Present-day sources and past variability of mercury in the Arctic atmosphere and ocean

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ACCESS XII
25-27 July 2013
Methylmercury is a potent neurotoxin that bioaccumulates in marine food webs.

High mercury concentrations have been observed in Arctic species that make up traditional northern diets.

Atmospheric transport brings mercury to the Arctic, but atmosphere-ocean cycling is uncertain.

**Goal:**
Understand the factors contributing to elevated mercury in the Arctic atmosphere & ocean
The atmosphere-ocean mercury cycle - an Arctic perspective

Mid-latitudes

Arctic

Hg\(_0\) \rightleftharpoons Hg^{\text{II}}

Geogenic \hspace{1cm} \text{Anthropogenic} \hspace{1cm} \text{Biomass burning} \hspace{1cm} \text{Vegetation, soil, snow}

Soil \hspace{1cm} Ocean surface \hspace{1cm} Snow/ice

Ocean subsurface
The atmosphere-ocean mercury cycle - an Arctic perspective

Mid-latitudes

Geogenic
Anthropogenic
Biomass burning
Vegetation, soil, snow

Hg$^0$ → Hg$^{II}$

Arctic

Snow/ice

Hg$^{II}$ → Hg$^0$

Ocean surface

Ocean subsurface
The atmosphere-ocean mercury cycle - an Arctic perspective

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Arctic

Geogenic | Anthropogenic | Biomass burning | Vegetation, soil, snow

Ocean surface

Snow/ice

Ocean subsurface

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Mid-latitudes

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Geogenic, Anthropogenic, Biomass burning, Vegetation, soil, snow

Ocean surface

Hg$^0$, Hg$^{II}$

Snow/ice

Ocean subsurface

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The unique seasonal cycle of Arctic mercury

Observations: multi-year mean over three Arctic sites (Alert, Amderma, Zeppelin)

Can we explain the summer peak using our standard understanding of mercury cycling?
The GEOS-Chem biogeochemical mercury model:

- Global, gridded model
- Driven by input meteorology from an assimilated GCM
- 3-D atmosphere: emissions, chemistry, transport, and deposition
- 2-D slab ocean mixed layer: chemistry, evasion, subsurface mixing and export
- Cryospheric processes: AMDEs, snowpack re-emission, snowmelt delivery to ocean

Represents our best *a priori* understanding of mercury sources & processes
Testing our current understanding: model comparison to atmospheric observations

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Observations: multi-year mean over three Arctic sites

Model: GEOS-Chem at these sites in 2008
We test hypotheses using model sensitivity simulations

Atmospheric transport, snowpack processing, ocean chemistry cannot explain peak.
We test hypotheses using model sensitivity simulations

With a large river / coastal erosion source included, GEOS-Chem can reproduce the observed summer peak — a promising hypothesis, but more data are needed!
Factors affecting Arctic mercury have changed dramatically

Streets et al. (2011)

Hg emissions growth: 1979-2010

Air temperature change: 1979-2010

May sea ice extent trend: 1979-2010

What are the implications for past — and future — variability in Arctic Hg?
Combined model-observation analysis lends insight

1. 30-year GEOS-Chem simulation of Arctic Hg (1979-2008)

2. Evaluated by long-term atmospheric observations
   - Alert, Canada (1995-2008)
   - Zeppelin, Ny Ålesund (2000-2008)
   - Pallas, Finland (1996-2008)

3. Extended to simulation of surface ocean, where long-term records unavailable
We use interannual variability to identify drivers of change

Focus on unique Arctic signatures in spring and summer

Spring-summer trends are negligible, but IAV is large in observations & model
Atmospheric Hg variability governed by a combination of meteorological drivers

Impacts of high T + low sea ice + high radiation + shallow PBL

Environmental drivers of IAV identified using a principal component analysis (PCA).

Dominant mode explains 80% IAV in spring, 43% in summer.
Surface ocean mercury driven by snowmelt & rivers

Arctic ocean mercury and IAV peak in summer

No trends in surface ocean mercury
Surface ocean mercury driven by snowmelt & rivers

Arctic ocean mercury and IAV **peak in summer**

**No trends** in surface ocean mercury

**Surface ocean inputs increase with:**
- **Meltwater**
  - ↑ summer solar radiation (↓ cloudiness)
  - ↑ spring-summer T difference = ΔT
- **Rivers**
  - ↑ May river flow
- **Deposition**
  - ↑ summer wind speed
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Arctic ocean mercury and IAV peak in summer

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GCMs predict future ↑ cloudiness & ↓ ΔT → less Hg may be added to the Arctic Ocean in future!