HISTORICAL TEMPERATURE TRENDS IN LOS ANGELES COUNTY, CALIFORNIA

By

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DEDICATION

I would like to dedicate my thesis to my family and more specifically to my wife. Christa has taken on a lot of extra burden because a lot of my time is spent on my schoolwork and she has always supported me in completing my master's degree. For this motivation and support, I could not be more thankful. Also, a special thanks goes to my wonderful and loving parents, Robert and Judy Reed. My Dad has always been an excellent role model because he instilled within me a hard-work ethic, to always reach for your dreams, and to always do the best that I can. Even though my Mom is not here to experience this life achievement and her death leaves an unexplainable emptiness in my heart, it is comforting to know that she is my angel watching over me and is always guiding me in the right direction.

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A special thanks is owed to my best friend and wife, Christa, who has always made keep pushing even when I was ready to throw in the towel, and to my parents who always put my best interests before their needs. I love you three more than you will ever know!

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LIST OF ABBREVIATIONS

C2ES	Center for Climate and Energy Solutions
CNV	California-Nevada Region
COOP	National Weather Service Cooperative Network
CSV	Comma-Separated Value
DWR	Department of Water Resources
GISS	NASA Goddard Institute for Space Studies
IPCC	Intergovernmental Panel on Climate Change
JMA	Japanese Meteorological Agency
km	Kilometer
LAX	Los Angeles International Airport
MOHC	Met Office Hadley Centre/Climatic Research Unit
NASA	National Aeronautics and Space Administration
NCDC	National Climatic Data Center
NOAA	National Oceanic and Atmospheric Administration
OEHHA	Office of Environmental Health Hazard Assessment
PCM	Parallel Climate Model
PRISM	Parameter-elevation Regressions on Independent Slopes Model
R^2	Coefficient of Determination
RSS	Remote Sensing Systems
T1	Temperature Threshold 1
T2	Temperature Threshold 2

UAH	University of Alabama-Huntsville
UCLA	University of California-Los Angeles
USC	University of Southern California
USHCN	US Historical Climate Network
WMO	World Meteorological Organization
WRCC	Western Regional Climate Center

ABSTRACT

Climate change is a global occurrence and is studied at multiple scales within Los Angeles County, California. Determining the type of surface temperature trend across Los Angeles County is best observed using historical daily, monthly, and yearly temperature data. Each type of historical temperature data is analyzed for various temperature and extreme temperature threshold trends: (1) thresholds of frost days (minimum temperature ≤ 32°F), misery days (maximum temperature ≥ 90°F), and heat wave events are examined at six weather stations; (2) type of linear trend is measured for monthly surface temperature at eight weather stations; and (3) type of linear trend is analyzed for yearly surface temperature and yearly summer surface temperature (July to September) for twenty weather stations from 1931 to 1950 and six weather stations from 1951 to 2010.

This study's major findings are (1) daily maximum and minimum surface temperature show strong departures from normal conditions for threshold temperature trends as Palmdale experiences an accelerated warming trend and Sandberg experiences an accelerated cooling trend; (2) a variance in decadal heat wave thresholds exists at each weather station for 80 years; (3) monthly mean surface temperature is a good source to reflect seasonal temperature variations; and (4) yearly surface temperature is not sufficient temperature data to track temperature trends. Analyzing surface temperature trends is a tool for monitoring how climate change is impacting temperatures globally.

The following chapters include: (1) introduction is the motivation and research questions; (2) literature review is previous studies on climate change and its impact on temperature; (3) data and methods are data sources and the implementation of these

sources; (4) results offer a detailed explanation and examples of the findings; (5) discussion is an overview of the important findings; and (6) references are sources that are cited within the manuscript.

CHAPTER ONE: INTRODUCTION

Numerous studies and agencies (International Panel on Climate Change 2007; National Aeronautic and Space Administration (NASA) 2014a; United States Environmental Protection Agency 2014; Office of Environmental Health Hazard Assessment 2014) have investigated climate systems from the local to global scales of analysis. Climate data can play a very important role in monitoring and predicting climate change by providing valuable temperature measurements across the globe. These valuable temperature measurements (observed, anomaly, and projected) serve as the primary source for discovering how temperature is changing at various global locations. Chapter one introduces examples of climate change at these various scales as well as population growth and its influence. Also, this chapter states the research questions for the study at hand.

1.1 Measuring Climate Change

Climate change and its effect on environmental, economic, and social issues is a debated topic throughout the public and government domain. There are numerous scientific organizations dedicated to understanding climate change and its effects. For instance, the Pew Center on Global Climate Change (now known as the Center for Climate and Energy Solutions (C2ES)), World Meteorological Organization (WMO), and the International Panel on Climate Change (IPCC) (State of California 2011) provide information about climate change and its impact on the world through several approaches.

These approaches include: (1) nonpartisan opinions about climate change (C2ES 2014); (2) the framework for global scale cooperation for meteorology and climate (WMO 2014); and (3) assessing the current status of climate change (IPCC 2014). Additionally, there are thousands of climate scientists throughout the world who are studying the cause and effect relationship of climate change. More specifically, the concern for this study is the effect on temperature due to climate change and ninety-seven percent of these scientists indicate that humans are impacting the global climate change (Anderegg et al. 2010, Doran et al. 2009, and Oreskes 2004).

The rise in global surface temperature anomaly (°C) is depicted in Figure 1 and is based on the results from four scientific institutions: NASA Goddard Institute for Space Studies (GISS), Met Office Hadley Centre/Climatic Research Unit (MOHC), NOAA National Climatic Data Center (NCDC), and the Japanese Meteorological Agency (JMA). An anomaly is the current climate variable's departure from average conditions for a particular place over a specific time period. Actual temperature observations from 1880 to the late 1930's for all four institutions demonstrate a cooling trend with temperatures at the greatest nearly -0.55°C below average temperatures. Additionally, the maximum temperature anomaly occurred since the late 1970's with an increase of nearly 0.65°C and the observed temperatures are greater than the average temperature for all four institutions since the late 1970's. This steady increase in temperature is unforeseen since 1880 and therefore is evidence of a changing climate. The following subchapters offer greater detail covering temperature trends at the global and local scale.

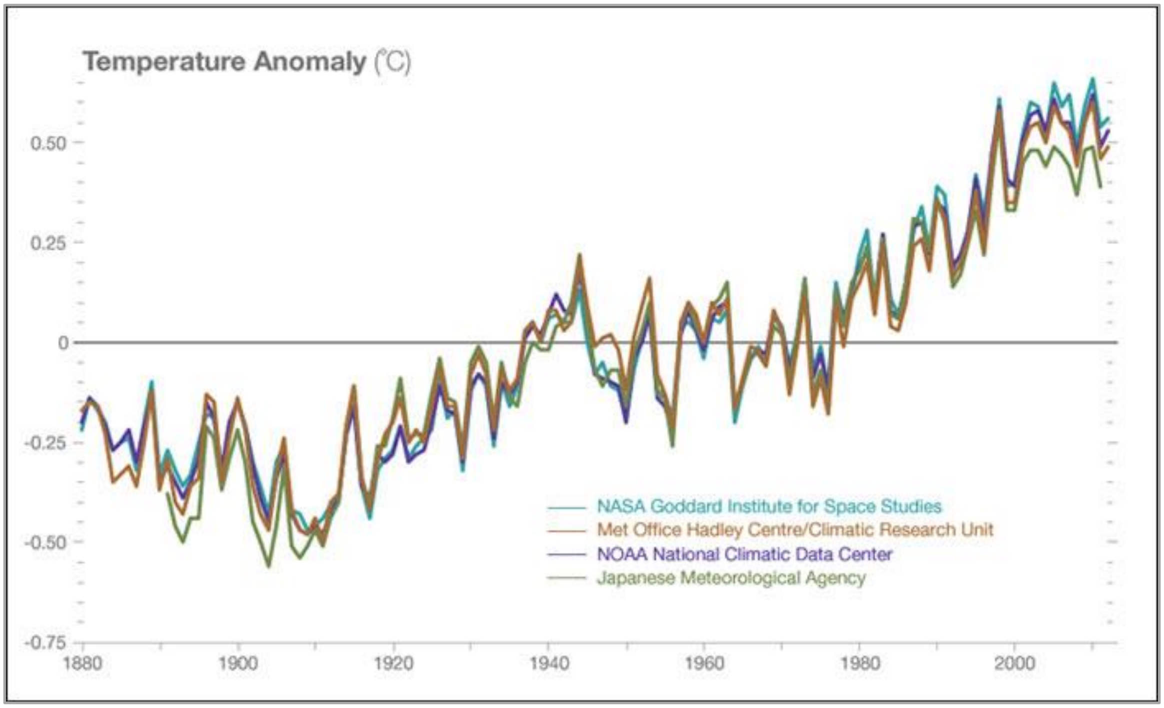

Figure 1: Global surface temperature anomaly (°C) for four worldwide scientific institutions from 1880-2020. These anomalies show a dramatic increase in temperature since 1980.
Source: National Aeronautic and Space Administration (http://climate.nasa.gov/scientific-consensus)

1.1.1 Climate Change across the World

According to the IPCC's Fourth Assessment Report (2007), global temperature is expected to rise from 2.5°F to 10°F over the next 100 years with projected changes at various locations: 1) tropical rainforests will be replaced with savannah in the eastern Amazon; 2) millions in Africa will suffer from increased water stress; 3) decrease in western North American mountain snowpack; 4) flash flooding increased in Europe; and 5) increased flooding along the Asian coastline. The positive or negative response to climate change, such as the five listed above, is solely dependent upon the characteristics of the individual species and ecosystems (Beaumont et al. 2011).

Global temperatures are increasing at a pace that does not seem to be slowing down and is further clarified by NASA's observation that "nine of the ten warmest years have occurred since 1998" (NASA 2014b). This statement is visually explained in Figure 2 where the graph measures temperature anomaly from 1901-2013 in degree Fahrenheit and shows that a fluctuation in negative and positive temperature anomalies occur until the late 1970's where only positive anomalies occur from this point forward. These positive anomalies indicate that temperatures have been increasing since 1901. This warming trend is further evident in the year 2012 as the ninth warmest global average surface temperature since 1880 was recorded (NASA 2014b). A study by Hansen et al. (2006), show global surface temperature has increased by approximately 0.2°C per year within the last three decades which is the expected warming determined by the 2007 IPCC's Fourth Assessment Report. Figure 3 shows that global surface temperature will nearly quadruple with estimated temperatures of 1 to 1.5°F in 2020 to 4.5 to 7.5°F in 2099 (2007). Furthermore, scientific evidence shows that the probability is less than 5 percent that the increase in global surface temperature is caused by anything other than anthropogenic climate change (greenhouse gas forcing) as compared to internal climate variability (IPCC 2007).

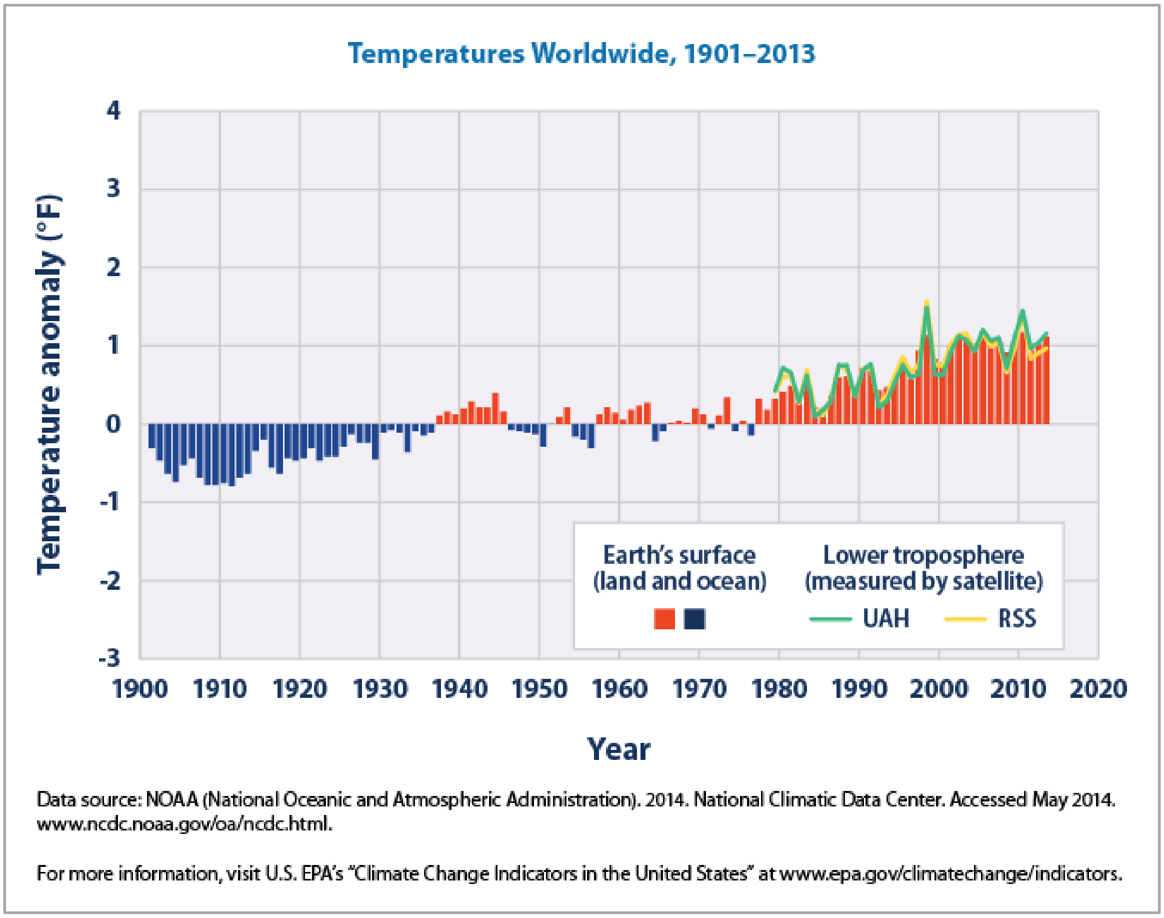

Figure 2: Global surface temperature anomaly (°F) from 1901-2013. The bar graph depicts actual temperature measurements with a positive (red) temperature anomaly or a negative (blue) temperature anomaly. The linear trend line represents satellite measurements in the lower troposphere and analyzed by two different groups: University of Alabama-Huntsville (UAH) and Remote Sensing Systems (RSS).
Source: United States Environmental Protection Agency (www.ncdc.noaa.gov/oa/ncdc.html)

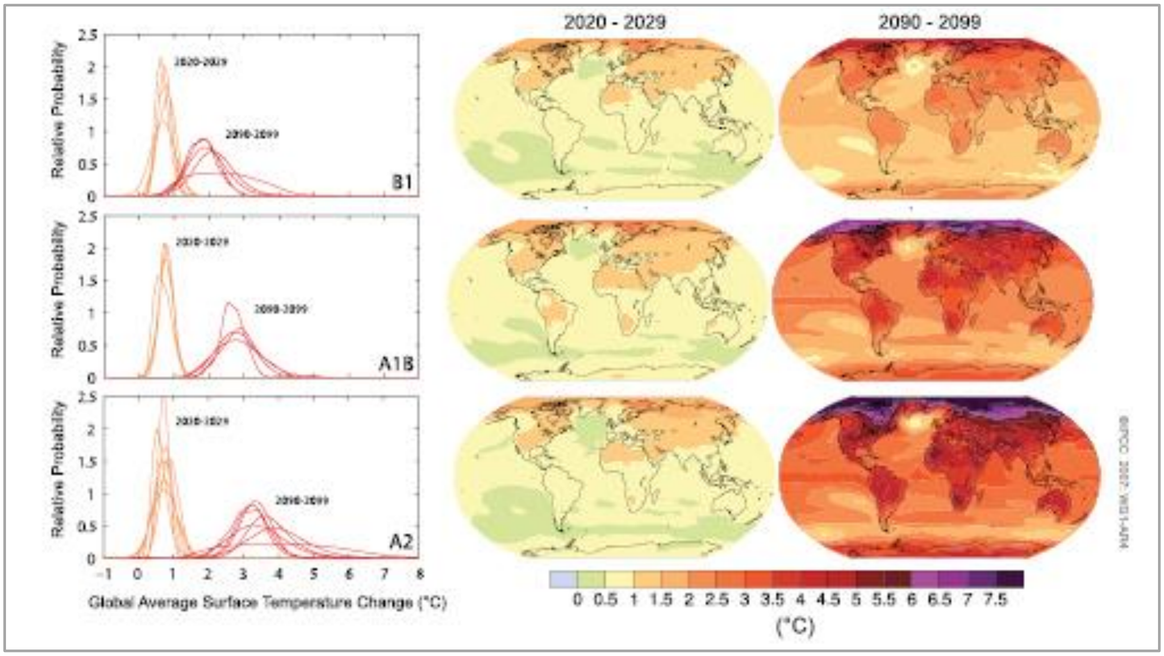

Figure 3 Global average surface temperature (°C) projections for 2020-2029 and 2090-2099.
Source: International Panel on Climate Change
(http://www.ipcc.ch/publications_and_data/ar4/wg1/en/spmsspm-projections-of.html)

1.1.2 Climate Change in the United States

According to the United States Environmental Protection Agency (2014), the United States is reporting that the contiguous 48 states experienced a 0.14°F increase in average surface temperature per decade since 1901. Figure 4 illustrates the fluctuation of surface temperature since 1901 with the most distinguishable temperature change occurring from the late 1990s to 2013 with a difference of more than 3°F. Also, the average surface temperature increased from 0.31°F to 0.48°F per decade starting in the late 1970s. Additionally, Karl et al. (2009, p. 9) states: "The winter months are undergoing the greatest warming trend in the last 30 years." An example from the report is that they indicate that the Midwest (i.e., Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Ohio, and Wisconsin) and the Northern Great Plains (i.e., Montana, Nebraska, North Dakota, South Dakota, and Wyoming) is a heavily impacted region with an increase of 7°F during these months (2009).

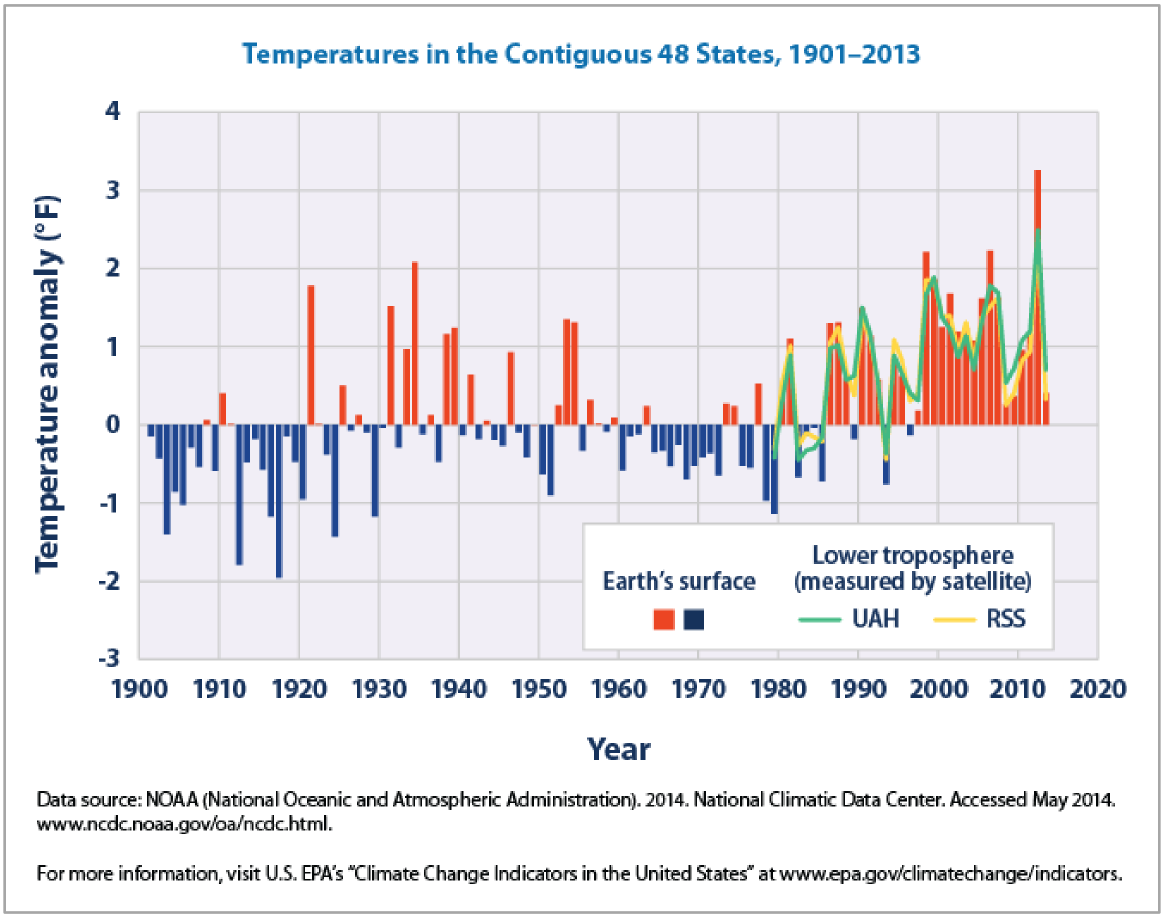

Figure 4: U.S. temperature anomaly (°F) from 1901-2013 across the contiguous 48 states. The bar graph depicts actual temperature measurements with a positive (red) temperature anomaly or a negative (blue) temperature anomaly. The linear trend line represents satellite measurements in the lower troposphere and analyzed by two different groups: University of Alabama-Huntsville (UAH) and Remote Sensing Systems (RSS). Source: United States Environmental Protection Agency (www.ncdc.noaa.gov/oa/ncdc.html)

1.1.3 Climate Change in Southern California

Southern California, as referred to by the Southern California Association of Governments (2009), is composed of six counties (i.e., Imperial, Los Angeles, Orange, Riverside, San Bernardino, and Ventura) within a Mediterranean climate. Mediterranean climate zones typically experience wet winters with relatively warm temperatures and dry summers with hot temperatures (Marietta College 2014). While this climate zone's high temperatures and low precipitation is normal, indication of temperature rise and climate change are found in Southern California.

The Office of Environmental Health Hazard Assessment (OEHHA) finds an increase in annual average temperatures statewide and more specifically in Southern California of 1.5°F per century beginning the year of 1895 (OEHHA 2013). Figure 5 clearly illustrates a temperature increase over the past 117 years with a sustained increase in temperature of approximately 1°F since the 1970's. It is important to note that the statewide temperature data for this one reporting system are monthly average temperatures acquired by the National Weather Service Cooperative Network (COOP) observers and Parameter-elevation Regressions on Independent Slopes Model (PRISM) data for 195 COOP stations throughout California (Western Regional Climate Center 2014).

Figure 6 illustrates that the departure from the average increases for the mean temperature, minimum temperature, and maximum temperature starting in 1895 (Figure 6). OHEAA states that according to Figure 6 the fastest increase in temperature is minimum temperature with a 1.99°F increase per 100 years; on the other hand, maximum temperatures only increased at a rate of 1.01°F per 100 years (2013). More specifically, the South Coast Region which includes the Los Angeles Basin and San Diego has experienced a warming trend since 1895 (2013). Figure 7 clarifies the temperature trend for the South Coast region where the annual departure values are derived from 1949 to 2005 averages. Overall, temperature is increasing in Southern California and this temperature increase is an indication that climate change is a factor.

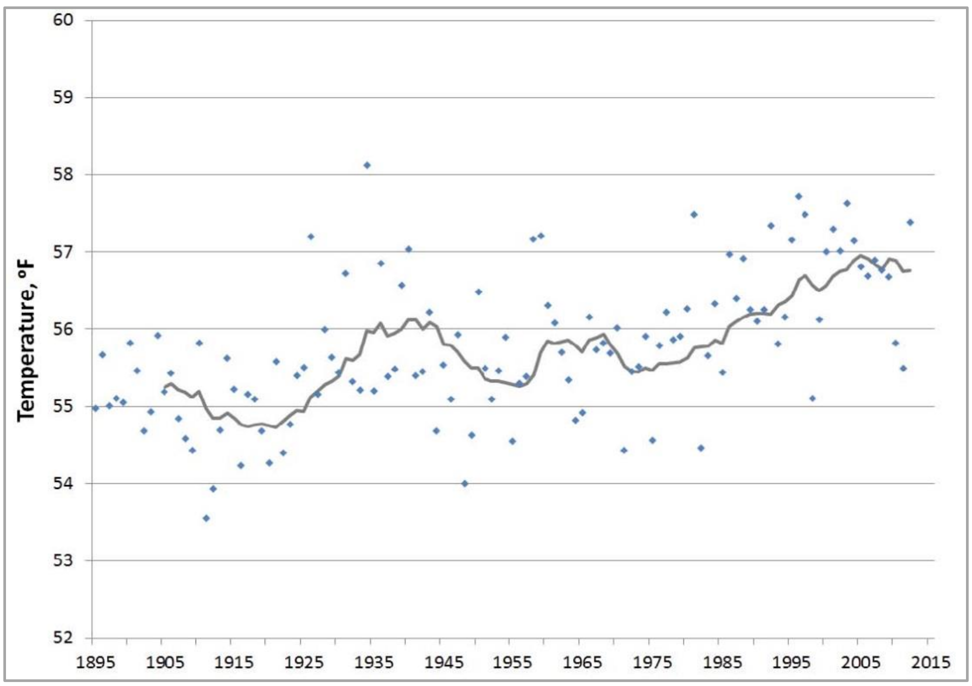

Figure 5: Annual average temperature trend for the State of California (1895-2012). The bold line is the 11-year running mean for 195 COOP stations statewide.
Source: Office of Environmental Health Hazard Assessment
(http://www.wrcc.dri.edu/monitor/cal-mon/index.html)

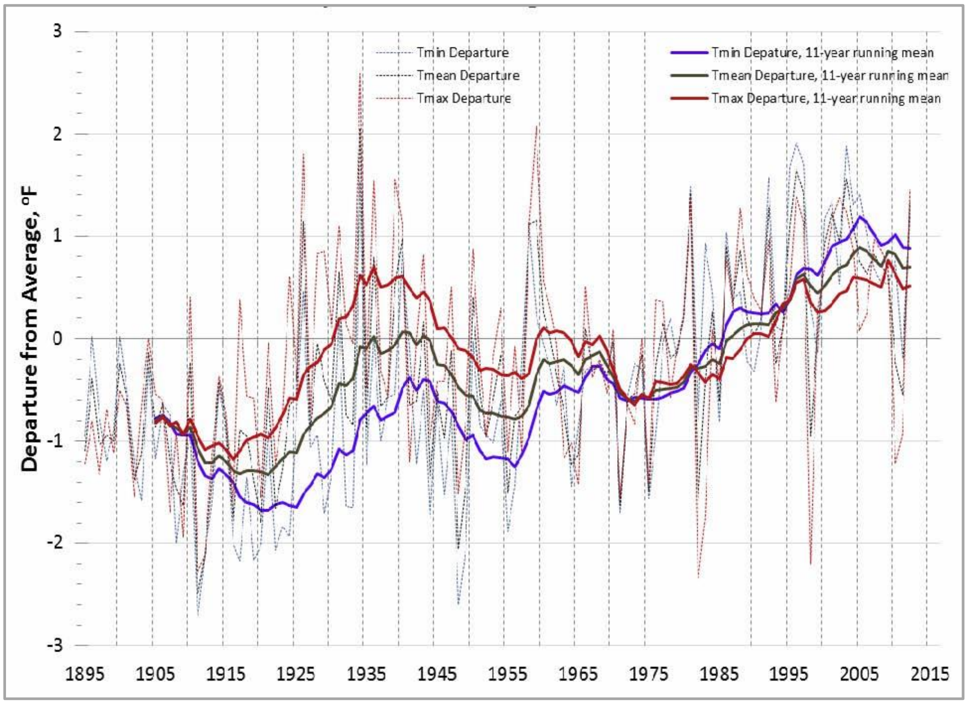

Figure 6: Departure from average for mean temperature, minimum temperature, and maximum temperature for the State of California (1895-2012). The bold line is 11-year running mean and the thin line is the departure from the mean for 195 COOP stations statewide.

Source: Office of Environmental Health Hazard Assessment (http://www.wrcc.dri.edu/monitor/cal-mon/index.html)

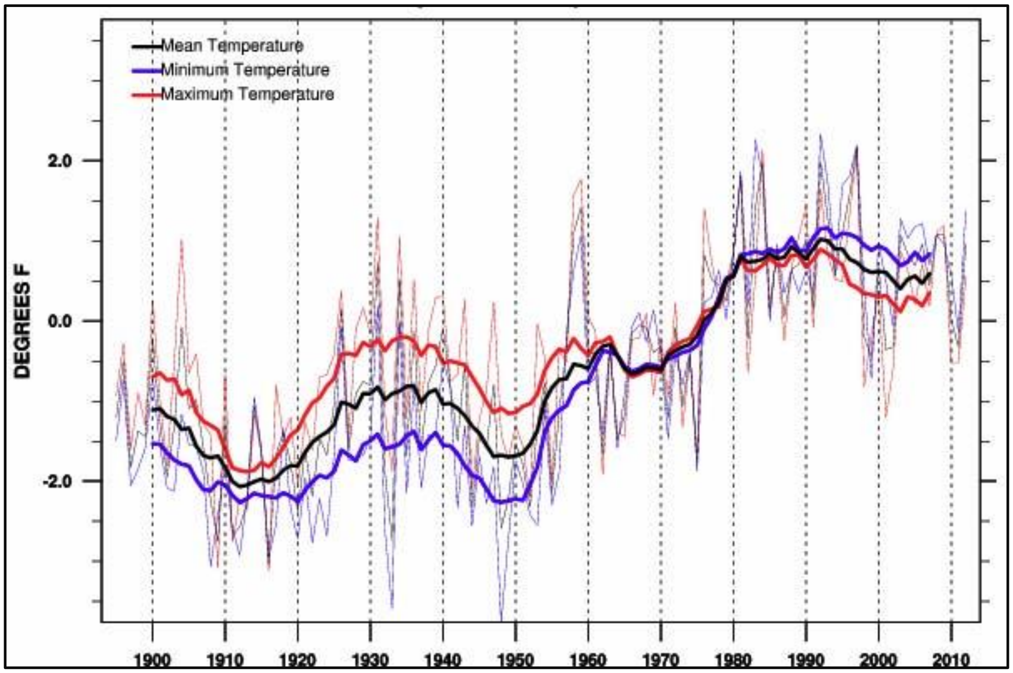

Figure 7: Departure from average for mean temperature, minimum temperature, and maximum temperature for the South Coast Region in the State of California. The bold line is 11-year running mean and the thin line is the departure from the mean for a region between Point Conception and the Mexico border.
Source: Office of Environmental Health Hazard Assessment (http://www.wrcc.dri.edu/monitor/cal-mon/index.html)

1.2 Research Questions

According to recent scientific studies (Hansen et al. 2006; Intergovernmental Panel on Climate Change 2007; Karl et al. 2009; Office of Environmental Health Hazard Assessment 2013; and United States Environmental Protection Agency 2014), a changing climate at various scales (global to local) is easily confirmed. Therefore, records of historical climate data can provide evidence of historical temperature trends in an area. The goal of this study is to analyze and interpret historical temperature data from 1931 to 2010 in Los Angeles County. Specifically, this study attempted to answer the research questions below:

1. What are the roles of daily, monthly, and yearly temperature to interpret the historical temperature trends in Los Angeles County?

2. How have mean temperature and extreme temperature thresholds changed and what are the characteristics of these trends (changes) across Los Angeles County?

CHAPTER TWO: LITERATURE REVIEW

The following are scientific studies describing the impact of climate change on temperature changes, study of extreme temperature thresholds, and the urban heat island effect across the globe.

2.1 Climate Change and its Impact on Temperature Changes

Climate change affects global temperatures and researchers are studying and analyzing its effects to provide scientific models and evidence that our planet is warming at an unforeseen rate. Schlesinger (2011) discusses how the amount of incoming solar radiation has increased due to human-induced greenhouse gases. According to Schlesinger (2011), air temperature is expected to increase between 2°C to 4.5°C because of the greenhouse-gas impact. Implications of this warming trend are explained by Schlesinger when he states that the ocean's warming temperature, slower than the Earth's atmosphere, increases the rate of evaporation, and in turn increases the amount of water vapor in the atmosphere and an increase in the absorption of incoming solar radiation (Schlesinger 2011). The effects of climate change and a warming atmosphere is felt in the United States and a regional study of the United States is described below.

A temperature analysis of the western United States uses daily temperature and precipitation data from 1950 to 2005 to monitor temperature changes over six different regions (Booth et al. 2012). The main finding of this study is that climate change is impacting the western United States and historical temperature data verifies this trend. Additionally, Booth et al. (2012) discover that the California-Nevada region is undergoing a trend favoring increasing daily minimum temperatures and a decreasing number of frost days. Another important finding during this study is the lack of any significant trends for maximum temperature in the California-Nevada region (Booth et al. 2012). Even though there is no apparent trend for maximum temperature, there is a defined warming trend for northern and southern California with coastal regions of the state experiencing a cooling trend during the time series (Booth et al. 2012). Further evidence that climate change is occurring in California is described by the following studies.

Cordero et al. (2011) analyze climatic data from 1918 to 2006 for the State of California. According to their study, minimum and maximum temperatures are increasing significantly across the entire State of California. As a result, minimum temperatures increased by 0.17°C per decade while maximum temperatures increased by 0.07°C per decade (Cordero et al. 2011). Also, the study finds that Southern California is undergoing the largest warming trend in California with a greater warming trend occurring with maximum temperature rather than minimum temperature in Southern California (Cordero et al. 2011).

Projection studies provide further evidence that a changing climate, more specifically a warming climate, is occurring in California (Cayan et al. 2008). Two different climate models (Parallel Climate Model and NOAA Geophysical Fluid Dynamics Laboratory CM2.1) are tested to identify the type of temperature trend taking place in California. The models produced results that include an increase in temperature across California during the twenty-first century with projections ranging from 1.7°C to 5.8°C from 2000 to 2100 (Cayan et al. 2008). Gregory Bohr (2009) analyzes daily maximum and minimum temperature data in California for 44 rural and 46 urban sites from 1950 to 2005. The overall trend is warming temperatures statewide with an increase in daily minimum and maximum temperatures (Bohr 2009). Also, California is undergoing the largest increase in temperature from daily minimum temperatures (Bohr 2009). Also, Bohr's findings show that largest temperature difference occurs with warmer daily temperature minimums and cooler daily temperature maximums compared to hot summer months maximum daily temperature and winter's cold minimum daily temperature. The effects of a changing climate are analyzed at metropolitan areas across the United States and their results are described by the following.

Vimal Mishra and Dennis Lettenmaier (2011) analyze climate data for 100 of the largest cities in the continental United States spanning 1950 to 2009. The author's results include a significant decreasing trend in heating degree days across the United States with approximately 50 percent of the metropolitan areas experiencing this decline (Mishra et al. 2011). Another important find is a statistically significant increase in warm nights with 6.5 percent of the metropolitan areas indicating a warming trend and a statistically significant declining trend of cool nights is predominant for the same metropolitan areas in this study (Mishra et al. 2011). Overall, a strong warming trend is occurring across the United States and is a clear indication that our climate is changing and temperatures are increasing.

Taha (1997) explains that the human influence on climate change (anthropogenic climate change) has the potential to affect near-surface temperatures in urban areas. The findings show that anthropogenic temperature fluxes are the largest during the winter months at cold climate metropolitan regions (Taha 1997). Also, day and night temperatures are expected to rise between 2°C to 3°C in an urban region due to anthropogenic temperature fluxes (1997). Overall, Taha states that an increase in temperature resulting from anthropogenic forcing plays a role in urbanized areas, but this temperature increase is “negligible in residential and commercial areas” (1997, p. 102).

Global surface temperature change is analyzed from 1870 to 1990 and 1998 to 2008 to determine the role of anthropogenic forcing on global temperature for this time period (Kaufmann et al. 2006; Kaufmann et al. 2011). These two studies execute a climate model that incorporates three equations using variables such as global surface temperature, CO_2, and CH_4 (Kaufmann et al. 2006). Kaufmann et al. (2006) find that the global surface temperature increase is statistically significant from 1870 to 1990, and this global surface temperature increase is most likely associated with greenhouse gases, anthropogenic sulfur emissions, and solar activity. On the other hand, Kaufmann et al. (2011) find that intensity of warming global surface temperature declines compared to their previous study. This changing global temperature trend is related to an increase in anthropogenic sulfur emissions which reduces the forcing effect of solar radiation (Kaufmann et al. 2011). These two studies show that anthropogenic forcing can affect global surface temperature in various ways and Kaufmann et al. state that “anthropogenic factors have well known warming and cooling effects” (2011, p. 11792).

2.2 Threshold Temperature Analysis

In addition to maximum, minimum, and mean temperatures, scientists also examine temperature thresholds as an indicator of temporal variability of temperature (Meehl et al. 2004; Ruddell et al. 2013). Recently, Ruddell et al. (2013) studied the temporal variability of temperature in Phoenix and Gila Bend, Arizona. Ruddell and his colleagues use three daily temperature threshold variables (i.e., frost day, misery day, and extreme heat event) to measure temporal variability for multiple time-series in Phoenix and Gila Bend. Ruddell et al. define frost days as any day with a minimum temperature of less than 32°F, misery days is any with a maximum daily temperature value greater than or equal to 110°F (Ruddell et al. 2013). The last temperature threshold variable is an extreme heat event and three criteria are required to classify an event as extreme heat event with T1 and T2 defined as the 97.5 percentile of the normal conditions and the 81 percentile of the normal conditions, respectively (Meehl et al. 2004; Ruddell et al. 2013). The three criteria include: (1) three consecutive days of daily maximum temperature above T1; (2) entire period must have T1 below the average daily maximum temperature; and (3) entire period must have T2 below daily maximum temperature (2004, p. 995; 2013, p. 205).

The authors approach to the results includes dividing each weather station's temperature data into ten year increments from 1900 to 2007. The results show that a decreasing number of frost days and an increasing number of misery days, especially between 1970 and 2007, are occurring at Phoenix. Also, the number of extreme heat events increase greatly over the same time period. Hence, these trends provide evidence that Phoenix is experiencing an enhanced warming trend from 1900 to 2007 (Ruddell et al. 2013). In contrast, Gila Bend experienced only a slight, even relatively stable, warming trend from 1900 to 2007 with a decrease in frost days but only a slight increase in misery days (Ruddell et al. 2013). The threshold analysis results in changes of temporal variability in temperature which can cause significant impacts on various systems. Furthermore, this temporal study shows that an urbanized area like Phoenix is experiencing the effects of climate change more than the rural area of Gila Bend, Arizona.

Meehl and Tebaldi (2004) study extreme heat events using a global coupled climate model known as the Parallel Climate Model (PCM). The two PCMs include a four-member ensemble and a five-member ensemble which measures 20th century (1961 to 1990) and 21st century (2080 to 2099) climate variability and climate change for extreme heat events at Chicago, Illinois and Paris, France (Meehl et al. 2004). The four-member ensemble is a "model run four times from different initial states and the four members are averaged together to reduce noise" and includes various forcing variables (i.e., greenhouse gases, sulfate aerosols, ozone, volcanic aerosols, and solar variability) to analyze heat wave events (2004, p. 994). The five-member ensemble model follows the same averaging process as its predecessor (four-member ensemble model), but the model is run five times and five members are averaged together to reduce noise. Also, this five-member ensemble "assumes little in the way of policy intervention to mitigate greenhouse gas emissions" (2004, p. 994). These two climate models are compared to predict the characteristics of extreme heat events in these two locales based upon the definition of a heat event (2004, p. 995). The four-member and five-member ensembles results show that occurrences of heat waves and the duration of heat waves are predicted to increase in the 21st century. The comparison between the four-member and five-member ensemble models predicts a 25 percent increase in heat wave occurrences in Chicago, Illinois and a 31 percent increase in heat wave occurrences in Paris, France. Additionally, the duration of heat waves is predicted to increase at both Chicago and Paris in the future. The five-member ensemble climate model expects the duration of heat waves in Chicago, Illinois to be 8.47 to 9.24 days compared to the four-member ensemble climate model that shows the current duration trend at 5.39 to 8.85 days. In comparison, the five-member ensemble model predicts the duration of a heat wave to be 11.81 to 17.04 days compared to 8.33 to 12.69 days by the four-member ensemble model at Paris, France.

2.3 Urban Heat Island Effect

Luke Howard (1833) is the first to document the impact of the urban heat island on surface temperature and his study discussed temperature changes in London, England. His study clarifies the urban heat island effect by finding that mean surface temperature increases by 2°F within the urban area of London (Howard 1833). Another important finding is the largest fluctuations in mean temperature occur during the winter months and these large fluctuations are directly related to warm city nights where a difference can be up to 3.7°F. Since Luke Howard, other scientists analyzed the relationship between higher temperatures and urbanized areas, and specific studies results are detailed by the following (Oke 1982; Camilloni et al. 1997; Taha 1997; Goodridge 1992).

Oke (1982) digs into the causes of the heat island effect at various levels of atmosphere (i.e., urban canopy layer and urban boundary layer). His results are discussed in Table 2 (1982, p. 17) with some key results explaining possible causes of the urban heat island at various atmospheric levels: (1) increased absorption of short-wave radiation at the canopy and boundary layer; (2) influence of anthropogenic heat sources at the canopy and boundary layer; (3) decreased evapotranspiration at the canopy layer; (4) increased incoming long-wave radiation and decreased long-wave radiation loss at the canopy layer; (5) sensible heat storage increasing and total turbulent heat transport decreasing at the canopy layer; and (6) increase of the sensible heat input-entrainment above and below the boundary layer. Oke summarizes that the effect of the urban canopy and boundary layer on the urban heat effect is not the same because the canopy layer is related to "site character" and the boundary layer is impacted by the advection of warmer air from above and "internal radiative effects" (1982, p. 21).

Camilloni et al. (1997) study the impact of the urban heat island and temperature trends across Argentina, Australia, and the United States for closely located urban and rural weather stations. Specifically, Camilloni et al. (1997) analyze 31 urban/rural pairs for the yearly mean temperature difference °C (urban minus rural) and discover that the urban regions year-to-year variability is less significant than its rural counterpart (Camilloni et al. 1997). Camilloni et al. (1997) report a statistically significant cooling trend of -0.04°C per year is discovered from 1925 to 1946 at the San Bernardino weather station and a statistically significant warming trend of 0.03°C per year at the same station from 1946 to 1968. Overall, the United States urban/rural paired stations experience a warming trend before 1930 and a cooling trend after 1970 during these two time periods (Camilloni et al. 1997).

Another urban heat island study involves modeling albedo, evapotranspiration, and anthropogenic heating to discover the effect of urbanization on temperature changes at various global cities, including Los Angeles, California (Taha 1997). The results for Los Angeles include an albedo of 0.20 at the center of the city and an albedo difference of 0.09 between the rural areas surrounding Los Angeles. Albedo is a key factor in surface temperature in Los Angeles because an increase in albedo of 0.13 can decrease temperatures between 2°C and 4°C (Taha 1997). Moreover, evapotranspiration plays such an important role in an urban area that "evapotranspiration can create 'oases' that are 2 to 8°C cooler than their surroundings" (1997, p. 101). The effect of anthropogenic heating is examined in Los Angeles and Taha (1997) finds that the anthropogenic heating measurement is 21 Wm^{-2} and the net wave radiation is 108 Wm^{-2}. As a comparison, the maximum anthropogenic heating measurement is 159 Wm^{-2} in Manhattan, New York and the minimum measurement is 16 Wm^{-2} in St. Louis, Missouri; the maximum net wave radiation measurement is Los Angeles at 108 Wm^{-2} and the minimum measurement is 18 Wm^{-2} at Fairbanks, Alaska. Furthermore, the inclusion of anthropogenic heating at any large urban area can increase surface temperature between 2°C and 3°C (Taha 1997).

Goodridge (1992) investigates the urban impact on long-term temperature trends at 112 weather stations over an 80 year time period (1910 to 1989) using monthly mean temperature measurements. The study reveals a warming trend across the entire State of California with an increase in combined average annual temperature of 0.014°F per year for all 112 weather stations (Goodridge 1992). Also, this warming trend is statistically significant with an R^2 equal to 0.15 and provides further evidence of a warming trend from 1910 to 1989. Additionally, according to Figure 2 (1992, p. 2) stations located within Los Angeles County demonstrate an increase of 0.2°F to 0.4°F per year, and an average annual temperature increase between 0.032°F (World Weather Record dataset) and 0.014°F (World Weather Record and Historical Climatological Network datasets) at urban locations across the state (Goodridge 1992).

CHAPTER THREE: DATA SOURCES AND METHODS

The existence of temperature records in Los Angeles County since the late 1870s describes how climate has changed over the last 140 years in the county. Also, the daily, monthly, and yearly historical surface temperature data is compared to recognize temperature and extreme temperature threshold trends occurring throughout Los Angeles County. This chapter provides a description of the study area in conjunction with the necessary data and analytic methods.

3.1 Description of Study Area

The area for this investigation is Los Angeles County, located in the southwest of California (Figure 8). It sustains a moderate climate with an average temperature in the coldest month of December of 48.3° F and a temperature of 84.8°F in the warmest month of August (rssWeather 2014). Notably, Los Angeles County is the most populous county in the United States with a total population of 9,818,605 and a population density of 2,419 per square mile in 2010 (U.S. Census Bureau 2014b). Additionally, the estimated population at Los Angeles County on July 1st, 2013 is 10.0 million and is approximately 4.7 more people than the second largest county of Cook County, Illinois (U.S. Census Bureau 2014a and b). This current estimate from 2013 is an approximate increase of more than 9.9 million people since 1900 (total population: 170,298) in Los Angeles County (U.S. Census Bureau 1995). Moreover, the City of Los Angeles, the second most populous metropolitan area in the United States with a total population of 3,792,621 in 2010, is located within Los Angeles County (National League of Cities 2013). The current population and extreme changes in population over the last century is revealing a changing climate. Hence, a projected increase in annual-mean surface temperature of approximately 3°F to 5°F and an increase in extreme hot days of approximately zero to fifty-five is expected to occur in Los Angeles County by the mid-21st century (Hall et al. 2012).

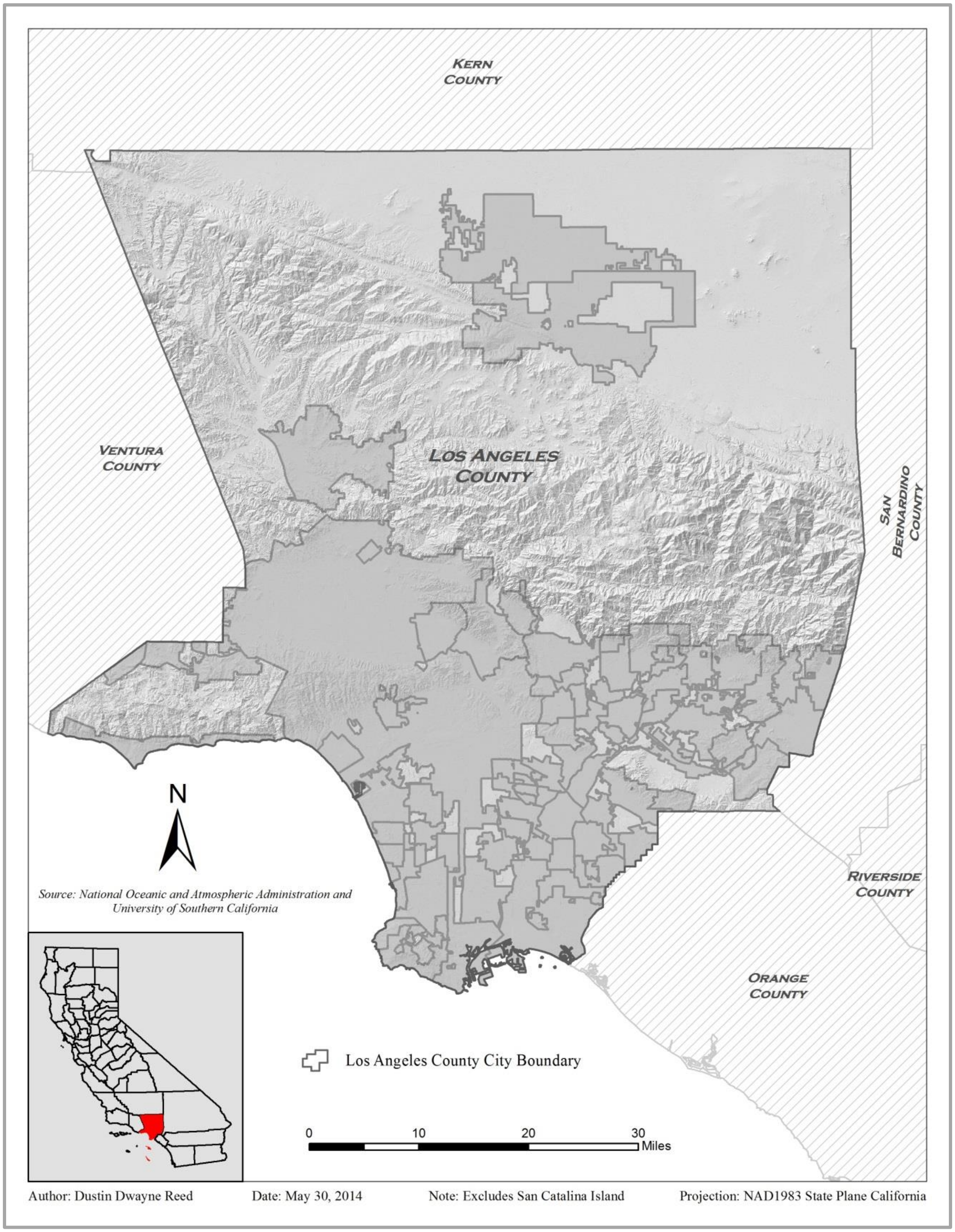

Figure 8: Los Angeles County and its location within the State of California. The grey areas indicate 88 cities and metropolitan areas in Los Angeles County.

Also unique to Los Angeles County is its geographic character. The county is surrounded by high elevation mountains, low-lying valleys, dry deserts, and miles of Pacific coastline. More specifically, there is a total of 4,084 square miles of land area with 1,875 square miles of mountains and 75 miles of coastline within this total land area (County of Los Angeles 2014). The lowest point in Los Angeles County is in Wilmington with an elevation of nine feet below sea level and the highest point is in Mount San Antonio in the San Gabriel Mountain range with an elevation of 10,080 above sea level (County of Los Angeles 2014). A portion of the Mojave Desert lies in the northeastern portion of Los Angeles County. The Mojave desert is located between the Great Basin Desert and the Sonoran and is also known as a “high desert” because its elevation extent is greater than 2,000 feet above sea level (U.S. Department of the Interior 2014; Michaelson 2009) Also, the elevation of the Mojave Desert influences its average minimum and maximum daily temperatures during the winter and summer months (Michaelson 2009).

3.2 Data

The following subchapters describe where daily and monthly temperature data are acquired and the type of temperature variables available from each temperature dataset. These datasets are the primary source for determining the trend in temperature and extreme temperature thresholds across Los Angeles County.

3.2.1 Historical Surface Temperature

The study utilizes the wide-range and easy accessibility of historical daily and monthly temperature data for Los Angeles County via the World Wide Web. The daily surface temperature dataset is accessed through the Western Regional Climate Center (WRCC) domain. Additionally, the monthly surface temperature dataset is obtained at the National Oceanic and Atmospheric Administration (NOAA) and the State of California Department of Water Resources (DWR) domain. The following describes in greater detail the acquisition and the use of the daily and monthly surface temperature datasets.

3.2.1.1 Daily Surface Temperature

Daily surface temperatures across Los Angeles County are acquired from the WRCC website, and this dataset includes daily minimum temperature, daily maximum temperature, and daily mean temperature for all WRCC stations in California. To recognize a trend in extreme temperature thresholds, an 80 year time period is chosen because the most complete daily temperature data spans from 1931 to 2010. The selection results in six weather stations (Fairmont, Los Angeles, Palmdale, Pasadena, Sandberg, and UCLA) that contain the required temperature data. These station's historical temperature data provide the required information to analyze the decadal trends of frost days, misery days, and heat wave events.

3.2.1.2 Monthly Surface Temperature

There are hundreds of available weather stations in Los Angeles County from NOAA's NCDC database. The database offers monthly minimum temperature, monthly maximum temperature, and monthly mean temperature spanning from 1931 to 2012. Additionally, the State of California DWR is a contributor to monthly surface temperature which provides monthly mean temperature data for the Los Angeles Civic Center from 1878 to 2004. These two contributors provide monthly temperature data for a total of 106 weather stations across Los Angeles County (Figure 9).

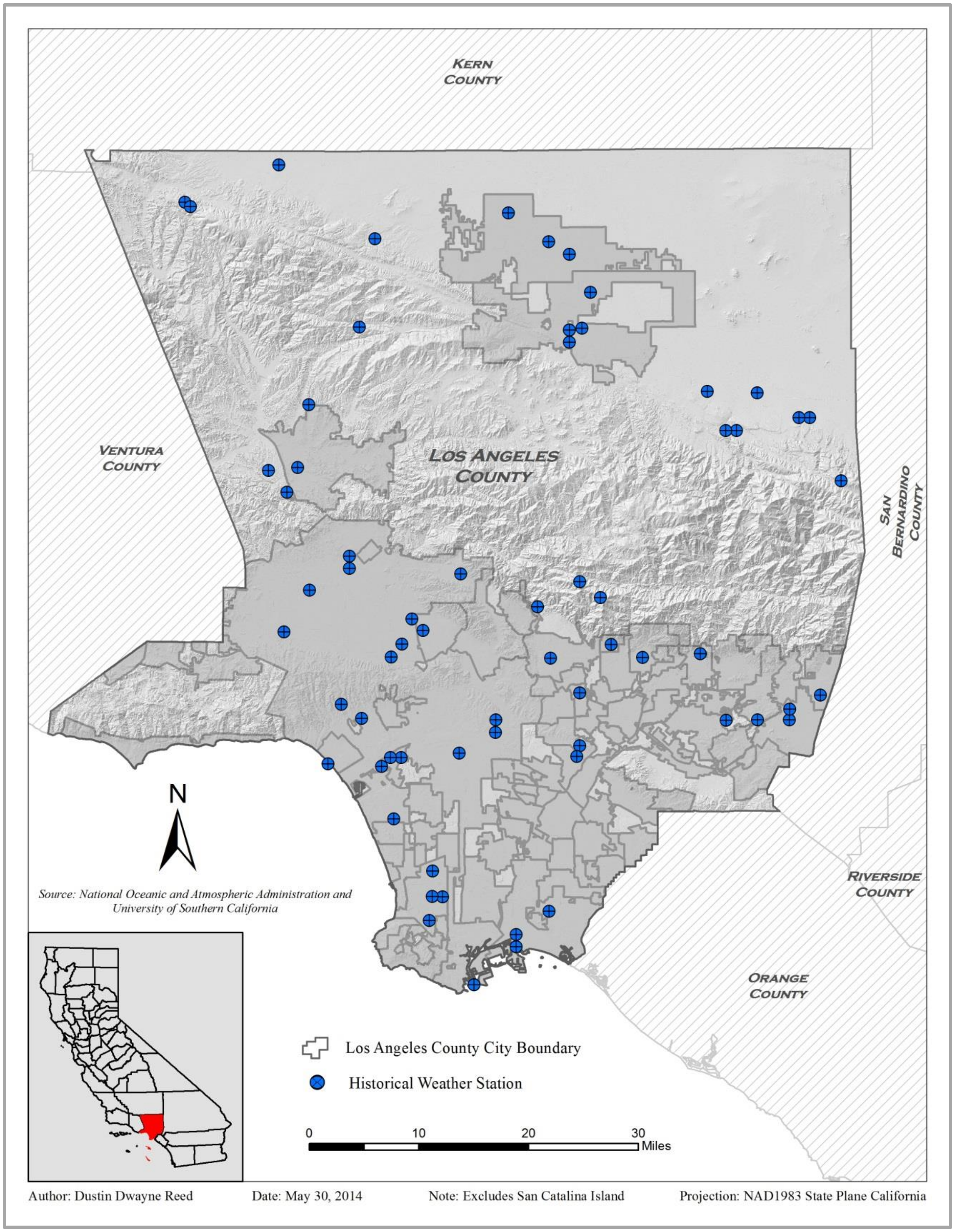

Figure 9: Distribution of 106 weather stations containing historical monthly surface temperature across Los Angeles County, California. Each blue circle represents a single station that currently or previously measured daily temperature. The grey areas indicate 88 cities and metropolitan areas in Los Angeles County.

3.3 Selection of Weather Stations

3.3.1 Weather Stations for Daily Surface Temperature

The methods for selecting the required stations begins by establishing the criteria that each station must contain approximately 80 years of daily surface temperature data from the WRCC temperature database. The manual selection discovers a total of six weather stations that meet these criteria (Table 1; Figure 10). Table 1 is described briefly by the following: 1) four stations contain 80 years of daily temperature data (i.e., Fairmont, Los Angeles, Palmdale, and Pasadena) and 2) two stations contain 78 years of daily temperature data (i.e., Sandberg and UCLA). Also, the data completeness is at a minimum in Sandberg with a percentage of 74.1 and at a maximum in Los Angeles with data completeness of 99.9 percent (See details in Table 1). Additionally, three stations (Fairmont, Sandberg, and UCLA) data completeness range between 74.1 percent and 76.0 percent, and the last three stations (Los Angeles, Palmdale, and Pasadena) data completeness range between 99.3 percent and 99.9 percent.

Table 1: Operating time period for the six weather stations containing daily temperature data between 1931 and 2010.

Weather Station	First Month of Collection	First Year of Collection	Last Month of Collection	Last Year of Collection	Data Completeness (%)
Fairmont	January	1931	August	2010	74.4
Los Angeles	January	1931	December	2010	99.9
Palmdale	April	1931	December	2010	96.5
Pasadena	January	1931	December	2010	99.3
Sandberg	January	1933	December	2010	74.1
UCLA	January	1933	December	2010	76.0

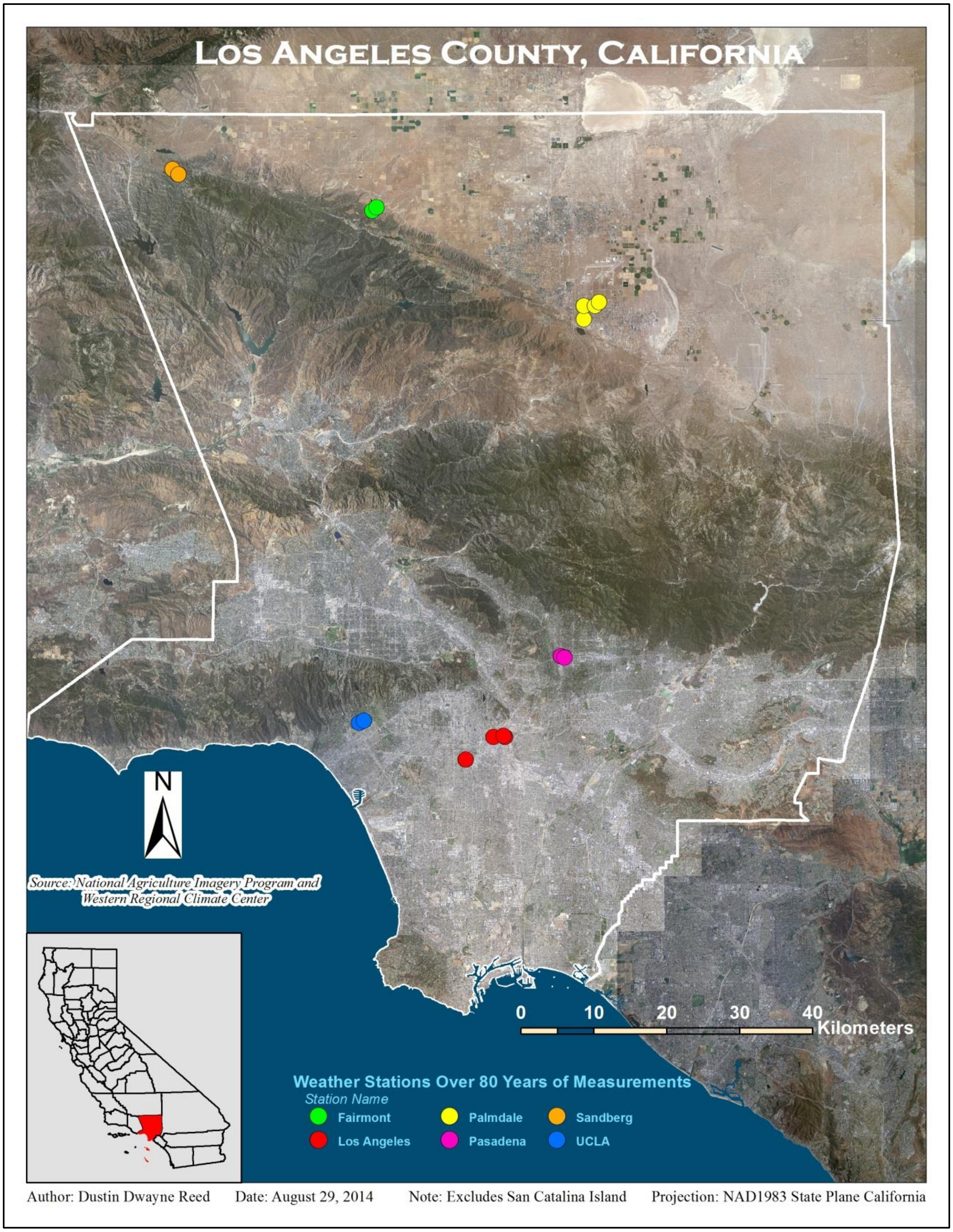

Figure 10: Spatial location of six weather stations with 80 years or more of historical daily temperatures. Each colored circle, as denoted in the legend to its respective station, represents a single station that currently or previously measured daily temperature.

3.3.1.1 Characteristics of Daily Temperature Data at Six Stations

Table 2 describes the characteristics of the six weather stations that contain historical daily temperature measurements that operated for more than 80 years within the boundary of Los Angeles County. The stations listed in Table 2 are still in operation with the earliest recorded measurements from the early 1930s. While these six stations started operating over 80 years ago, the recorded measurements do not span the same length of time. For instance, Fairmont, Los Angeles, Palmdale, and Pasadena start recording daily temperature data in 1931; Conversely, Sandberg and UCLA started recording daily temperature data in 1948.

The combination of Table 2 and Figure 10 show the spatial distribution of the six weather stations across Los Angeles County. Three of the stations are located in northern Los Angeles County (Fairmont, Palmdale, and Sandberg) and three of the stations are located in southern Los Angeles County (Fairmont, Los Angeles, and UCLA). Figure 11 shows (assisted by aerial imagery) that Los Angeles, Pasadena, and UCLA are located in an urban area while Fairmont and Palmdale are located in fairly rural, desert regions of the county. Moreover, Sandberg is spatially located in the mountainous region of the San Gabriel Mountain Range. Also, there is a large variance in elevation for all six weather stations (Table 2). For example, there are weather stations located in low lying regions with their average elevation listed by the following: (1) Los Angeles at 275 feet; (2) Pasadena at 863 feet; and (3) UCLA at 433 feet. The other end of the spectrum includes weather stations that are located in high elevation regions and their average elevation is as follows: (1) Fairmont at 3,060 feet; (2) Palmdale at 2,628 feet; and (3) Sandberg at 4,517 feet.

Figure 11 visualizes how weather stations have maintained the same weather station, but their latitude and longitude location have changed over time. For instance, Los Angeles changed latitude and longitude location three times from 1931 to 2010 with a greatest distance between station locations at more than 6,000 meters. Also, Sandberg moved to three different latitude and longitude locations with the greatest distance at only 25 meters. Furthermore, Figure 11 visually describes the type of land use (i.e., desert, mountain, or urban) at each weather station location. The results show that the Los Angeles, Pasadena, and UCLA weather stations are located in urban areas. On the other hand, the Fairmont and Palmdale weather stations are located in desert regions, and the Sandberg weather station is located in a desolate, mountainous area.

Table 2: Characteristics of the six weather stations containing daily temperature data.

Weather Stations	Operational Period	Latitude	Longitude	Elevation (feet)	Land use
Fairmont	01/01/1931 -05/18/1999 05/18/1999-Present	34°42’00” 34°42’15”	-118°26’00” -118°25’39”	3,060 3,060	Desert
Los Angeles (Civic Center, USC, & WB City)	01/01/1931-12/31/1939 01/01/1940-07/13/1964 07/13/1964-11/21/1985 07/13/1964-07/31/1964 11/21/1985-06/24/1999 06/24/1999-07/07/2007 07/07/2007-Present	34°03’00” 34°03’04” 34°03’04” 34°03’04” 34°03’04” 34°03’04” 34°01’18”	-118°15’00” -118°14’00” -118°14’00” -118°14’00” -118°14’00” -118°14’07” -118°17’29”	361 312 270 312 270 230 171	Urban
Palmdale	04/01/1931-06/30/1948 07/01/1948-03/01/1952 03/01/1952-12/01/1962 12/01/1962-01/01-1982 01/01/1982-11/01/1993 11/01/1993-Present	34°35’00” 34°34’00” 34°35’00” 34°35’00” 34°35’00” 34°35’16”	-118°07’00” -118°07’00” -118°07’00” -118°06’00” -118°06’00” -118°05’39”	2,661 2,651 2,661 2,602 2,596 2,596	Desert
Pasadena	01/01/1931 -06/01/1952 06/01/1952-09/12/2000 09/12/2000-02/11/2010 02/11/2010-Present	34°09’00” 34°09’00” 34°08’54” 34°08’53”	-118°09’00” -118°09’00” -118°08’41” -118°08’40”	860 864 864 864	Urban
Sandberg WSMO	01/01/1933-01/01/1982 01/01/1982-04/01/1996 04/01/1996-09/12/2000 09/12/2000-Present	34°45’00” 34°45’00” 34°44’37” 34°44’37”	-118°44’00” -118°44’00” -118°43’28” -118°43’27”	4,524 4,517 4,517 4,510	Mountain
UCLA	01/01/1933-05/09/1957 05/09/1957-09/12/2000 09/12/2000-Present	34°04’00” 34°04’00” 34°04’11”	-118°27’00” -118°27’00” -118°26’34”	440 430 430	Urban

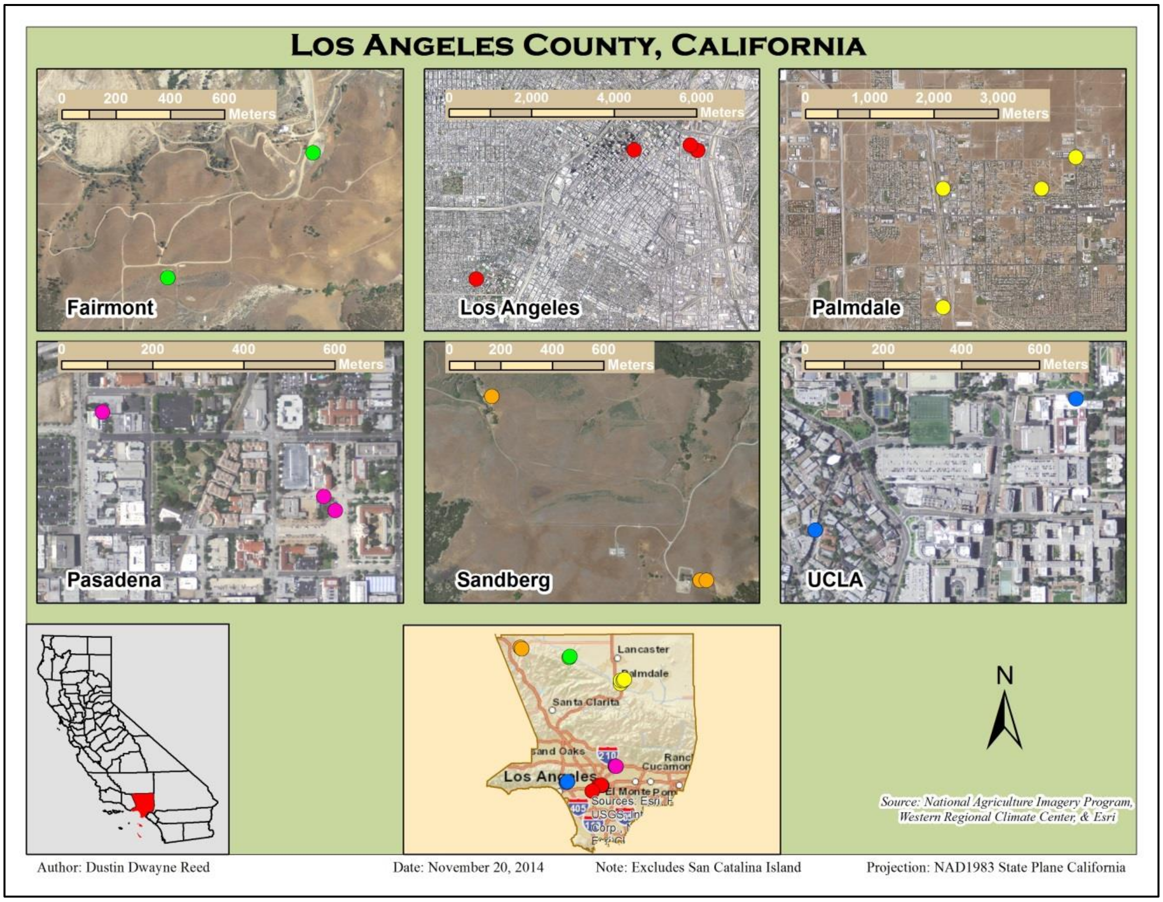

Figure 11: Large-scale aerial imagery representation of six weather stations across Los Angeles County. The six images, located in the top to rows, show the type of land cover and the distance between each station's measuring locales. The image on the bottom row is a small-scale spatial representation of the six weather stations with eighty years or more of daily temperature measurements.

3.3.2 Weather Stations for Monthly and Yearly Surface Temperature

A fitness to use method is used to locate widely distributed weather stations because multiple weather stations have relocated without changing the station's name. Therefore, a multitude of processes are executed using Esri ArcMap 10.2.2 and Microsoft Excel 2010 to discover the final selection of weather stations.

A point location for each weather station is identified by executing the ArcMap tool *Display X & Y Coordinates* using each station's unique identifying coordinates within the NCDC and DWR monthly temperature dataset. After running this tool, a point feature is created and displayed in ArcMap depicting their latitude and longitude locations. An export of these point features creates two new shapefiles with one shapefile containing the NCDC monthly temperature data and the second containing DWR monthly temperature data. A consolidation of these two shapefiles is obtained by executing the ArcMap tool *Merge*, which in turn creates a new, single shapefile with all the monthly temperature data within its attribute table. Additionally, the *Dissolve* tool is used to create a single row of information for each station by their respective latitude and longitude, and the end process is a single table containing 106 rows, or 106 weather stations.

After analyzing the new shapefile's attribute table, the dataset contains weather stations that have the same station name but contain different latitude and longitude coordinates. The question becomes: "Should each station be considered as a separate entity or create one central location (centroid) for the stations that have the same name?" This question is answered by executing the *Near* ArcMap tool because it calculates the distance from one station to the (next) nearest station. After examining the results, it is determined to create a centroid for the weather stations that share the same station name within 1 kilometer (km) of its (next) nearest weather station.

The creation of the centroid for the (next) nearest station is a complicated process. The first objective is to create a 1 km buffer using the *Buffer* tool in the ArcMap Analysis toolbox for all one hundred six weather stations. Once the *Buffer* tool is executed, there is a manual selection of the weather stations within a 1 km radius and the operation of the *Mean Center* tool within the ArcMap Spatial Statistics Toolbox. This *Mean Center* tool is a centroid process that includes selecting all the stations to be included as one, central location, which in return creates a new shapefile. After performing the same procedure for all the LBS within the 1 km buffer, a total of 22 new shapefiles are created with a new centroid or mean center. Now that all the centroids are created, a new CSV spreadsheet is created and imported into ArcMap. Next, the *Display X & Y Coordinates* tool is implemented to plot sixty-six weather stations in Los Angeles County.

The final selection of the weather stations is straight-forward and its purpose is to analyze historical surface temperature data at various time periods across Los Angeles County. The objective is to analyze complete data (temperature values for all 12 months of each collected year), and to analyze consecutive 20 year and 60 year data for as many stations as possible. While these objectives are reasonable, temperature data is not always complete for each station. Since inconsistencies exist, subjective reasoning should be applied for the final selection of the weather station. The final selection includes 21 weather stations with monthly surface temperature measurements stretching from 1931 to 2010 (Table 3). All 21 stations (Figure 12) provide the necessary spatial and temporal material to assist in locating and analyzing surface temperature trends in Los Angeles County.

Table 3: Operating time period for the 21 weather stations containing monthly surface temperature data between 1931 and 2010.

Weather Station	First Month of Collection	First Year of Collection	Last Month of Collection	Last Year of Collection
Claremont Pomona College	January	1931	December	1980
Culver City	January	1935	June	1967
Fairmont	January	1931	October	2012
LAX	August	1944	November	2012
Llano	January	1931	April	1945
Long Beach Aquarium	January	1931	November	1969
Los Angeles Terminal Annex	November	1940	December	1952
North Hollywood	January	1936	March	1950
OPIDS	January	1933	May	1958
Palmdale	April	1931	June	1948
Pasadena	January	1931	November	2012
Pomona Fairplex	January	1931	December	1969
San Fernando	January	1931	June	1961
San Pedro	January	1931	August	1964
Sierra Madre Henszey	January	1931	June	1958
Table Mountain	January	1931	August	1961
Torrance Airport	January	1932	August	1955
UCLA	January	1933	November	2012
USC	January	1878	August	2012
Valyermo FD	February	1938	November	1971
Woodland Hills Pierce College	July	1949	November	2012

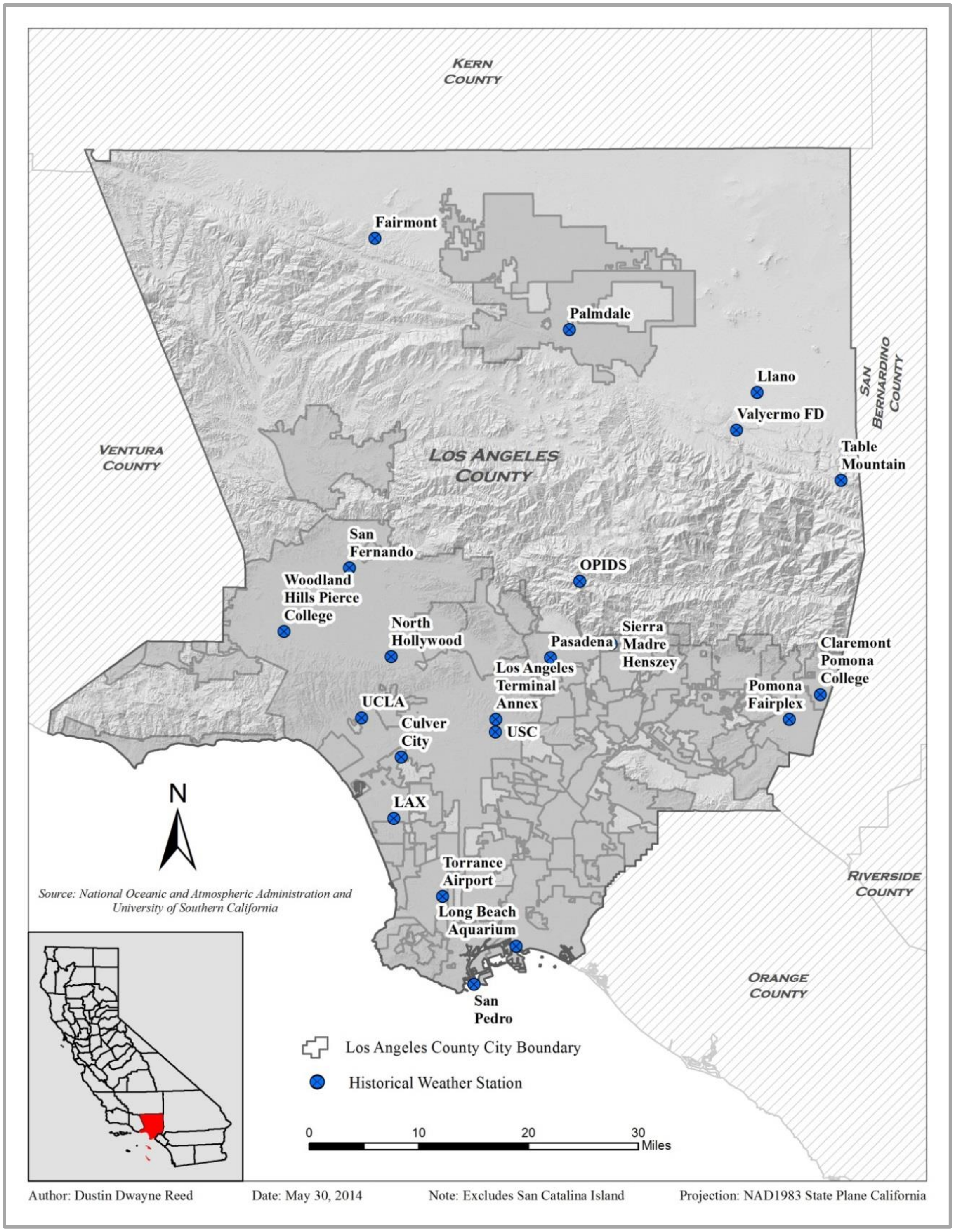

Figure 12: Selected 21 weather stations across Los Angeles County, California for monthly surface temperature. Each blue circle represents a single station that currently or previously measured daily temperature. The grey areas indicate 88 cities and metropolitan areas in Los Angeles County.

3.3.2.1 Weather Stations for Monthly Surface Temperature

The selection of the necessary weather stations is performed manually by selecting stations from Table 1 and Table 3 that that meet the criteria that more than 40 years of monthly surface temperature data exists. After performing the manual selection, a total of eight stations exist matching the predetermined criteria (Table 4; Figure 13). The length of time varies for some of the stations and the following statistics state the number of station(s) for each length of time, name of the station(s), and the length of time with monthly temperature data: 1) three stations for 80 years (i.e., Fairmont, Palmdale, and Pasadena); 2) two stations for 78 years (i.e., Sandberg and UCLA); 3) one station for 69 years (i.e., USC); 4) one station for 68 years (i.e., LAX); and 5) one station for 63 years (i.e., Woodland Hills Pierce College). Also, the eight stations data completeness range between 72.9 percent (Sandberg) to 100.0 percent (LAX). Additionally, seven out the eight weather stations (excluding Sandberg) contain more than 96.0 percent data completeness (Table 4).

Table 4: Operating time period for the eight weather stations containing monthly surface temperature data between 1931 and 2010.

Weather Station	**First Month of Collection**	**First Year of Collection**	**Last Month of Collection**	**Last Year of Collection**	**Data Completeness (%)**
Fairmont	January	1931	August	2010	96.0
LAX	August	1944	December	2010	100.0
Palmdale	April	1931	December	2010	98.2
Pasadena	January	1931	December	2010	99.9
Sandberg	January	1933	December	2010	72.9
UCLA	January	1933	December	2010	99.6
USC	January	1950	December	2010	99.6
Woodland Hills Pierce College	July	1949	December	2010	99.6

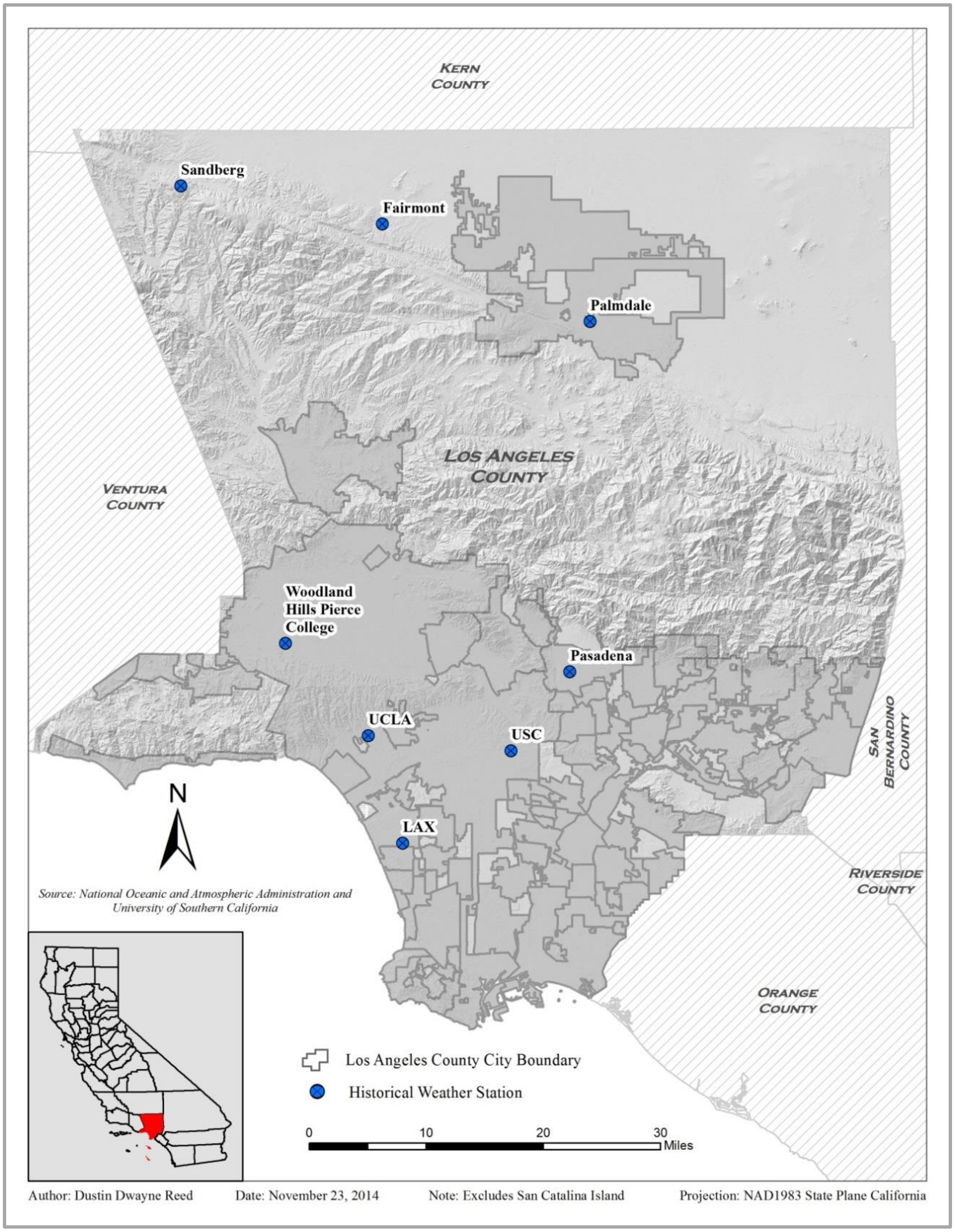

Figure 13: Spatial location of eight weather stations with approximately 80 years of historical monthly temperatures. Each blue circle represents a single station that currently or previously measured daily temperature. The grey areas indicate 88 cities and metropolitan areas in Los Angeles County.

3.3.2.2 Weather Stations for Yearly Surface Temperature

Yearly surface temperature is analyzed for trends over two different time periods using averaged monthly mean surface temperature data. The time periods include 1931 to 1950 and 1951 to 2010 to determine if specific trends exist at shorter (20 years) and longer (60 years) time periods. The selection of the specific stations is completed by manually selecting stations from Table 3 that fall within one or both time periods. After each station is selected for its respective time period, a total of six stations span from 1951 to 2010 (Table 5) and 20 stations fall within the period from 1931 to 1950 (Table 6). Table 5 shows that the data completeness for all six stations range from 91.5 percent (USC) to 100.0 percent (LAX and UCLA). Also, the range in data completeness for Table 6 is 93.1 percent (Los Angeles Terminal Annex and OPIDS) to 100.0 percent (Culver City, Pasadena, Pomona Fairplex, Table Mountain, and USC).

Table 5: Operating time period for the six weather stations containing yearly surface temperature data between 1951 and 2010.

Weather Station	First Month of Collection	First Year of Collection	Last Month of Collection	Last Year of Collection	Data Completeness (%)
Fairmont	January	1951	August	2010	94.9
LAX	January	1951	December	2010	100.0
Pasadena	January	1951	December	2010	99.9
UCLA	January	1951	December	2010	100.0
USC	January	1951	December	2010	91.5
Woodland Hills Pierce College	January	1951	December	2010	99.9

Table 6: Operating time period for the 20 weather stations containing yearly surface temperature data between 1931 and 1950.

Weather Station	First Month of Collection	First Year of Collection	Last Month of Collection	Last Year of Collection	Data Completeness (%)
Claremont Pomona College	January	1931	December	1950	99.2
Culver City	January	1935	December	1950	100.0
Fairmont	January	1931	December	1950	99.9
LAX	August	1944	December	1950	91.7
Llano	January	1931	April	1945	99.4
Long Beach Aquarium	January	1931	December	1950	97.9
Los Angeles Terminal Annex	November	1940	December	1950	93.1
North Hollywood	January	1936	March	1950	95.3
OPIDS	January	1933	December	1950	93.1
Palmdale	April	1931	June	1948	94.2
Pasadena	January	1931	December	1950	100.0
Pomona Fairplex	January	1931	December	1950	100.0
San Fernando	January	1931	October	1950	98.3
San Pedro	January	1931	December	1950	96.7
Sierra Madre Henszey	January	1931	December	1950	97.5
Table Mountain	January	1931	December	1950	100.0
Torrance Airport	January	1932	December	1950	96.9
UCLA	January	1933	December	1950	98.1
USC	January	1878	December	1950	100.0
Valyermo FD	February	1938	December	1950	96.8

3.4 Analysis of the Climate Trend

3.4.1 Daily Temperature

The selection of weather stations using daily temperature data is complete and analyzing extreme temperature threshold trends (i.e., frost day, misery day, and heat wave events) for these six stations is the next step. The 80 years of daily maximum and minimum temperature data are divided into ten year increments for each station (i.e., 1931 to 1940, 1941 to 1950, 1951 to 1960, 1961 to 1970, 1971 to 1980, 1981 to 1990, 1991 to 2000, and 2001 to 2010) and analyzed for their respective extreme temperature threshold (Ruddell et al. 2013). The statistical findings include the mean and total number of frost and misery days, as well as threshold temperatures (T1 and T2), frequency, intensity, and average duration of heat wave events. Furthermore, the linear regression results for frost and misery days are analyzed for statistical significance using the standard least squares regression model.

Frost days are defined as any day that has an observed minimum daily temperature less than or equal to 32°F. Misery days are defined as any day that has an observed maximum daily temperature greater than or equal to 90°F (Tamrazian et al. 2008). As for the heat wave event, T1 (97.5 percentile of the normal conditions) and T2 (81 percentile of the normal conditions) must match all three criteria derived from Meehl et al. (2004, p. 995) and they are as follows: 1) three consecutive days of daily maximum temperature above T1; 2) the entire study period must have T1 below the average daily maximum temperature; and 3) entire study period must have T2 below daily maximum temperature. The following define the remaining heat wave event variables: 1) frequency is the number of heat wave events based on the determination of a heat wave event using T1 and T2 daily maximum temperature; 2) intensity is the average maximum temperature of the heat wave event; and 3) average duration is the average span of each heat wave event (Ruddell et al. 2013).

3.4.2 Monthly Temperature

After the selection of each weather station is complete, the temperature trend for all eight stations is graphed. This temperature trend models each station's monthly mean temperature change during their respective time period. These time periods span from 1931 to 2010, 1944 to 2010, 1949 to 2010, and 1950 to 2010. Lastly, the linear regression results for monthly mean temperature are analyzed for statistical significance using the standard least squares regression model.

3.4.3 Yearly Temperature

Once the selection of each weather station is complete, the yearly surface temperature is calculated by averaging each year's monthly mean surface temperature data into a single or yearly temperature value for each time period. Now that the yearly temperature measurements are calculated for each weather station, they are graphed for two types of temperature trends during their respective time period (1931 to 1950 and 1951 to 2010). These temperature trends include: 1) yearly surface temperature and 2) yearly summer surface temperature where summer is defined as including the months of July thru September.

CHAPTER 4: RESULTS

The following chapter contains three approaches to analyze temperature and extreme temperature threshold trends. The three approaches implement the use of historical daily, monthly, and yearly surface temperature data for the period spanning from 1931 to 2010.

4.1 Daily Temperature and Its Trend

4.1.1 Frost and Misery Day Annual and Decadal Statistics

Table 7 and Figure 14 show that misery days are increasing and frost days are decreasing at the Fairmont weather station spanning the entire 80 year time period. Statistically, Fairmont's misery days increases by 561 days during the full 70 years of daily temperature data (1950 to 2010) and a total of 3,799 misery days during the 80 year period (1931 to 2010). On the other hand, the number of frost days decreases by 71 days during the 70 years of continuous daily temperature data (1950 to 2010) and a total of 1,689 frost days over the 80 year span (1931 to 2010). Additionally, the decade from 1941 to 1950 has 89 frost days and 154 frost days with an increase to 283 frost days and 596 misery days spanning from 1951 to 1960. This large increase in frost and misery days is corresponding to the lack of daily temperature data spanning the decade from 1941 to 1950. The maximum and minimum number of frost days are 58 in 1987 and 3 in 1986, respectively. On the other hand, the maximum and minimum number of misery days are 102 in 2003 and 37 in 2009.

Table 7: Total number and annual mean of frost days and misery days measured by decade at the Fairmont weather station for a total of 80 years (1931 to 2010). Frost days represent temperatures less than or equal to 32 degrees Fahrenheit and misery days are greater than or equal to 90 degrees Fahrenheit.

Decade	Frost Days		Misery Days	
	No.	Mean	No.	Mean
Fairmont	*Weather Station*			
1931-1940	Incomplete	Incomplete	Incomplete	Incomplete
1941-1950	89	8.9	154	15.4
1951-1960	283	28.3	596	59.6
1961-1970	281	28.1	579	57.9
1971-1980	271	27.1	539	53.9
1981-1990	333	33.3	590	59.0
1991-2000	220	22.0	626	62.6
2001-2010	212	21.2	715	71.5
Total	1,689	21.1	3,799	47.5

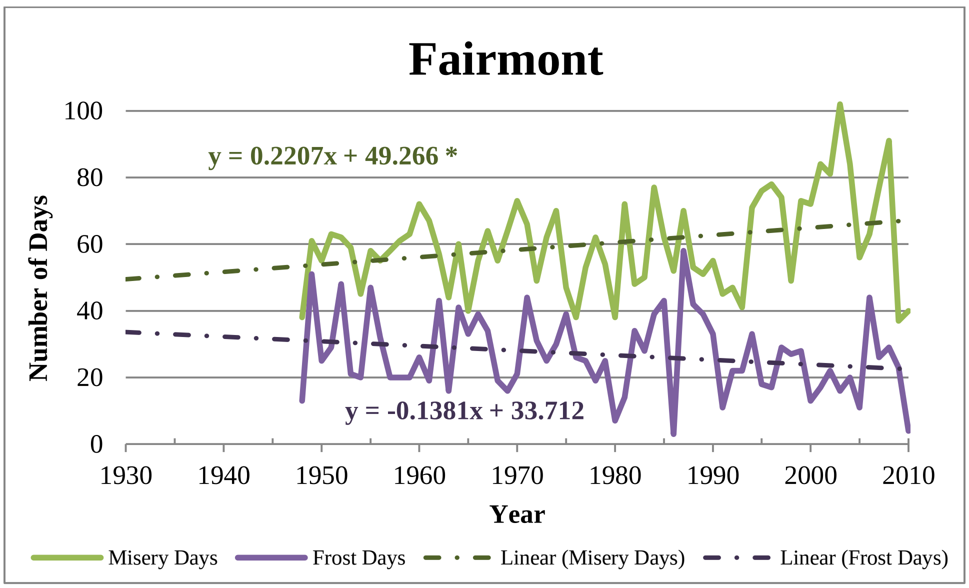

Figure 14: Annual number of frost days and misery days using daily temperature data at the Fairmont weather station from 1948 to 2010. The bold green line represents the trend of misery events and the dashed green line represents the trend line for misery events. The bold purple line represents the trend of frost events and the dashed purple line represents the trend line for frost events. A single asterisk (*) represents statistical significance at p-value < 0.05 and a double asterisk (**) represents statistical significance a p-value < 0.01.

Los Angeles undergoes an increase in misery days versus frost days with more than 1,700 misery days than frost days over the 80 year period (Table 8; Figure 15). Therefore, this period has a total of 10 frost days and 1,732 misery days. Also, the number of misery days nearly double from 128 days (1941 to 150) to 229 days (1951 to 1960). The maximum and minimum number of frost days are 4 in 1949 and 0 for 74 different years of record, respectively. Conversely, the maximum and minimum number of misery days are 47 in 1983 and 5 in 2001, respectively.

Table 8: Total number and annual mean of frost days and misery days measured by decade at the Los Angeles weather station for a total of 80 years (1931 to 2010). Frost days represent temperatures less than or equal to 32 degrees Fahrenheit and misery days are greater than or equal to 90 degrees Fahrenheit.

Decade	Frost Days		Misery Days	
	No.	Mean	No.	Mean
Los Angeles	*Weather Station*			
1931-1940	2	0.2	150	15.0
1941-1950	4	0.4	128	12.8
1951-1960	1	0.1	229	22.9
1961-1970	0	0.0	207	20.7
1971-1980	3	0.3	239	23.9
1981-1990	0	0.0	290	29.0
1991-2000	0	0.0	277	27.7
2001-2010	0	0.0	212	21.2
Total	10	0.13	1,732	21.7

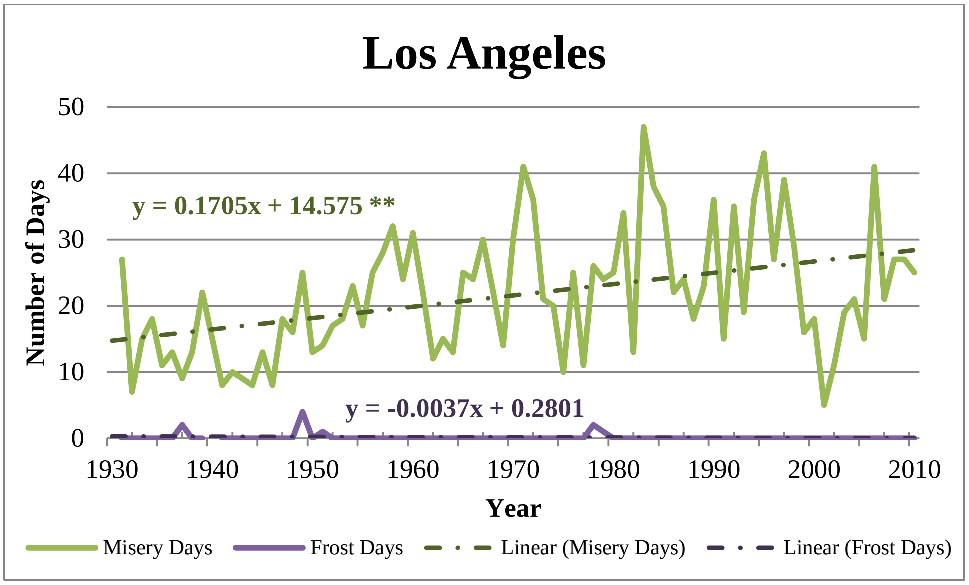

Figure 15: Annual number of frost days and misery days using daily temperature data at the Los Angeles weather station from 1931 to 2010. The bold green line represents the trend of misery events and the dashed green line represents the trend line for misery events. The bold purple line represents the trend of frost events and the dashed purple line represents the trend line for frost events. A single asterisk (*) represents statistical significance at p-value < 0.05 and a double asterisk (**) represents statistical significance a p-value < 0.01.

The Palmdale weather station experiences the most definitive contrast between extreme temperature thresholds (Table 9; Figure 16). There are 4,234 frost days and 8,345 misery days recorded in this 80 year period. The departure between these events are 4,111 and is second only to Pasadena. The largest change in decadal trends occurs during frost day events between the years of 1981 and 1990 (604) as well as 1991 and 2000 (395) with a difference of 209 frost days during this ten year period. The maximum and minimum number of frost days are 86 in 1948 and 0 in 1931. Also, the maximum and minimum misery days are 137 in 2003 and 41 in 1932, respectively. The minimum number of frost and misery days are subjective due to the missing daily temperature measurements from January 1st, 1931 until March 31st, 1931 and October 1st, 1931 until August 15th, 1932. Therefore, these inconsistencies are reflected in the trends for frost and misery days within Figure 16.

Table 9: Total number and annual mean of frost days and misery days measured by decade at the Palmdale weather station for a total of 80 years (1931 to 2010). Frost days represent temperatures less than or equal to 32 degrees Fahrenheit and misery days are greater than or equal to 90 degrees Fahrenheit.

Decade	Frost Days		Misery Days	
	No.	Mean	No.	Mean
Palmdale	*Weather Station*			
1931-1940	462	46.2	927	92.7
1941-1950	651	65.1	948	94.8
1951-1960	567	56.7	1,100	110.0
1961-1970	551	55.1	928	92.8
1971-1980	660	66.0	1,018	101.8
1981-1990	604	60.4	1,079	107.9
1991-2000	395	39.5	1,181	118.1
2001-2010	344	34.4	1,164	116.4
Total	4,234	52.9	8,345	104.3

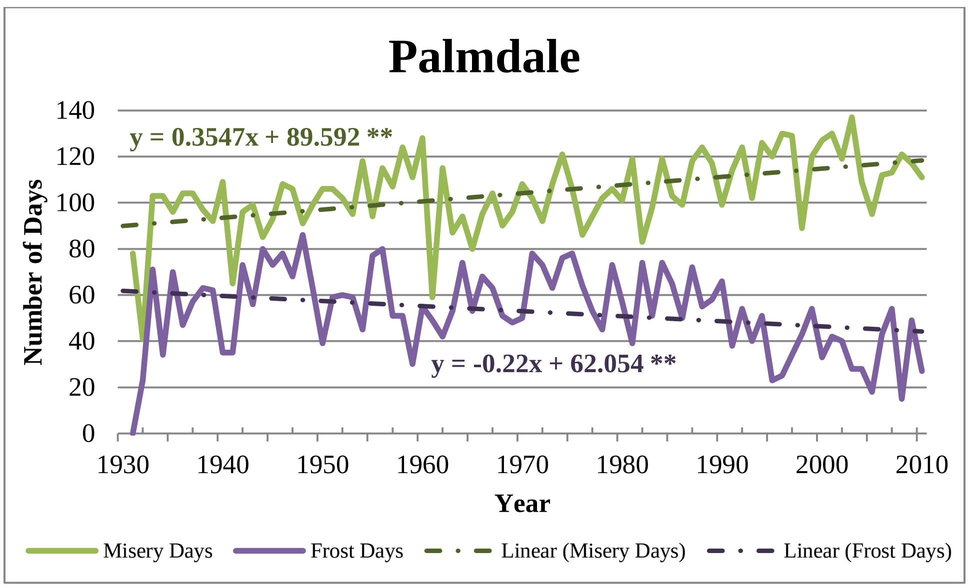

Figure 16: Annual number of frost days and misery days using daily temperature data at the Palmdale weather station from 1931 to 2010. The bold green line represents the trend of misery events and the dashed green line represents the trend line for misery events. The bold purple line represents the trend of frost events and the dashed purple line represents the trend line for frost events. A single asterisk (*) represents statistical significance at p-value < 0.05 and a double asterisk (**) represents statistical significance a p-value < 0.01.

Another weather station that experiences an increase in misery days and a decrease in frost days over 80 years is Pasadena (Table 10; Figure 17), and the increase in misery days over time is the most influential than any of the six weather stations observed. Hence, Pasadena experiences the greatest range between frost and misery days for 80 years with a difference of 4,445 days with a total of 142 frost days and 4,587 misery days. A noteworthy decadal trend occurs from 1931 to 1950 where the frost days remain the same for 20 years (44 days) but the misery days decrease by 156 days (527 to 371 days). The maximum and minimum number of frost days are 16 in 1937 and 0 for 38 different years of record, respectively. Also, the maximum and minimum number of misery days are 98 in 1990 and 24 in 1944, respectively.

Table 10: Total number and annual mean of frost days and misery days measured by decade at the Pasadena weather station for a total of 80 years (1931 to 2010). Frost days represent temperatures less than or equal to 32 degrees Fahrenheit and misery days are greater than or equal to 90 degrees Fahrenheit.

Decade	Frost Days		Misery Days	
	No.	Mean	No.	Mean
Pasadena	*Weather Station*			
1931-1940	44	4.4	527	52.7
1941-1950	44	4.4	371	37.1
1951-1960	17	1.7	504	50.4
1961-1970	6	0.6	556	55.6
1971-1980	15	1.5	544	54.4
1981-1990	13	1.3	700	70.0
1991-2000	1	0.1	761	76.1
2001-2010	2	0.2	624	62.4
Total	142	1.8	4,587	57.3

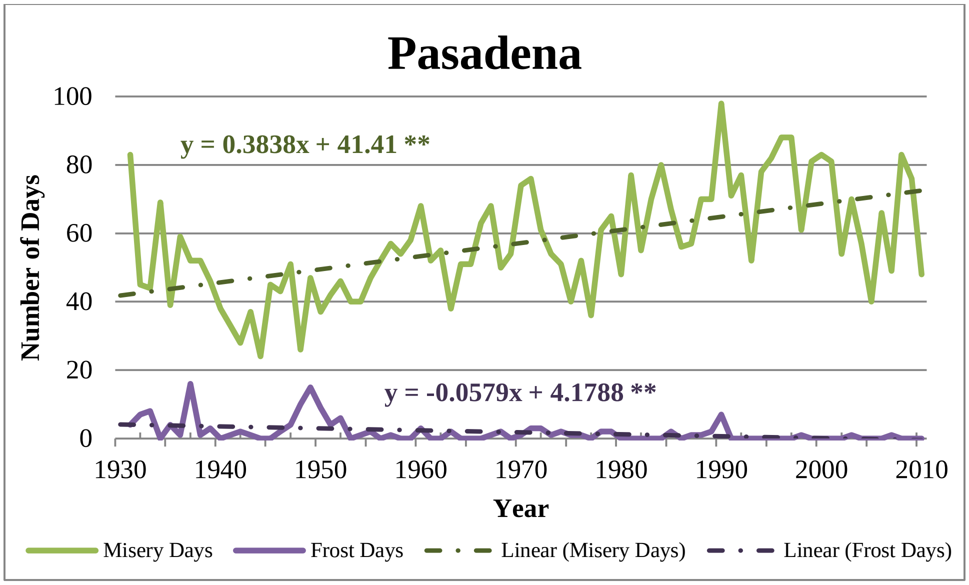

Figure 17: Annual number of frost days and misery days using daily temperature data at the Pasadena weather station from 1931 to 2010. The bold green line represents the trend of misery events and the dashed green line represents the trend line for misery events. The bold purple line represents the trend of frost events and the dashed purple line represents the trend line for frost events. A single asterisk (*) represents statistical significance at p-value < 0.05 and a double asterisk (**) represents statistical significance a p-value < 0.01.

Sandberg is the only weather station that demonstrates an increase in frost days and a decrease in misery days over the 80 year period (Table 11; Figure 18). Sandberg contains no daily temperature records from 1931 to 1940 and has missing daily temperature data for a majority of the decade spanning from 1941 to 1950 (January 1st, 1941 to June 30th, 1948). This missing daily temperature data reveals biased results for both frost and misery days spanning 1941 to 1950 where caution needs to be asserted when analyzing this decadal trend. Therefore, the greatest decadal trend recognized is from 1961 to 2000 because an increase of 77 frost days and a decrease of 365 misery days exist for this time period. Another important finding is that while a trend in decreasing misery days is discovered, the overall trend for misery reveals that there is a larger number of total misery days (2,993) compared to frost days (1,256). Moreover, the maximum and minimum number of frost days are 49 in 1995 and 4 in 1963, respectively. On the other hand, the maximum and minimum number of misery days are 90 in 1952 and 8 in 1995, respectively.

Table 11: Total number and annual mean of frost days and misery days measured by decade at the Sandberg weather station for a total of 80 years (1931 to 2010). Frost days represent temperatures less than or equal to 32 degrees Fahrenheit and misery days are greater than or equal to 90 degrees Fahrenheit.

Decade	Frost Days		Misery Days	
	No.	Mean	No.	Mean
Sandberg	*Weather Station*			
1931-1940	Incomplete	Incomplete	Incomplete	Incomplete
1941-1950	59	5.9	160	16.0
1951-1960	219	21.9	542	54.2
1961-1970	167	16.7	643	64.3
1971-1980	154	15.4	558	55.8
1981-1990	169	16.9	347	34.7
1991-2000	244	24.4	278	27.8
2001-2010	244	24.4	465	46.5
Total	1,256	15.7	2,993	37.4

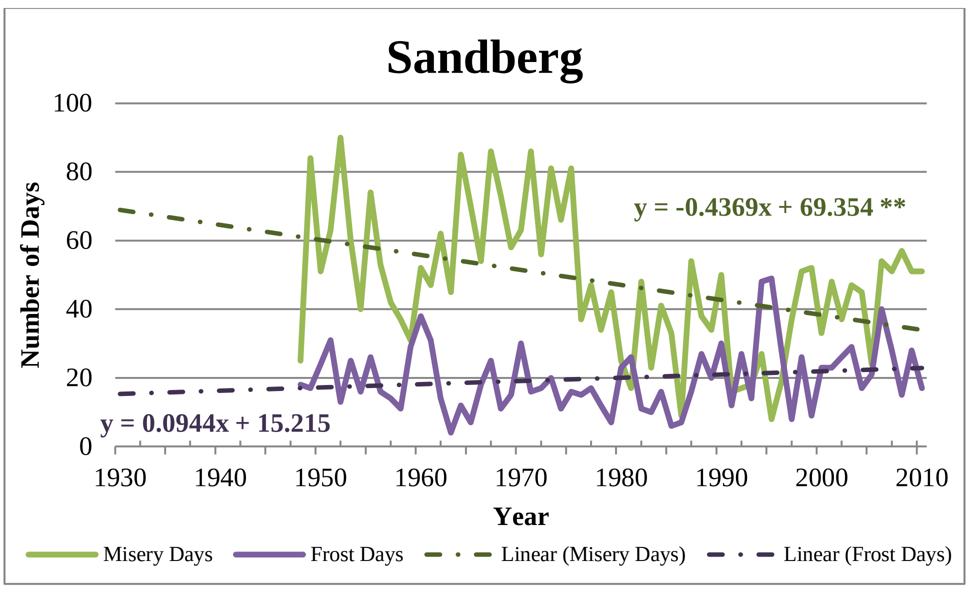

Figure 18: Annual number of frost days and misery days using daily temperature data at the Sandberg weather station from 1948 to 2010. The bold green line represents the trend of misery events and the dashed green line represents the trend line for misery events. The bold purple line represents the trend of frost events and the dashed purple line represents the trend line for frost events. A single asterisk (*) represents statistical significance at p-value < 0.05 and a double asterisk (**) represents statistical significance a p-value < 0.01.

The UCLA weather station is the last weather station that experiences an increase in misery days and a decrease in frost days; however, the decrease in frost day events is very subtle (Table 12; Figure 19). UCLA has no daily temperature records for the decade spanning from 1931 to 1940 and a majority of the decade from 1941 to 1950. The missing daily temperature data spans from January 1st, 1941 to June 30th, 1948 and July 3rd, 1948 to July 11th, 1948. Once again, this missing daily temperature data introduces biased results, urging caution in the results for this time period.

An important decadal trend discovered from 1961 to 2010 include no frost days recorded for 50 years, and another decadal trend from 1941 to 2010 is the steady increase in misery days for 70 years (21 to 101). The maximum and minimum number of frost days are 2 for two years (1949 and 1957) and 0 for 61 different years of record, respectively. Also, the maximum and minimum number of misery days are 21 for two years (2008 and 2009) and 0 in 2001. The totals for the 80 year period are 4 frost days and 536 misery days.

Table 12: Total number and annual mean of frost days and misery days measured by decade at the UCLA weather station for a total of 80 years (1931 to 2010). Frost days represent temperatures less than or equal to 32 degrees Fahrenheit and misery days are greater than or equal to 90 degrees Fahrenheit.

Decade	Frost Days		Misery Days	
	No.	Mean	No.	Mean
UCLA	*Weather Station*			
1931-1940	Incomplete	Incomplete	Incomplete	Incomplete
1941-1950	2	0.2	21	2.1
1951-1960	2	0.2	73	7.3
1961-1970	0	0.0	76	7.6
1971-1980	0	0.0	88	8.8
1981-1990	0	0.0	85	8.5
1991-2000	0	0.0	92	9.2
2001-2010	0	0.0	101	10.1
Total	4	0.05	536	6.7

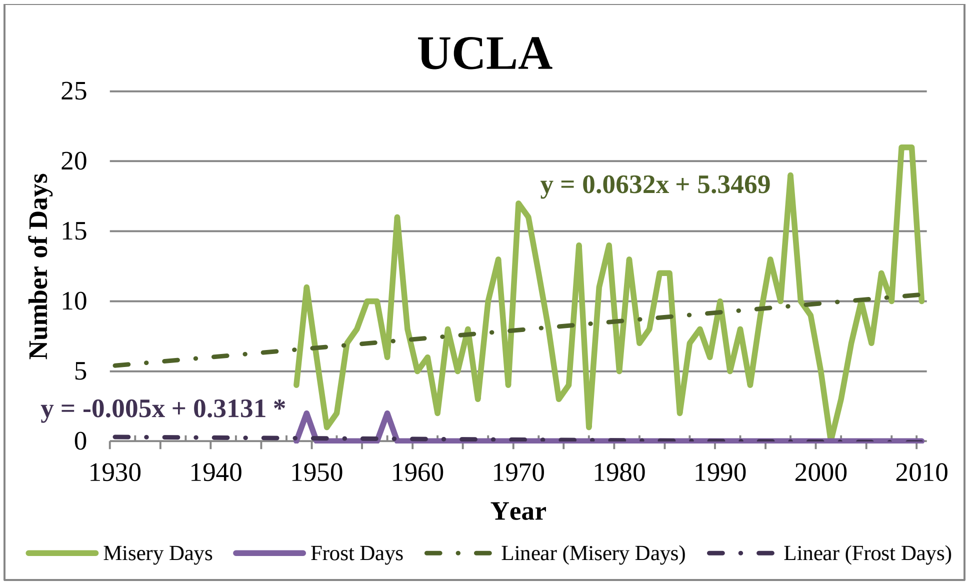

Figure 19: Annual number of frost days and misery days using daily temperature data at the UCLA weather station from 1931 to 2010. The bold green line represents the trend of misery events and the dashed green line represents the trend line for misery events. The bold purple line represents the trend of frost events and the dashed purple line represents the trend line for frost events. A single asterisk (*) represents statistical significance at p-value < 0.05 and a double asterisk (**) represents statistical significance a p-value < 0.01.

4.1.1.1 Frost and Misery Day Linear Regression Significance

The evaluation of each station's frost and misery day linear regression line is accomplished by determining the statistical significance of each extreme temperature threshold. This evaluation process includes executing the standard least squares regression with the independent variable (y) set as year and the dependent variable (x) set as frost day or misery day. This regression analysis shows multiple statistical results from the execution of the standard least square analysis (i.e., R^2, adjusted R^2, root mean square error, sum of squares, F ratio, etc.); however, this analysis only investigates the adjusted coefficient of determination (R^2), slope coefficient, and the p-value < 0.05 (95 percent level) or p-value < 0.01 (99 percent level) statistics for the frost and misery day linear regression line.

Table 13 and Table 14 categorize the statistical significance results for all six weather stations for the entirety of their respective time period and their results are as follows. Fairmont, Los Angeles, and Sandberg are not significant at either p-value level during frost days, but misery days are statistically significant at the 95 percent level (0.0209), the 99 percent level (0.0001), and the 99 percent level (0.0013), respectively. Also, these three stations adjusted R^2 values are 0.0694, 0.1603, and 0.1438, respectively, and the adjusted R^2 value indicates how efficiently the linear regression line represents the misery day threshold data. On the other hand, UCLA is the only weather station that experiences statistical significance only during frost days with a p-value at the 95 percent level of 0.0405 and an adjusted R^2 value of 0.0517.

Palmdale and Pasadena experience statistically significant frost and misery days at the 99 percent level. Palmdale's frost days p-value is 0.0096 and adjusted R^2 is 0.0710, and the misery days p-value is 0.0001 and adjusted R^2 is 0.2438. Additionally, Pasadena's frost days p-value is 0.0001 and adjusted R^2 is 0.1769, and the misery days p-value is 0.0001 and adjusted R^2 is 0.2958. Overall, all six stations show statistical significance, either $p\text{-value} < 0.05$ or $p\text{-value} < 0.01$, during frost or misery days, and two stations (Palmdale and Pasadena) demonstrate statistical significance at the 99 percent level for both frost and misery days.

Table 13: Statistical significance characteristics for frost days at all six weather stations. A single asterisk (*) represents statistical significance at p-value < 0.05 and a double asterisk (**) represents statistical significance a p-value < 0.01.

Weather Station	Data Time Period	Adjusted R^2	Slope Coefficient	p-value
Fairmont	1948-2010	0.0306	-0.1380	0.0903
Los Angeles	1931-2010	0.0099	-0.0037	0.1856
Palmdale	1931-2010	0.0710	-0.2199	0.0096 **
Pasadena	1931-2010	0.1769	-0.0579	0.0001 **
Sandberg	1948-2010	0.0167	0.0944	0.1569
UCLA	1948-2010	0.0517	-0.0049	0.0405 *

Table 14: Statistical significance characteristics for misery days at all six weather stations. A single asterisk (*) represents statistical significance at p-value < 0.05 and a double asterisk (**) represents statistical significance a p-value < 0.01.

Weather Station	Data Time Period	Adjusted R^2	Slope Coefficient	p-value
Fairmont	1948-2010	0.0694	0.2207	0.0209 *
Los Angeles	1931-2010	0.1603	0.1705	0.0001 **
Palmdale	1931-2010	0.2438	0.3547	0.0001 **
Pasadena	1931-2010	0.2958	0.3838	0.0001 **
Sandberg	1948-2010	0.1438	-0.4369	0.0013 **
UCLA	1948-2010	0.0443	0.0632	0.0535

4.1.1.2 Spatial Discontinuity of Three Weather Stations and Their Trends

The results from the frost and misery day annual trends discover that a further investigation into spatial discontinuity is required for Los Angeles, Palmdale, and Sandberg. Since these stations are spatially dispersed the farthest apart for their respective location (Figure 11), an investigation is required to determine the trend of frost and misery days as well as the statistical significance of each linear regression line during the weather station's respective time period by using the standard least squares regression. The parameter for the independent variable (y) is set as year and the dependent variable (x) is set as frost day or misery day, and the listed results are the adjusted coefficient of determination (R^2), slope coefficient, and the p-value < 0.05 (95 percent level) or p-value < 0.01 (99 percent level). These three stations linear trend and standard least squares regression results are as follows.

Figure 20, 21, 22, 23, 24, and 25 illustrate the occurring trend for frost and misery days from 1931 to 1939, 1940 to 1964, 1964 to 1985, 1985 to 1999, 1999 to 2007, and 2007 to 2010 at the Los Angeles weather station, respectively. These six different spatially located Los Angeles stations experience slight variability at each temperature measuring instance based upon the linear regression model. A slight decrease in misery days and increase in frost days occurs from 1931 to 1939, and a slight increase in misery days and decrease in frost days occurs from 1940 to 1964. Also, the period from 1964 to 1985 experiences a modest increase in misery and frost days. Evidence suggests that a warming trend occurred during these three time periods (1985 to 1999, 1999 to 2007, and 2007 to 2010) because of a linear increase in misery days and no recorded frost days during these time periods. Additionally, the only extreme threshold linear regression line that shows any statistical significance is misery days from 1964 to 1985 with an adjusted R^2 of 0.2602 and p-value < 0.01 of 0.0054 (Table 15; Table 16).

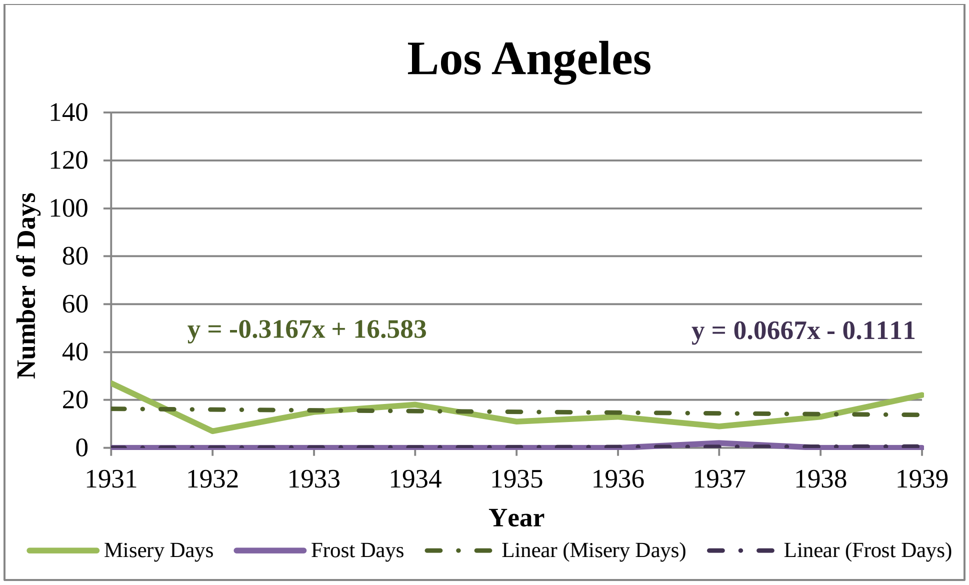

Figure 20: Annual number of frost days and misery days using daily temperature data at the Los Angeles weather station from 1931 to 1939. The bold green line represents the trend of misery events and the dashed green line represents the trend line for misery events. The bold purple line represents the trend of frost events and the dashed purple line represents the trend line for frost events. A single asterisk (*) represents statistical significance at p-value < 0.05 and a double asterisk (**) represents statistical significance a p-value < 0.01.

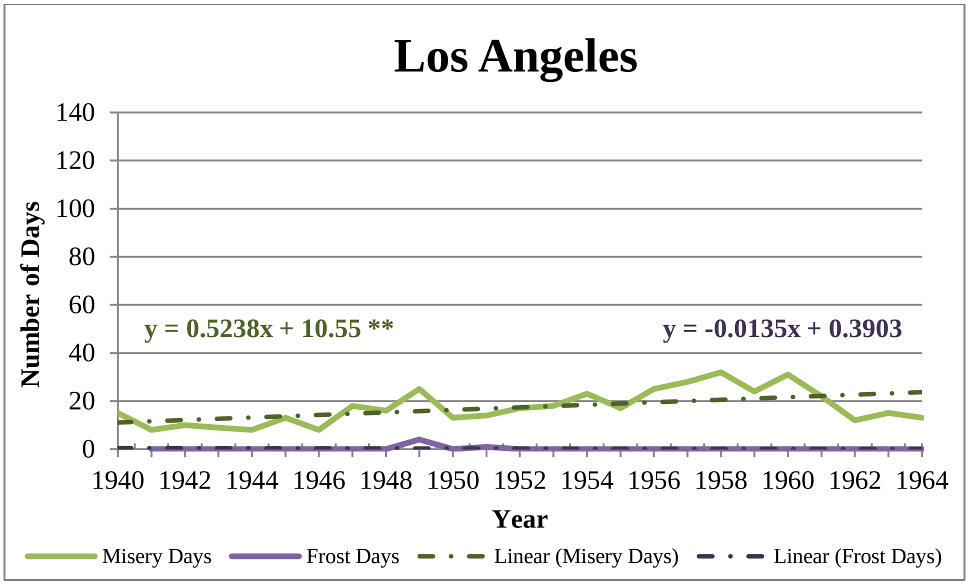

Figure 21: Annual number of frost days and misery days using daily temperature data at the Los Angeles weather station from 1940 to 1964. The bold green line represents the trend of misery events and the dashed green line represents the trend line for misery events. The bold purple line represents the trend of frost events and the dashed purple line represents the trend line for frost events. A single asterisk (*) represents statistical significance at p-value < 0.05 and a double asterisk (**) represents statistical significance a p-value < 0.01.

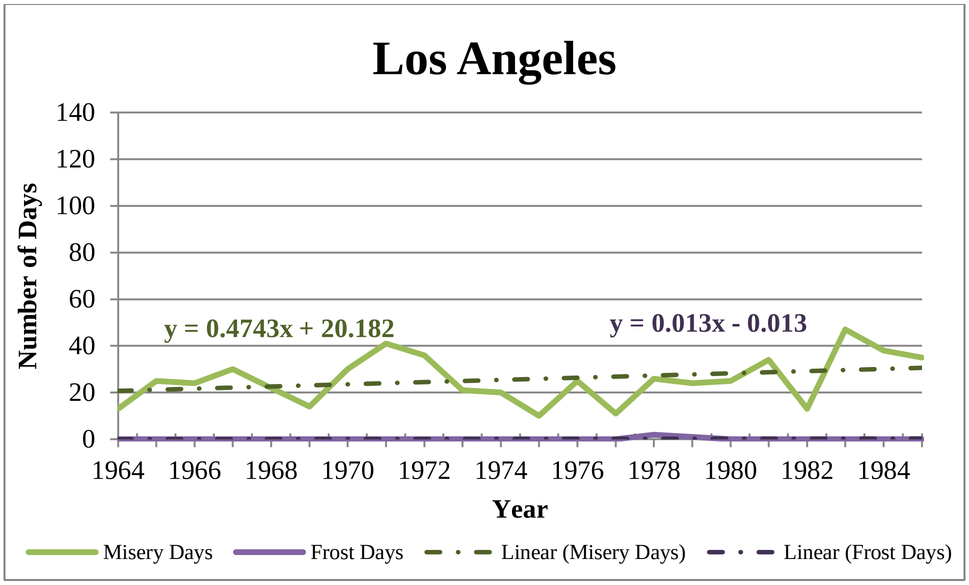

Figure 22: Annual number of frost days and misery days using daily temperature data at the Los Angeles weather station from 1964 to 1985. The bold green line represents the trend of misery events and the dashed green line represents the trend line for misery events. The bold purple line represents the trend of frost events and the dashed purple line represents the trend line for frost events. A single asterisk (*) represents statistical significance at p-value < 0.05 and a double asterisk (**) represents statistical significance a p-value < 0.01.

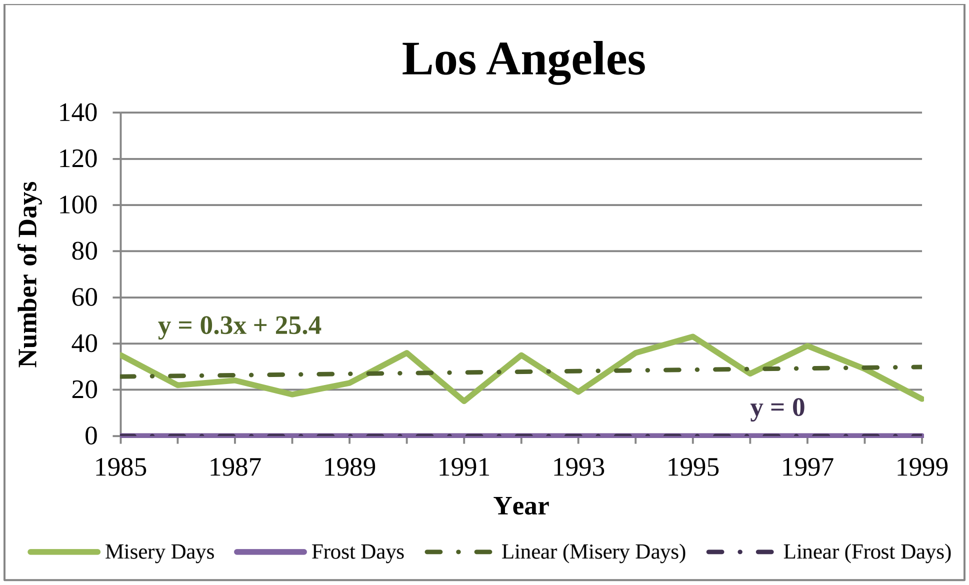

Figure 23: Annual number of frost days and misery days using daily temperature data at the Los Angeles weather station from 1985 to 1999. The bold green line represents the trend of misery events and the dashed green line represents the trend line for misery events. The bold purple line represents the trend of frost events and the dashed purple line represents the trend line for frost events. A single asterisk (*) represents statistical significance at p-value < 0.05 and a double asterisk (**) represents statistical significance a p-value < 0.01.

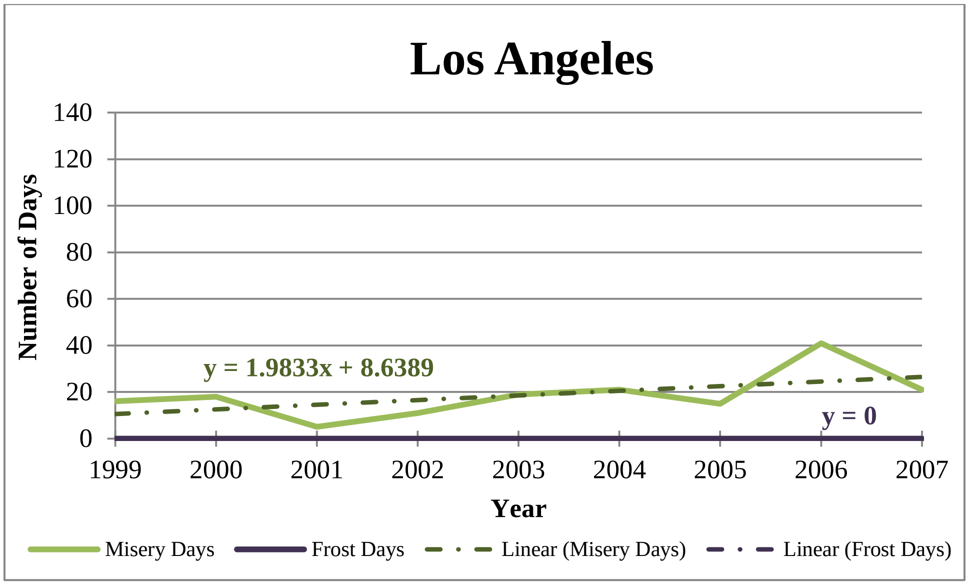

Figure 24: Annual number of frost days and misery days using daily temperature data at the Los Angeles weather station from 1999 to 2007. The bold green line represents the trend of misery events and the dashed green line represents the trend line for misery events. The bold purple line represents the trend of frost events and the dashed purple line represents the trend line for frost events. A single asterisk (*) represents statistical significance at p-value < 0.05 and a double asterisk (**) represents statistical significance a p-value < 0.01.

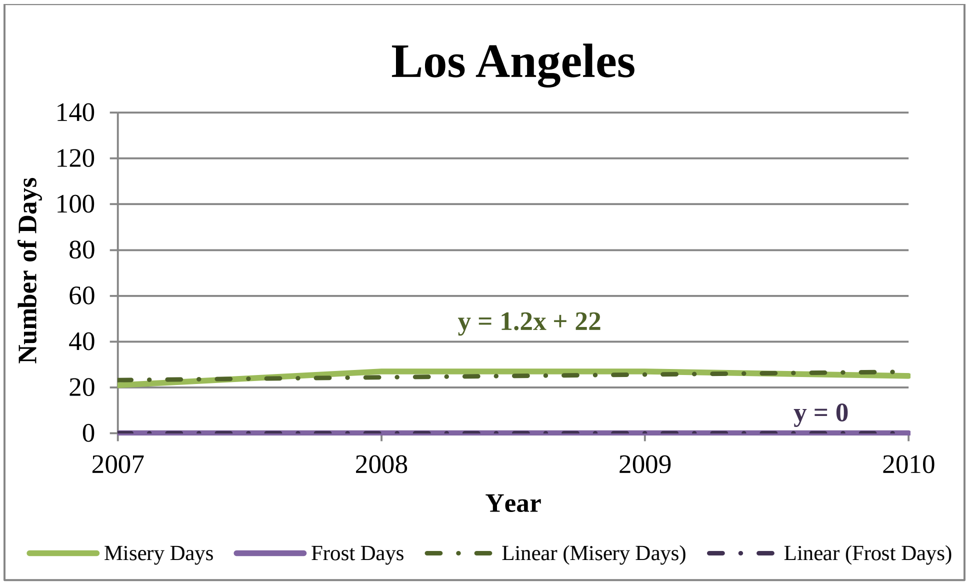

Figure 25: Annual number of frost days and misery days using daily temperature data at the Los Angeles weather station from 2007 to 2010. The bold green line represents the trend of misery events and the dashed green line represents the trend line for misery events. The bold purple line represents the trend of frost events and the dashed purple line represents the trend line for frost events. A single asterisk (*) represents statistical significance at p-value < 0.05 and a double asterisk (**) represents statistical significance a p-value < 0.01.

Table 15: Statistical significance characteristics for frost days at Los Angeles. A single asterisk (*) represents statistical significance at p-value < 0.05 and a double asterisk (**) represents statistical significance a p-value < 0.01.

Weather Station	Data Time Period	Adjusted R2	Slope	p-value
Los Angeles	1931-1939	-0.0571	0.0666	0.4758
Los Angeles	1940-1964	-0.0318	-0.0135	0.5945
Los Angeles	1964-1985	-0.0158	0.0129	0.4218
Los Angeles	1985-1999	Null	0.0000	Null
Los Angeles	1999-2007	Null	0.0000	Null
Los Angeles	2007-2010	Null	0.0000	Null

Table 16: Statistical significance characteristics for misery days at Los Angeles. A single asterisk (*) represents statistical significance at p-value < 0.05 and a double asterisk (**) represents statistical significance a p-value < 0.01.

Weather Station	Data Time Period	Adjusted R2	Slope	p-value
Los Angeles	1931-1939	-0.1218	-0.3167	0.7275
Los Angeles	1940-1964	0.2602	0.5238	0.0054 **
Los Angeles	1964-1985	0.0479	0.4743	0.1669
Los Angeles	1985-1999	-0.0532	0.3000	0.5976
Los Angeles	1999-2007	0.2046	1.9833	0.1238
Los Angeles	2007-2010	-0.0500	1.2000	0.4523

Figure 26, 27, 28, 29, 30, and 31 illustrates that higher variability in frost and misery days occur as compared to the Los Angeles weather station from 1931 to 1948, 1948 to 1952, 1952 to 1962, 1962 to 1982, 1982 to 1993, and 1993 to 2010. The linear regression model identifies a noticeable frost day trend occurring from 1931 to 1933 with an accelerated increase in frost days (71 days) and an accelerated decrease in frost days occurs from 1948 to 1950 (47 days). On the other hand, an accelerated increase in misery days (62 days) occurs from 1932 to 1933 and an accelerated decrease in misery days (69 days) occurs from 1960 to 1961.

Additionally, the linear regression model shows that the time periods from 1931 to 1948 and 1962 to 1982 experience an increasing trend in misery days and frost days. Also, the two time periods (1952 to 1962 and 1993 to 2010) experience a decreasing trend in misery days and frost days. The final two time periods spanning from 1948 to 1952 and 1982 to 1993 saw an increase in misery days and decrease in frost days which suggests that a warming trend occurred during these two time periods. Also, the standard least squares regression proves that the misery day linear regression line from 1931 to 1948 is statistically significant at p-value < 0.01 (99 percent level) and an adjusted R^2 value of 0.4153, and the misery day linear regression line is statistically significant at p-value < 0.05 (95 percent level) and an adjusted R^2 value of 0.2937 from 1982 to 1993 (Table 17; Table 18).

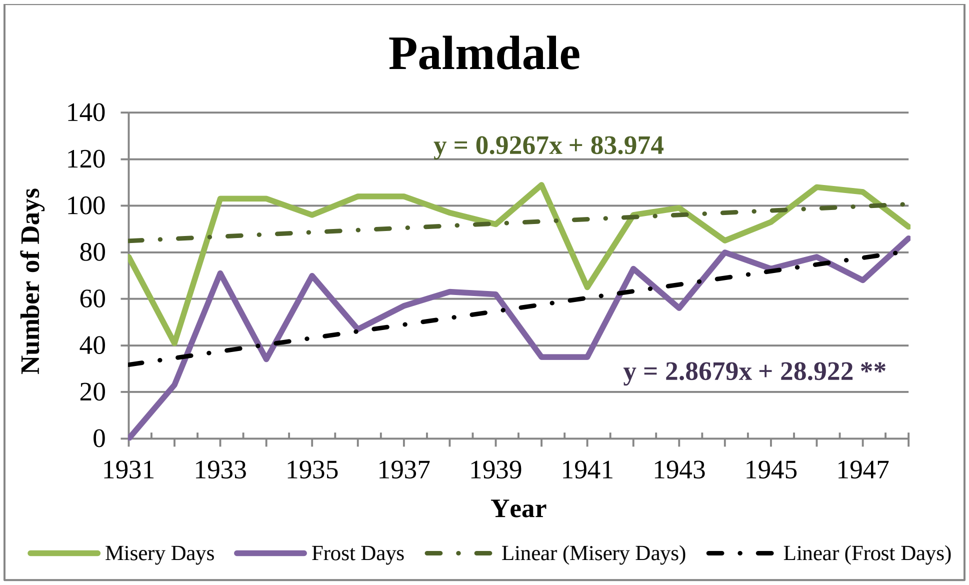

Figure 26: Annual number of frost days and misery days using daily temperature data at the Palmdale weather station from 1931 to 1948. The bold green line represents the trend of misery events and the dashed green line represents the trend line for misery events. The bold purple line represents the trend of frost events and the dashed purple line represents the trend line for frost events. A single asterisk (*) represents statistical significance at p-value < 0.05 and a double asterisk (**) represents statistical significance a p-value < 0.01.

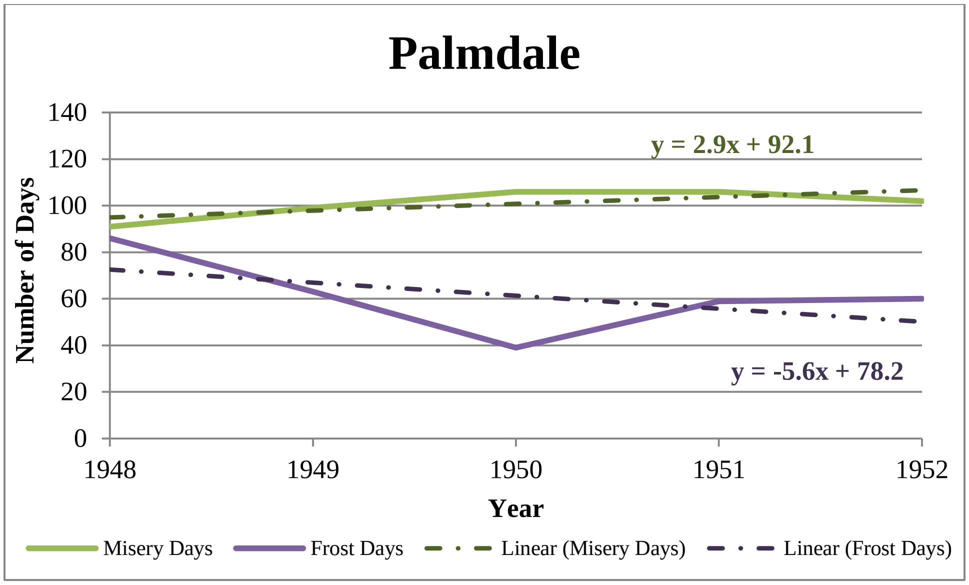

Figure 27: Annual number of frost days and misery days using daily temperature data at the Palmdale weather station from 1948 to 1952. The bold green line represents the trend of misery events and the dashed green line represents the trend line for misery events. The bold purple line represents the trend of frost events and the dashed purple line represents the trend line for frost events. A single asterisk (*) represents statistical significance at p-value < 0.05 and a double asterisk (**) represents statistical significance a p-value < 0.01.

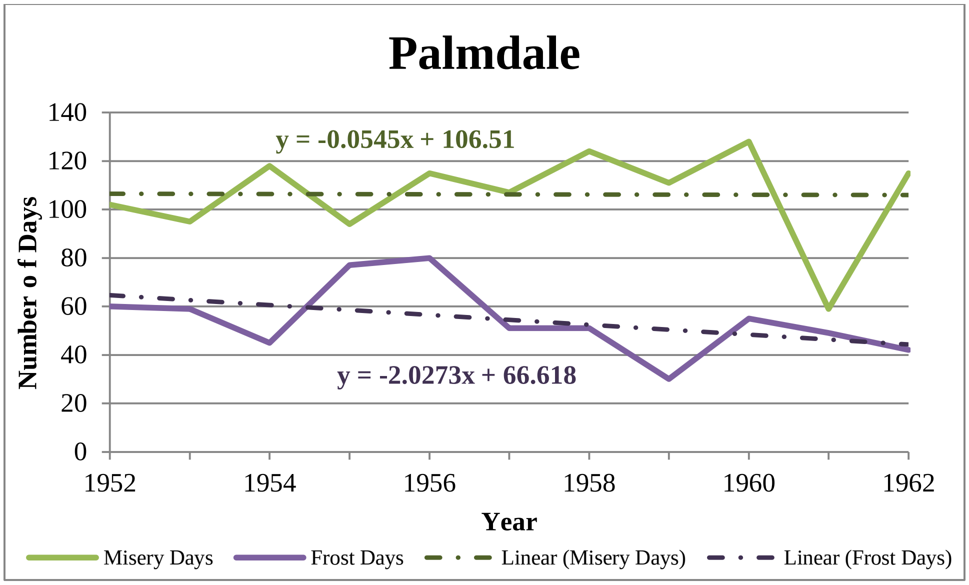

Figure 28: Annual number of frost days and misery days using daily temperature data at the Palmdale weather station from 1952 to 1962. The bold green line represents the trend of misery events and the dashed green line represents the trend line for misery events. The bold purple line represents the trend of frost events and the dashed purple line represents the trend line for frost events. A single asterisk (*) represents statistical significance at p-value < 0.05 and a double asterisk (**) represents statistical significance a p-value < 0.01.

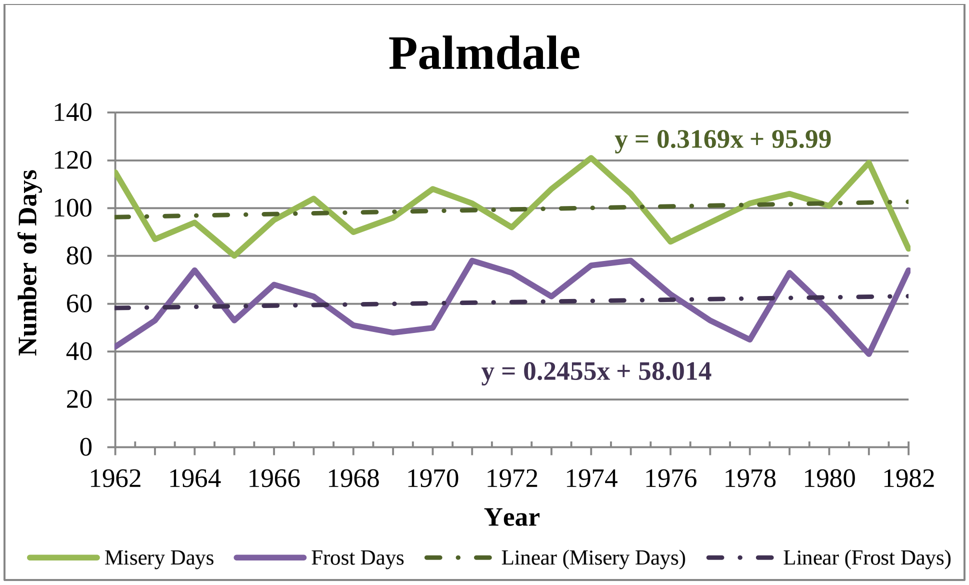

Figure 29: Annual number of frost days and misery days using daily temperature data at the Palmdale weather station from 1962 to 1982. The bold green line represents the trend of misery events and the dashed green line represents the trend line for misery events. The bold purple line represents the trend of frost events and the dashed purple line represents the trend line for frost events. A single asterisk (*) represents statistical significance at p-value < 0.05 and a double asterisk (**) represents statistical significance a p-value < 0.01.

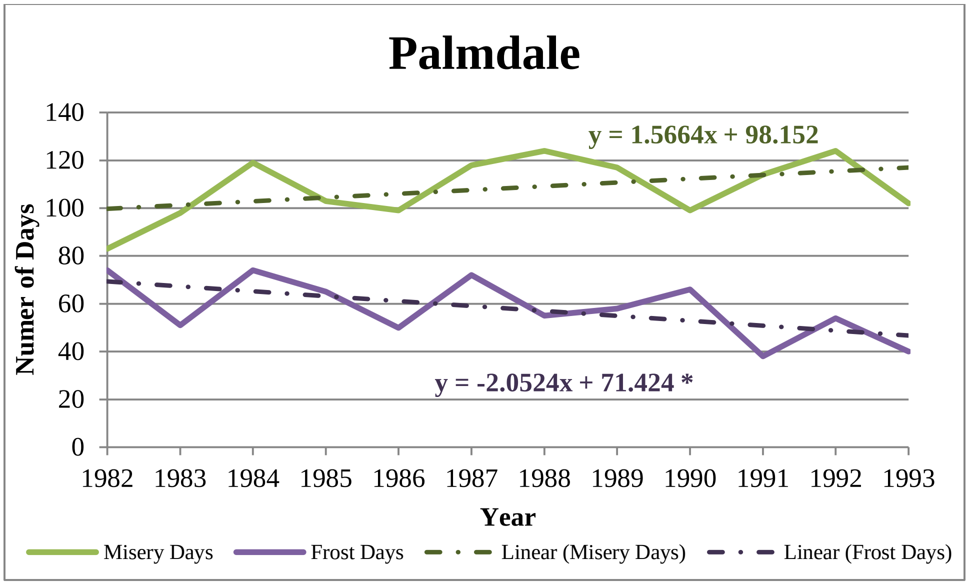

Figure 30: Annual number of frost days and misery days using daily temperature data at the Palmdale weather station from 1982 to 1993. The bold green line represents the trend of misery events and the dashed green line represents the trend line for misery events. The bold purple line represents the trend of frost events and the dashed purple line represents the trend line for frost events. A single asterisk (*) represents statistical significance at p-value < 0.05 and a double asterisk (**) represents statistical significance a p-value < 0.01.

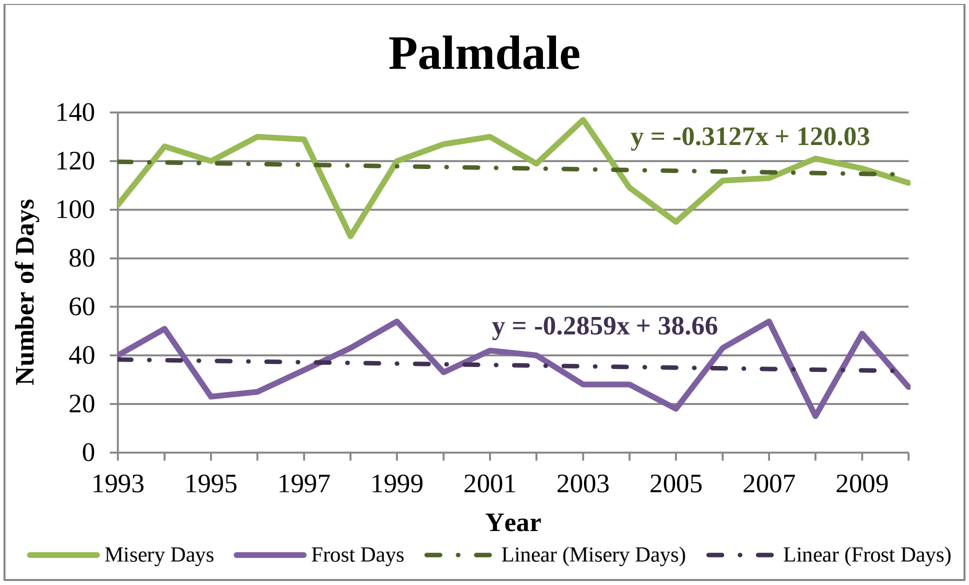

Figure 31: Annual number of frost days and misery days using daily temperature data at the Palmdale weather station from 1993 to 2010. The bold green line represents the trend of misery events and the dashed green line represents the trend line for misery events. The bold purple line represents the trend of frost events and the dashed purple line represents the trend line for frost events. A single asterisk (*) represents statistical significance at p-value < 0.05 and a double asterisk (**) represents statistical significance a p-value < 0.01.

Table 17: Statistical significance characteristics for frost days at Palmdale. A single asterisk (*) represents statistical significance at p-value < 0.05 and a double asterisk (**) represents statistical significance a p-value < 0.01.

Weather Station	Data Time Period	Adjusted R2	Slope	p-value
Palmdale	1931-1948	0.4153	2.8680	0.0023 **
Palmdale	1948-1952	0.0409	-5.6000	0.3585
Palmdale	1952-1962	0.1271	2.0272	0.1515
Palmdale	1962-1982	-0.0373	0.2454	0.6027
Palmdale	1982-1993	0.2937	-2.0524	0.0399 *
Palmdale	1993-2010	-0.0456	-0.2859	0.6177

Table 18: Statistical significance characteristics for misery days at Palmdale. A single asterisk (*) represents statistical significance at p-value < 0.05 and a double asterisk (**) represents statistical significance a p-value < 0.01.

Weather Station	Data Time Period	Adjusted R2	Slope	p-value
Palmdale	1931-1948	0.0269	0.9267	0.2428
Palmdale	1948-1952	0.3910	2.9000	0.1553
Palmdale	1952-1962	-0.1110	-0.0545	0.9779
Palmdale	1962-1982	-0.0210	0.3169	0.4528
Palmdale	1982-1993	0.1148	1.5664	0.1503
Palmdale	1993-2010	-0.0441	-0.3127	0.6027

As compared to Palmdale, Sandberg shows high misery and frost day variability from 1948 to 1981, 1982 to 1996, 1996 to 2000, and 2000 to 2010 (Figure 32; Figure 33; Figure 34; Figure 35). The linear regression shows that an accelerated shift in frost days occurs during two time periods: (1) accelerated increase (34 frost days) occurs from 1993 to 1994 and (2) accelerated decrease (34 frost days) occurs from 1960 to 1963. Also, two time periods experience a shift in misery days: (1) accelerated increase (45 misery days) occurs from 1986 to 1987 and (2) accelerated decrease (64 misery days) occurs from 1975 to 1981.

Specifically, the linear regression model identifies 1948 to 1981 as a time period that experiences a decrease in misery and frost days. Also, an accelerated increase in misery days and decrease in frost days occurs from 1996 to 2000 and 2000 to 2010 which suggests that a warming trend is occurring at Sandberg. Conversely, an accelerated decrease in misery days and an accelerated increase in frost days occurs from 1982 to 1996 and this threshold trend suggests that a cooling trend occurs at Sandberg.

Furthermore, the results from the standard least squares regression model (Table 19; Table 20) identify only one statistically significant linear regression line as frost days from 1982 to 1996 with a p-value of 0.0029 (significant at the 99 percent level) and an adjusted R^2 value of 0.4691.

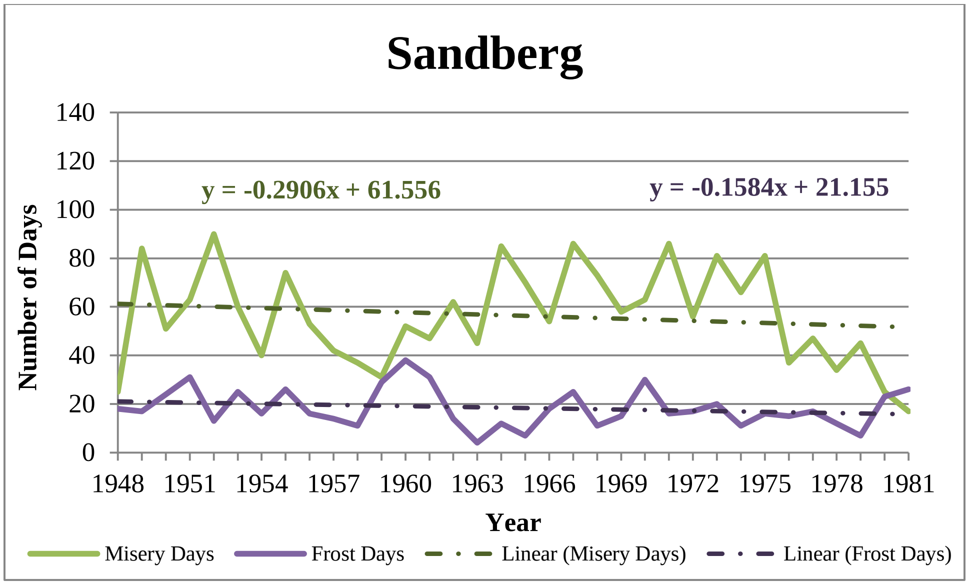

Figure 32: Annual number of frost days and misery days using daily temperature data at the Sandberg weather station from 1948 to 1981. The bold green line represents the trend of misery events and the dashed green line represents the trend line for misery events. The bold purple line represents the trend of frost events and the dashed purple line represents the trend line for frost events. A single asterisk (*) represents statistical significance at p-value < 0.05 and a double asterisk (**) represents statistical significance a p-value < 0.01.

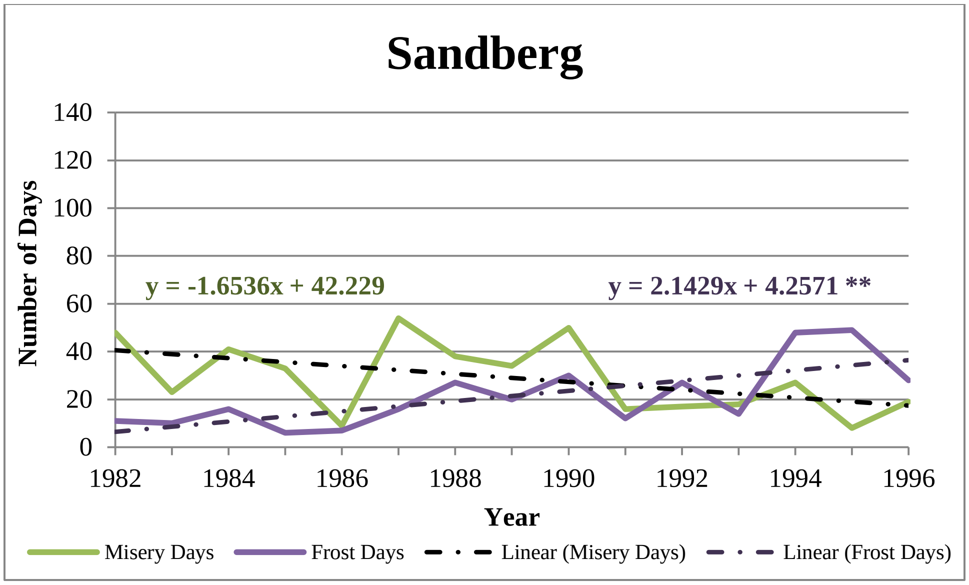

Figure 33: Annual number of frost days and misery days using daily temperature data at the Sandberg weather station from 1982 to 1996. The bold green line represents the trend of misery events and the dashed green line represents the trend line for misery events. The bold purple line represents the trend of frost events and the dashed purple line represents the trend line for frost events. A single asterisk (*) represents statistical significance at p-value < 0.05 and a double asterisk (**) represents statistical significance a p-value < 0.01.

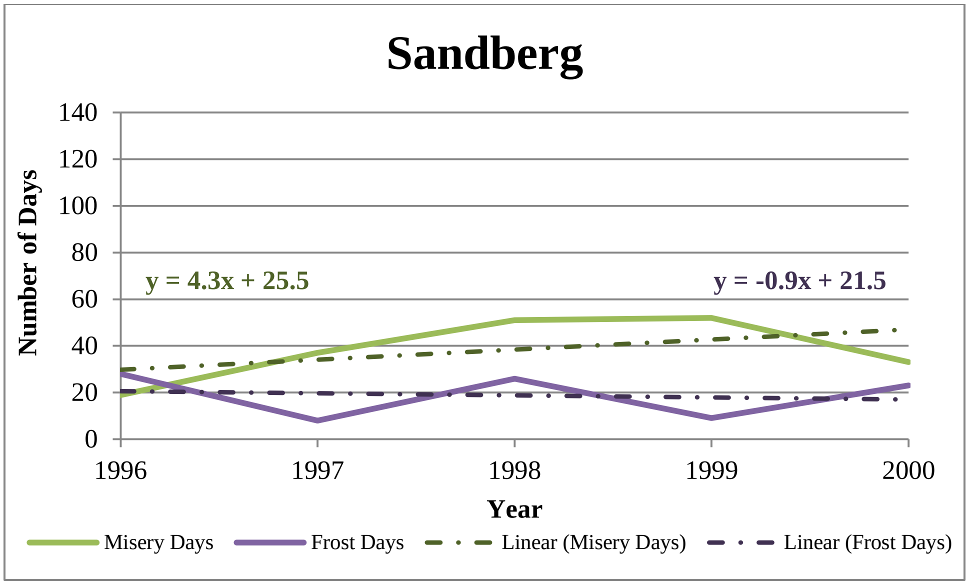

Figure 34: Annual number of frost days and misery days using daily temperature data at the Sandberg weather station from 1996 to 2000. The bold green line represents the trend of misery events and the dashed green line represents the trend line for misery events. The bold purple line represents the trend of frost events and the dashed purple line represents the trend line for frost events. A single asterisk (*) represents statistical significance at p-value < 0.05 and a double asterisk (**) represents statistical significance a p-value < 0.01.

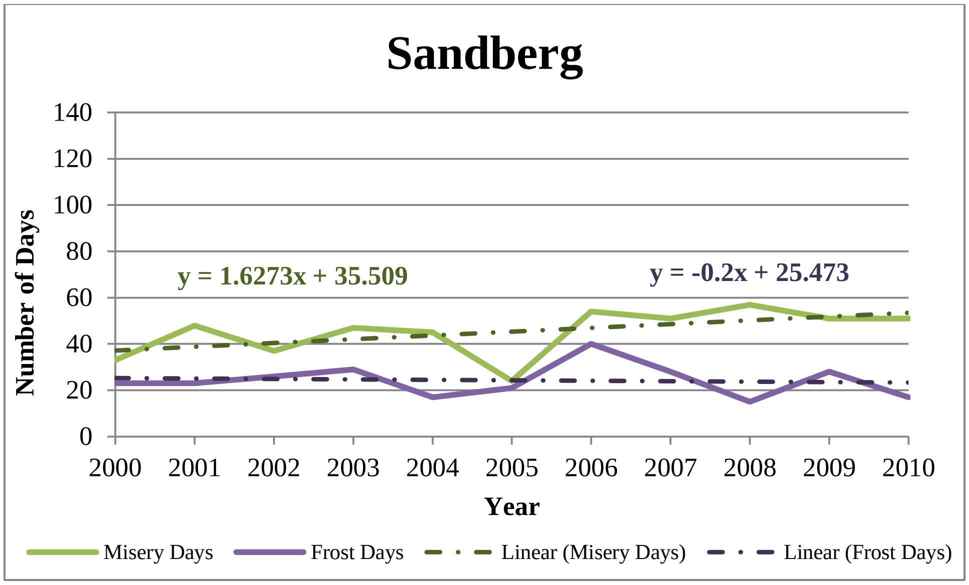

Figure 35: Annual number of frost days and misery days using daily temperature data at the Sandberg weather station from 2000 to 2010. The bold green line represents the trend of misery events and the dashed green line represents the trend line for misery events. The bold purple line represents the trend of frost events and the dashed purple line represents the trend line for frost events. A single asterisk (*) represents statistical significance at p-value < 0.05 and a double asterisk (**) represents statistical significance a p-value < 0.01.

Table 19: Statistical significance characteristics for frost days at Sandberg. A single asterisk (*) represents statistical significance at p-value < 0.05 and a double asterisk (**) represents statistical significance a p-value < 0.01.

Weather Station	Data Time Period	Adjusted R2	Slope	p-value
Sandberg	1948-1981	0.0103	-0.1584	0.2551
Sandberg	1982-1996	0.4691	2.1429	0.0029 **
Sandberg	1996-2000	-0.3039	-0.9000	0.8115
Sandberg	2000-2010	-0.1015	-0.2000	0.7851

Table 20: Statistical significance characteristics for misery days at Sandberg. A single asterisk (*) represents statistical significance at p-value < 0.05 and a double asterisk (**) represents statistical significance a p-value < 0.01.

Weather Station	Data Time Period	Adjusted R2	Slope	p-value
Sandberg	1931-1981	-0.0095	-0.2906	0.4119
Sandberg	1982-1996	0.1883	-1.6536	0.0599
Sandberg	1996-2000	-0.0052	4.3000	0.3953
Sandberg	2000-2010	0.2144	1.6273	0.0855

4.1.2 Heat Wave Decadal Thresholds

The characteristics of heat waves for all six weather stations are summarized within each of the following: Table 21, 22, 23, 24, 25, and 26. These tables describe decadal trends for temperature thresholds T1 and T2, frequency, intensity, and the average duration of heat waves for their respective station location over the 80 year period (1931 to 2010). Specific heat wave trends and characteristics are described by the following paragraphs.

The first weather station is Fairmont (Table 21) and it is important to note that the decade spanning from 1931 to 1940 contain no daily temperature records and a portion of the decade from 1941 to 1950 has missing temperature data. Also, the 20 year span between 1991 and 2010 experience the highest T1 and T2 thresholds at 100.0°F and 89.9°F, respectively. The maximum and minimum number of heat wave events (frequency) are 13 from 2001 to 2010 and 4 from 1941 to 1950, respectively. The maximum and minimum intensity is 103.8°F from 1991 to 2000 and 100.2°F from 1941 to 1970, respectively. The final characteristic is an average duration of a heat wave event and its maximum and minimum duration is 5.4 days from 1951 to 1960 and 2.1 days from 1981 to 2000, respectively.

Table 21: Heat wave characteristics by decade from daily temperature data for the Fairmont weather station from 1931 to 2010. T1 and T2 define the 97.5 percentile and 81 percentile of normal conditions, respectively. Frequency is the number of heat wave events, intensity is the average maximum temperature of the heat wave, and average duration is average span of each heat wave event.

Decade	Heat wave characteristics				
	T1 (°F)	T2 (°F)	Frequency	Intensity (°F)	Average duration (d)
	Fairmont Weather Station				
1931-1940	98.1	87.9	Incomplete	Incomplete	Incomplete
1941-1950	98.1	87.9	4	100.2	3.6
1951-1960	98.1	87.9	7	100.2	5.4
1961-1970	98.1	87.9	8	100.2	5.0
1971-1980	98.1	87.9	11	101.5	2.5
1981-1990	98.1	87.9	6	101.5	2.1
1991-2000	100.0	89.9	11	103.8	2.1
2001-2010	100.0	89.9	13	103.5	2.5
Average:	98.6	88.5	8.6	101.5	3.3

Another weather station with heat wave characteristics is Los Angeles (Table 22). Temperature threshold T1 and T2 reaches its maximum threshold conjointly from 1961 to 1980 with measurements of 92.1°F and 84.0°F, respectively. Additionally, the maximum frequency is 14 heat events during two decades (1951 to 1960 and 1971 to 1980), and the minimum frequency is 3 heat events from 1941 to 1950. Maximum and minimum intensity is 98.9°F during the 1971 to 1980 decade and 95.7°F from 1941 to 1950, respectively. The maximum average duration of a heat event is 4.3 days which occurred from 1951 to 1960 and the minimum average duration of a heat event is 2.0 days and spans from 1941 to 1950.

Table 22: Heat wave characteristics by decade from daily temperature data for the Los Angeles weather station from 1931 to 2010. T1 and T2 define the 97.5 percentile and 81 percentile of normal conditions, respectively. Frequency is the number of heat wave events, intensity is the average maximum temperature of the heat wave, and average duration is average span of each heat wave event.

Decade	Heat wave characteristics				
	T1 (°F)	T2 (°F)	Frequency	Intensity (°F)	Average duration (d)
	Los Angeles	Weather	Station		
1931-1940	91.9	82.0	4	95.9	4.0
1941-1950	91.9	82.0	3	95.7	2.0
1951-1960	91.9	82.0	14	95.5	4.3
1961-1970	92.1	84.0	9	98.2	3.2
1971-1980	92.1	84.0	14	98.9	2.5
1981-1990	92.1	84.0	18	98.6	3.0
1991-2000	92.1	82.9	10	97.7	3.0
2001-2010	92.1	82.9	8	96.9	3.0
Average:	93.2	82.9	10	97.2	3.1

The weather station at Palmdale (Table 23) demonstrates maximum T1 measurement of 104.0°F and T2 measurement of 96.1°F conjointly from 1991 to 2010. Frequency reaches its maximum from 1951 to 1960 and 1991 to 2000 with 13 heat wave events. The minimum number of heat events (frequency) occurs from 1941 to 1950 with 5 heat wave events. Maximum and minimum intensity measurements are 106.5°F from 1991 to 2010 and 104.9°F from 1961 to 1970, respectively. The final heat wave characteristic is average duration with its maximum measurement is 6.7 days from 1961 to 1970 and its minimum measurement is 2.5 days from 1931 to 1940. Moreover, the minimum measurement of 2.5 days from 1931 to 1940 must be considered with caution because missing daily temperatures exist from January 1st, 1931 until March 31st, 1931 and October 1st, 1931 until August 15th, 1932. Furthermore, maximum measurements are recorded in Palmdale for T1 (103.6°F), T2 (94.8°F), intensity (105.9°F), and average duration (3.7 days) compared to all six weather stations. Therefore, these extremes show that heat wave events are very intense and pronounced at the Palmdale location.

Table 23: Heat wave characteristics by decade from daily temperature data for the Palmdale weather station from 1931 to 2010. T1 and T2 define the 97.5 percentile and 81 percentile of normal conditions, respectively. Frequency is the number of heat wave events, intensity is the average maximum temperature of the heat wave, and average duration is average span of each heat wave event.

Decade	Heat wave characteristics				
	T1 (°F)	T2 (°F)	Frequency	Intensity (°F)	Average duration (d)
	Palmdale	Weather	Station		
1931-1940	104.0	95.0	11	106.2	2.5
1941-1950	104.0	95.0	5	106.5	3.7
1951-1960	104.0	95.0	13	105.8	3.7
1961-1970	102.9	93.9	6	104.9	6.7
1971-1980	102.9	93.9	11	105.9	2.9
1981-1990	102.9	93.9	11	105.6	2.7
1991-2000	104.0	96.1	13	106.5	4.4
2001-2010	104.0	96.1	9	106.5	2.8
Average:	103.6	94.8	9.9	105.9	3.7

Pasadena (Table 24) temperature threshold T1 and T2 reach their maximum from 1991 to 2010 with measurements of 98.9°F and 89.1°F, respectively. The maximum and minimum number of heat events (frequency) are 20 from 1981 to 1990 and 7 from two temporally distant decades (1931 to 1940 and 1961 to 1970). Noteworthy is the frequency trend from 1961 to 1990 where the number of heat events increases by 13 in a 30 year period. Also, the recorded number of heat events is the most in Pasadena from 1931 to 2010 compared to all six weather stations which suggest that heat wave events are experienced more here than any other weather station location. The maximum intensity temperature is 102.7°F from 1991 to 2000 and the minimum intensity temperature is 99.5°F from 1951 to 1960. Also, the maximum average duration of a heat wave event is 4.1 days from 1951 to 1960 and the minimum average duration of a heat wave event is 2.1 days from 1941 to 1950.

Table 24: Heat wave characteristics by decade from daily temperature data for the Pasadena weather station from 1931 to 2010. T1 and T2 define the 97.5 percentile and 81 percentile of normal conditions, respectively. Frequency is the number of heat wave events, intensity is the average maximum temperature of the heat wave, and average duration is average span of each heat wave event.

Decade	Heat wave characteristics				
	T1 (°F)	T2 (°F)	Frequency	Intensity (°F)	Average duration (d)
	Pasadena	Weather	Station		
1931-1940	96.9	87.1	7	100.8	3.5
1941-1950	96.9	87.1	9	100.4	2.1
1951-1960	96.9	87.1	15	99.5	4.1
1961-1970	98.1	87.9	7	101.7	2.7
1971-1980	98.1	87.9	13	102.6	2.7
1981-1990	98.1	87.9	20	102.0	2.7
1991-2000	98.9	89.1	16	102.7	2.5
2001-2010	98.9	89.1	8	101.7	3.2
Average:	97.9	87.9	11.9	101.5	2.9

Sandberg (Table 25) most defining heat wave characteristics are described by the following statistics. The decade from 1931 to 1940 contains no daily temperature records and the decade from 1941 to 1950 contains approximately a year and half of daily temperature data. Additionally, temperature threshold T1 and T2 reaches there maximum from 1991 to 2010 with measurements of 93.9°F and 82.9°F, respectively. The minimum frequency is 4 heat wave events, biased results must be considered due to the missing daily temperature data, from 1941 to 1950; on the other hand, the maximum frequency is 10 heat wave events stretching 30 consecutive years (1971 to 2000). Also, the 80 year frequency average is at the minimum in Sandberg with 7.7 heat wave events compared to all six weather stations. This frequency statistic shows that heat wave events are less frequent than any of the other six weather stations. The maximum and minimum intensity measurements are 93.0°F from 1961 to 1970 and 96.4°F from 1991 to 2010, respectively. Sandberg experiences the maximum average duration from 1961 to 1970 with a result of 5.8 days and a minimum average duration of 2.4 days from 1951 to 1960.

Table 25: Heat wave characteristics by decade from daily temperature data for the Sandberg weather station from 1931 to 2010. T1 and T2 define the 97.5 percentile and 81 percentile of normal conditions, respectively. Frequency is the number of heat wave events, intensity is the average maximum temperature of the heat wave, and average duration is average span of each heat wave event.

Decade	Heat wave characteristics				
	T1 (°F)	T2 (°F)	Frequency	Intensity (°F)	Average duration (d)
	Sandberg	Weather	Station		
1931-1940	91.9	82.9	Incomplete	Incomplete	Incomplete
1941-1950	91.9	82.9	4	94.1	3.9
1951-1960	91.9	82.9	7	95.4	2.4
1961-1970	91.6	82.0	8	93.0	5.8
1971-1980	91.6	82.0	10	94.1	3.1
1981-1990	91.6	82.0	10	93.6	2.7
1991-2000	93.9	82.9	10	96.4	3.0
2001-2010	93.9	82.9	5	96.4	2.7
Average:	92.3	82.6	7.7	94.6	3.4

The final weather station discussed is the UCLA (Table 26) weather station and this station has no daily temperature records from 1931 to 1940 and missing daily temperature data for over a year and half of the collection period spanning from 1941 to 1950. Maximum temperature threshold T1 and T2 is recorded from 1991 to 2010 with measurements of 89.9°F and 78.9°F. The maximum frequency is 12 heat wave events and occurs from 1981 to 1990, and the minimum frequency is 1 heat wave event and this occurrence is from 1941 to 1950. However, this minimum frequency result must be considered biased due to the lack of daily temperature data spanning this decade. The intensity of heat wave events reaches its maximum from 1981 to 1990 with a recorded measurement of 94.8°F and a minimum recorded measurement of 90.9°F. Once again, this minimum measurement needs to be considered with caution due to the lack of daily temperature data for this time period. The average duration of heat wave events is at its maximum from 1991 to 2010 at 3.8 days and is at its minimum with 2.4 days spanning from 1991 to 2010. Overall, UCLA experiences the lowest T1 (89.2°F) and T2 (78.3°F) measurements, the lowest intensity temperature (93.7°F), and a shared shortest average duration of heat wave events (2.9 days) comparative to all six weather stations spanning an 80 year time period.

Table 26: Heat wave characteristics by decade from daily temperature data for the UCLA weather station from 1931 to 2010. T1 and T2 define the 97.5 percentile and 81 percentile of normal conditions, respectively. Frequency is the number of heat wave events, intensity is the average maximum temperature of the heat wave, and average duration is average span of each heat wave event.

Decade	Heat wave characteristics				
	T1 (°F)	T2 (°F)	Frequency	Intensity (°F)	Average duration (d)
	UCLA	Weather	Station		
1931-1940	89.1	78.1	Incomplete	Incomplete	Incomplete
1941-1950	89.1	78.1	1	90.9	3.0
1951-1960	89.1	78.1	9	94.5	3.3
1961-1970	89.1	78.1	11	93.7	2.6
1971-1980	89.1	78.1	10	94.3	3.8
1981-1990	89.1	78.1	12	94.8	2.6
1991-2000	89.9	78.9	7	93.7	2.4
2001-2010	89.9	78.9	7	94.5	2.4
Average:	89.2	78.3	8.1	93.7	2.9

An important note to mention is the mean results for T1, T2, frequency, intensity, and average duration is not tested for statistical significance within this current study. The difference of means test (t-test) would clarify the importance and significance of these mean results. This test would measure the significance of differences between the true mean and one or two sample means using the t-statistic result (University of Oregon 2014).

4.2 Monthly Temperature and Its Trend

The eight weather stations described in Table 4 are plotted to determine their monthly temperature trend from approximately 1931 to 2010 (Figure 36, 37, 38, 39, 40, 41, 42, and 43). These eight figures illustrate that each station demonstrates a unique trend over their respective time period and an increase in monthly surface temperature over time. In addition, all of the stations exhibit a fluctuation in monthly surface temperature due to seasonal variability. Seasonal variability can be explained as the change in temperature from season to season; for example, winter months will experience the coldest temperatures and summer months will experience the warmest temperatures throughout the year. The following describes each weather station's monthly temperature trends in greater detail.

Fairmont (Figure 36) has a maximum monthly temperature of 85.6°F for the July 1st, 1931 measurement and a minimum monthly temperature of 31.3°F for the January 1st, 1937 measurement. These maximum and minimum monthly temperatures are evidence that Fairmont experiences the largest range (difference between the maximum and minimum monthly temperature) than any other weather station measuring monthly surface temperature (54.3°F). Moreover, the period spanning from January 1st, 1981 to December 1st, 1982 shows lower than normal monthly surface temperatures. These lower monthly temperatures are ultimately caused by 13 months of missing monthly temperature records during this two year time period.

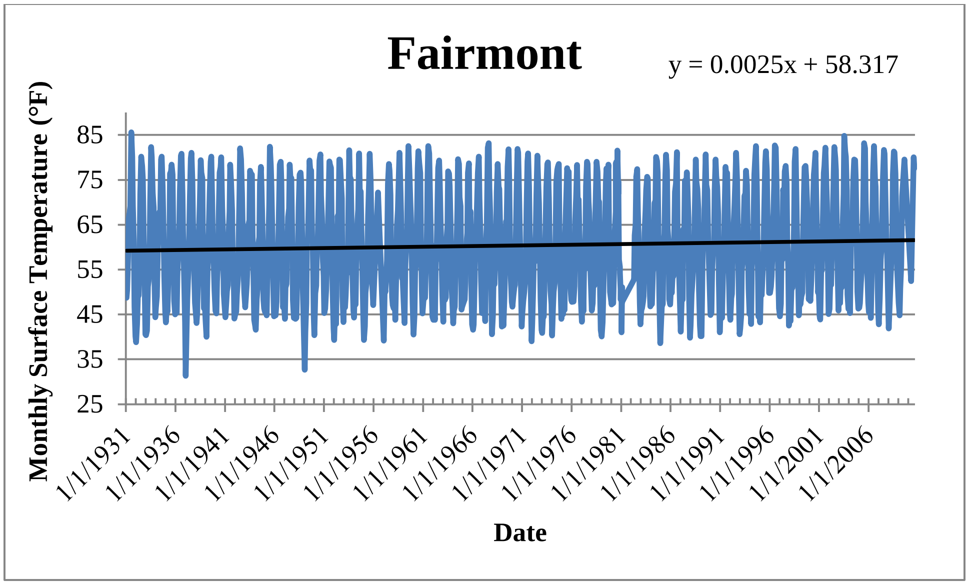

Figure 36: Monthly surface temperature trend at the Fairmont weather station from 1931 to 2010. The bold blue line represents the monthly surface temperature and the bold black line represents the trend line for monthly surface temperature. A single asterisk (*) represents statistical significance at p-value < 0.05 and a double asterisk (**) represents statistical significance a p-value < 0.01.

The LAX (Figure 37) weather station experienced normal seasonal monthly temperature fluctuations, but an unordinary dip in December monthly temperatures occurs in 1949 and 1950. The two lowest recorded monthly temperatures occur during these two years with a temperature of 47.0°F in 1949 and 48.5°F in 1950. The warmest monthly temperature on record at LAX is 76.5°F during the September 1st, 1984 measurement.

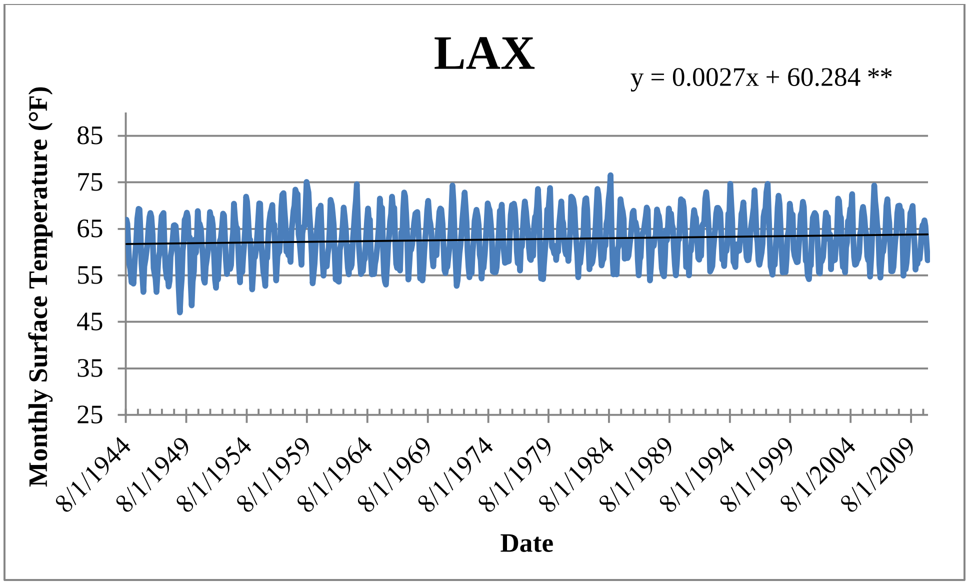

Figure 37: Monthly surface temperature trend at the Los Angeles International Airport weather station from 1944 to 2010. The bold blue line represents the monthly temperature and the bold black line represents the trend line for monthly surface temperature. A single asterisk (*) represents statistical significance at p-value < 0.05 and a double asterisk (**) represents statistical significance a p-value < 0.01.

Palmdale (Figure 38) experiences a normal seasonal trend of monthly temperatures with the coldest temperature of 33.4°F recorded on the January 1st, 1937 measurement and the warmest temperature of 87.0°F recorded on the July 1st, 1931 and July 1st, 1959 measurement. Additionally, biased results must be adhered to because 11 months of monthly temperature data is missing from April 1st, 1931 to December 1st, 1932.

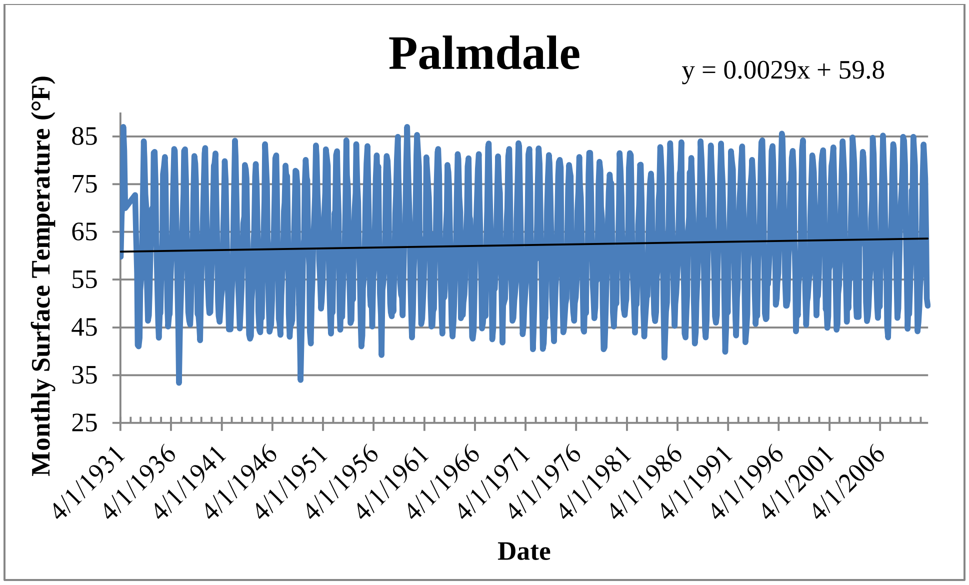

Figure 38: Monthly surface temperature trend at the Palmdale weather station from 1931 to 2010. The bold blue line represents the monthly surface temperature and the bold black line represents the trend line for monthly surface temperature. A single asterisk (*) represents statistical significance at p-value < 0.05 and a double asterisk (**) represents statistical significance a p-value < 0.01.

Pasadena (Figure 39) undergoes an increasing trend in monthly temperatures during its respective time period. Monthly temperature records provide evidence of a warming trend as seven of the monthly measurements have temperatures of 80°F or greater since the August 1st, 1967 measurement with two of the station's warmest monthly temperatures of 81.6°F and 82.4°F takin place during the last 13 years; respectively August 1st, 1998 and July 1st, 2006. A minimum monthly temperature is recorded on the January 1st, 1937 measurement with a temperature of 43.4°F.

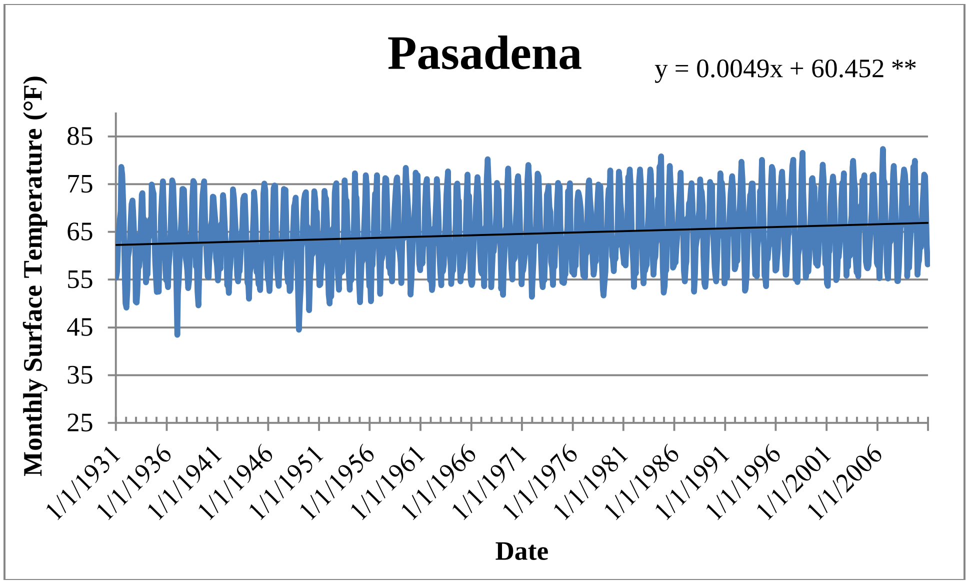

Figure 39: Monthly surface temperature trend at the Pasadena weather station from 1931 to 2010. The bold blue line represents the monthly surface temperature and the bold black line represents the trend line for monthly surface temperature. A single asterisk (*) represents statistical significance at p-value < 0.05 and a double asterisk (**) represents statistical significance a p-value < 0.01.

Sandberg (Figure 40) experiences a wide range in minimum and maximum monthly temperatures over the station's time period. The maximum monthly temperature recorded is 79.5°F on the August 1st, 1994 measurement and the minimum monthly temperature is 27.1°F on the January 1st, 1949 measurement with this January temperature the coldest on record compared to all eight weather stations. Important to mention, the Sandberg monthly temperature data is lacking monthly temperature measurements for 40 months spanning from August 1st, 1996 to October 1st, 2000. This large gap in data explains the severe drop in monthly temperature illustrated in Figure 40.

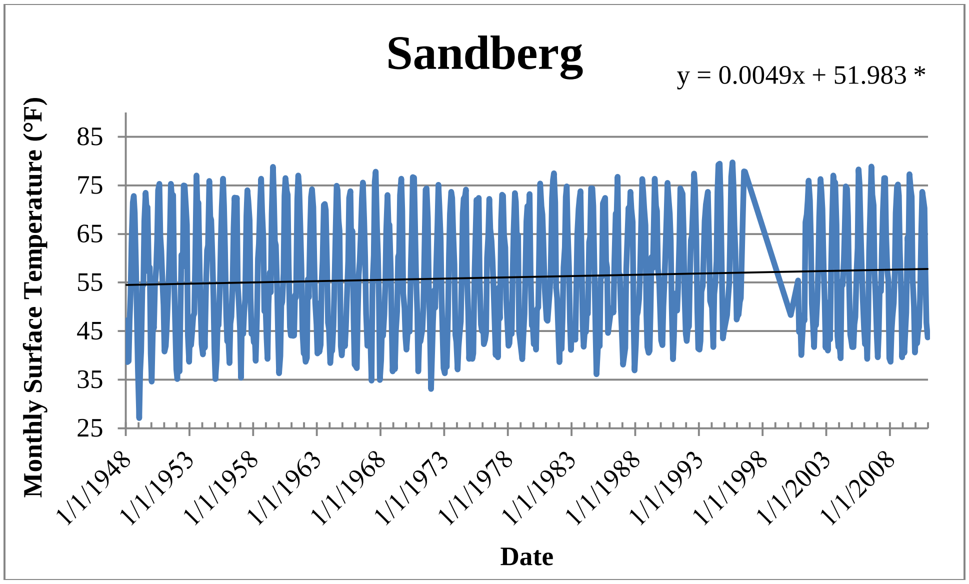

Figure 40: Monthly surface temperature trend at the Sandberg weather station from 1948 to 2010. The bold blue line represents the monthly surface temperature and the bold black line represents the trend line for monthly surface temperature. A single asterisk (*) represents statistical significance at p-value < 0.05 and a double asterisk (**) represents statistical significance a p-value < 0.01.

The results suggest that less extreme monthly temperature variations occur at UCLA (Figure 41). The minimum monthly temperature at UCLA is 46.6°F and occurs during the January 1st, 1937 measurement. Conversely, the maximum monthly temperature experienced at this station is 77.2°F during the September 1st, 1984 measurement. Importantly, evidence suggests a shift in monthly temperatures since 1976 because UCLA experiences only three occurrences of monthly temperatures below 55°F; however, prior to 1976 there are 19 occurrences of minimum monthly temperatures below 55°F.

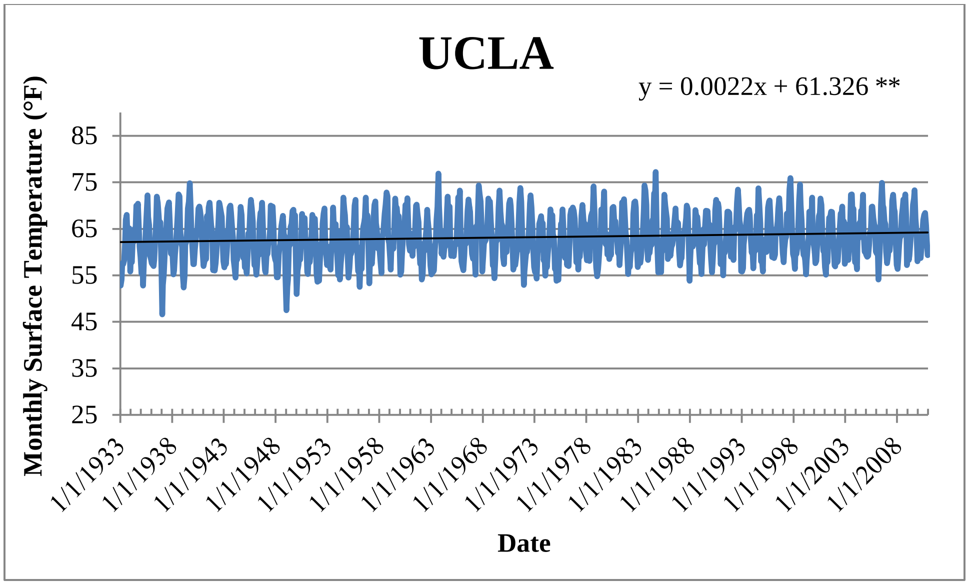

Figure 41: Monthly surface temperature trend at the UCLA weather station from 1933 to 2010. The bold blue line represents the monthly surface temperature and the bold black line represents the trend line for monthly surface temperature. A single asterisk (*) represents statistical significance at p-value < 0.05 and a double asterisk (**) represents statistical significance a p-value < 0.01.

Another weather station that is experiencing less extreme monthly temperature variations is USC (Figure 42). This evidence is illustrated in Figure 26 with its minimum monthly temperature measured at 56.7°F and occurs on February 1st, 1950. USC's maximum temperature is recorded on September 1st, 1984 with a monthly temperature measurement of 81.3°F. Additionally, this maximum monthly temperature measurement is shared with UCLA and suggests that an occurrence of an accelerated temperature increase is taking place at this time.

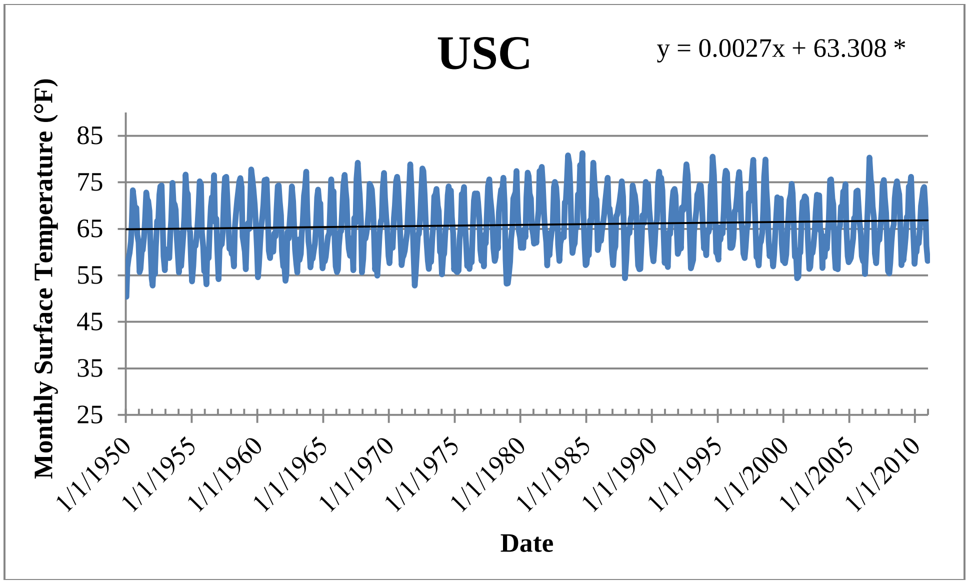

Figure 42: Monthly surface temperature trend at the USC weather station from 1950 to 2010. The bold blue line represents the monthly surface temperature and the bold black line represents the trend line for monthly surface temperature. A single asterisk (*) represents statistical significance at p-value < 0.05 and a double asterisk (**) represents statistical significance a p-value < 0.01.

Another station experiencing a subtle increase in their monthly temperature trend is Woodland Hills (Figure 43) as compared to Pasadena's more accelerated increase in monthly temperature. Woodland Hills recorded a minimum monthly temperature of 45.6°F during the January 1st, 1950 measurement and a maximum monthly temperature of 81.6°F during the August 1st, 1992 measurement. Also, larger seasonal temperature variations are evident in Figure 43 with the largest range in seasonal temperatures (30.8°F) occurring between the August 1st, 1992 measurement of 81.6°F and the December 1st, 1992 measurement of 50.8°F.

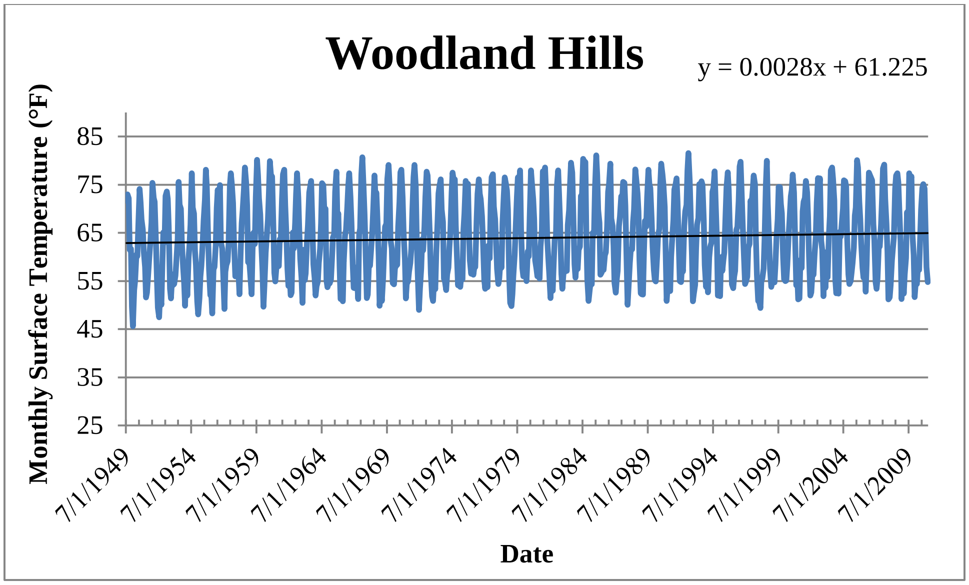

Figure 43: Monthly surface temperature trend at the Woodland Hills weather station from 1949 to 2010. The bold blue line represents the monthly surface temperature and the bold black line represents the trend line for monthly surface temperature. A single asterisk (*) represents statistical significance at p-value < 0.05 and a double asterisk (**) represents statistical significance a p-value < 0.01.

4.2.1 Monthly Temperature Linear Regression Significance

The monthly temperature linear regression line is analyzed for its statistical significance using the standard least squares regression analysis for all eight weather stations and multiple statistics [i.e., coefficient of determination (R^2), the slope coefficient, and the p-value < 0.05 (95 percent level) or p-value < 0.01 (99 percent level)] is categorized in Table 27. Also, the regression analysis sets the independent variable (y) as date and the dependent variable (x) is set as monthly temperature.

Table 27 confirms that the linear regression line for the Fairmont, Palmdale, and the Woodland Hills weather stations do not experience statistically significant monthly temperature trends. The p-value and R^2 results are as follows: (1) Fairmont: p-value is 0.1148 and R^2 is 0.0027; (2) Palmdale: p-value is 0.0649 and R^2 is 0.0036; and (3) Woodland Hills: p-value is 0.0596 and R^2 is 0.0048. On the other hand, Sandberg and

USC are statistically significant at the p-value < 0.05 level (95 percent level) with their p-value and R^2 results as follows: (1) Sandberg: p-value is 0.0407 and R^2 is 0.0061 and (2) USC: p-value is 0.0204 and R^2 is 0.0074. LAX, Pasadena, and UCLA are proven statistically significant at the p-value < 0.01 level (99 percent level) with their p-value and R^2 results as follows: (1) LAX: p-value is 0.0015 and R^2 is 0.0127; (2) Pasadena: p-value is 0.0001 and R^2 is 0.0301; and (3) UCLA: p-value is 0.0005 and R^2 is 0.0129.

Overall, three weather stations (Fairmont, Palmdale, and Woodland Hills) are not statistically significant per the standard least squares regression analysis. Two weather stations are proven statistically significant at the 95 percent level and they include Sandberg and USC. Lastly, three weather stations are statistically identified as significant by the regression analysis and they include LAX, Pasadena, and UCLA.

Table 27: Statistical significance characteristics for monthly temperature at all eight weather stations. A single asterisk (*) represents statistical significance at p-value < 0.05 and a double asterisk (**) represents statistical significance a p-value < 0.01.

Weather Station	Time Period	R^2	Slope Coefficient	p-value
Fairmont	1931-2010	0.0027	0.0025	0.1148
LAX	1944-2010	0.0127	0.0027	0.0015 **
Palmdale	1931-2010	0.0036	0.0029	0.0649
Pasadena	1931-2010	0.0301	0.0049	0.0001 **
Sandberg	1948-2010	0.0061	0.0049	0.0407 *
UCLA	1933-2010	0.0129	0.0022	0.0005 **
USC	1950-2010	0.0074	0.0027	0.0204 *
Woodland Hills	1949-2010	0.0048	0.0028	0.0596

4.3 Yearly Temperature and Its Trend

4.3.1 Recorded Temperature at the Twenty-One Weather Stations

The 21 weather stations described in Table 3 are divided into a 20 year time period (1931 to 1950) and a 60 year time period (1951 to 2010). These two time periods are analyzed for two types of yearly temperature trends: 1) yearly surface temperature and 2) yearly summer surface temperature; summer months are defined as the three months of July, August, and September. Furthermore, the yearly temperatures are obtained by averaging the monthly mean surface temperature dataset for each weather station during their respective time period.

4.3.1.1 Recorded Temperature from 1931 to 1950

The trend analysis in Figure 44 illustrates the yearly surface temperature trends for 20 weather stations in Los Angeles County. This figure reflects that the warmest recorded yearly surface temperature occurring at the Palmdale station in 1931 with a yearly temperature of 73.1°F. However, this extremely warm temperature must be questioned due to Palmdale missing yearly temperature data during the coldest months of the year (January thru March). These missing yearly temperature measurements would thus lower the yearly temperature for 1931. Another obvious yearly temperature trend is at the Table Mountain weather station. Table Mountain experiences the coldest yearly temperature trend compared to all 20 weather stations. Hence, the coldest yearly temperature recorded is 46.03°F in 1941 at Table Mountain.

Figure 44 illustrates a large fluctuation in yearly temperature between 1942 and 1945 at the OPIDS weather station. In 1942 a recorded yearly temperature of 55.3°F is recorded and a yearly temperature of 57.68°F is recorded in 1945; a difference of 2.38°F over a three year span which is the largest difference of all 20 weather stations. This below average temperature is related to missing yearly temperature data from July to October of 1937; therefore, this missing yearly temperature data explains the extreme drop in yearly temperature over the average trend. Overall, the yearly surface temperature trend shows low yearly temperature variability for most of the 20 weather stations during the 20 year period, and this low variability suggests that neither a cooling nor a warming trend exists for these weather stations.

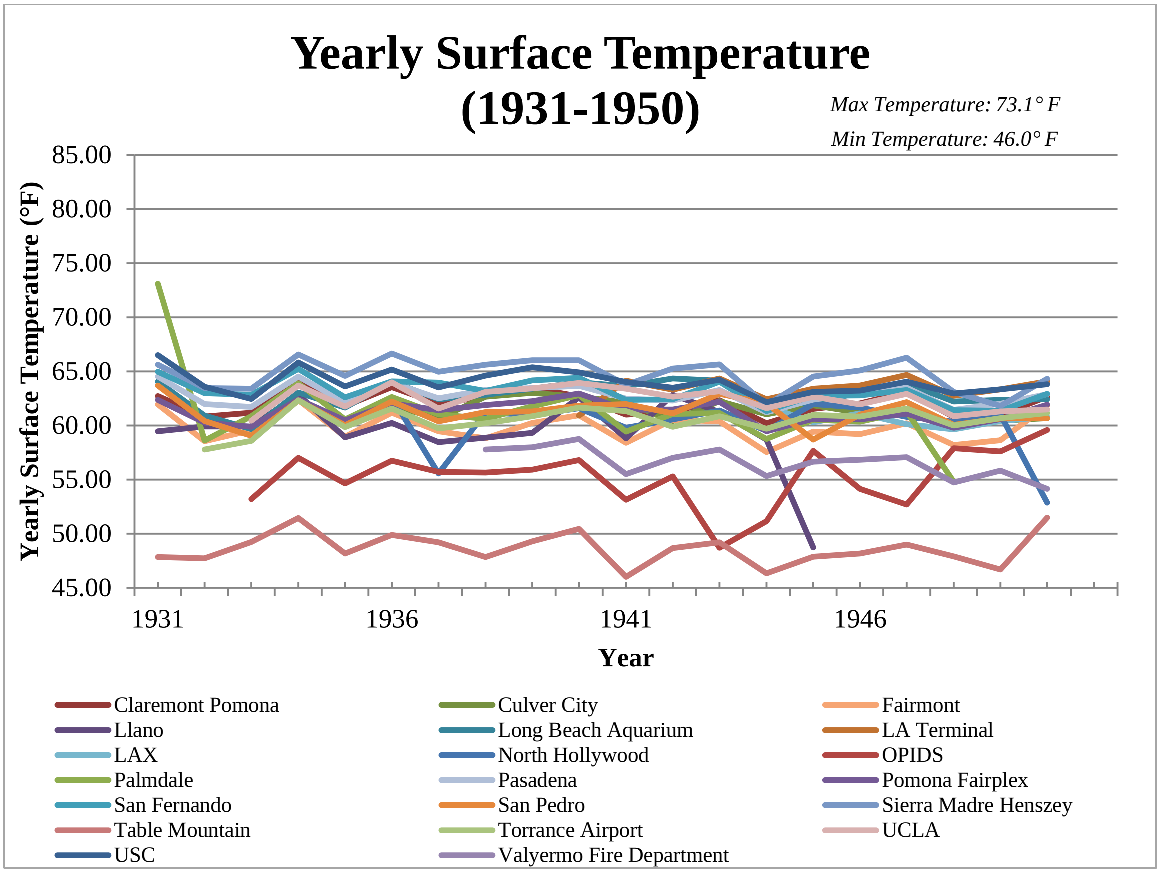

Figure 44: Yearly surface temperature for the 20 weather stations in Los Angeles County, California. The time period spans from 1931 to 1950 with the maximum and minimum yearly surface temperature values recorded as compared to all 20 weather stations.

The next trend analyzed is yearly summer surface temperature for the same 20 weather stations from 1931 to 1950 (Figure 45). Figure 45 illustrates how these 20 stations yearly summer temperatures experience a higher variability of yearly temperatures as compared to yearly surface temperature (Figure 44). Palmdale observes the highest yearly summer temperature in 1937 with a recorded measurement of 80.0°F. Moreover, Palmdale's 20 year time period undergoes the warmest yearly summer temperature trend compared to all other weather stations yearly summer temperature measurements. Conversely, the coldest yearly summer temperature compared to all weather stations is recorded at the Table Mountain station with a recorded temperature of 62.0°F in 1941. Another important discovery from yearly summer temperature is the Sierra Madre Henszey weather station temperature increases by 4.47°F between 1941 and 1946, and this increase in yearly summer temperature suggests that a warming trend exists during these five years. However, this warming trend must be questioned due to the averaging process of monthly mean temperatures to calculate yearly summer temperature.

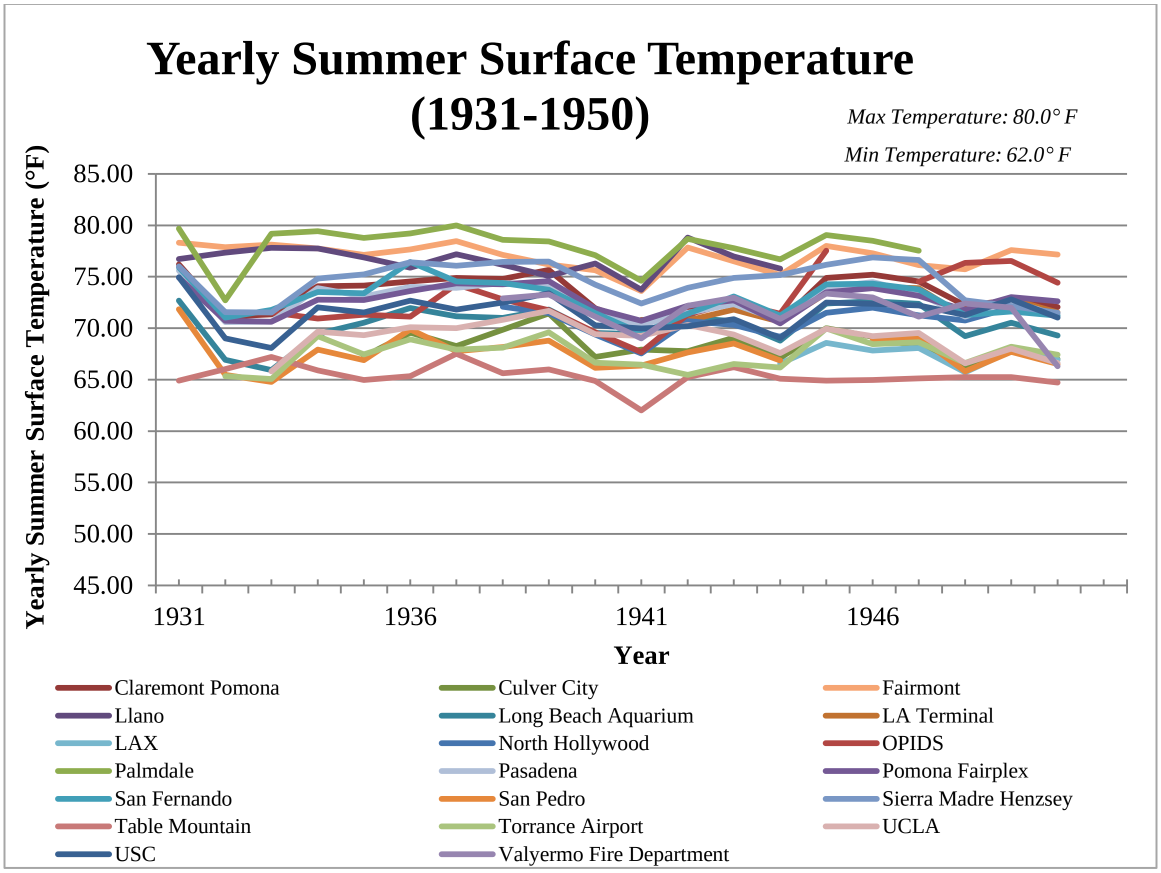

Figure 45: Yearly summer surface temperature for the 20 weather stations in Los Angeles County, California. The time period spans from 1931 to 1950 with the maximum and minimum yearly summer surface temperature values recorded as compared to all 20 weather stations.

4.3.1.2 Recorded Temperature from 1951 to 2010

Figure 46 illustrates six weather stations yearly surface temperature trend for a total of 60 years. While all six stations are experiencing a warming trend, the most pronounced warming trend occurs at the Pasadena weather station and LAX is undergoing the most subtle warming trend of all six weather stations. The warmest yearly surface temperature recorded is 68.89°F at the USC weather station, and a large drop in yearly temperature occurs between 1997 and 1999 with a range of 4.18°F over the three year period. Another important discovery is the coldest yearly temperature recorded is 58.28°F in 1998 and 2009 at the Fairmont weather station. Also, large portions of yearly temperature data is missing in 1956 and 1981 so these two year's temperature data is removed to avoid any skewness in the yearly surface temperature trend.

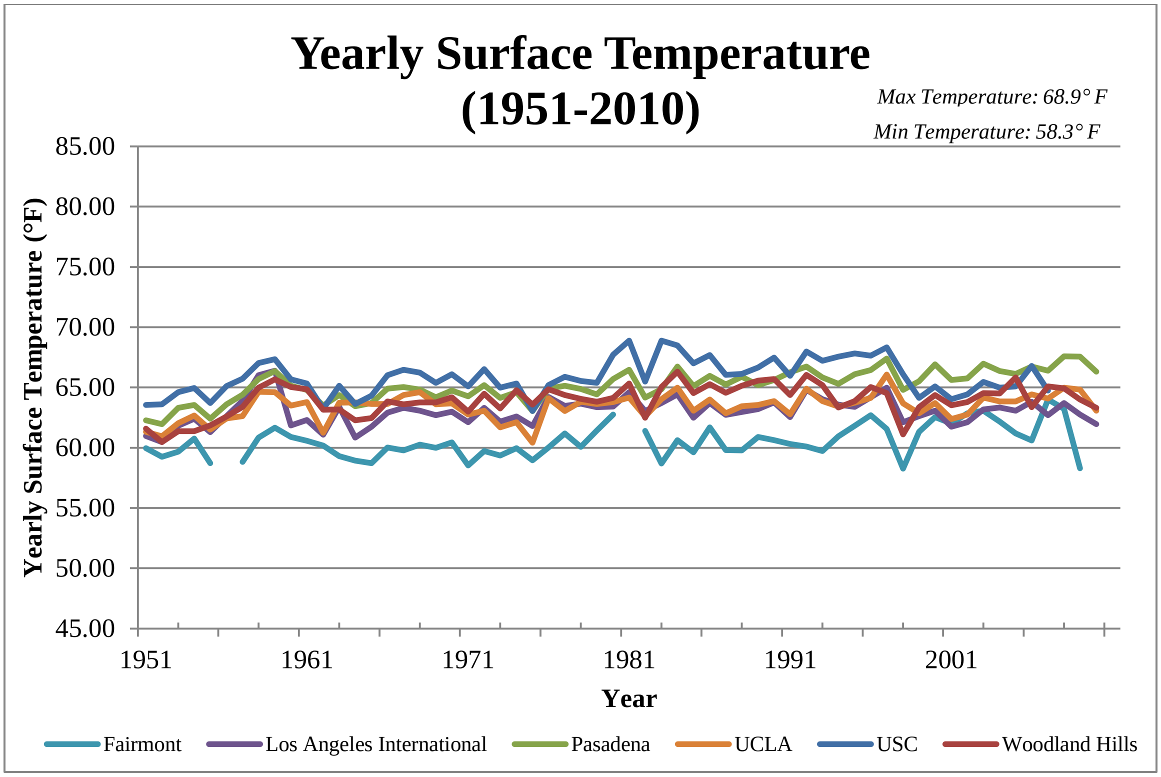

Figure 46: Yearly surface temperature for the six weather stations in Los Angeles County, California. The time period spans from 1951 to 2010 with the maximum and minimum yearly surface temperature values recorded as compared to all six weather stations.

Yearly summer surface temperature (Figure 47) illustrates some very different trends for yearly summer surface temperature trends compared to yearly surface temperature trends (Figure 46) from 1951 to 2010. The first difference in the temperature trends suggests that a cooling trend exists for LAX and UCLA during their 60 year time period. UCLA's cooling trend is more accelerated compared to LAX's more modest cooling trend. Another difference between Figure 46 and Figure 47 is the maximum and minimum yearly summer temperature measurements. Fairmont has the warmest recorded yearly summer temperature in 2003 with a measurement of 82.13°F and the coldest yearly summer temperature measurement is recorded at LAX in 2010 at 66.17°F. One similarity between the two yearly temperature trends is the accelerated warming trend at the Pasadena weather station for the 60 year time period. Additionally, the most accelerated cooling trend occurs in UCLA between 1984 and 1986 with a range of 6.94°F during these three years. On the contrary, the most accelerated warming trend occurs between 1982 and 1984 at Woodland Hills with a difference of 4.87°F during these three years.

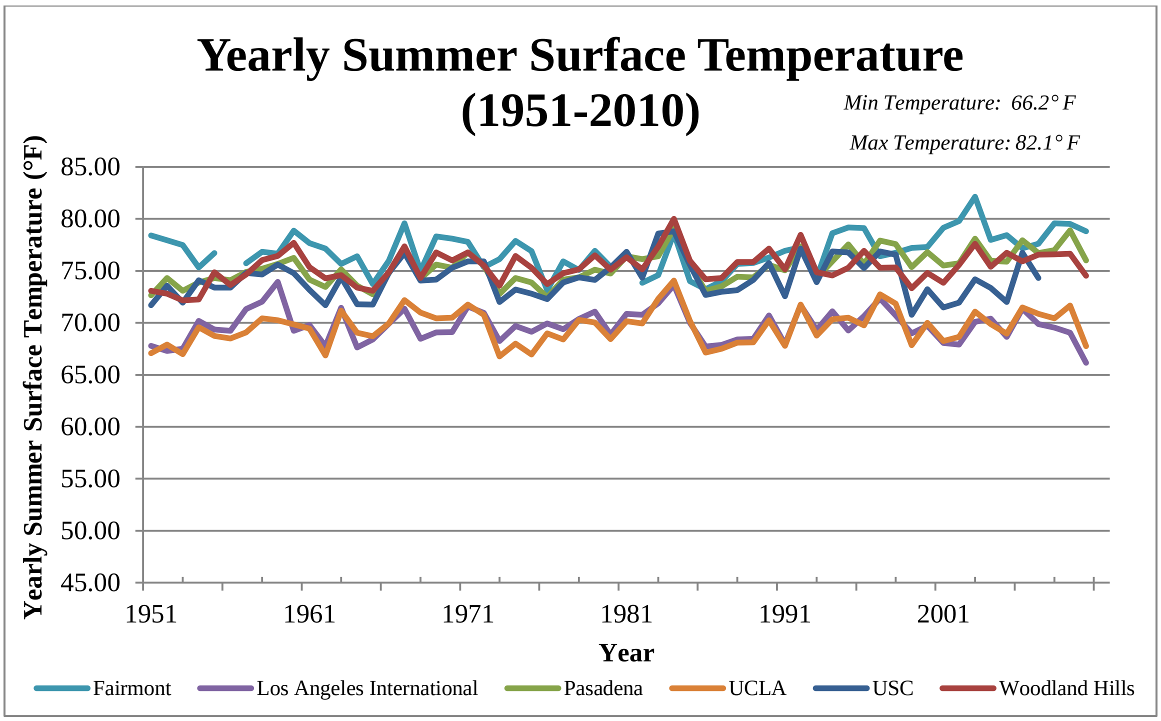

Figure 47: Yearly summer surface temperature for the six weather stations in Los Angeles County, California. The time period spans from 1951 to 2010 with the maximum and minimum yearly summer surface temperature values recorded as compared to all six weather stations.

CHAPTER 5: DISCUSSION & CONCLUSION

5.1 Extreme Temperature Threshold Observations

5.1.1 Weather Stations Experiencing an Accelerated Warming Trend

Three extreme temperature threshold variables (frost days, misery days, and heat wave events) are analyzed and the results show that various trends are occurring at the six weather stations. The evidence suggests an accelerated warming trend for the Palmdale weather station and this warming trend is reflected by the pronounced increase in misery days and decrease in frost days. Additionally, the misery and frost days linear regression line is statistically significant at p-value < 0.01 or the 99 percent level. A possible contributor to the resulting extreme temperature threshold trend and a suggested warming trend in Palmdale is its geography.

For example, the Palmdale weather station is located in the high desert of Southern California which experiences hot summer and mild winter temperatures. Also, Palmdale is located on the leeward side of the San Gabriel Mountains and the orographic effect can play a role on warmer temperature at these locales. The orographic effect assists in warmer temperatures by the following: an accelerated descent of dry air particles down the leeward side of a mountain leads to primarily cloudless skies; thus, an increase in incoming solar radiation leads to a warmer surface temperature.

Furthermore, an investigation into the spatial discontinuity at Palmdale's six different daily temperature measuring locales reveals that high temperature variability exists at this weather station. This high variability is greatly impacted by the station's surrounding physical features (i.e., type of landscape, adjacency to heat driven objects, and the location of field measurements: near the surface or at the top of a building), the distance between measuring locations (over 3,000 meters at maximum distance), and the measuring locations are not in highly urbanized areas which reduces the impact of the urban heat island effect.

Extreme temperature threshold results suggest another warming trend is occurring at Fairmont during its respective time period. The warming trend, as compared to Palmdale, experiences an accelerated increase in misery days and decrease in frost days. A statistically significant linear regression line (p-value < 0.05 or the 95 percent level) for misery days shows that this accelerated increase of misery days is occurring and impacting Fairmont. Also, further evidence of a possible warming trend is documented when heat wave records reveal that from 1991 to 2010 there are 24 heat wave events with the most occurring since 1931 in the last decade (13 heat waves). Once again, geography is a possible factor of the observed threshold trend at the Fairmont weather station because it is located in the high desert of Southern California and its location on the leeward side of the San Gabriel Mountains. Therefore, these warming trends over the last 80 years is an indication of a changing climate at the Fairmont and Palmdale weather station

5.1.2 Weather Station Experiencing an Accelerated Cooling Trend

On the contrary, the extreme temperature threshold analysis identifies a cooling trend occurring at the Sandberg weather station. This cooling trend is identified by an accelerated increase in frost days and decrease in misery days. A statistically significant linear regression line at p-value < 0.01 exists for misery days. The geographic location of

Sandberg is a possible contributor to this suggestive cooling trend and is described by the following.

The temperature threshold influences at the Sandberg weather station is possibly related to its high elevation at over 4,500 feet above sea level. Another suggestive factor is Sandberg's geographical location within an inland desolate, mountainous area. This inland location is important on daily temperature variations because more intense temperature fluctuations occur over land as compared to large bodies of water. These large temperature fluctuations occur because energy or heat is absorbed rapidly at the Earth's surface and in turn large temperature changes occur over land. Another influence from Sandberg's location is the impact of urbanization is greatly reduced by negating the urban island effect.

However, an extreme decreasing shift in misery days starting in 1975 requires further research to determine the significance and cause of this decreasing extreme temperature threshold shift. The study of the four spatially distributed daily temperature measuring locations reveals high temperature variability at all four locations. Also, the linear regression line during the extreme temperature threshold shift starting in 1975 is not statistically significant which suggests that these threshold shifts are related more to the measuring locations surrounding physical features and geography then to actual extreme temperature threshold trends occurring at Sandberg.

5.1.3 Weather Stations Experiencing a Modest Warming Trend

Los Angeles, Pasadena, and UCLA extreme temperature thresholds are experiencing a more modestly increasing warming trend, while Fairmont, Palmdale, and Sandberg show stronger deviations of extreme threshold trends from historical conditions. This indicative modest warming trend is suggested by the increase in misery days and a more modest decrease in frost days. Also, the linear regression line for misery days is statistically significant for Los Angeles and Pasadena at the p-value < 0.05. On the other hand, Pasadena and UCLA experience a statistically significant linear regression line for frost days at p-value < 0.01 and p-value < 0.05, respectively. Some possible explanations for these three weather stations extreme temperature threshold trends are discussed by the following.

This modest warming trend at these three weather stations is partially explained by their close proximity to the Pacific Ocean. The close proximity to this large body of water contributes to the moderation of temperatures at these weather stations. Another reason for these moderate conditions is their low lying elevations with the average elevations ranging at a minimum of 275 feet in Los Angeles and a maximum of 863 feet in Pasadena (Table 2). Moreover, one might expect the urban heat island effect to play a larger role on extreme temperature thresholds; thus, an accelerated warming trend at these three weather stations would occur. This unexpected warming trend introduces the possibility that other climate factors (internal or anthropogenic) are playing a larger role in daily temperature observations and extreme temperature thresholds.

A deeper investigation into the spatial discontinuity at the six daily temperature measuring locations for Los Angeles discovers that there is less threshold variability compared to the six Palmdale and four Sandberg locations. The linear regression line for misery days indicates statistical significance at the $p\text{-value} < 0.01$ level from 1940 to 1964 and no statistical significance for any of the six linear regression lines for frost days. Once again, these results suggest that extreme temperature thresholds are highly susceptible to the weather station's physical surroundings and geography. Furthermore, the result from the spatial discontinuity analysis in Los Angeles helps clarify the former assumption that internal climate variability or anthropogenic forcing is playing a larger role than the urban heat island effect.

5.2 Monthly Surface Temperature Observations

Monthly surface temperature shows an increasing trend in monthly surface temperature for all eight stations analyzed and is an excellent data source to represent seasonal temperature variability occurring at the eight weather stations. The largest seasonal temperature fluxes occur at the Fairmont, Palmdale, and the Sandberg weather stations and are attributed to their geographical location. Fairmont and Palmdale are located in the high desert of Southern California with its characteristics defined as hot and dry summer temperatures as well as relatively mild winter temperatures. Also, Sandberg is located at a high elevation of 4,500 feet above sea level which produces warm summer months and cold winter months. The standard least square regression model affirms that linear regression line is not statistically significant for Fairmont and Palmdale, but is statistically significant at the $p\text{-value} < 0.05$ level for Sandberg. The large temperature fluxes at Fairmont, Palmdale, and Sandberg can be attributed to their location in remote, mostly rural regions which greatly reduces the impact of the urban heat island effect.

Pasadena is indicative of a warming trend (statistically significant: p-value < 0.01) and high seasonal variability from the linear regression model and suggestive reasoning is explained by the following three characteristics. Pasadena's inland location limits the effect of the moderate coastal climate and warmer temperatures that are experienced at this weather station location. Another characteristic is the Mediterranean climate zone that Pasadena is located within. The Köeppen climate classification of Cs, or a Mediterranean climate zone, helps explain the extreme warming trend with very hot summer days and mild winter days (George 2014). The last characteristic of Pasadena is its urban locale because urban growth and urban landscape are playing a role in its increase in monthly surface temperature.

LAX, UCLA, and USC are three stations that their linear regression line is statistically significant at the p-value < 0.01 level and p-value < 0.05 level, and the linear regression model indicates very modest seasonal variability for monthly temperature. These stations are geographically located close to the Pacific Ocean which moderates the seasonal variability and they are located within highly urbanized regions which increases temperatures due to the urban landscape and influences monthly surface temperatures and seasonal variability. Temperatures within urban landscapes will not experience the daily temperature variability that is experienced in the rural surrounding thus moderating monthly and seasonal temperatures. Overall, the modest warming trend introduces the possibility that other climate factors (internal and anthropogenic) are playing a larger role in dictating monthly temperature trends.

Woodland Hills is a prime example why monthly temperature is not an appropriate temperature data source to analyze these temperature trends. The linear regression model indicates that Woodland Hills is experiencing a very subtle increasing warming trend over its respective 71 years, but its geographic location would suggest a different monthly temperature trend. The geographic location of Woodland Hills is within the Mediterranean climate zone and historical temperature records confirm that very warm seasonal temperatures typically occur at this weather station. An example like Woodland Hills proves that monthly surface temperature data is not a sufficient dataset to identify a true representation of the occurring temperature trend, so the need to use daily surface temperature data is required to represent the true historical temperature trends.

5.3 Yearly Surface Temperature Observations

Originally, the study's goal was to collect as much yearly surface temperature data and for as many stations in Los Angeles County spanning as many years as possible. However, research and collection of historical temperature data clarified that extensive yearly temperature data is limited and only one station in Los Angeles County had more than 80 years of temperature data (Los Angeles Civic Center). In response to this limited historical temperature data, the yearly surface temperature study is limited to 80 years. These 80 years are subdivided into 20 (1931 to 1950) and 60 (1951 to 2010) year time periods, and these two time periods are analyzed for yearly surface temperature and yearly summer surface temperature. Analyzing these various time periods reveals that yearly temperature trends show some explainable consistency such as warming trends during specific time periods.

One explainable consistency is Table Mountain's coldest yearly surface and yearly summer surface temperature trend from 1931 to 1950. These cold temperatures are explained by the elevation at Table Mountain with an approximate elevation of 7,500 feet above sea level. This extremely high elevation keeps temperatures lower in the summer months, as compared to temperatures in lower elevations, and frigid temperatures in the winter months. Another consistency occurs during the yearly summer surface temperature trend analysis from 1951 to 2010. Fairmont, Pasadena, and Woodland Hills typically demonstrate the most extreme warming trends during these 60 years. These stations locations within the high desert, further inland, and within a Mediterranean climate zone help explain this yearly summer temperature trend. Also during this same time period, LAX and UCLA experience a cooling trend over 60 years. This cooling trend can be related to their proximity to Pacific Ocean as this large body absorbs and loses energy or heat very slowly. This heat absorption process reflects the year round moderate temperatures and less frequent extreme heat events. However, LAX and UCLA are located within urbanized areas which suggests that the urban heat island effect would produce a warming trend instead of a cooling trend at these two weather stations.

5.4 Overall Surface Temperature Observations

Daily surface temperature is a sufficient dataset for analyzing extreme temperature thresholds and for determining the type of linear temperature trend occurring at the six weather stations. On the other hand, the monthly surface temperature dataset identifies seasonal variability, but does not provide sufficient temporal evidence of surface temperature trends for the eight weather stations. Additionally, the yearly surface temperature dataset does not provide adequate evidence of many explainable linear temperature trends or seasonal variations for the 21 weather stations. A majority of the yearly temperature trends show unexplainable inconsistencies because of the averaging of monthly temperatures to obtain yearly surface temperature measurements. This averaging loses the temperature extremes that are revealed within the daily surface temperature data. Thence, the analyzation of daily surface temperatures is the key to obtaining a true trend of surface temperature data. Most importantly, daily surface temperature is a required dataset for measuring temperature trends over time, and an analytical comparison of monthly and yearly surface temperatures is required to point out that these two datasets are not adequate enough to analyze temperature temporally.

5.5 Spatial Characteristics and Distribution of the Weather Stations

The spatial distribution of the six daily surface temperature weather stations are scattered across the north-northwest and south-central portions of Los Angeles County with their characteristics following. Fairmont and Palmdale are located in northern portion of the county and within the high desert region. Also, Fairmont is located in a rural area and Palmdale is in a modestly urbanized area. Sandberg is located in the northwest portion of the county and within a desolate, highly elevated region of the San Gabriel Mountains. Pasadena, UCLA, and Los Angeles are located in the south-central portion of the county and are within highly urbanized regions of the county. Also, UCLA and Los Angeles are in close proximity of the Pacific Ocean.

The spatial distribution for the eight monthly surface temperature weather stations are spread across the north-northwest and south-southcentral portions of the county.

Fairmont, Palmdale, Pasadena, Sandberg, USC (Los Angeles), and UCLA are described formerly in the daily surface temperature weather stations. Woodland Hills is located in the southcentral portion of the county and physically located within a highly urbanized campus area. LAX is located in the southern portion of the county and is located within an urbanized area bordering the Pacific Ocean with the area containing buildings, airplane hangars, and tarmac.

Lastly, the 21 yearly surface temperature weather stations are dispersed throughout the entire portion of Los Angeles County. Mostly the stations are located in the south-southcentral-southeastern and north-northeastern region of the county. Three weather stations (Fairmont, Llano, and Valyermo) are located in rural to desolate regions of the high desert. On the other hand, Palmdale is located in modestly urban region of the high desert. Table Mountain is located in the northeastern region at a high elevation in the San Gabriel Mountain. Southcentral located weather stations include Long Beach, Torrance Airport, LAX, and Culver City with all four of these stations located close to Pacific Ocean and within modestly to highly urbanized areas. Two southeastern stations include Claremont Pomona and Pomona Fairplex, and these stations are on the windward side of the San Gabriel Mountains within highly urbanized areas. The remaining stations within the southcentral portion of the county include: Woodland Hills; San Fernando; North Hollywood; OPIDS; Sierra Madre Henszey; Pasadena; Los Angeles Terminal; USC; and UCLA. All of these stations, except for OPIDS which is highly elevated within the San Gabriel Mountains, are located at low lying elevations along the windward side of the formerly mentioned mountain range. Also, all of these weather stations are located within highly urbanized areas of Los Angeles County.

5.6 Current and Future Approaches

5.6.1 Current Study Advantages and Disadvantages

There are several advantages of the approaches used within the current temperature analysis and they include the following. First, the extreme temperature thresholds are prime indicators of warming or cooling trends over a long period of time at any specific location. Also, the decadal trends of extreme temperature events show the extreme temperature trends at certain time periods. Another positive approach is the use of monthly temperatures to monitor the trends of seasonal variability. Lastly, the aid of ArcGIS and Excel greatly reduces manual computations by performing tedious and difficult algorithms and calculations for the location of weather stations as well as various temperature calculations (i.e., yearly temperature, linear temperature trends, linear regression line of temperature, etc.). There are definite advantages to the approaches used within this study, but certain disadvantages are discovered and they are as follows.

The first disadvantage is that yearly temperature does not consistently show a definitive temperature trend for a majority of the weather stations and the use of daily temperature is required to discover a trend over time. Another disadvantage is the time consuming and tedious process of manually dividing the daily temperature WRCC data into ten year increments. Additionally, the manual process of dividing the monthly temperature NCDC data for each station is extremely time consuming and very tedious work. Another time consuming and tedious manual method is the averaging of monthly temperature data into yearly temperature and yearly summer temperature. These disadvantages are important forethoughts and must be considered for any future studies.

5.6.2 Future Study

The current study reveals that additional linear trend and regression analyses are needed to provide a better understanding and greater insight into temperature trends and possible contributors that affect temperature. For instance, further research would involve a larger study area that includes the six Southern California counties: Imperial, Los Angeles, Orange, San Bernardino, San Diego, and Riverside (SCAG 2009). Broadening the study area introduces more weather stations and in turn yields more historical temperature data. Obtaining large amounts of historical temperature data will greatly increase the true representation of temperature fluxes and their temperature trends across the southern part of California.

The other research route includes a large-scale regression analysis for two metropolitan weather stations in Southern California and the selection of the cities plays a very important role. This important role of the regression analysis will determine if population plays the main role in temperature changes at the chosen locations or does other chosen parameters (i.e., maximum temperature, minimum temperature, land cover, etc.) the key factor to temperature changes at each city. The two cities are selected by these criteria: 1) population growth increasing in the last ten years (i.e., Irvine, California); and 2) population growth is slowing or declining in the last ten years (i.e., Bakersfield, California). Hence, a regression analysis can provide solutions in order to correlate a relationship between temperature trends and possible influences such as population growth.

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