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Multi-scale numerical simulation of typhoon wind effects on urban building blocks

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SUMMARY:
Based on the mesoscale WRF (Weather Research Forecast) model and CFD (Computational Fluid Dynamics) simulation, a coupling numerical simulation framework aiming to resolve typhoon wind field around urban blocks has been developed in this paper. This framework mainly consists of the mesoscale model, microscale CFD model and the coupling interface. Typhoon weather reanalysis and wind field simulation are conducted by the WRF model with nested computational domains incorporating high-resolution topography data. The wind profiles generated by the WRF model are applied in the coupling interface as the inlet boundary conditions for the downscaled CFD model with urban building blocks through the interpolation technique. The Wind field around K11 building in Hong Kong during Typhoon Kammuri was simulated by the multi-scale framework, and the simulation result was compared to the full-scale measurement wind speed data at the top of K11 building. Turbulent wind interferences of building blocks including vortex shedding, corner separations and channeling effects have been resolved in detail.

Keywords: typhoon, multi-scale, urban building blocks

1. INTRODUCTION

Urbanization is one of the trends of global social development. Rapid urbanization greatly changes the local topography and local wind climate. Highly densified urban regions are especially vulnerable to the impact of natural hazards. On the other hand, most of coastal mega-cities of China are also located in a typhoon-prone area. Typhoons always bring high winds and heavy rains to coastal cities, and would cause severe damages to buildings and other facilities in urban districts. It is therefore necessary to develop a numerical framework to simulate urban wind fields under typhoon conditions for wind-resistant design of tall buildings and typhoon hazard mitigations. Numerical simulation is likely to be one of the most promising methods for urban aerodynamics, since it is the most affordable, accurate, and informative (Chen, 2004). Typhoon represents a violent and rapidly changing mesoscale wind weather system, and temporal-spatial variability and multiscale eddy structures could be produced under typhoon conditions. Various studies have been devoted to couple CFD and NWP models (Zajaczkowski et al., 2011; Takemi et al., 2019). Based on WRF model and CFD method, a high fidelity coupling numerical simulation framework of urban wind field during typhoon is implemented in this paper.

2. NUMERICAL METHODOLOGY

As shown in Fig. 1, the proposed urban wind field simulation framework can be divided into three components: mesoscale simulation, microscale simulation and coupling interface. The mesoscale simulation task aims to resolve typhoon weather process and generate wind profiles as inputs for the downscale CFD simulation. The LES model is employed as microscale simulation to capture fluctuating flow field information around building blocks with refined meshes. The lateral boundary conditions of LES could be determined by the WRF mesoscale simulation. The coupling from the WRF output to the LES model has been implemented by a polynomial interpolation scheme.

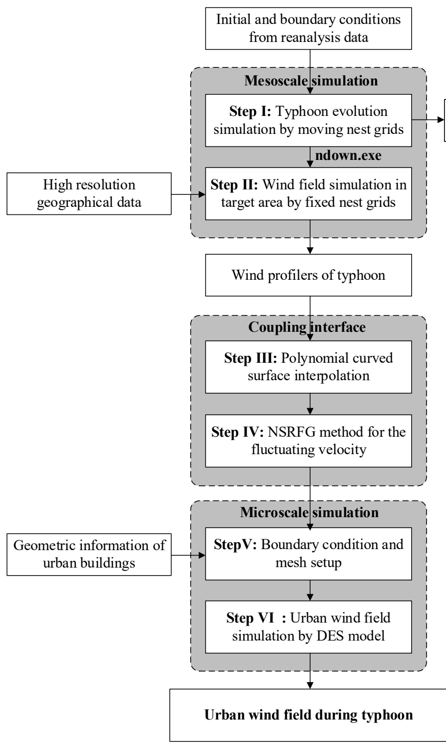


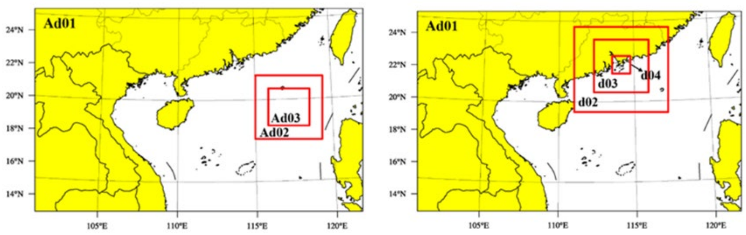
Figure 1. Framework of proposed multi-scale typhoon wind field simulation method.

3. MULTI-SCALE SIMULATION OF TYPHOON KAMMURI

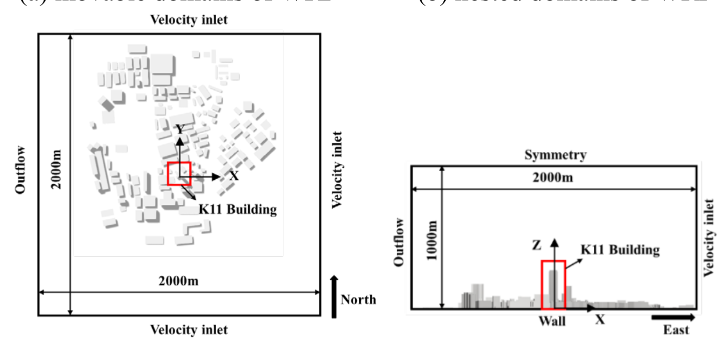
In order to verify the effectiveness of the simulation frame work, typhoon urban wind filed simulation has been carried out for Typhoon Kammuri attacking Hong Kong in 2008. The simulation is centered on K11 Building in Hong Kong, which has 73 floors and a total height of 270 meters.

3.1. Simulation settings

According to the multi-scale simulation framework, a WRF mesoscale simulation of Typhoon Kammuri was performed firstly. The 72-hour simulation duration is from 0:00 on August 5 to 0:00 on August 8, 2008 (UTC). Fig. 2(a) shows a triply nested grid configuration scheme for typhoon evolution simulation which contains one fixed domain and two moved domain. The fixed nested grids are also designed to simulate the wind field in the target area as shown in Fig. 2(b).



(a) movable domains of WRF (b) nested domains of WRF



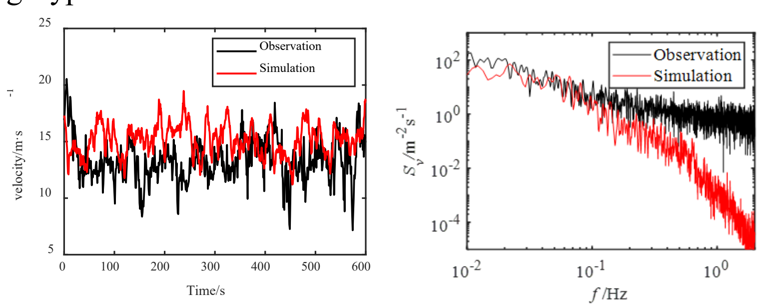
(c) plan view of CFD domain (d) side view of CFD domain

Figure 2. Computational domains of WRF and CFD simulation.

As Fig.2(c)(d) shows, the size of computational domain is 2000m (length)×2000m (width)× 1000m (height). The northern, southern and eastern patches of domain are set as the velocity-inlet boundary whose initial values are provided by the WRF results. All building faces and the ground are defined as no-slip walls, where the wind velocity is set to zero.

3.2. Evaluation of simulation results

The 10-miniute duration wind speed (02：30 to 02：40 on August 6, 2008) at the top of K11 building was obtained by the LES model and compared with the measured results of the anemometer. It can be seen that the LES model just slightly overestimated the mean wind speed by 1.73 m/s compared to the measured one. Fig. 3(b) compares the power spectrums of fluctuating wind speed between simulation and measurement. It indicates that the low frequency part of the simulation results is in good agreement with the measured spectrum but the simulated spectrum drops much rapidly than the measured one at the high frequency range, i.e., greater than 0.5 Hz. That is to say, the current LES model is capable of reproducing the fluctuation of large eddies in the urban typhoon field, but cannot fully resolve the high frequency turbulence. In general, the proposed simulation framework could generate the fluctuating wind field around K11 building during Typhoon Kammuri.

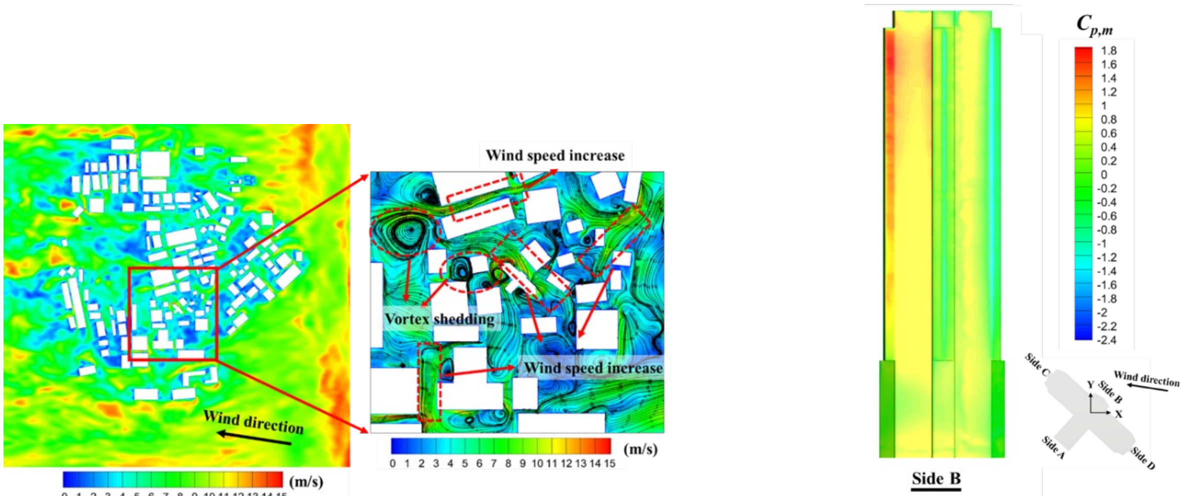


(a) wind speed time histories (b) power spectrums of wind speed

Figure 3. Comparison between simulation and measurement.

3.3. Urban wind field results of the LES model

Fig. 4 presents the 10m-height wind field obtained by the downscale CFD simulation. While the maximum wind speeds exceeding 15m/s occur in the open area of the computational domain, flow stagnations are observed in the downwind locations of the urban blocks. By plotting wind-velocity streamlines around K11 building in Fig. 4, obvious wind speed up can be observed at several narrow channels and several building-size vortexes form around the building corners.



(a) Contours of wind velocities (m/s) at 10 m above the ground (b) Mean wind pressure on K11 building

Figure 4. Typhoon wind effects on building blocks Contours of wind velocities (m/s) at 10 m above the ground.

4. CONCLUSIONS

Based on the WRF model and CFD simulation, a coupling numerical simulation framework of typhoon wind fields has been presented in this study which combines the advantages of WRF and CFD. The wind field simulation around K11 Building in Hong Kong during Typhoon Kammuri has been carried out to verify the robustness and accuracy of this framework. The coupling numerical simulation framework is capable of accurately and efficiently simulating the track and the strengthening process of typhoon Kammuri. The proposed urban typhoon wind field simulation framework could adequately generate turbulent wind flows around building blocks and fluctuating wind pressure on the target building.

ACKNOWLEDGEMENTS

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