A Simplified CFD Approach for Modeling Urban Dispersion

S. Chan, T. Humphreys, and R. Lee
Lawrence Livermore National Laboratory
Livermore, CA

Symposium on Planning, Nowcasting, and Forecasting
in the Urban Zone
2004 AMS Annual Meeting
Seattle, WA
January 11-15, 2004

UCRL-PRES-200976
Work is performed under the auspices of the U.S Department of Energy by the Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

Objective and Approach

- To develop a fast, simplified CFD model suitable for emergency response applications
- Model targeted buildings explicitly with fine grid resolution and others as drag elements (or virtual buildings) with coarser grid resolution
- Some advantages
  - Greatly reduced computer time and storage
  - Less effort needed in grid generation
  - Ability to compute on much larger domains to provide improved parameterization, such as form drag, for use in larger scale models

Governing Equations

$$\frac{\partial}{\partial t}u_i + u_j\frac{\partial u_i}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left(-\overline{u_i' u_j'}\right) - C_d\left|u\right|u_i$$

$$\frac{\partial}{\partial x_j}u_j = 0$$

$$\frac{\partial C}{\partial t} + u_j\frac{\partial C}{\partial x_j} = \frac{\partial}{\partial x_j}\left(-\overline{u_j' c'}\right)$$

Plus appropriate turbulence model, such as Smagorinsky SGS turbulence model (1963) with wall damping function by Piomelli, et al. (1987)

Dispersion Simulation around a Cube: Solid vs. Virtual Building Approach

Atmospheric and Source Conditions:

Mean velocity: **0.6 m/s at z = H**

Friction velocity: **0.0356 m/s**

Neutral stability

Continuous source at 2H in front of the cube

Grid and Boundary Conditions:

Domain size (H): **8 x 6 x 2 (graded mesh)**

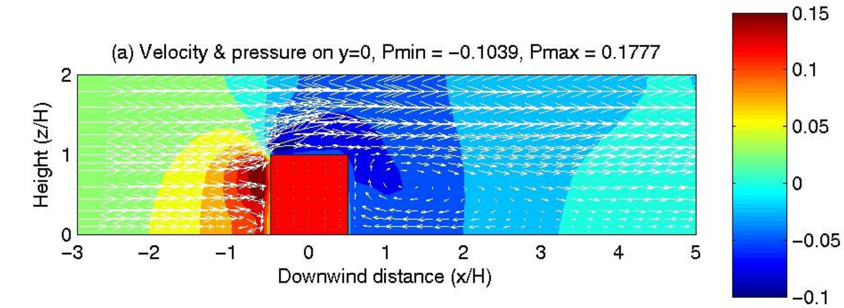
No. of Grid points: **43 x 33 x 15 = 21,285**

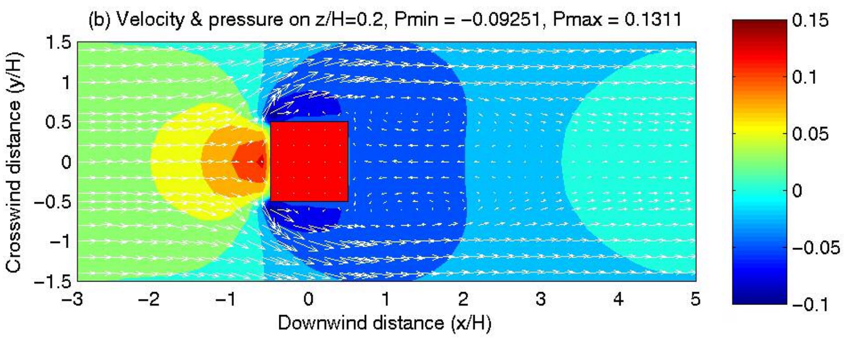
Boundary conditions:

- **No slip on ground surface & no penetration on top boundary**
- **Logarithmic profile on the left inlet plane**

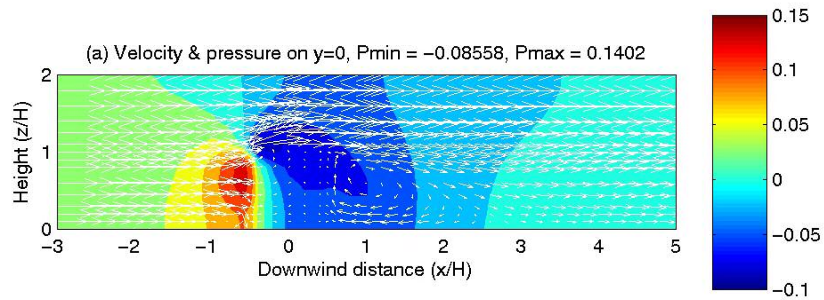
Comparison of Predicted Velocity and Pressure on Two Planes of a Cubical Building

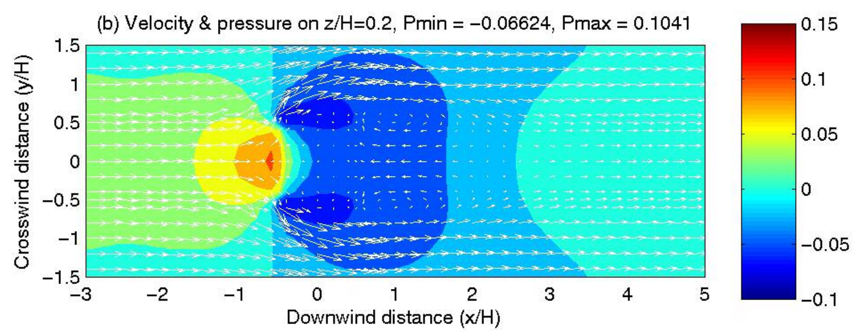
(a) Solid building





(b) Virtual building

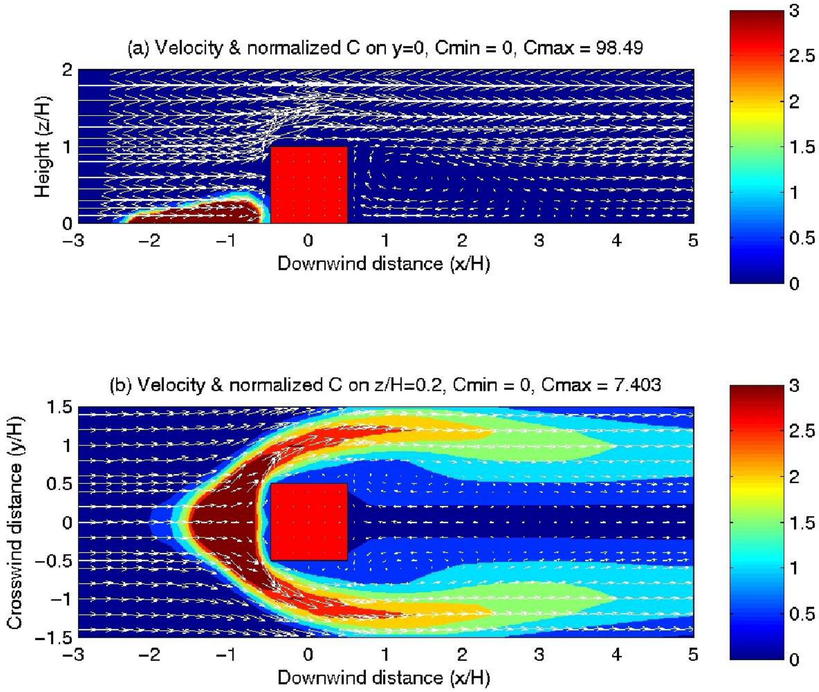




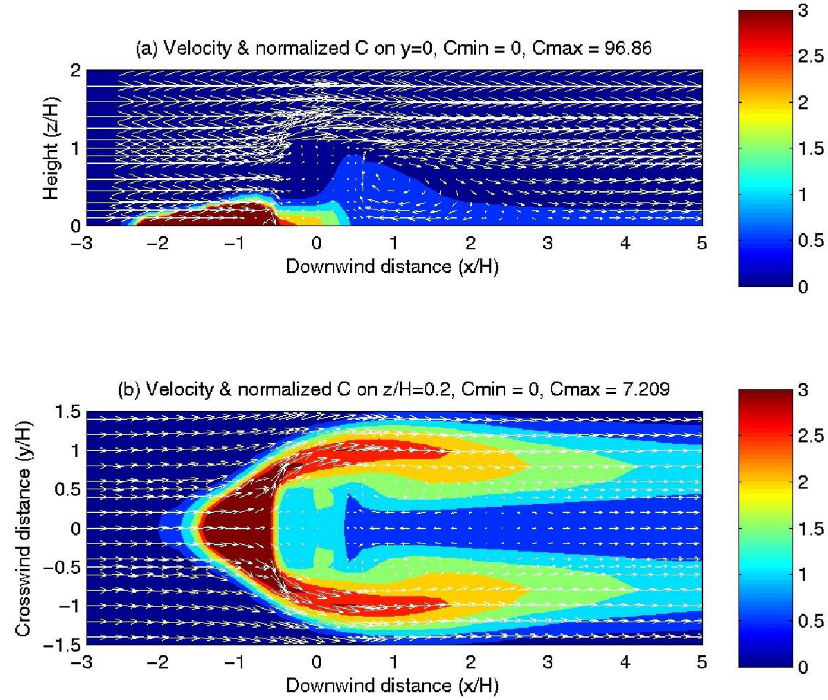
Good agreement is seen regarding the main features of the flow field, including the stagnation zone, flow separations, and the large wake region. Pressure fields also compare reasonably well.

Comparison of Predicted Velocity & Concentration Patterns on Two Planes of a Cubical Building

(a) Solid building



(b) Virtual building



The virtual building approach reproduces essentially the same horseshoe-shape plume horizontally and very similar plume shape in the vertical except a small amount of tracer seeping through the virtual building near the ground surface

Dispersion Simulations of a Hypothetical Tracer Gas Release in Downtown Salt Lake City

Atmospheric and Source Conditions:

Mean velocity: 3 m/s at z = 10 m

Friction velocity: 0.232 m/s

Source: 1 kg/s (of tracer released on ground for 10 min)

Neutral stability

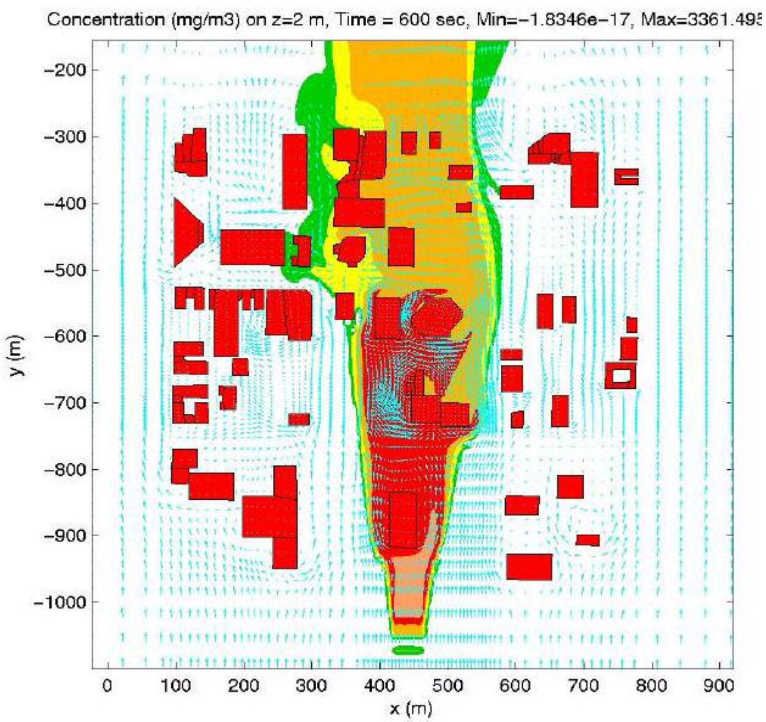
Simulations:	Solid Buildings	Virtual Buildings
Domain size (m):	943 x 945 x 210	1000 x 1000 x 100
Grid points:	229 x 227 x 35 (~1.82 M)	101 x 101 x 20 (~204K)

Boundary conditions:

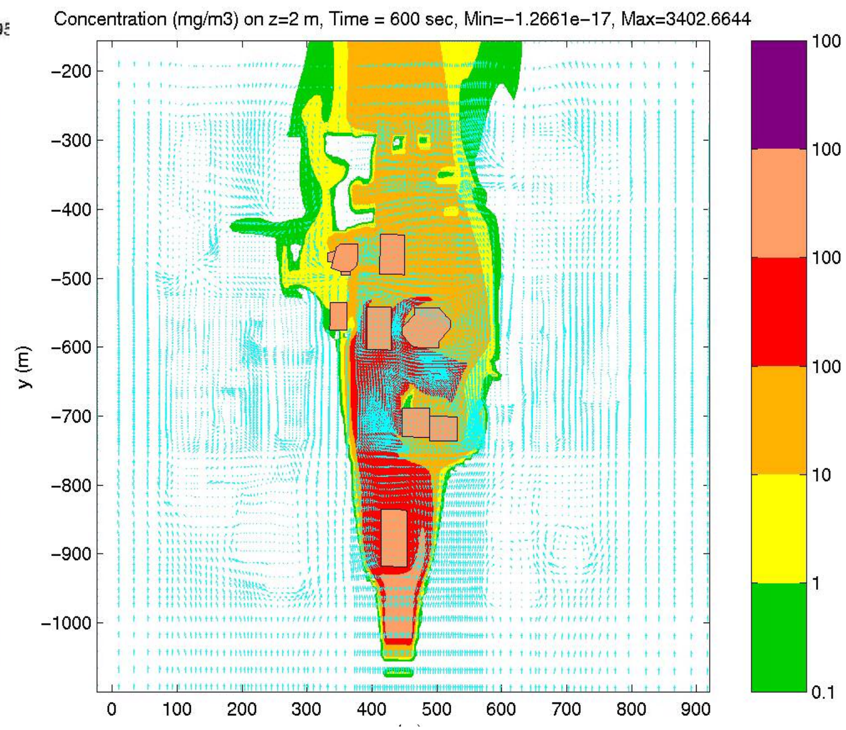
- No slip on ground surface & no penetration on top boundary
- Logarithmic velocity profile on south inlet plan

Comparison of Velocity/Concentration Patterns from Two Different Treatments of Buildings

(a) Solid buildings



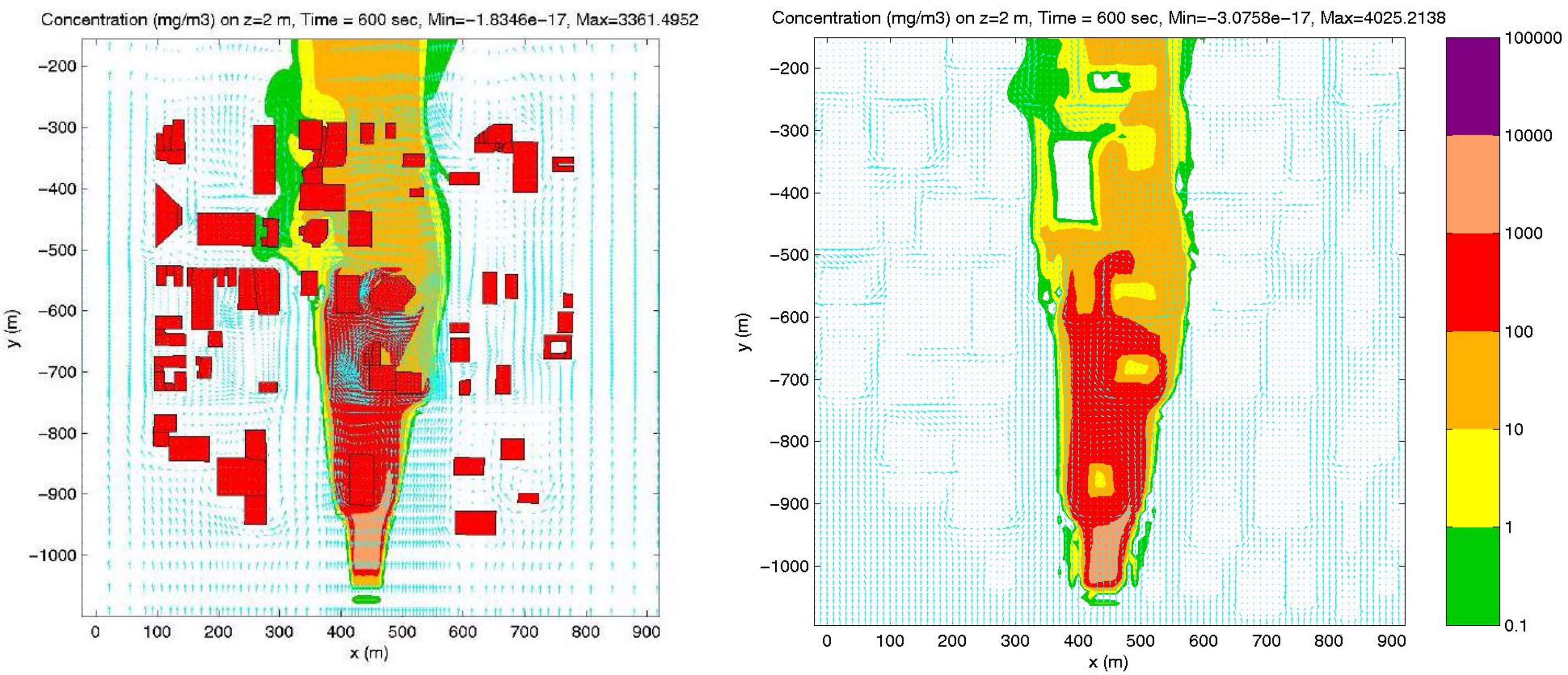
(b) Solid & virtual buildings



Non-targeted buildings are modeled as drag elements (or virtual buildings) without seriously compromising the overall solution accuracy

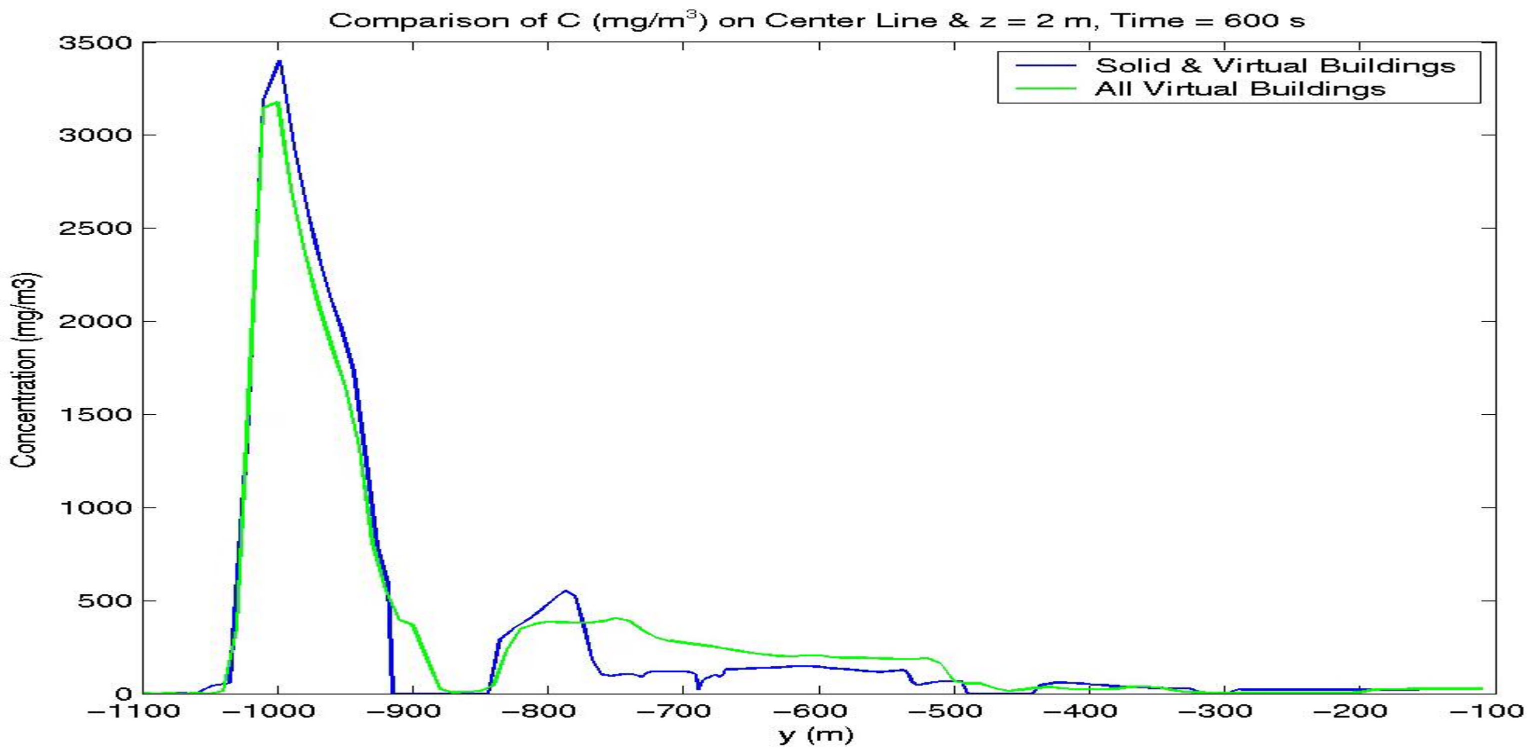
Comparison of Velocity/Concentration Patterns from Solid and Virtual Building Approaches

(a) Solid buildings **(b) Virtual buildings**



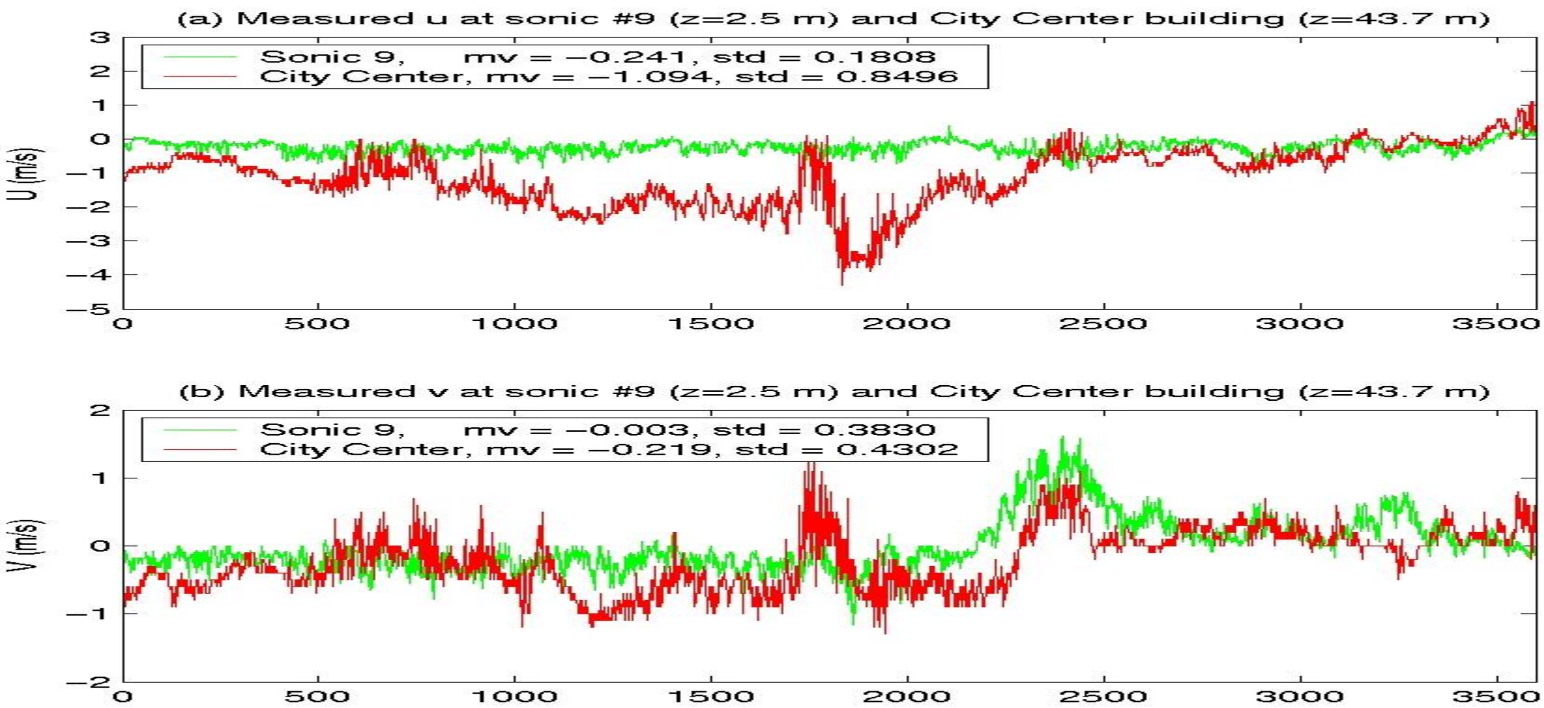
Modeling the buildings as drag elements (or virtual buildings) leads to an order-of-magnitude savings in computer storage and cost

Comparison of Predicted Concentrations along Centerline in the Downwind Direction



Despite a slight under-prediction of certain peak values, the all virtual-building approach has yielded results similar to those from the more rigorous approach at significantly reduced cost.

Light and Variable Winds Observed During IOP 7 of Urban 2000 Experiment



Above data were used to construct steady and time-dependent boundary conditions, with logarithmic variations in the vertical direction, in the LES simulations

Observed Data vs. Predicted Concentration Patterns (for t=50-55 min) Using Various BCs

LES Simulations of IOP7 Release 1

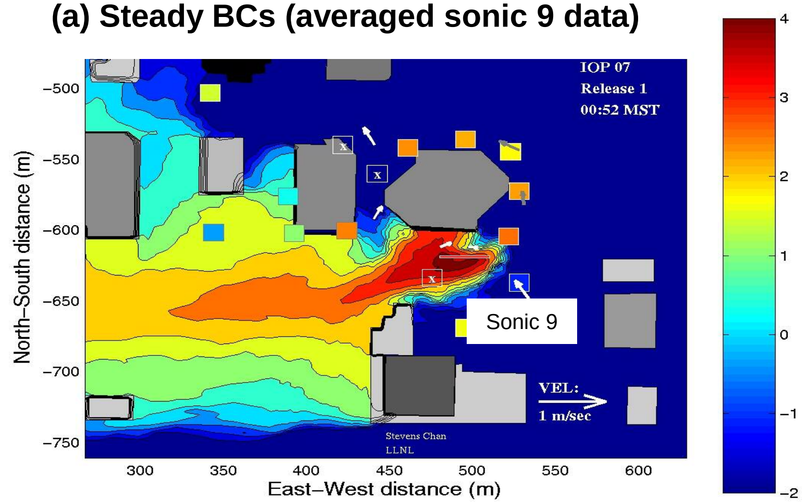
Winds: light and highly variable

Source: SF_6 released near ground at a rate of 1 g/s for 1 hour

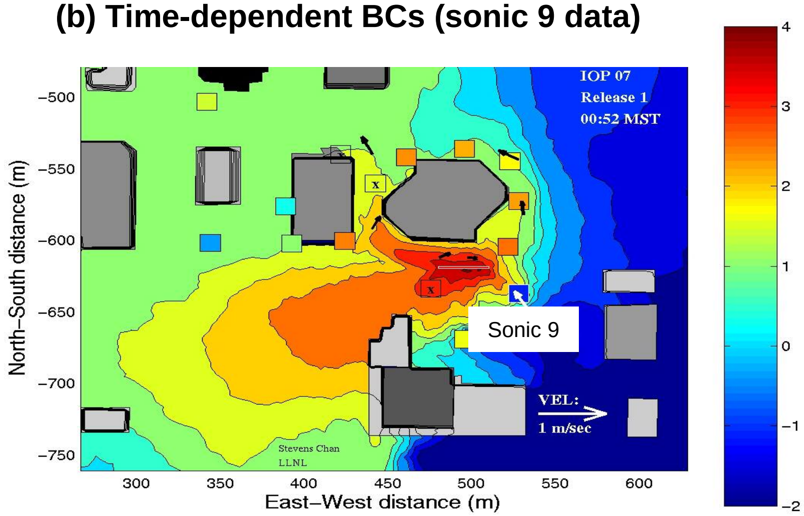
Domain: 943 x 945 x 210 m (graded mesh)

Grid points: 229 x 227 x 35 (~1.82M)

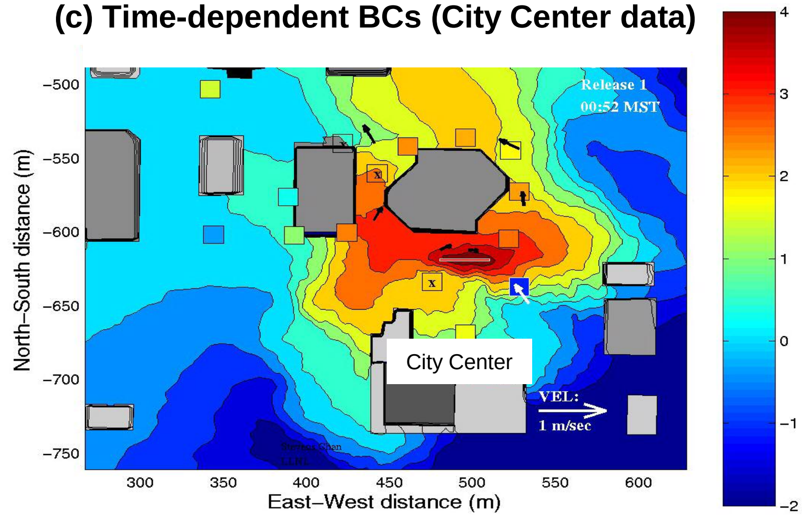
(a) Steady BCs (averaged sonic 9 data)



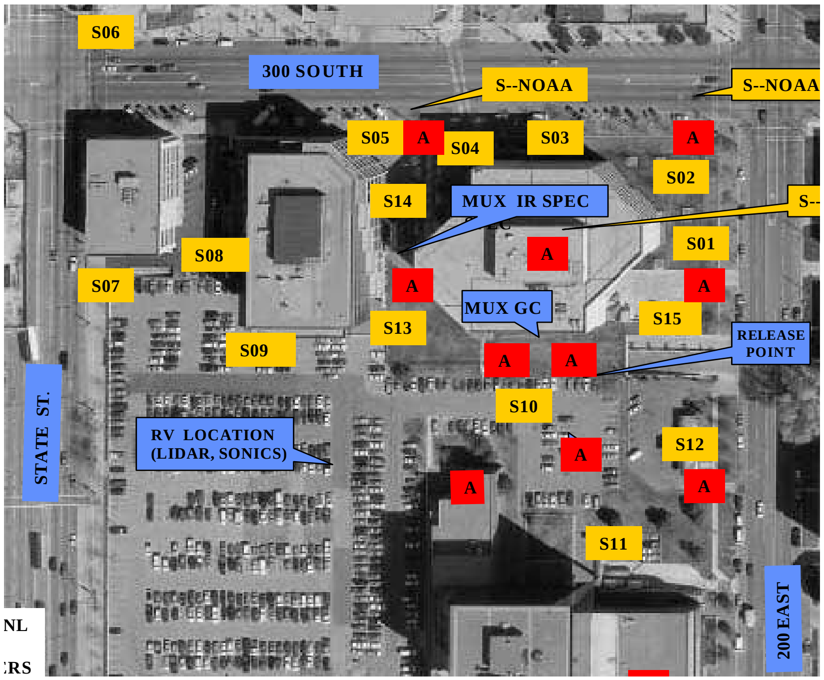
(b) Time-dependent BCs (sonic 9 data)



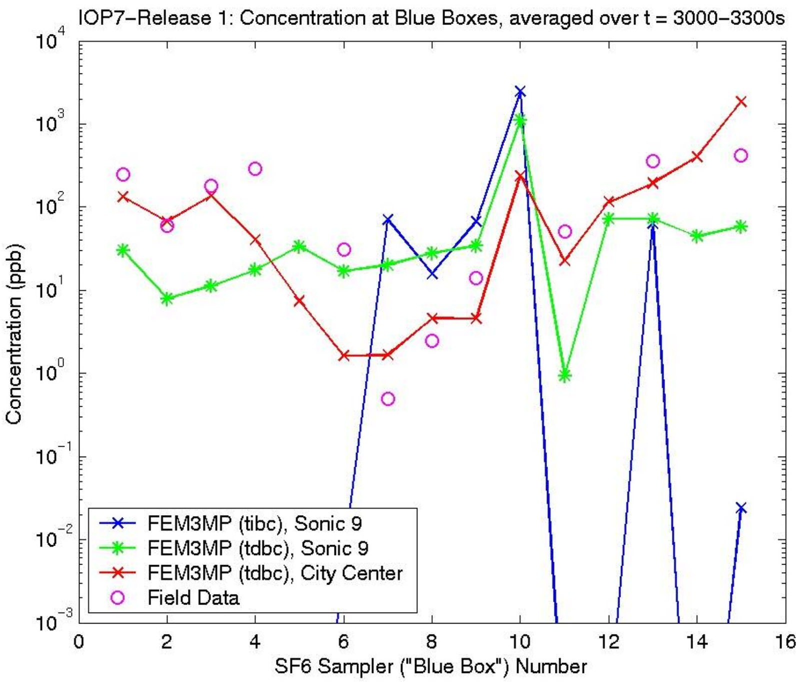
(c) Time-dependent BCs (City Center data)



Comparison of Time-averaged Concentrations (for t=50-55 min) at SF_6 Sampler Locations



Instrumentation in the source vicinity of the Urban 2000 experiment in Salt Lake City. Yellow boxes indicate SF_6 sampler locations



Comparison of predicted concentrations (with various boundary conditions) vs. observed data at SF_6 sampler locations for time = 50-55 min

Conclusions

- A simplified CFD approach for modeling urban dispersion has been presented and early test results indicate the approach is highly cost-effective.
- Our simulation for a nighttime SF_6 release in the Salt Lake City downtown area demonstrates clearly the important role time-dependent forcing plays in such dispersion scenarios.
- For accurate dispersion predictions under light and variable winds, both temporal and spatial data to adequately describe the time-dependent forcing are needed.