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3.5 INFLUENCE OF BUILDINGS AND TREES ON TURBULENCE PARAMETERS IN THE URBAN ROUGHNESS SUBLAYER

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ABSTRACT

Most experiments attempt to place instrumentation at an elevation high enough to avoid the influence of individual surface features while still remaining low enough to be in the constant flux layer. In complex urban environments, these two conditions cannot always be satisfied simultaneously. This study looks at the effects of local features on data from sonic anemometers placed within the urban roughness sublayer. Within the roughness sublayer, trees produce a magnitude of turbulence comparable to the turbulence produced by buildings of similar height.

1. INTRODUCTION

Surface layer relationships, derived over flat homogeneous terrain, are the basis of urban boundary layer models. Most experiments attempt to place instrumentation above the effects of local influences in order to take measurements in a region of the atmosphere where fluxes are relatively constant with height and that represent a large typical area (Grimmond 1998, Roth 2000). However, the complex rough surface makes for a deep roughness sublayer that can extend well into the mixed layer region of the boundary layer eliminating the existence of any constant flux layer where surface scaling relationships apply (Mahrt 2000). As a result, it cannot be assumed that a constant flux surface layer exists or even that the instrumentation is in the constant flux layer when one does exist. A better understanding is needed of the flow within the roughness sublayer in order to make sense of the complex data obtained from the urban environment. This information will also become more important as computer models incorporate more surface detail and finer scale grids near the surface.

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2. DATA

The Army Research Laboratory (ARL) deployed an array of sonic anemometers (RM Young 81000) mounted on five towers in Oklahoma City, Oklahoma, during the Joint Urban 2003 field campaign, a cooperative undertaking to study turbulent transport and dispersion in the atmospheric boundary layer within an urban environment. The towers were located in a variety of locations to sample both industrial (urban) and semi-rural (suburban) conditions.

Each tower had sonic anemometers at 10 meter and 5 meter elevations. The 10m sonics were mounted above the tower, so little influence is expected from the tower for these instruments. The 5m instruments were mounted due south of the tower.

Tower locations 1, 3 and 4 are categorized as suburban. The tower 1 location is a transit authority parking lot about 5 km SW of the central business district (CBD) and is surrounded by fields to the S, E and N and by a few one to two story buildings to the W and residential areas further to the W (Figure 1). There is also a mobile trailer office, approximately 2m tall, about 30m to the SSW. The tower 3 location is a Parks and Recreation Department field about 5 km SE of the CBD. A golf course is located to the S and SE, stands of trees are to the E and W and a one story building is to the N. The tower 4 location is about 5 km N of the CBD in a grassy field near a church and school. The surroundings are mostly open except for a wooded area to the N and NE and a building to the W.

Tower locations 2 and 5 are categorized as urban. The tower 2 location is about 1.0 km E of the CBD located in an open area surrounded by industrial buildings on all sides (Figure 2). The buildings nearest to the tower are to the N and W. The longest clear fetch is to the E and SE. The buildings range in height from 8-10 meters. The tower 5 location is about 1.5 km W of the CBD, and is located near low industrial buildings to the E, S and W. To the N is an open area with several widely spaced tall trees 20 meters or more from the tower. To the SW is a tall tree, approximately 12m in height, only about 15 meters from the tower. Another tall tree (10-12m) is located between buildings to the SE over 50 meters from the tower. The buildings range in height from 5-7.5 meters.

Fig. 1 Aerial photos of the suburban tower sites courtesy of the United States Geological Survey. The white circles mark the tower locations.

Fluxes are computed as deviations from 10 min averages for daytime (1400-1300 UTC) and from 5 min averaged for night time data (0300-1100 UTC). Tilt correction is done by setting $\overline{v} = \overline{w} = 0$ for each 10 min (5min) segment. Half hour average values are then constructed from three (six) fluxes. Only data with stationary wind directions are used (Klipp 2006). Winds were primarily out of the S or SW for most of the month. Sparseness of data for some directions, in combination with the stationarity requirement, results in some wind directions having no data.

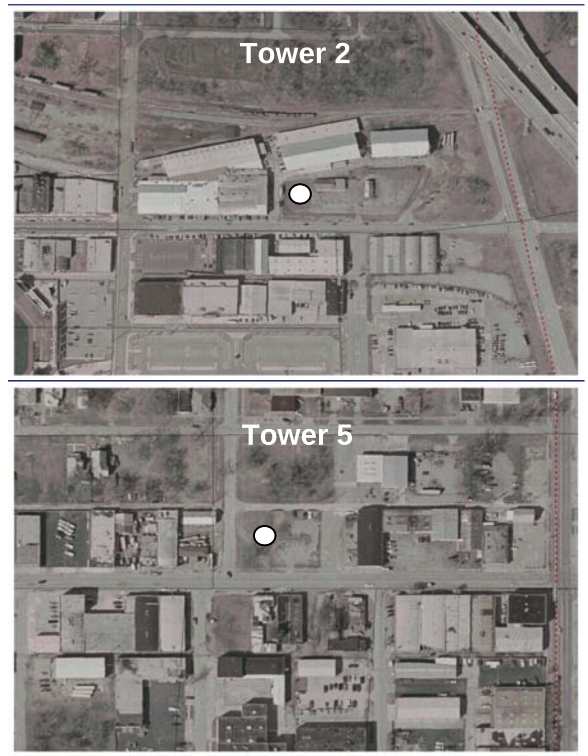

Fig. 2 Aerial photos of the urban tower sites courtesy of the United States Geological Survey. The white circles mark the tower locations.

3. DRAG COEFFICIENT

The drag coefficient, $\mathrm{C_D} = u_*^2 / \overline{\mathrm{U}}^2$, is known to vary over different surfaces. Average measured C_D values are much higher at the urban towers 2 and 5 compared to the values at the suburban towers 1, 3 and 4 (Table 1). Mean night time values are slightly lower than mean daytime values.

As can be seen in figures 3 and 4, C_D values vary greatly depending on the upwind fetch. Tower 1 is relatively open with few local obstructions and little corresponding change in C_D.

Tower 2 C_D values are largest to the north where a 12m tall building is located. Shorter buildings are located farther away to the south. C_D values approach tower 1 values for winds from the east, where the fetch is relatively free of obstructions. A comparably sized building is located to the west, but due to sparse data from that wind direction there is little data.

At tower 3, a low building to the north and a stand of trees to the west produce elevated C_D values. Many of the data segments for data with east winds at this tower fail to meet the chosen stationarity criteria, resulting in very few data points with this fetch where a large stand of trees and a low building are located. The few remaining data points for winds from that sector have large values of C_D.

Tower 4 fetches are mostly open. A forested area is located to the north and northeast. None the less, C_D values are similar to tower 1 values except to the northeast where the fetch to the trees is the shortest.

Tower 5 is located in an area of low industrial and commercial buildings (5-8m) and isolated tall trees (9-12m). The trees to the north and southwest, which are closest to the tower, produce C_D values comparable to the building to the north of tower 2. The other fetch directions have lower C_D values but they are still larger than the C_D values from areas with open fetches such as tower 1.

Tab. 1 Drag coefficient values for the 10m and 5m levels at all towers for both day and night.

tower	Day		Night	
	10m	5m	10m	5m
1	0.016	0.017	0.015	0.017
2	0.039	0.047	0.036	0.044
3	0.023	0.022	0.016	0.014
4	0.026	0.026	0.021	0.021
5	0.051	0.041	0.040	0.034

In general the night time C_D values are smaller than day time values, however the presence of an upwind obstruction tends to produce slightly larger C_D values. The tree obstructed fetches ate tower 5 are the most dramatic examples.

In general the data from the 5m levels are similar to the 10m data. The one notable exception is the tower 5 daytime plot where the drag coefficients for the SW fetch are of the same magnitude as the drag coefficients from the 90°–180° fetch directions.

Large trees produce C_D values comparable to C_D for similar sized buildings. The larger C_D values are due more to reduced wind speeds in the lea of the largest obstructions than to larger u_* values.

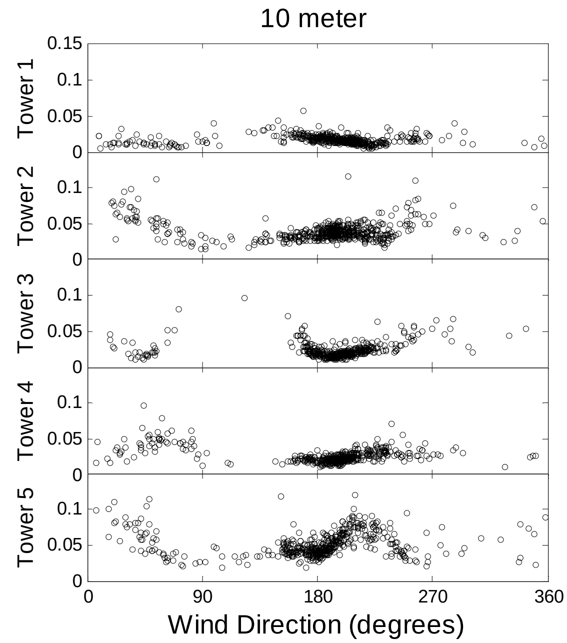

Fig. 3 Daytime coefficient of drag values at 10m for all 5 sites. 5m data is similar. See text for discussion.

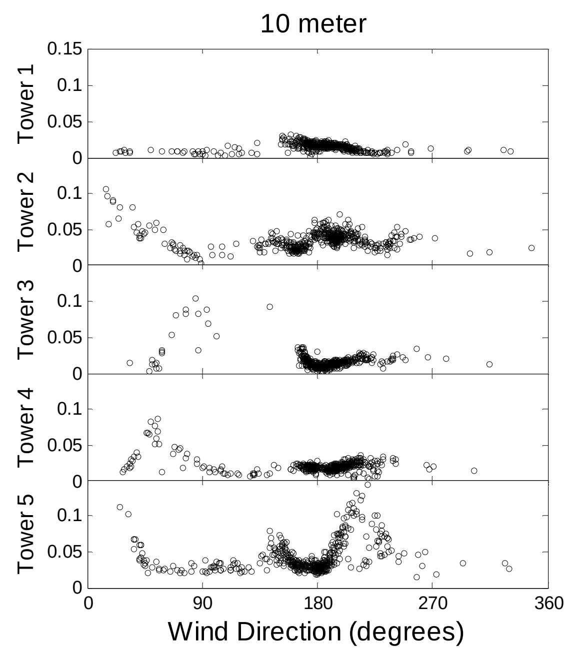

Fig. 4 Nighttime coefficient of drag values at 10m for all 5 sites. 5m data is similar. See text for discussion.

4. SCALED TKE

Scaled turbulent kinetic energy, TKE/u_*^2, where $\mathrm{TKE} = \left(\overline{u'u'} + \overline{v'v'} + \overline{w'w'}\right)/2$, is usually taken to be a constant at night and a stability dependent value in the daytime (Sorbjan 1989). From figures 5 and 6 it can be seen that most of the night time values tend to be between 3.5 and 5 except in the vicinity of the tree near tower 5, especially at the 5m level.

Daytime values are more scattered and fall primarily in the 5-10 range. In general the daytime suburban values are more scattered than the urban values. The tree near tower 5 results in large values at the 5m level, but trees and obstructions further away have little influence. Conditions throughout the month were fairly uniform, so z/L values remained in a fairly narrow range and were close to neutral both day and night. This makes stability effects difficult to evaluate.

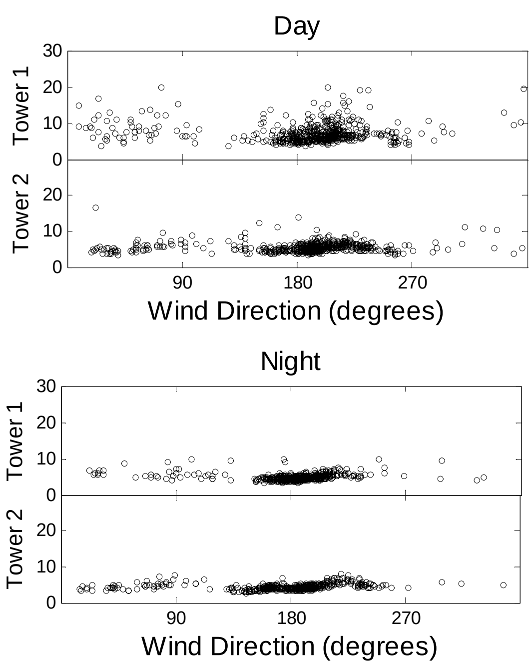

Fig. 5 Scaled TKE values at 10m for towers 1 and 2. 5m data is similar. Data for towers 3 and 4 are similar to tower 1 data.

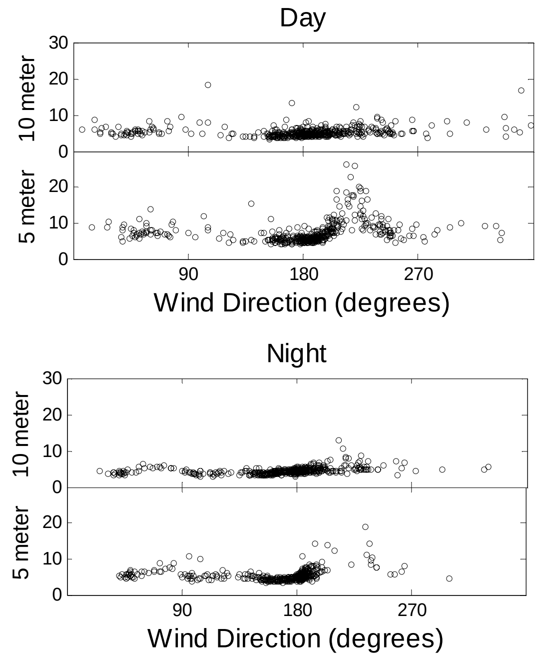

Fig. 6 Scaled TKE values for towers 5.

5. CONCLUSIONS

In the roughness sublayer, local obstructions can significantly affect the measured values of turbulence parameters such as C_D and scaled TKE. The magnitude of the effect is in proportion to the size and distance of the obstruction and is the same whether the obstruction is a tree or a building. The nature of the turbulence due to buildings or trees may be different, but the effect on the standard flux measures is comparable.

Acknowledgements

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REFERENCES

Gimmond, C. S. B., T. S. King, M. Roth and T. R. Oke, 1998: Aerodynamic roughness of urban areas derived from wind observations. *Bound.-Layer Meteor*., **89**, 1-24.

Klipp, C. L., 2006: Wind direction dependence of atmospheric boundary layer turbulence parameters in the roughness sublayer. In review for *J. Appl. Meteorol*.

Mahrt, L., 2000: Surface heterogeneity and vertical structure of the boundary layer. *Bound.-Layer Meteor.*, **96**, 33-62.

Roth, M., 2000: Review of atmospheric turbulence over cities. *Quart. J. Roy. Meteor. Soc.*, **126**, 941-990.

Sorbjan, Z., 1989: *Structure of the Atmospheric Boundary Layer*. Prentice Hall, 317 pp.