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Determination of Urban Surface Aerodynamic Characteristics Using Marquardt Method

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1. Introduction

Surface aerodynamic parameters, including roughness length (z_0), displacement height (d) and friction velocity (u_*) impact the atmospheric boundary layer structure and evolution directly. The determination of urban surface aerodynamic parameters is an important question in the researches of urban wind field characters, urban microclimate, urban air pollution, urban wind energy development and so on. Grimomond, *et al*. (1998) summarized the main methods in this field and further works were carried out by other scientists (e.g. Martano 2000, Gao and Hu 2004, Arfield 2003, Al-Jiboori and Hu 2005), but it is still a challenge due to the complexities of urban area. In this paper the nonlinear least square Marquardt method is used to estimate the urban aerodynamic parameters of Beijing City with the observation data from a 325 m observation tower.

2. Methodology and Data

The Marquardt algorithm (Marquardt 1963) has been proved to be an effective and popular way to solve nonlinear least square problems. In this paper Marquardt algorithm is applied on logarithmic velocity profile under neutral atmospheric boundary layer condition for our purpose.

The 325 m meteorology observation tower is in Institute of Atmosphere Physics, Chinese Academy (IAP), Beijing, China, locating at (39°58'N,116°22'E), with an elevation of 43 m. The tower is at the metropolitan of Beijing city, surrounded by clusters of buildings (details information refered to Al-Jiboori and Hu 2005). This site has been an ideal observation location for urban micrometeorology. Slow-response wind anemometers are mounted at 15 observation layers of 8, 15, 32, 47, 63, 80, 102, 120, 140, 160, 180, 200, 240 and 320 m.

The levels between 47 m and 120 m (47, 63, 80, 102, 120 m) were proved to be in the constant layer by Liu and Hong (2002). In this paper, the winter (November, December, January and February) and summer (July, August, September) observations at these five layers in 2001, 2002 and 2003,including wind speed, wind direction, temperature and relative humidity, are used. The

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original data are of sampling interval of 20s and are averaged in an interval of 10 minutes after quality control. Bulk Richardson are calculated to determine the stratification conditions and 11418 groups of neutral condition cases are run out of the total 60679 available observations.

3. Results

First, all wind speed between 47 m and 120 m using logarithmic wind profile function are simulated with the estimated d, z_0 and u_*., and compared with the observations. This simulated wind speed is very close to the observed speed with a correlation ratio of 0.96. The linear fit equation between observations (U_{obs}) and simulations (U_{sim}) is: $U_{sim} = 1.05*U_{obs}$. This indicates that U_{sim} overestimates 5% of U_{obs} over an ensemble average of all samples. This overestimation always happens when U_{obs} is greater than 8m/s; the samples under such a condition are only of 2% of the all observation samples. The comparison between U_{obs} and U_{sim} demonstrates that the Marquardt method can give reliable d, z_0 and u_* using this database.

Drag coefficient is always used to reflect the rough status of a surface, which is defined as $C_d = (u_*/U)^2$. In this paper, the linear fit ratio between u_* and U is 0.125 in this paper. This is greater than the ratio 0.1 for natural smooth surface ($z_0 < 0.01$ m). This result is less than 0.17 estimated by Liu and Hong (2002). The potential reasons caused this difference may lay on the estimation and observation methods. In Liu and Hong (2002), the u_*/U was estimated with sonic anemometer observations and averaged under all atmosphere stability conditions.

Both displacement height (d) and roughness length (z_0) are determined by the rough elements combining the underlying surface. Due to the very inhomogeneous of urban surface, it has been proved that d and z_0 vary with incoming flow direction in in-situ observations due to different wind fetches and land surface characteristics. The observation area around observation tower is divided into eight directional sectors of 45°: N-NE(1-45), NE-E (46-90), E-SE (91-135), SE-S (136-180), S-SW (181-225), SW-W (226-270), W-NW (271-315) and NW-N(316-360). The rough element height in a radius of 1 km z_H in different sectors and the averaged estimated d and z_0 under the respective inflow wind directions are listed in Table 1. The results show that the spatial variations of d and z_0 depend well on the spatial change of z_H. Both d and z_0 are maxim in the sectors of S-SW in which sector the roughness element is highest.

The mean value of z_0 is 1.2 m and the mean d is 7.6 m. This result in this paper agrees well with the previous researchers results as shown in Table 2. It should be noticed that the value of z_0 is

Table 1 Rough element height (z_H), displacement height (d), roughness length (z_0) at different sectors

Sector	N-NE	NE-E	E-SE	SE-S	S-SW	SW-W	W-NW	NW-N	Average
z_H (m)	7.7	8.7	10.2	11.9	18.7	14.9	6.1	11.0	11.2
d (m)	6.9	7.1	7.6	7.7	9.2	9.0	5.7	7.5	7.6
z_0 (m)	1.2	0.9	1.1	1.1	1.5	1.4	0.9	1.1	1.2

Table 2 Comparison of displacement height (d), roughness length (z_0) with other researchers' works

Urban Type	z_0 (m)	d (m)	Observation location	Reference
Low buildings and Trees	0.5	3.5	Vancouver	Steyn(1982)
	1.3	12	Kobenhavn	Jensen (1958)
Regular building clusters	1.0	8	Uppsala	Karlsson (1986)
	1.2	7.6	Beijing	this paper

lower than that estimated by Al-Jiboori and Hu (2005) using a ten day observation in April, 2000. Further investigation on long-term observations is needed to compare the results from different method. The ratio of d/z_H is 0.69, which is very close to d/z_H =2/3 recommended by Garratt (1980). Our work indicates that reliable urban aero dynamical parameters can be gained from the low-response observations with Marquardt method and it is an expansion to the works in Table 2.

4. Summary

Marquardt method is used to estimate the aerodynamic parameters in urban area of Beijing City, China, including displacement length (d), roughness length (z_0) and friction velocity (u_*) and drag coefficient. The surface drag coefficient defined as the ratio between friction velocity and mean wind speed is 0.125 in our research, which is close to typical urban area value. The averaged d and z_0 are 1.2 m and 7.6 m. d and z_0 change with direction because of the surface heterogeneity over urban surface and reach their maximum values at S-SW sector, this tendency agrees with the surface rough element distribution around the observation tower.

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