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Turbulent Flow Over Urban Areas of Osaka, Japan – From Building-Resolving Large-Eddy Simulation Towards the Downscaling of Mesoscale Perturbations

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Abstract

Urban turbulent flow at different heights exhibit greatly differing statistical properties. Close to the urban canopy, where the flows are strongly perturbed by the roughness elements mounted on the ground, there is a high inhomogeneity in the mean flow and turbulence statistics. At higher levels, the flows are eventually devoid of the influence from the morphometric features of urban surfaces and are essentially driven by large-scale forcing. Knowledge of the complex interaction between the urban topography and the atmospheric turbulent boundary layer not only requires improved urban canopy parameterisation (UCP) but also optimised schemes for the downscaling of mesoscale meteorological perturbations. Using large-eddy simulation (LES) and wavelet analysis, relevant results are presented for realistic urban areas (Fig.1) in Osaka, Japan.

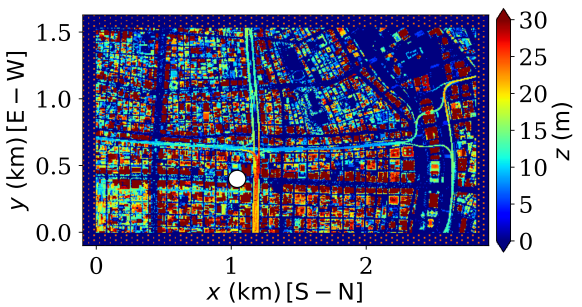
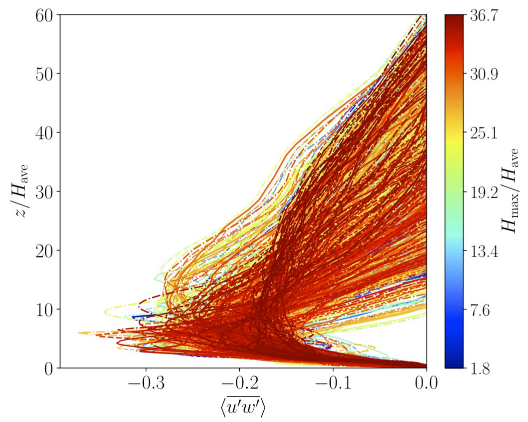


Fig.1 Building-height distribution over an area of Osaka, Japan. The white dot indicates the sampling point for the wavelet analysis.

Results and Discussion

Fig.2a shows that the inertial sub-layer, wherein close-to-constant Reynolds shear stresses are often expected [Cheng & Castro, 2002], may not be always clearly identified; nonetheless this does not preclude the establishment of well-defined logarithmic wind profiles (Fig.2b). While the vertical range of the

(a)



(b)

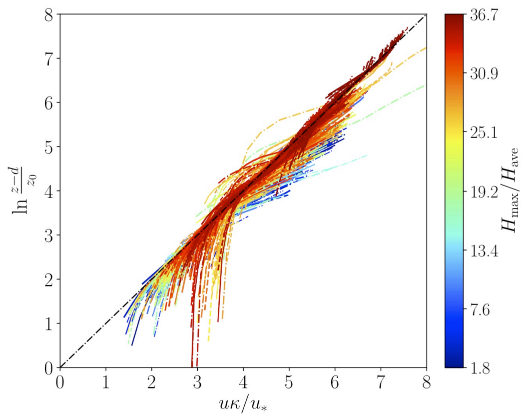


Fig.2 (a) Vertical profiles of the mean Reynolds shear stress, u′w′; (b) logarithmic mean wind profiles scaled with z_o and d.

logarithmic region may be very narrow and the profiles may intercept with the reference one (the diagonal line) at different vertical levels, the scaling with the surface aerodynamics parameters, z_o and d

(the roughness length and the zero-plane displacement height) is in good agreement with the log law. The parameterisation of z_o and d in terms of the plan-area and frontal-area densities, λ_p and λ_f, the mean and maximum building heights, H_{ave} and H_{max}, and the building-height variation, σ_{H}, which characterise the morphometric features of urban surfaces [Kanda et al., 2013], are discussed. The objective is to derive improved UCP schemes that allow more accurate parameterisation of momentum fluxes in mesoscale models through the Monin-Obukhov similarity theory.

On the other hand, the multiscale nature of atmospheric boundary layers prohibits turbulence from being resolved across the entire spectra of spatial and temporal scales [Orlanski, 1976]. Technically-simple and computationally-inexpensive techniques for the downscaling of mesoscale meteorological perturbations are desired for the accurate modeling of fine-scale dynamics in urban microenvironments, in particular to improve the prediction of urban extremes, which include wind gusts and strong turbulence that typically excited by severe mesoscale meteorological disturbances, e.g. typhoons [Takemi et al., 2019]. Fig.3a shows that

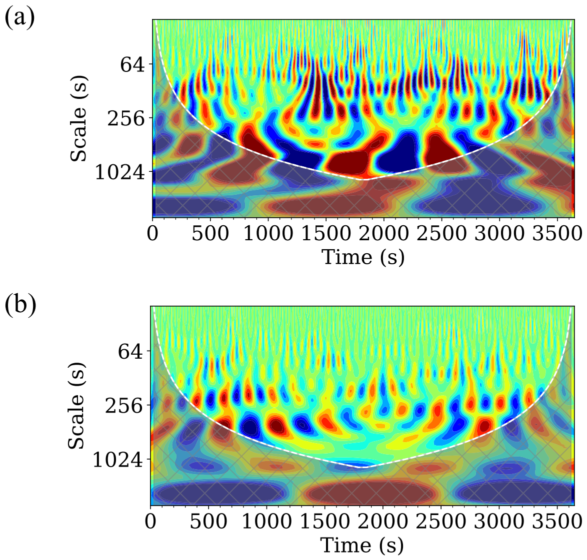


Fig. 3 Wavelet coefficients of the streamwise wind fluctuation, u′. (a) Near the surface roughness sub-layer, z=50 m; (b) above the log-law region, z=404 m.

turbulence eddies are much more fluctuated at lower heights; by contrast, the eddies away from the surface layers are well organized on different scales (Fig.3b). The results suggest that the downscaling of mesoscale perturbations needs to be treated differently according to the vertical heights within the urban computational fluid dynamics (CFD) models that the perturbations are incorporated. This work also discusses the potential of applying wavelet analysis, which may allow signals to be coupled in a means respecting both the multiscale nature and the unsteadiness of large-scale forcing.

Acknowledgments

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