An Overview of the HYSPLIT Modeling System for Trajectory and Dispersion Applications

http://www.arl.noaa.gov/ready/hysplit4.html

Richard S. Artz
Material provided by:
Roland Draxler, Mark Cohen, Glenn Rolph,
Ariel Stein, and Barbara Stunder
October 22, 2008

Workshop Agenda

Model Overview

- Model history and features
- Computational method
- Trajectories versus concentration
- Code installation
- Model operation
- Example calculations
- Updating HYSPLIT

Meteorological Data

- Data requirements
- Forecast data FTP access
- Analysis data FTP access
- Display grid domain
- Vertical profile
- Contour data

Examples 1-5

Particle Trajectory Methods

- Trajectory computational method
- Trajectory example calculation
- trajectory model configuration
- Trajectory error
- Multiple trajectories
- Terrain height
- Meteorological analysis along a trajectory
- Vertical motion options

Pollutant Plume Simulations

- Modeling particles or puffs
- Concentration prediction equations
- Turbulence equations
- Dispersion model configuration
- Defining multiple sources
- Simulations using emission grids
- Concentration and particle display options
- Converting concentration data to text files
- Example local scale dispersion calculation

Special Topics

- Automated trajectory calculations
- Trajectory cluster analysis
- Concentration ensembles
- Chemistry conversion modules
- Pollutant deposition
- Source attribution using back trajectory analysis
- Source attribution using source-receptor matrices
- Source attribution functions
- GIS Shapefile output
- KML/KMZ output
- Customizing map labels
- Scripting for automated operations

Extra Topics

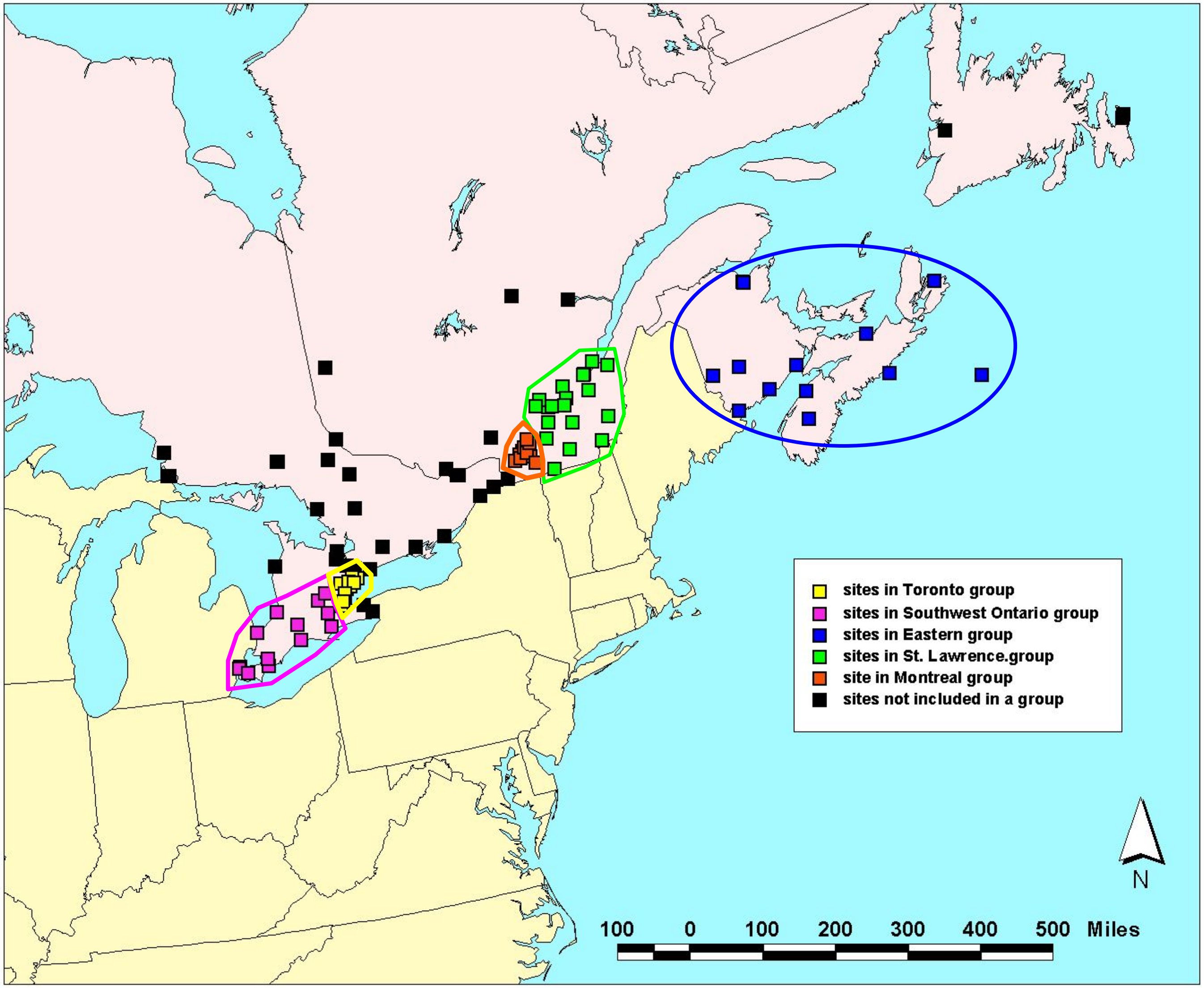
- Modeling PM10 emissions from dust storms
- Restarting the model from a particle dump file

HYSPLIT Model Features

- Predictor-corrector advection scheme; forward or backward integration
- Linear spatial & temporal interpolation of meteorology
- Converters available ARW, ECMWF, RAMS, MM5, NMM, GFS, …
- Vertical mixing based upon SL similarity, BL Ri, or TKE
- Horizontal mixing based upon velocity deformation, SL similarity, or TKE
- Mixing coefficients converted to velocity variances for dispersion
- Dispersion computed using 3D particles, puffs, or both simultaneously
- Modelled particle distributions (puffs) can be either Top-Hat or Gaussian
- Air concentration from particles-in-cell or at a point from puffs
- Multiple simultaneous meteorology and concentration grids
- Latitude-Longitude or Conformal projections supported for meteorology
- Nested meteorology grids use most recent and finest spatial resolution
- Non-linear chemistry modules using a hybrid Lagrangian-Eulerian exchange
- Standard graphical output in Postscript, Shapefiles, or Google Earth (kml)
- Distribution: PC and Mac executables, and UNIX (LINUX) source

Some Example Applications

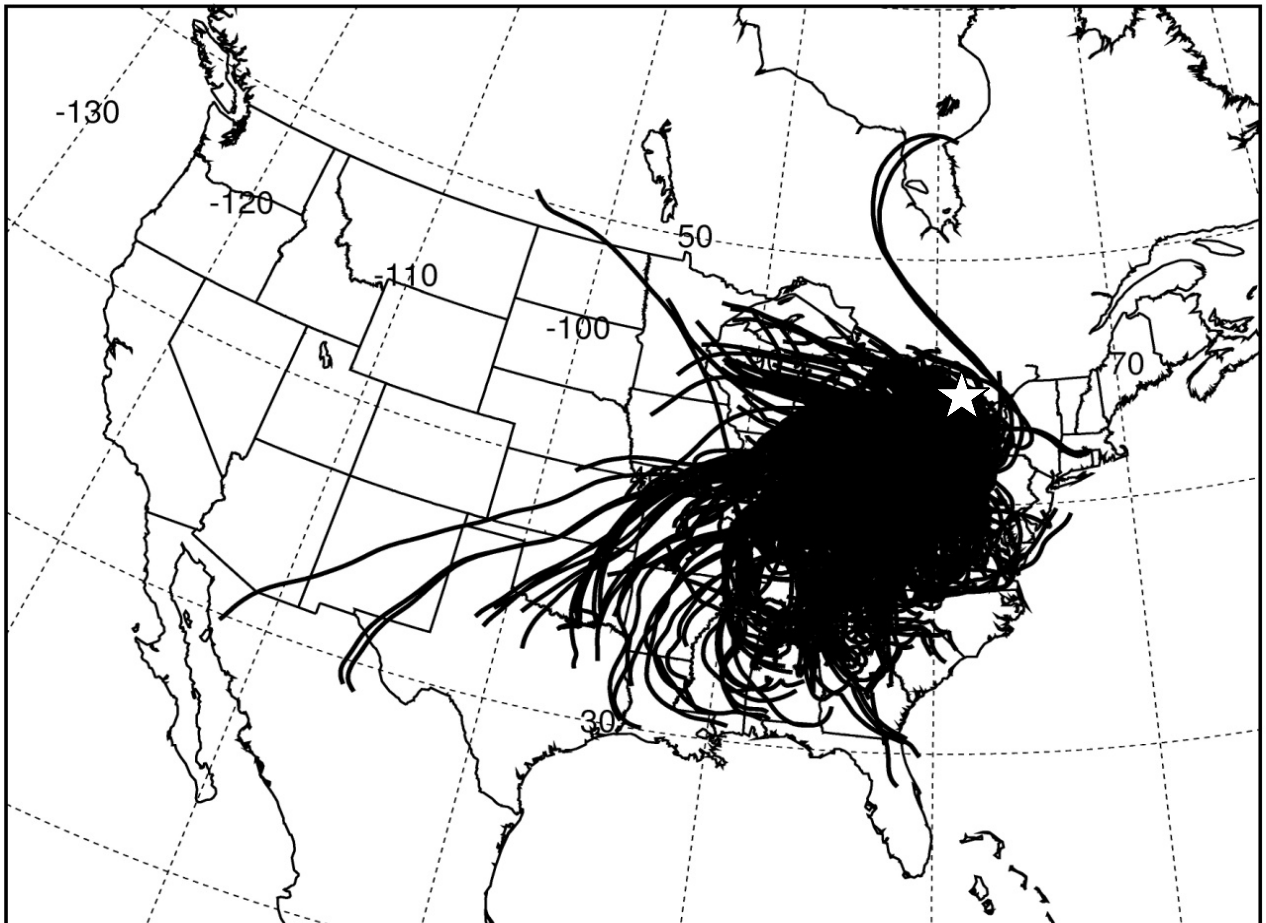
- Source region identification


sites in Toronto group
sites in Southwest Ontario group
sites in Eastern group
sites in St. Lawrence.group
site in Montreal group
sites not included in a group
N
100
0
100
200
300
400
500
Miles

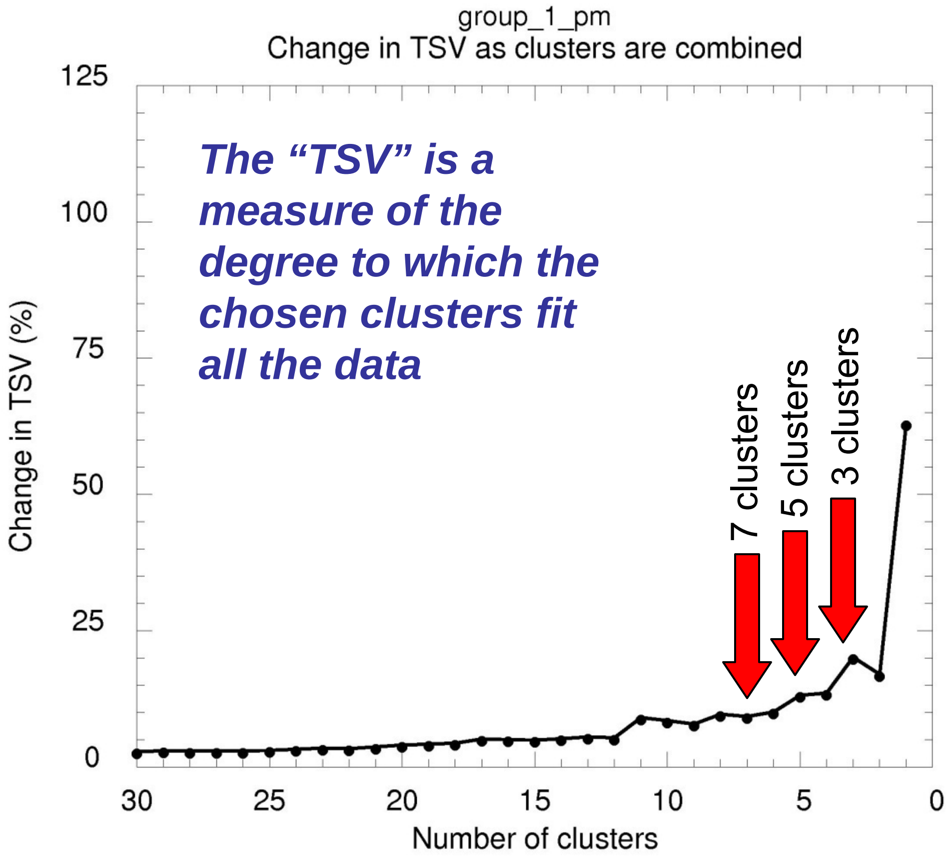
Methodology

- *205 episodes* identified from 14 sites in the Toronto region: 139 PM + 66 O_3
- Multiple 72-hr *back-trajectories* were run with the NOAA HYSPLIT model for each episode, starting at the middle of the mixed layer:
  - *24-hr PM episodes:* 7 trajectories run for each episode, once every 4 hours (at 0, 4, 8, 12, 16, 20, and 24 hours after the start of the episode)
  - *8-hr O3 episodes:* 5 trajectories run for each episode, once every 2 hours (at 0, 2, 4, 6, and 8 hours after the start of the episode)
- Following the above methodology, a *total of 1303 back-trajectories* were attempted
- Preliminary *cluster analysis* performed for each group of sites, for PM and O_3 episodes
- Preliminary analysis of *gridded trajectory frequency* performed for each group of sites for PM and O_3 episodes

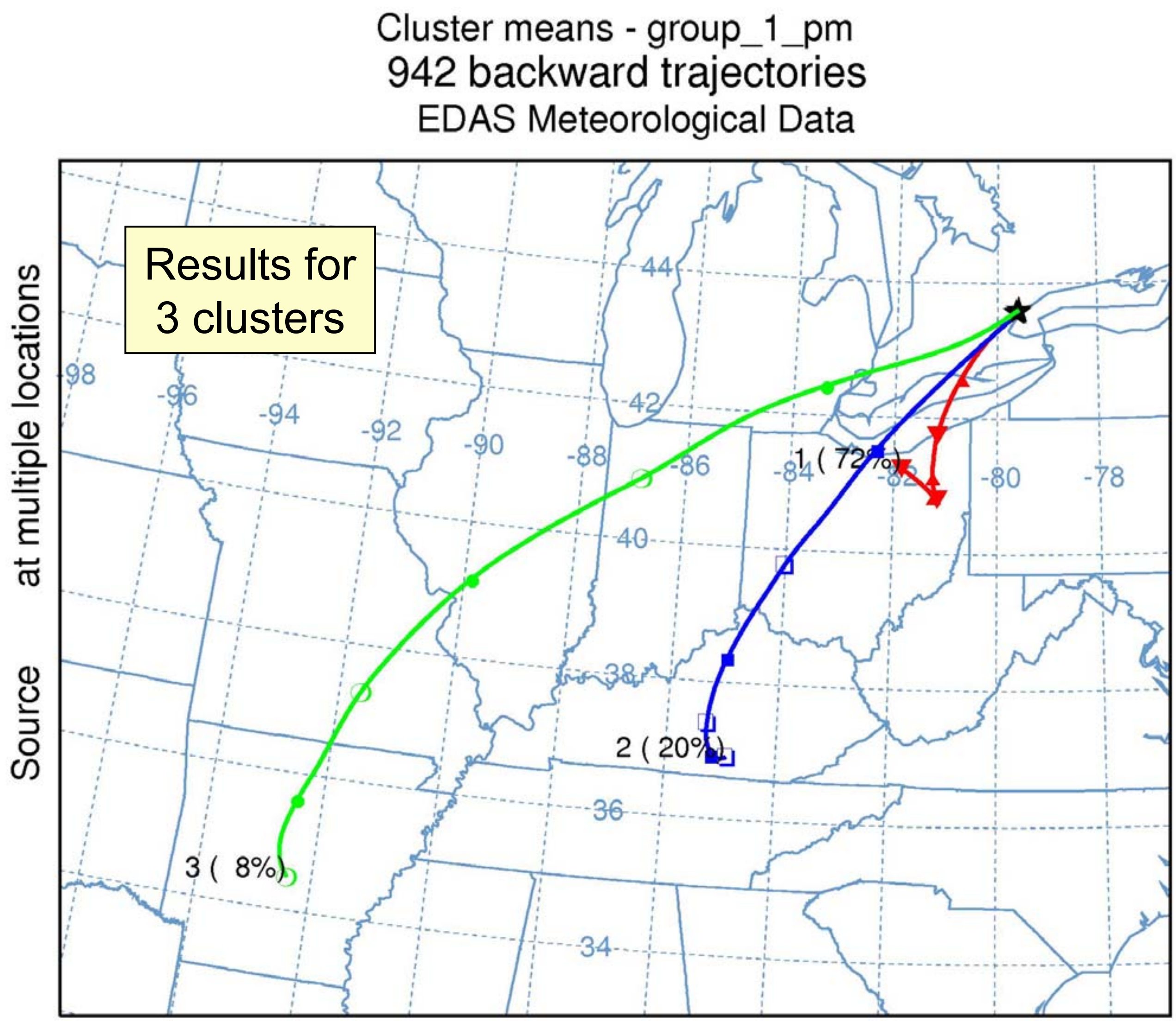
Source ★ at multiple locations



Summary of Clustering results for Toronto group (group #1) PM events

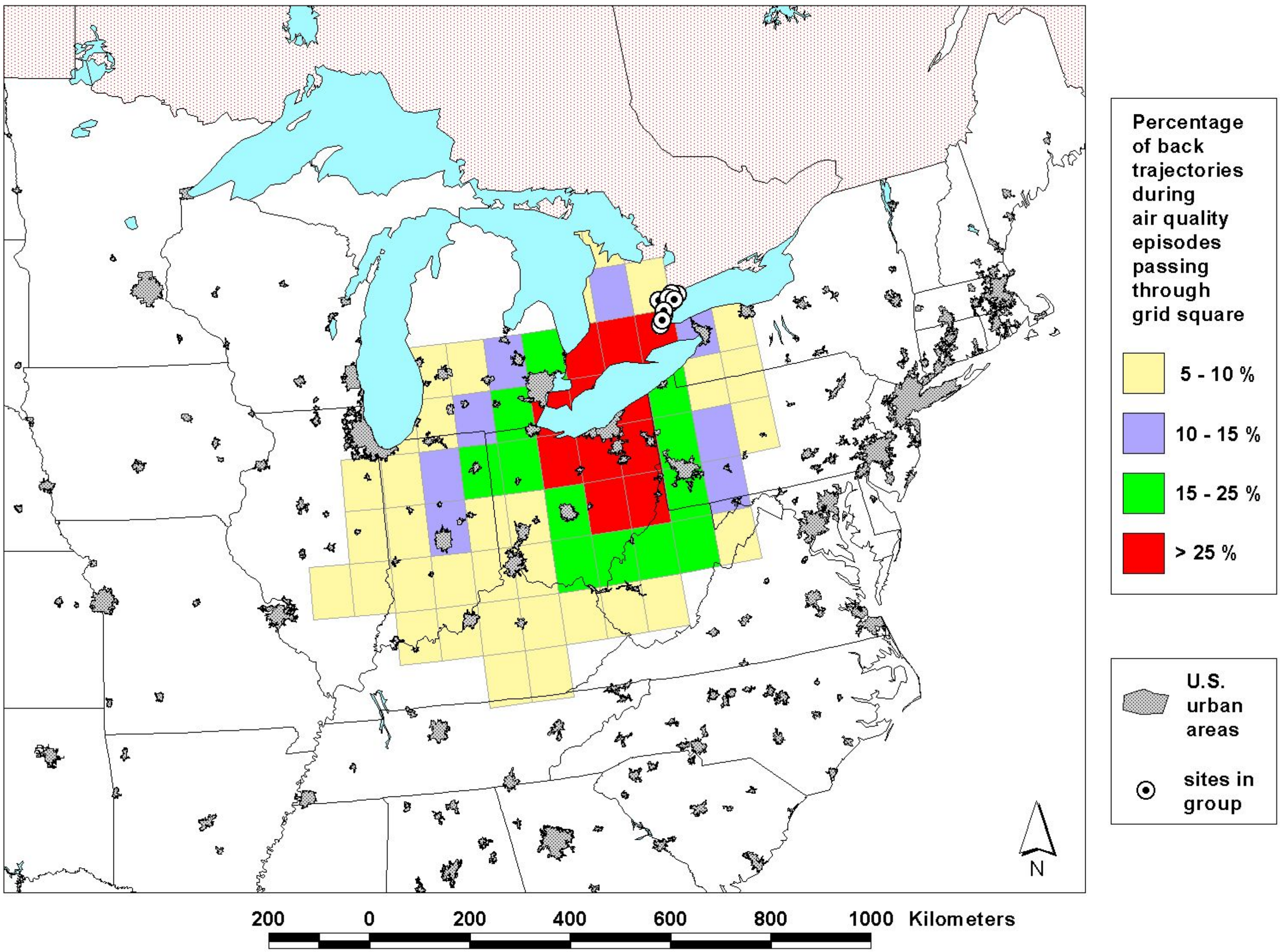


As one increases the number of clusters, a point of "diminishing returns" is reached in terms of reducing the "scattering" around the group of clusters

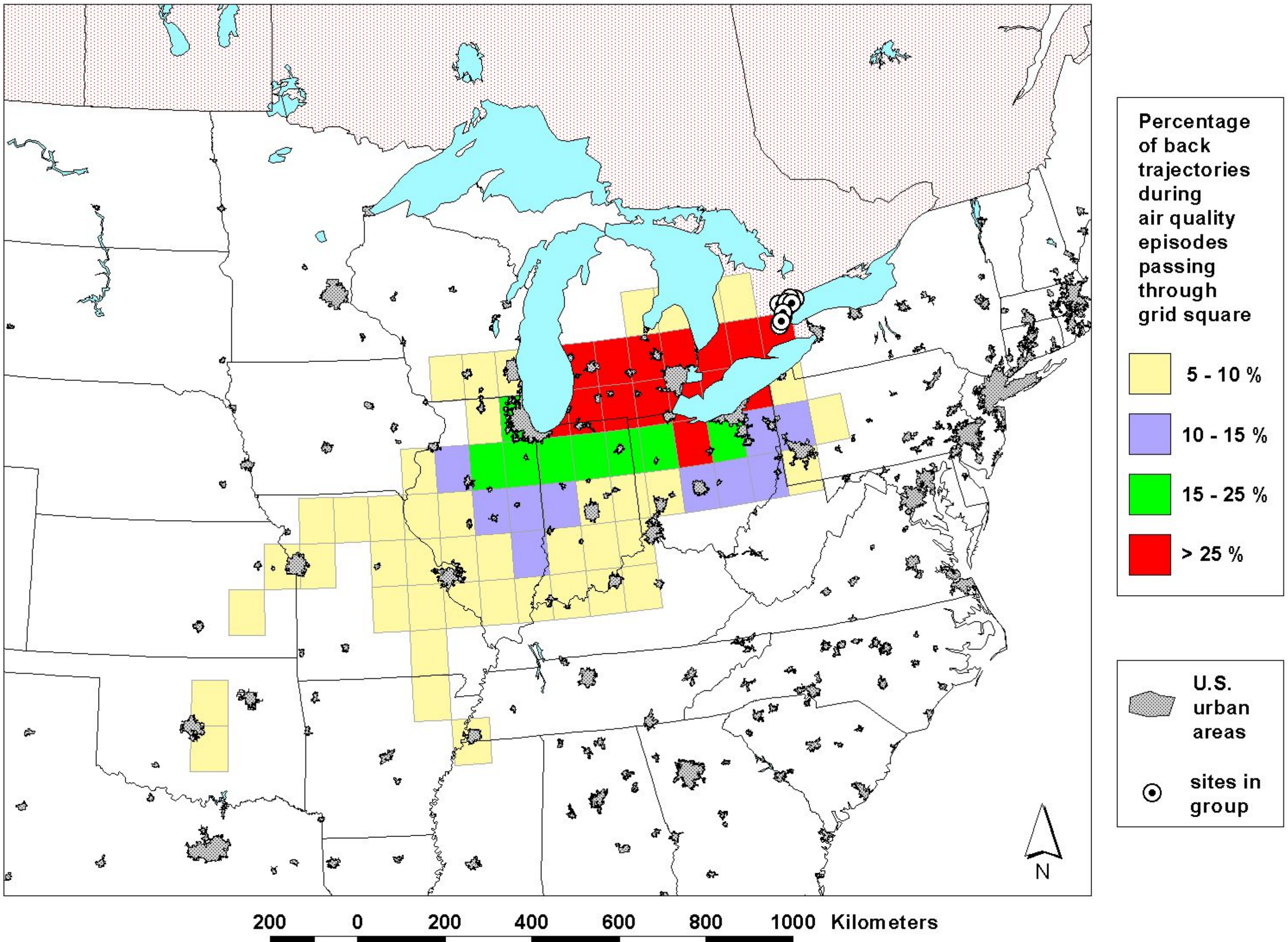


Cluster means - group_1_pm
942 backward trajectories
EDAS Meteorological Data
Results for
3 clusters
Source at multiple locations
1 (72%)
2 (20%)
3 (8%)
-98
-96
-94
-92
-90
-88
-86
-84
-82
-80
-78
44
42
40
38
36
34

Another way to look at the universe of back-trajectory results is to determine the fraction of trajectories that pass through a given grid square (in this case a 1° x 1° grid). Here is an example for the overall results for 984 back trajectories run for the PM episodes at sites in the Toronto group.

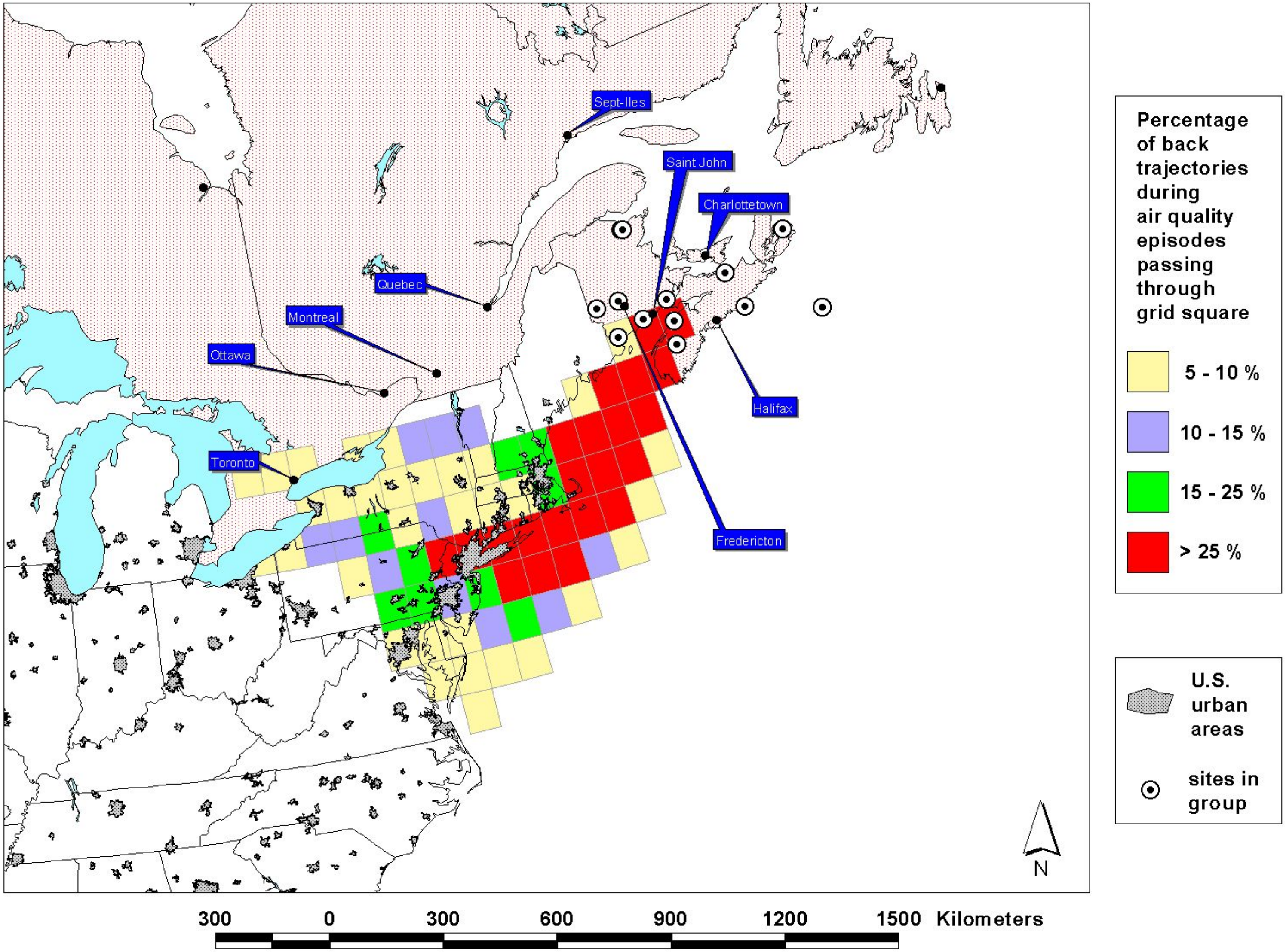


Ozone events for the "Toronto" group of monitoring sites



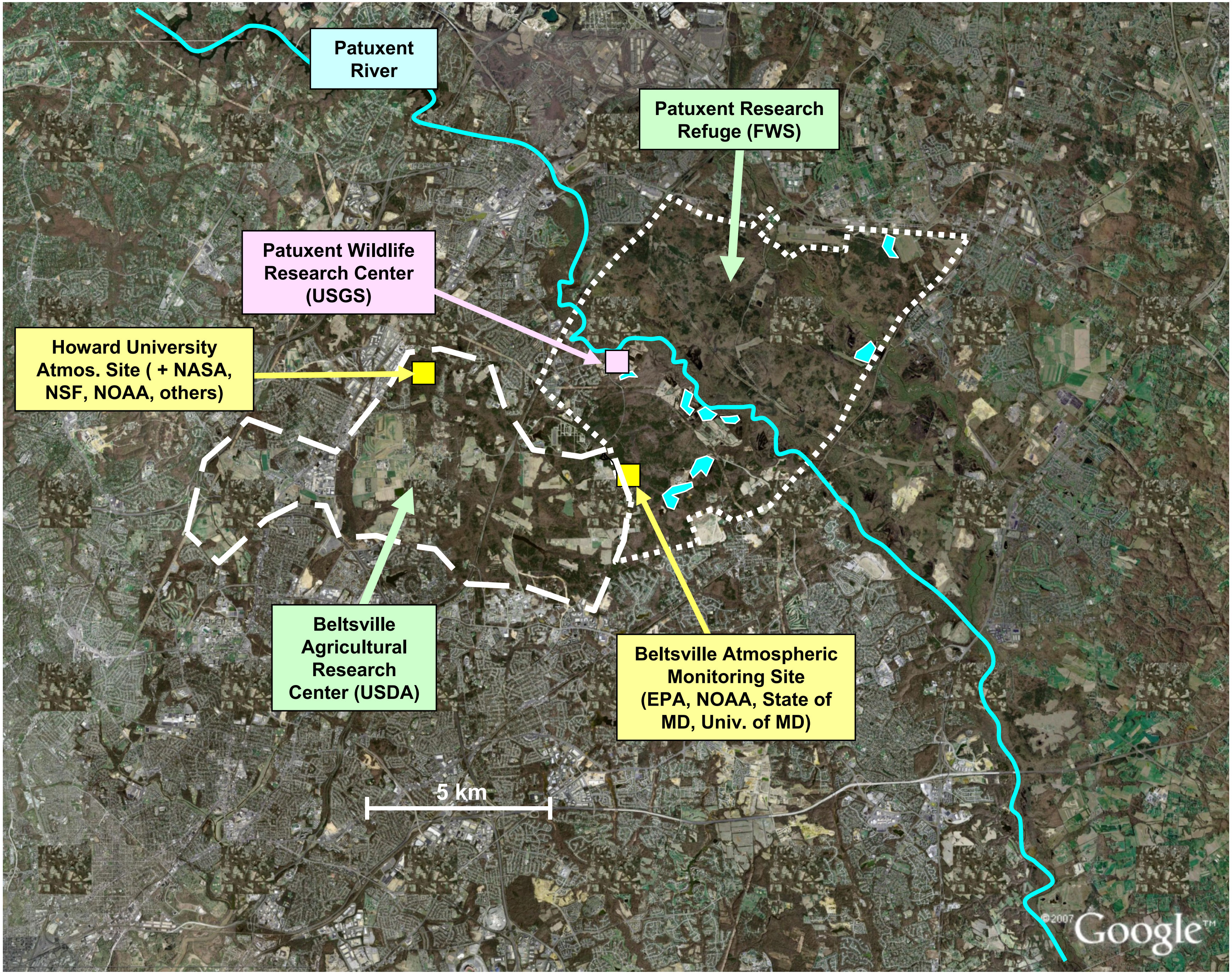
another example of grid-frequency results:

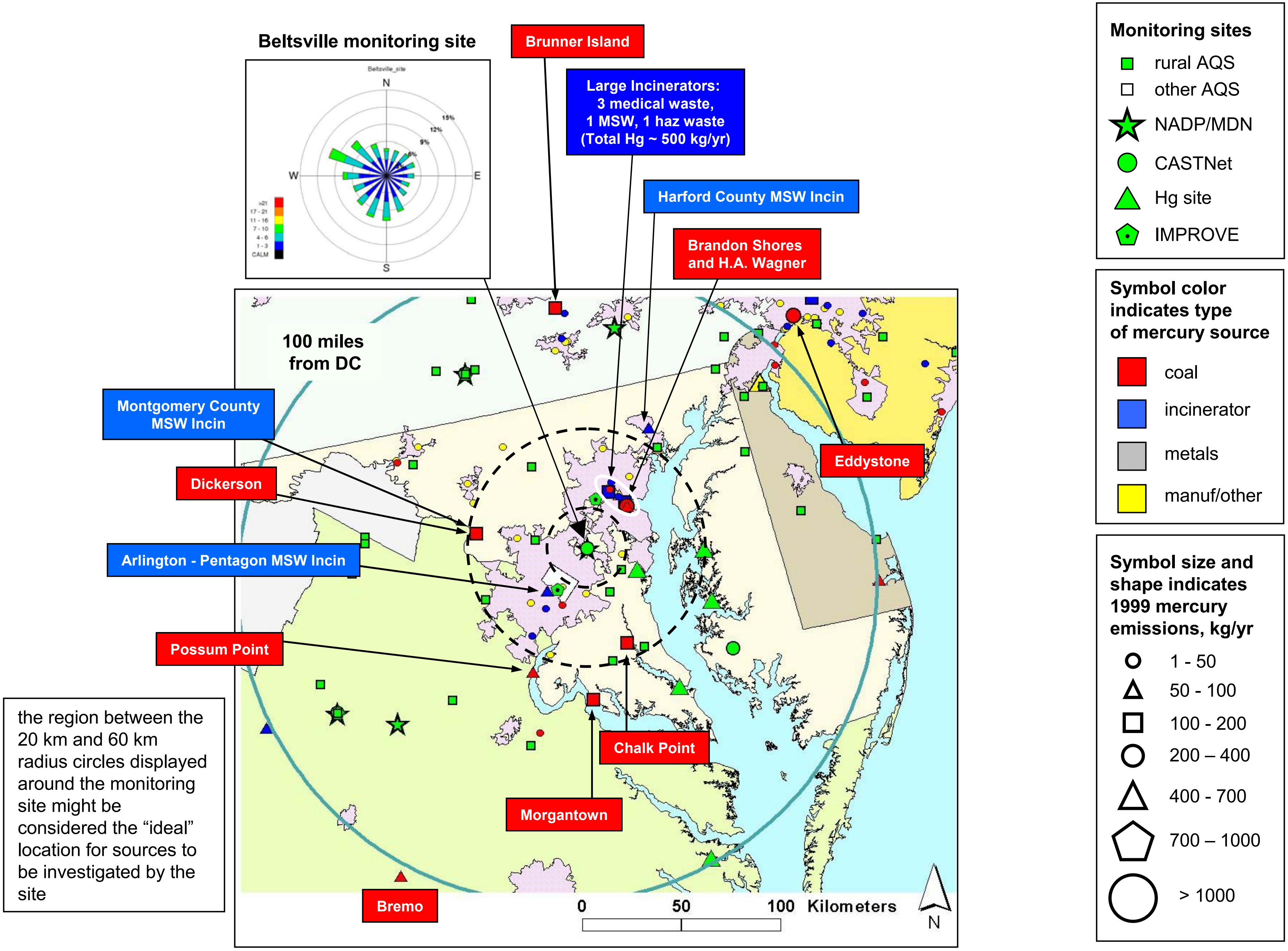
Ozone events for the "Eastern" group of monitoring sites



Some Example Applications

- Source region identification
- Site selection and data interpretation

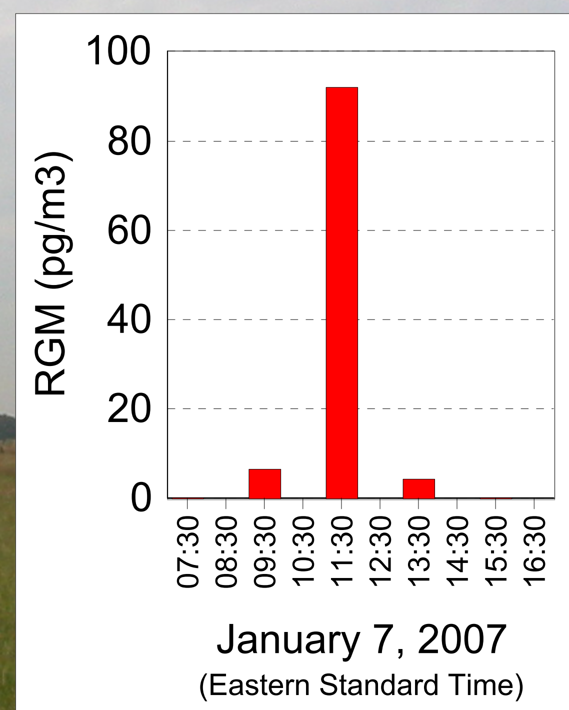

Patuxent River
Patuxent Research Refuge (FWS)
Patuxent Wildlife Research Center (USGS)
Howard University Atmos. Site (+ NASA, NSF, NOAA, others)
Beltsville Agricultural Research Center (USDA)
Beltsville Atmospheric Monitoring Site (EPA, NOAA, State of MD, Univ. of MD)
5 km
©2007 Google™



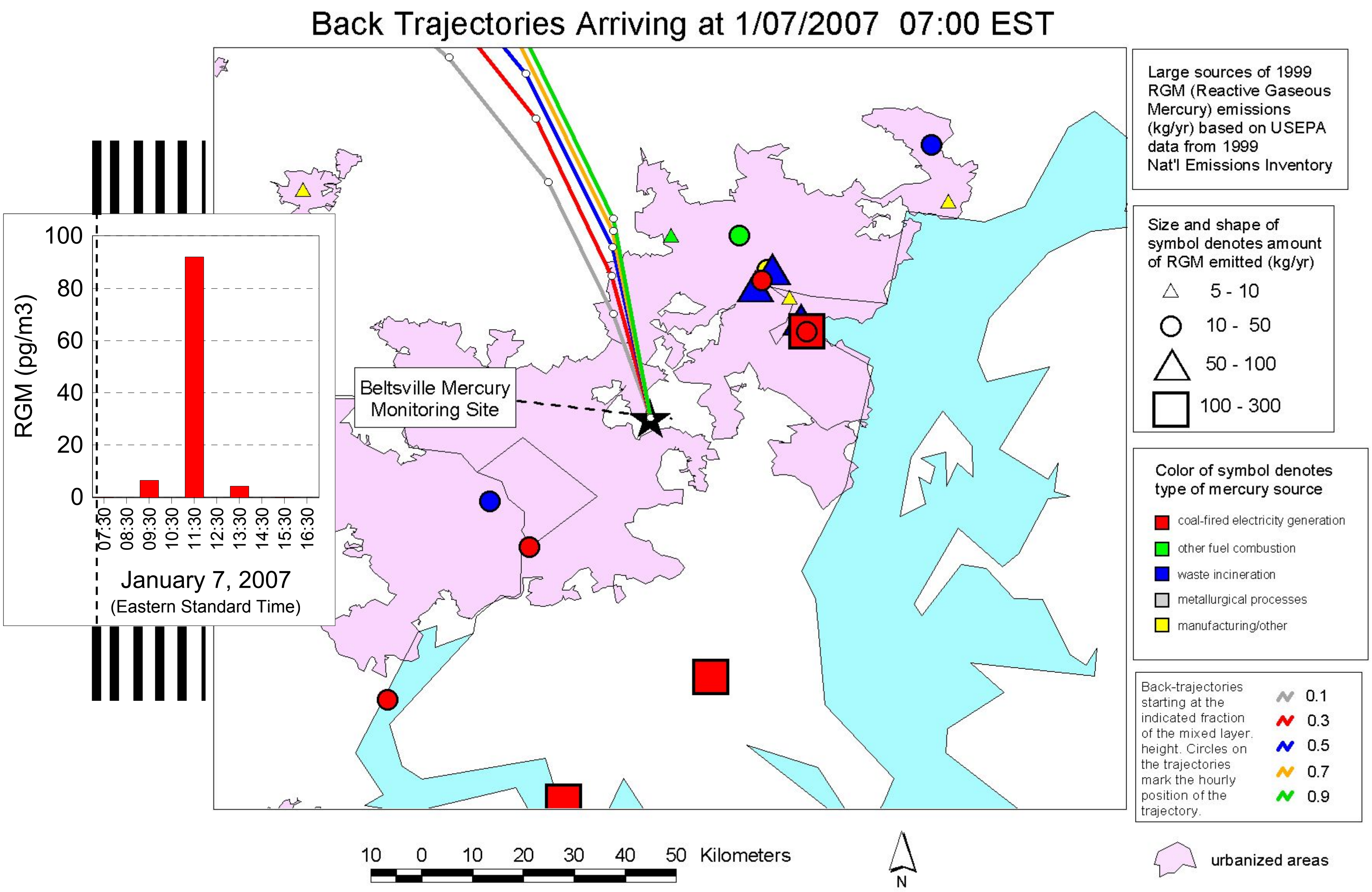
Beltsville monitoring site
Beltsville_site
N
S
E
W
15%
12%
9%
6%
>21
17 - 21
11 - 16
7 - 10
4 - 6
1 - 3
CALM
Brunner Island
Large Incinerators:
3 medical waste,
1 MSW, 1 haz waste
(Total Hg ~ 500 kg/yr)
Harford County MSW Incin
Brandon Shores
and H.A. Wagner
Eddystone
100 miles
from DC
Montgomery County
MSW Incin
Dickerson
Arlington - Pentagon MSW Incin
Possum Point
Chalk Point
Morgantown
Bremo
0
50
100
Kilometers
N
the region between the 20 km and 60 km radius circles displayed around the monitoring site might be considered the “ideal” location for sources to be investigated by the site
Monitoring sites
rural AQS
other AQS
NADP/MDN
CASTNet
Hg site
IMPROVE
Symbol color indicates type of mercury source
coal
incinerator
metals
manuf/other
Symbol size and shape indicates 1999 mercury emissions, kg/yr
1 - 50
50 - 100
100 - 200
200 – 400
400 - 700
700 – 1000
> 1000

Sometimes, we see evidence of local and regional "plume" impacts

Beltsville Episode January 7, 2007

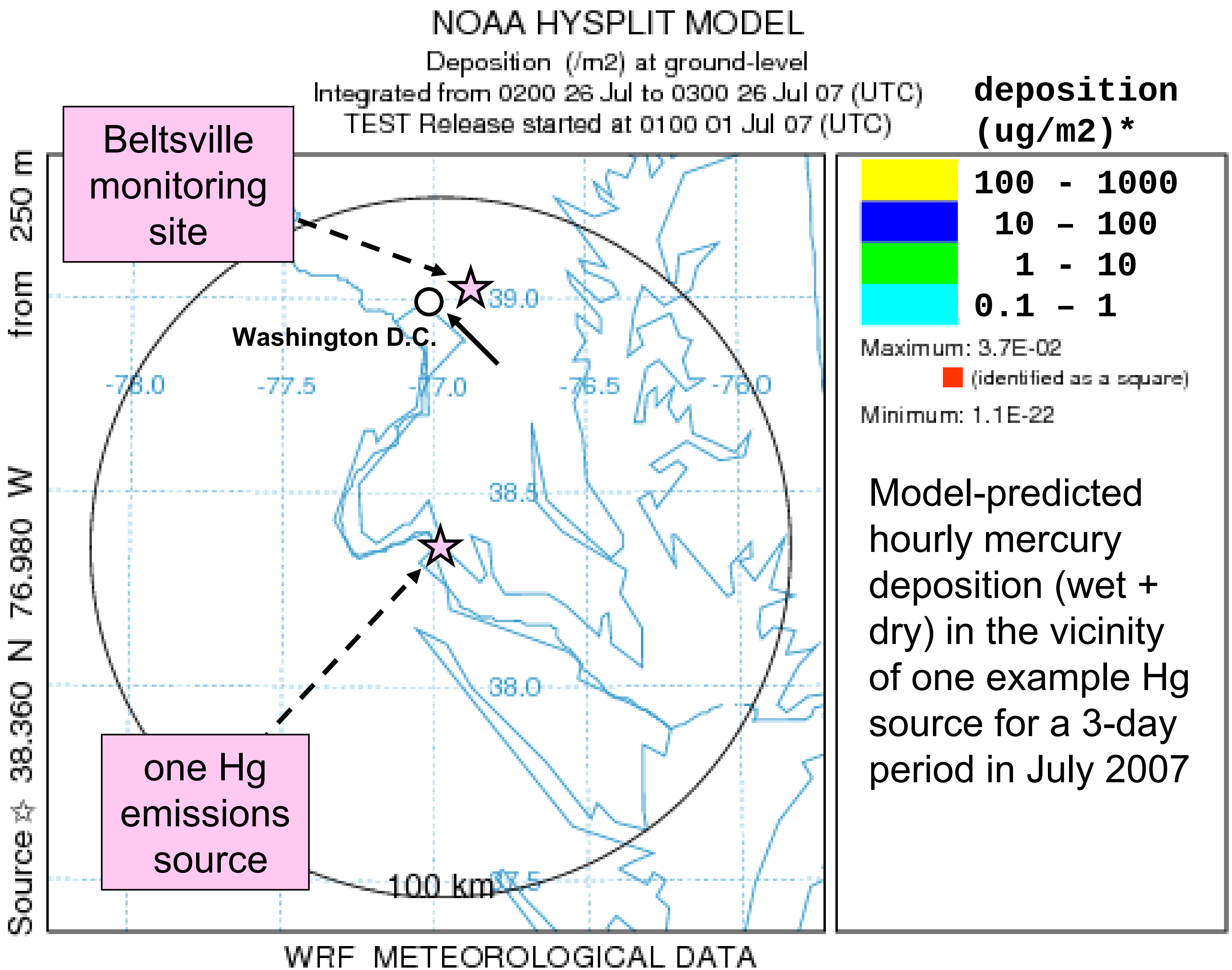


Sometimes, we see evidence of local and regional "plume" impacts



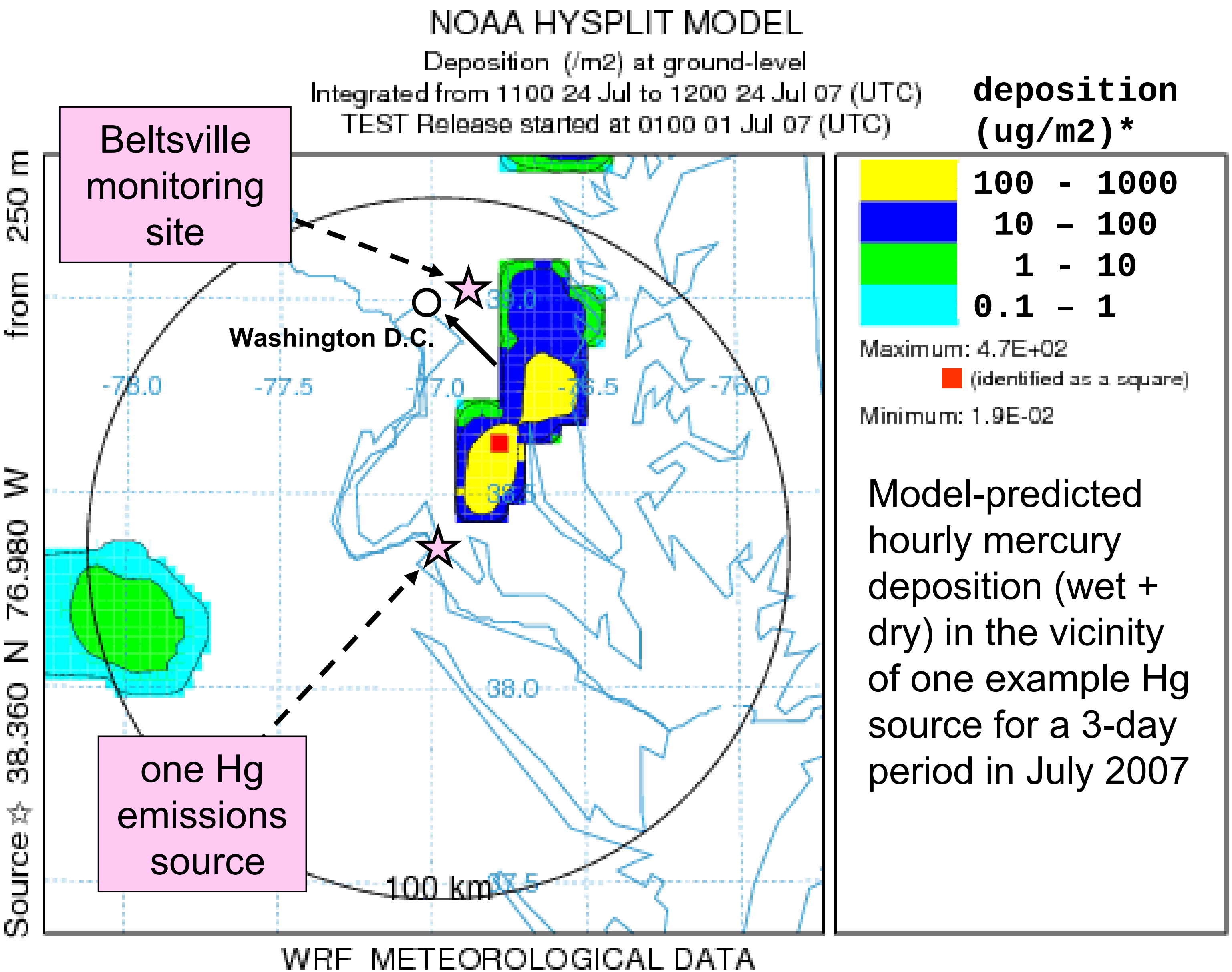
Some Example Applications

- Source region identification
- Site selection and data interpretation
- Source attribution



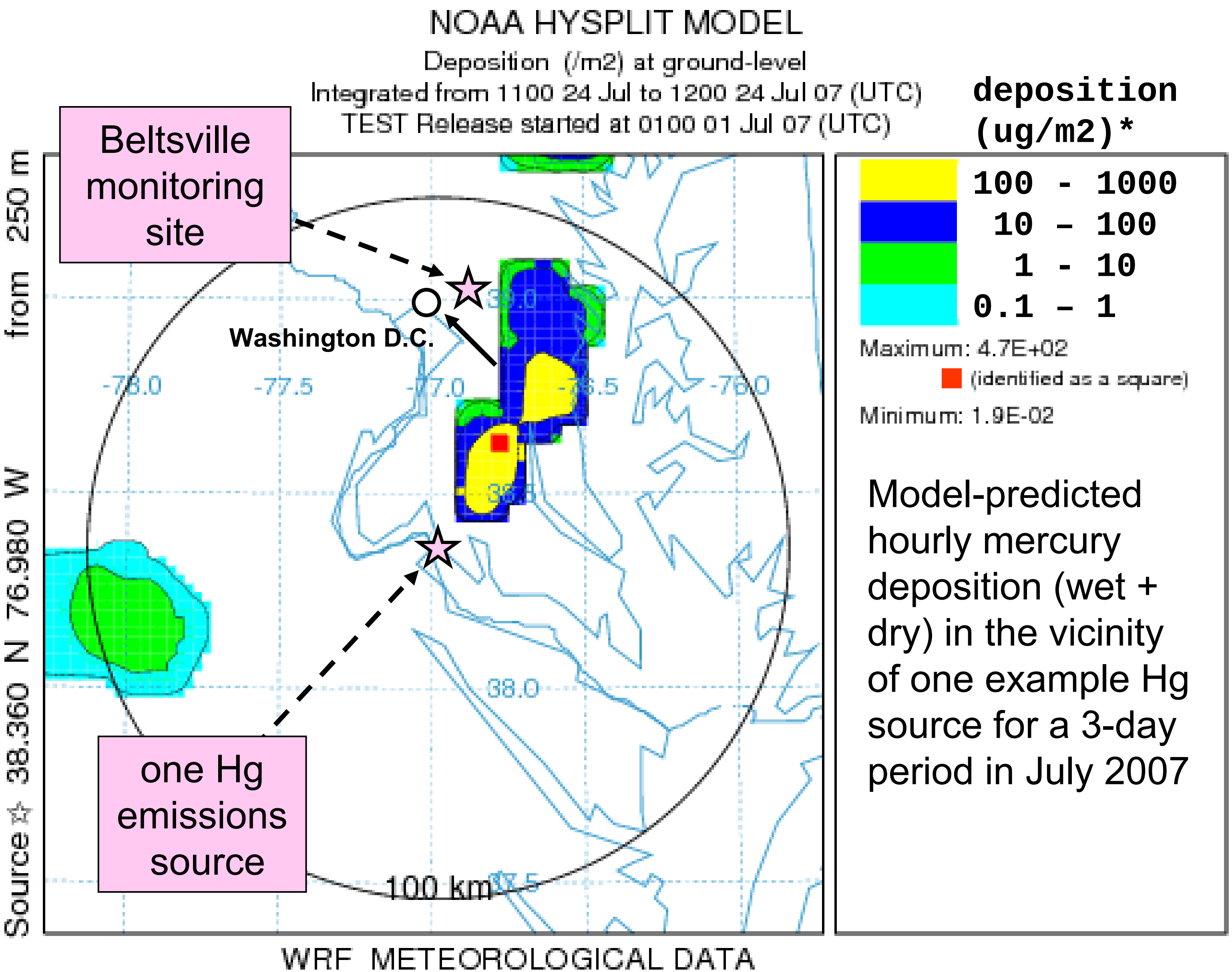
Model-predicted hourly mercury deposition (wet + dry) in the vicinity of one example Hg source for a 3-day period in July 2007

** hourly deposition converted to annual equivalent*



* *hourly deposition converted to annual equivalent*

Large, time-varying spatial gradients in deposition & source-receptor relationships



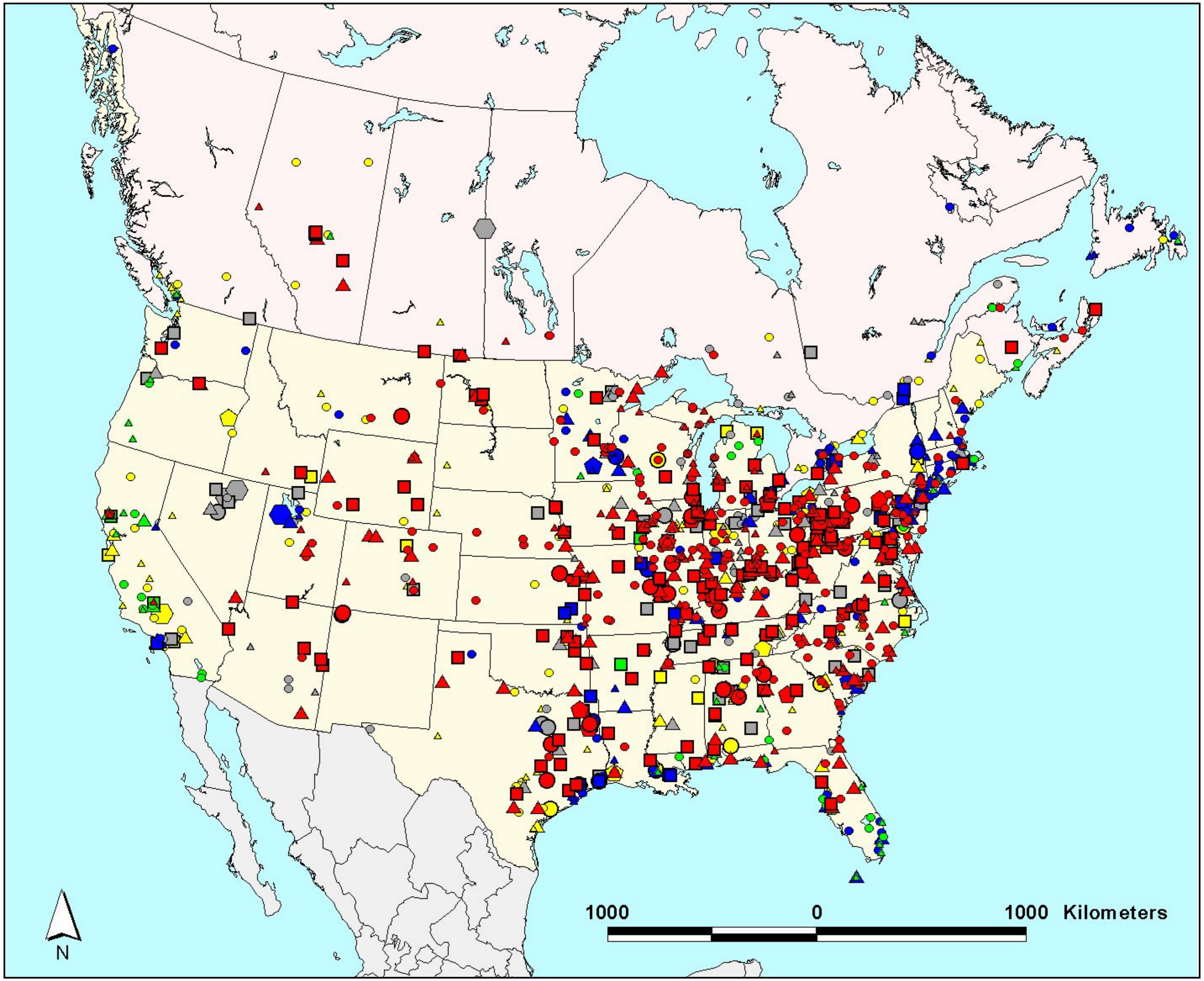
Model-predicted hourly mercury deposition (wet + dry) in the vicinity of one example Hg source for a 3-day period in July 2007

** hourly deposition converted to annual equivalent*

Some Example Applications

- Source region identification
- Site selection and data interpretation
- Source attribution
- Estimation of deposition by source

2002 U.S. and Canadian Emissions of Total Mercury [Hg(0) + Hg(p) + RGM]



Large Point Sources of Mercury Emissions Based on the 2002 EPA NEI and 2002 Envr Canada NPRI*

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

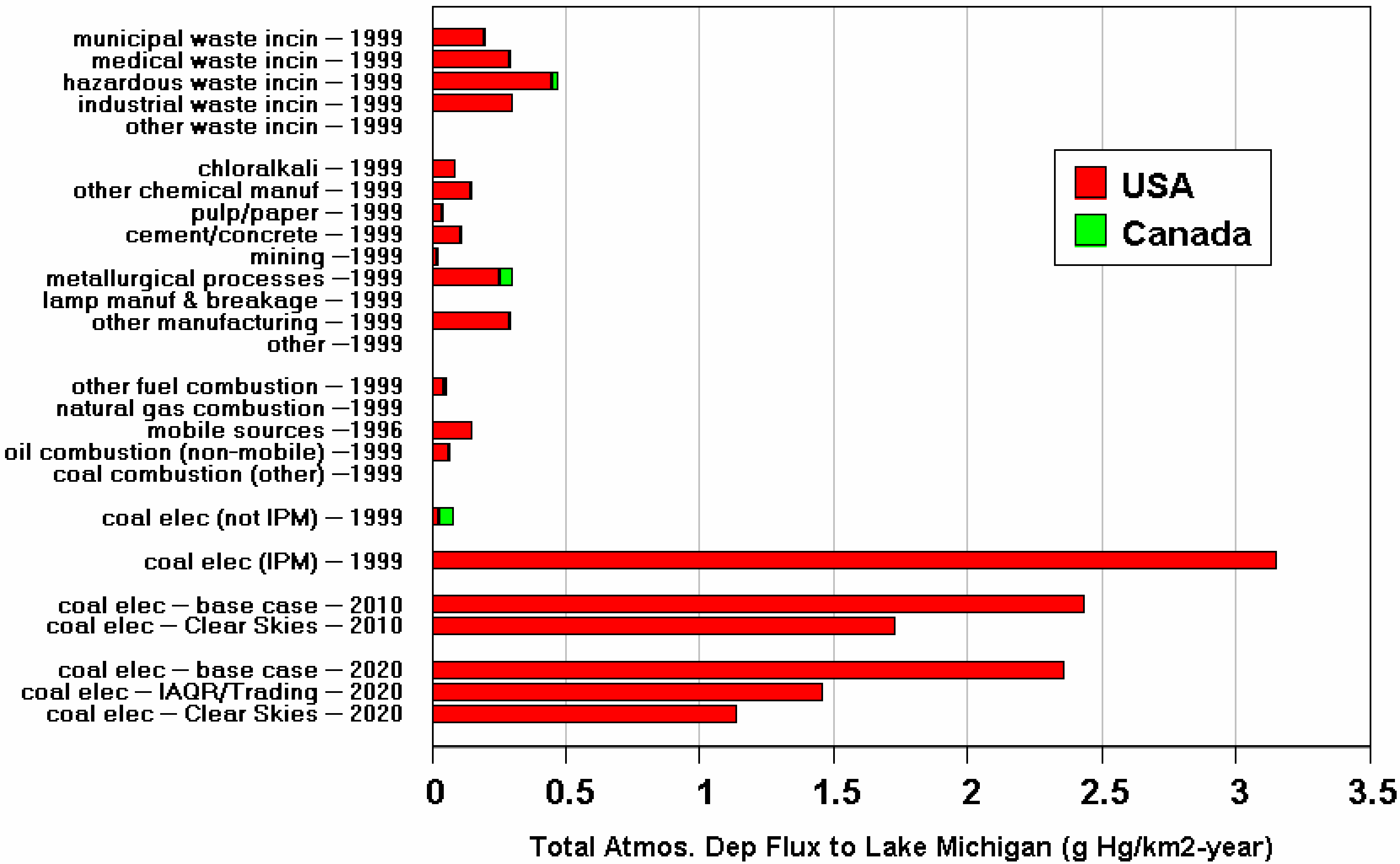
small triangle	5 - 10
small circle	10 - 50
triangle	50 - 100
square	100 – 300
circle	300 - 500
pentagon	500 - 1000
hexagon	1000 - 3000

color of symbol denotes type of mercury source

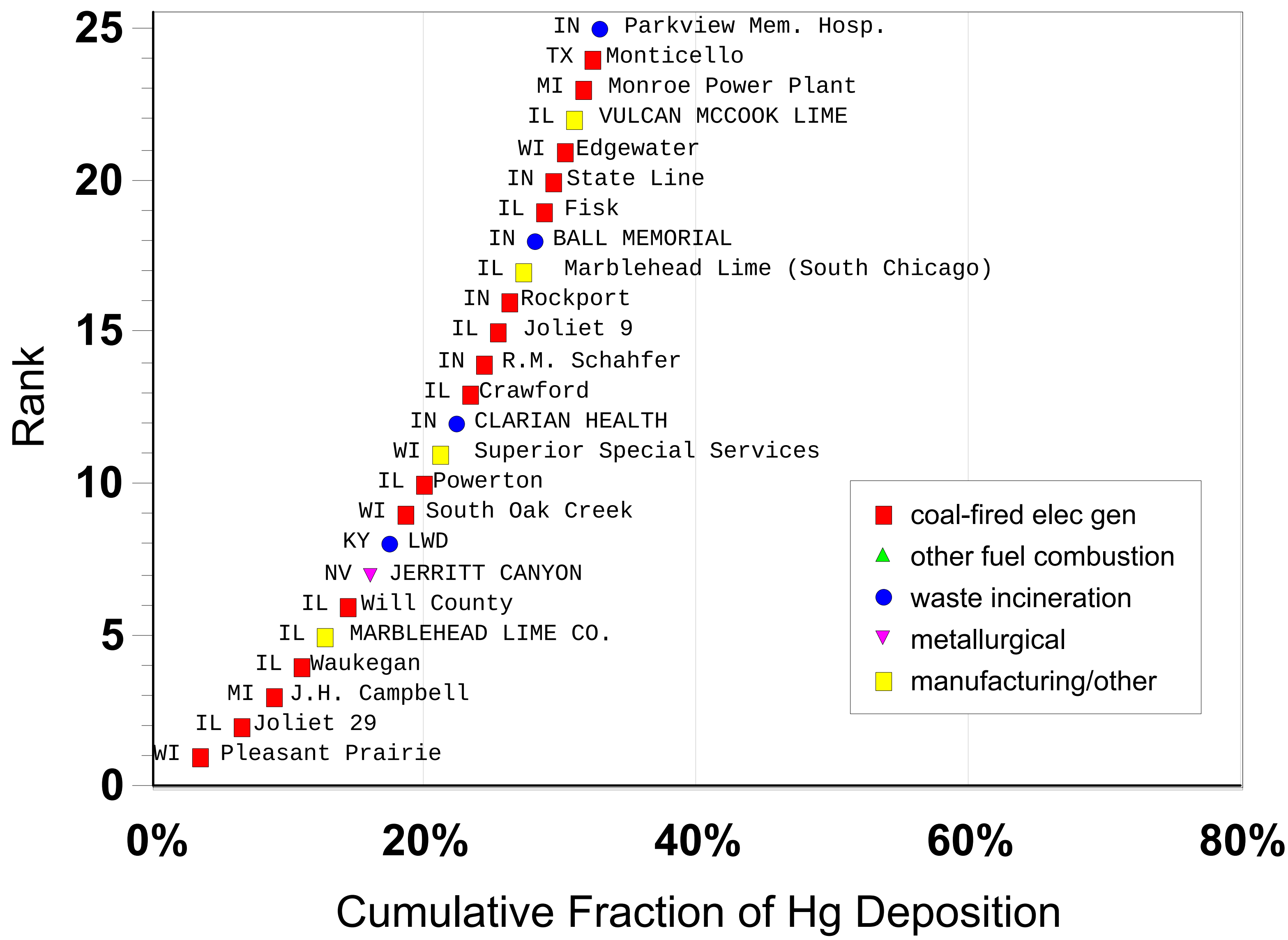
- red: coal-fired power plants
- green: other fuel combustion
- blue: waste incineration
- gray: metallurgical
- yellow: manufacturing & other

** Note – some large Canadian point sources may not be included due to secrecy agreements between industry and the Canadian government.*

Atmospheric Deposition Flux to Lake Michigan from Anthropogenic Mercury Emissions Sources in the U.S. and Canada

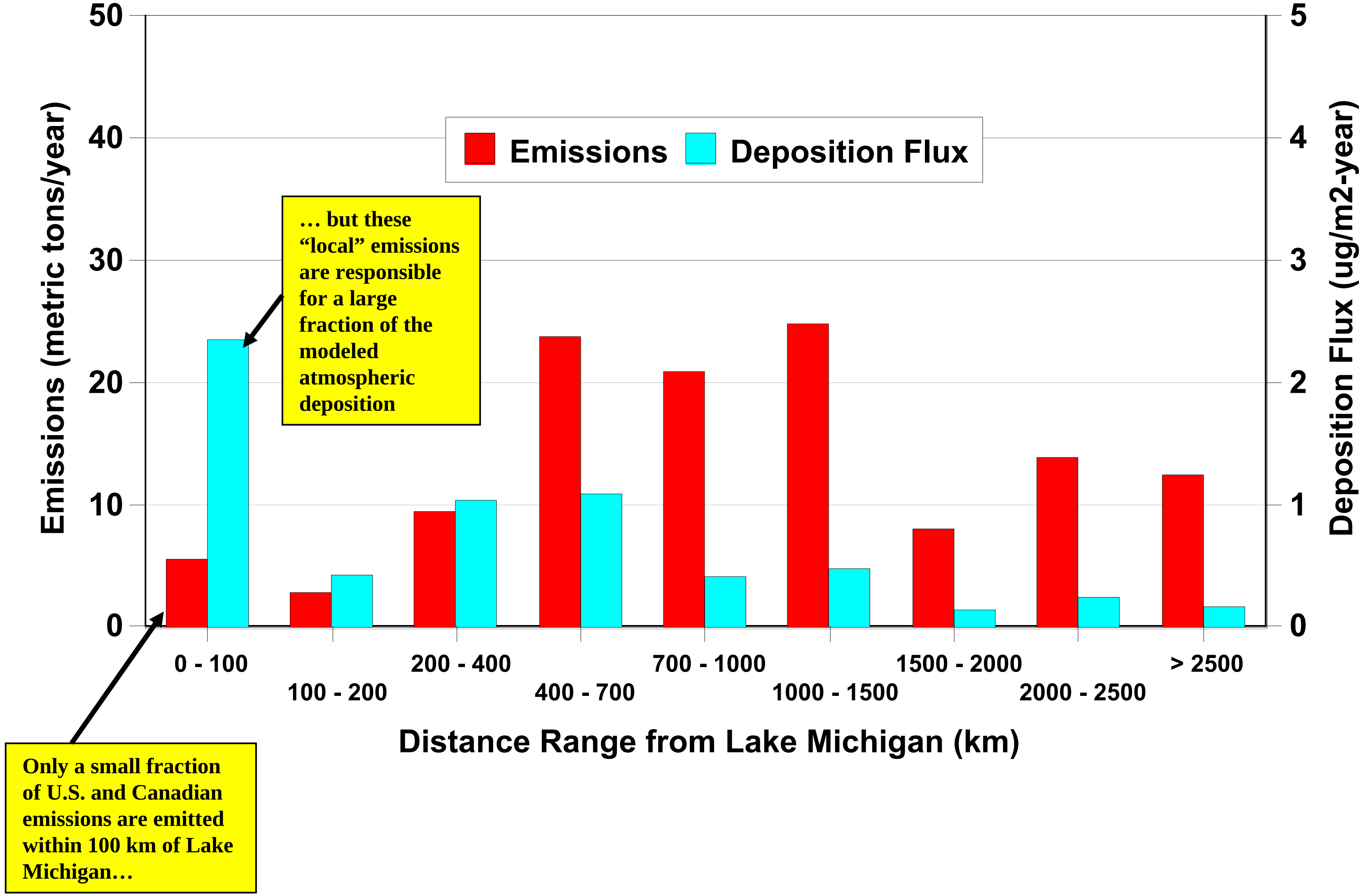


Top 25 modeled sources of atmospheric mercury to Lake Michigan (based on 1999 anthropogenic emissions in the U.S. and Canada)



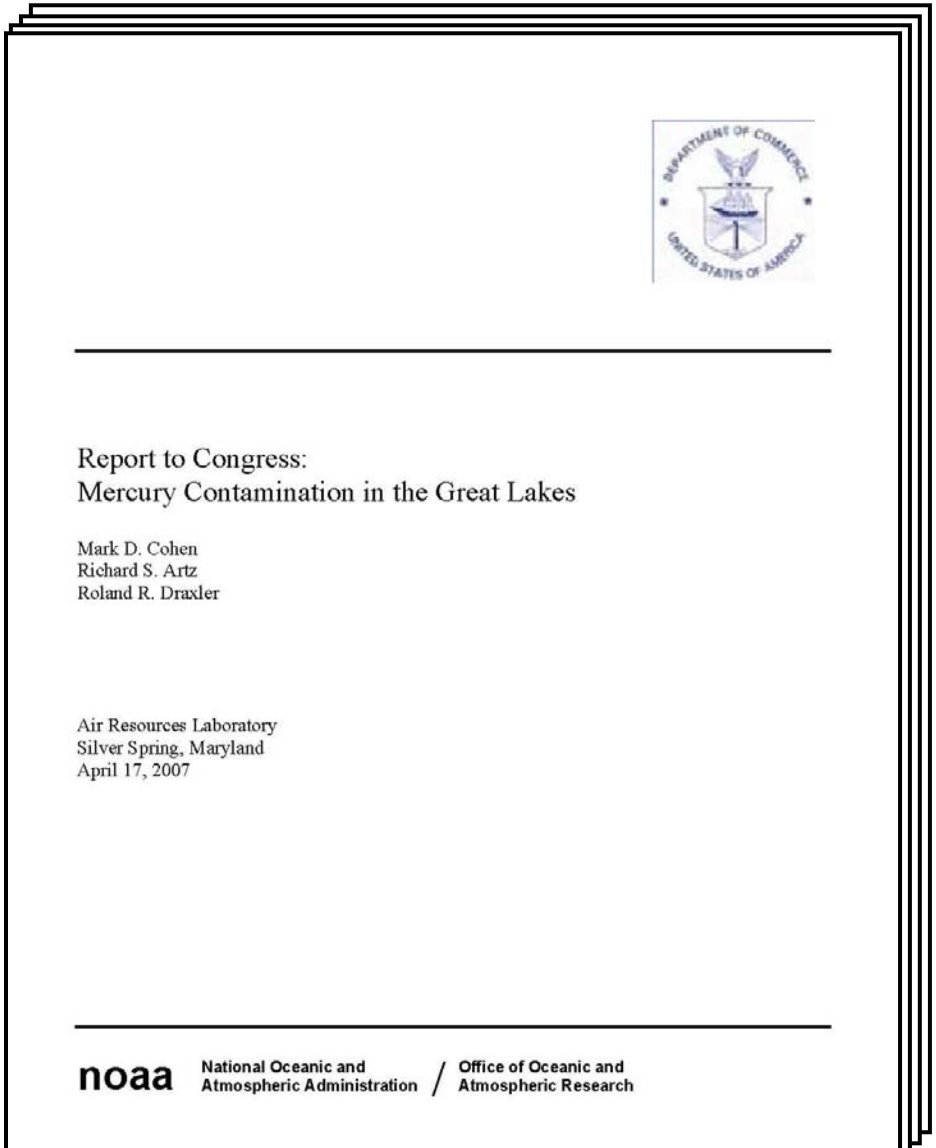
Emissions and deposition to Lake Michigan arising from different distance ranges

(based on 1999 anthropogenic emissions in the U.S. and Canada)



NOAA Report to Congress on Mercury Contamination in the Great Lakes

http://www.arl.noaa.gov/data/web/reports/cohen/NOAA_GL_Hg.pdf



Report to Congress:
Mercury Contamination in the Great Lakes

Mark D. Cohen
Richard S. Artz
Roland R. Draxler

Air Resources Laboratory
Silver Spring, Maryland
April 17, 2007

noaa National Oceanic and Atmospheric Administration / Office of Oceanic and Atmospheric Research

- The Conference Report accompanying the consolidated Appropriations Act, 2005 (H. Rpt. 108-792) requested that NOAA, in consultation with the EPA, report to Congress on mercury contamination in the Great Lakes, with trend and source analysis.
- Reviewed by NOAA, EPA, DOC, White House Office of Science and Technology Policy, and Office of Management and Budget (OMB).
- Review process took ~2 years.
- Transmitted to Congress on May 14, 2007

Chicago Tribune
ONLINE EDITION

http://www.chicagotribune.com/services/site/premium/interceptlogin.register

Nearby coal plants said to harm lake

By Michael Hawthorne
Tribune staff reporter

September 19, 2005

Contradicting a key part of the Bush administration's environmental policy, a new federal study estimates most of the mercury falling into Lake Michigan comes from smokestacks close to the shoreline.

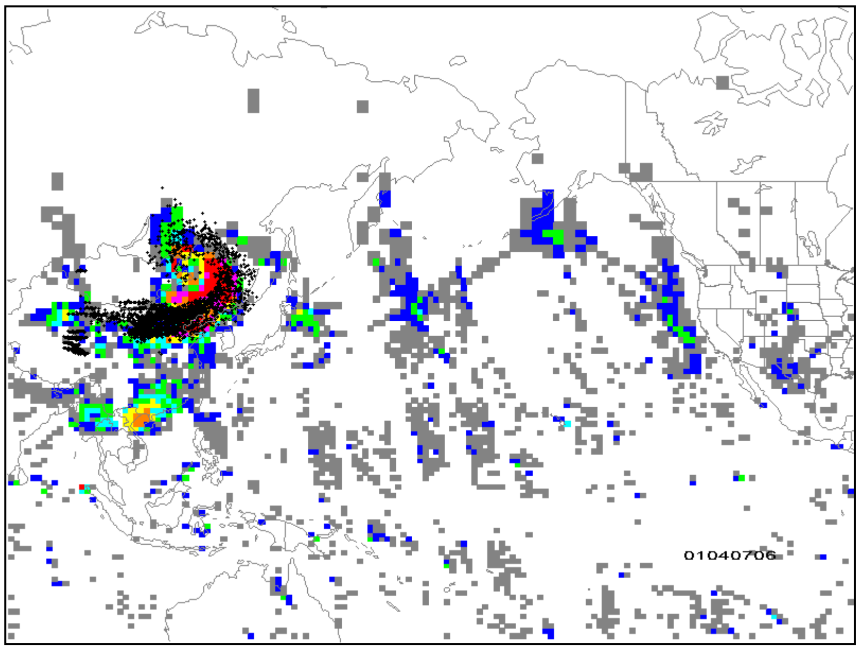
Sixteen of the top 25 sources of mercury dropped into the lake are coal-fired power plants, according to the study by the National Oceanic and Atmospheric Administration (NOAA). Some of the toxic metal comes from as far away as Nevada and Texas, the study found, but most blows toward the lake from coal plants and factories in Illinois, Wisconsin, Michigan and Indiana.

•
•
•

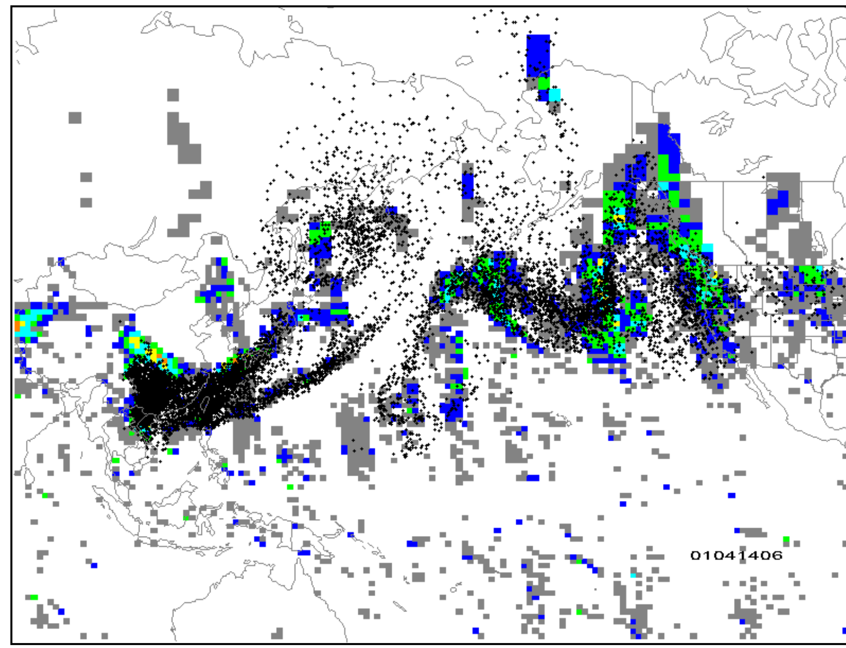
Some Example Applications

- Source region identification
- Site selection and data interpretation
- Source attribution
- Estimation of deposition by source
- Asian dust and wildfire smoke

China April 2001
Particle Distribution and TOMS Aerosol Index



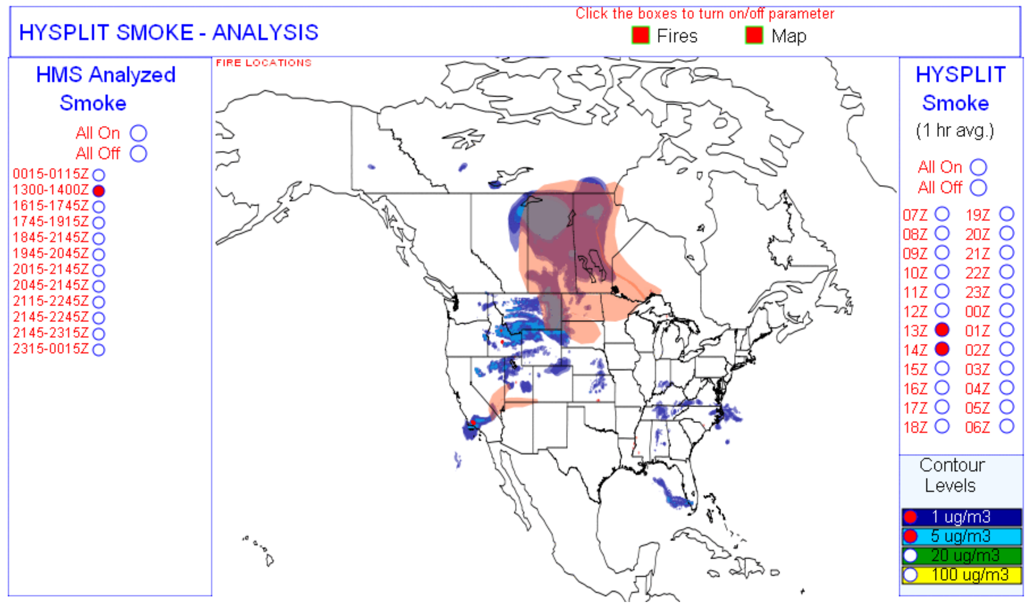
April 7th 0600 UTC

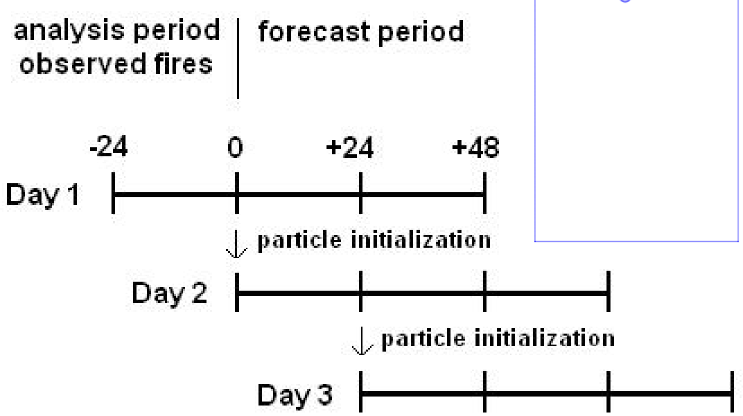


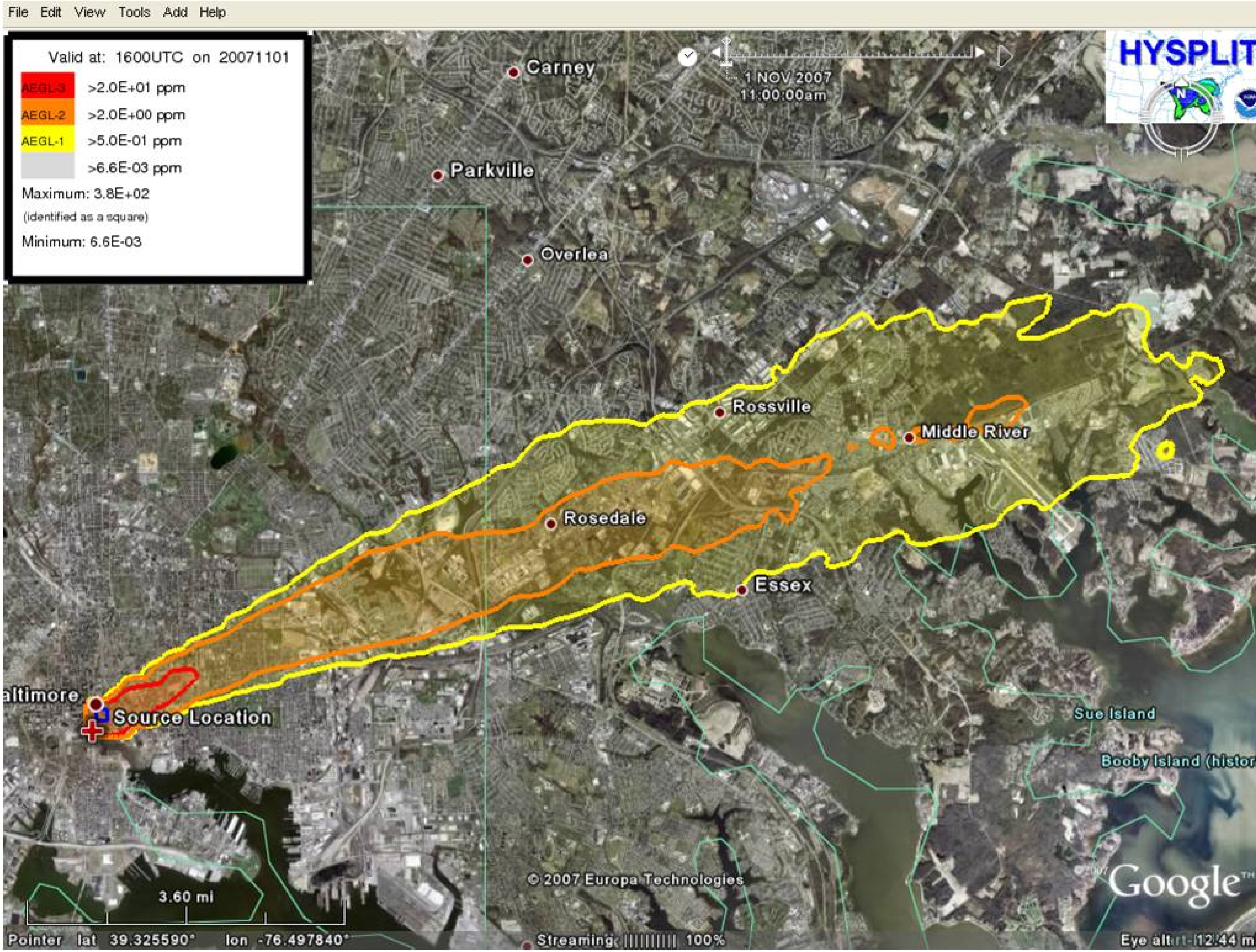
April 14th 0600 UTC

National Oceanic and Atmospheric Administration
Transport Modeling and Assessment Group
Air Resources Laboratory

Wild Fire Smoke Verification
http://www.arl.noaa.gov/smoke






File Edit View Tools Add Help
Valid at: 1600UTC on 20071101
AEGL-3 >2.0E+01 ppm
AEGL-2 >2.0E+00 ppm
AEGL-1 >5.0E-01 ppm
>6.6E-03 ppm
Maximum: 3.8E+02
(identified as a square)
Minimum: 6.6E-03
1 NOV 2007
11:00:00am
HYSPLIT
Carney
Parkville
Overlea
Rossville
Middle River
Rosedale
Essex
altimore
Source Location
Sue Island
Booby Island (historic
3.60 mi
© 2007 Europa Technologies
Google
Pointer lat 39.325590° lon -76.497840°
Streaming 100%

What's in the pipeline for version 4.9 …

- Web interactive verification linked to DATEM
- Integrated global model for background contributions
- Chemical (CAMEO) and radiological effects database
- GIS-like map background layers for graphical display
- Model physics ensemble
  - meteorology and turbulence already in existing version
- Completely revised user's guide with examples

HYSPLIT Atmospheric Model

Extras

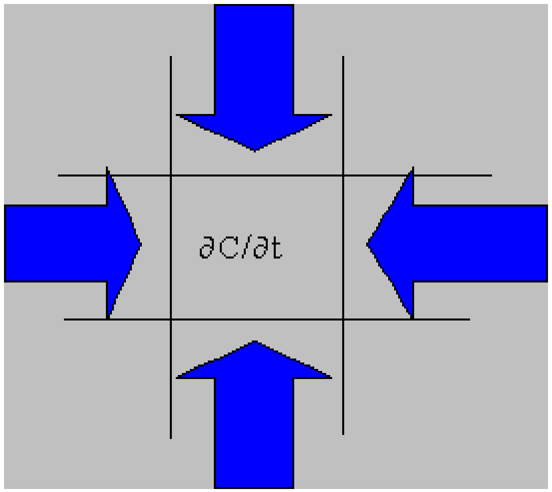
Model History

Version

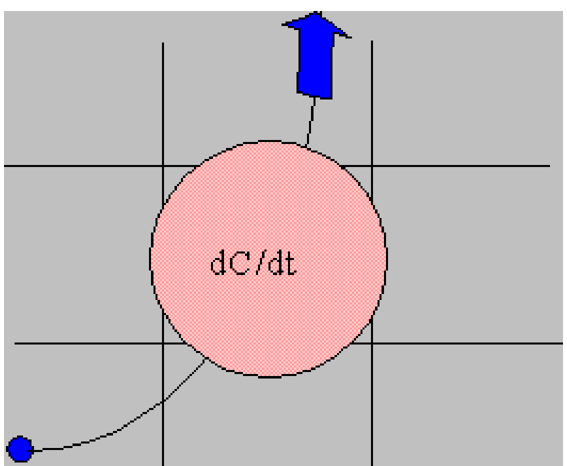
1.0 - 1979	rawinsonde data with day/night (on/off) mixing
2.0 - 1983	rawinsonde data with continuous vertical diffusivity
3.0 - 1987	model gridded fields with surface layer interpolation
4.0 - 1996	multiple meteorological fields and combined particle-puff (NOAA Technical Memo ERL ARL-224)

- 4.0 - 8/1998 - switch from NCAR to PostScript graphics for PC
- 4.1 - 7/1999 - isotropic turbulence for short-range simulations
- 4.2 - 12/1999 - terrain compression of sigma and use of polynomial
- 4.3 - 3/2000 - revised vertical auto-correlation for dispersion
- 4.4 - 4/2001 - dynamic array allocation and support of lat-lon grids
- 4.5 - 9/2002 - ensemble, matrix, and source attribution options
- 4.6 - 6/2003 - non-homogeneous turbulence correction and dust storm
- 4.7 - 1/2004 - velocity variance, TKE, new short-range equations
- 4.8 - 2006 - CMAQ compatibility, expanded ensemble options, plume rise, Google Earth, trajectory clustering, staggered grids

Integration Methods



- **Eulerian**
  - Local derivative
  - Solve over the entire domain
  - Ideal for multiple sources
  - Easily handles complex chemistry
  - Problems with artificial diffusion

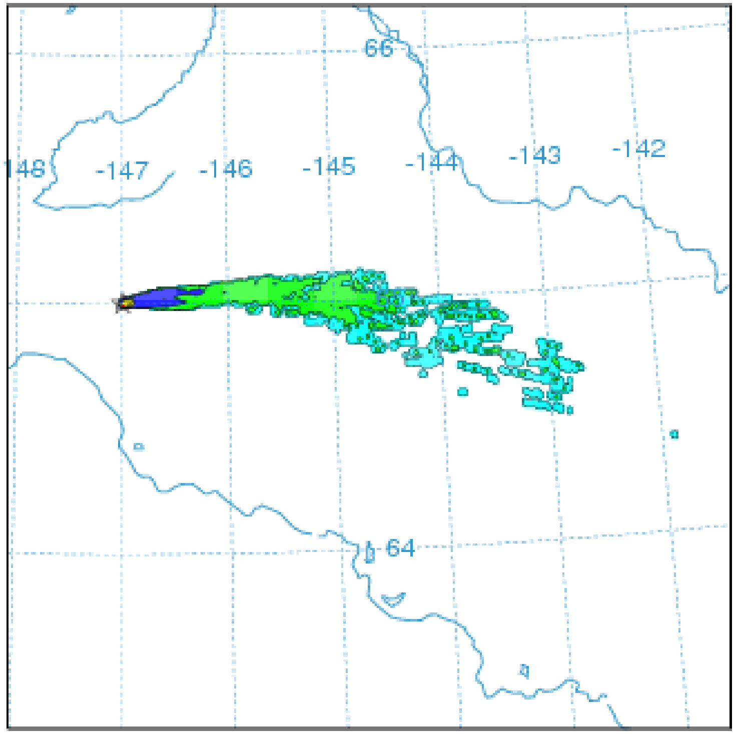


- **Lagrangian - HYSPLIT**
  - Total derivative
  - Solve only along the trajectory
  - Ideal for single point sources
  - Implicit linearity for chemistry
  - Non-linear solutions available
  - Not as efficient for multiple sources

Sensitivity to Particle Number - Why Puff Dispersion?

- A puff simulation models the growth of the particle distribution, the particle standard deviation
- Requires fewer puffs than particles to represent distribution
- Puff growth uses the same turbulence parameters as particle method
- The Puff-Particle Hybrid method
  - Fewer puffs required for horizontal distribution
  - Vertical shears captured more accurately by particles

500 3D-particles



HYSPLIT Default Deposition Configuration

- **$D_{wet+dry} = M\,[\,1 - \exp(-\Delta t\,\{\beta_{dry} + \beta_{gas} + \beta_{inc} + \beta_{bel}\})\,]$**

- **Dry Deposition**
  - $\beta_{dry} = V_d / \Delta Z_p$
  - V_d user defined; $V_d = V_g$; Resistance method
  - V_g gravitational settling (Stokes equation)

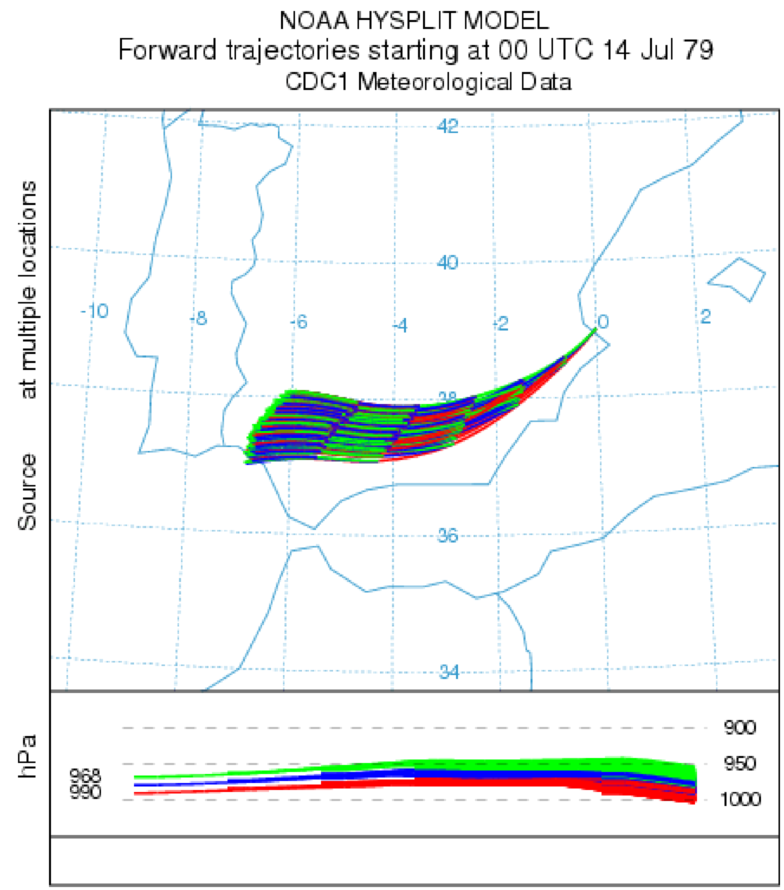
- **Cloud Layer Definition**
  - Cloud bottom: 80% Rh
  - Cloud top: 60% Rh

- **Particle Wet Deposition**
  - Within cloud: $\beta_{inc} = V_{inc} / \Delta Z_p$; $V_{inc} = S\,P$; $S=3.2 \times 10^5$
  - Below cloud: $\beta_{bel} = 5 \times 10^{-5}\ s^{-1}$

- **Gaseous Wet Deposition**
  - $\beta_{gas} = V_{gas} / \Delta Z$; $V_{gas} = H\,R\,T\,P\,10^3$

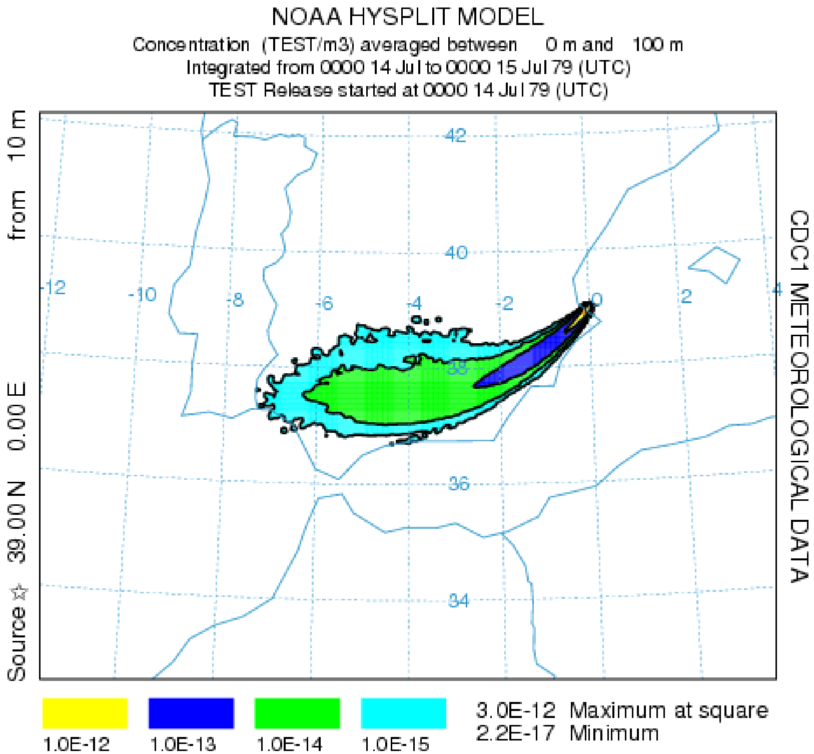
Representation of a Plume using Trajectories

- A single trajectory cannot properly represent the growth of a pollutant cloud when the wind field varies in space and height
- The simulation must be conducted using many pollutant particles
- In the illustration on the right, new trajectories are started every 4-h at 10, 100, and 200 m AGL to represent the boundary layer transport
- It looks like a plume because wind speed and direction varies with height in the boundary layer



Trajectory based Plume Simulation Options

- **Particle**: a point mass of contaminant. A fixed number is released with mean and random motion.
- **Puff**: a 3-D cylinder with a growing concentration distribution in the vertical and horizontal. Puffs may split if they become too large.
- **Hybrid**: a circular 2-D object (planar mass, having zero depth), in which the horizontal contaminant has a "puff" distribution and in the vertical functions as a particle.



Lagrangian Puff Atmospheric Fate and Transport Model