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Study of the urban turbulent boundary layer above realistic urban environments using computational fluid dynamics method

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Urban ventilation and dispersion patterns are strongly affected by the building configuration and geometry of the urban area. In particular, for cities with high-building density, the prevalent free-stream mean wind is significantly blocked by the buildings and does not contribute effectively to the ventilation and dispersion in the urban environments. Under this condition, turbulence is important for the transport/removal of heat, water vapor and air pollutants. Existing related research studies on the turbulence characteristics of urban boundary layer (UBL) mainly focused on the turbulent flow passes idealized urban geometries like 2D street canyons and building block arrays. In comparison, the turbulence characteristics above and within realistic urban canopies is less investigated. Real cities usually have complex and heterogeneous building configurations that often implies the different turbulent production and transport mechanisms compared with those of idealized urban canopies. In order to explore the different turbulence characteristics between idealized and realistic UBLs, the objective of this study is to use computational fluid dynamics (CFD) method to simulate and analyze the boundary layer flow above explicitly-resolved real urban building geometries and compare it with those of the idealized ones.

We collected the building map data of three representative downtown urban areas with high building density and heterogeneous building configurations. These include the Kowloon Peninsula of Hong Kong, Lujiazui Peninsula of Shanghai, and Manhattan of New York city. Based on a validated mesh preparation protocol using the open-source CFD code OpenFOAM, we performed Reynolds-averaged Naiver Stokes (RANS) simulations of the turbulent boundary layer flow passes the abovementioned peninsulas in neutral thermal stability conditions. The development of the internal boundary layer (IBL) above the urban areas are investigated. The results suggested the dominant roles of skyscrapers on the turbulence characteristics and the development of the IBL. In addition, the temporally- and local-horizontally-averaged vertical profiles of the mean wind, turbulent shear stress and velocity standard deviations are calculated. The profiles are compared with the results of idealized urban canopies, and the differences will be pointed out in the presentation. The simulation results were also used to examine the accuracy of current existing urban canopy flow models.