Modeling the Transport and Deposition of Atmospheric Mercury to the Great Lakes

(and the Chesapeake Bay)

Dr. Mark Cohen
NOAA Air Resources Laboratory
Silver Spring, Maryland

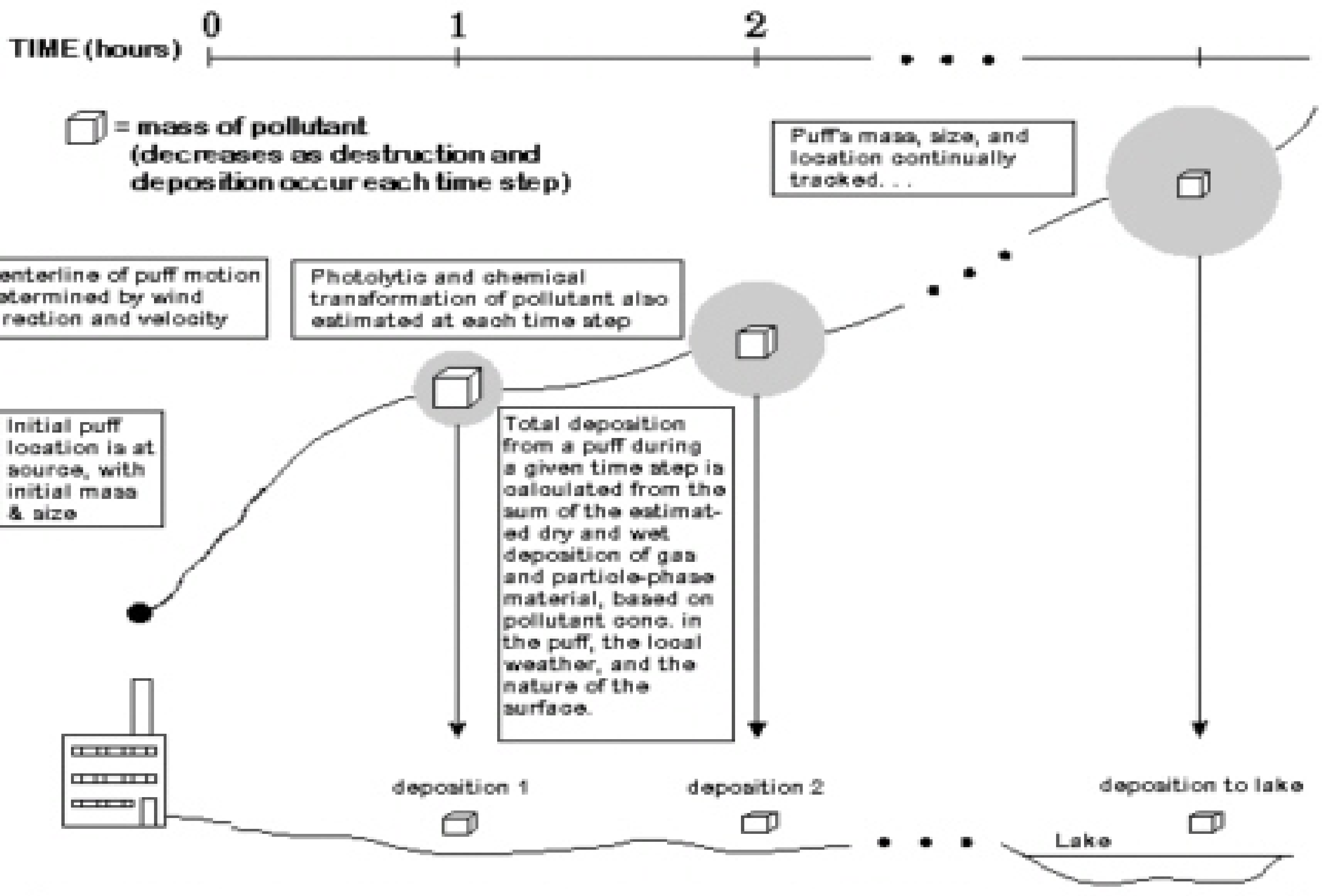
Presentation at the International Conference on Mercury as a Global Pollutant (ICMGP), Llubljana, Slovenia, June 27-July 2, 2004

Goal: **Estimate impacts of *each emissions source* on receptors of interest (e.g., Great Lakes, Chesapeake Bay, etc.) under past, present, and future emissions regimes**

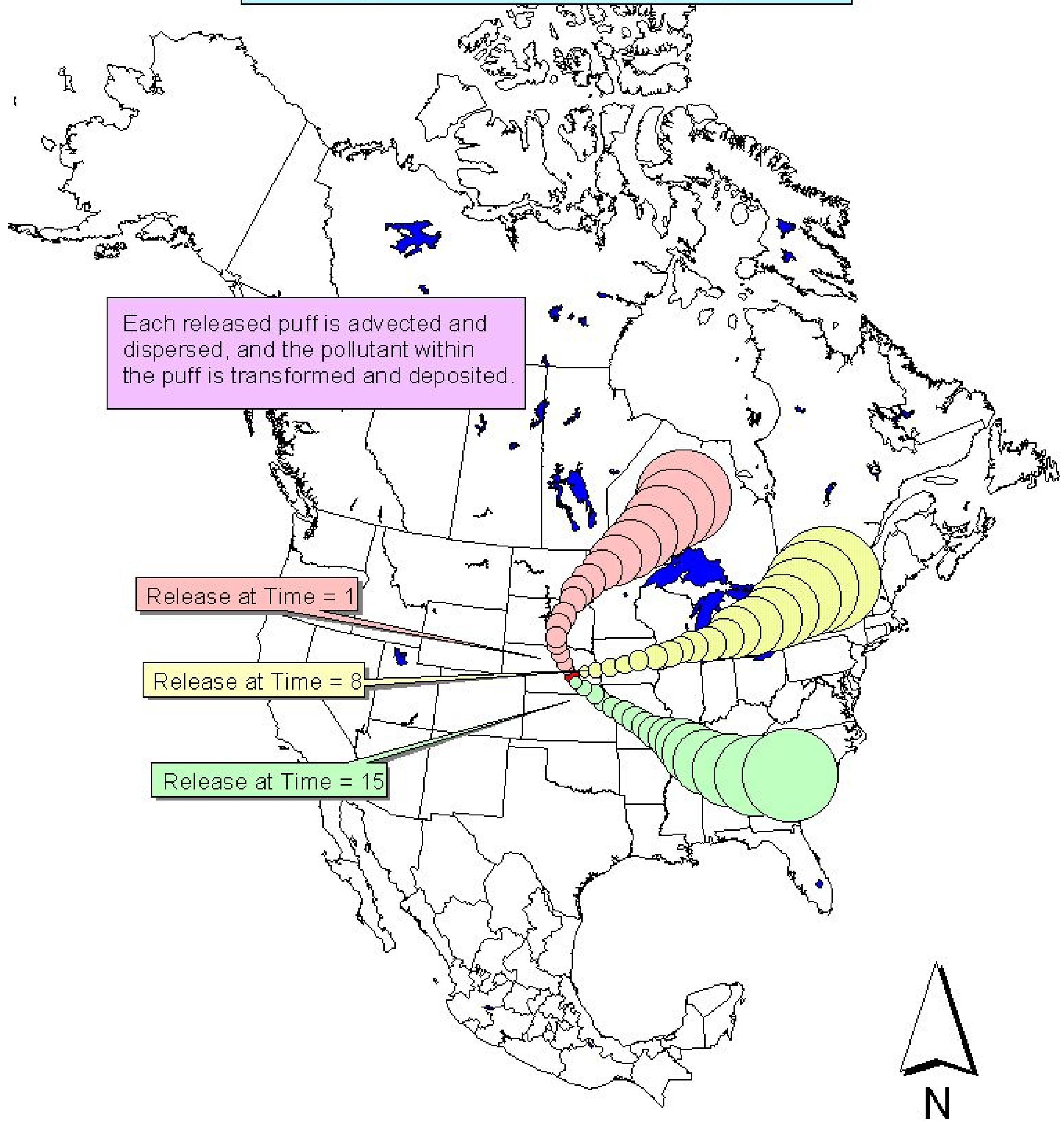
Why? **In order to evaluate reduction strategies, its obviously useful to know the relative importance of different sources, source types, and source regions**

Modeling Methodology

Figure 1. Lagrangian Puff Air Transport and Deposition Model



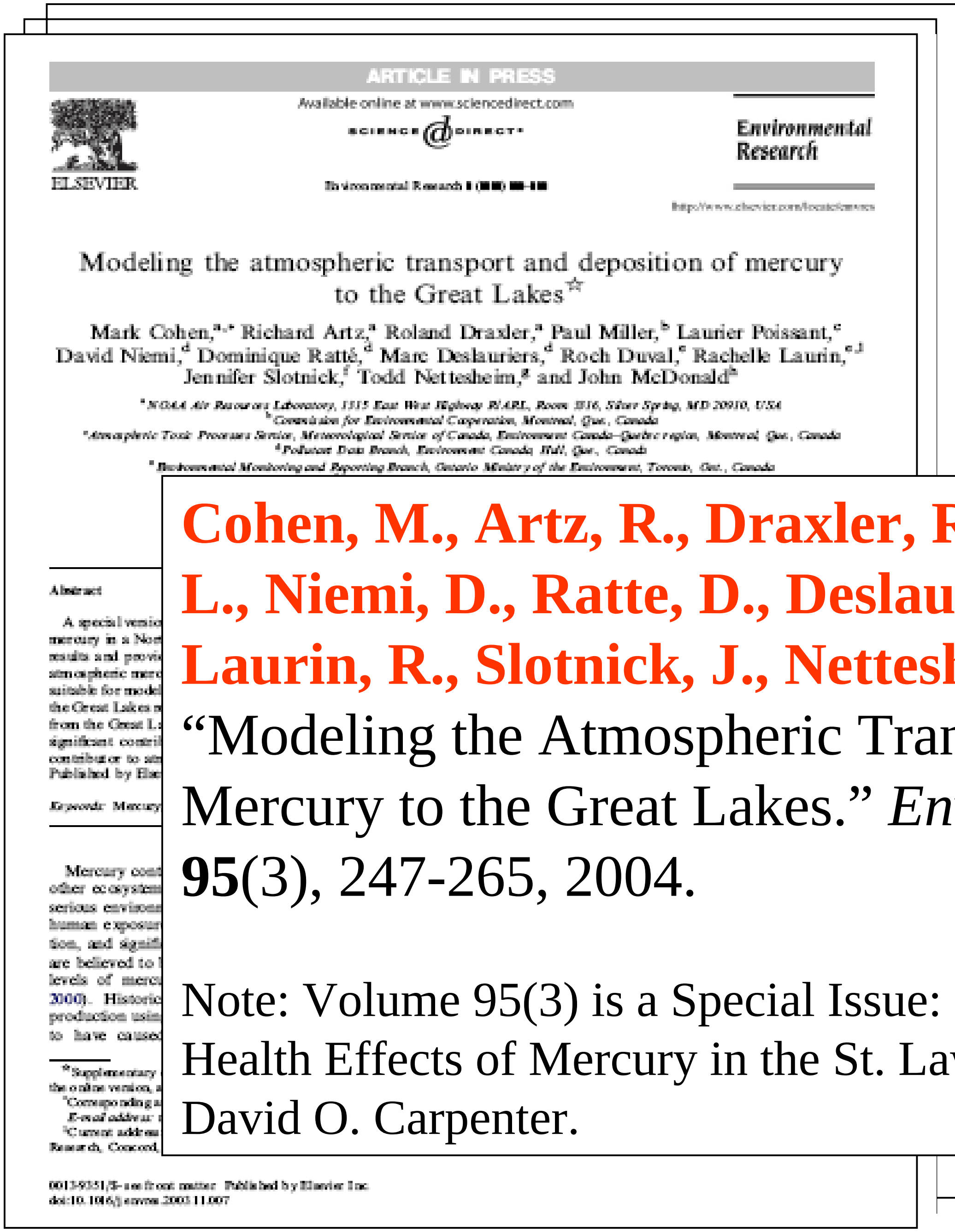
Over the entire modeling period (e.g., one year), puffs are released at periodic intervals (e.g., once every 7 hours).



- **In principle, we need do this for each source in the inventory**

- **But, since there are more than 100,000 sources in the U.S. and Canadian inventory, we need shortcuts…**

- **Shortcuts described in Cohen *et al***
  Environmental Research **95**(3), 247-265, 2004


ARTICLE IN PRESS

Available online at www.sciencedirect.com

SCIENCE @ DIRECT

ELSEVIER

Environmental Research

Modeling the atmospheric transport and deposition of mercury to the Great Lakes☆

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

Cohen, M., Artz, R., Draxler, R., Miller, P., Poissant, L., Niemi, D., Ratte, 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.

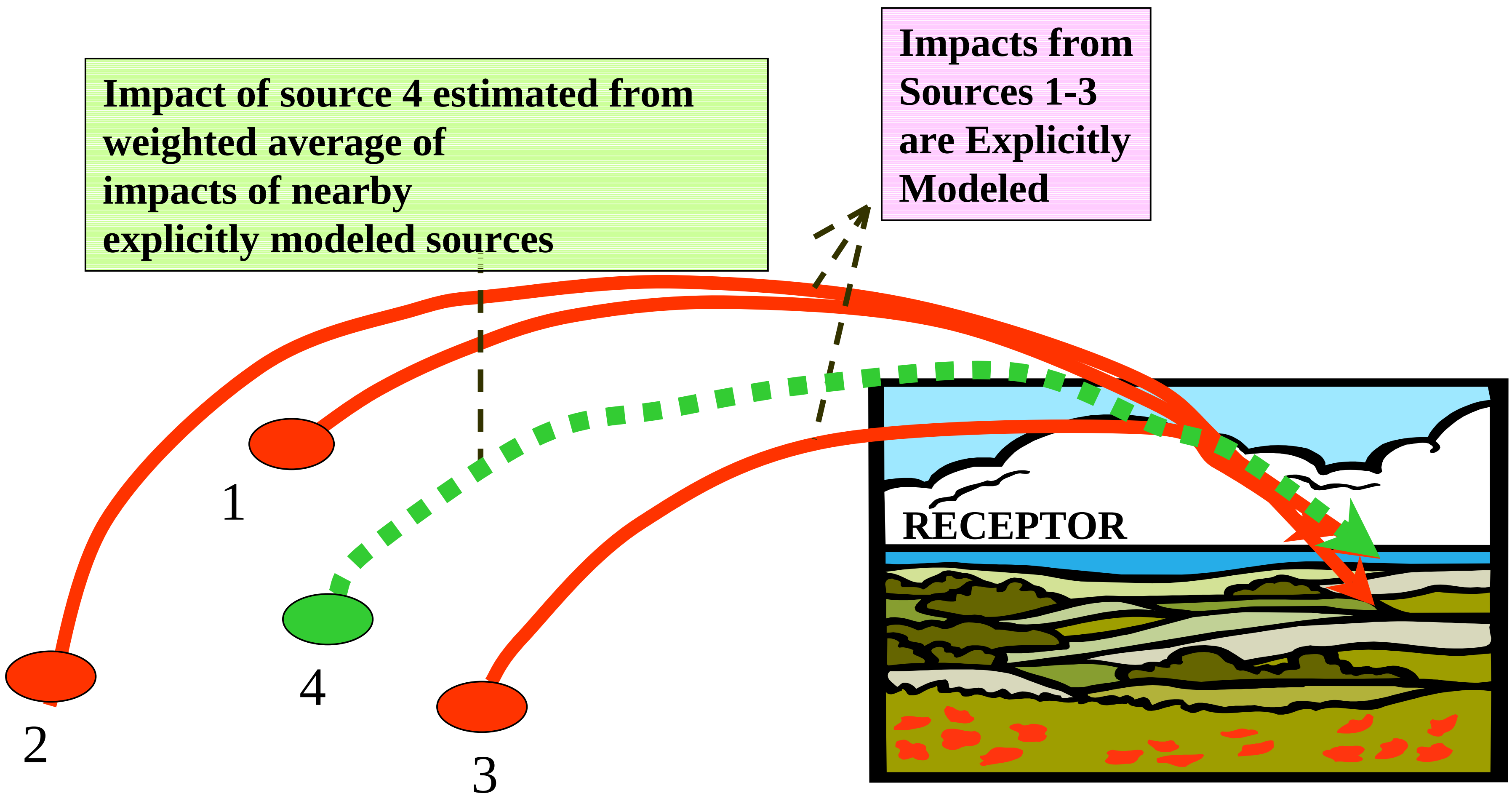
Note: Volume 95(3) is a Special Issue: "An Ecosystem Approach to Health Effects of Mercury in the St. Lawrence Great Lakes", edited by David O. Carpenter.

- **For each run, simulate fate and transport *everywhere*, but only keep track of impacts on each selected receptor (e.g., Great Lakes, Chesapeake Bay, etc.)**

- **Only run model for a limited number (~100) of hypothetical, individual unit-emissions sources throughout the domain**

- **Use spatial interpolation to estimate impacts from sources at locations not explicitly modeled**

Spatial interpolation

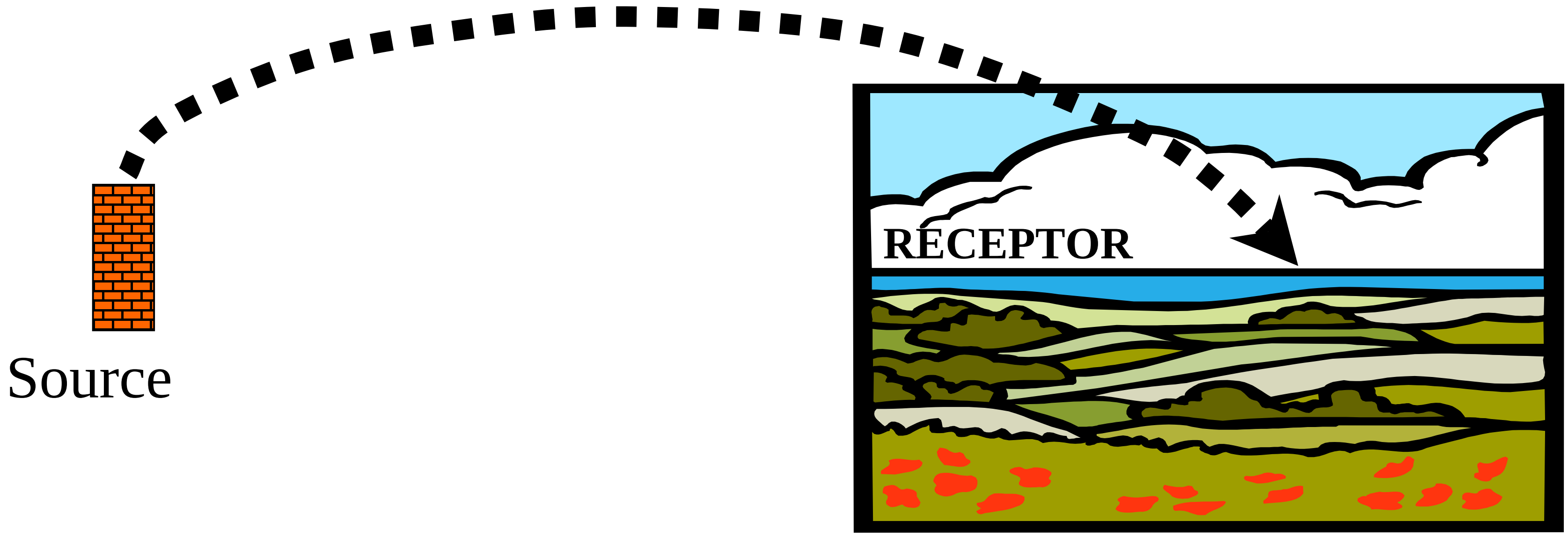


- **Perform separate simulations at each location for emissions of pure Hg(0), Hg(II) and Hg(p)**

  [*after emission, simulate transformations between Hg forms*]

- **Impact of emissions mixture taken as a linear combination of impacts of pure component runs on any given receptor**

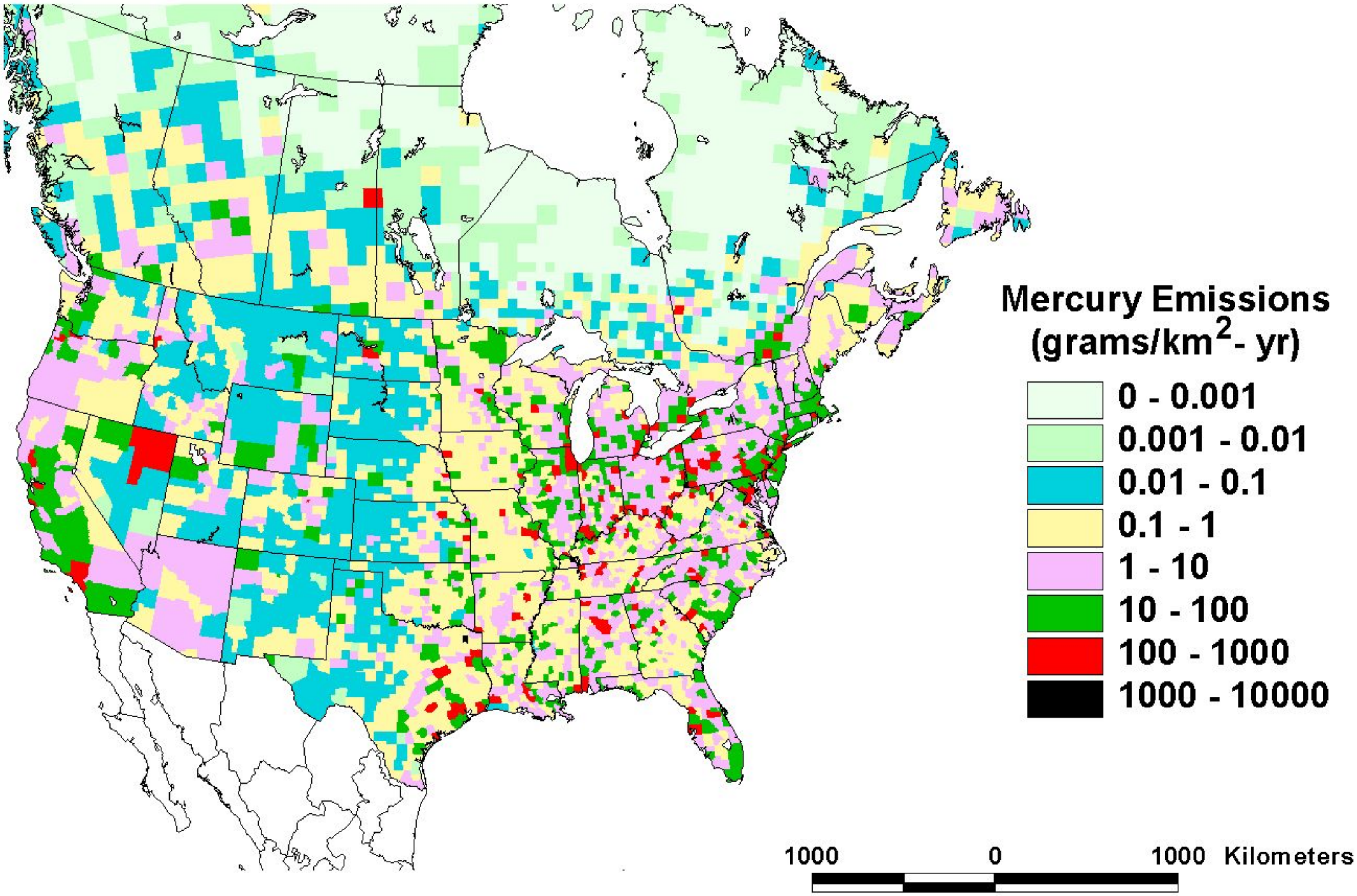
"Chemical Interpolation"

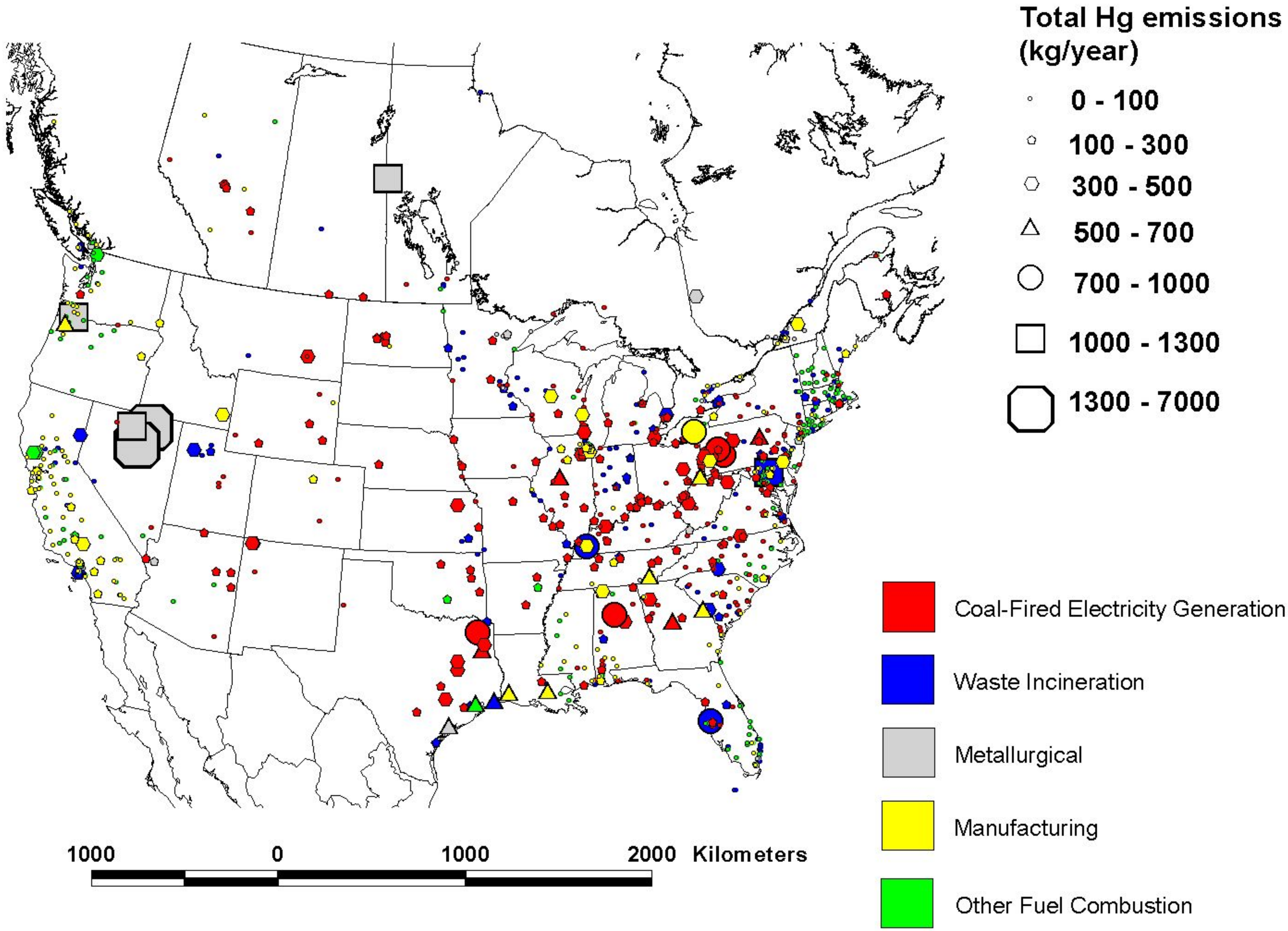


Impact of Source Emitting 30% Hg(0) 50% Hg(II) 20% Hg(p)	=	**0.3 x**	**Impact of Source Emitting Pure Hg(0)**
			+
		0.5 x	**Impact of Source Emitting Pure Hg(II)**
			+
		0.2 x	**Impact of Source Emitting Pure Hg(p)**

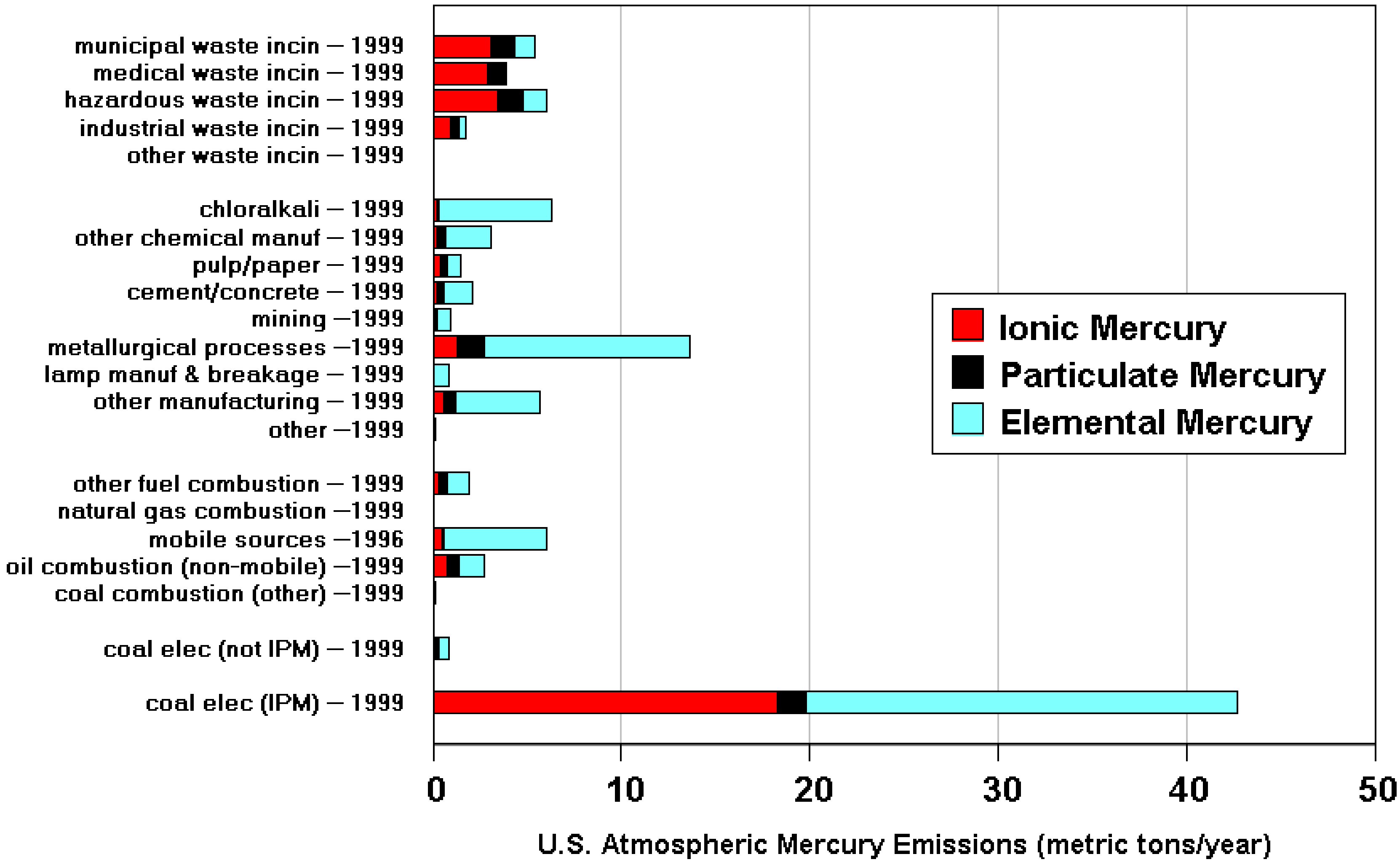
Mercury Emissions Inventory

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

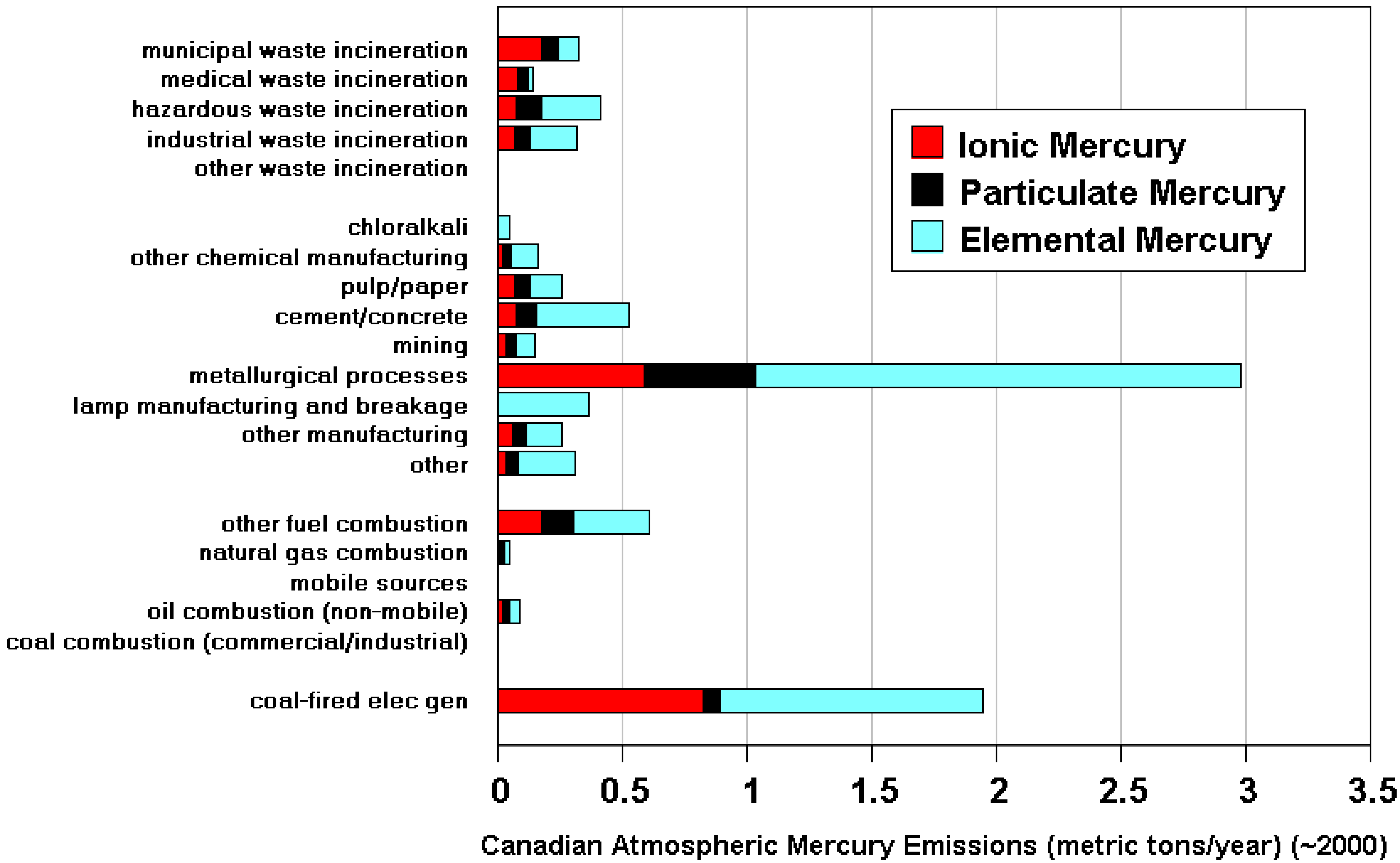



Total Hg emissions (kg/year)
0 - 100
100 - 300
300 - 500
500 - 700
700 - 1000
1000 - 1300
1300 - 7000
Coal-Fired Electricity Generation
Waste Incineration
Metallurgical
Manufacturing
Other Fuel Combustion
1000
0
1000
2000
Kilometers

Estimated 1999 U.S. Atmospheric Anthropogenic Mercury Emissions



Estimated 2000 Canadian Atmospheric Anthropogenic Mercury Emissions

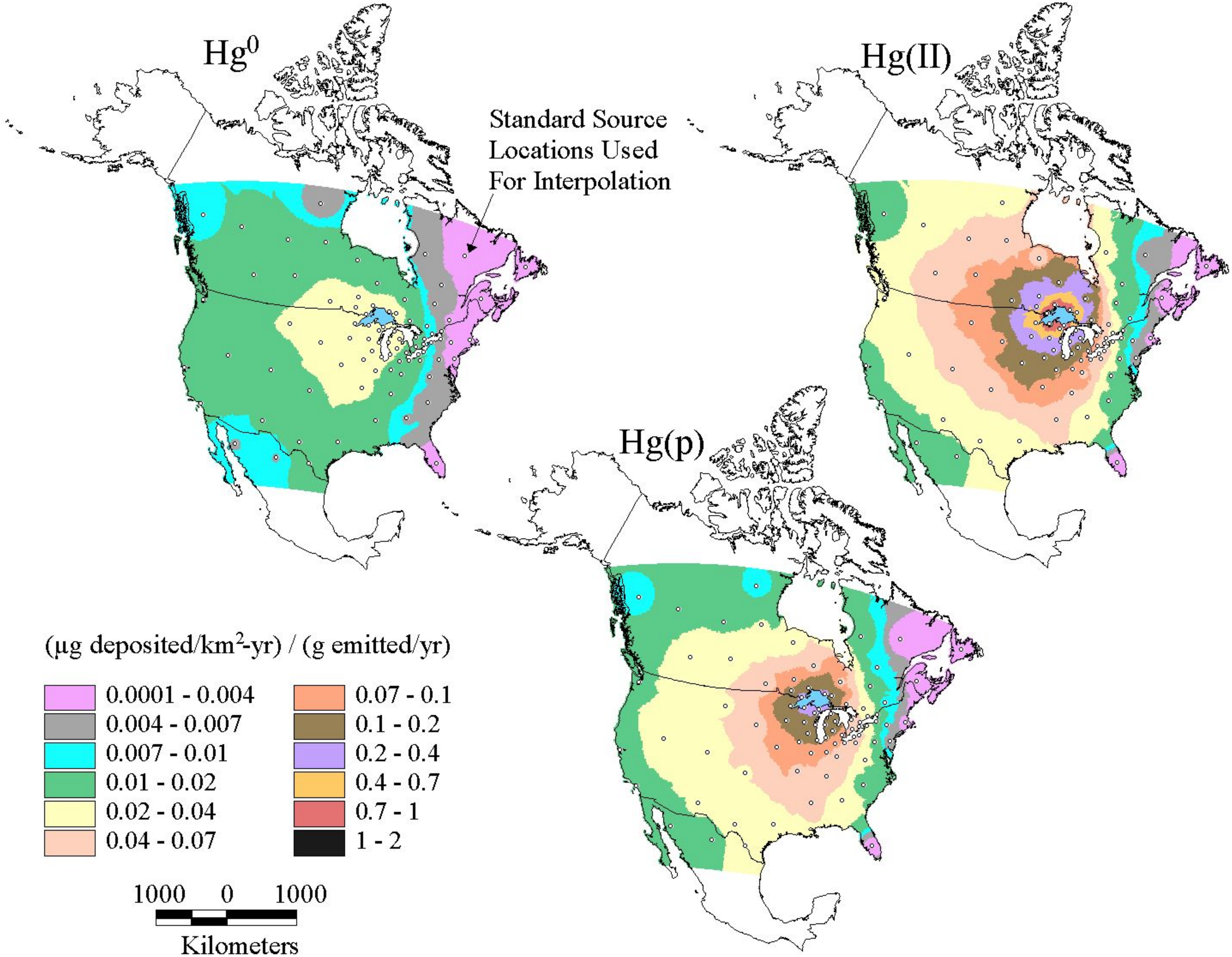


Very important to know how much of each form of mercury

-- Hg(II), Hg(p), and Hg(0) --

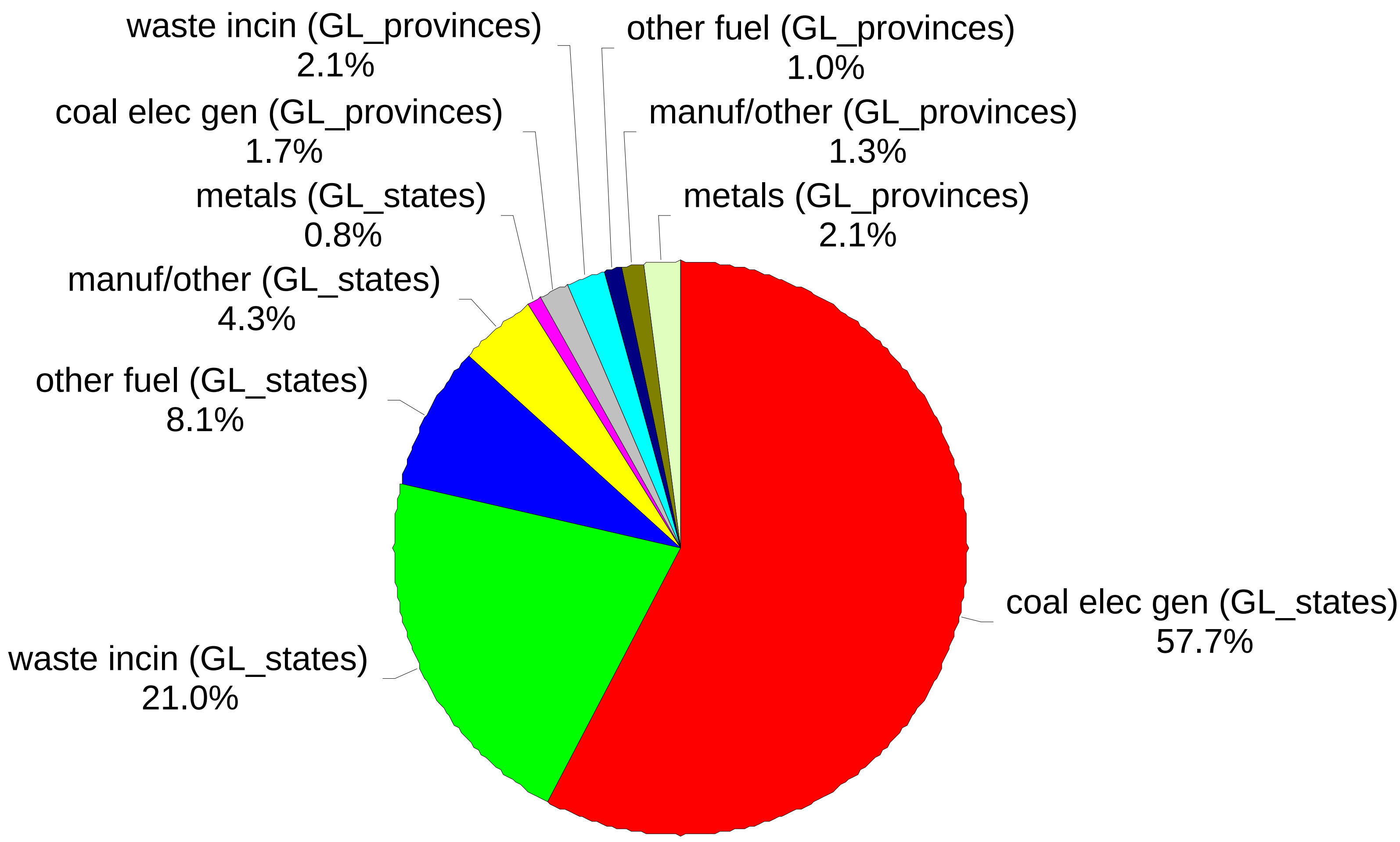
is emitted from each source…

(this is usually very uncertain)



Hg0
Hg(II)
Hg(p)
Standard Source Locations Used For Interpolation
(µg deposited/km2-yr) / (g emitted/yr)
0.0001 - 0.004
0.004 - 0.007
0.007 - 0.01
0.01 - 0.02
0.02 - 0.04
0.04 - 0.07
0.07 - 0.1
0.1 - 0.2
0.2 - 0.4
0.4 - 0.7
0.7 - 1
1 - 2
1000 0 1000
Kilometers

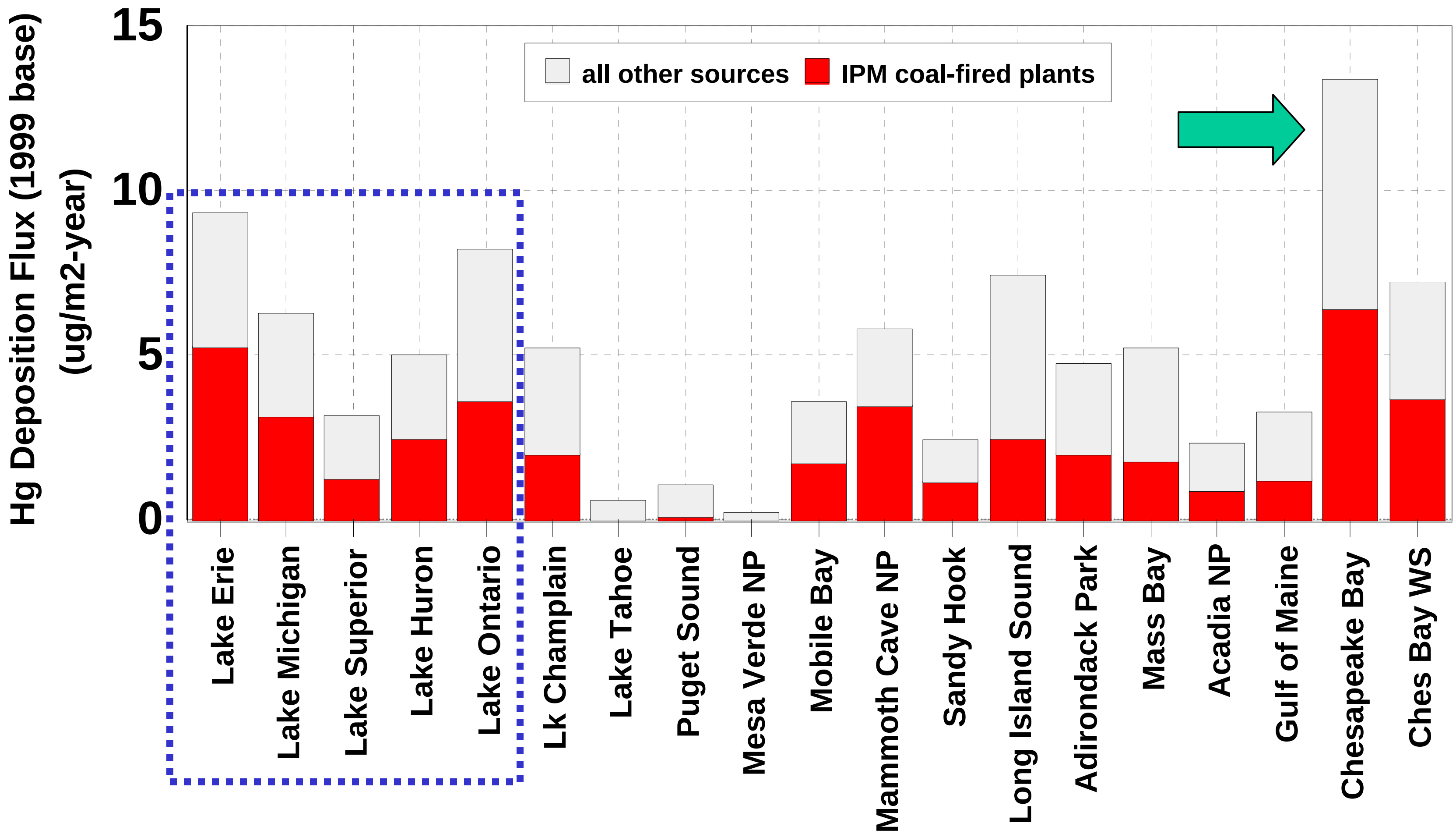
Emissions of Ionic Mercury (RGM) from Different Anthropogenic Source Sectors in Great Lakes States and Provinces (~1999-2000)
[Total RGM emissions = 13.4 metric tons/year]



Some Overall Results

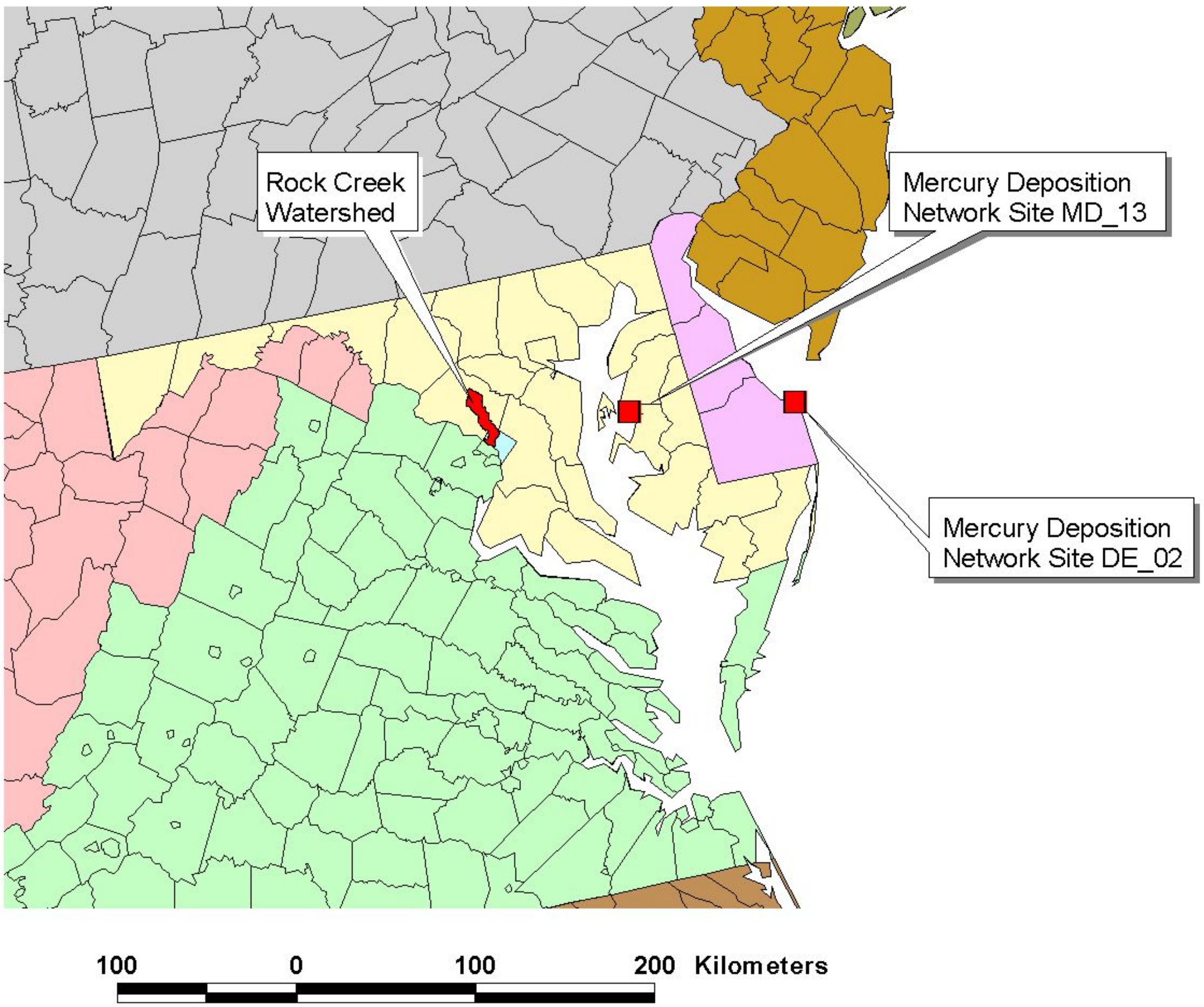
- **Modeling domain: North America**
- **U.S. and Canadian anthropogenic sources**
- **1996 meterology**
- **Model evaluation:**
  - **1996 emissions**
  - **1996 monitoring data**
- **Results: 1999 emissions**

Mercury deposition at selected receptors arising from 1999 base-case emissions from anthropogenic sources in the United States and Canada (IPM coal fired plants are large coal-fired plants in the U.S. only)

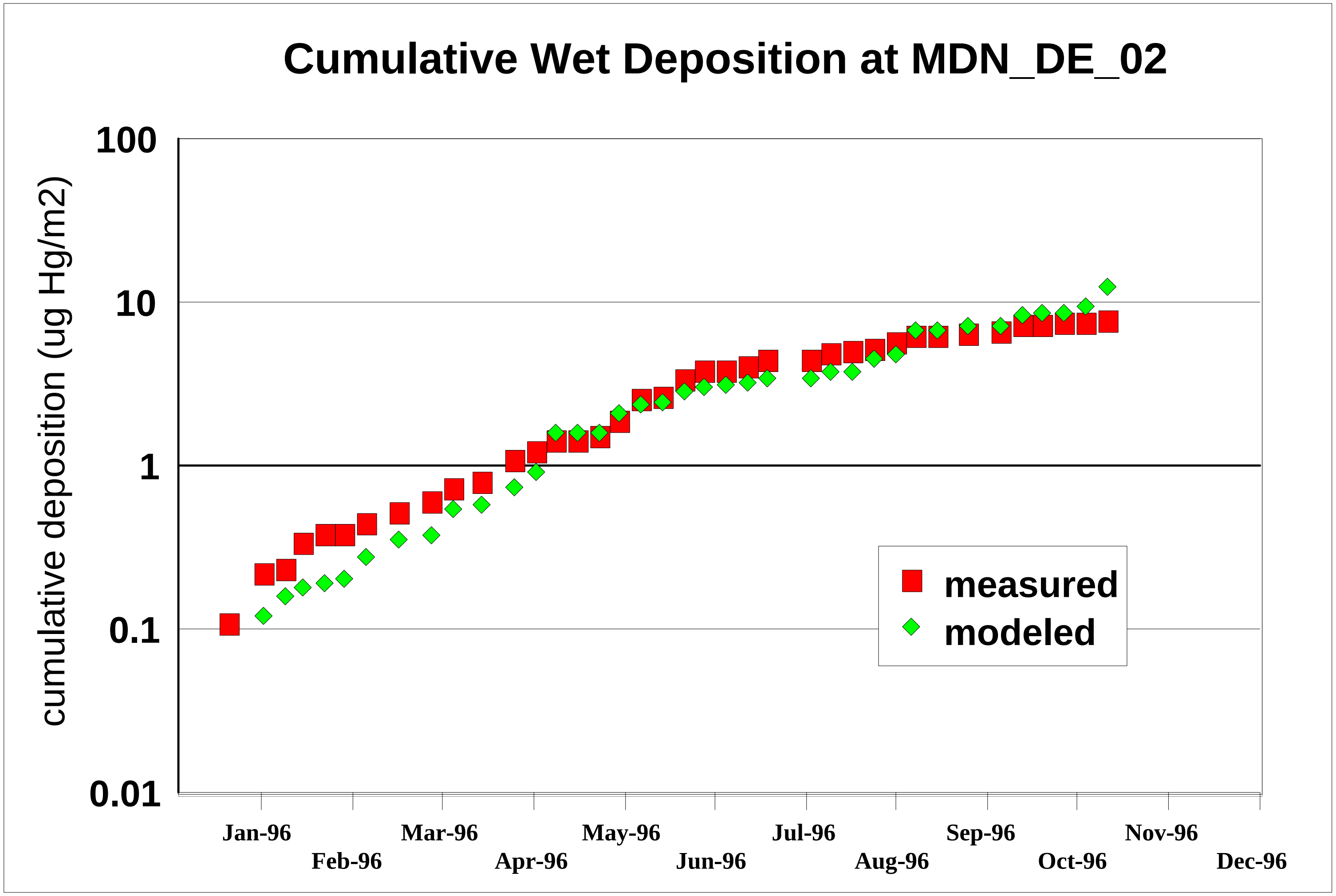


Model Evaluation

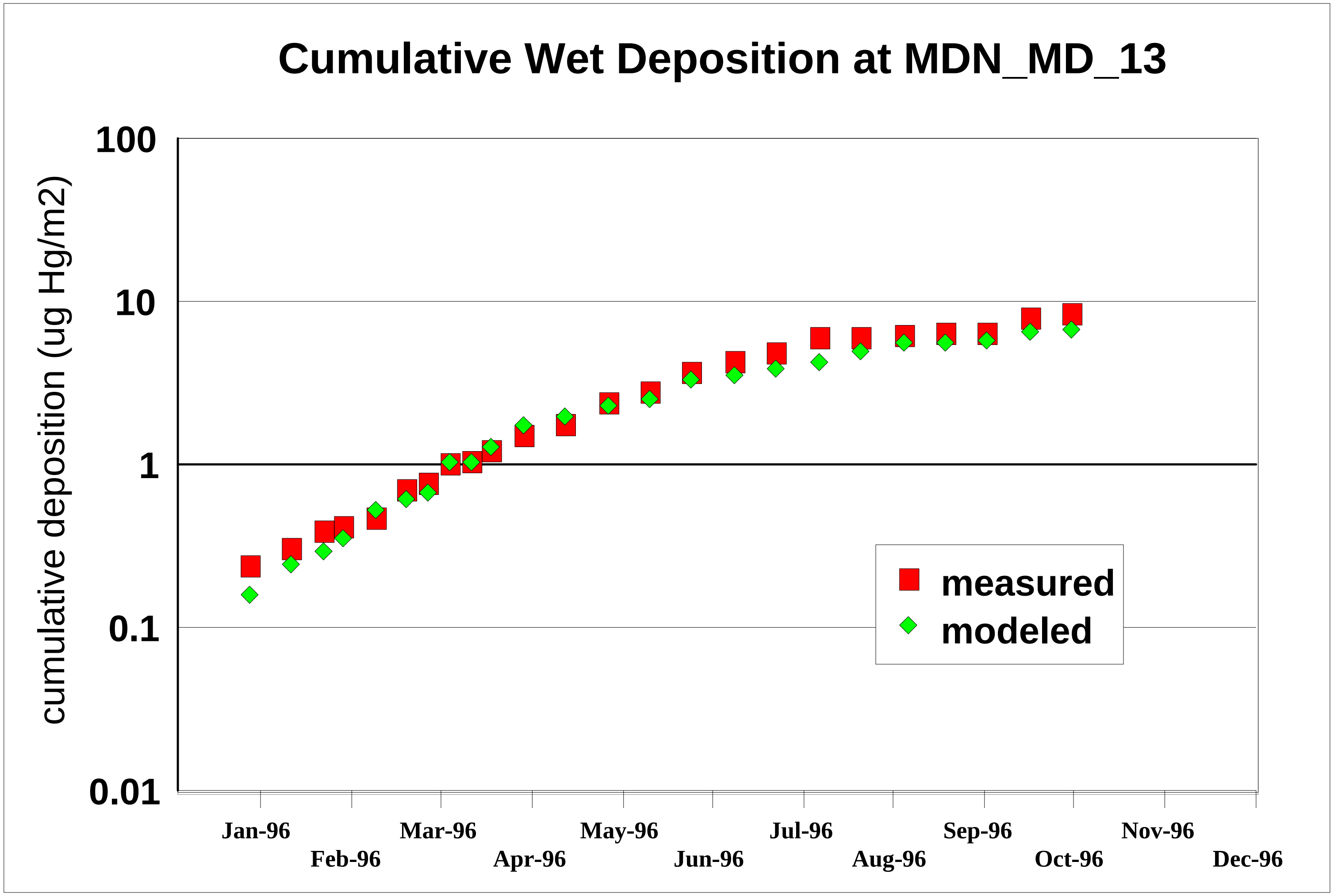
Mercury Deposition Network Sites with 1996 data in the Chesapeake Bay Region

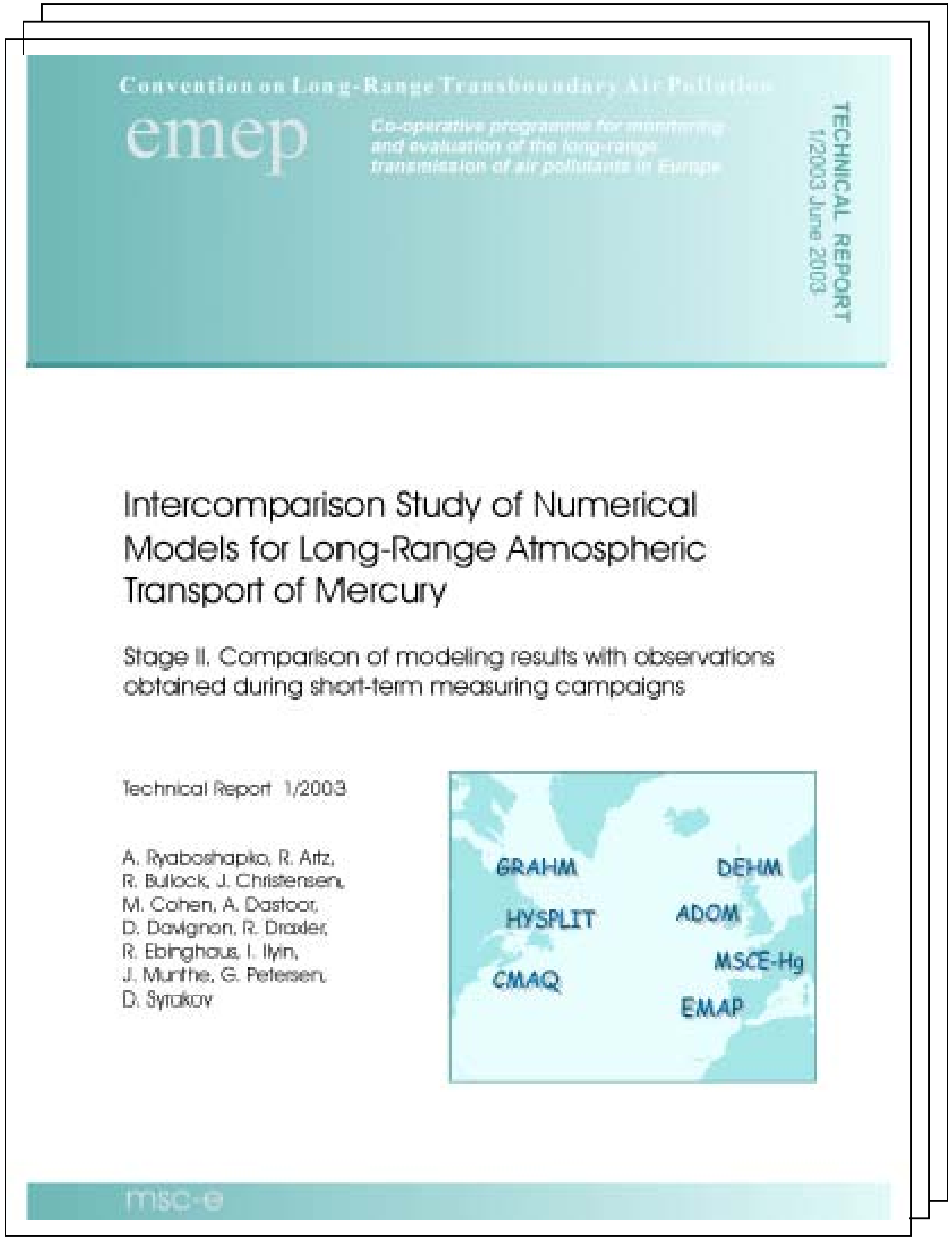


Modeled vs. Measured Wet Deposition at Mercury Deposition Network Site DE_02 during 1996



Modeled vs. Measured Wet Deposition at Mercury Deposition Network Site MD_13 during 1996




Convention on Long-Range Transboundary Air Pollution

emep

Co-operative programme for monitoring and evaluation of the long-range transmission of air pollutants in Europe

TECHNICAL REPORT
1/2003 June 2003

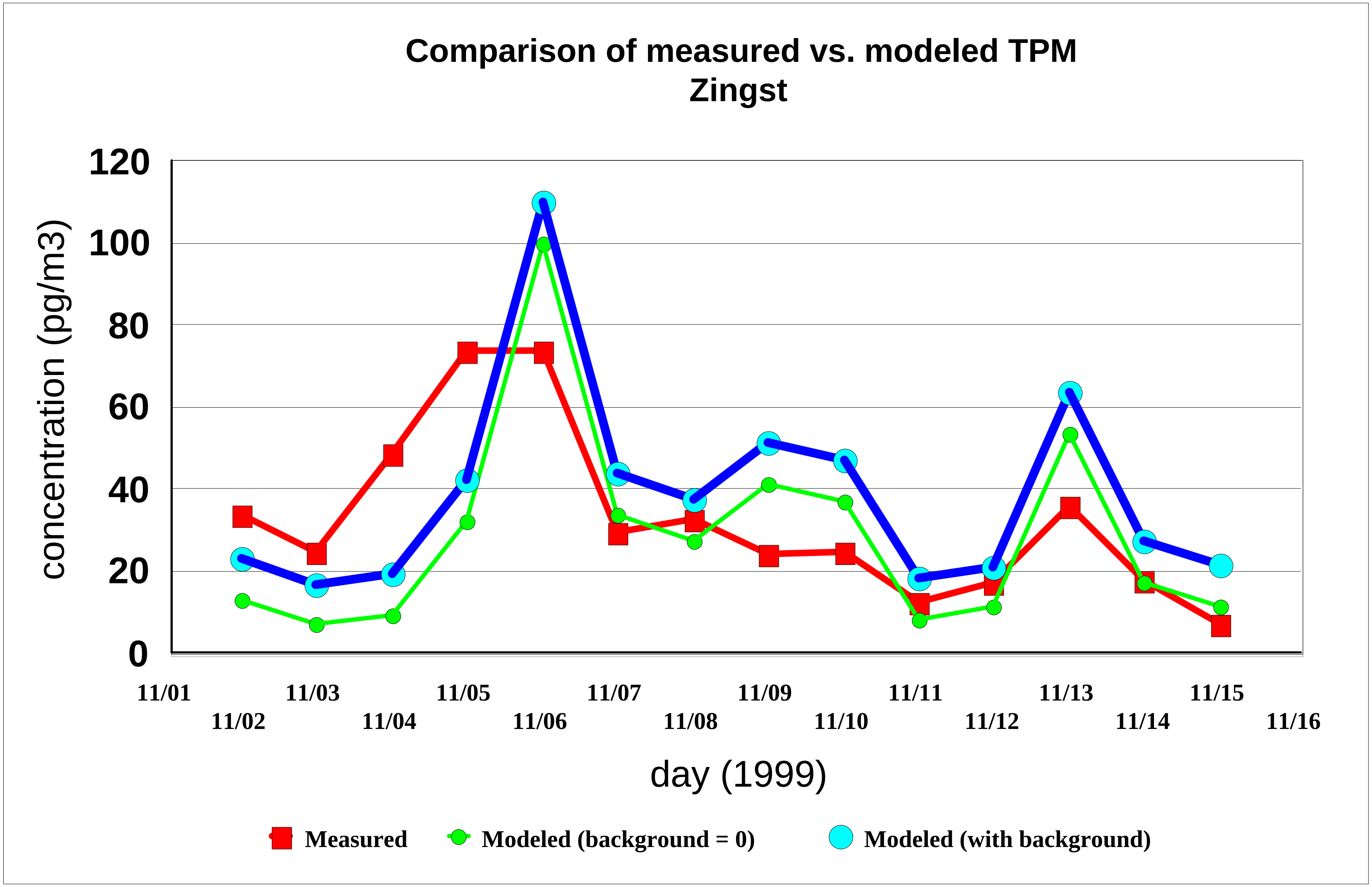
Intercomparison Study of Numerical Models for Long-Range Atmospheric Transport of Mercury

Stage II. Comparison of modeling results with observations obtained during short-term measuring campaigns

Technical Report 1/2003

A. Ryaboshapko, R. Artz, R. Bullock, J. Christensen, M. Cohen, A. Dastoor, D. Davignon, R. Draxler, R. Ebinghaus, I. Ilyin, J. Munthe, G. Petersen, D. Syrakov

msc-e


Comparison of measured vs. modeled TPM
Zingst
concentration (pg/m3)
0
20
40
60
80
100
120
11/01
11/02
11/03
11/04
11/05
11/06
11/07
11/08
11/09
11/10
11/11
11/12
11/13
11/14
11/15
11/16
day (1999)
Measured
Modeled (background = 0)
Modeled (with background)

- **Models can be extremely useful, e.g., maybe the only way to develop comprehensive source receptor relationships…**
    - ***But we know the models are not perfect…***
- **When simulations don't agree with measurements, what is reason?**
    - ***There can be errors in simulation of***
        - **emissions**
        - **meteorology**
        - **dispersion**
        - **atmospheric chemistry**
        - **wet and dry deposition**
    - **How to tease out the most important reasons for discrepancies?**

- **How to tease out the most important reasons for discrepancies?**

    - **Critical to have sufficient data for model evaluation**
        - **Mercury Deposition Network very useful!**
        - **need network for ambient concentrations of RGM, Hg(p), Hg(0)**
        - **also -- data at different heights in the atmosphere**
        - **also – identification and quantification of individual RGM species**

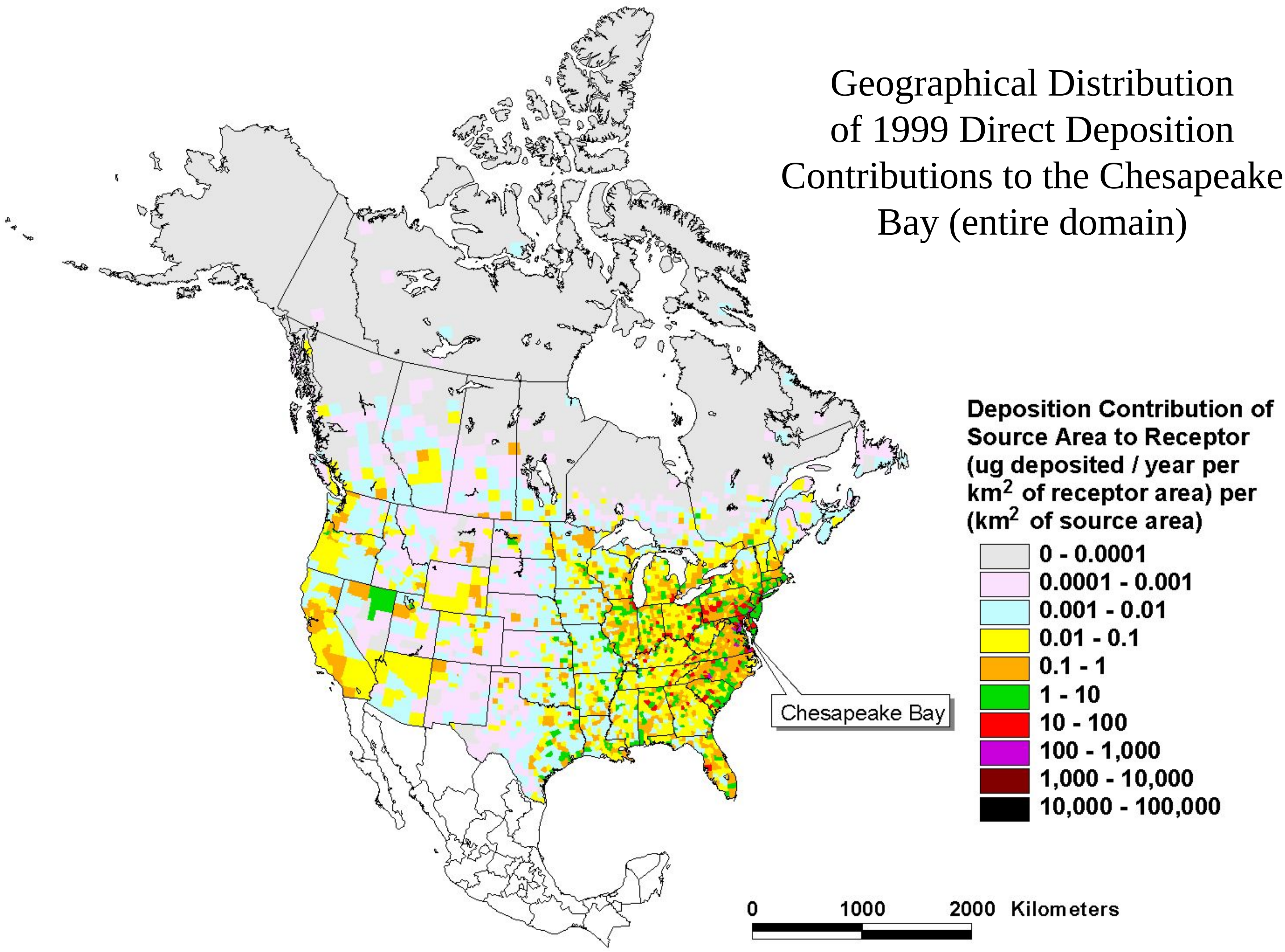
    - **Model intercomparison studies can be extremely useful**
      (why are they so hard to get funding for?)

    - **Does a model have to be perfect in order to be useful?**
      (No, often just need qualitatively reasonable results…)

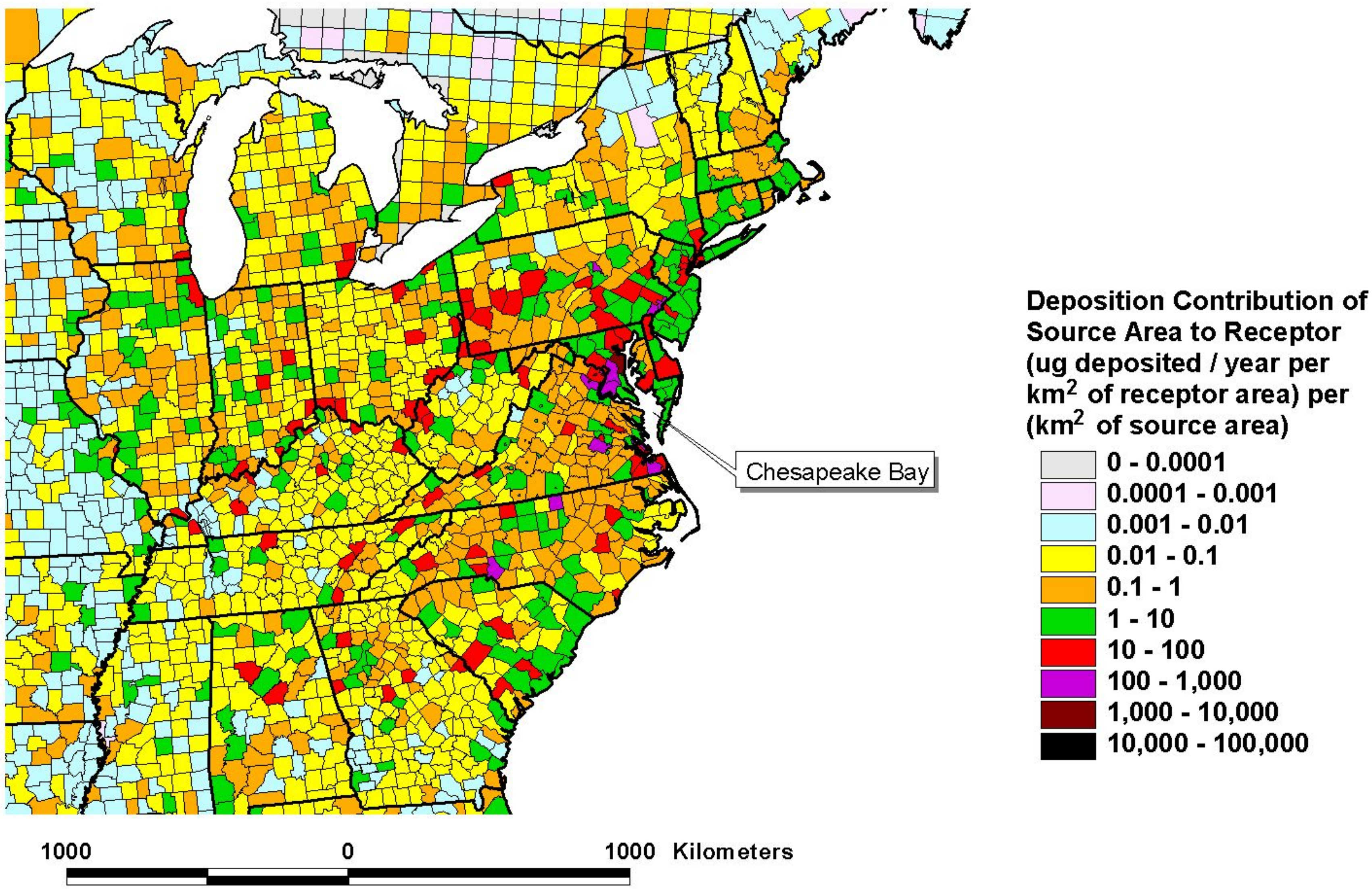
      Most if not all data and information used in decision-making has uncertainties – public health impacts, economic impacts (why do we demand perfection of models?)

1999 Results for Chesapeake Bay

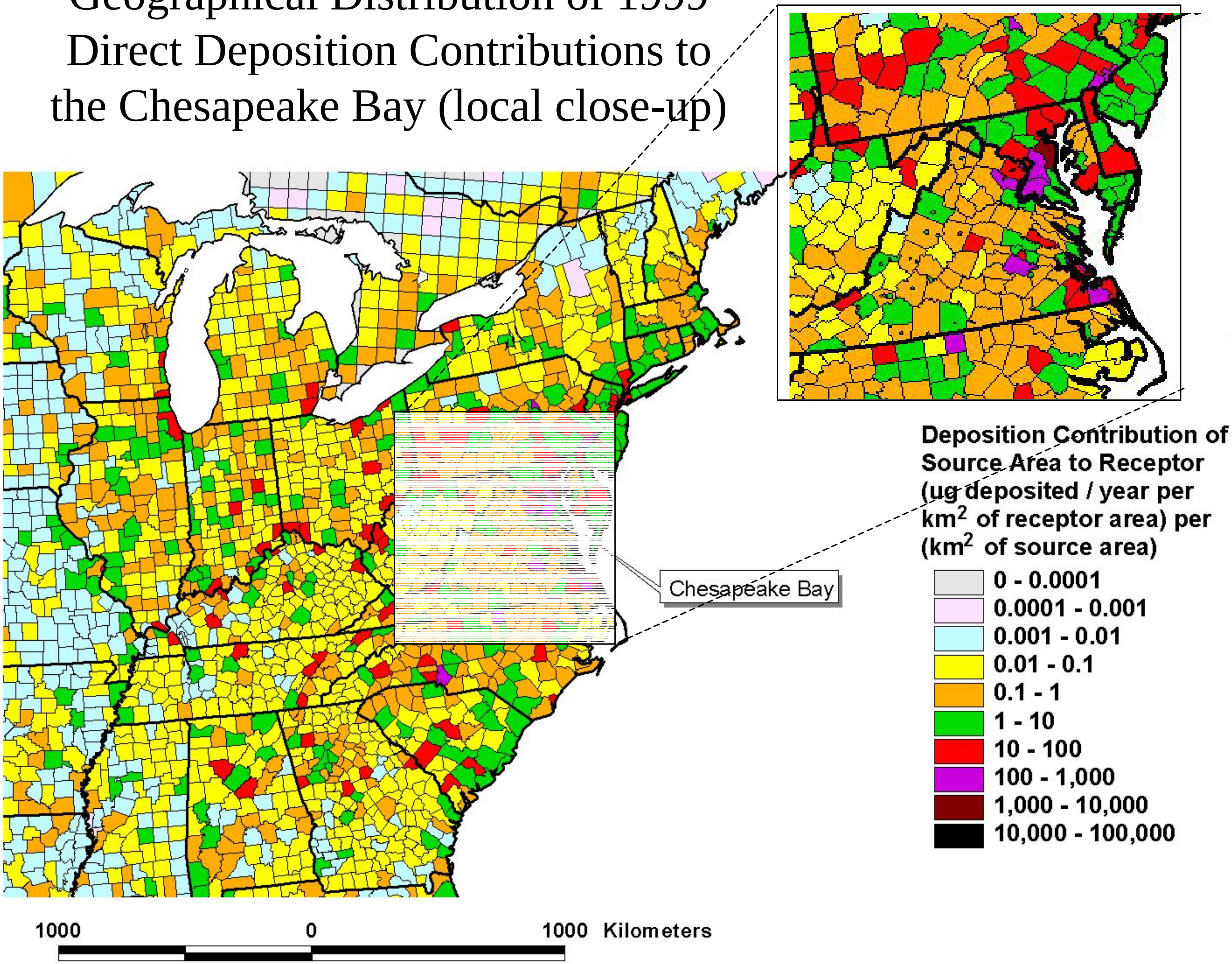
Geographical Distribution of 1999 Direct Deposition Contributions to the Chesapeake Bay (entire domain)



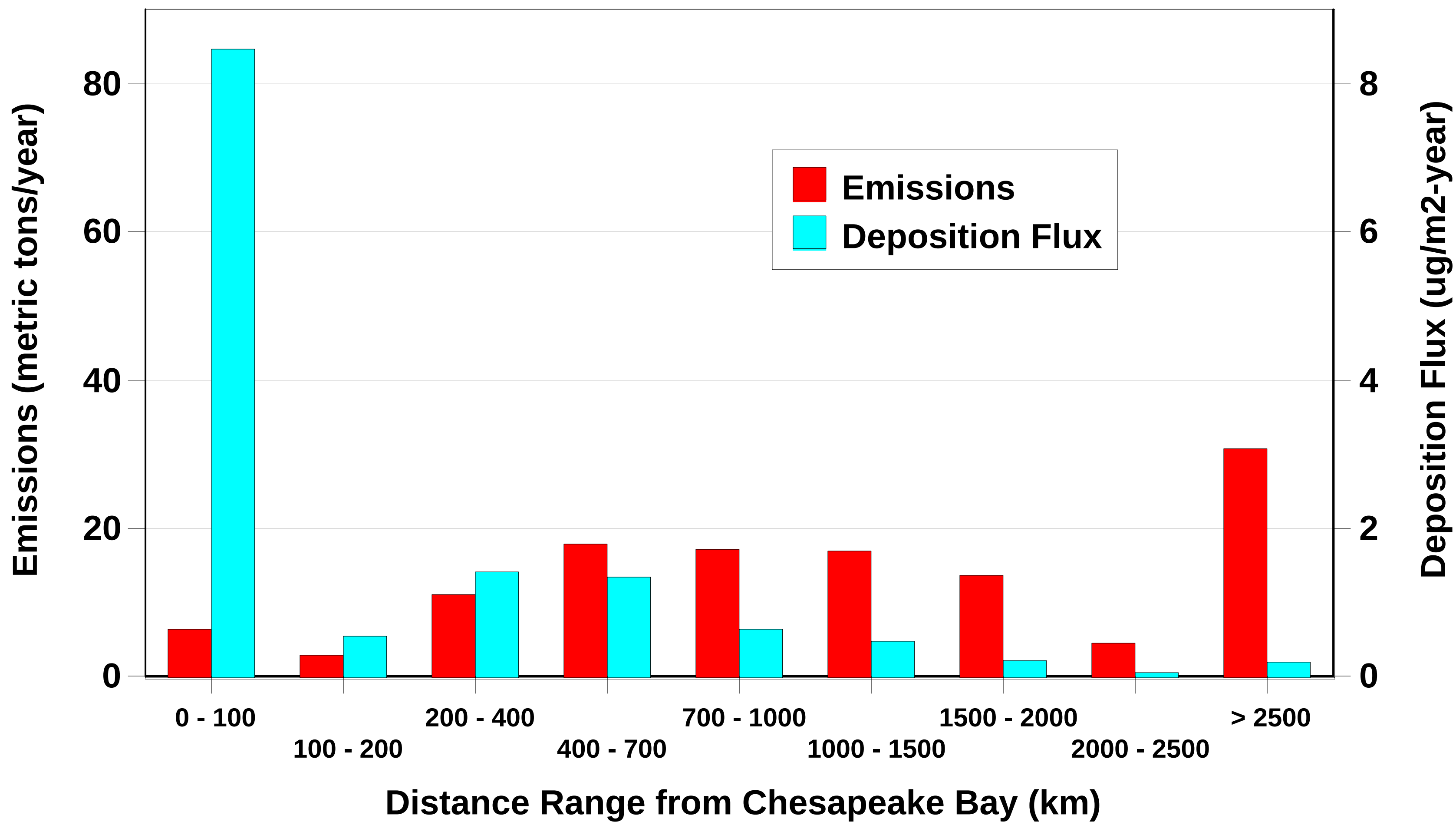
Geographical Distribution of 1999 Direct Deposition Contributions to the Chesapeake Bay (regional close-up)



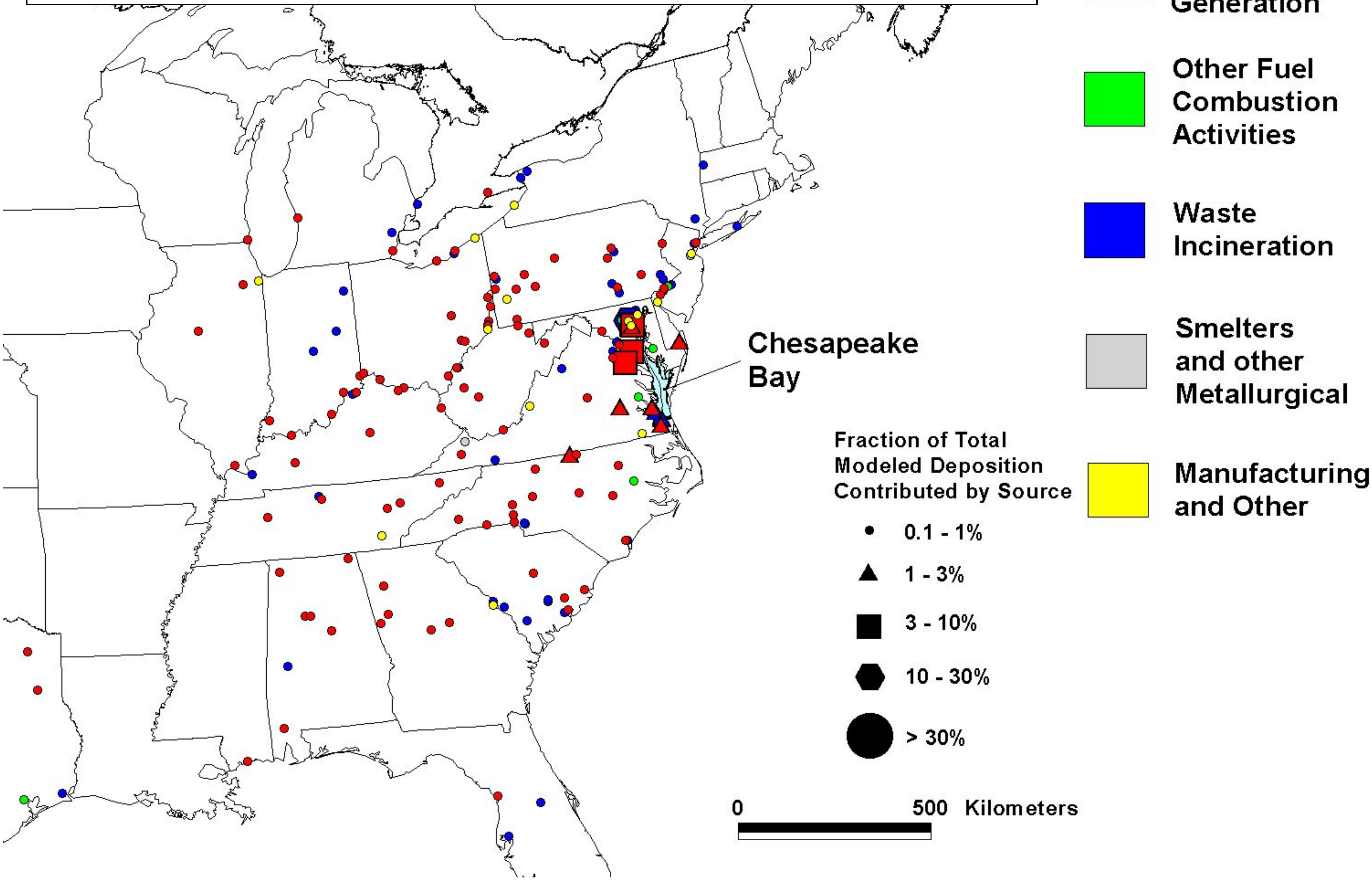
Geographical Distribution of 1999 Direct Deposition Contributions to the Chesapeake Bay (local close-up)



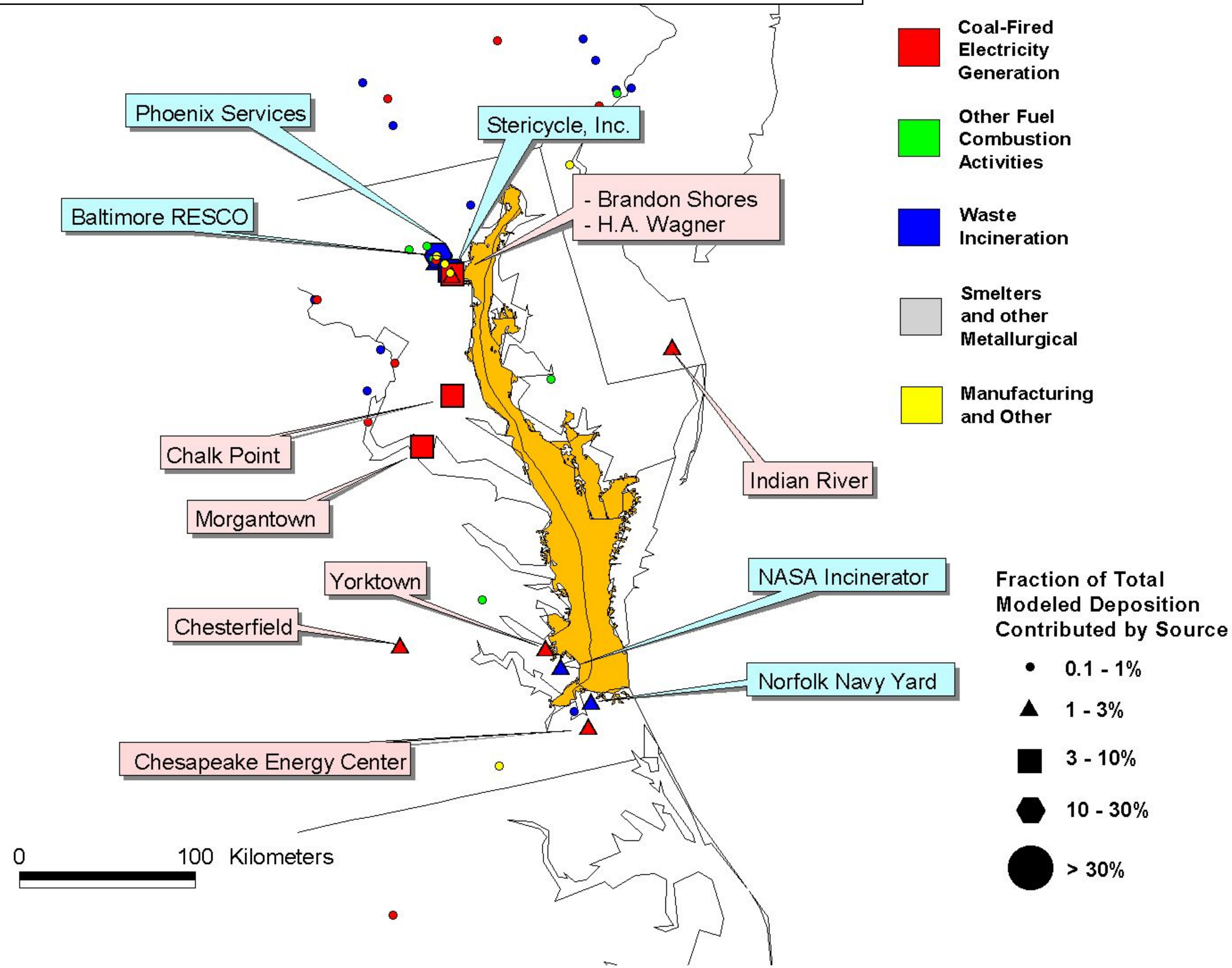
Emissions and Direct Deposition Contributions from Different Distance Ranges Away From the Chesapeake Bay



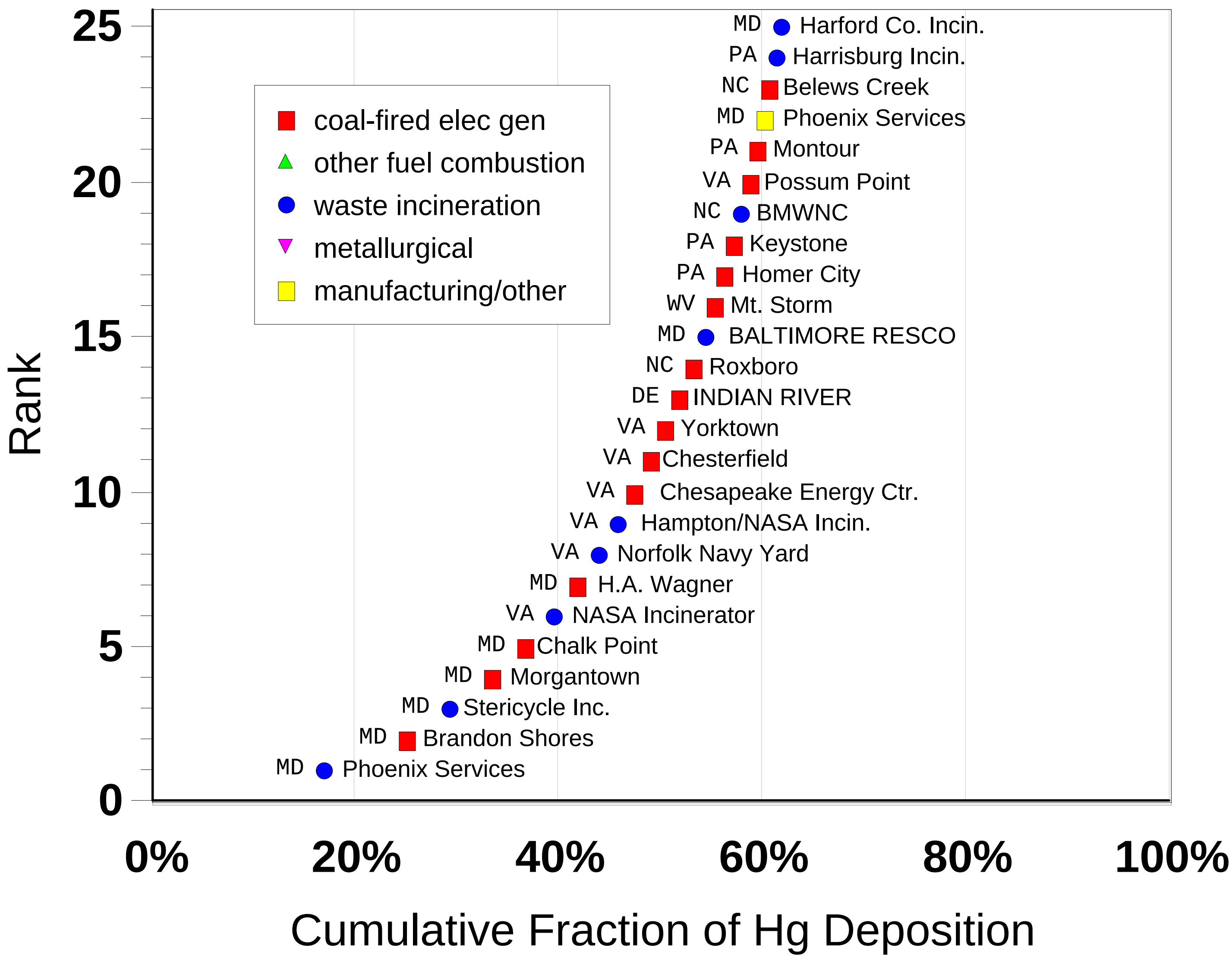
Largest Regional Individual Sources Contributing to 1999 Mercury Deposition Directly to the Chesapeake Bay



Largest Local Individual Sources Contributing to 1999 Mercury Deposition Directly to the Chesapeake Bay



Top 25 Contributors to 1999 Hg Deposition Directly to the Chesapeake Bay



Some Next Steps

- **Use more highly resolved meteorological data grid**
- **Expand model domain to include global sources**
- **Simulate natural emissions and re-emissions of previously deposited Hg**
- **Additional model evaluation exercises ... more sites, more time periods, more variables *[Measurements underway in Chesapeake Bay region]***
- **Sensitivity analyses and examination of atmospheric Hg chemistry (e.g. marine boundary layer, upper atmosphere)**
- **Dynamic linkage with ecosystem cycling models**