THE CANADIAN URBAN DISPERSION MODELING SYSTEM

RESULTS FROM SENSITIVITY TESTS OVER VANCOUVER

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Introduction

Context

- Growing concern among public security professionals about accidental or terrorist releases of a chemical, biological, radiological or nuclear (CBRN) agent in large cities, particularly densely populated downtown areas.
- Complex urban wind and turbulence patterns: updrafts, downdrafts, channeling of the wind along street canyons and possible transport of CBRN agents upwind from source, and calm wind areas or wake regions, where CBRN agents may become trapped and retained between buildings for a long time.
- Most existing transport and dispersion models have no building awareness, could be misapplied in urban settings, and make it difficult to describe realistic dispersion of released agent.

CUDM System Overview

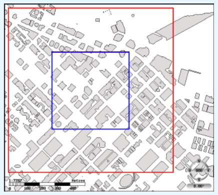
- The Canadian Urban Dispersion Modeling (CUDM) system was developed over the past five years, through funding from Defence R&D Canada's CBRN Research and Technology Initiative (CRTI) program.
- The CUDM is a multiscale system designed to predict the flow and turbulence in an urban environment and the dispersion of contaminants for responses to real incidents or in planning scenarios or forensic assessments.
- It has three main components:
  - a cascade from the meteorological operational regional model to an urbanized mesoscale model capable of simulating the urban micrometeorology (urbanGEM).
  - a building-aware computational fluid dynamics (CFD) model which resolves the flow down to the street or building scale (urbanSTREAM), using inflow and high resolution lateral boundary conditions obtained from urbanGEM and the building details from high fidelity city digital models.
  - a Lagrangian stochastic urban dispersion model (urbanLS), driven using the full 3D flow fields provided by urbanSTREAM to compute forward or reverse time paths of particles released from transient or continuous sources.
- components were validated during the first phase of the project, using measurement data from the Joint Urban 2003 campaign in Oklahoma City. The second phase, in progress, aims to integrate system components into an operational prototype.

Goal

Qualitatively investigate the sensitivity of the prototype to varying inputs and configurations using simulations from the Vancouver 2010 Winter Olympic Games. This will improve understanding of the system.

Experimental setup

- all simulations assumed a neutral boundary layer
- urbanSTREAM driven by:
  - constant-direction power-law wind profiles based on wind specified at ~100 m height applied uniformly over the domain, or
  - 3D wind fields
- source positioned at 1.9 m from the surface and released one instantaneous puff
- inner grid (resolved buildings) horizontal extent of 500 m x 500 m
- vertical extent of domain: 500 m



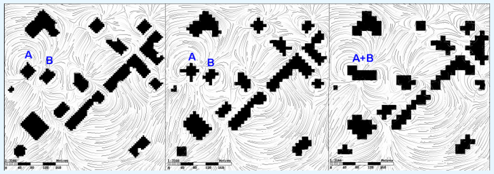
A partial rendering of the Vancouver building vector data: the downtown location of the entire simulation domain (red) and the resolved buildings area (blue)

The effects of varying five parameters were examined:

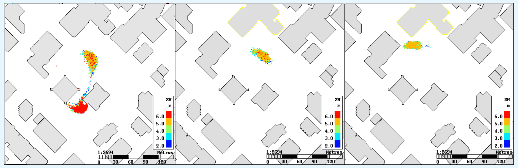
1. - **different horizontal grid resolutions (for low-level wind of 5 m/s from 45 deg)**
   - inner grid: 5, 10, 15 m horizontal resolution, vertical resolution of 5 m
2. - **different vertical grid resolutions (same wind profile as case 1)**
   - inner grid: 5 and 8 m vertical resolution, horizontal resolution of 5 m
3. - **changes in the imposed wind speed (inner grid resolution: 5 m)**
   - wind profile: based on speeds varied between 2 and 10 m/s; direction from 45 deg
4. - **changes in the imposed wind direction (inner grid resolution: 5 m)**
   - wind profile: based on speed of 5 m/s and direction varied between 35 and 55 deg
5. - **power-law wind profile versus a 3D wind field** from urbanGEM
   - power-law profile: produced from urbanGEM values
   - 3D wind field: urbanGEM winds are interpolated onto the urbanSTREAM vertical and horizontal gridpoints. Both wind direction and speed vary over the domain.

Results

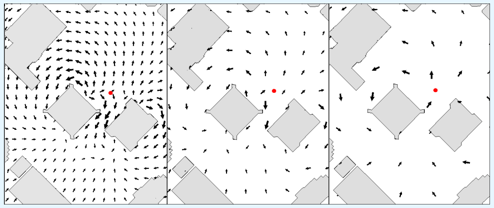
1. Coarser horizontal grid → loss of obstacle detail → significant impact on dispersion



Buildings as "seen" by the model at horizontal resolution of 5m (left), 10 m (center) and 15 m (right), and modeled wind field streamlines at 5.1 m height.

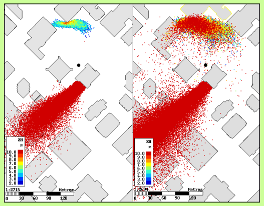


Instantaneous particle positions 150 s after release for horizontal resolutions of 5 m (left), 10 m (center) and 15 m (right)



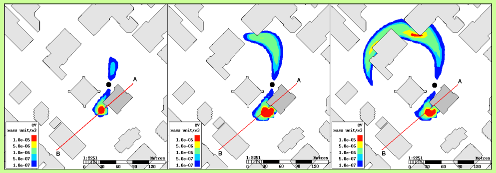
Wind vector at 5.1 m height for horizontal resolutions of 5m (left), 10 m (center) and 15 m (right)

2. Coarser vertical grid → significant impact on dispersion

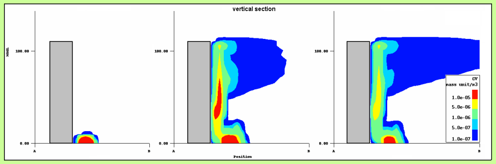


Instantaneous particle positions for vertical resolutions of 5m (left) and 8 m (right)

3. Different wind speeds → significant impact on dispersion

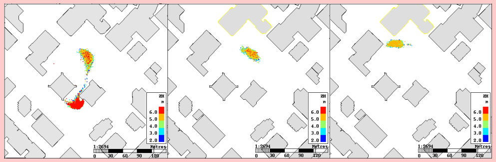


5-minute average concentration for wind speeds of 2 m/s (left), 5 m/s (center) and 10 m/s (right)

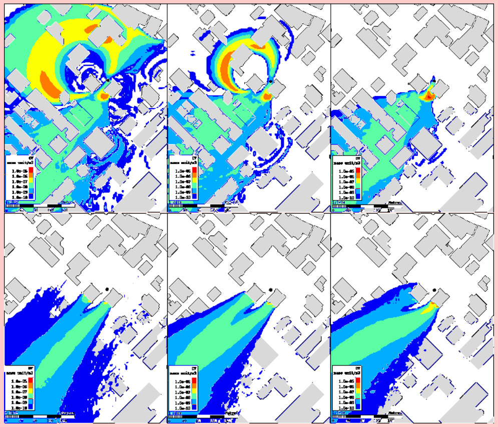


Cross section of the 5-minute average concentrations in the recirculation region behind a building, for wind speeds of 2 m/s (left), 5 m/s (center) and 10 m/s (right)

4. Different wind directions → significant impact on dispersion

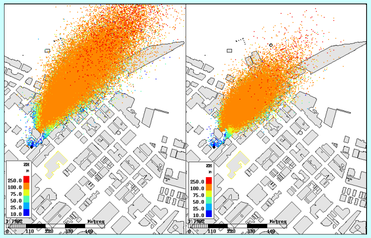


Particle positions 50 s (top) and 150 s (bottom) after release for wind from 35 deg (left), 45 deg (center) and 55 deg (right)

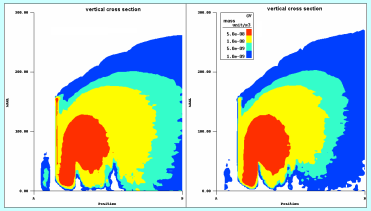


30-minute average concentrations at 5.1 m (top) and at 90.9 m (bottom) for wind directions from 35 deg (left), 45 deg (center) and 55 deg (right)

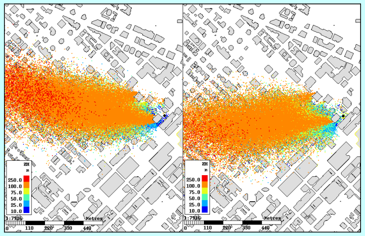
5. Power law profile vs. 3D wind field → significant impact on dispersion



Instantaneous particle positions 450 s after release for 3D field (left) and power-law profile (right), on 28 March 2010 02 UTC



Cross section of 5-minute average concentrations along the axis of the plume for 3D wind field (left), and power-law profile (right) on 28 March 2010 02 UTC



Instantaneous particle positions 450 s after release for 3D field (left) and power-law profile (right), 21 March 2010 20 UTC

Conclusions

- The CUDM is sensitive to changes in all tested inputs and configurations. Changes in wind direction or horizontal grid resolution cause the most notable differences in the modeled wind field and subsequent dispersion patterns.
- A high resolution is necessary to resolve correctly all the building footprint contours. Detailed, complete, and up-to-date building vector data files are needed in order to obtain the most realistic flow.
- The wind direction is critical. A detailed wind field will yield a different plume compared to one produced with a constant-direction wind. The latter is equivalent to using an observed wind at a single level.
- This sensitivity to many parameters encourages us to explore the possibility of producing probabilistic outputs.

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Funding: This work was supported by Defence Research and Development Canada under project number CRTI 07-0196TD

References:

- Lien F-S, Yee E. 2004: Numerical modelling of the turbulent flow developing within and over a 3-D building array, Part I: A high resolution Reynolds-averaged Navier–Stokes approach. *Boundary-Layer Meteorol.* **112**: 427–466.
- Wilson J.D., E. Yee, N. Ek, R. d'Amours**,** 2009: Lagrangian simulation of wind transport in the urban environment. *Q. J. R. Meteorol. Soc.* **135**: 1586–1602.
- Leroyer S., J. Mailhot, S. Bélair, A. Lemonsu, I.B. Strachan, 2010: Modeling the Surface Energy Budget during the Thawing Period of the 2006 Montreal Urban Snow Experiment. *J. Appl. Meteor. and Clim.*, **49**, 68-84.