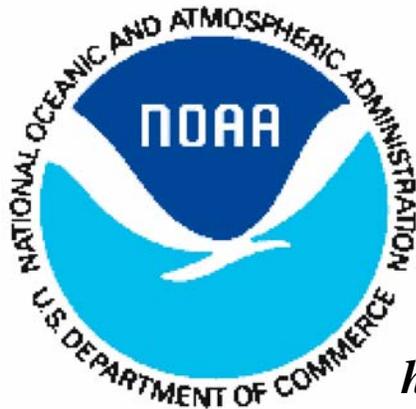


Local and Regional Deposition Impacts of Atmospheric Mercury Emissions



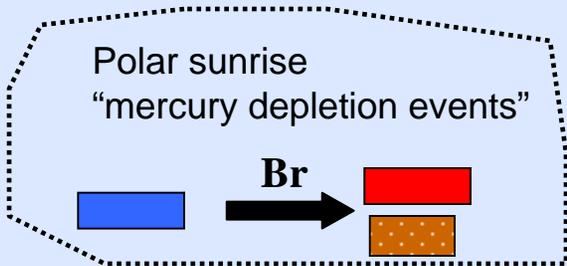
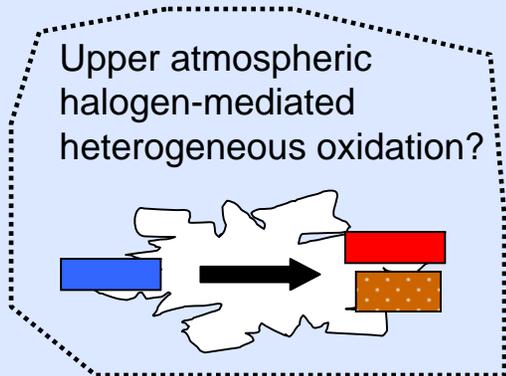
Dr. Mark Cohen
NOAA Air Resources Laboratory
1315 East West Highway,
R/ARL, Room 3316
Silver Spring, Maryland, 20910
mark.cohen@noaa.gov

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

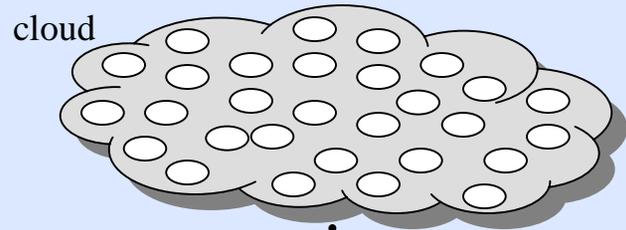


Presentation at
Mercury Rule Workgroup Meeting
PA Department of Environmental Protection
Harrisburg, PA, November 18, 2005

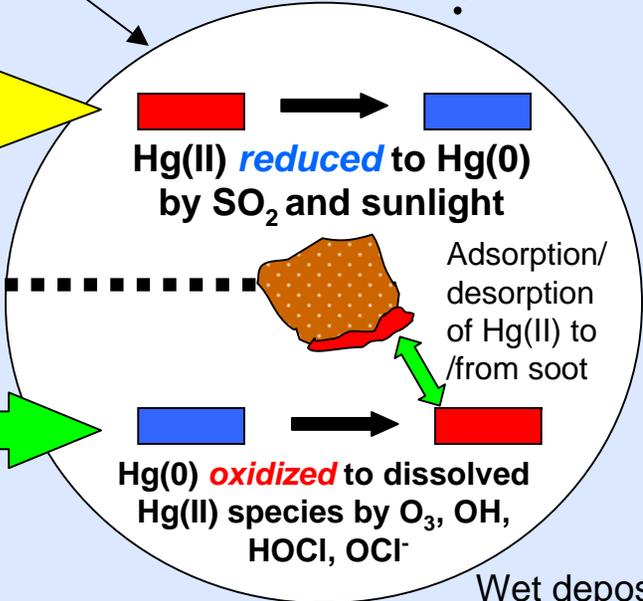
Atmospheric Mercury Fate Processes



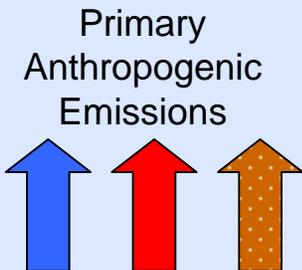
- Elemental Mercury [Hg(0)]
- Hg(II), ionic mercury, RGM
- Particulate Mercury [Hg(p)]



CLOUD DROPLET



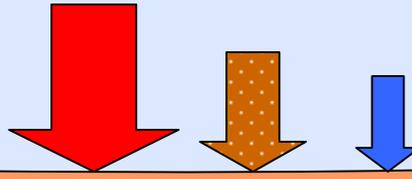
Vapor phase:
Hg(0) oxidized to RGM and Hg(p) by O₃, H₂O₂, Cl₂, OH, HCl



Natural emissions

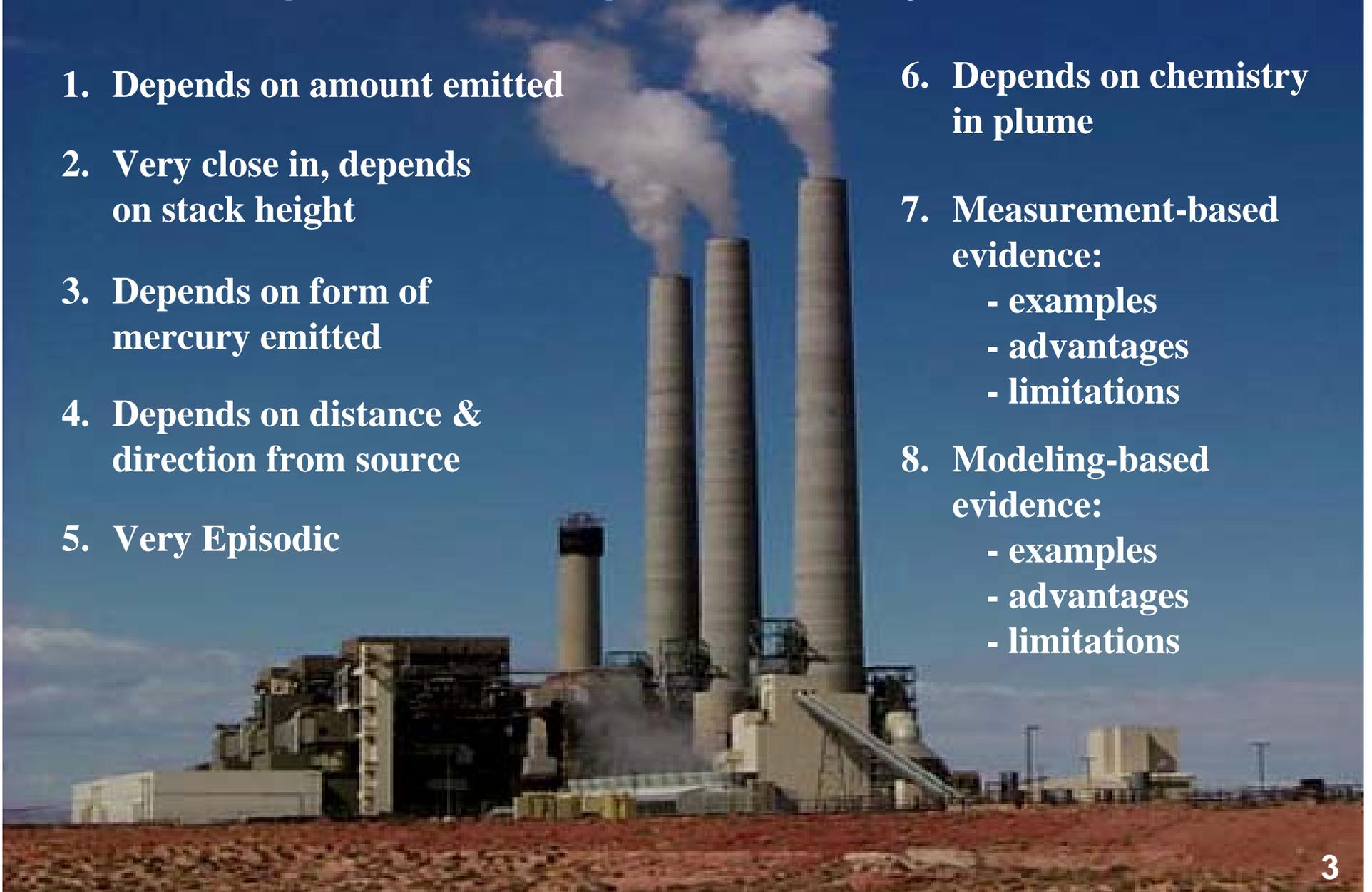
Re-emission of previously deposited anthropogenic and natural mercury

Wet deposition
Dry deposition



What are the local and regional deposition impacts of atmospheric mercury emissions?

1. Depends on amount emitted
2. Very close in, depends on stack height
3. Depends on form of mercury emitted
4. Depends on distance & direction from source
5. Very Episodic
6. Depends on chemistry in plume
7. Measurement-based evidence:
 - examples
 - advantages
 - limitations
8. Modeling-based evidence:
 - examples
 - advantages
 - limitations



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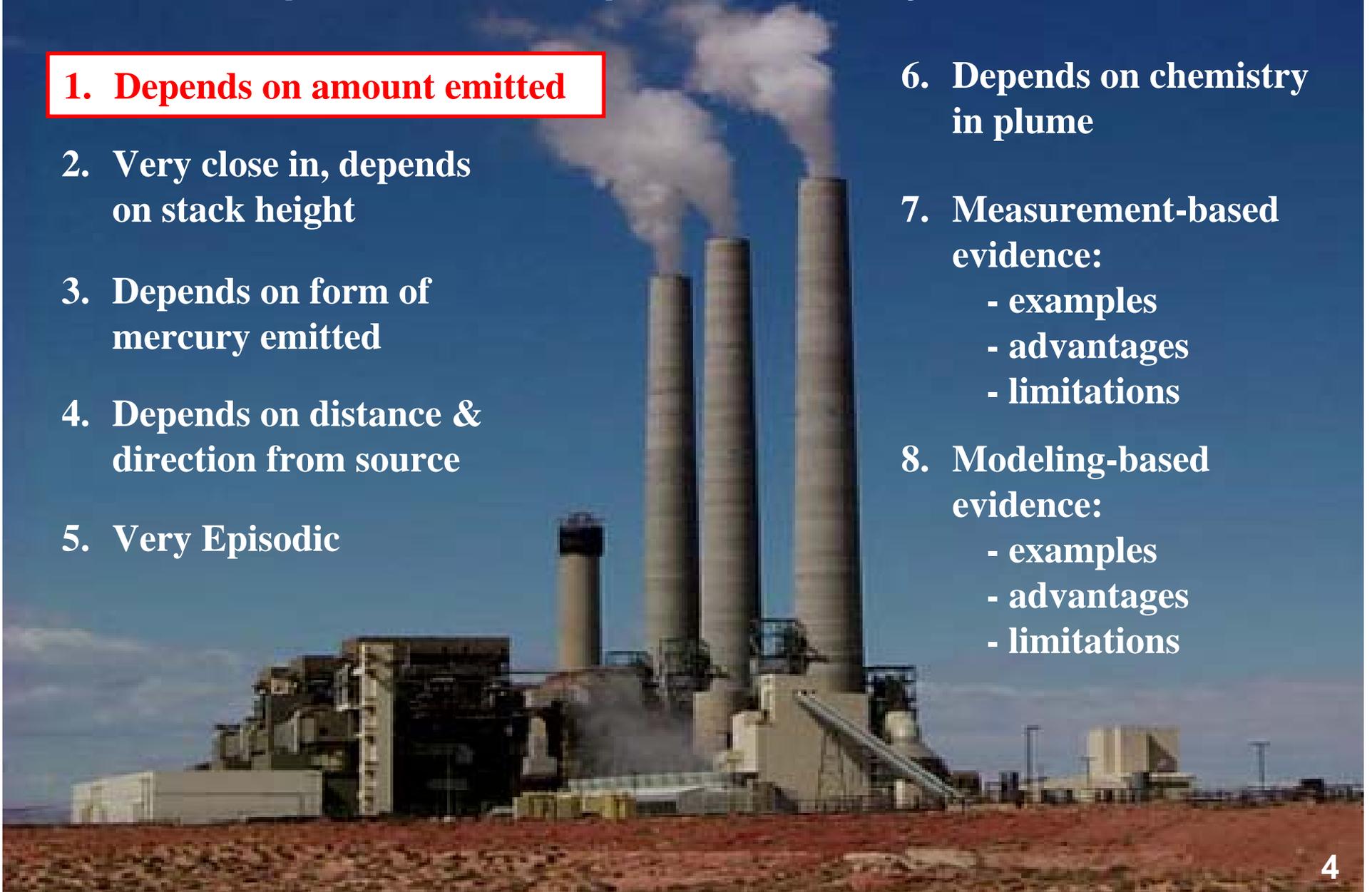
6. Depends on chemistry in plume

7. Measurement-based evidence:

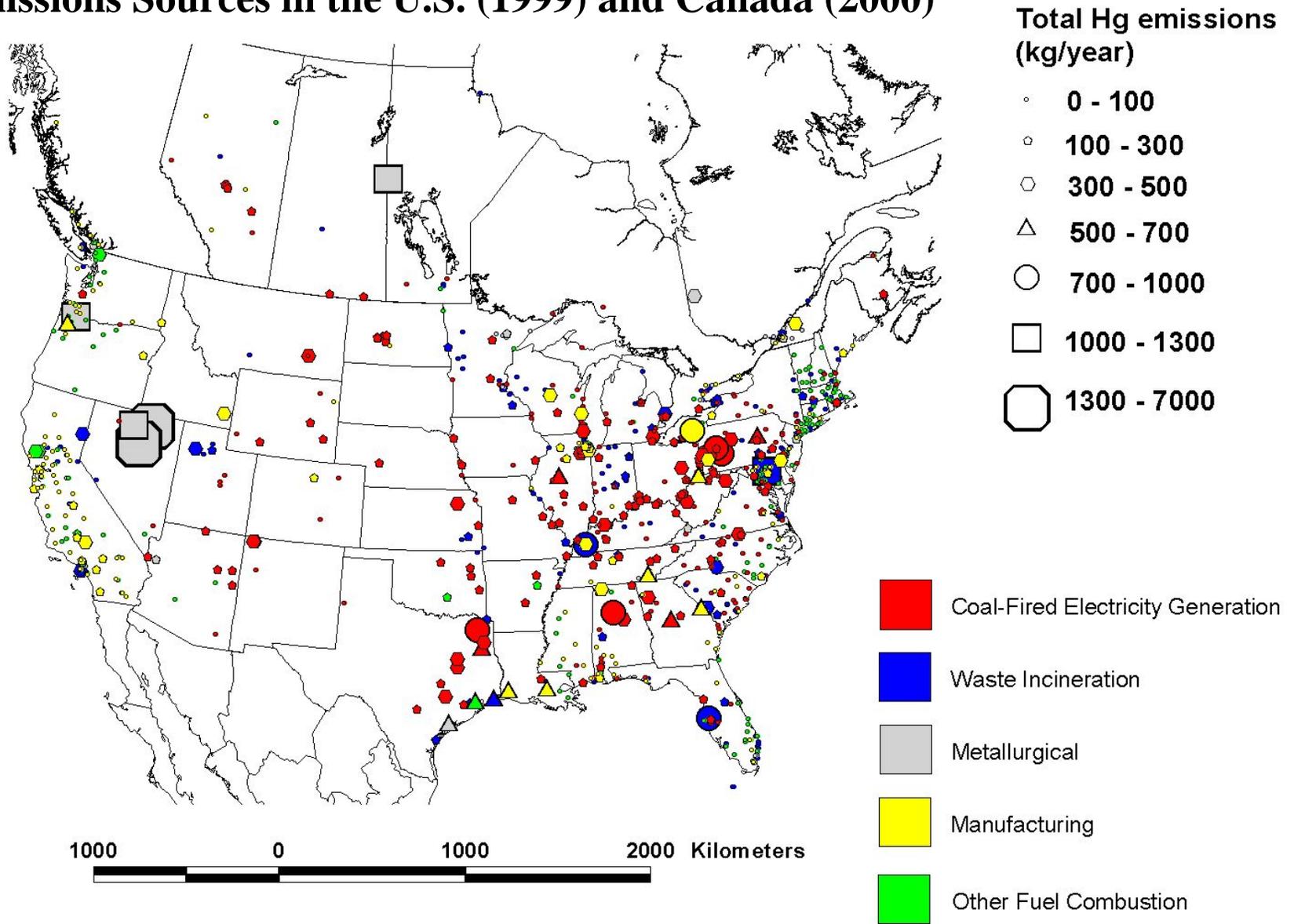
- examples
- advantages
- limitations

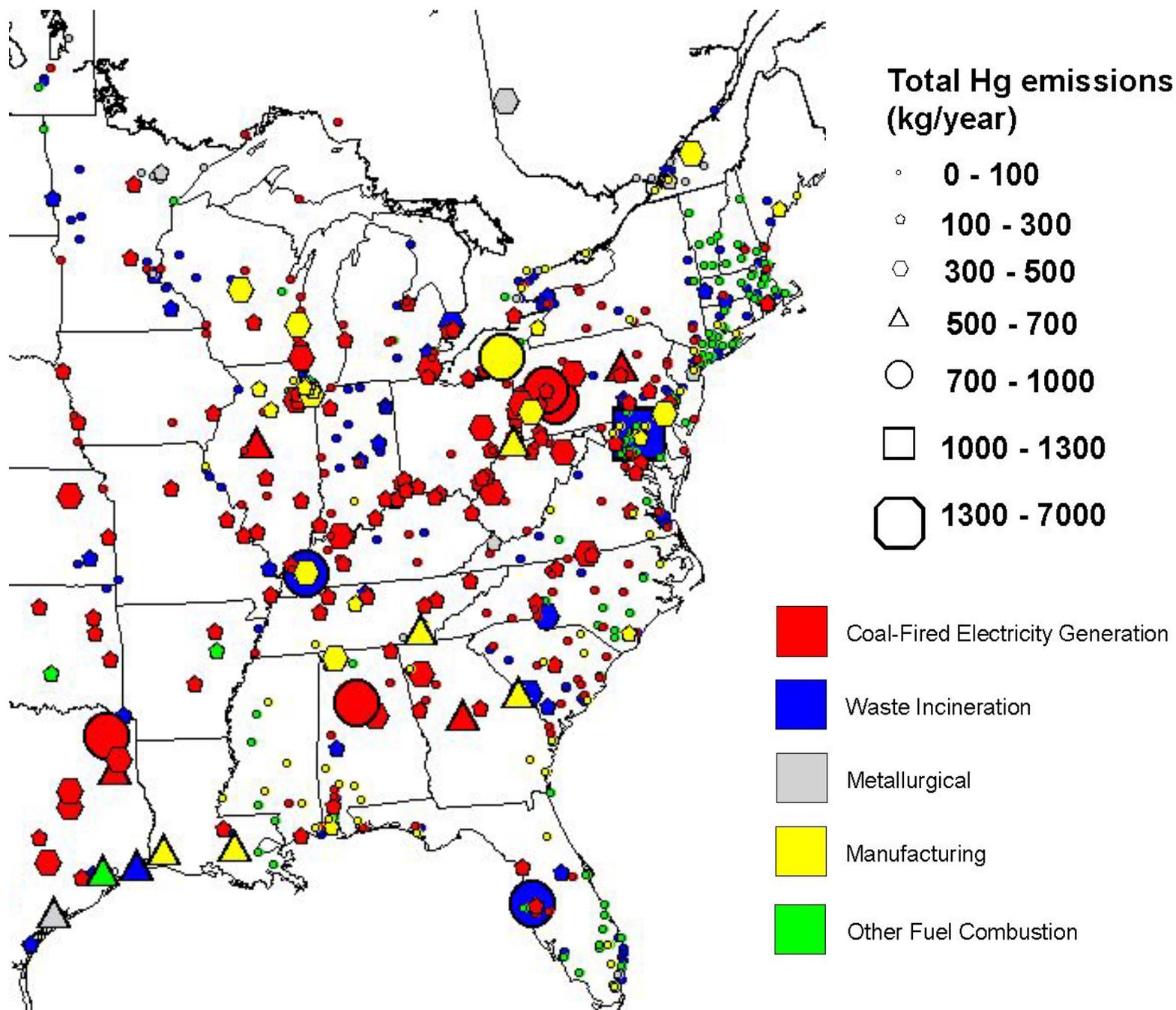
8. Modeling-based evidence:

- examples
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- limitations



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





What are the local and regional deposition impacts of atmospheric mercury emissions?

1. Depends on amount emitted

2. Very close in, depends on stack height

3. Depends on form of mercury emitted

4. Depends on distance & direction from source

5. Very Episodic

6. Depends on chemistry in plume

7. Measurement-based evidence:

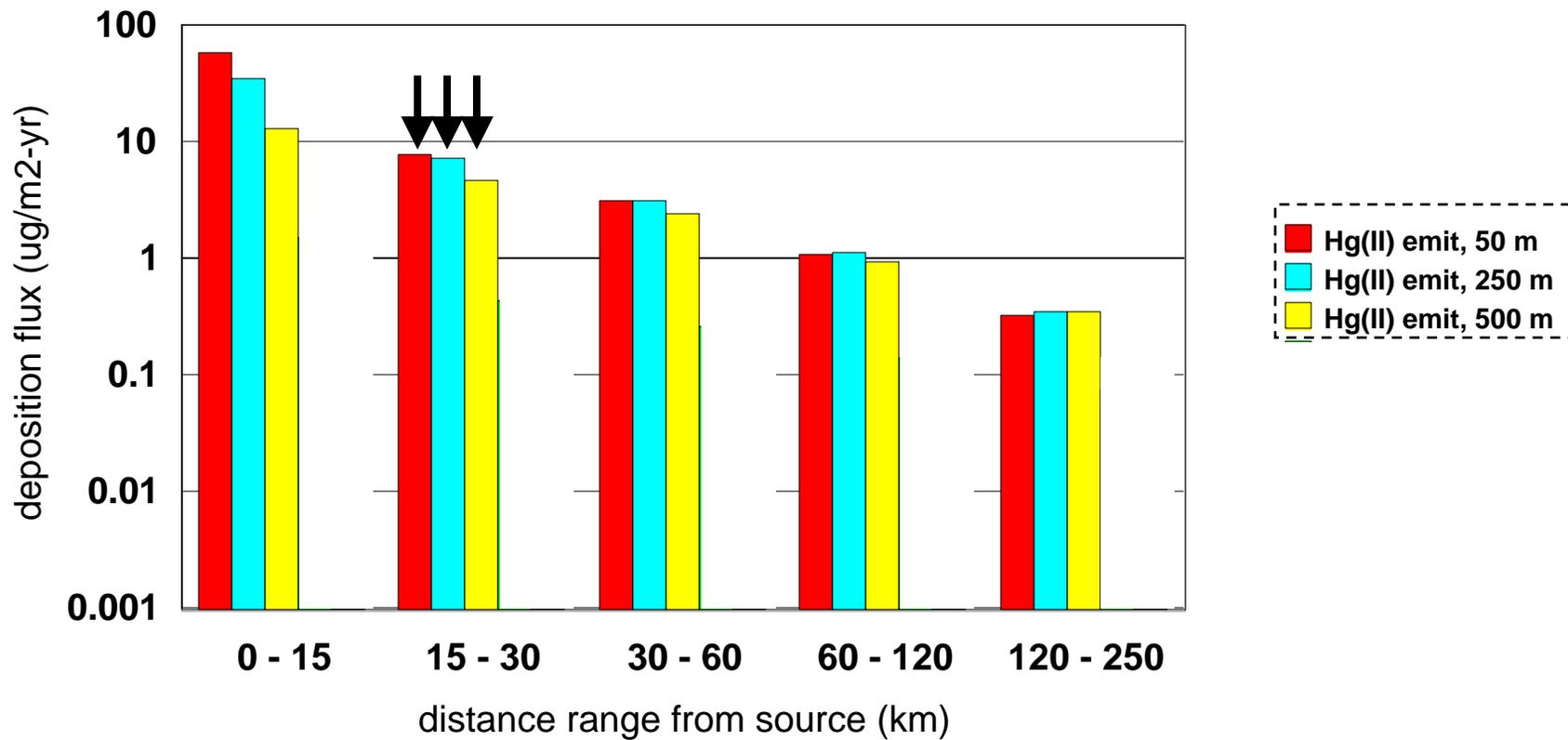
- examples
- advantages
- limitations

8. Modeling-based evidence:

- examples
- advantages
- limitations



Deposition flux within different distance ranges from a hypothetical 1 kg/day source



Source at Lat = 42.5, Long = -97.5; simulation for entire year 1996 using archived NGM meteorological data

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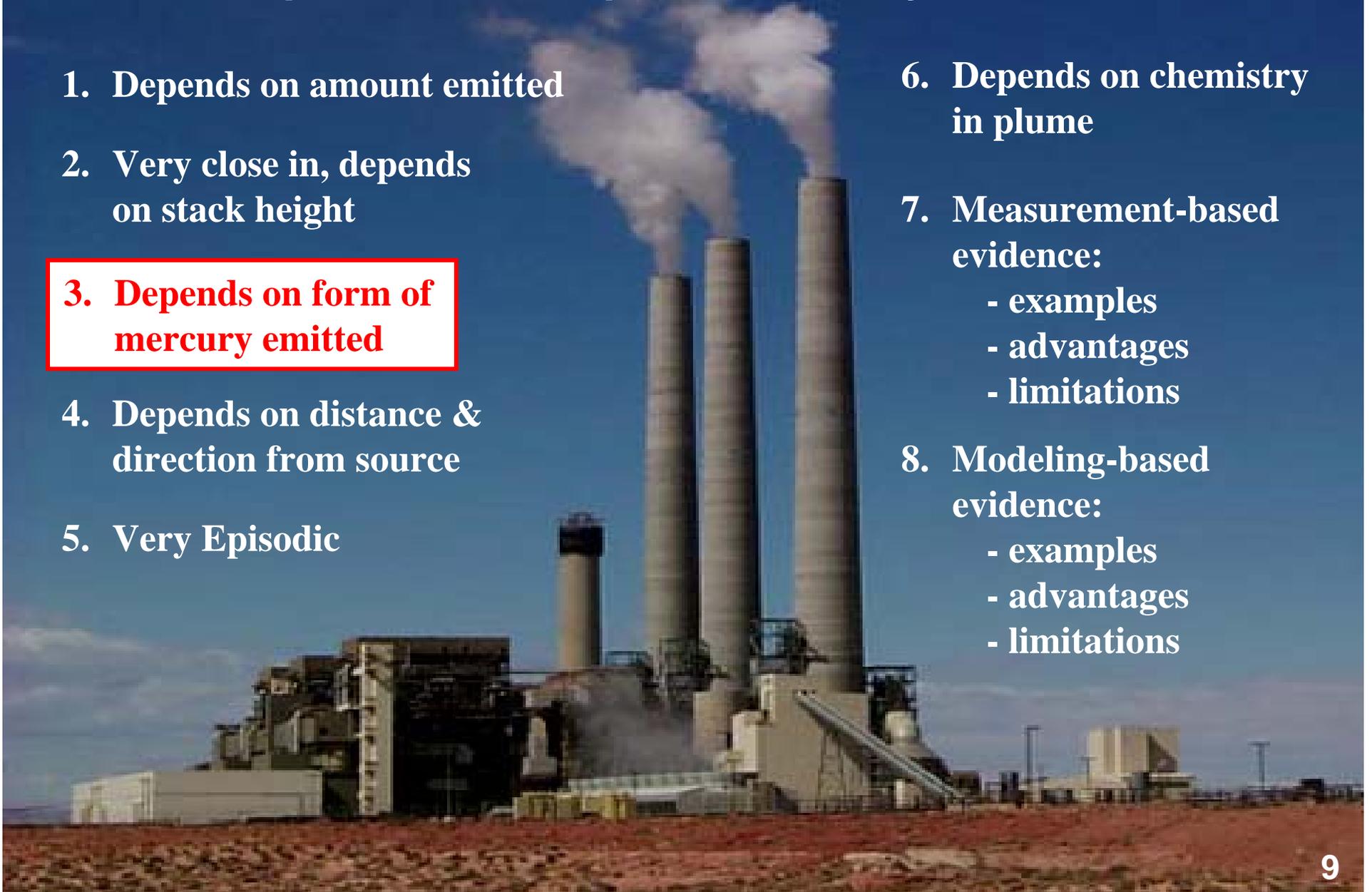
6. Depends on chemistry in plume

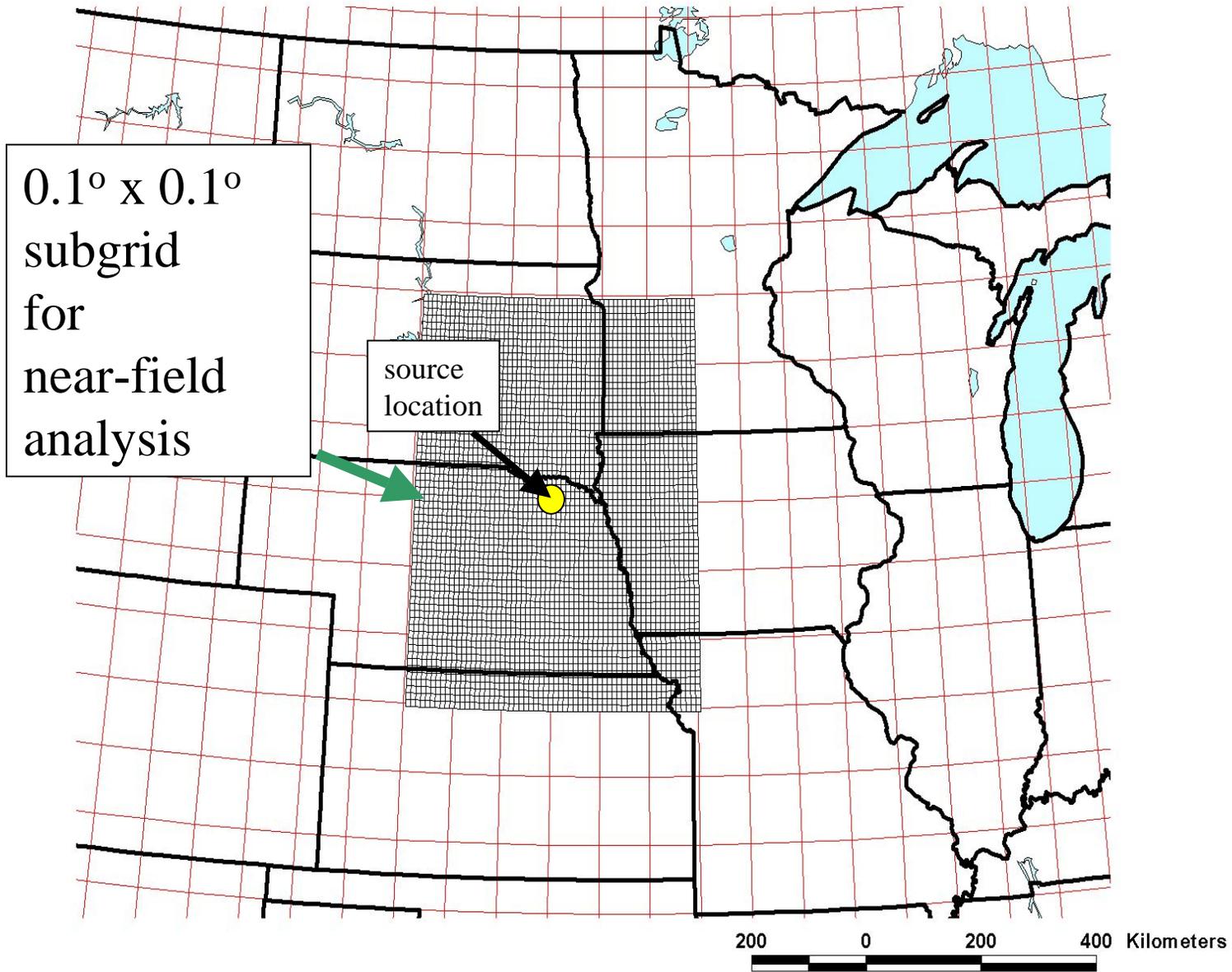
7. Measurement-based evidence:

- examples
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- limitations

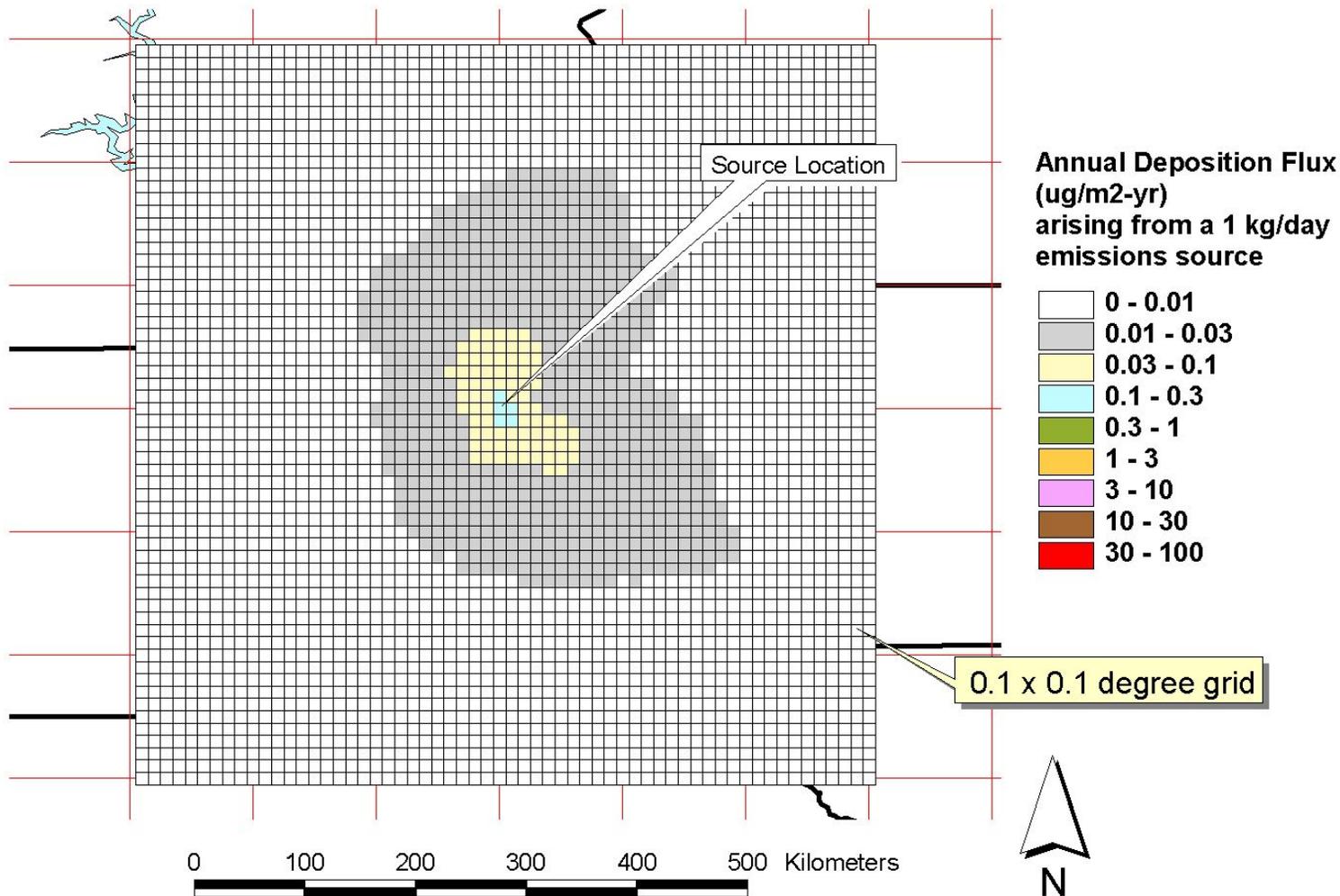
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- examples
- advantages
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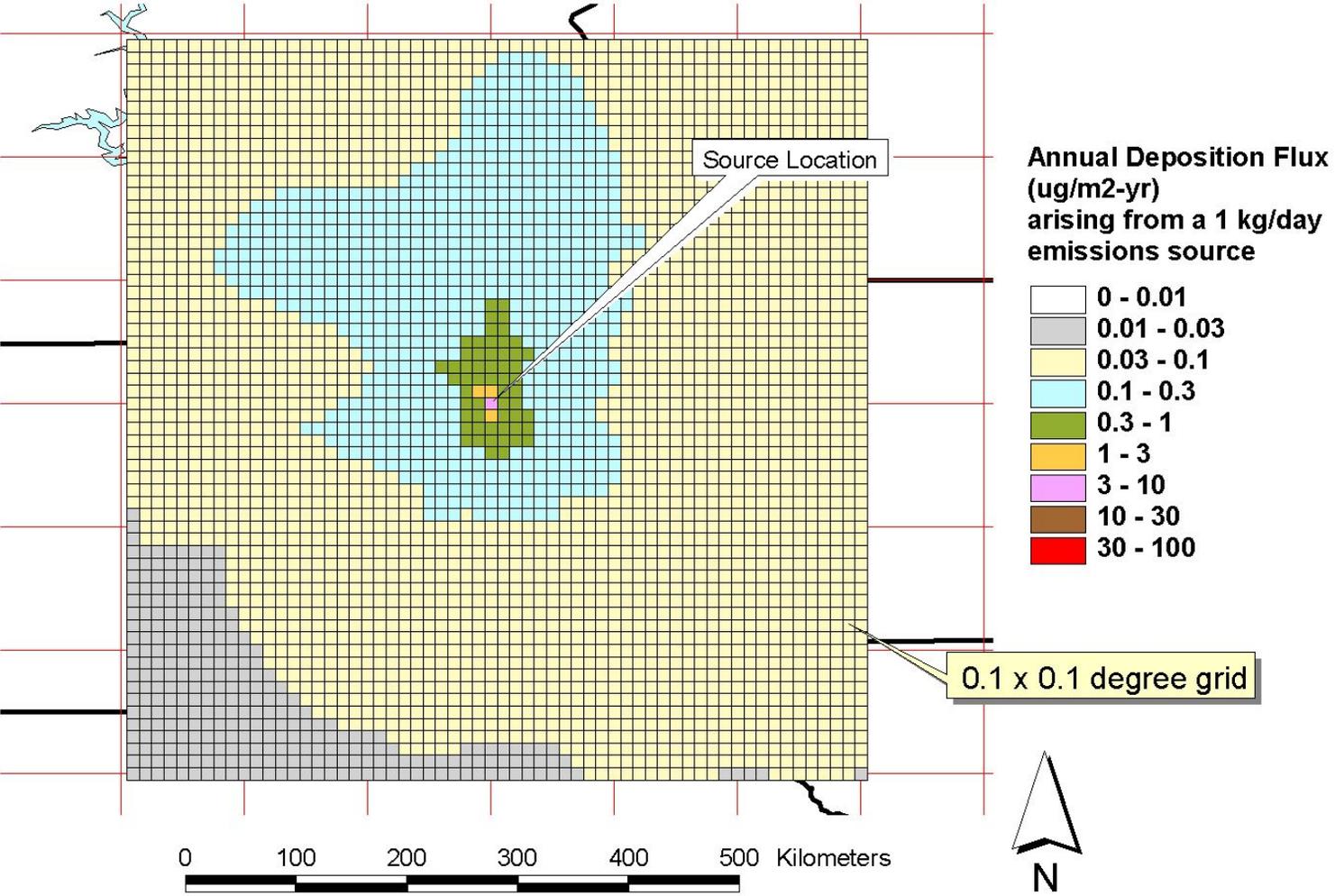


Annual deposition summary for emissions of elemental Hg from a 250 meter high source



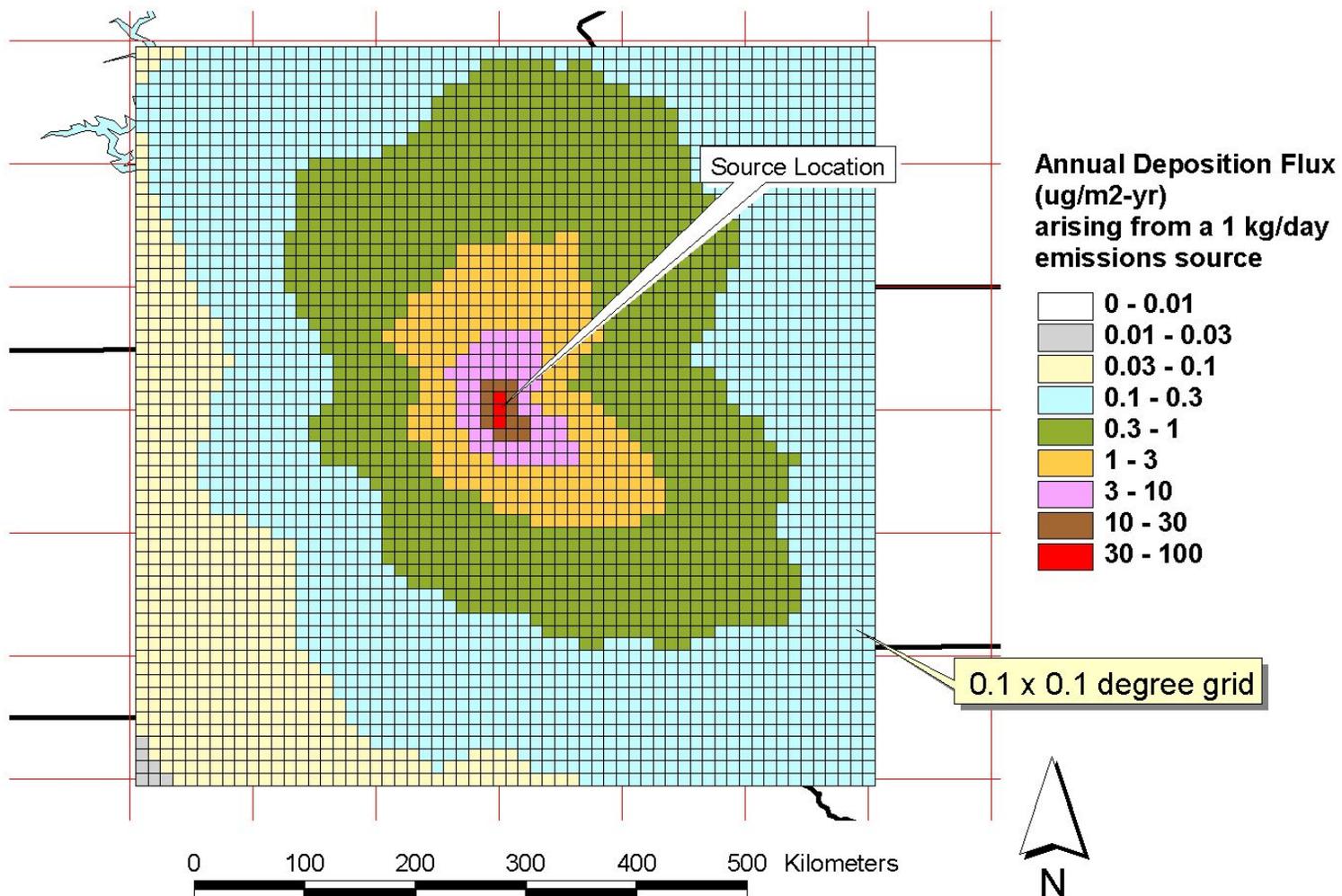
Hypothetical emissions source at lat = 42.5, long = -97.5;
simulation for entire year 1996 using archived NGM meteorology (180 km resolution)

Annual deposition summary for emissions of particulate Hg from a 250 meter high source



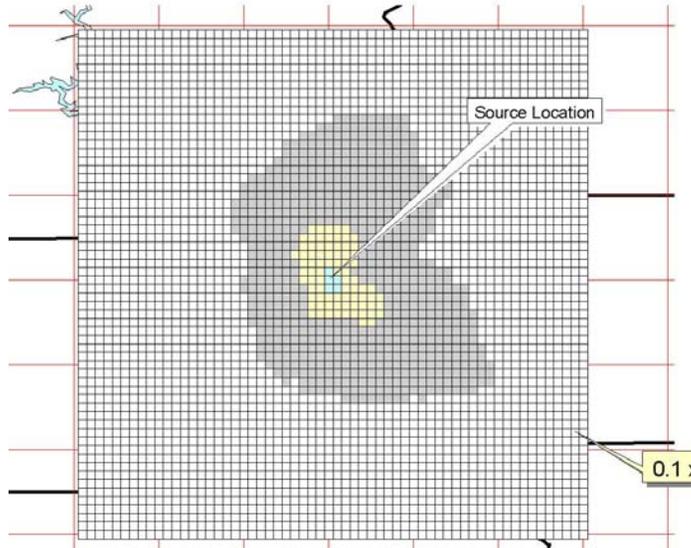
Hypothetical emissions source at lat = 42.5, long = -97.5;
simulation for entire year 1996 using archived NGM meteorology (180 km resolution)

Annual deposition summary for emissions of ionic Hg from a 250 meter high source

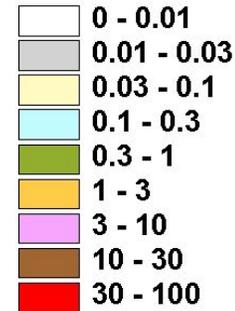


Hypothetical emissions source at lat = 42.5, long = -97.5;
simulation for entire year 1996 using archived NGM meteorology (180 km resolution)

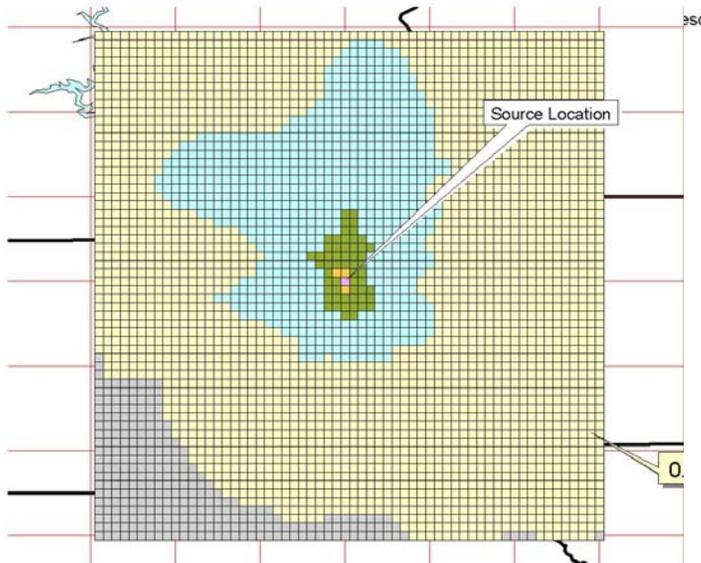
Annual deposition summary for emissions of elemental Hg from a 250 meter high source



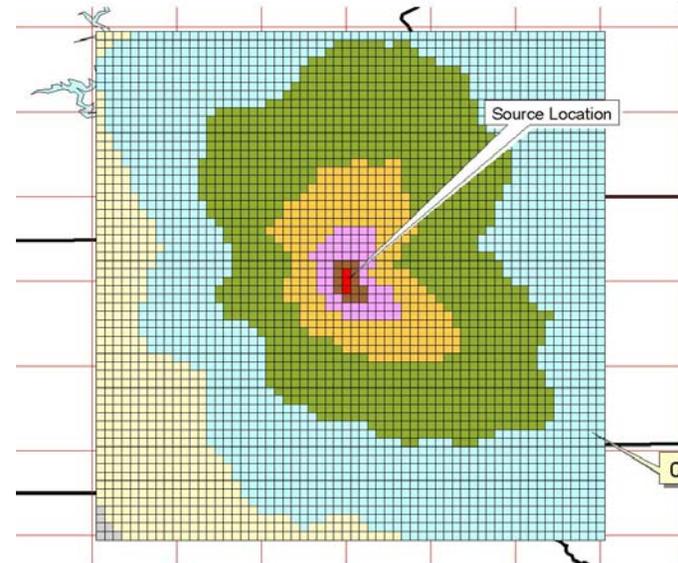
Annual Deposition Flux (ug/m2-yr) arising from a 1 kg/day emissions source



Annual deposition summary for emissions of particulate Hg from a 250 meter high source



Annual deposition summary for emissions of ionic Hg from a 250 meter high source



0 100 200 300 400 500 Kilometers

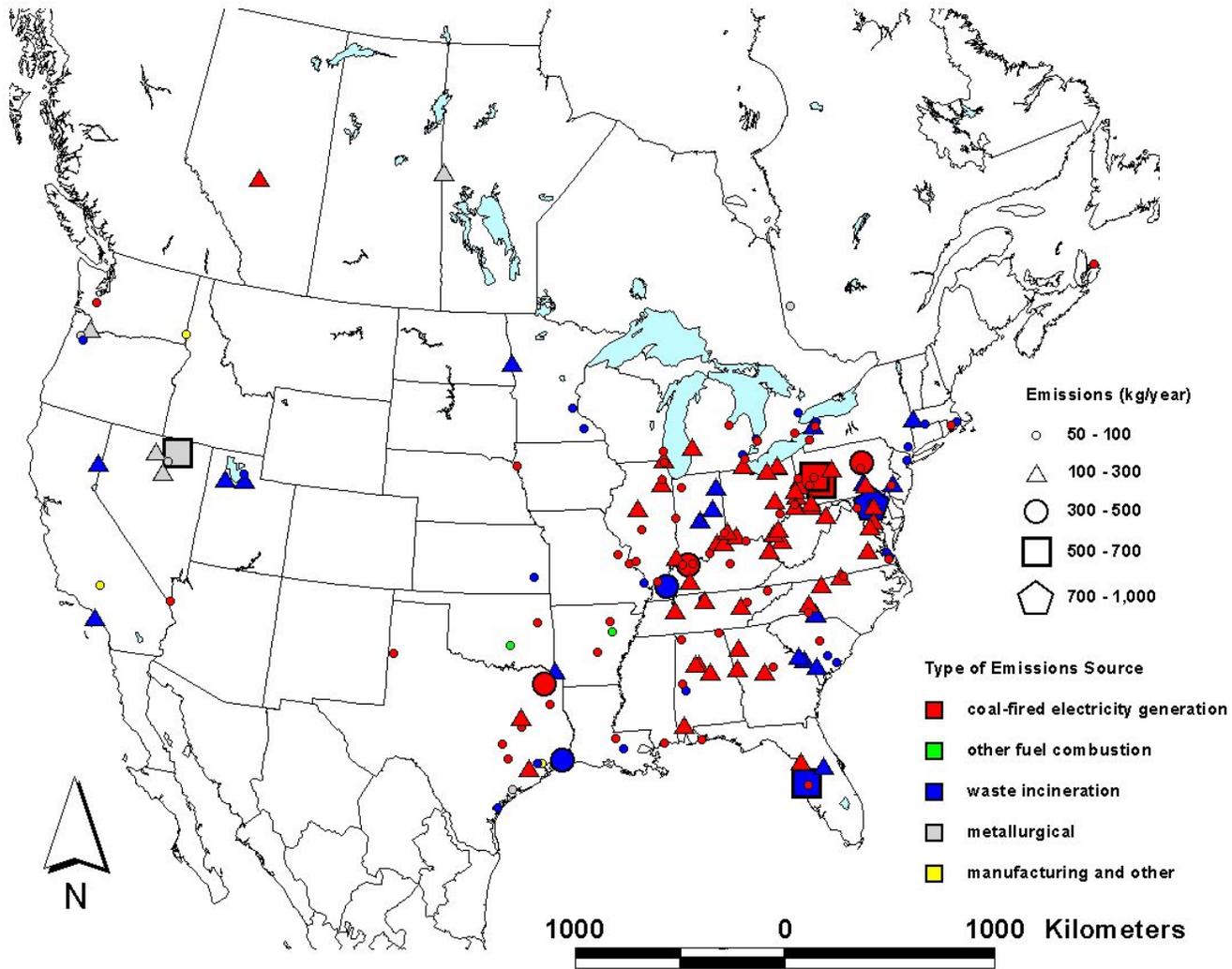
Hypothetical emissions source at lat = 42.5, long = -97.5; simulation for entire year 1996 using archived NGM meteorology (180 km r

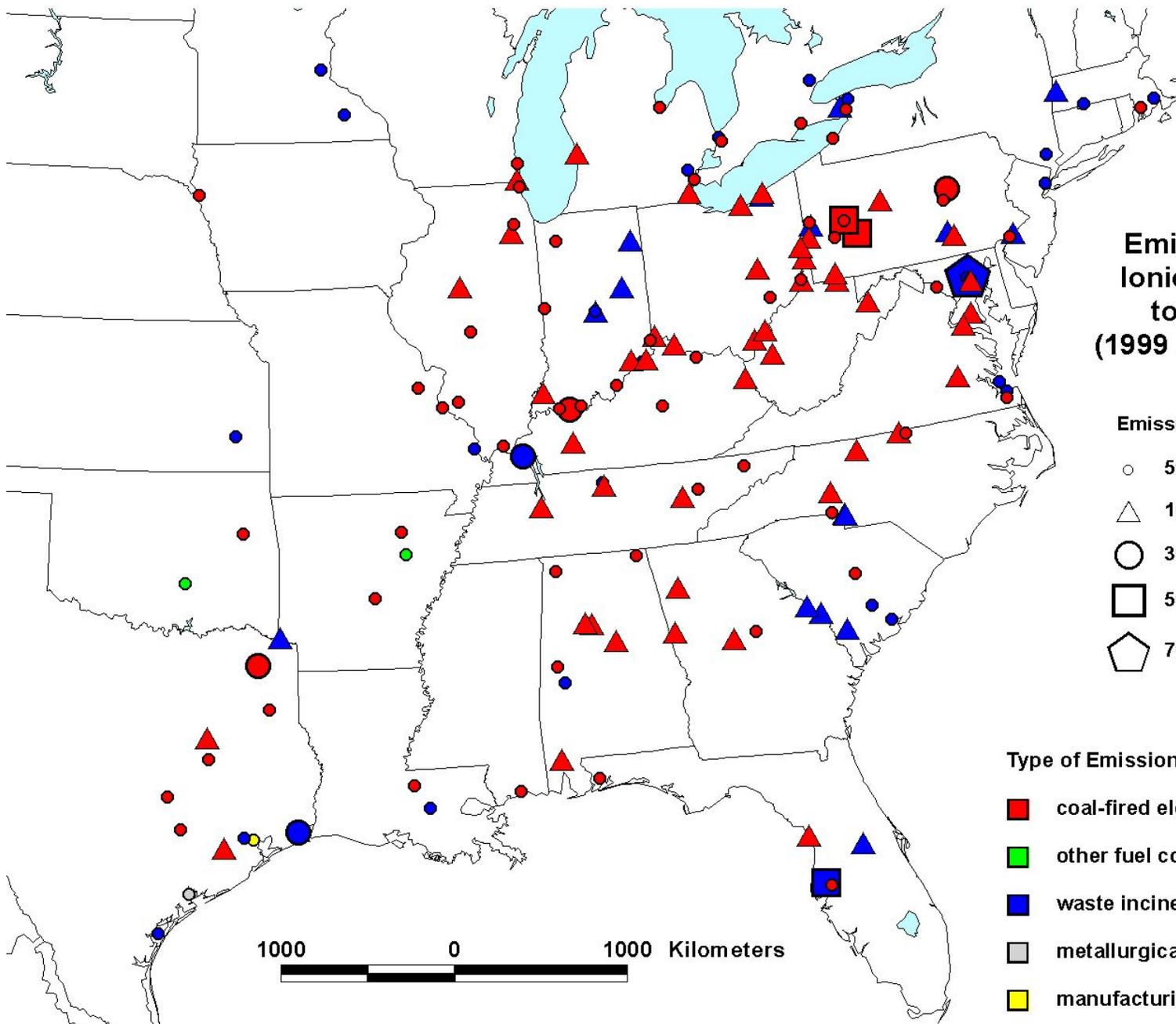
0 100 200 300 400 500 Kilometers

Hypothetical emissions source at lat = 42.5, long = -97.5; simulation for entire year 1996 using archived NGM meteorology (180 km r

So where is RGM emitted?

Emissions of Ionic Mercury to the Air





Emissions of Ionic Mercury to the Air (1999 USEPA NEI)

Emissions (kg/year)

- 50 - 100
- △ 100 - 300
- 300 - 500
- 500 - 700
- ⬠ 700 - 1,000

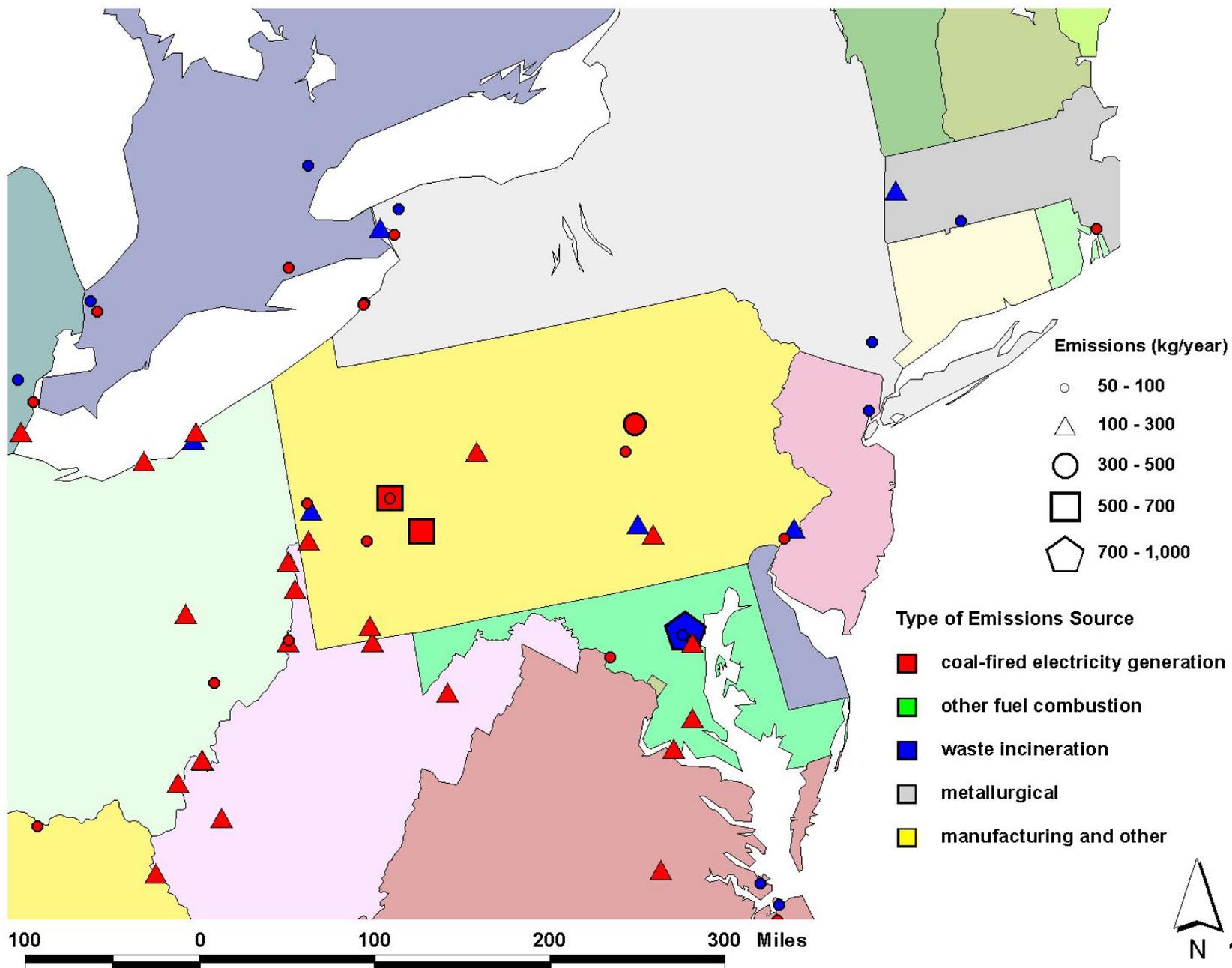
Type of Emissions Source

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

1000 0 1000 Kilometers



Reactive Gaseous Mercury Emissions (based on USEPA 1999 NEI)



What are the local and regional deposition impacts of atmospheric mercury emissions?

1. Depends on amount emitted

2. Very close in, depends on stack height

3. Depends on form of mercury emitted

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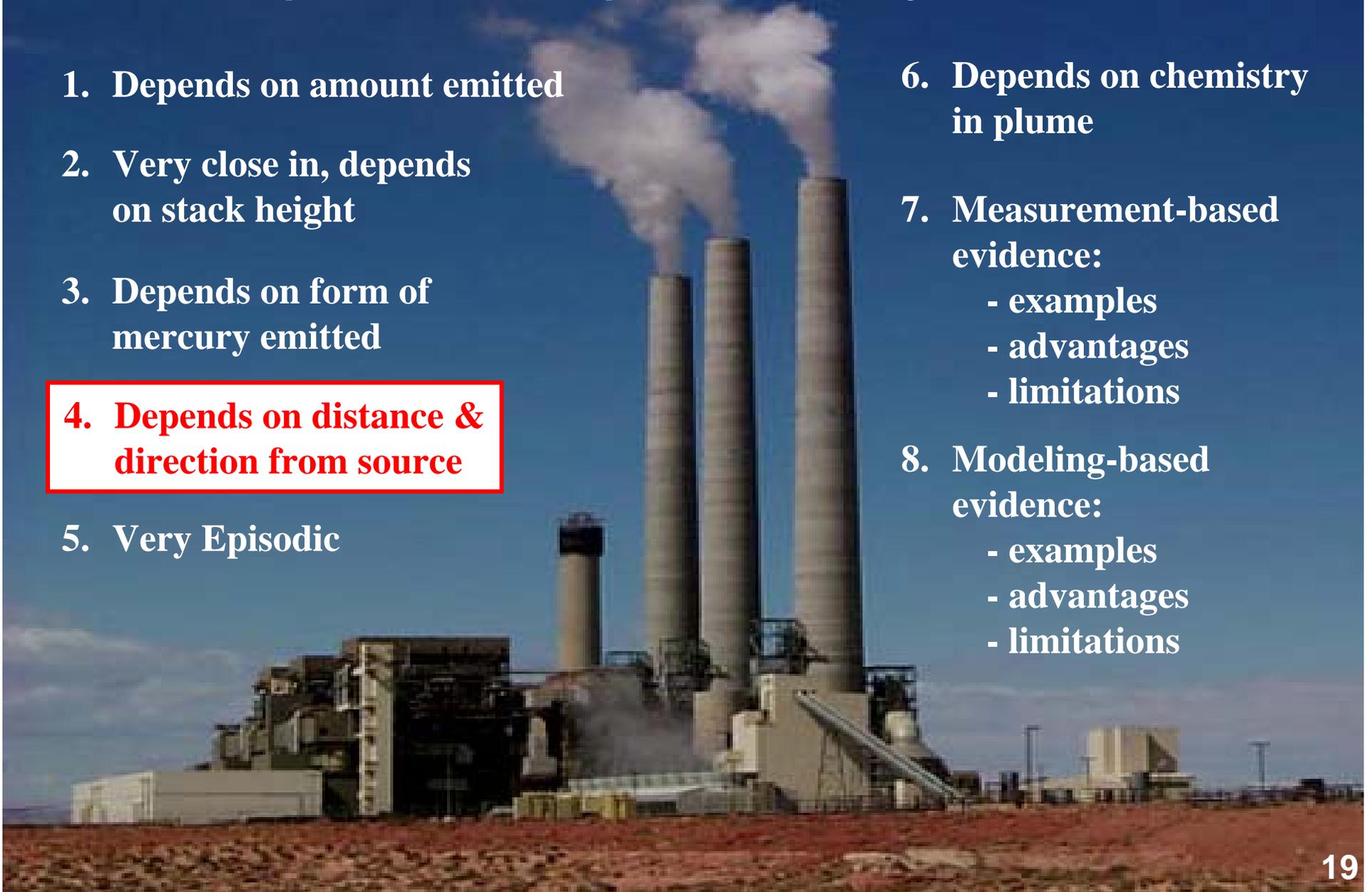
6. Depends on chemistry in plume

7. Measurement-based evidence:

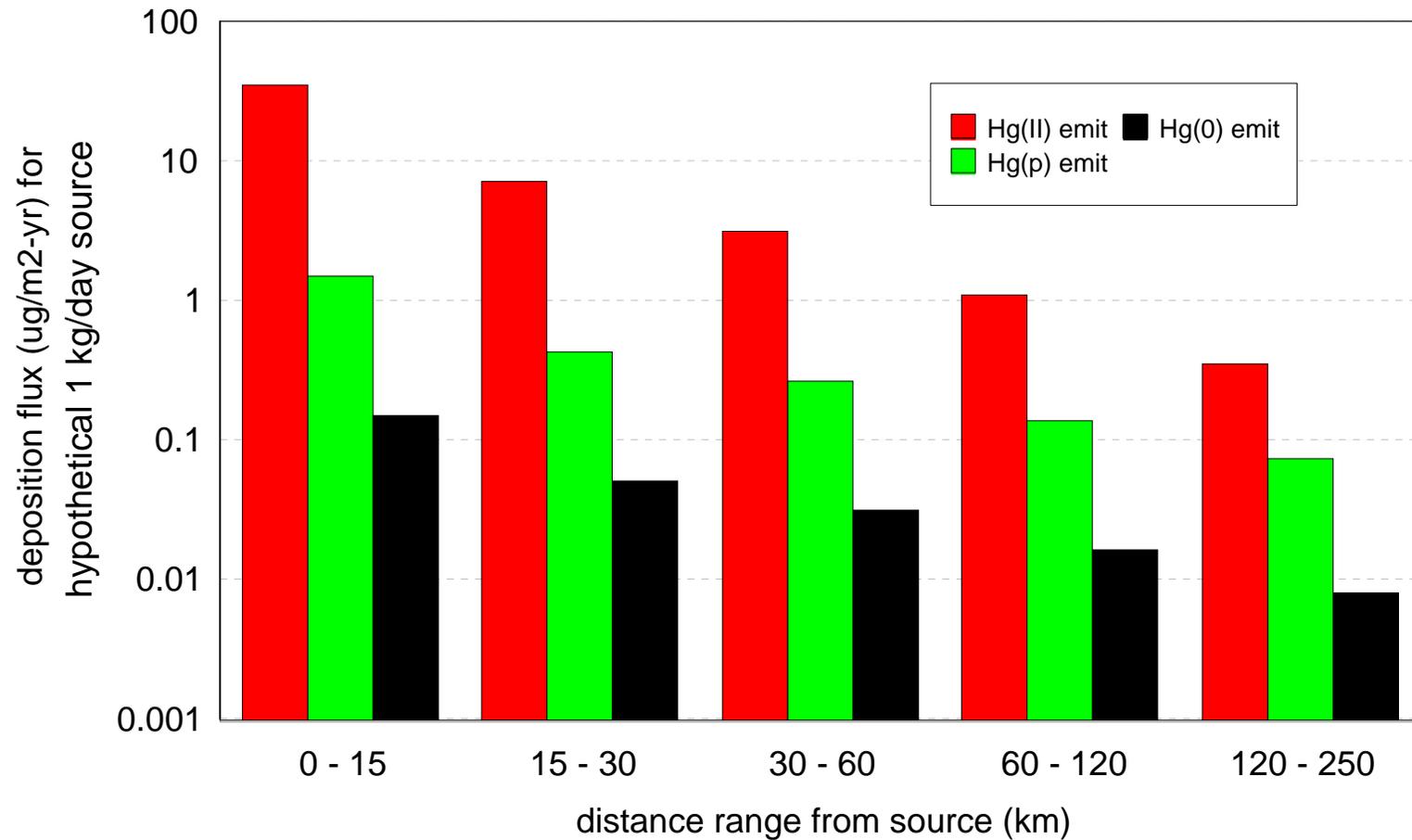
- examples
- advantages
- limitations

8. Modeling-based evidence:

- examples
- advantages
- limitations



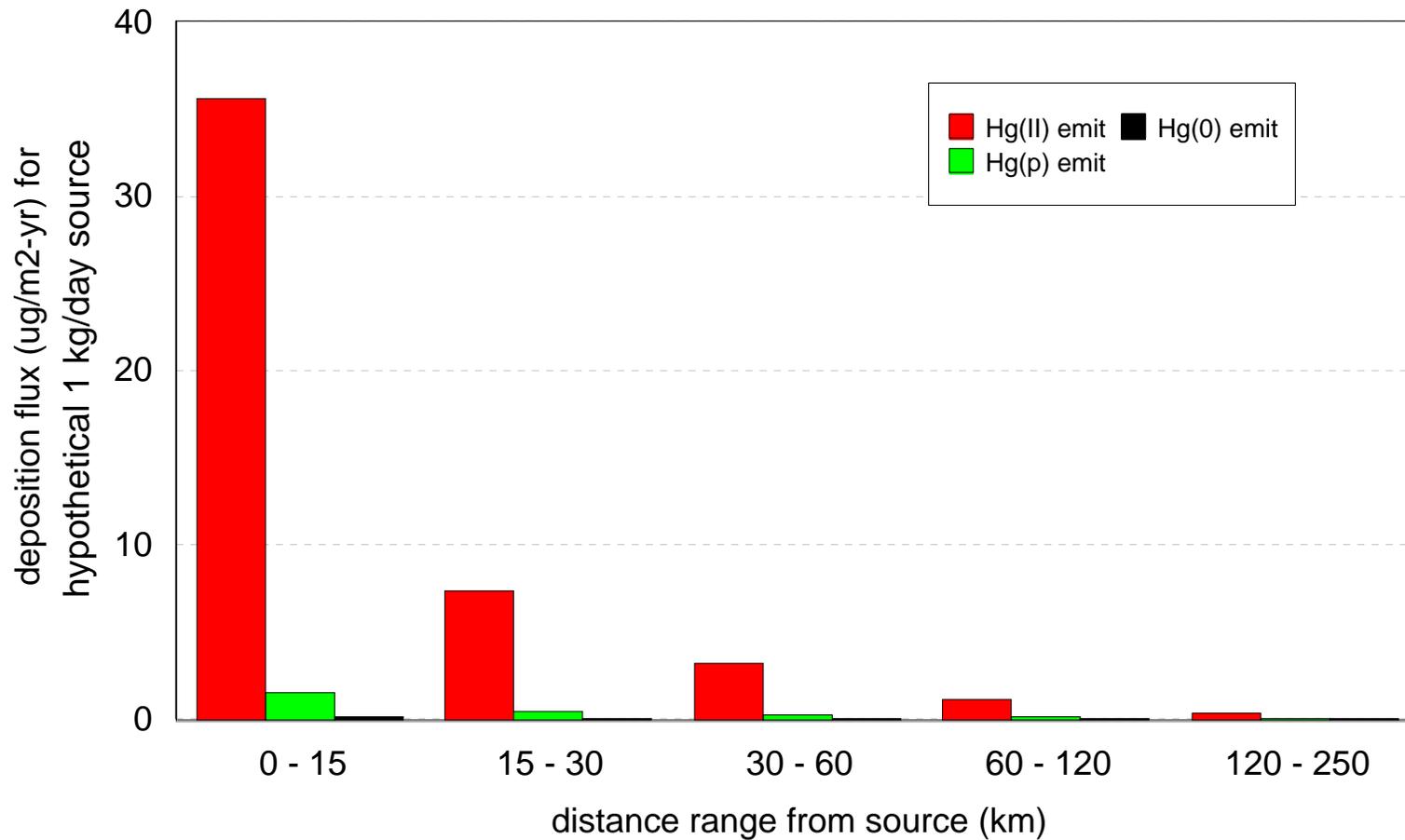
Why is emissions speciation information critical?



Logarithmic

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

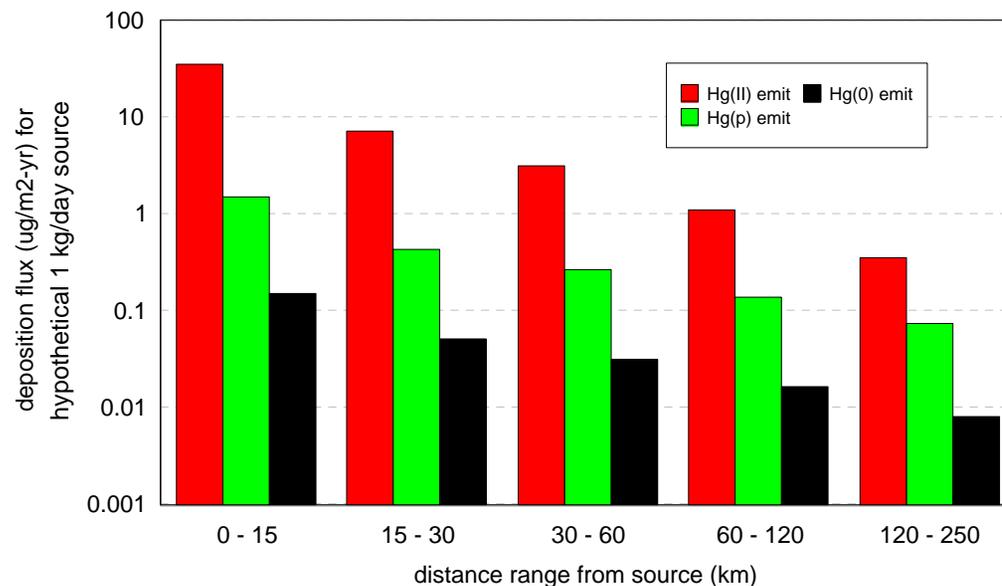
Why is emissions speciation information critical?



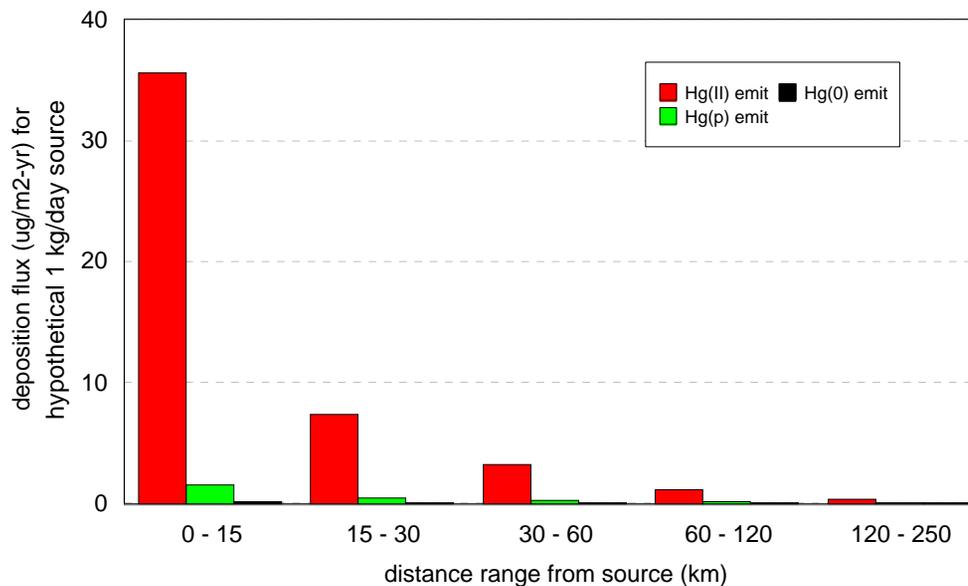
Linear

Why is emissions speciation information critical?

Logarithmic

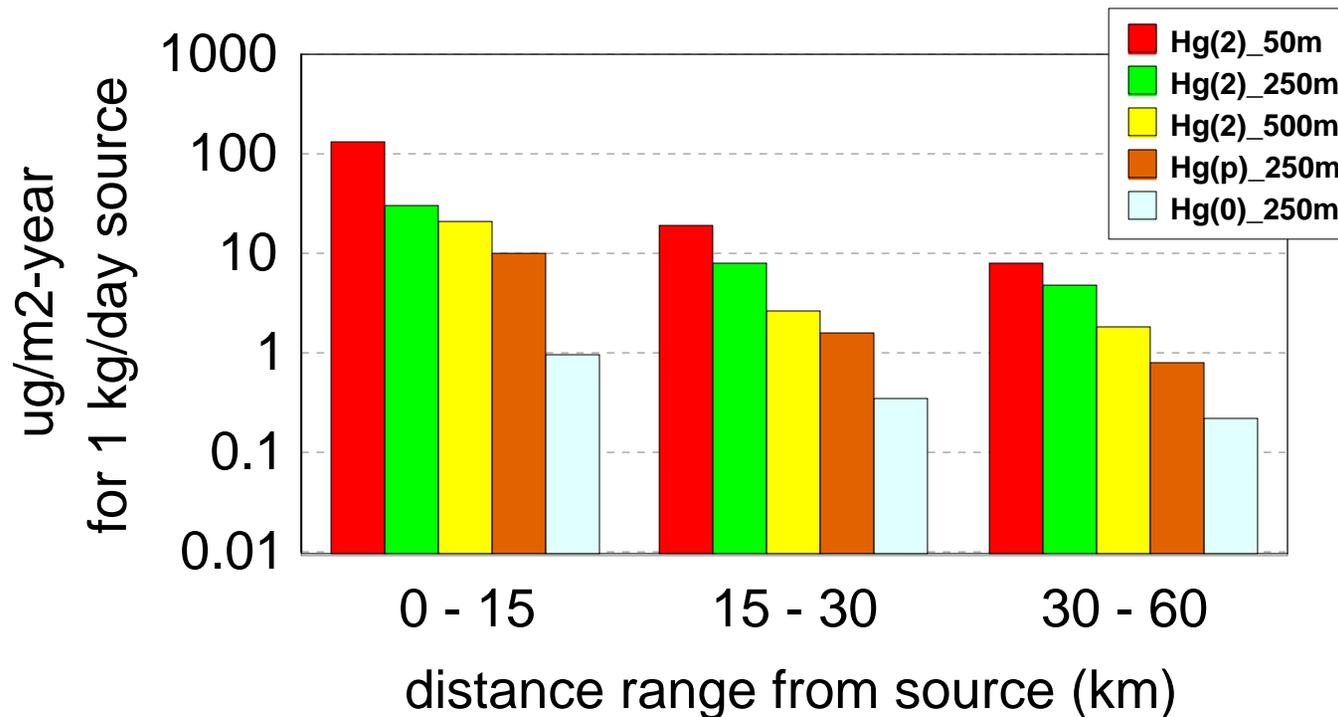


Linear



Wet + Dry Deposition: ISC (Kansas City)

for emissions of different mercury forms from different stack heights

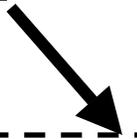


Calculated from data used to produce Appendix A of USEPA (2005): Clean Air Mercury Rule (CAMR) Technical Support Document: Methodology Used to Generate Deposition, Fish Tissue Methylmercury Concentrations, and Exposure for Determining Effectiveness of Utility Emissions Controls: Analysis of Mercury from Electricity Generating Units

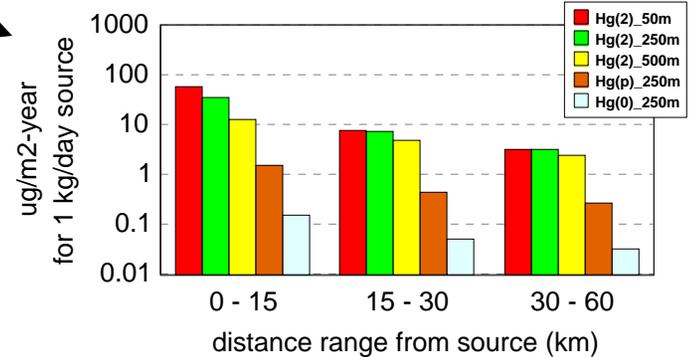
HYSPLIT 1996



ISC: 1990-1994

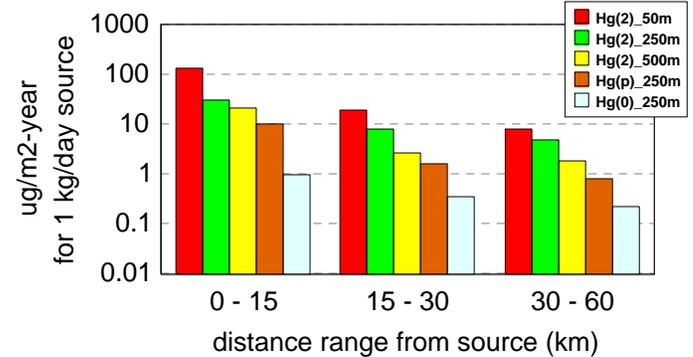


Wet + Dry Deposition: HYSPLIT (Nebraska)
for emissions of different mercury forms from different stack heights

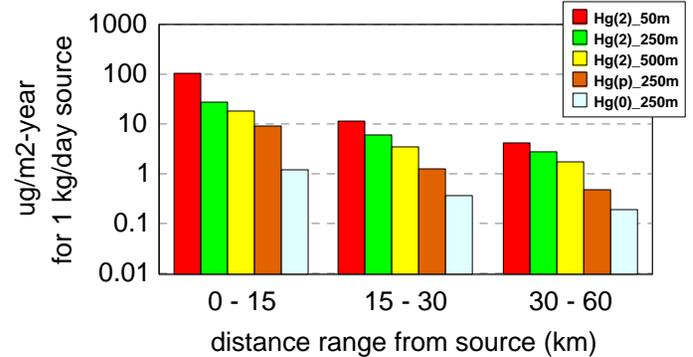


Different Time Periods and Locations, but Similar Results

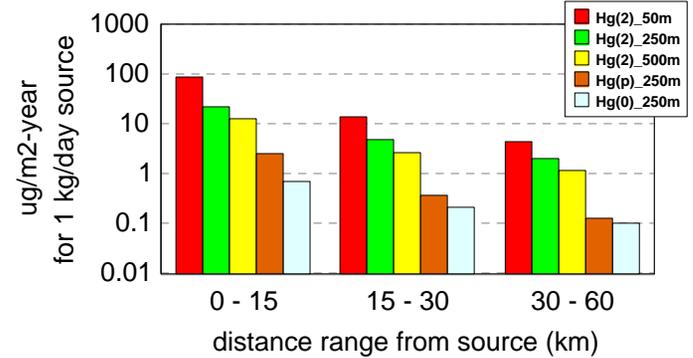
Wet + Dry Deposition: ISC (Kansas City)
for emissions of different mercury forms from different stack heights



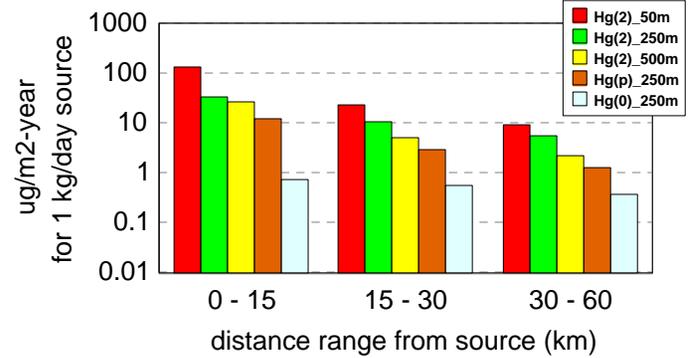
Wet + Dry Deposition: ISC (Tampa)
for emissions of different mercury forms from different stack heights



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

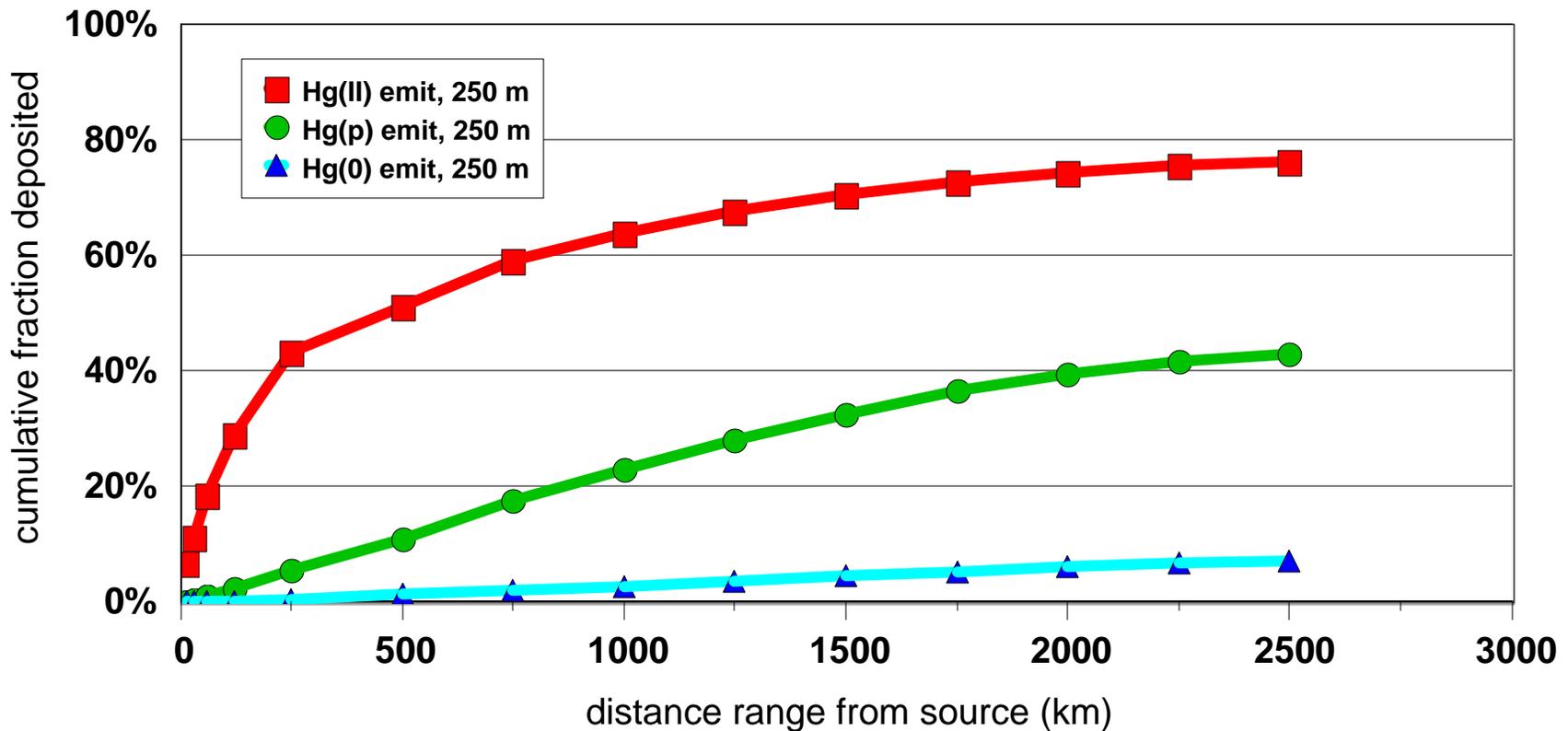


Wet + Dry Deposition: ISC (Indianapolis)
for emissions of different mercury forms from different stack heights



***The fraction deposited and the deposition flux are both important, but they have very different meanings...
The fraction deposited nearby can be relatively “small”,
But the area is also small, and the relative deposition flux can be very large...***

Cumulative Fraction Deposited Out to Different Distance Ranges from a Hypothetical Source



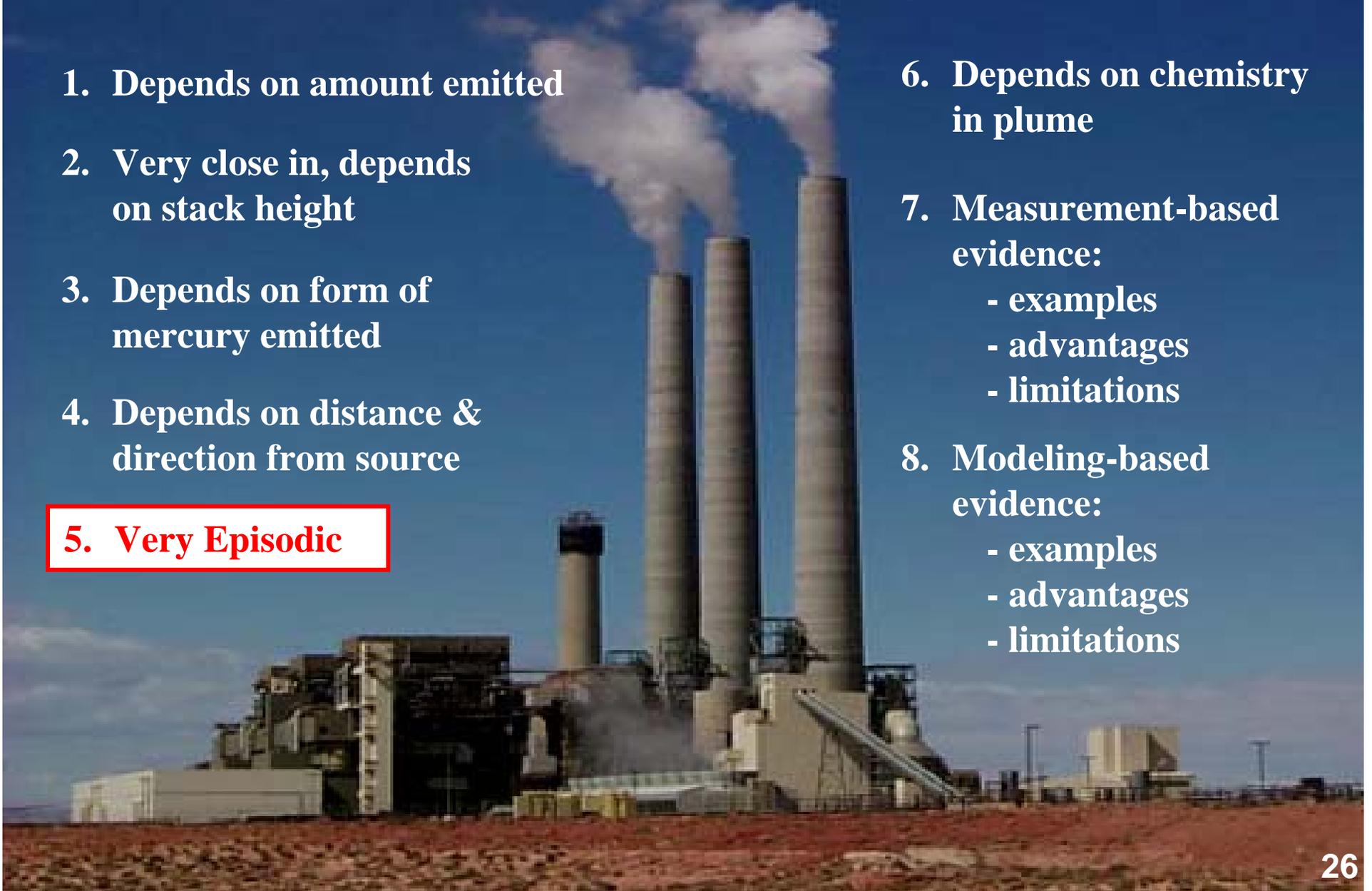
Source at Lat = 42.5, Long = -97.5; simulation for entire year 1996 using archived NGM meteorological data

What are the local and regional deposition impacts of atmospheric mercury emissions?

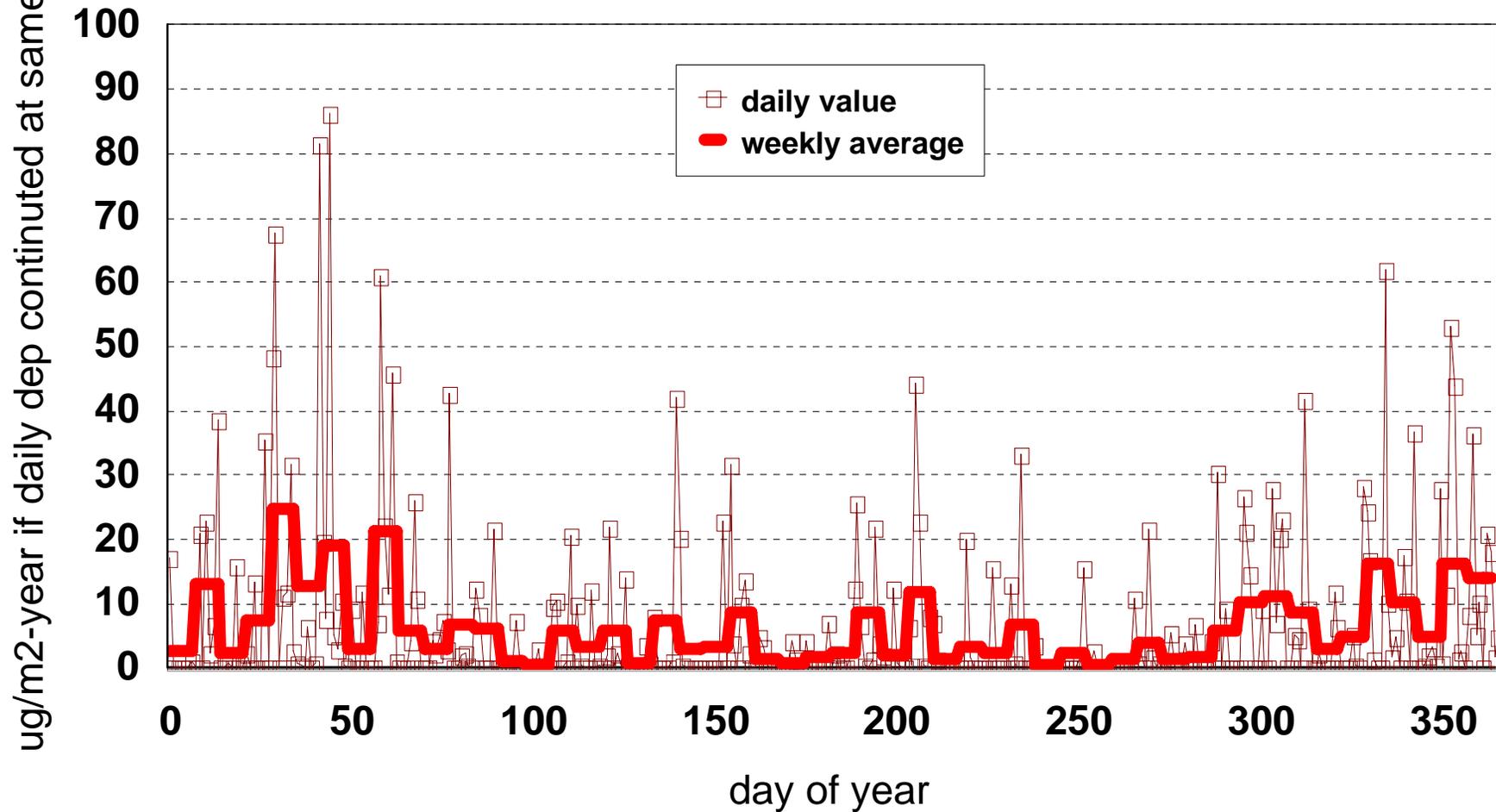
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5. Very Episodic

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7. Measurement-based evidence:
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 - limitations



Illustrative example of total deposition at a location
~40 km "downwind" of a 1 kg/day RGM source

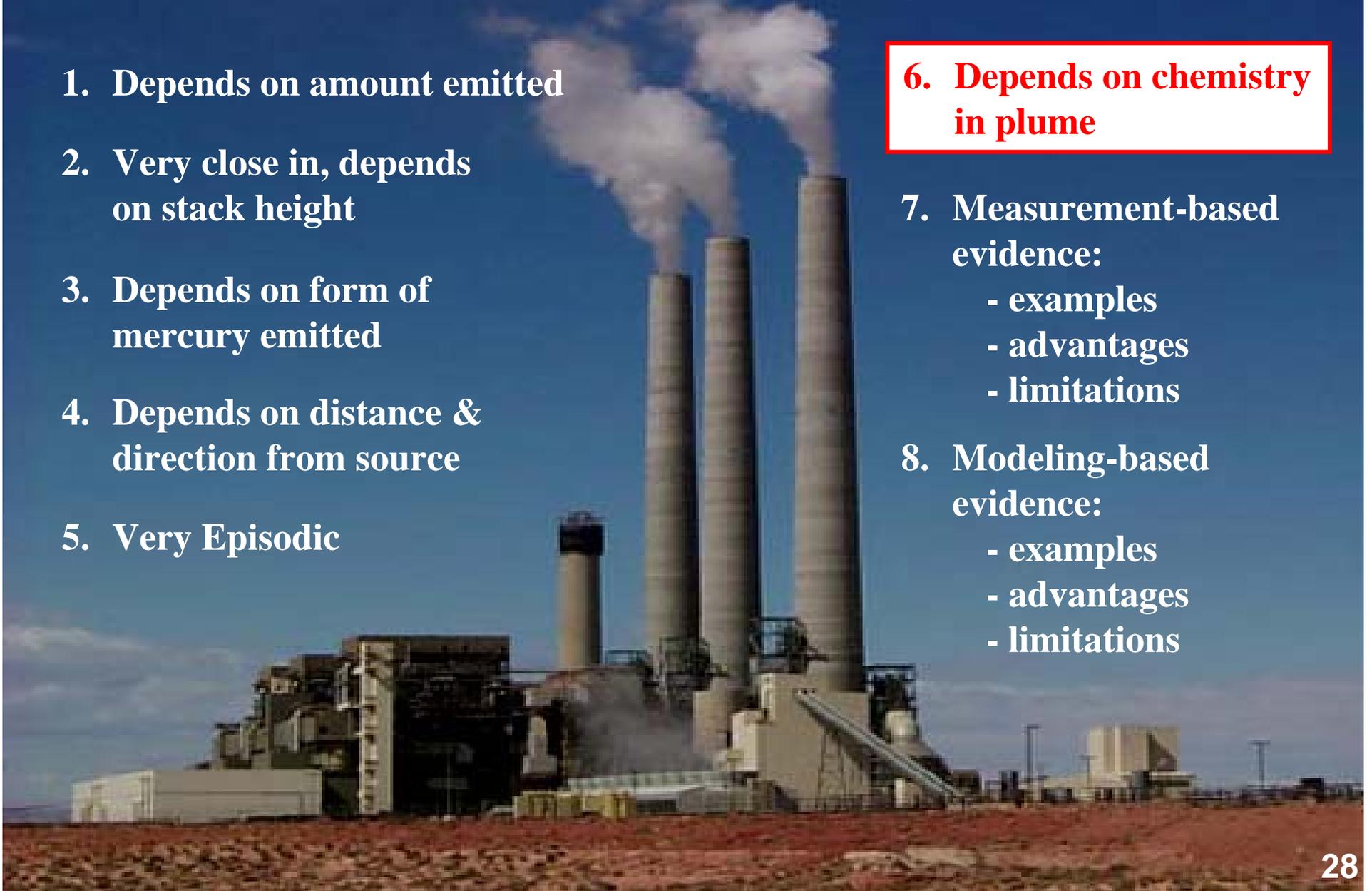


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If significant reduction of RGM to Hg(0) is occurring in power-plant plumes, then it would have a big impact on local/regional deposition

No known chemical reaction is capable of causing significant reduction of RGM in plumes –

e.g. measured rates of SO₂ reduction can't explain some of the claimed reduction rates

Very hard to measure

Aircraft

Static Plume Dilution Chambers (SPDC)

Ground-based measurements

Interconversion of Emitted Atmospheric Mercury Species in Coal-Fired Power Plant Plumes

E. Prestbo and P. Swartzendruber (Frontier Geosciences)

L. Levin (EPRI)

D. Laudal, R. Schulz and G. Dunham (EERC),

W. Aljoe (U.S. Department of Energy)

J. Jansen and L. Monroe (Southern Company)

R. Valente (TVA)

D. Michaud (WE Energies)

Air Quality V Conference

September 2005



SPDC - Hg Species Interconversion Results for all Study Sites 1995-2003

Power Plant	Year	Coal	PCD	Hg(II) to Hg ⁰ conversion as a percent of total mercury	Mass Balance	n
Presque Ilse, MI*	1995	W-SB	ESP 1 Unit	33% ± 6.8%	96% ± 14%	10
Dickerson, MD*	1998	E-SB	Scrubber 2 Units ESP Scrubber	41% ± 7.9%	128% ± 22%	8
Dickerson, MD	1998	MW	and-Carbon Inj.	-23% ± 12%	84% ± 15%	7
EERC Pilot Plant	2000	E-B	ESP	23% ± 6.0%	86% ± 19%	8
EERC Pilot Plant	2000	E-B	Baghouse	11% ± 8.0%	75% ± 9.2%	6
Bowen, GA	2002	E-B	ESP	9.4% ± 2.9%	109% ± 6.6%	6
Pleasant Prairie, WI	2003	PRB	ESP/SCR	3.2% ± 3.7%	90% ± 22%	3

* value may be biased high due to bias in fluegas speciation measurements

Comparison of SPDC and Airplane Plume Hg Species Interconversion at Bowen and P4

Power Plant	Method	Hg(II) to Hg ⁰ conversion as a percent of total mercury	Mass Balance	n
Bowen, GA	2002	9.4% ± 2.9%	109% ± 6.6%	6
"	Aircraft	13%		4
Pleasant Prairie, WI	SPDC	3.1% ± 3.7%	90% ± 22%	3
"	Aircraft - 0km	15% ± 6.5%	123% ± 24%	5
"	Aircraft - 8km	23% ± 2.6%	198% ± 120%	4
"	Aircraft - 16km	24% ± 5.3%	152% ± 62%	3

➤ Note: Airplane results were as of July, 2004

How important is RGM reduction in power-plant plumes?

- Most current state-of-the-science models – including the EPA CMAQ model used to generate analyses for the CAIR/CAMR rulemaking process – 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**

What are the local and regional deposition impacts of atmospheric mercury emissions?

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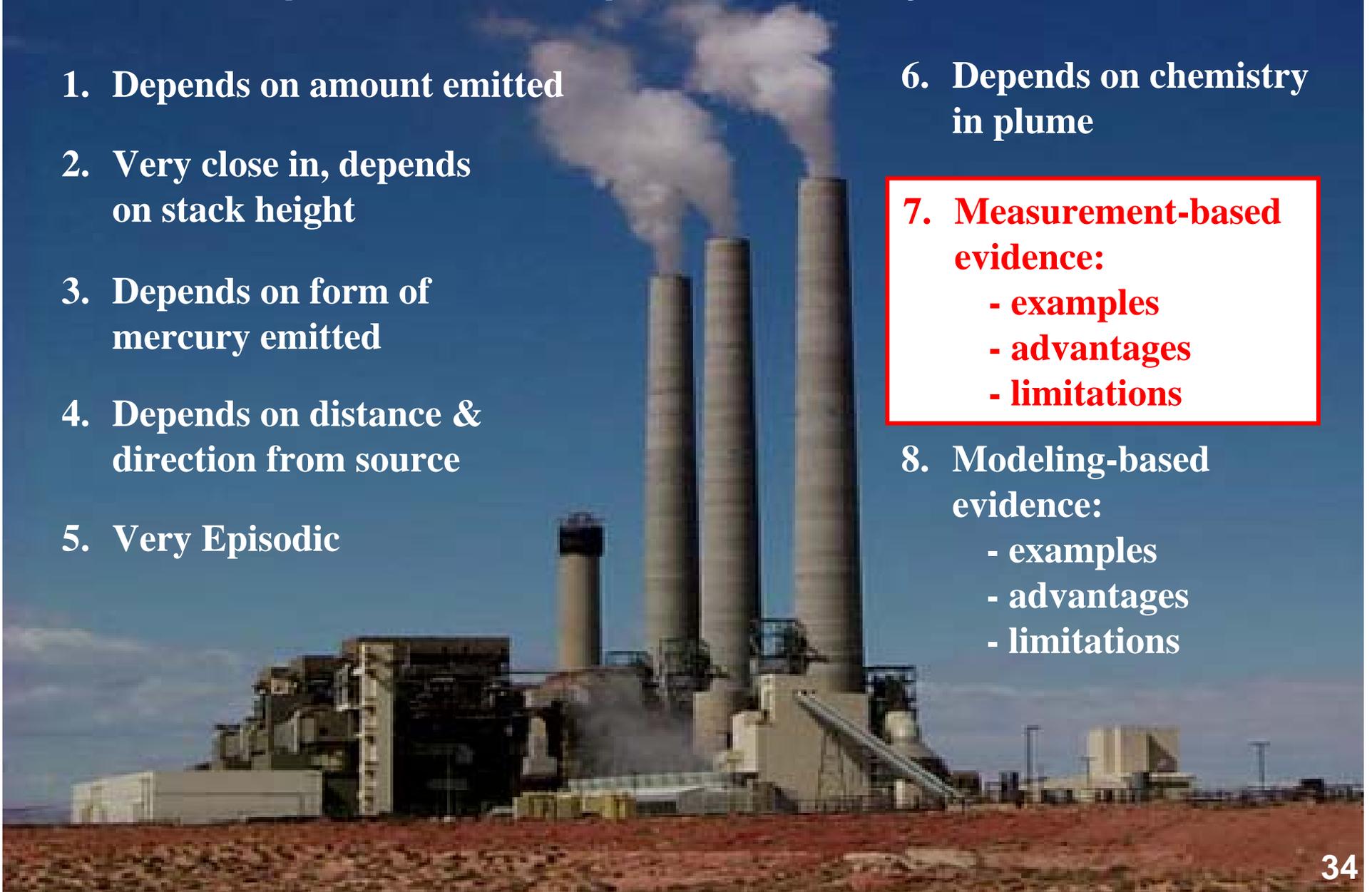
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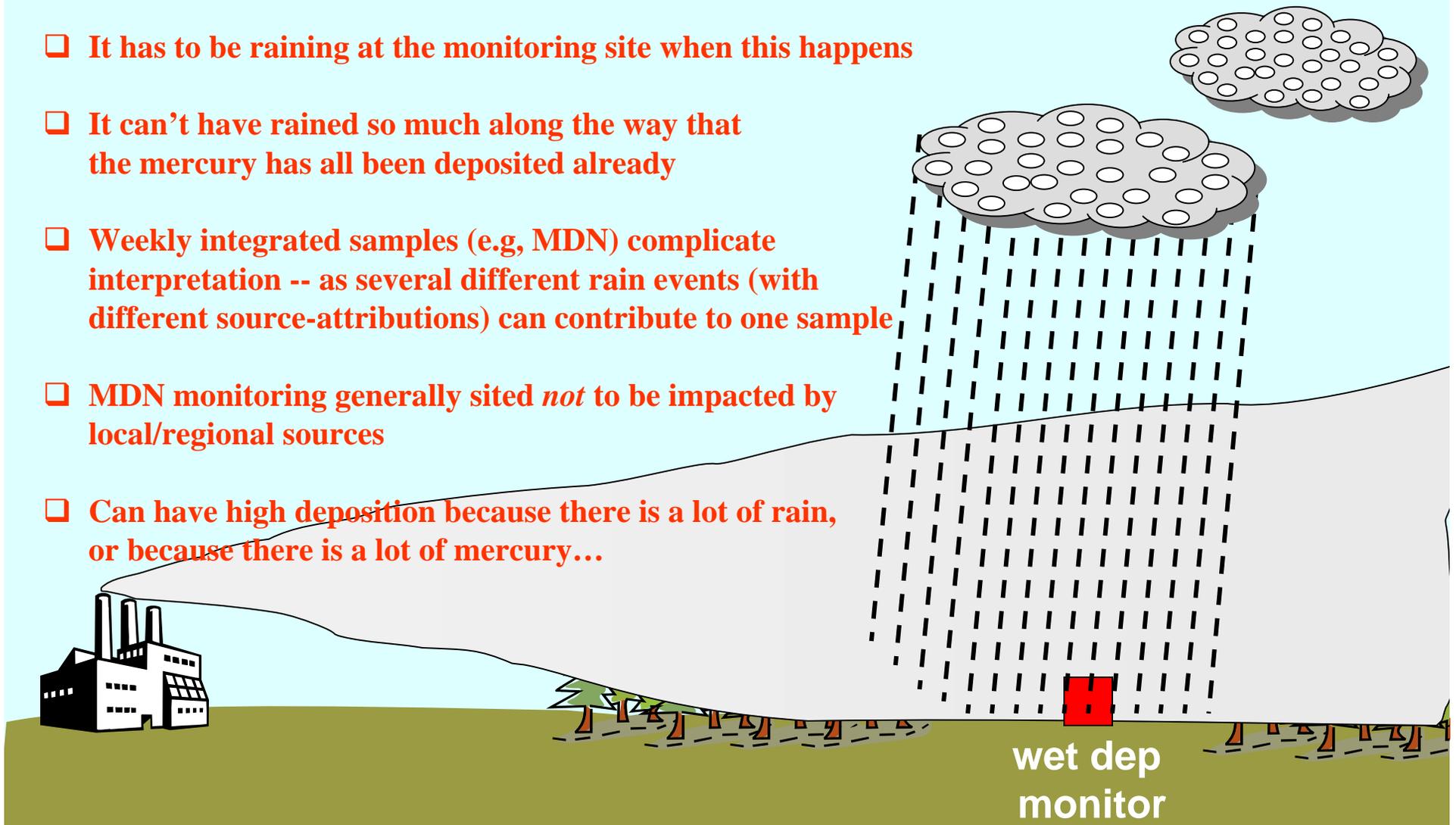
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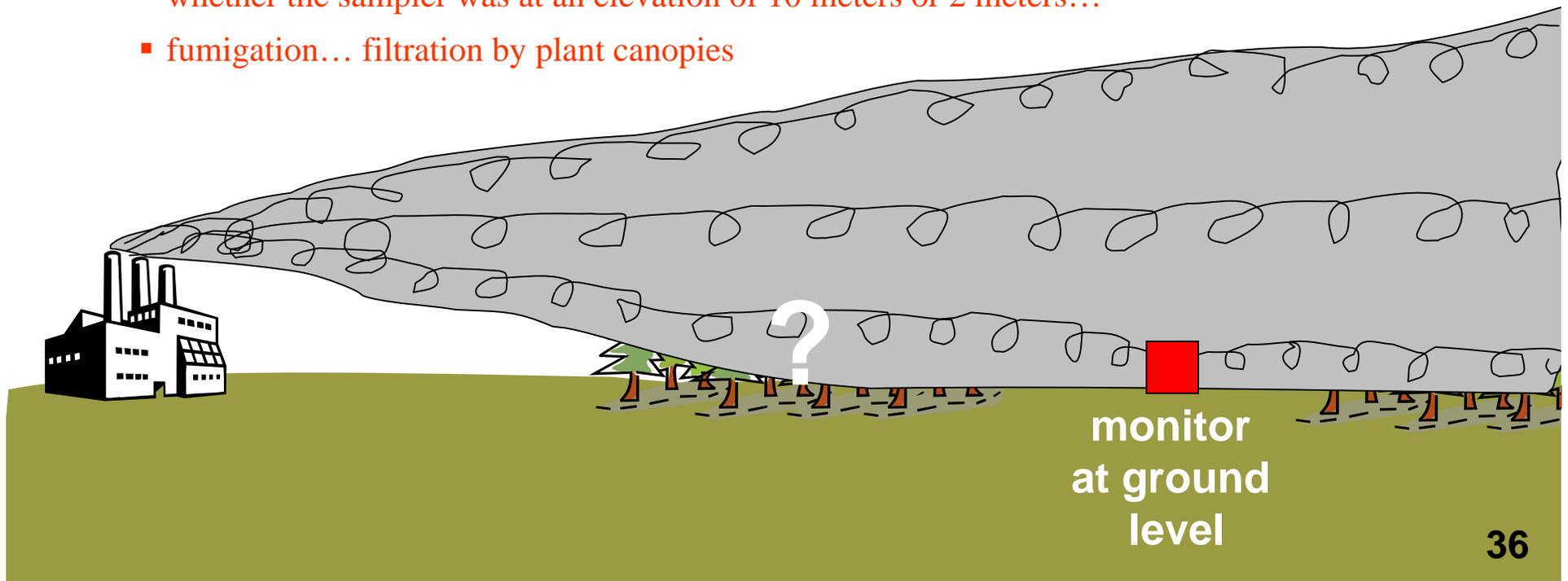
Challenges of using wet deposition data to assess local and regional deposition impacts...

- ❑ Wind has to blow from source to monitoring site
- ❑ It has to be raining at the monitoring site when this happens
- ❑ It can't have rained so much along the way that the mercury has all been deposited already
- ❑ Weekly integrated samples (e.g, MDN) complicate interpretation -- as several different rain events (with different source-attributions) can contribute to one sample
- ❑ MDN monitoring generally sited *not* to be impacted by local/regional sources
- ❑ Can have high deposition because there is a lot of rain, or because there is a lot of mercury...



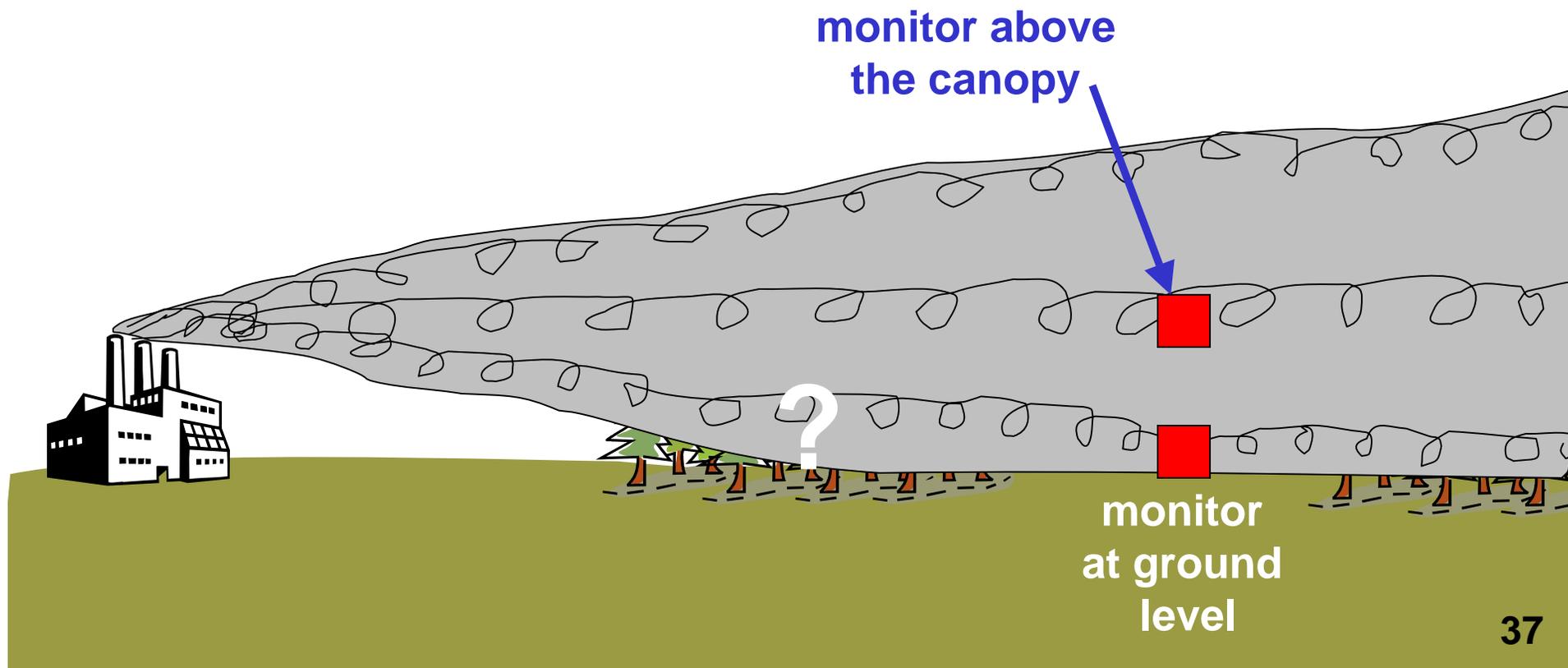
Challenges of using air concentration data to assess local and regional deposition impacts...

- **Need speciated data (Hg₀, Hg(p), RGM)**
- **Relatively expensive and time-consuming**
- **Still have problem of having the plume hit the site, but can measure continuously... and the plume hit and rain doesn't have to occur at the same time (as with wet dep monitors) ...**
- **Results from ground-level monitors can be hard to interpret –**
 - rapid dry deposition ... large vertical gradients ... measuring right where things are changing very rapidly ... don't want the whole analysis to depend on whether the sampler was at an elevation of 10 meters or 2 meters...
 - fumigation... filtration by plant canopies

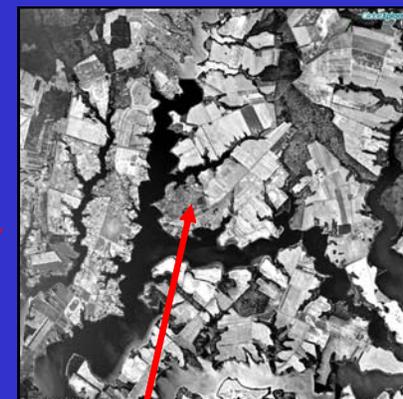
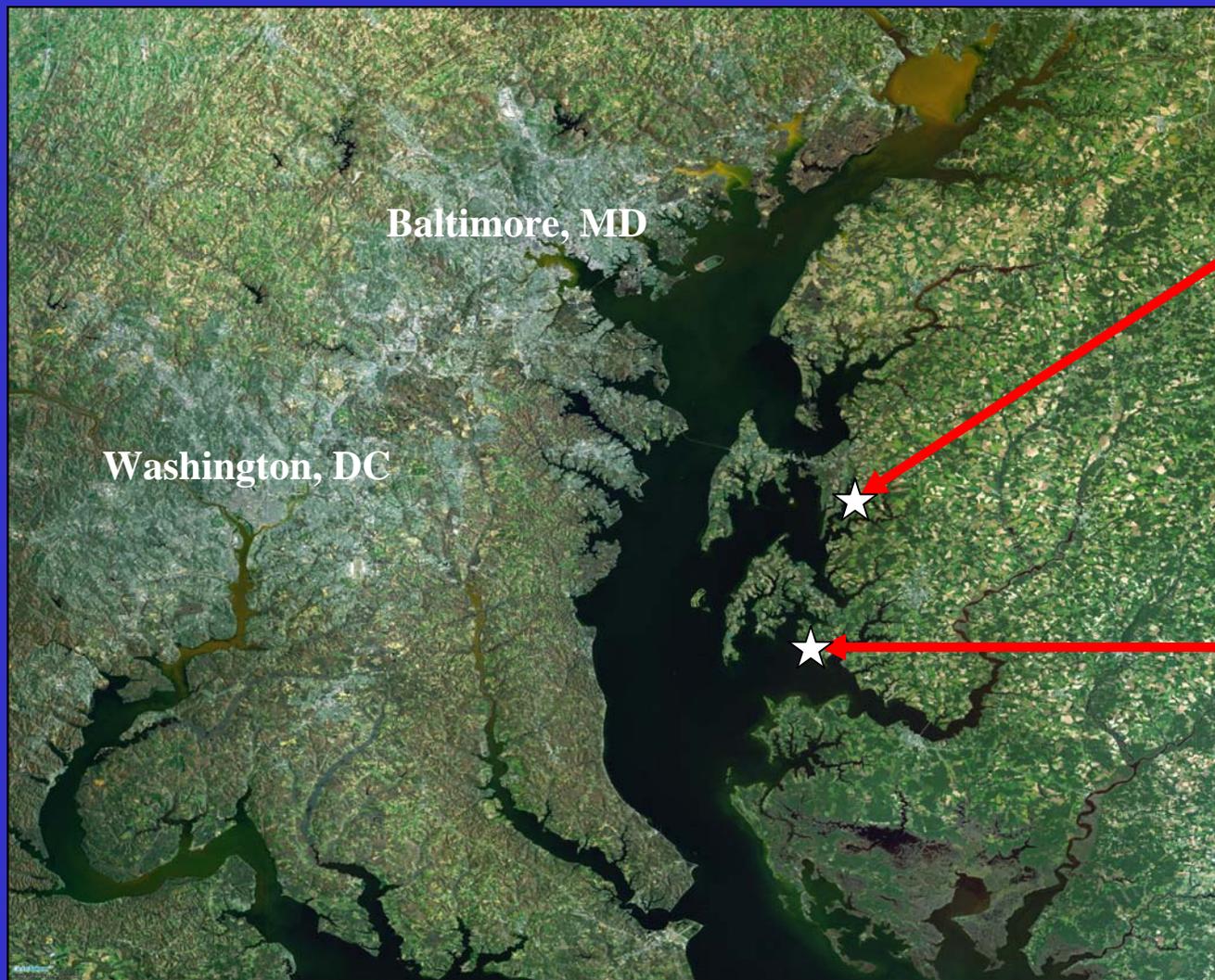


Observations of “depleted” RGM at ground-based stations downwind of power plants – sometimes thought to be evidence of RGM reduction to Hg⁰ -- might be strongly influenced by RGM dry deposition...

would be better to have a monitor far above the canopy...



Summer 2004 NOAA ARL Hg Measurement Sites

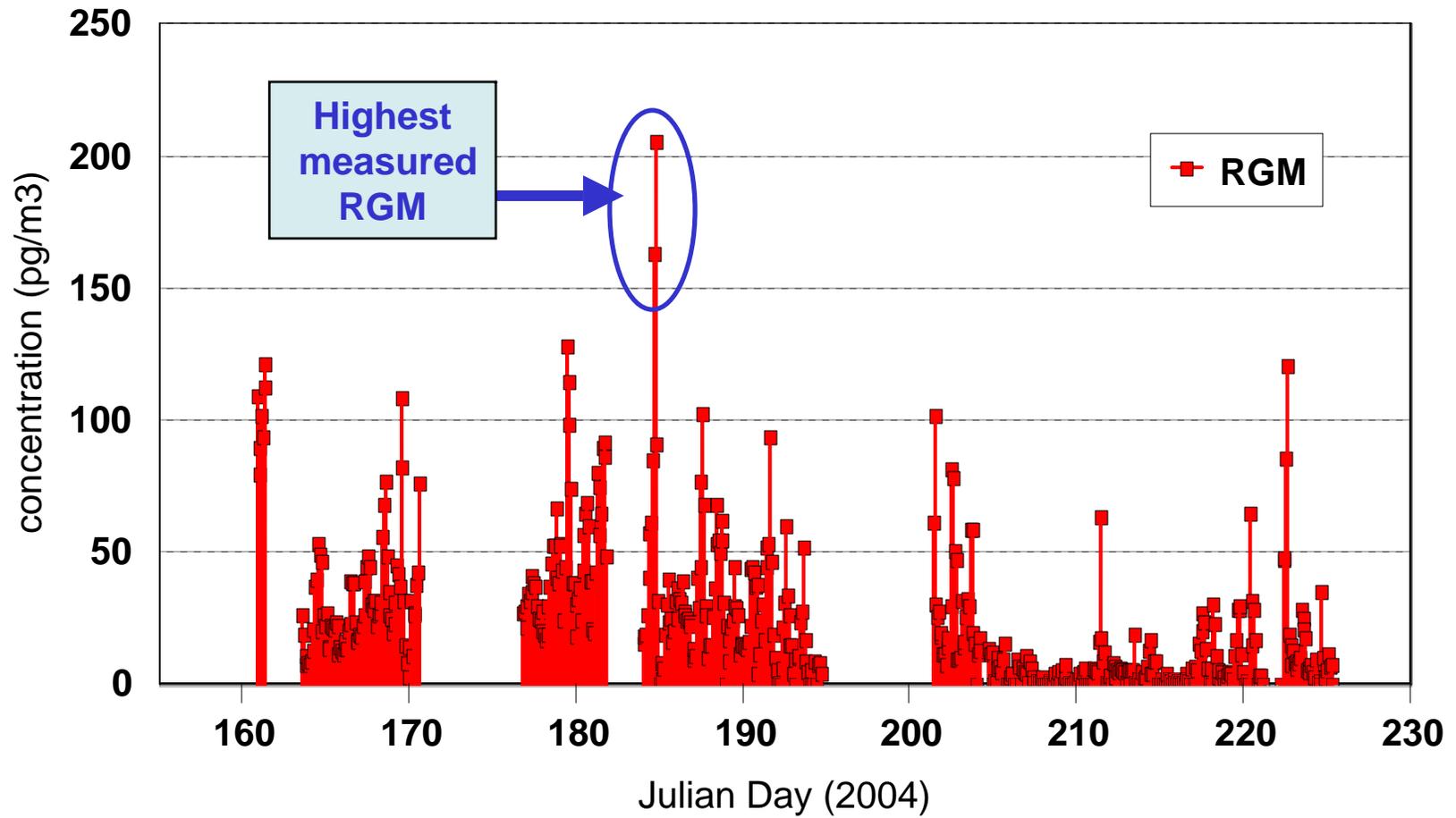


Wye Research and
Education Center
(38.9131°N, 76.1525°W)

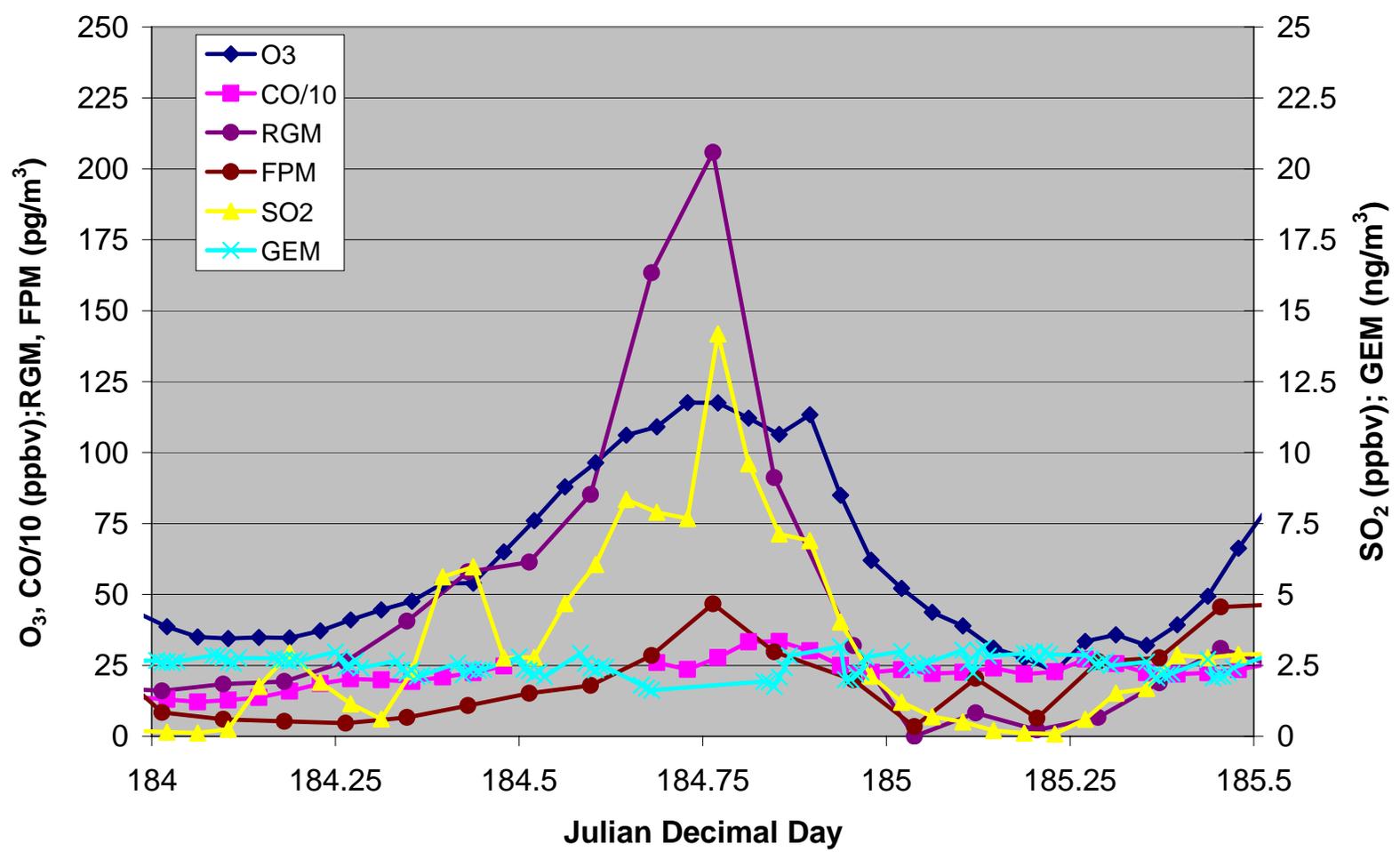


Cooperative Oxford Lab
(38.678°N, 76.173°W)

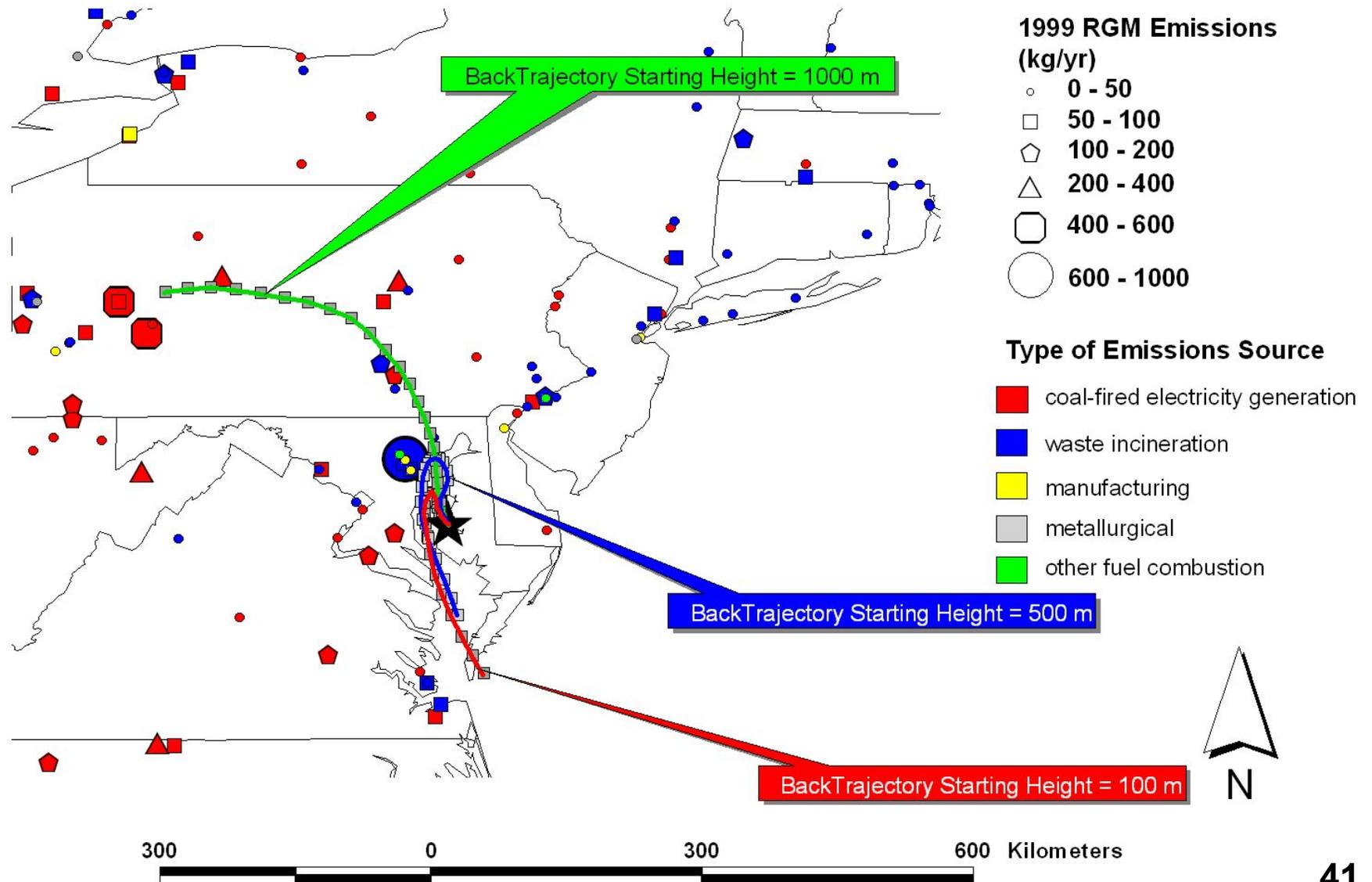
Measured Atmospheric Concentrations at Oxford MD, Summer 2004



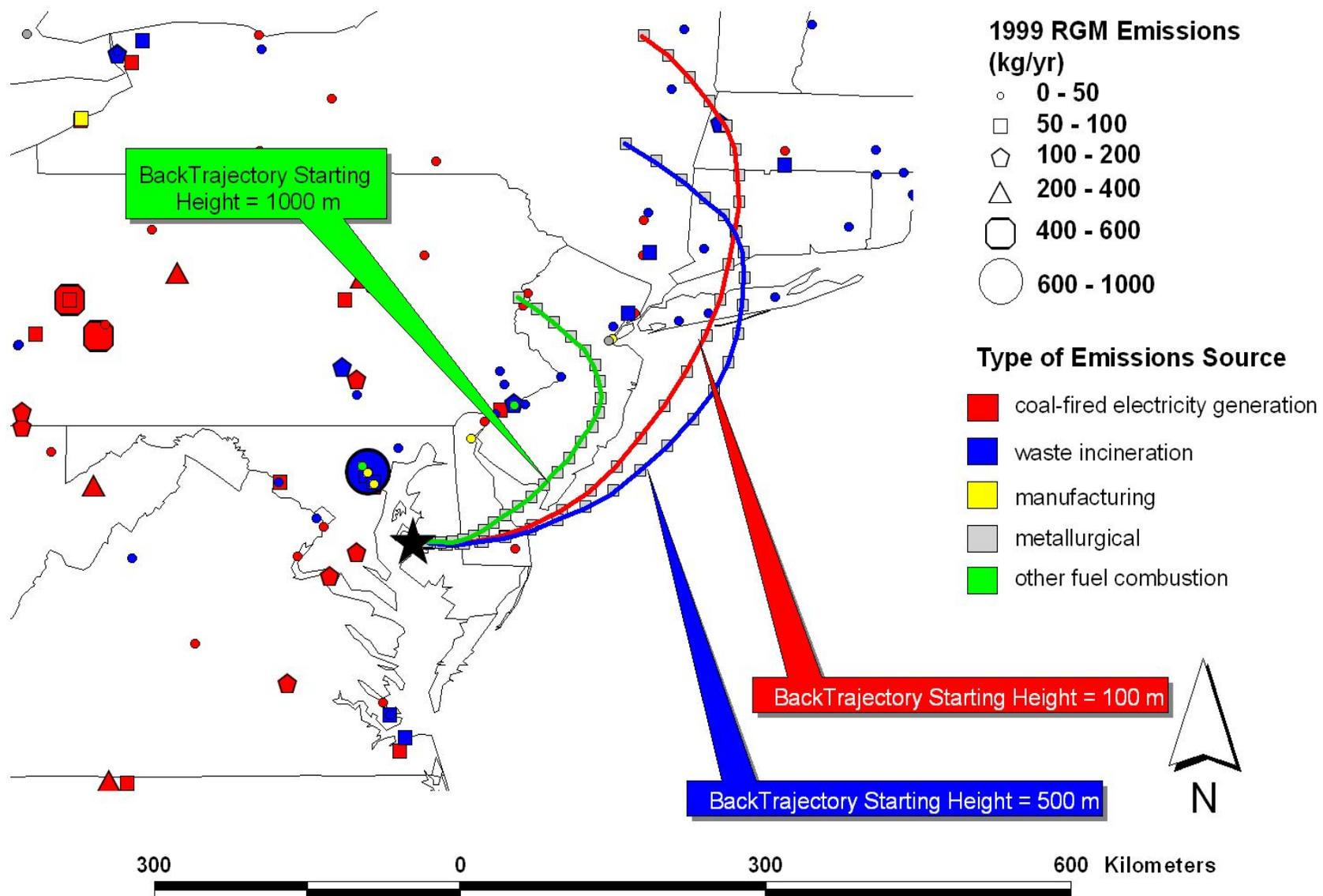
Concentrations Measured at Oxford, MD



Oxford July 2, 2004 Peak Concentration in RGM



Oxford July 3, 2004 -- one day after Peak Concentration in RGM



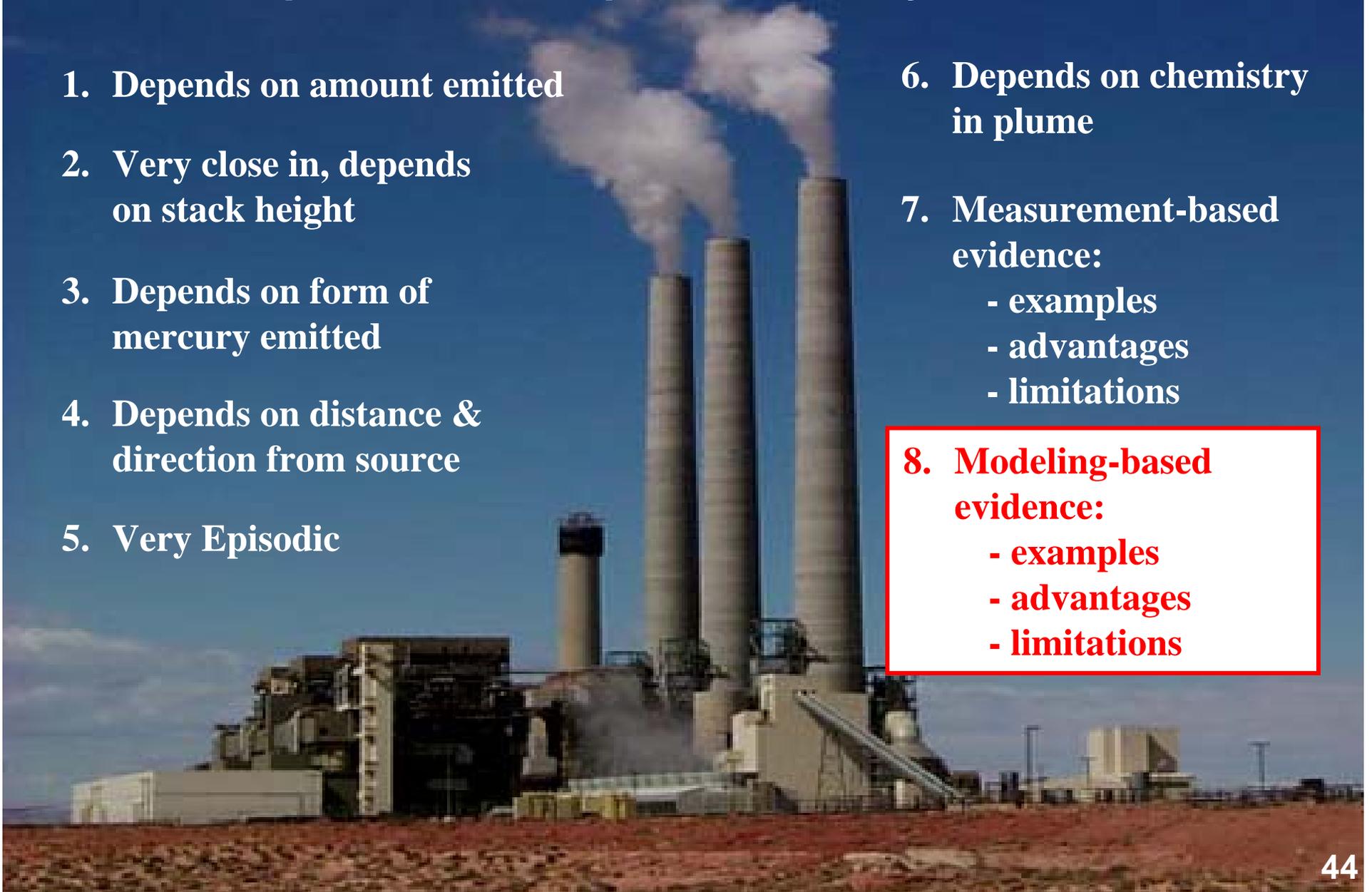
Measurements tell you the “exact” answer (ignoring measurement uncertainties for the moment) but it is usually very difficult to figure out what that answer is telling you, e.g., regarding source-attribution for measured quantities

What are the local and regional deposition impacts of atmospheric mercury emissions?

1. Depends on amount emitted
2. Very close in, depends on stack height
3. Depends on form of mercury emitted
4. Depends on distance & direction from source
5. Very Episodic

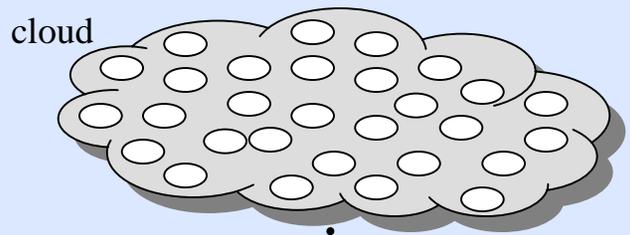
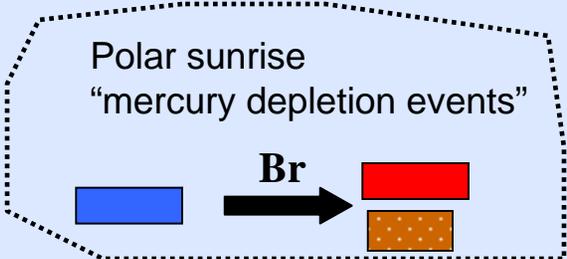
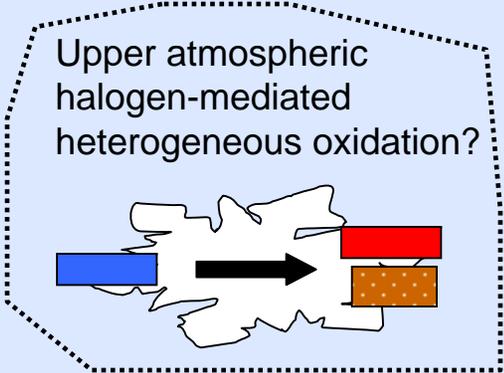
6. Depends on chemistry in plume
7. Measurement-based evidence:
 - examples
 - advantages
 - limitations

- 8. Modeling-based evidence:**
 - examples**
 - advantages**
 - limitations**

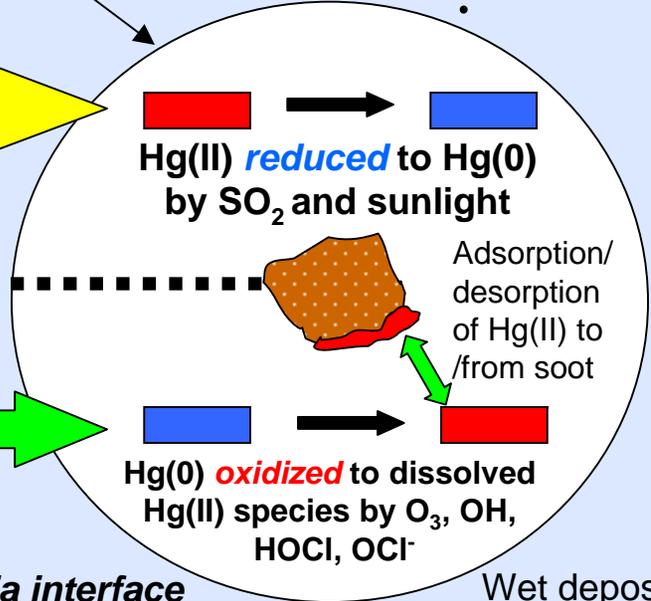


Atmospheric Mercury Fate Processes

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



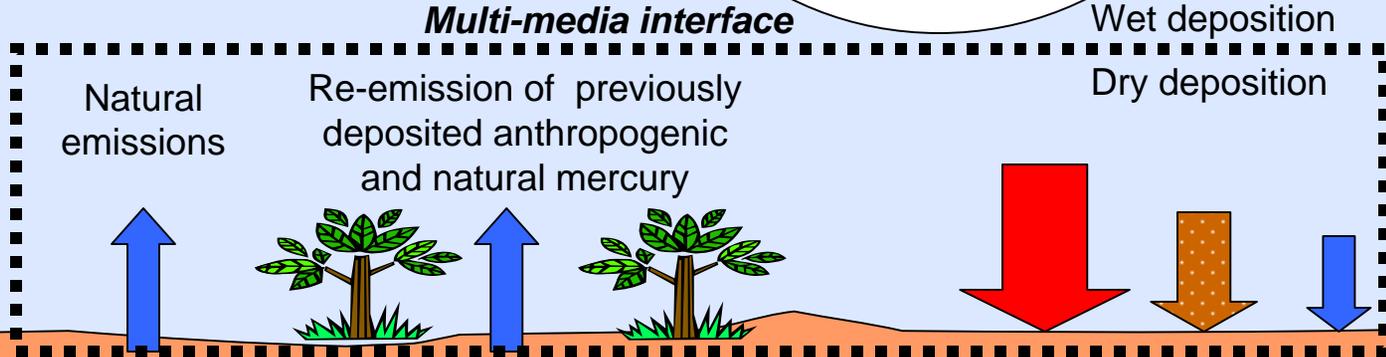
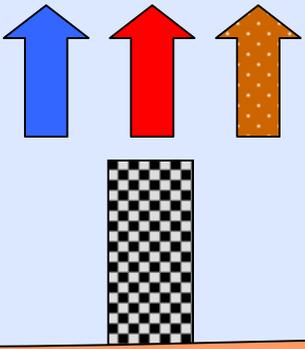
CLOUD DROPLET



Vapor phase:

Hg(0) oxidized to RGM and Hg(p) by O₃, H₂O₂, Cl₂, OH, HCl

Primary Anthropogenic Emissions



*So how good are current models,
and how do they compare
with one another?*

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

**EMEP/TFMM
Workshop on the Review
of the MSC-E Models
on HMs and POPs
Oct 13-14, 2005
Hotel Mir, Moscow Russia**

**Summary presented
by Mark Cohen,
NOAA Air Resources
Laboratory,
Silver Spring,
MD, USA**



Intro- duction	Stage I	Stage II			Stage III			Conclu- sions
	Chemistry	Hg ⁰	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. LohmanUSA..... AER/EPRI
 A. Ryaboshapko, I. Ilyin, O.Travnikov...EMEP..... MSC-E

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

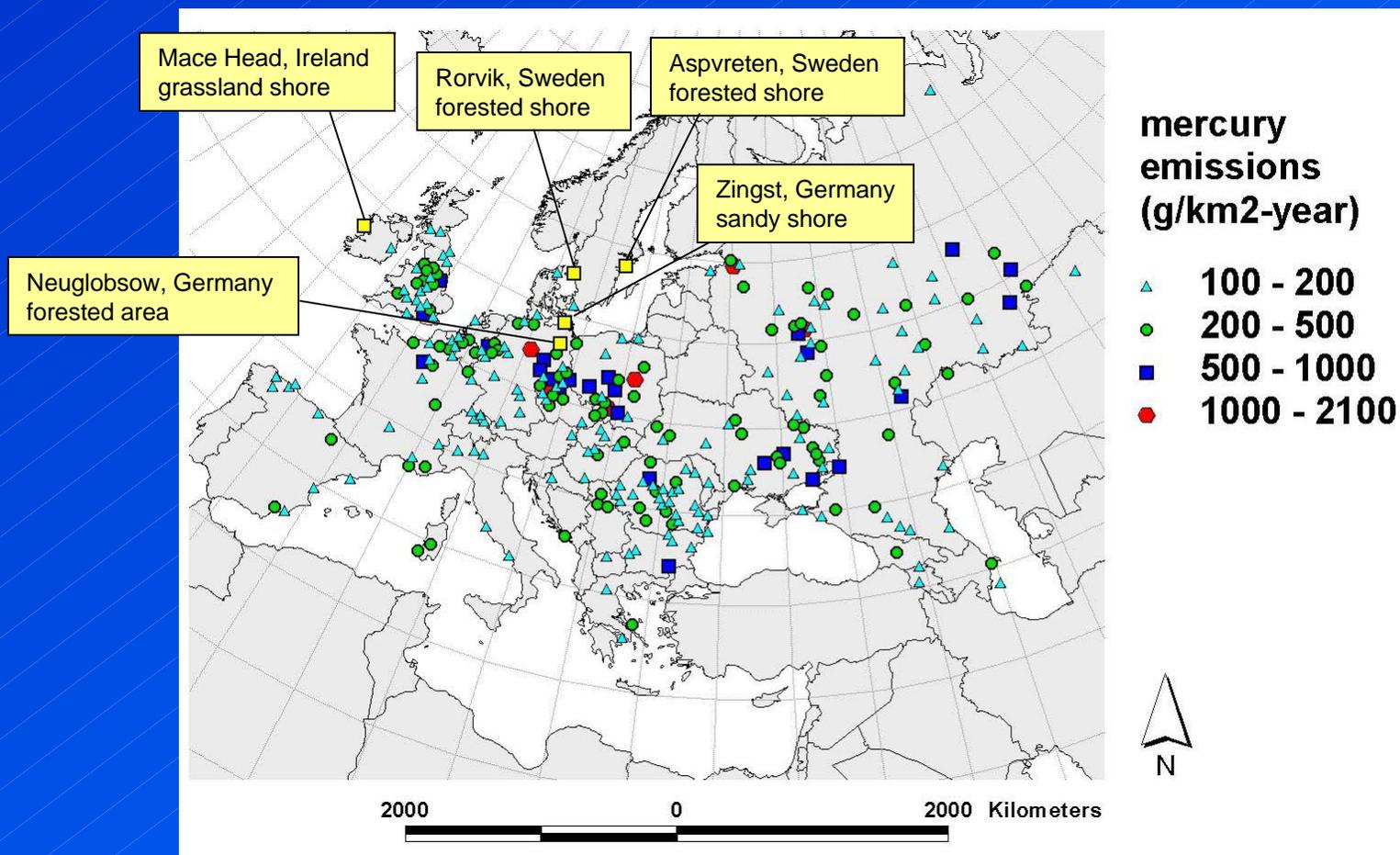
Participating Models

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			

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

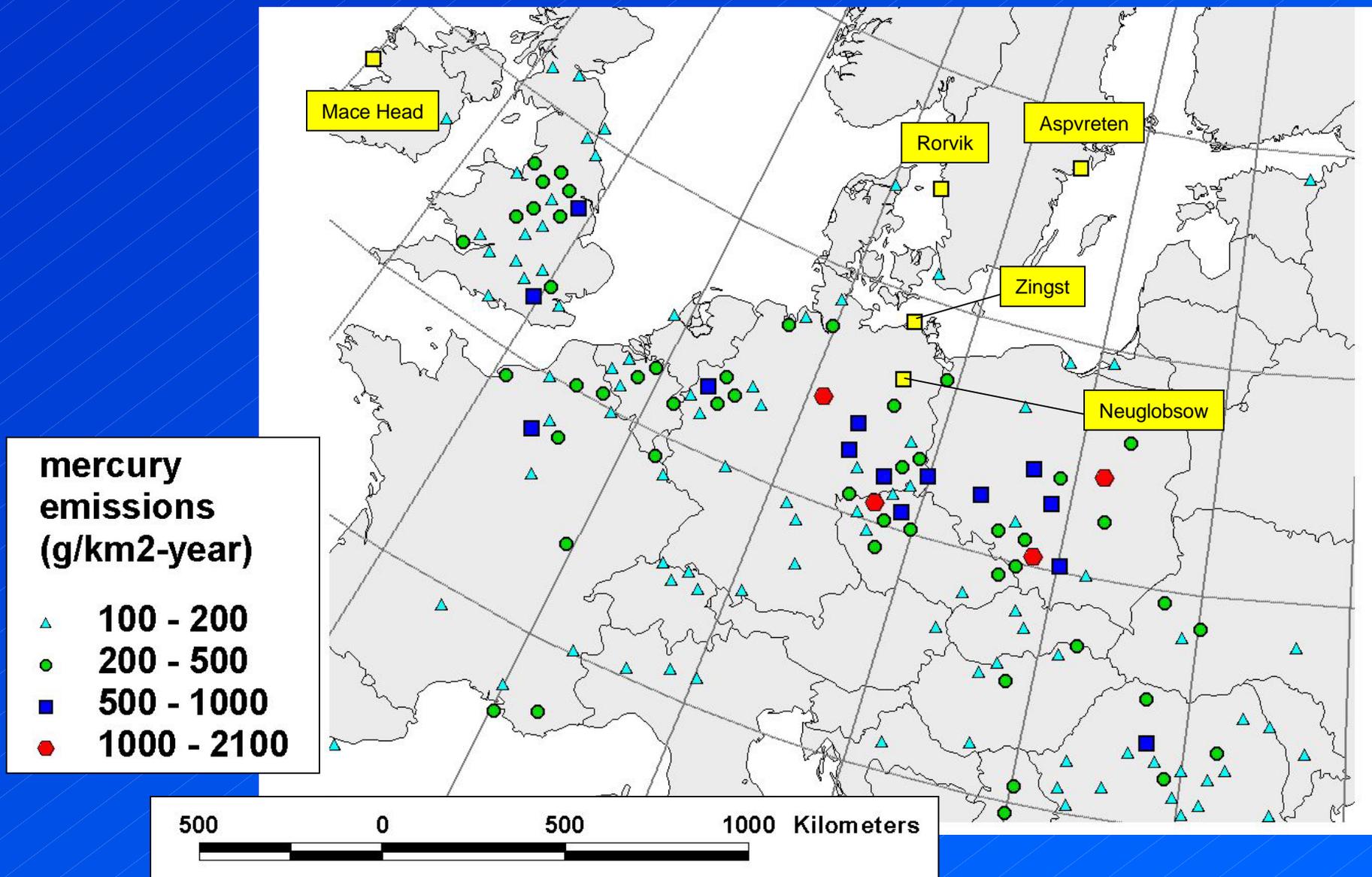
Anthropogenic Mercury Emissions Inventory and Monitoring Sites for Phase II

(note: only showing largest emitting grid cells)



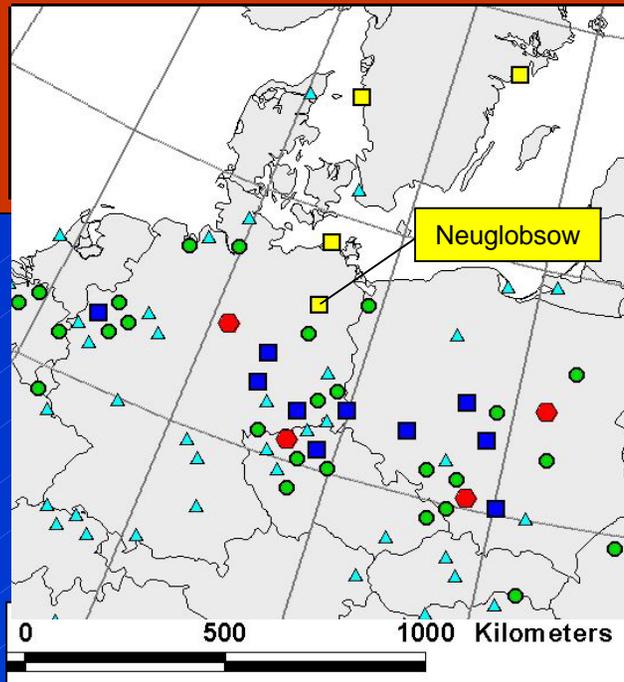
EMEP Intercomparison Study of Numerical Models for Long-Range Atmospheric Transport of Mercury

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

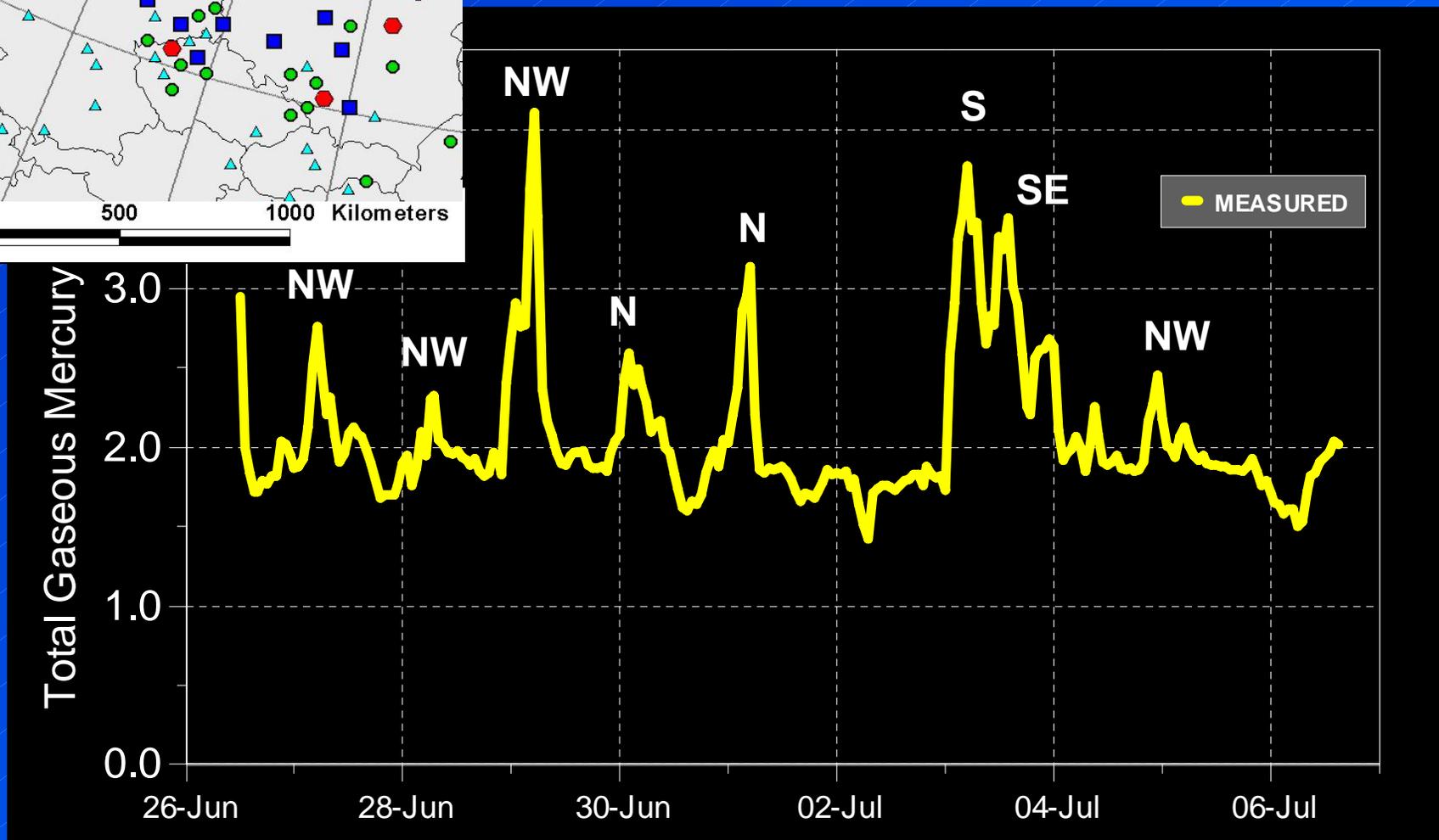


of Numerical Models for Long-Range Atmospheric Transport of Mercury

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



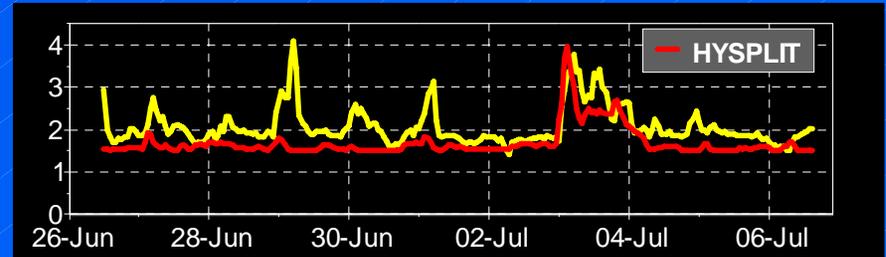
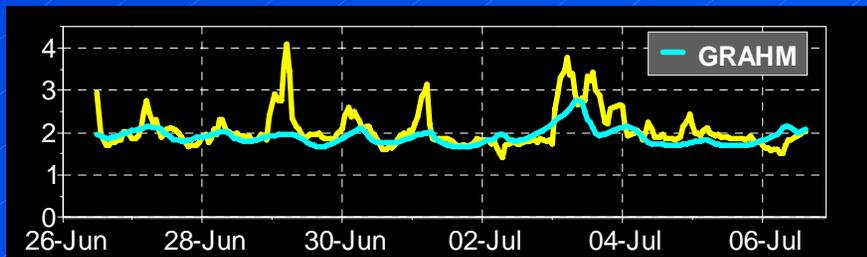
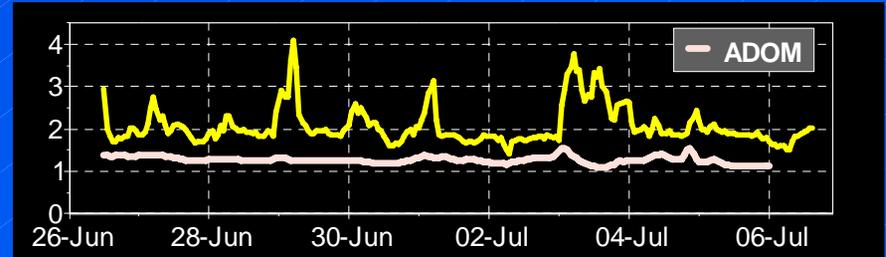
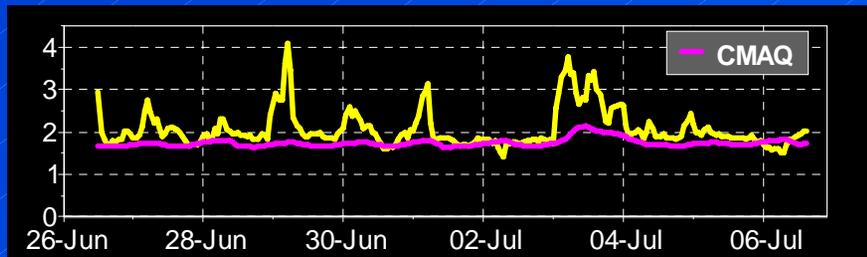
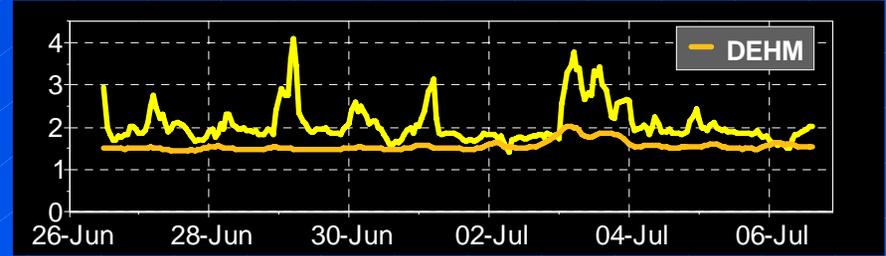
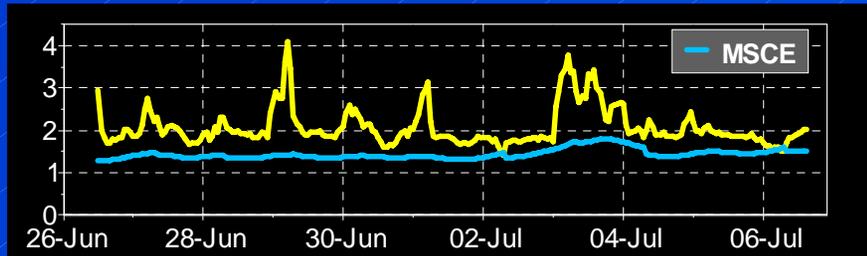
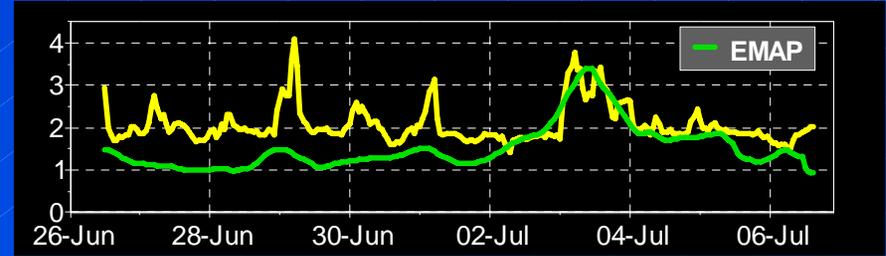
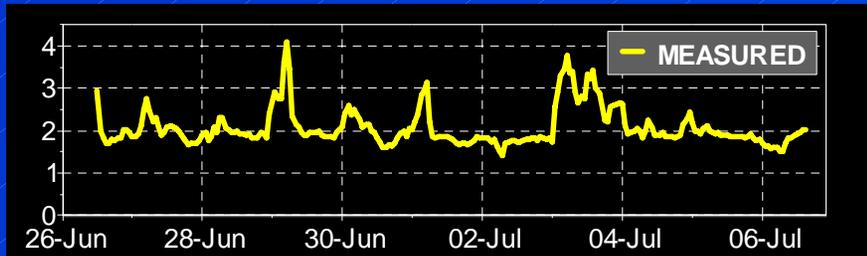
Mercury at Neuglobsow: June 26 – July 6, 1995



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

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

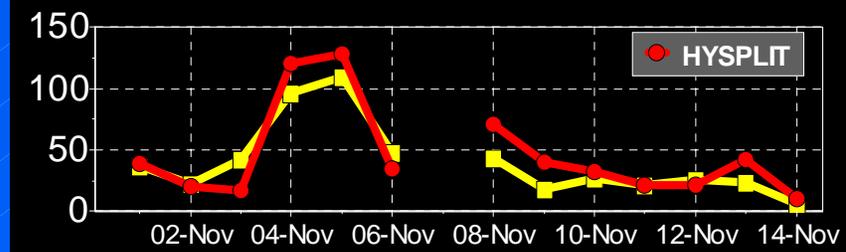
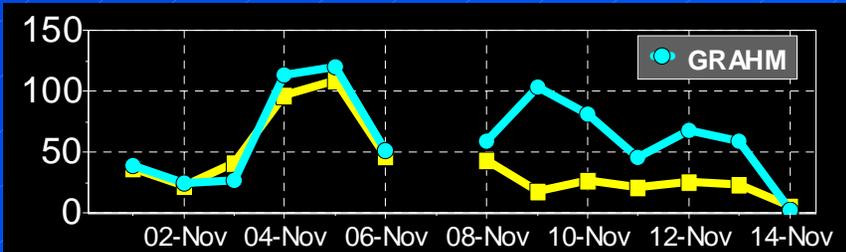
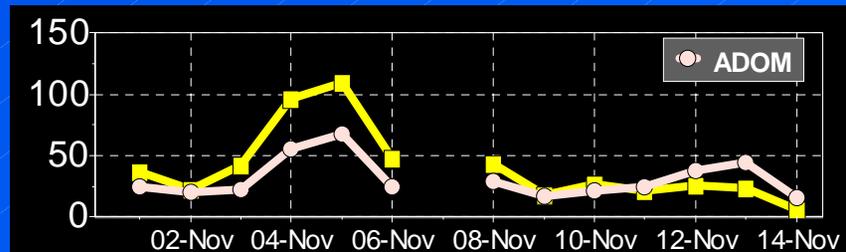
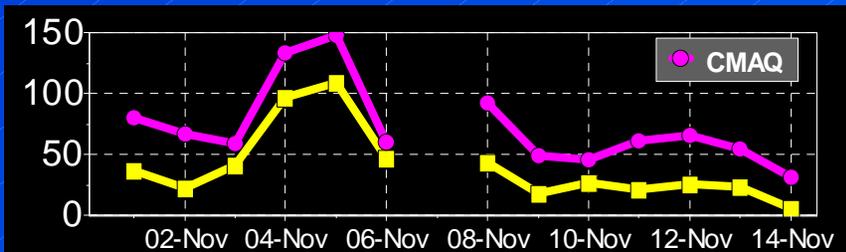
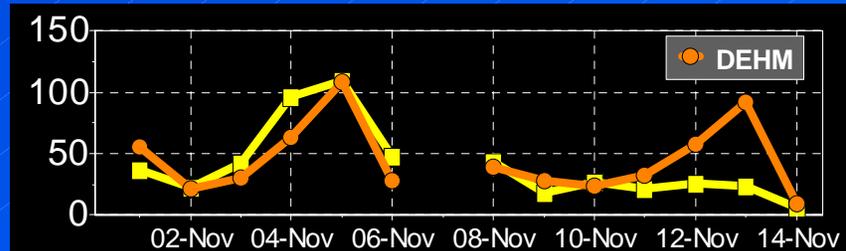
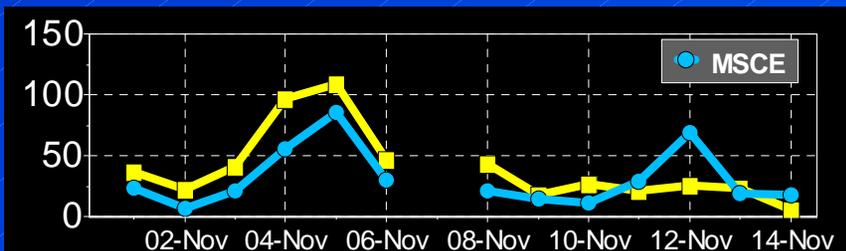
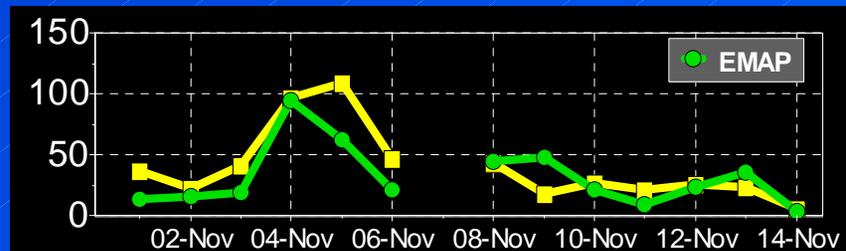
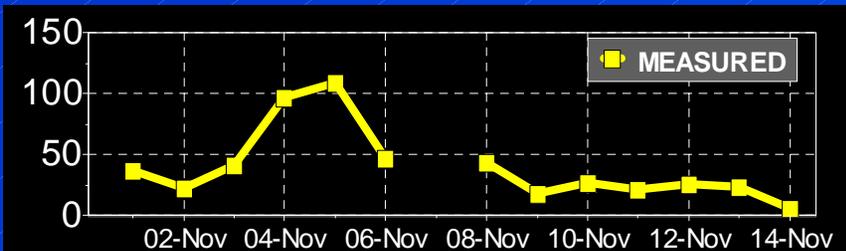
Total Gaseous Mercury (ng/m³) at Neuglobsow: June 26 – July 6, 1995



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

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

Total *Particulate* Mercury (pg/m³) at Neuglobsow, Nov 1-14, 1999



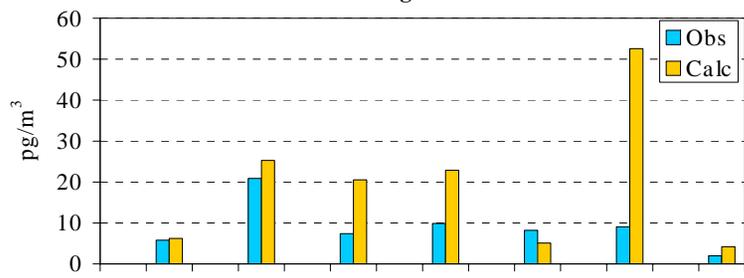
EMEP Intercomparison Study of Numerical Models for

Intro- duction	Stage I	Stage II		
	Chemistry	Hg ⁰	Hg(p)	RGM

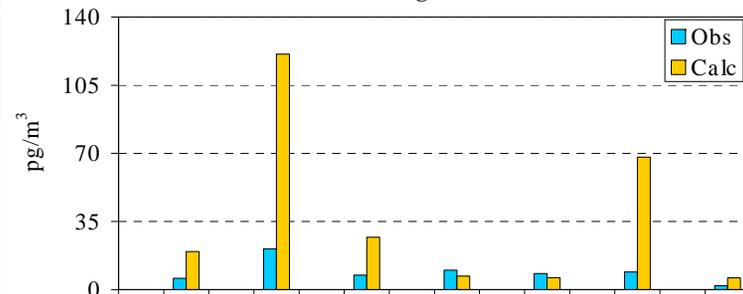
clu-
ons

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

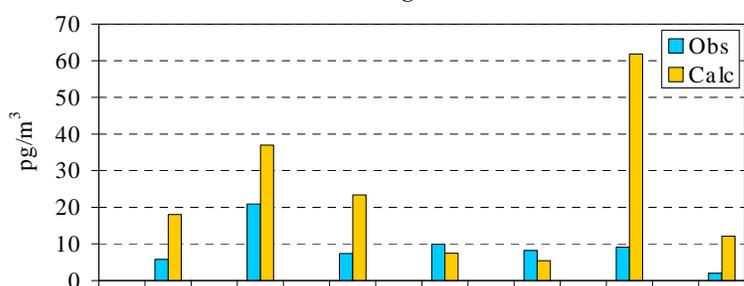
MSCE Neuglobsow RGM



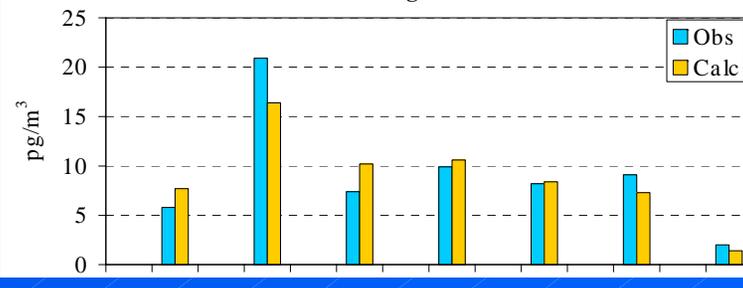
GRAHM Neuglobsow RGM



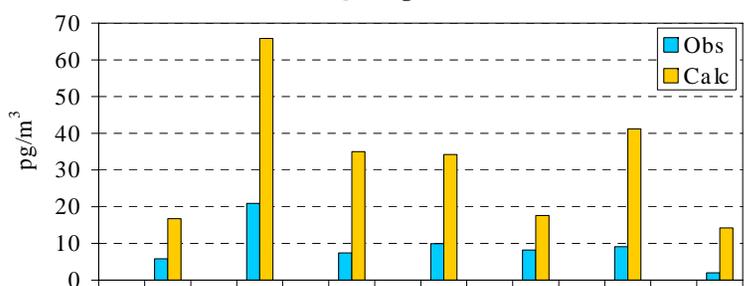
ADOM Neuglobsow RGM



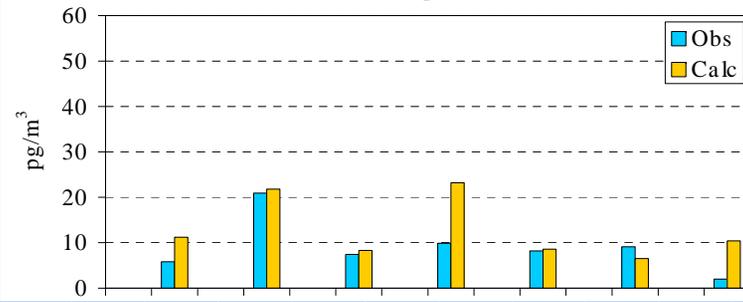
EMAP Neuglobsow RGM



CMAQ Neuglobsow RGM



HYSPLIT Neuglobsow RGM



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

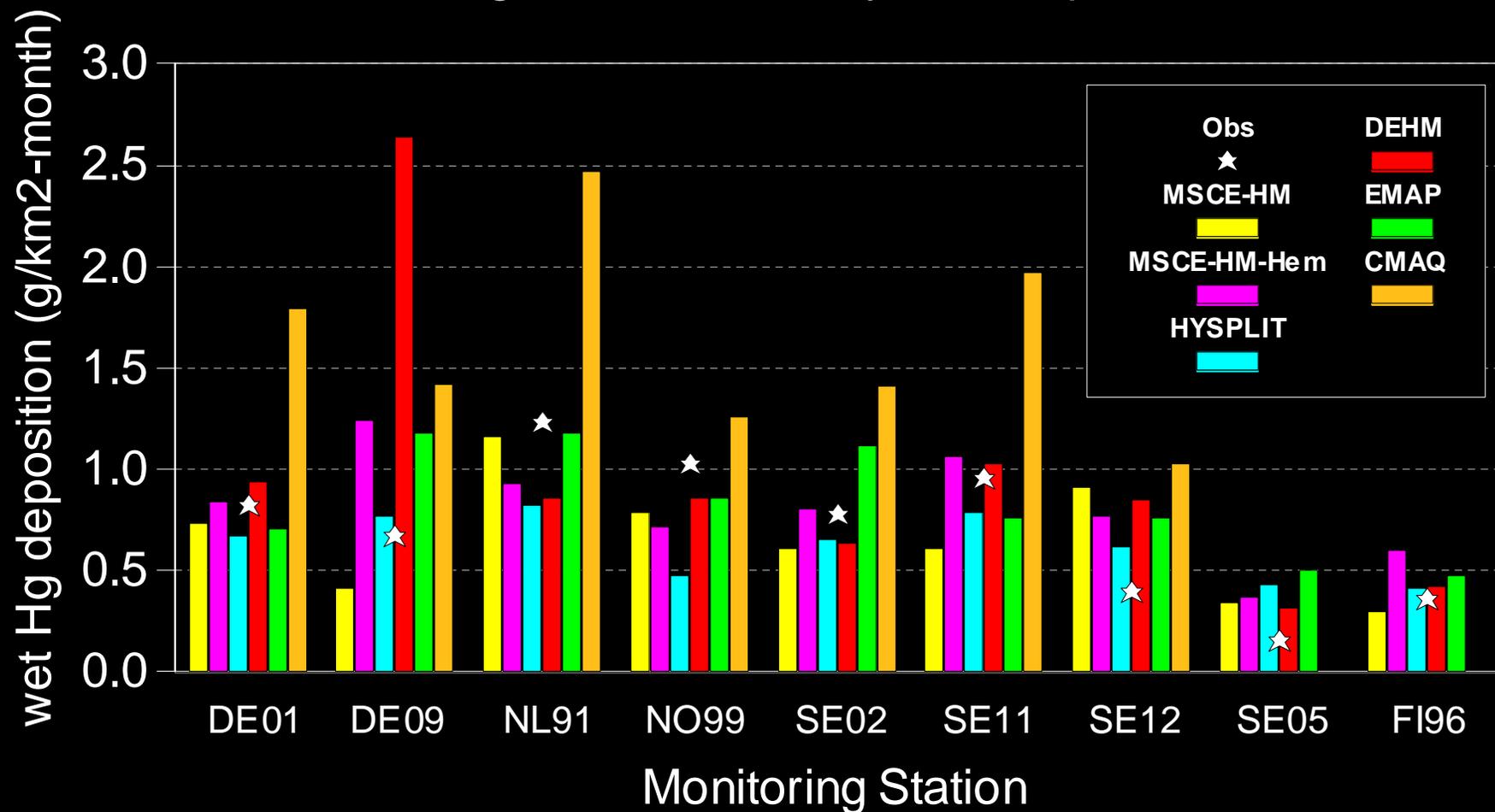
Stage II Publications:

- 2003** Ryaboshapko, A., Artz, R., Bullock, R., Christensen, J., Cohen, M., Dastoor, A., Davignon, D., Draxler, R., Ebinghaus, R., Ilyin, I., Munthe, J., Petersen, G., Syrakov, D. *Intercomparison Study of Numerical Models for Long Range Atmospheric Transport of Mercury. Stage II. Comparisons of Modeling Results with Observations Obtained During Short Term Measuring Campaigns.* Meteorological Synthesizing Centre – East, Moscow, Russia.
- 2005** Ryaboshapko, A., Bullock, R., Christensen, J., Cohen, M., Dastoor, A., Ilyin, I., Petersen, G., Syrakov, D., Artz, R., Davignon, D., Draxler, R., and Munthe, J. *Intercomparison Study of Atmospheric Mercury Models. Phase II. Comparison of Models with Short-Term Measurements.* Submitted to Atmospheric Environment.

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

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

August 1999 Mercury Wet Deposition



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

Stage III Publication:

- 2005** Ryaboshapko, A., Artz, R., Bullock, R., Christensen, J., Cohen, M., Draxler, R., Ilyin, I., Munthe, J., Pacyna, J., Petersen, G., Syrakov, D., Travnikov, O. *Intercomparison Study of Numerical Models for Long Range Atmospheric Transport of Mercury. Stage III. Comparison of Modelling Results with Long-Term Observations and Comparison of Calculated Items of Regional Balances.* Meteorological Synthesizing Centre – East, Moscow, Russia.

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

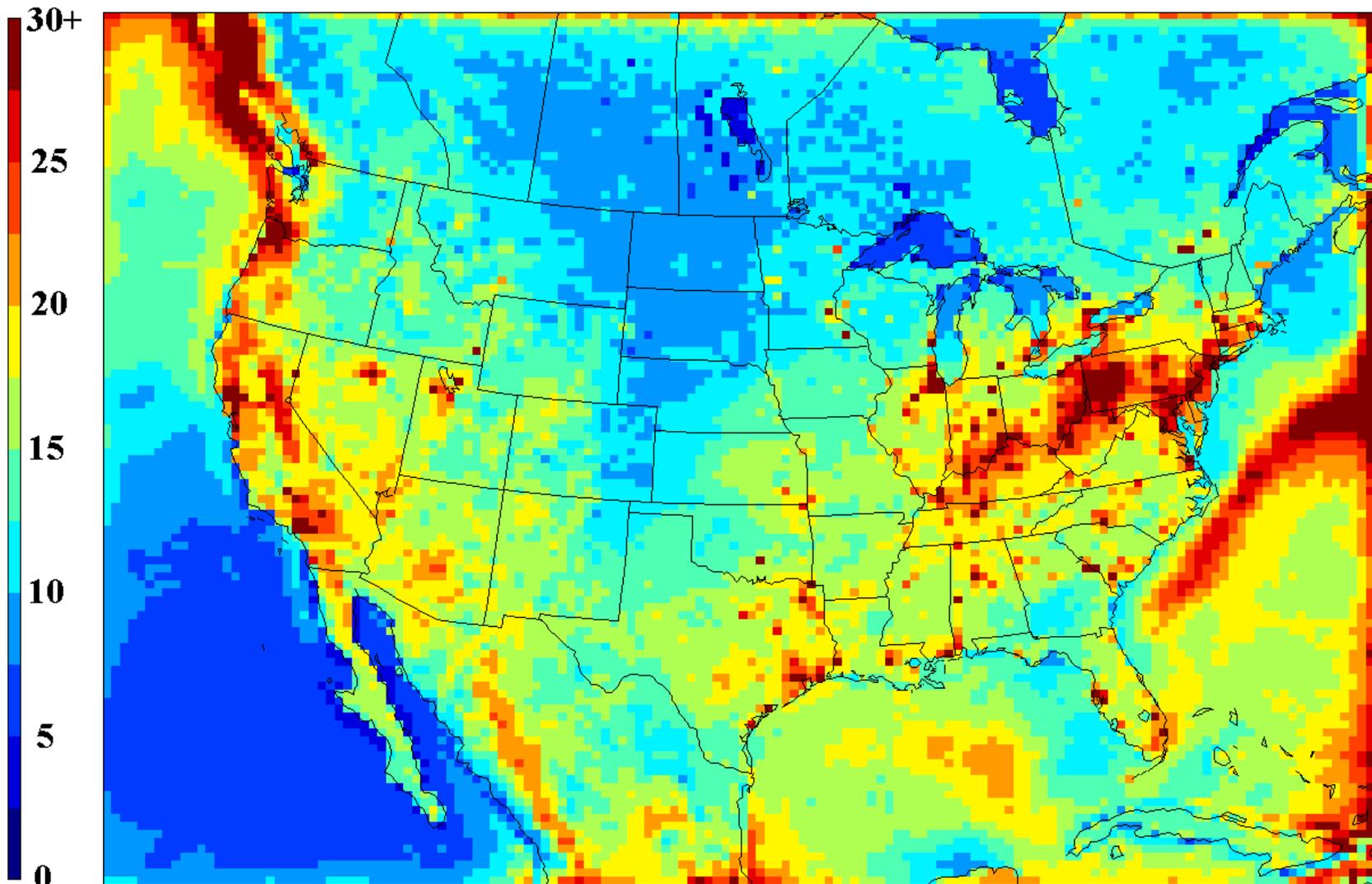
Conclusions: Uncertainties in Mercury Modeling

- Elemental Hg in air - factor of **1.2**
- Particulate Hg in air - factor of **1.5**
- Oxidized gaseous Hg in air - factor of **5**
- Total Hg in precipitation - factor of **1.5**
- Wet deposition - factor of **2.0**
- Dry deposition - factor of **2.5**
- Balances for countries - factor of **2**

Models give you a lot of information about why a given concentration or deposition occurs, and gives you information over broad areas, but due to uncertainties – in emissions, meteorology, chemistry, and deposition processes – current models cannot generally give you the exact answer...

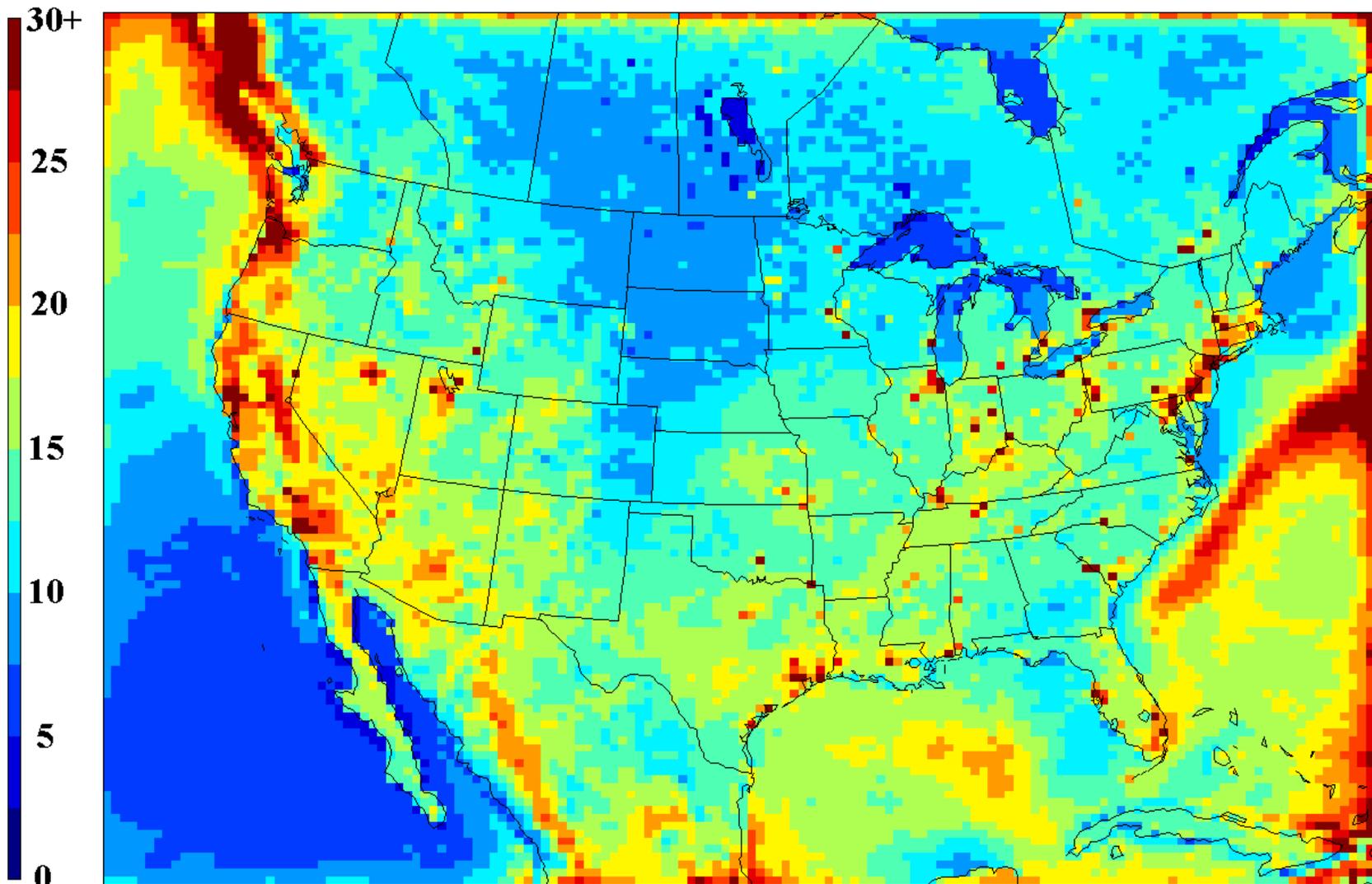
***Some CMAQ results,
used in the development
of the CAMR rule,
courtesy of
Russ Bullock, EPA***

CMAQ-simulated total mercury deposition for 2001 (micrograms per square meter)



Base case

CMAQ-simulated total mercury deposition for 2001 (micrograms per square meter)



Utility Zero Out

Possible underestimation of local and/or regional impacts in CMAQ-Hg modeling done in support of CAMR:

- **36 km grid too coarse to capture local impacts – they are artificially diluted**

USEPA (2005). Clean Air Mercury Rule (CAMR) Technical Support Document: *Methodology Used to Generate Deposition, Fish Tissue Methylmercury Concentrations, and Exposure for Determining Effectiveness of Utility Emissions Controls: Analysis of Mercury from Electricity Generating Units*, page 4

- **inclusion of hydroperoxyl radical (HO₂•) chemical reaction reducing RGM back to elemental mercury – most models no longer include this reaction since strong evidence exists that it does not occur in the atmosphere**

Gardfeldt, K. and M. Jonnson (2003). Is bimolecular reduction of Hg(II)-complexes possible in aqueous systems of environmental importance? *J. Phys. Chem. A*, **107** (22): 4478-4482.

Possible overestimation of global impacts in CMAQ-Hg modeling done in support of CAMR:

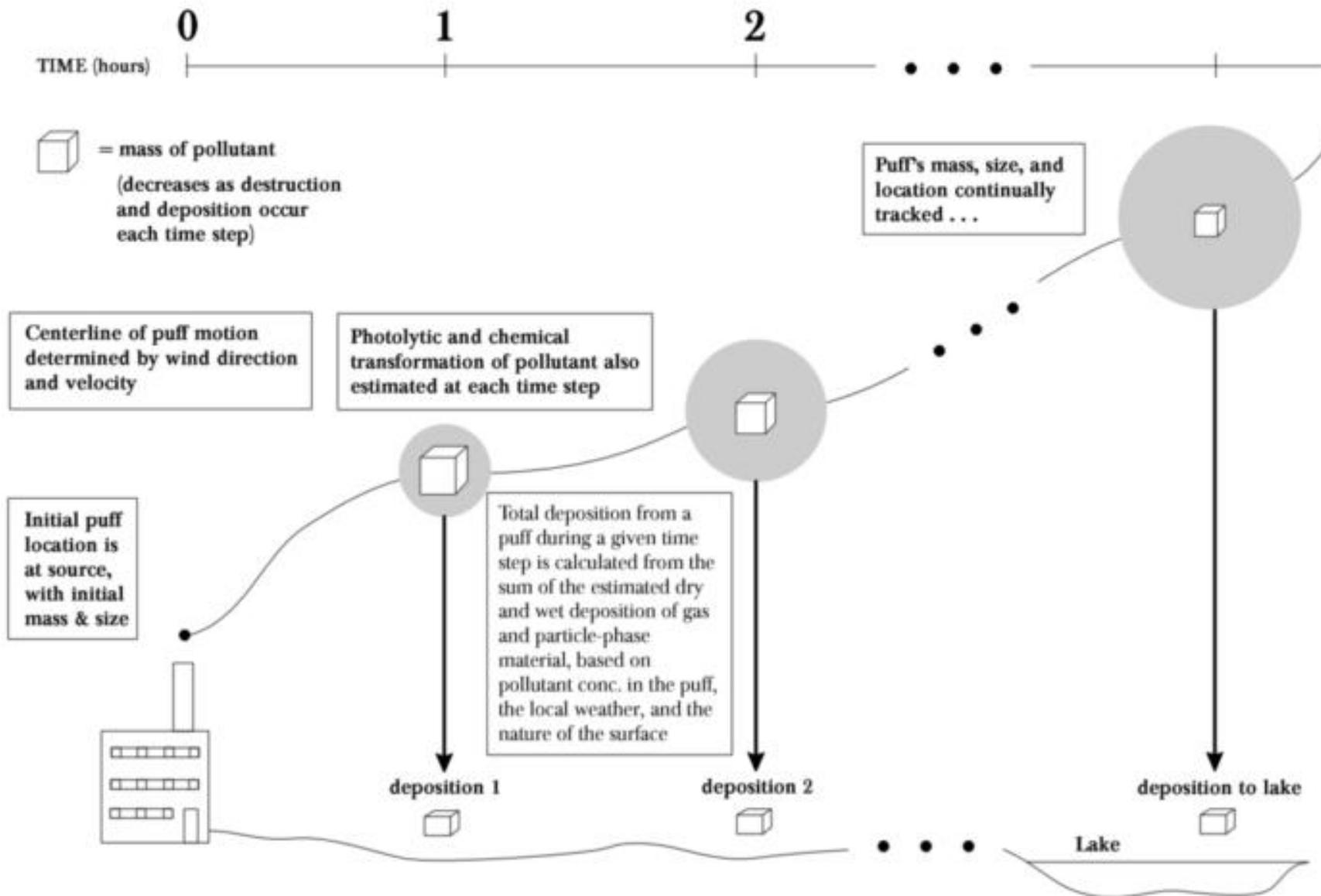
- **Strong influence of boundary conditions; appears that RGM may have been specified too high on the boundary; *perhaps* (?) due to an inconsistency in physics/chemistry between global model (GEOS-Chem) providing boundary conditions and that of CMAQ-Hg?**
- **Two reactions included in CMAQ oxidizing elemental Hg to RGM may have been significantly overestimated (O₃ and OH)**

Calvert, J., and S. Lindberg (2005). Mechanisms of mercury removal by O₃ and OH in the atmosphere. *Atmospheric Environment* 39: 3355-3367.

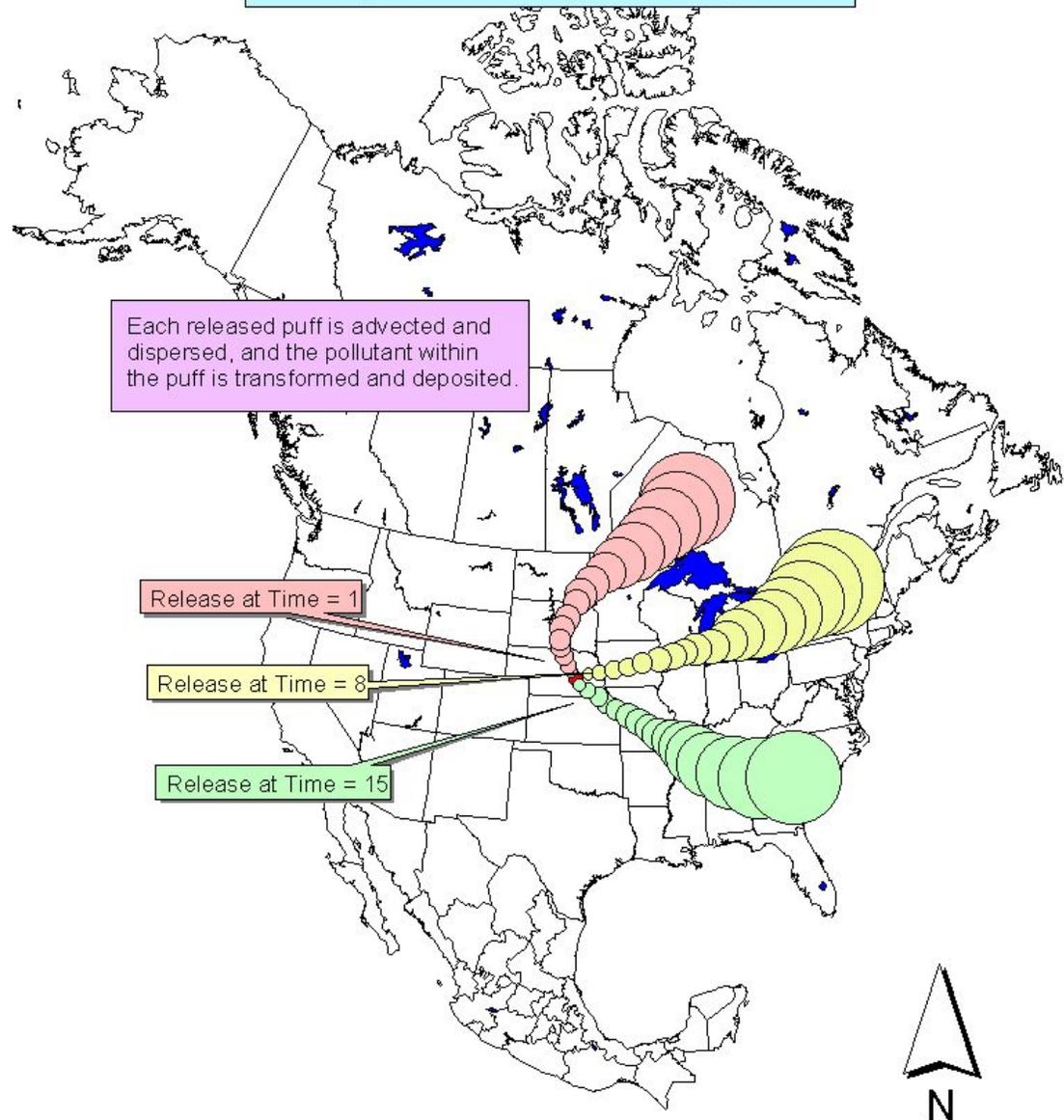
***Some HYSPLIT-Hg results,
for impacts of U.S. and
Canadian anthropogenic
sources on selected receptors***

NOAA HYSPLIT MODEL

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).





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,d} Jennifer Slotnick,^f Todd Nettesheim,^g and John McDonald^h

^a NOAA Air Resources Laboratory, 1315 East West Highway, BART, Room 316, Silver Spring, MD 20910, USA

^b Commission for Environmental Cooperation, Montreal, Que., Canada

^c Atmospheric Toxicology

^d Biometrics

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.

Abstract

A special version of mercury in a North American region and provide estimates of atmospheric mercury available for model evaluation in the Great Lakes region from the Great Lakes. Significant contribution to atmospheric mercury is published by Elsevier.

Keywords: Mercury; Atmospheric transport; Deposition; Great Lakes

Mercury contamination of other ecosystems is a serious environmental problem. Human exposure to mercury, and significant levels of mercury (2000). Historical production using the to have caused in

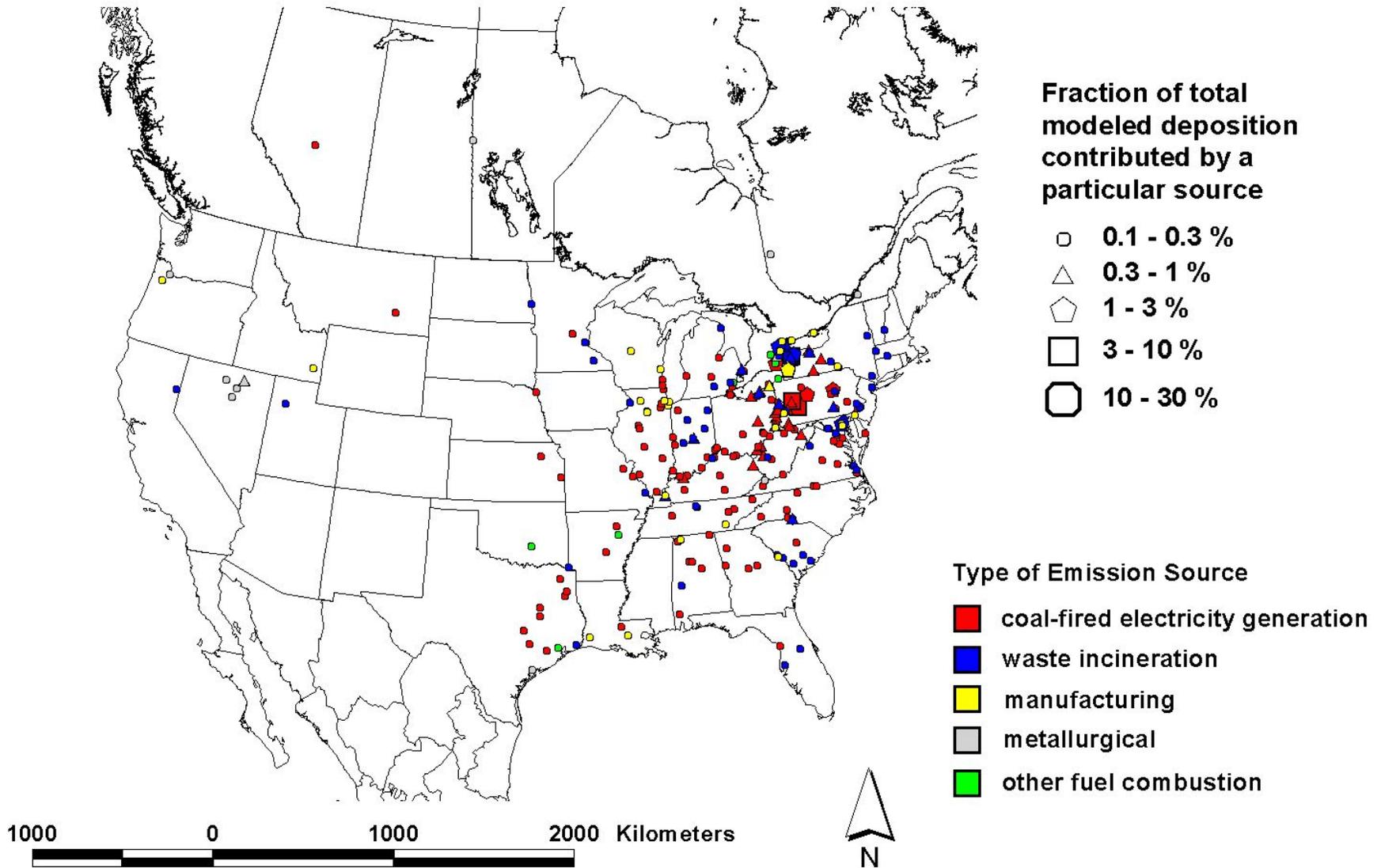
[☆] Supplementary data available on the online version, at doi:10.1016/j.envres.2003.11.007

* Corresponding author. E-mail address: mark.cohen@noaa.gov (M. Cohen).

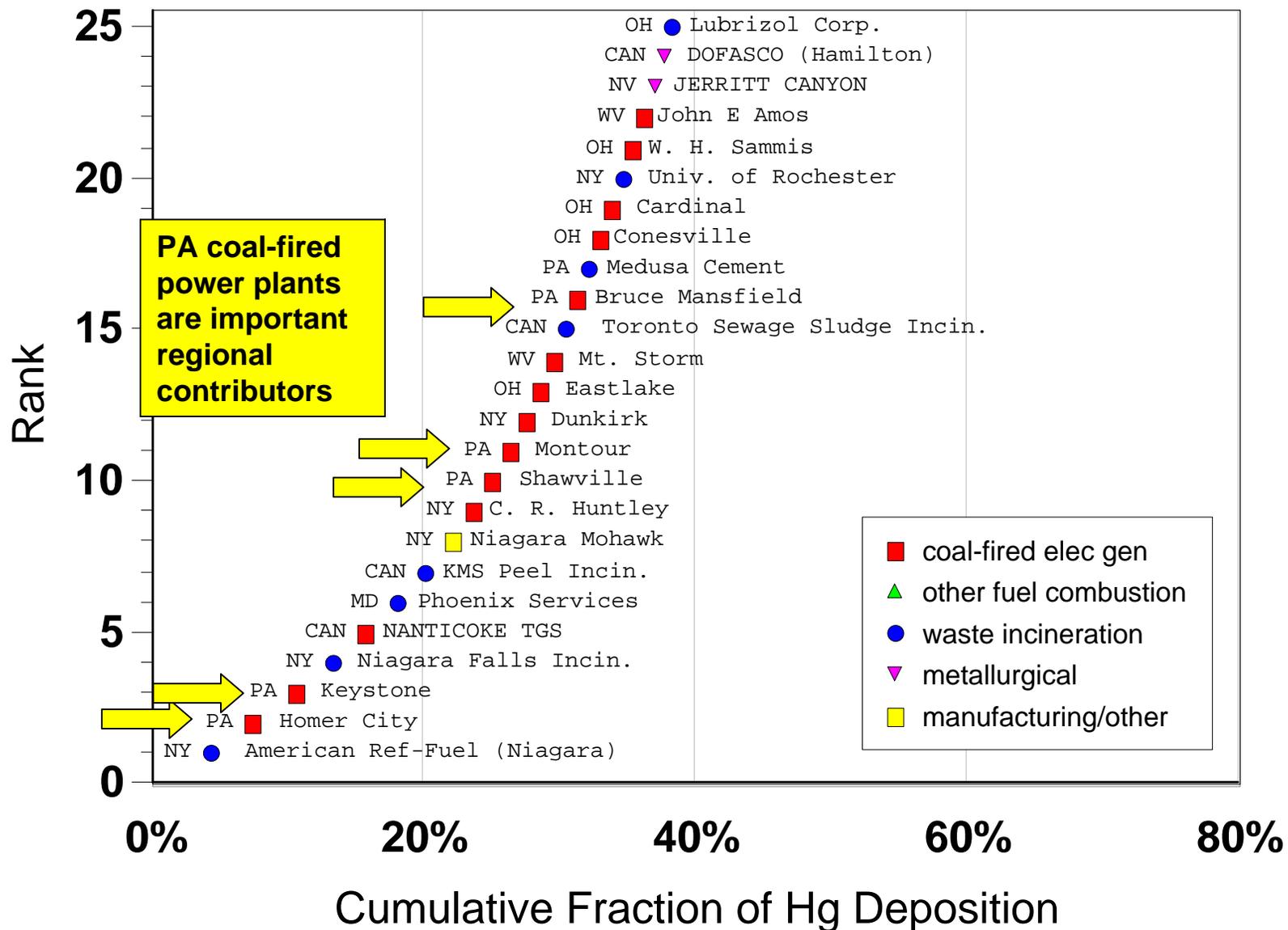
^h Current address: IAPRA, Canada, The Institute of Environmental Research, Concord, Ontario, Canada

has developed detailed source-receptor relationships for the Great Lakes, as advocated in Annex 15 of the Great

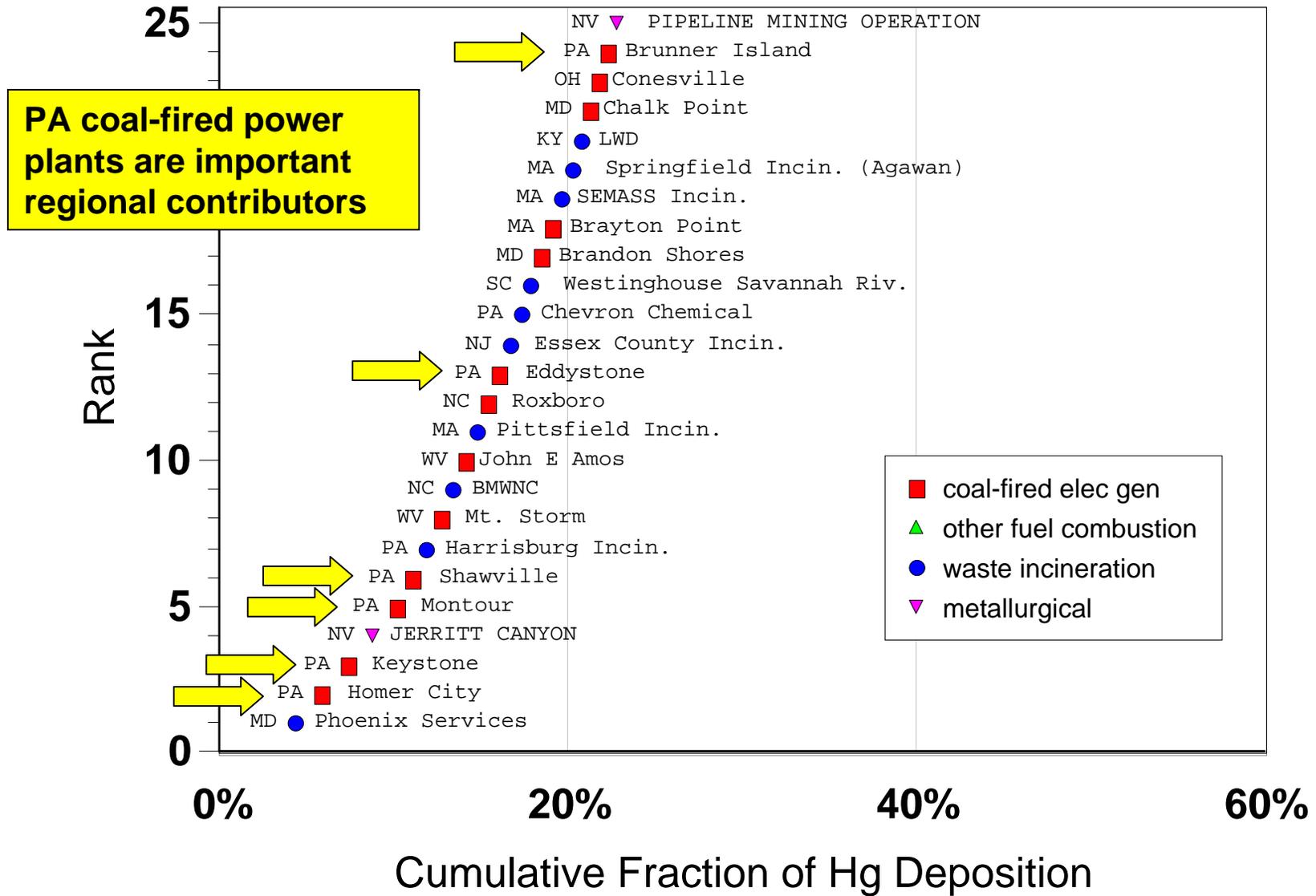
Largest atmospheric deposition contributors to Lake Ontario based on 1999-2000 emissions



Top 25 Contributors to 1999 Hg Deposition Directly to Lake Ontario



Top 25 Contributors to 1999 Hg Deposition to Acadia National Park



- ❑ The HYSPLIT modeling results presented here have only considered the impacts from anthropogenic sources in the United States and Canada**

- ❑ the model is currently being extended to a global domain... but results are not yet available**

- ❑ However, even if every source in the world was modeled, it is highly likely that these local and regional sources would still be the top contributing sources to local/regional receptors...**

- ❑ It is unlikely that a coal-fired power plant in China, for example, could contribute as much to one of these receptors as a comparable facility in the U.S.**

Concluding Observations



Coal-fired power plants emit large amounts of mercury



Local and regional impacts depend on a number of factors (e.g., relative proportions of the different forms emitted)



Challenges in using monitoring approaches to assess impacts

- local/regional impacts are highly episodic and spatially variable
- measurements to date can't unambiguously assess such impacts
- *definitive field experiments have not yet been carried out*



Challenges in using modeling analyses to assess impacts

- significant uncertainties in emissions, meteorology, and fate processes
- *adequate data for model evaluation and improvement not yet available*



However, limited model evaluations are encouraging and suggest that models are generating reasonable results



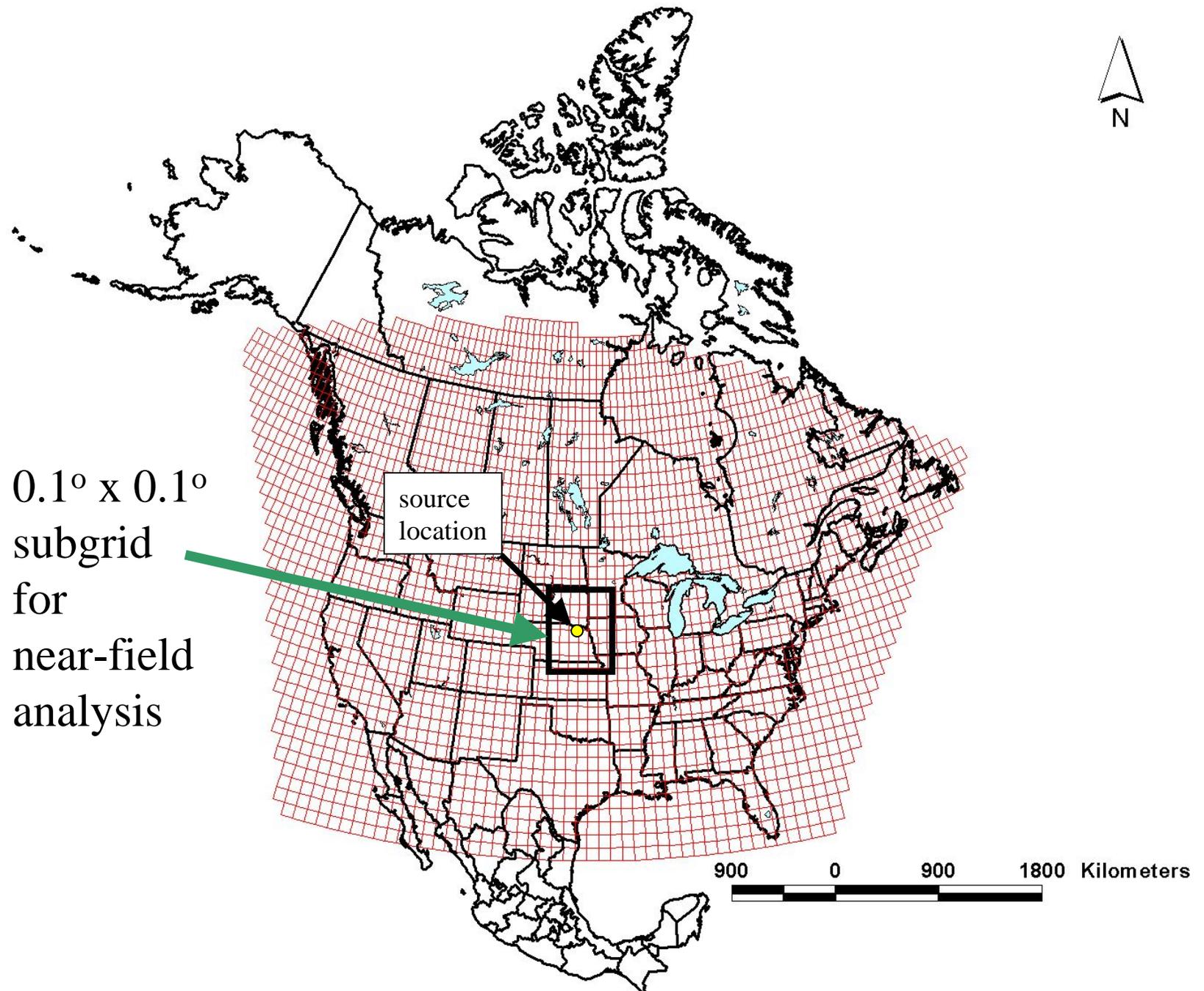
Modeling tends to show significant local/regional impacts



Emissions trading will result in winners and losers...

Thanks!

Extra Slides



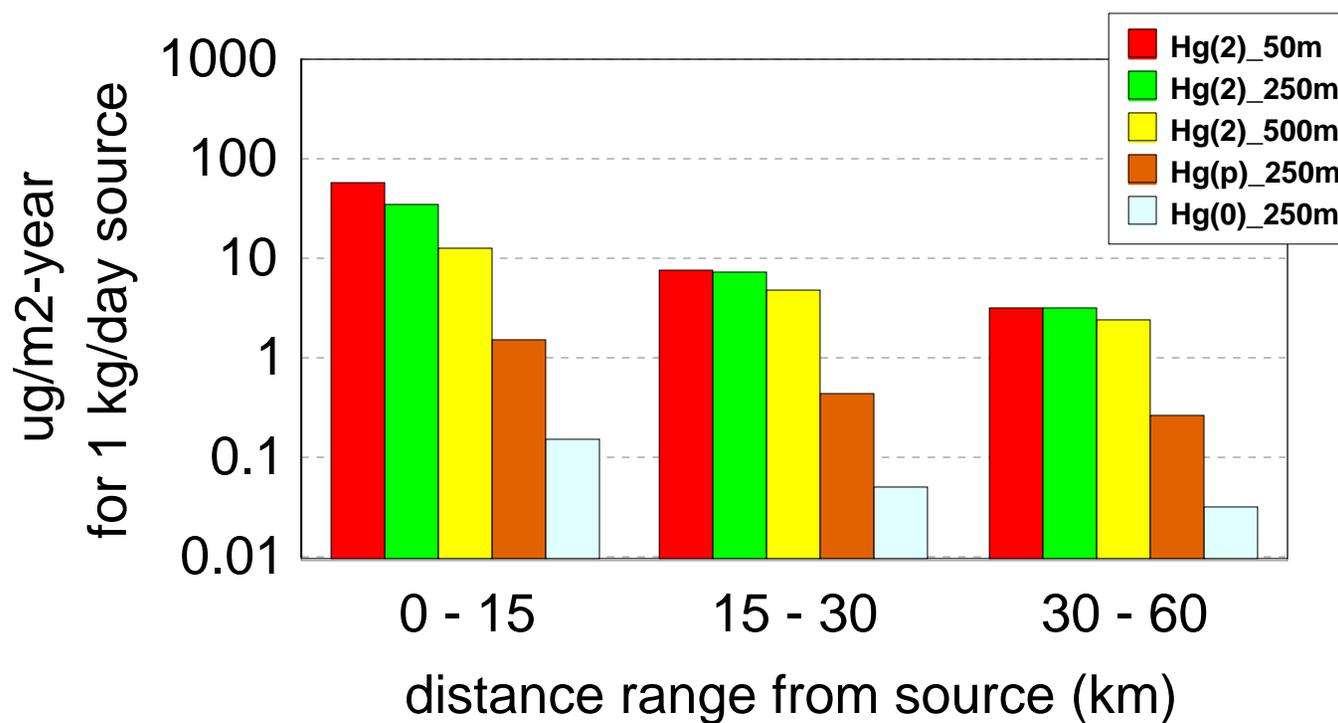
0.1° x 0.1°
subgrid
for
near-field
analysis

source
location

900 0 900 1800 Kilometers

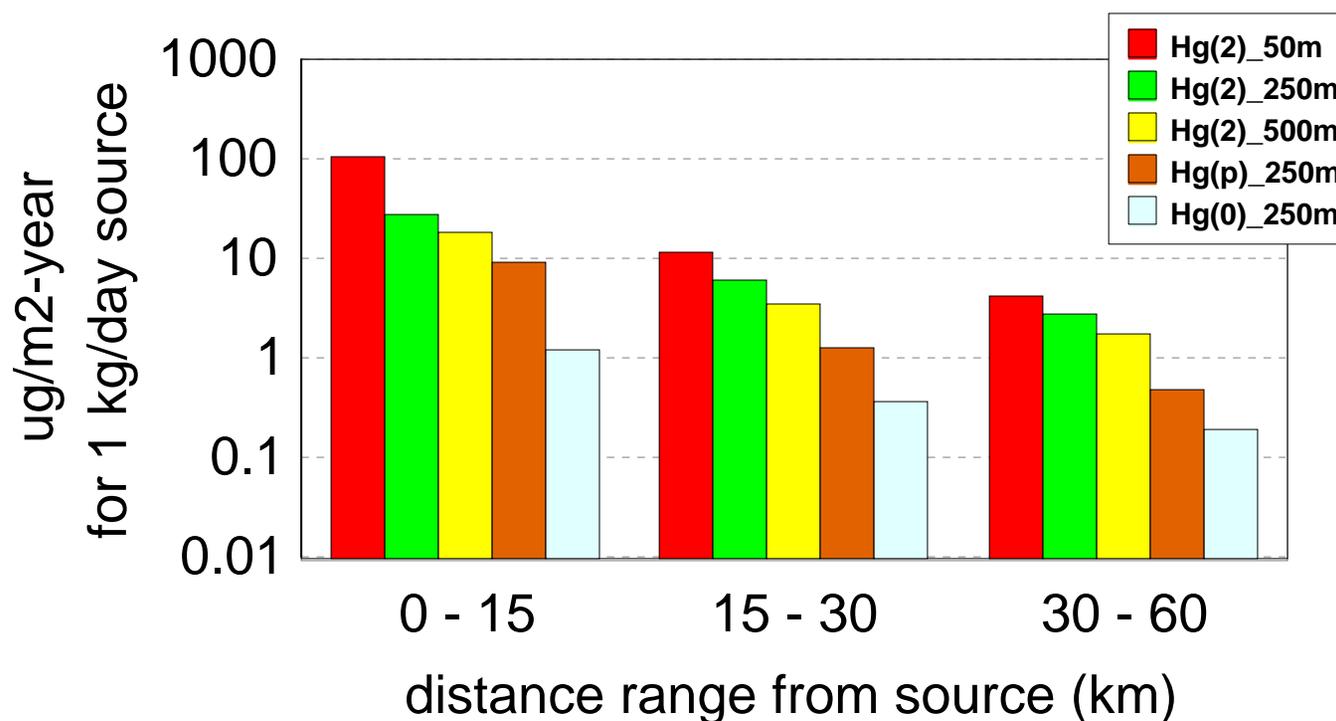
Wet + Dry Deposition: HYSPLIT (Nebraska)

for emissions of different mercury forms from different stack heights



Wet + Dry Deposition: ISC (Tampa)

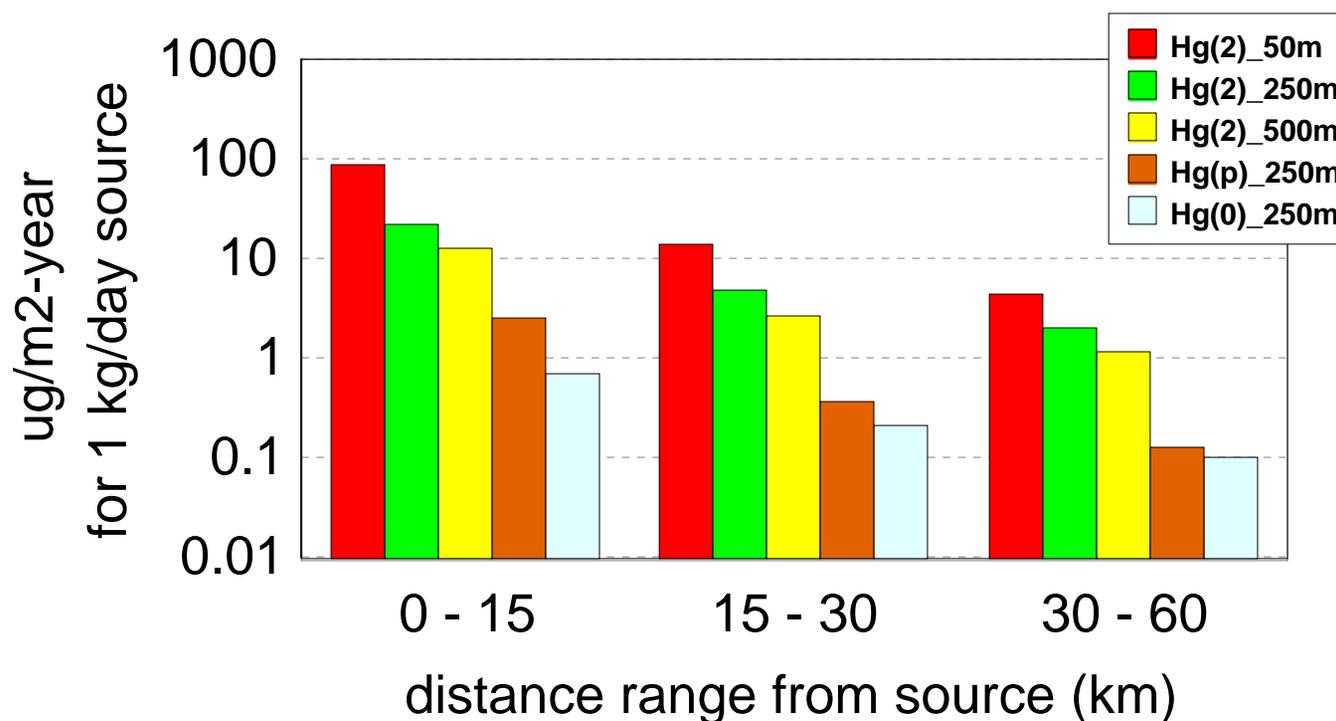
for emissions of different mercury forms from different stack heights



Calculated from data used to produce Appendix A of USEPA (2005): Clean Air Mercury Rule (CAMR) Technical Support Document: Methodology Used to Generate Deposition, Fish Tissue Methylmercury Concentrations, and Exposure for Determining Effectiveness of Utility Emissions Controls: Analysis of Mercury from Electricity Generating Units

Wet + Dry Deposition: ISC (Phoenix)

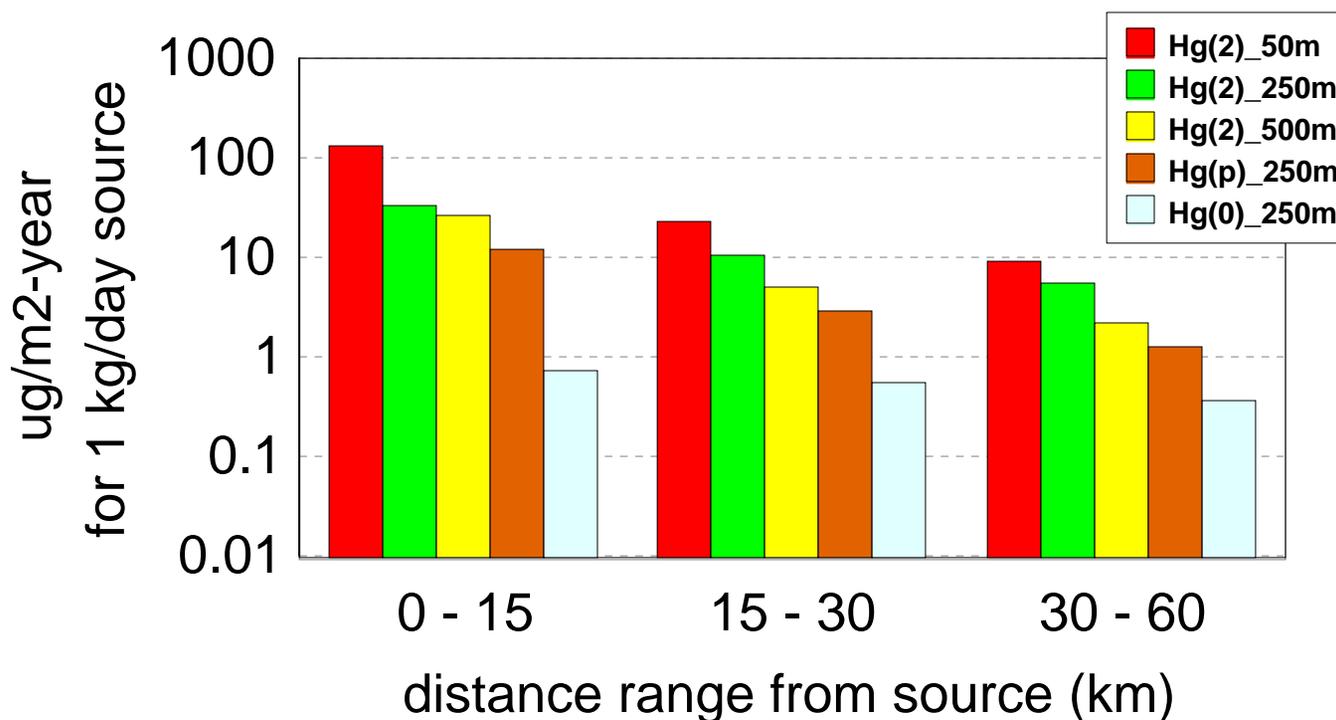
for emissions of different mercury forms from different stack heights



Calculated from data used to produce Appendix A of USEPA (2005): Clean Air Mercury Rule (CAMR) Technical Support Document: Methodology Used to Generate Deposition, Fish Tissue Methylmercury Concentrations, and Exposure for Determining Effectiveness of Utility Emissions Controls: Analysis of Mercury from Electricity Generating Units

Wet + Dry Deposition: ISC (Indianapolis)

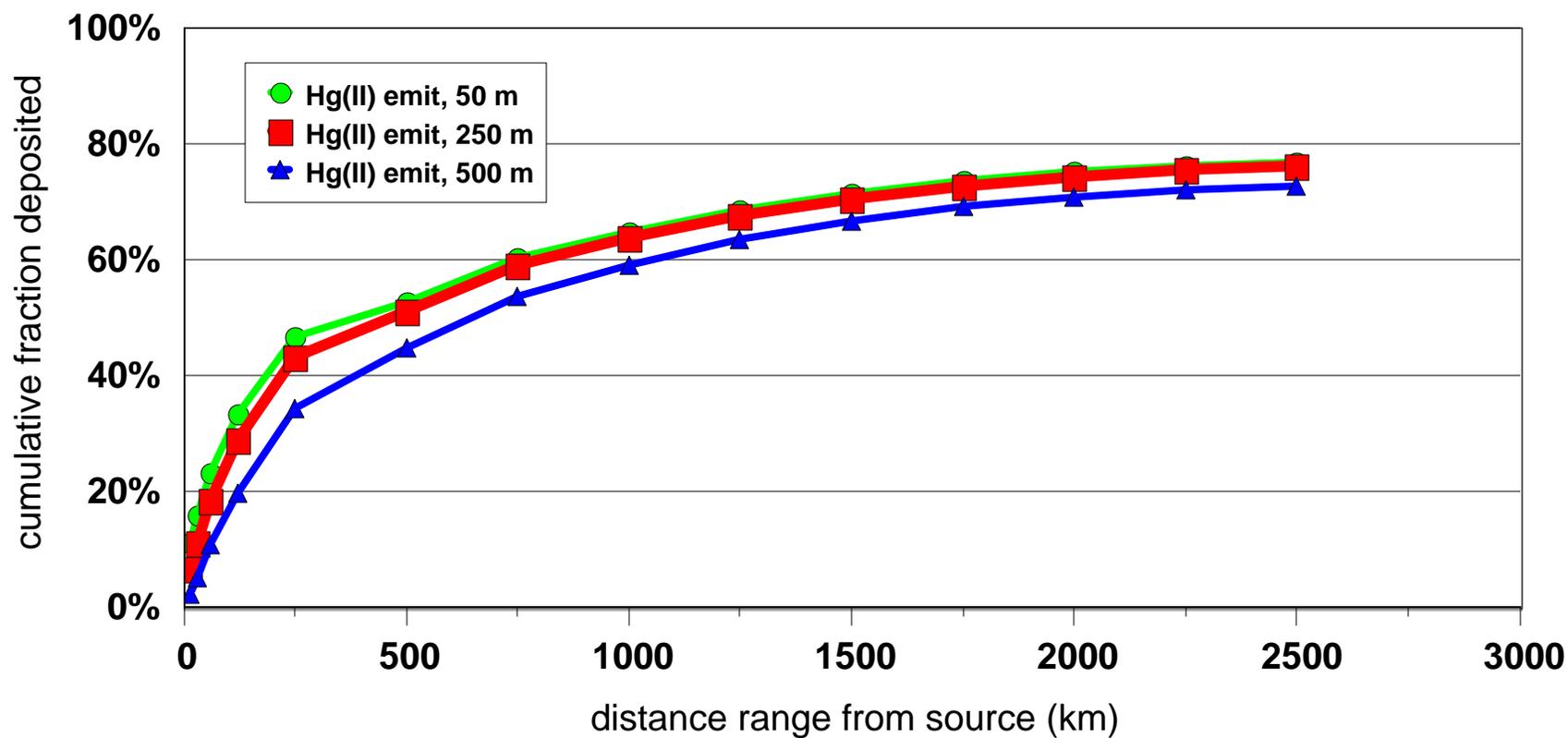
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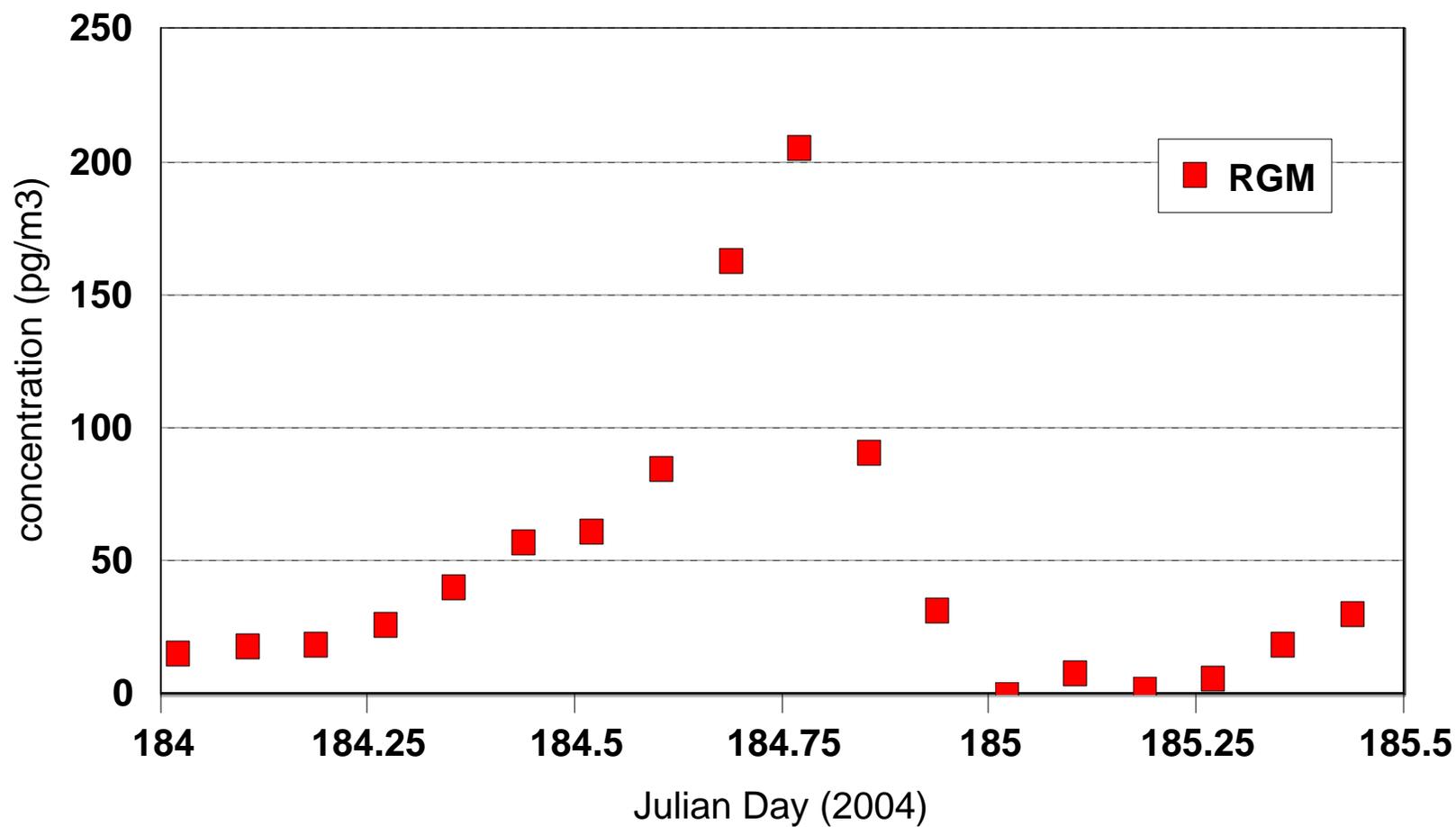
ionic Hg emitted from different source heights

Cumulative Fraction Deposited Out to Different Distance Ranges from a Hypothetical Source



Source at Lat = 42.5, Long = -97.5; simulation for entire year 1996 using archived NGM meteorological data

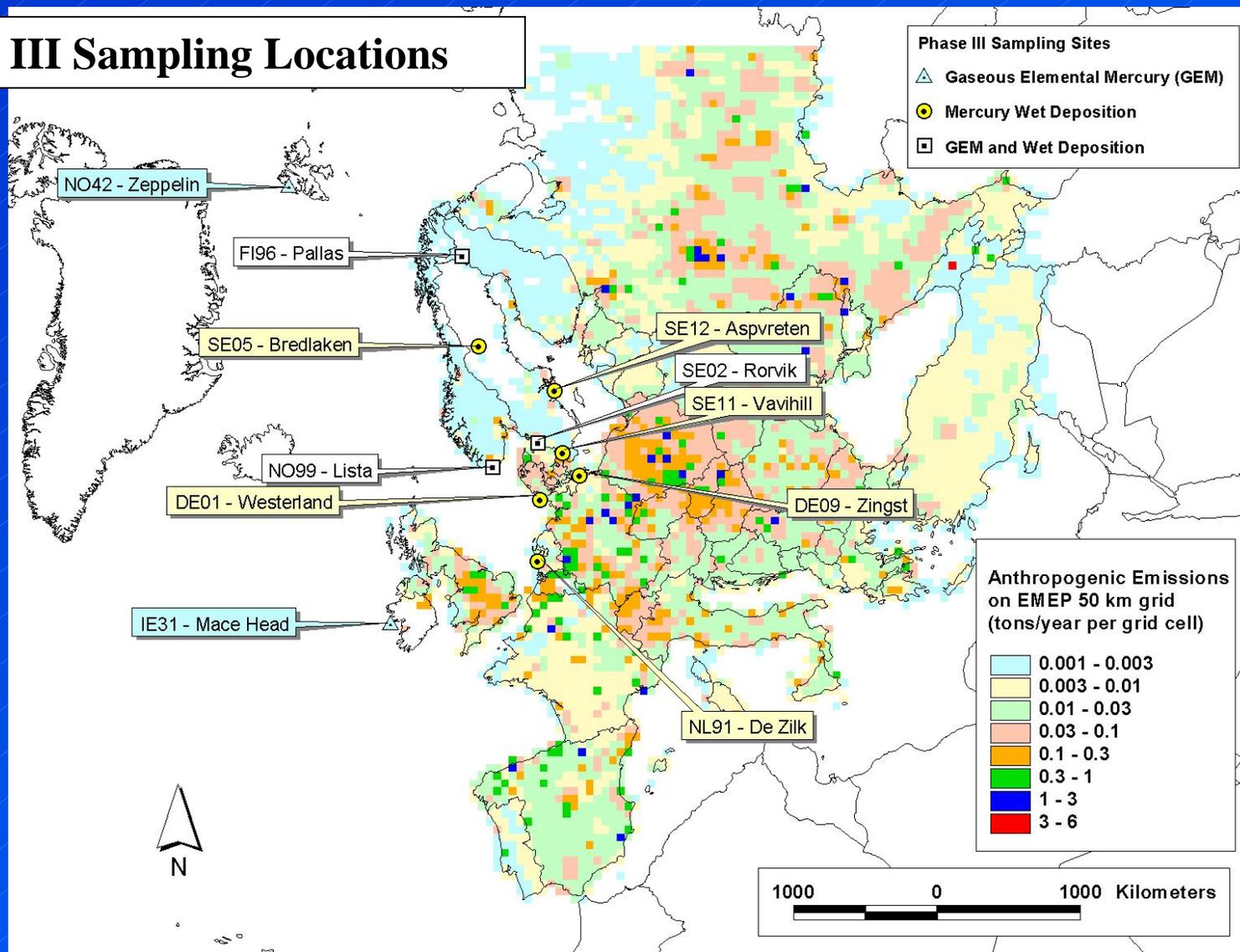
Measured Atmospheric Concentrations at Oxford MD, Summer 2004



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

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

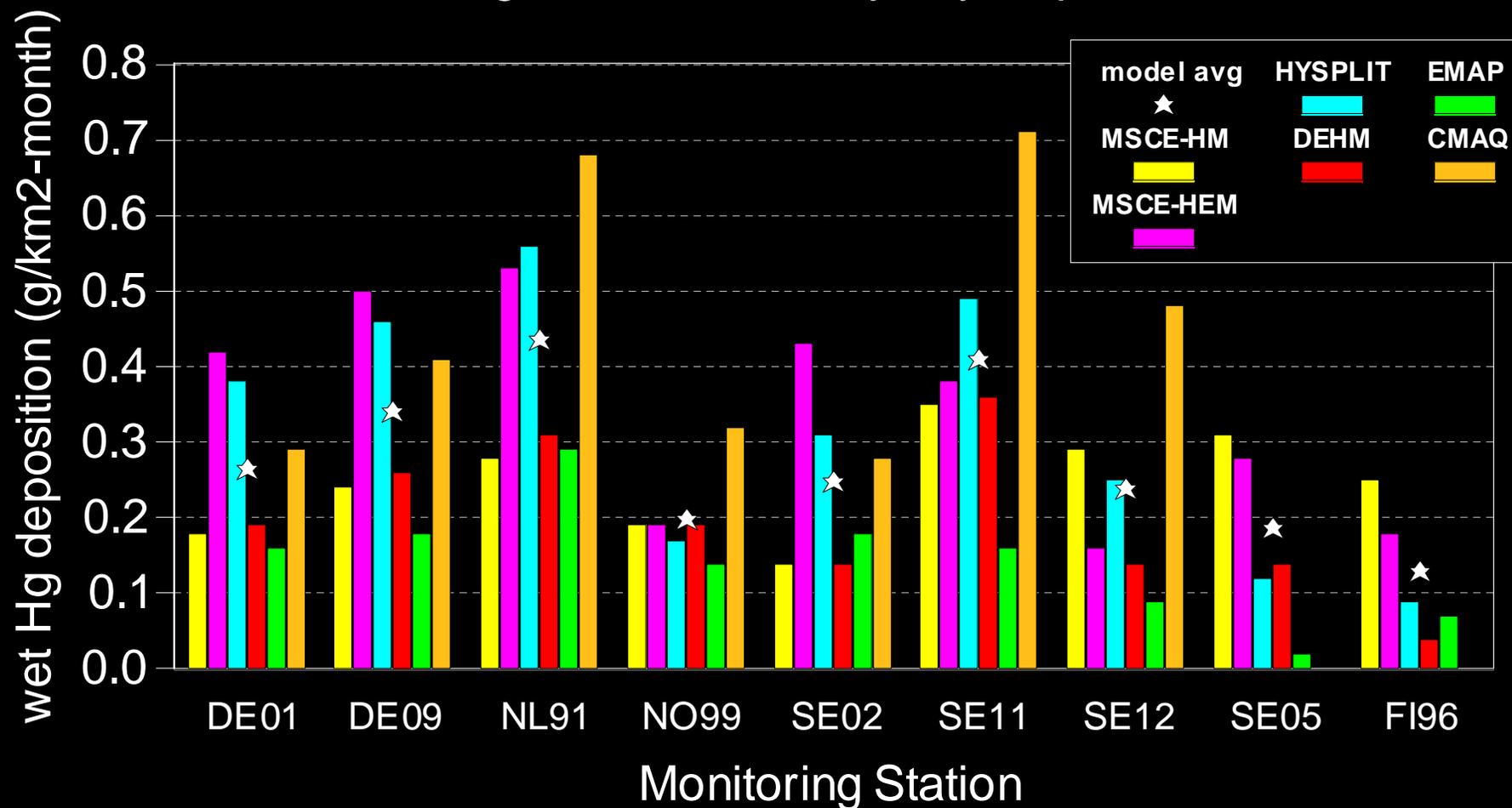
Phase III Sampling Locations



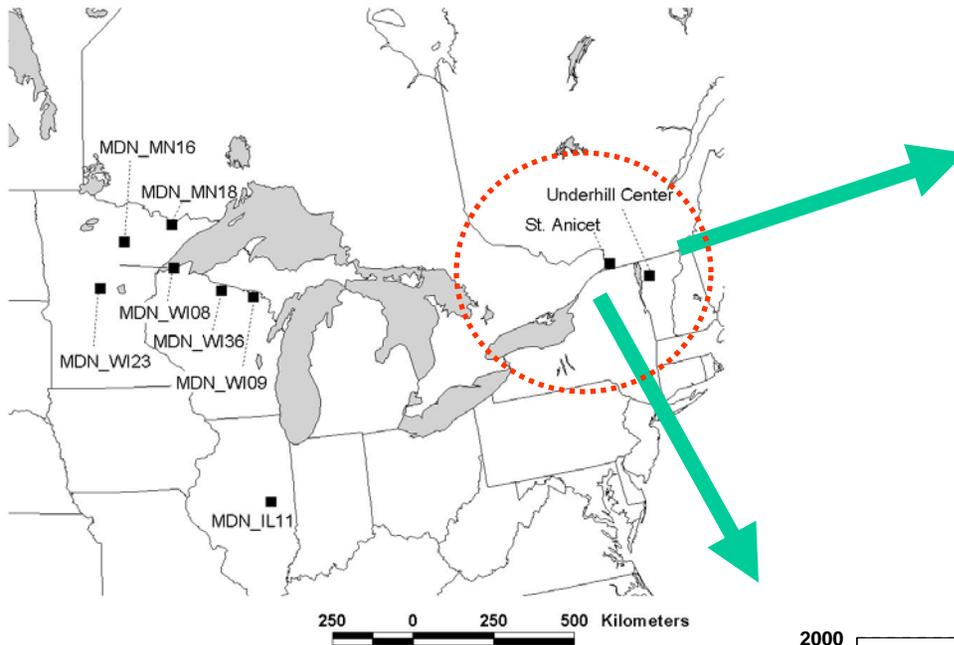
EMEP Intercomparison Study of Numerical Models for Long-Range Atmospheric Transport of Mercury

Intro- duction	Stage I	Stage II			Stage III			Conclu- sions
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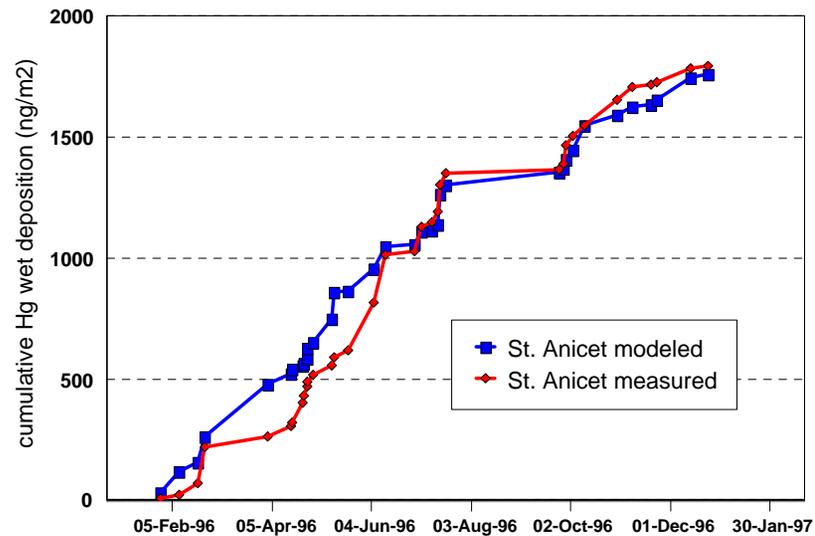
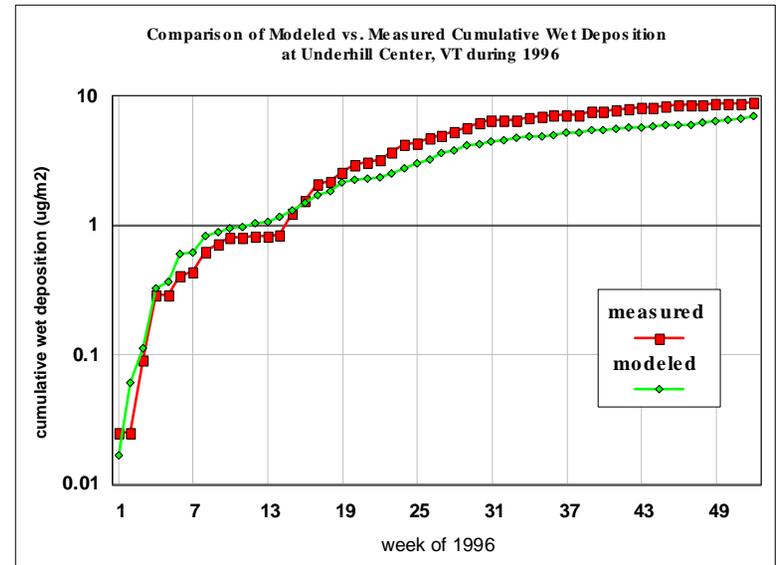
August 1999 Mercury Dry Deposition

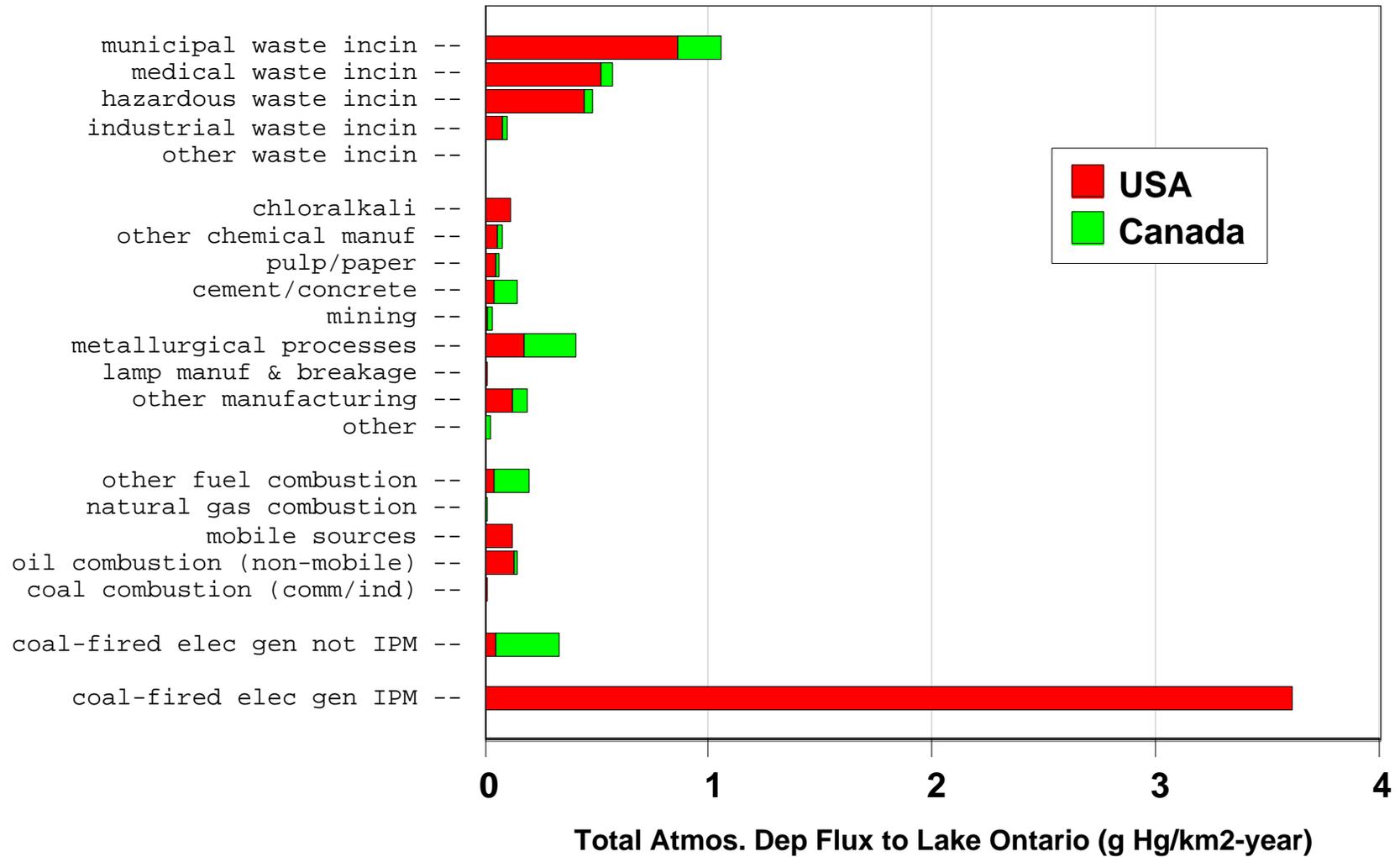


Sites with 1996 mercury wet deposition data in the Great Lakes region

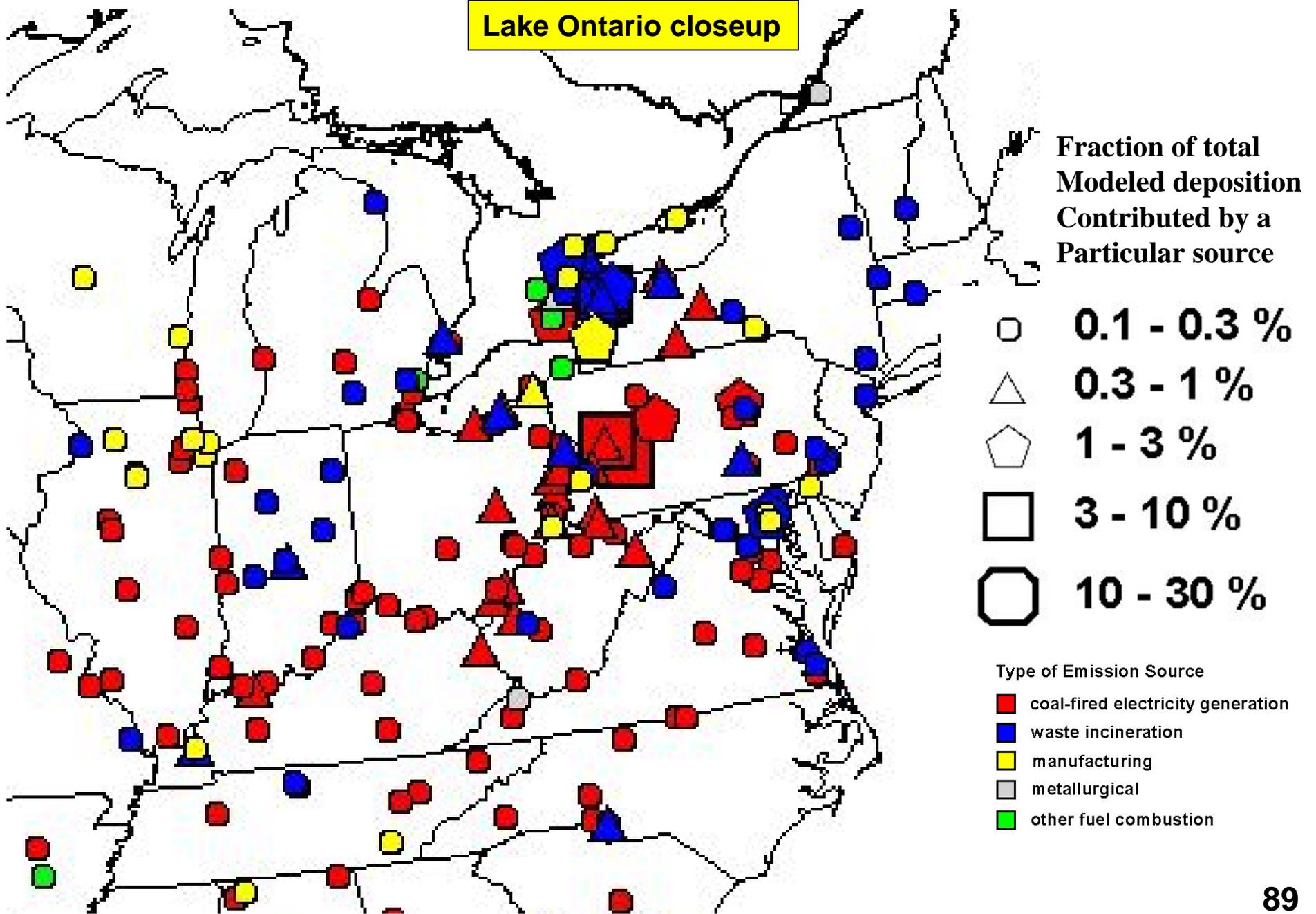


Seem to be getting reasonable results near Lake Ontario, but need to do much more evaluation...

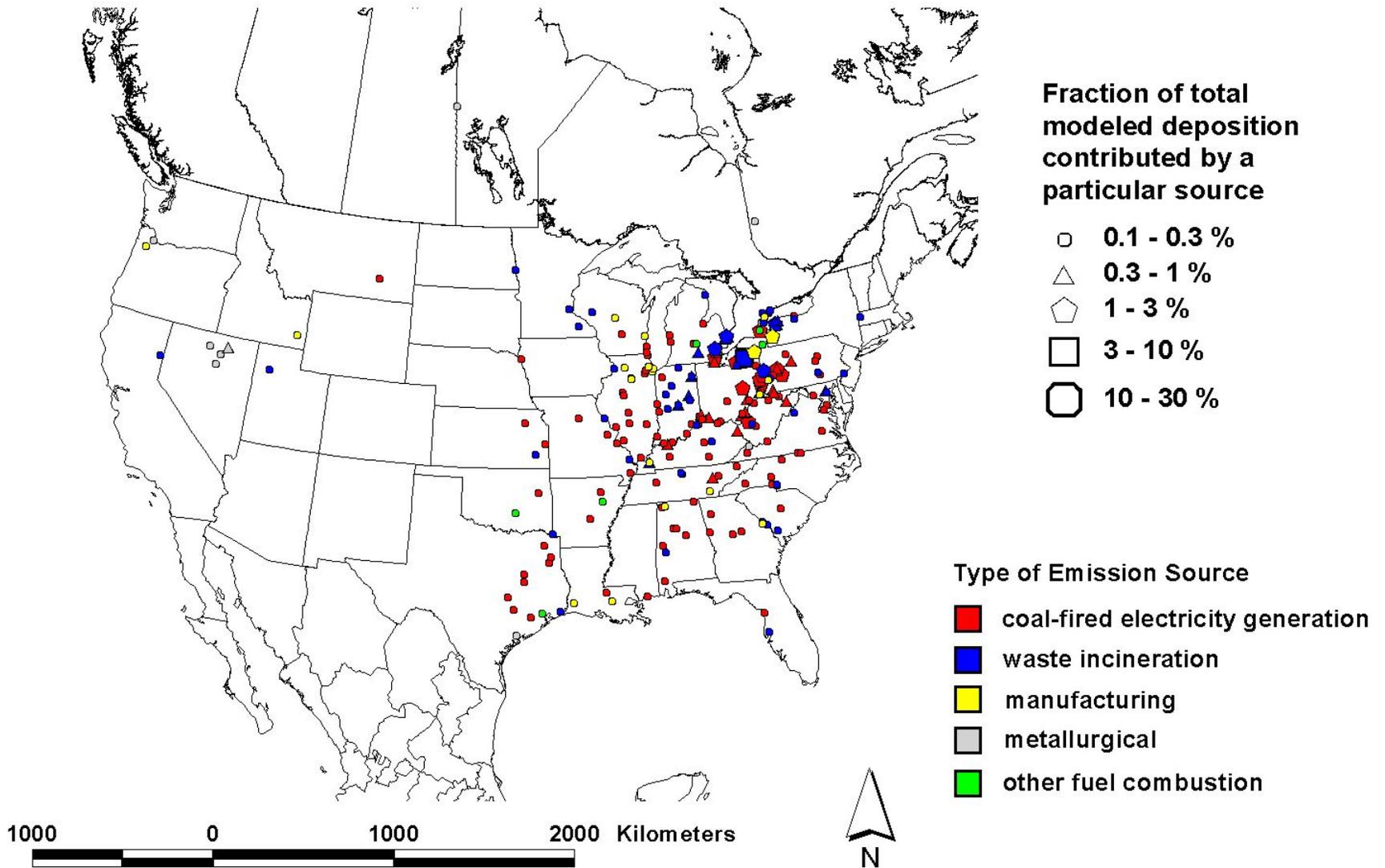


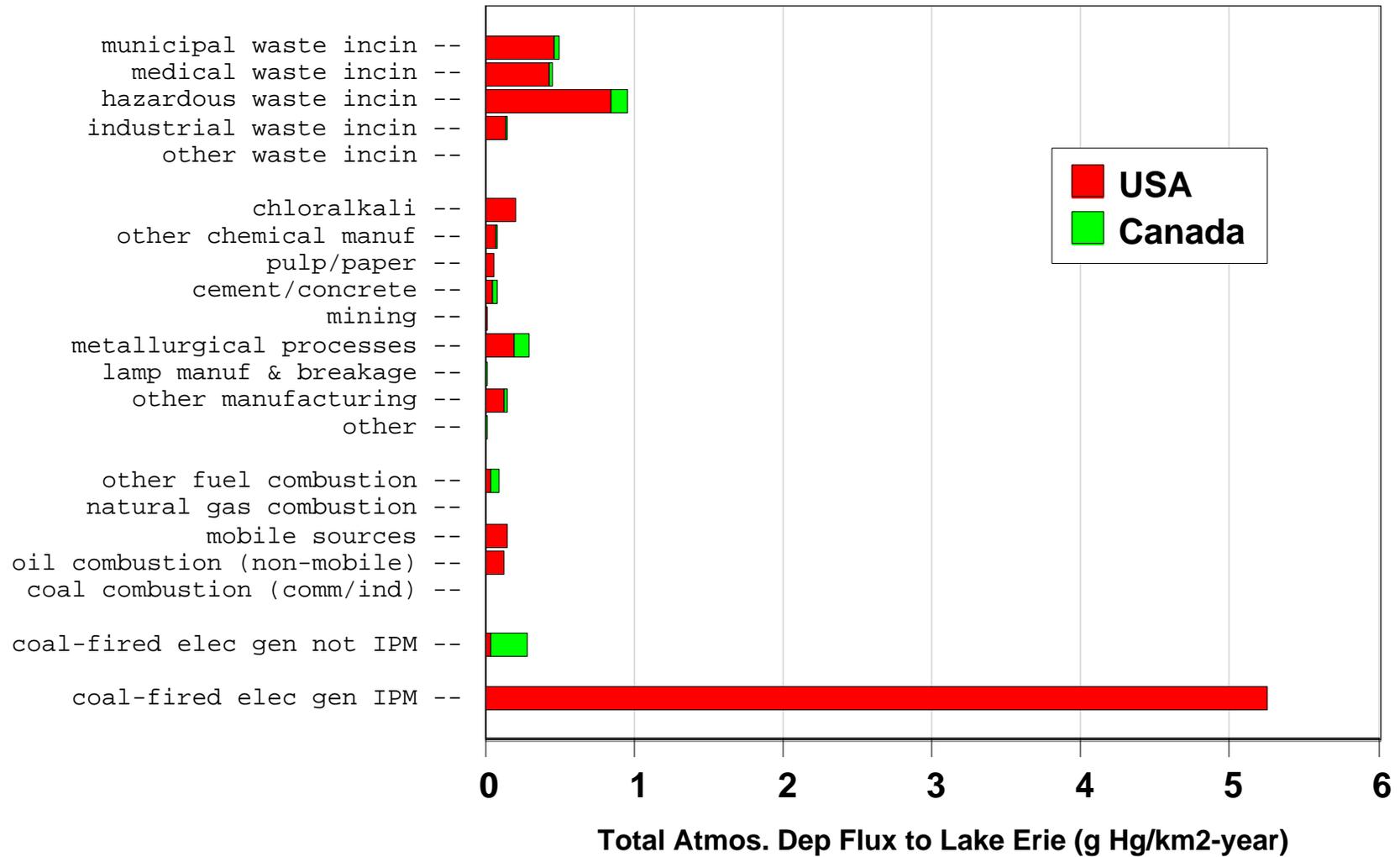


Lake Ontario closeup

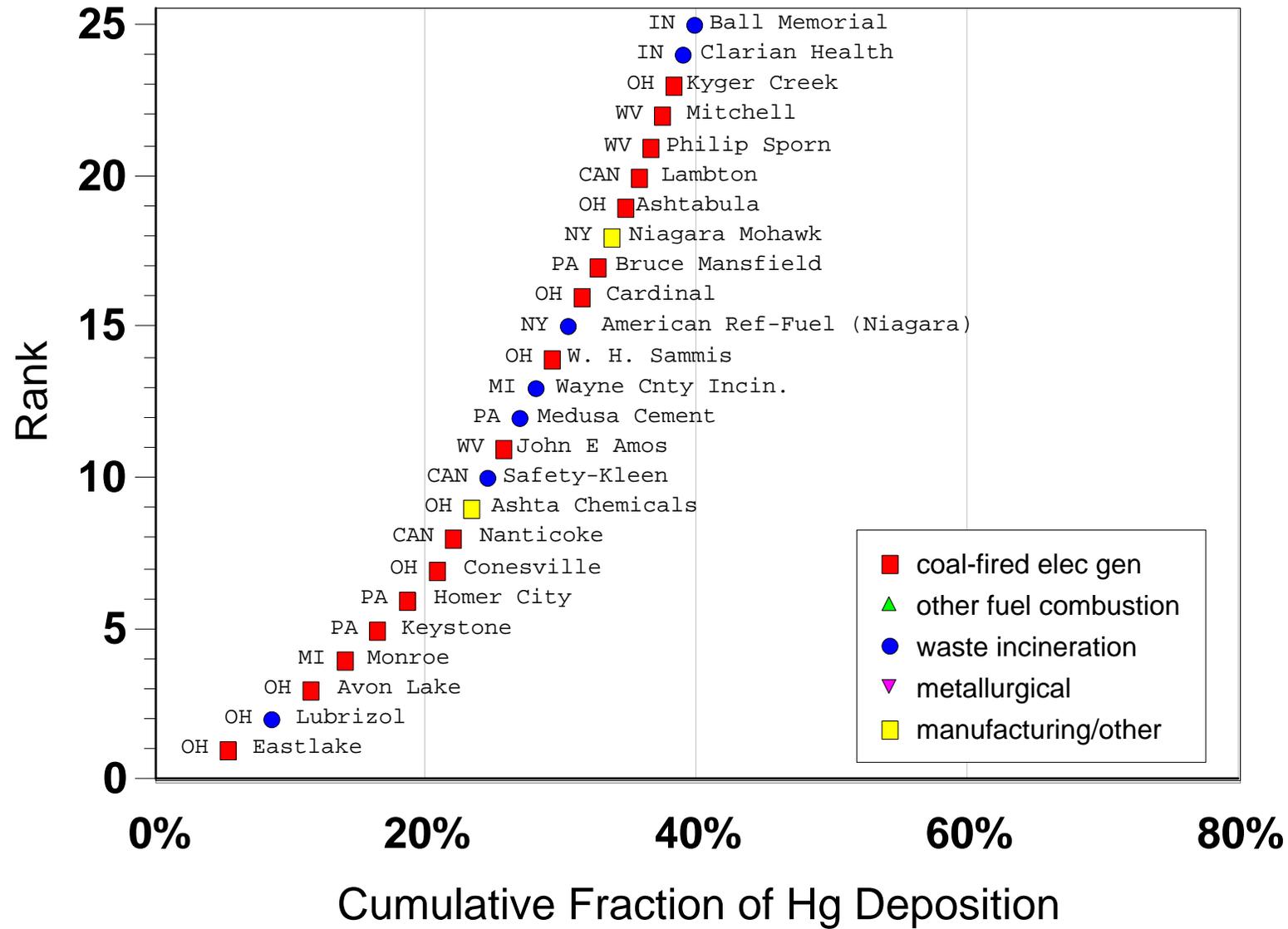


Largest atmospheric deposition contributors to Lake Erie based on 1999-2000 emissions

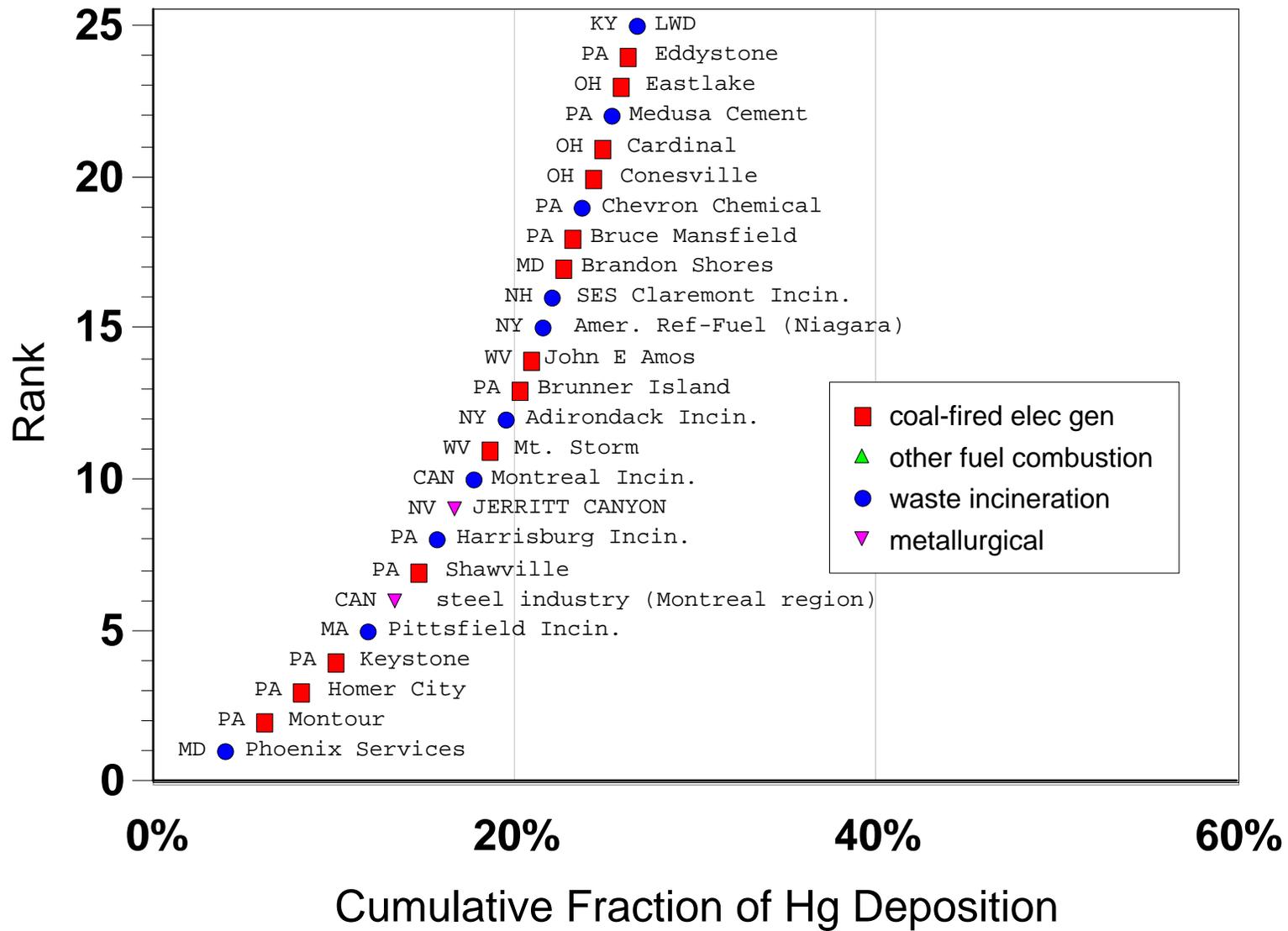




Top 25 Contributors to 1999 Hg Deposition Directly to Lake Erie



Top 25 Contributors to 1999 Hg Deposition Directly to Lake Champlain



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

