The global importance of deforestation as an anthropogenic driver of mercury pollution

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https://www.dw.com/en/brazil-amazon-deforestation-hits-new-high/a-61717387

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What image do we associate with mercury?

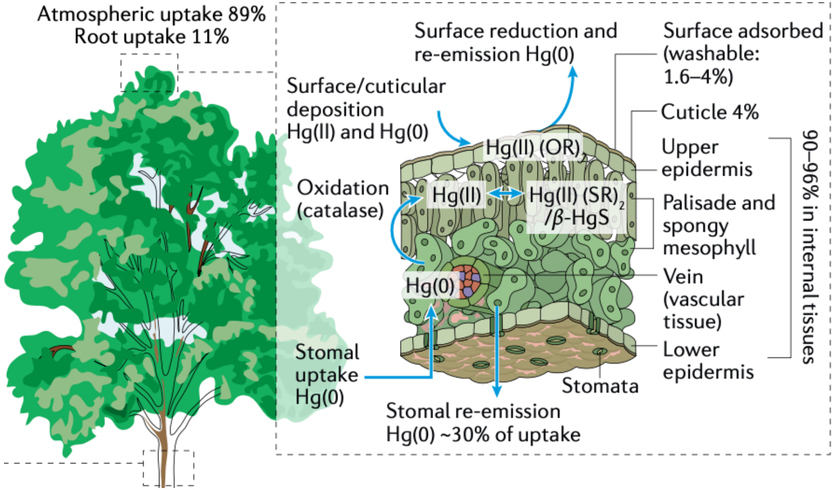
Getty Images: https://www.bbc.com/news/science-environment-68339664

WILLIAM MILLIKEN-RBG KEW: *https://www.bbc.com/news/science-environment-34880656*

Forests play a crucial role in the global mercury cycle

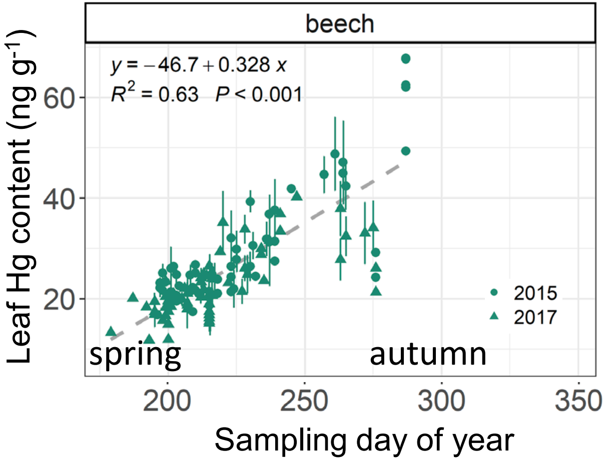
New measurements have led to reevaluation of vegetation sink

Recent literature shows that vegetation uptake of Hg^0 accounts for ~**30% of total atmospheric sink, 60–90% of soil Hg source**



Zhou et al., *Nat. Rev. Earth Environ.* (2021)

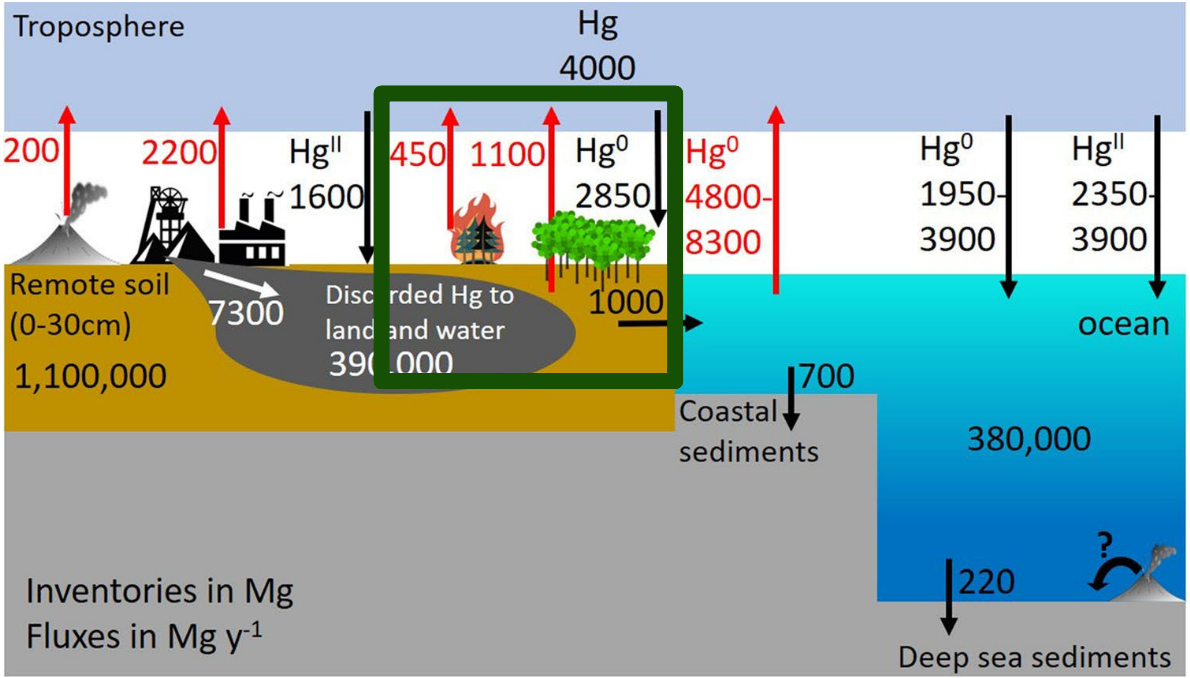
Like CO_2, foliage takes up elemental Hg^0 over the growing season



Wohlgemuth et al., *Biogeosciences* (2022)

Newly recognized (past decade or so) importance of land sink thanks to field measurements and isotopic analysis

Terrestrial biosphere is an important sink of atmospheric mercury



Storage on land reduces amount of Hg entering the marine food chain

In soils: Hg is generally less mobile & less methylated than in ocean

(Amos et al., 2013; Gerson et al., 2022; Zhang et al., 2020)

Sonke et al., *Ambio* (2023)

Ensuring that the GEOS-Chem atmospheric model captures importance of vegetation

Study published: Feinberg et al., *Environ. Sci. Process. Impacts* (2022): "Evaluating atmospheric mercury (Hg) uptake by vegetation in a chemistry-transport model" doi: [10.1039/D2EM00032F](https://doi.org/10.1039/D2EM00032F)

Inputs

Meteorology (MERRA-2)
Offline emissions

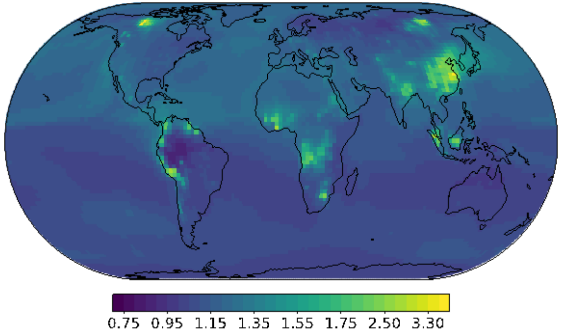
GEOS Chem

Online emissions
Transport

Chemistry
Deposition

72 vertical levels
2.0° × 2.5° resolution

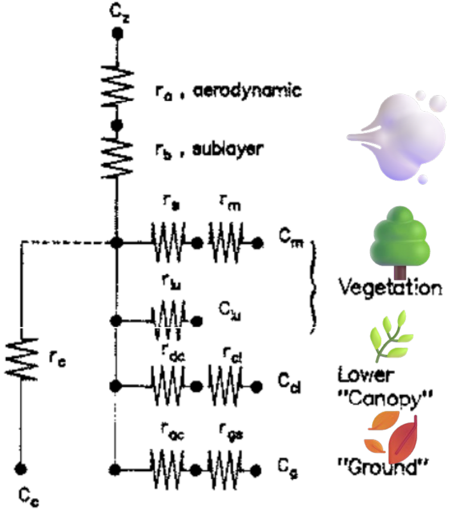
Outputs
Concentrations
Deposition fluxes



[Hg^0] (ng m^{-3})

GEOS-Chem Hg model:
Selin et al., *J. Geophys. Res.* (2007); Horowitz et al., *Atmos. Chem. Phys* (2017)

Dry deposition resistance scheme



Factors: T, wind, leaf area, land type
Species: reactivity and solubility

Wesely, *Atmos. Environ.* (1989)

How does modeled Hg^0 deposition compare to measurements?

Direct measurements of Hg^0 uptake by forests

Micrometeorological approach

Common for O_3 but only very few flux-gradient study for Hg^0 over forests

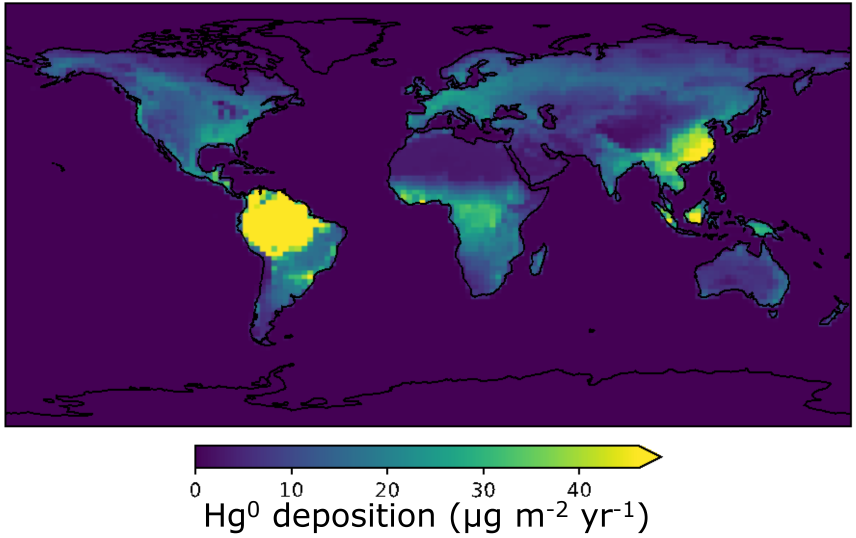
Biomass balance approach

Total foliar uptake

More studies for Hg, but less accurate

Revised model improves agreement with atmospheric Hg observations

Global dry deposition of Hg^0 = 2276 Mg yr^{-1}



Agrees with other recent estimates
(2000–3000 Mg yr^{-1})

(Chen et al., 2024; Yuan et al. 2023; Zhou and Obrist, 2021)

Evaluated with:

- 93 forest measurements of ecosystem exchange (flux tower), litterfall, and throughfall

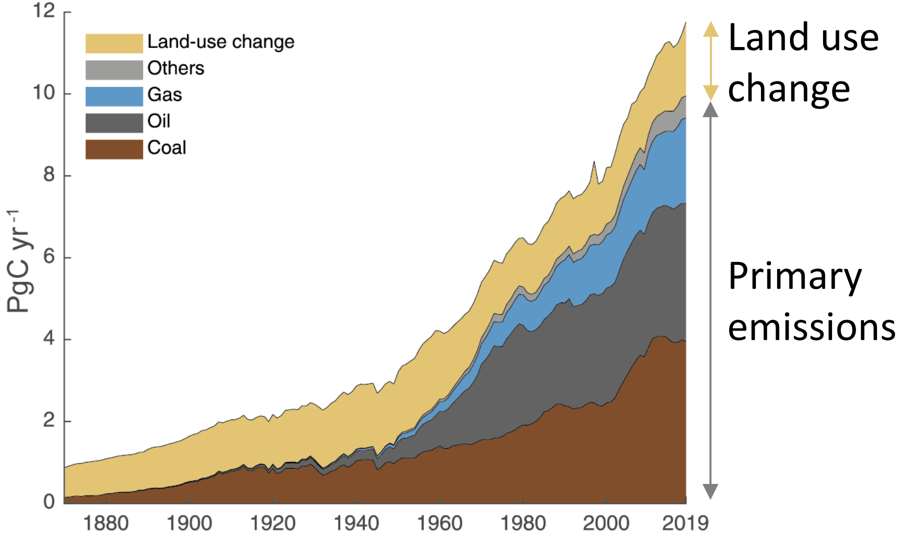
- Atmospheric Hg measurements from ECCC, EMEP, AMNet, GMOS, and LAPAN networks (Travnikov et al., 2017; AMAP/UNEP, 2018; Sprovieri et al., 2016; Koenig et al., 2021;Quant, 2021)

Humans perturb land sink through land use and climate change

Land use and land cover change (LULCC)

(de)forestation, wood harvest, crop cultivation, irrigation

(a) Anthropogenic global CO_2 emissions



Climate change and other factors

growing season length, wildfires, drought, storms, permafrost thaw, CO_2 fertilization, nitrogen deposition

For CO_2: land use change is **13%** of total anthropogenic emissions (IPCC)

Minamata Convention on Mercury does not address land use change, role in Hg budget is unknown

IPCC, AR6, WG1 Ch5 (2021)

Which Hg fluxes are affected by deforestation?

Biomass burning emissions

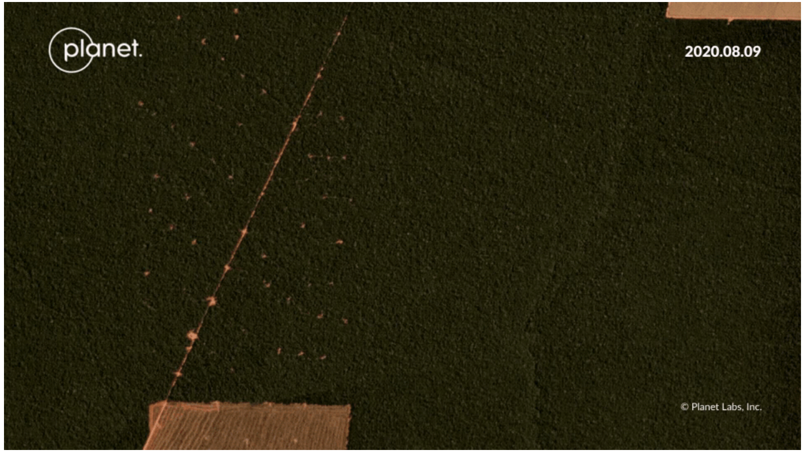
Veiga et al. (1994), Michelazzo et al. (2010), McLagan et al. (2021)

Reduced atmospheric uptake of Hg^0

Fostier et al. (2015), Zhou et al. (2021), Gerson et al. (2022)

Increased Hg reduction in soils, Hg^0 emissions

Magarelli and Fostier (2005), Carpi et al. (2014), Eckley et al. (2021)



Credit: Matthew Finer (MAAP) produced video with Planet satellite data

Finer M, Villa L (2021) Amazon Fire Tracker 2021: Brazilian Amazon Fire Season Intensifies. MAAP.

Increased soil erosion

Roulet et al. (1999), Eckley et al. (2018), Adler Miserendino et al. (2018)

Enhanced Hg methylation (?)

Garcia and Carignan (1999), Eklöf et al. (2014), Bishop et al. (2020)

Now with 3-D atmospheric models, can analyze combined effect and Hg fate

Apply improved model to study impacts of deforestation on Hg

Study published: Feinberg et al., *Environ. Sci. Technol.* (2024): "Deforestation as an Anthropogenic Driver of Mercury Pollution", doi: [10.1021/acs.est.3c07851](https://doi.org/10.1021/acs.est.3c07851)

Goal: Estimate net atmospheric fluxes driven by deforestation

Idealized regional deforestation scenarios (alter land, Leaf Area Index [LAI] inputs)

→

3D global atmospheric Hg model

GEOS Chem

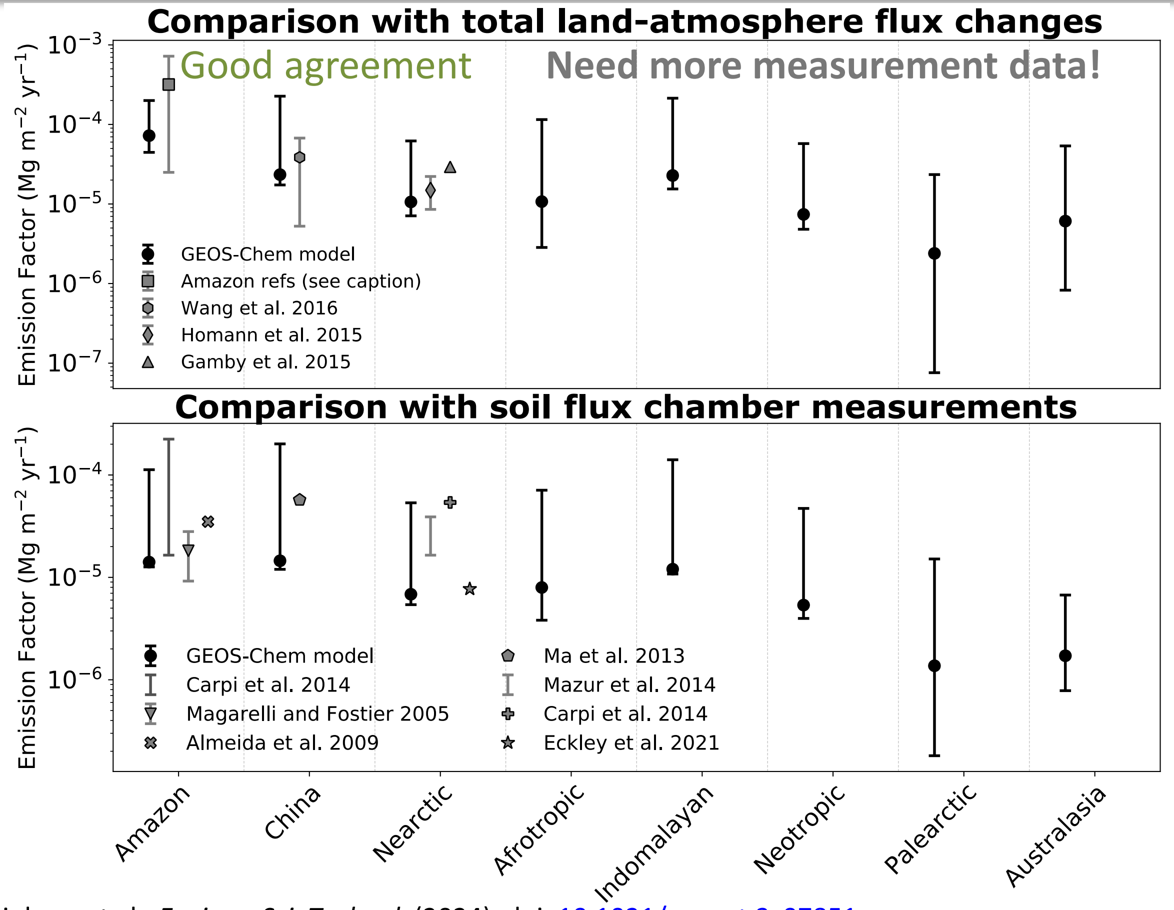
Capture response of Hg^0 soil emissions and deposition to removed vegetation

→

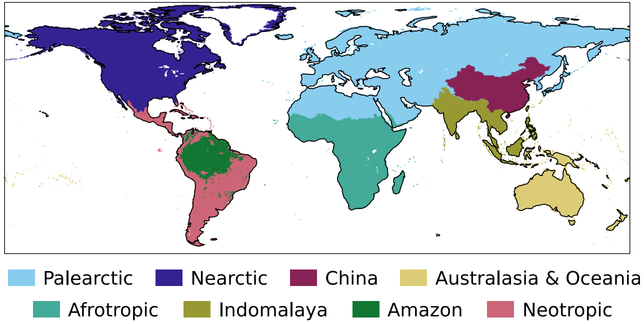
Regional emission factors (EFs) due to deforestation

$$\mathrm{EF} = \frac{\Delta\mathrm{Emissions} - \Delta\mathrm{Deposition}}{\mathrm{Area\ Deforested}}$$

GEOS-Chem model agrees with measurements of Hg deforestation impacts



Region definitions



Model error bars show uncertainty due to soil emission and deposition parametrizations

Amazon soil data sourced from: Almeida et al. (2005; 2009); Carpi et al. (2014); Lacerda et al. (2004); Gerson et al. (2022); Fostier et al. (2000); Beliveau et al. (2009; 2017); Comte et al. (2013); Magarelli and Fostier (2005); Mainville et al. (2006); Patry et al. (2013); Roulet et al. (1998); Wasserman et al. (2007)

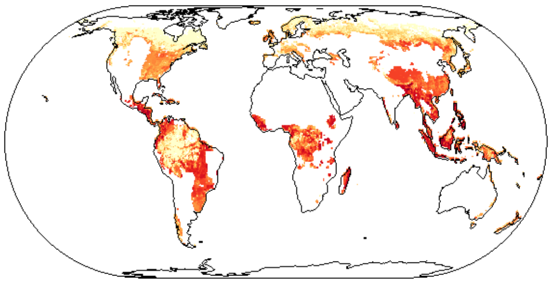
Feinberg et al., *Environ. Sci. Technol.* (2024), doi: [10.1021/acs.est.3c07851](https://doi.org/10.1021/acs.est.3c07851)

Estimating impact of global deforestation on atmospheric Hg fluxes

Goal: Estimate net atmospheric fluxes driven by deforestation

Regional emission factors (EFs) due to deforestation

X



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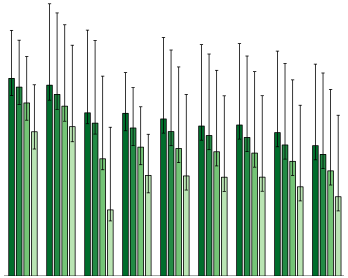
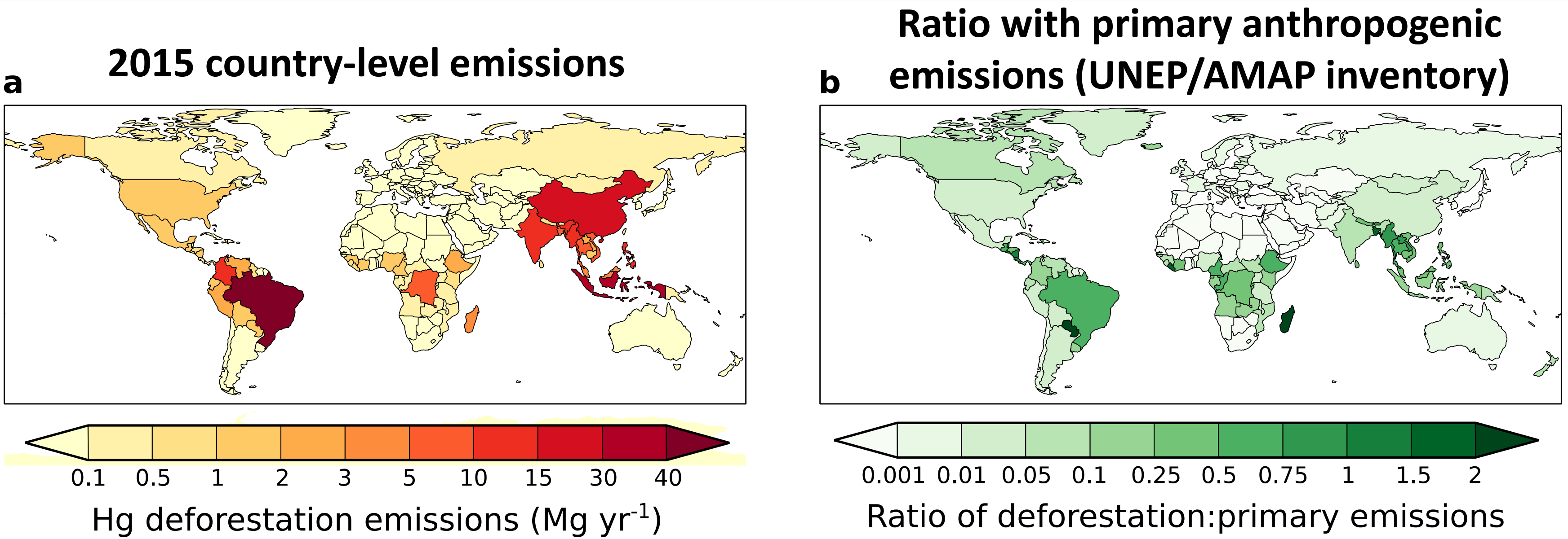


Deforested area over 45 years (1970–2014) from CMIP6 LUH2 dataset (Hurtt et al., 2020)

Global deforestation emissions in 2015

Feinberg et al., *Environ. Sci. Technol.* (2024), doi: 10.1021/acs.est.3c07851

Global atmospheric Hg emissions due to deforestation are substantial



- Net deforestation emissions are **217 Mg yr^{-1}** (134–1650 Mg yr^{-1}) in 2015
  = 10% of primary anthropogenic emissions of Hg, **2222 Mg yr^{-1}** (UNEP/AMAP inventory)
- For (sub)tropical countries (e.g., in Africa), deforestation is up to 10–230% of primary emissions

How will these deforestation emissions vary in future with policy choices?

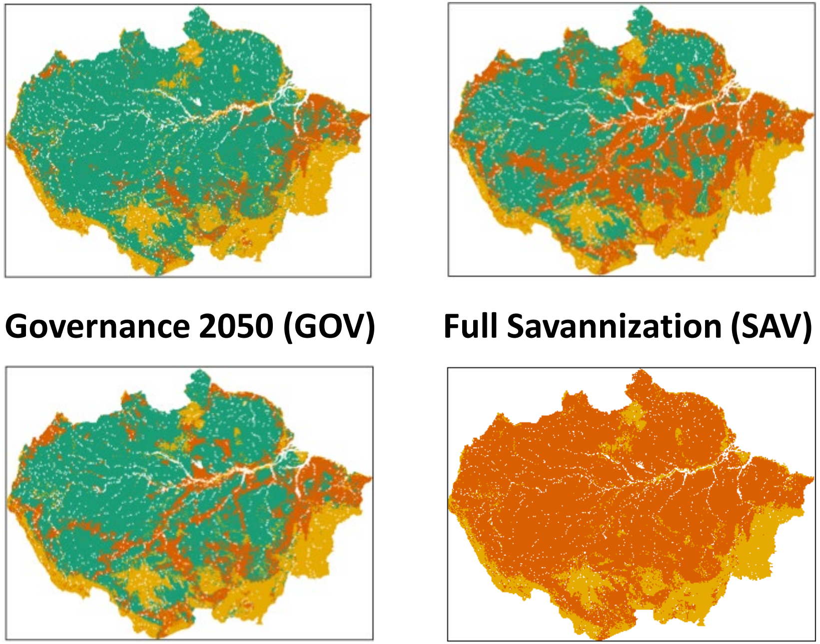
Feinberg et al., *Environ. Sci. Technol.* (2024), doi: [10.1021/acs.est.3c07851](https://doi.org/10.1021/acs.est.3c07851)

Impact of conservation and reforestation policies on Hg fluxes

Amazon deforestation scenarios

Historical 2003 (HIST) | Business as Usual 2050 (BAU)

Governance 2050 (GOV) | Full Savannization (SAV)

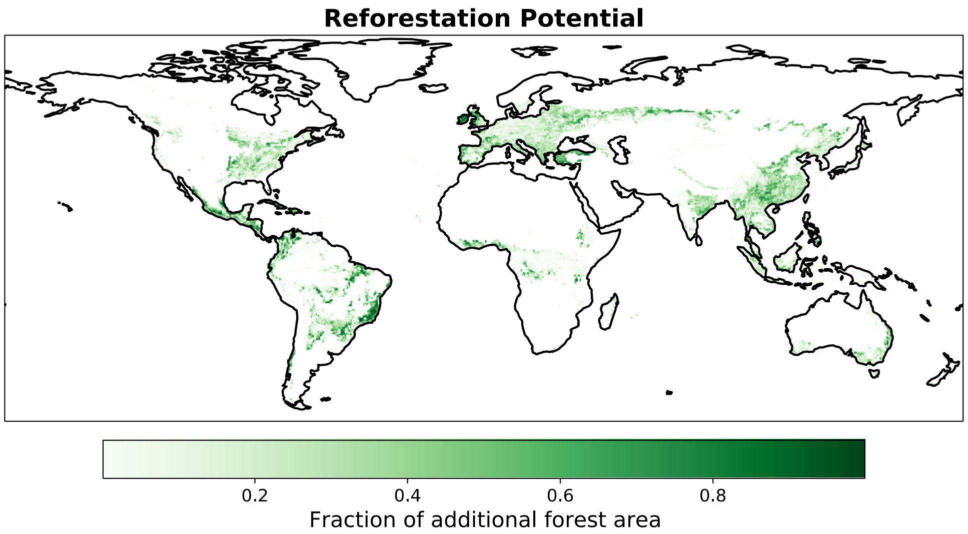


Forest Forest Loss Non-Forest

Soares-Filho et al., *Nature* (2006)

Global reforestation scenario

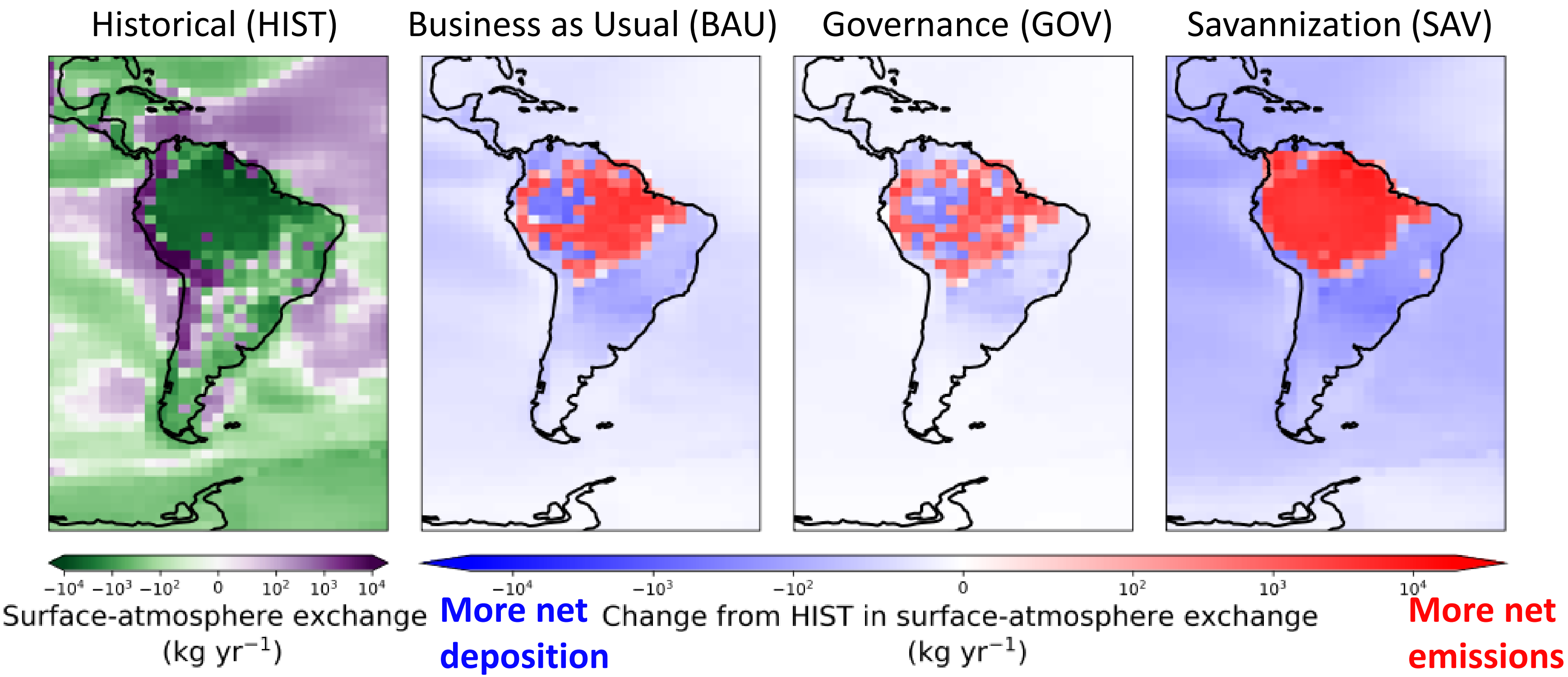
Potential for conversion to forest for areas where forests are native, without converting croplands



Griscom et al., *PNAS* (2017)

Run scenarios in GEOS-Chem model, evaluate impact on Hg fluxes

Deforestation increases Hg inputs to ocean, risks for fish consumption

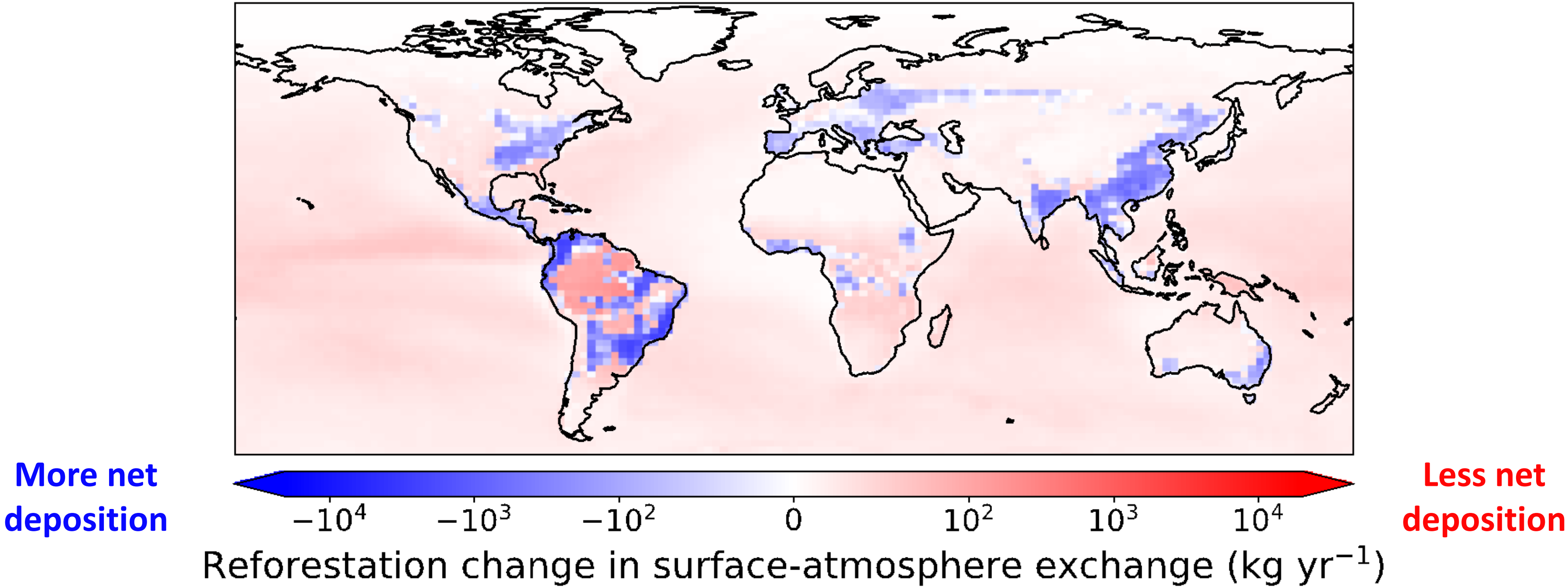


108 Mg yr^{-1} additional Hg deposits to ocean in Business as Usual scenario

92 Mg yr^{-1} net emissions avoided by improved conservation (GOV vs. BAU)

Feinberg et al., *Environ. Sci. Technol.* (2024), doi: 10.1021/acs.est.3c07851

Reforestation impact on surface-atmosphere exchange of Hg

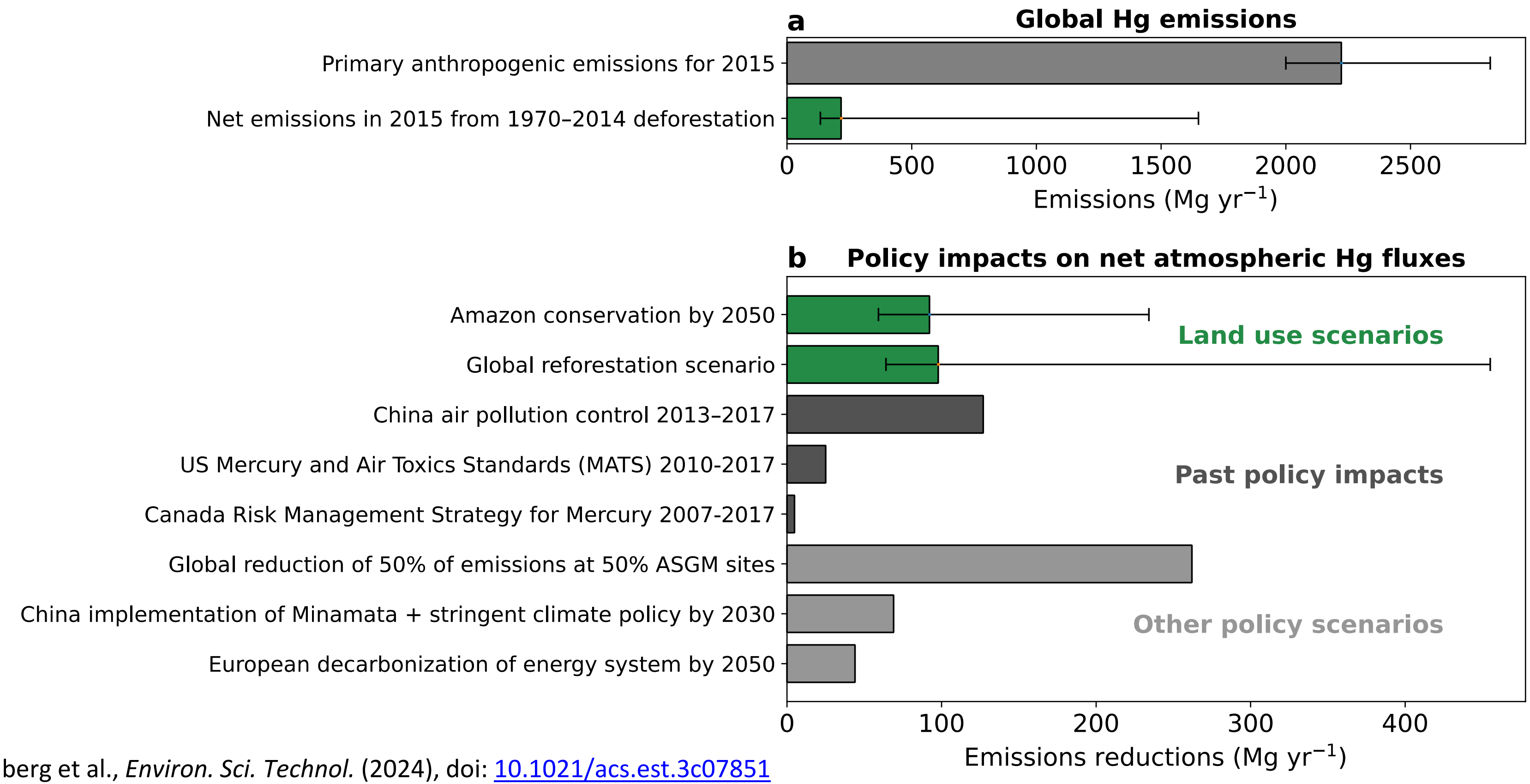


Reforestation reduces Hg inputs to the ocean by 98 Mg yr^{-1} (~5% of anthropogenic emissions)

Mainly driven by enhanced uptake of Hg^0 in tropical forests

Feinberg et al., *Environ. Sci. Technol.* (2024), doi: [10.1021/acs.est.3c07851](10.1021/acs.est.3c07851)

Like in CO_2 case, reducing primary emissions is paramount; however, land use policy is an overlooked lever in the Hg cycle



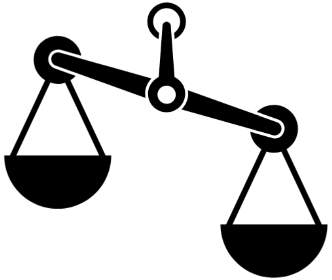
Feinberg et al., *Environ. Sci. Technol.* (2024), doi: 10.1021/acs.est.3c07851

Hg emission policy assessments from: Liu et al., 2019; EPA; 2019; Environment and Climate Change Canada, 2020; Bruno et al., 2022; Mulvaney et al., 2020; Rafaj et al., 2014

How has land sink affected recent trends in atmospheric Hg^0?

Land sink

Source
Deforestation emissions



Sink
"Global greening" (CO_2 fertilization and N deposition)

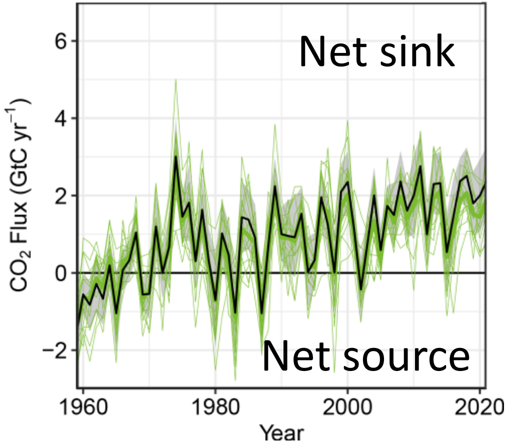
Jiskra et al. (2018): using carbon ratio, estimate Hg sink grew **+140 Mg yr^{-1}** from 1990 to 2010

Could land sink play a role in why atmospheric Hg^0 concentrations are declining?

Our analysis suggests **minor driver** (talk: Fri Session 31)

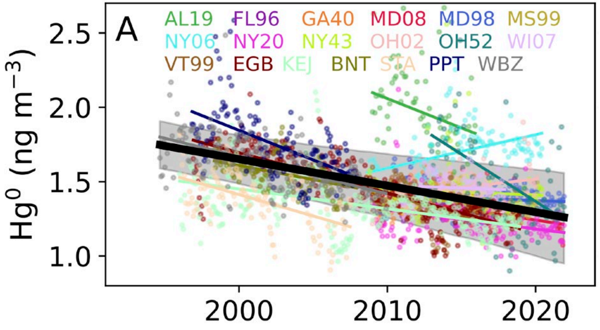
This driver will be analyzed in the multi-model intercomparison MCHgMAP project (Dastoor et al., *Geosci. Model Dev. Discuss.*, 2024)

Trend in land carbon sink



Friedlingstein et al., *Earth Syst. Sci. Data* (2023)

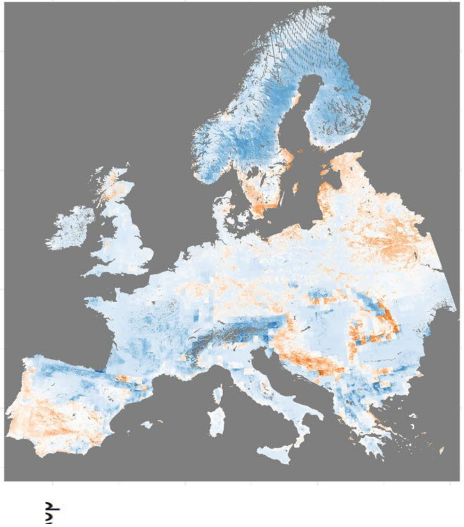
(5) East N America



Feinberg et al. preprint (2024), doi: 10.31223/X5B38K

Just the start of investigating impacts of global change on Hg land sink…

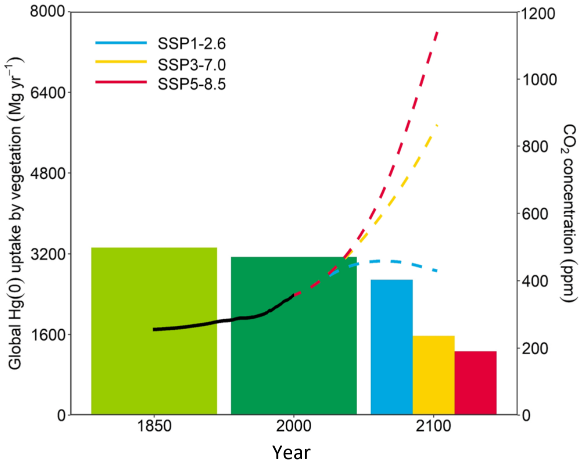
Hg uptake by vegetation suppressed by drought



Change in pine needle Hg uptake flux in RCP8.5 compared to 2018

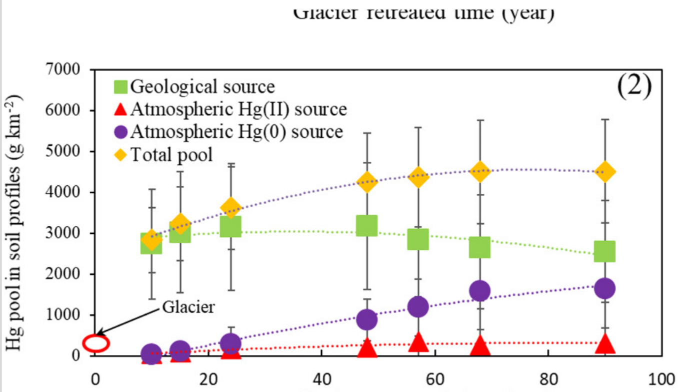
Wohlgemuth et al., *Global Biogeochem. Cycles* (2023)

Enhanced CO_2 inhibits the stomatal uptake of Hg^0



Yuan et al., *Nature Commun.* (2024)

Vegetation sequesters atmospheric Hg^0 in glacier retreat areas



Wang et al., *Proc. Natl. Acad. Sci.* (2020)

Still much to learn, demands close collaboration between modelers and experimentalists across the globe!

Outlook on research on global change and Hg land sink

Conclusions

Deforestation emissions of Hg are substantial and may grow in the future, highlighting importance to account for them in inventories and policy

Future research needs

- Better accounting of the **historical and future Hg fluxes** from land use change
- More **measurements** of Hg stocks and fluxes in areas where deforestation is occurring (especially (sub)-tropical **Africa, Southeast Asia**)
- Observations to understand **timescales of Hg fluxes** during deforestation and regrowth of vegetation
- **Development of terrestrial and Earth System models** to capture how Hg land sink will change in the future