URBAN HEAT ISLAND EXPANSION IN THE GREATER LAS VEGAS METROPOLITAN AREA

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ABSTRACT

The growth of human settlements into vast urban metropolitan areas is often accompanied by relatively higher temperatures in comparison with surrounding rural country sides, a phenomenon known as the "urban heat island effect." The city of Las Vegas has been selected as an examination of this trend because of its unprecedented urban growth in the last 50 years, which has been mapped by satellite imagery for several decades. Studying the growth of Las Vegas' relatively new heat island can provide valuable insight into the causes and magnitude of all urban heat islands in general.

In this investigation, a series of temperature records were collected between the years 1973 and 2009 from two weather stations: one located in an urban area and the other located in a nearby rural area. The records from these weather stations were used to construct tables and figures in order to directly and effectively compare Las Vegas' urban and rural climates. Analysis shows that the minimum temperatures in Las Vegas' urban areas have been increasing at significantly higher rates than surrounding rural minimum temperatures. This trend has been especially pronounced since the early 1990's, when the urban weather station used in this analysis became entirely surrounded by urban features. A comparative analysis of Las Vegas' rural and urban temperature data produces statistically significant evidence for the presence of an urban heat island effect in the area.

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INTRODUCTION

Background

One of the most obvious and important anthropogenic climate change manifestations is the phenomenon known as the 'urban heat island effect.' An urban heat island is defined as a metropolitan area where air and surface temperatures are measurably warmer than their rural surroundings (Gartland, 2008). A certain degree of this heat island effect is present in every city and town in the world because most common construction materials absorb and retain more of the sun's heat than natural surfaces in less-developed rural areas. Urban heat islands, in turn, modify local meteorological conditions, such as wind patterns, cloud cover, humidity, and rates of precipitation. However, this report will focus on their most obvious and distinct characteristic – higher local temperatures – to provide a singular and stark assessment of their primary manifestation. Air temperatures in urban heat islands have been measured to be up to ten degrees Celsius (18 degrees Fahrenheit) warmer than the air temperature of their surrounding rural areas (Carlowicz, 2009).

The urban heat island effect also has a number of serious socioeconomic impacts. Poor air quality as well as the increased frequencies and higher intensities of heat waves contribute to detrimental human health conditions and increased mortality rates (IPCC, 2000). Those who are most vulnerable to urban heat related deaths include elderly people, the very young, people in ill health, and the more impoverished. Warmer temperatures create a larger demand for electricity because of the increased use of air conditioning and refrigeration, that further increase anthropogenic heat emissions, greenhouse gas emissions and overall temperatures. Warmer temperatures also result in a larger demand on water utilization within a metropolitan area, which has become an increasingly valuable and diminishing resource. Considering that more than 50 percent of the world's population currently lives in urban areas, such heat island impacts pose serious environmental and health hazards that warrant careful study and remedy (United Nations, 2007).

I have chosen the city of Las Vegas as the case study for urban heat islands because it is located in the desert, has detailed climate data over the past several decades, and has experienced an unprecedented rate of development and expansion in the past half century. At 36 degrees North latitude, Las Vegas' extremely hot, dry, and calm desert climate can mostly be attributed to subtropical high pressure systems caused by the Hadley cell. Under stationary high-pressure systems – a common occurrence for the Las Vegas climate – temperature differences between urban and rural areas become most pronounced (Landsberg, 1981).

Las Vegas is also the fastest growing metropolitan area in the United States. In 1950, the city of Las Vegas was home to 24,624 people. By 2008, the population of the Las Vegas Valley (the city and surrounding settlement areas) was over 1.8 million people, not including its many tourists (US Census Bureau, 2009). Between the years 2000 through 2008, Las Vegas experienced an unprecedented 35.6% increase in population, the greatest increase of any metropolitan city in the United States during that time period (US Census Bureau, 2009). Due to this exceptionally fast population explosion, Las Vegas' metropolitan area has rapidly grown from 37,677 acres to 206,708 acres as shown in *Figure 1*, and will most certainly continue to expand. According to

Lisa Gartland, an expert on heat islands, "Areas with the least vegetation and greatest development tend to be hottest, and heat islands tend to become more intense as cities grow larger" (Gartland, 2). That is why the city of Las Vegas is a superb case study for the urban heat island phenomenon. I hypothesize that temperatures in the downtown Las Vegas area have increased over the past 50 years compared to the temperatures of its rural surrounds.

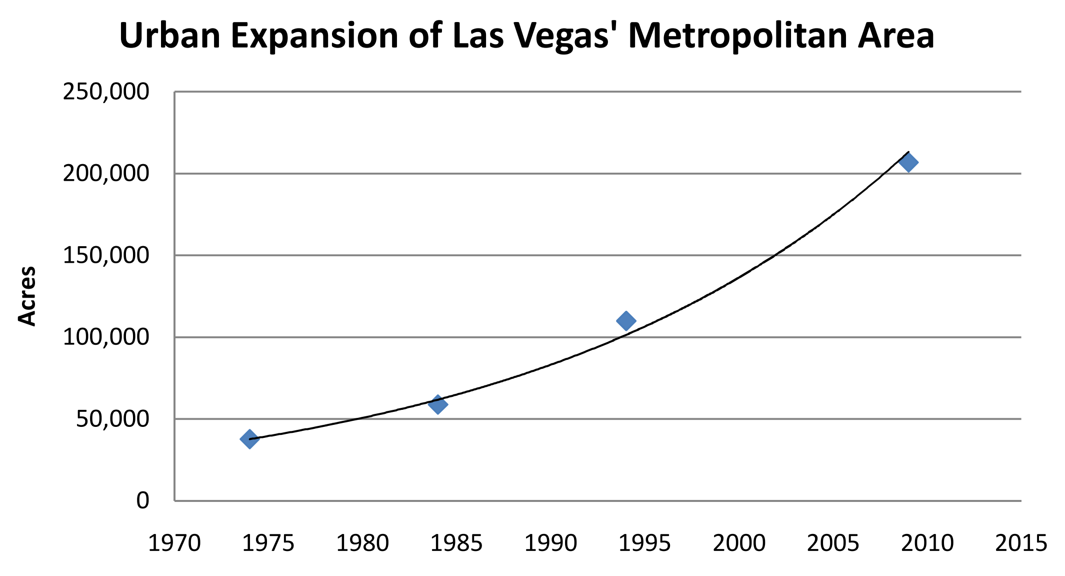

Figure 1

Objectives

This project has two objectives: 1) to map the growth of Las Vegas' metropolitan area through satellite imagery; and 2) to determine the presence and intensity of any urban heat island effect in the Las Vegas area.

MATERIALS AND METHODS

Acquiring Satellite Imagery

Satellite images were acquired in order to display Las Vegas' rapid urban expansion and to measure the growth of its metropolitan area by acreage. A total of four visuals are presented in this report. *Image 1* was captured in 1974, *Image 2* was captured in 1984, *Image 3* was captured in 1994, and *image 4* was captured in 2009. All satellite photos were downloaded from the USGS Earth Resources Observation and Science (EROS) Center's website. Then each compressed file was unzipped by "winzip" software and imported into the computer program "ERDAS IMAGINE." Because each image covered terrain far beyond the area of examination, an Area of Interest (AOI) was selected in order to focus on the greater Las Vegas area. Each image was assigned a common AOI in order to ensure that the map scales and areas displayed are identical, ensuring no possibility for scale distortion.

Image 1 shows the earliest clear satellite image of Las Vegas, captured in 1974 by "LANDSAT 1-TM (thematic mapper), which has only four spectral bands. The color red was assigned to spectral band number 4 (near-infrared), green was assigned to band number 3 (red), and blue was assigned to band number 2 (green) in order to make the urban features more visually pronounced compared to the natural surface. This selection of spectral bands makes urban features appear orange in *Image 1*. *Images 2-4* were captured by the more modern satellite "LANDSAT 5-MSS (multi-spectral scanner) which has seven spectral bands. For *Images* 2-4, the colors red and blue were still assigned to band numbers 4 and 2 respectively. However, green was assigned to band number 7 (thermal), causing the urban features to appear red.

Lastly, the "measure" tool was used in ERDAS IMAGINE to draw a polygon around Las Vegas' metropolitan area within each image and then calculate the total acreage inside each polygon. The approximate metropolitan area is stated below each image and is graphed in *Figure 1*. By analyzing *Images 1-4* in chronological order, Las Vegas' speedy urban growth becomes obvious.

Selection of Weather Stations

As stated in the introduction, an urban heat island is defined as a metropolitan area where temperatures are measurably warmer than its rural surroundings (Gartland, 2008). Therefore, the two ideal locations to retrieve weather data would be in the center of Las Vegas' metropolitan area (where the heat island effect would be expected to be most pronounced) and in a nearby site that has an identical climate and is completely isolated from any human presence (to simultaneously provide temperatures under "normal" conditions). Additionally, each weather station used needed to have accurate data spanning back further than 30 years. Data from both weather stations were retrieved from the Western Regional Climate Center's (WRCC) website.

For this report's urban weather data, the weather station at McCarran International Airport (Las Vegas' main airport) was used because of its detailed temperature archive and its centralized location to the city. A white pin is located in the center of *Images 1-4* and marks the location of this weather station, which begins on the outskirts of Las Vegas in 1974 and is encompassed into the city's center in 2009. For this report's rural weather data, Nevada's Valley of Fire State Park weather station was used. This site, located only 43 miles Northeast of McCarran International Airport, is only 127 feet lower in elevation, and continues to be devoid of human development. Therefore, temperatures recorded from both weather stations should be very similar without human alterations, given their geographic proximity and comparable elevation.

Acquisition of Data

All temperatures evaluated in this report were recorded from McCarran International Airport's weather station and Nevada's Valley of Fire State Park weather station between January of 1973 and December of 2009. In each of these 36 years, average maximum and minimum monthly temperatures were assessed (see *Tables 1* and *2* in appendices). The solstices usually occur on June and December 21st and mark the official beginnings of summer and winter respectively, while the equinoxes usually occur on March 20th and December 22nd and mark the official beginning of spring and autumn respectively. However, there is always a lag time of about a month between the official start of a season and the sensible weather of that season. For example, although June 21st officially marks the start of summer on our calendars, the hottest month of the year is usually July. Accordingly, the months of January, April, July, and October have been chosen to represent each of the four seasons.

Average monthly maximum and minimum temperatures from both weather stations have been evaluated in order to understand each sites normal climate, and to compare the urban site to the rural site. The average diurnal temperature ranges of both sites for each month (maximum temperature minus minimum temperature) have also been evaluated in *Tables 4* and *5* and their trends are displayed in *Figures 18-27*. To directly compare both sites, the difference between the airport and state park's maximum and minimum temperatures were calculated for each month and can be seen in *Table 3.* The temperature differences between the two sites can be seen in *Figures 28-35.* All tables and figures displayed in this report have been produced from each of the four different evaluation methods described in the "Results and Discussion" section.

RESULTS AND DISCUSSION

Maximum and minimum temperatures have been recorded for the months of January, April, July, and October between the years 1973 and 2009 from the weather stations at McCarran International Airport and Nevada's Valley of Fire State Park. Using this data, four different evaluation methods are mentioned below and have been conducted in order to determine the presence and intensity of an urban heat island in the Las Vegas area. *Tables 1-5* and *Figures 1-35* are presented in the appendices in order to enhance the clarity and comprehension of each method's results. It should be noted that temperatures measured before significant human settlement show a natural disparity between the two sites. Specifically, the park averages 1-3°F warmer temperatures than the Las Vegas urban area throughout the year, regardless of any human influence on climate (Weather America, 2000). Therefore, these differences in specific recorded temperatures from each site are irrelevant because they merely show a slight disparity in natural climate between the two sites, not a proof or disproof of an urban heat island effect, and will therefore be ignored in this section. Instead, the presence or absence of any long term trends in temperature change will be the determining factor in assessing the accuracy of this paper's hypothesis.

(1) <u>Maximum Monthly Temperatures (Appendix C)</u>

After investigating the average maximum seasonal temperatures at Nevada's Valley of Fire State park and McCarran International Airport since 1973, it has been determined that there is no statistically significant comparative change over this time frame for both of the urban and rural locations. *Tables 2-9* show that the maximum temperatures for every month have remained relatively normal since 1973, with monthly highs from year to year occurring at random. The lack of an increasing temperature trend in maximum temperatures is surprising and seems to disprove the presence of an urban heat island in Las Vegas. However, further research into the matter proved that these results are typical of heat islands. According to Dr. Helmut E. Landsberg, an expert on urban climates, "daytime urban heat island intensity…is generally quite small…" and is sometimes even non-existent (Landsberg, 100).

There is a simple explanation for the absence of a daytime heat island effect. The sun's radiation, which ultimately is converted into heat at the earth's surface, is most intense during the middle of the day when the angle between the earth and sun is at its greatest. Not surprisingly, high temperatures are typically recorded at around 3:00pm. By the time a high temperature is recorded for each day, natural materials in rural areas, such as soil and wood, as well as construction materials in urban areas, such as concrete and stone, have been heated up to their full capacity and have a roughly equal heating effect on air temperatures (Gartland, 2008). This is especially true in a desert climate, such asLas Vegas, because its surface receives some of the highest levels of solar radiation on the planet. Therefore, it should not be surprising that maximum temperatures in Las Vegas and its rural surroundings have remained unchanged over the time period being measured. *Figure 6*, which displays average January maximum temperatures, is comparable to all recorded maximum temperatures shown in *Figures 2-9* and illustrates that there are minimal maximum temperature trends.

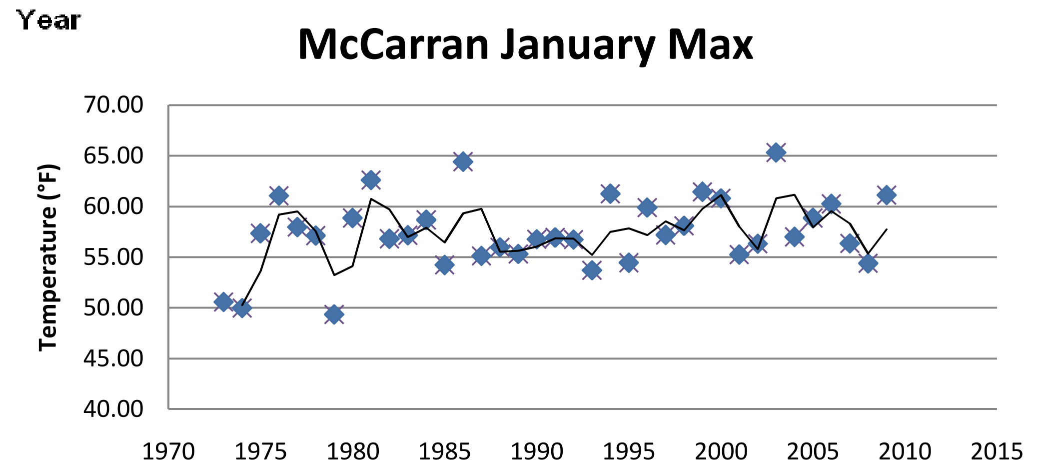

Figure 6

Figure 6 illustrates maximum temperatures in January from 1973 to 2009 at Mccarran International Airport.

(2) <u>Minimum Monthly Temperatures (Appendix D)</u>

In sharp contrast to the relatively stable maximum temperatures in Las Vegas, the average minimum temperatures at the urban and rural locations since 1973 shows that minimum temperatures in Las Vegas' metropolitan area have been increasing at a remarkable rate. During this same time period, minimum temperatures in Las Vegas' rural surroundings have shown no statistically significant change or upward trend. McCarran International Airport shows a clear trend of increasing minimum temperatures, especially since 1990. A white pin is visible in the center of *Images 1-4* and marks the location of McCarran International Airport's weather station, which is at the outskirts of Las Vegas in 1974 and progresses into the city's center in 2009. In *Image 2,* which was captured in 1984, McCarran's weather station is still located on the outskirts of Las Vegas' metropolitan area; however, by 1994 the weather station has been completely surrounded by urban features. The fact that minimum temperatures begin to rapidly increase at around the same time that the weather station becomes engulfed by urban features provides significant evidence that Las Vegas is producing and experiencing an urban heat island effect. During this same time period, there have been no indications of any statistically significant changes in minimum temperatures at Nevada's Valley of Fire State Park.

According to Lisa Gartland, an expert on urban heat islands, "The heat island intensity is usually largest at night, since urban surfaces continue to give off heat and slow the rate of night-time cooling" (Gartland, 3). This phenomenon occurs because of specific heat, which is a material's capacity to gain and lose heat. The greater the specific heat value of a material, the greater the capacity for that material to store heat. Common urban features, such as concrete and stone, tend to have a higher specific heat than do common rural features, such as soil and wood. Consequently, once the sun goes down, rural materials quickly lose their stored heat and have no effect on night-time cooling, which is when minimum temperatures are measured. In contrast, urban materials retain the heat they stored from the sun during the day and slowly release it throughout the night, thereby diminishing overall night-time cooling and increasing minimum temperatures in the area.

Figure 14 illustrates minimum temperatures in the month of January from 1973 to 2009 at Nevada's Valley of Fire State Park. Between 1973 and 1990, January's average minimum temperatures were approximately 38°F at this rural site. Between 1991 and 2009, the average minimum temperature in January rose to 39°F, only a 1°F increase. In direct contrast, *Figure 10* illustrates elevations of average minimum temperatures in the month of January from 1973 to 2009 at McCarran International Airport. Between 1973 and 1990, the average minimum temperature in January was approximately 35°F at this urban site. Between 1991 and 2009, the average minimum temperature in January rose to 39°F, a 4°F increase. To summarize, Las Vegas' urban minimum temperatures have increased 3°F more than its rural surroundings since 1991. This comparison between *Figure 14* and *Figure 10* prove that average minimum temperatures in Las Vegas' metropolitan area are increasing at a significantly faster rate than those for the rural surroundings, a distinct trait of heat islands.

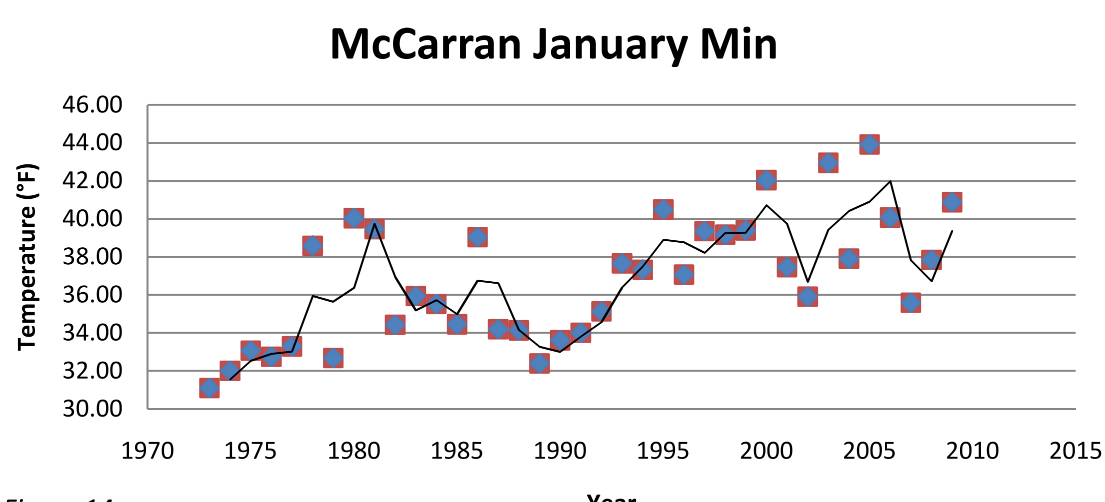

Figure 14

Figure 14 illustrates minimum temperatures in January from 1973 to 2009 at Mccarran International Airport.

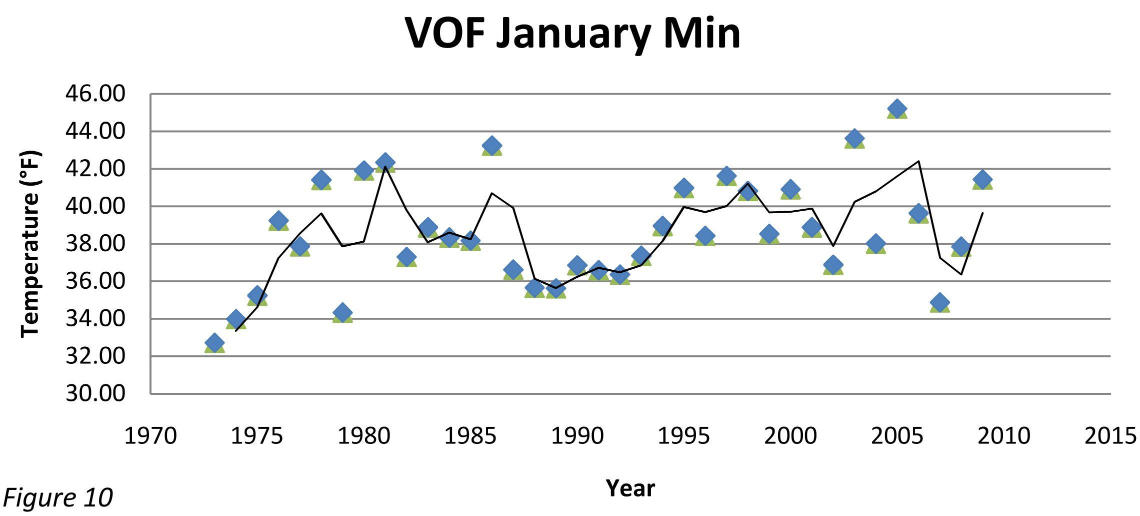

Figure 10

Figure 10 illustrates minimum temperatures in January from 1973 to 2009 at Nevada's Valley of Fire State Park.

(3) <u>Diurnal Temperature Ranges (Appendix E)</u>

Evaluating the diurnal temperature ranges of both urban and rural locations can provide compelling evidence as to the presence of an urban heat island. A diurnal temperature range is a meteorological term that represents the variation in temperature that occurs between the highs of the day and the lows of the night. This value can be retrieved by subtracting the night-time low temperature from the day-time high temperature. Because increased minimum temperatures and relative unaltered maximum temperatures are a common characteristic of urban heat islands, it is expected that the diurnal range of an urban area should show a decreasing trend over time, while a rural area's diurnal range should remain relatively constant.

Because the weather station located at McCarran International Airport became completely surrounded by urban features around the year 1990, the average diurnal temperature range between 1973 and 1990 will be directly compared to the average diurnal temperature range from 1991 to 2009 in order to assess the presence of any long term trends. The average diurnal temperature range at McCarran International Airport is 3.375°F lower between the years of 1991 and 2009 than it was from 1973 to 1990 (*see Figure 24*). In contrast, the average diurnal temperature range at Nevada's Valley of Fire State Park has only decreased by 0.375°F during these same time periods (*see Figure 19*). Therefore, the average diurnal temperature range in Las Vegas' urban areas has decreased by 3°F more than its rural surroundings. This change between urban and rural diurnal temperature differences provides further evidence that Las Vegas is producing and experiencing a heat island effect. A direct comparison between *Figures 19* and *24* clearly demonstrates this phenomenon.

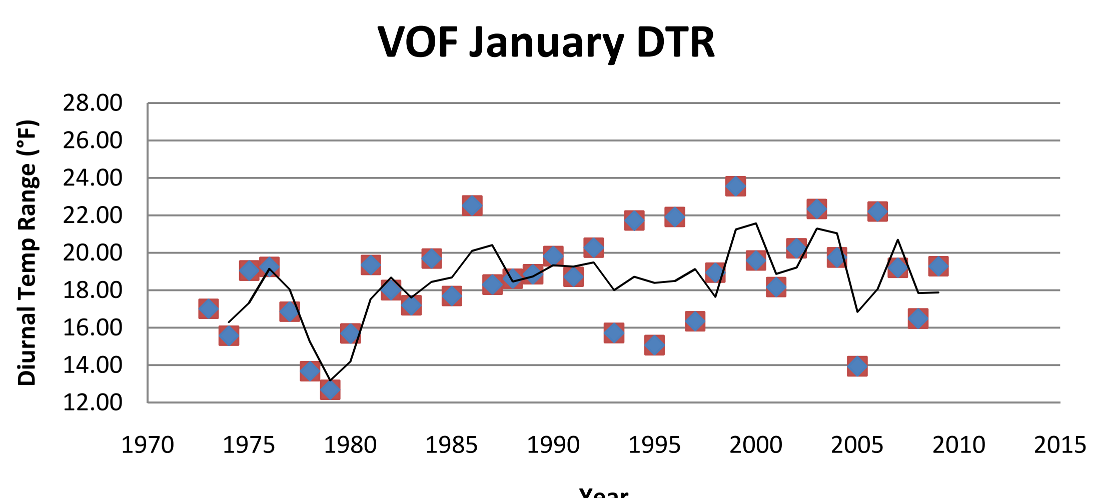

Figure 19

Figure 19 illustrates January's diurnal temperature range from 1973 to 2009 at Nevada's Valley of Fire State Park.

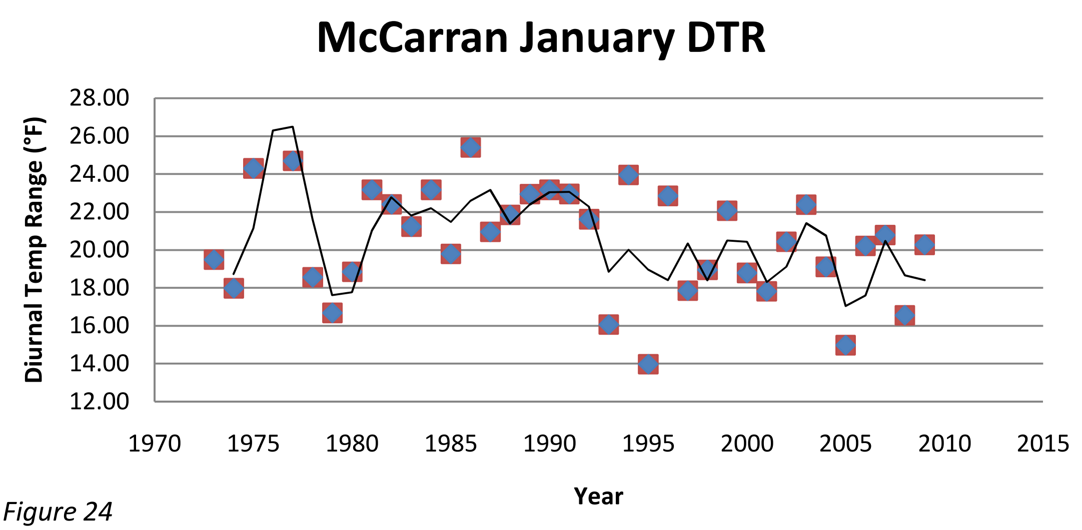

Figure 24

Figure 24 illustrates January's diurnal temperature range from 1973 to 2009 at Mccarran Internation Airport.

(4) <u>Urban and Rural Minimum Temperature Differences (Appendix F*)*</u>

Differences in minimum temperature have been calculated by subtracting the average rural minimum temperature from the average urban minimum temperature within the same month. After investigating minimum temperature differences since 1973, it has been determined that the difference between urban and rural minimum temperatures have been increasing. The growth of this difference over time proves that Las Vegas' urban minimum temperatures have been increasing at a significantly greater rate than its rural surroundings. For example, *Figure 29* demonstrates that the average minimum temperature in January at McCarran International Airport has warmed by approximately 3°F more than the average minimum temperature in Nevada's Valley of Fire State Park during this same month.

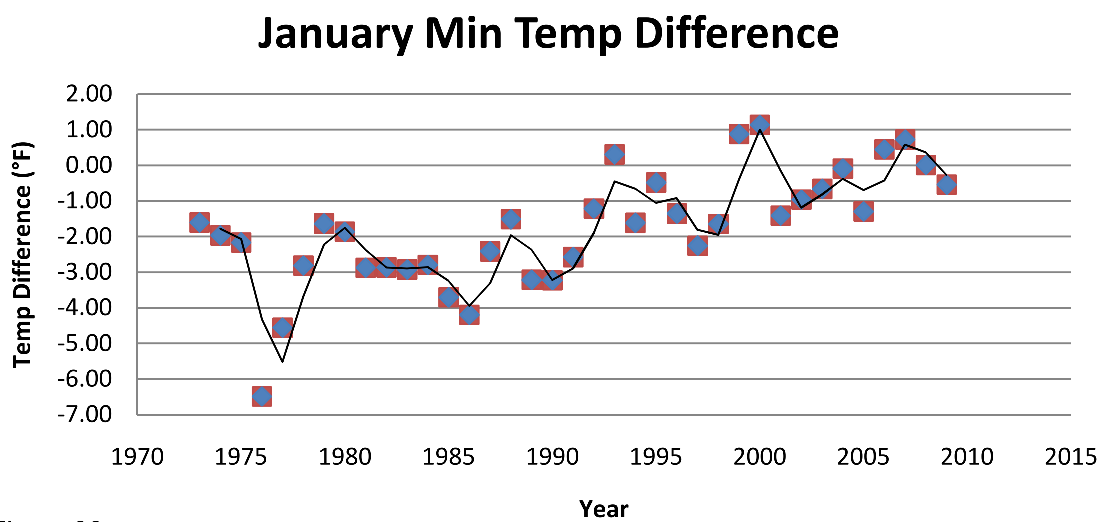

Figure 29

Figure 29 illustrates the difference between urban and rural minimum January temperatures from 1973 to 2009.

CONCLUSION

Las Vegas' Urban Heat Island

After evaluating Las Vegas' rural and urban temperature data, this paper has found statistically significant evidence for the presence of an urban heat island effect in the area. As expected, the first evaluation method, which examined rural and urban maximum temperatures in the Las Vegas area, did not provide any intelligible evidence to support this paper's hypothesis. The second evaluation method, which examined Las Vegas' urban and rural minimum temperatures, reveals that Las Vegas' urban minimum temperatures have been increasing at a substantial rate, while minimum temperatures in its rural surroundings have shown no statistically significant changes or trends. The third evaluation method shows that these unnatural increases in minimum temperatures have reduced the diurnal temperature range of Las Vegas' urban areas by 3°F more than its rural surroundings. The fourth evaluation method, which is the only method that provides a long-term direct comparison between Las Vegas' urban and rural climates, shows that the difference between urban and rural minimum temperatures has been growing over time, mainly due to urban minimum temperatures increasing at a significantly greater rate than those in rural surroundings. Because an urban heat island is defined as a metropolitan area that has higher temperatures than its rural surroundings, the fourth evaluation method provides the most compelling evidence for Las Vegas' urban heat island.

Although Las Vegas' urban heat island is certainly measurable, it is not as intense as many other documented urban heat islands because of its surrounding environment. Heat island intensity is defined as "The greatest difference between urban and rural temperatures…" (Gartland, 2008). Heat island intensity is the same measurement as the fourth evaluation method, which calculated the difference between average urban and rural minimum temperatures. The fourth evaluation method determined Las Vegas' heat island intensity to be approximately 3°F between 1973 and 2009.

Astoundingly, Baltimore's heat island intensity has been measured to be as high as 18°F in 2009. The strength of a city's heat island intensity depends on its regional climate as well as the vegetation cover of the surrounding ecosystem that the city replaced (Carlowicz, 2009). According to NASA researchers, "Urban areas developed in arid and semi-arid regions show far less heating compared with the surrounding countryside than cities built amid forested and temperate climates" (Carlowicz, 2009). Therefore, the disparity in heat island intensity between Las Vegas and Baltimore can be attributed to the vast differences of their surrounding ecosystems. The city of Baltimore was built in a naturally forested area. High levels of urbanization have created a drastic alteration of its ecosystem. When the sun's radiation hits a tree, as is often the case in a heavily forested area, it evaporates the water held inside the tree's leaves and is converted into latent (or delayed) heat. Once it eventually rains, this latent heat becomes sensible heat and warms our upper atmosphere. However, when the sun's radiation hits an urban feature, it is immediately converted into sensible heat and directly warms the Earth's surface. As a result of this unnatural heating, there is a massive difference between Baltimore's urban and rural temperatures.

In contrast, Las Vegas is located in a barren desert with minimal vegetation cover, causing minimal ecosystem alterations. Consequently, the majority of the sun's radiation becomes sensible heat at the Earth's surface, regardless of whether it hits an urban feature or the desert floor. Ironically, there is more vegetation cover in the Las Vegas metropolitan area today than there was before human settlement, possibly creating an urban cooling effect during the day. Ultimately, the city of Las Vegas has a weaker heat island intensity than would typically be expected because it is located in an arid, desert-like ecosystem.

Between 1973 and 1990, very minimal statistically significant trends are revealed in the retrieved data. Since 1991, however, all trends mentioned above become more pronounced, signifying a noticeably abrupt change in the data. This can be explained by the rapid urbanization of land surrounding the urban weather station. Marked by a white point in the center of *Images 1* and *2,* McCarran International Airport's weather station is visibly located on the outskirts of Las Vegas' metropolitan area before 1990. However, by the year 1994, captured in *Image 3*, McCarran International Airport's weather station has become completely surrounded by urban features. By 2009, rapid urban expansion has relocated the relative position of this urban weather station to the middle of Las Vegas' metropolitan area. These images, coupled with trends in rising urban minimum temperatures, provide indisputable proof of the mechanism behind Las Vegas' urban heat island **–** the measured warming of urban minimum temperatures caused by the night-time release of heat from urban materials. In summary, Las Vegas' unprecedented urban growth in the last 50 years has made it an ideal location to study, measure, and confirm the presence, strength, and growth of an urban heat island effect in an arid setting.

REFERENCES

Carlowicz, Mike. "Ecosystem, Vegetation Affect Intensity of Urban Heat Island Effect." *NASA's Earth Science News Team*. NASA, 12 15 2009. Web. 07 May 2010. <http://www.nasa.gov/mission_pages/terra/news/heat-islands.html>.

Gartland, Lisa. *Heat Islands: Understanding and Mitigating Heat in Urban Areas*. 1st d. 1 vol. London: Earthscan, 2008. 1-3. Print.

"Las Vegas McCarran International Airport." *Weather America*. 2nd ed. Millerton, NY: Grey House Publishing, Inc., 2000. 2208. Print.

Landsberg, Helmut E. *The Urban Climate*. 1st ed. 28. London: Academic Press, Inc, 1981. 84-85, 100. Print.

Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, *World Population Prospects: The 2006 Revision* and *World Urbanization Prospects: The 2007 Revision*, Monday, May 17, 2010; 6:04:18 PM
<http://esa.un.org/unup>

Scott, Michael, and Sujata Gupta. "Human Settlements, Energy, and Industry." *IPCC Reports*. International Panel on Climate Control, 2000. Web. 10 May 2010. <http://www.ipcc.ch/ipccreports/tar/wg2/pdf/wg2TARchap7.pdf>.

United States. *Cumulative Estimates of Population Change for Metropolitan Statistical Areas and Rankings: April 1, 2000 to July 1, 2008*. , 2009. Print.

WRCC, "LAS VEGAS WSO AIRPORT, NEVADA (264436) ." *Western Regional Climate Center*. 12 31 2009. Web. 21 April 2010. <http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?nv4436>.

Appendix B (*Tables 1* and *2*)

Valley of Fire State Park, Nevada

Lat: 36°26° N **Long:** 114°31° W **Elev:** 1,998 ft.

Year	1MaxT	1MinT	4MaxT	4MinT	7MaxT	7MinT	10MaxT	10MinT
1973	49.71	32.71	75.70	50.60	108.54	79.36	83.71	57.71
1974	49.53	33.97	78.36	51.22	105.40	77.04	82.83	60.47
1975	54.27	35.23	70.28	48.03	105.59	80.13	81.07	55.69
1976	58.47	39.23	75.50	50.87	105.68	80.23	78.21	55.93
1977	54.70	37.85	81.96	56.07	106.77	81.58	85.52	62.58
1978	55.07	41.40	75.28	52.13	107.19	79.74	86.42	62.58
1979	47.00	34.32	78.93	52.63	106.87	78.87	86.42	60.55
1980	57.58	41.90	78.20	51.80	106.61	79.42	83.81	59.00
1981	61.67	42.33	83.57	59.80	107.94	84.16	78.61	57.13
1982	55.29	37.29	77.30	53.20	103.39	78.29	76.48	54.39
1983	56.06	38.87	71.43	49.87	104.58	79.52	80.97	58.74
1984	58.00	38.32	76.77	53.70	101.81	80.45	76.48	53.26
1985	55.84	38.16	83.23	57.20	106.06	80.68	80.48	57.42
1986	65.74	43.23	79.60	56.40	101.52	78.29	78.87	56.19
1987	54.90	36.61	82.80	56.60	101.55	76.26	85.71	61.97
1988	54.26	35.65	77.37	53.50	107.19	82.16	90.35	64.61
1989	54.45	35.61	88.47	60.20	107.10	81.45	87.63	61.72
1990	56.65	36.84	81.83	57.33	104.19	80.00	83.13	59.23
1991	55.29	36.58	76.57	53.43	104.42	77.84	86.13	60.77
1992	56.61	36.35	82.71	56.13	101.35	77.32	84.19	60.35
1993	53.06	37.35	80.24	54.67	102.53	78.50	83.14	57.65
1994	60.65	38.94	83.60	51.95	107.81	82.65	79.71	55.77
1995	56.03	40.97	77.00	53.07	106.06	79.03	85.03	57.45
1996	60.32	38.42	84.63	56.70	107.29	82.87	81.61	56.06
1997	57.94	41.61	76.90	52.87	103.42	78.06	81.61	57.06
1998	59.74	40.81	74.37	52.37	105.35	78.87	79.26	55.94
1999	62.06	38.52	72.23	50.50			86.57	60.23
2000	60.48	40.90	84.83	60.21	105.90	79.43	79.26	59.19
2001	57.03	38.87	78.45	54.77	104.35	79.90	86.26	60.77
2002	57.10	36.87	83.30	59.23	108.00	83.81	79.39	58.06
2003	65.94	43.61	75.67	53.33	109.61	83.84	89.06	64.68
2004	57.74	38.00	79.93	57.30	105.03	81.39	78.96	59.42
2005	59.13	45.20	75.50	52.50	107.60	81.12	81.29	59.16
2006	61.81	39.62	78.17	55.57	106.45	81.81	77.90	58.23
2007	54.05	34.86	81.03	57.47	107.94	84.06	81.03	58.39
2008	54.32	37.84	79.33	54.97	105.74	81.65	83.77	58.68
2009	60.69	41.42	76.90	54.40	107.61	83.48	78.35	57.32

Table 1

LAS VEGAS McCarran International Airport

Lat: 36°05° N **Long:** 115°10° W **Elev:** 2,125

Year	1MaxT	1MinT	4MaxT	4MinT	7MaxT	7MinT	10MaxT	10MinT
1973	50.58	31.10	74.50	49.77	106.29	77.00	82.52	52.87
1974	49.97	32.00	77.03	49.83	102.06	75.39	81.32	57.16
1975	57.35	33.06	68.03	45.10	103.74	76.84	79.61	52.58
1976	61.06	32.74	75.90	49.17	100.71	73.06	78.94	54.03
1977	57.97	33.29	84.20	53.03	106.48	78.16	86.52	56.29
1978	57.13	38.58	75.80	50.37	106.94	76.84	88.10	58.81
1979	49.35	32.68	80.50	51.57	106.77	75.29	84.29	57.13
1980	58.87	40.03	76.43	50.60	105.48	78.35	82.81	55.00
1981	62.61	39.45	84.03	57.10	105.90	79.52	76.45	55.29
1982	56.81	34.42	76.00	51.47	101.29	74.84	75.42	50.65
1983	57.16	35.94	69.10	47.77	101.71	75.16	79.52	56.00
1984	58.68	35.52	75.40	50.67	99.97	76.26	74.65	51.42
1985	54.23	34.45	81.93	54.37	105.19	78.81	80.32	54.32
1986	64.42	39.03	78.97	53.30	100.65	74.48	77.81	52.06
1987	55.13	34.19	82.97	53.83	101.32	72.39	84.29	57.58
1988	55.97	34.13	77.17	51.07	106.87	78.26	89.39	60.26
1989	55.32	32.39	86.83	58.47	107.29	79.35	80.58	53.68
1990	56.77	33.61	82.00	55.63	103.74	77.87	82.81	55.58
1991	56.94	34.00	76.60	51.77	104.19	76.19	85.00	59.35
1992	56.74	35.13	83.50	57.50	101.00	76.26	83.26	58.48
1993	53.71	37.65	80.07	54.80	102.58	76.23	81.65	56.48
1994	61.26	37.32	79.10	56.07	106.42	80.13	79.26	55.03
1995	54.45	40.48	76.37	53.23	105.29	79.35	83.42	55.35
1996	59.90	37.06	81.13	55.53	105.97	80.52	78.87	54.71
1997	57.19	39.35	76.53	54.27	101.03	75.35	79.26	55.29
1998	58.10	39.16	72.27	49.80	104.81	78.61	77.48	55.61
1999	61.45	39.39	71.40	50.43	99.00	77.35	85.13	58.03
2000	60.81	42.03	83.30	59.07	104.71	79.77	77.10	57.42
2001	55.26	37.45	75.93	54.00	102.10	78.55	83.94	60.23
2002	56.32	35.90	81.70	57.70	106.48	82.58	78.61	56.23
2003	65.32	42.94	72.80	52.93	106.58	82.94	87.16	63.48
2004	57.00	37.90	78.13	57.53	104.61	81.45	77.87	58.61
2005	58.87	43.90	76.67	54.67	106.97	83.58	79.94	60.84
2006	60.26	40.06	77.80	55.33	105.52	83.65	77.61	57.87
2007	56.35	35.58	81.60	59.33	107.06	83.65	80.61	58.87
2008	54.39	37.84	79.33	55.93	104.81	82.52	82.71	59.42
2009	61.13	40.87	77.90	54.03	105.97	83.35	77.48	56.45

Table 2

Appendix C (*Figures 2-9*)

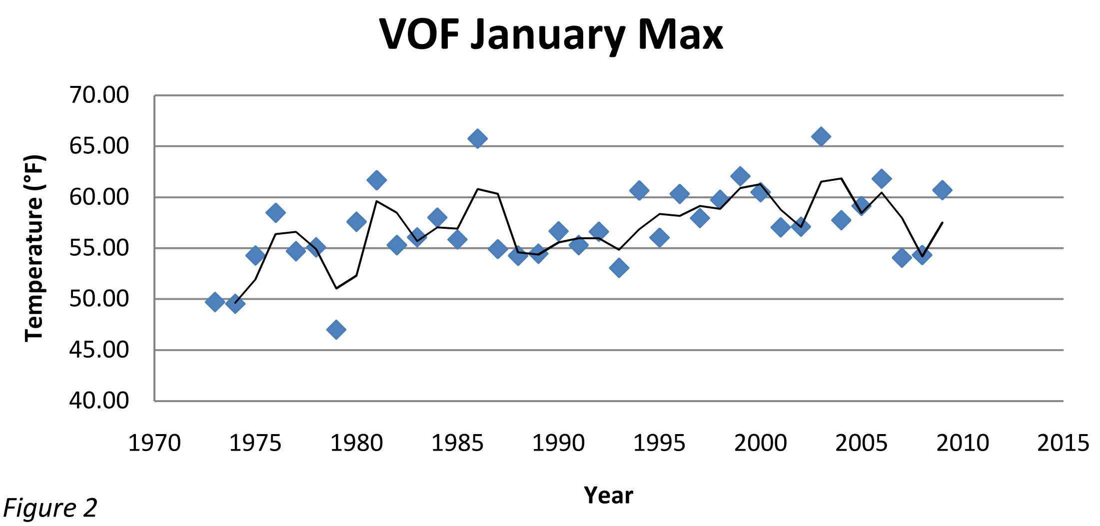

Figure 2

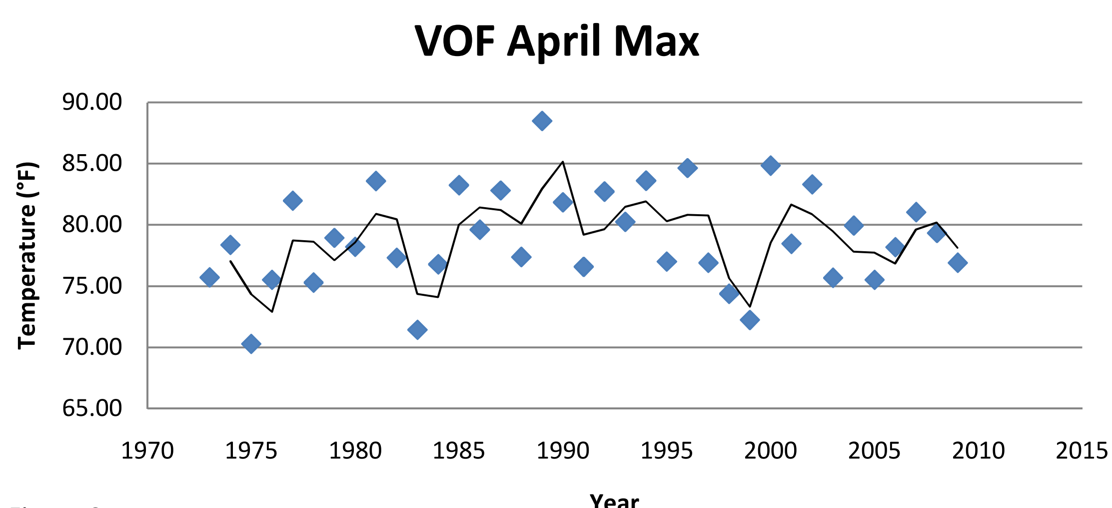

Figure 3

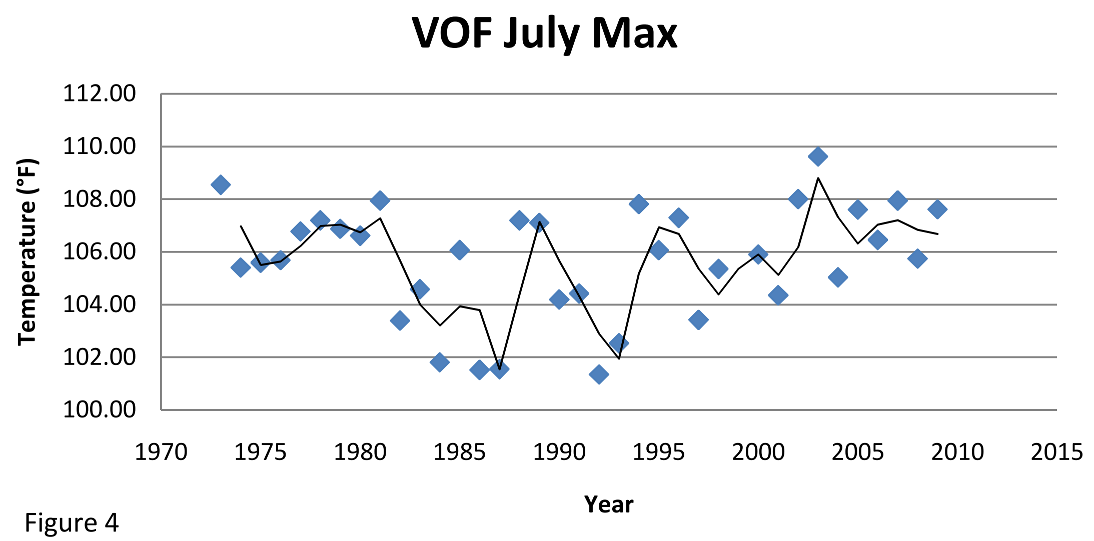

Figure 4

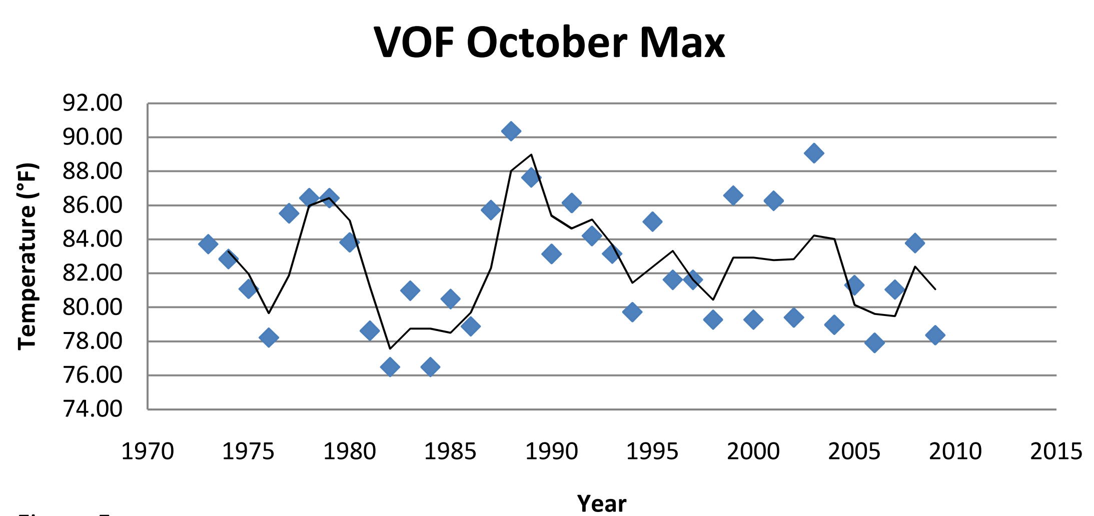

Figure 5

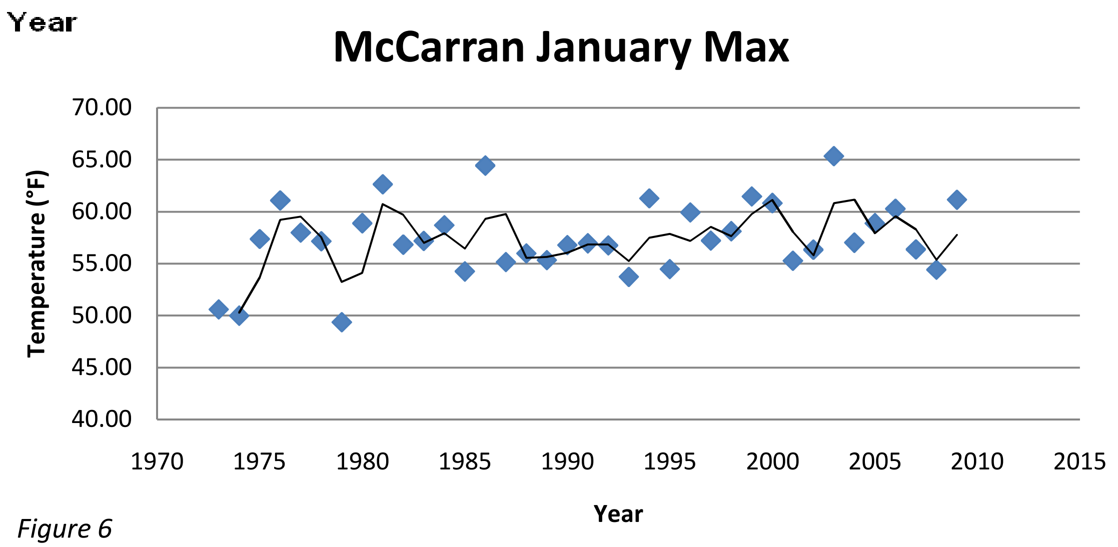

Figure 6

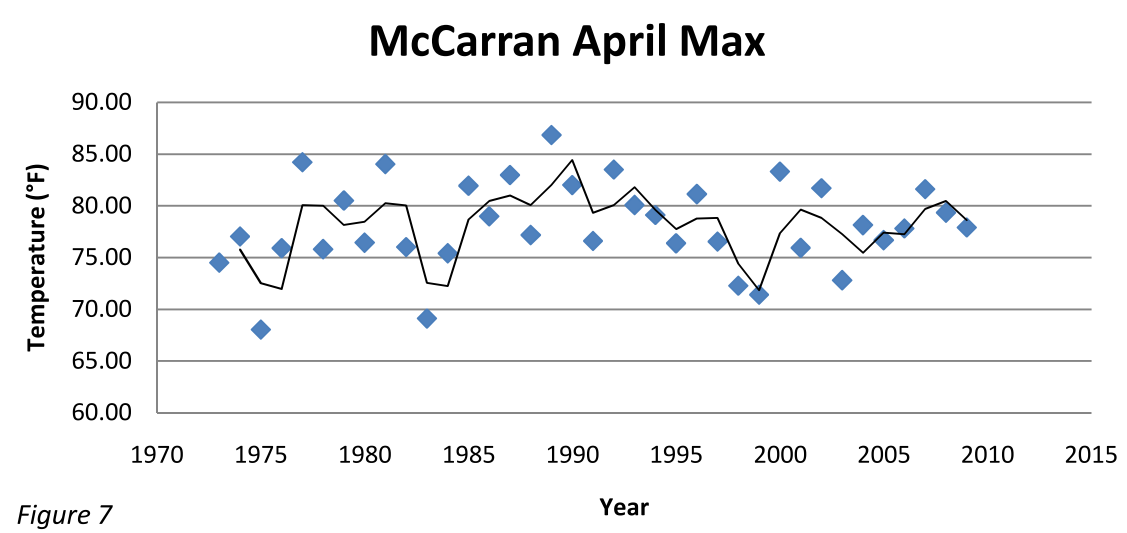

Figure 7

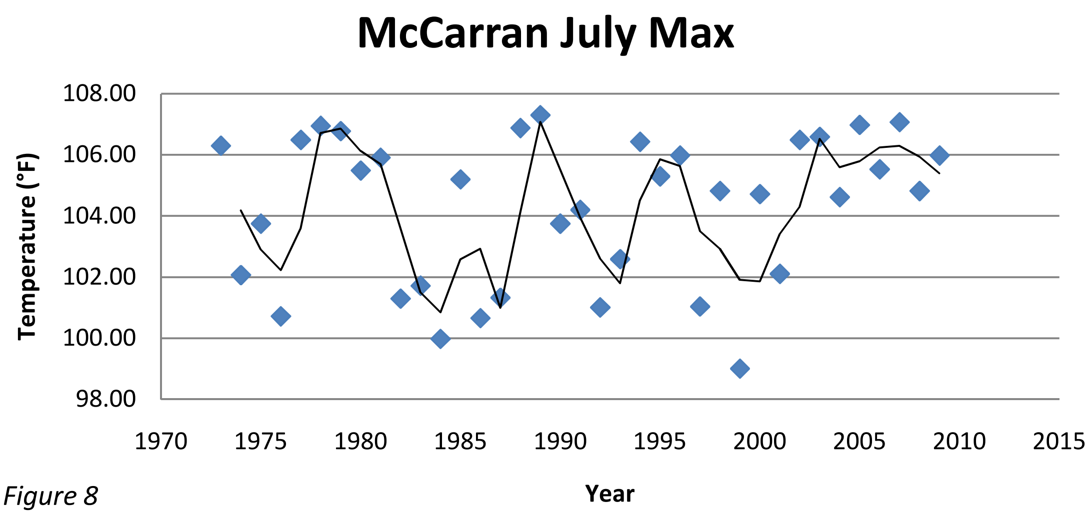

Figure 8

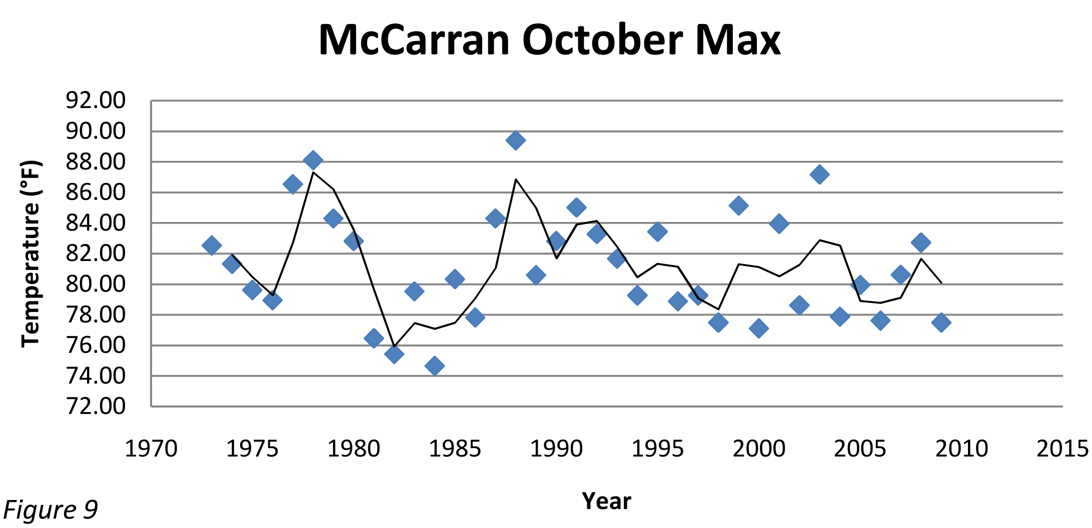

Figure 9

Appendix D (*Figures 10-17*)

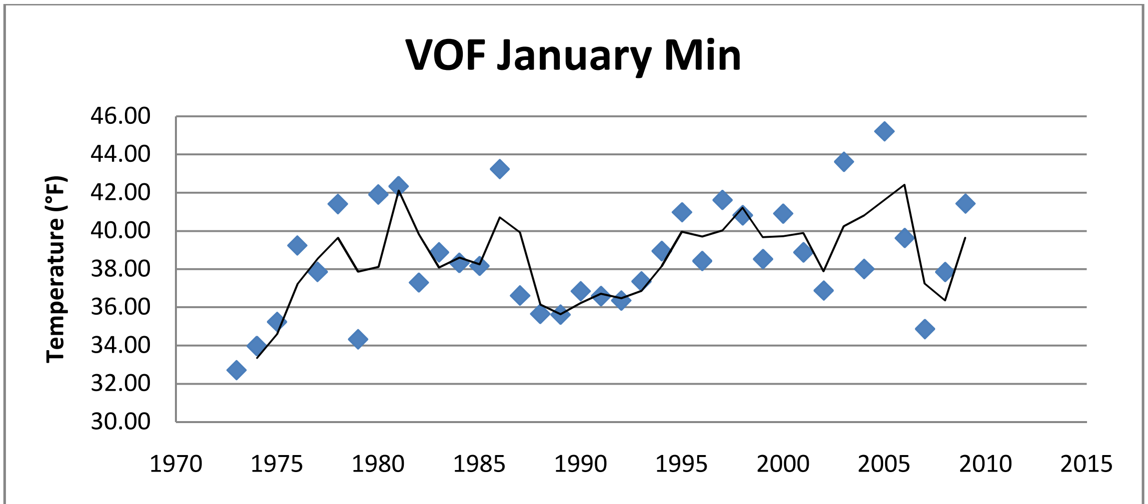

Figure 10

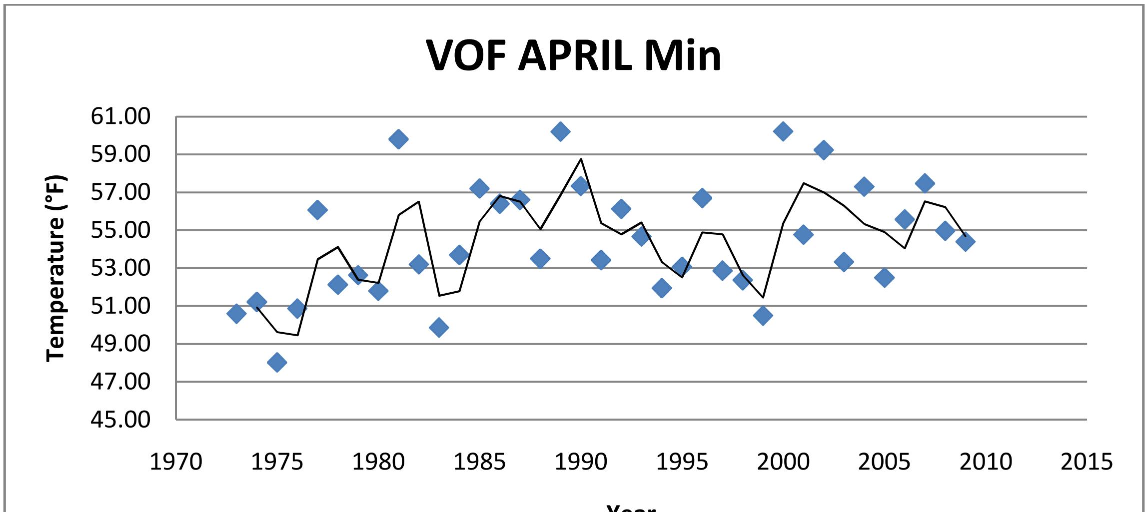

Figure 11

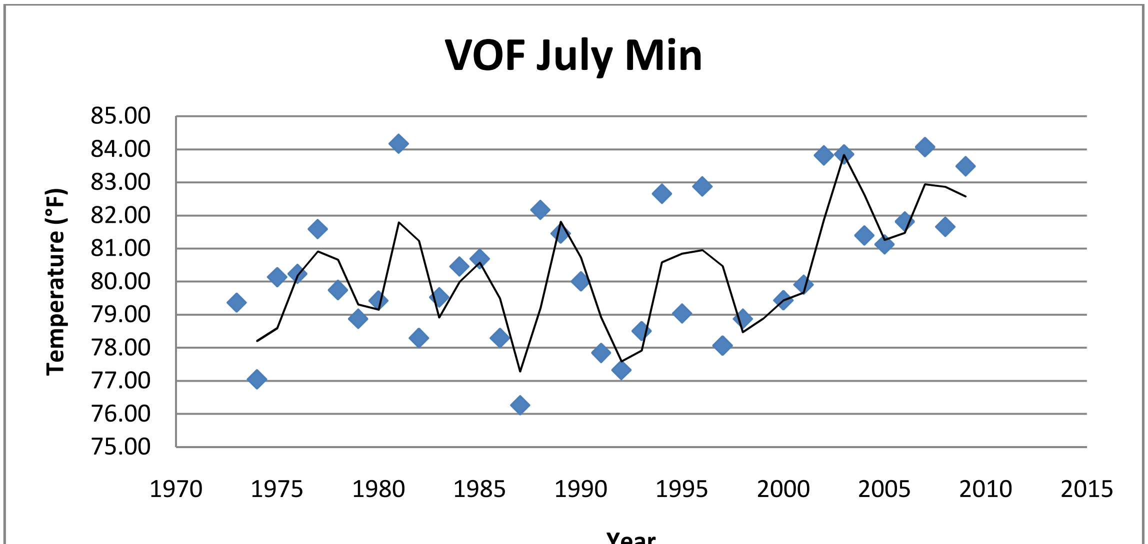

Figure 12

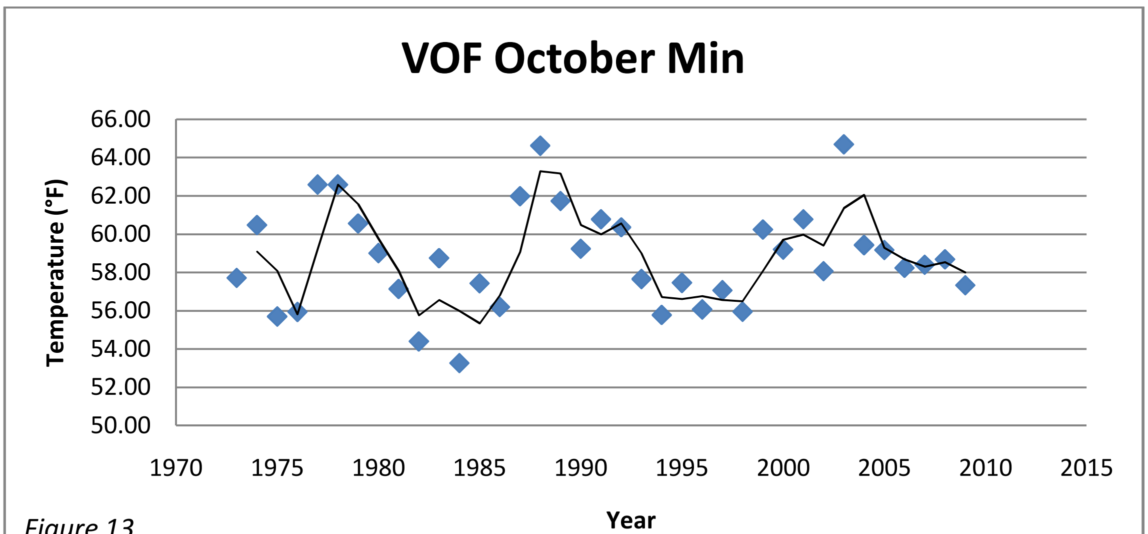

Figure 13

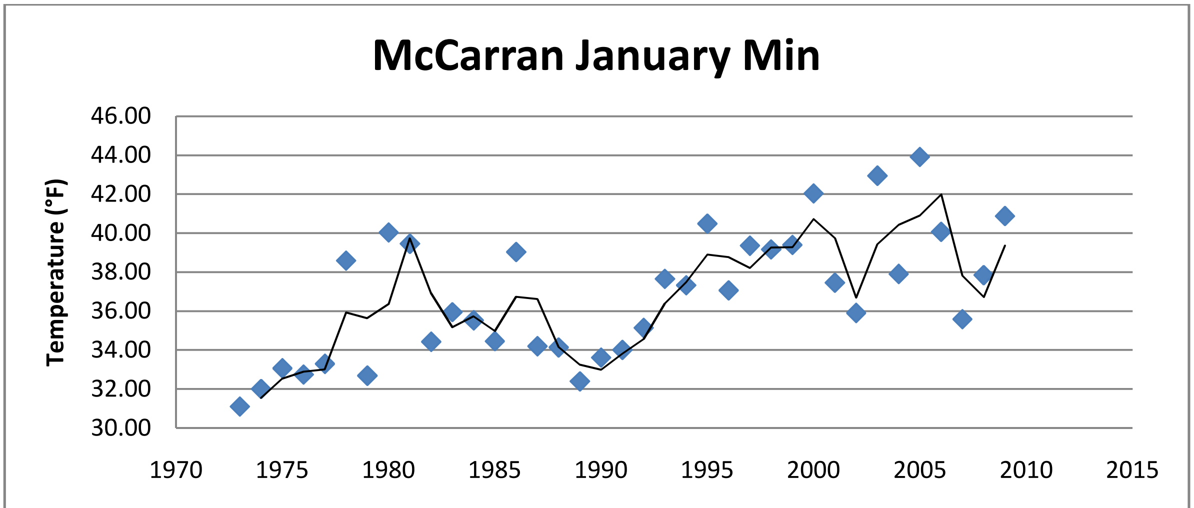

Figure 14

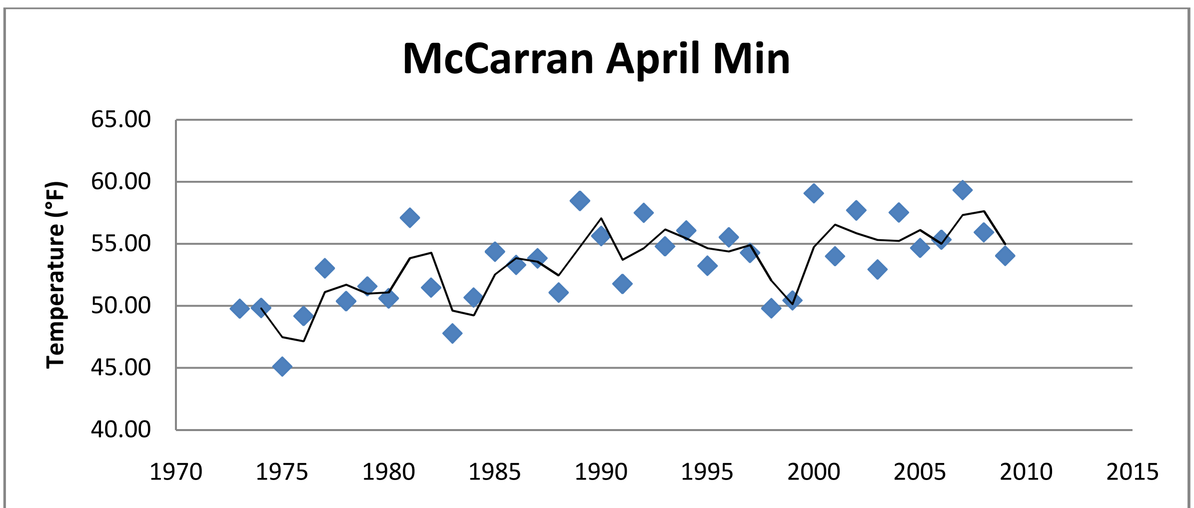

Figure 15

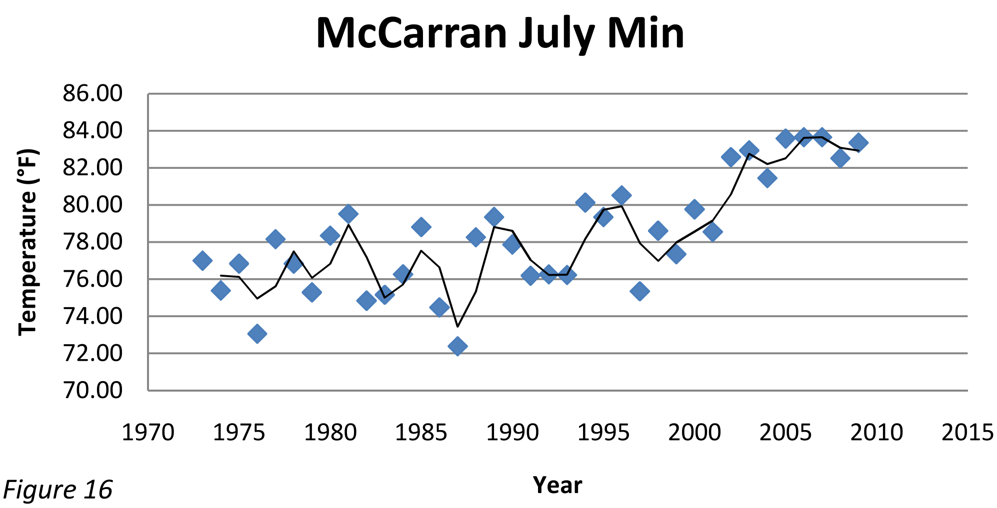

Figure 16

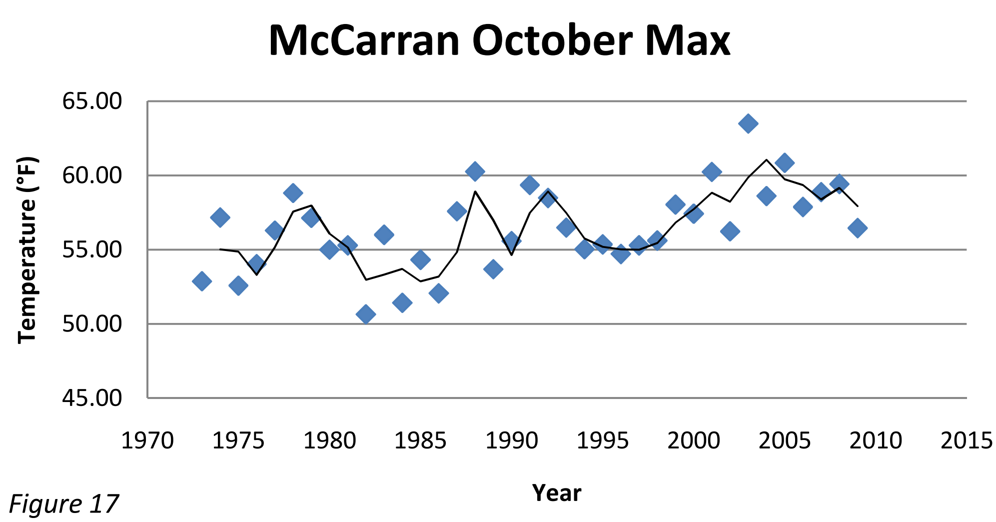

Figure 17

Appendix E (*Tables 3-4* and *Figures 18-27*)

VOF Diurnal Temp Difference

Year	Jan Diff	April Diff	July Diff	Oct Diff
1973	17.00	25.10	29.18	26.00
1974	15.56	27.14	28.36	22.36
1975	19.04	22.25	25.46	25.38
1976	19.24	24.63	25.45	22.28
1977	16.85	25.89	25.19	22.94
1978	13.67	23.15	27.45	23.84
1979	12.68	26.30	28.00	25.87
1980	15.68	26.40	27.19	24.81
1981	19.34	23.77	23.78	21.48
1982	18.00	24.10	25.10	22.09
1983	17.19	21.56	25.06	22.23
1984	19.68	23.07	21.36	23.22
1985	17.68	26.03	25.38	23.06
1986	22.51	23.20	23.23	22.68
1987	18.29	26.20	25.29	23.74
1988	18.61	23.87	25.03	25.74
1989	18.84	28.27	25.65	25.91
1990	19.81	24.50	24.19	23.90
1991	18.71	23.14	26.58	25.36
1992	20.26	26.58	24.03	23.84
1993	15.71	25.57	24.03	25.49
1994	21.71	31.65	25.16	23.94
1995	15.06	23.93	27.03	27.58
1996	21.90	27.93	24.42	25.55
1997	16.33	24.03	25.36	24.55
1998	18.93	22.00	26.48	23.32
1999	23.54	21.73		26.34
2000	19.58	24.62	26.47	20.07
2001	18.16	23.68	24.45	25.49
2002	20.23	24.07	24.19	21.33
2003	22.33	22.34	25.77	24.38
2004	19.74	22.63	23.64	19.54
2005	13.93	23.00	26.48	22.13
2006	22.19	22.60	24.64	19.67
2007	19.19	23.56	23.88	22.64
2008	16.48	24.36	24.09	25.09
2009	19.27	22.50	24.13	21.03

Table 3

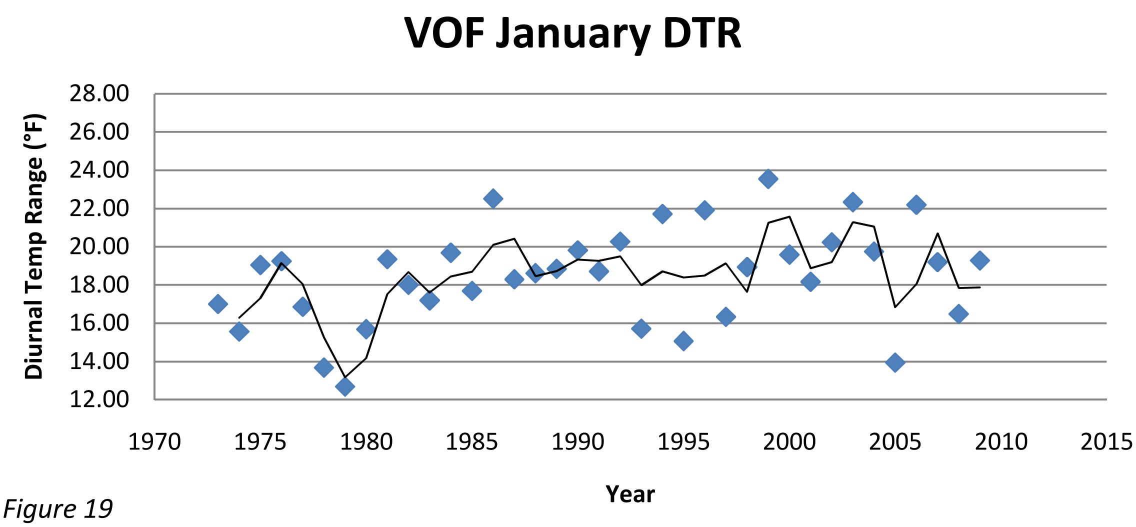

Figure 19

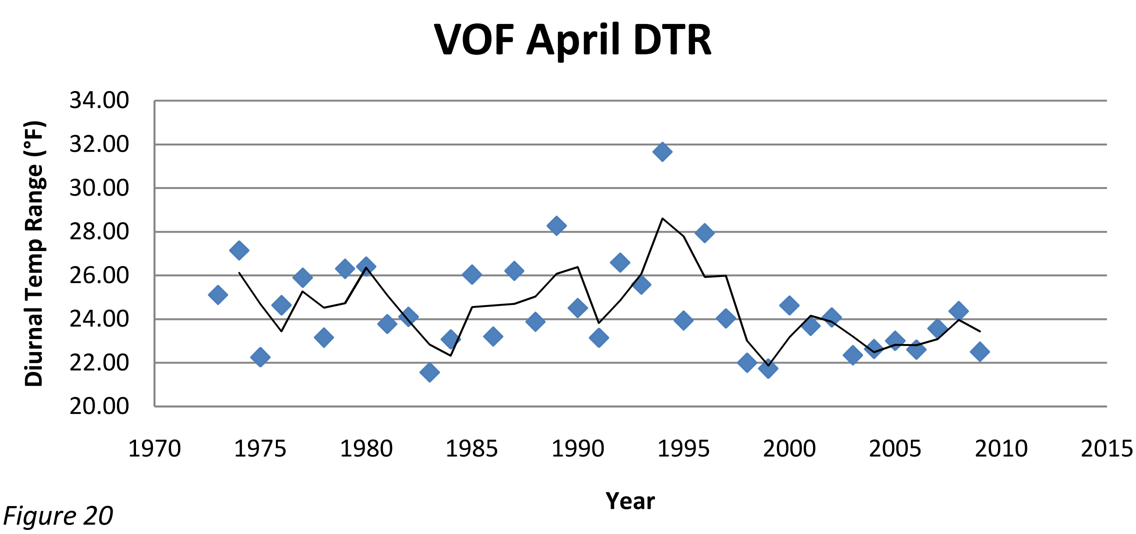

Figure 20

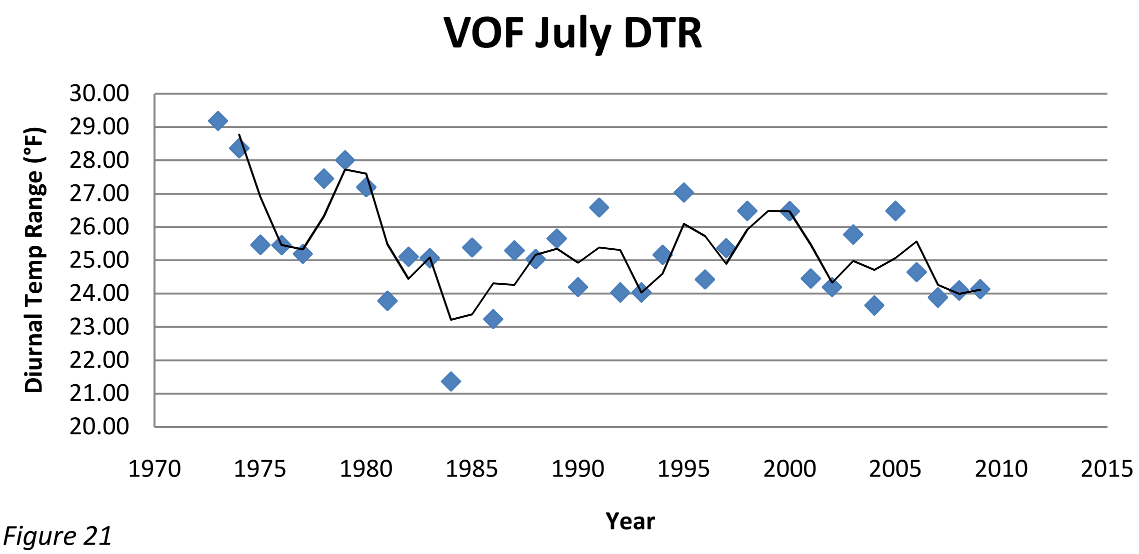

Figure 21

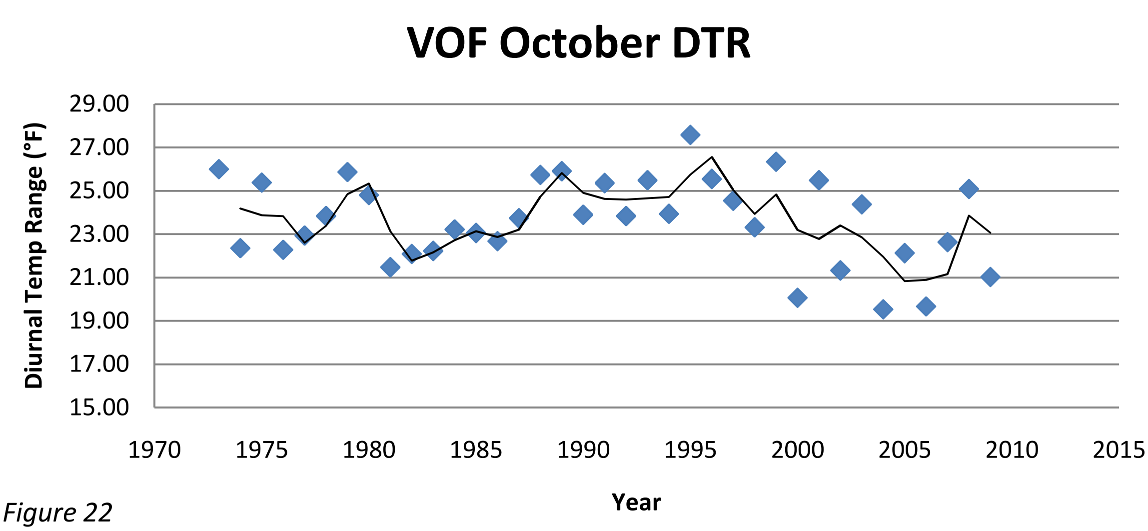

Figure 22

McCarran Diurnal Temp Difference

Year	Jan Diff	April Diff	July Diff	Oct Diff
1973	19.48	24.73	29.29	29.65
1974	17.97	27.20	26.67	24.16
1975	24.29	22.93	26.90	27.03
1976	28.32	26.73	27.65	24.91
1977	24.68	31.17	28.32	30.23
1978	18.55	25.43	30.10	29.29
1979	16.67	28.93	31.48	27.16
1980	18.84	25.83	27.13	27.81
1981	23.16	26.93	26.38	21.16
1982	22.39	24.53	26.45	24.77
1983	21.22	21.33	26.55	23.52
1984	23.16	24.73	23.71	23.23
1985	19.78	27.56	26.38	26.00
1986	25.39	25.67	26.17	25.75
1987	20.94	29.14	28.93	26.71
1988	21.84	26.10	28.61	29.13
1989	22.93	28.36	27.94	26.90
1990	23.16	26.37	25.87	27.23
1991	22.94	24.83	28.00	25.65
1992	21.61	26.00	24.74	24.78
1993	16.06	25.27	26.35	25.17
1994	23.94	23.03	26.29	24.23
1995	13.97	23.14	25.94	28.07
1996	22.84	25.60	25.45	24.16
1997	17.84	22.26	25.68	23.97
1998	18.94	22.47	26.20	21.87
1999	22.06	20.97	21.65	27.10
2000	18.78	24.23	24.94	19.68
2001	17.81	21.93	23.55	23.71
2002	20.42	24.00	23.90	22.38
2003	22.38	19.87	23.64	23.68
2004	19.10	20.60	23.16	19.26
2005	14.97	22.00	23.39	19.10
2006	20.20	22.47	21.87	19.74
2007	20.77	22.27	23.41	21.74
2008	16.55	23.40	22.29	23.29
2009	20.26	23.87	22.62	21.03

Table 4

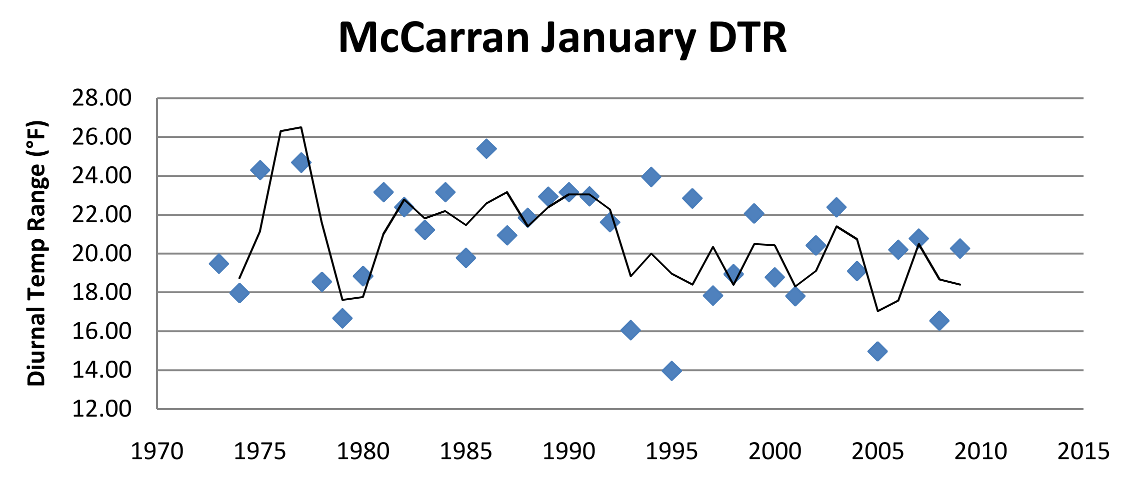

Figure 24

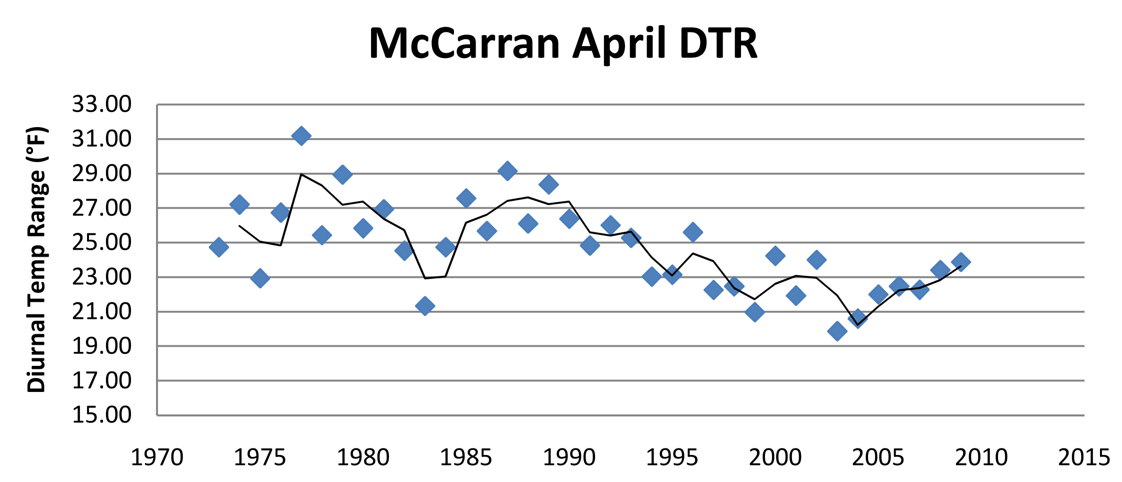

Figure 25

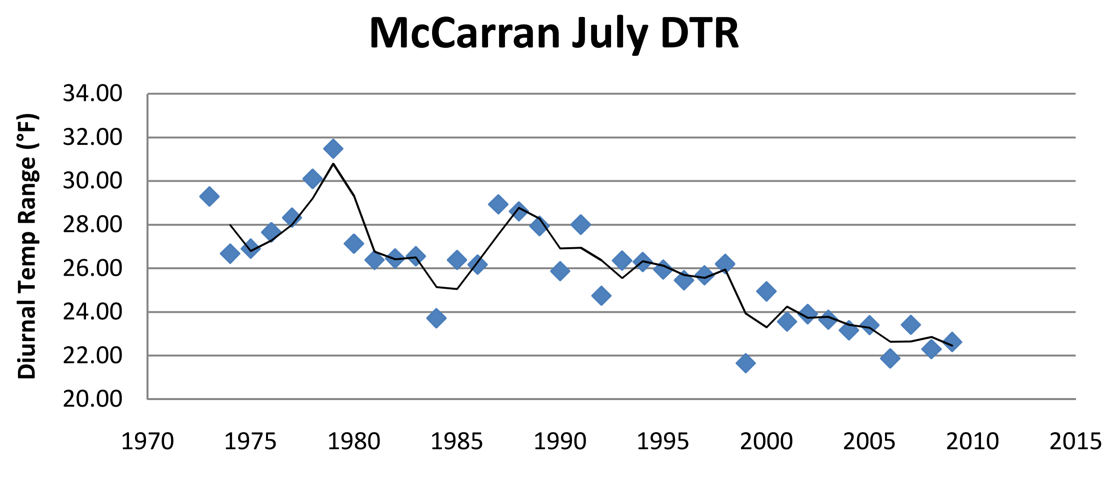

Figure 26

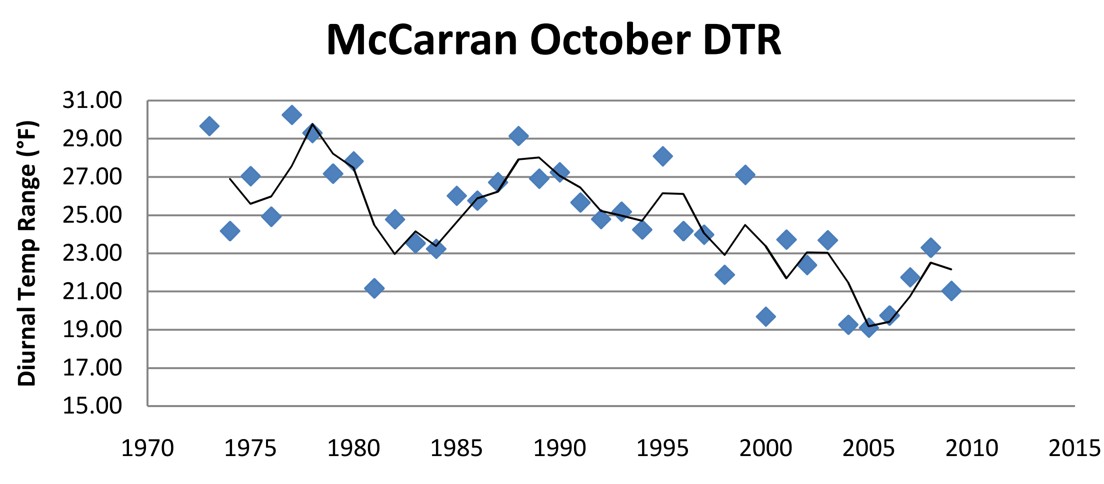

Figure 27

Appendix F (*Table 5* and *Figures 28-35*)

Differences (Airport Temp minus Park Temp)

Year	Jan Max	Jan Min	April Max	April Min	July Max	July Min	Oct Max	Oct Min
1973	0.87	-1.61	-1.20	-0.83	-2.25	-2.36	-1.19	-4.84
1974	0.44	-1.97	-1.33	-1.39	-3.34	-1.65	-1.51	-3.31
1975	3.08	-2.17	-2.25	-2.93	-1.85	-3.29	-1.46	-3.11
1976	2.59	-6.49	0.40	-1.70	-4.97	-7.17	0.73	-1.90
1977	3.27	-4.56	2.24	-3.04	-0.29	-3.42	1.00	-6.29
1978	2.06	-2.82	0.52	-1.76	-0.25	-2.90	1.68	-3.77
1979	2.35	-1.64	1.57	-1.06	-0.10	-3.58	-2.13	-3.42
1980	1.29	-1.87	-1.77	-1.20	-1.13	-1.07	-1.00	-4.00
1981	0.94	-2.88	0.46	-2.70	-2.04	-4.64	-2.16	-1.84
1982	1.52	-2.87	-1.30	-1.73	-2.10	-3.45	-1.06	-3.74
1983	1.10	-2.93	-2.33	-2.10	-2.87	-4.36	-1.45	-2.74
1984	0.68	-2.80	-1.37	-3.03	-1.84	-4.19	-1.83	-1.84
1985	-1.61	-3.71	-1.30	-2.83	-0.87	-1.87	-0.16	-3.10
1986	-1.32	-4.20	-0.63	-3.10	-0.87	-3.81	-1.06	-4.13
1987	0.23	-2.42	0.17	-2.77	-0.23	-3.87	-1.42	-4.39
1988	1.71	-1.52	-0.20	-2.43	-0.32	-3.90	-0.96	-4.35
1989	0.87	-3.22	-1.64	-1.73	0.19	-2.10	-7.05	-8.04
1990	0.12	-3.23	0.17	-1.70	-0.45	-2.13	-0.32	-3.65
1991	1.65	-2.58	0.03	-1.66	-0.23	-1.65	-1.13	-1.42
1992	0.13	-1.22	0.79	1.37	-0.35	-1.06	-0.93	-1.87
1993	0.65	0.30	-0.17	0.13	0.05	-2.27	-1.49	-1.17
1994	0.61	-1.62	-4.50	4.12	-1.39	-2.52	-0.45	-0.74
1995	-1.58	-0.49	-0.63	0.16	-0.77	0.32	-1.61	-2.10
1996	-0.42	-1.36	-3.50	-1.17	-1.32	-2.35	-2.74	-1.35
1997	-0.75	-2.26	-0.37	1.40	-2.39	-2.71	-2.35	-1.77
1998	-1.64	-1.65	-2.10	-2.57	-0.54	-0.26	-1.78	-0.33
1999	-0.61	0.87	-0.83	-0.07			-1.44	-2.20
2000	0.33	1.13	-1.53	-1.14	-1.19	0.34	-2.16	-1.77
2001	-1.77	-1.42	-2.52	-0.77	-2.25	-1.35	-2.32	-0.54
2002	-0.78	-0.97	-1.60	-1.53	-1.52	-1.23	-0.78	-1.83
2003	-0.62	-0.67	-2.87	-0.40	-3.03	-0.90	-1.90	-1.20
2004	-0.74	-0.10	-1.80	0.23	-0.42	0.06	-1.09	-0.81
2005	-0.26	-1.30	1.17	2.17	-0.63	2.46	-1.35	1.68
2006	-1.55	0.44	-0.37	-0.24	-0.93	1.84	-0.29	-0.36
2007	2.30	0.72	0.57	1.86	-0.88	-0.41	-0.42	0.48
2008	0.07	0.00	0.00	0.96	-0.93	0.87	-1.06	0.74
2009	0.44	-0.55	1.00	-0.37	-1.64	-0.13	-0.87	-0.87

Table 5

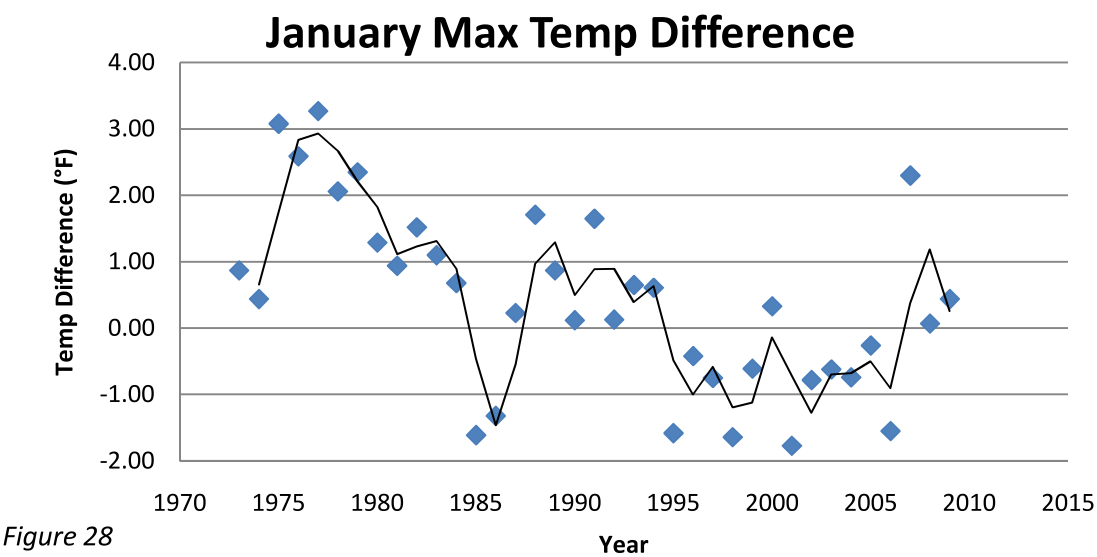

Figure 28

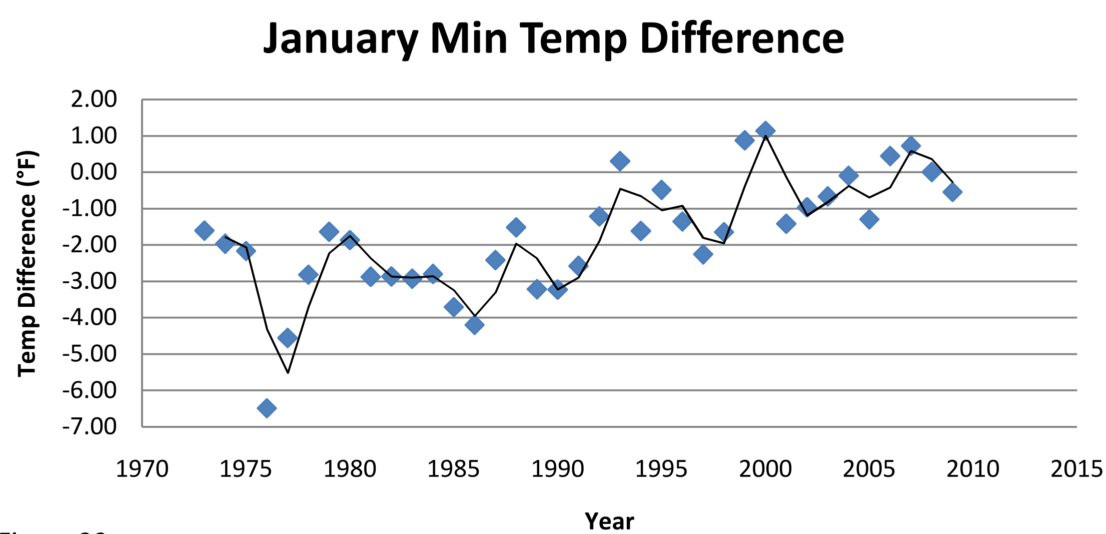

Figure 29

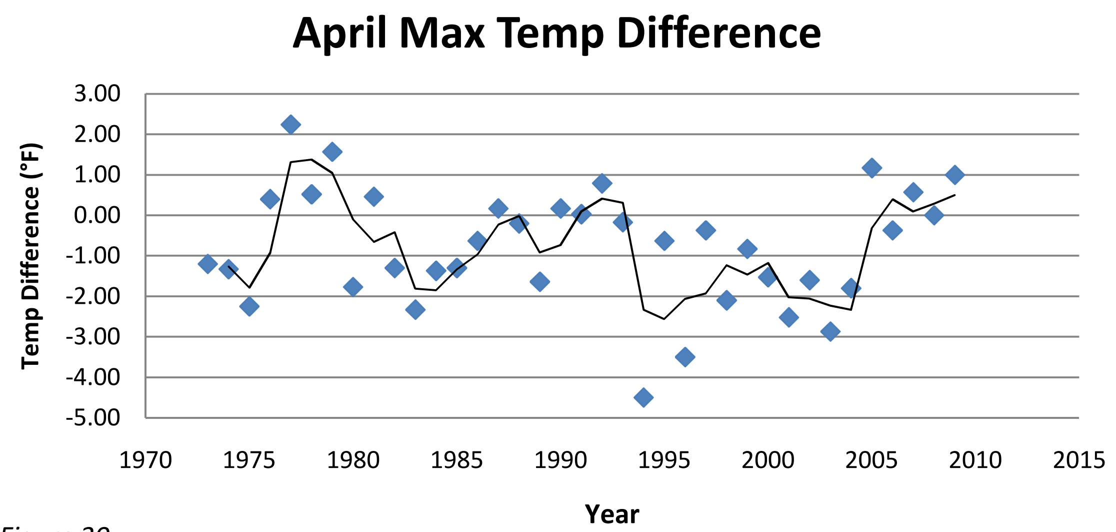

Figure 30

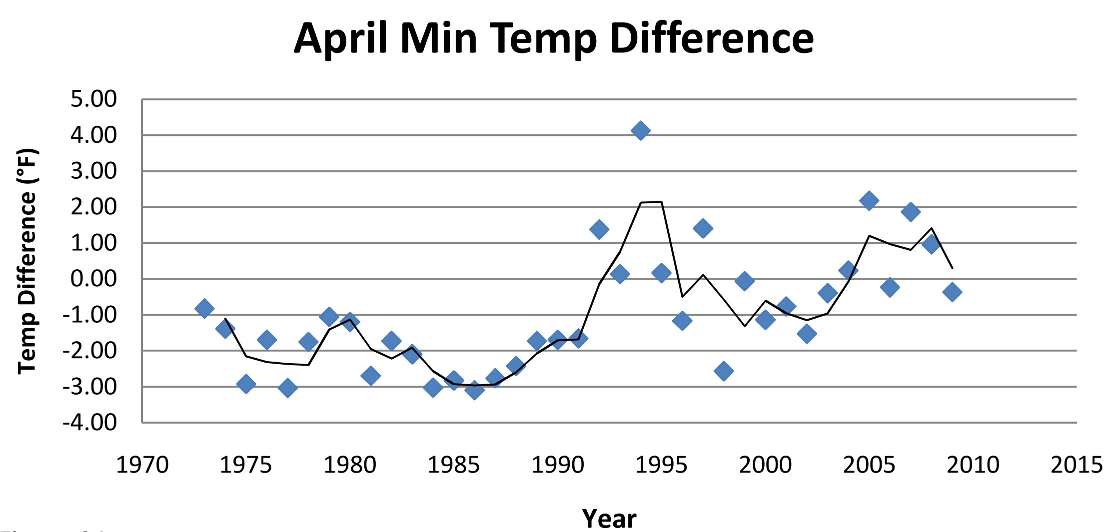

Figure 31

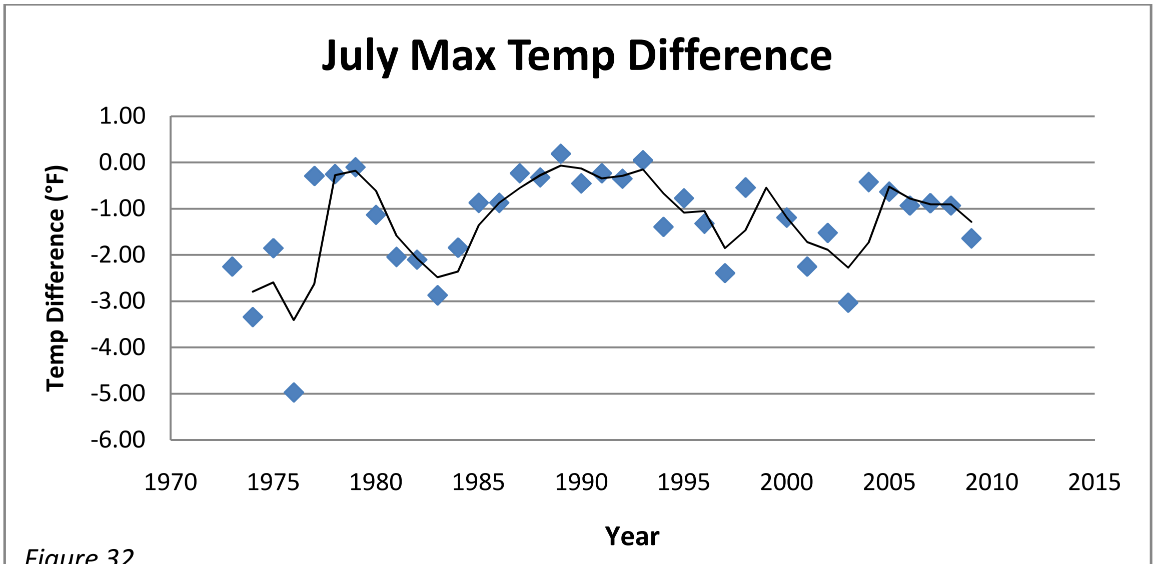

Figure 32

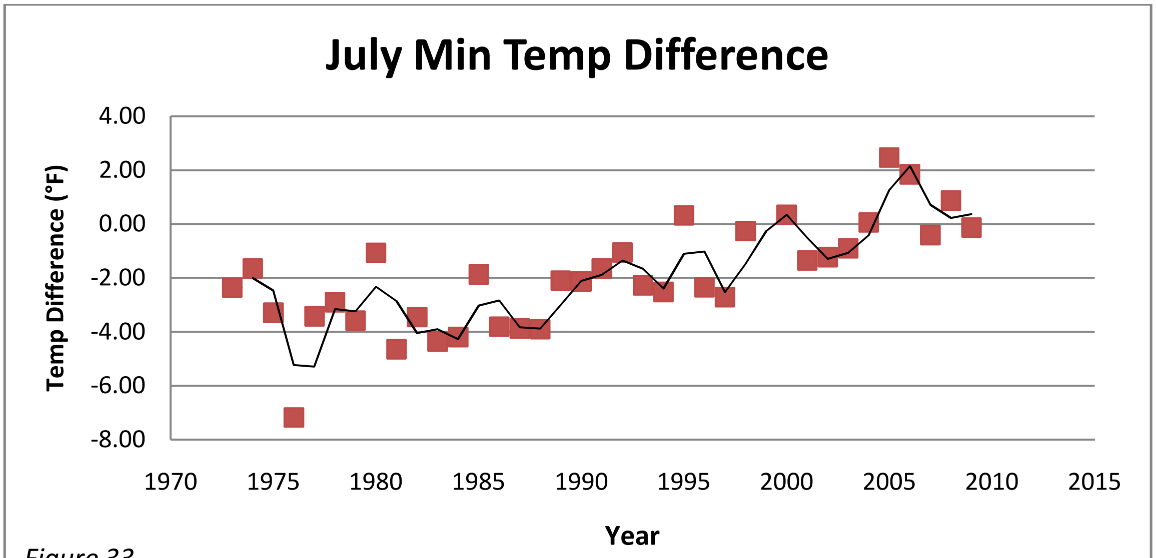

Figure 33

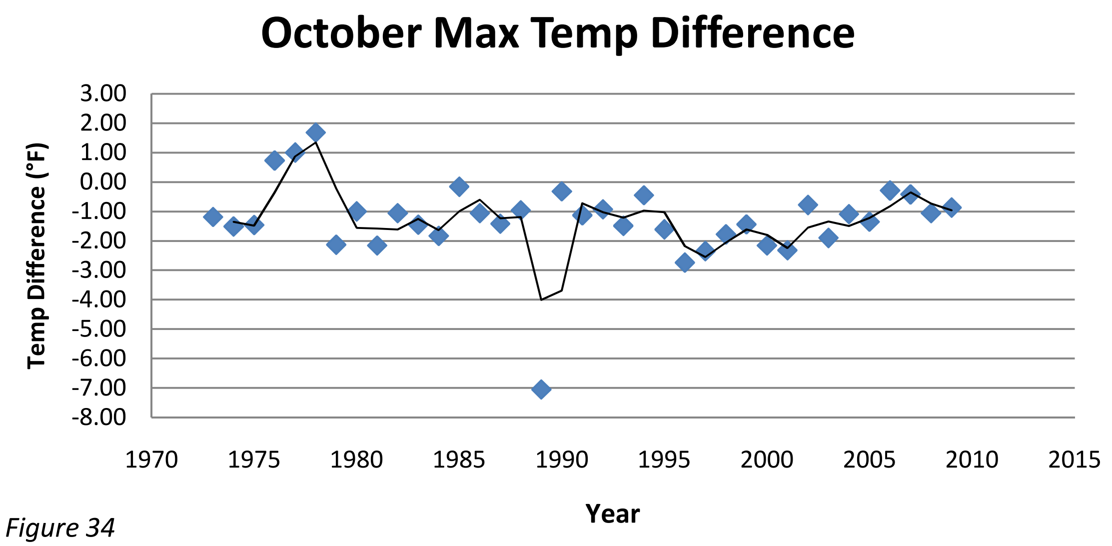

Figure 34

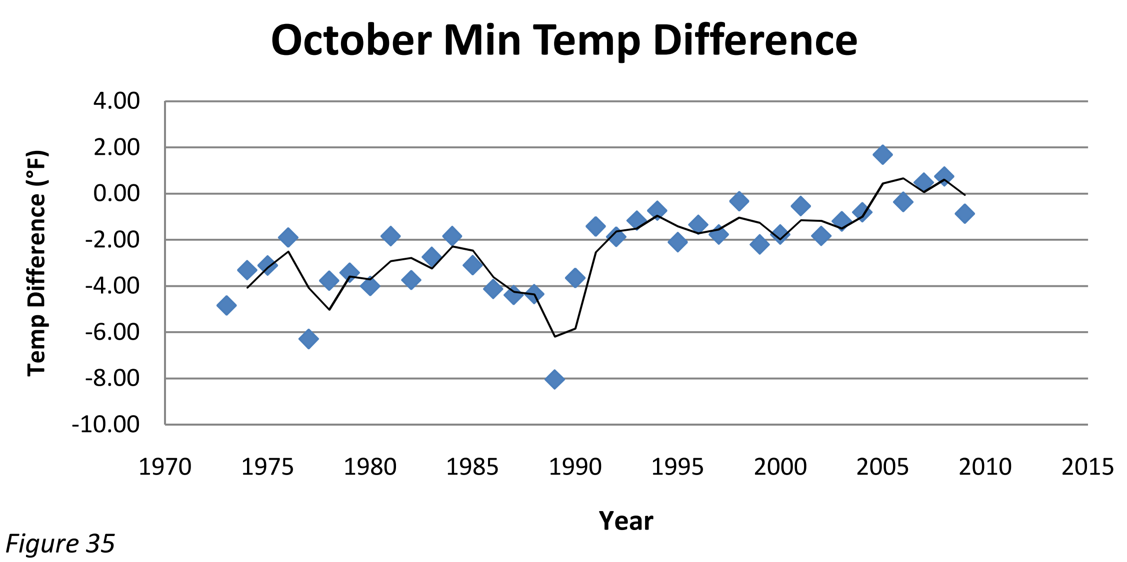

Figure 35