The Effect of Urban Building on PBL 3-Dimensional Structure Simulated by WRF

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1. Introduction

Urban buildings make great effect on micro- and meso-scale flow fields. The Urban canopy parameterization (UCP) model was developed to describe the momentum flux, heat flux and turbulence kinetic energy (TKE) affected by urban building for both ideal (Martilli, 2002) and real study (Brown and Williams, 1998; Dupont, 2003; Otte et al, 2004; Li et al, 2004). With the development of the meso-scale model, the spatial resolution can be very high. It is important to consider the urban building effects more particularly at neighborhood scale. We set up an urban boundary layer parameterization (We called UBP) to study the building impact on wind and temperature by considering the building dynamics on drag force and turbulence production, anthropogenic heat flux et al. We incorporate the UBP into WRF model and present preliminary results for Beijing area simulation.

2. Model description

The momentum and TKE equations are modified to account for the effect of the urban elements.

$$\frac{\partial u}{\partial t} = \frac{\partial}{\partial z}\left(K_M \frac{\partial u}{\partial z}\right) + F_u \qquad (1)$$

$$\frac{\partial v}{\partial t} = \frac{\partial}{\partial z}\left(K_M \frac{\partial v}{\partial z}\right) + F_v \qquad (2)$$

$$\frac{\partial E}{\partial t} - \frac{\partial}{\partial z}\left(lqS_q \frac{\partial E}{\partial z}\right) = P_s + P_b - \varepsilon + F_E \qquad (3)$$

and the length scale modified as:

$$\frac{1}{l} = \frac{1}{l_0} + \frac{1}{kz} + \frac{1}{l_b} \qquad (4)$$

where F_u, F_v, F_E and l_b are the terms of urban effects.

$$F_u = -\mu_V A(0) C_d A(z) u V^{0.5} \qquad (5)$$

$$F_v = -\mu_V A(0) C_d A(z) v V^{0.5} \qquad (6)$$

$$F_E = \mu_E A(0) C_d A(z) \left[|u|^3 + |v|^3 \right] \qquad (7)$$

$$\frac{1}{l_b} = \sum_{z=z}^{z_h} A(z) z^{-1}, \quad z_a \le z \le z_h \qquad (8)$$

In UBP, only the anthropogenic heat flux is included in the air temperature equation.

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left(K_H \frac{\partial \theta}{\partial z}\right) + F_Q \qquad (9)$$

The anthropogenic heat term is expressed as:

$$F_Q = \chi \frac{A(z)}{\rho C_p} Q_F \qquad (10)$$

The parameter $A(z)$ can determined by the urban building height data.

Here the modifications on both dynamics and thermodynamics are implemented in WRF through the TKE-based MYJ PBL scheme.

3. Simulation results

This study focuses on simulating the PBL

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structures at fine scales (3.333-km horizontal grid spacing, and high vertical resolution in PBL which has 11 σ-levels in 1500m) for Beijing area from 8:00am 02 to 20:00pm 03 July 2004, 36 hours by clear skies and significant daytime heating. Winds in Beijing area were northeast in the night and turn to south in the daytime. The temperature in urban area is close to 35℃ and decreased to 23℃ at night. We compare the results simulated by MYJ scheme and UBP scheme to the observation.

The results show that WRF model simulate the wind direction well. UBP scheme gives the results more close to the observation on urban temperature (Figure 1). The anthropogenic heat flux increases the temperature at each hour, but the warming is much stronger while the anthropogenic heat flux is weaker during the night (Figure 2). The turbulent mixing in the steady PBL at night is weak and PBL height is very low, then the anthropogenic heat flux can only heating the low-layer atmosphere, which lead to the stronger temperature increasing in the lower boundary layer. While the sunrise, the PBL developing and the free convective eddies become active in transporting the anthropogenic heat flux on higher atmosphere. Moreover UBP scheme can reproduce the nocturnal inversion layer at 200 meters height (Figure 3).

According to the observation, the wind in the urban area is weaker than the rural place. MYJ scheme simulate much stronger wind in the urban area, while UBP gives more reasonable wind speed with considering the drag effect of the building (Figure 4).

By considering the building effects on TKE, we found the TKE in boundary layer is much higher and decrease toward the ground at 14:00 (Figure 5a). The TKE maximum is larger at night because of the decreased mixing in the PBL (Figure 5b).

Acknowledgement

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References

Brown, M. J., M. D. Williams, An Urban Canopy Parameterization for Mesoscale Meteorological Models, Proceedings of the AMS Conference on 2nd Urban Environment Symposium, 2-7 November 1998, Albuquerque, NM, Amer. Meteor. Soc., 144~147.

Dupont S, Introduction of Urban Canopy Parameterizations into MM5 to Simulate Urban Meteorology at Neighborhood Scales, Symposium on Planning, Nowcasting, and Forecasting in the Urban Zone on The 84th AMS Annual Meeting, 2003, Seattle, WA, Amer. Meteor. Soc., 4.2.

Li Xiaoli, et al, The Design of Urban Canopy Parameterization of MM5 and it's Numerical Simulation, *ACTA METEOROLOGICA SINICA*, 2003, 526~539, (in Chinese).

Martilli A., Numerical Study of Urban Impact on Boundary Layer Structure: Sensitivity to Wind Speed, Urban Morphology, and Rural Soil Moisture, J. Appl. Meteo., 2002, 41(12), 1247~1266.

Otte T. L., A. Lacser, S. Dupont, J. K. S. Ching, Implementation of an Urban Canopy Parameterization in a Mesoscale Meteorological Model, J. Appl. Meteo., 2004, 43(11), 1648~1665.

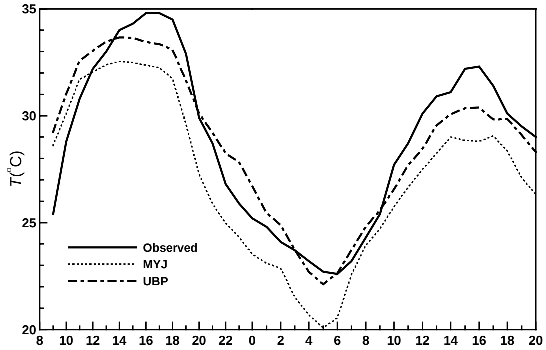

Figure 1. Time series of temperature (℃) averaged in urban area

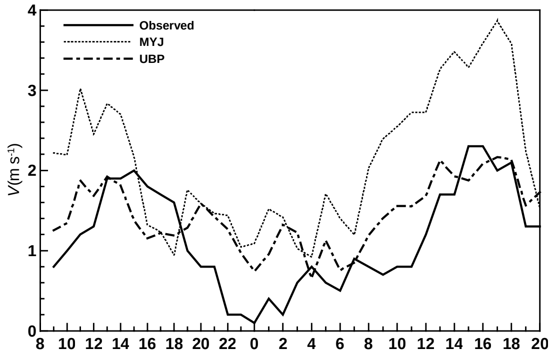

Figure 4. Time series of wind speed (m s^{-1}) averaged in urban area

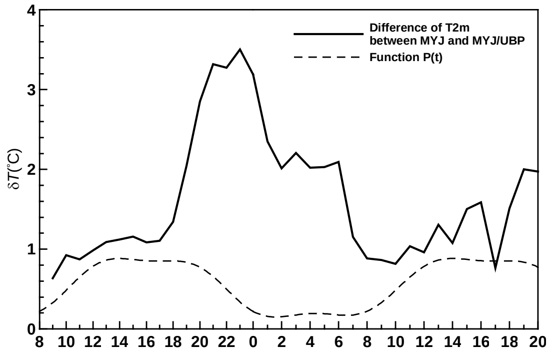

Figure 2. The differences of temperature simulated by MYJ scheme and UBP scheme

Dashed line is the diurnal evolution function of anthropogenic heat flux

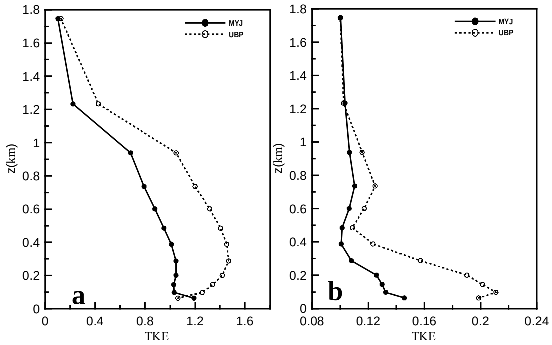

Figure 5. The TKE profiles averaged in urban area

(a) 14:00(b) 02:00

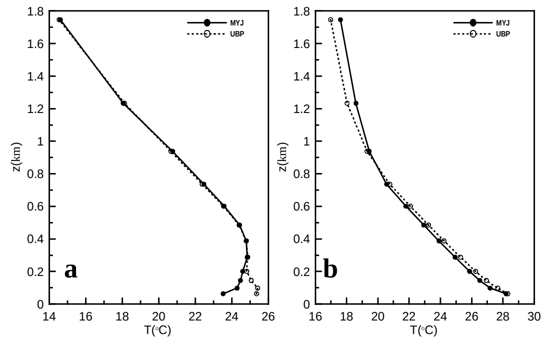

Figure 3. The urban averaged temperature profiles

(a) 02:00 (b) 14:00