Modeling the Transport and Deposition of Atmospheric Mercury to the Great Lakes (and the Chesapeake Bay)

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**Goal:** Estimate impacts of *each emissions source* on receptors of interest (e.g., Great Lakes, Chesapeake Bay, etc.) under past, present, and future emissions regimes

**Why?** In order to evaluate reduction strategies, it's obviously useful to know the relative importance of different sources, source types, and source regions
Modeling Methodology
Figure 1. Lagrangian Puff Air Transport and Deposition Model

- **TIME (hours)**: 0, 1, 2, ...

- **Mass of pollutant**: decreases as destruction and deposition occur each time step.

- **Centerline of puff motion**: determined by wind direction and velocity.

- **Photolytic and chemical transformation of pollutant**: also estimated at each time step.

- **Initial puff location**: is at source, with initial mass & size.

- **Total deposition**: from a puff during a given time step is calculated from the sum of the estimated dry and wet deposition of gas and particle-phase material, based on pollutant cons. in the puff, the local weather, and the nature of the surface.

- **Deposition 1**

- **Deposition 2**

- **Deposition to lake**

- **Puff’s mass, size, and location**: continually tracked...
Over the entire modeling period (e.g., one year), puffs are released at periodic intervals (e.g., once every 7 hours).

Each released puff is advected and dispersed, and the pollutant within the puff is transformed and deposited.
• In principle, we need do this for each source in the inventory

• But, since there are more than 100,000 sources in the U.S. and Canadian inventory, we need shortcuts…

• Shortcuts described in Cohen et al. *Environmental Research* 95(3), 247-265, 2004


Note: Volume 95(3) is a Special Issue: "An Ecosystem Approach to Health Effects of Mercury in the St. Lawrence Great Lakes", edited by David O. Carpenter.
• For each run, simulate fate and transport everywhere, but only keep track of impacts on each selected receptor (e.g., Great Lakes, Chesapeake Bay, etc.)

• Only run model for a limited number (~100) of hypothetical, individual unit-emissions sources throughout the domain

• Use spatial interpolation to estimate impacts from sources at locations not explicitly modeled
Spatial interpolation

Impact of source 4 estimated from weighted average of impacts of nearby explicitly modeled sources

Impacts from Sources 1-3 are Explicitly Modeled
• Perform separate simulations at each location for emissions of pure Hg(0), Hg(II) and Hg(p)

[after emission, simulate transformations between Hg forms]

• Impact of emissions mixture taken as a linear combination of impacts of pure component runs on any given receptor
"Chemical Interpolation"

Impact of Source Emitting Pure Hg(0) \(0.3\) x

Impact of Source Emitting Pure Hg(II) \(0.5\) x

Impact of Source Emitting Pure Hg(p) \(0.2\) x
Mercury Emissions Inventory
Estimated 2000 Canadian Atmospheric Anthropogenic Mercury Emissions

Canadian Atmospheric Mercury Emissions (metric tons/year) (~2000)
Very important to know how much of each form of mercury -- $\textit{Hg(II)}$, $\textit{Hg(p)}$, and $\textit{Hg(0)}$ -- is emitted from each source...

(this is usually very uncertain)
Emissions of Ionic Mercury (RGM) from Different Anthropogenic Source Sectors in Great Lakes States and Provinces (~1999-2000)
[Total RGM emissions = 13.4 metric tons/year]
Some Overall Results
• Modeling domain: North America

• U.S. and Canadian anthropogenic sources

• 1996 meteorology

• Model evaluation:
  • 1996 emissions
  • 1996 monitoring data

• Results: 1999 emissions
Mercury deposition at selected receptors arising from 1999 base-case emissions from anthropogenic sources in the United States and Canada (IPM coal fired plants are large coal-fired plants in the U.S. only)
Model Evaluation
Mercury Deposition Network Sites with 1996 data in the Chesapeake Bay Region
Modeled vs. Measured Wet Deposition at Mercury Deposition Network Site DE_02 during 1996

Cumulative Wet Deposition at MDN_DE_02

- **Measured**
- **Modeled**

Cumulative deposition (ug Hg/m^2)

- Jan-96
- Feb-96
- Mar-96
- Apr-96
- May-96
- Jun-96
- Jul-96
- Aug-96
- Sep-96
- Oct-96
- Nov-96
- Dec-96
Modeled vs. Measured Wet Deposition at Mercury Deposition Network Site MD_13 during 1996

Cumulative Wet Deposition at MDN_MD_13

- Measured
- Modeled
Intercomparison Study of Numerical Models for Long-Range Atmospheric Transport of Mercury

Stage II. Comparison of modeling results with observations obtained during short-term measuring campaigns

Technical Report 1/2003

Comparison of measured vs. modeled TPM
Zingst

- Measured
- Modeled (background = 0)
- Modeled (with background)
• Models can be extremely useful, e.g., maybe the only way to develop comprehensive source receptor relationships…

  • *But we know the models are not perfect…*

• When simulations don’t agree with measurements, what is reason?

  • *There can be errors in simulation of*

    • emissions
    • meteorology
    • dispersion
    • atmospheric chemistry
    • wet and dry deposition

  • How to tease out the most important reasons for discrepancies?
• How to tease out the most important reasons for discrepancies?

• Critical to have sufficient data for model evaluation
  • Mercury Deposition Network very useful!
  • need network for ambient concentrations of RGM, Hg(p), Hg(0)
  • also -- data at different heights in the atmosphere
  • also – identification and quantification of individual RGM species

• Model intercomparison studies can be extremely useful
  (why are they so hard to get funding for?)

• Does a model have to be perfect in order to be useful?
  (No, often just need qualitatively reasonable results…)

Most if not all data and information used in decision-making has uncertainties – public health impacts, economic impacts (why do we demand perfection of models?)
1999 Results for Chesapeake Bay
Geographical Distribution of 1999 Direct Deposition Contributions to the Chesapeake Bay (entire domain)
Geographical Distribution of 1999 Direct Deposition Contributions to the Chesapeake Bay (regional close-up)
Geographical Distribution of 1999 Direct Deposition Contributions to the Chesapeake Bay (local close-up)
Emissions and Direct Deposition Contributions from Different Distance Ranges Away From the Chesapeake Bay
Largest Regional Individual Sources Contributing to 1999 Mercury Deposition Directly to the Chesapeake Bay
Largest Local Individual Sources Contributing to 1999 Mercury Deposition Directly to the Chesapeake Bay
Top 25 Contributors to 1999 Hg Deposition Directly to the Chesapeake Bay

Coal-fired electric generation
Other fuel combustion
Waste incineration
Metallurgical
Manufacturing/other

Cumulative Fraction of Hg Deposition
Rank

Md.
Pa.
Va.
Wv.
Nc.
De.
H.A. Wagner
Chalk Point
Morgantown
Stericycle Inc.
Brandon Shores
NASA Incinerator
Hampton/NASA Incin.
Chesapeake Energy Ctr.
Chesterfield
INWDC
INDIAN RIVER
Yorktown
Roxboro
Baltimore RESCO
Montour
Possum Point
Keystone
Homer City
Mt. Storm
Harrisburg Incin.
Belews Creek
Harford Co. Incin.
Phoenix Services
Norfolk Navy Yard
Montour
Some Next Steps

- Use more highly resolved meteorological data grid
- Expand model domain to include global sources
- Simulate natural emissions and re-emissions of previously deposited Hg
- Additional model evaluation exercises ... more sites, more time periods, more variables [Measurements underway in Chesapeake Bay region]
- Sensitivity analyses and examination of atmospheric Hg chemistry (e.g. marine boundary layer, upper atmosphere)
- Dynamic linkage with ecosystem cycling models