UCRL-CONF-236785

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November 27, 2007

American Nuclear Society 2nd Joint Emergency Preparedness and Response & Robotics and Remote Systems Topical Meeting
Albuquerque, NM, United States
March 9, 2008 through March 12, 2008

Submitted to American Nuclear Society 2nd Joint Emergency Preparedness and Response & Robotics and Remote Systems Topical Meeting
March 9 - 12, 2008, Albuquerque, New Mexico

ADVANCES IN NATIONAL CAPABILITIES FOR CONSEQUENCE ASSESSMENT MODELING OF AIRBORNE HAZARDS

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This paper describes ongoing advancement of airborne hazard modeling capabilities in support of multiple agencies through the National Atmospheric Release Advisory Center (NARAC) and the Interagency Atmospheric Modeling and Atmospheric Assessment Center (IMAAC). A suite of software tools developed by Lawrence Livermore National Laboratory (LLNL) and collaborating organizations includes simple stand-alone, local-scale plume modeling tools for end user's computers, Web- and Internet-based software to access advanced 3-D flow and atmospheric dispersion modeling tools and expert analysis from the national center at LLNL, and state-of-the-science high-resolution urban models and event reconstruction capabilities.

I. INTRODUCTION

Lawrence Livermore National Laboratory (LLNL) and collaborating organizations develop hazardous material plume modeling tools to support a large number of federal, state and local emergency managers and responders.[1] This paper describes current capabilities and recent advances in airborne hazard modeling support for multiple agencies under the auspices of the National Atmospheric Release Advisory Center (NARAC) and the Interagency Atmospheric Modeling and Atmospheric Assessment Center (IMAAC).

The primary sponsors of NARAC/IMAAC operation are the Office of Emergency Operations in the U.S. Department of Energy's (DOE) National Nuclear Security Administration (NNSA), the U.S. Naval Nuclear Propulsion Program, and the Department of Homeland Security (DHS). NARAC is an integral part of DOE's contribution to the Federal Radiological Monitoring and Assessment Center (FRMAC) and also provides support to over 40 individual DOE and U.S. Department of Defense (DOD) facilities. NARAC also supports DOE's International Emergency Management and Cooperation (IEMC) Program which cooperates with other governments on nuclear emergency preparedness technology. Under the auspices of both DOE and DHS, NARAC/IMAAC works with over 300 collaborating state and federal organizations involved in emergency preparedness activities.

According to the U.S. National Response Plan (Notice of Change, 2006), "The IMAAC provides a single point for the coordination and dissemination of Federal dispersion modeling and hazard prediction products that represent the Federal position during actual or potential incidents requiring federal coordination".[2] The DHS-led IMAAC is supported by collaborating agencies including the Department of Commerce's National Oceanic and Atmospheric Administration (NOAA), the Department of Defense (DoD), the Department of Energy (DOE), the Environmental Protection Agency (EPA), the Department of Health and Human Services (HHS), the National Aeronautics and Space Administration (NASA), and the Nuclear Regulatory Commission (NRC). The IMAAC was created under the auspices of the Homeland Security Council on April 15, 2004 and NARAC is the designated interim provider of IMAAC capabilities.

A recent paper reviewed the NARAC simulation models and systems, including their testing and evaluation.[1] Described below are recent advances of LLNL-based modeling tools and products in collaboration with other organizations in support of the NARAC and IMAAC.

II. SIMULATION MODELS AND DATABASES

The mission to provide near-real-time model predictions of atmospheric dispersion anywhere in the world requires access to large volumes of observational and forecast weather data, and to extensive databases of population density, geographical information, hazardous material source characteristics, radiological, chemical, and biological material properties, dose factors, dose limits, and protective action guides.[1]

The quality and resolution of the available geospatial data sets are steadily improving. Incorporating such data into the operational system and model inputs results in more accurate consequence predictions. Last year, NARAC/IMAAC integrated the National Elevation Dataset (see http://ned.usgs.gov/) for terrain elevation at approximately 10 and 30 m resolution covering the U.S. and the National Geospatial Agency (NGA) data at approximately 30 m and 100 m resolution.

NARAC/IMAAC uses population density data to estimate the number of people potentially affected by a particular contamination or dose level. The operational versions of the Oak Ridge National Laboratory (ORNL) LandScanGlobal (approximately 1 km horizontal resolution) and LANL Day-Night (approximately 250 m resolution) population data were updated to their most current versions. The ORNL LandScanUSA Day-Night population data (approximately 100 m resolution) is being integrated into the operational system, and represents an important improvement in resolution and quality over previous data.

The LODI atmospheric dispersion model has historically used a static (i.e., non-dynamic), effective cloud representation of the initial contaminant distribution from a chemical high-explosive detonation (e.g., Radiation Dispersal Device). This distribution is based on measurements from the Roller Coaster set of experiments conducted at the Nevada Test Site, and models the initial cloud so that it will simulate the aerosolized material distribution as it was observed several minutes after the detonation. An interface to Sandia National Laboratories' PUFF dynamic cloud rise model for high-explosive detonations[3] now provides LODI with the ability to more realistically simulate the evolving explosive cloud during the first few minutes after a high-explosive detonation that disperses particulate matter. The PUFF sub-model calculates the time-dependent rise of the thermally-buoyant cloud resulting from the high-explosive detonation for use in LODI.

This time-dependent cloud rise capability provides improved accuracy of the developing cloud geometry during the first several minutes after the detonation, and more accurately models the near-surface contamination levels close to the detonation location. Figure 1 shows an example of a LODI-simulated particle distribution projected on a vertical plane along with the location of the spherical cloud (shown by the circle) of hot gas at 5 minutes after detonation. Particles falling outside of this spherical explosive gas cloud have settled and de-entrained and are under the influence of ambient atmospheric conditions. The complex distribution of these particles reflects the 3-dimensional variation in the mean winds (which are primarily blowing from the right to the left). Location of the detonation was in the lower right corner of the figure, at approximately 1650 meters above mean sea-level.

The PUFF cloud rise results have been previously validated against Roller Coaster explosive detonation data. Ongoing work is proceeding on validation of the LODI-PUFF code, making use of the Roller Coaster Clean Slate 1 and Double Tracks shots. The example in Figure 1 comes from a simulation of the Roller Coaster Clean Slate 1 field experiment.

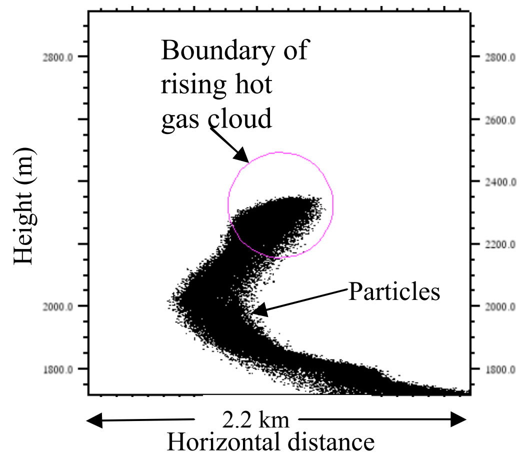

Figure 1. Example of LODI-simulated particle positions projected on a vertical plane at 5 minutes after detonation. Heights are meters above mean sea-level.

The ability to specify a nuclear detonation radioactivity source term has also been added to the LODI atmospheric transport and diffusion model. The source term (i.e. initial effective spatial distribution and particle size distribution of radioactivity) is based on algorithms originally developed for the KDFOC3 nuclear detonation fallout model.[4] This source description is derived from regression analysis of the key cloud parameters to give good agreement to the fallout patterns produced by some of the atmospheric test shots at the Nevada Test Site. Using the KDFOC3 source term in LODI, the full range of LODI modeling capabilities (e.g. 3-D winds, terrain, precipitation and weathering effects) can be brought to bear on nuclear detonation dispersion and fallout simulations. KDFOC3 and LODI comparison runs verified that LODI generates very similar results to KDFOC3 when simplified atmospheric conditions (appropriate to KDFOC3) are used.

To significantly reduce the computer time needed for LODI simulations, and allow timely simulation on less-powerful, field-deployable computer platforms, an optional horizontal diffusion algorithm has been implemented which reduces LODI's run time by a factor of 3-10 (depending on the scenario and code options used). The more efficient calculation method uses Gaussian distributions to simulate horizontal diffusion, instead of the Lagrangian particle random-walk method.[1] To retain high resolution in the vertical direction, in which wind and turbulence fields are typically much less homogeneous, the existing random-walk simulation method using discrete Lagrangian particles is retained.

A series of comparison runs using the existing and new horizontal diffusion methods are being completed for a range of meteorological and topographic complexity. The simplest conditions modeled were those from the Prairie Grass experiment gas air concentrations from 50 to 800 meters downwind of a point source over a relatively flat terrain. For this relatively simple case, results from the new method using 5000 particles with Gaussian distributions in the horizontal directions, and existing method using 200,000 discrete Lagrangian particles produced nearly identical results, but significantly less computer time. Cases involving more complex terrain are being evaluated.

A LLNL urban Computational Fluid Dynamics modeling capability, FEM3MP, has been extensively validated using data from recent urban dispersion experiments: Urban 2000, Joint Urban 2003, and Urban Dispersion Program.[5,6]Currently we are expanding applicability of our model to applications involving aerosol dispersion as well as dense gas dispersion.[7] LLNL recently received building data from NGA for more than 133 cities, which can be used to develop grids and building characteristics for indoor and outdoor urban models.

To enable tighter coupling of mesoscale simulations with urban scale simulations we are extending Weather Research and Forecasting (WRF) model to urban-scale and complex terrain applications.[8] We are adding state-of-the-art subfilter models into WRF for large-eddy simulations of atmospheric boundary layers.[9] We are also introducing immersed boundary capability for simulations of flows over complex terrain.[10] These extensions will significantly enhance WRF's applicability to a wide range of problems related to dispersion in complex terrain and urban environments.

IV. INTEGRATION OF MEASUREMENT DATA WITH MODEL PREDICTIONS

Because of limitations and uncertainties in input data (e.g., source term estimates) and other modeling assumptions, it is important to incorporate field measurements into predictions and assessments of dose as soon as possible during an incident or accident.

NARAC/IMAAC continues to work as part of the FRMAC to utilize measurement data for updating model predictions. Data are collected, assessed, and stored in FRMAC databases, and then electronically transmitted to NARAC/IMAAC. An Extensible Markup Language (XML) file has been developed in a collaboration with other DOE Office of Emegency Response contractors to electronically transfer measurement data from FRMAC databases to the NARAC modeling system.[11] XML continues to prove to be a simple, flexible, self-describing text format for this use.

In order to automate the use of measurement data to infer unknown source characteristics and produce improved plume model predictions, LLNL is continuing to develop a flexible and robust data-driven modeling capability that will be suitable for future operational integration. The LLNL approach couples data and predictive models with Bayesian inference and stochastic sampling to provide backward analyses to estimate unknown source characteristics, develop optimal forward predictions for consequence assessment, and dynamically reduce uncertainty as additional data become available. We have recently demonstrated the effectiveness and flexibility of this methodology by carrying out source inversions using experimental data and data from real world accidents at a wide range of scales, from urban to continental scale.[12,13,14] The robustness of the methodology was demonstrated by corrupting a large fraction (up to 30%) of data used in the inversion process.[15] Finally, we have shown how to use the Bayesian stochastic methodology to determine spatial and temporal resolution requirements as well as required sensitivities of sensor networks for effective source characterization. [16]

IV. SOFTWARE SYSTEMS AND TOOLS

NARAC/IMAAC's software system utilizes a multi-tiered distributed software architecture that provides real-time access to global meteorological and geographical databases and atmospheric modeling tools. The *NARAC/IMAAC Web* is a secure web site that permits remote users to input release scenarios, automatically run both 3-D and simpler Gaussian plume models[17] and view and manage the results of model runs. The NARAC/IMAAC Web provides authorized users with the ability to share information with other users (e.g., plume results, aerial photographs, field measurement data), and an opportunity to directly access analyses from NARAC/IMAAC subject matter experts. The *NARAC iClient* is a more sophisticated desktop application that provides NARAC/IMAAC reach-back capability and stand-alone operation using local models on a user's remote system. It was designed using Java and web-based technology to provide a platform independent tool for deployed emergency response analysts.

Currently, there are several hundred iClient users and two thousand NARAC/IMAAC Web users from federal, state, and local agencies. The NARAC-IMAAC Web has been used very successfully in major national exercises, such as the recent Top Officials 4 exercise series, to quickly share model and measurement-based products describing hazard areas with multiple users at all levels of government.

Recent additions to the NARAC/IMAAC Web include the ability for external users to run models for dispersion and fallout using a nuclear detonation source. In addition, the user now has the option to select source parameters based on multiple pre-defined scenarios that include nuclear, radiological, chemical, and biological release types. This capability significantly enhances user efficiency and flexibility. Likewise, users can display plume results over maps of satellite images.

Recent additions to the iClient software (version 2.0) include the ability to generate atmospheric plume simulations world-wide (previously, only simulations at pre-defined fixed sites could be performed). In addition, extensive mapping capabilities have been added to the iClient tool. These include high resolution street maps of North America and world-wide coverage using satellite and areal images. Like the NARAC/IMAAC Web, predefined scenarios are now available with the iClient 2.0 software, which is currently undergoing Beta testing.

V. CONSEQUENCE ASSESSMENT PRODUCTS

Atmospheric dispersion and deposition models predict quantities such as time-integrated or time-averaged air concentration, peak air concentration experienced at any interval during the total exposure time, and accumulated surface deposition. These quantities are converted into products, such as dose and corresponding protective action guide dose limits, which are used by a wide range of users, including emergency responders, support scientists, emergency managers, and decision makers.

LLNL recently began utilization of a greatly-expanded set of radiological dose conversion factors. These factors were generated by Oak Ridge National Laboratory and are functions of the isotope, dose pathway (e.g., inhalation), the particle size for inhalation pathways, and the age of the target population in the DCFPAK 2.0 package. Factors for both short-term deterministic effects and longer-term stochastic effects are included. NARAC/IMAAC users may choose to use factors based on the older International Commission on Radiological Protection (ICRP) 26/30 tissue weighting factors, and biokinetic and dosimetric models, or on the newer ICRP 60/70 factors and models. [18]

Presentation of model prediction results and accompanying supporting information is constantly updated to meet the needs and priorities of those in the emergency response community. Over the last two years, NARAC/IMAAC has implemented an expanded format and content for the reports disseminated to decision makers responsible for responding to atmospheric releases of toxic material. In a joint effort with Sandia National Laboratories, a unified multi-page report format was developed for radiological releases, which includes a summary of the release scenario(s) and their consequences on the downwind population, detailed scenario information, individual dose and health effect model products with accompanying multi-paragraph interpretation guides, tables of input meteorological data and model-calculated centerline concentrations or doses, and relevant appendices discussing key points related to the release scenario. This expanded format is now available in addition to the previously-used brief report format.

VI. SUMMARY

This paper has described some current capabilities and ongoing advancement of hazardous airborne material dispersion prediction capabilities by Lawrence Livermore National Laboratory and collaborating organizations. In order to accomplish the mission of providing near-real-time atmospheric hazard predictions, a wide range of supporting databases, computer models, software systems, and services have been integrated. Utilization of capabilities such as these has proven extremely valuable for situational awareness and emergency management in the recently completed Top Officials 4 (TOPOFF4) national exercise. Ongoing advances include (1) higher resolution affected population estimates that vary with time of day, (2) more detailed and efficient simulation models for explosive dispersal and nuclear fallout, (3) urban effects in atmospheric flow and transport models, (4) improved methods of integrating measurement data into model predictions, (5) updated dose conversion factors, (6) Internet- and Web-based technologies for quickly obtaining and sharing hazard predictions with more detailed maps and reports of model results.

Additional information on NARAC/IMAAC can be found at http://narac.llnl.gov.

ACKNOWLEDGEMENTS

Portions of this work were sponsored by the DOE NNSA Office of Emergency Operations, Naval Nuclear Propulsion Program, DHS Science and Technology Directorate, and the LLNL Laboratory Directed Research and Development program. Lawrence Livermore National Laboratory is operated by Lawrence Livermore National Security, LLC, for the U.S. Department of Energy, National Nuclear Security Administration under Contract DE-AC52-07NA27344.

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