URBAN HEAT ISLAND IN SAN ANTONIO, TEXAS

An Undergraduate Research Scholars Thesis

by

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ABSTRACT

Urban Heat Island in San Antonio, Texas. (May 2015)

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Research of the Urban Heat Island (UHI) is an area of continuous investigation for reasons including the potential effects it may have on the living conditions for people, such as increased heat stress. Problems like this will continue to persist in the future because of the continuing trend of increased urbanization across the world. Through data from the COOP network, the San Antonio, Texas area was studied statistically to quantify the magnitude of the UHI. This was achieved by comparing temperature trends before and after the increase of urbanization in this area. For both time periods, differences of mean seasonal temperature values of San Antonio to multiple neighboring cities were calculated. The method used shows the seasons that are most affected, along with removing differences caused by seasonal variation. This study shows that the change of the UHI magnitude over time can be seen most notably in the maximum temperatures. This research can be applied in future studies to quantify the degree urbanization and how it will affect future generations.

CHAPTER I

INTRODUCTION

The UHI is an effect on local temperatures resulting from the change of natural land cover to man-made structures. Some examples of this transition include decreasing natural vegetation and increasing roads, tall buildings, and other assorted urban surfaces. This altered land cover has the tendency to absorb more incoming solar radiation, due to a lower albedo (Daranpob et. al 2009). This surge in energy at the surface can best be observed as an increase of temperatures in an urban center due to the direct flux of sensible heat from the warmer city surfaces to the atmosphere. However, the temperature change felt in the city limits can also be seen outside the main urban center. A previous research analysis found the change of mean temperatures could be seen up to 10 km away from the city center (Gall et al. 1996). This type of research results is one of the reasons the UHI has been a constant concern for scientists for over 150 years (Streutker 2003). Furthermore, the study of the UHI remains relevant because of the continued trend of people moving to urban centers. The United Nations has found that by the year of 2025 eighty percent of people will live in cities (United Nations 2003).

There are multiple causes, such as those mentioned above, theorized to contribute to the UHI. Tall buildings provide considerable surface areas for absorption of solar radiation that is then re-emitted as IR radiation. The buildings can also affect circulation within the city by blocking wind inhibiting mixing of the atmosphere. The reduced mixing will strengthen temperature inversions, especially at night, which lessens cooling and traps pollution at the surface. Air pollution at the

surface will increase temperatures justified by the greenhouse gas effect. In short, the greenhouse effect raises the albedo resulting in increased IR energy reradiating to the surface (Streutker 2003). This occurs at higher levels in cities with higher population density because of the larger quantities of air pollution sources, including automobiles and industry.

There are still large amounts of uncertainty concerning the UHI, even though there have been numerous studies done. A source of uncertainty includes the range of magnitudes in temperature change. Numerous cities must be studied to be able to differentiate the causes for change of temperature to be able to single out the changes caused by the UHI solely. For this study, temperature measurements are studied for deviations in the San Antonio, Texas area. There have been other studies done in the state of Texas that can be compared to the results found in this study. One in particular for the Ft. Worth-Dallas area found that subtropical climate zones have lower magnitudes of UHI. The reason for this was found to be from multiple factors such as the magnitude of heat storage and land characteristics (Winguth and Kelp 2011). San Antonio, like the Ft. Worth-Dallas area, can be classified as a subtropical climate zone. Another study was done using satellite data to survey four major cities in Texas, one of them being San Antonio. This research found an effect on the microclimate from the UHI during the nighttime hours for all cities throughout the year. However, the daytime hours had large amount of cloud cover during the time period to not allow conclusions to be made (Prado 2010). This study of San Antonio uses ground based measurements to allow both the day and night hours to be studied.

San Antonio, Texas

San Antonio is an excellent choice to study the UHI, because it is "one of the fastest growing metropolitan areas in the USA" (Kreuter et al. 2001). The growth of the San Antonio urban area has been mainly symmetrical over the past 70 years. However, there has been a slight favor of growth on the north and northwest sides seen in figure 1 when compared to the original city limits. Consequently, stations on both the north and south side of the city were chosen to observe changes caused by the varying spread of urbanization. If there is a major difference, the northern station, San Antonio International Airport, should have a stronger UHI signal than the southern airport.

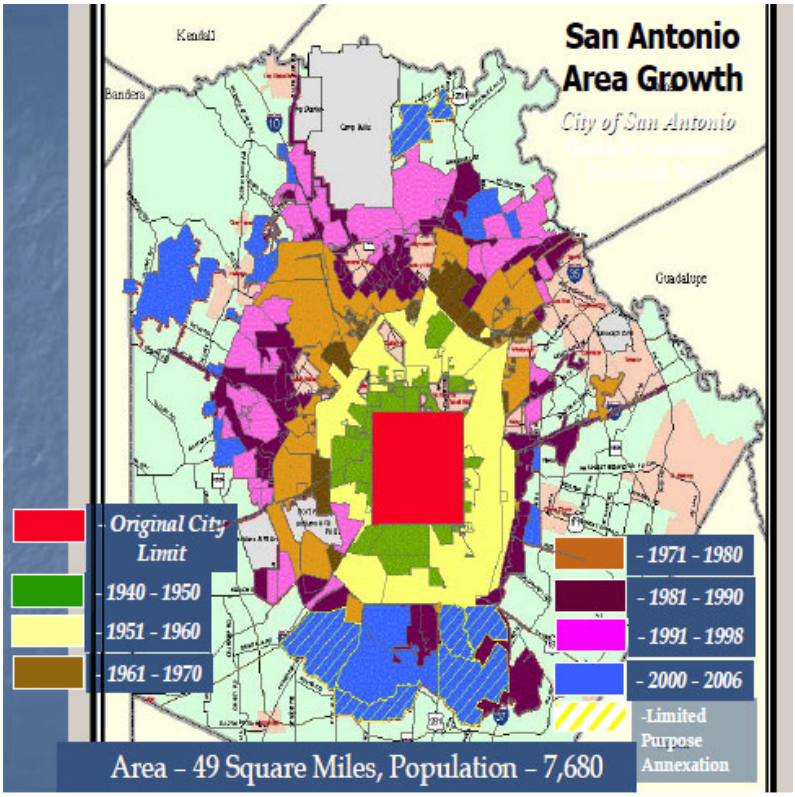

Figure 1: The San Antonio growth range can be seen with a slight favor of growth to the north. (Schacherl 2008)

Temperature values were collected for this study in San Antonio, San Marcos, Boerne, Poteet, Hondo, Blanco, Luling, New Braunfels, and Brooks AFB/Stinson Municipal AP (Brooks/S. Municipal). These locations were first chosen based on their proximity to San Antonio and the range of sizes of these stations. The population for each decade in this study, seen in the table below from the US census, can quantify the size of a city. Comparing these two decades will aid in looking at the potential UHI by looking at the difference from before and after the development of San Antonio.

Table 1: Average populations of each station for both decades

City	1950-1960	2003-2013
Boerne	1,537	8,325
San Antonio	498,080	1,236,027
New Braunfels	9,593	47,117
Hondo	4,590	8,350
San Marcos	11,347	39,814
Blanco	718	1,624
Poteet	2,401	3,283
Luling	4,285	5,256

Before calculations were completed, there were multiple other factors surveyed that can cause modifications in temperature leading to false conclusions. For this study, these factors included varying geography, times of observation (TO), and weather between stations and decades along with individual station relocation. The varying TO and station relocations are discussed in more detail in the following section. The geography, including water sources and elevation differences, was compared for differences that would induce error. The influence on

temperatures by bodies of water is a general moderating effect, proven for an urban city in a previous study (Suomi and Käyhkö 2012). The differences in elevation can alter temperatures with the values being lower at higher altitudes. Finally for weather, the two decades were also chosen based on similar amounts of precipitation that leads to the conclusion of overall weather being similar as well.

Water sources, such as river and lakes, were located because water has a higher specific heat and tends to result in smaller yearly ranges in temperature. This will have a local cooling influence during warm seasons that could offset the UHI and the opposite effect during the cold seasons in areas with large bodies of water. San Antonio is relatively close to the Gulf of Mexico, but not close enough that any particular location would be highly affected. The center of San Antonio has only a few major bodies of water in the southern part of the city including the Calaveras, Victor Brauning, and Mitchell Lakes located close together. Additionally, there is a creek that runs near the southern airports, but does not reach a size that would impact meteorological conditions. San Marcos and New Braunfels are both near major rivers called the Guadalupe and Comal rivers. Likewise, Blanco has a series of rivers and lakes stemming from the Blanco River. Poteet, Hondo, and Boerne all have a variety of small lakes, creeks, and small rivers in the surrounding area. In contrast, the city of Luling does not have any significant bodies of water in the area. The cities that were chosen created a mixture of sites that do and do not have water sources in the area to reduce the bias. Also, it can be stated without significant changes to these water sources the effects will be seen equally for both decades.

Below is a topographic map of the greater San Antonio area to illustrate the general differences between stations. The area of this map covers all locations that are being used in this study. In general, the city of San Antonio and stations southward are at similar elevations. However, to the north and northwest of San Antonio, the elevation starts to rise due to a shift to the hill country of Texas. Based on the contour maps seen in later figures, the difference in elevation between San Antonio and these northern cities is approximately 700 feet. Assuming an average dry adiabatic lapse rate, the temperature difference between the two elevations is 1.4˚C. This is a large impact on temperature that was considered when comparing the data from the urban San Antonio area to the more rural northern cities such as Boerne and Blanco.

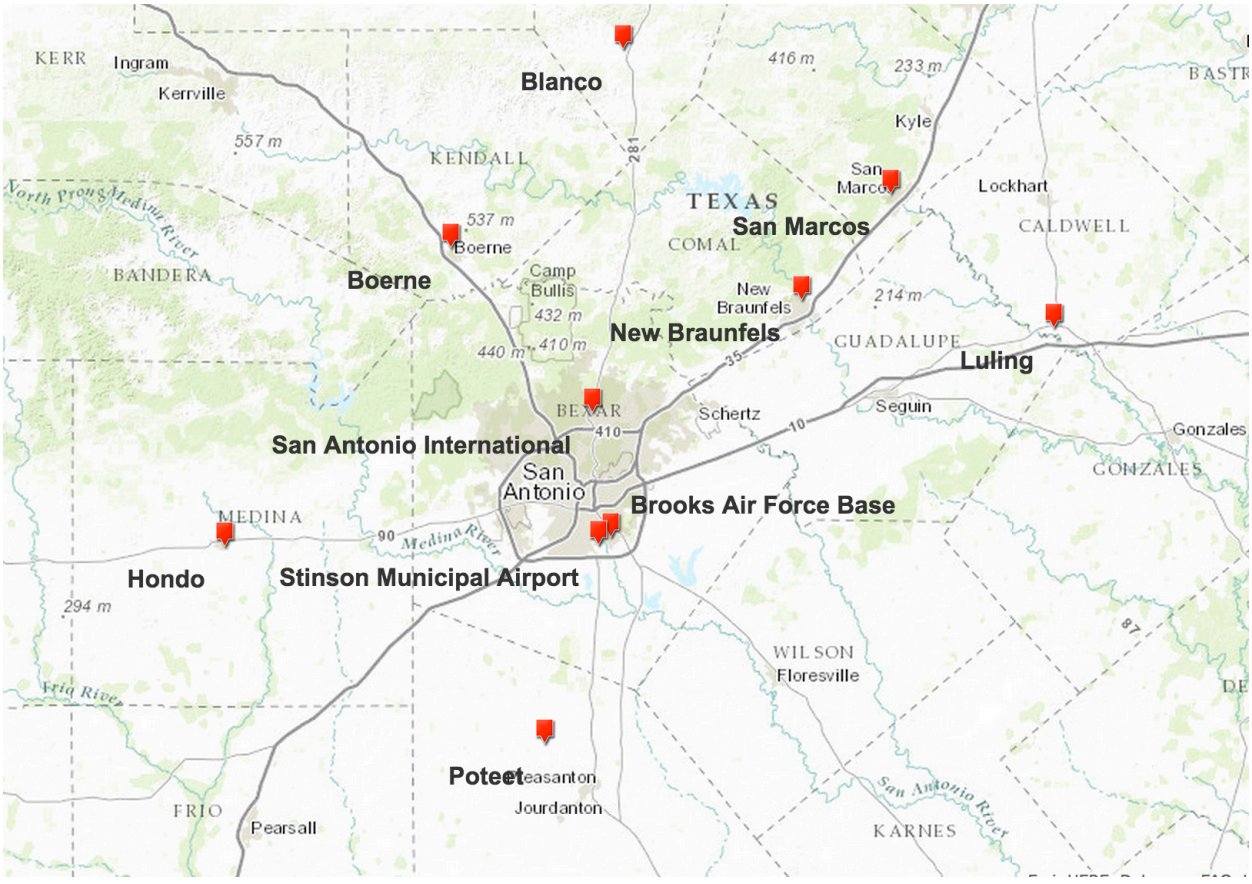

Figure 2: This map shows the location of each station and the topographic information for this area.

San Antonio has been proven to be an appropriate location to study the UHI with an increase in size over time and minimal factors to cause inaccuracy. The data, after corrections were made, was then analyzed to find values that can be contributed to this increase in urbanization. This paper's foremost purpose is to find the magnitude and range this urban effect is felt from an urban center through temperature.

CHAPTER II

DATA ANALYSIS

The data for this research was collected through the National Oceanic and Atmospheric Administration (NOAA). NOAA has a database through the National Weather Service (NWS) called the Cooperative Observer Network (COOP). Volunteers take COOP data across the country since 1890 that allows for a high concentration of stations to aid in climatological research. Even though COOP began in 1890, there is still a challenge in finding stations in the early 20th century, inhibiting a thorough database of the meteorological history of any location. The stations chosen for this research were the only ones near San Antonio that had data for both of the decades.

Each year was categorized into four seasons in order to examine differences in seasonal averages. This method of research was also completed for a city in Wisconsin recently. The major finding was the change in temperature due to the UHI had higher magnitudes during the warmer summer months in the city center compared to the colder winter (Schatz and Kucharik 2014). This method of looking at the UHI is not very common and provides a rare viewpoint that supplements valuable knowledge to the field of UHI research. For the data in this study, multiple challenges were corrected for from the station relocations, different times of observation, and missing data.

Station Relocations

The table below for all stations gives a list of all relocations from 1950 to 2013 along with the distances of each relocation. These were found using both NOAA's website and past archived paperwork for previous decades. Information of a station's history can be found on NOAA's webpage with the Historical Observing Metadata Repository. This webpage includes multiple specifics ranging from location, elevation, and changes of site position. The relocations for the earlier years were not always included on NOAA and had to be further researched with the past paperwork. From the archived paperwork, the earlier decade's movements were recorded in latitude and longitude values accurate to the nearest minute. The exact location was then deduced from supplemental data recorded on the station change records. The exact thought process and conclusion of locations are included in the Appendix A. Elevation maps were made from these locations to examine any changes of elevation; because of the previously mentioned effect it can have on temperature.

Brooks AFB and Stinson Municipal AP had to be given particular consideration, since these two separate stations were combined together to create a continuous record. The Brooks AFB data was used for the early decade and Stinson Municipal for the later decade. This combination could be done because of the two sites being less than a mile from each other with very similar geographic characteristics. The positive outcome of this combination was a second station within the San Antonio urban area on the south side compared to the other San Antonio location on the north side. This will be extremely beneficial because it will allow for a more conclusive result if there is an UHI signal in both data sets.

Table 2: Relocations for each Station

City	Number of Relocations	Elevation Range (feet)
Boerne	3	241
San Antonio	3	6
New Braunfels	3	63
Hondo	5	17
San Marcos	3	141
Blanco	3	23
Poteet	2	35
Brooks AFB	0	0
Luling	3	50
Stinson Municipal	1	0

Note: This table lists all of the stations used in this study with the corresponding number of relocations and the elevation range over all station relocations.

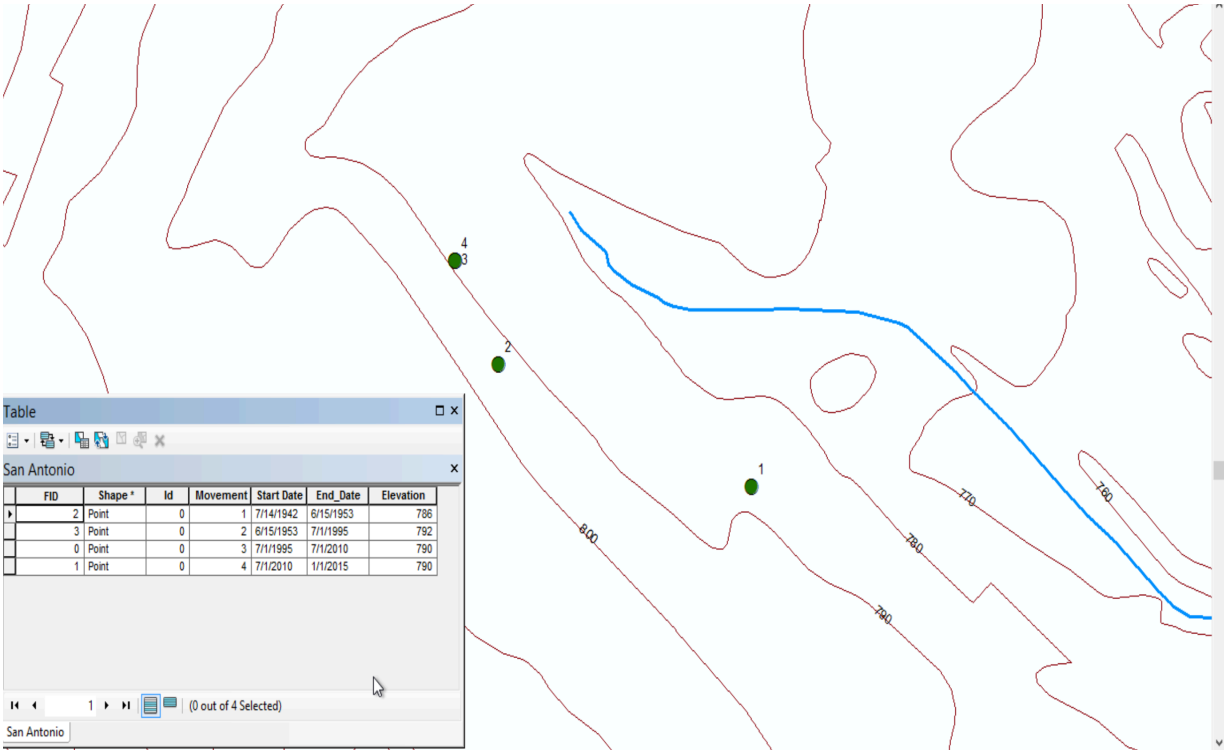

Figure 3. Each entry represents the locations of the San Antonio station over time, as seen by the movement_N and the date columns in the table.

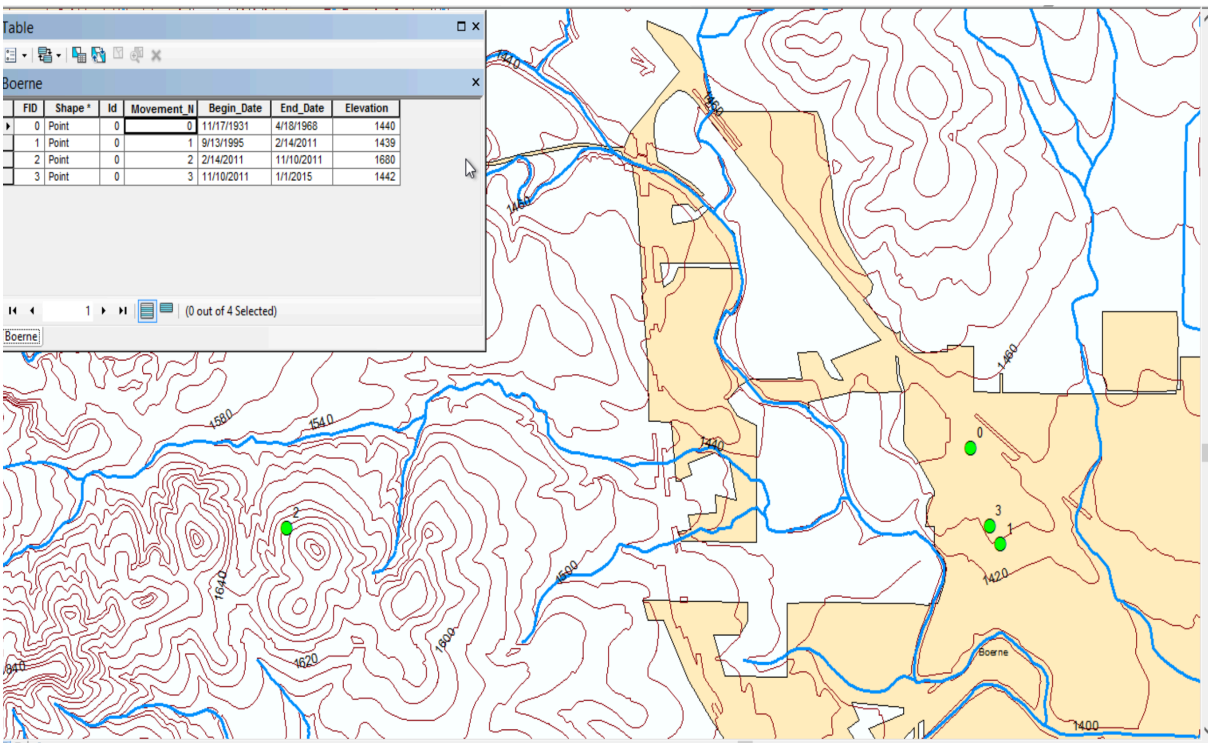

Figure 4: Same as figure 3 for Boerne

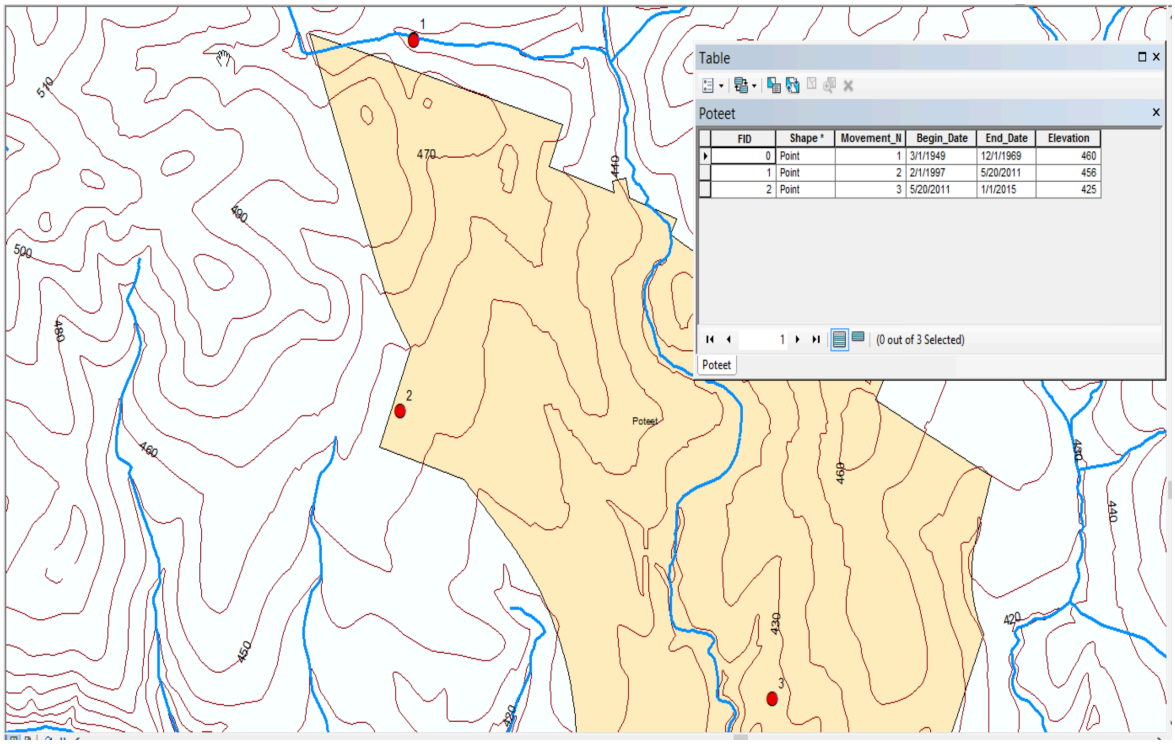

Figure 5. Same as figure 3 for Poteet

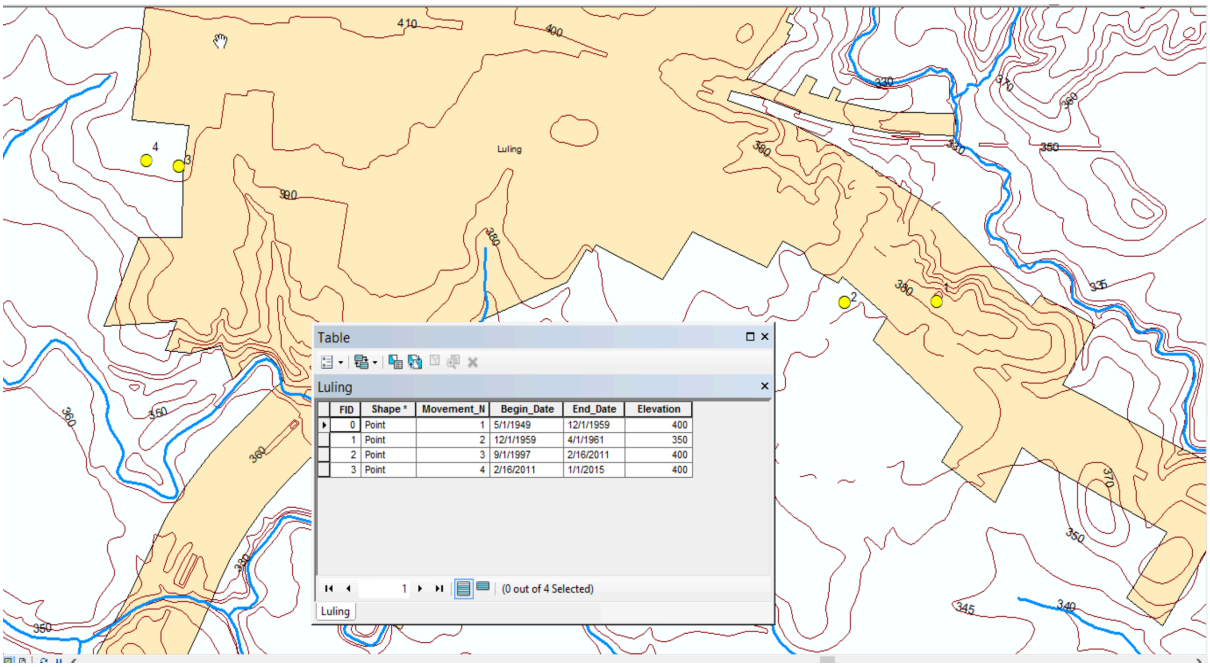

Figure 6: Same as figure 3 for Luling

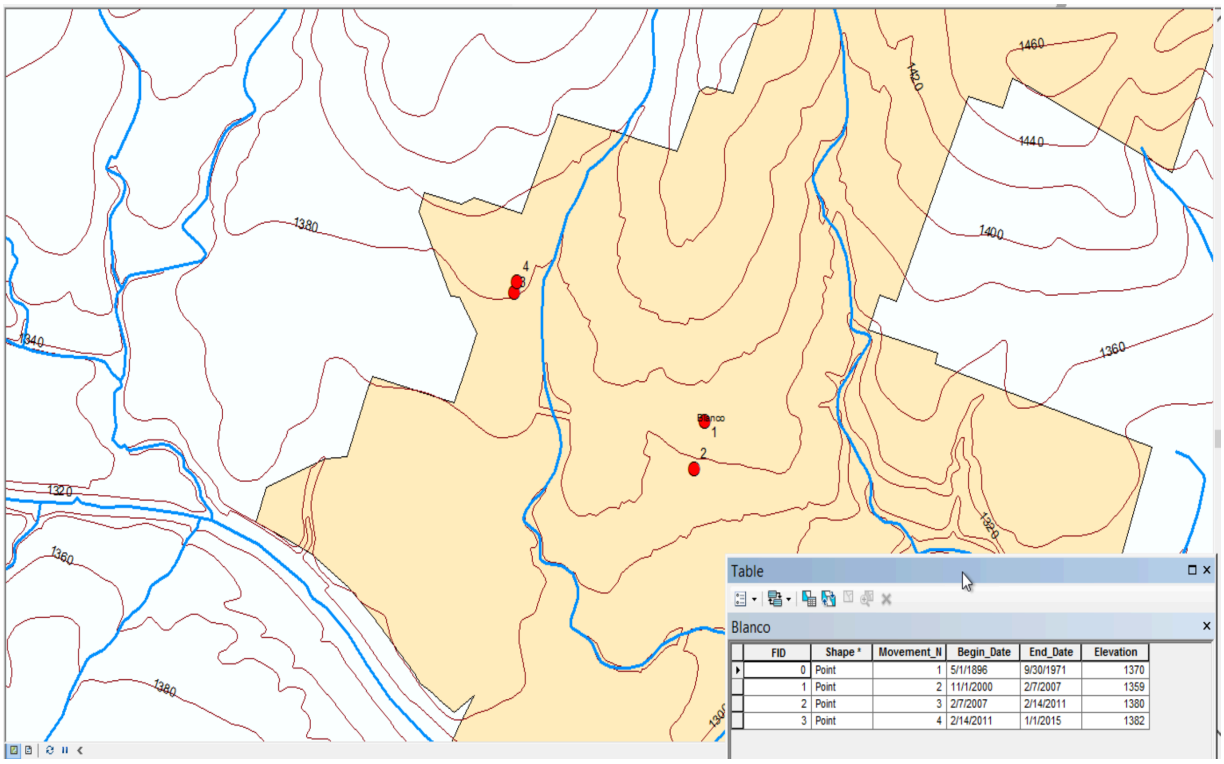

Figure 7: Same as figure 3 for Blanco

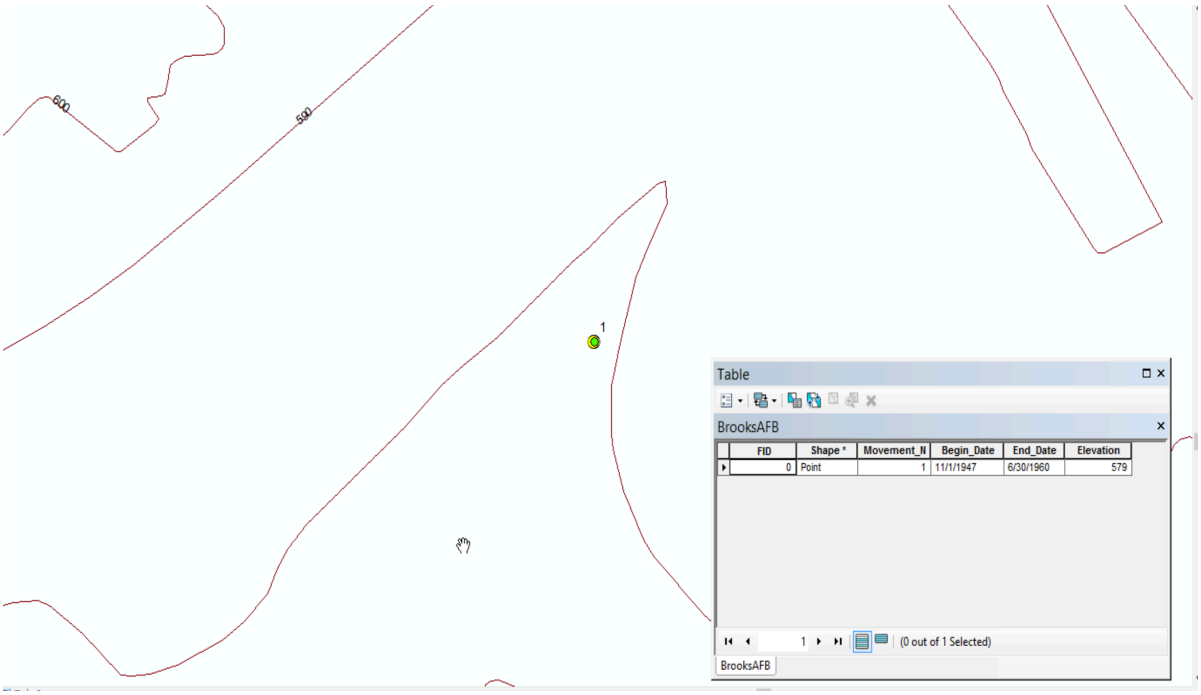

Figure 8: Same as figure 3 for Brooks AFB

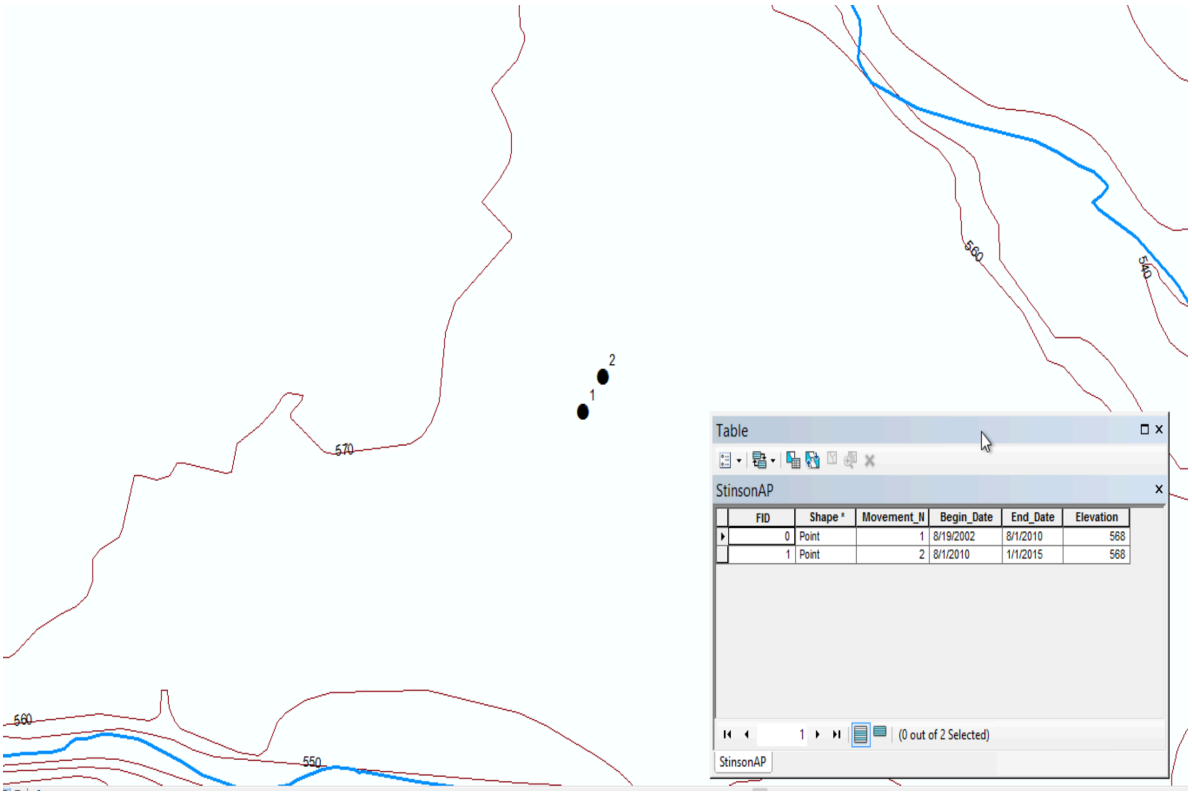

Figure 9: Same as figure 3 for Stinson Municipal

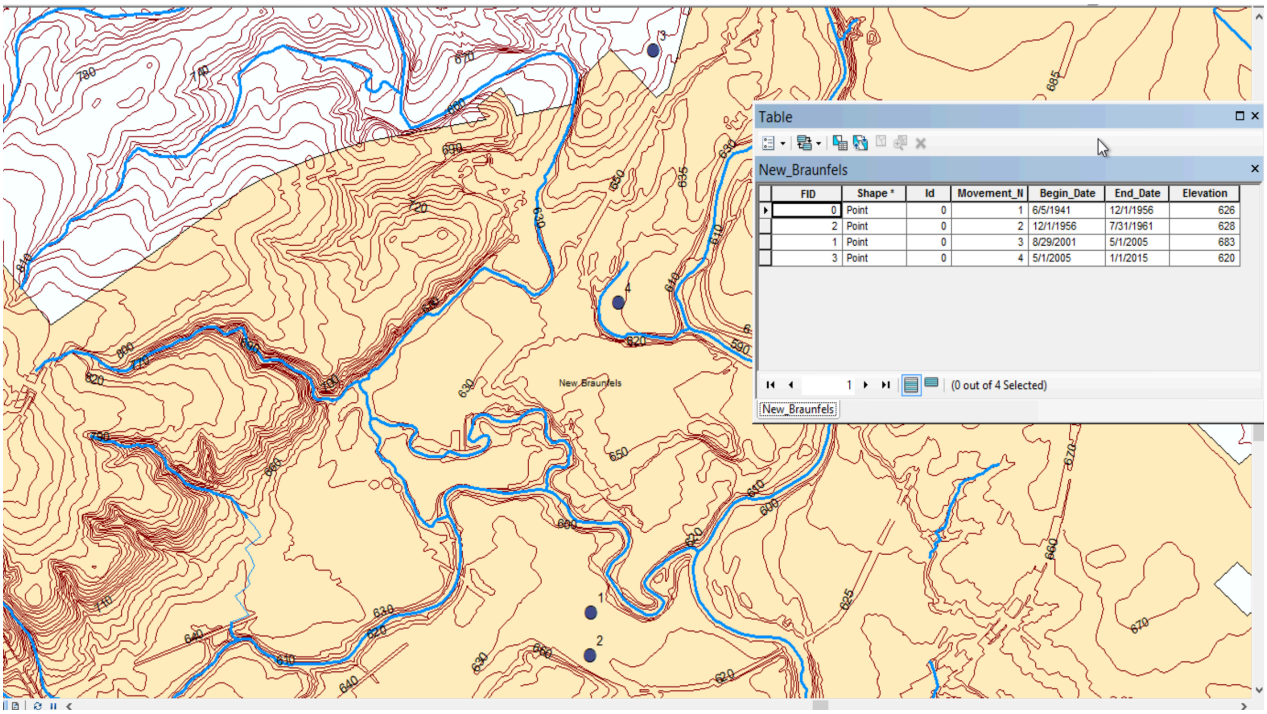

Figure 10: Same as figure 3 for New Braunfels

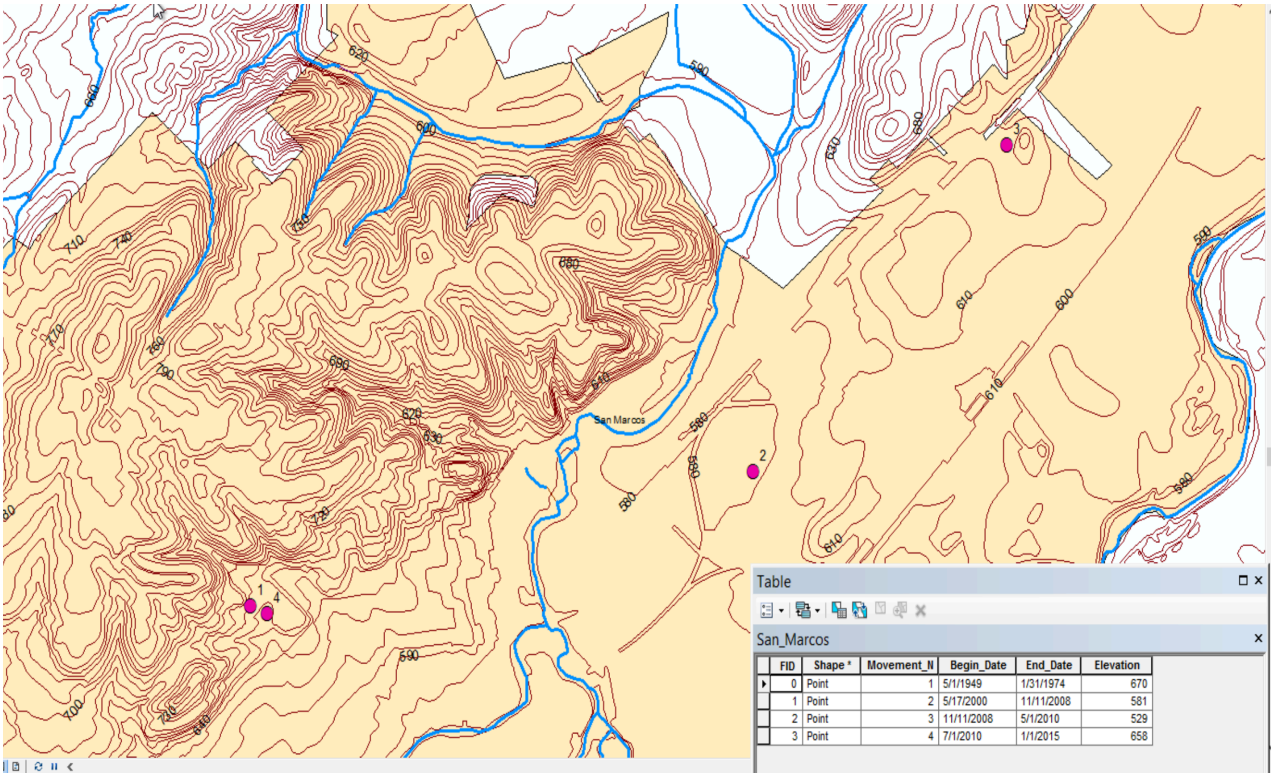

Figure 11: Same as figure 3 for San Marcos

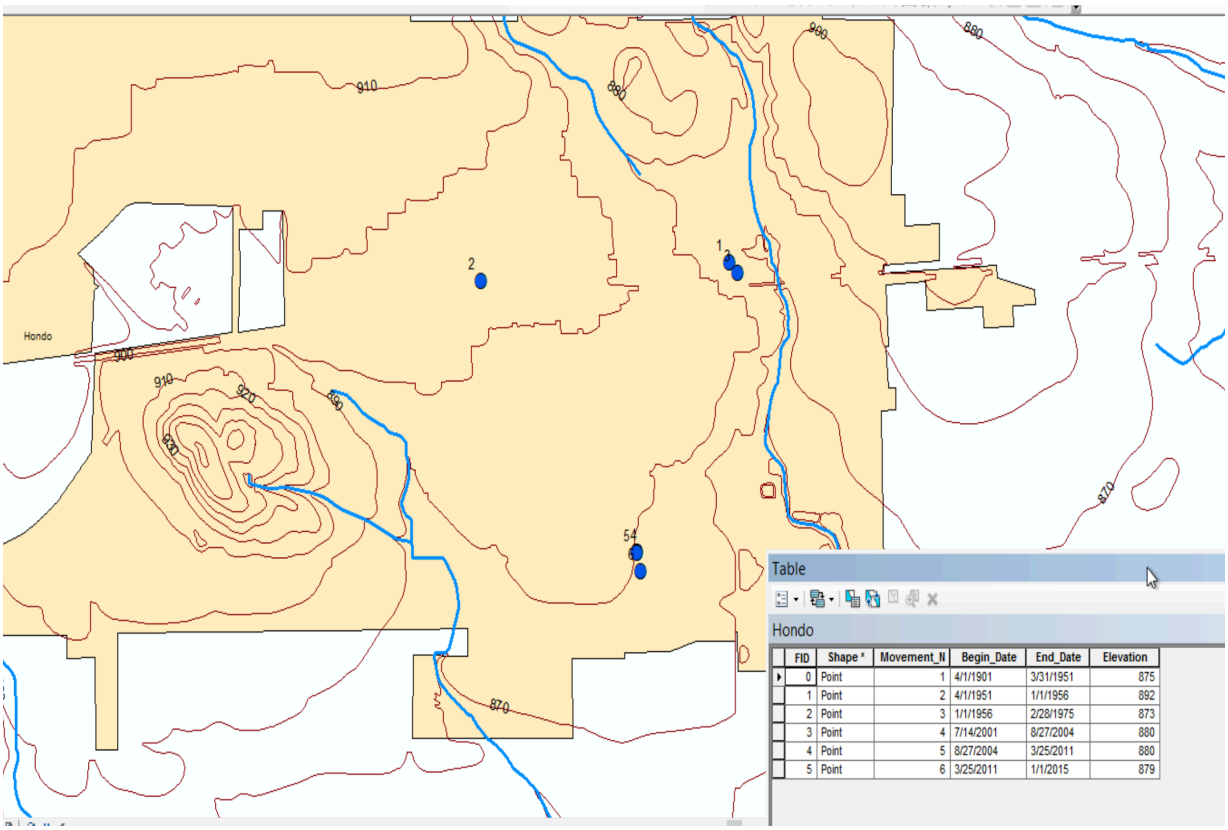

Figure 12 : Same as figure 3 for Hondo

Times of Observation

The next issue came from the variances in TO for each station and decade, called the time of observation bias (TOB), shown in table 3. The exact definition of TOB is described as a source of error that occurs when comparing two locations that have different times at which observations are taken (Karl et al. 1985). This can lead to major discrepancies in the data because the maximum or minimum temperature values between the stations may be considerably skewed. This is especially true during frontal passages in the winter and seasonal transitions when temperatures tend to fluctuate more. An example that illustrates the TOB would be if the minimum temperature for a particular day occurred during the 300 hour. This would result in a difference in the daily minimum temperature between a 2400 and 700 TO. The 2400 TO would use this value while the 700 TO would not since it occurred before the time period began. This example shows how the error can come about and the reason a correction needs to be applied.

The correction method that was chosen began with acquiring hourly data for the San Antonio station for both of the decades used in the study. This data made it possible to change every station to the TO of 700. For every TO that occurred during this study, the maximum and minimum temperatures were found for that 24-hour time period. If for example the TO was at 800, then both temperature values would be located from 800 on one day to 800 the following day. The next step was for the maximum and minimum temperatures for each TO to then be subtracted from the temperatures at the 700 TO. This resulted in having a difference for each day for the maximum and minimum values. These differences were then averaged by month, then by season, and then applied to each station in both decades. The magnitude of the TOB corrections, which were applied to the station temperatures, varied depending season and by the difference

between the TOs. The values ranged from hundredths of a degree to a little less than one degree Celsius.

Table 3: Time of Climatological Observations for each Station by Decade

City	OBS time (1950-1960)	OBS time (2003-2013)
San Antonio	2400	2400
San Marcos	0800	0800
Hondo	0800	0800
Boerne	0700	0700
Brooks AFB	2400	N/A
Stinson Mun.	N/A	2400
Luling	0800	0730
Poteet	0800	0800
Blanco	0700	0700
New Braun.	0700	0700

Missing Data

There were multiple methods attempted in order to accurately deal with the problem of missing data. The first method attempted was to average both the previous and subsequent value for a missing time to then be imputed in the missing slot. This was tested for accuracy using a time period with no missing values to allow for comparison of the computed and actual value. After multiple attempts, this technique was not found to improve the data set from its prior status with missing data. Another method that could be used for missing climatological values is using data from neighboring stations. This method could not be used because of all the adjacent stations already being included in this research. The method that was selected, after discussion with our advisor, was to simply ignore any missing values in the data. This viable because only three stations, New Braunfels, Hondo, and San Marcos, had missing data. The exact total of missing

values for these stations were New Braunfels with two, Hondo with six, and San Marcos with 12 missing daily temperatures. This is a very insignificant amount, especially when looking at an averaged decade's worth of results.

Data Calculation

After the data had been verified with possible sources of error established, graphics to show data trends were made for all of the stations. The four seasons split the year up in such a way that summer was June through August (JJA), fall was September through November (SON), winter was December through February (DJF), and spring was March through May (MAM). First for each station and decade, the maximum and minimum values were averaged by month then season. Since the first season of each time period is winter, the December monthly maximum and minimum values from the previous year (1949 and 2002) are used instead of eliminating December values entirely for the first year of the time period. After this step, the previous correction mentioned for TOB was applied. For 2400, the calculated difference was added to the averages and for 0800 and 0730 the difference was subtracted resulting in corrected temperatures. After this final correction, the maximum and minimum temperatures of each station were subtracted from San Antonio for every month. These temperature differences for each station and both decades were then averaged by season in order to obtain the UHI temperature trend. These values, along with other statistics, were then made into the figures shown in the results and conclusions section seen below.

CHAPTER III

RESULTS

City Difference in Temperature between the Decades

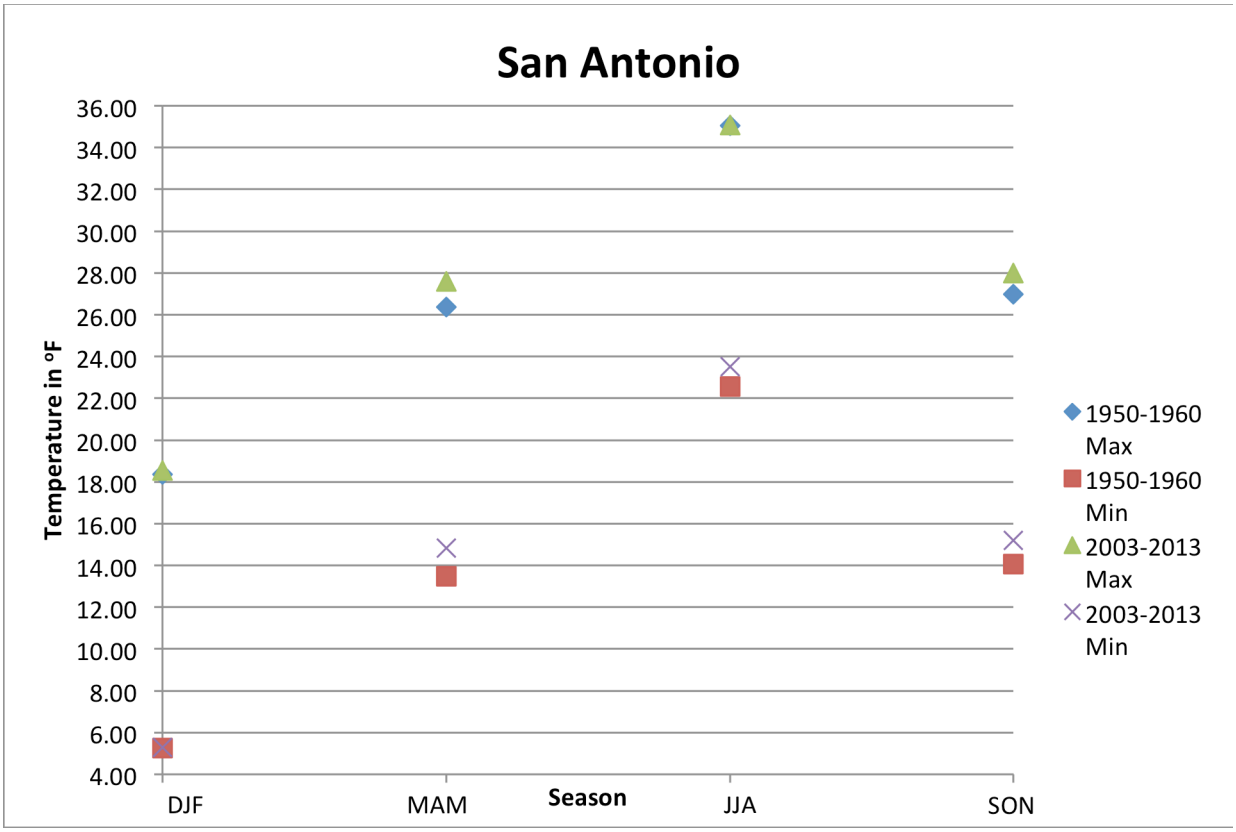

Figure 13: San Antonio, Texas temperatures for both decades and types of temperature separated into seasons.

In general, there was an increase in maximum and minimum temperatures for San Antonio. The maximum temperature had a relatively small magnitude of increase in both the winter and summer season. For minimum temperatures, the smallest change was for winter as well with summer being in close second. The other two seasons had almost equal magnitudes of increase in

temperature for both types of temperature values. In order to be able to analyze the differences more easily graphs were then made of difference values between the two decades for each city.

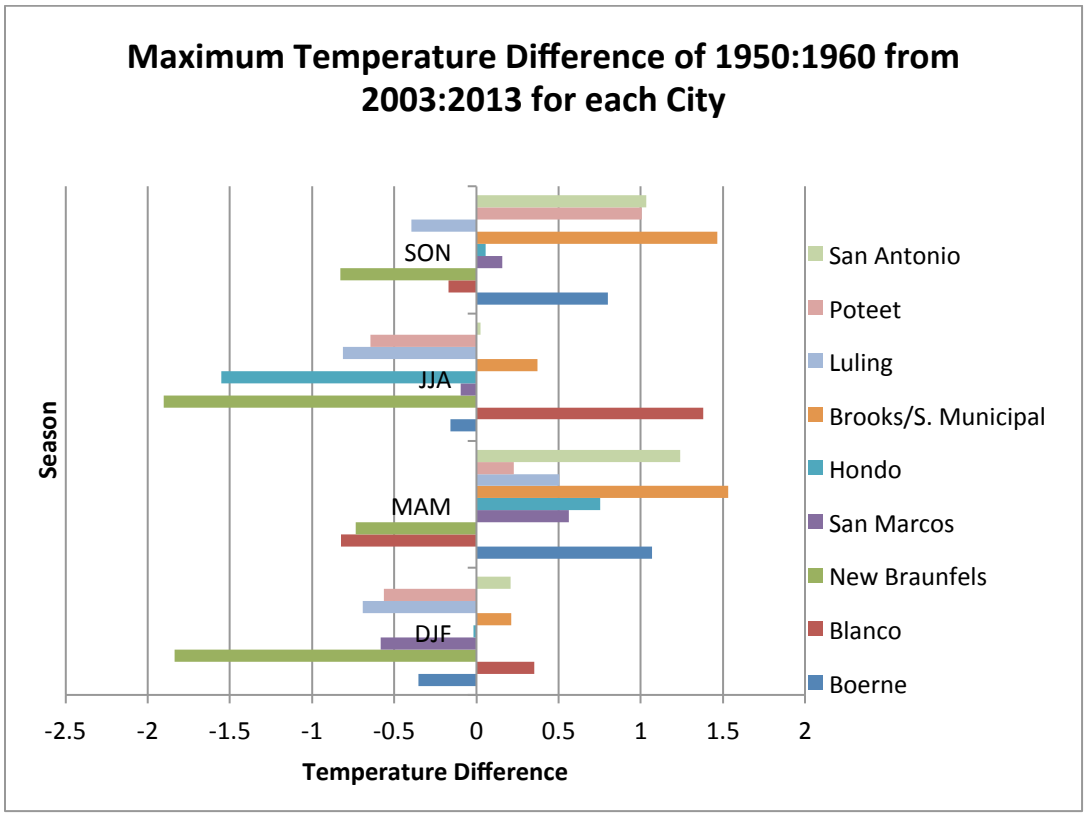

Figure 14: The difference for each station in averaged maximum temperatures for each season found from subtracting the earlier decade from the later decade.

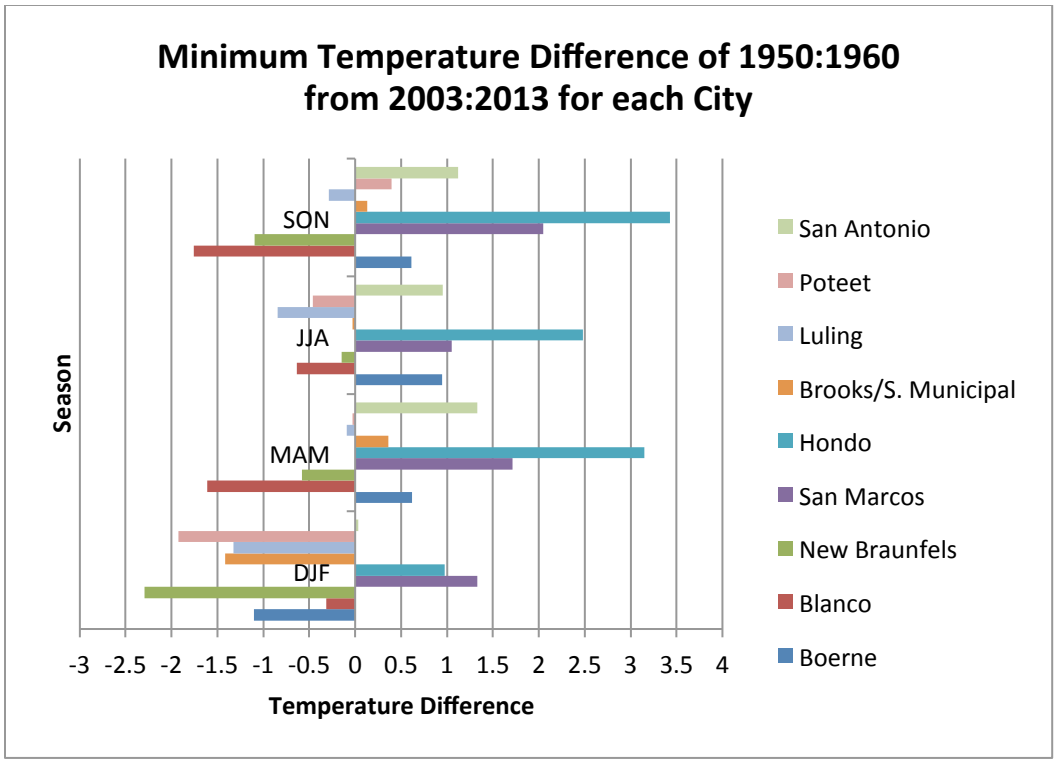

Figure 15: Same as above for minimum temperature

Beginning with the maximum temperature difference, each season was examined for both positive and negative differences in each station. If there is a positive difference, this implies an increase in temperature from 1950-1960 to 2003-2013. There were some cities that had notable differences with a 1^{o}F change or more. In fall, there were large positive values for Poteet, San Antonio, Brooks/S. Municipal, and Boerne along with no cities showing large negative values. San Antonio and Brooks/S. Municipal likewise had large positive increase for the fall with no other cities showing significant changes for this season. For the summer season, Blanco had an increase in temperatures and a decrease in temperature occurred for both Boerne and New Braunfels. New Braunfels continued the trend with a negative difference for the winter. Luling, Hondo, and San Marcos all had some minor changes through the seasons, but not to the degree as the stations listed previously.

The minimum temperature differences were then compared with positive values still having the same denotation of an increase of temperature. In the fall and spring, San Antonio, Boerne, and San Marcos all had sizable rises in temperature along with Blanco having a decrease in values. New Braunfels had a negative difference as well for the fall season, but not for the spring. San Marcos and Hondo then continued their positive trend in the summer and winter. During the winter, there were also negative changes at many stations including Poteet, Luling, Brooks/S. Municipal, New Braunfels, and Boerne. All of the stations for minimum temperatures had at least one instance of a considerable change in magnitude.

Each city can then be analyzed separately to find any stations that had trends of general increase or decrease in temperatures. As found earlier, San Antonio for both types of temperature experienced an increase. New Braunfels had with all occasions agree as well but with a decrease in temperature. Poteet, for the most part, had a decrease in minimum temperatures and mixed results for the maximum. Except for the spring maximum, Luling had a negative difference. Brooks/S. Municipal agreed for all seasons with an increase of temperature for the maximum temperature. However, the minimum temperature values had mixed results with both positive and negative. This station also had a significant large negative difference for winter. On the other hand, Hondo and San Marcos had values that agreed for minimum temperatures with all increasing in significant numbers of magnitude. Blanco's minimum temperatures also all agreed, but with a decrease in temperature. Boerne did not have any general trends, but did have large positive magnitudes for all of the minimum temperature seasons, except for winter.

Comparison with San Antonio

The maximum and minimum temperatures for each city were then compared to San Antonio during each decade. This will then be able to show if San Antonio is an UHI compared to surrounding cities.

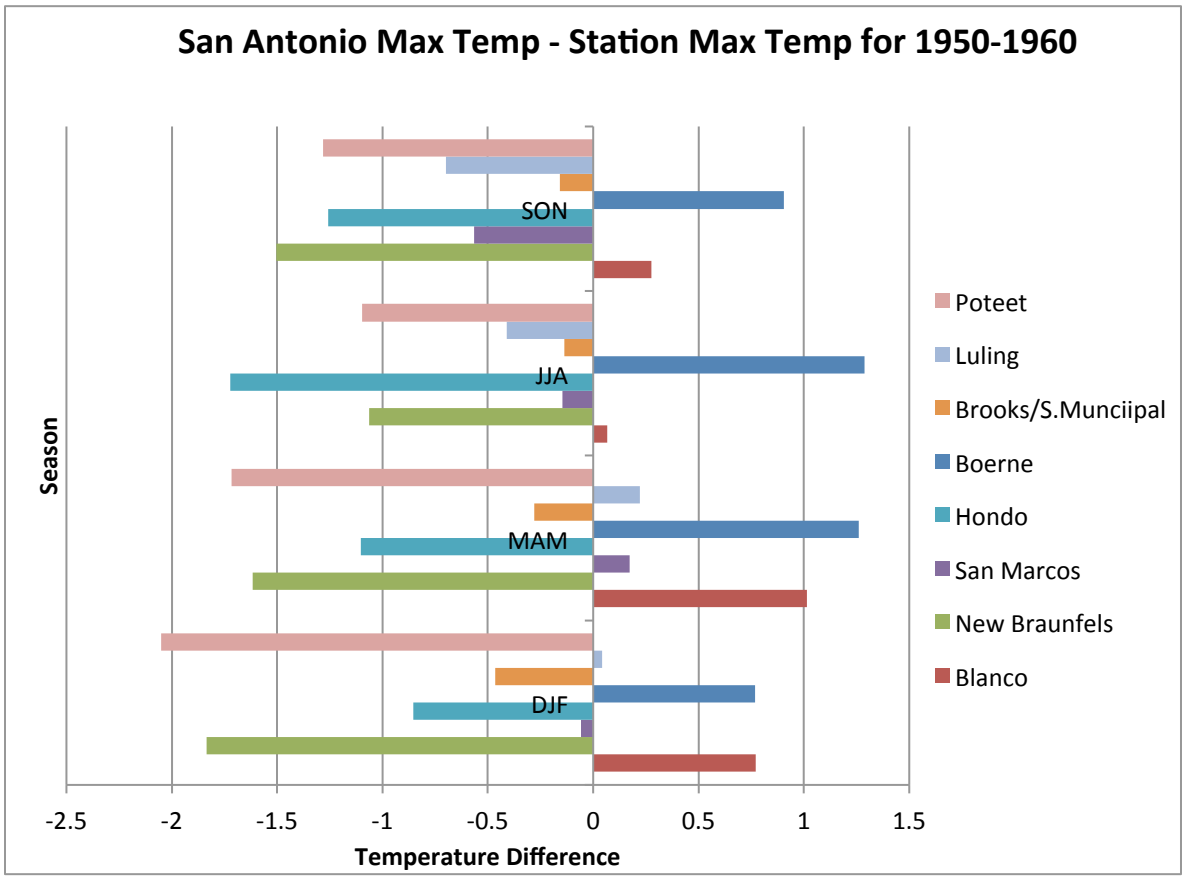

Figure 16: The difference for each station in averaged maximum temperatures in 1950-1960 for each season found from subtracting each station from San Antonio.

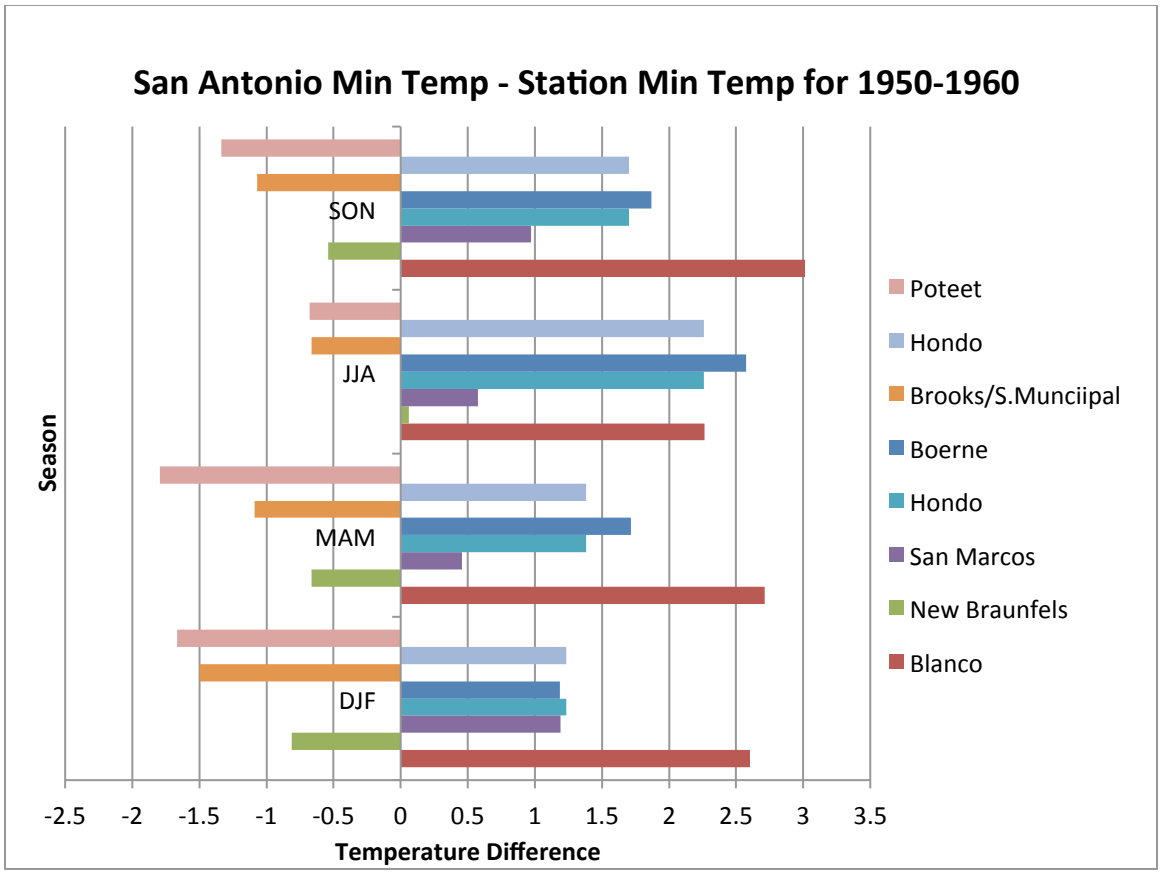

Figure 17: Same as above, but for minimum temperatures

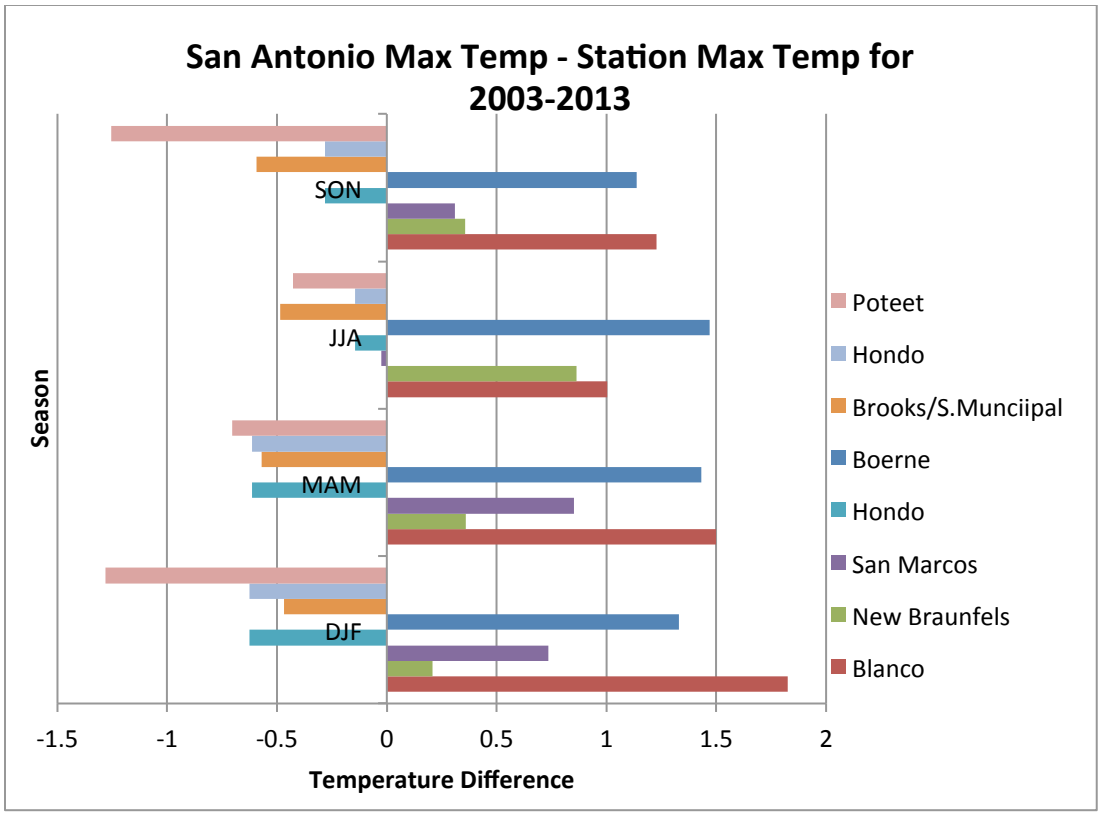

Figure 18: The difference for each station in averaged maximum temperatures in 2003-2013 for each season found from subtracting each station from San Antonio.

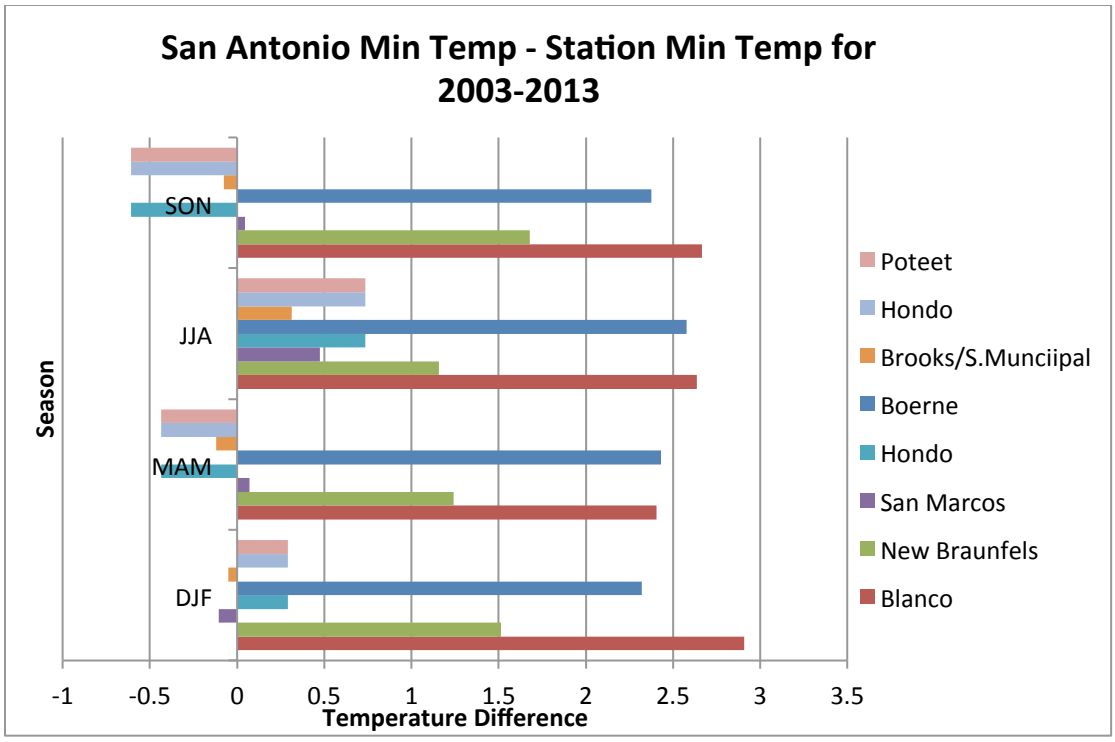

Figure 19: Same as above for minimum temperature

For the 1950-1960 maximum temperatures, most instances had negative values correlating with San Antonio being colder than the other station. This is not necessarily contradictory to the hypothesis because the goal is the see if the UHI grew with time. However, Boerne and Blanco were constantly warmer than San Antonio, with Boerne having a larger difference than Blanco. Luling, Hondo, and New Braunfels had the largest negative magnitudes out of all the cities. The minimum temperature differences for this decade were largely positive. The exceptions to this rule included Poteet, Brooks/S. Municipal, and New Braunfels. The stations that did primarily have higher temperatures than San Antonio were higher by large values with most being at least 1^{o}F up to 3^{o}F.

The other decade's maximum temperature differences had more instances of stations being on average colder than San Antonio. Also, the magnitudes of negative differences were comparatively smaller than the previous decade. The four foremost stations with negative differences included Luling, Hondo, Poteet, and Brooks/S. Municipal. However, Luling only had negative values for fall and summer and Hondo was the opposite with occurrences during spring and winter. The positive difference also had times of larger magnitudes compared to the previous decade. For the minimum temperature, there were very few times the station was warmer than San Antonio. If the station was warmer, it was only by about ½ ^{o}F or less. The positive differences had very high magnitudes like the previous decade did.

CHAPTER IV

DISCUSSION AND CONCLUSIONS

Discussion

For this study, there were two clear outcomes that were expected. First, the UHI phenomenon should have been quite apparent when comparing temperature trends between San Antonio and the surrounding rural cities. The second objective was to ascertain whether or not the UHI had gotten larger with time as the urbanization of the greater San Antonio area had increased. Both of these outcomes were obtained by looking at the temperature trends by season between the rural and urban areas over two nonconsecutive decades with similar meteorological conditions. The results section above provides an insight into the analysis of the raw data. For the most part San Antonio was much warmer than the surrounding rural cities during most seasons and both decades, which indicates that the first goal of this study was met. This was not unexpected since the UHI has been a documented phenomenon in San Antonio before now. The more interesting results occur when comparing the 2003-2013 decade to the 1950-1960 decade. Below are figures 20 and 21 that present the overall change in the UHI between decades. These figures were obtained by taking using the formula $(T_{\text{San Antonio}} - T_{\text{rural city}})_{2003\text{-}2013} - (T_{\text{San Antonio}} - T_{\text{rural city}})_{1950\text{-}1960}$. This formula is able to quantify how the UHI affected the temperatures between the two decades by filtering out most of the persistent geographical errors present in the data. A positive result indicates that the temperature difference increased over time, which means that the UHI effect also increased. A negative result indicates that the temperature difference decreased over time, which means the UHI effect between San Antonio and the rural city got smaller with time.

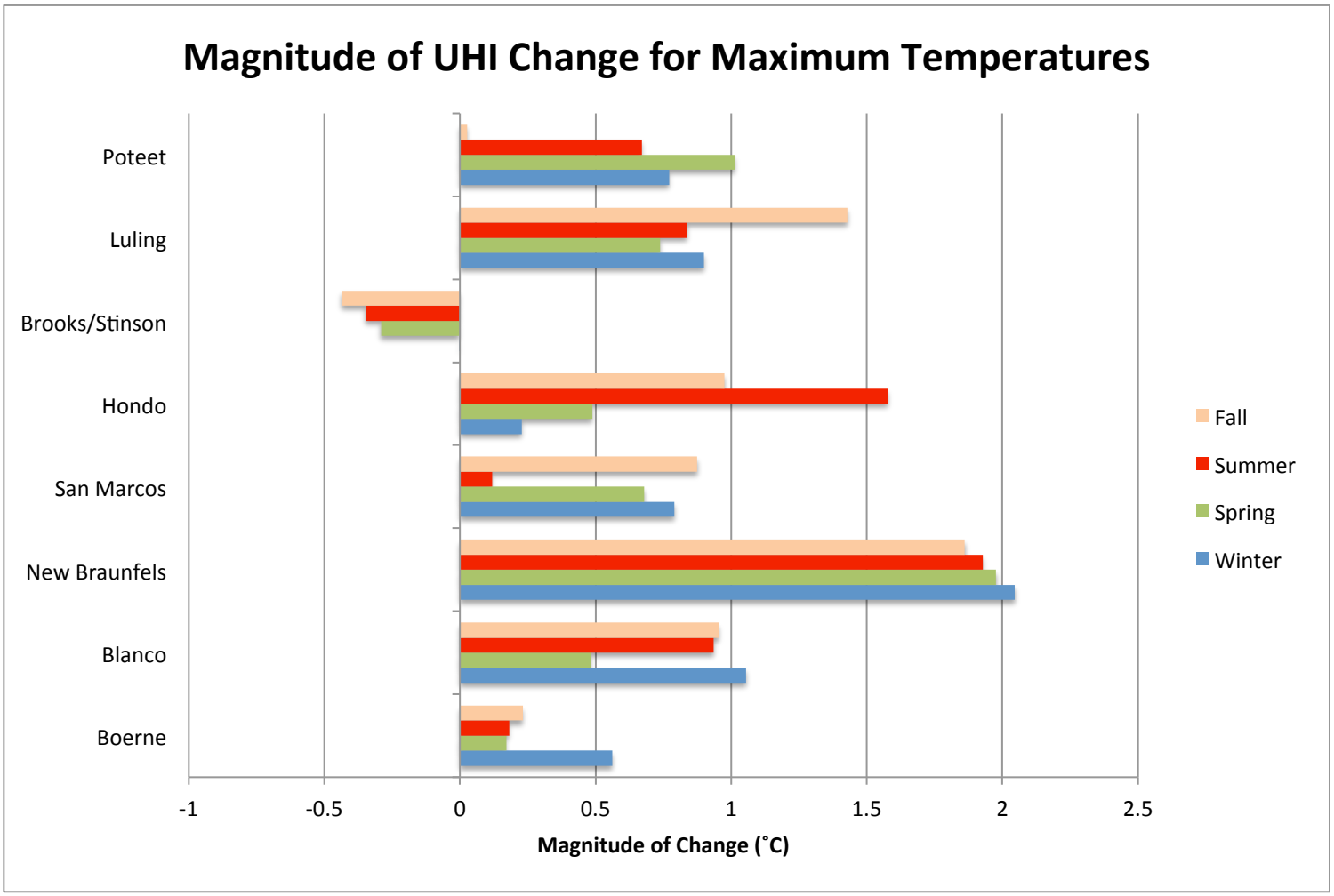

Figure 20: The difference between the UHI effect in the decade from 2003-2013 and the decade from 1950-1960 for maximum temperatures.

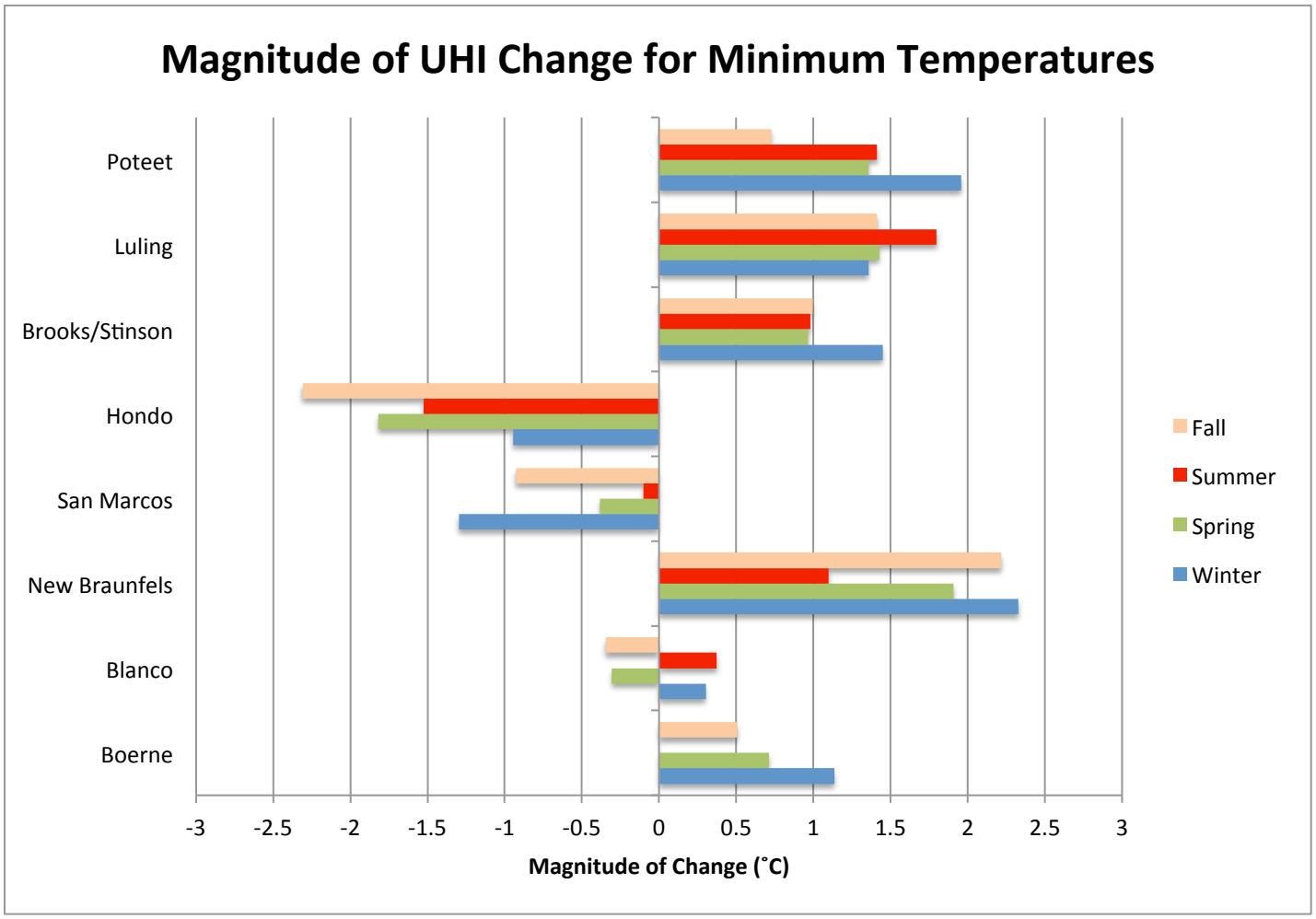

Figure 21: The difference between the UHI effect in the decade from 2003-2013 and the decade from 1950-1960 for minimum temperatures.

The conclusions that can be drawn from figure 20 are that the UHI effect increased over time for the rural stations over all seasons and that the Brooks/Stinson station was the only station that showed a negative trend. This negative trend results from the fact that the station was also located within the urbanized portion of San Antonio. However, the southern portion of San Antonio became more urbanized in recent years, as seen in figure 1. The difference between maximum temperatures was larger in the 1950-1960 decade than in the 2000s, which implies that

the UHI was migrating further to the south. On the other hand, the rural stations all showed a positive trend, which means that the UHI grew with time since San Antonio urbanized much faster than any of the other cities. It should be noted that the results for New Braunfels are slightly skewed. During the more recent decade, the station was moved to a valley with a stream running through it. This seems to have led to a cooling effect on the New Braunfels temperatures for the 2003-2013 decade. Due to this trend, the UHI appears magnified because the difference between the San Antonio and the New Braunfels maximum temperatures are larger than they would be without microclimate impacts. New Braunfels appears to be the only station with impacts as drastic as this one.

Figure 21 shows that there was a lot more variance among minimum temperature differences than there was in the maximum temperature differences. The two biggest surprises were seeing that Hondo and San Marcos actually had a negative trend for the UHI. Hondo is easily explained due to the fact that it was located in a valley near a river during a good portion of the 1950-1960 decade. This means that the difference in temperature between San Antonio and the Hondo station was larger in the 1950-1960 decade with microclimate influence than it was in the 2003-2013 decade. San Marcos is a situation where there was over a hundred foot difference in elevation between the 1950-1960 decade and the 2003-2013 decade. This leads to an apparent decrease in the magnitude of the UHI over time because the difference in temperatures between San Antonio and the 1950s station is larger than the temperature difference in the 2000s. Overall, the magnitude of the UHI with respect to minimum temperature differences did increase even with some anomalous results being present.

Table 4: Average Magnitude of the UHI Change by Season for Maximum Temperatures

Winter	0.79
Spring	0.66
Summer	0.74
Fall	0.74
Average	0.73

Table 5: Average Magnitude of the UHI Change by Season for Minimum Temperatures

Winter	0.79
Spring	0.48
Summer	0.50
Fall	0.28
Average	0.51

Tables 4 and 5 condense the results of this study down into two numbers. Overall, the average magnitude of the San Antonio International Airport UHI has increased by 0.73˚C for the maximum temperatures and by 0.51˚C for minimum temperatures over the last fifty years.

Statistical Verification

At this point it seems appropriate to examine whether or not the results seen above are actually statistically significant. In order to do this, the change in temperature between 1950-1960 and 2003-2013 for San Antonio will be treated as the anticipated result (Ho) while the change for all of the other stations will be treated as the sample (H_{α}**)**. Since there are less than 30 sample stations, a T-distribution will be utilized to complete the analysis. Below is a compilation of the p-values for each season along with an annual average. The table is broken down into maximum, minimum, and overall. The overall category is the average of the maximum and minimum temperature difference for each city. The level of significance being used here is 0.05. If the p-value is below 0.05, then it can be assumed that there is a statistical difference between the

temperature trends of San Antonio when compared to the temperature trends of the cities that should not have an UHI.

Table 6: P-values by season and annually

	Maximum	Minimum	Overall
Winter	0.001	0.031	0.004
Spring	0.003	0.097	0.015
Summer	0.003	0.061	0.002
Fall	0.003	0.248	0.028
Annual	0.001	0.015	0.002

The cells with green shading indicate that the results are noteworthy using the significance level of 0.05. It can be seen that the maximum and overall temperature trends in San Antonio are statistically different than those that were assumed to not have a discernable UHI. However, the minimum temperature trend for San Antonio is only statistically different in the winter months and when averaged annually.

Summary

From the onset of this project the goal was to ascertain whether or not the UHI in San Antonio, TX had growth between the decades of 1950-1960 and 2003-2013 and if the signal would be seen differently depending on the season. To determine the change of the UHI magnitude over time, the monthly maximum and minimum temperature data for both San Antonio International Airport and eight surrounding stations that were considered rural when compared to the sprawling San Antonio urban area. This data was then corrected for missing entries, the time of bias error, and station relocations. Once these modifications were made, data analysis was preformed in order to quantify the change in the UHI from the 1950s to the 2000s. The emphasis was to take monthly data measurements for each station and turn them into seasonal temperature

trends. In the end, it was found the UHI could be seen most prominently, and with the strongest statistical confidence, in the maximum temperatures. Although these results may have some inherent inaccuracies, averaging over long periods of time with similar meteorological conditions should compensate for much of the error. These results demonstrate that not only is the UHI a phenomenon that is affecting our cities, but it is also growing over time. These changes may not seem huge now, but over time they will continue to grow. It is imperative that changes are made so that our cities do not become urban hotboxes and endanger the safety and wellbeing of all that dwell within the cities.

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APPENDIX A

The station locations that were obtained from the 2003-2013 period are reasonably accurate due to the increased usage of GPS technology along with standardized geographic datums. However, location measurement was not nearly as accurate in the decade from 1950-1960. The diminished accuracy requires a different approach for more exactly determining the locations of each station from this decade. By using the site descriptions and other location-based information contained within the climate records, it is possible to narrow down the location of stations that existed in the 1950s decade. The latitude and longitude coordinates contained within the records only give an approximate location of each station because coordinate accuracy was not as precise as it is today. The main methods by which station locations will be adjusted are looking at the recorded elevation of the station, looking at how the station was located in reference to the post office of a town, and using the characteristics contained within the site description.

San Antonio International Airport:

- This station was most radically moved before the 1950s decade. During the time period that is being studied, there was only a minor change in location. The elevation records indicate the first location was at 786 feet above sea level and the second station was 1,200 feet to the northwest at 792 feet above sea level. Based on the general location given by the latitude and longitude coordinates, the stations have bee adjusted slightly so that they fit better with this description.

Luling:

- The Luling station had two locations during the 1950s decade. The first location was more precisely located by using the elevation of 400 feet above sea level and the fact that the station was suppose to be about 2 miles ESE from the post office. The second location had no other information than the coordinates. Since the latitude was exactly the same as the first location and there was only a slight change in longitude, the second location was placed just to the west of the first location.

New Braunfels:

- This station also had two different locations during the 1950s. This adjustment was a little difficult because the reported elevation values were nowhere near what the elevation map was showing. The climate records indicated that the elevation above sea level was around 720 feet. The contour map was showing an elevation of about 620 feet. The locations that were chosen were based off of the fact that the stations were supposed to be about 5 blocks to the south east of the post office. The second location was reported to be about 1,000 feet to the south of the first station location.

Stinson Municipal Airport:

- This airport was not used for collecting climate records during the 1950s decade so it is not necessary to made adjustments.

Brooks Air force base:

- This station was only used during the 1950s decade and it did not move once during the time period. In fact, it has remained in the same location to this day but

it is no longer an Air Force base. Due to this, the exact latitude and longitude by current standards are easy to locate in public records.

Poteet:

- When going through the archived records, no station details were found concerning Poteet during the 1950s. The metadata repository records show that there was only one station location during the decade. However, no other information is given besides the latitude and longitude. This creates an issue because there is no way to accurately adjust the location of the Poteet station during the 1950s. Luckily the area within 2 miles of Poteet is relatively consistent so this should not lead to any major errors

Boerne:

- This station was reported to be in a valley and about two miles to the north-north west of the post office. Based on these two facts, the station was adjusted slightly to the southeast to better fit the description from the climate records.

Hondo:

- There were three locations for this station during the 1950 decade. The first two are documented in the climate records. The first location was 2 blocks east-south east of the post office and the second location was half a mile west-south west of the post office. The third location came from the metadata repository and it essentially was a location very similar to the first location.

Blanco:

- There was only one station location during the 1950s decade. The station had an elevation of 1370 feet above sea level and it was0.3 miles to the north west of the

post office. The adjustment to the location was based on the combination of these two factors.

San Marcos:

- There was only one station location during the 1950s. This location had a reported elevation of 670 above seal level. Within the roughly two-mile radius of error, there was only one area that had this elevation. So, the station location was adjusted to meet this measurement.