Modeling of Hg and POPs Links to Integrated Assessment

Noelle E. Selin

Esther and Harold E. Edgerton Career Development Assistant Professor of Engineering Systems and Atmospheric Chemistry
Massachusetts Institute of Technology

With: Shaojie Song (MIT), Carey L. Friedman (MIT), Amanda Giang (MIT) et al.

Task Force on Hemispheric Transport of Air Pollution
Global and Regional Modeling Workshop
San Francisco, CA 5 December 2013

MIT JOINT PROGRAM GLOBAL CHANGE SCIENCE POLICY

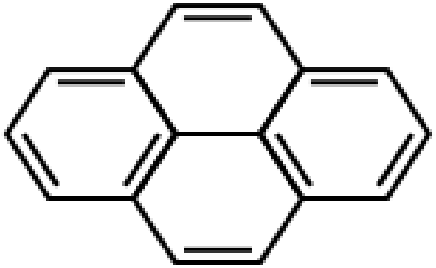
EAPS

MIT ESD Massachusetts Institute of Technology Engineering Systems Division

Modeling Global Transport and Impacts

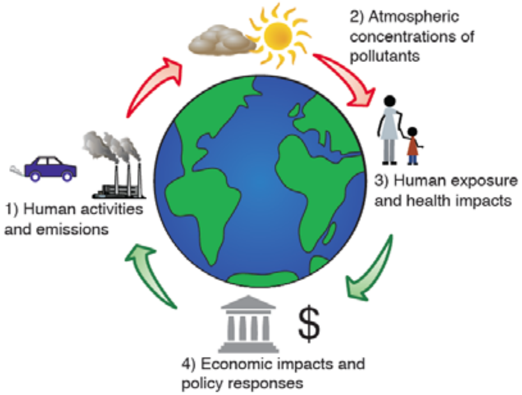
Mercury

Projecting Future Hg under Policy (Selin, ETC, 2013)
Inverse analysis with GEOS-Chem (Song et al. in prep)



POPs

Climate and future PAHs (Friedman et al ES&T 2013)
*PAHs and SOA (Friedman et al., **AGU poster**)*
PCBs and PFOS/PFOA (under construction)



Integrated Assessment

Quantifying US benefits from Hg treaty (in prep)
PM and O3 co-benefits from US carbon policies
*(Thompson et al., submitted; **AGU talk on regional carbon policy results**)*

Transport and Fate of Toxics

Changes in meteorology, chemistry, transport

Long-range transport

Atmospheric concentrations

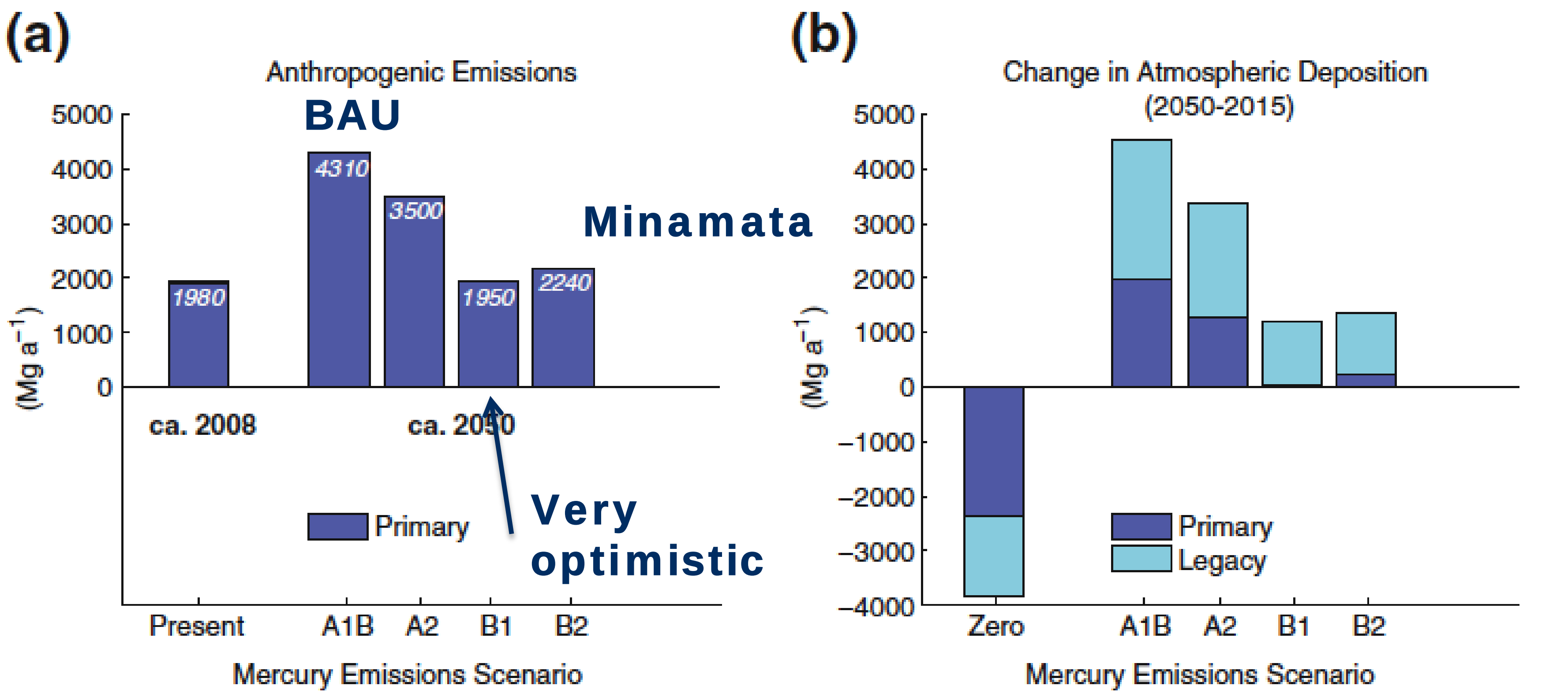
Primary emissions: Controlled by policies (national and global)

Secondary emissions, may increase due to climate change

Concentrations in environmental reservoirs (ice, ocean, land)

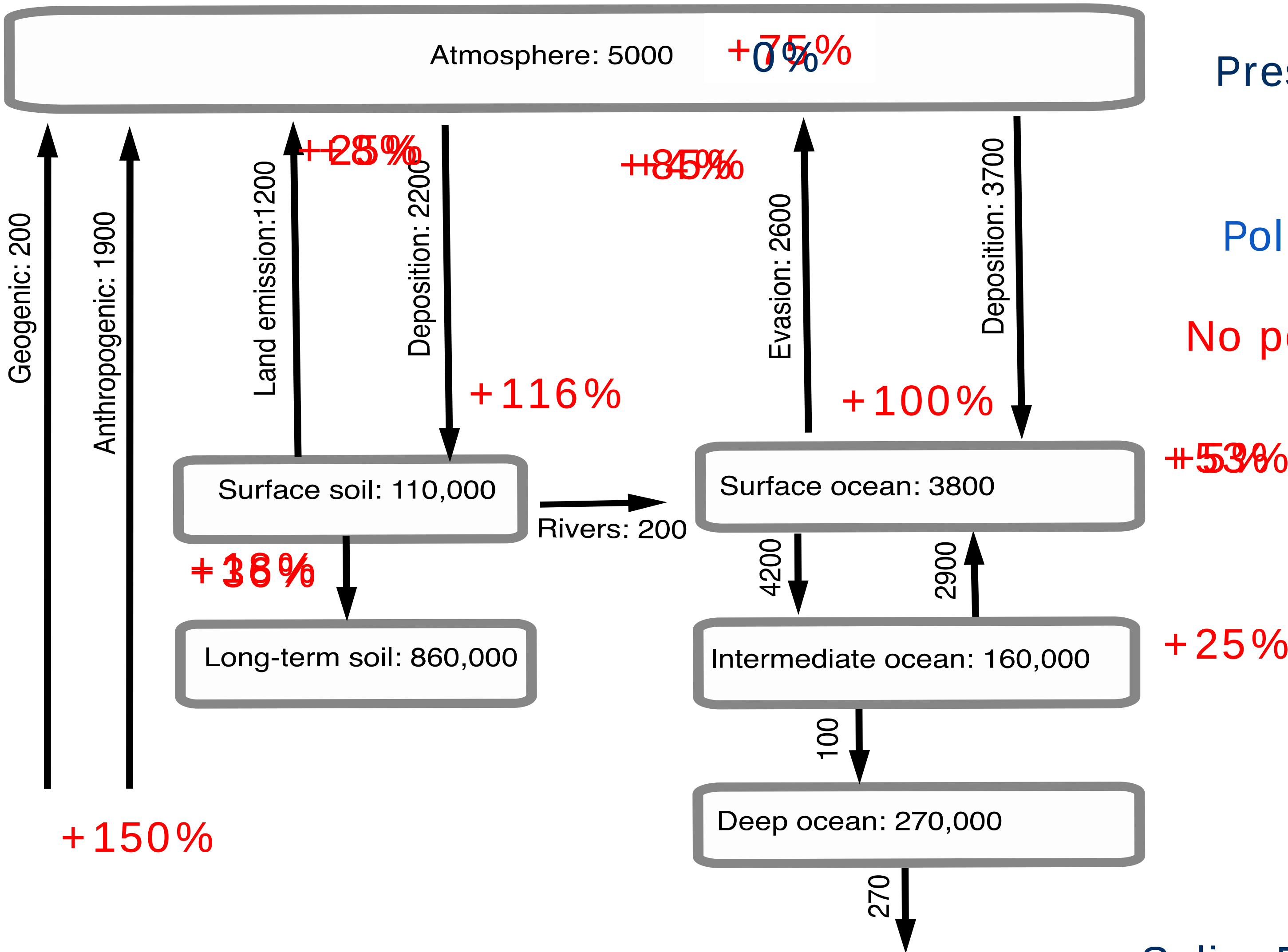
Ecosystem and human impacts

Future mercury projections



Sunderland and Selin, Env Hlth, 2013

Modeling of Future Hg under Policy



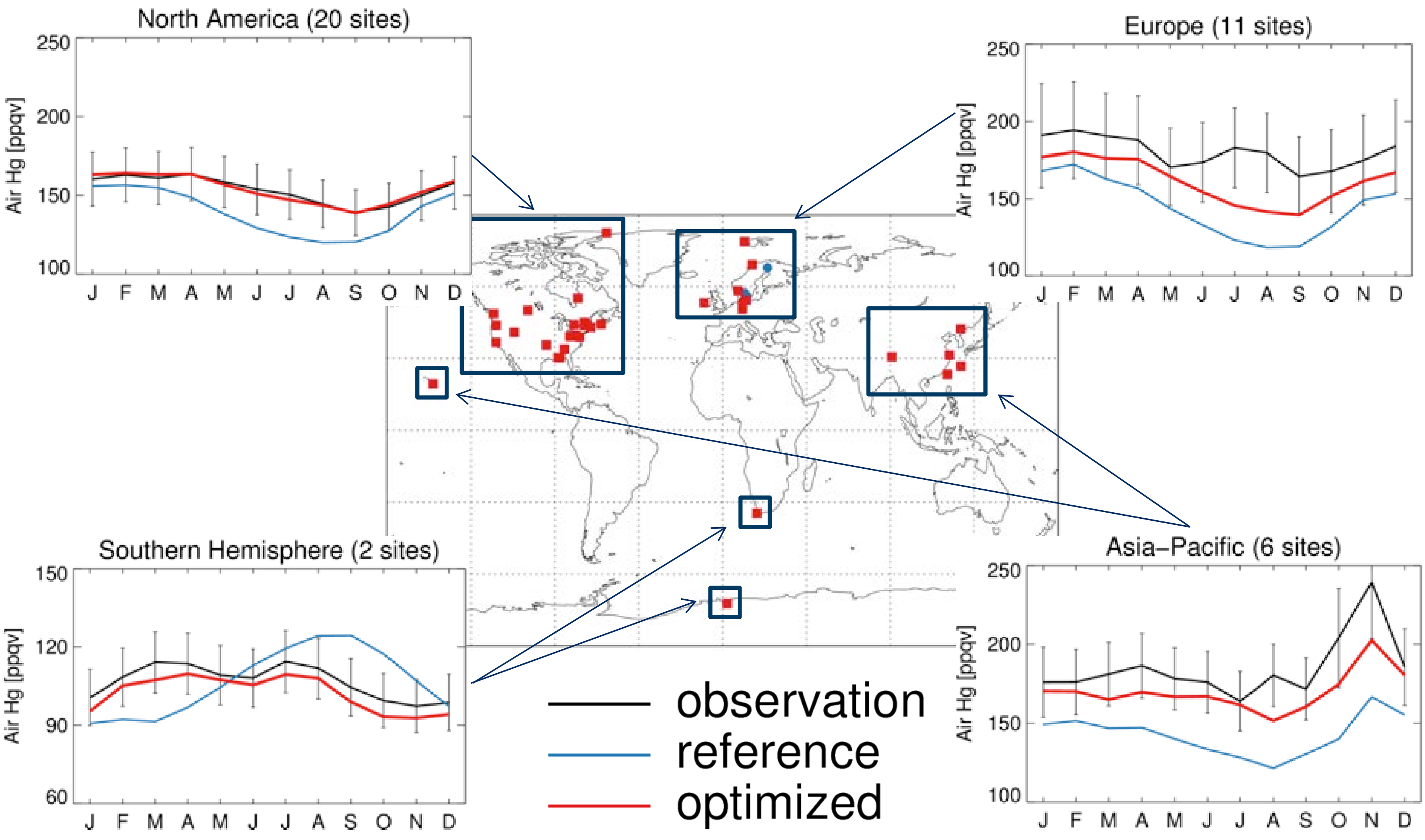
Present

Policy (2050)

No policy (2050)

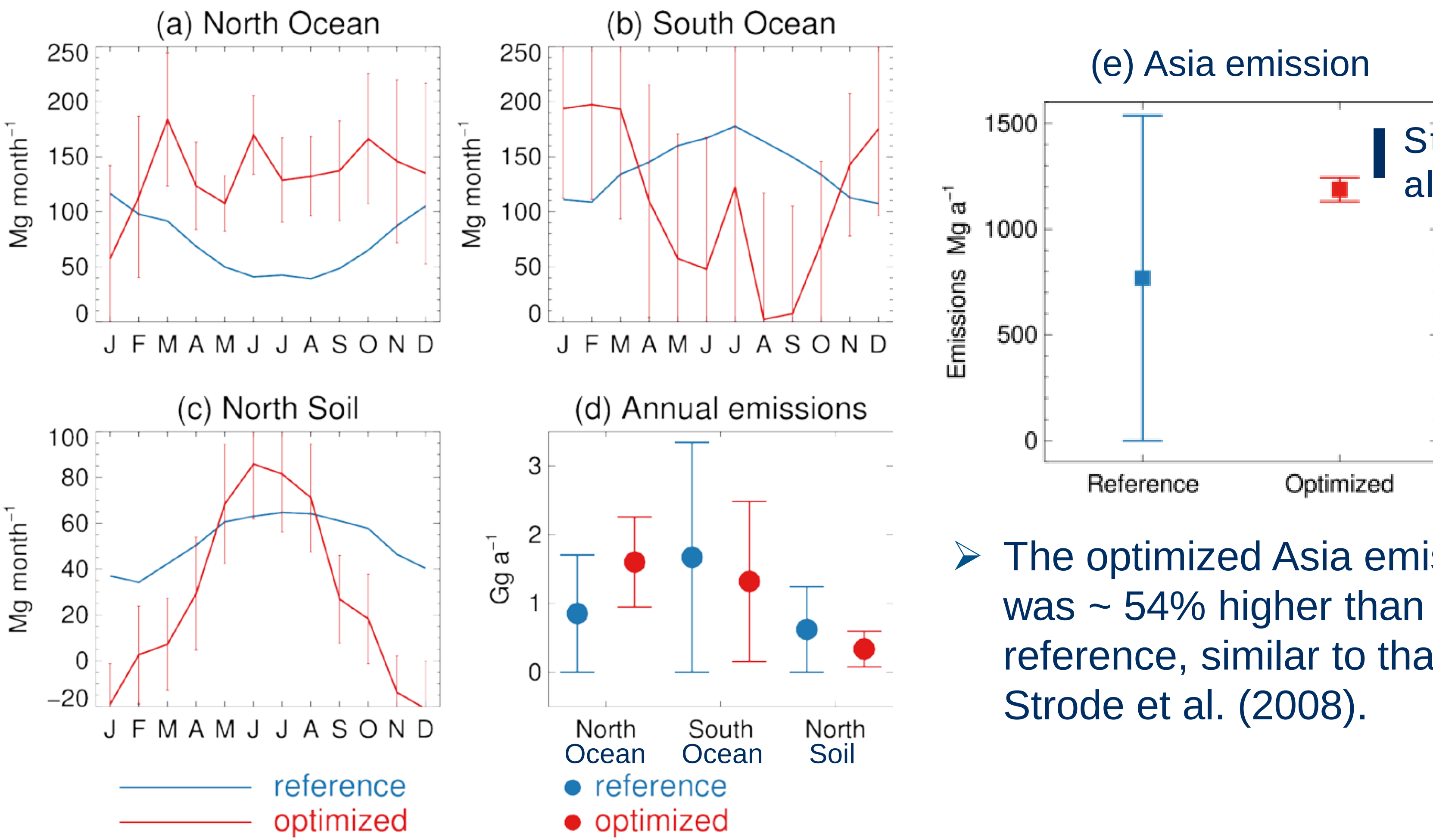
Selin, ETC, 2013

GEOS-Chem mercury simulation



S. Song et al., in prep

Inverse modeling to constrain emissions

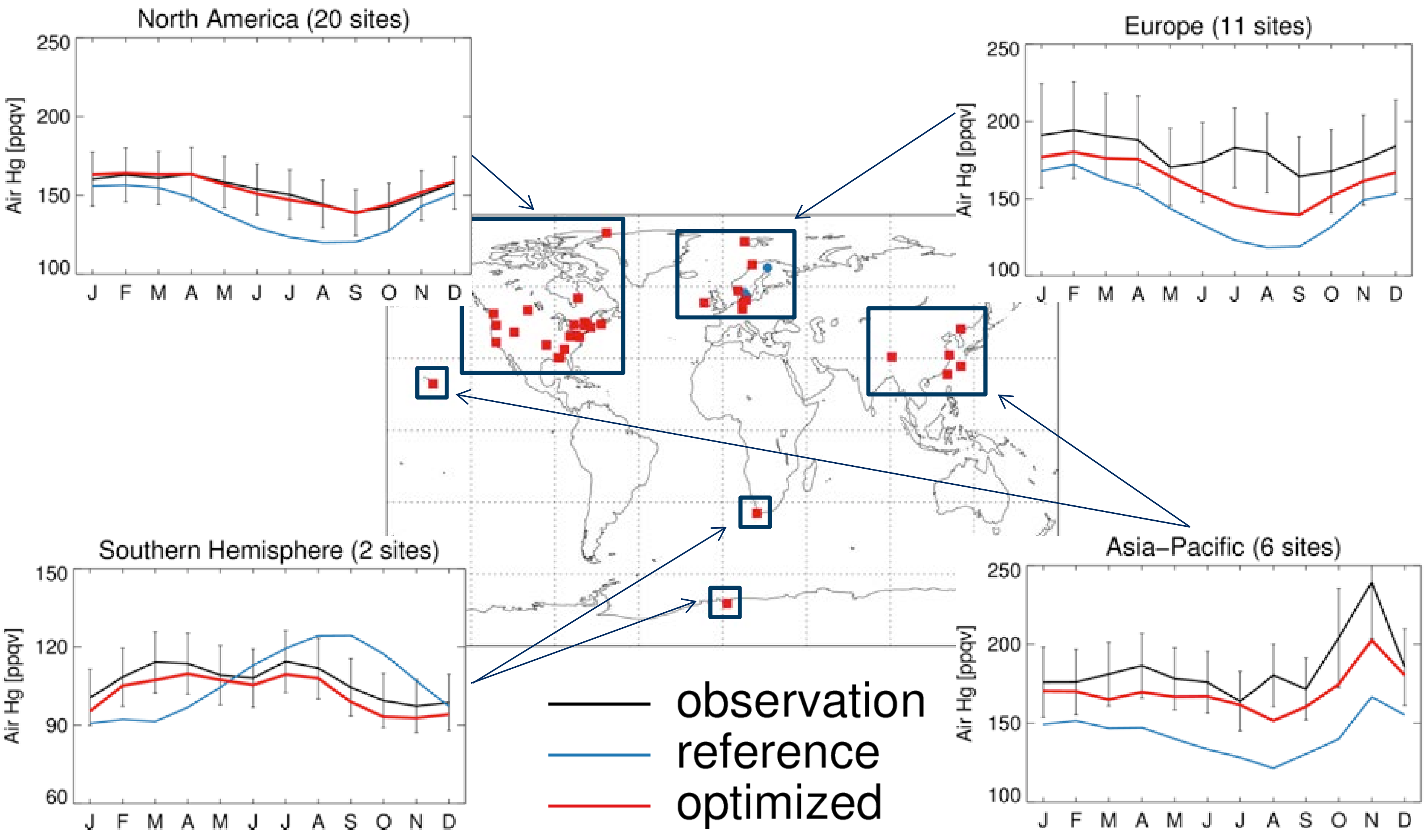


Strode et al., 2008

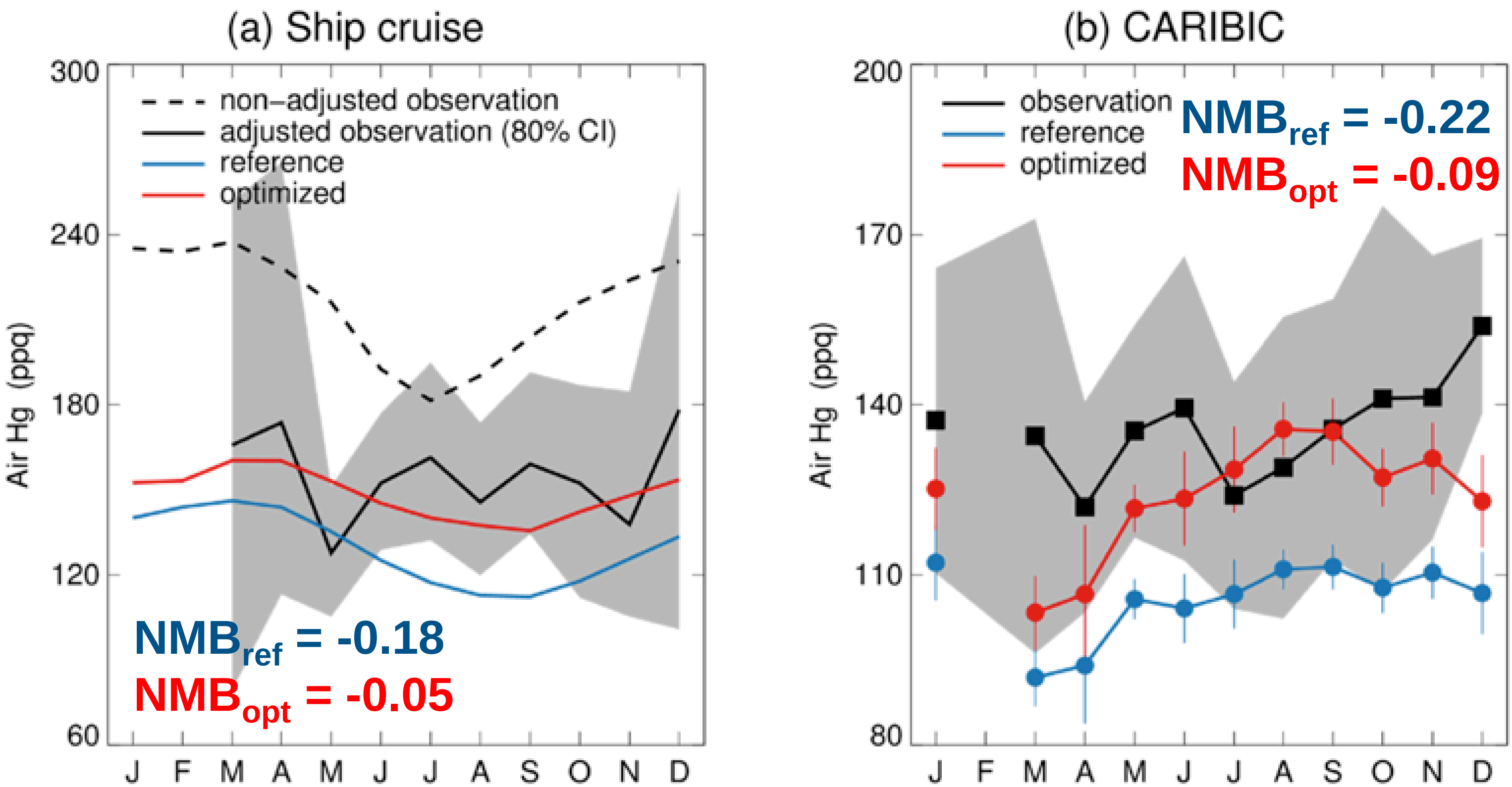
- The optimized Asia emission was ~ 54% higher than the reference, similar to that by Strode et al. (2008).

- The average uncertainties are reduced from 100% to ~ 64%.
- Significant changes in the seasonality of ocean and soil emissions.

GEOS-Chem mercury simulation



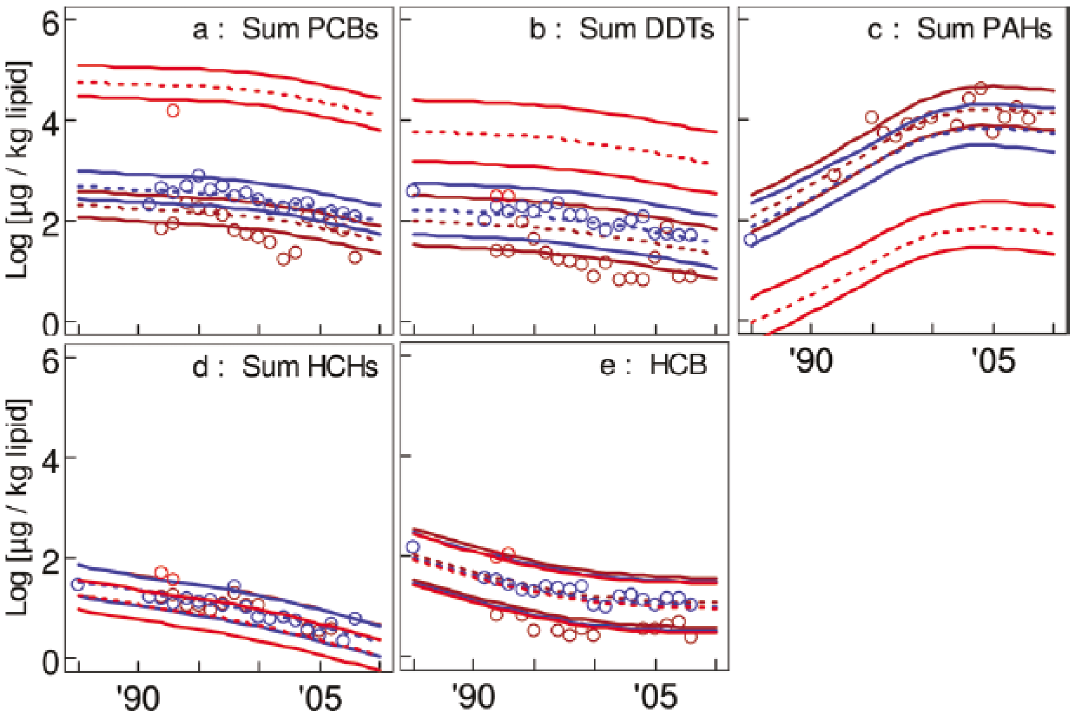
Independent tests of the inversion



- The North Atlantic Ocean region was selected for both data sets.
- Independent data sets from ship cruise and aircraft measurements were better reproduced using optimized emissions.

Ship cruise data source: Soerensen et al., 2010a; Soerensen et al., 2012

PAHs are increasing in the Arctic



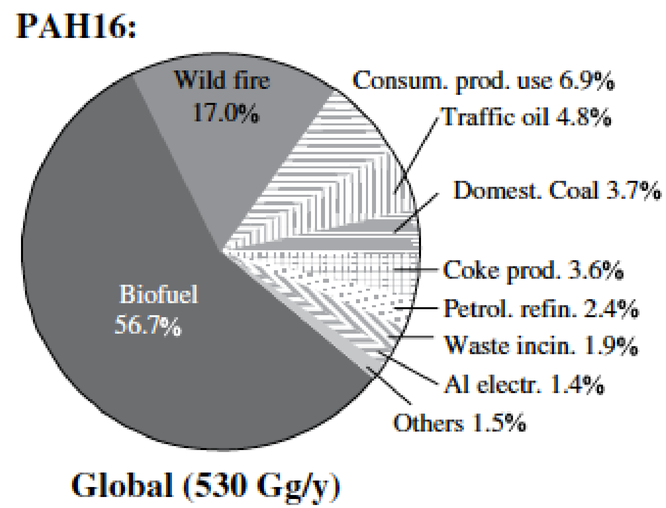


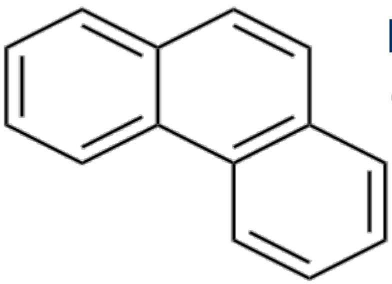
Figure 2. Observed (dots) and modeled tissue concentrations (median: dotted lines; 95% uncertainty interval: solid lines) of 5 pollutant classes in North East Arctic cod (*Gadus morhua*, blue), Blue mussel (*Mytilus edulis*, brown) and Polar bear (*Ursus maritimus*, red). Sum PCBs includes congeners 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

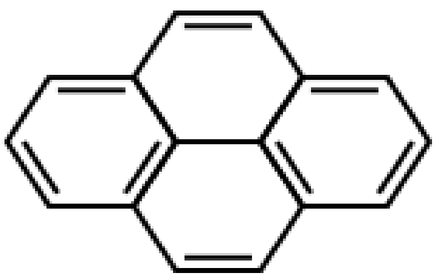
GEOS-Chem POPs Simulation

Polycyclic Aromatic Hydrocarbons (PAHs)

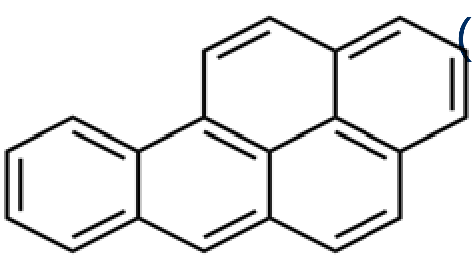
GAS-PHASE



Phenanthrene (PHE)

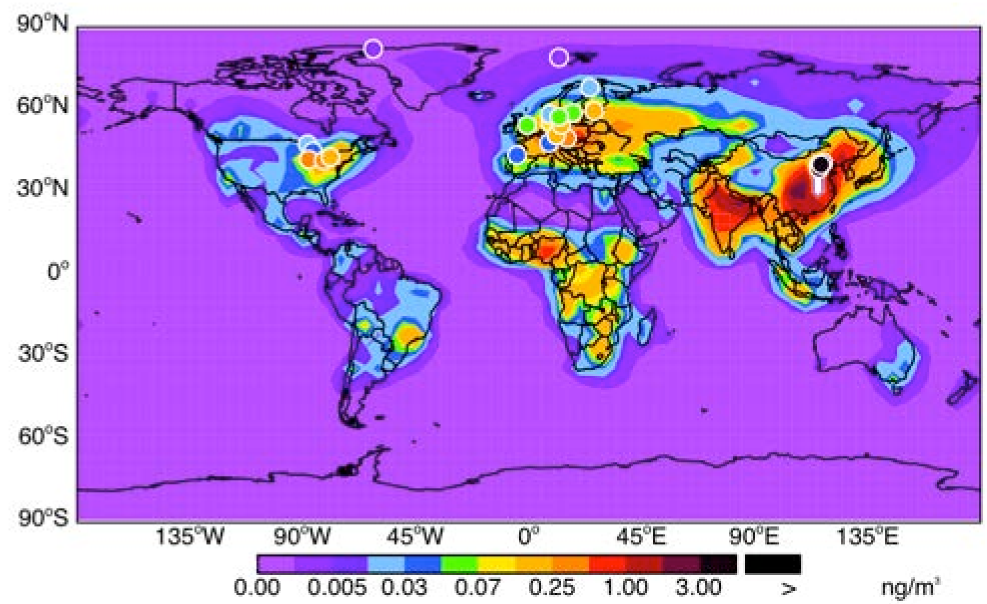


Pyrene (PYR)



Benzo[a]pyrene (BaP)

PARTICLE-PHASE

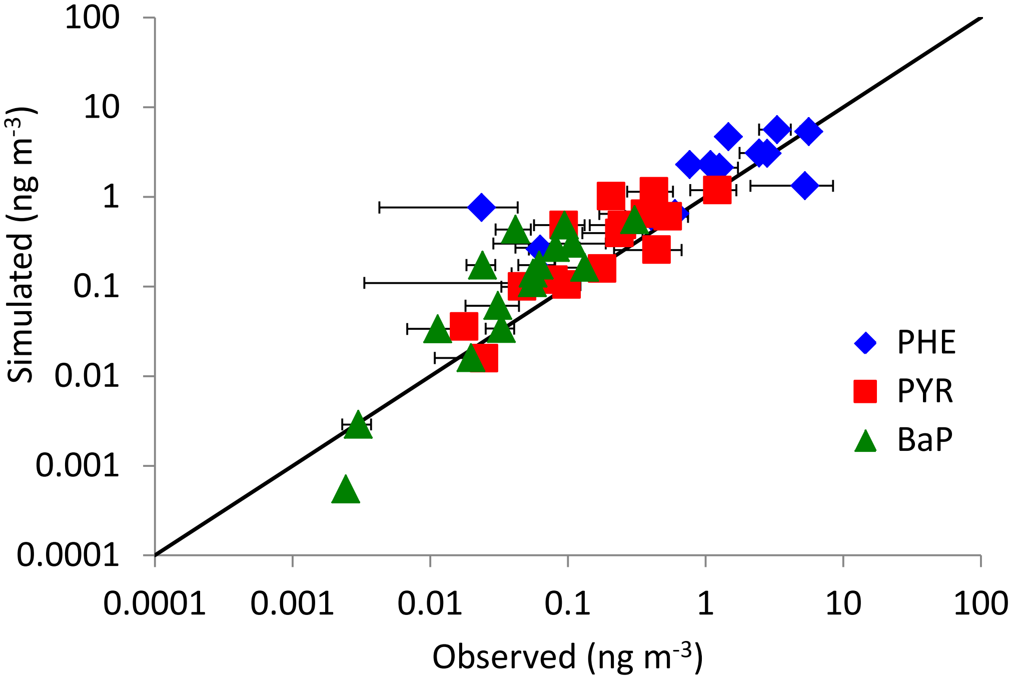


Annual average benzo[a]pyrene vs. observations, mean 2005-2009

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?

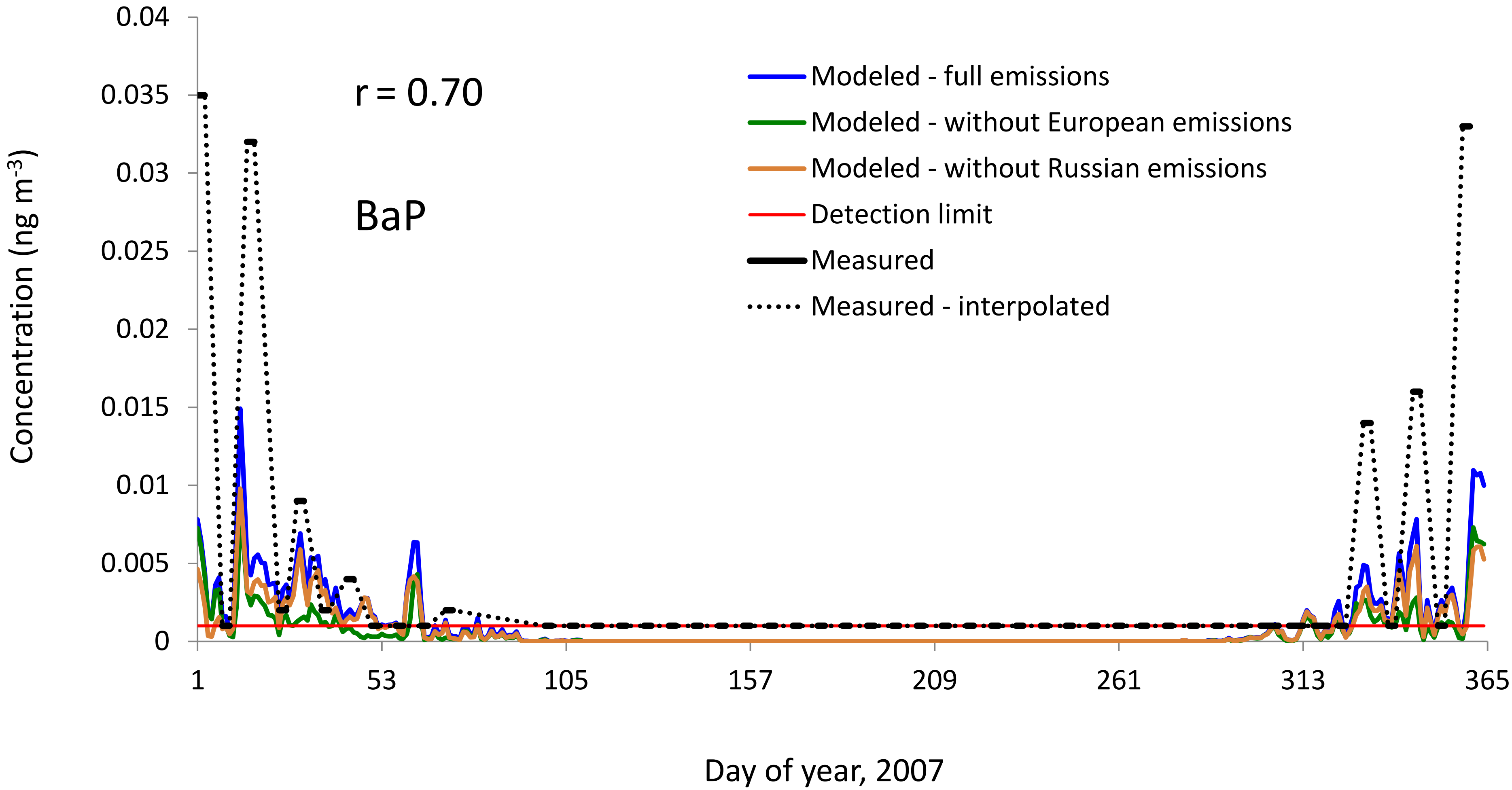


Atmospheric lifetimes (**hours**):
PHE: 4
PYR: 3
BaP: 6

- Our atmospheric lifetime is much shorter than the “threshold” criteria for regional/global action (2.8 days)
- 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

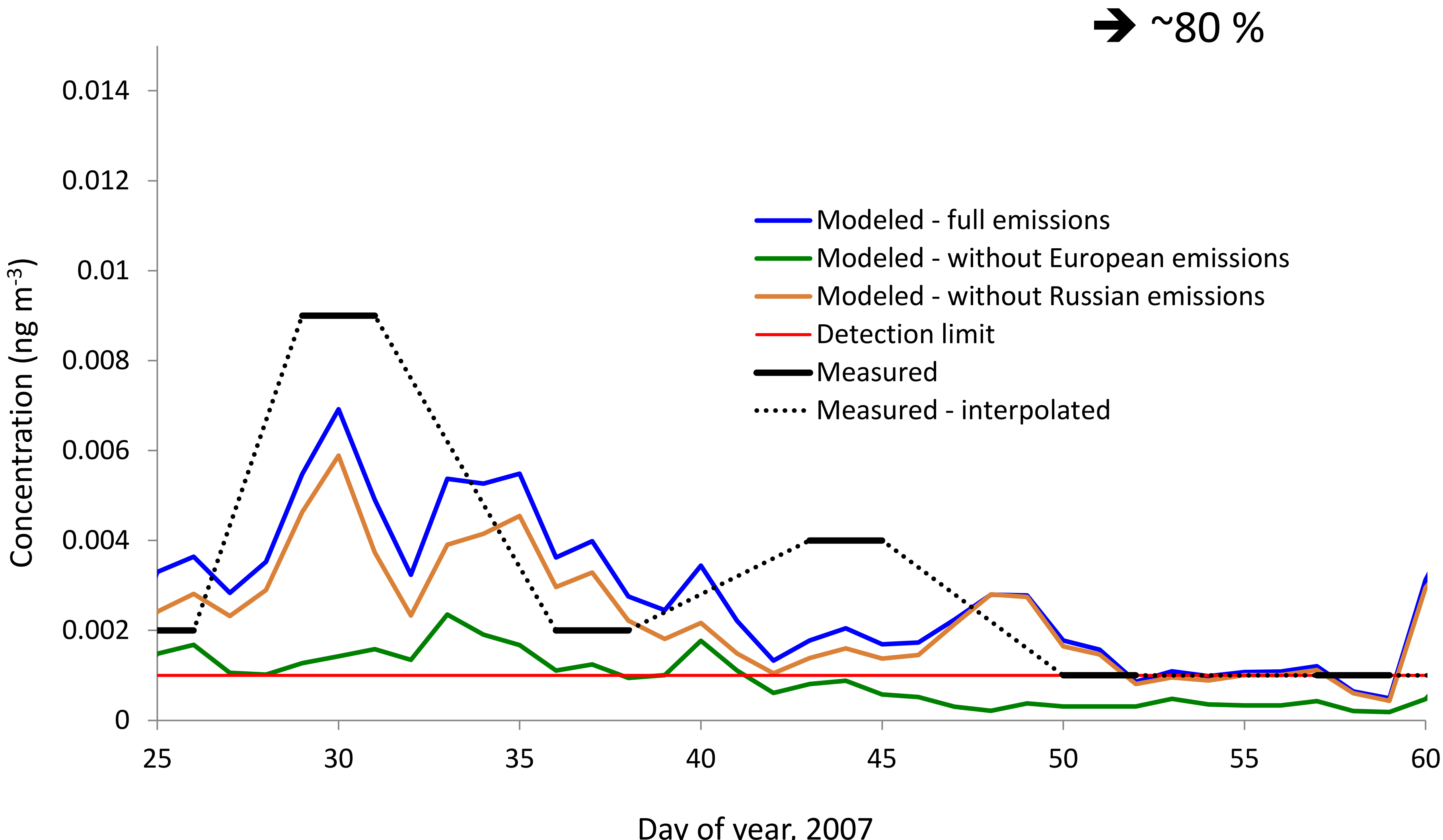
[Friedman and Selin, ES&T, 2012]

Europe and Russia influence Spitsbergen



[Friedman and Selin, ES&T, 2012]

Europe and Russia influence Spitsbergen

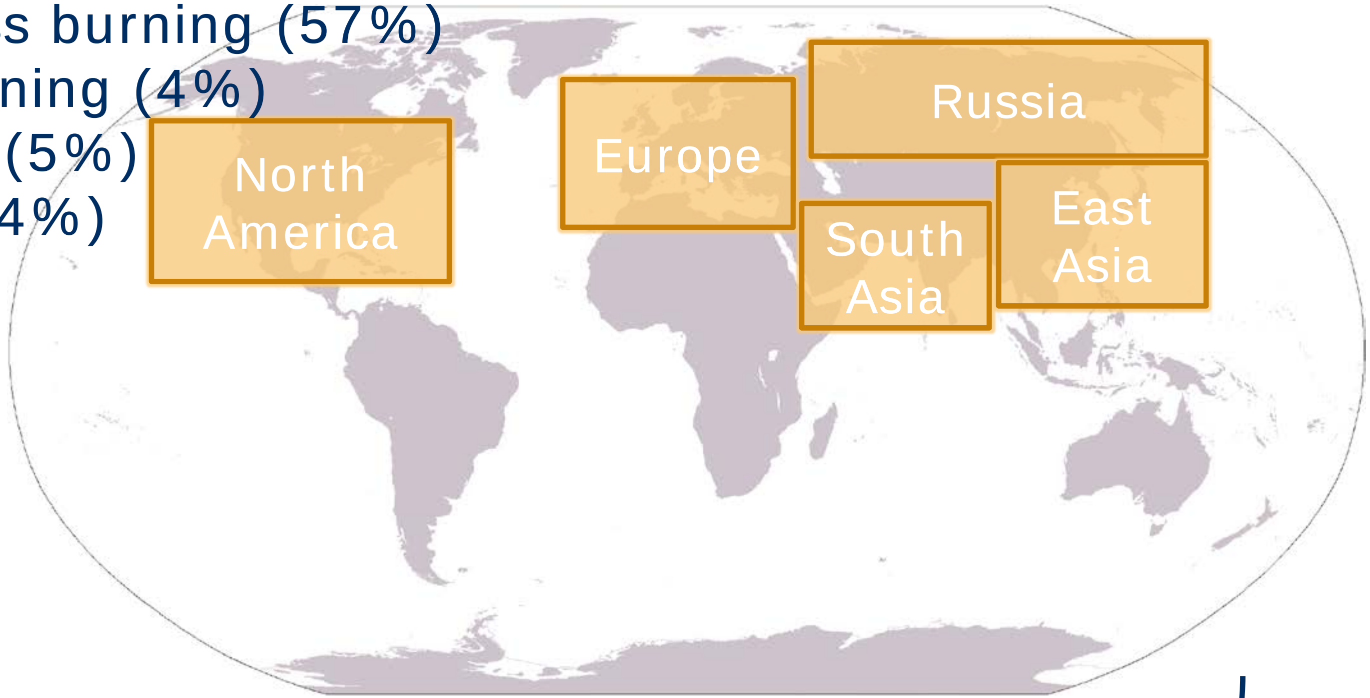


[Friedman and Selin, ES&T, 2012]

Future emissions and future climate

We scale the top (70%) global anthropogenic sources from the Zhang and Tao (*Atmos. Environ.*, 2009) inventory from ~2000 to 2050:

Traditional biomass burning (57%)
Domestic coal burning (4%)
Vehicle emissions (5%)
Coke production (4%)



EMISSIONS GO DOWN

[Friedman et al. ES&T 2013]

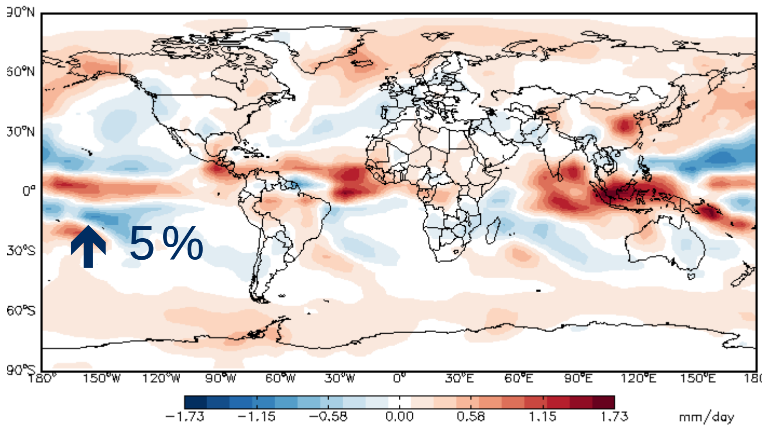
Particles: OC ↓ BC ↓ Oxidants: OH ↑ O_3 ↑

Future emissions and future climate

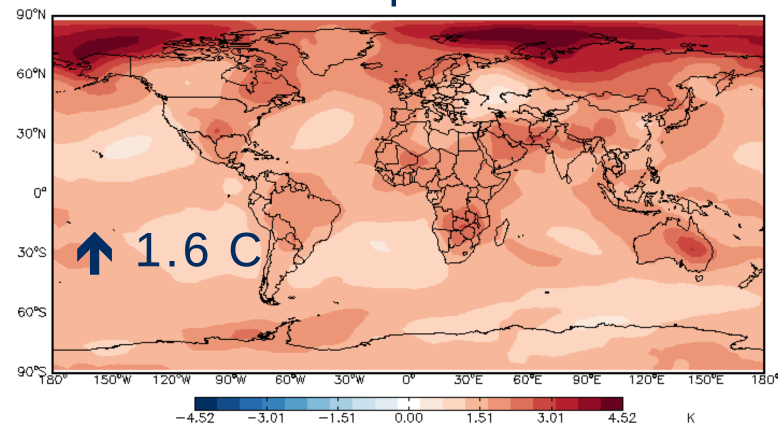
We simulate present and future climate with GISS GCM meteorology (A1B)

	Present climate	Future climate (IPCC A1B)
Mean of simulated years:	1997-2003	2047-2053

Precipitation



Temperature



Wildfire emissions (17%) ↑ or no change

[Friedman et al. ES&T 2013]

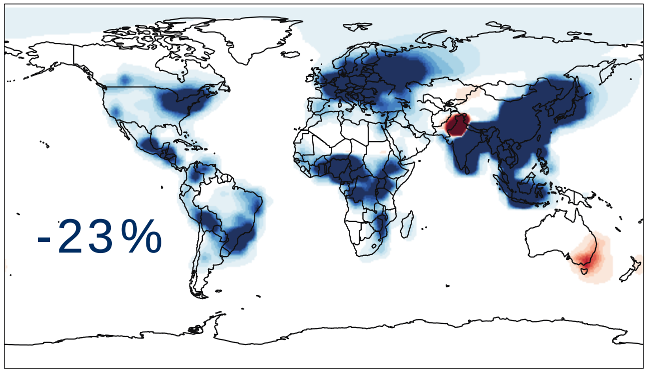
Particles: OC ↓ BC ↓ Oxidants: OH↓ O_3↓

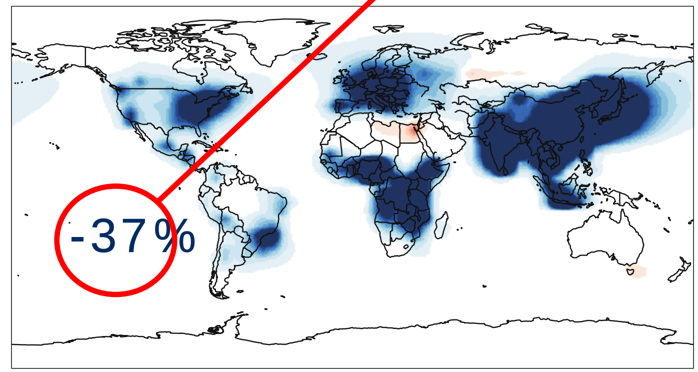
Results: Volatility Matters

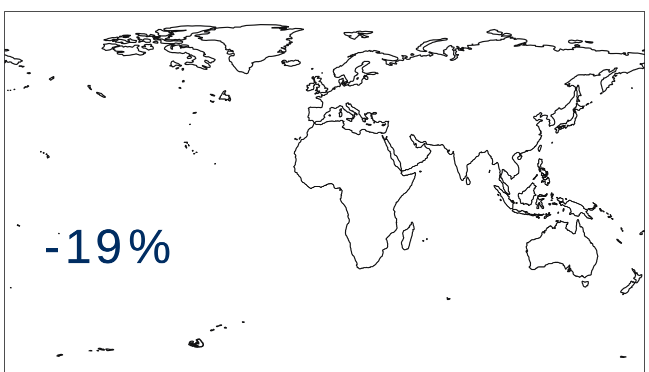
Change in mean northern hemisphere concentrations

2050-2000:

	Phenanthrene (volatile)	Benzo[a]pyrene (non-volatile)
Emissions	-23%	-37%
Climate	+4%	-3%
Emissions & Climate	-19%	-38%





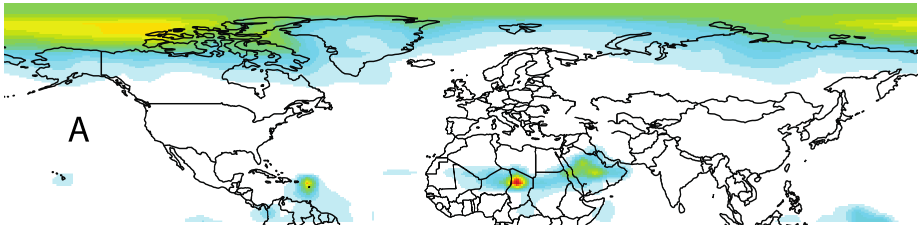


CLIMATE PENALTY: 19%

CLIMATE BENEFIT: 5%

ng/m3

Arctic stations can resolve climate vs. emissions



A

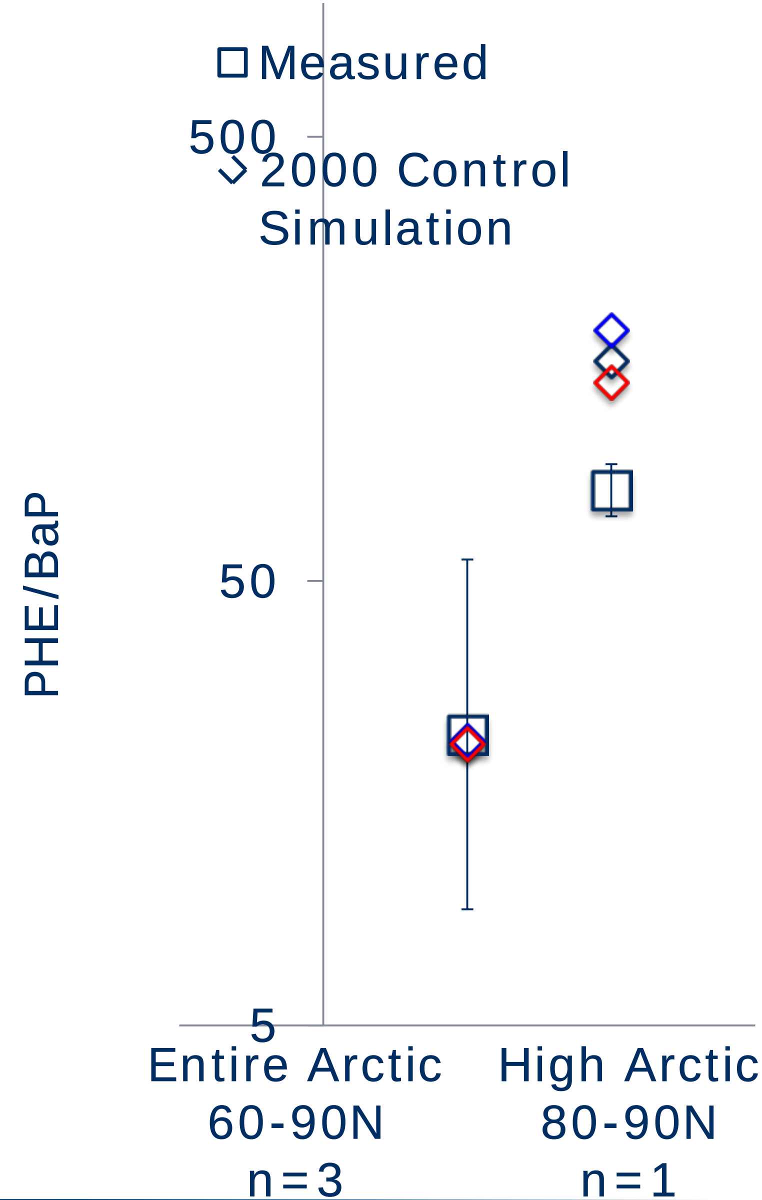
B

ΔPHE/BaP

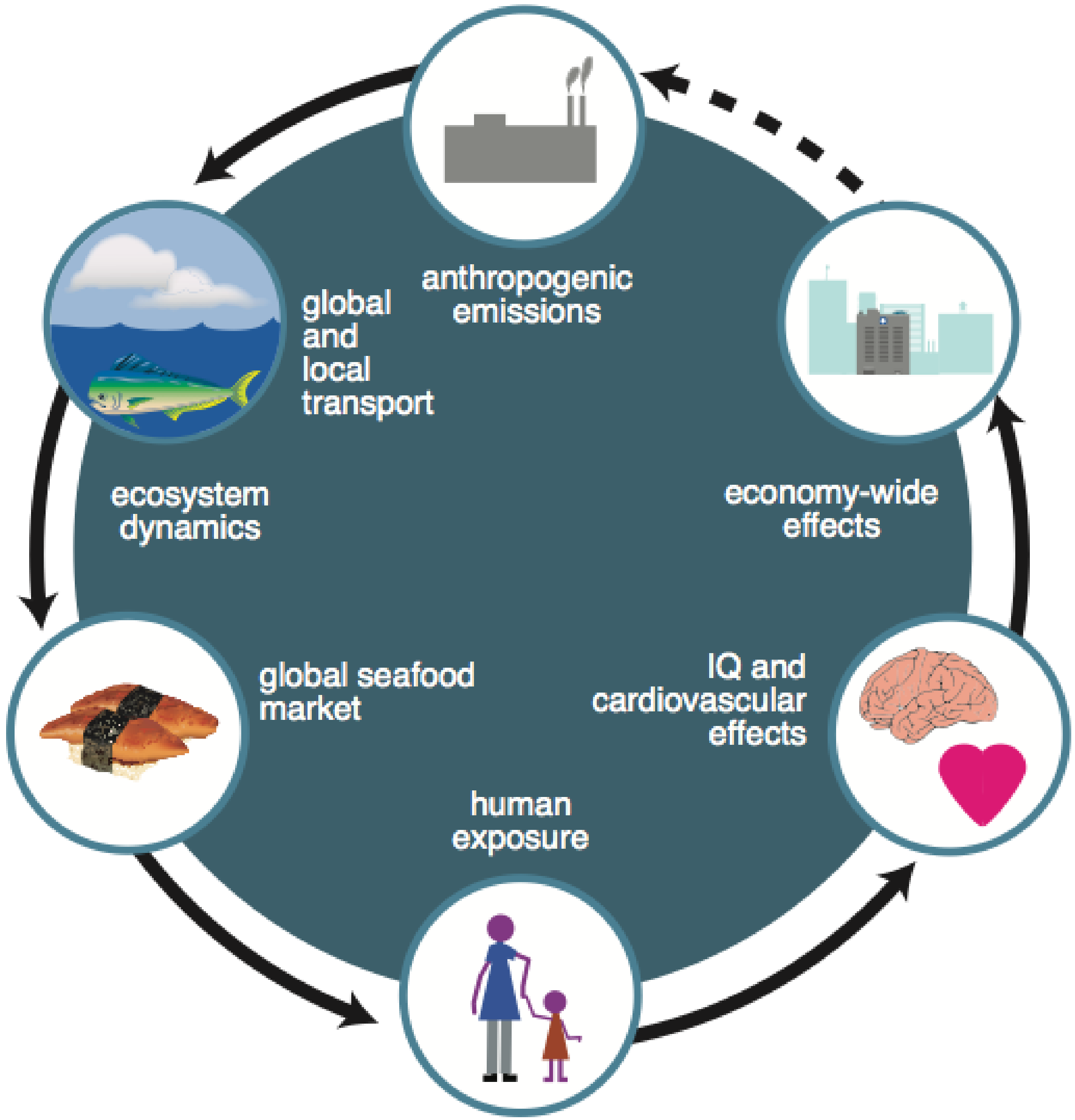
MATE

C

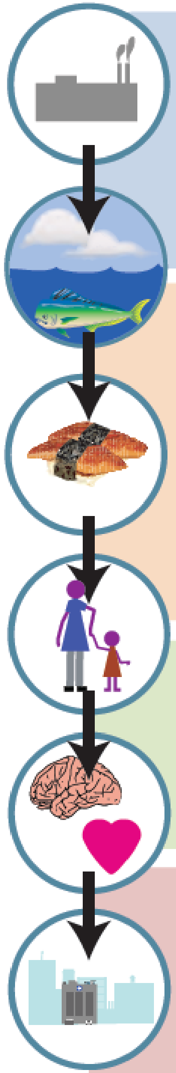
ΔPHE/BaP



Emissions to Impacts: Mercury



Integrated Assessment for Mercury



Chemical Transport Modelling: GEOS-Chem

Zhang et al. 2012, Corbitt et al. 2011, Streets et al. 2009, Amos et al. 2012

Ecosystem and Exposure Intake Modelling

Chen et al. 2012, Knightes et al. 2009, Mason et al. 2012, Sunderland and Mason 2007, Sunderland 2007, Pirrone et al. 2010, Mahaffey et al. 2009

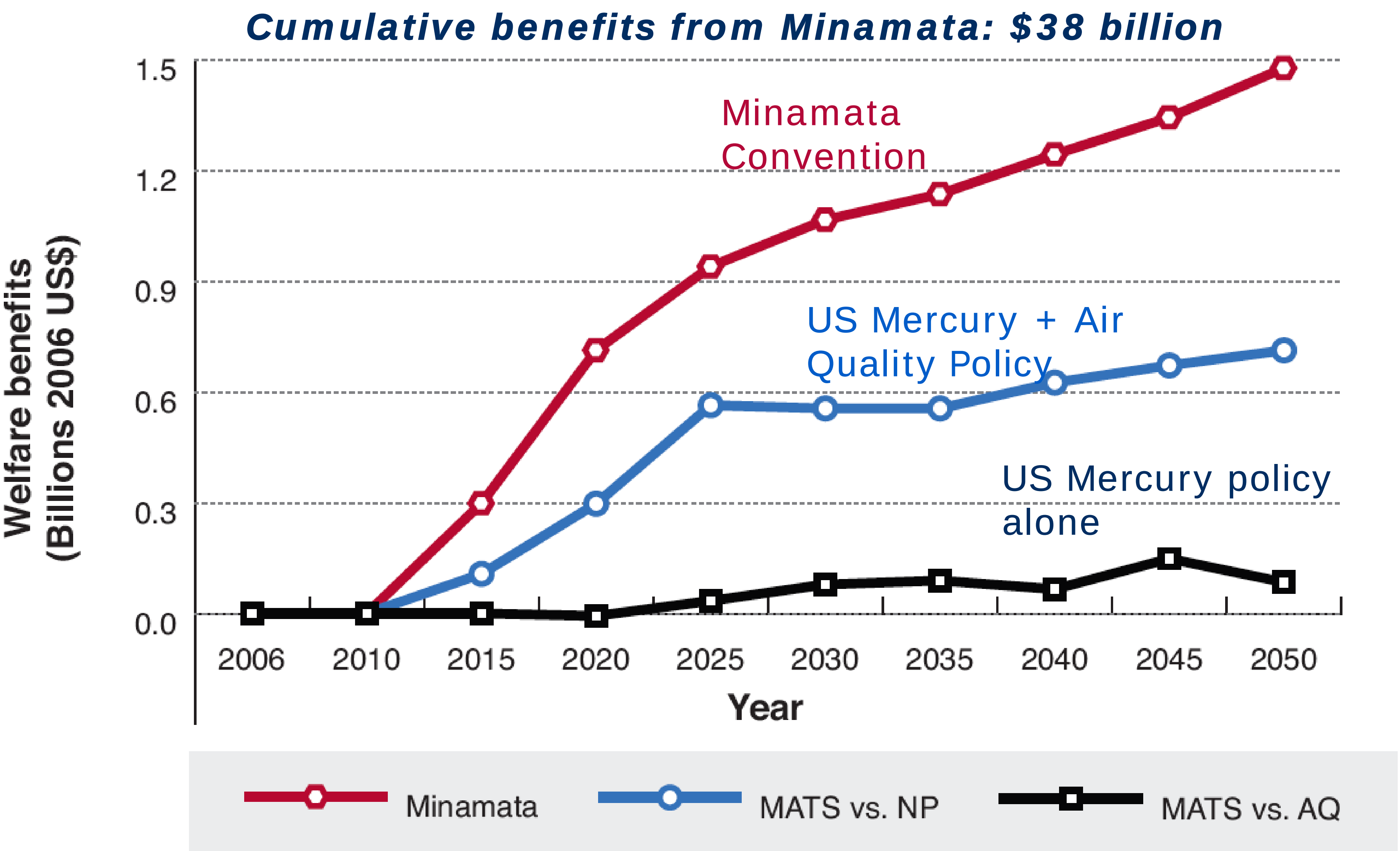
Health Impacts Modelling

Rice et al. 2010, Axelrad et al. 2007, Budtz-Jorgensen et al. 2007, Virtanen et al. 2005, Roman et al. 2011, Guallar et al. 2002

Economic Modelling: US Regional Energy and Environmental Policy Model (USREP)

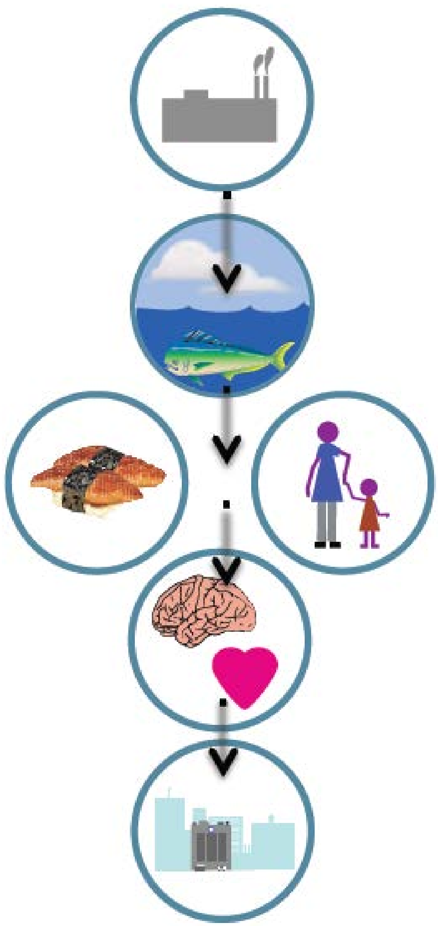
Rausch 2010, Saari et al. 2013

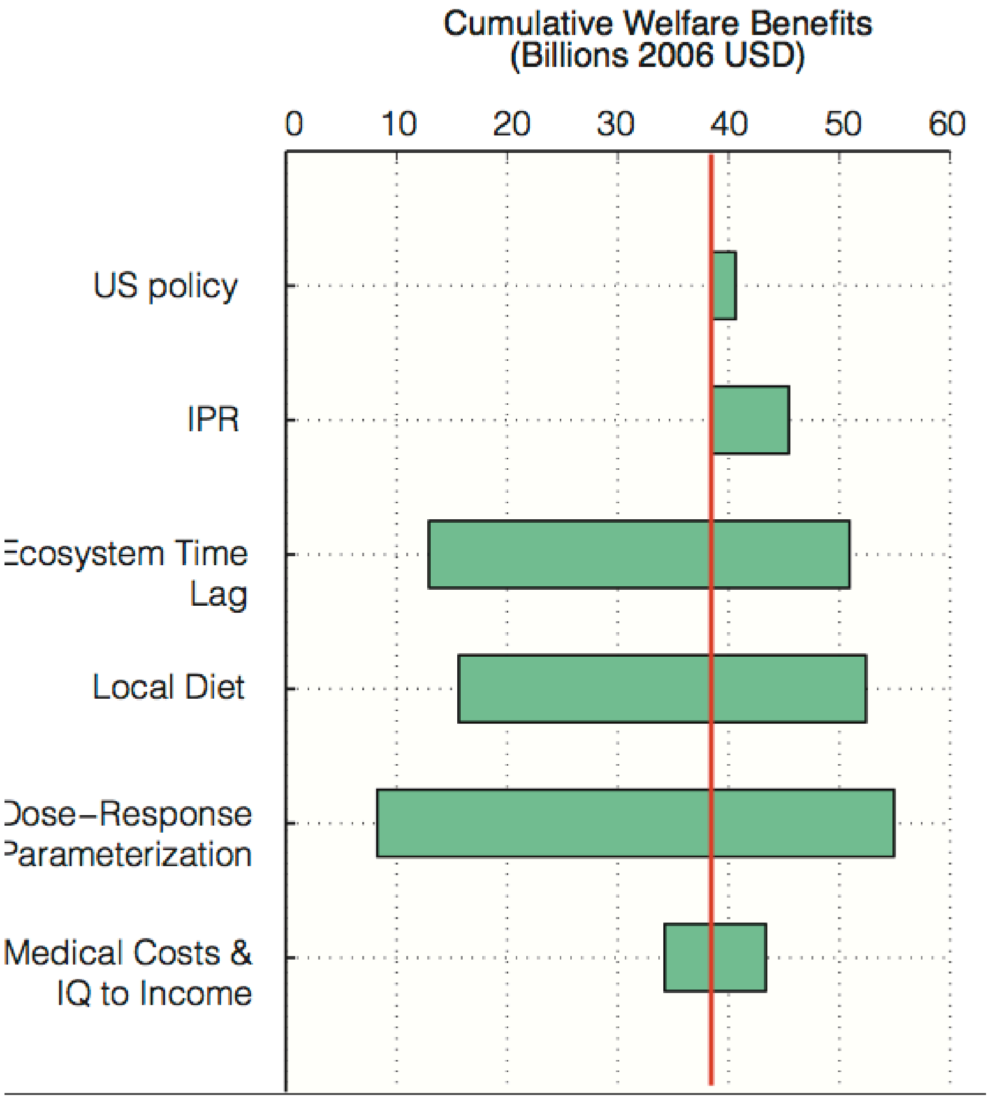
U.S. benefits from Minamata Convention



Discounted at 3%

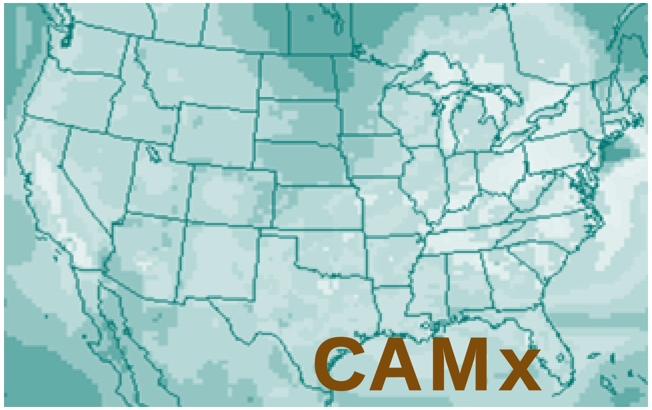
Policies-to-impacts sensitivity analysis





Integrated Assessment of PM and O_3

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



Health and Economic Impacts of Air Pollution ← BenMAP ← Concentrations

Thompson et al., submitted

Thompson et al., regional study: **talk at AGU**

Acknowledgments: Selin Group 2013

- **Postdocs:**
  - Carey Friedman (PhD, URI): Transport and fate of persistent organic pollutants
  - Fernando Garcia Menendez (PhD, Ga. Tech): Climate uncertainty and air pollution
- **Graduate Students:**
  - Rebecca Saari, Engineering Systems 4th yr: Air pollution health impacts
  - Ellen Czaika, Engineering Systems 4th yr: Sustainability decision-making
  - Shaojie Song, Earth, Atmospheric & Planetary Sciences, 3rd yr: Mercury
  - Colin Pike-Thackray, Earth, Atmospheric & Planetary Sciences, 3rd yr : POPs
  - Amanda Giang, Engineering Systems, 1st yr: Mercury
  - Mingwei Li, Earth, Atmospheric & Planetary Sciences, 1st yr: Air pollution transport
  - Leah Stokes, Urban Studies/Planning DUSP 4th yr: Mercury science-policy (primary advisor: Larry Susskind)
  - Jareth Holt, EAPS 4th yr: Air pollution uncertainties (co-advised with Susan Solomon)
  - Corey Tucker, Technology and Policy Program, 1st yr: Mercury
- **Recent alumni:**
  - Tammy Thompson (PhD, U. Texas): Regional-to-global atmospheric chemistry modeling, now at CIRA/Colorado State University as Research Scientist

Funding Sources: NSF: Atmospheric Chemistry Program CAREER grant; NSF Office of Polar Programs; NSF Coupled Natural and Human Systems Program; MIT Research Support Committee Ferry fund; MIT Research Support Committee Wade Fund; U.S. EPA: Science to Achieve Results (STAR) Program; Leading Technology and Policy Initiative at MIT