Building-Resolved Urban Dispersion Models Evaluated with MID05 Data

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Background

The Urban Dispersion Program (UDP) was a collaborative research program involving a number of national laboratories, federal agencies, and universities. Research activities under this program were conducted from 2004 through 2007, and comprised several major elements:

- Limited-scale dispersion study in the vicinity of Madison Square Garden in New York City (MSG05)
- Large-scale dispersion study in Midtown Manhattan in New York City (MID05)
- Permanent meteorological network and web-accessible observations for emergency response
- Modeling of MSG05 and MID05 cases to improve urban dispersion modeling

Overview

It is vitally important that models are evaluated against field data to identify the strengths and weaknesses of the models. This assessment of the model output guides improvements to modeling systems and informs users on the limitations of the model output.

In this study, six building-resolved urban dispersion modeling systems were evaluated using data from the MID05 field experiment. The models that were evaluated account for urban geometries when calculating wind and concentration fields, and are therefore useful tools for emergency planning and response and long-term recovery.

The primary objective of this study was to evaluate the performance of state-of-the-science building-resolved models that are available for application in addressing national homeland security needs. A secondary objective was to identify critical technical gaps in urban dispersion modeling and to recommend future research needed to fill these gaps. The concept for this evaluation study was to examine the effectiveness of the modeling system as a whole in simulating the cases that were presented. Staff at Pacific Northwest National Laboratory (PNNL) served as the model evaluation team. Five modeling groups used unique computational fluid dynamic (CFD) codes, while one group used a semi-empirical building resolved model.

Table 1. Model Evaluation Study Participants

Participant	Model	Turbulence Model
CFD Research Corporation (CFDRC)	CFD-Urban	RANS k-ε with "ABL" coefficients
GexCon	FLACS	RANS standard k-ε
National Oceanic and Atmospheric Administration / Environmental Protection Agency (NOAA/EPA)	EPA-Fluent	RANS realizable k-ε
Lawrence Livermore National Laboratory (LLNL)	FEM3MP	RANS similarity closure
Navy Research Laboratory (NRL)	FAST3D-CT	MILES (implicit LES)
Los Alamos National Laboratory (LANL)	QUIC	Local gradient & non-local mixing

Figure 1. The horizontal bounds of the model domains for each of the model participants. The grid of red and blue markers in the center represent locations of 30-min average tracer measurements..

The model evaluation team, in cooperation with the modeling groups, developed a model evaluation plan.

- Simulate four tracer experiments from the MID05 study
  - Tracer experiment consisted of a 30-minute long tracer release from up to 3 locations.
  - Each simulation was a 2-hr period starting at the beginning of the tracer release.
- The model evaluation team provided necessary data to the modeling groups including:
  - Building geometry
  - Meteorological measurements (starting with the hour preceding the simulation period)
  - Tracer release rate and location

Model Evaluation Methods

Two setup cases and two blind cases were simulated by the modeling groups. Setup cases were designed to allow modelers to optimize their models for the modeled conditions. Blind cases then challenged the model configurations.

Setup Cases
- Tracer and wide variety of met data provided (street-level met, rooftop met, rooftop sodar, radar wind profiler at multiple avg. times)

Blind Cases
- No tracer data and limited met data provided (rooftop met, rooftop sodar, radar wind profiler - only data available for emergency response in NYC)

The modeling teams were asked to provide concentrations at positions that coincided with sampling instruments as well as tracer concentrations and velocity vectors on regular grids of horizontal and vertical resolution that were prescribed by the model evaluation team.

Figure 2. Examples of the horizontal bounds of the coarse- and fine-resolution output grids requested of each modeling group.

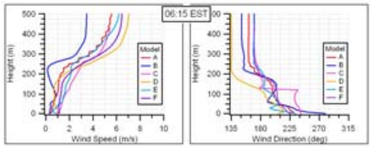

Figure 3. Vertical profiles of predicted wind speed and wind direction for the half-hour concurrent with a tracer release period. Profile location is center of 6th Ave between 50th and 51st St near the center MID05 release location.

Statistical Evaluation
- BOOT code (Chang and Hanna, 2005)
  - Fractional bias, normalized root mean square error, geometric mean, FAC2, FAC10, etc.
- Aggregate model performance score

Graphical Evaluation
- Horizontal contour plots of observed and predicted tracer concentration at 3m AGL
- Horizontal dot plots of false positive, false negative, and common tracer concentrations
- Scatter plots of predicted vs. observed tracer concentrations
- Vertical profiles of modeled WS and WD near the center of the study domain
- Vertical contour plots of predicted tracer concentrations (for a selected case)

Results

A rigorous evaluation of the model performance was conducted, comparing concentrations paired in time and space. Hour1 was generally simulated well, while the Hour2 simulation performance was not as strong.

- Concentrations differ due to differences in approach flow conditions rather than differences in fundamental model formulations
- No appreciable differences in the model performance between the setup and blind cases

The best Hour1 model performance features:
- Predicted plume overlapped approximately 70% of the observed plume (Avg. - 50%)
- 10% of predicted plume concentrations were false negative values (Avg. - 20%)
  - Include a conservative band around predicted plume for emergency response
- 90% of predicted concentrations were within a factor of 10 of observations (Avg. - 60%)
- 40% of predicted concentrations were within a factor of 2 of observations (Avg. - 20%)

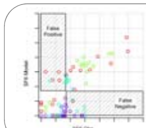

Figure 4. Sample scatter plot to evaluate modeled tracer concentrations at receptor points. Colors represent 30-min time periods. Period 1 = Red, 2 = Green, 3 = Blue, 4 = Purple

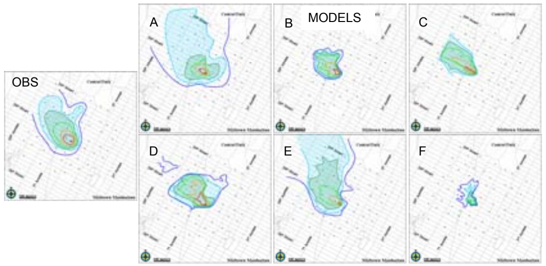

Figure 5. Near-surface tracer plume from the six models compared with measurements. Half-hour average concentrations coincident with a tracer release period (same as Figure 6). Wind speeds were moderate and the wind speed was steady from the south.

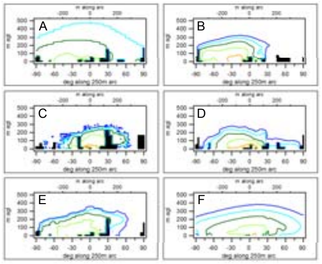

Figure 6. Vertical mixing of tracer on a half-cylinder 250m from the source. (Shown as the smallest radius arc in the top panel.) Half-hour average concentrations coincident with a tracer release period (same as Figure 5).

Research Gaps

Based on results of this study as well as input from the modeling groups, several fundamental research gaps in urban dispersion modeling were identified:

- *Lateral boundary conditions*
  Even with extensive meteorological networks deployed for field campaigns, it is often not apparent how to assign proper boundary conditions, especially when winds are unsteady. This problem is magnified in real-life scenarios with sparse meteorological data.
- *Turbulence*
  The generation and maintenance of turbulence is still not handled well in urban dispersion models. Although various "fixes" exist, sound theoretical basis is lacking.
- *Thermal effects*
  Buoyancy effects driven by differential heating in urban street canyons is expected to become more important as synoptic winds become light. Models do not typically address this process, and data needed to evaluate this feature in models is scarce.
- *Urban geometry*
  Although geometric descriptions of buildings and terrain are available in a variety of formats, not all models work with these formats easily. For the timely and effective application of building-resolved models, a common format and/or conversion tools are necessary.

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