High-Resolution Numerical Analysis of Turbulent Flow in an Urban Area by Merging Numerical Weather Prediction Model and Large-Eddy Simulation Model

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1. Introduction

Atmospheric flows in an urban area are highly turbulent owing not only to meteorological disturbances but also to complex and complicated distribution of roughness obstacles (i.e., buildings and structures). Numerical modeling is an important research tool to investigate turbulent flows in urban areas in addition to laboratory experiments and field observations. In previous meteorological models, urban areas are regarded as a very rough surface that has either a large roughness length or a slab of resistant layer. This type of simplified approaches is useful in cases of flows over urban areas with sparsely-distributed, low-rise buildings with uniform heights. However, recent urbanization makes urban surfaces covered with densely-distributed, high-rise buildings with variable heights. In order to numerically examine flows over such highly rough urban surfaces, a computational fluid dynamical (CFD) approach is promising in spite of high cost in computational resources. In case of turbulent simulations, a large-eddy simulation (LES) is useful. Recent studies have demonstrated that a numerical weather prediction (NWP) model is capable of performing LESs for turbulent flows in convective boundary layer (e.g., in case of the Weather Research and Forecasting (WRF) model (Skamarock et al. 2008), Moeng et al. 2007; Wang and Feingold 2009; Wang et al. 2009; Ohno and Takemi 2010a, 2010b). However, it is quite difficult to perform LESs of flows in a neutral or a stable environment with commonly used NWP models. Therefore, the present study proposes an approach to examine turbulent flows in a densely-built environment with the mixture of high-rise and low-rise buildings by merging the WRF and an LES model.

2. Numerical approach and results

The NWP model used here is the Advanced Research WRF (ARW) model, while the LES model used is one developed by Nakayama et al. (2010, submitted). The governing equations of the LES are a filtered Navier-Stokes equation and a filtered continuity equation for incompressible flow without any thermal effects. The subgrid-scale eddy viscosity is parameterized by the standard Smagorinsky model.

The cases examined here are strong wind events over Tokyo: a winter storm on 5 December 2004 (maximum instantaneous wind speed: 40.2 m/s) and a typhoon attack on 8 October 2009 (max. instantaneous wind speed: 30.2 m/s). The WRF model simulates the meteorological phenomena by using JMA and/or NCEP analyses to downscale the Tokyo area at the 60-m horizontal grid spacing. The WRF outputs at the 60-m grid are used as initial and boundary conditions for the LES model. Turbulence is generated either by driving flows over a long fetch or by a recycling technique based on Lund et al. (1998).

Figure 1 compares the wind speeds at the 100-m height simulated by the WRF and the LES model and observed at the 75-m height for the winter storm case on 5 December 2004. Turbulence in the LES domain is created by setting a long fetch. The WRF result is relatively flat, although the LES results indicate highly turbulent behavior. In addition, the LES peak winds well correspond to the observed instantaneous wind speeds. The results suggest that the present approach is capable of representing instantaneous wind speeds within an urban canopy. The present approach is tested against the typhoon case.

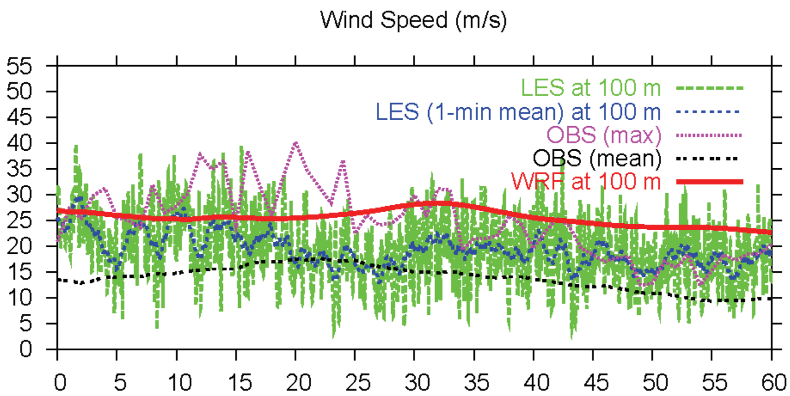

Figure 1: Time series of wind speeds for the winter storm over Tokyo on 5 December 2004.

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