Modeling Micro-Scale Park-Cooling Effects Within the ASU Campus: An Evaluation of the Envi-Met Climate Model

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Figure 1

2007 aerial photograph of study area, including study boundary noted by purple line.

Figure 2

Traverse was conducted on bicycle outfitted with GPS, Qstarz model BT-Q1000 data-logger, and T&D model TR-72U temperature monitors at 0.1, 1, 2, and 3 m.

Figure 3

Sample locations from mobile traverse starting at 0530 in the morning of Oct. 28, 2007. Each point (approx. 3100) represents temperature data collected at 0.1, 1, 2, and 3 m.

Introduction and Study Objective

The urban heat island (UHI) is an inadvertent consequence of urbanization resulting in elevated urban temperatures, potentially increasing heat vulnerability in areas with existing high temperatures, i.e. Phoenix (Harlan et al. 2006). One effective method of mitigating UHI is to increase areas of green-space, which lowers ambient temperatures mainly through increased evaporative cooling, i.e. the park cool island (PCI) effect. PCI is well-documented through measurements by temperature sensors (e.g. Spronken-Smith and Oke 1998); however, modeling of the PCI has not been extensively researched, especially at a micro-scale level (i.e. <1 km^2). Modeling could be a potentially effective policy tool, especially when quantifying mitigation for urban areas. This is contingent on model evaluations with observed data under different conditions and urban contexts.

This study uses observed temperature data to evaluate the Envi-Met model (Bruse 2004; free download of software at http://www. envi-met.com), a relatively simplified micro-scale numerical model designed to simulate urban effects on climate. It is applied to a small section of the ASU-Tempe campus to document the PCI effect and evaluated through qualitative comparisons with observed data, as well as with statistical analysis of difference measures.

Methodology

Study Area

The study was set in a 23 ha area centered on a 3 ha green-space lawn, the Student Resource Center (SRC) field on the ASU-Tempe campus. The SRC field is surrounded by an assortment of surface types, vegetation areas, and urban structures (Figure 1).

Data Collection

Temperature data were collected in a traverse across the study area starting at 0530hr on October 28, 2007. A bicycle was outfitted with T&D Corporation model TR-72U temperature sensors, a Qstarz model BT-Q1000 data logger, and a GPS recorder (Figure 2). Sensors were placed on a pole at 0.1, 1, 2, and 3 m heights and were then, along with the GPS, attached to the data logger, so that temperature data (*T*) could be cross-referenced with the geographical coordinate. Approximately 3100 locations at each level were sampled on the traverse (Figure 3). Ambient meteorological conditions (e.g. air temperature, relative humidity, wind speed, wind direction), were recorded at a weather station located approximately 670 meters SSW of the SRC field center.

Envi-Met Model

The Envi-Met 3.0 micro-climate model was configured for this study by first compiling an area-input file. This file is a grid, which was defined in our study as 2x2 m. Using Figure 1 as a template, urban structures, vegetation, and soil/surface types were entered onto the grid and defined using the model's default parameters (Figure 4). A configuration file was also compiled, which contained ambient meteorological data (e.g. wind speed/direction, soil temperatures) from the nearby weather station. The model was then run at 250x250x25 grid configuration for a 6 hr simulation from 0000 – 0600 hr on 10/28/07, with the model state being saved every 30 min. The model produces temperature outputs in each 3-D model grid cell, which can be examined using the accompanying LEONARDO software. In this study, temperature output at the surface and 2 m heights were analyzed.

Geographical Information System (GIS) and Georeferencing

Using aerial photographs, the entire study area was digitized into a GIS. Using the GPS coordinates of the mobile traverse data, all observed temperature data were entered into the GIS and georeferenced to their sample location.

Envi-Met model results were exported as XY coordinates in a .dat file, which were then rasterized within the GIS. Using the clearly outlined buildings in the Envi-Met output, raster data could then be georeferenced to the study area. The rasters were subsequently converted to polygon layers. This georeferencing technique is novel; there are no prior attempts to spatially join observed temperatures with predicted model temperatures for comparison and evaluation in the literature.

Results & discussion

Figures 5 and 6 show the Envi-Met output for surface and 2m heights respectively. The outputs show the shifting of PCI from the SRC fields from advection of easterly winds. The inversion layer from observed data was also detected from the model output. Figures 6 and 7 show the difference between observed and modeled output at each traverse point. At 0m, the model generally over-predicts *T* over non-urban surfaces and under-predict *T* in urban surfaces; at 2m, the model consistently under-predicts *T* for all surfaces. A strong boundary effect, especially at the southern study area border, is also observed, leading to large under-prediction of *T*.

Rather than using correlation coefficients to evaluate model performance that are inconsistent with prediction accuracy, we used a suite of difference measures that examined model bias – root mean square error (RMSE), which is partitioned to systematic (S) and unsystematic (U) components in the units of measurement (°C), and a non-dimensional index of agreement (*d*) derived from MSE that allows for unbiased models comparison (Willmott 1982). Results for both study heights are shown (Table 1).

The relatively low RMSE magnitudes in this study are acceptably low compared to similar application of Envi-Met in Phoenix under nocturnal conditions (Emmanuel and Fernando 2007), although this study under-estimated nocturnal *T* instead. The higher systematic RMSE at the surface suggests that model parameterization can be improved, which is unsurprising given the study's use of default area input parameters. Higher surface *d* suggest that surface processes are adequately modeled, although the lower 2m *d* possibly indicates surface-atmospheric exchange processes could be improved.

Table 1: Model evaluation statistics with observed data

Height	*Mean T (observed) (°C)*	*Mean T (modeled) (°C)*	*RMSE (°C)*	*RMSE (S/U) (°C)*	*d*	R^2
0m	16.41	14.65	2.36	1.55/1.78	0.52	0.14
2m	17.01	14.93	2.22	0.52/2.16	0.31	0.08

Conclusion

The Envi-Met model adequately simulated T at both 0 and 2m heights using qualitative and quantitative measures, and the strong PCI effect from the SRC field was illustrated. Future research aims would include (i) improving the area-input files for the model i.e. via parameterization of desert plants on campus; (ii) model evaluation under daytime conditions or in other seasons; and (iii) cross-evaluation of model output with data interpolation techniques i.e. kriging or inverse-distance weighing methods.

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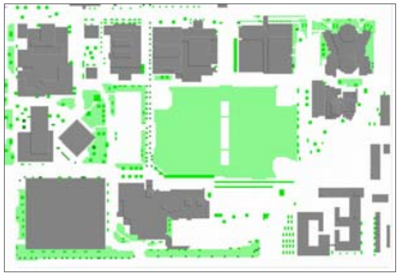

Figure 4

Area input file from the Envi-Met micro-climate model. Each cell on the grid represents a 2x2 m area and defines elevations, urban structures, surface types, and vegetation leaf area densities.

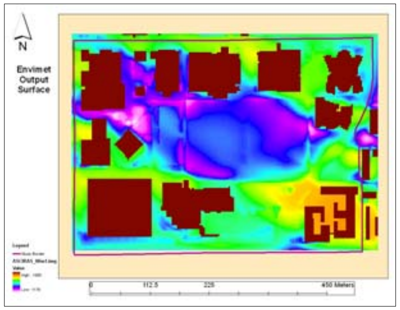

Figure 5

Envi-Met model output at 0m (surface) elevations after being converted to a GIS raster file. Colors represent temperature gradients from 11.76 to 16.85 ºC. The PCI effect is evident here.

Figure 7

Model estimation factors of observed vs. predicted temperatures at 0m (surface) elevation. Blue points (negative) indicate an overestimation in *T*, green to brown points (positive) indicate an underestimation.

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Figure 8

Model estimation factors of observed vs. predicted temperatures at 2m elevation. Blue points (negative) indicate an overestimation in *T*, green to brown points (positive) indicate an underestimation.

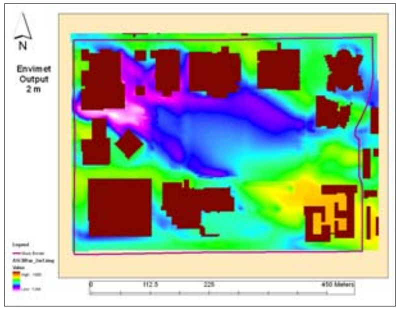

Figure 6

Envi-Met model output at 2m elevations after being converted to a GIS raster file. Colors represent temperature gradients from 12.44 to 16.85 ºC. Note the strong advection of PCI towards the MU