

Avraham Lacser¹ and Tanya L. Otte^{2+*}¹Israel Institute for Biological Research, Ness Ziona, Israel²Atmospheric 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:

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

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

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

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 I_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 I_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 I_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 , I_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 $\sim 2^{\circ}\text{C}$ overnight and $\sim 0.5^{\circ}\text{C}$ 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 ($\sim 2\text{-m}$) 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.

PHL Temperature — 14 July 1995

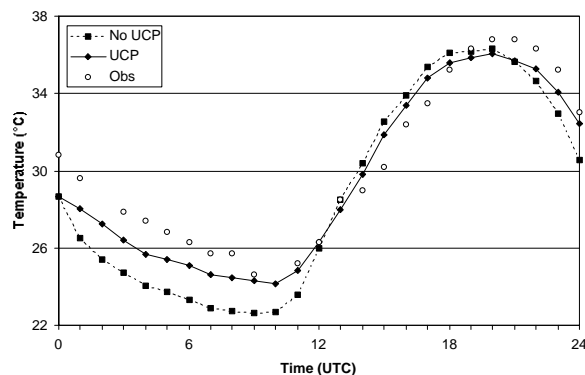


Figure 1. Temperature at PHL for 14 July 1995 for observations and simulations with and without UCP.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave Blank) PB2004-101310		2. REPORT DATE 2003	3. REPORT TYPE AND DATES COVERED	
4. TITLE AND SUBTITLE: Implementation of an Urban Canopy Parameterization in MM5.			5. FUNDING NUMBERS None	
6. AUTHOR(S) A. Lacser and T.L. Otte*				
7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(ES) Israel Institute for Biological Research Ness Ziona, Israel			8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) *National Exposure Research Laboratory -RTP, NC ORD, U.S. EPA, Research Triangle Park, N.C. 27711			10. SPONSORING/MONITORING AGENCY REPORT NUMBER EPA/600/A-03/050	
11. SUPPLEMENTARY NOTES				
12a. DISTRIBUTION/AVAILABILITY STATEMENT Release to the General Public			12b. DISTRIBUTION CODE EPA/600/9	
13. ABSTRACT (Maximum 200 words) The Pennsylvania State University/National Center for Atmospheric Research Mesoscale Model (MM5) 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 to capture the details of pollutant spatial distributions in urban areas.				
14. SUBJECT TERMS			15. NUMBER OF PAGES 5	
			16. PRICE CODE A01	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT None	