Evaluation of Transport and Deposition of Mercury in the Great Lakes Region

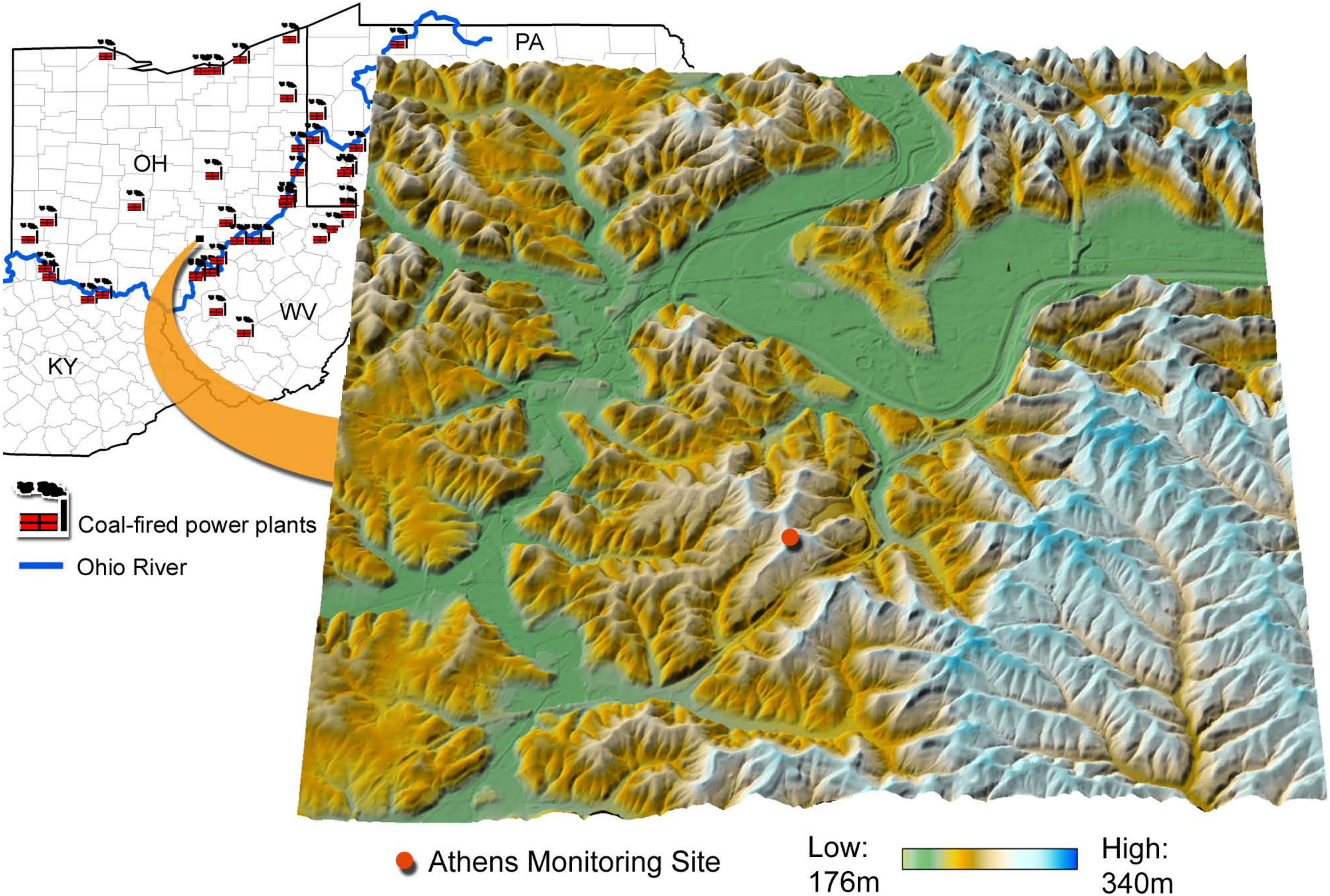
Center for Air Quality

OHIO UNIVERSITY
1804

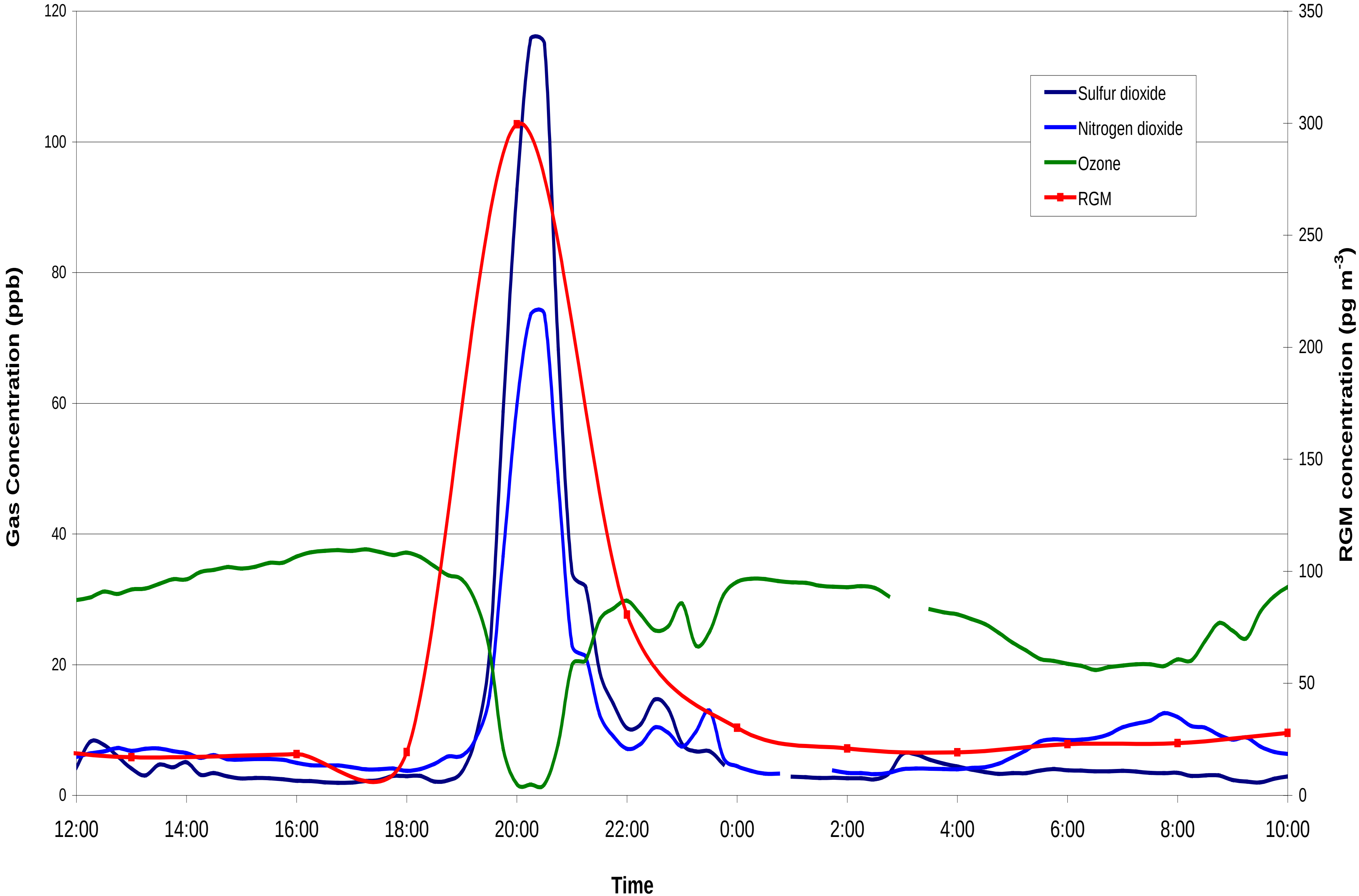
Introduction

- The Eastern United States is viewed as a major source region because of its high number of coal-fired power plants, mining activities, and industrial plants including chemical, metal smelting and manufacturing activities.
- Ohio University, in collaboration with Argonne National Laboratory are evaluating the impact of emissions from coal-fired power plants and industries in the Ohio River Valley region as they relate to the transport and deposition of mercury and other pollutants.

Ohio River Valley

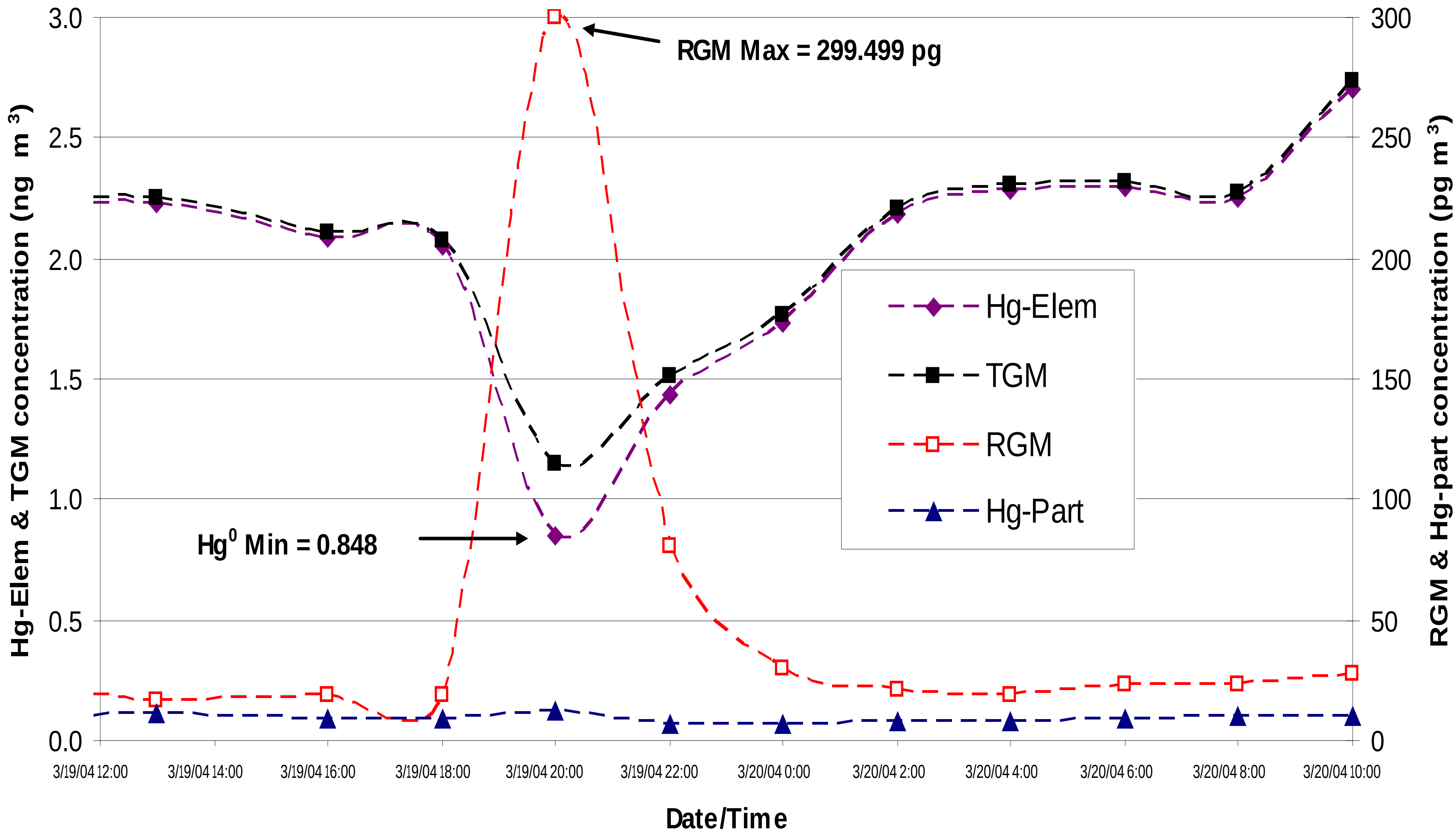


Episode 1



Sulfur dioxide
Nitrogen dioxide
Ozone
RGM
Gas Concentration (ppb)
RGM concentration (pg m^{-3})
Time
0
20
40
60
80
100
120
0
50
100
150
200
250
300
350
12:00
14:00
16:00
18:00
20:00
22:00
0:00
2:00
4:00
6:00
8:00
10:00

Episode 2

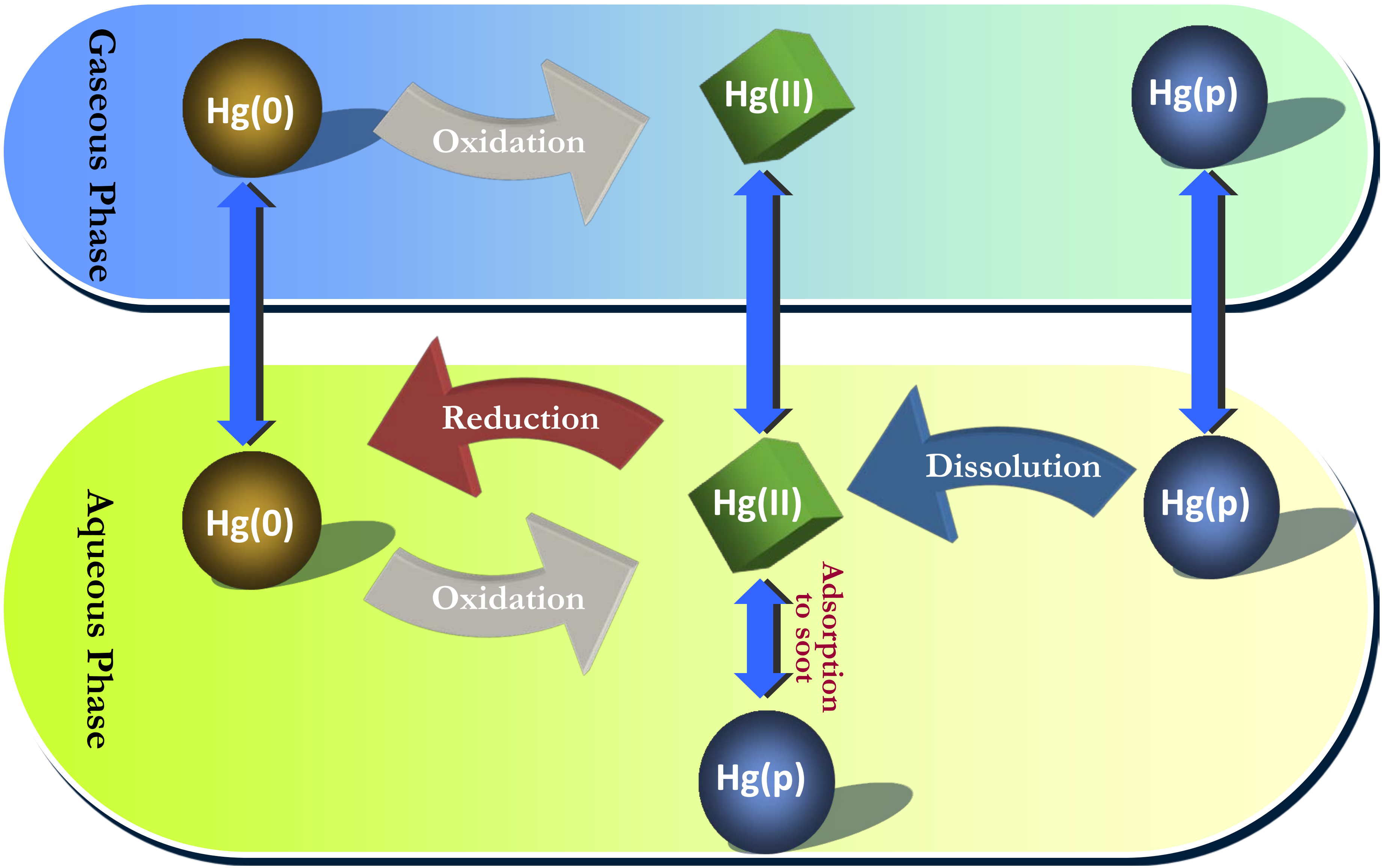


RGM Max = 299.499 pg
Hg^0 Min = 0.848
Hg-Elem
TGM
RGM
Hg-Part
Hg-Elem & TGM concentration (ng m^{-3})
RGM & Hg-part concentration (pg m^{-3})
Date/Time
0.0
0.5
1.0
1.5
2.0
2.5
3.0
0
50
100
150
200
250
300
3/19/04 12:00
3/19/04 14:00
3/19/04 16:00
3/19/04 18:00
3/19/04 20:00
3/19/04 22:00
3/20/04 0:00
3/20/04 2:00
3/20/04 4:00
3/20/04 6:00
3/20/04 8:00
3/20/04 10:00

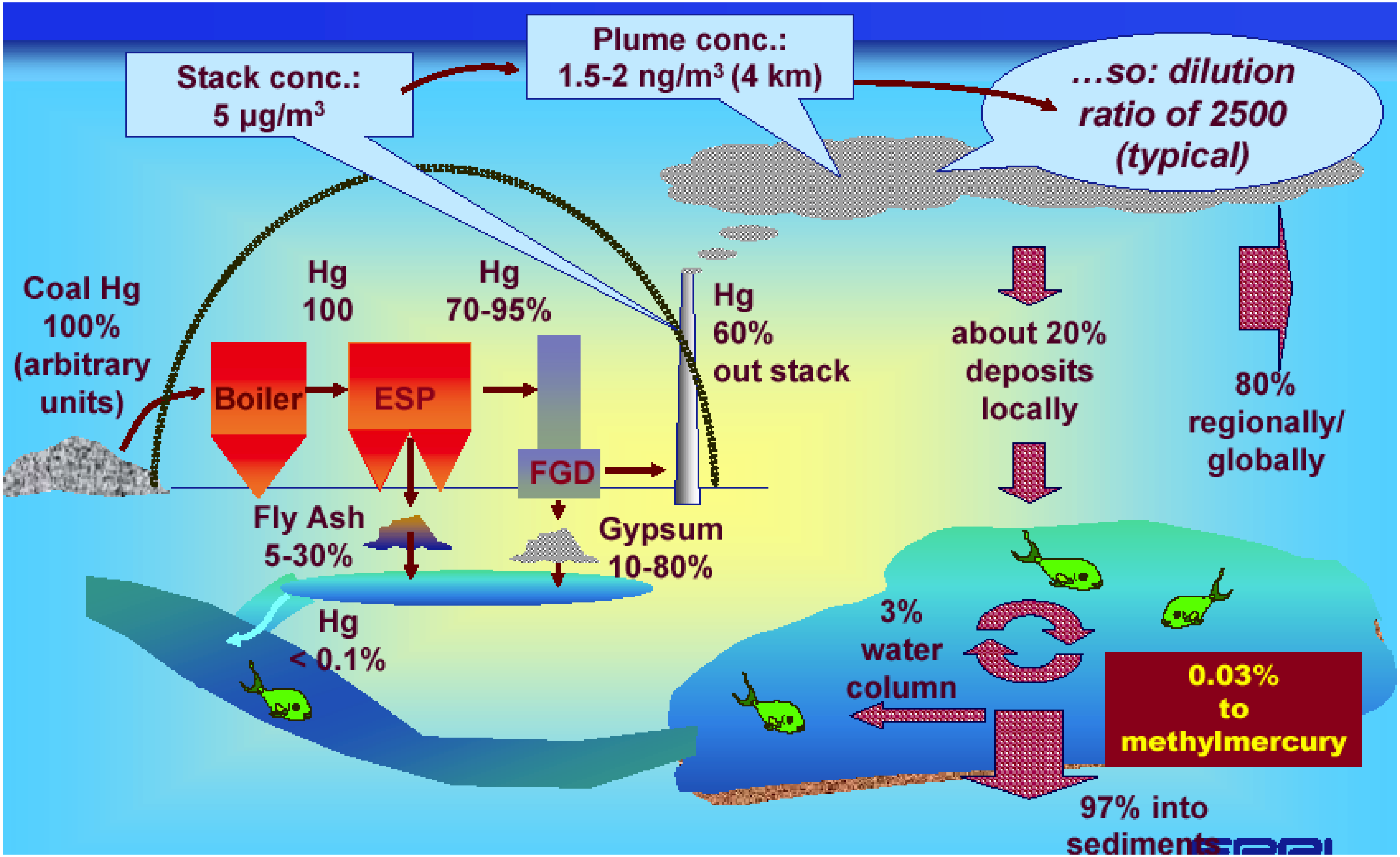
Objectives

- To evaluate transport and deposition of mercury using the chemical transport modeling, EPA Model3 (MM5-SMOKE-CMAQ)
- To improve the mercury modeling performance, detailed preparations are required to
  - improve precipitation prediction with MM5.
  - assess impact of global anthropogenic mercury emissions using global mercury modeling.

Atmospheric Chemistry of Mercury

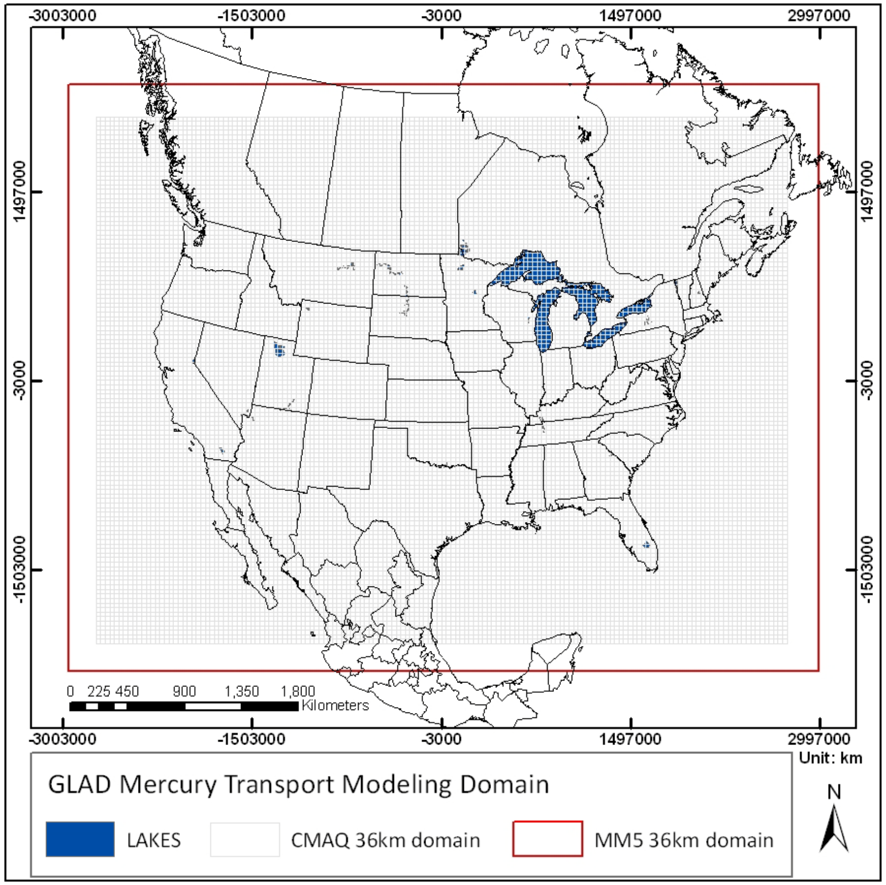


Fate of Mercury Emissions from Power Plant
-from METAALICUS and Aircraft Measurements



Source: Leonard Levin, Valuing Externalities Workshop,

Modeling Domain



- LCP at (-97, 40) and true latitudes at 33 and 45
- 23 Vertical Layers
- 36 km Domain

  (152 ×116)
- Southwest Corner

  (-2,736 km, 2,088 km)

Global Mercury Modeling

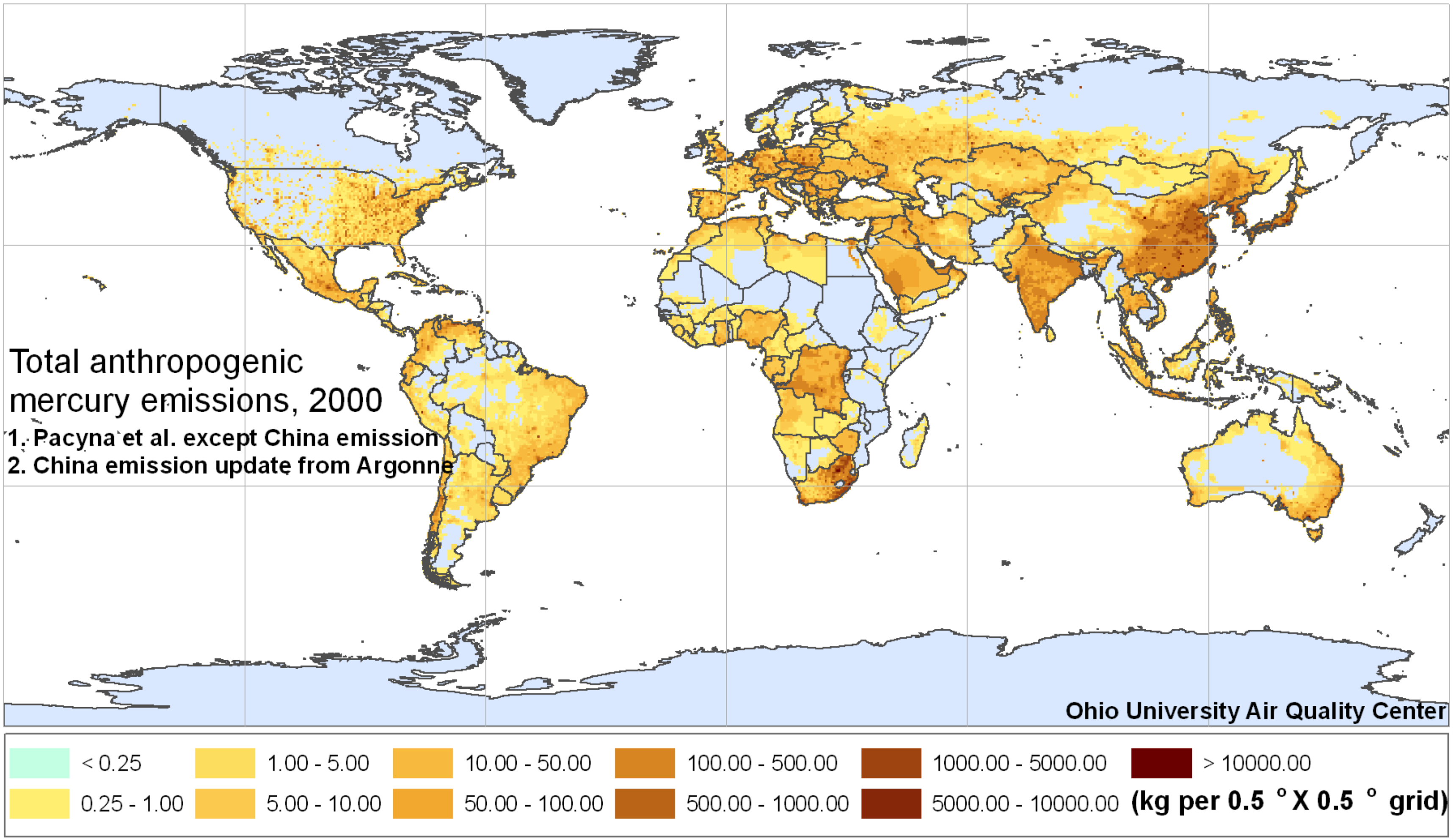
Model for Ozone and Related Chemical Tracers (MOZART)

– a global chemical transport model particularly suited for studies of the troposphere (Emmons et al, 2009).
– provides spatial and temporal distributions for 52 chemical tracers, with a chemistry scheme similar to the one described by Brasseur et al. [1998]
– modified to include mercury chemistry

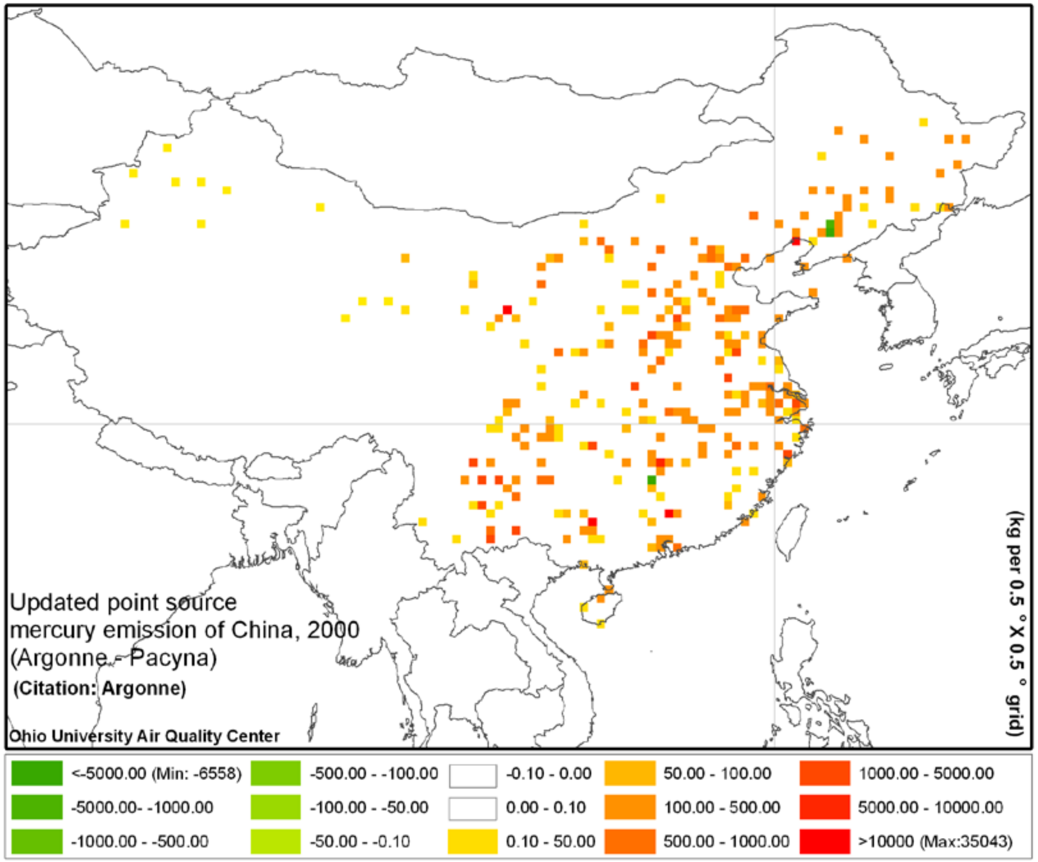
Global Mercury Modeling

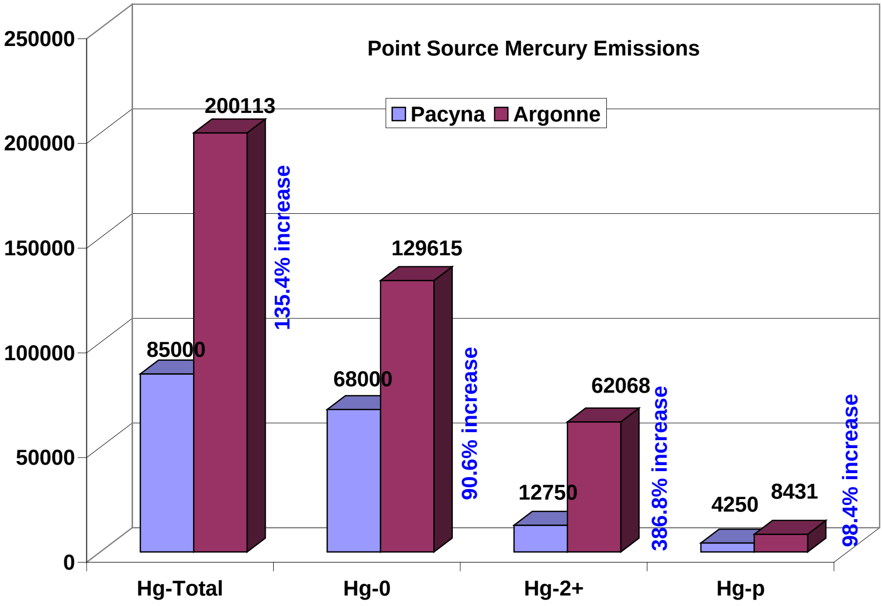
- Argonne national laboratory has updated China emissions of mercury species for point source and distributed emissions (area emissions) for 2000.
- These emission inventories with revised China emissions are currently being used in MOZART 3D global modeling to provide temporal variability of initial and background concentration for regional mercury transport modeling.

Revised Global Anthropogenic Mercury Source



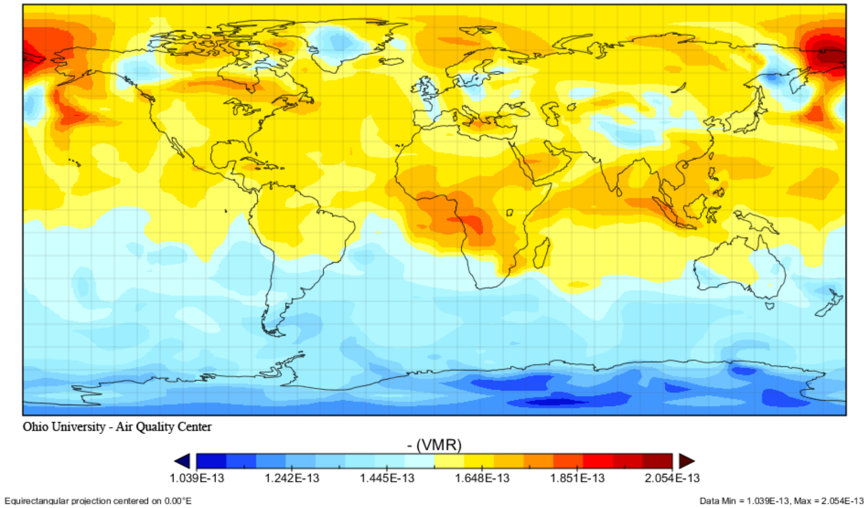
Updated China Point Sources



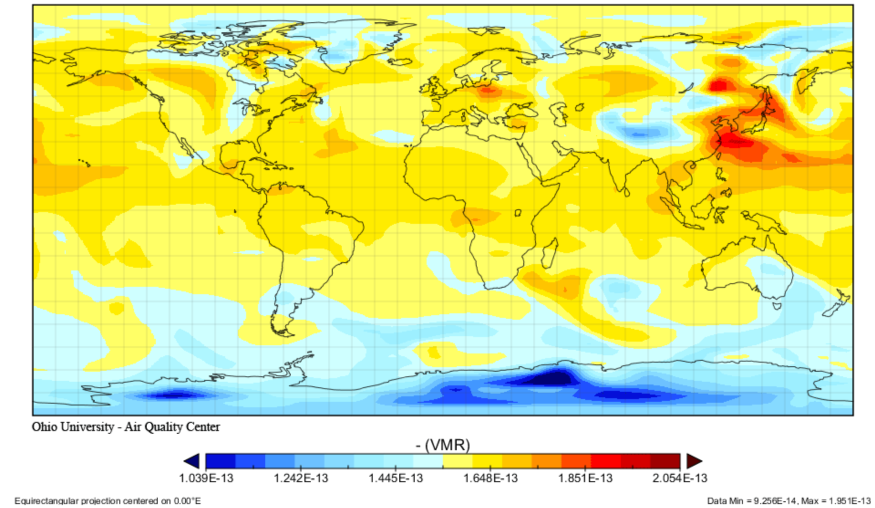


Seasonal Variation of Elemental Mercury

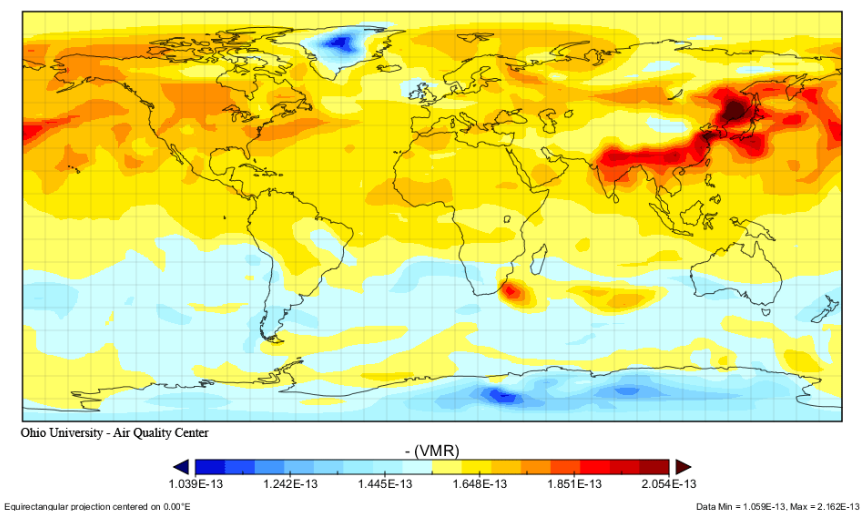
January 1, 2004



May 1, 2004



July 1, 2004



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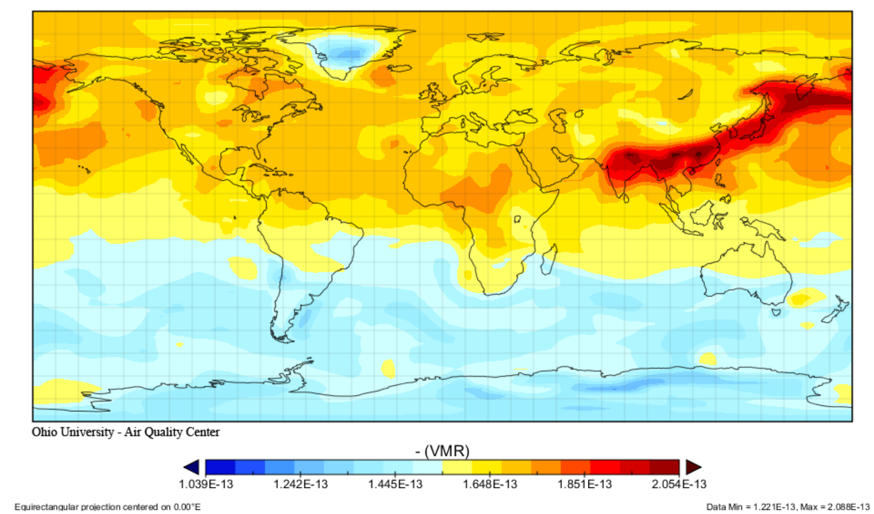
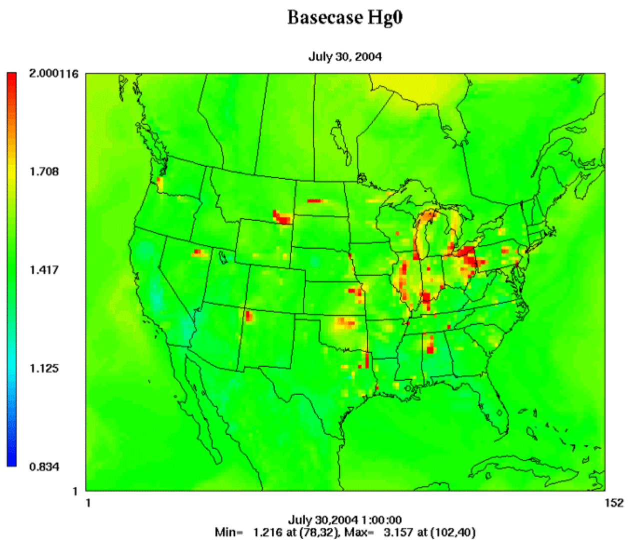
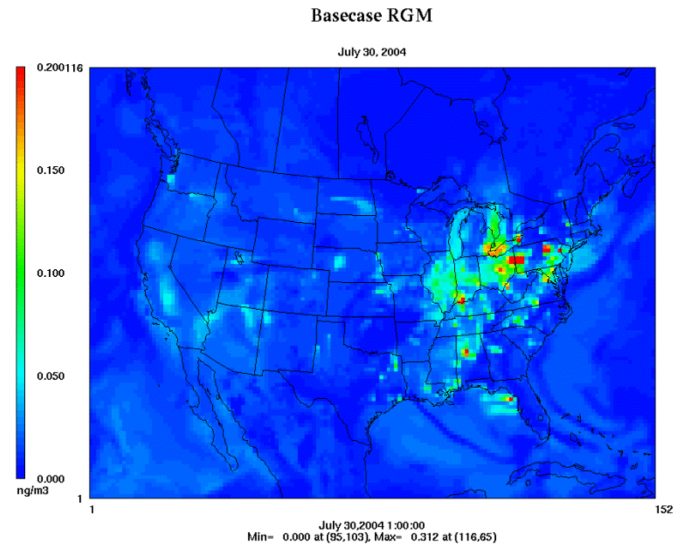


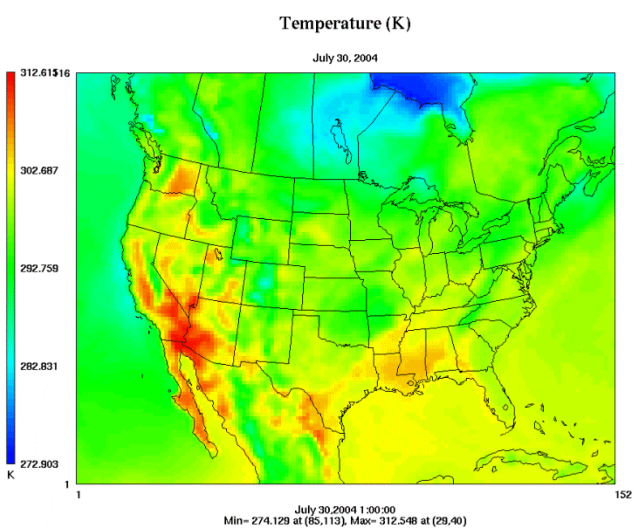
Chemical Transport Modeling

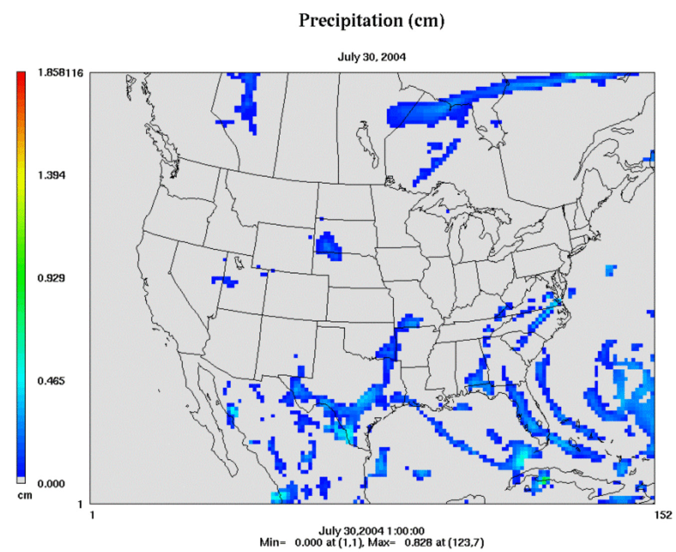
- MODELS3 (MM5-SMOKE-CMAQ4.6)
  - 36km resolution116x152 grid system covering North America
- MM5
  - FDDA utilized to improve precipitation
- SMOKE
  - SMOKE2.5
    - Point sources : IPM (power generating utilities) and Non-IPM
- CMAQ4.6
  - MOZART results were provided to provide background concentration (BC) and Initial concentration (IC) for CMAQ

Base Case Results of Chemical Transport Modeling

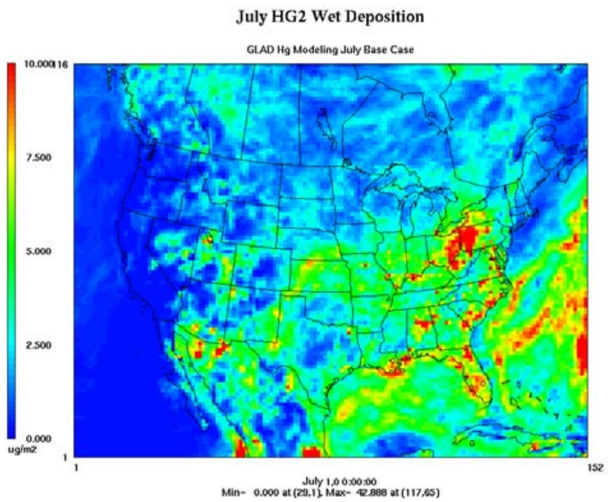


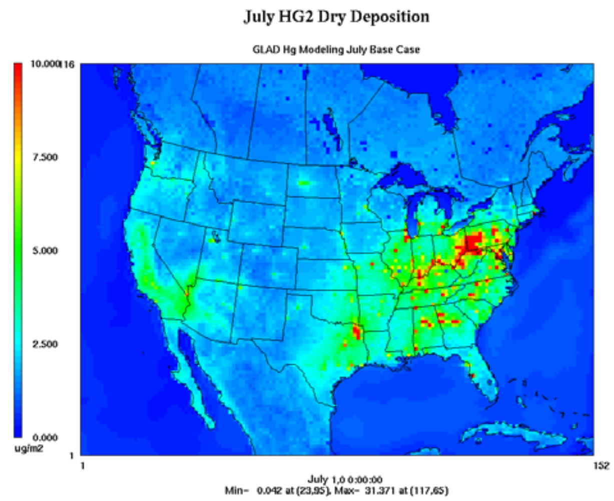


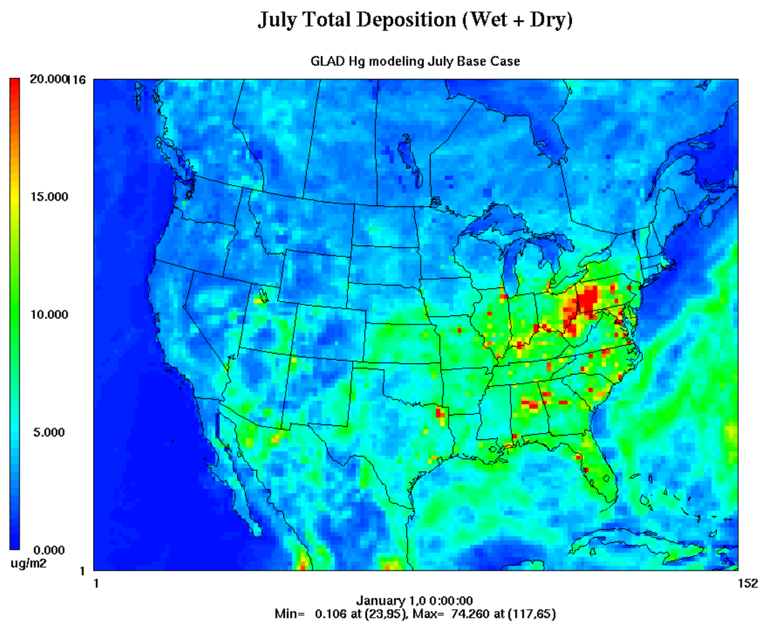




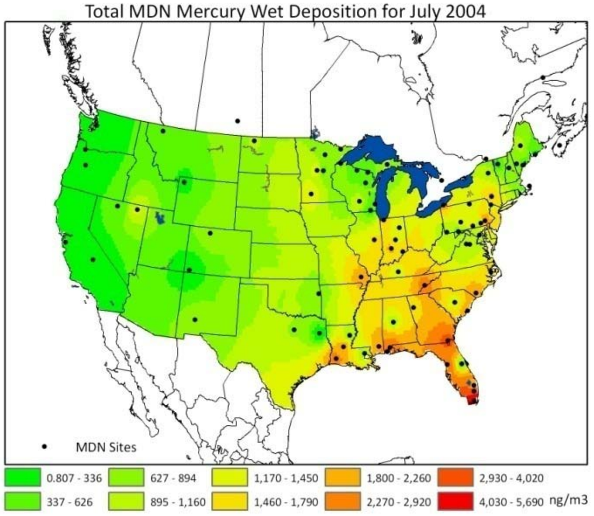
Base Case Results of Chemical Transport Modeling

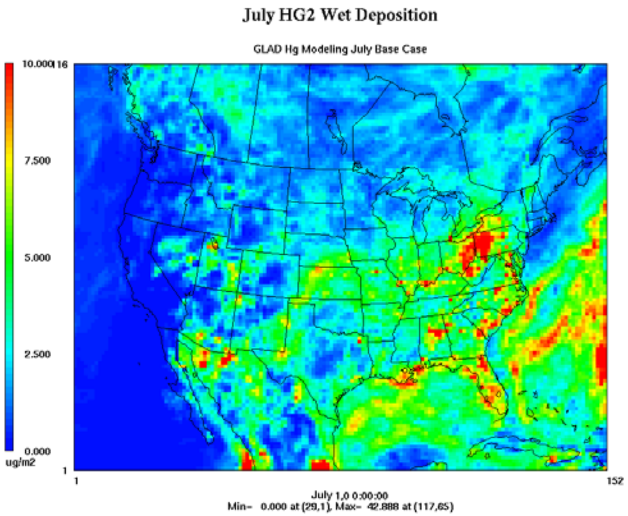


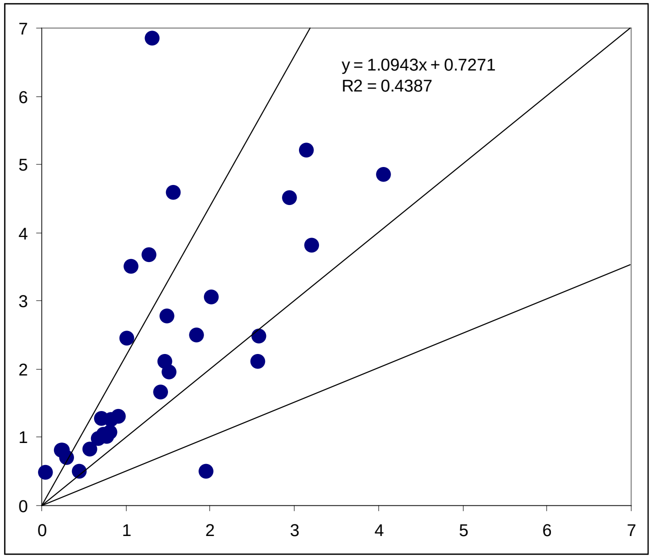




Base Case Results
Comparison with Observations

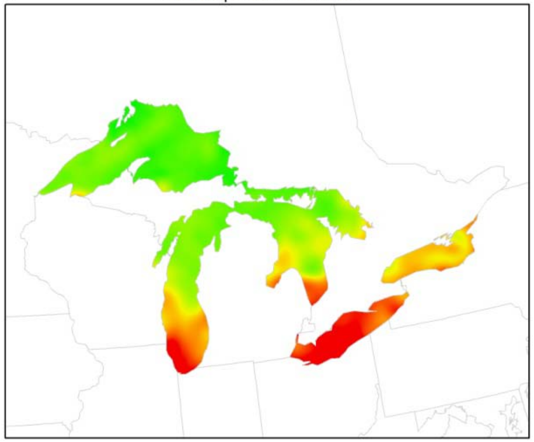




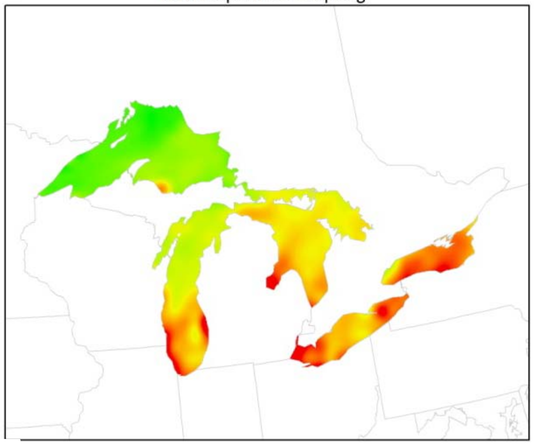


Sensitivity Results – IPM sources zero-out

Average % Contribution of IPM Utilities to Total Deposition in Winter



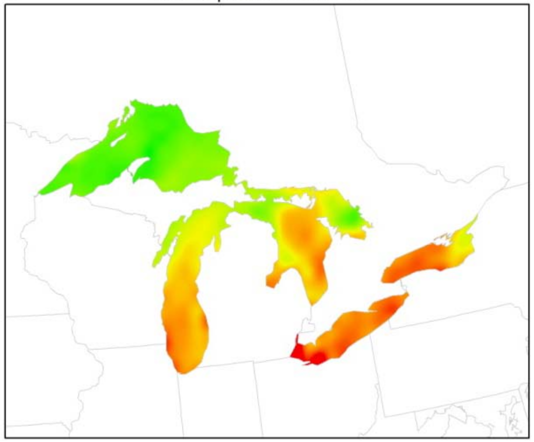
Average % Contribution of IPM Utilities to Total Deposition in Spring



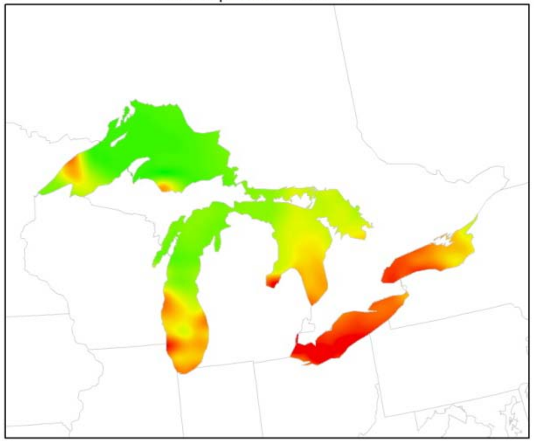
High 80.4%

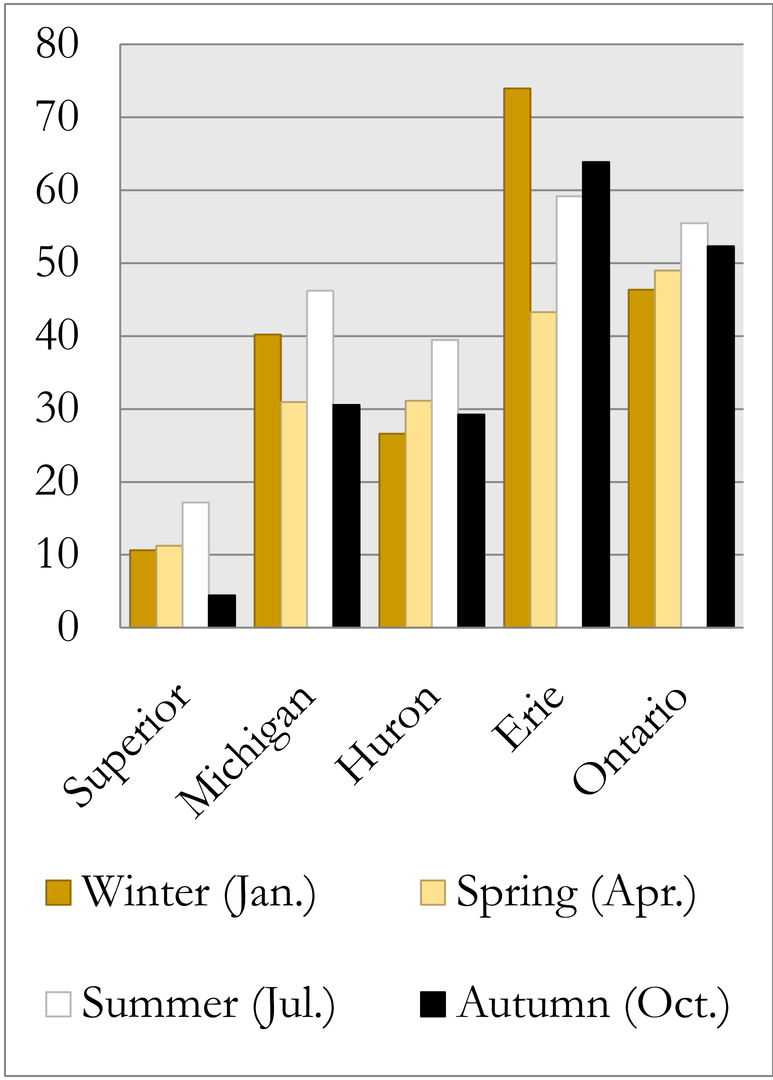
Low 2.6%

Average % Contribution of IPM Utilities to Total Deposition in Summer

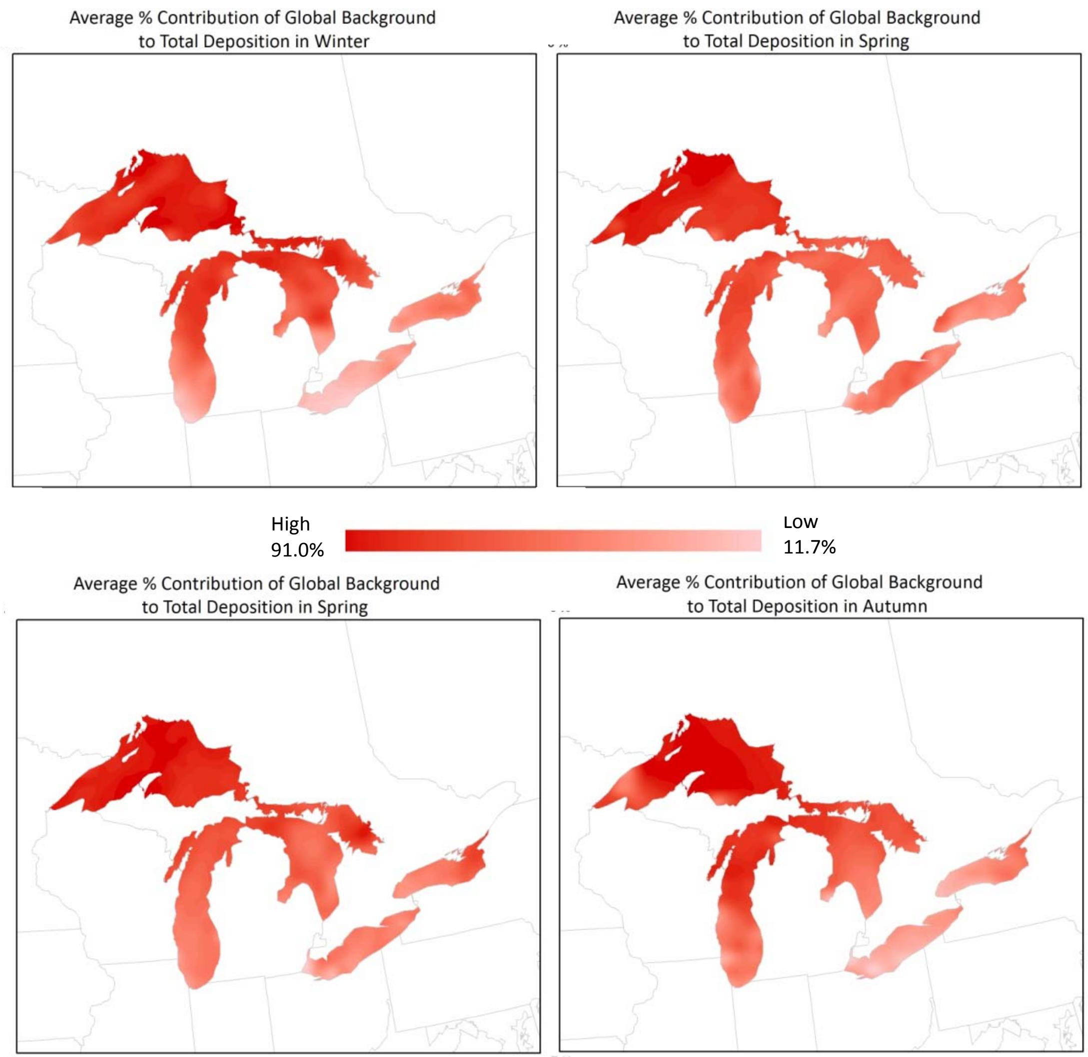


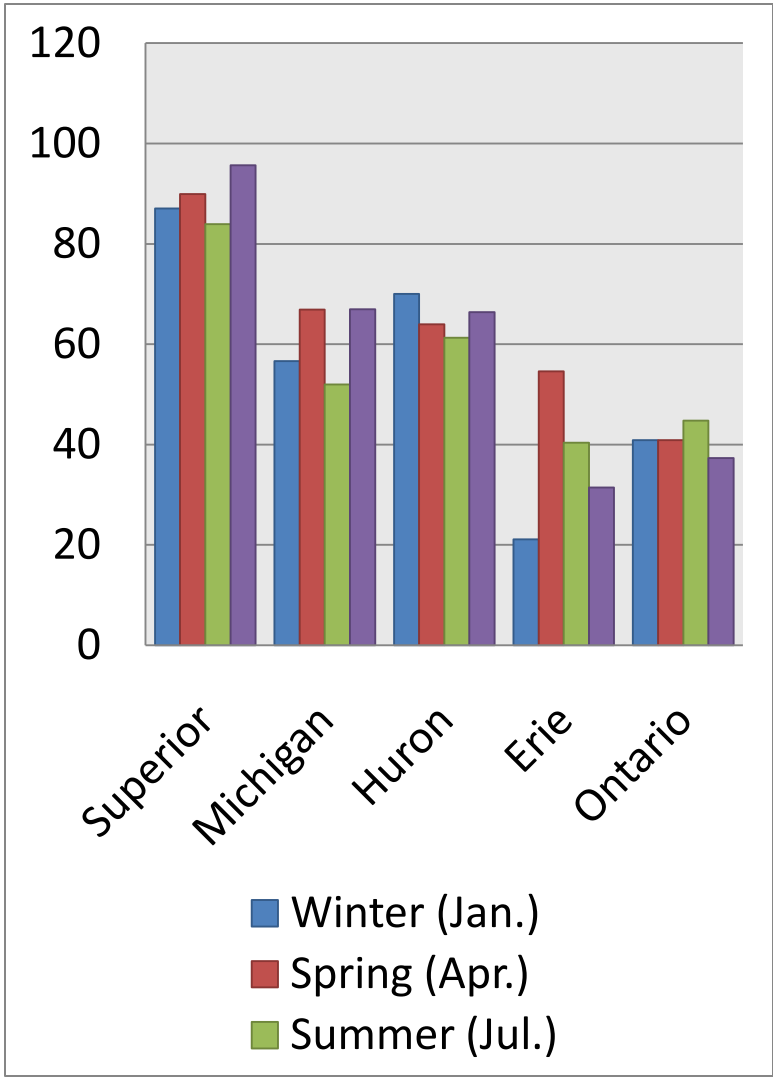
Average % Contribution of IPM Utilities to Total Deposition in Autumn



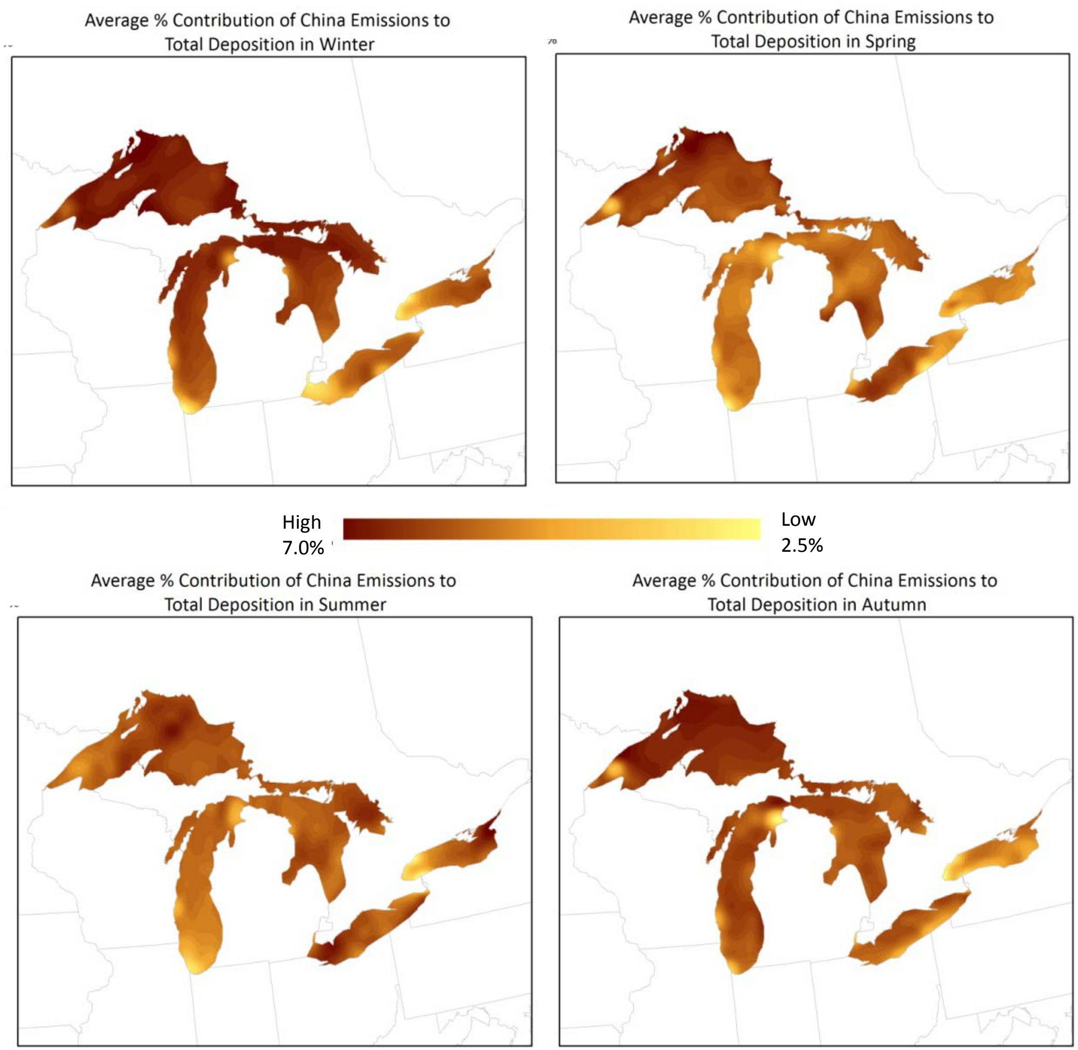


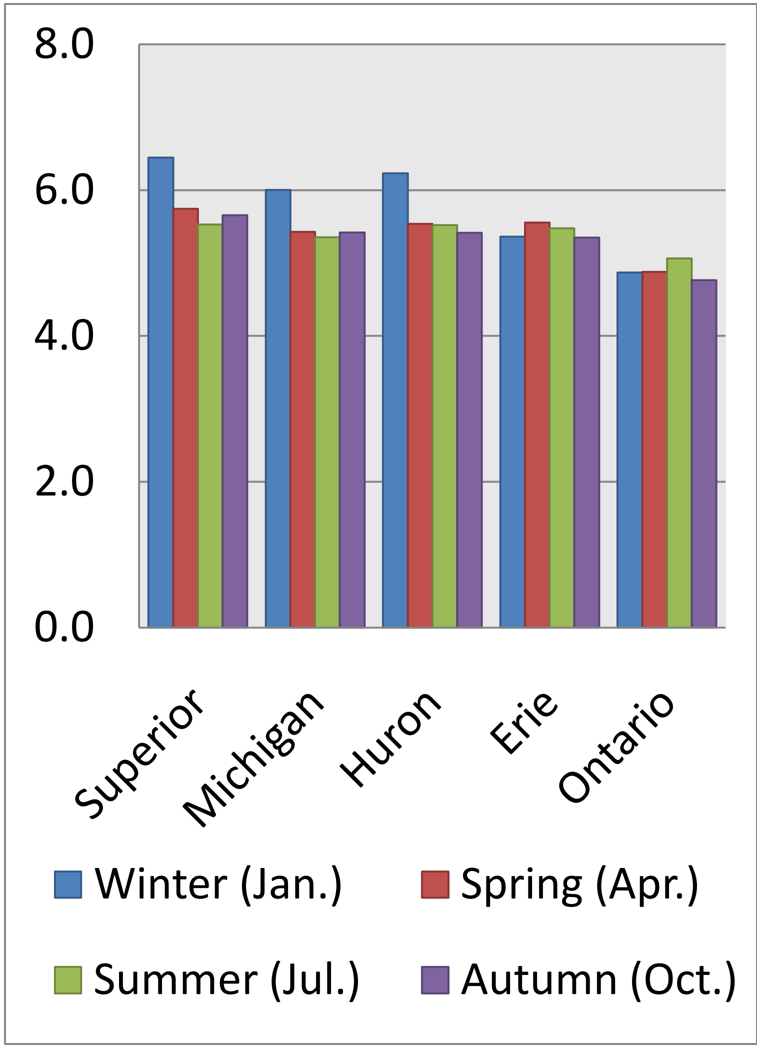
Sensitivity Results – Global Emissions Zero-Out





Sensitivity Results – China Emissions zero-out





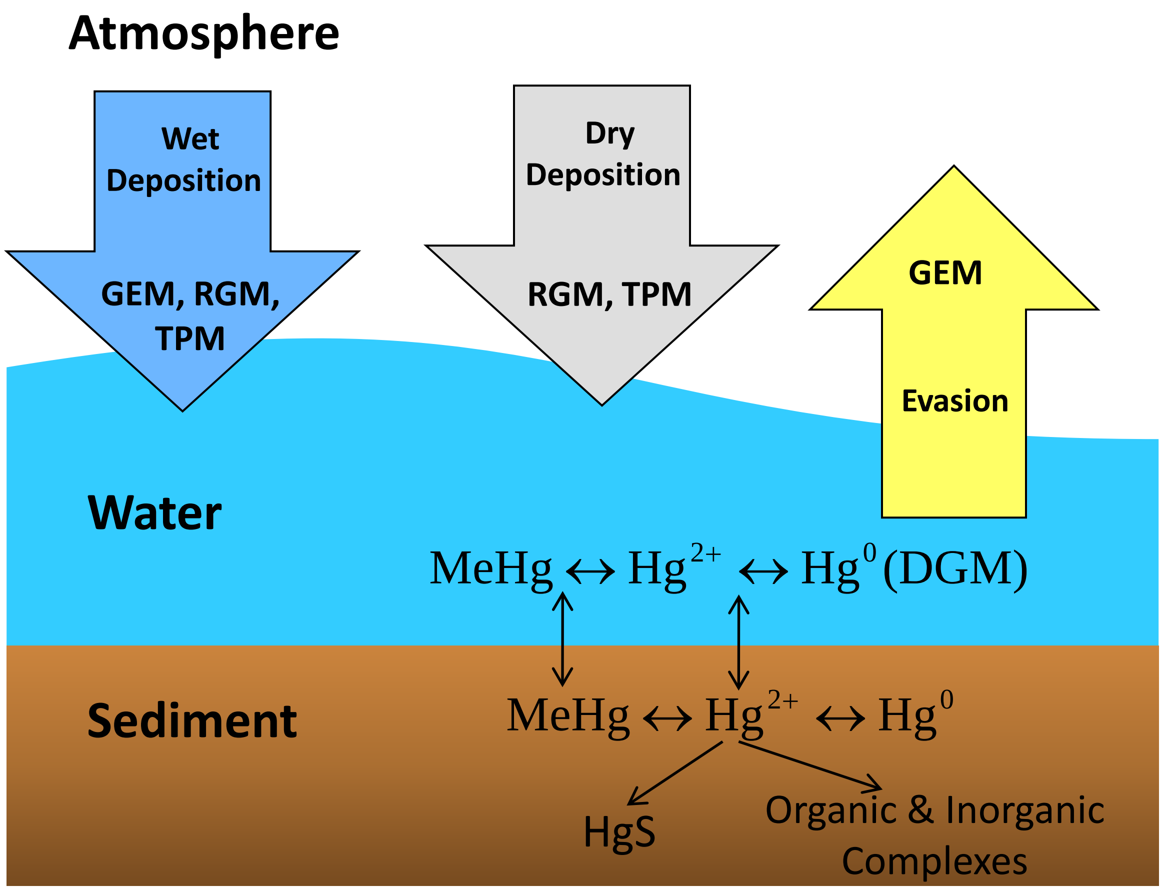
Sensitivity Results – Summary

Table: Percentage contribution to Mercury deposition into the Great Lakes

		Winter (January)			Spring (April)			Summer (July)			Autumn (October)		
		Wet	Dry	Total	Wet	Dry	Total	Wet	Dry	Total	Wet	Dry	Total
Lake Superior	China Emissions	5.19	6.64	6.45	5.53	6.08	5.74	5.54	5.47	5.53	5.53	5.84	5.66
	IPM	14.63	7.98	10.65	12.93	5.49	11.25	12.65	20.56	17.18	5.51	2.38	4.44
	Global Background	70.15	90.49	87.06	87.91	95.15	89.9	85.31	82.58	83.89	94.58	97.36	95.66
Lake Michigan	China Emissions	5.02	6.1	6	5.42	5.3	5.43	1.31	5.35	5.35	5.33	5.54	5.42
	IPM	26.13	42.66	40.19	29.82	33.05	30.94	7.81	46.32	46.24	27.3	32.46	30.53
	Global Background	59.7	54.13	56.63	68.5	61.82	66.91	16.06	51.88	51.98	71.52	63.74	66.96
Lake Huron	China Emissions	2.73	6.28	6.23	5.54	5.61	5.54	1.58	5.51	5.52	5.42	5.39	5.42
	IPM	8.38	28.19	26.63	31.9	25.92	31.12	12.27	39.62	39.46	30.19	20.34	29.22
	Global Background	35.93	68.46	70	63.33	68.5	63.98	16.56	61.3	61.3	65.87	72.32	66.4
Lake Erie	China Emissions	5.03	5.37	5.36	5.74	4.78	5.55	5.53	5.04	5.48	5.42	4.91	5.35
	IPM	49.56	74.51	73.95	31.69	59.97	43.27	58.21	67.47	59.18	60.43	75.17	63.84
	Global Background	42.63	20.61	21.1	67.84	33.92	54.61	41.61	29.67	40.33	35.03	19.35	31.45
Lake Ontario	China Emissions	4.09	4.9	4.87	5.26	4.43	4.88	5.21	4.67	5.06	5	3.98	4.76
	IPM	31.33	46.04	46.34	49.34	42.8	49	55.55	44.77	55.49	49.17	60.25	52.33
	Global Background	38.07	40.86	40.86	43.14	42.02	40.86	46.23	50.78	44.79	42.01	24.63	37.33

Water-Air Exchange Flux

Conceptual Mercury Transfer



Model

$$F = K_{ol}\left(DGM - {GEM}/{H}\right)$$

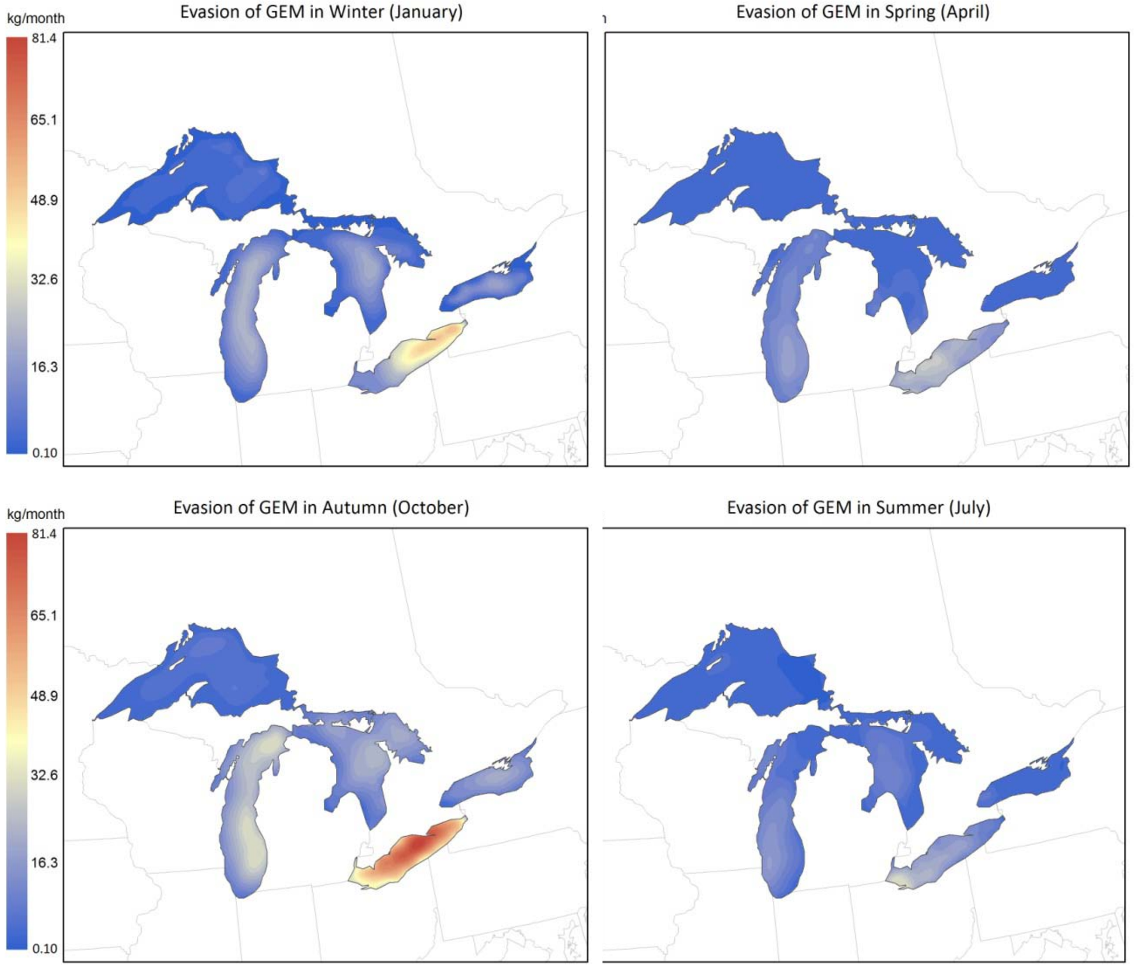
$$\frac{1}{K_{ol}} = \frac{1}{K_w} + \frac{1}{K_a}$$

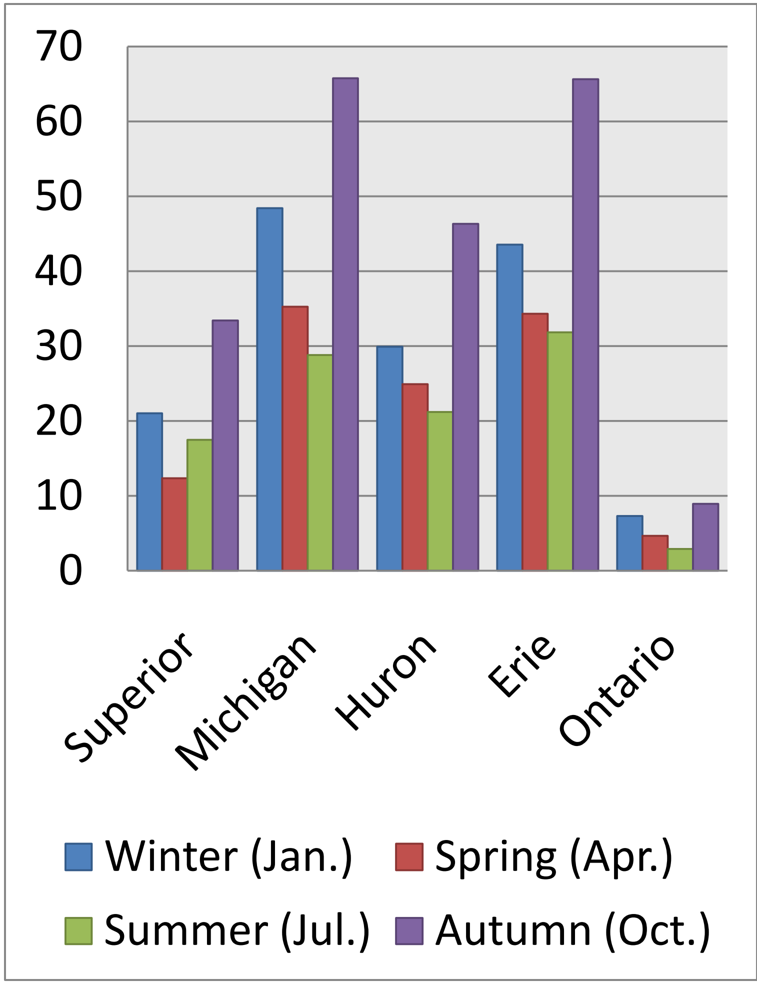
$$K_a >> K_w \therefore \frac{1}{K_a} \approx 0$$

- F → Net Hg Flux
- K_{ol} → Liquid mass transfer coefficient
- K_w → Mass transfer coefficient through water film
- K_a → Mass transfer coefficient through air film

Water-Air Exchange Flux (Contd.)

Evasion





Net Mercury Loading

Table: Total mercury exchange fluxes (ug/ m^2) and loading (kg) of GEM into the Great Lakes

		Hg^0 deposition		RGM dry deposition		Hg_p dry deposition		Total Wet deposition		Seasonal net loading	
		Flux	Loading	Flux	Loading	Flux	Loading	Flux	Loading	Flux	Loading
Lake Superior (82,400 km^2)	Winter	-0.255	-21.03	1.184	97.6	0.032	2.64	1.5	123.4	2.459	202.6
	Spring	-0.15	-12.36	0.426	35.1	0.003	0.28	1.37	112.8	1.648	135.8
	Summer	-0.212	-17.5	0.272	22.4	0.002	0.18	2.46	202.4	2.518	207.5
	Autumn	-0.406	-33.43	0.557	45.9	0.006	0.49	1.01	83.3	1.168	96.3
Lake Michigan (58,000 km^2)	Winter	-0.835	-48.44	1.861	107.9	0.03	1.73	1.76	102.4	2.821	163.6
	Spring	-0.608	-35.28	1.332	77.3	0.007	0.41	1.7	98.6	2.431	141
	Summer	-0.497	-28.83	1.158	67.1	0.005	0.32	2.55	147.9	3.216	186.5
	Autumn	-1.134	-65.76	1.991	115.5	0.016	0.93	1.78	103.4	2.655	154
Lake Huron (59,600 km^2)	Winter	-0.502	-29.92	1.125	67	0.023	1.39	2.64	157.5	3.288	196
	Spring	-0.418	-24.93	0.992	59.1	0.007	0.42	2.46	146.7	3.043	181.3
	Summer	-0.356	-21.21	0.766	45.7	0.005	0.27	2.78	165.7	3.194	190.4
	Autumn	-0.777	-46.32	1.272	75.8	0.011	0.63	1.97	117.6	2.477	147.7
Lake Erie (25,700 km^2)	Winter	-1.696	-43.58	2.418	62.2	0.029	0.75	2.94	75.6	3.695	95
	Spring	-1.336	-34.35	2.672	68.7	0.014	0.35	3.2	82.2	4.547	116.9
	Summer	-1.24	-31.87	2.678	68.8	0.014	0.35	6.36	163.3	7.808	200.7
	Autumn	-2.555	-65.66	3.583	92.1	0.034	0.86	3.78	97.2	4.844	124.5
Lake Ontario (19,500 km^2)	Winter	-0.375	-7.314	1.948	38	0.033	0.64	2.58	50.3	4.186	81.6
	Spring	-0.239	-4.665	1.652	32.2	0.011	0.22	1.97	38.5	3.396	66.2
	Summer	-0.148	-2.895	1.668	32.5	0.011	0.21	6.1	118.9	7.626	148.7
	Autumn	-0.459	-8.957	2.073	40.4	0.015	0.3	2.85	55.6	4.481	87.4

Acknowledgement

- Great Lakes Air Deposition Program (GLAD)