Microclimate Analysis of Observations in a Master-Planned Residential Community in Arizona

Benjamin L. Ruddell, Winston T.L. Chow

Introduction

- The urbanization process affects microclimates, which are distinct small scale (~10–100 m²) weather controlled by variations in urban structure, cover, fabric and metabolism (Oke 2006).
- Understanding how to best manage these microclimates through urban planning and design is important for stakeholders in residential areas (e.g. Mills et al. 2010).
- The management of microclimates to enhance urban sustainability through reducing exposure to environmental hazards (e.g. heat island and thermal discomfort effects) is an important goal in applied geographical research, especially in the desert Southwest US (e.g. Chou et al. 2012). However, results from detailed observations are lacking in the research literature.

Research Questions

- How does vegetation and outdoor water use affect the urban microclimate of a residential neighborhood?
- Do these impacts vary according to season (winter vs. summer) and spatial scale?
- What are effective patch sizes, and can we separate patch-scale from neighborhood-scale and larger microclimate effects?

General Methodology

- The master-planned residential community of Power Ranch (PR) is located in Gilbert, one of fastest growing suburban town in the US.
- The US Census Bureau reported that its population nearly doubled from 109,000 in 1990, to 208,000 in 2010.
- We conducted an intensive micro-climate monitoring campaign from Feb 2011–Jul 2012 involving a combination of microclimate and instrumental trajectories throughout the study neighborhood (Fig 1; Table 1).
- We obtained authorization from several homeowners to install weather stations in their back yards (WeatherHawk Signature Model 232; Fig 2). In this study, we analyzed data from ten such weather stations from Aug 2011–Jul 2012, while summer and winter periods were defined as 14 day periods before and after each solstice (i.e. Jun 8 – Jul 6 and Dec 8 – Jan 5 respectively). These data were quality controlled prior to analysis.
- Detailed GIS land cover data from the Town of Gilbert were also obtained. These data were used to derive study area land covers through an object-based image analysis (OBIA) method first utilized in Ruddell et al. (2010), and were also supplemented by periodic on-site ground-truthing surveys.
- Residential outdoor water use at each station were documented at 15 min intervals with automated water meters and totaled for each hour. Permission from each homeowner was also obtained prior to installation of meters.
- Permission from each homeowner was also obtained prior to installation of meters.

Table 1: PR weather stations and their descriptive land covers

<table>
<thead>
<tr>
<th>PR Station</th>
<th>Yard Type</th>
<th>Site description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0245</td>
<td>xeric</td>
<td>shade trees, gravel mulch, swimming pool</td>
</tr>
<tr>
<td>0425</td>
<td>oasis</td>
<td>grass, gravel mulch, swimming pool, shade trees</td>
</tr>
<tr>
<td>0241</td>
<td>oasis</td>
<td>swimming pool, grass, gravel mulch</td>
</tr>
<tr>
<td>0335</td>
<td>xeric</td>
<td>gravel mulch</td>
</tr>
<tr>
<td>0439</td>
<td>oasis</td>
<td>swimming pool, grass, concrete walkway</td>
</tr>
<tr>
<td>0445</td>
<td>xeric</td>
<td>swimming pool, grass, concrete walkway, gravel mulch</td>
</tr>
<tr>
<td>0424</td>
<td>mesic</td>
<td>grass, shade trees</td>
</tr>
<tr>
<td>0470</td>
<td>oasis</td>
<td>grass, gravel mulch, shade trees</td>
</tr>
</tbody>
</table>

Results

- Significant seasonal differences in mean station temperatures (T) at the local/neighborhood scale exist, but trends of seasonal hourly warming/cooling rates (ΔT/h) are similar, with notable differences in timing of peak warming or cooling possibly due to variations of day length and soil moisture inputs (Fig 3).
- There exists significant variations of vegetation surface cover at the microscale (~<50), but cover converges to ~40% veg. The three most (and least) vegetated microscale stations are grouped ~4241, 4395, 4575 and 4353, 4488, 4700 respectively. ΔT/h group is in Fig. 5. Significant differences exist in the afternoon.

Scalability Methodology

When air flows downward from one patch to a different patch with different thermal and physical properties, this convective process affects microclimate downward to a certain extent that is a fraction of the temperature difference between the patches. The patch scale radiative effect is difficult to directly estimate or observe, but is the essential signature of a patch's microclimate properties. Adapting and discretizing in time equations from Lee et al. (2012), for a patch 'A' amid a large heterogeneous matrix of surrounding patches, the time rate of increase of air temperature in the patch is ΔT, and is the net sum of the temperature-changing effects of convective 'C' and radiant 'R' processes acting on temperature, so ΔT(t+1) = ΔT(t) + ΔT(t). When wind speed is close to zero (approximated as U=0.3 m/s; a low wind speed which is similar to the Weatherhawk's saturation speed), the convective term is dropped and only the patch-scale radiant term causes temperature change. Furthermore, adapting from Lee et al. (2012) exp. 4, the convective term can be approximated as ΔT(t) = (T(t) - T(t-1)) * (C/A) = kA * (T(t-1) - T(t)), where T(t) is the elapsed time, 1 hour in this case, L is the patch size, approximated as 300m in this case (average minimum distance between towers), T is the average air temperature in the immediately upwind patches (approximated as the average of all patch temperatures excluding patch A), and k is a sensitivity factor which is larger when a patch is more sensitive to convective effects (due to canopy structure, shading, topography, patch size, etc.). This implementation falls for arrays much smaller than Lx tx t (because then T is not representative of the source area) or if there is a lot of directional asymmetry in the sensitivity of A to convection (because T is not representative, and because k will vary directionally).

To estimate k, choose t = 5 pm because U(t-1) >> 0 (neglect radiant effects) and ΔT(t) = 0, so ΔT(t) = ΔT(t) now only k is unknown. A sample of days yields a gaussian distribution of estimates of k (Table 2). These are generally 0 < k < 1. The absolute value of P*, T is used to fit. Summer n=29, winter n=14.

The convective effects ΔT(t) are plotted in Fig. 6. The radiative effects are estimated as the difference between the observed rate of change and the convective, so ΔT(t) = ΔT(t) + ΔT(t). P* is the absolute value of the ratio between convective and radiative effects. It is a dimensionless number describing the dominance of one patch at a specific time and place. It is plotted in Fig. 7, for summer.

References

This research was supported by the NSF Earth Systems Models (ESM) Program Award #EPS-1044251, by CAP-LTER (BCS-1026865), and by an ASC-CREC grant from the Salt River Project. All opinions, findings, conclusions and recommendations expressed herein are those of the authors and do not necessarily reflect the views of the sponsors.