Dry Deposition of Atmospheric Mercury to the Great Salt Lake

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Outline

- Goals and Objectives
- AMNet Site Description
- Annual, Seasonal, and Diurnal Mercury Variations
- Dry Deposition Model Description
- Dry Deposition Estimates
- Conclusions

Objectives (2009-2012)

1) Characterize the annual, seasonal, and daily variations of speciated atmospheric mercury concentrations near the Great Salt Lake

2) Determine whether the UT96 site is representative of urban, rural or mixed conditions for atmospheric Hg

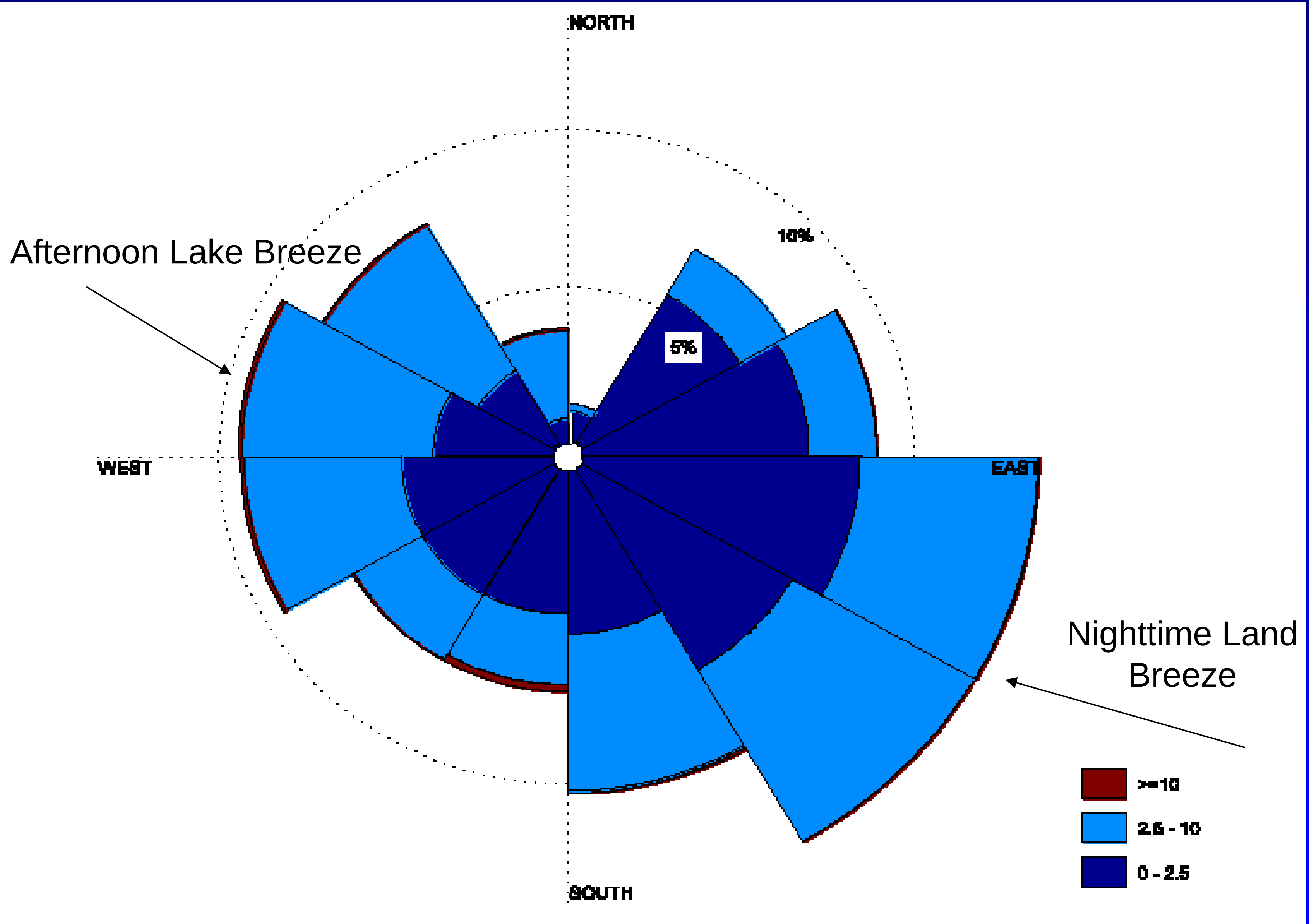
3) Use data from the UT96 site to estimate the dry deposition of Hg to the Great Salt Lake

AMNet Sites


Alert, Nunavut
Atmospheric Mercury Sites
AMNet Sites
CAMNET
EPA CAMD 8/2010

UT96 Site Location

Meteorological Wind Rose



Instrumentation

- Tekran Mercury Monitoring System
- Micrometeorological Measurement System
- 8-Stage Rotating Drum Impactor

Speciated Mercury and PM Measurements

Campbell Scientific Inc.
CSAT 3D Sonic Anemometer

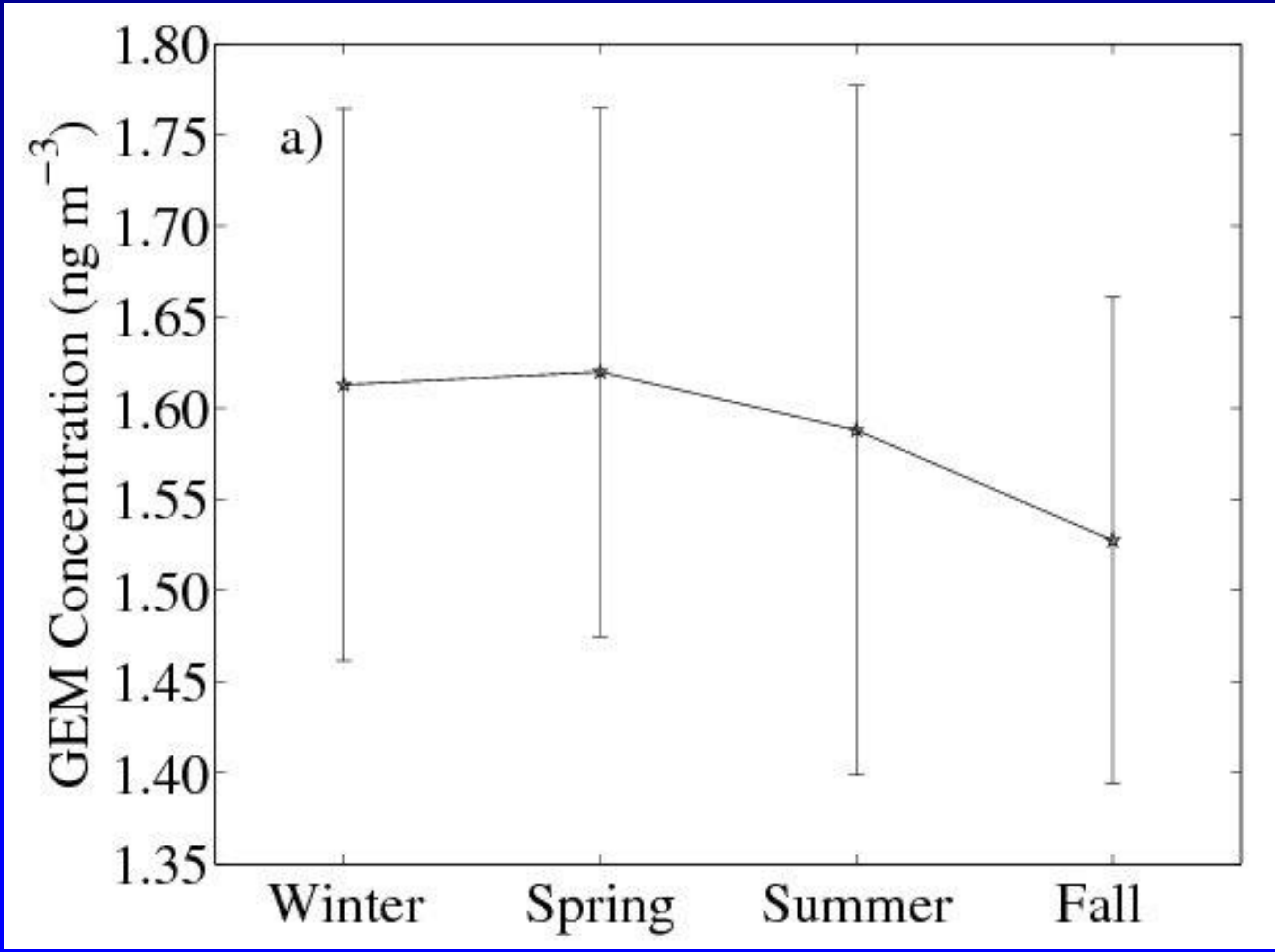
- 7.44 m height
- 10 Hz measurements
  - 3D wind
  - Temperature
- CR 1000 datalogger

Annual Statistics

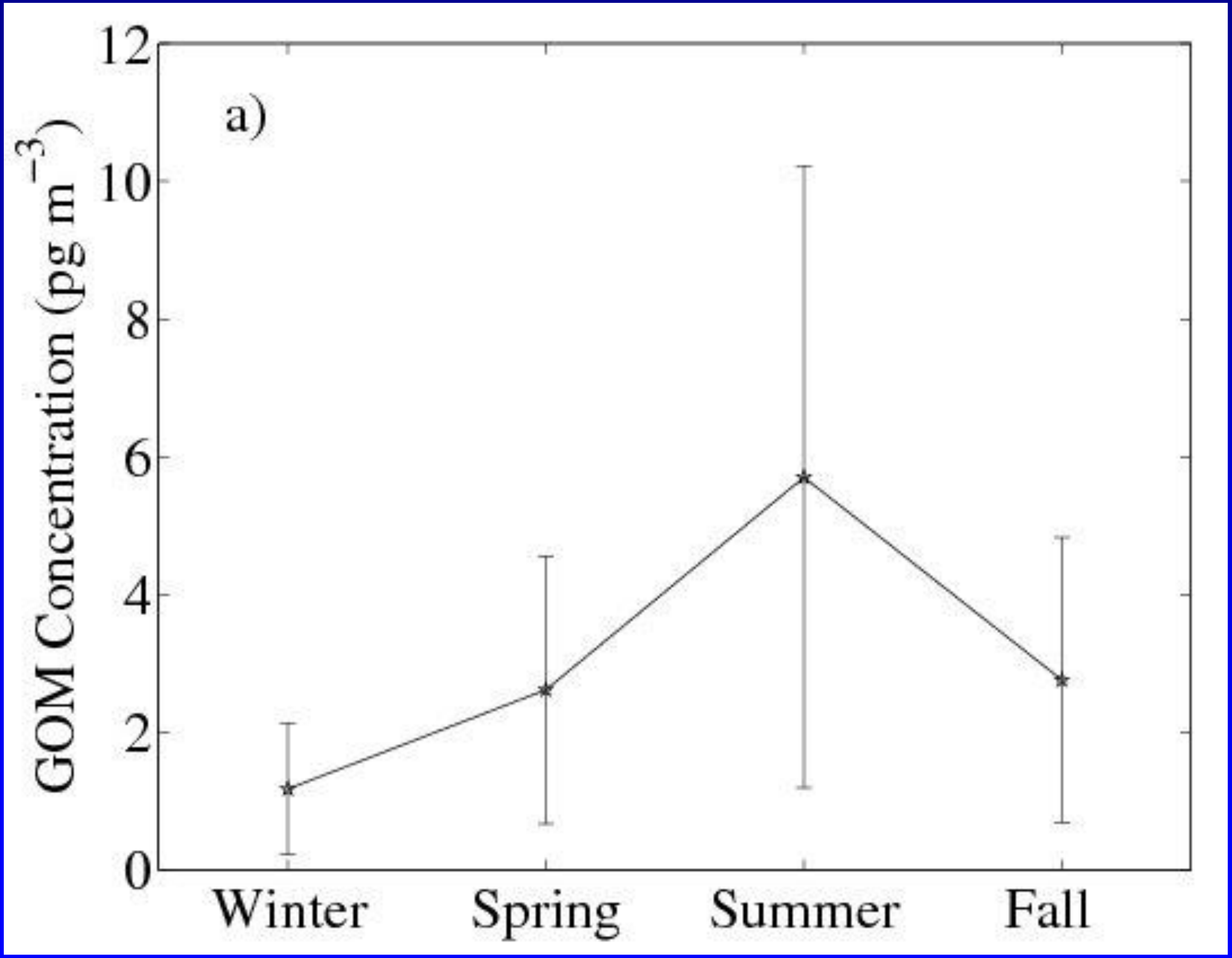
(July 1, 2009- June 30, 2012)

	GEM ($ng\ m^{-3}$)	GOM ($pg\ m^{-3}$)	PBM ($pg\ m^{-3}$)
Mean	1.63 ± 0.57	7.4 ± 14.4	10.0 ± 18.2
Median	1.59	5.8	2.6
Minimum	<0.4	0.0	0.0
Maximum	64.5	225.6	803.2

GEM Seasonal Variations
(July 1, 2009- June 30, 2012)

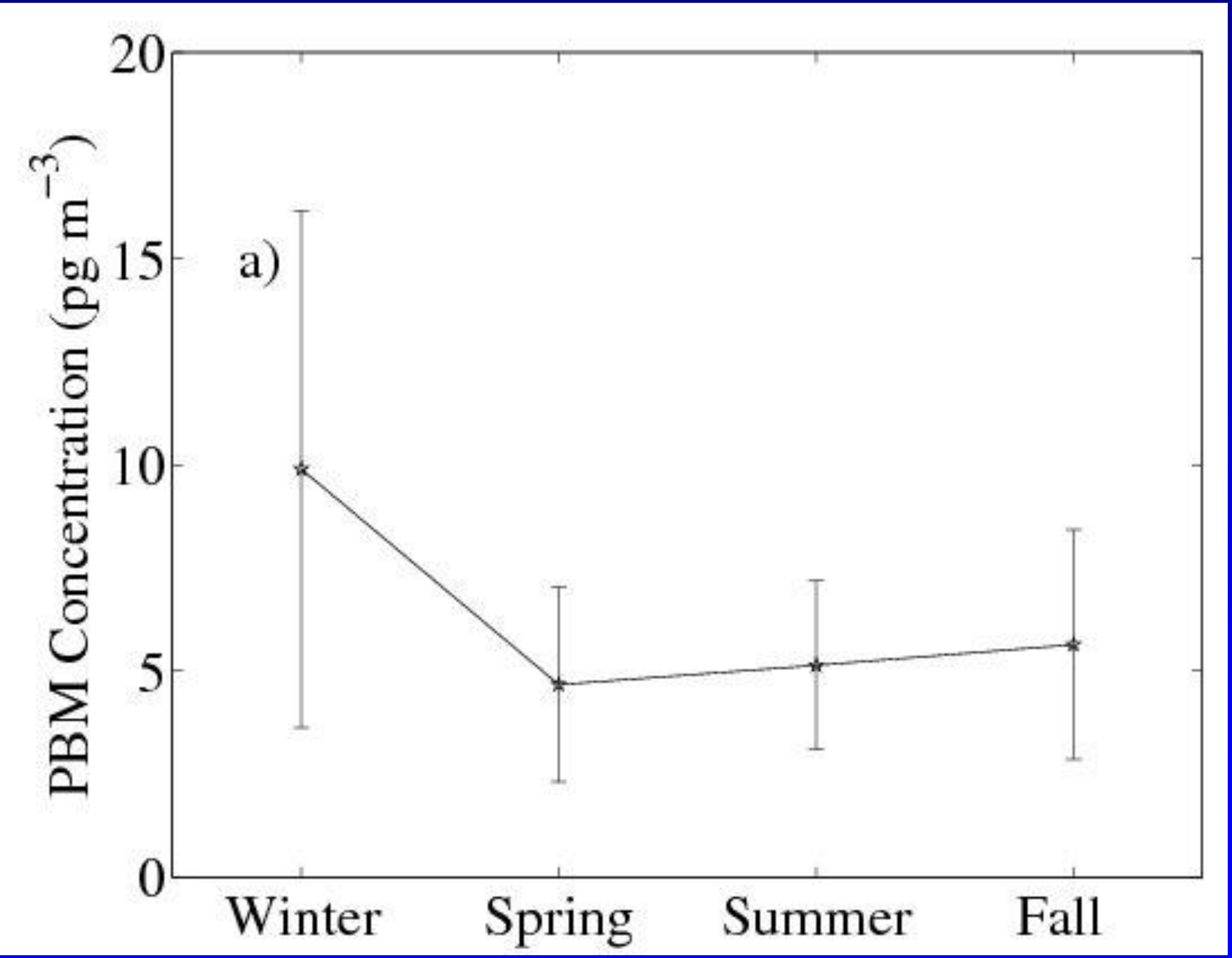


GOM Seasonal Variations
(July 1, 2009- June 30, 2012)



PBM Seasonal Variations

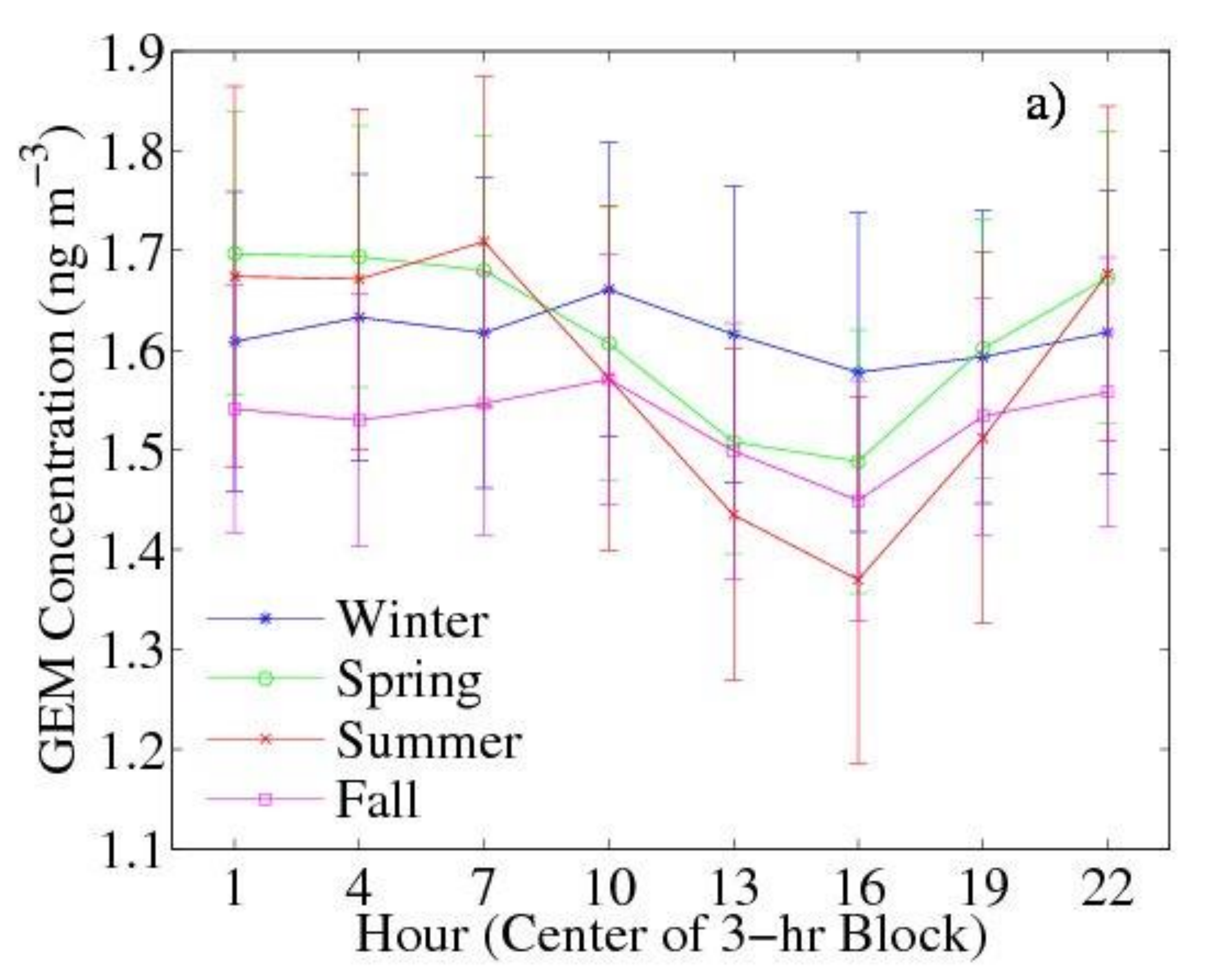
(July 1, 2009- June 30, 2012)



GEM Seasonal Variations
(July 1, 2009- June 30, 2012)

	GEM	GOM	PBM
Winter	99.3%	0.1%	0.6%
Spring	99.5%	0.2%	0.3%
Fall	99.3%	0.4%	0.3%
Summer	99.4%	0.2%	0.4%

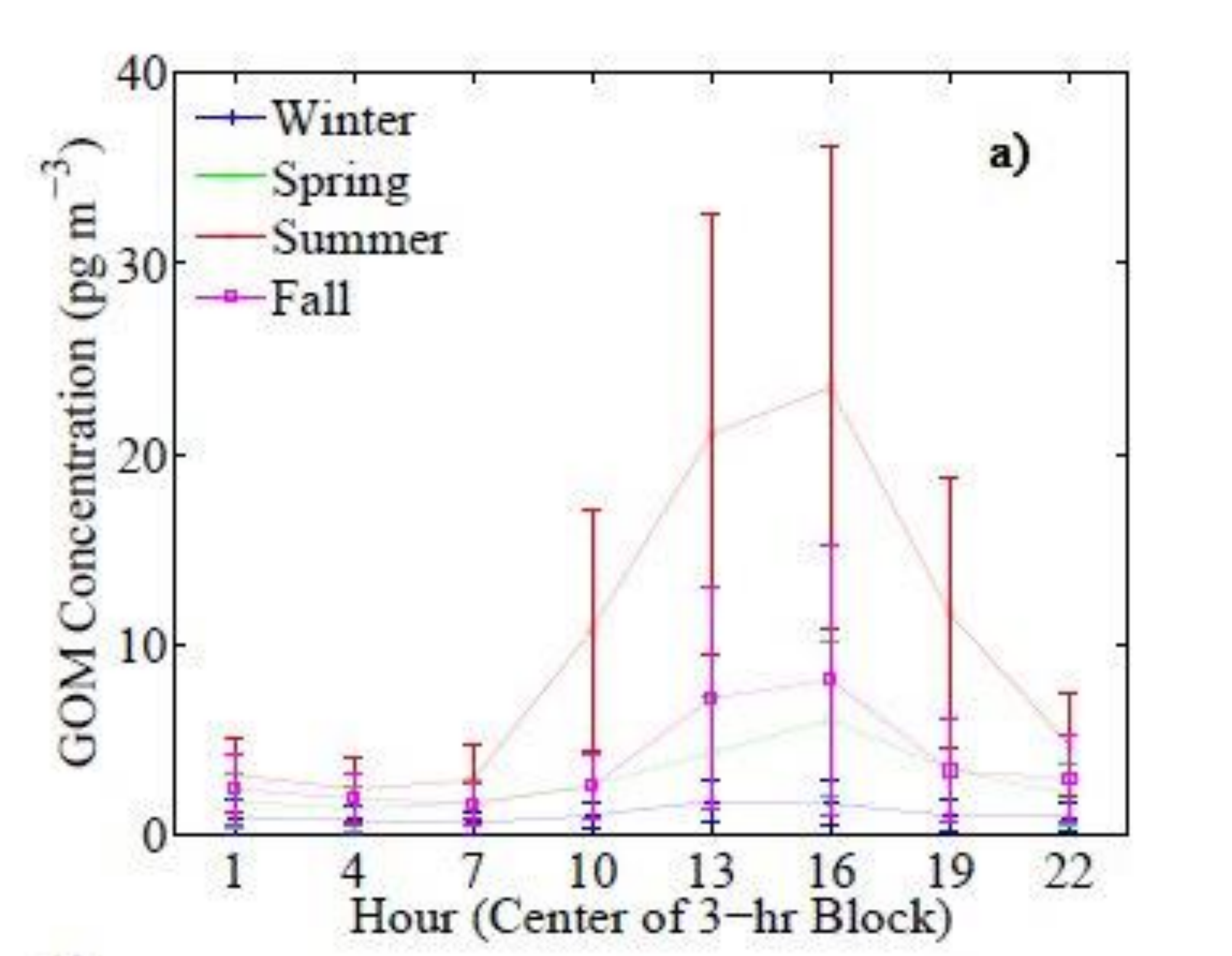
Diurnal GEM Cycles



Afternoon minimum could result from:

1) Higher deposition velocities during afternoon
2) Chemical transformation of GEM to GOM and/or PBM
3) Dilution of GEM through entrainment of free-tropospheric air

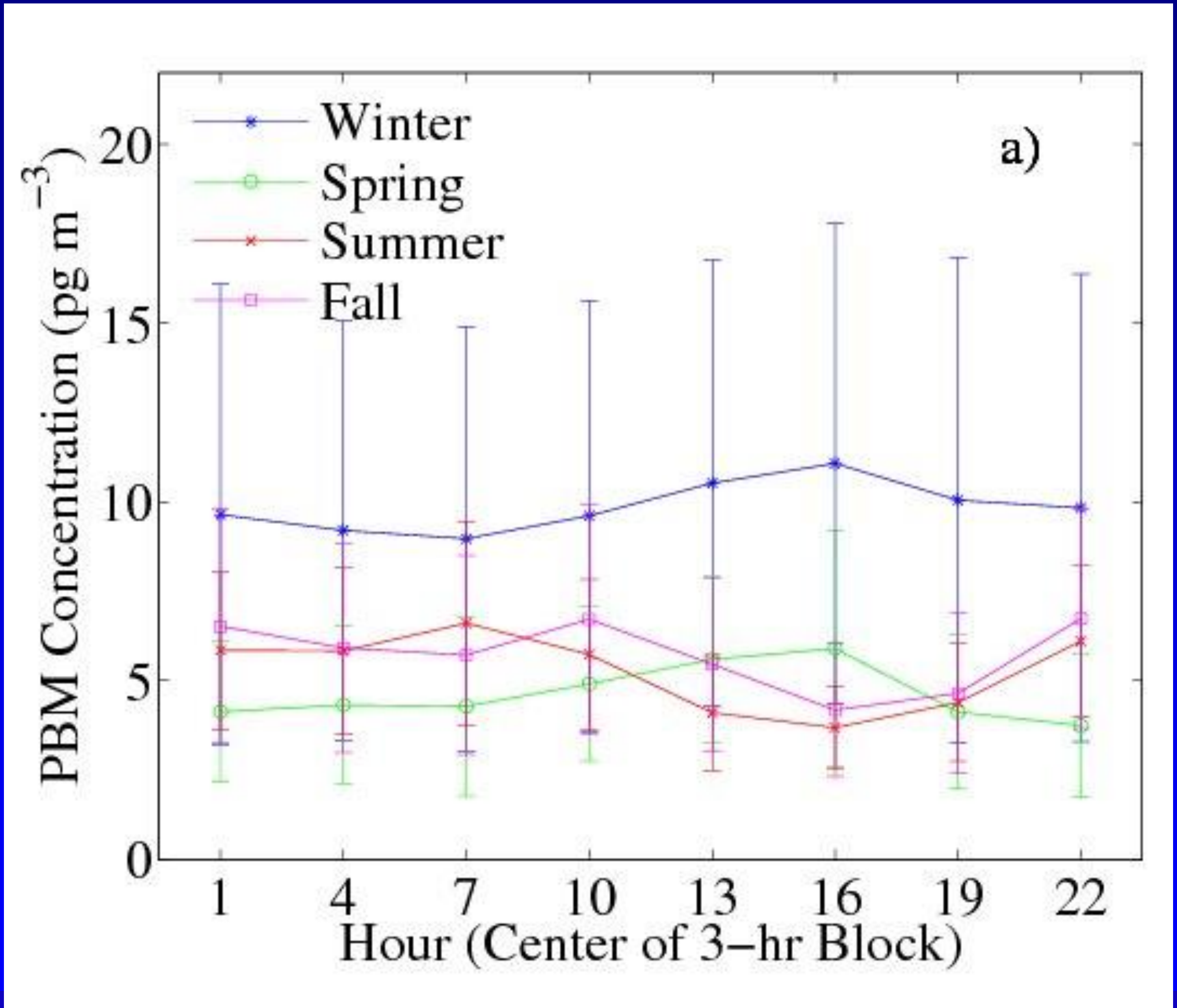
Diurnal GOM Cycles



Afternoon maximum could result from:

1) Chemical transformation of GEM to GOM
2) Entrainment of air from the free-troposphere

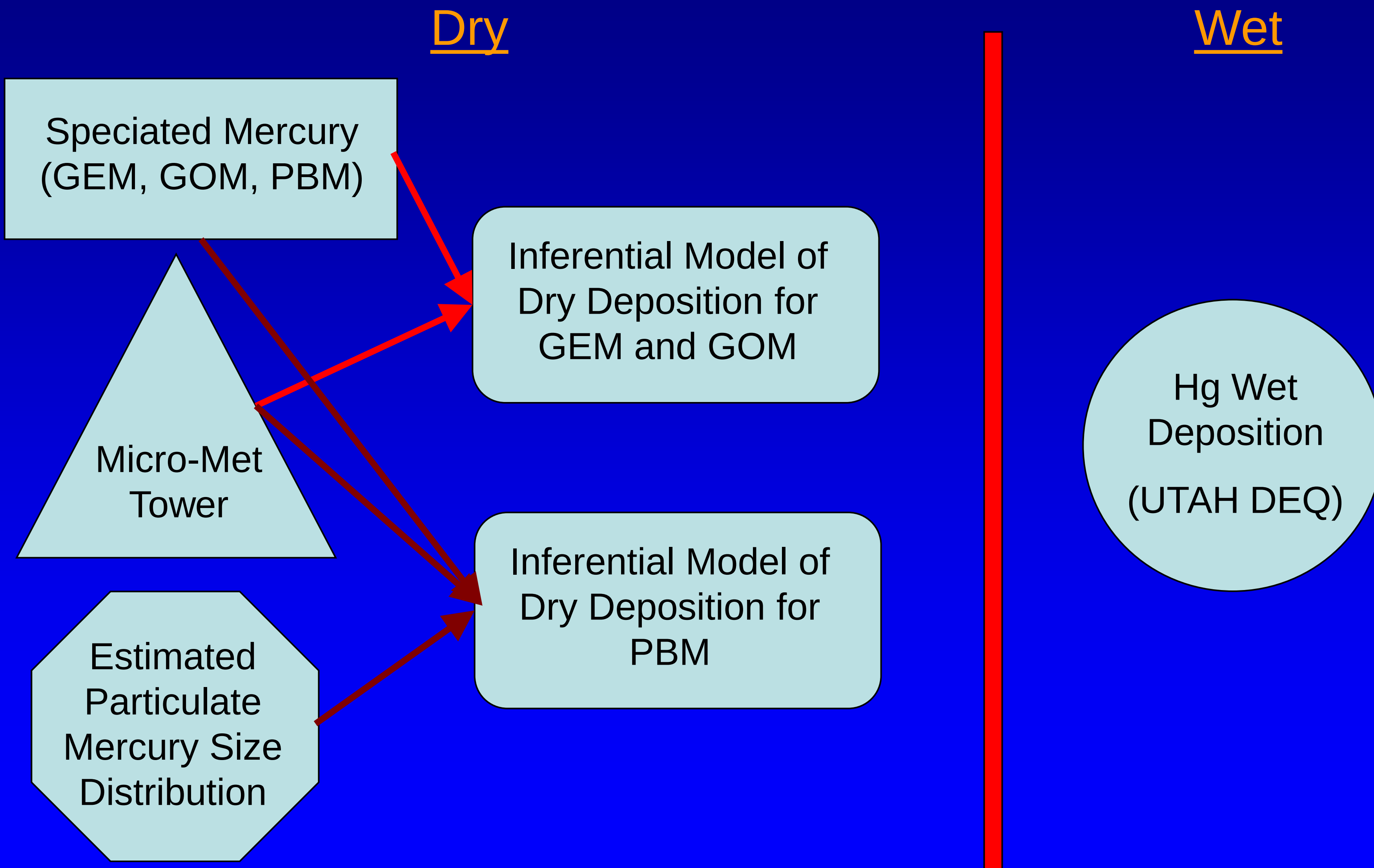
Diurnal PBM Cycles



Afternoon minimum could result from:

1) Higher deposition velocities during afternoon
2) Conversion of PBM to GOM and/or GEM
3) Dilution of PBM through entrainment of free-tropospheric air

Mercury Deposition



Hg Dry Deposition Flux (F_{Hg})

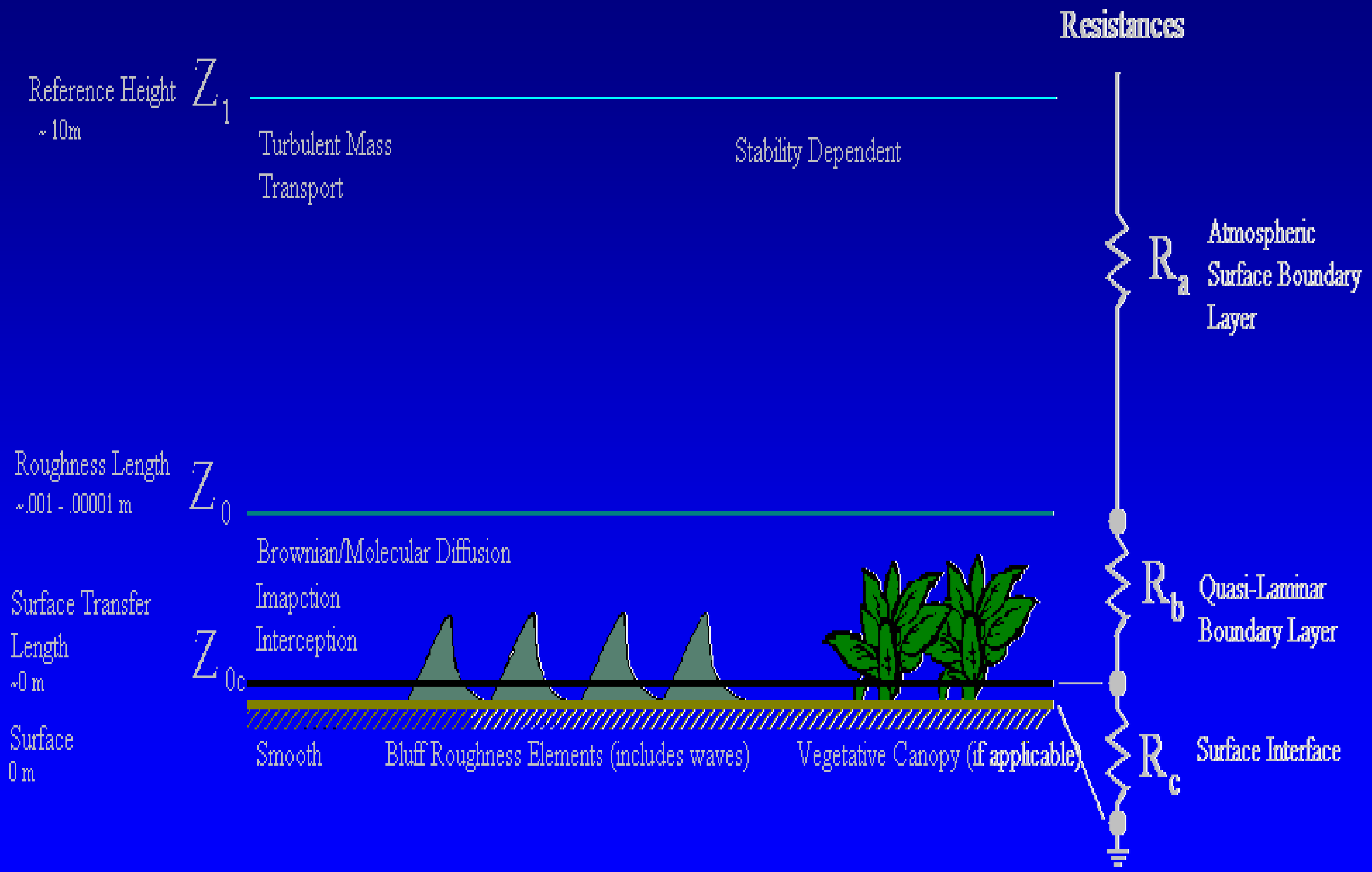
$$F_{Hg} = -V_d C_{Hg}$$

V_d = deposition velocity
C_{Hg} = speciated mercury concentration

Resistance Model for V_d

$$V_d = \frac{1}{R_a + R_b + R_c + R_a R_b V_s} + V_s$$

R_a = aerodynamic resistance
R_b = boundary layer resistance
R_c = surface layer resistance
V_s = settling velocity (for particles only)



Resistances
Reference Height
~ 10m
Z_1
Turbulent Mass
Transport
Stability Dependent
R_a
Atmospheric
Surface Boundary
Layer
Roughness Length
~.001 - .00001 m
Z_0
Brownian/Molecular Diffusion
Imapction
Interception
R_b
Quasi-Laminar
Boundary Layer
Surface Transfer
Length
~0 m
Z_{0c}
Surface
0 m
Smooth
Bluff Roughness Elements (includes waves)
Vegetative Canopy (if applicable)
R_c
Surface Interface

Aerodynamic Resistance (R_a)

$$\zeta_0 = z_0 / L$$

$$R_a = \begin{cases} \dfrac{\Pr}{\kappa u_*}\left[\ln\left(\dfrac{z_1}{z_0}\right) + 4.7(\zeta - \zeta_0)\right] & \text{(stable)} \\ \dfrac{\Pr}{\kappa u_*}\ln\left(\dfrac{z_1}{z_0}\right) & \text{(neutral)} \\ \dfrac{\Pr}{\kappa u_*}\left[\ln\left(\dfrac{z_1}{z_0}\right) + 2\left(\dfrac{(1+\eta_0)}{(1+\eta)}\right)\right] & \text{(unstable)} \end{cases}$$

$$\eta_0 = \sqrt{(1-9\zeta_0)}$$

$$\eta = \sqrt{(1-9\zeta)}$$

Boundary Layer Resistance (R_b)

Gases

$$R_b = \frac{2}{\kappa u_*}\left(\frac{Sc}{\Pr}\right)^{2/3}$$

Boundary Layer Resistance (R_b)

Particles

$$R_b = \frac{1}{3(E_B + E_{IM} + E_{IN})R_1}$$

Brownian Diffusion related to Schmidt Number and Surface Roughness

Impaction with the surface. Function of Stokes Number

Interception by surface elements @ GSL $E_{IN} = 0$

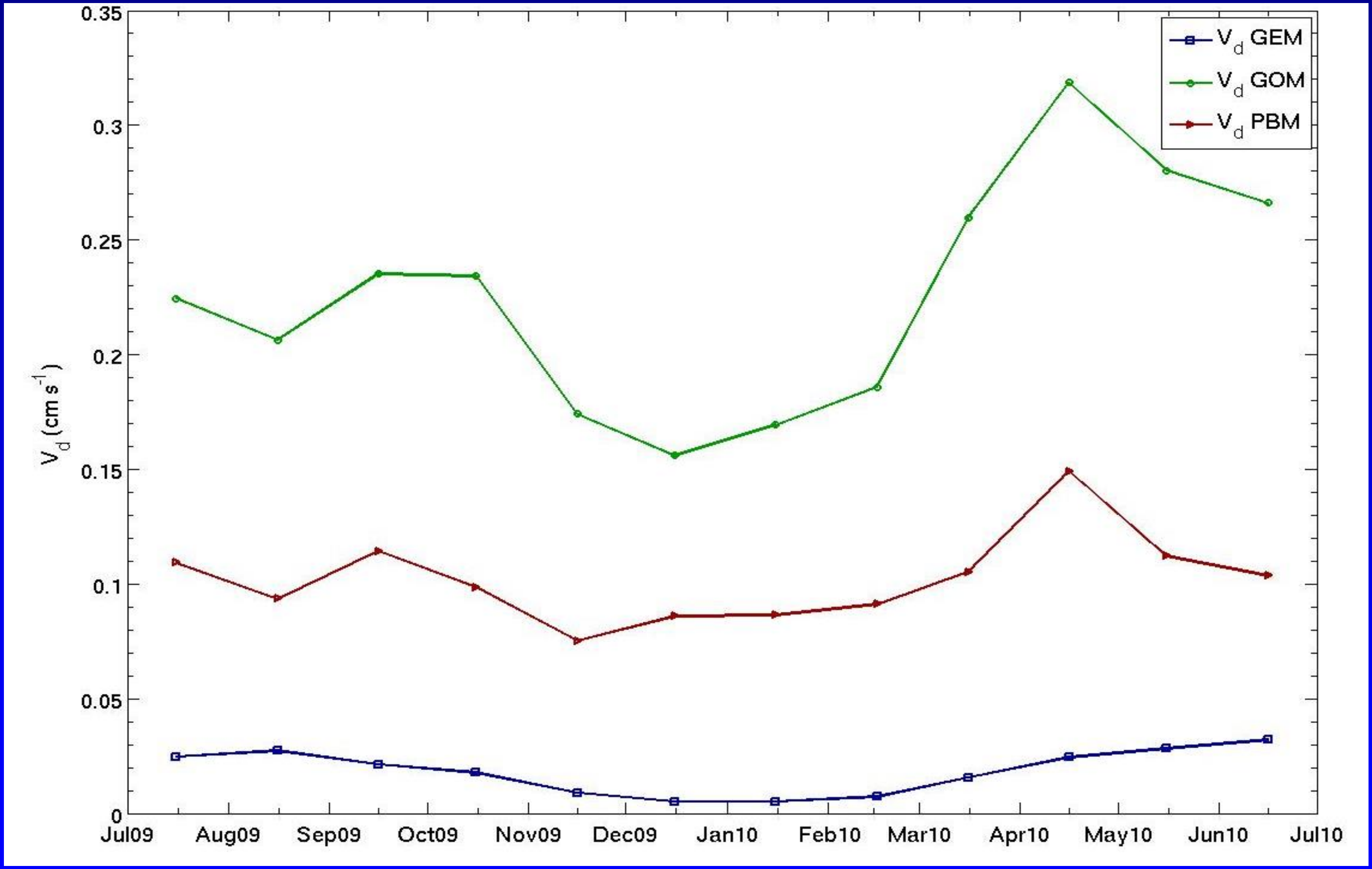
fraction of particles that stick @ GSL R_1=1

Surface Layer Resistance (R_c)

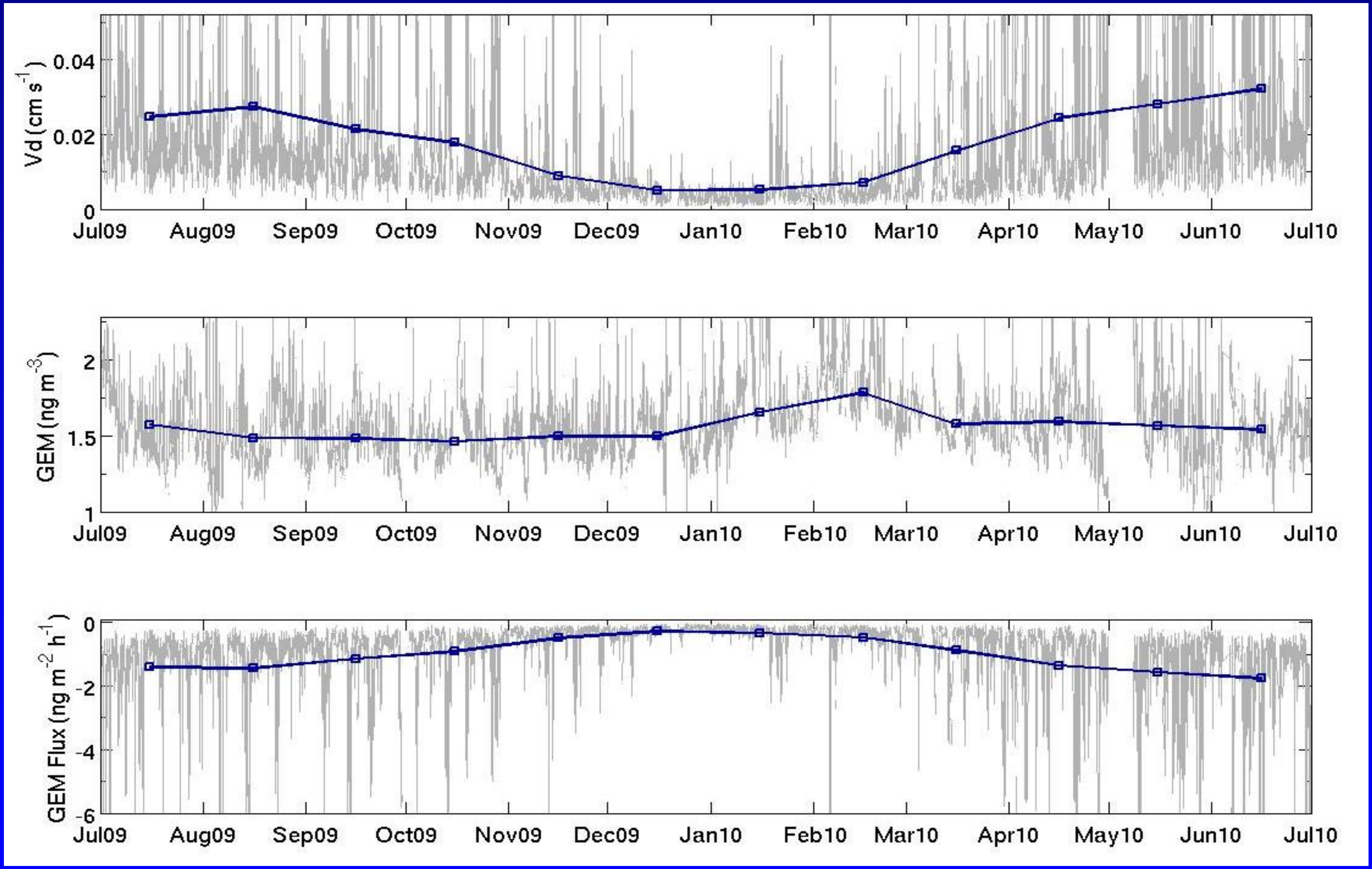
$$R_C = \frac{1}{K_L H_A} + \frac{1}{K_G}$$

K_L = liquid-phase mass transport coefficient
K_G = gas-phase mass transport coefficient
H_A = Dimensionless Henry's Law coefficient

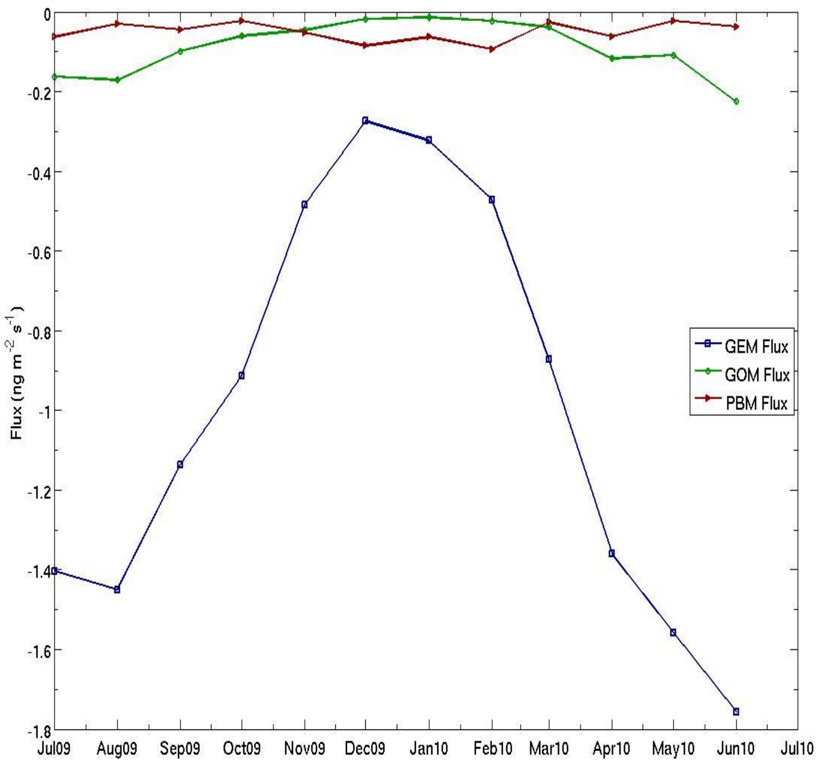
Monthly-Averaged Dry Deposition Velocities

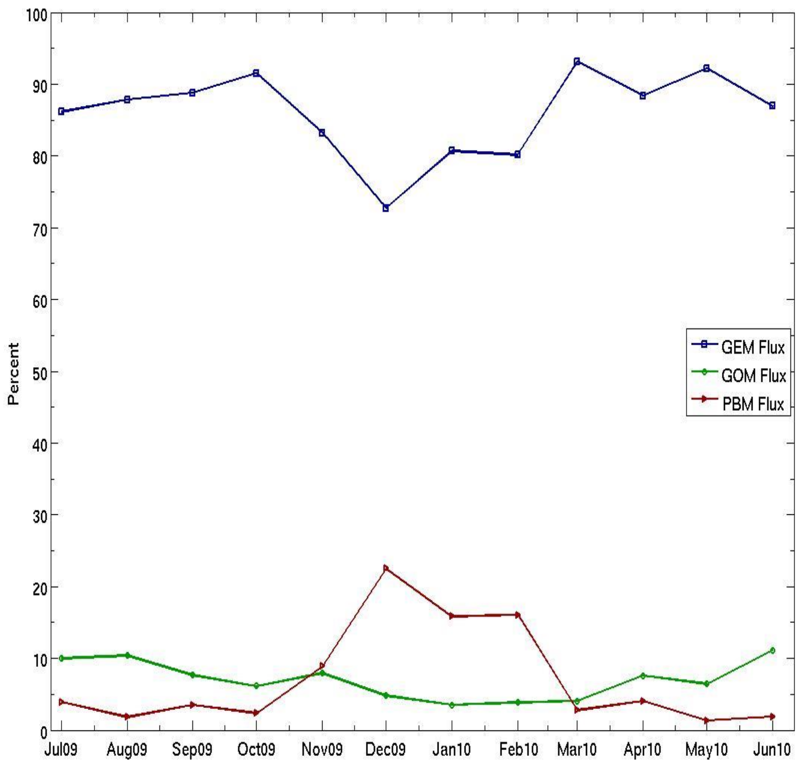


GEM Flux ($F=-V_dC_{Hg}$)



Flux Comparison





Dry Deposition Totals

($\mu g\ m^{-2}\ yr^{-1}$)

	Year 1	Year 2	Year 3
GEM	8.8	9.9	10.7
GOM	0.5	0.5	0.4
PBM	0.2	0.2	0.3
Total	9.5	10.6	11.4

Mercury Influx Pathways

- Dry Deposition
  - 10.5 µg m^{-2} yr^{-1}
- Wet Deposition (MDN – UT DEQ)
  - 8.1 µg m^{-2} yr^{-1}
- Riverine influx (Naftz et al. 2009)
  - 1.9 µg m^{-2} yr^{-1}
- Coarse PBM (Carling et al. 2012)
  - 3 µg m^{-2} yr^{-1}
- Total
  - 23.5 µg m^{-2} yr^{-1}

Conclusions

- The UT96 site is a mixed rural/urban receptor site
- The UT06 site is periodically impacted by SIGNIFICANT local sources
- Dry deposition is the dominant influx pathway for mercury to the Great Salt Lake accounting for 45% of the total Hg input
- Wet deposition is responsible for 34% of the total Hg input
- Riverine input is responsible for 8% of the total Hg input
- Coarse PBM could contribute more than 10% of the total Hg input