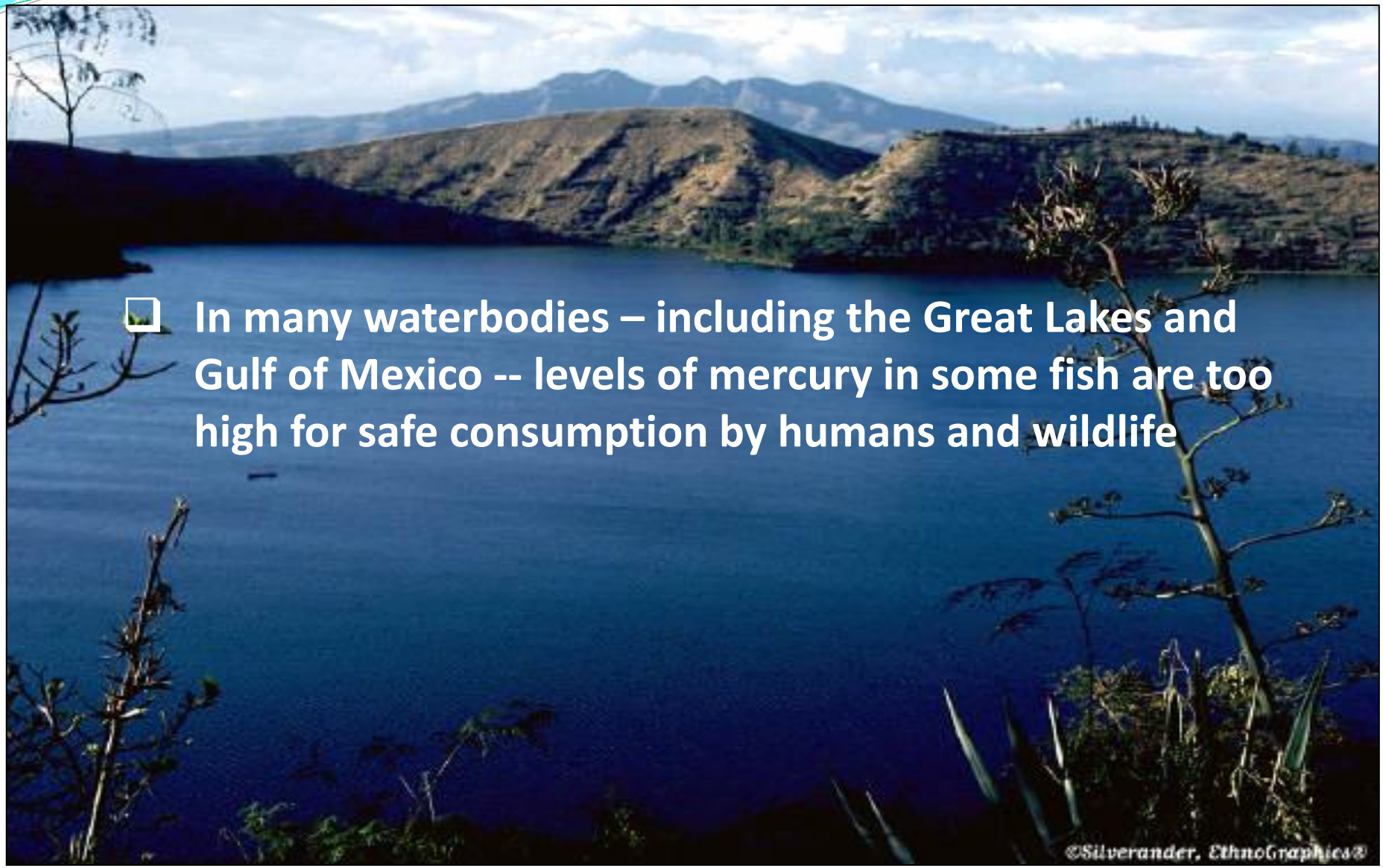
Atmospheric Mercury Modeling 101

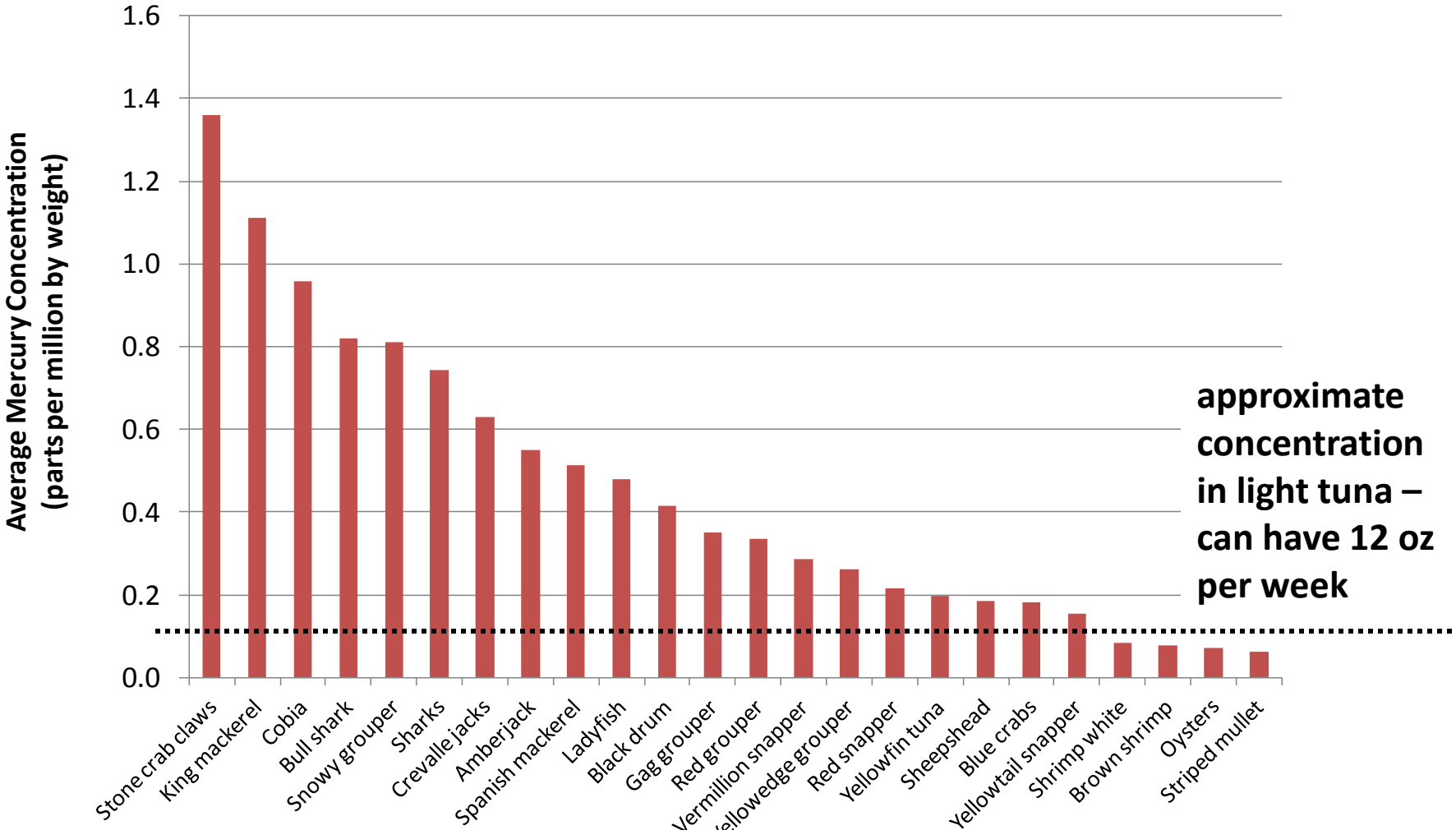
Mark Cohen
Air Resources Laboratory

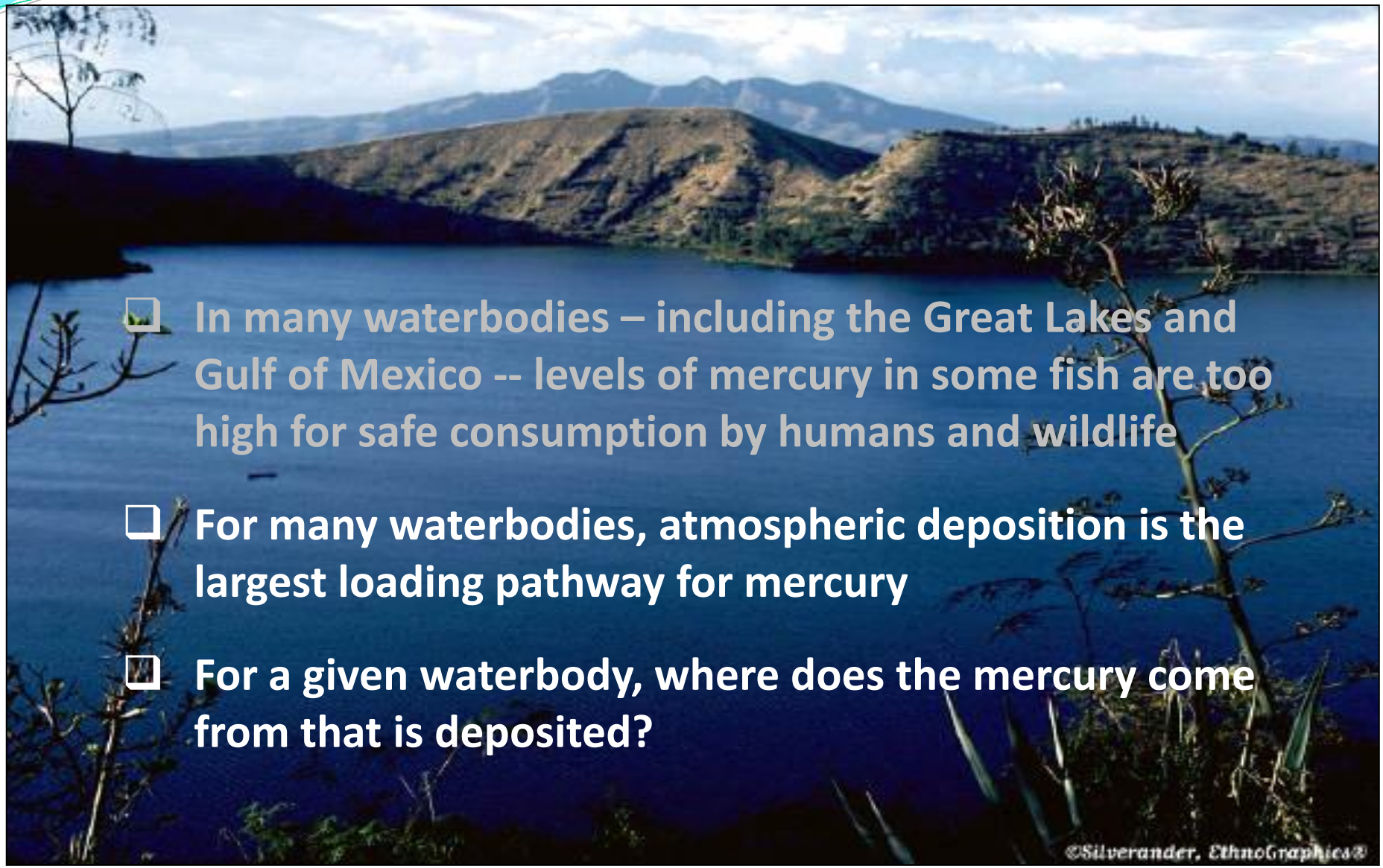
ARL 101
June 19, 2012



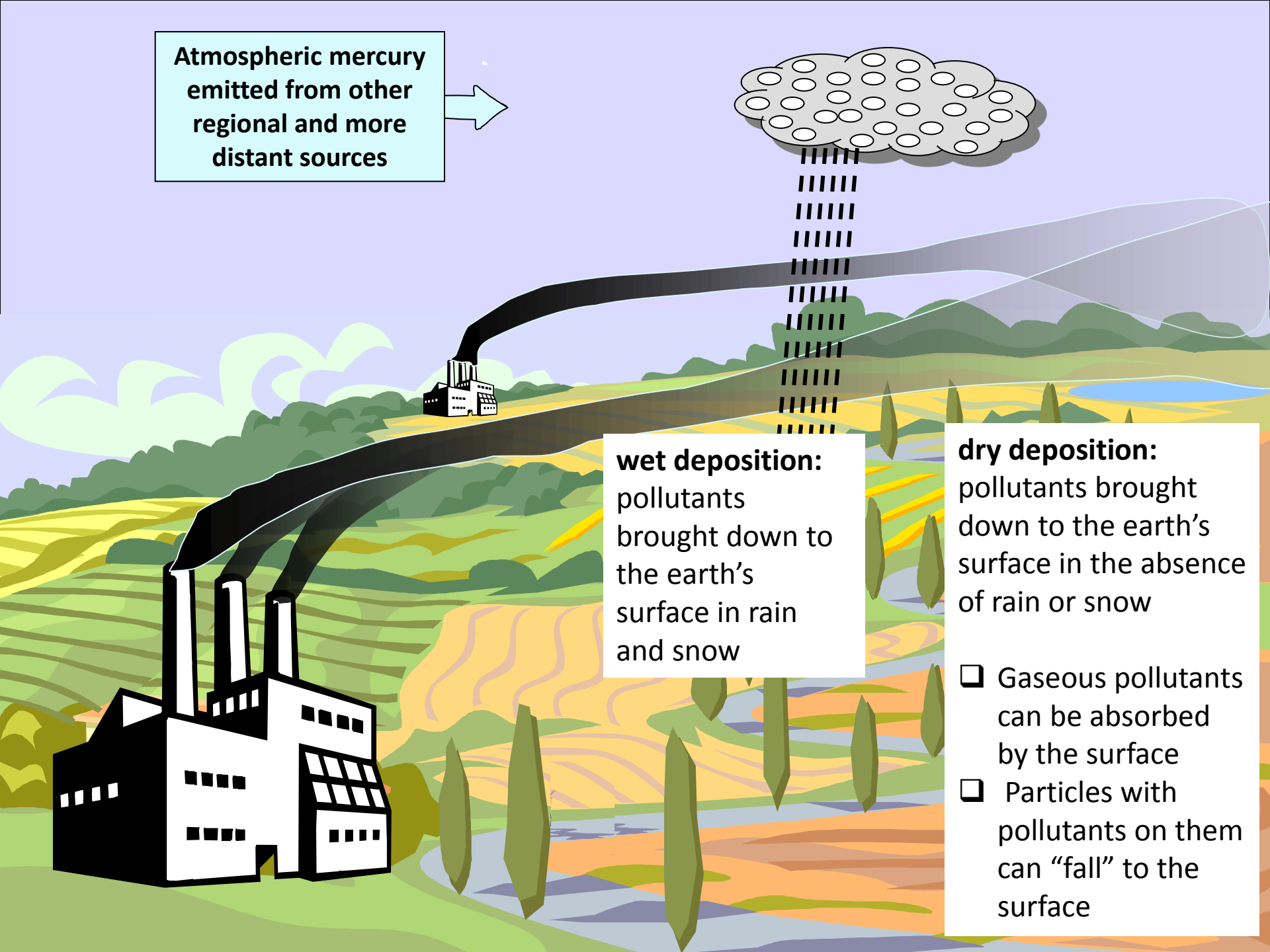
- In many waterbodies – including the Great Lakes and Gulf of Mexico -- levels of mercury in some fish are too high for safe consumption by humans and wildlife

Mercury Concentrations in Gulf of Mexico Seafood Species



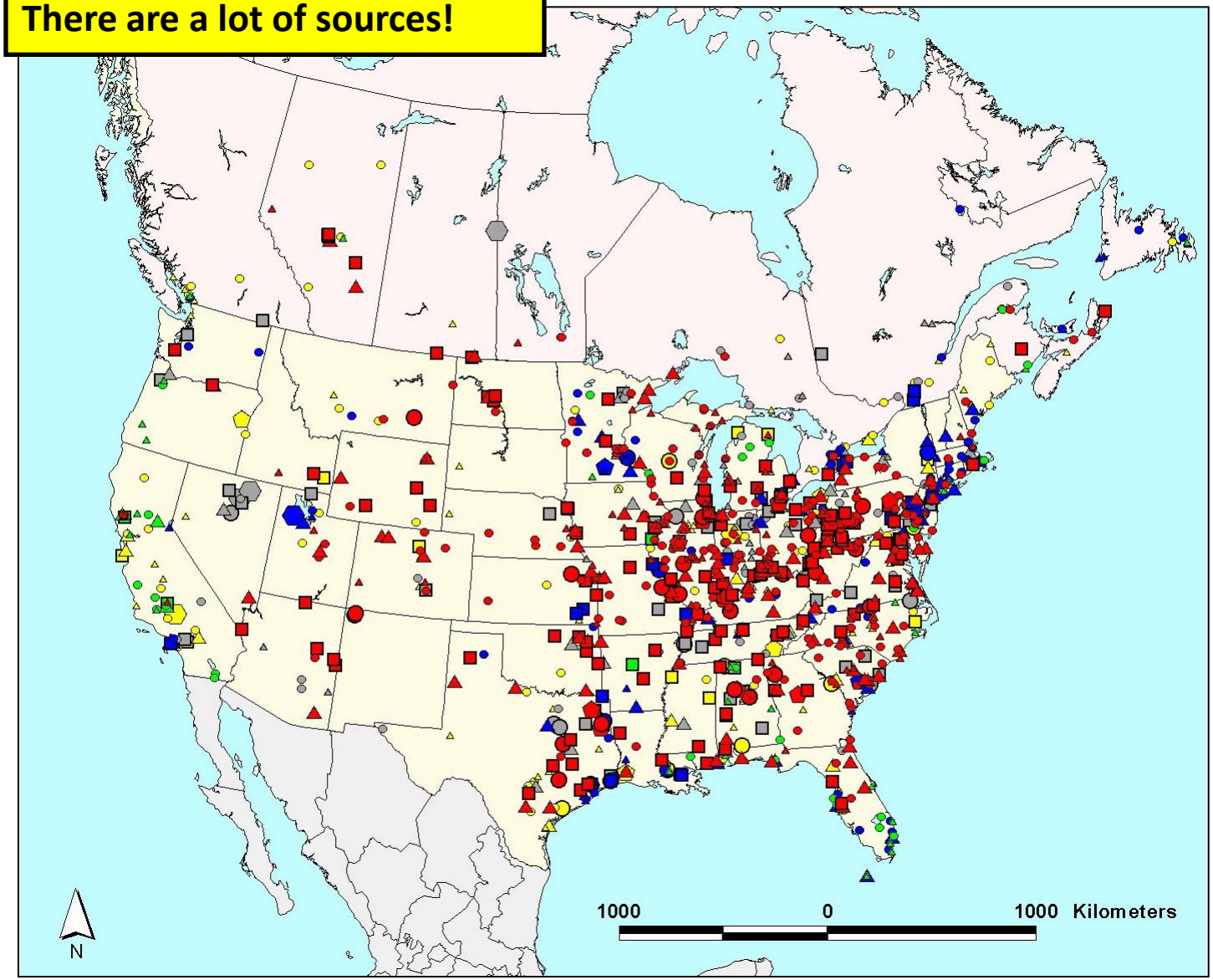


- In many waterbodies – including the Great Lakes and Gulf of Mexico -- levels of mercury in some fish are too high for safe consumption by humans and wildlife
- For many waterbodies, atmospheric deposition is the largest loading pathway for mercury
- For a given waterbody, where does the mercury come from that is deposited?


Atmospheric mercury emitted from other regional and more distant sources
wet deposition: pollutants brought down to the earth's surface in rain and snow
dry deposition: pollutants brought down to the earth's surface in the absence of rain or snow
Gaseous pollutants can be absorbed by the surface
Particles with pollutants on them can "fall" to the surface

2002 U.S. and Canadian Emissions of Total Mercury [Hg(0) + Hg(p) + RGM]

There are a lot of sources!



Large Point Sources of Mercury Emissions Based on the 2002 EPA NEI and 2002 Envr Canada NPRI*

size/shape of symbol denotes amount of mercury emitted (kg/yr)

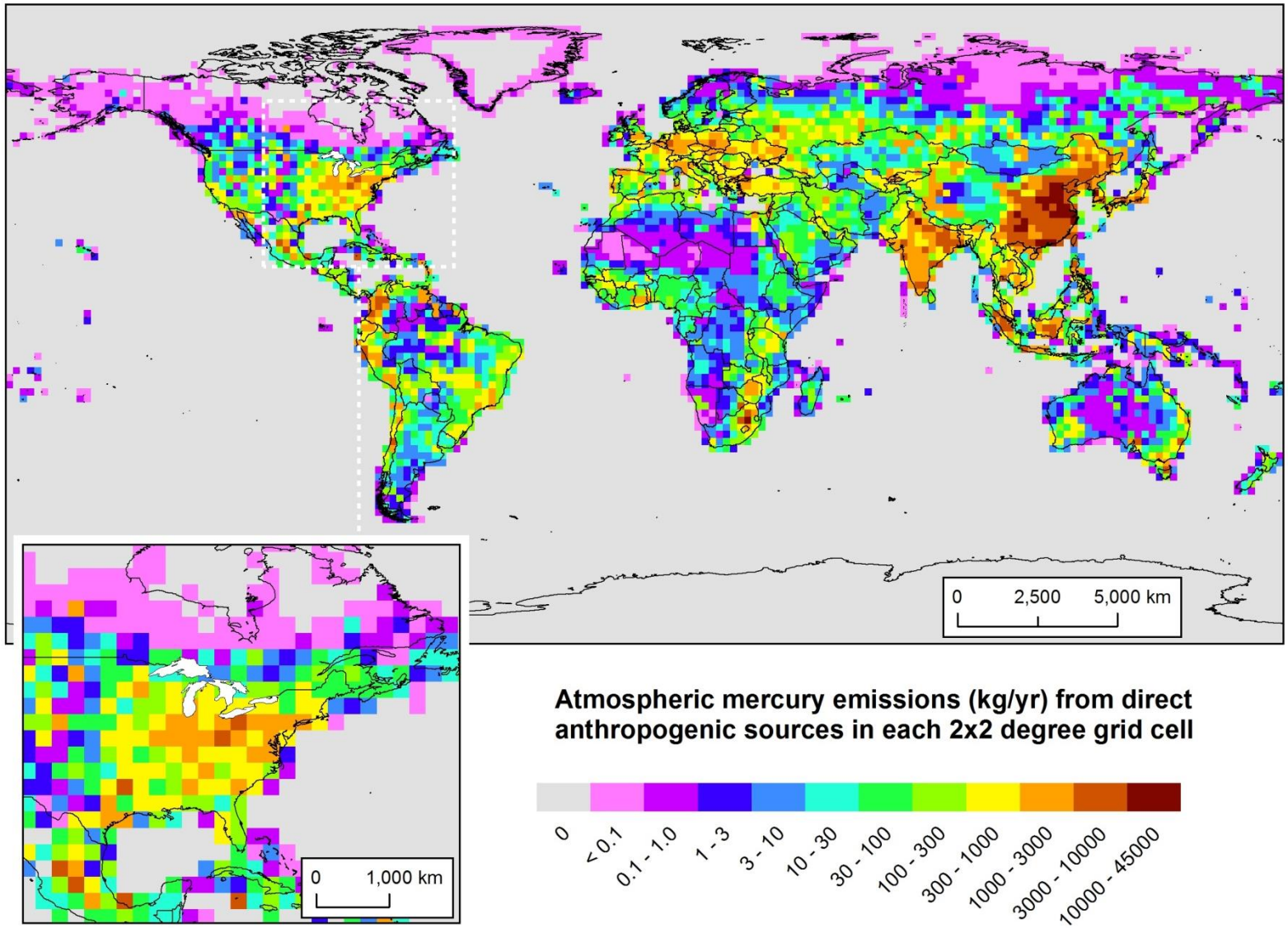
△	5 – 10
○	10 – 50
△	50 – 100
□	100 – 300
○	300 – 500
⬠	500 – 1000
⬡	1000 – 3000

color of symbol denotes type of mercury source

- coal-fired power plants
- other fuel combustion
- waste incineration
- metallurgical
- manufacturing & other

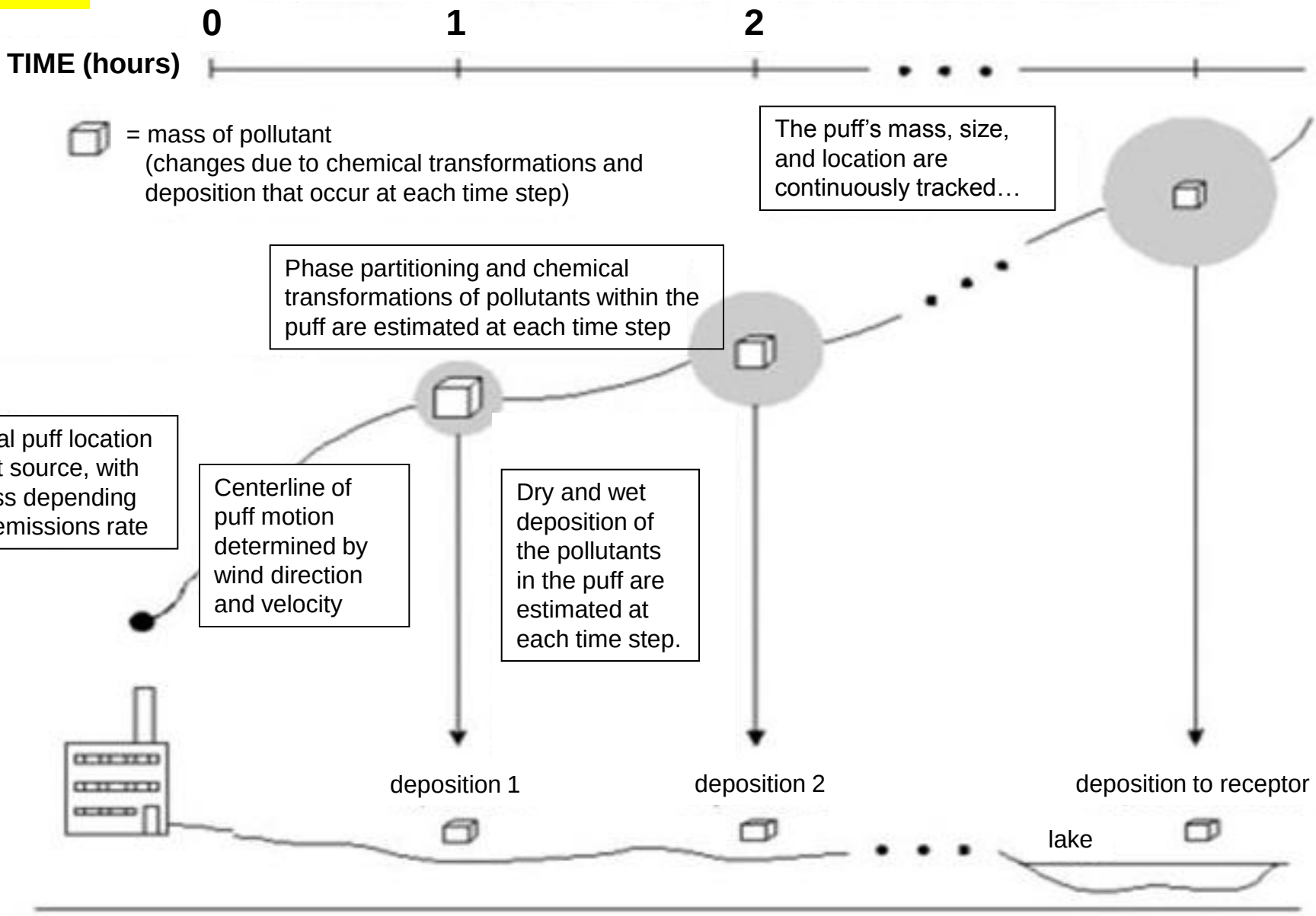
** Note – some large Canadian point sources may not be included due to secrecy agreements between industry and the Canadian government.*

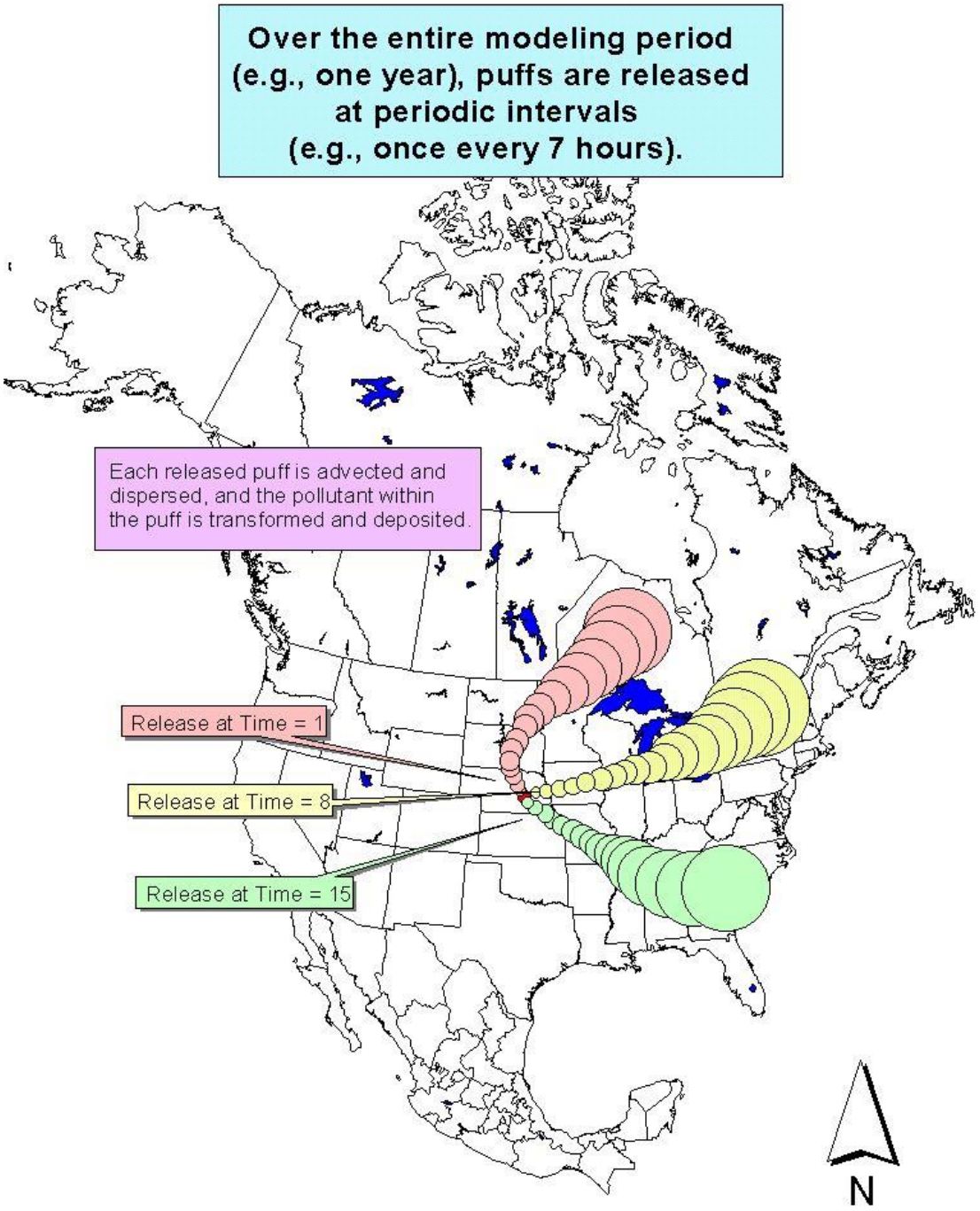
Anthropogenic Mercury Emissions (ca. 2005)

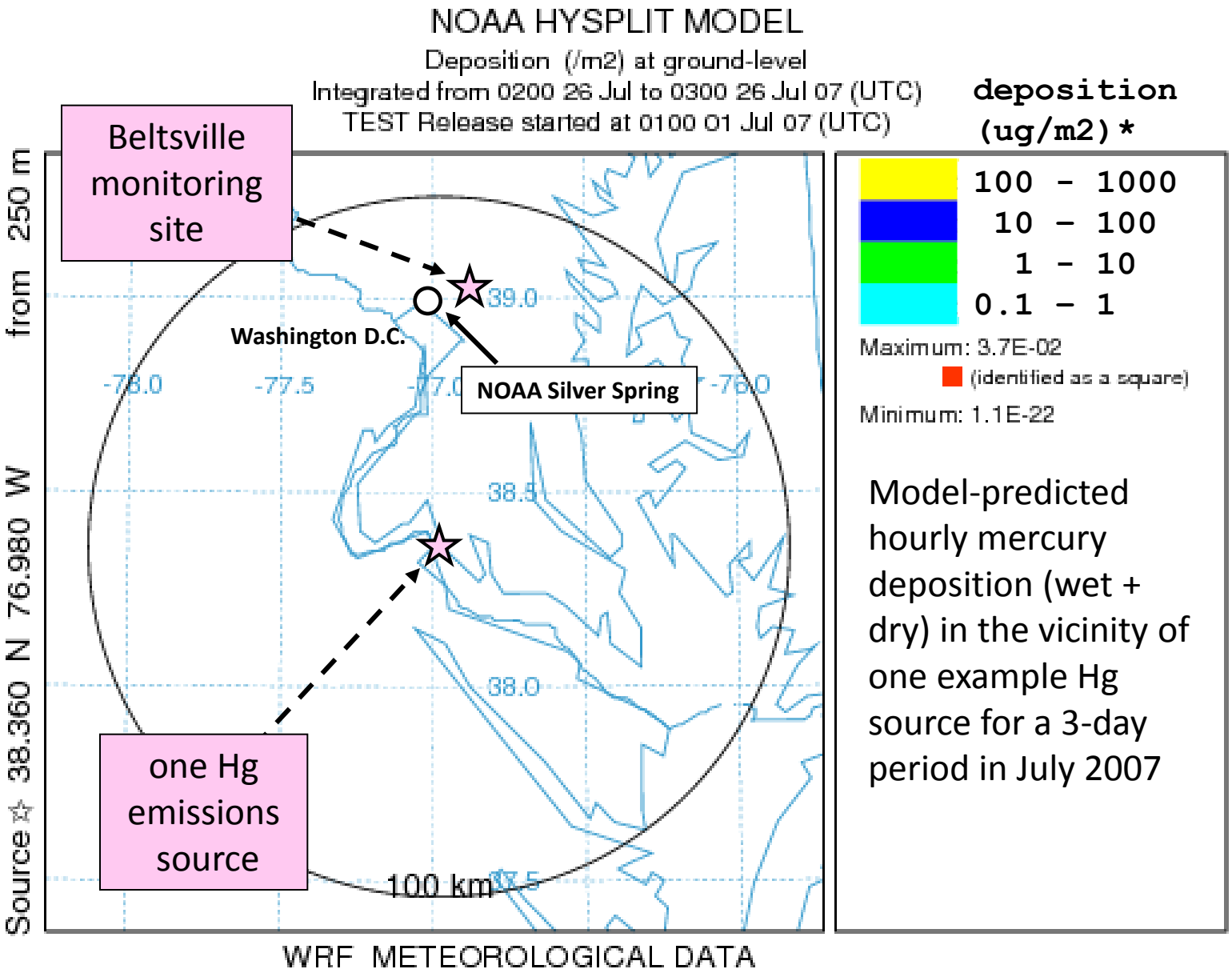


NOAA HYSPLIT MODEL

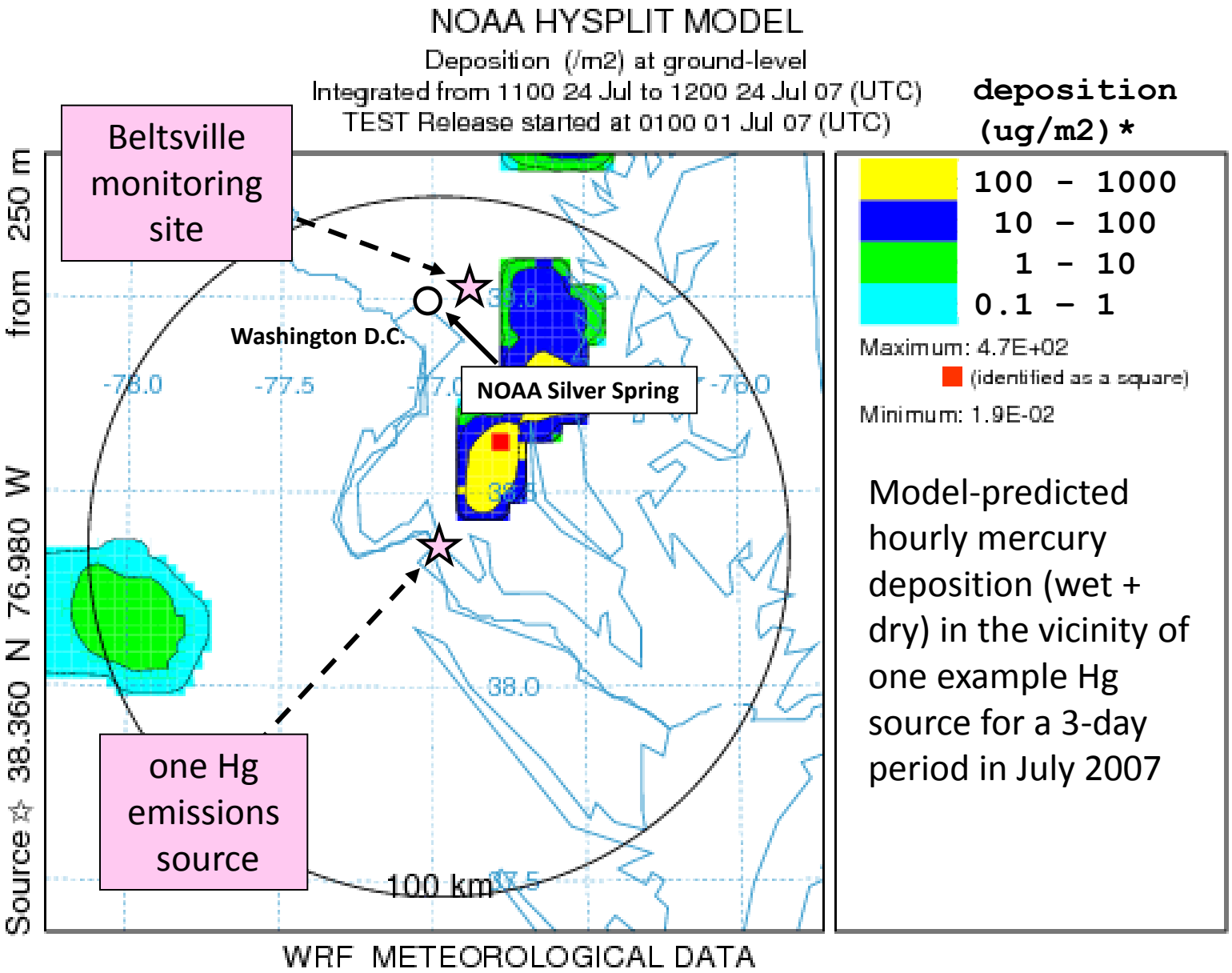
Lagrangian Puff Atmospheric Fate and Transport Model



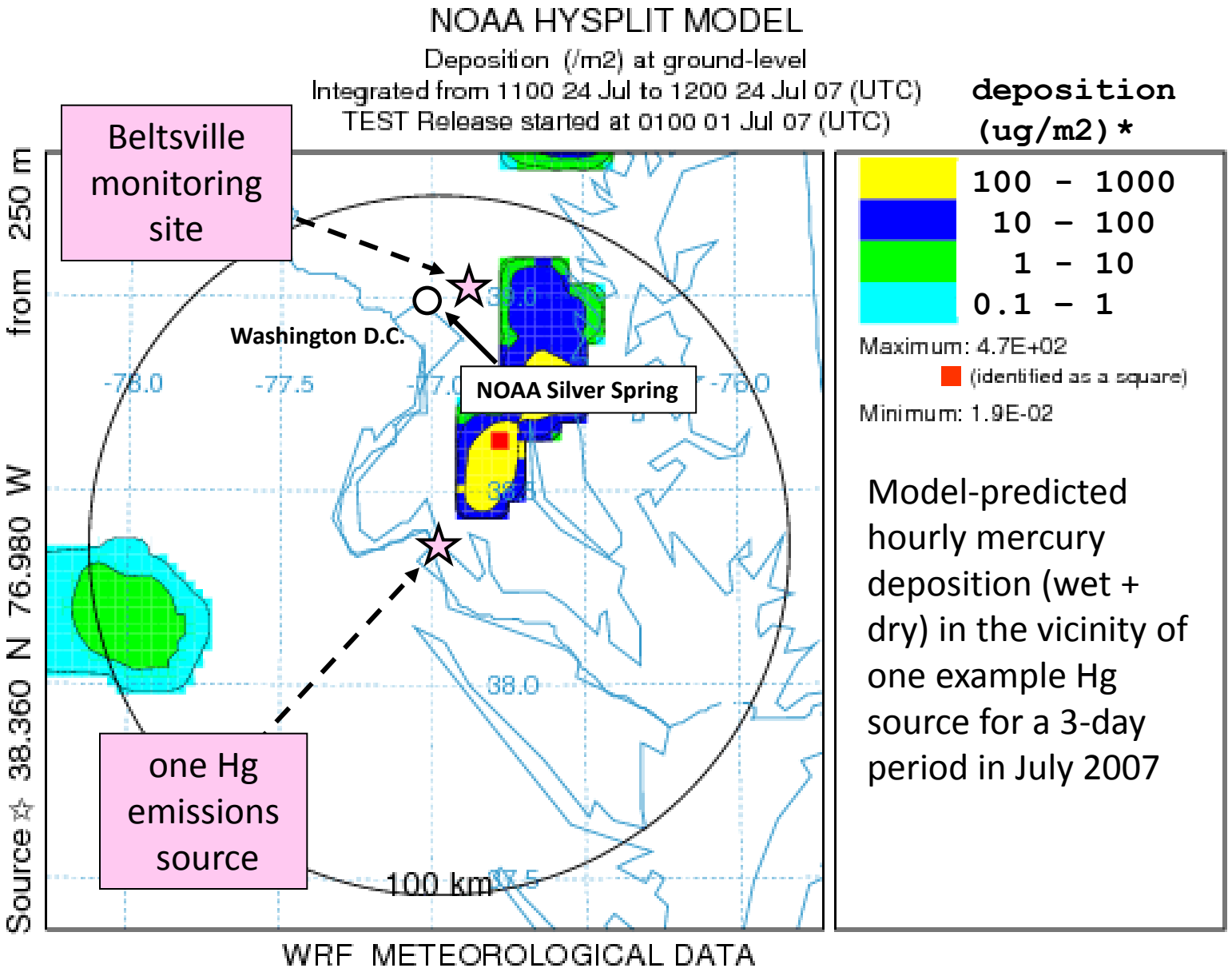

Over the entire modeling period (e.g., one year), puffs are released at periodic intervals (e.g., once every 7 hours).
Each released puff is advected and dispersed, and the pollutant within the puff is transformed and deposited.
Release at Time = 1
Release at Time = 8
Release at Time = 15
N



** hourly deposition converted to annual equivalent*


NOAA HYSPLIT MODEL
Deposition (/m2) at ground-level
Integrated from 1100 24 Jul to 1200 24 Jul 07 (UTC)
TEST Release started at 0100 01 Jul 07 (UTC)
deposition (ug/m2)*
100 - 1000
10 - 100
1 - 10
0.1 - 1
Maximum: 4.7E+02
(identified as a square)
Minimum: 1.9E-02
Beltsville monitoring site
Washington D.C.
NOAA Silver Spring
one Hg emissions source
Source ☆ 38.360 N 76.980 W from 250 m
-78.0
-77.5
38.0
100 km
WRF METEOROLOGICAL DATA
Model-predicted hourly mercury deposition (wet + dry) in the vicinity of one example Hg source for a 3-day period in July 2007
* hourly deposition converted to annual equivalent

Large, time-varying spatial gradients in deposition & source-receptor relationships



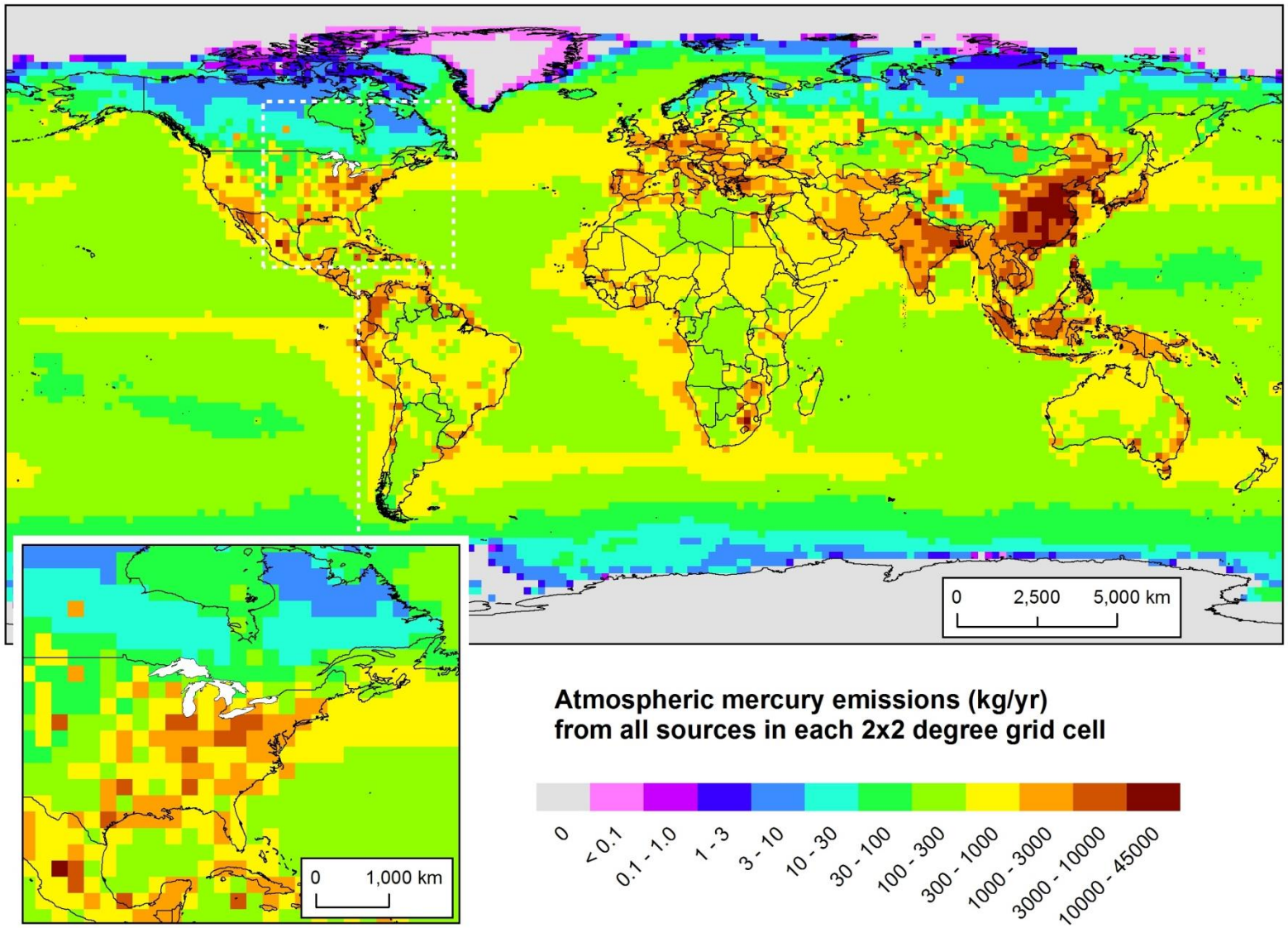
Model-predicted hourly mercury deposition (wet + dry) in the vicinity of one example Hg source for a 3-day period in July 2007

** hourly deposition converted to annual equivalent*

Here's where the mercury is emitted from...

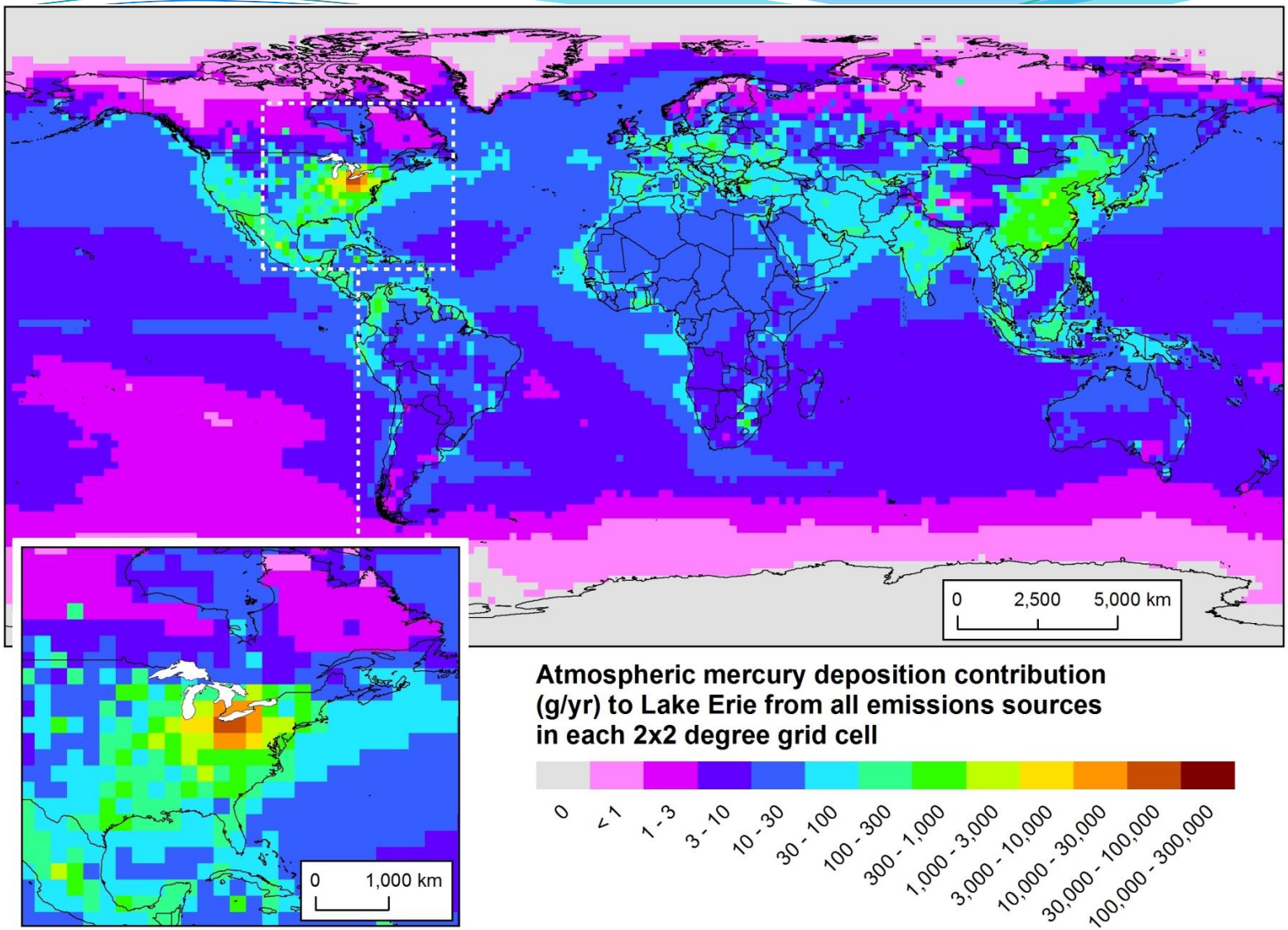
But what is the relative importance of different source regions to atmospheric deposition of mercury to the Great Lakes?

Does most of it come from China?



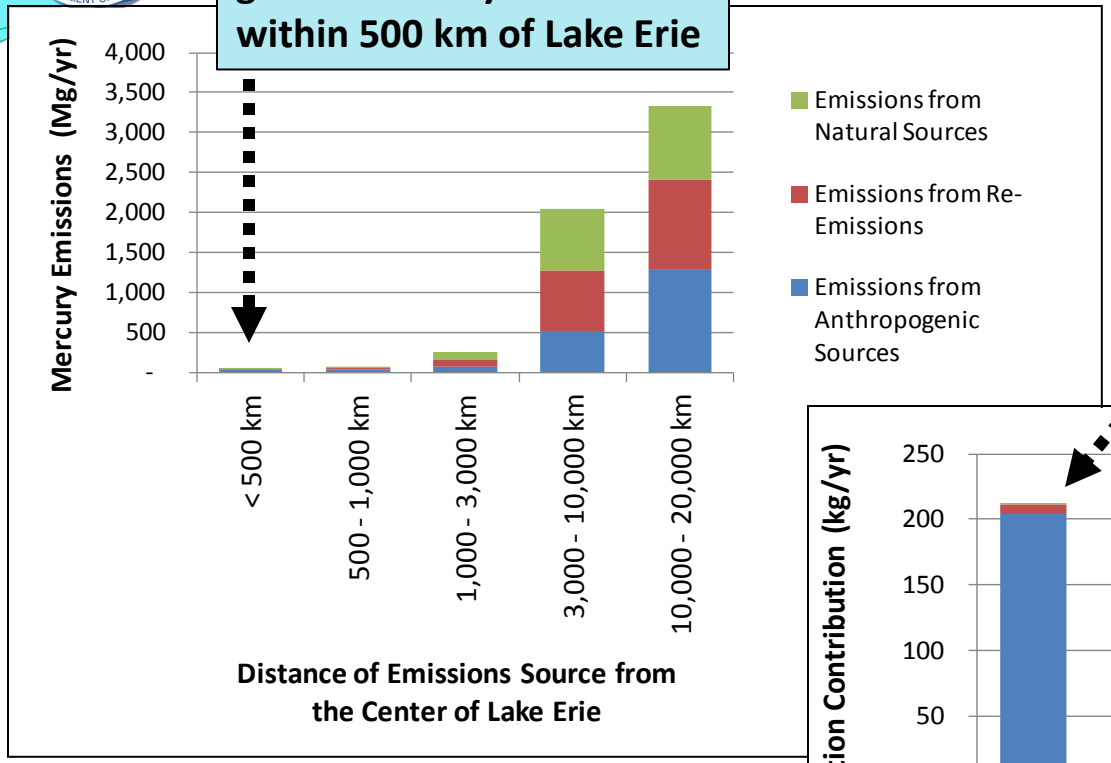
Geographical Distribution of 2005 Atmospheric Mercury Emissions (Natural + Re-emit + Direct Anthropogenic)

Here's where the mercury came from that was deposited to Lake Erie (~2005)

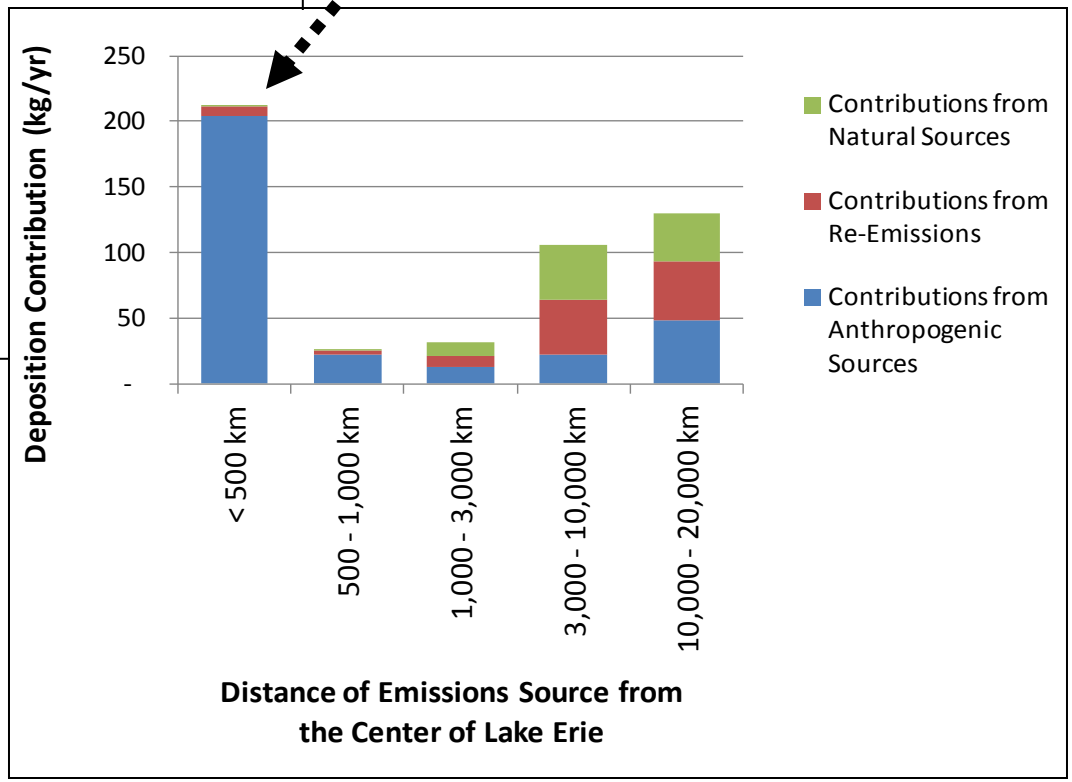


Geographical Distribution of 2005 Atmospheric Mercury Deposition Contributions to Lake Erie

A tiny fraction of 2005 global mercury emissions within 500 km of Lake Erie

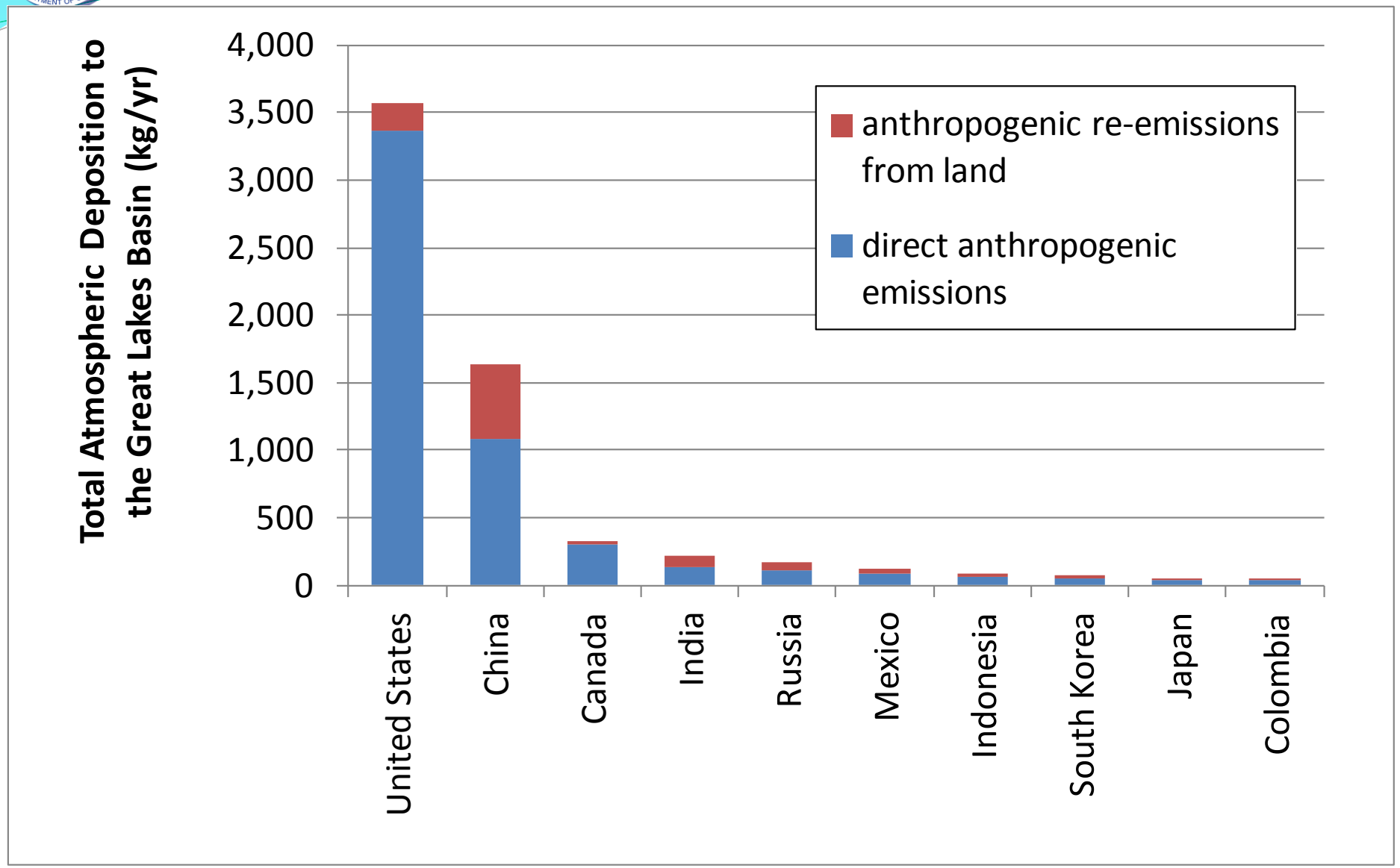


Modeling results show that these "regional" emissions are responsible for a large fraction of the modeled 2005 atmospheric deposition

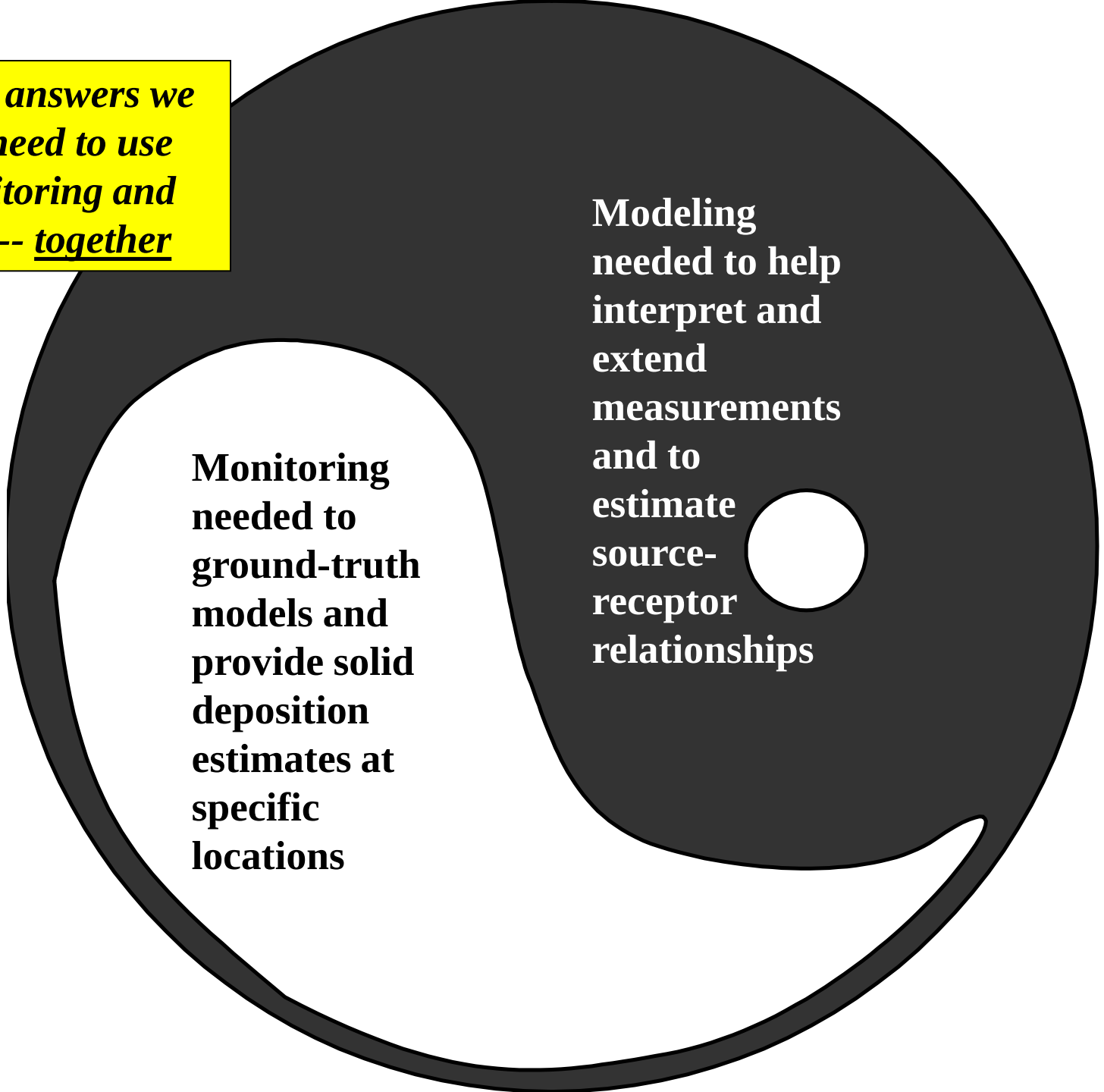


Important policy implications!

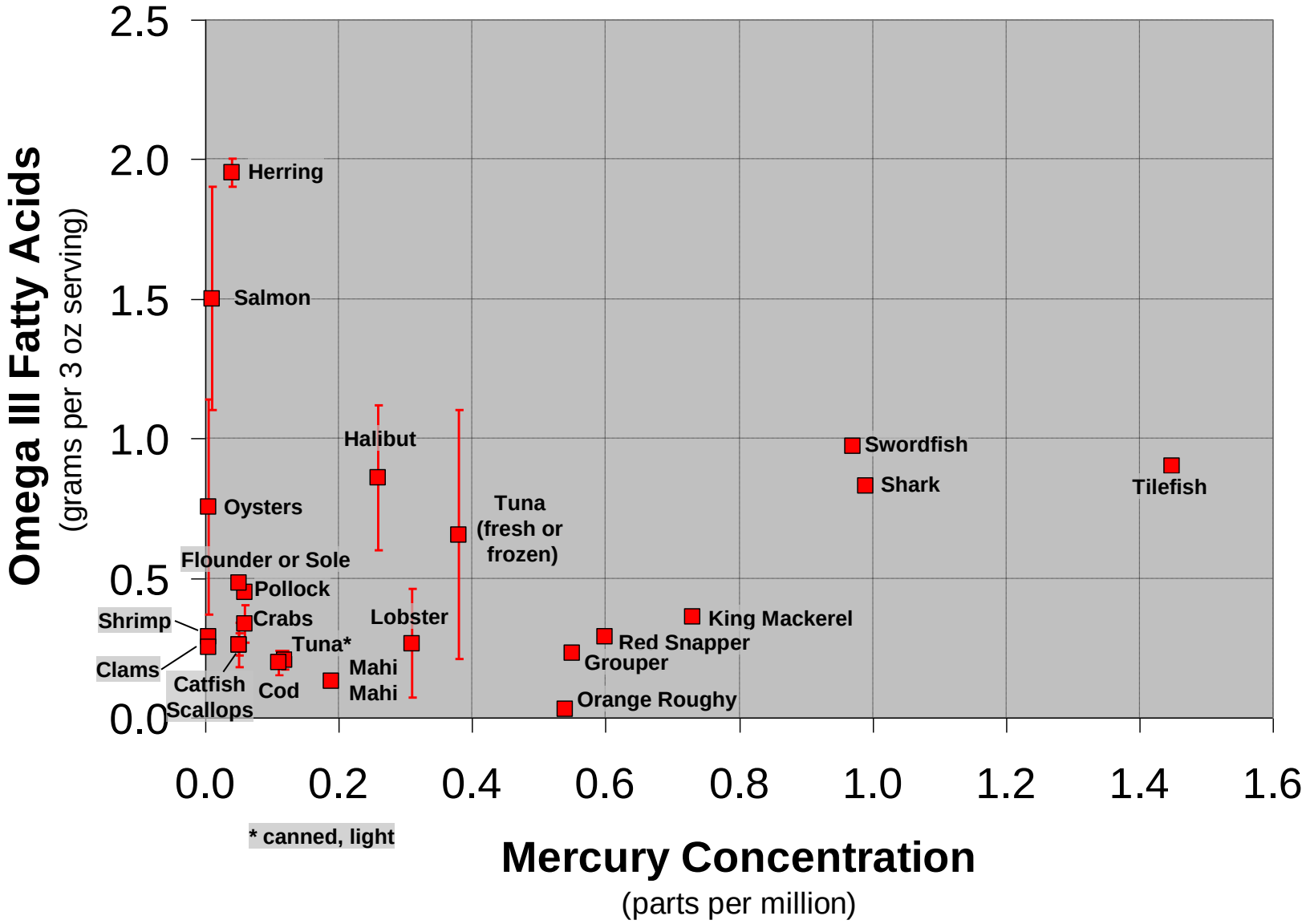
Model-estimated 2005 deposition to the Great Lakes Basin from countries with the highest modeled contribution from direct and re-emitted anthropogenic sources



To get the answers we need, we need to use both monitoring and modeling -- <u>together</u>

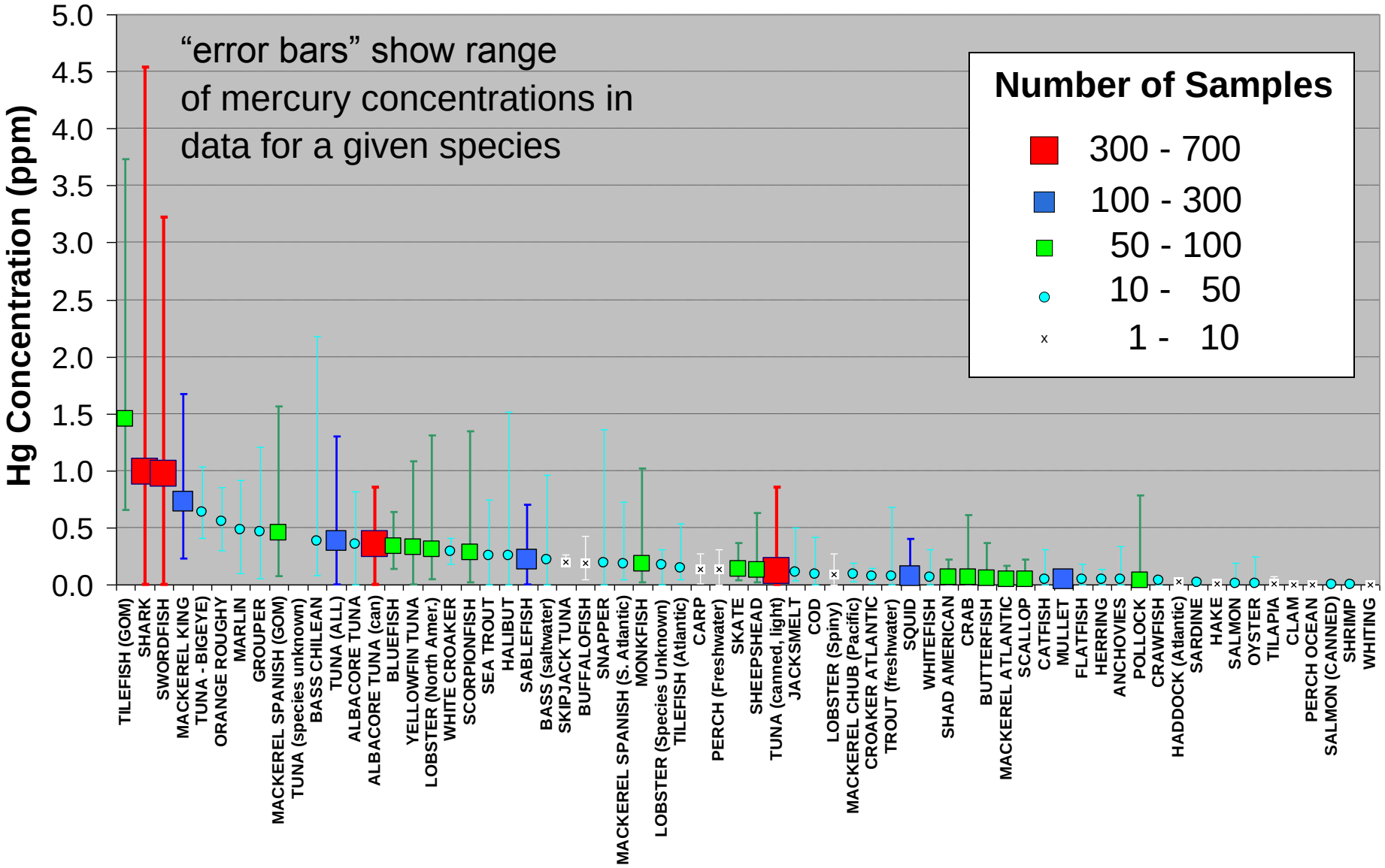


Extra Slides



Graph based on data presented by the American Heart Association -- http://www.americanheart.org

Mercury Levels in Commercial Fish and Shellfish

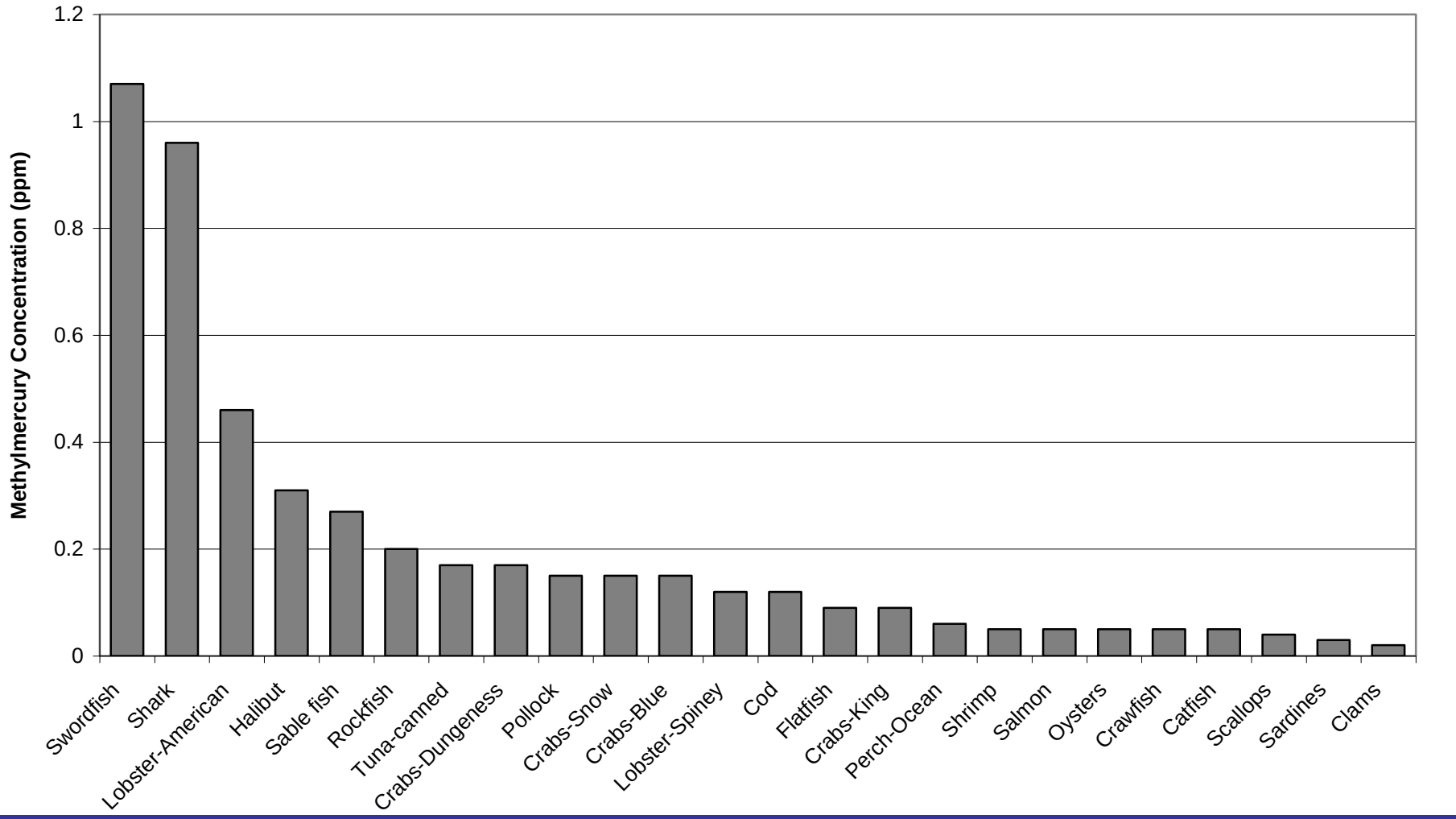


Fish concentration data from NOAA and FDA. Downloaded Sept 2008 from the EPA-FDA fish-mercury website:
http://www.cfsan.fda.gov/~frf/sea-mehg.html

What Influences Hg Levels in Fish?

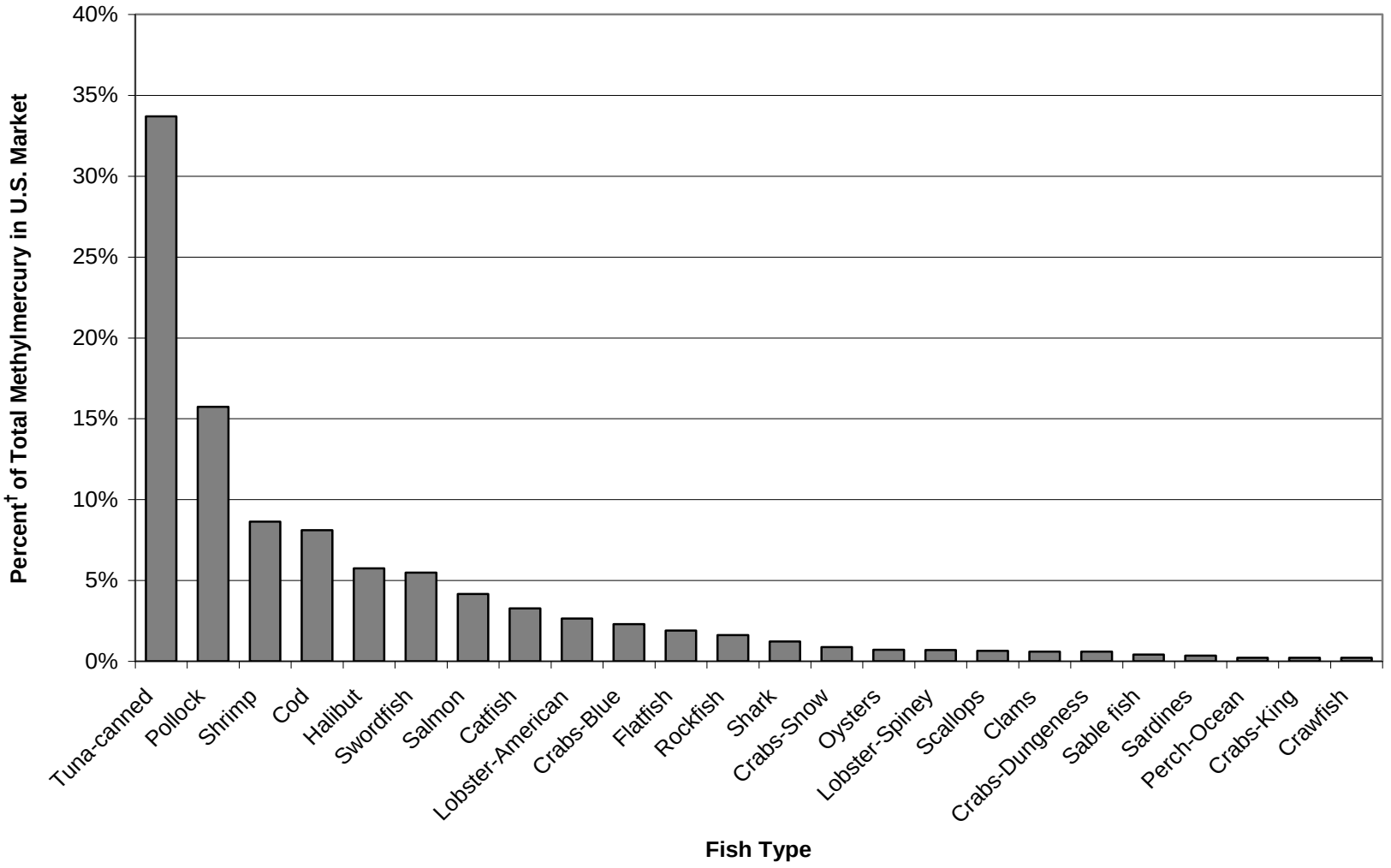
- Current / past atmospheric and other Hg inputs to the fish's ecosystem
- Biogeochemical factors influencing the degree of mercury methylation in the ecosystem (sulfate, dissolved organic carbon, pH, etc)
- Food web structure of the waterbody and trophic level of species
- Age (size) of fish – as fish age, they accumulate more and more mercury
- History of that particular fish
- Note – Hg in fish muscle tissue, so can't easily avoid it
  (PCB's, Dioxins and other hydrophobic contaminants concentrated in fat)
- Knowledge gaps for Hg levels and reasons for levels:
  - freshwater (inland) fish -- LARGE
  - estuarine & marine fish -- VERY LARGE

Mean Methylmercury Concentrations for "Top 24" Types of Fish Consumed in U.S. Commercial Seafood Market



Source of data: Carrington and Bolger, 2002
Based on slide from: Elsie Sunderland, USEPA

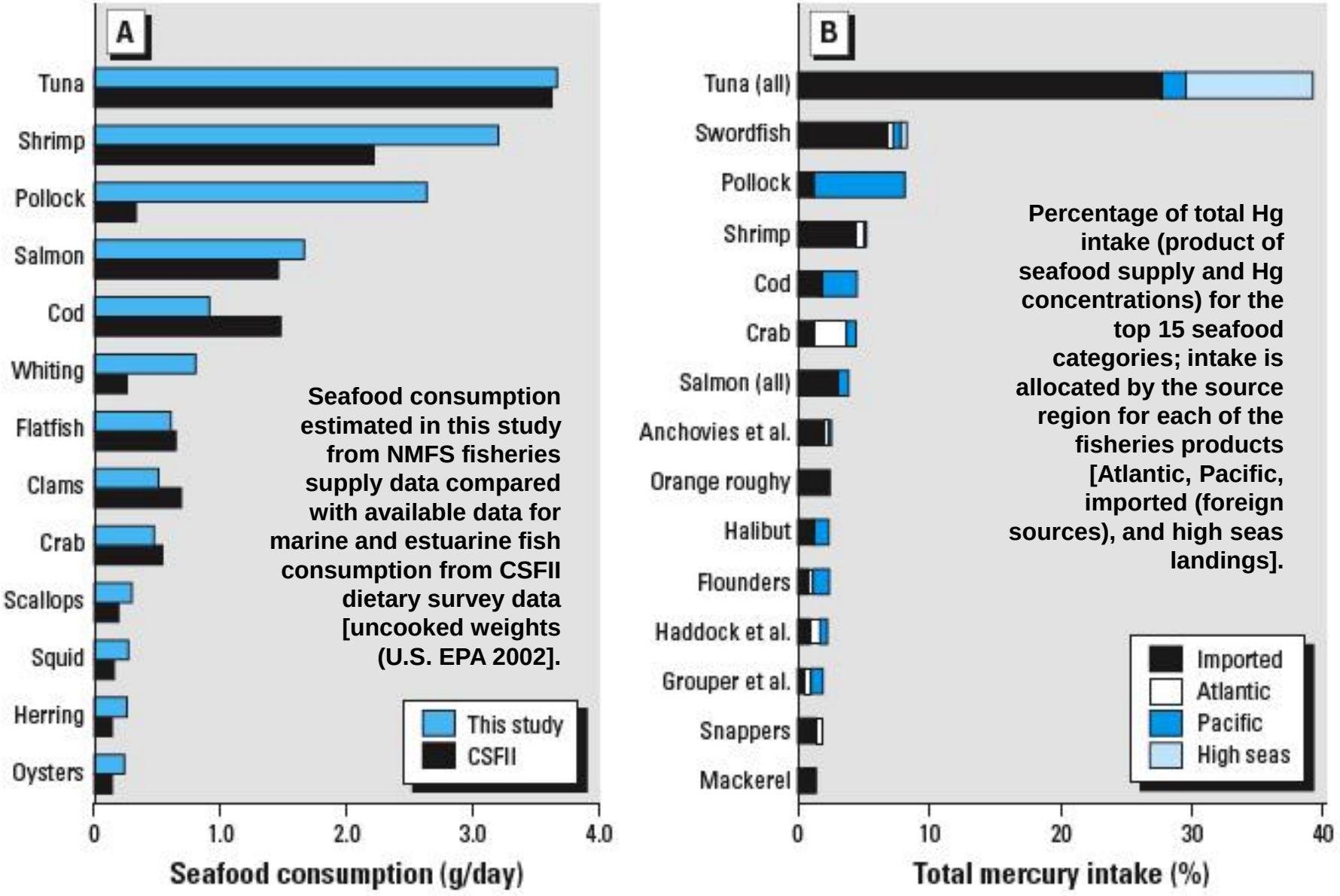
Percent Contribution to per capita Methylmercury Intake by Fish Type for "Top 24" Types of Fish in U.S. Commercial Seafood Market



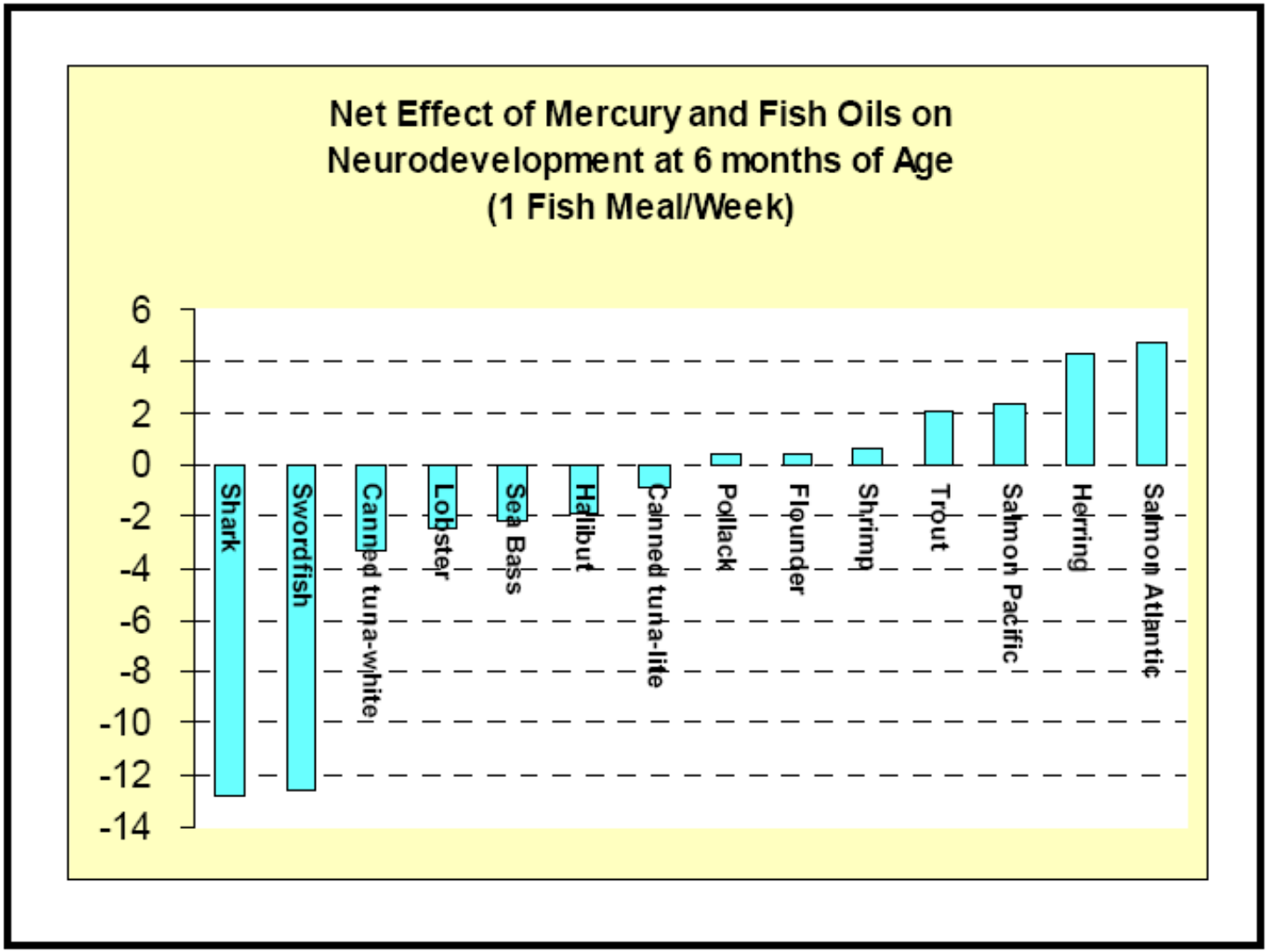
Source of data: Carrington and Bolger, 2002

Based on slide from: Elsie Sunderland, USEPA

U.S. Population-Wide Consumption & Hg Exposure for Marine and Estuarine Fish

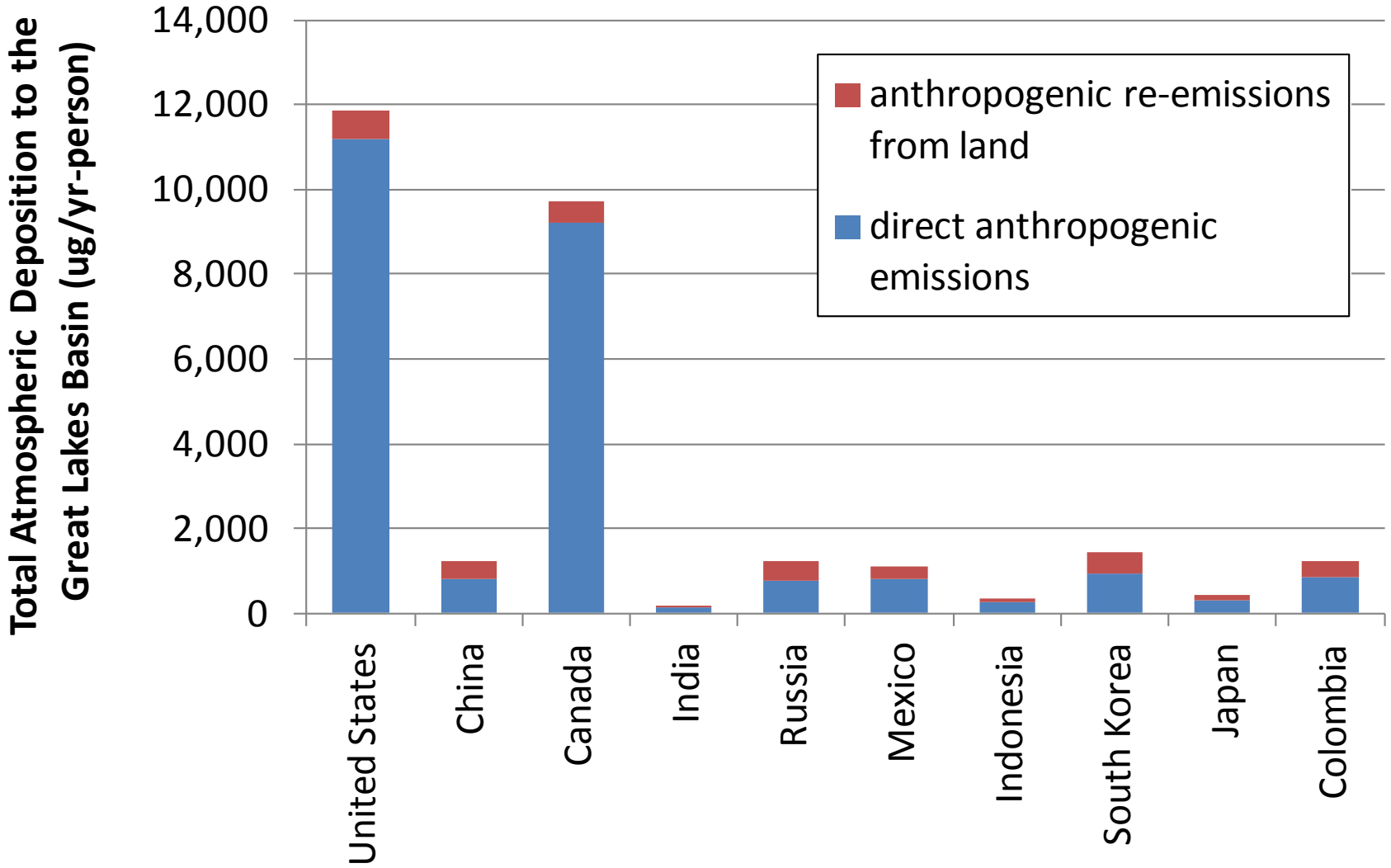


Sunderland, E. (2007). Mercury exposure from domestic and imported estuarine and marine fish in the U.S. seafood market. *Environ Health Perspect* **115**(2):235-42.



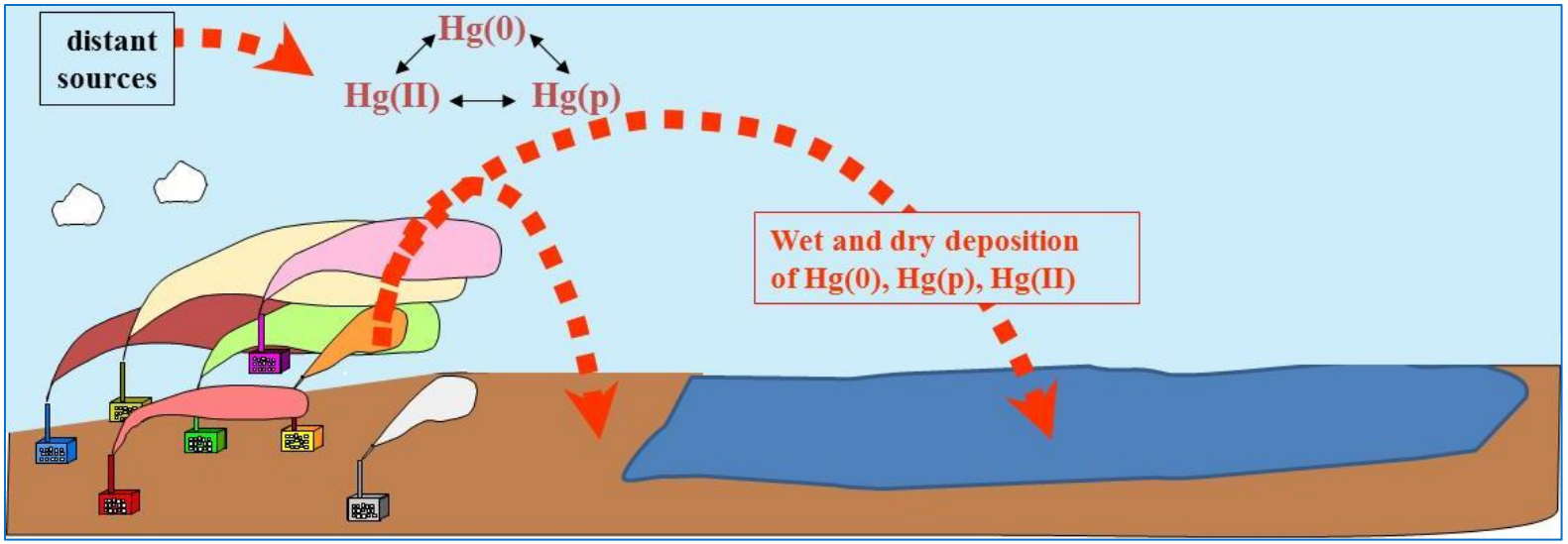
Source: Gary Ginsberg, Connecticut Dept of Public Health (2007). "Risk-Benefit Synthesis for Fish Consumption Advisories," presented at National Forum on Fish Contaminants, Portland, ME. http://www.epa.gov/waterscience/fish/forum/2007/pdf/section2f.pdf

Model-estimated *per capita* 2005 deposition to the Great Lakes Basin from countries with the highest modeled contribution from direct & re-emitted anthropogenic sources



Modeling – Approaches

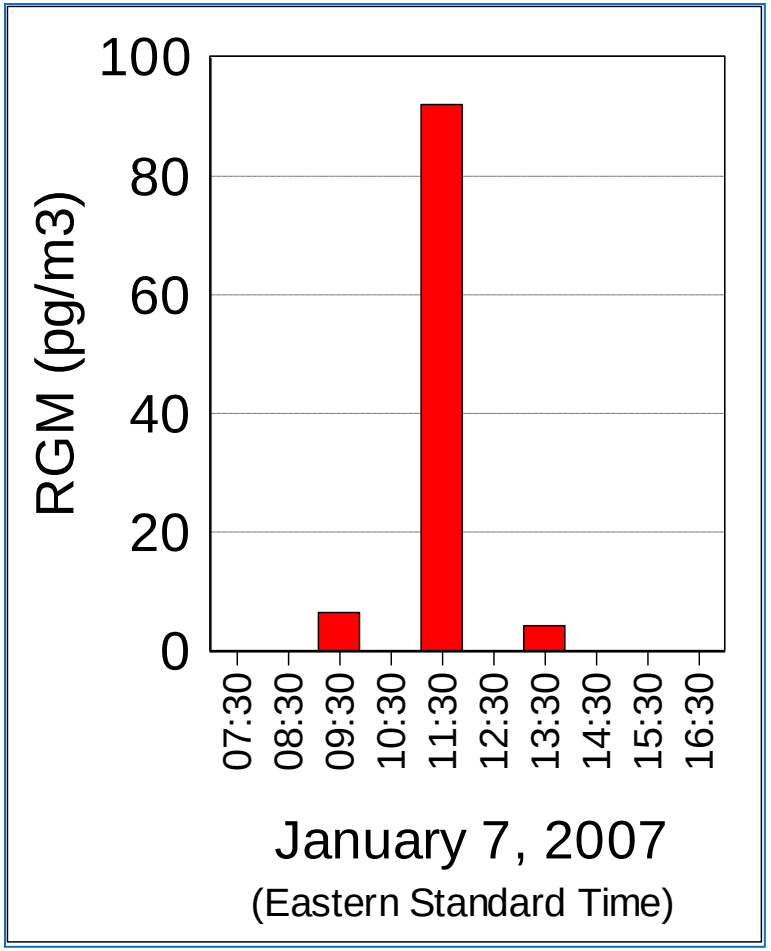
- Back-trajectory analyses with HYSPLIT
- Fate and transport modeling with HYSPLIT-Hg



…focus on source-receptor relationships

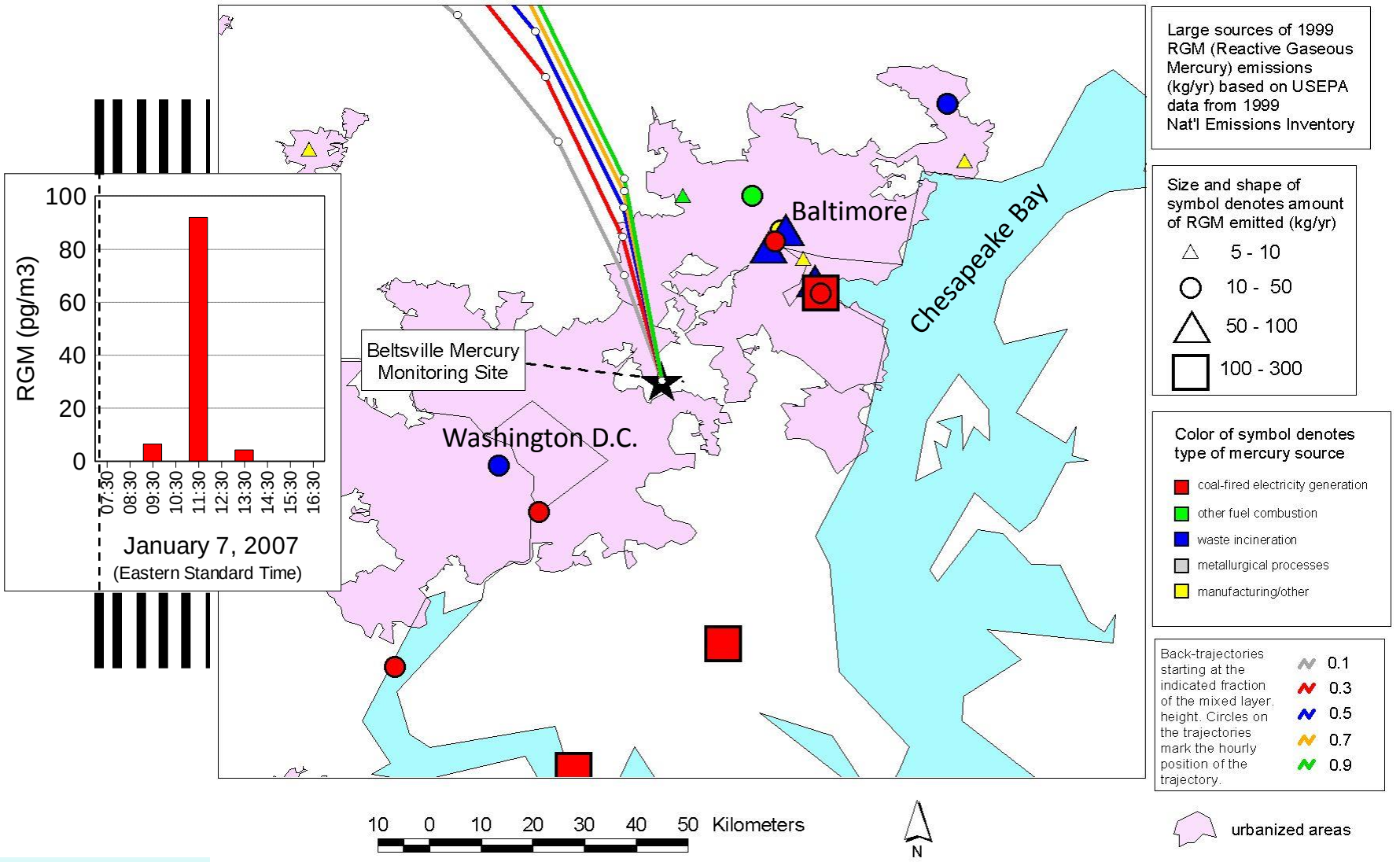
Back Trajectory Analysis – Episodes

Beltsville, Maryland
mercury site



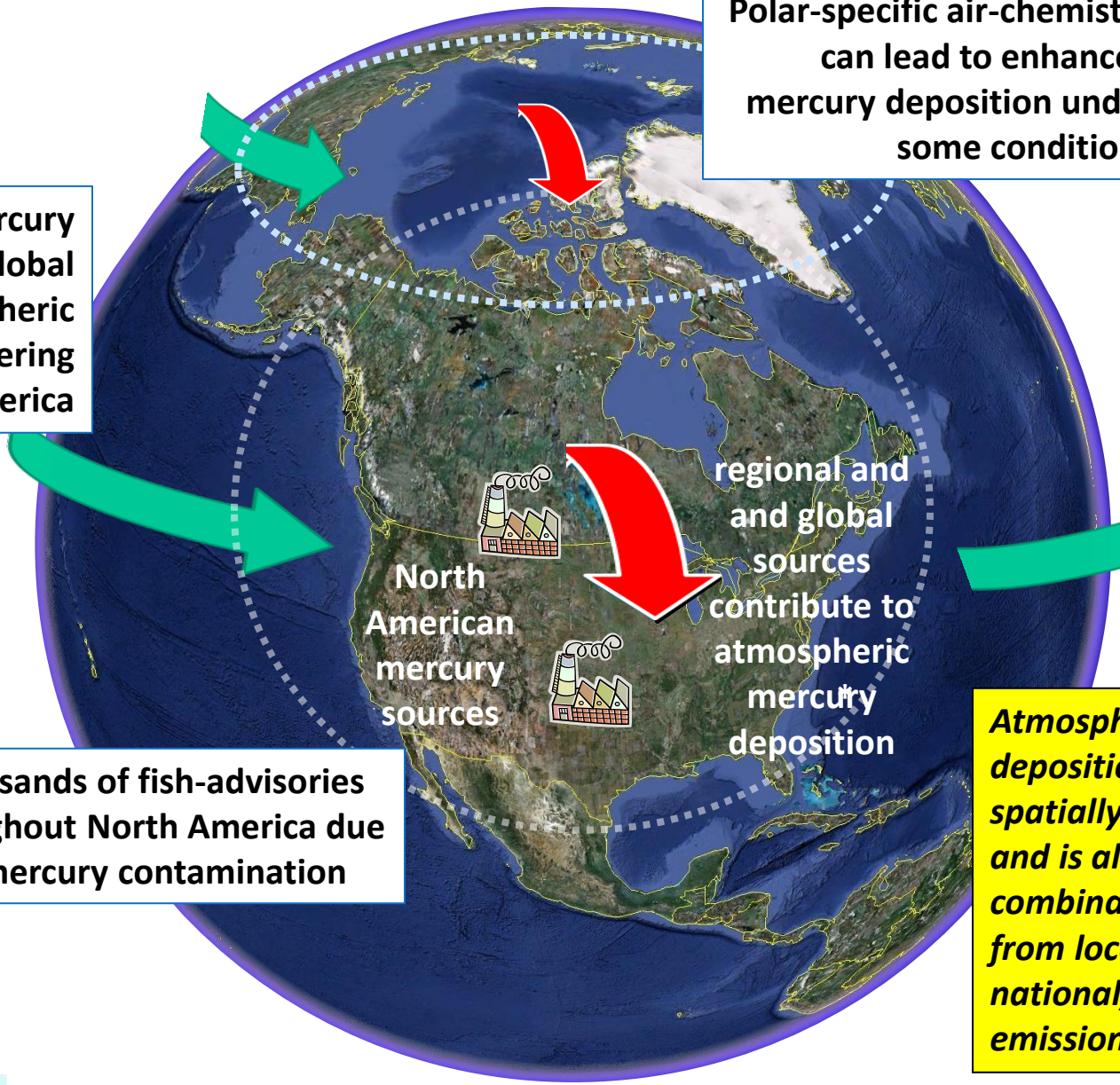
Reactive Gaseous Mercury episode

Back Trajectories Arriving at 1/07/2007 07:00 EST



Polar-specific air-chemistry can lead to enhanced mercury deposition under some conditions

mercury from global atmospheric pool entering North America

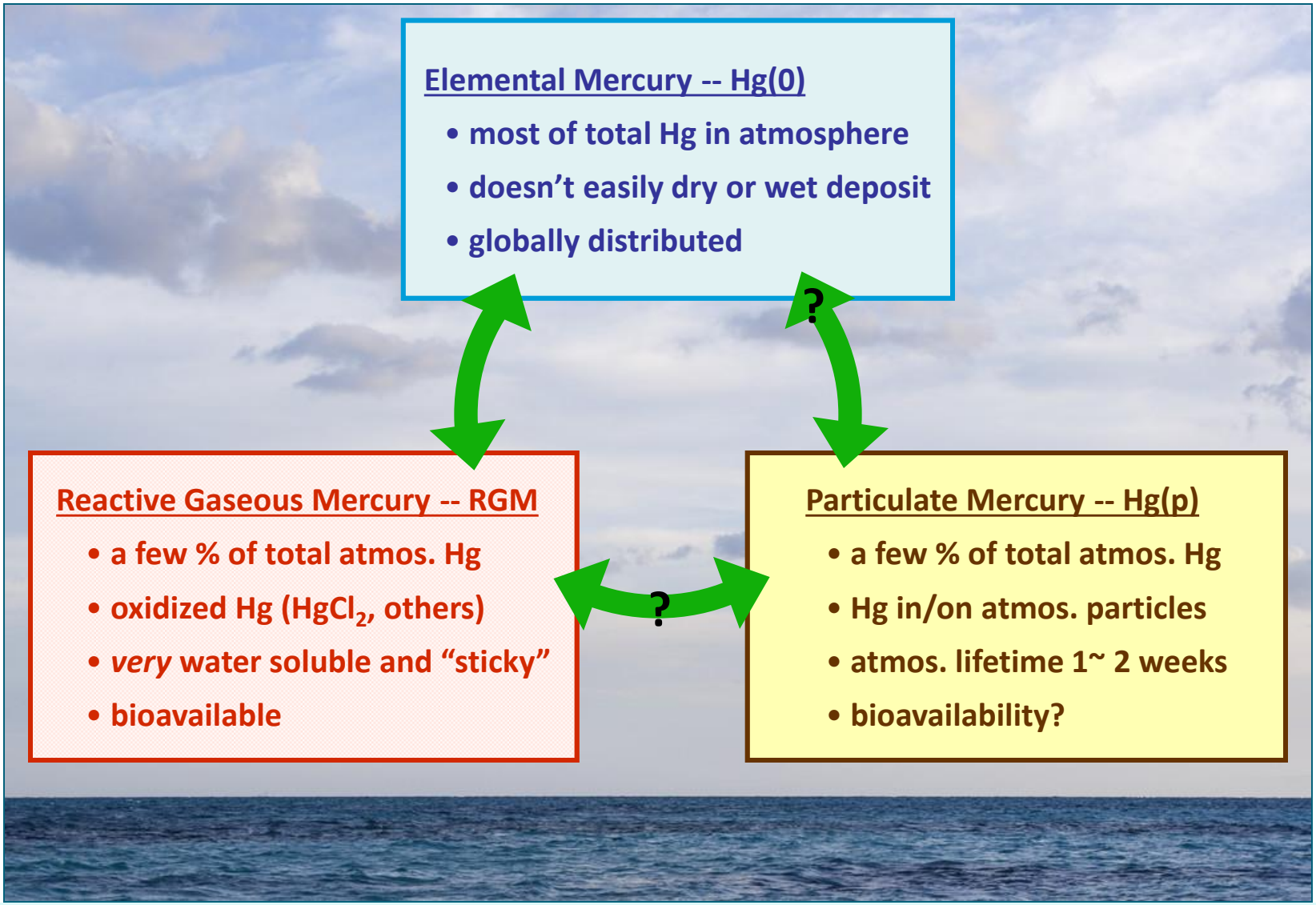


mercury that doesn't deposit continues its global circulation

Thousands of fish-advisories throughout North America due to mercury contamination

Atmospheric mercury deposition varies spatially and temporally, and is always a complex combination of impacts from local, regional, national, and global emissions sources.

Different "forms" of mercury in the atmosphere



Modeling – Comprehensive Fate and Transport Simulations

- Start with an emissions inventory
- Use gridded meteorological data
- Simulate the dispersion, chemical transformation, and wet and dry deposition of mercury emitted to the air
- Source-attribution information needed at the end, so optimize modeling system and approach to allow source-receptor information to be captured
- HYSPLIT-Hg developed over the last ~10 years with specialized algorithms for simulation of atmospheric mercury

Context

- Mercury exposure via fish consumption is an important public health concern
- NOAA has a primary stewardship responsibility for the nation's fisheries
- Atmospheric emissions and subsequent deposition is a significant pathway through which mercury contamination enters sensitive aquatic ecosystems

Goals

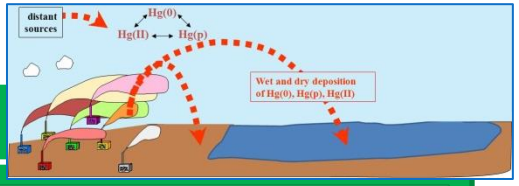
- Provide sound scientific information on the emission, dispersion, transformation, and air-surface exchange of atmospheric mercury compounds
- Measure and understand spatial and temporal trends in air concentrations and air-surface exchange
- Provide robust source-attribution information for atmospheric mercury deposition to sensitive ecosystems, to inform policies to reduce loadings

Mercury: Measurements and Modeling

MEASUREMENTS

- speciated atmospheric mercury
- other air pollutants, e.g., SO_2, O_3, CO
- wet deposition
- air-surface exchange

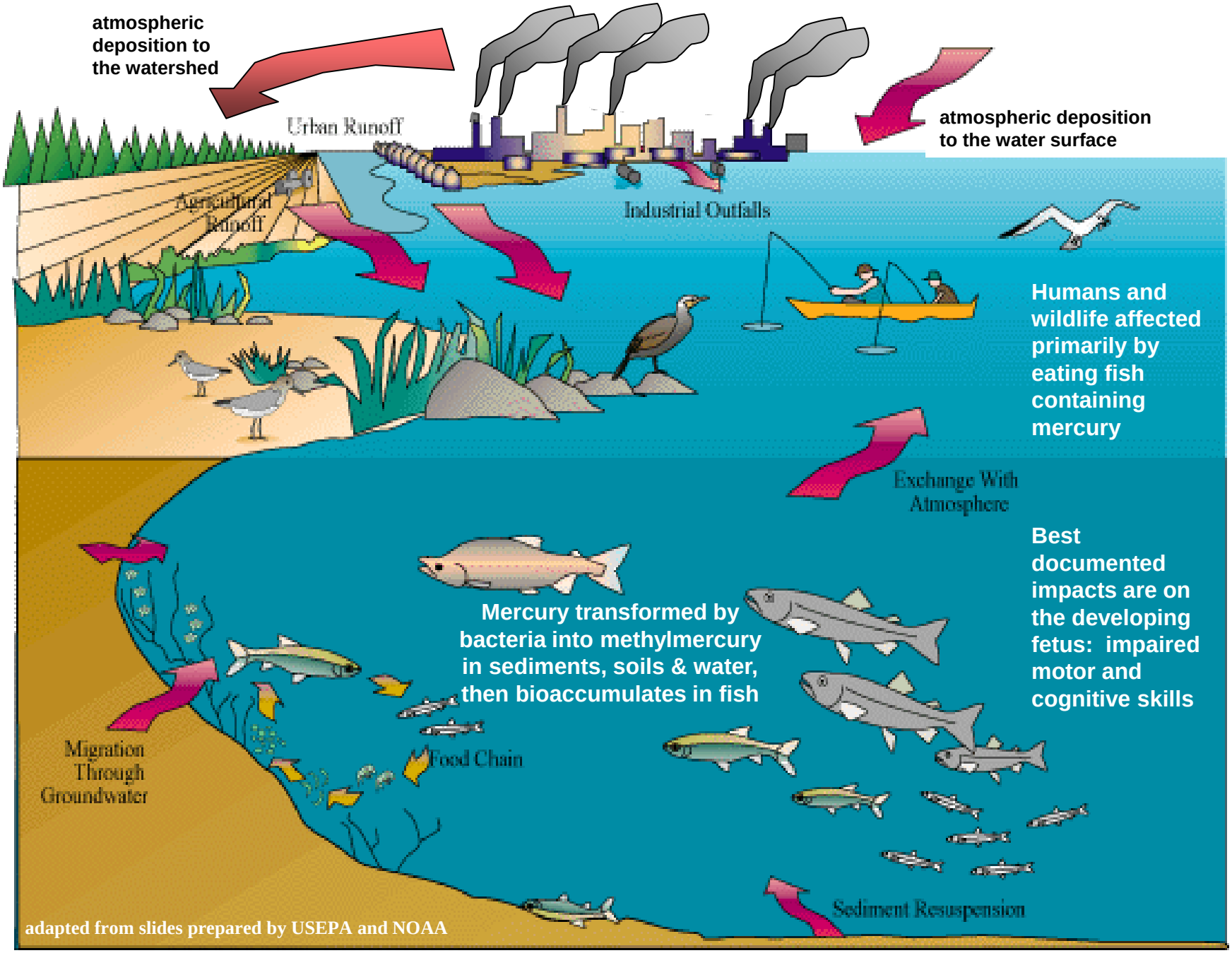
Modeling used to aid in data interpretation and measurement planning



MODELING

- back trajectories
- comprehensive fate and transport
- source-attribution for deposition

Measurements used for model evaluation and improvement

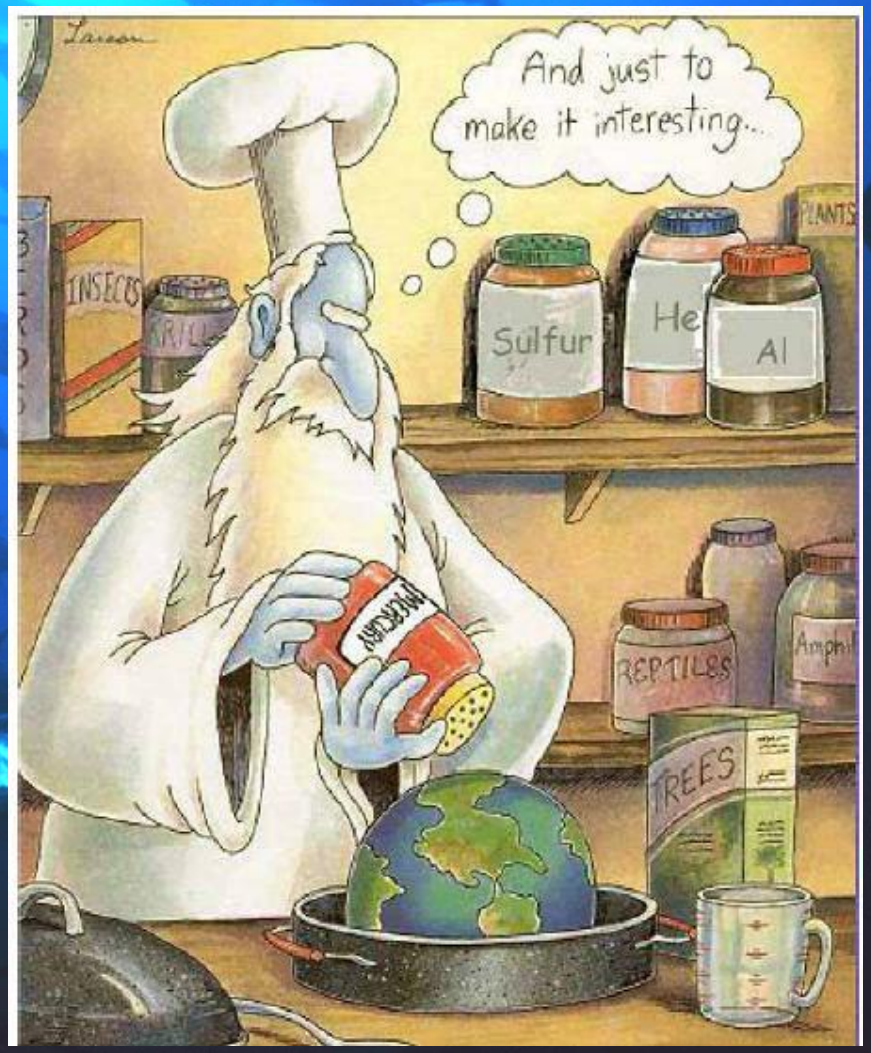

atmospheric deposition to the watershed
Urban Runoff
atmospheric deposition to the water surface
Agricultural Runoff
Industrial Outfalls
Humans and wildlife affected primarily by eating fish containing mercury
Exchange With Atmosphere
Best documented impacts are on the developing fetus: impaired motor and cognitive skills
Mercury transformed by bacteria into methylmercury in sediments, soils & water, then bioaccumulates in fish
Migration Through Groundwater
Food Chain
Sediment Resuspension
adapted from slides prepared by USEPA and NOAA

Environmental Mercury Cycling -- Natural vs. Anthropogenic

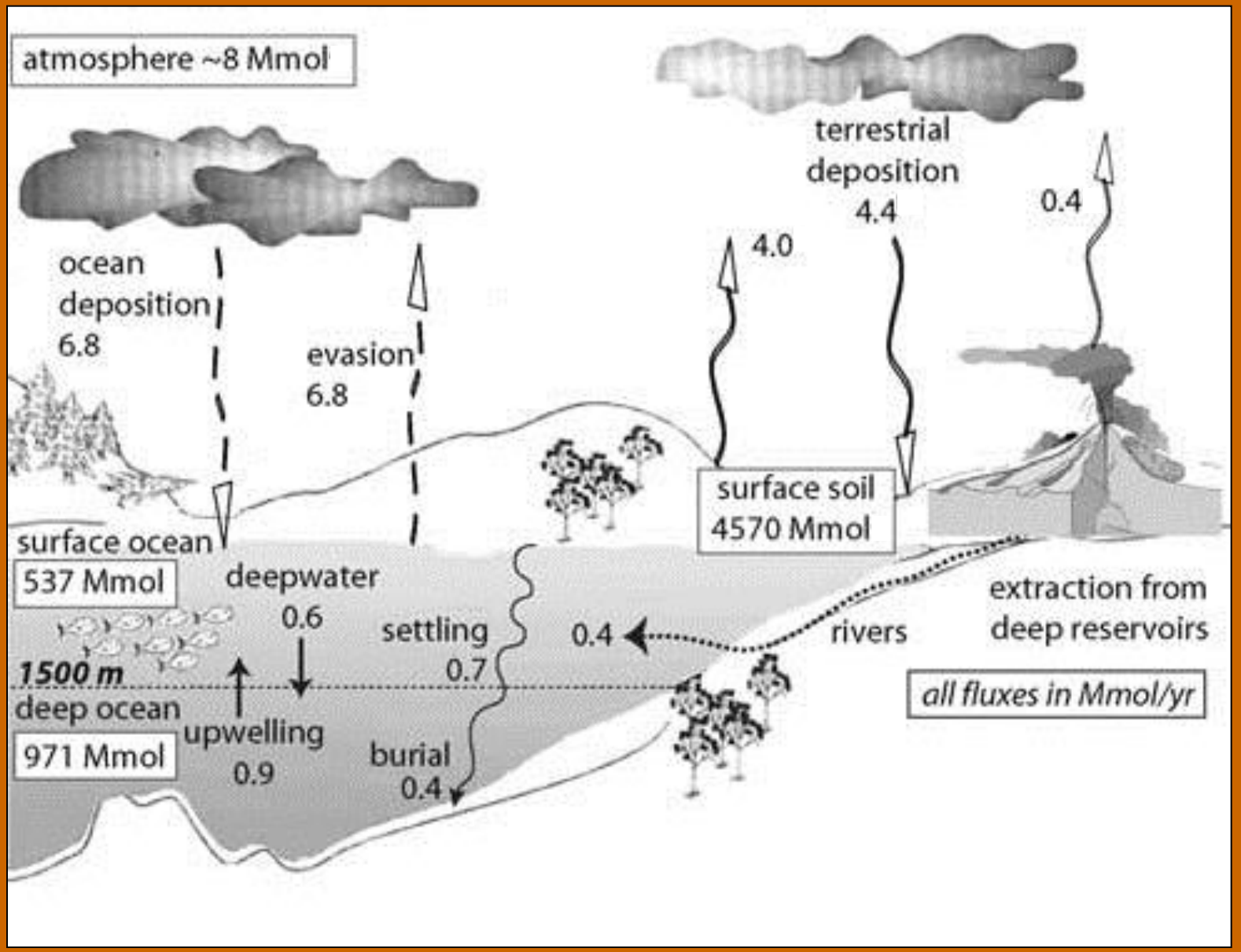
- Mercury (Hg) is an element... there is the same amount of mercury on Earth today as there always has been

- "natural" Hg cycle:
  - transported throughout the environment
  - chemical transformations interconvert different mercury species

- This has always been going on, ... always has been Hg in fish



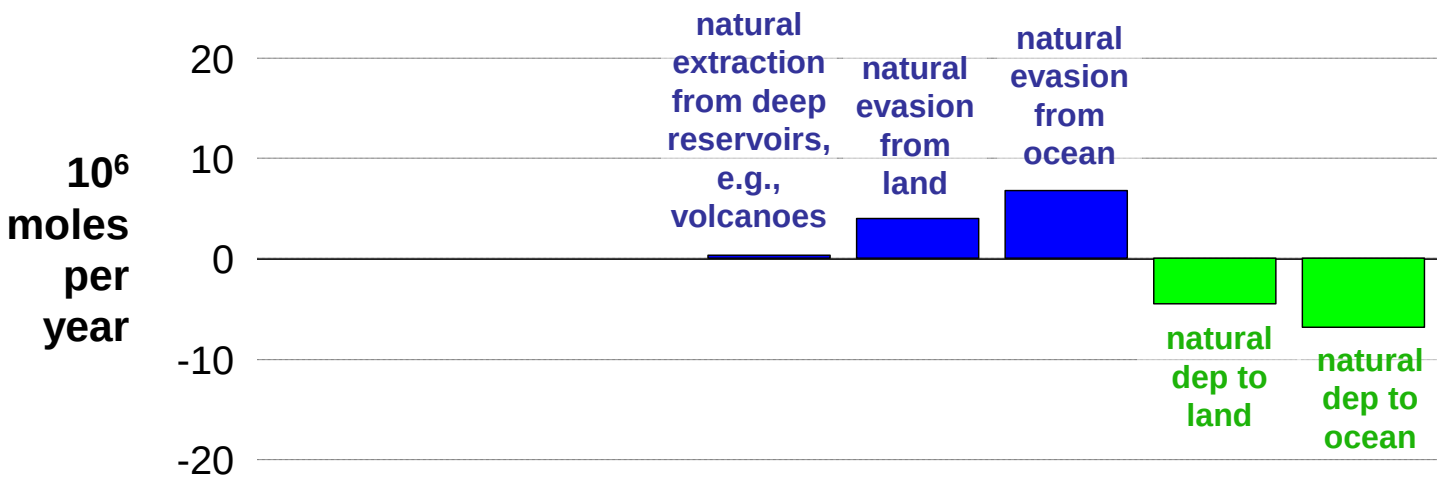
Pre-Industrial Global Mercury Cycling



Sunderland and Mason (2007). Global Biogeochemical Cycles 21, 4022

GLOBAL MERCURY CYCLING

(note -10^6 moles ~ 200 metric tons)



pre-industrial: **total mercury in atmosphere ~ 8.0 x 10^6 moles**

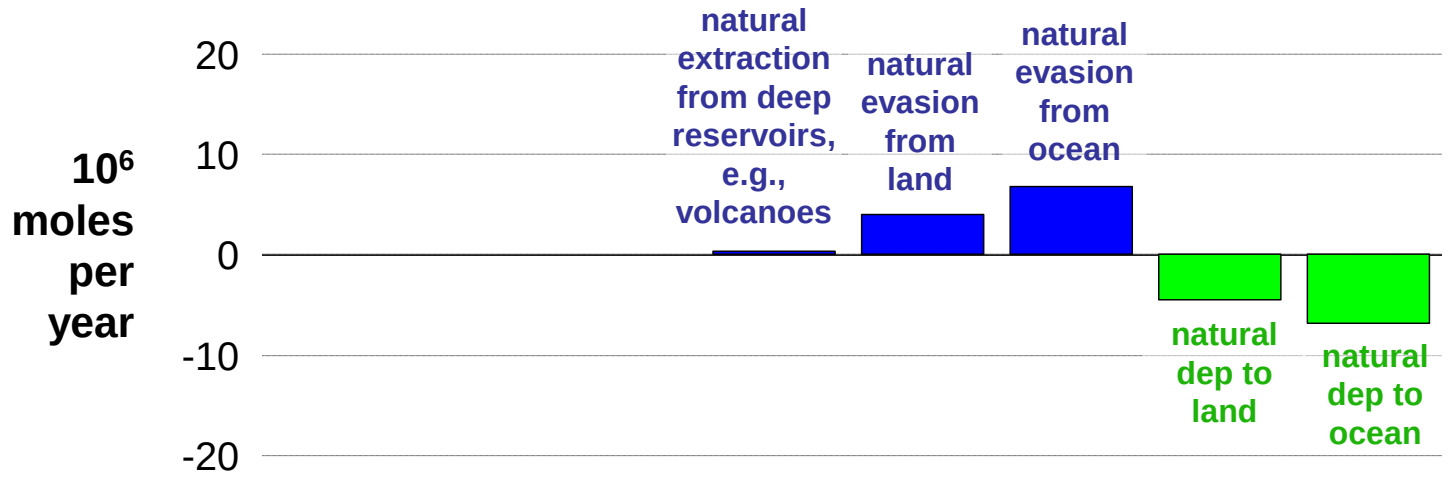
Based on data presented in Sunderland and Mason (2007) *Global Biogeochemical Cycles* **21**: GB4022

Environmental Mercury Cycling -- Natural vs. Anthropogenic

- Mercury (Hg) is an element... there is the same amount of mercury on Earth today as there always has been
- "natural" Hg cycle – Hg is transported throughout the environment, and chemical transformations interconvert different mercury species
- This has always been going on, and there has always been Hg in fish
- But, we make some Hg unexpectedly "bioavailable"
- Most anthropogenic Hg is "released" as atmospheric emissions:
  - Hg in *coal* is released to the air when coal is burned
  - Hg in *other fuels* is released to the air when they are processed and burned
  - Hg in *ores* is released to the air during metallurgical processes
  - Hg in *products* is released to the air when burned or landfilled after being discarded (e.g., batteries, switches)
- Average, current atmospheric Hg deposition is ~3x pre-industrial levels
- Evidence suggests that newly deposited Hg is more bioavailable

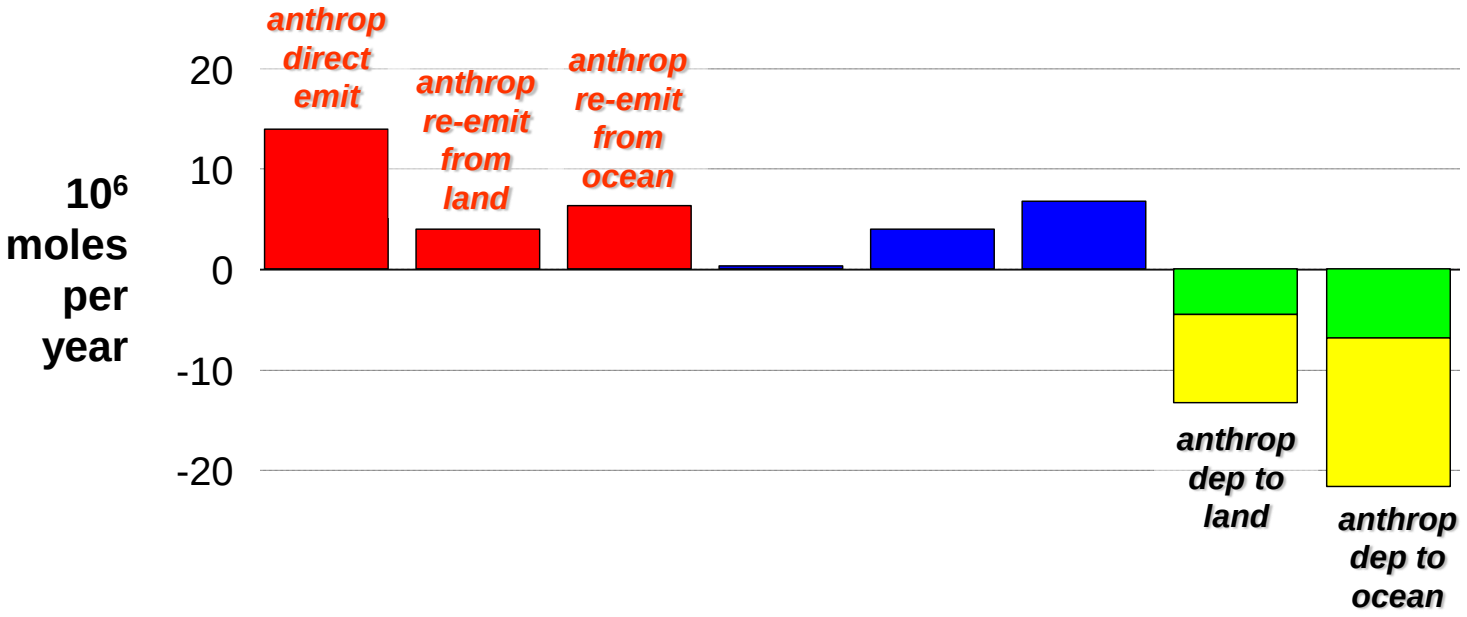
GLOBAL MERCURY CYCLING

(note -10^6 moles ~ 200 metric tons)



pre-industrial: **total mercury in atmosphere ~ 8.0 x 10^6 moles**

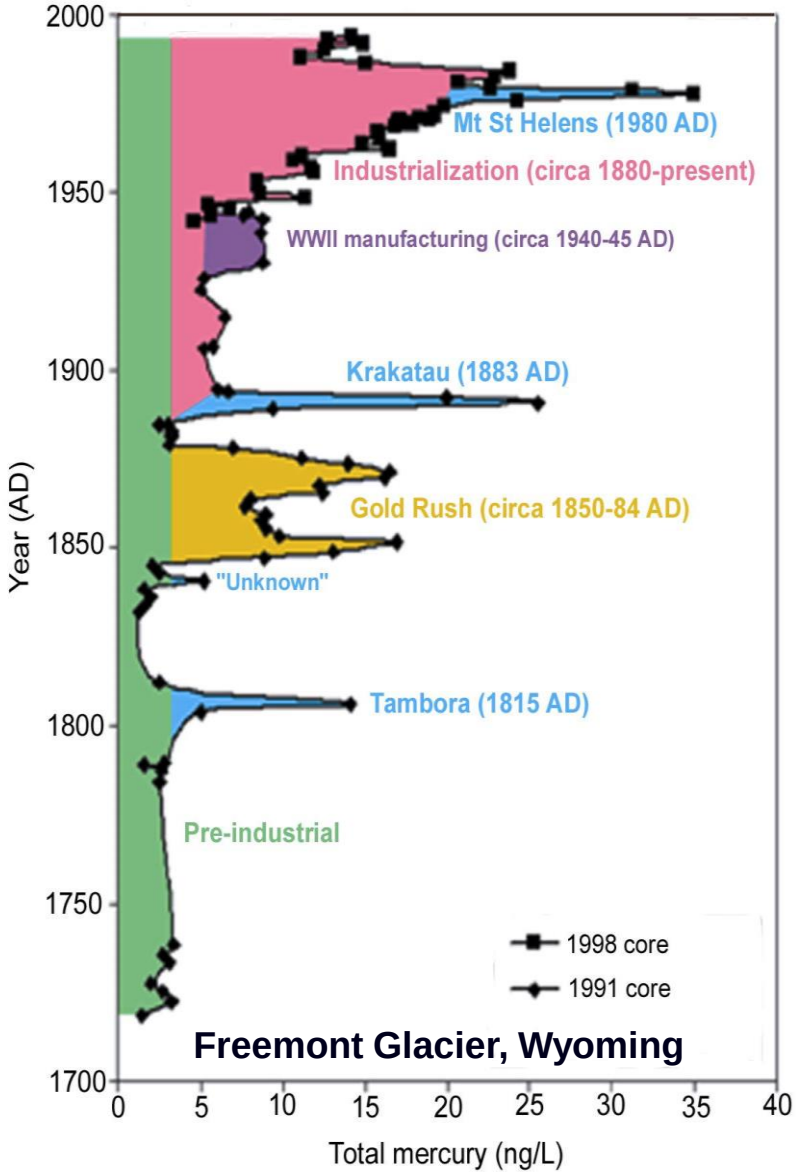
Based on data presented in Sunderland and Mason (2007) *Global Biogeochemical Cycles* **21**: GB4022



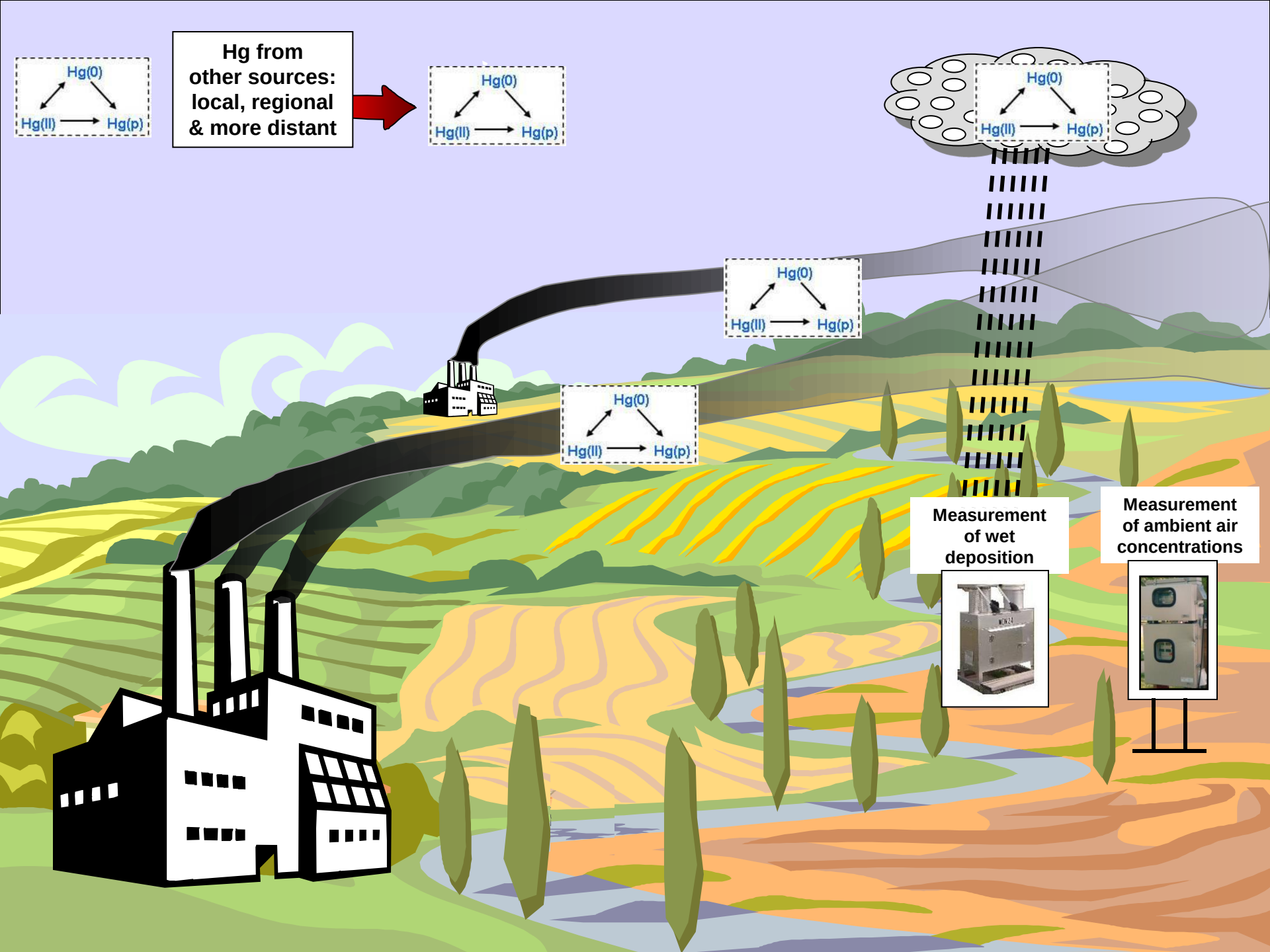
contemporary: **total mercury in atmosphere ~ 28.0 x 10^6 moles**

Natural vs. anthropogenic mercury?

Studies show that anthropogenic activities have typically increased bioavailable Hg concentrations in ecosystems by a factor of 2 – 10



source: USGS, Shuster et al., 2002


Hg(0)
Hg(II)
Hg(p)
Hg from other sources: local, regional & more distant
Hg(0)
Hg(II)
Hg(p)
Hg(0)
Hg(II)
Hg(p)
Hg(0)
Hg(II)
Hg(p)
Hg(0)
Hg(II)
Hg(p)
Measurement of wet deposition
Measurement of ambient air concentrations