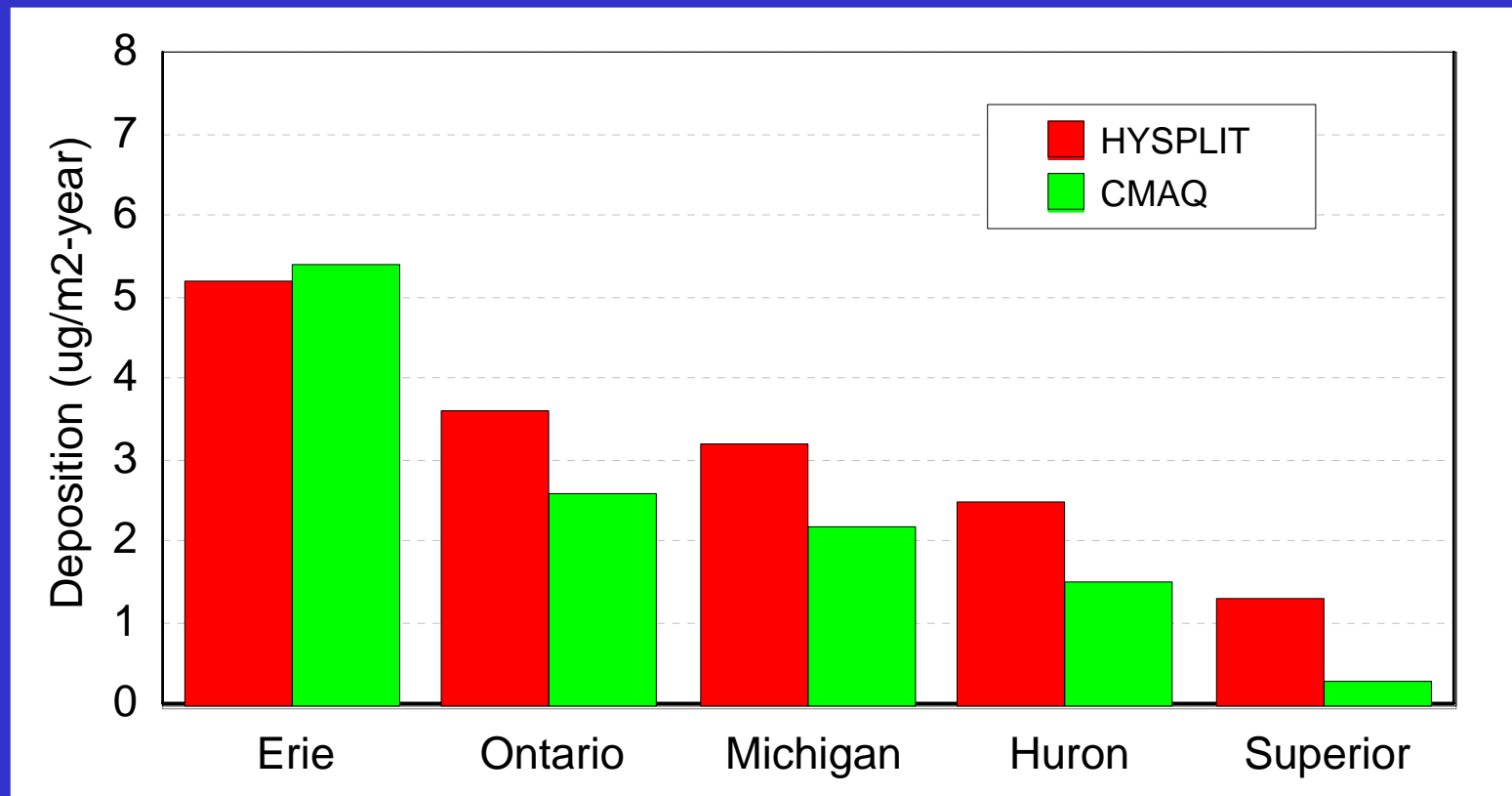
## *CMAQ-Hg results from EPA analysis performed for the Clean Air Mercury Rule*



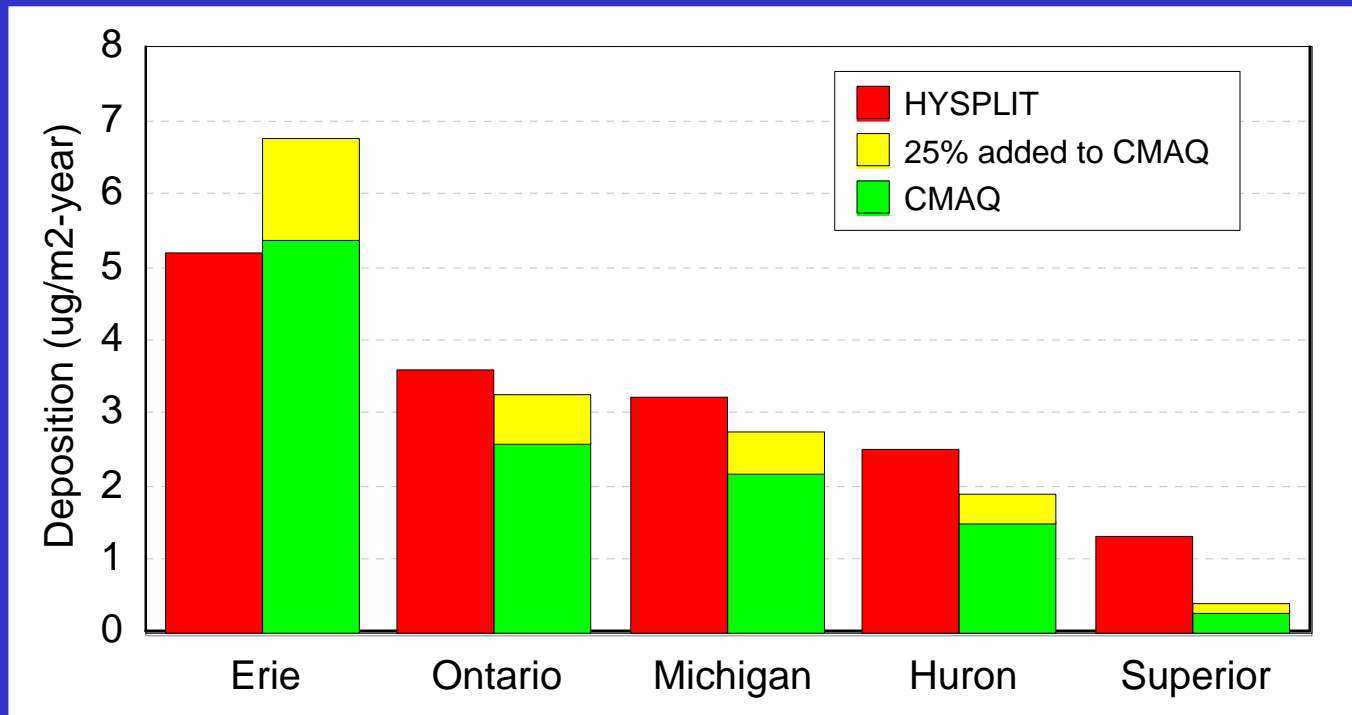
**Modeled Mercury  
Deposition in the  
Great Lakes Region  
from all sources  
during 2001**



**Modeled Mercury  
Deposition in the  
Great Lakes Region  
attributable to U.S.  
coal-fired power  
plants during 2001**



**Model-estimated U.S. utility atmospheric mercury deposition contribution to the Great Lakes: HYSPLIT-Hg (1996 meteorology, 1999 emissions) vs. CMAQ-HG (2001 meteorology, 2001 emissions).**



- Model-estimated U.S. utility atmospheric mercury deposition contribution to the Great Lakes: HYSPLIT-Hg (1996 meteorology, 1999 emissions) vs. CMAQ-Hg (2001 meteorology, 2001 emissions).
- This figure also shows an added component of the CMAQ-Hg estimates -- corresponding to 30% of the CMAQ-Hg results -- in an attempt to adjust the CMAQ-Hg results to account for the deposition underprediction found in the CMAQ-Hg model evaluation.

# Outline of Presentation

- ❑ modeling methodology
- ❑ some preliminary results for Mobile Bay  
*(based on this methodology)*
- ❑ model intercomparisons
- ❑ **summary of previous work; current goals; challenges**

## **Emissions Inventories**

### **Previous Work**

- **1996, 1999 U.S. NEI**
- **1995, 2000 Canada**



## Emissions Inventories

### Previous Work

- 1996, 1999 U.S. NEI
- 1995, 2000 Canada

### Current Objectives

- 2002 U.S. NEI
- 2002 Canada
- Global – 2000 (Pacyna-NILU)
- Natural sources
- Re-emitted anthropogenic

## Emissions Inventories

<b>Previous Work</b>	<ul style="list-style-type: none"><li>• 1996, 1999 U.S. NEI</li><li>• 1995, 2000 Canada</li></ul>
<b>Current Objectives</b>	<ul style="list-style-type: none"><li>• 2002 U.S. NEI</li><li>• 2002 Canada</li><li>• Global – 2000 (Pacyna-NILU)</li><li>• Natural sources</li><li>• Re-emitted anthropogenic</li></ul>
<b>Challenges and Notes</b>	<ul style="list-style-type: none"><li>• <b>Speciation?</b></li><li>• <b>Short-term variations (e.g. hourly) [CEM's?]</b></li><li>• <b>Longer-term variations (e.g., maintenance)?</b></li><li>• <b>Mobile sources</b></li><li>• <b>Harmonization of source-categories</b></li><li>• <b>Emissions inventories currently only become available many years after the fact; how can we evaluate models using current monitoring data?</b></li></ul>

## **Meteorological Data**

### **Previous Work**

- **For U.S./Canadian modeling, 1996 data from NOAA Nested Grid Model (NGM), 180 km**

## Meteorological Data

### Previous Work

- For U.S./Canadian modeling, 1996 data from NOAA Nested Grid Model (NGM), 180 km

### Current Objectives

- U.S. – NOAA EDAS 40 km, 3 hr
- Global – NOAA GDAS 1° x 1°, 3 hr

## Meteorological Data

<b>Previous Work</b>	<ul style="list-style-type: none"><li>• For U.S./Canadian modeling, 1996 data from NOAA Nested Grid Model (NGM), 180 km</li></ul>
<b>Current Objectives</b>	<ul style="list-style-type: none"><li>• U.S. – NOAA EDAS 40 km, 3 hr</li><li>• Global – NOAA GDAS 1° x 1°, 3 hr</li></ul>
<b>Challenges and Notes</b>	<ul style="list-style-type: none"><li>• <b>Forecast vs. Analysis</b></li><li>• <b>Data assimilation</b></li><li>• <b>Precipitation??</b></li><li>• <b>Difficult to archive NOAA analysis datasets</b></li><li>• <b>Need finer-resolution datasets, especially for near-field analysis and model evaluation</b></li><li>• <b>We have conversion filters (e.g., for MM5), but these data are not readily available</b></li><li>• <b>What is the best way to archive and share data?</b></li></ul>

## Atmospheric Chemistry and Physics

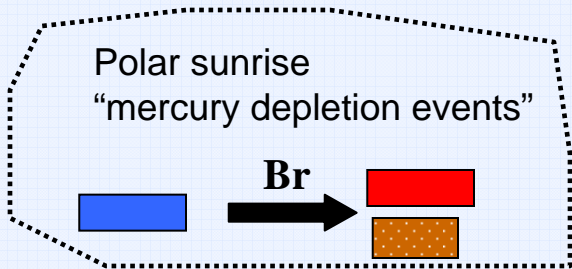
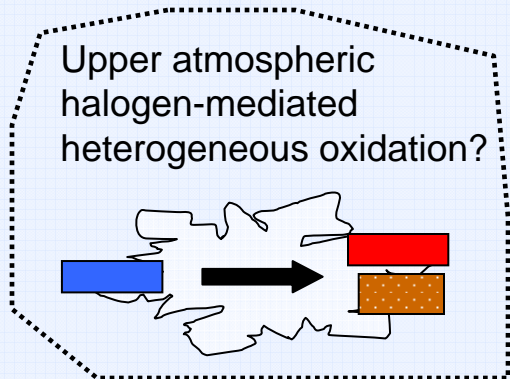
### Previous Work

- Typical chemical mechanism
- Prescribed fields for reactive trace gases (e.g., O<sub>3</sub>, OH, SO<sub>2</sub>) and other necessary constituents (e.g., soot) based on modeled, measured, and/or empirical relationships

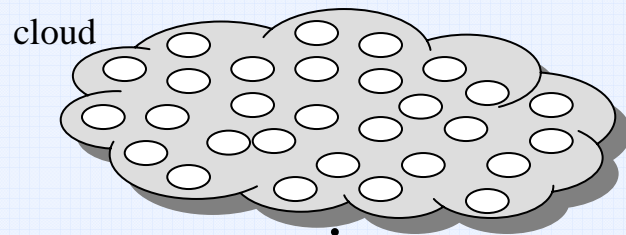
# Atmospheric Chemical Reaction Scheme for Mercury

Reaction	Rate	Units	Reference
<b><i>GAS PHASE REACTIONS</i></b>			
$\text{Hg}^0 + \text{O}_3 \rightarrow \text{Hg(p)}$	3.0E-20	cm <sup>3</sup> /molec-sec	Hall (1995)
$\text{Hg}^0 + \text{HCl} \rightarrow \text{HgCl}_2$	1.0E-19	cm <sup>3</sup> /molec-sec	Hall and Bloom (1993)
$\text{Hg}^0 + \text{H}_2\text{O}_2 \rightarrow \text{Hg(p)}$	8.5E-19	cm <sup>3</sup> /molec-sec	Tokos et al. (1998) (upper limit based on experiments)
$\text{Hg}^0 + \text{Cl}_2 \rightarrow \text{HgCl}_2$	4.0E-18	cm <sup>3</sup> /molec-sec	Calhoun and Prestbo (2001)
$\text{Hg}^0 + \text{OH}\cdot \rightarrow \text{Hg(p)}$	8.7E-14	cm <sup>3</sup> /molec-sec	Sommar et al. (2001)
<b><i>AQUEOUS PHASE REACTIONS</i></b>			
$\text{Hg}^0 + \text{O}_3 \rightarrow \text{Hg}^{+2}$	4.7E+7	(molar-sec) <sup>-1</sup>	Munthe (1992)
$\text{Hg}^0 + \text{OH}\cdot \rightarrow \text{Hg}^{+2}$	2.0E+9	(molar-sec) <sup>-1</sup>	Lin and Pehkonen(1997)
$\text{HgSO}_3 \rightarrow \text{Hg}^0$	$T * e^{((31.971 * T) - 12595.0) / T} \text{ sec}^{-1}$ [T = temperature (K)]		Van Loon et al. (2002)
$\text{Hg(II)} + \text{HO}_2\cdot \rightarrow \text{Hg}^0$	~ 0	(molar-sec) <sup>-1</sup>	Gardfeldt & Jonnson (2003)
$\text{Hg}^0 + \text{HOCl} \rightarrow \text{Hg}^{+2}$	2.1E+6	(molar-sec) <sup>-1</sup>	Lin and Pehkonen(1998)
$\text{Hg}^0 + \text{OCl}^{-1} \rightarrow \text{Hg}^{+2}$	2.0E+6	(molar-sec) <sup>-1</sup>	Lin and Pehkonen(1998)
$\text{Hg(II)} \leftrightarrow \text{Hg(II)}_{(\text{soot})}$	9.0E+2	liters/gram; t = 1/hour	eqnbrm: Seigneur et al. (1998) rate: Bullock & Brehme (2002).
$\text{Hg}^{+2} + \text{h} < \rightarrow \text{Hg}^0$	6.0E-7	(sec) <sup>-1</sup> (maximum)	Xiao et al. (1994); Bullock and Brehme (2002)

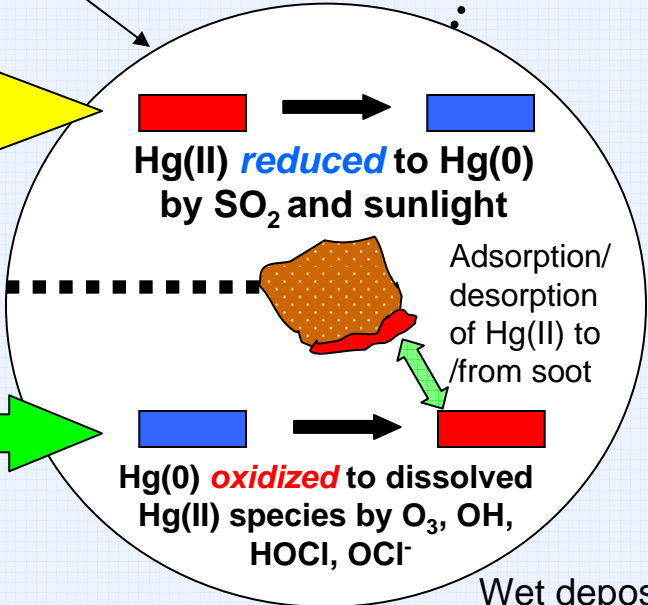
# Atmospheric Mercury Fate Processes



- Elemental Mercury [Hg(0)]
- Hg(II), ionic mercury, RGM
- Particulate Mercury [Hg(p)]



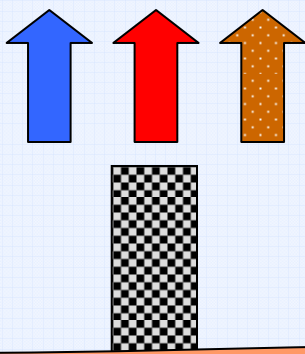
CLOUD DROPLET



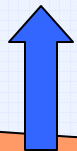
Vapor phase:

Hg(0) oxidized to RGM and Hg(p) by O<sub>3</sub>, H<sub>2</sub>O<sub>2</sub>, Cl<sub>2</sub>, OH, HCl

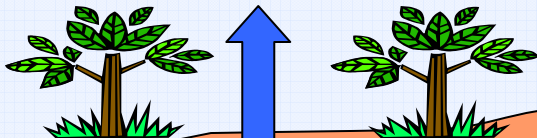
Primary Anthropogenic Emissions



Natural emissions

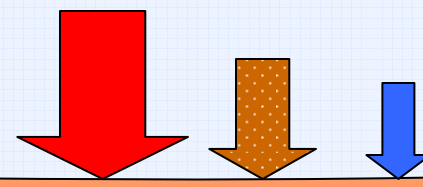


Re-emission of previously deposited anthropogenic and natural mercury



Wet deposition

Dry deposition





## Atmospheric Chemistry and Physics

### Previous Work

- Typical chemical mechanism
- Prescribed fields for reactive trace gases (e.g., O<sub>3</sub>, OH, SO<sub>2</sub>) and other necessary constituents (e.g., soot) based on modeled, measured, and/or empirical relationships

### Current Objectives

- **Include new information on chemistry, e.g., bromine reactions, etc.**
- **Sensitivity analyses**
- **Use gridded chemical output from full-chemistry atmospheric model (e.g., CMAQ)**
- **Option - run HYSPLIT in Eulerian mode for chemistry; conduct one-atmosphere simulation**

## Atmospheric Chemistry and Physics

Previous Work	<ul style="list-style-type: none"><li>• Typical chemical mechanism</li><li>• Prescribed fields for reactive trace gases (e.g., O<sub>3</sub>, OH, SO<sub>2</sub>) and other necessary constituents (e.g., soot) based on modeled, measured, and/or empirical relationships</li></ul>
Current Objectives	<ul style="list-style-type: none"><li>• Include new information on chemistry, e.g., bromine reactions, etc.</li><li>• Sensitivity analyses</li><li>• Use gridded chemical output from full-chemistry atmospheric model (e.g., CMAQ)</li><li>• Option - run HYSPLIT in Eulerian mode for chemistry; conduct one-atmosphere simulation</li></ul>
Challenges and Notes	<ul style="list-style-type: none"><li>• <b>What is RGM?</b></li><li>• <b>What is Hg(p)?</b></li><li>• <b>What is solubility of Hg(p)?</b></li><li>• <b>Fate of dissolved Hg(II) when droplet dries out?</b></li><li>• <b>What reactions don't we know about yet?</b></li><li>• <b>What are rates of reactions?</b></li></ul>

## Model Evaluation

### Previous Work

- **US: 1996 MDN measurements**
- **Europe: 1999 speciated ambient concentrations in short-term episodes, monthly wet deposition**

## Model Evaluation

### Previous Work

- **US: 1996 MDN measurements**
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### Current Objectives

- **Attempt to utilize all available 2002-2005 speciated ambient concentrations and wet deposition data from U.S. and other regions**

## Model Evaluation

<b>Previous Work</b>	<ul style="list-style-type: none"><li>• <b>US: 1996 MDN measurements</b></li><li>• <b>Europe: 1999 speciated ambient concentrations in short-term episodes, monthly wet deposition</b></li></ul>
<b>Current Objectives</b>	<ul style="list-style-type: none"><li>• <b>Attempt to utilize all available 2002-2005 speciated ambient concentrations and wet deposition data from U.S. and other regions</b></li></ul>
<b>Challenges and Notes</b>	<ul style="list-style-type: none"><li>• <b>Comprehensive evaluation has not been possible due to large gaps in availability of monitoring and process-related data</b></li><li>• <b>Need data for upper atmosphere as well as surface</b></li><li>• <b>Need data for both source-impacted and background sites</b></li><li>• <b>Use of recent monitoring data with EPA 2002 inventory?</b></li><li>• <b>Time-resolved monitoring data vs. non-time-resolved emissions?</b></li><li>• <b>Hard to diagnose differences between models &amp; measurements</b></li><li>• <b>Can we find better ways to share data for model evaluation (and other purposes)? To this end, discussion is beginning on national, cooperative, ambient Hg monitoring network</b></li></ul>

# Thanks!

**For more information on this modeling research:**

*<http://www.arl.noaa.gov/ss/transport/cohen.html>*