Correlating an Upwind Source-Footprint with Urban Emissions Data Using the MM5/MCIP/CALPUFF Modeling System

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Overview

- As part of the Urban Metabolism and Trace Gas Respiration Project a Source-Footprint system is being developed.

- Goal is to link observed concentrations with emission fluxes to examine the upwind source area using available models.

Theory

- Plume diffusion modeling along a forward trajectory maps out the distribution of pollutant concentrations due to an upwind source.
- Application of plume diffusion theory along a back-trajectory yields the upwind source distribution (source-footprint) affecting a receptor at the trajectory initial point.

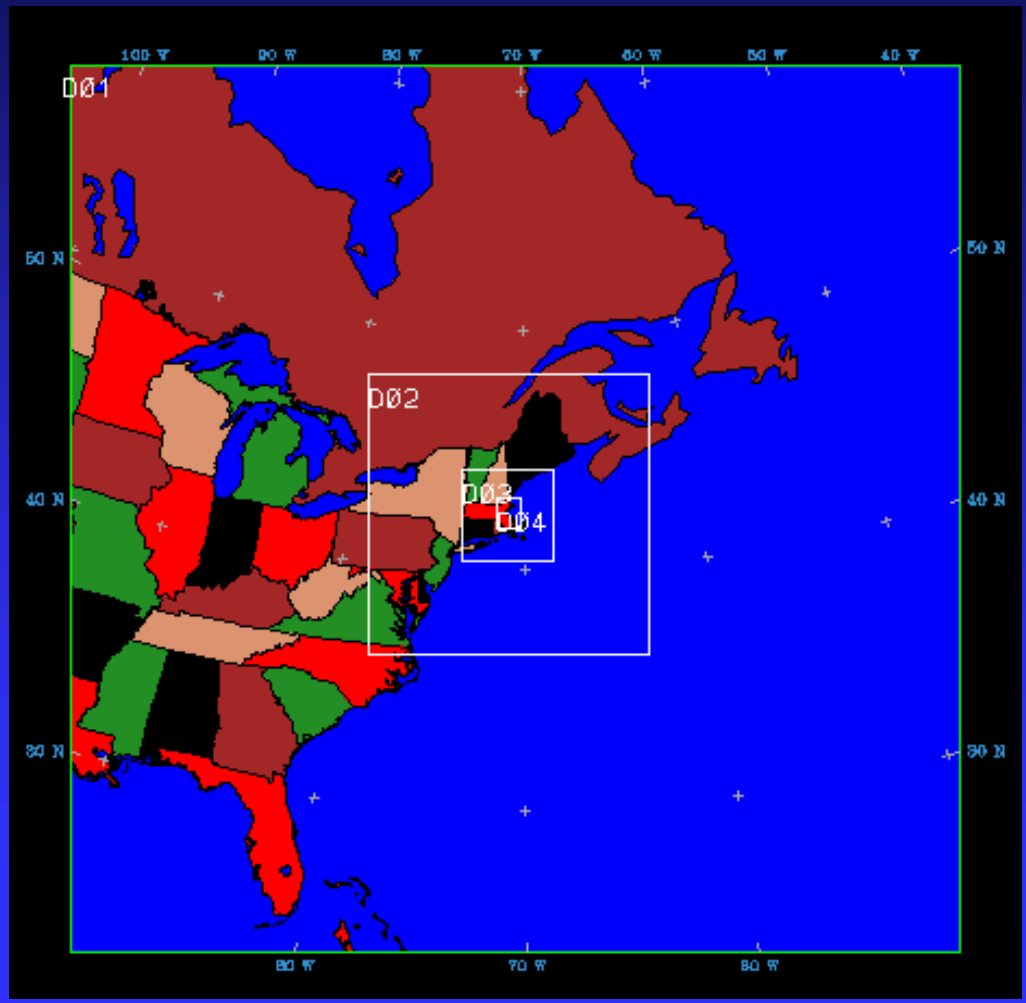
Approach

- Mesoscale modeling of the regional wind field with MM5.
- Application of a meteorological post-processor such as MCIP or CALMET, and inversion of the wind field.
- Application of the CALPUFF puff dispersion model to the inverted wind field.
- Correlation of an existing Emission Inventory with the source-footprint.

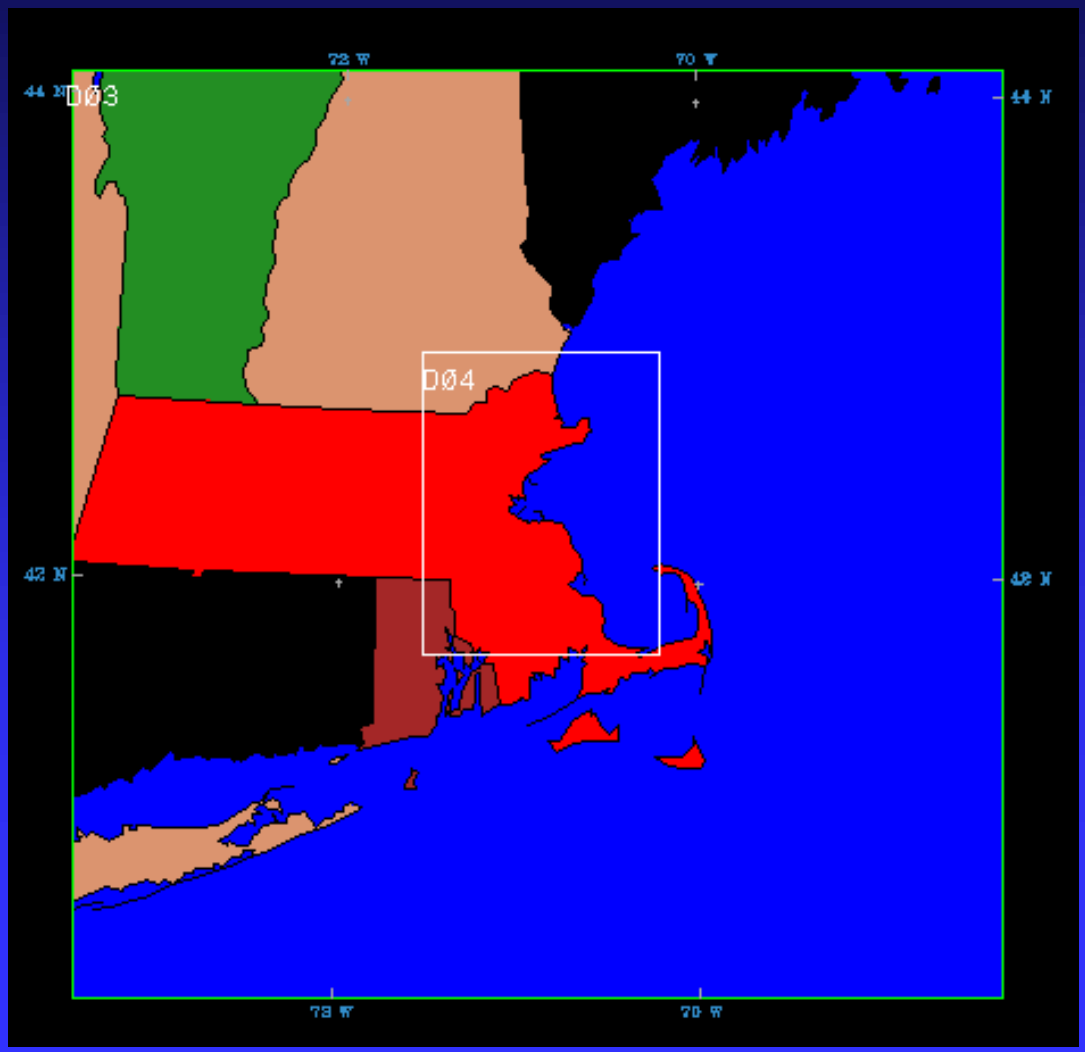
Application - Boston May 25, 1999

- MM5 Domain
  - 4 nested domain
  - Grid Resolutions: 1 km, 3 km, 9 km, 27 km
- Other Meteorology
  - Sodar operating at MIT
  - RAOBS - Chatham, MA

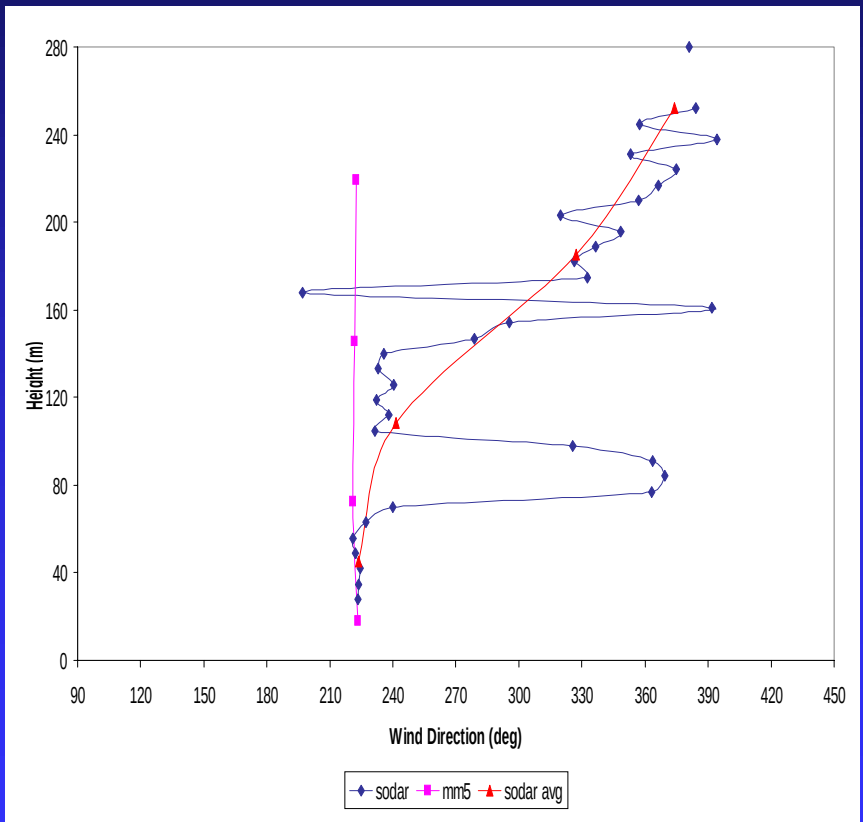
Nested MM5 domains

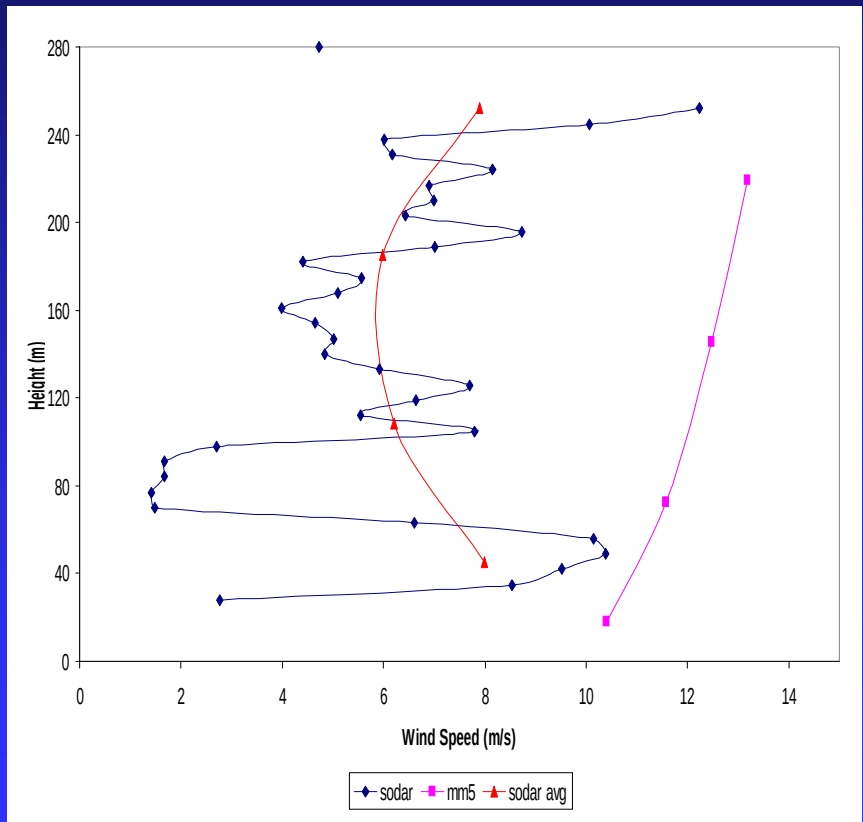


MM5 3 km Domain

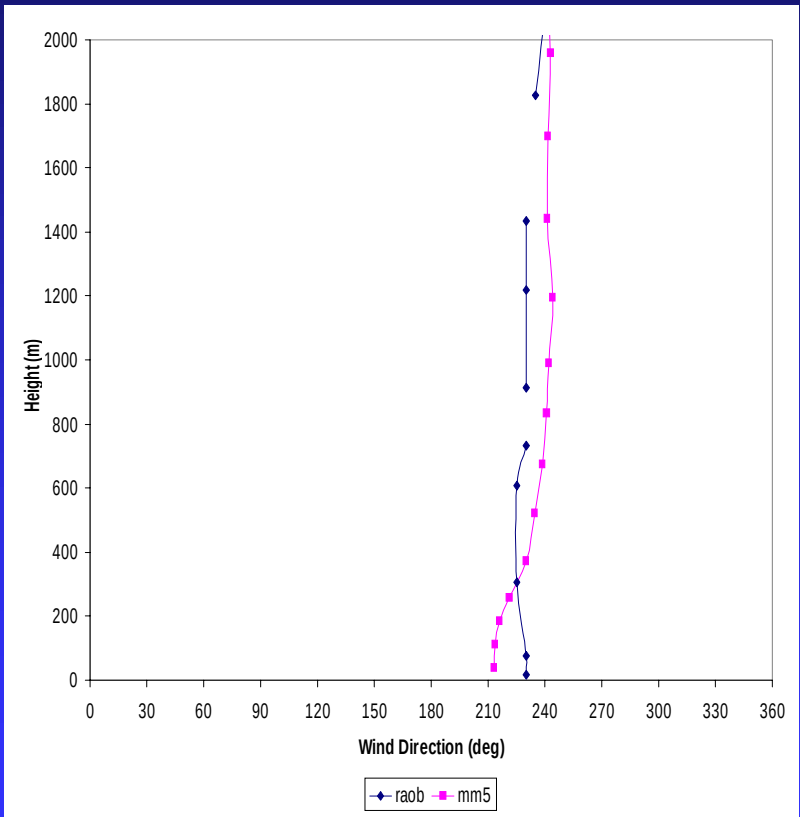


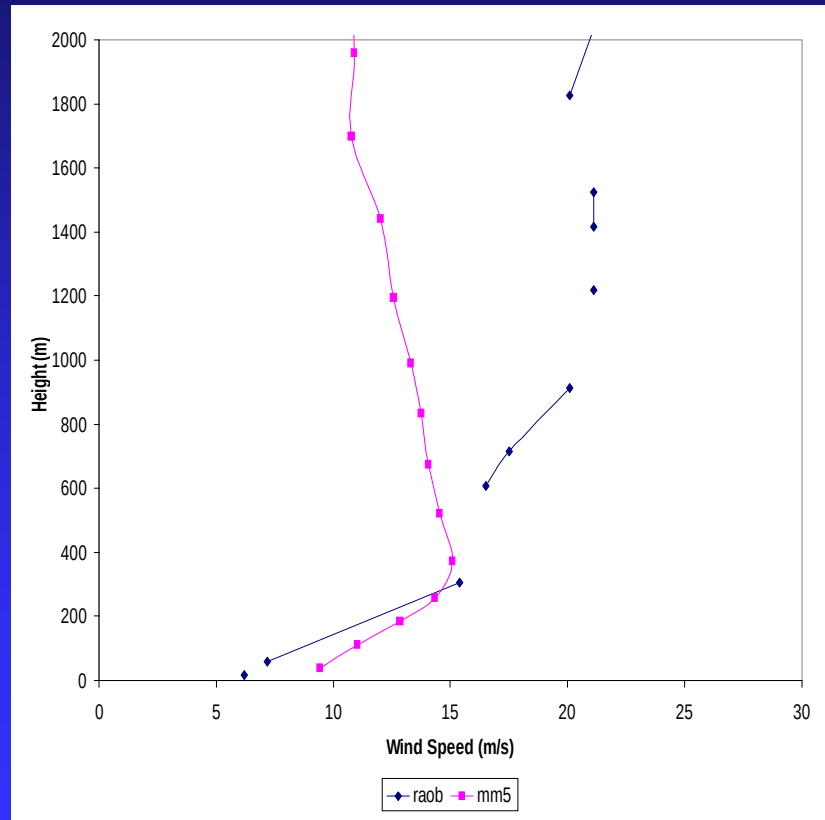
Comparison of MM5 and Sodar Wind Direction & Wind Speed at MIT on May 25, 1999 at 5 PM





Comparison of MM5 and RAOBs Wind Direction & Wind Speed at Chatham, MA on May 25, 1999 at 7 PM

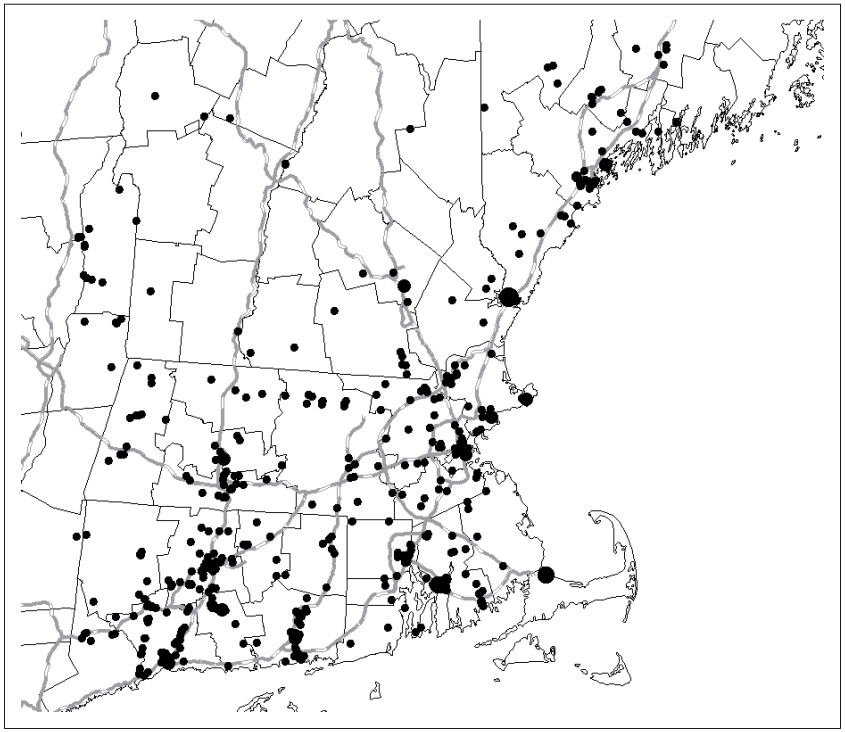


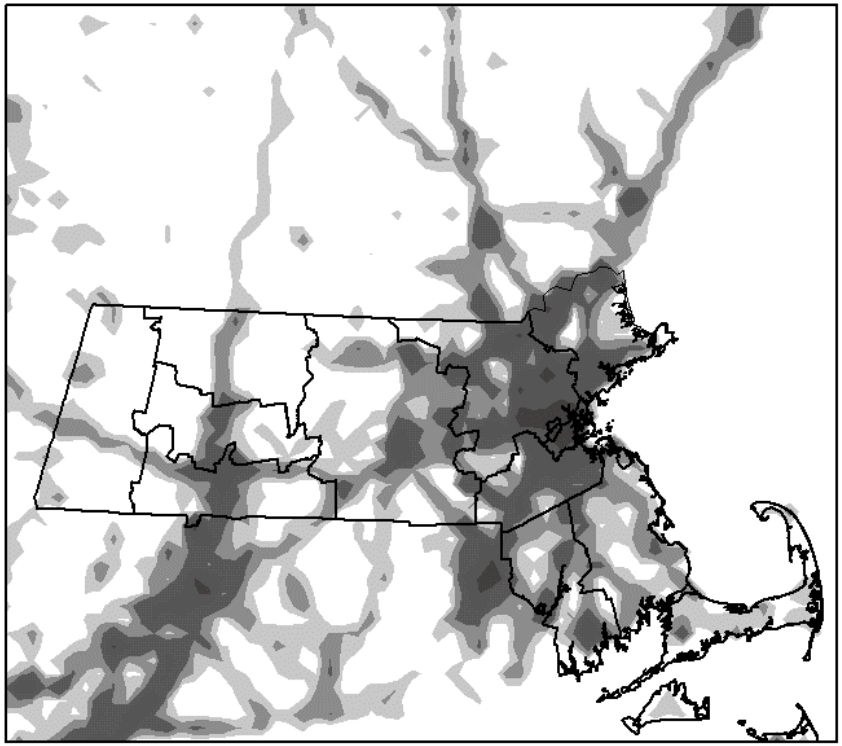


Emission Inventory

- 1988 Emission Inventory obtained from the Massachusetts Department of Environmental Quality.
- Point and Area Source Data Gridded at a 5 km resolution for the Carbon Bond IV Chemical Mechanism
- Assumption - Pollutant relative strengths have not changed since 1988.

NOx Point and Area Emissions Data applied to May 25, 1999 at 12 PM

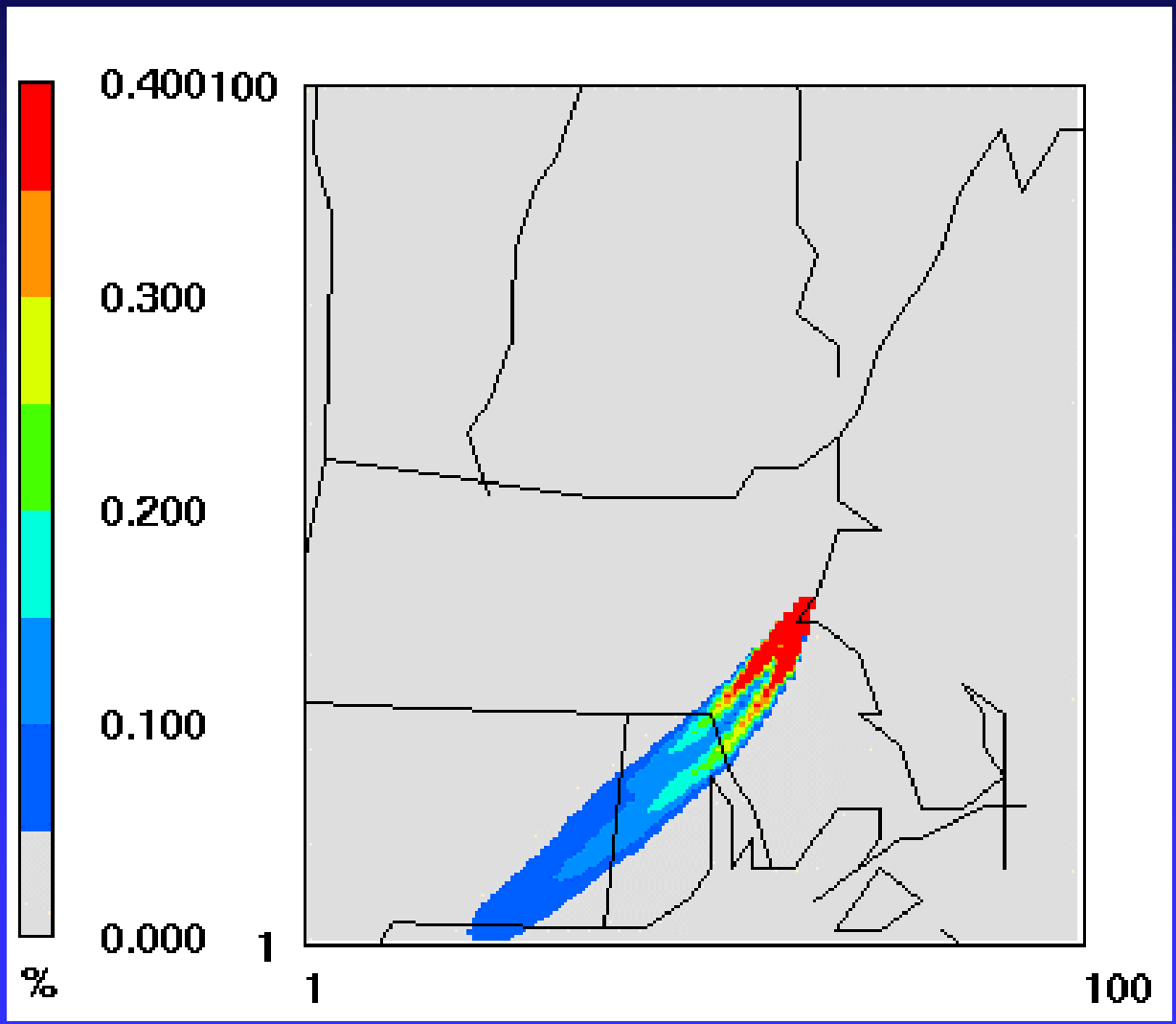




Inverse Modeling Approach

- CALPUFF was applied to simulate the upwind source probability distribution for a receptor by application of plume dispersion theory along a back trajectory.
- Boston is the receptor.
- Results: Steady SW winds yielded a source-footprint indicating that pollutants traveled from Connecticut and Rhode Island during the period of 11am - 5pm May 25, 1999.

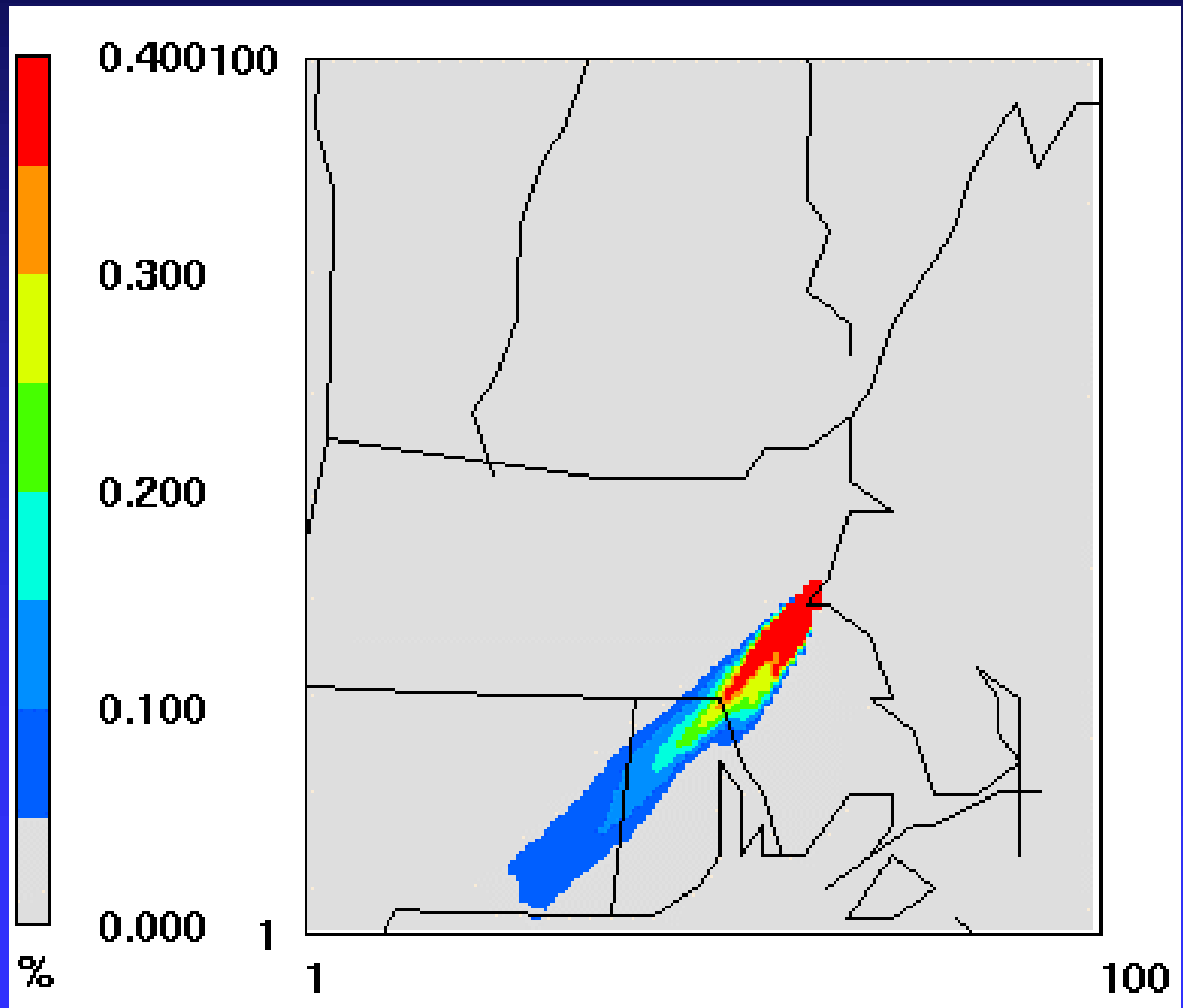
Upwind Source Area Influencing Boston, MA May 25, 1999 at 5 PM



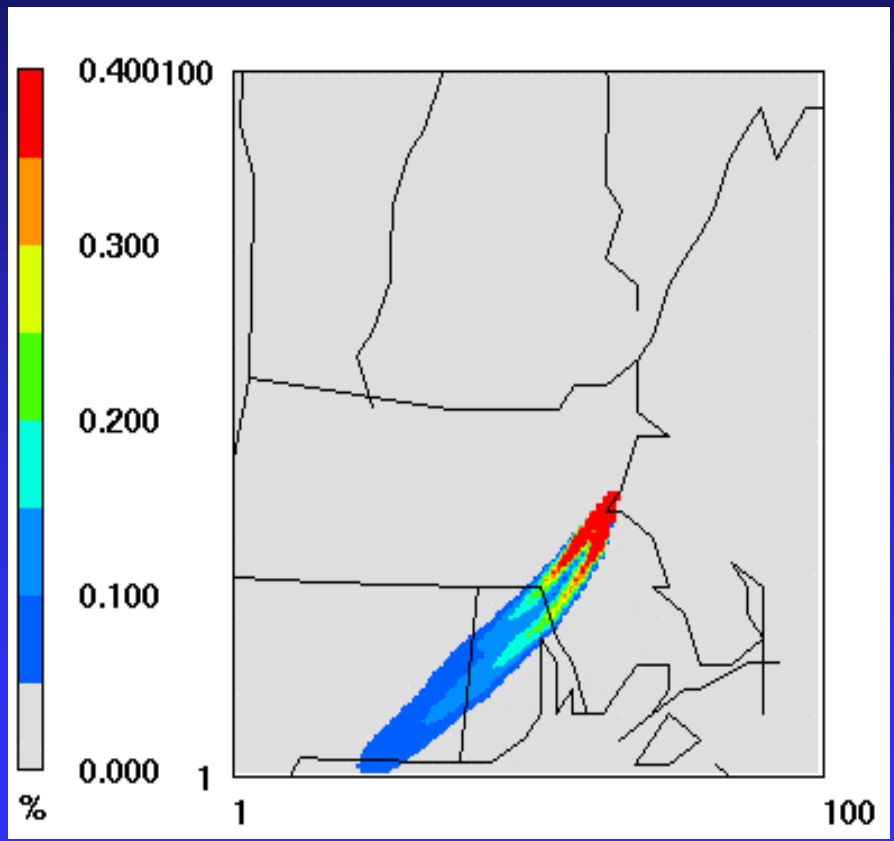
Source Contribution/Proof of Concept

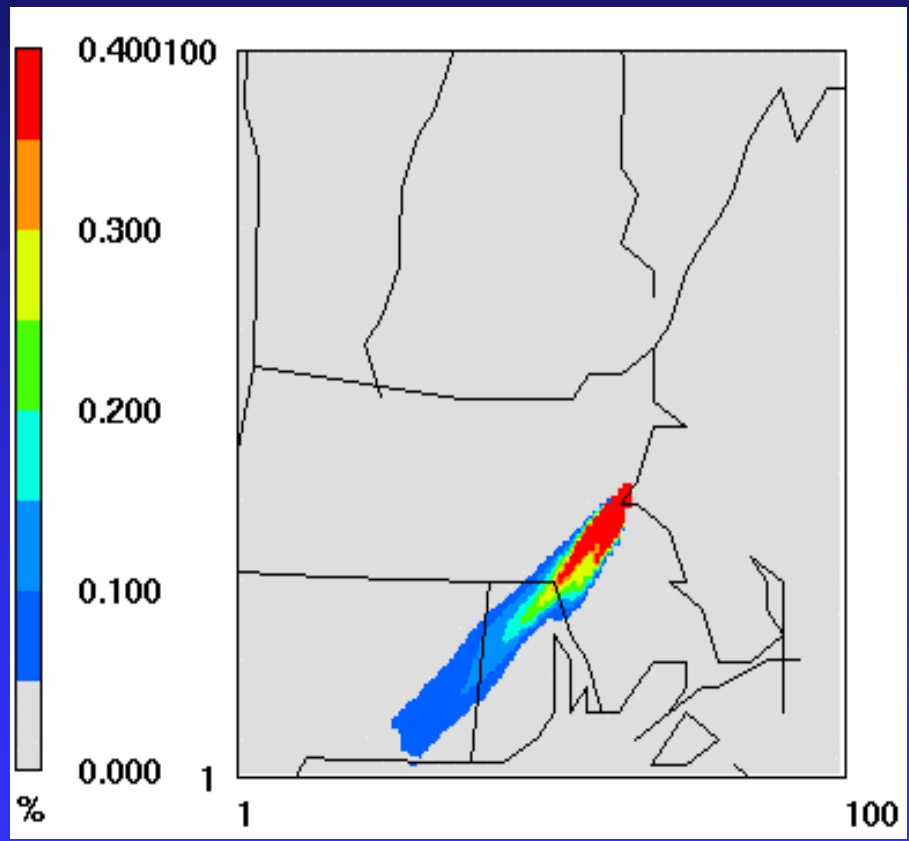
- The upwind source contribution area can be obtained by running CALPUFF in the forwards mode, with every grid acting as a source, and tracking each source's contribution to the total concentration at Boston
- Each source's contribution is normalized by the total concentration at Boston. This should yield a similar result as the source-footprint.
- CALPUFF was run 3600 (80 columns x 45 rows) times with each grid point acting as a source.

Results of Source Contribution Area Calculation for Boston, MA May 25, 1999 at 5 PM



Comparison of Source Contribution with Source-Footprint





Travel Time

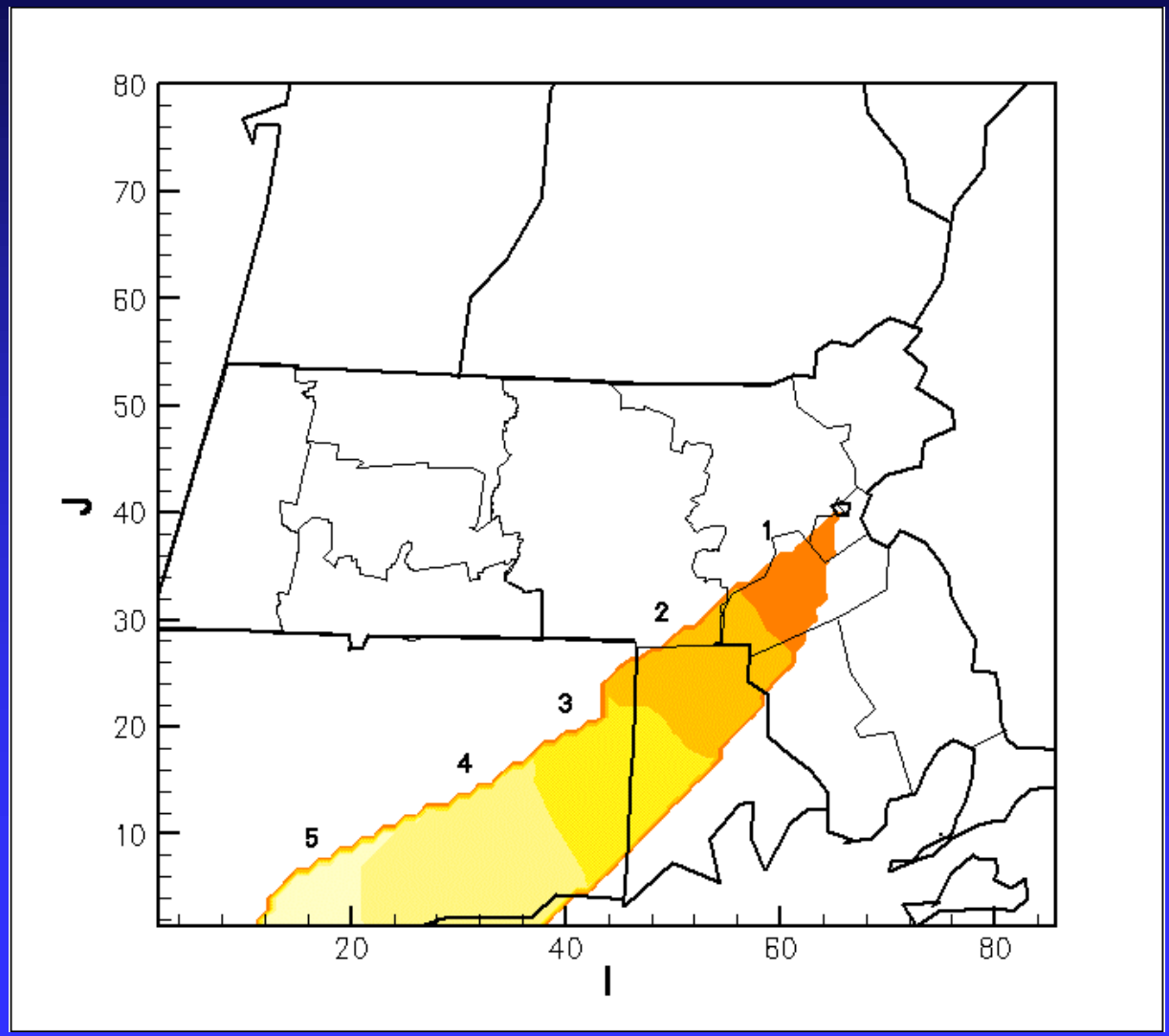
- Knowledge of Travel Time is necessary to correlate the source-footprint with an emission inventory.

$$t_{avg}(i,j,t) = \frac{\sum_{k=1}^{N} T(i,j,t,k) * C(i,j,t,k)}{C_T(i,j,t)} \qquad (1)$$

Where,

- N = # of puffs emitted from the receptor from the beginning of the simulation to time t.
- $T(i,j,t,k)$ = Travel time of puff k from the receptor to the grid location i,j, at time t.
- $C(i,j,t,k)$ = Concentration that puff k contributes to grid location i,j, at time t.
- $C_T(i,j,t)$ = Total concentration from all puffs at grid location i,j, at time t.

Average Pollutant Source Travel Times for Boston, MA May 25, 1999 at 5 PM



Emission Inventory Correlation

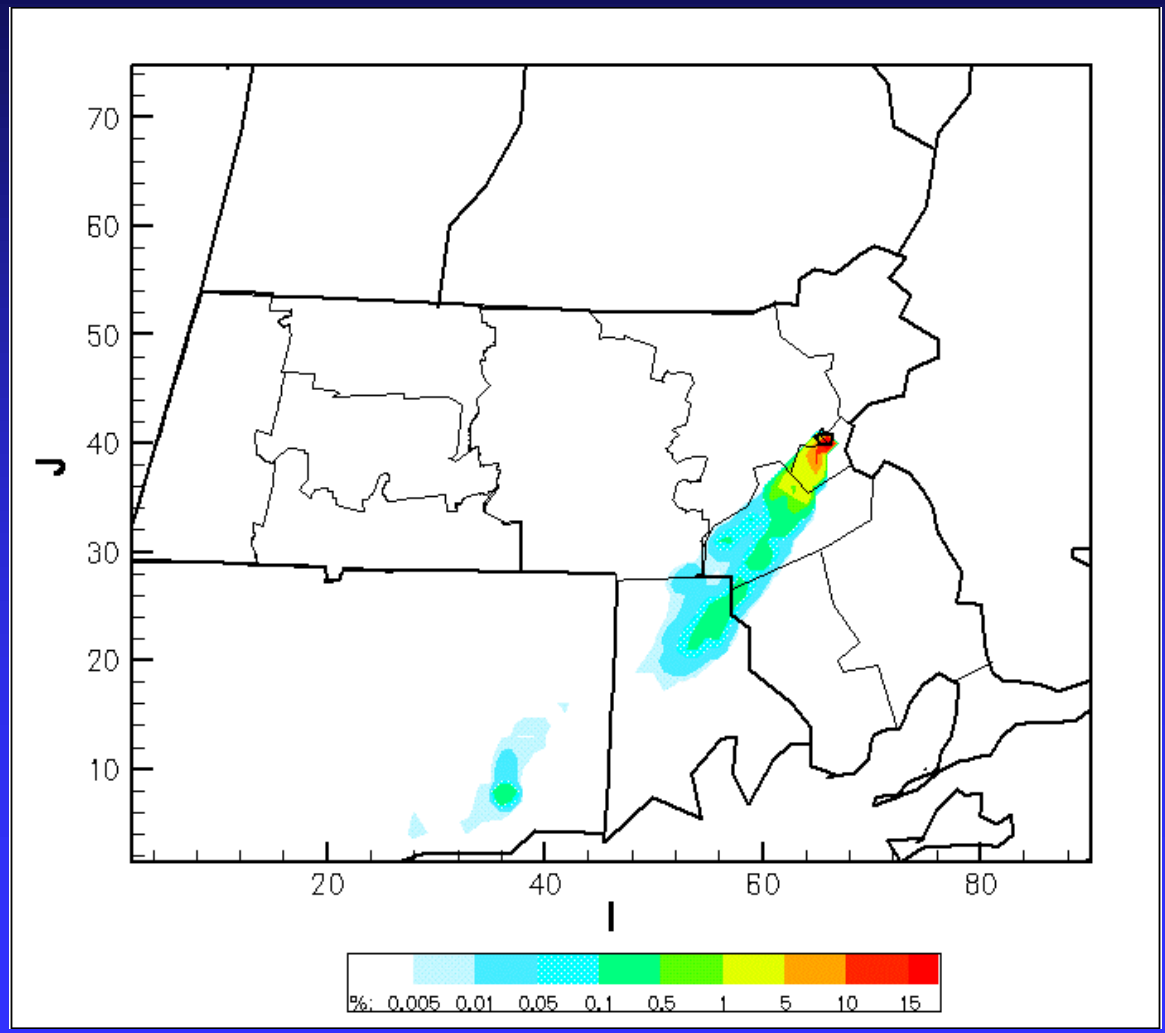
- Fractional Contribution of a particular grid point emission to the concentration recorded at the receptor is calculated by:

$$f(i,j,t) = \frac{Emis(i,j,t - t_{avg}(i,j,t)) * Conc(i,j,t)}{\sum_{i=1}^{R}\sum_{j=1}^{C} Emis(i,j,t - t_{avg}(i,j,t)) * Conc(i,j,t)} \qquad (2)$$

Where,

- C, R = Number of columns and rows in the domain.
- $Emis(i,j,t\text{-}t_{avg}(i,j,t))$ = Emission rate from the emission inventory contributing to the receptor concentration at time t.
- $Conc(i,j,t)$ = Concentration (as an indicator of probability) from the backward CALPUFF plume.

Fractional Source Contributions of NOx on the receptor concentrations at Boston, MA at 5 PM May 25, 1999

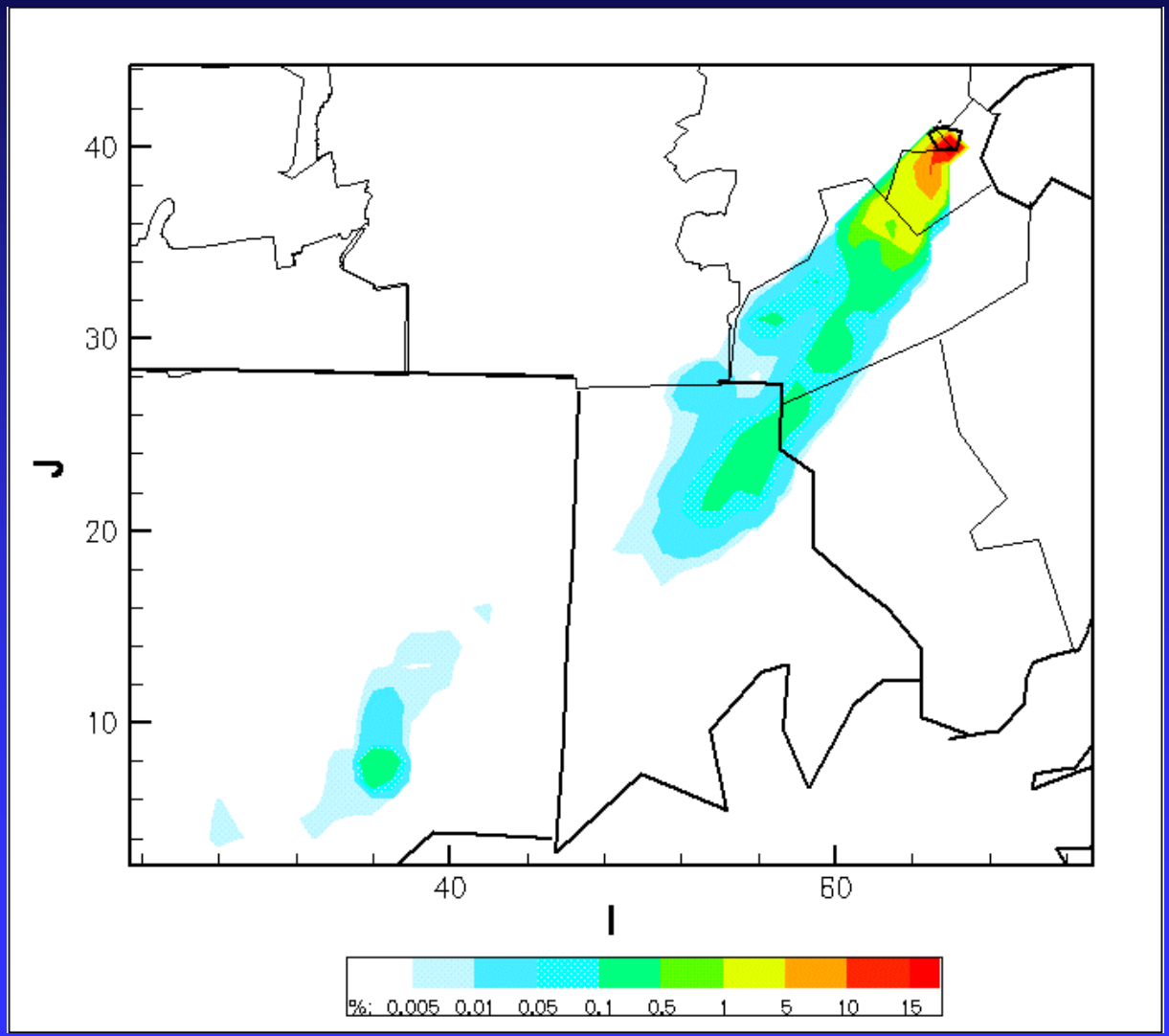


Radial Upwind Areas Contributing to the Fractional Contribution

- Percent Contribution of Emissions to the Boston Receptor at Incrementel Radial Distances.

Radial Number of Grids	0 - 5,	5 - 10,	10 - 25,	25 - 50
Radial Distance (km)	0 - 15,	15 - 30,	30 - 75,	75 - 150
Contribution (%)	83.1	9.4	6.0	1.5

Fractional Source Contributions of NOx within 75 km of the Receptor, Boston, MA at 5 PM May 25, 1999.



Summary

- The source-footprint modeling system is a simple means to identify upwind source areas responsible for downwind pollutant concentrations.
- A single application of CALPUFF with an inverted wind field is much easier than 3600 CALPUFF runs with the regular wind field.
- Further verification of the method is underway.

Acknowledgments

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