Estimation of roughness parameters of urban area using wind profile data obtained by a Doppler lidar system

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INTRODUCTION

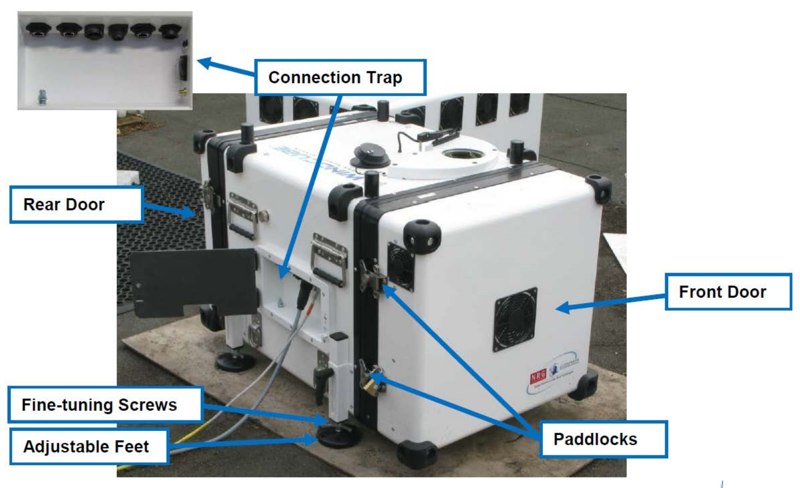
Recently, observational studies on wind profile and turbulence in and above the urban canopy layer becomes more important, as the urban energy balance schemes for the atmospheric model have been more sophisticated. However, such observations are very few especially for wind profile and turbulence at the urban area with approx. 100 m heights of skyscrapers. This is because setting up an observation tower and operation of kytoons at such highly urbanized area are virtually impossible.

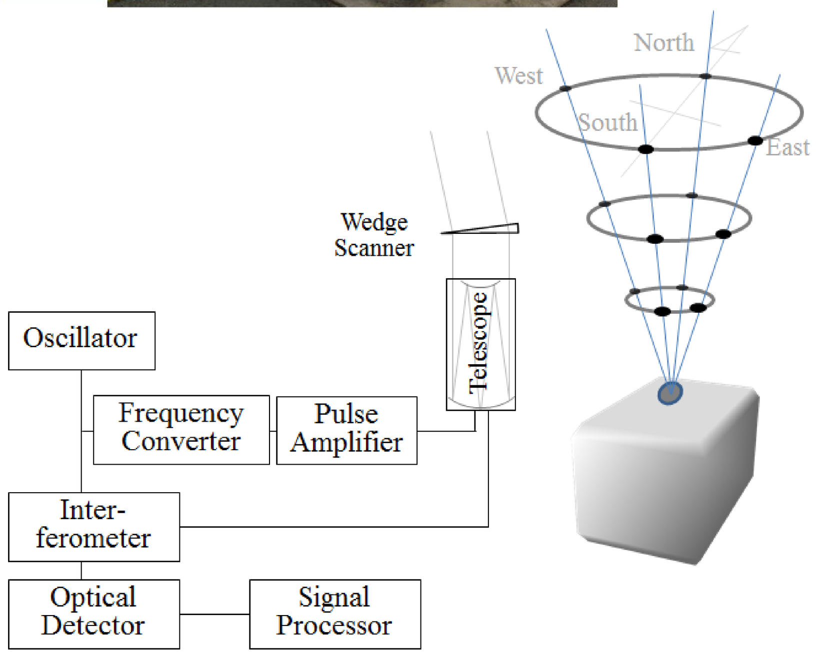
On the other hand, in the remote sensing research fields, the developments of actively wind detection system such as optical Doppler lidar is showing great progress. Especially, some Doppler lidar systems which are optimized for the assessment of wind power energy fields have suitable specifications for the wind profile observation above the urban area because the Doppler lidar systems have good specs of approx. 20 m range resolution, maximum detection height up to 200 m, and the fine sampling duration of a few seconds. It is also the best point for the observation of turbulences under fine weather conditions, that an amount of aerosols suspending in the urban atmosphere is the main target of the lidars.

We tried to estimate the roughness parameters using the wind profile data obtained at the urban building area by a small Doppler lidar system (WINDCUBE®) !

OBSERVATION OVERVIEW

System : WINDCUBE® WLS7 (Leosphere / EKO Instruments co., Ltd.)





Specifications of WINDCUBE® WLS7

Laser
- Wavelength : 1543 nm
- Pulse Energy : 10 μJ
- Eye Safety : IEC60825-1

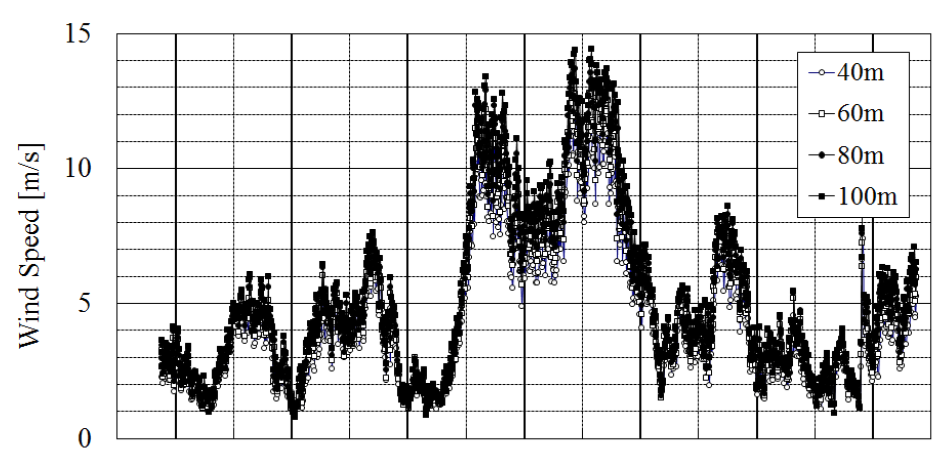
Observational Configuration
- Observation Range : 40〜200 m
- Accumulation Time : 0.5 s
- Data Output Frequency : 1 Hz
- Range Resolution : 20 m
- Scanning Cone Angle : 14.99 °
- Accuracy of Wind Speed : 0.2 ms^{-1}
- Accuracy of Wind Direction : 1.5 °
- Data Availability : > 95 % up to 150 m

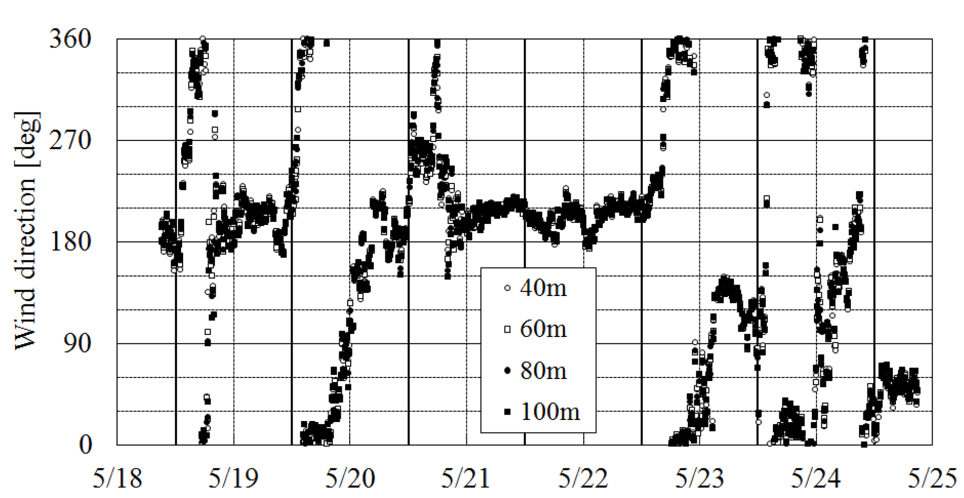
Environment
- Temperature : -15 – 40 ° C
- Operating Humidity : IP65
- Rain Protection : Wiper (with water pump)

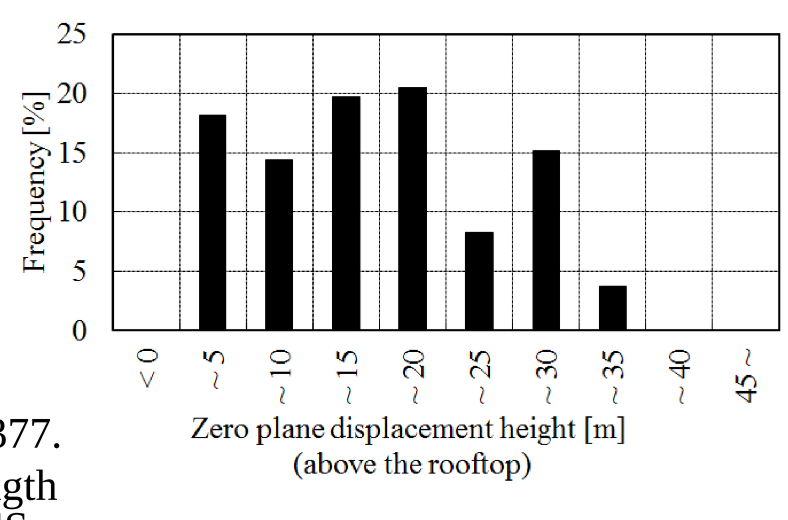
Dimensions
- Dimensions : 900 × 550 × 550 mm
- Weight : 60 kg

Power Supply Specifications
- Electric Power Supply : DC 27 V
- Power Consumption : 375 W

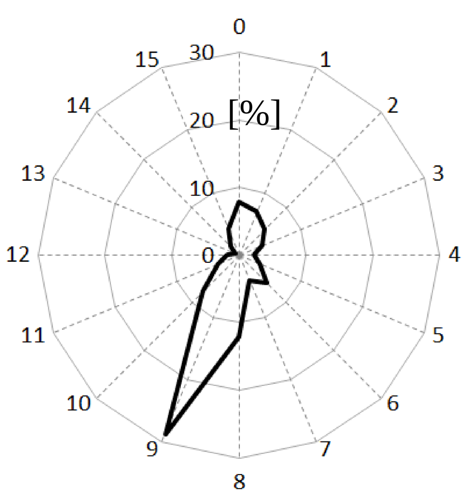
Observation Site : Roof top (~12 m a.g.l.) of a 4-story office building at Shibuya
Observation term : 2009/05/18 21:00 JST – 2009/05/25 09:00 JST
Obtained data number : 936 profiles of 10 minutes mean velocity







Windrose



Distribution of building story numbers around the observation site

Mean building height H_{ave} [m]	7.15
Mean building height in the top 1 % of all H_{max} [m]	29.5
Standard deviation of building heights σ_H [m]	3.47
Plan area ratio of buildings λ_p	0.4

SUMMARY

Estimation of roughness length and zero-plane displacement height was made by fitting the observed wind profiles in the urban building area to the log-law type equation for neutrally-stratified atmosphere utilizing the nonlinear least square method. The obtained profiles without numerical divergence were grouped in hours of dawn and evening, showing that this procedure can get a certain number of eligible profiles without any arbitrary data selections.

The roughness length and zero-plane displacement height estimated from the wind profiles obtained by the Doppler lidar system were 0.60±0.88 m and 26.8±8.8 m (above the rooftop ~12 m), respectively. The ratio of the roughness length to the mean building height was approximately one-tenth, which is consistent with the conventional knowledge. The zero-displacement height, on the other hand, was estimated clearly higher than the mean building height. This result was far from the conventional knowledge for the vegetation canopies and others.

We also tried to estimate the roughness parameters by a newly method proposed by Kanda et al. (2013) with some statistical values on the building heights around the observation point. As a result, the estimated roughness length and the zero-plane displacement height were 0.74 m and 31.7 m, respectively. It is confirmed that these estimated values were in good agreement with the values estimated from the wind profile data obtained by the Doppler lidar system at the urban building area.

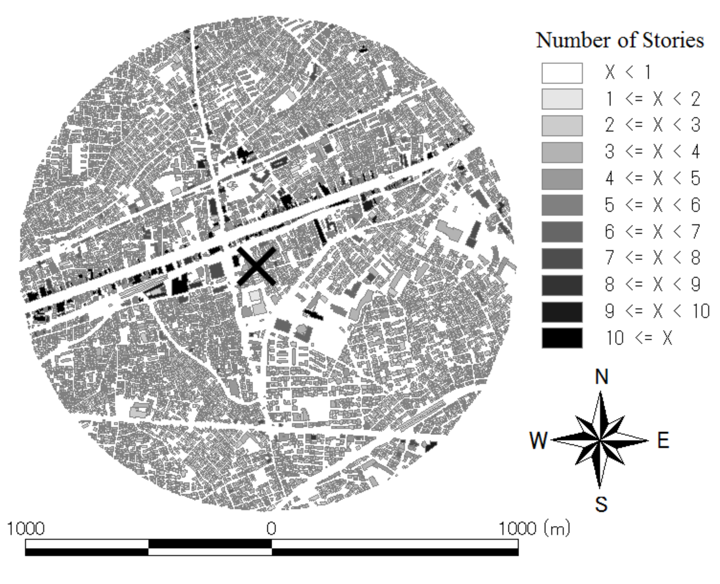
DATA ANALYSIS

Assuming neutrally-stratified atmosphere ...

$$u(z) = \frac{u_*}{k}\ln\left(\frac{z-d}{z_0}\right)$$

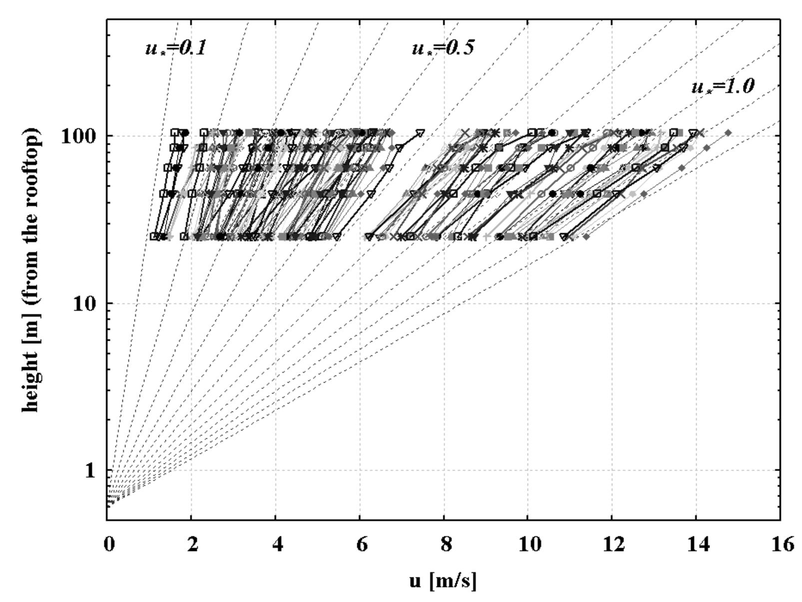
- $u(z)$: wind speed u_* : friction velocity
- k : von Karman's constant
- d : zero-plane displacement height
- z_0 : roughness length

Data will be fit to the equation using the non-linear least square method.



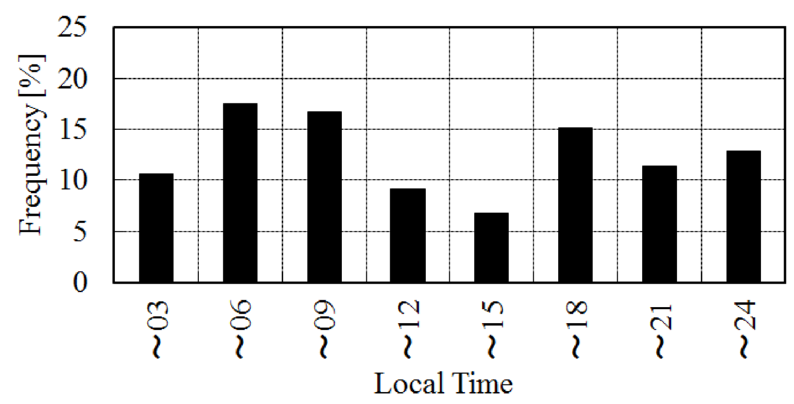
Number of profiles be solved well : 132
(Northerly : 26%, Easterly : 15%, Southerly : 57%, westerly : 2%)

The solved 132 data are grouped at dawn and evening.
→ The data obtained under the neutrally-stratified atmosphere seem to be solved numerically stably.
→ Without any arbitrary data selections, we can get a certain number of eligible profiles.



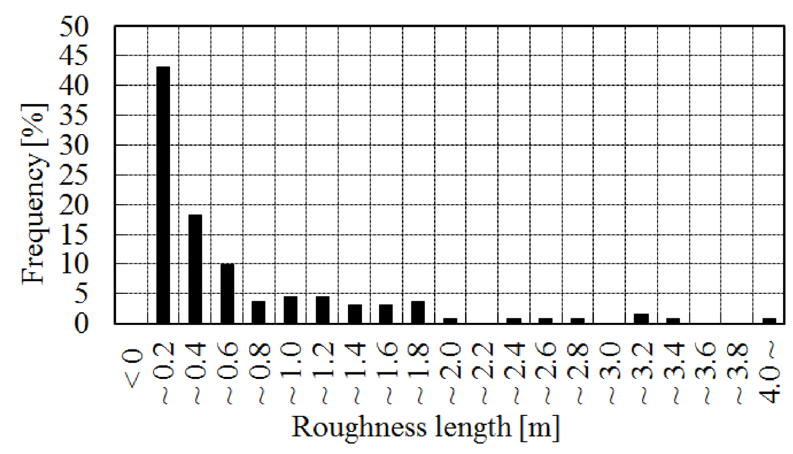
z_0 : 0.60±0.88 m (median = 0.27 m)

d : 14.8±8.8 m (median = 14.4 m)
*above from the roof top of 12 m a.g.l.



The estimated roughness length was about one-tenth of the mean building height H_{ave} = 7.15 m.
→ Conventional knowledge is confirmed for this.

The estimated zero-plane displacement height was quite higher than the mean building height H_{ave} = 7.15 m.
→ This is largely different from the conventional knowledge for the vegetation canopies, that is $d \simeq 0.75\,H_{ave}$.



How about with another estimation method ?

Kanda et al. (2013) : *Bound.-Layer Meteorol.*, **148**, 357-377.
They proposed a new method to estimate roughness length and zero-plane displacement height derived from an LES simulation database by setting realistic asperities in the urban area.

$$X = \frac{\sigma_H + H_{ave}}{H_{max}} \quad Y = \frac{\lambda_p \sigma_H}{H_{ave}} \quad \lambda_f = 1.42\lambda_p^2 + 0.4\lambda_p$$

$$z_{0\_Kanda} = \left(a_1 + b_1 Y^2 + c_1 Y\right) H_{ave} A^{-\lambda_p}\left(1-\lambda_p\right)\exp\left[-\left\{0.5\beta\frac{C_{1b}}{\kappa^2}A^{-\lambda_p}\left(1-\lambda_p\right)\lambda_f\right\}^{-0.5}\right]$$

$$d_{Kanda} = H_{max}\left[c_0 X^2 + \left(a_0 \lambda_p^{b_0} - c_0\right)\right]$$

where $(a_0, b_0, c_0, a_1, b_1, c_1, C_{1b}, k, A, b)$
= (1.29, 0.36, -0.17, 0.71, 20.21, -0.77, 1.2, 0.4, 4.43, 1.0)

Apply the values on the left table ...

z_{0_Kanda} : 0.74 m
d_{Kanda} : 31.7 m

in good agreement with the values estimated from the Doppler lidar observations !

Acknowledgement

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