14.5 DOPPLER LIDAR AND WIND TUNNEL OBSERVATIONS OF FLOW OVER AN URBAN CANOPY

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1. INTRODUCTION

Within an urban area the flow over and around roughness elements (buildings) is very inhomogeneous. The standard procedure for parameterising urban areas within mesoscale and forecasting models is to assume a roughness length which is larger than that used to describe a homogeneous surface. The roughness length parameter is defined by the logarithmic wind profile found in the over-lying inertial sublayer. In rural areas this type of parameterisation has been found to be sufficient to describe surface layer flow. This is not true for urban and suburban areas. In urban areas the roughness elements are far larger and more inhomogeneous.

The vertical structure of the atmospheric flow can be divided into four regions; the canopy layer flow in and around the actual buildings, the roughness sublayer flow above the level of the roughness elements, but where the flow is still determined by the local surface morphology (sometimes referred to as the transition, interfacial or wake layer, Roth 2000), above these are the inertial sublayer and the mixed layer. In consequence an attempt to parameterise a whole complex structure of the urban boundary layer with a simple roughness length is impossible.

The aim of this project was to develop and validate a more comprehensive urban canopy parameterisation scheme. The funding for this research was from the UK government URGENT programme. The collaborators in this project, mentioned below, form part of the UWERN urban meteorology group.

- University of Salford: urban meteorological wind flow data using Doppler lidar.
- University of Surrey: wind tunnel data taken over a variety of urban type surfaces.
- University of Reading: development of an urban canopy parameterisation scheme.

In this work a particular subset of data has been used to look at the internal boundary layer downwind of a step change in roughness. The data has been analyzed to determine an urban canopy adjustment length scale.

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2. URBAN FIELD MEASUREMENTS USING DOPPLER LIDAR

Measurements of wind velocity were taken using the Salford Doppler lidar over a site in central Salford that is part of the Manchester City conurbation. The Salford lidar is a pulsed Doppler lidar capable of measuring radial wind velocities to an accuracy of 0.5 ms^{-1}. The range resolution is 112 m. It has a minimum range of 336 m and a theoretical maximum range of 4.5 km, which is dependant on the aerosol loading of the atmosphere. More details of the system can be found in Pearson and Collier (1999). A scanning mechanism acts to direct the laser beam in azimuth and elevation. The data used in this work was processed to retrieve velocity returns at a rate of 0.33 Hz.

The Salford lidar is mounted in a van and on the day of the field experiment the van was situated within the university grounds. This site was directly upwind of a modern urban housing estate the area was fairly homogeneous consisting primarily of randomly distributed 2 storey houses. Data was analyzed to investigate the adjustment of the wind flow over the housing estate. Upwind of the lidar site was a more inhomogeneous region of multi-storey university buildings, a playing field, a steep embankment and more multi-storey buildings.

The data analyzed for this work was taken on the 3rd April 2001 from 12:00 to 16:00 UTC. The stability of the atmosphere was near neutral ($-z/L = 0.2$, calculation by K.Bozier, presentation **14.2**). The wind flow was South-South-Westerly (190°) and there was a well developed mixed layer seen in radiosonde data taken at a separate location.

Radial wind velocity data was collected along the direction of the mean wind and in a direction perpendicular to it. The data was retrieved for angles 5° - 42° in elevation. The mean wind profiles were then calculated from the lidar data using a method outlined in Gal-Chen *et al*. (1992).

For low elevation angles it can be assumed that the vertical component of the radial wind is very small and that horizontal wind velocity, u, can be approximated by

$$u = R \cos \theta \qquad (1)$$

where R is the radial wind velocity and θ is the elevation angle. For these low elevation angles the horizontal wind velocity can be plotted as a function of both downwind range and height as shown in figure 1.

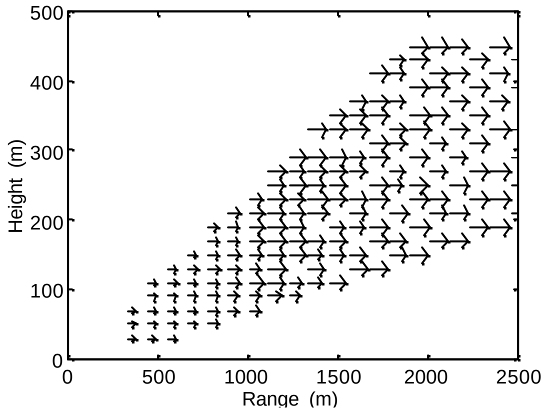

Figure 1. Horizontal wind velocity downwind of the lidar position (Arrows scaled by maximum wind speed = 14.9 m s^{-1})

Plotting this data in the more usual fashion of measurement height against wind speed, figure 2, shows a curve which is comparable to the rough-smooth transition shown in figure 4.2 of Kaimal and Finnigan (1994) .

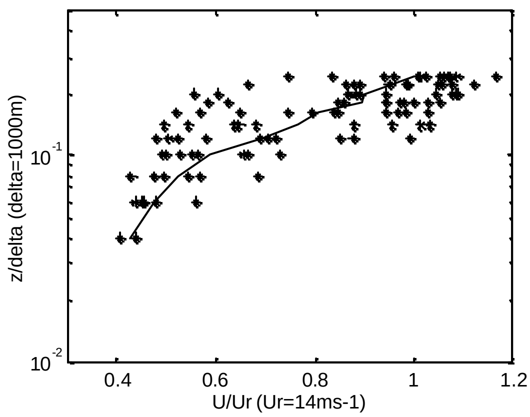

Figure 2. Plot of measurement height, z, non-dimensionalized by the boundary layer depth, δ which is taken to be 1000m, against non-dimensional horizontal wind velocity.

3. COMPARISON OF RESULTS WITH MODEL AND WIND TUNNEL MEASUREMENTS

The horizontal wind flow in figure 1 shows much lower wind velocities immediately downwind wind of the lidar position. This is thought to be due to the wake effect of the buildings next to and upwind of the lidar position. Belcher and Coceal (2001) in an online paper on important scales within the urban boundary layer define a canopy adjustment length scale, L_c, that is determined by calculating the distributed drag over an urban canopy region. The idea of a 'distributed drag' over an urban canopy region follows on from the morphometric methods discussed by Grimmond and Oke (1999) and the details of the urban canopy model are discussed more fully in Belcher, Jerram and Hunt (2001).

The canopy adjustment length scale is calculated from

$$L_c = \frac{\beta h}{c_D \lambda} \qquad (2)$$

where β is the fraction of floor area covered by buildings, h is the height of the buildings, c_D is the drag coefficient and λ is the ratio of the sum of the frontal area of the buildings to the total floor area.

In the case described here, using $c_D = 4.3\times10^{-3}$ as calculated by Bozier *et al* (2001) the canopy adjustment lengthscale, L_c, is calculated to be 1180m. This lengthscale coincides with the speed up in the horizontal wind velocity seen over the urban housing estate that is the less rough surface in this step change experiment.

As part of the collaboration with the University of Surrey wind tunnel data taken over a step change in roughness has been plotted in such a way as to be directly compared to the Salford lidar data (see figure 3 below).

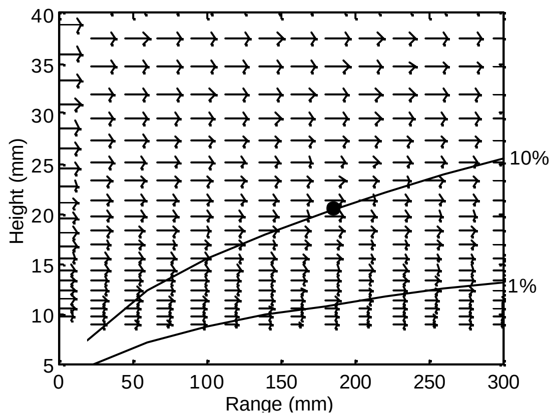

Figure 3. Horizontal wind velocity downwind of a smooth-rough step change with urban type roughness elements in a wind tunnel. (Arrows are scaled by a maximum wind speed = 10.2 ms^{-1}). The curves denote the equilibrium layer over the new surface as defined when the measured windspeed reaches a 10% and a 1% difference from the mean velocity, as calculated by Cheng and Castro (2001). The circle denotes the top of the roughness sublayer over the 'rough' surface, z_0=1.11 mm.

Cheng and Castro (2001) describe the details of the University of Surrey wind tunnel experiment. Figure 3 shows the development of an equilibrium layer downwind of a smooth-rough step change transition. As the internal boundary layer (IBL) develops only the lowest portion of the IBL is in equilibrium with the new surface. This equilibrium layer is defined by Cheng and Castro (2001) using either a 1% or 10% difference in mean velocity. Using the 10% definition, the top of the equilibrium layer reaches the top of the roughness sublayer at a range of 166 z_0, as shown in figure 2. However if a 1% difference is used, the fetch length at which the top of the roughness sublayer coincides with the equilibrium layer, is 886 z_0 (or 987 mm). Calculating the canopy adjustment lengthscale for the rough surface from equation (2) gives us an adjustment length, L_c, of 1040 mm, which is in agreement with the 1% difference fetch length shown above.

4. CONCLUSIONS

The horizontal wind flow shown in figure 1 is unique in that it shows the wind flow within and above the roughness sublayer over an inner city region downwind of a roughness step change. The Salford Doppler lidar has been designed to be used in urban areas, (it is completely eye-safe), and as such is an ideal tool to investigate wind and turbulence over otherwise inaccessible urban areas. Given high enough levels of atmospheric aerosols the Salford lidar can potentially retrieve data upto cloud base level. Roth (2000) notes how few urban boundary layer experiments have been carried out and consequently how little is known of the flow within and above the urban roughness sublayer.

As with any new tool the data and analysis techniques are slightly different from conventional measurements. This paper compares wind profiles from the lidar data in the same context as those from more conventional sources. By putting the wind flows side by side, a comparison has been made to investigate the growth of the internal boundary layer. An adjustment lengthscale, L_c, defined by Belcher and Coceal (2001), has been used successfully to calculate the downwind fetch where the flow has adjusted to the new surface, as shown in the lidar data. This lengthscale, L_c, compares well with the fetch calculated by Cheng and Castro (2001), as defined by their 1% velocity difference definition for the equilibrium layer.

Unfortunately one of the limitations of working with the lidar in urban areas is that the lowest elevation angles for line of sight measurements are determined by the heights of the roof tops in the vicinity of the lidar system. This has limited the ability of the lidar to retrieve data immediately above roof-top level at ranges of greater than about 1 km in the case shown here.

The lidar data shown in this study was taken as a preliminary study and more extensive measurement campaigns are planned to take place in Salford from April 2002. The lidar system is at present being upgraded. This will increase the maximum range of the system to approximately 10 km and improve its reliability and make the system more user friendly. The Salford lidar system is also be involved in an extensive field campaign project to be conducted in Greater London funded by the UK government Department of Environment, Food and Rural Affairs (DEFRA). The project title is 'Air Quality - improvements in pollution forecasting in urban areas', and will consist of both a summer time and a winter time field campaign to be conducted in 2003/2004. The project will involve the deployment of two Doppler lidar systems to retrieve simultaneous wind profile and turbulence data through the whole depth of the urban boundary layer.

5. REFERENCES

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