Atmospheric Mercury Measurements and Modeling at NOAA's Air Resources Laboratory (ARL)

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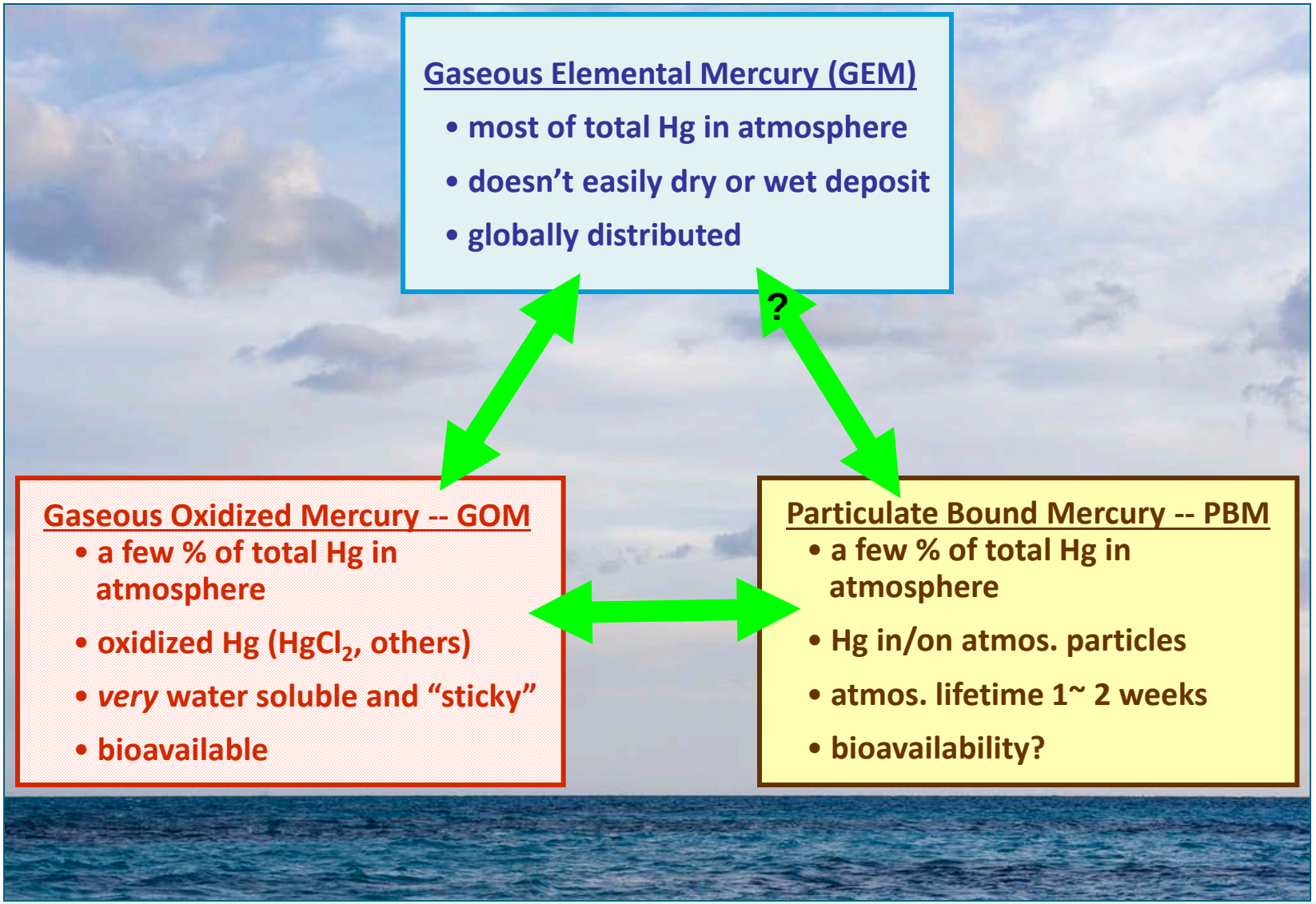
NOAA/ARL, College Park, MD

Prepared for the Asia-Pacific Mercury Monitoring Network Workshop
September 10-12, 2014
Hanoi, Vietnam

Different "forms" of mercury in the atmosphere



Measurements – Approaches

- **Process Studies and Field Intensives**

  Brooks et al., Mercury species measured atop the Moody Tower TRAMP site, Houston, Texas, *Atmos. Environ.*, **44** (33), 4045-4055, 2010

  Rolison et al., Isotopic composition of species-specific atmospheric Hg in a coastal environment, *Chemical Geology,* **336**, 37-49, 2013

  Ren et al., Mercury Speciation at a Coastal Site in the Northern Gulf of Mexico: Results from the Grand Bay Intensive Studies in Summer 2010 and Spring 2011; *Atmosphere*, **5**, 230-251; 2014

  Brooks et al., Airborne Vertical Profiling of Mercury Speciation near Tullahoma, TN, USA; *Atmosphere*, **5**, 557-574; 2014

- **Long-Term Monitoring**

  Zhang et al., Nested-grid simulation of mercury over North America, *Atmos. Chem. Phys.*, **12**, 6095-6111, 2012

  Lan et al., Seasonal and diurnal variations of atmospheric mercury across the US determined from AMNet monitoring data, *Atmos. Chem. Phys.*, **12**, 10569-10582, 2012

Process Studies and Field Intensives

- Various locations around the U.S., at the **surface and aloft** (fixed-wing aircraft)
- Generally large, multi-investigator studies
- Measurements of:
  - **Concentrations** of mercury and other species
  - **Air-Surface exchange** using micrometeorological and surrogate-surface techniques
- Investigating:
  - **halogen chemistry** in the marine boundary layer and free troposphere
  - **vertical profiles** of gas- and aerosol-phase Hg species
  - **transport** from middle and upper troposphere
  - local/regional/global **emissions**
  - natural/anthropogenic **processes**

University of Tennessee Space Institute Piper Navajo

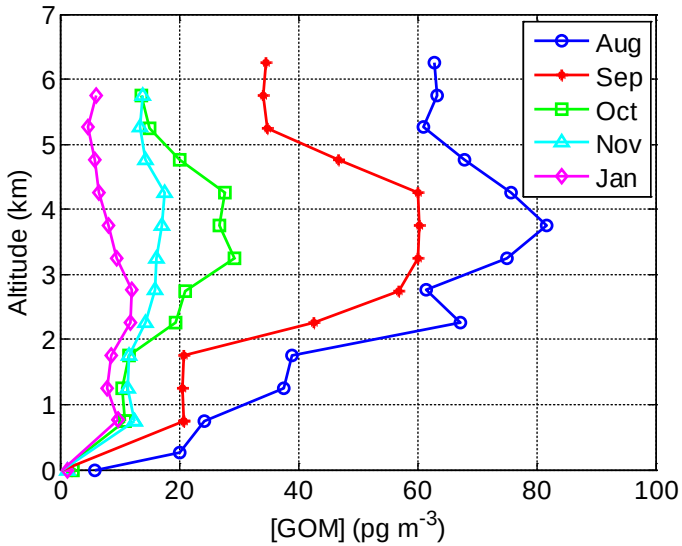
Inlet System

GOM and PBM Collection Equipment

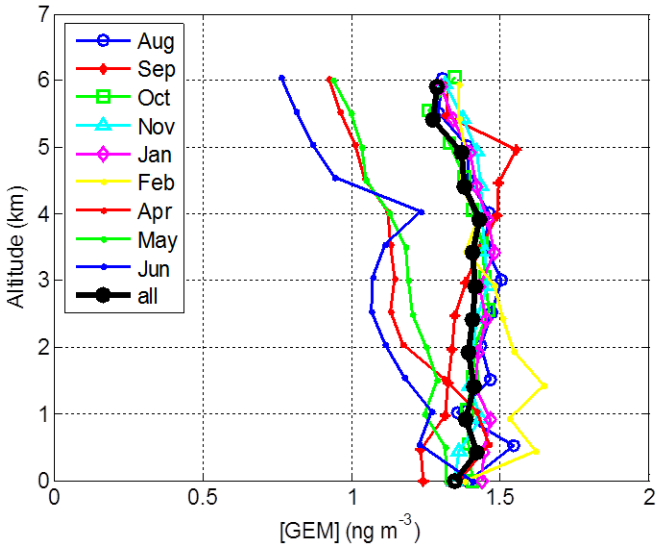
Process Studies and Field Intensives:

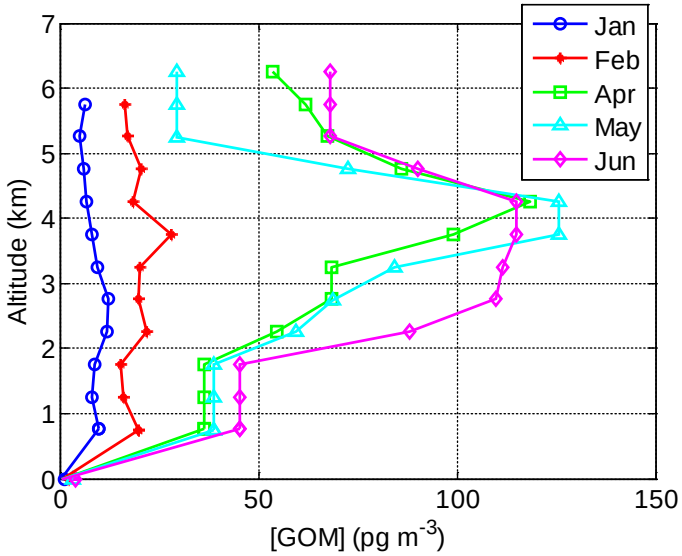
Airborne Mercury Measurements

GOM



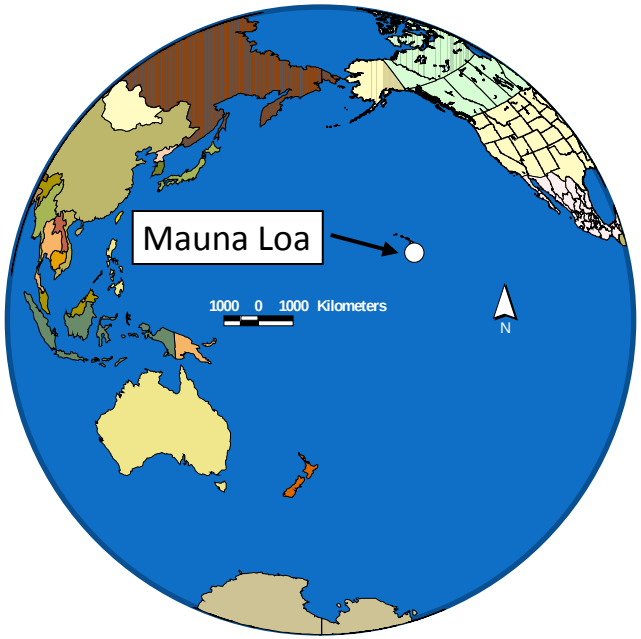
GEM

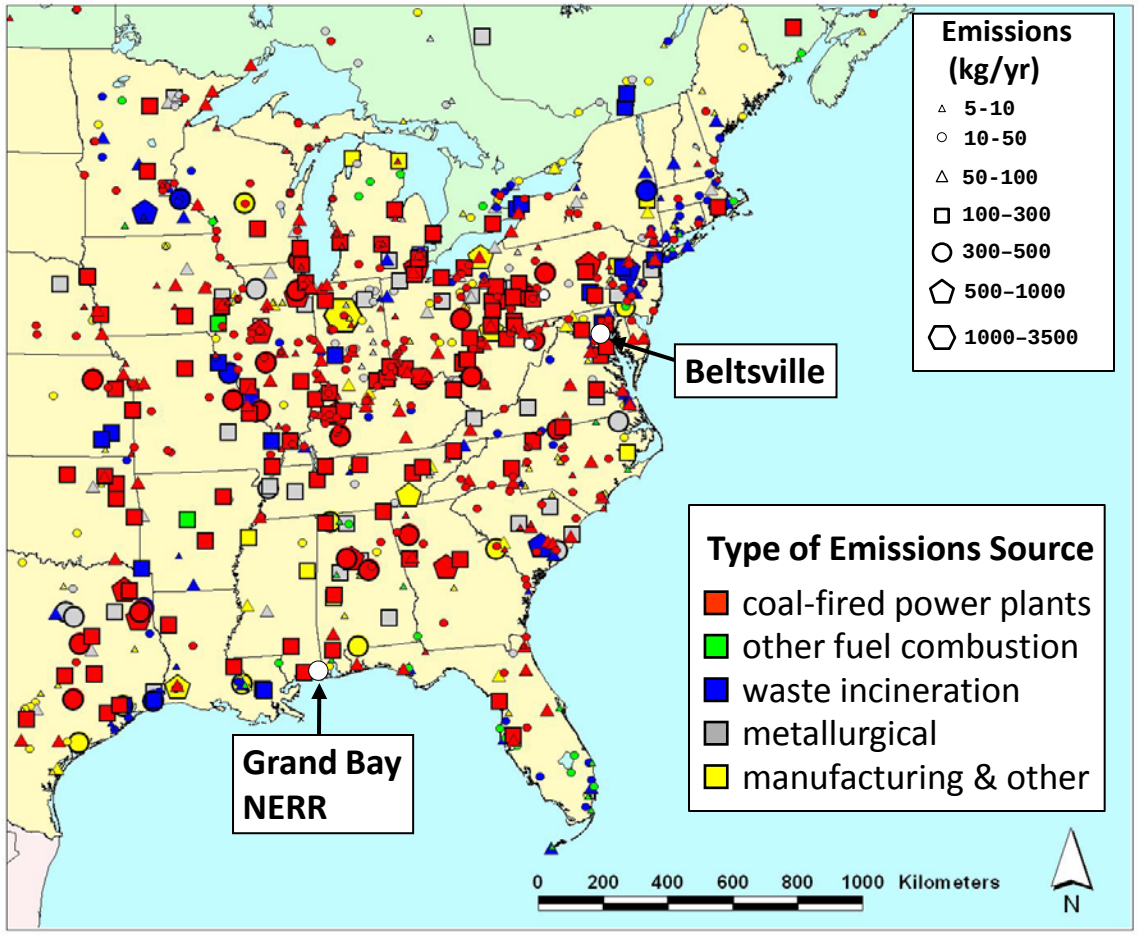




- GOM concentrations peaks spring to summer
- Max. [GOM] between ~3 and 4.5 km.
- Relatively uniform GEM vertical profiles from Aug. 2012 to Feb. 2013. Slight GEM depletion above 5 km.
- Flights from Apr. to Jun. 2013: GEM levels decreased as altitude increased; **one flight for each month only**.

Long-Term Monitoring





Two ARL long-term mercury measurement sites in the continental U.S., one in Hawaii; 2002 mercury emissions sources based on data from USEPA, Envr. Canada and the CEC

Long-Term Monitoring

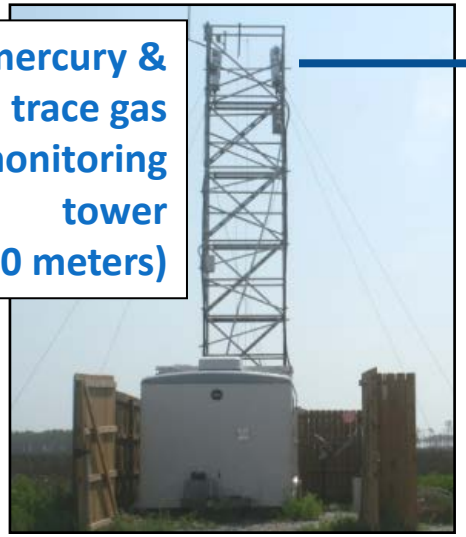
Grand Bay NERR

Ancillary Measurements of:

- SO_2
- O_3
- CO
- NO/NO_Y
- Black Carbon
- Meteorology
- Solar Radiation

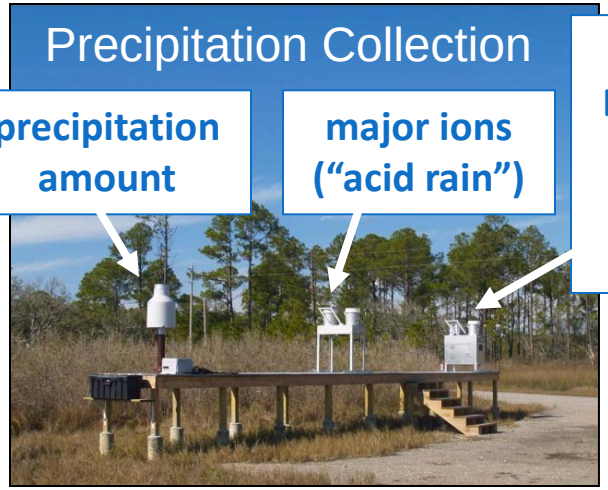
To Address:

- Source attribution and characterization
- Local/Regional emissions
- Air-surface exchange
- Trend analysis
- Model evaluation



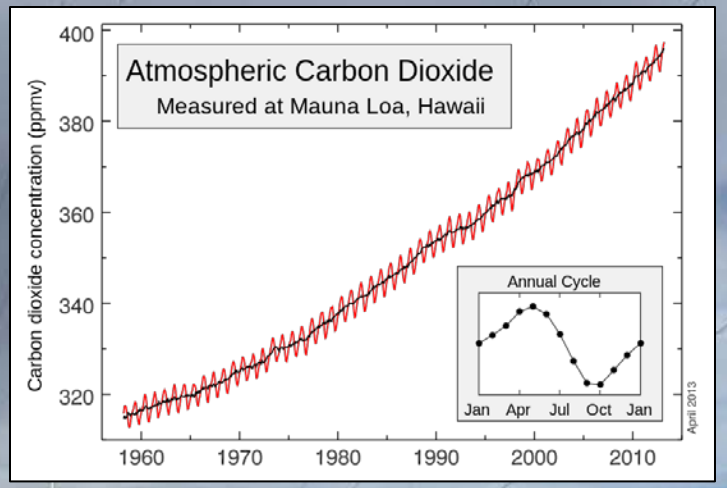
mercury & trace gas monitoring tower (10 meters)

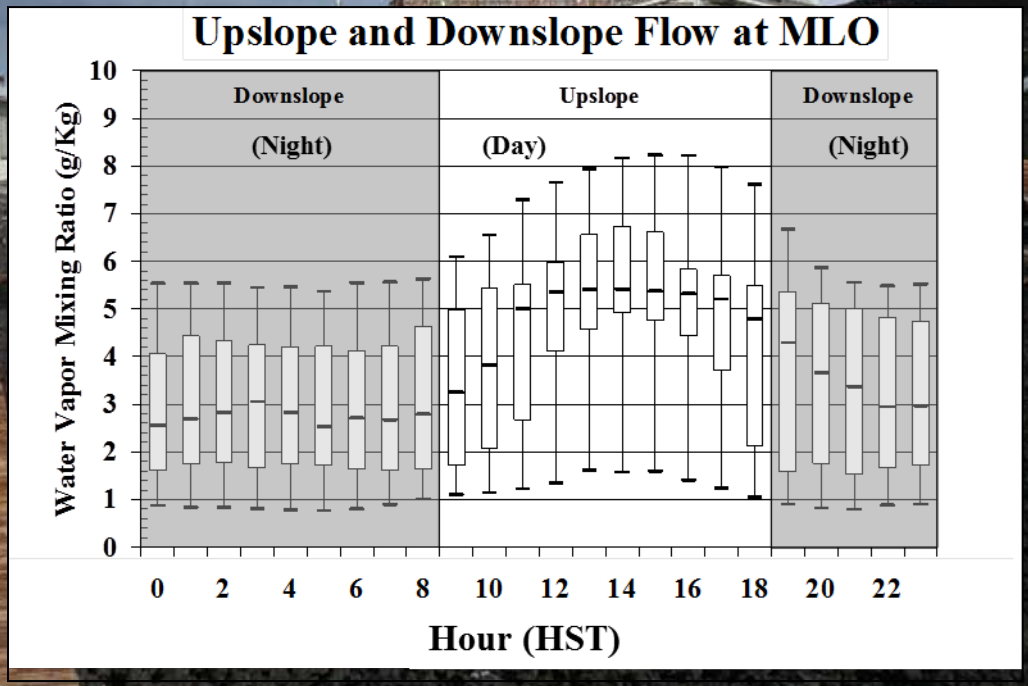
top of tower with two sets of GOM and PBM collectors



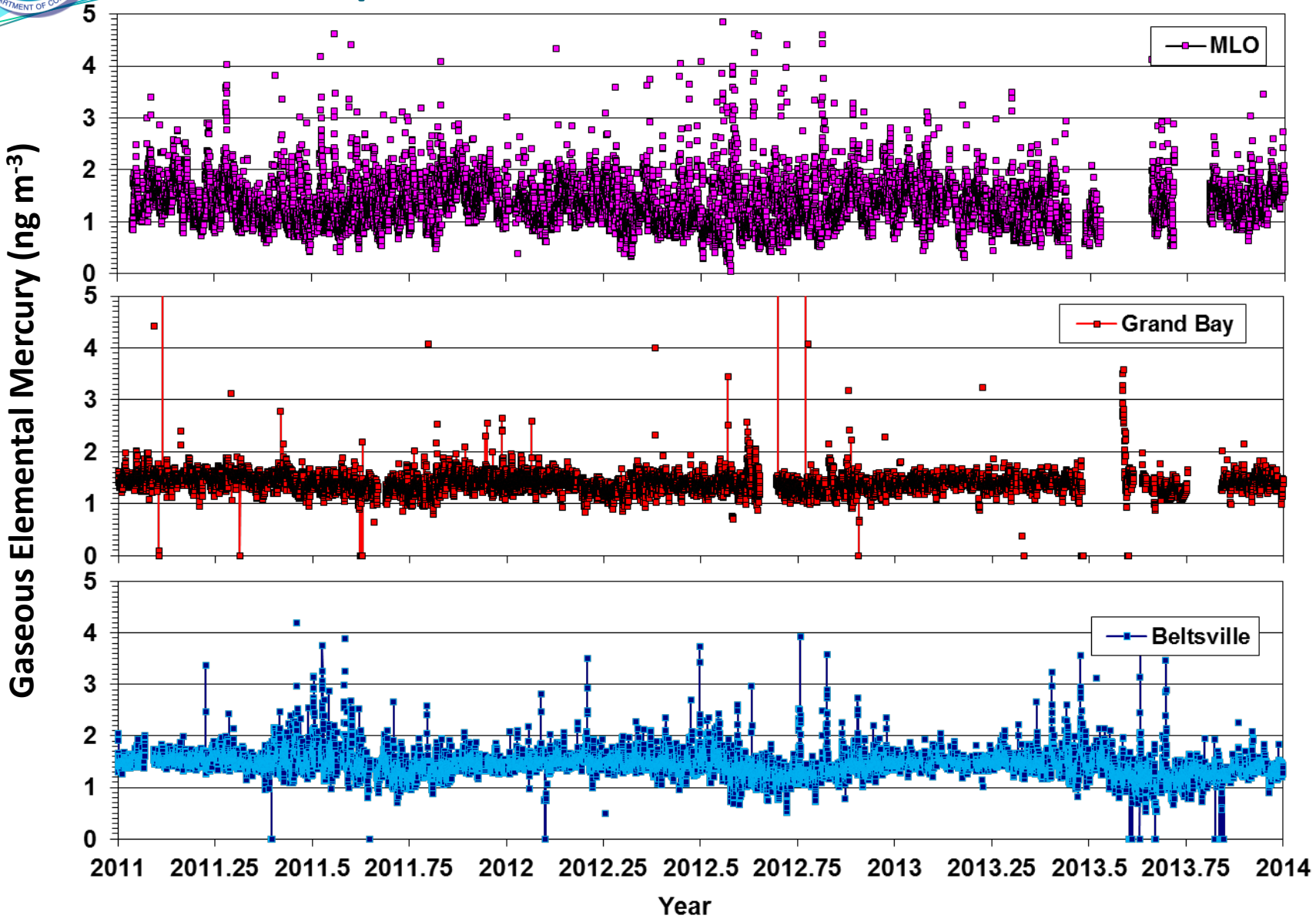
Long-Term Monitoring: Mauna Loa Observatory

Mercury measurement instruments on roof and inside historic Keeling Building, near the summit of Mauna Loa

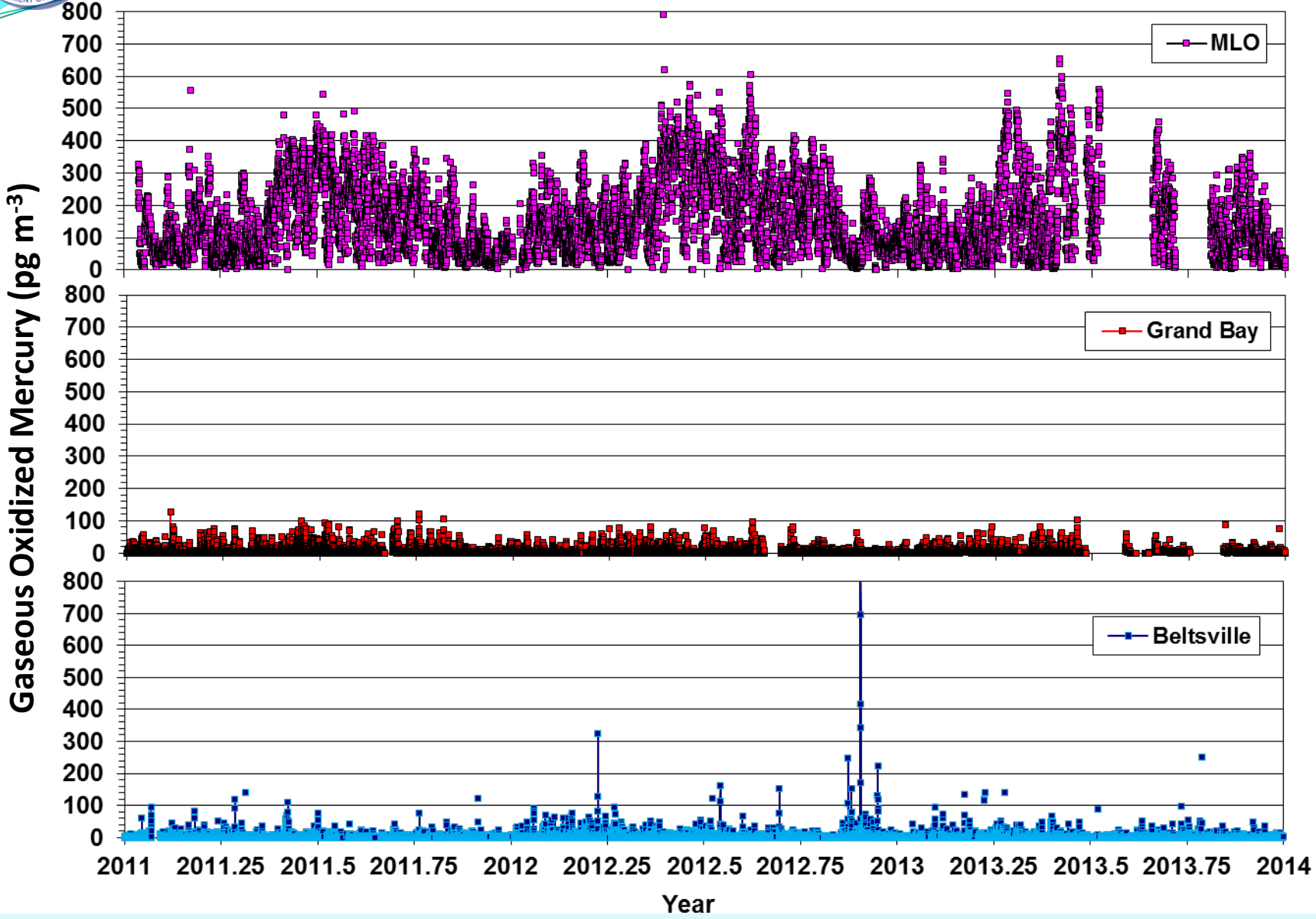




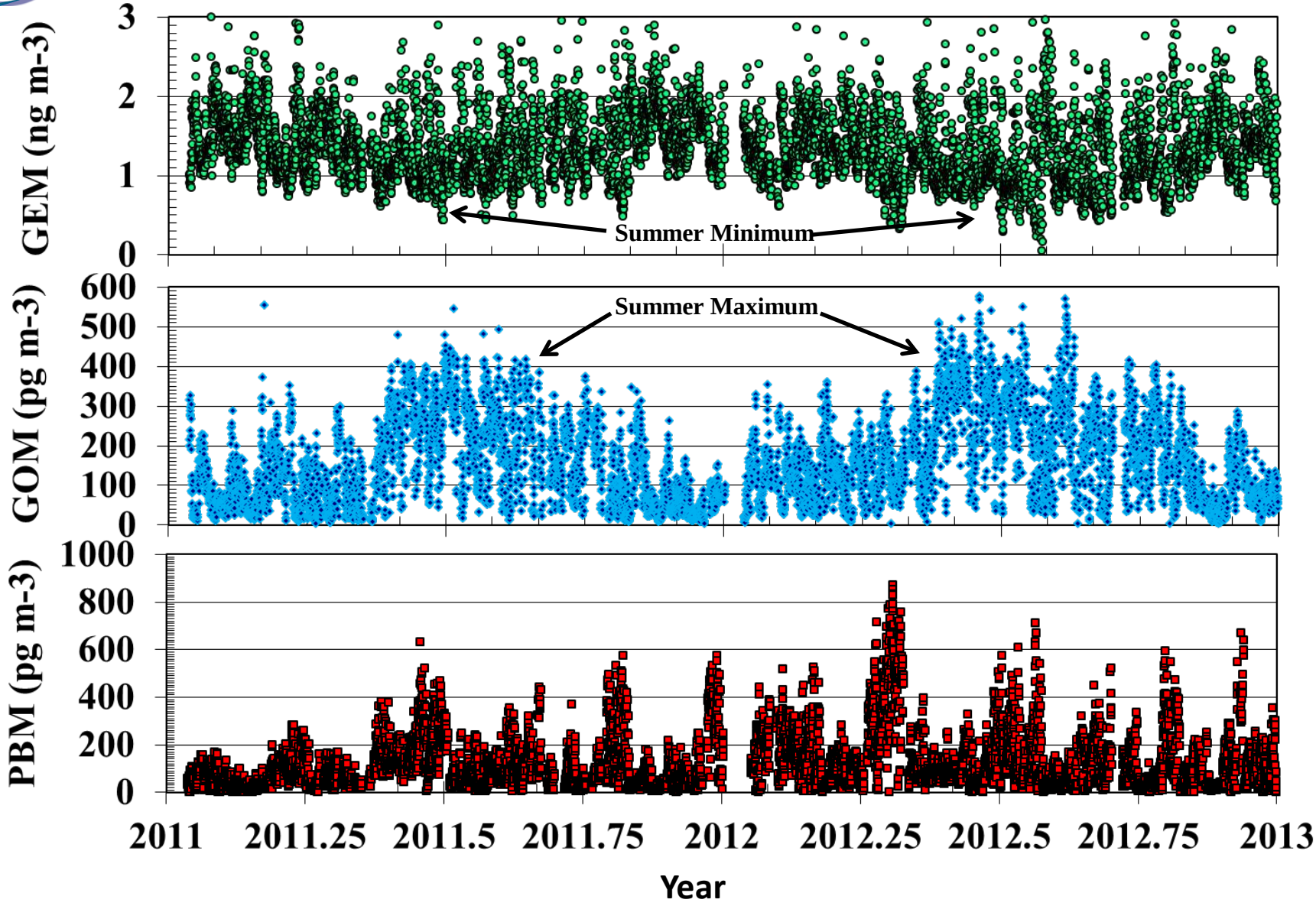
Comparison Across 3 Sites –Unvetted Data

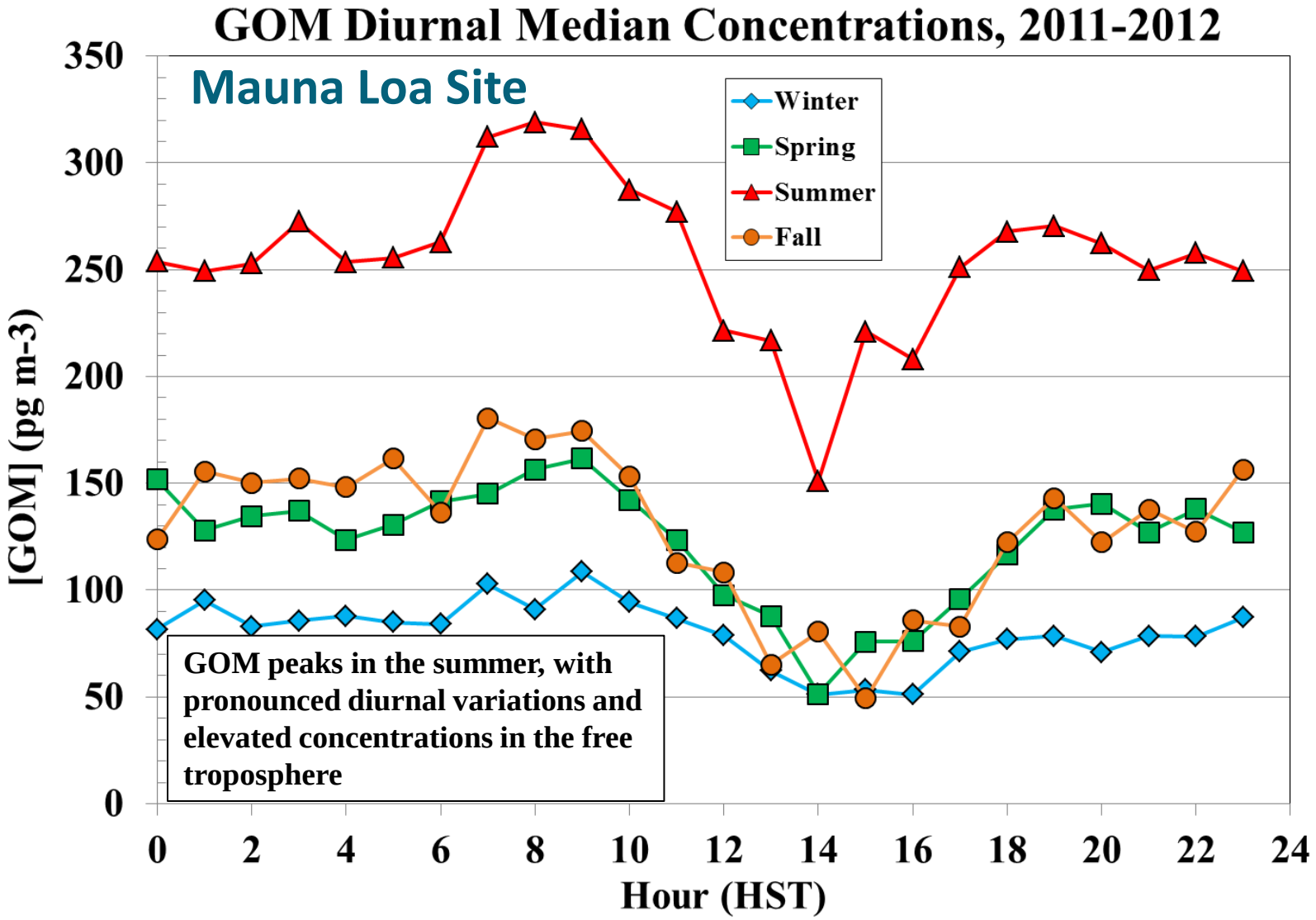


Comparison Across 3 Sites –Unvetted Data

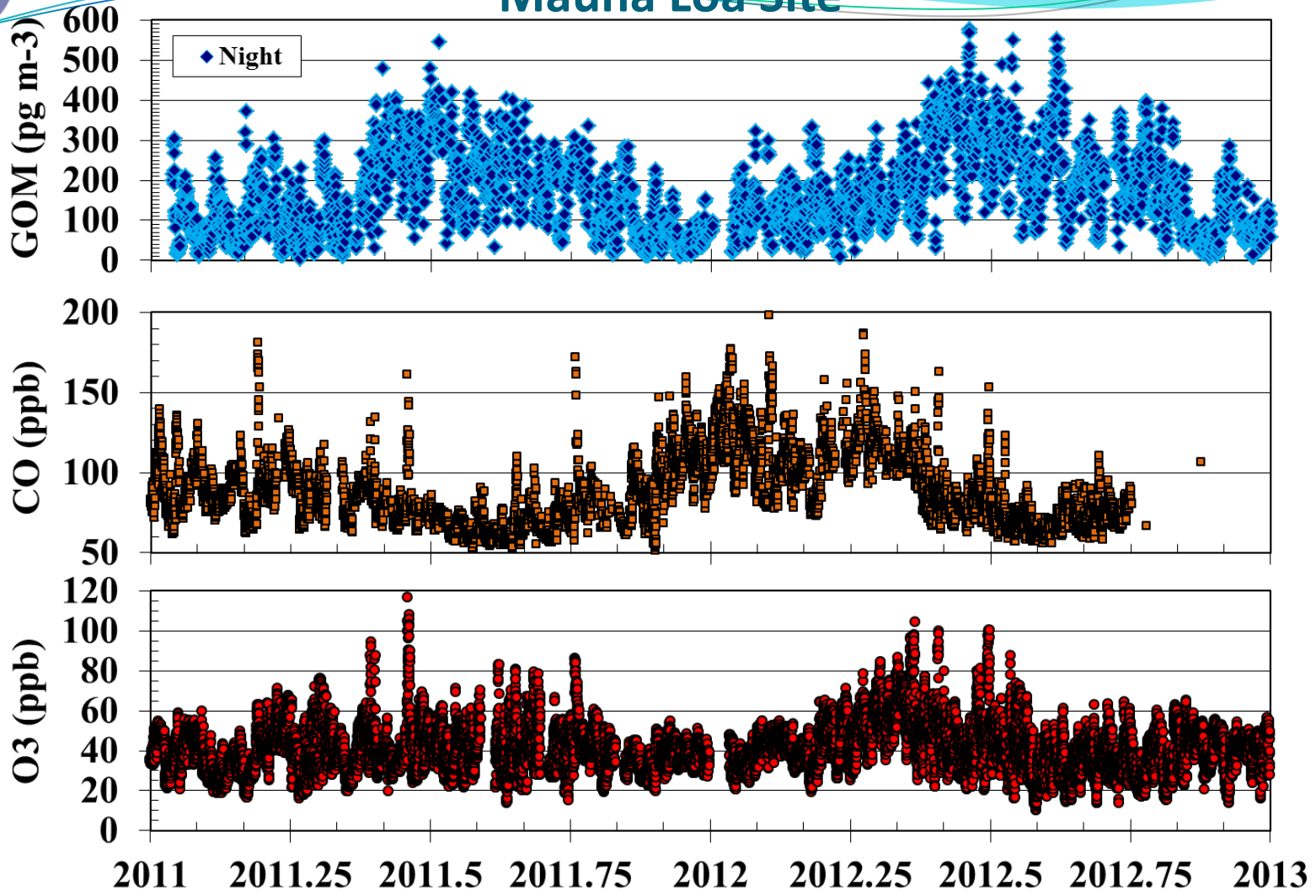


Mauna Loa Site



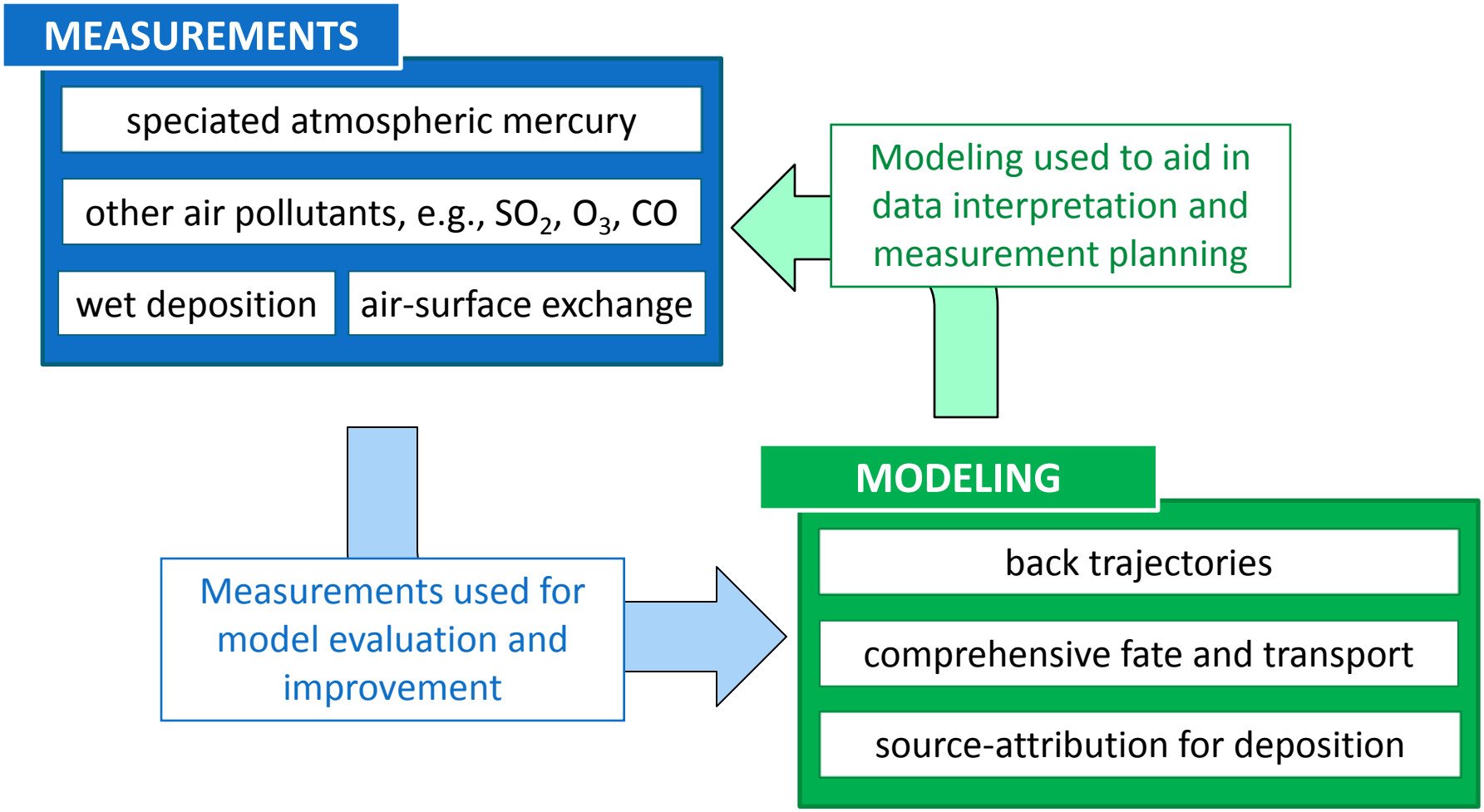

GOM Diurnal Median Concentrations, 2011-2012
Mauna Loa Site
Winter
Spring
Summer
Fall
[GOM] (pg m-3)
350
300
250
200
150
100
50
0
0
2
4
6
8
10
12
14
16
18
20
22
24
Hour (HST)
GOM peaks in the summer, with pronounced diurnal variations and elevated concentrations in the free troposphere

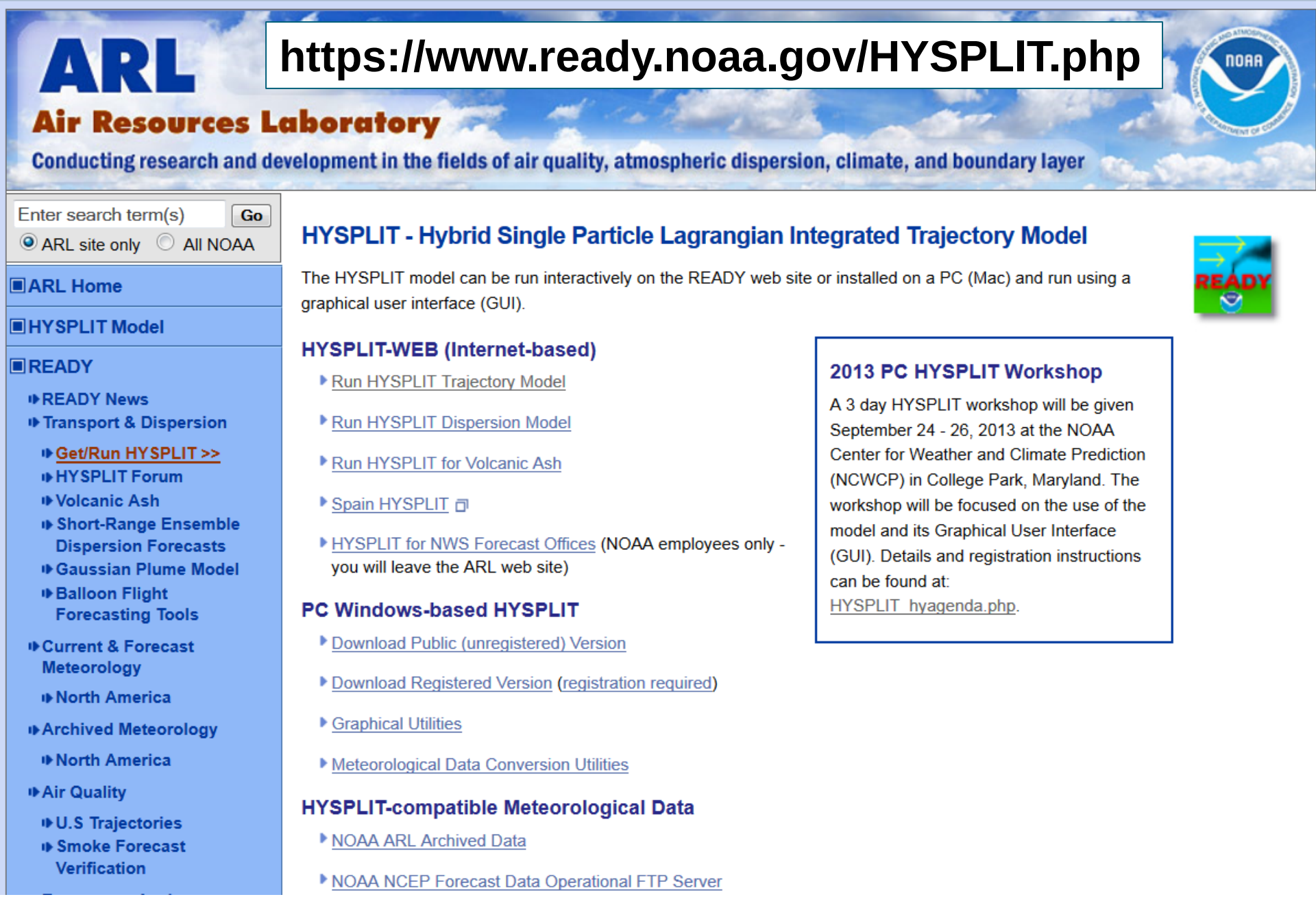
Mauna Loa Site



Summer maxima of GOM correspond to minima in CO (increased oxidation by ·OH), and GEM, suggesting a photochemical origin of GOM

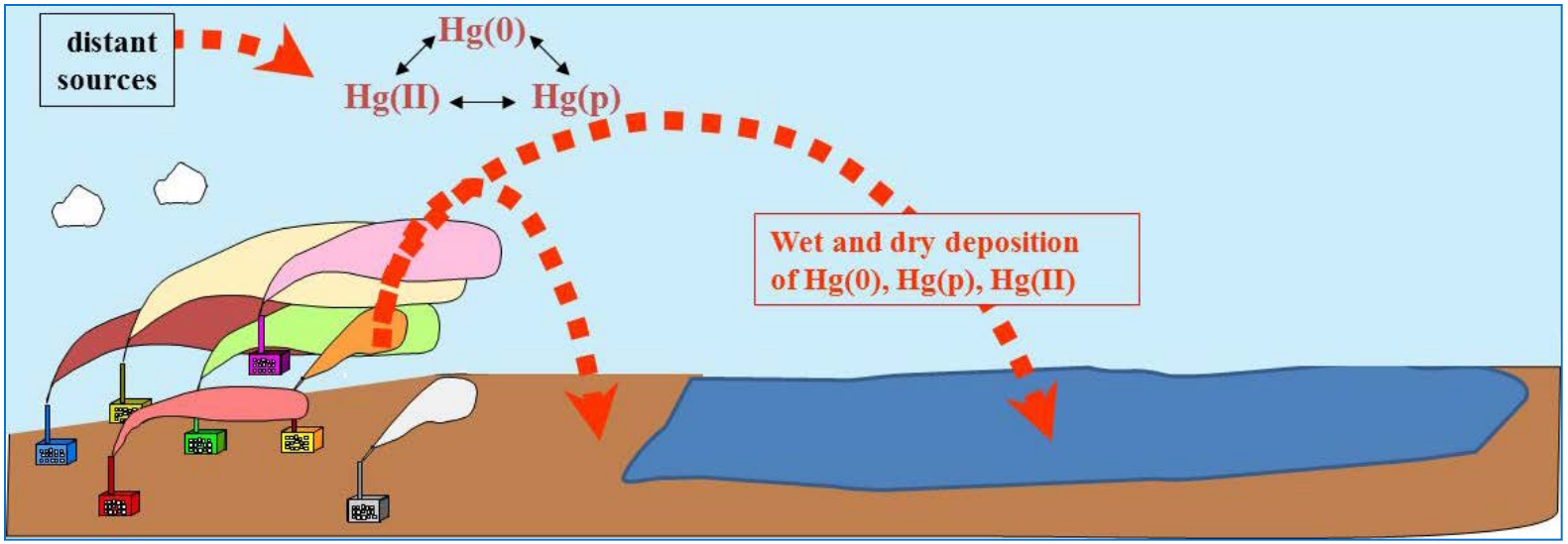
Mercury: Measurements and Modeling




ARL
https://www.ready.noaa.gov/HYSPLIT.php
Air Resources Laboratory
Conducting research and development in the fields of air quality, atmospheric dispersion, climate, and boundary layer
Enter search term(s)
Go
ARL site only
All NOAA
ARL Home
HYSPLIT Model
READY
READY News
Transport & Dispersion
Get/Run HYSPLIT >>
HYSPLIT Forum
Volcanic Ash
Short-Range Ensemble Dispersion Forecasts
Gaussian Plume Model
Balloon Flight Forecasting Tools
Current & Forecast Meteorology
North America
Archived Meteorology
North America
Air Quality
U.S Trajectories
Smoke Forecast Verification
HYSPLIT - Hybrid Single Particle Lagrangian Integrated Trajectory Model
The HYSPLIT model can be run interactively on the READY web site or installed on a PC (Mac) and run using a graphical user interface (GUI).
HYSPLIT-WEB (Internet-based)
Run HYSPLIT Trajectory Model
Run HYSPLIT Dispersion Model
Run HYSPLIT for Volcanic Ash
Spain HYSPLIT
HYSPLIT for NWS Forecast Offices (NOAA employees only - you will leave the ARL web site)
PC Windows-based HYSPLIT
Download Public (unregistered) Version
Download Registered Version (registration required)
Graphical Utilities
Meteorological Data Conversion Utilities
HYSPLIT-compatible Meteorological Data
NOAA ARL Archived Data
NOAA NCEP Forecast Data Operational FTP Server
2013 PC HYSPLIT Workshop
A 3 day HYSPLIT workshop will be given September 24 - 26, 2013 at the NOAA Center for Weather and Climate Prediction (NCWCP) in College Park, Maryland. The workshop will be focused on the use of the model and its Graphical User Interface (GUI). Details and registration instructions can be found at: HYSPLIT_hyagenda.php.

Modeling – Approaches

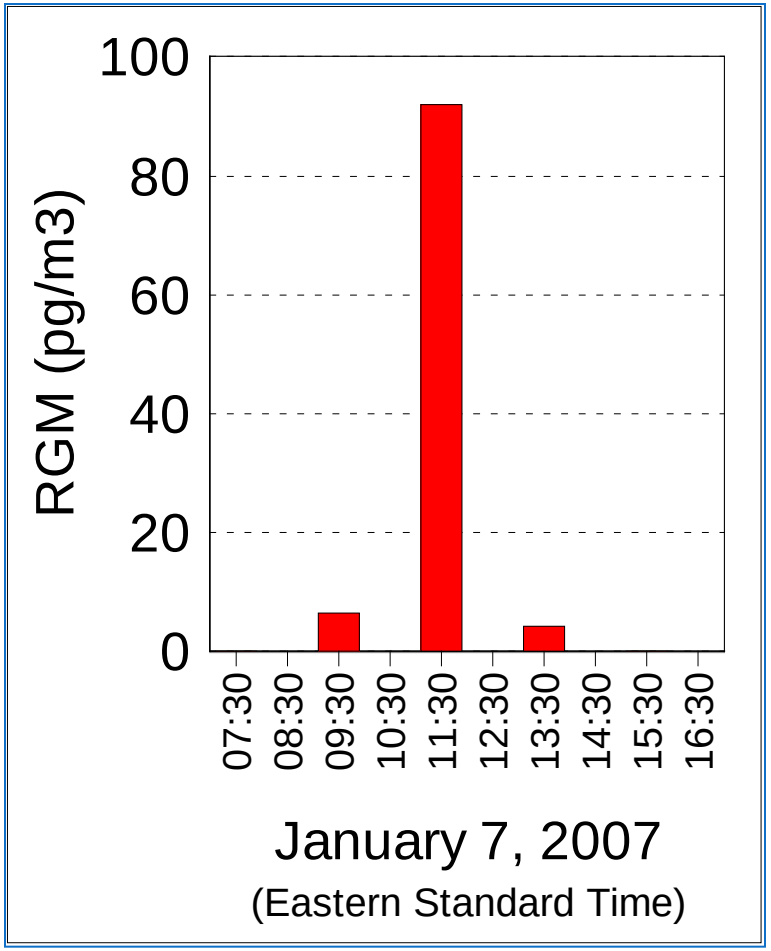
- Back-trajectory analyses with HYSPLIT
- Fate and transport modeling with HYSPLIT-Hg



…focus on source-receptor relationships

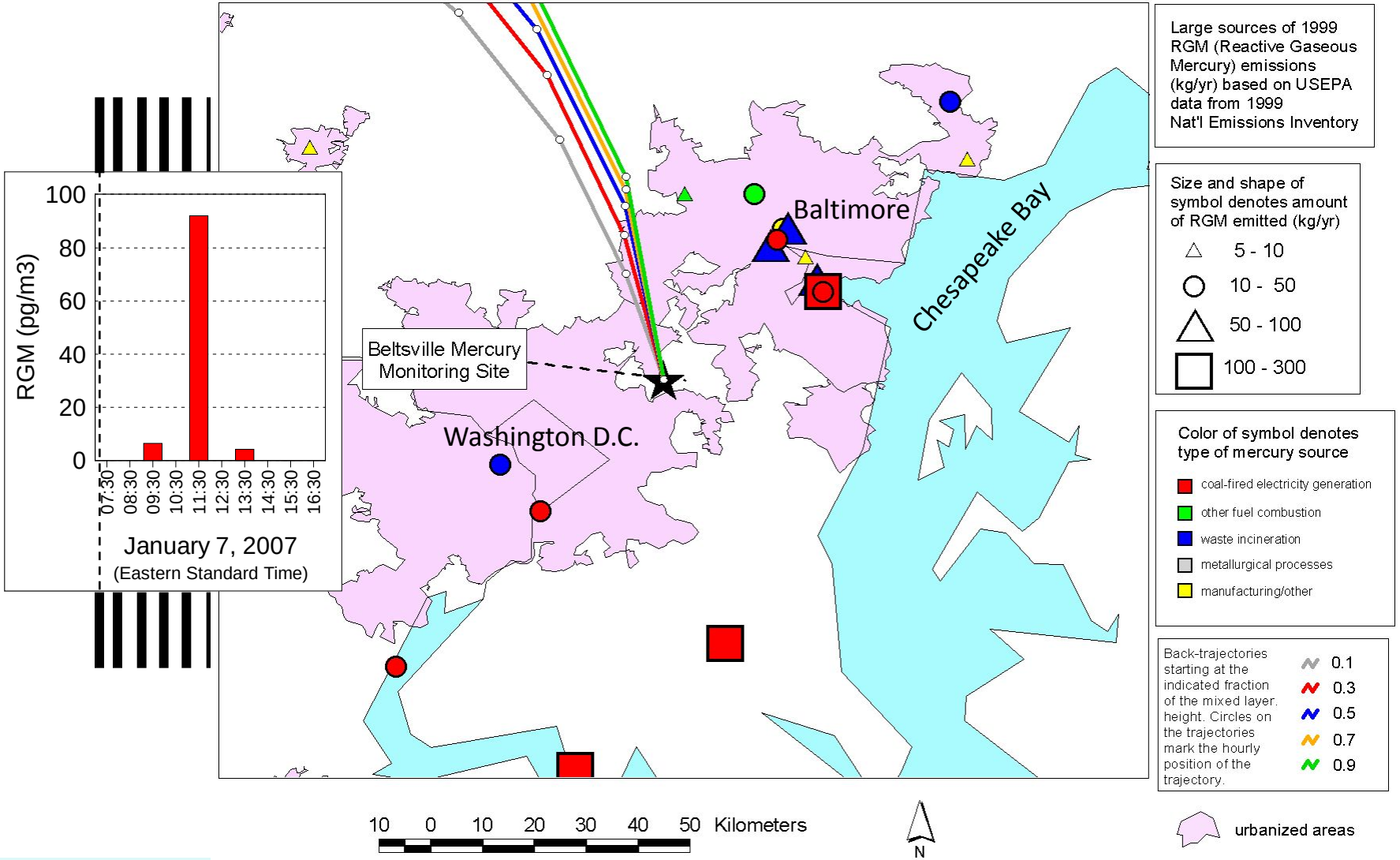
Back Trajectory Analysis – Episodes

Beltsville, Maryland
mercury site



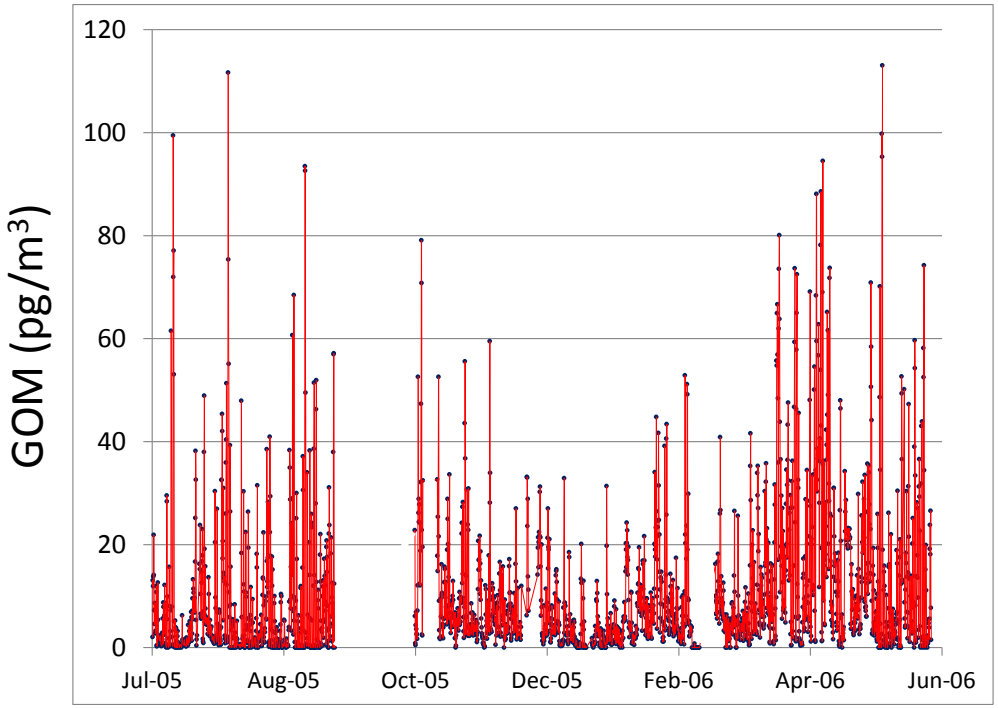
Reactive Gaseous Mercury episode

Back Trajectories Arriving at 1/07/2007 07:00 EST



Back Trajectory Analysis – "Gridded Trajectory Frequencies"

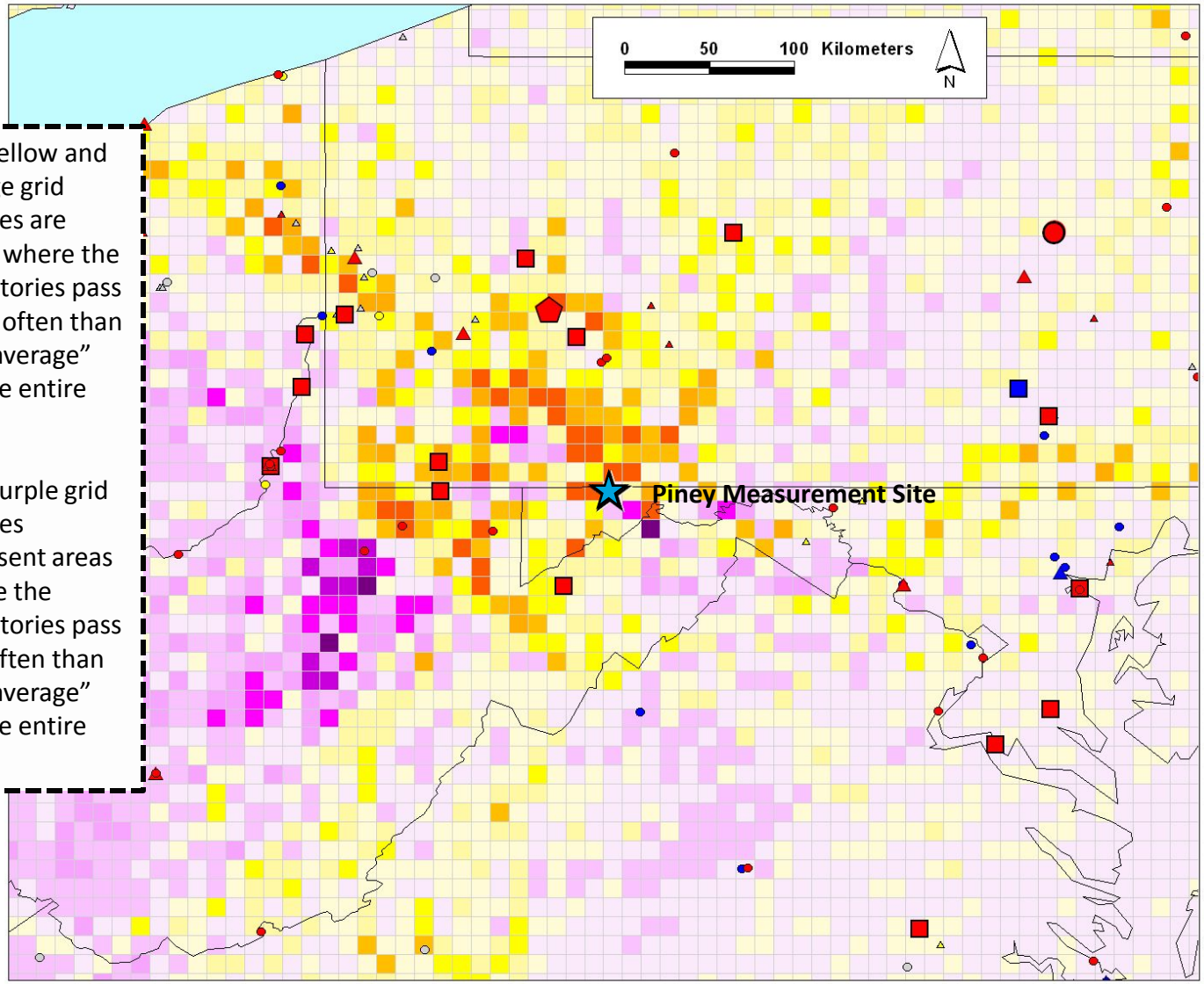
Instead of single-event analysis, a way to analyze a more extensive data record at a given site



One year of hourly Gaseous Oxidized Mercury (GOM) measurements at the Piney Reservoir site in Western Maryland, courtesy of Dr. Mark Castro, University of Maryland

- When measured concentrations at a given site are relatively high (or low), where do the air masses arriving at the site tend to come from?
- Are these regions related to known mercury sources?
- What fraction of trajectories for a given subset of measurements (e.g., top 10% of RGM measurements) pass through each grid square throughout a given domain?
- How does this geographical "trajectory gridded frequency" pattern compare with locations of known mercury air emissions sources?

Where the air tended to come from when the measured GOM at the Piney Reservoir site was HIGH



The yellow and orange grid squares are areas where the trajectories pass more often than the "average" for the entire year

The purple grid squares represent areas where the trajectories pass less often than the "average" for the entire year

Difference between selected case and total year in percent of back-trajectories passing through grid square

> 2.5	< -2.5
2 – 2.5	-2.5 to -2
1.5 - 2	-2 to -1.5
1 to 1.5	-1.5 to -1
0.5 - 1	-1 to -0.5
0 to 0.5	-0.5 to 0

Air Emissions

size/shape of symbol denotes amount of mercury emitted (kg/yr)

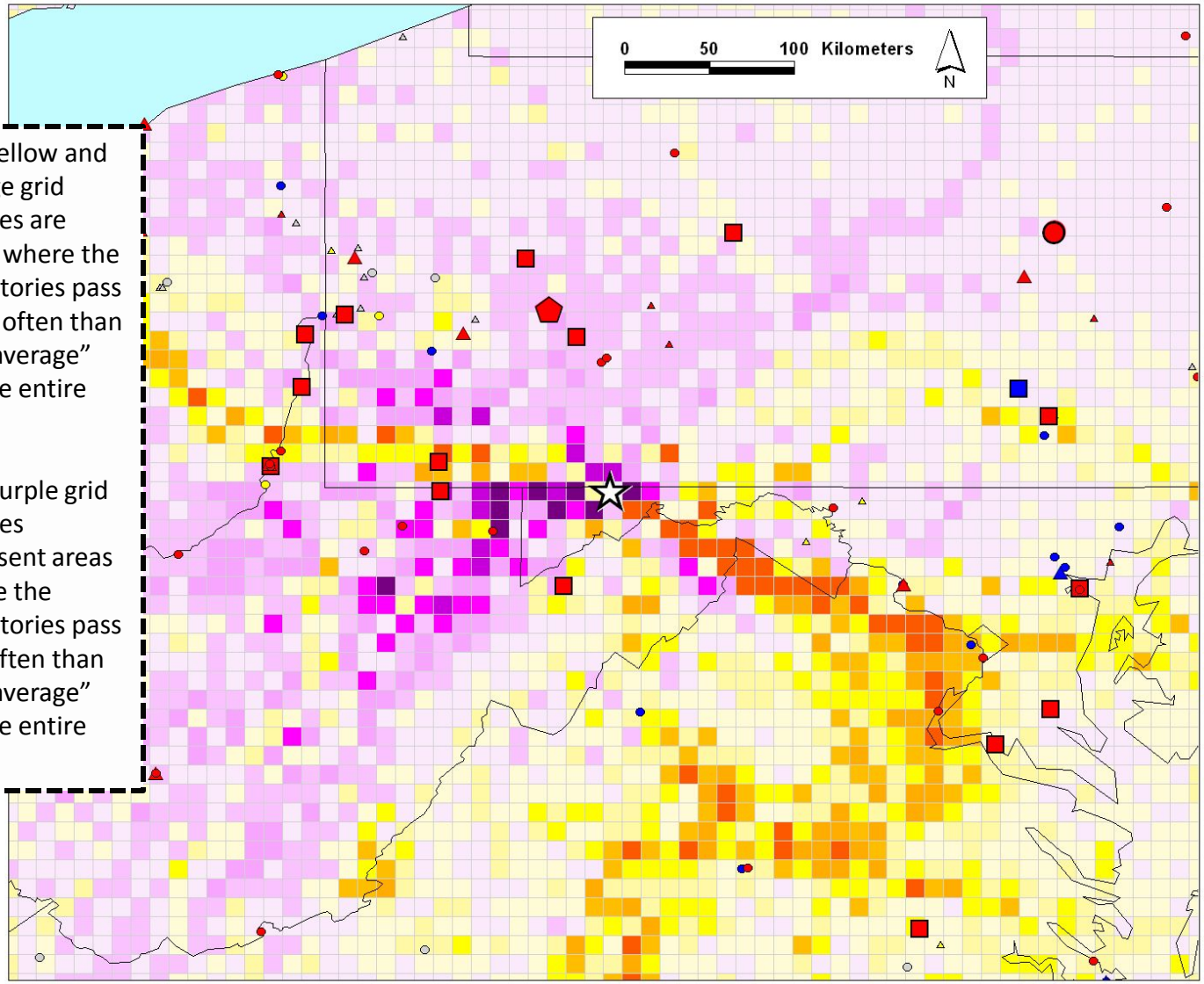
△	5 - 10
○	10 - 50
△	50 - 100
□	100 – 300
○	300 - 500
⬠	500 - 1000
⬡	1000 - 3500

color of symbol denotes type of mercury source

- coal-fired power plants
- other fuel combustion
- waste incineration
- metallurgical
- manufacturing & other

0.1 degree lat/long regional grid

Where the air tended to come from when the measured RGM at the Piney Reservoir site was LOW



The yellow and orange grid squares are areas where the trajectories pass more often than the "average" for the entire year

The purple grid squares represent areas where the trajectories pass less often than the "average" for the entire year

Piney Measurement Site

Difference between selected case and total year in percent of back-trajectories passing through grid square

> 2.5	< -2.5
2 – 2.5	-2.5 to -2
1.5 - 2	-2 to -1.5
1 to 1.5	-1.5 to -1
0.5 - 1	-1 to -0.5
0 to 0.5	-0.5 to 0

Air Emissions

size/shape of symbol denotes amount of mercury emitted (kg/yr)

△	5 - 10
○	10 - 50
△	50 - 100
□	100 – 300
○	300 - 500
⬠	500 - 1000
⬡	1000 - 3500

color of symbol denotes type of mercury source

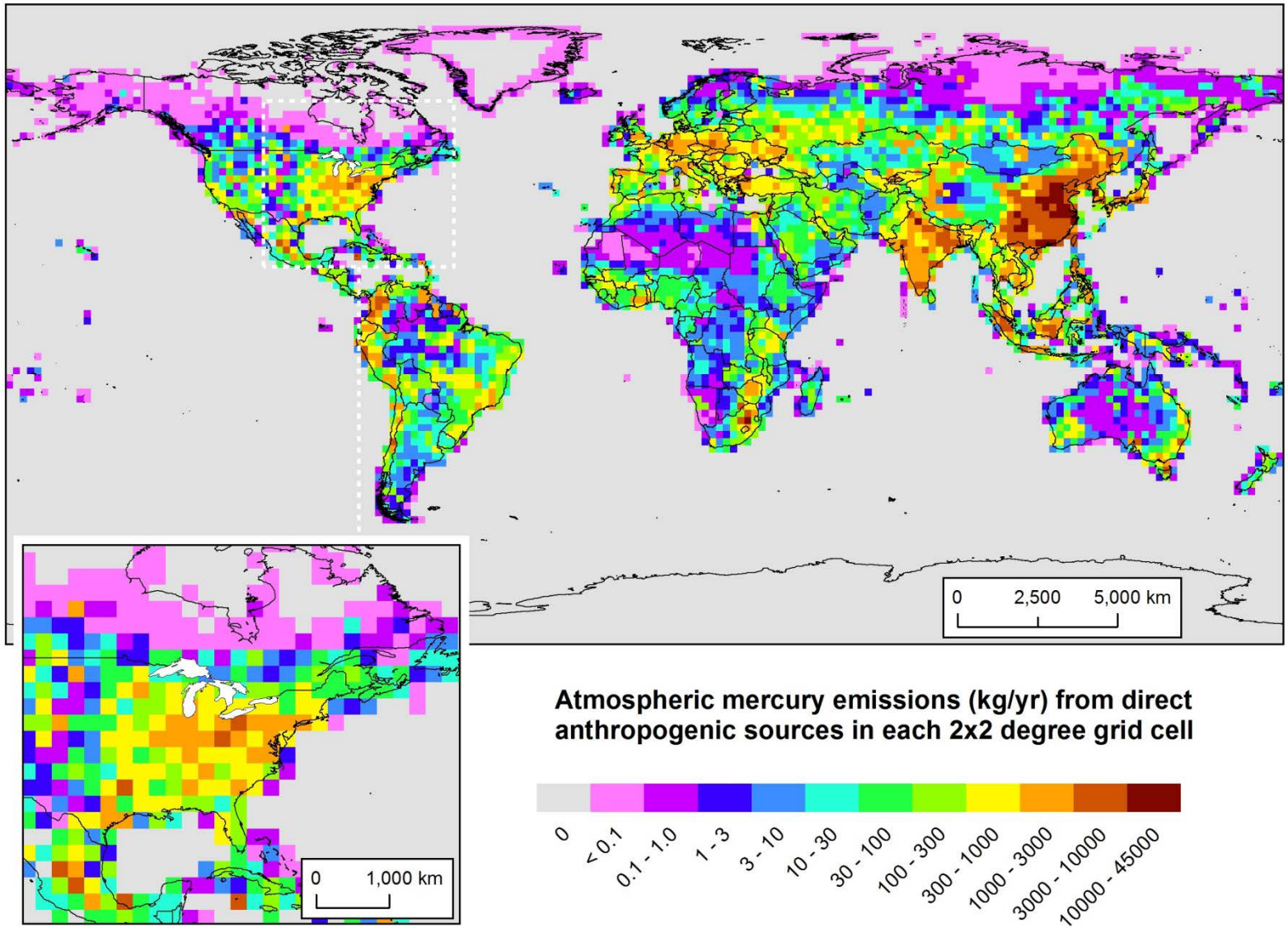
- coal-fired power plants
- other fuel combustion
- waste incineration
- metallurgical
- manufacturing & other

0.1 degree lat/long regional grid

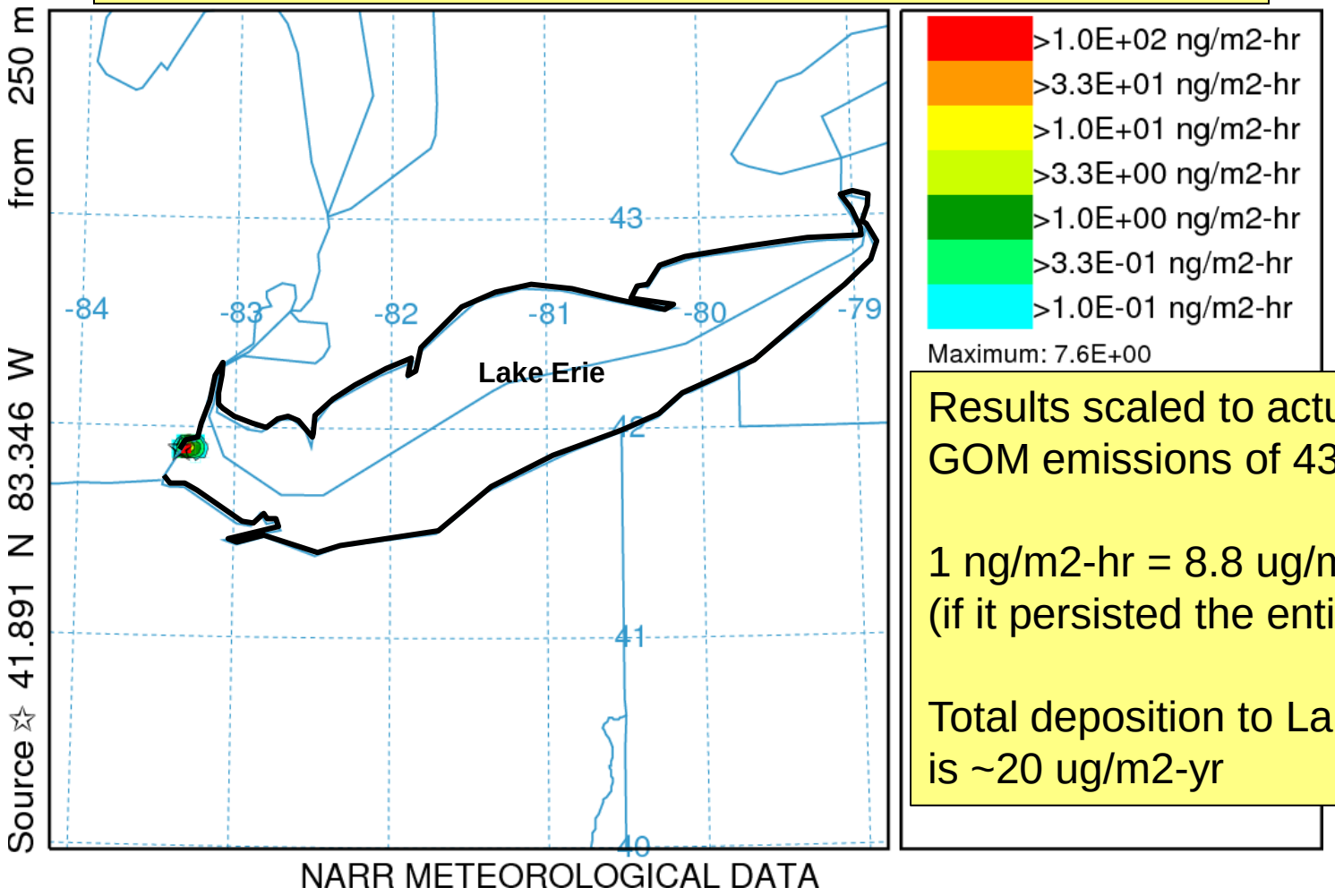
Modeling – Comprehensive Fate and Transport Simulations

- Emissions inventory
- Gridded meteorological data
- Simulate the dispersion, chemical transformation, and wet and dry deposition of mercury emitted to the air
- Source-attribution and source-receptor information captured
- HYSPLIT-Hg developed over the last ~10 years with specialized algorithms for simulation of atmospheric mercury

Anthropogenic Mercury Emissions (ca. 2005)



Simulation of Gaseous Oxidized Mercury (GOM) emissions from one power plant on the shore of Lake Erie: hourly deposition estimates for the first two weeks in May 2005

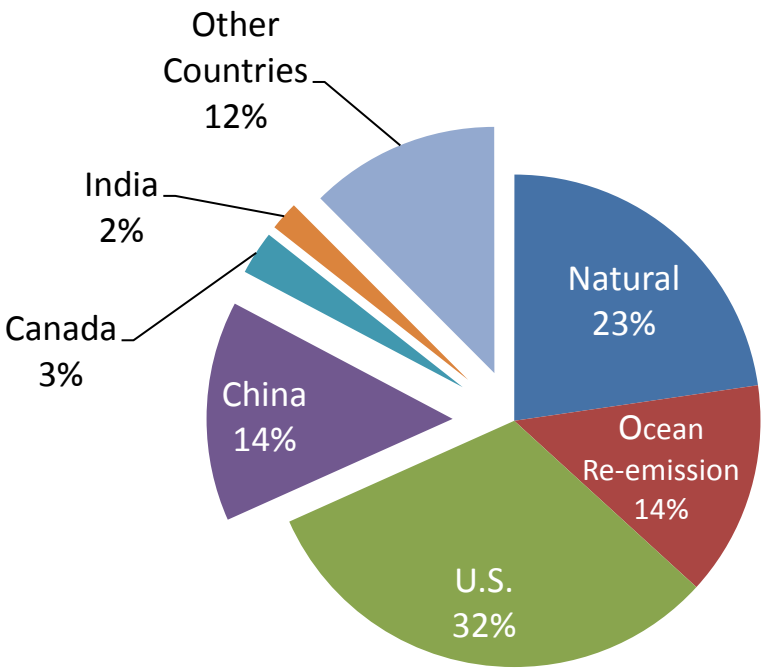


Results scaled to actual GOM emissions of 43.6 g/hr

1 ng/m2-hr = 8.8 ug/m2-yr (if it persisted the entire year)

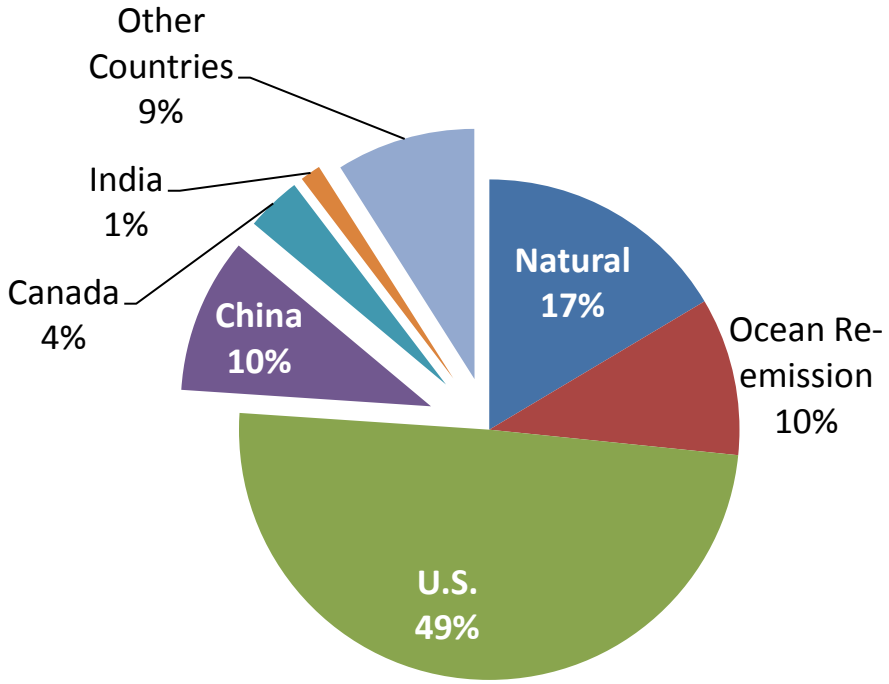
Total deposition to Lake Erie is ~20 ug/m2-yr

Sources of Mercury Deposition to the Great Lakes Basin 2005 Baseline Analysis

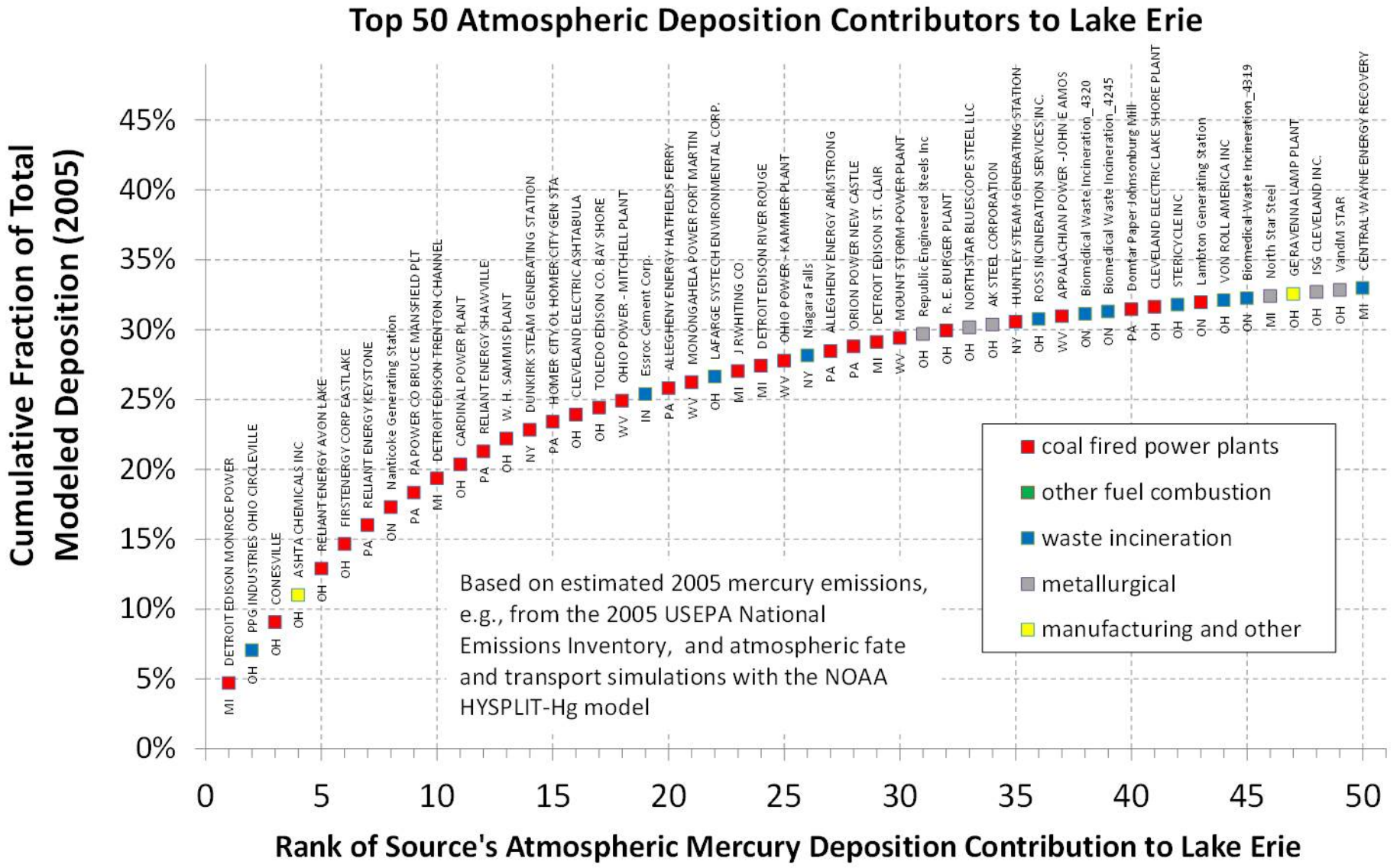


Total = 11,300 kg/yr

Sources of Mercury Deposition to the Lake Erie Basin 2005 Baseline Analysis



Total = 2,300 kg/yr


Top 50 Atmospheric Deposition Contributors to Lake Erie
Cumulative Fraction of Total Modeled Deposition (2005)
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
0
5
10
15
20
25
30
35
40
45
50
Rank of Source's Atmospheric Mercury Deposition Contribution to Lake Erie
MI DETROIT EDISON MONROE POWER
OH PPG INDUSTRIES OHIO CIRCLEVILLE
OH CONESVILLE
OH ASHTA CHEMICALS INC
OH RELIANT ENERGY AVON LAKE
OH FIRSTENERGY CORP EASTLAKE
PA RELIANT ENERGY KEYSTONE
ON Nanticoke Generating Station
PA PA POWER CO BRUCE MANSFIELD PLT
MI DETROIT EDISON TRENTON CHANNEL
OH CARDINAL POWER PLANT
PA RELIANT ENERGY SHAWVILLE
OH W. H. SAMMIS PLANT
NY DUNKIRK STEAM GENERATING STATION
PA HOMER CITY OL HOMER CITY GEN STA
OH CLEVELAND ELECTRIC ASHTABULA
OH TOLEDO EDISON CO. BAY SHORE
WV OHIO POWER - MITCHELL PLANT
IN Essroc Cement Corp.
PA ALLEGHENY ENERGY HATFIELDS FERRY
WV MONONGAHELA POWER FORT MARTIN
OH LAFARGE SYSTECH ENVIRONMENTAL CORP.
MI J R WHITING CO
MI DETROIT EDISON RIVER ROUGE
WV OHIO POWER - KAMMER PLANT
NY Niagara Falls
PA ALLEGHENY ENERGY ARMSTRONG
PA ORION POWER NEW CASTLE
MI DETROIT EDISON ST. CLAIR
WV MOUNT STORM POWER PLANT
OH Republic Engineered Steels Inc
OH R. E. BURGER PLANT
OH NORTHSTAR BLUESCOPE STEEL LLC
OH AK STEEL CORPORATION
NY HUNTLEY STEAM GENERATING STATION
OH ROSS INCINERATION SERVICES INC.
WV APPALACHIAN POWER - JOHN E AMOS
ON Biomedical Waste Incineration_4320
ON Biomedical Waste Incineration_4245
PA Domtar Paper Johnsonburg Mill
OH CLEVELAND ELECTRIC LAKE SHORE PLANT
OH STERICYCLE INC
ON Lambton Generating Station
OH VON ROLL AMERICA INC
ON Biomedical Waste Incineration_4319
MI North Star Steel
OH GE RAVENNA LAMP PLANT
OH ISG CLEVELAND INC.
OH VandM STAR
MI CENTRAL WAYNE ENERGY RECOVERY
Based on estimated 2005 mercury emissions, e.g., from the 2005 USEPA National Emissions Inventory, and atmospheric fate and transport simulations with the NOAA HYSPLIT-Hg model
coal fired power plants
other fuel combustion
waste incineration
metallurgical
manufacturing and other