Application of a non-hydrostatic meteorological model to flow and dispersion of tracers in a street canyon

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Abstract

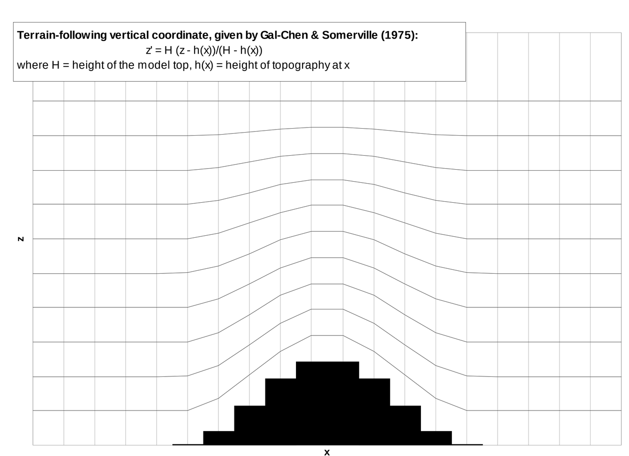
Non-hydrostatic atmospheric models are currently widely used in meteorological research and forecasting. They are able to describe the turbulent eddies, structures and transport of chemical species in convectively active clouds and small scale processes, and include the effects of the full feedback between the dynamical and thermodynamical processes. However, their use of terrain following coordinate meshes has not enabled them to be applied to steep orography and canyon flow. New advances in mathematical techniques now enable flows over almost vertical obstacles (up to 89 degrees) to be modelled using terrain following coordinates.

This poster provides an example of the flow over a street canyon in York. Dispersion of an inert tracer is included. The flow patterns show typical turbulence patterns, and present a tool that can be used as a dynamical base for inclusion of chemical interactions between different species. This model has the advantage of being able to include the full range of atmospheric thermodynamical and dynamical processes, and can be used with a variable spatial grid structure.

Description of the model
(Grabowski & Smolarkiewicz, 2002 MWR, 130, 939-56)

- non-hydrostatic, Eulerian time-stepping in this simulation, with the cfl condition limiting time step.
- anelastic equation set (which filters sound waves) structured, A grid, with ability to be spatially variable
- terrain-following vertical coordinates, as developed by Gal-Chen & Somerville (1975):

$z' = H (z - h(x,y))/ (H - h(x,y))$



- Successfully applied to:
  - mountain-valley flows
  - convective clouds
  - aircraft wake vortices
  - solar convection
  - oceanic flows

Set-up for Gillygate experiment:
(Dixon et al, 2005, submitted Atmos Env)

- periodic domain, with uniform z_0 = 0.1m
- grid-boxes: 231 x 261 x 60, for dx = dy = dz = 1m
- time: 1200 time steps, for dt = 0.025s
- model spin up ~ 30s - results computed for 30s run time – it is anticipated that the spin up and run times need to be longer for statistically significant outputs
- Rayleigh damping sponge above 50m
- Neutral, (constant potential temperature), u_0= 5ms^{-1} from right to left. The periodic boundaries develop a logarithmic type surface layer

Plan of Gillygate, York - Dashed outline defines the model domain. Two lampposts G3 and G4 are marked on the diagram

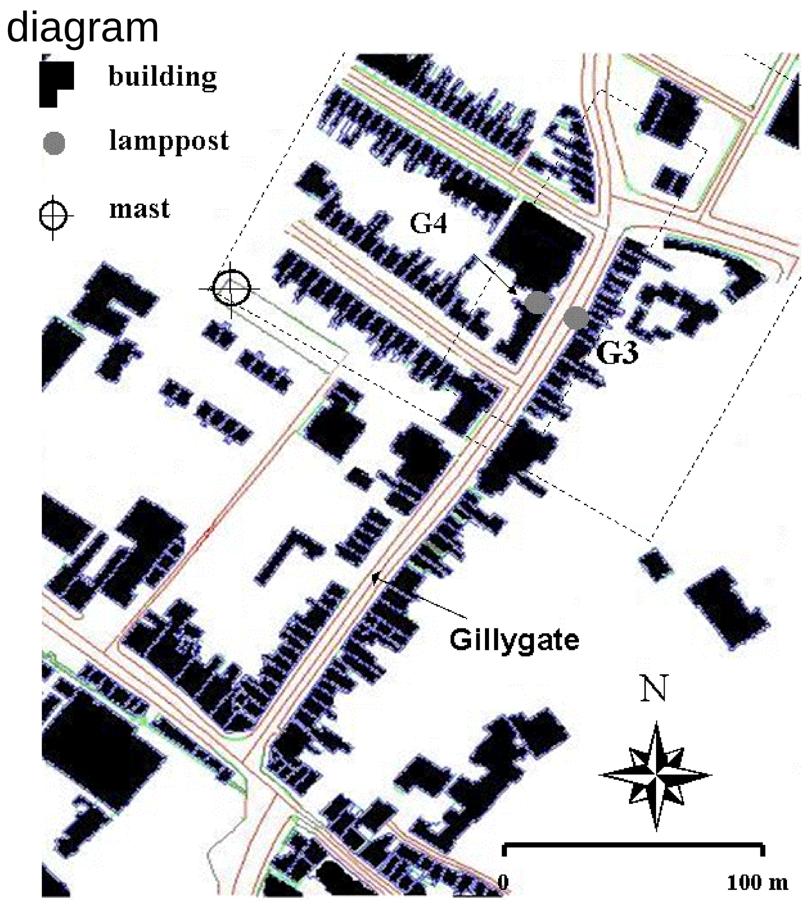


Figure 1: Vertical velocity, *w*, (ms^{-1}) at a height of 2m. Colours illustrate the magnitude of *w*; arrows indicate the resultant velocity in the horizontal plane. Lampposts G3 and G4 are marked at positions (x=29, y=7) and (x=17, y=7) respectively

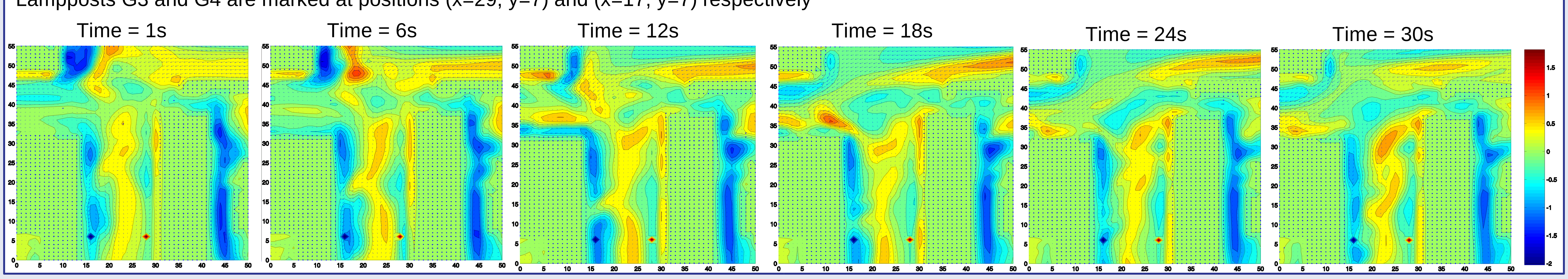
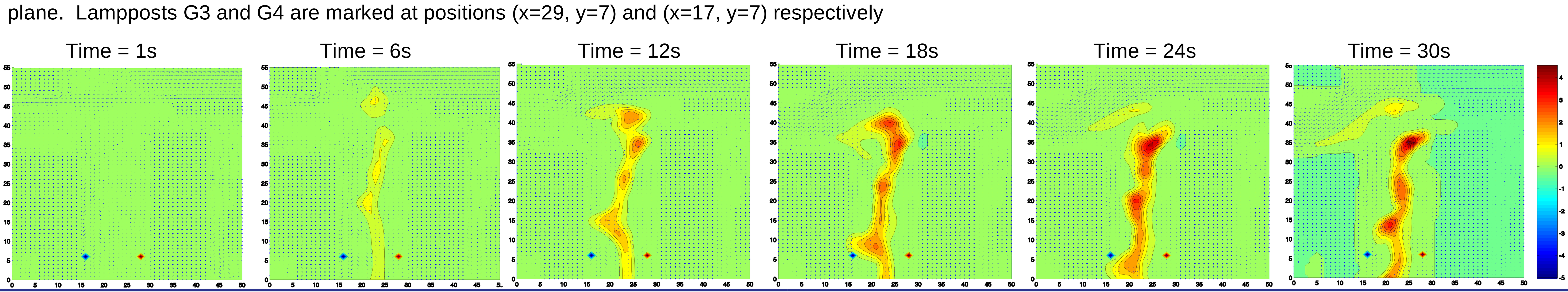


Figure 2: Chemical concentration at a height of 2m. Colours illustrate the magnitude of the concentration; arrows indicate the resultant wind velocity in the horizontal plane. Lampposts G3 and G4 are marked at positions (x=29, y=7) and (x=17, y=7) respectively



Discussion

The aim of this poster is to do a preliminary study applying an anelastic meteorological model to examine flow in a street canyon. Problems associated with obtaining a convergent solution to the Helmholtz (pressure) equation, have prevented meteorological models to be used for these flows, where orography slopes at more than 45^0. The model (Prusa & Smolarkiewicz, 2003, JCP, 190, 601-622, and Smolarkiewicz, 2004, ECMWF workshop 6-10 September 2004) produces a stable and accurate solution. Successful demonstration of this algorithm will enable this model to be used within a larger scale meteorological model, with application to thermodynamically stable and unstable flows, including meso-scale atmospheric structures.

Figure 1 shows velocity plots and Figure 2 shows chemical concentrations for a subsection of the domain, 50m * 55m, with Gillygate in the centre of the image. The inert pollutant release was produced by using a 6m*100m source at the surface and centred between the lamp posts. Plots are shown at 2m in height, showing the concentrations assuming a release flux of 1 unit m^{-2}s^{-1}. Using a non-dimensional formulation of the release (Dixon et al, Atmos Env) for comparison with observational data, where K = C * U_{ref} * H * L / Q , C is the raw concentration, U_{ref} is the reference wind speed at 19m, H is the height of the canyon (10m) and Q/L is the emission per unit length, values of K = 25 and K = 6 were observed on the two sides of the canyon. Even in this short run, structured movement of the chemical along the canyon can be seen. Model solutions show K values varying between 1 and 15 at lamppost G4 and between 2 and 7 at lamppost G3; and the ratio of those values at G3 to G4 varying between 0.3 and 6.0. The tracer is seen to disperse down the canyon in a series of well defined eddies, as in Figure 2, with the corresponding velocities in Figure 1.

Conclusions

This poster demonstrates that this modelling approach can be successfully used to model the dispersion of pollutants in an urban environment. Although only one species has been used for this study, it is possible to include more species and chemical reactions.

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