Simulating the Atmospheric Fate and Transport of Mercury using the NOAA HYSPLIT Model

Mark Cohen, Roland Draxler and Richard Artz
NOAA Air Resources Laboratory
1315 East West Highway,
R/ARL, Room 3316
Silver Spring, Maryland, 20910

Presentation at the
NOAA Atmospheric Mercury Meeting
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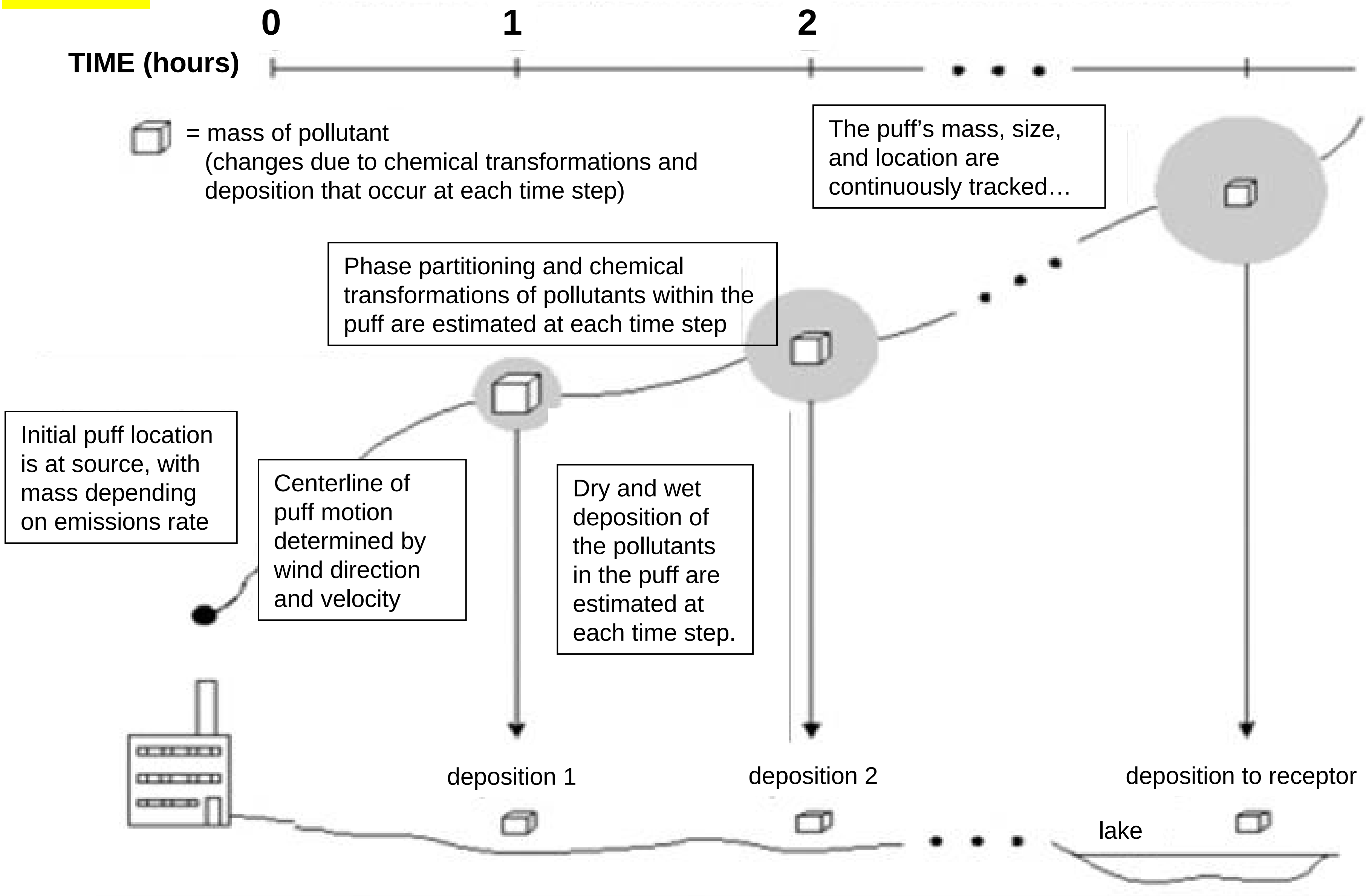
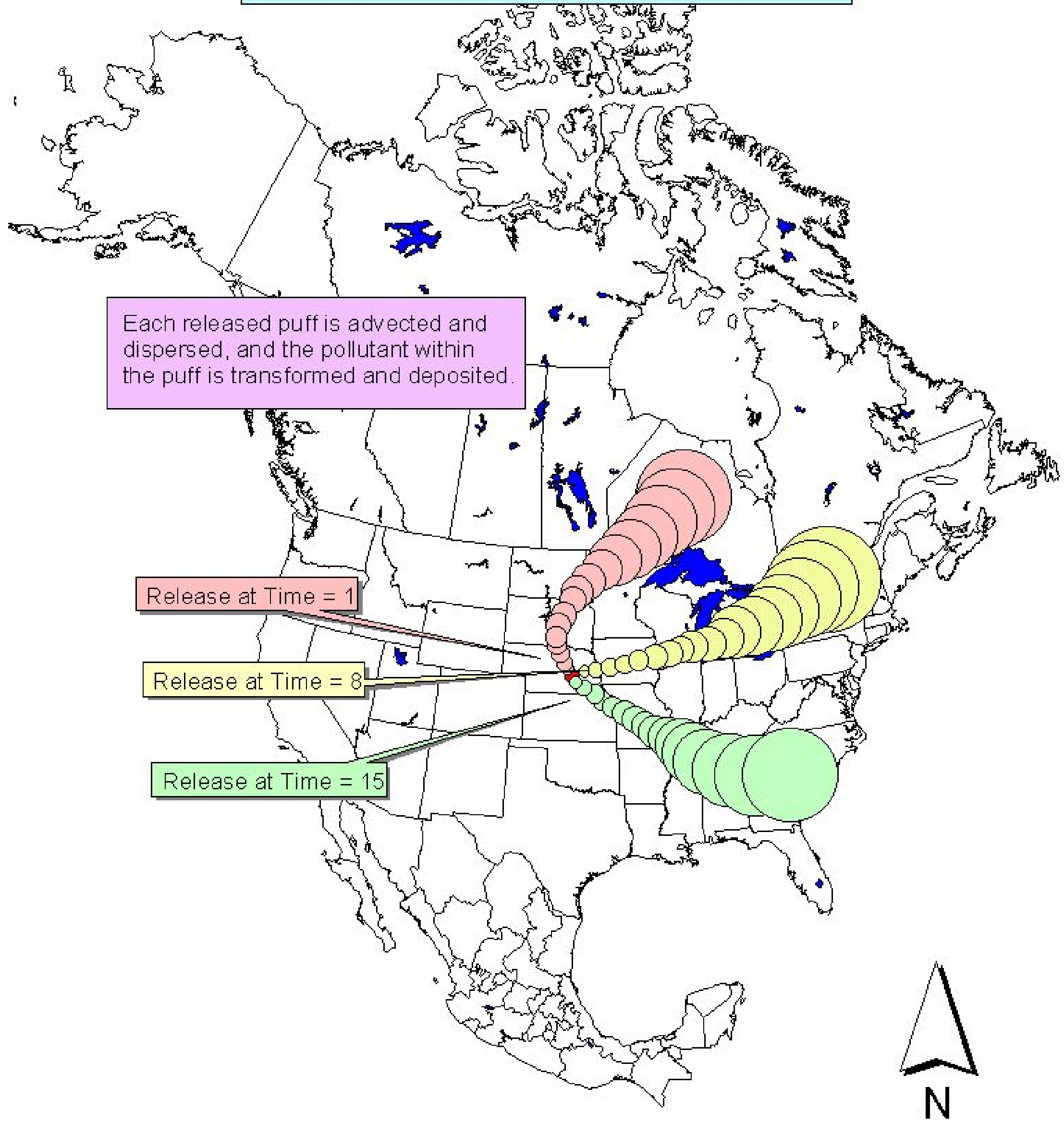
methodology

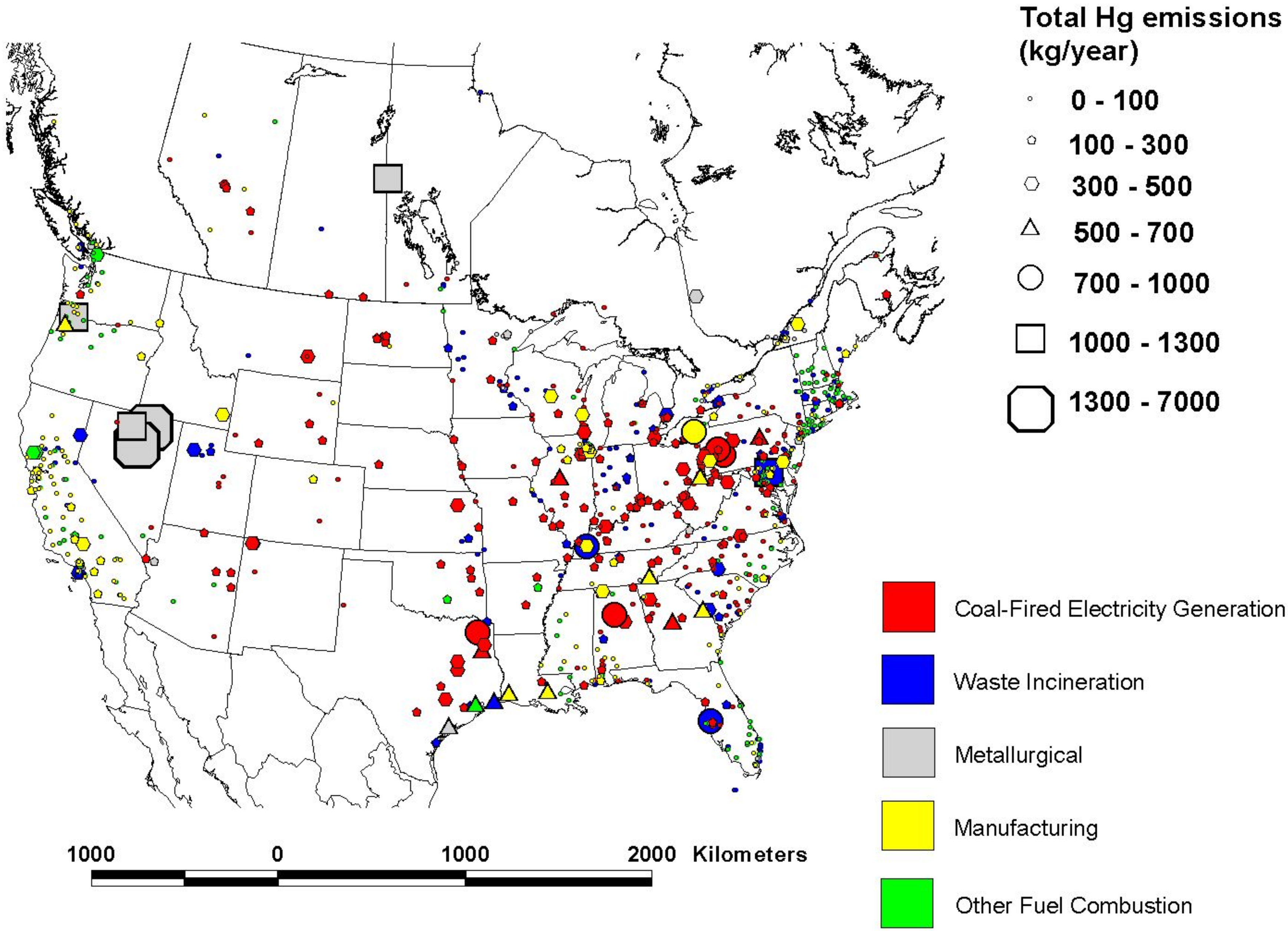
NOAA HYSPLIT MODEL

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).




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

- **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

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Environmental Research

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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,[e] Rachelle Laurin,[e,1] Jennifer Slotnick,[f] Todd Nettesheim,[g] and John McDonald[h]

[a] NOAA Air Resources Laboratory, 1315 East West Highway R/ARL, Room 3316, Silver Spring, MD 20910, USA

[b] Commission for Environmental Cooperation, Montreal, Que., Canada

[c] Atmospheric Toxic Processes Service, Meteorological Service of Canada, Environment Canada–Quebec region, Montreal, Que., Canada

[d] Pollutant Data Branch, Environment Canada, Hull, Que., Canada

[e] Environmental Monitoring and Reporting Branch, Ontario Ministry of the Environment, Toronto, Ont., Canada

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.

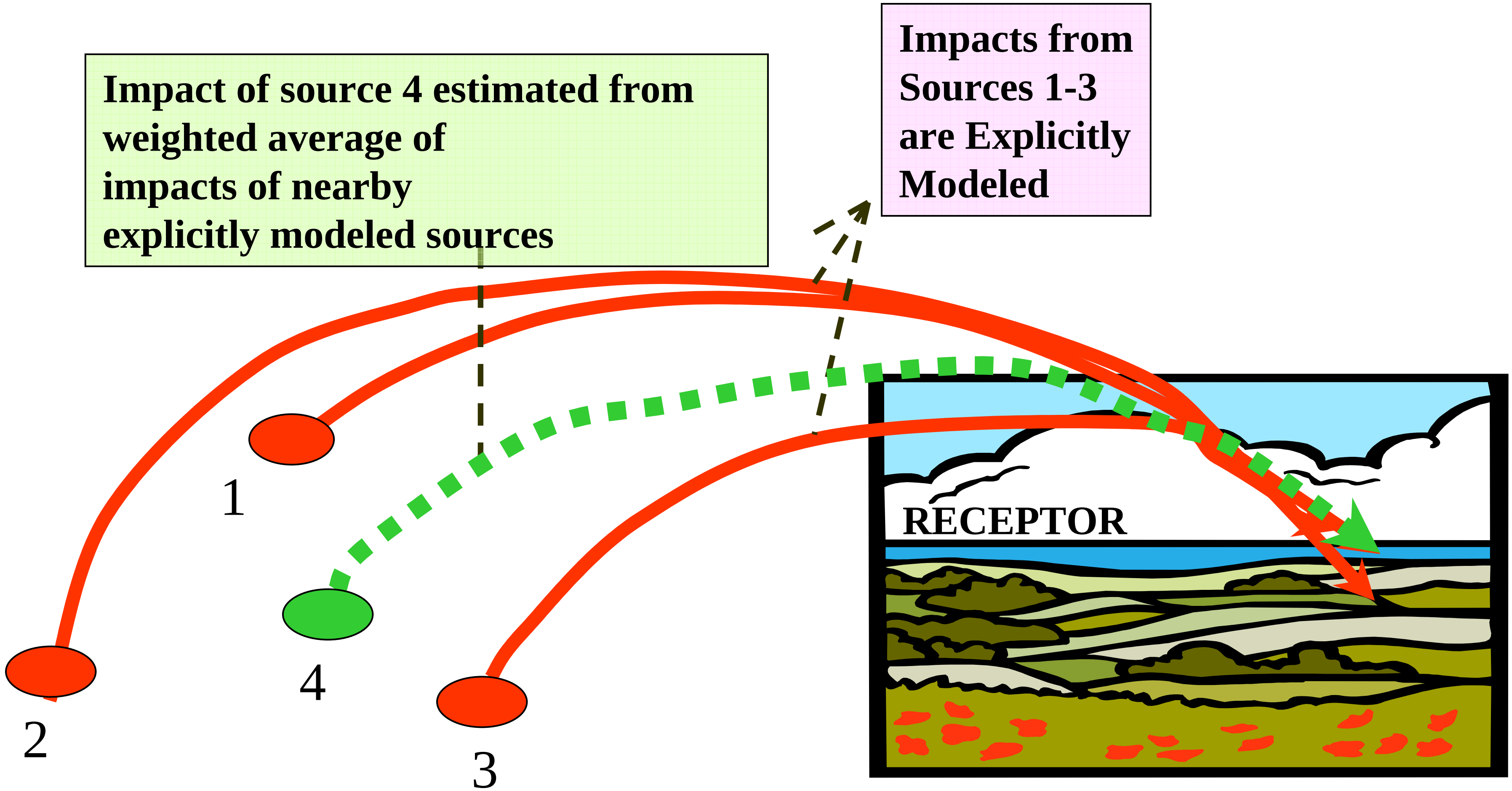
Note: Volume 95(3) is a Special Issue: "An Ecosystem Approach to Health Effects of Mercury in the St. Lawrence Great Lakes", edited by David O. Carpenter.

- **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

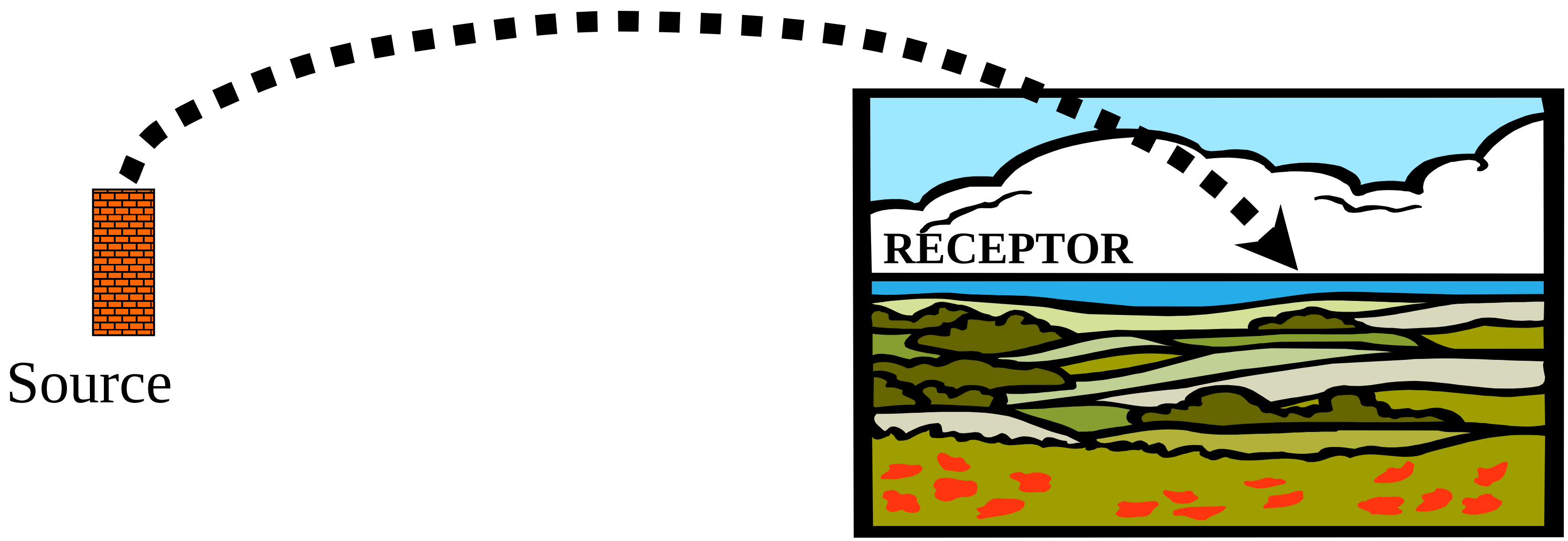


- **Perform separate simulations at each location for emissions of pure Hg(0), Hg(II) and Hg(p)**

  [*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)

What do atmospheric mercury models need?

Emissions Inventories

Meteorological Data

Scientific understanding of phase partitioning, atmospheric chemistry, and deposition processes

Ambient data for comprehensive model evaluation and improvement

Emissions Inventories	
Previous Work	• 1996, 1999 U.S. NEI • 1995, 2000 Canada

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Current Objectives	• 2002 U.S. NEI • 2002 Canada • Global – 2000 (Pacyna-NILU) • Natural sources • Re-emitted anthropogenic
Challenges and Notes	• **Speciation?** • **Short-term variations (e.g. hourly) [CEM's?]** • **Longer-term variations (e.g., maintenance)?** • **Mobile sources** • **Harmonization of source-categories** • **Emissions inventories currently only become available many years after the fact; how can we evaluate models using current monitoring data?**

Meteorological Data	
Previous Work	• **For U.S./Canadian modeling, 1996 data from NOAA Nested Grid Model (NGM), 180 km**

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Challenges and Notes	• Forecast vs. Analysis • Data assimilation • Precipitation?? • Difficult to archive NOAA analysis datasets • Need finer-resolution datasets, especially for near-field analysis and model evaluation • We have conversion filters (e.g., for MM5), but these data are not readily available • What is the best way to archive and share data?

Atmospheric Chemistry and Physics	
Previous Work	• **Typical chemical mechanism** • **Prescribed fields for reactive trace gases (e.g., O_3, OH, SO_2) 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
GAS PHASE REACTIONS			
$Hg^0 + O_3 \rightarrow Hg(p)$	3.0E-20	cm^3/molec-sec	Hall (1995)
$Hg^0 + HCl \rightarrow HgCl_2$	1.0E-19	cm^3/molec-sec	Hall and Bloom (1993)
$Hg^0 + H_2O_2 \rightarrow Hg(p)$	8.5E-19	cm^3/molec-sec	Tokos et al. (1998) (upper limit based on experiments)
$Hg^0 + Cl_2 \rightarrow HgCl_2$	4.0E-18	cm^3/molec-sec	Calhoun and Prestbo (2001)
$Hg^0 + OH\bullet \rightarrow Hg(p)$	8.7E-14	cm^3/molec-sec	Sommar et al. (2001)
AQUEOUS PHASE REACTIONS			
$Hg^0 + O_3 \rightarrow Hg^{+2}$	4.7E+7	$(\text{molar-sec})^{-1}$	Munthe (1992)
$Hg^0 + OH\bullet \rightarrow Hg^{+2}$	2.0E+9	$(\text{molar-sec})^{-1}$	Lin and Pehkonen(1997)
$HgSO_3 \rightarrow Hg^0$	$T*e^{((31.971*T)-12595.0)/T)}$ sec^{-1} [T = temperature (K)]		Van Loon et al. (2002)
$Hg(II) + HO_2\bullet \rightarrow Hg^0$	~ 0	$(\text{molar-sec})^{-1}$	Gardfeldt & Jonnson (2003)
$Hg^0 + HOCl \rightarrow Hg^{+2}$	2.1E+6	$(\text{molar-sec})^{-1}$	Lin and Pehkonen(1998)
$Hg^0 + OCl^{-1} \rightarrow Hg^{+2}$	2.0E+6	$(\text{molar-sec})^{-1}$	Lin and Pehkonen(1998)
$Hg(II) \leftrightarrow Hg(II)_{(soot)}$	9.0E+2	liters/gram; t = 1/hour	eqlbrm: Seigneur et al. (1998) rate: Bullock & Brehme (2002).
$Hg^{+2} + h< \rightarrow Hg^0$	6.0E-7	$(sec)^{-1}$ (maximum)	Xiao et al. (1994); Bullock and Brehme (2002)

Atmospheric Chemistry and Physics	
Previous Work	• Typical chemical mechanism • Prescribed fields for reactive trace gases (e.g., O_3, OH, SO_2) 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.** • **Add SO2 and potentially other compounds into in-situ plume chemistry treatment** • **Sensitivity analyses** • **Consider using gridded chemical output from full-chemistry atmospheric model (e.g., CMAQ)** • **Option - run HYSPLIT in Eulerian mode for chemistry; conduct one-atmosphere simulation**

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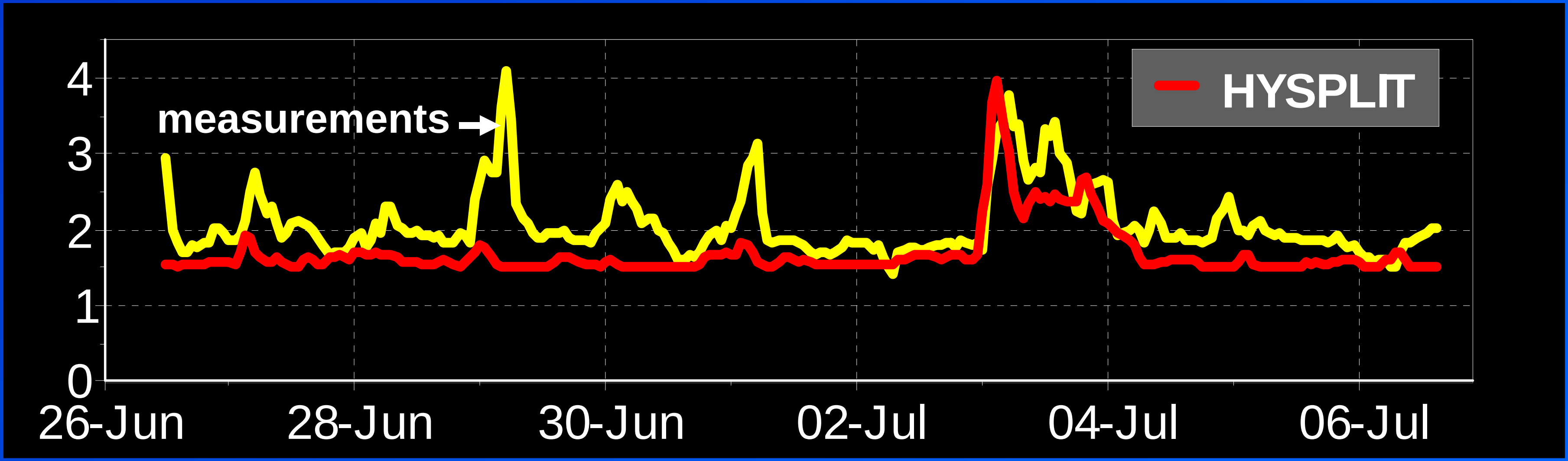
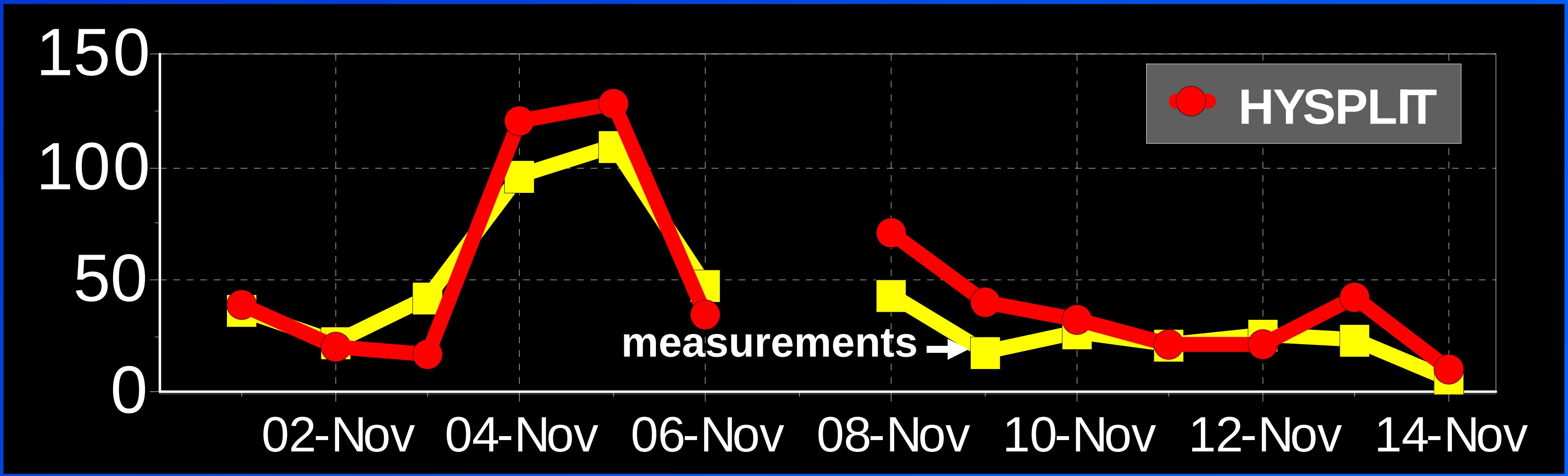
Challenges and Notes	• What is RGM? • What is Hg(p)? • What is solubility of Hg(p)? • Fate of dissolved Hg(II) when droplet dries out? • What reactions don't we know about yet? • What are rates of reactions? • Uncertainties in wet & dry deposition processes...

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

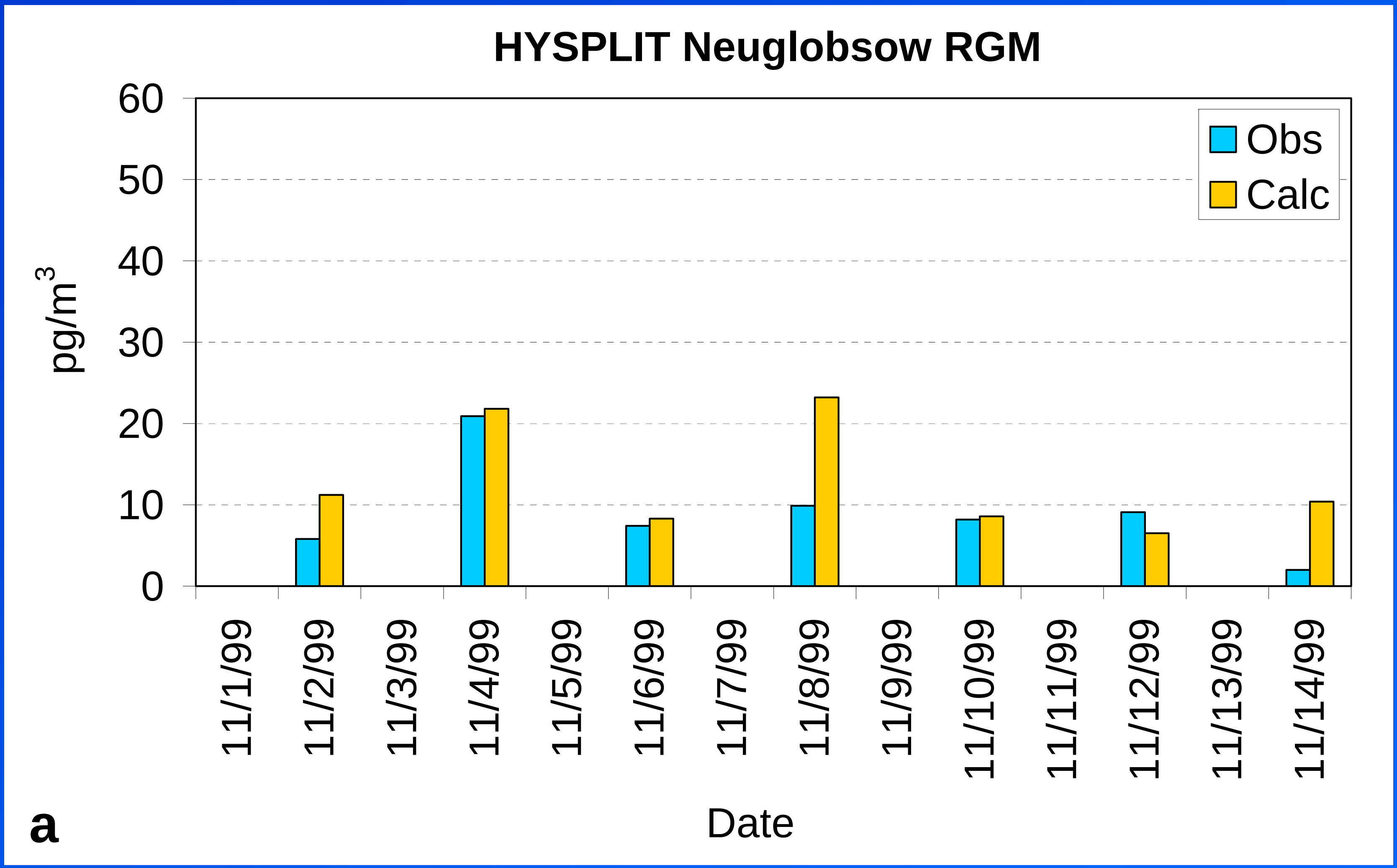
Total Gaseous Mercury (ng/m³) at Neuglobsow: June 26 – July 6, 1995



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



Reactive Gaseous Mercury at Neuglobsow, Nov 1-14, 1999



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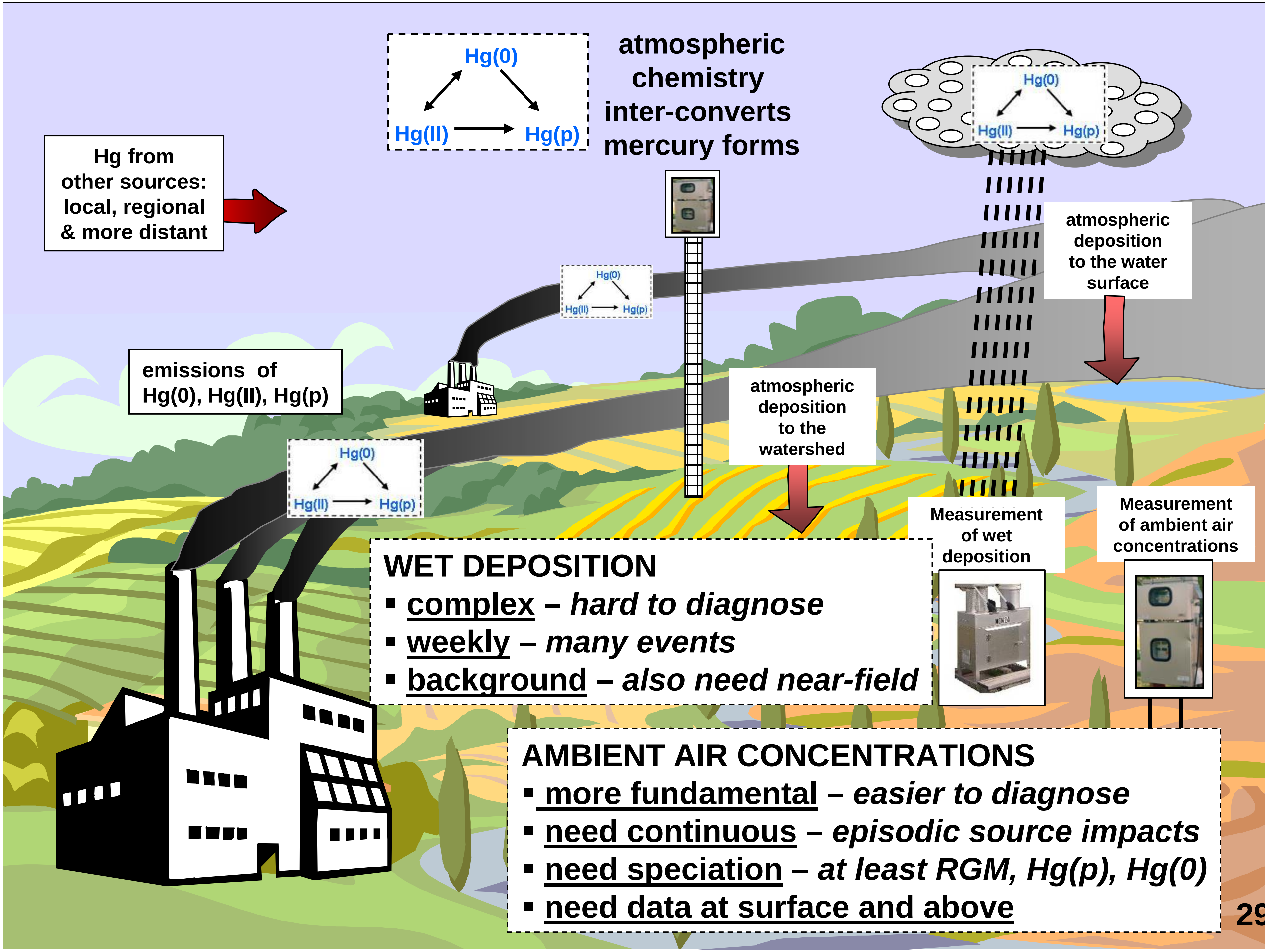
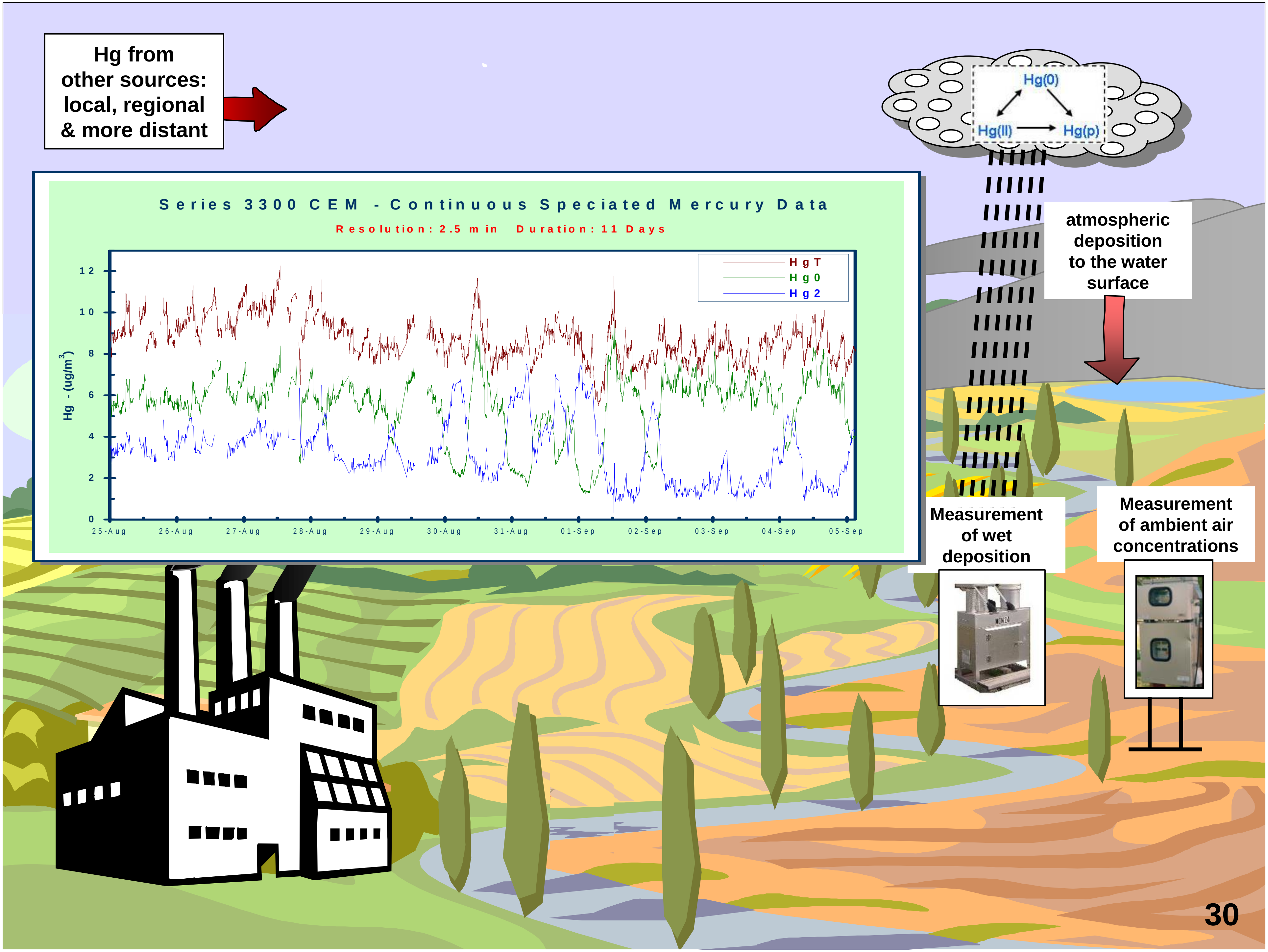
Challenges and Notes	• Comprehensive evaluation has not been possible due to large gaps in availability of monitoring and process-related data • Need data for upper atmosphere as well as surface • Need data for both source-impacted and background sites • Use of recent monitoring data with EPA 2002 inventory? • Time-resolved monitoring data vs. non-time-resolved emissions? • Hard to diagnose differences between models & measurements • 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


Hg(0)
Hg(II)
Hg(p)
atmospheric chemistry inter-converts mercury forms
Hg from other sources: local, regional & more distant
emissions of Hg(0), Hg(II), Hg(p)
atmospheric deposition to the water surface
atmospheric deposition to the watershed
Measurement of wet deposition
Measurement of ambient air concentrations
WET DEPOSITION
▪ complex – hard to diagnose
▪ weekly – many events
▪ background – also need near-field
AMBIENT AIR CONCENTRATIONS
▪ more fundamental – easier to diagnose
▪ need continuous – episodic source impacts
▪ need speciation – at least RGM, Hg(p), Hg(0)
▪ need data at surface and above


Hg from other sources: local, regional & more distant
Hg(0)
Hg(II)
Hg(p)
Series 3300 CEM - Continuous Speciated Mercury Data
Resolution: 2.5 min Duration: 11 Days
HgT
Hg0
Hg2
Hg - (ug/m3)
0
2
4
6
8
10
12
25-Aug
26-Aug
27-Aug
28-Aug
29-Aug
30-Aug
31-Aug
01-Sep
02-Sep
03-Sep
04-Sep
05-Sep
atmospheric deposition to the water surface
Measurement of wet deposition
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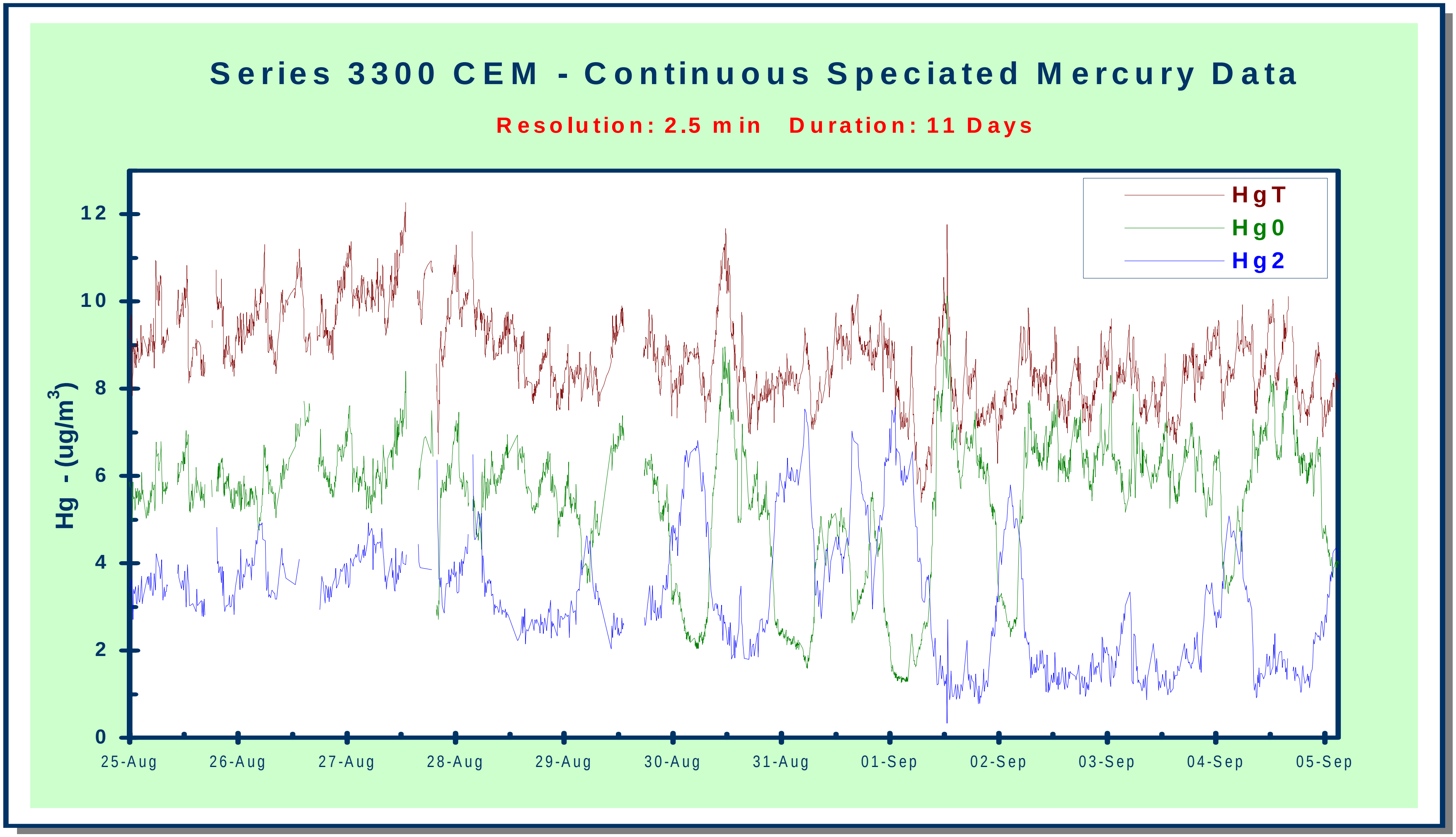
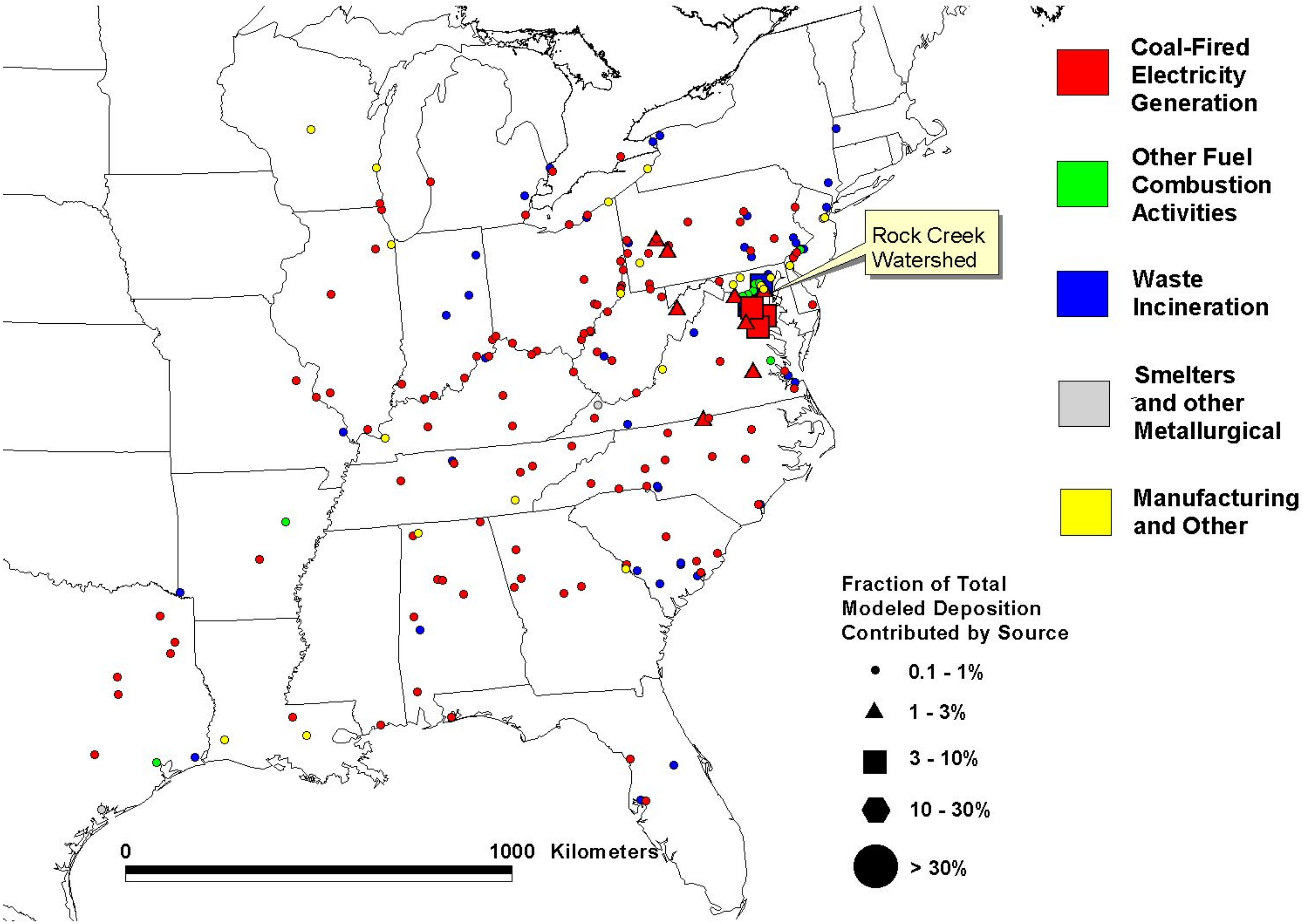


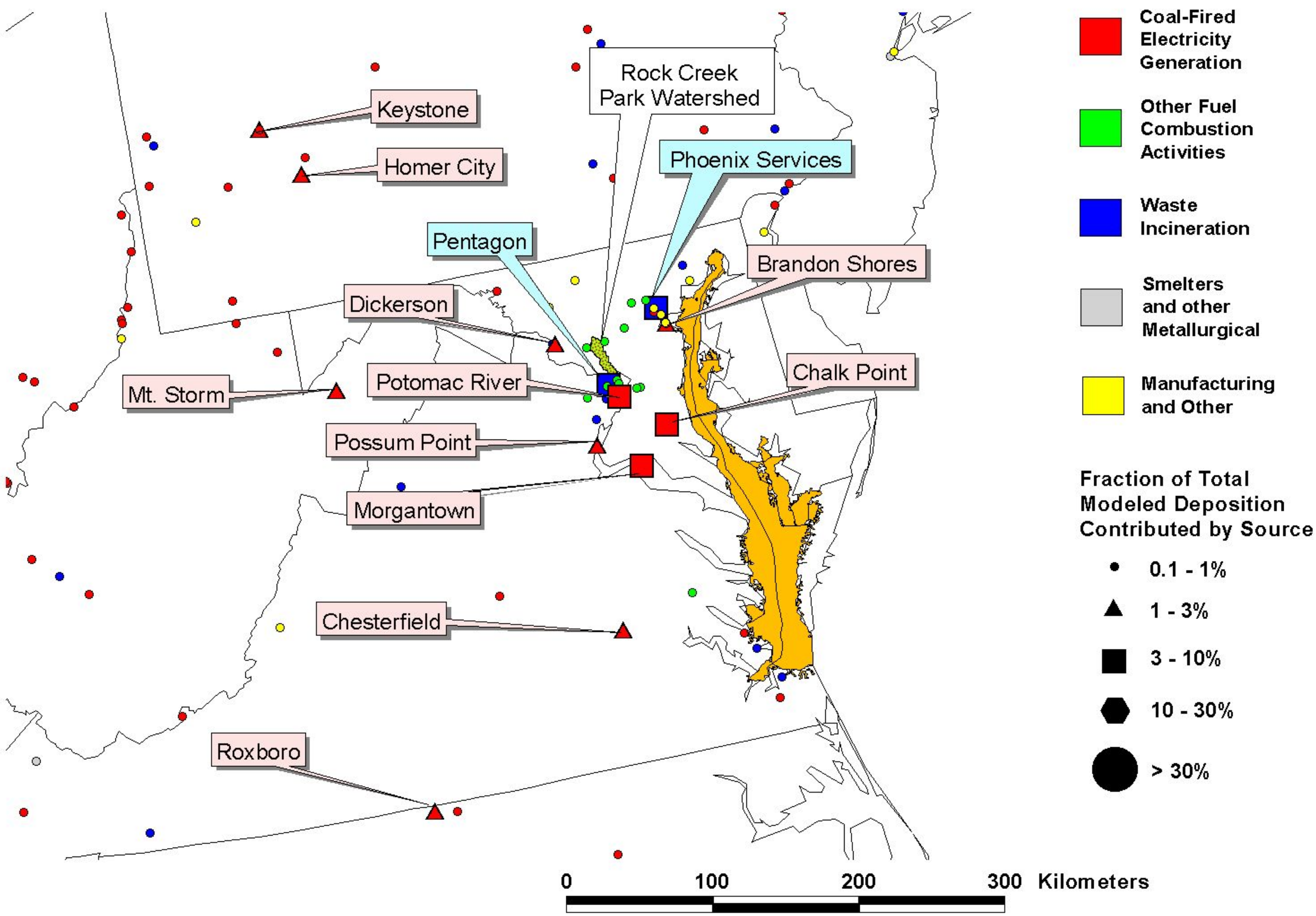
Source: ***Tekran Instruments Corporation***

Example of results: Rock Creek Watershed

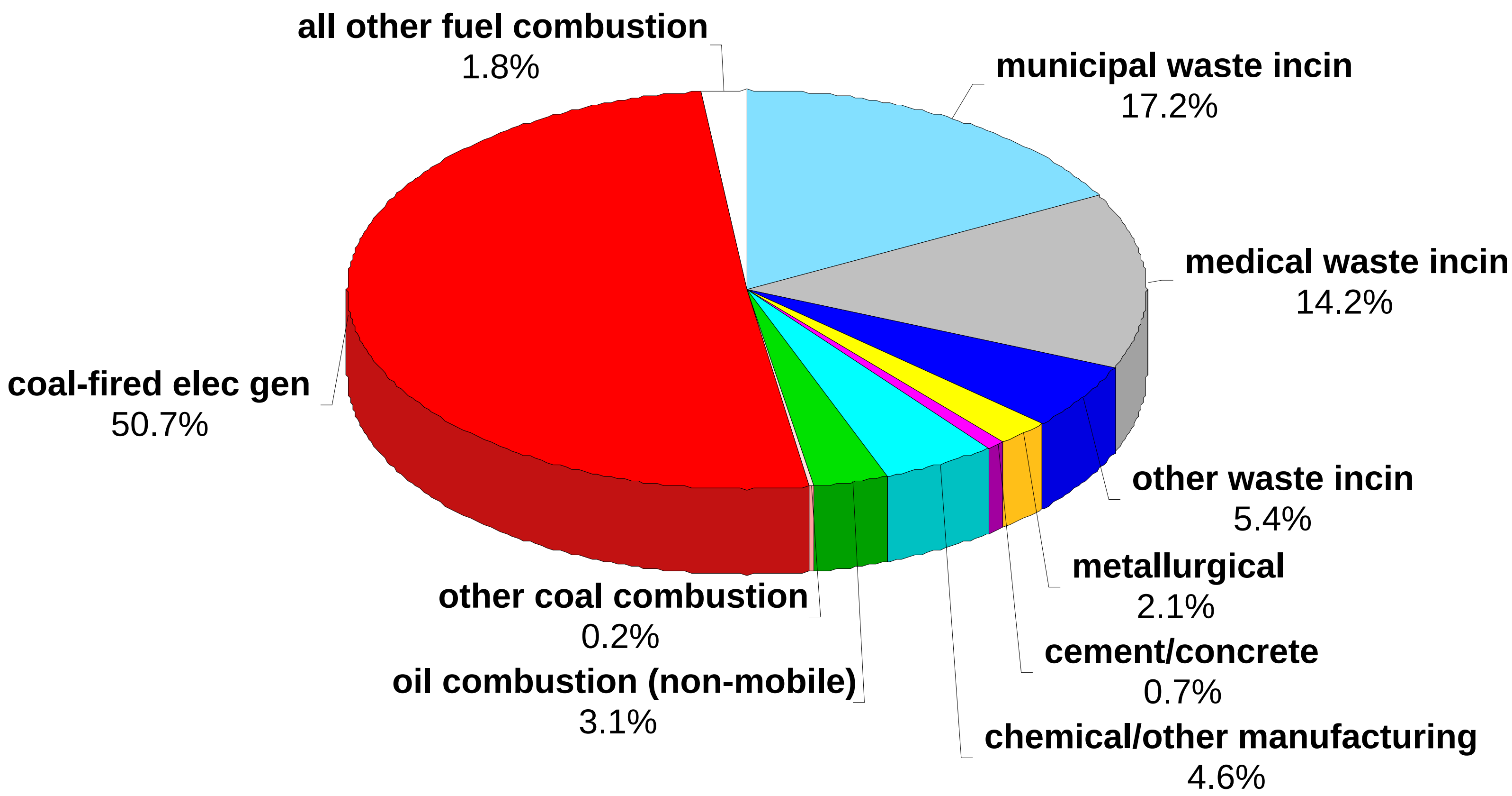
Largest Model-Estimated U.S./Canada Anthropogenic Contributors to 1999 Mercury Deposition to the Rock Creek Watershed (large region)



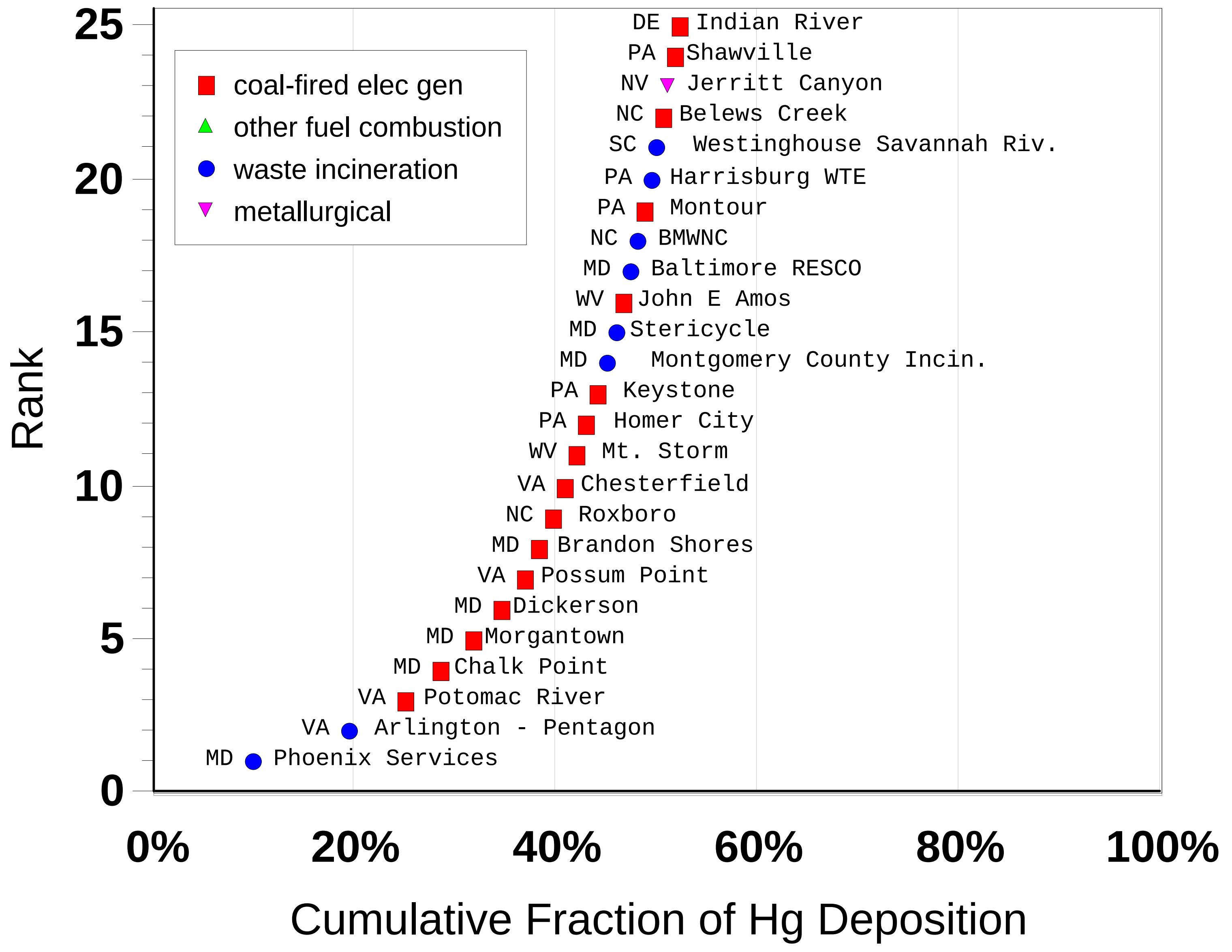
Largest Model-Estimated U.S./Canada Anthropogenic Contributors to 1999 Mercury Deposition to the Rock Creek Watershed (close up)



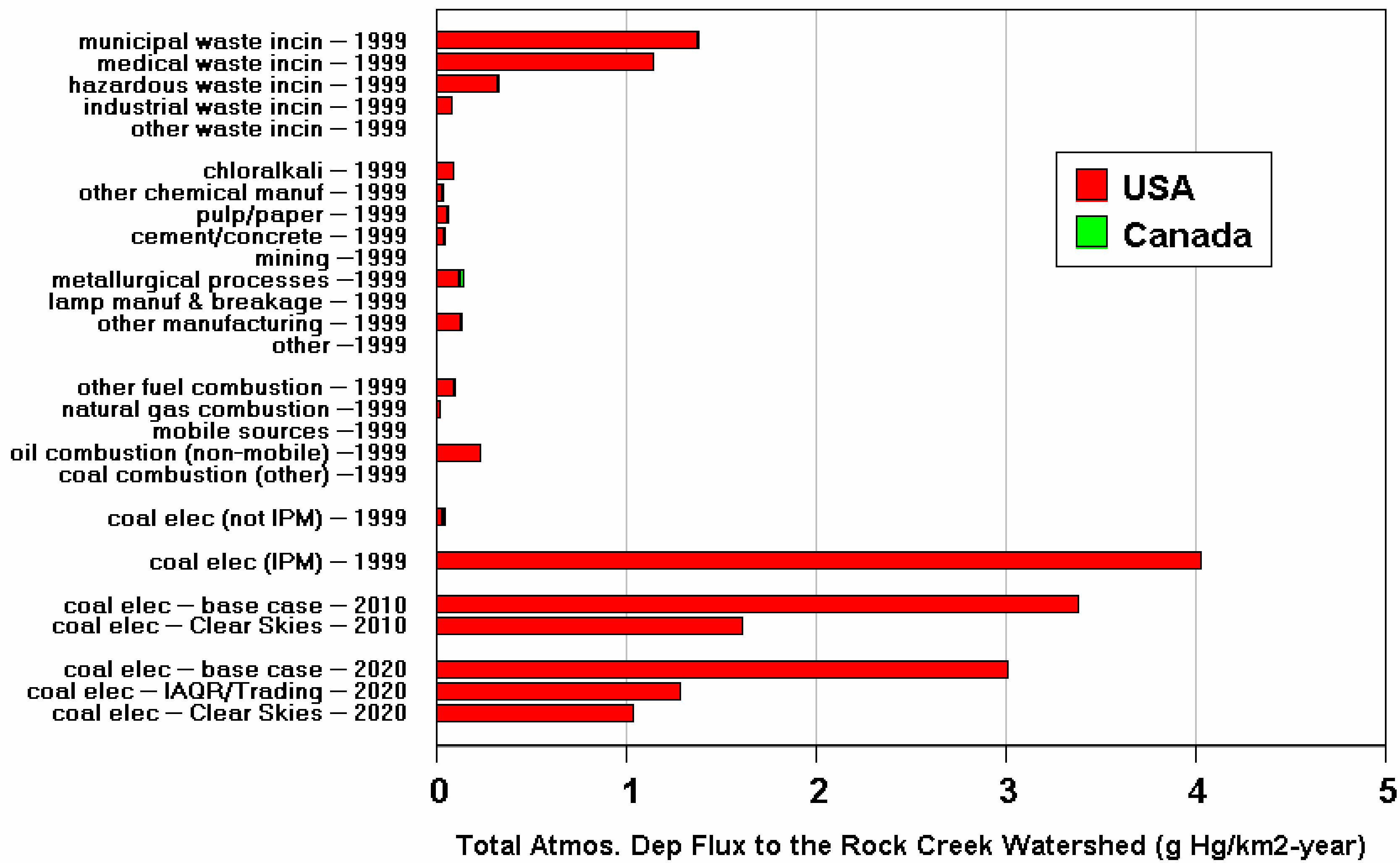
Proportions of 1999 Model-Estimated Atmospheric Deposition to the Rock Creek Watershed from Different Anthropogenic U.S./Canada Mercury Emissions Source Sectors



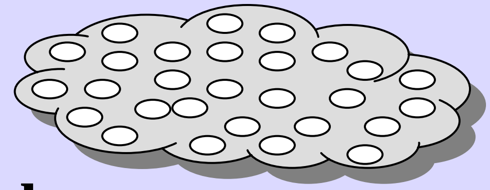
Top 25 Contributors to Hg Deposition to Rock Creek Watershed



Atmospheric Deposition Flux to the Rock Creek Watershed from Anthropogenic Mercury Emissions Sources in the U.S. and Canada

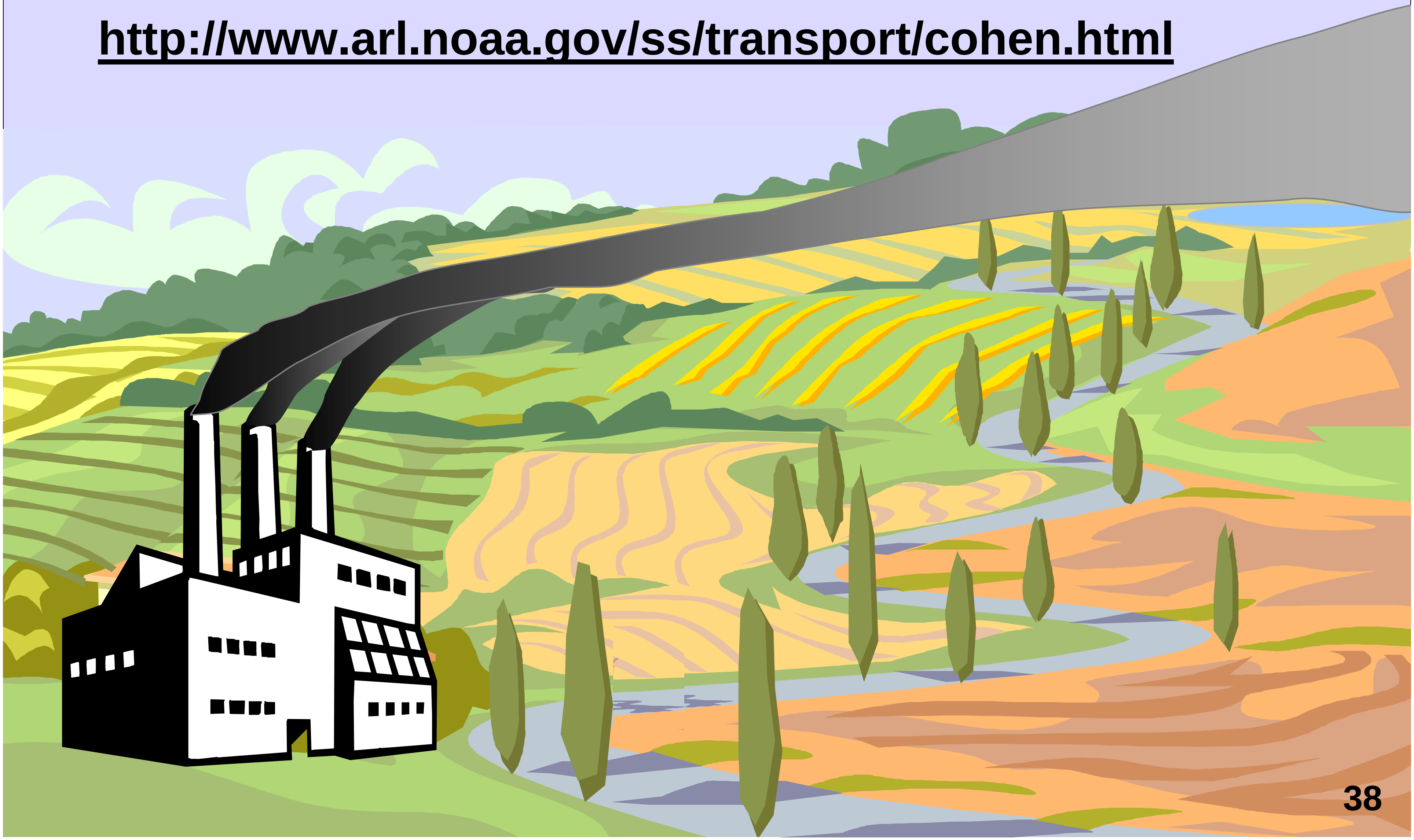


Thanks!



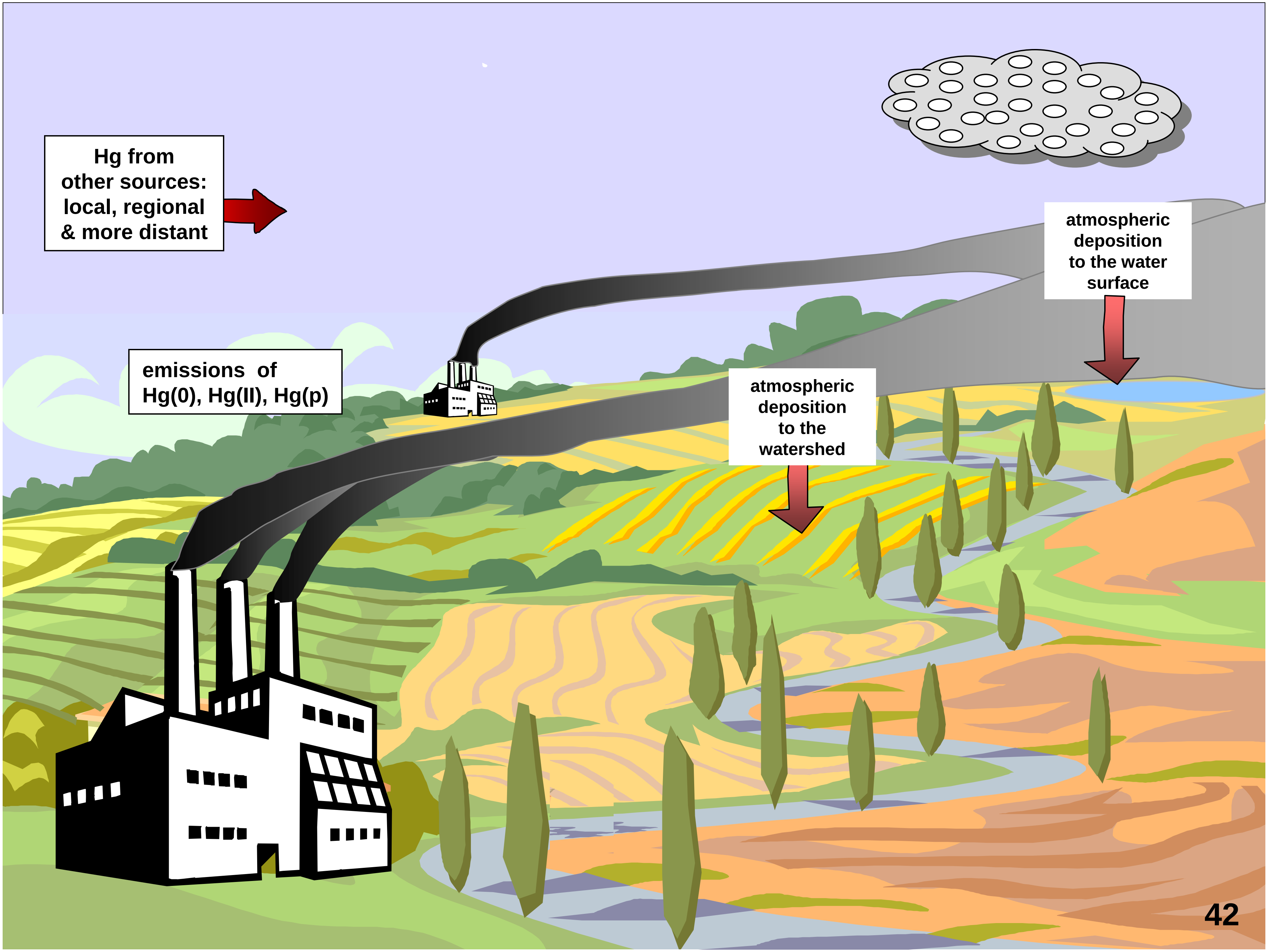
For more information on this research:

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



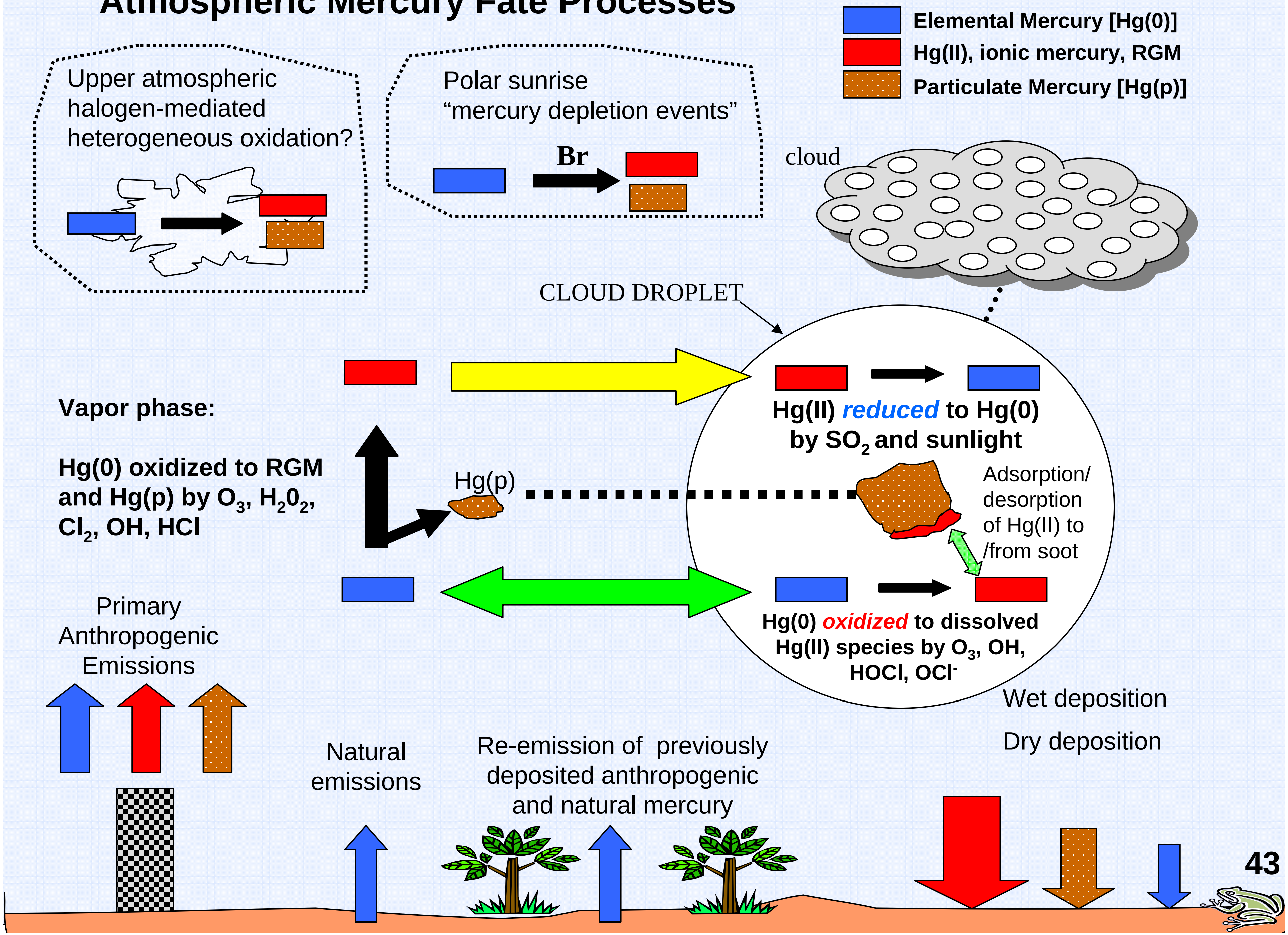
Extra Slides

Context



Hg from other sources: local, regional & more distant
emissions of Hg(0), Hg(II), Hg(p)
atmospheric deposition to the watershed
atmospheric deposition to the water surface

Atmospheric Mercury Fate Processes

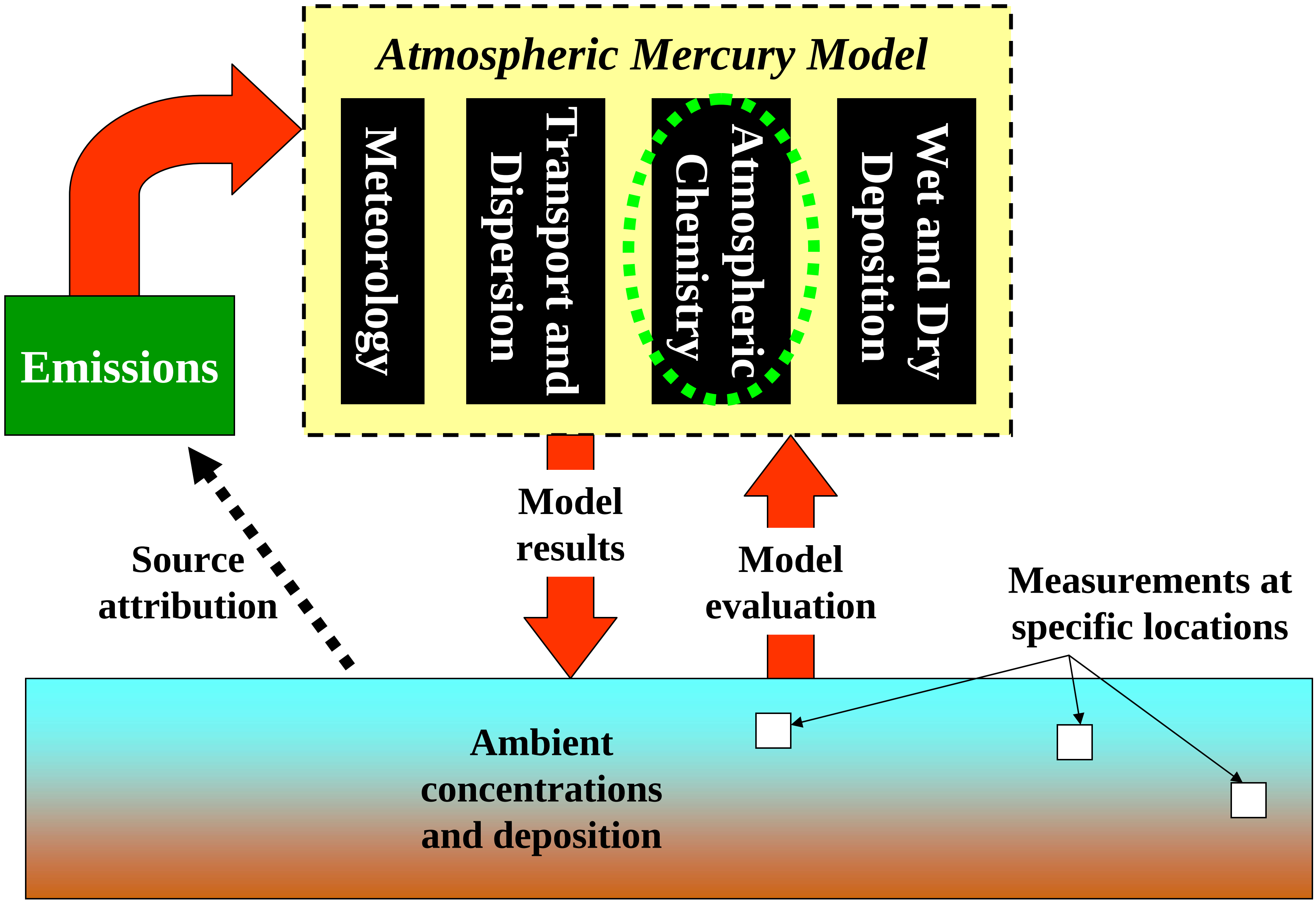


- ***policy development* requires:**
  - **source-attribution (*source-receptor* info)**
  - **estimated impacts of alternative future scenarios**

- **estimation of *source-attribution* & *future impacts* requires atmospheric models**

- ***atmospheric models* require:**
  - **knowledge of atmospheric chemistry & fate**
  - **emissions data**
  - **ambient data for “ground-truthing”**

methodology


Atmospheric Mercury Model
Meteorology
Transport and Dispersion
Atmospheric Chemistry
Wet and Dry Deposition
Emissions
Model results
Model evaluation
Source attribution
Measurements at specific locations
Ambient concentrations and deposition

Some Current Atmospheric Chemistry Challenges

- ***Plume chemistry***, e.g., rapid reduction of RGM to elemental mercury?

  - ***If* significant reduction of RGM to Hg(0) is occurring in power-plant plumes, then much less local/regional deposition**

RGM reduction in power-plant plumes?

- *If* significant reduction of RGM to Hg(0) is occurring in power-plant plumes, then much less local/regional deposition

- No known chemical reaction is capable of causing significant reduction of RGM in plumes – e.g. measured rates of SO_2 reduction can't explain some of the claimed reduction rates

- Very hard to measure
  - Aircraft
  - Static Plume Dilution Chambers (SPDC)
  - Ground-based measurements

RGM reduction in power-plant plumes?

- Most current state-of-the-science models do not include processes that lead to significant reduction in plumes
- Recent measurement results show less reduction
- Significant uncertainties – e.g., mass balance errors comparable to measured effects…
- Current status – inconclusive… but weight of evidence suggest that while some reduction may be occurring, it may be only a relatively small amount
- Recent measurements at Steubenville, OH appear to show strong local mercury deposition from coal-fired power plant emissions.

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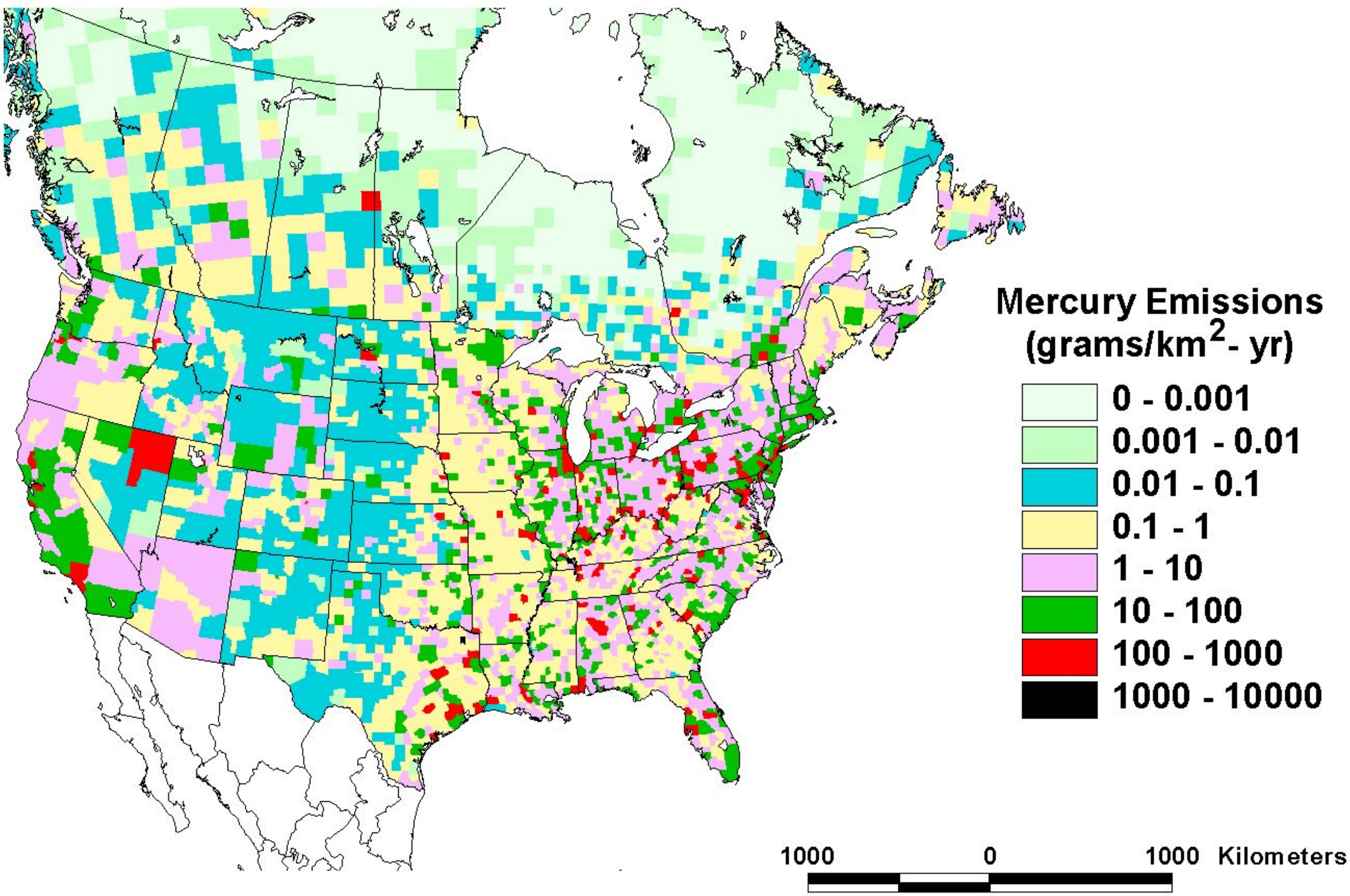
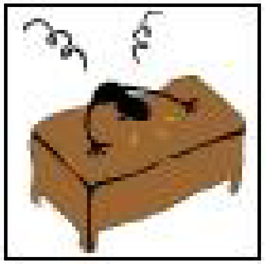
- ***Source-Receptor answers influenced by above factors***

emissions

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

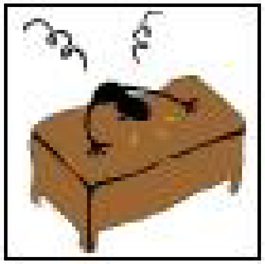


Temporal Problems with Emissions Inventories



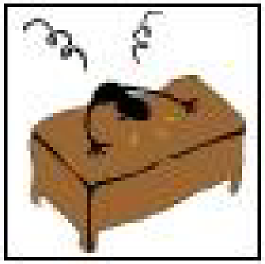
Variations on time scales of minutes to hours

- *CEM's needed – and not just on coal-fired power plants*
- *CEM's must be speciated or of little use in developing critical source-receptor information*
- *Clean Air Mercury Rule only requires ~weekly total-Hg measurements, for purposes of trading*



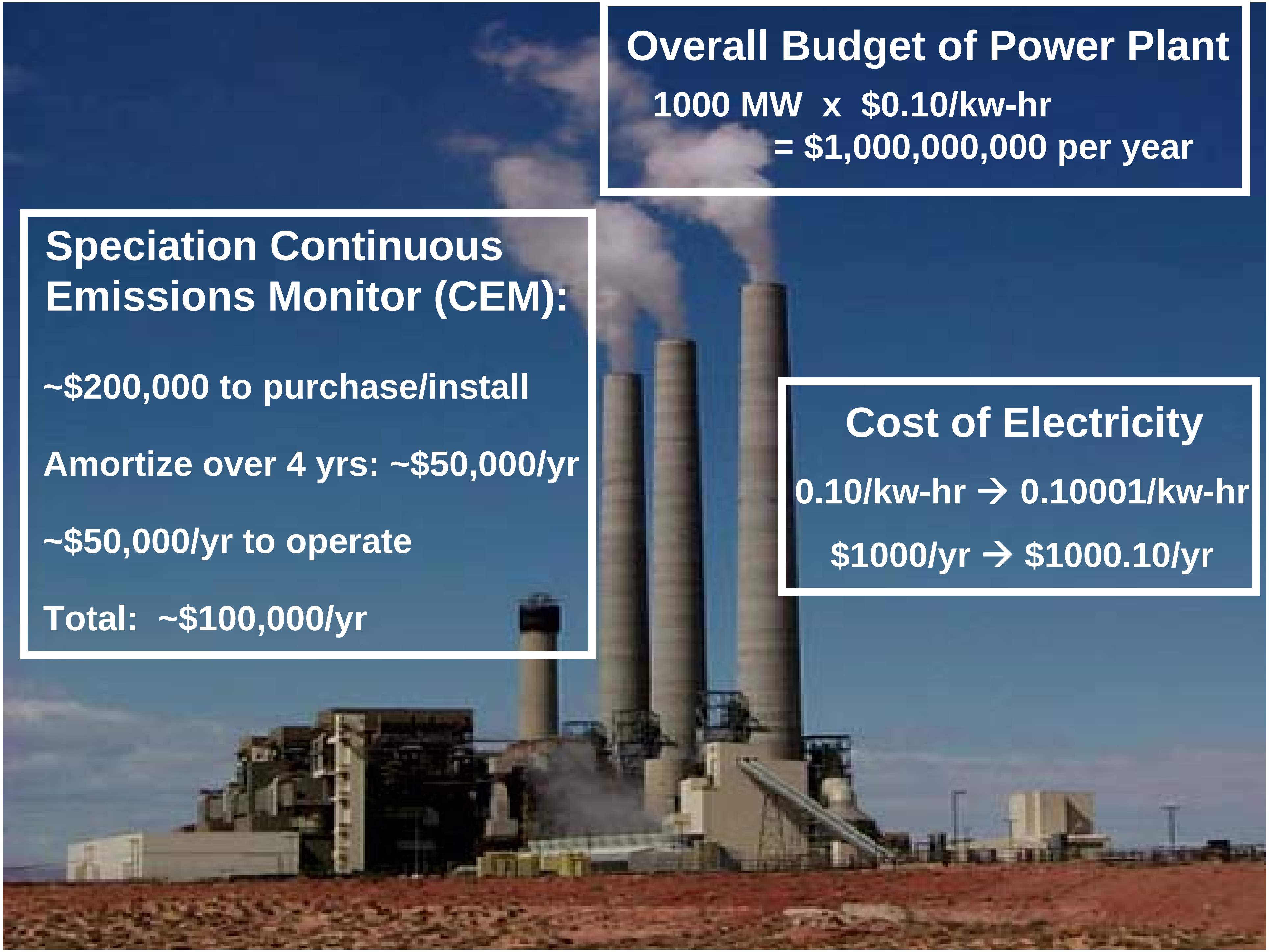
We don't have information about major events

- *e.g., maintenance or permanent closures, installation of new pollution control devices, process changes*
- *Therefore, difficult to interpret trends in ambient data*



Long delay before inventories released

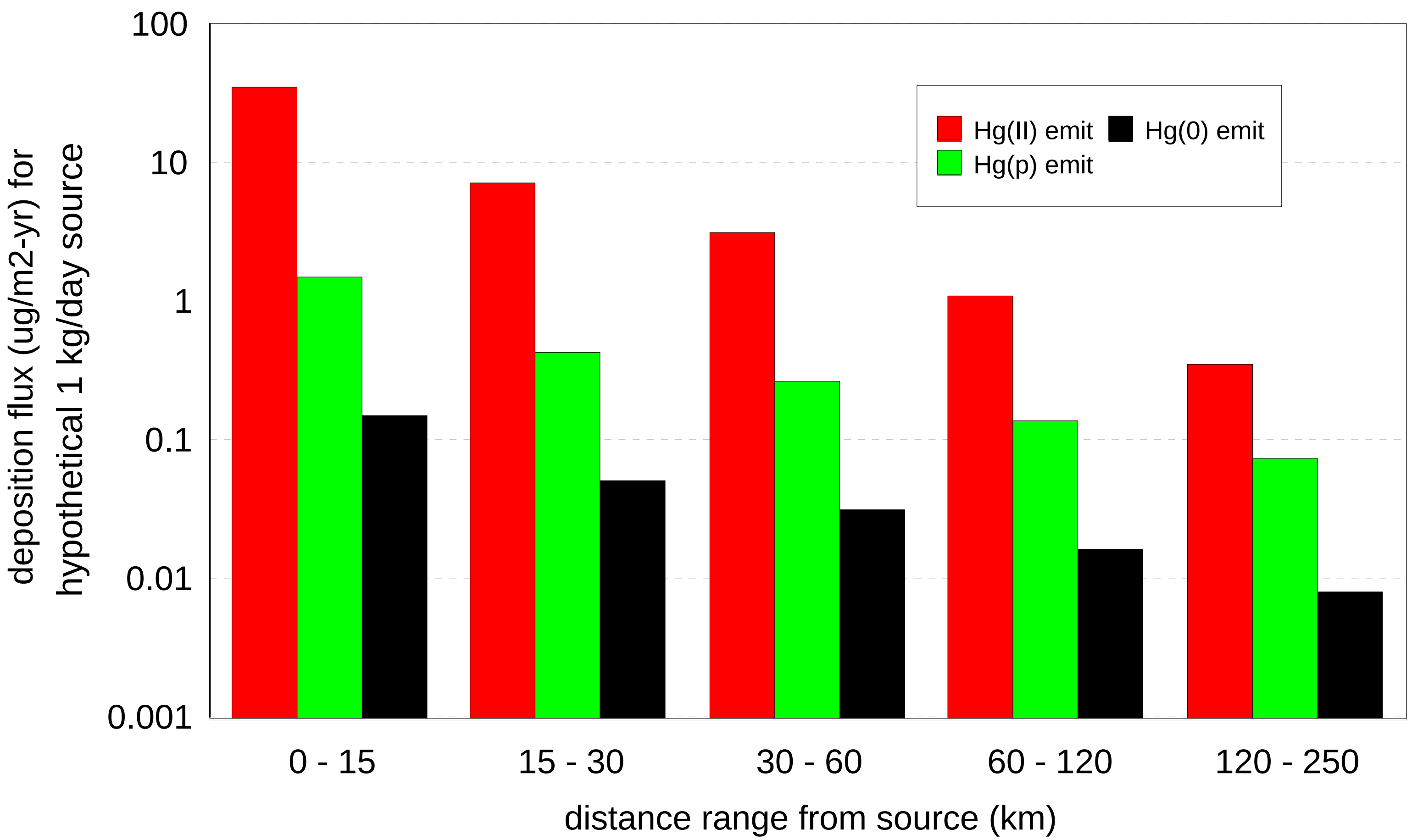
- *2002 inventory is being released this year in U.S.; till now, the latest available inventory was for 1999*
- *How can we use new measurement data?*



Overall Budget of Power Plant
1000 MW x $0.10/kw-hr
= $1,000,000,000 per year
Speciation Continuous Emissions Monitor (CEM):
~$200,000 to purchase/install
Amortize over 4 yrs: ~$50,000/yr
~$50,000/yr to operate
Total: ~$100,000/yr
Cost of Electricity
0.10/kw-hr → 0.10001/kw-hr
$1000/yr → $1000.10/yr

illustrative model results

Why are emissions speciation data - and potential plume transformations -- critical?



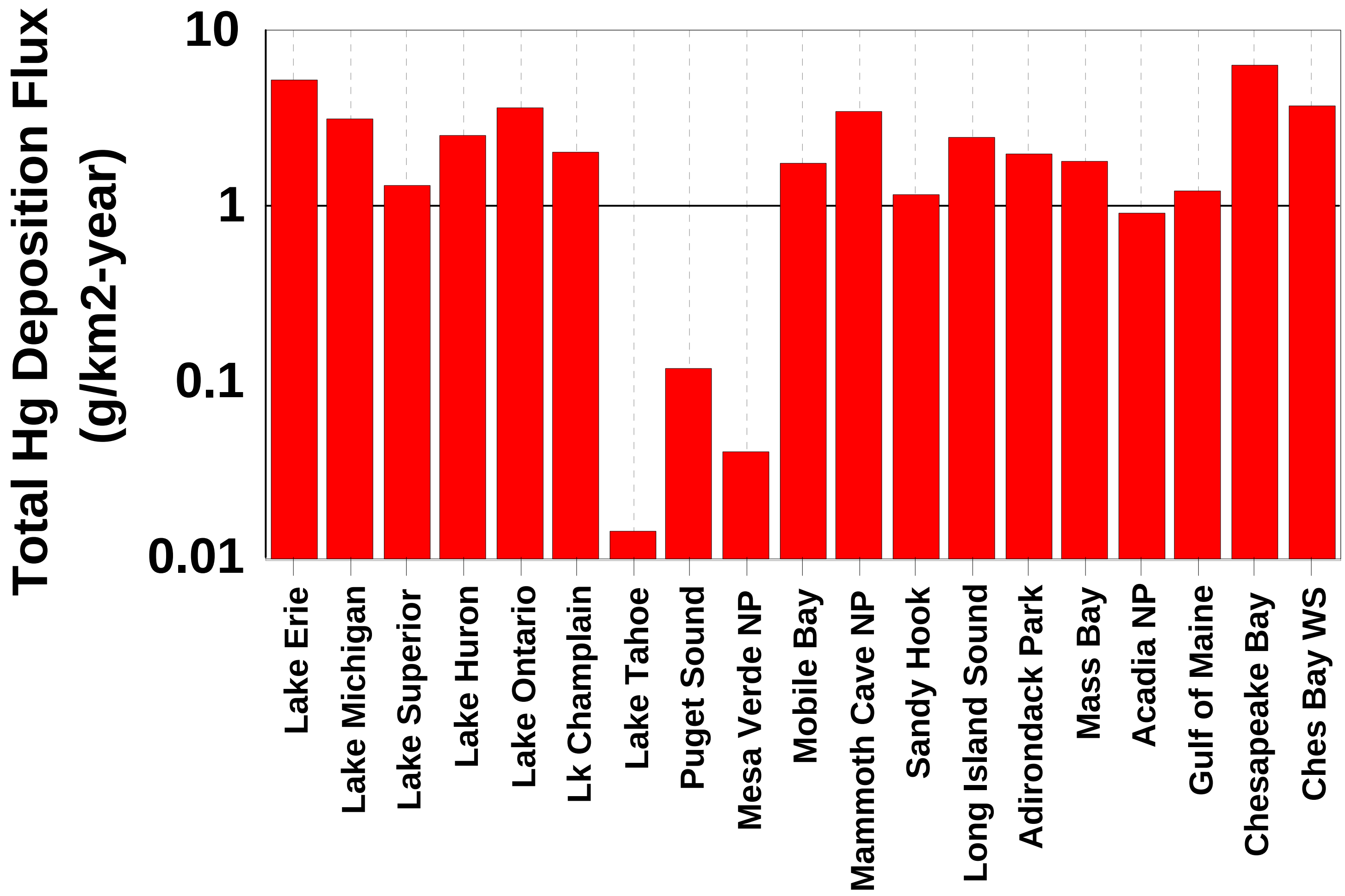
Logarithmic

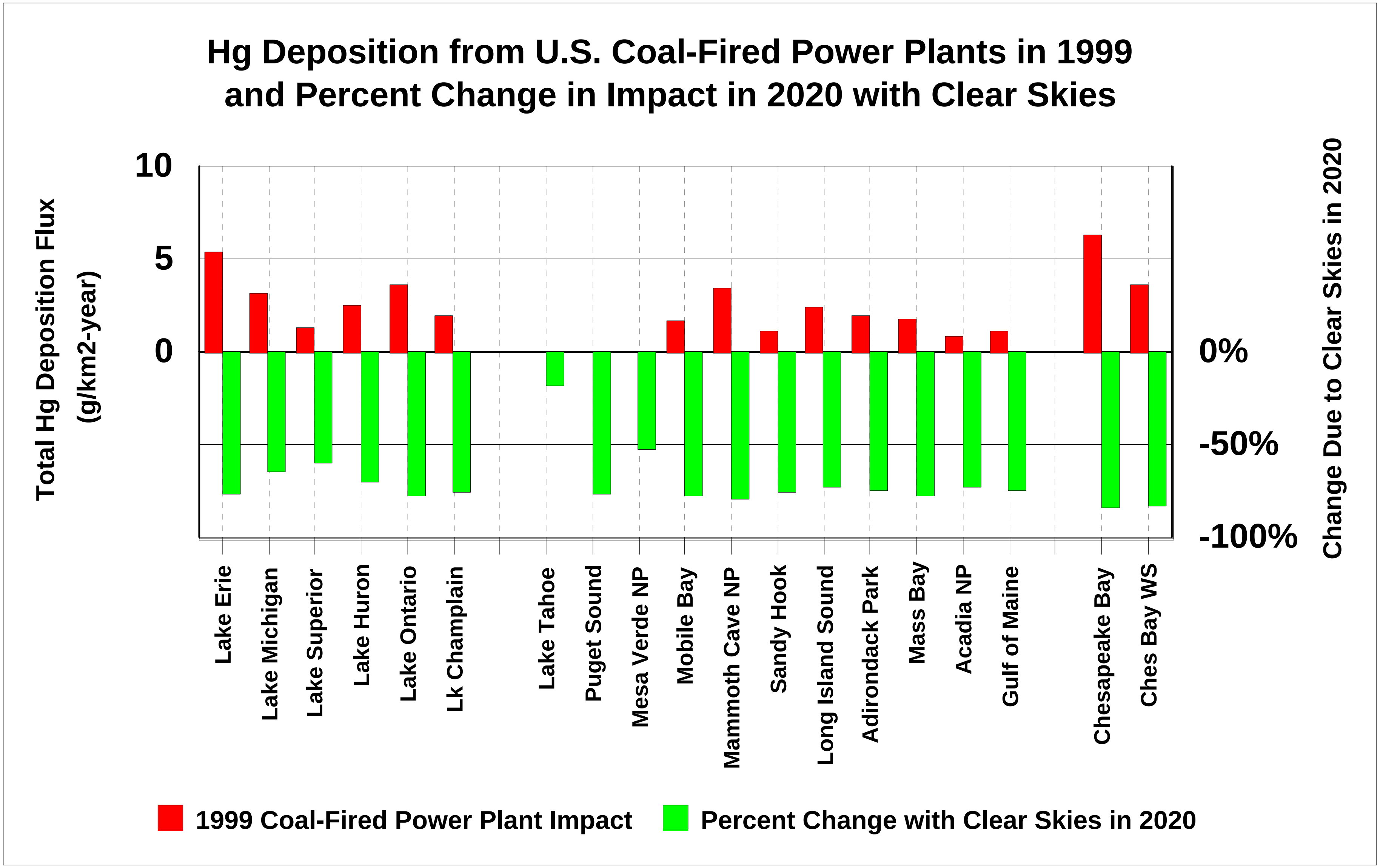
NOTE: distance results averaged over all directions – Some directions will have higher fluxes, some will have lower

source-receptor results

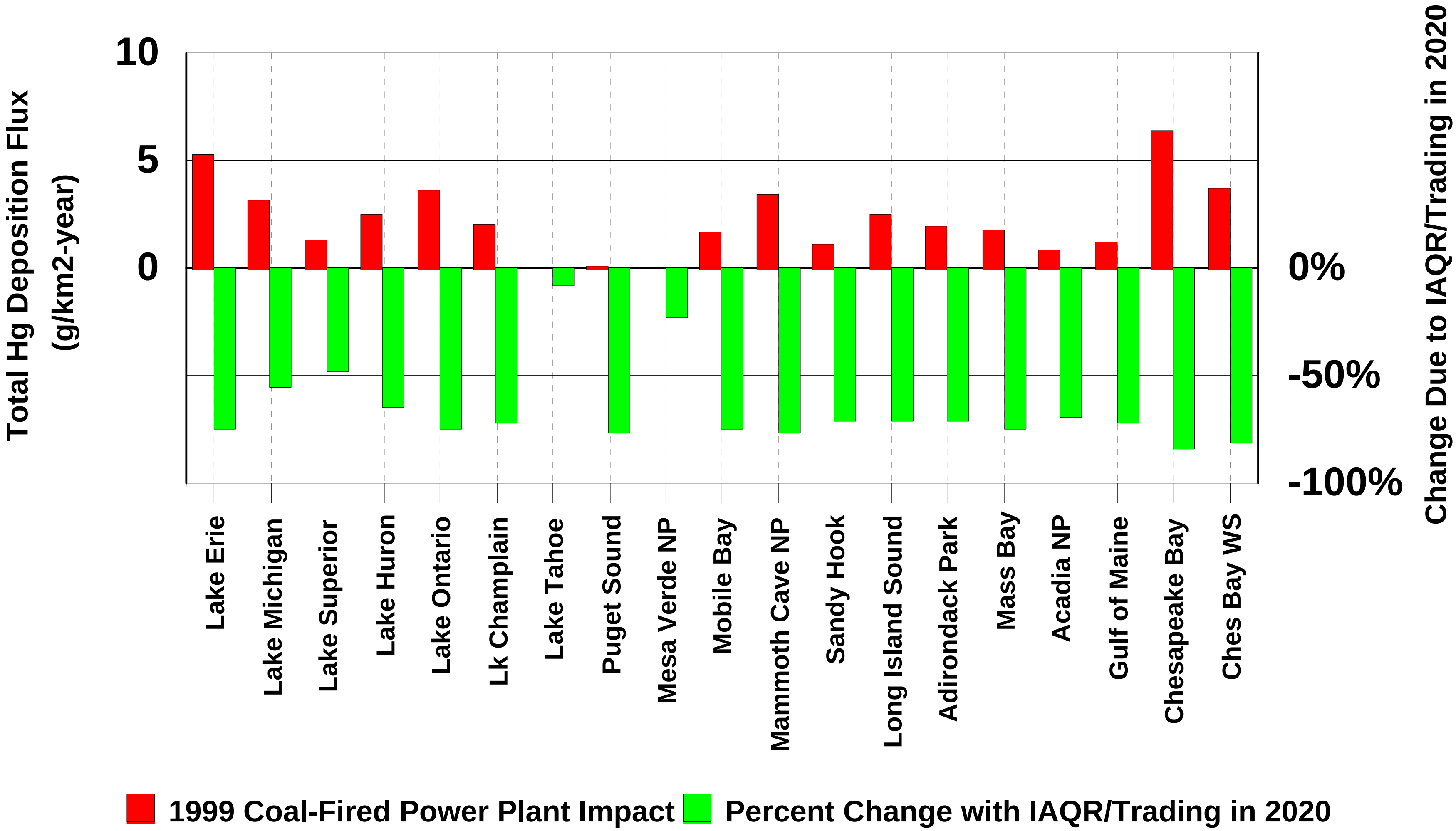
New Receptors from David Schmeltz, March 2003

Figure __. Hg Deposition From U.S. Coal-Fired Power Plants in 1999

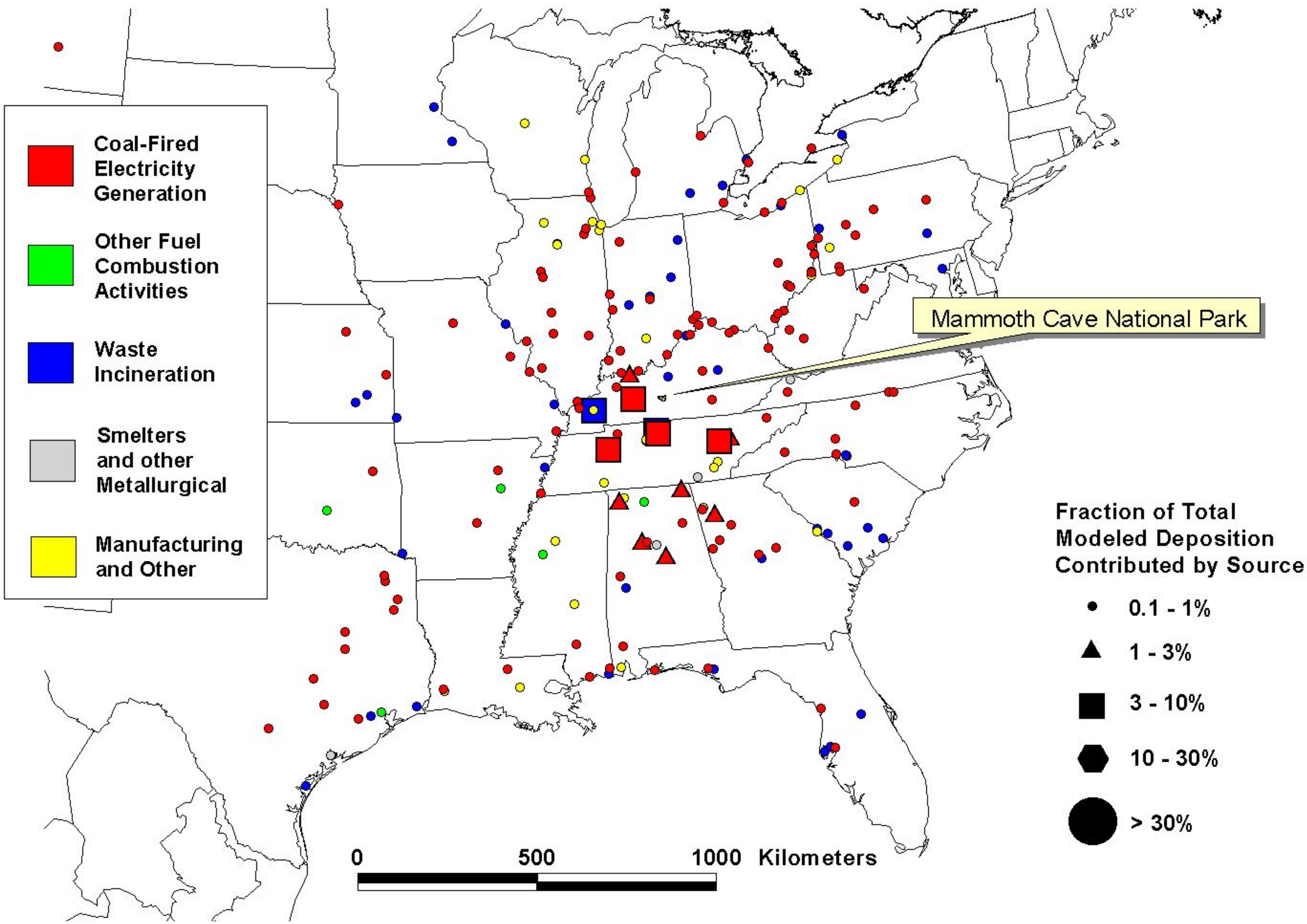


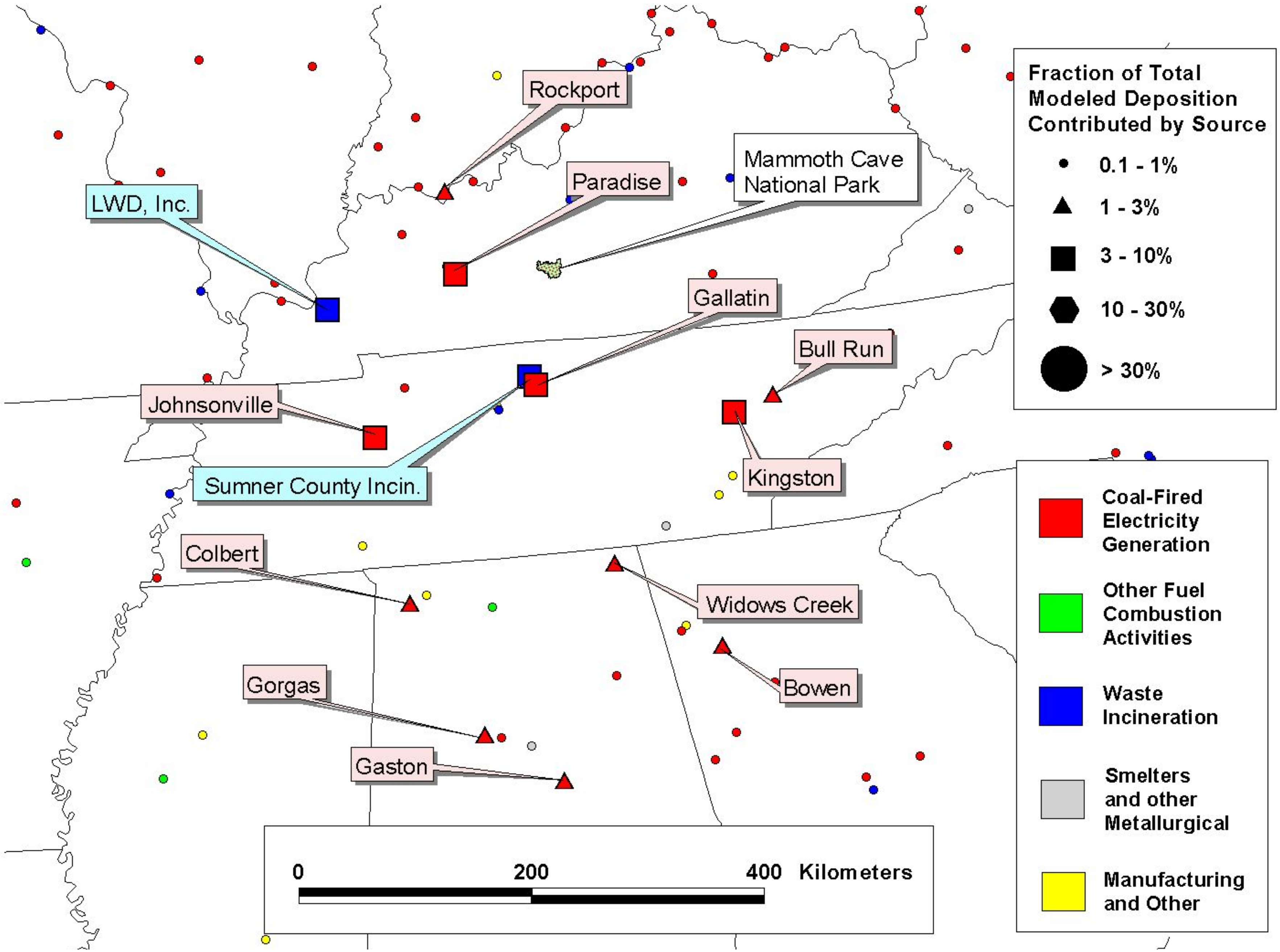

Hg Deposition from U.S. Coal-Fired Power Plants in 1999
and Percent Change in Impact in 2020 with Clear Skies
Total Hg Deposition Flux
(g/km2-year)
10
5
0
0%
-50%
-100%
Change Due to Clear Skies in 2020
Lake Erie
Lake Michigan
Lake Superior
Lake Huron
Lake Ontario
Lk Champlain
Lake Tahoe
Puget Sound
Mesa Verde NP
Mobile Bay
Mammoth Cave NP
Sandy Hook
Long Island Sound
Adirondack Park
Mass Bay
Acadia NP
Gulf of Maine
Chesapeake Bay
Ches Bay WS
1999 Coal-Fired Power Plant Impact
Percent Change with Clear Skies in 2020

Hg Deposition from U.S. Coal-Fired Power Plants in 1999 and Percent Change in Impact in 2020 with IAQR/Trading Scenario

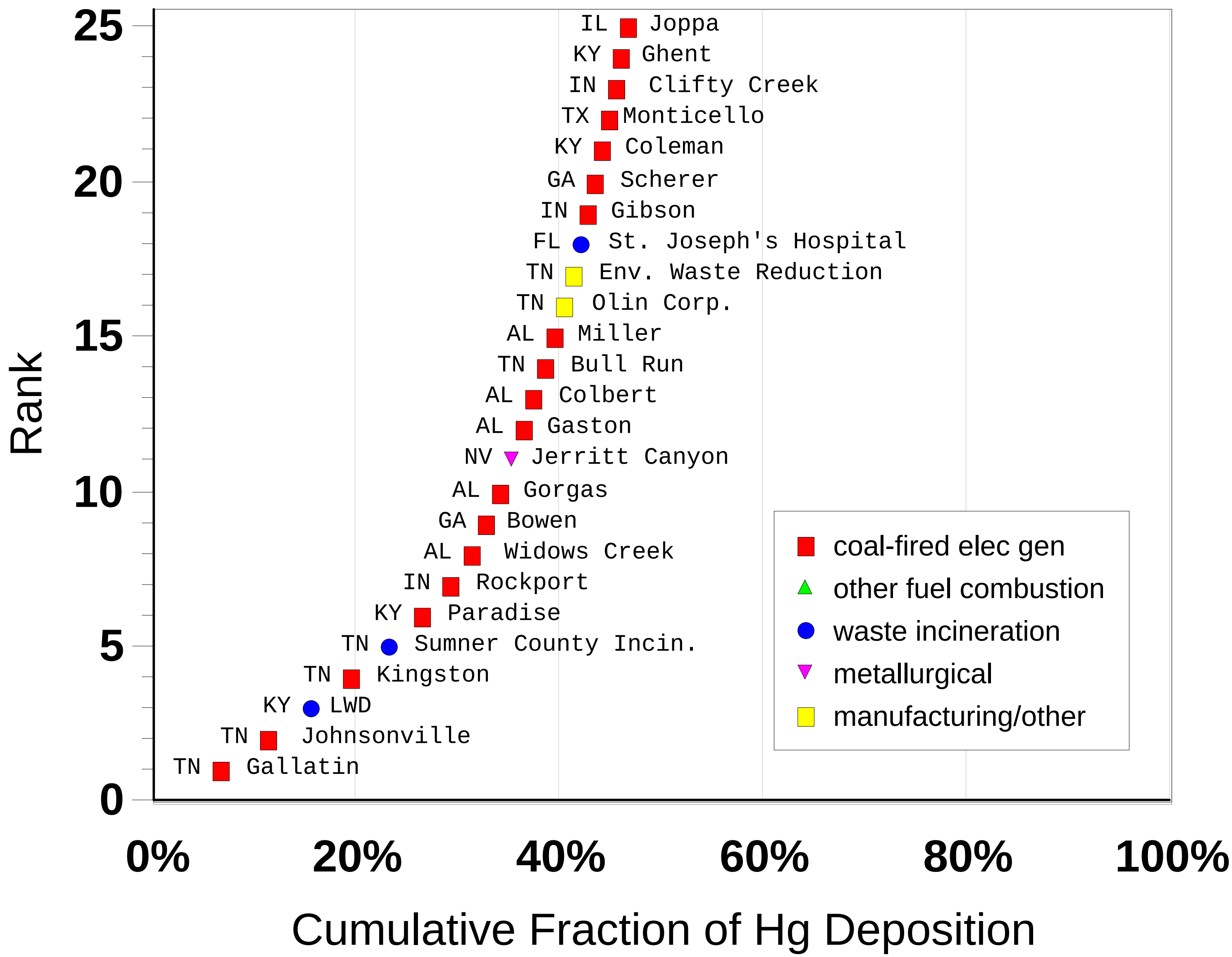


Results for Mammoth Cave National Park

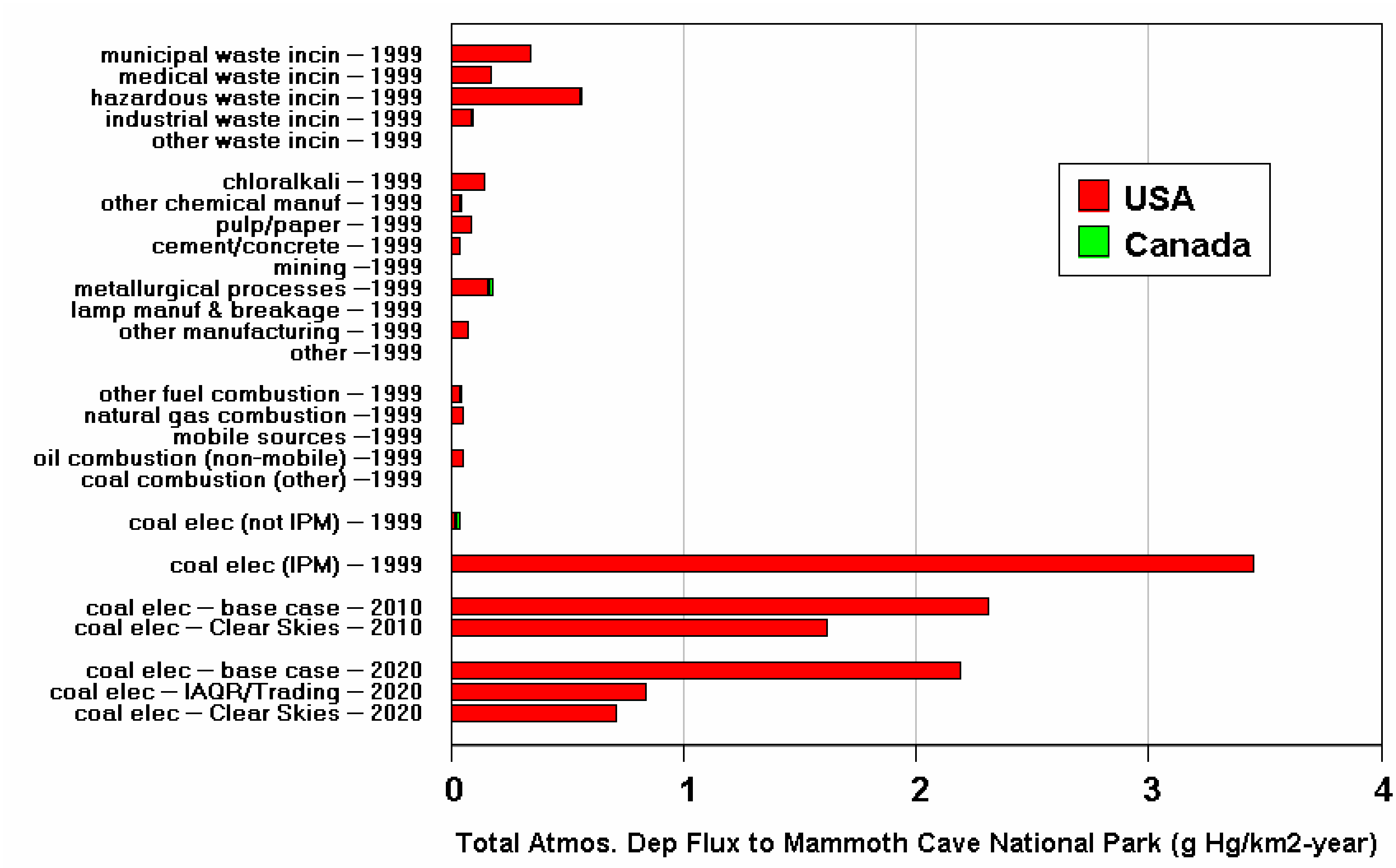

Coal-Fired Electricity Generation
Other Fuel Combustion Activities
Waste Incineration
Smelters and other Metallurgical
Manufacturing and Other
Mammoth Cave National Park
Fraction of Total Modeled Deposition Contributed by Source
0.1 - 1%
1 - 3%
3 - 10%
10 - 30%
> 30%
0
500
1000 Kilometers


Rockport
Paradise
Mammoth Cave
National Park
LWD, Inc.
Gallatin
Bull Run
Johnsonville
Kingston
Sumner County Incin.
Colbert
Widows Creek
Bowen
Gorgas
Gaston
0
200
400
Kilometers
Fraction of Total
Modeled Deposition
Contributed by Source
0.1 - 1%
1 - 3%
3 - 10%
10 - 30%
> 30%
Coal-Fired
Electricity
Generation
Other Fuel
Combustion
Activities
Waste
Incineration
Smelters
and other
Metallurgical
Manufacturing
and Other

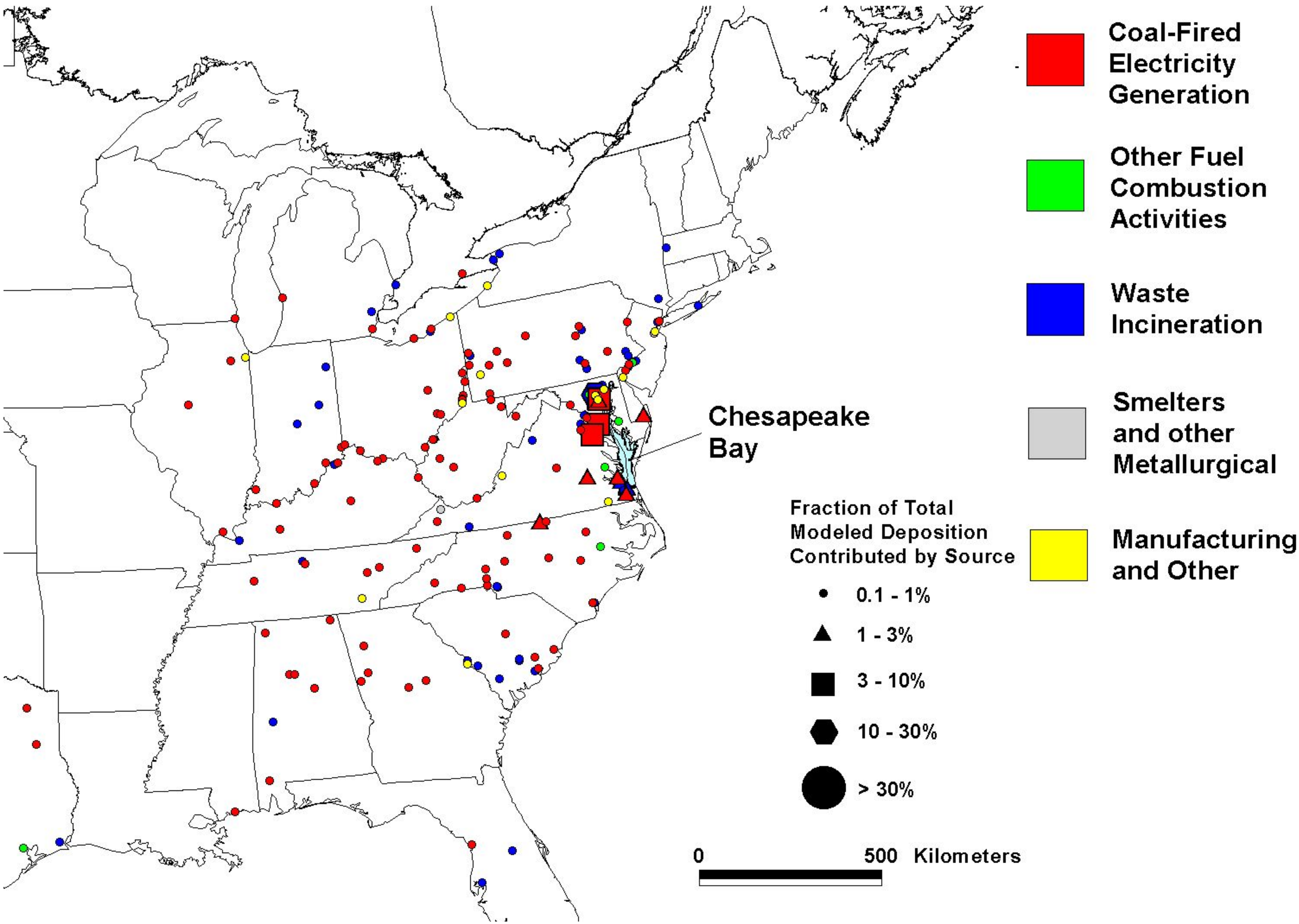
Top 25 Contributors to Hg Deposition to Mammoth Cave National Park

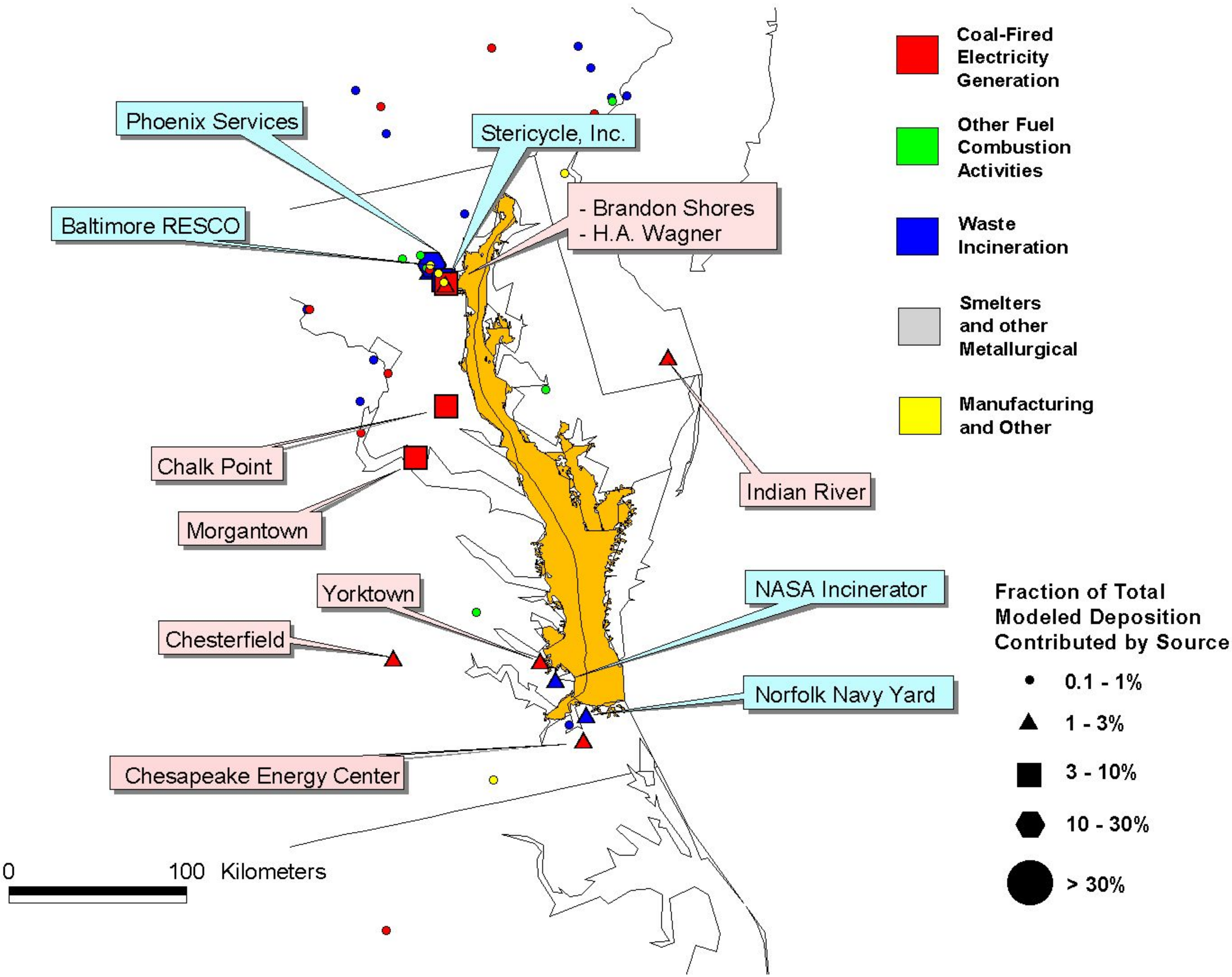


Atmospheric Deposition Flux to Mammoth Cave National Park from Anthropogenic Mercury Emissions Sources in the U.S. and Canada



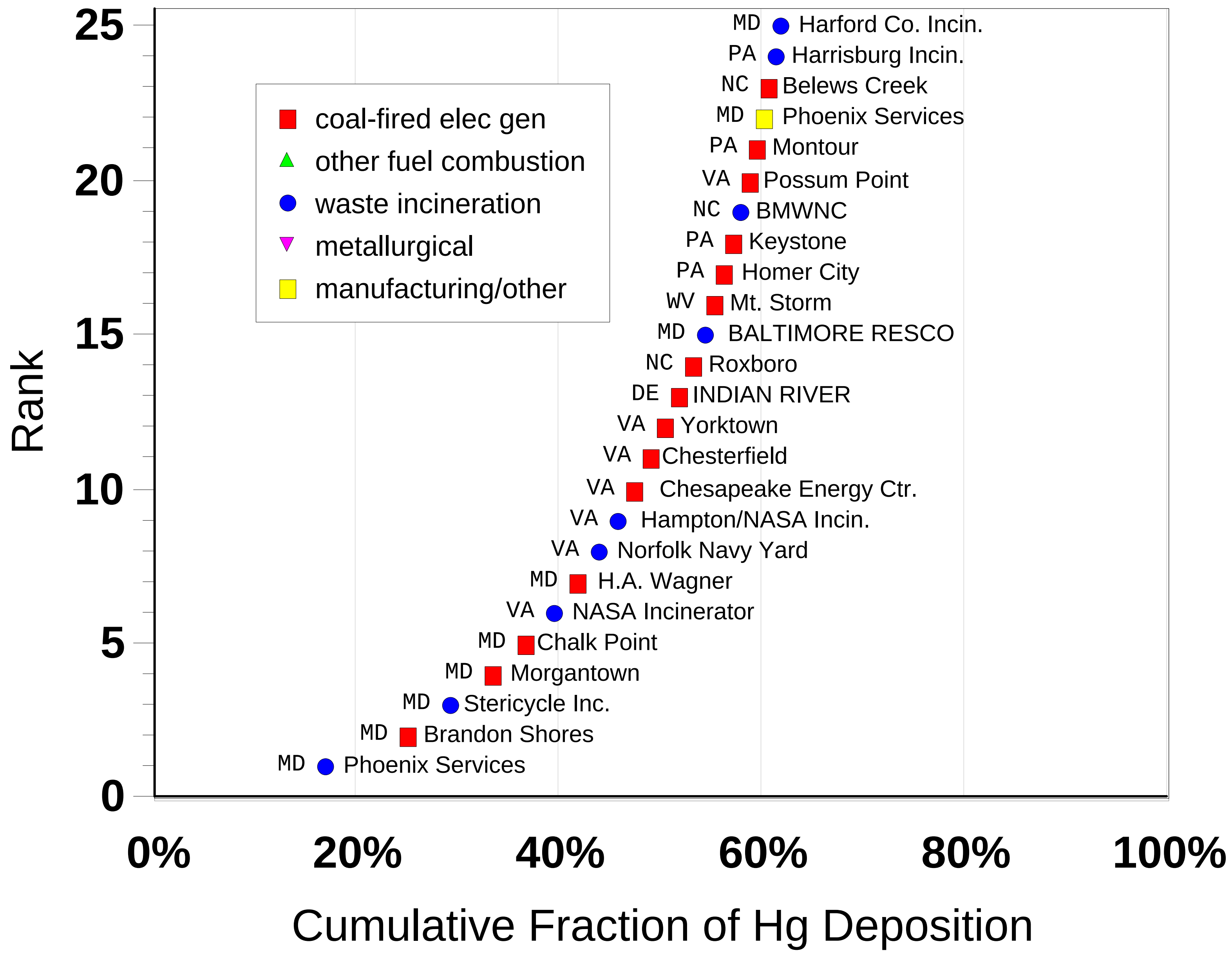
Results for Chesapeake Bay


Coal-Fired Electricity Generation
Other Fuel Combustion Activities
Waste Incineration
Smelters and other Metallurgical
Manufacturing and Other
Chesapeake Bay
Fraction of Total Modeled Deposition Contributed by Source
0.1 - 1%
1 - 3%
3 - 10%
10 - 30%
> 30%
0
500 Kilometers

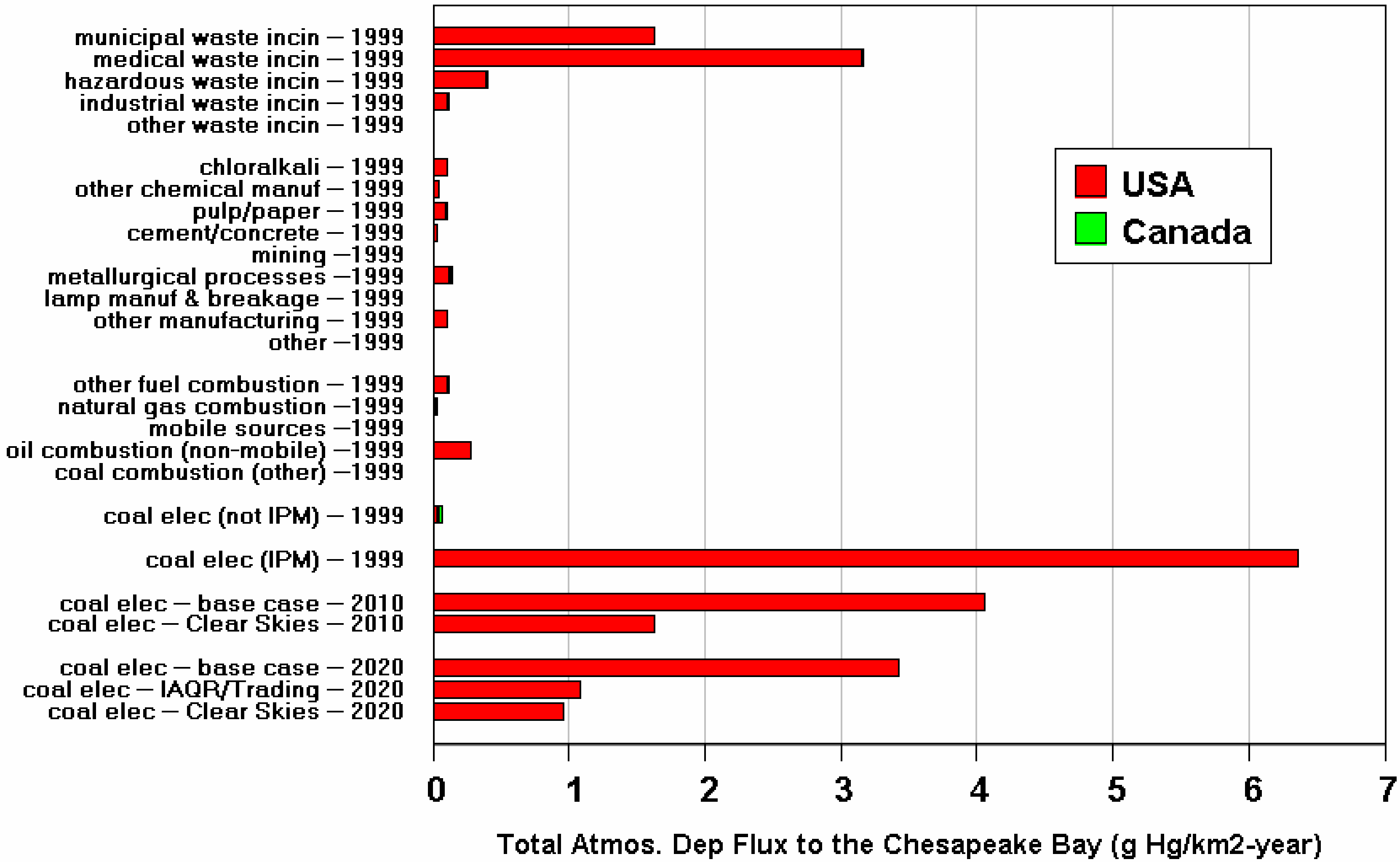


Coal-Fired Electricity Generation
Other Fuel Combustion Activities
Waste Incineration
Smelters and other Metallurgical
Manufacturing and Other
Phoenix Services
Stericycle, Inc.
Baltimore RESCO
- Brandon Shores
- H.A. Wagner
Chalk Point
Morgantown
Indian River
Yorktown
Chesterfield
NASA Incinerator
Norfolk Navy Yard
Chesapeake Energy Center
Fraction of Total Modeled Deposition Contributed by Source
0.1 - 1%
1 - 3%
3 - 10%
10 - 30%
> 30%
0
100 Kilometers

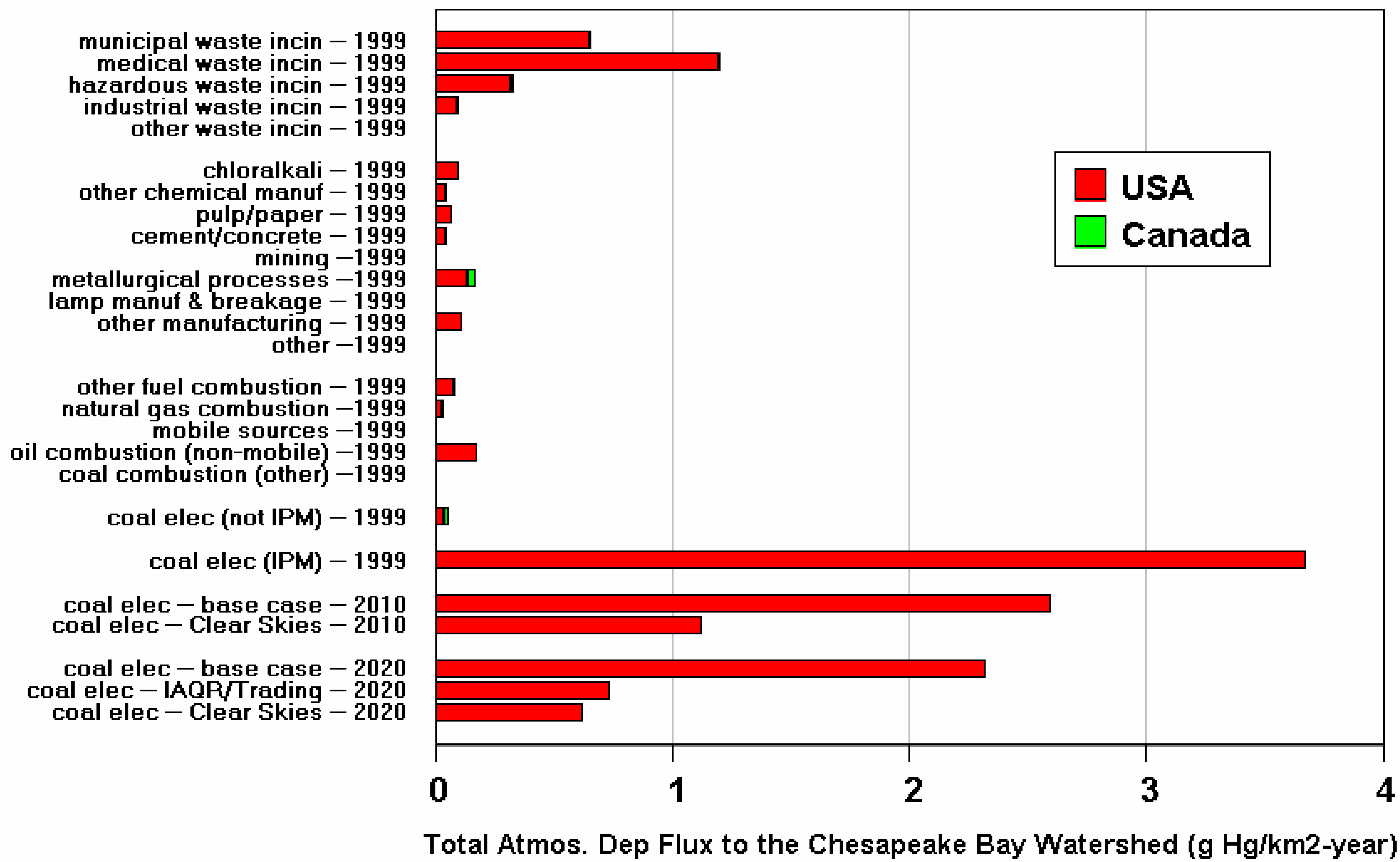
Top 25 Contributors to 1999 Hg Deposition Directly to the Chesapeake Bay



Atmospheric Deposition Flux to the Chesapeake Bay from Anthropogenic Mercury Emissions Sources in the U.S. and Canada



Atmospheric Deposition Flux to the Chesapeake Bay Watershed from Anthropogenic Mercury Emissions Sources in the U.S. and Canada



model evaluation

What do atmospheric mercury models need?

Emissions Inventories

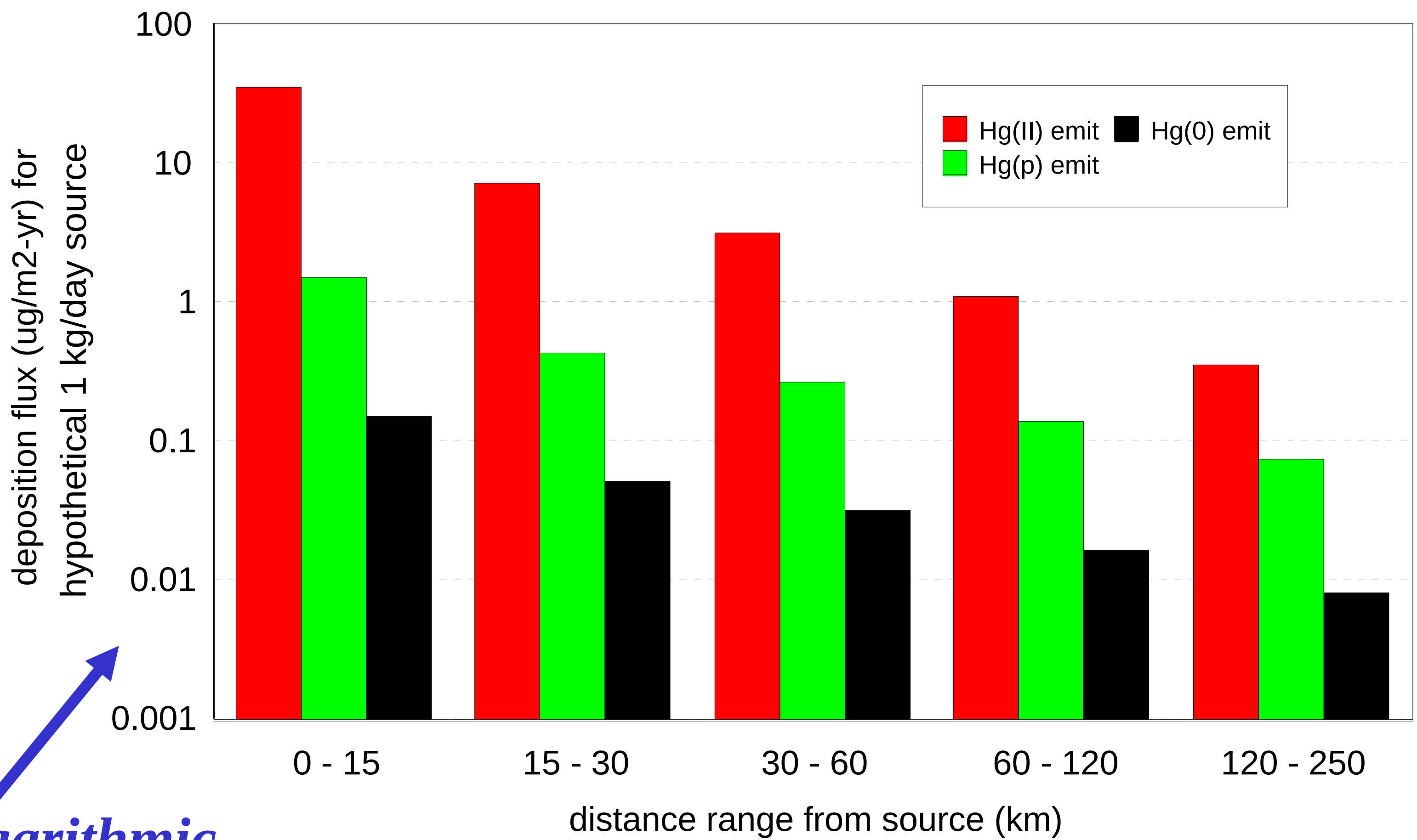
Meteorological Data

Scientific understanding of phase partitioning, atmospheric chemistry, and deposition processes

Ambient data for comprehensive model evaluation and improvement

	some challenges facing mercury modeling
emissions inventories	• need *all* sources • accurately divided into *different Hg forms* • **U.S. 1996, 1999, 2003** / **CAN 1995, 2000, 2005** • *temporal* variations (e.g. shut downs)
meteorological data	• precipitation not well characterized
scientific understanding	• what is RGM? what is Hg(p)? • accurate info for known reactions? • do we know all significant reactions? • natural emissions, re-emissions?
ambient data for model evaluation	• Mercury Deposition Network (MDN) is great, but: • also need RGM, Hg(p), and Hg(0) concentrations • also need data above the surface (e.g., from aircraft) • also need source-impacted sites (not just background)

Why is emissions speciation information critical?



Logarithmic

Hypothesized rapid reduction of Hg(II) in plumes?
If true, then dramatic impact on modeling results…

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Atmospheric Chemical Reaction Scheme for Mercury

Reaction	Rate	Units	Reference
GAS PHASE REACTIONS			
Hg^0 + O_3 → Hg(p)	3.0E-20	cm^3/molec-sec	Hall (1995)
Hg^0 + HCl → $HgCl_2$	1.0E-19	cm^3/molec-sec	Hall and Bloom (1993)
Hg^0 + H_2O_2 → Hg(p)	8.5E-19	cm^3/molec-sec	Tokos et al. (1998) (upper limit based on experiments)
Hg^0 + Cl_2 → $HgCl_2$	4.0E-18	cm^3/molec-sec	Calhoun and Prestbo (2001)
Hg^0 +OHC → Hg(p)	8.7E-14	cm^3/molec-sec	Sommar et al. (2001)
AQUEOUS PHASE REACTIONS			
Hg^0 + O_3 → Hg^{+2}	4.7E+7	$(\text{molar-sec})^{-1}$	Munthe (1992)
Hg^0 + OHC → Hg^{+2}	2.0E+9	$(\text{molar-sec})^{-1}$	Lin and Pehkonen(1997)
$HgSO_3$ → Hg^0	$T*e^{((31.971*T)-12595.0)/T}$ sec^{-1} [T = temperature (K)]		Van Loon et al. (2002)
Hg(II) + HO_2C → Hg^0	~ 0	$(\text{molar-sec})^{-1}$	Gardfeldt & Jonnson (2003)
Hg^0 + HOCl → Hg^{+2}	2.1E+6	$(\text{molar-sec})^{-1}$	Lin and Pehkonen(1998)
Hg^0 + OCl^{-1} → Hg^{+2}	2.0E+6	$(\text{molar-sec})^{-1}$	Lin and Pehkonen(1998)
Hg(II) ↔ $Hg(II)_{(soot)}$	9.0E+2	liters/gram; t = 1/hour	eqlbrm: Seigneur et al. (1998) rate: Bullock & Brehme (2002).
Hg^{+2} + h< → Hg^0	6.0E-7	$(\text{sec})^{-1}$ (maximum)	Xiao et al. (1994); Bullock and Brehme (2002)

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Some Additional Measurement Issues (from a modeler's perspective)

- **Data availability**
- **Simple vs. Complex Measurements**

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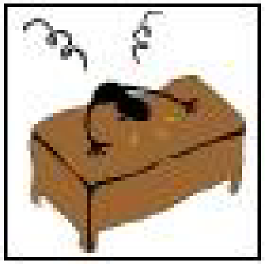
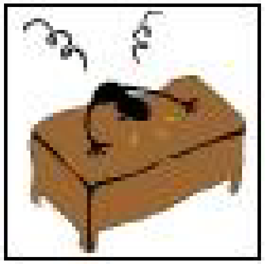
- **Simple vs. Complex Measurements**

Data availability



A major impediment to evaluating and improving atmospheric Hg models has been the lack of speciated Hg air concentration data



There have been very few measurements to date, and these data are rarely made available in a practical way (timely, complete, etc.)

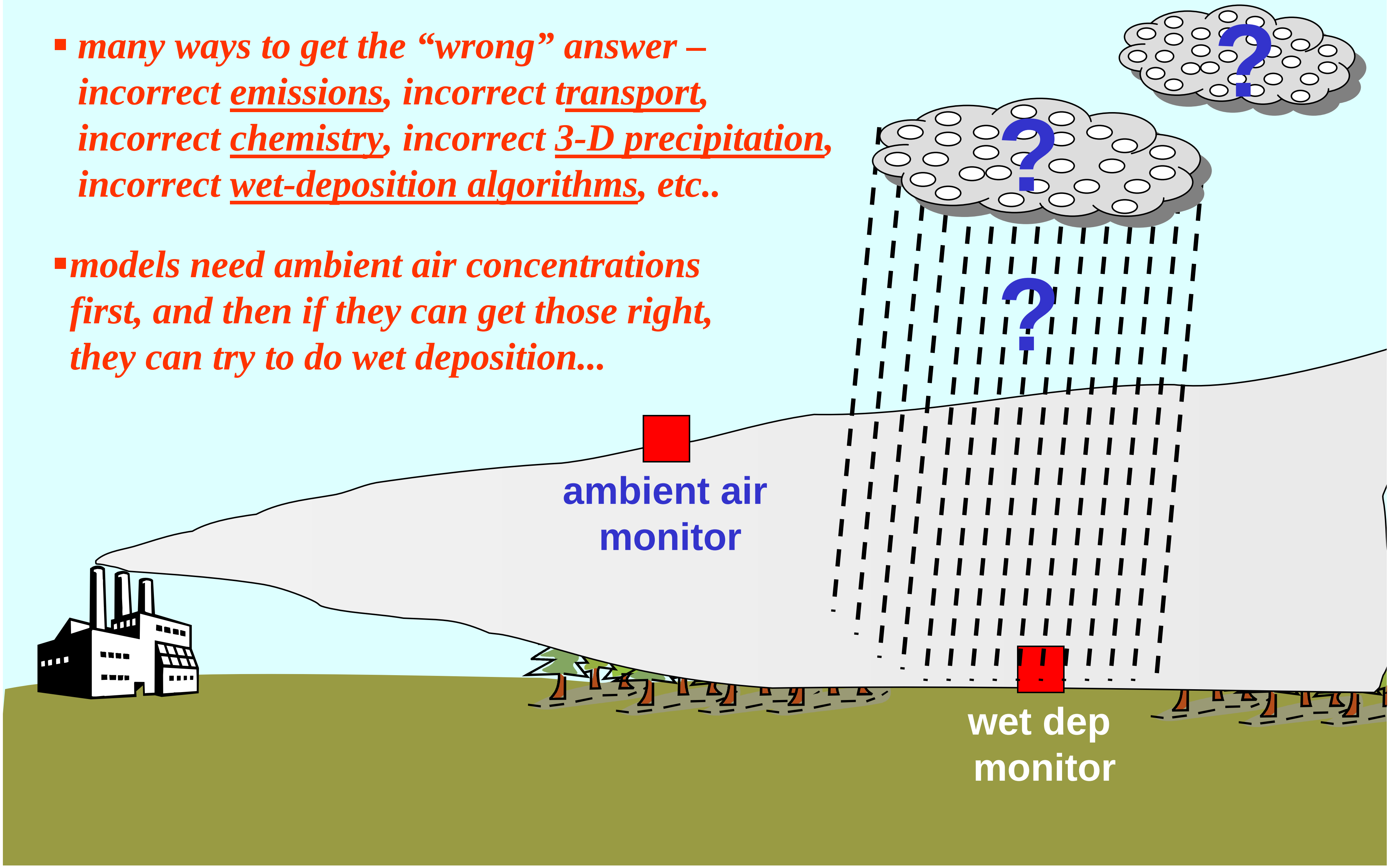
The data being collected at Piney Reservoir could be extremely helpful!

Some Additional Measurement Issues (from a modeler's perspective)

- **Data availability**
- **Simple vs. Complex Measurements**

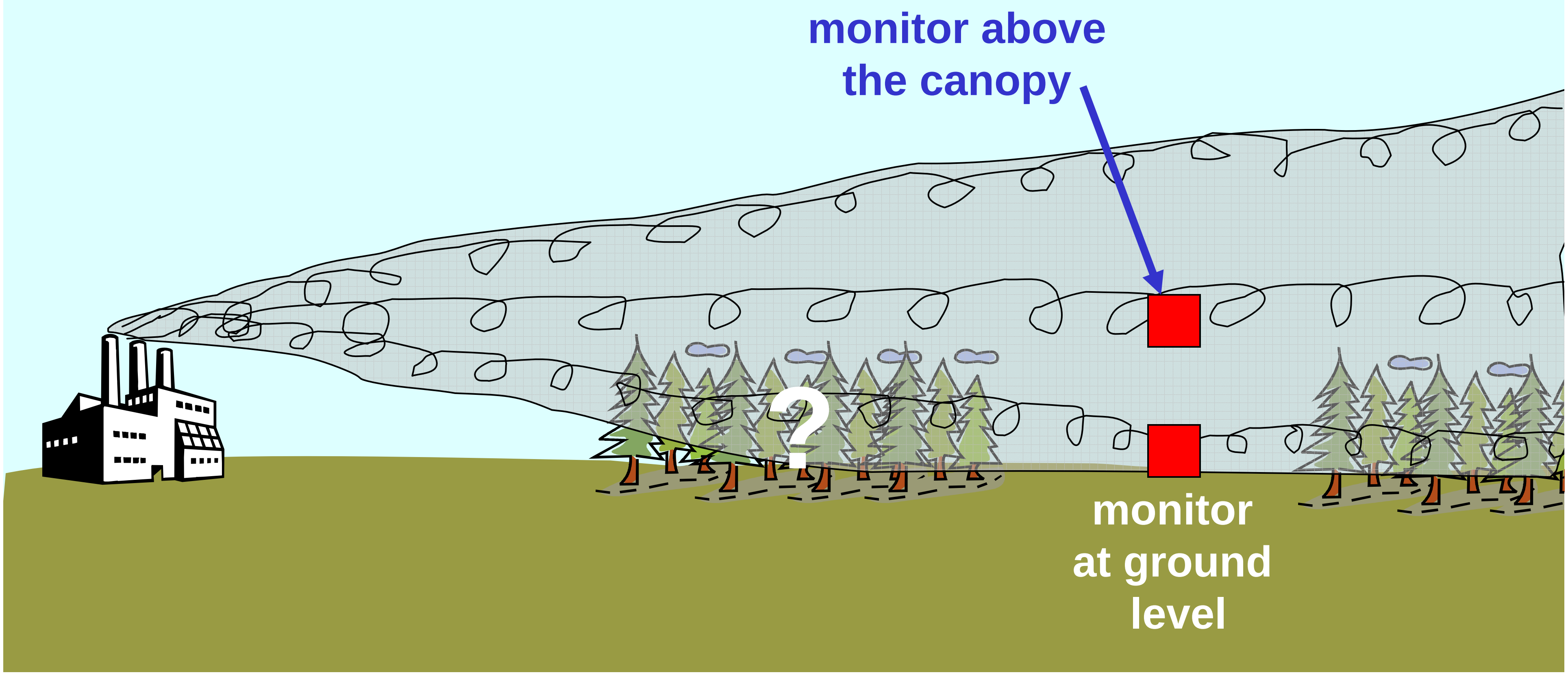
Simple vs. Complex Measurements:
1. Wet deposition is a very complicated phenomena...

- ***many ways to get the "wrong" answer – incorrect emissions, incorrect transport, incorrect chemistry, incorrect 3-D precipitation, incorrect wet-deposition algorithms, etc..***
- ***models need ambient air concentrations first, and then if they can get those right, they can try to do wet deposition...***



Simple vs. Complex Measurements:
2. Potential complication with ground-level monitors...
(“fumigation”, “filtration”, etc.)...

- *atmospheric phenomena are complex and not well understood;*
- *models need “simple” measurements for diagnostic evaluations;*
- *ground-level data for rapidly depositing substances (e.g., RGM) hard to interpret*
- *elevated platforms might be more useful (at present level of understanding)*



Simple vs. Complex measurements - 3. Urban areas:

a. **Emissions inventory poorly known**
b. **Meteorology very complex (flow around buildings)**
c. **So, measurements in urban areas not particularly useful for current large-scale model evaluations**

Simple vs. Complex Measurements – 4: extreme near-field measurements

- Sampling near intense sources?
- Must get the fine-scale met "perfect"

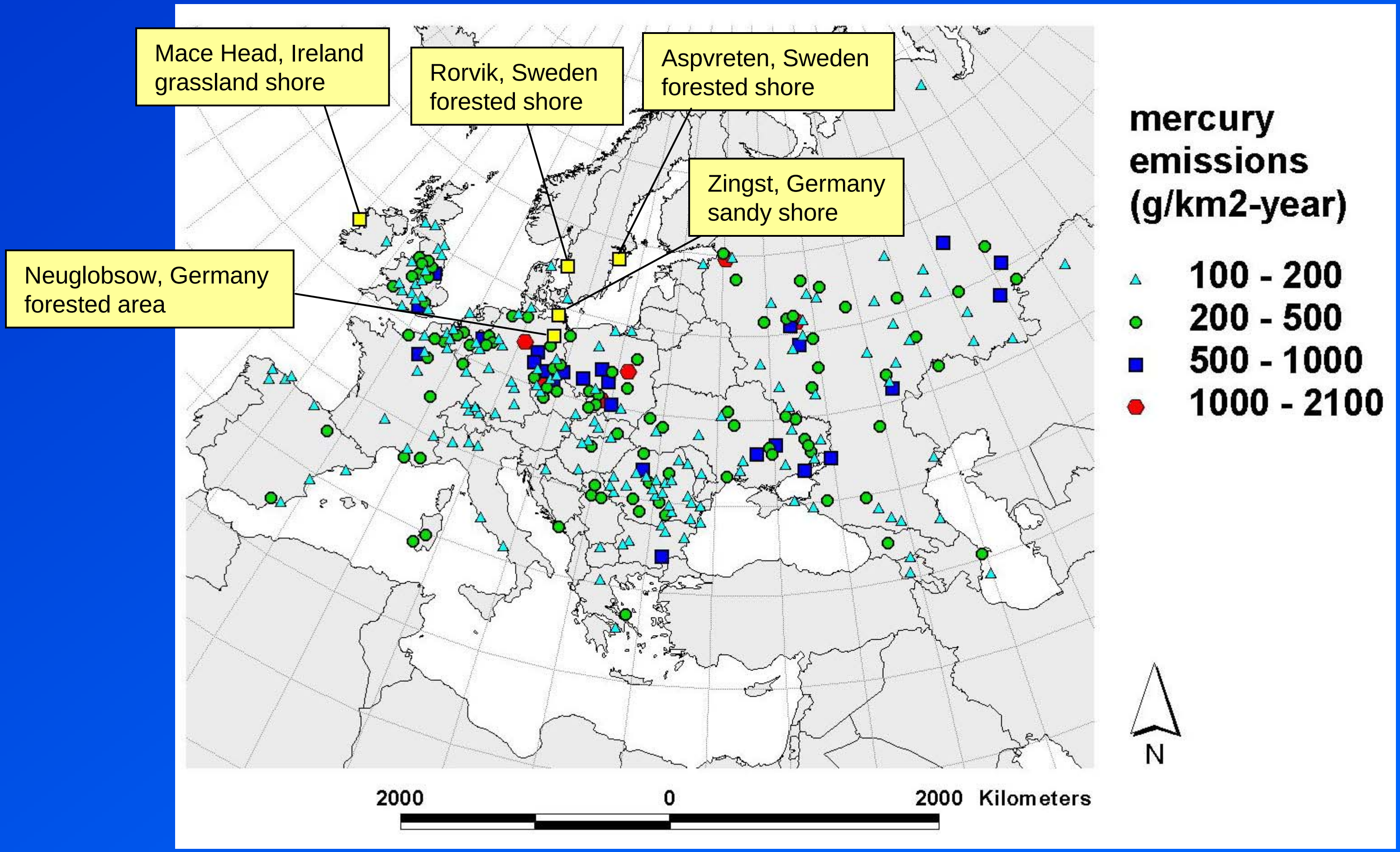
Ok, if one wants to develop hypotheses regarding *whether or not this is actually a source* of the pollutant *(and you can't do a stack test for some reason!).*

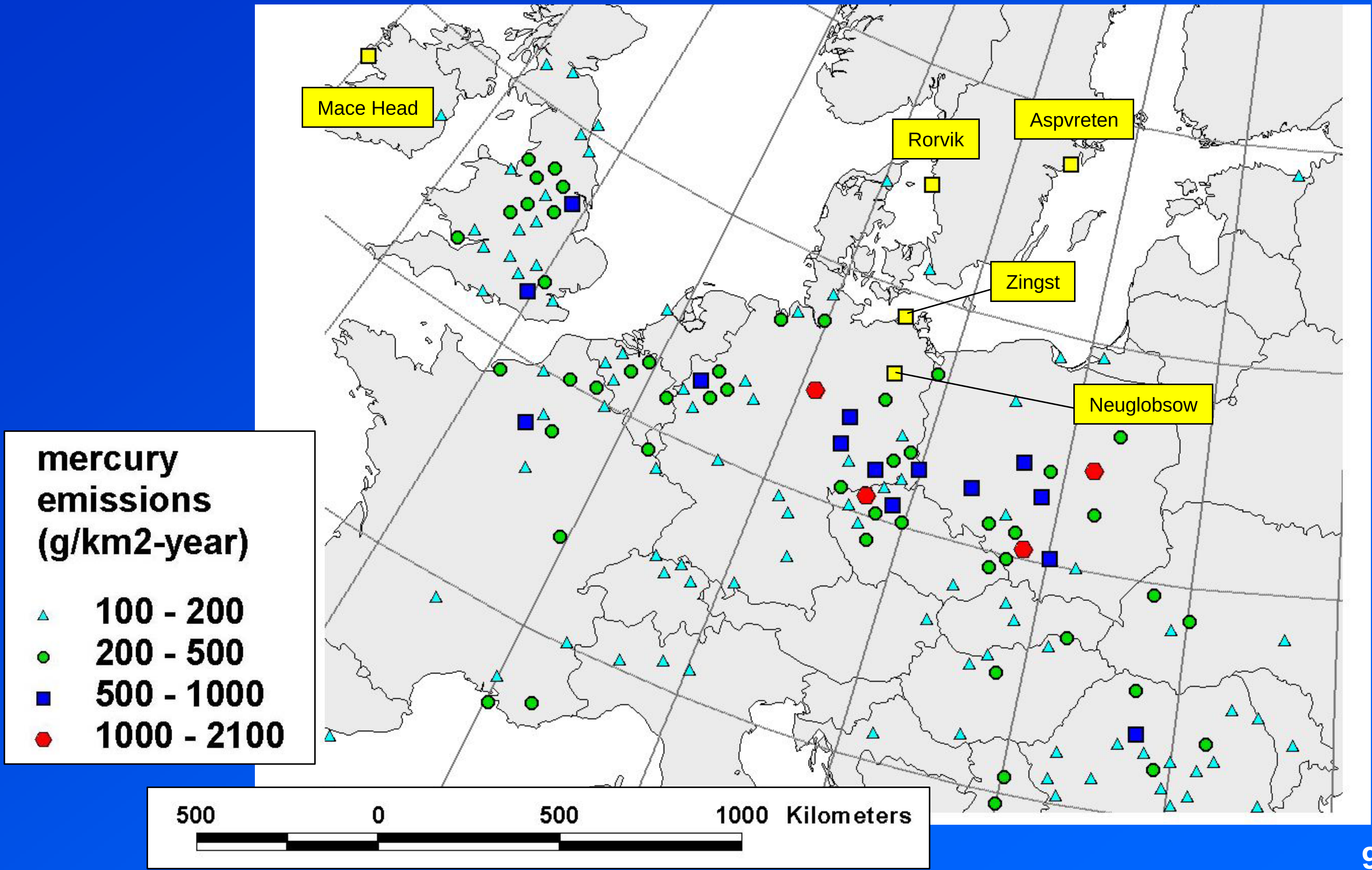
Complex vs. Simple Measurements – 5: Need some source impacted measurements

- **Major questions regarding plume chemistry and near-field impacts (are there “hot spots”?)**
- **Most monitoring sites are designed to be “regional background” sites (e.g., most Mercury Deposition Network sites).**
- **We need some source-impacted sites as well to help resolve near-field questions**
- ***But not too close – maybe 20-30 km is ideal (?)***

Anthropogenic Mercury Emissions Inventory and Monitoring Sites for Phase II

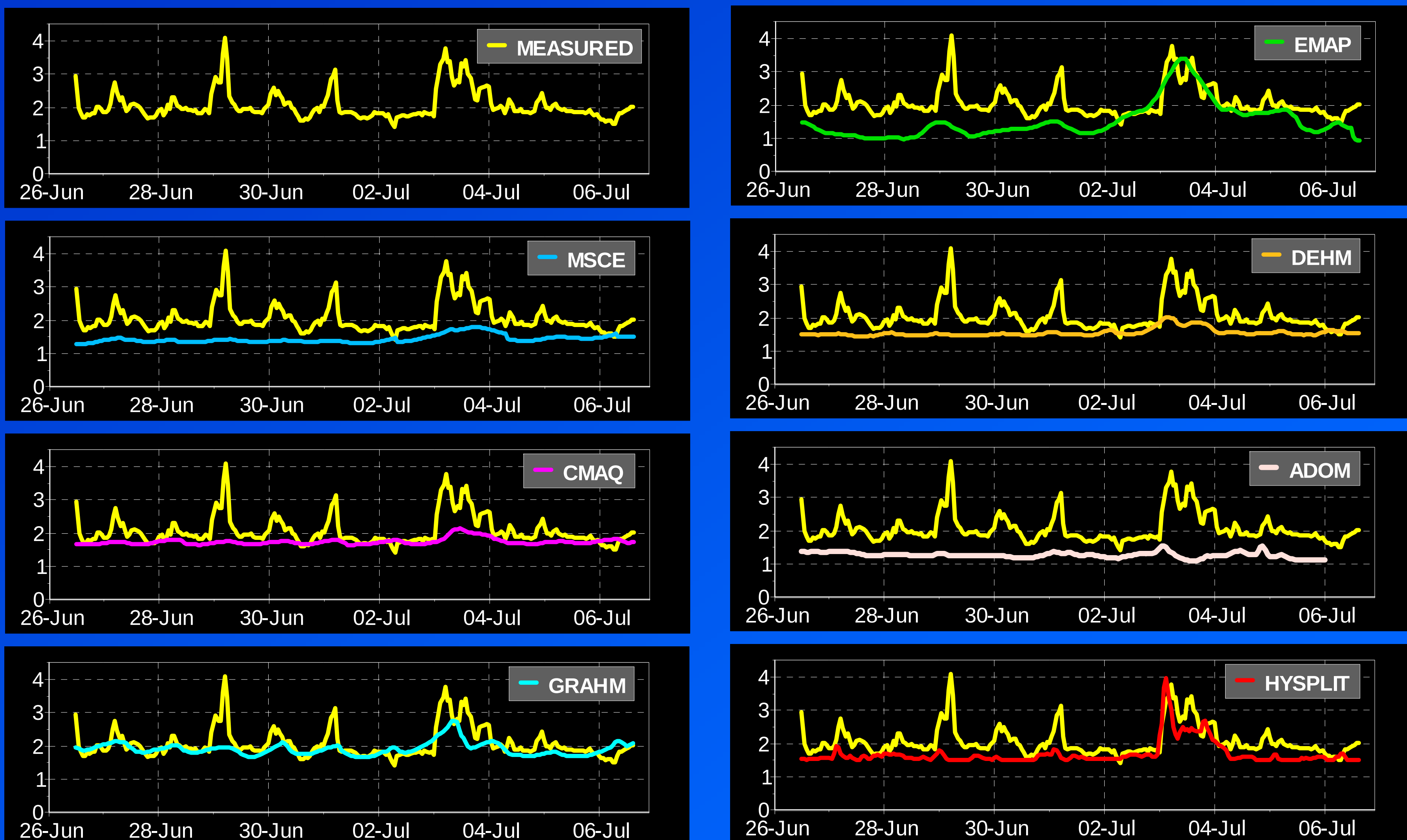
(note: only showing largest emitting grid cells)



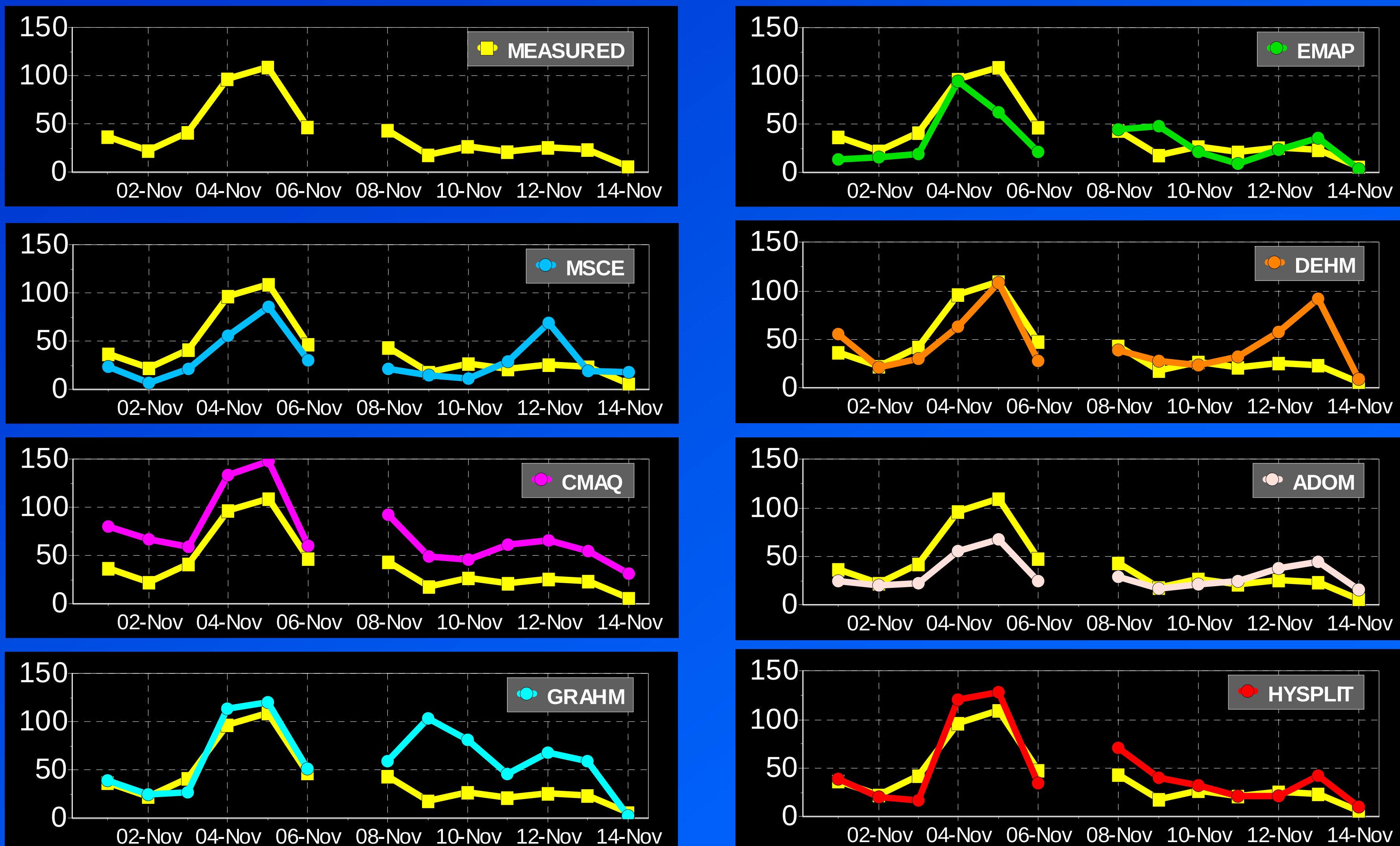


Mace Head
Rorvik
Aspvreten
Zingst
Neuglobsow
mercury emissions (g/km2-year)
100 - 200
200 - 500
500 - 1000
1000 - 2100
500
0
500
1000
Kilometers

Total Gaseous Mercury (ng/m^3) at Neuglobsow: June 26 – July 6, 1995



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



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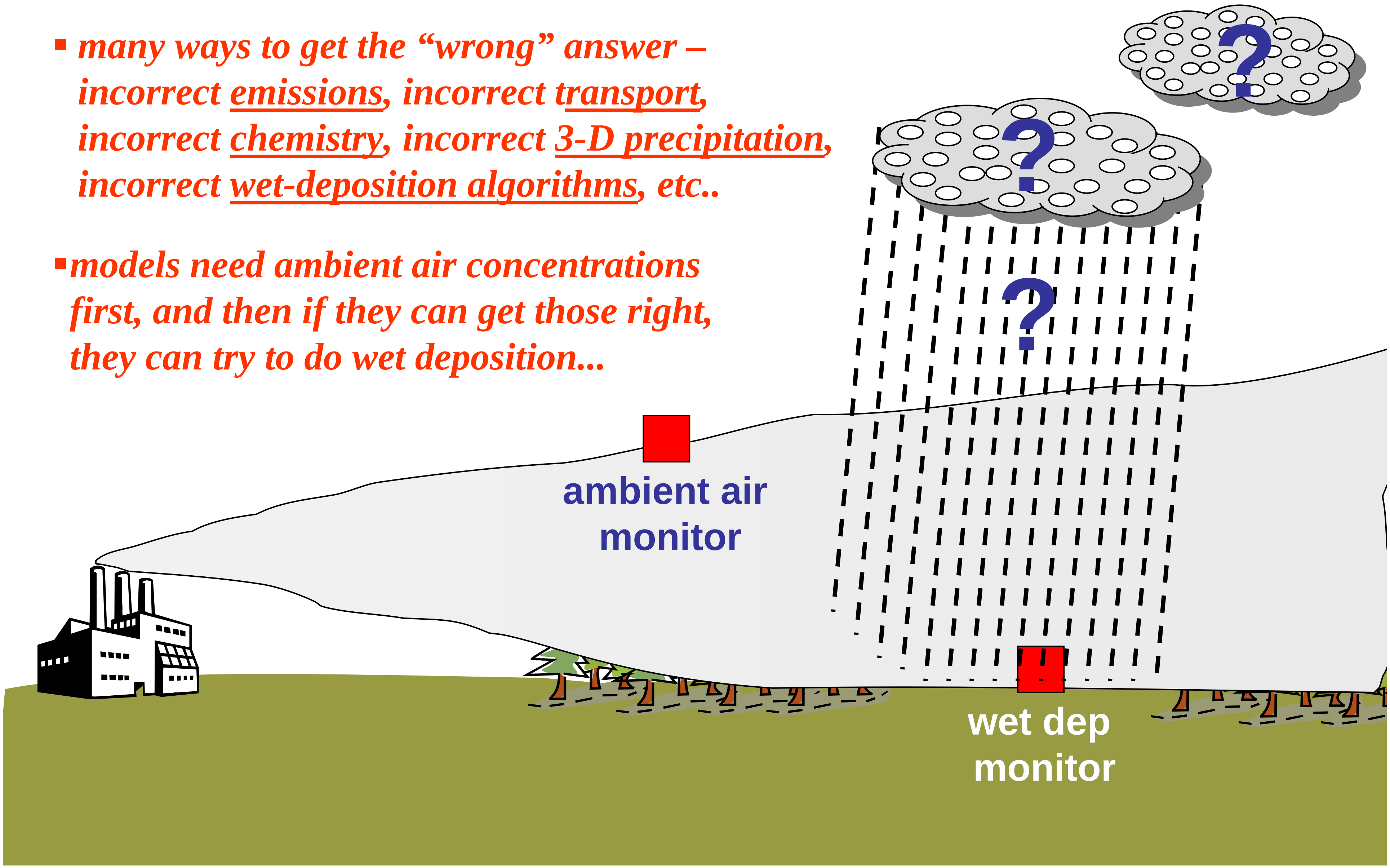
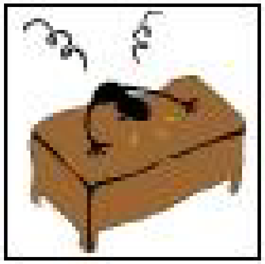
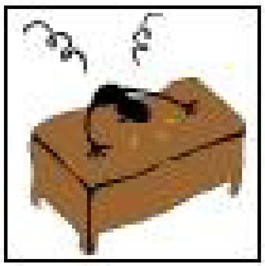




speciated ambient concentration data is scarce

- *few measurement sites at ground level*
- *very few measurements aloft*



therefore, atmospheric mercury models have not really been comprehensively evaluated yet

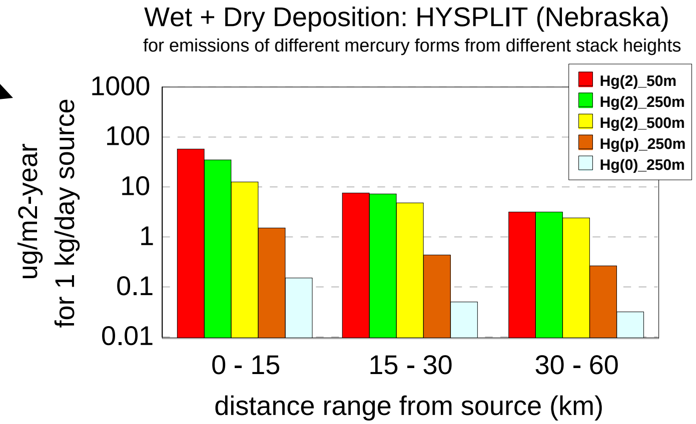
- *we don’t really know how good or bad they are*

collaboration between measurement and modeling community is key

- *measurers need modelers to help interpret data*
- *modelers need measurements to evaluate models*

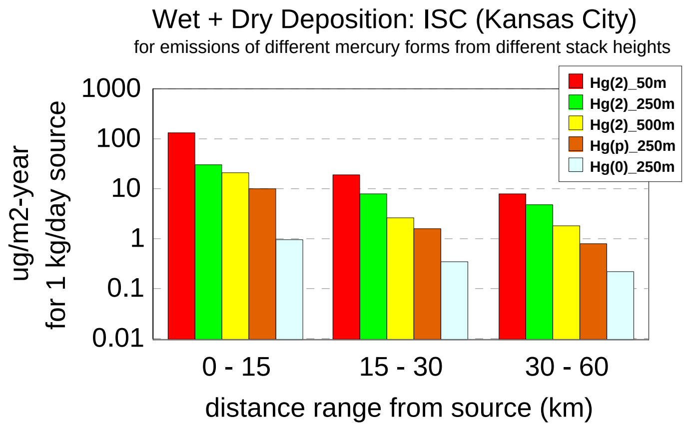
model intercomparison

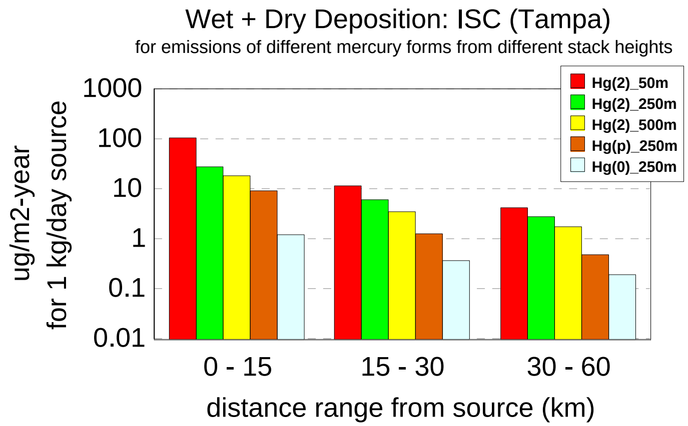
HYSPLIT 1996

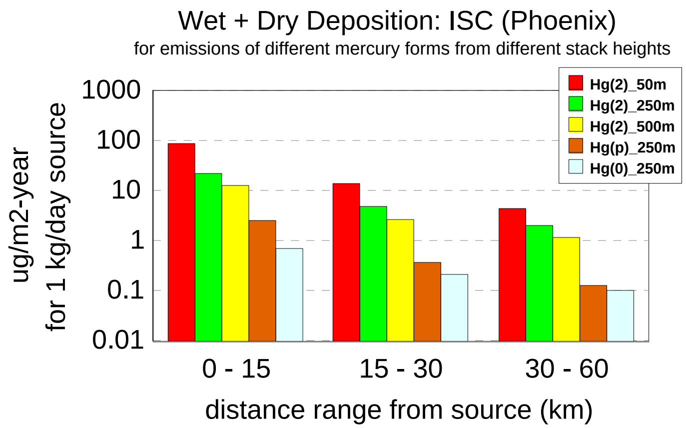


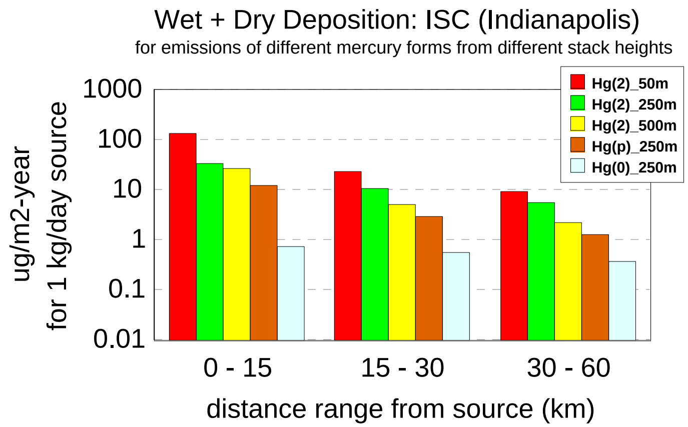
Different Time Periods and Locations, but Similar Results

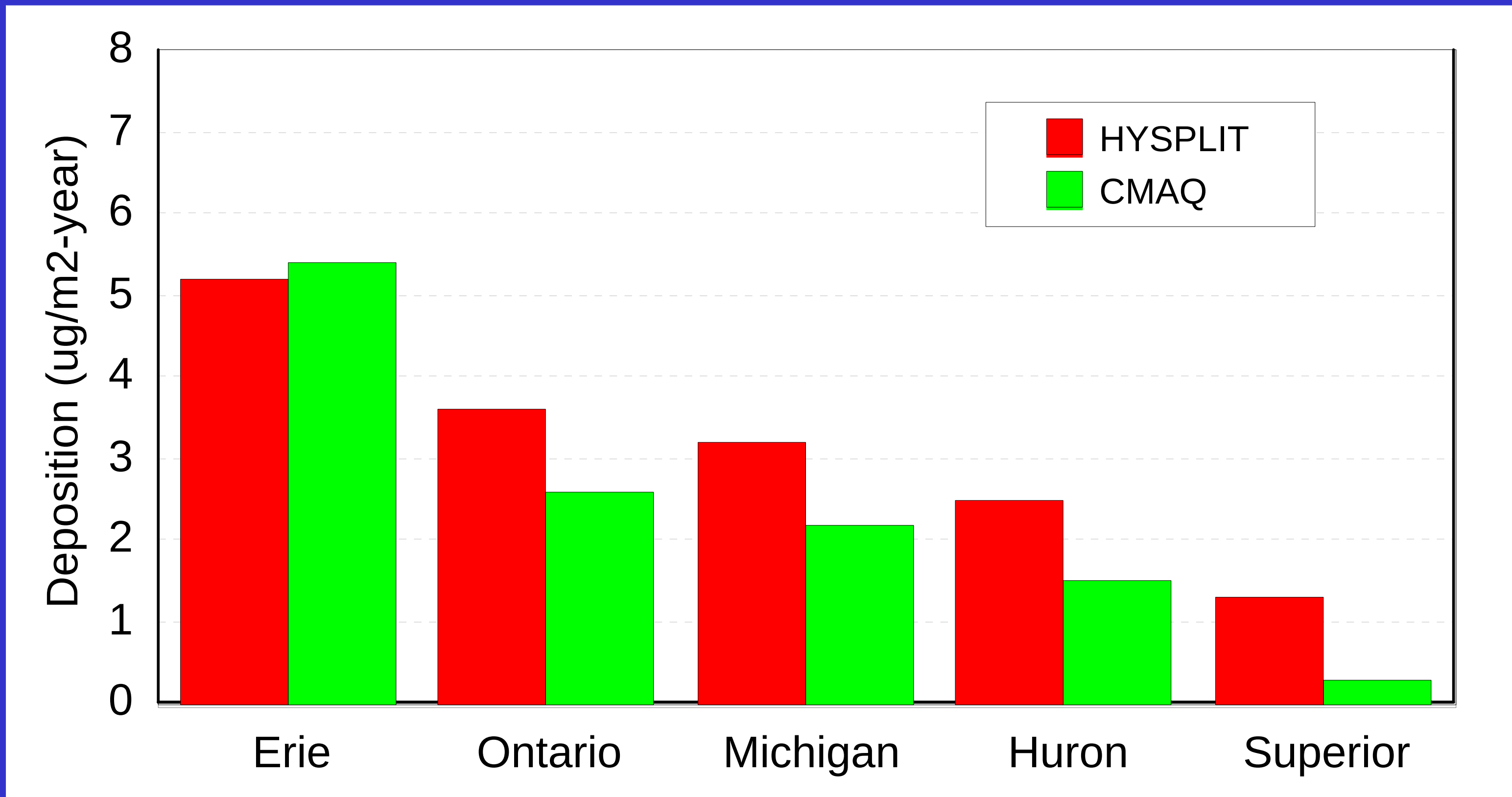
ISC: 1990-1994



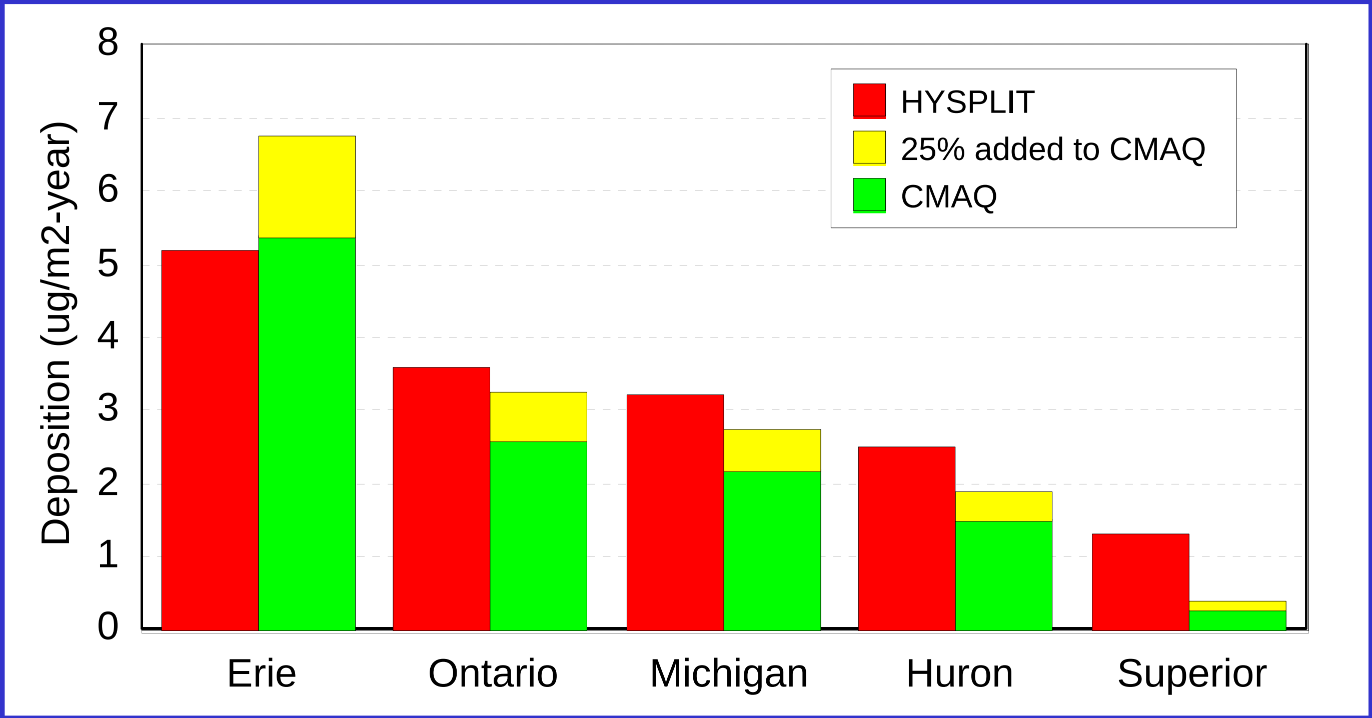








Model-estimated U.S. utility atmospheric mercury deposition contribution to the Great Lakes: HYSPLIT-Hg (1996 meteorology, 1999 emissions) vs. CMAQ-HG (2001 meteorology, 2001 emissions).



- 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.

MANY THANKS TO:

- **Gary Foley, J. David Mobley, Elsie Sunderland, Chris Knightes (EPA); Panos Georgopolous and Sheng-Wei Wang (EOSHI Rutgers Univ); John McDonald (IJC):** *collaboration on multimedia Hg modeling*

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- **David Ruple, Mark Woodrey (Grand Bay NERR), Susan White , Gary Matlock, Russell Callender, Jawed Hameedi (NOAA), and Durwin Carter (U.S. Fish and Wildlife Service):** *collaboration at NOAA Grand Bay NERR atmospheric monitoring site*

- **Anne Pope and colleagues (EPA):** *U.S. mercury emissions inventory*

- **David Niemi, Dominique Ratte, Marc Deslauriers (Environment Canada):** *Canadian mercury emissions inventory data*

- **Mark Castro (Univ. Md, Frostburg), Fabien Laurier (Univ Md Ches Biol Lab), Rob Mason (Univ CT), Laurier Poissant (Envr Can):** *ambient Hg data for model evaluation*

- **Roland Draxler, Glenn Rolph, Rick Artz (NOAA):** *HYSPLIT model and met data*

- **Steve Brooks, Winston Luke, Paul Kelley (NOAA) :** *ambient Hg data*