Approaches for incorporating soil-atmosphere fluxes of H_2 and Hg into CLM

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Environmental impact of H_2 emissions

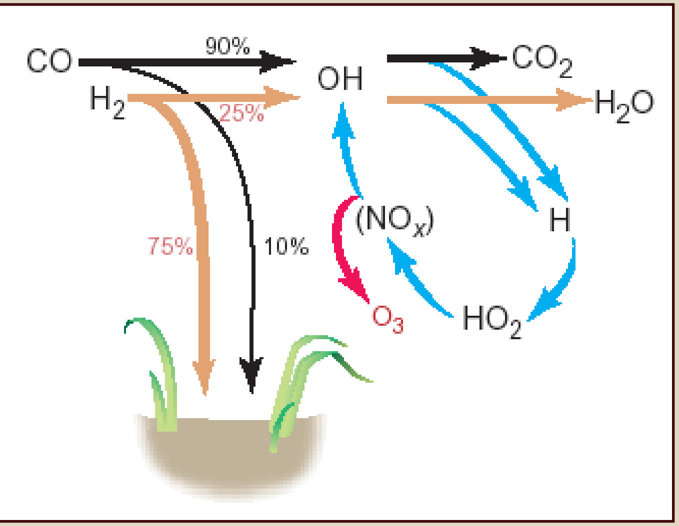
Higher H_2 and reduced emissions of…

NO_X

Leads to

lower levels of…

$OH^{\bullet}$



Decreasing tropospheric ozone

Increasing lifetimes of CH_4 and CO

$\uparrow \tau_{CH_4}$ & CO

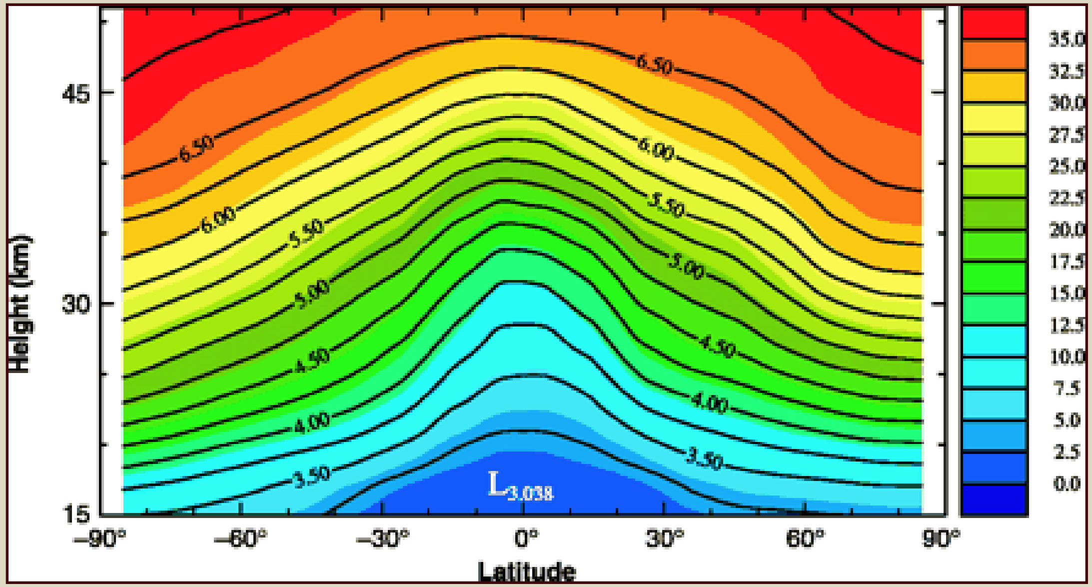
Schultz et al. 2003

Environmental impact of H_2 emissions

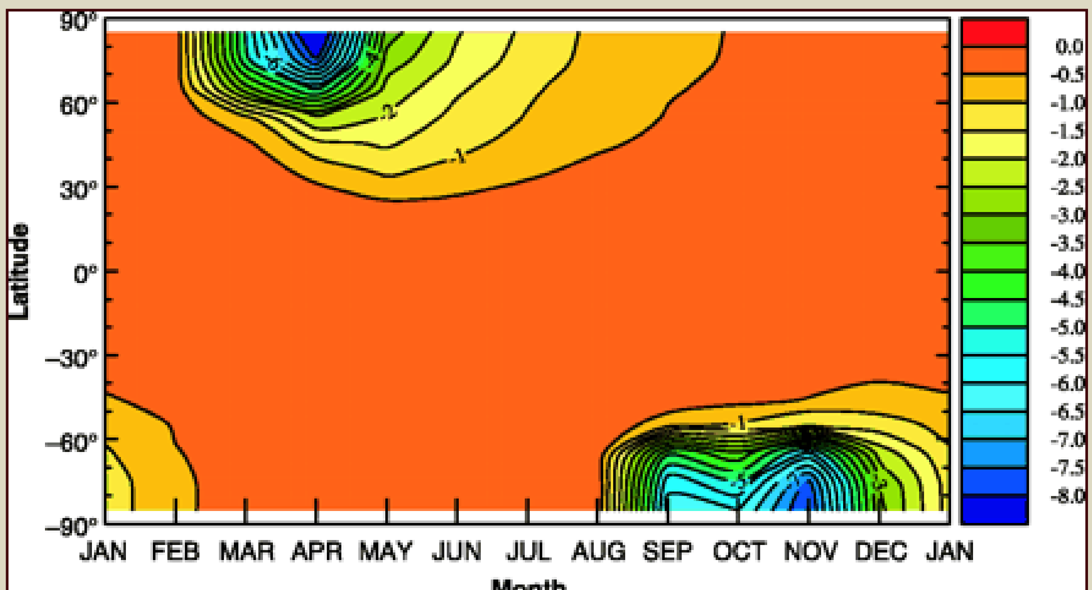
Stratospheric O_3 Loss

Assume

- 10% loss of H_2
- no change in soil sink
- 4x increase in tropospheric $[H_2]$
- Leads to moistening and cooling of stratosphere
- Loss of O_3



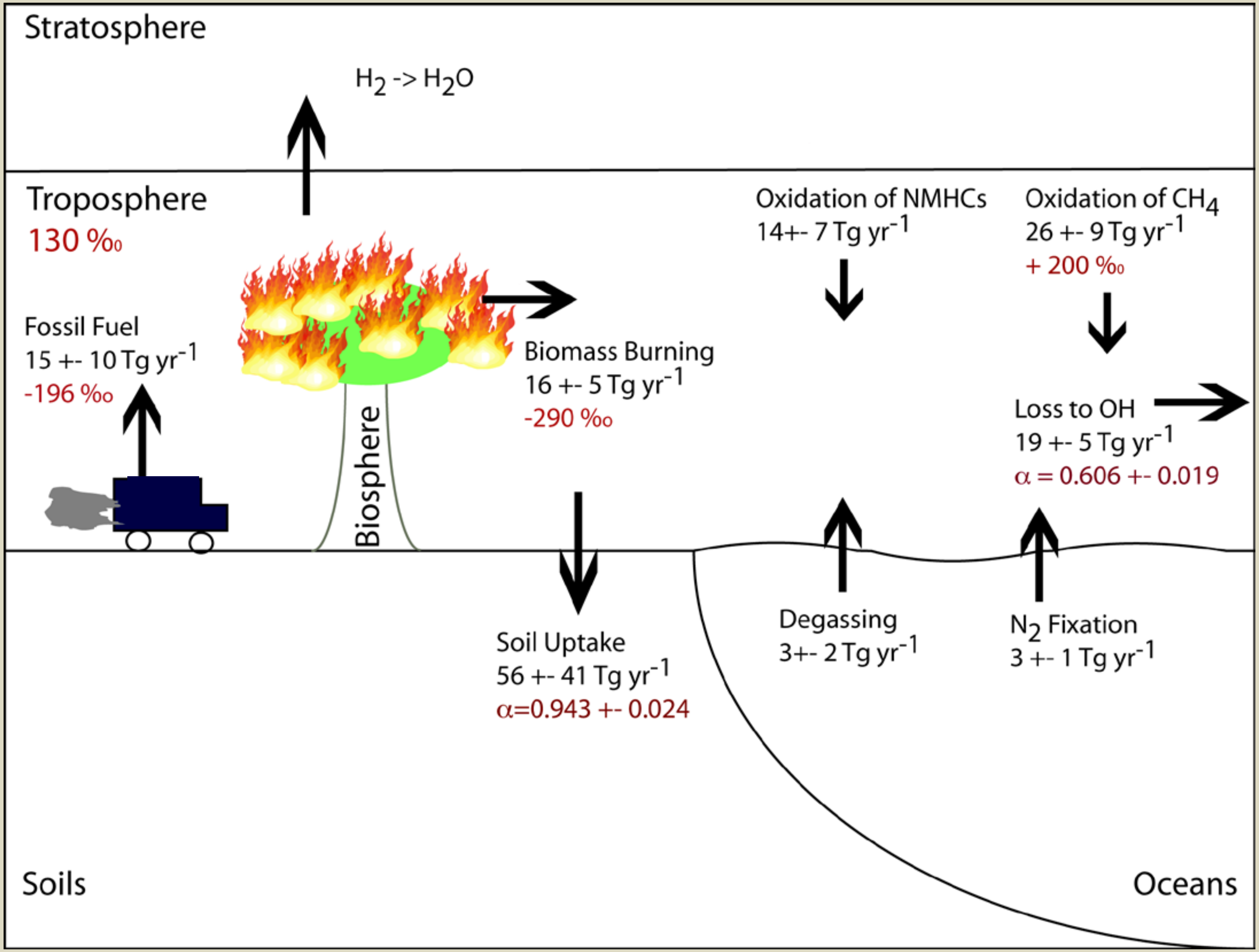
Contours - background H_2O mixing ratio
Colors - % change H_2O



Colors - % change O_3

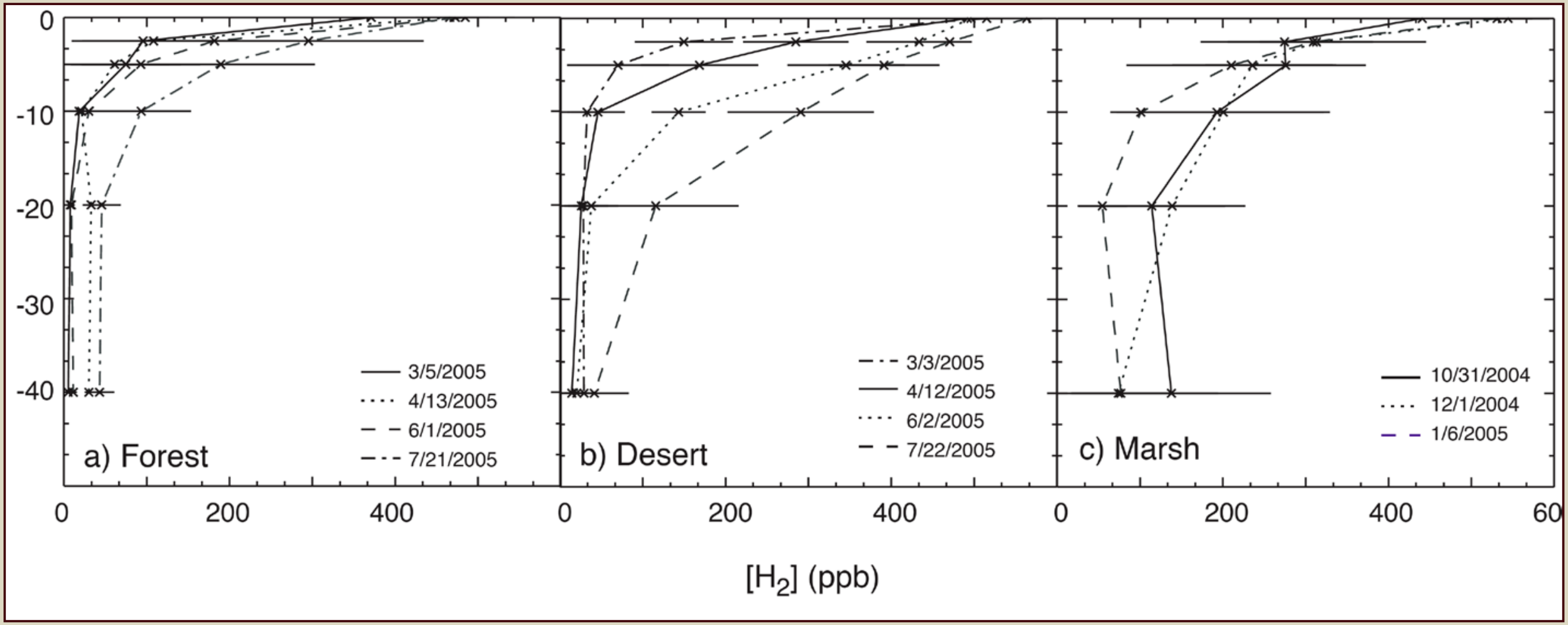
(Tromp et al. 2003)

Atmospheric H_2 Budget



Arrows represent fluxes from one reservoir to another.
Data from *Novelli et al*. [1999], *Gerst and Quay* [2001] and *Rahn et al.* [2002].

Soil Profiles



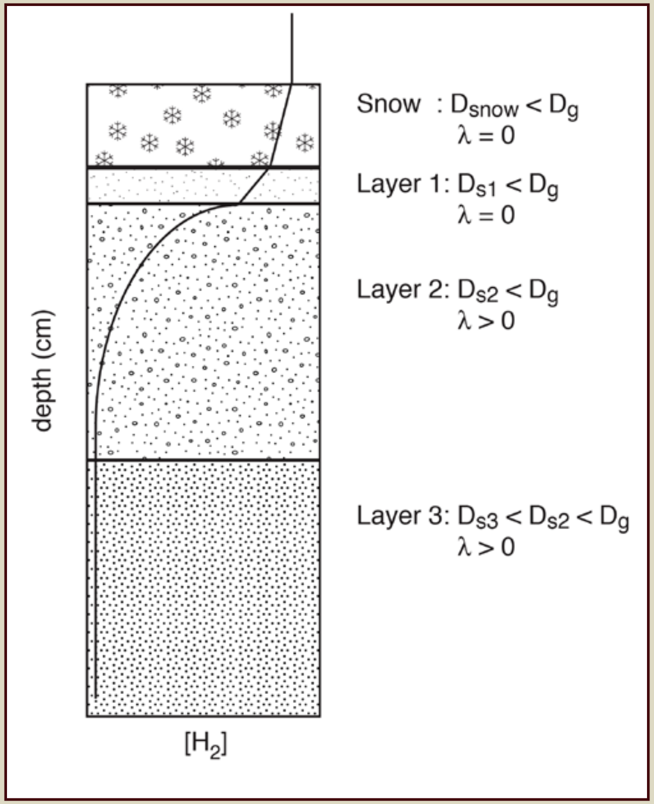
Mean Fluxes

	Forest	Desert	Marsh
H_2	-8.3 nmol/m^2/s	-8.2 nmol/m^2/s	-5.9 nmol/m^2/s
CO_2	5.6 μmol/m^2/s	1.8 μmol/m^2/s	

Smith-Downey et al. 2008 – JGR

The Diffusion Equation

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial z}\left(D_s \frac{\partial C}{\partial z} \right) - \frac{\lambda}{\varepsilon} C \qquad F = D_s \frac{\partial C}{\partial z} \Big|_{z=0}$$

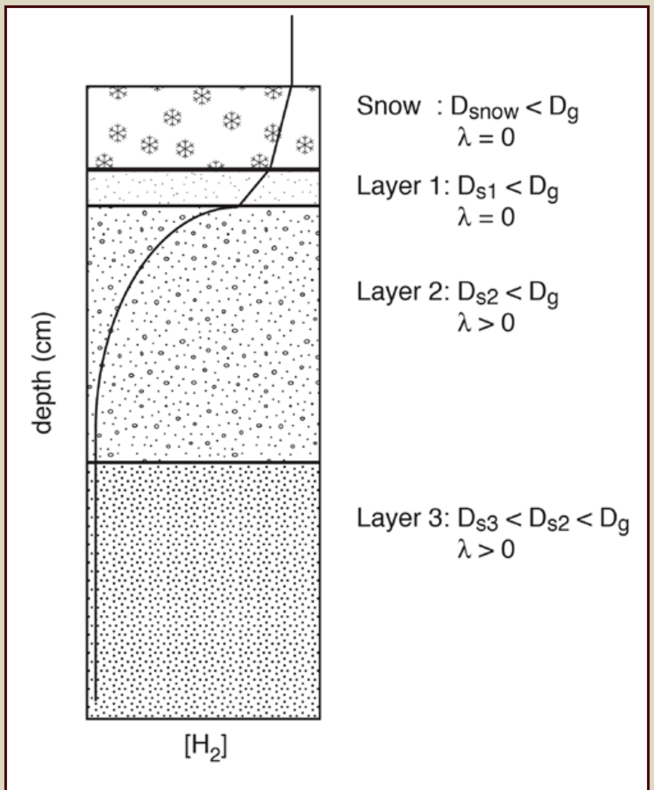


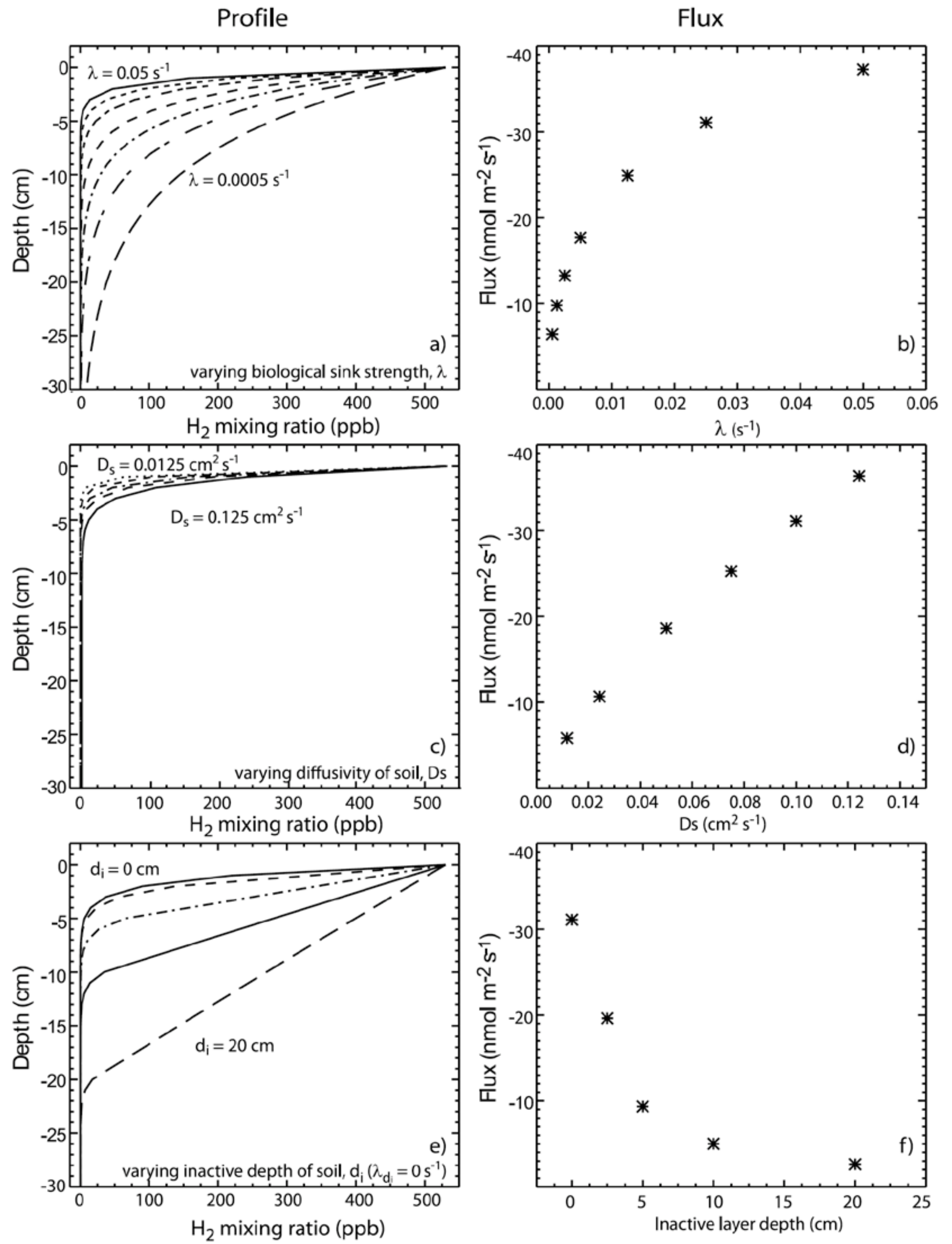
C - $[H_2]$ (mol cm^{-3})
z - depth (cm)
D_s - diffusivity of H_2 ($cm^2\ s^{-1}$)
λ - uptake rate (s^{-1})
ε - soil porosity
F - flux (mol $cm^{-2}\ s^{-1}$)

Boundary Conditions:
- $C_{z=0}$ - set by Novelli 1999
- zero flux at the bottom

Soil layers and spacing were chosen to match CLM

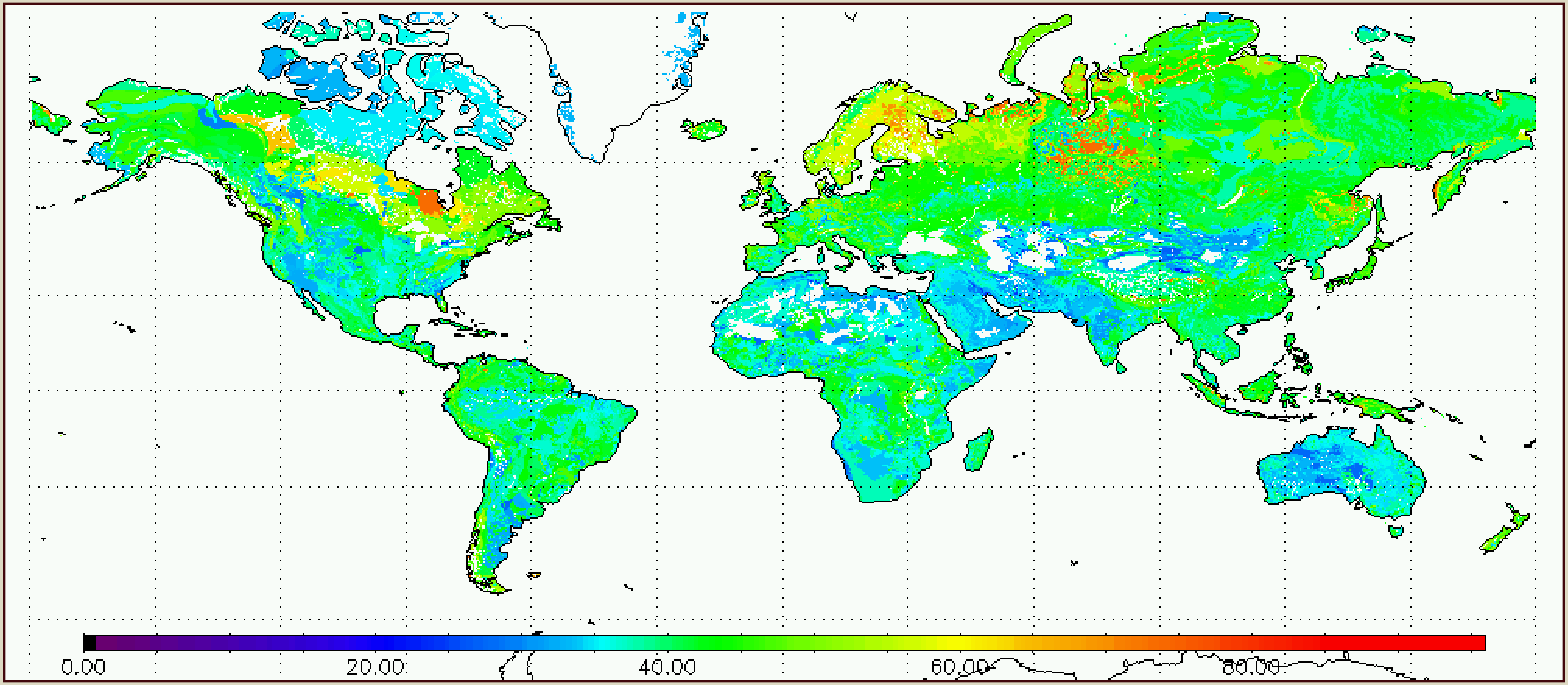
Sensitivity Experiments





Smith-Downey et al. 2008 – JGR

D_s - Diffusivity of H_2 in Soils



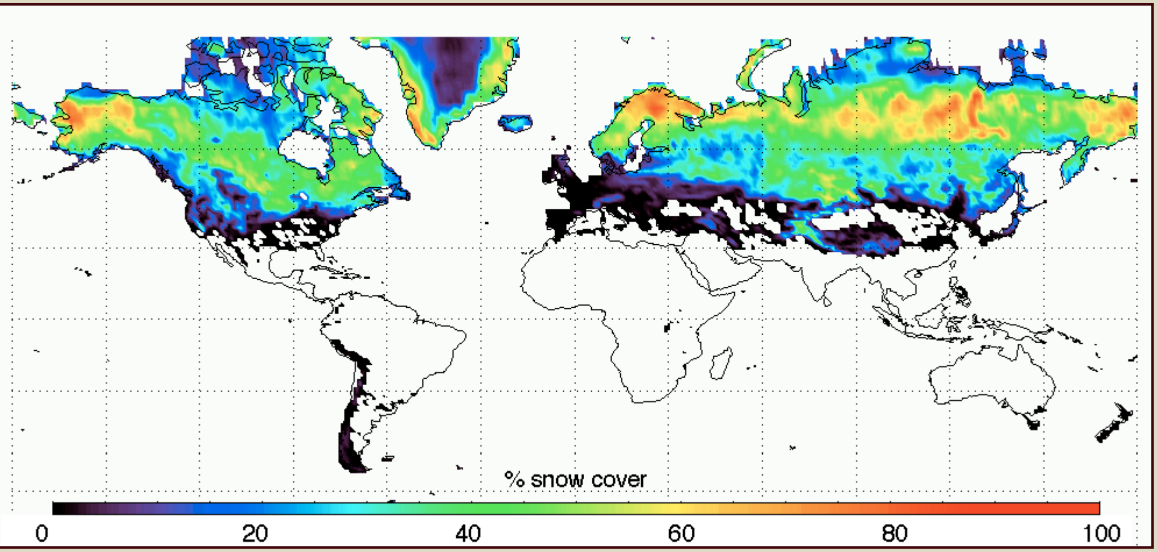
Global map of soil porosity (% by volume, Φ) (Reynolds et al. 1999)

$$\frac{D_s}{D_g(T)} = \Phi^2 \left(\frac{\varepsilon(M)}{\Phi} \right)^{2.9 \cdot F_{clay}}$$

where ε is air filled pore space calculated monthly using soil moisture from the CLM land surface model

Moldrup et al. 2003

Snow – Diffusive Barrier to H_2



MODIS fractional snow cover (March 2001)

Snow depth is parameterized as a function of fractional snow cover (Romanov et al.)

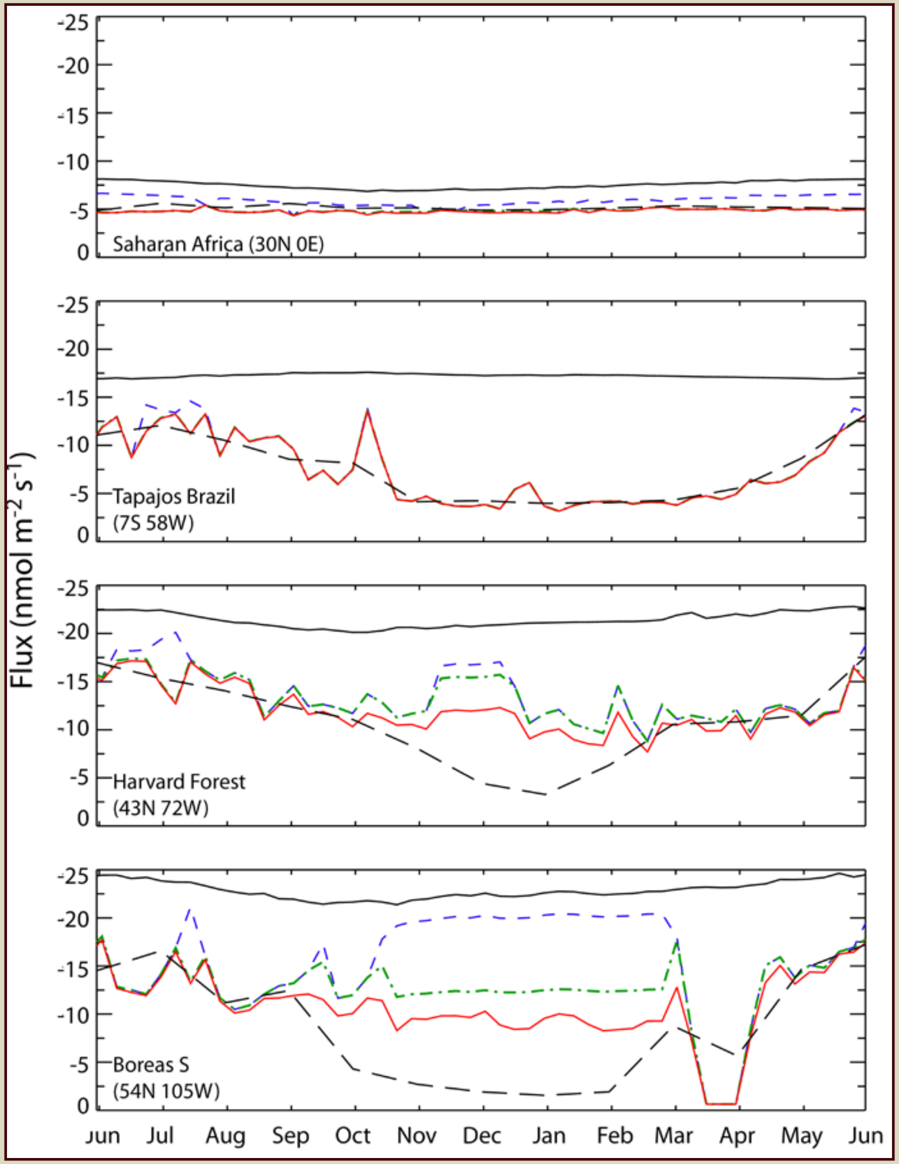
$D_{snow} = 0.608\ D_g$
(Hubbard et al. 2005)

$$Flux = f_{snow} \cdot F_{snow} + (1 - f_{snow}) \cdot F_{no\_snow}$$

Dynamic model that allows for growing and shrinking of snow pack depth

Could also use modeled snow depth and density from CLM

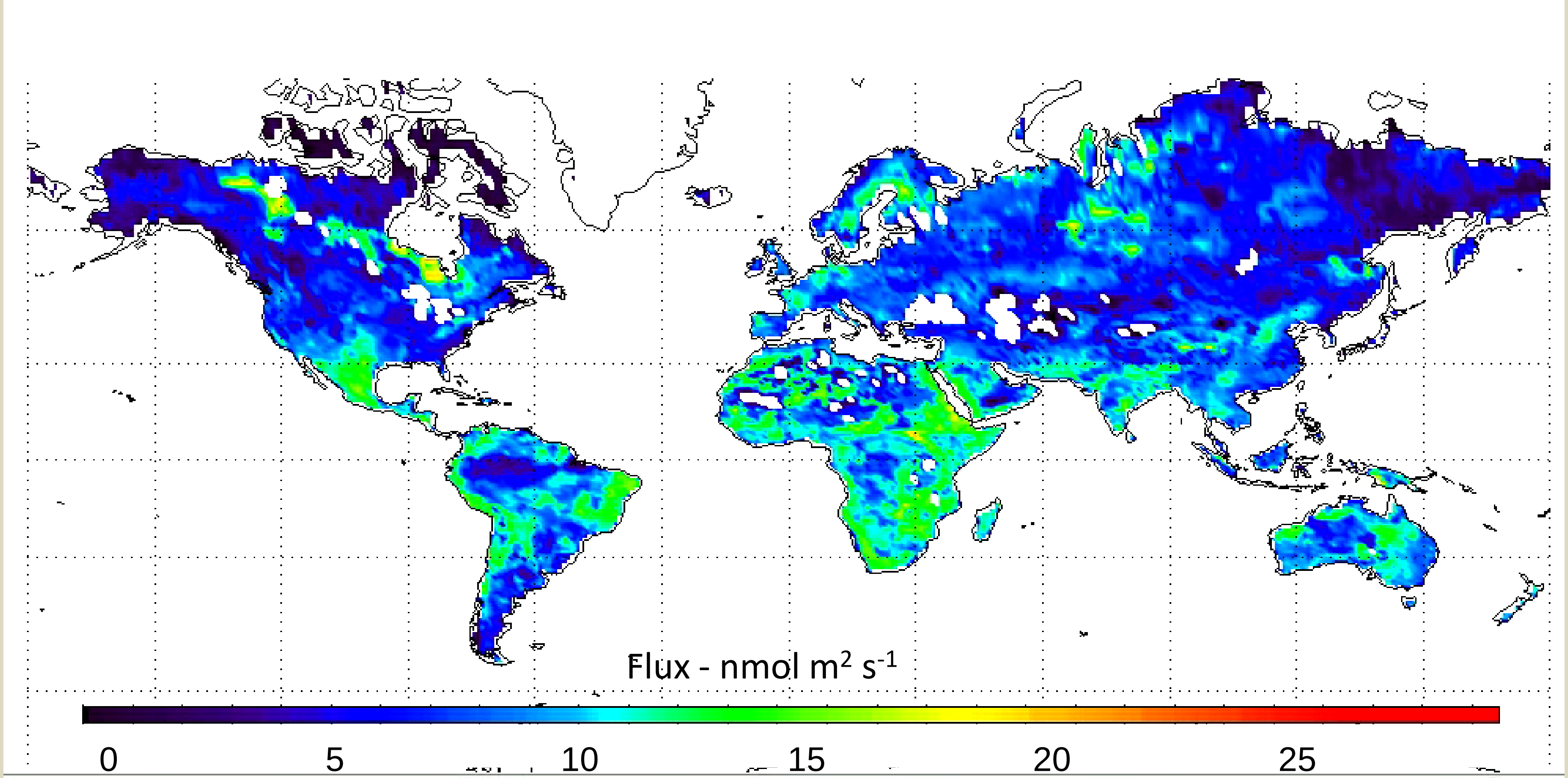
Site level - What controls uptake



Scalar Addition Experiments

Ran into some problems with top soil layer saturating and shutting off all diffusion into soils (this was CLM2), so I averaged the top 3 layers

Global H_2 Uptake Pattern

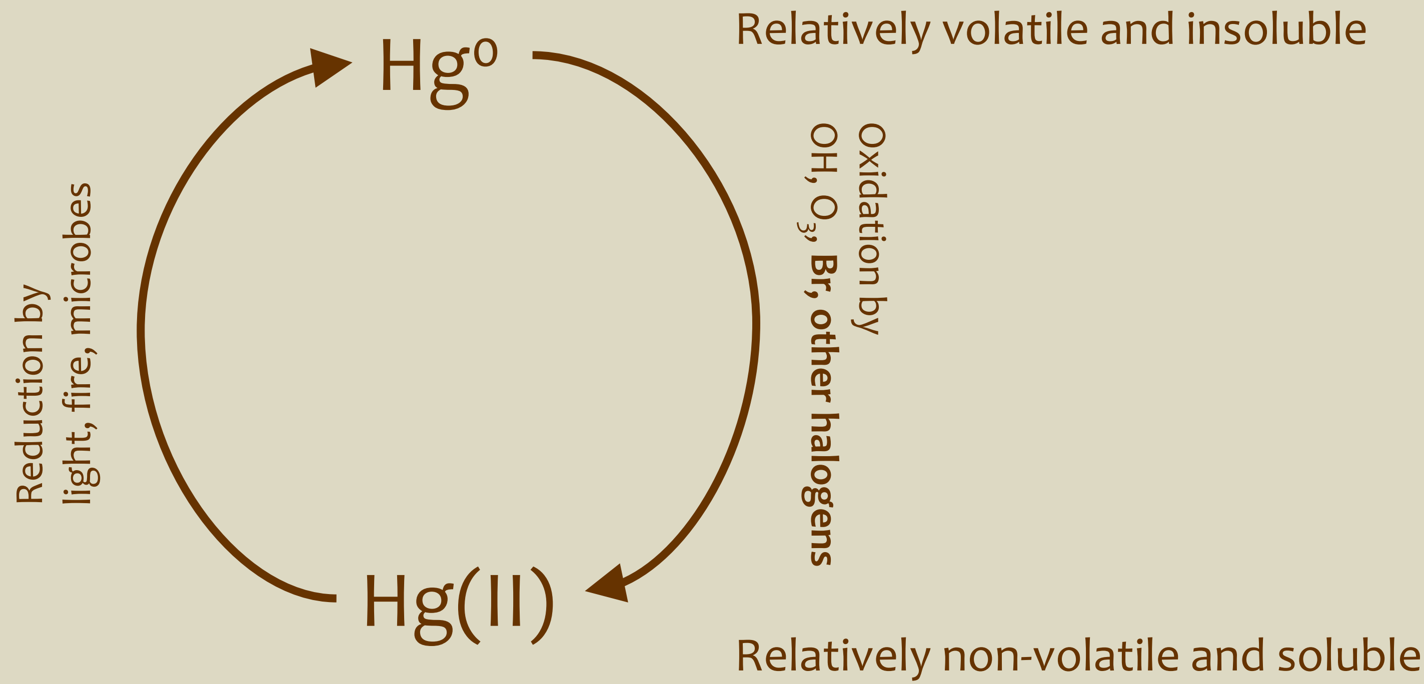


Total Global Uptake of H_2 by soils 68 ± 5.5 Tg year^{-1}
(Novelli et al. estimate 56 ± 41 Tg year using flask measurements)

Most importantly – the physics that control H_2 uptake make it relatively easy to model, especially given the built in soil structure and moisture in CLM

Global Terrestrial Hg Cycling

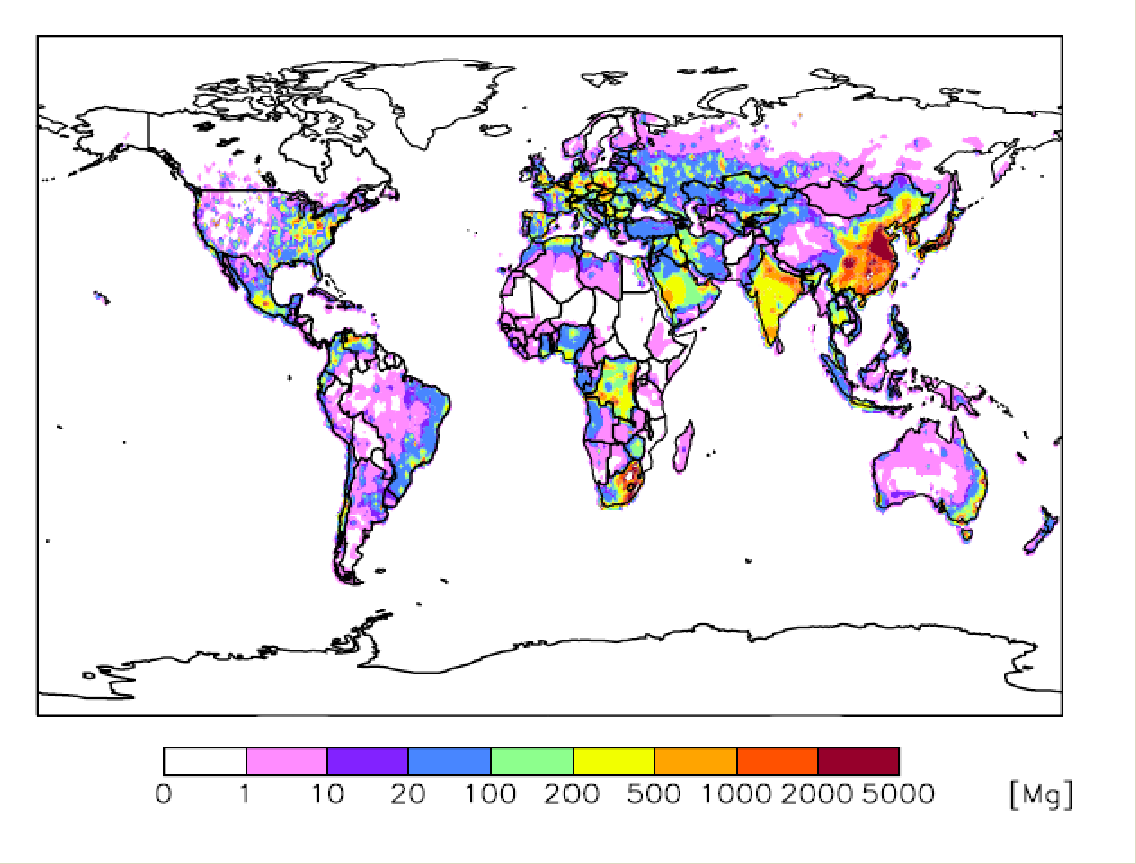
Mercury Speciation – Atmospheric Cycle



Sources of Hg

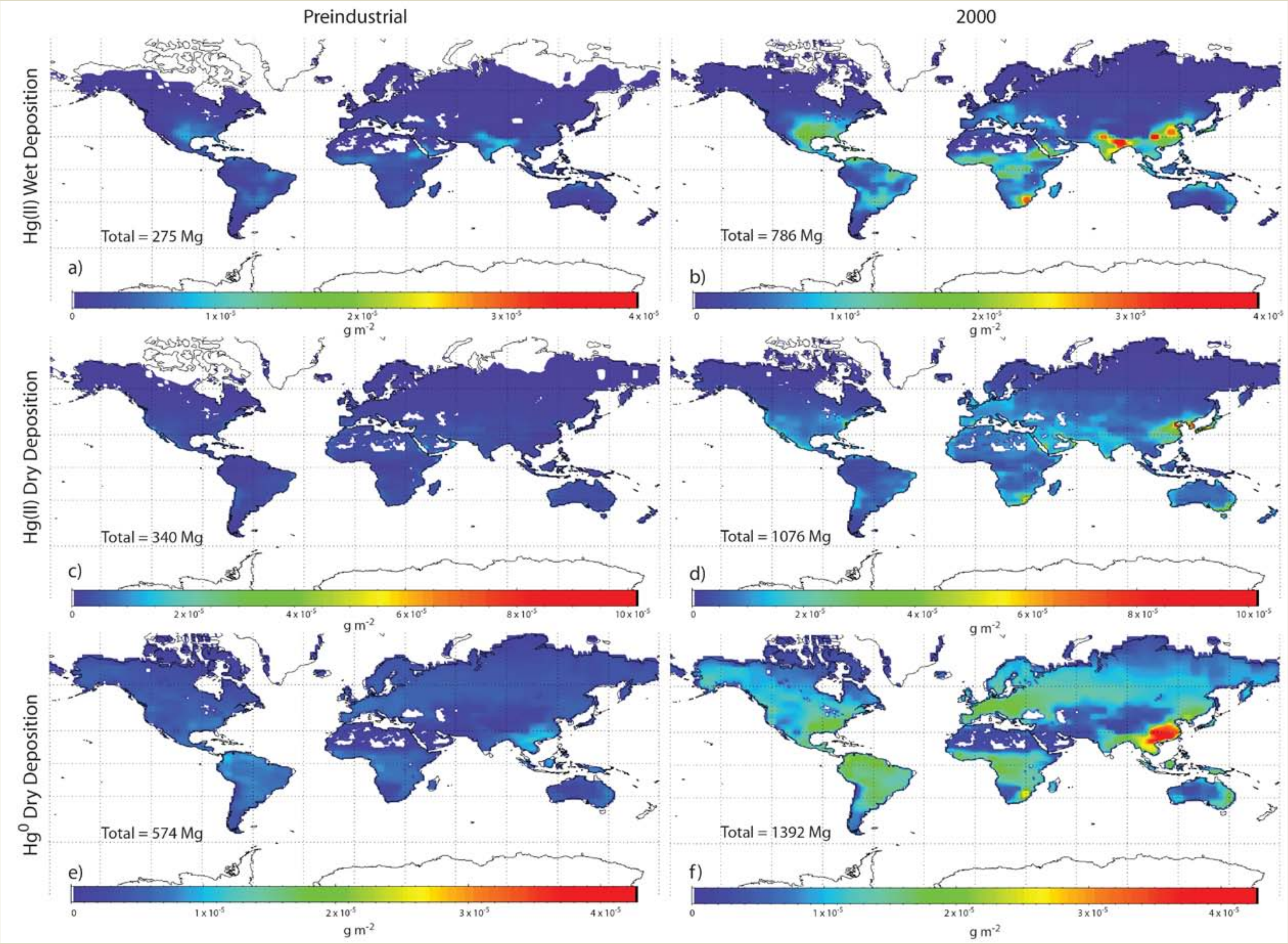
- Coal Combustion
- Metal Smelting
- Waste Incineration

- Soils
- Vegetation*
- Biomass Burning
- Oceans
- Volcanoes



[Pacyna et al. 2005]

Deposition from GEOS-Chem



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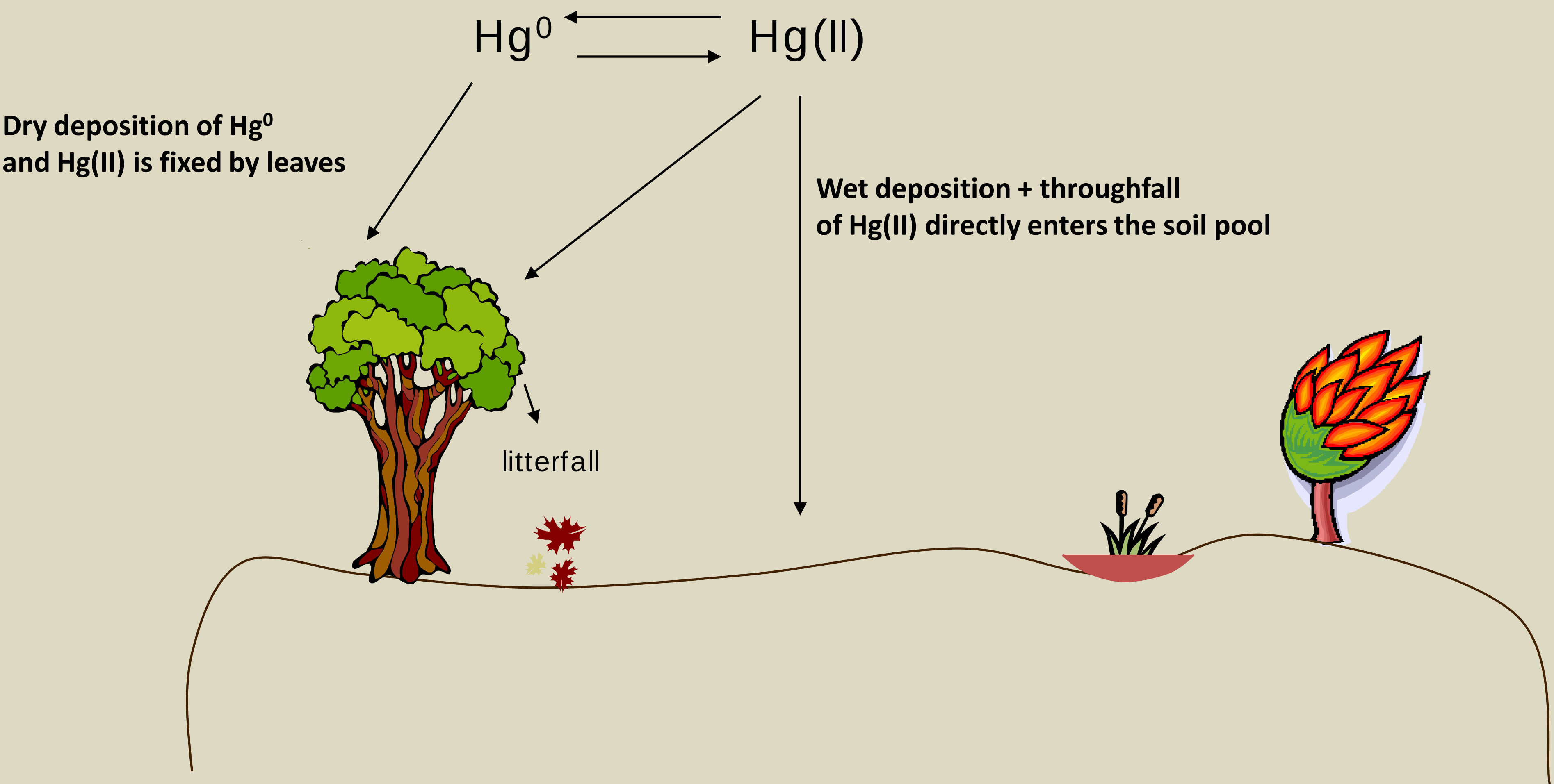
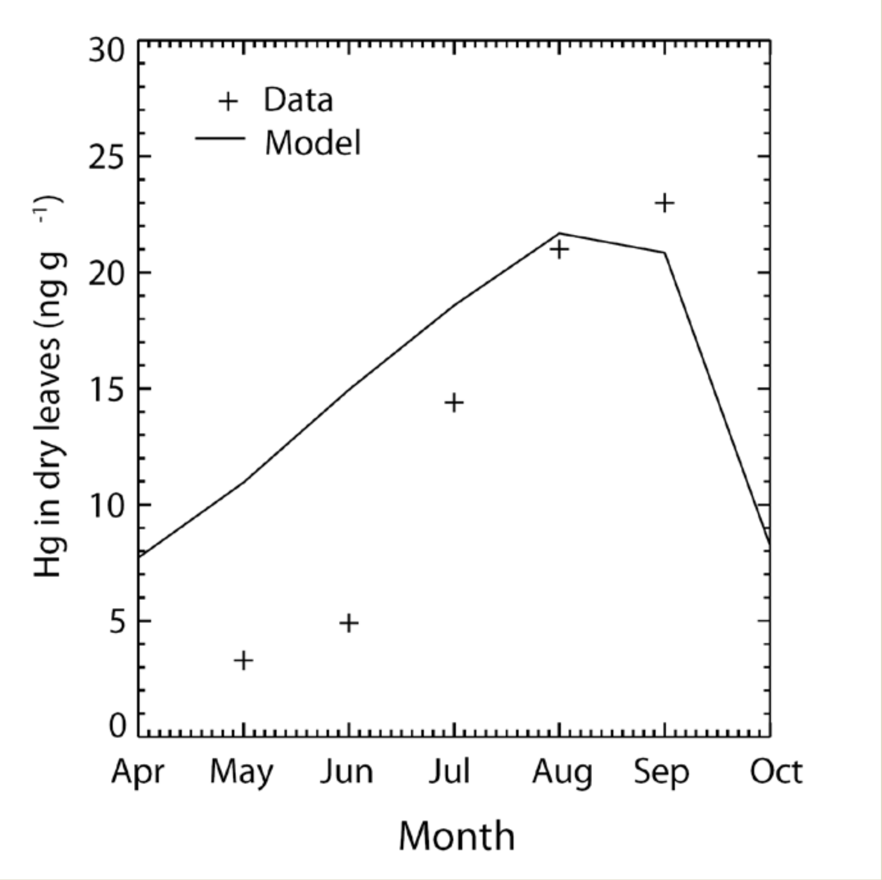
Terrestrial Hg Deposition



Hg fixed by leaves

- Field measurements by Rea et al. [2002] show a seasonal increase in leaf Hg concentration

- Used leaf concentration data to tune model



$$H_{f\ \ i} = 0.2\ g_e(d\ _d\ 5^0 + \mathbf{d} \quad (I\ )dH\ m\ I\ )\left(\frac{L}{1.2}\ H\ ,1g0\ i\right)$$

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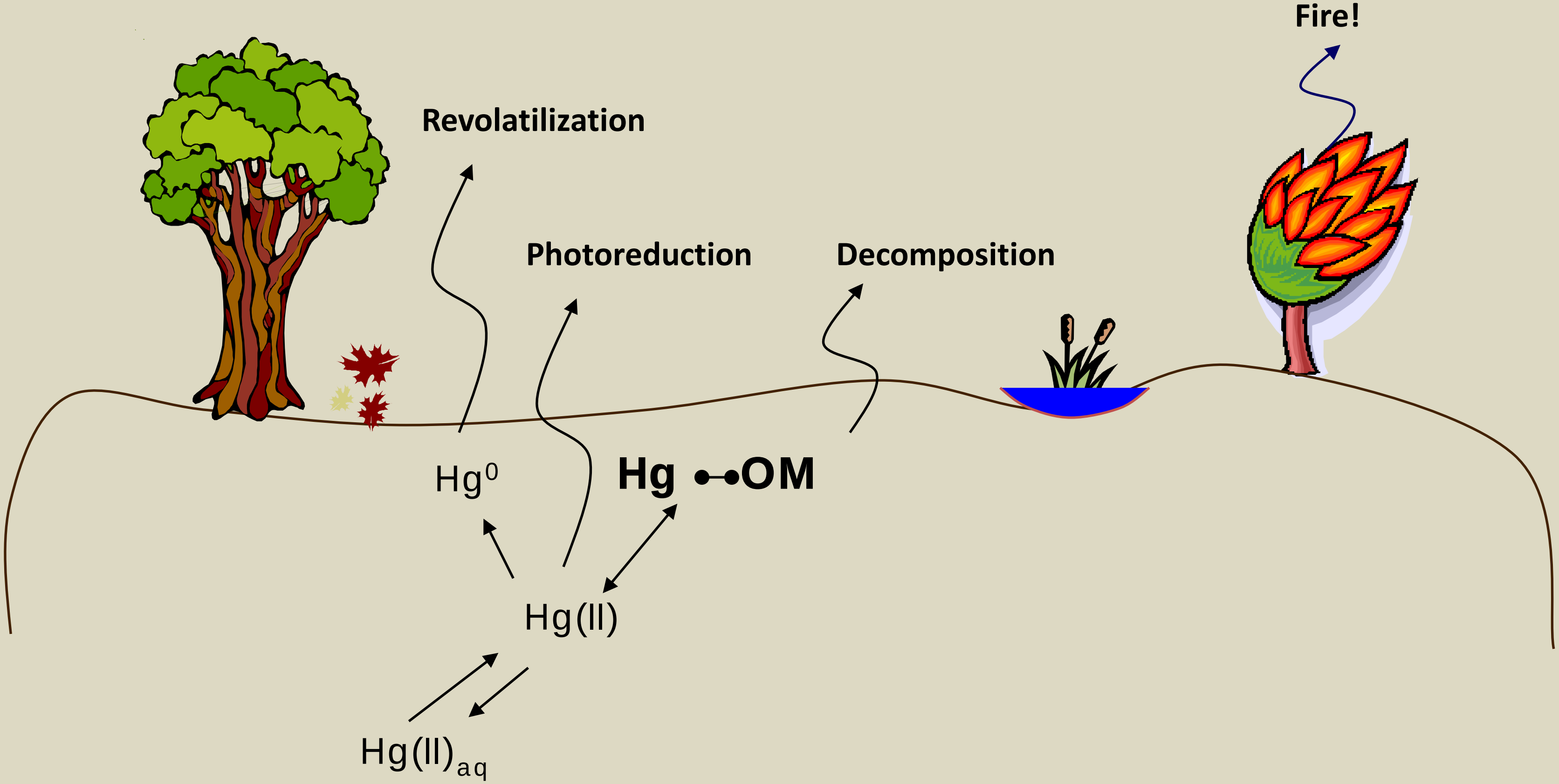
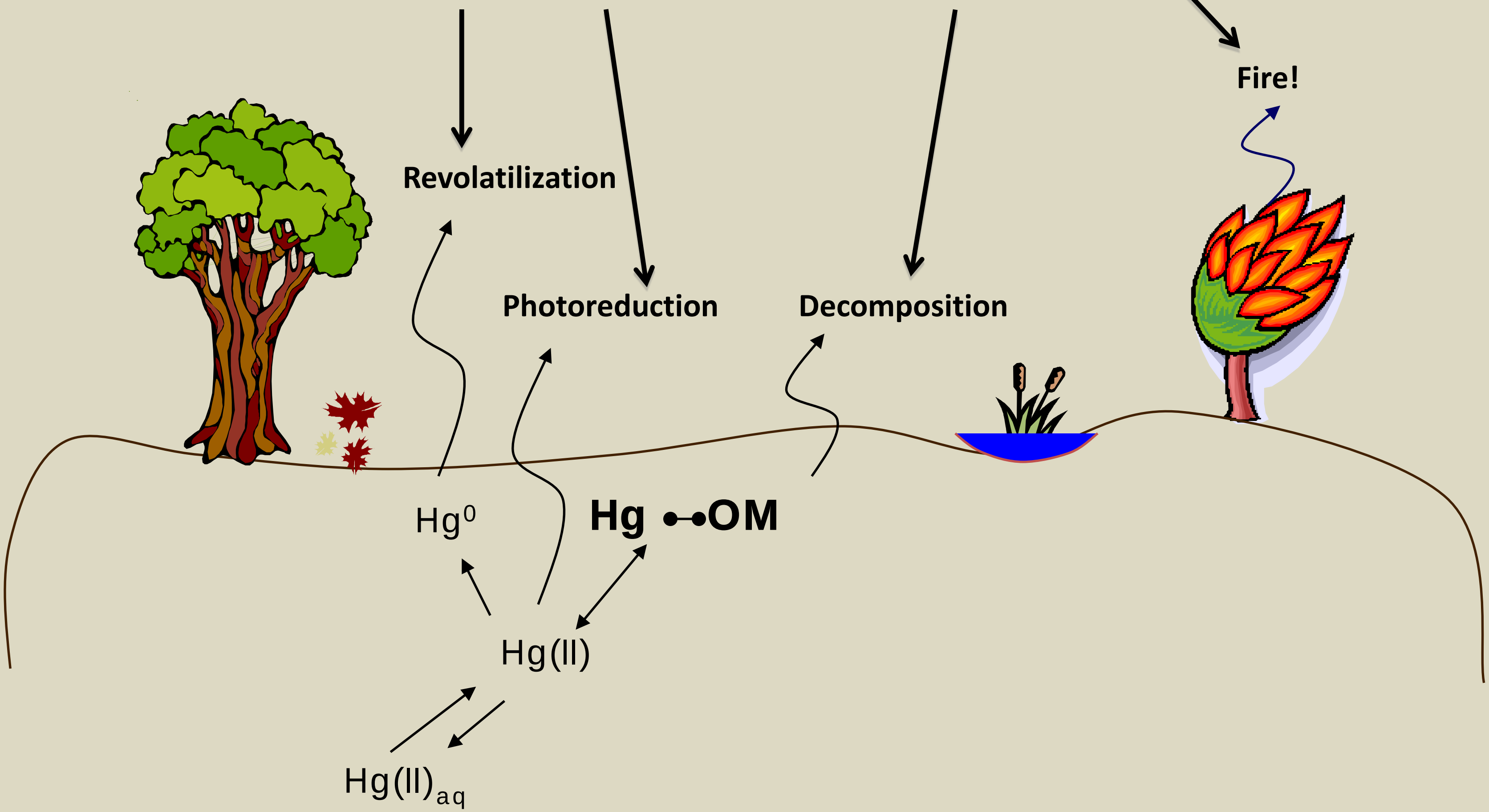
Terrestrial Hg Emissions



Terrestrial Hg Emissions

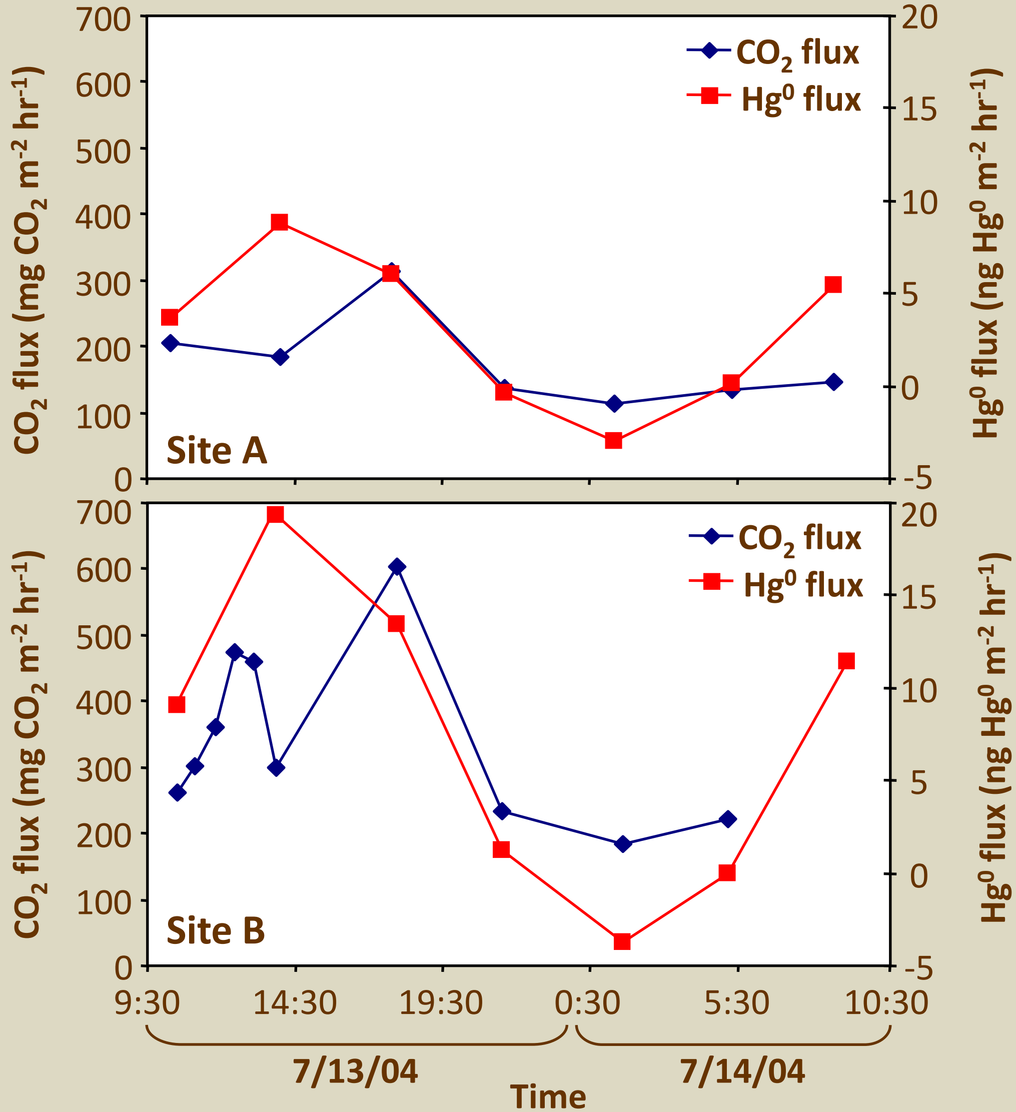
Largely controlled by deposition, T, light -> equilibrates rapidly with deposition

Largely controlled by deposition, C-turnover, and Fires -> equilibrates with deposition and ecosystem processes

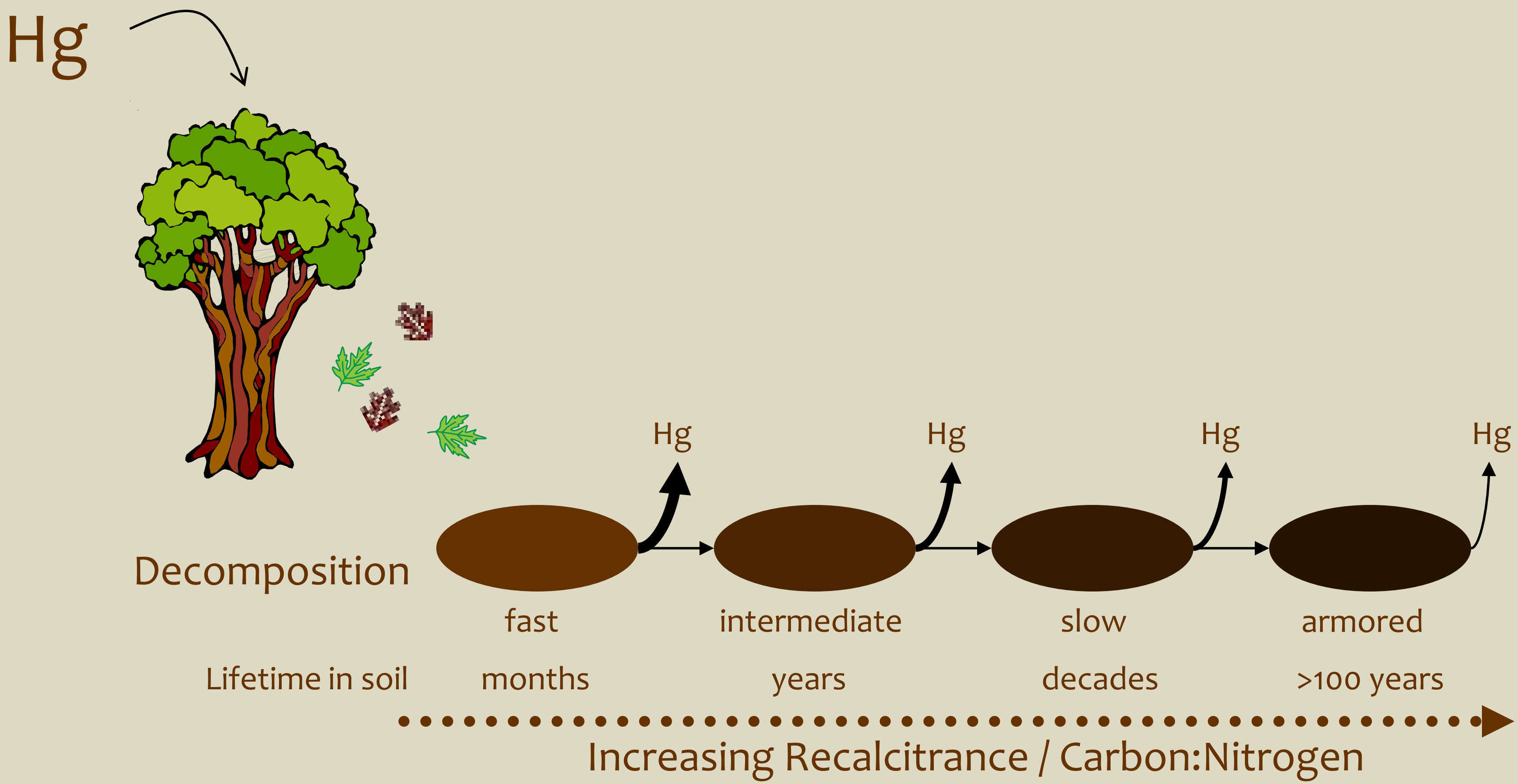


Hg and Decomposition

Kim Wickland (USGS) has been measuring Hg and CO_2 fluxes in Boreal ecosystems



Soil Carbon + Hg Dynamics In CASA



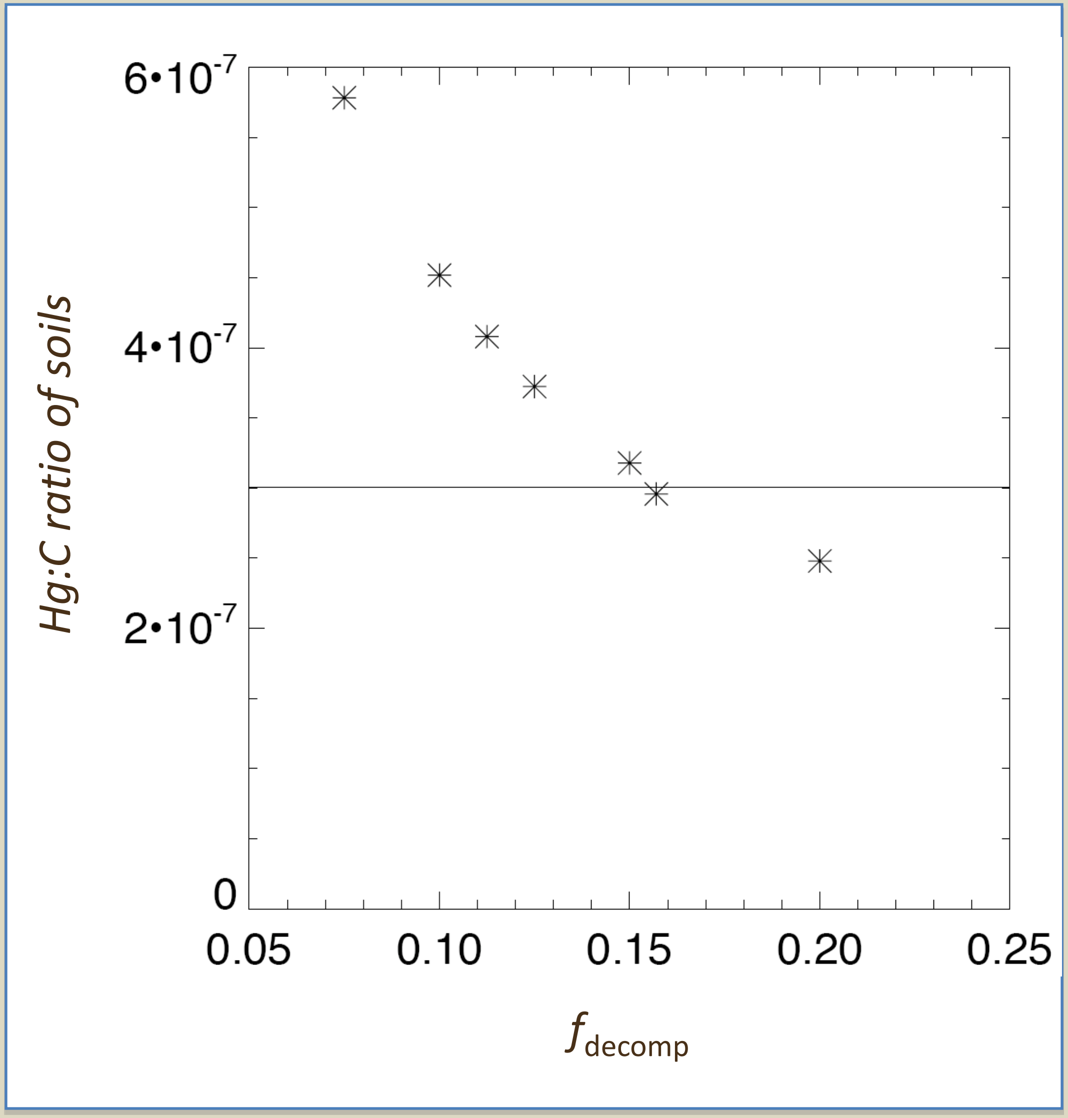
The fraction of Hg lost during decomposition f_{decomp} controls soil Hg content

But… we don't have measurements of f_{decomp}
So used observed Hg:C ratios in organic soils to estimate f_{decomp}

Adapted from Trumbore 1997

Comparison with USGS Soil

- Compared Hg:C ratio of soils in model to measurements across transect of US (USGS 2005)
- Tested a range of models with f_{decomp} ranging between 0.01 → 1.0
- $f_{decomp} = 0.16$ fit the data best



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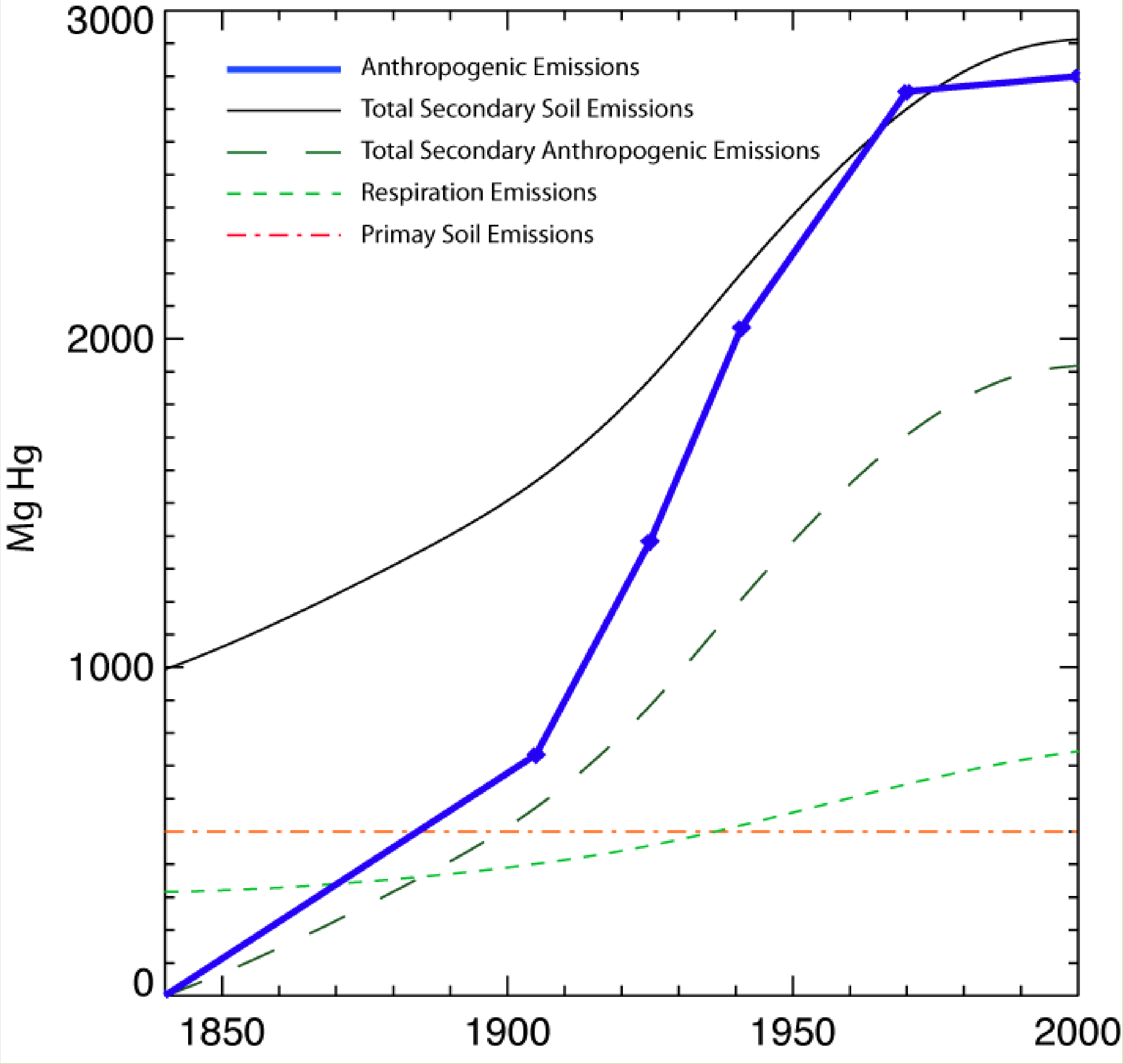
Soil Hg Emissions



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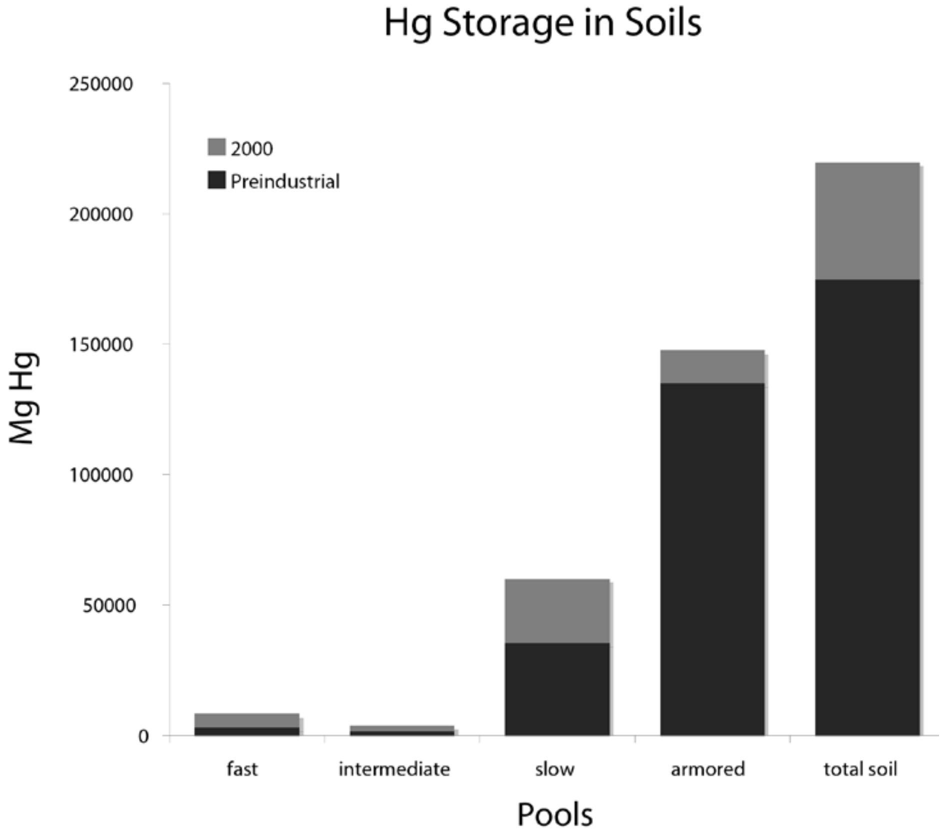
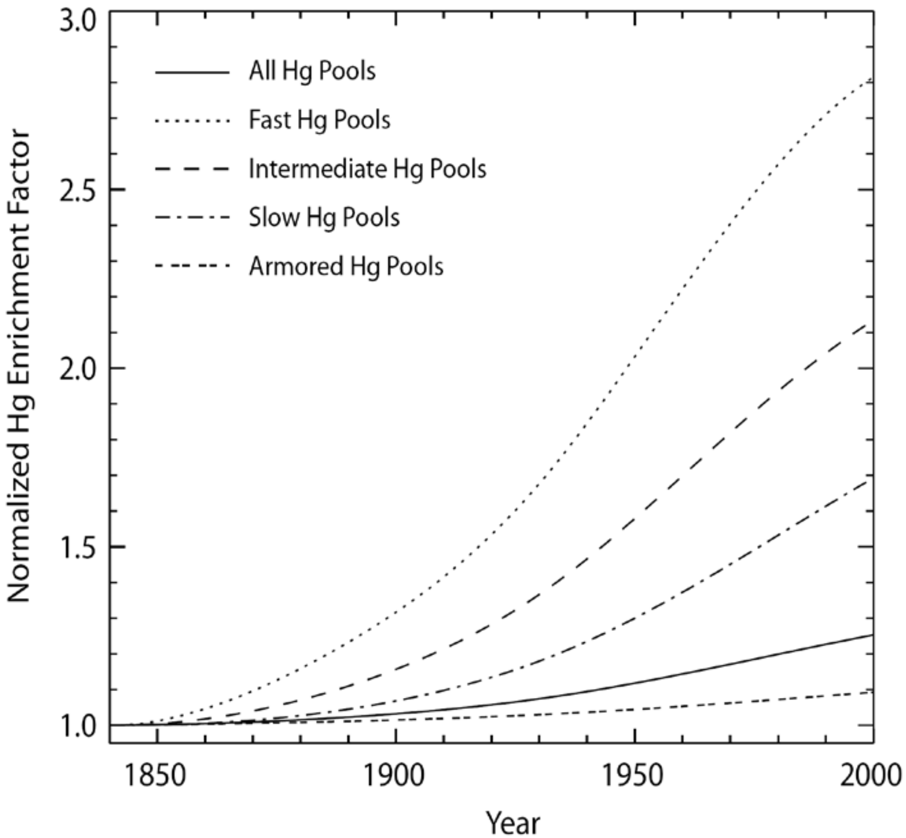
Soil Hg Storage





Can piggyback Hg simulation on existing C simulation

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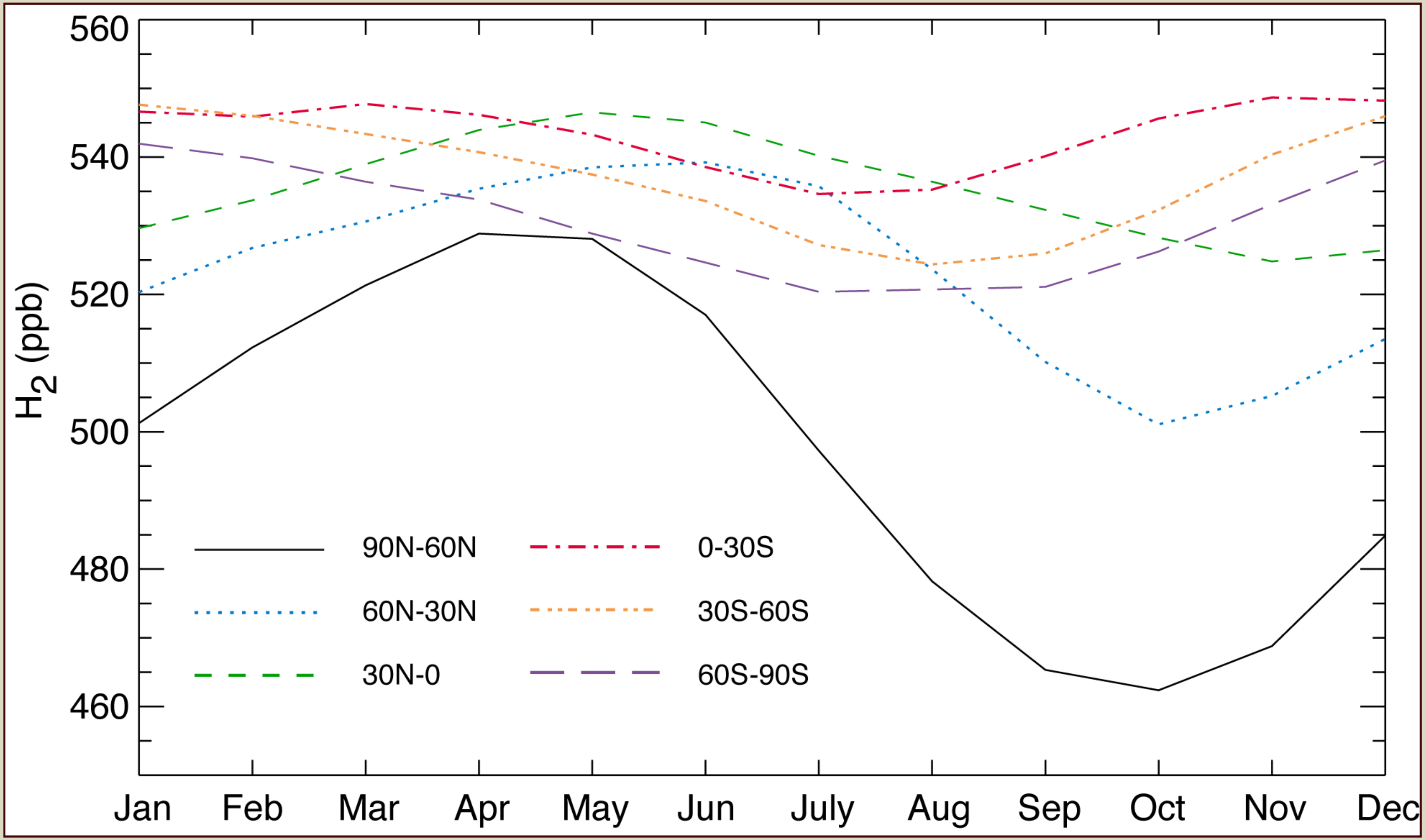
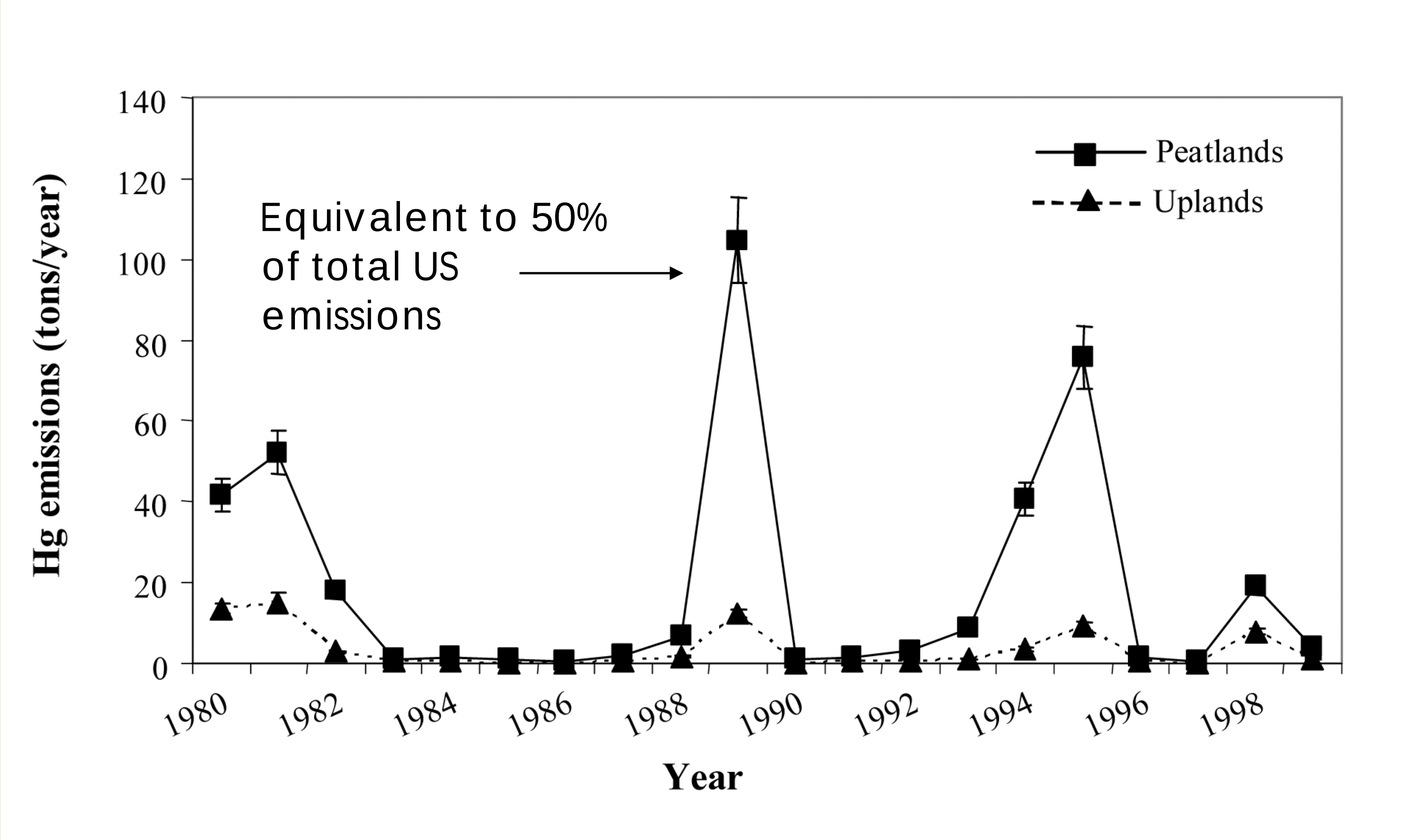
Atmospheric H_2 Record



Data from *Novelli et al.* [1999]

Hg emissions from peat fires



Turetsky 2006