

MCHgMAP: Tracking mercury in the environment to inform the Minamata Convention’s effectiveness evaluation

Ari Feinberg

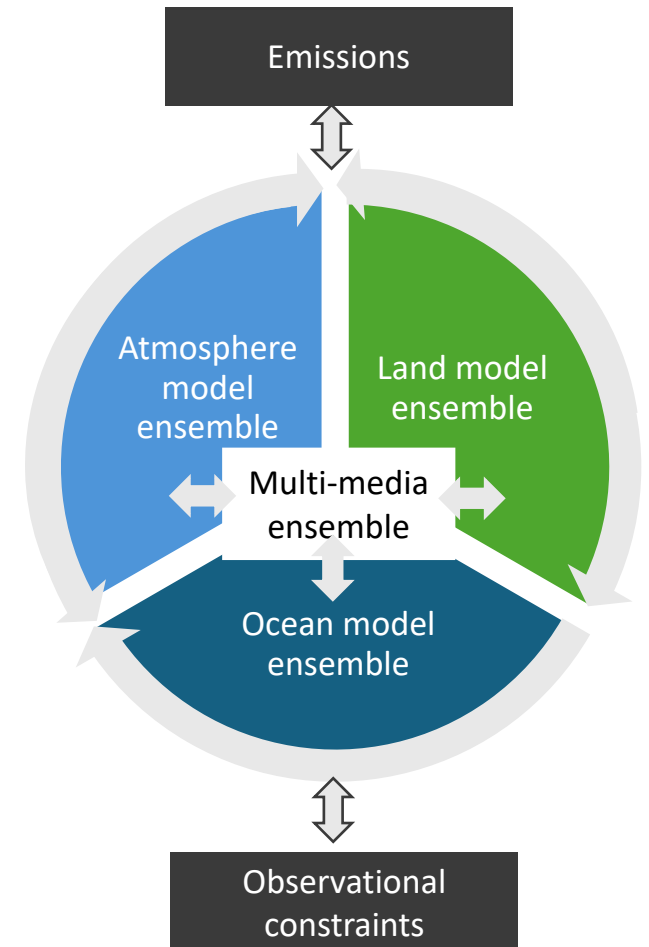
Johannes Bieser

Hélène Angot



Multi-Compartment Hg Modeling and Analysis Project (MCHgMAP)

- **Aim** – Multi-model assessment and attribution of geospatial variation and temporal trends in Hg pollution
- **Objective** – Support effectiveness evaluation of multilateral environmental agreements – LRTAP and Minamata Conventions
- **Approach** – Coupling atmospheric, oceanic, terrestrial, and mass balance models for multi-compartment simulation of Hg dispersion
- **Collaboration** – Integrates Hg emissions, monitoring, and modelling communities to enhance data collection and simulation processes



White paper:

Dastoor et al., *Geosci. Model Dev.*, 2025

MCHgMAP team

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Atmospheric modelling:

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Terrestrial modelling:

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Xun Wang (IGCAS)

Mass balance modelling:

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Benjamin Geyman (Harvard Univ.)

Emissions and measurements:

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Models

Atmospheric models

GEM-MACH-Hg	Environment and Climate Change Canada (Canada)
GEOS-Chem	Massachusetts Institute of Technology (USA)
WACCM	Institute of Physical Chemistry Blas Cabrera (Spain)
GLEMOS*	Jožef Stefan Institute (Slovenia)

Ocean models

ICON-MERCY	HEREON (Germany)
MITgcm	Tulane University (USA)

Multi-media mass balance model

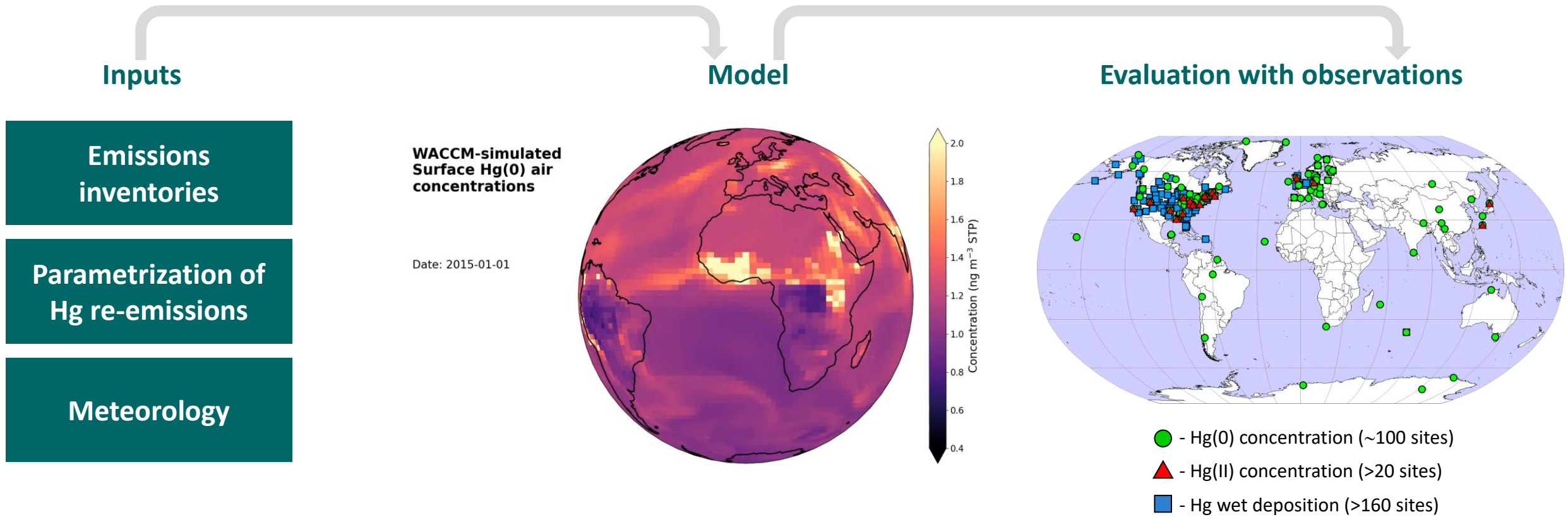
Global Biogeochemical Box Model (GBBM)	University Grenoble Alpes, CNRS (France), Harvard University (USA)
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Terrestrial model

2D air-land Hg exchange model	University of West Florida (USA), Institute of Geochemistry, CAS (China)
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* did not participate in the current round

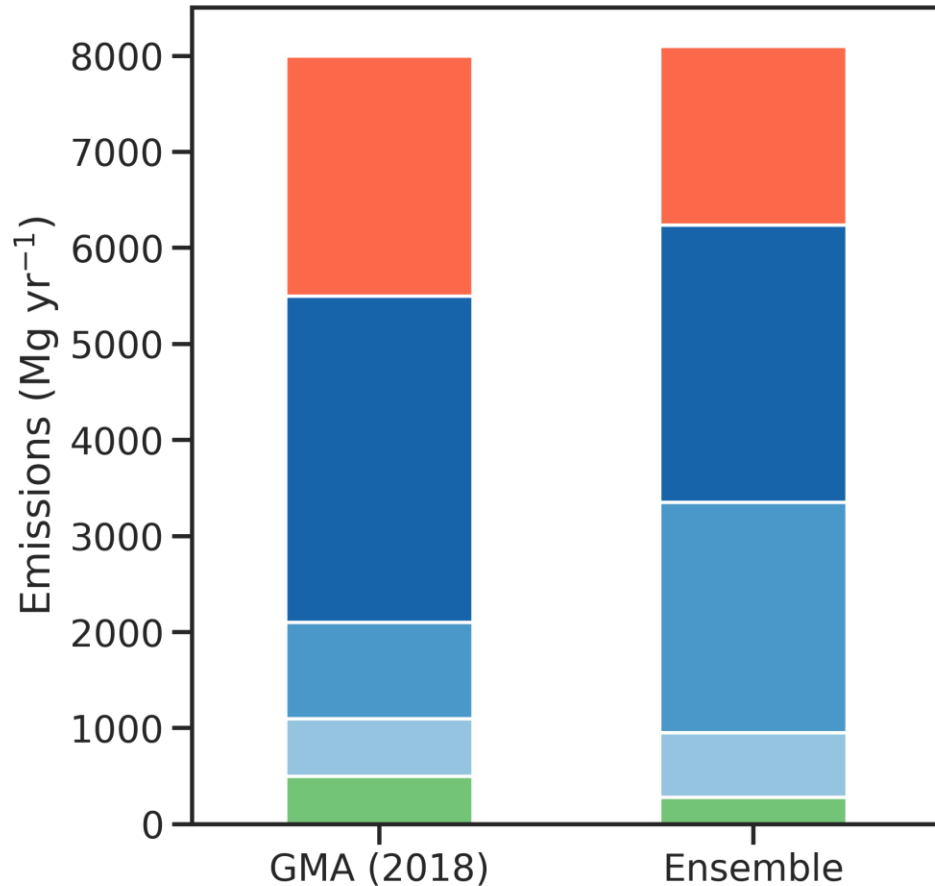
Modelling atmospheric mercury cycling



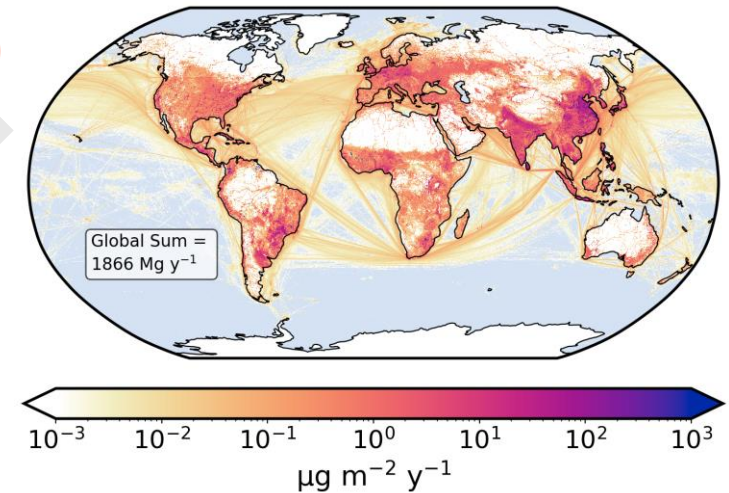
Models can: **1.** fill gaps in areas where measurements are not available
2. evaluate our current understanding of mercury sources and cycling

New emissions inventories based on available data

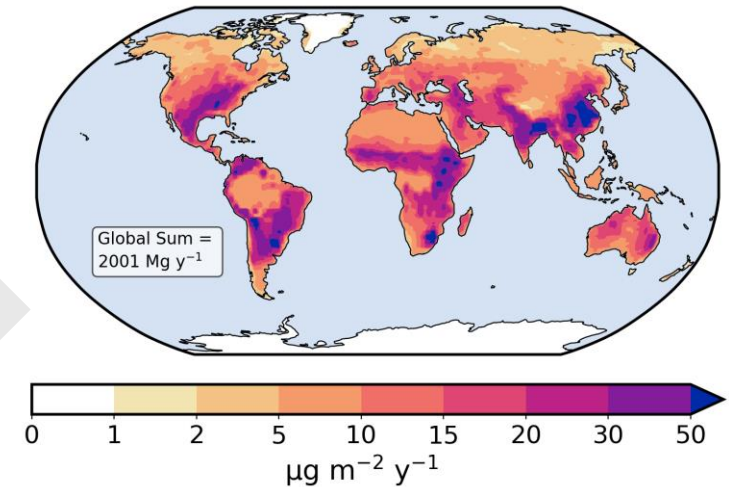
2015 Hg global emissions



Anthropogenic emission (EDGAR)



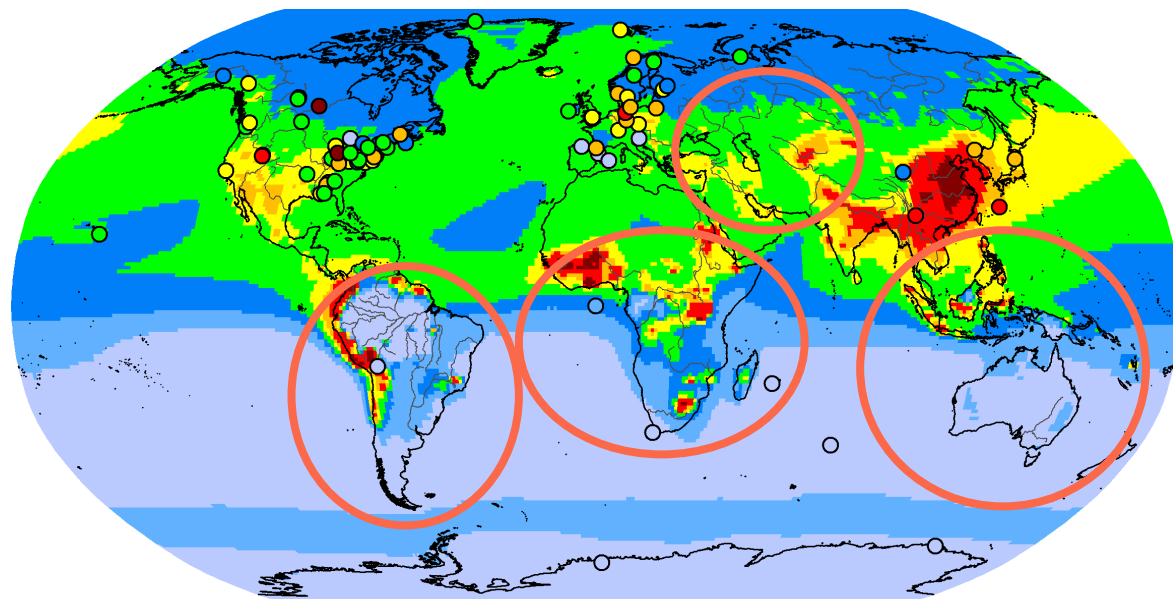
Land re-emission



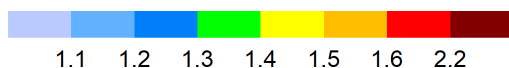
Compared to Global Mercury Assessment (2018), consistent levels of total mercury emissions, but uncertainties remain in individual sources

Evaluating spatial pattern in atmospheric models

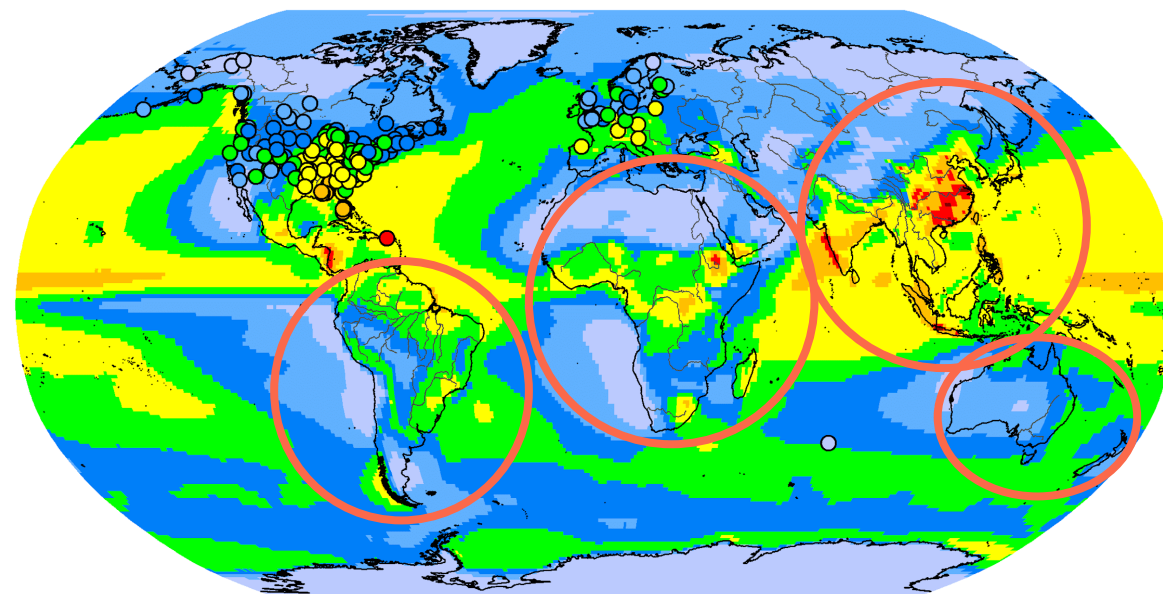
Air Hg⁰ concentrations



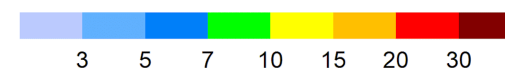
Air concentration [ng m^{-3}]



Hg wet deposition



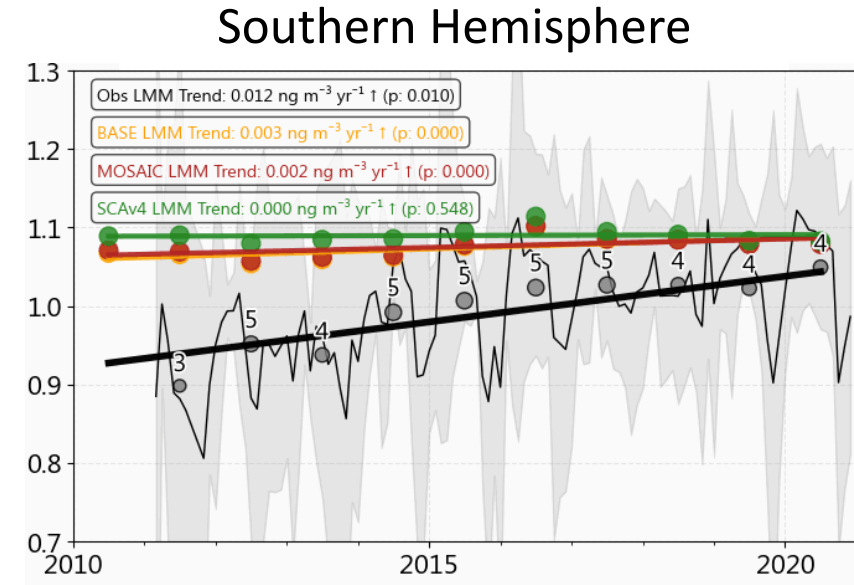
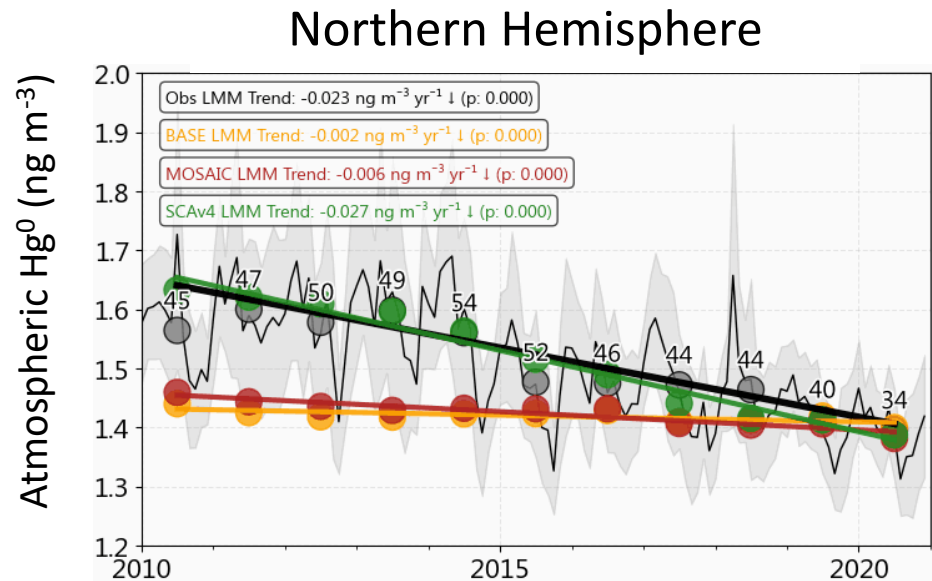
Wet deposition [$\text{g km}^{-2} \text{y}^{-1}$]



Models capture spatial variation of Hg observations (2010-2020), demonstrating confidence in science behind models

BUT many regions lack observational coverage

Observed Hg^0 trends can be explained by declining anthropogenic emissions trends



Observations

Simulation with EDGAR emissions (stable/increasing emissions trends)

Simulation with MOSAIC emissions (stable/increasing emissions trends)

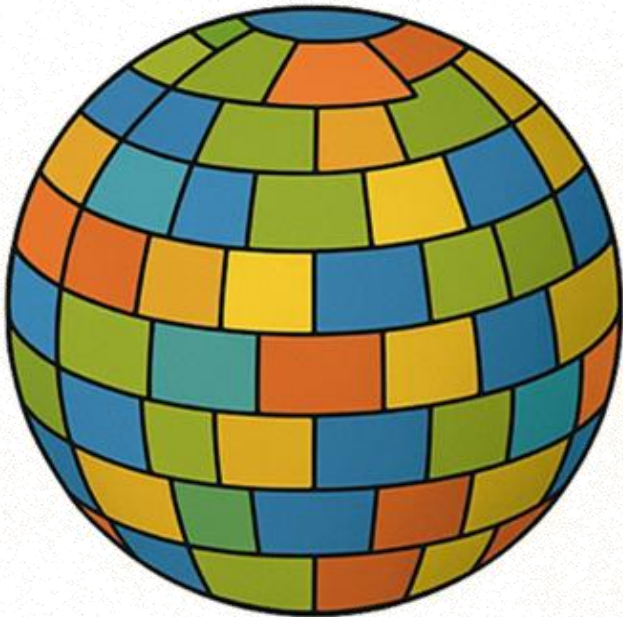
Simulation with scaled emissions (decreasing emissions trends)

- Decline in atmospheric mercury observations suggests decreasing anthropogenic emissions in the Northern Hemisphere (early success of Minamata Convention)
- Analysis of trends in Southern Hemisphere limited by number of observations

Modeling mercury in the ocean (concept)

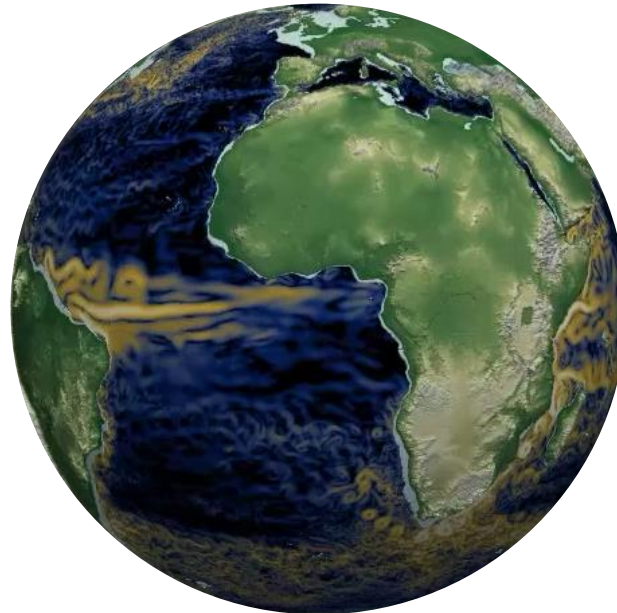
High-resolution modeling

Many small cells represent detailed regional processes



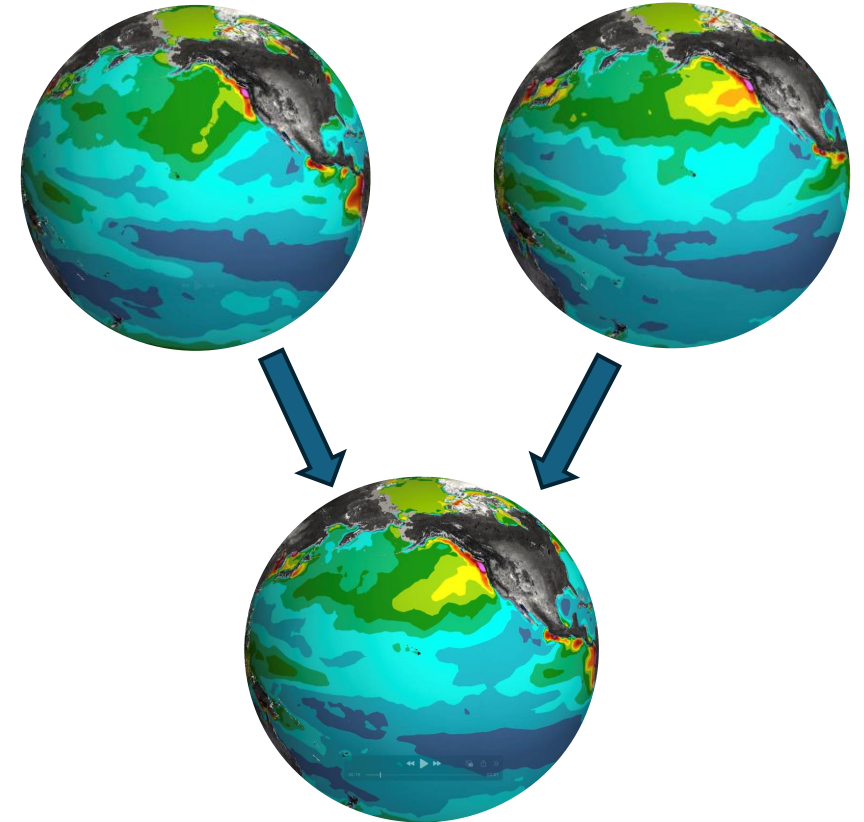
Ocean models

Model ocean physics, marine ecosystem, and mercury chemistry



Multi-compartment model ensemble

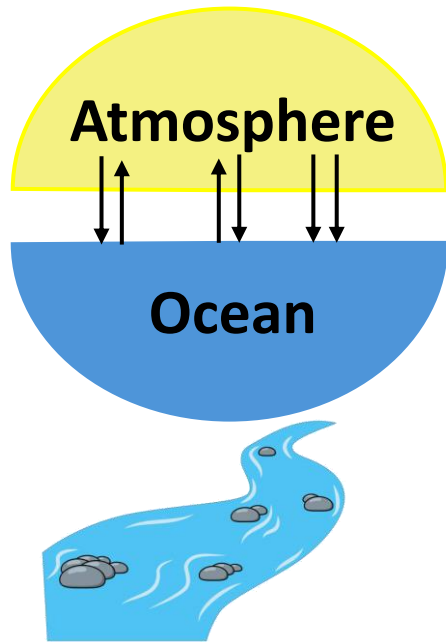
The average result of the two individual ocean models used



Modeling mercury in the ocean

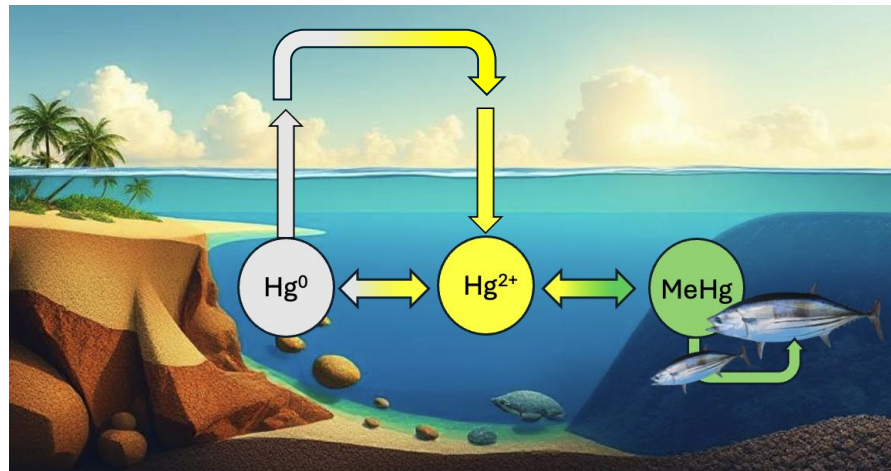
Model input

Atmospheric deposition
and river discharge



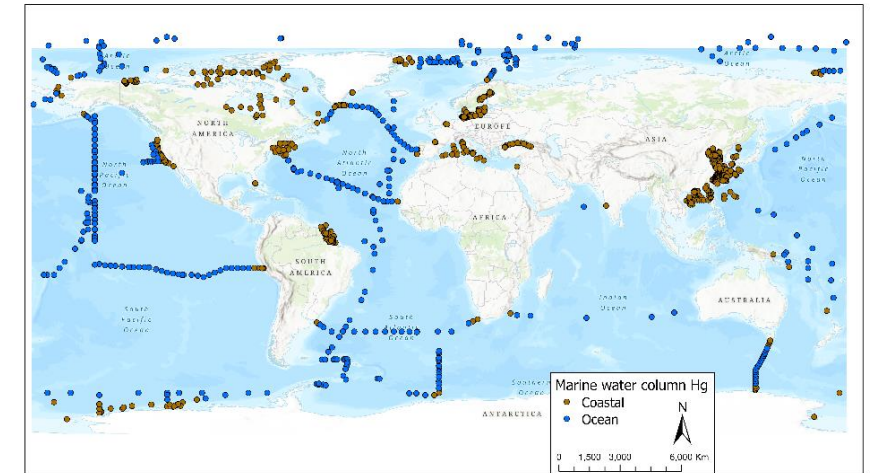
Model simulation

Bioaccumulation in the marine
ecosystem and mercury chemistry



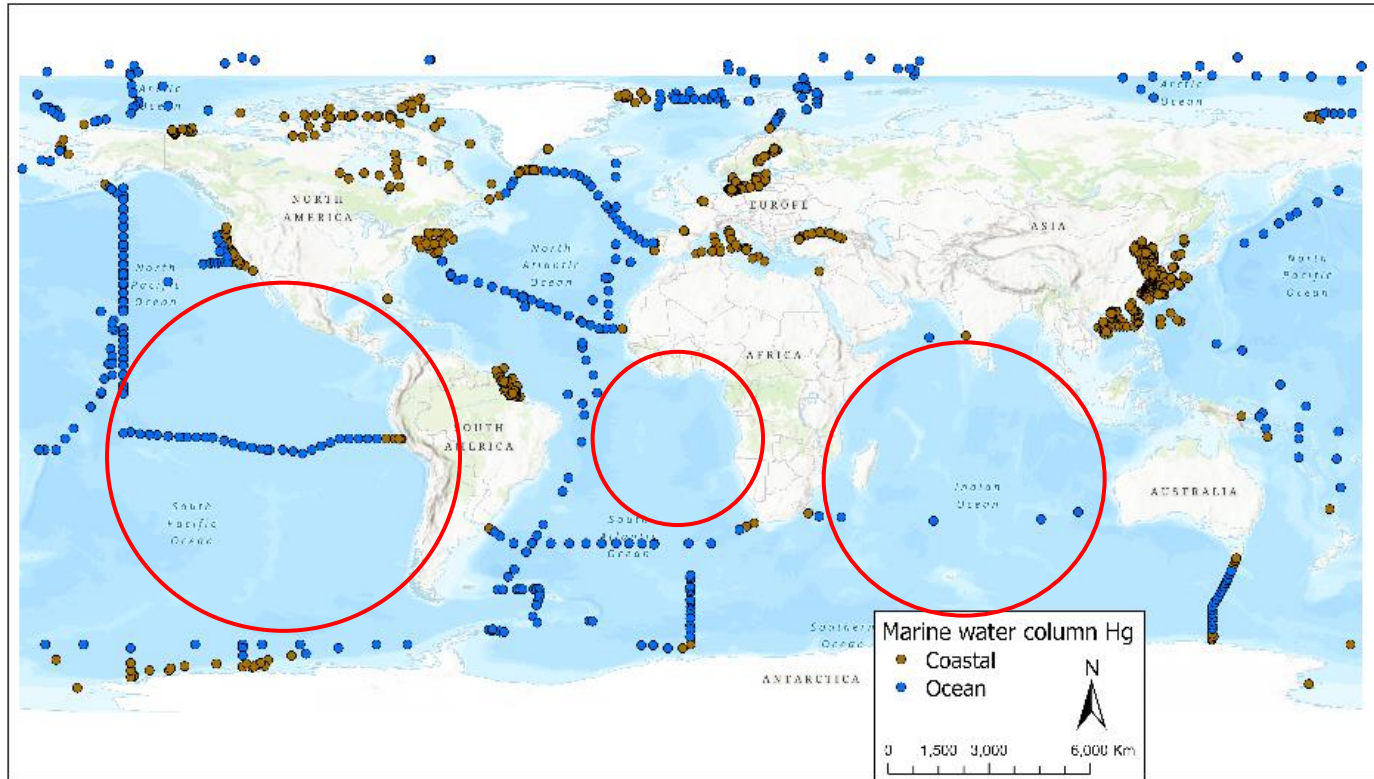
Model validation

Observed concentrations of individual
mercury species in the ocean



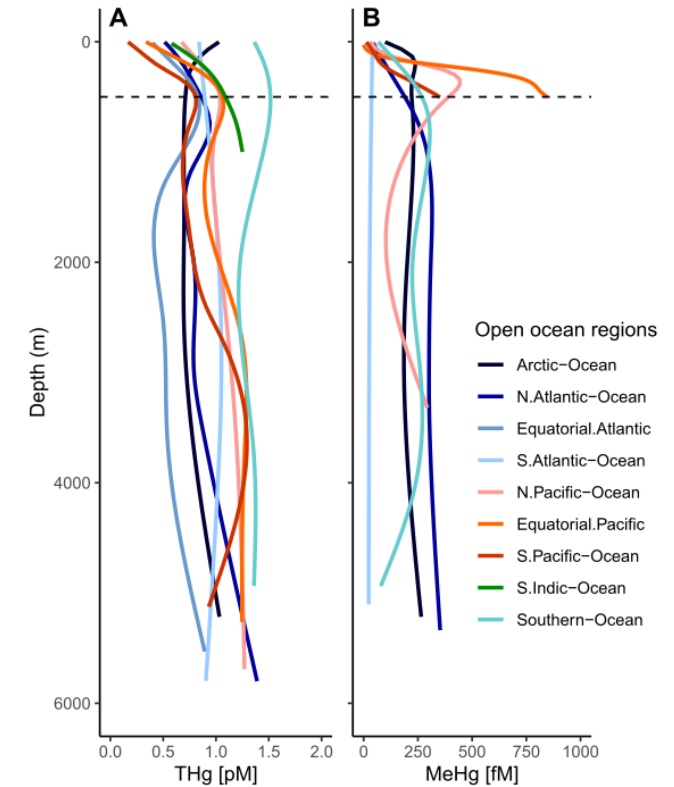
Our **ocean model ensemble** completes the global mercury cycle by
integrating marine chemistry and bioaccumulation

Observational constrains



Data compilation: 60 marine water column datasets from 2005-2024

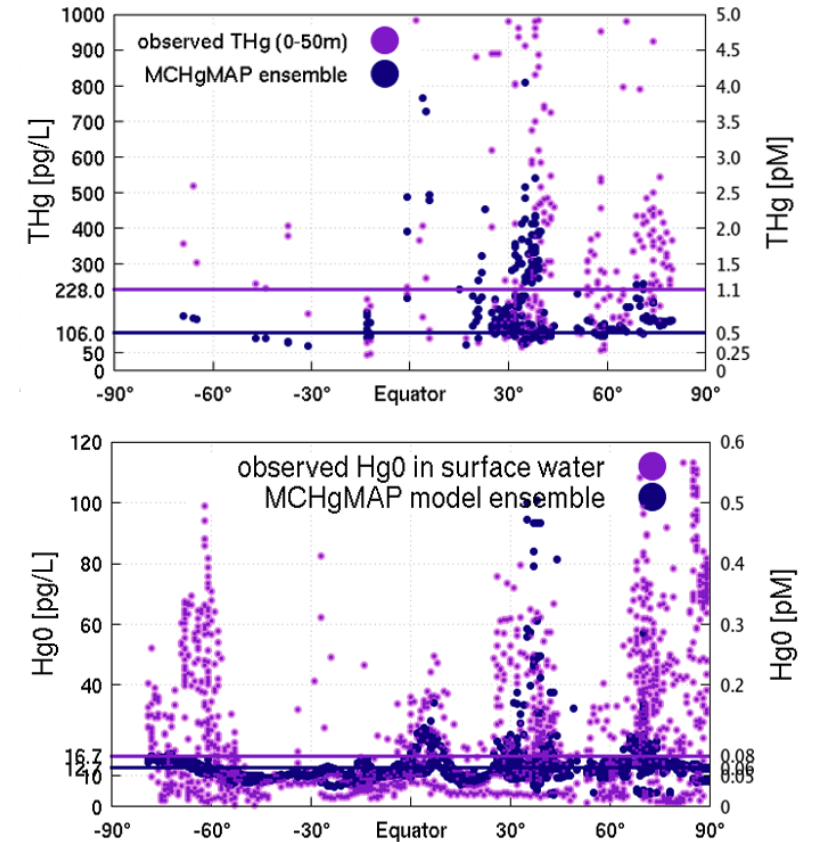
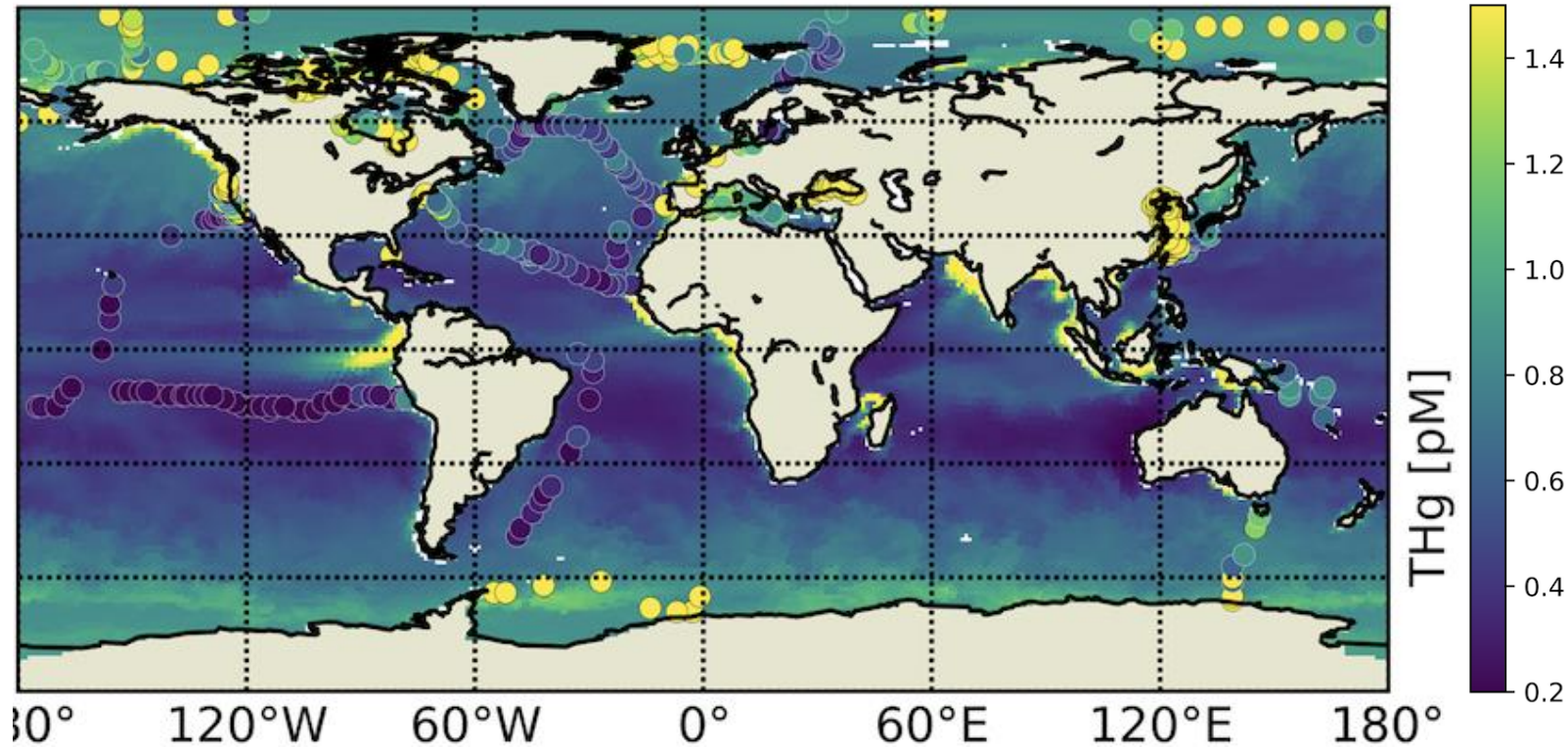
Caveats: large gaps in spatial and temporal coverage



Average total Hg and methylated Hg profiles for 9 open ocean IPCC regions (a gam smoother was applied to observations)

The observational data is also used as part of the “Other media” integrated analysis & report

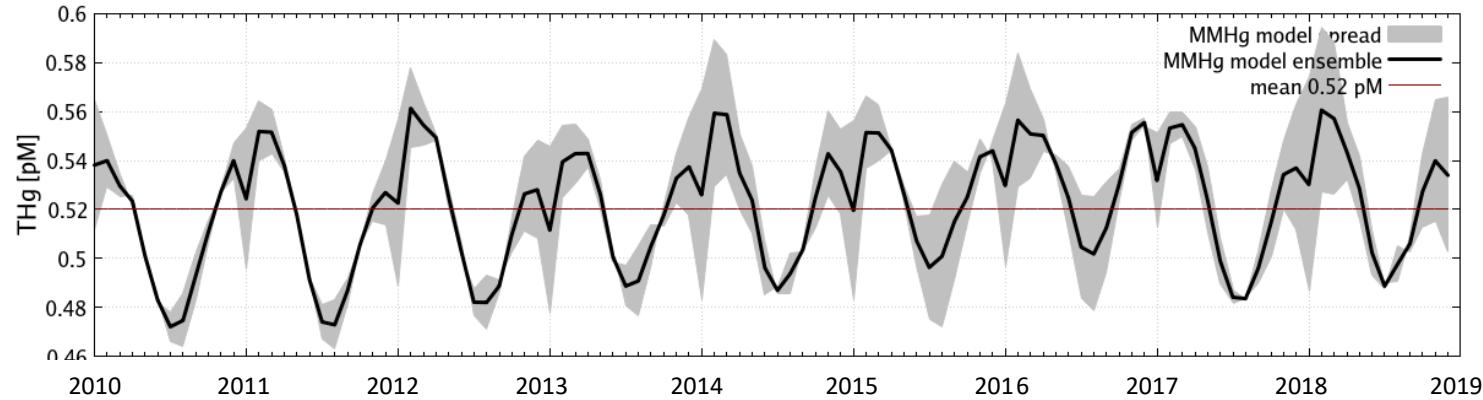
Ocean model validation



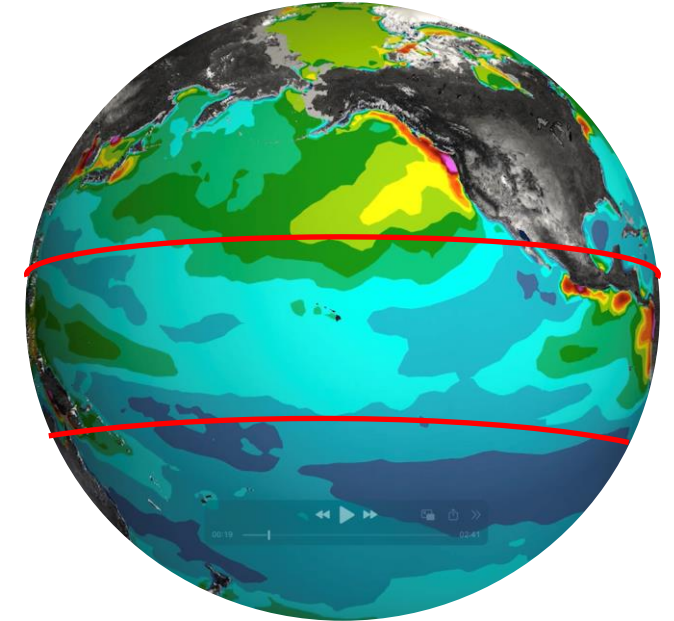
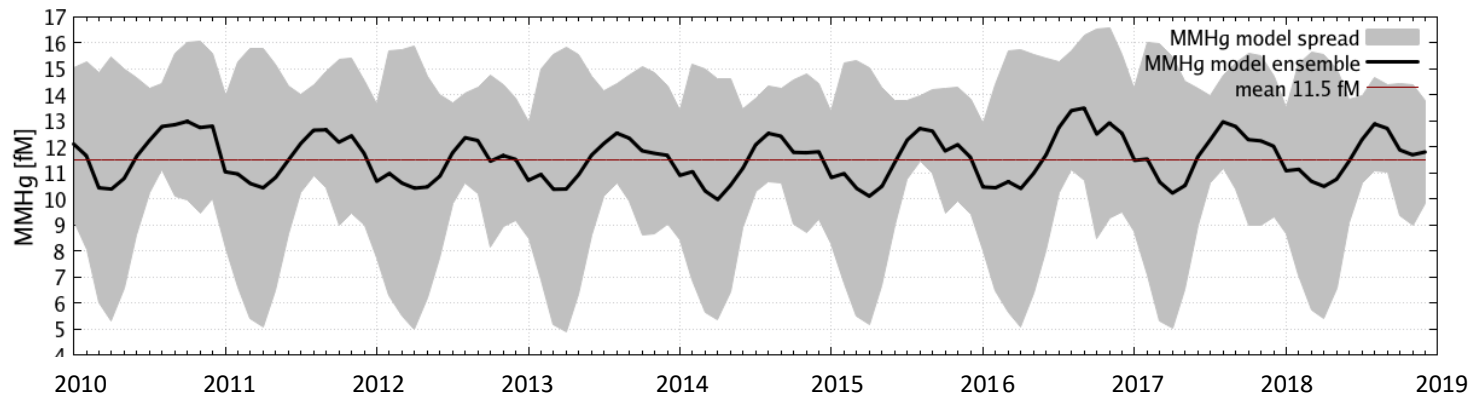
- Models are able to capture the global patterns of ocean Hg distribution
- Models can reproduce ocean concentrations of individual Hg species
- Models struggle to reproduce large variability observed in marine polar regions

First ocean model results

30S-30N degree tropical North Pacific mean surface layer THg concentration



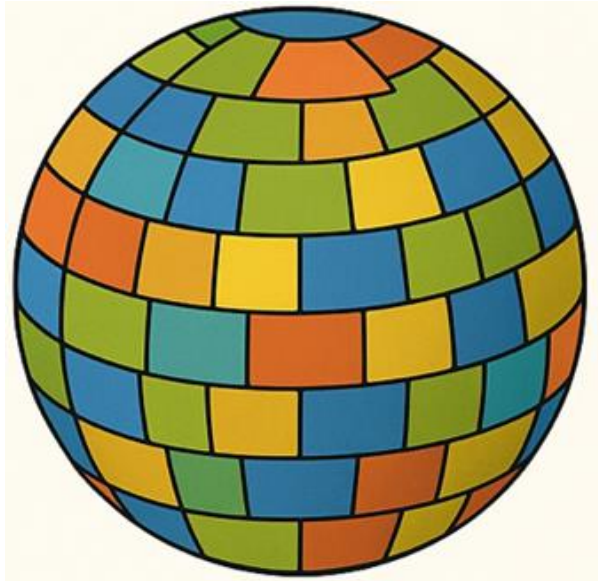
30S-30N degree tropical North Pacific mean surface layer MMHg concentration



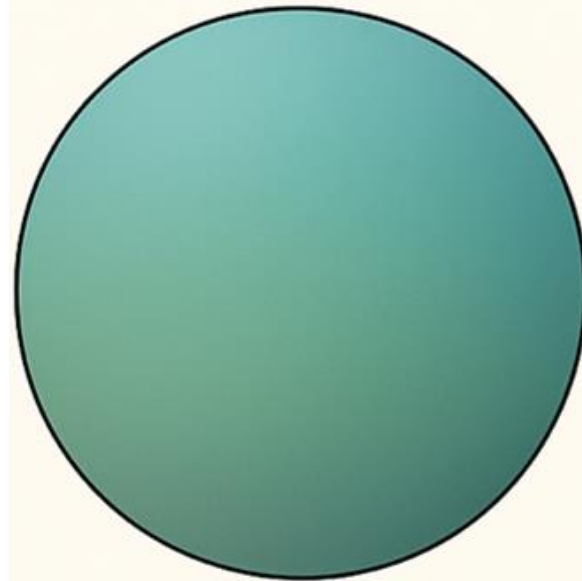
- Ocean Hg concentrations and bioaccumulation potential were stable in the period 2010-2020
- Not enough aquatic Hg observations to determine trends, but ->
- This is consistent with observations in marine biota

From complex models to conceptual understanding: What is a box model?

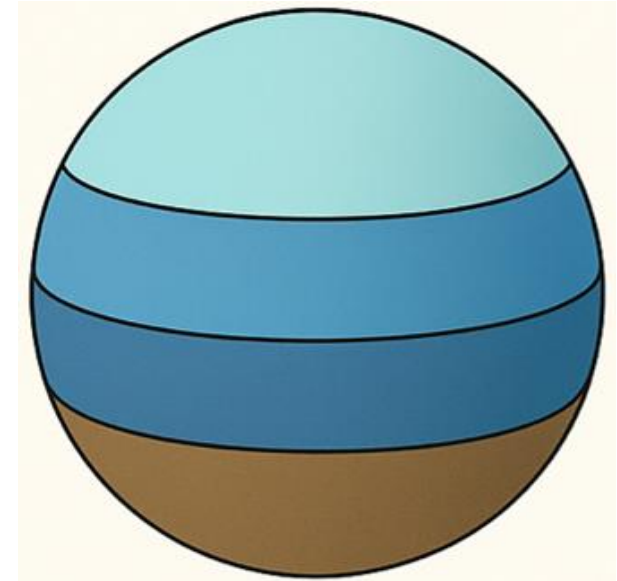
High-resolution models:
Many small cells represent detailed regional processes



Box model: A simplified planet.
We lose spatial detail, but keep the big picture

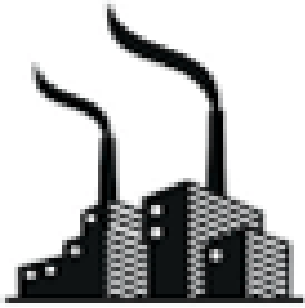


Our Box model: couples the atmosphere, ocean, and soils, ideal for long-term (millennia)



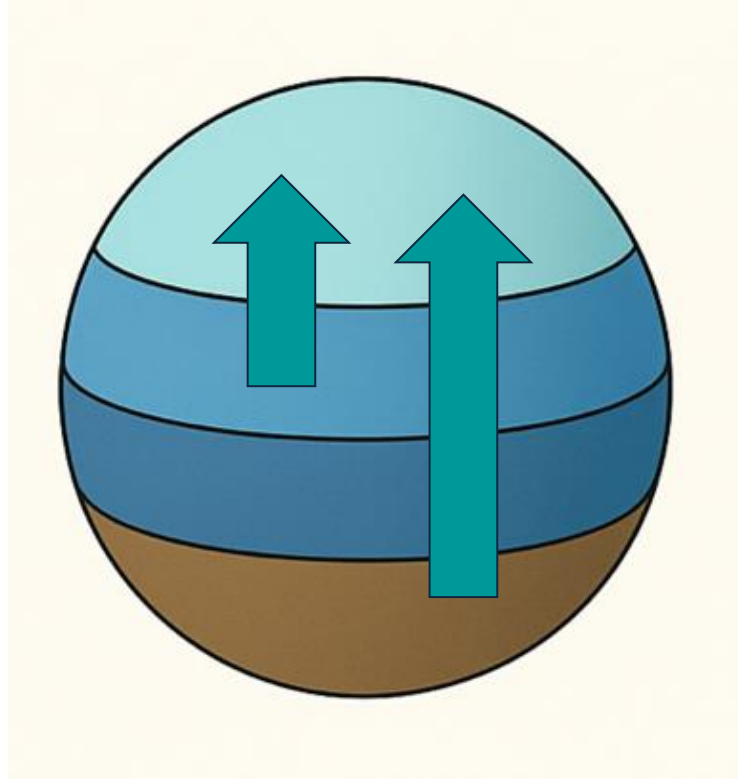
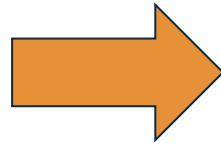
Box models simplify the world into **key interconnected reservoirs** – allowing us to explore how mercury responds to changes in emissions.

Tracking where mercury comes from



Primary emissions

Directly released from human activities

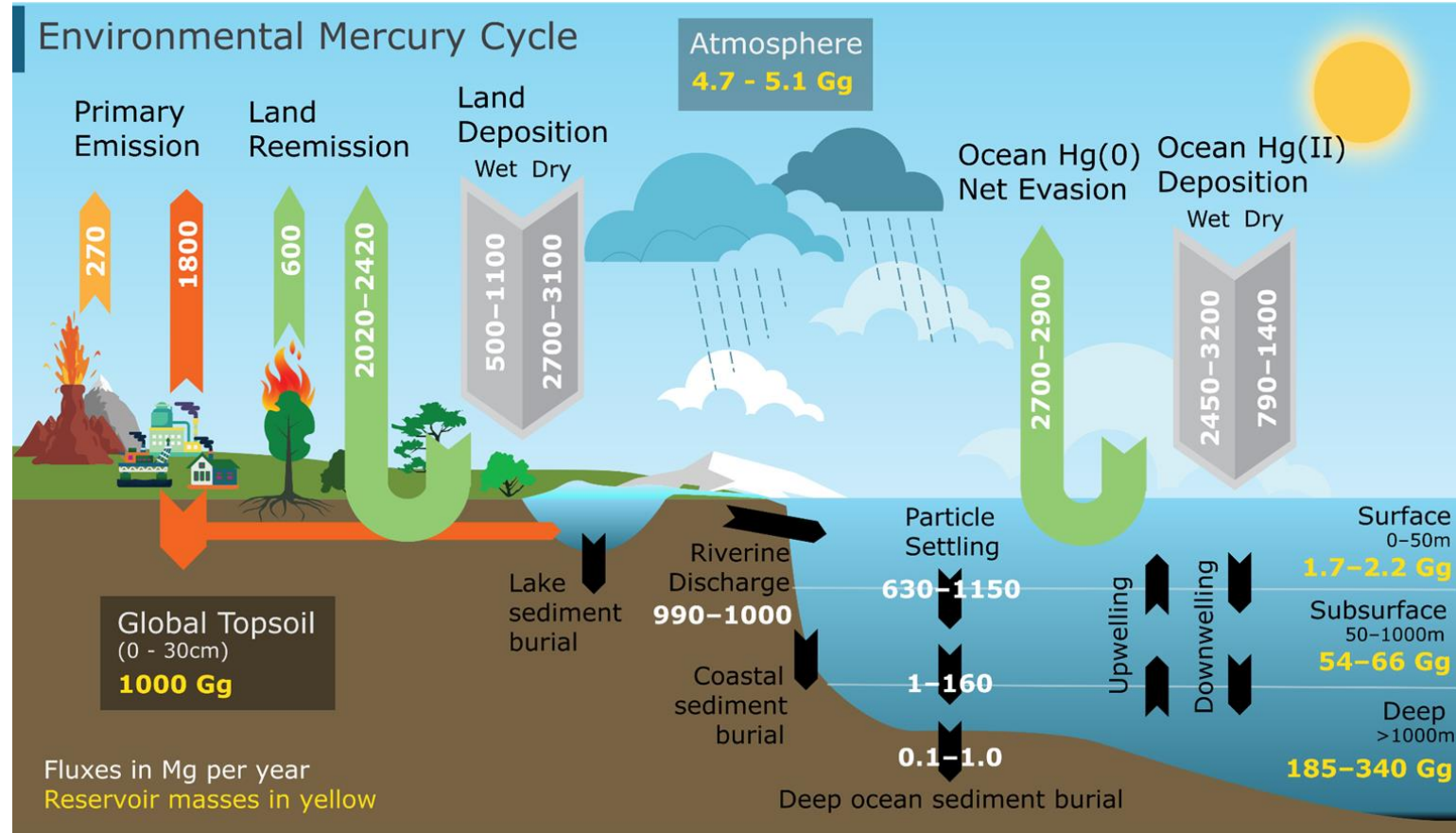


Secondary emissions

Re-emission of previously deposited mercury (legacy) from soils and oceans

Our box model quantifies how much of today's mercury in the atmosphere comes from **current emissions vs. re-emission** of legacy mercury

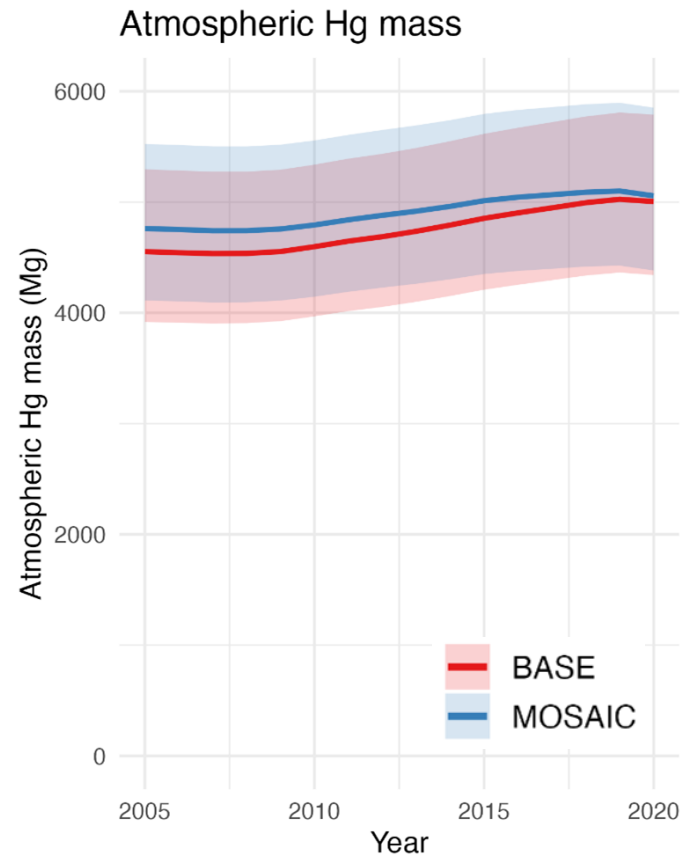
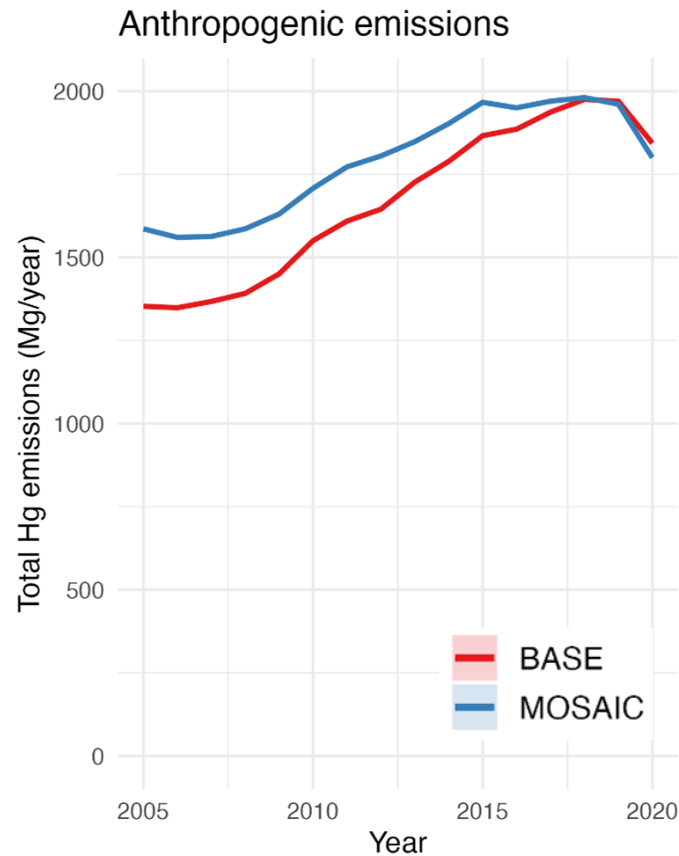
Tracking where mercury comes from



Most mercury in the atmosphere today is recycled, not new

Legacy mercury from soils and oceans account for **~70%** of global emissions each year, while current human activities contribute only **~25%**

Long-term changes of mercury in the atmosphere



Recent trends show a worrying feedback

Between 2010 and 2020, re-emissions from soils and oceans have risen, driven by continued primary emissions

Cutting emissions now is critical

Only a rapid and sustained reduction in new mercury releases will slow and reverse the buildup of legacy emissions over time