Dynamic Data-Driven Event Reconstruction for Atmospheric Releases

The role of an event-reconstruction capability in a case of an atmospheric release is to characterize the source by answering the critical questions: How much material was released? When? Where? What are the potential consequences? Accurate estimation of the source term is essential to accurately predict plume dispersion, effectively manage emergency response, and mitigate consequences. We are developing a capability that seamlessly integrates observational data streams with predictive models to provide probabilistic estimates of unknown source term parameters consistent with both data and model predictions. Our approach uses Bayesian inference with stochastic sampling with Markov Chain Monte Carlo (MCMC) and Sequential Monte Carlo (SMC) methodology.

Project Goals

We are developing a flexible and adaptable data-driven event-reconstruction capability that provides 1) quantitative probabilistic estimates of principal source-term parameters such as the time-varying release rate and location; 2) predictions of increasing fidelity as an event progresses and additional data become available; and 3) analysis tools for sensor network design and uncertainty studies. Our computational framework incorporates multiple stochastic algorithms, operates with a range and variety of atmospheric models, and runs on multiple computer platforms, from workstations to large-scale computing resources. Our final goal is a multi-resolution capability for both real-time operational response and high-fidelity multiscale applications.

Relevance to LLNL Mission

This project addresses a critical need for tools to support the rapidly growing number of operational detection, warning, and incident characterization systems being developed and deployed by the Department of Homeland Security (DHS) and DOE. Our event-reconstruction and sensor-siting tools are targeted for integration into the next-generation National Atmospheric Release Advisory Center (NARAC) and DHS's new Interagency Modeling and Atmospheric Analysis Center, based at LLNL.

FY2005 Accomplishments and Results

In FY2005, we accomplished the following:

1. demonstrated efficiency and robustness of MCMC capability with the NARAC 3-D Lagrangian particle dispersion model LODI, using concentration measurements from a ~10 km-scale tracer field experiment;
2. developed a hybrid MCMC-SMC methodology and demonstrated its effectiveness in characterizing releases from complex, multiple sources;
3. used optimization methods to develop a prototype sensor network design tool;
4. implemented a computational fluid dynamics model for the simulation

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of urban dispersion into the MCMC capability and tested it using data from the Oklahoma City Joint Urban 2003 experiment;
5. developed a computational framework including MCMC, SMC, and hybrid algorithms on massively-parallel platforms;
6. explored methods for incorporating alternative input data types; and
7. significantly enhanced performance on massively-parallel platforms for efficient event reconstruction of complex atmospheric releases.

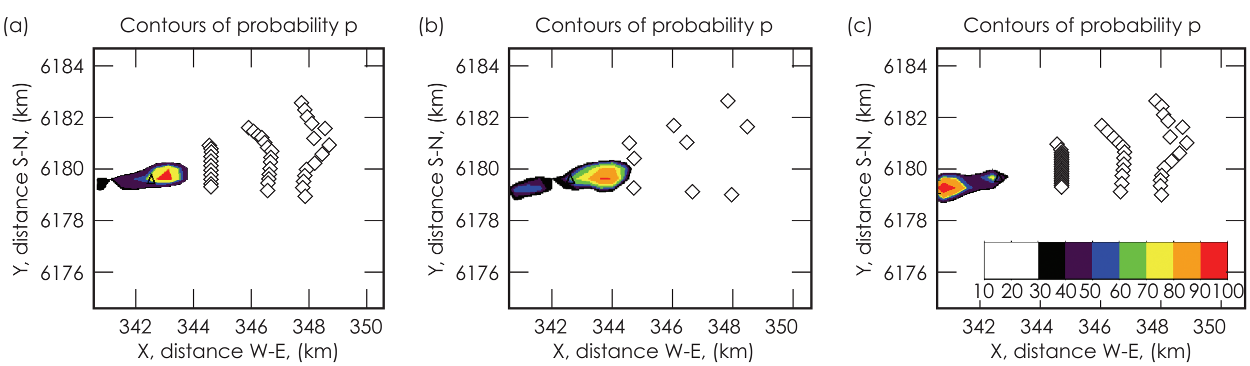
The figure shows sample results.

Related References

1. Chow, T., B. Kosovic, and S. Chan, "Source Inversion for Contaminant Plume Dispersion in Urban Environments Using Building-Resolving Simulations," *Ninth Annual George Mason University Conference on Atmospheric Transport and Dispersion Modeling*, July 18-20, 2005.
2. Kosovic, B., G. Sugiyama, S. Chan, F. Chow, K. Dyer, R. Glaser, W. Hanley, G. Johannesson, S. Larsen, G. Loosmore, J. Lundquist, A. Mirin, J. Nitao, R. Serban, and C. Tong, "Stochastic Source Inversion Methodology and Optimal Sensor Network Design," *Ninth Annual George Mason University Conference on Atmospheric Transport and Dispersion Modeling*, July 18-20, 2005.
3. Kosovic, B., G. Sugiyama, K. Dyer, W. Hanley, G. Johannesson, S. Larsen, G. Loosmore, J. K. Lundquist, A. Mirin, J. Nitao, and R. Serban, "Dynamic Data-Driven Event Reconstruction for Atmospheric Releases," *Second Sandia Workshop on Large-Scale PDE-Constrained Optimization*, Santa Fe, New Mexico, May 19-21, 2004.
4. Kosovic, B., G. Sugiyama, K. Dyer, W. Hanley, G. Johannesson, S. Larsen, G. Loosmore, J. K. Lundquist, A. Mirin, J. Nitao, and R. Serban, "Dynamic Data-Driven Event Reconstruction for Atmospheric Releases," *Eighth Annual George Mason University Transport and Dispersion Modeling Conference*, Fairfax, Virginia, July 13-15, 2004.
5. Johannesson, G. and W. Hanley, "Sequential Monte Carlo Approach to Dynamic Data-Driven Event Reconstruction for Atmospheric Releases," *Joint Statistical Meetings*, Minneapolis, Minnesota, August 2005.

FY2006 Proposed Work

In FY2006 we will:
1. extend the event-reconstruction capability to handle complex continental-scale atmospheric releases;
2. implement quantification procedures for data, input parameters, and internal model error, into the computational framework;
3. implement a multi-resolution capability for more efficient source characterization;
4. continue developing and testing efficient stochastic sampling and convergence algorithms;
5. demonstrate methods for incorporating alternative input data types; and
6. continue performance enhancement of the computational framework on the range of platforms for efficient event reconstruction of complex atmospheric releases.



Sample results using data from Copenhagen tracer field experiment. Color contours represent probability distribution of source location. The actual source is denoted with a triangle; the sensors are denoted with diamonds. (a) Event reconstruction using data from all 51 sensors; (b) source characterization based on data from only nine sensors; (c) results obtained using all 51 sensors, of which 30% were broken in some way. The effect of inaccurate data is evident through the bias in the solution; however, the robustness of the methodology is demonstrated.