P.844 The Canadian Urban Dispersion Modeling (CUDM) System: results from sensitivity tests over Vancouver

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1. INTRODUCTION

A growing concern exists among public safety professionals regarding terrorist or accidental releases of a chemical, biological, radiological or nuclear (CBRN) agent in large cities. In downtown areas, buildings create complex turbulent flows, with updrafts, downdrafts, and channeling of the wind along the street canyons. Most existing transport and dispersion models have little or no building awareness and therefore can not realistically describe the dispersion of agents released in urban areas. The Canadian Urban Dispersion Modeling (CUDM) system was designed to address this issue. It can be applied to planning scenarios, forensic assessments, and during incident responses,. The CUDM system has been under development since 2003, through funding from Defence R&D Canada's CBRN Research and Technology Initiative (CRTI) program.

The multiscale CUDM system consists of 3 main components. The first component is a cascade of meteorological forecast models. This cascade starts with the regional configuration of the Canadian operational Global Environmental Multiscale (GEM) model, and it ends with urbanGEM, an urbanized high-resolution version of GEM.

The second component is urbanSTREAM, a building-aware computational fluid dynamics (CFD) model which resolves the highly disturbed flow to the street or building scale. The boundary conditions for urbanSTREAM are extracted from the output of urbanGEM.

The third component is urbanLS, the urban Lagrangian stochastic (LS) dispersion model. UrbanLS simulates the release of a large number of passive-tracer particles, which are individually followed as they are carried along in the turbulent wind field.

The different components of the CUDM system were validated during the first phase of the project, primarily using the Oklahoma City Joint Urban 2003 measurement campaign data. The second phase, in progress, is focused on the seamless integration of the different modeling components to produce an operational prototype. This prototype was run in test mode during the Vancouver 2010 Winter Olympic and Paralympic Games, and during the G8/G20 summits in Toronto in June 2010.

This paper presents a qualitative evaluation of the sensitivity of the CUDM system to wind conditions and grid resolution.

2. EXPERIMENTAL SETUP

The CUDM prototype was tested for sensitivity to the following urbanSTREAM inputs and configurations:

(1) horizontal resolution,
(2) vertical resolution,
(3) wind speed,
(4) wind direction,
(5) simplified wind versus 3D wind.

In order to isolate the effects of the first four, a simplified wind field was used instead of the urbanGEM output. For each simulation, urbanSTREAM used a single wind speed and direction, specified at 100 m height, to generate a constant-direction wind profile based on power-law under neutral stability. This profile was applied uniformly on the simulation domain boundaries. For all tests the source was a single near-instantaneous puff released at 1.9 m height. Figure 1 presents a rendering of the Vancouver building vector data illustrating the downtown locations of the entire simulation domain and of the resolved buildings area. The latter had a horizontal extent of 500 m x 500 m and is referred to as the "inner grid". The vertical extent of the simulation domain was 500 m.

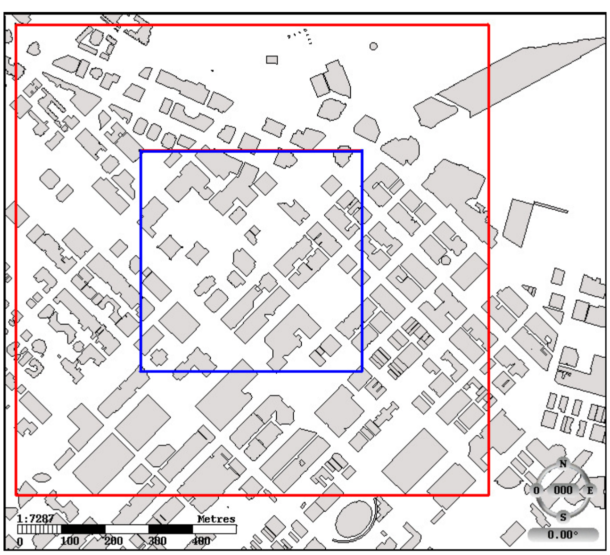

Figure 1. Simulation domain (red square) containing the inner grid (blue square)

The first test aimed to investigate the response of urbanSTREAM and urbanLS to changes in horizontal grid resolution. The inner grid was covered by 100 x 100, 50 x 50 and 33 x 33 points, meaning an horizontal resolution of 5, 10 and 15 m respectively (160 x 160, 90 x 90 and 63 x 63 points on the respective entire domains), at the same vertical resolution of 5 m. The wind profile was based on a speed of 5 m/s and a direction from 45 degrees.

The second test evaluated the sensitivity of the models to changes in vertical grid resolution. The horizontal inner grid resolution was 5 m while the vertical resolution was changed from 5 to 8 m (34 and 21 vertical levels, respectively, or 50 and 32 levels for the respective entire domains). The wind profile from the first test was used.

The third test examined the models' response to changes in the input wind speed. The wind profiles were based on speeds varied between 2 and 10 m/s, while keeping a constant direction from 45 degrees. The horizontal and vertical grid resolution was 5 m.

The fourth test investigated the effect of changes in the input wind direction. The wind profiles were based on directions varied between 35 and 55 degrees, while keeping a constant speed of 5 m/s. The grid was the same as for the third test.

In the fifth test, prototype runs driven by full 3D wind fields were compared to runs driven by constant-direction wind profiles. The 3D wind fields were interpolated from urbanGEM onto the urbanSTREAM domain boundaries. Thus both wind direction and speed varied over the simulation domain. The power-law profiles were based on the wind speed and direction at one point on the first GEM atmospheric level (~126 m height) from the 3-dimensional urbanGEM forecast.

3. RESULTS AND DISCUSSIONS

3.1 Horizontal grid resolution

Buildings are well-resolved at a grid resolution of a few meters. At a grid resolution comparable to the horizontal building dimensions, closely-spaced buildings will often appear to be merged. A single obstacle will then be generated from two or more otherwise distinct building footprint contours. This loss of detail is likely to result in major impacts on subsequent flow modeling. Depending on the buildings resolved by the model, different trajectories and plume duration can evolve from the same source location. Figure 2 presents the resolved buildings and the modeled streamlines at 2.5 m height, for horizontal grid resolutions of 5 m, 10 m and 15 m. The two buildings A and B are distinct and well-resolved at 5m resolution but have merged at 15 m resolution.

Figure 3 presents the wind vectors at 2.5 m height for the 5 m, 10 m and 15 m horizontal resolution. The red dot marks the source position, in the neighborhood of buildings A and B from Figure 2. In the 5 m resolution case, the source lies in a divergence area which is not simulated in the other cases due to the loss of obstacle detail with decreasing resolution.

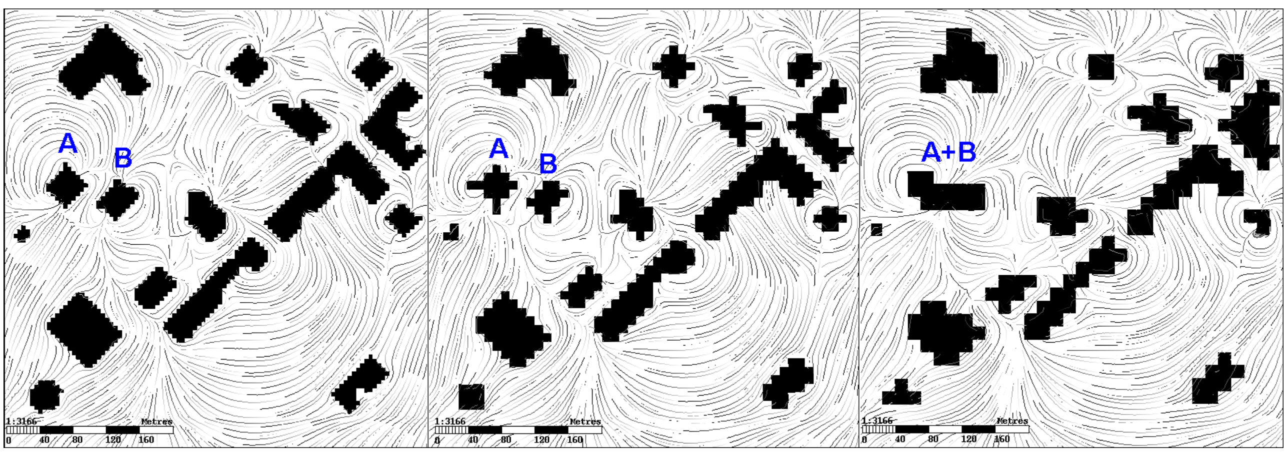

Figure 2. Buildings as “seen” by the model at horizontal resolution of 5m (left), 10 m (center) and 15 m (right), and modeled streamlines.

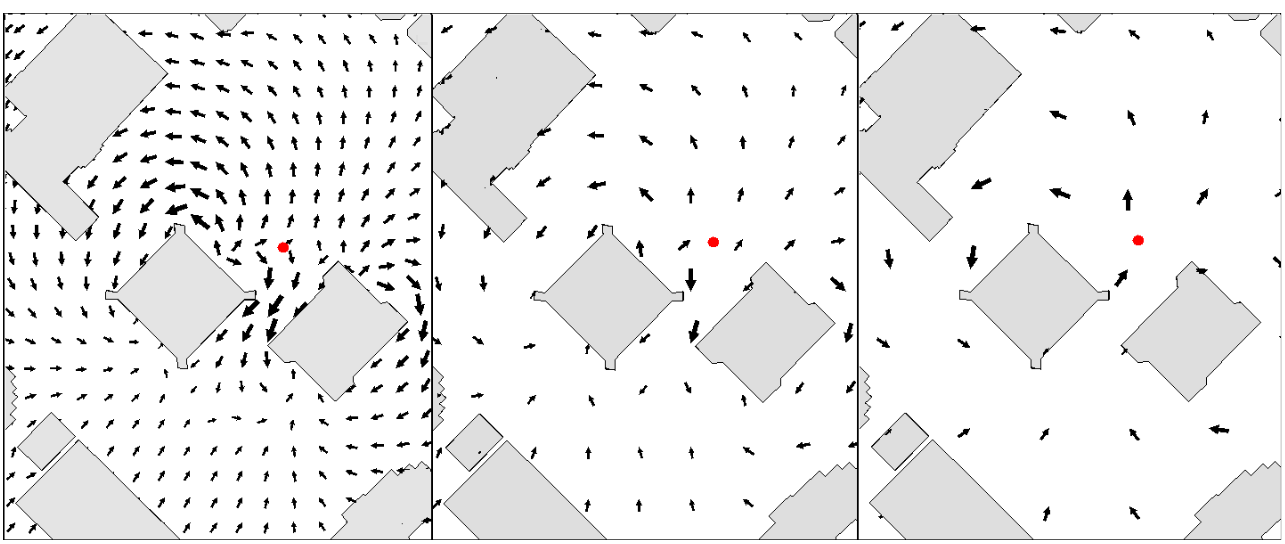
Figure 3. Wind vector at horizontal resolutions of 5m (left), 10 m (center) and 15 m (right).

Figure 4 shows the instantaneous position (elevation and extent) of the urbanLS particles 150 s and 300 s after the release. The bilobate dispersion pattern in the left images results from the divergent flow of the 5 m grid resolution simulation. Particles in the red colored part of the plume have split from the initial puff, moving between the two buildings A and B into the recirculation area along the leeward face of building B. The center and right images indicate that, in this experiment, the model produces a slightly faster dispersion at the coarser resolution.

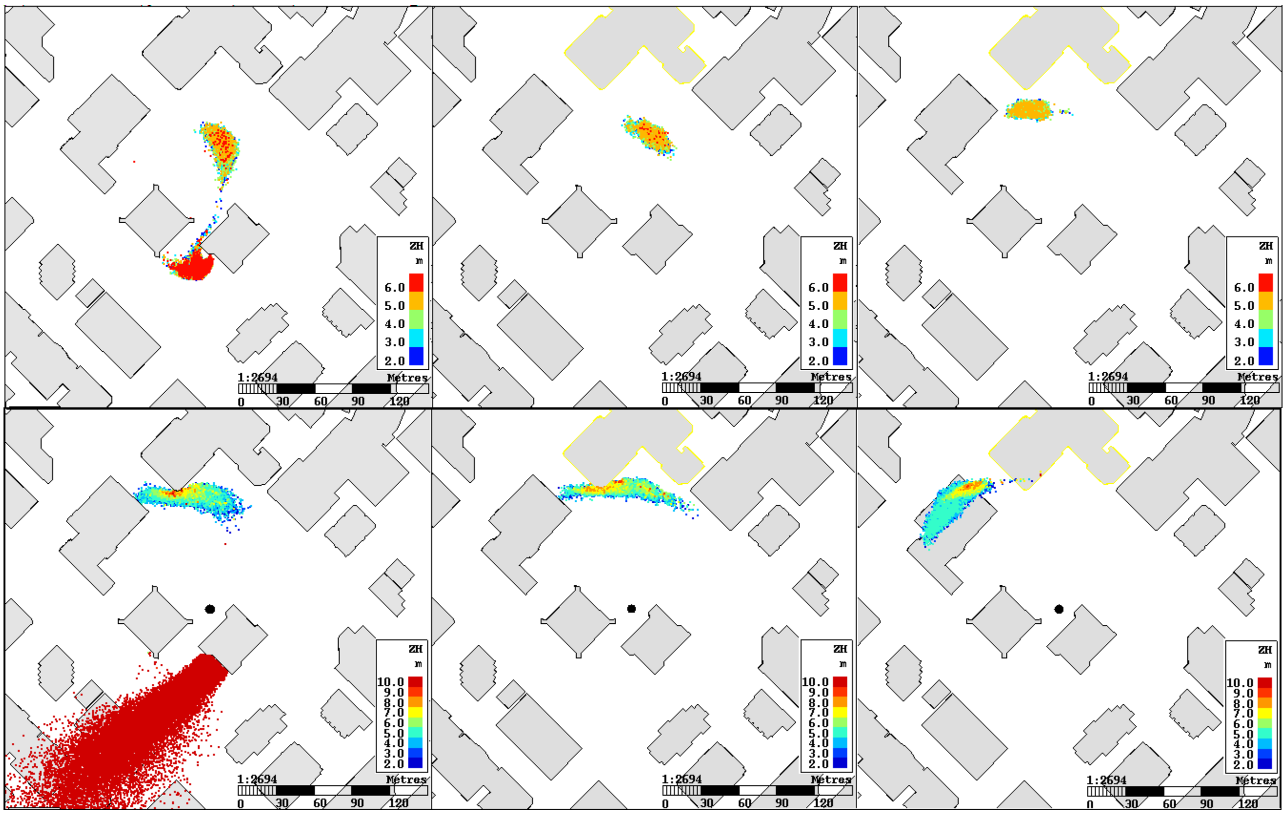

Figure 4. Instantaneous particle positions 150 s (top) and 300 s (bottom) after release, for horizontal resolutions of 5 m (left), 10 m (center) and 15 m (right).

3.2 Vertical resolution

Figure 5 shows instantaneous particle positions 300 s after the release, from two simulations at the same horizontal resolution of 5 m, but for vertical resolutions of 5 m and 8 m. The horizontal dispersion patterns are similar. The particles are lifted and dispersed faster at the coarser vertical grid resolution.

3.3 Wind speed

Figure 6 presents a 5-minute time-average concentration (CV) of the plume in units of mass/m^3 at 5.1 m height. The particles disperse faster as the speed is increased. Figure 7 shows a vertical section through the 5-minute average concentration along the red line (AB) from Figure 6. The plume rises more rapidly with increasing horizontal wind speed.

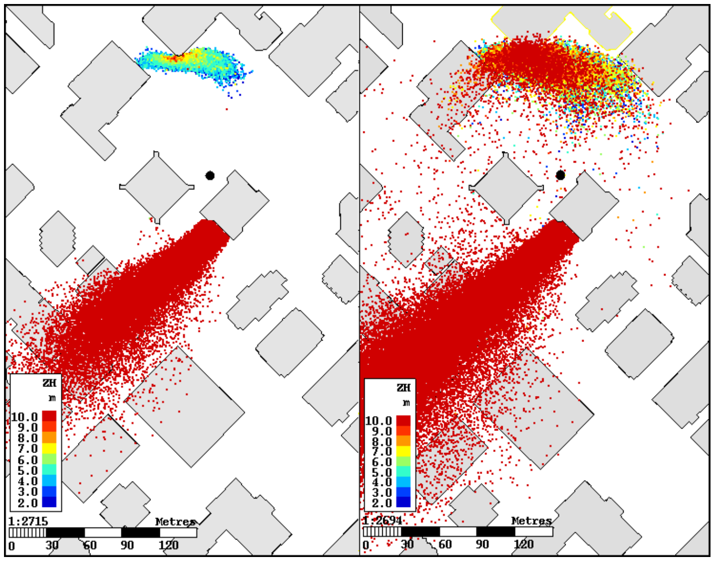

Figure 5. Instantaneous particle positions for vertical resolutions of 5m (left) and 8 m (right)

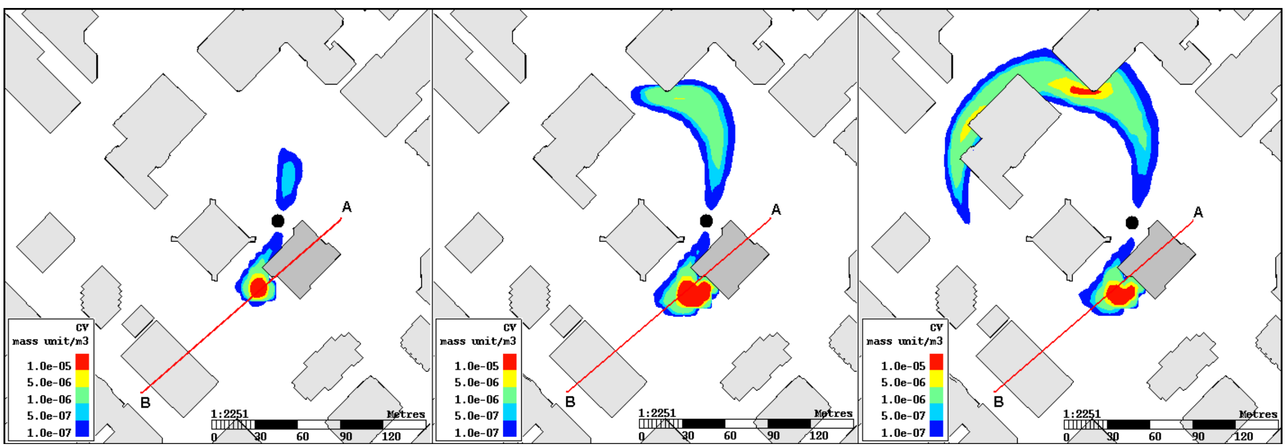

Figure 6. Five-minute time-average CV for wind speeds of 2 m/s (left), 5 m/s (center) and 10 m/s (right)

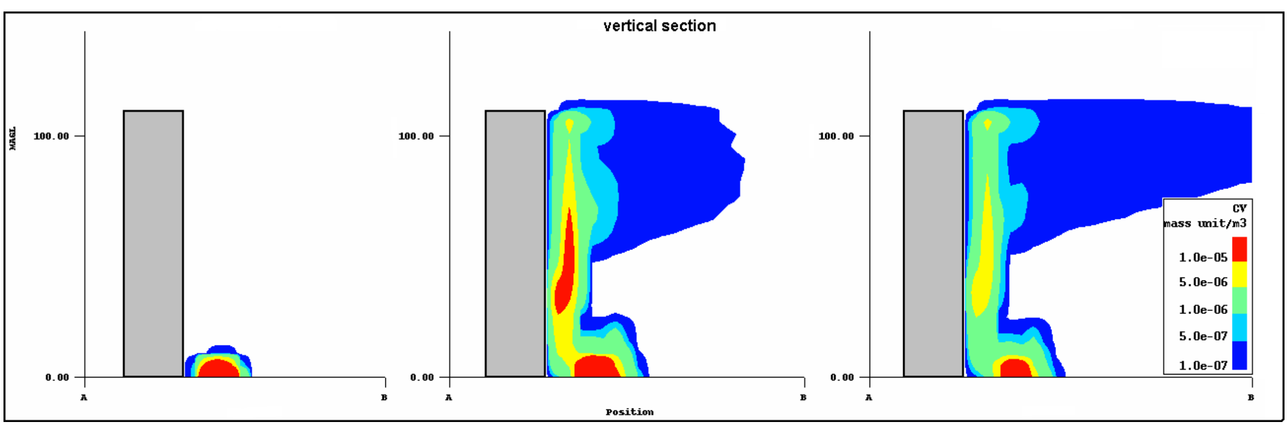

Figure 7. Cross section of 5-minute CV in the recirculation region along a building, for wind speeds of 2 m/s (left), 5 m/s (center) and 10 m/s (right)

3.4 Wind direction

Figure 8 shows the instantaneous particle positions 50 s and 150 s after release, for inflow wind from 35, 45 and 55 degrees. The modeled flow field corresponding to an inflow wind from 55 degrees produces only a southeastward channeling of the release between the western and eastern buildings. For inflow winds from 45 and 35 degrees, the plume splits, with one part channeled between the buildings and the other moving north and then westward in a semicircular trajectory. Figure 9 presents the concentration CV, averaged over the 30-minute simulation, at 5.1 m and 90.9 m height. Near the ground, the effect of varying wind direction is much greater than at rooftop.

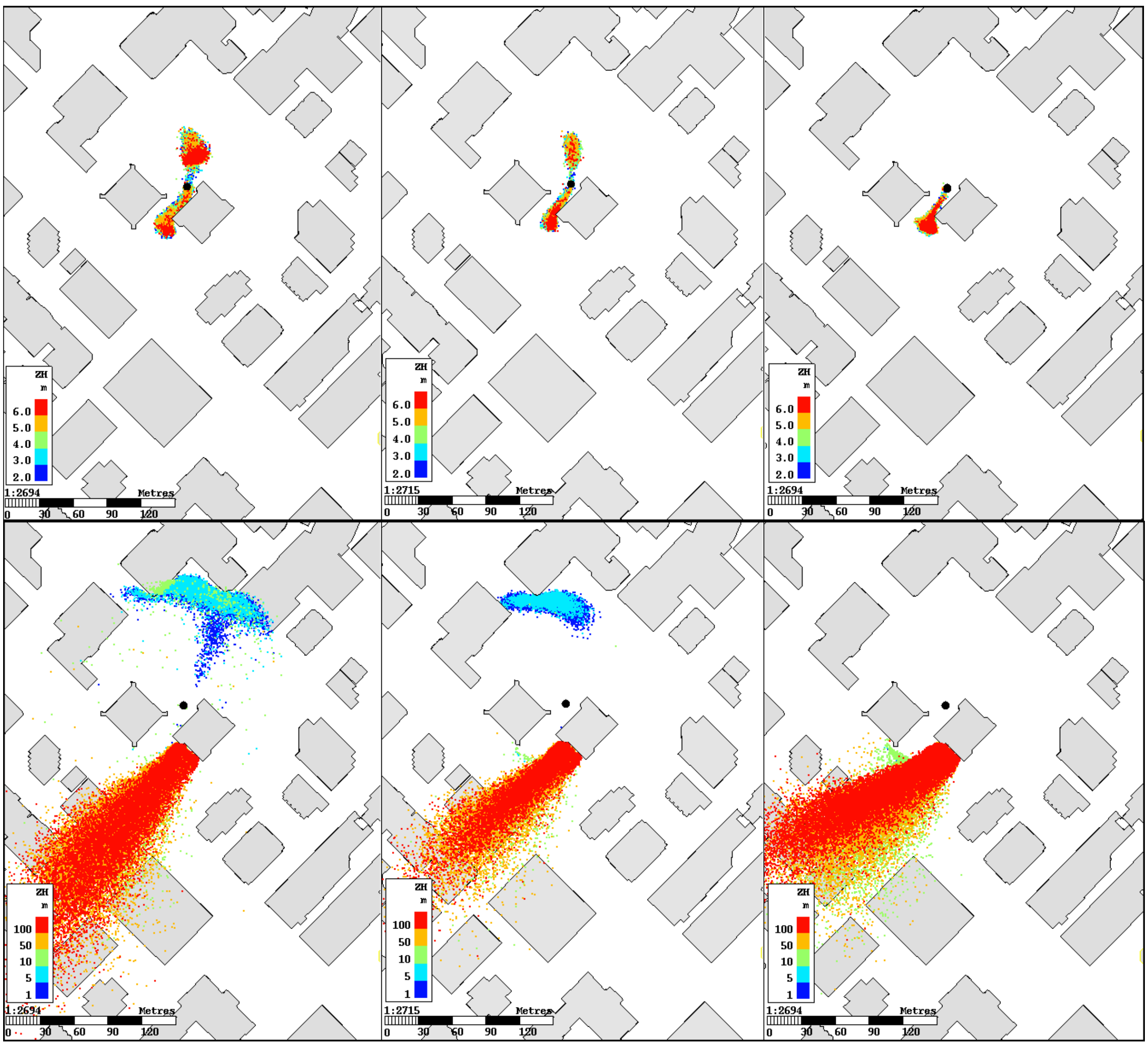

Figure 8 . Instantaneous particle positions 50 s (top) and 150 s (bottom) after release, for wind from 35 deg (left), 45 deg (center) and 55 deg (right)

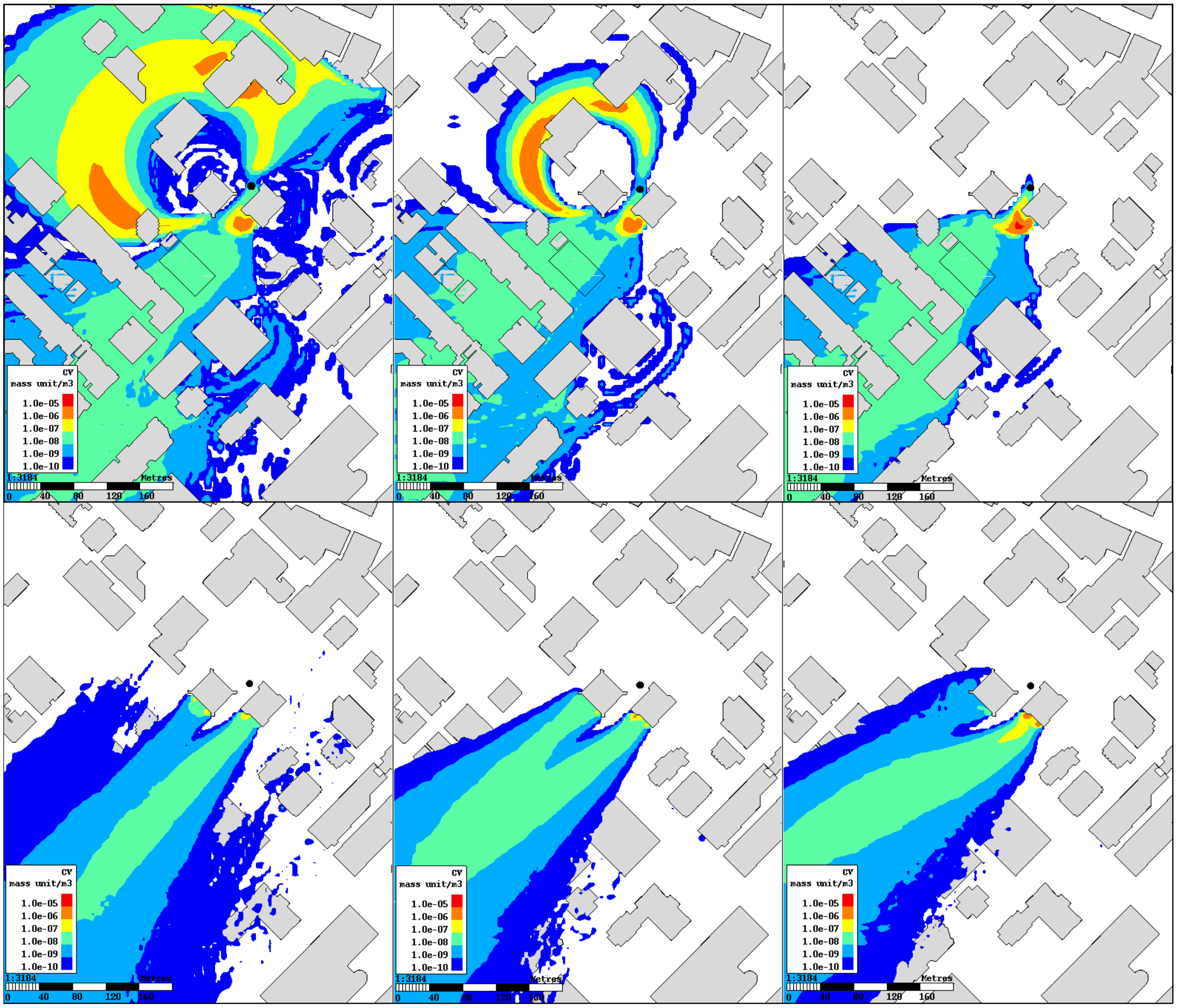

Figure 9. 30-minute average CV at 5.1 m (top) and at 90.9 m (bottom) for wind directions from 35 deg (left), 45 deg (center) and 55 deg (right)

3.5 Simplified wind vs. 3-D wind field

Figures 10, 11, and 12 compare simulations driven by power-law wind profiles, to those driven by urbanGEM 3-D wind fields. Figure 10 shows a cross section of 5-minute average CV (top) and of 30-minute average CV (bottom), along the longitudinal axis of the plume, for the case of 21 March 2010 at 20 UTC. Intermediate 5-minute averages are different but the 30-minute averages are similar. In this case transport is faster when urbanSTREAM is driven with the 3-D urbanGEM winds. Figure 11 shows the instantaneous particle positions 450 s after the release, for the same date. A profile based on a southwesterly wind resulted in slower transport than when the model was driven with a 3-D wind field. Figure 12 gives the instantaneous particle positions 450 s after release, for the case of 28 March 2010 at 02 UTC. When driven by the full 3-D wind field, the plume extended west to northwestward. When driven by the easterly constant-direction power-law wind profile, the plume extended west to southwestward.

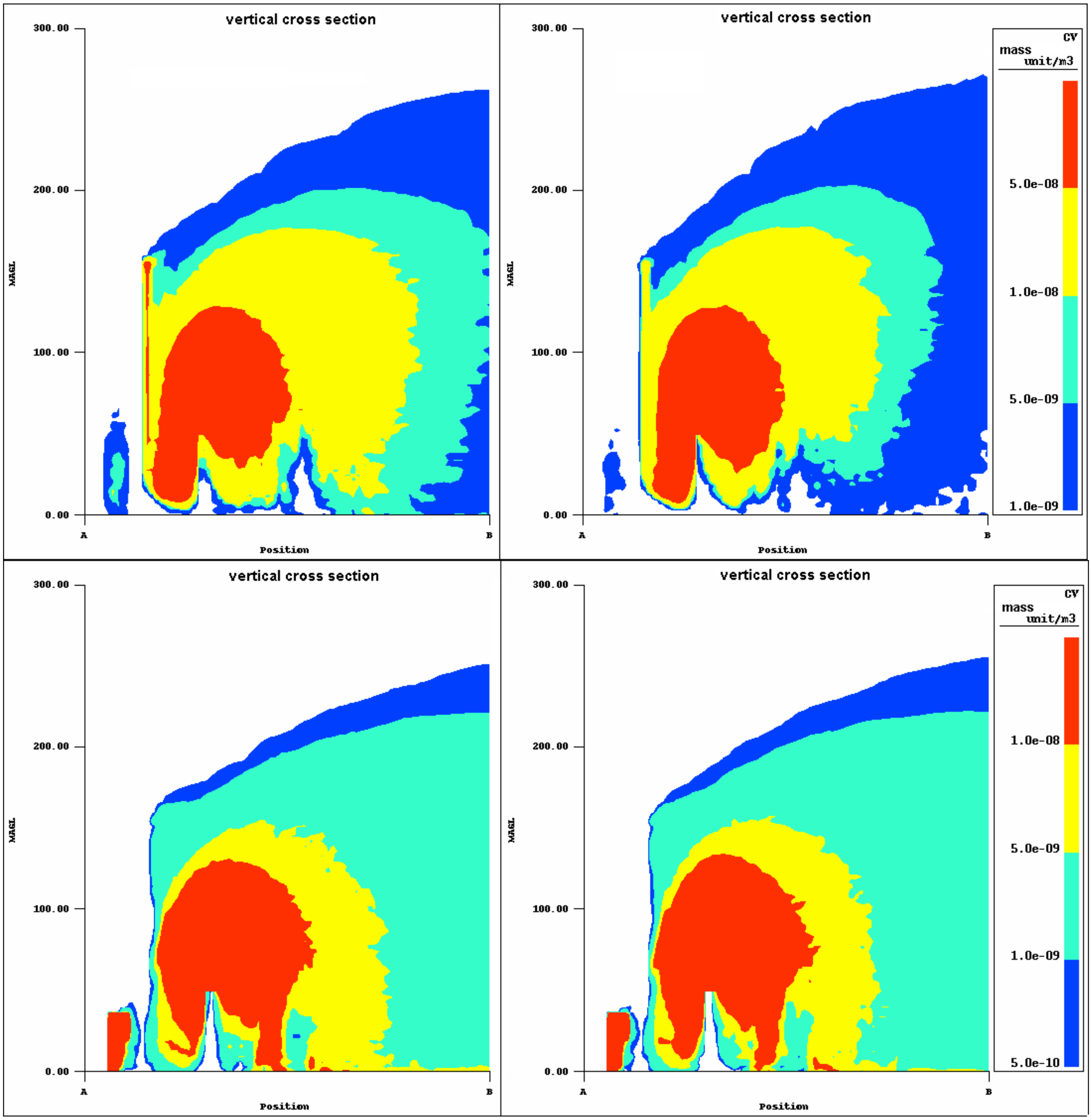

Figure 10. Cross section of 5-minute (top) and 30-minute (bottom) average CV along the axis of the plume, for 3D wind field (left) and constant-direction power-law wind profile (right), forecast valid 21 March 2010 at 20 UTC

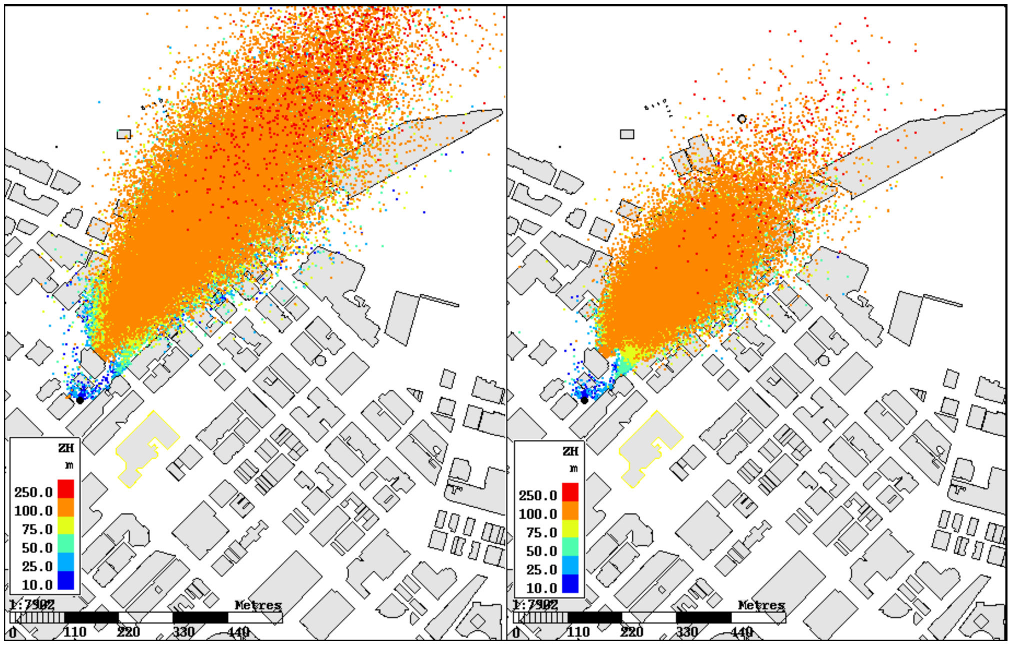

Figure 11. Instantaneous particle positions 450 s after release, for simulations driven with urbanGEM 3D winds (left) and constant-direction power-law wind profile (right), forecast valid 21 March 2010 at 2 UTC

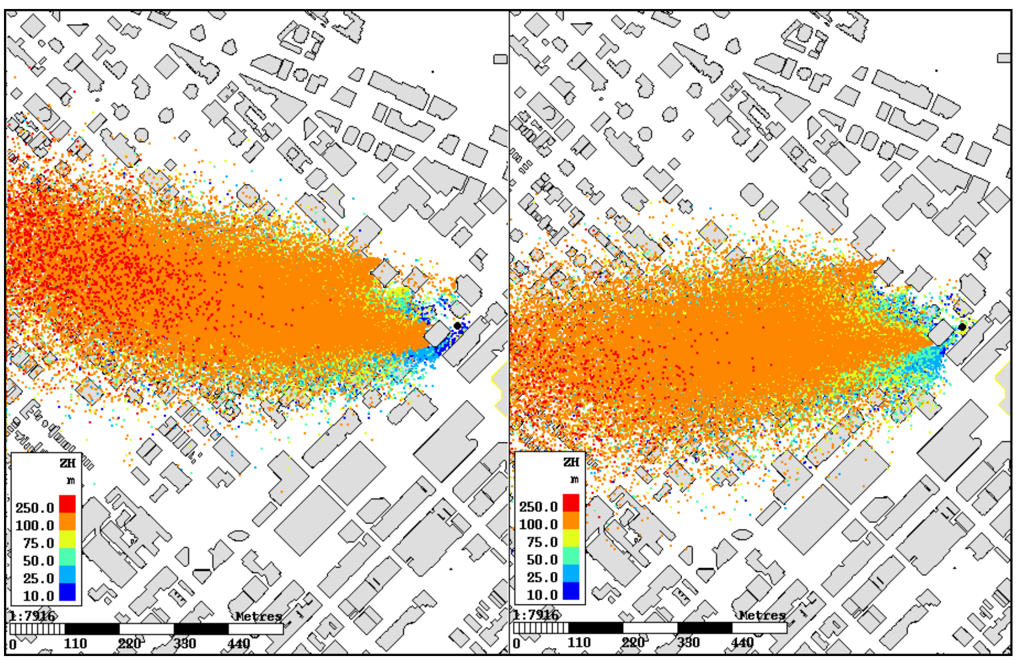

Figure 12. Instantaneous particle positions 450 s after release, for simulations driven with urbanGEM 3D winds (left) and constant-direction power-law wind profile (right), forecast valid 28 March 2010 at 02 UTC

4. CONCLUSIONS

The CUDM is sensitive to all of the input parameters tested. Variations in wind direction and horizontal grid resolution cause the most notable differences in the modeled wind field and subsequent dispersion.

A high resolution setting is required to resolve the buildings. Detailed, complete and up-to-date building vector data are needed in order to obtain the most realistic flow.

The modeled flow is sensitive to the wind input, particularly wind direction. Given the inherent variability of the wind, high-resolution NWP outputs, if available, should be used to ensure that the CFD model is driven with the most realistic 3-D wind field.

It is computationally expensive to use a high grid resolution, but these sensitivity results suggest that the use of a lower grid resolution could significantly reduce accuracy.
During the initial phase of real release incidents, source parameters are often unknown or only approximately known. Thus, given the high sensitivity of the CUDM system, application to real-time response will be challenging and should be considered with caution.

The results of this short study suggest that a probabilistic approach should be taken into consideration. This would aid to address the inherent uncertainties in this type of applications.

CONTRIBUTORS

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