11.4 IMPLEMENTATION OF AN URBAN CANOPY PARAMETERIZATION IN MM5

Avraham Lacser[1] and Tanya L. Otte[2+*]

[1]Israel Institute for Biological Research, Ness Ziona, Israel
[2]Atmospheric Sciences Modeling Division, NOAA ARL, Research Triangle Park, North Carolina
[+]On assignment to the National Exposure Research Laboratory, U.S. EPA

1. INTRODUCTION

The Pennsylvania State University/National Center for Atmospheric Research Mesoscale Model (MM5) (Grell et al. 1994) has been modified to include an urban canopy parameterization (UCP) for fine-scale urban simulations (~1-km horizontal grid spacing). The UCP accounts for drag exerted by urban structures, the enhancement of turbulent kinetic energy (TKE) especially near the tops of the buildings, and the modification of the energy budget within the urban canopy (i.e., from the surface to the tops of buildings). This UCP is applied to grid cells in MM5 that have a non-zero fraction of urban land use. This refinement of MM5 is targeted to enable the Community Multiscale Air Quality (CMAQ) Modeling System (Byun and Ching 1999) to capture the details of pollutant spatial distributions in urban areas.

2. URBAN CANOPY PARAMETERIZATION

2.1 *Momentum*

The horizontal components of the momentum equations are modified to account for the area average effect of the sub-grid urban elements following Brown (2000). The modifications are implemented in MM5 via the TKE-based Gayno-Seaman planetary boundary layer (PBL) parameterization scheme (e.g., Shafran et al. 2000). The momentum equations accounting for the urban elements are:

$$\frac{\partial U}{\partial t} = F_U - 0.5 f_{\text{urb}} C_d A(z) U \left(U^2 + V^2\right)^{0.5}$$

$$\frac{\partial V}{\partial t} = F_V - 0.5 f_{\text{urb}} C_d A(z) V \left(U^2 + V^2\right)^{0.5}$$

$$\frac{\partial \text{TKE}}{\partial t} = F_{TKE} + 0.5 f_{\text{urb}} C_d A(z) \left(U^2 + V^2 + W^2\right)^{1.5}$$

where F are the general forcing terms in each equation; U, V, and W are the wind components; and TKE is the turbulent kinetic energy. In this formulation, it is assumed that the buildings affect the flow, but do not take up any volume within the grid cell. C_d is a drag coefficient (assumed to be constant and set to 1). The urban fraction of the grid cell is described by f_{urb}. $A(z)$ is the canopy area density, or the surface area of the obstacle (e.g., building) perpendicular to the wind, per unit volume of the urban canopy, expressed in m^{-1}. There are several approaches to describe $A(z)$ (e.g., Uno et al. 1989, Brown 2000) where the function reaches its maximum at the ground level, but vanishes at the top of the obstacles (so the drag term vanishes also at that level). The integral of $A(z)$ from the ground level to the tops of the tallest buildings (H) is l_f, which corresponds to the ratio of the frontal area to the total surface area of the buildings. In general $A(z)$ is a function of the location within the domain as it depends on building morphology. $A(z)$ can be estimated from l_f and H assuming some functional form for $A(z)$; here we use a linear function.

To solve the modified momentum equations (the added new term), we follow the analytical solution suggested by Byun and Arya (1986). The TKE equation is solved explicitly. To take proper account of the influence of $A(z)$, the vertical resolution in MM5 is increased in the domain such that several prognostic layers are below H.

2.2 *Energy Budget*

To account for the impact of urban settings on the energy budget, the anthropogenic heat flux is included in the heat equation and not in the surface energy budget (e.g., Chin et al. 2000). The anthropogenic heat flux is set as a function of urban land use subcategory, and it has a temporal weighting function (e.g., Taha 1999). The heat equation also includes the heat contribution of the city canyons following Yamada (1982); the contribution due to rooftops has not yet been implemented. The surface energy balance includes the shadowing/trapping effect of the net radiation reaching the ground in the city canyons modified by extinction of the radiation through the urban canopy using a simple exponential function (e.g., Brown 2000).

2.3 *Urban Morphology*

Parameters that are required for the UCP (e.g., H and l_f) can be extracted from digital imagery (e.g., Ratti et al. 2001) which is commercially available from several vendors for various cities and with different degrees of accuracy and precision. We did not have access to a true urban morphology database for our area of interest, so we modified the MM5 land use database for our domain to have seven subcategories of urban areas adapted from Ellefsen (personal communication 2001). These categories crudely represent urban zones such as high-rise, industrial, and urban residential. Each of the urban subcategories has a different value for H, l_f, canyon fraction, and maximum anthropogenic heat flux.

3. PRELIMINARY RUNS

The unmodified MM5 was run in a one-way nested mode for several days in July 1995 during which there

---

*Corresponding author address: Tanya Otte, U.S. EPA, MD E243-03, RTP, NC 27711; otte.tanya@epa.gov

was a high-ozone episode in the Northeastern U.S. that coincided with a photochemical field study. The MM5 domains included a five-domain configuration (108, 36, 12, 4, and 1.33 km grid spacing). The first four domains were run with 30 vertical layers (about 12 layers in the PBL, and lowest level at 19 m) and physics options appropriate for each resolution.

To include the influence of smaller obstacles, the UCP was used on the 1.33-km domain with 40 layers that included 10 new layers in the lowest 100 m (lowest level at 2 m). Several simulations have been made with the 1.33-km domain to determine the impact of the UCP and the morphology on the simulation. As expected, the UCP acted to increase the TKE at the top of the urban canopy (near rooftops) and decrease wind speed within the urban canopy. The TKE profile exhibited a peak at the top of the canopy that is consistent with wind tunnel measurements for a simulated urban area (e.g., Kastner-Klein and Rotach 2001). At urban points, the UCP increased the surface temperature by ~2°C overnight and ~0.5°C in late afternoon in the city center compared to the runs without the UCP. In addition, the UCP created an unstable temperature profile overnight at urban points (not shown). At non-urban points, the TKE, wind speed, and temperature profiles remained largely unchanged.

Figure 1 shows a comparison of the surface (~2-m) temperature for Philadelphia International Airport (PHL) from runs with and without the UCP compared to observations for 14 July 1995. This figure shows that the experiment with the UCP had significantly better temperatures overnight and somewhat better temperatures during the day. Overall, the diurnal temperature pattern of the simulation with the UCP compares more favorably with observations.

4. FUTURE DIRECTIONS

Additional comparisons against observational data will be performed to assess the viability of the UCP for air quality modeling applications. The parameterization will be expanded to add the roof energy budget and to use more detailed land use databases and morphology databases so that the urban areas can be more accurately characterized. Finally, the urban canopy parameterization will be coupled with a land-surface model and urban soil model.

Disclaimer. The information in this manuscript has been prepared under funding by the United States Environmental Protection Agency. It has been subjected to Agency review and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

5. REFERENCES

Brown, M. J., 2000: Urban parameterizations for mesoscale meteorological models. *Mesoscale Atmospheric Dispersion*. Ed., Z. Boybeyi.

Byun, D. W., and S. P. S. Arya, 1986: A study of mixed layer momentum evolution. *Atmos. Environ*., **20**, 715–728.

Byun, D. W., and J. K. S. Ching, 1999: Science algorithms of the EPA Models-3 Community Multiscale Air Quality (CMAQ) Modeling System. EPA-600/R-99/030, U.S. EPA.

Chin, H. S., M. L. Leach, and M. J. Brown, 2000: A sensitivity study of the urban effect on a regional scale model: an idealized case. Preprints, *Third Sym. on the Urban Environment*, Davis, CA, Amer. Meteor. Soc.

Grell, G., J. Dudhia, and D. R. Stauffer, 1994: A description of the fifth-generation Penn State/NCAR Mesoscale Model (MM5). NCAR Tech. Note, NCAR/TN398+STR, 138 pp.

Kastner-Klein, P., and M. W. Rotach, 2001: Parameterization of wind and turbulent shear stress profiles in the urban roughness layer. Proceedings, *Third Int. Conf. on Urban Air Quality*, Loutraki, Greece.

Ratti, C., S. Di Sabatino, R. E. Britter, M. J. Brown, F. Caton and S. Burian, 2001: Analysis of 3-D urban databases with respect to pollution dispersion for a number of European and American cities. Proceedings, *Third Int. Conf. on Urban Air Quality*, Loutraki, Greece.

Shafran, P. C., N. L. Seaman, and G. A. Gayno, 2000: Evaluation of numerical predictions of boundary layer structure during the Lake Michigan Ozone Study. *J. Appl. Meteor*., **39**, 412–426.

Taha, H., 1999: Modifying a mesoscale meteorological model to better incorporate urban heat storage: A bulk parameterization approach. *J. Appl. Meteor*., **38**, 466–473.

Uno, I., H. Ueda, and S. Wakamatsu, 1989: Numerical modeling of the nocturnal urban boundary layer. *Bound-Layer Meteor*., **49**, 77–98.

Yamada, T., 1982: A numerical model study of turbulent airflow in and above a forest canopy. *J. Met. Soc. Japan*, **60 (1)**, 439–454.

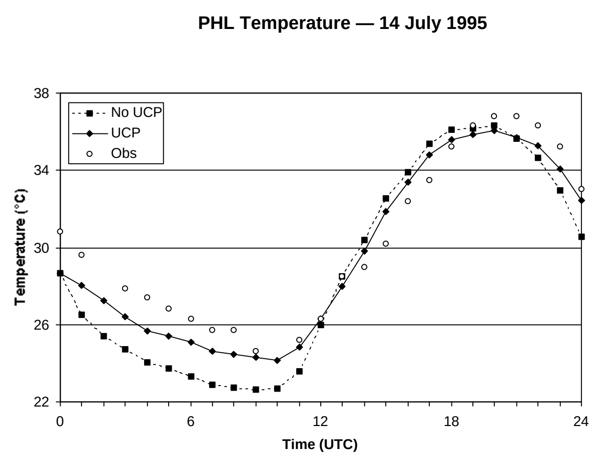

Figure 1. Temperature at PHL for 14 July 1995 for observations and simulations with and without UCP.