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Evaluation of results of a numerical simulation of dispersion in an idealised urban area for emergency response modelling

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ABSTRACT

WinMISKAM is evaluated from an emergency response perspective. Comparisons are made between ground level concentrations observed during selected Mock Urban Setting Test (MUST) field trials and predictions generated by the model. The model was driven by 5 min averaged on-site meteorological data, and used minimum grid spacing of 0.5 m in both the horizontal and vertical. The code was found to perform well, with 46% of all predictions (paired in time and space) and 83% of arc maxima predictions within a factor of two of observed concentrations. The model was found to perform better for neutral cases than stable cases with 27% of stable case predictions and 57% of neutral case predictions within a factor of two when compared in time and space.

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1. Introduction

During the last decades, with the growth in urban terrorist incidents, interest has grown in understanding and predicting pollutant pathways within built-up urban areas (Milliez and Carissimo, 2007; Britter and Hanna, 2003). In such areas, traditional methods of predicting pollutant transport and diffusion (T&D), such as Gaussian plume modelling can fail due to critical assumptions not being met, e.g. complex morphology disrupting flows (Gailis and Hill, 2006). With advances in computing power, computational fluid dynamics (CFD) models can now resolve individual buildings and predict wind pathways through such complex terrain as an urban centre. Such models are increasingly being used to simulate the T&D of pollutants within urban areas, where the population is at risk (Milliez and Carissimo, 2007). If such models are to be used in emergency contexts, where success is measured in lives and health, it is of interest to evaluate model performance.

For urban dispersion problems, validation comes traditionally in the form of tracer release and capture studies. Whilst the optimum tracer study for validation of an urban T&D model occurs in a real urban centre within the planetary boundary layer (PBL), cost and difficulty have limited the number of such full scale investigations to a handful (Grimmond, 2006; Batchvarova and Gryning, 2006). In the same way that homogeneous terrain studies have invaluably aided understanding of more complex situations (Fernando et al., 2001), so too does the study of flows within a stylised area aid in understanding flow in more complex geometries, such as a real urban area. The Mock Urban Setting Test (MUST) (Biltoft, 2001b) investigations provide a simplified or stylised urban area, allowing the investigation of the underlying physics involved in urban T&D, without the overwhelming complexities observed in a real urban area (Biltoft, 2001b). The data also capture T&D under a number of different atmospheric conditions, along with a wealth of meteorological data, resulting in an ideal dataset for the validation of urban dispersion models.

From an emergency response perspective, the MUST dataset provides a unique opportunity to investigate the performance of dispersion models, with a view to determining the best response options available to emergency responders in the case of accidental or deliberate airborne releases within urban areas. With the growth of computing power showing no signs of abating, CFD models will soon be able to be run in much shorter timeframes, giving responders access to hitherto unknown information with which to make crucial decisions regarding the preservation of human life and health within highly populated urban areas.

The MUST dataset has been used extensively in the formulation and validation of digital models (e.g., Brook et al., 2003; Milliez and Carissimo, 2007; Santiago and Martilli, 2007; Goricsan et al., 2007). While Goricsan et al. (2007) compared the windfields generated by WinMISKAM to those measured on site during the MUST campaign, and Milliez and Carissimo (2007) analysed the concentration predictions of the CFD code Mercure_Saturne (Archambeau et al.,

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2004) against MUST observations, no-one has yet compared concentration predictions by WinMISKAM against the MUST data.

This paper investigates the performance of WinMISKAM (Lohmeyer et al., 2002a) when run against selected MUST trials. The MUST experiment is outlined in Section 2 and the WinMISKAM model is described briefly in Section 3.1 with the simulation details outlined in Section 3.2. The statistical procedures used to evaluate the model's performance are based on Chang and Hanna (2004) and are outlined in Section 4. Section 5 presents results from the statistical comparison between observed ground level concentrations (C_{ground}) of the passive tracer propylene taken in the MUST investigation and WinMISKAM predictions. Concluding remarks in Section 6 outline possible applications of the model for emergency response situations, both now and in the future.

2. The MUST investigation

The MUST trials were designed to test the effects of an array of roughness elements (buildings) on the flow and dispersion of pollutants within an idealised urban morphology under a range of atmospheric stabilities (Biltoft, 2001a). MUST set up and details of all trials conducted are fully described in Biltoft (2001b). A brief description of parameters important to this study is given below.

120 shipping containers (each 12.2 m × 2.42 m × 2.54 m) were placed in a regular formation of 10 lines of 12 containers forming an approximately 200 m × 200 m square array. Meteorological data was sampled at a number of locations, including four 6 m towers which were distributed within the array, one in each quadrant, each holding two 3-D sonic anemometers (sonics), one at 4 m and the other at 6 m (see Fig. 1). Propylene was used as the tracer and 40 photoionisation detectors (digiPIDs) were arranged in four sampling 'lines' or 'arcs' approximately 25, 60, 95 and 125 m from release locations; these were placed at a height of 1.6 m above ground level (AGL). The sampling calibration range of these detectors was 0.04–1000 ppm(v) (Biltoft, 2001b).

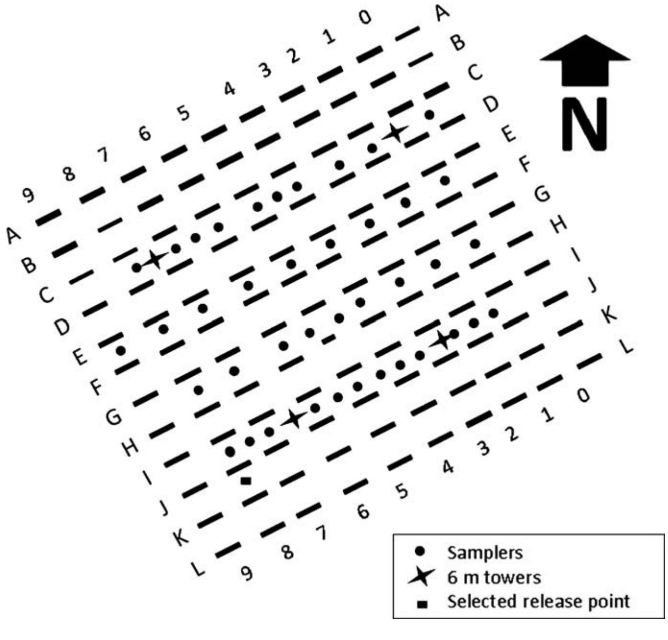

Fig. 1. Diagram of MUST array showing 120 containers, four 6 m towers holding the sonics used in this study (stars) and sampler locations (dots) arranged in 4 lines – line 1 is towards the bottom of the figure between rows I and J and line 4 is towards the top between rows C and D. The release point for runs 2681829 and 2681849 is shown as a small rectangle between containers K8 and J8.

3. The WinMISKAM model

3.1. Model description

MISKAM is a 3-D non-hydrostatic flow and dispersion model for the prediction of the T&D of passive scalars within complex geometric environments, such as those found in built-up urban areas (Eichhorn et al., 1988). The model solves the Reynolds-averaged Navier–Stokes equations with a modified k–ε closure scheme in a non-uniform Cartesian grid and uses the Eulerian dispersion equation to calculate the concentration of scalars across that grid (Eichhorn, 2008). With the Windows interface designed by Lohmeyer Consulting Engineers, WinMISKAM can upload morphology directly from ArcView shape files and requires a single wind vector, along with a vertical potential temperature gradient and information on surface roughness values, to generate a windfield. The model has undergone extensive validation (e.g. Schatzmann and Leitl, 2002; Lohmeyer et al., 2002b; Dixon et al., 2006; Goricsan et al., 2007; Eichhorn and Kniffka, 2007). Version 2.1.2 (with MISKAM 5.02) of WinMISKAM has been used in this study.

Goricsan et al. (2007) compared velocity profiles from the full scale MUST and the wind tunnel simulation performed by Bezpalcova and Harms (2005) to those profiles predicted by two CFD models, MISKAM 5.02 and FLUENT 6.3.26 for a case where the wind blew perpendicularly onto the long sides of the containers. The WinMISKAM model performed well for horizontal wind speeds and directions, with only slight underpredictions near the surface and slight overpredictions at higher altitudes.

Although WinMISKAM has a vertical potential temperature stability setting, the model is designed primarily for use in urban areas where neutral stability dominates (Lohmeyer et al., 2002a). This assumption of urban neutrality can be seen to be valid in a range of studies showing that strong diurnal changes in stability are absent in urban areas (Oke, 1987) and slightly unstable to neutral stability conditions are the norm (Bowne and Ball, 1970; Yersel and Goble, 1986; Kahn and Simpson, 1997; Britter and Hanna, 2003; Salmond et al., 2005; Hanna et al., 2006; Harman and Belcher, 2006; Lundquist and Chan, 2007).

Taking one wind vector as model input, along with roughness and stability information, WinMISKAM assumes a logarithmic wind profile at inflow boundaries. This is consistent with other windfield and dispersion models which do not require numerical weather prediction windfield input such as CAMEO/ALOHA (EPA, 1999), Hotspot (Homann, 1994) and A2C (Yamada, 2004). In this study a dynamical aspect is included by updating the windfield every 5 min and dispersing a theoretical tracer in this changing windfield. The tracer release has been modelled at a height in accordance with the release height of the individual runs, which varied between 0.15 m and 5.2 m. Information on release heights are presented in Table 1.

3.2. Numerical simulations

The WinMISKAM grid used to model the MUST dispersion, first used by Goricsan et al. (2007), contained 400 × 400 × 30 cells, representing 314 × 300 × 130 m, with 50% of grids set to the minimum horizontal grid spacing of 0.5 m and a maximum horizontal grid spacing of 2 m. The minimum vertical grid spacing was 0.5 m, and the maximum at the top of the computational domain was 21.6 m; the lowest 10 cells were set to 0.5 m, with a stretching factor of 1.21 (the maximum recommended by (COST, 2007)) above this level.

Modelled containers (each 12.2 m × 2.42 m × 2.54 m) required between 23 × 5 × 5 grid cells at 0.5 m horizontal spacing and 12 × 2 × 5 cells at 1 m horizontal spacing. All containers were modelled within the area of the grid with 1 m horizontal spacing or

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