An online model for air-sea exchange of mercury: insights for the influence of atmospheric deposition on ocean concentrations

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Mercury as an element

The only metal that is liquid at standard state, vapor as a noble gas in air.
Mercury as a Neurotoxin

Minamata Convention on mercury

- Requires best available technology for coal-fired power plants
- Mercury mining to be banned in 15 years
- Regulation of mercury use in artisanal gold mining

A Key challenge: quantify land/ocean re-emissions
Importance of air-sea exchange in global mercury cycle

Biggest reservoir for Hg

Holmes et al., 2010

Key questions so far:
1. Lack of observations
2. Flux highly uncertain
3. Driving factors/seasonal cycle unclear
Impact factors for air-sea exchange of mercury

Soerensen et al., 2014
A brief history of air-sea exchange models


- 2-box model
- 3-box model
- 14-box model
- 3d offline model
- 2d slab model
Develop an online air-sea exchange model for mercury
Interpret cruise observations
Explore driving factors for air-sea exchange
Models

V9-02 (Horowitz et al, 2017)
4x5 resolution, 47 layer
GEOS5 (2008-2013)
Hourly time step

V1.27 (Zhang et al, in prep)
1x1 resolution, 50 layer
Hourly time step

Hg\text{II} deposition flux,
Atmospheric Hg\text{0} concentration

Net Hg\text{0} evasion flux

Regrider

MITgcm
Results

- Air-sea exchange is highly episodic, influenced by cyclone
- Resolution dependent: 1x1 is ~10% than 4x5 model

01-Jan-2014, Hg0 Evasion, kg m\(^{-2}\) s\(^{-1}\)
Comparison with observations: tropical ocean

Sorensen et al. 2014

Hg0 air, ng/m3

Hg0 aq, pM

Observation
Offline model
Online model
Comparison with observations: tropical ocean

Wang and Xie et al. in prep
Comparison with observations: Southern Ocean

Dec, 2014 – Jan, 2015

Wang et al. 2017
Hg0aq vs instantaneous precipitation

Precipitation over May 4, 2009 18:00 2°S (peak time)

Hg0aq data well correlated with instantaneous 6-hour precipitation data
Deposition as wet or dry

Model underestimates high concentration peaks but overestimates lower concentration regions:

**Hg\textsuperscript{II} wet deposition**
- Convective rain scavenging
  - Bias low tropical Pacific & Atlantic
  - Bias high or okay at Middle and high latitudes

**Hg\textsuperscript{II} dry deposition**
- Loss via sea salt & gas/particle partitioning
  - Double counting
  - Rate-limited & instant equilibrium
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Nonlinearity in piston velocity calculation

4x5 resolution

0.7x0.7 resolution
Air-sea exchange of mercury

- Multiple pathways: gas exchange, bubbles, spray
- Gas exchange: controlled by concentration gradient
- Piston velocity: influenced by wind speed, wave, etc. \( \alpha U^2 \)

Mathematical model:

\[
F = k_w(C_{air} - C_{water}/H)
\]

- \( F \): Exchange flux
- \( k_w \): Piston velocity
- \( C \): [Hg\(^0\)]
- \( H \): Henry’s Law constant
Correlation between rain and HgOaq

\[ y = 38.29x + 0.0375 \]

\[ R^2 = 0.5209 \]
Scale deposition flux (4x5) by instantaneous rain (1x1) data?