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AN ANALYSIS OF THE OKLAHOMA CITY URBAN HEAT ISLAND

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1. INTRODUCTION

The percentage of humans living in urban areas continues to grow worldwide. Currently in the United States, 64% of the population lives within less than 2% of the U.S. land area (Dabberdt et al. 2000). In addition, a recent study by the United Nations found that by 2025, 80% of the world's population will live in cities (United Nations 2003), and by 2015, 26 megacities will exist worldwide with populations in excess of 10 million inhabitants (United Nations Human Settlements Program 1997). As such, the rapid urbanization process has created a critical issue facing the global society: the impact of urban environments on human health.

The need to quantify urban-atmosphere relationships has spurred research in numerous areas and recent studies have documented a number of processes including changes to surface humidity, varying roughness and turbulence, the energy and radiation budgets, the development of the urban boundary layer, precipitation and hydrological processes, and air quality, dispersion, and pollution. However, a critical phenomenon which links the aforementioned processes to one another and poses a significant human impact is the urban heat island (UHI) that results from differential thermal storage between rural and urban areas.

Urban heat islands have been measured worldwide in climates that are tropical such as Mexico City, Mexico (Oke et al. 1999), Tuscon, Arizona (Comrie 2000), and Pheonix, Arizona (Hawkins et al. 2004; Fast et al. 2005), in temperate zones near large bodies of water including Melbourne, Australia (Morris et al. 2001) and Athens, Greece (Livida et al. 2002), in intercontinental regions with cool climates (e.g., Lodz, Poland; Klysik and Fortuniak 1999), and in arctic regions (e.g., Barrow, Alaska; Hinkel et al. 2003). In addition, the UHI phenomenon has been observed for megacities (e.g., Mexico City, New York City, etc.) as well as relatively minor urban areas (i.e., population centers less than 500,000 inhabitants) such as Durham, North Carolina (Kopec 1970).

During June and July 2003, the Joint Urban 2003 field experiment (JU2003; Allwine et al. 2004) was conducted in Oklahoma City (OKC). The primary objective of JU2003 was to collect observations of atmospheric conditions and tracers for the purpose of improving urban dispersion models. Prior to JU2003, instruments were temporarily installed to acquire preliminary measurements of the urban atmosphere in Oklahoma City from July 2002 through May 2003. In addition, during JU2003, a vast array of atmospheric sensors collected high-resolution observations in and around the central business district of Oklahoma City.

Due to the extensive dataset collected during JU2003, this study focused on (a) consolidating the available air temperature observations collected prior to and during the JU2003 period and (b) quantifying the urban heat island of Oklahoma City using an index value.

2. BACKGROUND

During June and July 2003, the JU2003 field project occurred in downtown Oklahoma City (Allwine et al. 2004). Between the dates of 28 June and 31 July 2003, the vast array of instrument systems installed specifically for JU2003 collected high-resolution observations of meteorological variables in and around Oklahoma City. The instruments continuously gathered data from surface-based and tower-based measurements at ground level, on traffic poles, the sides of buildings, and on rooftops. Additional instruments were installed on the perimeter of the city to gather information on the vertical profile of wind speed, wind direction, and temperature.

3. DATA AND METHODS

This study utilized two main datasets collected prior to and during Joint Urban 2003. The former included temperature values collected from several PWIDS (Portable Weather and Information Display Systems) stations deployed within Oklahoma City on traffic poles and observations from six Oklahoma Mesonet sites for the period spanning 1 July 2002 until 30 April 2003. The second dataset focused on the JU2003 period and included PWIDS and Oklahoma Mesonet data as well as observations collected from 37 HOBO temperature dataloggers installed across Oklahoma City at a height of 2 meters.

3.1 *Portable Weather Information Display System (PWIDS)*

As part of a preliminary study for JU2003, Portable Weather and Information Display Systems (PWIDS; Vernon et al., 2004) sites were installed in and near the CBD of Oklahoma City for nearly a year beginning in July 2002. The PWIDS sites measured wind speed, wind direction, temperature, and relative humidity.

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Thirteen of the PWIDS sites were mounted atop street light/traffic light poles, approximately eight meters above ground level. These PWIDS sites were within four blocks of each other. The other two PWIDS sites were located on a building rooftop approximately 1 kilometer south of the CBD, and were not used for this study.

During JU2003, the location of the PWIDS sites were changed to better support the field experiment. Again, thirteen PWIDS sites were located on street light/traffic light poles, approximately eight meters above ground level. Seven of the PWIDS sites were co-located with HOBO sites (discussed later).

3.2 *HOBOs*

In order to measure the air temperature near the surface (two meters above ground level), 37 HOBOs (http://www.onsetcomp.com/index.html) were deployed in the CBD during JU2003. Nineteen HOBOs were deployed north to south through the CBD, while the remaining eighteen were setup west to east through the CBD. As previously mentioned, seven HOBOs were co-located with PWIDS stations.

3.3 *The Oklahoma Mesonet*

The Oklahoma Mesonet is an automated network of 116 remote, meteorological stations across Oklahoma (Brock et al. 1995; Shafer et al. 2000). Each station measures core parameters that include: air temperature and relative humidity at 1.5 m, wind speed and direction at 10 m, atmospheric pressure, incoming solar radiation, rainfall, and bare and vegetated soil temperatures at 10 cm below ground level. In addition, 101 sites measure soil moisture at 4 depths: 5, 25, 60, and 75 cm and 100 sites measure air temperature at 9 m. Mesonet data are collected and transmitted to a central point every 5 minutes where they are quality controlled, distributed and archived (Shafer et al. 2000; http://www.mesonet.org).

3.4 *The Urban Heat Island Index*

Hawkins et al. (2004) demonstrated that rural variability could impact the calculation of the magnitude of the urban heat island. At the same time, the goal of the study was to create a robust tool that could be used real-time to diagnose the strength of the urban heat island over various temporal intervals. As such, an index value was developed to quantify the composite magnitude of the urban heat island for Oklahoma City:

$$UHII_m = Tu_m - Tr_m \qquad (1)$$

Where UHII is the urban heat island index, Tu_m is the mean temperature of the urban observations, Tr_m is the mean temperature of the rural observations, and m is the height of the measurements. For example, the $UHII_9$ was computed for the Pre-JU2003 period using the difference between mean temperature collected at the PWIDS (urban temperature mean) and the mean Mesonet temperature (rural temperature mean). Similar computations were applied to the JU2003 at both the 2 and 9 meter heights

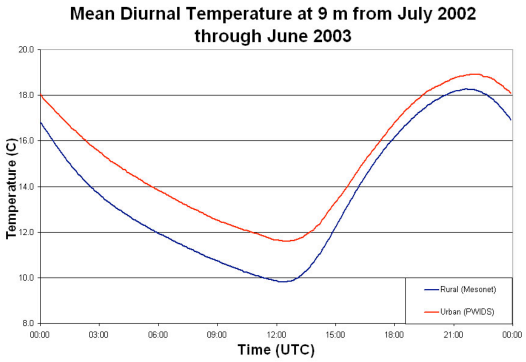

Figure 1. Mean diurnal temperature at urban and rural locations at 9 m during From July 2002 to June 2003.

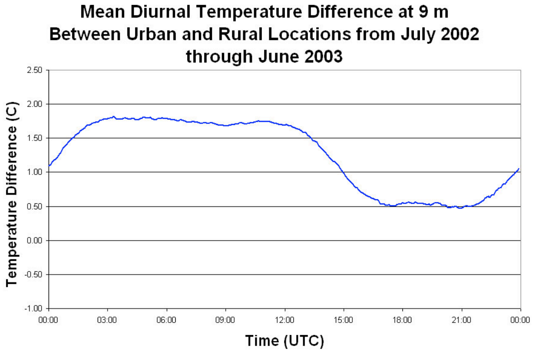

Figure 2. Mean diurnal temperature difference between urban and rural locations at 9 m during From July 2002 to June 2003.

4. THE OKLHAOMA CITY URBAN HEAT ISLAND

4.1 *Pre-JU2003 Analysis*

To quantify the overall UHI in Oklahoma City during the 10-month period prior to JU2003, a composite analysis utilizing the UHII was performed for the whole period. Figures 1 and 2 show that at the 9-meter height, the UHII was consistently 0.5-1.75°C greater in the urban core of OKC than the surrounding rural terrain. Further, as noted with previous UHI studies, the UHI impact was strongest during the overnight hours and weakest during the day.

A similar analysis was performed for the individual months prior to JU2003 at the 9-meter level. Again, the composite values represented by the UHII were consistently greater within the CBD of Oklahoma City than the surrounding rural areas by 0.5-2.25°C. In fact, the overall magnitude of the UHII values changed little

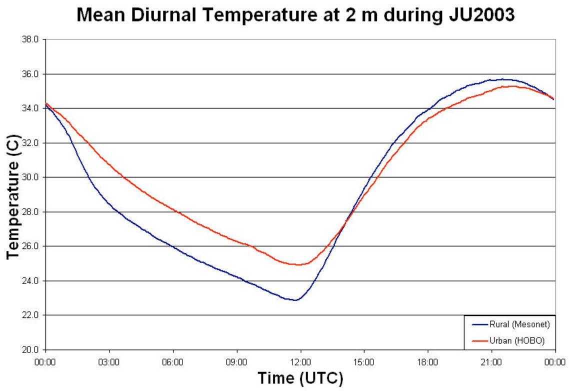

Figure 3. Mean diurnal temperature at urban and rural locations at 2 m during JU2003.

from month to month even as the seasons and the amount of downwelling solar radiation change. However, subtle changes were noted and the UHII to be strongest during the fall months and weakest during the winter months.

Inspection of the temperature data also revealed a slight lag between the rural and the urban data. In this case, the rural values warmed quicker than the urban values following sunrise and cooled quicker following sunset. This lag is likely due to multiple factors: greater turbulent mixing in the rural locations following sunrise coupled with the shadowing of urban sites by large buildings, the greater heat storage in the urban zone following sunset, and the greater spatial variability of the Mesonet sites used in the study.

4.2 *JU2003 Analysis*

A separate analysis of the 9-meter observations was performed for the JU2003 data due to the fact that the PWIDS were redeployed through the urban zone for the project. Even so, only minimal differences existed in the UHII values between the JU2003 and the pre-JU2003 period. As such, during the overnight hours, or roughly 0300-1200 UTC, urban setting was approximately 1.5°C warmer than the rural composite while during the daytime (1400-0100 UTC) the UHII decreased to approximately 0.5°C (not shown).

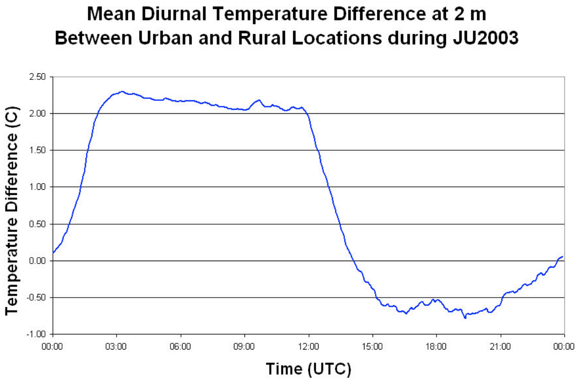

Figure 4. Mean diurnal temperature difference between urban and rural locations at 2 m during JU2003.

A second analysis was performed using JU2003 data whereby observations from the Hobo sensors (urban) were compared with observations at Mesonet sites (rural) for the 2-meter height. The results of the 2-meter analysis during JU2003 included significantly differences from the 9-meter analysis. For example, while the UHII was still heavily influenced by the diurnal cycle, the magnitudes were greater at all times of the day (Figs. 3 and 4). During overnight hours the UHII values were typically greater than 2°C warmer than surrounding rural location. Conversely, during daytime the UHII was actually negative and revealed that the urban core was over 0.5°C *cooler* than the urban locations. Thus, during the peak heating of the day, the urban core behaved as a "cool island" at 2-meters during JU2003.

4.3 *Inversion Strength*

During JU2003 the mean rural and urban inversion strength was calculated. Inversions strength from the six surrounding Mesonet sites were averaged to compute the mean the rural inversion. To calculate the urban inversion strength, only the locations with both a 2-meter and 9-meter observations within approximately 30 m of one another were used. The results of this comparison are presented in Figure 5 and demonstrate a general lack of any significant inversion in downtown Oklahoma City throughout the entire study period. Conversely, observations from the rural locations demonstrated a consistent, significant nocturnal inversion.

5. CONCLUSIONS

The results from this study demonstrated a mean UHI of 1-2 Celsius at the 9-meter height which persisted regardless of time of year. However, the observations collected at 2 meters during JU2003 revealed a strong UHI signal during the overnight period and a weak urban cool island (UCI) signal during the daylight period. As such, temperatures within the CBD of Oklahoma City were, on average, slightly cooler than the surrounding rural observations during daylight periods. Further, for those sites with co-located temperature observations at 2 and 9 meters, the strength of the nocturnal inversion was significantly greater at the rural Mesonet sites than within the CBD.

ACKNOWLEDGEMENTS

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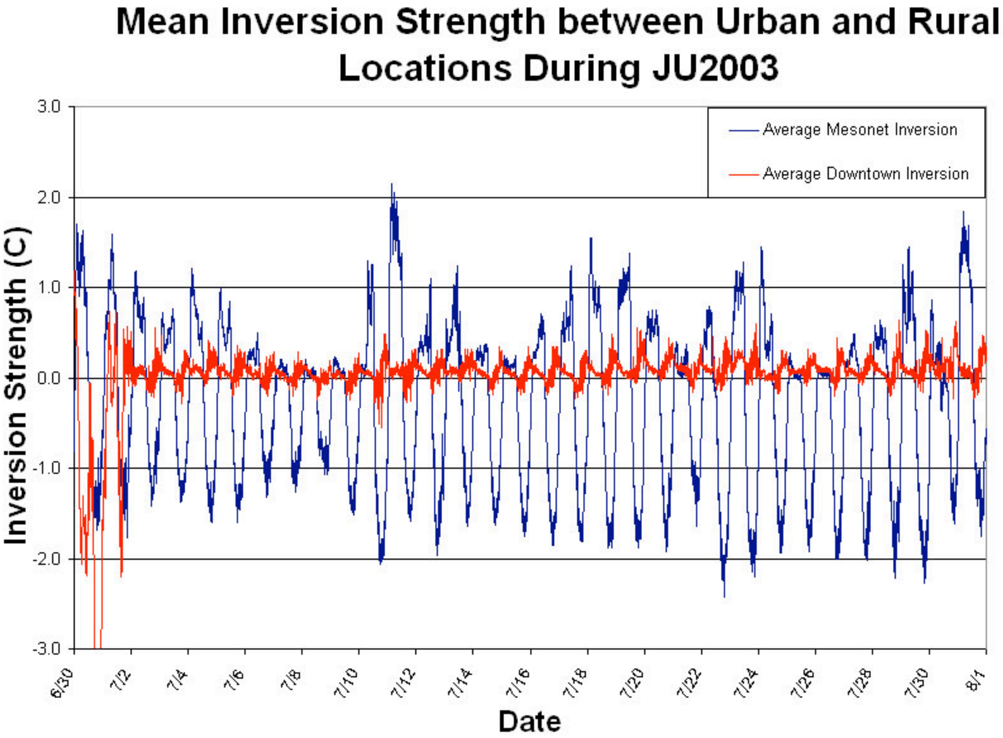

Figure 5. Mean inversion strength between urban and rural locations during JU2003.

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