Pollution, Impacts and Policy: A Systems Approach to Atmospheric Chemistry

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PAOC
PROGRAM IN ATMOSPHERES, OCEANS AND CLIMATE

EAPS

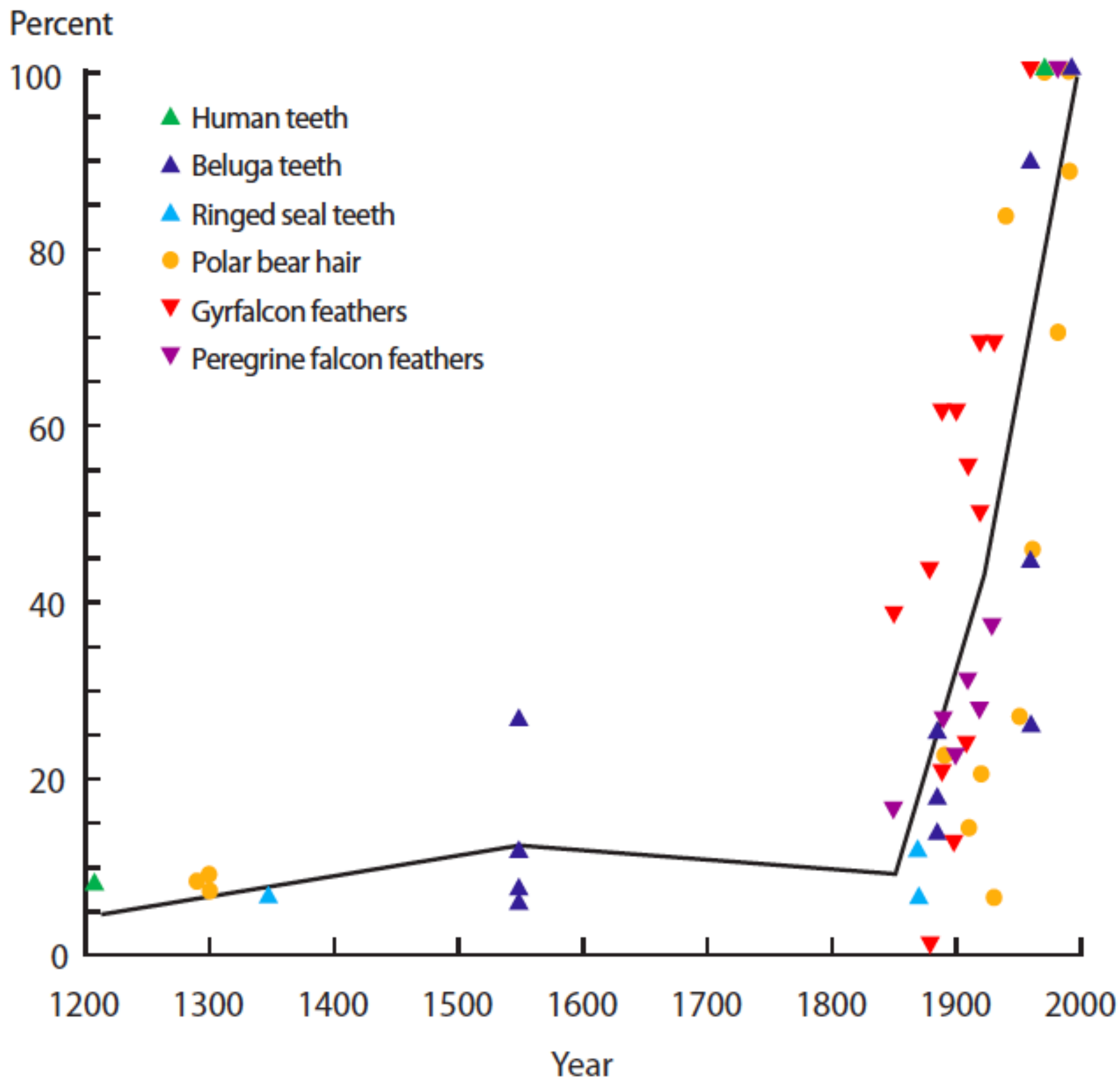
“Human fingerprints on the Earth System”….

Humans “are modifying physical, chemical, and biological systems in new ways, at faster rates, and over larger spatial scales than ever recorded on Earth.”
(Lubchenko, 1998)

or

Understanding Atmospheres, Oceans and Climate requires investigating both natural and human systems, as well as their complex, coupled interactions

Toxic Footprints: Mercury



Arctic Monitoring and Assessment Programme, 2011

Why should we care about toxics in the atmosphere?

Ozone and particulate matter cause asthma attacks, cardiovascular effects, and premature mortalities

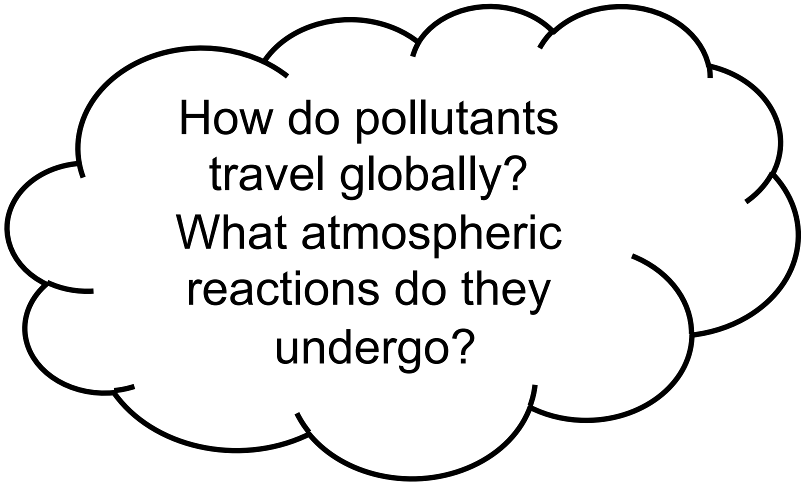
Some beluga whales contain such a high concentration of toxics that they are considered hazardous waste

300,000+ newborns in the US each year at risk of learning disabilities due to elevated mercury exposure

Transport and Fate of Pollutants: Fundamental Questions and Uncertainties

What pollutants are emitted from human sources?

How will emissions respond to policies?



How does the natural system respond to human impacts and feedbacks?

What are the impacts of pollutants on human societies and ecosystems?

Outline

- History and Context
- Three examples using modeling tools to do policy-relevant research:
  - Linking atmospheric chemistry to policy: the case of mercury
  - Present and future Arctic transport of polycyclic aromatic hydrocarbons (PAHs)
  - Climate policy and air pollution health impacts
- How to find out more…

Policy Context: U.S.

9304 Federal Register / Vol. 77, No. 32 / Thursday, February 16, 2012 / Rules and Regulations

ENVIRONMENTAL PROTECTION AGENCY

40 CFR Parts 60 and 63

[EPA–HQ–OAR–2009–0234; EPA–HQ–OAR–2011–0044, FRL–9611–4]

RIN 2060–AP52; RIN 2060–AR31

National Emission Standards for Hazardous Air Pollutants From Coal- and Oil-Fired Electric Utility Steam Generating Units and Standards of Performance for Fossil-Fuel-Fired Electric Utility, Industrial-Commercial-Institutional, and Small Industrial-Commercial-Institutional Steam Generating Units

AGENCY: Environmental Protection Agency (EPA).

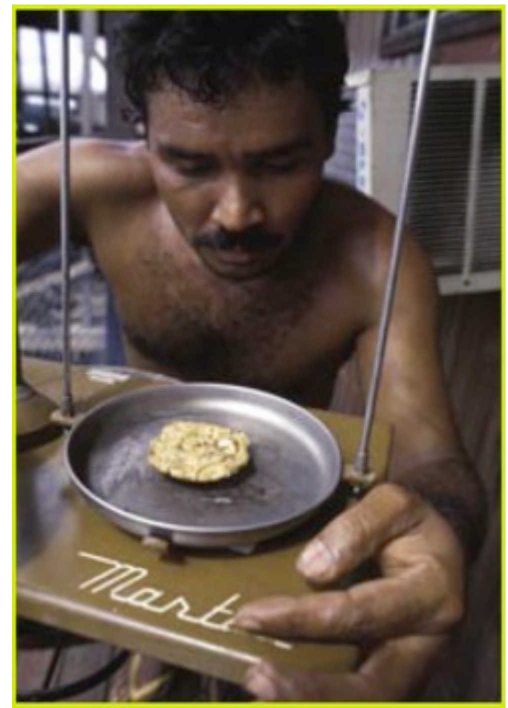
ACTION: Final rule.

EPA–HQ–OAR–2011–0044 (NSPS action) or Docket ID No. EPA–HQ–OAR–2009–0234 (NESHAP action). All documents in the dockets are listed on the *http://www.regulations.gov* Web site. Although listed in the index, some information is not publicly available, e.g., confidential business information or other information whose disclosure is restricted by statute. Certain other material, such as copyrighted material, is not placed on the Internet and will be publicly available only in hard copy form. Publicly available docket materials are available either electronically through *http://www.regulations.gov* or in hard copy at EPA's Docket Center, Public Reading Room, EPA West Building, Room 3334, 1301 Constitution Avenue NW., Washington, DC 20004. This Docket Facility is open from 8:30 a.m. to 4:30

Policy Context: International

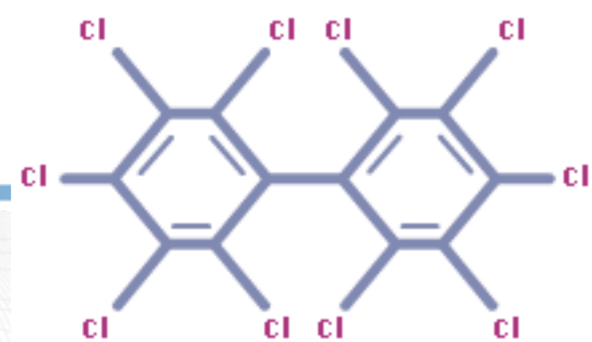
Stockholm Convention on persistent organic pollutants (POPs)

LRTAP
Long-range Transboundary Air Pollution



A first foray into policy-relevant research….

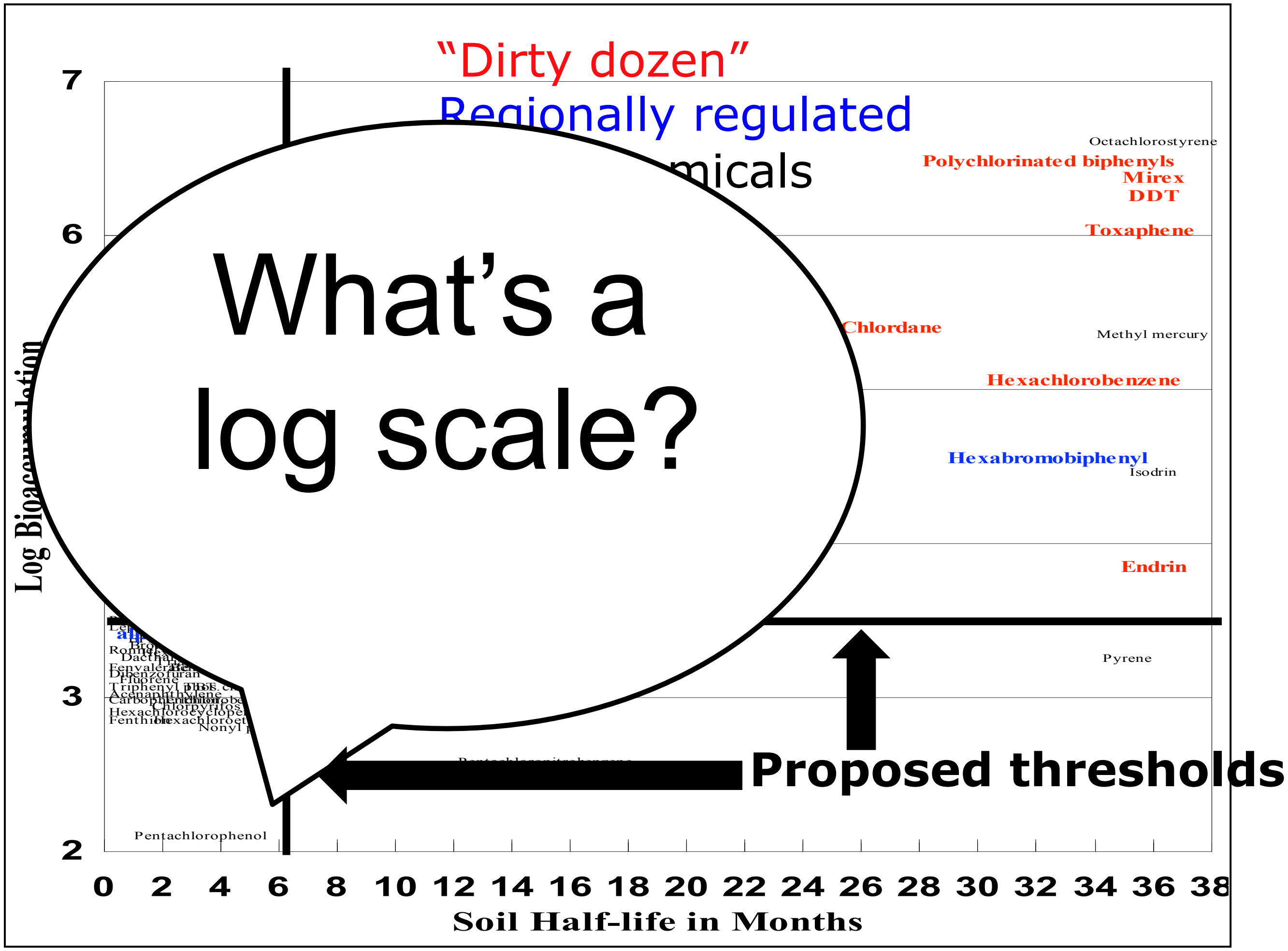
- U.S. was preparing to start negotiating global treaty on persistent organic pollutants (POPs), starting with the “dirty dozen”
- EPA wants to know what other POPs are out there, and what criteria can be used to define them
- “List of lists” approach combined with analysis of scientific basis for criteria of persistence, bioaccumulation



"Dirty dozen" chemicals are uniquely persistent, bioaccumulative

Bioaccumulation factor: ratio of concentration in fatty tissue to water (log scale)

Only a few chemicals above proposed thresholds; lots just below



For more information: B. D. Rodan, D. W. Pennington, N. Eckley, and R. S. Boethling. 1999. "Screening for Persistent Organic Pollutants: Techniques to Provide a Scientific Basis for POPs Criteria in International Negotiations." *Environmental Science and Technology* 33: 3482-3488.

What's the problem?

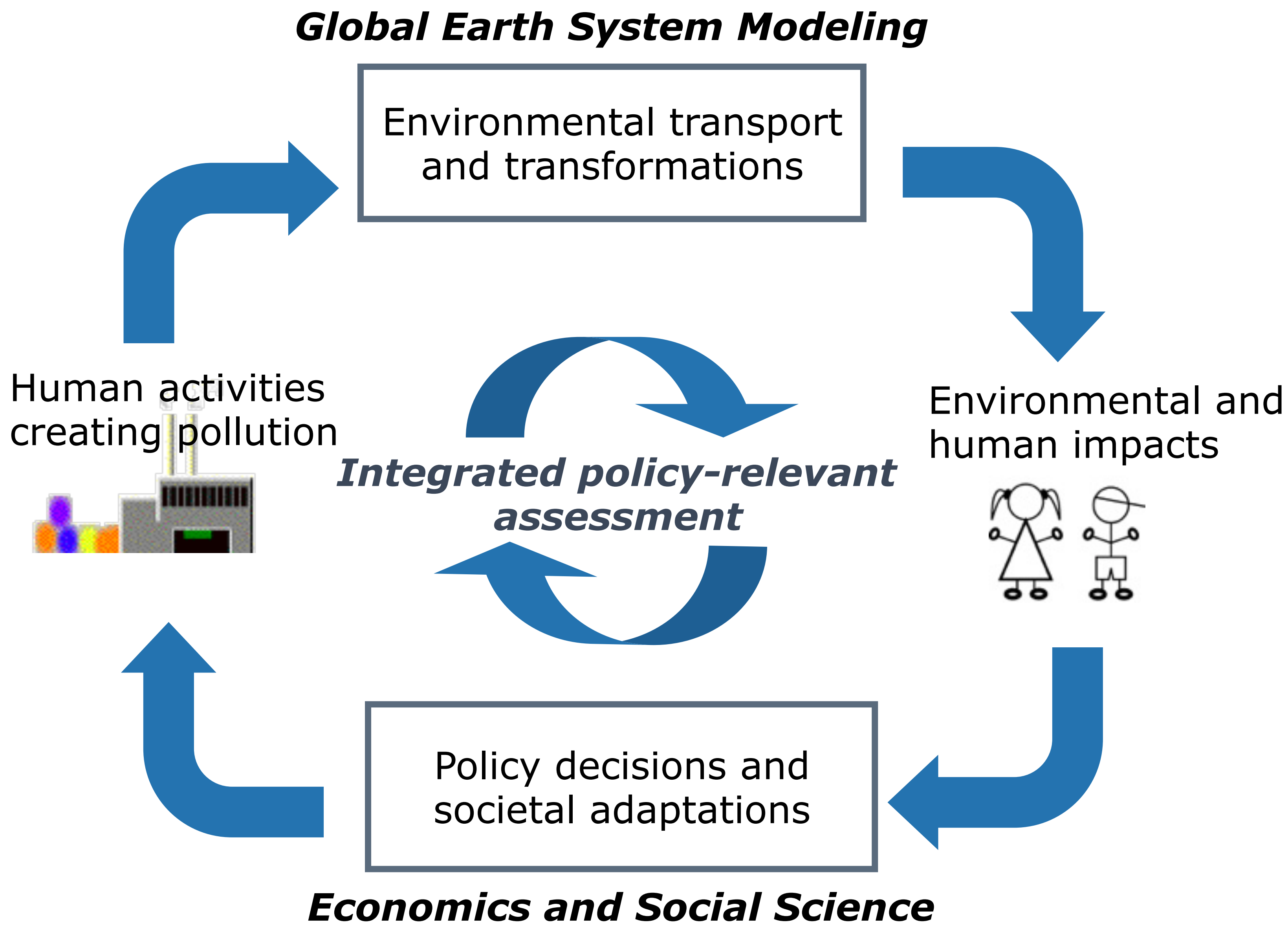
- Lack of fundamental understanding of Earth system (including humans) and its complex behavior and interactions
- Large gap between basic research and implementation in policy and practice

➢ A need for ***translational research*** in atmospheric, ocean and climate sciences

Guiding Questions

- How can we better understand the transport and fate of toxic atmospheric constituents, in ways relevant to policy?
  - What are the pathways by which pollutant emissions impact people?
  - What are the feedbacks and interactions between pollutants and society?
  - How can we inform more effective policies?
- We use modeling and data analysis to address these questions

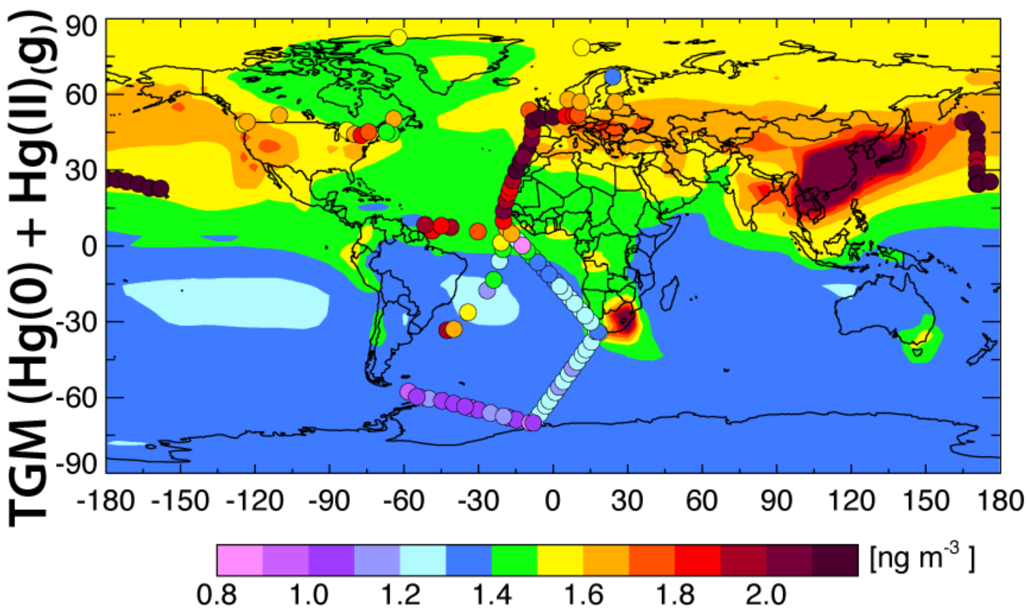
Framework for assessing pollution and impacts



Example 1: Mercury in the Atmosphere

- Research Question Highlights
  - Why is U.S. Hg deposition higher in the Southeast than downwind of major power plant sources?
  - How does historically-emitted mercury affect present-day exposure?
- For more information:
  - N.E. Selin, D.J. Jacob, R.J. Park, R.M. Yantosca, S. Strode, L. Jaeglé and D. Jaffe, 2007. “Chemical cycling and deposition of atmospheric mercury: Global constraints from observations.” Journal of Geophysical Research-Atmopsheres, 112, D02308
  - N.E. Selin, D.J. Jacob, R.M. Yantosca, S. Strode, L. Jaeglé, and E.M. Sunderland. 2008. "Global 3-D land-ocean-atmosphere model for mercury: present-day vs. pre-industrial cycles and anthropogenic enrichment factors for deposition," Global Biogeochemical Cycles, 22, GB2011
  - N.E. Selin and D.J. Jacob. 2008. “Seasonal and spatial patterns of mercury wet deposition in the United States: Constraints on the contribution from North American anthropogenic sources.” Atmospheric Environment, 42, 5193-5204, 2008, doi:10.1016/j.atmosenv.2008.02.069.
  - N.E. Selin. 2009. "Global Biogeochemical Cycling of Mercury: A review." Annual Review of Environment and Resources 34:43-63
  - N.E. Selin, E. M. Sunderland, C.D. Knightes, and R.P. Mason. 2010. "Sources of mercury exposure for U.S. seafood consumers: Implications for policy." Environmental Health Perspectives, 118(1):137-143, doi:10.1289/ehp.0900811

Methods: Global Modeling using GEOS-Chem

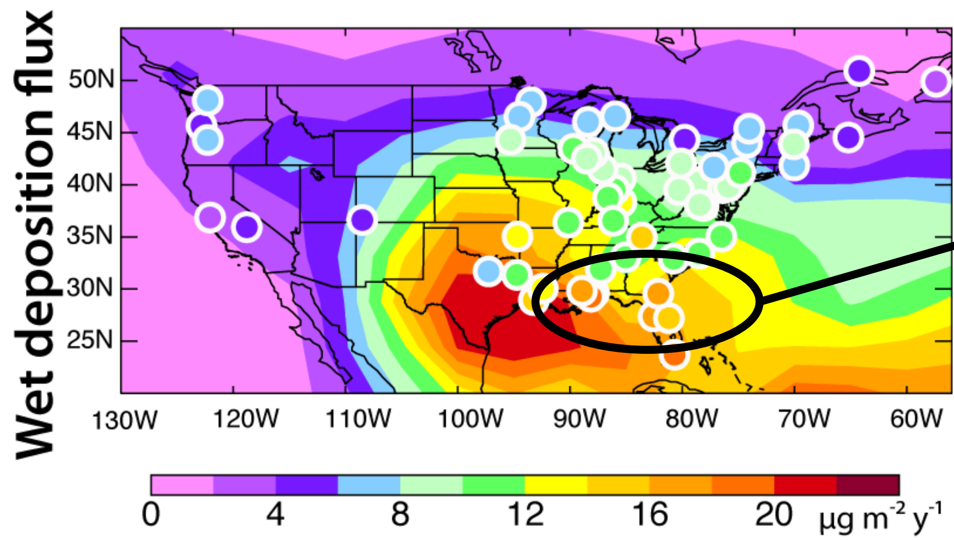


Global, 3D tropospheric chemistry model, 4x5 degree resolution, assimilated meteorology

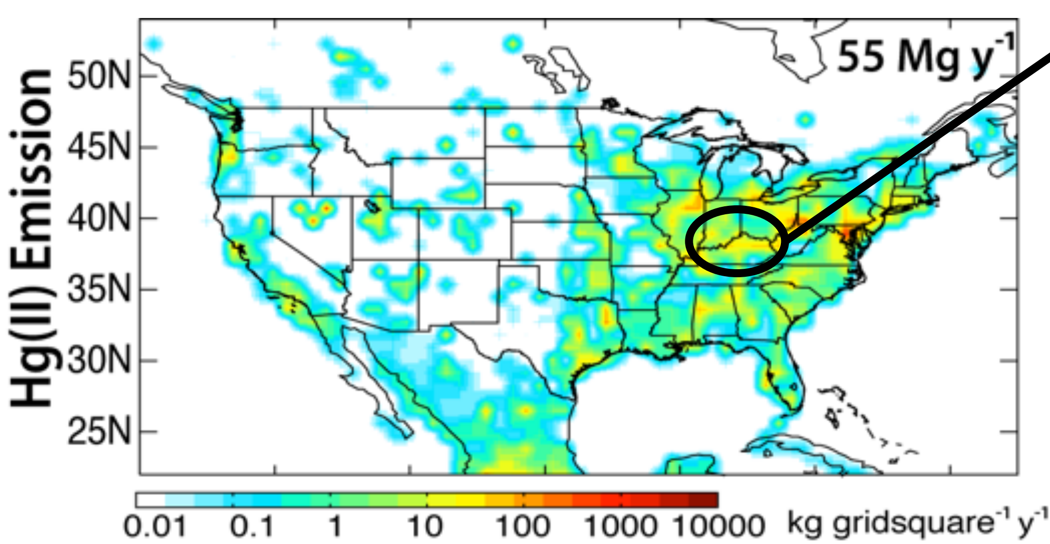
[*Bey et al.*, 2001]

Mercury simulation includes land-atmosphere-ocean coupling *(Selin et al., 2007, 2008; Strode et al., 2007; Holmes et al., 2010; Soerensen et al., 2010)*

Why is U.S. Hg deposition as high or higher in the Southeast than downwind of power plant sources?



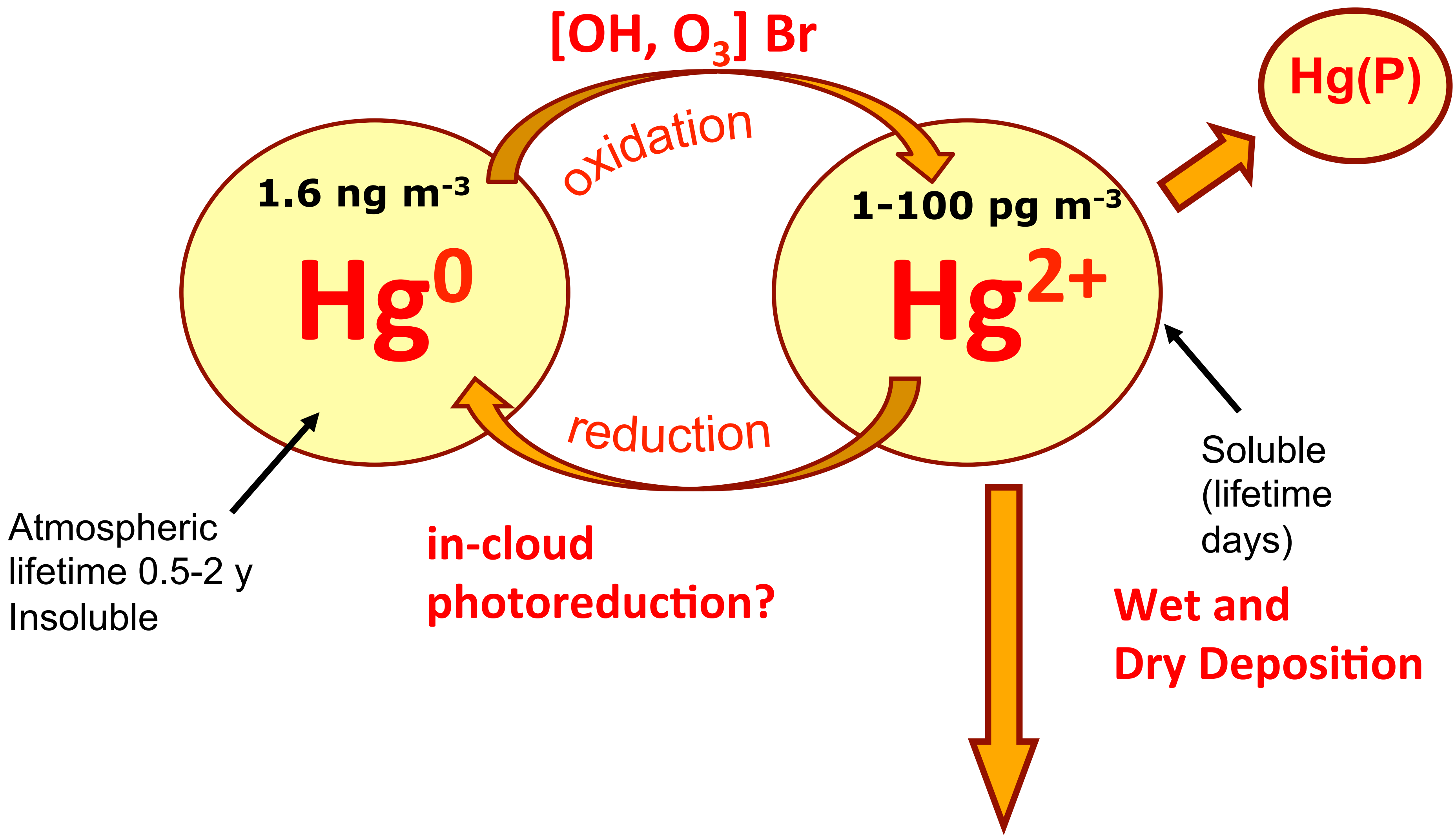
Southeast has highest wet deposition in the U.S. (model: background, circles: measurements from U.S. mercury deposition network)



Highest emission is from coal power plants in the Midwest

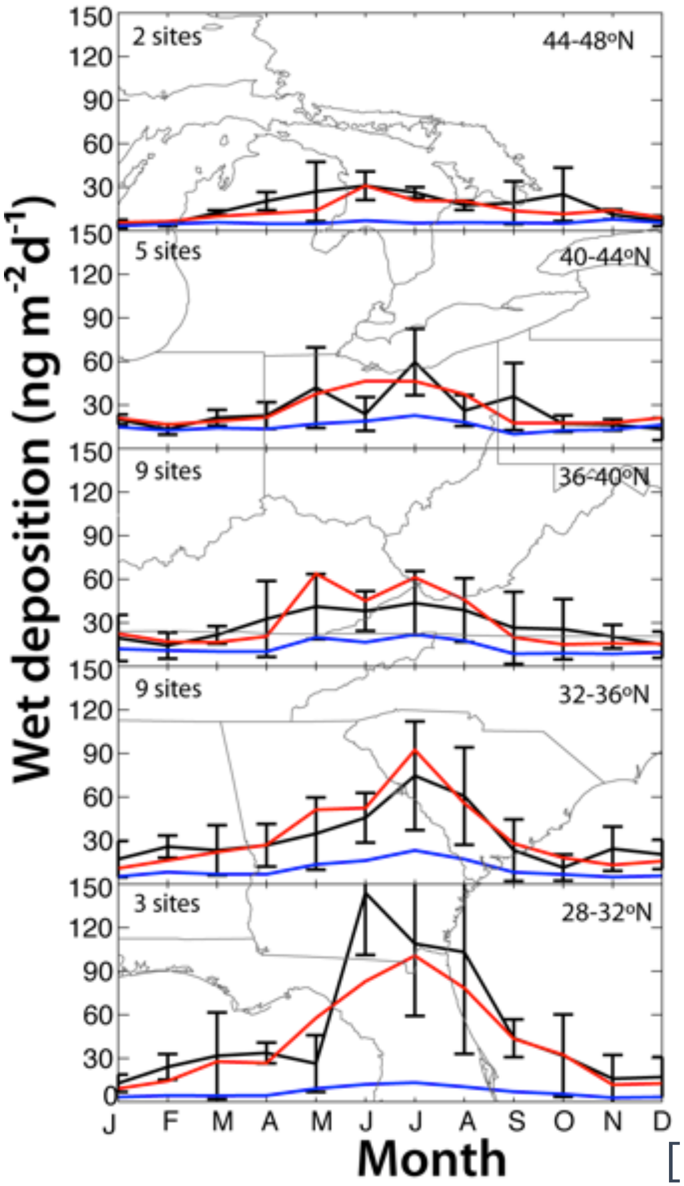
[*Selin & Jacob, Atmos. Env. 2008*]

Atmospheric Reactions of Mercury



Measurements: TGM=Total Gaseous Mercury, RGM=Reactive Gaseous Mercury

Seasonal variations help diagnose the cause



Measurements

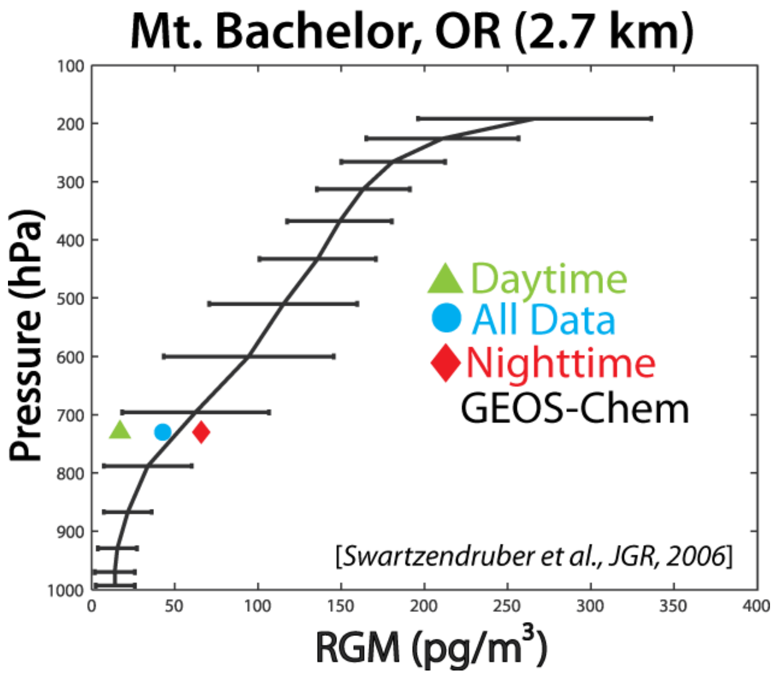
GEOS-Chem

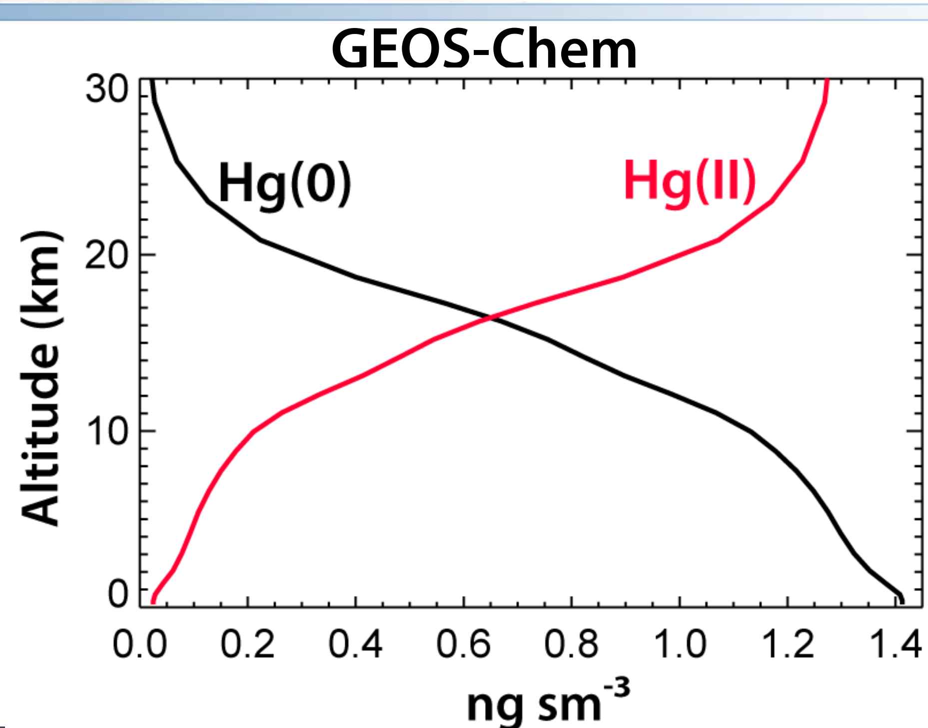
North American contribution

- Amplitude of seasonal variation has latitudinal dependence
- GEOS-Chem captures magnitude, amplitude of regional variation
- Contributing factors:
  - Oxidation
  - Inefficient wintertime scavenging
  - Downwelling & convective scavenging from free troposphere

[Measurements: MDN; Model: *Selin & Jacob, AE 2008*]

Hg(II)/Hg(0) ratio increases with altitude

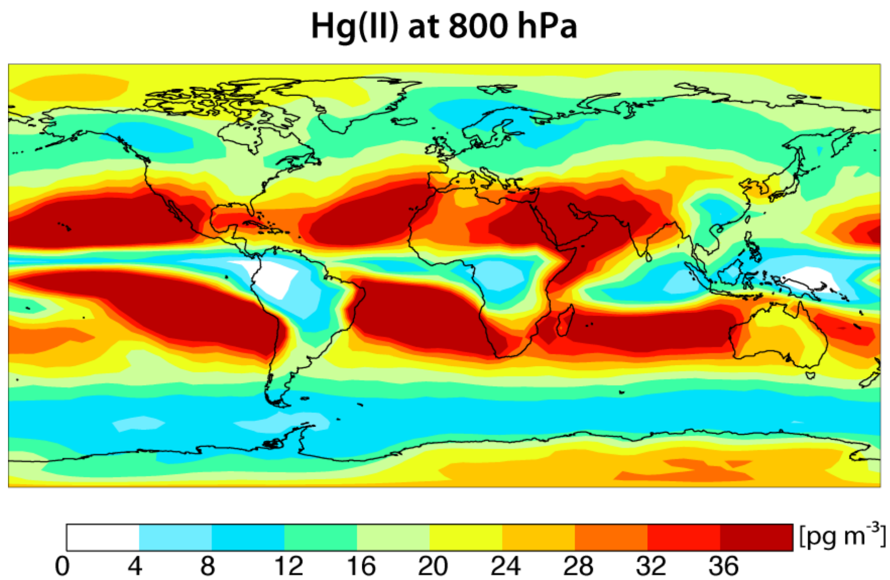




- GEOS-Chem shows increasing Hg(II) with altitude:
  - Source = oxidation from Hg(0)
  - Sinks = Aqueous reduction (dry at altitude), wet and dry deposition (near-surface)
- Measurements from Mt. Bachelor showed elevated RGM over surface levels (higher levels in subsidence at night)
- Murphy et al. [2006] showed Hg associated with particles in the upper troposphere
- Supported by aircraft measurements (more to come!)

[*Selin et al. JGR 2007*]

Subsidence brings Hg(II) downwards



- Hg(II) at higher altitudes will descend where there is subsidence
- High levels of Hg(II) in the model associated with subsidence in the Hadley Cell (subtropical desert regions)
- Potential to affect the surface, but few measurements in these areas!

[*Selin et al. GBC 2008*]

Ongoing research: North American Airborne Mercury Experiment

Is Br the main mercury oxidant in the troposphere?
Is Hg(II) elevated in the free troposphere?
Can we use measurements and modeling to better constrain Hg sources?

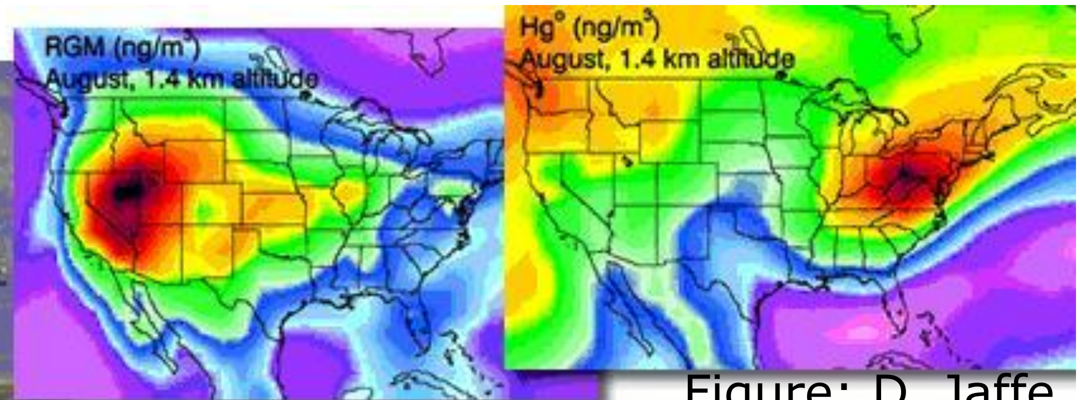


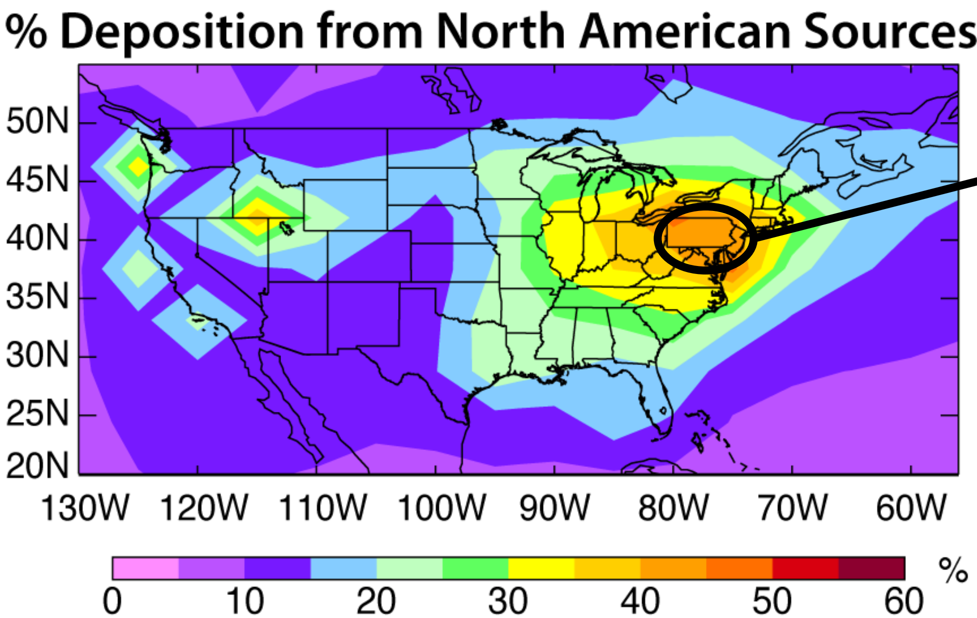
Figure: D. Jaffe

Will be part of the Nitrogen, Oxidants, Mercury and Aerosol: Distributions, Sources and Sinks (NOMADSS) *aircraft campaign, June 1 – July 15, 2013, flying from Nashville, TN*

Selin group will provide near-real-time modeling of atmospheric Hg during the campaign, and post-mission model-measurement analysis

NSF: "Collaborative Research: Mercury in the Atmosphere Over the Eastern United States", with U. Washington (D. Jaffe and L. Jaegle), 10/2012-9/2015

North American Contribution to Mercury Deposition



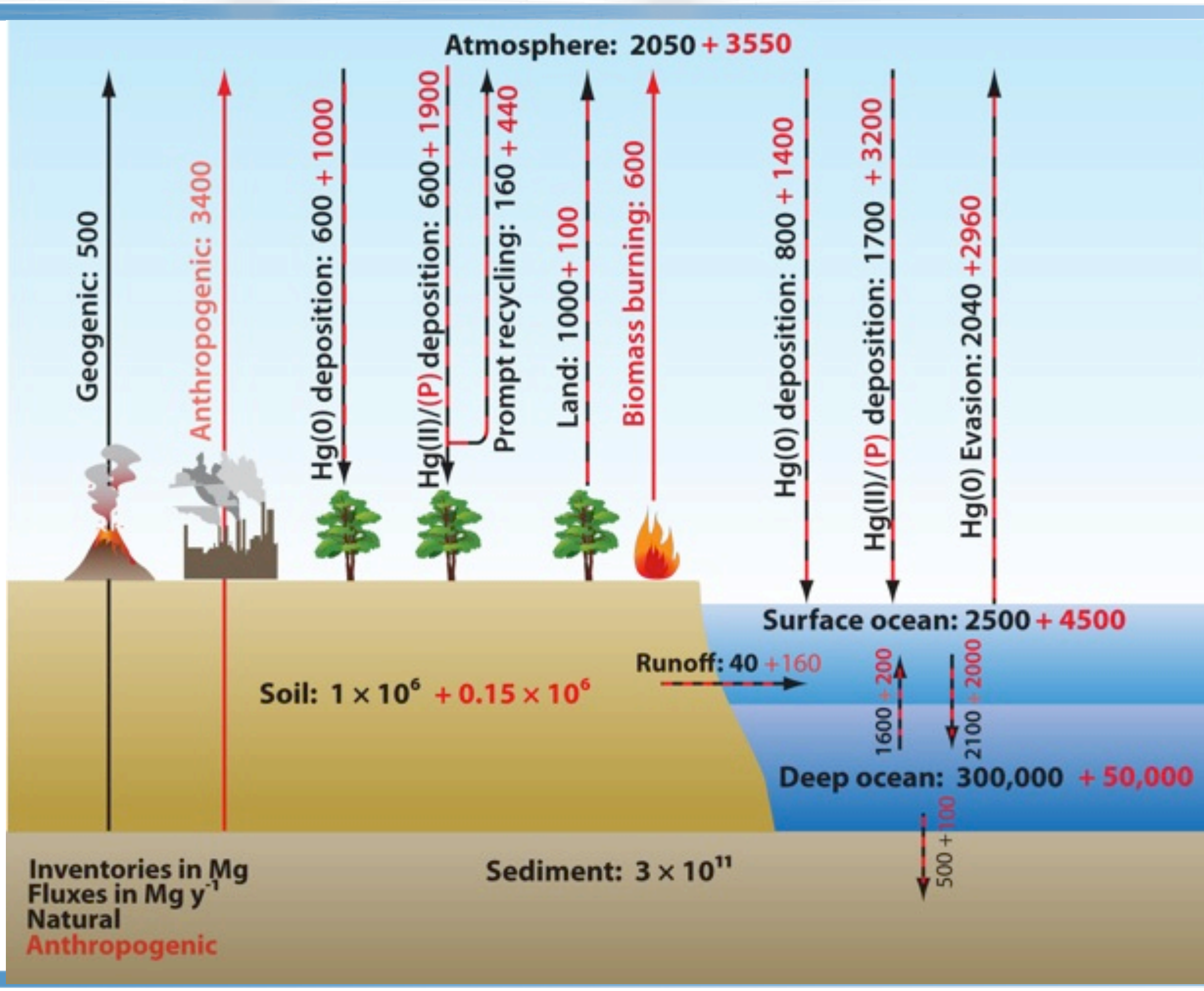
Up to 60% of deposition in Midwest/Northeast U.S. is from domestic sources

Southeast has highest wet deposition in the U.S., but mostly from non-US sources: this is due to rainout of mercury from higher altitudes in summertime

Policy implications:
Reducing deposition in both Midwest and Southeast will require actions on multiple political scales (national and global)

[*Selin & Jacob, Atmos. Env. 2008*]

How does historically-emitted mercury affect present-day exposure?



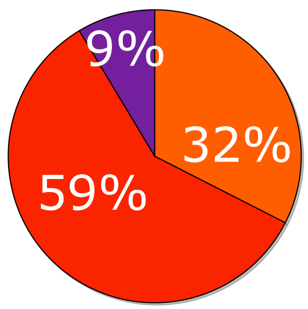
[*Selin, Ann. Rev. Env. Res., 2009*]

Freshwater Deposition and Source Attribution

How do sources affect fish methylmercury, and on what timescales?

Northeast U.S.

24.21 $\mu g\ m^{-2}\ y^{-1}$



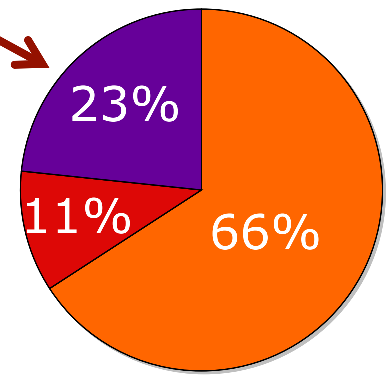
International Anthropogenic

Pre-industrial + Historical

N. American Anthropogenic

Southeast U.S.

34.08 $\mu g\ m^{-2}\ y^{-1}$



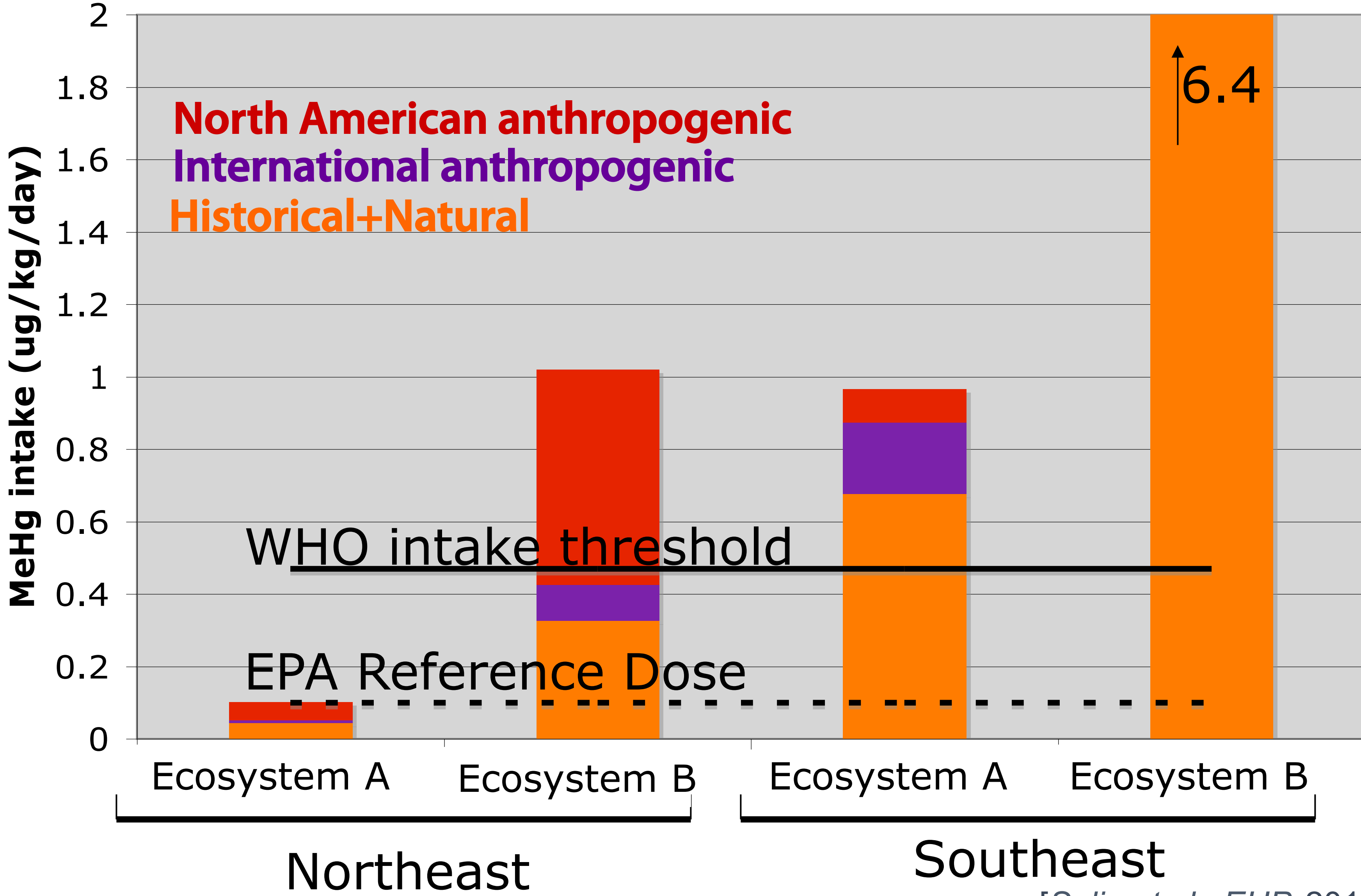
Lake, River, Watershed, and Aquatic food web models
[Knightes et al., 2009]

Policy and Timescale Analysis

[Selin et al., Environ. Health Persp., 2010]

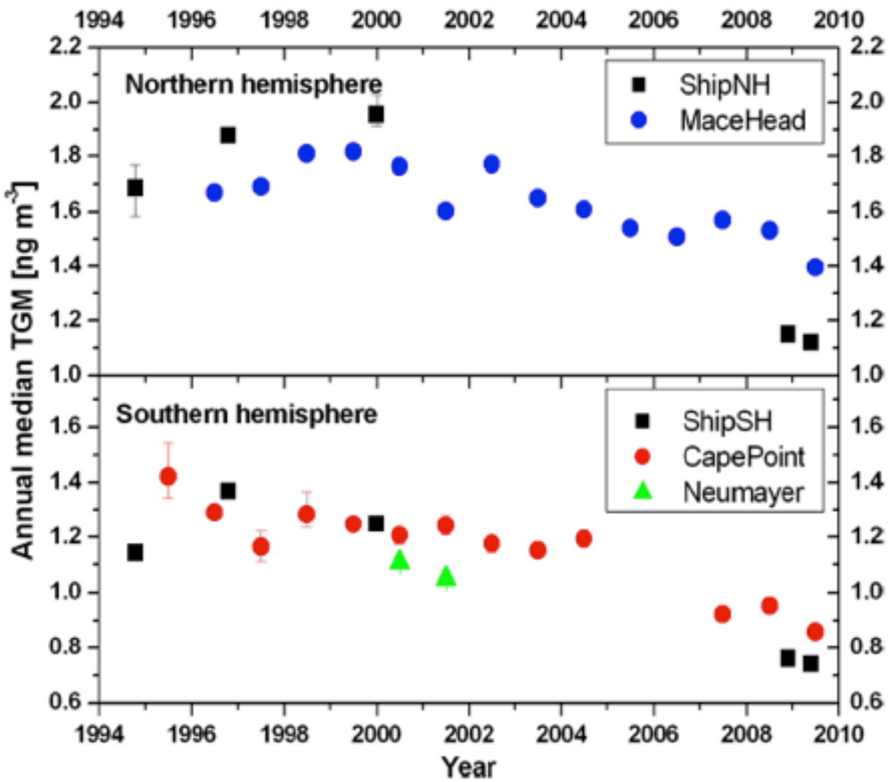
Local Exposure from Freshwater Fish

2 x 100 g fish meals/week (60 kg person) @ t=40 y

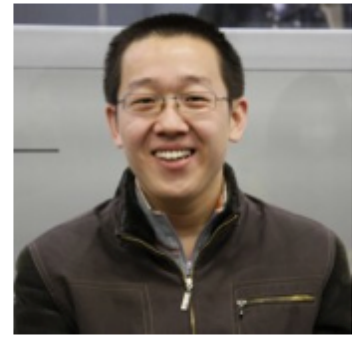


[*Selin et al., EHP,* 2010]

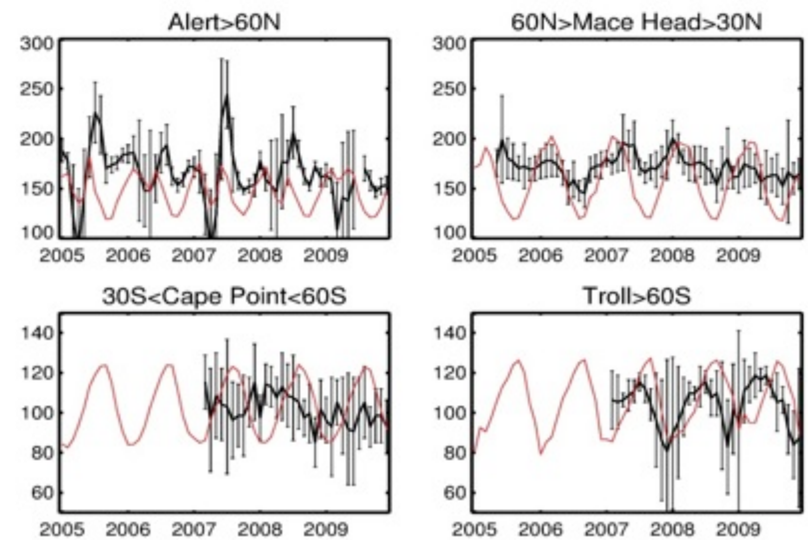
Ongoing research: Quantifying Hg sources using inverse modeling approaches



Why has atmospheric Hg decreased by ≈20% over the past 15 years?
(Slemr et al., 2011)



Shaojie Song, PAOC
2nd year PhD student



NSF: “"CAREER: Understanding Chemistry, Transport and Fate of Mercury and Persistent Organic Pollutants through Global Atmospheric Modeling,” 3/11-2/16

Ongoing research: Quantifying economic impacts of Hg exposure

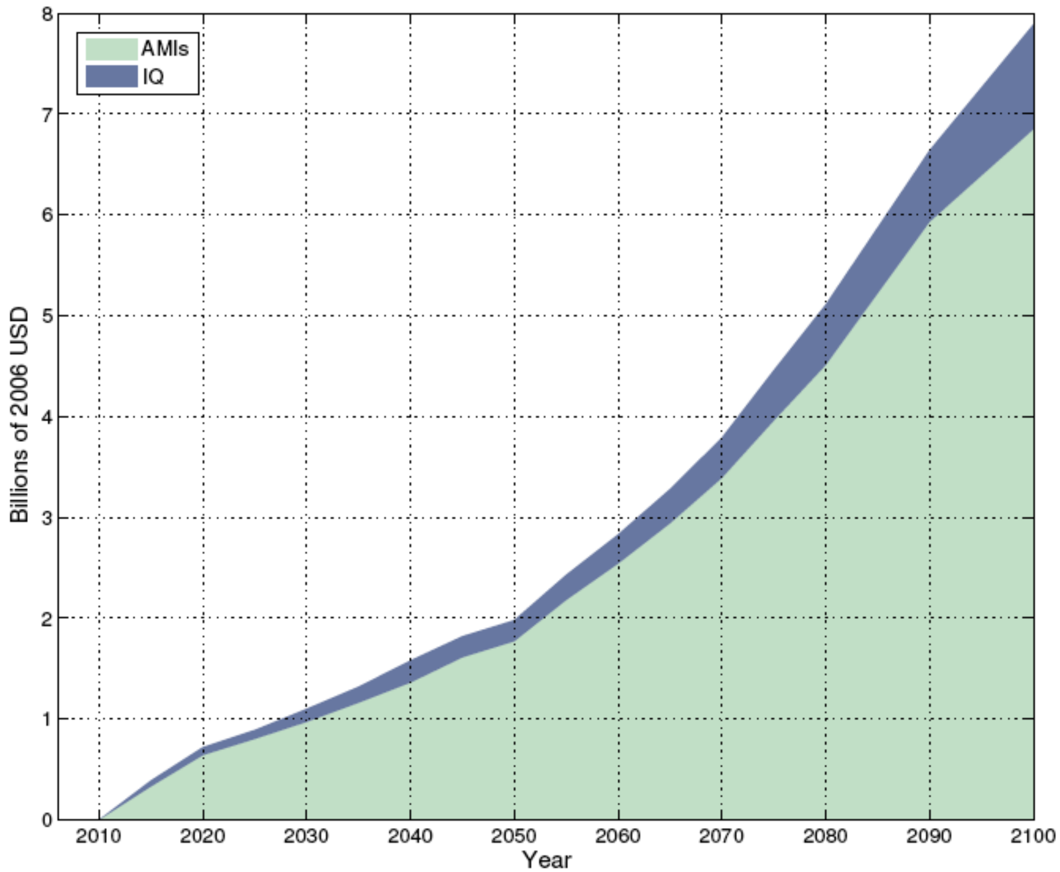
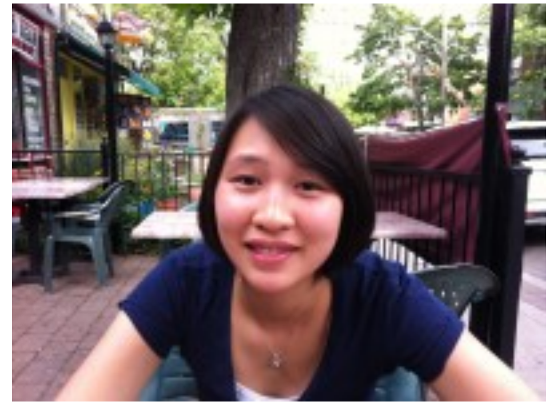


Figure 1: Welfare (consumption and leisure) benefits associated with 10% exposure reduction, by health endpoint. Share attributable to cardiovascular effects ranges from 85 - 90%.



Amanda Giang, 2nd year
ESD/TPP, PAOC Affiliate

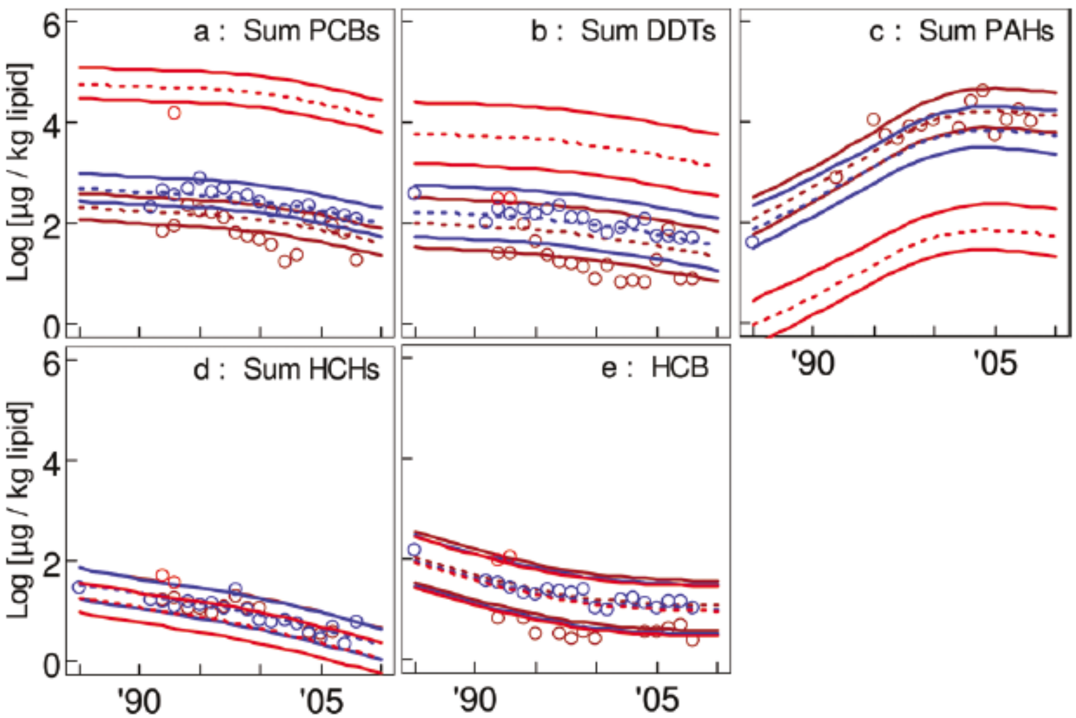
Example 2: Polycyclic Aromatic Hydrocarbons (PAHs)*

- Research questions:
  - What atmospheric processes influence PAH transport to the Arctic?
  - What regions contribute most to Arctic concentrations?
  - Will climate change alter PAH transport and fate?
- For more information:
  - Friedman, C. L. and N.E. Selin. "Long-range transport of polycyclic aromatic hydrocarbons: A global 3-D model analysis including evaluation of Arctic sources." Environmental Science and Technology, 46, 9501-9510, 2012.

Carey Friedman, postdoc

*a category of persistent organic pollutants (POPs)

PAHs are increasing in Arctic wildlife, while other “legacy POPs” are decreasing



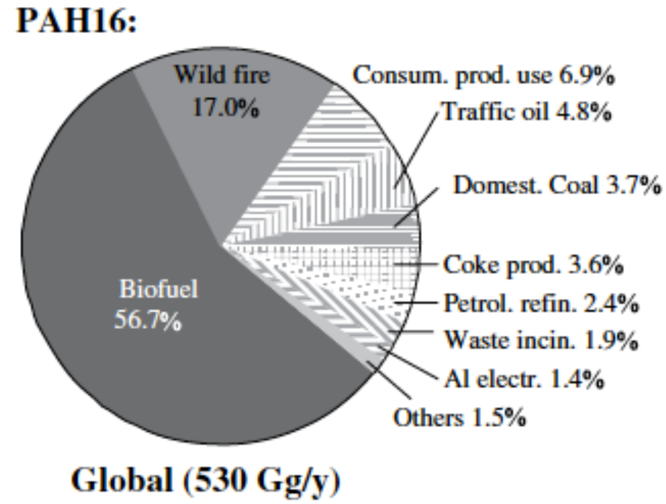


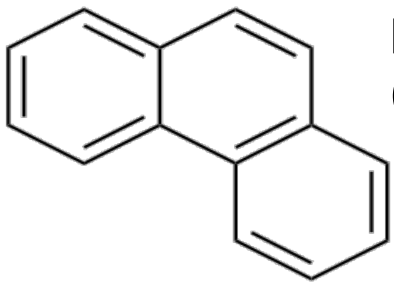
Figure 2. Observed (dots) and modeled tissue concentrations (median: dotted lines; 95% uncertainty interval: solid lines) of 5 pollutant classes in North East Arctic cod (*Gadus morhua*, blue), Blue mussel (*Mytilus edulis*, brown) and Polar bear (*Ursus maritimus*, red). Sum PCBs includes congeners 28, 52, 101, 105, 118, 138, 153, 156, and 180. Sum DDT includes *p,p*'-DDE and *p,p*'-TDE. Sum PAHs includes benzo[ghi]perylene, benzo[a]pyrene, benzo[a]anthrancene, antracene, pyrene, phenanthrene, fluoranthene, benzo[e]pyrene, fluorene, acenaphtylene, and indeno[1,2,3-cd]pyrene. Sum HCHs is α-HCH and γ-HCH.

De Laender et al., 2011

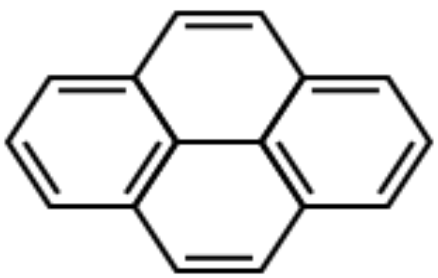
GEOS-Chem POPs Simulation

Polycyclic Aromatic Hydrocarbons (PAHs)

GAS-PHASE

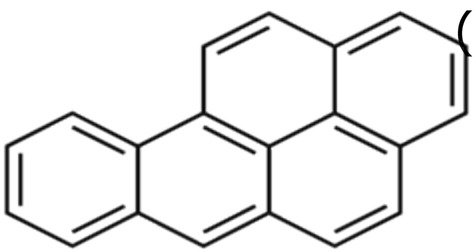


Phenanthrene
(PHE)

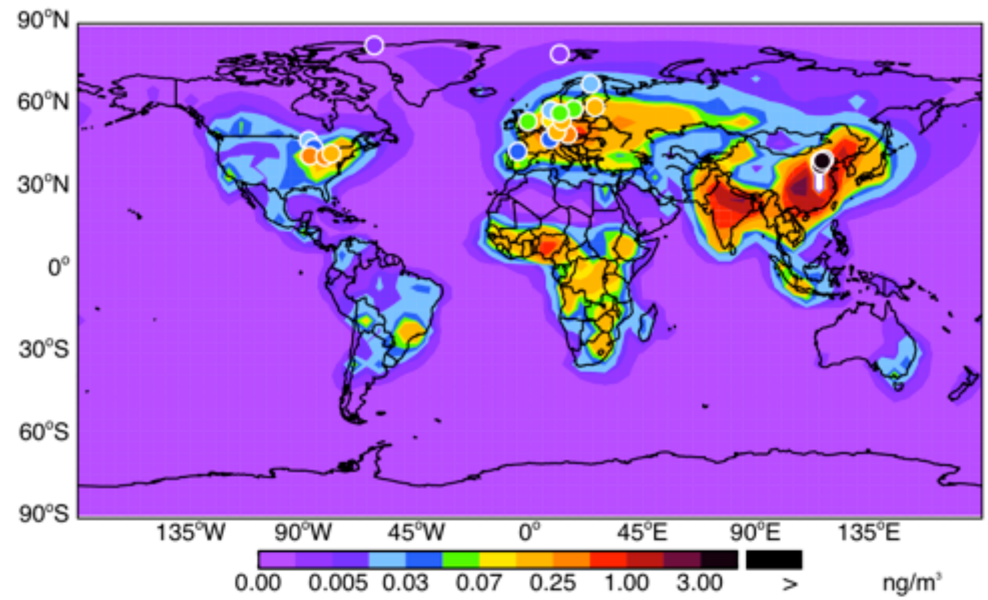


Pyrene
(PYR)

Benzo[a]pyrene
(BaP)



PARTICLE-PHASE

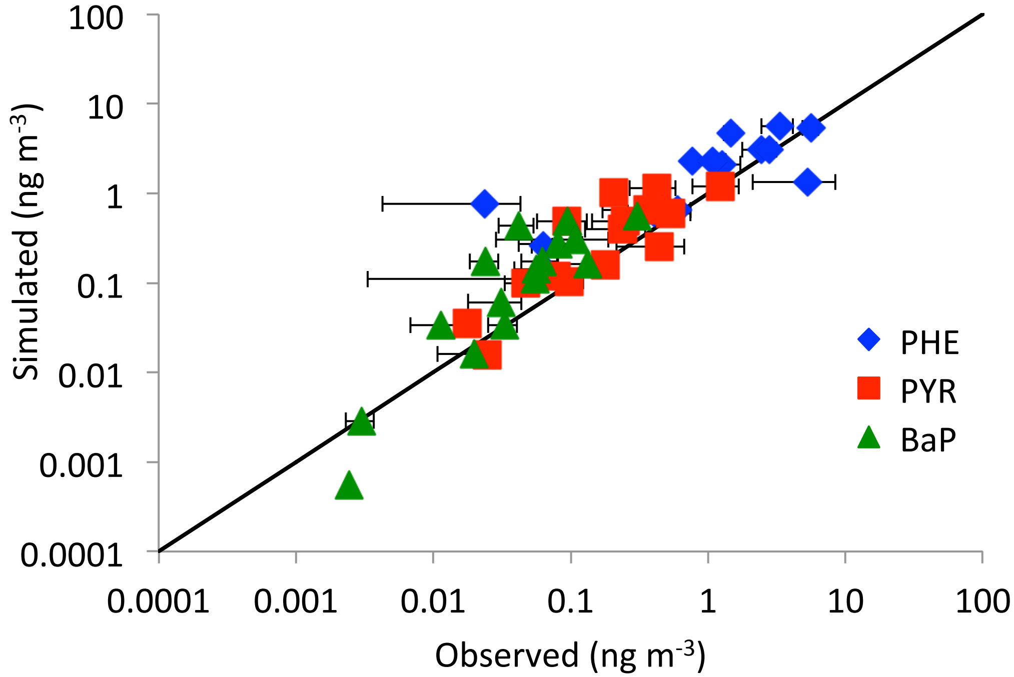


Annual average benzo[a]pyrene vs. observations, mean 2005-2009

Emissions from Zhang and Tao [2009], GEOS-Chem at 4°x5°; includes gas-particle partitioning (to BC/OC), gas-phase oxidation by OH; wet/dry deposition; (particle-phase oxidation)

[Friedman and Selin, ES&T, 2012]

What processes influence PAH transport?

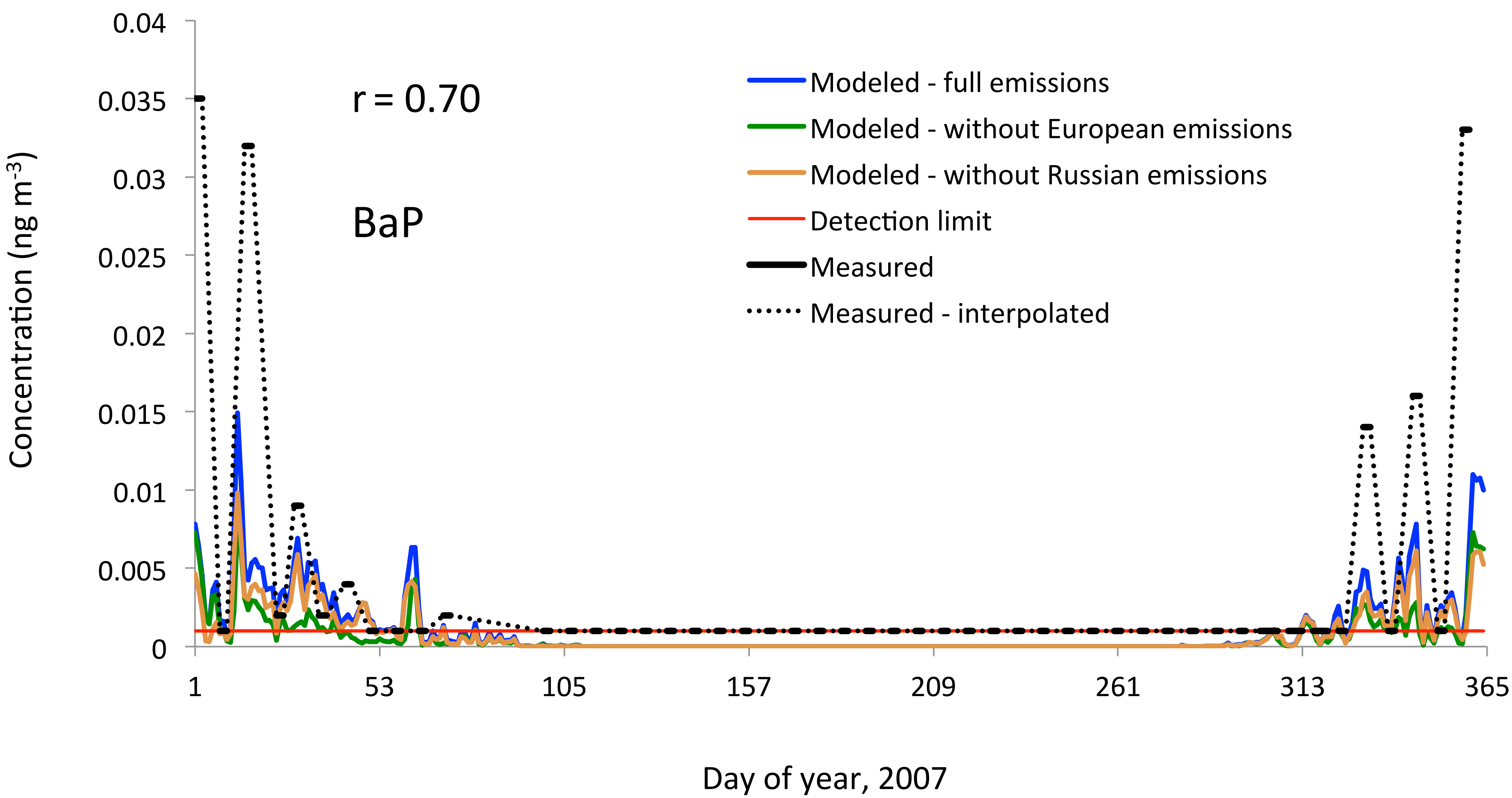


Atmospheric lifetimes (hours):
PHE: 4
PYR: 3
BaP: 6

- Previously thought that phase (particle vs. gas) was most important in controlling transport. This is not the case.
- Simulation sensitive to: temperature sensitivity of partitioning, on-particle oxidation
- Our atmospheric lifetime is much lower than the “threshold” criteria for regional/global action (2.8 days)

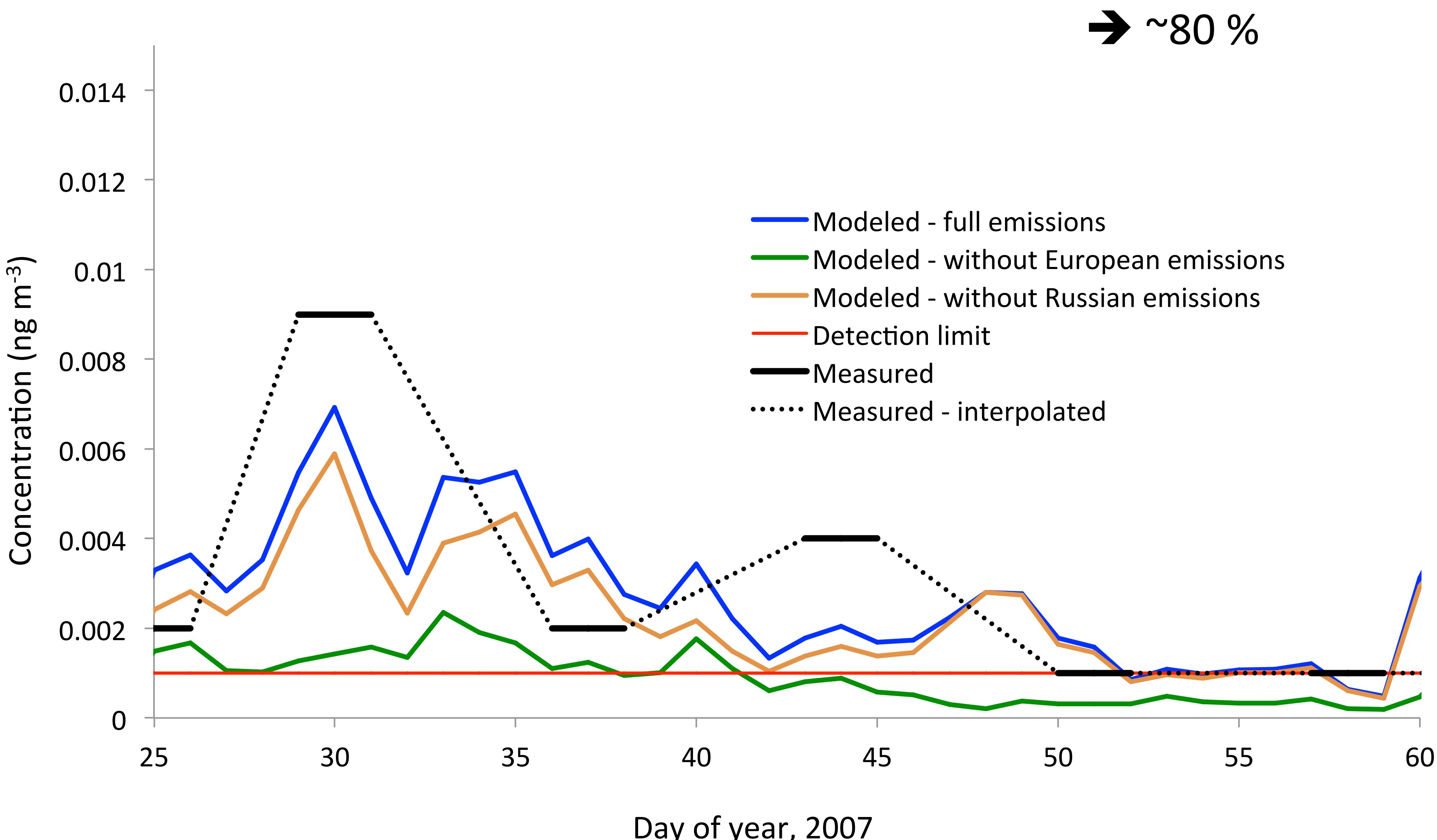
[Friedman and Selin, ES&T, 2012]

European and Russian sources contribute the most to [BaP] at Spitsbergen



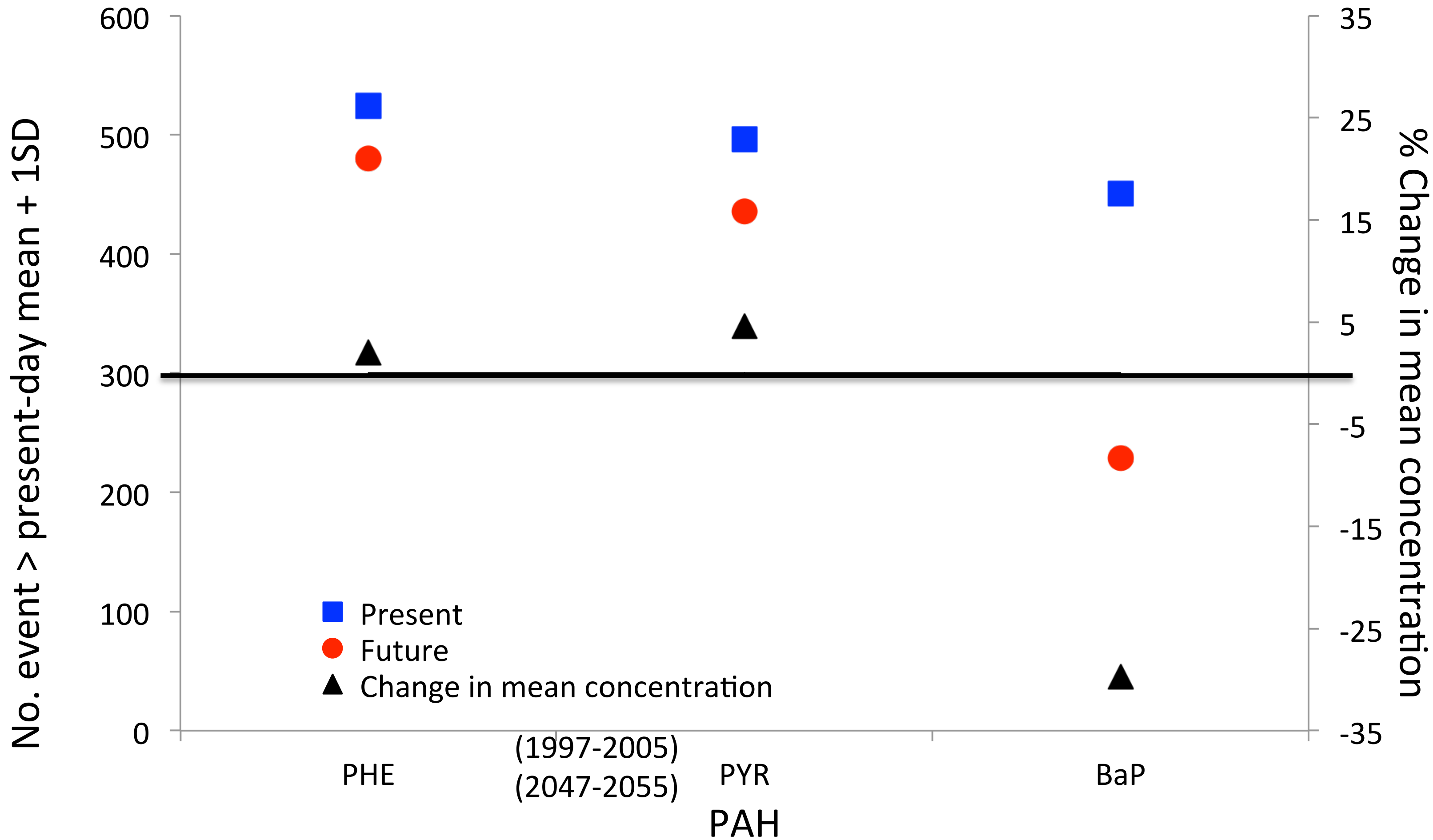
[Friedman and Selin, ES&T, 2012]

European and Russian sources contribute the most to [BaP] at Spitsbergen



[Friedman and Selin, ES&T, 2012]

Ongoing research: Future climate will influence atmospheric BaP



What about future emissions? How does the influence compare?

[Friedman and Selin, in prep]

Ongoing research: Pathways of PFASs

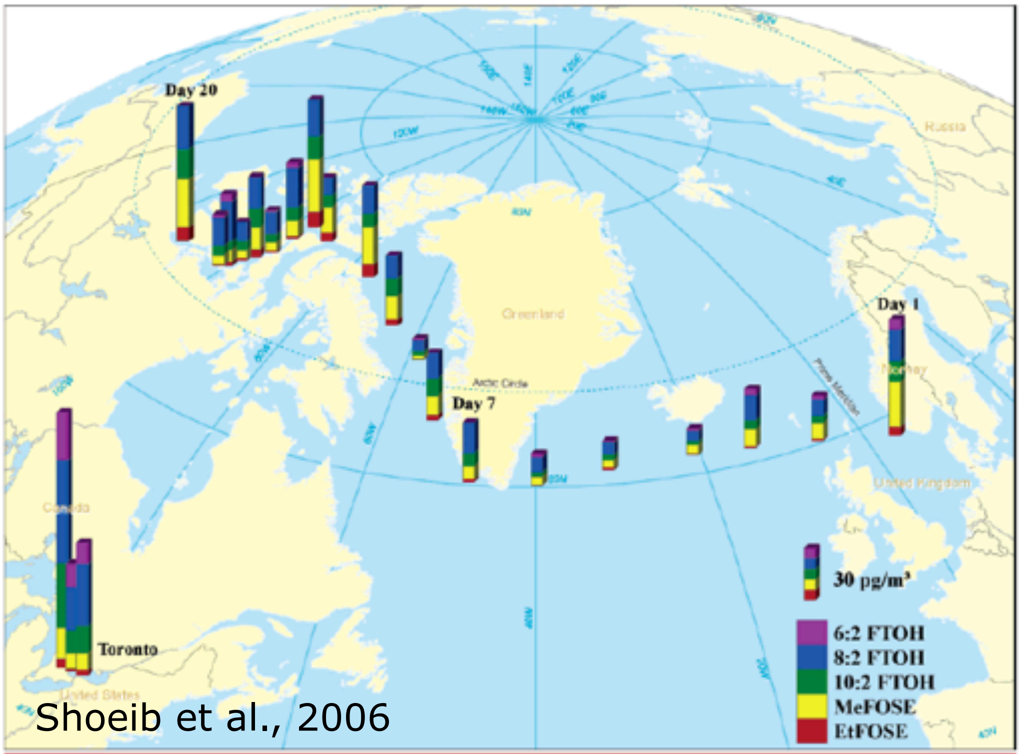
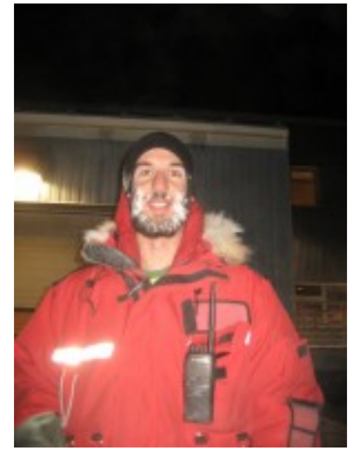


FIGURE 2. Total air concentrations (sum of gas phase and particle phase) for FTOHs and PFASs across the North Atlantic Ocean and Canadian Archipelago (see Figure 1 cruise track) and in Toronto, Canada.



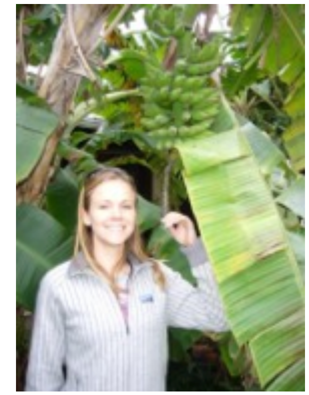
Colin Pike-Thackray, PAOC 2nd year PhD student

How do perfluorinated alkyl substances (such as PFOS/PFOA, chemicals used in Scotchgard/Teflon) reach the Arctic?

NSF: "Collaborative Research: Evaluating the Competing Impacts of Global Emissions Reductions and Climate Change on the Distribution and Retention of selected POPs in the Arctic Ocean," 8/2012-7/2015 (with U. Rhode Island and Harvard School of Public Health)

Example 3: Climate and Air Pollution Impacts

- Research Questions:
  - What are the co-benefits of climate policies for air pollution impacts?
  - How can we model air pollution in ways that facilitate policy evaluation of health impacts?
- For more information:
  - T. M. Thompson and N. E. Selin. 2012. "Influence of Air Quality Model Resolution on Uncertainty Associated with Health Impacts." Atmospheric Chemistry and Physics, in press



Tammy Thompson, postdoc

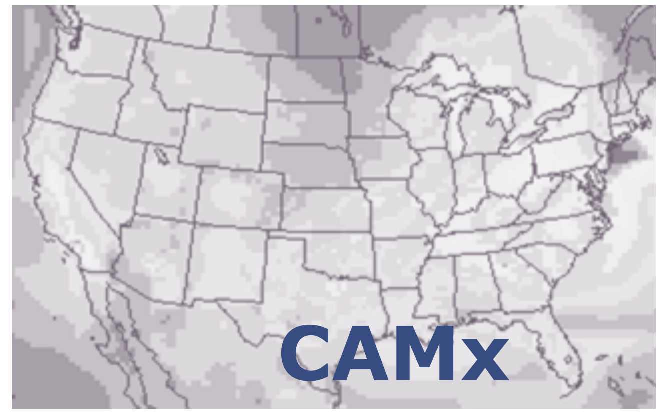
Rebecca Saari, ESD 3rd yr PhD student and PAOC affiliate

A coupled assessment framework for climate policy and air pollution impacts

Climate and Air pollution policy → Emissions → ***Atmospheric chemistry and transport***

Economy

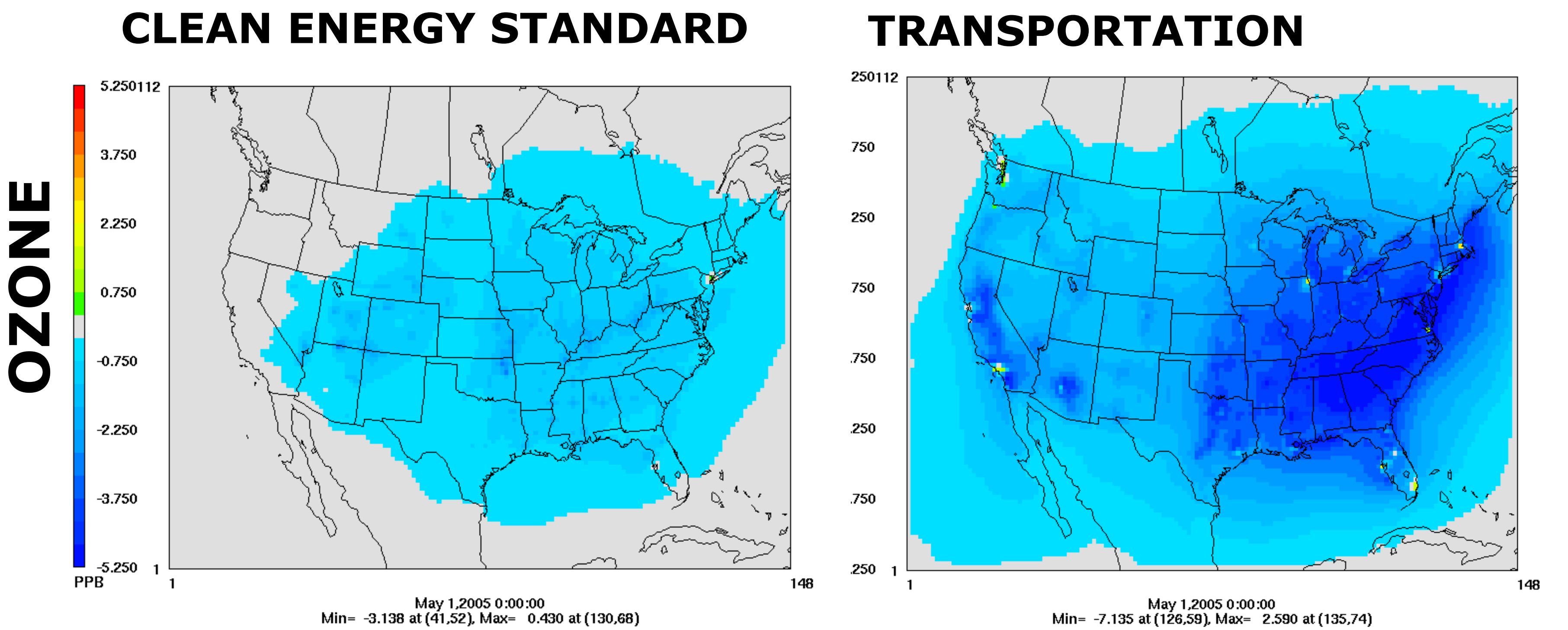
Air Quality



Concentrations

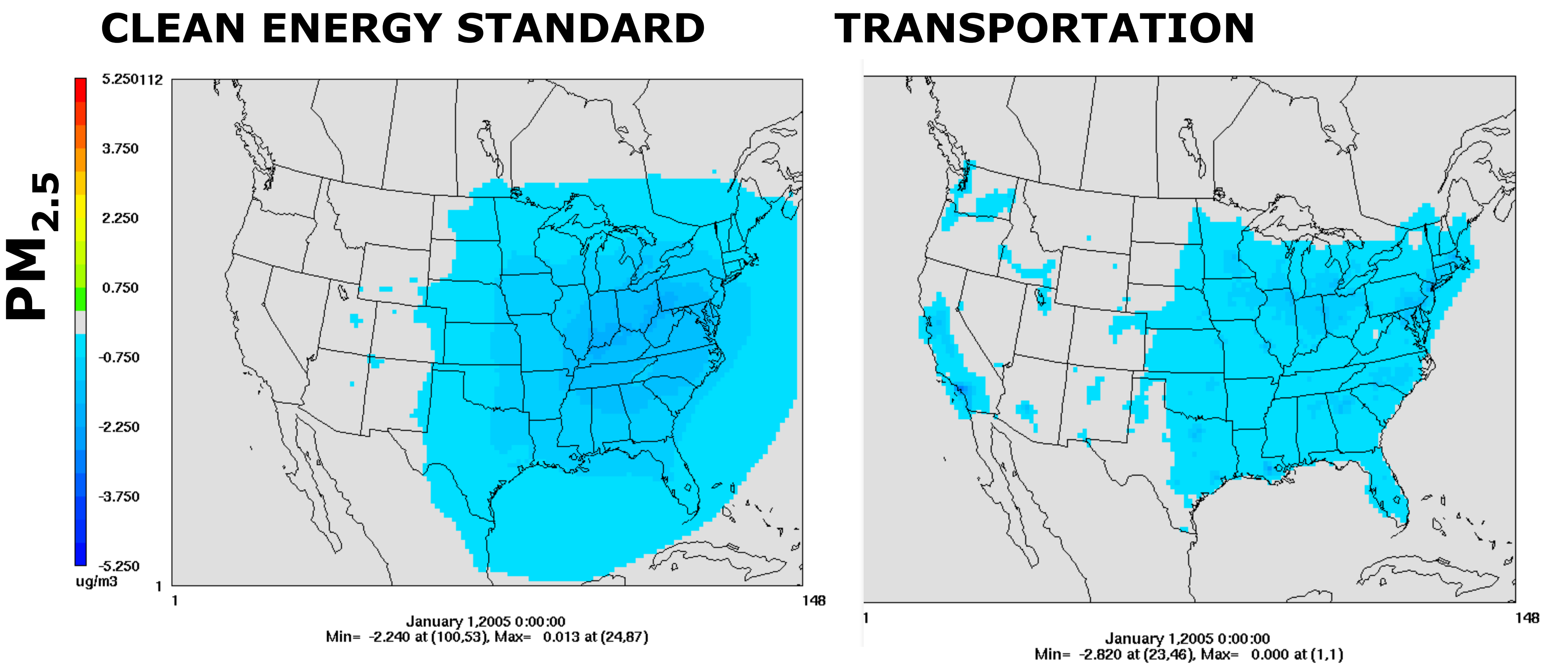
Health and Economic Impacts of Air Pollution

For equivalent CO_2 reductions, transport-focused policy has larger ozone benefits….



[Thompson et al. in prep]

For equivalent CO_2 reductions, clean energy standard has larger $PM_{2.5}$ benefit



**Transport policy focuses on non-commercial vehicles*

[Thompson et al. in prep]

How to Learn More about Science-Policy Interactions

- ❑ How does scientific information inform global environmental policies?
- ❑ What are best practices for scientists to have an impact?

Global mercury treaty expected in 2013

Courses:
12.844 Modeling and Assessment for Policy
12.845 Sustainability Science and Engineering
12.846 Global Environmental Science and Politics
ESD.S50 Global Environmental Negotiations: Mercury*

Play the “Mercury Game” **http://mit.edu/mercurygame**

Leah Stokes, DUSP PhD student with L. Susskind

*Special IAP 2013 subject; field trip to Hg negotiations

The Selin Group 2012

- **Postdocs:**
  - Carey Friedman (PhD, URI): Transport and fate of persistent organic pollutants
  - Tammy Thompson (PhD, U. Texas): Regional atmospheric chemistry and integrated assessment modeling
- **Graduate Students:**
  - Rebecca Saari, ESD 3rd yr: Air pollution health impacts
  - Ellen Czaika, ESD 3rd yr: Sustainability decision-making
  - Shaojie Song, PAOC 2nd yr: Mercury
  - Colin Pike-Thackray, PAOC 2nd yr (1/2012): POPs
  - Amanda Giang, TPP/ESD 2nd yr: Mercury
  - Leah Stokes, DUSP 3rd yr: Mercury science-policy (primary advisor: L. Susskind)

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