JP 4.7 Urban Southern California Heat Waves Are Becoming More Frequent and Longer *

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Introduction

Recent deadly heat waves in the western United States in 2006 and 2007 have generated a great deal of attention (Abdollah, 2007). California, known for its mild climate, experienced two consequtivelv deadly heat waves in 2006 and 2007. Hoerling et al. (2007) looked at the 2006 heat waves to determine its most probable cause. Kozlowski and Edwards (2007) analyzed the spatial and temporal variability in the July 2006 heat waves in California, while Maxwell (2007) conducted a similar analysis but focused only on San Diego County. Heat waves lead to excess deaths and this relationship in large U.S. cities has been reviewed by Davis et al. (2004). Global climate models have predicted more intense, more frequent and longer lasting heat waves in North America and Europe in the future 21st Century (Meehl and Tebaldi, 2004). In this present study, we look at the problems involved in defining heat waves and in identifying trends in heat waves in the southern California urban area.

A number of recent studies have focused on the frequency and intensity of extreme weather events (e.g.). Because of the long records available, several studies concentrate on temperature extremes. Among these, are long-term temperature series of local, regional and global surface air temperatures. On a global scale, Jones et al. (1999) found that the Northern Hemisphere has been heating at a rate of 0.5-0.7 ^{o}C since 1860. The possibility exists that this warming is speeding up, Globally, the warmest eight years have occured since 1983 (WMO, 1997). Regional studies, such as ECSN, European Climate Support Network(1995) reviewed surface temperature records spanning much of the 20th Century from one hundred European stations They noted warming from the beginning of the century to the 1940s, a period of stability or even cooling until about 1970, followed by temperature increases up to the present. The ECSN study also found that the 1990s decade was the warmest of the recent temperature records. Similar studies for the southern European area and for the Czech Republic reviewed heat wave frequencies and associated atmospheric conditions (Baldi et al. 2006; Kysely 2002).

Individual temperature records have been studied too.. Many of these long-term series are from cities. The 105-year record of surface temperatures for Athens, Greece, was analyzed for trends in diurnal and seasonal warming patterns (Founda et al. 2004). The authors show that Athens urban centers have temperature warming trends above those of more rural surroundings suggesting an urban heat island effect.. The urban heat island (UHI) is defined by a warmer urban core surrounded by a cooler rural environment (Oke, 1997). Oke (1987) also showed that generally, the UHI increases as population increases, In California, populations of urban centers have increased and consequently these centers have warmed faster than the rest of the state (LaDochy et al. 2007). This pattern seems to be occurring worldwide (Oke 1997).

In this study we examine increasing temperatures trends in southern California, and Los Angeles in particular, over the last 100 years and their impacts on increased heat wave frequency and duration, and decreasing cold spells. Additionally, we study data from Pierce College in the heavily populated San Fernando Valley of metro Los Angeles, to confirm similar trends. No universal definition of what constitutes a heat wave and extreme heat days exists, Therefore, we chose fairly common definitions, which although arbitrary, do reveal significant trends.. Similarly cold spells are defined using a similar arbitrary threshold.

A meteorological definition for heat wave is based on a run of extreme days, where the definition of extreme is linked to the local temperature distribution (Robinson 2001). In the U.S., definitions vary by region, however, a heat wave is usually defined as a period of at least three consecutive days above 90 ^{o}F (32.2 ^{o}C). The National Weather Service issues a heat warning when a maximum heat index exceeds 115 ^{o}F (46.1 ^{o}C) and a minimum of 80 ^{o}F (26.7 ^{o}C) is expected or is occurring (NWS 2008). The heat index uses a formula based on a combination of maximum air temperature and ambient humidity. Often the humidity, rather than the heat alone is responsible for deaths (Posey 1980).

For this study, a heat wave is defined as three consecutive days with temperatures above 90 ^{o}F for the downtown Los Angeles Department of Water & Power (DWP) station. This definition allows us to establish trends in the numbers and duration of heat waves over the last 100 years, This definition also allows us to establish the magnitude of the trend and whether the number of days above our threshold of 90 ^{o}F are increasing? We also look at the trend in the number of occurrences of both heat wave events and days above threshold for DWP. Because minimum temperature is often increasing in cities faster than maximum temperature (Gallo et al 1999), we test the trend in the number of cold days per year, by choosing an arbitrary minimum of 45 ^{o}F (7.2 ^{o}C). These threshold values of 90 and 45 appear to be extreme enough throughout the DWP record so that comparisons can be made. However, these values may not be as extreme in other parts of the

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city. In assessing heat and cold days in the more inland valleys, such as represented by Pierce College, we chose threshold values of 100 °F and 32 °F as extremes. Although arbitrary, there is precedence in the use of these values as measures of heat and cold waves(Robinson 2001) and they do provide data outside at least one standard deviation from the mean.

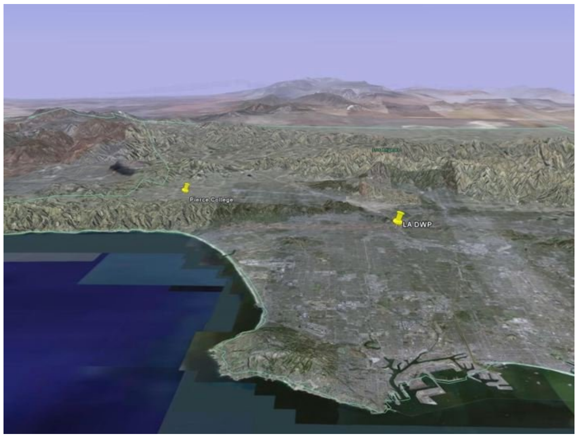

Figure 1: Study Area showing locations of DWP and Pierce College stations from which temperature records were gathered

Data

The analysis presented here relied on data recorded at the Department of Water and Power station in Los Angeles, the official weather station for downtown Los Angeles up until 1999, The data examined consisted of the daily maximum and daily minimum temperatures spanning 1906 to 2006. Except for gaps in data from late 1907 to 1908 and from 1914-1921 these data still provide a 100 year record of Los Angeles climate history. This record allows the establishment of long term trends. The Department of Water and Power was the official weather station of downtown Los Angeles until 1999 when it was then moved to the University of Southern California (USC) campus, away from the downtown core nearly 6 km to the southwest of the DWP location. Patzert et al. (2007) argue that this move has significantly altered the weather readings compare to its original site . This move did not impact the data used in this study because DWP observations are still being collected after the official move. All daily data used for this report is from DWP and extends from 1906-2006. The Department of Water and Power weather station is located in the downtown core at a location that is not impacted by surrounding buildings. l,Additionally, daily maximum and minimum temperature data from 1949 to 2006 were analyzed from Pierce College in the western end of the San Fernando Valley (Figure 1). Pierce College is located in one of the warmest locations in the urban portion of Los Angeles County. On July 22, 2006, the College weather station recorded the highest temperature ever in LA County, 119 °F, at the peak of the July 2006 heat wave.

Results

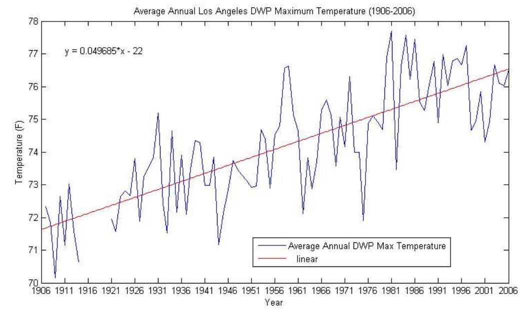

Figure 2: Los Angeles Average Annual Maximum Temperature vs. Year with least fit linear trend line. Graph shows a warming of 5°F per century.

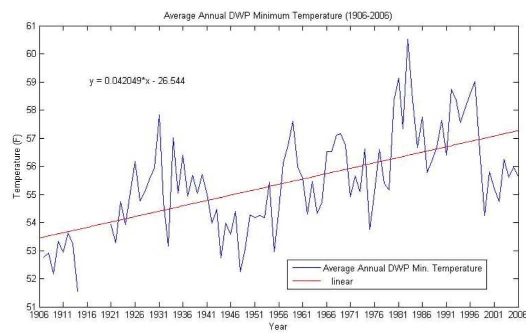

Figure 3: Los Angeles Average Annual Minimum Temperature vs. Year with least squares linear trend line. Annual minimum temperatures have increased about 4.2°F per century.

Analysis of these data revealed that the average annual maximum temperature in Los Angeles is warming by 5.0±0.2 (standard error) degrees F per century (Figure 2). Also the average annual minimum temperature is steadily warming at 4.2±0.1 (standard error) degrees F per century (Figure 3). A month to month breakdown of the data shows that the greatest rate of increase occurred during the summer months with peak increases at June (6.13 °F/century) and July (5.19 °F/century) for maximum temperature, respectively (Figure 4). Summer, with a higher sun and longer daylengths, favors a more intense urban heat island, where the city core is

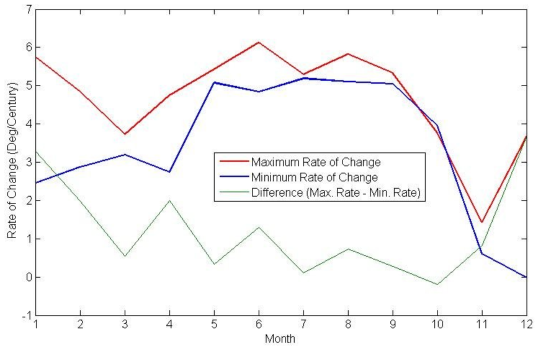

Figure 4: Rate of change at DWP (^{o} F/century) vs. Month.

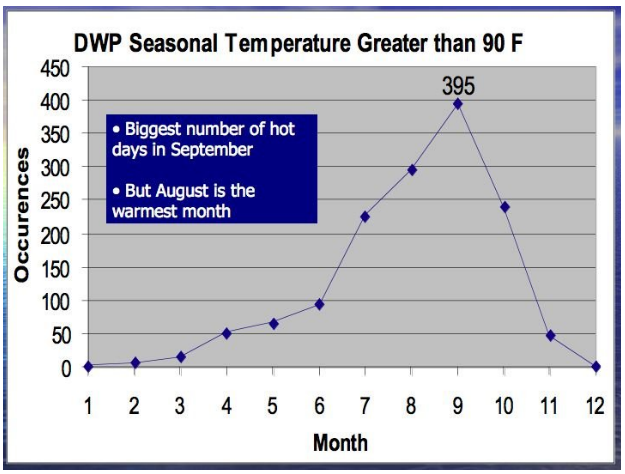

Figure 5: The total number of heat days at DWP by month.

warmer than the rural surroundings (Oke 1995). However, when the number of days with daily maximum temperatures above 90 ^{o}F is shown by month, September temperatures leads by a large margin over August, which happens to be the warmest month on average for DWP (Figure 5). Although most U.S. cities begin cooling in September, west coast cities still have some of their hottest days in early fall as the Pacific SSTs (sea surface temperatures) usually reach their peak at this time and subtropical Pacific high pressure systems tend to stall over the western states also during this time (Bruno and Ryan 2000).

Also, a dramatic increase in heat days and heat waves was observed in the DWP records. We define a heat wave as three or more consecutive days above 90° F. Heat waves increased by 3.09±0.8 (standard error) events per century (Figure 6) and heat days (a single day above 90° F) increased by 22.8±4.7 (standard error) occurrences per century (Figure 7). Cold days, defined as minimum temperature below 45 ^{o}F decreased over the same period by about 9 days. Pierce College also showed increases in heat days (days above 100 ^{o}F) and a decrease in cold days (days below 32 ^{o}F) of nearly 25days and 24 days respectively (Figure 8).

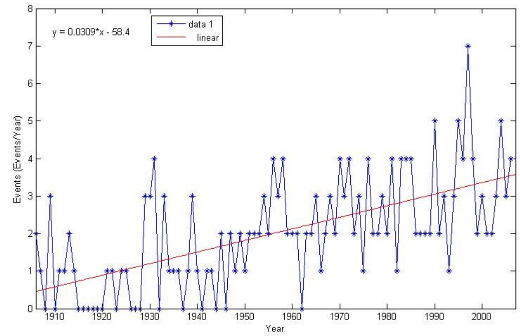

Figure 6: Heat Wave events vs. Year at DWP. Heat wave events are increasing throughout.

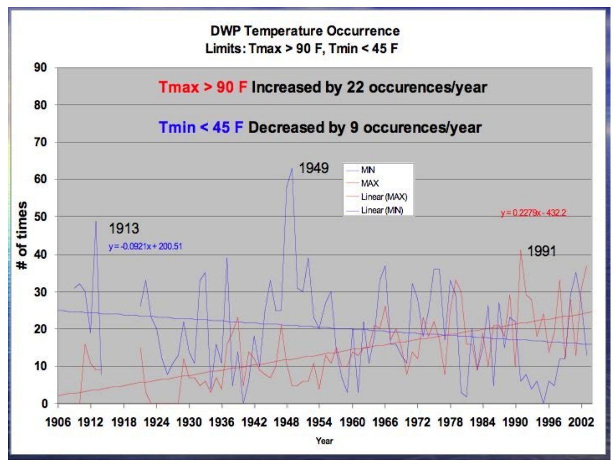

Figure 7: Frequency of heat days and cold days at DWP, 1906-2006.

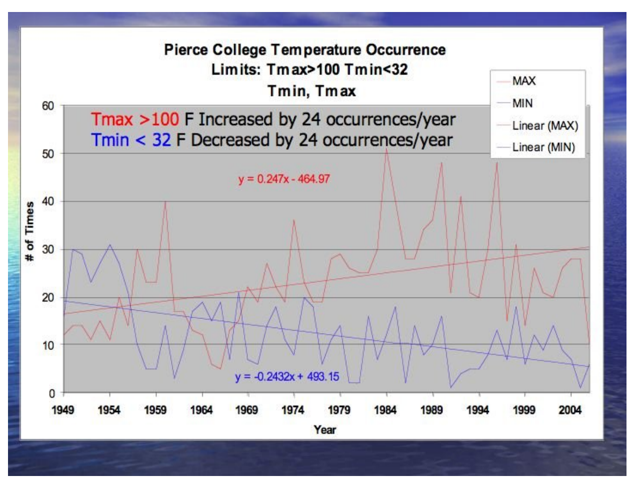

Figure 8: Frequency of heat days and cold days at Pierce College, 1949-2006.

Furthermore, associated with the increase in heat waves is an increase in heat wave duration at DWP (Figure 9). The duration of a heat event is an important factor in deaths as , as found in the Chicago 1995 heat event death toll (Livezey and Tinker 1996). Note in Figure 8 that a heat wave lasting longer than six days occurred regularly after the seventies but was non existent from the start of 1906 to September 1956 when the first 6 day heat wave was recorded. During the July 2006 heat wave, Pierce College in Woodland Hills recorded temperatures of 100 ^{o}F or greater for 21 consecutive days, which is the longest such heat streak since records began there in 1949 (Kozlowski and Edwards 2007). In their study of western European heat waves from 1880 to 2003, Della-Marta et al. (2007a,b) found that the duration of summer heat waves had doubled and the frequency of hot days had nearly tripled.

Discussion

Because of its location Los Angeles experiences mild winters and hot summer weather. However, due to urbanization Los Angeles has been steadily warming. According to the United States Census (2007), the population in Los Angeles in 1910 was 319,198. That number has jumped by about 12 times to a staggering 3,844,829 in 2005. The heating of Los Angeles due to urbanization is called the urban heat island effect. Mostly occurring in metropolitan areas, the heat island effect can increase the the urban air temperature by 2-10 degrees F when compared to the surrounding country side (Landsberg 1981). Several causes lead to an urban heat island. With increasing population comes increased demands for buildings and roads. Landscape is also converted from natural settings to concrete and asphalt. Because concrete and asphalt have different heat properties than grass and trees, more thermal radiation is absorbed and released slowly by these structures than natural surfaces causing hotter air around them. The same radiative effect applies to the increase in night time temperature. Since elements of urban development are able to store more heat, long after the sun goes down these buildings and roads slowly emit their thermal radiation into the night air (Oke 1987). Although the urban heat island effect is considered to be the greatest contributor of the gradual heating in Los Angeles, global warming plays a small role as well. Since the global average temperature has increased by about 1.3 degrees F (0.74 ^{o}C) in the last century (IPCC 2007), This global temperature increase represents only 26.5% of the overall heating in Los Angeles.

Los Angeles Heat Waves and Extreme Heat Days

One direct consequence of warming temperatures in Los Angeles is the more frequent occurrences of heat waves and extreme heat days. For this paper a valid heat wave is defined as three or more consecutive days above 90 ^{o}F and an extreme heat day is defined as a single day above 90 ^{o}F. According to these data heat waves have increased by 3.09 events a century (Figure 6). Notice that the year of 1997 set the Los Angeles climate history record with seven events, with the longest event lasting seven days .. Data analysis, data also shows an increase in heat wave duration (Figure 9). Important to note are the two 13 day long heat waves on August-12-1983 and August-29-1995. Also, note the increased density of the dots as time increases for almost all durations. For example, four day event is rare in the early part of the data, but these events become more common in the more recent data,; hence, the increased dot density which correspond to increased heat wave duration. Along with heat waves, heat days have increase by a staggering 22.8 occurrences a century (Figure 5). Also, extreme cold days (blue line), shows some decline.

The Effect on Population

Surely, if these climatic trends in Los Angeles continue then residents will suffer harsh consequences. As heat waves become more common, people susceptible to hyperthermia will be at greater risk. Hyperthermia occurs when one's body absorbs more heat than it can dissipate causing life-threatening situations. Since the night time temperature is increasing heat waves will become more brutal as the relief of cold night time temperature become less profound. As indicated previously, our data increased durations of heat wave. Therefore, Los Angeles resident should expect to see more heat waves, which will last longer, paired with ever increasing night time temperatures. Research by Davis et al. (2004) shows that excess heat-related deaths have declined in major U.S. urban areas as a whole implying that people have better adapted to heat waves through technology and increased vigilance by public relief organizations. There is no data to show that Californians have thus adapted.

Changing climatic trends mean that the Department of Water and Power will be working full force to provide much needed water and electricity to the millions of people living in southern California. Excess strain on the water and electrical systems result in rolling black outs which in turn lead to a more greatly stressed population. As dry air from Santa Ana winds,, a Foehn like wind, combine with the increasing warm temperature in Los Angeles, wild fires may become a more common disaster. Wild fires that normally occur mostly in fall at the end of the dry season occurred throughout the 2007 year; which is quite unusual.

Economically, heat waves affect more than health and power outages. The July 2006 heat wave also impacted the agricultural industry. The diary industry alone estimated losses at nearly $1 billion as cows do not produce enough milk, or in some cases die from heat (Wright 2006). But heat waves are lethal to humans too. The 1980 heat wave in the south central plains resulted in nearly 1300 deaths and a total loss of about $16 billion, in 1980 dollars (Karl and Quayle 1981).

Conclusion

This study explores the changes in Los Angeles temperature using hourly and daily records from different weather stations in Southern California. Analysis of the data revealed the following:

1. The average annual Los Angeles maximum temperature is heating up by 5.0±0.2 (standard error) degrees F. per century and the average annual minimum temperature is heating up by 4.2±0.1 (standard error) degrees F. per century. This warming is caused by the urban heat island effect and, minimally, atmospheric global warming.
2. Los Angeles is experiencing more heat waves, an event defined by 3 consecutive days above 90 degrees F, and also more extreme heat days, defined as days above 90 degrees F. These numbers have increased by 3.09±0.8 per century and 22.8±4.7 per century occurrences, respectively. Both are a direct consequence of the steady heating of Los Angeles. Cold events may be decreasing.
3. The duration of heat wave events is also increasing, which increases the impact of events.

These changes in Los Angeles climate will surly become a problem for residents of Los Angeles. Higher risk of heat related deaths and more strain on water, power and agriculture may result as a direct consequence of rising Los Angeles temperatures.

Acknowledgements

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