Validation and sensitivity testing of CityZoom-AERMOD model

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ABSTRACT: CityZoom is a computer-based tool where different design and planning attributes can be considered simultaneously, aiming to optimize the urban planning process. The current research has two objectives: (1) to enhance CityZoom and provide fast computation of air flow and pollution for urban planners; (2) to build an integrated CFD simulation into CityZoom to link urban planning and architectural engineering consultancy. This paper reviews the work done on the first objective: EPA's preferred regulatory model, AERMOD, is chosen for this task. A methodology for modelling traffic emission profiles and building geometries is developed to allow the use of AERMOD downwash algorithms in this integrated environment. Parametric tests are performed for different sets of meteorological conditions and urban scenarios. The sensitivity of the model to changes in wind speed, wind direction and the built environment is studied. To validate the model, tests are performed against data from the DAPPLE Project.

1 INTRODUCTION

To evaluate the impact of existing or alternative building layouts on the dispersion of pollutants in an urban district is not a trivial task. The interactions between different factors must be considered, such as the buildings and their layouts, the natural environment conditions and the impact of human activities. The use of a computational tool to make preliminary assessments and to help establish relationships between these different factors would prove advantageous.

CityZoom (Turkienicz et al. 2008) is a software developed by the SimmLab – UFRGS (Laboratory for the Simulation and Modelling in Architecture and Urbanism – Federal University of Rio Grande do Sul – Brazil) which attempts to provide a computational environment where different design and planning attributes can be considered simultaneously, aiming to optimize the urban planning process. CityZoom can currently help users to evaluate and to modify the city model according to different constraints such as building regulations, solar radiation, luminance, planning regulations and the terrain permeability.

The present research project aims to extend CityZoom, with two objectives: (1) to provide fast computation of air flow and pollution for urban planners; (2) to build an integrated CFD simulation into CityZoom to make it possible to expand CityZoom urban planning function to include CFD engineering consultancy. This paper reviews some of the work done on the first objective and presents the methodology and results of the sensitivity and validation tests to which the developed tool was subjected.

CityZoom was extended to include urban dispersion calculation capabilities through integration with AERMOD (Cimorelli et al. 1998). The resulting software is capable of representing the correlation and effects of planning regulations along with pollution parameters over a large amount of urban plots. This tool can be used by planners, architects, engineers and government authorities to investigate how different building alternatives (building profiles) interact with different traffic operation conditions (emission profiles) to affect the dispersion of pollutants in urban environments.

2 DISPERSION MODELLING

Atmospheric dispersion modelling uses mathematical formulations to characterize the atmospheric processes that disperse a pollutant emitted by a source (SCRAM 2008). It is usually performed with computer programs that solve the mathematical equations (e.g., Gaussian distribution) and algorithms which simulate the pollutant dispersion. Based on emissions from sources (e.g., industrial plants and vehicular traffic), meteorological inputs (e.g., wind speed and direction, atmospheric stability class, ambient air temperature), terrain elevations, and obstruction data, dispersion models can be used to predict concentrations at downwind receptor locations.

The general Gaussian dispersion equation, used by many steady-state plume models, is

$$C(x,y,z;H) = \frac{Q}{2\pi\sigma_y\sigma_z u}\cdot\exp\left[-\frac{y^2}{2\sigma_y^2}\right]\cdot\left\{\exp\left[-\frac{(H-z)^2}{2\sigma_z^2}\right]+\exp\left[-\frac{(H+z)^2}{2\sigma_z^2}\right]\right\} \tag{1}$$

where C is the air pollutant concentration (kg/m^3), Q is the pollutant emission rate (kg/s), u is the wind speed at the point of release (m/s), σ_y is the standard deviation of the crosswind concentration distribution at a distance x downstream (m), σ_z is the standard deviation of the vertical concentration distribution at a distance x downstream (m) and H is the effective height of the centreline of the plume (m).

The U.S. Environmental Protection Agency (EPA) Guidelines on Air Quality Models (1986) provides a list of dispersion models, such as AERMOD, ADMS-3 (Carruthers et al. 1994) and ISC3 (EPA 1995). These models are typically used to determine whether existing or proposed new industrial facilities are or will be in compliance with the National Ambient Air Quality Standards (NAAQS) in the United States and other nations. The models have also been used to assist in the design of effective control strategies to reduce emissions of harmful air pollutants (Murena et al. 2008) and to predict the dispersion of contaminants in large cities (Pullen et al. 2005). Semi-empirical parametric models also exist, specially designed to produce pollutant concentrations within or around near-regular street canyons, such as the Danish OSPM (Berkowicz 2000) and the English TEMMS (Namdeo et al. 2002) and PUFFER (Hargreaves and Baker 1997).

3 INTEGRATION OF AERMOD INTO CITYZOOM

In 1991, the American Meteorological Society (AMS) and the EPA created the AMS/EPA Regulatory Model Improvement Committee (AERMIC) working group, with the goal of introducing current Planetary Boundary Layer (PBL) concepts into regulatory dispersion models. The AERMIC Model – AERMOD – was developed as a complete replacement for the EPA Industrial Source Complex Model – ISC3.

AERMOD is a steady-state plume model that assumes that concentrations at all distances during a modelled hour are governed by the temporally averaged meteorology of the hour. The tool was designed for short-range dispersion of air pollutant emissions from point, area and volume sources and can estimate enhanced plume growth and restricted plume rise for plumes affected by building wakes through the Plume Rise Model Enhancements (PRIME) algorithms (Schulman et al. 2000).

AERMOD was chosen for integration with CityZoom for several reasons: it is an open source system, which is well documented, validated and accepted; it can deal with building downwash and the input and output files are simple to read and generate.

CityZoom was extended to generate the AERMOD input files, trigger an AERMOD run, read the generated output text files and export them for visualization with appropriate tools. The runstream setup file is the basic AERMOD input and contains the selected modelling options, as well as source location and parameter data, receptor locations, meteorological data file specifications, and output options.

CityZoom was designed as a tool for urban planning purposes, capable of dealing with city objects and their geometry. To provide the capability to also manage sources and receptors, required for the integration with AERMOD, the city model was modified as shown in Figure 1.

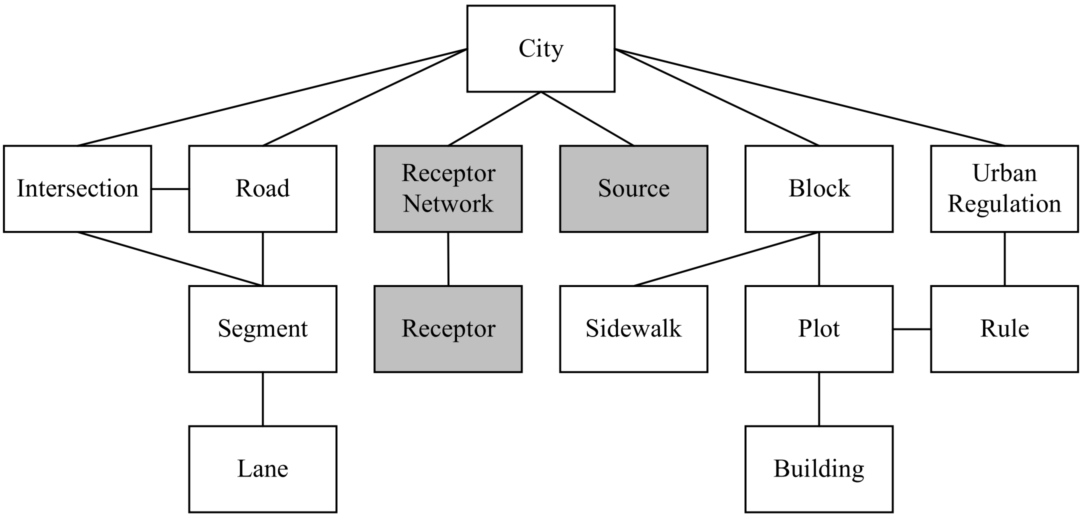

Figure 1: CityZoom city model. New classes are highlighted in grey (Adapted from Turkienicz et al. 2008).

4 SENSITIVITY STUDY

To verify that the CityZoom-AERMOD model behaved consistently to variations of the different urban parameters, a set of tests was designed with the assistance of the LASTRAN (Laboratory for Transport Systems, UFRGS, Brazil) staff. An urban scenario was modeled, consisting of an array of 4 x 4 blocks of side 300 m, with either spread out 2-storey buildings (Fig. 2a) or clustered 10-storey buildings (Fig. 2b). Sources were distributed in 10 m intervals along the streets axes. The sources had the following properties: exit temperature = environment temperature + 50°C; exit velocity = 0.001 m/s and height = 0.03 m. Emission rates were set based on 2 traffic profiles with equal total emissions: one corresponding to uniform emissions (Profile 1) along the street axis and one representative of heavy traffic with traffic lights at every intersection (Profile 2).

A set of neutral atmospheres was created for the tests, using AERMET (AERMOD meteorological pre-processor) to generate combinations of the following parameters: surface wind speeds of 4 and 8 m/s, surface wind directions of 270 and 315 degrees from the north and roughness lengths of 1 m and 3 m, to be used with the 2- and 10-storey scenarios respectively. The simulations were run for a single hour. Concentrations were measured at the default

AERMOD above ground-level height of 0.0 m. Initial tests showed that a domain size of at least 1000m was necessary to capture all the highest concentrations for the proposed data set.

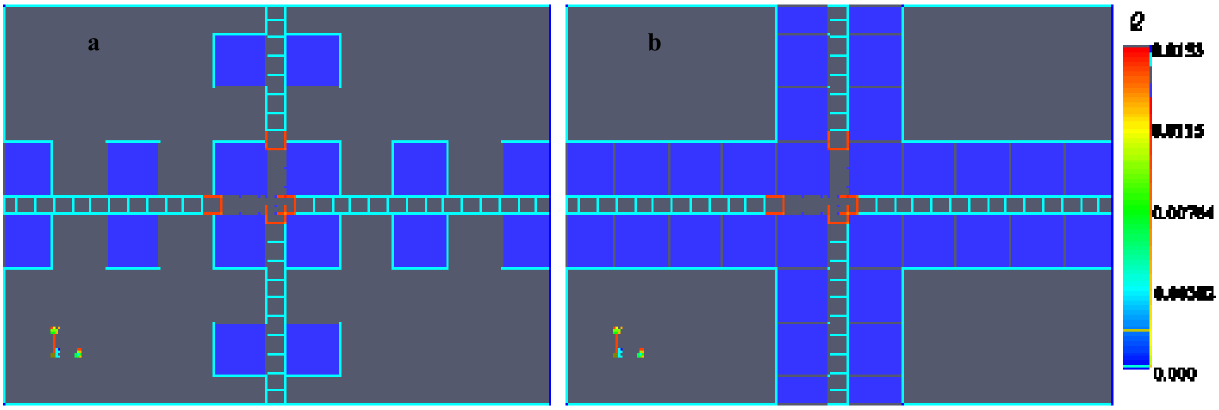

Figure 2: Emission rates at an intersection for traffic Profile 2 with 2-storey (a) and 10-storey (b) buildings.

The sensitivity to surface wind speed was studied. Final concentrations are higher for the 8 m/s tests than for the 4 m/s, since the higher wind speeds carry the pollutants further, hence the receptors are influenced by a larger number of sources. The same idea was used to verify the sensitivity to surface roughness. The 10-storey scenario was simulated for roughness lengths of 1m and 3m. Roughness acts by reducing the surface wind speed, i.e. higher roughness results in lower concentrations.

The highest (Fig. 3) and plotted (Fig. 4-5) concentrations are shown for the combination of parameters: surface wind speed of 4 m/s, wind directions of 270 (Fig. 4) and 315 (Fig. 5) degrees from the north, urban scenarios with 2- and 10-storey buildings (z_0 of 1m and 3m respectively) and traffic profiles Profile 1 and Profile 2.

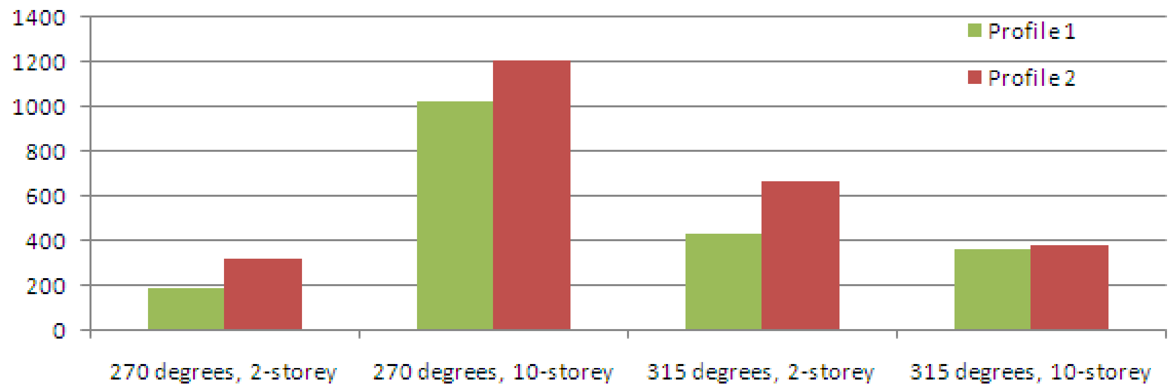

Figure 3: Highest concentrations for the combination of parameters.

Sensitivity to emission profiles and to the built environment are verified. Profile 2 always results in higher concentrations, as the emissions are much higher near the intersections. The relative impact of the different emission profiles is more noticeable on the 2-storey building case, as the focused high emissions on the intersections are enhanced by the emissions from the other sources. Tall buildings in conjunction with winds parallel to the street axes result in very high concentrations, since the buildings act by funneling the wind and the pollutants, which cause receptors to be influenced by more distant sources as well as near ones. When the wind direction is diagonal to the street axes, the tall buildings act by reducing the wind speed and result in a reduction of the transport of pollutants.

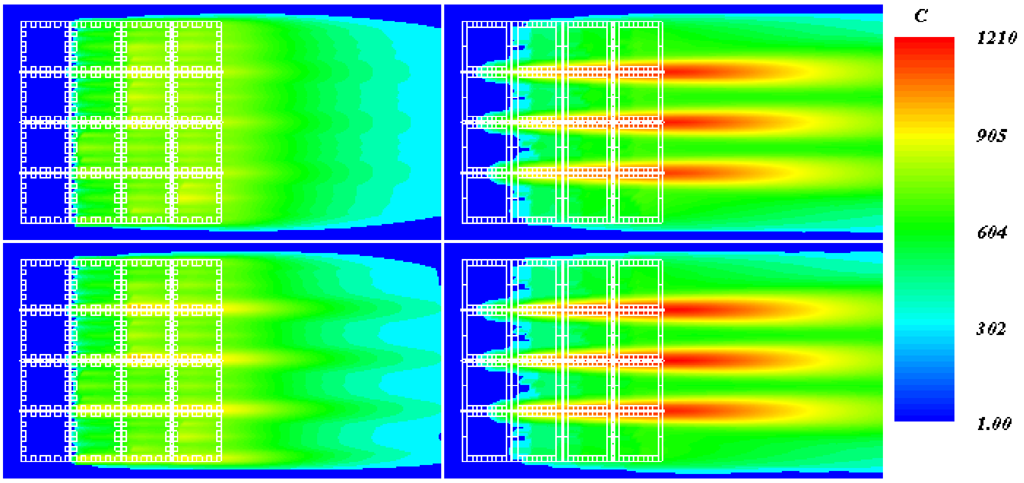

Figure 4: Contour plot of simulated concentrations for wind direction 270 degrees from the north. Top: Profile 1. Bottom: Profile 2. Left: 2-storey buildings. Right: 10-storey buildings.

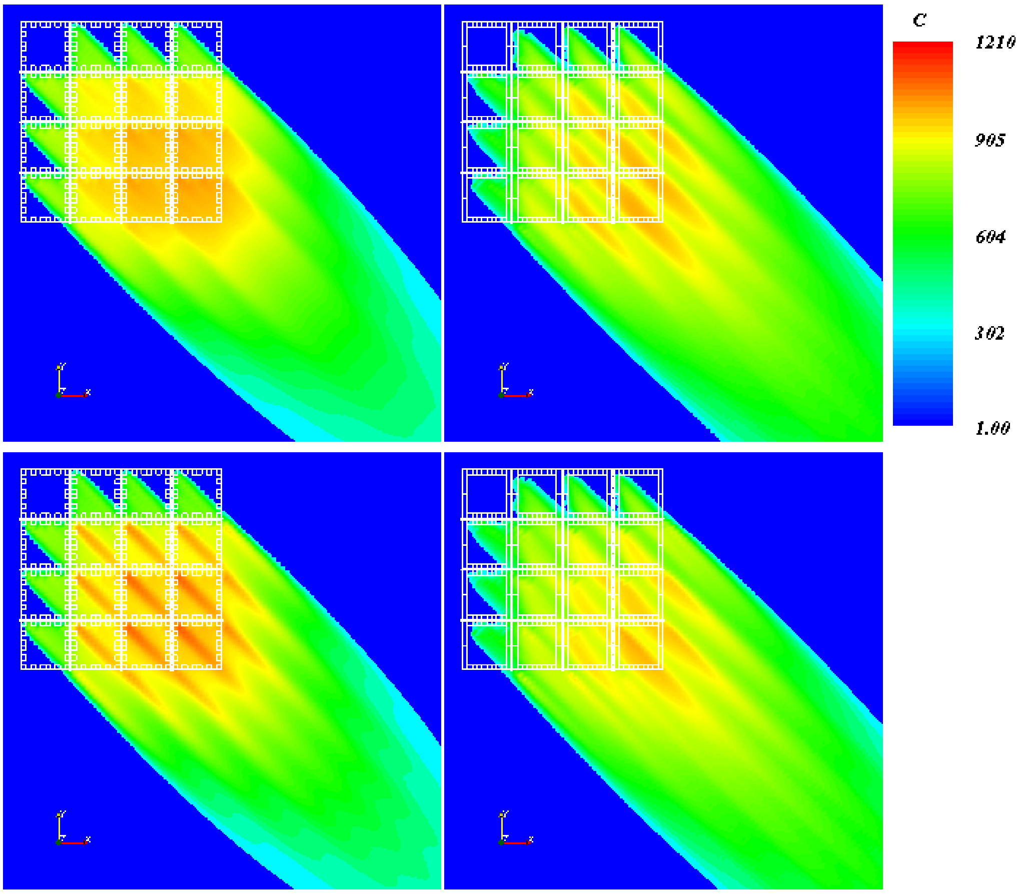

Figure 5: Contour plot of simulated concentrations for wind direction 315 degrees from the north. Top: Profile 1. Bottom: Profile 2. Left: 2-storey buildings. Right: 10-storey buildings.

5 VALIDATION STUDY

To validate the CityZoom-AERMOD model, a comparison with the wind tunnel experimental campaign from the DAPPLE project (Arnold et al. 2004) data was conducted. The site geometry was scaled to real size and imported into CityZoom, because AERMOD cannot handle such small scales. Two cases were then modeled: a single source positioned at X = -6.4 m, Y = -177.6 m, Z = 2 m to use with wind direction 180 degrees from the north and another at X = -55.8 m, Y = -14.4 m, Z = 2 m to use with wind direction 45 degrees from the north. Figure 6 shows the model on CityZoom and highlights the source positions in yellow. Additional source parameters were also scaled to: Q = 0.000583 g/s (equivalent to 2.005 l/m at 17400 ppm), diameter = 1 m, exit velocity = 0.001 m/s and exit temperature = 0.0 (interpreted by AERMOD as equal to ambient temperature). The atmospheric conditions were modeled to try to replicate the wind tunnel conditions.

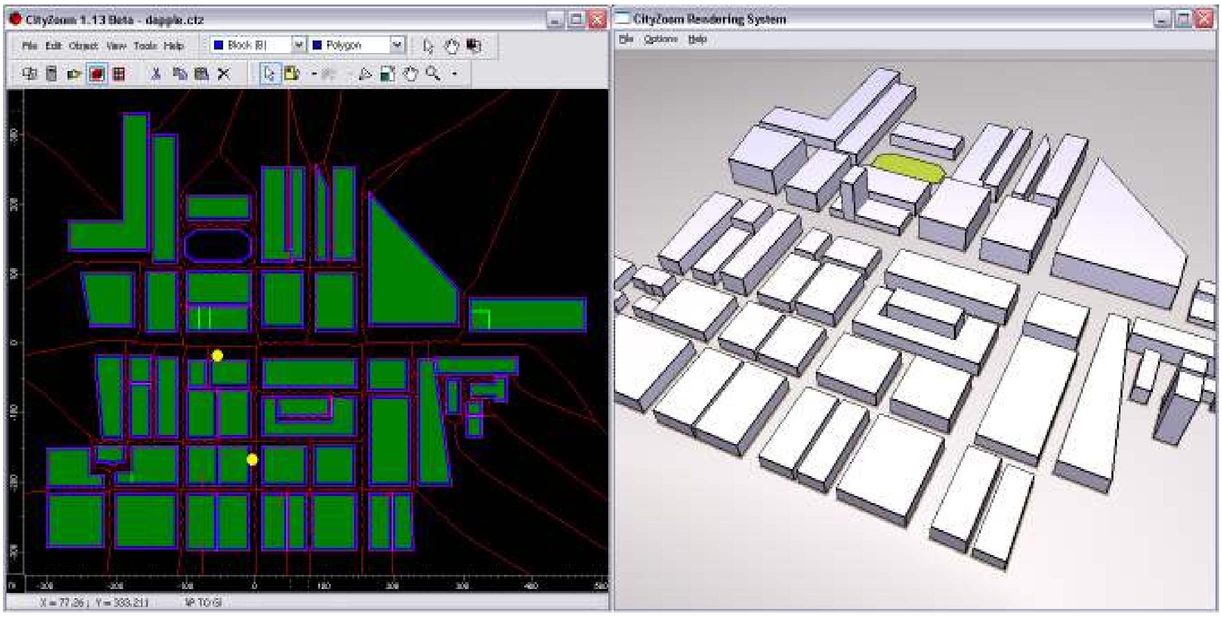

Figure 6: The DAPPLE site geometry on CityZoom.

To establish comparison between the DAPPLE wind tunnel data and the CityZoom-AERMOD simulation results, the non-dimensional concentration, CUA/Q, is used, where U is the surface wind speed and A is the square of the average building height (e.g. 0.11 m for the wind tunnel model and 22 m for the CityZoom model). Figure 7 shows the results for the receptors along the X = 0 axis, with the source positioned at (-6.4 m, -177.6 m, 2 m) and wind direction 180 degrees from the north. Figure 8 shows the non-dimensional concentrations by non-dimensional distance to the source. The straight-line distance R is nondimensionalized by H, the average building height. Figure 9 shows the contour plot of the simulated concentrations.

The maximum simulated concentration results are within one order of magnitude of the measured wind tunnel concentrations. One of the reasons for these differences is the fact that the buildings are not explicitly modeled in AERMOD, but only their influence over each source is considered. These results are relatively good for the computational time needed to achieve them and are acceptable for the purposes of a strategic urban decision tool. For more precise results, a detailed approach such as CFD is recommended, which is becoming available in our tool.

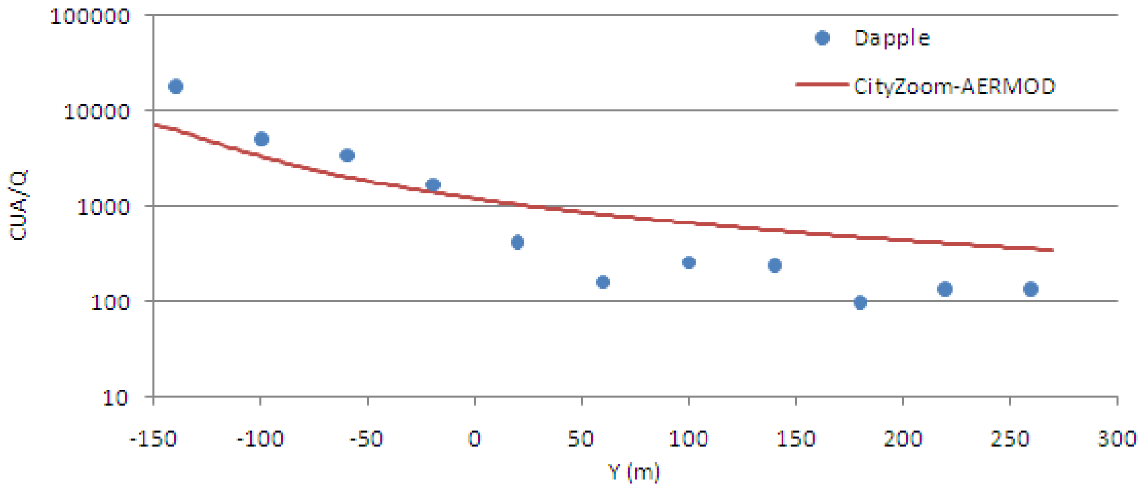

Figure 7: *CUA/Q* at X = 0 for wind direction 180 degrees from the north.

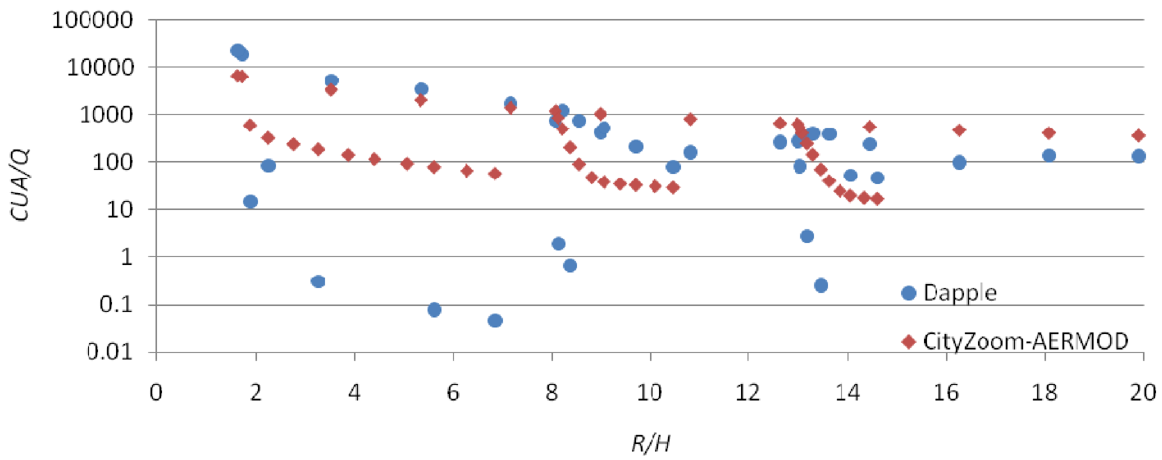

Figure 8: Non-dimensional concentration *CUA/Q* by non-dimensional distance *R/H* to the source.

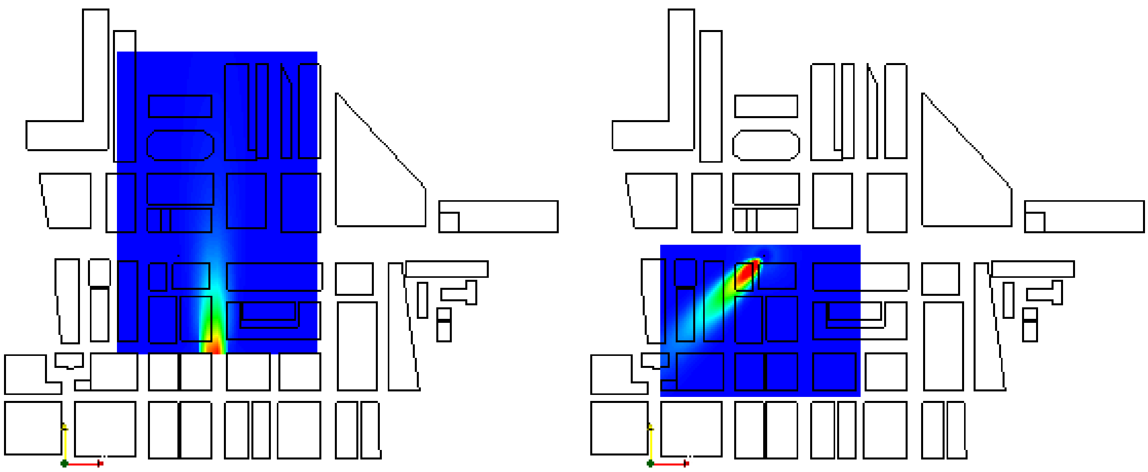

Figure 9: Contour plot of AERMOD simulated concentrations.

6 CONCLUSIONS AND FUTURE WORK

This paper has presented the CityZoom-AERMOD tool and the tests to which it was subjected. The tool can be used for strategic planning, quickly providing results for several different alternatives of built environment, meteorological and traffic profiles. Once the blocks and roads are modeled, CityZoom can be used to generate building alternatives and set the emission profiles then AERMOD can simulate the dispersion of pollutants in no more than a few minutes.

A tool to automatically generate the meteorology files for the different stability classes, in order to test the resulting concentration values for each class, is being developed and should help speed up the process further.

While this fast approach has great strategic value, alternative methods, such as detailed CFD simulations, should be used when more precise results are demanded locally. This is also undertaken as the second part of the present research and preliminary results will be shown at the conference.

7 ACKNOWLEDGEMENTS

This research is supported by the Programme Alβan, the European Union Programme of High Level Scholarships for Latin America, scholarship no. E06D104001BR. The wind tunnel data from the DAPPLE Project was kindly provided by Dr. Paul Hayden, University of Surrey.

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