Opportunities for Mercury Collaboration between the Air Resources Laboratory and the Environmental Research Program

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meeting with
Environmental Research Program
February 16, 2005, Silver Spring, MD

Outline of Presentation

- brief overview of Air Resources Laboratory
- mercury problem / role of atmospheric Hg
- ARL mercury programs and collaborations
- opportunities for collaboration within ERP

overview of the Air Resources Laboratory

Air Resources Laboratory

Headquarters
Silver Spring, Maryland
Director B. B. Hicks
Deputy R. S. Artz

- Transport Modeling & Assessment
- Climate Variability & Trends
- Air Surface Exchange & Chemistry
- Radiation and Aerosols

19 Federal employees
4 Contractors

Exec. Assistant: Betty Wells
Administration: Sharon Hamilton

Surface Radiation Research Branch
Boulder, CO
J. J. Michalsky

4 Federal employees
11 CIRES
3 Others

Secretary: Gwen Andersen

Atmospheric Turbulence and Diffusion Division
Oak Ridge, TN
Director R. P. Hosker
Deputy T. P. Meyers

Dispersion Studies
Air-Surface Interactions
Measurement Technologies
Aircraft Operations

12 (+1) NOAA employees
23 Contractors (ORAU)
6 Others

Secretary: Sharon Conger
Administration: Barbara Shifflett

Atmospheric Sciences Modeling Division
Research Triangle Park, NC
Director S. T. Rao
Deputy W. B. Petersen

Atmospheric Model Development
Air-Surface Processes Modeling
Model Evaluation and Applications
Air Policy Support

50 NOAA employees
4 Contractors
23 Others

Secretary: Patricia McGhee
Administration: Herb Viebrock

Field Research Division
Idaho Falls, ID
Director K. L. Clawson
Deputy T. B. Watson

Dispersion Analyses and Modeling
INEEL Meteorology & Dispersion
Atmospheric Tracers

10 NOAA employees
3 Contractors

Secretary: Joyce Silvester
Administration: Paulette Fee

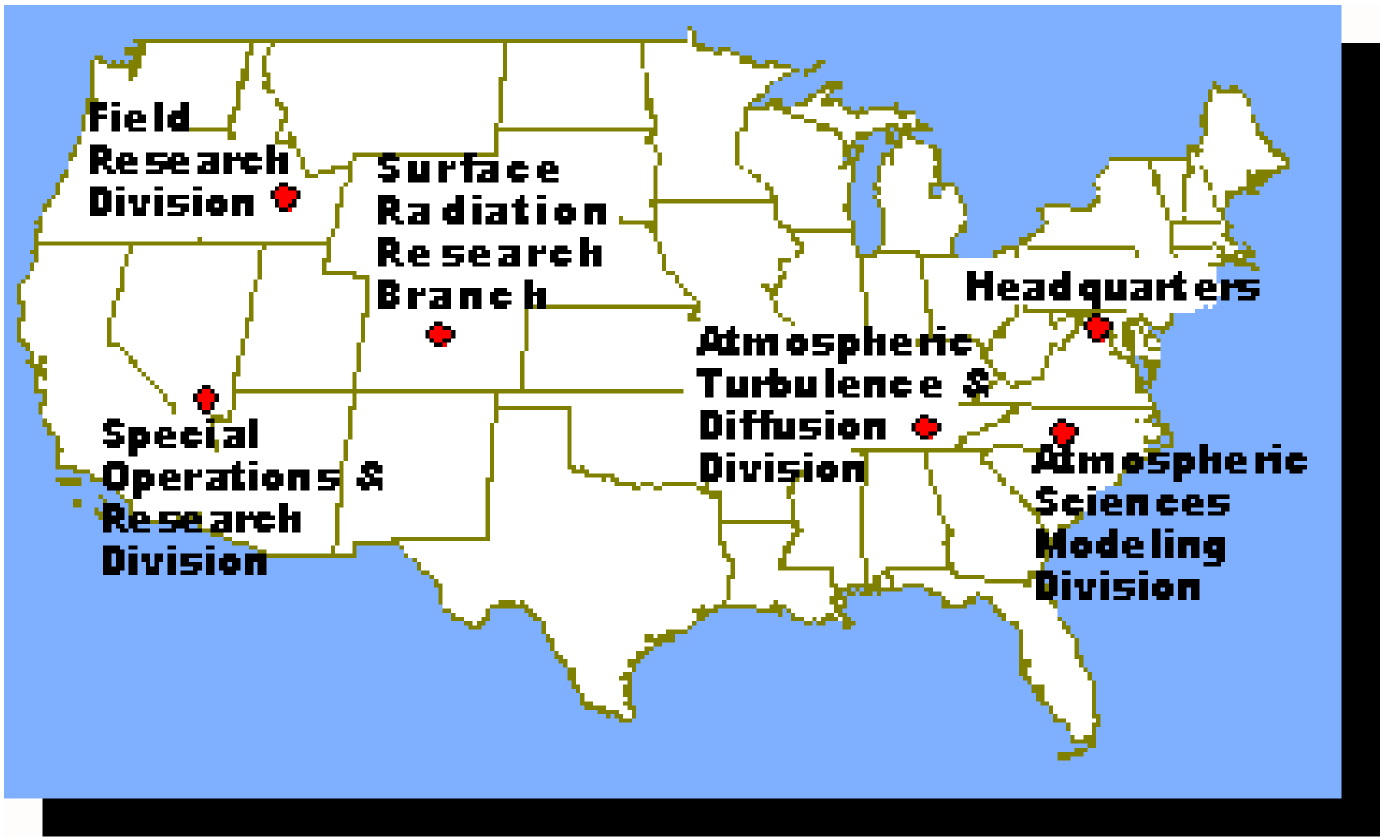
Special Operations and Research Division
Las Vegas, NV
Director D. Randerson
Deputy D. A. Soule

Dispersion Studies
NTS Meteorology and Dispersion
Technical Services

17 NOAA employees
3 Contractors
CIASTA (JI)

Secretary: Boots Parker
Administration: Barbara Pierce

Air Resources Laboratory

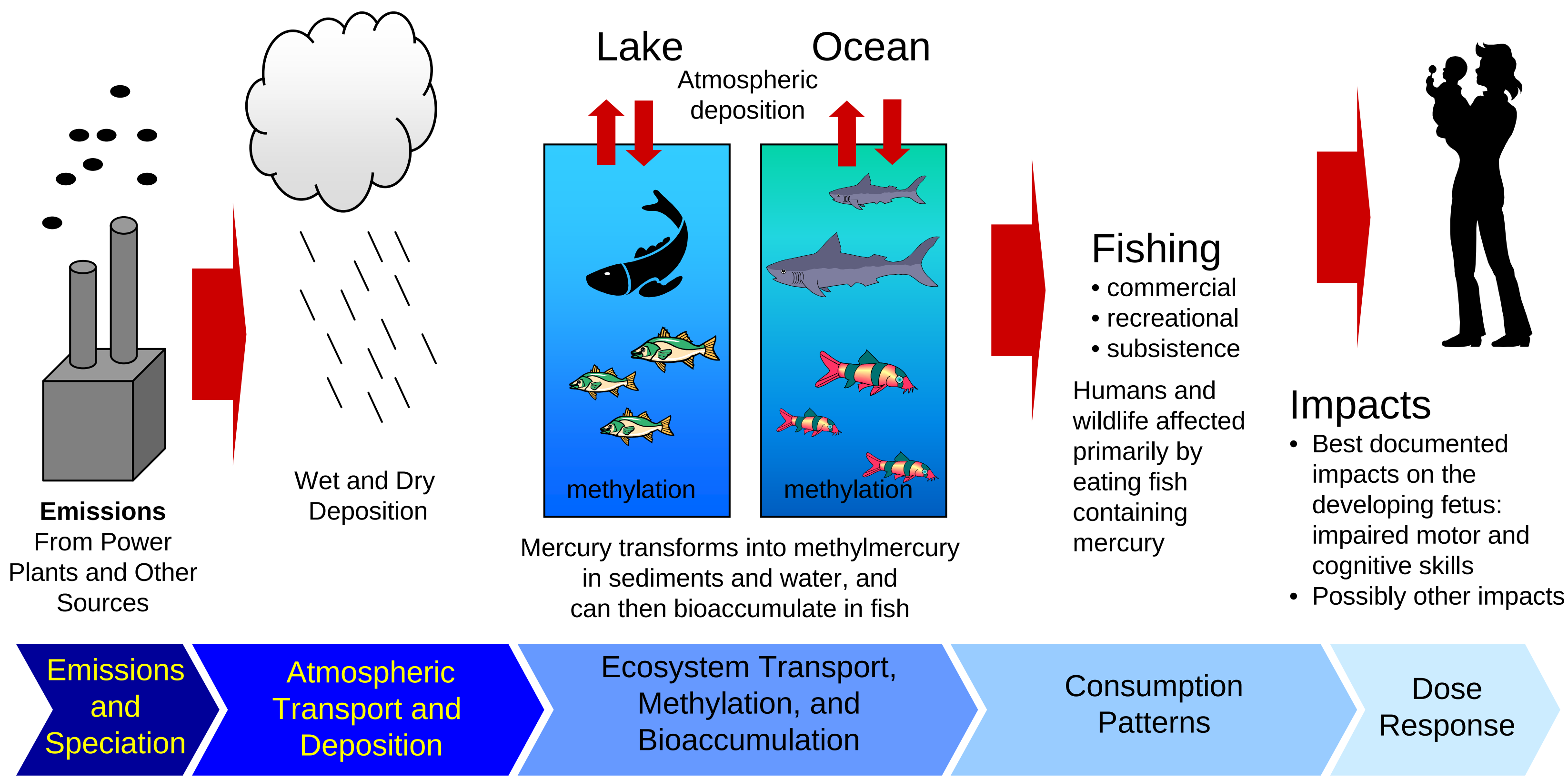


the mercury problem and the role of atmospheric mercury

The Mercury Problem

- EPA has estimated that 1 out of every 6 children born in the U.S. have already been exposed in-utero to levels of mercury that may cause problems with neurological development
- There are additional potential mercury-related health hazards to children, adults, and to wildlife
- Fish-consumption advisories due to mercury contamination are widespread throughout U.S. rivers, lakes, and coastal areas
- The primary exposure route is through fish consumption
- Atmospheric deposition is a significant – often the most significant – pathway for mercury loading to aquatic ecosystems

Mercury Exposure Pathway



source: USEPA

Three "forms" of atmospheric mercury

Elemental Mercury: Hg(0)

- ~ 95% of total Hg in atmosphere
- *not* very water soluble
- long atmospheric lifetime (~ 0.5 - 1 yr); globally distributed

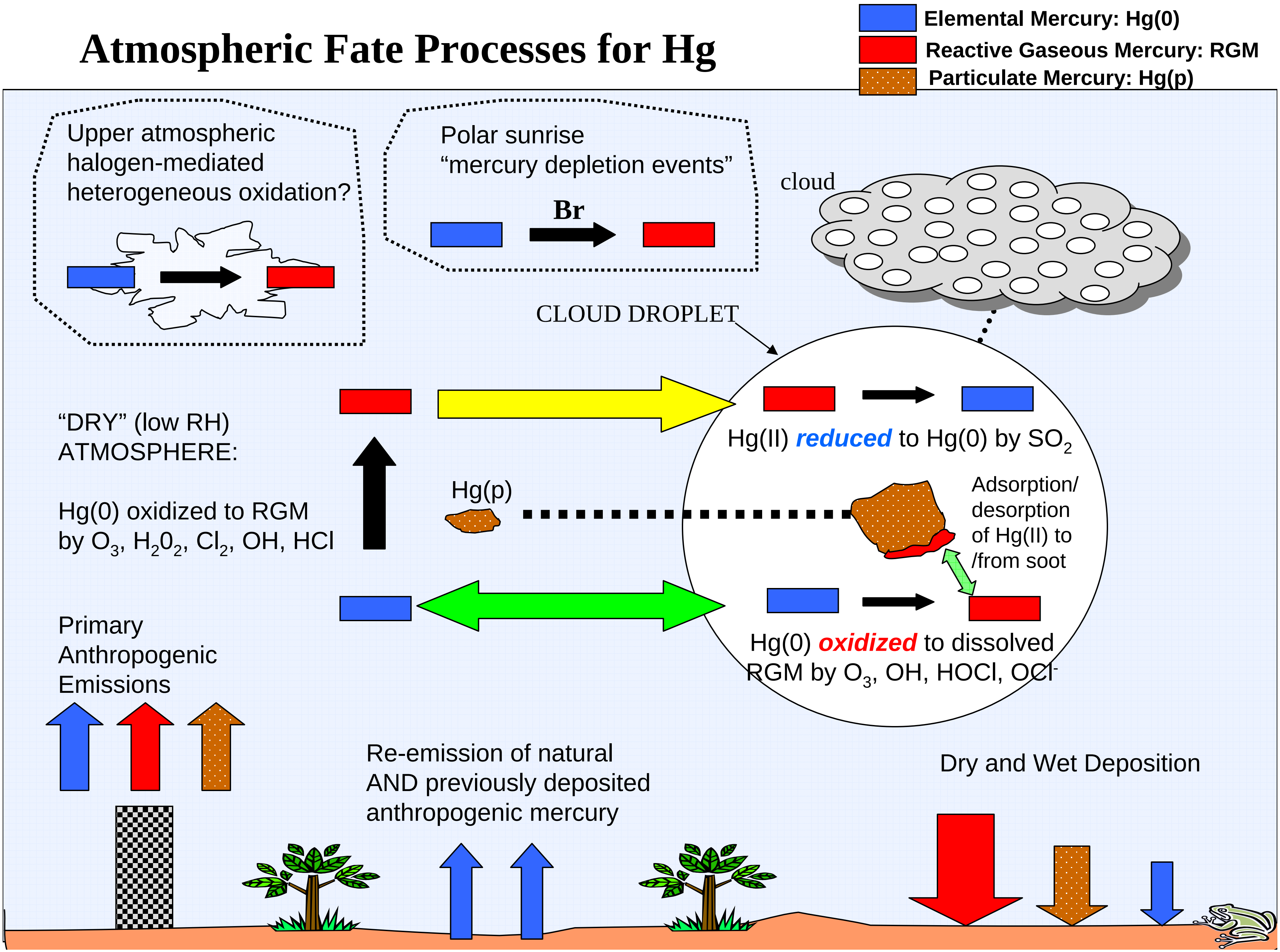
Reactive Gaseous Mercury ("RGM")

- a few percent of total Hg in atmosphere
- oxidized mercury: Hg(II)
- HgCl2, others species?
- somewhat operationally defined by measurement method
- *very* water soluble
- short atmospheric lifetime (~ 1 week or less);
- more local and regional effects

Particulate Mercury (Hg(p))

- a few percent of total Hg in atmosphere
- not pure particles of mercury…
  (Hg compounds associated with atmospheric particulate)
- species largely unknown (in some cases, may be HgO?)
- moderate atmospheric lifetime (perhaps 1~ 2 weeks)
- local and regional effects
- bioavailability?

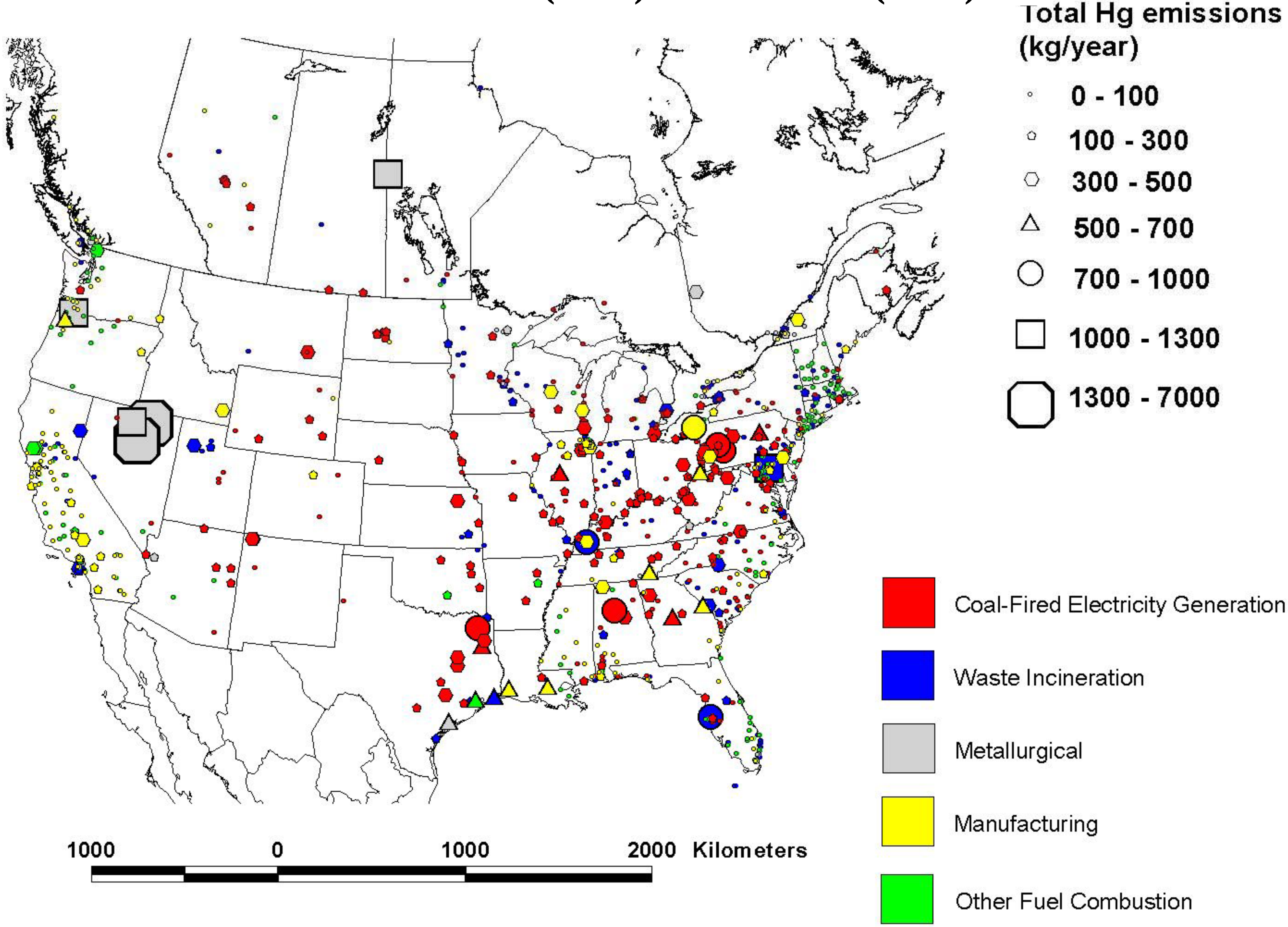
Atmospheric Fate Processes for Hg



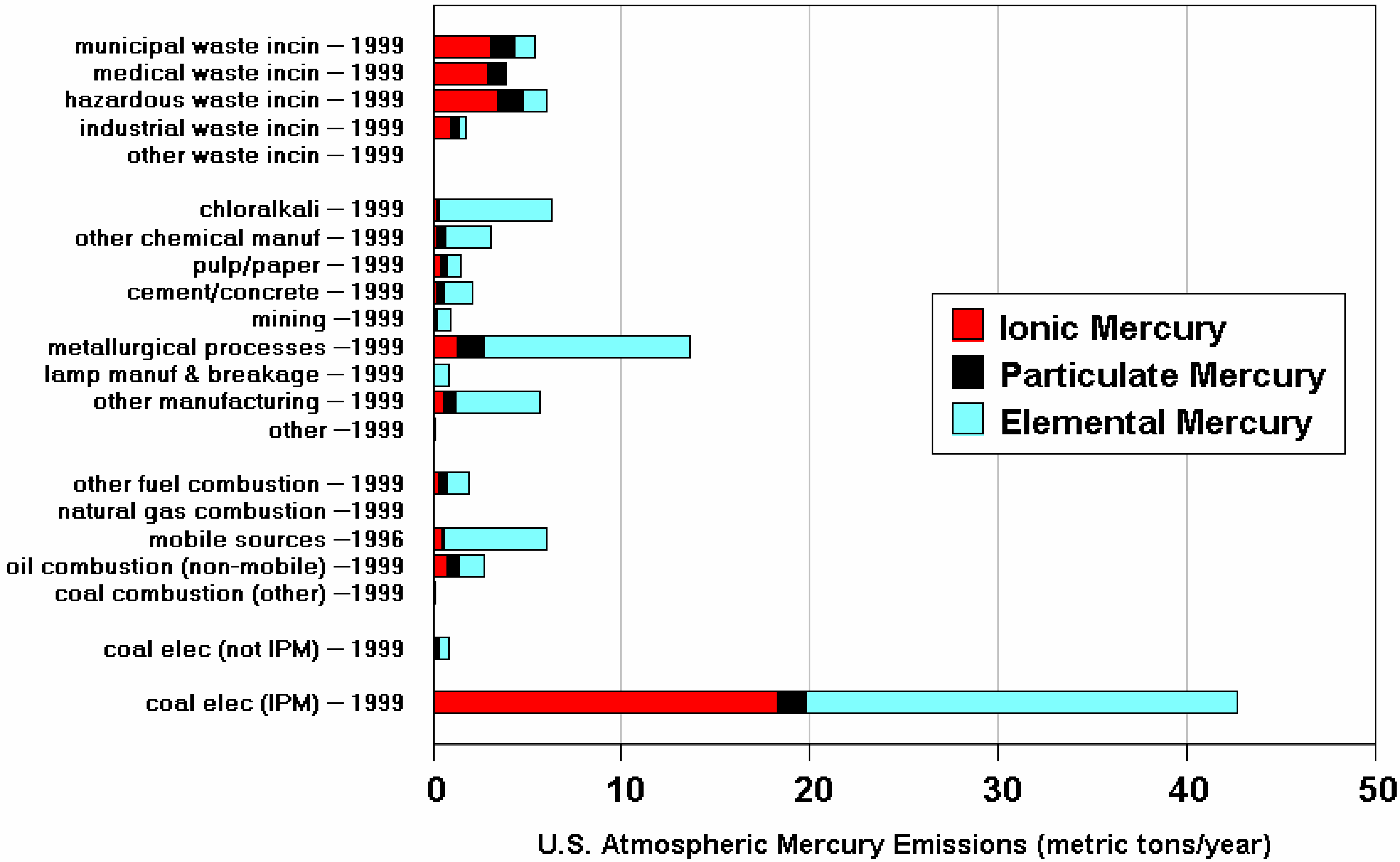
Atmospheric Chemical Reaction Scheme for Mercury

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

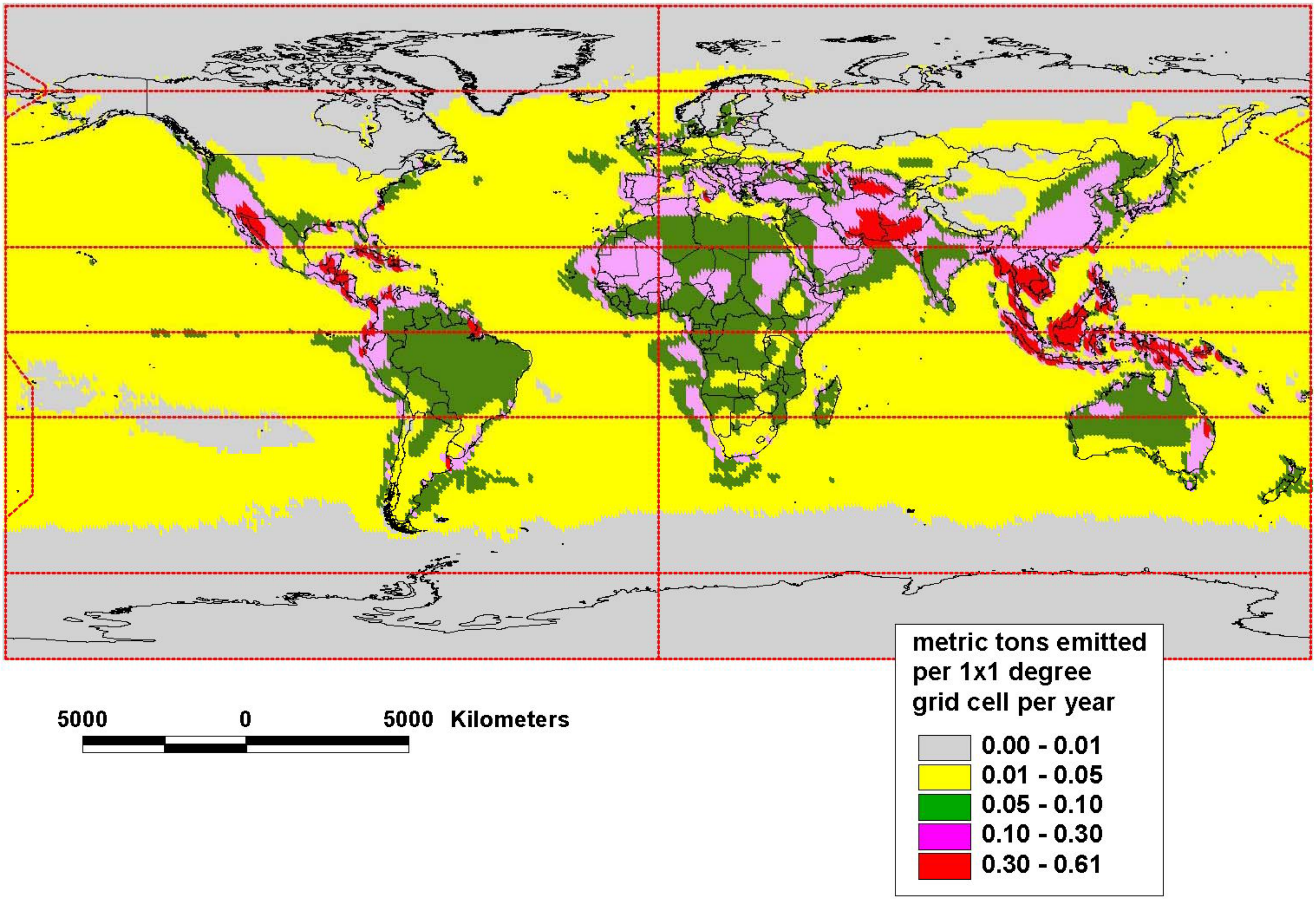
Geographic Distribution of Largest Anthropogenic Mercury Emissions Sources in the U.S. (1999) and Canada (2000)



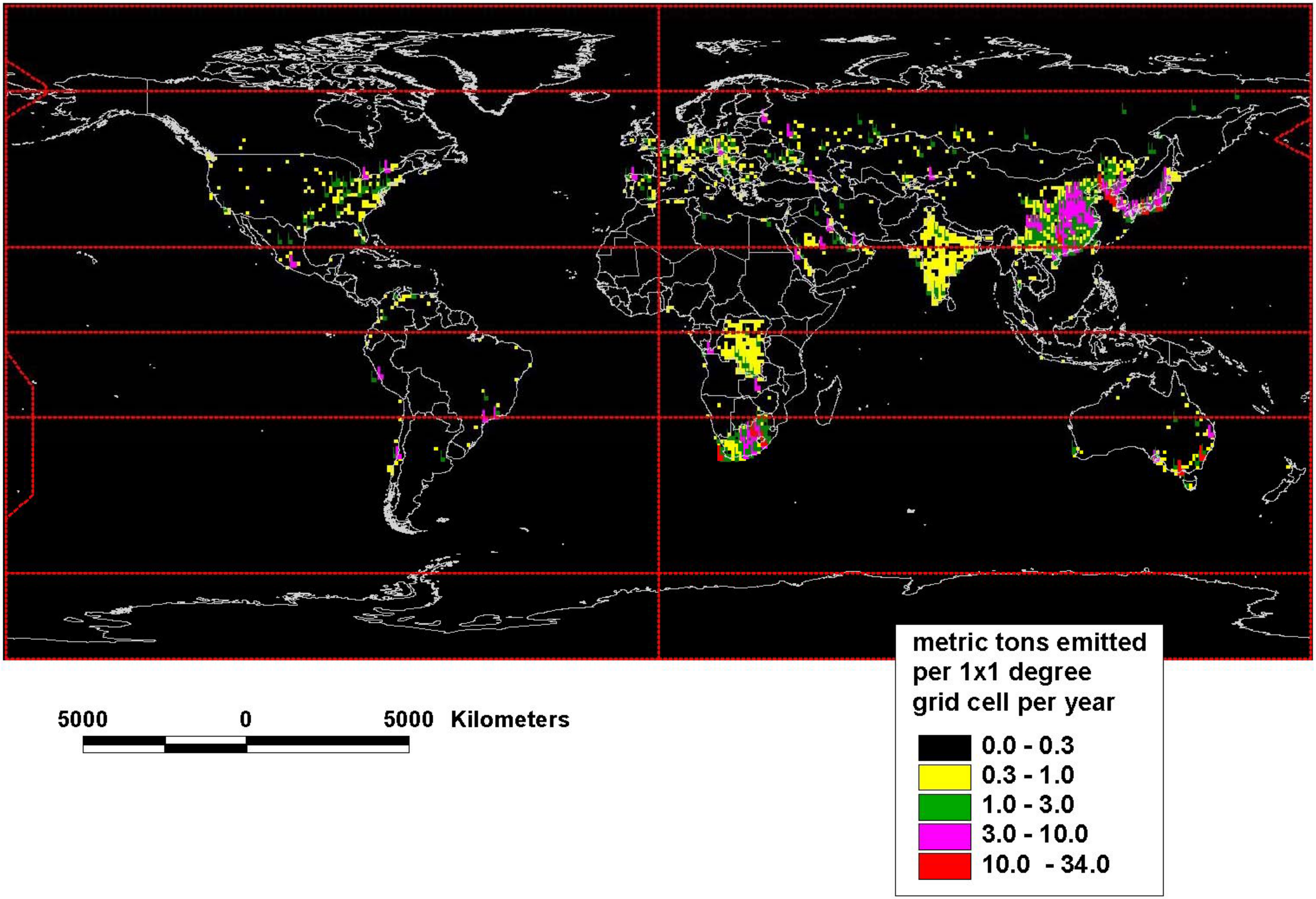
Estimated 1999 U.S. Atmospheric Anthropogenic Mercury Emissions



estimated natural emissions (1999)

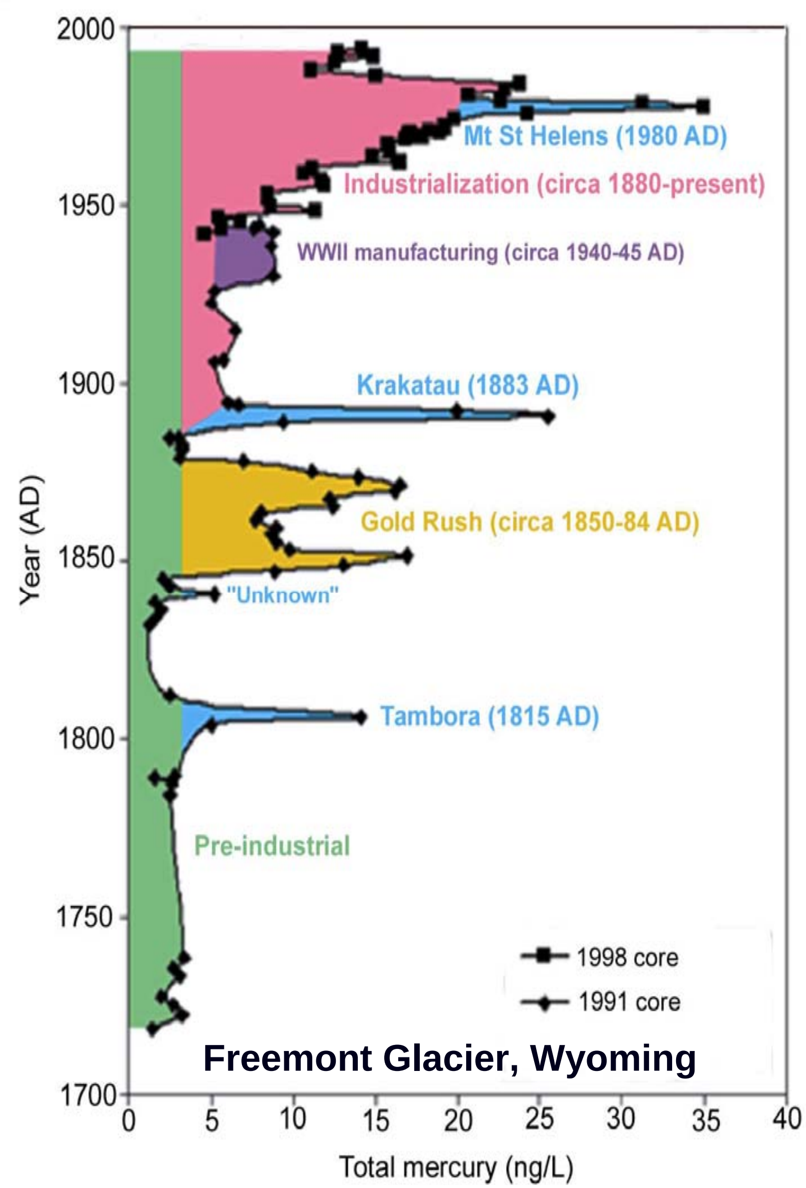


estimated anthropogenic emissions (1995)



Natural vs. anthropogenic mercury?

Studies show that anthropogenic activities have typically increased bioavailable Hg concentrations in ecosystems by a factor of 3-10



source: USGS, Shuster et al., 2002

Air Resources Laboratory: Atmospheric Mercury Research and Collaborations

ARL Mercury Research

Atmospheric measurements

- process understanding,
- study spatial/temporal trends
- develop & evaluate models

- ground-level speciated air concentrations
- upper-air speciated air conc. using aircraft
- wet and dry deposition
- surface exchange

Atmospheric modeling

- to interpret measurements,
- to get source-receptor data,
- to predict future impacts

- back-trajectory modeling using HYSPLIT
- HYSPLIT-Hg atmos. fate and transport model
- CMAQ-Hg atmospheric fate and transport model

ARL Mercury Collaborations

- Within NOAA
- External to NOAA

Examples of Mercury Collaborations within NOAA

- NOAA Chesapeake Bay Office
  - Maggie Kerchner, Bob Wood
  - ongoing measurement and modeling study FY 2004-2005
  - proposal in the works for continued collaboration

- NOAA Arctic Program Office
  - with CMDL, ORNL, EPA, others
  - measurements and modeling at Barrow Alaska

- *and discussions for potential projects with:*
  - Lake Champlain Sea Grant
  - MS/AL Sea Grant (Gulf of Mexico)
  - NCCOS (Jawed Hameedi, David Whitall)

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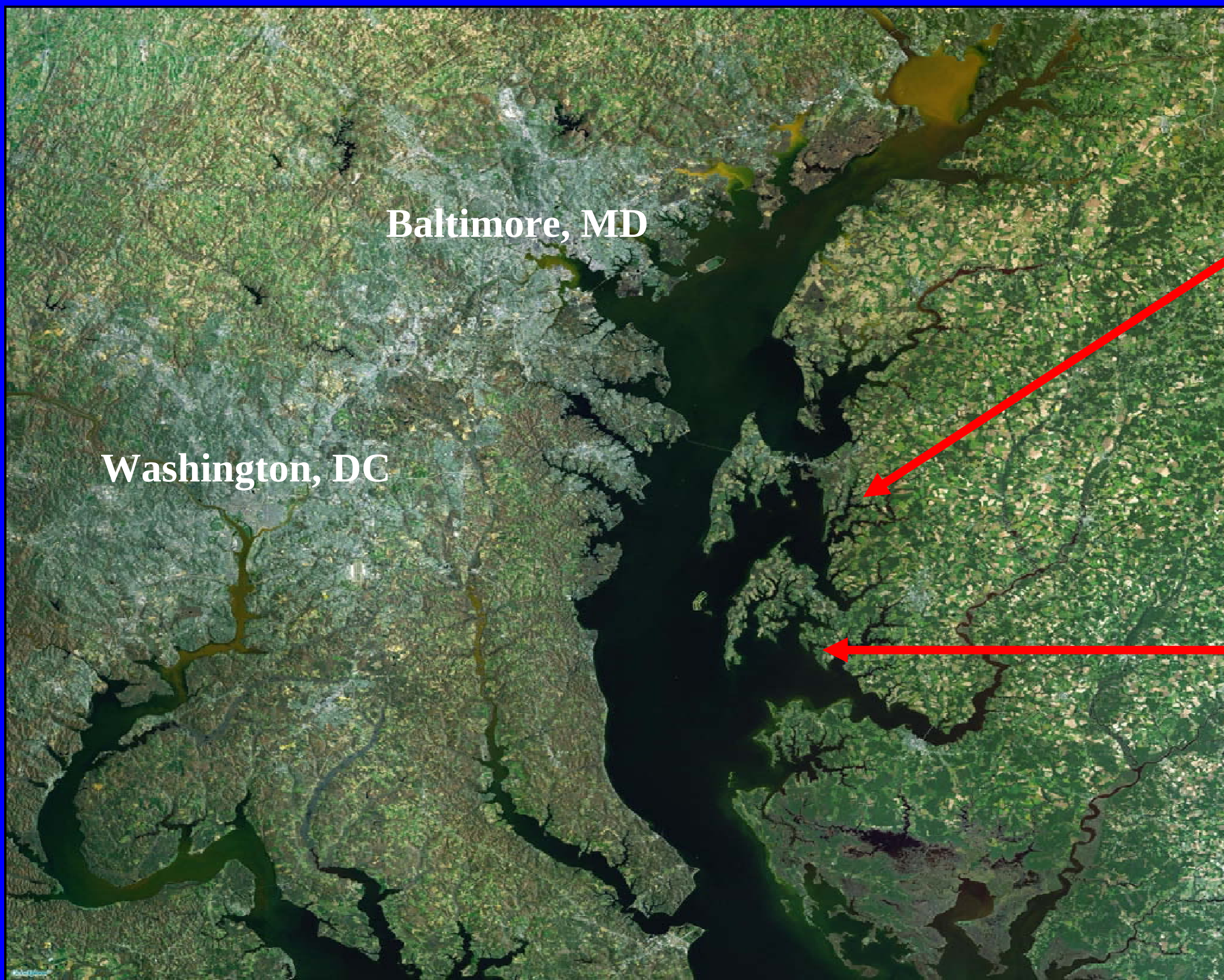
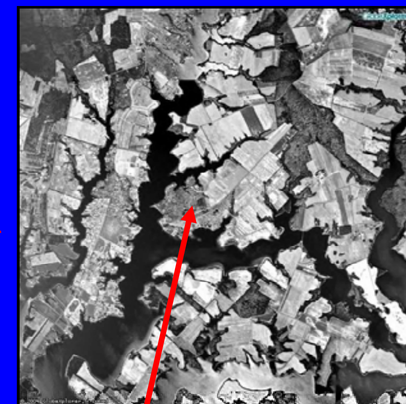
Summer 2004 Chesapeake Bay Atmospheric Mercury Measurement Sites

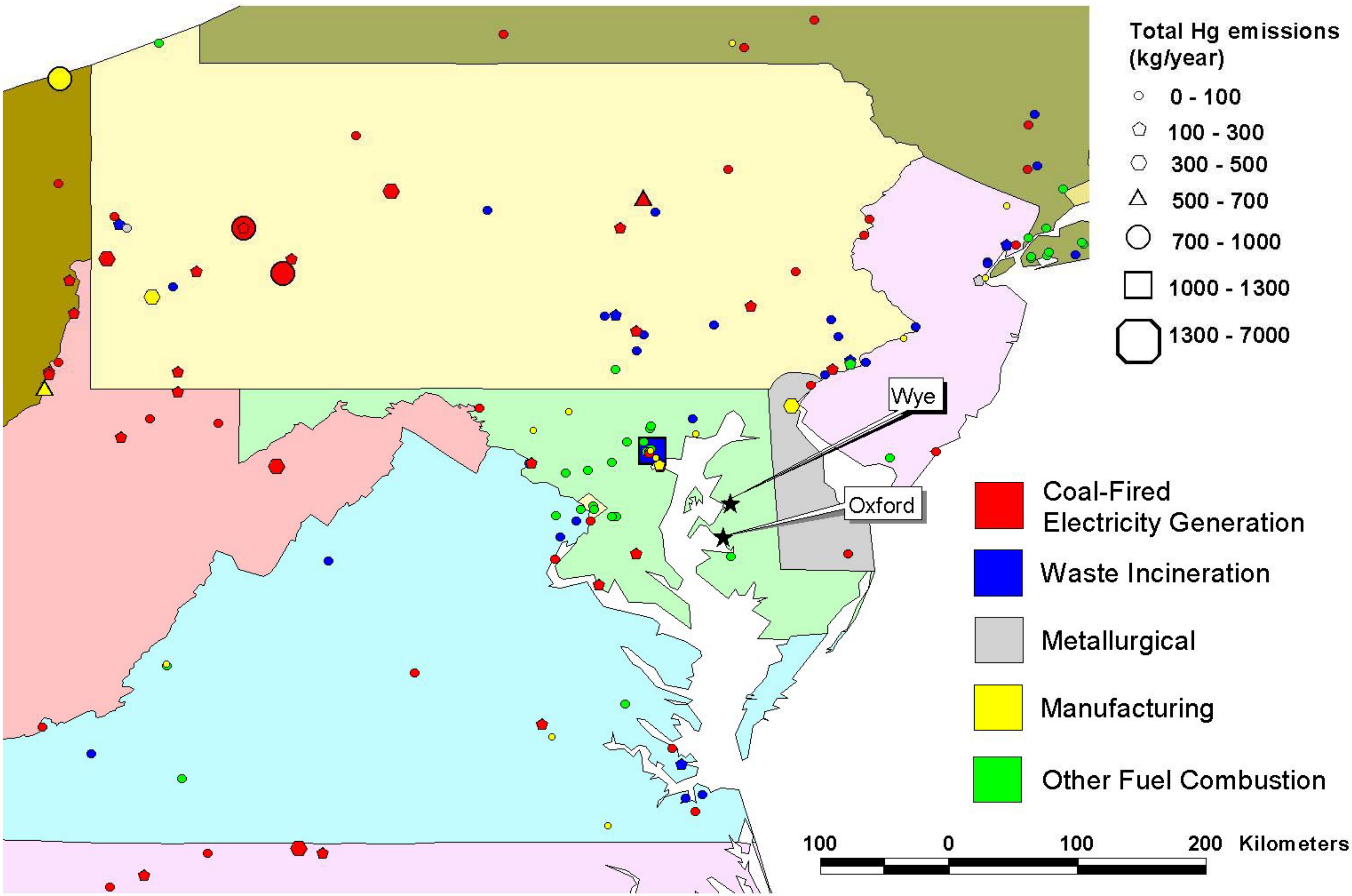




Wye Research and Education Center (38.9131EN, 76.1525EW)

Cooperative Oxford Lab (38.678EN, 76.173EW)

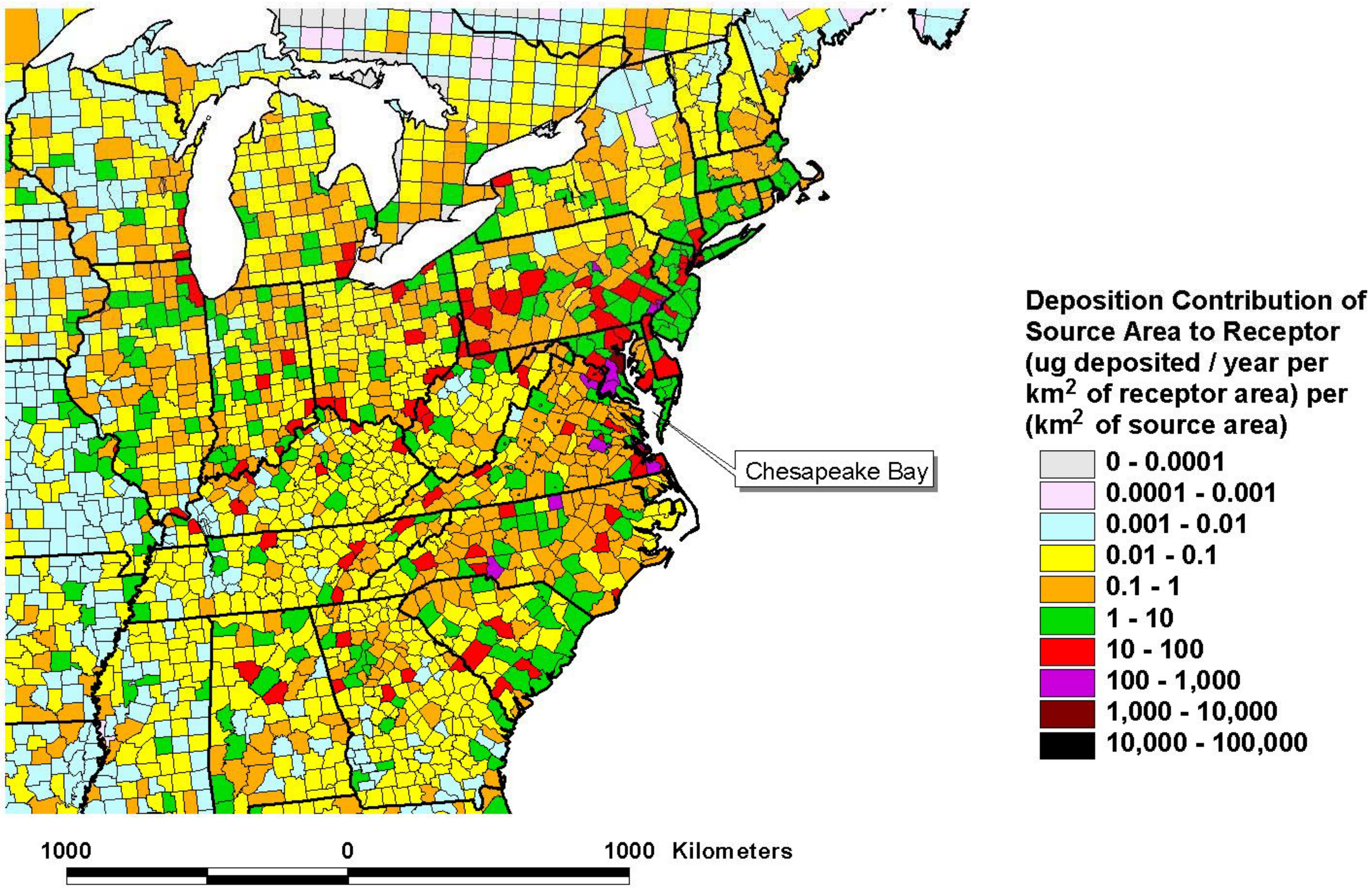
regional emissions (1999) and sampling sites for summer 2004 Ches Bay Hg study



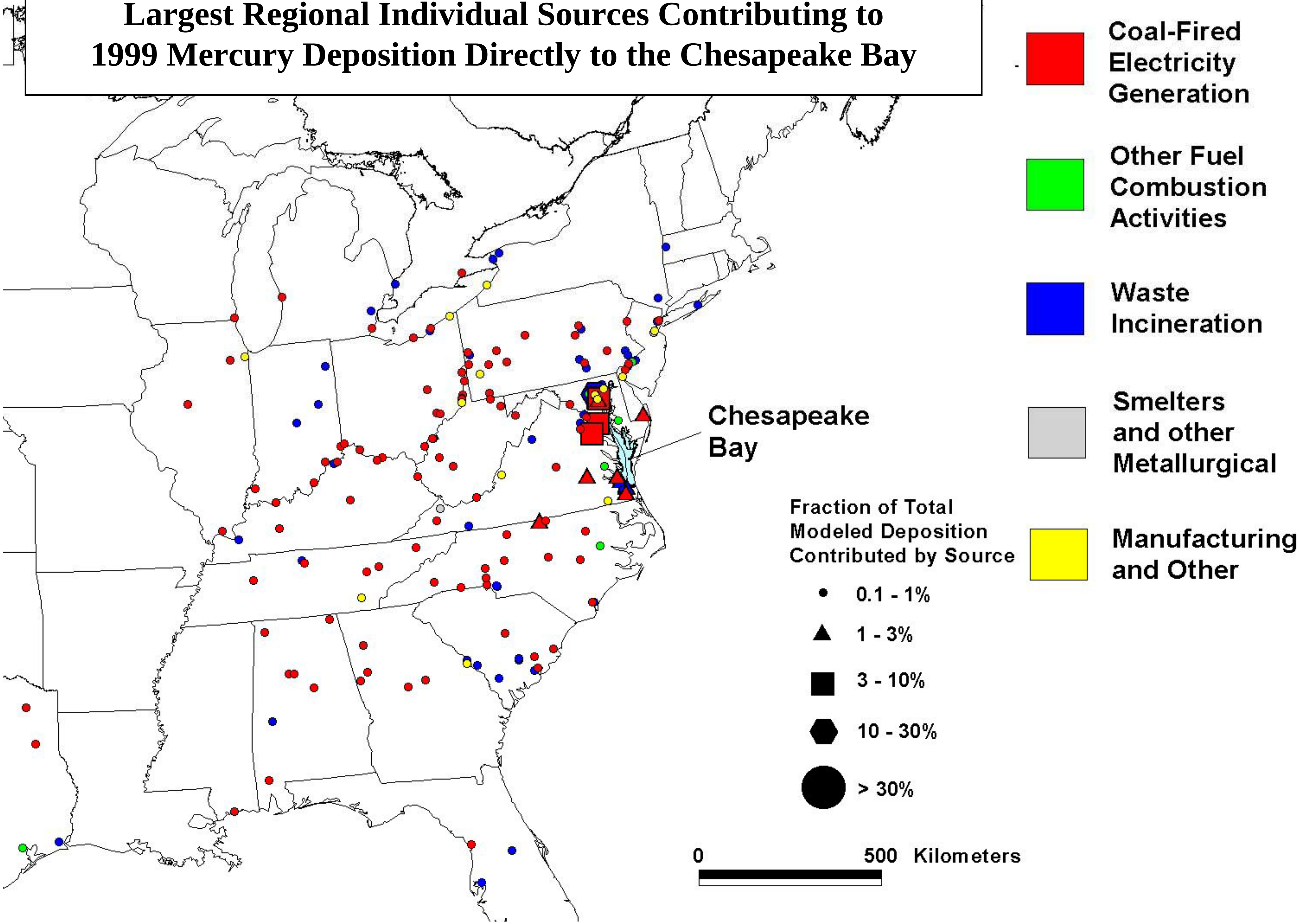
Summer 2004 Chesapeake Bay Atmospheric Hg Study
(June – August 2004)

	Oxford	Wye
Event-based precipitation samples analyzed for Hg	✓	✓
Speciated Hg concentrations in ambient air (RGM, Hg(p), Hg^0)	✓	✓
Ambient concentration of ozone and sulfur dioxide	✓ (continuous)	✓ (weekly via AirMON Dry)
Ambient concentration of carbon monoxide	✓	
Meteorology	✓	✓ (via NADP/NTN site)
Major ions in precipitation		✓ (via NADP/NTN site)

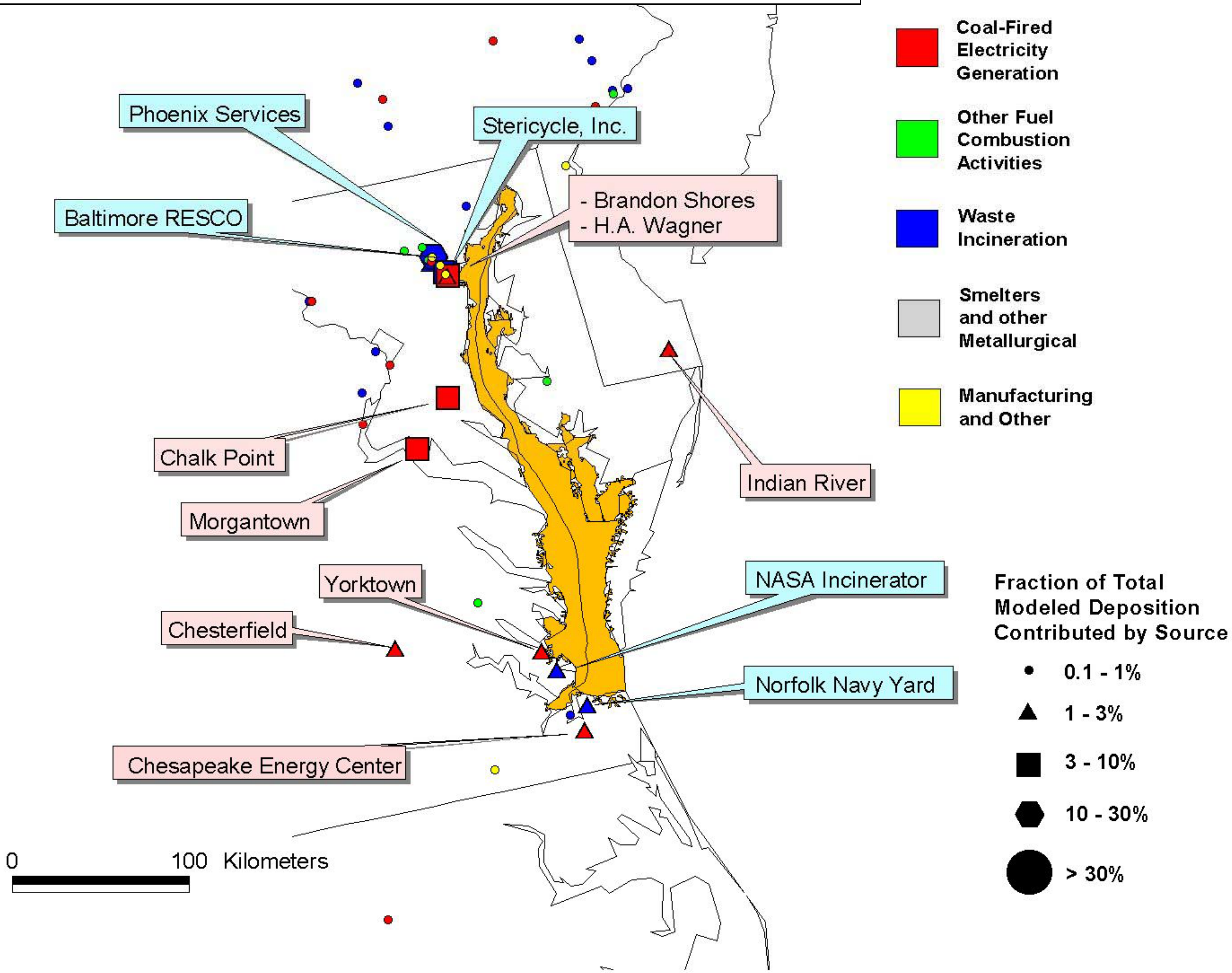
Geographical Distribution of 1999 Direct Deposition Contributions to the Chesapeake Bay (regional close-up)



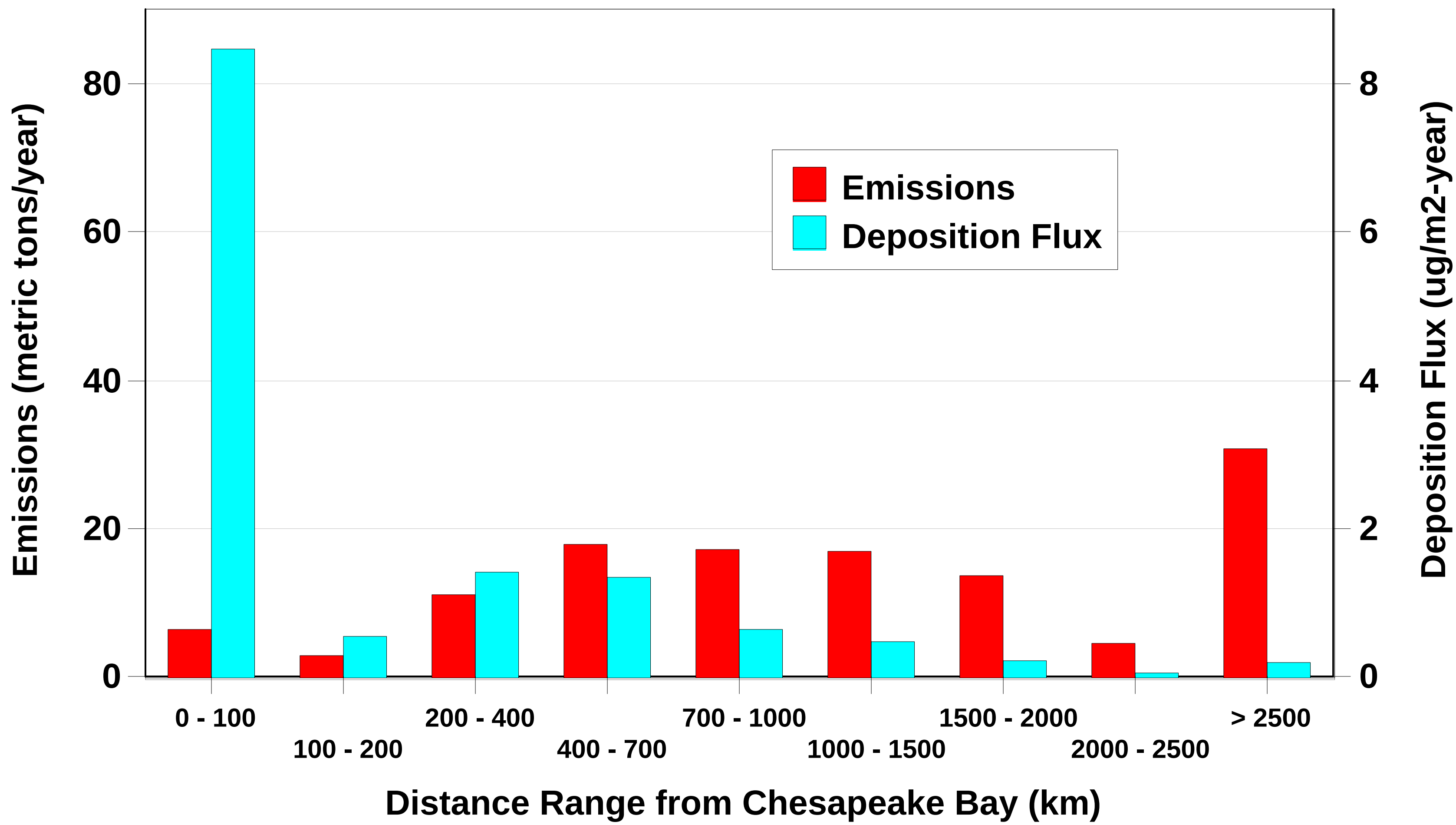
Largest Regional Individual Sources Contributing to 1999 Mercury Deposition Directly to the Chesapeake Bay



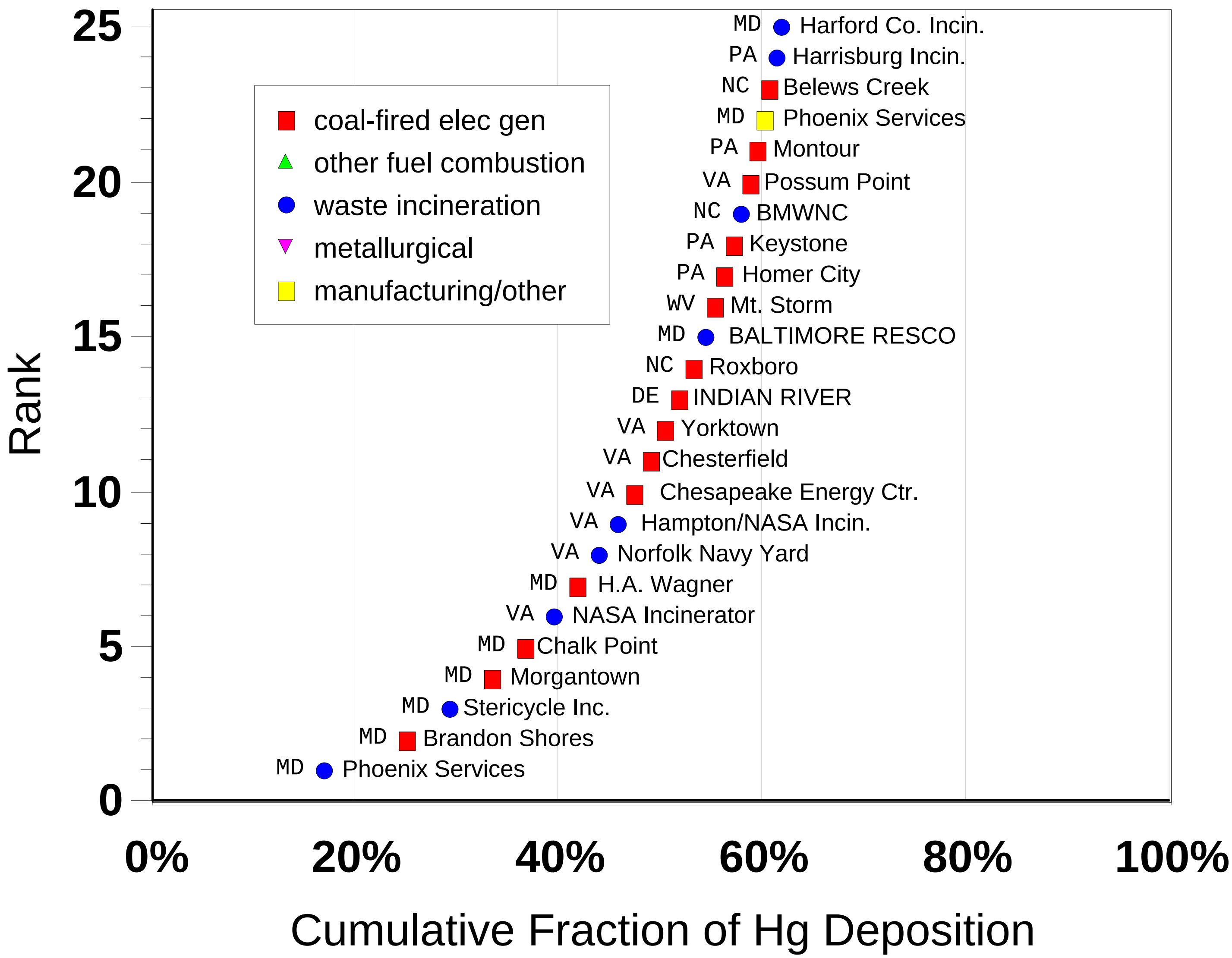
Largest Local Individual Sources Contributing to 1999 Mercury Deposition Directly to the Chesapeake Bay



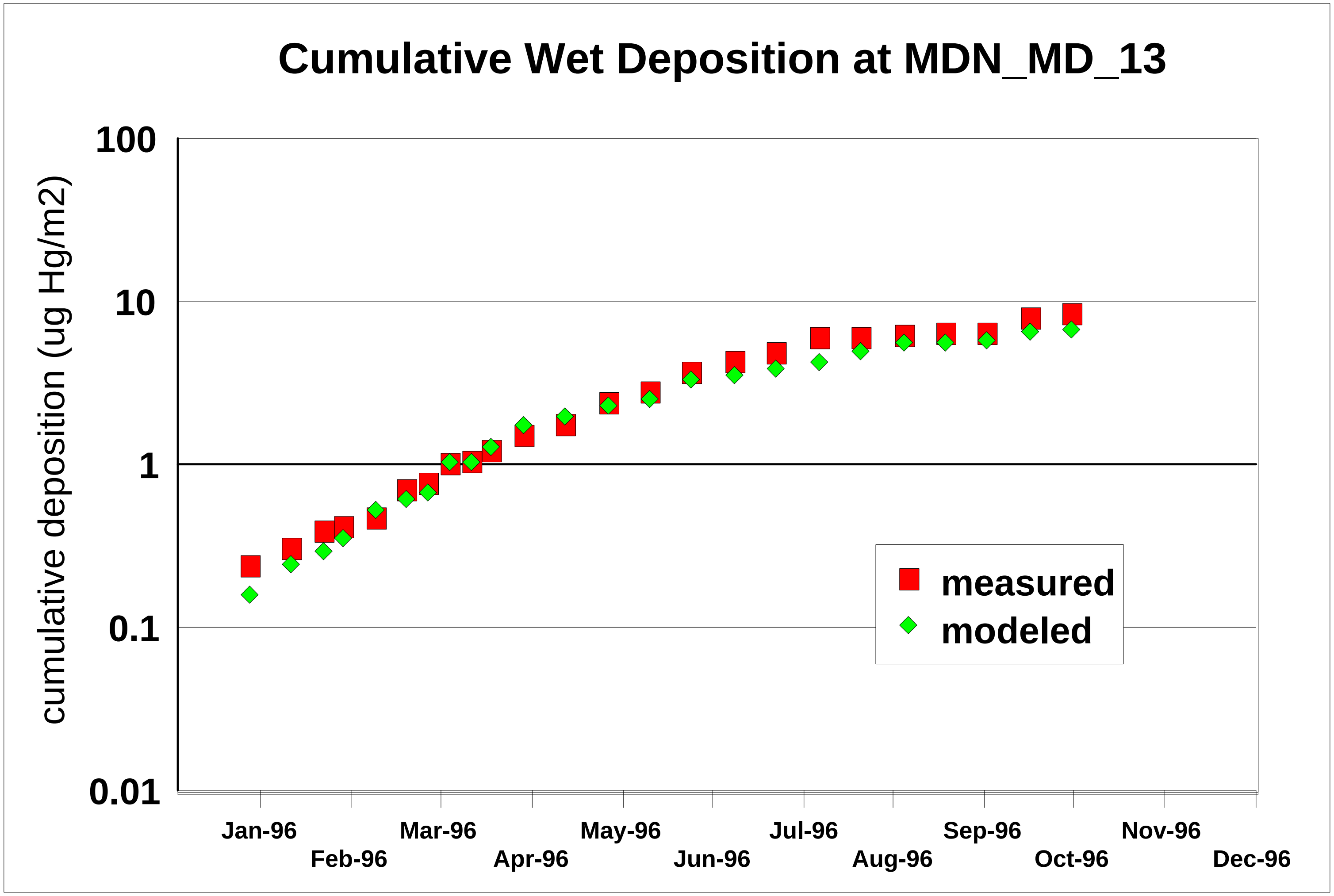
Emissions and Direct Deposition Contributions from Different Distance Ranges Away From the Chesapeake Bay



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



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



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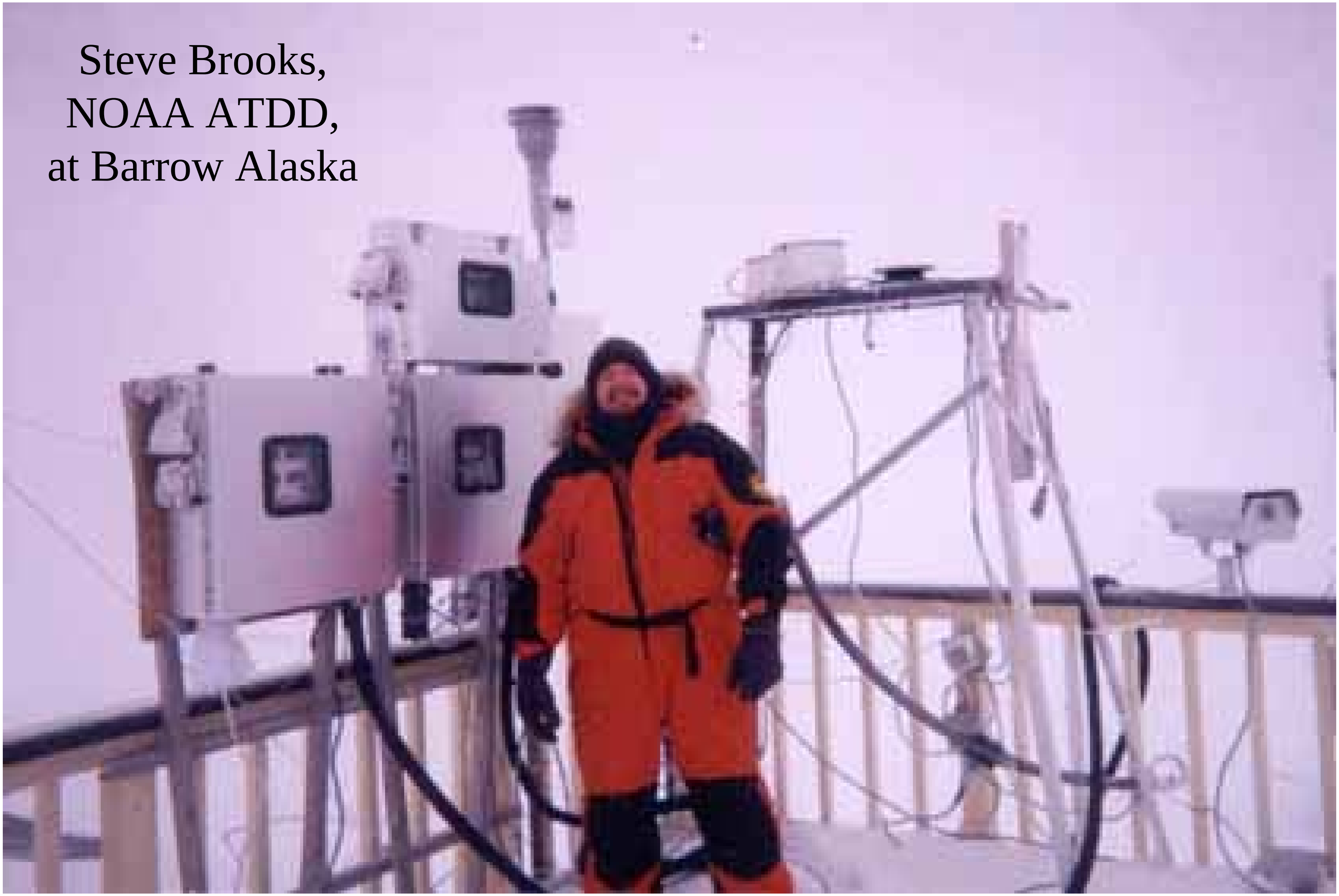
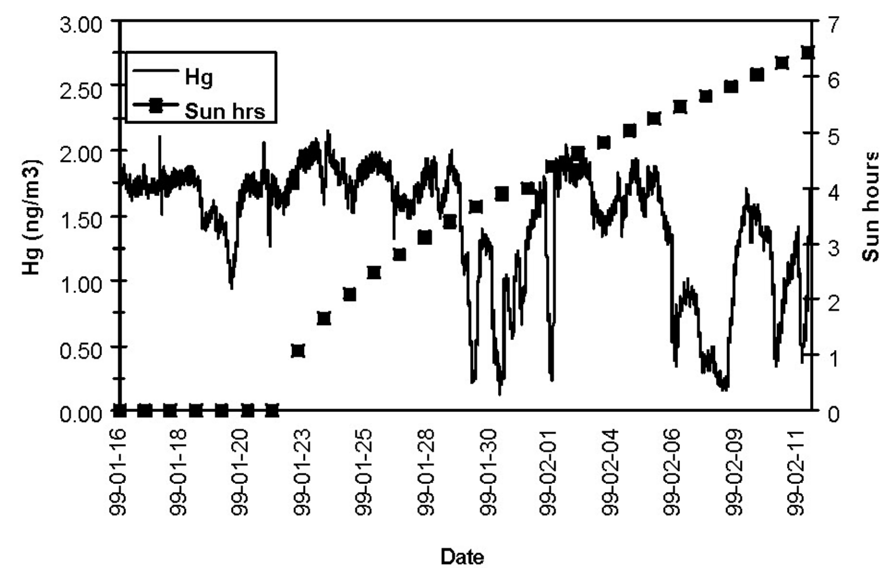


Steve Brooks,
NOAA ATDD,
at Barrow Alaska

in very simplified terms:

$$Hg(0) \xrightarrow{BrO} Hg(II)\ (\text{“RGM”})$$

Fig. 1. First Confirmation of Mercury Depletion Events in the U. S. Arctic, Barrow, AK (January, 1999).



ARL Scientists played a key role in discovering and explaining the Mercury Depletion Events occurring in the Arctic at Polar Sunrise

Examples of External Mercury Collaborations -- Modeling

- Environmental Protection Agency
  - National Exposure Research Laboratory
  - Clean Air Markets Division
  - Great Lakes National Program Office

- International Joint Commission (Great Lakes)
  - Int'l Air Quality Advisory Board

- Commission for Environmental Cooperation (NAFTA)
  - Atmospheric Hg deposition to the Gulf of Maine
  - Hg deposition impacts of future energy generation scenarios

- EMEP LRTAP Protocol (Europe)
  - Mercury model intercomparison (HYSPLIT-Hg, CMAQ-Hg)

- Environment Canada
  - Emissions inventories

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MULTI-MEDIA MERCURY MODELING PROJECT

Update for the International Air Quality Planning Board

January 26, 2005

Principal Investigators:
Dr. Mark Cohen, NOAA
Dr. Panos Georgopoulos, EOHSI
Dr. John Johnston, USEPA
Dr. Elsie Sunderland, USEPA

Environmental and Occupational Health Sciences Institute (EOHSI)

EPA United States Environmental Protection Agency

Multi-Media Hg Modeling System

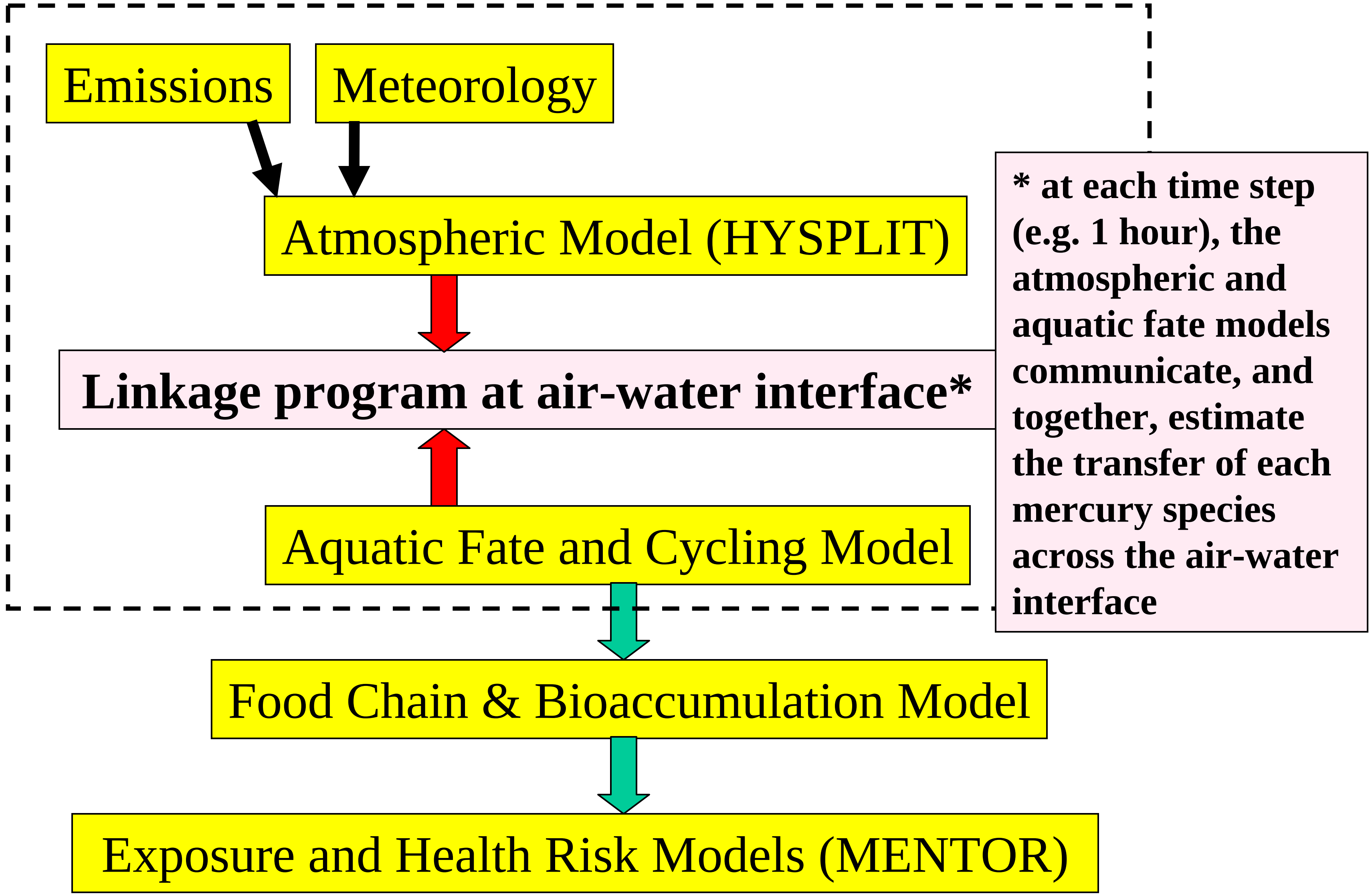

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Figure 35-A. Geographical Distribution of 1999 Direct Deposition Contributions to Lake Michigan (entire domain)

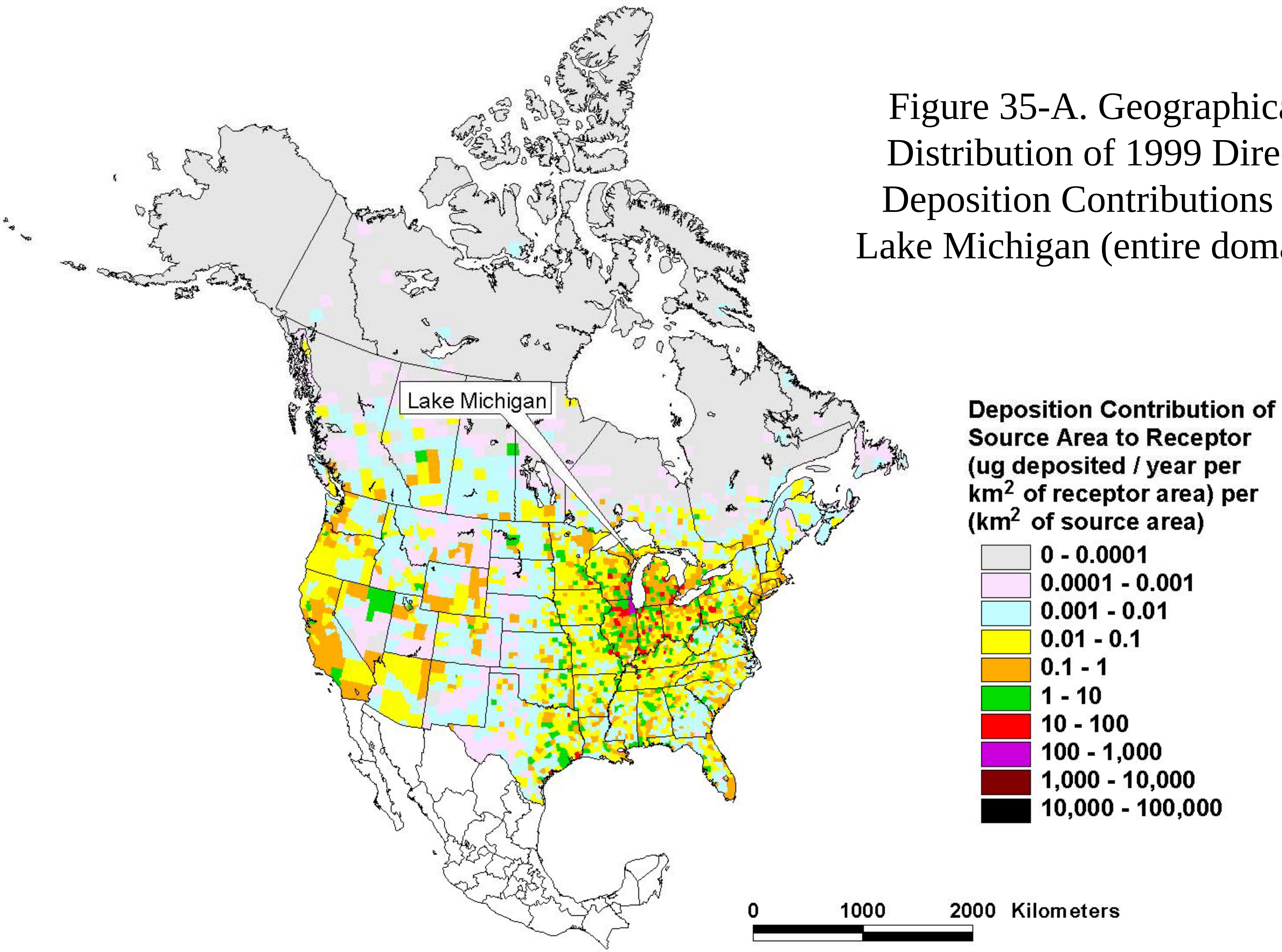


Figure 35-B. Geographical Distribution of 1999 Direct Deposition Contributions to Lake Michigan (regional view)

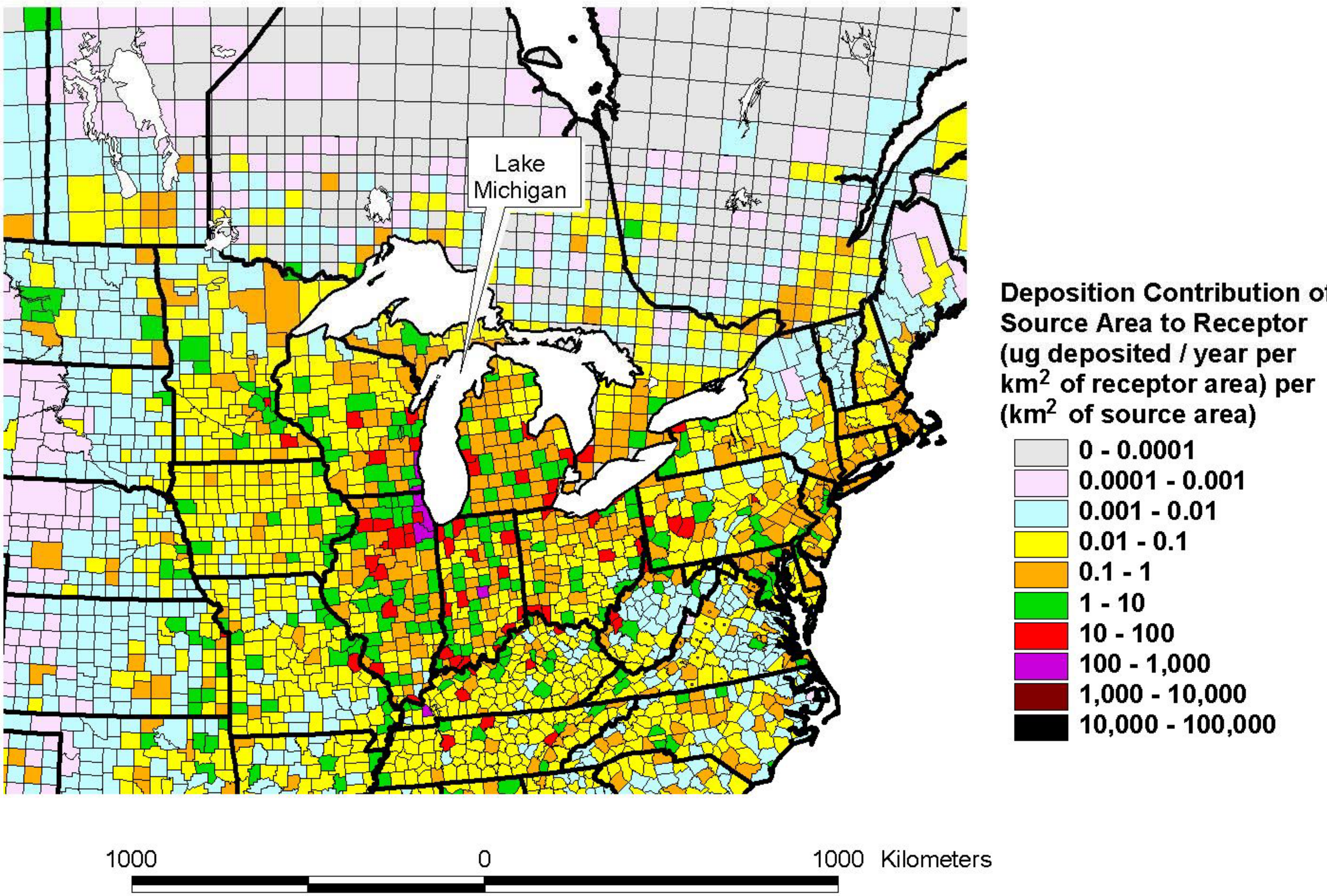
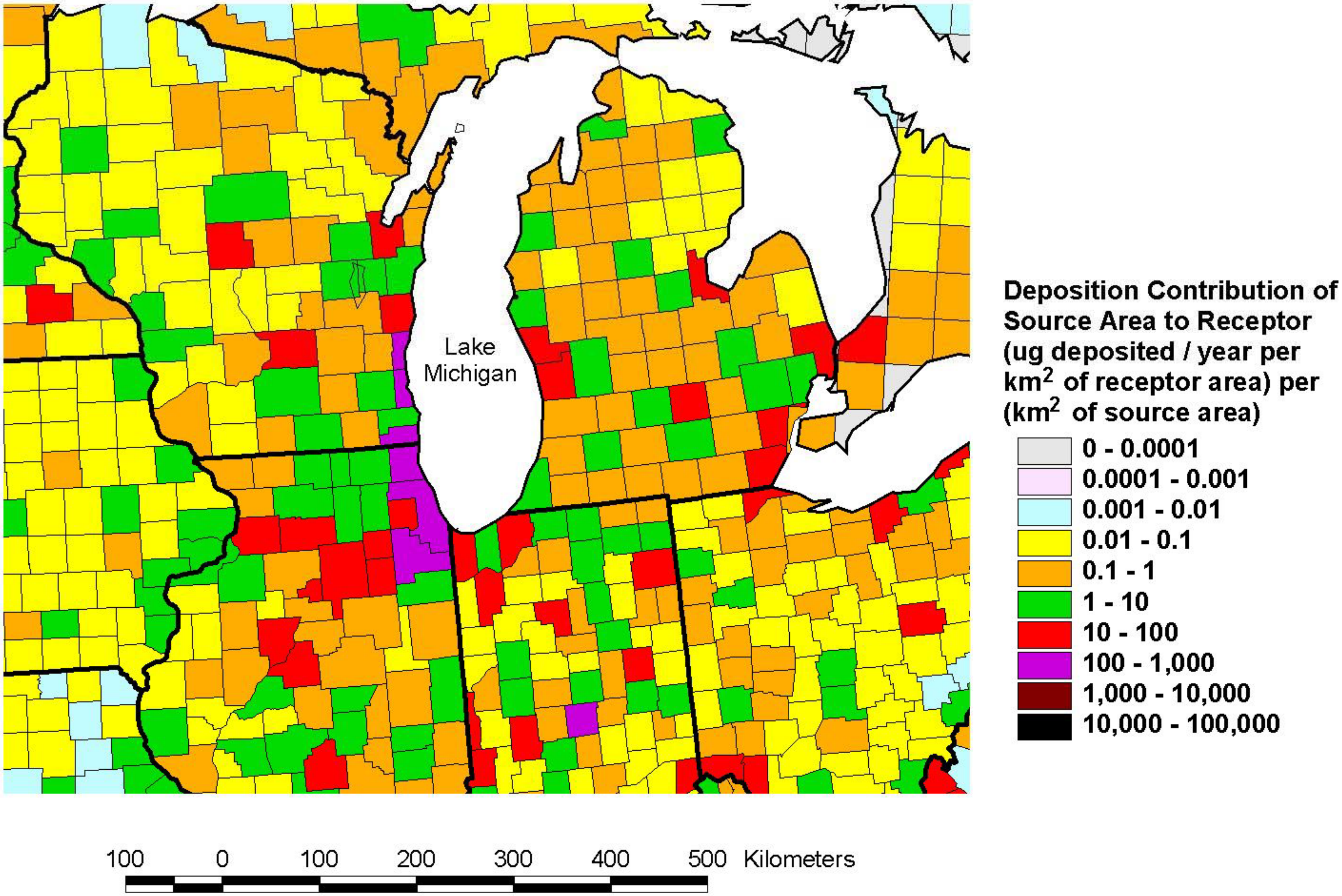


Figure 35-C. Geographical Distribution of 1999 Direct Deposition Contributions to Lake Michigan (more local view)



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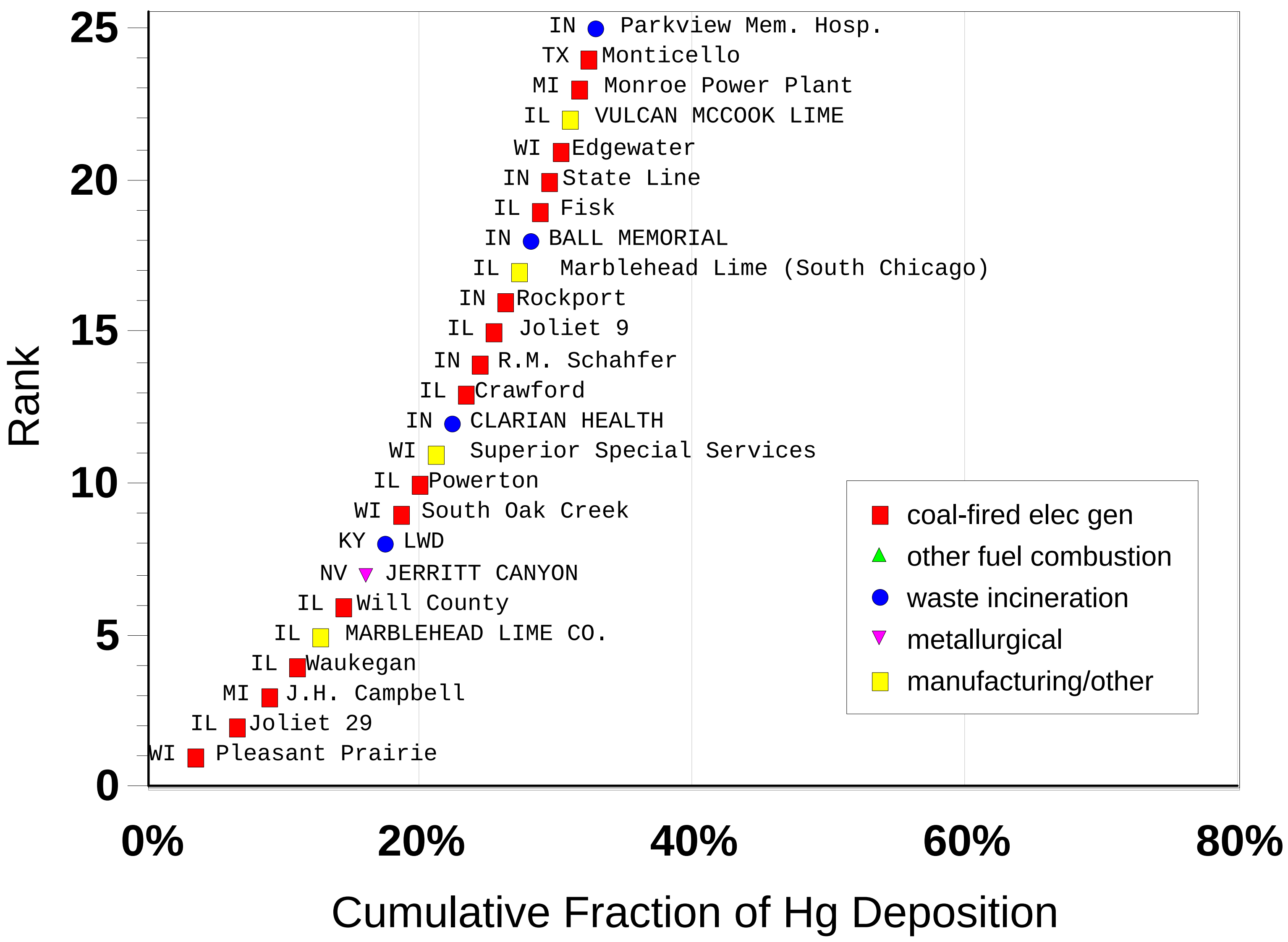

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Modeling the atmospheric transport and deposition of mercury to the Great Lakes☆

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[c] *Atmospheric Toxic Processes Service, Meteorological Service of Canada, Environment Canada Quebec region, Montreal, Que., Canada*
[d] *Pollutant Data Branch, Environment Canada, Hull, Que., Canada*
[e] *Environmental Monitoring and Reporting Branch, Ontario Ministry of the Environment, Toronto, Ont., Canada*
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[g] *US EPA Great Lakes National Program Office, Chicago, IL, USA*
[h] *International Joint Commission, Windsor, Ont., Canada*

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Examples of External Mercury Collaborations -- ***Monitoring***

- Environmental Protection Agency
  - National Exposure Research Laboratory – aircraft Hg measurements
- International Measurement Intercomparison Campaigns
  - Arctic (polar sunrise phenomena)
  - Antarctic
- University of Alabama (Sea Grant)
  - measurements in the Gulf of Mexico region – ship-based and land-based measurements.

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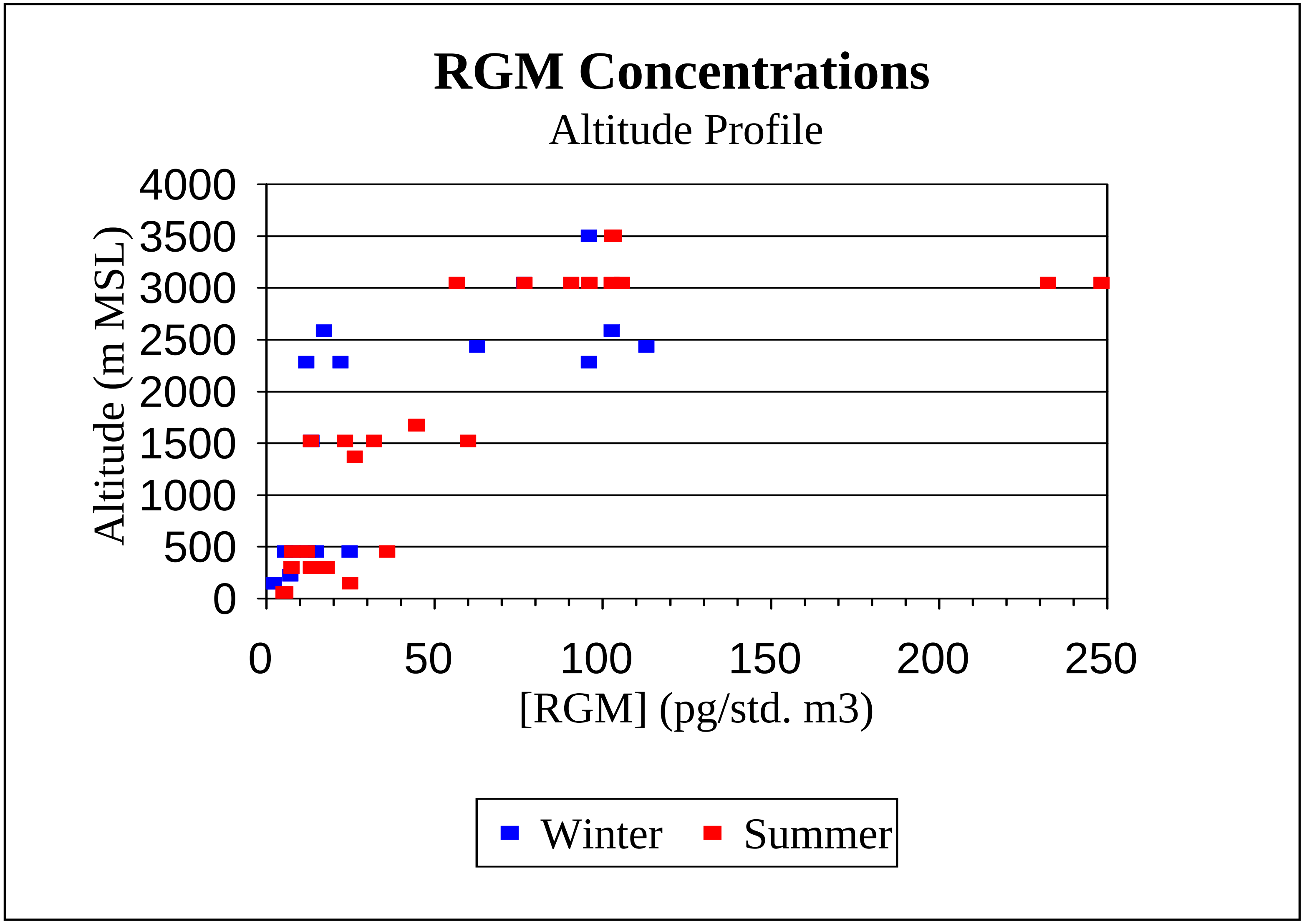
DeHavilland DHC-6 Twin Otter

<u>measurements include:</u>

- **atmospheric parameters**
- **trace gases (O_3, SO_2, NO_x, etc.)**
- **speciated mercury**

Unexpectedly high concentrations of Reactive Gaseous Mercury (RGM) were found in the upper atmosphere!



Collaboration Possibilities within ERP

<u>Hg research goals and questions for any given ecosystem or region:</u>

- Establish and update status of mercury contamination in NOAA trust resources
  ...Gulf of Mexico, Chesapeake Bay, Upper Atlantic, Great Lakes, Lake Champlain...

  - Characterize and understand reasons for spatial and temporal trends
  - Construct mass balance of mercury (relative loading from air, tributaries, etc.)
  - Quantify past, present, and future sources of mercury contamination
  - Understand fate and cycling of mercury, e.g., sedimentation, methylation
  - Understand watershed processing
  - Understand the food web and mercury bioaccumulation
  - Understand effects on wildlife (e.g., fish-eating birds)

- What are the major uncertainties? How can we reduce these uncertainties?

- With the above, provide information for risk communication and sound science to support decision-making at the local, regional, national, and international level

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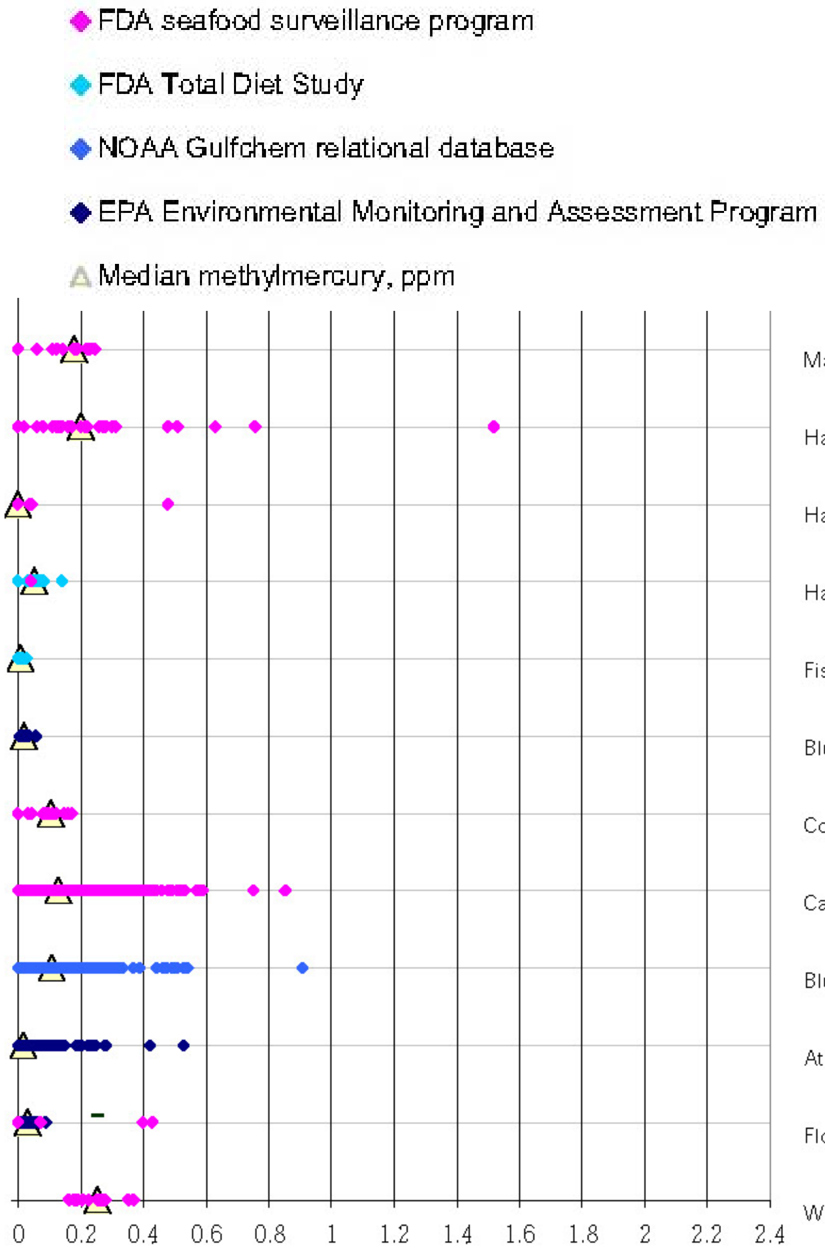
Distribution of methyl-mercury concentrations in different fish species



	number of samples	Methylmercury concentration (ppm) average	median	range
Mahi mahi	18	0.164	0.18	0 - 0.245
Halibut	31	0.273	0.214	0 - 1.52
Hake	9	0.062	0	0 - 0.48
Haddock	23	0.056	0.053	0 - 0.14
Fish sticks	16	0.008	0.008	0 - .03
Blue crab - Atlantic	20	0.021	0.018	0.006 - 0.059
Cod	17	0.099	0.1	0 - 0.17
Canned tuna	361	0.166	0.13	0 - 0.852
Blue mussel	269	0.144	0.108	0 - 0.909
Atlantic croaker	202	0.044	0.015	0 - 0.529
Flounder	39	0.047	0.029	0 - 0.43
White croaker	15	0.258	0.252	0.162 - 0.369

source: Environmental Working Group

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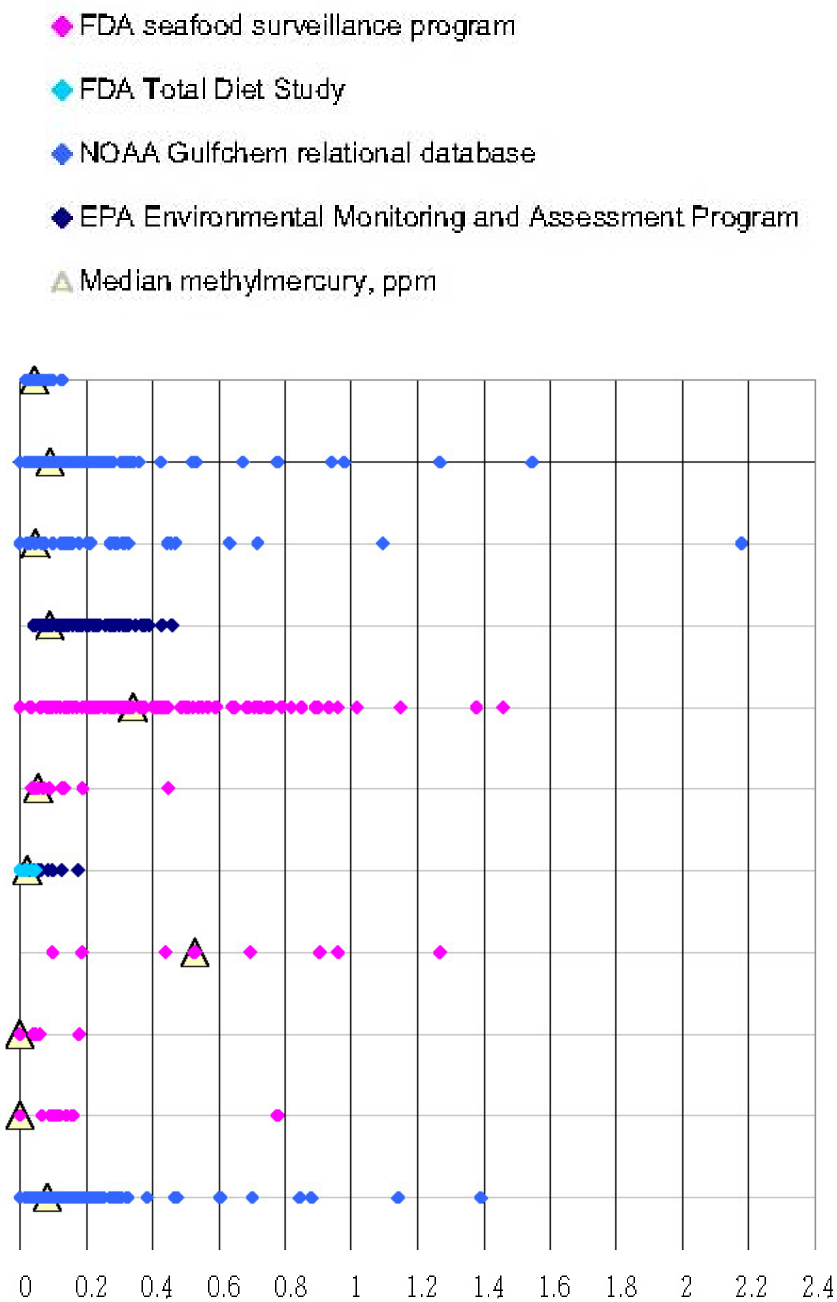

	number of samples	Methylmercury concentration (ppm) average	median	range
Lake Whitefish	88	0.051	0.045	.018 - .126
Gulf Coast Oysters	396	0.123	0.09	0 - 1.55
Gulf Coast Crabs	47	0.228	0.047	1 - 2.18
Great Lakes Salmon	88	0.173	0.09	0.05 - 0.43
Tuna steaks	122	0.417	0.34	0 - 1.46
Smelt	16	0.097	0.054	0.036 - 0.45
Shrimp	59	0.033	0.023	1 - 0.177
Sea bass	10	0.606	0.529	0.1 - 1.27
Salmon	51	0.008	0	0 - 0.18
Pollock	32	0.063	0	0 - 0.78
Oyster	396	0.111	0.083	0 - 1.392

source: Environmental Working Group

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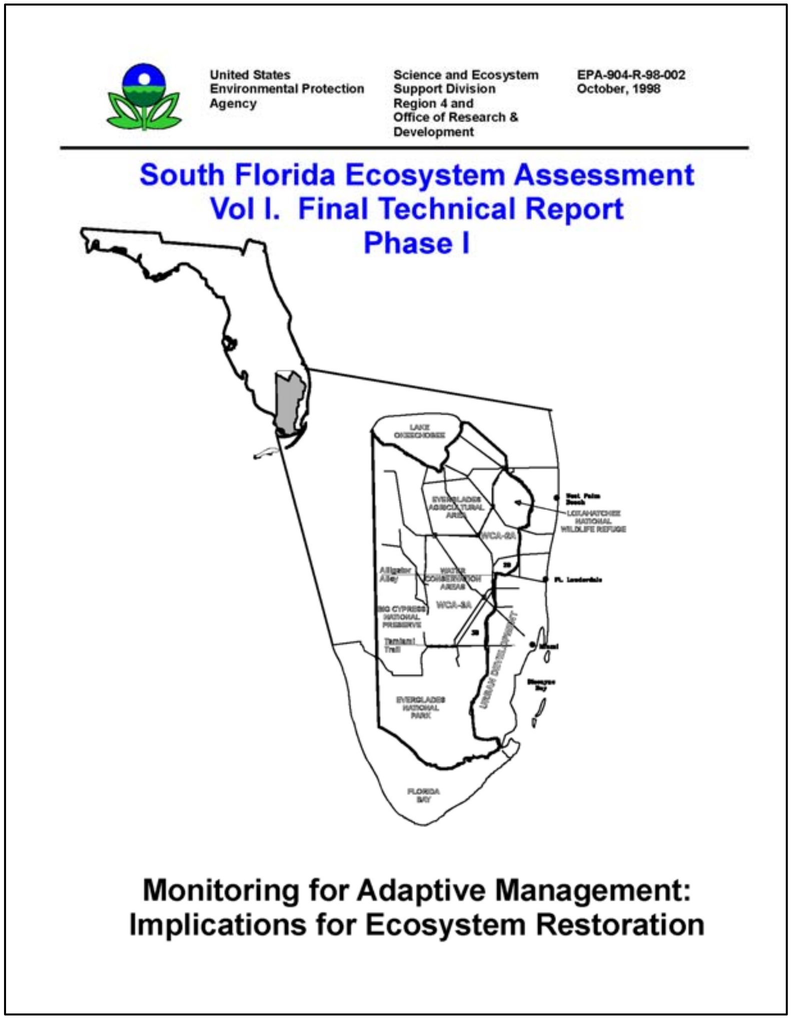
- ❑ With the above, provide information for risk communication and sound science to support decision-making at the local, regional, national, and international level



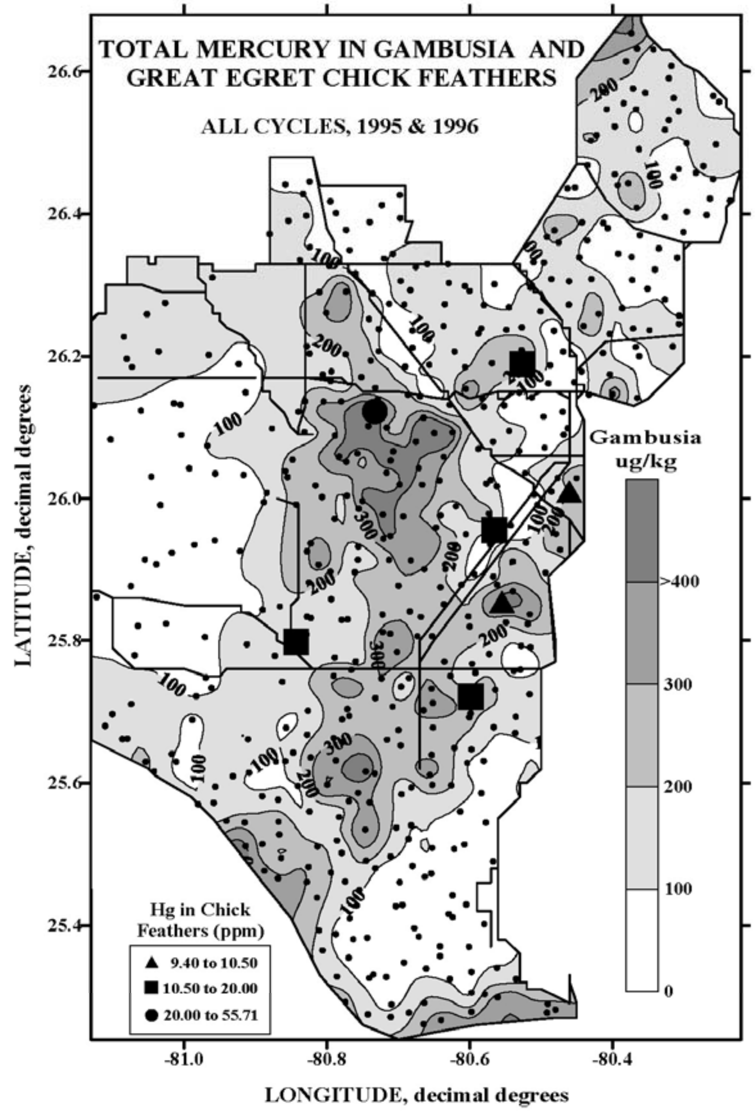


Figure 8.55 Hg concentrations in Great Egret chick feathers and mosquitofish indicate spatial distribution of Hg bioaccumulation.

http://www.epa.gov/region4/sesd/reports/epa904r98002.html

Hg research goals and questions for any given ecosystem or region:

- Establish and update status of mercury contamination in NOAA trust resources
  ...Gulf of Mexico, Chesapeake Bay, Upper Atlantic, Great Lakes, Lake Champlain...

  - Characterize and understand reasons for spatial and temporal trends
  - Construct mass balance of mercury (relative loading from air, tributaries, etc.)
  - Quantify past, present, and future sources of mercury contamination
  - Understand fate and cycling of mercury, e.g., sedimentation, methylation
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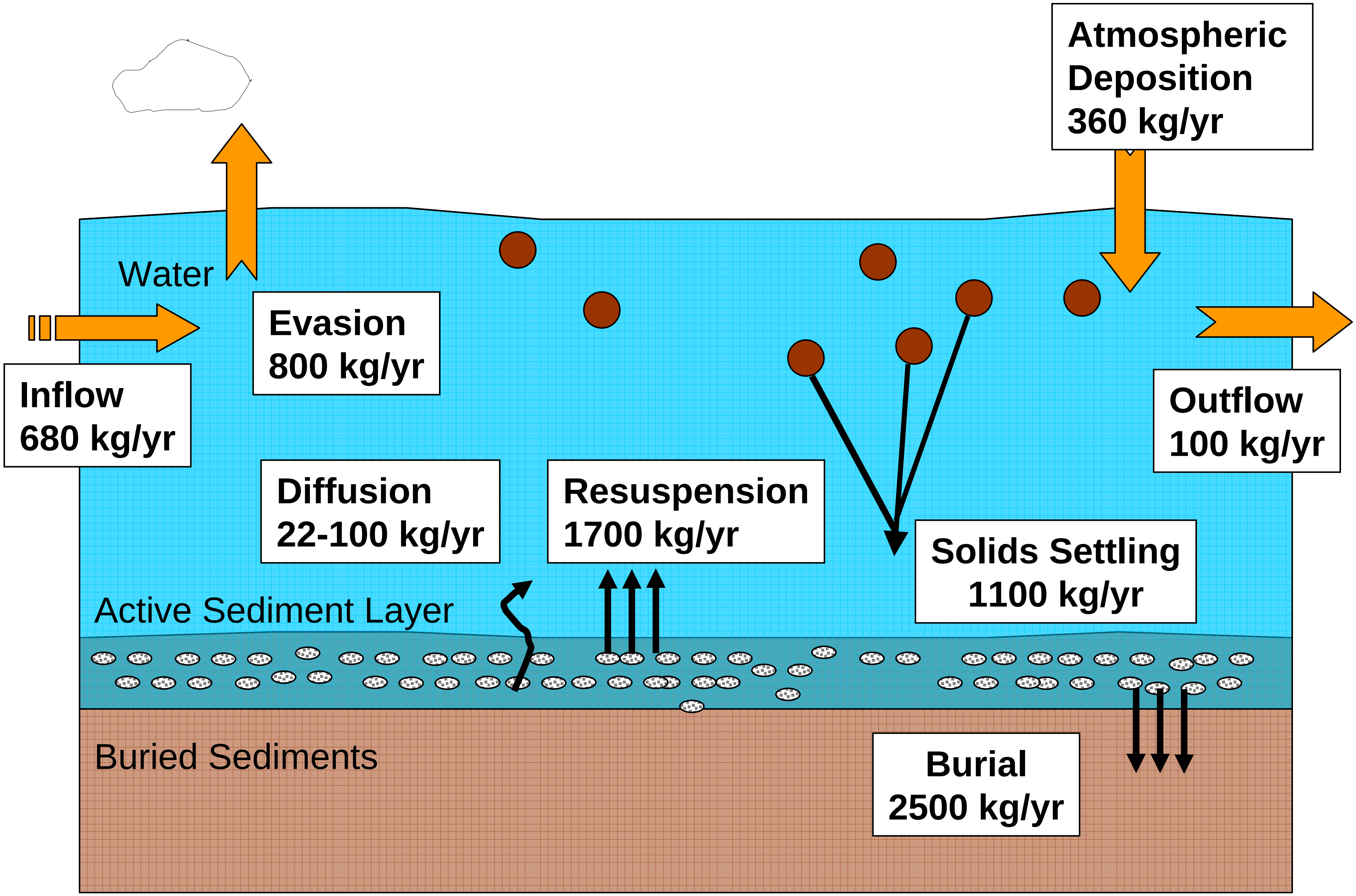
Total Mercury Fluxes Lake Ontario



slide courtesy of Elsie Sunderland, USEPA

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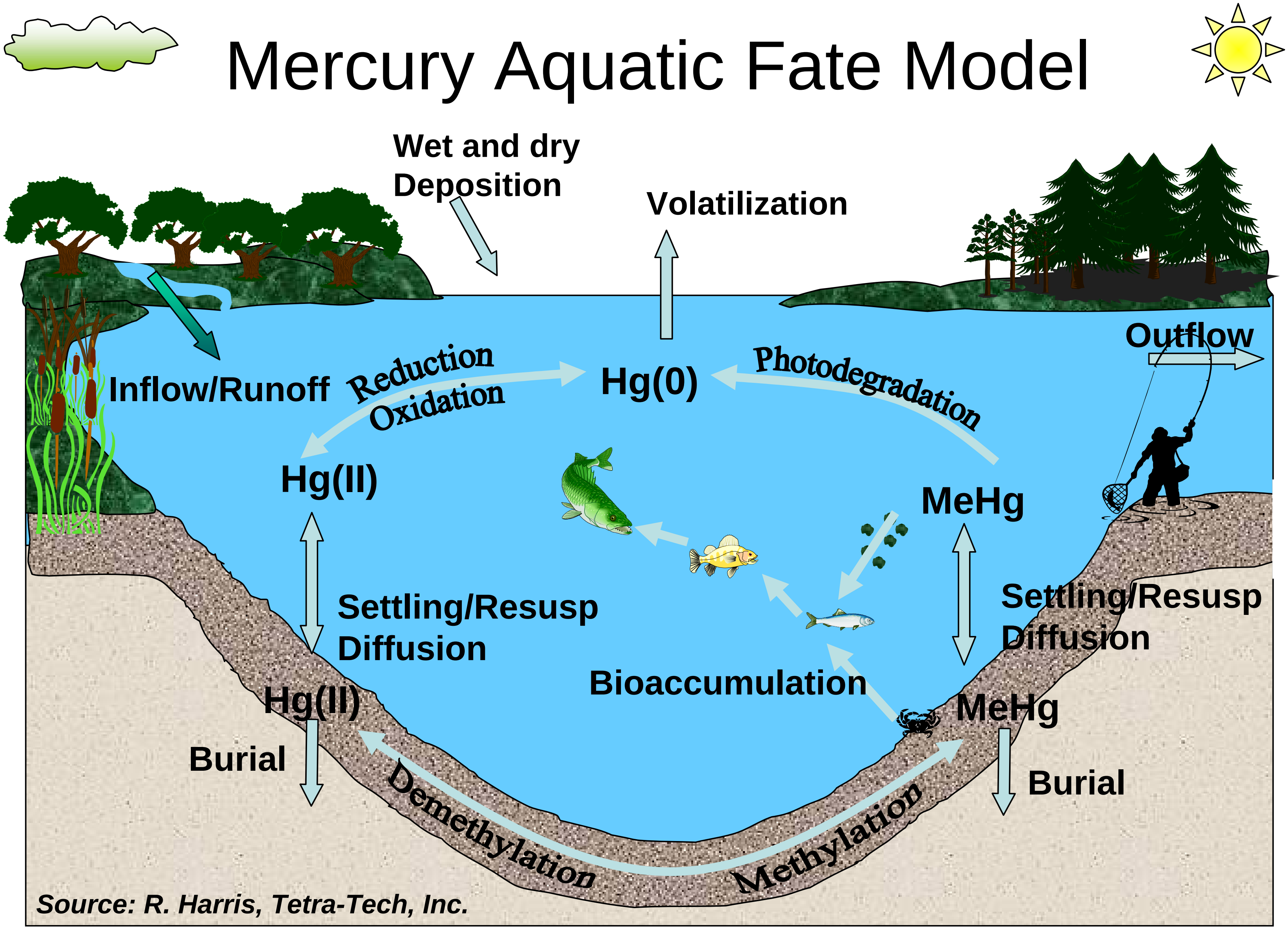
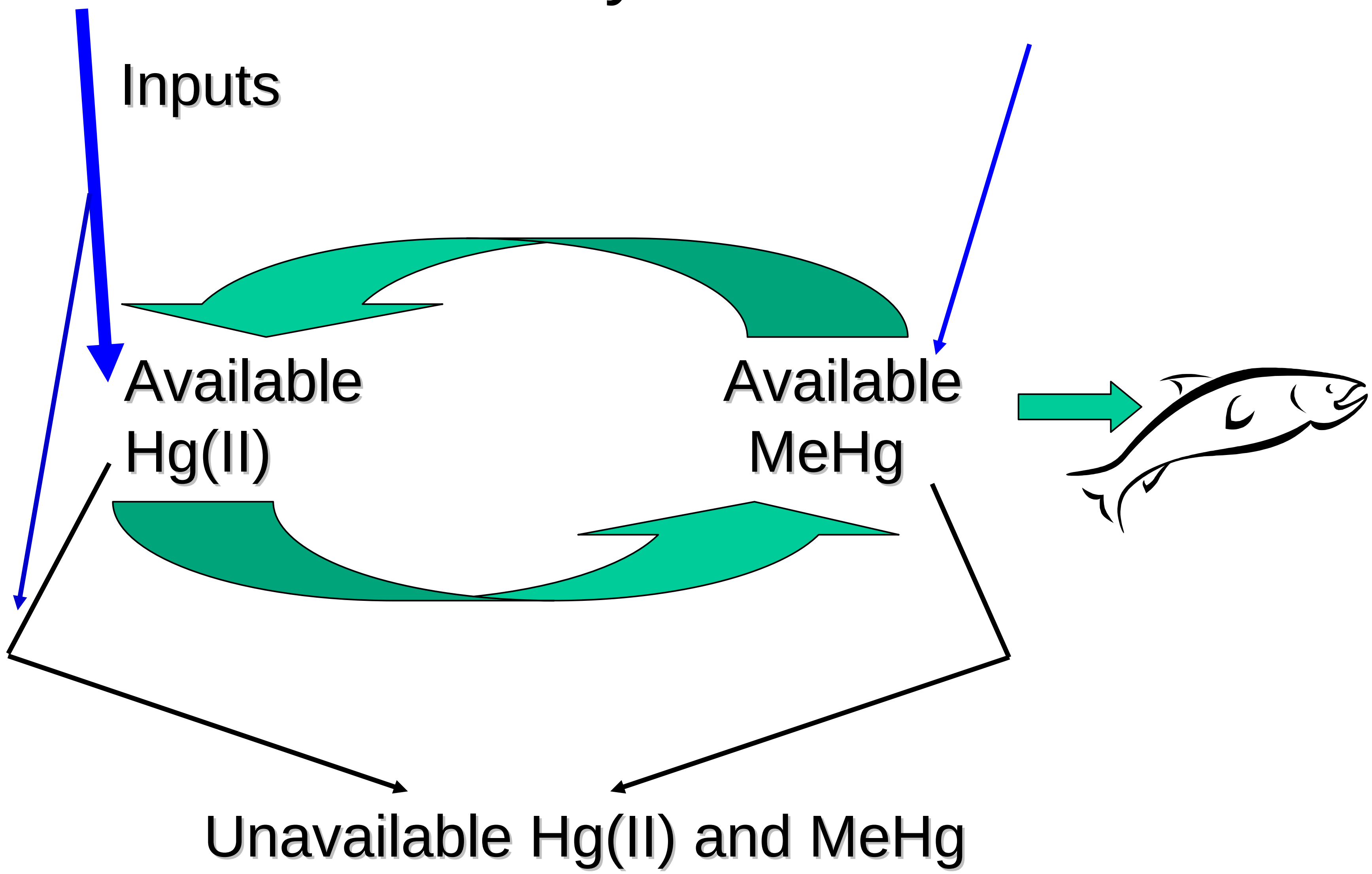
Mercury Aquatic Fate Model



slide courtesy of Elsie Sunderland, USEPA

Conceptualization:
How Mercury Reaches Fish



slide courtesy of Elsie Sunderland, USEPA

Summary:
Factors Affecting Methylation

- **Hg Bioavailability in Different Ecosystems**
  - Sulfide
  - Chemistry (dissolved organic carbon, pH)
  - Amount and types of solids in water and sediments

- **Microbial Activity Producing Methylmercury**
  - Temperature
  - Suitable environments (oxygen, resuspension)
  - Sulfate
  - Organic matter
  - Other biological processes that affect chemistry (sulfide oxidizers; iron reducers)

slide courtesy of Elsie Sunderland, USEPA

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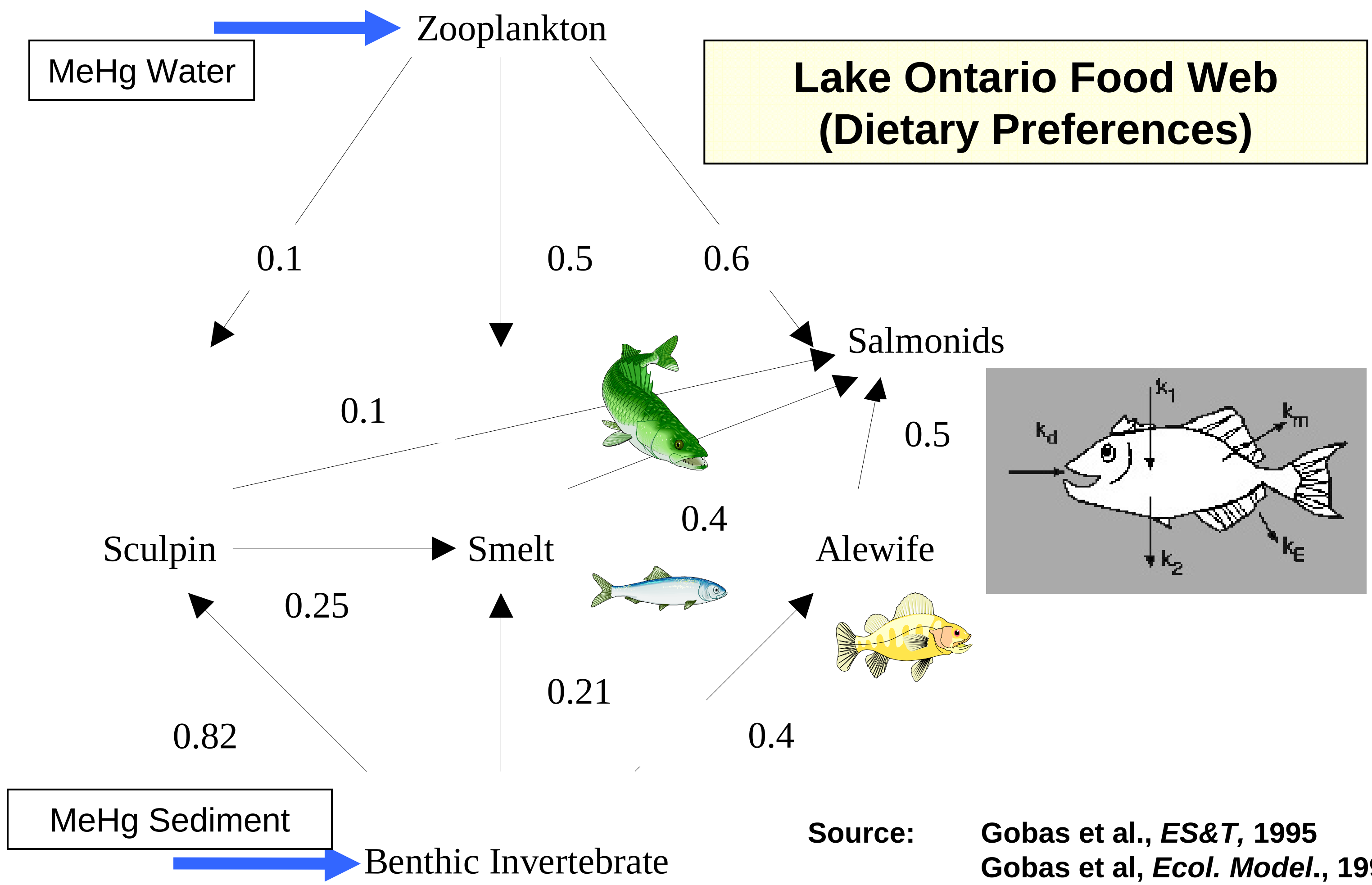
Bioaccumulation Model Framework



Source: Gobas et al., ***ES&T,*** 1995
Gobas et al, ***Ecol. Model.***, 1993

slide courtesy of Elsie Sunderland, USEPA

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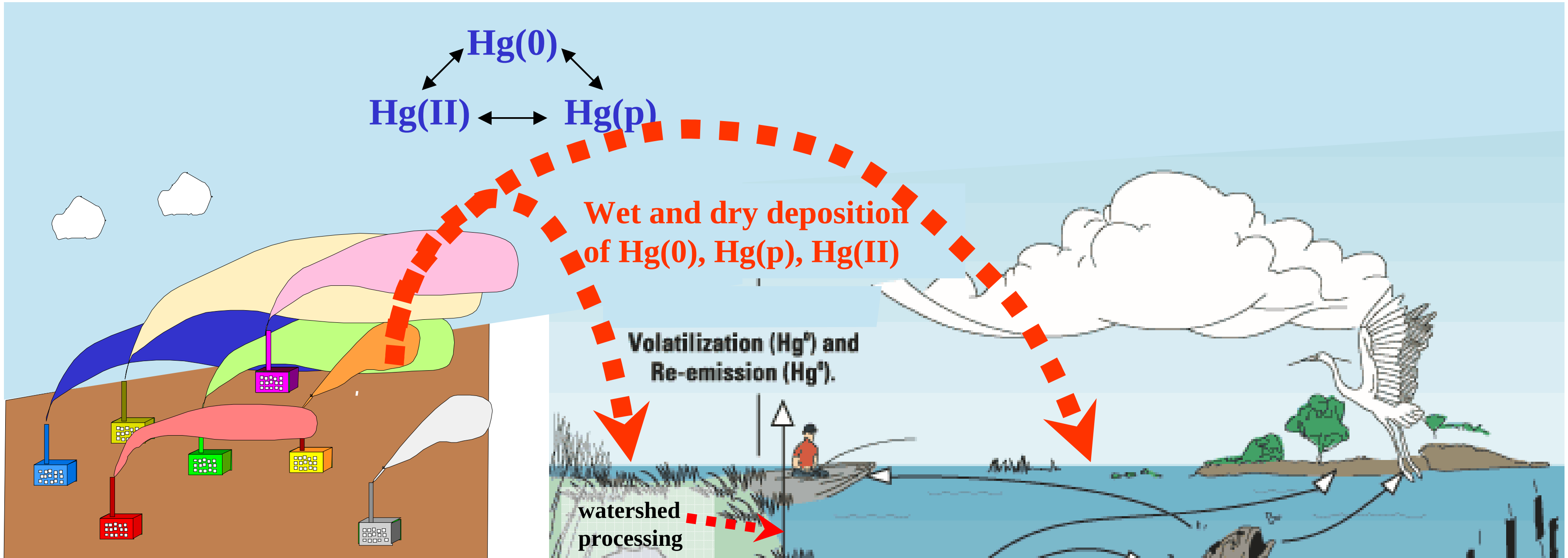
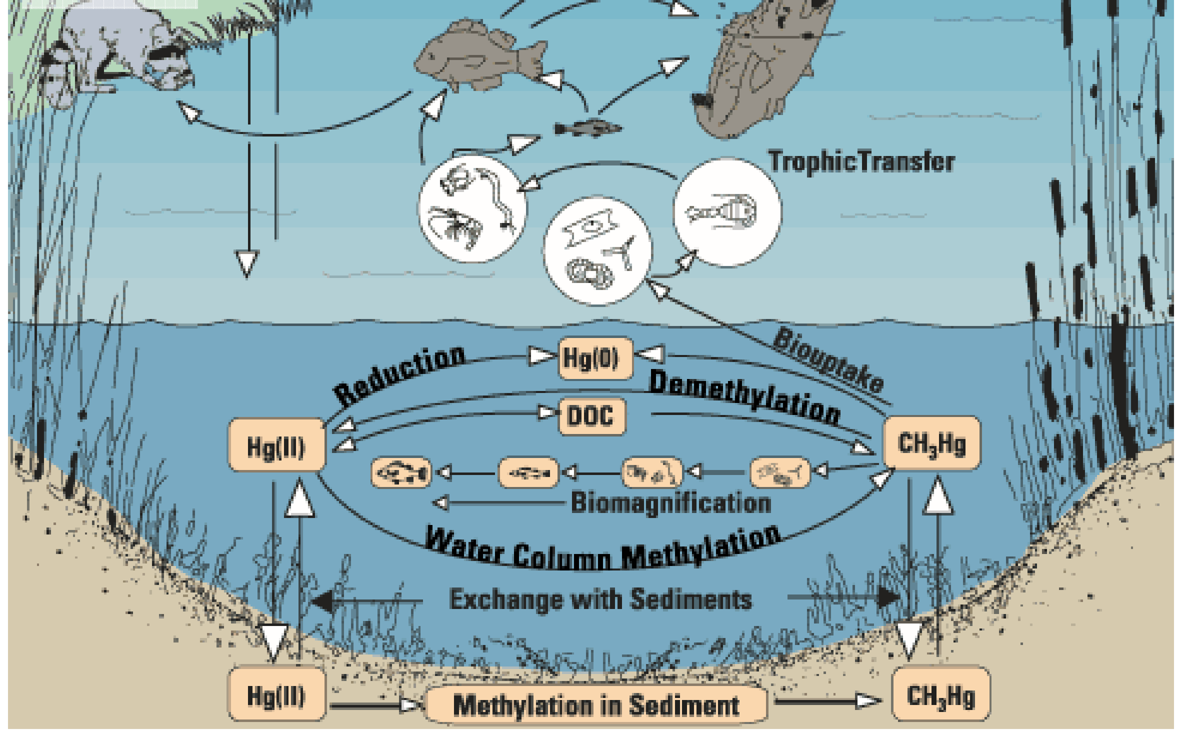
potential Air Resources Laboratory contributions to collaborative mercury work within NOAA:

- Further process-related monitoring and model development to increase understanding of atmospheric transport and deposition of mercury
- Monitoring and modeling used together to estimate the atmospheric deposition of different forms of mercury to a give waterbody or watershed
- Monitoring and modeling used together to estimate the relative contributions of different source regions and source types to the atmospheric deposition of mercury to a given waterbody or watershed
- Modeling to estimate past and possible future atmospheric loadings to a given waterbody or watershed.
- Monitoring and modeling to help understand and characterize re-emissions processes at the air-water interface and the air-watershed interface





We need to understand Hg in the environment enough to be able to fix the problem

Many scientific disciplines need to work in collaboration to achieve this understanding

NOAA appears uniquely qualified to tackle Hg problems; ARL would like to help

THANKS !

ADDITIONAL BACKGROUND SLIDES

Air Resources Laboratory

Hg **Headquarters Division -- HQ** (Silver Spring, MD)
development of improved transport and dispersion models;
making ARL products operational through direct interaction with NCEP.

Hg **Atmospheric Sciences Modeling Division – ASMD** (Research Triangle Park, NC)
development of improved air quality models, for both assessment and forecasting,
through direct interaction with the EPA and other federal partners.

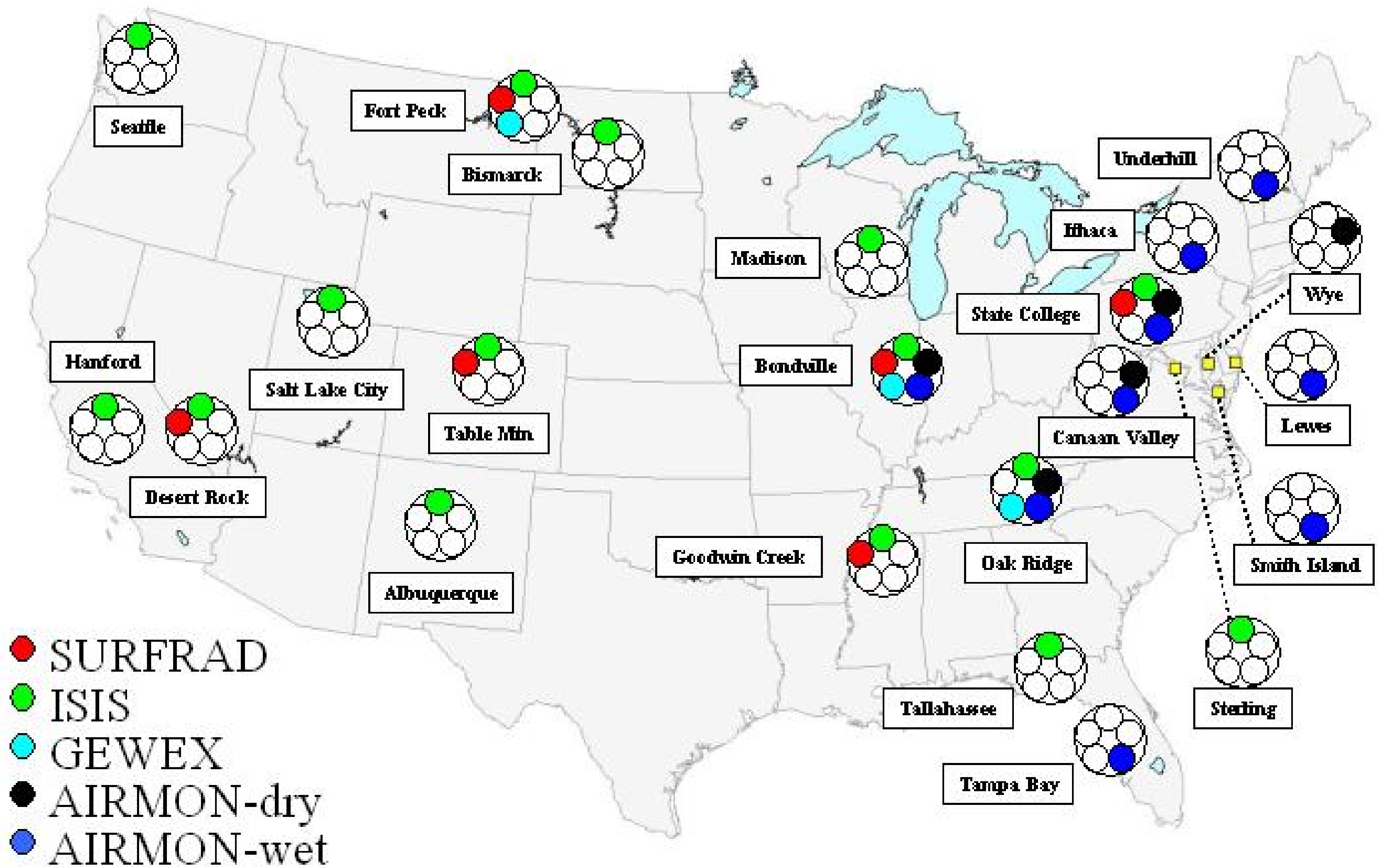
Hg **Atmospheric Turbulence and Diffusion Division – ATDD** (Oak Ridge, TN)
improving descriptions of atmospheric dispersion and deposition in models,
emphasizing complex situations, and on developing improved instrumentation.

Field Research Division – FRD (Idaho Falls, ID)
field atmospheric tracer testing facility, for developing transport and diffusion models;
FRD's mesonet and modeling expertise supports the Idaho National Laboratory.

Special Operations and Research Division – SORD (Las Vegas, NV)
models atmospheric transport, dispersion, and deposition over complex terrain;
studies the effects of airborne particles on atmospheric radiation and opacity;
and provides dispersion guidance to DOE managers of the Nevada Test Site.

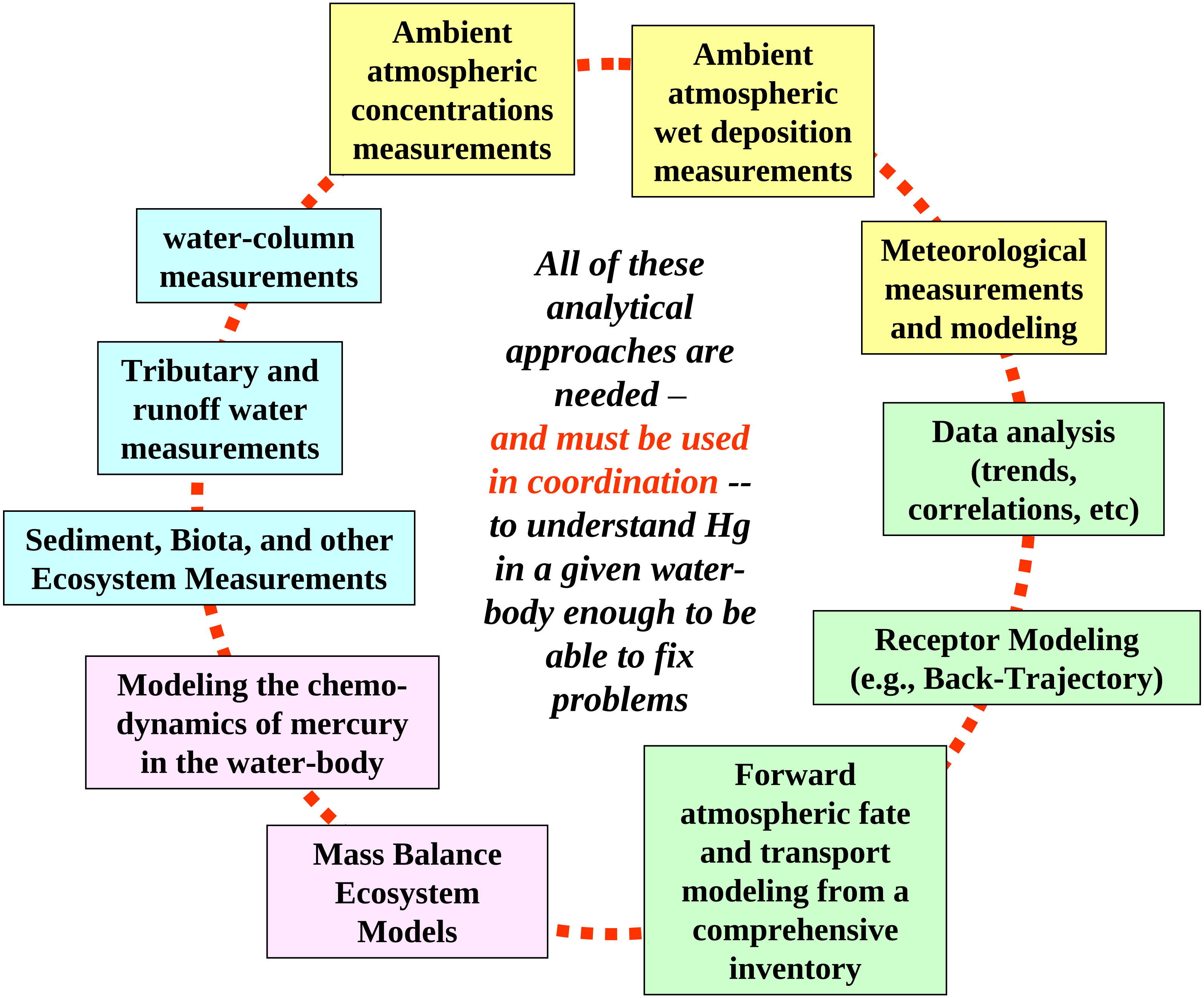
Surface Radiation Research Branch – SRRB (Boulder, CO)
provides basic data on radiation fields, for the next generation of atmospheric transport
and dispersion models, by climate assessments, and by evaluations of climate models.

NOAA Air Resources Laboratory Research and Monitoring Sites

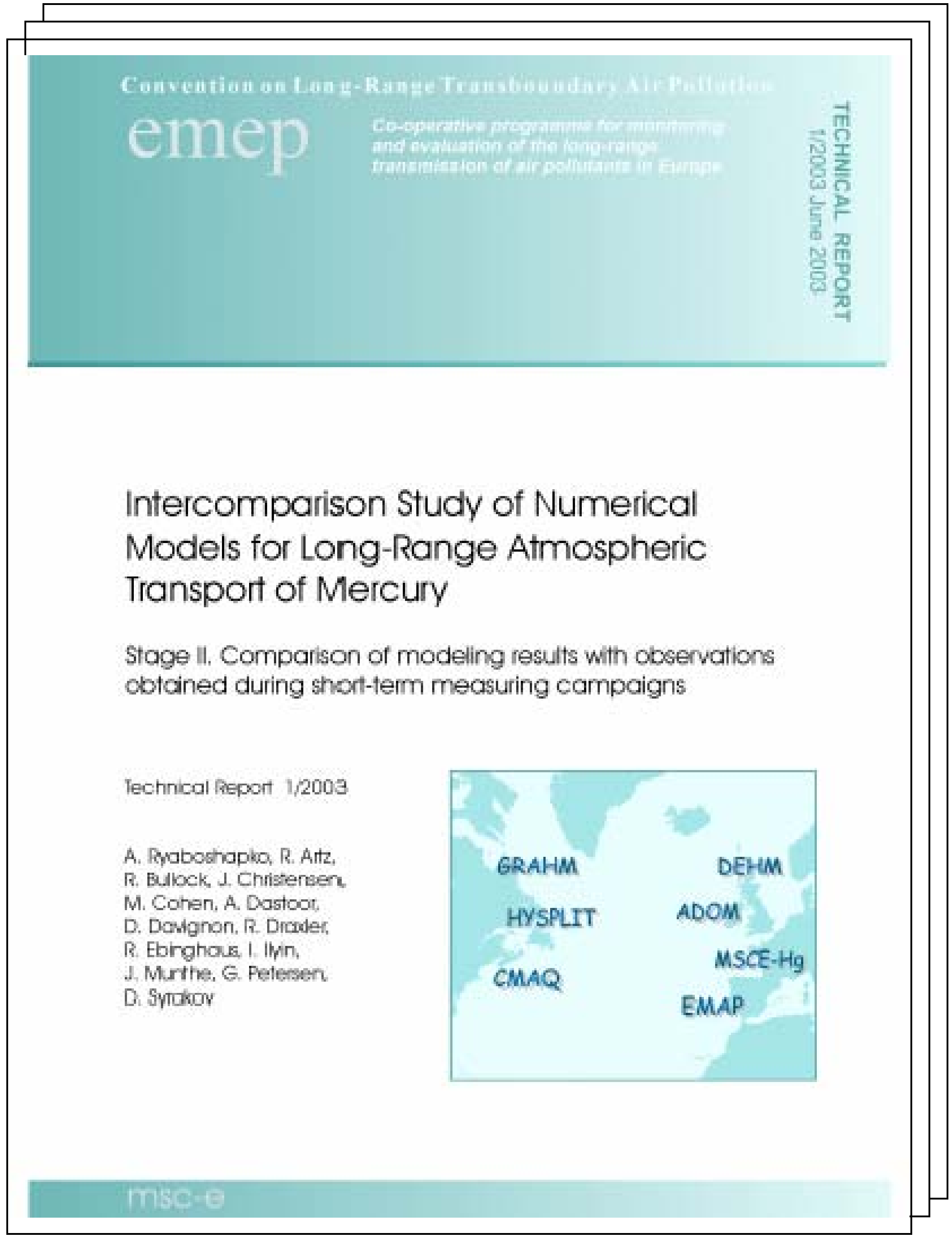


Aircraft Chemical Instrumentation (in addition to mercury)

Species	Method	LOD (ppbv)	response
O_3	UV Absorption	2	10 s
CO	NDIR/GFC	30	15 s
SO_2	Pulsed Fluorescence	0.4	15 s
NO	Ozone CL	0.02	1 s
NO_2	Photolysis/CL	0.06	2 s
NO_Y	Molybdenum/CL	0.06	1 s
CN	Optical Counts	< 100 cm^{-3}	0.2 s
HNO_3	Converter Difference	0.25	5 s
Major Ions	Filter Pack	N/A	N/A
Aerosol size	Optical Counts	0.3 to 10 um	1s
CH_2O	Liquid Phase Fluorescence	0.1	90 s
H_2O_2	Liquid Phase Fluorescence	0.02	90 s
PAN	Fast GC/Luminol	0.01	30 s
NMHCs	Grab Samples/GCFID	varies	30 s


Ambient atmospheric concentrations measurements
Ambient atmospheric wet deposition measurements
Meteorological measurements and modeling
Data analysis (trends, correlations, etc)
Receptor Modeling (e.g., Back-Trajectory)
Forward atmospheric fate and transport modeling from a comprehensive inventory
Mass Balance Ecosystem Models
Modeling the chemo-dynamics of mercury in the water-body
Sediment, Biota, and other Ecosystem Measurements
Tributary and runoff water measurements
water-column measurements
All of these analytical approaches are needed – and must be used in coordination -- to understand Hg in a given water-body enough to be able to fix problems

Nevertheless, many models seem to be performing reasonably well, i.e., are able to explain a lot of what we see


Convention on Long-Range Transboundary Air Pollution

emep

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

TECHNICAL REPORT
1/2003 June 2003

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

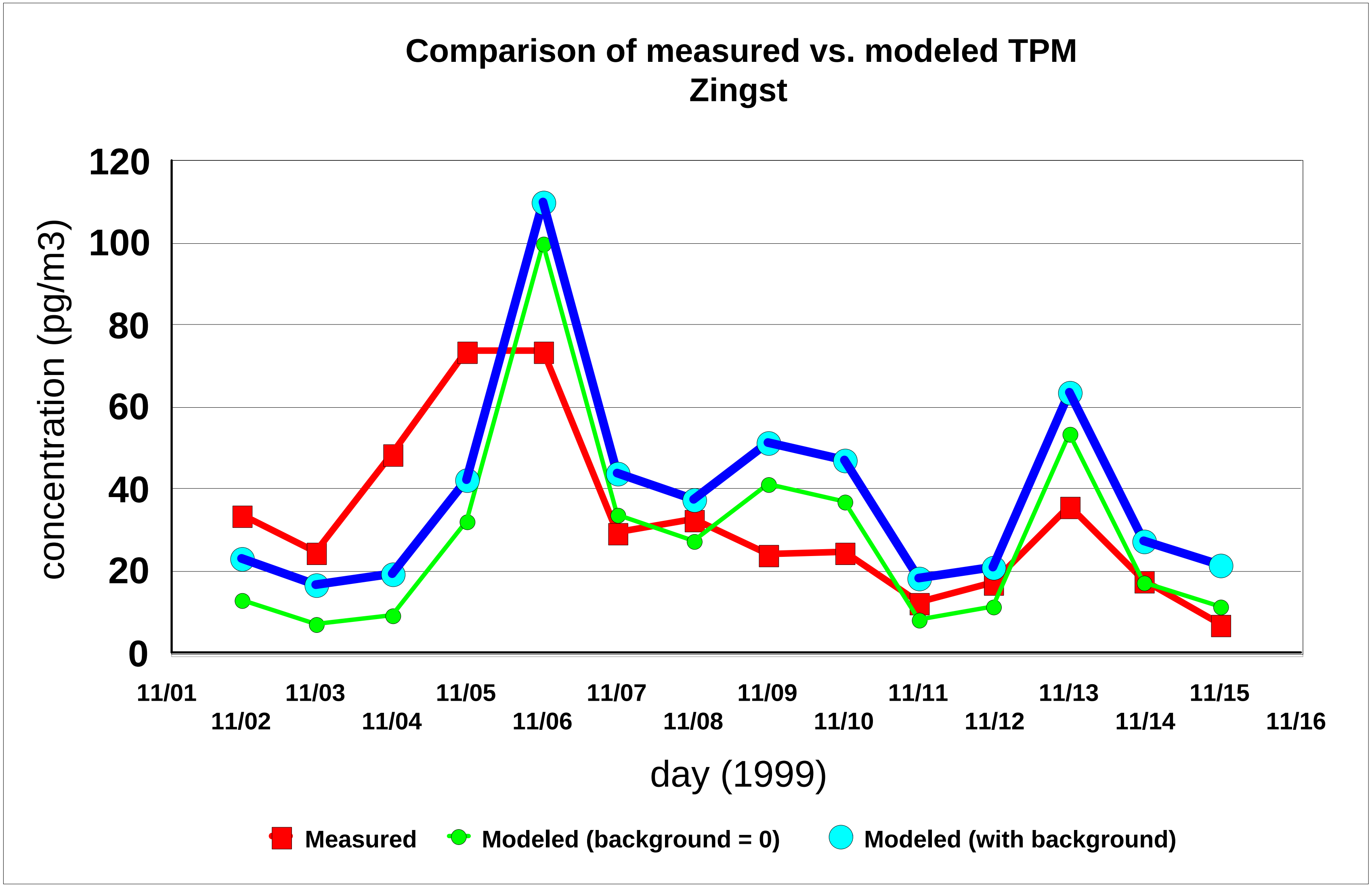
Stage II. Comparison of modeling results with observations obtained during short-term measuring campaigns

Technical Report 1/2003

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

GRAHM
DEHM
HYSPLIT
ADOM
MSCE-Hg
CMAQ
EMAP

msc-e



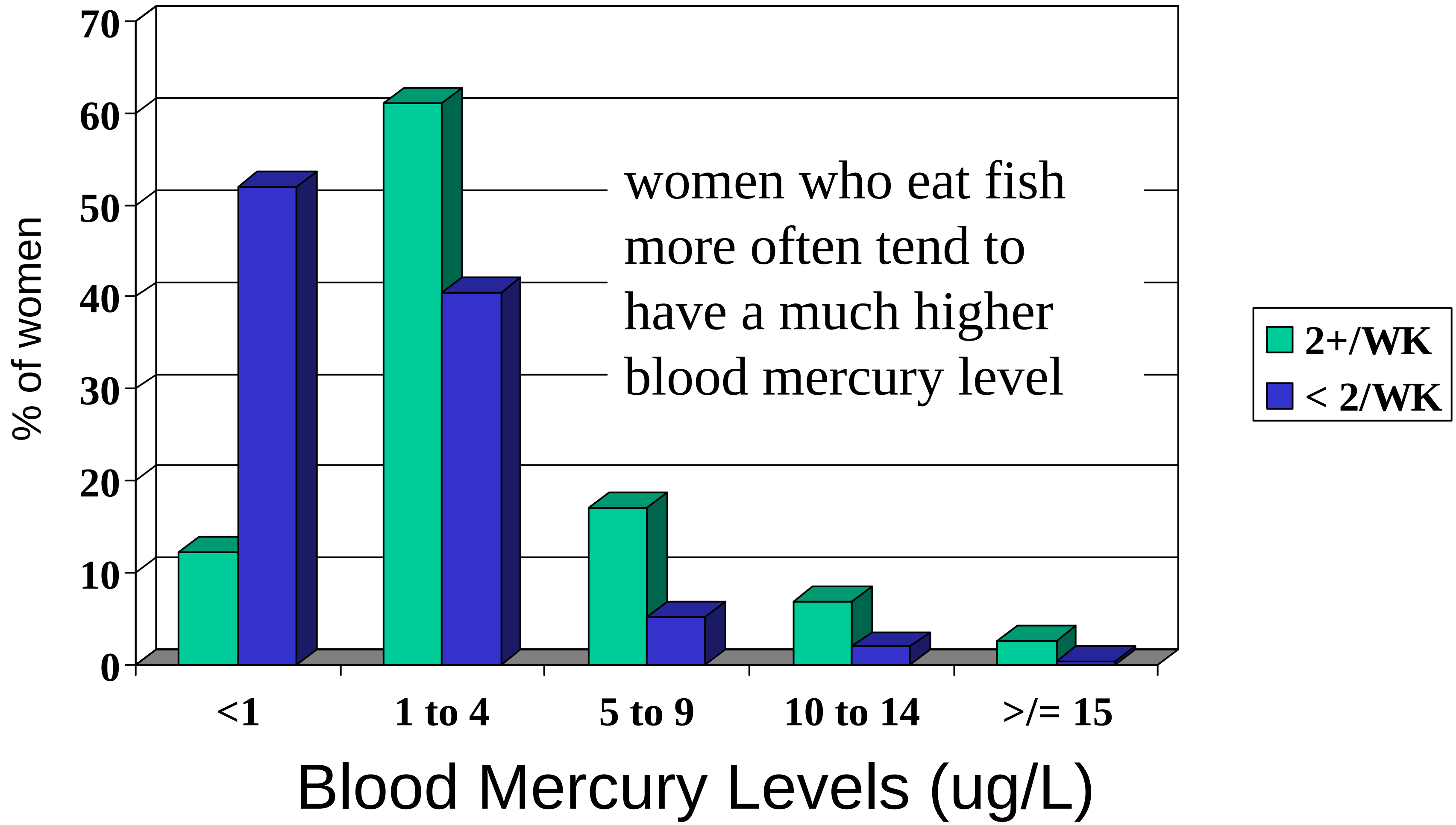
Comparison of measured vs. modeled TPM
Zingst
concentration (pg/m3)
120
100
80
60
40
20
0
11/01
11/02
11/03
11/04
11/05
11/06
11/07
11/08
11/09
11/10
11/11
11/12
11/13
11/14
11/15
11/16
day (1999)
Measured
Modeled (background = 0)
Modeled (with background)

<u>Estimated Number of Newborns with *In Utero* Methylmercury Exposures >/= RfD</u>

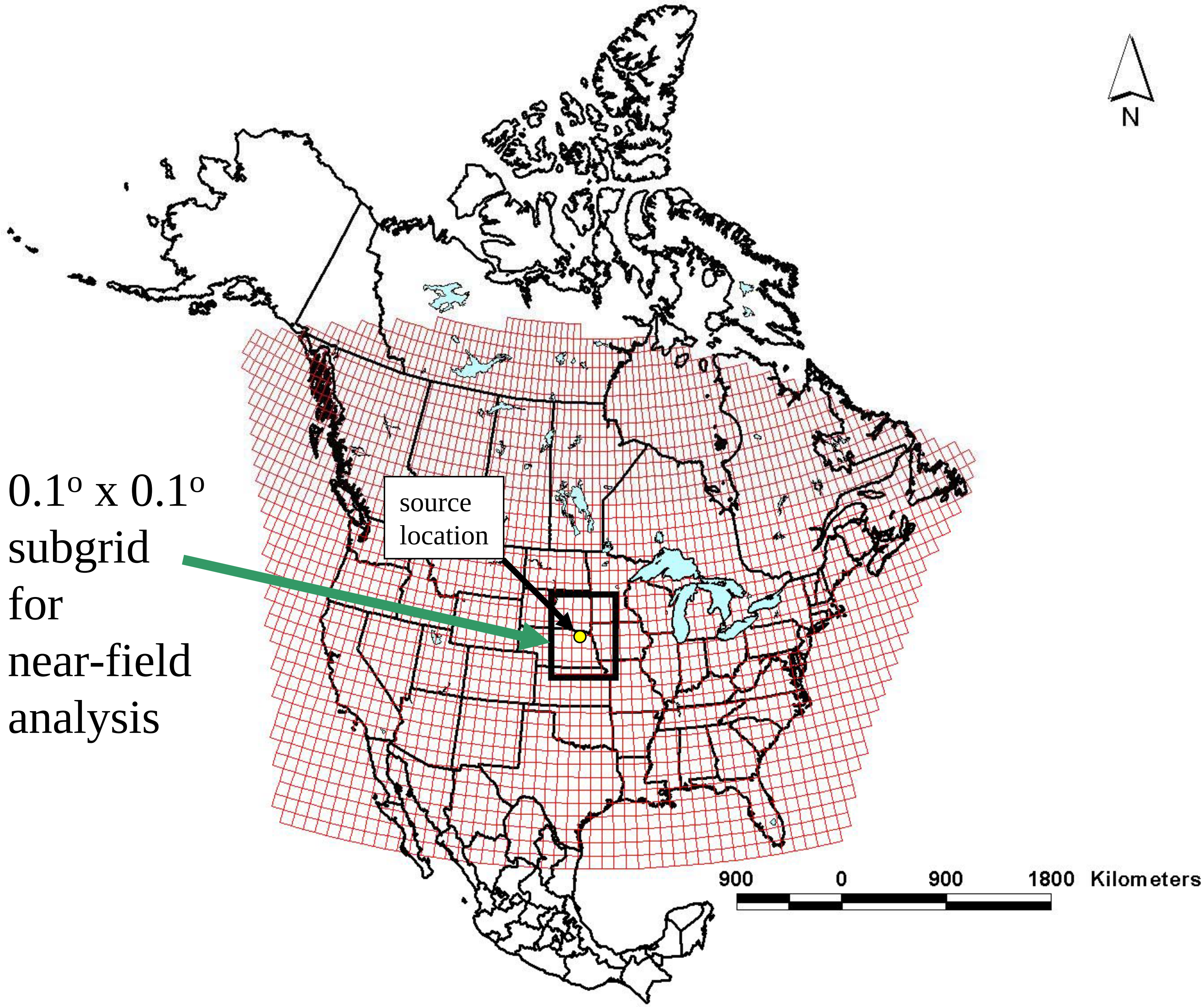
- Number of US births in 2000: 4,058,814 (*National Vital Statistics Reports*).
- 1 : 1 ratio of cord to maternal blood [Hg], i.e., 5.8 cord to 5.8 maternal, 7.8% of women had total blood [Hg] >/= 5.8, ~ 300,000 newborns each year > 5.8 ug/L (Mahaffey et al., 2003).
- 1.7 : 1 ratio of cord to maternal blood [Hg], i.e. 5.8 cord to ~ 3.5 maternal, 15.7% of women had total blood [Hg] >/= 3.5 ug/L, ~ 630,000 newborns each years >/= 5.8 ug/L cord blood.

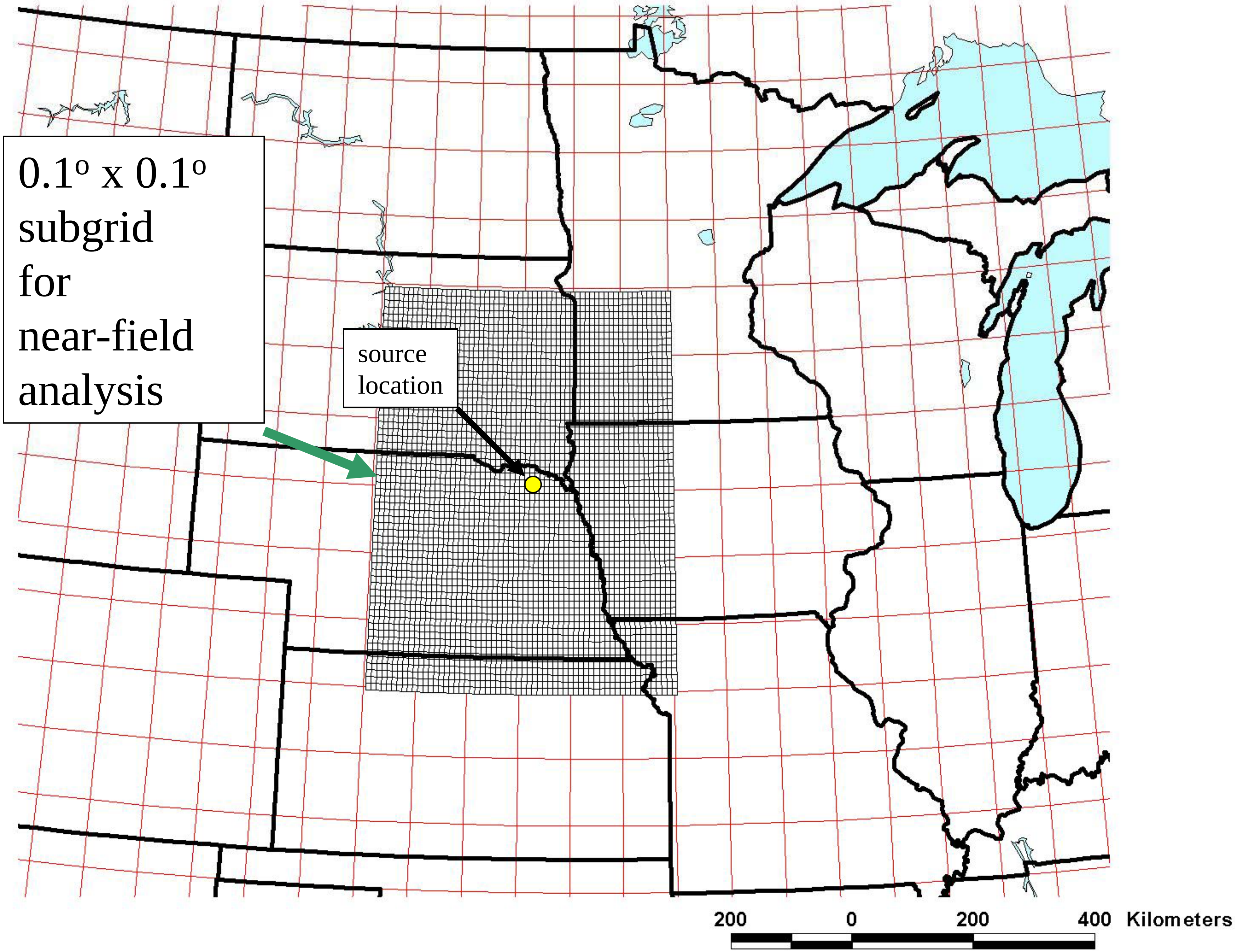
source: Kate Mahaffey, USEPA

Total Mercury Levels in Women, Aged 16-49
by Weekly Fish Consumption Levels

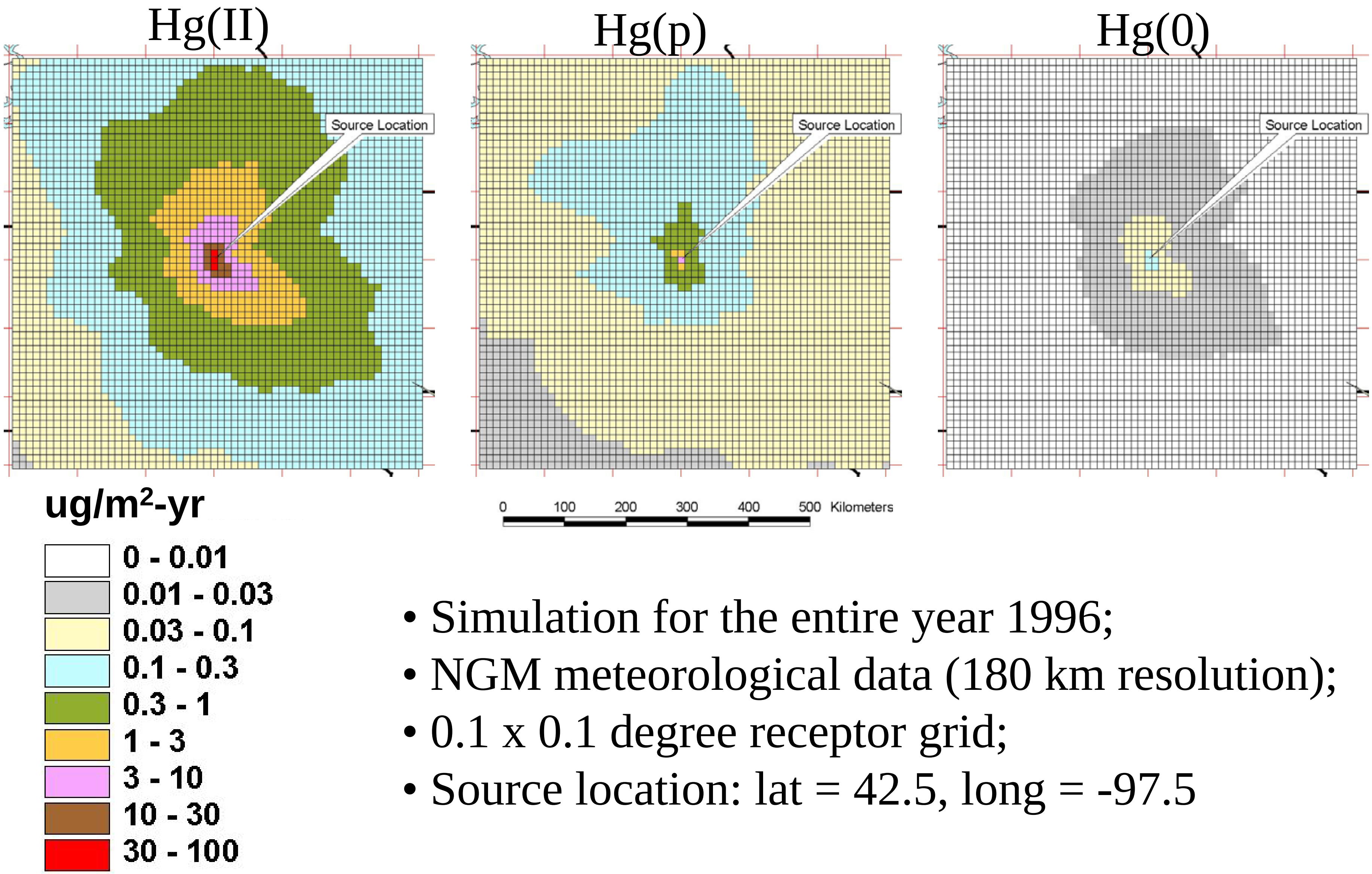


source: Kate Mahaffey, USEPA

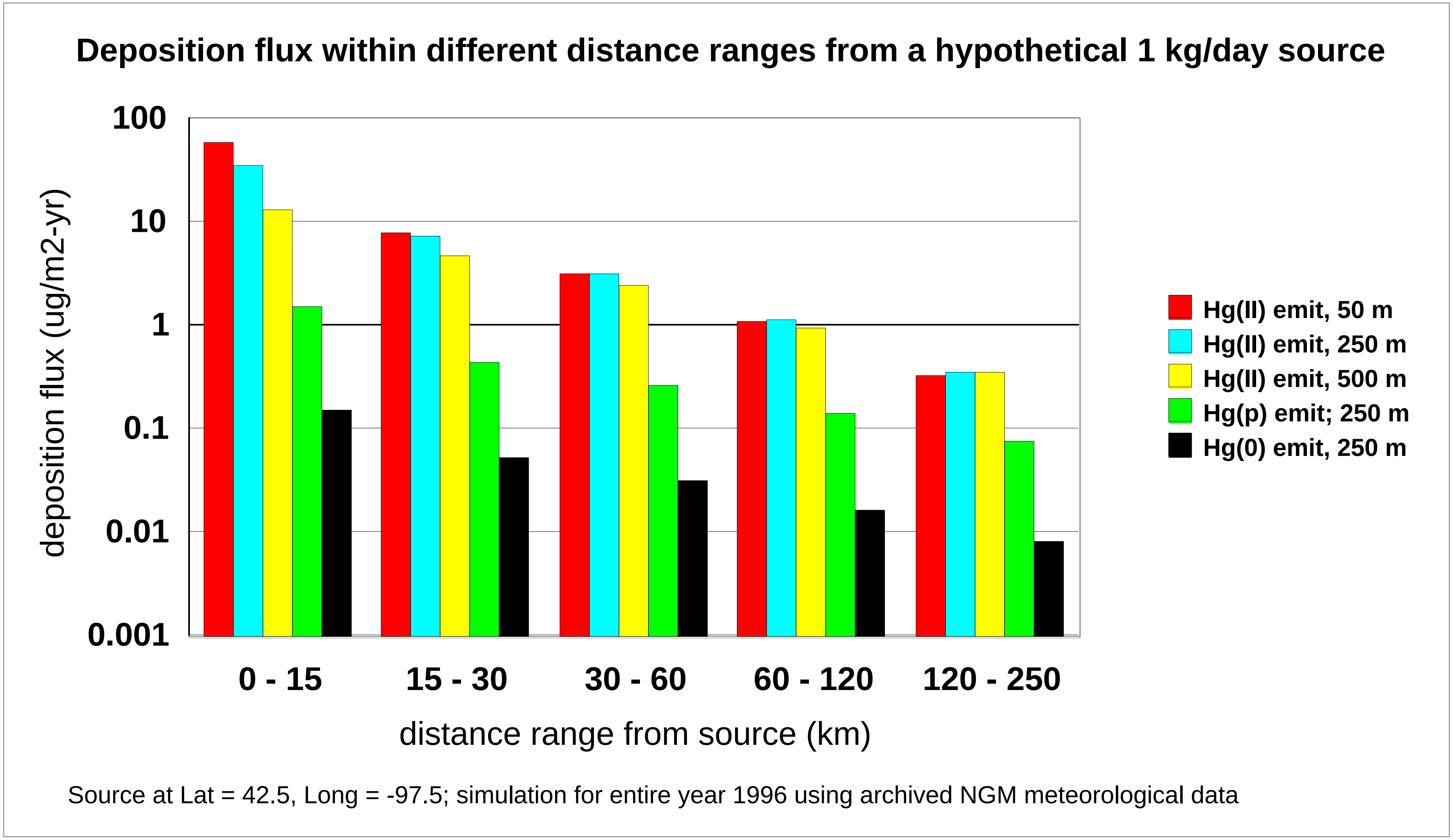

0.1° x 0.1° subgrid for near-field analysis
source location
N
900 0 900 1800 Kilometers


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

Annual deposition flux arising from a hypothetical 1 kg/day 250 meter high source of different forms of mercury



- Simulation for the entire year 1996;
- NGM meteorological data (180 km resolution);
- 0.1 x 0.1 degree receptor grid;
- Source location: lat = 42.5, long = -97.5



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
Hg(p) emit; 250 m
Hg(0) emit, 250 m
Source at Lat = 42.5, Long = -97.5; simulation for entire year 1996 using archived NGM meteorological data

Methodological Approaches for Analysis of the Atmospheric Deposition Pathway

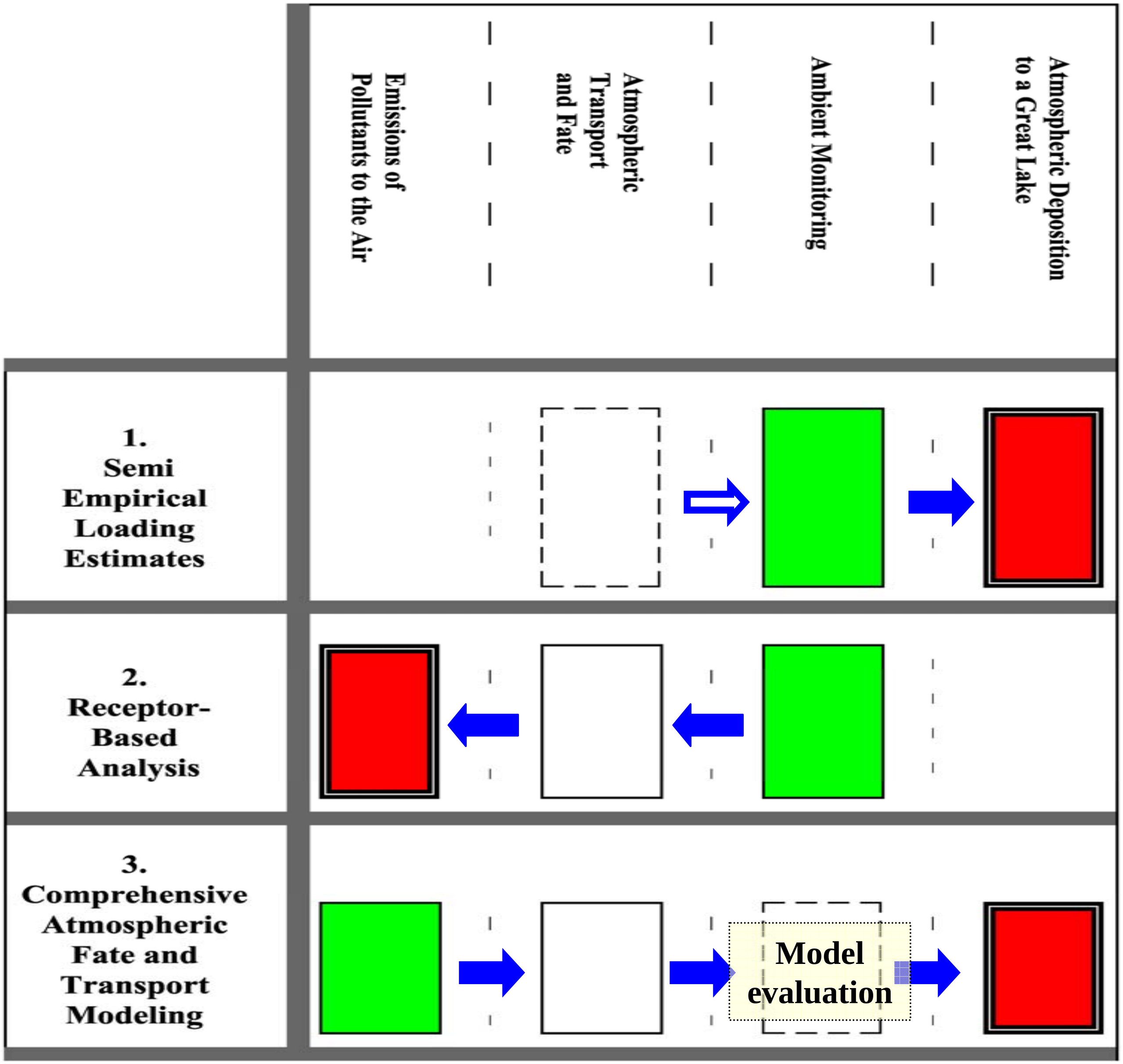
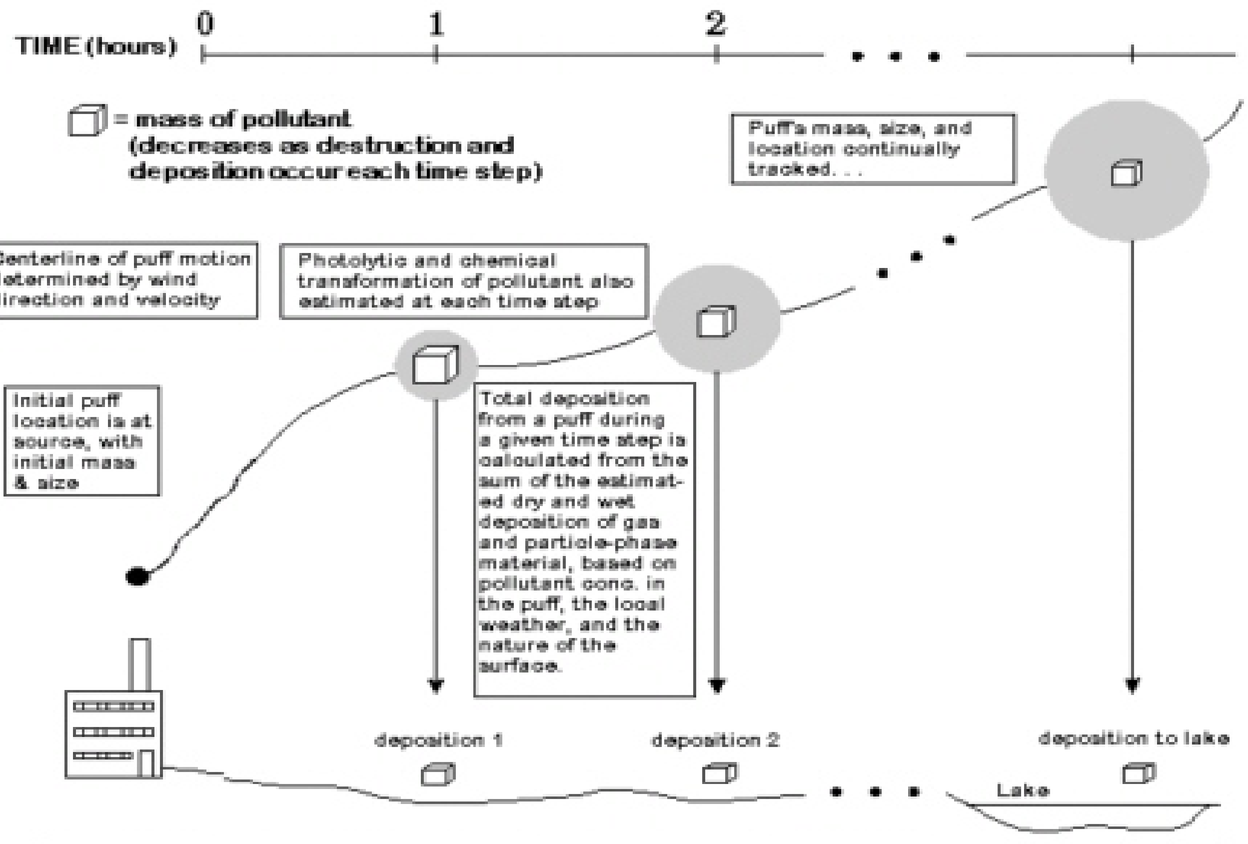


Figure 1. Lagrangian Puff Air Transport and Deposition Model



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