9.12 CFD MODELING OF FINE SCALE FLOW AND TRANSPORT IN THE HOUSTON METROPOLITAN AREA, TEXAS

*Sang-Mi Lee, Harindra.J.S. Fernando,
Environmental Fluid Dynamics Program
Arizona State University, Tempe, AZ 85287-9809

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Daewon W. Byun,
Institute for Multidimensional Air Quality Studies
University of Houston, Houston, TX

and

Jason Ching,
AMD/NERL, US EPA, RTP, NC 27711
(On assignment from the Air Resources Laboratory of NOAA to the NERL of the US EPA)

1. INTRODUCTION

Fine scale modeling of flows and air quality in Houston, Texas has been performed. A computational fluid dynamics (CFD) model, a gridded model in Eulerian frame, is applied to investigate the influence of urban morphology on the sub-grid scale transport and dispersion of pollutants in grid models with grid sizes of the order of 1 km.

Meteorological flow fields of urban scales are in the realm of meso and micro scales. According to Orlanski (1975), meso α, β and γ scales are of the scale of 2000-200 km, 200-20 km, and 20-2 km, respectively, and micro α, β and γ scales 2 km - 200 m, 200-20 m, and less than 20 m. Mesoscale phenomena including local thermally driven land-sea and mountain-valley flows have been successfully simulated by mesoscale meteorological models, such as MM5 (Dudhia *et al.* 2003), RAMS (Pielke *et al.* 1992), ARPS (Xue *et al.* 1995), OMEGA (Bacon *et al.* 2000), and COAMPS (Hodur 1997). However, several constraints limit the direct applicability of meso-scale models for urban flows. While a mesoscale model needs to be "scaled-down" and parameterized to simulate urban wind flow, computational fluid dynamics (CFD) models can be "scaled-up" and solve for flow fields explicitly for the same purpose. CFD is being widely utilized in engineering flow analysis and building and structural design applications, and its utility for urban wind flow predictions has been increasingly recognized in recent years (Baik and Kim 1999). CFD has been used not only for urban flow simulations, but also for estimating air pollutant concentrations and human exposure (Cheatham *et al.* 2000; Emery *et al.* 2000; Chan *et al.* 2000, Huber *et al.* 2000). In the urban flow modeling community, however, CFD is often viewed with caution as an advanced, numerically expensive computational tool with questionable utility in simulating meteorological processes that are largely statistical rather than deterministic in character (Lee *et al.* 2000). In addition, specification of accurate boundary conditions required for CFD is not tenable in urban modeling. Recently, meso-scale and CFD models have been jointly used to perform simulations of urban wind flow in a nested configuration (Smith *et al.* 2000; Cox *et al.* 2000; Brown *et al.* 2000). One of the promising ways of simulating urban flows is to nest a meso-scale model that generates a mean state of meteorological variables with a CFD model dealing with perturbations to the meso-scale flow by variability within urban morphology.

Considering the inherent limitations and algorithms of mesoscale models and CFD, we simulated flow fields within urban morphology in a nested application using the following methodology. A mesoscale model provides an undisturbed background flow field devoid of urban structures, which reflects synoptic forcing as well as local differential thermal forcing due to topography and land-use type. Then, a CFD code is used to explicitly resolve the flow fields around an urban building canopy with initial and boundary values provided by the mesoscale model and urban building morphology. We employed one of the most widely applied mesoscale meteorological model MM5 and a CFD code (Lee and Park 1994, Kim and Baik 1999, Baik *et al.* 2003) for examining flow and dispersion in a commercialized area of Houston .

2. THE MODEL DESCRIPTION AND THE CONFIGURATION OF THE SIMULATION

The CFD code used in the study consists of primitive governing equations, namely, the Reynolds-averaged equations of momentum (with Boussinesq approximation) as well as conservation equations for heat, mass and passive scalar with closure realized by 'eddy diffusivity' modeling of Reynolds stresses

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* Corresponding author address: Dr. Sang-Mi Lee
Arizona State University, Environmental Fluid Dynamics Program/Civil & Environmental Eng, P.O.Box 879809, Tempe, AZ 85287-9809
e-mail: smlee@asu.edu
web: http://www.eas.asu.edu/~pefdhome

and turbulent heat and mass fluxes (Baik and Kim 1999, Baik *et al*. 2003). Eddy diffusivities, in turn, are calculated using prognostic equations for Turbulent Kinetic Energy (TKE) and the dissipation rate. The governing set of equations is solved numerically on a uniform grid system using a finite volume method. A semi-implicit method is used for the pressure linked equation (SIMPLE) algorithm (Patankar 1980).

A part of a commercialized area of Houston with high buildings and deep street canyons were selected for a CFD simulation (Fig. 1). The computational domain has 352, 302, and 82 grid elements in x, y, z direction, respectively. Grid spacing was 2 m in both horizontal and vertical directions. A vertical profile of winds from MM5 simulations was assigned as an initial value for CFD modeling. The assigned initial winds were westerly and slightly increased with respect to height. The background meteorological fields were assumed to be stationary during the 1-hour period of urban simulation. The performance of MM5 on various conditions has been validated by numerous studies and thus here we focus mainly on the CFD results.

3. PRELIMINARY RESULTS AND FUTURE WORKS

Figure 2 represents the output of this urban flow model generated under the given wind profile produced by MM5. As evident from Figure 2, the model predicts complex wind patterns such as flow deflection, vortex wake zones, accelerations and decelerations around the irregularly arranged building clusters. Concentration fields are asymmetric rather than following the Gaussian distribution due to the building structures and are further modified by the enhanced dilution at the lateral edges of buildings parallel to the incident winds, possibly due to the increase turbulence effect.

However, the trapping of pollutants within street canyons located around at the position of (550, 300) from the origin in Fig. 3 that is perpendicular to the incident wind was not very distinct in the simulations. Enhanced mixing by turbulence at the building top (which is suspected of overestimated) and weak vortices induced by weak downward motion at the leeside of the obstacles partly can be attributed this phenomenon. A standard k-ε model employed in this study was found to overestimate the turbulent kinetic energy around the frontal corner of bluff obstacles and underestimate the lateral components of normal stress in the recirculation region (e.g. see Murakami *et al*. 1990).

In the future, this study will examine the influence of lateral boundary conditions by utilizing the output from an urbanized version of MM5 at 1 km grid resolution which is to be implemented an advanced urban module called DA-SM2U (Dupont et al., 2004). This module requires an advanced set of urban canopy parameters (UCPs) gridded at 1 km resolution, which have been developed using the same set of detailed, high resolution (order 1 m) fully consistent data obtained for the CFD study. Note that the current results presented in Figs 2 and 3 were simulated by using the standard version of MM5 which does not have a sophisticated urban module. During the examining of the sensitivity, the CFD results will be contrasted against the use of other meteorological inputs such as the obtained using (a) the standard version of MM5, and (b) airport observations.

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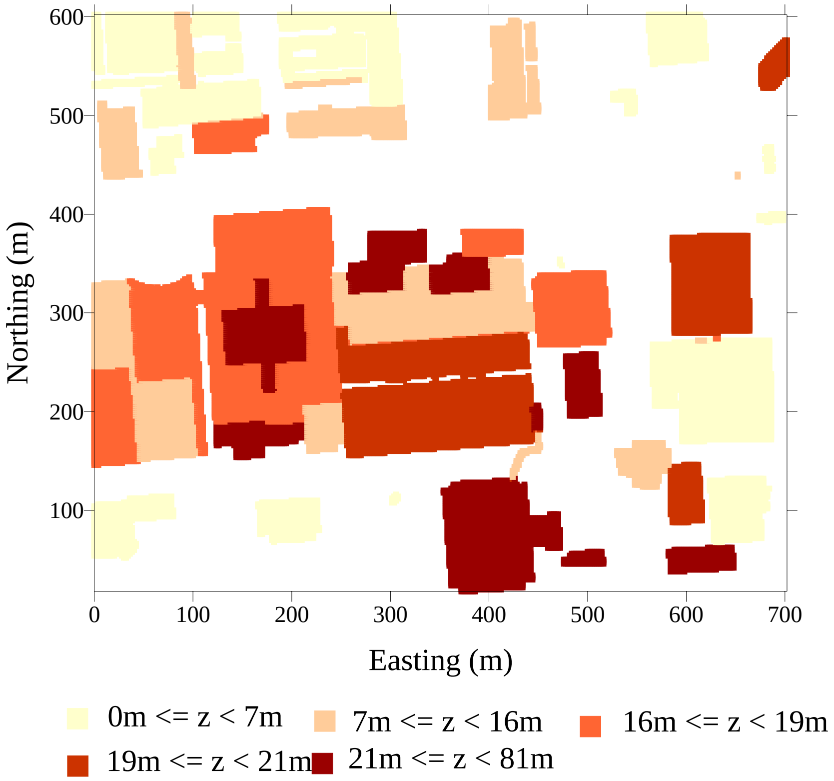

Fig. 1. The building geometry in the computational domain.

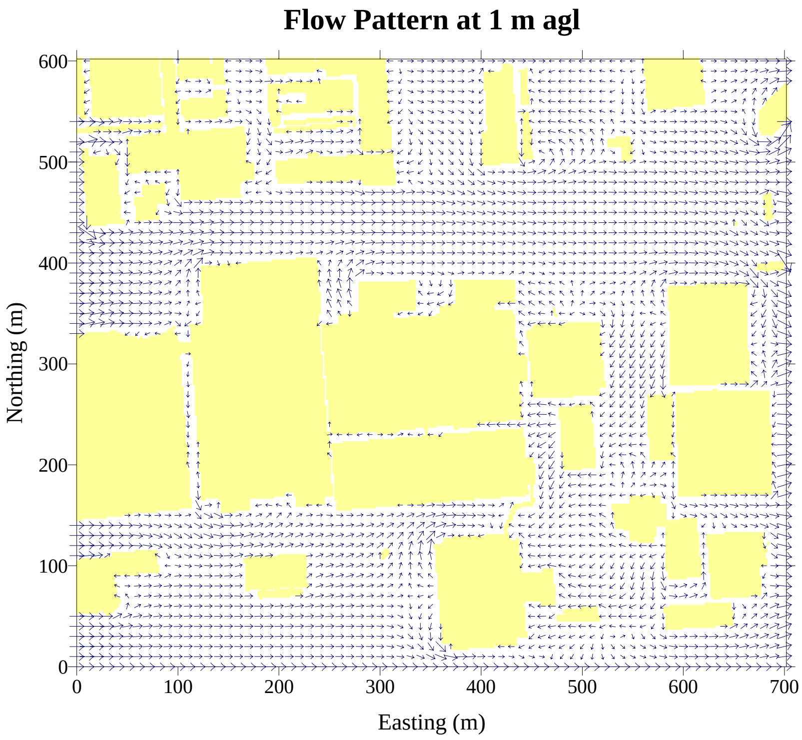

Fig. 2. Simulated flow field at 1 m above ground level. Filled polygons represents buildings.

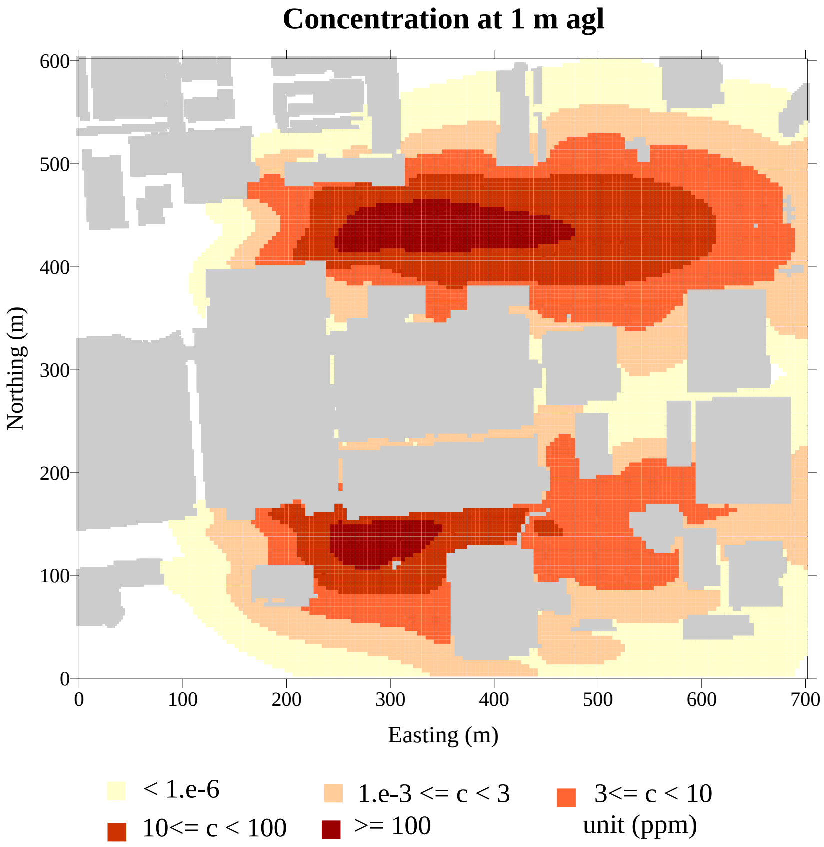

Fig. 3. Concentration field of a tracer species 2300 sec after a release at the positions of (100, 134) and (100, 420) from the origin.