Statistical methods for estimating low-occurrence strong wind speed in actual urban area based on the Weibull distribution

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Abstract

In urban areas, the pedestrian-level wind environment, especially the strong wind, is a crucial factor that affects the safety and comfort of people. Conventionally, the time-series data is the prerequisite to the probability density function for determining LOSWS. However, it is practically inaccessible to handle and store the entire time-series data of the urban area cases with high spatial resolution because of the huge data size. To address this problem, this study developed two statistical methods (3W and 2W methods) for estimating low-occurrence strong wind speeds (LOSWSs) of an actual urban case (Case-TPU) with reduced requirement of data size. The 3W and 2W methods are based on the three-parameter and two-parameter Weibull distributions, respectively. The 3W method necessitates the mean, standard deviation, and skewness of wind speed, while the 2W method only requires the mean and standard deviation. The large-eddy simulation (LES) results of Case-TPU were validated using the wind tunnel experimental results and applied to the statistical analysis of the 3W and 2W methods. An analysis was conducted to assess the suitability of the 3W and 2W for fitting wind speed data obtained from the LES. The results showed that even though the 3W had a better fit than the 2W owing to the location parameter of 3W enhancing its adaptability, both methods exhibited a satisfactory fit to the wind speed data at the majority of points. Furthermore, the 3W and 2W methods showed high estimation accuracies of LOSWSs. For LOSWSs with exceedance probabilities of q = 10%, 1%, and 0.1%, the 3W method produced relative errors within 10%, while the 2W method yielded relative errors within 20%. The high estimation accuracy of LOSWSs for Case-TPU proved the robustness of the 3W and 2W methods for the urban area case with complicated building layout.

Introduction

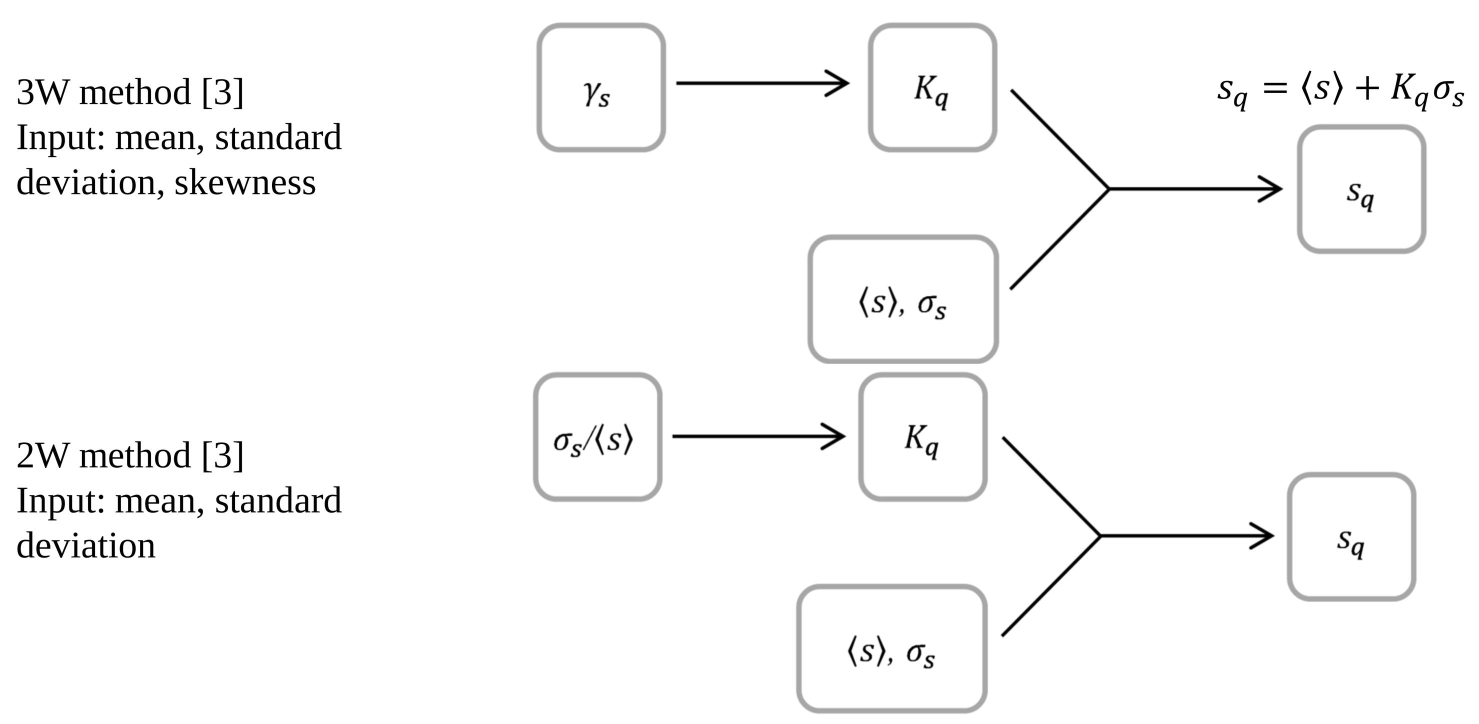
- In urban areas, the pedestrian-level wind environment (PLWE) is a crucial factor that affects the safety and comfort of people [1]. However, because of the huge computational cost, few studies have discussed the PLWE of actual urban cases [2].
- Previous studies on PLWEs in both idealized and actual urban scenarios have primarily focused on examining the distributions or characteristics of mean wind speeds. However, given the chaotic and stochastic nature of turbulent flows, instantaneous wind speed is a better indicator for PLWE studies, particularly the low-occurrence strong wind speeds (LOSWSs).
- Conventionally, the time-series data is the prerequisite to the probability density function for determining LOSWS. However, it is practically inaccessible to handle and store the entire time-series data of the urban area cases with high spatial resolution because of the huge data size.

Methodology

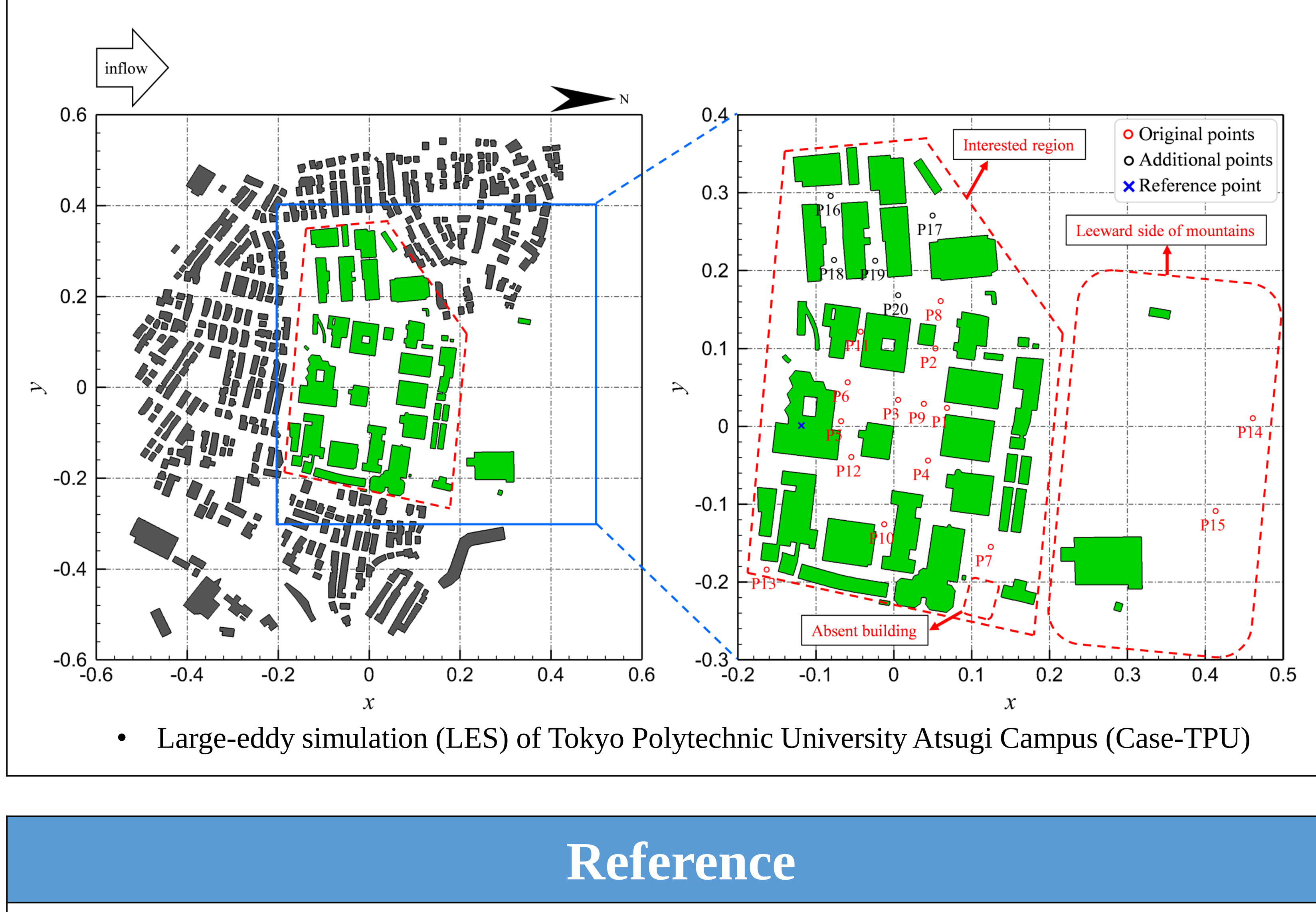
- Three-parameter Weibull distribution: $f(x) = \frac{\beta}{\alpha}\left(\frac{x-\zeta}{\alpha}\right)^{\beta-1} \exp\left[-\left(\frac{x-\zeta}{\alpha}\right)^{\beta}\right], x \geq \zeta$

2W is a special case of 3W when the location parameter $\zeta = 0$.

- Mean: $\mu = \zeta + \alpha\Gamma(1+1/\beta)$
- Standard deviation: $\sigma = \alpha[\Gamma(1+2/\beta) - \Gamma^2(1+1/\beta)]^{1/2}$
- Skewness: $\gamma = \frac{\Gamma(1+3/\beta) - 3\Gamma(1+2/\beta)\Gamma(1+1/\beta) + 2\Gamma^3(1+1/\beta)}{[\Gamma(1+2/\beta) - \Gamma^2(1+1/\beta)]^{3/2}}$
- Peak factor K_q with exceedance probability q: $K_q = \frac{[-\ln(q)]^{1/\beta} - \Gamma(1+1/\beta)}{[\Gamma(1+2/\beta) - \Gamma^2(1+1/\beta)]^{1/2}}$



Actual urban case

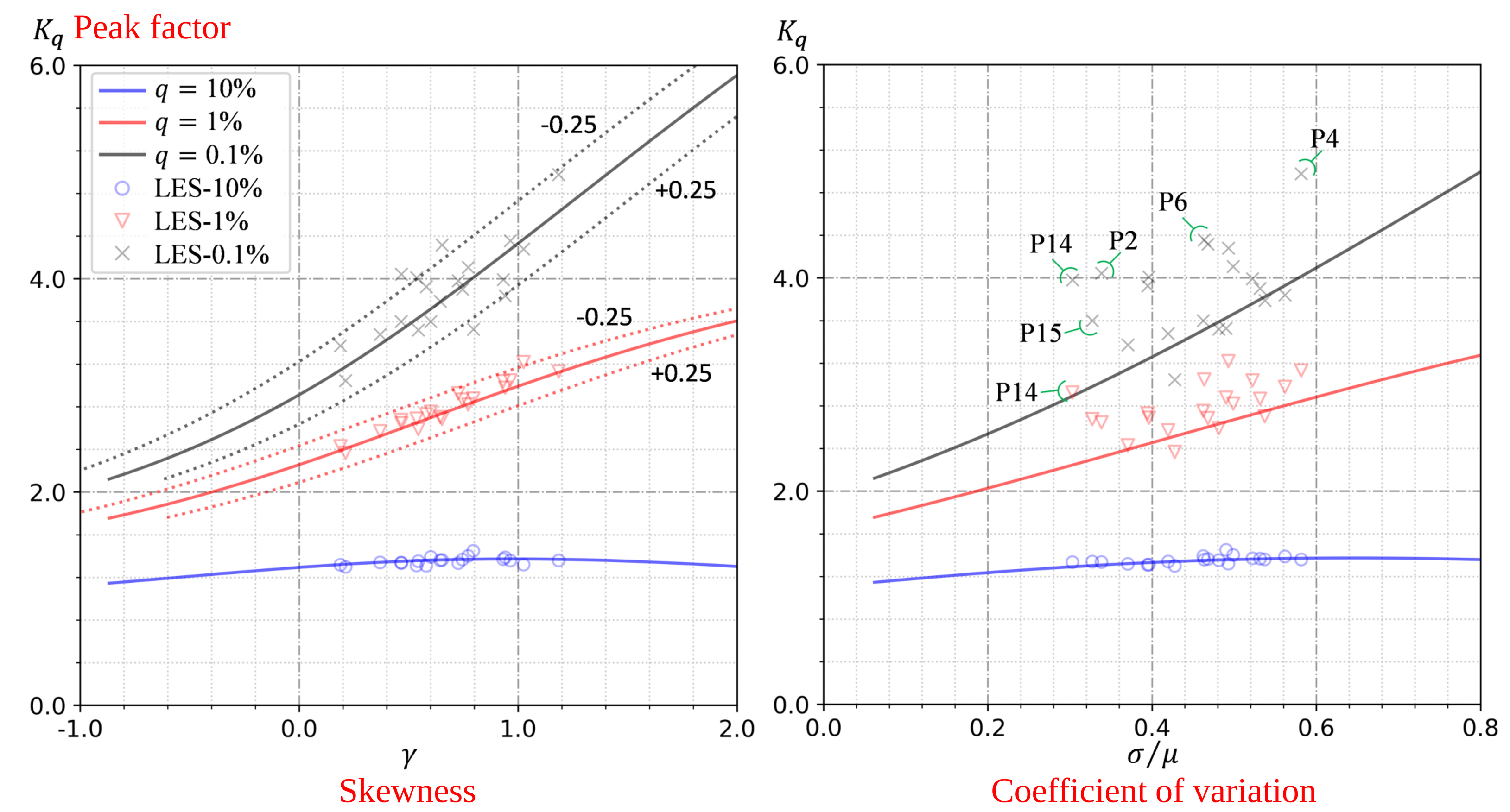


- Large-eddy simulation (LES) of Tokyo Polytechnic University Atsugi Campus (Case-TPU)

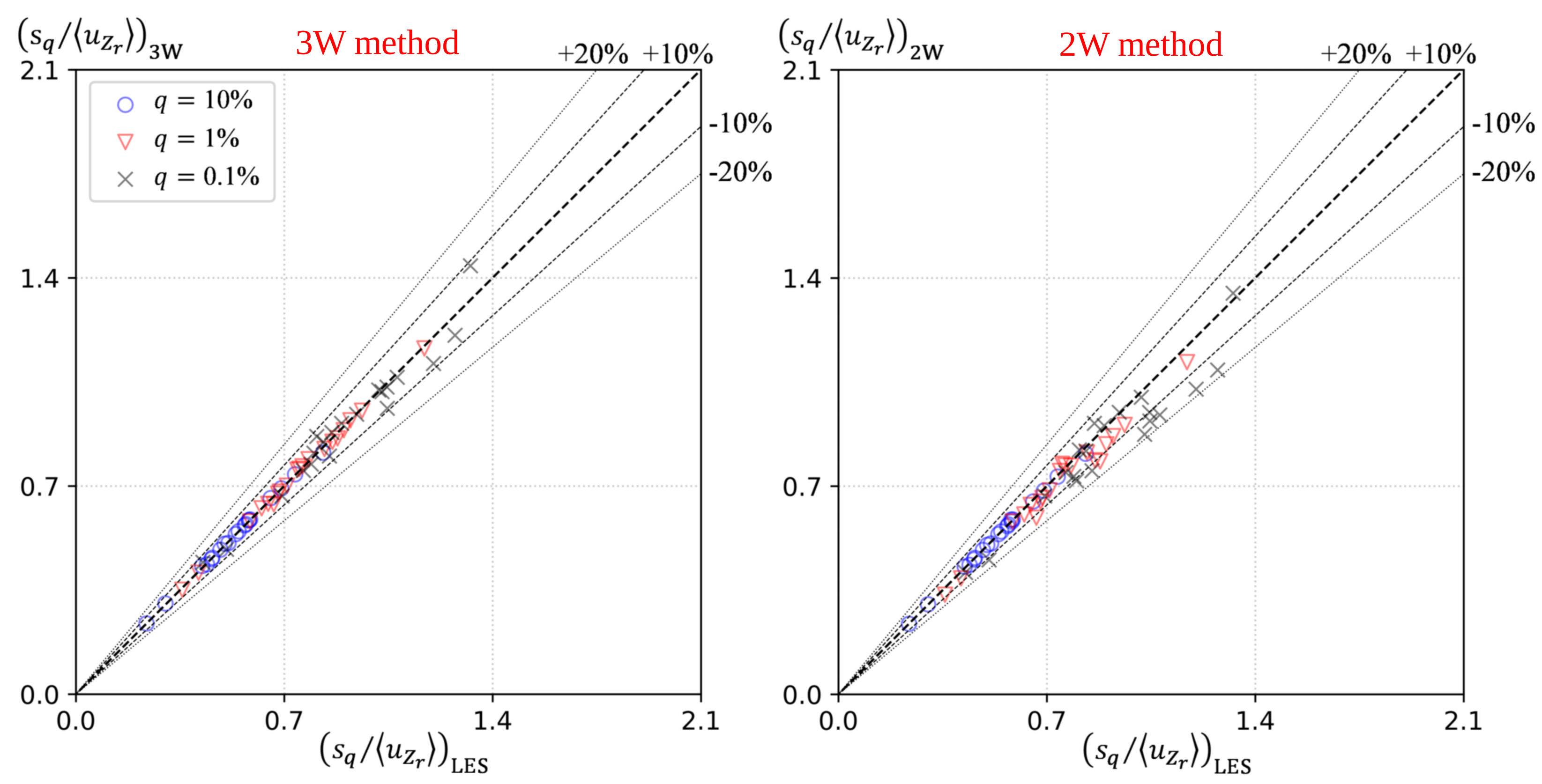
Reference

[1] T. Stathopoulos, J. Wind Eng. Ind. Aerodyn. 94 (2006) 769–780. https://doi.org/10.1016/j.jweia.2006.06.011.
[2] W. Wang, T. Okaze, Build. Environ. 244 (2023) 110781. https://doi.org/10.1016/j.buildenv.2023.110781.
[3] W. Wang, T. Okaze,, Build. Environ. 209 (2022) 108644. https://doi.org/10.1016/j.buildenv.2021.108644.

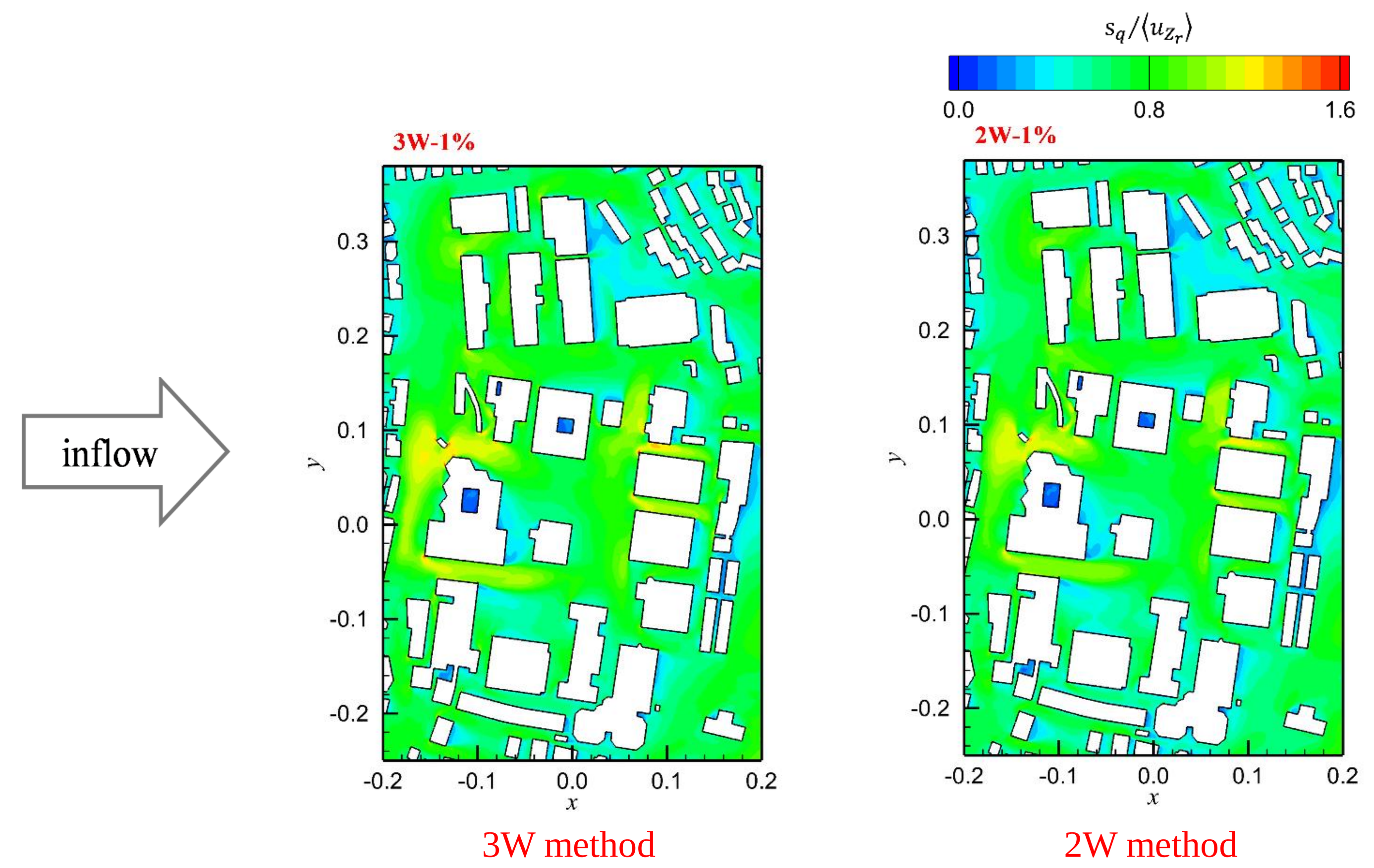
Statistical analysis



- Relationships between statistics. Lines: Weibull distribution. Scatters: LES results.



- Comparison of LOSWSs with q = 10%, 1% and 0.1%. (a) 3W method; (b) 2W method



- Distribution of LOSWS with q = 1%

Conclusion

- The methods to estimate peak factors by skewness (3W method) and coefficient of variation (2W method) were derived.
- The Weibull parameters do not need to be estimated in these methods. The time-series data is not required for estimating LOSWS by these methods.
- For the estimation of LOSWS of isolated building and actual urban cases, high accuracies by both 3W method and 2W method were obtained (i.e., errors are less than 10% at most points). 3W method is more accurate than 2W method.