Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

AAS022-01 Room:104 Time:May 25 08:30-08:45

Turbulent analysis of strong wind variability by merging numerical weather prediction and large-eddy simulation models

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The variability of wind speed in urban areas is influenced not only by meteorological disturbances and topography but also by buildings and social infrastructures. Particularly in densely built metropolitan areas with high-rise buildings, there is a local-scale wind structure with patches of high/weak wind speeds and high/low wind variability. These characteristic features of local-scale winds are an important factor in dealing with disaster prevention, atmospheric environment, and energy management in urban areas. For understanding the local-scale structure of winds in urban areas, there are two approaches: one is to deploy a surface observation network with densely distributed sites and/or a long-range remote-sensing network; and the other is to use computational simulation techniques by numerical models. It is important to develop numerical simulation models appropriate for applications in order to take a numerical approach. In general, meteorological models are useful in simulating wind variability induced by meteorological disturbances and topography. For example, weather forecasting is based on the numerical simulation techniques by numerical weather prediction (NWP) models; the data produced by NWP models are provided to our community as daily weather information. The resolutions of NWP simulations become higher and higher down to an order of kilometers (an order of 100 meters for research purposes). Wind flows in urban areas with complex surface features, however, are not reproduced by NWP models that cannot incorporate realistic building information. On the other hand, such local-scale wind flows in urban areas are studied in computational fluid dynamics (CFD) communities. The CFD techniques, if coupled with meteorological simulation techniques, should be promising in numerical approaches for representing wind flows in real urban areas under real meteorological conditions. Specifically, large-eddy simulation (LES) techniques are considered to be appropriate for the numerical analyses of wind flows in urban areas with complex surface features. Therefore, the purpose of this study is to propose a numerical approach for quantitative analyses of wind flows in real urban areas. We conduct numerical simulations for strong winds and gusts over the central business district of Tokyo during the passage of Typhoon Melor (2009). The Weather Research and Forecasting (WRF) model is used for the meteorological simulation; Mesoscale Analysis data by Japan Meteorological Agency (JMA) are used as the initial and boundary conditions. The nesting technique is used to resolve the area including central Tokyo at 60-m grid. The high-resolution temporal and spatial data from the WRF model are then used as the initial and boundary conditions for an LES model. The lower boundary of the LES model is determined by a building-height dataset for the analysis area. A turbulent simulation of wind flows in the realistic urban area is conducted with the LES model. The simulation successfully captures the wind variability and peaks observed at a surface site of JMA.

Keywords: Turbulent flow, Urban, Meteorological model, large-eddy simulation, wind gust, environmental fluid dynamics