Wind velocity profile observations for roughness parameterization of real urban surfaces

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Background: the logarithmic law

The logarithmic wind profile

- The wind velocity u with height in purely mechanical turbulence can be derived from the logarithmic law.
- Two major aerodynamic parameters, the roughness length z_0 and displacement height d, can be derived from the logarithmic law.

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

u = the observed mean wind velocity,
u_* = the friction velocity,
z = the observation height,
z_0 = the aerodynamic roughness length,
d = the displacement height,
κ = the von Karman constant.

Background: estimating z_0 and d

Methods to estimate z_0 and d (Liu et al., 2009)

- **Morphological (or geometric) methods**

  (using parameters related to surface morphology)
- Anemometric methods

  (using field observations of wind and turbulence)

Theurer (1993)

- z_0 is mainly related to the ratio of **the frontal area** of the obstacles to the lot area of the obstacles
- d is mainly a function of the ratio of **the plan area** of the obstacles to the lot area.

Raupach (1994), Bottema (1995), Macdonald et al. (1998), Kanda et al. (2013)…

Background: estimating z_0 and d

Methods to estimate z_0 and d (Liu et al., 2009)

•**Morphological (or geometric) methods**

(using parameters related to surface morphology)

•Anemometric methods

(using field observations of wind and turbulence)

However,

- Most are based on empirical relations derived from wind tunnel experiments. (idealized flows over simplified arrays)
- In real cities,
  - the wind direction is ever changing.
  - the street pattern is irregular.
  - the size and shape of roughness elements is variable.

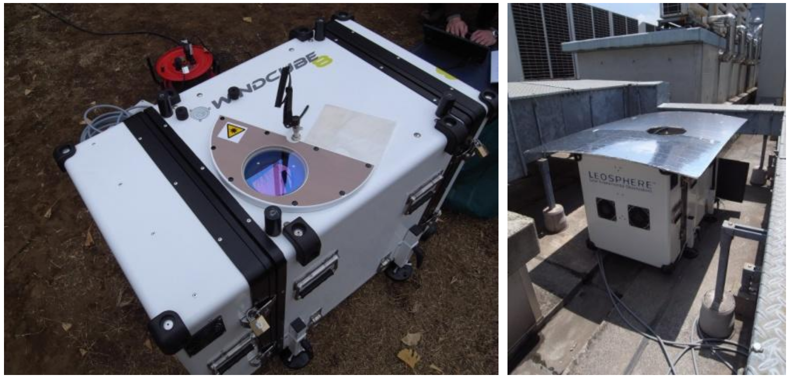
Study objective

Our question

- Difference of z_0 and d with wind directions
- Relations between estimated z_0 and d and surface morphology

Method

- Observation of wind velocity profile using Doppler LIDAR system
- Urban morphological analysis using GIS data
- In Tokyo, Japan (densely developed urban area)



DLS installed in I.I.S

Presentation outline

1. The outline of observation using Doppler LIDAR system
2. Data processing for estimating z_0 and d
3. Estimating result for z_0 and d
4. Issues that remain to be explores

Observation details

Study site: Meguro-ku, Tokyo, Japan

•The central part of Tokyo

•Doppler LIDAR system (DLS) on a building rooftop

- latitude: 35°40'N
- longitude: 139°41'E
- altitude: 40 m
- height from ground level: 27.5 m

•The surroundings are mainly residential areas.

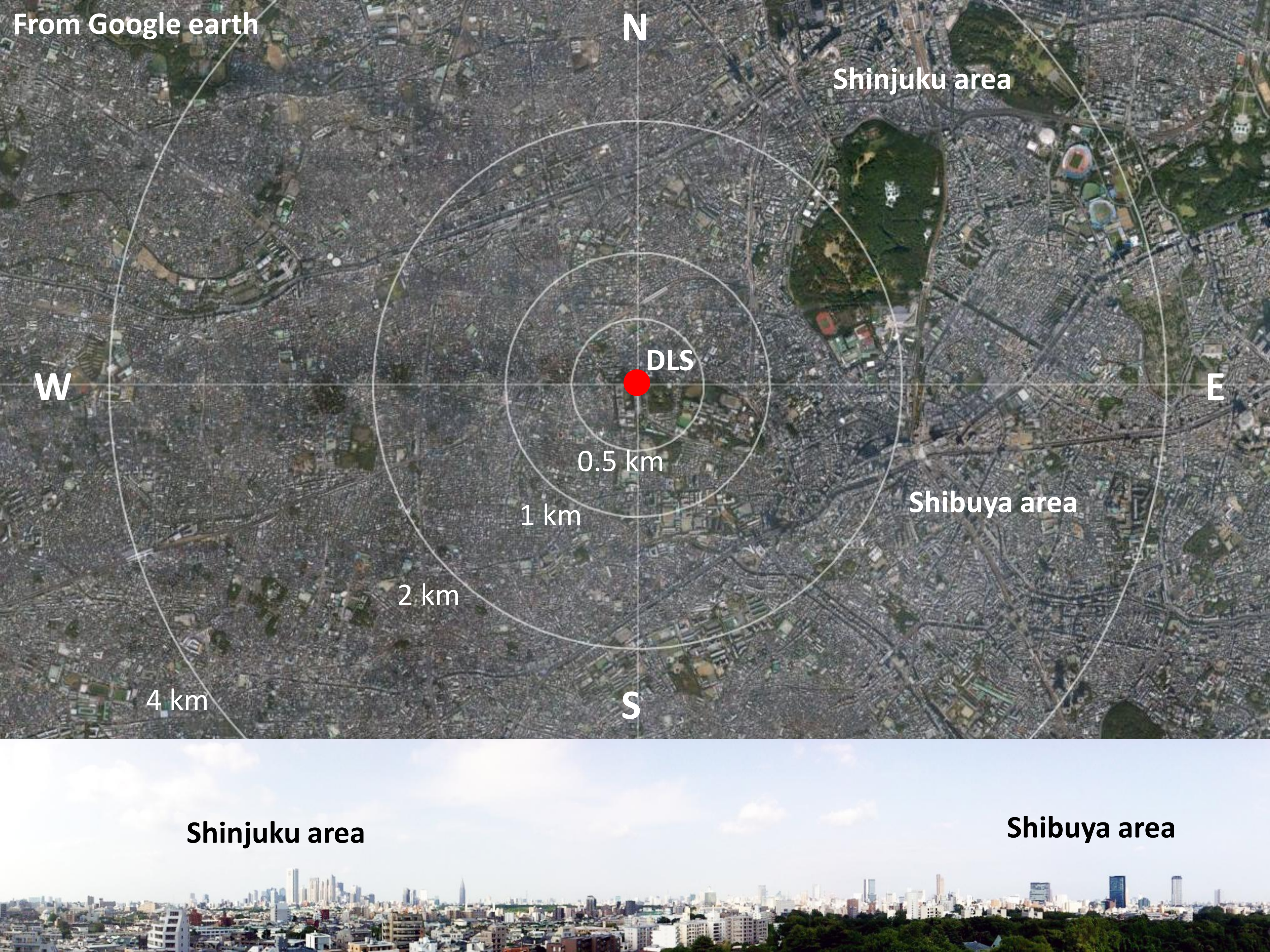
- some large greenery areas
- commercial areas in a few kilometers away

Observation period: 7 months

•Sep. – Dec. in 2013 and Apr. – Jun. in 2014

Observation heights: 67.5 – 527.5 m

- every 20 m (total 24 levels)


From Google earth
N
Shinjuku area
DLS
W
E
0.5 km
1 km
Shibuya area
2 km
4 km
S
Shinjuku area
Shibuya area

Atmospheric stability

Panofsky and Dutton (1984)

•The logarithmic wind profile is often called the neutral wind profile.

Filtering the data for neutral atmospheric condition

•Use atmospheric stability statistics which were obtained from eddy covariance method (ECM).*

•ECM data were collected from the ultrasonic anemometer at the 52 m level of the broadcast tower, which is located about 600 m east-northeast direction of DLS.

•Use the value of $1/L$ as a parameter which represents atmospheric stability, where L is the Monin−Obukhov length.

*We acknowledge Prof. Hirofumi Sugawara of National Defense Academy of Japan, for making the observation data available.

Determining the atmospheric neutrality

Data processing

•Data for wind velocity < 5 m/s are not used because significant fluctuation for wind direction.

•The wind directions were divided into 16 sectors with an interval of 22.5^{o}, which are numbered 1 (N), 2 (NNE), ..., and 16 (NNW).

•1/*L* was divided with an increment of 0.00125.

•All data were classified into corresponding data bins.

•Estimate z_0 and d from the mean wind velocity profiles within each data bin.

•The conventional two-parameter fitting of z_0 and d using the least-squares method with the von Karman constant of 0.4.

•All fitting were performed for the level between 67.5 m and 147.5 m

Determining the atmospheric neutrality

Definition of a normalized error E_n of the logarithmic law

•< >: Ensemble average, Temporal average

•Observed profiles were fitted to the logarithmic law using the least-square method

•Root-mean-square-errors between observed data and the logarithmic law function are calculated to evaluate the approximate errors of the logarithmic law.

$$RMSE = \sqrt{\frac{1}{N_z}\sum_{k=1}^{N_z}\left(\langle u(z_k)\rangle - \frac{u_*}{\kappa}\ln\left(\frac{z_k - d}{z_0}\right)\right)^2} \qquad E_n = \frac{RMSE}{u_{67.5}}$$

N_z = the number of measurement heights used in curve fittng (=5)

z_k = a measurement height,

u_* = the friction velocity,

z_0 = the aerodynamic roughness length,

d = the displacement height,

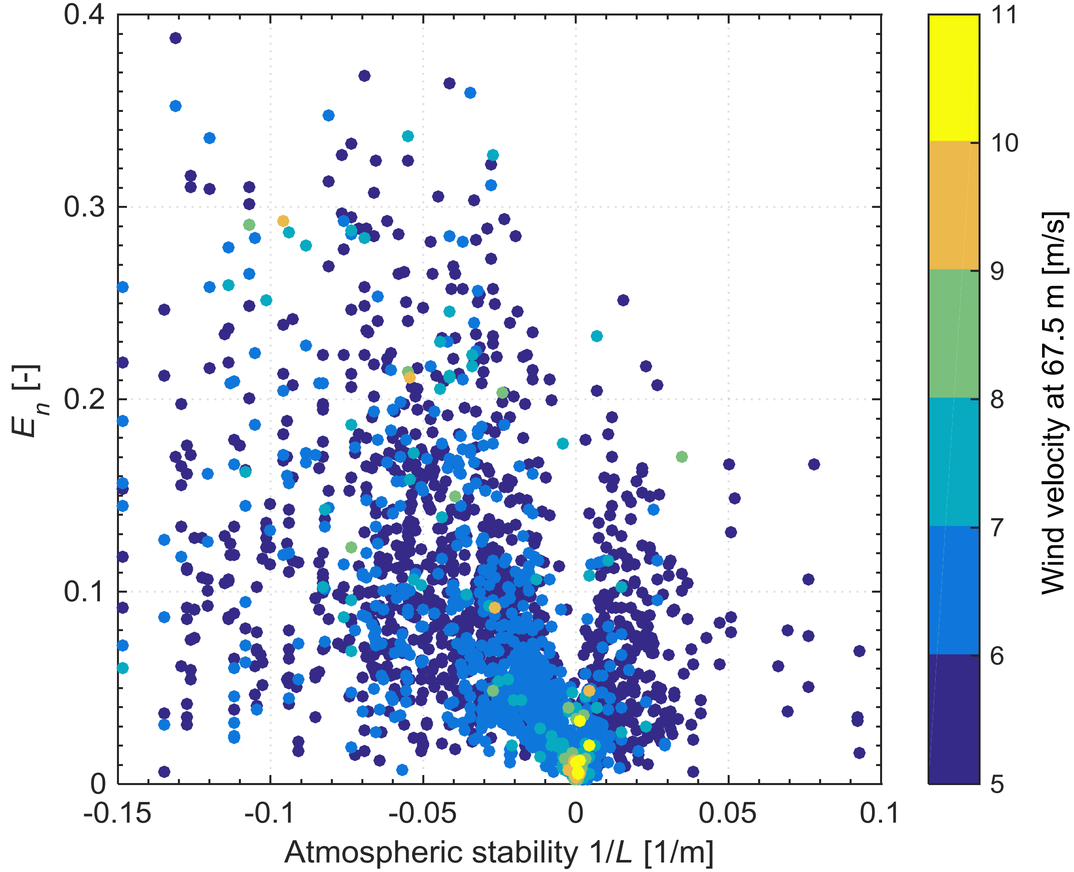
κ = the von Karman constant,

$u_{67.5}$ = the reference wind velocity at 67.5 m.

Determining the atmospheric neutrality

Fitting accuracy of the logarithmic wind profile

- Fitting accuracy increase when $1/L$ is nearly zero.

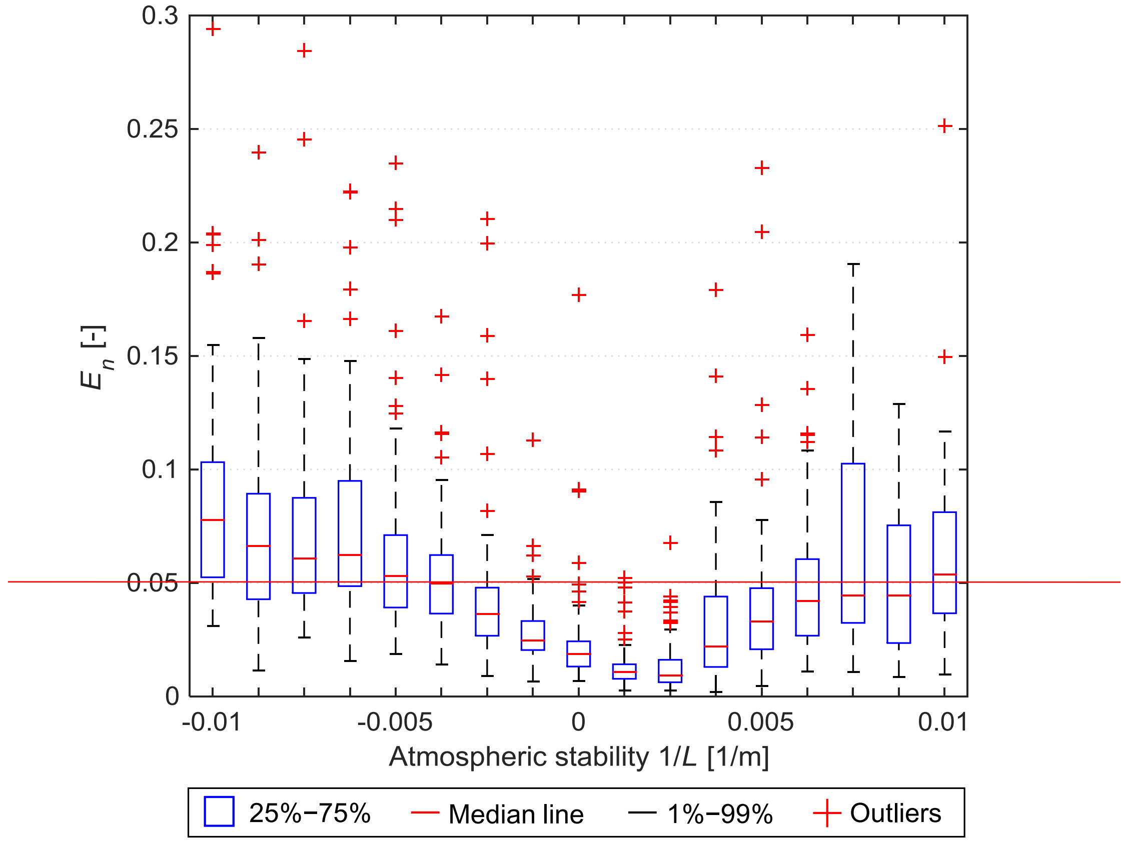


Relation between fitting accuracy and atmospheric stability

Determining the atmospheric neutrality

Neutral atmospheric condition in this study,

- 25−75% of $E_n < 0.05$
- $-0.0025 \leq 1/L \leq 0.005$

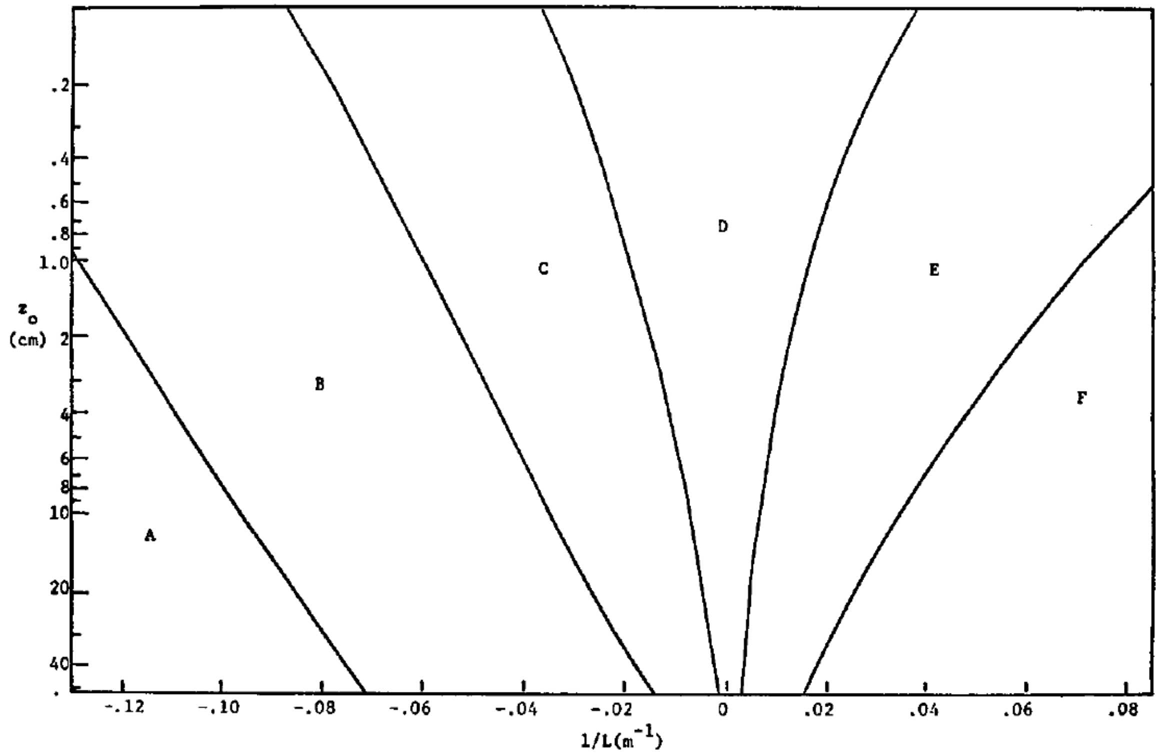


Relation between fitting accuracy and atmospheric stability (1/L ~ 0)

Determining the atmospheric neutrality

Neutral atmospheric condition in this study,

- Mean building height within the field of 1 km radius ≈ 7 m
- Empirically $z_0 \approx 0.7$ m
- Good agreement with the result by Golder (1972)



1/L as a function of Pasquill class and z_0 (from Fig. 4 in Golder (1972))

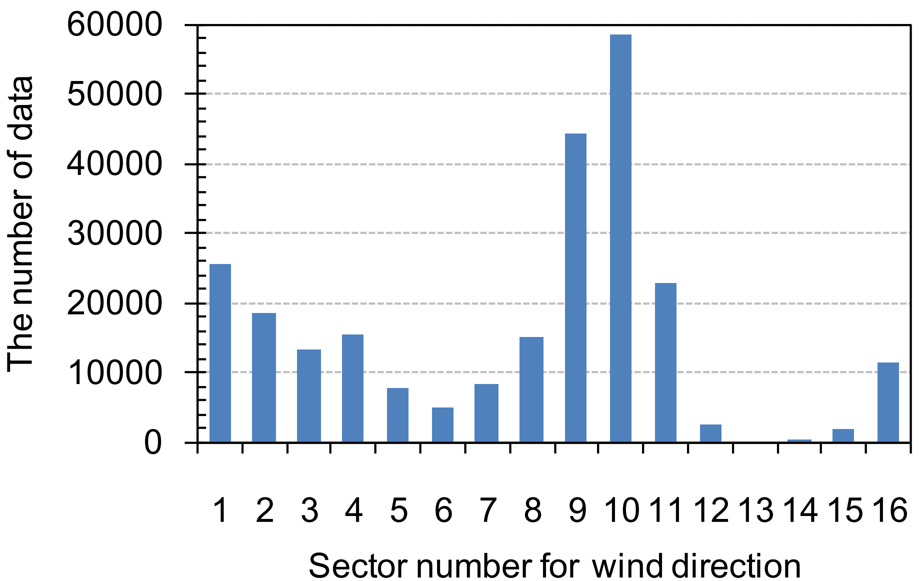
Estimating z_0 and d

30-min ensemble averaged wind profiles

•DLS generates observation data for every 7 sec.

•We random-selected 257 data for each wind direction and then averaged that data.

•300 of ensemble averaged wind profiles were generated for each wind direction.

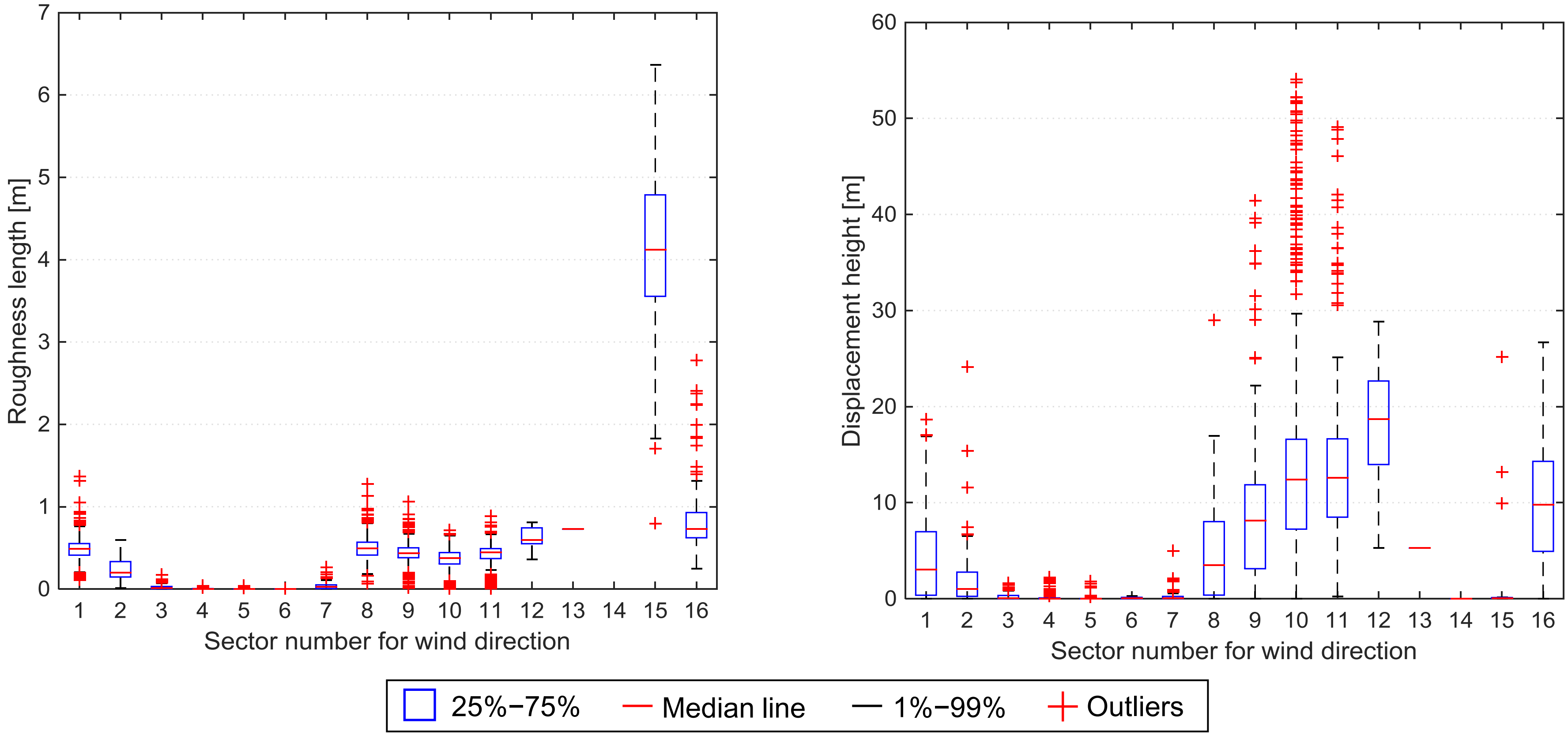


The number of data for each wind direction

Estimating z_0 and d

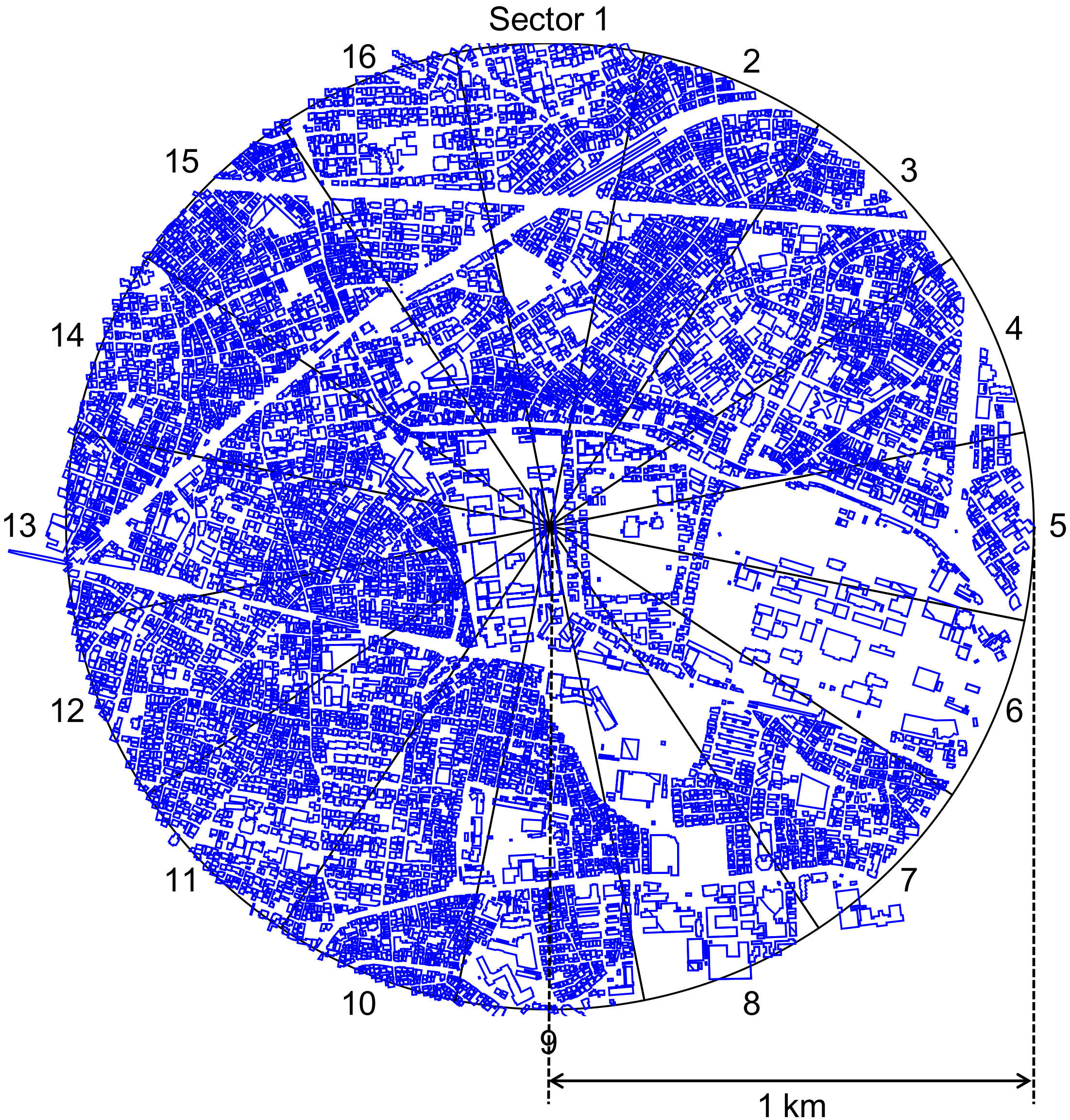
The values varies with the wind direction.

- $z_0 \approx 0.4$ m for sectors 8–11, < 0.03m for sectors 3–7.

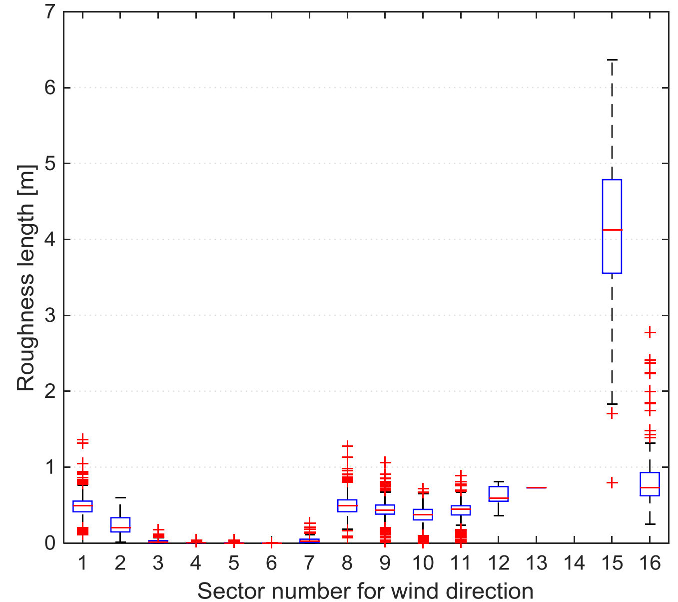


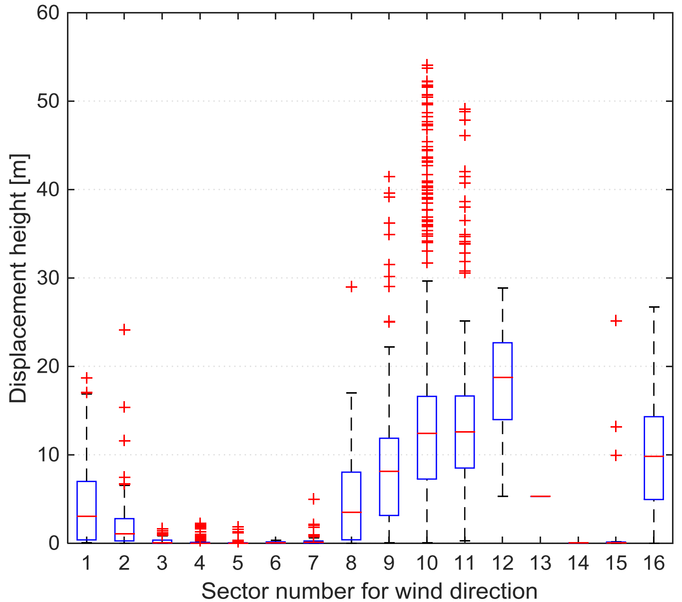
Estimated values of z_0 (left)and d (right)

Morphological characteristics

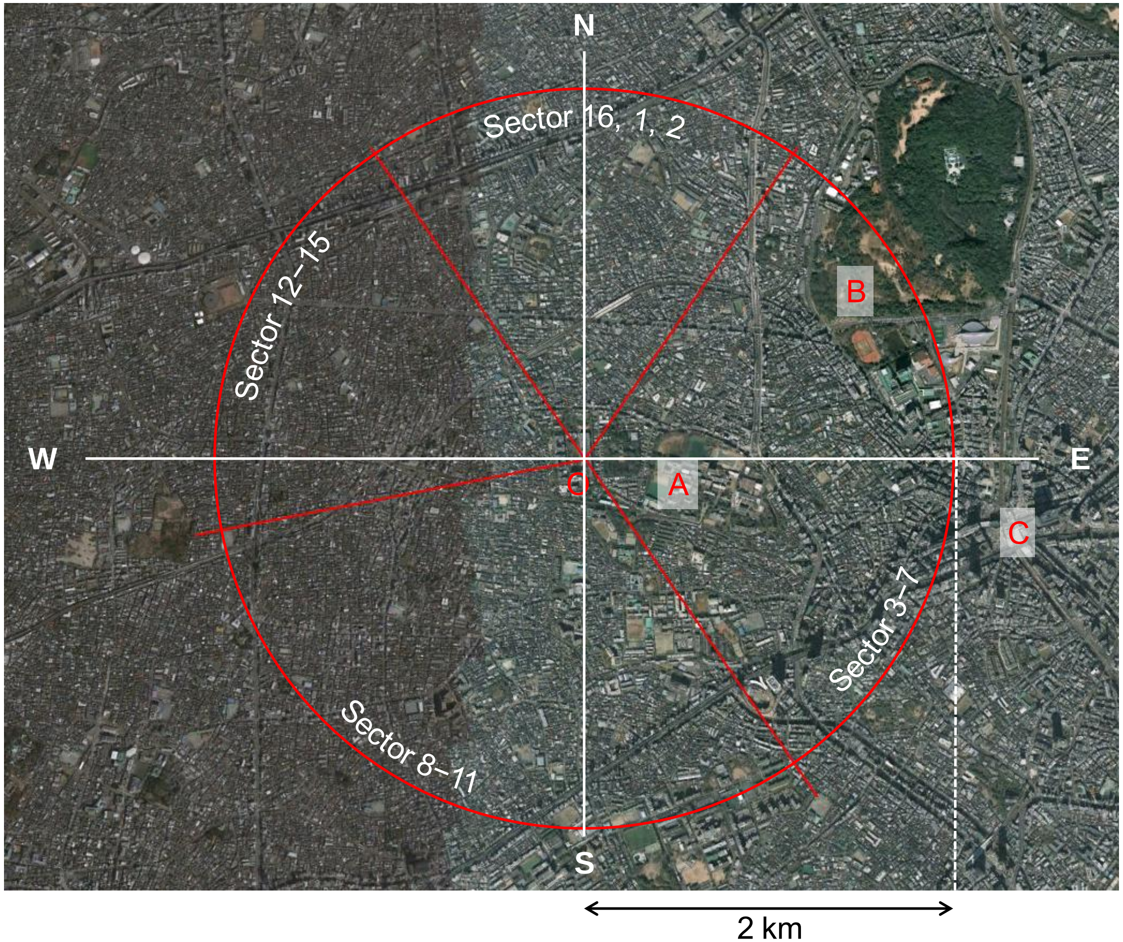


Building footprints within the field of 1 km radius



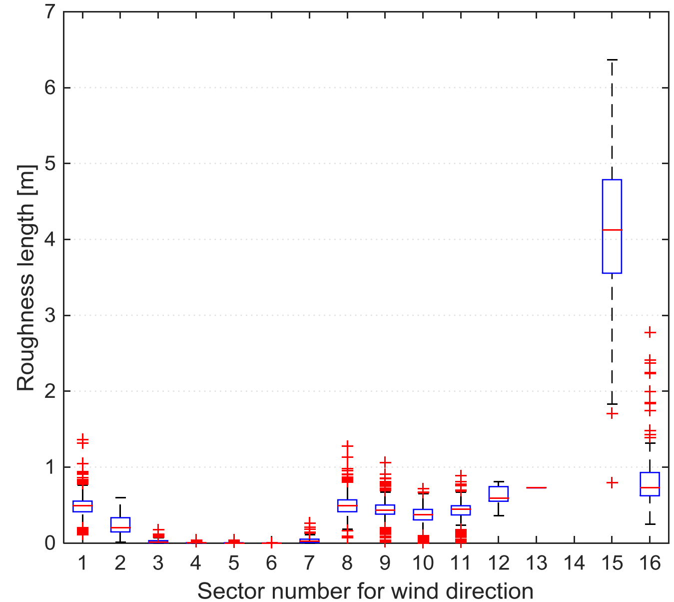


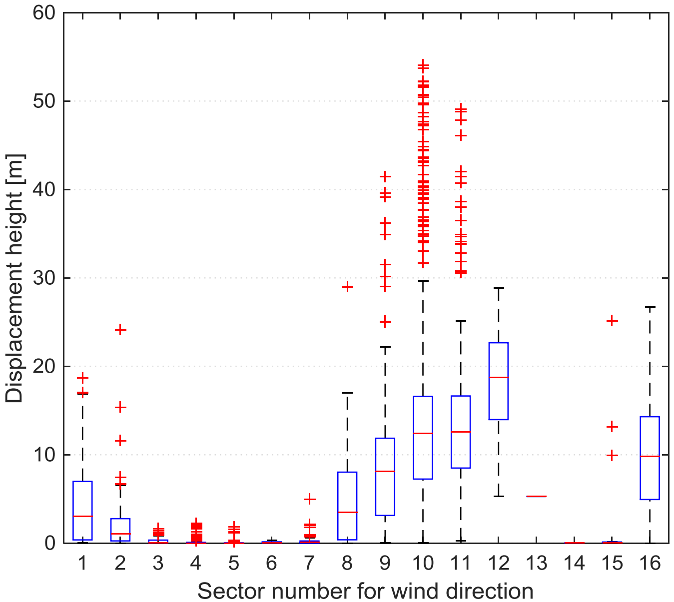
Morphological characteristics



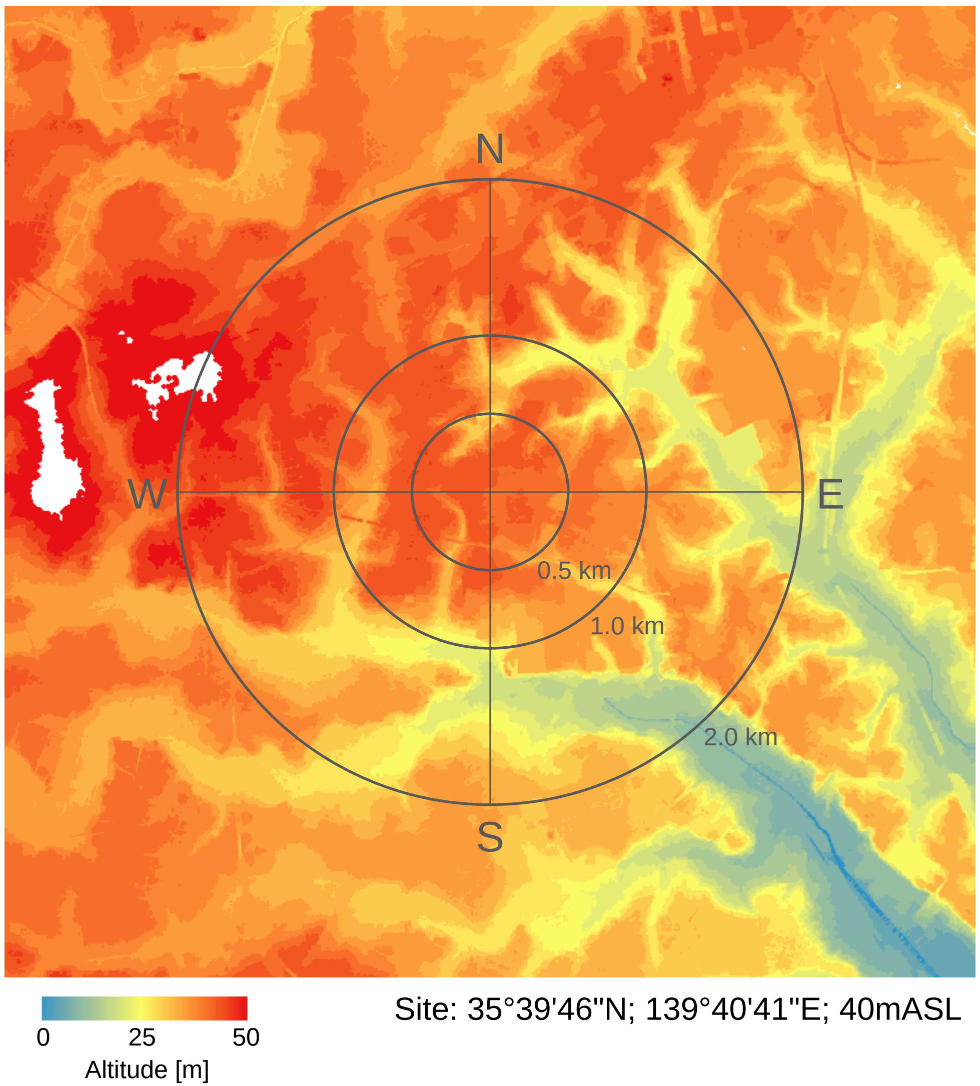
A: The campus of university,
B: Large green area,
C: Commercial area with high-rise buildings

Aerial picture of observation site



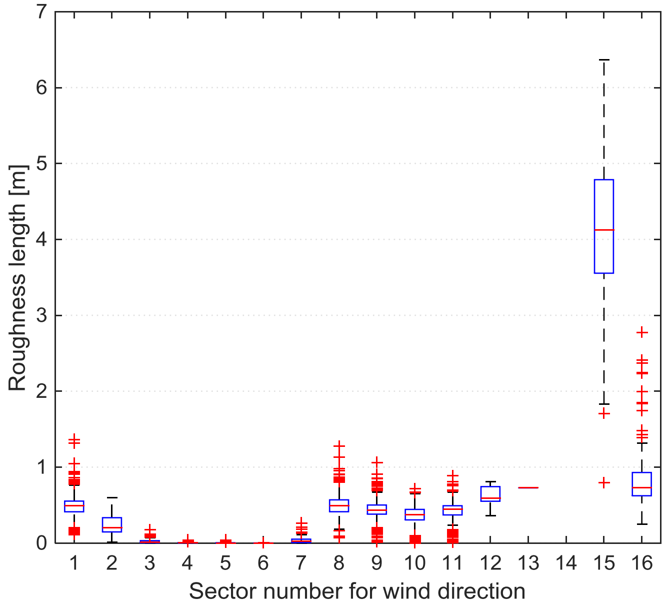


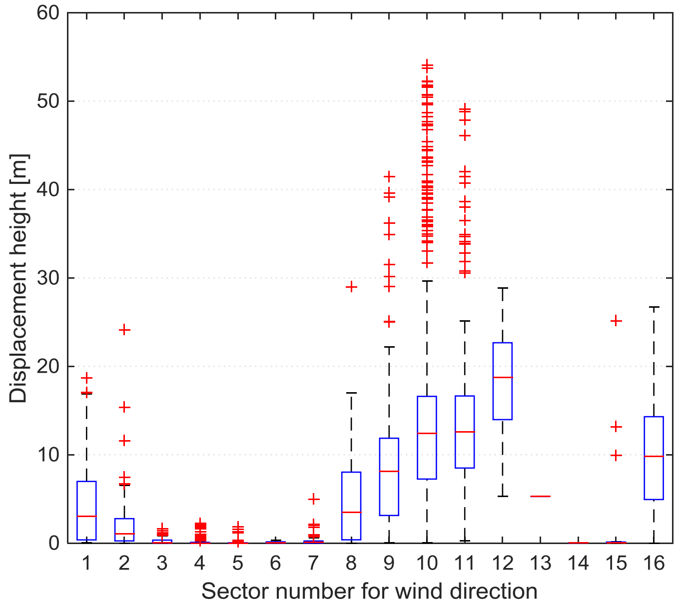
Topographical characteristics



Site: 35°39'46"N; 139°40'41"E; 40mASL

Altitude data of observation site





Concluding remarks

Vertical profiles of wind velocity in the urban boundary layer were measured in the Tokyo Center District for 7 months.

•A DLS (Doppler lidar system) was used in the measurement.

•60% of the time during the measurement, wind velocity was lower than 6 m/s in 10-minute average at the height of 247.5 m.

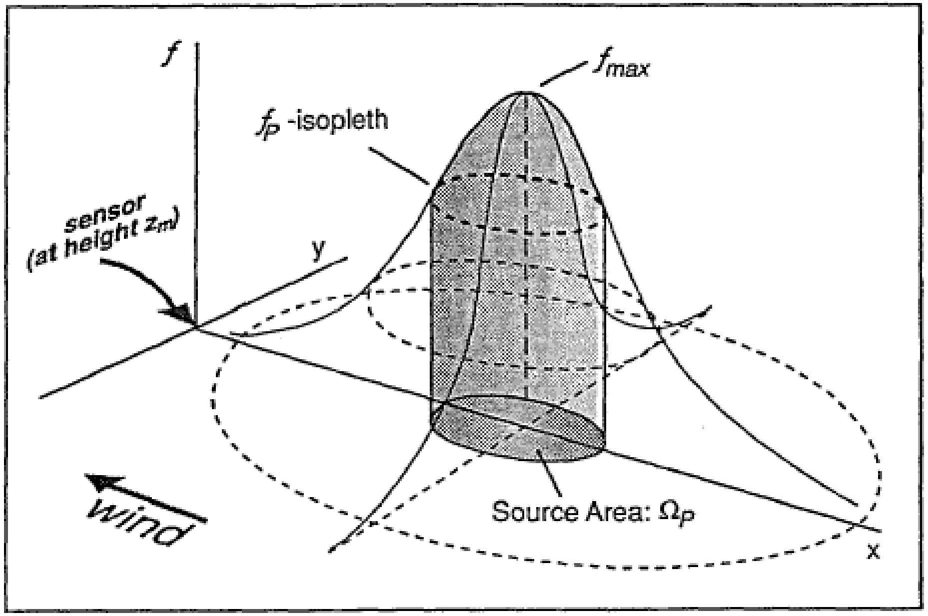
We applied the Logarithmic wind profile to approximate the measured wind profiles and discussed the surface roughness.

•The values of z_0 and d varies with the wind direction.

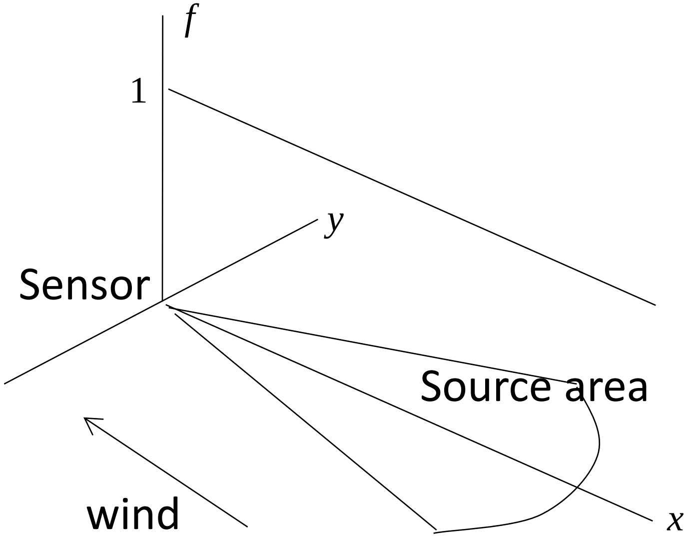
•It was not to easy to clearly define the relation between the roughness parameters and urban morphological parameter.

Concluding remarks

We think the definition of the roughness source area significantly impacts on roughness parameterization using morphological method.



The source area and its relation to the source weight function (from Fig. 1 in Schmid (1993))



The source area in this study

Thank you for your attention.

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I also acknowledge Prof. Hirofumi Sugawara of National
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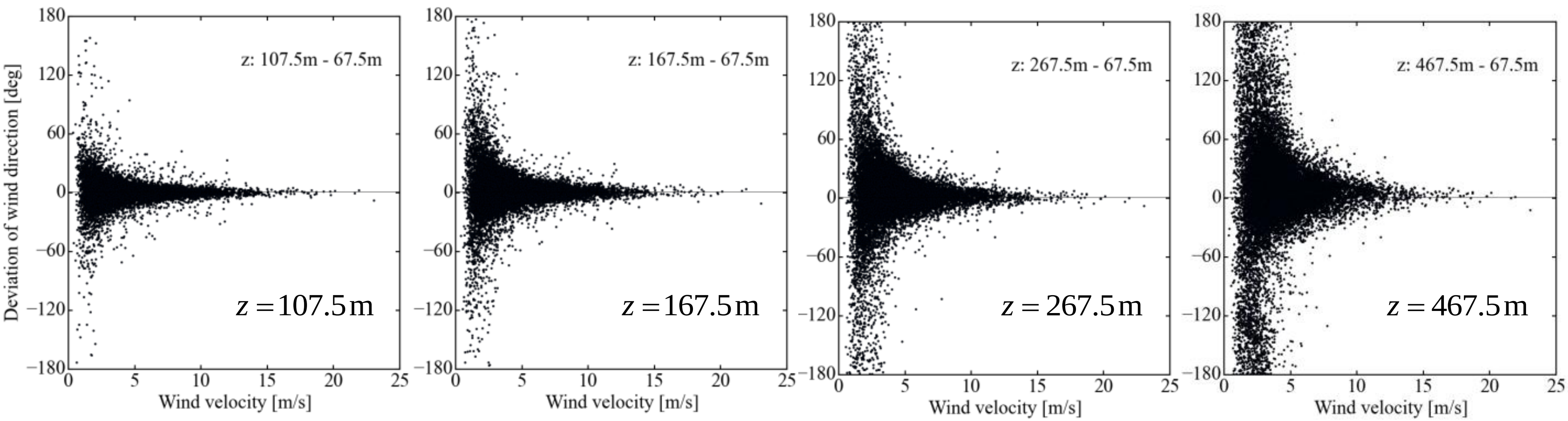
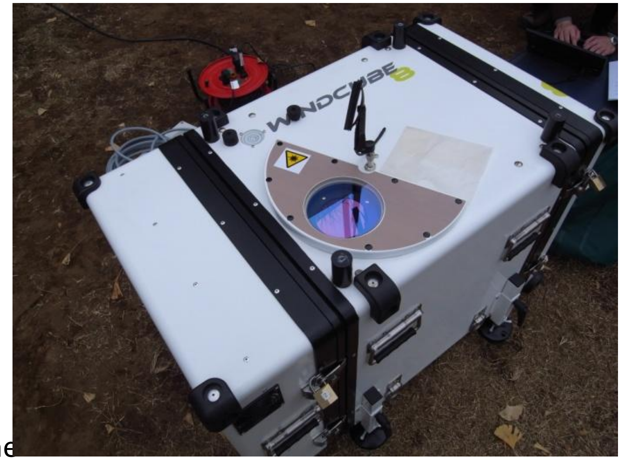


Relationship between the wind velocity and deviation in the wind direction for z = 107.5, 167.5, 267.5, and 467.5 m based on the wind velocity (u_b) and direction (wd_b) at a height of 67.5 m (10 min average)

DLS: Doppler Lidar System



Lidar: Light Detection and Ranging

Windcube WLS8

•Manufactured by Leosphere (France)

•Principle of measurement:

1. Emission of pulse lasers (λ = 1.54 μm)
2. Scattering of the laser by aerosols
3. Measurement of velocity component in the line of sight using the Doppler shifts of the scattered light
4. Calculation of 3D velocity components vector synthesis of 4 directions

•Measurement height: 40 - 500 m

•Minimum interval of height: 20 m

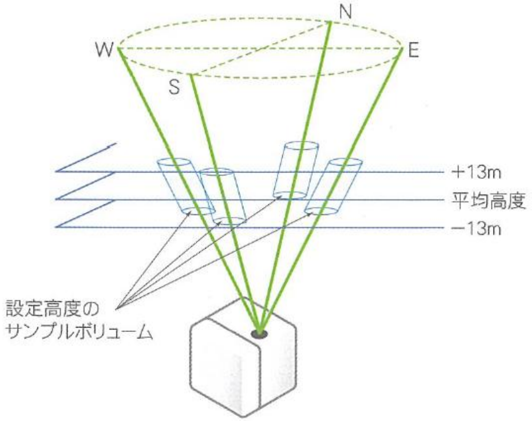
•Covered wind speed: 0 - 60 m/s

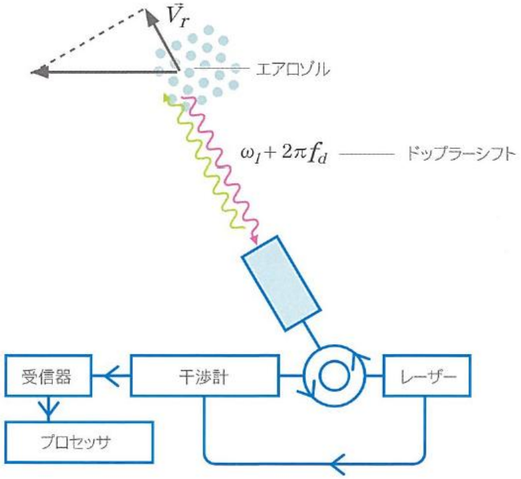
•Accuracy:
- Wind direction: 1.5 °
- Wind speed: 0.2 m/s

•Data output rate: every 10 seconds

•Size, Weight:

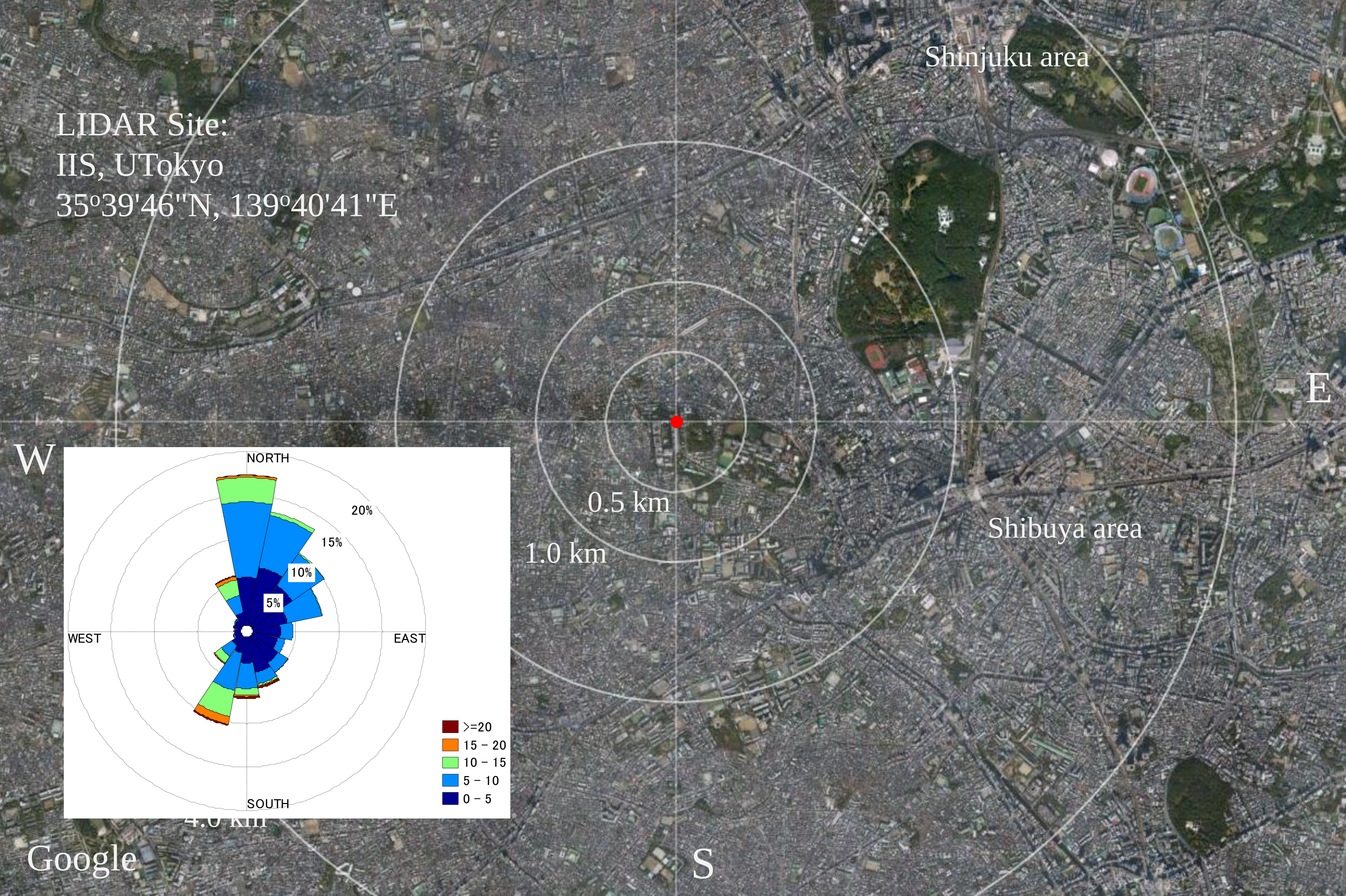
940 x 740 x 640 mm, 90 kg



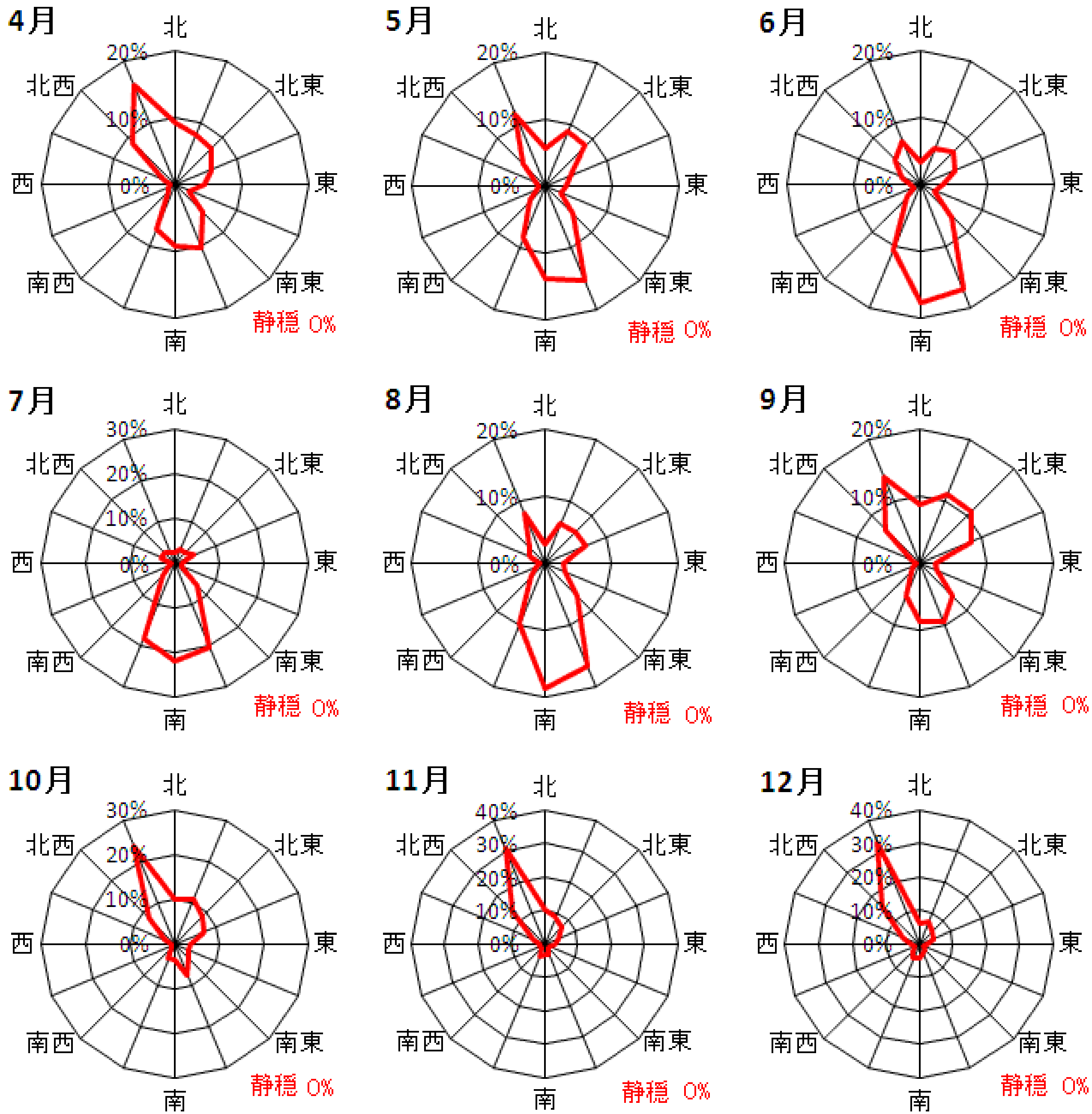


ドップラーヘテロダインライダーの原理

Observation site



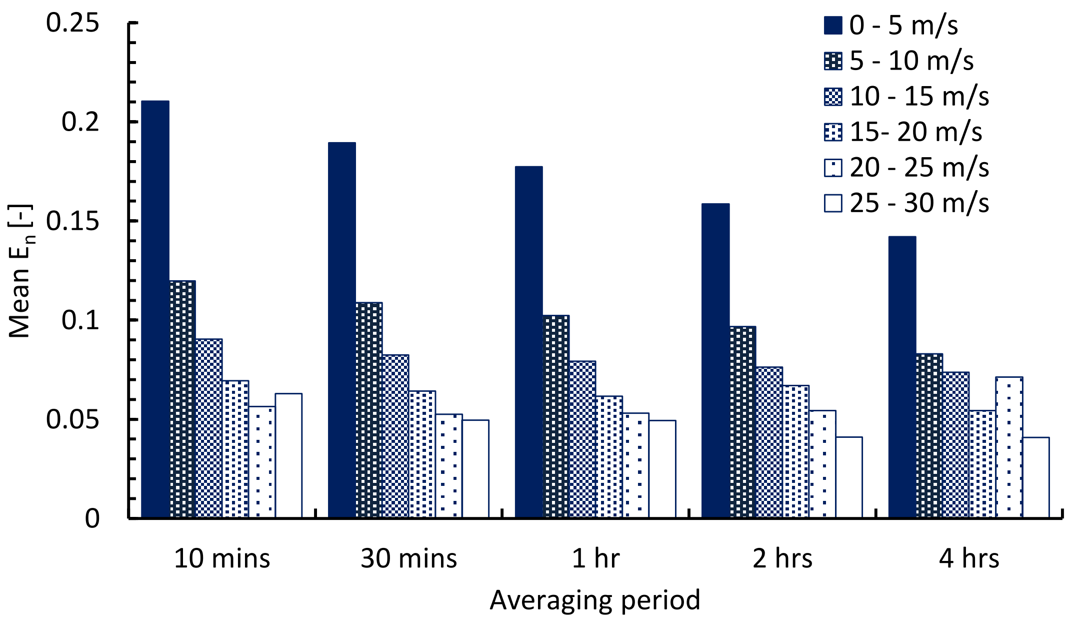
風配図：東



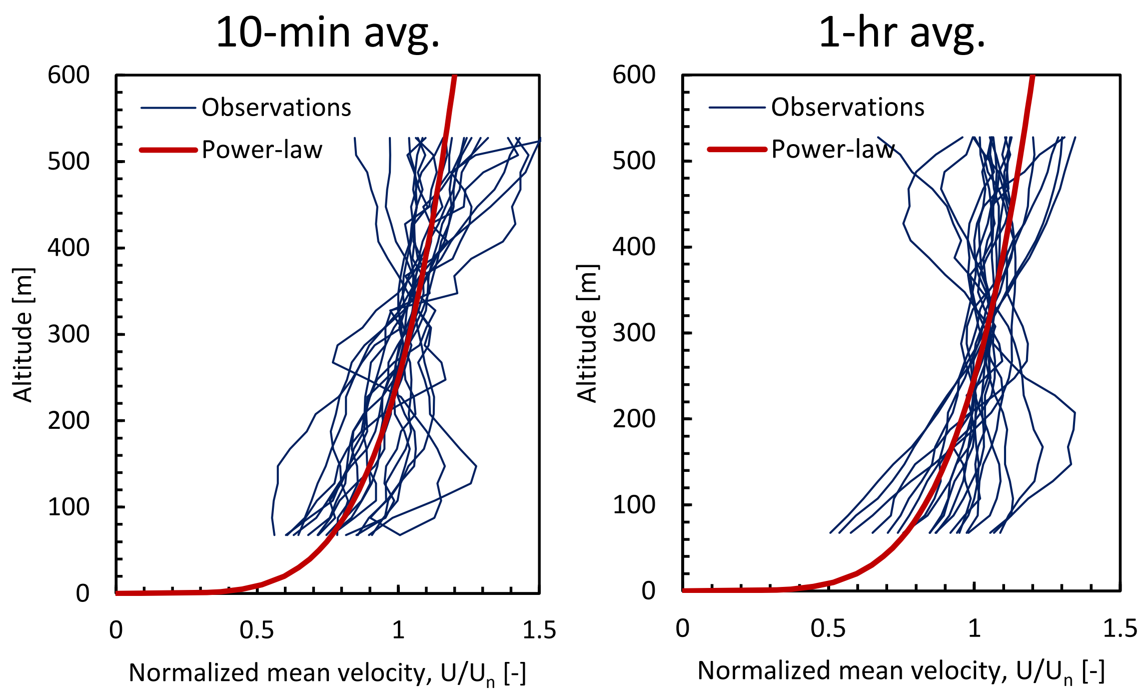
東京管区気象台での風配図（気象庁）

Wind velocity / Average time and PL accuracy

- Change of mean approx. errors with average time / velocity
  - **Increase of wind velocity:** Rapid decrease in the errors
  - **Increase of average time:** Moderate decrease in the errors
    - 1

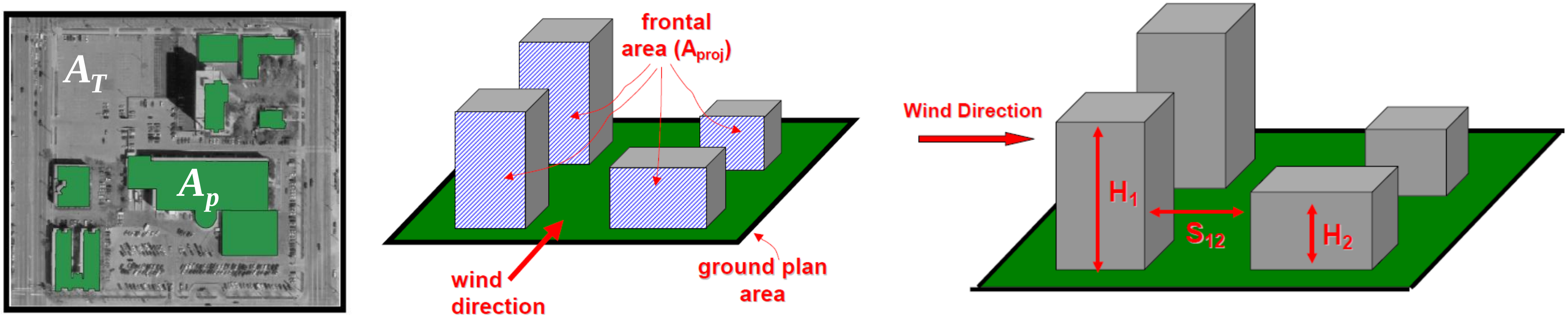


Mean approximate accuracy using the PL (α = 0.206)
according to the averaging time period and wind velocity
(Average wind velocities at all heights were used to classify data based on velocity)



Sample wind velocity profiles

(20 samples and the PL (α = 0.206))



$$\lambda_p = \frac{A_p}{A_T}$$

$$\lambda_f(\theta) = \frac{A_{proj}}{A_T}$$

$$\lambda_S = \frac{(H_1 + H_2)/2}{S_{12}}$$

Fig. Illustration of each parameter. (Burian et al., 2002)

Contribution of building to urban ventilation potential

•Building plan area fraction (λ_p) - the ratio of **the plan area** of the obstacles to the lot area.

•Frontal area ratio (λ_f) - the ratio of **the frontal area** of the obstacles to the lot area of the obstacles

•Height-to-width ratio (λ_s)