4.14 THE USE OF AN URBAN CANOPY PARAMETERIZATION FOR MM5: APPLICATION TO THE PHOENIX AIRSHED

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1. INTRODUCTION

In mesoscale models, the effect of an urban surface is usually parameterized using the roughness approach, which in turn is based on the constant flux layer approximation for the surface layer. This approach, however, cannot reproduce the vertical structure of turbulent fields in the urban roughness sublayer (URSL) -- the layer from the street level up to the height where the effects of individual surface roughness elements are felt. The URSL is considered approximately 2-5 times the depth of the urban canopy layer (Martilli et al., 2002). The goal of the present work is to study the implementation of an urban canopy parameterization (UCP) in the mesoscale model MM5, based on the work of Otte et al. (2004), who first employed the drag force approach rather than the roughness approach in realistic MM5 simulations. The modeling system to be used in this context is referred to as UCP-MM5. The sensitivity of the forms of the momentum and thermodynamic equations on the UCP-MM5 predictions is studied, and suitable forms of model drag parameters for UCP is proposed by comparing simulation results with the data of the Phoenix SUNRISE-2001 Experiment (Lee et al., 2003). This experiment was conducted in the Phoenix metropolis during June 2001 to study the transport of ozone precursors, and a part of the project was dedicated to study flow mechanisms responsible for episodic high ozone events, which are believed to be related to mixing induced by a low-level jet that occurs during the night and early morning. Owing to the rapid growth of the city surrounding the metro Phoenix area, including construction of high rise buildings and wide roads, land-use data from the default USGS 30'' database are not suitable to represent current land use types of the Phoenix area. In the present study, UCP inputs based on urban morphology data of Ellefsen (1991) and Burian et al. (2002) are employed.

The inclusion of the UCP leads to the development of an urban heat island in the Phoenix area and the formation of a low level jet during the early morning.

2. THEORETICAL BACKGROUND

The UCP accounts for dynamic and thermodynamic effects on flow caused by the presence of urban elements, which are further discussed below.

2.1 Effects on dynamics

The drag-force approach is implemented in UCP-MM5 to represent the dynamic effects of buildings. Here, terms are added to the momentum and turbulent kinetic energy (TKE) equations to account for the obstacle drag, much the same way as in dealing with vegetation canopies. The production of TKE by the drag is a linear function of the drag coefficient C_d and is dependent on the shape and distribution of buildings within a grid cell. The UCP-MM5 of Otte et al. (2004) uses C_d values ranging from 0.7 to 1.5 for urban structures, as suggested by Brown (2000). Also, in their case, the momentum and TKE modifications were accounted for through the TKE-based Gayno-Seman PBL (GSPBL) scheme. Martilli et al. (2002) work is also similar to that of Otte et al. except that the drag coefficient is set to 0.4, a value corresponding to wind-tunnel measurements of Raupach (1992) carried out with cubic element arrays.

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2.2 Effects on thermodynamics

The effects of the urban environment on flow thermodynamics are represented in the UCP by simplified versions of the air temperature tendency equation, the ground surface energy budget and thermodynamic equations. These equations are composed of those for the modification of sensible heat flux from roofs and vegetations as well as three dimensional energy contributions from the anthropogenic heat flux. In UCP-MM5, the anthropogenic heat flux (q_{urb}) is included in the air temperature equation rather than in the surface energy budget, considering that the heat is released to the atmosphere. The soil thermodynamics in UCP-MM5 is included in the form of a 'slab' surface model (Zhang and Anthes 1982). This soil model assigns only a single category of urban surface (f_{roof}) for simulations.

One of the most important effects of urban surfaces is the modification of heat flux due to shadowing and radiation- trapping effects. To this end, Martilli et al. (2002) suggested a detailed computation method for energy radiation based on a two-dimensional model. In this method, the energy budget is calculated for every surface, from which the temperatures of the roof surfaces, walls and streets are calculated using the heat diffusion equation.

3. NUMERICAL CONFIGURATION

3.1 MM5 set-up and numerical tests

Numerical tests were conducted using the basic UCP-MM5 [which is the version used by Otte et al. (2004)] and also a version in which some of the parameters were modified ['improved version']. In the latter, changes to the parameterizations in momentum, thermodynamic and TKE equations were made based on the suggestions of Martilli et al. (2002). Both tests of UCP-MM5 employed the following options: 1.5-order closure, prognostic TKE-based GSPBL scheme, force-restore soil model, Rapid-radiative transfer model for longwave radiation, Dudhia shortwave radiation, mixed-phase microphysics and explicit convection. Five domains of computation with 81, 27, 9, 3, and 1km horizontal grid resolution were used, and the first four domains were run with 30 vertical layers, with about 17 layers in the PBL, the lowest-layer being 10m in height. The techniques of nesting and multi-scale 4-D data assimilation (FDDA) were used for the first four domains.

The 1km domain includes 121 × 121 grid points covering the metro-Phoenix area with 40 layers, including 12 layers in the lowest 100m. As mentioned, it does not include FDDA so that the influence of data ingestion has a lesser influence on the simulation results; this allows a better evaluation of the efficacy of UCP. The 1km domain uses initial and boundary conditions that are interpolated from simulations with 3km domain.

In the basic UCP-MM5 runs the surface roughness is set to a constant value (0.05m) for all urban subcategories. Given the paucity of available detailed observations, only a few comparisons could be made. The simulation of 1km domain was initialized at 0000UTC 18 June 2001 and ended at 0000 UTC 23 June 2001, and this period was characterized by the occurrence of high ozone concentrations. As mentioned, in the improved UCP-MM5 simulations, changes were made to the substrate thermal conductivity of material and to the specific heat and emissivity of the surface. Surface albedo and surface roughness are changed according to each surface type (see below).

3.2 UCP-MM5 inputs

The morphological parameters for Phoenix in UCP-MM5 were selected by utilizing (*i*) sample urban data provided by Burian et al. (2002) for a smaller domain covering 16.7 km^2 area for downtown Phoenix, and (*ii*) MAG land-use information that provided 30m horizontal resolution data for a domain of 121 × 121 km^2 covering the metro-Phoenix (which is the area for 1-km resolution simulations). Burian's data was made using GIS tools, thus enabling the handling of urban data with 3D building datasets, digital photos, detailed land-use and land-cover information as well as bald-earth topography and roads in downtown Phoenix. The input data for the 121 × 121 km^2 area was prepared by extrapolating Burian's data and reclassifying MAG data into required urban subcategories following Otte et al. (2004).

In UCP-MM5 study, approximately 23% of the grid cells of the computational domain were represented by the urban area. The surface roughness, albedo and emissivity were set to constant values of 0.05m, 0.12, and 0.9, respectively, for all subcategories in Phoenix (Table 1, Figure 1). However, for the improved UCP-MM5, these parameters were set according to the roof, floor and surface characteristics: surface roughness = 0.05 to 0.1; albedo = 0.12 to 0.2 and emissivity = 0.9 to 0.95.

Table 1: UCP parameters associated with each urban subcategory for Phoenix. Urban category is classified as: 1=urban area not included in Ellefsen (1992); 2=low commercial and residential; 3=Apartment less then 4 stories and low industrial; 4=low shopping center and modern commercial ribbon; 5=administrative and cultural from low to medium height; 6=commercial officers and retail, with 4 or more stories; 7=high rise commercial officers

Urban Cat.	Percent. of total area (%)	Canyon fraction	Average Building Height (m)	Max. anthropogenic heat flux(W/m^{-2})
1	76.8	0.85	3	50
2	14.7	0.7	10	100
3	3.5	0.6	11	100
4	3.3	0.9	6	100
5	0.9	0.85	10	100
6	0.6	0.4	45	100
7	0.2	0.85	90	100

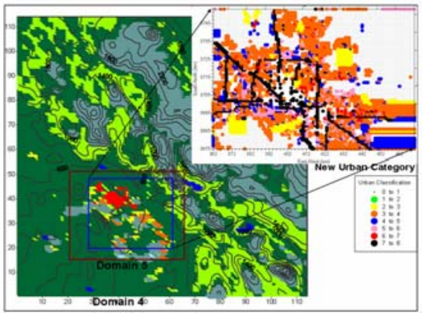


Figure 1. USGS land-use (left) and new land-use data (right) for Phoenix; the latter was used for UCP-MM5

Average height and canyon fractions in each category were roughly specified following the method used by Ellefsen (1992) because of the absence of pertinent data for Phoenix.

4. RESULTS

4.1 Results of simulations with UCP

The simulation results were compared with surface observations taken at a single location during the SUNRISE-2001 experiment – the Arizona State Fairground (ASF) site. These data do not give averaged quantities for the grid cell in point, but they can be considered as representative information for the grid cell and include the urban influence (Figure 2 and Table 2). Interestingly, most of the simulation results for surface winds and heat fluxes showed a good agreement with data with errors less than 4%.

The improved UCP-MM5 showed better performance than the basic version with regard to the heat flux and radiation.

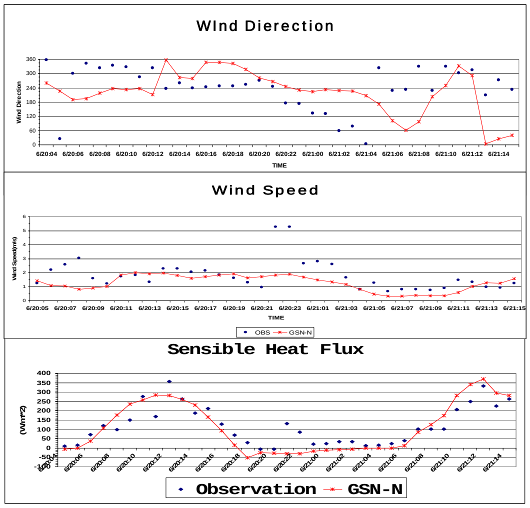


Figure 2. Simulation results of basic UCP-MM5 for ASF and comparison with SUNRISE-2001 observations.

4.2 Urban Heat Island influence

The urban heat island (UHI) arises due to the differential heating/cooling of sunlit/shaded surfaces, radiation trapping in street canyons and heat storage in buildings and land surfaces.

There is no observational data for the Phoenix downtown area of surface temperature and winds of sufficient resolution to enable us to compare with the simulation results and to unambiguously capture the UHI effect.

Table 2. The numerical results based on basic and improved UCP-MM5 simulations. The observational data from the Phoenix SUNRISE-2001 experiment is also given for comparisons.

			WD	WS	SHF	Net Rad.
MEAN /STD	DAY	OBS	269.3 /37.9	1.56/ 0.56	181/ 104.3	-142.0 /297.4
		Basic UCP-MM5	54.7/ 13.1	1.23/ 0.53	173/ 118.3	710.8/ 259.6
	NHT	OBS	171.3 /104.1	2.10/ 1.14	26.8/ 28.0	-590.0 / 66.2
		Basic UCP-MM5	221.0 /48.0	1.14/ 0.43	-8.0/ 16.4	-0.5/ 55.5
RMSE	DAY	Basic UCP-MM5	23.5	0.13	14.60	153.2
		Improve	23.3	0.58	13.82	145.2
	NHT	Basic UCP-MM5	22.0	0.46	4.107	112.2
		Improve	21.8	0.32	3.383	108.8
RRSE	DAY	Basic UCP-MM5	3.7	1.36	0.840	3.1
		Improve	3.5	1.62	0.794	2.9
	NHT	Basic UCP-MM5	1.2	1.19	1.619	9.2
		Improve	0.9	0.93	0.874	7.7

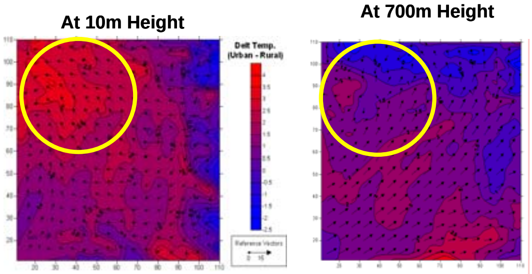
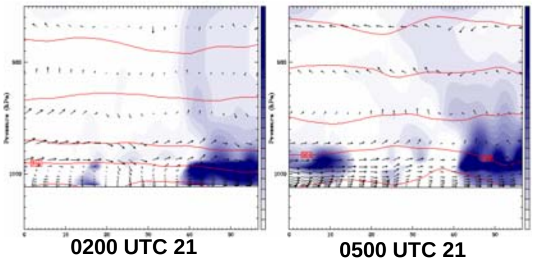


Figure 3. The numerical results of wind and temperature fields in basic UCP-MM5 at 0500 UTC 21 Jun 2001. The urban area is concentrated within the yellow circle.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0500 UTC 21

Figure 4: The wind and potential temperature distributions at different height levels in the boundary layer.

The surface winds converge toward the urban center so as to create an updraft therein, and this also leads to divergent winds at the top of the boundary layer. The UHI-generated small-scale circulation in the inner urban canopy makes significant surface winds in the form of low level jets in the early morning (Figure 4).

5. CONCLUSIONS

An Urban Canopy Parameterization (UCP) has been implemented into MM5 mesoscale meteorological model by Otte et al. (2004), which was used in conjunction with fine-scale (1km horizontal grid) resolution simulations for the metro-Phoenix urban area.

Two types of simulations were conducted. The basic UCP-MM5 version followed those of Otte et al. (2004) and in the improved version the parameterizations were adjusted following the suggestions of Martilli et al. (2002). The results captured such important urban effects as the urban heat island and low level jets in the urban core. The improved version of UCP-MM5 was prepared by changing parameters of the basic UCP-MM5, in particular those of the thermodynamic equations (vis-à-vis the change of a single parameter in the momentum equation). As such, a significant improvement of the surface temperature predictions could be seen in the improved UCP-MM5 simulations.

ACKNOWLEDGMENTS

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