Urban Heat Island (UHI) measures for the S.E. Metropolitan Area of the CAPLTER: Transects versus Fixed Stations.

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ABSTRACT

Various observations of urban heat islands have been conducted by urban climate researchers and ecologists using mobile surveys (airplanes, autos, bikes, and walks), fixed weather stations, and remote sensing platforms. Each method has advantages, but each has its distinct disadvantages which may account for differing estimates. We use fixed stations versus automobile transects to investigate the degree to which these two methods produce different estimates of the UHI at night for a region stretching from Tempe to Queen Creek in the S.E. Valley region. The advantage of the transect method is that a researcher is able to more fully characterize the "landscape spatial gradient" of temperatures, whereas fixed sites are typically in a station network that is suspect as to accurately representing land cover spatially. The disadvantages lay in the fact that a mobile transect is very difficult to do simultaneously (time sampling problem over large distances) and with great repetitiveness over time (days on end). Fixed sites record continuously. We use an urban (Phoenix Sky Harbor or "SH"), residential (Alameda PRISMS or "AL"), and rural (Rittenhouse PRISMS or "R") weather site for fixed stations, and over a 27 day period (spanning July through November, 2001) ran post-sundown mobile transects between Tempe and Queen Creek for comparison purposes as to the dimension of the maximum UHI observed along the entire transect. Each transect ran from urban through residential to agricultural/desert rural landscapes. A maximum urban and residential UHI was determined from the fixed sites by calculating ΔT_{SH-R} and ΔT_{AL-R} for the period ca. 9-10 pm at night – the same time as each transect was completed. Similarly, we calculated the urban to rural and residential to rural ΔT as determined from more complete information along the transect route. On average, transects revealed a maximum UHI or $\Delta T_{urb-rur}$ of 7.3°C and $\Delta T_{urb-res}$ of 3.0°C, whereas the fixed site result was ΔT_{SH-R} of 4.8°C and ΔT_{AL-R} of 2.3°C.

Introduction

This study investigates two approaches to measuring the UHI across the urban to rural gradient in the S.E. Phoenix Metropolitan area indicated by Figure 1. The first approach being the typical urban – rural fixed station method, and the second approach using a more comprehensive mobile transect data collection.

Figure 1. Study area indicated by rectangle. Three Asterisks indicate SH, AL, and R arrayed NW to SE.

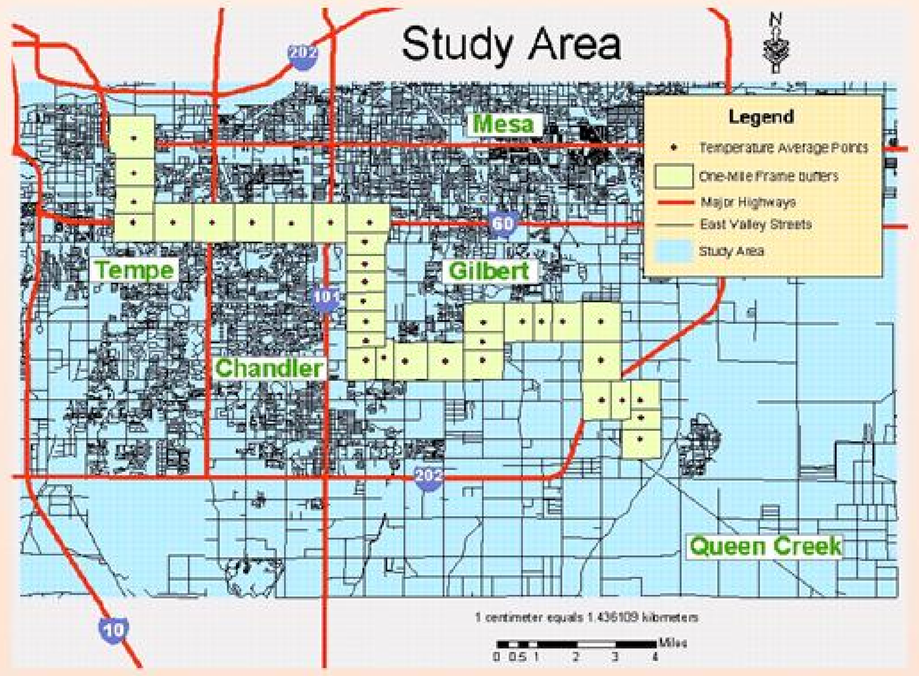

Figure 2. Automobile Transect Route extending from Tempe to Gilbert, with a street density background.

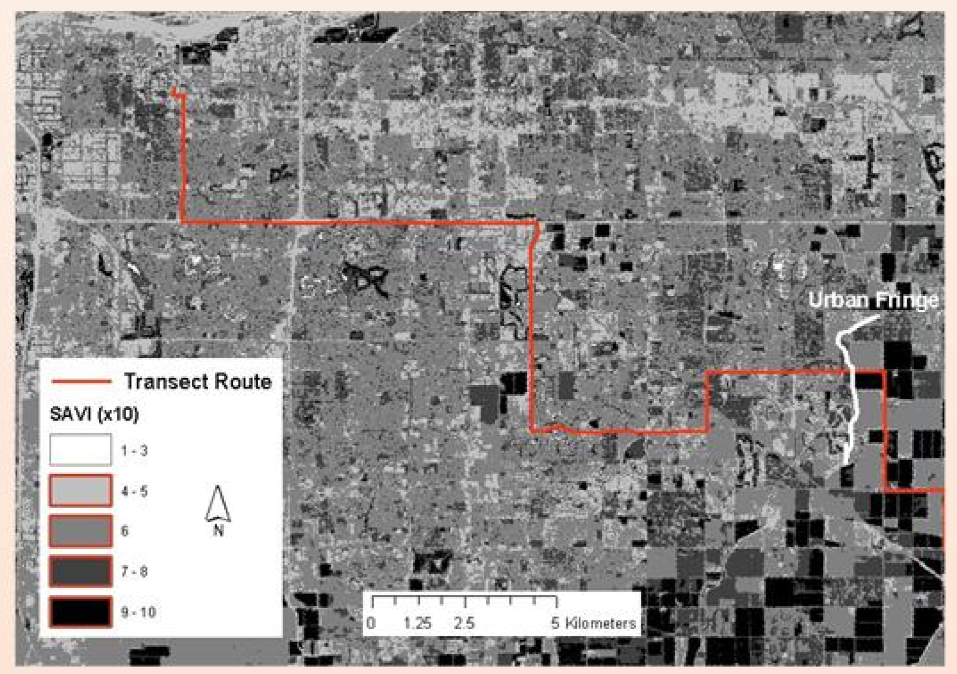

Figure 3. SAVI values within the study area, with lighter shades representing less vegetation and surface moisture levels.

Methodology

Data collection:

1. Automobile Transects – temperature and dew points collected along route extending from Arizona State University to agricultural regions in Gilbert (Fig. 2) 27 times from July 2 to November 30, 2001. Car-mounted instrumentation (Figure 4) measured temperature and dew point averaged per minute while driving.
2. Fixed Stations – temperature and dew point records obtained for July – November 2001 from two PRISMS (Phoenix Real-time Instrumentation for Surface Meteorological Studies) Alameda (AL), located in Tempe, and Rittenhouse (R), located in Queen Creek, as well as an ASOS station (Phoenix Sky Harbor, or SH).
3. SAVI data – A soil-adjusted vegetation index image was obtained which was taken in July 2001 and clipped to the study area for use as comparison to dew point measures (Fig. 3).

Data analysis:

1. Temperature and dew points were compiled by transect date and then systematically averaged for eastward and westward halves to obtain UHI max, which was the greatest difference between urban and rural, and UHI avg, which was the actual average of the two halves. Fig. 5 illustrates UHI avg on September 21, 2001, which was when the highest urban – rural difference of 11°C occurred.
2. Fixed station data was compared for various station combinations, such as SH-R (urban – rural) and SH – AL (urban – res), against transect UHI max and UHI avg values, as well as UHI values found in literature for a city of comparable size (Oke, 1973).

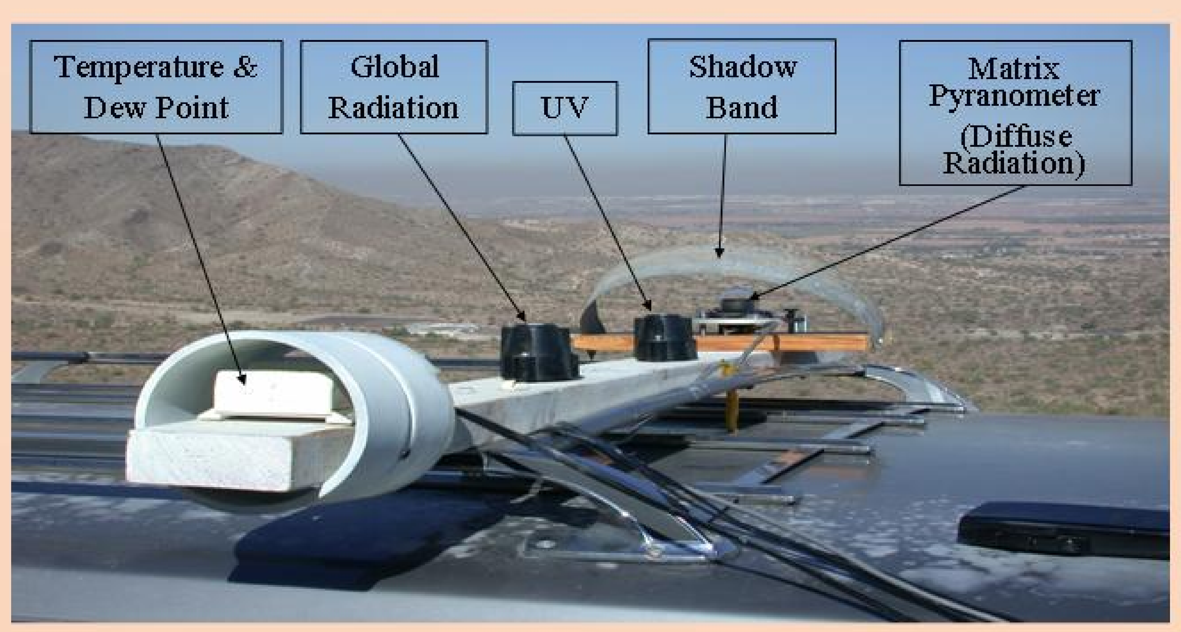

Figure 4. Car-mounted instrumentation used to collect Temperature and Dew Point along transect route.

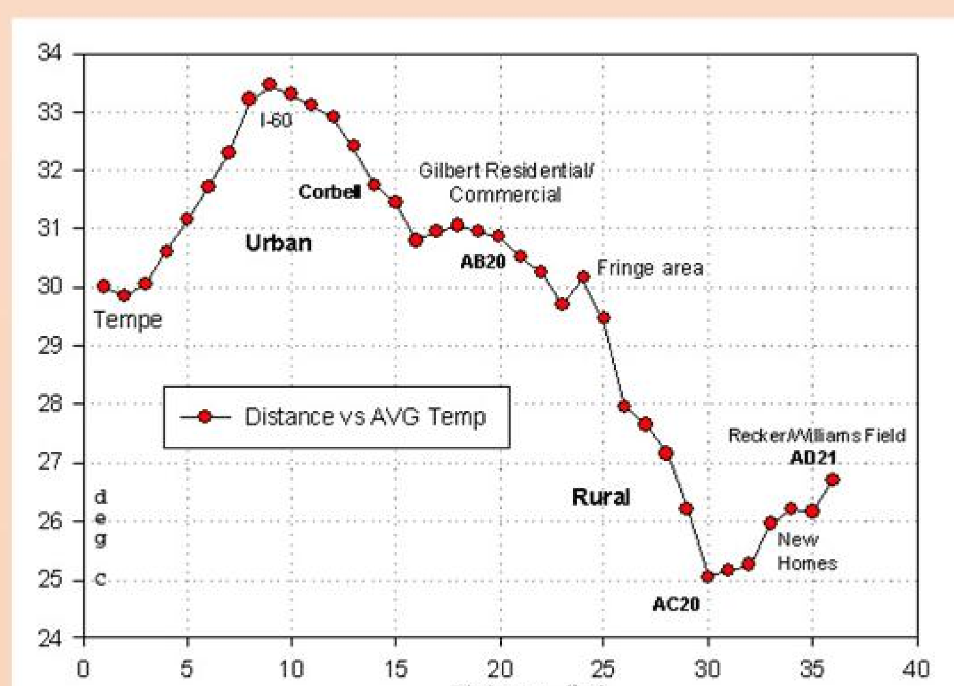

Figure 5. Average UHI along transect route for September 21, 2001, showing sharp drop in temperature at the urban fringe.

Findings

Variable	Mean (N=27) in °C	Variance in °C
$\Delta T_{urb-rur}$ transect	7.32	4.07
$\Delta T_{res-rur}$ transect	3.02	1.19
ΔT_{SH-R} fixed sites	4.82	7.72
ΔT_{AL-R} fixed sites	2.30	3.29

Table 1. UHI Descriptive Statistics for transect and fixed sites

Oke (1973) theory: UHI: $\Delta T \sim p^{1/4}/4 \cdot u^{1/2}$
$\Delta T_{urb-rur} = 11.64\ u^{-0.59}$ $r^2 = 0.52^*$
$\Delta T_{res-rur} = 5.72\ u^{-0.863}$ $r^2 = 0.48^*$
$\Delta T_{SH-R} = 13.02\ u^{-1.35}$ $r^2 = 0.38^*$
$\Delta T_{AL-R} = 4.83\ u^{-1.24}$ $r^2 = 0.17$

Table 2. Equations for selected UHI measure vs. Wind.
*significant at 0.05 level

Table 1 shows that there are larger differences between urban, residential, and rural parts of the transect than inferred from the three fixed sites representing this 35 km gradient in the SE Valley. Table 2 illustrates the important role of wind speed and the non-linear response of the temperature differences that arise for the contrasts among urban, residential, and rural legs of the transect and among the fixed sites. The Oke (1973) initial set of observations from his transects through different sizes of North American towns and cities showed that UHI ~ to $p^{1/4}/4 \cdot u^{1/2}$, where p = population and u = wind speed. The fixed and transect results from the 27 day sample from July 2 to November 30 generally conform to this functional relation. The transect urban minus rural temperature response in relation to wind speed (i.e., $\Delta T_{urb-rur}$) has virtually the same exponent value as the findings of Oke (1973), with the constant value based on p appropriate to the Phoenix area. The relation $\Delta T_{urb-rur}$ to u is significant where the fixed station relation of ΔT_{AL-R} to u is not. Oke's theory illustrated, and this study also indicates, that for wind speeds > ~4 $msec^{-2}$ the UHI tends to dampen at night. The higher winds we found were also collinear with higher dew points and cloudiness for some of the 27 day sample – these are other factors that would reduce UHI at night.

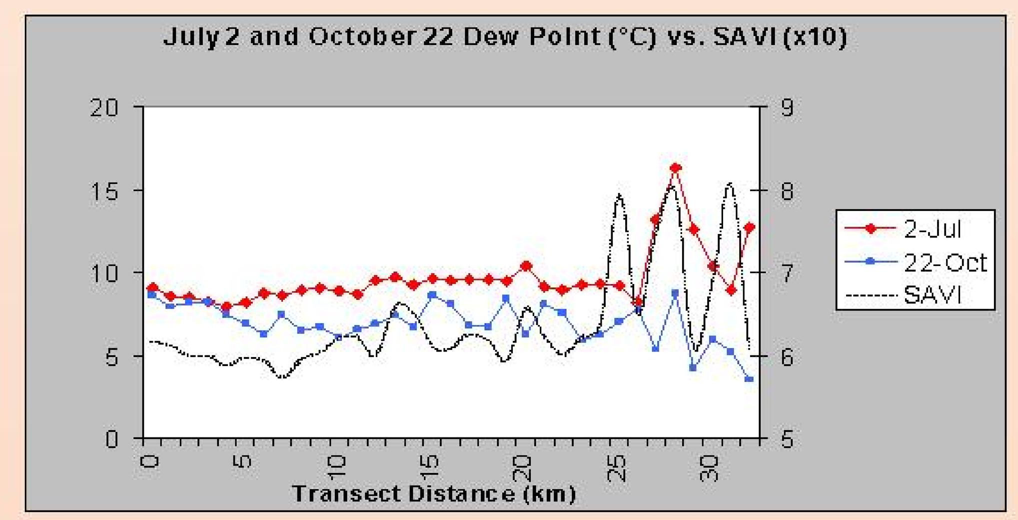

Figure 6. Dew points for a Summer day (July 2) and a Fall day (Oct.22) plotted against SAVI from mobile sampling.

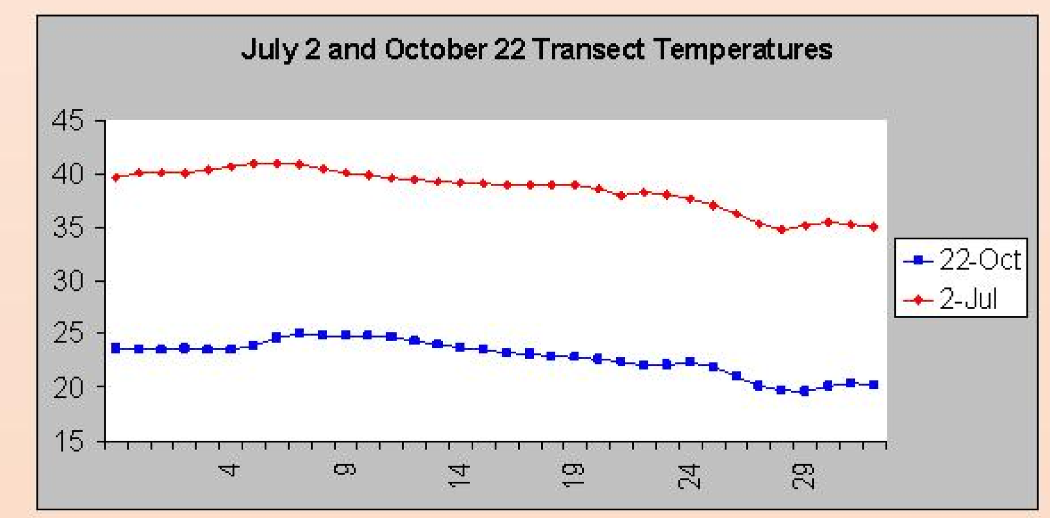

Figure 7. Mobile temp. values for July 2 and October 22, 2001.

An interesting result is seen in Fig. 6 for dew points that were observed along the transects. For two calm nights of July 2 and October 22 a transect of dew points suggest the role of evapotranspiration and thermal admittance (surface cooling rate) differences in explaining temperature patterns. In summer, higher dew points are seen in the rural area where there is much more agricultural activity and thus likely larger evaporative cooling effects during the day and subsequent early evening on July 2. The temperature differences may be related more to the role of moisture. During late October, there are actually lower dew points in the rural area compared to the residential and urban zones of the transect. In Fig. 7, the dimension of temperature change along the transect for 9-10 pm on July 2 and October 22 is very similar. The late October drop in temperature into rural areas is probably more a function of heat retentive properties in the urban/residential zone vs. lower thermal admittance soils in the drier fall period in the rural zone (thus faster cooling). This hypothesis for seasonal shifts in explanations of these temperature contrasts is ripe for further model development and testing. The Sept. 21 period has been modeled with good success by S. Grossman-Clarke and J. Zehnder using MM5, and presented at a recent ICUC conference (ref 1).

References

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2. Hedquist, B.C.: 2002, 'Spatio-Temporal Variation in the Phoenix East Valley Urban Heat Island', M.A. Thesis.
3. Oke, T.R.: 1973, 'City Size and the Urban Heat Island', *Atmos. Environ.*7, 769-779.

Acknowledgements

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