National Atmospheric Release Advisory Center (NARAC) Model Development and Evaluation

Gayle Sugiyama

Lawrence Livermore National Laboratory

9th International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes

June 2004
NARAC Provides Real-Time Assessments of Hazardous Releases

Event information
- Real-time weather data
- Nuclear, radiological, chemical, biological source information
- Terrain, land-use, population, health effect databases

Plume Models and Expertise
- Advanced, automated 3-D plume modeling globally relocatable in real-time
- Scientific and technical staff provides quality assurance, training, assistance and detailed analysis 24 hrs x 7 days

Consequence Management Information
- Hazard areas
- Health effects and exposed populations
- Protective action guidelines
- GIS, facility and map features
NARAC is a DOE/DHS Capability with a Multi-Agency Customer Base

**On-line Sites:**
- DOE
- DOD
- NR

**Major Programs:**
- DOE Atmospheric Release Advisory Capability (ARAC)
  - Nuclear Incident Response Team (NIRT) asset
  - FRMAC, ARG, NEST, RAP
- DHS Science & Technology (S&T)
  - DHS Operations (HSOC, FEMA)
  - Inter-Agency Modeling and Atmospheric Assessment Center (IMAAC)
- Local Integration of NARAC with Cities (LINC)

**Advisory Services:**
- FAA
- EPA
- NRC
- Local agencies

**Metadata Suppliers:**
- Air Force Weather Agency (AFWA)
- Fleet Numerical Meteorology and Oceanography Center (FNMOC)
- National Weather Service
- Mesonets
- On-line sites
Phased Modeling System Supports Different Release Types, Distance Scales, Response Times

- **Deployable rapid-response models**
  - Radiological plume model HOTSPOT (Homann, 1994)
  - Toxic industrial chemical model EPIcode (Homann, 1996)
  - ALOHA/CAMEO (NOAA/EPA)
  - INPUFF (2D puff model)

- **Regional-scale models**
  - ADAPT/LODI (coupled data assimilation/dispersion models)
  - COAMPS (in-house version of NRL’s weather forecast model)
  - Prompt effects (SNL) and KDOFC fallout code

- **Building-scale CFD models**
  - FEM3MP ->ADM
  - Empirical urban model UDM (Dstl, MOD U.K.)
NARAC Models Have Been Extensively Tested and Evaluated

- **Analytic solutions** test models versus known, exact results

- **Field experiments** test models in real-world cases.
  Examples: Project Prairie Grass, Savannah River Mesoscale Atmospheric Tracer Studies, Diablo Canyon Tracer Study, ETEX, URBAN

- **Operational applications** evaluate the usability, efficiency, consistency and robustness of models for operational conditions.
  Examples: Chernobyl, Kuwait oil fires, tire fires, industrial accidents, Algeciras Spain Cesium release, Tokaimura criticality accident, Cerro Grande (Los Alamos) fire, post Sept 11 threats
Urban Field Studies are Crucial for Evaluation of Atmospheric Transport and Fate Models

- **URBAN 2000 (Salt Lake City)**
  - Data has been quality assured and released to the general scientific community
  - Nocturnal conditions (October, 2000)

- **JU2003 (Oklahoma City)**
  - Data collection completed (July, 2003)
  - Day and night time conditions, outdoor and indoor studies

- **DHS Urban Dispersion Program (New York City)**
Regional model urban canopy parameterizations improve URBAN 2000 dispersion forecasts

- Urban model is a modified forest canopy model (Brown & Williams 1998; Chin et al. 2000)
  - Friction source in momentum equation
  - Turbulence production in TKE equation
  - Anthropogenic heat source in potential temperature equation

- Observed (red contours) compared with COAMPS/LODI predictions of SF6 concentrations for IOP 10 release (4km resolution)
Time-Dependent Boundary Conditions are Critical for LES in Light and Variable Conditions

(a) IOP10 time-independent BCs (averaged sonic 9 data)
(b) IOP7 time-independent BCs (averaged sonic 9 data)
(c) IOP7 time-dependent BCs (actual sonic 9 data)
(d) IOP7 time-dependent BCs (City Center data)
Virtual Building Approach Provides an Order of Magnitude Speed-Up for Future Operations
Adaptive Dispersion Model (ADM) is NARAC’s ext Generation Urban CFD Capability

- Geometry-to-mesh capability
  - Efficient grid generation techniques (cut-cell and/or curvilinear overset grids)
  - Support of complex geometries (spaces (public facilities), subways, airplane bodies)
  - Adaptive mesh refinement
- Improved physics (radiation, surface heating, neutral density and dense gas physics, chemical kinetics)
- Advanced LES turbulence
- Coupling w/larger-scale models
  - Highly-resolved area nested in larger domain -> commeasurable scales at boundaries
  - Forcing by larger scale flows
  - Time-dependent forcing (critical for variable wind conditions and/or fast-evolving plumes)
Goal: Determine indoor exposures to guide evacuation / shelter-in-place

Infiltration rate \( Q[m^3/s] = ELA \sqrt{f_w^2 \cdot \Delta T + f_s^2 \cdot U^2} \) [m^3/s] (Sherman, 1980):
- Effective leakage area (ELA) [m^2]
- Pressure force from \( U \) and \( \Delta T \)
- LBNL Residential air leakage building database

Maximum indoor concentration << outdoor, but indoor levels higher longer-term

BAYESIAN COMPARISON (Bayes Theorem)
\[ P(\theta | d) = \frac{P(d | \theta) P(\theta)}{P(d)} \]

STOCHASTIC SAMPLING OF UNKNOWN PARAMETERS
- Prior proposal estimation (Informed - non-linear optimization)
- Markov Chain Monte Carlo
- Sequential Monte Carlo
- Hybrid and multi-resolution methods

Accepted configuration
Update likelihood until convergence to a posterior distribution

Rejected configuration

METEOROLOGY

DISPERSION MODELS
- Global and regional models: (2D, 3D, puff, particle)
- Urban models: (empirical puff, CFD)

Model predictions

OBSERVED DATA

ERROR QUANTIFICATION
Sequential Monte Carlo (SMC): Moving Vehicle Example Generated Using Synthetic Data

- Moving source in 10x10km domain
  - Variable speed and direction of source indicated by arrows
  - Vehicle remains stationary for a brief time at location near grid center
  - Synthetic truth generated by using 30s puffs at 120 equally spaced locations along line of movement

- SMC data provided for square sensor array
  - Synthetic measurement noise and model error introduced
    - Mean=C, SD = 1e-10 + 0.1*C

- Prior/proposal distribution based on mixture of previous location and velocity

- SMC provides order of magnitude improvement in computational performance relative to classic Markov Chain Monte Carlo

- Tests against real-world data underway
SMC Determination of Moving Source Location From One Hour of Ten-Minute Averaged Data
SMC Simultaneous Determines Release Rate

Based on Data in the 0–10min Interval

Based on Data in the 0–20min Interval

Based on Data in the 0–30min Interval

Based on Data in the 0–40min Interval

Based on Data in the 0–50min Interval

Based on Data in the 0–60min Interval
Event Reconstruction Must Address Problems of Increasing Complexity and Uncertainty

- Simple model / synthetic data
- Efficient treatment of time dependent problems
- Meteorological uncertainty
- Meteorological complexity
- Data uncertainty
- Model uncertainty
- Multiple, complex sources
- Tracer data and operational models
- Disparate data types (remote sensing, imagery, qualitative, etc.)
- Complex models (regional-urban)
- Multi-resolution applications
NARAC is a Key Component of Detection, Warning, and Incident Characterization Systems

- DHS/HHS BioWatch environmental monitoring
- DHS Biological Warning and Incident Characterization System (BWIC)
- DOT/WMATA PROTECT subway chemical detection system
- DOE Nuclear Incident Response Team aerial and ground measurements

Analysis for environ. monitoring system

PROTECT subway crisis response system outdoor venting
NARAC Science Team and Collaborators Contributing to This Effort

- **Event Reconstruction:** William Hanley, Gardar Johannesson, Branko Kosovic, Shawn Larsen, Gwen Loosmore, Julie Lundquist, Arthur Mirin, John Nitao, Radu Serban, Kathy Dyer (LLNL)

- **Indoor Exposures/Building Infiltration**
  - Ashok Gadgil, Wan Yu Chan, Phillip Price (LBNL) and William Nazaroff (UC Berkeley)
  - Hoyt Walker and Gwen Loosmore (LLNL)

- **Rapid Response Models**
  - ALOHA/CAMEO: Mark Miller et al. (NOAA)
  - UDM Integration: Ian Griffiths et al. (Dstl, MOD, U.K.)

- **Subway System (PROTECT)**
  - Tony Policastro et al. (ANL)
  - Bill Eme, Joe Guensche, Connee Foster, Bob Shectman, Joe Tull (LLNL)

- **Urban Field Studies (+ other institutions)**
  - Jerry Allwine et al. (PNNL)
  - Martin Leach, Julie Lundquist, Joe Shinn, Frank Gouveia, Garrett Keating (LLNL)

- **Urban CFD models:** Stevens Chan, Branko Kosovic, Tom Humphreys, Bob Lee, Andy Wissink (LLNL)

- **Urban NWP models:** Martin Leach and Steve Chin (LLNL), Michael Brown (LANL)