Heat Waves in Southern California: Are They Becoming More Frequent and Longer Lasting?

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ABSTRACT

Los Angeles is experiencing more heat waves and also more extreme heat days. These numbers have increased by over 3 heat waves per century and nearly 23 days per century occurrences, respectively. Both have more than tripled over the past 100 years as a consequence of the steady warming of Los Angeles. Our research explores the daily maximum and minimum temperatures from 1906 to 2006 recorded by the Department of Water and Power (DWP) downtown station and Pierce College, a suburban valley location. The average annual maximum temperature in Los Angeles has warmed by 5.0°F (2.8°C), while the average annual minimum temperature has warmed by 4.2°F (2.3°C). The greatest rate of change was during the summer months for both maximum and minimum temperature, with late fall and early winter having the least rates of change. There was also an increase in heat wave duration. Heat waves lasting longer than six days occurred regularly after the 1970s but were nonexistent from the start of 1906 until 1956, when the first six-day heat wave was recorded. While heat days have increased dramatically in the past century, cold days, where minimum temperature is below 45°F (7.2°C), show a slight decreasing trend. Recent deadly heat waves in the western United States have generated increasing electricity demands. In light of the electricity response to recent extreme-heat events, such as July 2006 heat waves in California, Missouri and New York, these results suggest the future increase in peak electricity demand will challenge current transmission and supply methods as well as future supply capacities when population and income growth are taken into account.

Recent deadly heat waves in the western United States have generated a great deal of attention (Abdollah 2007). California, better known for its mild climate, experienced two deadly heat waves in a row. Hoerling et al. (2007) looked at the 2006 heat waves to determine the most probable cause. Kozlowski and Edwards (2007) analyzed the spatial and temporal variability in the July 2006 heat waves in California, while Maxwell (2007) did the same for San Diego County. The relationship between heat waves and excess deaths 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 (Meehl and Tebaldi). 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. 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 temperature. On a global scale, Jones et al. (1999) found that the Northern Hemisphere has been heating at a rate of 0.5–0.7°C since 1860. And the possibility is that this warming is speeding up; the warmest eight years globally have taken place since 1983 (WMO 1997). Regional studies, such as ECSN (1995) looked at surface temperatures from 100 European stations over much of the 20th century. They noted warming from the beginning of the century to the 1940s, a period of stability or even cooling until about 1970, followed by increases up to the present. ESCN also found that the decade of the 1990s was the warmest of the recent temperature records. Similar studies for the southern European area and for the Czech Republic look at heat wave frequencies and the atmospheric conditions that are associated with them (Baldi et al. 2006; Kysely 2002).

Individual temperature records have been studied to show trends and variations in many parts of the world, with many of these long-term series being from cities. The 105-year record of surface temperatures for Athens, Greece, has been analyzed for trends in diurnal and seasonal warming patterns (Founda et al. 2004). The findings show that urban centers have temperature warming trends above those of more rural surroundings. Oke (1987) has found that Urban Heat Island temperatures in general increase as population increases. In California, urban centers have warmed faster than the rest of the state (LaDochy et al. 2007), a pattern that seems to be occurring worldwide (Oke 1997). Our study explores how increasing temperatures over the past 100 years in southern California, and Los Angeles in particular, has led to an increase in heat wave frequency and duration, and that cold spells have decreased. Additionally, we look at data from Pierce College in the heavily populated San Fernando Valley of metropolitan Los Angeles, to see whether similar trends exist.

As there is no universal definition of what constitutes a heat wave and extreme heat days, we chose definitions commonly used in climate research for our own definitions. Although these definitions are arbitrary, they can be used to show trends. Cold spells are defined using a similarly arbitrary, but commonly used, threshold. While there is no universal definition of a heat wave, a meteorological definition can be developed based on a run of extreme days, where the definition of extreme is linked to the local temperature distribution (Robinson 2001). In the United States, definitions vary by region, but a heat wave can be defined most commonly as a period of at least three consecutive days above 90°F (32.2°C). For our study, a heat wave is defined as three consecutive days with temperatures above 90°F as recorded at the downtown Department of Water and Power (DWP) station. It is our intention to discover whether there is a trend in the number of heat waves and the duration of heat waves over the past 100 years and, if so, what the magnitude of the trend is. In addition, we want to uncover any change in the number of days above our threshold of 90°F. Thus, we look at the trend in the number of occurrences of both heat wave events and days above 90°F threshold for DWP. Since 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°F (7.2°C). These threshold values of 90 and 45 appear to be extreme enough throughout the DWP record that comparisons can be made. However, these values may not be extreme in other parts of the city. In assessing heat and cold days in the more inland valleys, such as Pierce College, we chose threshold values of 100°F and 32°F as extremes. Although these values are arbitrary, there is precedence in weather records to use them as measures of heat and cold waves, and they do provide data outside at least one standard deviation from the mean.

Our calculations used data recorded at the Department of Water and Power in Los Angeles, the official weather station for downtown Los Angeles until 1999, consisting of the daily maximum and the daily minimum temperatures spanning from 1906 to 2006. Except for some missing data from late 1907 to 1908 and a large gap from 1914 to 1921, these records still provide a 100-year record of Los Angeles climate history, making possible the discovery of any 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 and nearly four miles to the southwest of the

DWP location. It has been argued that this move has significantly altered the weather readings from its original site (Patzert et al. 2007). However, this move did not impact the data used in this study because DWP observations are still being collected even after the official move to USC. All of the data used from 1906 to 2006 is from DWP and does not include any data from USC. The Department of Water and Power weather station is located in the downtown core at a location that is not impacted by surrounding buildings. For purposes of comparison, 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 situated in one of the warmest locations in the urban portion of Los Angeles County and recorded the highest temperature ever in LA County, 119°F, at the peak of the July 2006 heat wave.

Figure 1.

When these data were analyzed, it became evident that the average annual maximum temperature in Los Angeles was indeed warming by 5.0±0.2 (standard error) degrees F over the 100-year period (Figure 2). The average annual minimum temperature is also

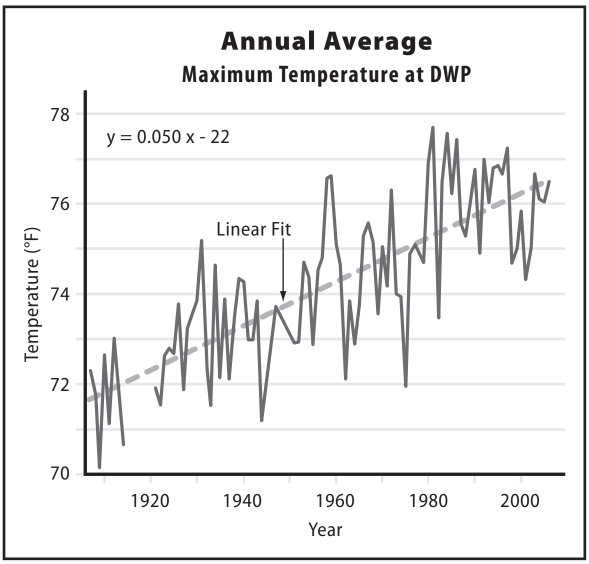
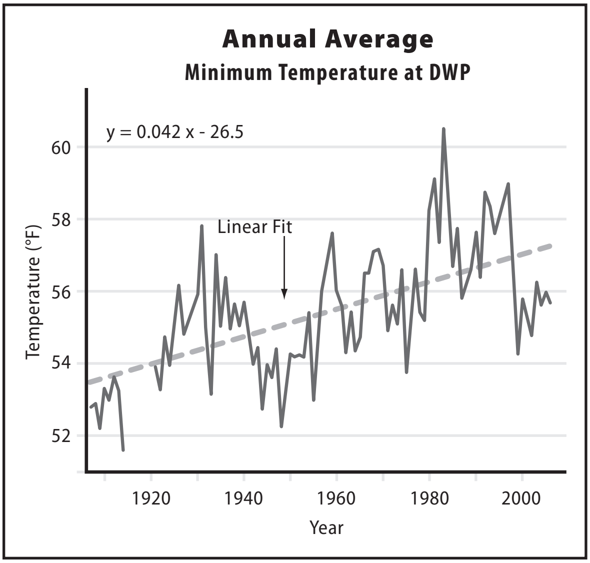


Figure 2.



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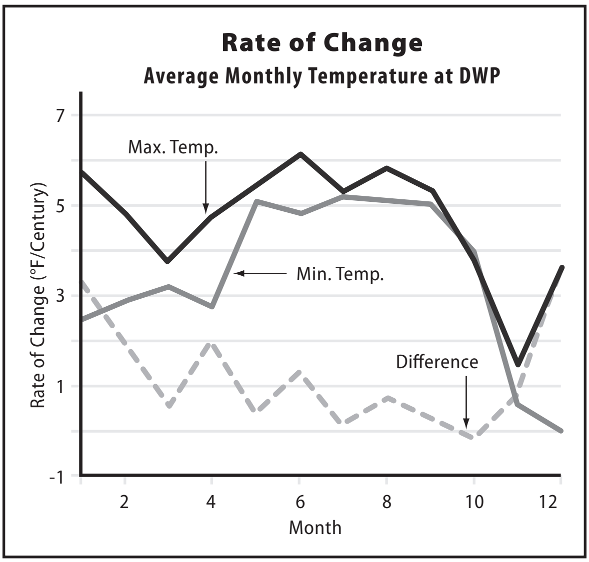
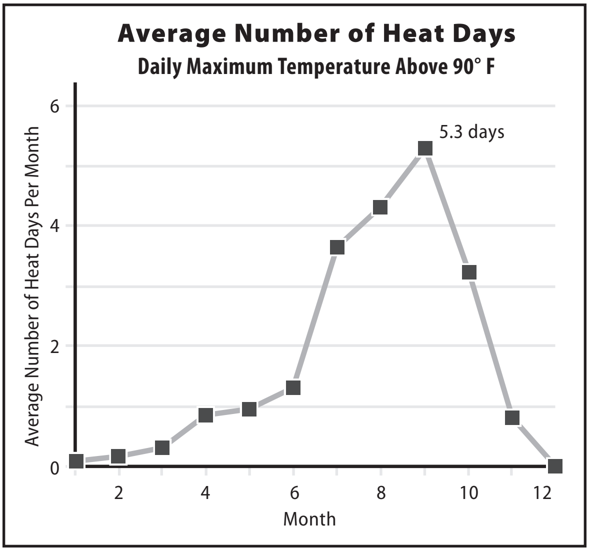


Figure 4.

steadily warming at 4.2±0.1 degrees F per century (Figure 3). When the 100-year data was broken down by months, it became noticeable that the greatest rate of increase was during the summer months with peaks in June (6.13°F) and July (5.19°F) for maximum temperature (Figure 4). However, when the number of days with daily maximum temperatures above 90°F is shown by month, September leads by a far 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 Sea Surface Temperatures usually reach their peak at this time and subtropical Pacific high-pressure systems tend to stall over the western states (Bruno and Ryan 2000).



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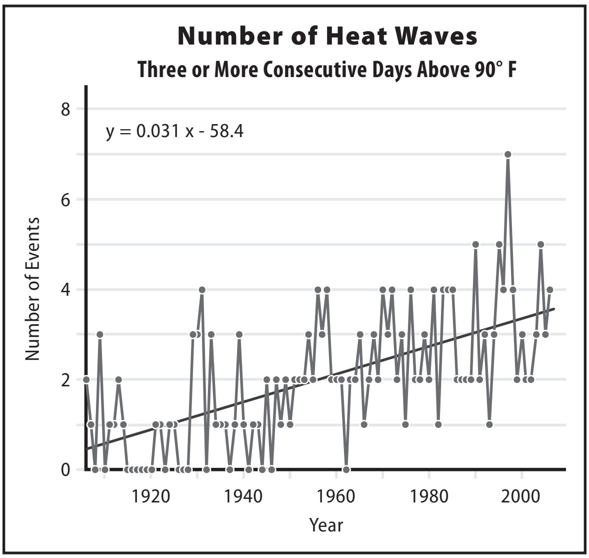
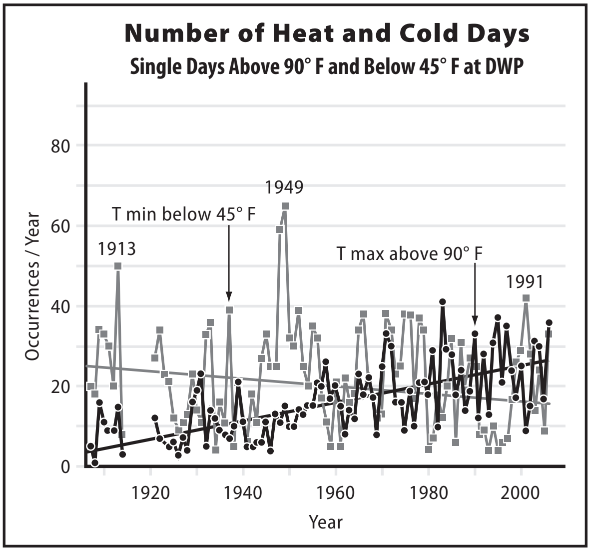


Figure 6.

A dramatic increase in heat days and heat waves was observed at DWP (a heat wave is defined as three or more consecutive days above 90°F). Heat waves increased by 3.09±0.8 events over the 100-year period (Figure 6) and heat days (a single day above 90°F) increased by 22.8±4.7 (Figure 7). Cold days, defined here as minimum temperature below 45°F, decreased over the same period by about 9 days. Pierce College also showed increases in heat days (days above 100°F) and a decrease in cold days (days below 32°F) of nearly 25 days and 24 days, respectively (Figure 8). Furthermore, along with the increase in heat waves there was an increase in heat wave duration at DWP (Figure 9). Duration of a heat event is an important factor in its impact, and heat waves lasting longer than 6 days occurred regularly after the 1970s but were nonexistent from 1906 until September 1956, when the first 6-day heat wave was recorded. During the July 2006 heat



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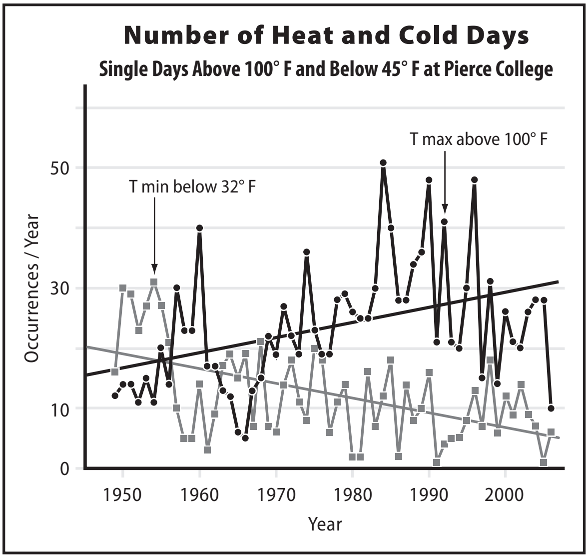

Figure 8.

wave, Pierce College recorded temperatures of 100°F or greater for 21 consecutive days, the longest such heat streak since records began there in 1949 (Kozlowski and Edwards 2007).

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, the population in Los Angeles in 1910 was 319,198. By 2005 that number had jumped to a staggering 3,844,829. The heating of Los Angeles can be attributed to the urban heat island effect. Mostly occurring in metropolitan areas, the heat island can increase the temperature of the urban air by 2 to 10 degrees F when compared to the surrounding countryside (Landsberg 1981). There are several causes of an urban heat island. The more the population increases in a city, the more the demand for buildings and roads and the more landscape is converted from natural settings to

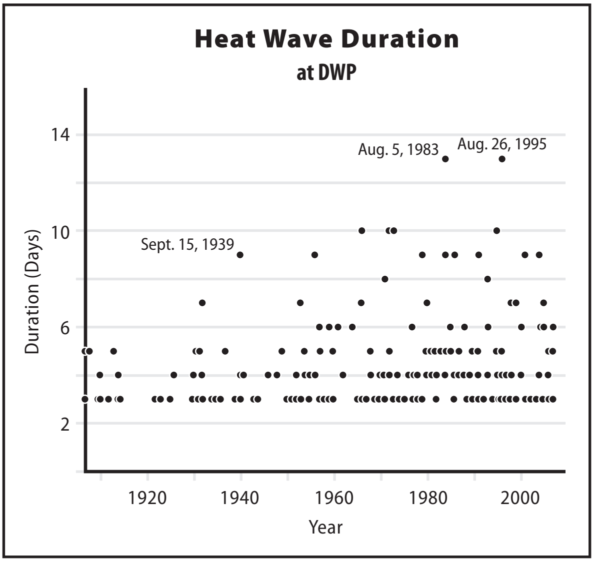

Figure 9.

concrete and asphalt. Since concrete and asphalt have different heat properties than grass and trees, more thermal radiation is absorbed and released slowly by these structures, thereby warming the surrounding air. The same applies to the increase in nighttime temperatures. Elements of urban development are able to store more heat, and at night these buildings and roads slowly emit their thermal radiation into the night air (Oke 1987). Although the urban heat island effect can be considered the greatest contributor to the gradual heating in Los Angeles, global warming does play a role. The global average temperature has increased by about 1.3 degrees F (0.74°C) in the past century (IPCC 2007), so we conclude that global warming contributes about 26.5 percent to the overall gradual heating occurring in Los Angeles.

A direct consequence of warming temperatures in Los Angeles is more frequent occurrences of heat waves and extreme heat days. We define a heat wave as three or more consecutive days above 90°F and an extreme heat day as a single day above 90°F. Thus, according to the data, heat waves have increased by 3.09 events per year over the 100-year period (Figure 6). In 1997 there were seven such events, with the longest event lasting a week. A close look at the data leads us to conclude that the duration of heat waves is increasing as well; in fact, the records show an increase in heat wave duration (Figure 9). Indeed, there were two 13-day-long heat waves, one beginning on August 12, 1983, and the other on August 25, 1995. Along with heat waves, heat days have increased by a staggering 22.8 occurrences per year over the 100-year study period (Figure 5). Also, cold days, where the high temperature is below 45°F, decline over the study period; minimum temperatures at DWP actually increased about 2.4°F during the period of record for heat waves alone.

Conclusion

Our study explores the changes in Los Angeles temperatures using hourly and daily records from different weather stations in southern California. Our analysis of the data revealed the following:

1. The average annual Los Angeles maximum temperature has heated up by 5.0±0.2 degrees F over the 100-year study period, and the average annual minimum temperature has increased by 4.2±0.1 degrees F over the same period. We attribute this warming to the urban heat island effect and, to a smaller degree, atmospheric global warming.
2. Los Angeles is experiencing more heat waves (periods of three consecutive days above 90 degrees F) and also more extreme heat days (days above 90 degrees F). These numbers have increased by 3.09±0.8 and 22.8±4.7 occurrences over the study period, respectively. Both are a direct consequence of the steady heating of Los Angeles. There is also some evidence that cold events may be decreasing.
3. The duration of heat wave events is also increasing.

These changes in Los Angeles climate will surely become a problem for residents of the city. A higher risk of heat-related deaths, an increase in wildfires, and more strain on water, power, and agriculture may be direct consequences of the rising Los Angeles temperatures.

Acknowledgments

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References Cited

Abdollah, T. 2007. "L.A. County heat wave toll now 18." *L.A. Times*, Sept. 7, 2007. Available at: http://www.latimes.com/news/local/la-me-deaths7sep07,1,2578917.story?coll=la-headlines-california

Baldi, M., G. Dalu, G. Maracchi, M. Pasqui, and F. Cesarone. 2006. "Heat waves in the Mediterranean: a local feature or a larger-scale effect?" *International Journal of Climatology* 26:1477–1487.

Bruno, D. and G. Ryan. 2000. *Climate of Los Angeles, California*. NOAA Tech Memo, NWS WR-261, Western Region, Salt Lake City, Utah.

Davis, R. E., P. C. Knappenberger, P. J. Michaels, and W. M. Novicoff. 2004. "Changing heat wave mortality in the United States." *Environmental Health Perspectives* 111:1712–1718.

European Climate Support Network (ECSN). 1995. *Climate of Europe: Recent Variation, Present State and Future Prospects*. KNMI, De Bilt.

Founda, D., K. H. Papadopoulos, M. Petrakis, C. Giannakopoulos, and P. Good. 2004. "Analysis of mean, maximum, and minimum temperature in Athens from 1897 to 2001 with emphasis on the last decade: trends, warm events, and cold events." *Global and Planetary Change* 44:27–38.

Gallo, K. P., T. W. Owen, D. R. Easterling, and P. F. Jamason. 1999. "Temperature trends of the US Historical Climatology Network based on satellite-designated land use/land cover." *Journal of Climatology* 12:1344–1348.

Hoerling, M., J. Eischeid, X. Quan, and T. Xu. 2007. "Explaining the record U.S. warmth of 2006." *Geophys Res Lett* 34, L17704, doi:10.1029/2007GL030343.

Intergovernmental Panel on Climate Change. 2007. *Climate Change 2007: The Physical Science Basis*. Cambridge, UK: Cambridge University Press.

Jones, P. D., E. B. Horton, C. K. Folland, M. Hulme, D. E. Parker, and T. A. Basnett. 1999. "The use of indices to identify changes in climatic extremes." *Climatic Change* 42:131–149.

Kozlowski, D. R. and L. M. Edwards. 2007. *An analysis and summary of the July 2006 record-breaking heat wave across the state of California*. NOAA Western Regional Tech Attach, No. 07-05 (February 27, 2007), Salt Lake City, Utah.

Kysely, J. 2002. "Temporal fluctuations in heat waves at Prague-Klementinum, the Czech Republic, from 1901–97, and their relationships to atmospheric circulation." *International Journal of Climatology* 22:33–50.

Maxwell, B. 2007. *Analysis of the 22–23 July 2006 extreme heat in San Diego County*. NOAA Western Region Tech Attach, No. 07-04 (January 23, 2007), Salt Lake City, Utah.

Meehl, G. A. and C. Tebaldi. 2004. "More intense, more frequent, and longer lasting heat waves in the 21st Century." *Science* 305:994–997.

Oke, T. M. 1995. "The heat island of the urban boundary layer: characteristics, causes and effects." In *Wind Climate in Cities*. Cermak, J. E., A. G. Davenport, E. J. Plate, and D. X. Viegas (eds), Dordrecht: Kluwer Academic, 81–107.

———. 1987. *Boundary Layer Climatology*. London: Methuen.

Patzert, W. C., S. LaDochy, J. K. Willis, and T. Mardirosian. 2007. "Will the real Los Angeles stand up: Impacts of a weather station relocation on climatic records (and record weather)." *16th Conference on Applied Climatology, AMS Annual Meet*. Available at: http://ams.confex.com/ams/87ANNUAL/16Applied/papers/index.cgi?username=119064&password=355783

Robinson, P. J. 2001. "On the definition of a heat wave." *Journal of Applied Meteorology* 40:762–775.

WMO. 1997. *WMO Statement on the Status of the Global Climate in 1996*. WMO No. 858. Geneva: World Meteorological Organization.