4.6 URBAN MORPHOLOGY FOR HOUSTON TO DRIVE MODELS-3/CMAQ AT NEIGHBORHOOD SCALES

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1. INTRODUCTION

Air quality simulation models applied at various horizontal scales require different degrees of treatment in the specification of the underlying surfaces. As we model neighborhood scales (~1 km horizontal grid spacing), the representation of urban morphological structures (e.g., building and area distributions, and compositional materials for impervious structures such as roads and parking areas) requires much greater detail. At the neighborhood scale, we expect that the heterogeneities of structures within the urban canopy (i.e., the layer between the surface and the tops of the buildings) will exert a strong influence on the urban boundary layer (UBL) wind and thermodynamic structure and a subsequent effect on the pollutant dispersion and resulting air quality predictions.

The U.S. EPA Models-3 Community Multi-scale Air Quality (CMAQ) modeling system (Byun and Ching 1999) will be applied at neighborhood scales to drive human exposure models and for human risk assessments purposes (Ching et al. 2000, 2002). CMAQ will be used to support modeling studies and air quality assessments of ozone, particulate matter(PM), and air toxics in Houston, Texas, using the Penn State/NCAR Mesoscale Model (MM5) (Grell et al. 1994) to provide meteorological input. This application requires developing more detailed treatment of the influence of urban structures in MM5 and using additional urban morphological databases as input.

2. APPROACH

In this study, MM5 is modified to incorporate formulations and urban morphology for (1) an advanced urban soil and canopy model that adjusts the thermodynamics of the UBL, and (2) the additional drag and turbulence induced by the presence of buildings and trees. The subsequent meteorological fields will better represent the effects of the urban areas on the momentum, turbulent kinetic energy (TKE), and energy balance at the neighborhood scales.

2.1 *Modeling the Urban Environment*

The surface dynamic and thermodynamic effects in MM5 are represented by momentum flux, sensible heat flux, and latent heat flux terms. Idealized horizontally uniform surface characteristics, boundary layer flows and structures are typically modeled using roughness length similarity formulations for momentum, temperature, and humidity. The basis of these formulations is the assumption that surface roughness elements are both small and statistically uniform relative to height, and the surface exchange coefficients use Monin-Obukhov similarity theory. However the theory generally requires statistical stationarity and spatial homogeneity, and is not satisfied in the urban atmosphere at the neighborhood scale. It does not, for example, model the wind profiles structure and TKE profiles in and above the urban canopy (Rotach 1995).

To address this problem, we extend the current theory by introducing an urban canopy-atmospheric interface method formulated for incorporating urban structures and materials. We adapt the methodology in Dupont (2001) and Dupont et al. (2002) which use an urban soil model, SM2-U, coupled with the French meteorological model, SUBMESO, to produce simulations of the UBL at fine grid resolution. The basis of the SM2-U is the model of Noilhan and Planton (1989). The extension to urban surfaces is the inclusion of an urban canopy that accounts for the heat stored by the building walls and radiative trapping by a street canyon effective albedo parameterization deduced following Masson (2000). In the Houston modeling effort, SM2-U is coupled with MM5.

In addition, an urban canopy parameterization was introduced into MM5 to account for drag exerted by urban structures, the enhancement of TKE (especially near the tops of the buildings), and the energy budget at the street level and between buildings. This urban canopy parameterization is also designed to effectively simulate the heterogeneous urban environment by allowing more urban land use subcategories than are part of the standard MM5 release. Otte and Lacser (2001) and Lacser and Otte (2002) show that using the urban canopy parameterization can improve the wind, temperature, and TKE fields in 1.3-km urban simulations with MM5. Preliminary simulations with the urban canopy parameterization also illustrated the need for heterogeneous representation of the urban morphology.

2.2 *Urban Morphological Parameterizations*

Recent technology including stereo photogrammetry and/or airborne lidar data is capable of producing 3-D digital building and tree datasets; this enables the required morphological parameters to be accurately determined for the location of interest using numerical analysis techniques. Computer-based analysis techniques (e.g., ArcView GIS tools) and methodologies described in Burian et al. (2002) are applied to various datasets, including digitized buildings,

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land use/land cover, and other essential datasets for the Houston area.

This effort produces a database of urban morphology parameters to drive and perform the requisite air quality and human exposure assessments. Two methods for deriving urban morphology for modeling purposes are developed based on the amount and spatial coverage of 3D building data information and land use database. First, and ideally, when building and vegetation data covers the full simulation domain, we can directly derive and apply the urban morphologies directly to our simulation domain. Second, with sparser data sets, relationships that correlate building morphological characteristics to underlying land use type are developed and applied. Subsequently, the morphological characteristics will be extrapolated throughout the simulation domain using the land use/land cover dataset.

Application of the urban canopy parameterizations described in Dupont (2001) and Lacser and Otte (2002) requires incorporating urban morphological data into MM5, including:

- Mean and standard deviation of building height
- Mean and standard deviation of vegetation height
- Building height histograms
- Area-weighted mean building height
- Area-weighted mean vegetation height
- Surface area of walls
- Plan area fraction as a function of height above the ground surface
- Frontal area index as a function of height above the ground surface
- Height-to width ratio
- Sky view factor
- Roughness length
- Displacement height
- Surface fraction of vegetation, roads, and rooftops
- Mean orientation of streets
- Impervious areas directly connected to the draining network

We are accumulating several commercial(and other publically) available datasets of digital elevation and terrain data in both raster and vector form for Harris County (which includes Houston) and surrounding areas into a GIS database. Further processing will be performed to differentiate buildings from tree elements. Then, we generate gridded values of the average values for the above parameters for desired grid resolutions of the coupled urban energy budget and mesoscale meteorological models. Finally, to extrapolate the land surface parameterization beyond the aerial extent of the digital database, average parameters will be computed for several urban land use categories. The data processing task will require tested techniques to be applied to an areal extent well beyond the size areas analyzed in past research efforts (Burian et al., 2002).

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3. REFERENCES

Burian, S. J., M. J. Brown, and S. P. Linger, 2002: Morphological analysis of buildings in downtown Los Angeles, California. LA-UR-02-0781 Los Alamos National Laboratory, 66 pp.

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.

Ching, J., A. Lacser, D. Byun, and W. Benjey, 2000: Air quality modeling of PM and toxics at neighborhood scales to improve human exposure assessments. *Third Sym. on the Urban Environment,* Davis, CA Amer. Meteor. Soc. P96-97.

Ching, J., A. Lacser, T. L. Otte, J. Herwehe, and D. Byun, 2002: Neighborhood scale modeling of $PM_{2.5}$ and air toxics concentration distributions to drive human exposure models. Preprints, *12th Joint AMS Conf. on Air Pollution Meteorology with the AWMA*, Amer. Meteor. Soc., Norfolk, VA.

Dupont, S., 2001: Modélisation dynamique et thermodynamique de la canopée urbaine: réalisation du modèle de sols urbains pour SUBMESO. Ph.D. thesis, ECN-Université de Nantes, France.

Dupont, S., I. Calmet, and P. Mestayer, 2002: Urban canopy modeling influences on urban boundary layer simulation. Preprints*, Fourth Sym. on the Urban Environment*, Amer. Meteor. Soc., Norfolk, VA.

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/TN-398+STR, 138 pp.

Lacser, A., and T. L. Otte, 2002: Implementation of an urban canopy parameterization in MM5. Preprints, *Fourth Sym. on the Urban Environment*, Amer. Meteor. Soc., Norfolk, VA.

Masson, V., 2000: A physically-based scheme for the urban energy budget in atmospheric models. *Bound-Layer Meteor.*, **98**, 357–397.

Noilhan, J., and S. Planton, 1989: A simple parameterization of land surface processes for meteorological models. *Mon. Wea. Rev.,* **117**, 536–549.

Otte, T. L., and A. Lacser, 2001: Implementation of an urban canopy parameterization in MM5 for meso-gamma-scale air quality modeling applications. Preprints, *Ninth Conf. on Mesoscale Processes*, Amer. Meteor. Soc., Ft. Lauderdale, FL, 78–81.

Rotach, M., 1995: Profiles of turbulence in and above an urban street canyon. *Atmos. Environ.*, **29**, 1473–1486.