5.40 NATIONAL ATMOSPHERIC RELEASE ADVISORY CENTER (NARAC) MODEL DEVELOPMENT AND EVALUATION

Gayle Sugiyama
Lawrence Livermore National Laboratory, Livermore CA, USA

INTRODUCTION

This paper describes model development and evaluation efforts of the National Atmospheric Release Advisory Center (NARAC) located at Lawrence Livermore National Laboratory (LLNL). NARAC is a U.S. Department of Energy (DOE) and Department of Homeland Security (DHS) operational system, which provides detailed predictions of the consequences of atmospheric releases of hazardous materials for real-time emergency response, pre-planning, and post-incident assessments. Automated predictions of plume exposure limits and protective action guidelines for emergency responders and managers are available in 5-10 minutes. These can be followed immediately by increasingly refined, quality-assured analyses performed by NARAC's 24 x 7 on-duty / on-call operational staff as additional information and/or data become available.

NARAC provides an all-hazards modeling system for assessments of chemical, biological, radiological/nuclear, and natural airborne hazards. The system employs a hierarchy of simulation tools, appropriate for different release types, distance and time scales, and/or response times. Source terms models are available for fires, explosions, hazardous material spills, sprayers, and momentum and buoyancy driven sources. The NARAC models are supported by extensive geographical, material, and health effects databases, as well as real-time access to worldwide meteorological observations and forecasts provided via redundant communications links to National Oceanic and Atmospheric Administration, the U.S. Navy and the U.S. Air Force.

Users request, view, and distribute NARAC predictions (Figure 1) via its remote access iClient/Web software. NARAC currently supports on the order of 5-10 alerts and emergencies, 100 interactive exercises, and several thousand automated responses each year, as well as numerous special assessments. Pilot projects underway in Seattle, New York, Albuquerque, Fort Worth, and Cincinnati under the Local Integration of NARAC with Cities (LINC) demonstration program are developing approaches for integrating NARAC capabilities with local emergency management agencies and responders. NARAC has also collaborated with Argonne National Laboratory to provide above-ground modeling support for a subway crisis management system and is a key player in new efforts to develop operational detection, warning, and incident characterization systems.

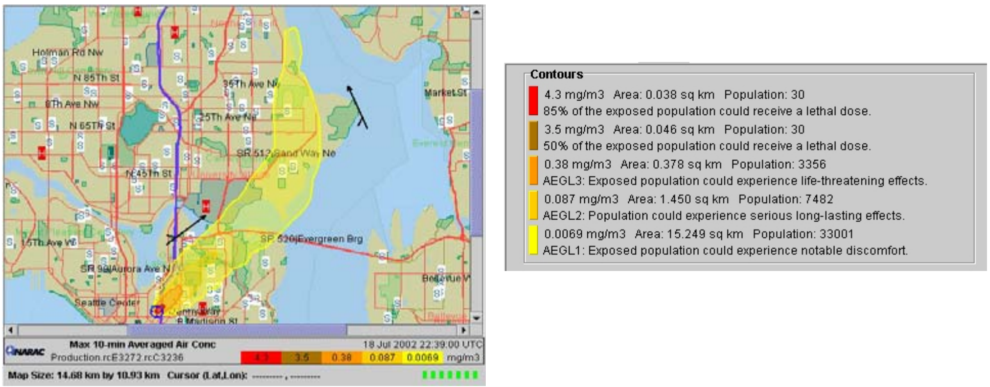

Figure 1. Example of a NARAC customer product.

NARAC URBAN MODEL DEVELOPMENT

NARAC's emergency response modeling system is under continuous development in order to incorporate new state-of-the-science tools. The system includes deployable rapid-response models, mesoscale meteorological and dispersion models, and computational fluid dynamics (CFD) models. A primary focus of recent research efforts has been on the treatment of urban releases, some examples of which are described below.

An urban canopy parameterization for numerical weather prediction models has been developed (Chin et al., 2000; Leach et al, 2001) and is being evaluated via its implementation in NARAC's in-house version of the Naval Research Laboratory's COAMPS model (Hodur, 1997). The urban parameterization includes the effects of increased turbulence due to building effects, altered radiation transfer due to the urban canopy, and modifications to the surface energy balance at street level and rooftops. Inputs to this model (e.g., average building heights, urban and rooftop fractions) are derived using NARAC utilities, which sample U.S. Geological Survey (USGS) 200m and 30m land-use databases and map land-use categories into the required parameters.

NARAC is developing computational fluid dynamics (CFD) models for simulating building-scale flow and dispersion. Our current model, FEM3MP (Chan and Stevens, 2000), solves the three-dimensional, time-dependent, incompressible Navier-Stokes equations. The numerical algorithm uses a finite element approach to accurately represent buildings and terrain, together with a semi-implicit projection method for efficient time integration (Gresho and Chan, 1998). The code has been implemented on massively parallel platforms and utilizes modern iterative solvers for solving the discretized system of equations, such as preconditioned conjugate gradient and multi-grid methods. Physical processes treated include atmospheric turbulence modeling via the RANS (Reynolds Averaged Navier-Stokes) and LES (Large Eddy Simulation) approaches, aerosols, UV radiation decay, chemical reactions (Humphreys and Lee, 2004), surface energy budgets, and vegetative canopies. The model has been extensively validated, using data from both wind tunnel and field experiments (Chan, et al., 2000 and 2001; Humphreys, et al., 2003). A simplified approach, which replaces outlying buildings by drag elements, has been shown to be able to reproduce the main flow features and concentration patterns, with an order-of-magnitude savings in computational cost. (Chan et al, 2004).

NARAC is developing a next-generation CFD model via a new adaptive dispersion model (ADM) framework, which couples our existing flow solver with rapid geometry-to-mesh and adaptive mesh refinement techniques. The new model will support geometrically complex structures and interior spaces (Kosovic and Chan, 2004). This effort utilizes the Structured Adaptive Mesh Refinement Application Interface (Hornung, et al., 2002) and new grid generation tools. The ADM will allow simultaneous simulation of both the area of interest at high resolution and the larger surrounding region, in order to provide seamless coupling of the CFD model with forcing flows and other fields derived from mesoscale models.

NARAC is collaborating with the U.K. Ministry of Defence's Defence Science and Technology Laboratory (Dstl) to integrate Dstl's Urban Dispersion Model (UDM). The UDM is an empirical urban model, which explicitly incorporates individual building effects near the release point. The UDM is currently the best candidate to fill a critical gap in NARAC's tool suite, due to its operational nature, supporting tools and databases, and model evaluation standards (Hall et al., 2003; Griffiths et al., 2002).

Indoor and outdoor concentrations can differ significantly (Figure 2). Quantitative predictions of the indoor exposures resulting from outdoor releases are critical in determining whether occupants are safer evacuating or temporarily sheltering in place. NARAC is currently integrating a residential building infiltration model (Chan et al., 2004) developed by Lawrence Berkeley National Laboratory (LBNL). This model predicts indoor exposures from outdoor concentrations, taking into account the statistical distribution of air exchange rates within each U.S. Census tract. NARAC is currently processing data to complete a residential building database to support this capability for the entire United States. Data on census-tract-specific house leakiness distributions is then extracted from the pre-calculated database, combined with weather data (necessary because air exchange depends both on leakiness and on parameters such as wind speed), and fed into the infiltration model to predict the distribution of indoor concentrations. Extensions to commercial buildings and new customer products for interpreting the effects on indoor populations are under development.

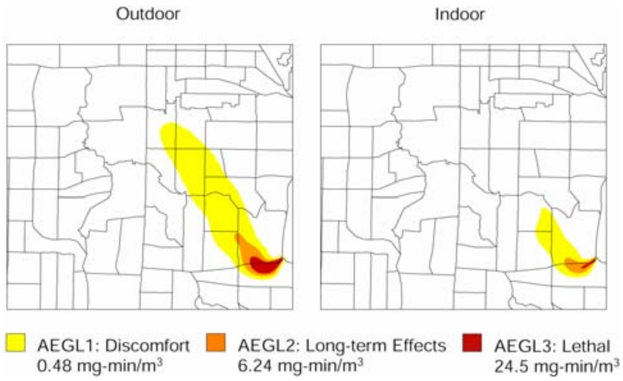

Figure 2. Comparison of outdoor and indoor exposures after 240 minutes for a hypothetical release in the Salt Lake City area. Divisions are census tracts.

Day-time U.S. population databases, developed by Los Alamos National Laboratory, have been integrated into NARAC. This database supplements U.S. Census 2000 and global coverage LandScan population data to provide improved estimates of the populations likely to be affected by a hazardous plume.

URBAN FIELD STUDIES AND MODEL EVALUATION

The U.S. DOE and DHS have been sponsoring LLNL's participation in large-scale urban tracer experiments, including the DOE's URBAN 2000 urban field study in Salt Lake City (Allwine et al., 2000) the DHS/Defense Threat Reduction Agency's Joint Urban 2003 (JU2003) experiment in Oklahoma City, and the recently formed DHS Urban Dispersion Program in New York City. URBAN 2000 data has been used to evaluate NARAC's current suite of urban models and JU2003 validation studies are underway.

Simulations have been completed for all six of the Intensive Observation Periods (IOPs) of the URBAN 2000 field study in Salt Lake City, using the urban canopy version of COAMPS coupled to the NARAC dispersion model LODI (Leach et al., 2002). For the nocturnal conditions of URBAN 2000, tracer data comparisons show that the urban model significantly improves the dispersion forecast, except in the lightest wind conditions. The simulations also show the critical interaction between the urban forcing and the larger mesoscale circulation. Comparisons with point wind and temperature observations in the urban core are of limited utility for canopy model evaluation, since these data are strongly affected by individual buildings, while the model predicts only the integrated or volume-averaged influence of these structures.

NARAC's CFD model FEM3MP has also been evaluated using all of the URBAN 2000 IOPs. IOPs (2, 4, and 7) involve highly variable wind conditions, with turbulent fluctuations on the same order as the mean velocity. A time-varying boundary (forcing) condition was therefore implemented in FEM3MP. Figure 3 contrasts Large Eddy Simulation (LES) concentration patterns for IOP 7, driven by steady-state forcing (left panel) or by time-dependent real-time anemometer data representative of the upstream conditions (right panel). The steady-state simulation performed very poorly, completely missing many of the sampler locations. In contrast, the use of time-dependent forcing resulted in obvious improvements, with most predicted values within a factor of five of the observed concentrations. (Humphreys et al., 2003).

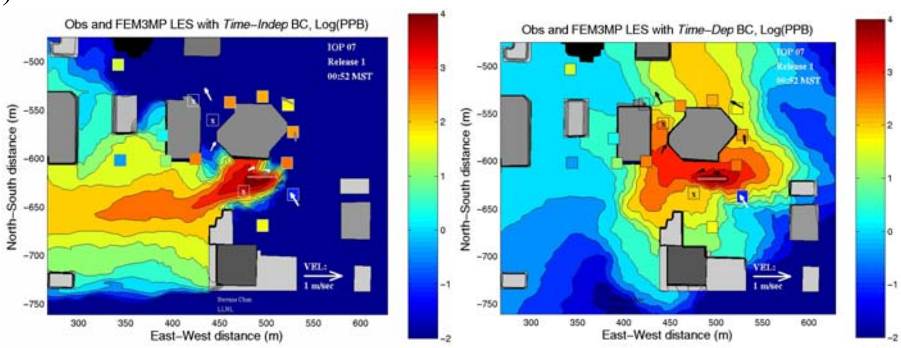

Figure 3. Predicted five minute time-averaged concentration patterns from simulations using steady-state (left) and time-dependent (right) inlet velocity component (URBAN 2000 data).

EVENT RECONSTRUCTION

In real-world events, the source term is often poorly defined and for a clandestine terrorist attack may be completely unknown, with the first indication of an event provided by sensor measurements, observations, or even casualties. Effective mitigation or response to an release requires rapid estimation of unknown source terms based on the available data, as well as accurate predictions of the future dispersion of the released material (Figure 4). NARAC is exploring methods coupling Bayesian inference, stochastic sampling, and non-linear optimization with predictive models and data in order to produce event reconstruction tools, which produce probabilistic estimates of source terms parameters, support disparate types of data, and take into account the error intrinsic to both data and models.

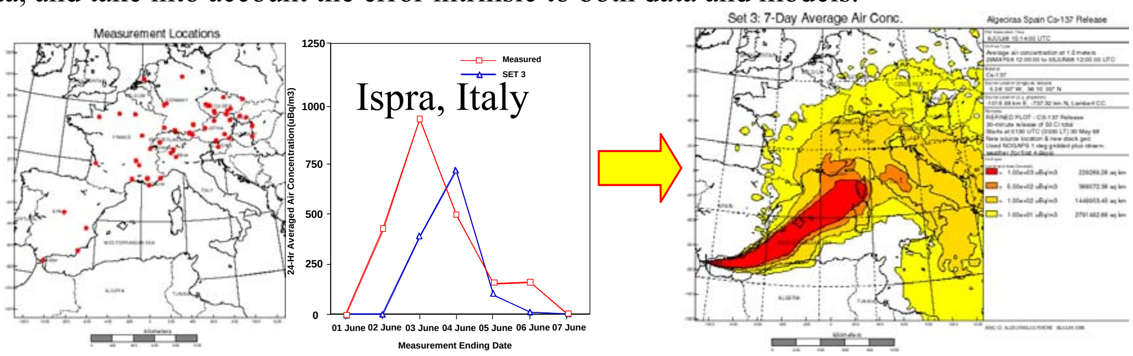

Figure 4. Manual event reconstruction example performed by NARAC for an accidentally melted medical source in Algeciras, Spain. Figure shows data locations (left), a model-data comparison for one loation (middle), and the best NARAC prediction (right).

ACKNOWLEDGEMENT
This work was performed under the auspices of the U.S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

REFERENCES

Allwine, K., J. Shinn, G. Streit, K. Clawson, and M. Brown, 2002: Overview of URBAN 2000, *Bulletin of the American Meteorological Society,* **83** (4), 521-536.

Chan, S. and D. Stevens, 2000: An Evaluation of Two Advanced Turbulence Models for Simulating the Flow and Dispersion Around Buildings, *The Millennium NATO/CCMS Int. Tech. Meeting on Air Pollution Modeling & its Appl.*, Boulder CO, May 2000, 355-362.

Chan, S., D. Stevens, and W. Smith, 2001: Validation of Two CFD Urban Dispersion Models Using High Resolution Wind Tunnel Data, *3rd Int. Sym. on Environ, Hydraulics*, ASU, Tempe, AZ, Dec. 2001, 107.

Chan, S., T. Humphreys, and R. Lee, 2004: A Simplified CFD Approach for Modeling Urban Dispersion, *AMS 84th Annual Meeting*, Seattle, WA, Jan. 11-15, 2004.

Chan, W., P. Price, A. Gadgil, W. Nazaroff, G. Loosmore, and G. Sugiyama, 2004: Evaluate Shelter-in-Place as Part of an Emergency Operation Plan, AMS Symposium on Planning, Nowcasting, and Forecasting in the Urban Zone*, AMS 84th Annual Meeting*, 2004 January 11-14.

Chin, H.N., M.J. Leach, and M.J. Brown, 2000: A Sensitivity Study of the Urban Effect on a Regional-Scale Model: An Idealized Case, 3rd AMS Urban Env. Symp., Davis, CA. UCRL-JC-139167.

Gresho, P. and S. Chan, 1998: Projection 2 Goes Turbulent – and Fully Implicit, *Int. J. of Comp. Fluid Dynamics*, 9, 249-272.

Hall, D.J., A.M. Spanton, I. H. Griffiths, M. Hargrave, and S. Walker, 2003: The Urban Dispersion Model (UDM): Version 2.2 Technical Documentation, *DSTL/TR04774*.

Hodur, R. M. 1997: The Naval Research Laboratory's Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS), *Mon. Wea. Rev*. **125**, 1414-1430.

Hornung, R. and S. Kohn, 2002: Managing Application Complexity in the SAMRAI Object-Oriented Framework*, Concurrency & Comp.: Practice & Experience* **14,** 347-368.

Humphreys, T. and R. Lee, 2004: Incorporation of Chemical Reactions Into Building-scale Flow, *AMS 84th Annual Meeting*, Seattle, WA, Jan. 11-15, 2004.

Humphreys, T., S. Chan, and R. Lee, 2003: Validation of CFD Near Building Dispersion with Urban 2000 Data for Steady and Time-dependent Boundary Conditions, *7th Annual GMU Transport and Dispersion Modeling Workshop*, Fairfax, VA, June 2003.

Griffiths, I.H., D.R. Brook, D.J. Hall, A. Berry, R.D. Kingdon, K. Clawson, C. Biltoft, J.M. Hargrave, D. C. Strickland, and A. M. Spanton, 2002: Urban Dispersion Model (UDM) Validation, *AMS 4th Symposium on the Urban Environment,* Norfolk VA.

Kosovic, B. and S.T. Chan, 2004: Integrated Urban Dispersion Modeling Capability, *Symposium on Planning, Nowcasting and Forecasting in the Urban Zone, 84th AMS Annual Meeting*, 2004 January 11-15, Seattle WA.

Leach, M.J., H.N. Chin, M.J. Brown, 2001: Validation of an urban parameterization in a mesoscale model, Proceedings of the *3rd International Symposium on Environmental Hydraulics,* Arizona State University, Tempe, Arizona, December 5-8, 2001.

Leach, M. J., H.N. Chin, J. Leone, G. Sugiyama, H. Walker, 2002, Urban effects in numerical models and evaluation with field experiment data: Part III: comparisons to tracer data, *Proceedings of the 4th Symposium on the Urban Environment,* American Meteorological Society, Norfolk, Virginia, May 20-24, 2002.