8^{th} Conference on Air Quality Modeling – A&WMA AB3 Comments on Nonstandard Modeling Approaches

By

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With contributions on CFD Issues from Alan Huber*

Air & Waste Management Association

Air Pollution Meteorology (AB-3) Committee

Comment Area
Refined models to be considered for complex near-field situations

- Computational Fluid Dynamics (CFD) modeling
- Wind-tunnel modeling

Advantages and Limitations of CFD and Wind-tunnel Modeling

- These models supplement routine models such as AERMOD for very complicated situations with complex interactions between the source and nearby flow obstacles.
- They can also be used for unusual source characteristics.
- They are highly site-specific.
- They cannot be used for all meteorological conditions, or for long simulation periods.
- They can be used to parameterize routine models.

Why Use CFD & Wind-tunnel Modeling in Air Quality Studies?

- Simulations can model where flow around buildings affect pollution transport and dispersion.
- Current routinely applied air quality models do not include physical models of specific buildings.
- Simulations can directly be used to understand details of a specific case study.
- Simulations can be used to support the development and use of better-simplified algorithms for general application.

CFD Modeling
(Computational Fluid Dynamics)

What is it?

- <u>Computational</u>
  (having to do with mathematics & computation)
- *<u>Fluid Dynamics</u>*
  (the dynamics of things that flow)

CFD software solves fundamental physics equations.
CFD software is characterized by the physical models and the ability of the software to closely match the true geometry of the physical objects and to simulate physical processes.

CFD Software

- Uses a study domain divided into discrete volumes/elements. Key flow features must be sufficiently resolved.
- Solves equations for mass, momentum, energy, and scalars such as a pollutant.
- Simulates physical processes (heating, particle motion/deposition, chemistry).
- Provides both steady-state and time-varying solutions. Many practical problems can be assumed steady-state (follow the hour by hour set up).

Making CFD Application Routine

- Computational resources. Today, industrial complexes can be practically modeled by most workstations, while complex urban areas can only be modeled by the largest systems.
- CFD software involves many lines of interacting code. Full range of applications needs to be completely tested to develop quality assured code .
- CFD, while solving fundamental physics equations, requires a model of turbulence for closure. Also, there are boundary conditions requiring some approximations.
- Develop best-practice methods. CFD codes have many options.
- Develop user-friendly interfaces for general application. Air quality modelers should be able to run routine applications.

Examples of CFD Simulations: See Following Slides

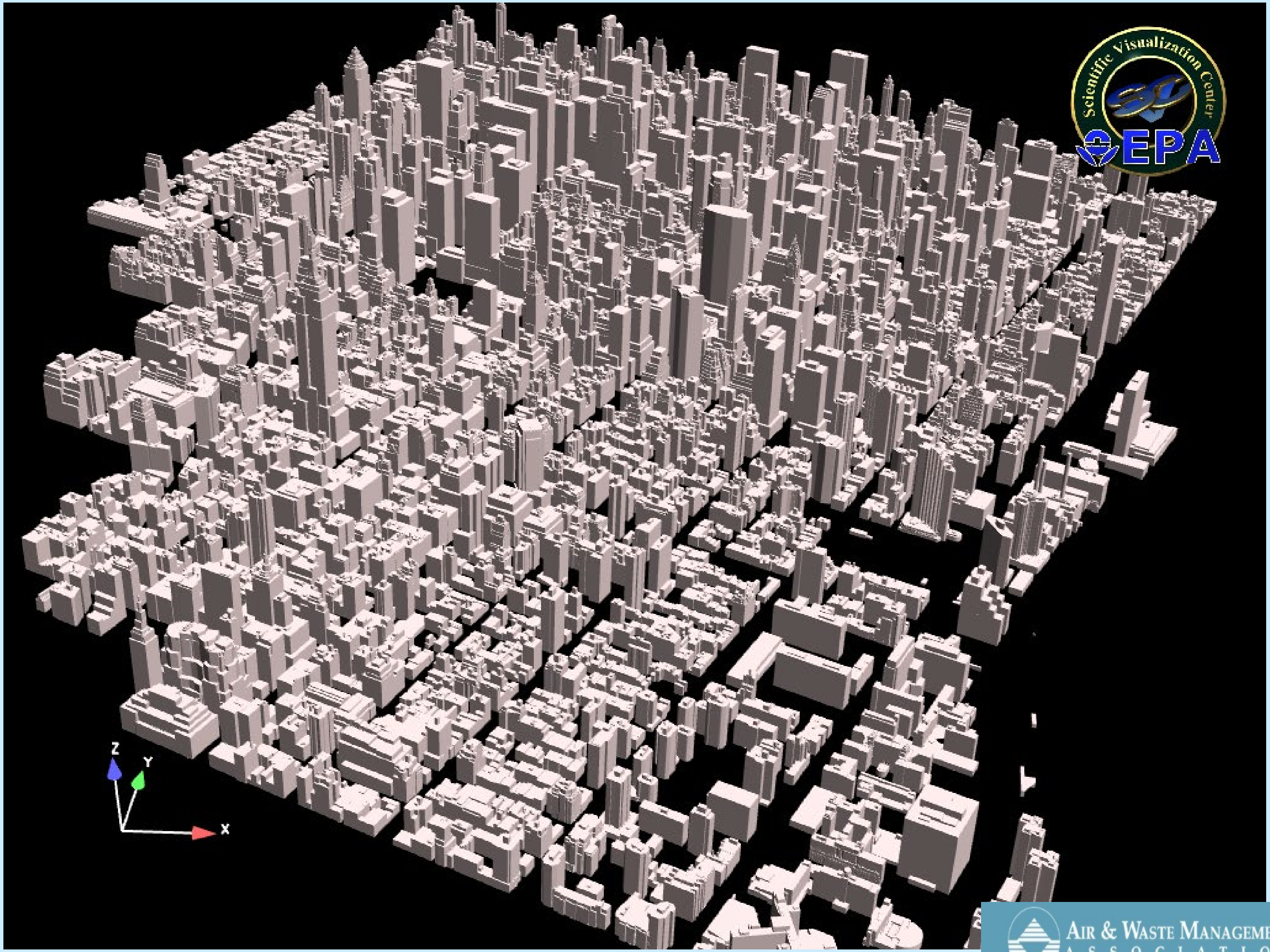
- **Simulation of point source plume without building influences**

- **Simulation of velocity with building influences .**

- **Simulation of concentrations of point source within a 3-Dimensional building canyons**

- **Simulations in urban environments.**
  (not possible using present regulatory models)

Building Geometry is Available for Many Urban Areas and can be Routinely Developed for any Industrial Site



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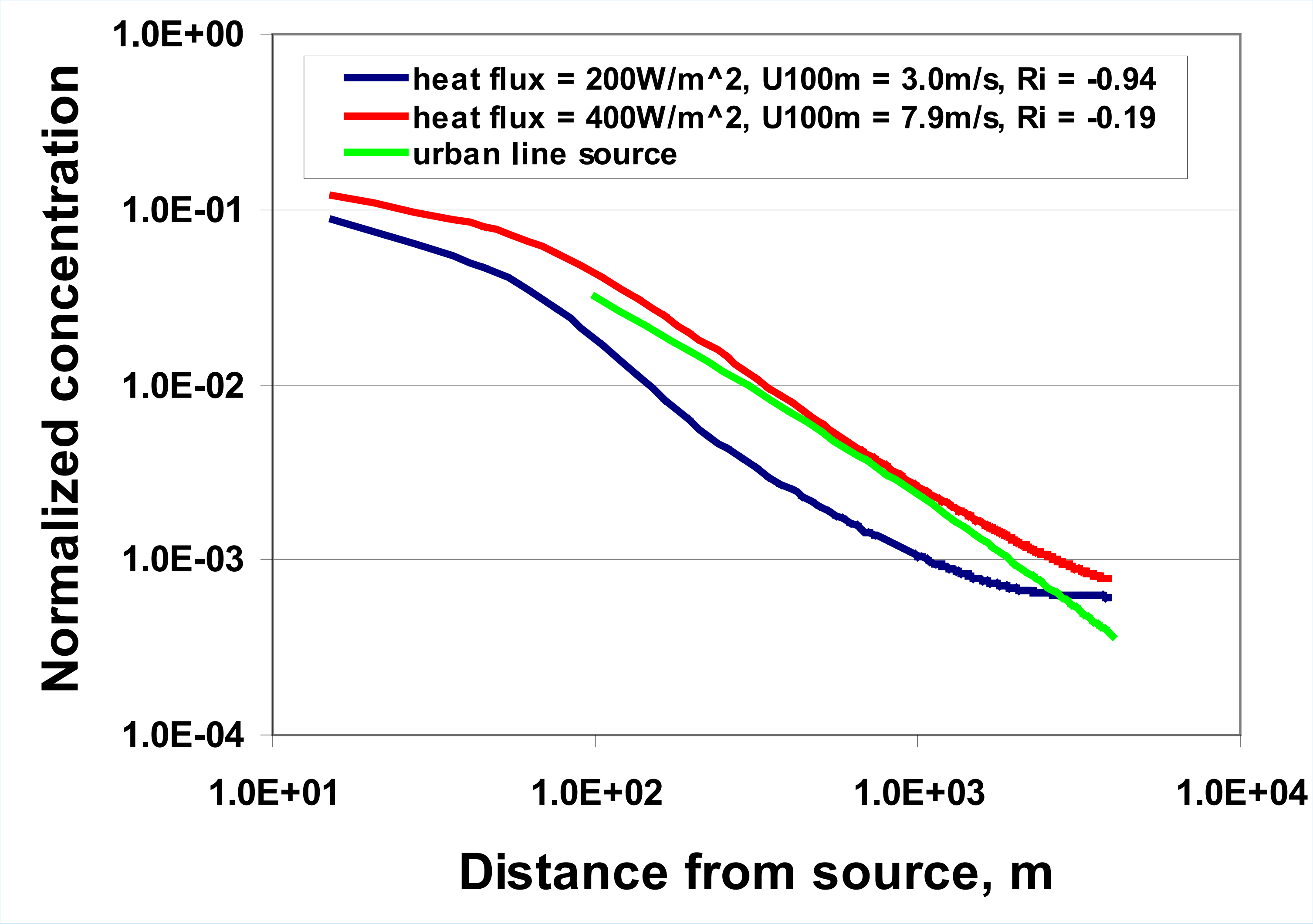
Example: Simulation of Point Source Plume without Building Influences

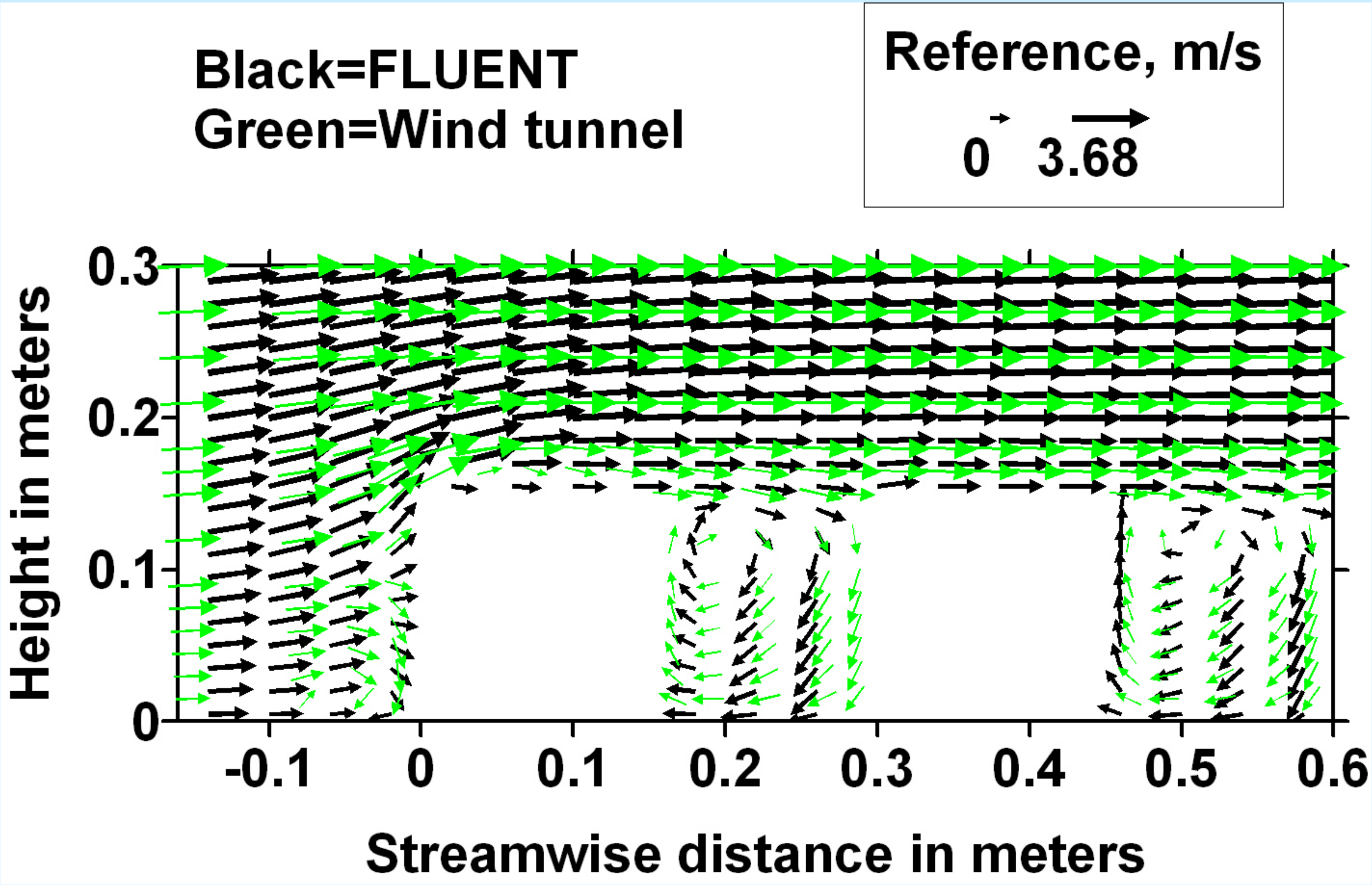
Comparison of Normalized CFD Model Concentrations (Cu/q, m^{-2}) with Urban P-G Line Source without Building Influences



Example: Simulation of Velocity with Building Influences.

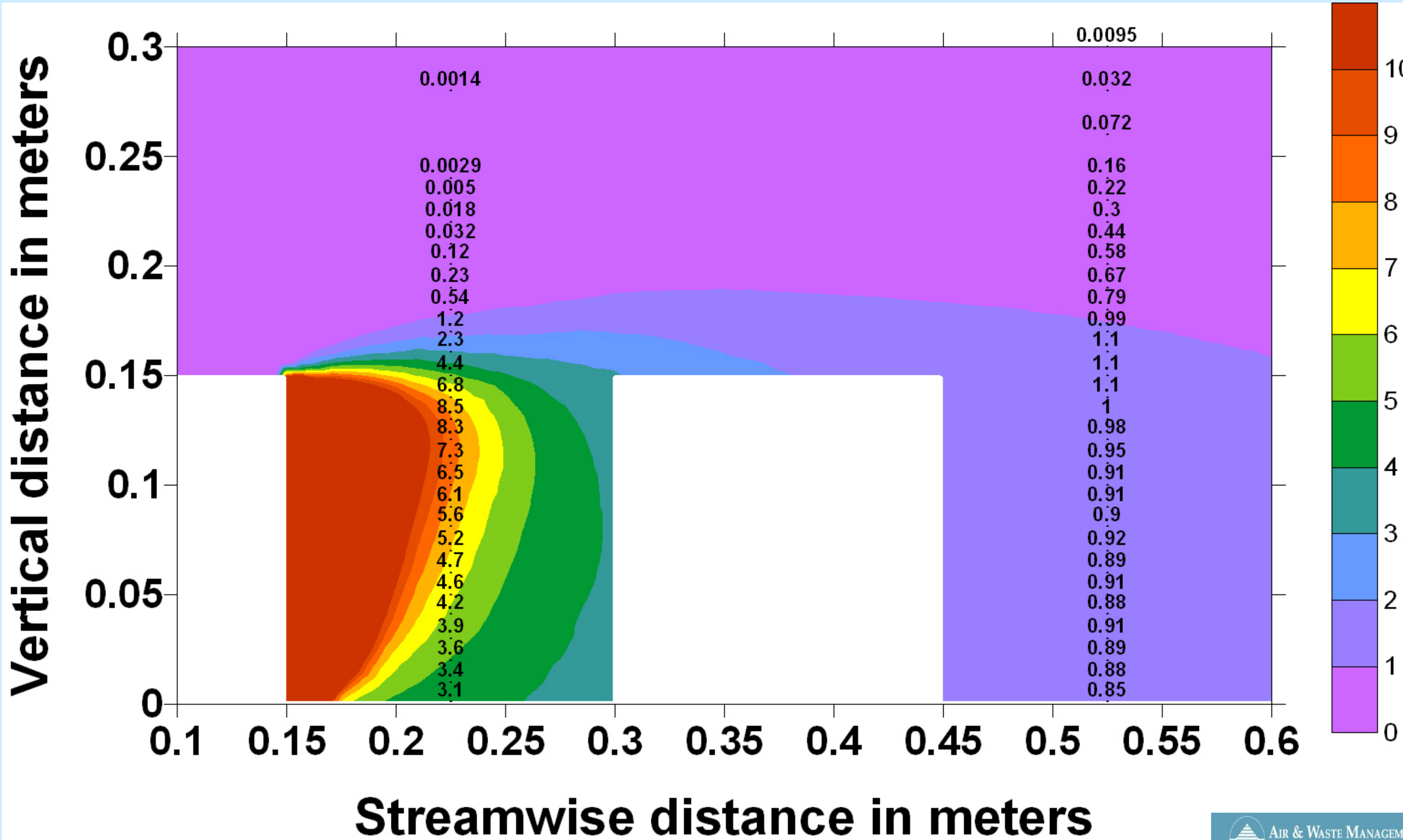
Vectors on building mid-plane for leading rows of cube-shaped buildings.

The CFD model (FLUENT) is compared with measurements (Wind Tunnel)

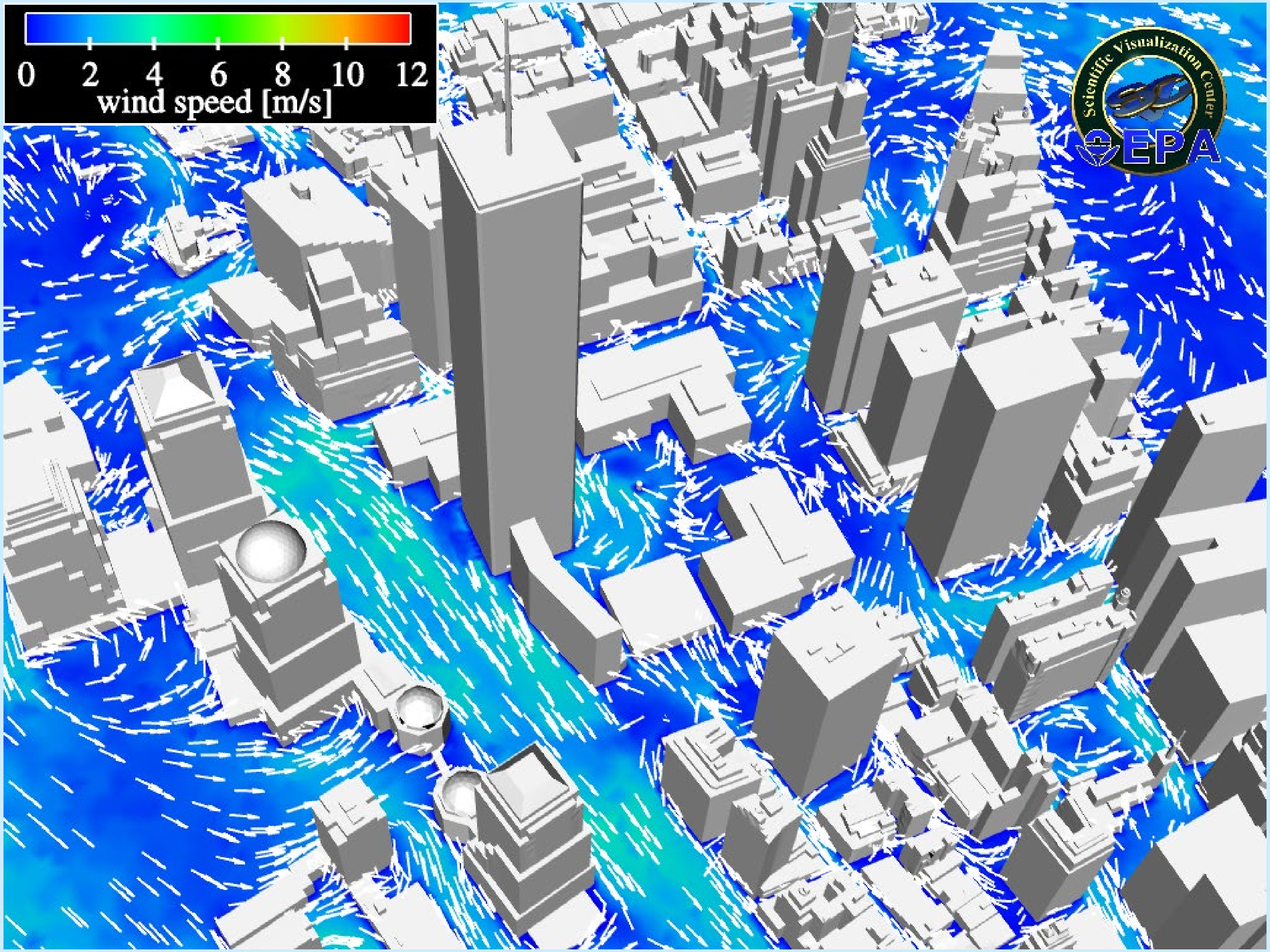


Example: Simulation of Concentrations of point source within 3-Dimensional Building Canyons

CFD color contour is compared with
Wind Tunnel Data Numbers (Courtesy Dr. Steven Perry, EPA).
Non-dimensional concentrations = Cuh^2/q



Example: Surface Winds from CFD Simulation. (not possible using present regulatory models)



Wind-tunnel Modeling
From EPA Fluid Modeling Guideline, 1981

- Basic equations are solved by simulating the flow at a reduced scale, then measuring the desired quantity
- An analog computer with near infinitesimal resolution and near infinite memory.
- A mathematical model should be able to simulate the results of an idealized laboratory experiment.

Wind Tunnel Modeling Background

- Wind and turbulence profiles consistent with underlying surface roughness.
- Dispersion matches boundary layer theory and consistent with surface roughness.
- Measured concentrations are steady-state averages – same as Gaussian plume models. No time scaling needed for steady winds.
- Best simulations for neutral stability.

Wind-tunnel modeling

- EPA Fluid Modeling Guideline on Methods for Modeling Dispersion
- ASCE Standard 7-02 for methods on using wind tunnel modeling for wind loading on structures
- Applications
  - GEP stack height determinations
  - Equivalent building dimensions for AERMOD input
  - Wake flow in complex terrain
  - Flow near complex buildings and urban areas

Good Engineering Practice stack height determinations
Wind tunnel modeling used for complex sites

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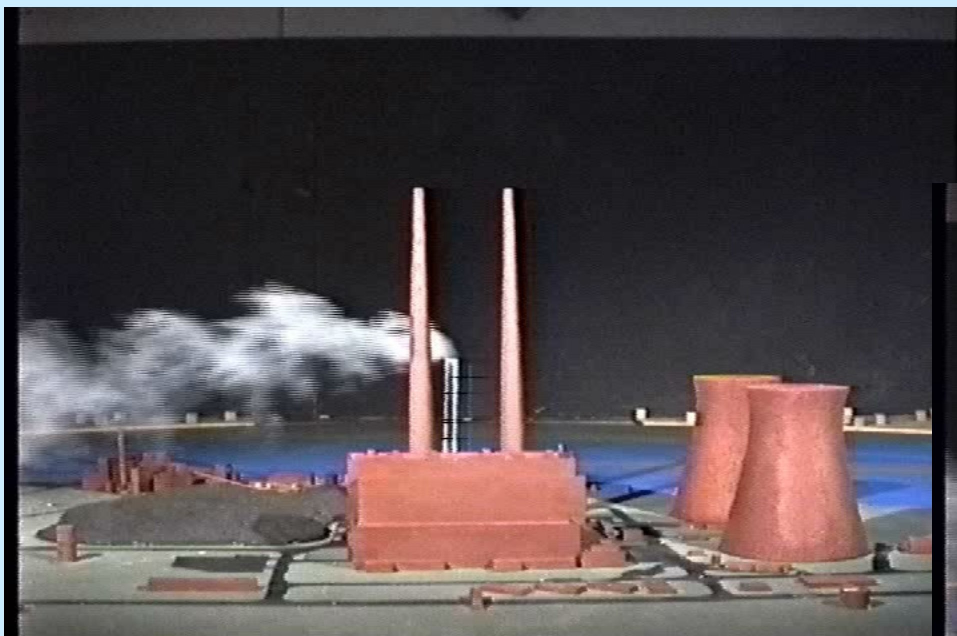
Equivalent Building Dimensions

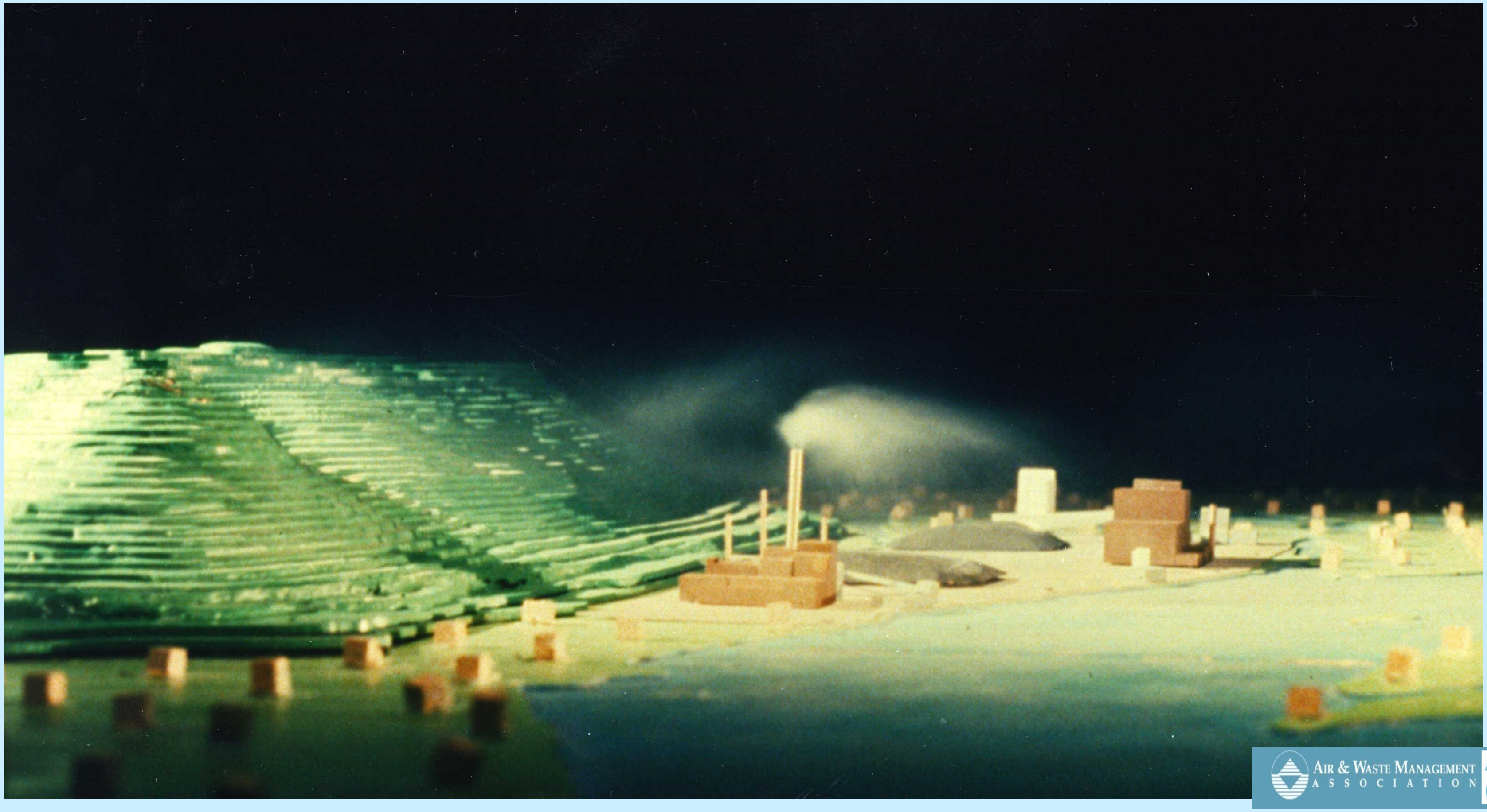
Wind tunnel modeling has been used to provide building dimension inputs that make the EPA models nearly site specific. Should this method be more widely used and encouraged?



Terrain wakes

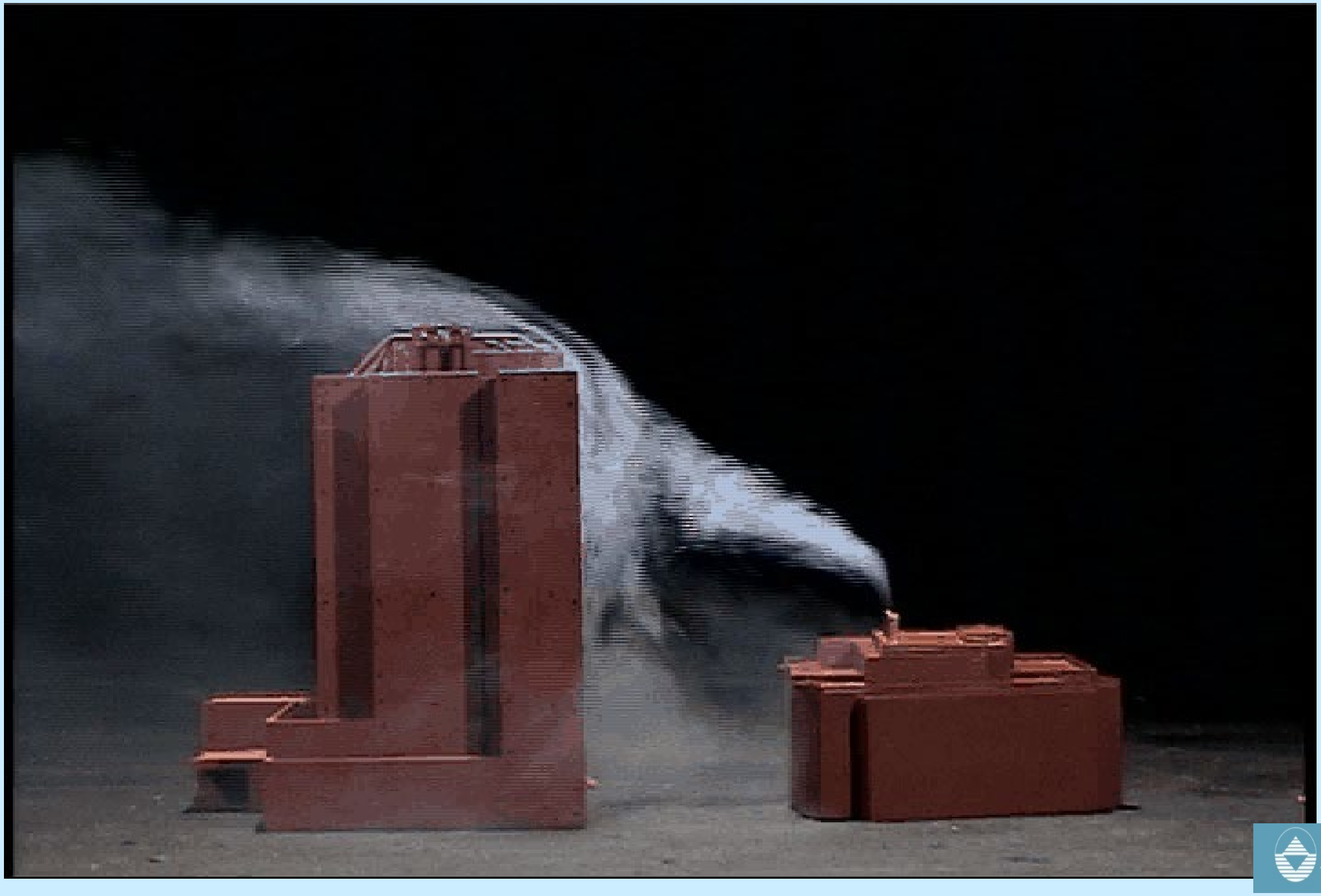
Current EPA models neglect this effect.

Should wind tunnel estimates be used for assessing compliance?



Flow around complex buildings

Use wind tunnel estimates directly for receptors on and around a building?



Flow around complex buildings

Use wind tunnel estimates directly for receptors in a building cavity?

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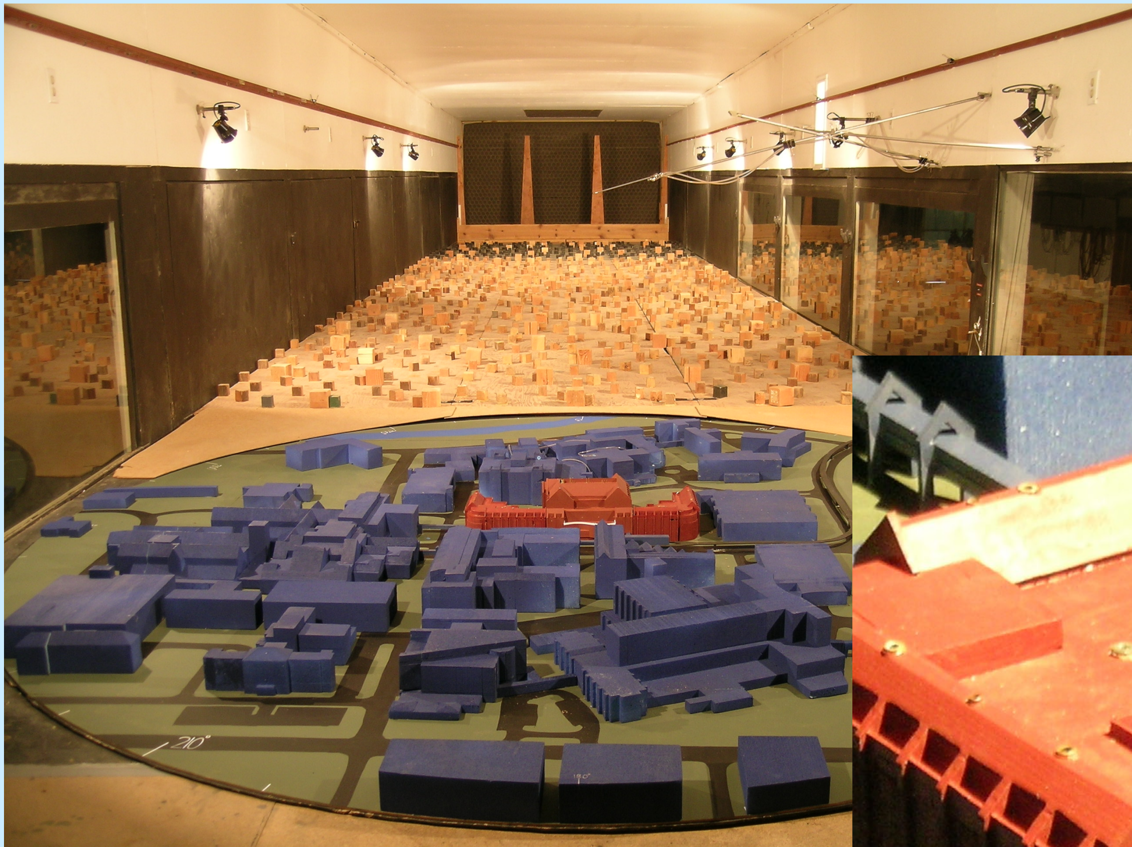
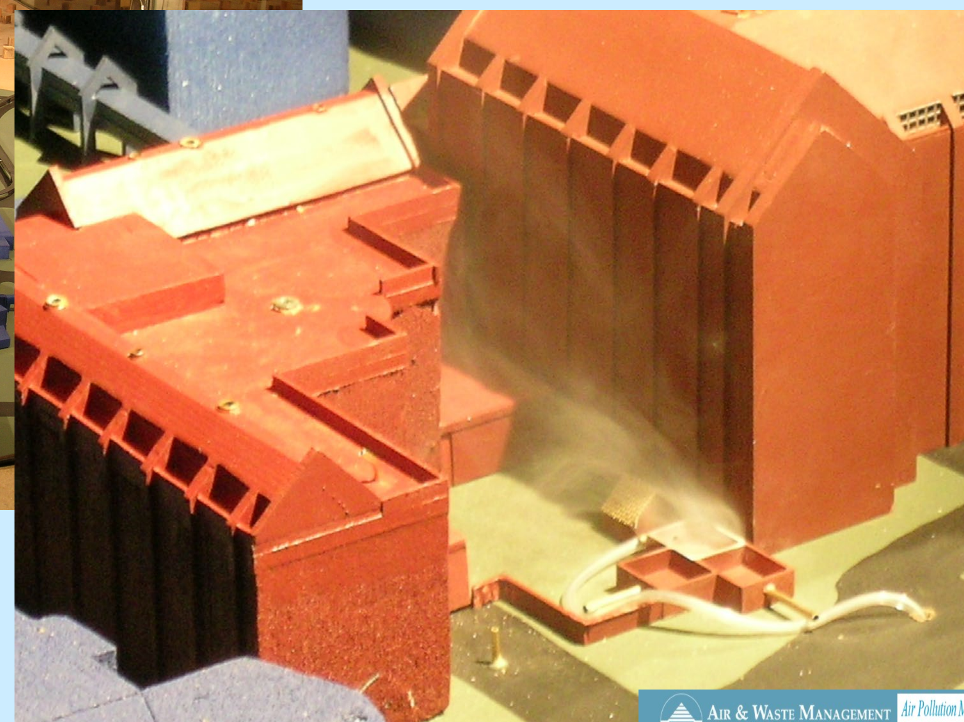
Dispersion in urban areas

Use wind tunnel estimates in the street canyons and on building surfaces?





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CFD and Wind Tunnel Implementation Issues

- Wind tunnel and CFD models can perform better than any of the present models for certain complex situations.
- The models cannot be practically applied for every hour of the year. How best can a subset of hourly simulations be substituted within an approved regulatory model?
- For a specific CFD code, the compiled version can be frozen and options/parameters fixed for establishing repeatable application.

CFD and Wind Tunnel Implementation Issues, cont.

- Performance of CFD codes can be established through comparisons with databases of analytical solutions, wind-tunnel measurements and field measurements.
- Guidance for regulatory application of these models is needed.
- Oversight of these applications is needed. Perhaps this can best be done through a working group of CFD and Wind Tunnel users with final oversight by EPA.

Recommendations on Implementation

- Determine areas where CFD and wind tunnel modeling may be used to complement existing approved models
- Include language allowing use of methods for these areas
- Include language outlining methodology
  - Update EPA Fluid Modeling Guideline
  - A CFD modeling Guideline
- Provide mechanism for peer review, evaluation, and documentation of these modeling methods

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Disclaimer

For Alan Huber, the research presented here was performed under the Memorandum of Understanding between the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Commerce's National Oceanic and Atmospheric Administration (NOAA) and under agreement number DW13921548. This work constitutes a contribution to the NOAA Air Quality Program. Although it has been reviewed by EPA and NOAA and approved for publication, it does not necessarily reflect their policies or views.