Effects of Land Cover Modifications in a Mesoscale Meteorological Model in the Phoenix Metropolitan Region

S. Grossman Clarke[1], J.A. Zehnder[2,3] and W.L. Stefanov[4]

[1]Department of Mechanical and Aerospace Engineering, ASU, P.O. Box 879809, Tempe, AZ 85287-9809, [2]Department of Geography, ASU; [3]Department of Mathematics, ASU; [4]Department of Geological Sciences, ASU.

Introduction

A new land cover classification for the Phoenix (Arizona, USA) metropolitan area was introduced in the fifth-generation PSU/NCAR mesoscale meteorological model MM5. The single urban category in the existing 24-category United States Geological Survey (USGS) land cover classification used in MM5 was divided into three classes: built-up urban, suburban mesic residential and suburban xeric residential. 30 meter land cover data were derived from 1998 LANDSAT Thematic Mapper (TM) satellite images. The data were upscaled to a 30-second grid and used to augment and correct the existing USGS land cover scheme in MM5. Ground truth information was used to determine the composition of mesic and xeric residential areas in terms of typical fractions of irrigated and total vegetation and man-made surfaces. This allowed us to derive varying water availability factors for the urban land use classes and hence to consider the influence of urban irrigation practices in the surface energy budget. Furthermore, bulk approaches for characteristics of the urban surface energy budget such as the production of anthropogenic heat and radiation trapping were introduced in MM5's Medium Range Forecast boundary layer scheme. The values for the volumetric heat capacity and soil thermal conductivity for the urban land cover classes were increased through changes in land class parameters. A 72-hour simulation was performed with MM5 on a 2 km x 2 km grid for the period of June 7, 1998 17:00 LST to June 10, 1998 17:00 LST which is in agreement with the time period of the satellite images on which the land use classification was based.

Materials and Methods

Land use data

The 12-category 1998 land use data (Stefanov et al. 2001) were inserted into MM5's 30-second USGS land use data file by reprojecting the land use map according to the geographic projection parameters of the 30-second land cover data using Geographical Information System techniques. Within the 30 second grid cells covering the extent of the 1998 land use map, zonal summing was applied to the land use data of the 30 m data set. The land use class with the highest fraction of cover was assigned to the 30-second grid cell. After mapping the 12-category land use classification to the 24 USGS categories (Figure 1) the original data in MM5's 30-second USGS binary file were replaced with the 1998 data.

Sky view factor

The goal of the study was to apply simple land use type dependent adjustments to improve the representation of urban land surfaces in MM5. The sky view factor ψ_g represents the radiation balance from a reference site on a free and horizontal surface and considers the radiative interaction of an important number of adjacent surfaces (Noilhan 1981) such as building walls and roads. An effective sky view factor, ψ_g, was implemented in the long wave radiation balance, $R_{long,n}$, leading to the following equation:

$$R_{long,n} = \Psi_g \varepsilon_g \left(L\downarrow - \sigma \cdot T_g^4 \right)$$

with T_g being the ground temperature, $L\downarrow$ the incoming long wave radiation from the sky, ε_g the emissivity of the surface and σ the Stefan Boltzmann constant, respectively. For example, according to Masson (2000) the sky view factors for a road, ψ_{road}, or building wall, ψ_{wall}, are calculated as functions of the road width, w, and the building height, h:

$$\Psi_{road} = \left[(h/w)^2 + 1 \right]^{0.5} - h/w \qquad \Psi_{wall} = 0.5(1.0 + h/w - \left[(h/w)^2 + 1 \right]^{0.5} - (h/w)^{-1}$$

Assuming a typical building height and road width for the Phoenix suburban areas of 5 m and 20 m respectively, the sky view factors are 0.75 for the roads and 0.5 for the walls. The sky view factor for roofs is equal to 1. Considering that the area fraction of roofs in a grid cell is about 0.3 we assume a bulk value for ψ_g of 0.8.

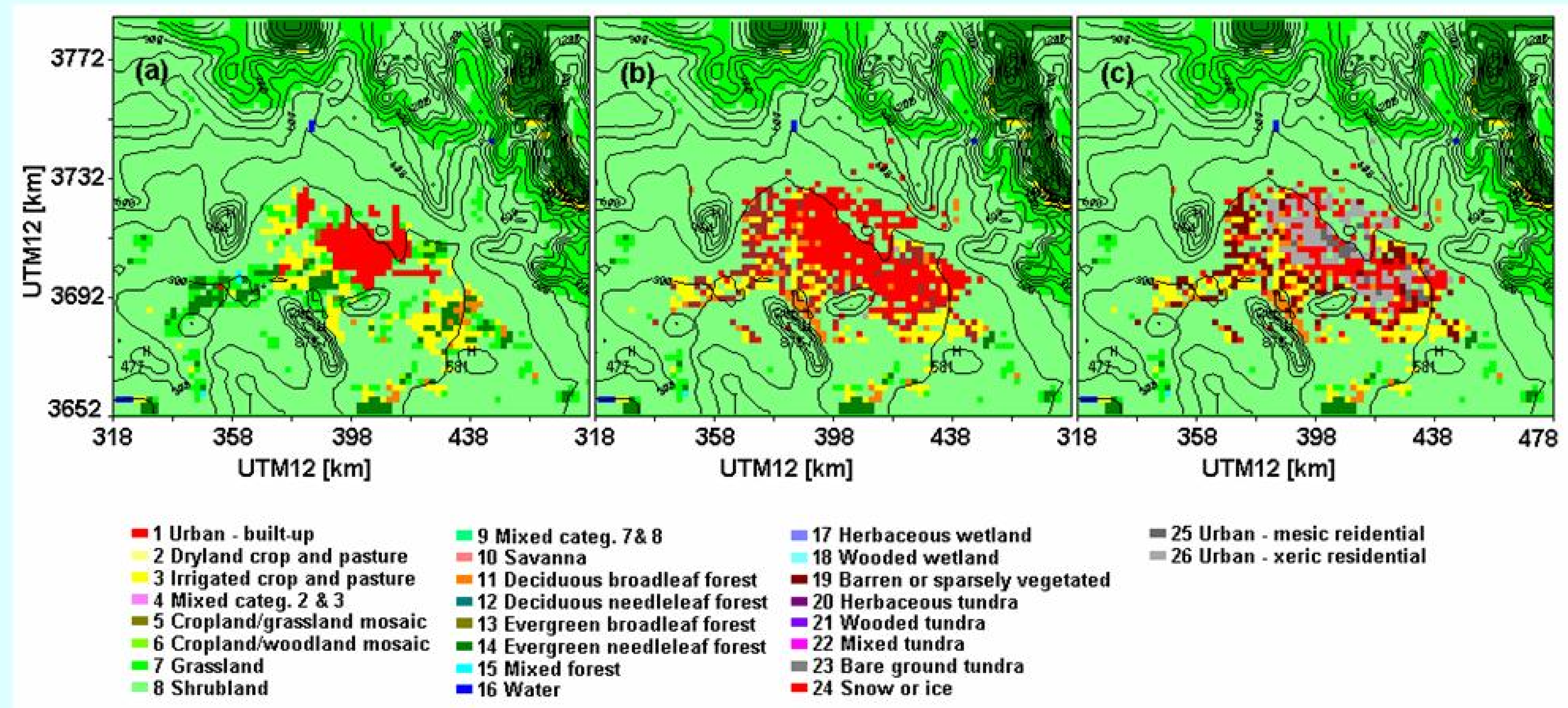
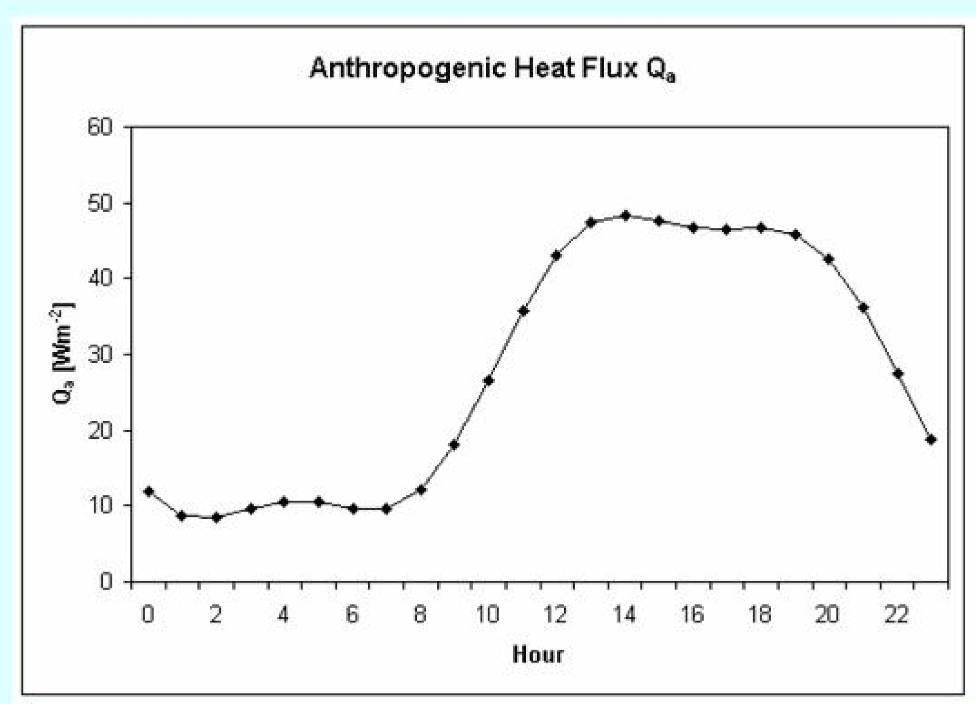


Figure 1: *Land use and terrain as produced by MM5's preprocessor TERRAIN for the modeling domain with a 2 km x 2 km grid resolution based on (a) original 30-second 24 category USGS land use data set as provided with MM5, (b) LANDSAT Thematic Mapper (TM) 1998 image derived land use data and (c) LANDSAT Thematic Mapper (TM) 1998 image derived land use data and two new urban land use classes represented by categories 25 - mesic (irrigated) and 26 – xeric (arid, partly irrigated) residential respectively (UTM12 - Universal Transverse Mercator Zone 12).*

Anthropogenic heat flux

The main sources for the anthropogenic heat flux, Q_a, in Phoenix arise from traffic combustion and air conditioners which are in general placed on roof tops. Ideally temporal profiles for Q_a would reflect the diurnal and seasonal variability of those heat sources. Considering that anthropogenic heat is released directly into the air in the urban canopy we included a source term in the equation for the calculation of the potential temperature at the first prognostic level. The daily varying anthropogenic heat flux was calculated according to Taha (1999) and peaks from the early afternoon hours to the early evening and therefore reflects the energy use through air conditioning. A maximum anthropogenic heat flux $Q_{a,max}$ of 50 W m^{-2} was assumed:

$$Q_a = Q_{a,\max} \cdot \left\{ \gamma + \sum_{n=1}^{3} \left[\lambda_n \cos\left(\frac{2n\pi t}{24}\right) + \phi_n \sin\left(\frac{2n\pi t}{24}\right) \right] \right\}$$



where t is time of day and γ=0.557, λ_1=-0.227, λ_2=-0.006, λ_3=-0.084, ϕ_1=-0.384, ϕ_2=0.016 and ϕ_3=-0.012.

Figure 2: *Diurnal variation of anthropogenic heat production Q_a as included in the mesoscale meteorological model MM5 for the urban land use classes*

Results and Conclusions

The course of the simulated and measured 2 m air temperatures for the period of June 7, 1998 17:00 LST to June 10, 1998 17:00 LST was analyzed for the land use scenarios – (I) MM5's original USGS 24 category land use data (II) original land use data with desert category and 1998 26-category land use data. Figure 3 shows the results for the prominent NWS station at Sky Harbor Airport. The simulated 2 m air temperatures significantly improved with the new land use data and classification during day-time.

However the strong discrepancies between simulated and observed night-time temperatures were not improved. In order to describe night-time 2 m air temperatures in the city sufficiently well, it was necessary to further implement parameterizations of physical processes such as radiation trapping, anthropogenic heat production and high heat storage in the model (Figure 4).

The updated land use data and the new land use classification had a significant impact on the turbulent heat fluxes and the evolution of the boundary layer and improved the capability of MM5 to simulate the near surface air temperatures across the urban area. The models ability to simulate night-time urban air temperatures was significantly improved. Accurate simulations of surface fluxes of heat, moisture, momentum and short/long wave radiation are also crucial for air quality applications because they are the primary mechanisms driving the development of the turbulent boundary layer.

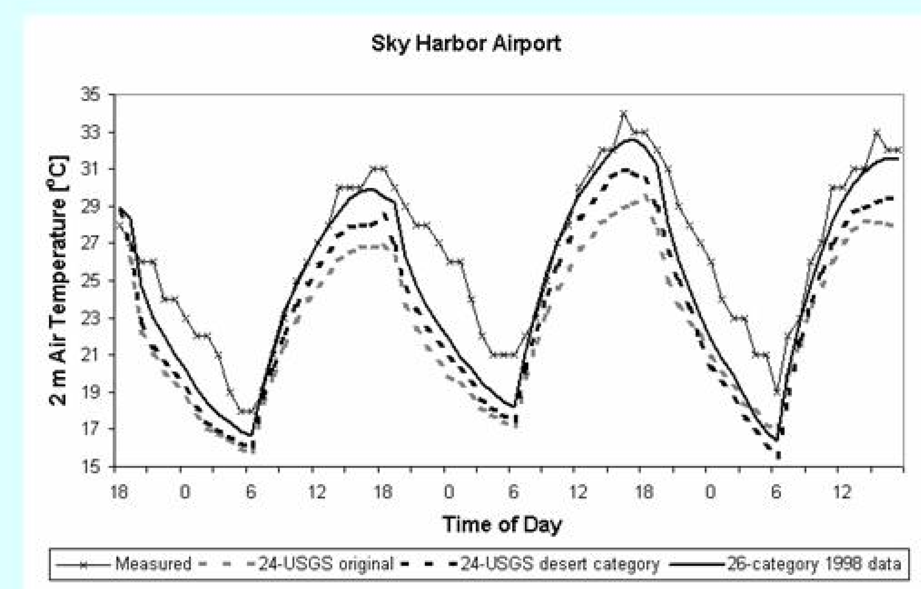


Figure 3:

Simulated and observed 2 m air temperatures for June 7, 1998 17:00 LST to June 10, 1998 17:00 LST for the NWS station at Sky Harbor Airport.

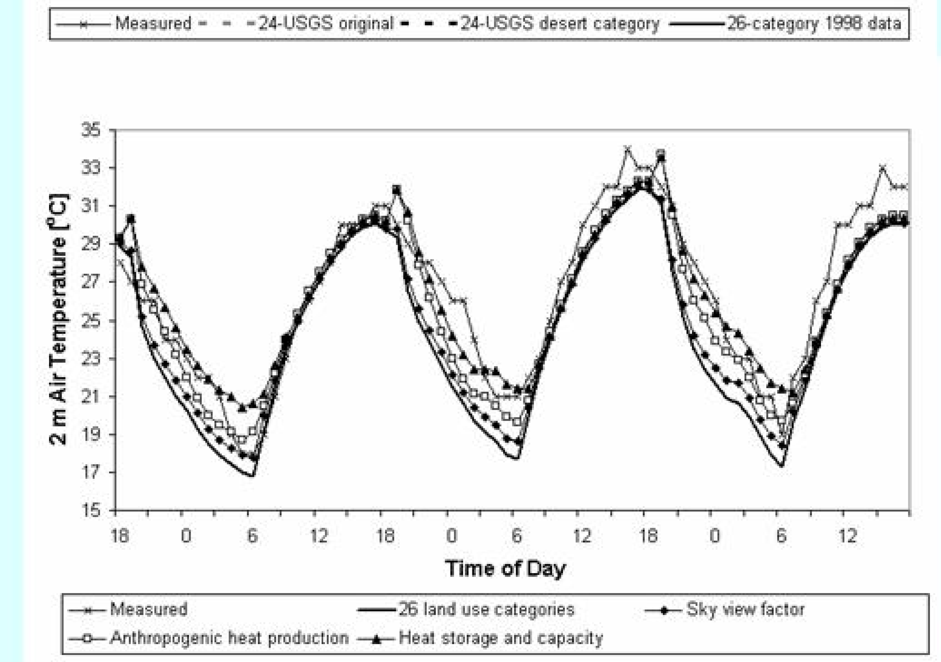


Figure 4:

Simulated and observed 2 m air temperatures for June 7, 1998 17:00 LST to June 10, 1998 17:00 LST for the NWS station at Sky Harbor Airport.

References

Noilhan, J. 1981: A model for the net total radiation flux at the surfaces of a building. *Building Environment* 16: 259-266.

Stefanov, W. L.; Ramsey, M. S.; Christensen, P. R. Remote Sens. Environ. 2001, 77, 173-185.

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