



Mercury Overview + Modeling the Atmospheric Transport and Deposition of Mercury to the Great Lakes

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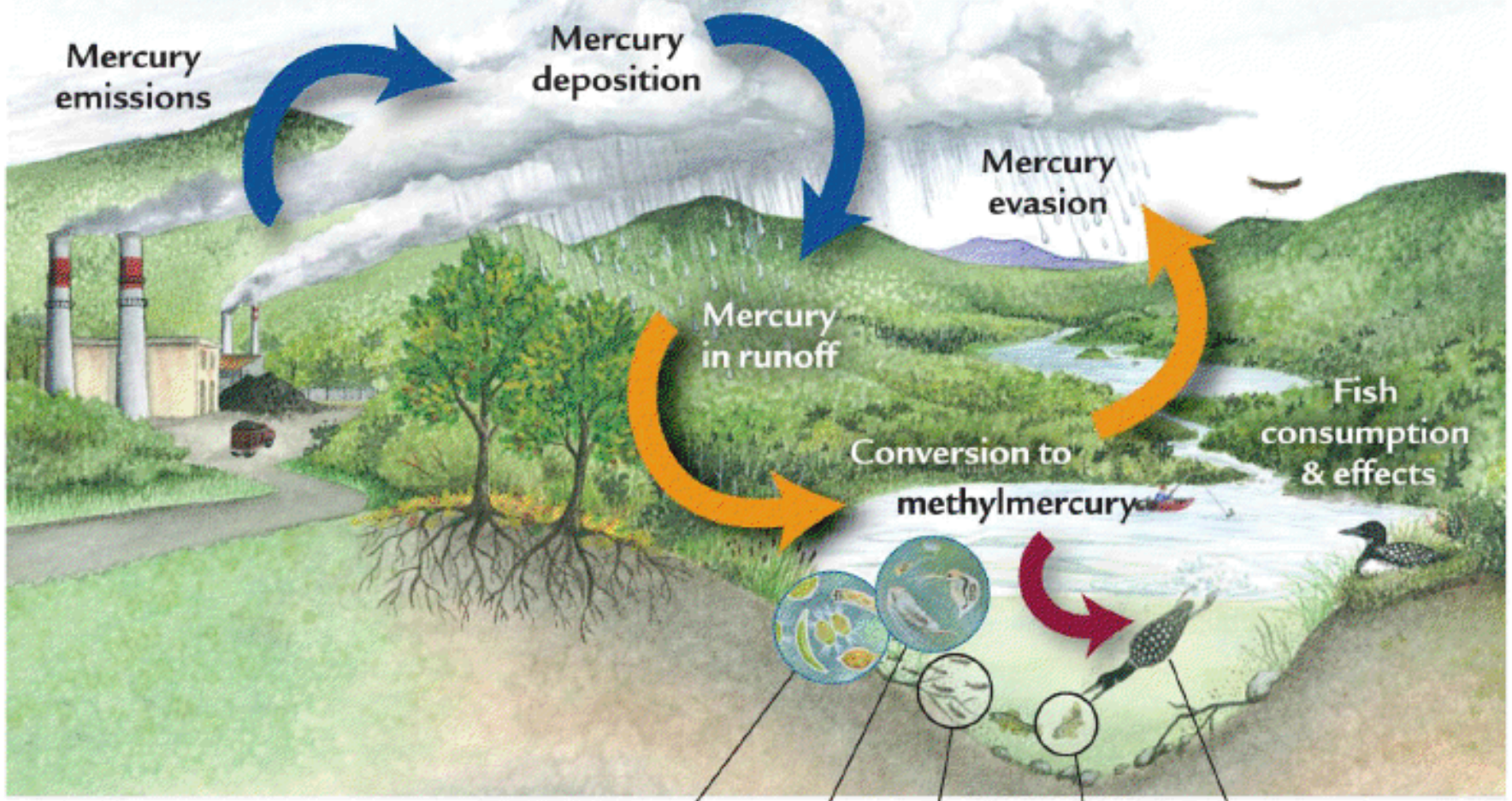
**CENRS Air Quality Research Subcommittee
Oct 16, 2014, Washington, DC**

Public Health Context

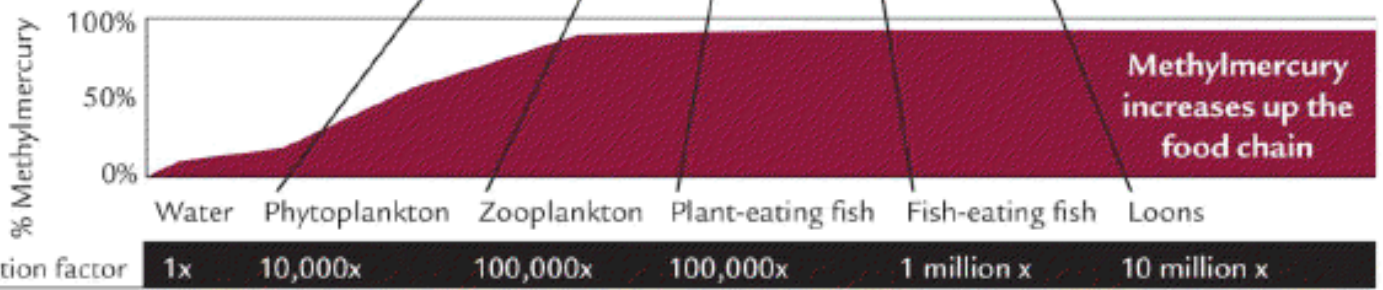
- ❑ Methyl-mercury is a developmental neurotoxin -- risks to fetuses/infants
- ❑ Cardiovascular toxicity might be even more significant (CRS, 2005)
- ❑ Uncertainties, but mercury toxicity *relatively* well understood
 - well-documented tragedies: (a) Minimata (Japan) ~1930 to ~1970; (b) Basra (Iraq), 1971
 - epidemiological studies, e.g., (a) Seychelles; (b) Faroe Islands; (c) New Zealand
- ❑ Critical exposure pathway: *methylmercury* from *fish consumption*
- ❑ Toxicity believed to be occurring at current exposures
- ❑ Widespread fish consumption advisories
- ❑ Methylmercury vs. Omega-III Fatty Acids
- ❑ Selenium – protective role?

**+ Wildlife
Health Issues
e.g., fish-eating birds**

Mercury in the Environment



Bioaccumulation of methylmercury in fish & wildlife



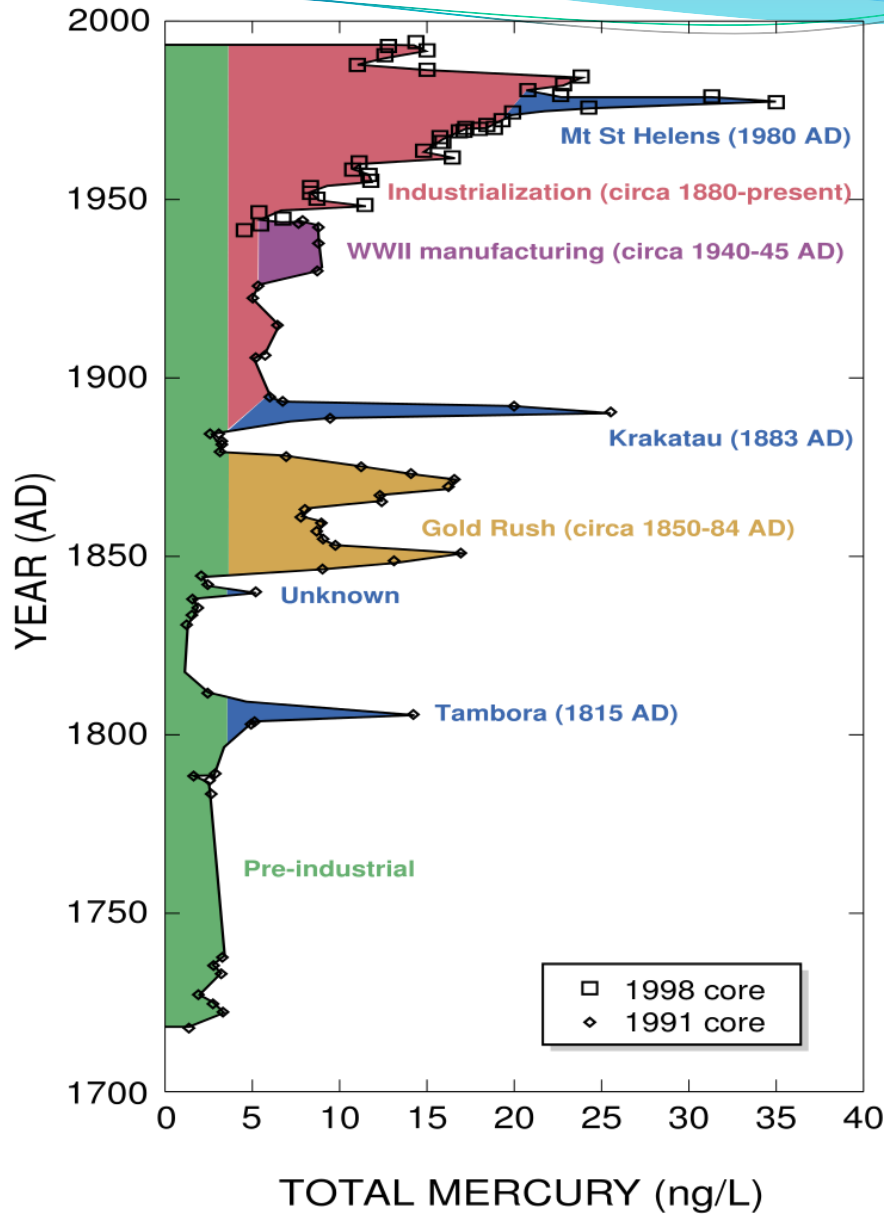
Environmental Mercury Cycling -- Natural vs. Anthropogenic

- ❑ 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 may be more bioavailable



Mercury in Ice Cores from the Upper Fremont Glacier

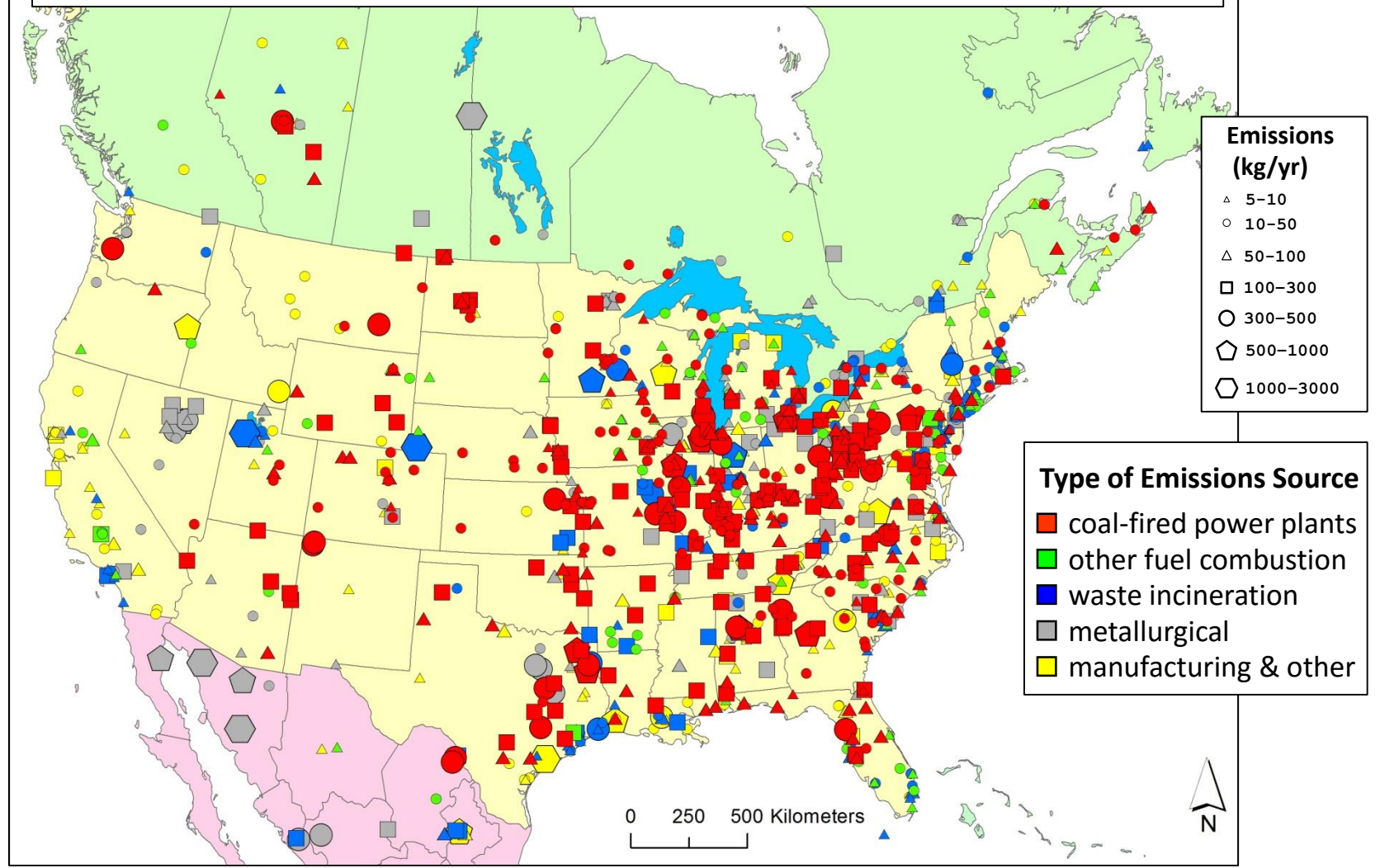
U.S. Geological Survey:
<http://toxics.usgs.gov/pubs/FS-051-02/pdf/fs-051-02.pdf>



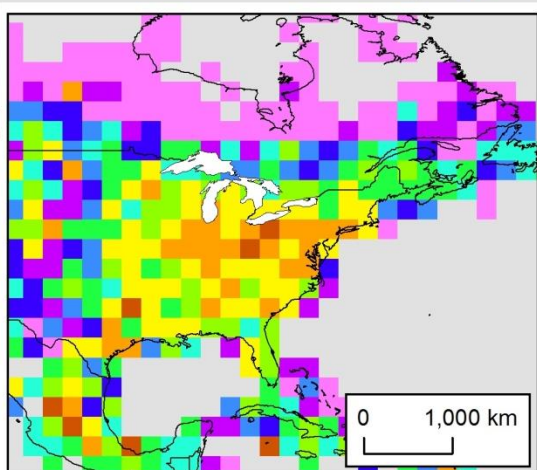
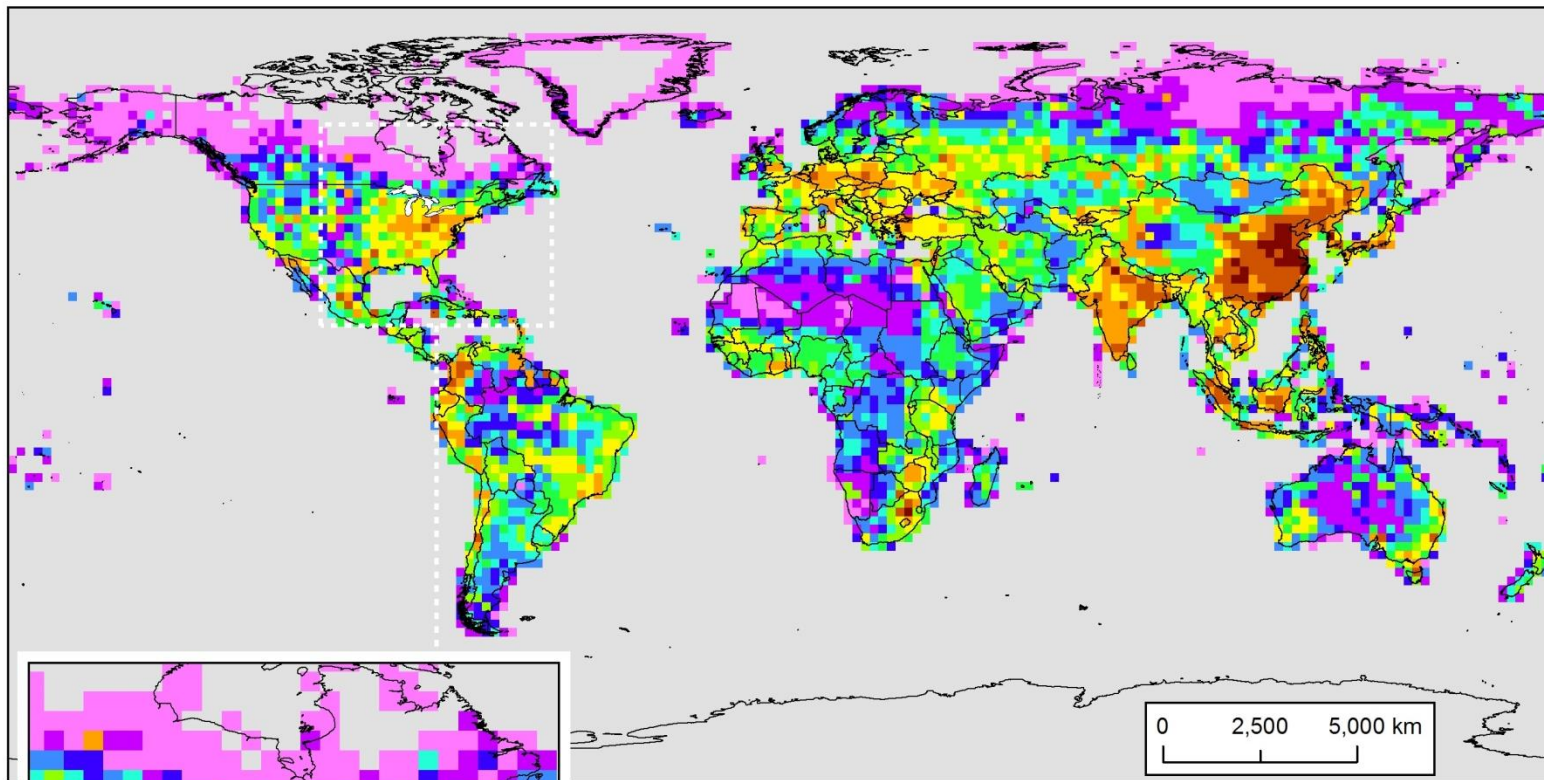
Natural vs. anthropogenic mercury?

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

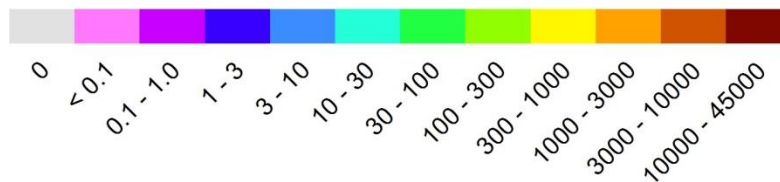
2005 Atmospheric Mercury Emissions from Large Point Sources



Anthropogenic Mercury Emissions (ca. 2005)

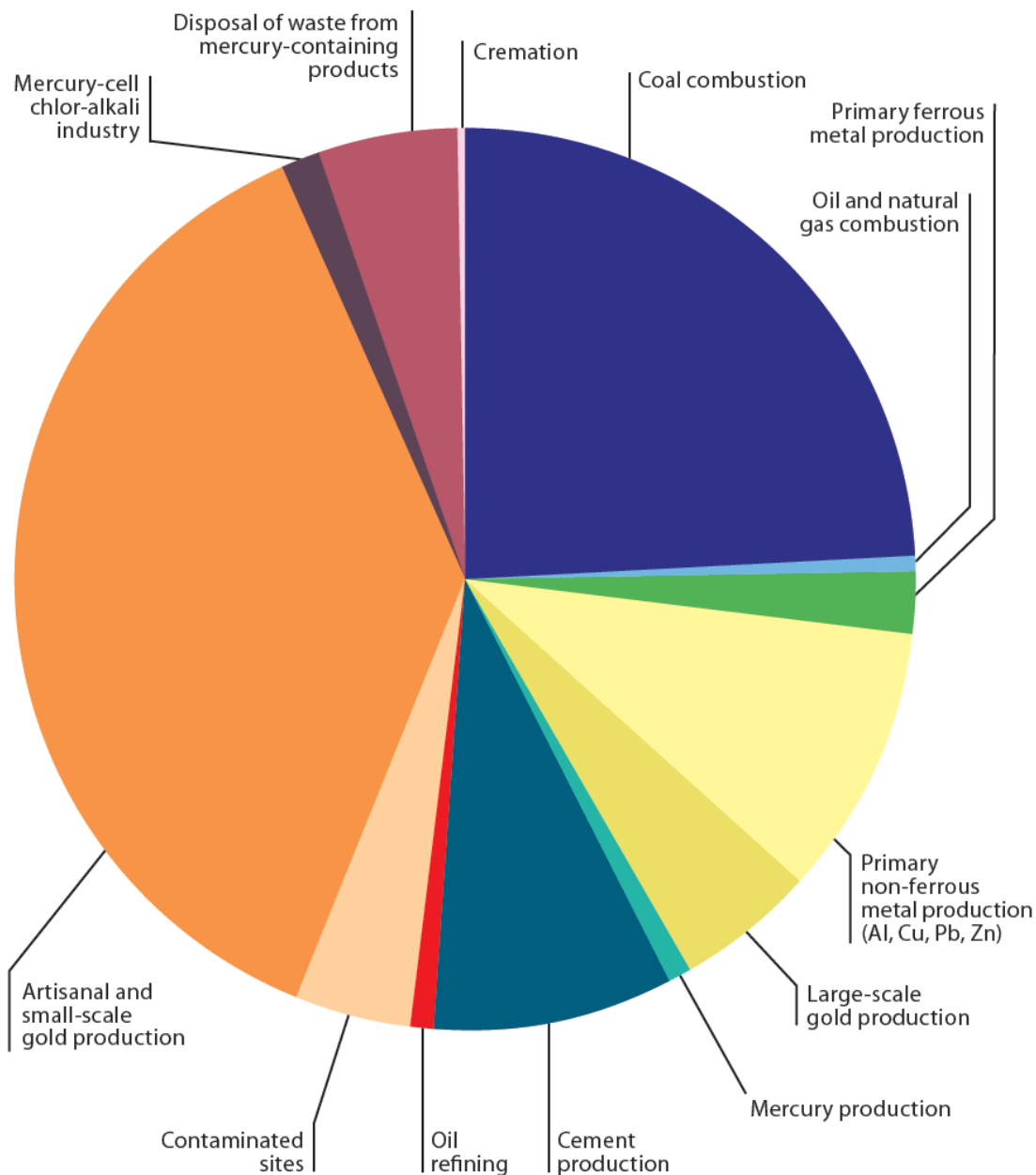


Atmospheric mercury emissions (kg/yr) from direct anthropogenic sources in each 2x2 degree grid cell

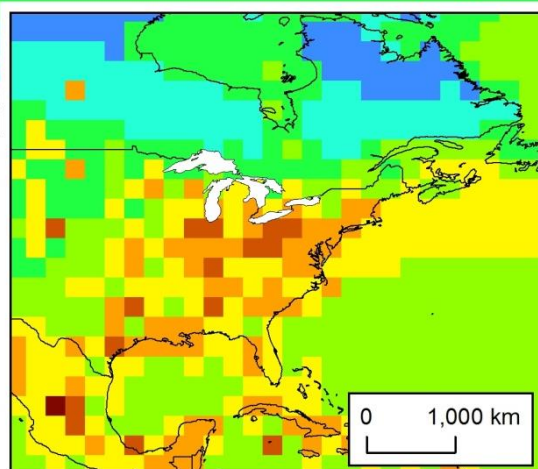
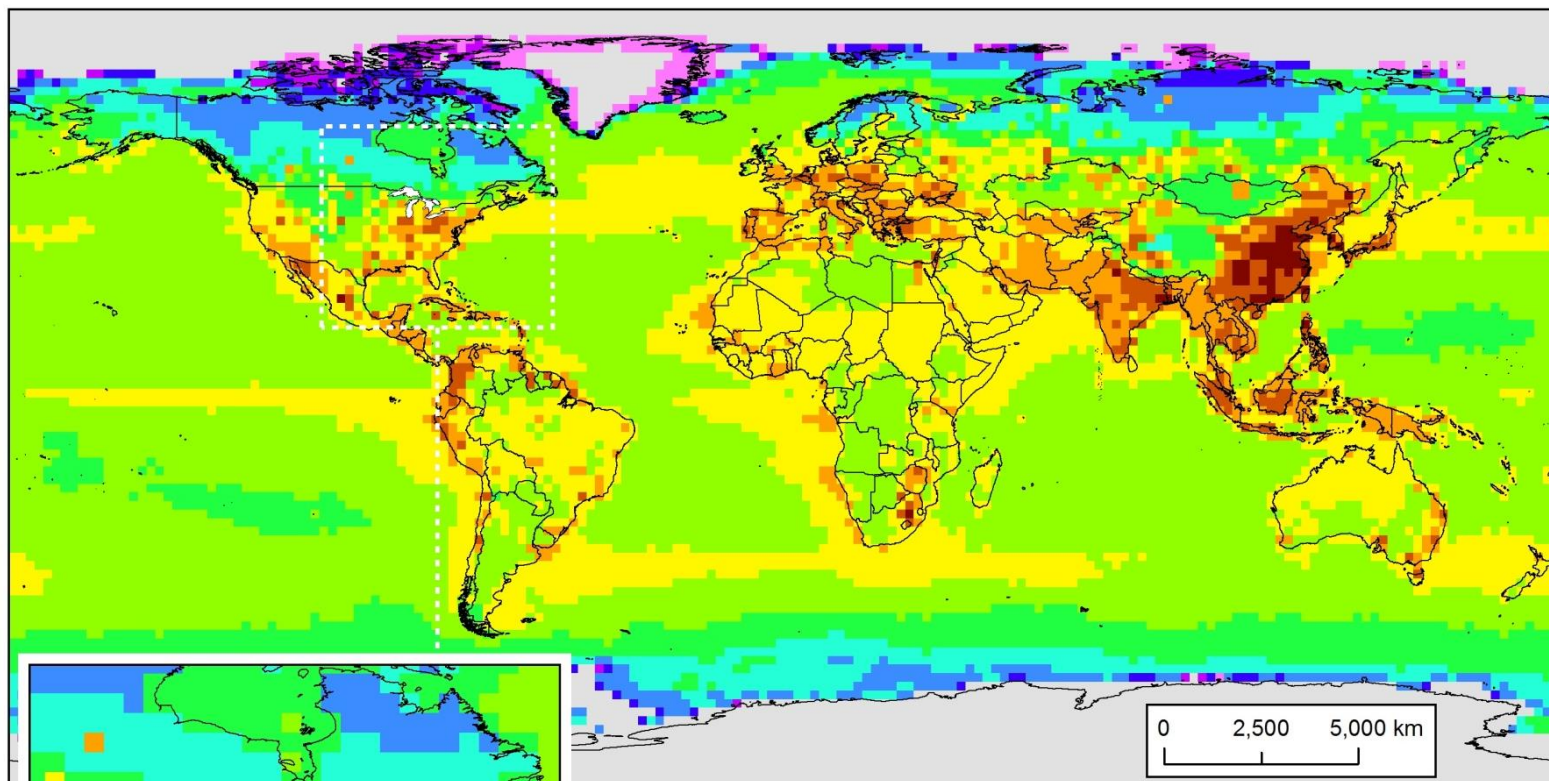


Proportions of global anthropogenic mercury emissions to air in 2010 from different sectors

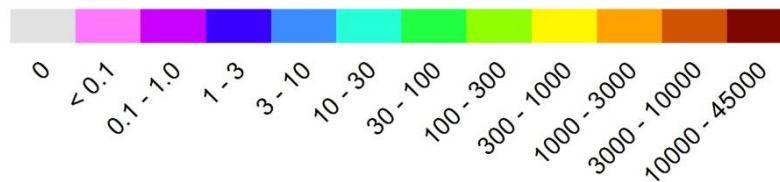
AMAP/UNEP, 2013. Technical Background Report for the Global Mercury Assessment 2013. Arctic Monitoring and Assessment Programme, Oslo, Norway/UNEP Chemicals Branch, Geneva, Switzerland. vi + 263 pp. Available at: <http://www.amap.no/documents/doc/technical-background-report-for-the-global-mercury-assessment-2013/848>

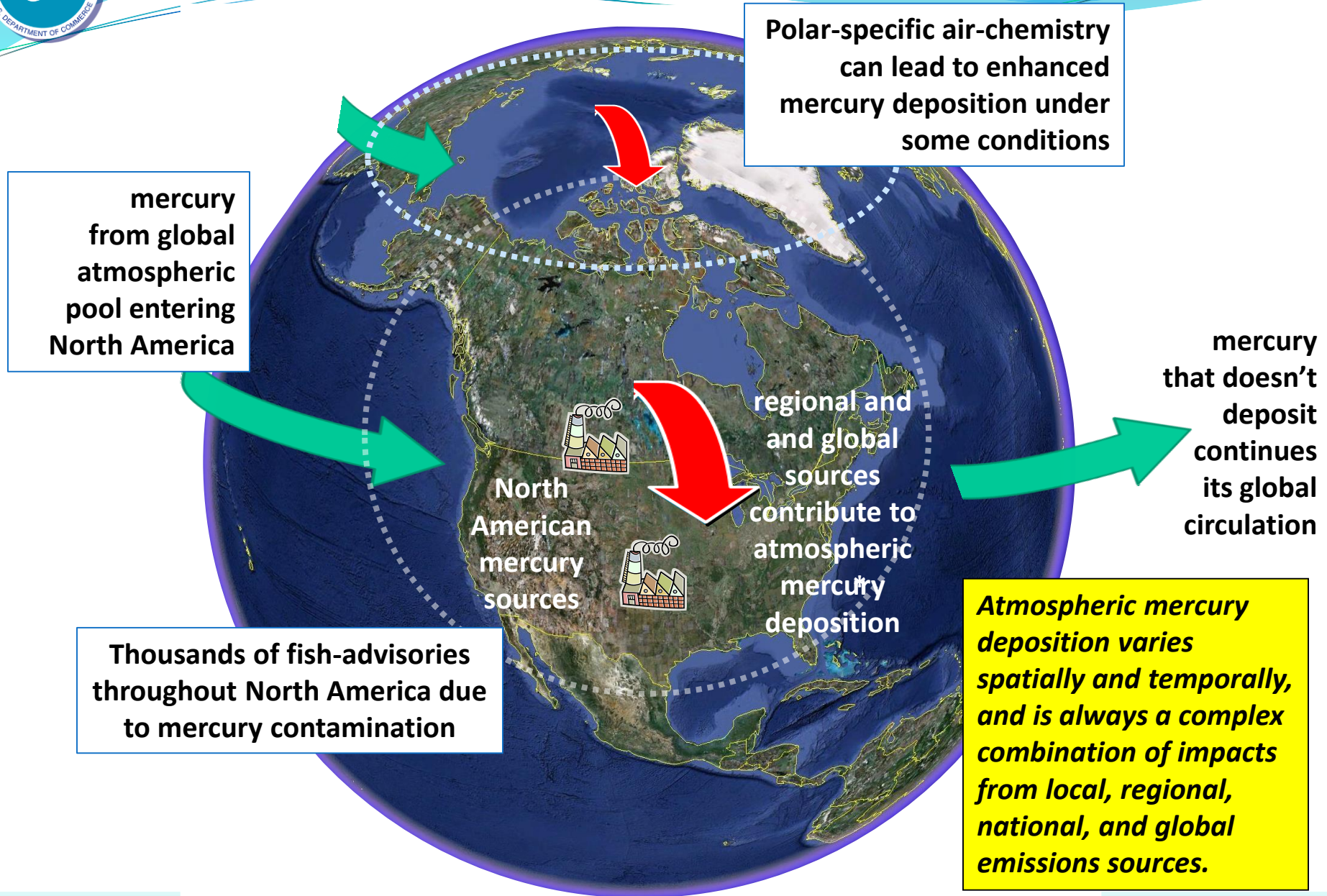


2005 Atmospheric Mercury Emissions (Direct Anthropogenic + Re-emit + Natural)



Atmospheric mercury emissions (kg/yr)
from all sources in each 2x2 degree grid cell





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

mercury from global atmospheric pool entering North America

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

North American mercury sources contribute to atmospheric mercury deposition

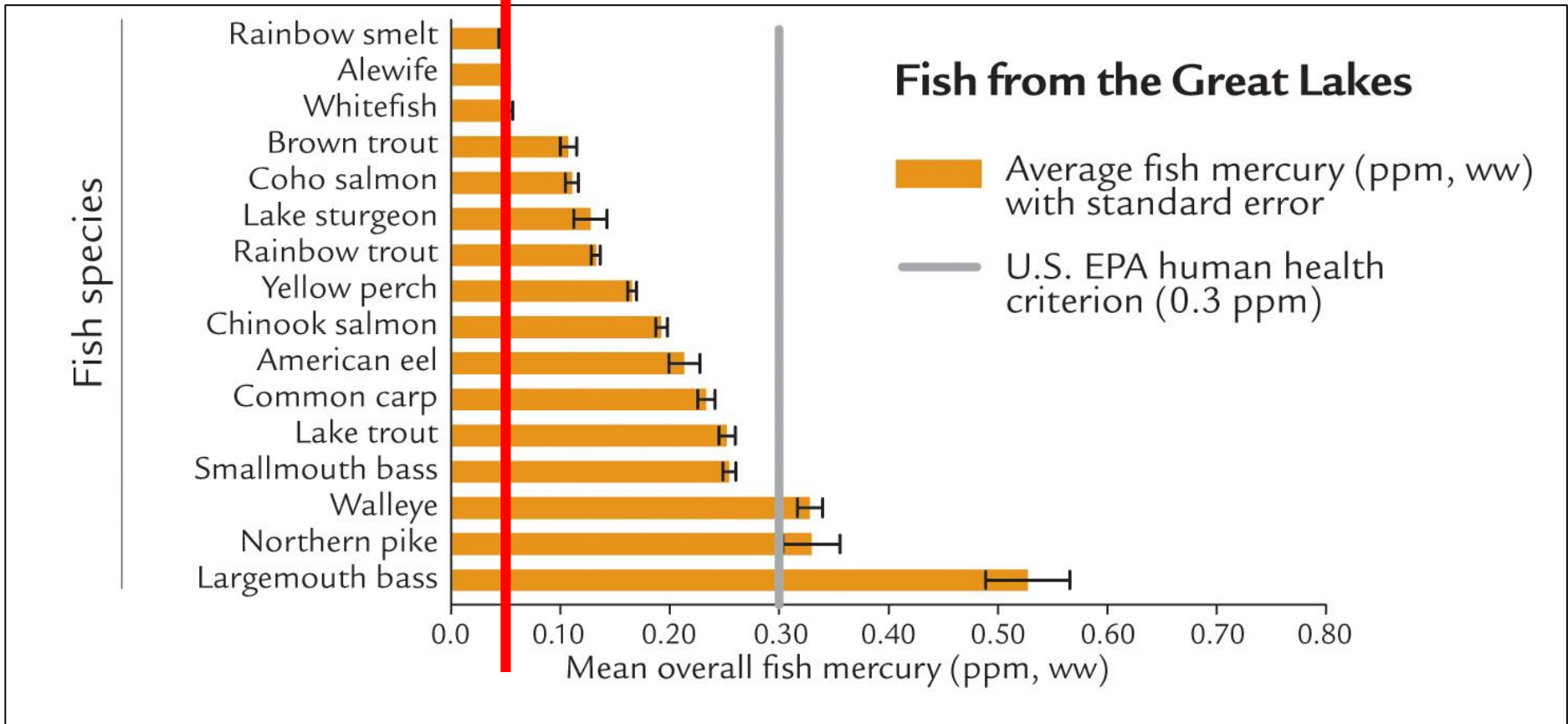
mercury that doesn't deposit continues its global circulation

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



0.05 ppm level recommended by the Great Lakes Fish Advisory Workgroup (2007)

Mercury in Great Lakes Fish



Evers, D.C., et al. (2011). *Great Lakes Mercury Connections: The Extent and Effects of Mercury Pollution in the Great Lakes Region*. Biodiversity Research Institute. Gorham, Maine. Report BRI 2011-18. 44 pages.

Atmospheric deposition is believed to be the largest current mercury loading pathway to the Great Lakes...

➤ How much is deposited and where does it come from?

(...this information can *only* be obtained via modeling...?)



Different “forms” of mercury in the atmosphere

Elemental Mercury -- Hg(0)

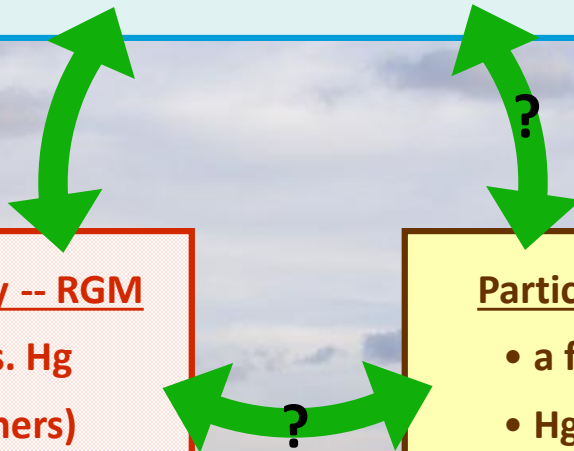
- most of total Hg in atmosphere
- doesn't easily dry or wet deposit
- globally distributed

Reactive Gaseous Mercury -- RGM

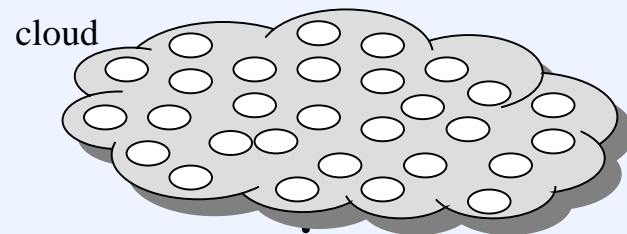
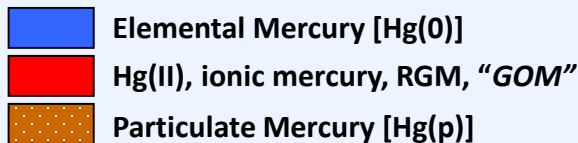
- a few % of total atmos. Hg
- oxidized Hg (HgCl₂, others)
- *very water soluble and “sticky”*
- bioavailable

Particulate Mercury -- Hg(p)

- a few % of total atmos. Hg
- Hg in/on atmos. particles
- atmos. lifetime 1~ 2 weeks
- bioavailability?



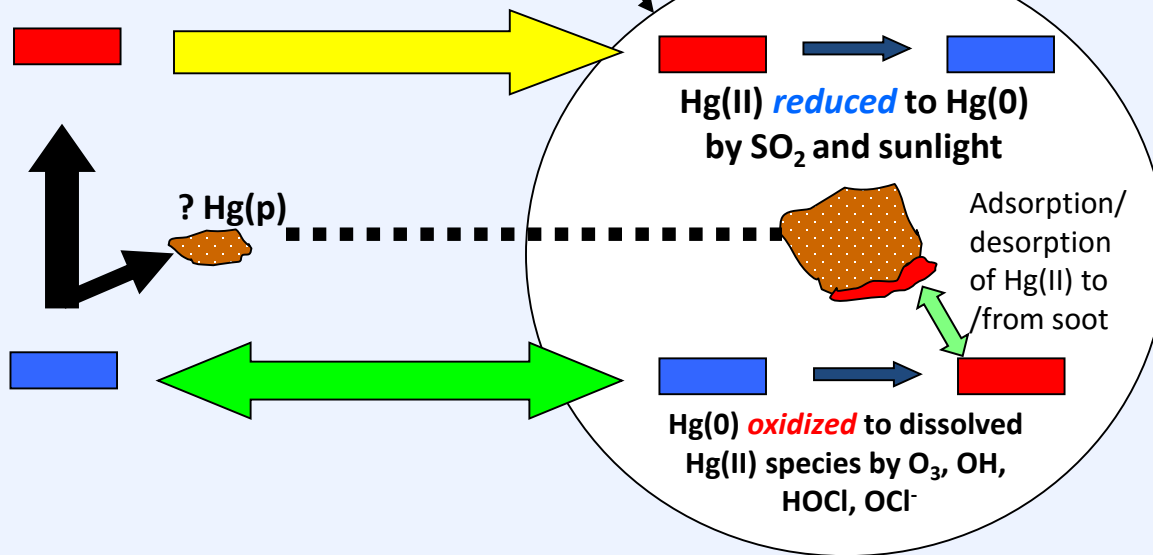
Atmospheric Mercury Fate Processes



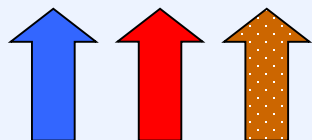
CLOUD DROPLET

Vapor phase:

Hg(0) oxidized to RGM [and maybe Hg(p)?] by O_3 , H_2O_2 , Cl_2 , OH, HCl, Br



In-plume reduction of Hg(II) to Hg(0)?



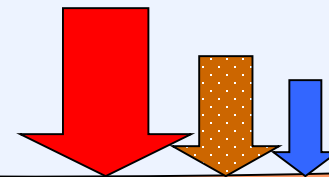
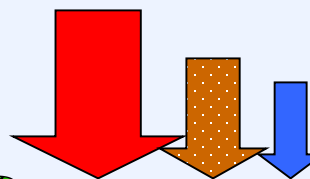
Anthropogenic Emissions

Natural emissions

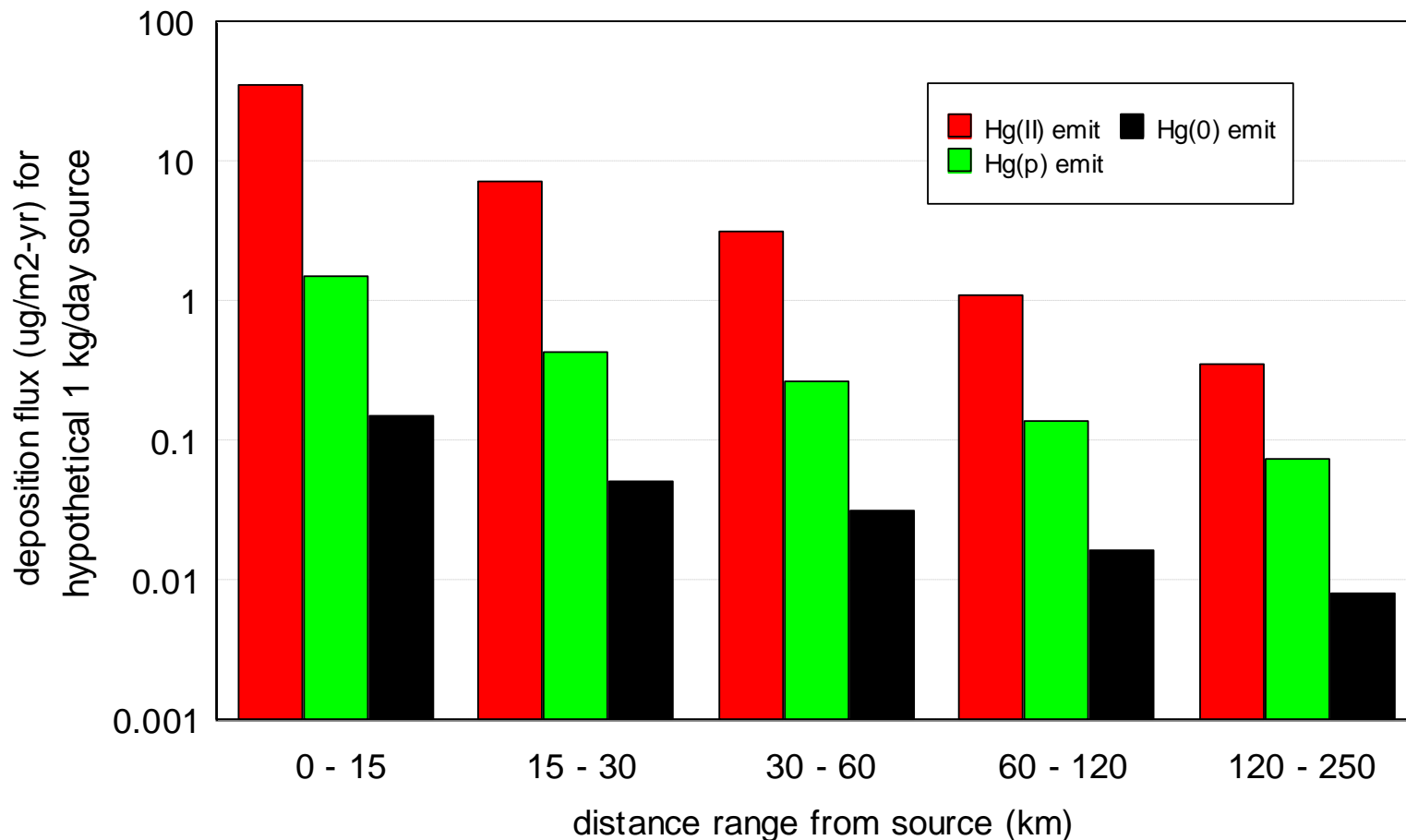
Re-emission of previously deposited anthropogenic and natural mercury

Wet deposition

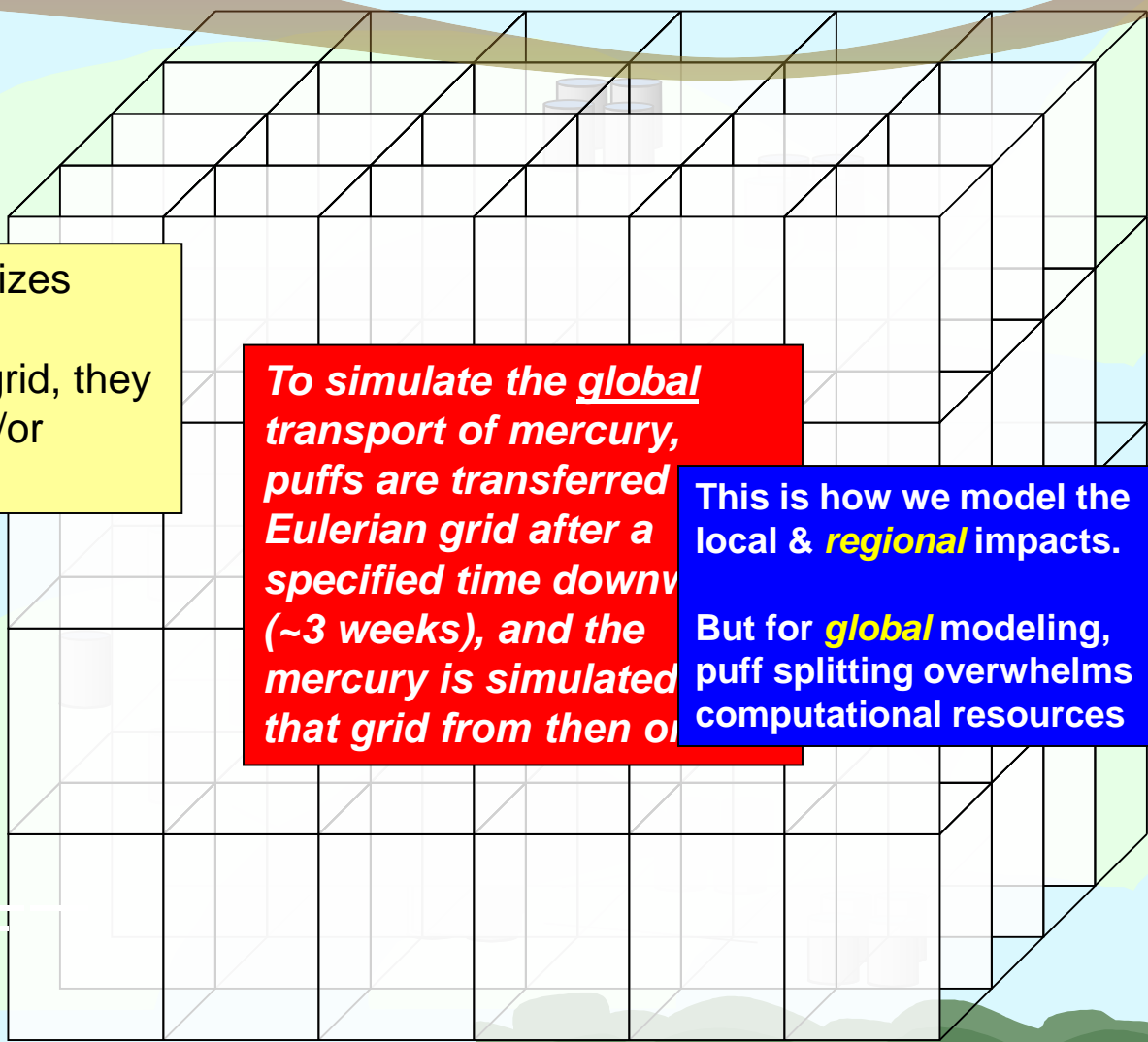
Dry deposition



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



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



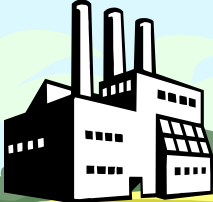
When puffs grow to sizes large relative to the meteorological data grid, they split, horizontally and/or vertically

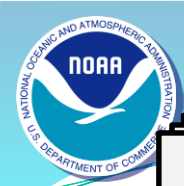
To simulate the global transport of mercury, puffs are transferred Eulerian grid after a specified time downwind (~3 weeks), and the mercury is simulated that grid from then on

This is how we model the local & *regional* impacts. But for *global* modeling, puff splitting overwhelms computational resources

Puffs of pollutant are emitted and dispersed downwind

Atmospheric chemistry and deposition simulated for each puff





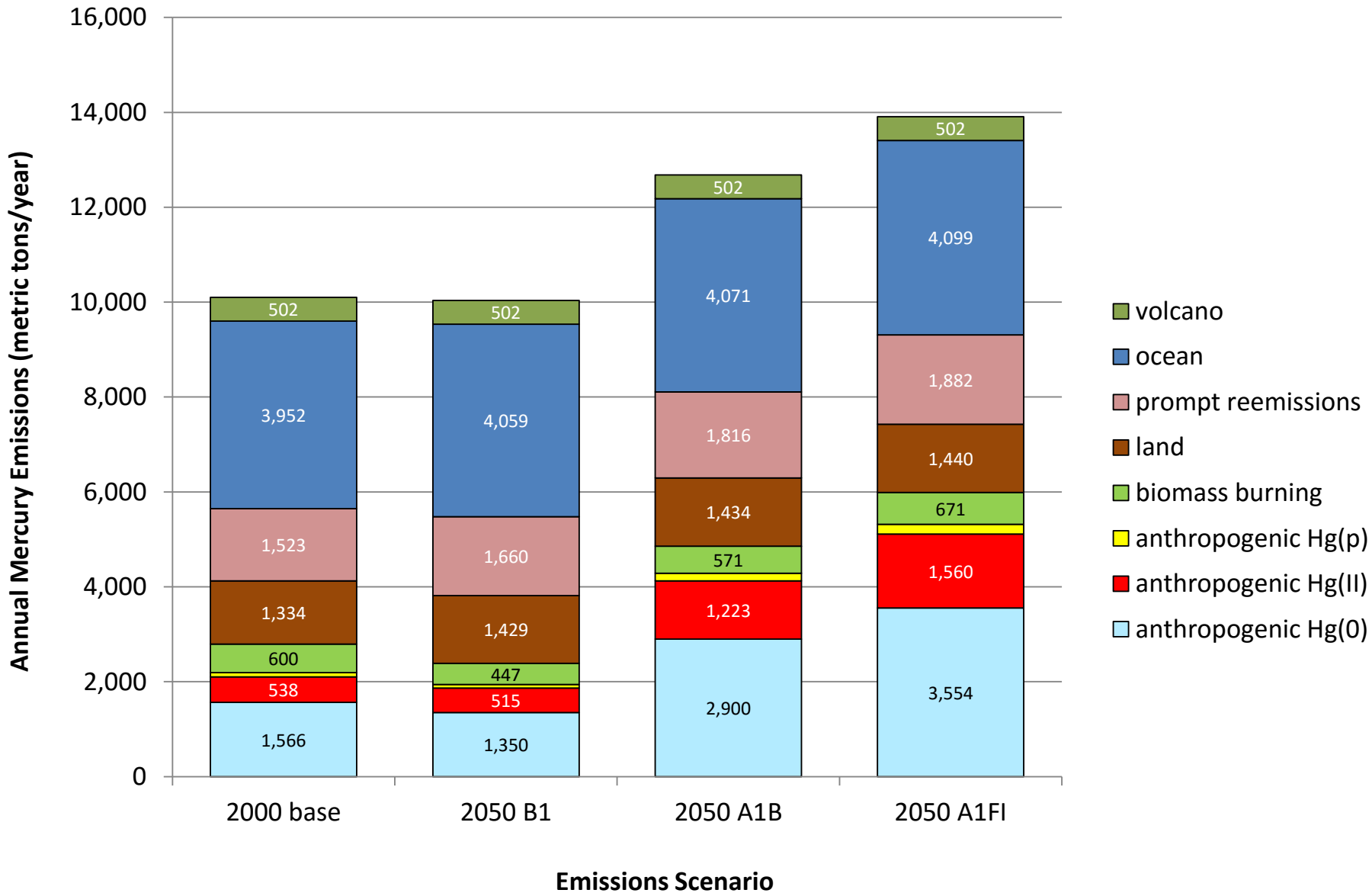
**Modeling Atmospheric Mercury
Deposition to the Great Lakes:
Projected Consequences of
Alternative Future Emissions Scenarios**

**Final Report for work conducted
with FY2012 funding from the
Great Lakes Restoration Initiative,
Oct 9, 2014, 194 pages.**

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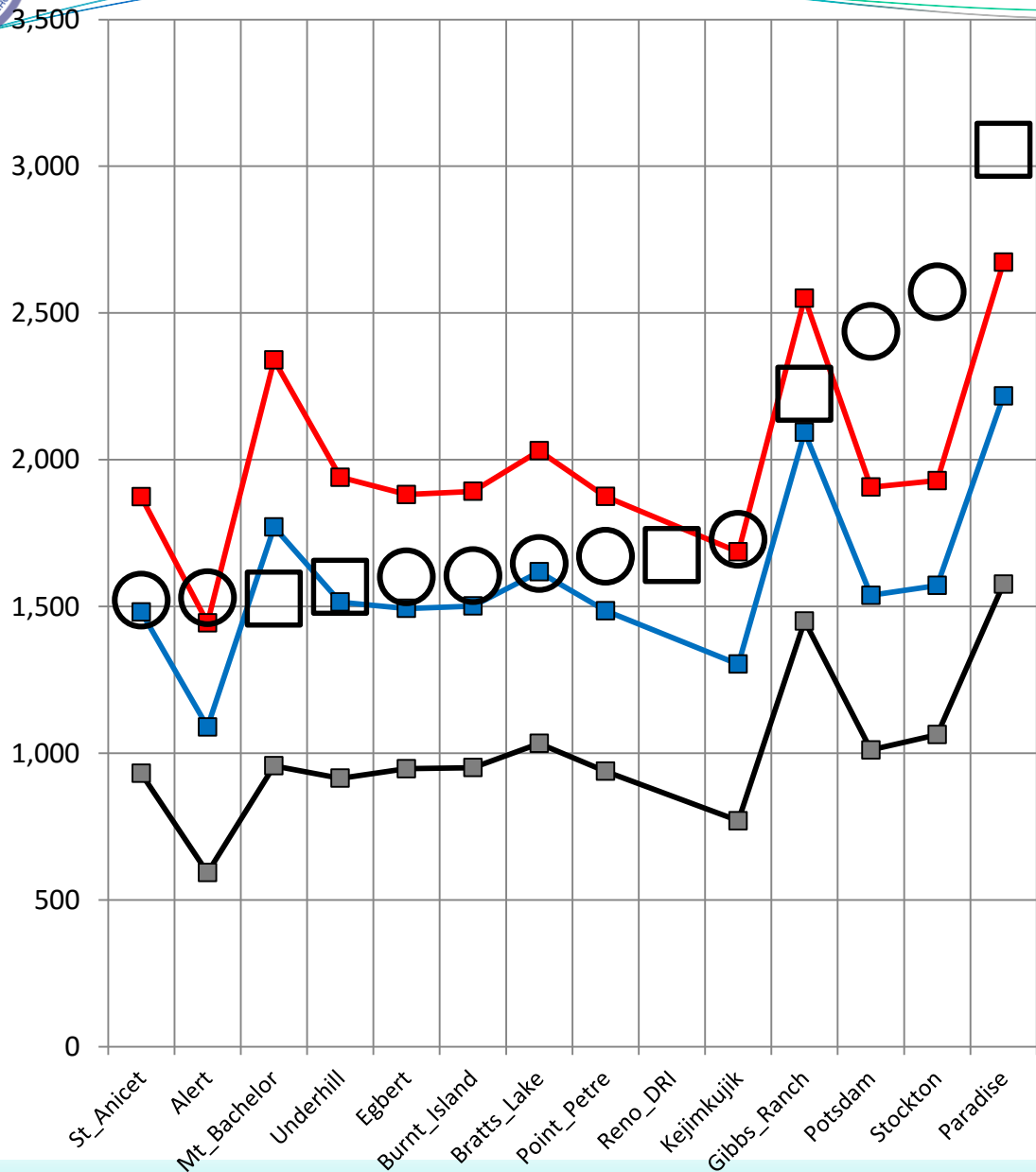
**Report has
just been
completed...**

*...this work
was carried
out just with
the Eulerian
grid approach*





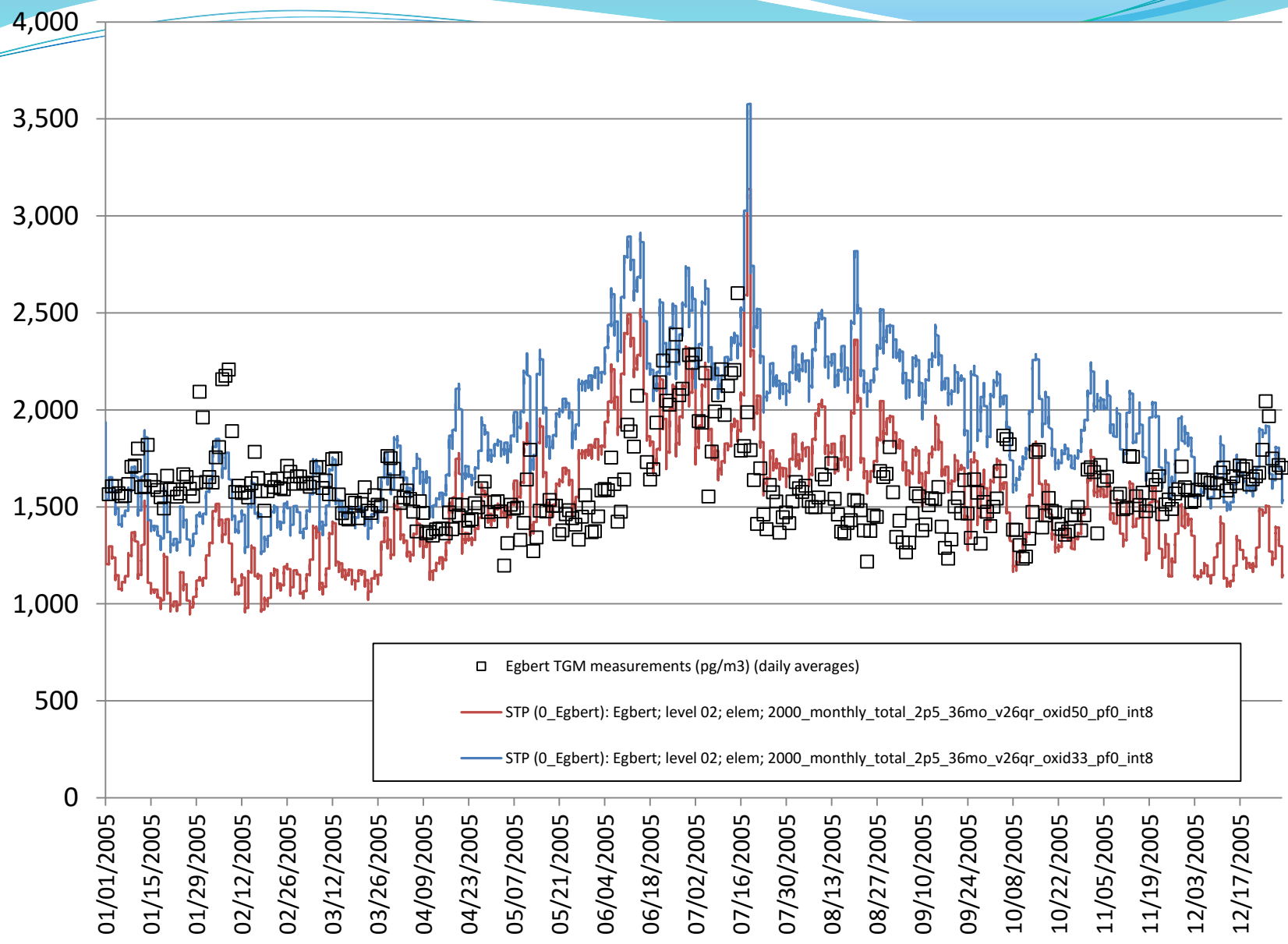
Atmospheric concentrations: modeled Hg(0)
vs. measured GEM or TGM (pg/m3)



- average GEM measured
- average TGM measured
- avg model, oxid50, pf0, elem, just when measured
- avg model, oxid33, pf0, elem, just when measured
- avg model, oxid100, pf100, elem, just when measured

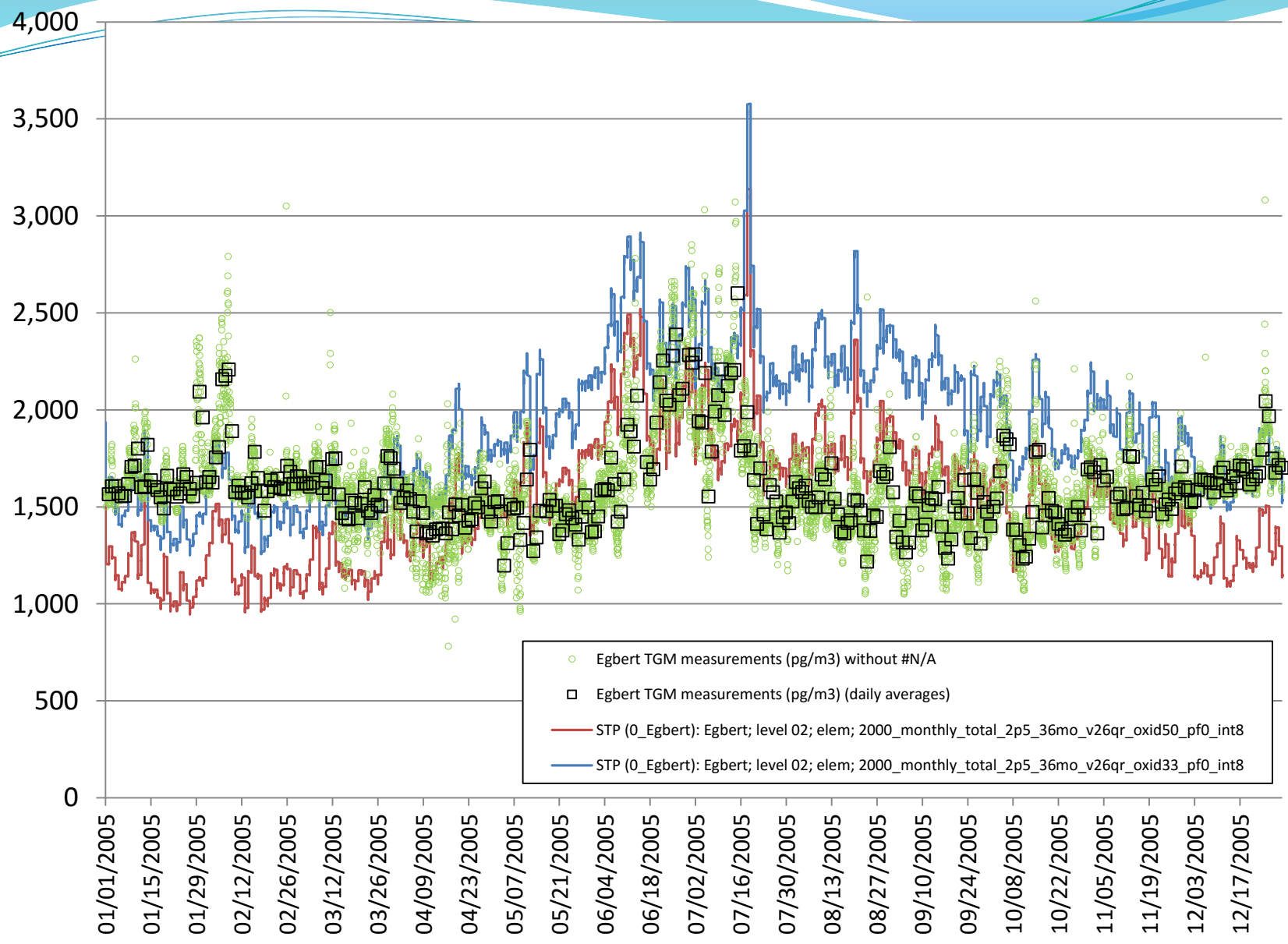


Atmospheric Mercury Concentration (pg/m3)





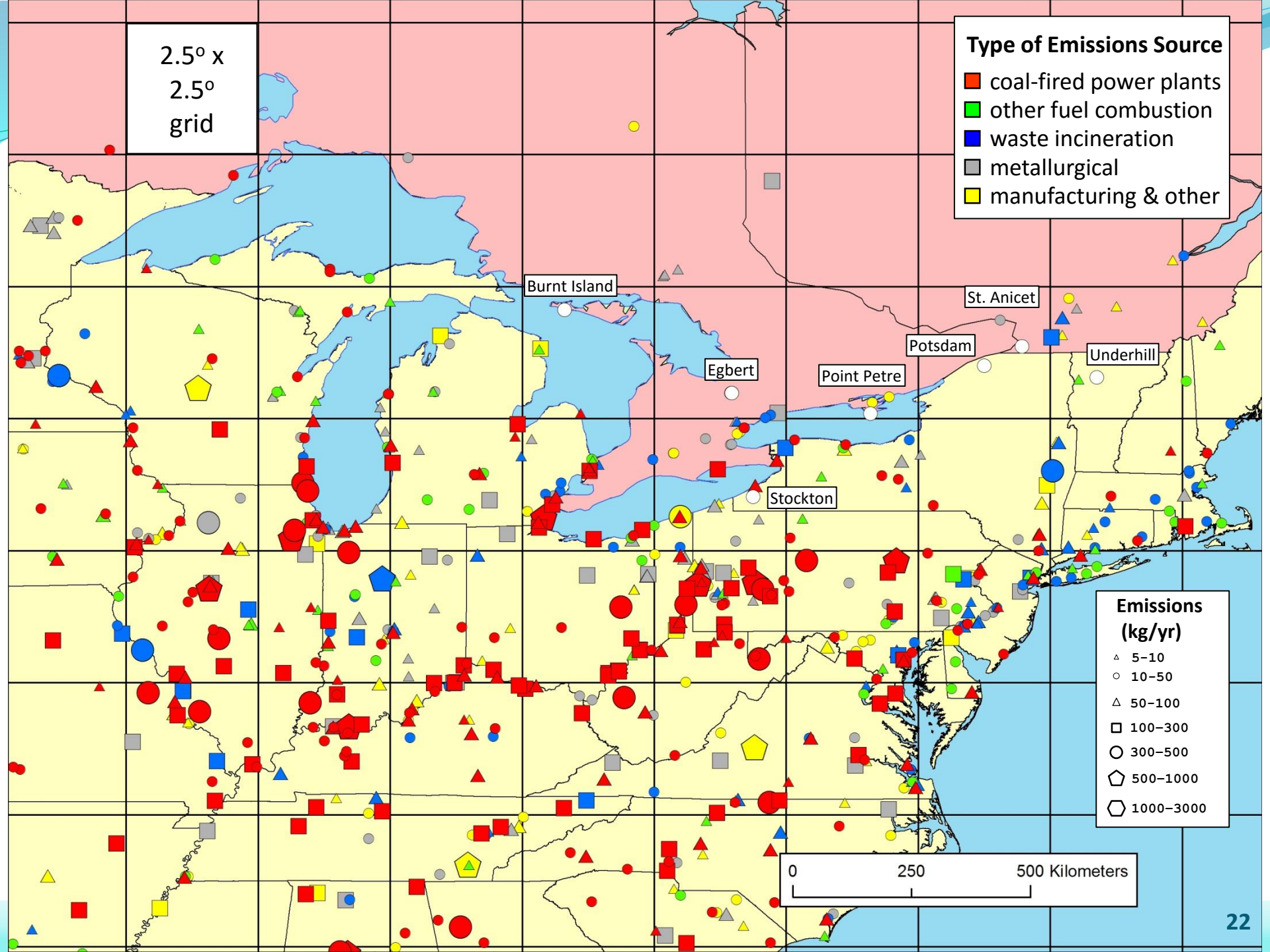
Atmospheric Mercury Concentration (pg/m3)



2.5° x
2.5°
grid

Type of Emissions Source

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

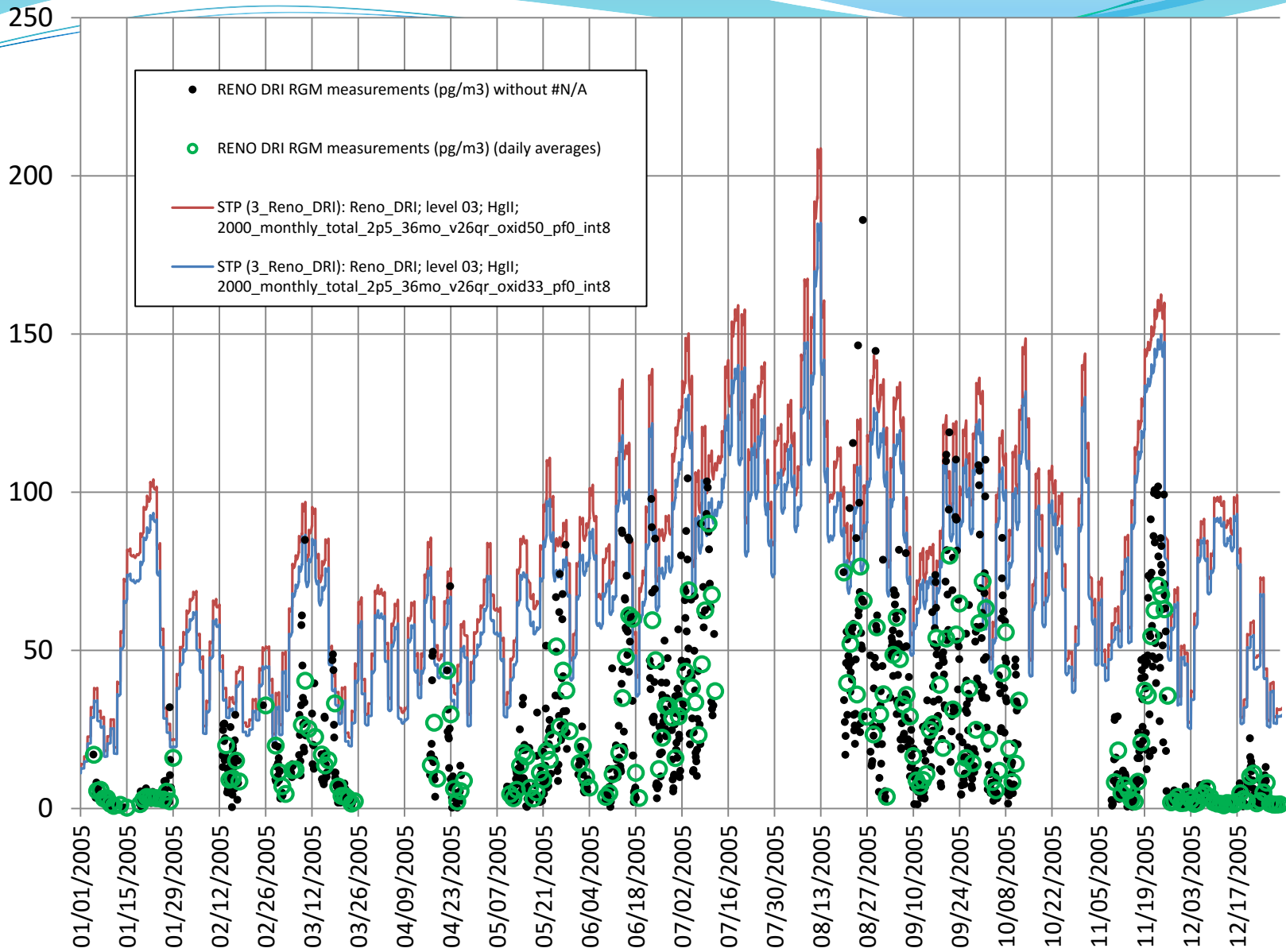


Emissions (kg/yr)

- △ 5-10
- 10-50
- △ 50-100
- 100-300
- 300-500
- ⬠ 500-1000
- ⬡ 1000-3000

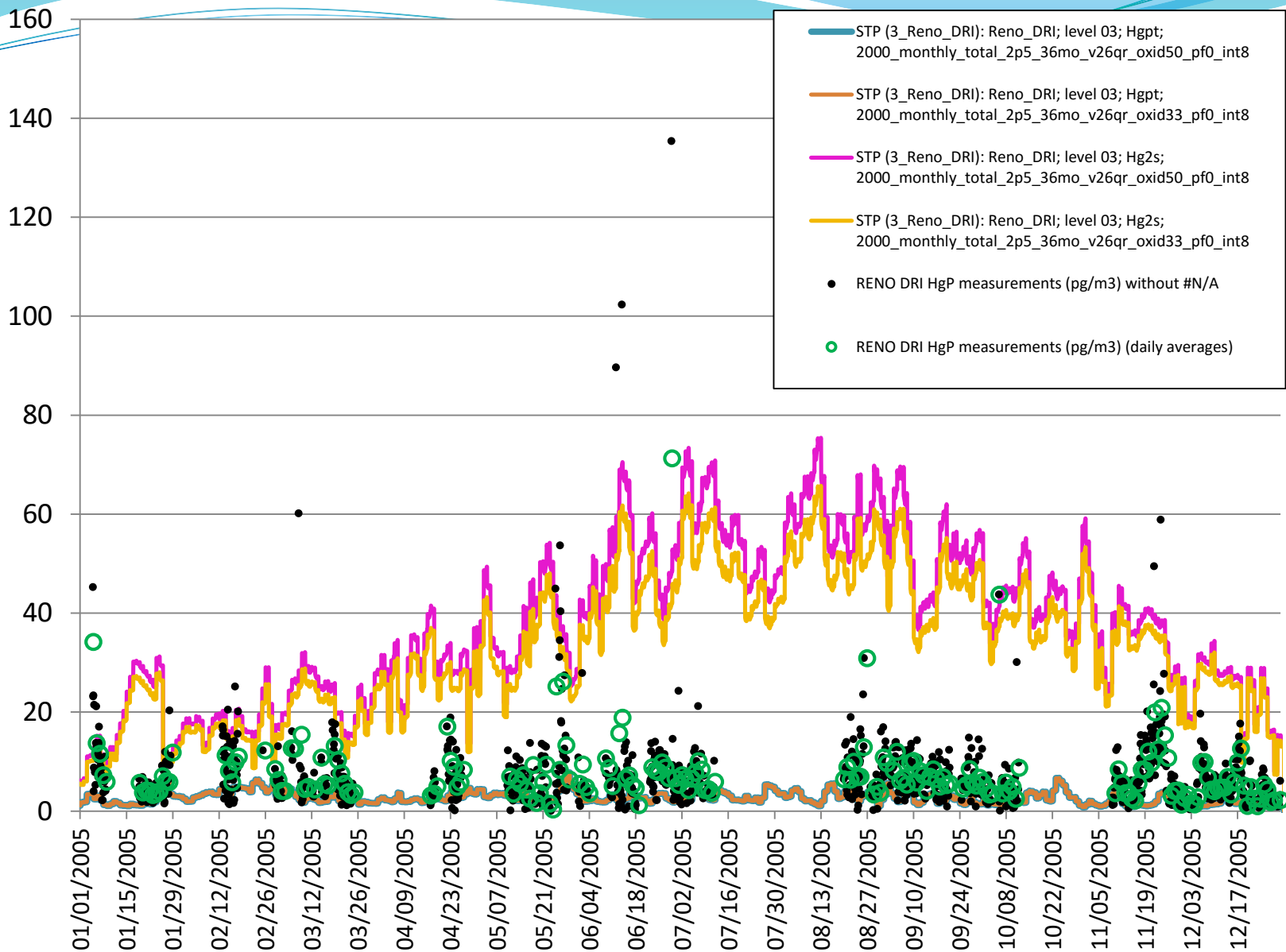


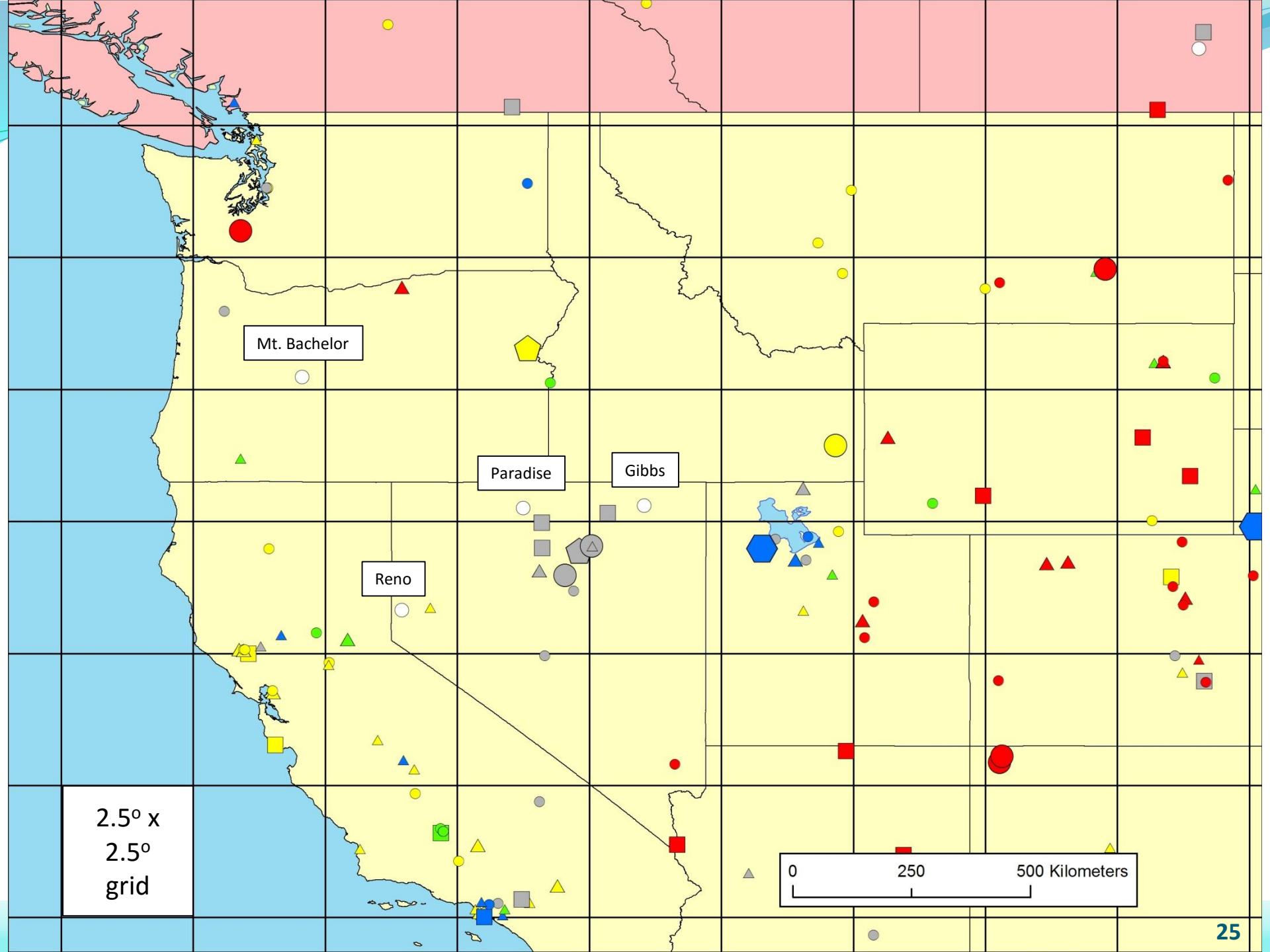
Atmospheric Mercury Concentration (pg/m3)





Atmospheric Mercury Concentration (pg/m3)





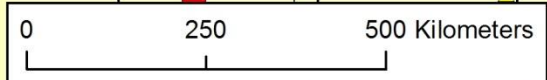
Mt. Bachelor

Paradise

Gibbs

Reno

2.5° x
2.5°
grid

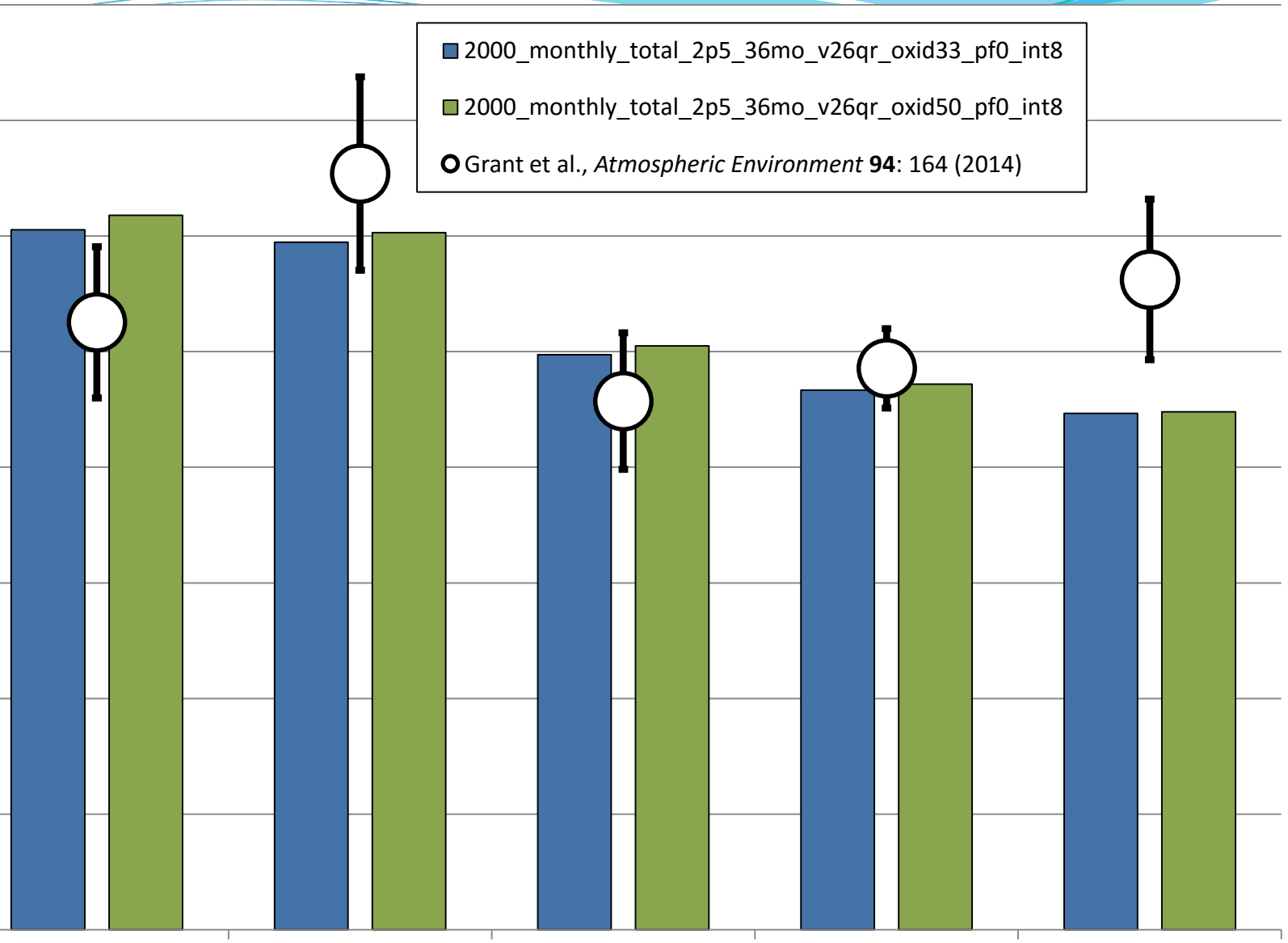


Total Mercury Deposition Flux (ug/m²-yr)

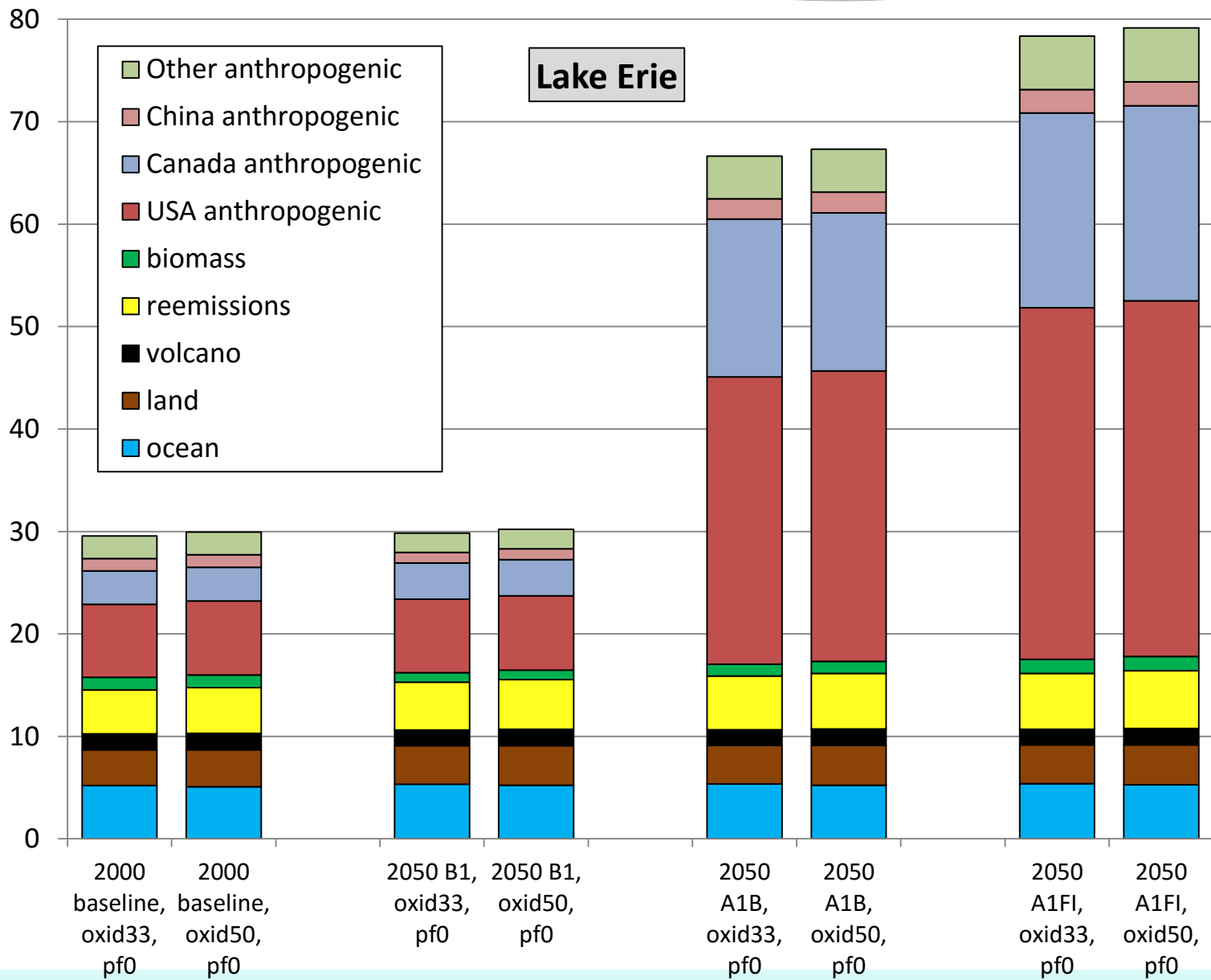
40
35
30
25
20
15
10
5
0

- 2000_monthly_total_2p5_36mo_v26qr_oxid33_pf0_int8
- 2000_monthly_total_2p5_36mo_v26qr_oxid50_pf0_int8
- Grant et al., *Atmospheric Environment* **94**: 164 (2014)

Lake Ontario Lake Erie Lake Superior Lake Huron Lake Michigan

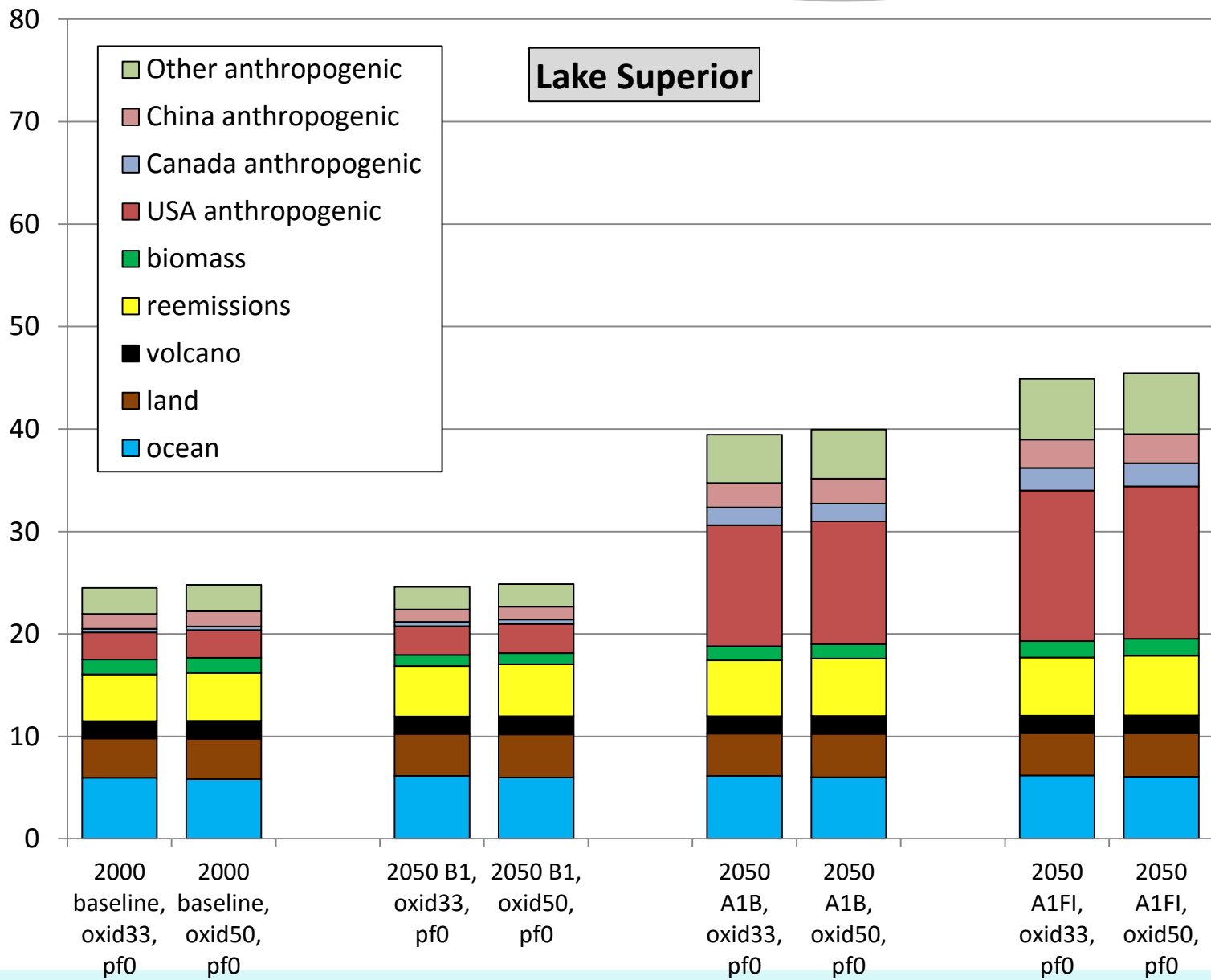


Model-estimated total mercury deposition flux (ug/m²-yr)



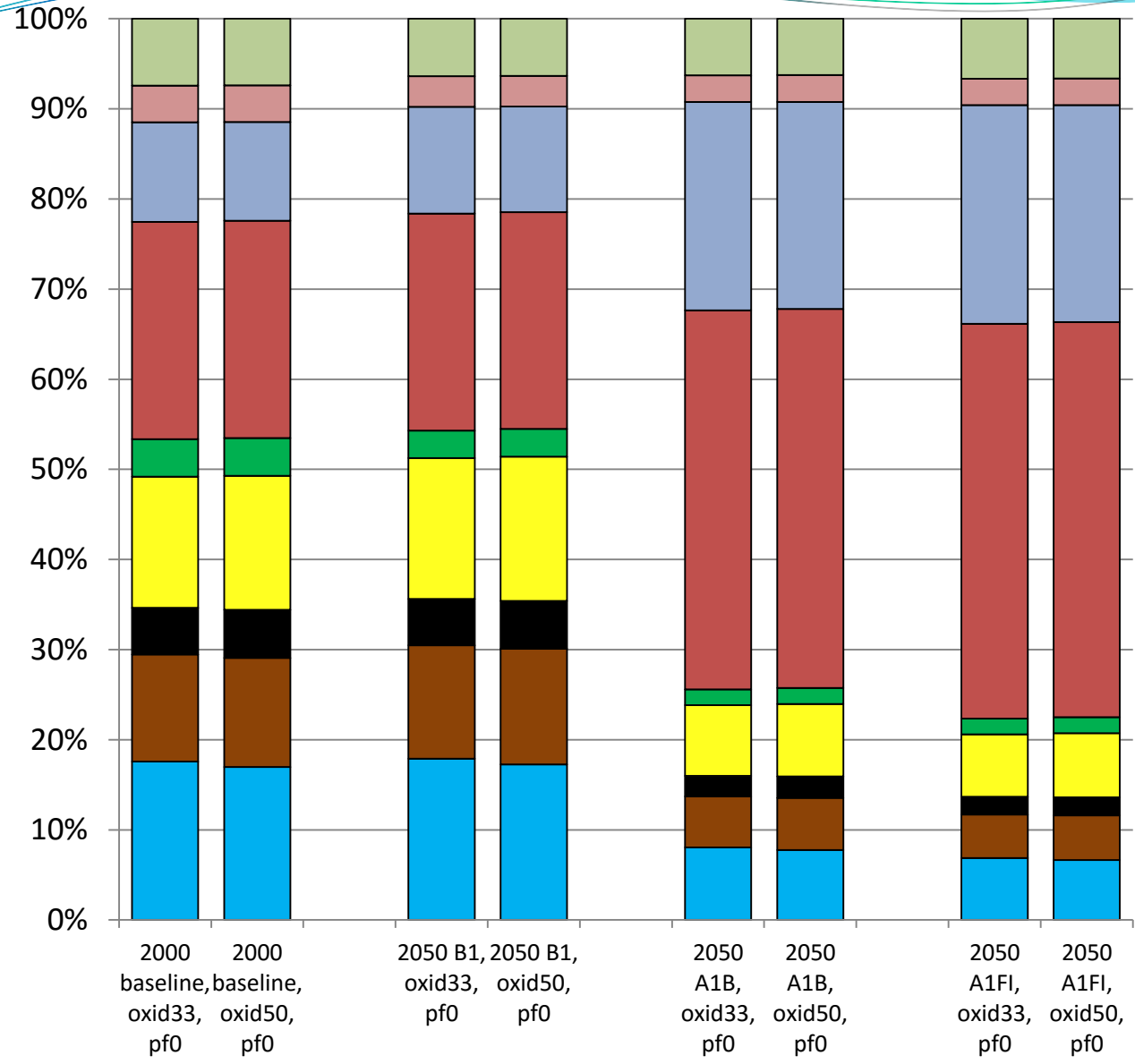


Model-estimated total mercury deposition flux (ug/m²-yr)

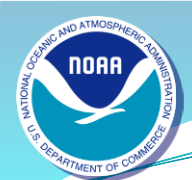




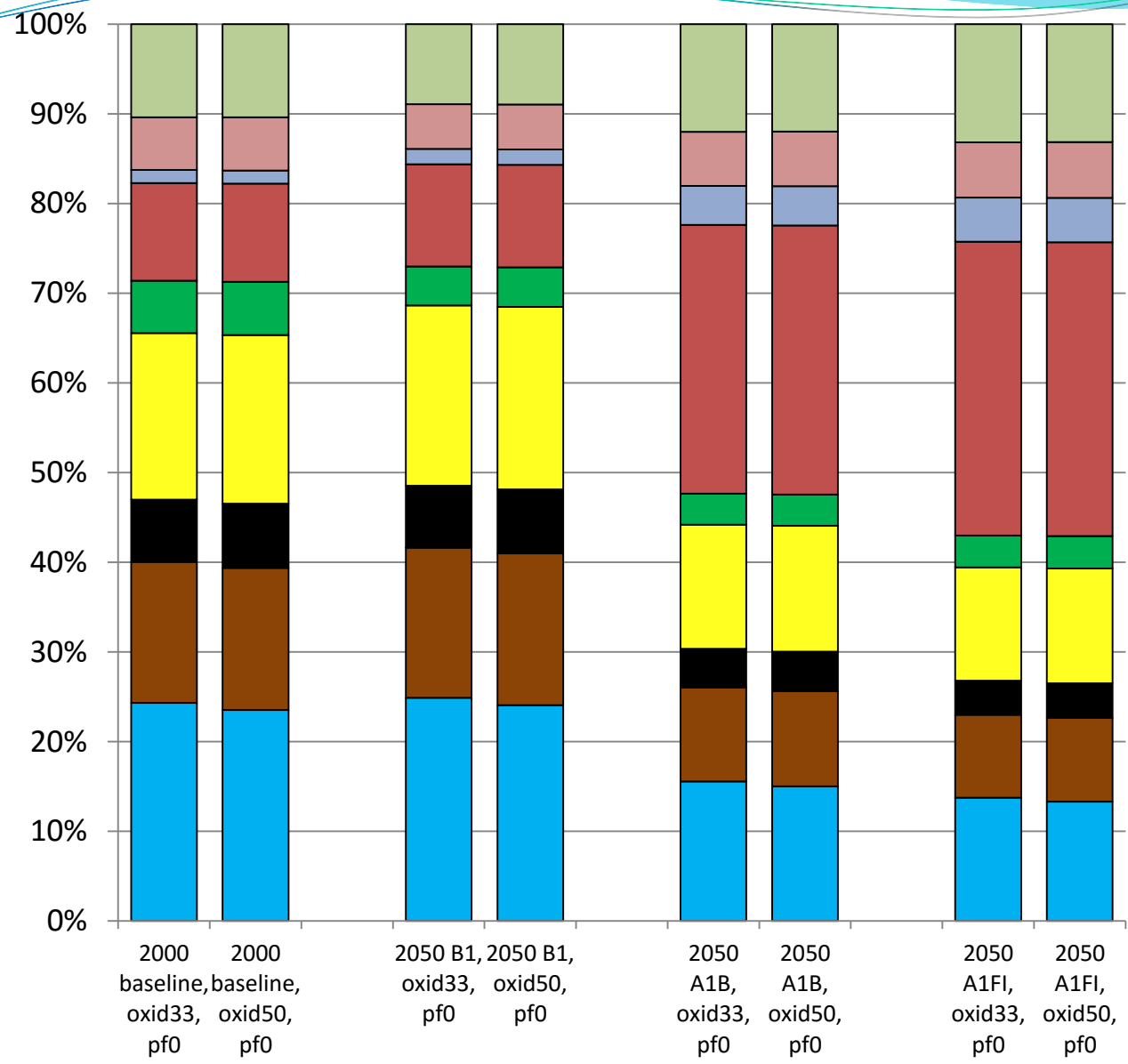
Fraction of total model-estimated mercury deposition flux arising from a given inventory or country-specific subset



- ### Lake Erie
- Other anthropogenic
 - China anthropogenic
 - Canada anthropogenic
 - USA anthropogenic
 - biomass
 - reemissions
 - volcano
 - land
 - ocean



Fraction of total model-estimated mercury deposition flux arising from a given inventory or country-specific subset



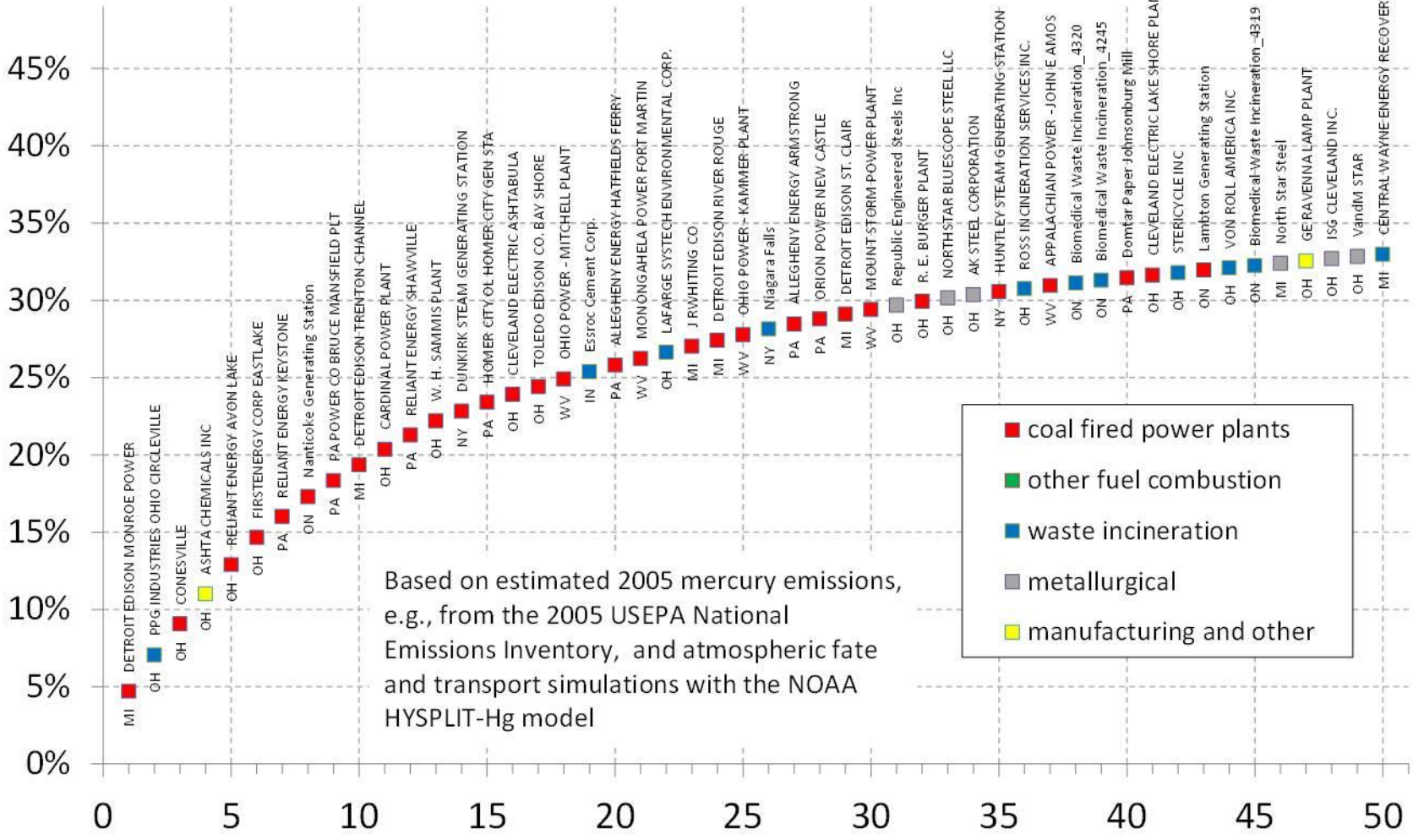
Lake Superior

- Other anthropogenic
- China anthropogenic
- Canada anthropogenic
- USA anthropogenic
- biomass
- reemissions
- volcano
- land
- ocean

From earlier Lagrangian + Eulerian work... very detailed source-receptor results

Cumulative Fraction of Total Modeled Deposition (2005)

Top 50 Atmospheric Deposition Contributors to Lake Erie



Thanks!

*This work was partially funded through
the Great Lakes Restoration Initiative*

