Drivers of mercury variability in the Arctic atmosphere and surface ocean: impacts of changing climate and emissions

Jenny A. Fisher¹ (jennyf@uow.edu.au), Anne L. Soerensen², Daniel J. Jacob², Helen M. Amos², Elizabeth S. Corbitt³, David G. Streets³, Qiaqiao Wang², Robert M. Yantosca², Elsie M. Sunderland²

¹University of Wollongong, Australia; ²Harvard University & Harvard School of Public Health, USA; ³Argonne National Laboratory, USA

SUMMARY

Long-term observations at Arctic sites (Alert and Zeppelin) show large interannual variability (IAV) in atmospheric mercury (Hg), implying a strong sensitivity to environmental factors and potentially to climate change. We use the GEOS-Chem global biochemical Hg model to interpret these observations and identify the principal drivers of spring and summer IAV in the Arctic from 1979-2008.

We find the model has moderate skill in simulating the observed atmospheric IAV at the two sites (r = 0.4) and successfully reproduces a long-term shift at Alert in the timing of the spring minimum from May to April (r = 0.7). Principal component analysis indicates that IAV in the model can be explained by a climate mode with high temperatures, low sea ice fraction, low cloudiness, and shallow boundary layer. This mode drives decreased bromine-driven deposition in spring and increased ocean evasion in summer. In the Arctic surface ocean, we find that modeled IAV is dominated by the meltwater flux of Hg previously deposited to sea ice, which is largest in years with high solar radiation (low cloudiness) and a large transition in air temperature from a cold spring to a warm summer. Projected future increased cloudiness and stronger warming in spring than summer may thus lead to decreased Hg inputs to the Arctic Ocean.

30-year Arctic Hg simulation

The GEOS-Chem global biochemical Hg model (v9-01-02) was run from 1979-2008, driven by meteorology from the MERRA reprocessed assimilated dataset at 4x5° horizontal resolution. Anthropogenic emissions are based on the Streets et al. (2011) inventory. The Arctic simulation is based on Fisher et al. (2012) with minor updates to bromine release, net primary productivity, UV-driven oceanic photooxidation, and freshwater discharges.

Factors driving interannual variability

We performed a principal component analysis and regression to identify the environmental factors driving IAV of atmospheric Hg. Environmental variables considered were: temperature (T, T_s), sea ice fraction (f_s), planetary boundary layer height (h_p), solar radiation (F), wind speed (v), ozone column (O_3), freshwater discharge (Q), and Arctic Oscillation Index (AOI).

Trends and interannual variability

• No long-term observations exist for Hg in the Arctic surface ocean. The GEOS-Chem model is consistent with present-day observations.
• The simulation shows no trends but large IAV in surface ocean Hg. Both concentrations and IAV peak in summer.

References

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Appendix: We performed a principal component analysis and regression to identify the environmental factors driving IAV of atmospheric Hg. Environmental variables considered were: temperature (T, T_s), sea ice fraction (f_s), planetary boundary layer height (h_p), solar radiation (F), wind speed (v), ozone column (O_3), freshwater discharge (Q), and Arctic Oscillation Index (AOI).

 Current and projected future changes associated with changing climate (high air temperatures, low sea ice area, stronger warming in spring, and high cloudiness) may decrease Hg levels in the Arctic Ocean.

• The first principal component (climate mode) was the same in spring and summer. Positive phases indicate “warm” years.
• This mode accounts for 80% of the IAV in simulated Hg in spring and 40% in summer. It is also moderately correlated with IAV in the observations (r = 0.4).
• Positive (“warm”) phases increase atmospheric Hg in both spring and summer, although the mechanisms differ.

• Simulated IAV in surface ocean Hg is dominated by IAV in the meltwater flux.
• The meltwater flux is largest in years with high solar radiation (low cloudiness) and when a cold spring (f_s) is followed by a warm summer (rapid melt limiting re-emission from snow).
• These variables combined with May river discharge and surface wind speed can explain 53% of the IAV in simulated surface ocean Hg in summer.