

New Science Implementation in CMAQ-Hg: Test over a Continental United States Domain

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4th Annual CMAS Models-3 User's Conference

Research Triangle Park, NC

September 26, 2005

Acknowledgements

- *US Environmental Protection Agency (USEPA)*
- *Texas Commission on Environmental Quality (TCEQ)*
- *Gulf Coast Hazardous Substance Research Center*
- Simo Pehkonen, National University of Singapore
- Steve Lindberg, Oak Ridge National Laboratory (Retired)
- Daewon Byun, the University of Houston
- Russell Bullock, USEPA ORD
- Thomas Braverman, USEPA OAQPS
- Christian Seigneur, Atmospheric & Environmental Research

Atmospheric Mercury

	Elemental (GEM)	Divalent (RGM, DAM, PHg)
Primary Source	Emissions	Emission, Products of Hg(0)
Abundance	> 95%	< 5 %
Phase	Gas	Gas, aqueous, solid
Water Solubility	Low (0.3 μM)	High (a few mM)
Henry's Constant	0.11 M/atm	$10^4 - 10^7$ M/atm
Lifetime	0.5 - 2 years	Days - Weeks
Transport	Long Range	Relatively short
Background Concentration	1~4 ng/m ³	Up to 900 pg/m ³ (RGM) 0.025~0.5 nM (DAM)

What makes Hg unique?

- Very small concentrations (often in sub-ppt levels) compared to criterion air pollutants
- Its “gaseous” forms have little human health concerns
- Has multiple chemical forms with diverse properties
- Has “its own” chemistry cycle – does not affect other air pollutants significantly
- Concurrent atmospheric processes involving multiple pollutants affect its transport and deposition
- Transformation occurs in multiple phases in the atmosphere
- Both dry and wet depositions cause problems
- Analytically challenging to measure
- Cycling in the environment

Modeling Atmospheric Hg

- **The Emission**

- Anthropogenic sources
- Natural sources
- Re-emissions?

The Transport – as determined by the advection and diffusion treatment in air quality models.

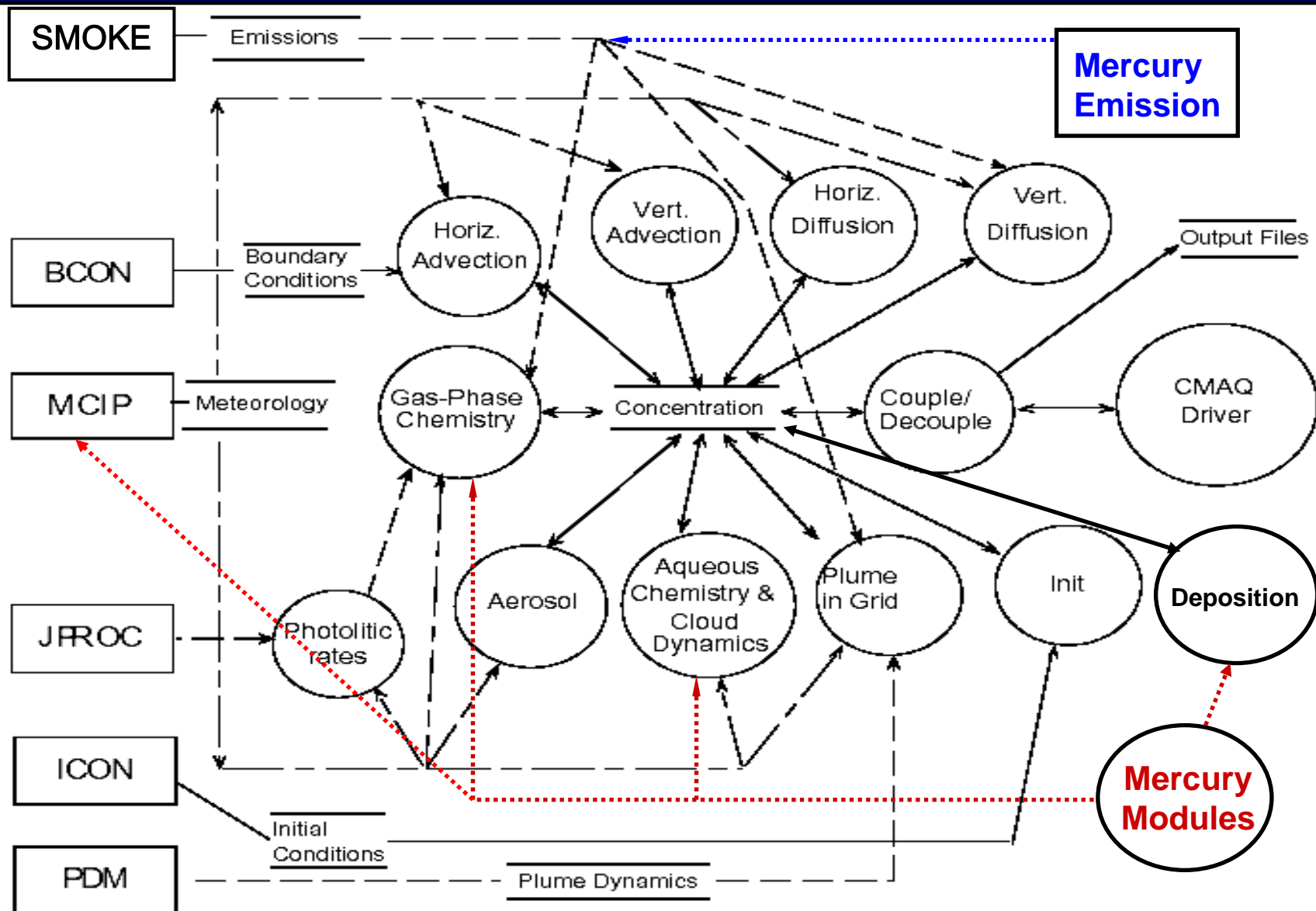
- **The Transformation**

- Gaseous phase – oxidation & product speciation
- Aqueous phase – oxidation, reduction and sorption
- Interfacial transfer – scavenging and evaporation

- **The Deposition**

- Dry deposition – GEM, RGM, PHg
- Wet deposition – Aqueous Hg(II)

CMAQ-Hg Model



CMAQ-Hg (Bullock & Brehme, 2002)

Emission	Anthropogenic (Point & Area)	Veg./re-emission needed
Gas Chemistry	O ₃ , Cl ₂ , H ₂ O ₂ , and OH, PHg as the oxidation product by OH and O ₃	New kinetics available & speciation need revision
Aq. Chemistry	Ox: O ₃ , OH, HOCl, and OCl ⁻	Speciation controlled
	Red: HgSO ₃ , Hg(OH) ₂ +hv, HO ₂	Speciation controlled
Aq. Speciation	SO ₃ ²⁻ , Cl ⁻ , OH ⁻	Major ligands considered but assume constant Cl ⁻
Aq. Sorption	Sorption of Hg(II) to ECA, bi-directional non-eq. kinetics w/ linear sorption isotherm	High sorption constant, no impact based on current formulation
Dry Deposition	V _{dep} of HNO ₃ for RGM deposition	No Hg ⁰ deposition. RGM deposition likely too high
	V _{dep} of I,J modes for PHg deposition	As sulfate deposition
Wet Deposition	Dissolved and Sorbed Hg(II) _{aq}	By precipitation & aqueous concentration

Science Issues in CMAQ-Hg

- Impact of emission natural/re-emission unclear.
- Widely varied kinetic data reported for same mechanisms (e.g., gaseous Hg^0 oxidation by O_3 and OH ; aqueous reduction of Hg(II) by sulfite).
- Uncertain reaction product distribution of gaseous oxidation (e.g., RGM or PHg?).
- Extrapolation of laboratory results may not be appropriate (e.g., aqueous reduction of Hg(II) by HO_2 , gaseous oxidation of Hg^0 by OH and O_3).
- Deposition velocity for both GEM and RGM not treated rigorously.
- Revision needed for sorption scheme in the aqueous phase (cloud water).

Sensitivity Cases

- Case 1: CMAQ-Hg as in Bullock & Brehme (2002)
- Case 2: include vegetative/natural emission in mercury emission inventory
- Case 3: incorporate dry deposition schemes for elemental mercury and RGM (as HgCl_2)
- Case 4: speciate mercury oxidation products to reactive gaseous mercury (RGM)
- Case 5: incorporate new aqueous sorption scheme based on new sorption isotherm
- Case 6: combine the modifications of Cases 2-5

Parameter of interest: wet/dry deposition of mercury

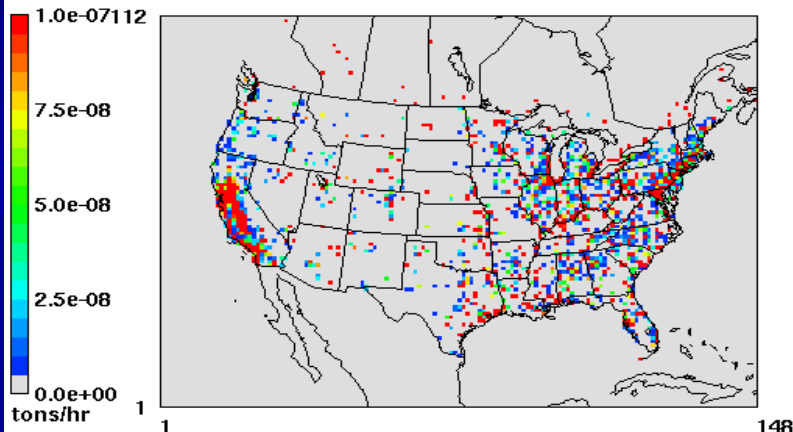
Simulation Details

- Modeling periods: January and July 2001
- Meteorology: 2001 USEPA 36-km MM5 fields in CONUS domain
- Vertical structure: model top 10,000 Pa, 25 layers collapsing into 14 layers
- Emission inventory: NEI99 final Version 3, mercury speciation EI based on Walcek *et al.* (2003); natural / vegetative emission based on Lin *et al.* (2005)
- Chemistry: CB4 + updated mercury mechanisms (Lin and Pehkonen, 1999; Lin *et al.*, 2005)
- Dry deposition: based on Wesley scheme (1989) with updated formulation for GEM and RGM
- Initial and boundary conditions: assumed typical background concentrations for GEM, RGM and PHg

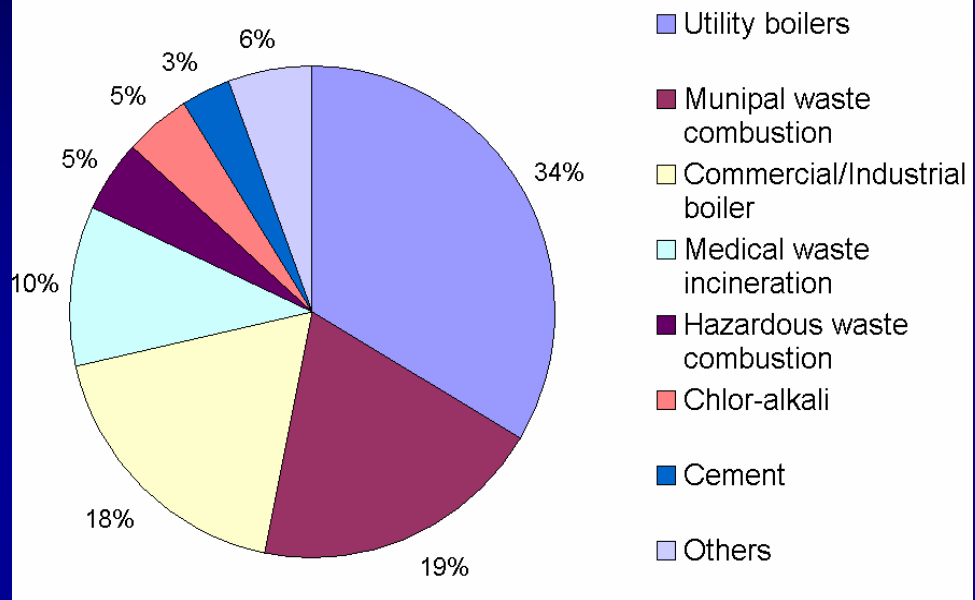
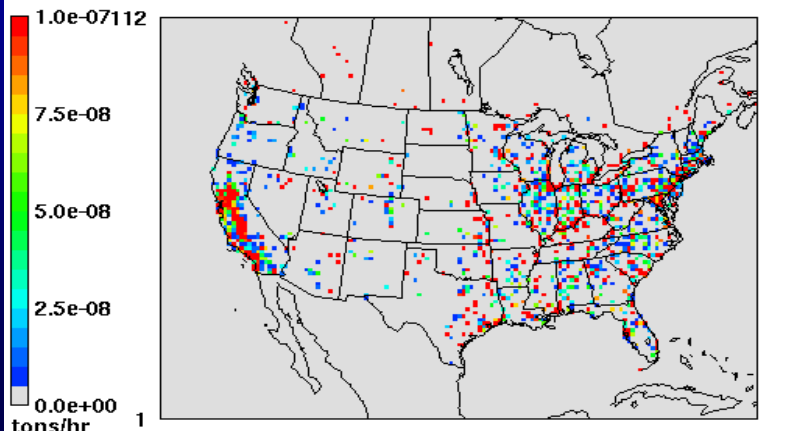
Anthropogenic Mercury Emission Inventory

Anthropogenic Source

Average Hg0



Average HgII

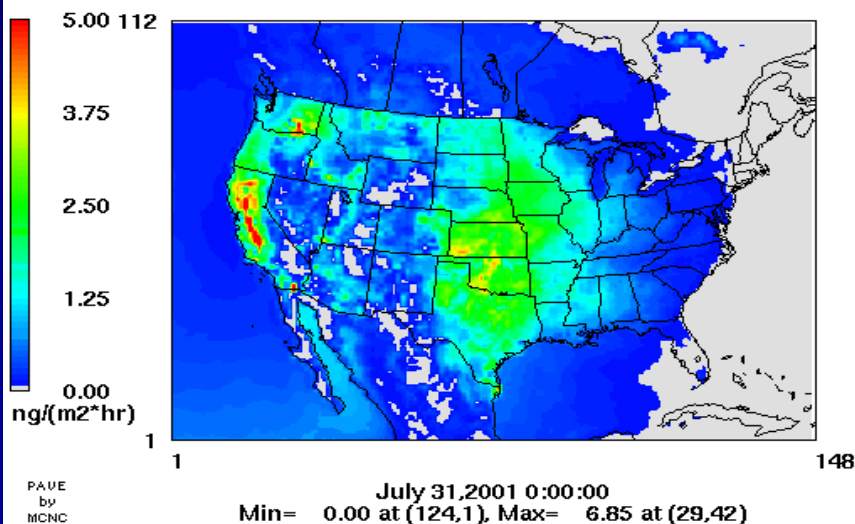


Anthropogenic Mercury Emission
 Total Annual Emission: 142 tons
 Hg(0) Emission: 78 tons
 Hg(II) Emission: 50 tons
 Particulate Hg Emission: 14 tons

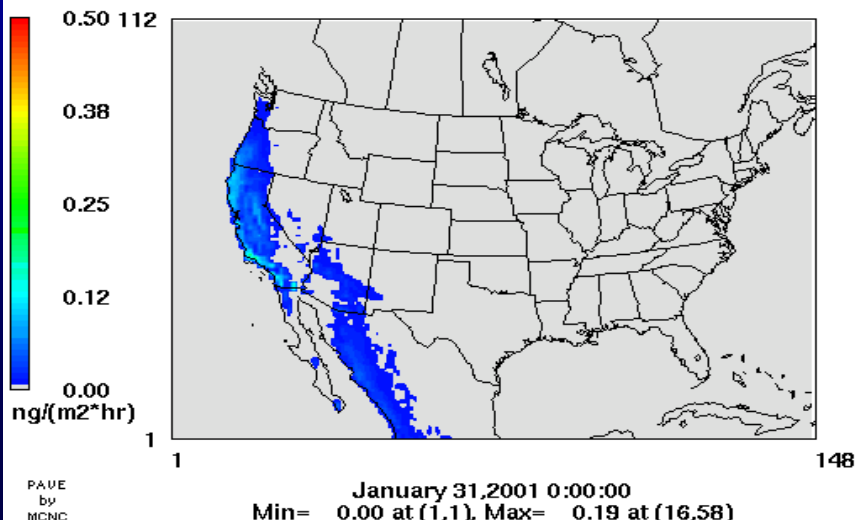
Based on NEI99 Final Version 3

Natural Mercury Emission Inventory

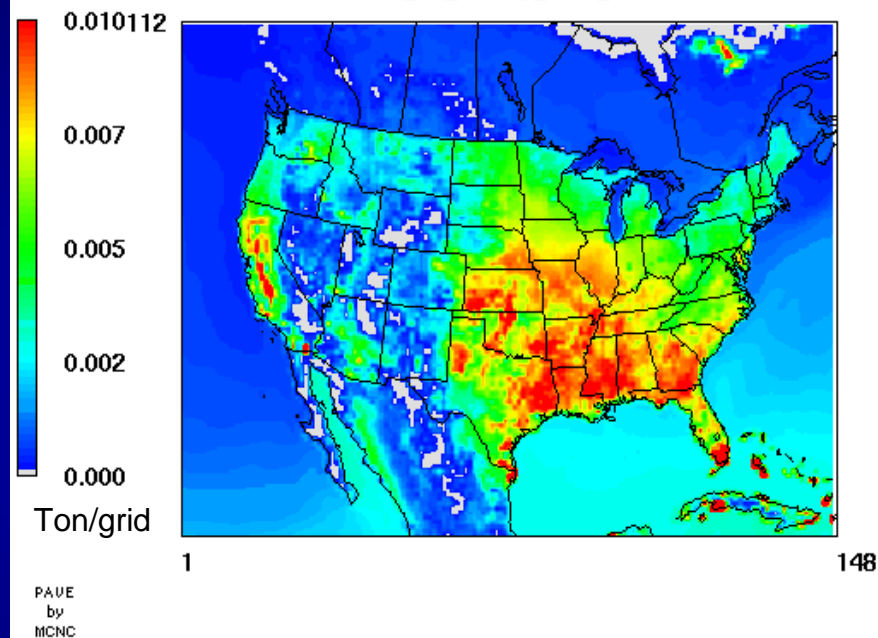
Typical Summer Emission



Typical Winter Emission



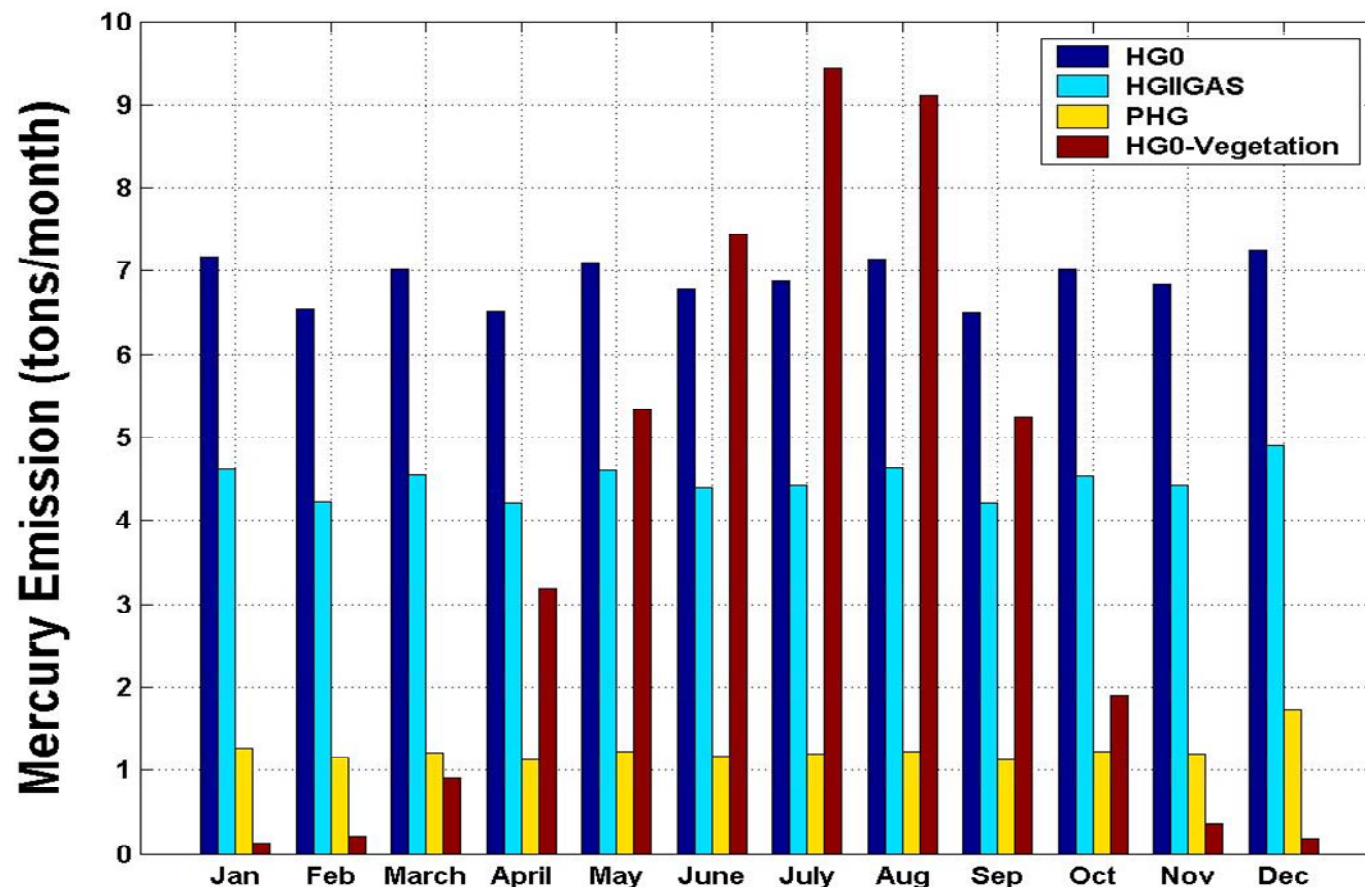
case_40_Yearly_HG0_Total



Annual Natural Emission:
Lower Limit = 31 tons
“Best” Available Estimate = 44 tons
Upper Limit = 136 tons

(Lin et al., 2005)

Anthropogenic vs. Natural*



Anthropogenic Hg Emission based on EPA NEI99 Final Version 3.

*: in the Continental United States.

$$F_{dry} = V_d \times C_g$$

Mercury Deposition

- Dry Deposition (Based on Wesley Scheme)

$$F_{dry} = -V_d \times C_g$$

$$V_d = (R_a + R_b + \mathbf{R_c})^{-1} + V_g$$

$$R_c = \left(\frac{1}{r_{sx} + r_{mx}} + \frac{1}{r_{lux}} + \frac{1}{r_{dc} + r_{clx}} + \frac{1}{r_{ac} + r_{gsx}} \right)^{-1}$$

- Wet Deposition

$$F_{wet} = P \times [Hg^{2+}]_{aq,total}$$

Hg V_{dep} Implementation - R_c

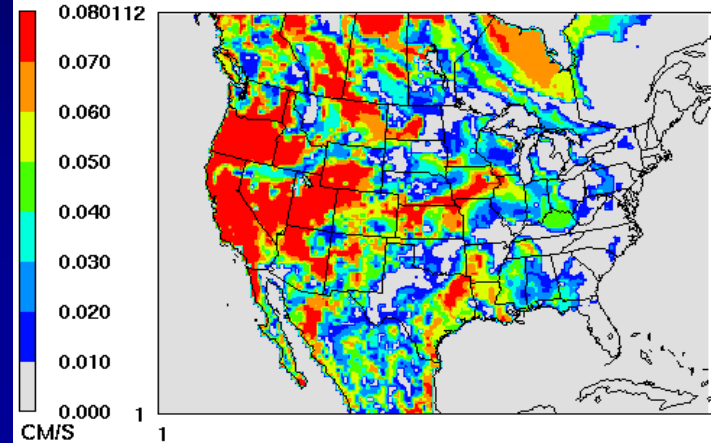
Terms	Formulation	Description	Remarks
r_{dc}	$100[1 + 1000(G + 10)^{-1}] (1 + 10000)^{-1}$	- Buoyant convection resistance	
r_{sx}	$r_s D_{H_2O}/D_x$, where $r_s = r_i \{1 + [200(G + 0.1)^{-1}]^2\} \{400[T_s(40 - T_s)]^{-1}\}$	- Stomatal resistance for substance x	RGM : $D_{RGM} = 0.086 \text{ cm}^2/\text{s}$; $D_{H_2O}/D_{RGM} = 2.53$ GEM : $D_{GEM} = 0.1194 \text{ cm}^2/\text{s}$; $D_{H_2O}/D_{GEM} = 1.82$
r_{clx}	$[k_H/(10^5 r_{clS}) + f_0/r_{clO}]^{-1}$	- Lower canopy resistance	RGM : $K_H = 2.8 \times 10^6 \text{ M atm}^{-1} (\text{HgCl}_2)$ $K_H = 2.7 \times 10^{12} \text{ M atm}^{-1} (\text{HgO})$ $f_0(\text{RGM}) = \mathbf{0.1 \text{ or } 1.0}$ GEM : $K_H = 0.139 \text{ M atm}^{-1}$, $f_0(\text{GEM}) = \mathbf{10^{-5}}$
r_{gsx}	$[k_H/(10^5 r_{gsS}) + f_0/r_{gsO}]^{-1}$	- Ground surf. resistance	
r_{mx}	$(k_H/3000 + 100 f_0)^{-1}$	- Mesophyll resistance	
r_{lux}	$r_{lu} (10^{-5} k_H + f_0)^{-1}$	- Leaf cuticular resist.	
	$[1/(3r_{lu}) + 10^{-7} k_H + f_0/r_{luO}]^{-1}$	- Dew or rain correction	
r_{lus}	100	- Leaf cuticular, SO_2 (Dew)	
	$[1/5000 + 1/(3r_{lu})]^{-1}$	- Rain correction	
r_{luO}	$[1/3000 + 1/(3r_{lu})]^{-1}$	- Leaf cuticular, O_3 (Dew)	
	$[1/1000 + 1/(3r_{lu})]^{-1}$	- Rain correction	

Note: r_i , r_{lu} , r_{clS} , r_{clO} , r_{ac} , r_{gsS} , r_{gsO} are parameters depending on land uses and seasons

Hg Dry Deposition Velocity

GEM

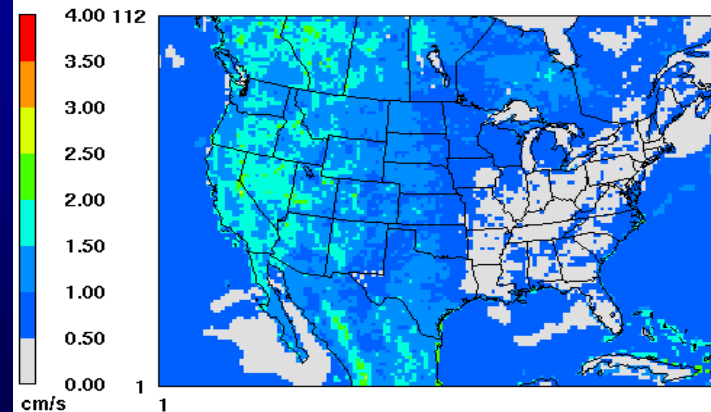
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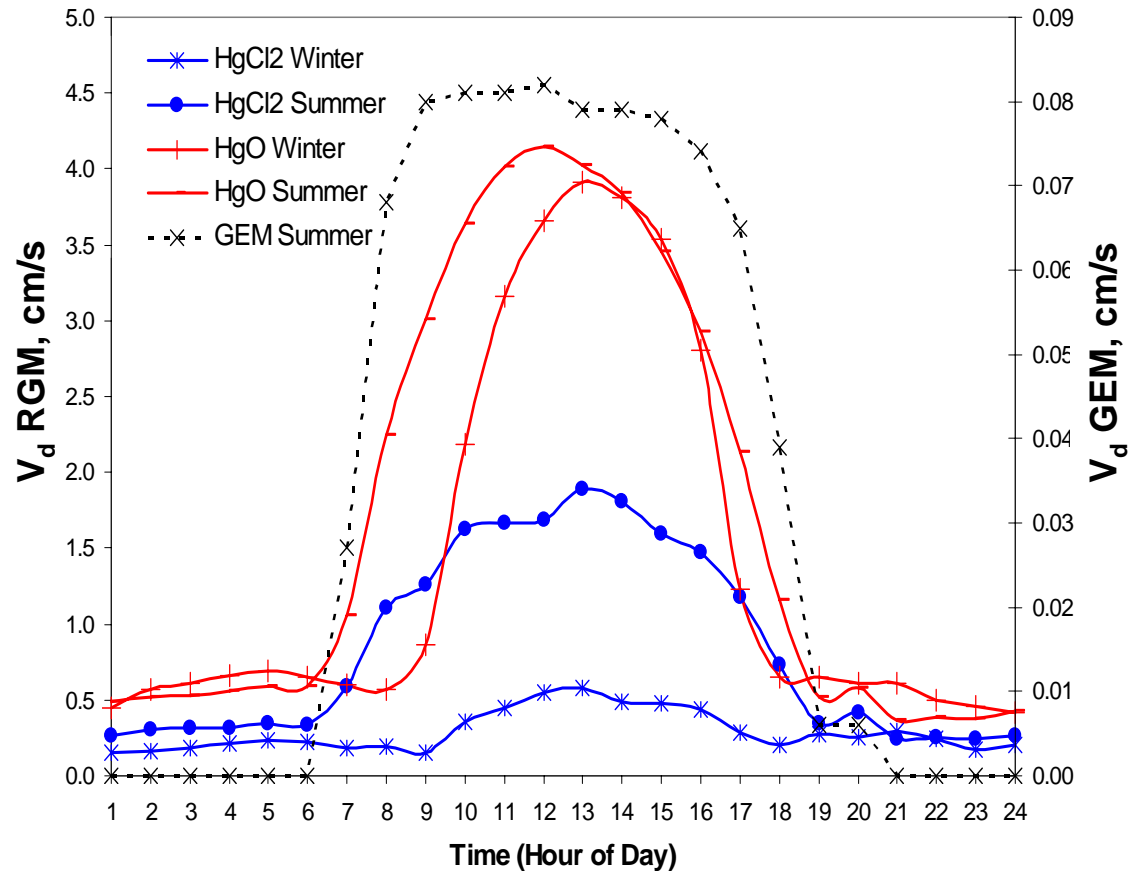
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Min= 0.000 at (110,98), Max= 0.091 at (25,83)

RGM – as HgCl_2

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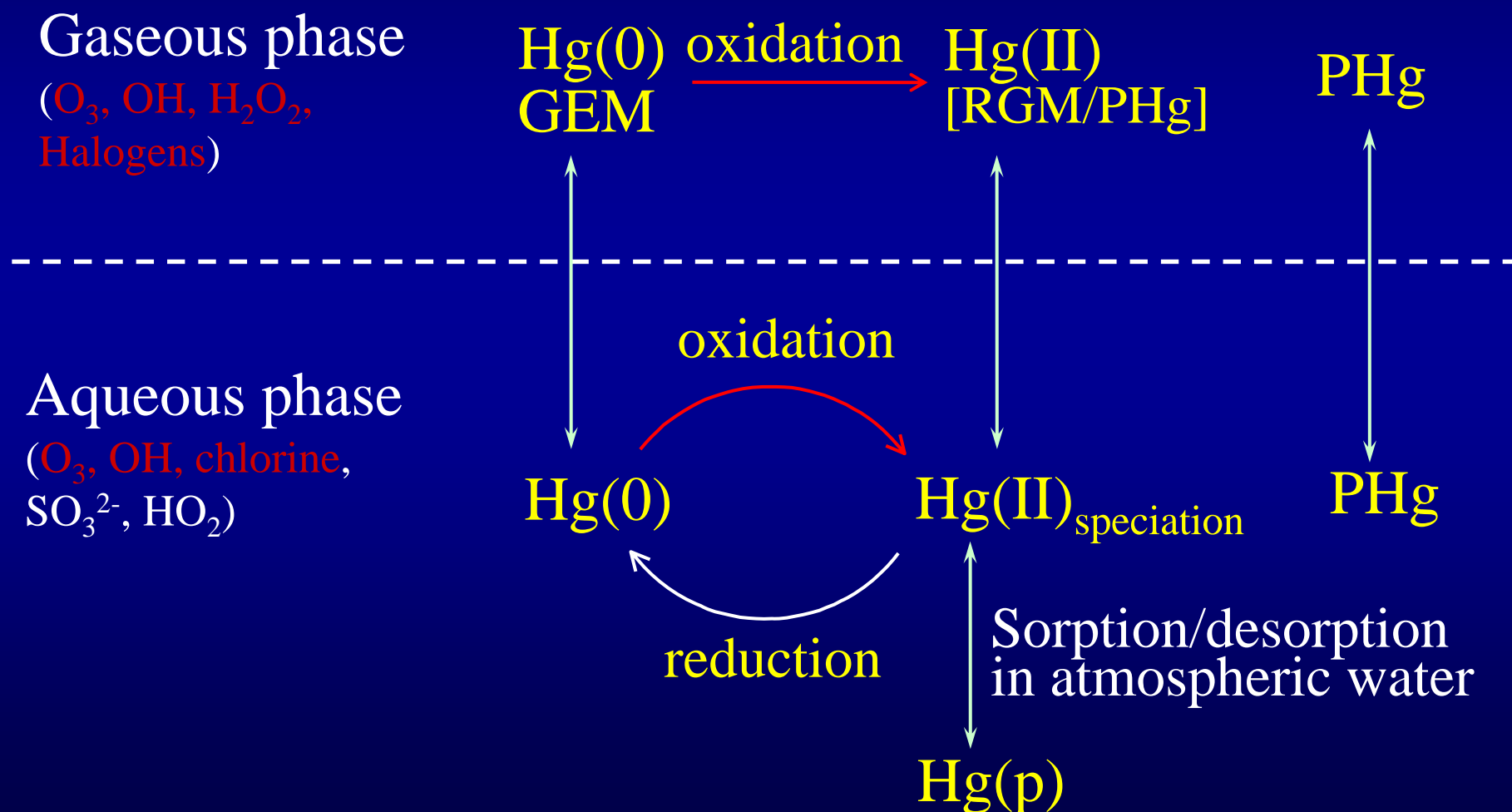


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Min= 0.02 at (23,94), Max= 2.61 at (56,3)



Average V_d in Domain

Simplified Hg Chemistry Scheme



Reaction Kinetics

Reaction	Rate constant	Type	
$\text{Hg}^0_{(\text{g})} + \text{O}_{3(\text{g})} \longrightarrow \text{RGM/PHg} + \text{O}_{2(\text{g})}$	$3\text{-}75 \times 10^{-20} \text{ cm}^3 \text{ molec}^{-1} \text{ s}^{-1}$	Ox	G
$\text{Hg}^0_{(\text{aq})} + \text{O}_{3(\text{aq})} + 2 \text{H}^+ \rightarrow \text{Hg}^{2+}_{(\text{aq})} + \text{H}_2\text{O} + \text{O}_2$	$4.7 \times 10^7 \text{ M}^{-1} \text{ s}^{-1}$	Ox	AQ
$\text{Hg}^0_{(\text{g})} + \bullet\text{OH}_{(\text{g})} \longrightarrow \text{RGM/PHg} + \text{Products}$	$8.7 \times 10^{-14} \text{ cm}^3 \text{ molec}^{-1} \text{ s}^{-1}$	Ox	G
$\text{Hg}^0_{(\text{aq})} + \bullet\text{OH}_{(\text{aq})} \longrightarrow \text{Hg}^{2+}_{(\text{aq})} + \text{Products}$	$2.0 \times 10^9 \text{ M}^{-1} \text{ s}^{-1}$	Ox	AQ
$\text{Hg}^0_{(\text{aq})} + \text{HOCl}_{(\text{aq})} \longrightarrow \text{Hg}^{2+}_{(\text{aq})} + \text{Cl}^- + \text{OH}^-$	$2.09 \times 10^6 \text{ M}^{-1} \text{ s}^{-1}$	Ox	AQ
$\text{Hg}^0_{(\text{aq})} + \text{OCl}^-_{(\text{aq})} \xrightarrow{\text{H}^+} \text{Hg}^{2+}_{(\text{aq})} + \text{Cl}^- + \text{OH}^-$	$1.99 \times 10^6 \text{ M}^{-1} \text{ s}^{-1}$	Ox	AQ
$\text{Hg}^0_{(\text{g})} + \text{H}_2\text{O}_{2(\text{g})} \longrightarrow \text{RGM/PHg} + \text{products}$	$8.5 \times 10^{-19} \text{ cm}^3 \text{ molec}^{-1} \text{ s}^{-1}$	Ox	G
$\text{Hg}^0_{(\text{g})} + \text{Cl}_{2(\text{g})} \longrightarrow \text{RGM} + \text{products}$	$2.6\text{-}4.8 \times 10^{-18} \text{ cm}^3 \text{ molec}^{-1} \text{ s}^{-1}$	Ox	G
$\text{Hg}^0_{(\text{g})} + \text{Br}_{2(\text{g})} \longrightarrow \text{RGM} + \text{products}$	$9 \times 10^{-17} \text{ cm}^3 \text{ molec}^{-1} \text{ s}^{-1}$	Ox	G
$\text{Hg}^0_{(\text{g})} + \text{Cl}_{(\text{g})} \longrightarrow \text{RGM} + \text{products}$	$1.0 \times 10^{-11} \text{ cm}^3 \text{ molec}^{-1} \text{ s}^{-1}$	Ox	G
$\text{Hg}^0_{(\text{g})} + \text{Br}_{(\text{g})} \longrightarrow \text{RGM} + \text{products}$	$3.2 \times 10^{-12} \text{ cm}^3 \text{ molec}^{-1} \text{ s}^{-1}$	Ox	G
$\text{Hg}^0_{(\text{g})} + \text{BrO}_{(\text{g})} \longrightarrow \text{RGM} + \text{products}$	$1.5 \times 10^{-14} \text{ cm}^3 \text{ molec}^{-1} \text{ s}^{-1}$	Ox	G
$\text{HgSO}_{3(\text{aq})} \longrightarrow \text{Hg}^0_{(\text{aq})} + \text{products}$	$\text{Texp}(31.971 - (12595/T)) \text{ s}^{-1}$	Red	AQ
$\text{Hg}(\text{OH})_{2(\text{aq})} + \text{UV} \longrightarrow \text{Hg}^0_{(\text{aq})} + \text{products}$	$3 \times 10^{-7} \text{ s}^{-1}$, midday 60°N	Red	AQ
$\text{Hg(II)}_{(\text{aq})} + \text{HO}_2\bullet_{(\text{aq})} \rightarrow \text{Hg}^+_{(\text{aq})} + \text{O}_2 + \text{H}^+$	$1.7 \times 10^4 \text{ M}^{-1} \text{ s}^{-1}$	Red	AQ

Hg Sorption Implementation

$$[Hg^{2+}]_{aq,total} = (1 + K_a [APM]_{aq}) [Hg_D^{2+}]_{aq}$$

Sources	Xiao & Thomas (2004)	Budinova et al. (2003)	Sanchez-Polo & Rivera-Utrilla (2002)	Manohar et al (2002)	Karabulut et al. (2001)	Seigneur et al. (1998)	Yin et al. 1997
Sorbents	Activated carbon, 0.002 g/mL	Furfural-based carbon, 0.0002 g/mL	Ozonated activated carbon, $\Phi=500-800 \mu m$, pH_{pzc} : 2.6-8.8, 0.002 g/mL	Clay ($\Phi=0.096 mm$, $A_s= 71.3 m^2/g$, porosity= $0.39 ml/g$, $\rho=1.39 g/mL$, cation exchange capacity: 2.3 meq/g, pH_{pzc} : 3.4, 0.002 g/mL	Coal (Lignite), 65 mesh ASTM, 1 g/mL	Atmospheric particulate matter, $\Phi < 62 \mu m$, 20 mg/L	15 Soil types (sand-loam), $\Phi < 2 mm.$, 0.01 g/mL
Hg Conc.	$Hg(NO_3)_2$: 48 - 4173 mM	$HgCl_2$: 10 - 40 mg/L	50 mg/L $Hg(II)$	25-1000 mg/L $Hg(II)$	10 - 100 ppm $Hg(II)$	THg: 1.67 ng/L	$Hg(NO_3)_2$: 1.0×10^{-7} - $1.1 \times 10^{-4} M$
Solution Conditions	T: 25 °C, pH: 1.97 - 3.90	pH: 2.0 - 5.0	T: 25 °C, pH: 2.0 - 12.0	T: 30 - 60 °C, pH: 4.0 - 8.0	T= 25 ± 2 °C, pH: 2.0 - 6.0	pH: 3.1 - 6.1	T= 25 ± 2 °C, pH=4.9-6.5. I= 0.001-0.1 M $NaNO_3$
Sorption Model ⁽¹⁾	q_{max} : 1.06 - 1.37 mmol g^{-1} , K_{ads} : 1.82 - 7.87 L $mmol^{-1}$	q_{max} : 134 - 174 mg/g, K_{ads}^{-1} : 0.11 - 1.40 mg/L	q_{max} : 38.61 - 62.11 mg/g, K_{ads} : 0.06 - 0.57 L/mg	q_{max} : 46.02 - 70.32 mg/g, K_{ads} : 0.037 - 0.123 l/mg	q_{max} : 2.03 mg/g, K_{ads}^{-1} : 9.81 mg/L	--	Log K_{ads} : 5.16 - 5.97 L mol^{-1} , q_{max} : 3.73 - 12.80 $\mu mol g^{-1}$
K_a , L/g ⁽²⁾	1.93 - 10.78	124 - 1,218	2-11	1.7 - 8.6	0.21	3 - 91	0.54 - 10.26

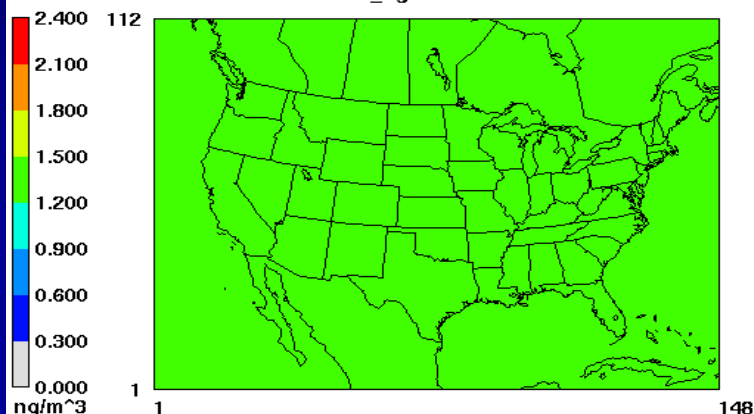
(1) All the sorption models are based on Langmuir isotherm except Seigneur et al. (1998).

(2) The K_a (as shown in Equation 1) values are calculated from the linear range of the Langmuir isotherm using the sorption parameters reported in the sorption models.

ICONs & BCONs

Layer 1 $1/1 * (HGx * 8178661)$

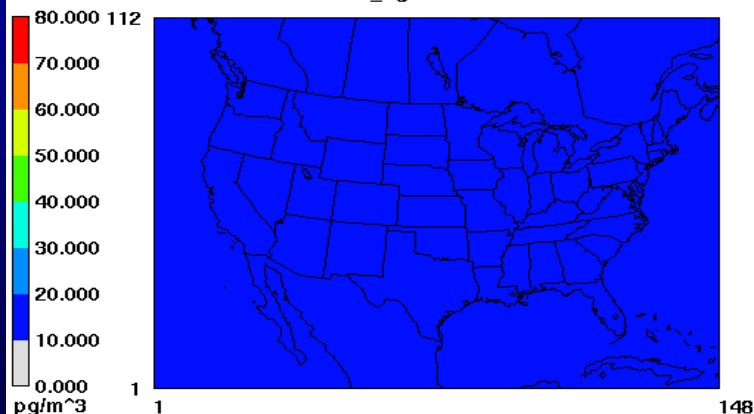
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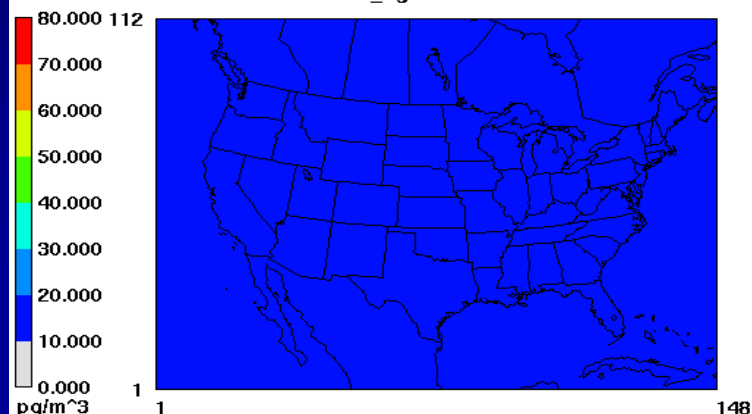
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Layer 1 $1/1 * ((APHGIx + APHGJx) * 1000000)$

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July 1, 2001 0:00:00
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σ layer	0.98	0.93	0.84	0.60	0.30	0.00
HG (ppmv)	1.78 E-07	1.77 E-07	1.76 E-07	1.75 E-07	1.74 E-07	1.73 E-07
HGIIGAS (ppmv)	2.00 E-09	3.00 E-09	4.00 E-09	5.00 E-09	6.00 E-09	7.00 E-09
APHGI ($\mu\text{g}/\text{m}^3$)	9.97 E-06	9.48 E-06	8.98 E-06	6.98 E-06	4.49 E-06	1.49 E-06
APHGJ ($\mu\text{g}/\text{m}^3$)	9.97 E-06	9.48 E-06	8.98 E-06	6.98 E-06	4.49 E-06	1.49 E-06

Simulation Results (July 2001)

Case 1

(Bullock & Brehme, 2002)

Case 2

(veggie/natural EI)

Case 3

(Dry deposition)

Case 4

(Oxidation products)

Case 5

(Sorption modification)

Case 6

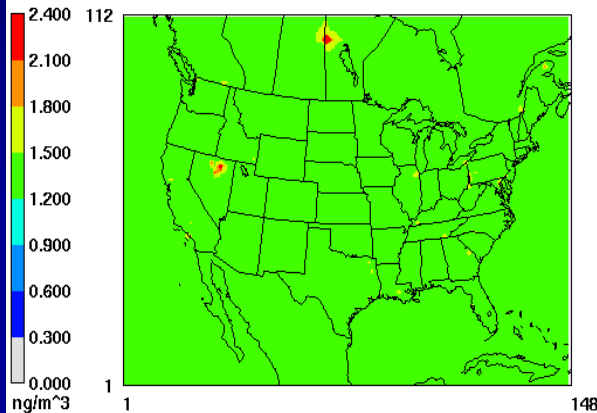
(All combined)



GEM Concentrations

Layer 1 1/1*(HGd*8178661)

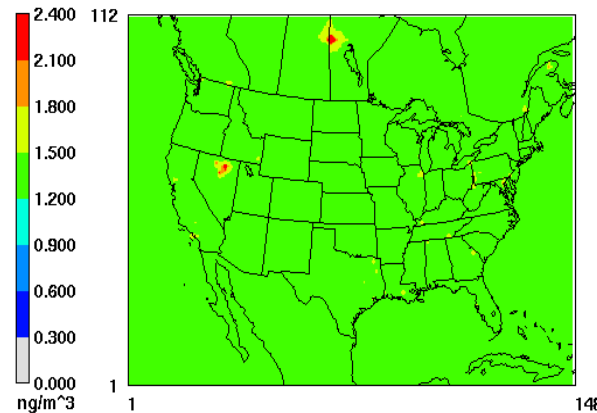
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July 1,2001 0:00:00
Min=1.248 at (73,48). Max=6.405 at (68,105)

Layer 1 1/1*(HGj*8178661)

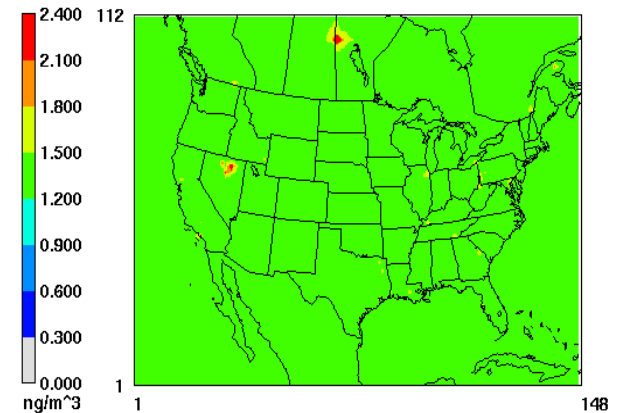
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July 1,2001 0:00:00
Min=1.269 at (77,49). Max=6.410 at (68,105)

Layer 1 1/1*(HGj*8178661)

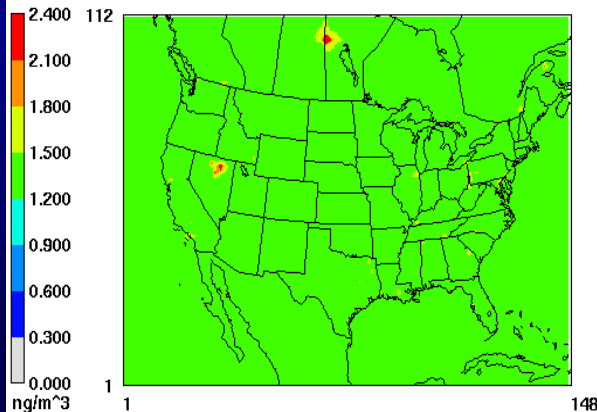
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Layer 1 1/1*(HGp*8178661)

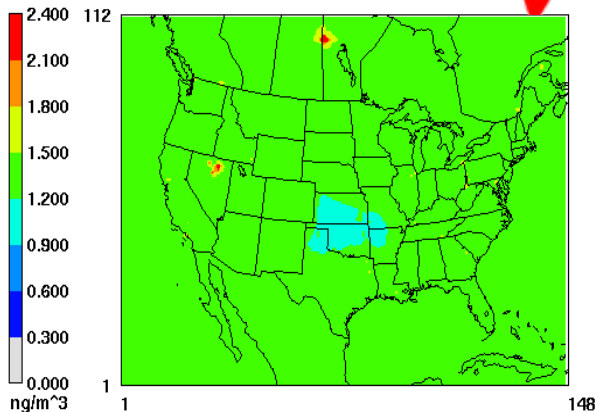
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Layer 1 1/1*(HGV*8178661)

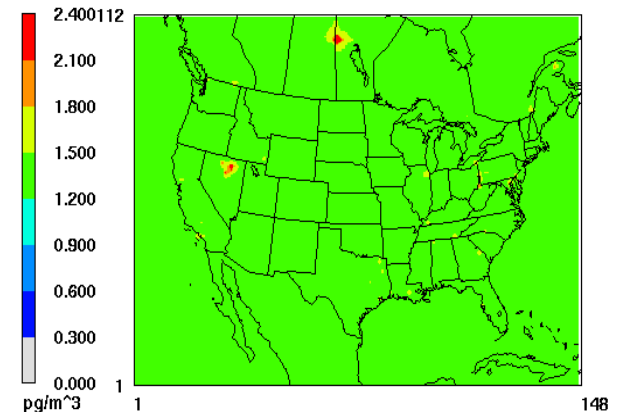
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Layer 1 1/1*(HGP*8178661)

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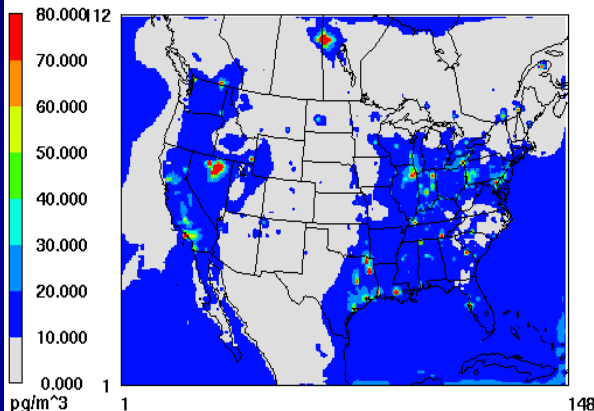


July 1,2001 0:00:00
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RGM Concentrations

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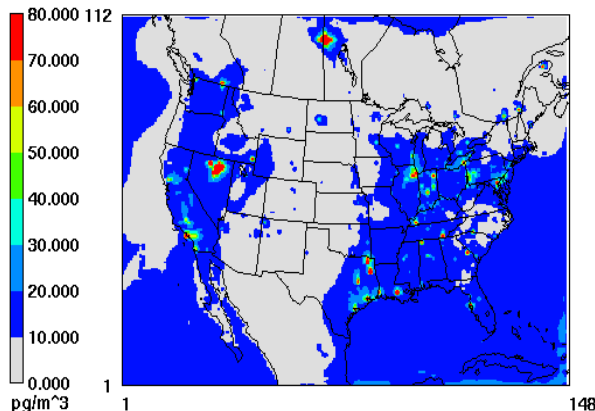
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July 1, 2001 0:00:00
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Layer 1 $1/1*(\text{HGIIGASj}*8178661*1000)$

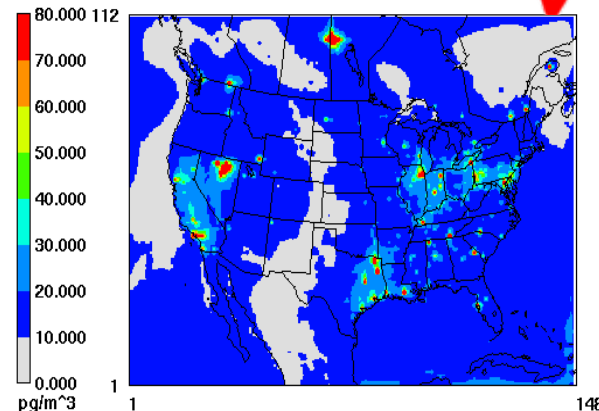
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Layer 1 $1/1*(\text{HGIIGASj}*8178661*1000)$

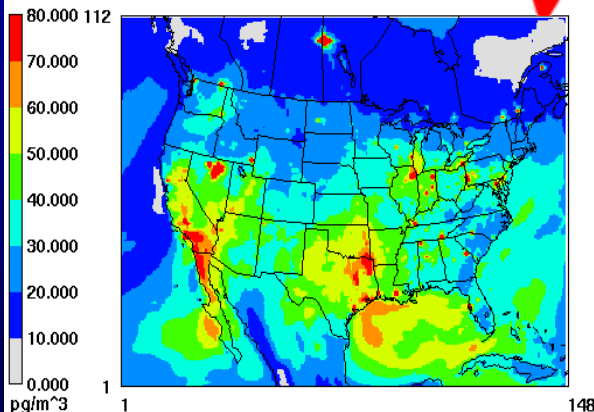
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July 1, 2001 0:00:00
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Layer 1 $1/1*(\text{HGIIGASp}*8178661*1000)$

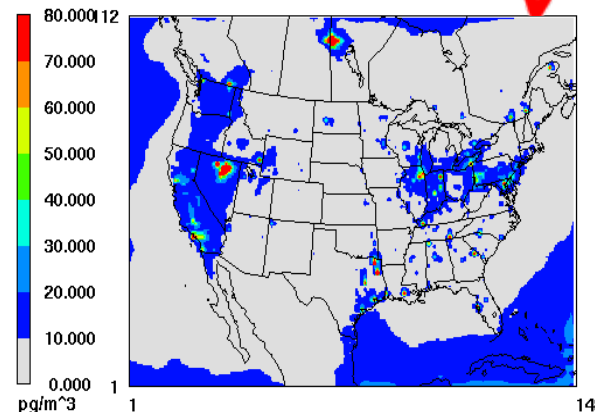
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July 1, 2001 0:00:00
Min=-5.856 at (14,61), Max=1547.482 at (68,105)

Layer 1 $1/1*(\text{HGIIGASv}*8178661*1000)$

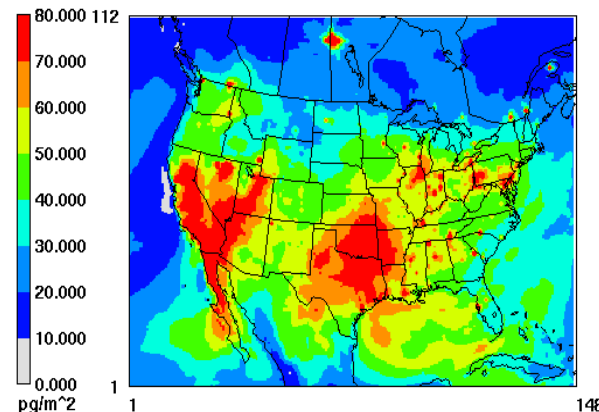
v=CCTM_hgbCONC.200107.ncra



July 1, 2001 0:00:00
Min= 1.700 at (14,61), Max=1537.916 at (68,105)

Layer 1 $1/1*(\text{HGIIGASp}*8178661*1000)$

p=CCTM_hgbCONC.200107.ncra

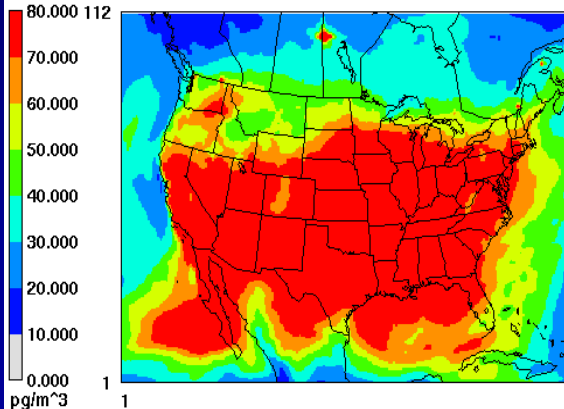


July 1, 2001 0:00:00
Min=6.097 at (14,61), Max=1779.606 at (68,105)

PHg Concentrations

Layer 1 $1/1*((APHGId+APHGJd)*1000000)$

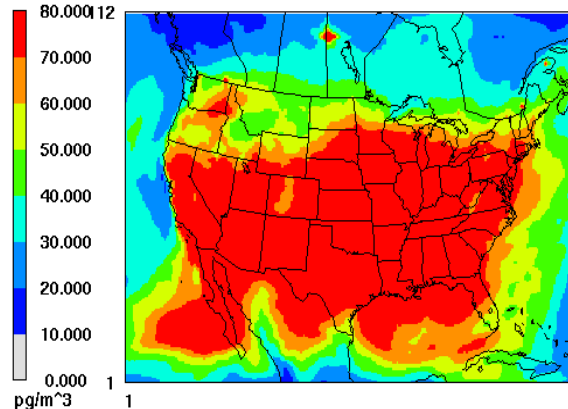
d=CCTM_hgbCONC.200107.ncra



July 1, 2001 0:00:00
Min=11.743 at (19,110), Max=833.168 at (68,105)

Layer 1 $1/1*((APHGJj+APHGJj)*1000000)$

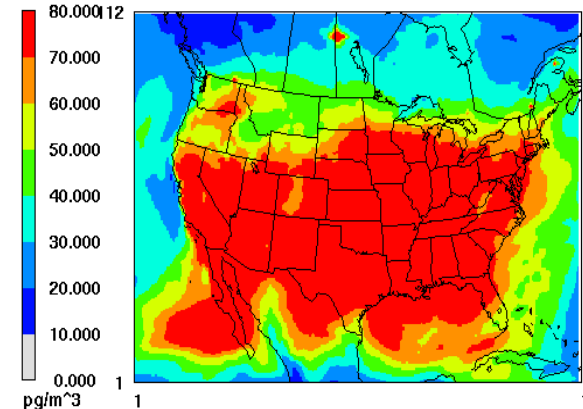
j=CCTM_hgbCONC.200107.nc



July 1, 2001 0:00:00
Min= 11.744 at (19,110), Max= 833.117 at (68,105)

Layer 1 $1/1*((APHGJj+APHGJj)*1000000)$

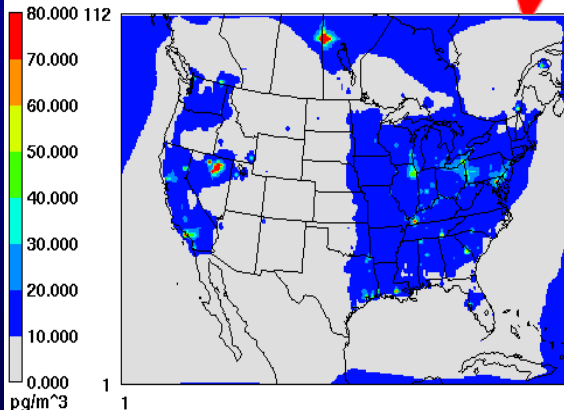
j=CCTM_hgbCONC.200107.ncra



July 1, 2001 0:00:00
Min= 11.730 at (19,110), Max= 833.364 at (68,105)

Layer 1 $1/1*((APHGIp+APHGJp)*1000000)$

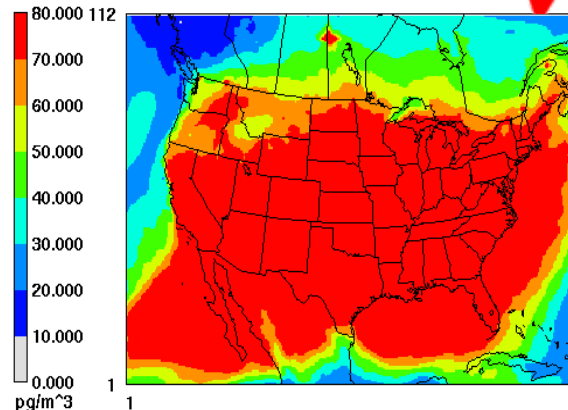
p=CCTM_hgbCONC.200107.ncra



July 1, 2001 0:00:00
Min=2.026 at (53,5), Max=813.466 at (68,105)

Layer 1 $1/1*((APHGJv+APHGJv)*1000000)$

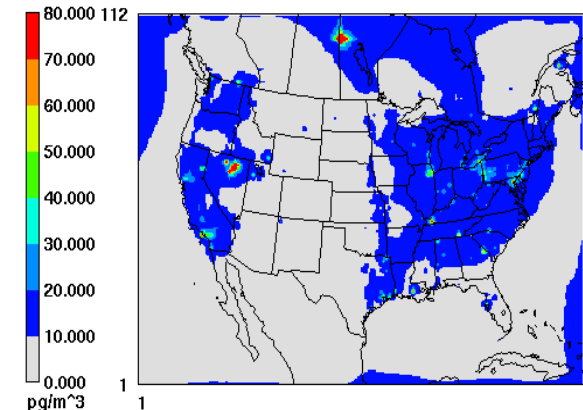
v=CCTM_hgbCONC.200107.ncra



July 1, 2001 0:00:00
Min=9.798 at (19,110), Max=841.173 at (68,105)

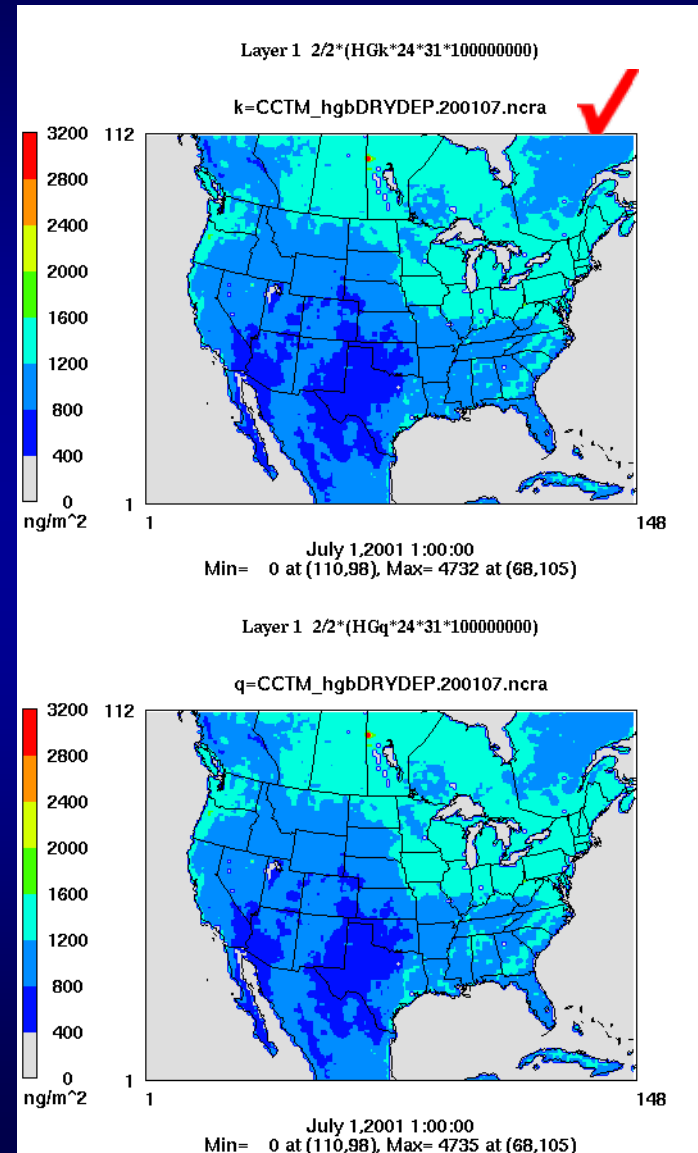
Layer 1 $1/1*((APHGIp+APHGJp)*1000000)$

p=CCTM_hgbCONC.200107.ncra



July 1, 2001 0:00:00
Min=3.031 at (54,5), Max=813.800 at (68,105)

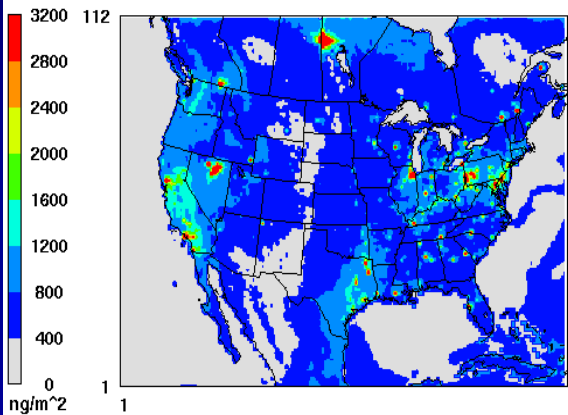
GEM Dry Deposition



RGM Dry Deposition

Layer 1 2/2*(HGIIGASe*24*31*100000000)

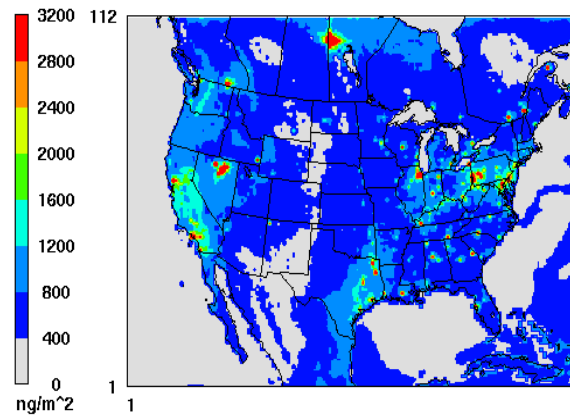
e=CCTM_hgbDRYDEP.200107.ncra



July 1,2001 1:00:00
Min= 9 at (23,95), Max=101656 at (68,105)

Layer 1 2/2*(HGIIGASK*24*31*100000000)

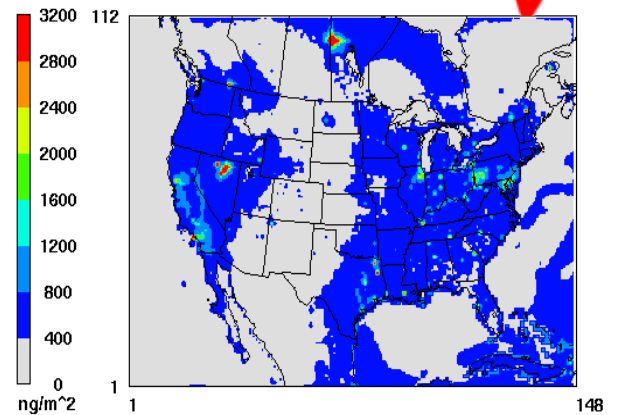
k=CCTM_hgbDRYDEP.200107.nc



July 1,2001 1:00:00
Min= 9 at (23,95), Max=101656 at (68,105)

Layer 1 2/2*(HGIIGASK*24*31*100000000)

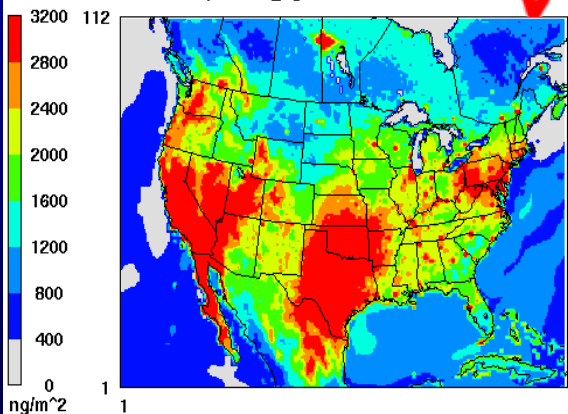
k=CCTM_hgbDRYDEP.200107.ncra ✓



July 1,2001 1:00:00
Min= 12 at (23,95), Max=52676 at (68,105)

Layer 1 2/2*(HGIIGASq*24*31*100000000)

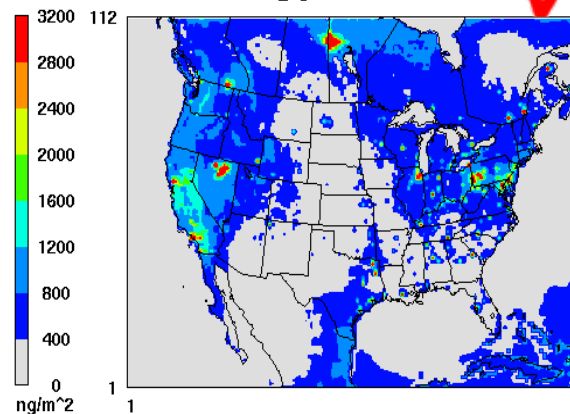
q=CCTM_hgbDRYDEP.200107.ncra ✓



July 1,2001 1:00:00
Min= 18 at (23,95), Max=102346 at (68,105)

Layer 1 2/2*(HGIIGASw*24*31*100000000)

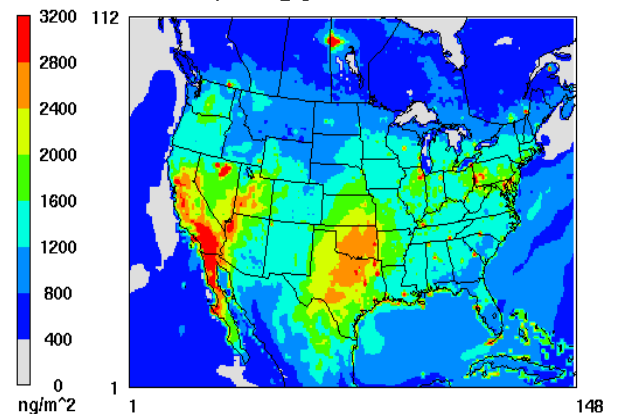
w=CCTM_hgbDRYDEP.200107.ncra ✓



July 1,2001 1:00:00
Min= 9 at (23,95), Max=101586 at (68,105)

Layer 1 2/2*(HGIIGASq*24*31*100000000)

q=CCTM_hgbDRYDEP.200107.ncra

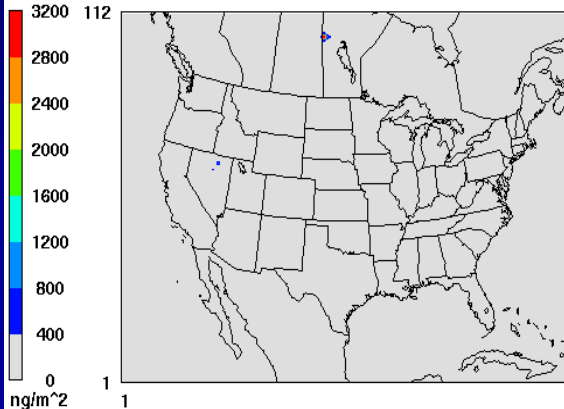


July 1,2001 1:00:00
Min= 24 at (23,95), Max=53074 at (68,105)

PHg Dry Deposition

Layer 1 $2/2*((APHGle+APHGJe)*24*31*100000000)$

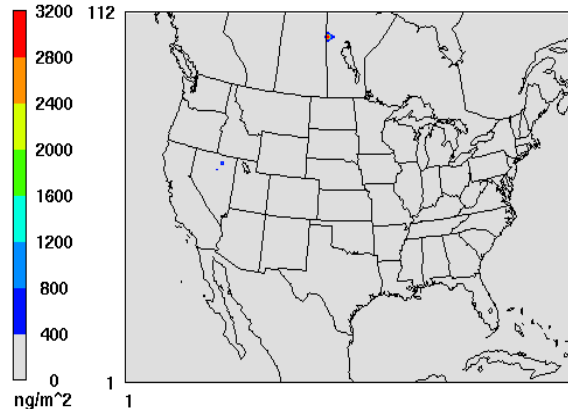
e=CCTM_hgbDRYDEP.200107.ncra



July 1,2001 1:00:00
Min= 5 at (23,95), Max= 4181 at (68,105)

Layer 1 $2/2*((APHGik+APHGJk)*24*31*100000000)$

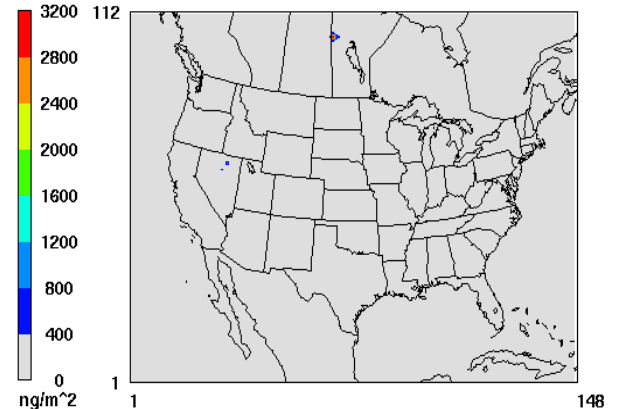
k=CCTM_hgbDRYDEP.200107.nc



July 1,2001 1:00:00
Min= 5 at (23,95), Max= 4196 at (68,105)

Layer 1 $2/2*((APHGik+APHGJk)*24*31*100000000)$

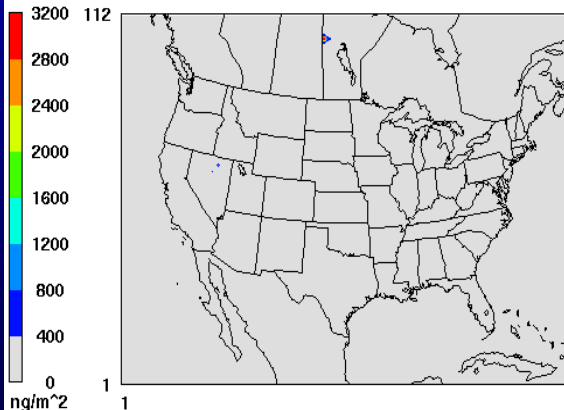
k=CCTM_hgbDRYDEP.200107.ncra



July 1,2001 1:00:00
Min= 5 at (23,95), Max= 4160 at (68,105)

Layer 1 $2/2*((APHGIlq+APHGJq)*24*31*100000000)$

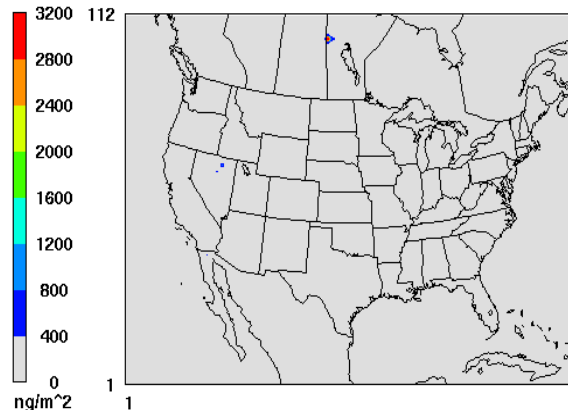
q=CCTM_hgbDRYDEP.200107.ncra



July 1,2001 1:00:00
Min= 2 at (23,95), Max= 4164 at (68,105)

Layer 1 $2/2*((APHGIlw+APHGJw)*24*31*100000000)$

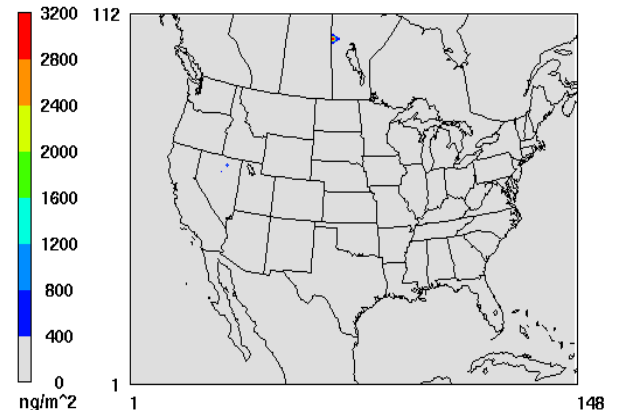
w=CCTM_hgbDRYDEP.200107.ncra



July 1,2001 1:00:00
Min= 5 at (23,95), Max= 4200 at (68,105)

Layer 1 $2/2*((APHGIlq+APHGJq)*24*31*100000000)$

q=CCTM_hgbDRYDEP.200107.ncra

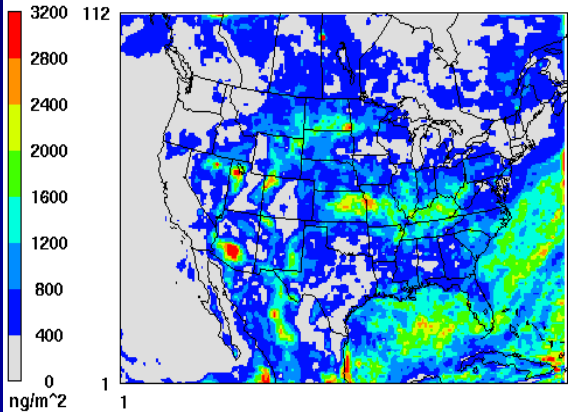


July 1,2001 1:00:00
Min= 2 at (23,95), Max= 4147 at (68,105)

RGM Wet Deposition

Layer 1 3/3*(HGIIGASf*24*31*100000000)

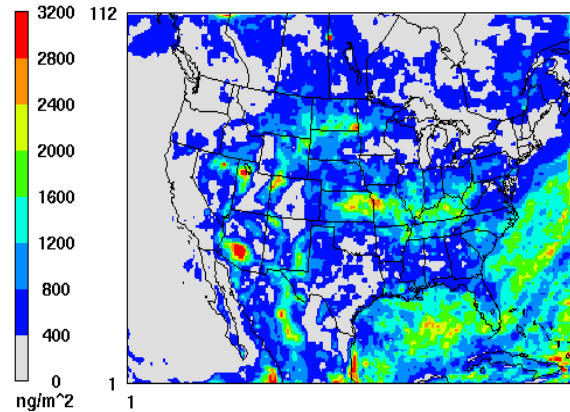
f=CCTM_hgbWETDEP1.200107.ncra



July 1,2001 1:00:00
Min= 0 at (18,57), Max= 8258 at (68,105)

Layer 1 3/3*(HGIIGASI*24*31*100000000)

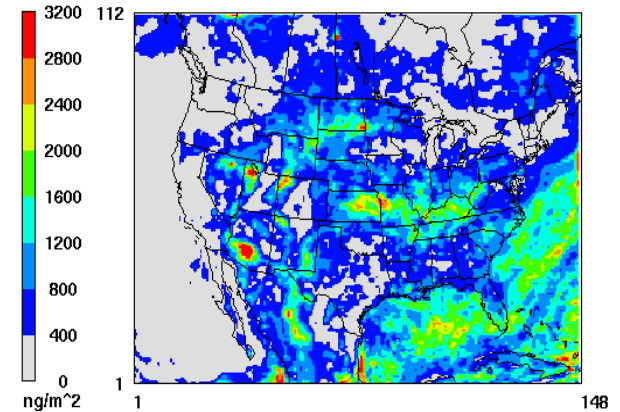
l=CCTM_hgbWETDEP1.200107.nc



July 1,2001 1:00:00
Min= 0 at (18,57), Max= 8259 at (68,105)

Layer 1 3/3*(HGIIGASI*24*31*100000000)

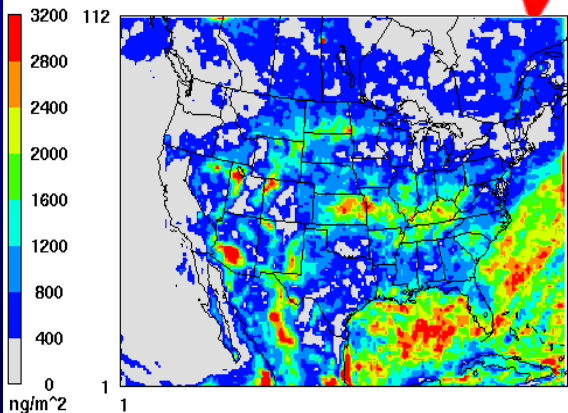
l=CCTM_hgbWETDEP1.200107.ncra



July 1,2001 1:00:00
Min= 0 at (18,57), Max= 8569 at (68,105)

Layer 1 3/3*(HGIIGASr*24*31*100000000)

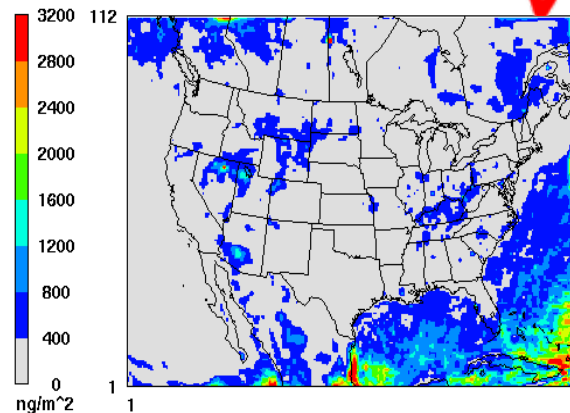
r=CCTM_hgbWETDEP1.200107.ncra



July 1,2001 1:00:00
Min= 0 at (18,57), Max= 8332 at (68,105)

Layer 1 3/3*(HGIIGASx*24*31*100000000)

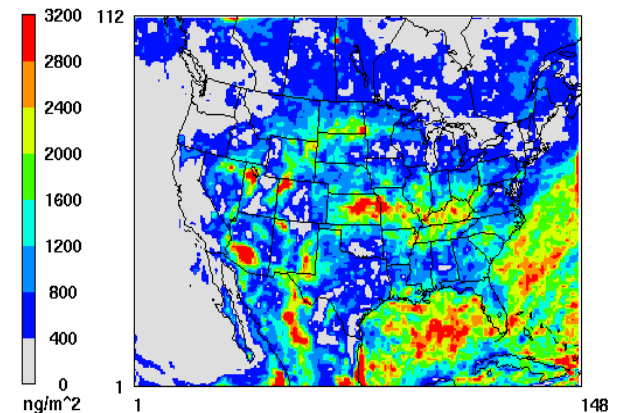
x=CCTM_hgbWETDEP1.200107.ncra



July 1,2001 1:00:00
Min= 0 at (18,57), Max= 8284 at (68,105)

Layer 1 3/3*(HGIIGASr*24*31*100000000)

r=CCTM_hgbWETDEP1.200107.ncra

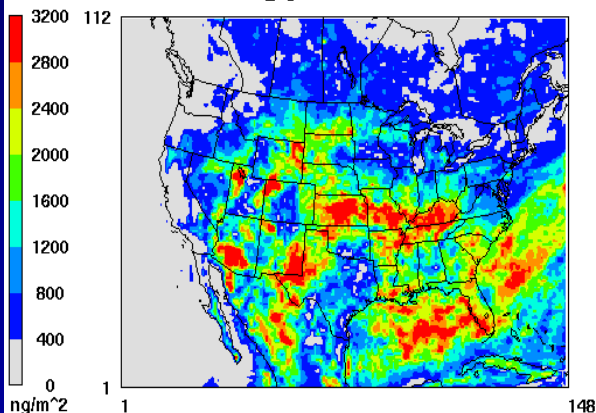


July 1,2001 1:00:00
Min= 0 at (18,57), Max= 8768 at (68,105)

PHg Wet Deposition

Layer 1 $\frac{3}{3} * ((APHGIf + APHGJf) * 24 * 31 * 100000000)$

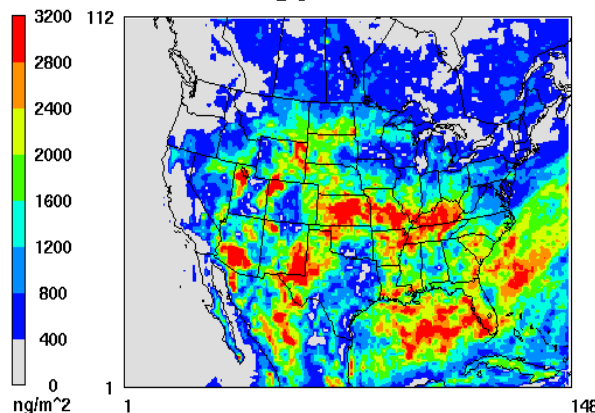
f=CCTM_hgbWETDEP1.200107.ncra



July 1, 2001 1:00:00
Min= 0 at (18,57), Max= 6400 at (38,41)

Layer 1 $\frac{3}{3} * ((APHGIl + APHGJl) * 24 * 31 * 100000000)$

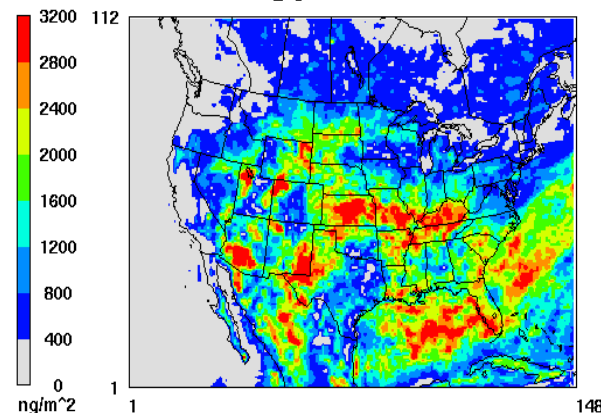
l=CCTM_hgbWETDEP1.200107.nc



July 1, 2001 1:00:00
Min= 0 at (18,57), Max= 6414 at (38,41)

Layer 1 $\frac{3}{3} * ((APHGIl + APHGJl) * 24 * 31 * 100000000)$

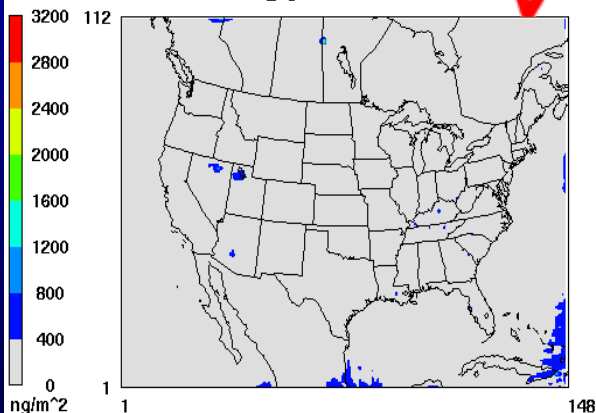
l=CCTM_hgbWETDEP1.200107.ncra



July 1, 2001 1:00:00
Min= 0 at (18,57), Max= 6340 at (38,41)

Layer 1 $\frac{3}{3} * ((APHGlr + APHGJr) * 24 * 31 * 100000000)$

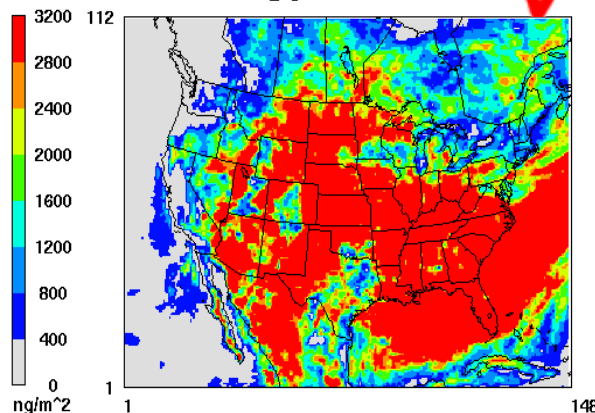
r=CCTM_hgbWETDEP1.200107.ncra



July 1, 2001 1:00:00
Min= 0 at (18,57), Max= 1943 at (68,105)

Layer 1 $\frac{3}{3} * ((APHGlx + APHGJx) * 24 * 31 * 100000000)$

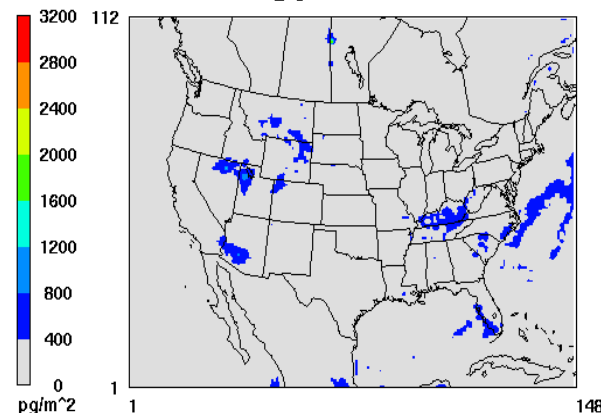
x=CCTM_hgbWETDEP1.200107.ncra



July 1, 2001 1:00:00
Min= 0 at (18,57), Max= 15804 at (39,41)

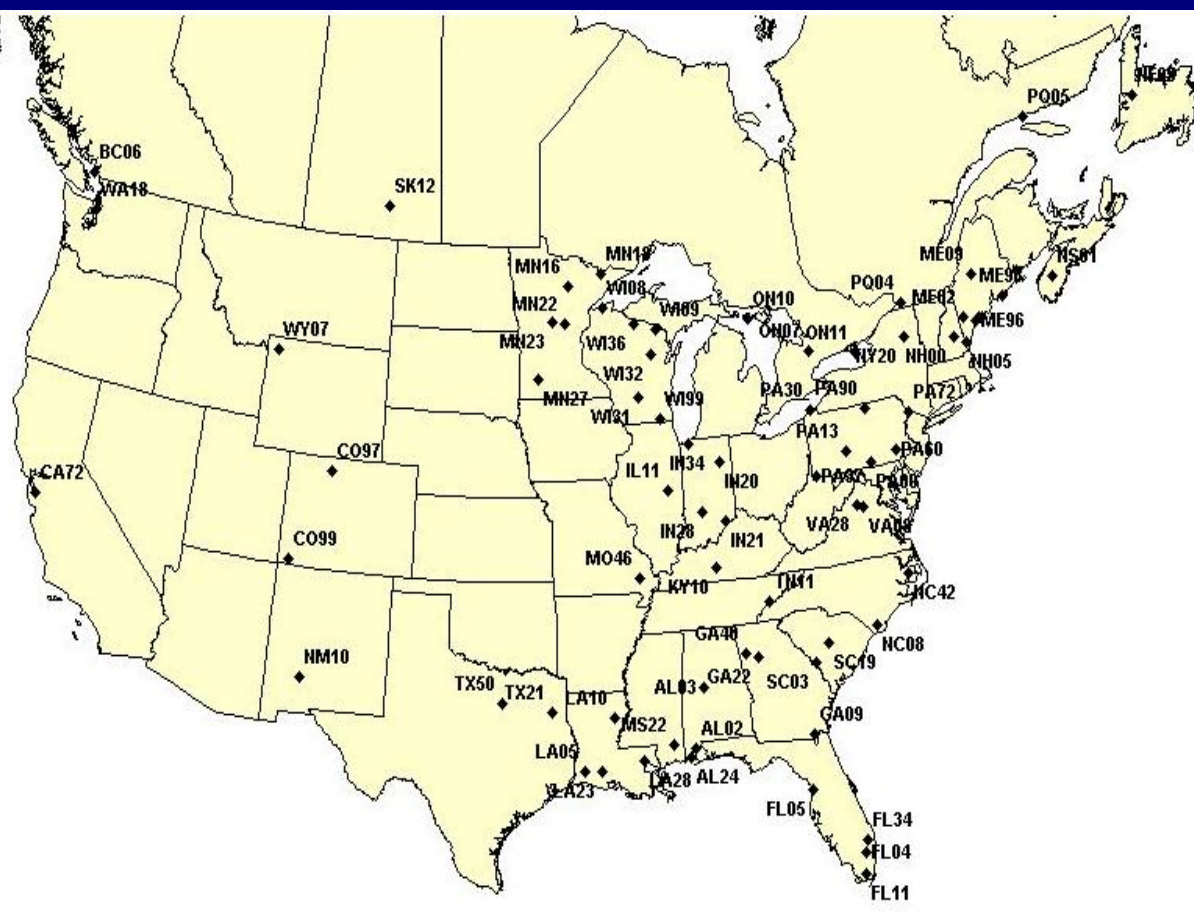
Layer 1 $\frac{3}{3} * ((APHGlr + APHGJr) * 24 * 31 * 100000000)$

r=CCTM_hgbWETDEP1.200107.ncra



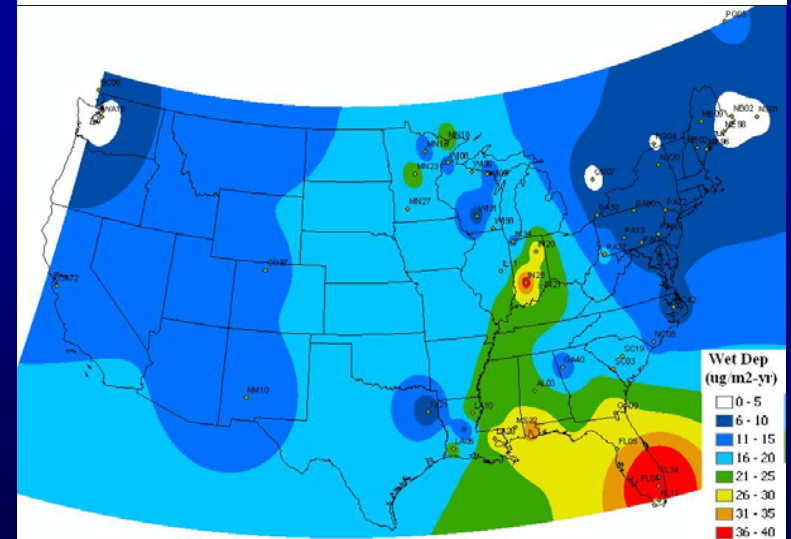
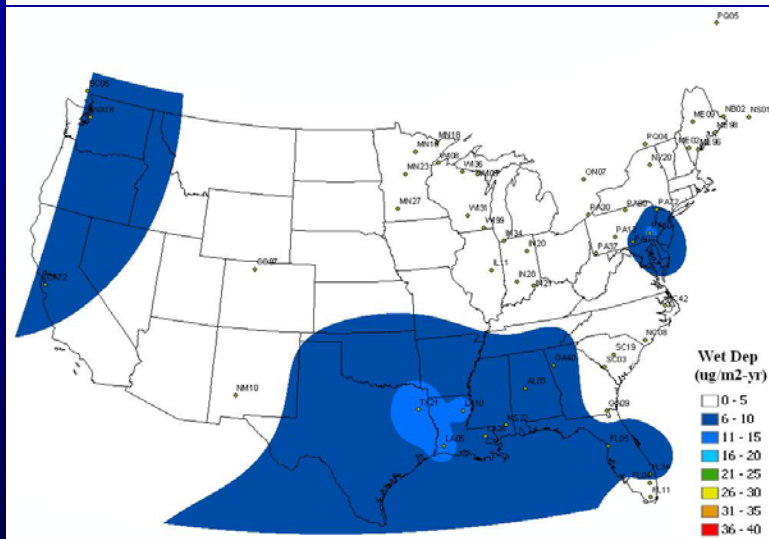
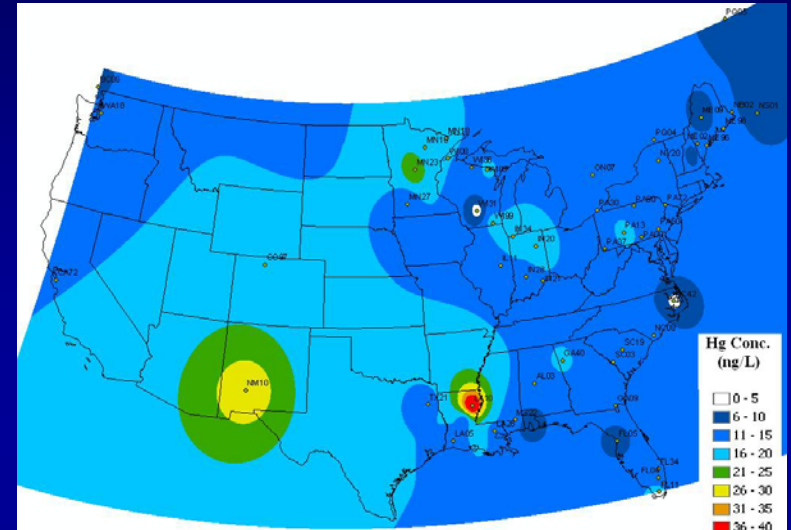
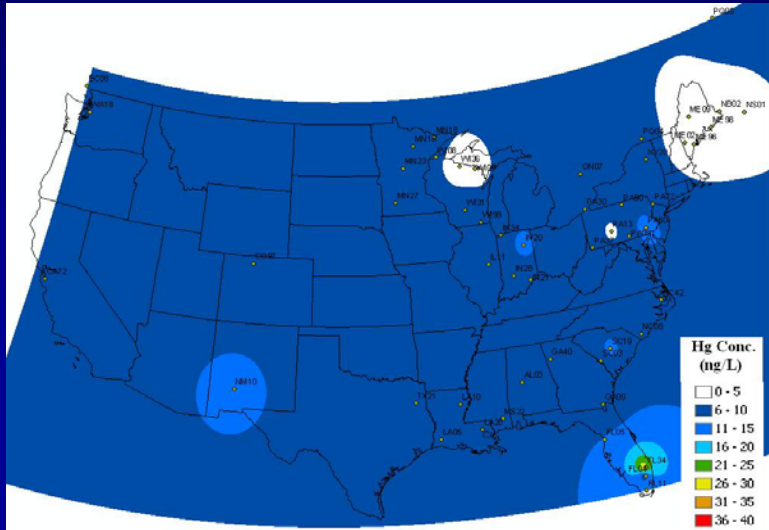
July 1, 2001 1:00:00
Min= 0 at (18,57), Max= 1830 at (68,105)

Mercury Deposition Network



- National network
- Started in 1995 at 13 sites
- Currently 89 active sites
- Monitors wet deposition of Hg and Me-Hg
- Weekly data in precipitation
- Weekly aqueous Hg concentrations
- Operated by Frontier Geosciences

Interpolated Aqueous Concentration Wet Deposition of Hg from MDN Data

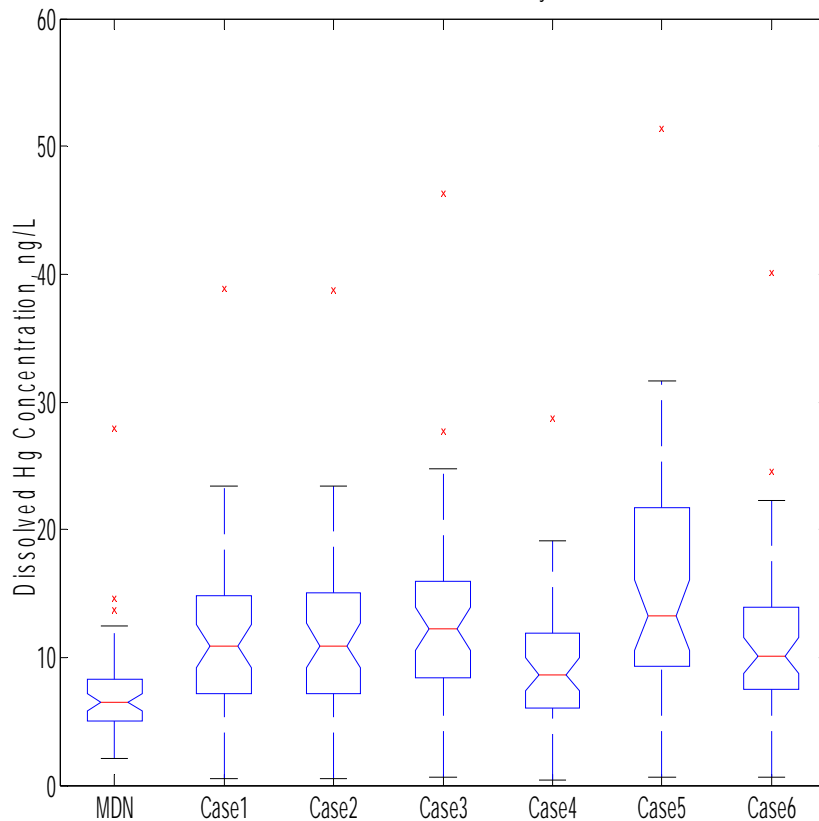


January 2001

July 2001

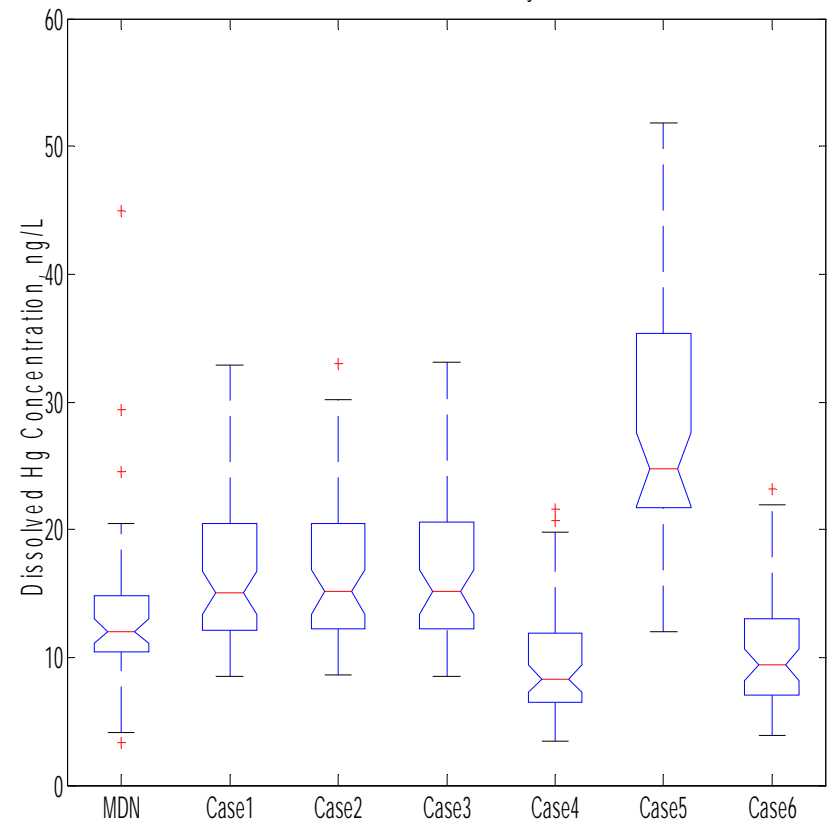
Model Verification – Aqueous Conc.

Box Plot of Dissolved Hg in the Precipitation from
MDN and Model Results: January 2001



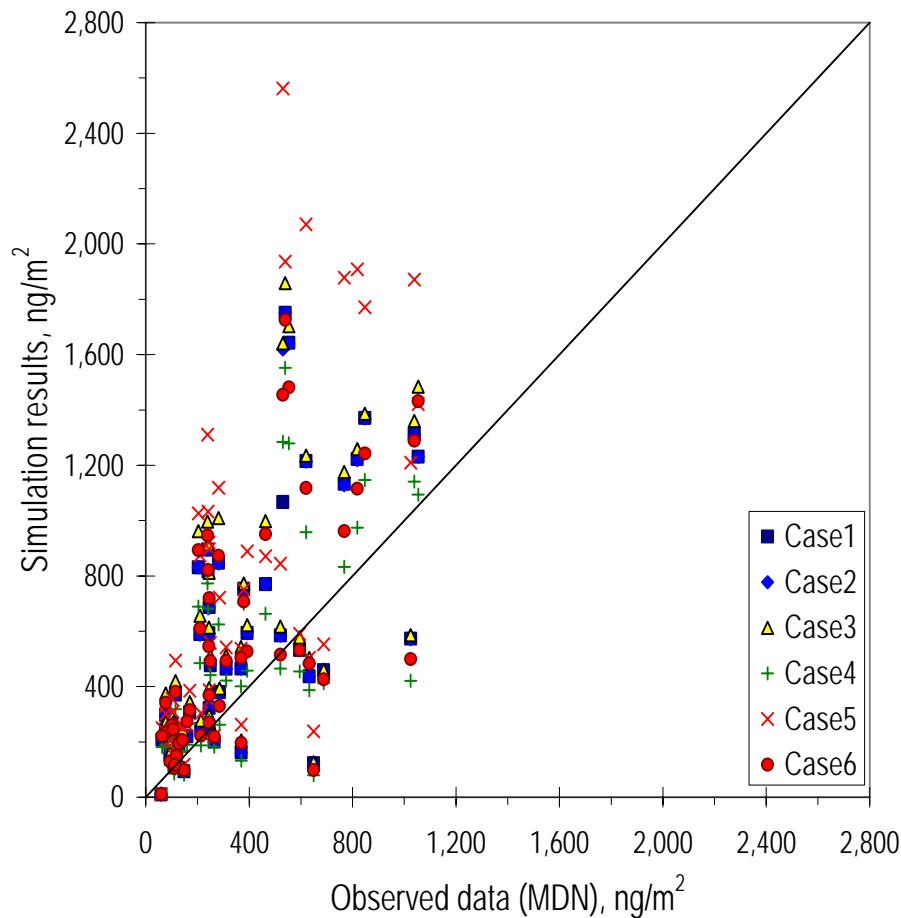
January 2001

Box Plot of Dissolved Hg in the Precipitation from
MDN and Model Results: July 2001

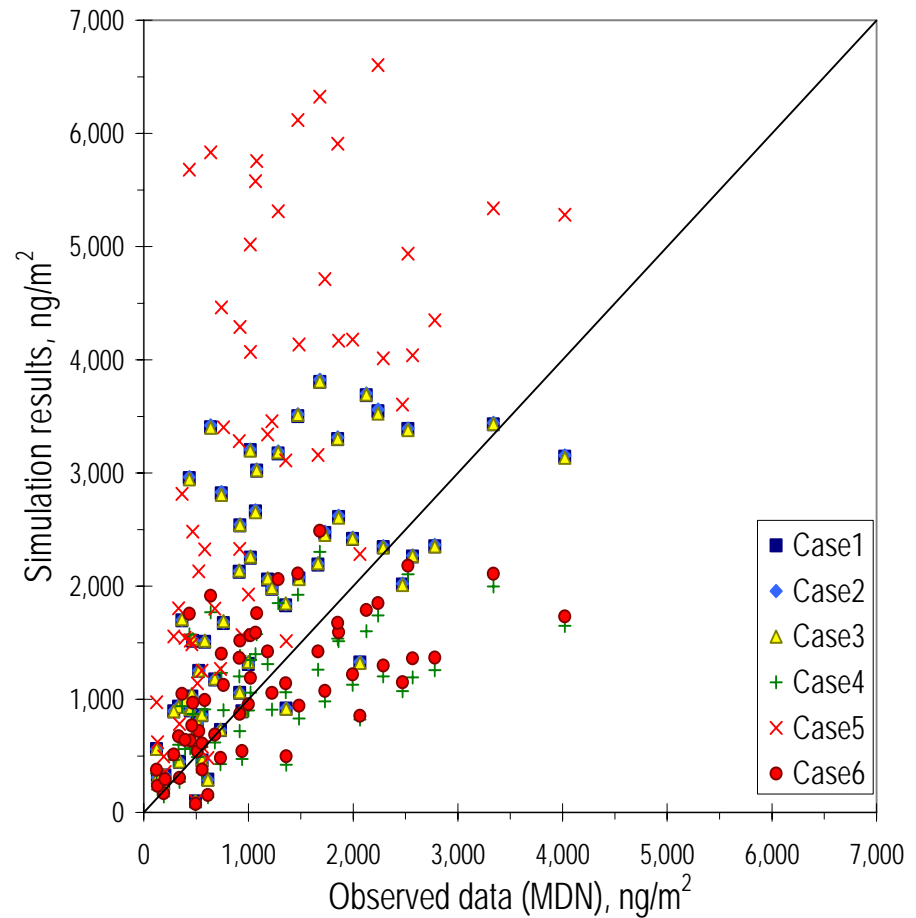


July 2001

Model Verification – Wet Deposition



January 2001



July 2001

Key Conclusions

- Mercury emission does not significantly change total ambient Hg concentration except near major point sources.
- Photochemical activities enhance mercury deposition.
- Atmospheric deposition (wet and dry) is forced mainly by chemistry except near major point sources.
- Vegetative Hg emission does not contribute significantly to Hg deposition, instead, it only slightly increases the concentration of GEM.
- The speciation of oxidized mercury products (RGM vs. PHg) has a strong effect on the relative concentration of RGM and PHg as well as their deposition intensity.
- Sorption/desorption equilibrium strongly affects the composition of deposited mercury in wet deposition. More experimental data are needed for further implementation.
- The science update development in this study shows improvement over the original CMAQ-Hg model.