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AN ANALYSIS OF THE JULY AND AUGUST 2008 HEAT WAVE USING OKLAHOMA CITY MICRONET OBSERVATIONS

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1. INTRODUCTION

The impact of urban environments on human health has become a critical issue facing the global society as the number and percentage of humans living in urban areas continues to grow worldwide (United Nations Human Settlements Program 1997; Dabberdt et al. 2000; United Nations 2003). With the occurrence of environmental hazards combined with increased urbanization, the direct and indirect weather-related accidents and deaths have continued to increase (Changnon 1992). In recent years, the effects of heat waves had devastating impacts in Chicago in 1995 (Changnon et al. 1996; Semenza et al. 1996) and Paris in 2003 where deaths due to heat-related illnesses were equally devastating (Pirard et al. 2005). Unfortunately, the frequency and intensity of heat waves will likely increase (Meehl and Tebaldi 2004) and, as a result, many cities have implemented heat watch-warning technologies to mitigate the impacts of heat waves and protect the populations of the associated urban areas (Sheridan and Kalkstein 1998; Ebi et al. 2004; Sheridan and Kalkstein 2004).

At the same time, urban areas have a profound impact on the local atmospheric conditions. In particular, the urban heat island (UHI) that results from differential thermal storage between rural and urban areas leads to increased temperature values within the urban zone when compared to surrounding rural areas (Bornstein 1968). In general, the UHI is most noticeable at night and under synoptic high pressure systems with calm conditions and clear skies (Bornstein 1968; Vukovich 1975; Nkemdirim 1980; Oke 1987 1988; Lu and Arya 1997) and has been measured in cities spanning varying climate regimes and sizes (Kopec 1970; Oke et al. 1999; Comrie 2000; Hawkins et al. 2004; Fast et al. 2005; Morris et al. 2001; Livada et al. 2002; Klysik and Fortuniak 1999; Hinkel et al. 2003).

During 2007 and 2008, a dense network of atmospheric monitoring sites were deployed across the Oklahoma City metropolitan area (the Oklahoma City Micronet; OKCNET) and observed an intense heat wave that covered central Oklahoma (including Oklahoma City and surrounding areas) in late July and early August 2008. Given the dense meteorological observations across the Oklahoma City metropolitan area and results from a recent study by Basara et al. (2008) that demonstrated a pronounced UHI signature in Oklahoma City, the objective of this study was to quantify the impact of the UHI in Oklahoma City on environmental conditions during the heat wave event and demonstrate how the UHI exacerbated conditions critical to human health.

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2. DATA AND METHODS

Oklahoma City is the largest city that is not a consolidated city-county in the United States (approximately 1610 km^2) with an urbanized area of approximately 630 km^2. Within the urbanized area of Oklahoma City is a well-defined central business district (approximately 20 km^2) with buildings to 120 m in height.

This study used two datasets collected from 15 July through 15 August 2008, which spanned the period prior to, during, and following the heat wave event. These datasets included observations collected from the Oklahoma City Micronet (OKCNET) as well as observations from 10 Oklahoma Mesonet sites in the Oklahoma City metropolitan area and the surrounding rural terrain.

2.1 *The Oklahoma Mesonet*

The Oklahoma Mesonet is an automated network of 120 remote, meteorological stations across Oklahoma (Brock et al. 1995; Shafer et al. 2000; McPherson et al. 2007). 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, downwelling solar radiation, rainfall, and bare and vegetated soil temperatures at 10 cm below ground level. In addition, over 100 sites measure air temperature at 9 m. In an effort to avoid anthropogenic influences, most Oklahoma Mesonet sites are located in rural areas. 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; McPherson et al. 2007). This study used data collected from the ten sites in and around the Oklahoma City metropolitan area in 2008: ELRE, GUTH, KING, MINC, NRMN, OKCE, OKCN, OKCW, SHAW, and SPEN (Fig. 1).

2.2 *The Oklahoma City Micronet*

The Oklahoma City Micronet (OKCNET) is an operational network designed to improve atmospheric monitoring across the Oklahoma City metropolitan area.

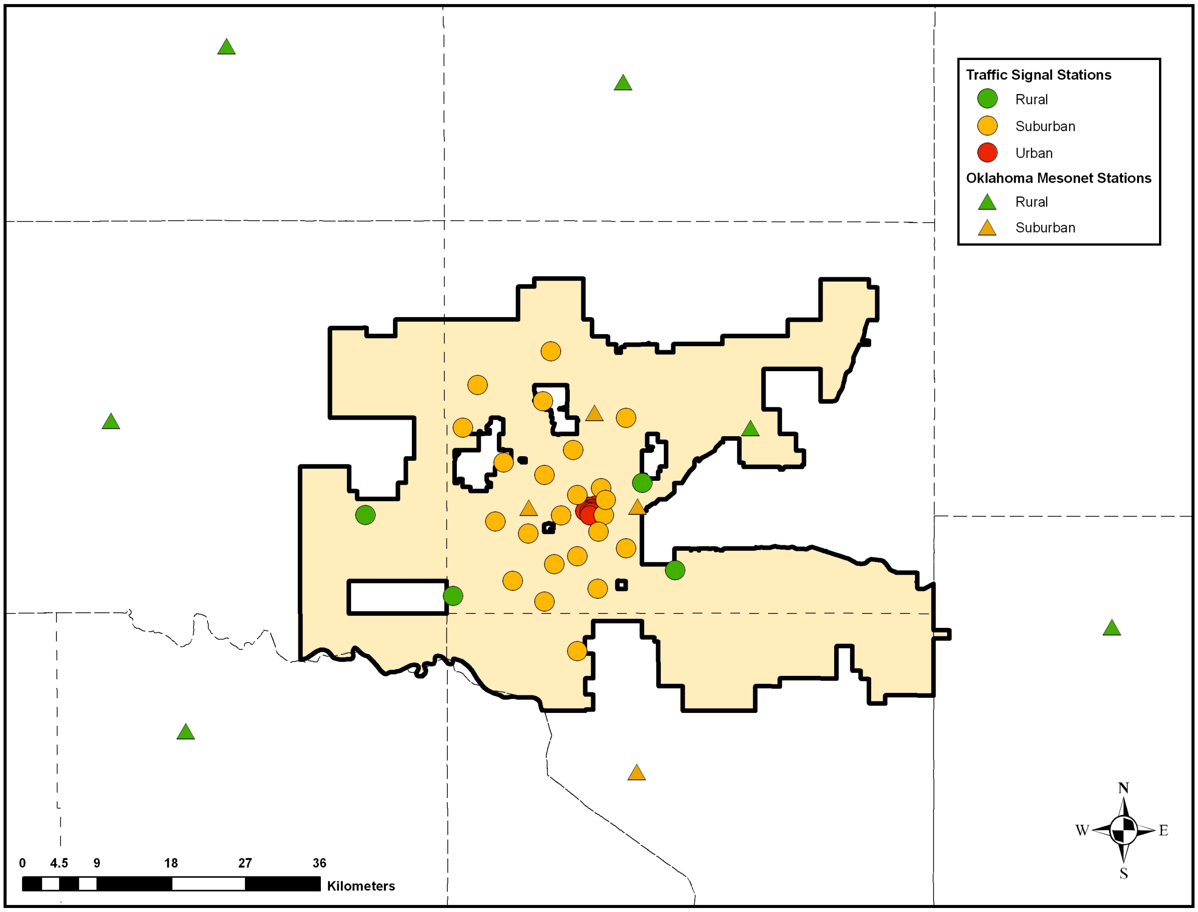

Figure 1. The locations of Oklahoma Mesonet and Oklahoma City Micronet stations used in this study. The highlighted area (tan) represents the municipal boundaries for the City of Oklahoma City.

The 40-station network consists of four Oklahoma Mesonet Stations (OKCE, OKCN, OKCW, and SPEN) and 36 stations mounted on traffic signals at a height of approximately 9 m; station spacing is approximately 3 km. At each traffic signal site, atmospheric conditions of air temperature, humidity, pressure, rainfall, wind speed, and wind direction are measured and transmitted every minute to a central facility 24 hours per day, year-round where they are quality controlled, distributed and archived using the Oklahoma Mesonet infrastructure. The Oklahoma City Micronet includes a cluster of stations within the central business district as well as stations throughout the Metropolitan area (Fig. 1).

2.3 *The Urban Heat Island Index*

To quantify the varying environmental conditions that existed between the urban and rural zones in and around Oklahoma City during the heat wave in late July and early August 2008, the magnitude of the UHI was calculated during the study period. UHI intensity is defined according to the availability of observations and, when a limited number of observation sites are present, UHI intensity is often determined using the difference between the peak urban-rural temperatures from individual observing locations (Ackerman 1985; Oke 1987). However, when numerous observation sites are available, UHI intensity can be calculated as the difference between mean urban and rural temperatures (e.g., Kim and Baik 2005; Basara et al. 2008). Such computations provide a more robust measure of UHI intensity and minimize the inherent variability between observing sites that can impact the magnitude of UHI values (Hawkins et al. 2004; Basara et al. 2008).

To complete the analysis of the UHI using the composite approach, sites were examined and grouped into one of three categories based on the surrounding land cover characteristics: urban, suburban, and rural (Fig. 1). The urban stations included nine OKCNET sites located within the central business district of Oklahoma City while the rural sites included a mixture of ten OKCNET and Oklahoma Mesonet stations at locations primarily utilized for agricultural purposes. The third category, suburban, comprised 27 locations (OKCNET and Mesonet stations) in areas with residential, commercial, and industrial structures.

To determine the magnitude of the UHI for both the Urban Core of Oklahoma City, an index value was used:

$$HII_u = T_u - T_r \qquad (1)$$

Where HII_u is the heat island intensity of the composite urban values, T_u is the mean temperature of the urban observations at 9 m, and T_r is the mean temperature of the rural observations at 9 m. A similar calculation was completed for the suburban conditions:

$$HII_S = T_S - T_r \qquad (2)$$

where HII_S is the heat island intensity of the composite suburban zone, T_S is the mean temperature of the suburban observations at 9 m, and T_r is the mean temperature of the rural observations at 9 m.

Because numerous studies have linked the impact of environmental conditions and heat to mortality (e.g., Changnon et al. 1996; Semenza et al. 1996; Davis et al. 2003; Hajat et al. 2006; Gosling et al. 2008), the composite values of the UHI features (HII_u and HII_S) were combined with observed values of humidity and wind speed to compute additional, traditional values used to estimate heat stress. These include heat index (Steadman 1979; Rothfusz 1990), the formulation of the Weather Stress Index (relative apparent temperature) by Kalkstein and Valimont (1986), a revised version of relative apparent temperature by Michelozzi et al. (2007), and the humidex by Conti et al. (2005).

3. RESULTS

During the waning days of July 2008, a heat wave event began to build across central Oklahoma with the most intense conditions spanning 31 July through 5 August 2008 (hereafter referred to as the "heat wave period"). Daily maximum temperature values across the region were 5-8^{o}C warmer than the typical climatological values and approached or exceeded 40^{o}C during the heat wave. Further, the official observing station for Oklahoma City (Will Rogers World Airport) observed record high temperature values on 3 and 4 August 2008, the latter breaking a record that had stood for 90 years. Thus, the most intense portion of the heat wave represented historic conditions for the period.

A consistent UHI occurred during the heat wave period as demonstrated in Figure 2a whereby conditions in the urban core of Oklahoma City were (a) typically 0.5^{o}C warmer during the day, (b) more than 2^{o}C warmer at night and, (c) were consistent with UHI intensities noted by Basara et al. (2008). At the same time, the suburban areas also displayed a warmer signal than the rural areas, especially during the overnight periods where conditions were typically 1.5^{o}C or more warmer.

Prior to the onset of the heat wave period, light precipitation occurred in central Oklahoma on 29 and 30 July. As a result, the combination of the elevated temperatures, local evapotranspiration, and a relatively moist airmass produced elevated heat index values from 31 July through 2 August. The impact of such features can be seen in Figure 2b, which incorporate the UHI intensity analyses from Figure 2a with associated humidity data, collected at the observing sites (i.e., UHI Heat Index). Thus, the result of the increased humidity during the onset of the heat wave period increased the Heat Index dramatically whereby the composite values in the urban core (suburban) were typically 1^{o}C (0.5^{o}C) or more warmer than the rural areas during the day and over 5^{o}C (3^{o}C) warmer at night. Evaluation of the Humidex developed by Conti et al. (2005) further underscores the importance of the elevated humidity combined with elevated temperature values during the onset of the heat wave period. As such, while daytime Humidex values climbed into the "Dangerous" category for six consecutive days (Fig. 3), the greatest Humidex values occurred during the afternoon on 2 August prior to the record breaking heat on 3 and 4 August. However, as the heat wave period progressed, the airmass dried, overall humidity decreased, the UHI Heat Index values decreased and became similar in magnitude to the observed UHI intensity values.

This study also investigated values of relevant apparent temperature computed according to Kalkstein and Valimont (1986; KV86) and apparent temperature by Michelozzi et al. (2007; M07). While the magnitudes of KV86 and M07 differ for the period (the peak values of KV86 tend to be approximately 4^{o}C warmer than M07; not shown), both show similar overall trends during the heat wave period. The values of KV86 and M07 steadily increase from 31 July through the period until reaching a maximum on 5 August. Both analyses demonstrate a consistent pattern whereby urban (suburban) temperature values were approximately 1^{o}C (0.5^{o}C) warmer than the rural areas during the day and 2^{o}C (1^{o}C) or warmer at night.

4. DISCUSSION AND CONCLUSIONS

The purpose of this study was to quantify the impact of the UHI of Oklahoma City during an intense heat wave that occurred in late July and early August 2008. The heat wave period lasted approximately one week and produced record maximum temperature values at the official meteorological observing site for Oklahoma City on 3 and 4 August 2008. Unfortunately, the airport observing site, which is located approximately 10 km to the southwest of the central business district, is not representative of the larger Oklahoma City metropolitan area. This is due to the fact that, while it is located on the rural/suburban interface, the surrounding conditions are mainly rural in land use.

Thus, the approach of this study focused on utilizing composite analyses for urban, suburban, and rural areas using observations from 46 locations comprising Oklahoma City Micronet and Oklahoma Mesonet

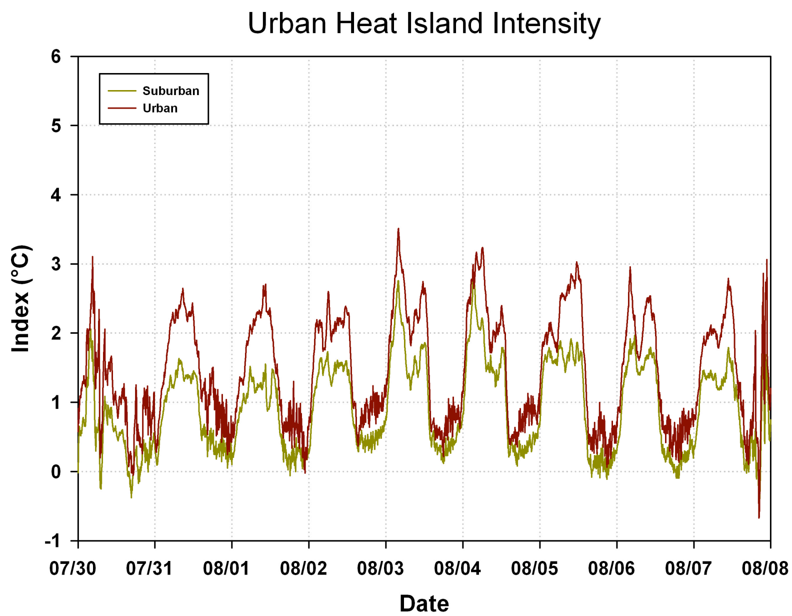

Figure 2a. Composite diurnal values of urban heat island intensity with respect to rural composite values for the urban (red) and suburban (gold) locations.

Figure to be shown during presentation in Phoenix.

Figure 2b. Composite diurnal values of UHI Heat Index with respect to rural composite values for the urban (red) and suburban (gold) locations.

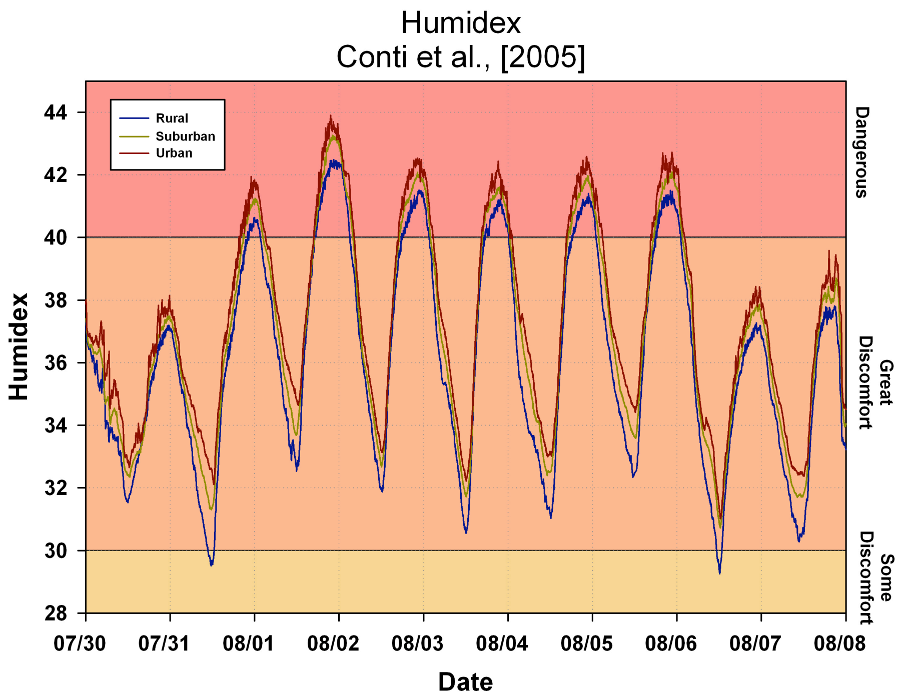

Figure 3. Composite urban (red), suburban (gold), and rural (blue) Humidex values and associated reference categories from 30 July 2008 to 8 August 2008.

stations. The robust composite analyses of temperature and the various formulations of apparent temperature (i.e., heat index, KV86, M07), consistently demonstrated that the urban core of Oklahoma City was warmer than the surrounding rural areas throughout the diurnal cycle and, while not as warm as the urban core, the suburban areas were also warmer than the surrounding rural zones. Thus, from a temperature standpoint, the UHI of Oklahoma City exacerbated an event that, in general, produced historic heat for the period by (a) yielding more intense heat during the daytime and (b) by increasing the minimum temperature values. As such, individuals living in the urban zone experienced increased heat and potential risk for heat related illness.

At the same time, other factors contributed to the overall impact of the urban zone on the heat wave event. Increased ambient humidity at the onset of the heat wave period coupled with the UHI produced large heat index and humidex (Conti et al. 2005) during the beginning of the period. As a result, during the heat wave period, the number of composite minutes that the urban areas experienced temperatures considered “Dangerous” according to the humidex was 3430 compared to 3005 for suburban and 2525 for the rural zones. Further, during the overnight periods spanning 31 July to 2 August, the UHI Heat Index values were considerably warmer than the rural areas. This was likely due, in part, to fact that as the urban areas cooled versus the rural zones, the temperature values in the rural areas cooled sufficiently such that the heat index was negligible from the temperature, regardless of humidity. However, because the urban zone cooled at a slower rate and remained warmer overall, the heat index values remained elevated during the nocturnal period and heat index values were much warmer than the rural areas. As a consequence, while temperature values were somewhat less during the onset of the heat wave period than during the most intense conditions, the UHI impacts combined with the humidity created temperatures in the urban core that “felt” significantly warmer and provided much less relief to individuals living in the environment.

It should be noted that the main limitation to this study is actually one of its main strengths: composite analyses. While concisely illustrating the general differences between urban, suburban, and rural areas during the heat wave period, specific spatial information is not portrayed. However, given the results of this study and new operational capabilities such as the Oklahoma City Micronet, new tools and analysis techniques can be developed and applied in future studies to provide specific heat information at the neighborhood scale for use in more refined public health analyses and mitigation strategies.

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