Dynamic Data-Driven Event Reconstruction for Atmospheric Releases

National Nuclear Security Administration
Laboratory Directed Research and Development Program
Annual Review

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Event reconstruction LDRD is supported by a large multi-disciplinary team

• Branko Kosovic	(Energy & Environment)	PI (current and technical lead)
• Chuck Baldwin	(Computations)	computational framework
• Rich Belles	(Computations)	computational framework
• Tina K. Chow	(UC Berkeley)	atmospheric applications
• Kathy Dyer	(Computations)	computational framework
• Lee Glascoe	(Engineering)	atmospheric applications
• Ron Glaser	(Engineering)	statistical analysis
• William Hanley	(Engineering)	stochastic methods
• Gardar Johannesson	(Engineering)	stochastic methods
• Shawn Larsen	(Computations)	parallelization, framework
• Gwen Loosmore	(Engineering)	applications and sensitivity
• Adam Love	(Energy & Environment)	applications
• Julie K. Lundquist	(Energy & Environment)	applications and field data
• Arthur Mirin	(Comp/CASC)	parallelization, framework
• Stephanie Neuman	(NAI)	summer student, atmospheric app.
• John Nitao	(Energy & Environment)	stochastic methods
• Radu Serban	(Comp/CASC)	optimization methods
• Alan Sicherman	(Engineering)	soft data applications
• Charles Tong	(Comp/CASC)	optimization methods

Event reconstruction uses data-driven simulation to answer critical questions about the release event

Release Event

Observations

What?
When?
Where?
How much?

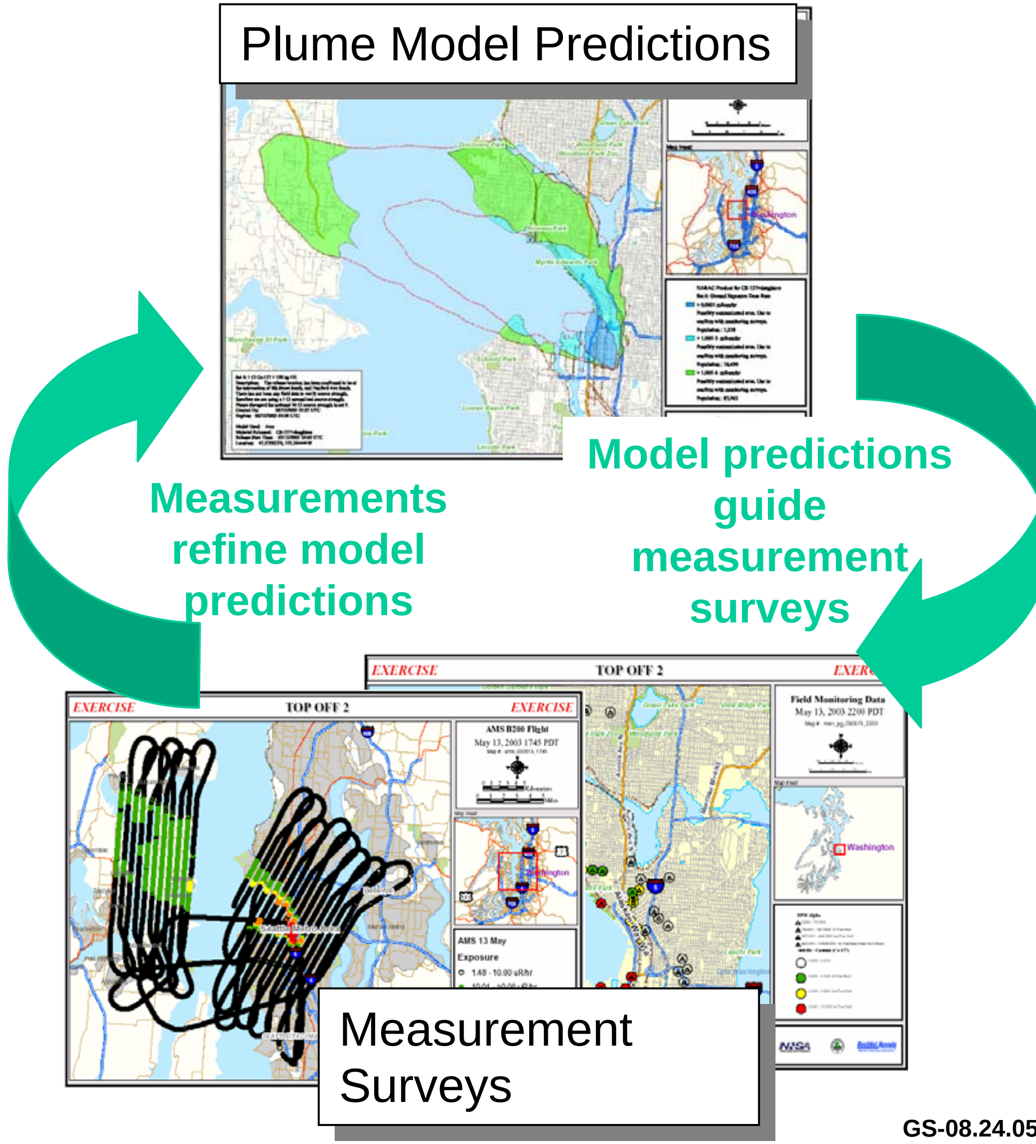
Event Reconstruction

Consequence Management

- ***Quantitative*** **estimates of unknown sources**
- ***Probabilistic*** **predictions consistent with data and models**
- **Dynamical *uncertainty* reduction as additional data become available**

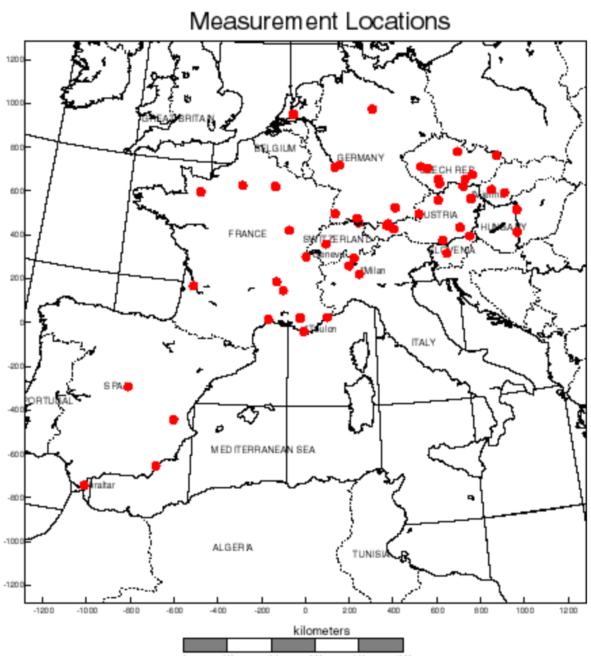
Event reconstruction is a core next-generation capability for NARAC / IMAAC

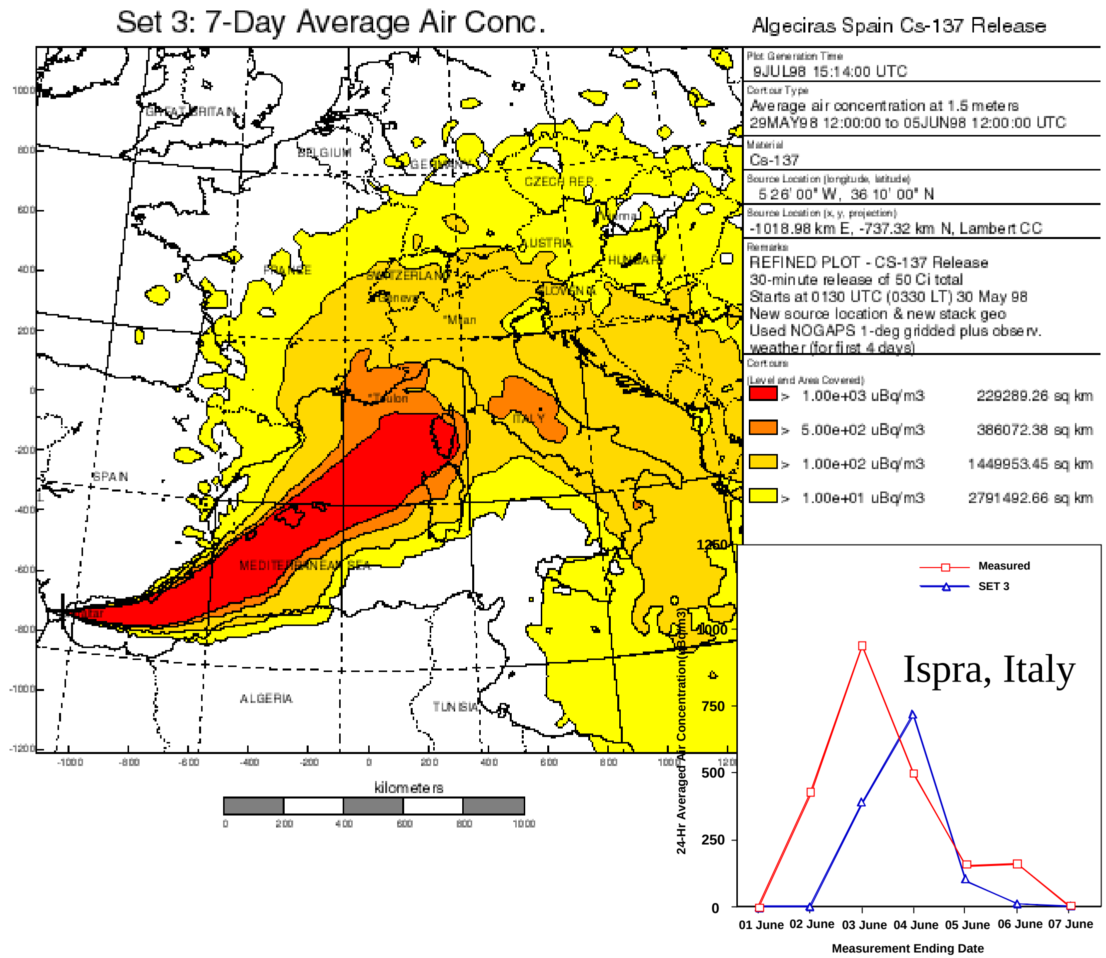
- **Operational centers**
  - — **National Atmospheric Release Advisory Center (NARAC)**
  - — **Inter-Agency Modeling and Atmospheric Assessment Center (IMAAC)**
- **Mission: provide the best possible airborne hazards predictions to support preparedness, response, and recovery**
- **Cyclical analysis couples measurements and simulation in operational applications**



Manual event reconstruction is time and labor intensive and dependent on analyst judgment

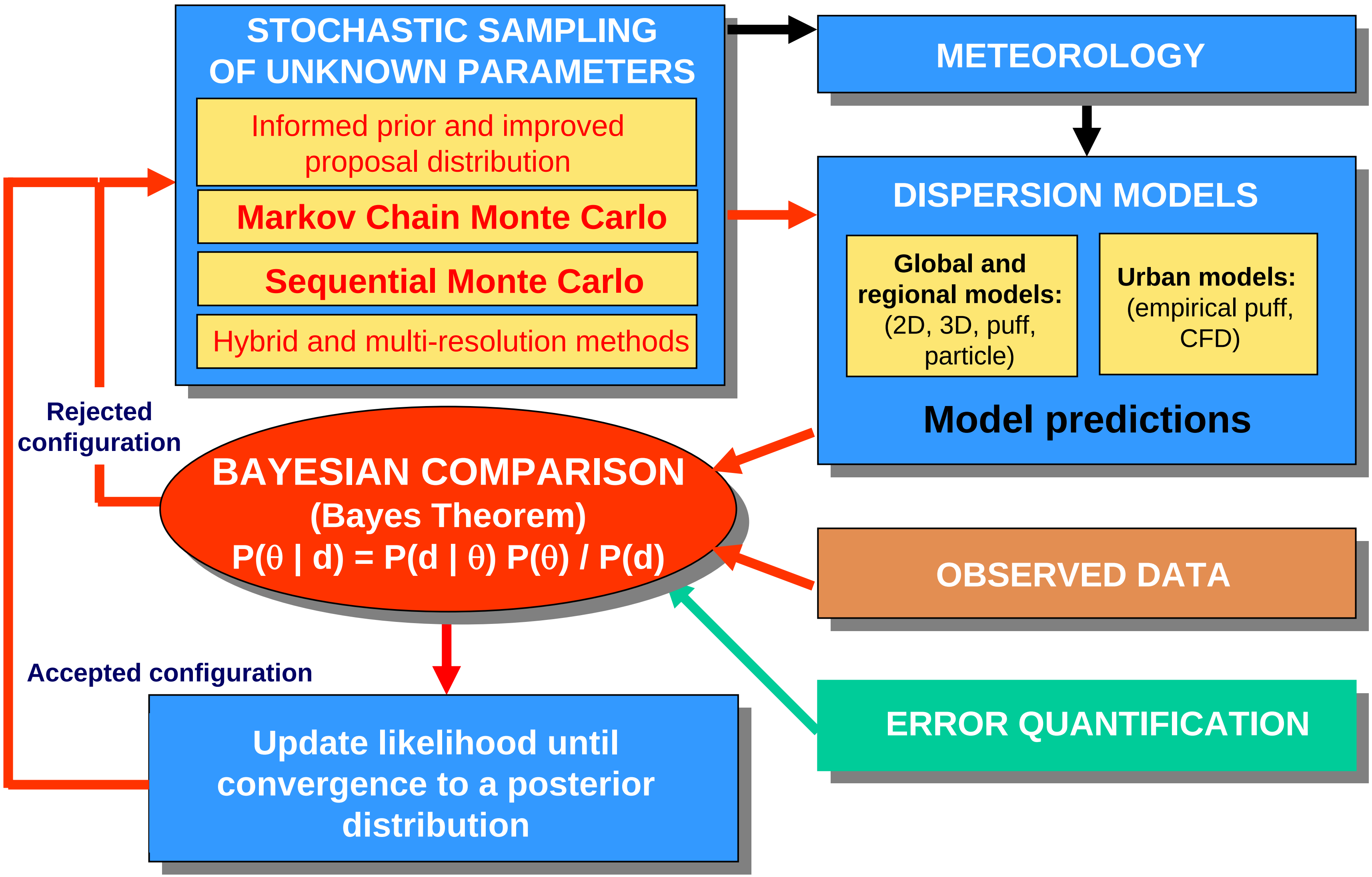
Radiation readings of 1000 times background reported by Switzerland, France and Italy (May-June, 1998)



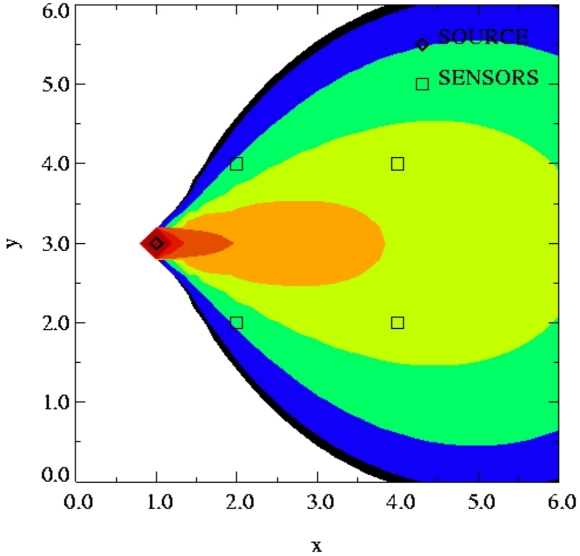


Spanish sources eventually estimated a 8-80 Ci release from a medical source melted in a Algeciras steel mill

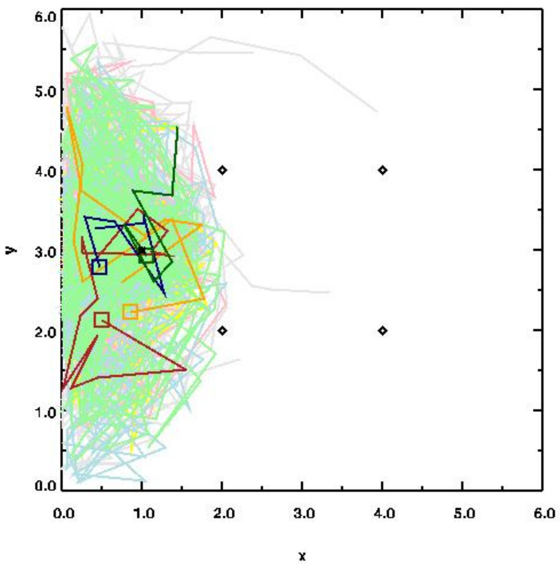
Event reconstruction problem is solved via Bayesian inferencing and stochastic sampling

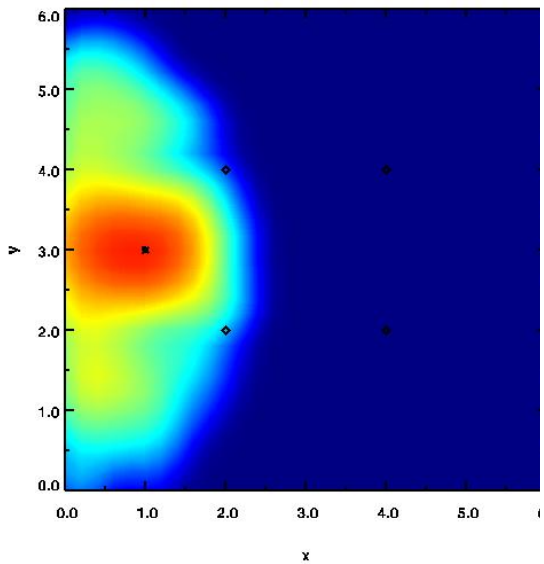


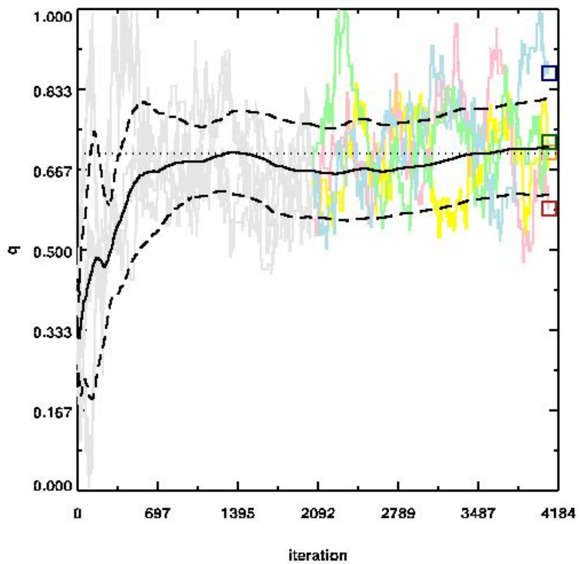
Our starting point is the Stochastic Engine developed for large geophysical applications



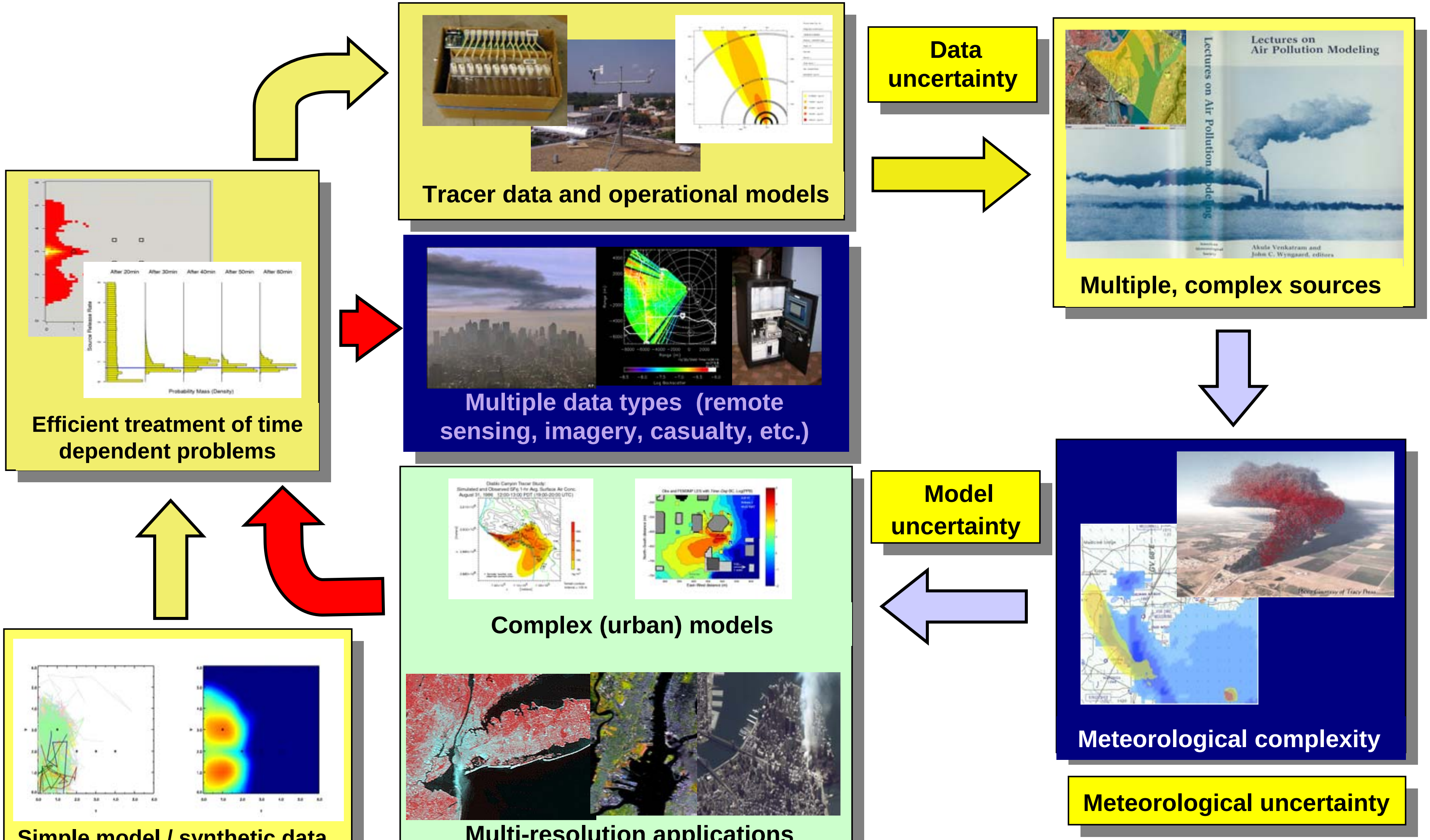
- **2D Gaussian puff example**
  - — Constant release rate
  - — Square sensor array
- **Four Markov chains (~5000 iterations)**
- **Simultaneous determination of release location and rate**





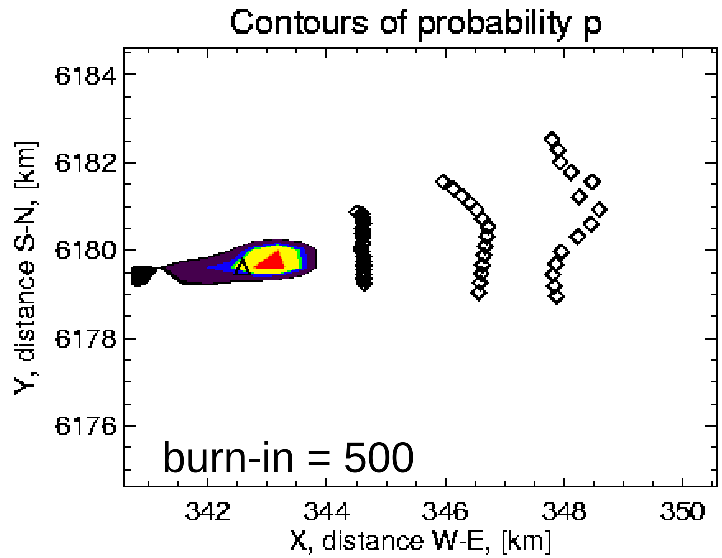


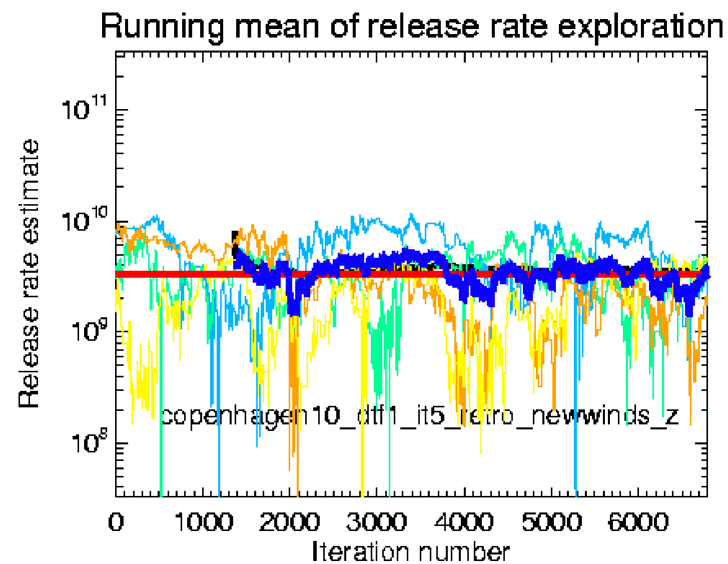
A spiral development process is being followed to address problems of increasing complexity



Event reconstruction has been successfully tested against real-world field studies

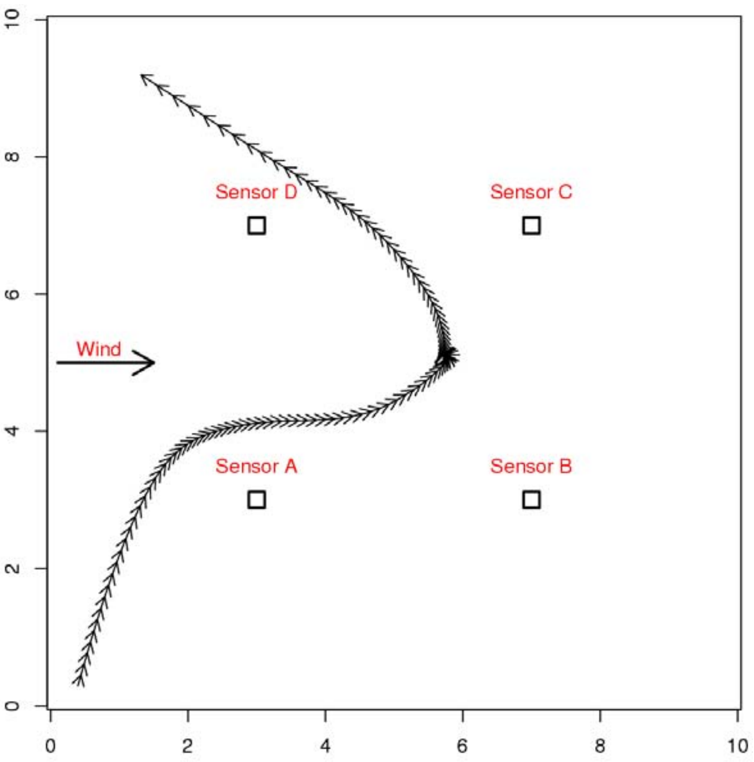
- **Copenhagen experiment**
  - — **Elevated release**
  - — **NARAC / IMAAC operational models**
- **Probability distribution of release location (top)**
  - — **Contours of probability mass**
  - — **Yellow:** top 30% of probability
  - — **Blue:** top 50% of probability
- **Convergence of release rate (bottom)**
  - — **Red line**: actual release rate
  - — **Blue line**: instantaneous mean
  - — **Pastel lines**: individual chains
- **Extensions**
  - — **Sub-sampled data (9 sensors)**
  - — **Introduced data error (15 sensors)**



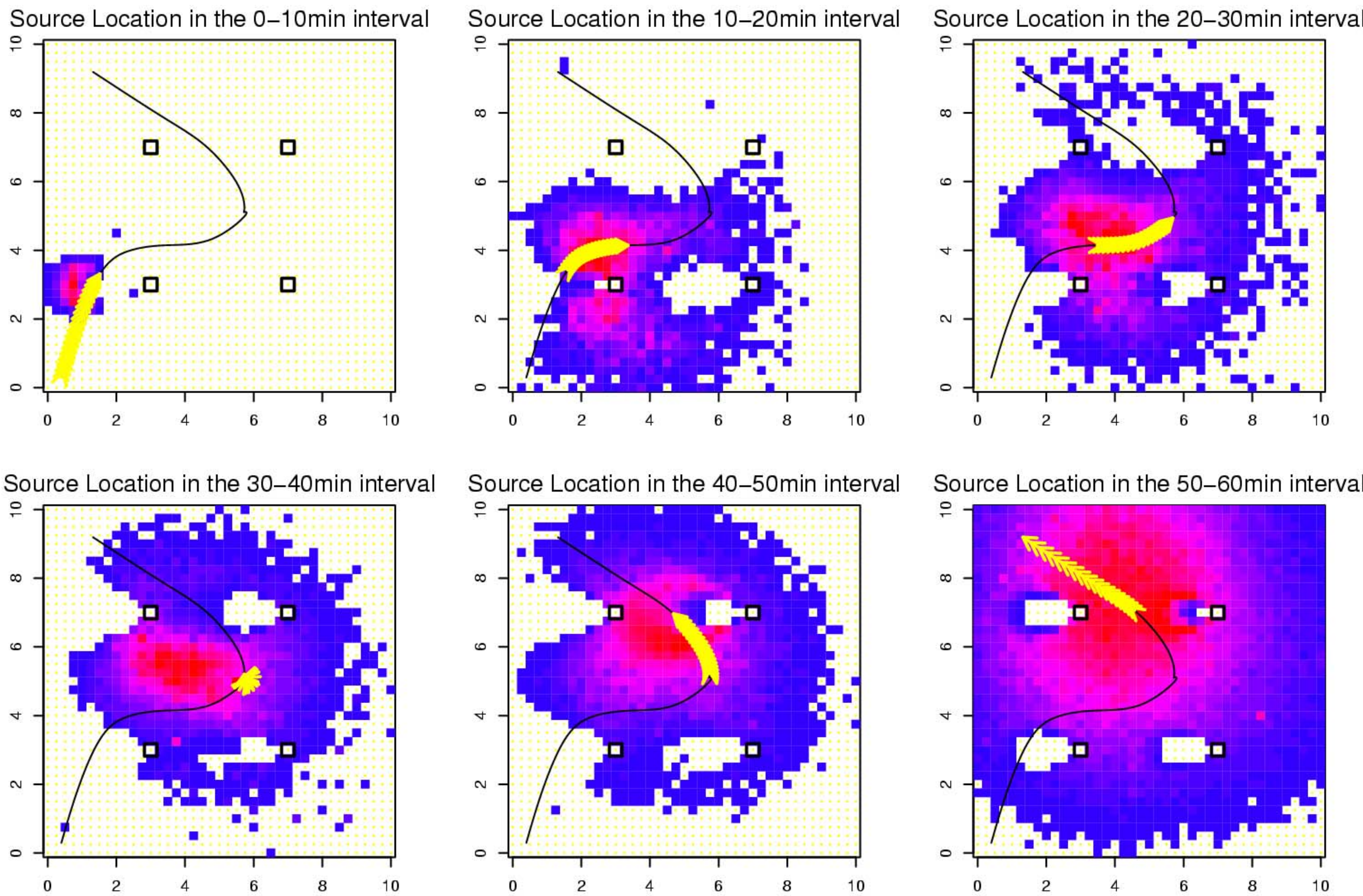


Moving vehicle case illustrates the ability to treat complex sources

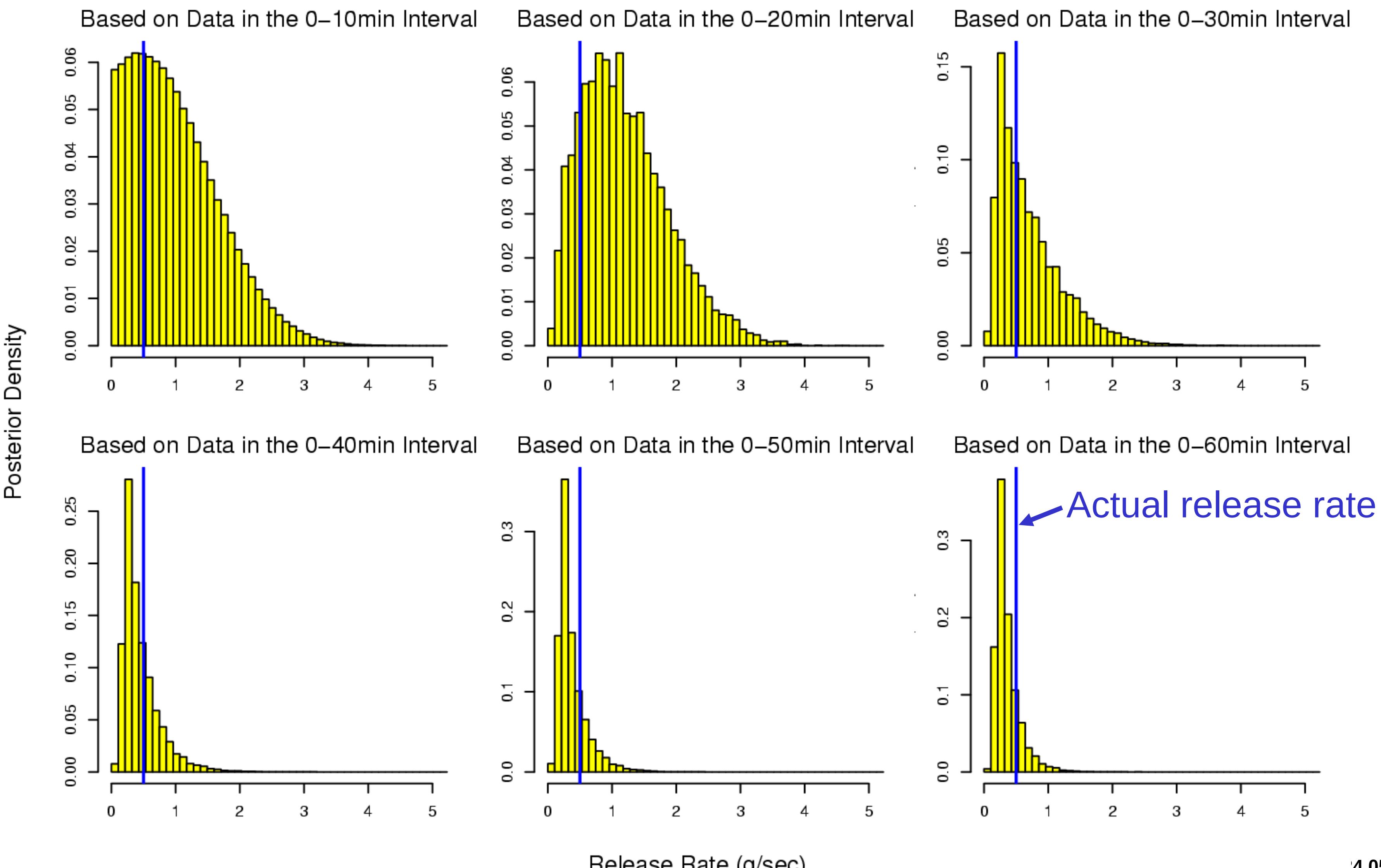
- Moving vehicle
  - — Variable speed and direction of source indicated by arrows
  - — Vehicle remains stationary for a brief time near grid center
- Synthetic data with introduced errors
  - — Model error via use of 10-minute averaging
  - — Measurement noise from normal distribution
- Prior/proposal distribution based on mixture of previous location and velocity



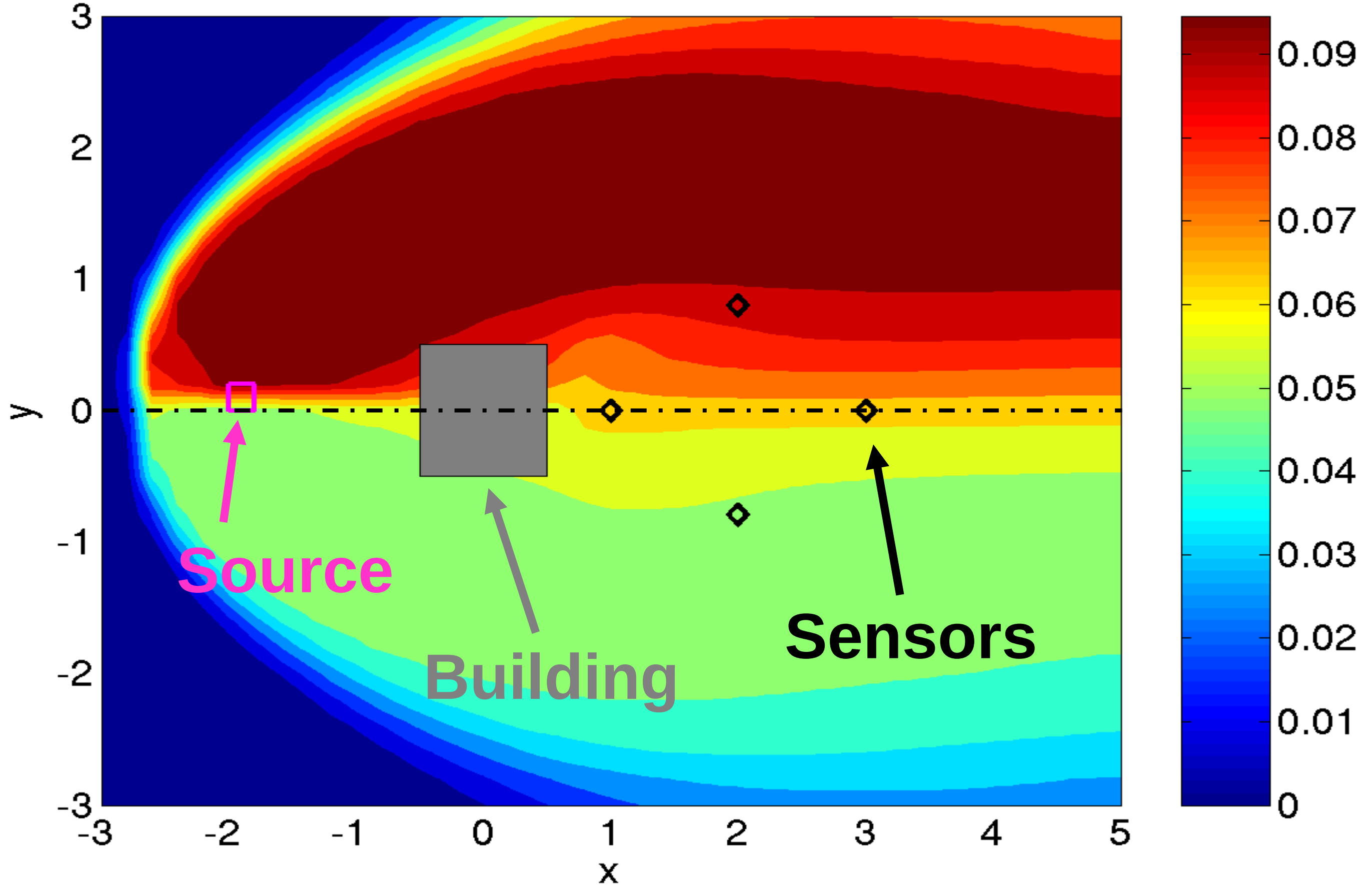
Source location is determined for each ten-minute interval (yellow vectors show actual vehicle location)



Moving vehicle release rate is simultaneously determined using ten-minute averaged data

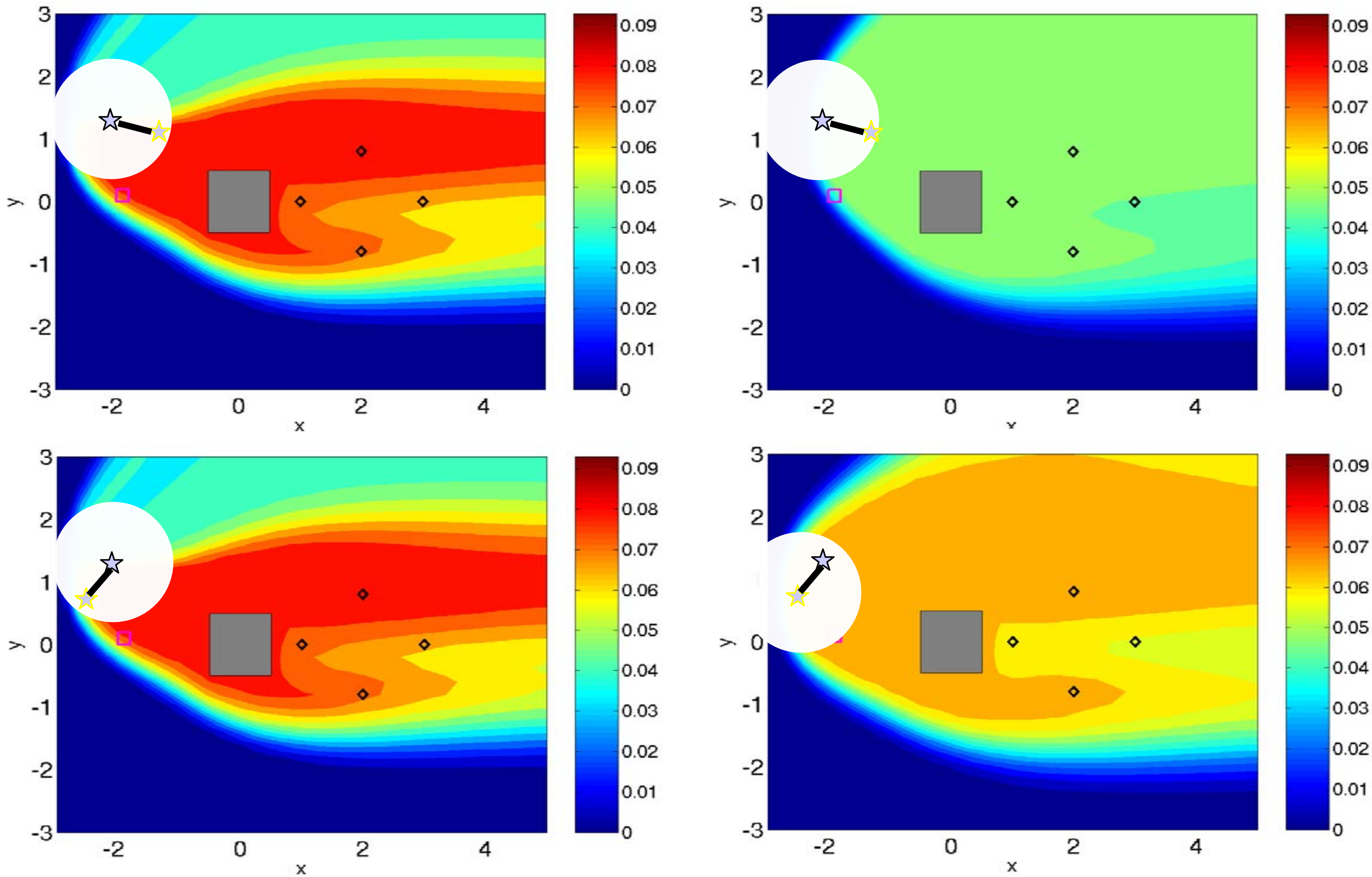


Cubical building with an off-centerline source produces a complex asymmetric plume

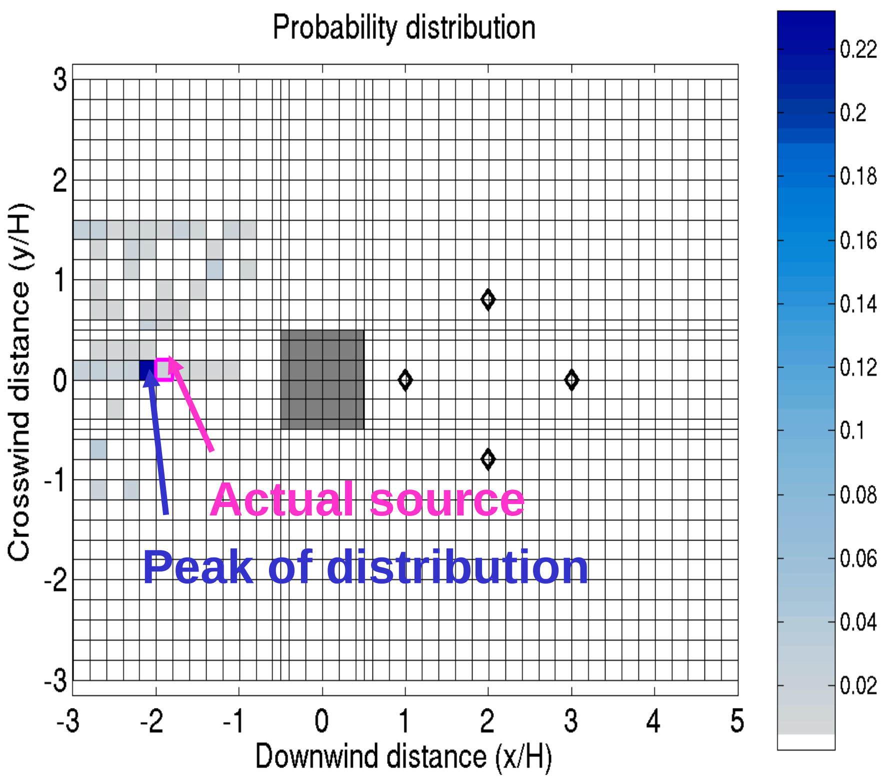


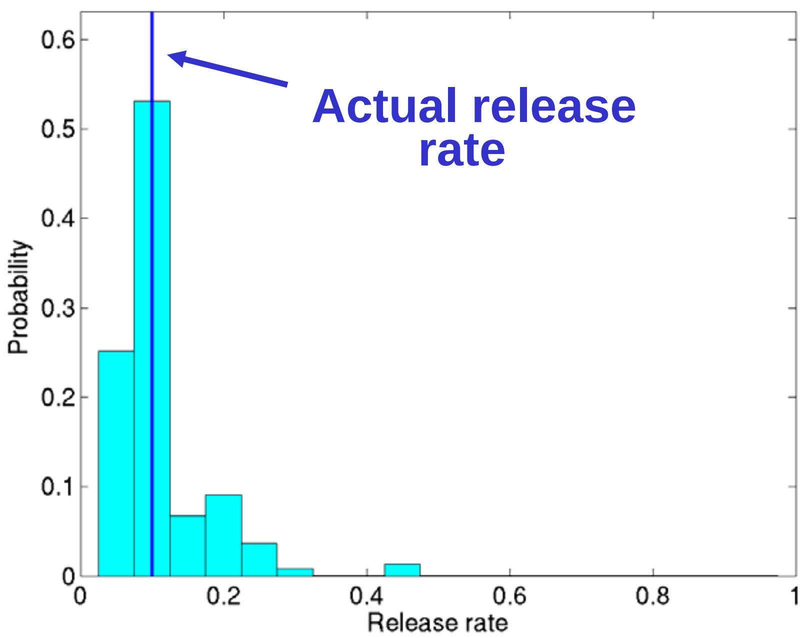
FEM3MP computational fluid dynamics (CFD) model is used for building-to-urban scale assessments

Markov chains sample potential release locations and rates guided by comparison with data

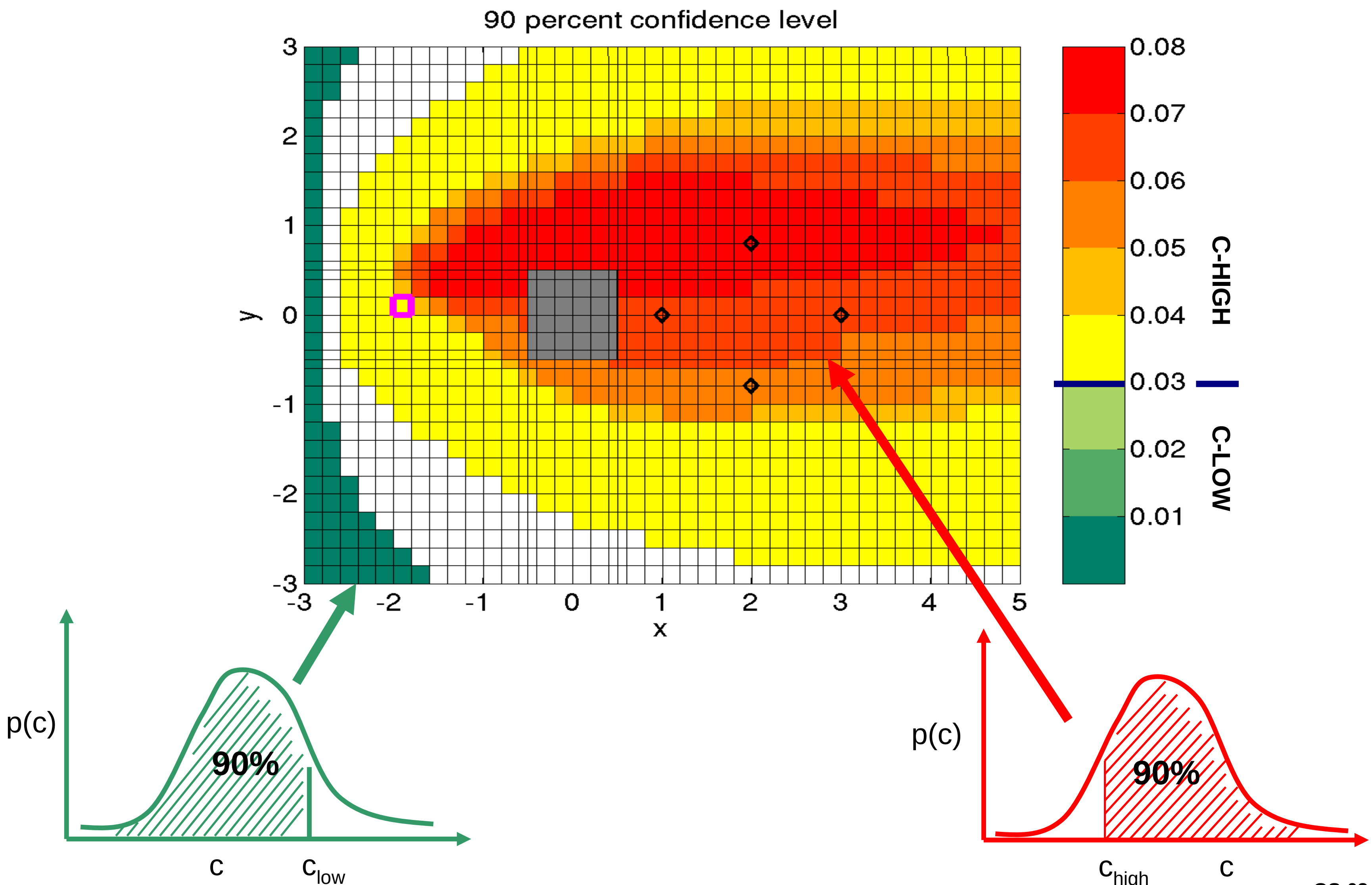


Event reconstruction simultaneously converges on source location and release rate

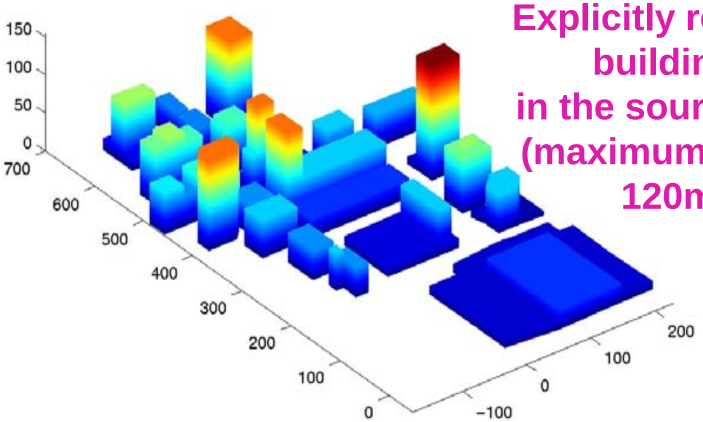




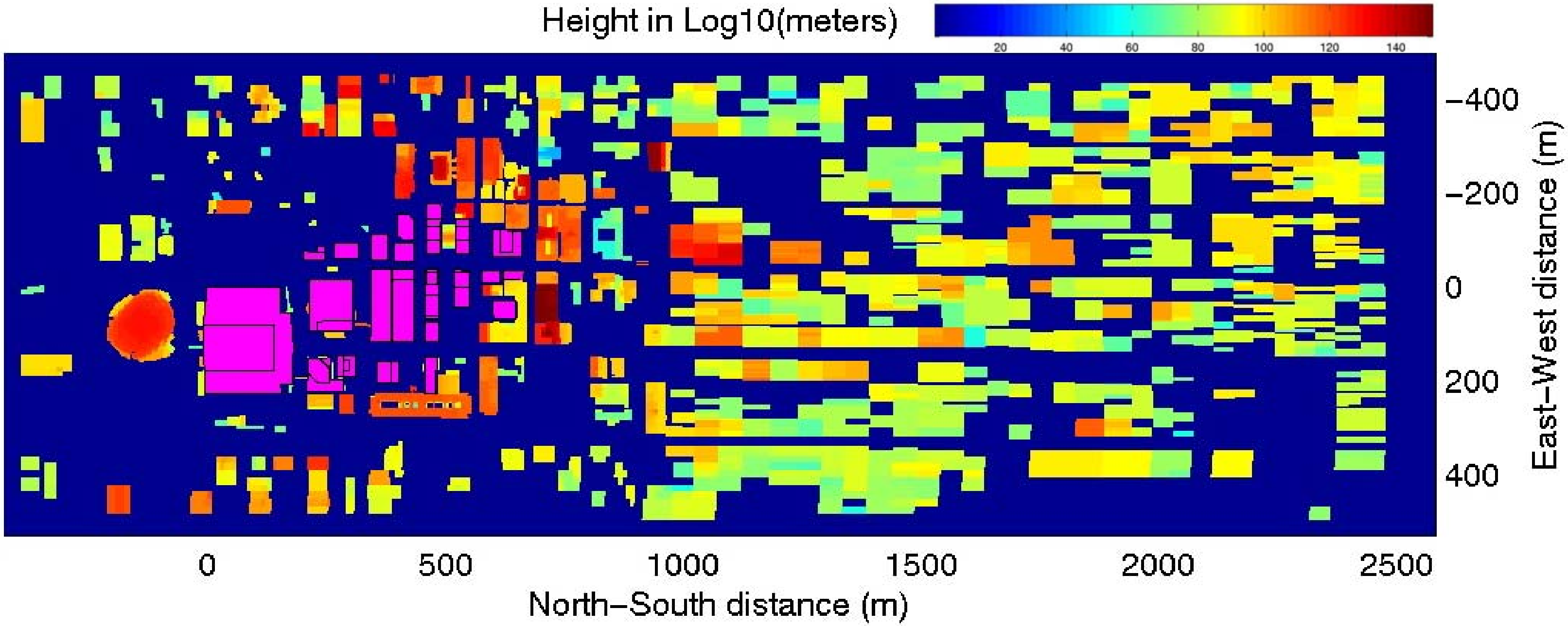
Composite plume constructed from stochastic sampling provides confidence levels



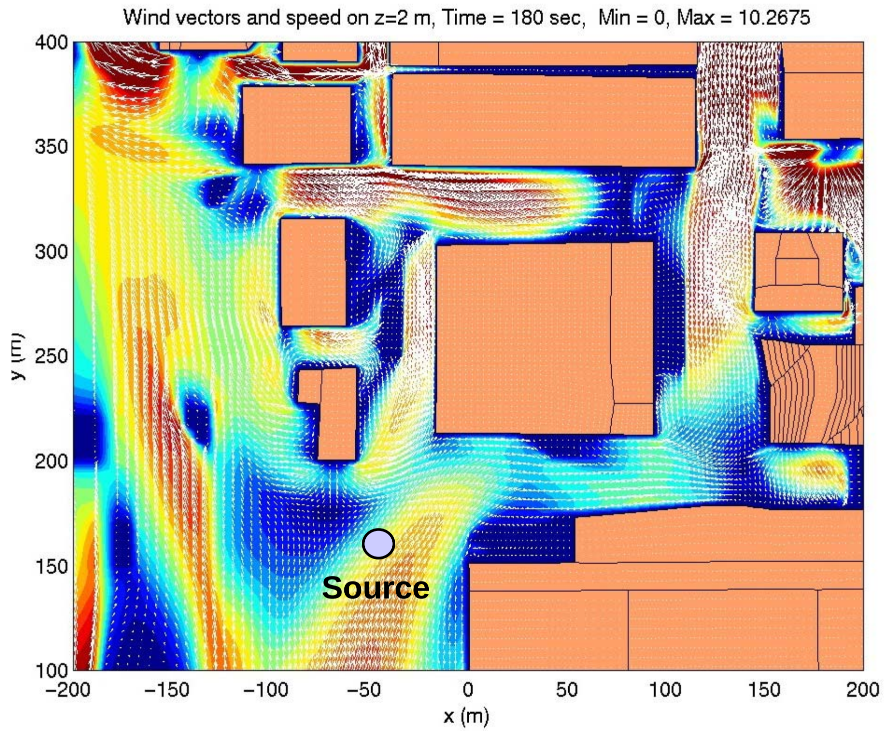
Urban event reconstruction is tested against Joint Urban 2003 Oklahoma City field study data

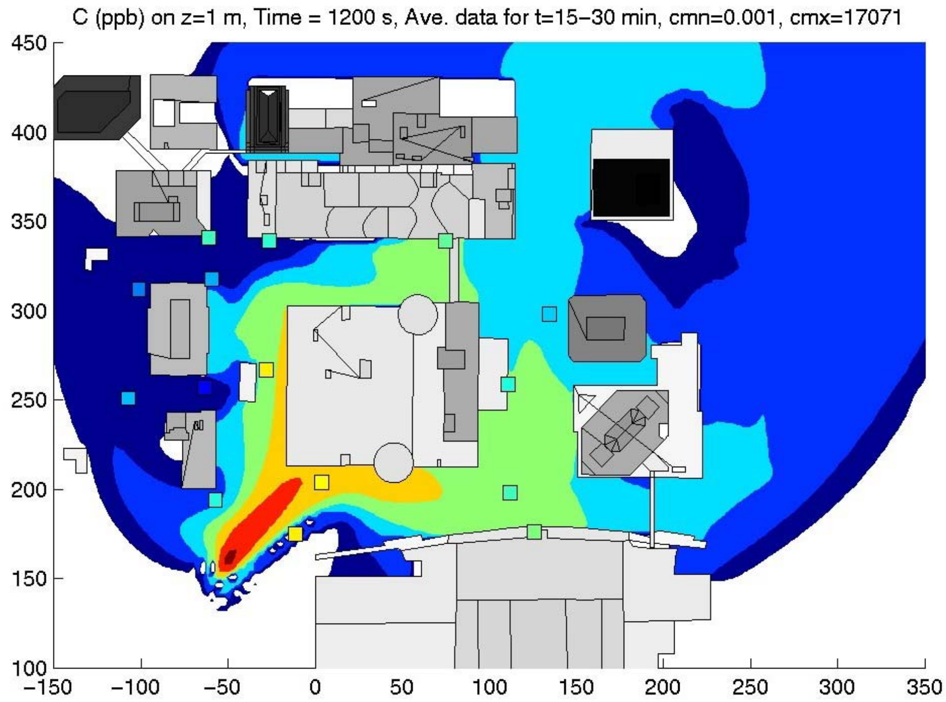


Explicitly resolved buildings
in the source area
(maximum height 120m)



Intensive Observation Period 3 daytime release is simulated using a building-resolving CFD model

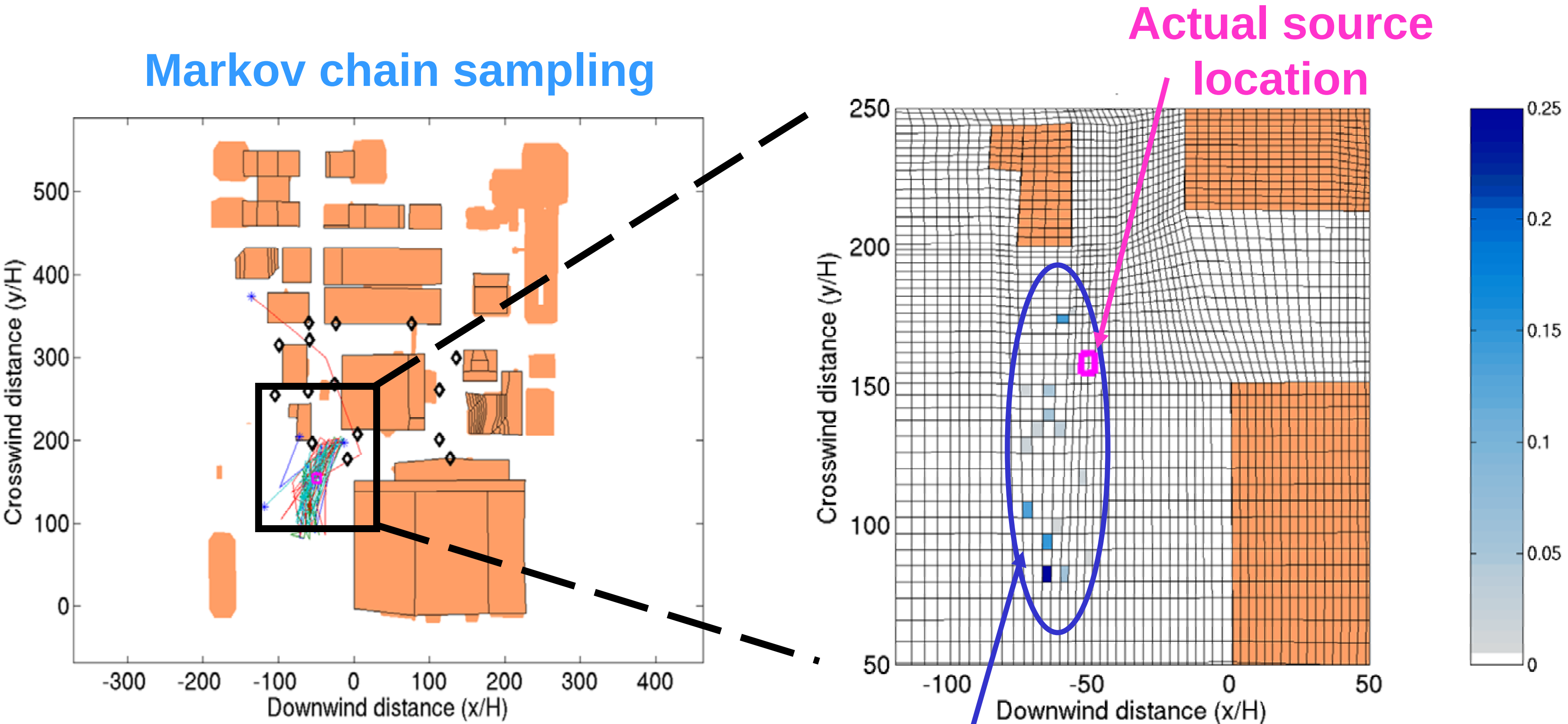


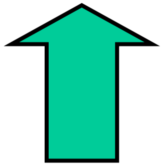


Complex flow in near-source area
- **Velocity vectors and speed contour**
- **Channeling, corner eddies, updrafts**

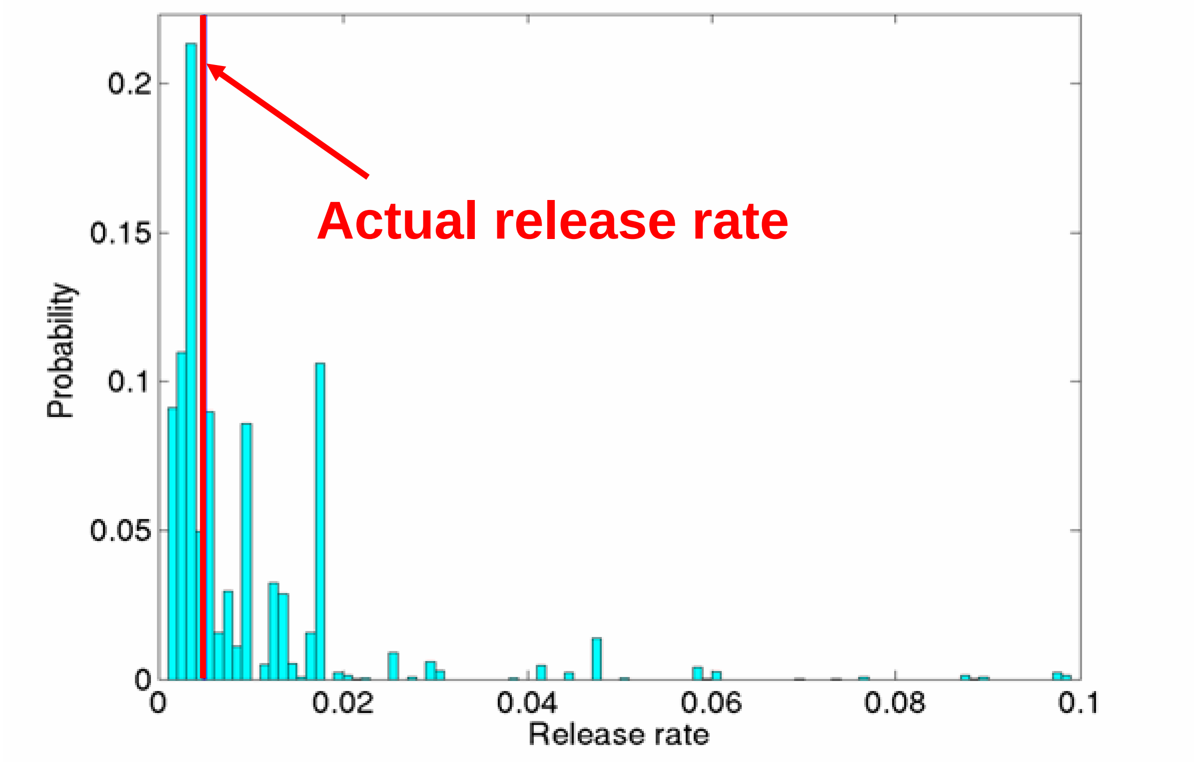
Plume splitting and hot spots
- **Contours – model predictions**
- **Small squares – blue box data**

Possible release locations are identified to within a ~25m x 150m area including the actual source





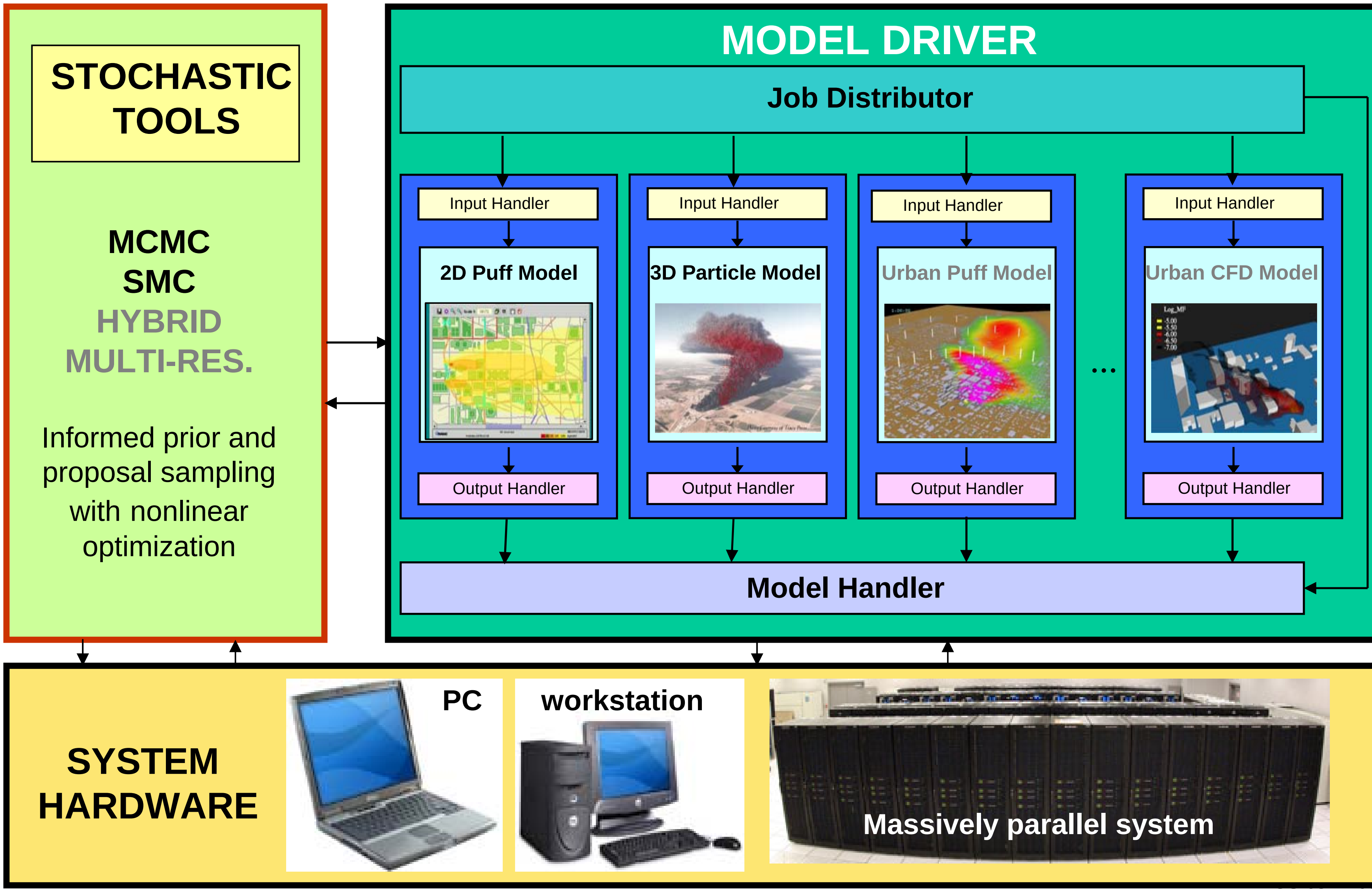
Histogram shows simultaneous determination of release rate to within 10% of actual value



Computational approach uses Green's function methodology

- 2560 pre-computed unit source simulations
- Total CPU = 13,056hrs (12+ hrs on 1024 2.4 GHz Xeon processors)
- Event reconstruction requires ~2 minutes (20000 Markov iterations)

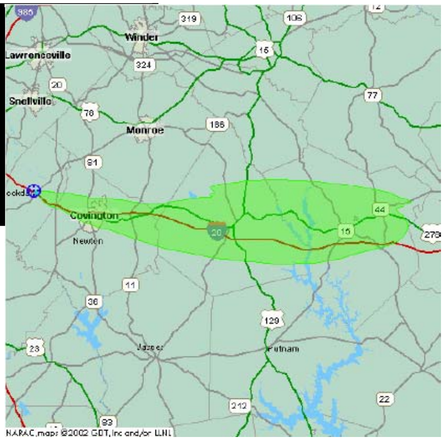
Computational framework supports multiple models, stochastic algorithms, platforms, and parallelism

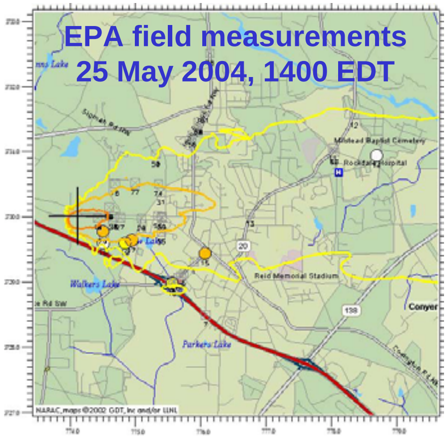


Event reconstruction is urgently needed to support detection, response, and decision support systems

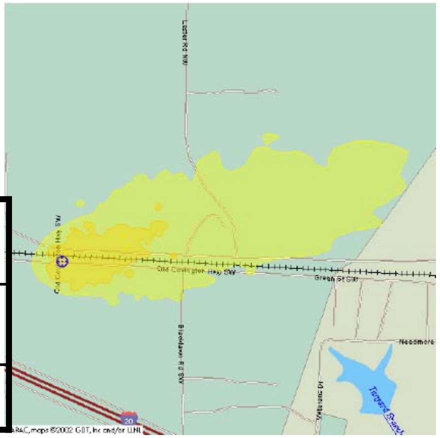
- Applications
  - — NARAC / Nuclear Incident Response (DOE NA-40)
  - — IMAAC (DHS)
  - — BioWatch (DHS)
  - — Facility safety (Nuclear Reactor)
  - — Facility and infrastructure protection
  - — Analysis tools for sensitivity and sensor network design studies
  - — Battlefield support and homeland defense (DoD/DTRA)
  - — Intelligence applications
- Related seed projects
  - — DOE NA-40 Technology Integration of field measurements
  - — DHS event reconstruction testbed
  - — DHS deployable chemical sensor network

Color	Level (g/m3)	Area (km^2)	Description
(cyan)	1e-9	0.4	Medium concentration Population = 49
(green)	1e-12	1608	Lower concentration Population = 40400





Conyers GA chlorine plant fire
2004 May 25-26



Color	Level (ppm)	Area (km^2)	Description
(orange)	2.8	0.05	>AEGL-2: Serious health effects or impaired ability to take protective action. Population = 0
(yellow)	0.5	0.4	>AEGL-1: Minor reversible health effects. Possible odor. Population = 3

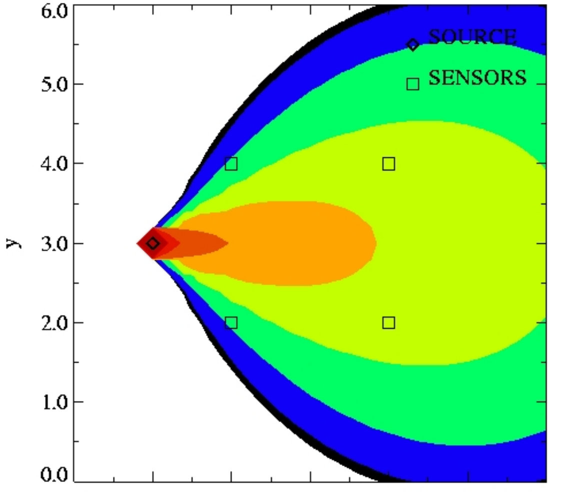
Data-driven simulation is leading to radical improvements in airborne hazards predictions

- Leverages enormous investments
  - — Sensor development
  - — Real-time data acquisition
  - — Predictive models
  - — Stochastic methods
  - — High performance computing
- Creates methodologies adaptable to other dynamic problems
  - — Transport in other media
  - — Tracking problems
- Provides optimal hazards predictions for decision-makers
  - — Order(s) of magnitude improvement in accuracy
  - — Quantification and reduction of uncertainties

Event reconstruction is transforming the management of hazardous airborne releases

Animation slide follows
Replace slide 6
in hardcopy version

Our starting point is the "Stochastic Engine" Markov Chain Monte Carlo method



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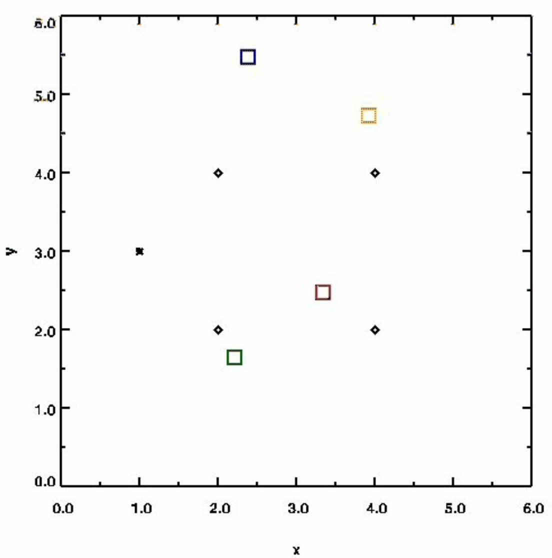
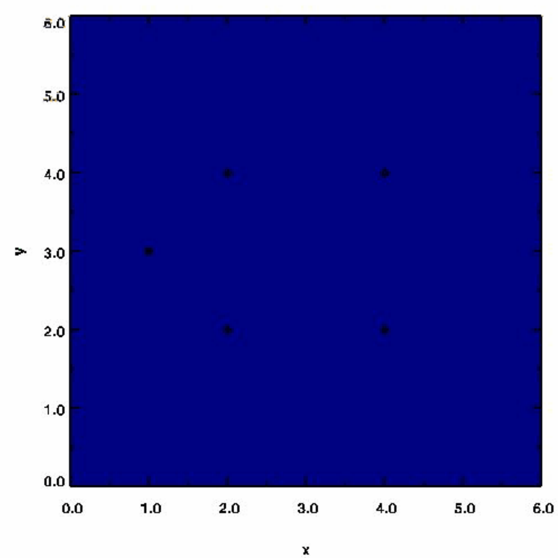
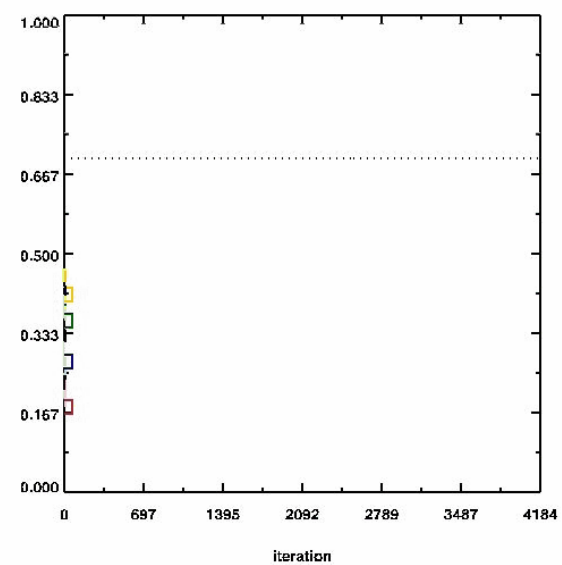




Release rate



Notes

- This LDRD is addressing the key outstanding scientific challenge in predicting the impacts of hazardous airborne release – the creation of event reconstruction capability
- Airborne releases of chemicals, biological agents, and nuclear/radiological materials pose a significant national and homeland security risk, since they can rapidly impact large populations, areas, and critical facilities/infrastructure
  - Observations provide the first evidence of a release (sensor measurements, direct observations, casualties)
  - Decision-makers need timely assessments of the potential impacts in order to make life-and-death decisions on evacuation, sheltering, mitigation, and treatment
  - In real-world situations the greatest unknown is almost always information about the release
- LDRD project stems directly from operational experiences and current trends in measurement / sensor systems
- Solution based on sampling of an ensemble of forward predictive simulations guided by *statistical* comparisons with measurement data
  - Predictive values are used to estimate likelihoods of available measurements
  - Measurement likelihoods are used to reduce uncertainties in estimates of unknown input parameters
- Innovative Monte Carlo methods and importance sampling are used for efficient generation of a sequence of possible input (state) variables
- Examples: ops, complex source, building-scale, urban
  - Given a highly complex domain, with buildings of various shapes and sizes, and concentration measurements at a few locations, is it possible to find the source of a contaminant plume?