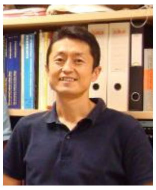

Hirofumi Sugawara

Measurement of roughness parameters over urban heterogeneous canopy

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1. Abstract

Zero-plane displacement height over urban canopy was measured in Yoyogi Tokyo. We determined the displacement height from the measured variance of temperature and Monin-Oukhov similarity equation. The measured displacement height was 24 to 35 m which is much larger than the mean building height. The displacement height was largest at the area with the skyscrapers and the least value was found in the park area. Exceeding mean building height should be due to the height variation of buildings in the canopy. The measured displacement height normalized by the maximum building height agreed with a previous numerical model study.

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2. Introduction

The zero-plane displacement height is an important parameter for evaluating wind speed profile and turbulent intensity above urban canopy. The morphometric methods are often used for determining the displacement height, however the Grimmond and Oke (1999) noted the existing morphometric equations can not fully express the observed displacement height. The building height variation, which is not considered in the previous morphometric equation, could be the reason for the discrepancy. Numerical model study by Nakamura et al. (2011) and Kanda et al. (2013) re-produced wind speed profile considering the height variation and determined the displacement height. They showed the larger displacement height than the previous morphometric method. Wind tunnel study by Zaki et al. (2011) showed experimentally that the displacement height increases as the height variation increases. However, little of field observation study deals with the building height variation as a controlling factor of the displacement height (e.g. Tanaka et al., 2011). We observed the displacement height over the urban canopy in Yoyogi Tokyo.

3. Observation

The study area is a mid-rise residential area in Yoyogi, Tokyo, Japan (Fig. 1). A sonic anemometer (WindMasterPro II, Gill) installed on a roof-top tower (52-m above ground, 25-m above roof) measured turbulent fluctuation of wind and temperature in 10 Hz. The mean height of the buildings was 9-m and the building height variation will be listed in Table 1. Analysis is focused for the fine days in winter (January 2013) and summer (Jul 2013). The Bowen ratio was 1.9 and 1.7 for these terms respectively.

We used the temperature variance method (Rotach, 1994), which uses the MOS equation for temperature variance,

$$\frac{\sigma_T}{T_*} = -c_1\left(c_2 - \frac{z-d}{L}\right)^{-1/3} \qquad (1)$$

where T_* is the friction velocity, *z* measurement height, *d* displacement height, and *L* Obukhov length. For the constants C_1 and C_2, we used values of 0.95, -0.02 respectively (Rotach, 1994), although the values in other study (0.99, 0.06 by Tillmann, 1972) would make the estimated displacement height 2 – 10 m larger. The displacement height was estimated for each 45°-width wind sector. The minimum RMSD between eq. (1) and the measured variance was adopted in the selected runs (N=10 – 30). The runs were selected for the data quality where, 1) –z/L > 0.3, 2) daytime, 3) no precipitation, 4) constant wind direction in the run(< 90°).

Fig. 1. The study area. Tower location is denoted by X.

4. Results

Figure 3 shows the RMS in fitting eq. (1) to the measured variance. The minimum RMS are less than 0.2, which is smaller than those (~0.4) of Rotach (1994). Given the 10% error in the measured variance of temperature, error range of the displacement height is 2 – 5 m.

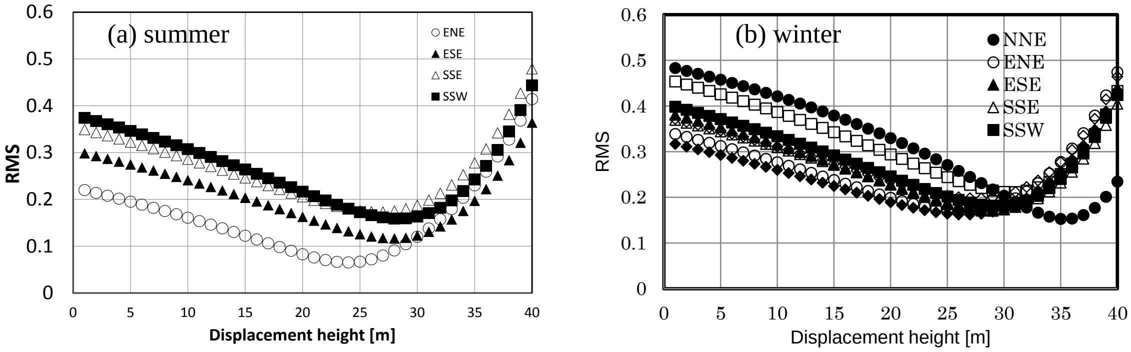

Fig. 2. Estimation result of displacement height for each wind sector. The vertical axis is RMS in fitting eq. 1.

Figure 4 summaries the results. The estimated displacement height were 24 – 35 m which exceed the mean building height (9 m). Variation for wind sector is apparent; the largest d of 35 m (winter) in 0 – 45° sector while smallest 26 m (winter) in 45 – 90° sector. This should be due to the land-cover variation. There are some skyscrapers taller than 300 m at NNE, on the other hand large park with open field at ENE.

The displacement height is smaller in summer rather than winter in every sector. Although the seasonal differences (1 – 2 m) is not statistically significant (N=10 – 30), the measured seasonal difference agrees the influence of the atmospheric stability suggested by the previous studies (Kanda et al., 2002: Zilitinkevich 2008). However, the temperature variance method uses Obukhov length L as the universal parameter and it is inconsistent that the resulted d depends on L. Note that use of inadequate values for C_1 and C_2 would make virtual dependency of d on L.

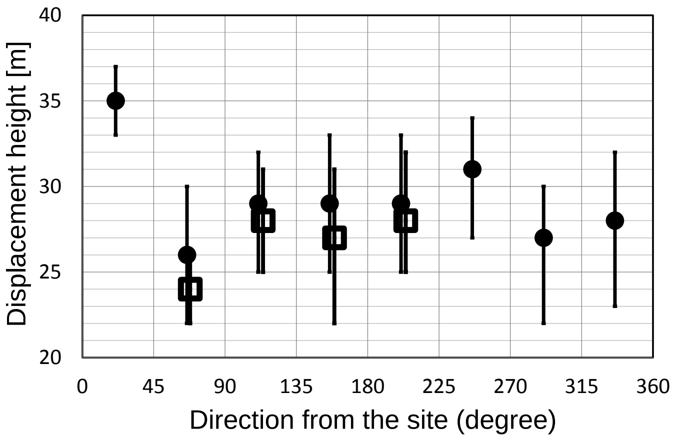

Fig. 3. Estimated displacement height. Black circle: winter; open box: summer. The error bar indicates estimated error range from 10% RMS 10%.

Comparison to the morphometric method (Macdonald et al., 1998) is shown for winter in Table 1 and Fig. 5(a). When the mean building height H_{avg} is used as the canopy height h in the morphometric method, the morphometric d is much smaller than the measurement. On the other hand, the maximum building height H_{max} is adopted, the morphometric d approached the measurement. Trial with $H_{avg} + \sigma$ showed similar results to that of H_{max}.

Table 1. Comparison between the measured displacement height d_{mes} and morphometric method d_{mpm}. H_{std} indicates the standard deviation of building height. λ_p is the plane area ratio of building.

Wind sector	H_{avg} [m]	H_{max} [m]	H_{std} [m]	λ_p	d_{mes} [m]	d_{mpm} (H_{avg}) [m]	d_{mpm} (H_{max}) [m]
NNE	20	221	18	0.33	35	12	130
ENE	12	77	7	0.22	26	5	34
WNW	9	73	8	0.35	27	6	45
NNW	10	37	6	0.32	28	6	24

Figure 5(b) also shows the comparison with LES-morphometric method developed in Kanda et al. (2013). The observed *d* is included in the range of LES simulation with real building geometry. One exception included in the LES for homogeneous canopy is the result in NNW sector where H_{std} is smaller than that of the other sectors.

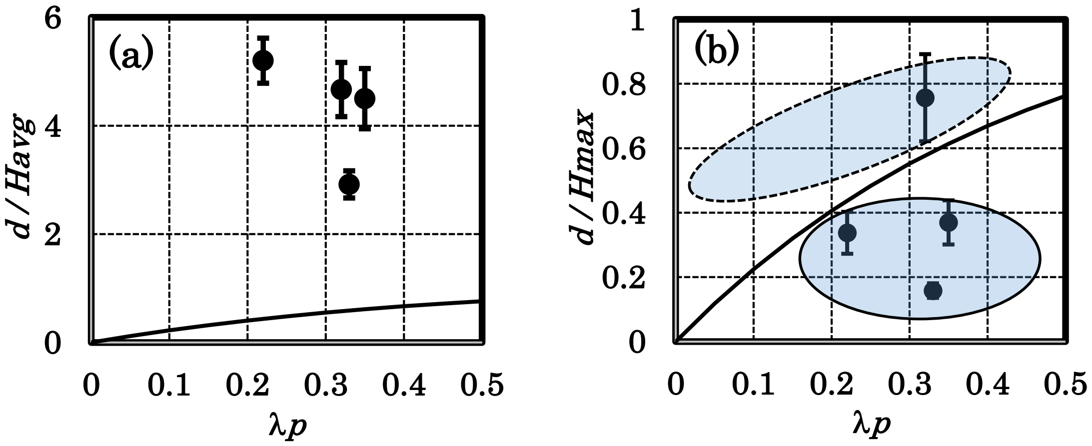

Fig. 4. Comparison between the observed results (filled circle) and morphometric method by Schmid et at. (1998) (line). H_{max}: maximum height of building; H_{avg}: average building height. In panel (b), the area enclosed by solid line indicates the results of real urban simulation in Kanda et al. (2013). The area with broken line is for results of homogeneous height canopy.

8. Conclusion

The zero-plane displacement height was measured in Yoyogi Tokyo. The measured displacement height was 24 – 35 m which is much larger than the mean building height 9 m. This could be due to the height variation of buildings. The displacement height normalized with maximum building height agreed with the LES study by Kanda et al. (2013).

Acknowledgment

The authors wish to thank Prof. Takashi Nakajima in Tokai Univ. for supporting the observation. This study was financially supported by Grants-in-Aid for Scientific Research from the Ministry of Education, Culture, Sports, Science and Technology, Japan (24241008).

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