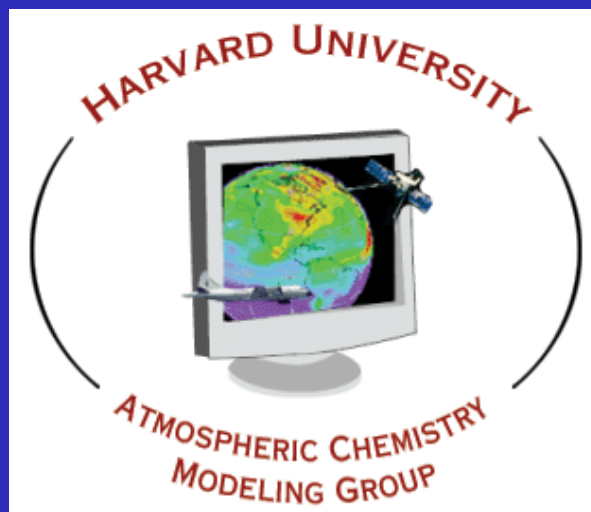


MERCURY IN THE ENVIRONMENT: from smokestack to stomach

Daniel J. Jacob

and the Harvard Team-Hg: Helen Amos, Bess Corbitt, Chris Holmes, Hannah Horowitz, Justin Parrella, Noelle Selin, Nicole Smith-Downey, Anne Soerensen, Elsie Sunderland

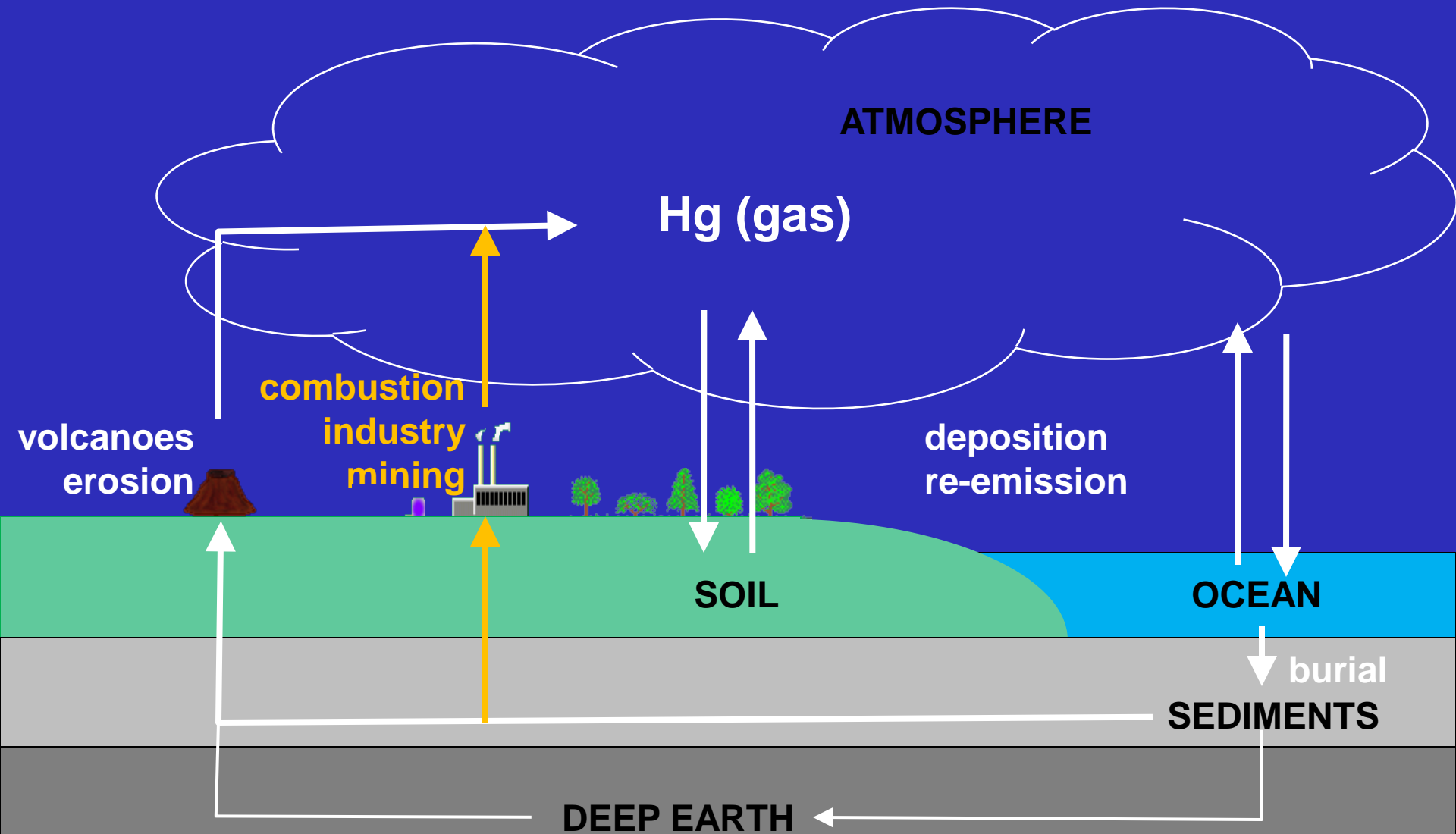


and funding from NSF, EPRI



MERCURY (Hg) IS A NATURAL ELEMENT

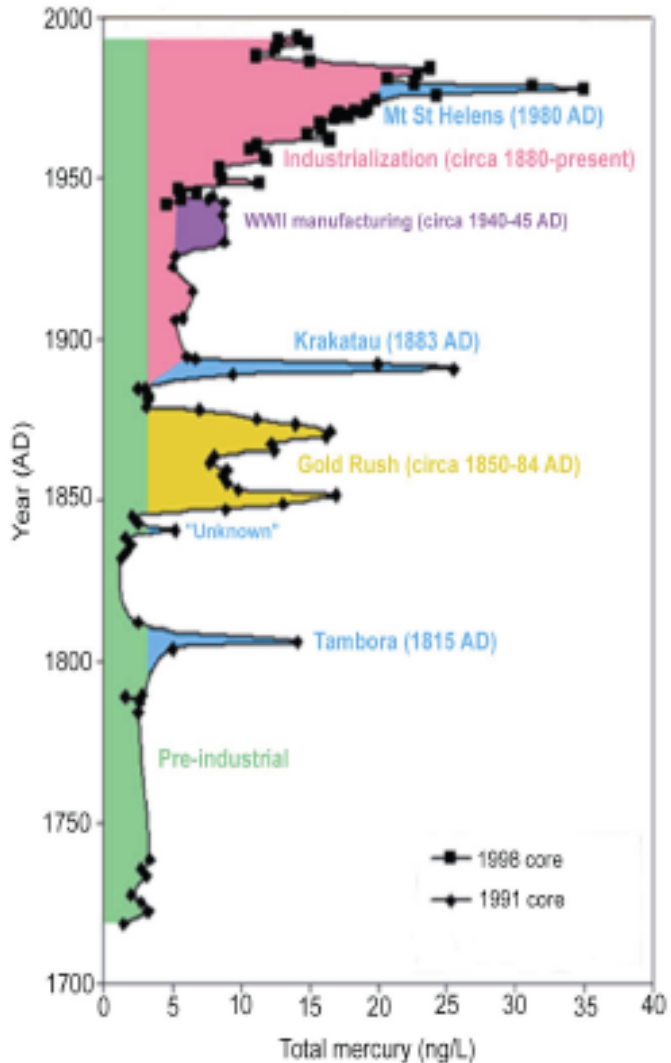
It cycles continuously between the different reservoirs of the Earth



RISING MERCURY IN THE ENVIRONMENT

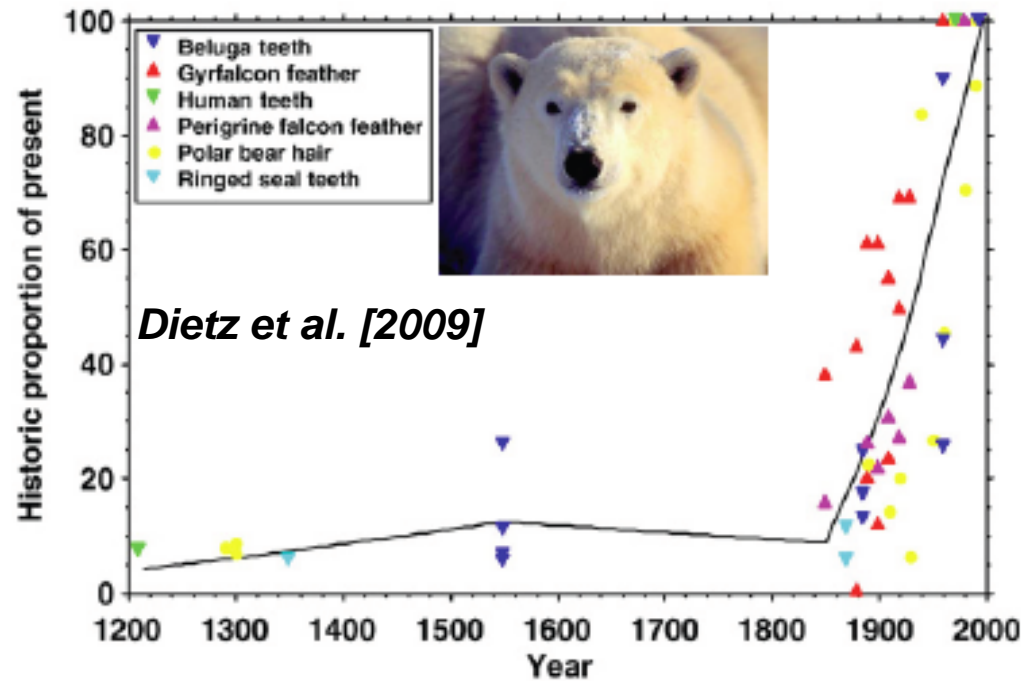
Global mercury deposition has roughly tripled since preindustrial times

Mercury In Wyoming Ice core



Schuster et al. 2002

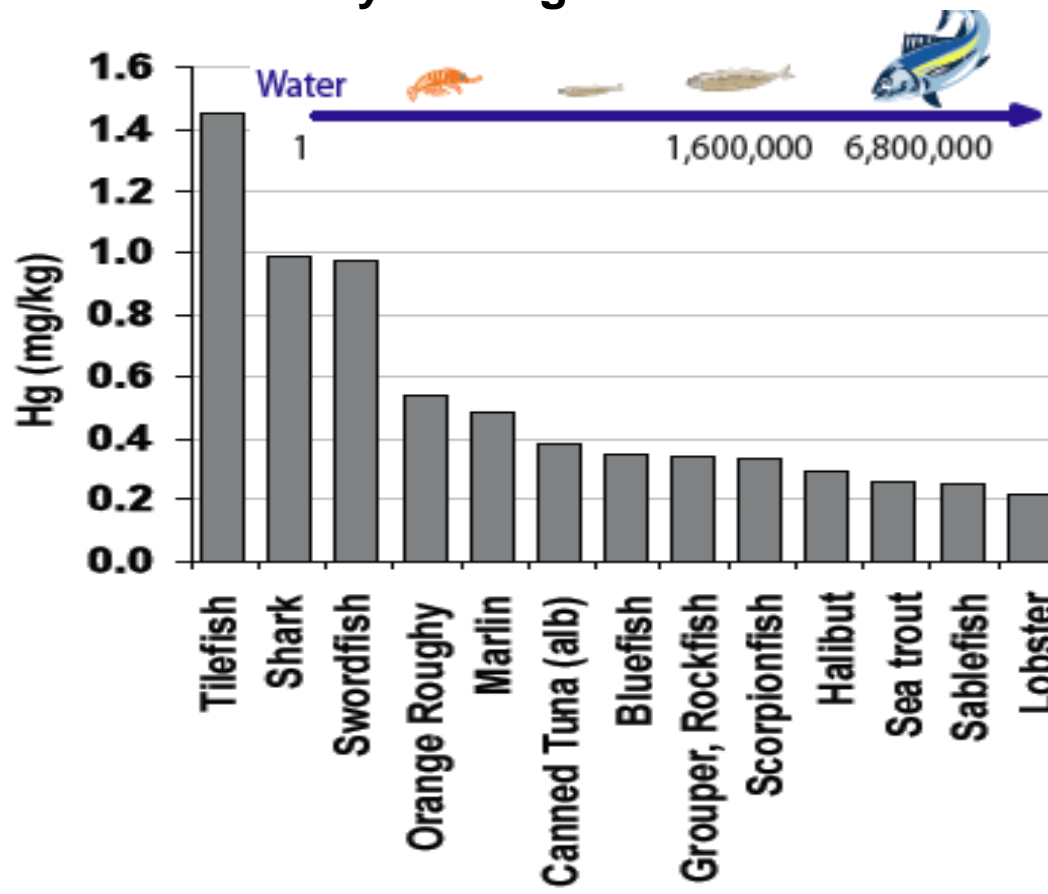
Mercury In Arctic wildlife



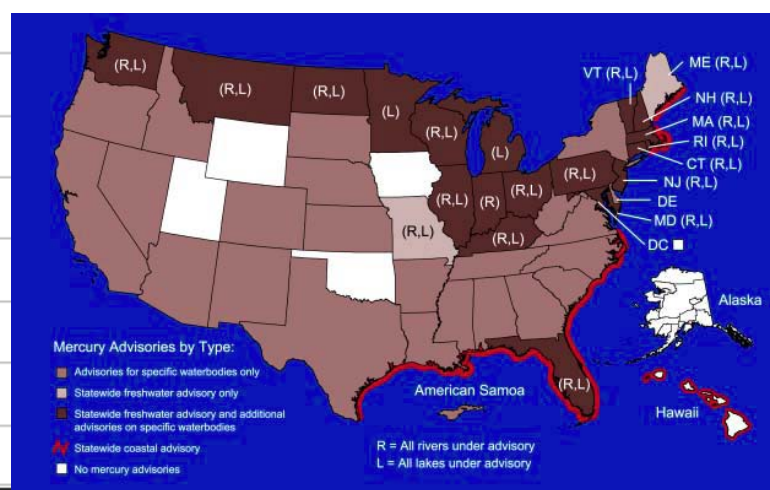
HUMAN EXPOSURE TO MERCURY IS MAINLY FROM FISH CONSUMPTION

Tuna is the #1 contributor

Mercury biomagnification factor



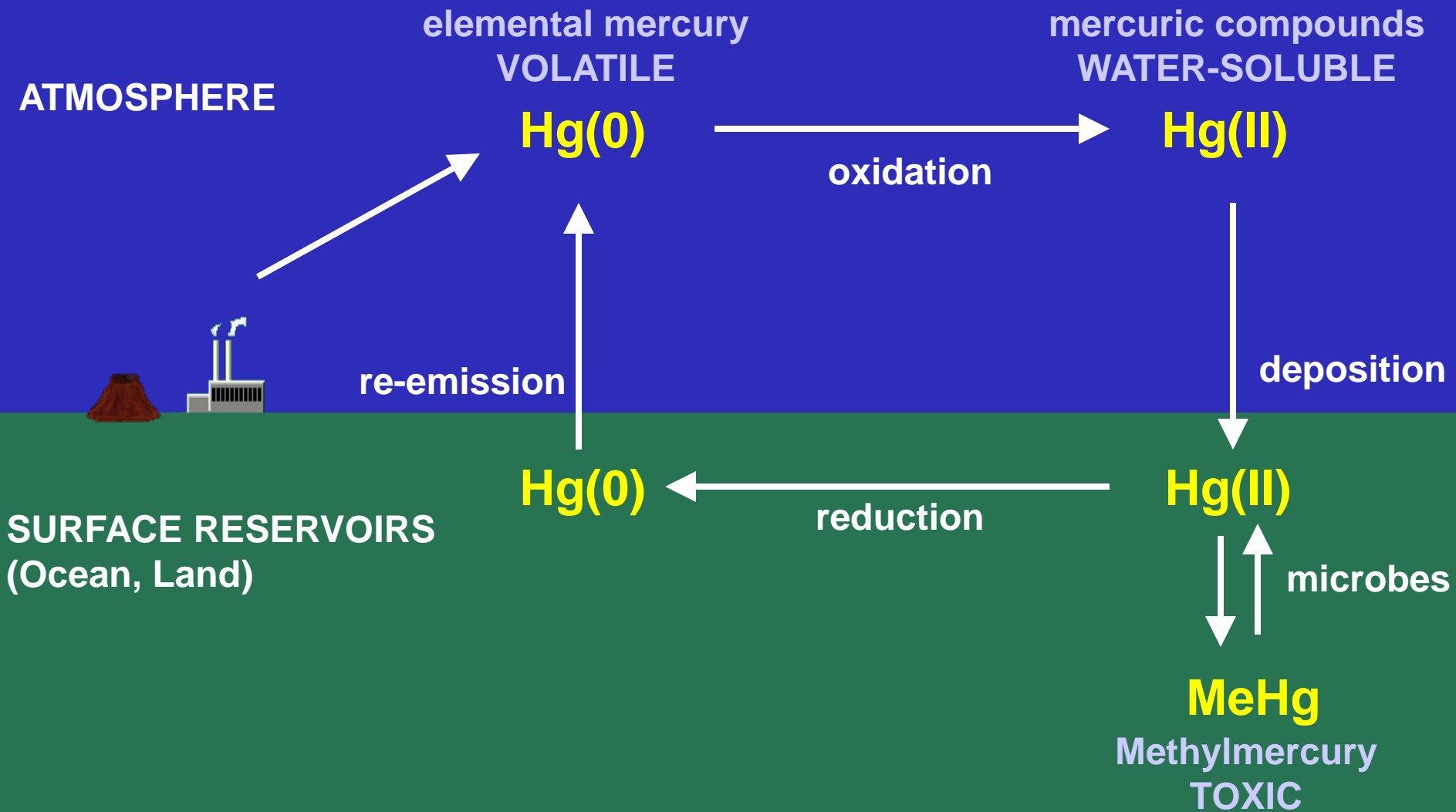
State fish consumption advisories



Source: FDA, 2007

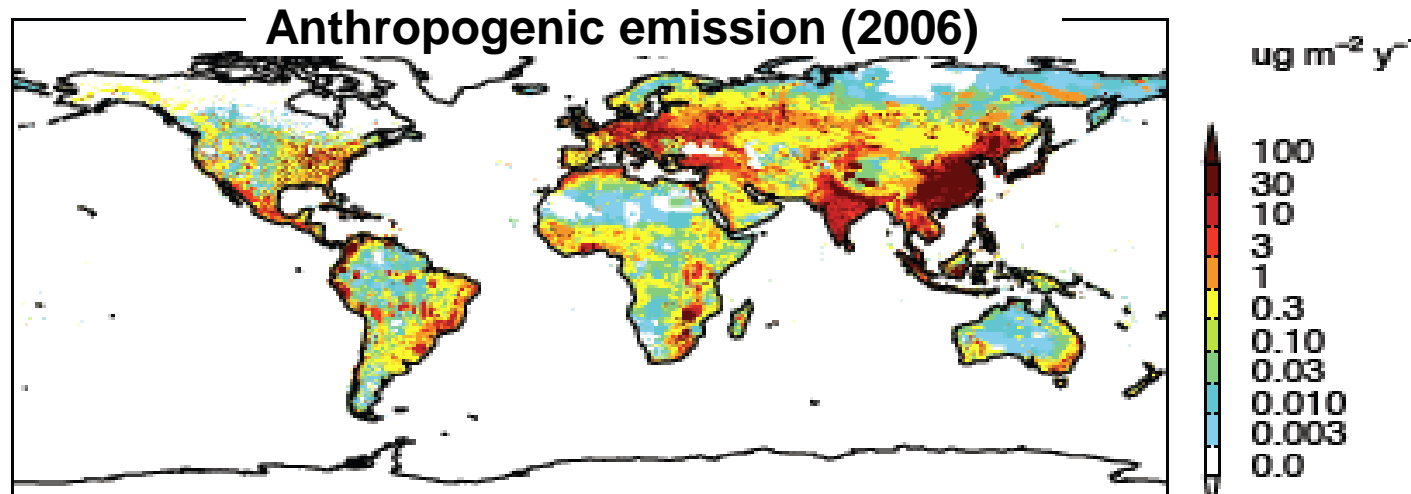
EPA reference dose (RfD) is $0.1 \mu\text{g kg}^{-1} \text{d}^{-1}$ (about 2 fish meals per week)

MERCURY CYCLING INVOLVES CHEMICAL TRANSFORMATIONS

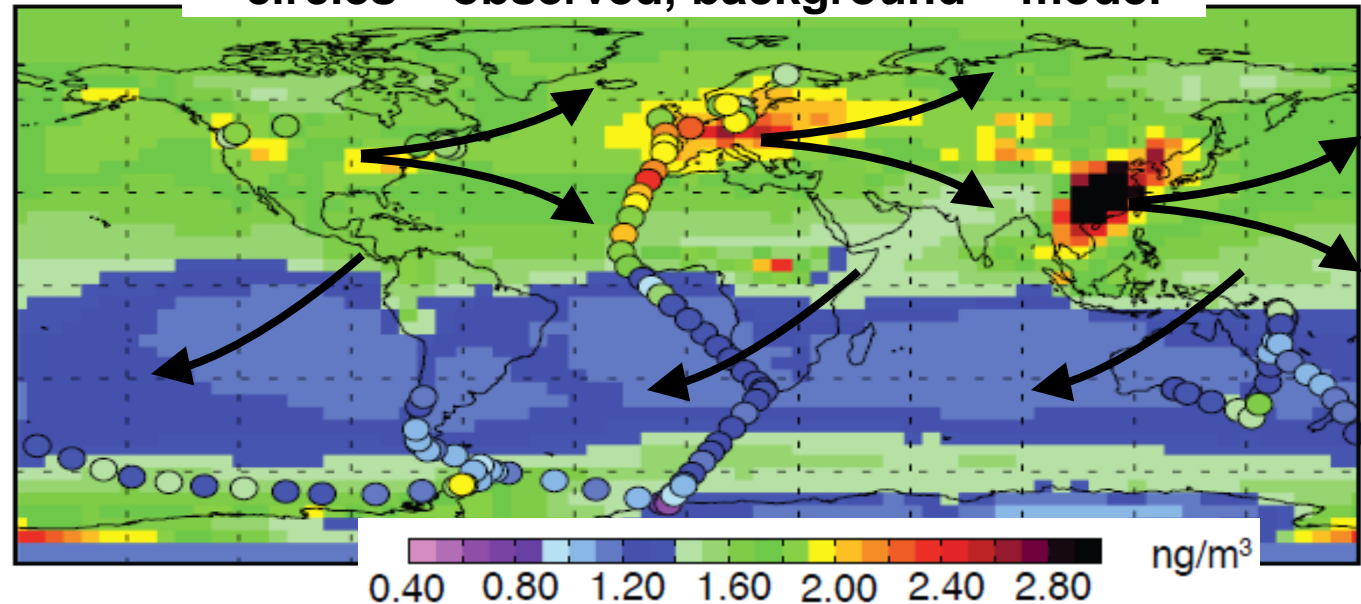


ELEMENTAL MERCURY IS WELL-MIXED IN ATMOSPHERE

Implies global-scale transport of anthropogenic emissions



Mean Hg(0) concentration in surface air:
circles = observed, background = model



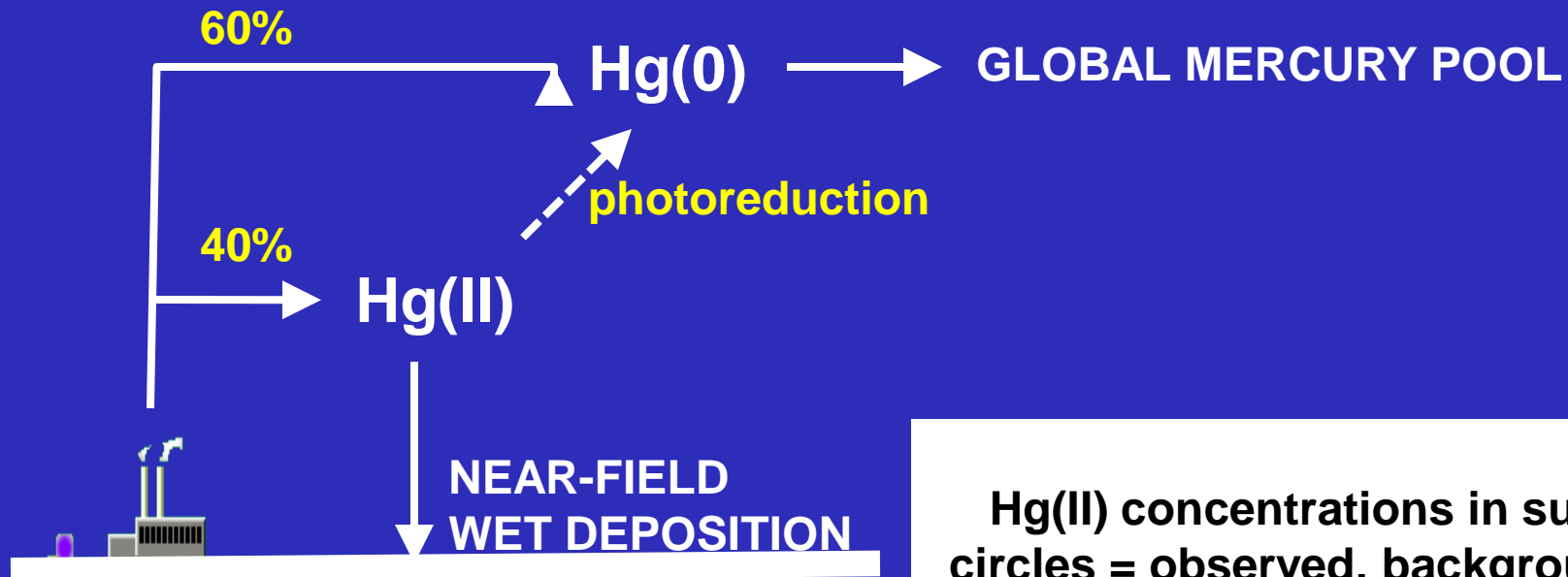
Transport around
northern mid-latitudes:
1 month

Transport to southern
hemisphere:
1 year

*Streets et al. [2009];
Soerensen et al. [2010]*

LOCAL POLLUTION INFLUENCE FROM EMISSION OF Hg(II)

High-temperature combustion emits both Hg(0) and Hg(II)

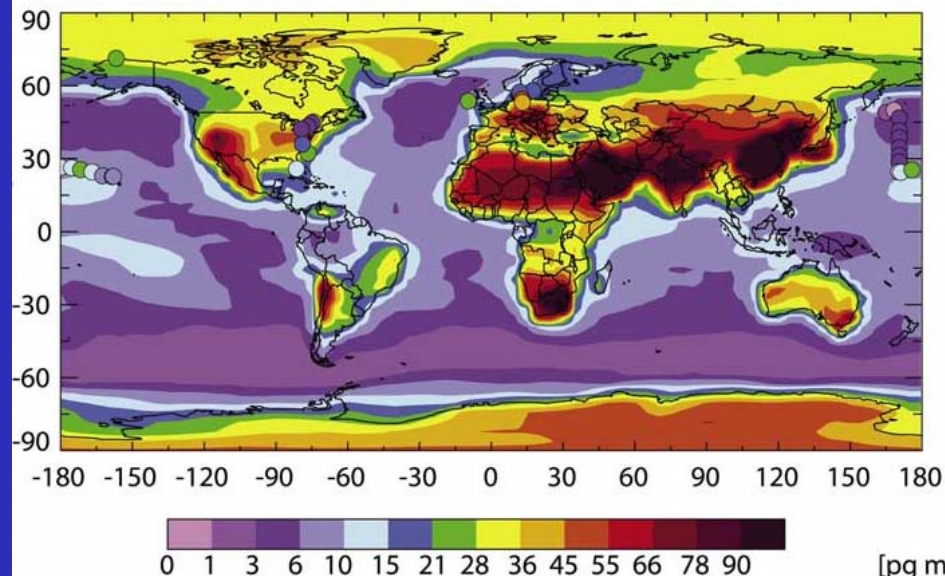


MERCURY DEPOSITION
"HOT SPOT"

Large variability of Hg(II) implies atmospheric lifetime of only days against deposition

Thus mercury is BOTH a global and a local pollutant!

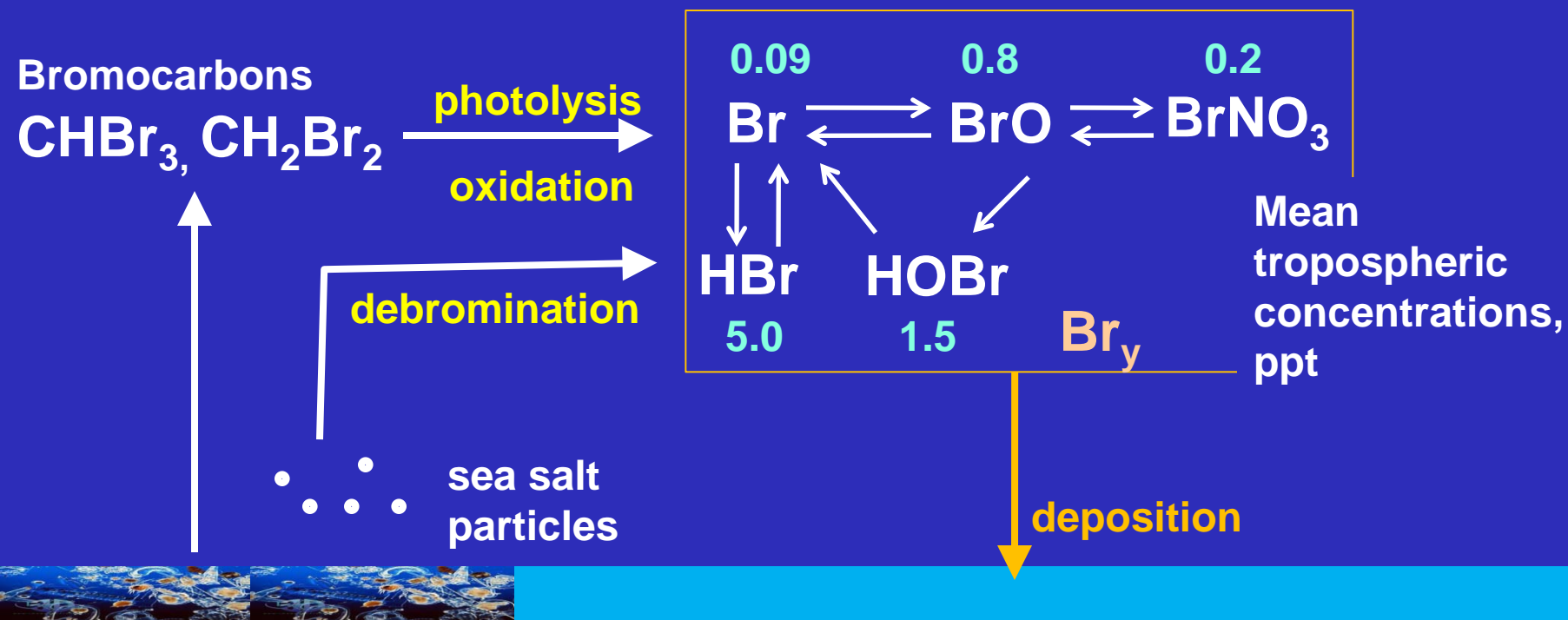
Hg(II) concentrations in surface air:
circles = observed, background=model



Hg(0) ATMOSPHERIC OXIDATION BY BROMINE ATOMS



promotes deposition of mercury to the oceans



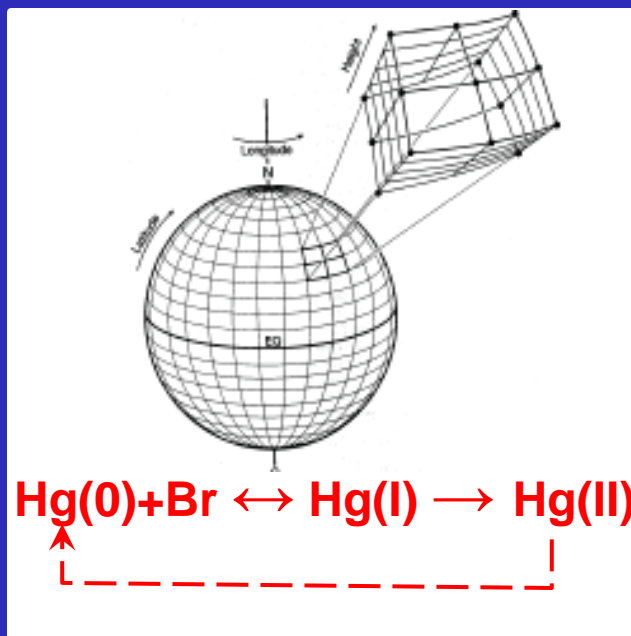
plankton

OCEAN

GEOS-Chem global model of mercury

3-D atmospheric simulation coupled to 2-D surface ocean and land reservoirs

GEOS-Chem 3-D atmospheric chemical transport model (CTM)



Anthropogenic and natural emissions



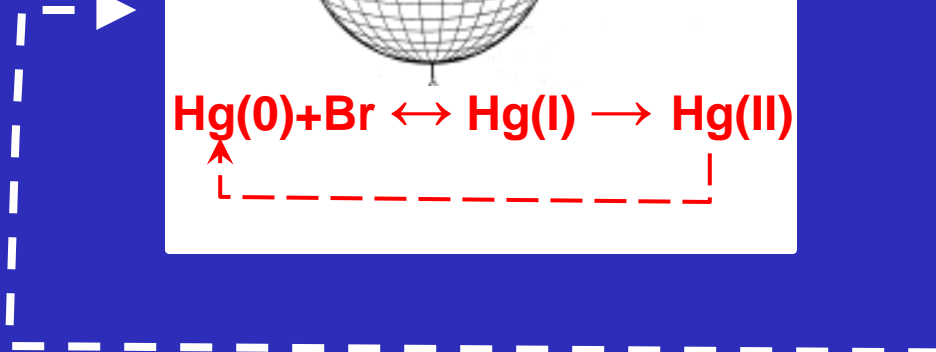
2-D surface reservoirs

- ocean mixed layer
- vegetation



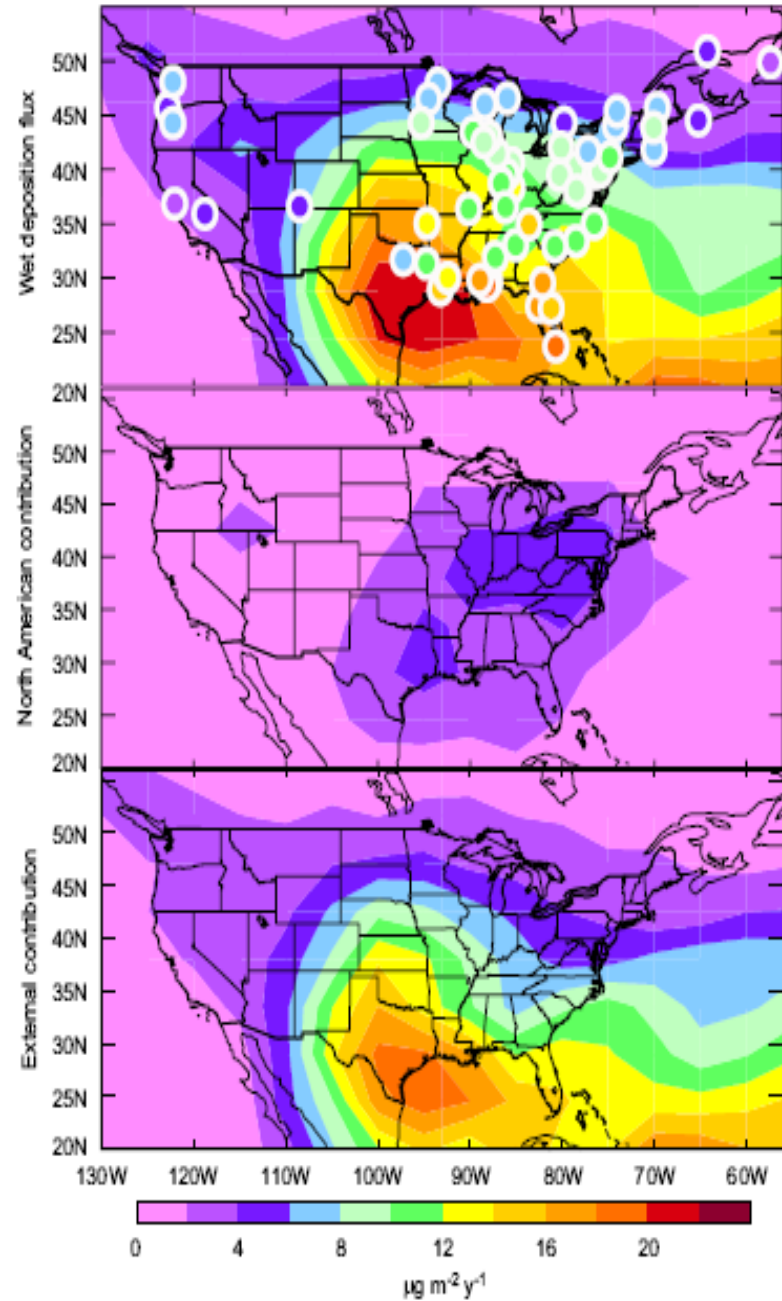
Long-lived reservoirs

- deep ocean
- soil



MERCURY WET DEPOSITION FLUXES, 2004-2005

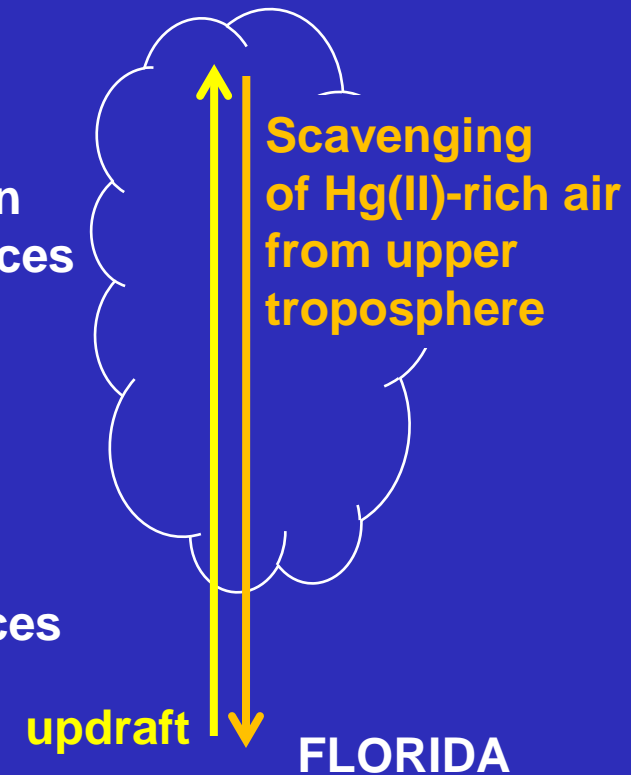
Circles: observations
Background: GEOS-Chem model



Model contribution from North American anthropogenic sources

Model contribution from external sources

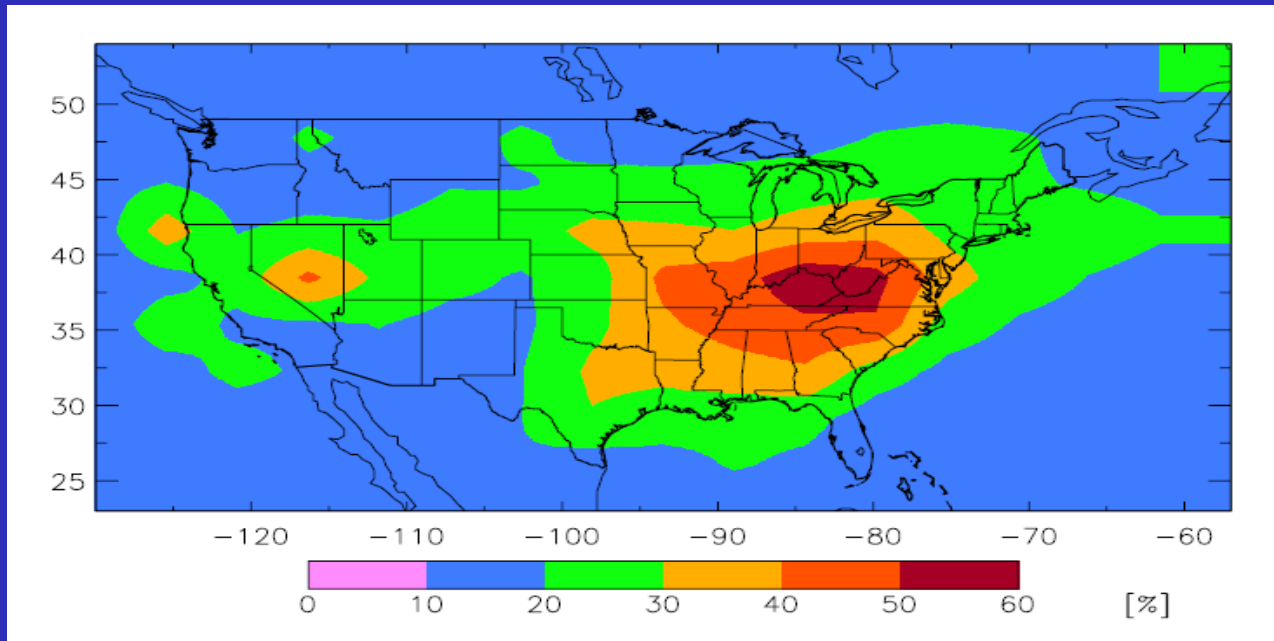
----- tropopause -----



SCAVENGING BY DEEP CONVECTION

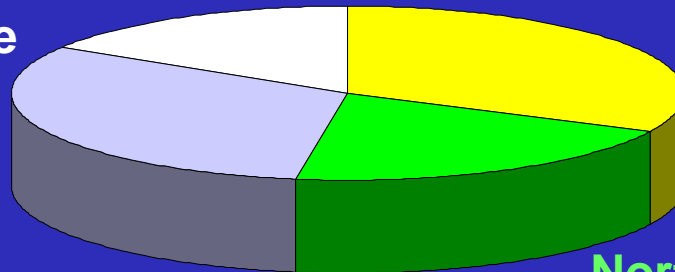
SOURCE ATTRIBUTION FOR U.S. MERCURY DEPOSITION

% contribution of North American sources to annual total mercury deposition



Legacy anthropogenic
re-emitted from soil and ocean
on centurial time scale
(17%)

Natural (32%)

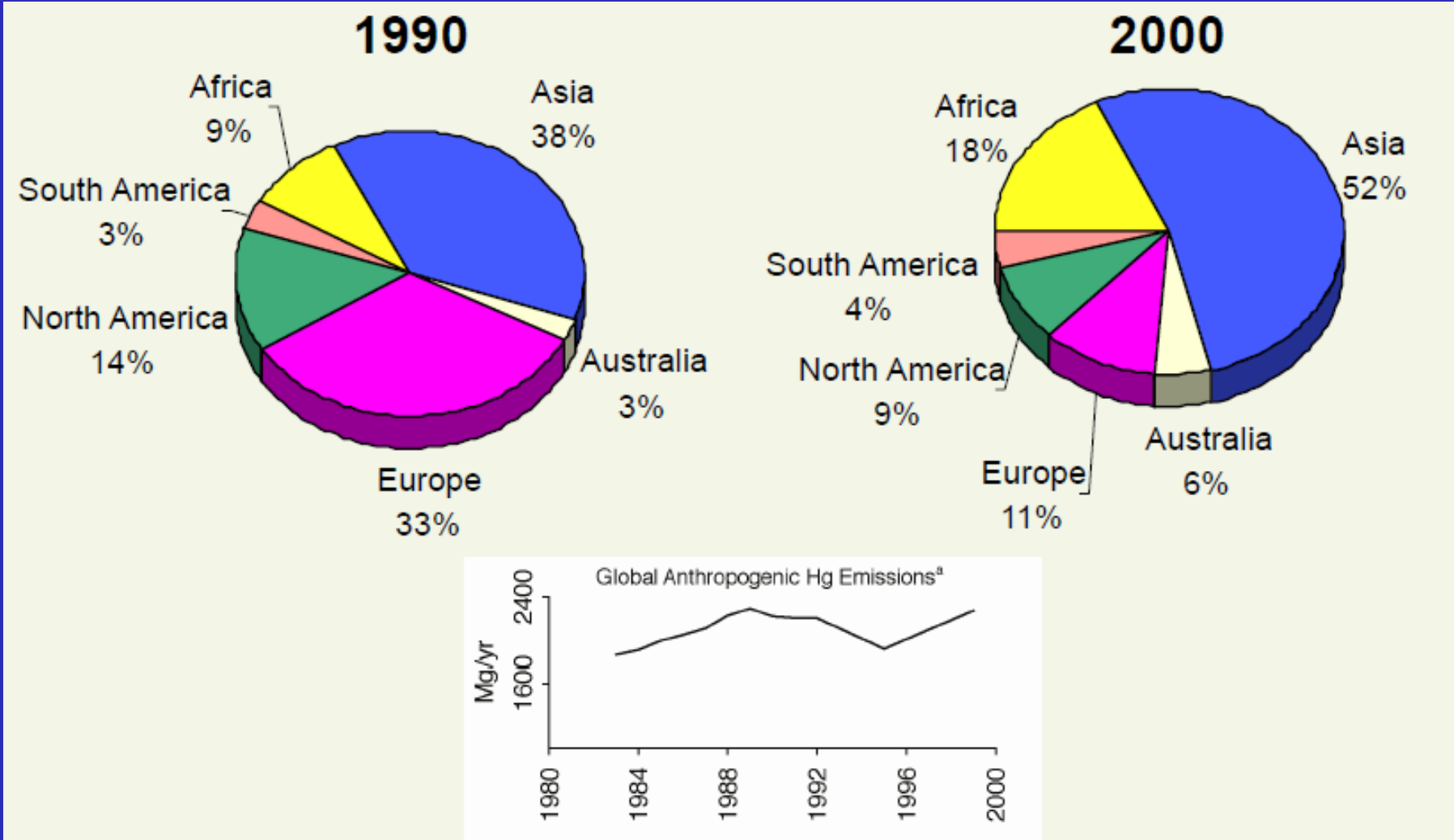


Rest of world anthropogenic (31%)

North American
anthropogenic (20%)

ASIA IS THE LARGEST CONTRIBUTOR TO GLOBAL MERCURY EMISSION

...but this is a recent development

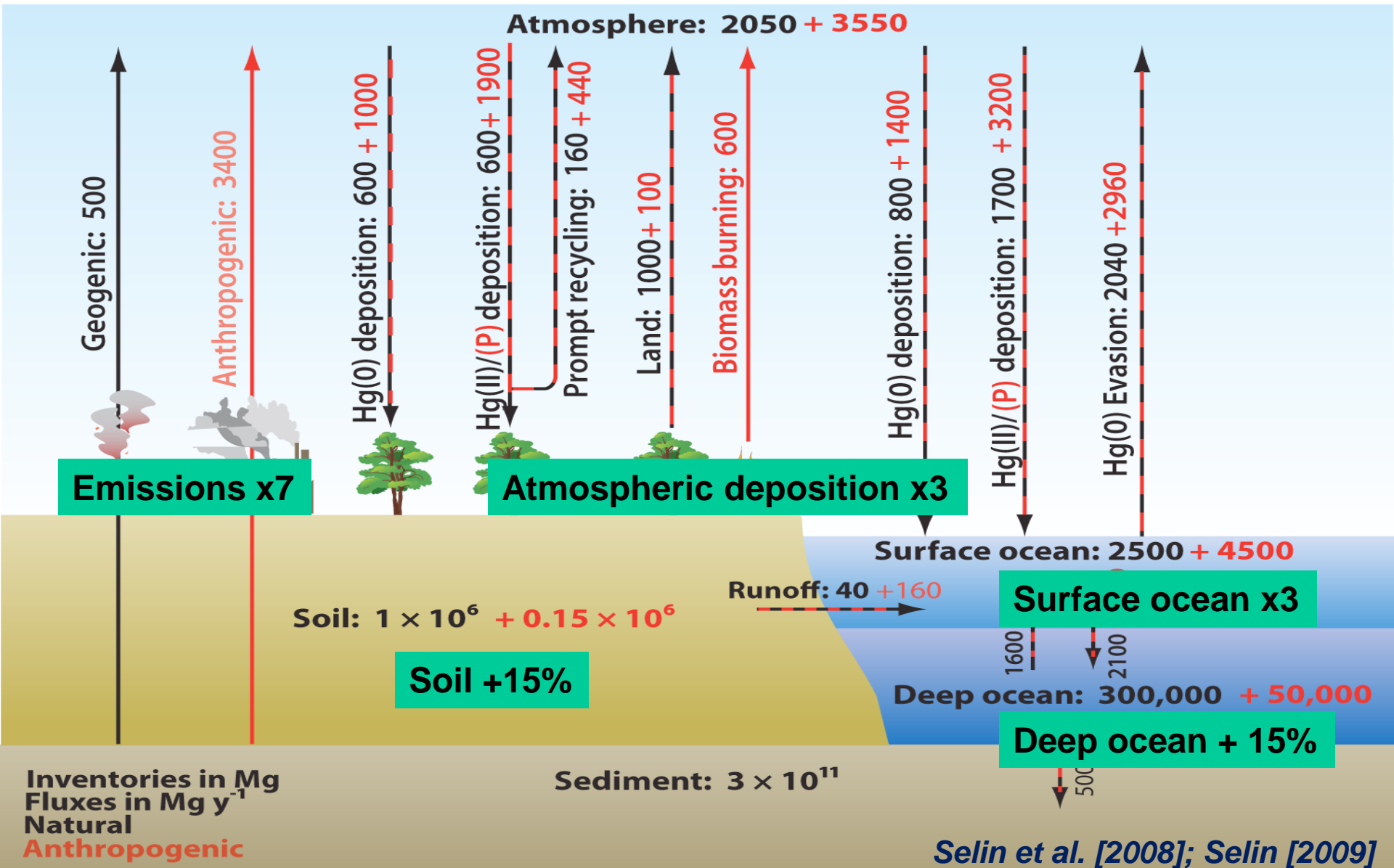


Global human emissions have been flat over past three decades due to compensation between rising Asian and African emissions, decreasing European and North American emissions

Pacyna et al. [2006]

GLOBAL BIOGEOCHEMICAL CYCLE OF MERCURY

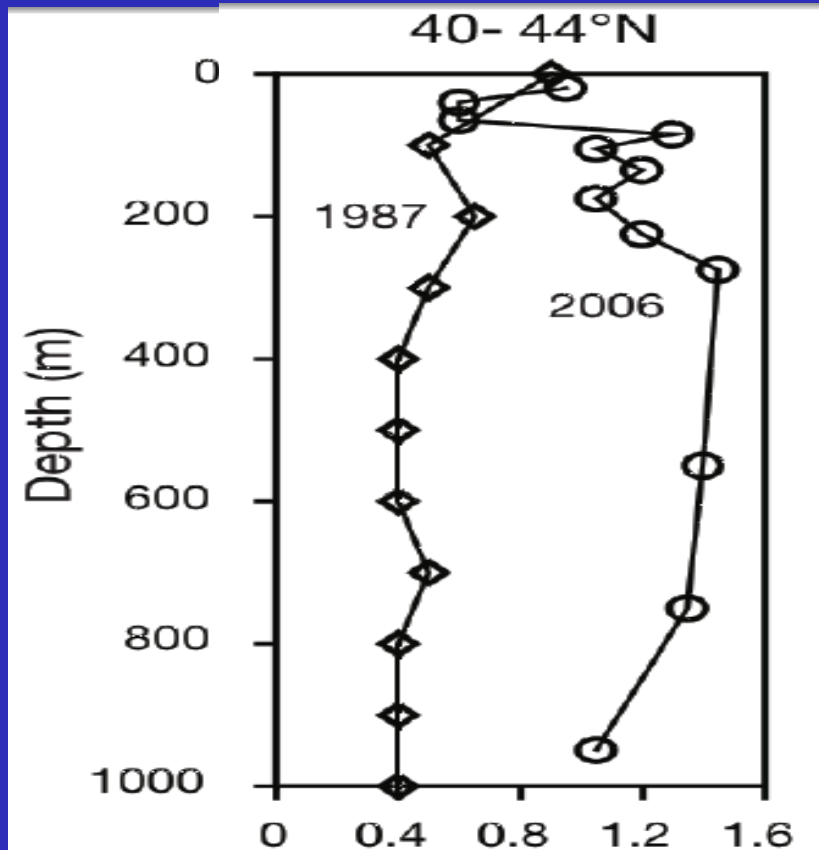
GEOS-Chem natural atmosphere + present-day human enhancement



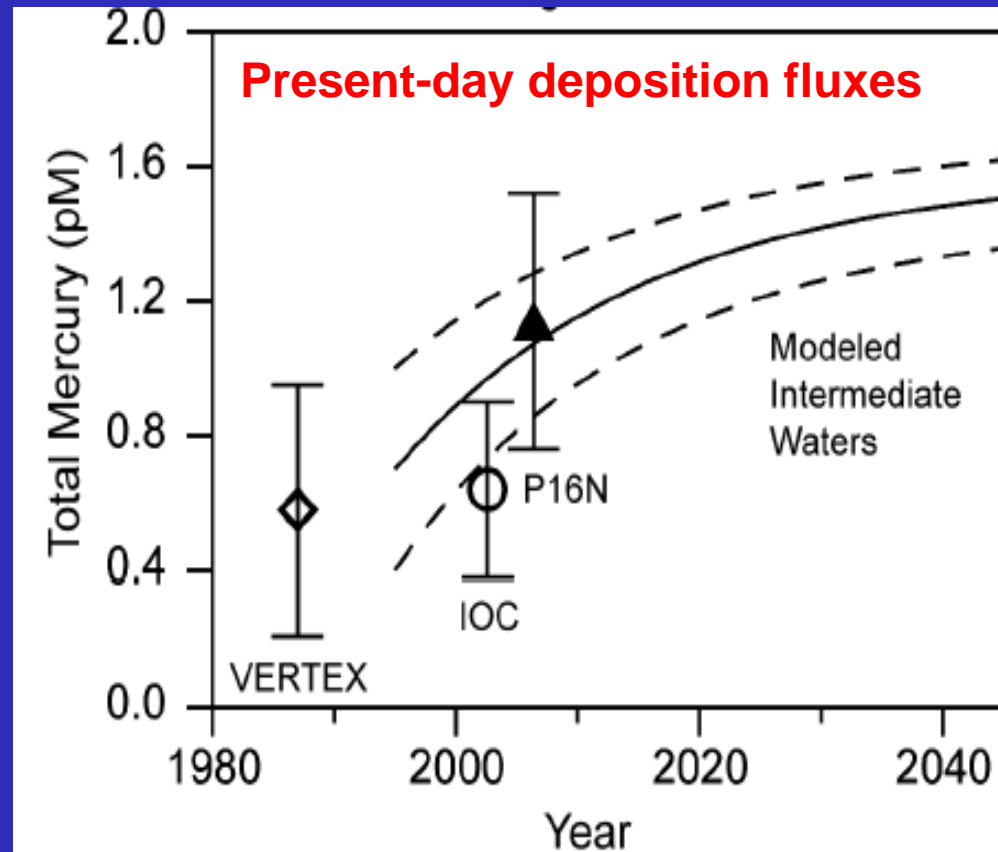
ACCUMULATION OF MERCURY IN THE OCEAN

Future increase in oceanic mercury is expected even if deposition stays constant

Hg observations in N. Pacific

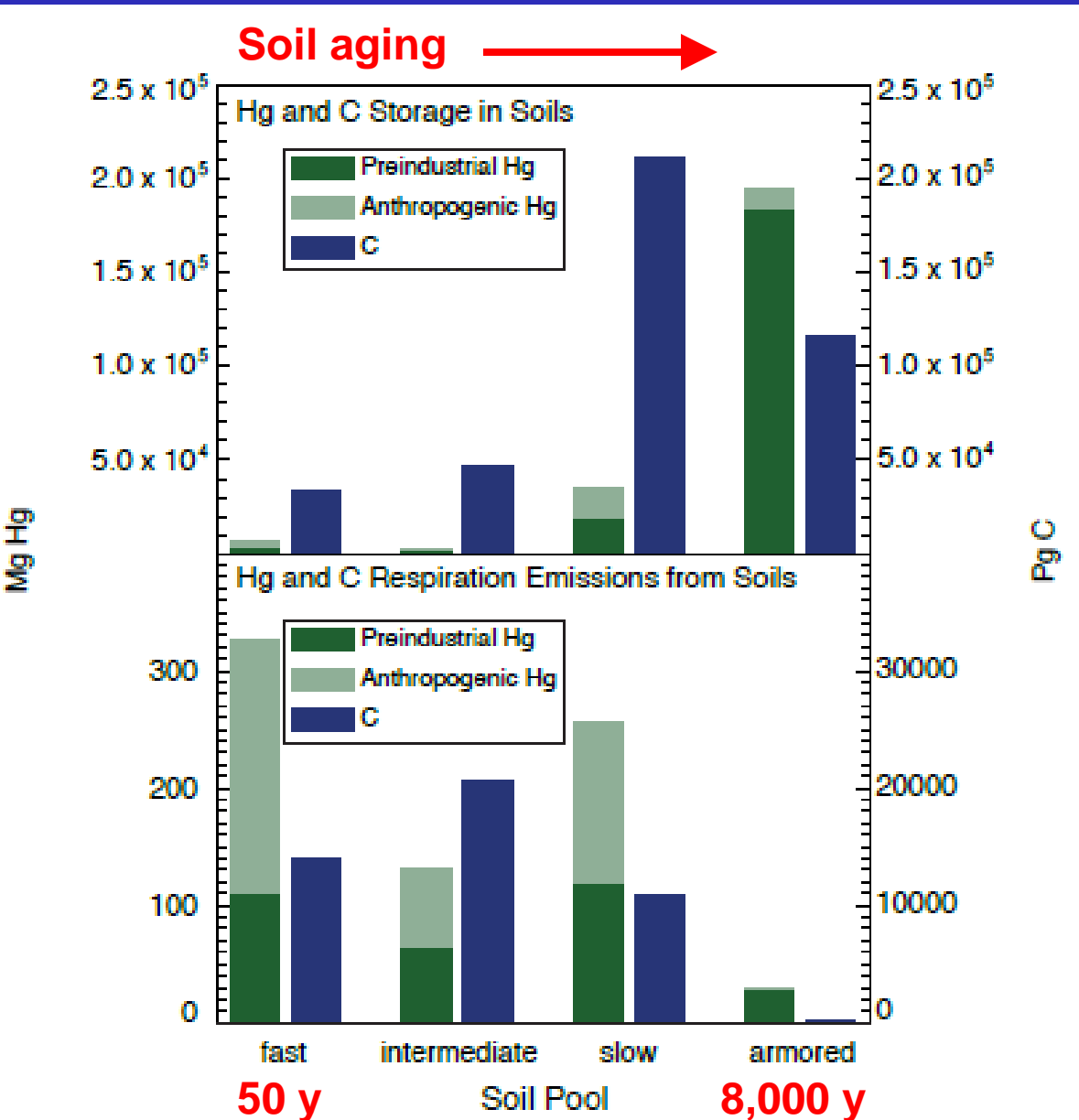


Projected N. Pacific accumulation



MOBILIZATION OF ANTHROPOGENIC Hg FROM SOILS

New version of GEOS-Chem accounts for soil pools with different lifetimes



- Mercury accumulates in soil by binding to organic carbon; part is volatilized when organic carbon is respired

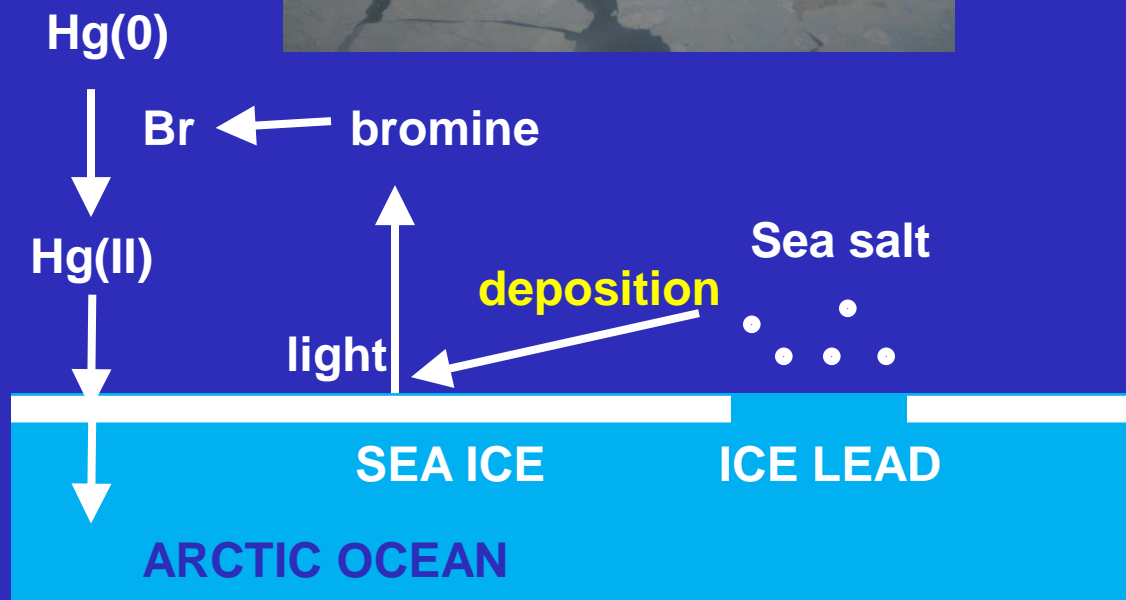
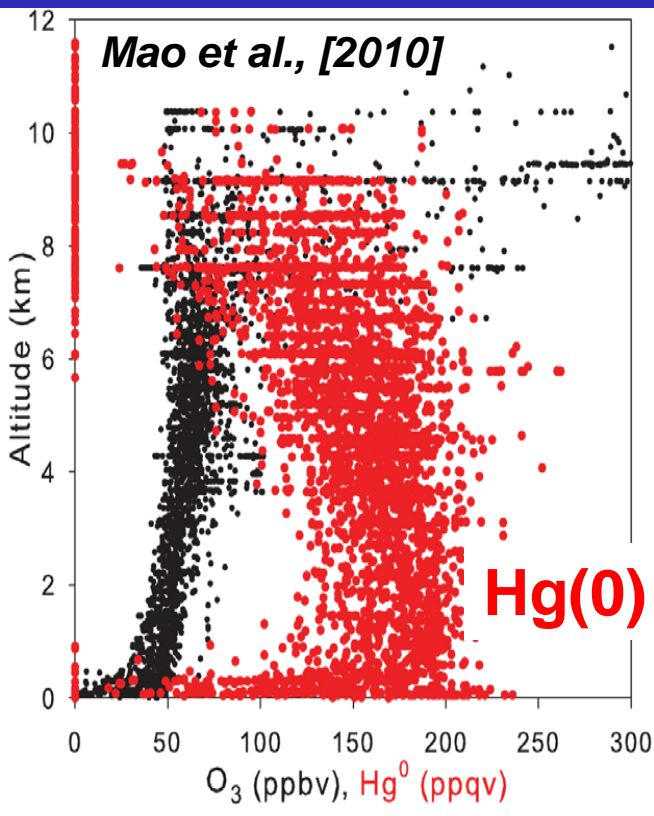
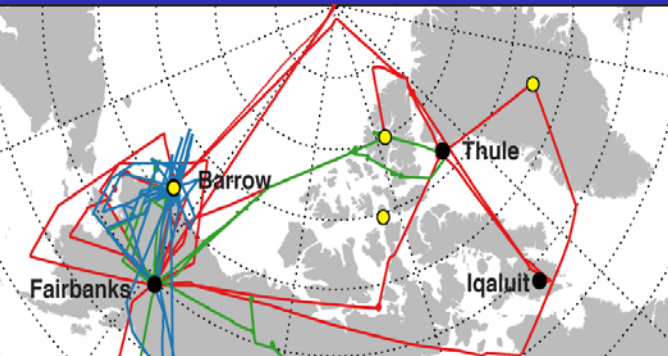
- Mercury has a mean lifetime in soil of 630 years, but deposited anthropogenic mercury has a lifetime of only 80 years

- Increased soil respiration in future climate could lead to large soil mercury release

Smith-Downey et al. [2010]

MERCURY DEPOSITION IN ARCTIC SPRING DRIVEN BY SEA ICE LEADS

NASA/ARCTAS aircraft campaign
(April 2008)



More ice leads and open ocean in warmer Arctic
will promote mercury deposition

TOWARDS A GLOBAL MERCURY TREATY:

Focus activity of United Nations Environmental Program (UNEP)



- February 2009: Governing Council of UNEP agrees on need for global legally binding instrument on mercury
- Goal is to complete negotiations by 2013
- In US; Clean Air Mercury Rule (CAMR) to reduce power plant emissions was struck down by courts in 2008; new effort is underway

CHALLENGES:

- How to regulate in the face of considerable uncertainty?
- How to account for legacy mercury from past US and European emissions?
- How to account for possible major effects of climate change?