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ON THE CHARACTERISATION OF URBAN BOUNDARY LAYER FLOW USING MORPHOLOGY AND DOPPLER LIDAR MEASUREMENTS

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1. INTRODUCTION

The structure of the urban boundary layer depends, in part, on the surface roughness. The nature and distribution of urban structures govern airflow within the urban area. As the density of the elements increases, so does the roughness, until a point where adding new elements reduces the effective drag of those already present due to sheltering. Oke (1987) describes the development of three different flow regimes; isolated, wake and skimming flow, depending on the spacing of the buildings, their height and density.

In this paper we analyse data gathered on 27th August 1998 and 3rd April 2001 with the Salford Doppler lidar system (Pearson and Collier, 1999) within the urban conurbation of Salford, Greater Manchester, United Kingdom. Information on the structure of the urban boundary layer has been obtained by deducing values for the aerodynamic roughness length, z_0, zero plane displacement height, z_d, and friction velocity, u_{*0}.

2. DIFFICULTY OF MAKING URBAN MEASUREMENTS

Grimmond and Oke (1999) compare z_0 and z_d derived using morphometric and micrometeorological methods. Micrometeorological methods use field observations of wind or turbulence to obtain aerodynamic parameters, and morphometric methods relate the aerodynamic parameters to measures of the spatial arrangement and size of surface roughness elements.

The relation between the height normalised values of zero plane displacement and aerodynamic roughness length and the packing density of the roughness elements was analysed by Grimmond and Oke (1999). Data obtained from scale model studies and from observational studies were used. The packing density, l_p, is defined as the plan area of roughness elements, A_p, relative to the total surface area, A_T, and the packing density, l_F, is defined as the facial area (vertical plane) of the roughness elements, A_F, relative to the total surface area, A_T. The analysis indicated that even the best available observations do not provide a standard against which morphometric methods can be tested.

3. CRITERIA FOR RETRIEVING HIGH QUALITY MEASUREMENTS IN AN URBAN ENVIRONMENT

The field and wind tunnel experiments reviewed by Grimmond and Oke (1999) and Roth (2000) were only accepted if they met criteria based on stringent experimental quality requirements, enabling a comparison to be made between different urban areas.

The measurement site at the University of Salford, within the urban conurbation of Greater Manchester, and the Salford Doppler lidar system meet the above criteria, and results derived from the system can be assessed against other matching data sets. This will give an indication of the ability of the system located there to provide high quality wind and turbulence measurements within the urban boundary layer.

4. VALUES OF THE FRICTION VELOCITY AND SURFACE DRAG COEFFICIENT

The vertical profiles of the momentum fluxes, $\overline{u'w'}$ and $\overline{v'w'}$, with height have been derived from the lidar data using the procedure outlined in Gal Chen *et al* (1992) on 27th August 1998 between 11.00 – 11.30 hours, and on 3rd April 2001 between 12.40 and 15.30 hours. The values of friction velocity, u_{*0}, were calculated for each measurement height. The friction velocity is much smaller for the first measurement height, 30 m, but similar values are obtained over the height range 40 – 70 m. The largest value occurs at 60 m. the average value over the height range 40 – 70 m is 0.58 m^2s^{-2}. The atmospheric stability on this day was near neutral ($-z/L$=0.8).

On 3rd April 2001 the values of friction velocity, u_{*0}, evaluated for the height range 50 – 300 m were measured. The friction velocity increases from 50 – 200 m and then decreased from 200 – 300 m. The wind speed varied approximately logarithmically with height in the surface layer. The wind speed increasing from 50 – 150 m, and then being relatively constant above 150 m, to a height of 550 m. The atmospheric stability was determined to be near neutral ($-z/L$= 0.2).

5. AERODYNAMIC ROUGHNESS LENGTH AND ZERO PLANE DISPLACEMENT HEIGHT

Calculation of the aerodynamic roughness length will include a value of the zero place displacement height, since the individual buildings are packed close

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enough so that the average roof top height acts on the airflow like the surface. On 27th August 1998 no clear value is indicted for the roughness length. At a height of 30 m, the value lies close to 2 m, at 40 – 50 m, the values lie close to 5 m and between 60 – 80 m, the values lie near to 10 m. For a mean roughness height of 10 m, a value of z_d = 7 m is obtained for the zero plane displacement height and a value of z_0 = 1 m is estimated for the aerodynamic roughness length. This provides an overall value of 8 m ($z_d + z_0$). Using the relationship between z_d and z_0 given by Grimmond and Oke (1999) values of z_d = 5.5 – 7m and z_0 = 0.8 – 1.6 m. On 3rd April 2001 values of z_d = 3.5 m and z_0 = 0.7 m between 50 and 150 m altitude.

6. PACKING DENSITY

The packing density of the surface roughness elements has been estimated for the urban surface to the west and to the north / north east of the lidar position. A comparison of the height normalised roughness values to the packing density has been made with the values published by Grimmond and Oke (1999). To the north / north east values of l_p = 0.45 (derived from a high resolution map and information on building geometry) has been used for the packing density of the surface roughness elements. To the west a value of l_p of 0.20 has been used.

7. URBAN FLOW REGIMES IN SALFORD

The values of the normalised roughness parameters versus packing density derived from the measurements made on the 27th August 1998 and 3rd April 2001 are plotted on Fig 1. Also shown are the field measurements reported by Grimmond and Oke (1999). The new values for Salford are within the limit defined for "real" cities by Grimmond and Oke (1999) from morphology. The roughness values obtained from the Salford observations are a useful addition to those values obtained from the field studies.

The packing density of the surface elements for the Salford measurements are lower than those given by Grimmond and Oke providing clarification of the aerodynamic roughness length and zero plane displacement values for isolated and wake airflow regimes.

8. CONCLUSIONS

Although the urban wind field velocity measurements provided by the lidar system in Salford are limited (especially the 27th August 1998 case), reasonable estimates of roughness parameters have been obtained. A comparison of the derived roughness values with published data collected from high quality urban field measurements show that the Salford Doppler lidar system is capable of providing useful measurements of wind field statistics, aerodynamic and roughness parameters within the urban boundary layer.

8. REFERENCES

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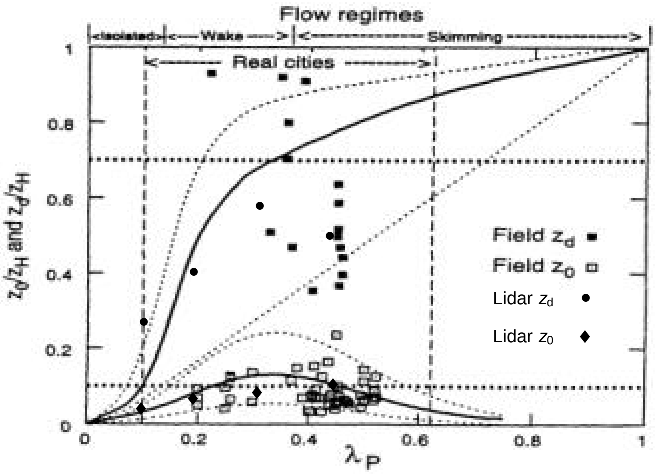

Fig 1: Values of height normalised zero plane displacement (z_d) and aerodynamic roughness length (z_0) estimated from Doppler Lidar measurements in Salford compared to values given by Grimmond and Oke (1999) as a function of packing density (l_p).