［共同研究成果］

A building-resolving simulation of sea breeze over Sendai downtown with a parallelized CFD model

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In the study, we develop a parallelized CFD model to realize the building-resolving simulation for one whole city. The test run on Sendai downtown at a high resolution of 3 m is conducted by the NEC SX-9 supercomputer at the Cyberscience Center of Tohoku University. The experiment is designed to simulate the winds and temperature during a typical sea breeze event. The general features of turbulent flows in the urban canopy layer are well reproduced. The results suggest that this parallelized CFD model is promising for the high-resolution urban weather forecast in the future.

1. Introduction

In recent years, a research project of high performance numerical weather prediction, as one part of the Strategic Programs for Innovative Research of Japan, is initiated to achieve the high-precision mesoscale forecast [1]. As a part of this project, the building-resolving CFD model is developed to realize the super high-resolution mesoscale modeling of the urban weather [2]. The purpose is to simulate the winds and temperature for big city with every buildings resolved.

One of the major difficulties we faced is the huge demand of calculation amount, and another is the memory limit at a single node. To solve these problems, we convert the source code of CFD model to support the high-performance calculation with the Message Passing Interface (MPI). This parallelized CFD model has been recently tested on the K computer at RIKEN Advanced Institute for Computational Science, for a large domain of 25 km with a resolution of 10 m. In this study, we transfer this CFD model to the NEC SX-9 supercomputer at the Cyberscience Center of Tohoku University. The test run on SX-9 is implemented to understand the performance of the CFD model at an even higher resolution of 3 m for the realistic complex building.

2. System configuration and experiment design

The CFD model used here is a local meteorological model based on large-eddy simulation [3]. The model is based on the Cartesian coordinate, with the block-off technique to treat the buildings and steep topography. The model equations are solved by an algorithm of the semi-implicit method for pressure-linked equation, and a full time-implicit scheme is applied. This CFD model has been applied to simulate the local flows and temperature on the small-scale buildings and street blocks [4]. The CFD code has been revised to support the MPI for parallel calculation. The parallel calculation is made at both X and Y directions, while the auto parallel split is applied at Z direction.

The sea breeze is a typical weather phenomenon during the summer season that greatly influences the local winds and temperature at the coastal areas [5]. At 13 JST June 19, 2007, sea breeze blows over the Sendai City. In this study, the experiment is designed to study this sea breeze penetration over the Sendai downtown. The model domain is centered at Sendai station with a scale of about 3 km (Figure 1). The spatial resolution is 3 m for X, Y, and Z directions. The model top is 300 m, with 100 vertical levels. Therefore, the total grid points are one hundred millions. The forecast time is about 120 seconds. The initial conditions of atmosphere and ground temperature are provided the short-range forecast of non-hydrostatic model [6, 7] from the assimilated data [8]. On SX-9 supercomputer, we use 16 nodes to perform the parallel calculation. It takes about 14 minutes to complete the forecast.

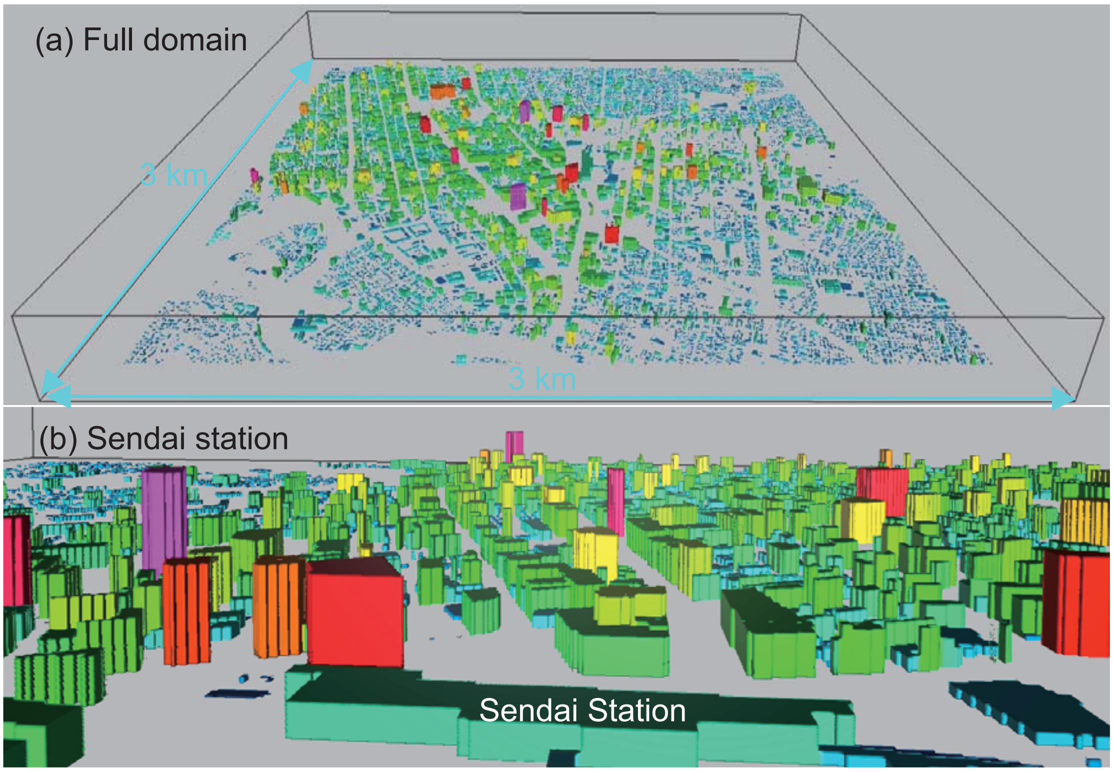

Figure 1. The buildings of Sendai downtown for the CFD model. (a) Full domain; (b) Sendai station

3. Results

Figure 2 shows the general pattern of zonal wind over the Sendai downtown at forecast time T=120 seconds. The tails of low wind speed are elongated at the lees of the buildings, with an horizontal extension of about 2-3 times of the buildings height, which are often interrupted by the downstream buildings. As a whole, the buildings drag is clearly shown to slow down the wind speed. In the vicinity of some tall buildings, the local maximum of high wind speed can be easily identified. Broadly speaking, in the urban canopy, the air flow exhibits strong turbulent characteristics due to the complex buildings structures. Compared to the low wind speed within the urban canopy, the sea breeze exhibits a relatively fast penetration at the high layer from the southeastern regions.

Figure 3 shows the spatial distribution of temperature near Sendai station. It is clearly shown that the air mass trapped in the urban canopy exhibits a strong turbulent feature near the major buildings. There are some warm bubbles that grow at the lees of the buildings, which are generally stretched downstream by sea breeze. Although the wind speed is some low in the urban canopy, there is an active vertical mixing that strongly transports warm air upward and cool air downward. Considering a relatively fast penetration of cool marine air above urban canopy, sea breeze helps to decrease the temperature near surface from top in the presence of strong vertical mixing. This suggests that sea breeze can bring an effective cooling to the urban areas, despite of the low wind speed by building drag. The cooling effect may be estimated by the wind speed of marine air above urban canopy and the vertical mixing within, which is usually related to the urban ventilation.

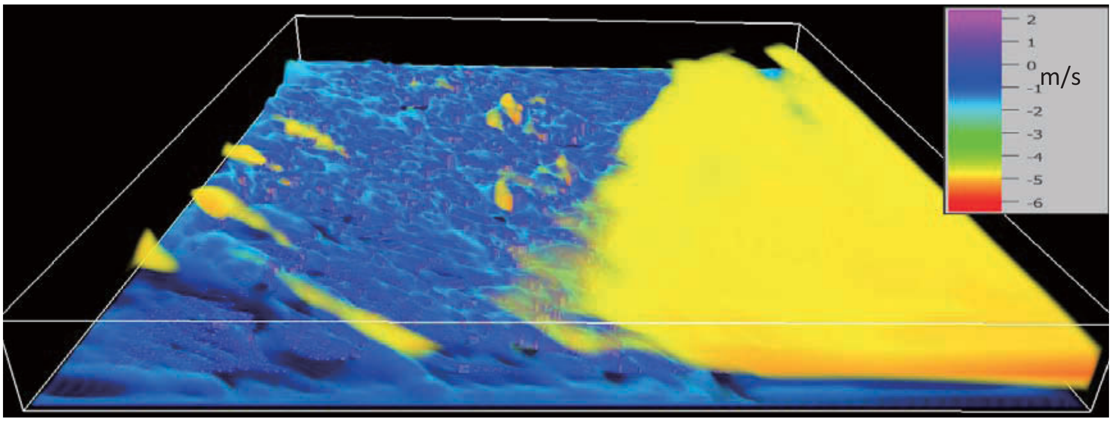

Figure 2. Spatial pattern of the zonal wind speed over Sendai downtown.

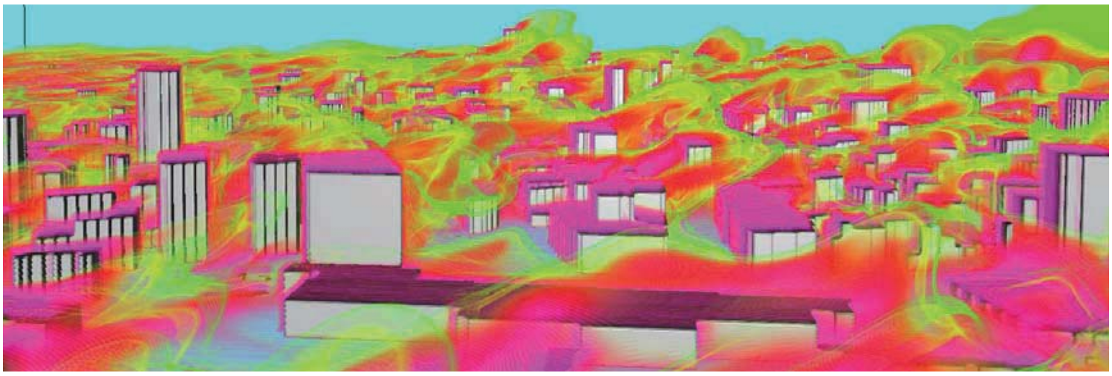

Figure 3. Spatial distribution of the temperature near Sendai station.

4. Summary

In this study, we have conducted the building-resolving CFD simulation on the sea breeze over the Sendai downtown. The general features of turbulent flows in the urban canopy are well simulated by the CFD model. The results suggest that the parallelized CFD model has a good performance at the very high resolution of 3 m. It should be emphasized that this is a realistic simulation of the weather conditions. With high-precision mesoscale forecast available to drive the CFD model, it seems reasonable to realize the high-resolution forecast of urban weathers for street corners in the coming years [1, 2]. In the ongoing works, we continue to perform more experiments and verify the system performance with intense observation network.

Acknowledgment

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