Local and Regional Deposition Impacts of Atmospheric Mercury Emissions

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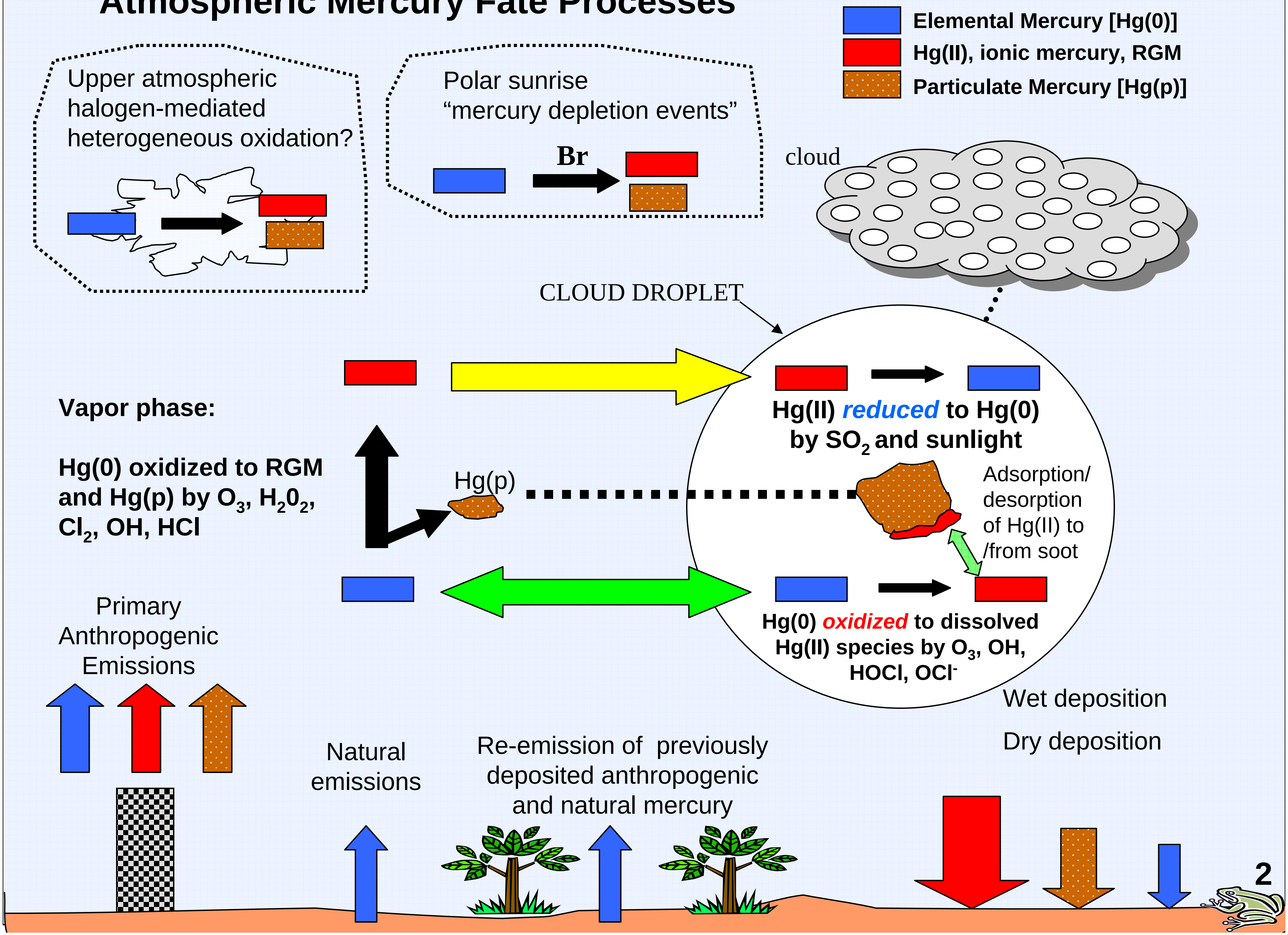
Presentation at
Mercury Rule Workgroup Meeting
PA Department of Environmental Protection
Harrisburg, PA, November 18, 2005

Atmospheric Mercury Fate Processes



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:**
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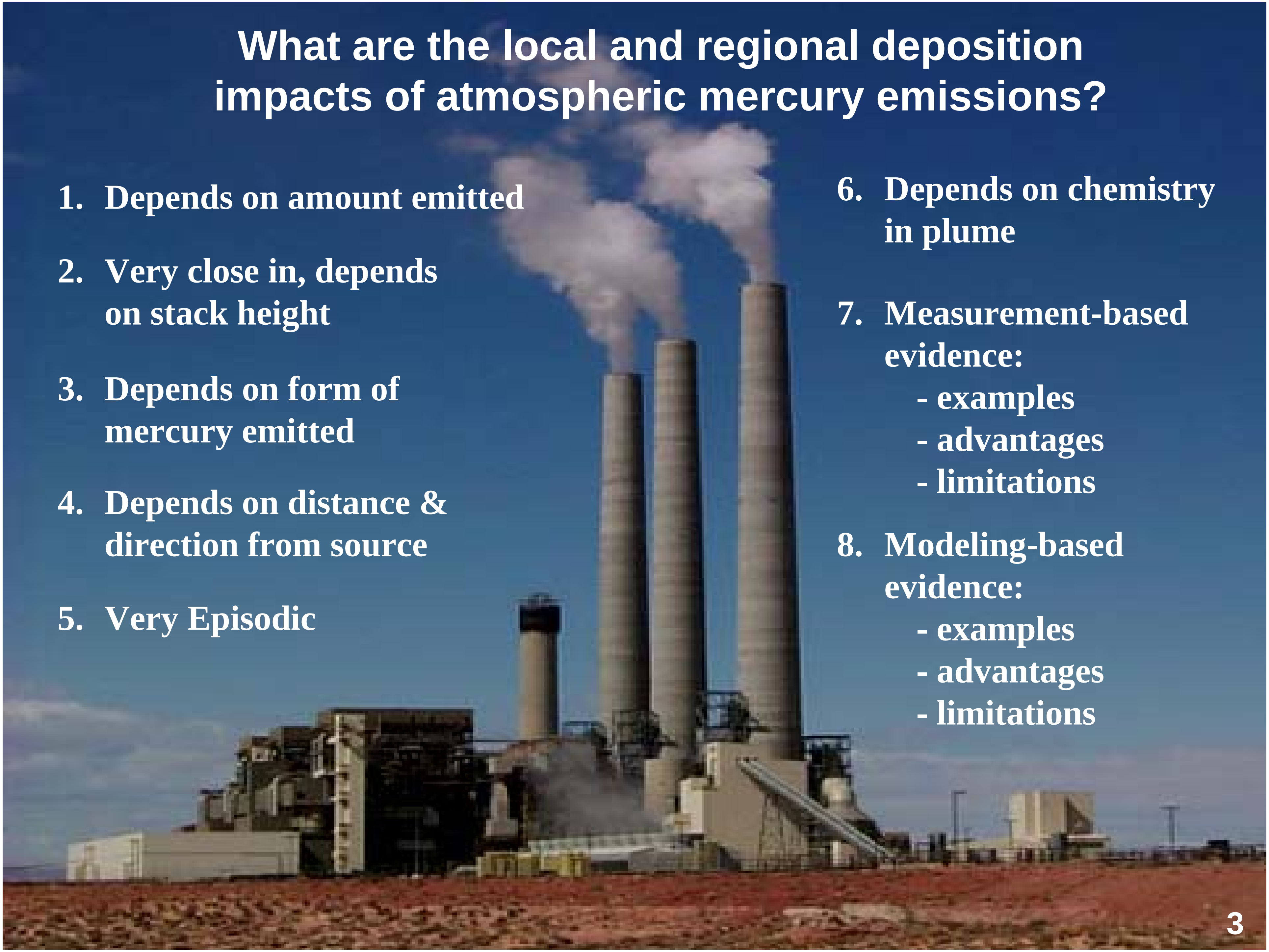

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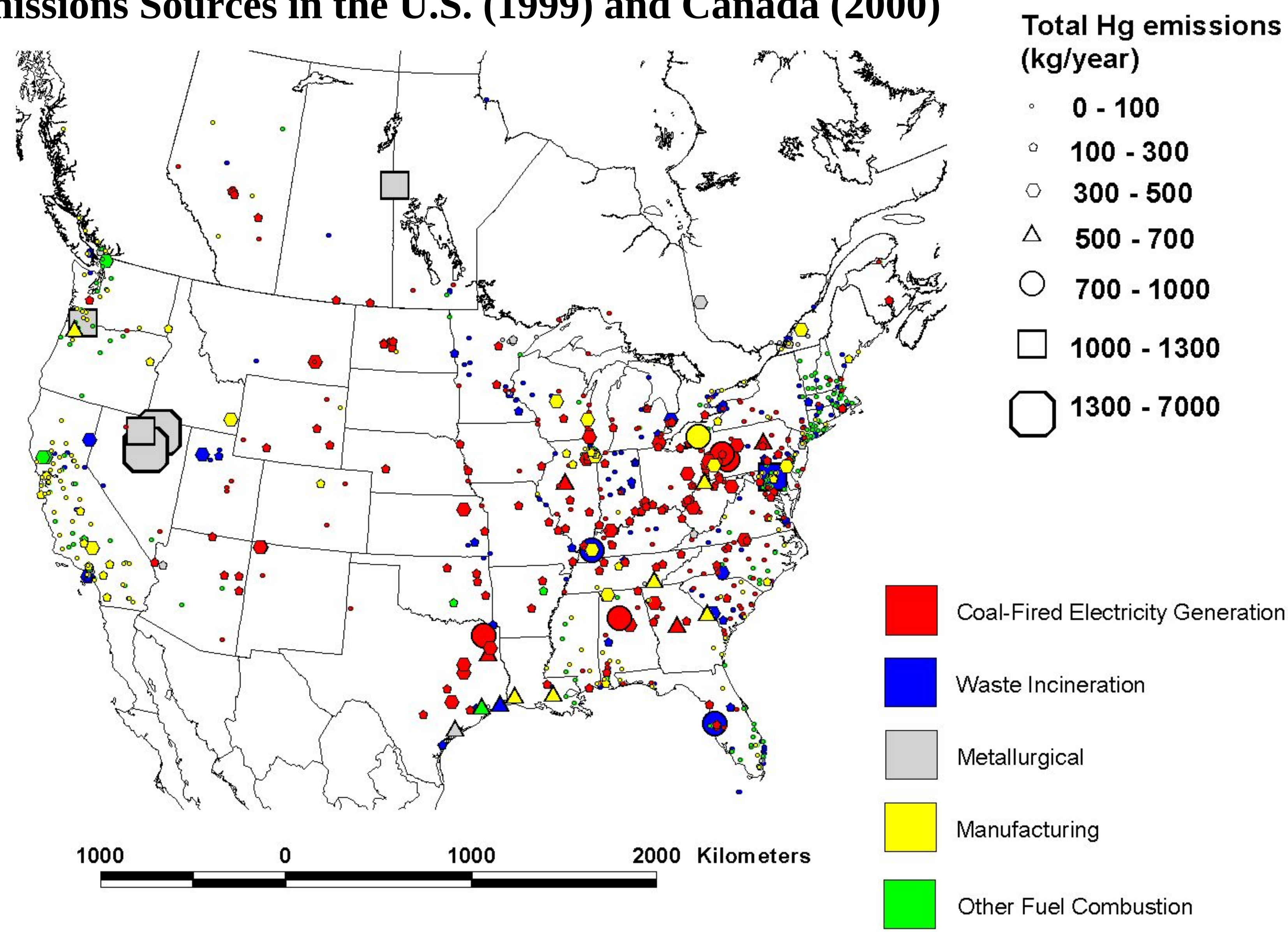
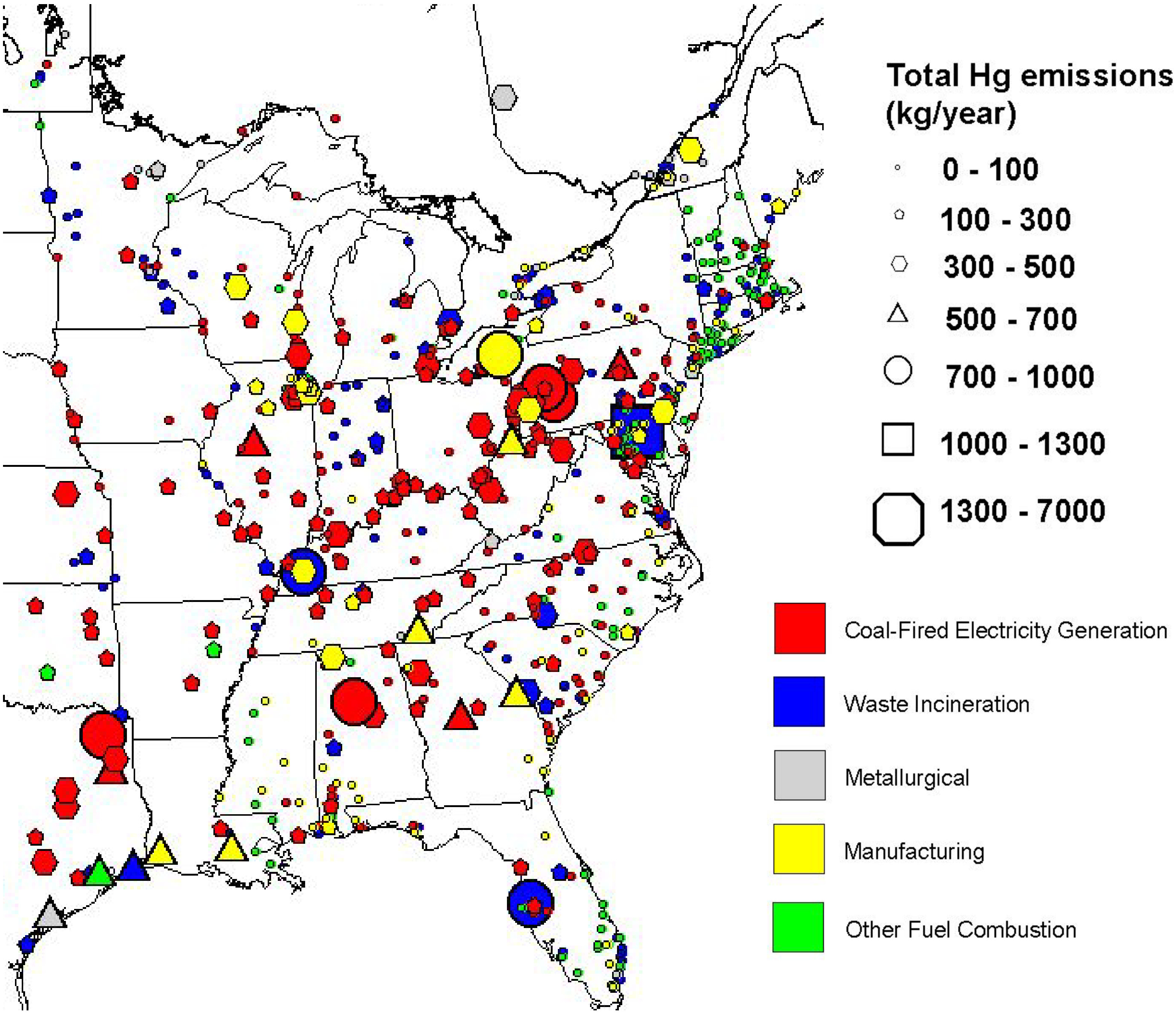
Geographic Distribution of Largest Anthropogenic Mercury Emissions Sources in the U.S. (1999) and Canada (2000)




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

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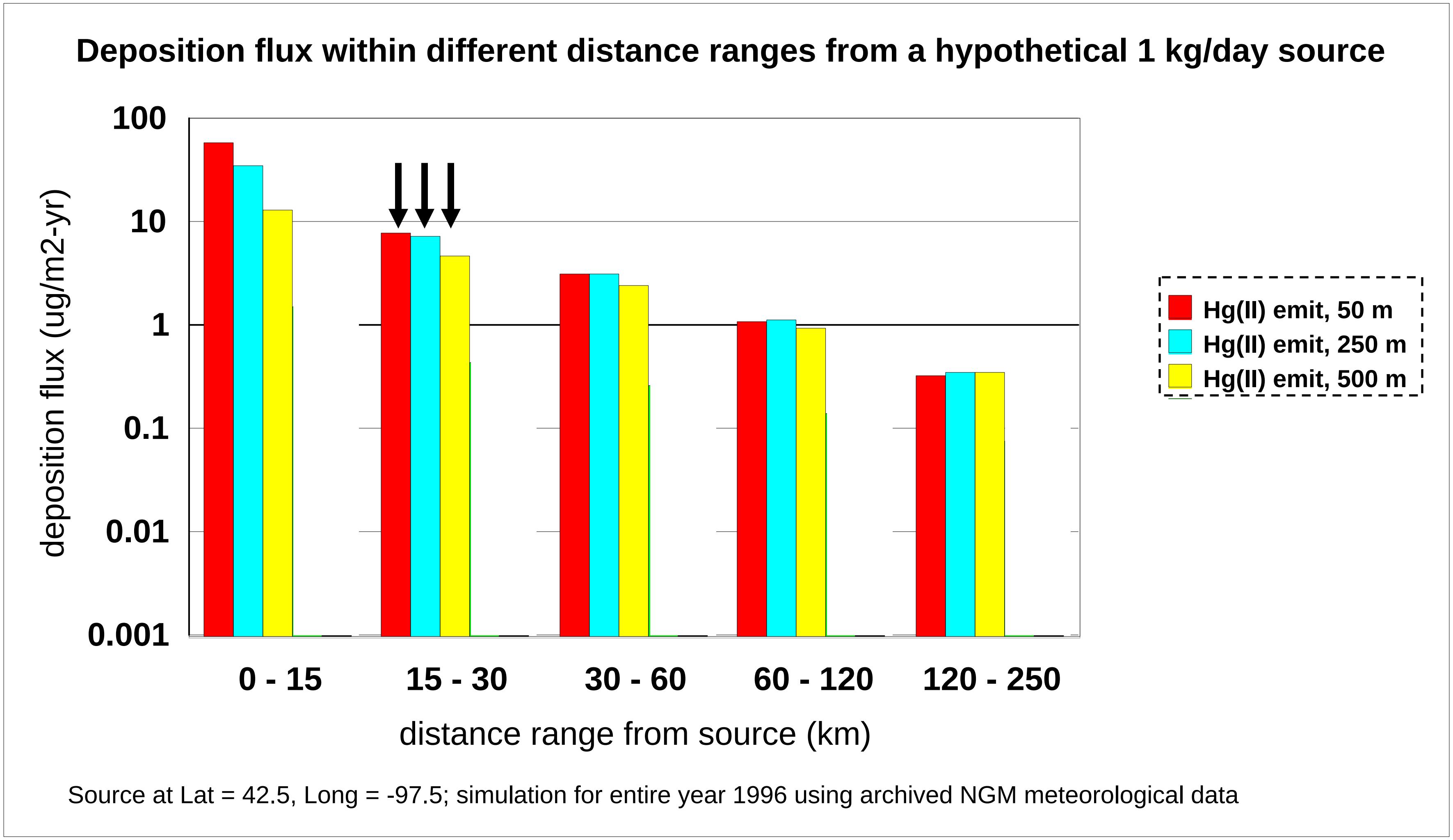
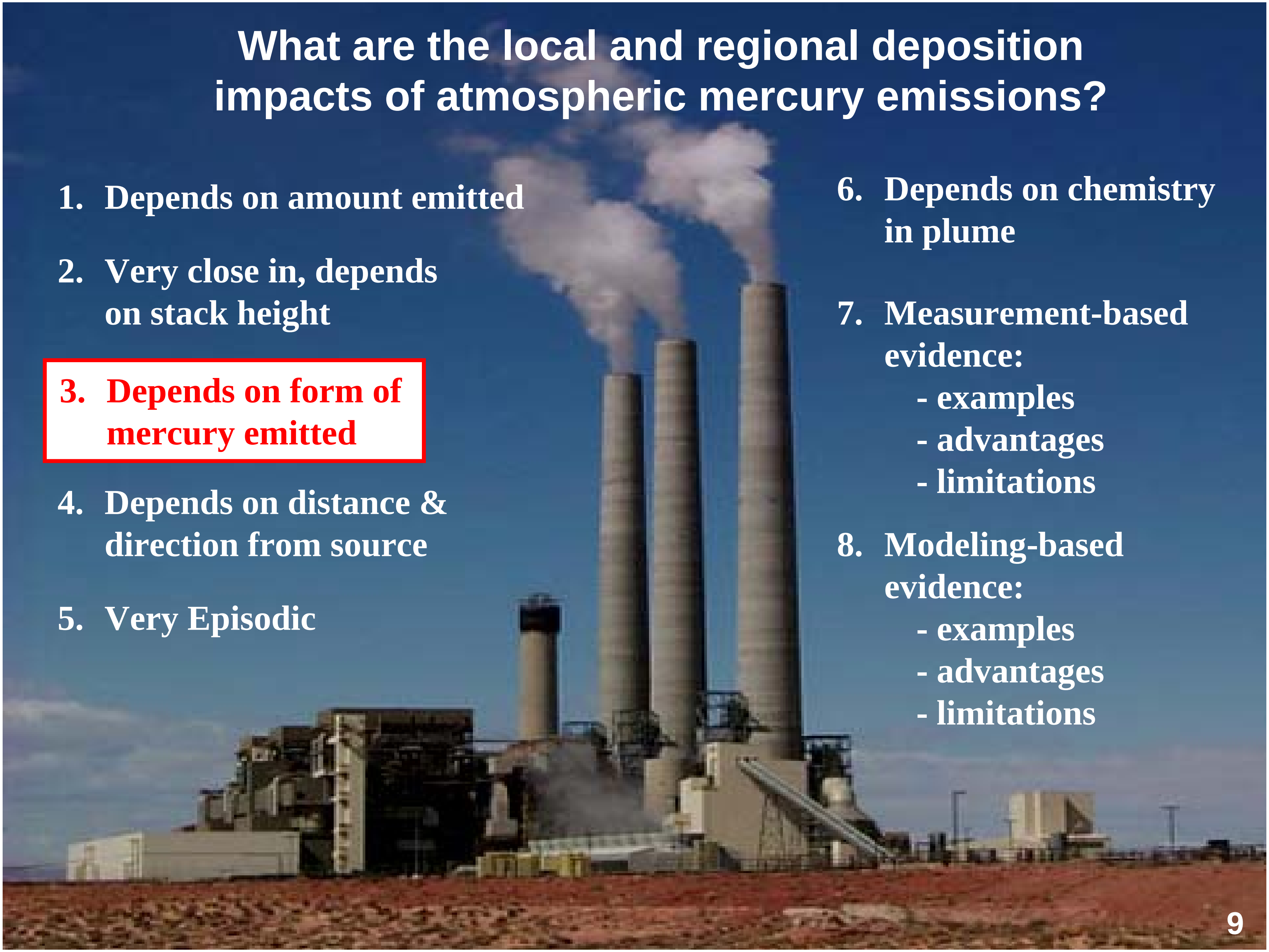

Deposition flux within different distance ranges from a hypothetical 1 kg/day source
100
10
1
0.1
0.01
0.001
deposition flux (ug/m2-yr)
0 - 15
15 - 30
30 - 60
60 - 120
120 - 250
distance range from source (km)
Hg(II) emit, 50 m
Hg(II) emit, 250 m
Hg(II) emit, 500 m
Source at Lat = 42.5, Long = -97.5; 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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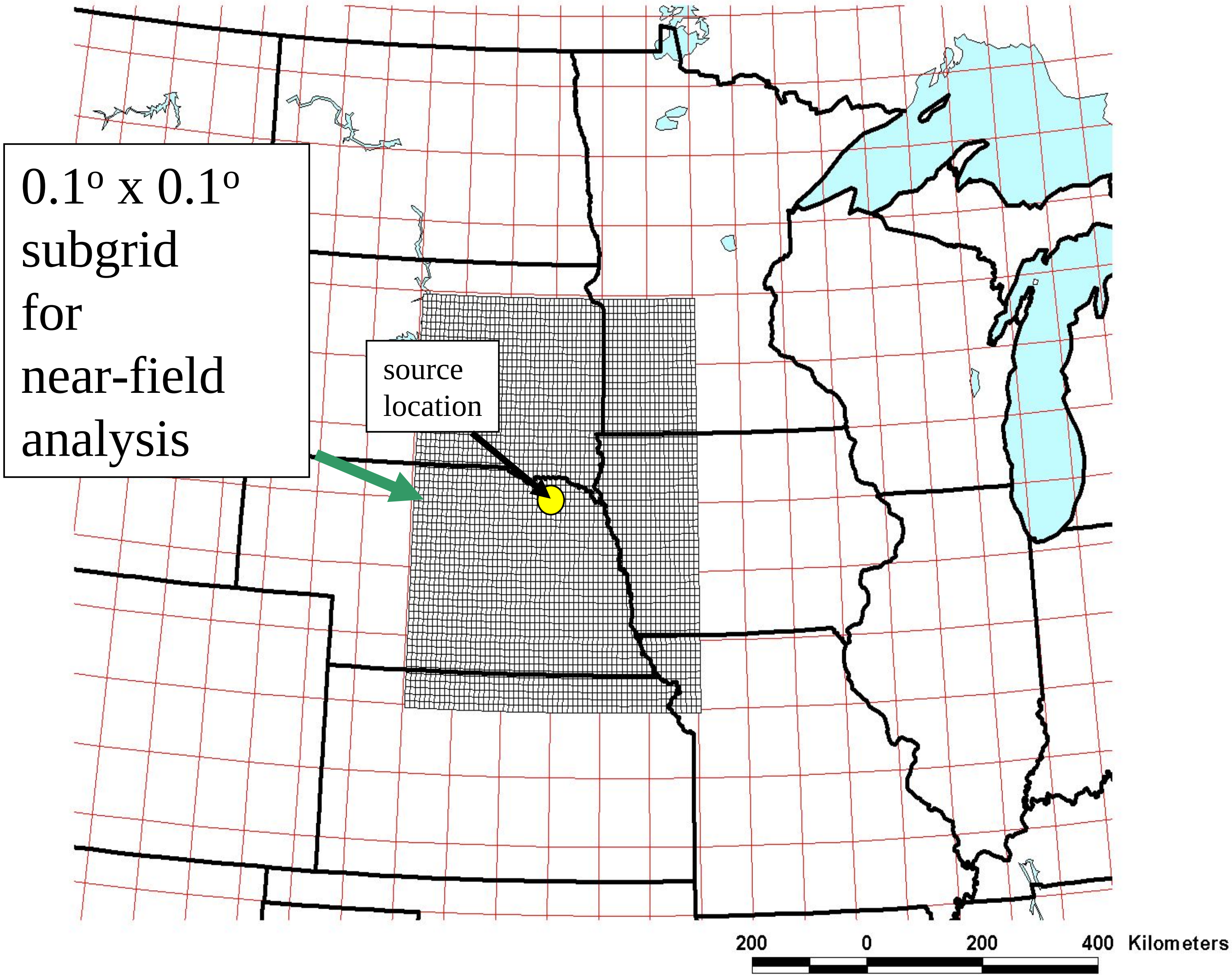
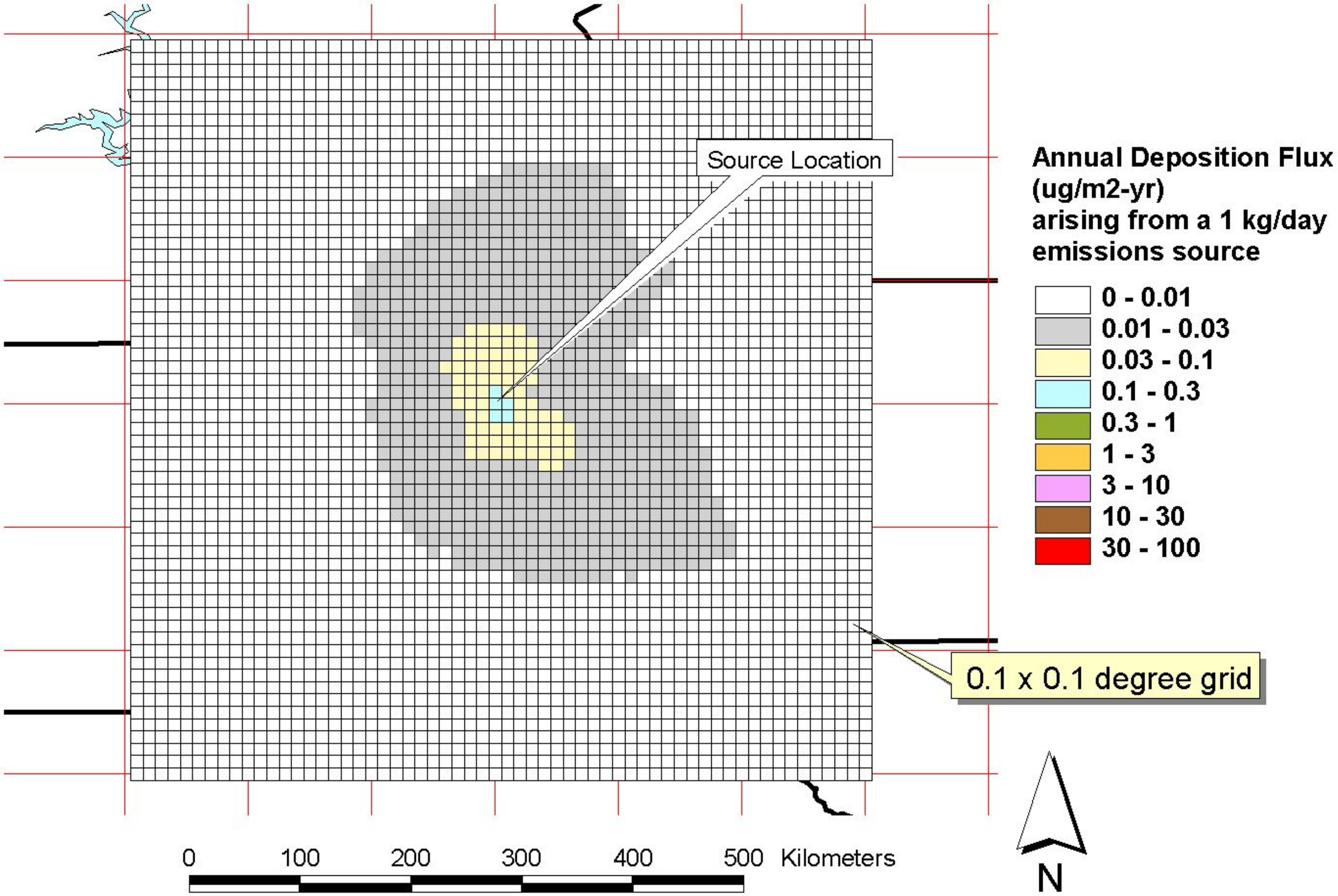
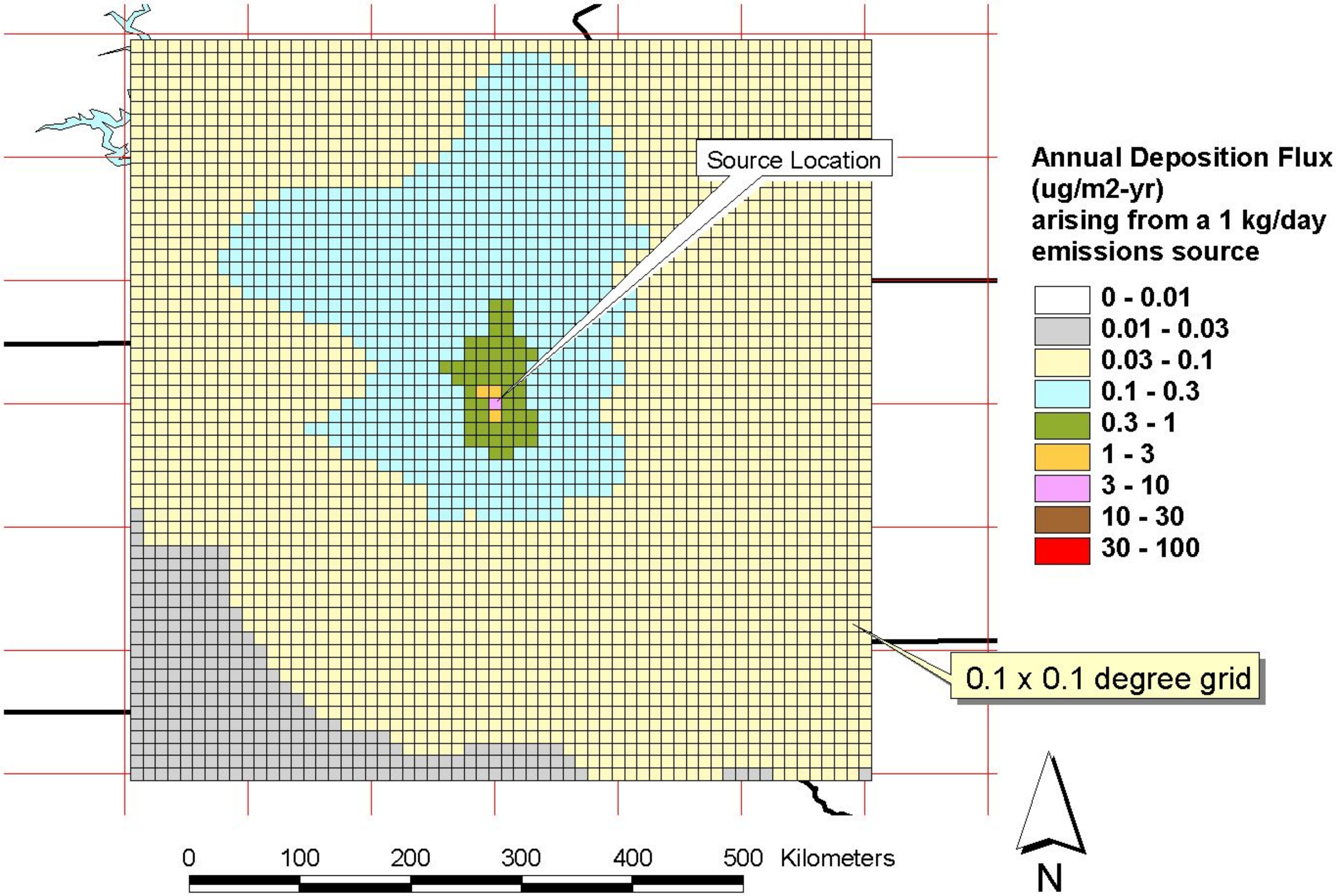

0.1º x 0.1º
subgrid
for
near-field
analysis
source
location
200 0 200 400 Kilometers

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



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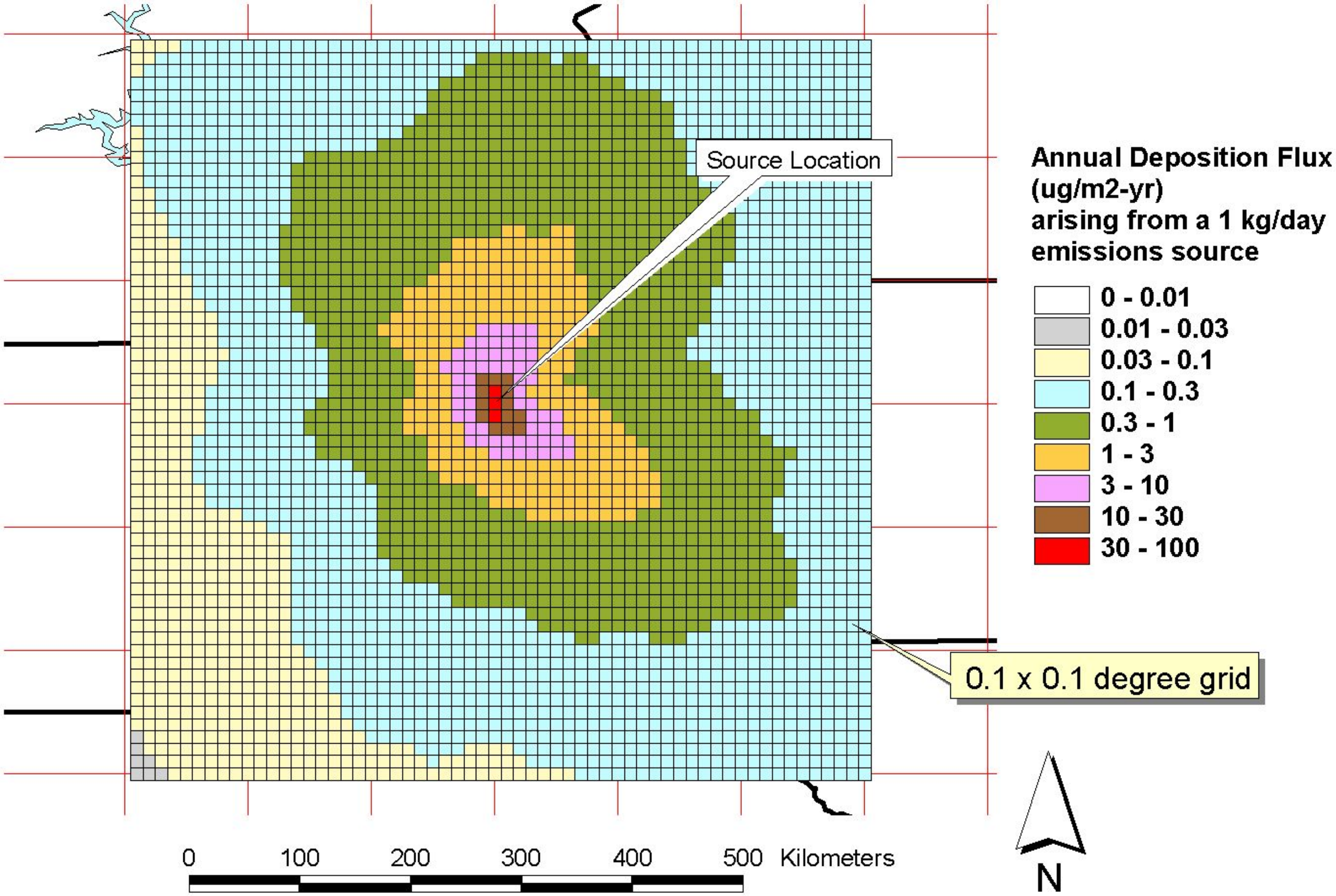

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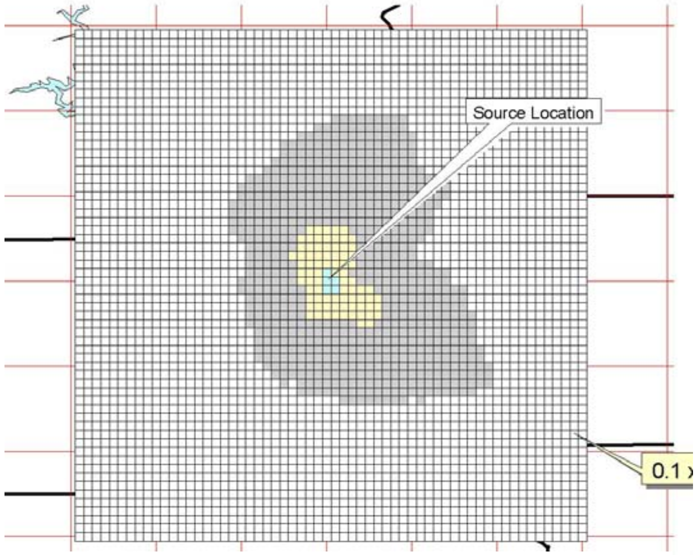

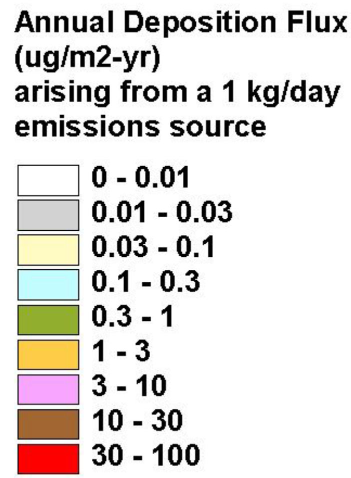

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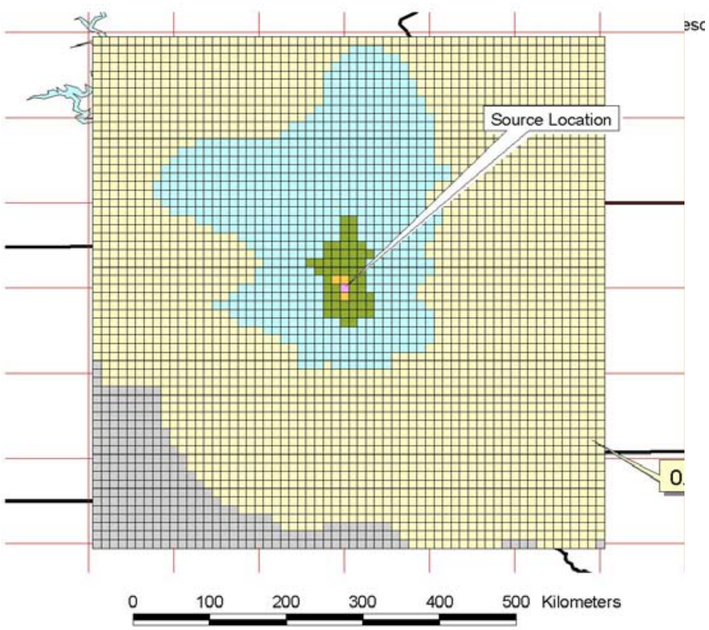

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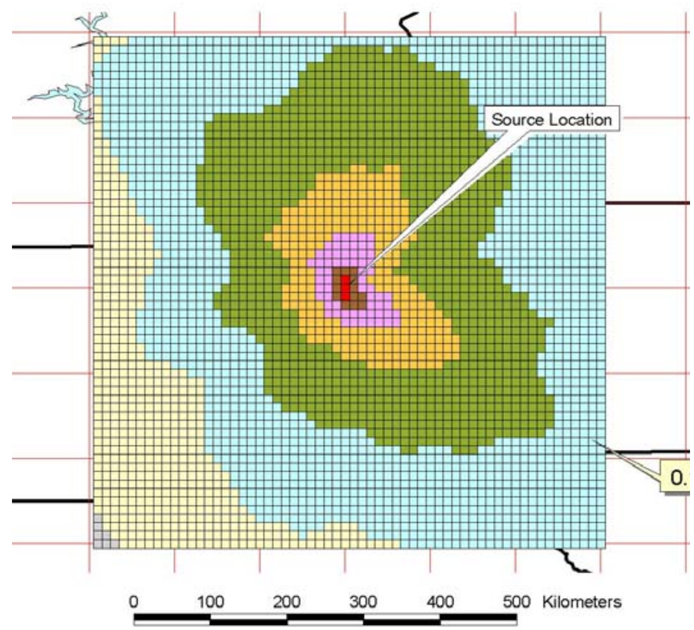

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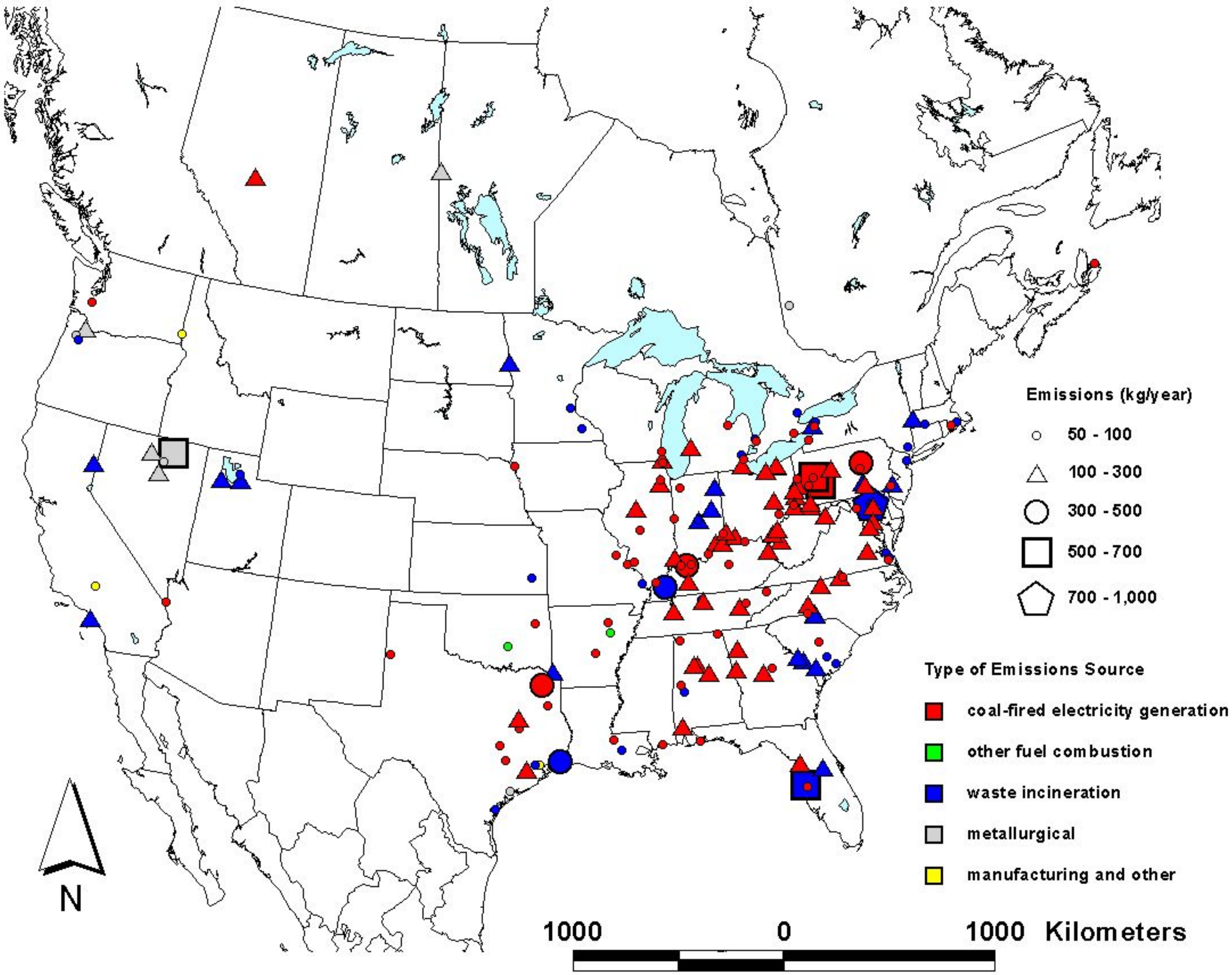
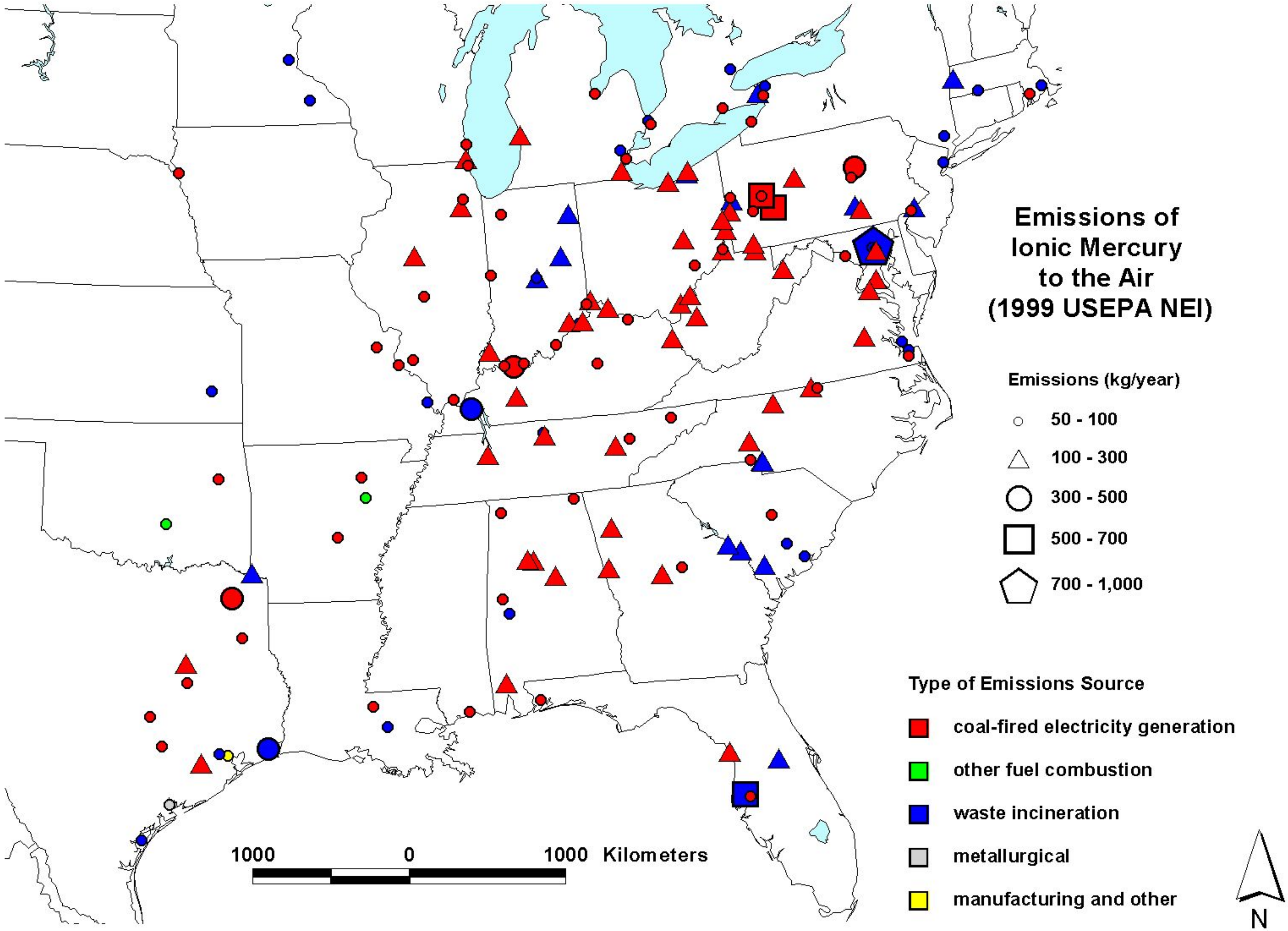
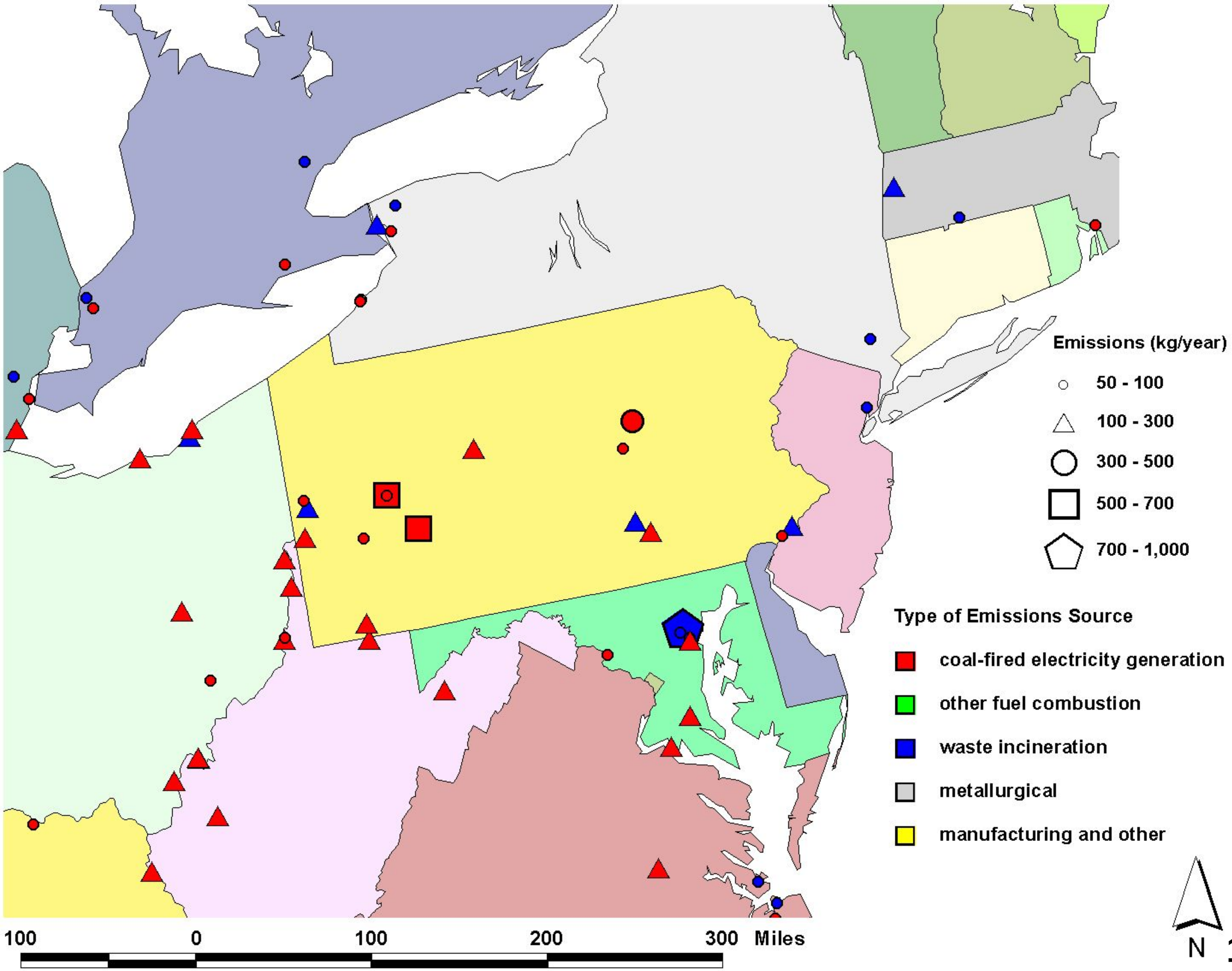
So where is RGM emitted?

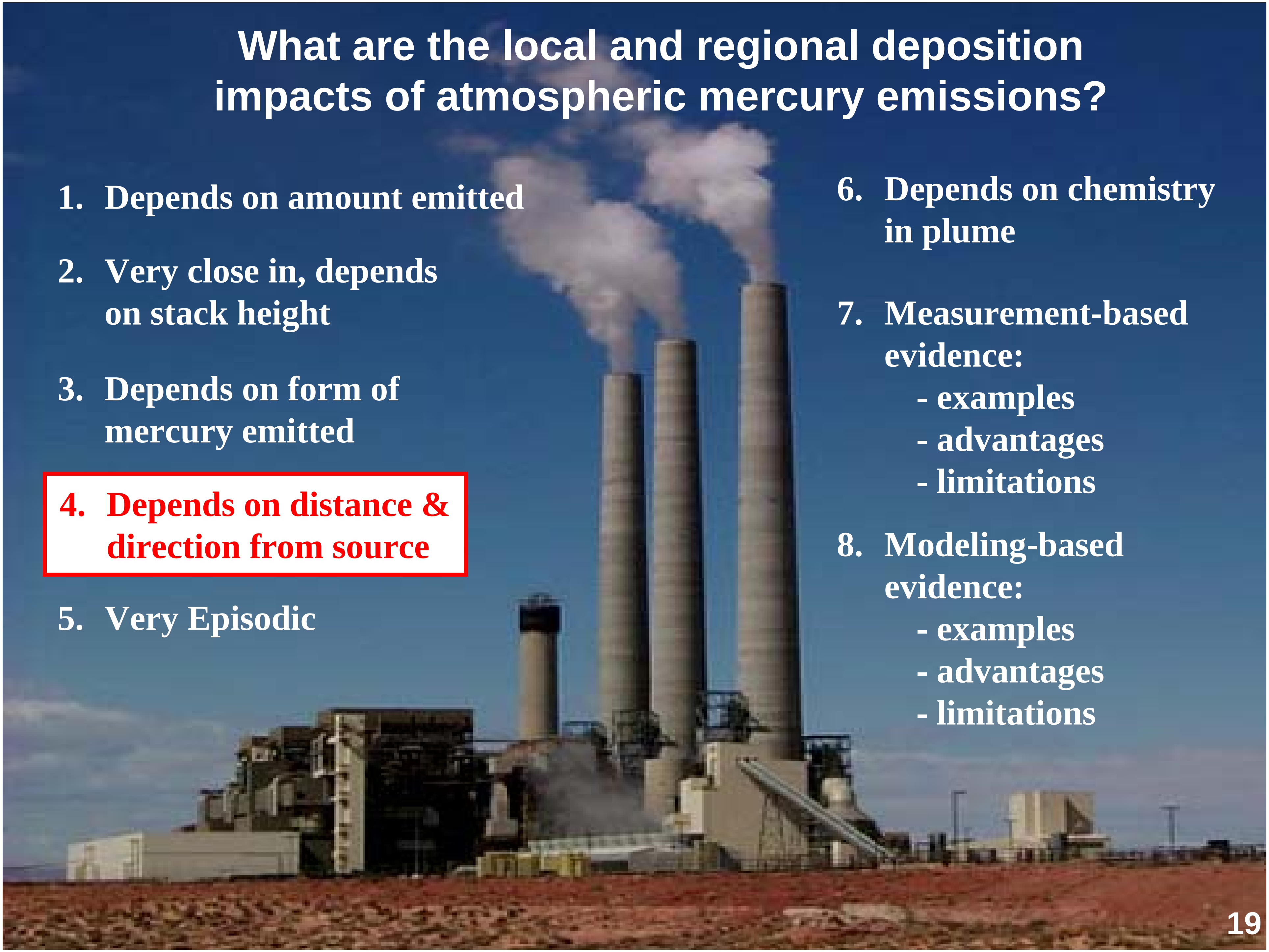
Emissions of Ionic Mercury to the Air




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
N

Reactive Gaseous Mercury Emissions (based on USEPA 1999 NEI)





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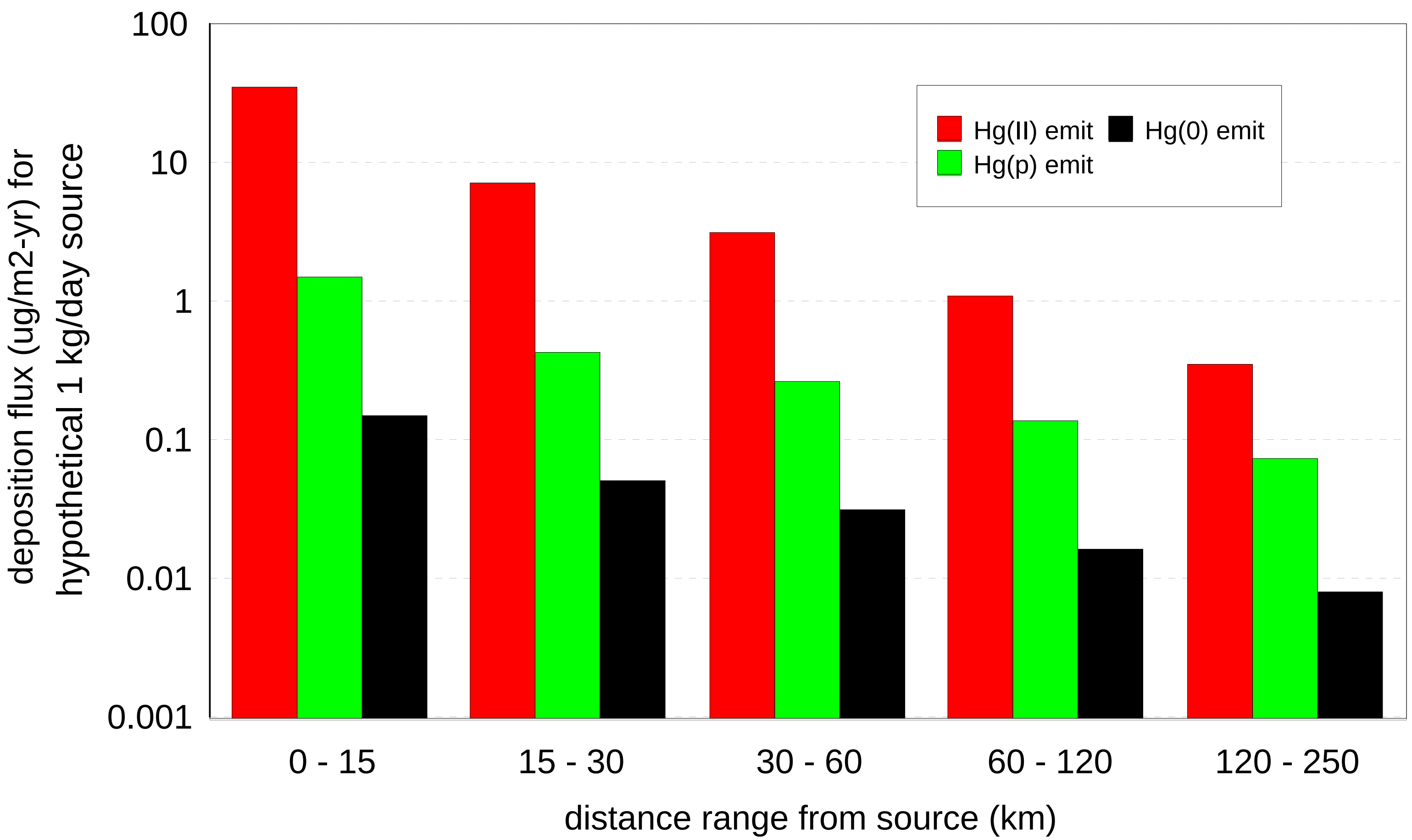
Why is emissions speciation information critical?



Logarithmic

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

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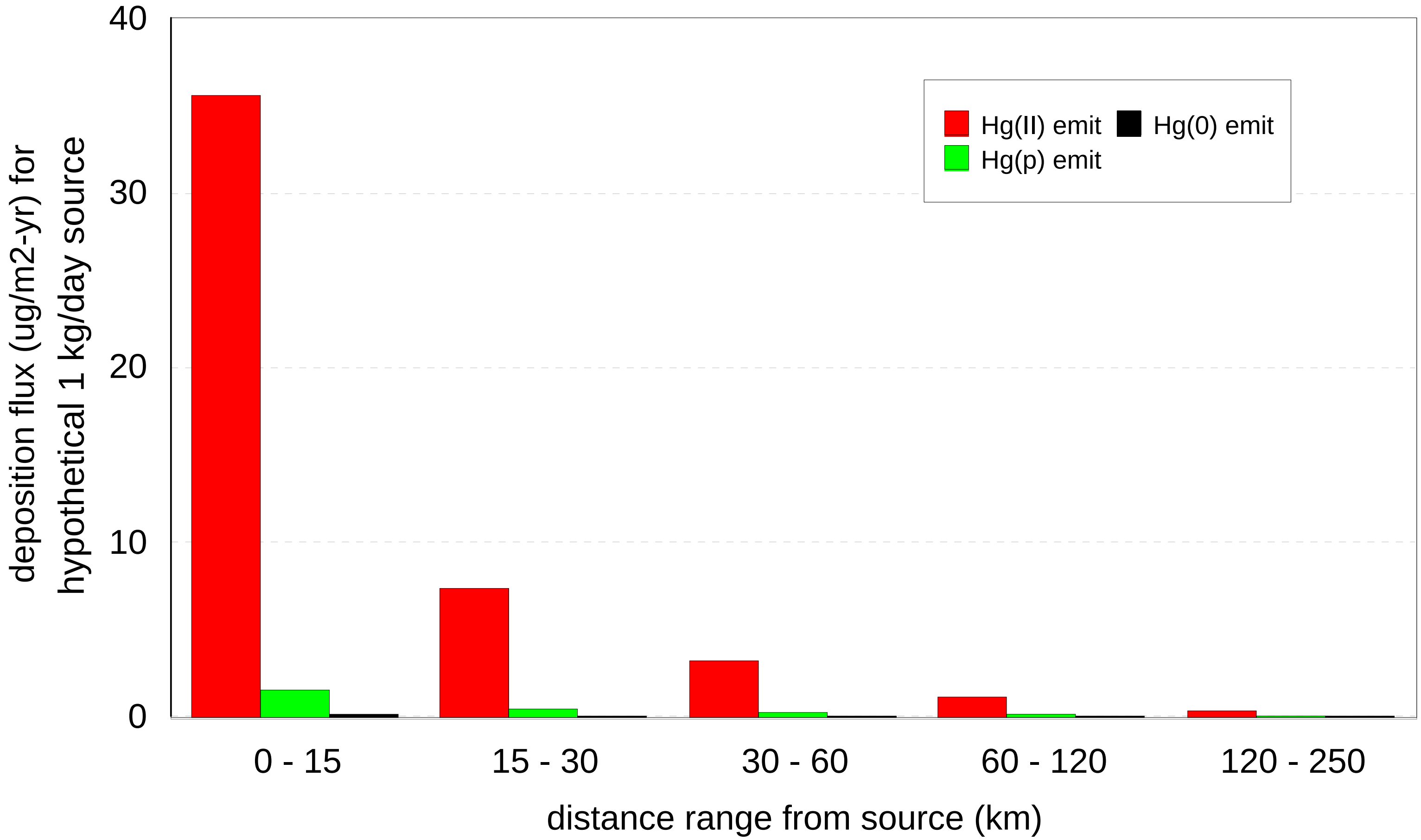
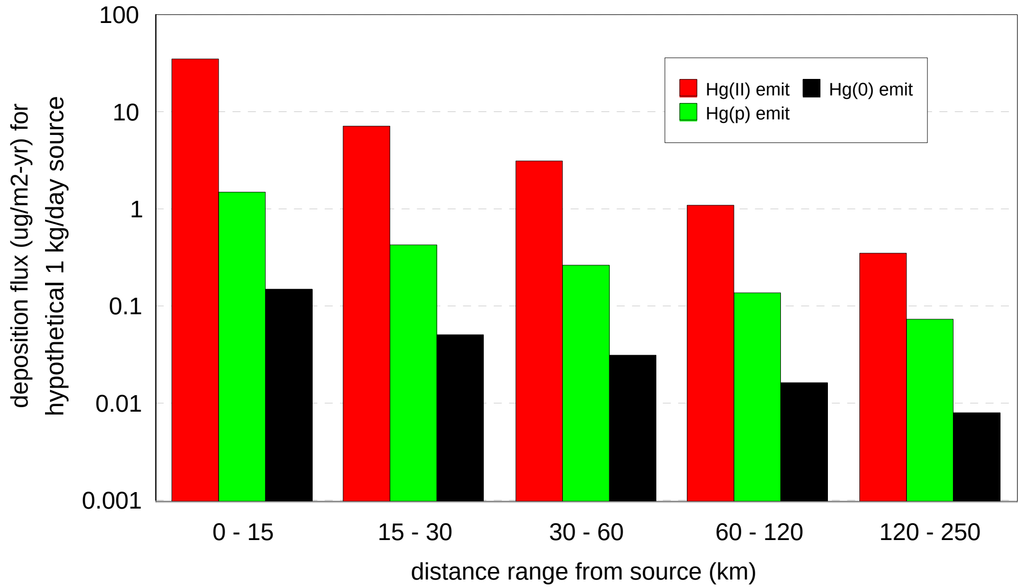


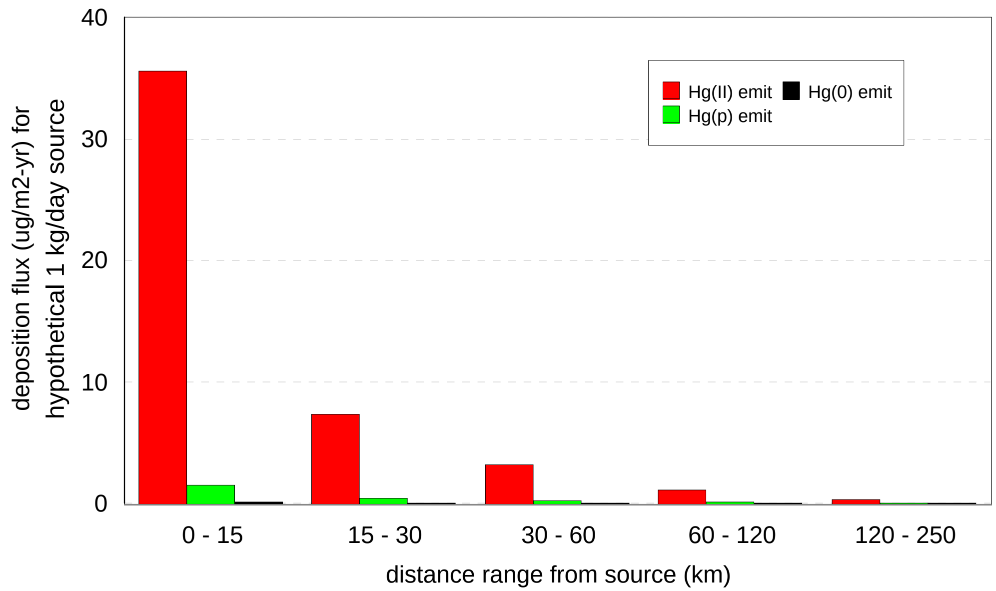
Linear

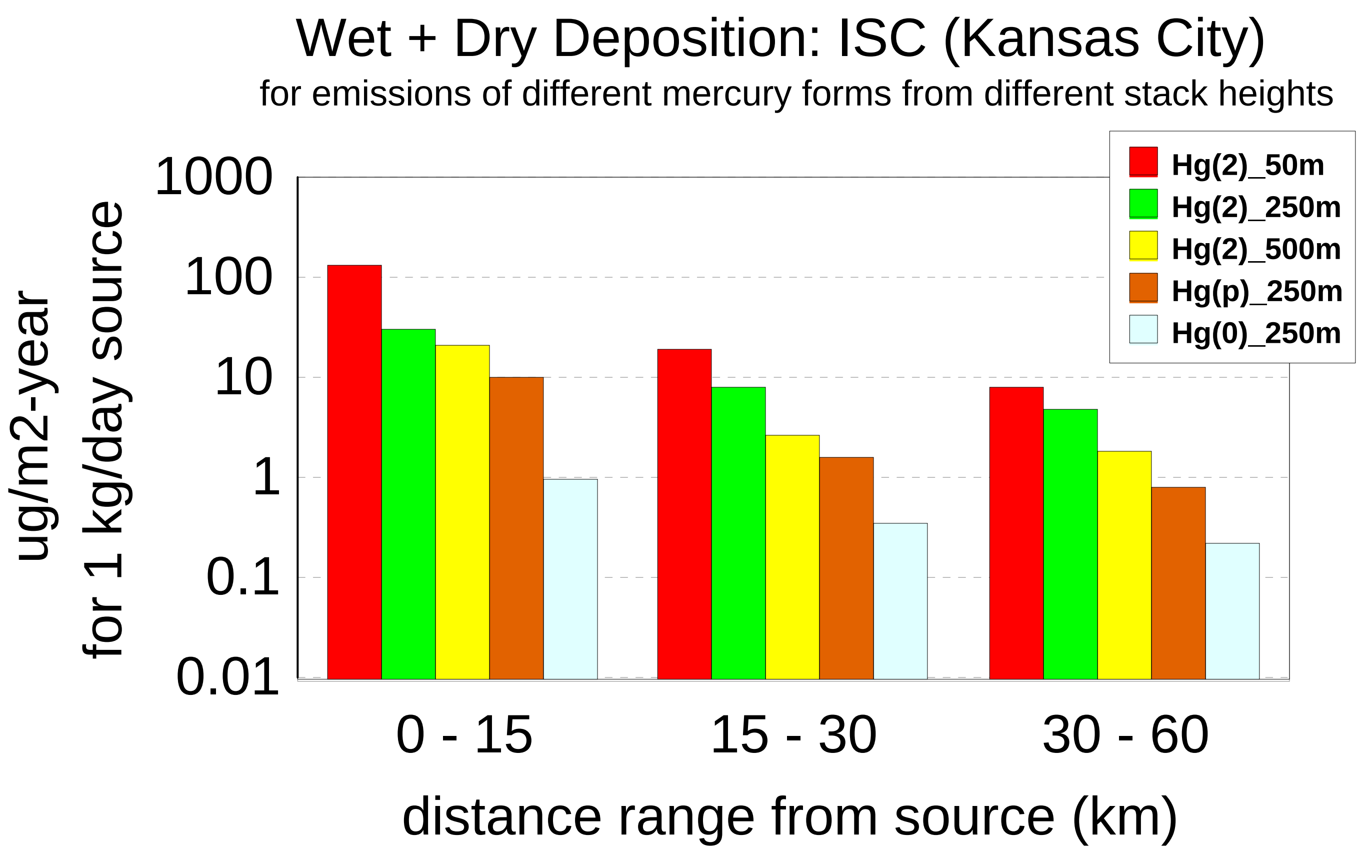
Why is emissions speciation information critical?

Logarithmic



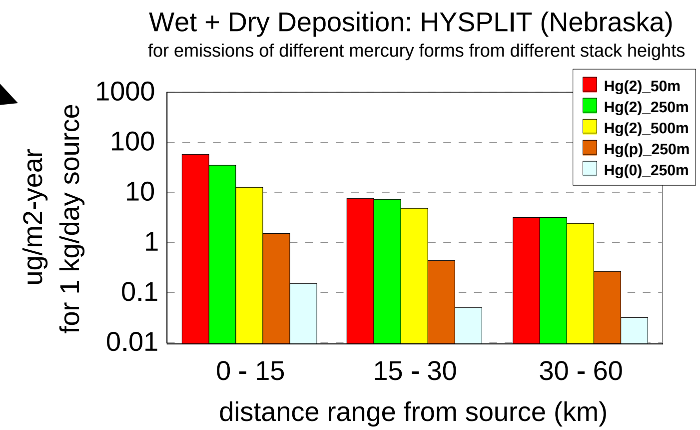
Linear





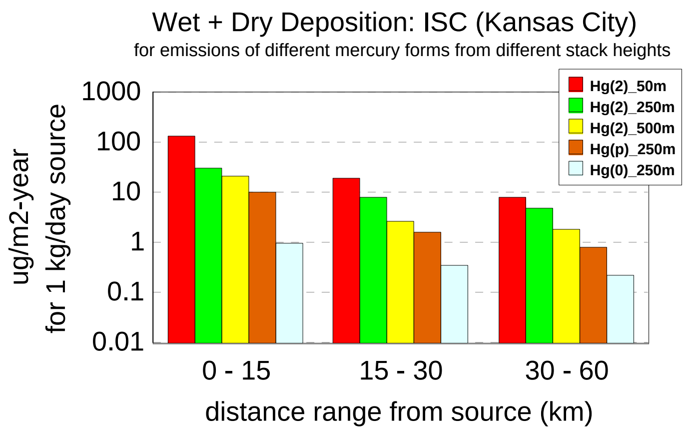
Calculated from data used to produce Appendix A of USEPA (2005): Clean Air Mercury Rule (CAMR) Technical Support Document: Methodology Used to Generate Deposition, Fish Tissue Methylmercury Concentrations, and Exposure for Determining Effectiveness of Utility Emissions Controls: Analysis of Mercury from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

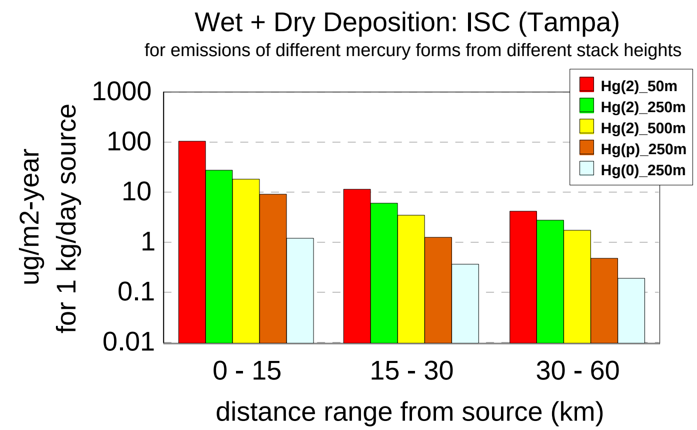
HYSPLIT 1996

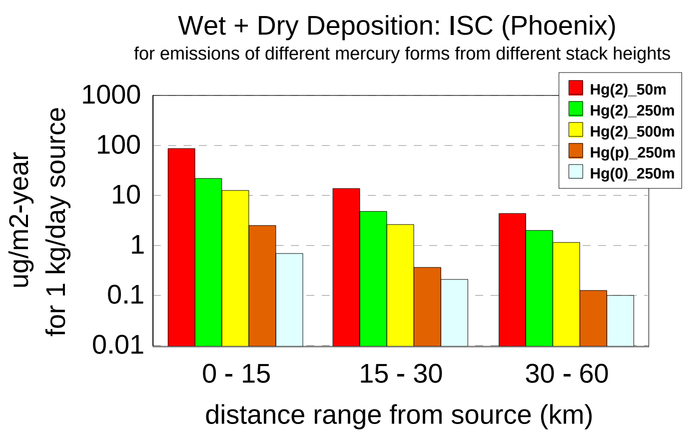


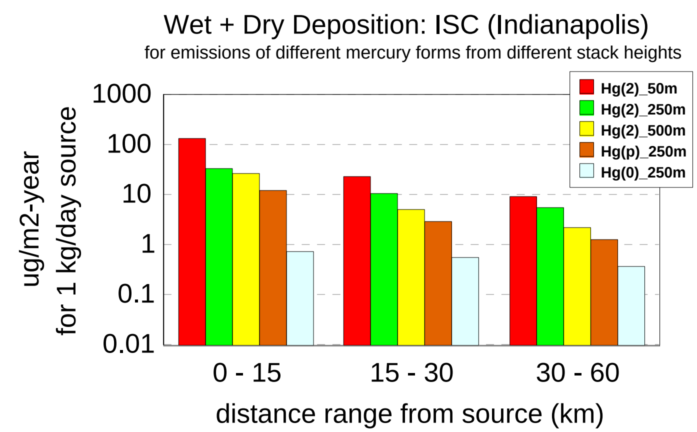
Different Time Periods and Locations, but Similar Results

ISC: 1990-1994



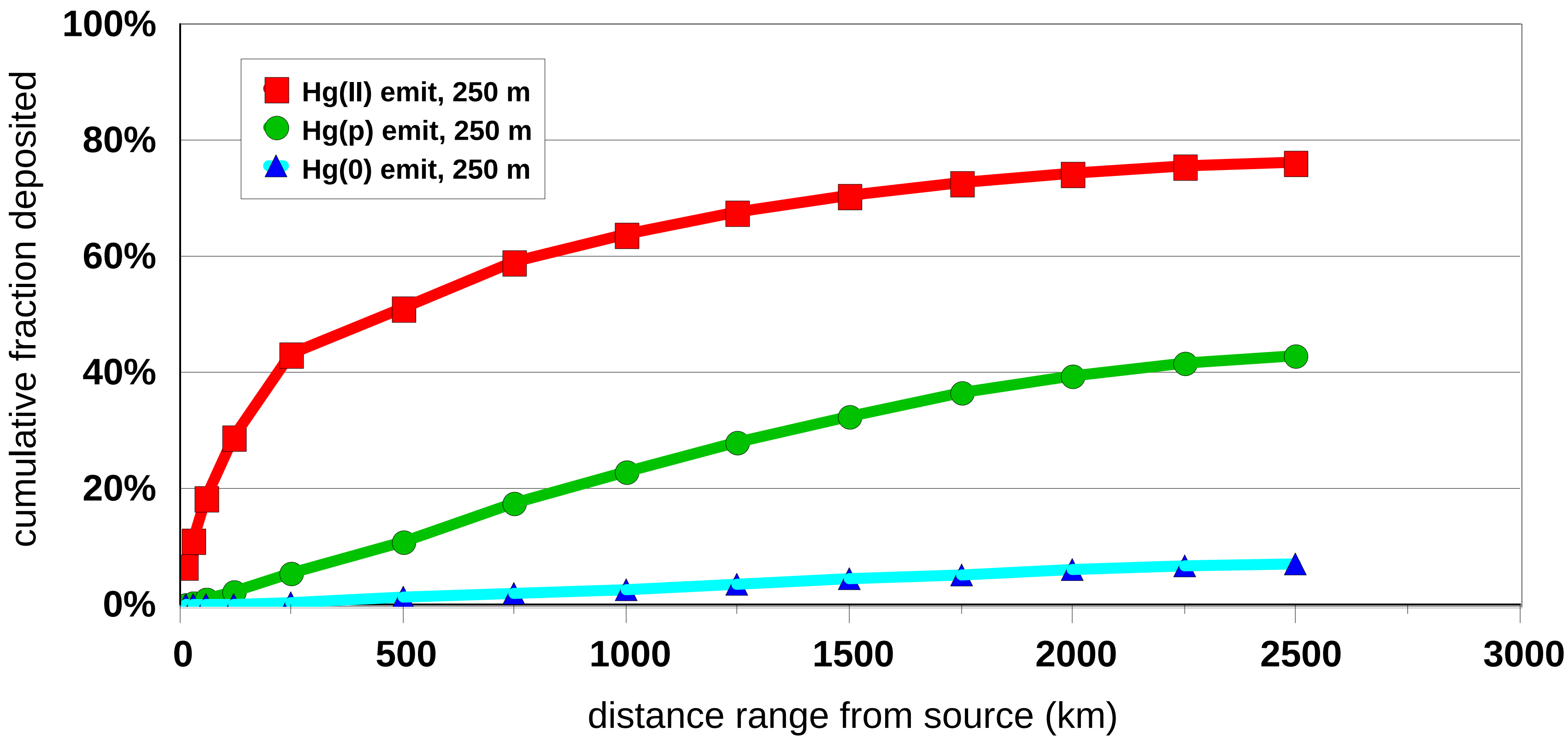






The <u>fraction deposited</u> and the <u>deposition flux</u> are both important,
but they have very different meanings…
The fraction deposited nearby can be relatively "small",
But the area is also small, and the relative deposition flux can be very large…

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



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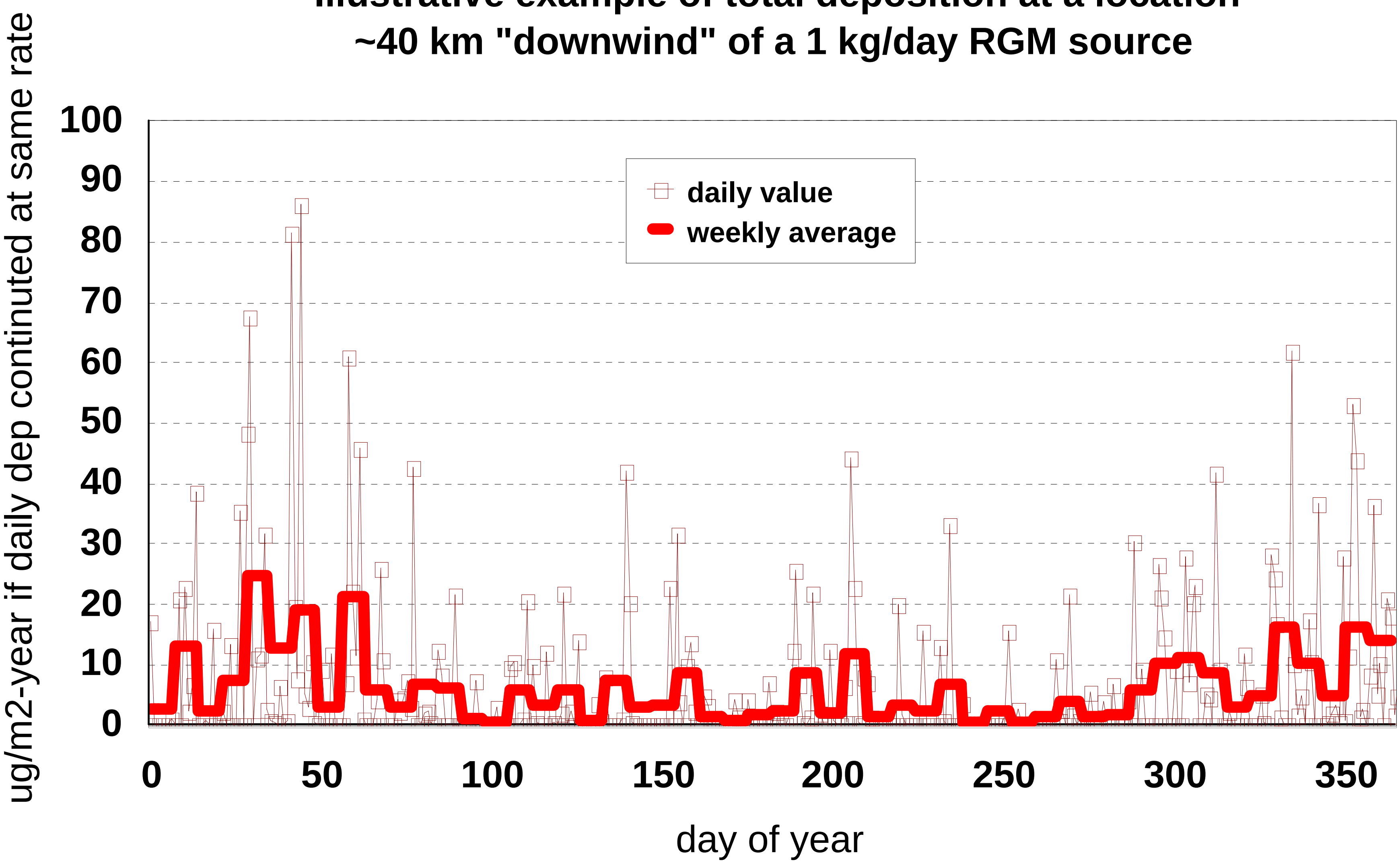
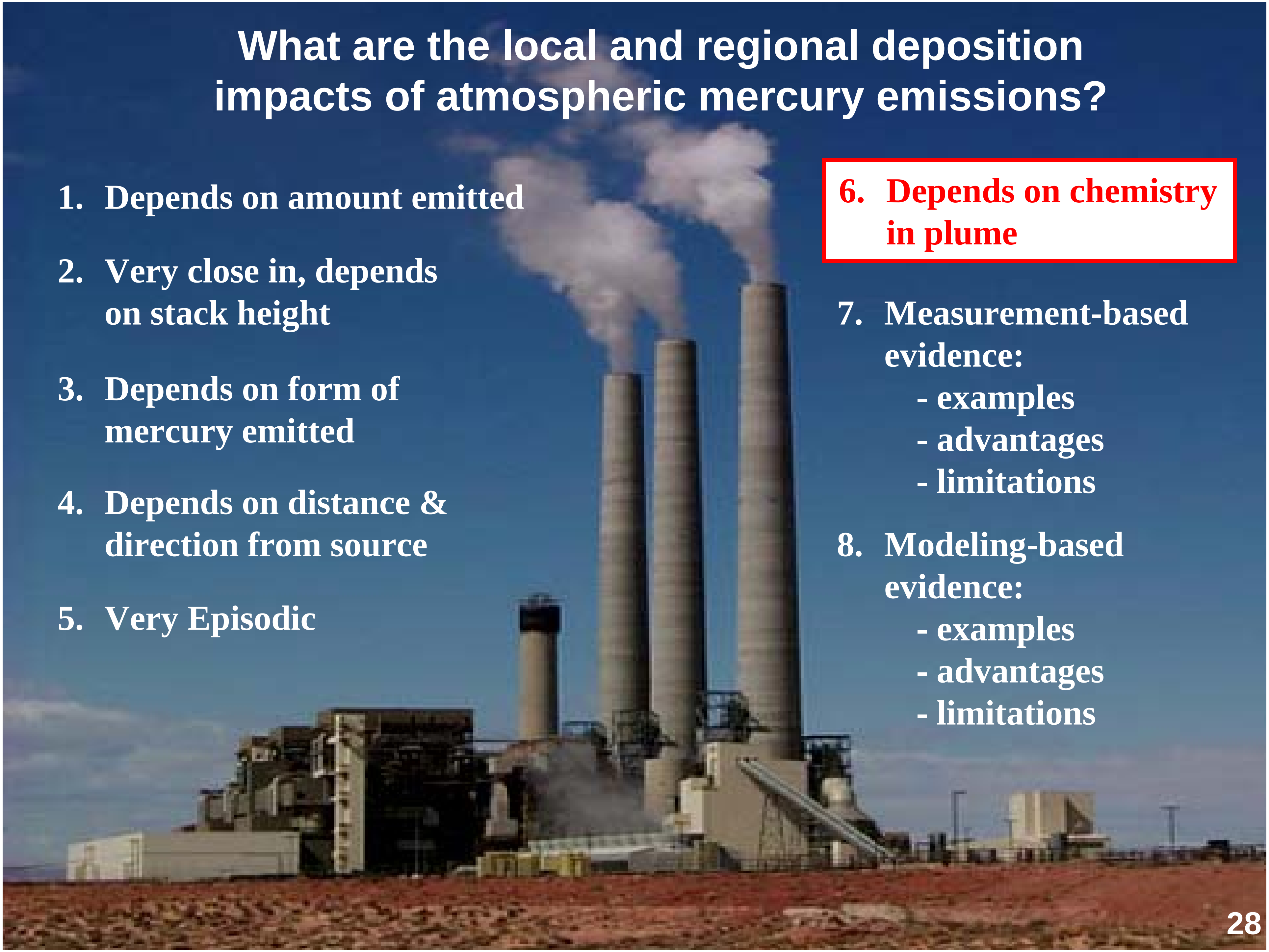
Illustrative example of total deposition at a location ~40 km "downwind" of a 1 kg/day RGM source





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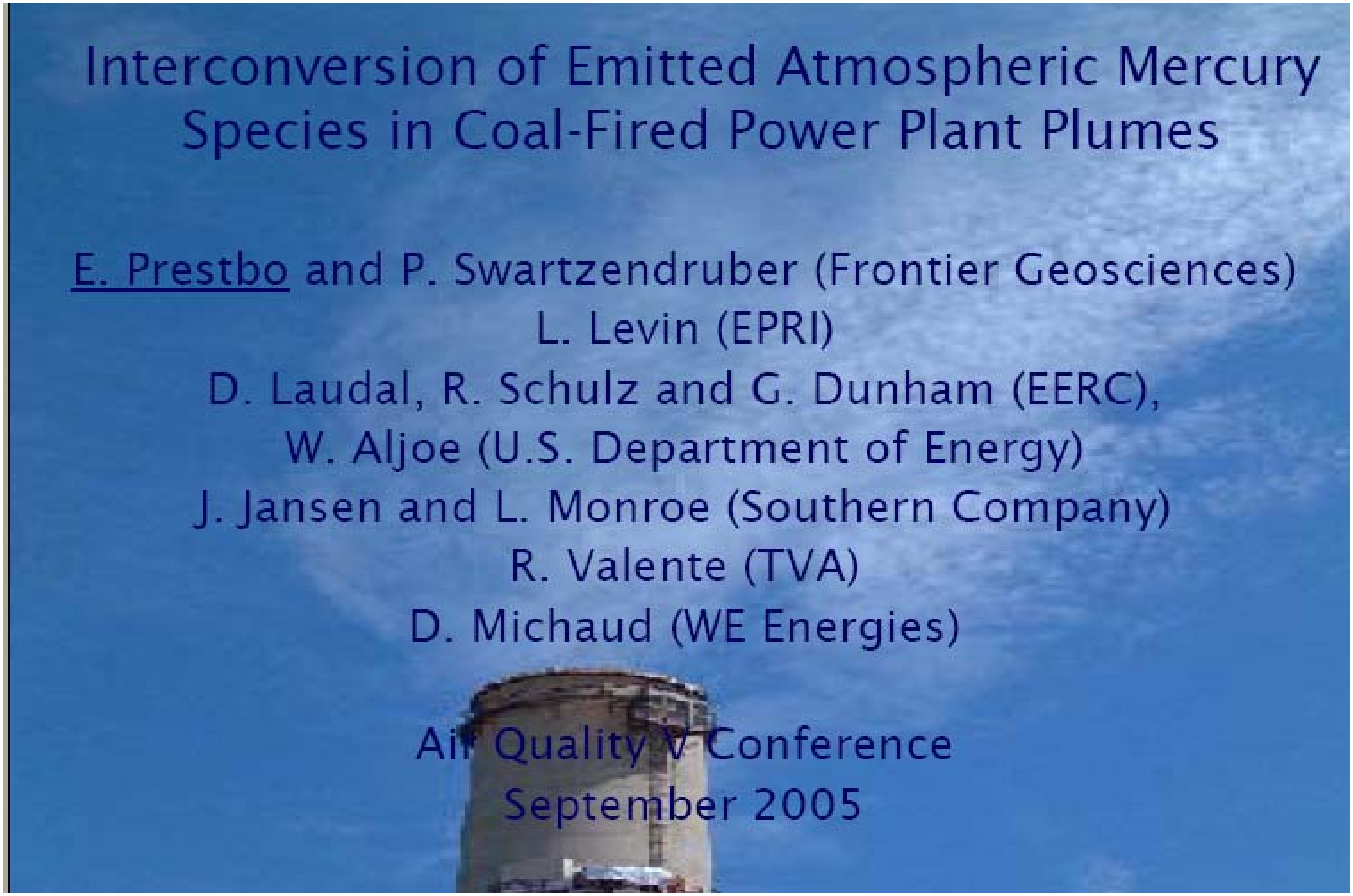
- ***If*** **significant reduction of RGM to Hg(0) is occuring in power-plant plumes, then it would have a big impact on local/regional deposition**

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

  e.g. measured rates of 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**


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	**33% ± 6.8%**	96% ± 14%	10
Dickerson, MD*	1998	E-SB	1 Unit Scrubber 2 Units ESP	**41% ± 7.9%**	128% ± 22%	8
Dickerson, MD	1998	MW	Scrubber 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 measurments

Eric Prestbo Ph.D. (ericp@frontiergeosciences.com)

Frontier GeoSciences Inc.

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

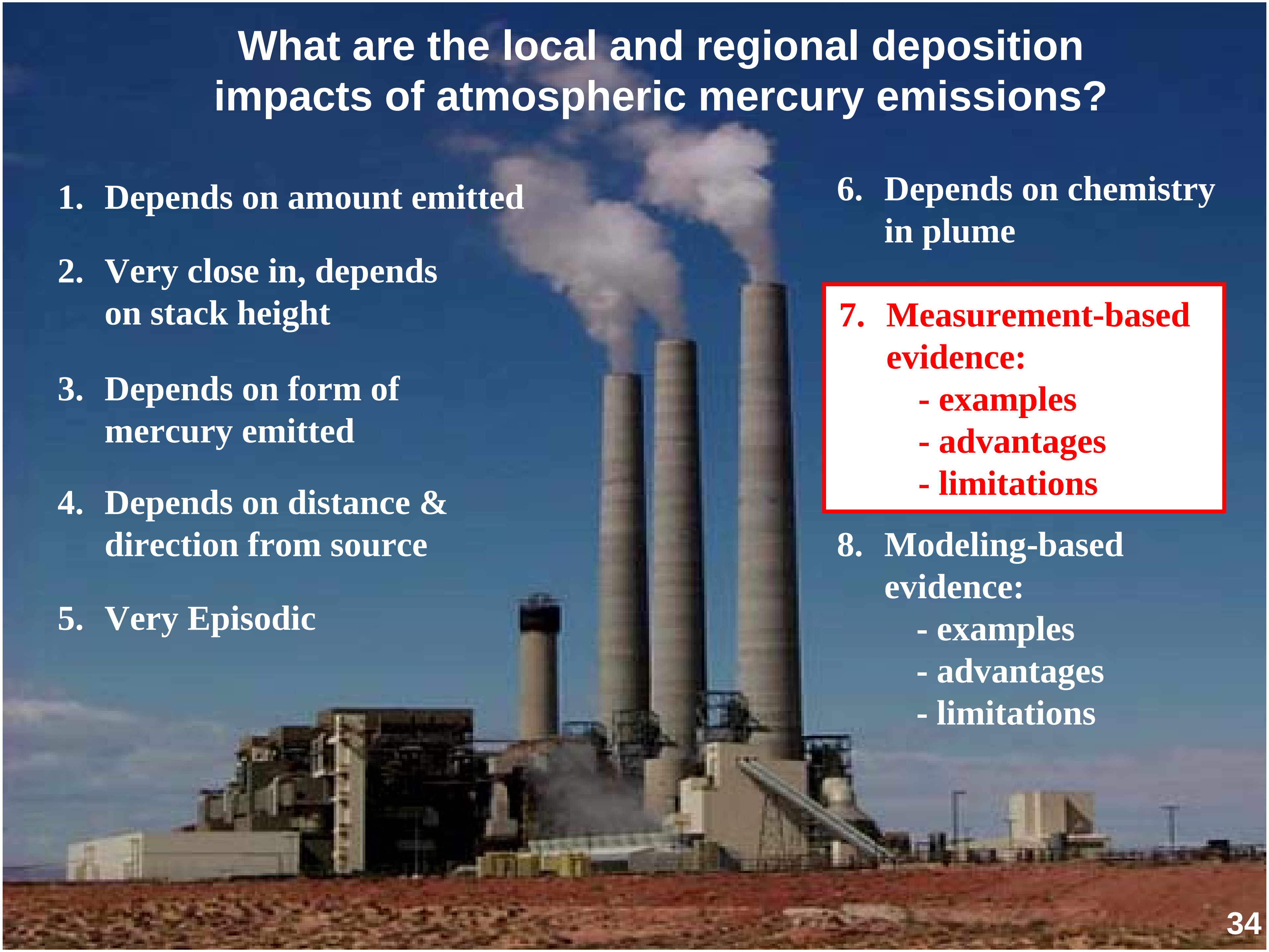
- Note: Airplane results were as of July, 2004

Eric Prestbo Ph.D. (ericp@frontiergeosciences.com)

Frontier GeoSciences Inc.

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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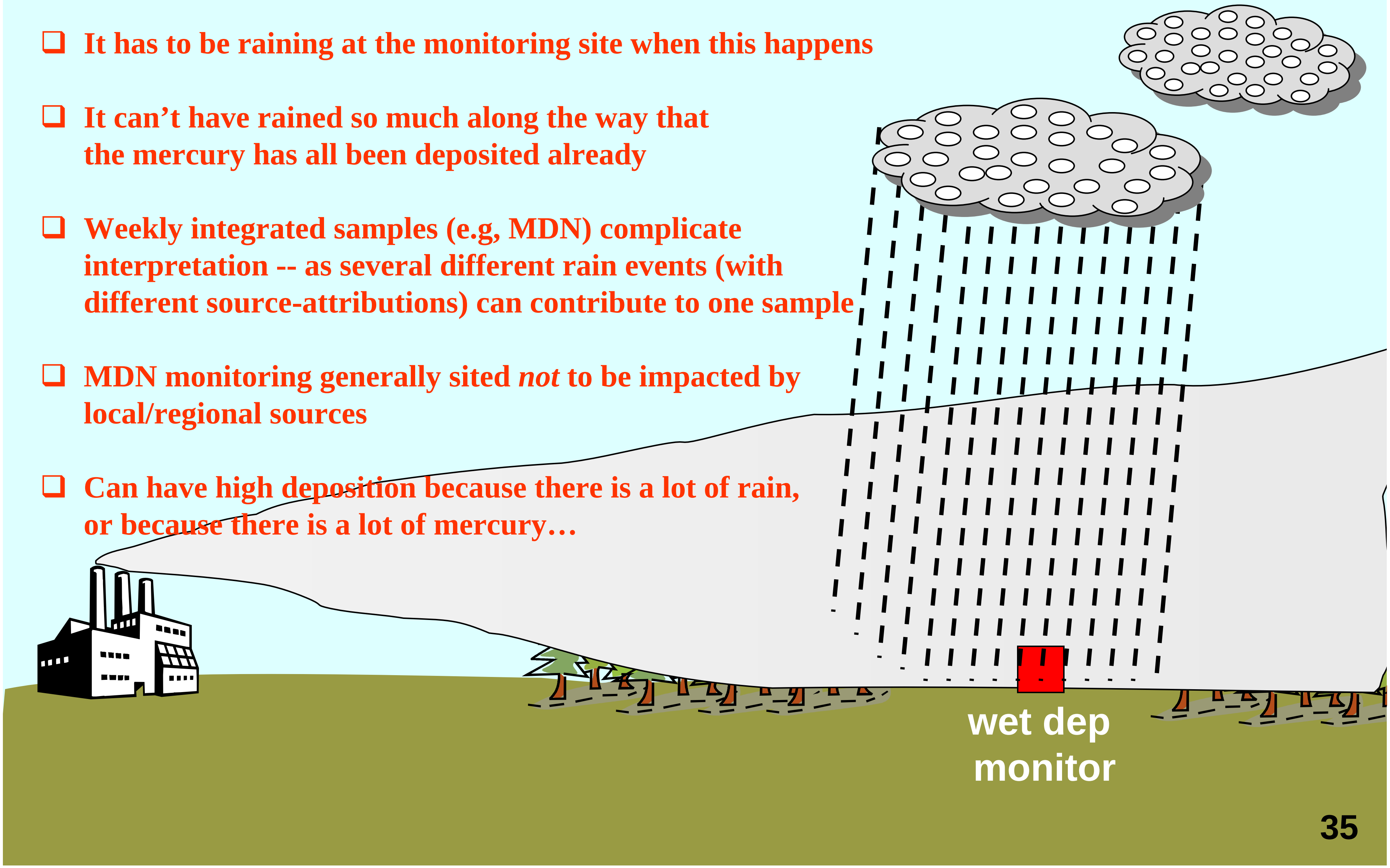
34

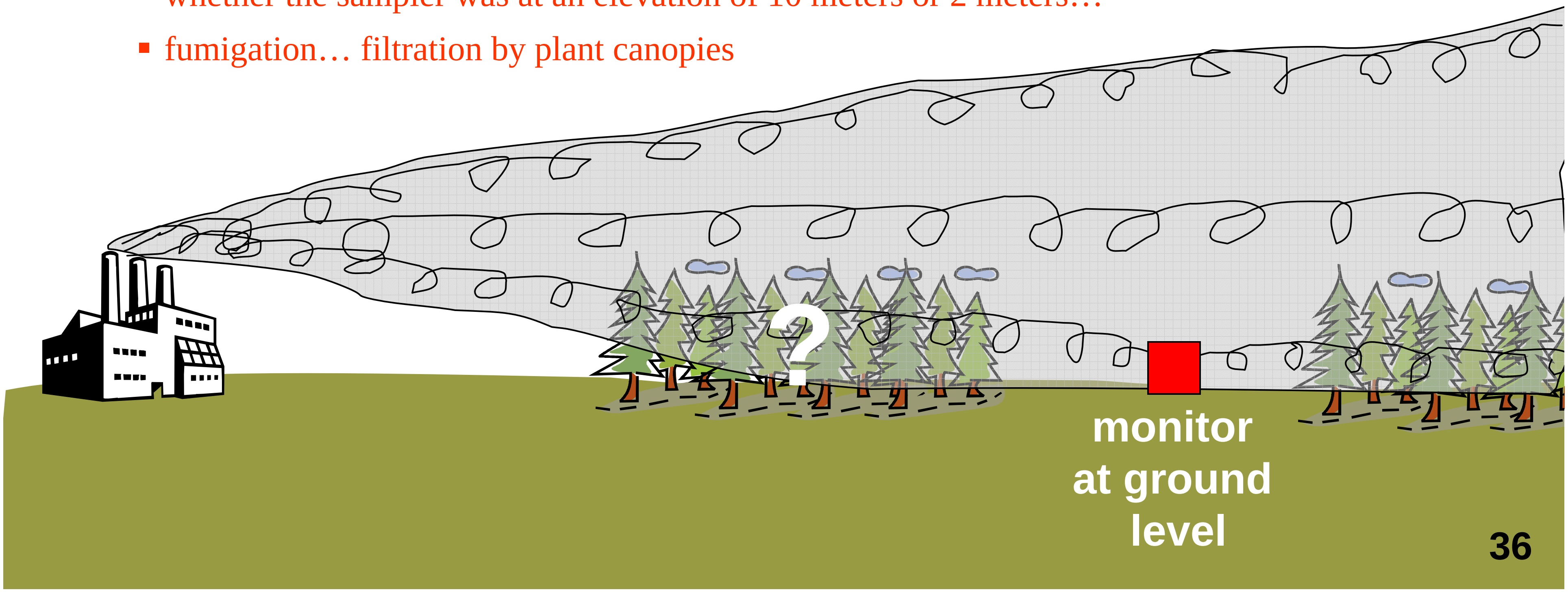
Challenges of using wet deposition data to assess local and regional deposition impacts…

- ❑ **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…**



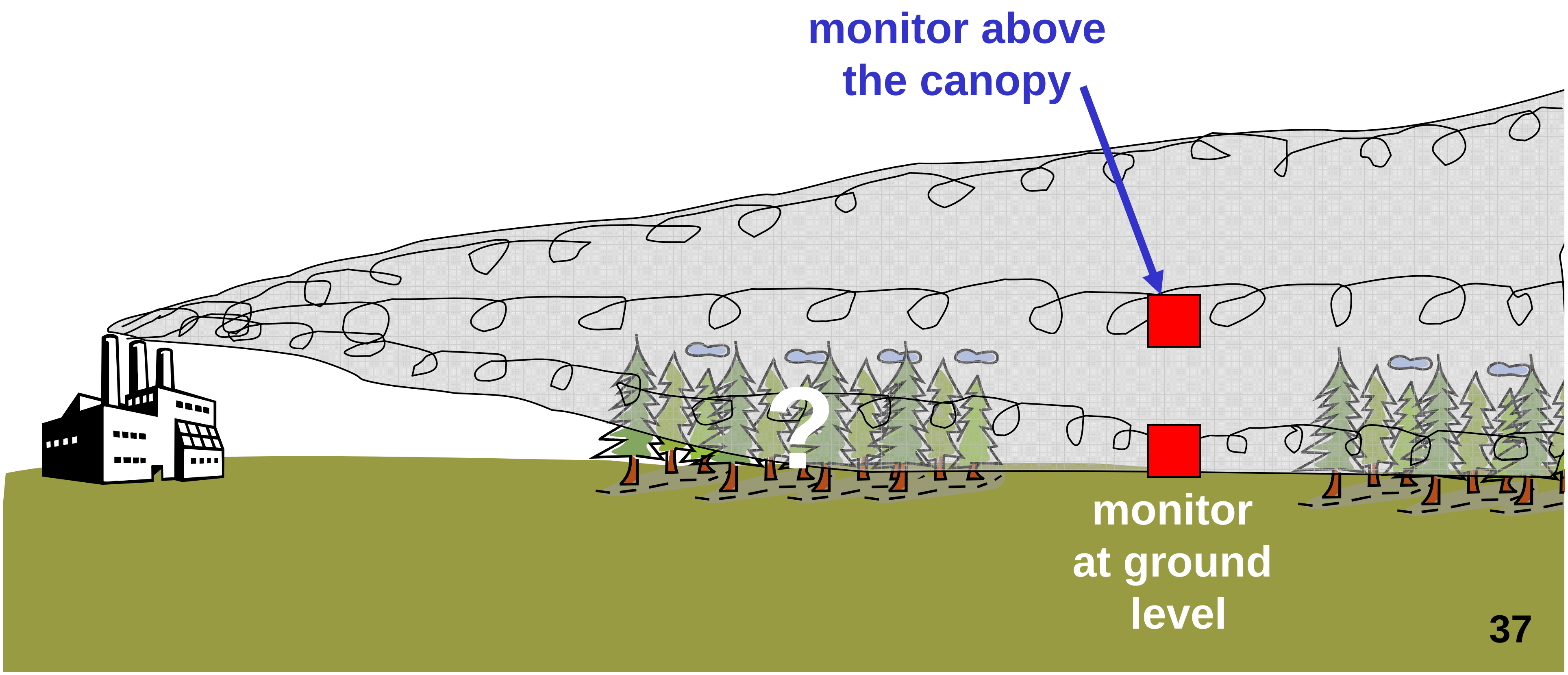
Challenges of using air concentration data to assess local and regional deposition impacts…

- **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

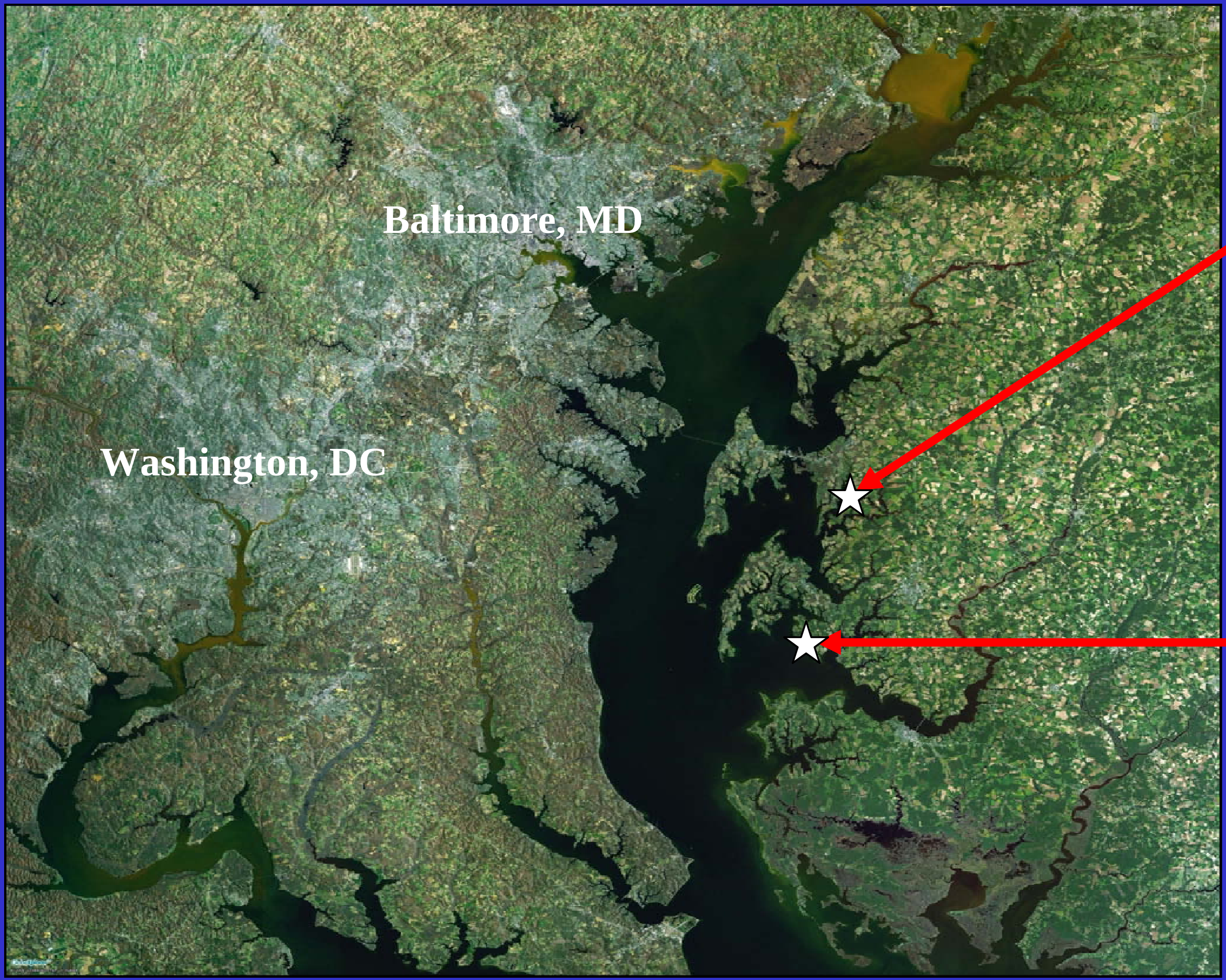


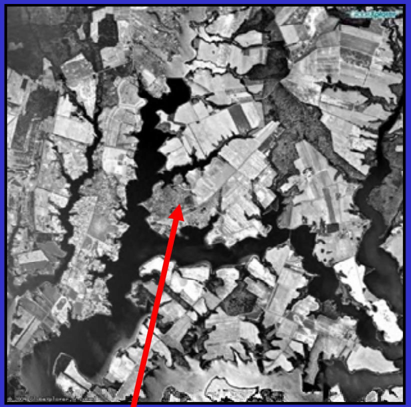
Observations of “depleted” RGM at ground-based stations downwind of power plants – sometimes thought to be evidence of RGM reduction to Hg0 -- might be strongly influenced by RGM dry deposition…

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



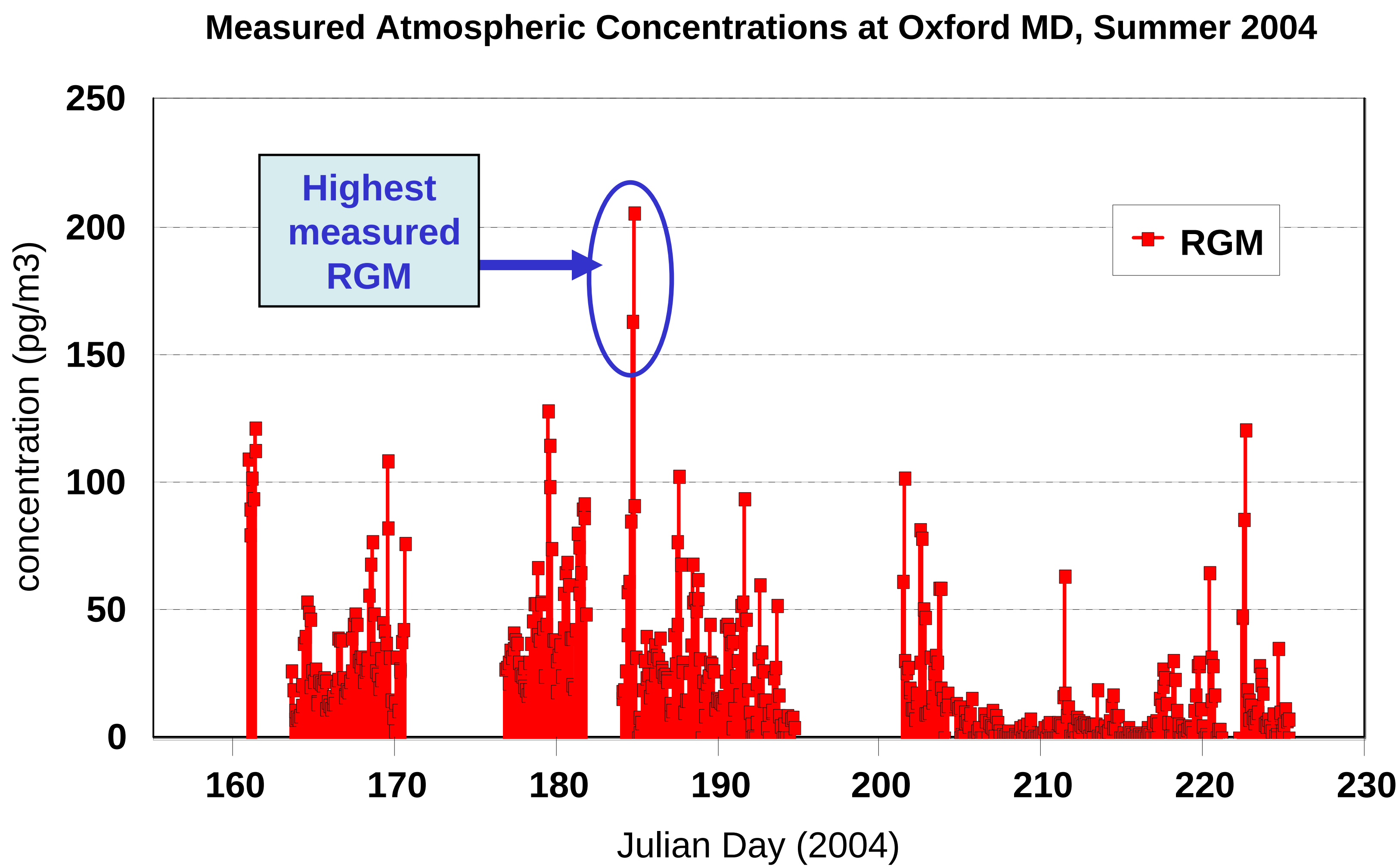
Summer 2004 NOAA ARL Hg Measurement Sites

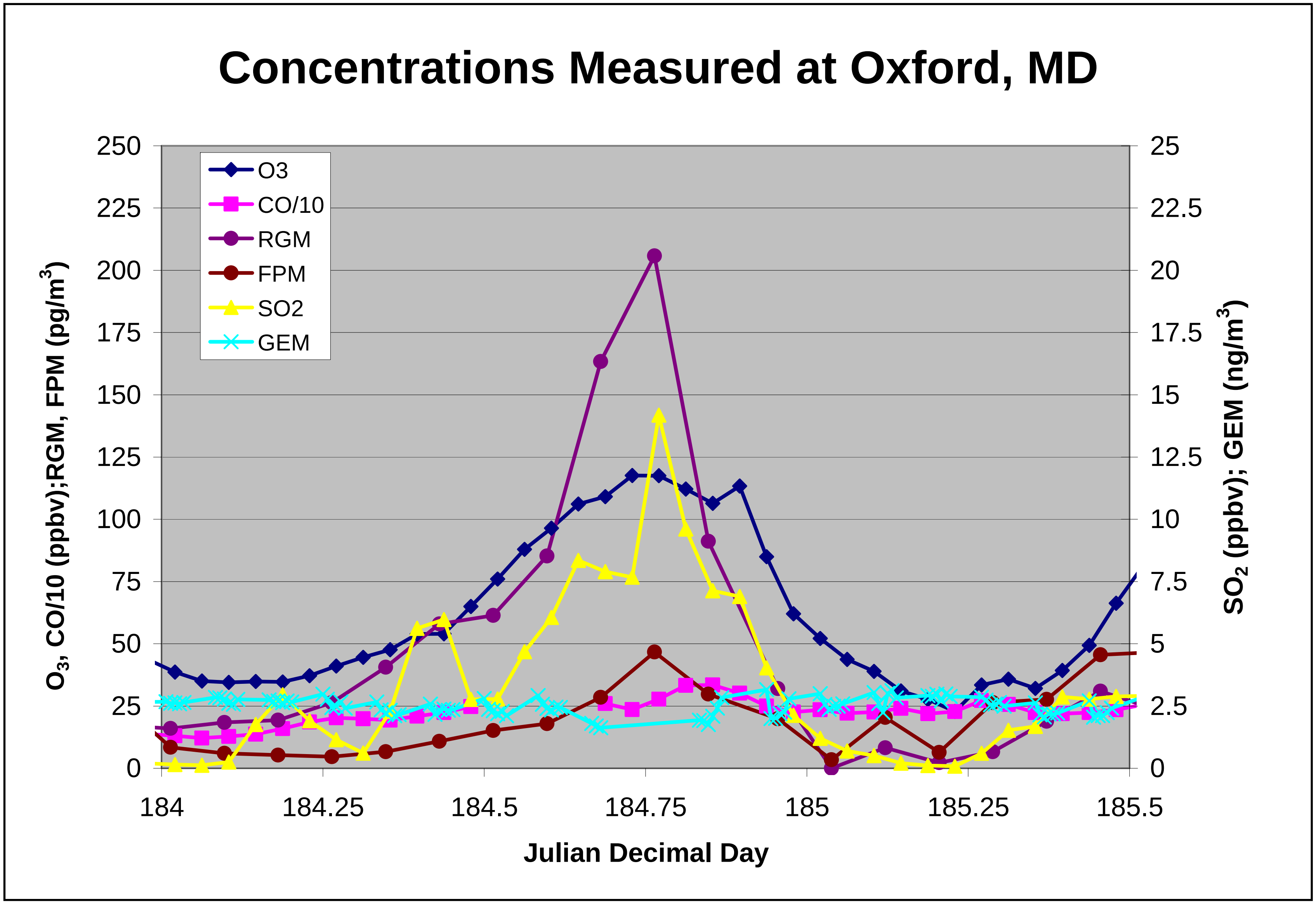




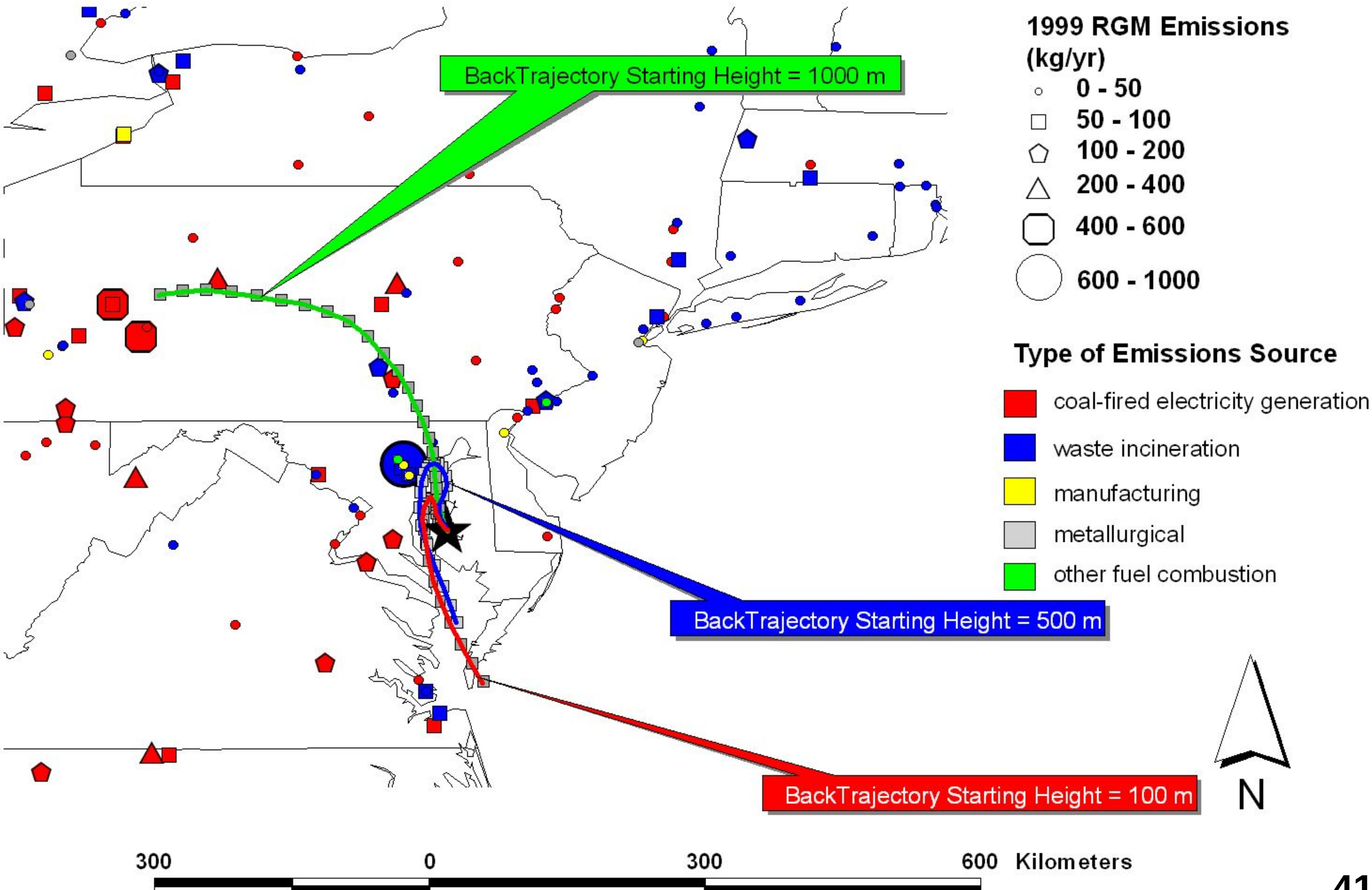
Wye Research and Education Center (38.9131EN, 76.1525EW)

Cooperative Oxford Lab (38.678EN, 76.173EW)

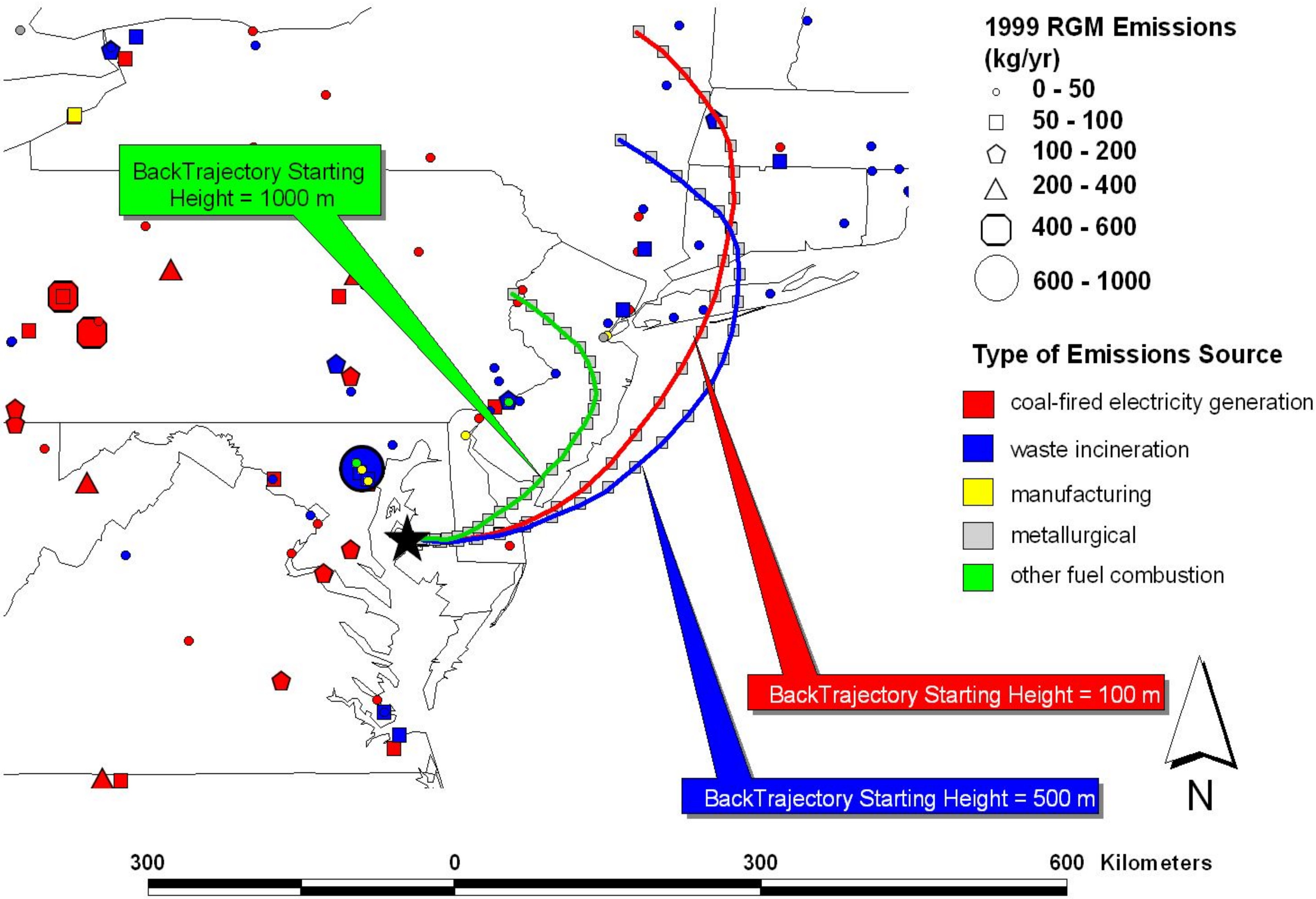

Measured Atmospheric Concentrations at Oxford MD, Summer 2004
Highest measured RGM
RGM
concentration (pg/m3)
Julian Day (2004)
250
200
150
100
50
0
160
170
180
190
200
210
220
230


Concentrations Measured at Oxford, MD
O3
CO/10
RGM
FPM
SO2
GEM
O_3, CO/10 (ppbv);RGM, FPM (pg/m^3)
SO_2 (ppbv); GEM (ng/m^3)
Julian Decimal Day
250
225
200
175
150
125
100
75
50
25
0
25
22.5
20
17.5
15
12.5
10
7.5
5
2.5
0
184
184.25
184.5
184.75
185
185.25
185.5

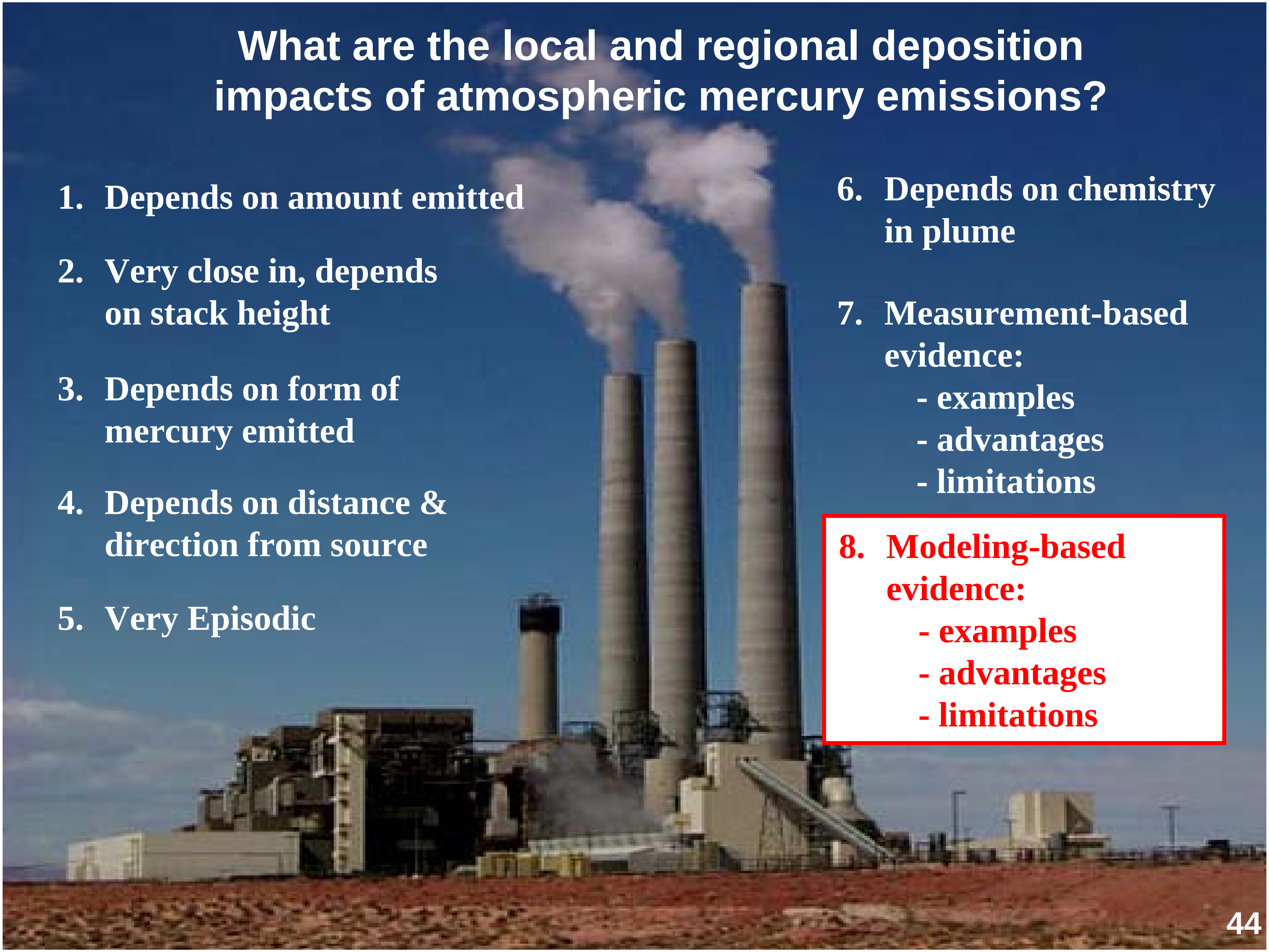
Oxford July 2, 2004 Peak Concentration in RGM



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



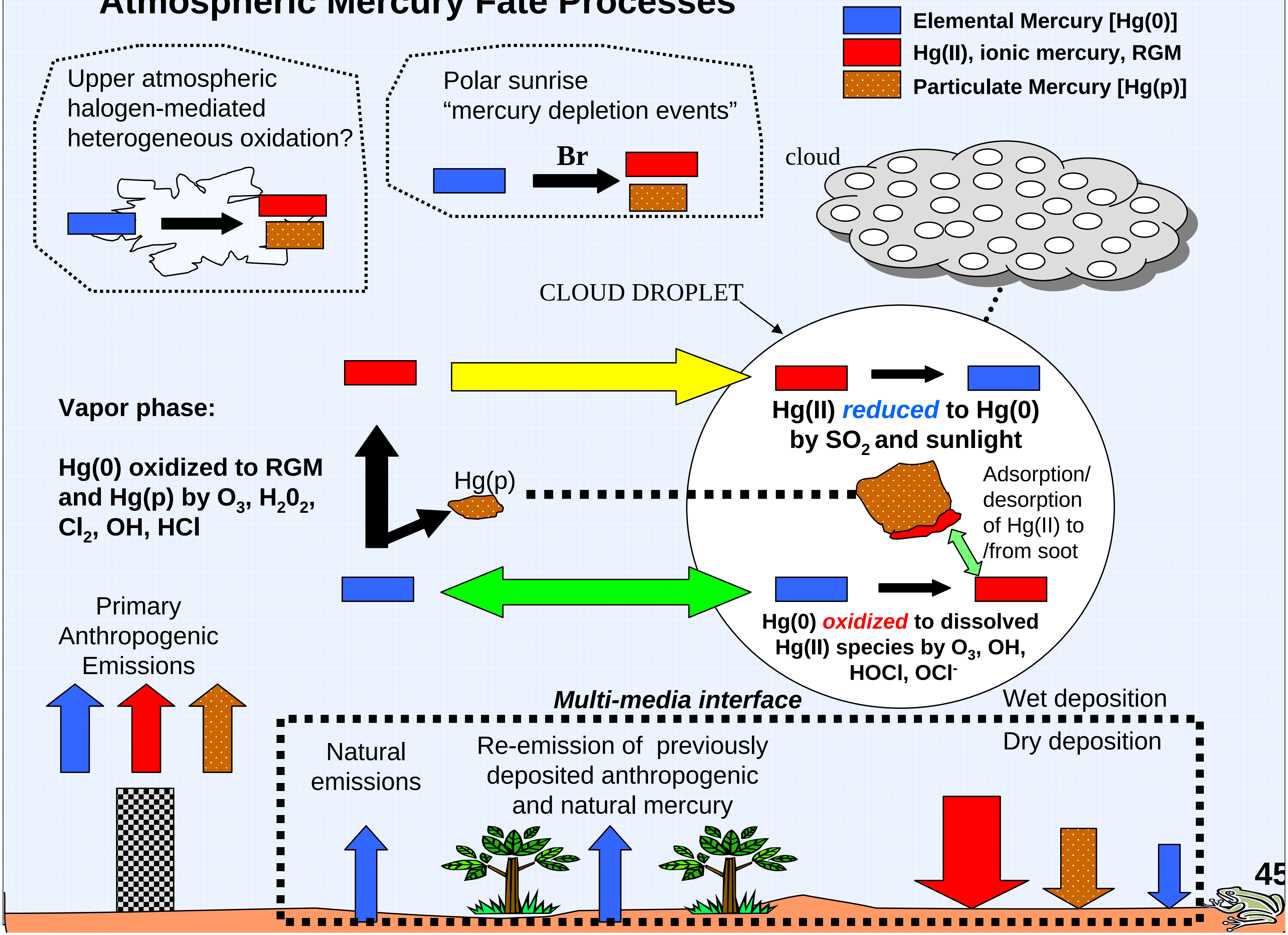
Measurements tell you the "exact" answer (ignoring measurement uncertainties for the moment) but it is usually very difficult to figure out what that answer is telling you, e.g., regarding source-attribution for measured quantities



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



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

Participants

D. Syrakov ………………………………. **Bulgaria**….**NIMH**

A. Dastoor, D. Davignon ………………. **Canada**...... **MSC-Can**

J. Christensen …………………………. **Denmark**…**NERI**

G. Petersen, R. Ebinghaus …………….... **Germany**…**GKSS**

J. Pacyna ………………………………. **Norway**…..**NILU**

J. Munthe, I. Wängberg ……………….. **Sweden**….. **IVL**

R. Bullock ………………………………**USA**………**EPA**

M. Cohen, R. Artz, R. Draxler ………….**USA**………**NOAA**

C. Seigneur, K. Lohman ………………..**USA**……... **AER/EPRI**

A. Ryaboshapko, I. Ilyin, O.Travnikov…**EMEP**……**MSC-E**

Intercomparison Conducted in 3 Stages

I. Comparison of chemical schemes for a cloud environment

II. Air Concentrations in Short Term Episodes

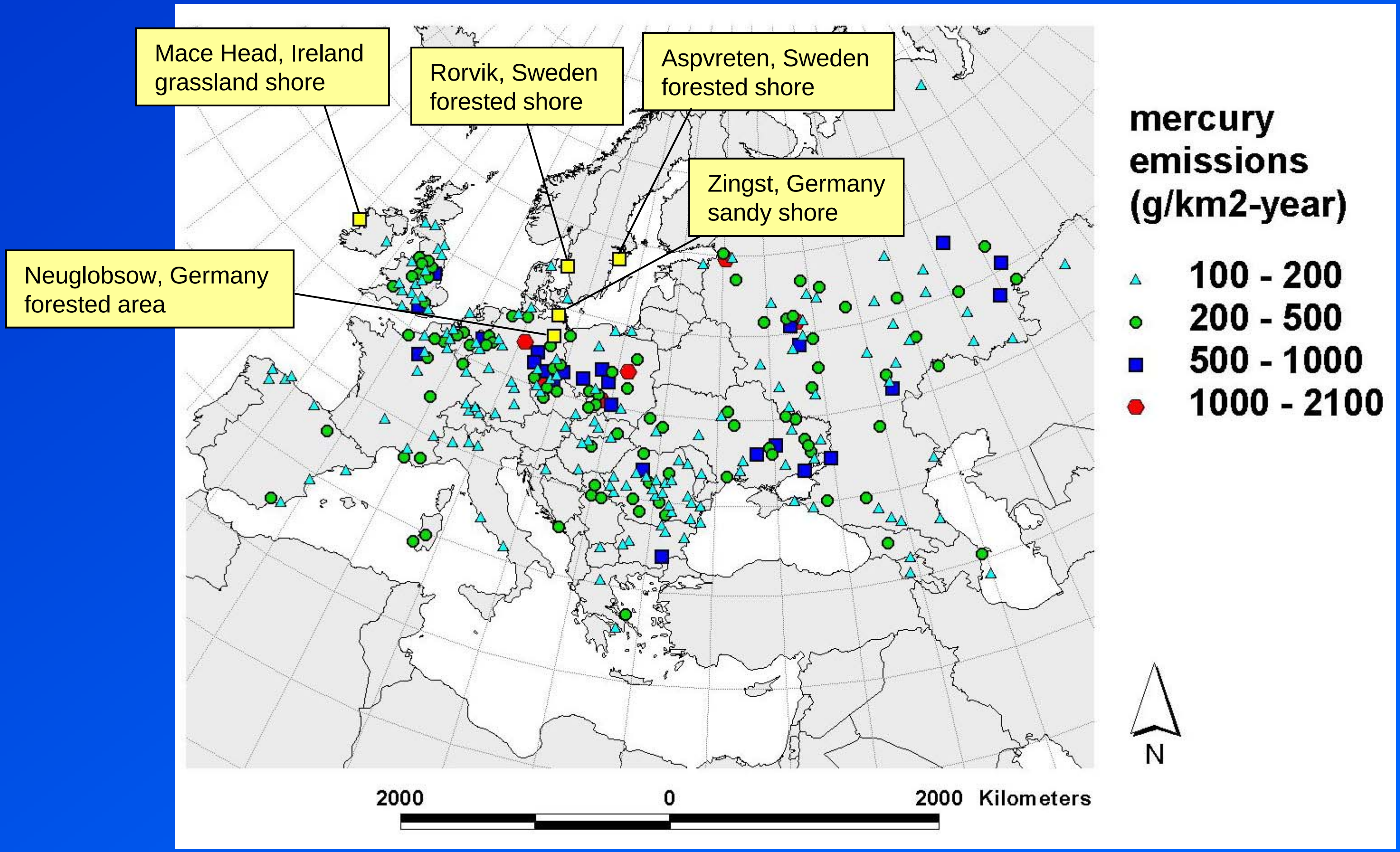
III. Long-Term Deposition and Source-Receptor Budgets

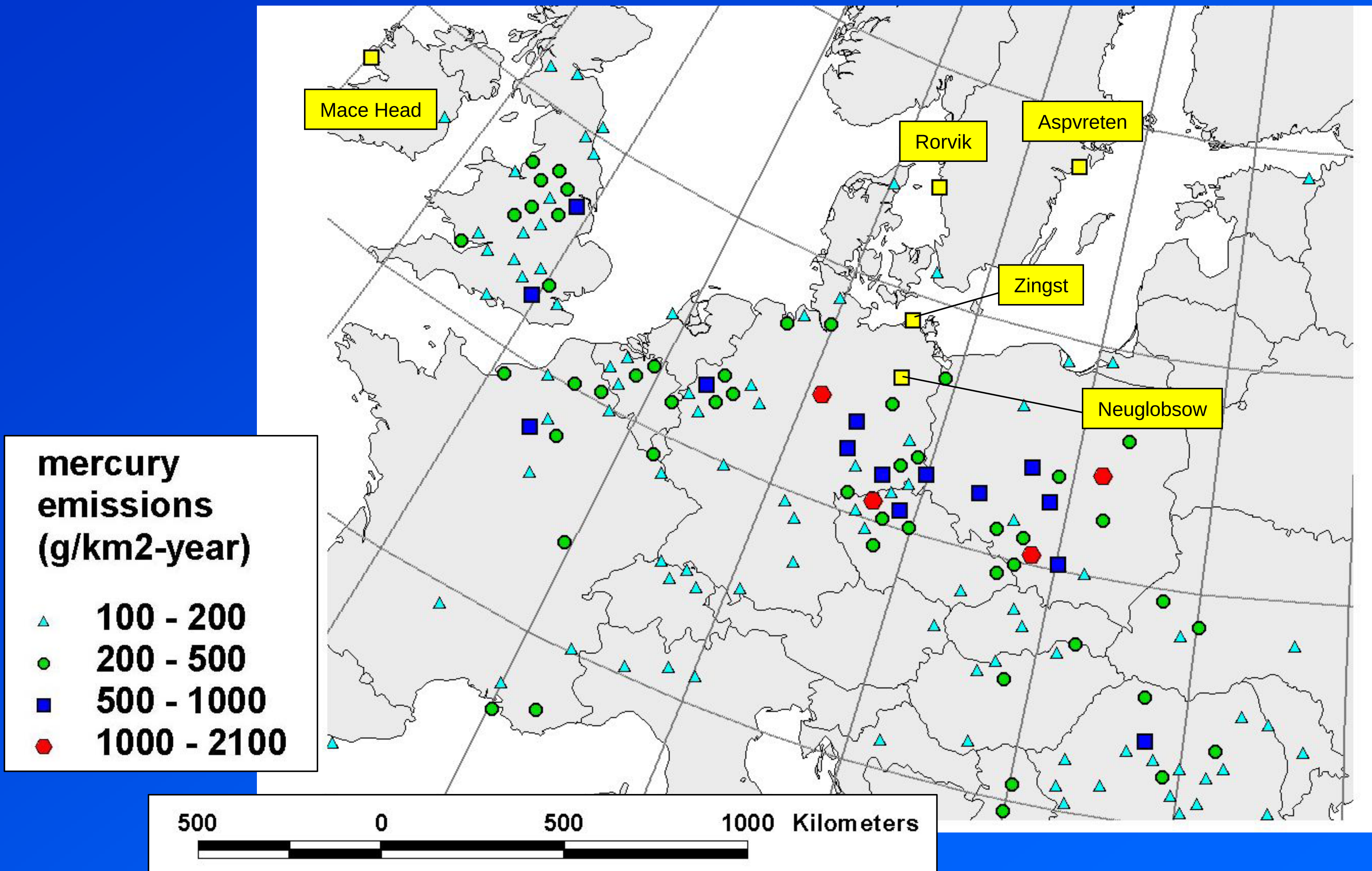
Participating Models

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

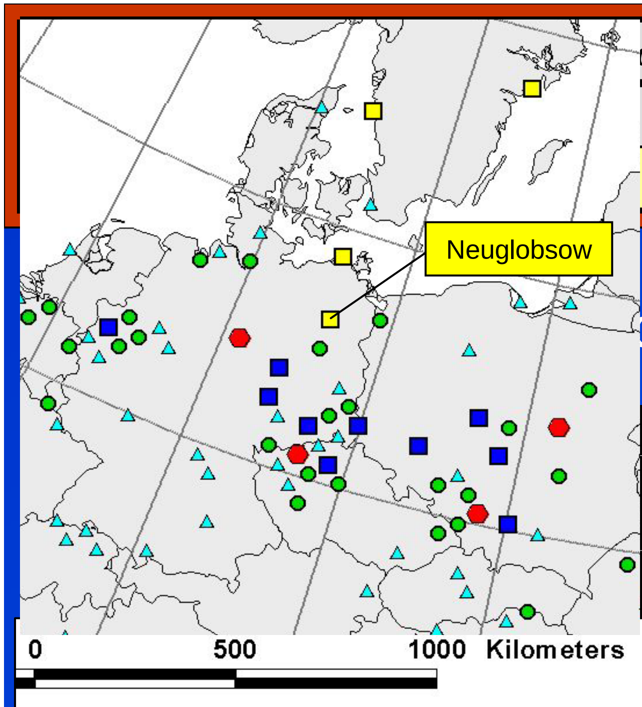
Anthropogenic Mercury Emissions Inventory and Monitoring Sites for Phase II

(note: only showing largest emitting grid cells)

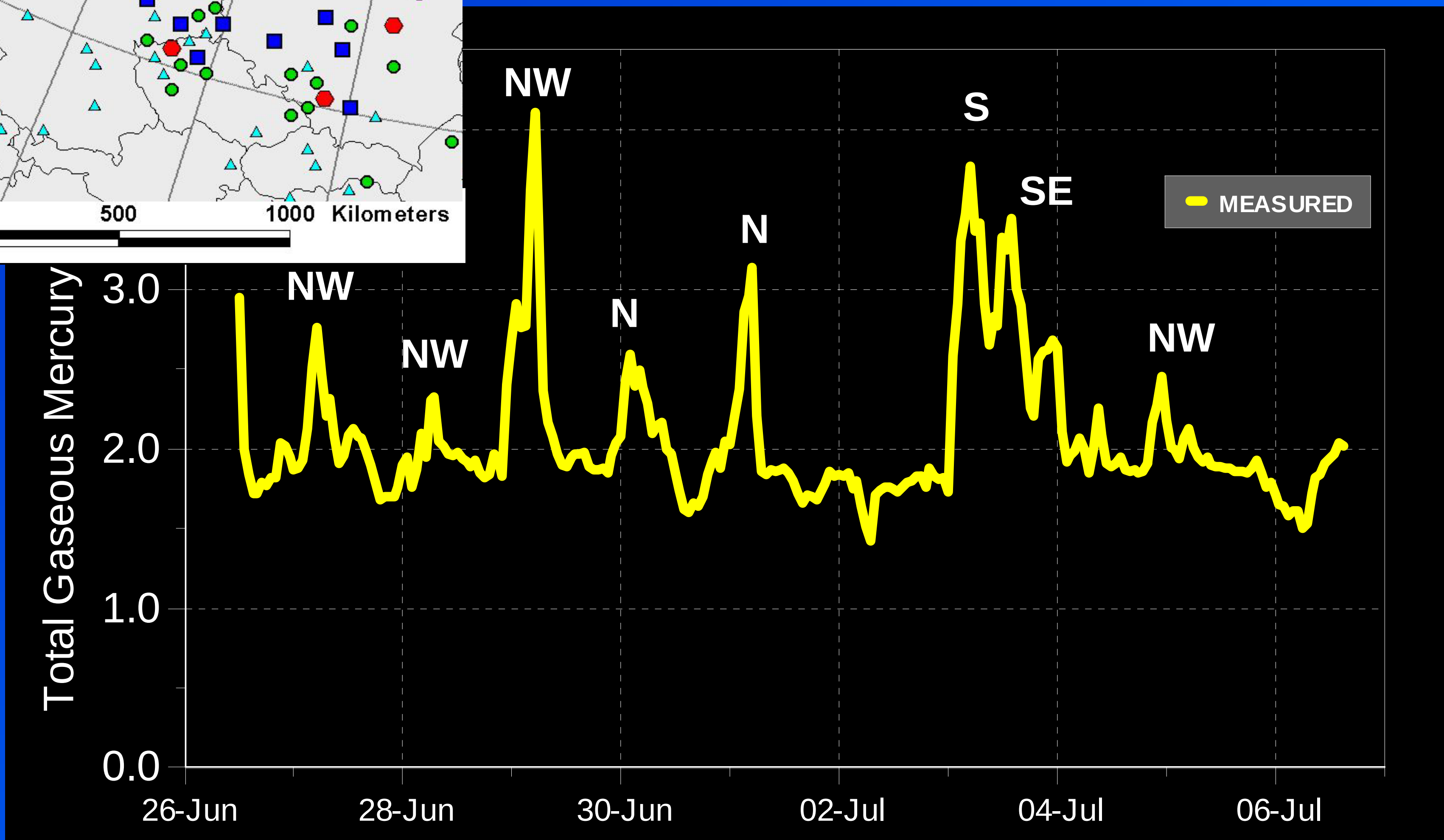




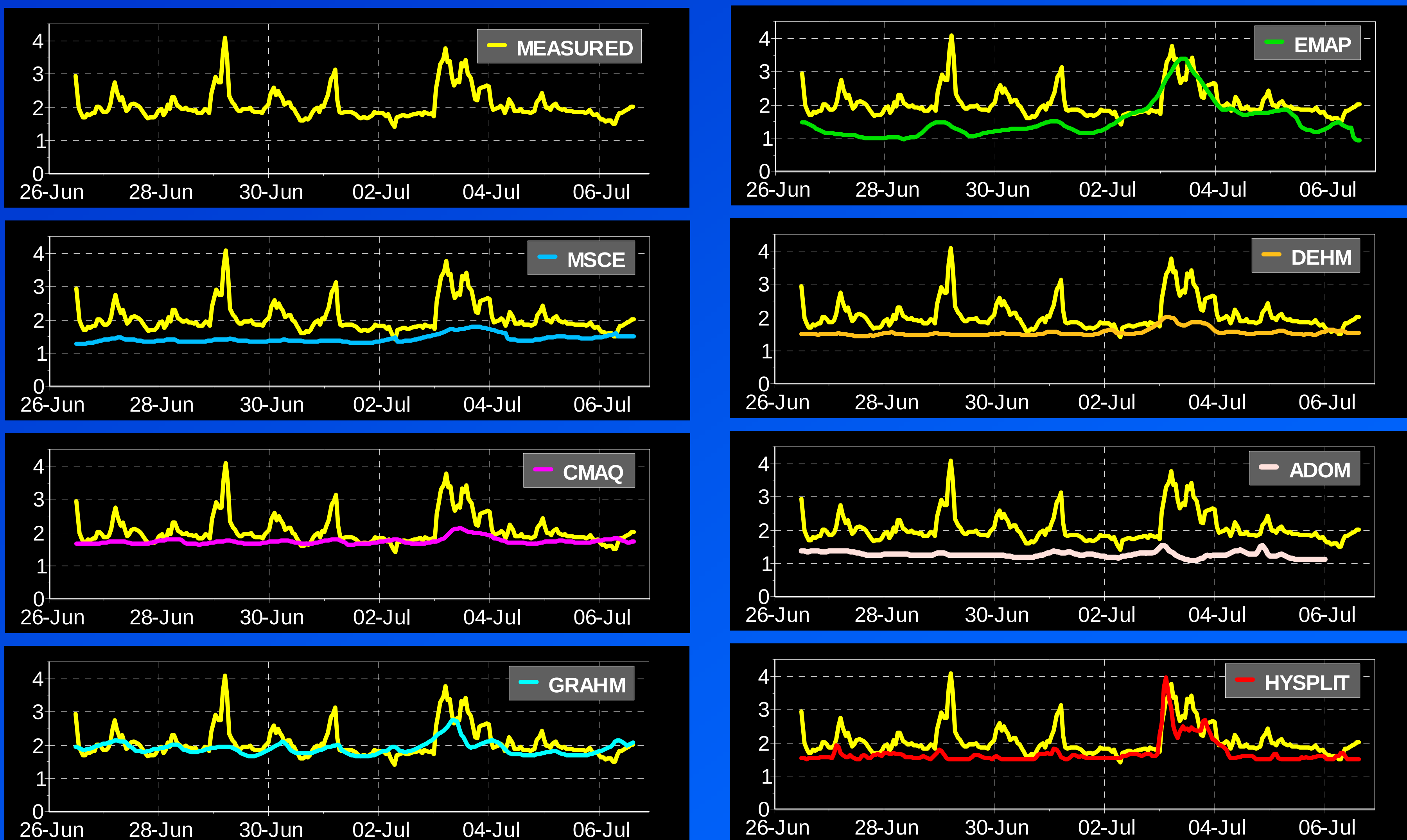
Mace Head
Rorvik
Aspvreten
Zingst
Neuglobsow
mercury emissions (g/km2-year)
100 - 200
200 - 500
500 - 1000
1000 - 2100
500
0
500
1000
Kilometers



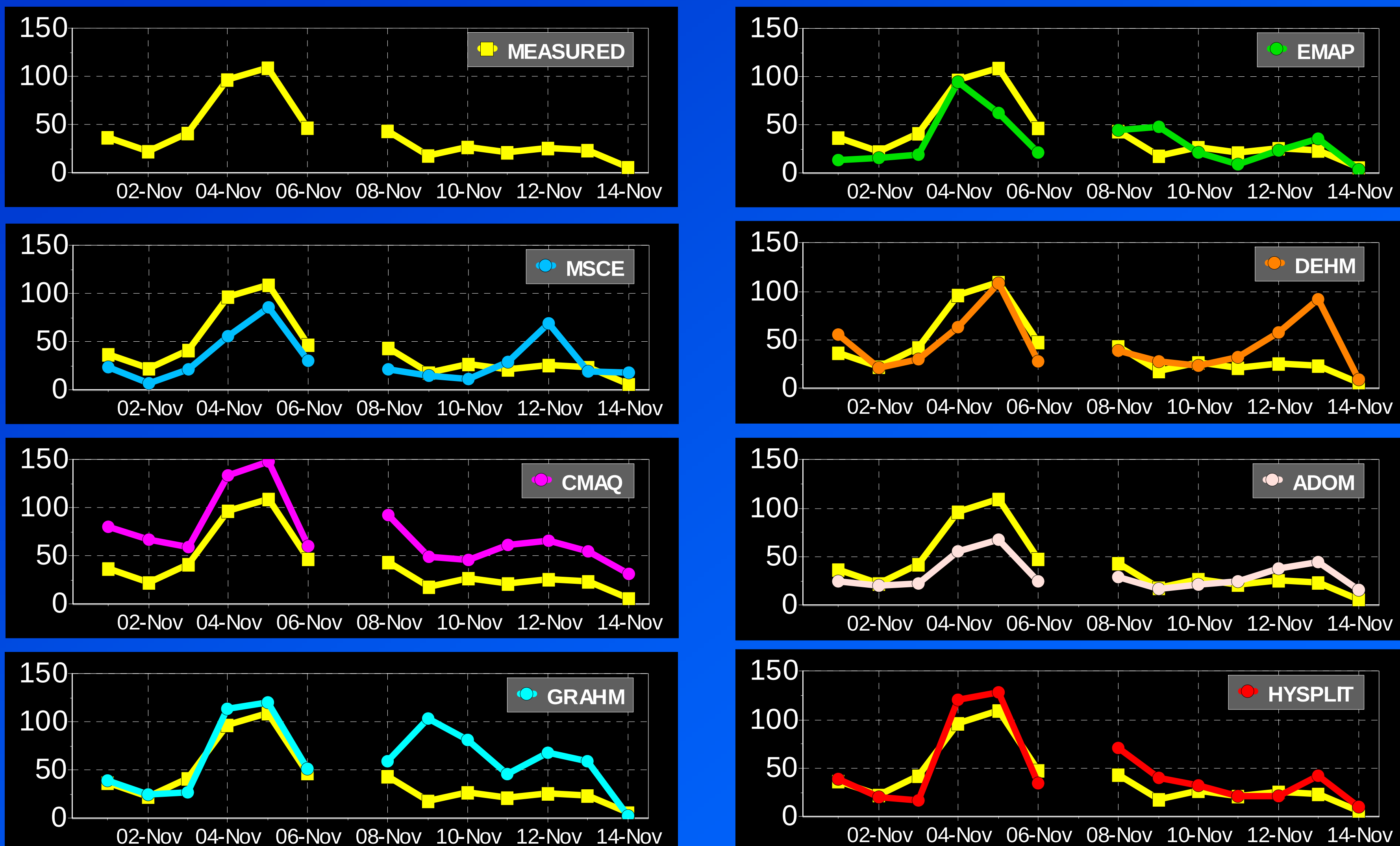
cury at Neuglobsow: June 26 – July 6, 1995



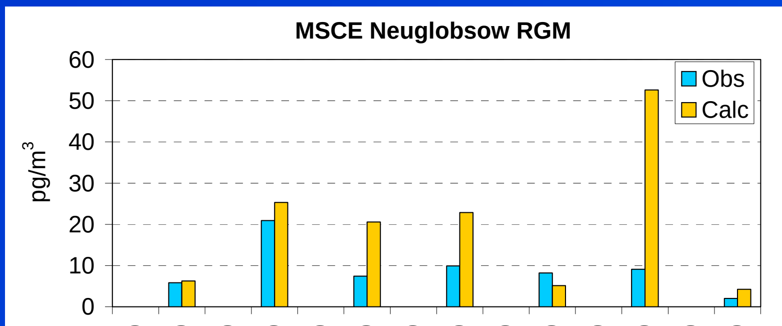
Total Gaseous Mercury (ng/m^3) at Neuglobsow: June 26 – July 6, 1995

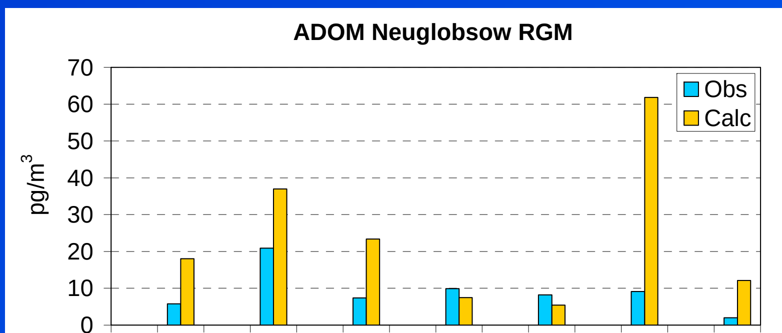


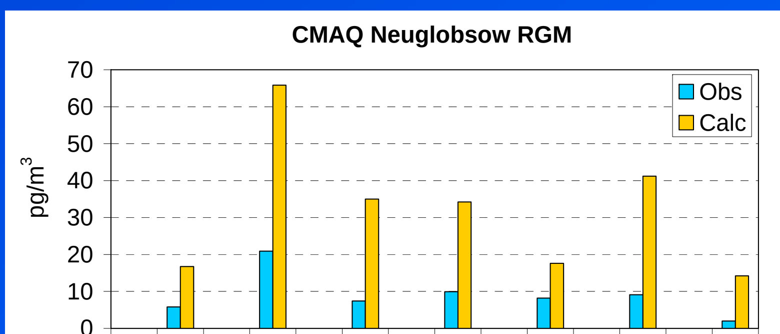
Total *Particulate* Mercury (pg/m³) at Neuglobsow, Nov 1-14, 1999

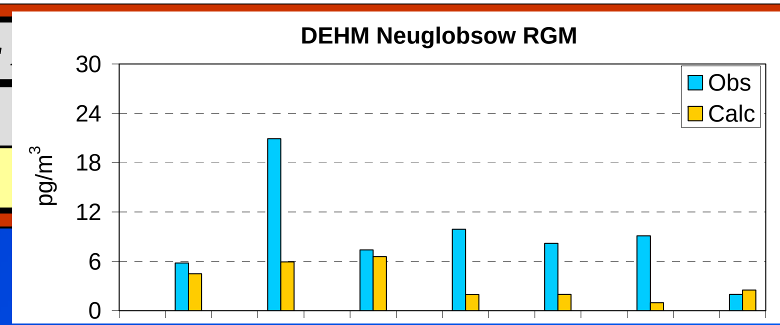


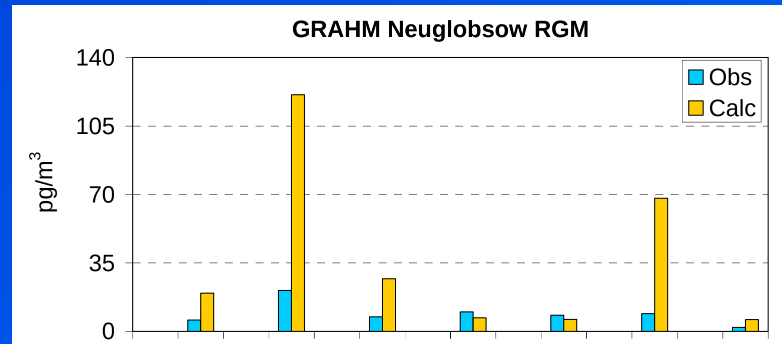
Reactive Gaseous Mercury at Neuglobsow, Nov 1-14, 1999

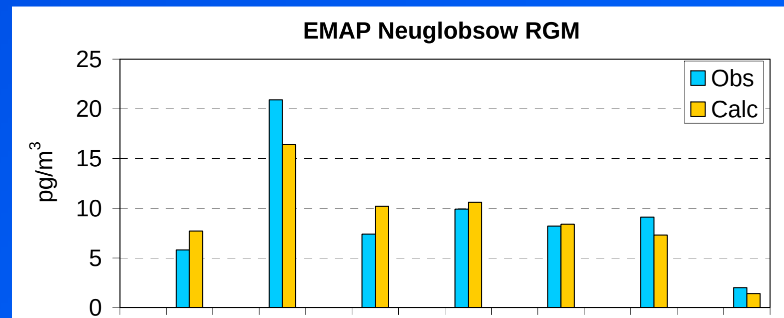


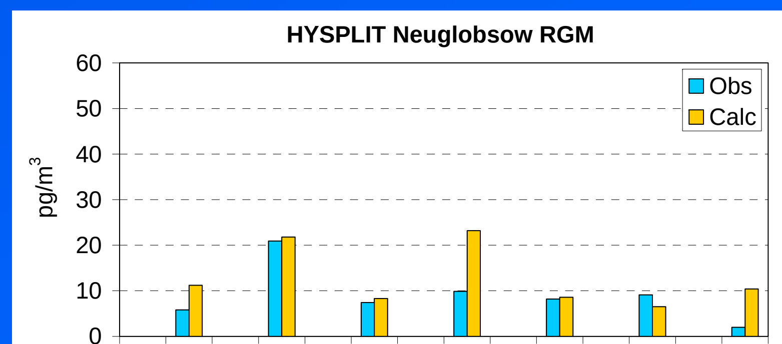








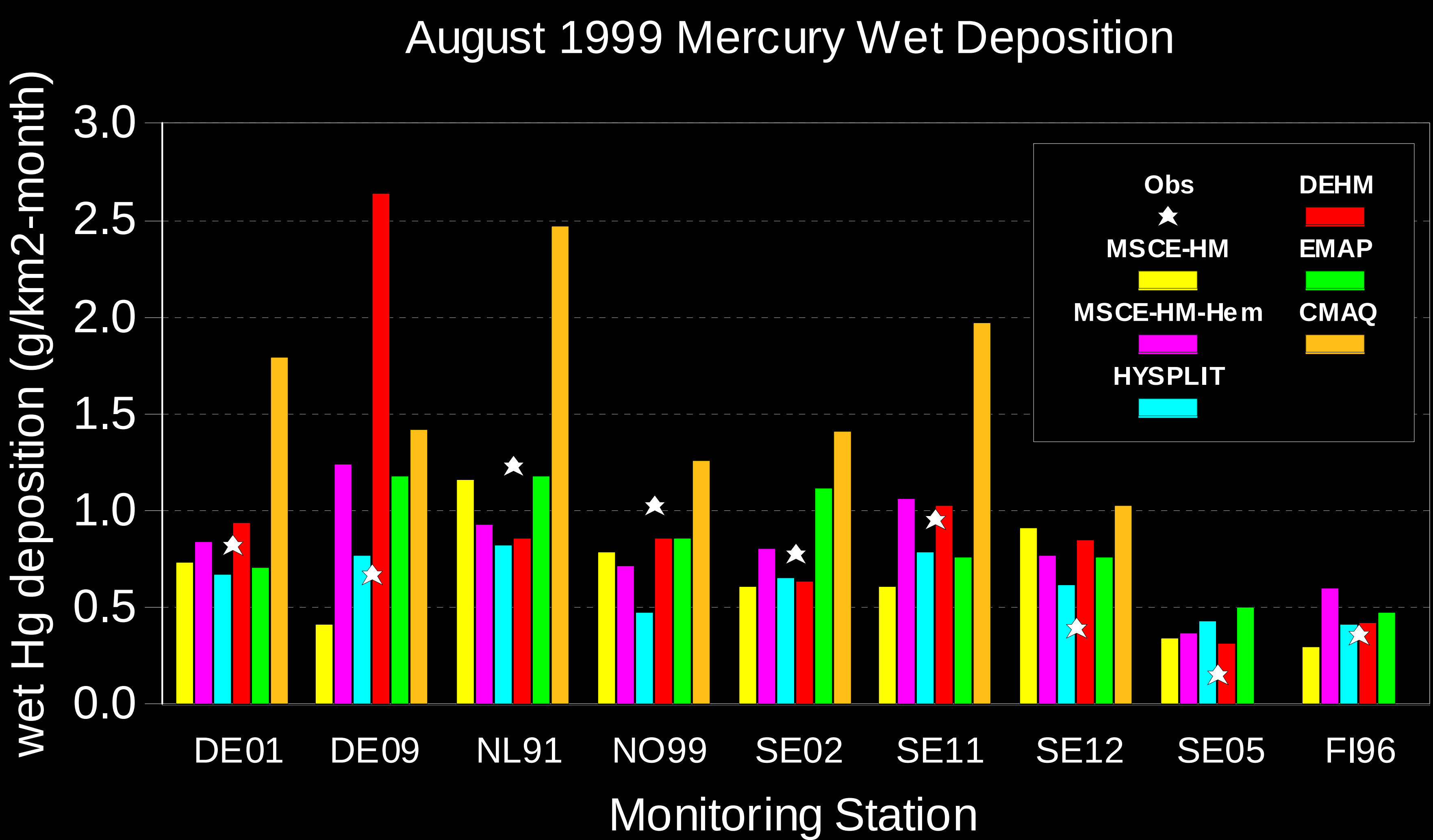




Stage II Publications:

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.


August 1999 Mercury Wet Deposition
wet Hg deposition (g/km2-month)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Obs
DEHM
MSCE-HM
EMAP
MSCE-HM-Hem
CMAQ
HYSPLIT
DE01
DE09
NL91
NO99
SE02
SE11
SE12
SE05
FI96
Monitoring Station

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.

Conclusions: Uncertainties in Mercury Modeling

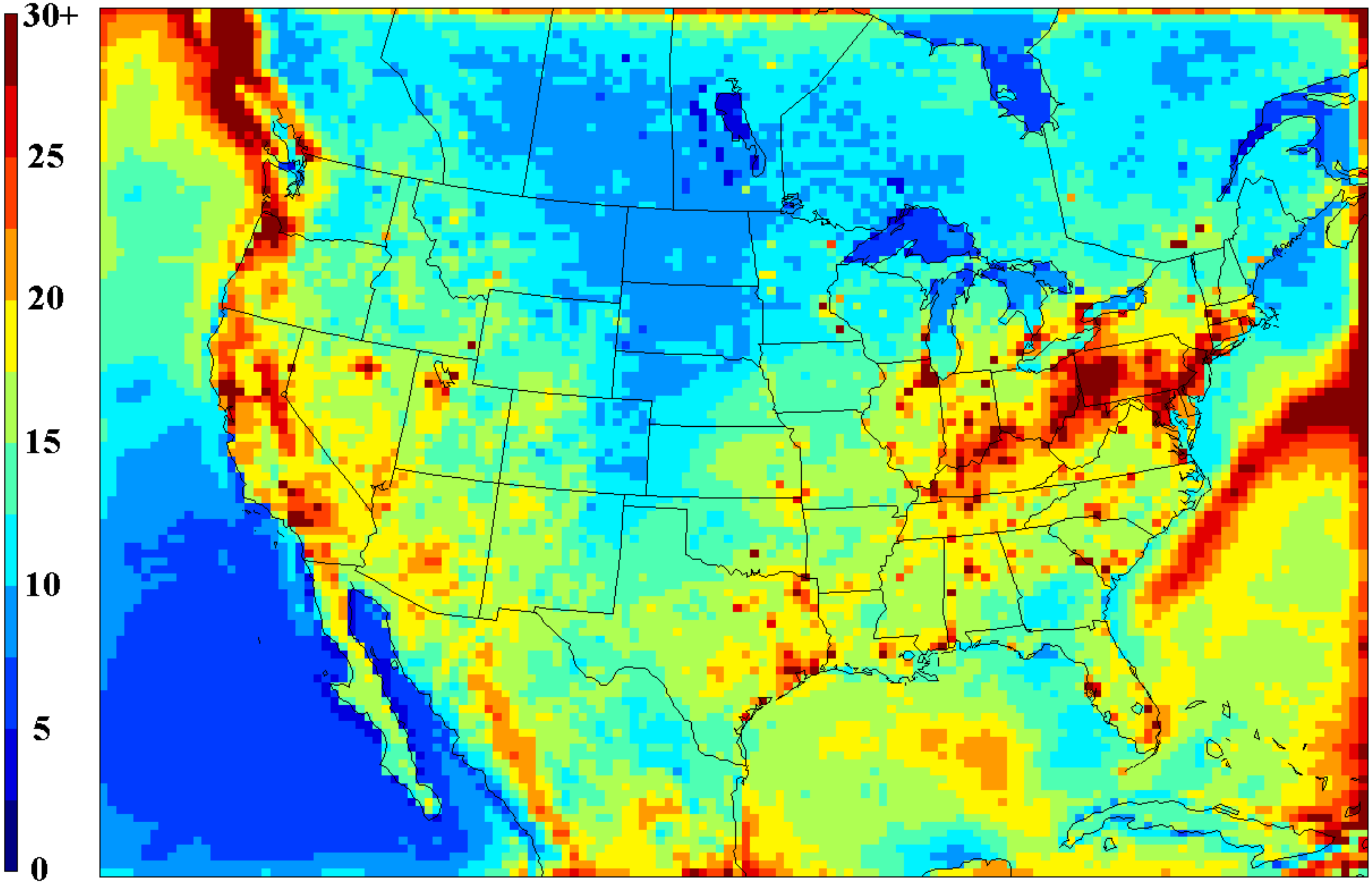
- Elemental Hg in air - factor of **1.2**
- Particulate Hg in air - factor of **1.5**
- Oxidized gaseous Hg in air - factor of **5**
- Total Hg in precipitation - factor of **1.5**
- Wet deposition - factor of **2.0**
- Dry deposition - factor of **2.5**
- Balances for countries - factor of **2**

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

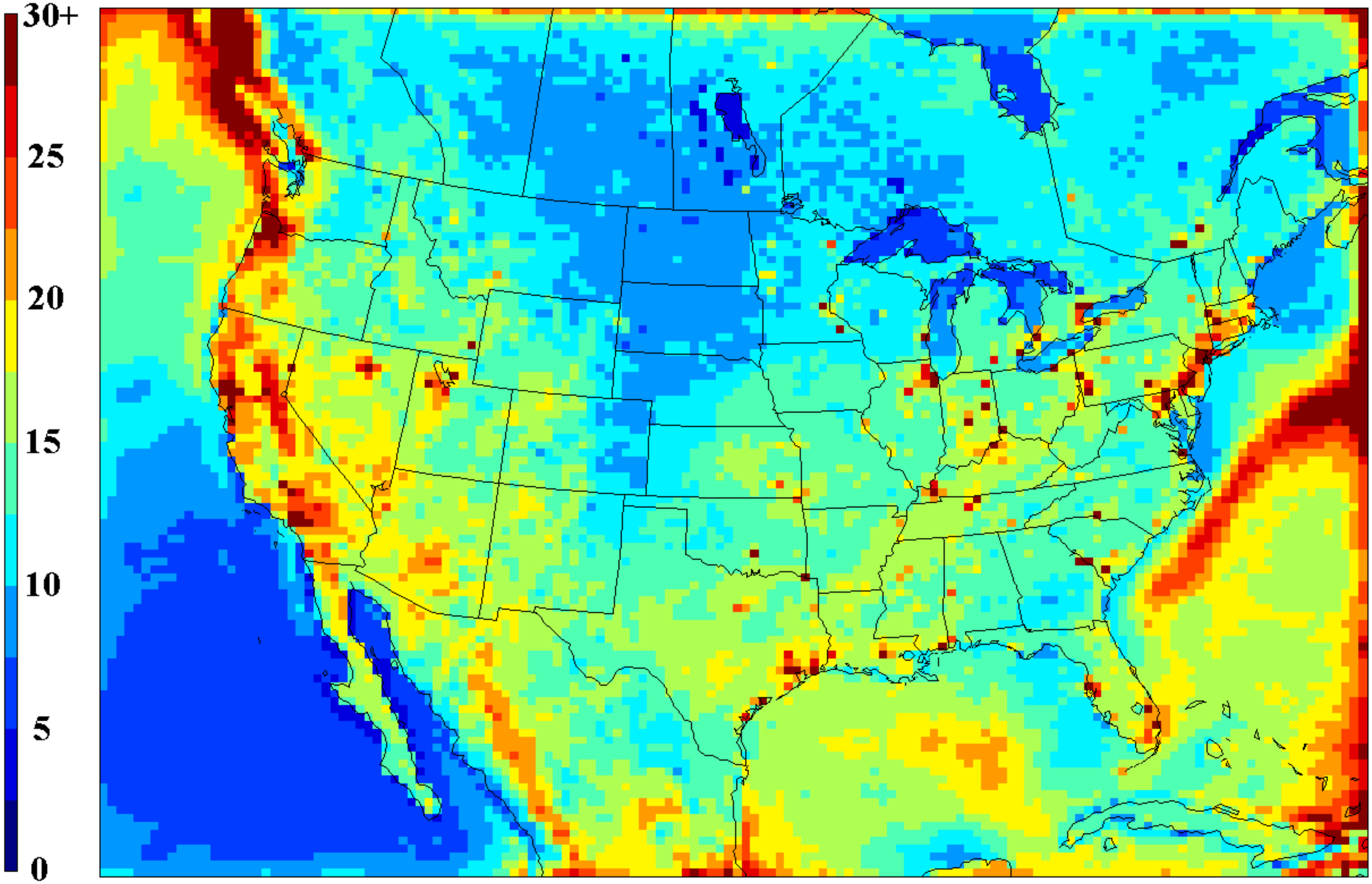
CMAQ-simulated total mercury deposition for 2001

(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?**

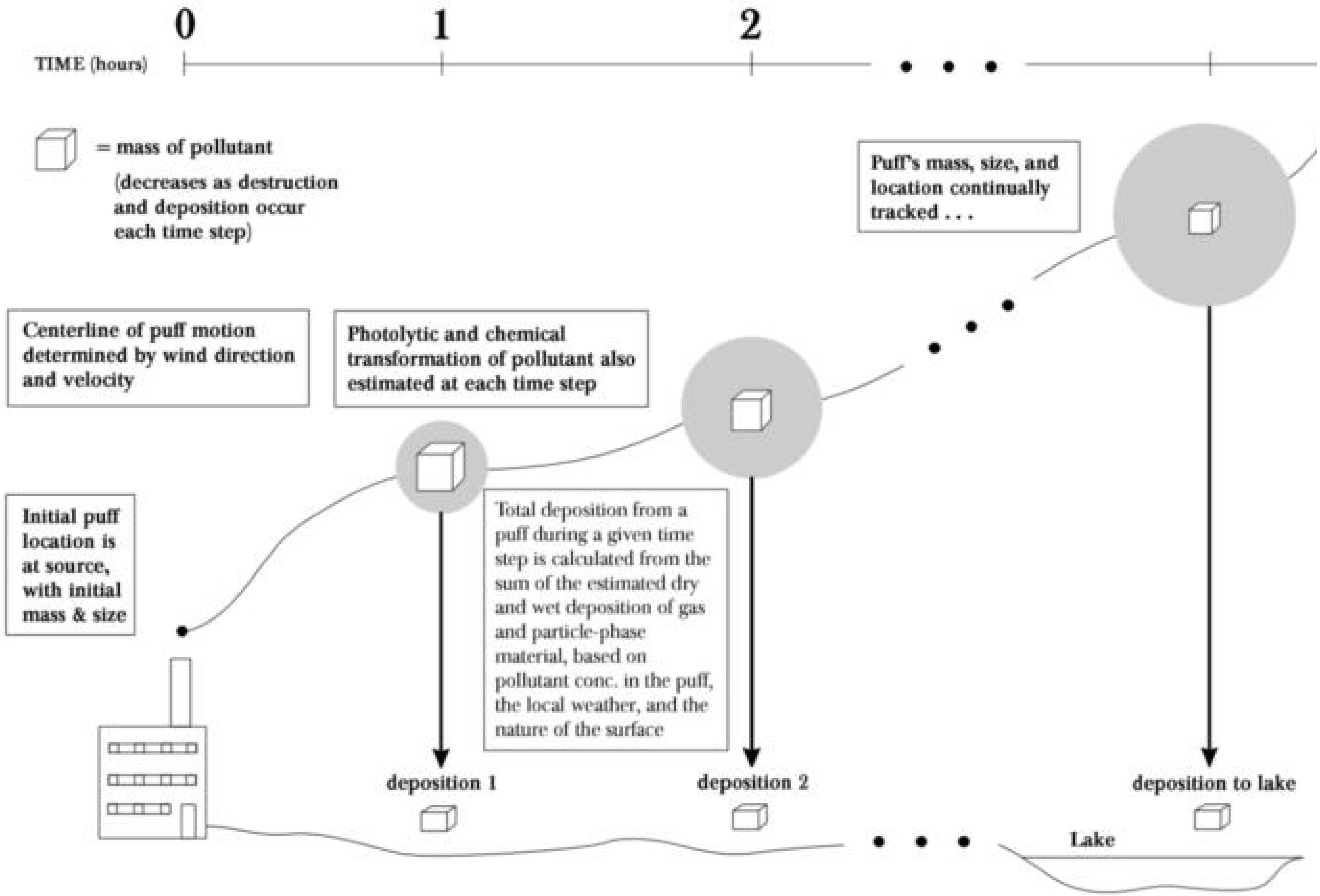
- **Two reactions included in CMAQ oxidizing elemental Hg to RGM may have been significantly overestimated (O_3 and OH)**

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

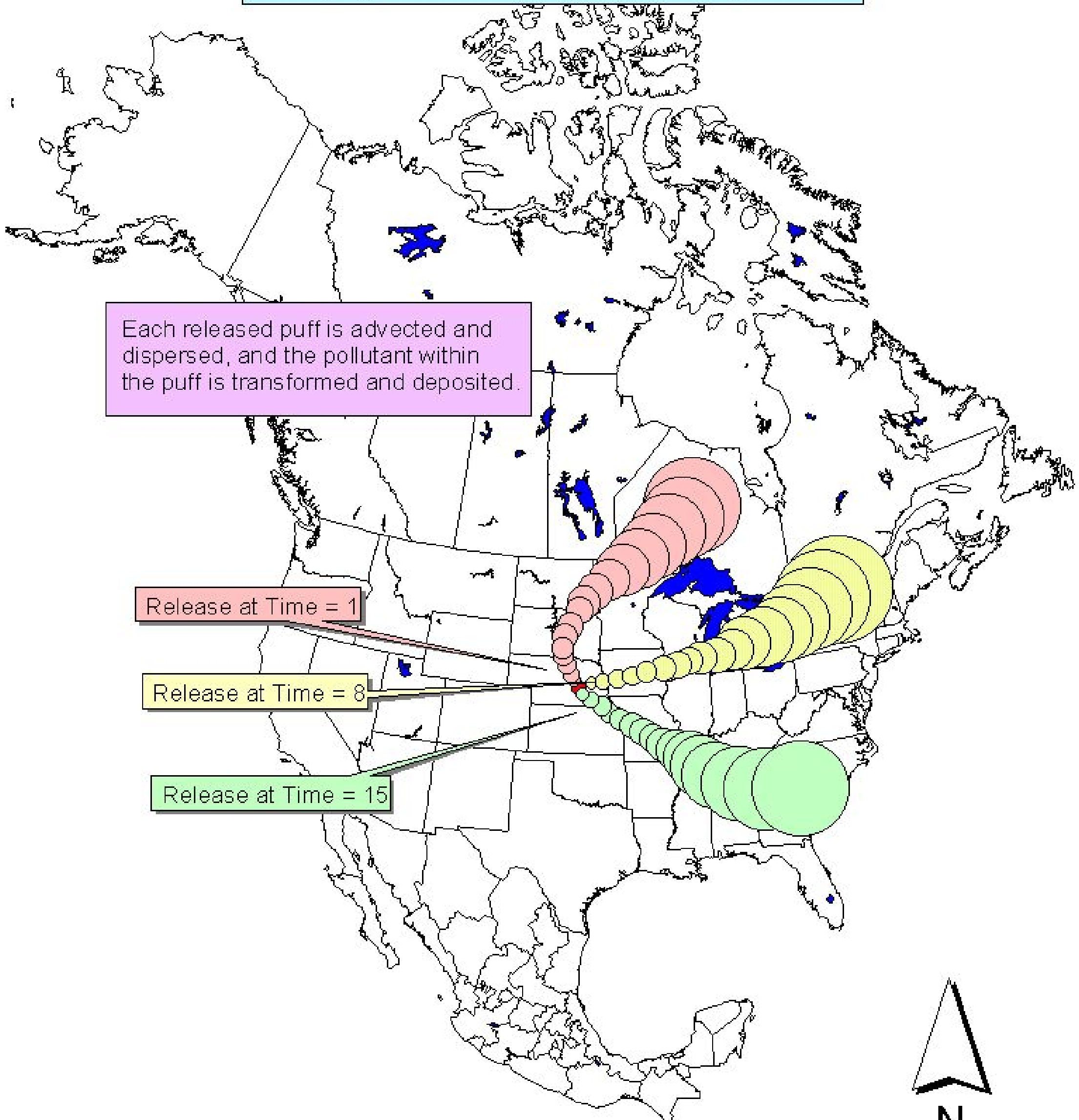
Some HYSPLIT-Hg results, for impacts of U.S. and Canadian anthropogenic sources on selected receptors

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).



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Environmental Research

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

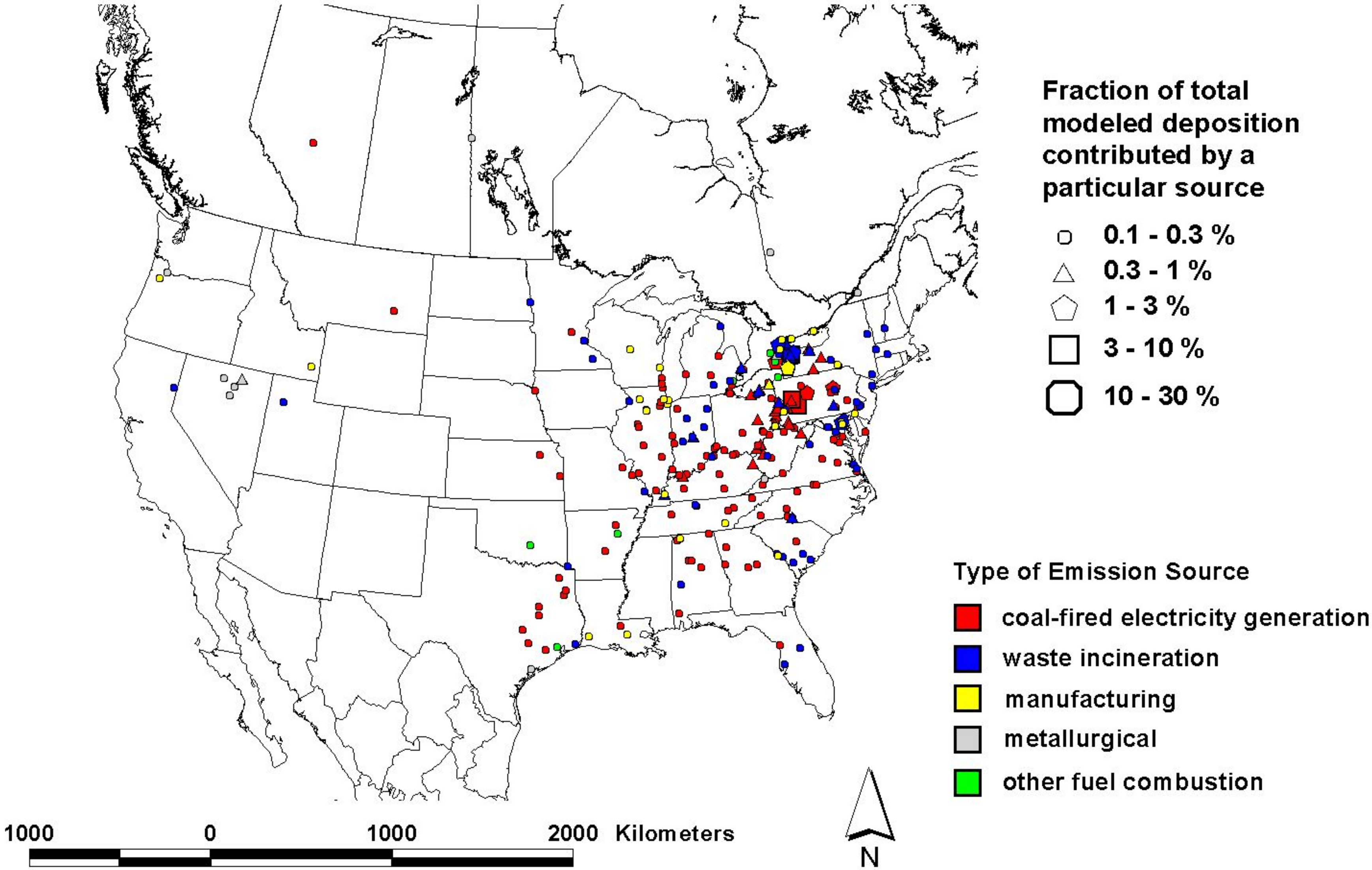
Mark Cohen, Richard Artz, Roland Draxler, Paul Miller, Laurier Poissant, David Niemi, Dominique Ratté, Marc Deslauriers, Roch Duval, Rachelle Laurin, Jennifer Slotnick, Todd Nettesheim, and John McDonald

Abstract

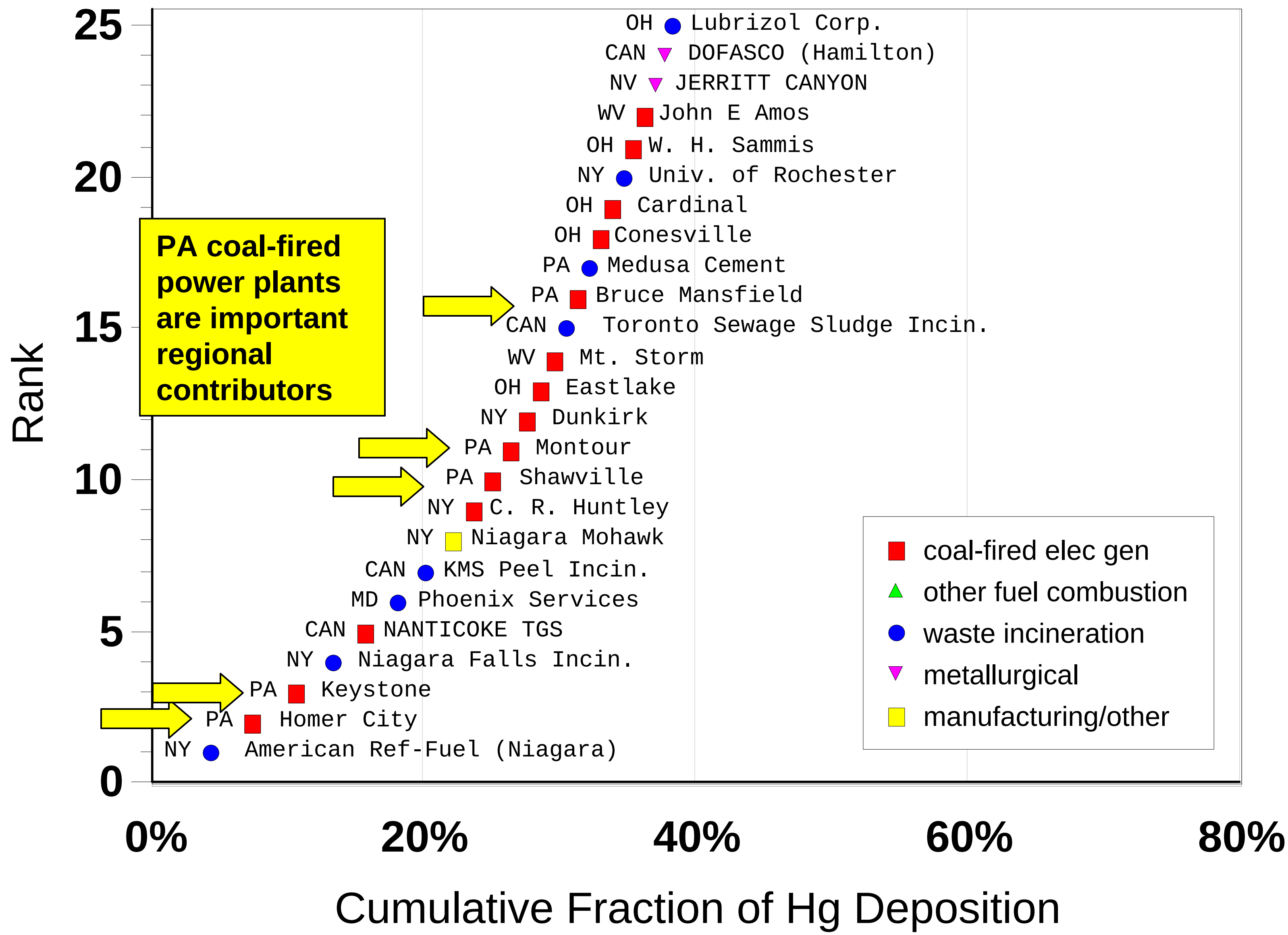
Cohen, M., Artz, R., Draxler, R., Miller, P., Poissant, L., Niemi, D., Ratte, D., Deslauriers, M., Duval, R., Laurin, R., Slotnick, J., Nettesheim, T., McDonald, J. "Modeling the Atmospheric Transport and Deposition of Mercury to the Great Lakes." *Environmental Research* **95**(3), 247-265, 2004.

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.

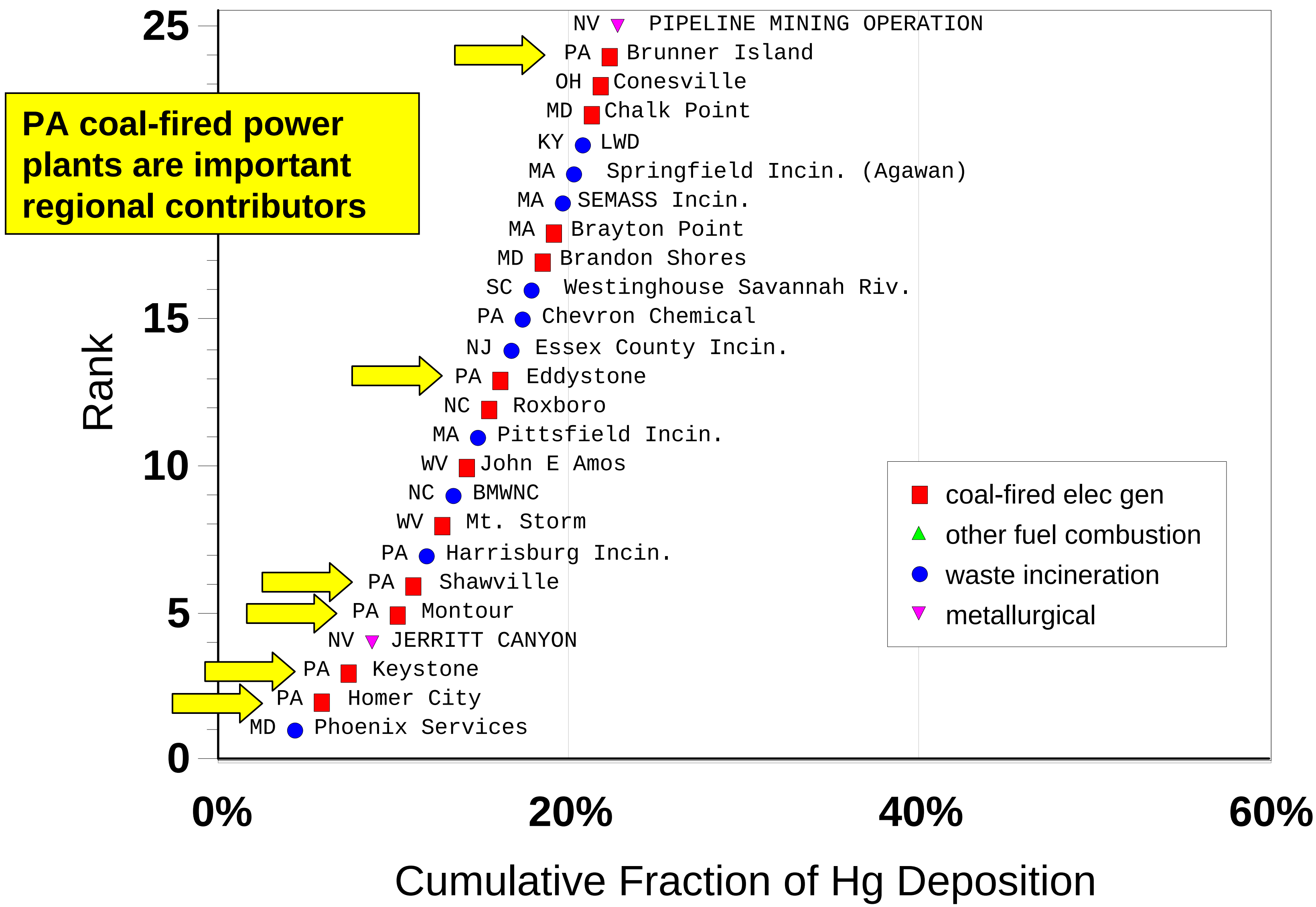
Largest atmospheric deposition contributors to Lake Ontario based on 1999-2000 emissions



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…

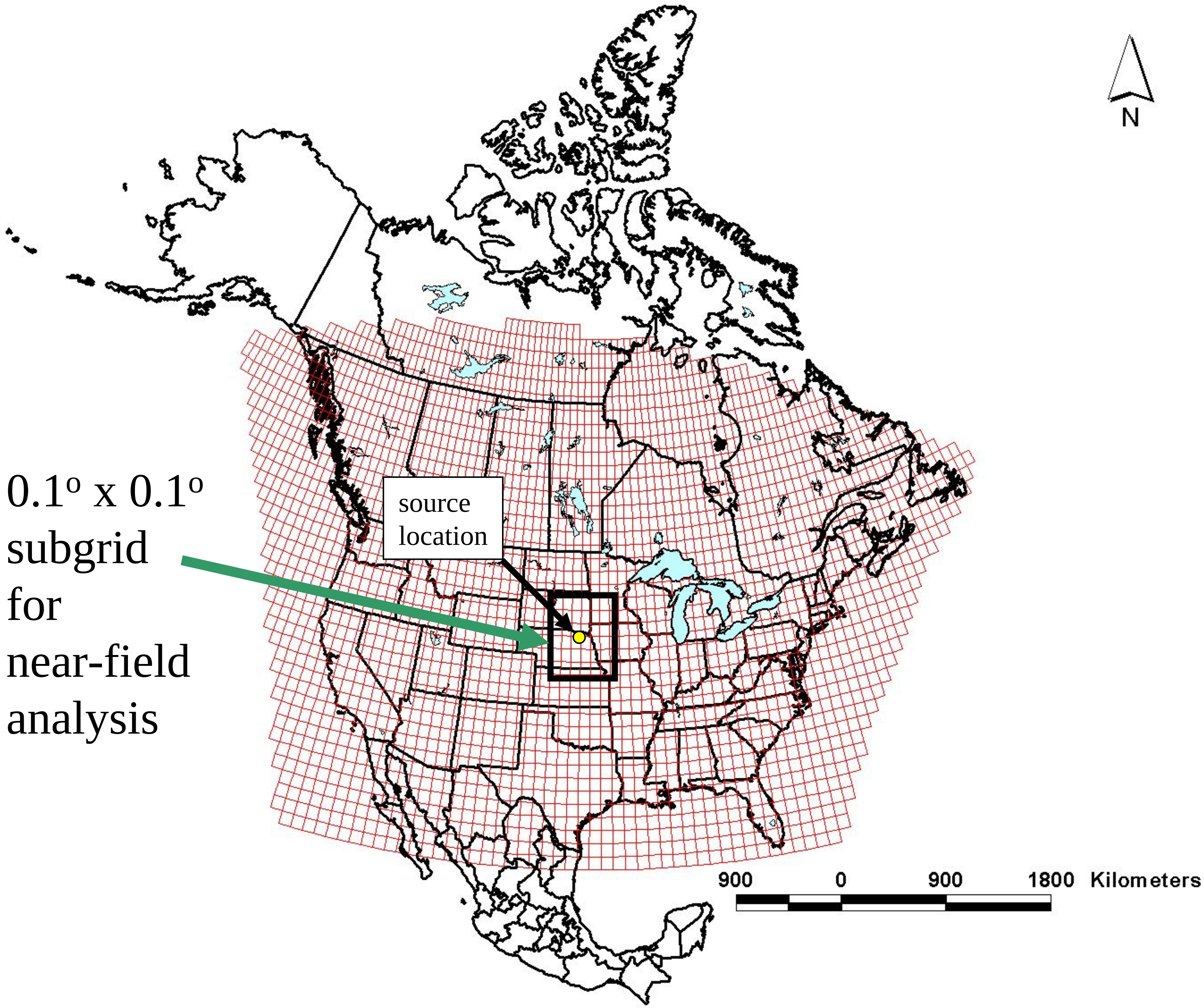
- It is unlikely that a coal-fired power plant in China, for example, could contribute as much to one of these receptors as a comparable facility in the U.S.

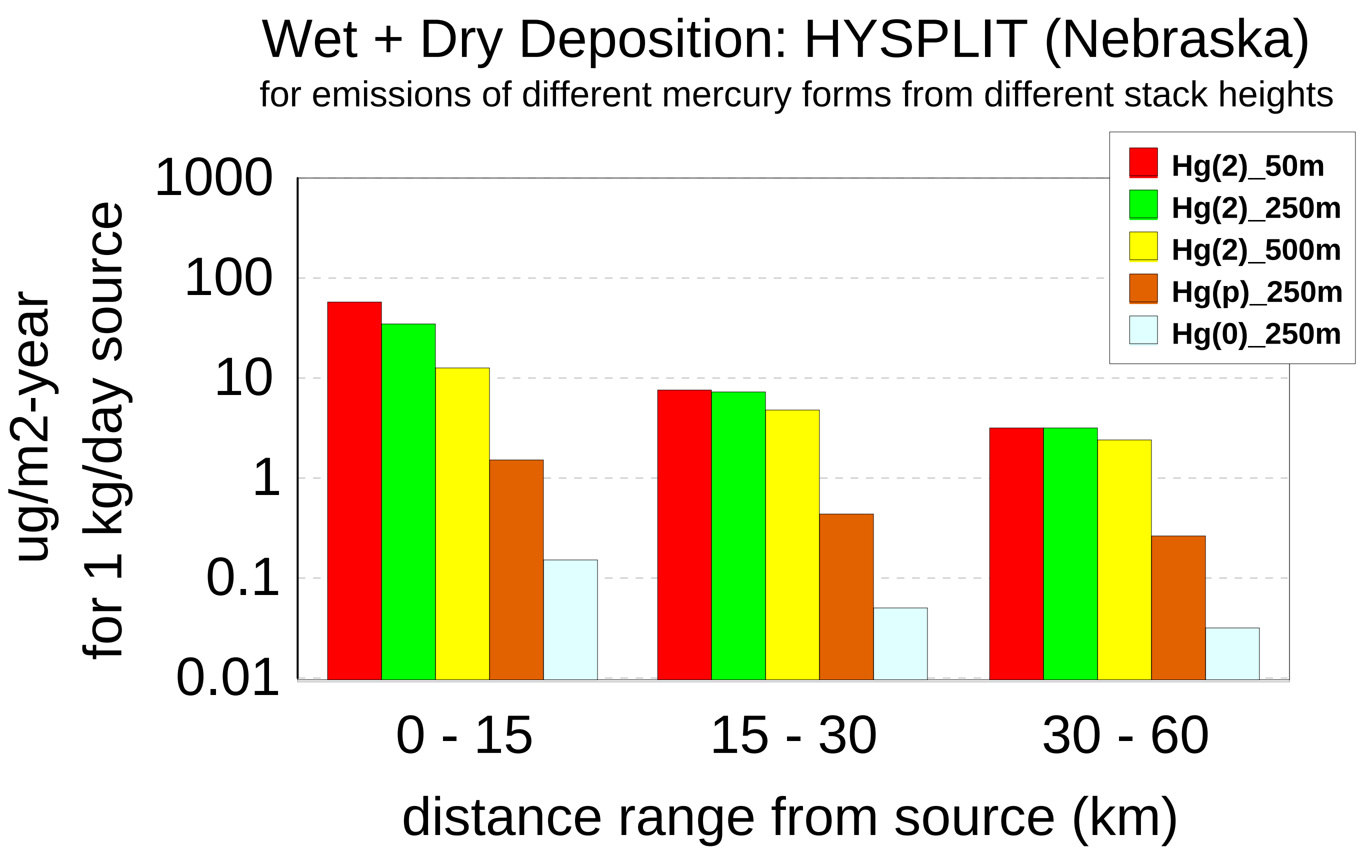
Concluding Observations

- **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…**

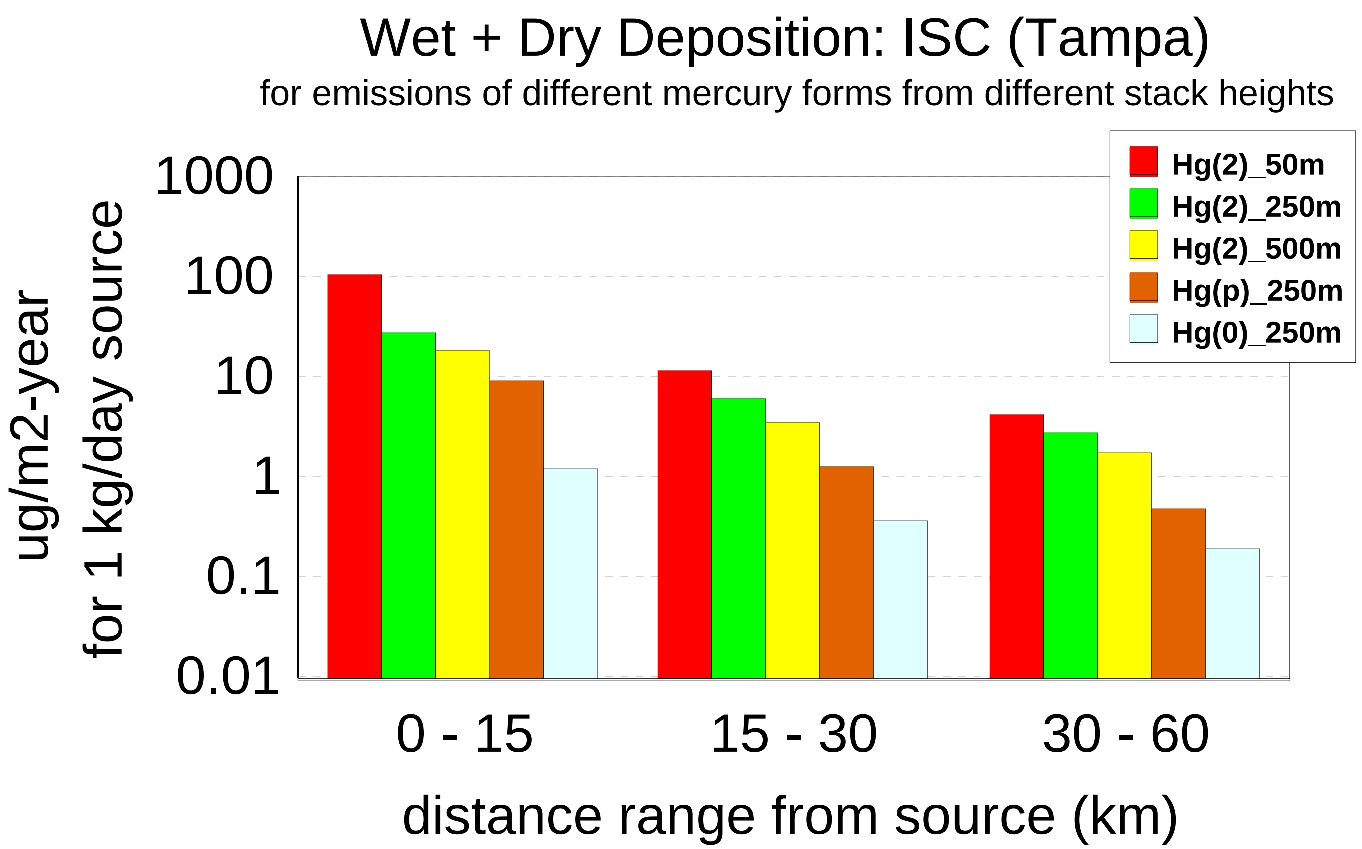
Thanks!

Extra Slides

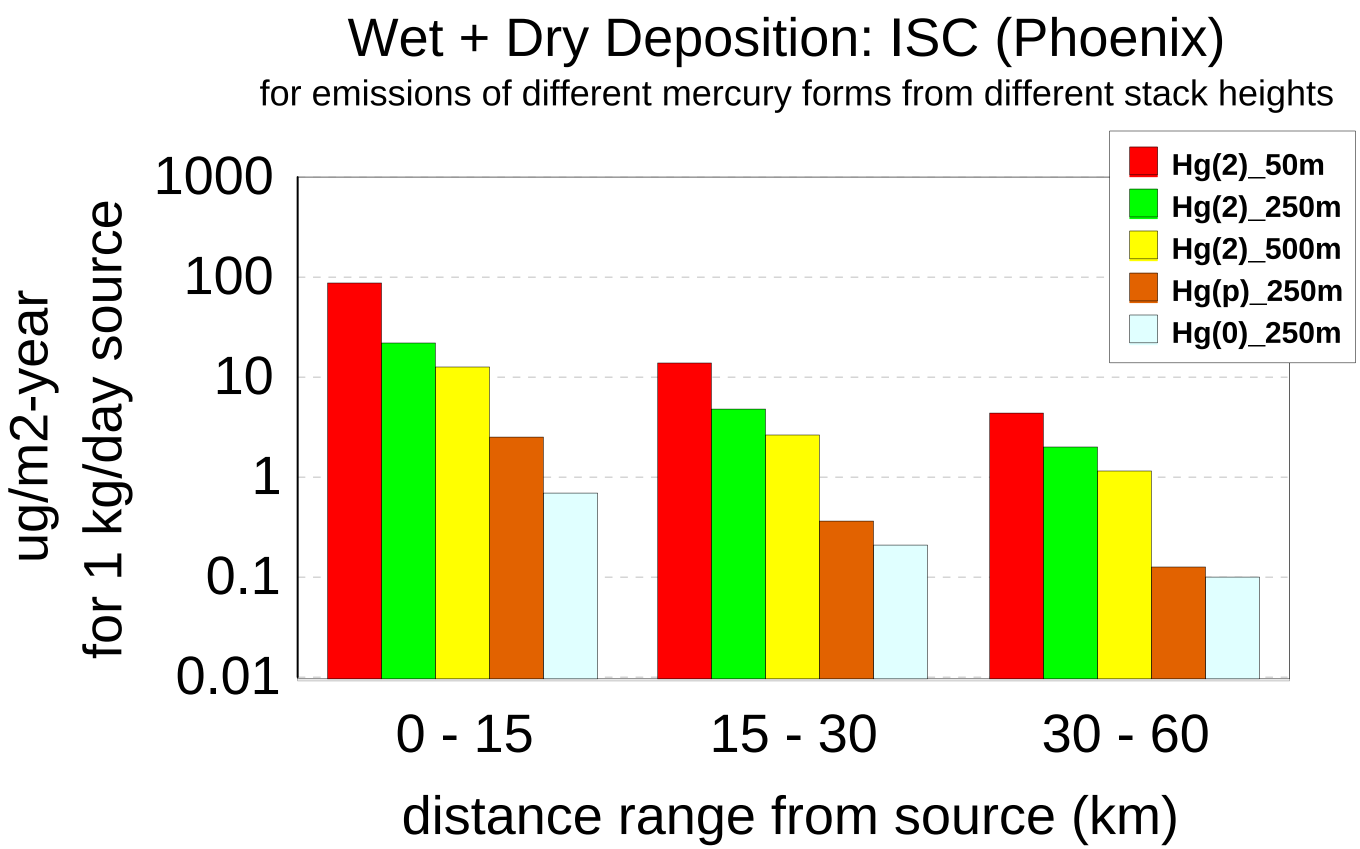

0.1° x 0.1°
subgrid
for
near-field
analysis
source
location
N
900 0 900 1800 Kilometers



Wet + Dry Deposition: HYSPLIT (Nebraska)
for emissions of different mercury forms from different stack heights
ug/m2-year
for 1 kg/day source
1000
100
10
1
0.1
0.01
Hg(2)_50m
Hg(2)_250m
Hg(2)_500m
Hg(p)_250m
Hg(0)_250m
0 - 15
15 - 30
30 - 60
distance range from source (km)



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



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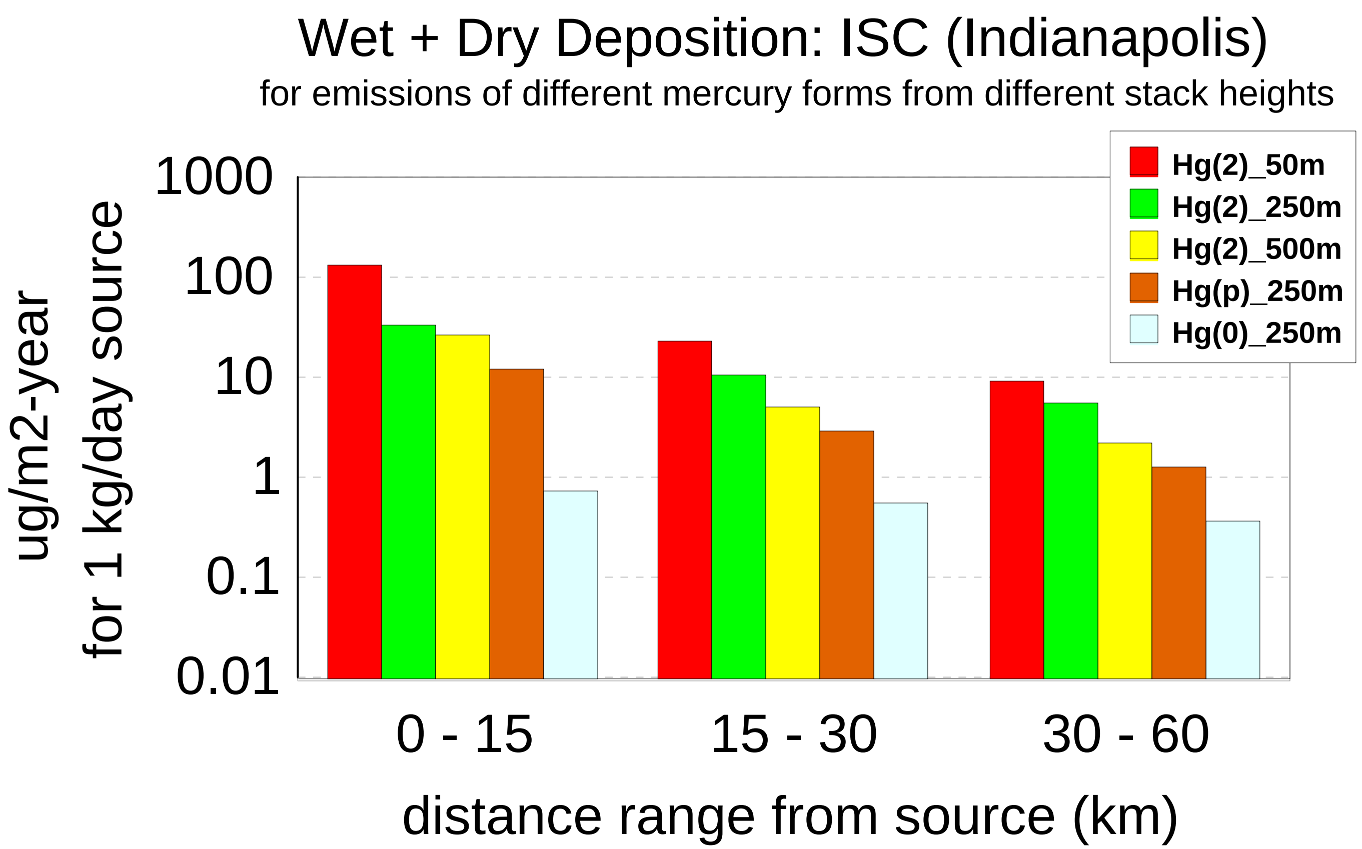
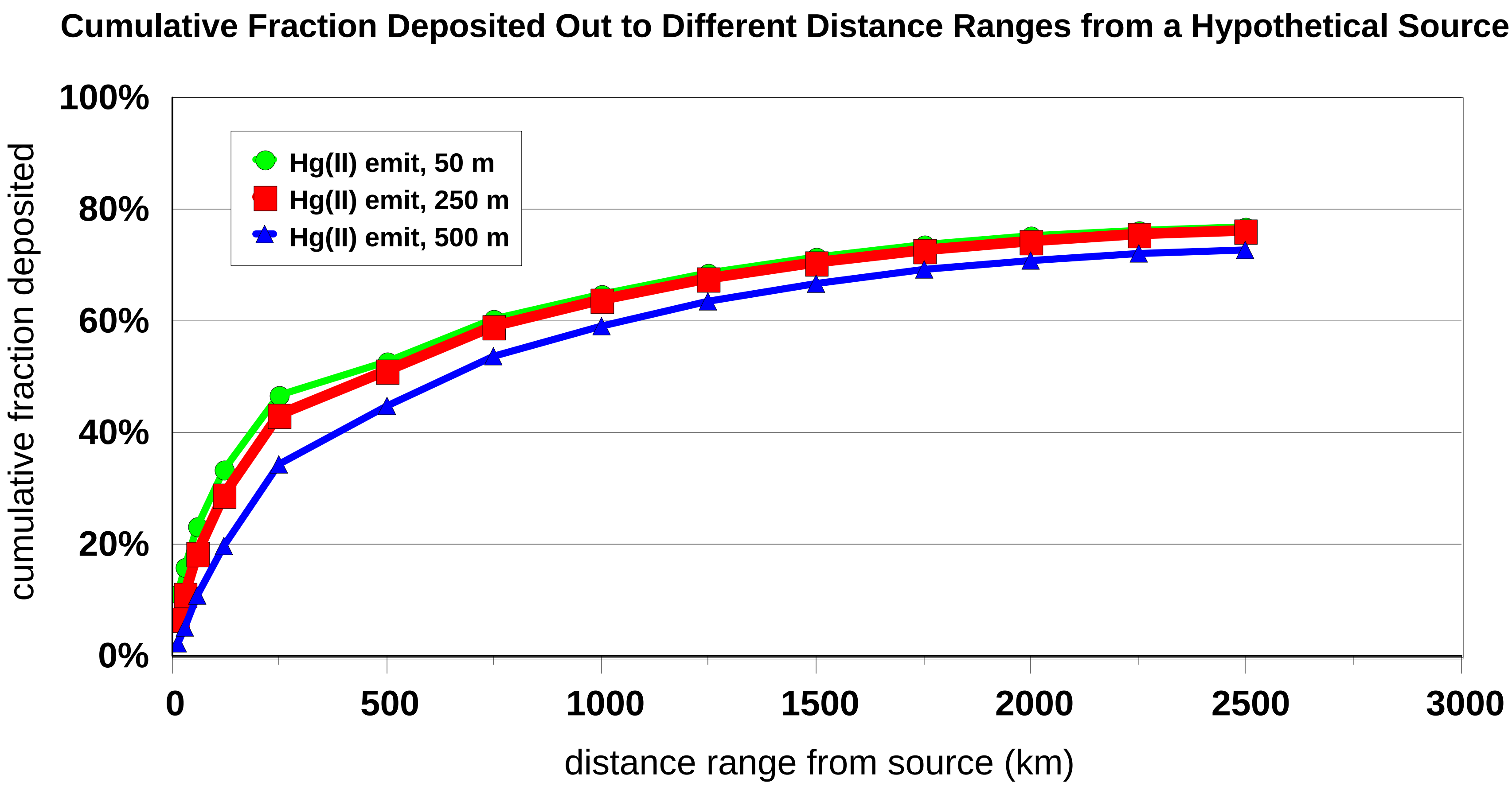
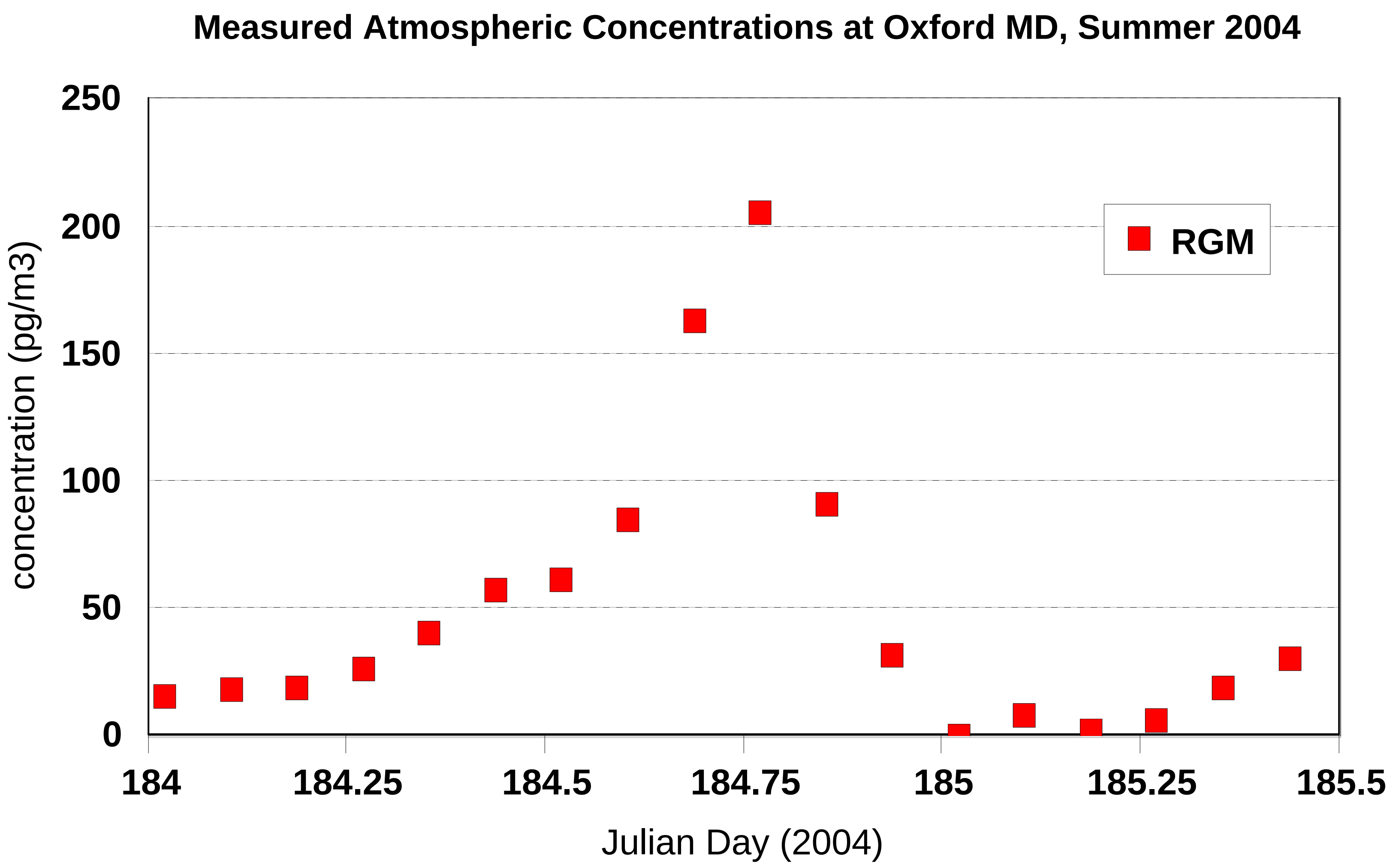


Calculated from data used to produce Appendix A of USEPA (2005): Clean Air Mercury Rule (CAMR) Technical Support Document: Methodology Used to Generate Deposition, Fish Tissue Methylmercury Concentrations, and Exposure for Determining Effectiveness of Utility Emissions Controls: Analysis of Mercury from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

ionic Hg emitted from different source heights

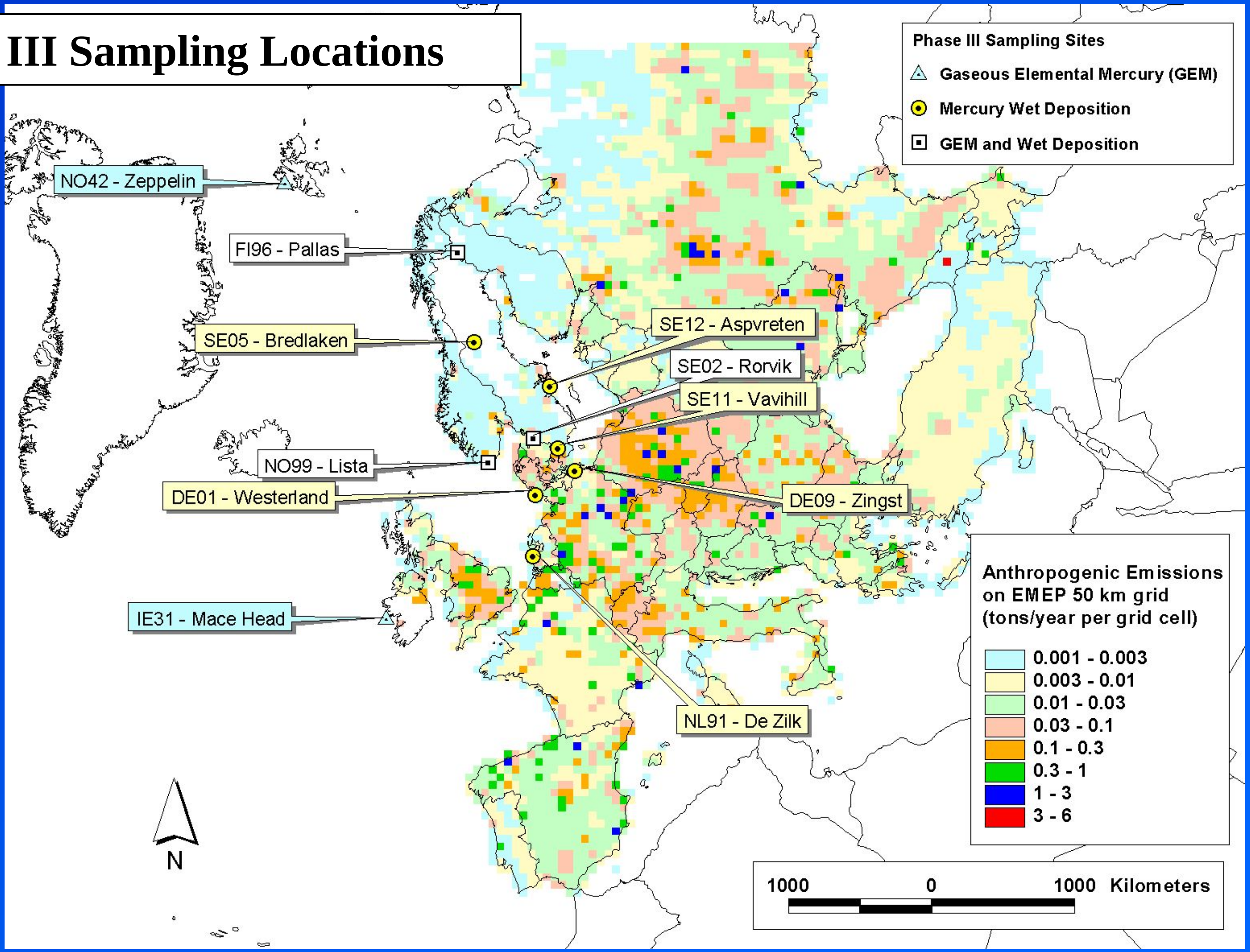


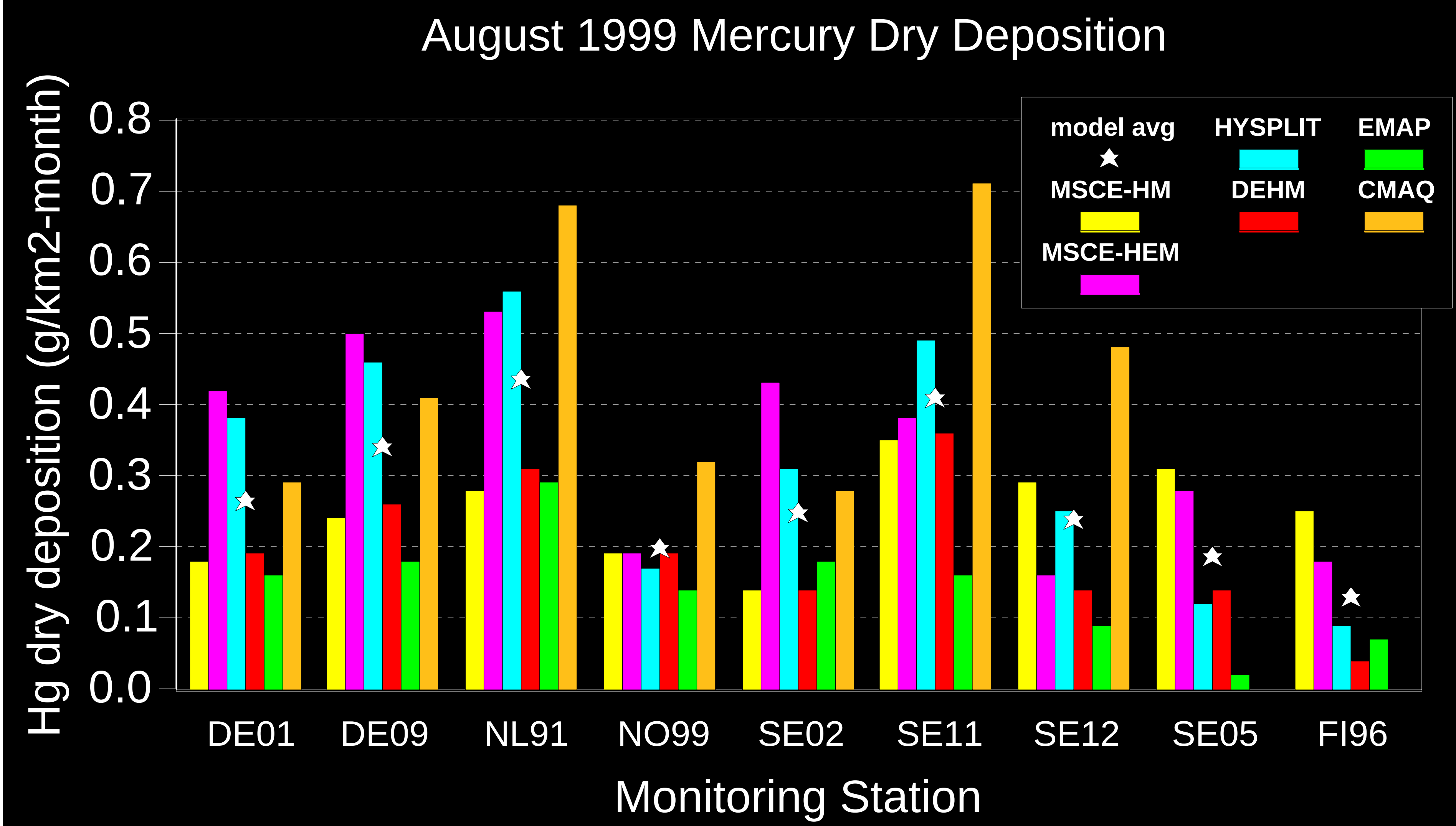
Source at Lat = 42.5, Long = -97.5; simulation for entire year 1996 using archived NGM meteorological data



Measured Atmospheric Concentrations at Oxford MD, Summer 2004
250
200
150
100
50
0
concentration (pg/m3)
RGM
184
184.25
184.5
184.75
185
185.25
185.5
Julian Day (2004)

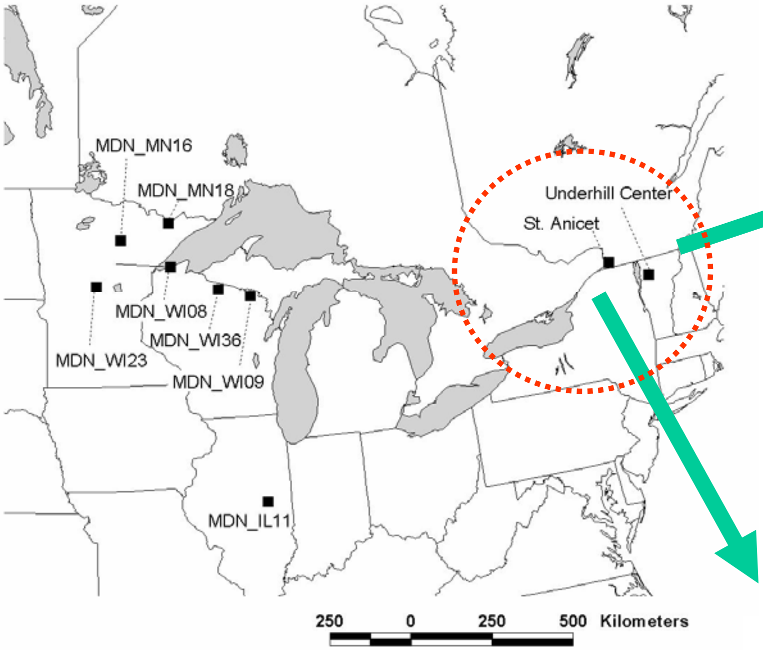
Phase III Sampling Locations

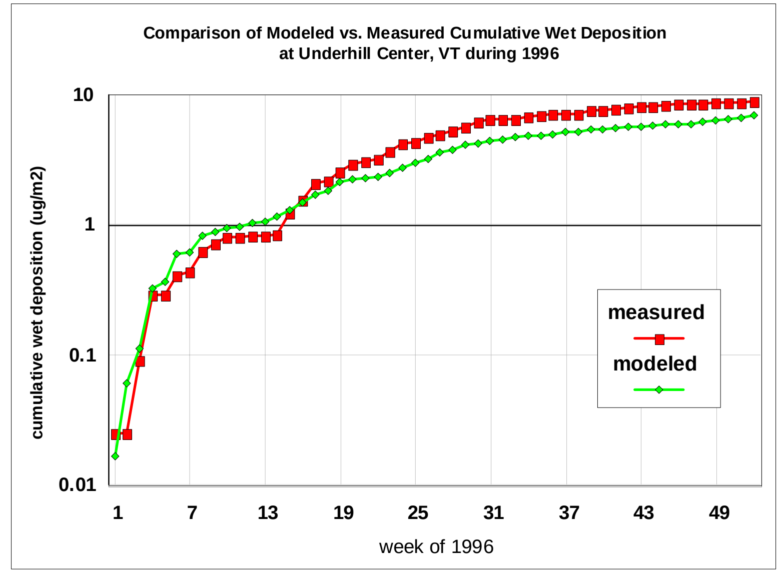


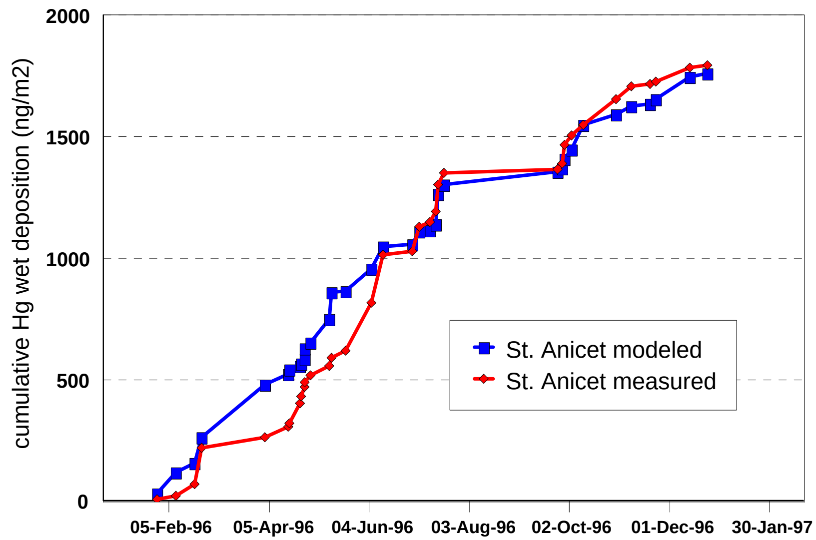


August 1999 Mercury Dry Deposition
Hg dry deposition (g/km2-month)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
model avg
HYSPLIT
EMAP
MSCE-HM
DEHM
CMAQ
MSCE-HEM
DE01
DE09
NL91
NO99
SE02
SE11
SE12
SE05
FI96
Monitoring Station

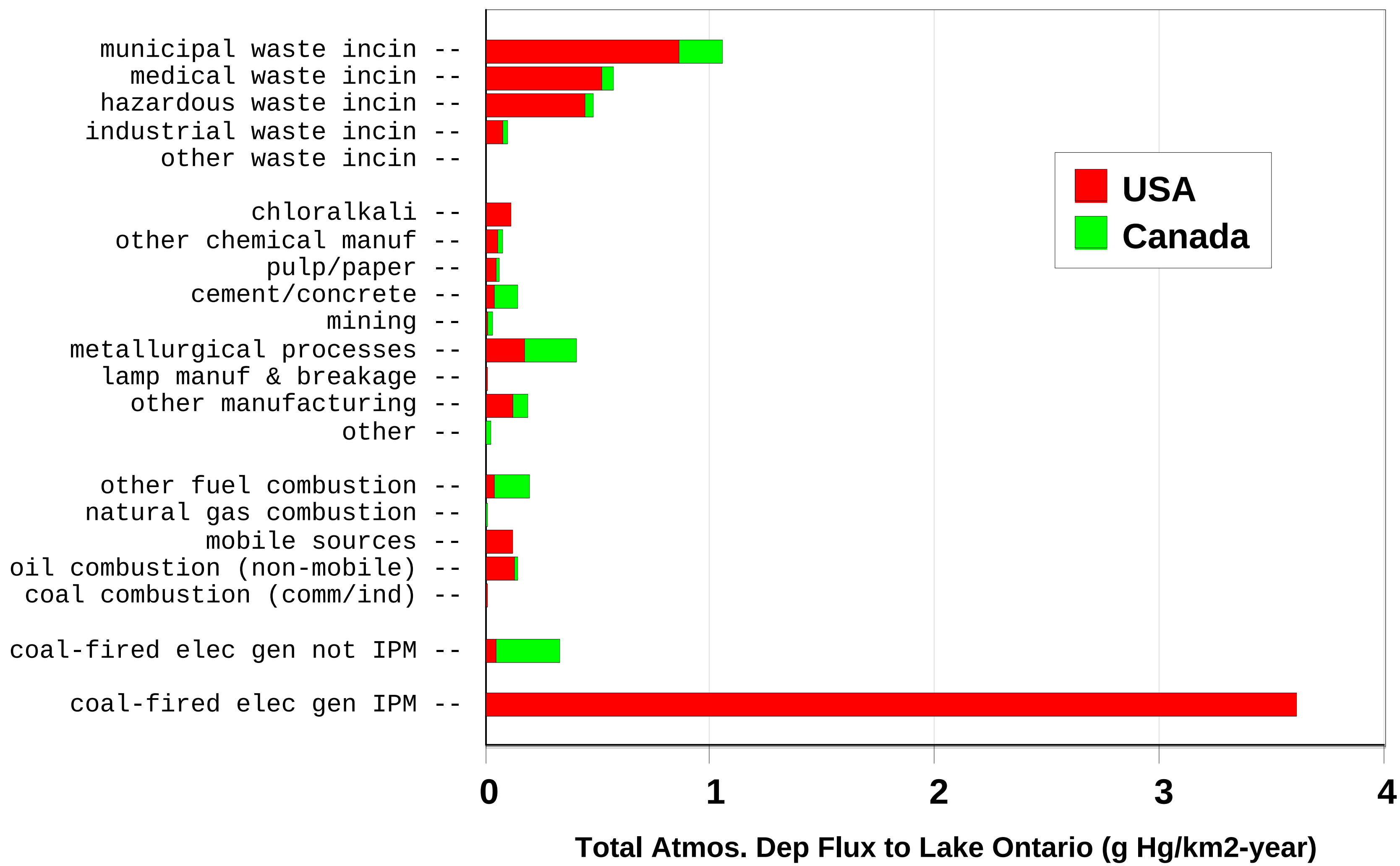
Sites with 1996 mercury wet deposition data in the Great Lakes region

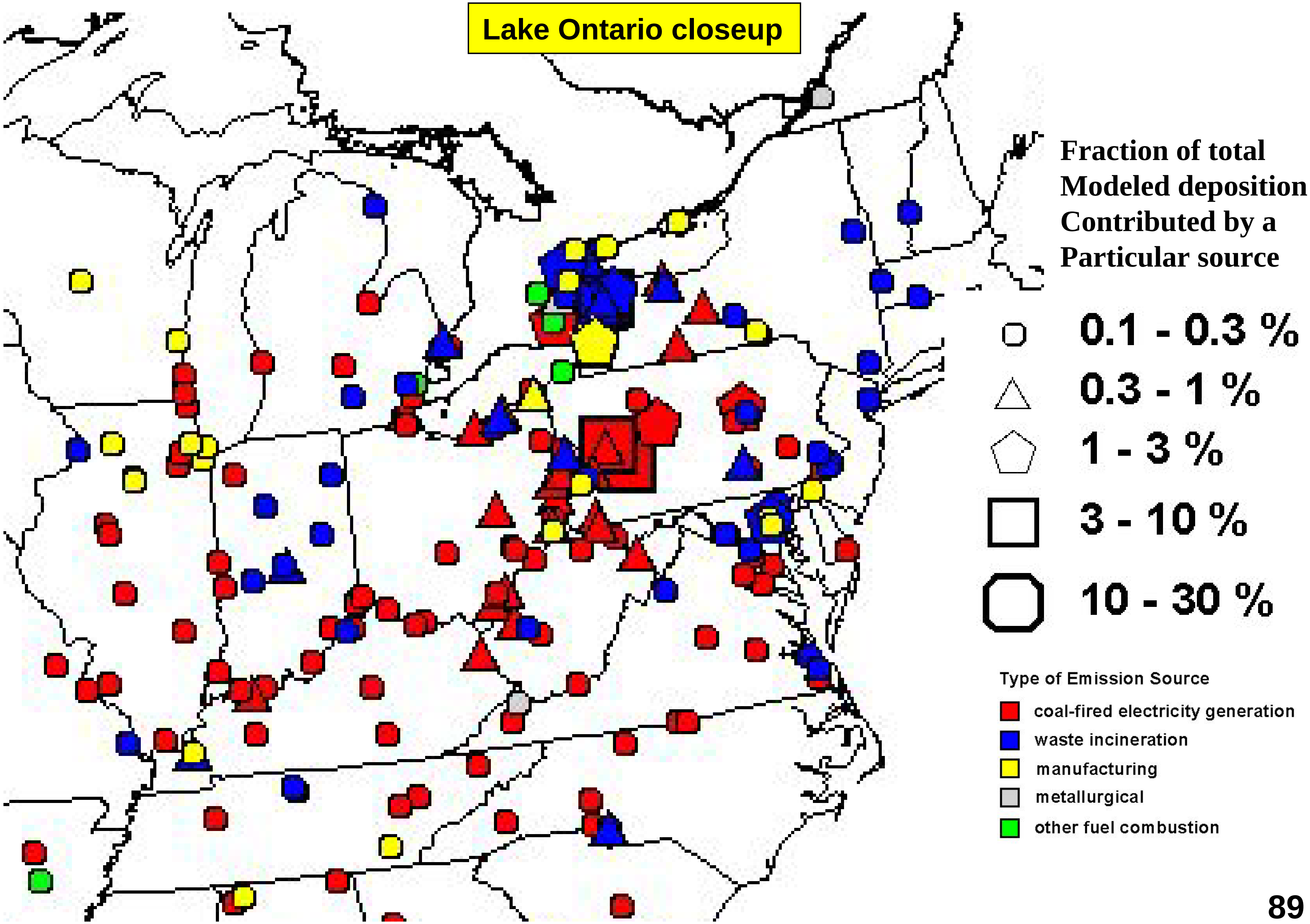






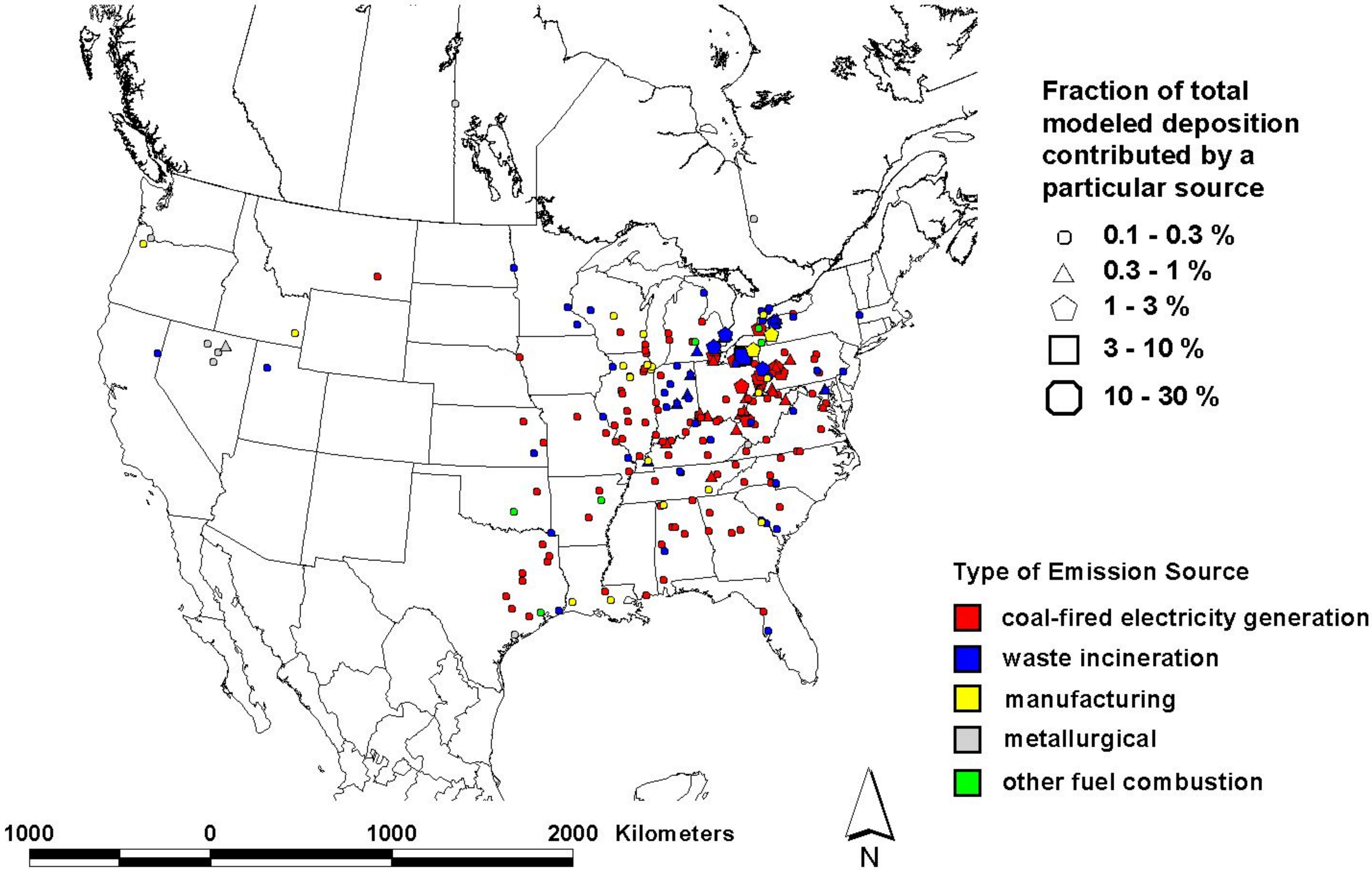
Seem to be getting reasonable results near Lake Ontario, but need to do much more evaluation…

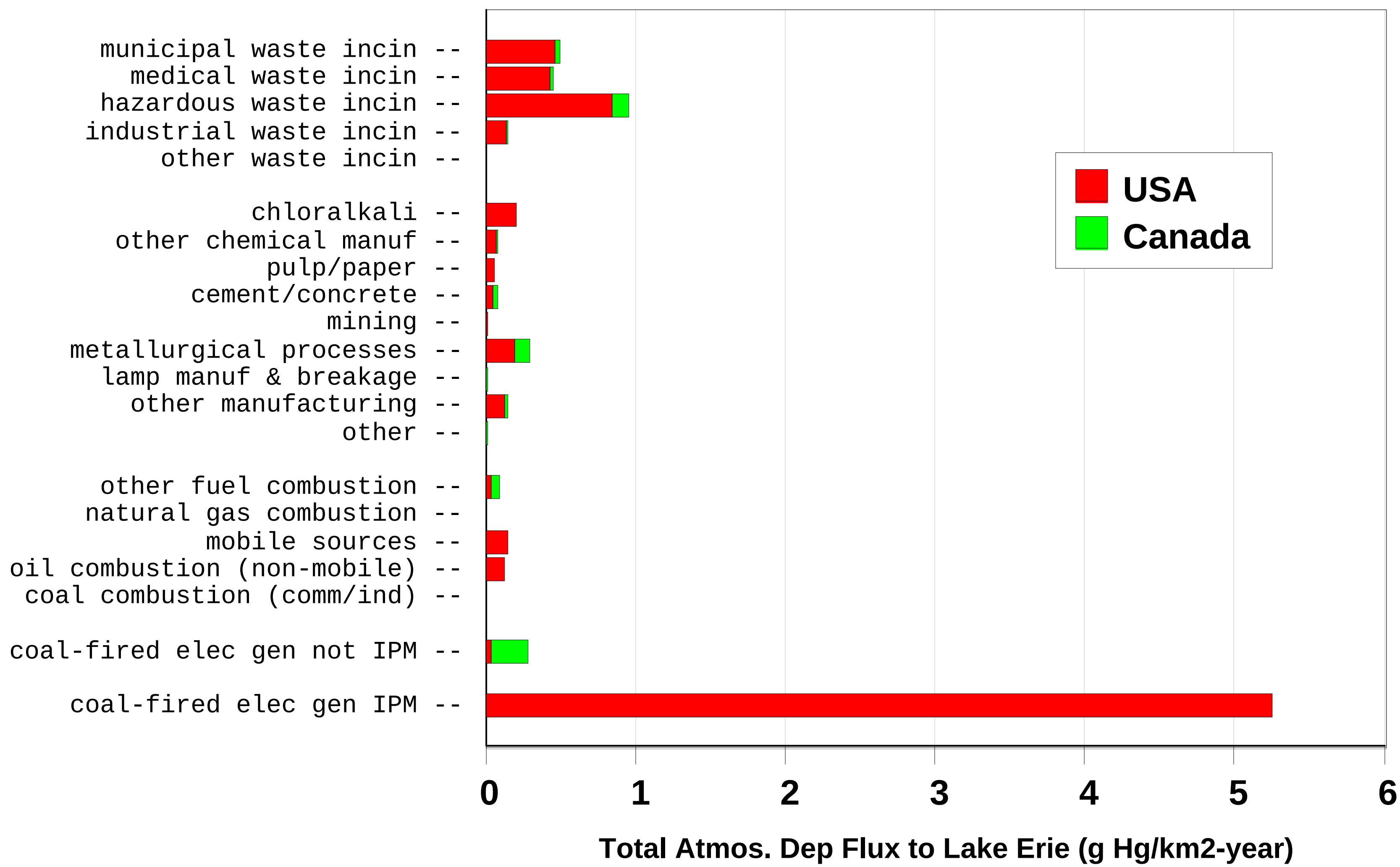

municipal waste incin --
medical waste incin --
hazardous waste incin --
industrial waste incin --
other waste incin --
chloralkali --
other chemical manuf --
pulp/paper --
cement/concrete --
mining --
metallurgical processes --
lamp manuf & breakage --
other manufacturing --
other --
other fuel combustion --
natural gas combustion --
mobile sources --
oil combustion (non-mobile) --
coal combustion (comm/ind) --
coal-fired elec gen not IPM --
coal-fired elec gen IPM --
USA
Canada
0
1
2
3
4
Total Atmos. Dep Flux to Lake Ontario (g Hg/km2-year)



Lake Ontario closeup
Fraction of total Modeled deposition Contributed by a Particular source
0.1 - 0.3 %
0.3 - 1 %
1 - 3 %
3 - 10 %
10 - 30 %
Type of Emission Source
coal-fired electricity generation
waste incineration
manufacturing
metallurgical
other fuel combustion

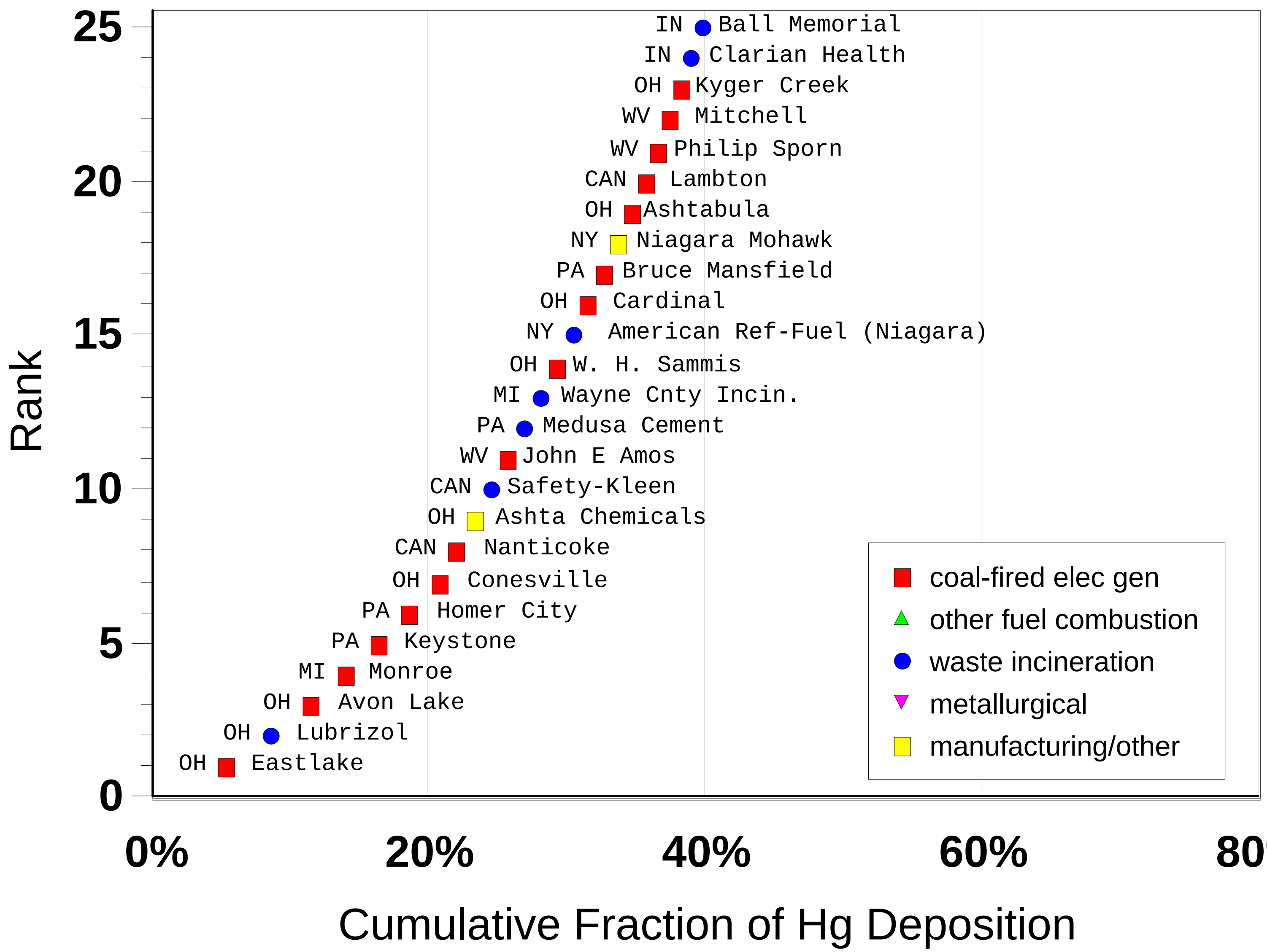
Largest atmospheric deposition contributors to Lake Erie based on 1999-2000 emissions



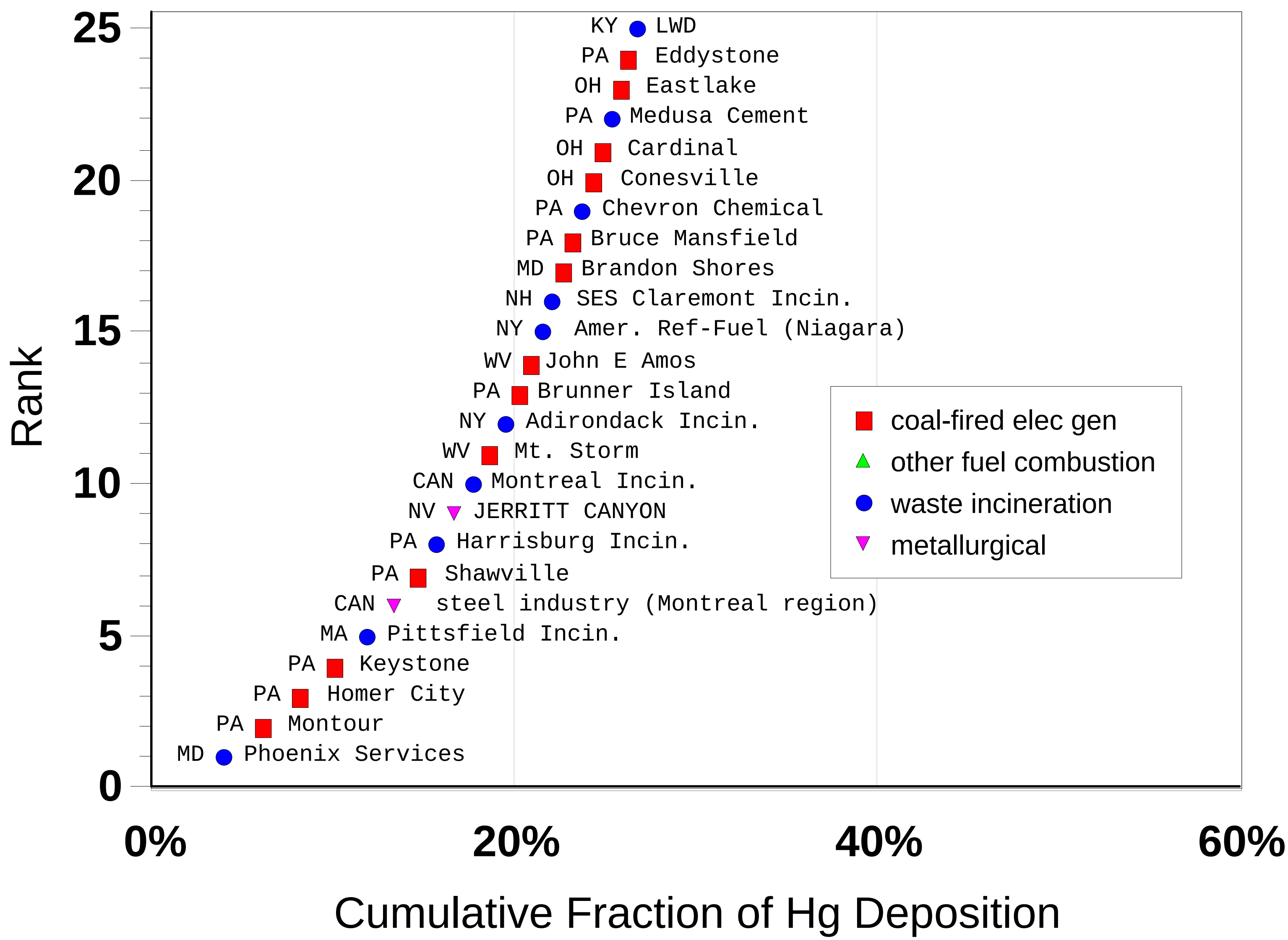


municipal waste incin --
medical waste incin --
hazardous waste incin --
industrial waste incin --
other waste incin --
chloralkali --
other chemical manuf --
pulp/paper --
cement/concrete --
mining --
metallurgical processes --
lamp manuf & breakage --
other manufacturing --
other --
other fuel combustion --
natural gas combustion --
mobile sources --
oil combustion (non-mobile) --
coal combustion (comm/ind) --
coal-fired elec gen not IPM --
coal-fired elec gen IPM --
USA
Canada
0
1
2
3
4
5
6
Total Atmos. Dep Flux to Lake Erie (g Hg/km2-year)

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