J8.3

ATMOSPHERIC BOUNDARY LAYER AND SCALAR DISPERSION WITH EXPLICITLY RESOLVED URBAN GEOMETRIES USING LARGE EDDY SIMULATION FOR CITY (LES-CITY)

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1. INTRODUCTION

Understanding the relationship between turbulent flow characteristics and surface geometry is very important for mitigating urban atmospheric problems such as pollution and the heat island effect. The mean flow and turbulent statistics have been extensively studied by laboratory experiments, field campaigns, and numerical simulations.

LES has a great advantage for investigating turbulent organized structures and the representative turbulent characteristics of canopy flow because it has high spatial and temporal resolution. Most of the previous applications of LES to urban surfaces were wind engineering studies of 3-D flows around a single obstacle. Few studies have applied LES to 3-D flow including obstacle arrays.

In this study, flow structures and scalar dispersions in urban boundary layers are analyzed, using large eddy simulation (LES-CITY) with an explicitly resolved urban geometry. Two types of urban surface geometry have been investigated. One is large square/staggered arrays of uniform building with various areal densities (Experiment-1), and the other is a real 3-D building geometry using GIS-data of Tokyo Metropolitan area (Experiment-2).

2. TECHNOLOGY OF LES-CITY

The model structure of LES-CITY is described in Kanda et al.(2004) and Kanda (2005).

The governing equations and the manner of turbulence closure in this large eddy simulation (LES) study are from Deardorff (1980). We use a mask method to solve these equations. Mask methods have a great advantage of easily implementing solid obstacles in the computational domain without using boundary fitted grids. They also reduce the computational cost. According to the mask method by Briscolini and Santangelo (1989), numerical integration proceeds in the following steps: (a) free evolution of the velocity field inside the entire computational domain neglecting the forcing term due to obstacles, (b) introduction of the forcing induced by the physical boundary conditions on the obstacle surfaces, and (c) pressure modification by requiring incompressible flow.

The governing equations are approximated by second-order central differences in space. The Adams-Bashforth scheme is applied to time integration. Although the Poisson equation of pressure can be solved by an iterative method such as SOR, it is very time-consuming. Instead, we use the following direct pressure-solver (Raasch and Schroter, 2001): the discretized Poisson equation is Fourier transformed along the x and y directions (2-D), (STEP1). The resulting tridiagonal system of the equations is solved in the z direction (STEP2), and then transformed back from phase space into Cartesian space (STEP3).

Although the parts of the current model are not new, the combination of features results in a very effective model, hereafter LES-CITY, for large eddy simulation of complicated airflow in cities.

3. EXPERIMENT-1 : estimation of momentum and scalar transfer coefficients for cube arrays using LES-CITY

The purpose of the Experiment-1 is to obtain basic knowledge for making simple urban canopy model for meso-scale simulations (SUMM : see J1.5 in this volume). We assume that large square or staggered arrays of uniform cube with various areal densities (Figure 1).

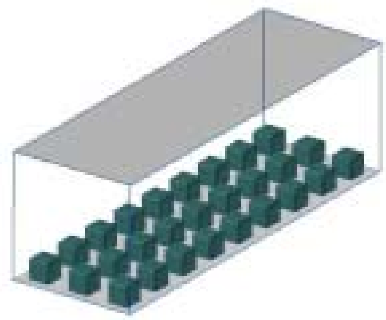

Figure 1 An array of cube for Experiments-1

First, a passive scalar was released at a constant flux from all constituent surfaces under fully developed turbulent flows, and then a dataset of relative value of local transfer coefficients of each constituent surface (Figure 2) and the roughness length for momentum (Z0m) and for scalar transport (Z0c) in the surface layer (Figure 3), was constructed.

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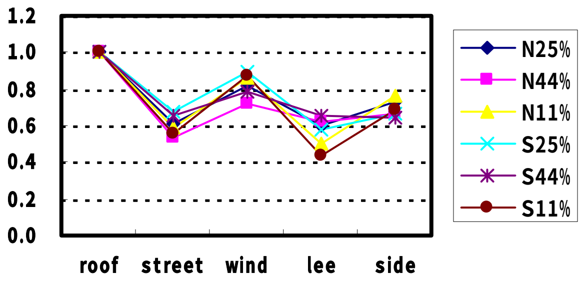

Figure 2 Relative values of bulk transfer coefficients of scalar transport for the cube constituent surfaces (i.e., roof, street, windward wall, leeward wall and side wall) estimated from LES-CITY results. The values are normalized by that of the roof. In the legend, N and S mean regular array and staggered array, respectively, and the number(%) means the plane aspect ratio of cube.

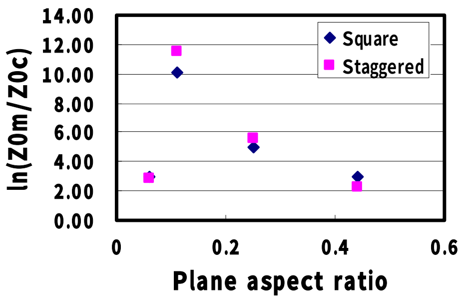

Figure 3 The roughness length for momentum (Z0m) and for scalar transport (Z0c). The vertical axis is log-plot of the ratio of two roughness lengths, and the horizontal is the plane aspect ratio of cube array.

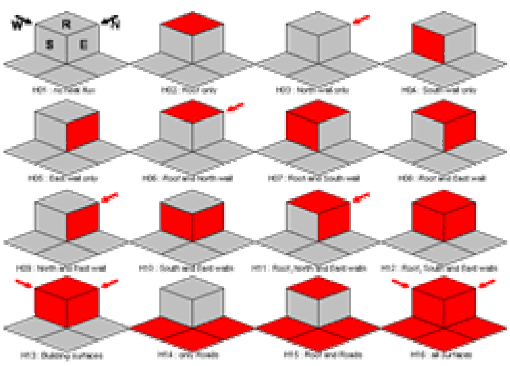

Figure 4 Various surface heating scenarios

Second, simulations with a constant heat flux 100 w m-2 to one of the constituent surfaces (four vertical walls, roof, and floor, respectively) were performed (Figure 4). The results revealed that the heating of windward-wall generates significantly larger Reynolds stress than the heating of the other surfaces even though the heat fluxes per unit lot area are all the same (Figure 5).

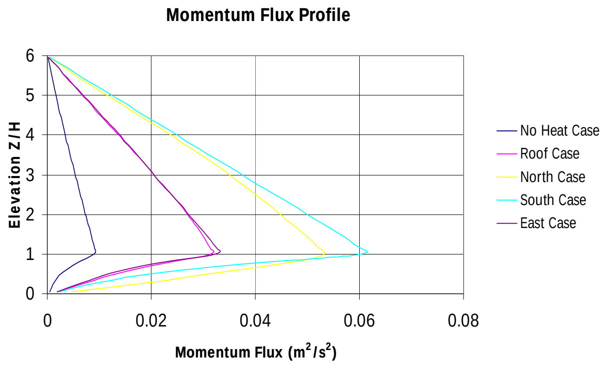

Figure 5 Horizontally averaged Reynolds stress profile for different surface heating.

4. EXPERIMENT-2 : application of realistic urban geometries

The purpose of the Experiment-2 is just a trial of application of LES-CITY to the assessment of the real atmospheric environmental issues. One of the great advantages of LES-CITY is the simple way of including obstacles by using flags of 1 (air) or 0 (obstacle) together with an immersed boundary method and the Cartesian coordinate system. Therefore, the users are free of complicated grid generation processes in the pre-processing, and also easy in transforming the computational results into general visualization packages in the post-processing.

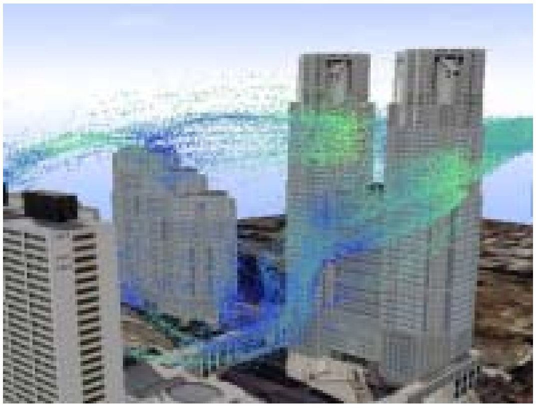

Figure 6 Scalar dispersion in Sinjuku-city simulated by LES-CITY. The results can be visualized using AVS together with the realistic urban texture mapping.

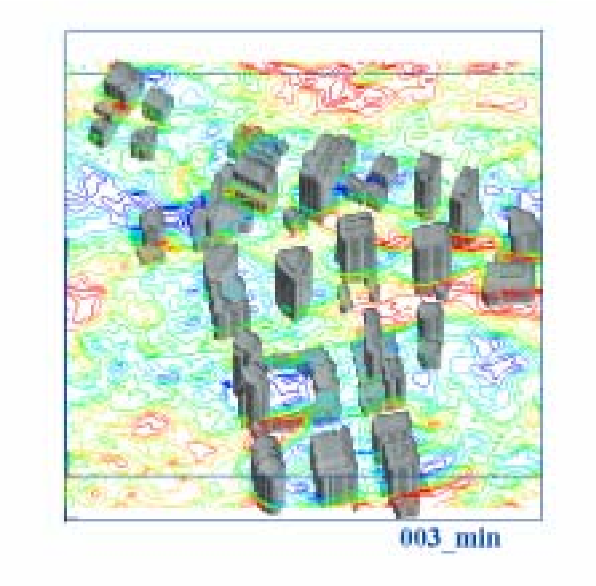

Figure 7 Contour map of horizontal wind velocity near the ground in Sinjuku-city.

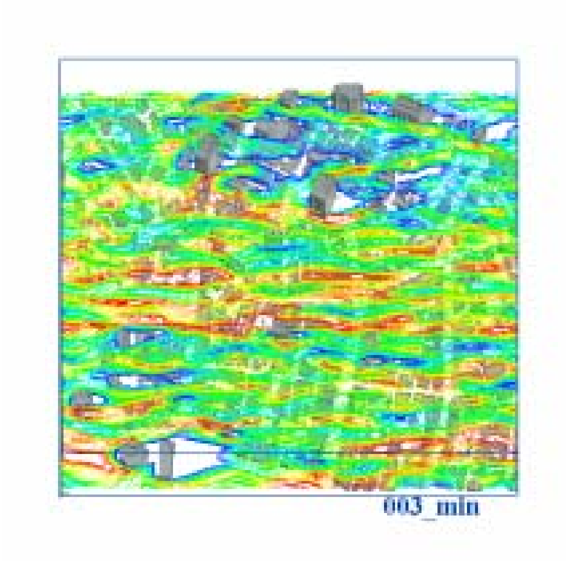

Figure 8 Contour map of horizontal wind velocity near the ground in Chiyoda-city. The streaky patterns corresponding to turbulent organized structures appear.

ACKNOWLEDGEMENTS

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