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ASSESSING EQUIVALENT TEMPERATURE TRENDS IN MAJOR EASTERN US CITIES

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by

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Summer (JJA) temperature (T) and equivalent temperature (T_E) for 18 of the largest cities in the eastern United States are investigated for two time periods: 1948-2014 and 1973-2014. Because temperature provides an incomplete description of lower tropospheric heat content, we supplement with T_E, which also accounts for the energy associated with moisture. An auxiliary investigation using air mass data from the Spatial Synoptic Classification (SSC) augments the investigation of T and T_E trends. The trend analysis revealed significant trends in T_{min} at all stations over the 67-year time period and over most stations for the shorter (41-year) period. Minimum T_E likewise increases nearly everywhere in the longer series, but at only around half of the stations in the shorter series. Stations with increasing T_E in the shorter period are primarily coastal or located in the southern and upper Midwest, where there has also been a noticeable lack of warming. Our results also exhibit a decrease in the diurnal T_E range that accompanies the documented decrease in diurnal temperature range over the same period. Trends in T and T_E are evaluated in the context of changes in air mass frequency. A heat wave analysis was also conducted to identify changes in intensity and frequency using T and T_E Overall, our findings suggest that T_E provides a more comprehensive perspective on recent climate change than T alone. With heat wave

frequency and intensity projected to increase, we recommend adoption of T_E to account for changes in total surface heat content.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Extreme heat events in the United States are responsible for more deaths on average than all other fatal weather events combined (National Weather Service, 2014). During the years 1999-2009 the United States experienced extreme heat events that claimed 7,233 lives, which is an average of 658 heat-related deaths per year (US Department of Health and Services, morbidity and mortality report, 2013). Many of these deaths often occur in large cities which tend to house their own microclimates by creating their own set of thermal, radiative and moisture conditions (Oke, 1997).

Urban microclimates have been studied intensely over the years, particularly because cities produce the urban heat island effect (UHI). The urban heat island effect refers to the warmer air temperatures that occur in cities when compared to their rural neighbors (Oke, 1986). Urban regions and their unique microclimates are important because it is where human activities display the changes they create in the atmosphere most (Oke, 1997). Large cities have copious amounts of asphalt, concrete and various metals, these impervious surfaces enable cities to modify the local hydrologic cycle.

High temperatures coupled with high humidity contribute to human heat stress. For this reason, it is important to analyze changes in heat wave events using metrics that account for both humidity and temperature. A thermodynamic metric called equivalent temperature T_E allows us to quantify the amount of energy in a parcel of air by using temperature, dew point, and pressure (Bolton, 1980). T_E is the temperature that an air parcel would have if all associated water vapor were condensed and the resulting latent heat is used to increase the temperature of the parcel (Schoof et al., 2014). Equivalent temperature (°C) allows us to quantify and separate the moist and dry components which contribute to its magnitude; this makes it a good metric for assessing heat waves (Davey, 2006; Fall et al., 2010; Schoof et al., 2014). High humidity prevents the body from sweating and therefore cooling itself off, this increases the chances for heat related stress and illness (Willett et al., 2007). When T_E is high both the temperature and dew point are high because it is dependent on both variables. By contrast the heat index, another common heat metric, is highly dependent on temperature (or apparent temperature) and can be high, even when the humidity is not. The T_E metric provides a more accurate measure of lower atmospheric energy content (Pielke, 2004).

Another important factor that may impact trends in T_E at a synoptic scale is the frequency of air masses over large cities. The influence of air mass frequency over large urban areas and their potential to influence equivalent temperature trends has yet to be investigated. Therefore, in addition to examining trends in T and T_E, this study will include an analysis of air mass data from the spatial synoptic classification system (SSC) (Kalkstein and Nichols, 1995; Sheridan, 2002). The purpose of this study is to analyze equivalent temperature trends in 18 of the largest cities in the eastern US (US Census Bureau, 2010) to better understand the relationship between temperature and T_E trends. In addition, SSC data will be analyzed in order to help determine the frequency of air masses in specific regions as well as their trends. Finally, this study will include two auxiliary analyses: 1) diurnal temperature range (DTR= T_{max}-T_{min}) and 2) heat wave frequency and intensity for the study period. Previous studies have found that due to differential changes between daily minimum and maximum temperatures

DTR is decreasing in many parts of the world (Easterling et al., 1997). The decrease in DTR is a signal of climate change and is important to consider since water vapor is a strong greenhouse gas and has the ability to retain heat (Trenberth, 1997). Heat wave intensity and frequency are also expected to increase (Meehl and Tebaldi, 2004), therefore observing the trends of heat waves using T_E will be helpful understanding its potential impacts.

Despite knowledge that humidity also plays a role in most heat waves, there has been relatively little attention paid to the role of humidity in studies of urban climate hazards. Surface heating trends can be influenced by moisture trends this can lead to changes in precipitation both in geographic distribution and intensity (Davey, 2006; Willett et al., 2007). This thesis is designed to answer three main questions: 1) How do temperature and equivalent temperature trends differ in urban areas? 2) How do synoptic-scale weather patterns and air masses relate to the observed temperature and equivalent temperature changes? 3) Are the intensities and frequencies of heat waves changing along with observed temperature and equivalent temperature trends? The purpose of this study is to expand on previous work dedicated to investigating the differences between T and T_E. The cities chosen for this study are all located east of the 100^{th} meridian; we refer to this area as the eastern United States (US). The cities are both in coastal and continental regions, and together in 2010 were home to over 21 million Americans (US Census Bureau, 2010). We expect to find positive significant trends in T and $T_{E,}$ particularly in the summer which has been found in previous works such as Davey (2006). Davey (2006) found that urban sites and sites that are closer to major bodies of water were relatively warmer in T_E when compared to T. Overall, we expect our findings to align with previous research which have found that trends in T_E to be larger in magnitude relative to trends in T (Davey, 2006), noticeable changes in air mass frequency (Kalkstein et al., 1998), decrease in DTR (Easterling et al., 1997) and increases in heat wave frequency and intensity (Meehl and Tebaldi, 2004). This study will contribute to existing literature on T_E by focusing on large cities over an extensive study period, one that is longer than any other study to date. Additionally, no other study that has used T_E as its metric to interpret surface heat content has taken into consideration the potential impacts of air masses, heat waves and their frequencies over urban regions.

CHAPTER 2

LITERATURE REVIEW

Climate related challenges are already on the rise in the US. In some areas of the country multiple threats can occur at once and often some communities are disproportionately vulnerable (Madrigano et al., 2015; Crimmins, 2016,). In this chapter, we discuss four main ideas that drive the scope of this study. First, we explore urban heat islands and their impacts. Second, we look at several definitions of heat waves in the US and note how they vary regionally. Finally, we discuss previous findings on equivalent temperature and humidity as well as other factors that influence their trends.

Urban Heat Islands

The urban regions of the United States (US) are representative of the growth and development experienced since the industrial age. Cities offer economic opportunity, cultural diversity, centralized business districts, extensive road systems, complex infrastructure, and a variety of jobs for booming populations. The urban heat island (UHI) effect refers to the warmer air temperatures that occur in cities when compared to their rural neighbors (Oke, 1986). Previous studies have found that the UHI can increase temperatures in urban regions by 8-10°F and even twice as warm as rural counterparts during the summer months (McCormick et al., 2016 and Wouters et al., 2017). The impacts that cities have on the environment is the focus of many studies because they show clear examples of human induced change, particularly when it comes to local climates (Oke, 1997).

Urban weather patterns are often driven by synoptic and meso-scale features. In addition to synoptic influences, they are unique to the local characteristics of the urban setting (Meir et al., 2013). Glanz (1990) noted that cities possess several characteristics which make them interesting" laboratories" or analogues in which research questions regarding the mechanisms and impacts of global climate change can be studied.

Differences in temperature in cities are related to land cover use/change, the predominance of impervious surfaces and the presence of low albedo construction materials, as well as other differences between cities and rural areas (Stewart and Oke, 2012). This is of important because half of the world's population lives in cities and this proportion continues to grow (Grimm et al., 2008). It is also important to recognize that the UHI effect is not limited to large cities, but can exist within built environments as small as 1 km^2 (Coseo and Larsen, 2014). Stone (2012) suggests that land cover use/change combined with waste-heat (byproduct of industrial activity) are making larger contributions to warming in US cities than global climate change. UHI's are not always found in the urban core, but may dispersed within the urban and suburban areas away from downtown (Coseo and Larsen, 2014). A study by Lo & Quattrochi (2003) found that over a 10-year period during the late 1990's, suburban areas of Atlanta had become warmer than the urban core of the city or downtown area. These irregularities can also be related to the amount of vegetation present in specific locations, affluent neighborhoods tend to have more areas of green space. It is also important to note that not all types of vegetation help equalize the UHI effect, for example grass is not as effective as trees that can cast shade and contribute more moisture with broad leaves. Stone and Norman (2006) determined that if the suburban neighborhoods of Atlanta reduced lawn areas by 25% and replaced it with trees, the heat related to UHI could be reduced by 13%.

In addition to their spatial variability, urban microclimates can be divided vertically into two separate areas: the urban boundary layer, the area above the building rooftops and the urban canopy layer is considered as the area that extends from the building tops to the surface (Oke, 1987). The air within the urban canopy is the air that impacts human health and comfort. Another perspective to consider with UHIs is the urban canyon ratio. It consists of measurements that include the height of the buildings relative to the width of the street (h/w). Tall buildings with narrow streets retain heat from solar radiation as absorbed by building walls, this also creates elevated air temperatures (Oke, 1988). Previous studies have shown that the urban canyon ratio is a useful predictor of air temperatures (Eliasson, 1996, Sakakibara, 1996). The contribution of increased air temperatures from impervious surfaces and the urban canyon ratio have been found to be approximately equal in UHI's (Oke et al., 1991). The orientation of city streets can also affect the amount of air circulation and shading received in an UHI, studies have found higher temperatures in east-west streets when compared to north-south streets (Coseo and Larsen, 2014). East-west streets lack shading during the course of the day contributing to warmer temperatures. In addition to shading, streets that are in alignment with prevailing wind patterns are expected to have lower air temperatures in comparison to temperatures in streets that were perpendicular (Ali-Toudert and Mayer, 2007).

Maximum UHI temperatures occur predominantly in the late afternoon, however research shows that night time air temperatures or minimum temperatures are the strongest predictor of heat-related mortality and morbidity (Kalkstein & Davis, 1989). A study in 2014 found that nighttime (minimum) temperatures in Chicago were significantly affected by the amount of tree canopy and impervious surfaces. These two factors within an urban block were attributable for 68% of the air temperature, the strength of this relationship increases to 91% during heat events (Coseo and Larsen, 2014). Buildings absorb heat during the day and release the stored heat at night. The released heat is then trapped in the thin atmospheric boundary layer which can continue to accumulate heat as the air moves across the urban area (Zhao et al., 2014). Parks in cities can create an "oasis" or cooling effect in urban areas due to evapotranspiration. Parks and other large green spaces that create this effect are also known as heat sinks (Oke, 1987; Jenerette et al., 2011; Zhao et al., 2014; Hall et al., 2016). Although green spaces can provide some cooling, it is not enough to offset daytime warming. One possible mitigation attempt is the increasing of urban albedo. This is accomplished with roofs being painted white or being covered in a highly reflective material. Increasing albedo would have little direct effect on minimum temperatures. The indirect effect is a reduction of heat storage throughout the day therefore less heat is being released back into the atmosphere at night (Zhao et al., 2014). Because of the UHI effect, cities are more vulnerable to heat waves or extreme heat events which threaten the livability and safety of densely populated urban environments.

Heat Waves in the US

Heat is the number one weather killer in the US; heat related deaths averaged 237 per year during the 10-year period of 1994-2003(National Weather Service, 2014). In fact, heat is attributed to more deaths annually than floods, lightning, tornadoes, and hurricanes combined. The precise definition of a heat wave is not uniform in the literature and varies by study region, there is no universally accepted definition of a heat wave (Souch and Grimmond, 2004). The thresholds for heat stress and illness vary from place to place, and factors such as prior conditioning, and social and cultural practices can influence human response to excess heat. Living in a particular climate as well as recent exposure to extreme events can impact how a population will be affected by a heat event (Souch and Grimmond, 2004). The National Weather Service (NWS) has created thresholds using generalized criteria for human heat stress: the challenge is that these thresholds cannot be applied nationwide. For example, the regions that have naturally occurring high levels of humidity will have a different human heat stress threshold than dry regions such as deserts. Populations are conditioned to their environments and climate; therefore, definitions generally carry some level of variation based on location and are not agreed upon in the scientific community (Souch and Grimmond, 2004). Many widely used measurements for heat waves found in scientific literature are expressed by different heat indices which combine different variables such as maximum temperatures, cloud cover, humidity and other factors that create multi-measurement indices (Perkins, 2015).

More generally, a heat wave is defined as an extended period of high atmosphere-related heat stress, which causes temporary modification of lifestyles and may have adverse health consequences for the affected population (Robinson, 2001). The heat index is a measure that is commonly used to communicate to the public how hot it really feels when relative humidity is factored in with the actual air temperature (NWS, 2017). The heat index expressed as apparent temperature in degrees Fahrenheit. A previously stated, the heat index is highly dependent of temperature (or apparent temperature) and can be high, even when the humidity isn't. Another common use of the term heat wave is defined by as an event that exceeds average temperatures for a minimum over a number of days, usually 2-3 (Peterson et al., 2013), this is also the definition used for European studies like Fischer and Schaar (2010). Heat waves can also be defined as multi-day periods in which T_{max} exceeds its summer 90th percentile value (Schoof et al., 2014, Meehl and Tebaldi, 2004). In this study, we adopt these strategies and define a heat wave day as any day above the 90th percentile of June, July and August (JJA).

A heat wave is defined by NWS as an event in which the maximum temperature meets or exceeds 90°F at least 3 consecutive days. Many cities in the US follow the NWS guidelines when issuing warnings and advisories while other cities modify the criteria to suit their specific needs. For example, New York City (NYC) will issue a heat advisory when temperatures reach 100-104°F for at least two consecutive hours and when the heat index is expected to reach 95-99°F for at least two consecutive days (weather.gov, 2016). The National Weather Service (NWS) issues heat advisories and warnings when heat index values reach 105°F (41°C) or greater. When the heat index has a potential to reach 110°F (43°C) or higher within a 24-48-hour period an excessive heat watch is issued. When the heat index values are expected to reach or exceed 110°F within a 12-14-hour period an excessive heat warning is issued (NWS, 2016).

One example of a high humidity and high temperature event is the heat-wave of Chicago in 1995, which claimed the lives of over 700 people, heat stress was amplified by high dew point temperatures (Palecki et al., 2001; Meehl and Tebaldi, 2004; Souch and Grimmond,2004). During a heat wave event, low winds coupled with higher temperatures offer no relief to urban areas at night. Heat waves in cities can be longer lasting and extend to the rural surroundings (Meir et al., 2013). Intensity and frequency of heat waves is expected to grow in the coming years (Meehl and Tebaldi, 2004). Studies have found that there is an interaction between UHI's and Heat Waves, UHI's provide the conditions necessary for heat to remain trapped in urban regions for days (Li and Bou-Zeid, 2012). Zhao (2014) suggested that UHI's will increase heat wave stress on humans, particularly in wet climates where high humidity is coupled with high temperatures such as the eastern US.

Impacts on population

A report by the US Department of Health and Human Services (2013) points out that the most vulnerable demographic is the elderly, especially people who live alone. During the Midwestern heat event of 2012 over 69% of the victims lacked air conditioning. Other factors that the study mentioned were that even with government response, many people do not use the cooling centers due a multitude of reasons. Some of the reasons listed include: stigmas attached to their use, lack of transportation, restriction of pets, and lack of awareness of the dangers that extreme heat poses. A study in Alabama used different heat indices to compare heat waves in urban vs. rural areas. It was discovered that having different heat index definitions resulted in different association estimates when studying extreme heat events and the effects that heat has on humans (Kent et al., 2004). This further proves that the public's responses and perceptions of what a heat wave is and how it is defined varies by region in the US. The researchers also emphasized the need to develop heat wave response systems that addressed both cities and rural areas since populations exhibited different responses.

Heat waves have effects that can last from days to a week after the event. A study from 2014 found that hospital admissions for people 65 and older generally increase by approximately 3% over the eight days that follow heat waves. In addition to an increase in cardiovascular diseases, hospital admissions increased by 15% for renal and 4% for respiratory issues in the 8-day period following an extreme heat event (Gronlund et al., 2014, Crimmins et al., 2016). The effects on the body are numerous, exposure to heat above 105°F (41°C) can lead to heat stroke, central nervous system dysfunction, and heat exhaustion (McCormick et al., 2016). Increased temperatures have also been found to be positively correlated with hospital trauma admissions for children and adults (Ali and Willett., 2015). There is a strong need to educate and target patients whose conditions may be worsened by extreme heat and humidity. There are also large social disparities in heat related deaths that reflect socio-economic advantages or lack thereof.

Several studies have confirmed that often hotter temperatures are present in poorer neighborhoods (Coseo and Larsen, 2014; Madrigano et al., 2015). A case study in New York City found that deaths related to heat in UHI's were more likely among

African American residents than any other ethnicity. In addition, most of the deceased lived in areas that had little or no green space; usually their neighborhoods contained more highly developed industrial environments and residents lack air conditioning (Madrigano et al., 2015). UHI’s often create a disproportionate burden for the poorest residents, a 2006 study found that for every $10K increase in annual household income leads to a 0.5°C in cooling due to the prevalence of more trees and grass in affluent neighborhoods in Phoenix (Jenerette et al., 2006; Coseo and Larsen, 2014; Hall et al., 2015).

Heat deaths are not always reported accurately and may also occur days after the event, therefore may not be categorized as such (Madrigano et al., 2015; McCormick et al., 2016). A different study in NYC also acknowledged that deaths due to hyperthermia can be difficult to assess and recognize since the cause of direct cause of death may be respiratory or cardiovascular disease for example, both of these conditions can be exacerbated with extreme heat and death would not be attributed to heat (Matte et al., 2016).

Souch and Grimmond (2004) report that ‘heat’ when referred to as a hazard goes largely under recognized as having a strong impact. Epidemiological studies have found a consistent relationship between increased morbidity and mortality related to heat events (McCormick et al., 2016). Another impact of heat is an increase in vector borne diseases such as west Nile virus. As temperatures increase so does the spatial variability and seasonal distribution of mosquitos, this includes activity happening earlier in the season (Crimmins et al., 2016). There is a need to better educate the public about UHI's and their potential impacts especially for the health and safety of children and the elderly (Madrigano et al., 2015; Crimmins et al., 2016).

Equivalent temperature (T_E)

Equivalent temperature (T_E) is the temperature that an air parcel would have if all associated water vapor were condensed and the resulting latent heat were used to increase the temperature of the parcel (Schoof et al., 2014). Equivalent Temperature uses observed air temperature and moist enthalpy.

$$T_E = T + L_v q / C_p \qquad (1)$$

where T is the observed air temperature in °C, L_v is the latent heat of vaporization in Joules per kilogram (J kg^{-1}), q is specific humidity (kg^{-1} kg^{-1}) and C_p is the specific heat of air at constant pressure (Joules per kilogram per Kelvin). The term on the right-hand side of the plus sign in the equation is the moist enthalpy contribution whose subcomponents are L_v q and C_p. This thermodynamic metric allows us to investigate the joint behavior of temperature and humidity as well as the heat content of near surface atmospheric moisture (Pielke, 2005; Davey, 2006; Fall et al., 2010; Schoof et al., 2014;).

T_E trends in the US have been found to be increasing in recent studies (Fall et al.,2010; Schoof et al, 2014). Pielke (2004) suggested that in order to properly measure the effects of "global warming" studying and analyzing temperature trends alone did not suffice. Equivalent temperature lets us look at surface heat content which accounts for water vapor; therefore, it is a more comprehensive way to analyze global climate trends (Pielke, 2004).

Fall (2010) used a combination of reanalysis data along with land use/cover classifications from 1979-2005 and concluded that T_E showed a strong relationship to vegetation cover and areas with higher transpiration and evaporation rates. Moisture in the atmosphere increases mostly from late spring to early fall, the warmest time of the year in the northern hemisphere, the largest contributions occur in the summer months (JJA) (Pielke, 2004). In addition to looking at surface trends, Fall (2010) analyzed T_E at different altitudes and found that nearly half of the water vapor in the air is found within the lowest 1.5 km of the atmosphere. The results help to exemplify this because T and T_E show increasing and positively correlated trends when measured at the standard station height of 2m, however, the relationship becomes weak at 300mb. The study found that temperature contributed more to the magnitude of T_E than the specific humidity did. Temperature can account for up to 90% of its magnitude (Fall et al., 2010).

Davey (2006) observed T_E trends for cities in the eastern half of US from 1982-1997, overall T_E trends were relatively warmer than temperature trends. This is an expected result since T_E accounts not only for sensible heating, but also heat which is driven by changes in the near surface atmospheric moisture. The magnitude of T_E is expected to be larger in places where moisture is available; for example: as a natural response to increased temperature more evaporation occurs near surface bodies of water. Increased evaporation will influence near-surface humidity; therefore, it will also influence T_E (Davey et al., 2006).

Humidity

The thorough investigation of moisture is of vital importance for understanding changes in T_E. Water vapor is an important greenhouse gas (GHG), it is considered a key driver for many atmospheric processes such as the hydrologic cycle and surface energy budgets, it is also the gas that absorbs the most solar radiation (Kiehl and Trenberth, 1997; Willett et al., 2007; Brown and DeGaetano, 2012). The two most commonly used measures of humidity are relative humidity (RH%), and specific humidity (*q, g kg-1*). The degree of saturation in the air relative to the temperature creates the ratio for RH, whereas *q* represents the amount of water vapor per unit mass of air (Brown and DeGaetano, 2012). The Clausius-Clapeyron equation shows that if relative humidity stays constant, specific humidity increases exponentially with temperature (Brown and DeGaetano, 2012; Willett et al., 2007). Studies based on observations and modeling are already confirming this relationship as the climate warms on a global scale (with regional variability): relative humidity is staying the same while increases in specific humidity are being documented (Willett et al., 2007). Willett (2007) identified significant increases in specific humidity on a global scale that are attributable to human influence. Water vapor in the atmosphere is expected to continue increasing along with other GHG's (Willet et al., 2007). Gaffen and Ross (1999) found that specific humidity trends in the US had increased over the period from 1961-1995. Trends for humidity also aligned with trends in apparent temperature (Ta), values were found to be twice as high in the eastern US when compared to the western states (Gaffen and Ross, 1999). Near surface specific humidity has significantly increased over the last 40 years; these increases are larger in the tropics and in the Northern hemisphere during summer (Willett et al.,2007). Brown and DeGaetano (2012) found significant increases in dew point temperatures over the period of 1947-2010 for all seasons except winter. The same study also found significant increases in annual dew point temperature minimums. As absolute humidity increases, heat events may become amplified in the humid tropical regions of the world and the midlatitudes, even if rising air temperatures are less than the global average (Willett and Sherwood, 2012).

Air masses: Spatial Synoptic Classification (SSC)

Air mass definitions have expanded and evolved over the years along with advances in climatological studies. Crowe (1971) defined an air mass as a large volume of air that has acquired characteristics of temperature and humidity related to the condition of the land sea or ice beneath it. This is very much in alignment with Bergeron's (1930) theory that air masses should be defined by their source regions. New definitions of air masses such as those provided by SSC are not based on source region alone; however, response is dependent most frequently on the meteorological character of the air at a place in time (Kalkstein et al., 1996). Air masses are composed of various thermal and moisture variables which include, but are not limited to cloud cover, visibility, and precipitation. These variables allow air masses to be defined by their distinctive thermodynamic characters. The criterion for categorization is rooted on similarities in moisture and thermal characteristics. It is possible that wind and pressure could exhibit considerable variations among the days within an air mass (Kalkstein et al., 1996). The foundation of the original SSC is dependent on proper identification of the character of each weather type for a location, this is done with the selection of seed days. Seed days are defined as the actual days in a station record that contain the typical meteorological characteristics of a particular weather type for the given location (Kalkstein et al., 1996). The original work done in the creation of SSC (1996) only provided air mass data for the summer and winter seasons. Sheridan (2002) improved the SSC system by including the use of 'sliding seed days', this allows for year-round classification of air masses. Spatial continuity of weather types was also improved because the number of stations increased to cover a larger area (Sheridan, 2002).

The SSC system defines six different air mass types applicable to stations in the contiguous United States. These are listed as: 1) DP-dry polar 2) DT-dry tropical 3) DM-dry moderate 4) MP-moist polar 5) MM-moist temperate and 6) MT-moist tropical. In relation to heat waves and extreme heat events, MM and MT are the masses which carry the highest amounts of moisture and heat and are of importance to our study. The MM air mass is warm and humid, it usually appears in areas south of MP and may be present for many days if frontal movement is sluggish. MT air masses are typically found in the warm sectors of frontal cyclones or in a gulf return flow on the western side of an anticyclone in the central and eastern US (Kalkstein et al., 1998; Sheridan, 2001).

Kalkstein (1998) focused a study on air mass frequency and found that MM is exclusively confined to the eastern half of the US. In the summers, it has frequencies of12-25% east of the Mississippi River (Kalkstein et al., 1998). Another air mass with much influence in the eastern US is MT. During the summer, frequencies are greater than 50% throughout much of the southeast and about 30% in large mid-Atlantic cities (Kalkstein et al., 1998). The presence of the MT air mass has been increasing significantly in many stations. Some have noted very high increases of approximately 2-

4% per decade in the interior southeast (Kalkstein et al., 1998). This increase in MT frequency is believed to be responsible for major contributions to increases in overnight cloudiness, upward trends in T_{min}, and increasing dew point temperatures (Kalkstein et al., 1998)

Diurnal Temperature Range (DTR)

Air temperature records from all over different parts of the world indicate that DTR has been decreasing since approximately 1950, this is due to larger increases in T_{min} than in T_{max} (Karl et al., 1993; Easterling et al., 1997; Vose et al., 2005;). Due to the UHI effect and impervious surfaces, studies have found increases in minimum temperatures in urban areas (Coseo and Larsen, 2014; Zhao et al., 2014). Many regions in the US have little to no increase in maximum temperatures, however the increasing minimum temperatures are responsible for smaller DTR in some areas (Lauritsen and Rogers, 2012). Studies have found that DTR is decreasing in a warming climate, specifically urban areas are experiencing a narrower DTR when compared to nearby rural areas (Easterling et al., 1997). Local land use, urban growth, desertification, and irrigation practices can have an effect on DTR. In addition, there are large scale influences that can also impact DTR such as increases in cloud cover, greenhouse gases, tropospheric aerosols and surface evaporative cooling from precipitation (Easterling et al., 1997, Karl et al., 1993). A study by Lauritsen and Rogers (2012) found that increasing trends in cloud cover have a significant effect on DTR trends in different regions of the US, particularity in the south-central US which also experienced a decrease in T_{max}.

CHAPTER 3

METHODS AND DATA

PART 1: Data

Weather station data was gathered for the 21 most populated cities in the eastern US (Table 1 and Figure 1). The data consists of hourly values for dew point in degrees °C (T_d), station pressure in mb (P) and temperature in degrees °C (T), these are necessary for the calculation of $T_{E.}$ The data was acquired from the National Oceanic and Atmospheric Administration (NOAA) Integrated Surface Database (ISD) which is available from the National Climatic Data Center (NCDC) along with all available station metadata for the period for 1948 to 2014. Four of the cities in this study did not have records that went back as far as 1948, however they were analyzed starting from the year 1973 to 2014. We refer to these time periods as the long 67-year series and the short 41-year series throughout the rest of the paper.

Table 1. Eastern US cities, population, land area per square mile and populations density. Source: US CENSUS BURAEU, 2010

Eastern US cities	**Census (2010)**	**Area per km2**	**Population Density: people per km2**
New York, NY	8,175,133	487.05	27,012.50
Chicago, IL	2,695,598	366.34	11,841.80
Philadelphia, PA	1,526,006	215.81	11,379.50
Jacksonville, FL	824,784	1202.18	1,100.10
Indianapolis, IN	820,445	581.67	2,270.00
Columbus, OH	787,033	349.50	3,624.10
Charlotte, NC	731,424	479.07	2,457.10
Detroit, MI	713,777	223.30	5,144.30
Memphis, TN	646,889	507.04	2,053.30
Baltimore, MD	620,961	130.26	7,671.50
Boston, MA	617,594	77.70	12,792.70
Washington, DC	601,723	98.25	9,856.60
Nashville, TN	601,222	764.65	1,265.40
Louisville, KY	597,337	523.44	1,836.60
Milwaukee, WI	594,833	154.69	6,188.30
Kansas City, MO	459,787	506.86	1,459.90
Virginia Beach, VA	437,994	400.76	1,758.90
Atlanta, GA	420,003	214.28	3,154.30
Raleigh, NC	403,892	229.98	2,826.30
Miami, FL	399,457	57.73	11,135.90
Total Population	24,775,343		

Figure 1. Major cities east of the 100th meridian in the United States. These cities naturally experience humid summers due to their location.

Homogeneity of the data is an important part of the investigative process since weather stations are often moved and the instruments change over time. Another factor that can affect the data is urbanization and land use change around the stations (Schoof et al. 2014; Peterson et al., 2013). It is crucial to measure, define and understand all the uncertainties that may be present in climatic historical records.

The accuracy of weather data is also dependent on the observers who collected the data and the level of training that observers received. Few stations in the country have meticulous record keeping by trained scientists (Changnon and Kunkel, 2006).

Changes in station elevation can also have an impact on recorded temperatures. For example, one of the stations with the best records in the US is in Urbana, Illinois. Its elevation was increased from 1.2 to 3 meters from 1904 to 1948, this change lowered the annual temperatures by 0.17°C for that period. That same station also recorded a temperature increase while it was in an urban area that experienced growth for a period of approximately 60 years. Annual average air temperatures had increased by 0.7°C during that time, this is likely due to the urban heat island effect. In 1984 when the station was relocated to a more rural setting, a change was noticed. The urban heat island effect was accounted for, annual air temperatures then decreased by 0.8°C (Changnon and Kunkel, 2006).

Instrument changes over the 67 years of data collected for this study have been verified with station metadata, however, not all changes were recorded and many of the records overall are incomplete. Wet bulb and dry bulb temperatures were measured by hand using mercury thermometers and sling psychrometers during the early 1960's before the installation of lithium chloride hygrothermometers (Gaffen and Ross, 1999). The hygrothermometers were used to measure T_d and T, they remained in operation for over 20 years until the installation of the model HO-83 in the mid 1980's. From 1987 to 1997 the Automatic Surface Observing System (ASOS) was introduced to the network, this change included the HO-83 sensors for T_d and T, a modification for the HO-83 system was introduced within the ASOS systems starting in 1991 (Gaffen and Ross, 1999). This change to the HO-83 system was implemented to reduce a warm bias. Per Karl (1995) the change to the HO-hygrothermometers may have led to false increases of 0.5°C in daily maximum temperatures and possibly a

0.1°C in daily minimum temperatures. Issues with data inhomogeneity due to the HO-83 have been addressed by previous studies. Gall (1992) found that if a station was not properly aspirated large biases were present, specifically the temperatures at a Tucson station were reporting 2-3°F higher than the ambient temperatures. The issue with insufficient aspiration reporting higher temperatures created the largest errors in environments in which solar radiation was quite high, this is why the problem was very noticeable in the Sonoran Desert. The cities in this study are all in vegetated and/or subtropical regions where moisture is present, a series of tests were conducted to address possible uncertainties in the record.

For a station to be included in this study, at least 90% of the time series needed to be present for the seasonal analysis, 4 stations (Kansas City, Jacksonville, Washington DC and Detroit) were eliminated due to insufficient records from the 68-year record (see table 2). The annual analysis includes stations that have over 85% of the data present, this was the highest percentage of annual data available for the long series (see table 2). The shorter 41-year time series required an additional adjustment, all stations have at least 90% of the data present for the seasonal analysis however, the parameter was reduced to 80% of data needing to be present in order for to be included (see table 3).

Table 2. Missing years of data used for trends 1948-2014. Data present: 90%= no more than 6 years missing for seasonal analysis and 85%=no more than 9 years missing for annual analysis. *Detroit series begins at 1958 .

City	Annual	Seasonal
1948-2014		
1) Atlanta	7	5
2) Boston	5	3
3) Charlotte	7	5
4) Chicago		
5) Columbus	7	4
6) Indianapolis	7	3
7) Louisville	6	4
8) Memphis	9	6
9) Miami	7	3
10) Nashville	7	4
11) New York City	6	5
12) Philadelphia	6	4
13) Raleigh	7	6
14) Virginia Beach	5	3
15) Detroit*	6	5

Table 3. Missing years of data used for trends 1973-2014. Data present: 90%= no more than 4 years missing for seasonal analysis and 80%=no more than 7 years missing for annual analysis.

City	Annual	Seasonal
1973-2014		
16) Jacksonville	5	3
17) Kansas City	7	4
18) Washington DC	7	4

Metadata from all 18 stations varied in a multitude of ways. In some cases, the values were recorded hourly, but not at the same time every hour. In these situations, traditional rounding principles were applied in the time records. For many of the stations during the mid-1960's to early 1980's values were recoded every 3 hours. In order to assure consistency over the time series, each day was partitioned into eight 3-hour blocks. If a 3-hour block contained at least 1 hour of valid data then it was used to calculate daily averages for: Maximum Temperature (T_{max}), Maximum Equivalent Temperature ($T_{E\ max}$), Minimum Temperature(T_{min}) and Minimum Equivalent Temperature ($T_{E\ min}$). For the calculation of monthly averages 90% of the month needed to not be missing in order for it to be used. Data was then separated into seasons, we specifically look at the summer months (JJA). In order for seasonal values to be calculated, all 3 months of data had to be present. Finally, we calculated annual averages in which all 12 months had to be present for a year to be considered.

Every station had documented moves and/or instrument changes. In order to assess whether or not these changes had an effect on the time series we conducted station t-tests were for instrument changes and station moves. Instrument changes happened in 1964, 1985, the mid 1990's (ASOS installation) and the early 2000's for DTS1 installations. For ASOS and DTS1 implementations, specific dates are associated with station history. Since the changes in the mid 1960's and 1980's occurred over a period of several years, 1964 and 1985 are used as the best possible estimates as in previous studies (Gaffen and Ross, 1999; Schoof et al., 2014). The t-tests for the difference in means were conducted with $\alpha = 0.05$ using monthly anomalies for 4 years before and after the instrument changes and documented station moves for all 4 variables: T_{max}, $T_{E\ max}$, T_{min} and $T_{E\ min}$, following Gaffen and Ross (1999).

Methods

Variations in heat can be related to changes in moisture content. Using moist static energy can help give a good description of available energy near the surface, this is a key variable in the computation of equivalent temperature (Pielke et al., 2004). The moist static energy (*H*) is given by:

$$H = C_p T + Lv_q \qquad (2)$$

C_p is the specific heat of air at a constant pressure (1005 J kg°C$^{-1)}$, *T* is the temperature of the air (°*C*), L_v is the latent heat of vaporization (J kg $^{-1}$) and q is the specific humidity (kg kg $^{-1}$). The division of H by CP gives us equivalent temperature (T_E; °C), this quantifies near-surface heat content and creates separate terms for both the moist and dry contributions:

$$T_E = \frac{H}{C_p} = T + \frac{L_v q}{C_p} \qquad (3)$$

The computation of equivalent temperature requires specific humidity as previously stated. For each station observation, Bolton's empirical relation was first used to derive the vapour pressure (*e*) from the recorded dew point temperature (T_d; °C):

$$e = 6.112 \exp\left(\frac{17.67T_d}{T_d+243.5}\right) \qquad (4)$$

The vapour pressure and observed station pressure were then used to compute specific humidity (*q*; kg kg $^{-1}$):

$$q = \frac{0.622e}{P-0.378e} \qquad (5)$$

Latent heat of vapourization (L_v, J kg $^{-1}$), is computed as a function of temperature (T, °C) following the Priestley-Taylor method as in Fall et al. (2010):

$$L_v = 2.5 - 0.0022T * 10^6 \qquad (6)$$

Daily estimates for maximum and minimum equivalent temperature were computed. The trend analysis was conducted using median of pairwise slopes regression(MPWS), with a 95% confidence level (MPWS; Lanzante, 1996). This technique was used in order to minimize the impact of unidentified inhomogeneities and is considered a robust regression method (Schoof et al., 2014).

CHAPTER 4

RESULTS

The results of this investigation will be presented in four parts. The first part will focus on temperature and equivalent temperature for two different time series. The second part will focus on air masses and their frequencies over the study area. The third part will present our analysis of DTR for all the cities. The fourth and final part will focus on heat wave intensity and frequency.

4.1 Temperature and Equivalent Temperature-Long Series

The long-time series shows significant increases in T_{min} for all 15 stations. Significant increases in $T_{E\ min}$ were present 13 out of 15 stations in the long-time series (except Charlotte and Memphis), all stations show warming (see figure 2)

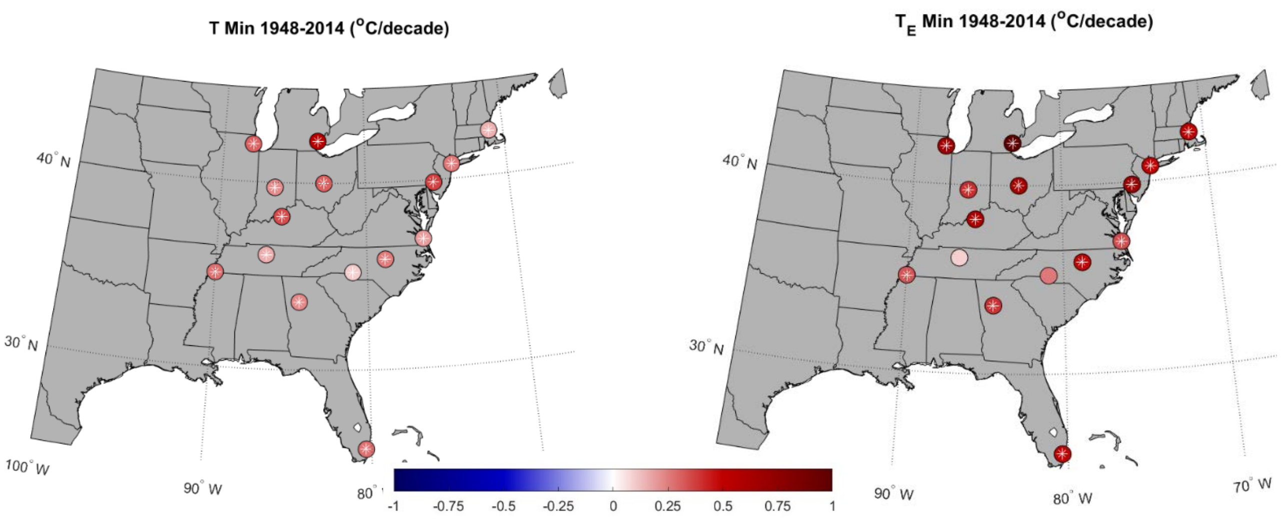

Figure 2. Summer (JJA) averages in degrees Celsius per decade. Long time series years: 1948-2014. Left minimum air temperature (T_{min}), right minimum equivalent temperature ($T_{E\ min}$).

Significant increases in maximum temperatures T_{max} were minimal in the long record exhibited in only 3 stations (Raleigh, Miami, and Philadelphia), two of which are located on the coast (see figure 3). Stations in the Midwest showed little to no trend in T_{max}. Maximum equivalent temperature ($T_{E\ max}$) had results that were similar to T_{max} only 3 coastal stations (Boston, NYC and Miami) showed significant increases in the long record while other stations, predominately in the Midwest showed significant decreases (see figure 3).

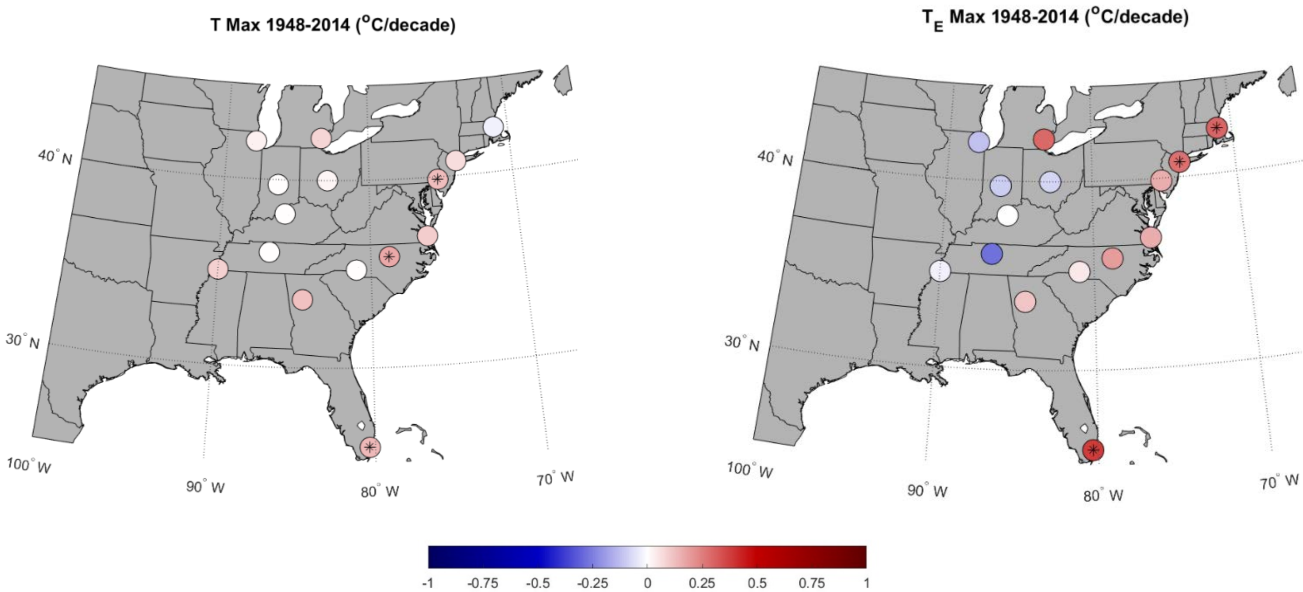

Figure 3. Summer (JJA) averages in degrees Celsius per decade. Long time series years: 1948-2014. Left maximum air temperature (T_{max}), right maximum equivalent temperature ($T_{E\ max}$).

Table 4. Long period trends 1948-2014 for the 18 largest cities in the eastern US. Maximum air temperature (T_{max}), maximum equivalent temperature ($T_{E\ max}$), minimum air temperature (T_{min}) and minimum equivalent temperature ($T_{E\ min}$). Units: C° per decade. *= significant at the 0.05 level.

City	T max	T_E max	T min	T_E min
New York	0.07	0.28*	0.26*	0.5*
Chicago	0.03	-0.12	0.31*	0.66*
Philadelphia	0.13*	0.16	0.37*	0.68*
Indianapolis	0	-0.1	0.22*	0.41*
Columbus	-0.02	-0.08	0.31*	0.62*
Charlotte	0	0.04	0.1*	0.26
Detroit	0.08	0.29	0.56*	1.1*
Memphis	0.09	-0.03	0.28*	0.33*
Boston	-0.03	0.3*	0.15*	0.5*
Nashville	0	-0.28	0.16*	0.09
Louisville	0	0	0.35*	0.59*
Virginia Beach	0.11	0.27	0.28*	0.62*
Atlanta	0.12	0.11	0.23*	0.4*
Raleigh	0.17*	0.19	0.25*	0.49*
Miami	0.14*	0.38*	0.28*	0.5*

4.2 Temperature and Equivalent Temperature-Short Series

The 41 -year (short) record consists of 18 stations total. In the shorter series 12 out of 18 stations had significant increases for T_{min}. Most of the stations show some warming and two stations show no trend (Memphis and Washington, DC). Here, only half of the stations show significant increases for $T_{E\ min}$ (see figure 4). These are located predominantly in coastal, southern and upper Midwest regions. Interestingly Memphis and Washington, DC show cooling of $T_{E\ min}$ while other stations show warming.

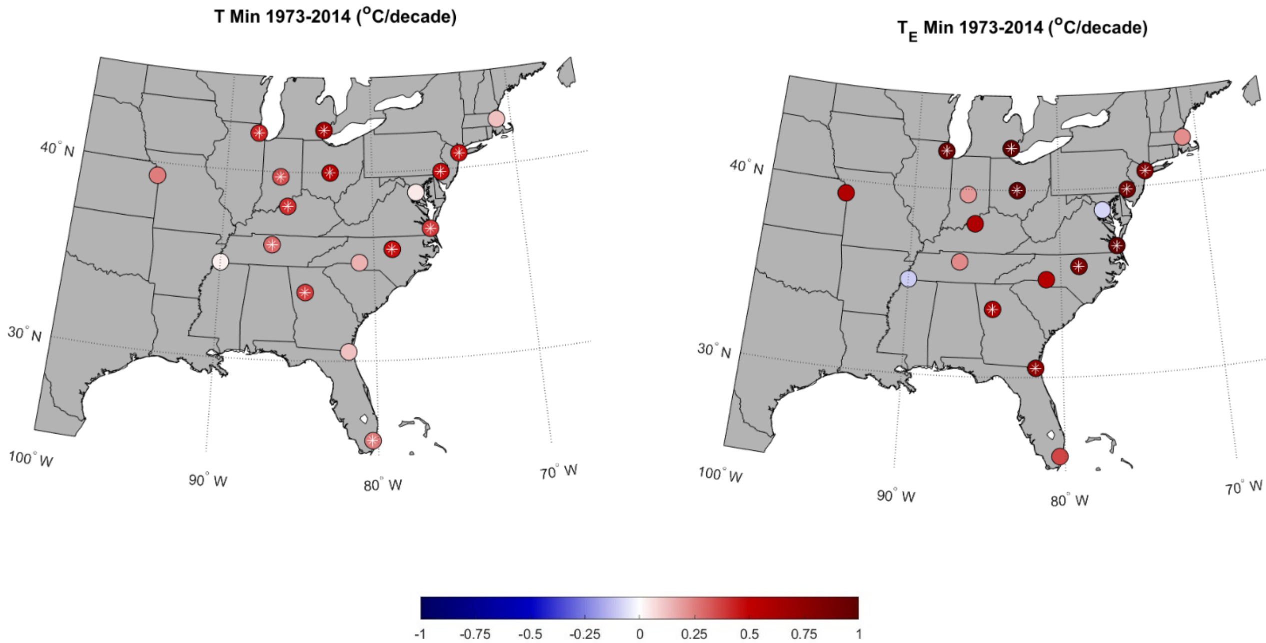

Figure 4. Summer time (JJA) averages in degrees Celsius per decade. Short time series years: 1973-2014. Left minimum air temperature T_{min}, right minimum equivalent temperature ($T_{E\ min}$).

In addition, significant decreases in T_{max} were noted in the shorter record and overall a noticeable lack of warming is present for many of the Midwestern states (see figure 5). These results are inconsistent as the cooling and warming signals show no consistent patterns. For $T_{E\,max}$, a cooling signal is present in the Midwest with Indianapolis showing a significant decrease in $T_{E\,max}$ as well as Washington, DC.

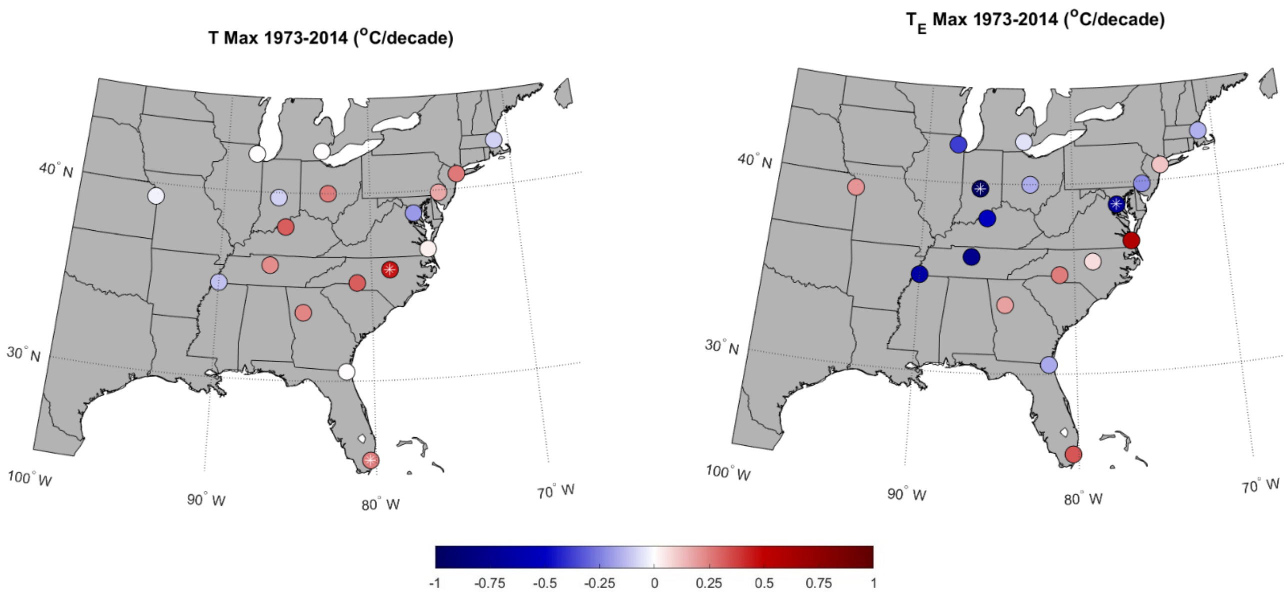

Figure 5. Summer time (JJA) averages in degrees Celsius per decade. Short time series years: 1973-2014. Left maximum air temperature (T_{max}), right maximum equivalent temperature ($T_{E\,max}$).

These results suggest that warming is present in T_{min} as well as $T_{E\,min}$, the two behave similarly especially during summer. Since T is one of the main drivers of increased moisture content (where moisture is available) we find that this variable follows a similar trend to T_{min}.

Table 5. Short period trends 1973-2014 for the 18 largest cities in the eastern US. Maximum air temperature (T_{max}), maximum equivalent temperature ($T_{E\,max}$), minimum air temperature (T_{min}) and minimum equivalent temperature ($T_{E\,min}$). Units: C° per decade. *= significant at the 0.05 level.

City	T max	T_E max	T min	T_E min
New York	0.26	0.11	0.47*	0.84*
Chicago	0	-0.38	0.43*	0.95*
Philadelphia	0.17	-0.22	0.48*	0.91*
Jacksonville	0	-0.17	0.15*	0.82*
Indianapolis	-0.09	-1.13	0.35*	0.2
Columbus	0.25	-0.16	0.57*	1.17*
Charlotte	0.32	0.25	0.15	0.57
Detroit	0	-0.06	0.65*	1.18*
Memphis	-0.12	-0.65	0.03	-0.1
Boston	-0.09	-0.15	0.12	0.22
Washington, DC	0.08	-0.47	0.18	0.2
Nashville	0.22	-0.77	0.29	0.23
Louisville	0.32	-0.52	0.41	0.6
Kansas City	-0.03	0.21	0.25	0.58
Virginia Beach	0.03	0.58	0.39*	1.1*
Atlanta	0.24	0.18	0.38*	0.62*
Raleigh	0.46	0.07	0.47*	0.87*
Miami	0.25*	0.33	0.25*	0.36

4.3 Air Masses

Air mass frequencies for all 18 stations were analyzed using data from the spatial synoptic classification system (SSC). The first step was to calculate trends for four air mass classifications: moist, dry, polar and tropical. The data analyzed focuses specifically on summer air masses which are defined as June, July and August (JJA). The first trend analysis (see figure 6) focuses on moist air masses versus dry air masses. This tells us something about the moisture component in the air from a synoptic scale point of view. Using MPWS (Lanzante, 1996), results show a significant increase in the frequency of moist air masses for 89% of the stations. Dry air mass frequencies showed in significant decreases for 67% of the stations. Located mostly in the Midwest and Northeast region from North Carolina to New England.

The second observation (see figure 6) separates the masses into two classifications: tropical and polar, this allows us to focus more on the temperature of the air masses. Tropical air mass frequency shows significant increases in the southern states as well as the northeast region, approximately 50% of the stations. Polar air masses show significant decreases for 67% of the stations. One station produced results that were inconsistent with nearby stations: Jacksonville results indicate a significant decrease in moist and tropical air masses. We tested stations in Daytona, FL and Savannah, GA and both showed increases in frequency. Miami also produced results which showed increases in moist and tropical (significant) air masses. There could be an error due to instrumentation or another factor that is affecting the results from Jacksonville.

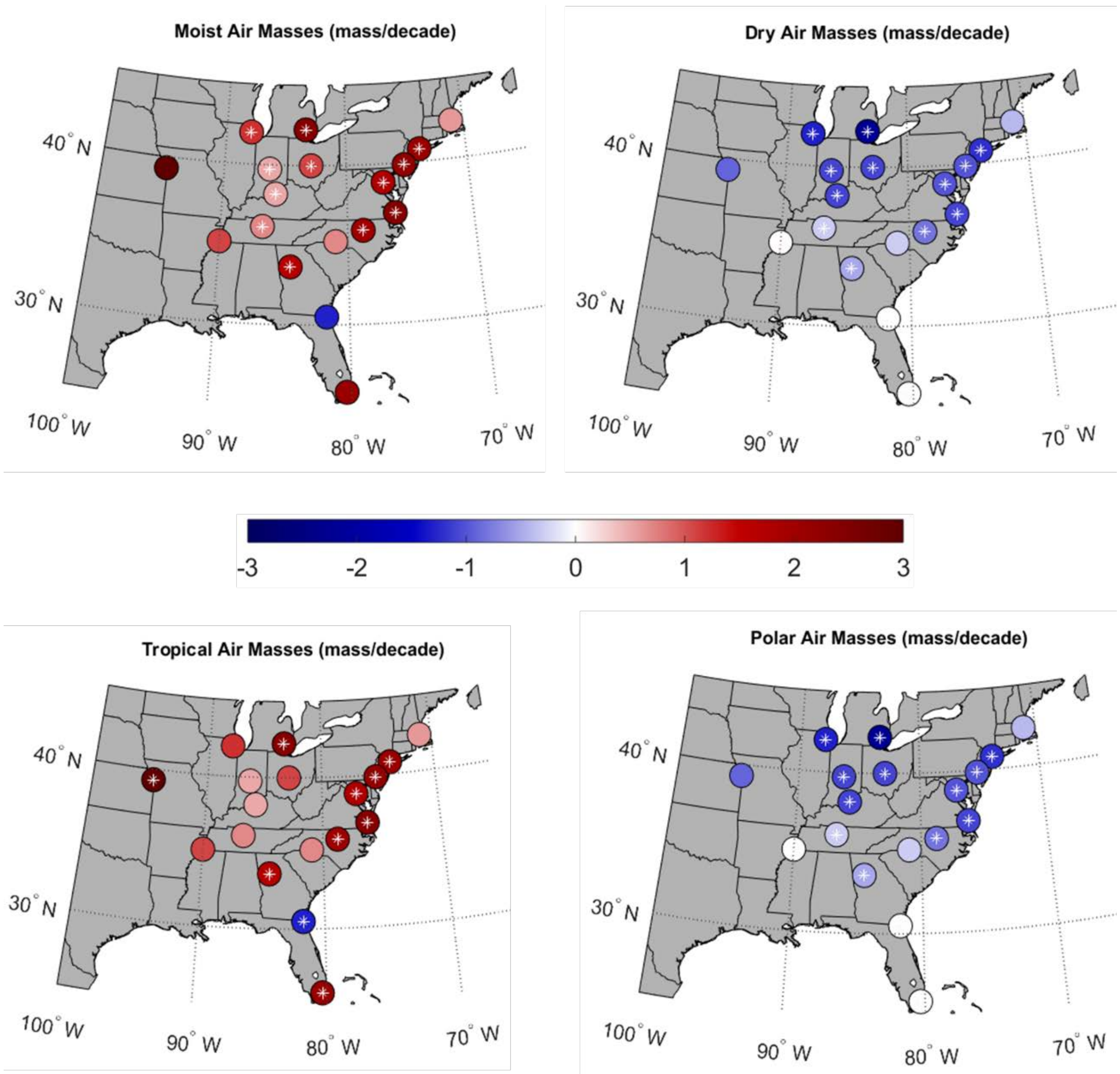

*Figure 6. Summer time(JJA) air mass frequency in mass per decade for period 1948-2014. Top left: moist air masses (polar, temperate and tropical). Top right: dry air masses (polar, moderate and tropical). Bottom left: tropical air masses (dry and moist). Bottom right: polar air masses (dry and moist). *= significant at the 0.05 level.*

Table 6. Trend analysis for air mass frequency show in mass per decade. Long time series years: 1948-2014. Categories are separated by temperature and moisture components. Dry and moist masses combined (polar, moderate and tropical) followed by P-value. Polar and Tropical (moist and dry) followed by their respective P-values.

City	Dry	P-Value	Moist	P-Value	Polar	P-Value	Tropical	P-Value
NYC	-0.08	0.122	0.09	0.083	-0.12	<0.001	0.21	0.001
Chicago	-0.07	0.107	0.08	0.082	-0.13	0.035	0.12	0.135
Philadelphia	0	0.968	0	0.872	-0.1	<0.001	0.22	0.000
Jacksonville	0	0.864	0	0.951	0	0.350	-0.13	0.008
Indianapolis	-0.09	0.072	0.1	0.053	-0.11	0.039	0.05	0.411
Columbus	-0.11	0.042	0.13	0.057	-0.11	0.005	0.11	0.082
Charlotte	-0.1	0.177	0.11	0.132	-0.03	0.125	0.07	0.227
Detroit	-0.26	0.001	0.24	0.001	-0.22	<0.001	0.24	0.005
Memphis	-0.13	0.035	0.1	0.115	0	0.128	0.11	0.189
Boston	-0.11	0.047	0.11	0.040	-0.04	0.157	0.06	0.182
Washington DC	-0.07	0.330	0.09	0.198	-0.1	<0.001	0.18	0.001
Nashville	-0.08	0.156	0.07	0.401	-0.03	0.042	0.07	0.290
Louisville	-0.16	0.006	0.13	0.032	-0.11	<0.001	0.05	0.329
Kansas City	-0.32	0.094	0.31	0.054	-0.09	0.317	0.33	0.050
Virginia Beach	-0.11	0.105	0.13	0.084	-0.11	<0.001	0.24	<0.001
Atlanta	-0.04	0.572	0.04	0.550	-0.05	0.006	0.17	<0.001
Raleigh	0.03	0.502	-0.02	0.578	-0.08	<0.001	0.2	0.001
Miami	-0.07	<0.001	0.06	0.003	0	0.878	0.21	<0.001

4.4 Diurnal Temperature Range (DTR)

Trends in diurnal temperature range show significant decreases in 16 of the 18 stations. The strongest trend was identified in Detroit with other Midwestern cities showing similar results. When the time series is broken up into two periods, the two trends show slightly different results. The early part of the series from 1948-1980 shows a normal looking distribution for almost all the cities. The late part of the series 1981-2014 shows a shift, with the probability of a smaller DTR occurring in the 25th percentile (figure6). The shift is virtually identical, this suggests that the entire distribution is shifting.

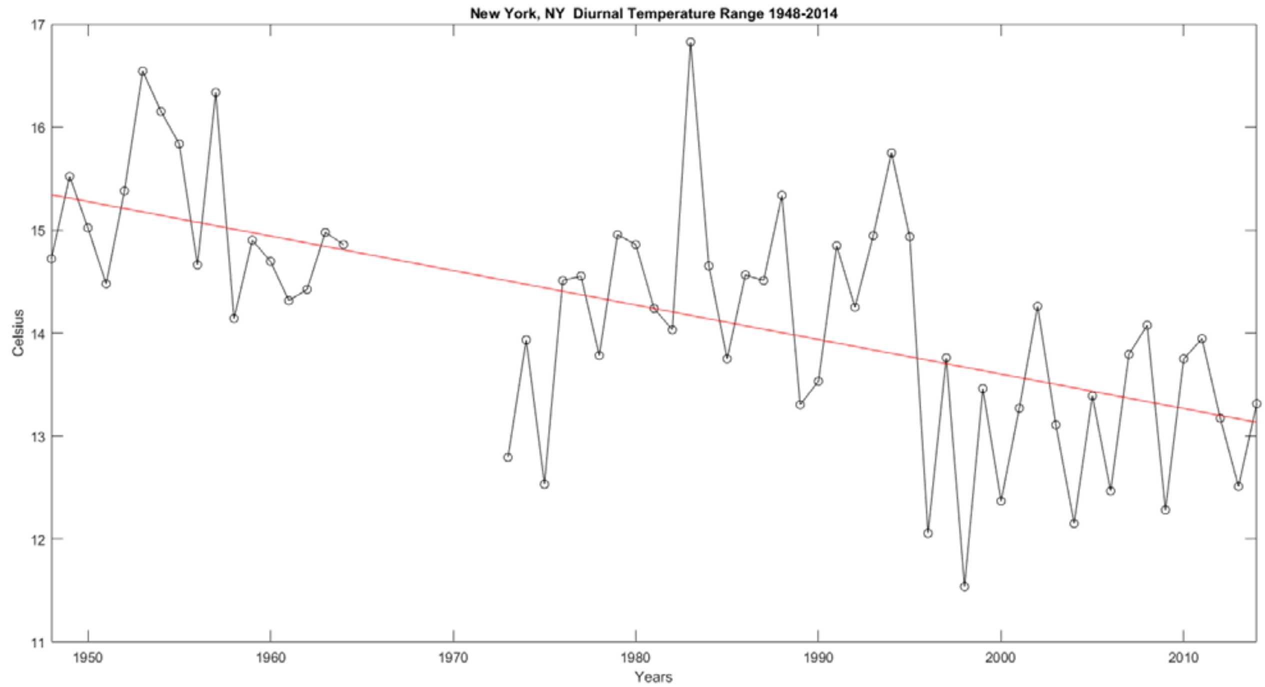

Figure 7. Diurnal temperature range for NYC 1948-2014 in degrees Celsius. Median of pairwise slopes was used to determine significance. The trend of-0.33°C per decade was significant at the 0.05 confidence level with an associated p-value of < 0.01.

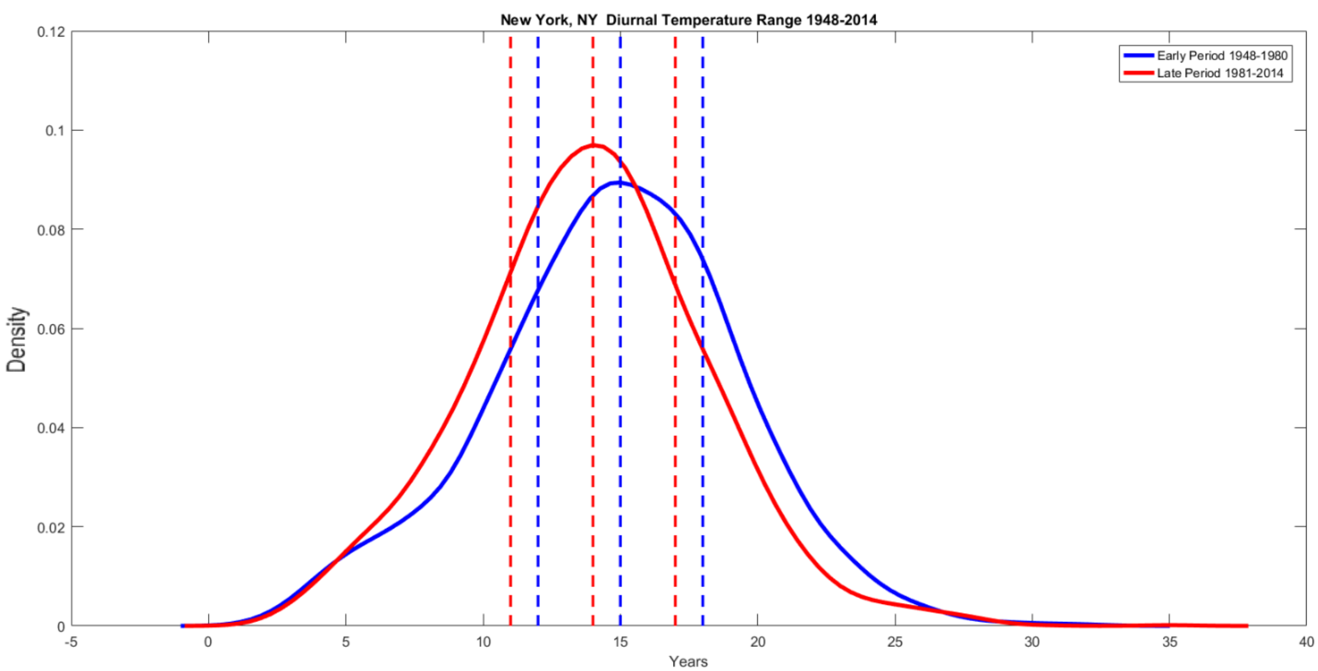

Figure 8. New York City trends in diurnal temperature range (top) and diurnal temperature range distributions for an early (1948-1980) period and a late period (1981-2014) (bottom). Vertical dotted lines represent 25^{th}, 50^{th} and 75^{th} percentile.

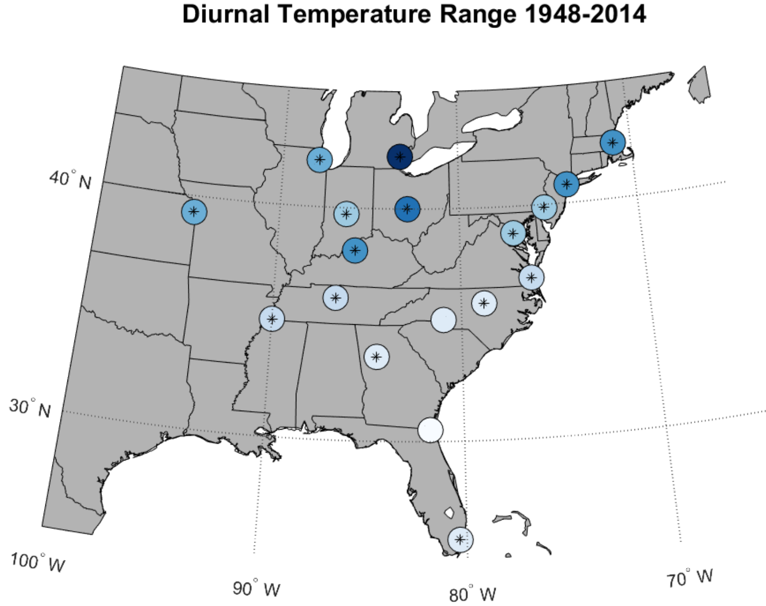

Figure 9. Diurnal Temperature Range trend analysis for 18 eastern US cities. Range is calculated by subtracting Maximum air temperature from minimum air temperature (DTR= Tmax-Tmin). Years: 1948-2014. *= significant at the 0.05 level

Table 7. Diurnal temperature range trend analysis for the 18 largest cities in the eastern US in degrees Celsius per decade. Years: 1948-2014. Trends were calculated using median of pairwise slopes, significant at the 0.05 level.

City	Trend/C°	P-Value
Atlanta	-0.14	0.02
Boston	-0.33	<0.001
Charlotte	-0.12	0.095
Chicago	-0.3	<0.001
Columbus	-0.38	<0.001
Detroit	-0.48	<0.001
Indianapolis	-0.25	<0.001
Jacksonville	-0.1	0.254
Kansas City	-0.29	0.029
Louisville	-0.34	<0.001
Memphis	-0.2	<0.001
Miami	-0.11	0.028
Nashville	-0.18	0.004
New York	-0.33	<0.001
Philadelphia	-0.23	<0.001
Raleigh	-0.14	0.0363
Virginia Beach	-0.2	<0.001
Washington, DC	-0.22	<0.001

4.5 Heat Waves

We calculated heat wave frequency and intensity for 17 cities using $T_{E\ min}$, T_{min}, $T_{E\ max}$ and T_{max}. Frequency is measured by increases or decreases in heat wave frequency by days per decade. Intensity is defined by increases or decreases in temperature in degrees C° per decade. Jacksonville was removed from this analysis due to inconsistencies with its record as previously mentioned in the air mass results section, there are 17 stations used for this analysis. Another change for this analysis is Detroit, here it is included in the short series and not the long series as previously done. This was done to improve the results with a full record for Detroit between 1958 and 2014.

To identify intensity, we calculated the 90th percentile for JJA for each variable, then the daily maximum value is subtracted, this defines a heat wave day. We then computed trends in annual frequency and actual daily values on heat wave days in order calculate frequency.

The results for $T_{E\ min}$ and T_{min} show some of the most extreme results in both time series and are discussed below. In this section, we focus on maps for the shorter series presented below, while the maps for the long series are available in appendix S. The results for $T_{E\ max}$ and T_{max} did not yield any trends, however, the results are presented in the appendix ($T_{E\ max}$ appendix U and T_{max} appendix V, respectively). Results for $T_{E\ min}$ and T_{min} exhibit some similarities with the results we've seen thus far for these variables with increases present in many of the stations.

$T_{E\ min}$ Heat Wave Frequency

When analyzing the linear trends in T_E min frequency in the long record, we see that every station except one (Nashville) shows a significant increase in days per decade with alpha at 0.05 (see appendix S). The shorter time series shows increases in frequency for all stations but one (Memphis), this time only 10 out of 17 stations show significant increases (see figure 10). In this map, most of the significant increases are in the southernmost and eastern stations from Atlanta to Washington DC.

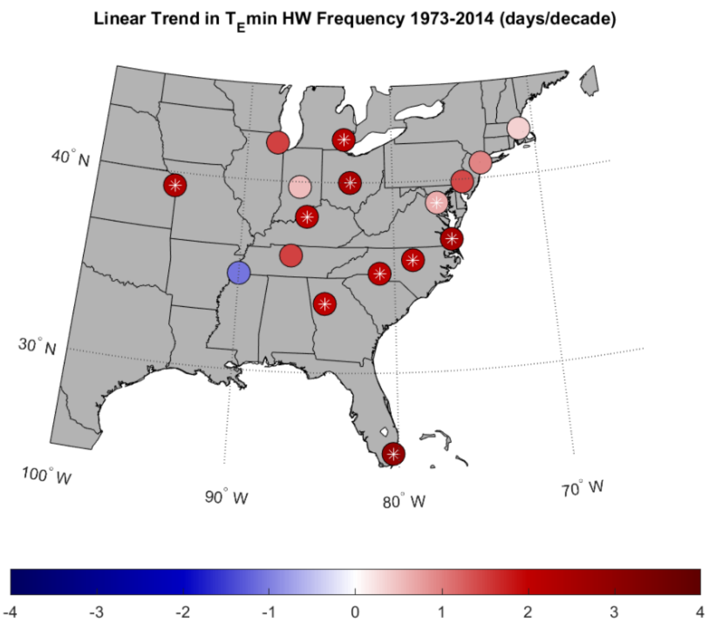

Figure 10. Linear trend in $T_{E\ min}$ heat wave frequency 1973-2014 in days per decade. *= significant at the 0.05 level

$T_{E\ min}$ Heat Wave Intensity

In the long record $T_{E\ min}$ heat wave intensity has significant increases in 8 out of 14 stations particularly from Charlotte up to New England with a few exceptions in the Midwest: Louisville and Columbus (see appendix S). Indianapolis has a neutral signal; however, all other stations show positive increases. The shorter record shows that heat wave intensity has increased in all stations but Memphis which appears to be cooling, however this time only 4 are significant. Eastern stations such as Raleigh, Virginia Beach along with Washington DC show some of the most extreme increases along with Kansas City (see figure 11).

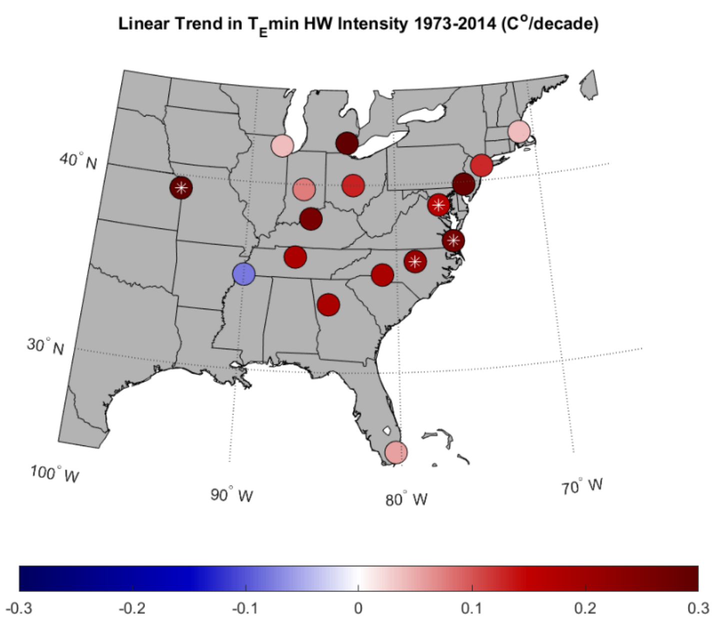

Figure 11. Linear trend in $T_{E\ min}$ heat wave intensity 1973-2014 in degrees C° per decade. *= significant at the 0.05 level

T_{min} Heat Wave Frequency

In the long series T min shows significant increases at every station in the study area (see appendix T). In the shorter series the results are different, while every station shows positive trends 13 out of 17 are significant. The only exceptions are Boston, Columbus, Memphis and Charlotte. Many of the stations have increases in heat wave frequency for 3-4 days per decade.

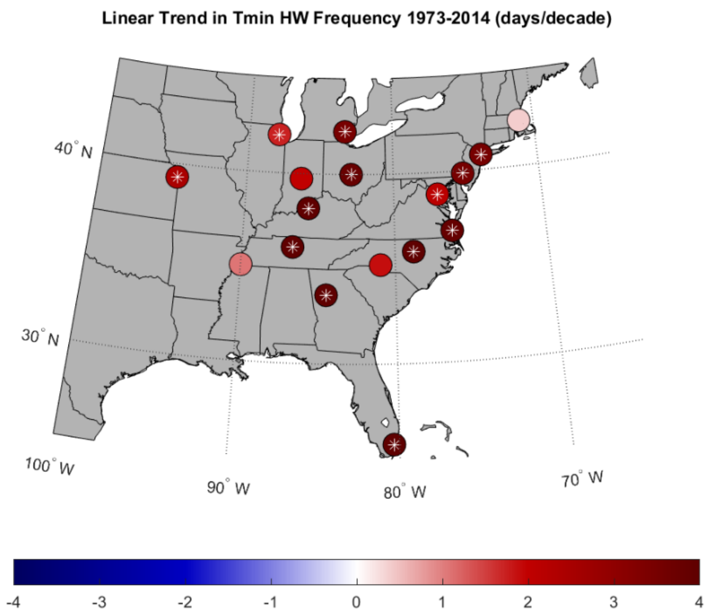

Figure 12. Linear trend in T_{min} heat wave frequency 1973-2014 in days per decade. *= significant at the 0.05 level

T_{min} Heat Wave Intensity

In the long series T min intensity during heatwaves shows significant increases in 10 out of 14 stations. In the east coast, results are significant from Atlanta to Philadelphia, with some of the most extreme changes happening in Virginia Beach and Philadelphia.

In the short series, all the stations show positive increases with only the Memphis station showing neutral results (see figure 13). The amount of intensity is only significant in 6 of the 17 stations with Philadelphia, Virginia Beach and Raleigh showing some of the strongest trends along the coast. Louisville and Nashville show some of the strongest trends inland.

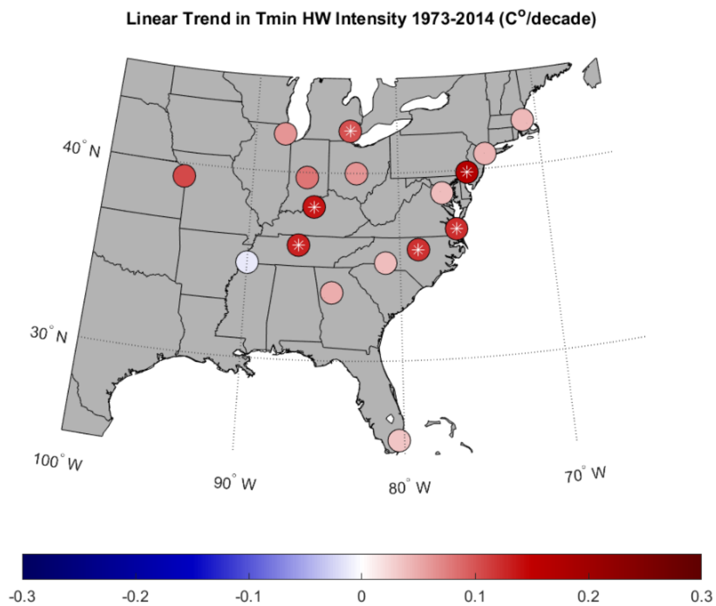

Figure 13. Linear trend in T_{min} heat wave intensity 1973-2014 in days per decade. *= significant at the 0.05 level

CHAPTER 5

DISCUSSION AND CONCLUSION

5.1 Discussion

This study focused on the 18 largest cities in the eastern US, which are collectively home to over 21 million people. All of these cities reside in humid subtropical or humid continental climates, meaning that atmospheric humidity is typically higher than semi-arid or arid environments. High temperatures in the summer coupled with high humidity can lead to heat stress, heat exhaustion and exacerbate many existing diseases. In the United States heat alone is responsible for more deaths on average than all other fatal weather events combined (National Weather Service, 2014). Future predictions of heat waves indicate that they are expected to increase in frequency, intensity and be longer lasting in the 21st century (Meehl and Tebaldi, 2004). Large cities have the added complexity of the UHI effect which amplifies the dangers of heat waves to vulnerable populations. Willett and Sherwood (2010) found that frequency of both single extreme event and extended periods of heat has increased in all regions since 1973. The results presented in this thesis contribute to a large body of existing literature which demonstrate that water vapor in the atmosphere has been increasing over recent decades (Kalkstein et al., 1998; Willett et al., 2007; Fall et al., 2010). A combination of high humidity and high temperatures create potentially dangerous conditions for people living in urban regions. Certain demographics are more vulnerable than others, government agencies and cities should take future precautions and provide education to the public regarding the potential dangers of heat waves especially when the event is combined with high levels of humidity.

5.2 Research questions

Q1) How do temperature and equivalent temperature trends differ in urban areas?

Our results show that air temperature and equivalent temperature behave similarly. Every city had a significant increase in T_{min} and all but two stations also had significant increases in $T_{E\ min.}$ Both variables look similar when plotted (see appendix) with T_E having larger values and being warmer than T_{min}. This result is consistent with previous findings since T_E also accounts for sensible heating it's magnitude is larger than temperature alone.

Regionally, increases of moisture in the Midwest have also been found by previous studies. Isaac and Van Winjngaarden (2011) which focused on surface water vapor pressure and temperature and found the largest temperature increases occur in the Midwest. In addition, the largest increasing water vapor pressure trends are found to be occurring in the summer, mainly in the eastern half of the US. Since the relationship of T and T_E are extremely similar and implicate increases in surface moisture, our findings also align with past research on humidity which observed that specific humidity has been increasing in response to rising temperatures (Willett et al., 2007a). Future projections indicate that heat events may worsen as much or more in humid tropical and mid latitude regions even if they warm less than the global average due to greater increases in absolute humidity (Willett and Sherwood, 2010). Surface specific humidity has increased significantly in many parts of the world including the tropics and Northern hemisphere especially during the summer months (Willett et al., 2007b). Studies which have focused on dew point temperatures along with relative humidity (RH) have also found similar results. Brown and DeGaetano (2012) observed that moistening was pronounced during Midwest summers while RH shows little change for 1947-2010. The analysis of DTR in this study provides evidence to the one of the effects of increasing minimum temperatures in urban regions. The diurnal temperature range is significantly decreasing in many large US cities (Easterling et al., 1997). All our stations except for two (Raleigh and Jacksonville) showed significant decreases in DTR. The largest trend was found in Detroit, MI with a decrease of -0.48°C per decade. A study by Lauritsen and Rogers (2012) found that increasing trends in cloud cover have a significant effect on DTR trends in different regions of the US since 1950, particularity in the south-central US which also experienced a decrease in T_{max}. The narrowing of DTR is representative of the increases in T_{min} and decreases in T_{max}. In addition, as previously stated, the decrease in DTR has a stronger signal in urban regions when compared to rural (Easterling et al., 1997, Vanos et al., 2014).

Q2) How do air mass frequency trends vary in urban regions as they relate to temperature and moisture?

Our results show that moist tropical air masses are increasing in frequency while dry polar air masses are decreasing, these findings are consistent with previous studies (Kalkstein et al., 1998, Vanos et al., 2015). It is important to consider the contribution of moisture brought into a region by these large synoptic scale features during the summer months. Kalkstein (1998) also found that moist moderate (MM) masses are common to the eastern half of the US, in summers it has an increase in frequency along with moist tropical (MT) masses. This increase in warm and moist air is believed to be responsible for major contributions to increases in overnight cloudiness, upward trends in T_{min}, and increasing dew point temperatures (Kalkstein et al., 1998, Vanos et al., 2014). The increase of moist tropical air mass frequency suggests potential challenges for populations in urban regions during summertime. Our findings indicate that significant increases of tropical air masses along the eastern seaboard could have an effect on these densely-populated areas from Raleigh, NC to New York City, NY. The significant decreases of dry and polar masses are also noteworthy since the decrease of these air masses means that urban populations will receive less relief during heat events if the trends continue. These decreases are strongest in the Midwest as well as the eastern seaboard and are consistent with previous studies (Vanos et al., 2014). Changes in air mass frequencies can also alter moisture variables such as soil moisture, precipitation and cloud cover.

Q3) Are the intensities and frequencies of heat waves changing along with observed temperature and equivalent temperature trends?

The intensities and frequencies of heat waves are increasing predominantly in the minimums, similarly to how Brown and DeGaetano (2012) saw increases in night time dew point temperatures. A significant increase of heat wave frequency was observed in the long record for every station in the study area for $T_{E\ min}$ except Nashville. In the short record, only 10 out of 17 stations showed significant increases in frequency these stations were located predominantly in the Southeast with a few in the Midwest, this result is also interesting because of the increases of warm humid air masses and their frequencies in these areas (Kalkstein, 1998). Changes in heat wave intensities for $T_{E\ min}$ in the long record were significant in 8 out of the 15 stations, many of these on the coast from Charlotte to New England. Increases in $T_{E\ min}$ heat wave intensities showed an increase in all stations except Memphis, however, only 4 out of 17 were significant. These findings support what previous research has found regrading increases in temperature and T_E heat wave days predominantly in the Central and Northeast regions of the US (Schoof et al. 2017).

5.3 Conclusion

The investigations carried out in this thesis demonstrate several aspects of climate change as it relates to average temperatures in large eastern US cities. The urban heat island effect combined with naturally occurring humidity in many cities increases dangerous conditions during extreme heat events. Our findings contribute to the body of evidence which shows that as humidity increases it also contributes to increasing nighttime minimum temperatures (Willett et al., 2007a). As heat events continue to occur, greater understanding of their effects particularly on vulnerable populations is necessary. The analysis conducted with air masses provides an example of synoptic factors which can contribute to heat waves during the summer time. The increase of minimum temperatures and equivalent temperatures was strikingly similar and could be affected by many factors present in cities. Influences from synoptic factors can only offer us a part of the story of what happens during extreme heat events. Heat sinks and high albedo rooftops may provide some relief; however, the effects would not be enough to offset the increasing temperatures. One result of increasing T_{min} is a narrowing of DTR which is has been occurring in many places since the latter half of the 20th century (Vose et al., 2005). This is also an indication that heat is being trapped in the lower atmosphere predominantly at night when relief from the heat is expected.

5.4 Study Limitations

The lack of complete data records was a challenge in this study. For many cities that were originally considered, climate records were incomplete or missing. In some cases, temperature and dew point temperature were available, but not station pressure. The multiple station moves and instrument changes also create the possibility of inhomogeneity in the data. Modern instrumentation is more reliable; however, those records do not go back far enough in many cases to carry out a robust study.

5.5 Future Work

This study could be improved by finding ways to combine datasets where data is missing. The use of reanalysis data for the computation of TE similar to the approach that Fall (2010) used may help bridge some of the gaps in missing records for cities like Milwaukee and Baltimore. These cities have large populations and incomplete records. Additionally, remotely sensed data can also help further this research. Infrared images at night time can provide qualitative analysis of “hot spots” in urban regions. Thermal imagery could offer a broader perspective on the UHI because the observations are not limited to a weather station at the local airport. Mapping these hot spots and over laying them with race and income data could lead to the creation of a “heat vulnerability index” which could be used to help identify the people that are at highest risk for heat related illness, morbidity and mortality.

The investigation of other synoptic influences could also help to further understand extreme heat events. Future work could also include a thorough analysis of the El Nino Southern Oscillation and high humidity heat events to look for possible correlations.

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APPENDIX

APPENDIX A

New York

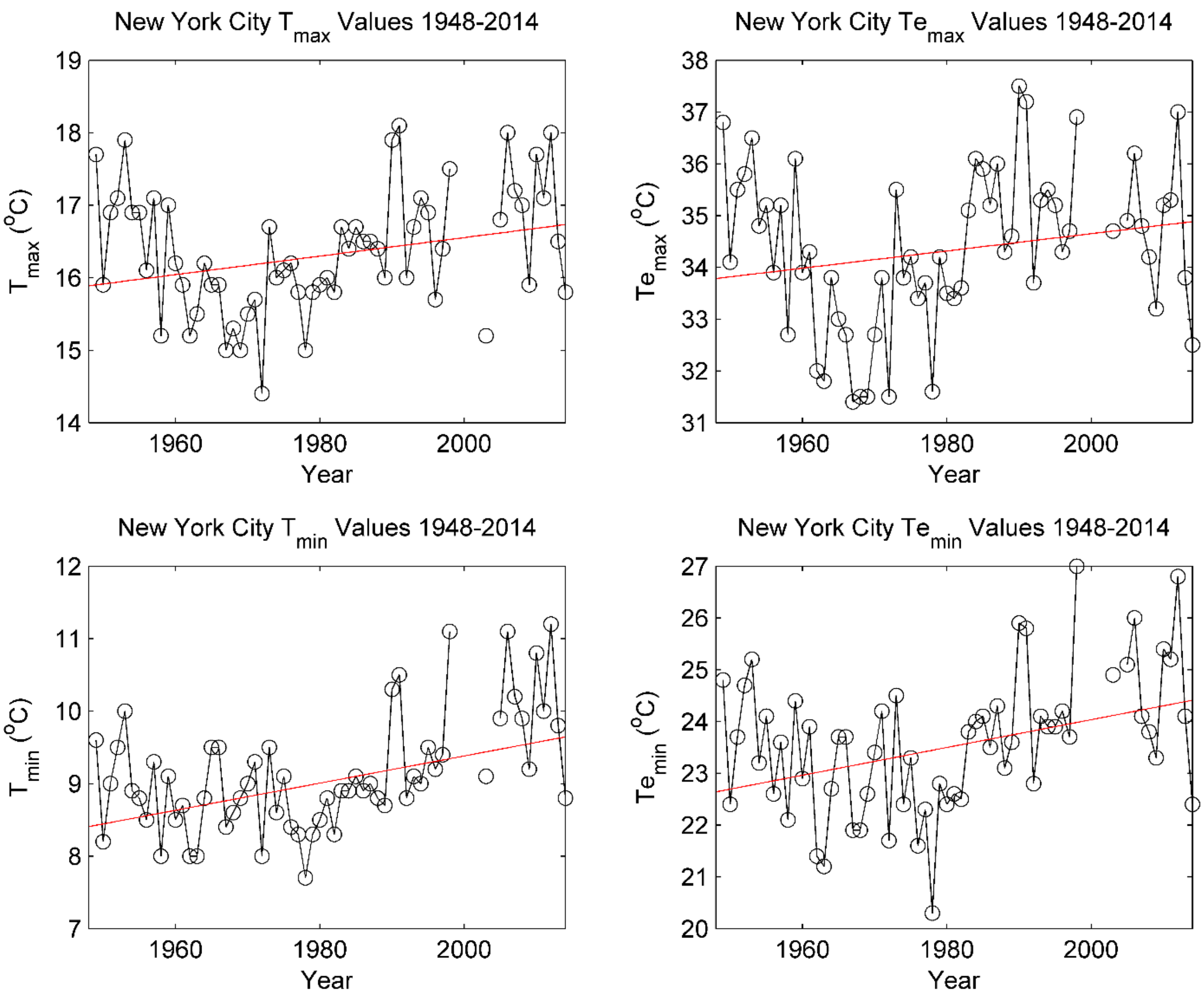
The weather station and New York's La Guardia Airport was moved one time and experienced 6 instrument changes for the time period of the study, some of these changes are confirmed and some are estimated. In 1961 the station was moved 0.6 miles west, t-test results showed a significant change for T_{max} and $T_{d\ max}$. For the estimated instrument change of 1964 $T_{d\ max}$ and T_{min} showed significant changes, however no other significant changes occurred in the rest of the series until the installation of the Vaisala DTS1 station in August 2004. After the instrument changes of 2004 T_{max} and $T_{d\ min}$ showed a significant change. By contrast Philadelphia also showed a significant change in T_{max} after the installation of DTS1 in 2003, however Boston did not. Analyzing the summer trends, we see positive correlations in all variables, and significant results for $T_{E\ max}$, T_{min} and $T_{E\ min}$. Significant increases were also noted for T_{min} and $T_{E\ min}$ in the annual trend results. New York City had a population of 8,175,133 in 2010 (US Census), land area per square mile of 303 and the population density of 27,012.

New York City_LaGuardia	Station Metadata		Latitude: 40.77944
	WBAN# 14732		**Longitude: 73.88028**
Year	**Site (m)**	**Instruments**	**Comments**
1948-1991	15.8 (1948-1961)	unknown	unknown, obs times 2400. 1991 instrument changed from unknown to Hygrothermometer
1991-Present	3(1961-1982)	Hygrothermo meter	Daily, obs times 2400, Receiver NCEI, Reporting Method: FOSJ-SFC
	3.4 (1982-Present)		
Station Moves			
Latitude	**Longitude**	**Initial**	**Final Date**
40.76667		10/1/1939	5/1/1996
	73.86667	10/1/1939	1/1/1961
40.77889		5/1/1996	11/12/2000
	73.88083	5/1/1996	11/12/2000
40.77917		11/12/2000	7/7/2007
	73.88	11/12/2000	7/7/2007
40.77944		7/7/2007	Present
	73.88028	7/7/2007	Present
T-test 1961	**Station move 06/30/1961 moved 0.6 miles west**		
T-test 1964	**estimated instrument change**		
T-test 1985	**estimated instrument change**		
T-test 1991	**instrument change from unknown to Hygrothermometer**		
T-test 1995	**estimated instrument change**		
T-Test 2004	**08/19/2004 DTS1 Installation**		

New York City	Median Pairwise Slopes 95% confidence	Degrees Celsius per decade	
Seasonal Trends			
Winter-Dec,Jan,Feb	**Significance**	**Trend**	**P-value**
T_max	not significant at 0.05	0.11C°	0.46288
Te_max	not significant at 0.05	0.04C°	0.79629
T_min	not significant at 0.05	0.14C°	0.119
Te_min	not significant at 0.05	0.15C°	0.27582
Spring-Mar,Apr,May			
T_max	not significant at 0.05	0.11C°	0.15731
Te_max	not significant at 0.05	0.18C°	0.30711
T_min	is significant at 0.05	0.16C°	0.00969
Te_min	is significant at 0.05	0.23C°	0.04921
Summer-June, July,August			
T_max	not significant at 0.05	0.07C°	0.23262
Te_max	is significant at 0.05	0.28C°	0.04352
T_min	is significant at 0.05	0.26C°	0.00001
Te_min	is significant at 0.05	0.50C°	0.00186
Fall-Sept, Oct, Nov			
T_max	not significant at 0.05	(-0.00C°)	0.74325
Te_max	not significant at 0.05	0.04C°	0.69042
T_min	is significant at 0.05	0.18C°	0.00546
Te_min	is significant at 0.05	0.24C°	0.03653

New York City	95% confidence	Degrees Celsius per decade	
Annual Trend			
	Significance	**Trend**	**P-value**
T_max	not significant at 0.05	0.13C°	0.10409
Te_max	not significant at 0.05	0.17C°	0.17646
T_min	is significant at 0.05	0.19C°	0.00041
Te_min	is significant at 0.05	0.27C°	0.00544

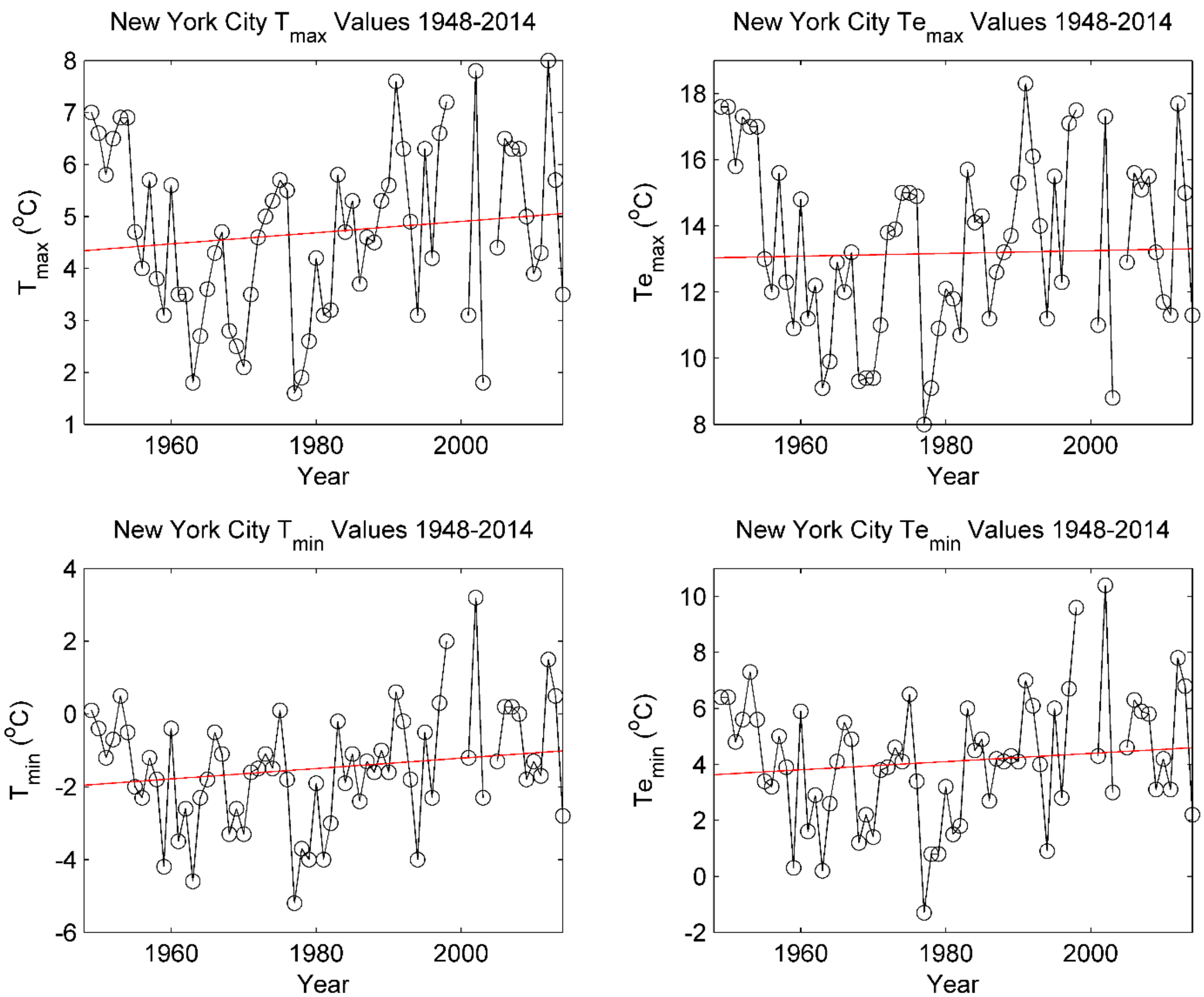
ANNUAL TREND



New York City	**95% confidence**	**Degrees Celsius per decade**	
Annual Trend			
	Significance	**Trend**	**P-value**
T_max	not significant at 0.05	0.13C°	0.10409
Te_max	not significant at 0.05	0.17C°	0.17646
T_min	is significant at 0.05	0.19C°	0.00041
Te_min	is significant at 0.05	0.27C°	0.00544

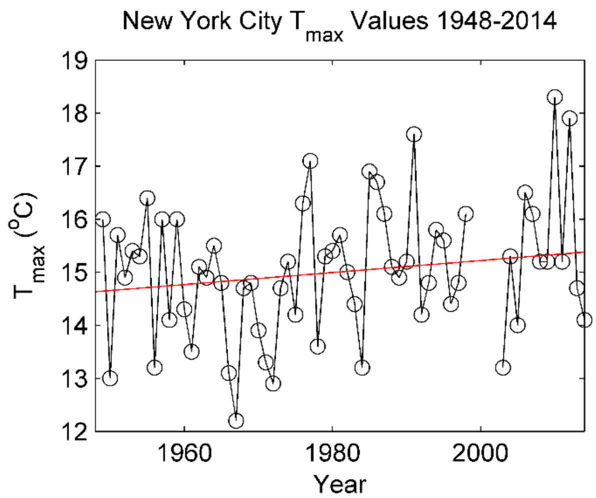
SEASONAL TRENDS

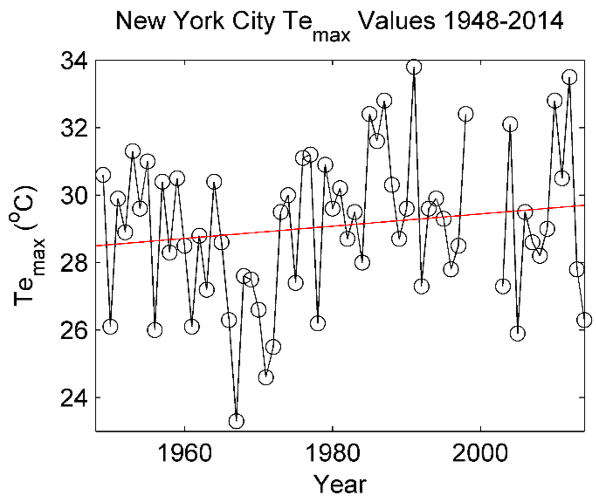
WINTER

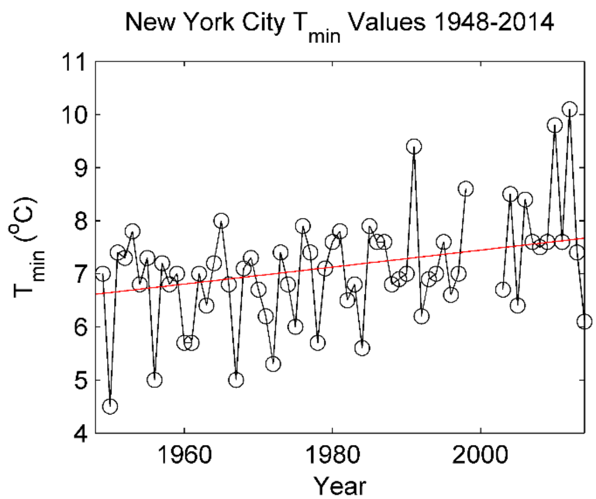


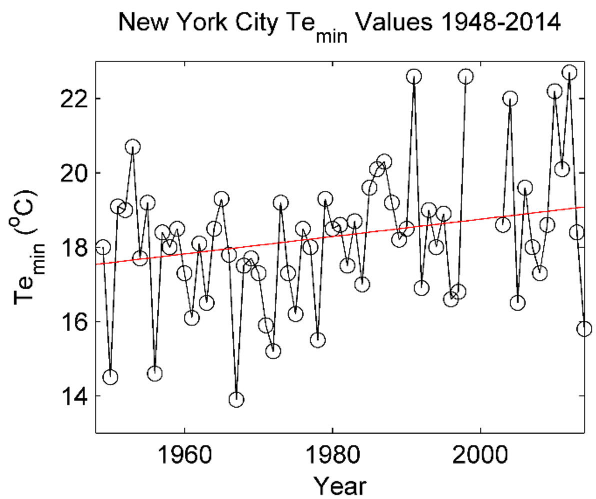
Winter-Dec,Jan,Feb	Significance	Trend	P-value
T_max	not significant at 0.05	0.11C°	0.46288
Te_max	not significant at 0.05	0.04C°	0.79629
T_min	not significant at 0.05	0.14C°	0.119
Te_min	not significant at 0.05	0.15C°	0.27582

SPRING



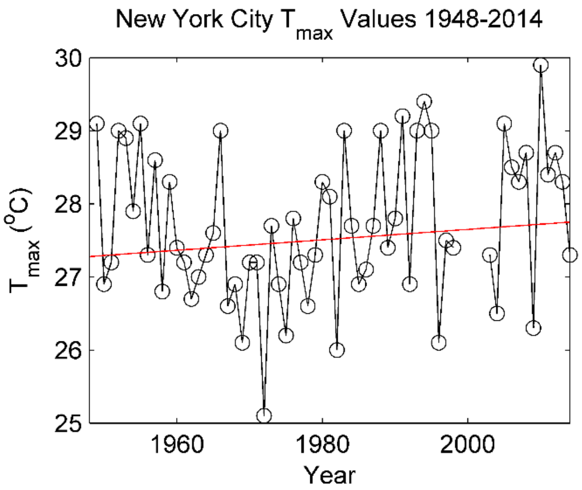


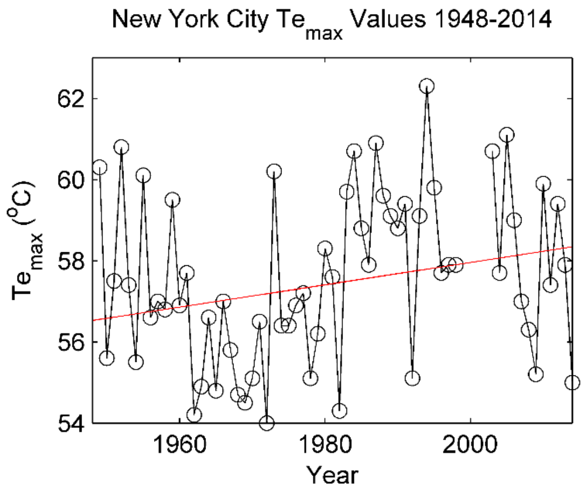


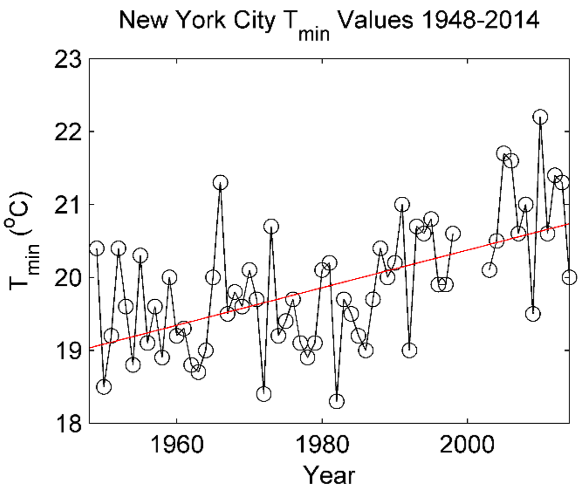


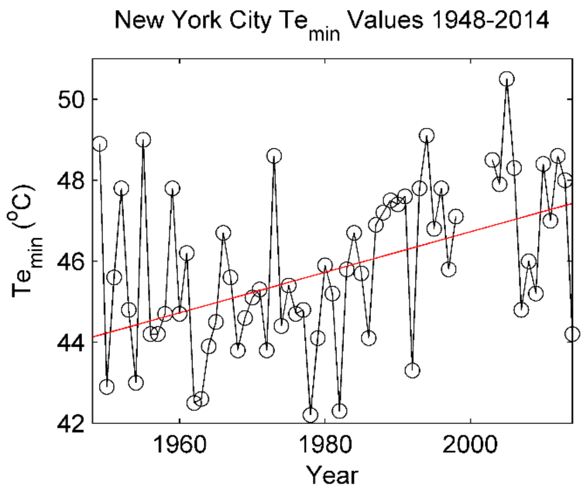
Spring-Mar,Apr,May			
T_max	not significant at 0.05	0.11C°	0.15731
Te_max	not significant at 0.05	0.18C°	0.30711
T_min	is significant at 0.05	0.16C°	0.00969
Te_min	is significant at 0.05	0.23C°	0.04921

SUMMER



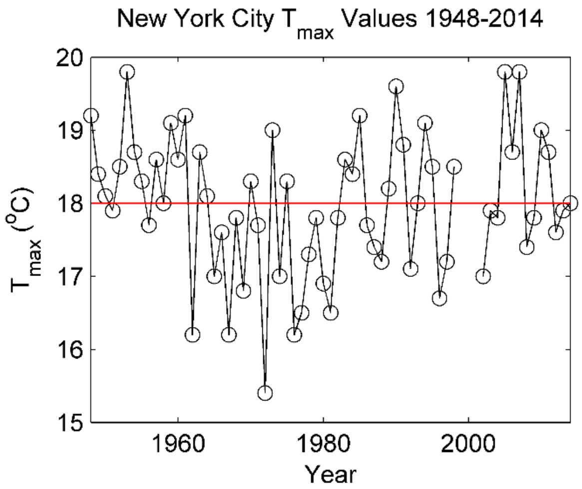


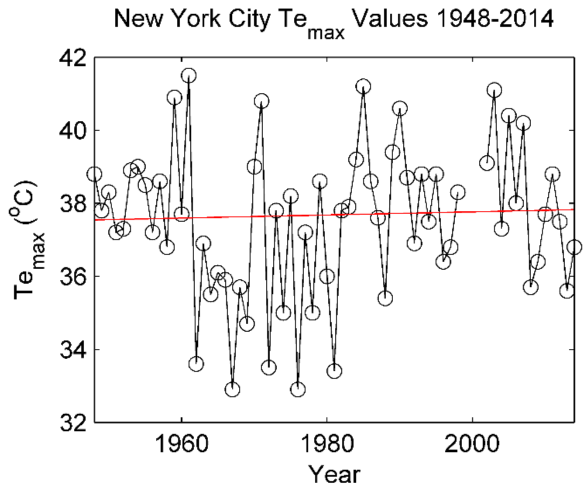


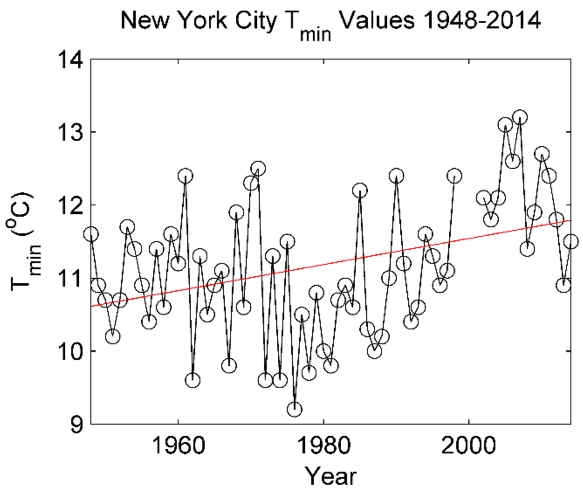


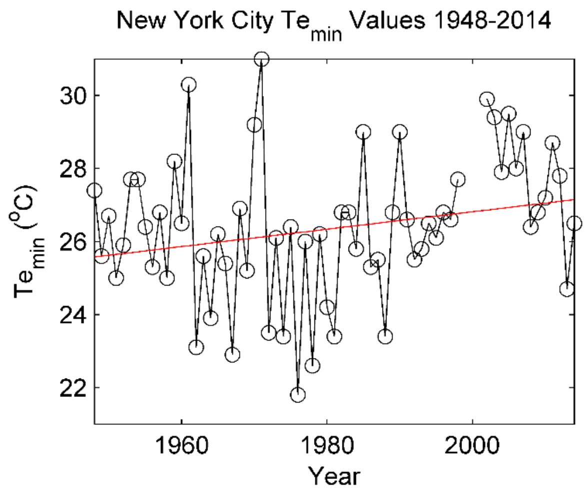
Summer-June, July,August			
T_max	not significant at 0.05	0.07C°	0.23262
Te_max	is significant at 0.05	0.28C°	0.04352
T_min	is significant at 0.05	0.26C°	0.00001
Te_min	is significant at 0.05	0.50C°	0.00186

FALL



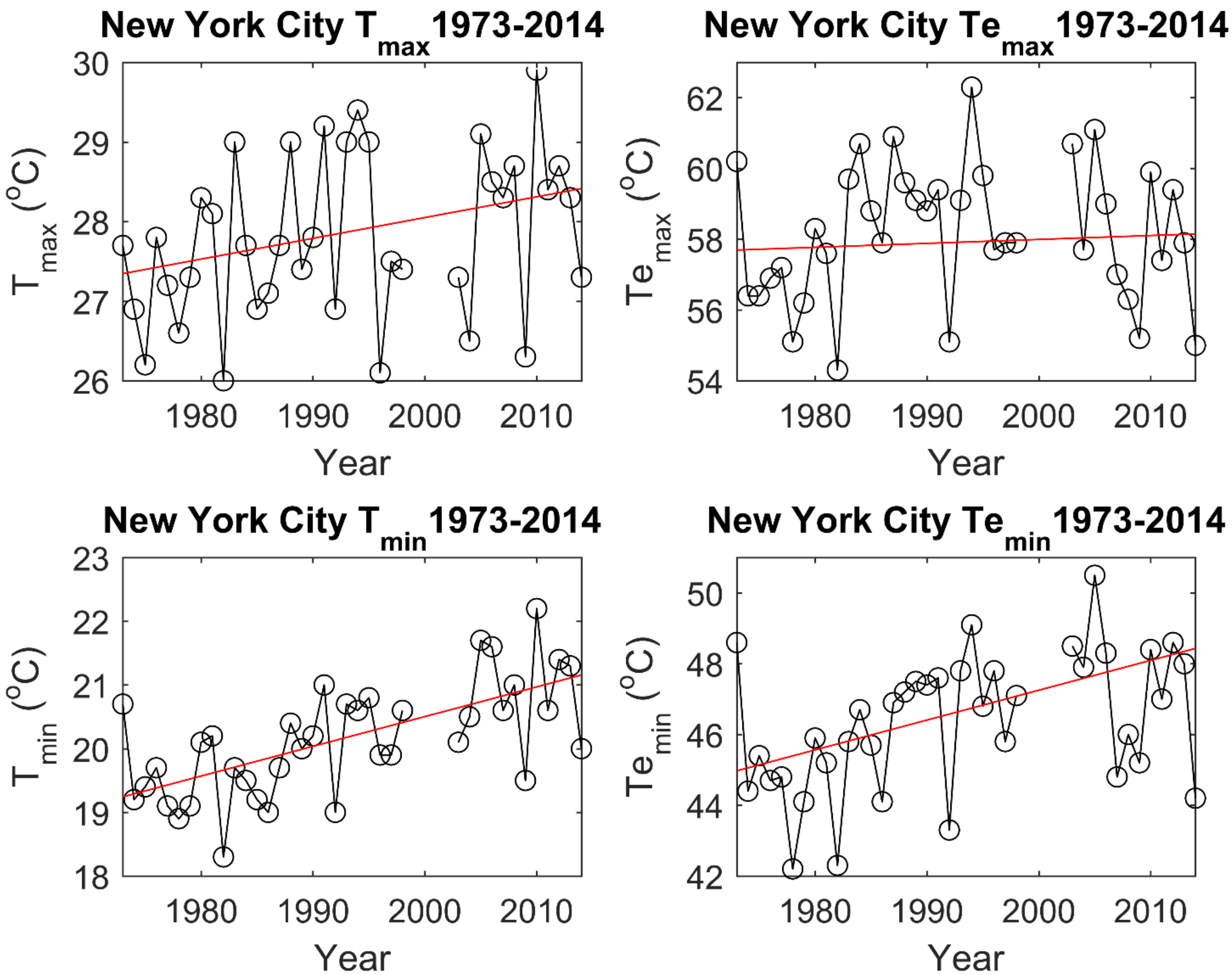






Fall-Sept, Oct, Nov			
T_max	not significant at 0.05	(-0.00C°)	0.74325
Te_max	not significant at 0.05	0.04C°	0.69042
T_min	is significant at 0.05	0.18C°	0.00546
Te_min	is significant at 0.05	0.24C°	0.03653

SUMMER 1973-2014



A.9 Summer trends 1973-2014

Summer-June, July,August	**Significance**	**Trend**	**P-value**
T_max	not significant at 0.05	0.26	0.05295
Te_max	not significant at 0.05	0.11	0.5959
T_min	is significant at 0.05	0.47	0.00005
Te_min	is significant at 0.05	0.84	0.00656

A.10 Two Tailed T-Tests: Station moves, instrument changes, DTS1 installation

New York/LaGuardia	Dew Point			1961	Station move 06/30/1961 (0.6 miles west)	
T-Test	1957-1960	1962-1965				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.0326	0.0591	1.3409	2.1686	94	1.5813
Tdmax	0.0013	0.4221	1.6904	3.3073	94	1.56460
Tmin	0.5389	-0.4069	0.7736	0.6167	94	1.4564
Tdmin	0.508	-0.4928	0.9886	0.6646	94	1.8276

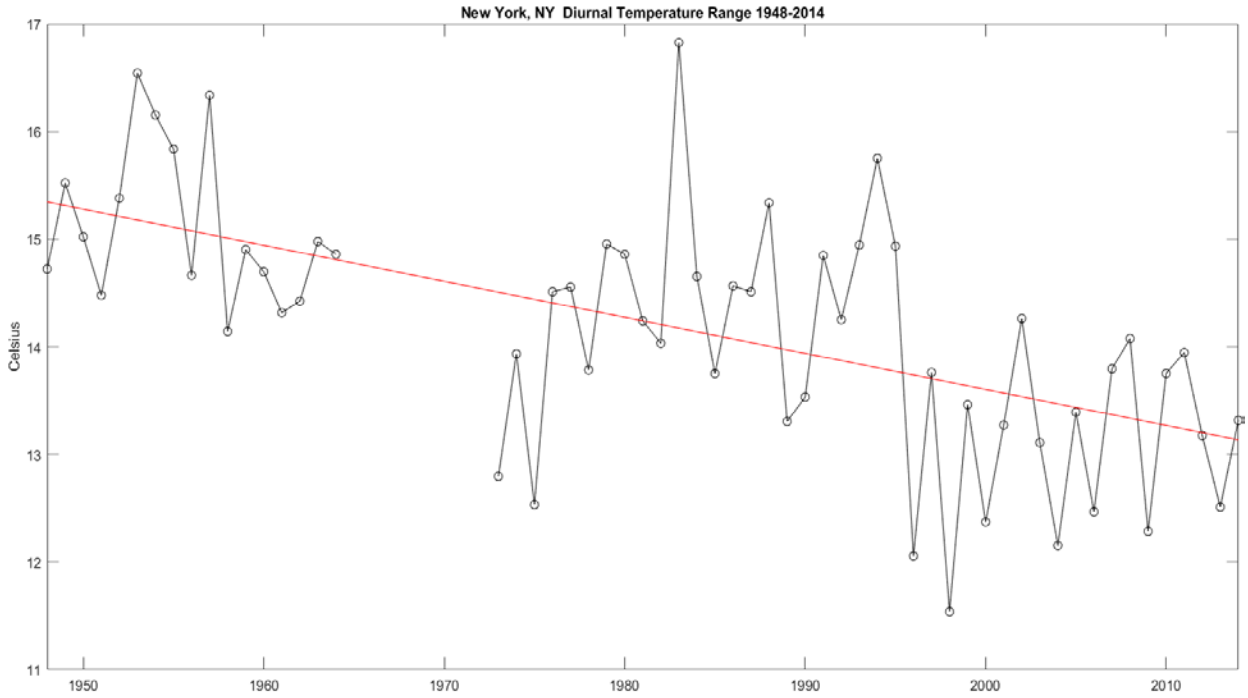
New York/LaGuardia	Dew Point			1964	Estimated instrument change	
T-Test	1960-1963	1965-1968				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.5277	-0.4576	0.8867	0.6339	94	1.6584
Tdmax	0.008	0.2533	1.6425	2.7096	94	1.71380
Tmin	0.024	-1.2908	-0.0925	-2.2921	94	1.4783
Tdmin	0.5146	-1.0171	0.513	-0.6542	94	1.8876

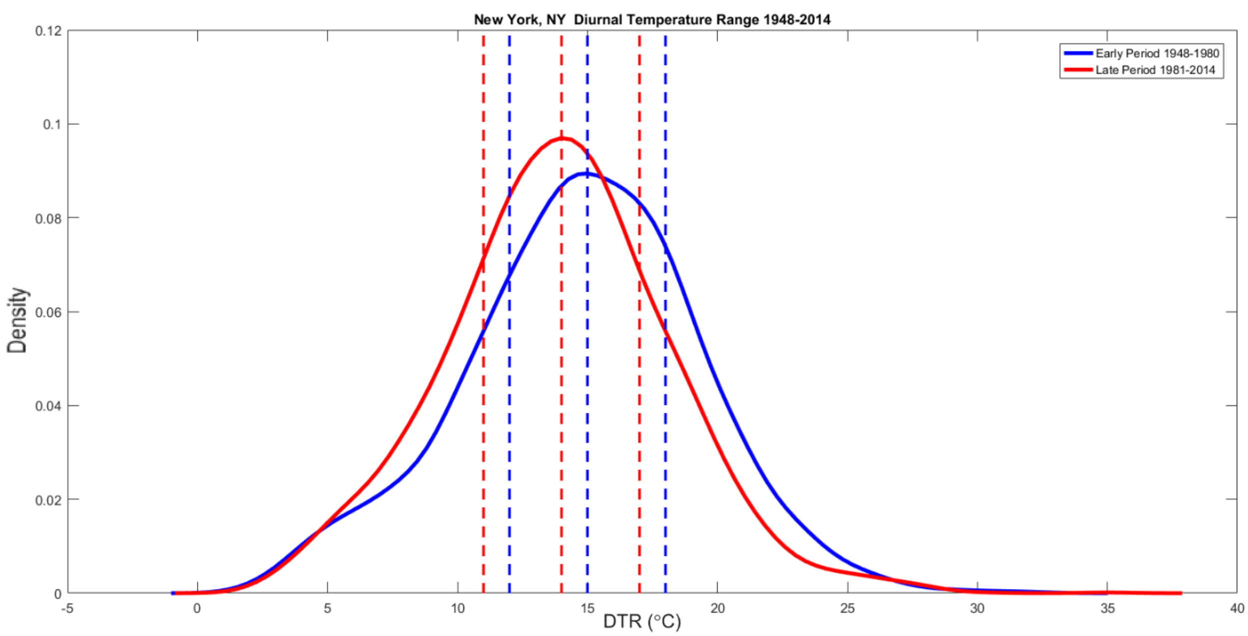
New York/LaGuardia	Dew Point			1985	Estimated instrument change	
T-Test	1981-1984	1986-1989				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.7649	-0.762	0.562	-0.2999	94	1.6335
Tdmax	0.5889	-0.9323	0.5323	-0.5423	94	1.8068
Tmin	0.7273	-0.7234	0.5067	-0.3497	94	1.5175
Tdmin	0.576	-0.6186	1.1061	0.5612	94	2.1277

New York/LaGuardia	Dew Point			1991	Instrument change from unknown to Hygrothermometer	
T-Test	1987-1990	1992-1995				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.9952	-0.6866	0.6825	-0.006	94	1.689
Tdmax	0.4635	-0.4456	0.9706	0.7361	94	1.74710
Tmin	0.6934	-0.5109	0.7651	0.3955	94	1.5741
Tdmin	0.2942	-0.3989	1.303	1.0549	94	2.0996

New York/LaGuardia	Dew Point			1995	Estimated instrument change	
T-Test	1991-1994	1996-1999				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.1748	-0.2114	1.1446	1.3684	85	1.5818
Tdmax	0.7187	-0.7253	0.5022	-0.3614	85	1.43180
Tmin	0.0679	-1.23	0.0446	-1.8493	85	1.4868
Tdmin	0.1333	-1.4544	0.1961	-1.5159	85	1.9253

New York/La Guardia	Dew Point			2004	DTS1 Installation 08/19/2004	
T-Test	1999-2003	2005-2008				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	7.87E-04	-2.1385	-0.5836	-3.4796	87	1.8394
Tdmax	0.6539	-0.5989	0.9493	0.4499	87	1.8314
Tmin	0.9711	-0.6891	-0.6643	-0.0364	87	1.601
Tdmin	1.52E-05	1.0145	2.5677	4.5841	87	1.8373


New York, NY Diurnal Temperature Range 1948-2014
Celsius
17
16
15
14
13
12
11
1950
1960
1970
1980
1990
2000
2010


New York, NY Diurnal Temperature Range 1948-2014
Early Period 1948-1980
Late Period 1981-2014
Density
0.12
0.1
0.08
0.06
0.04
0.02
0
-5
0
5
10
15
20
25
30
35
40
DTR (°C)

APPENDIX B

Chicago

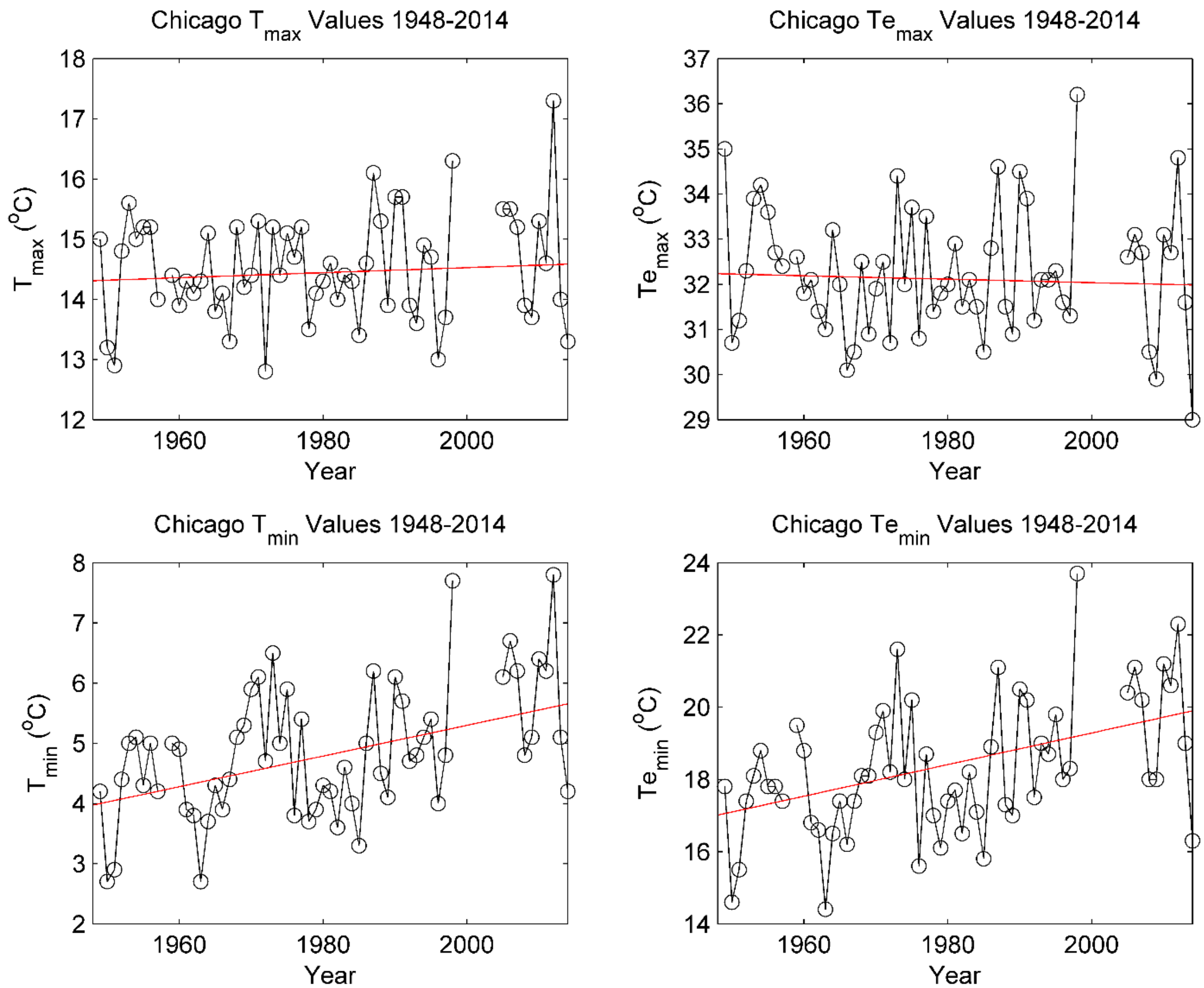
The weather station at Chicago's O'Hare Airport was moved two times and had a combined total of 4 instrument changes. T-tests for this station show that none of the instrument changes in the earlier part of the record created significant changes in the time series, however $T_{d\ max}$ and $T_{d\ min}$ did show a difference in 1989 when the station was moved 1.2 miles northeast. Maximum temperature seems to have been affected with an instrument change in 2004, this could be related to a change from the Hygrothermometer which had a warm bias, Indianapolis also showed an increase in $T_{d\ max}$; this could also be a regional increase that occurred during that time period. $T_{d\ min}$ shows a change with the installation of the DTS1 station in 2005. Seasonal summer trend analysis shows a significant increase of T_{min} (0.31°C) and $T_{E\ min}$ (0.66°C) for the study period of 67 years, this was consistent with significant increases in the annual record as well (see appendix). Interestingly $T_{E\ max}$ showed a decrease, although not significant, it is worth noting. According to the 2010 Census, Chicago's population was 2,695,598, land area per square mile 228 and the population density was 11,841.

Chicago O'Hare Int'l AP	**Station Metadata**		**Latitude: 41.995**	
	WBAN# 94846		**Longitude: -87.9336**	
Year	**Ground Elevation (m)**	**Instruments**	**Comments**	
1958-1960	200.6 (1958-1989)	Maximum and Minimum Thermometers	Daily/obs times 2400	
1960-1992	200.6 (1989-2013)	Hygrothermometer	Daily readings/ observation times 2400	
1992-2004	201.8 (2013-Present)	Tempx: Other temperature equipment	Observation times 2400, Reporting method: ASOS data downloaded to NCDC -MF1-10 from 1992-1996. From 1998-2004 Reporting method B91.	
2004-present		ATEMP: ASOS Hygrothermometer	ASOS-Era Data Downloaded to NCDC	
Station Moves				
Latitude	**Longitude**	**Initial**	**Final Date**	
41.98333		10/31/1958	1/1/1989	
	-87.9	10/31/1958	1/1/1989	
42		1/19/1989	2/1/1996	
	-87.88333	1/19/1989	2/1/1996	
41.98611		2/1/1996	1/1/2004	
	-87.91417	2/1/1996	1/1/2004	
41.995		1/1/2004	Present	
	-87.93361	1/1/2004	Present	
T-test 1960	**Instrument change from Max and Min Thermometer to Hygrothermometer**			
T-test 1964	**Estimated instrument change**			
T-test 1985	**Estimated instrument change and station move (0.75 miles east 03/11/1985)**			
T-test 1989	**Station move (1.2 miles NE 01/19/1989)**			
T-test 2004	**Instrument change from Tempx to ATEMP**			
T-test 2005	**06/03/2005 DTS1-Installation**			

Chicago O'Hare	**Median Pairwise Slopes 95% confidence**	**Degrees Celsius per decade**	
Seasonal			
Winter-Dec, Jan, Feb	**Significance**	**Trend**	**P-value**
T_max	not significant at 0.05	0.06C°	0.67563
Te_max	not significant at 0.05	0.06C°	0.75152
T_min	is significant at 0.05	0.33C°	0.04417
Te_min	is significant at 0.05	0.44C°	0.03989
Spring-Mar, Apr, May			
T_max	not significant at 0.05	0.18C°	0.09713
Te_max	not significant at 0.05	0.00C°	0.96172
T_min	is significant at 0.05	0.25C°	0.00061
Te_min	is significant at 0.05	0.35C°	0.00455
Summer-June, July, August			
T_max	not significant at 0.05	0.03C°	0.73617
Te_max	not significant at 0.05	-0.12	0.60175
T_min	is significant at 0.05	0.31C°	0.00091
Te_min	is significant at 0.05	0.66C°	0.00445
Fall-Sept, Oct, Nov			
T_max	not significant at 0.05	-0.1	0.39788
Te_max	not significant at 0.05	-0.18	0.21246
T_min	is significant at 0.05	0.27C°	0.001
Te_min	is significant at 0.05	0.47C°	0.00331

Chicago	**95% confidence**	**Degrees Celsius per decade**	
Annual Trend			
	Significance	**Trend**	**P-value**
T_max	not significant at 0.05	0.04C°	0.51466
Te_max	not significant at 0.05	(-0.04C°)	0.80483
T_min	is significant at 0.05	0.25C°	0.00055
Te_min	is significant at 0.05	0.44C°	0.00063

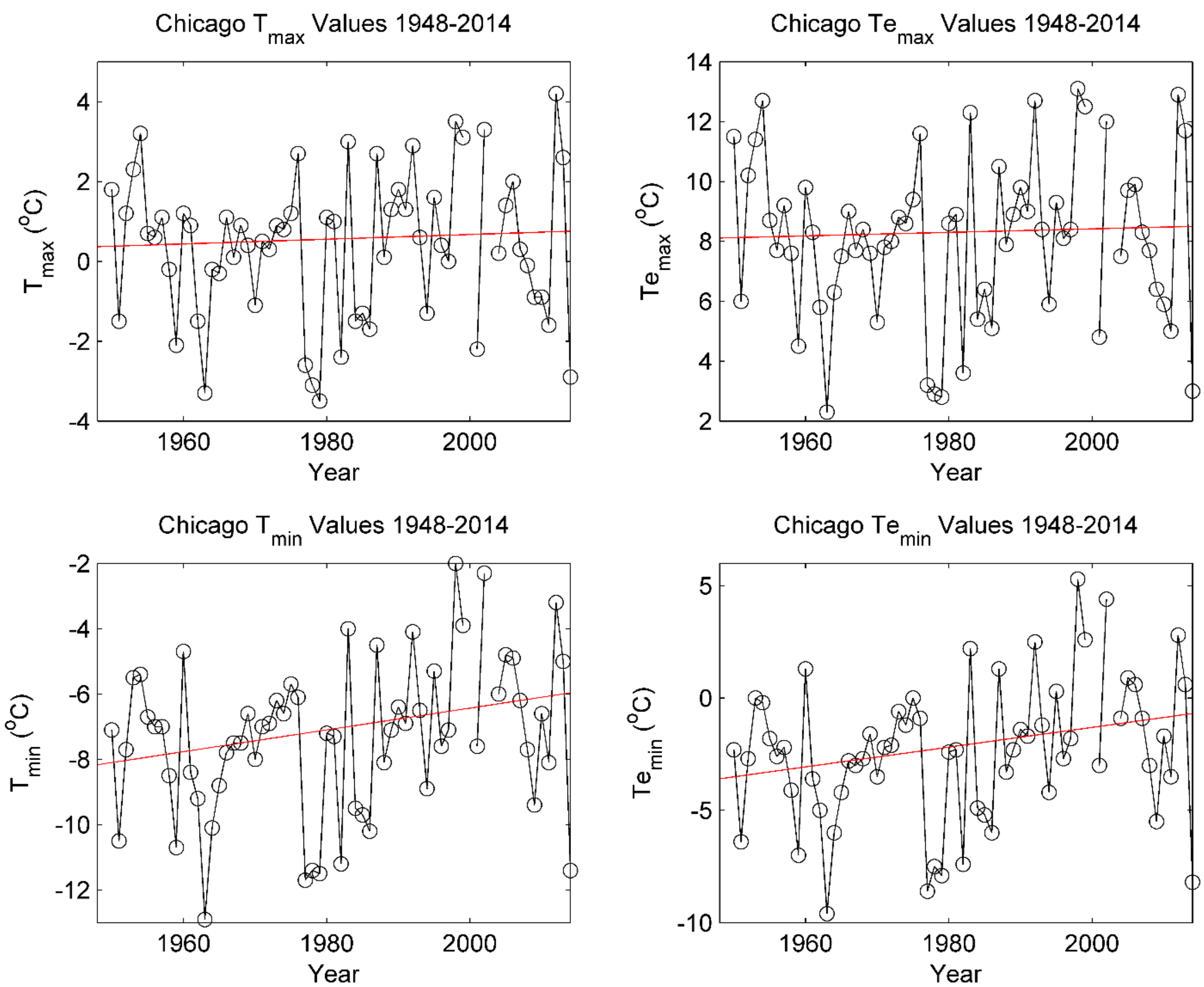
ANNUAL TREND



Chicago	95% confidence	Degrees Celsius per decade	
Annual Trend			
	Significance	**Trend**	**P-value**
T_max	not significant at 0.05	0.04C°	0.51466
Te_max	not significant at 0.05	(-0.04C°)	0.80483
T_min	is significant at 0.05	0.25C°	0.00055
Te_min	is significant at 0.05	0.44C°	0.00063

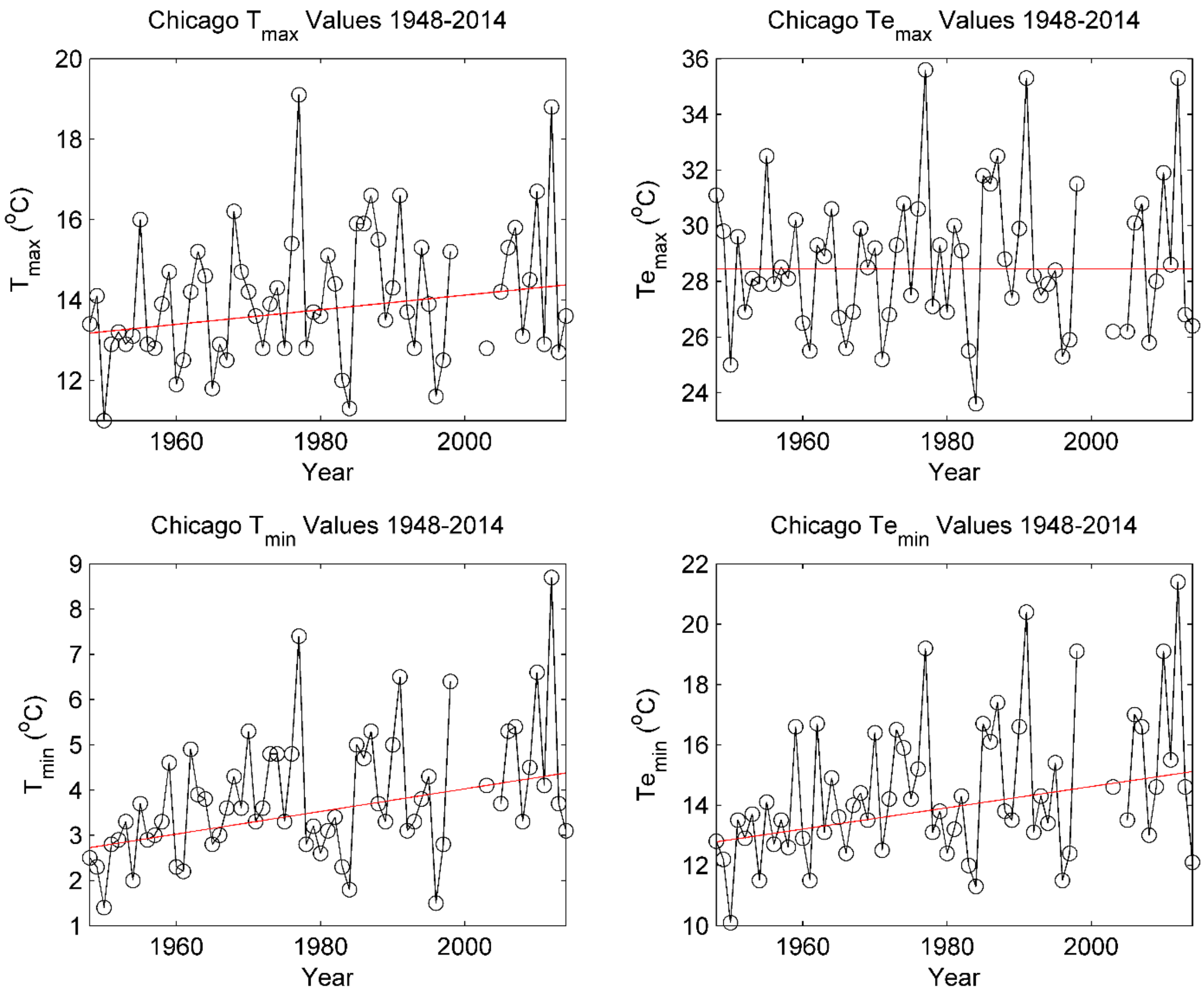
SEASONAL TRENDS

WINTER



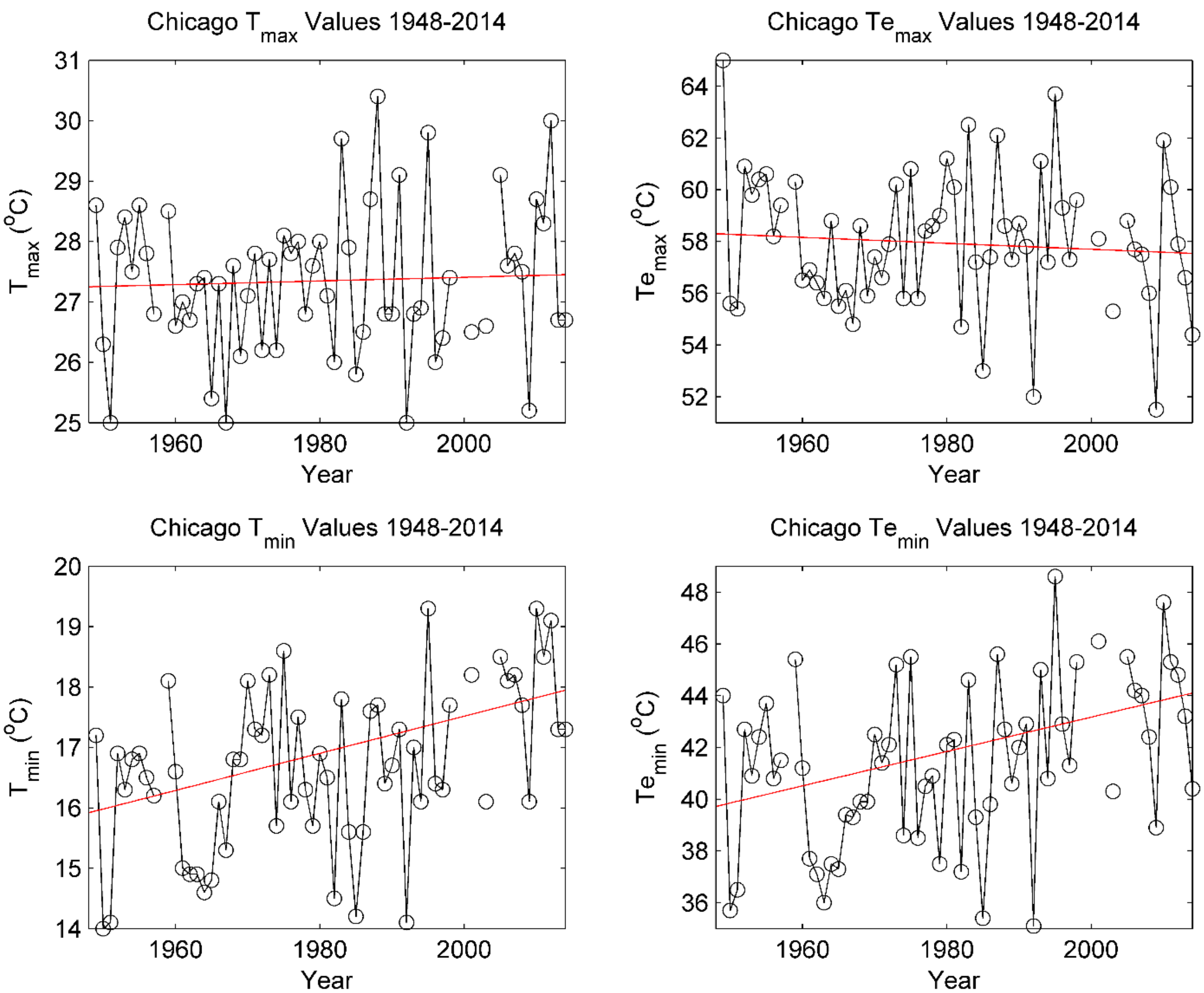
Winter-Dec, Jan, Feb	Significance	Trend	P-value
T_max	not significant at 0.05	0.06C°	0.67563
Te_max	not significant at 0.05	0.06C°	0.75152
T_min	is significant at 0.05	0.33C°	0.04417
Te_min	is significant at 0.05	0.44C°	0.03989

SPRING



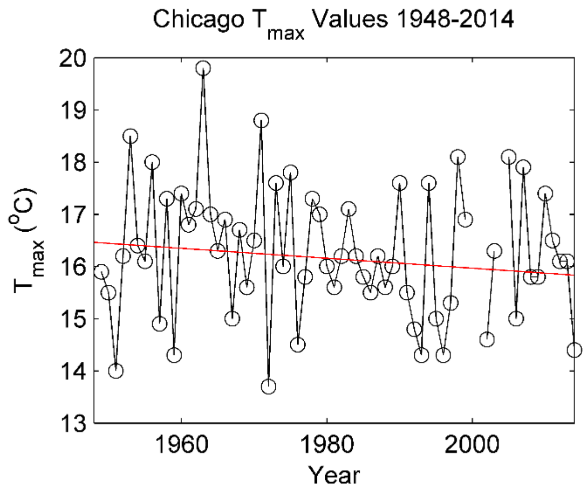
Spring-Mar, Apr, May	**Significance**	**Trend**	**P-Value**
T_max	not significant at 0.05	0.18C°	0.09713
Te_max	not significant at 0.05	0.00C°	0.96172
T_min	is significant at 0.05	0.25C°	0.00061
Te_min	is significant at 0.05	0.35C°	0.00455

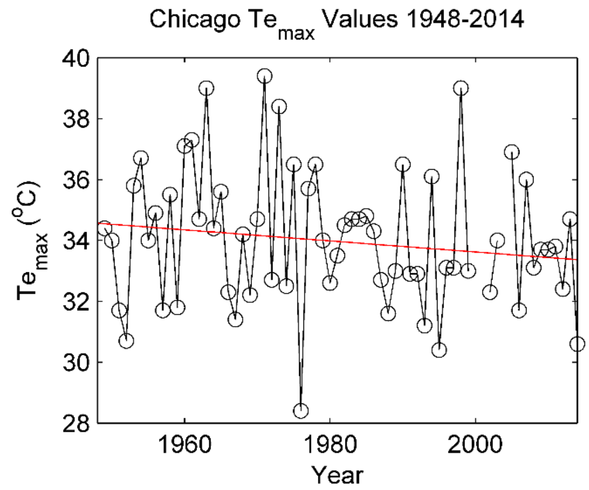
SUMMER

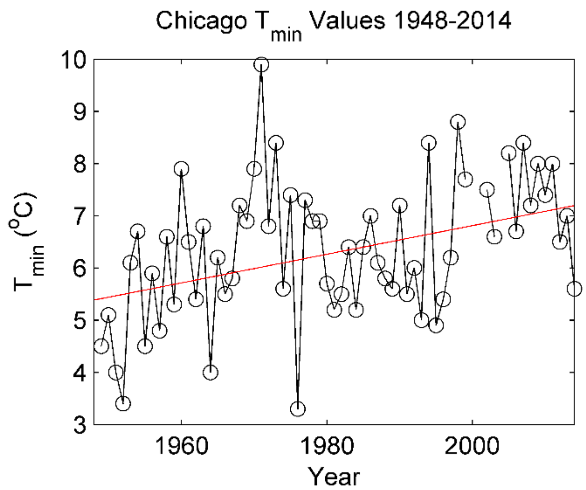


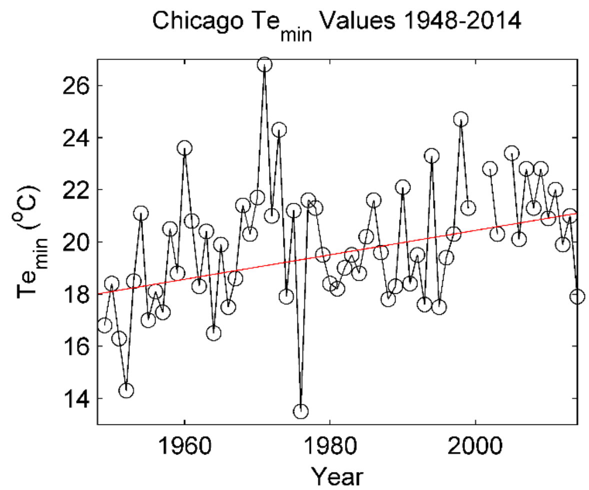
Summer-June, July, August	**Significance**	**Trend**	**P-Value**
T_max	not significant at 0.05	0.03C°	0.73617
Te_max	not significant at 0.05	-0.12	0.60175
T_min	is significant at 0.05	0.31C°	0.00091
Te_min	is significant at 0.05	0.66C°	0.00445

FALL



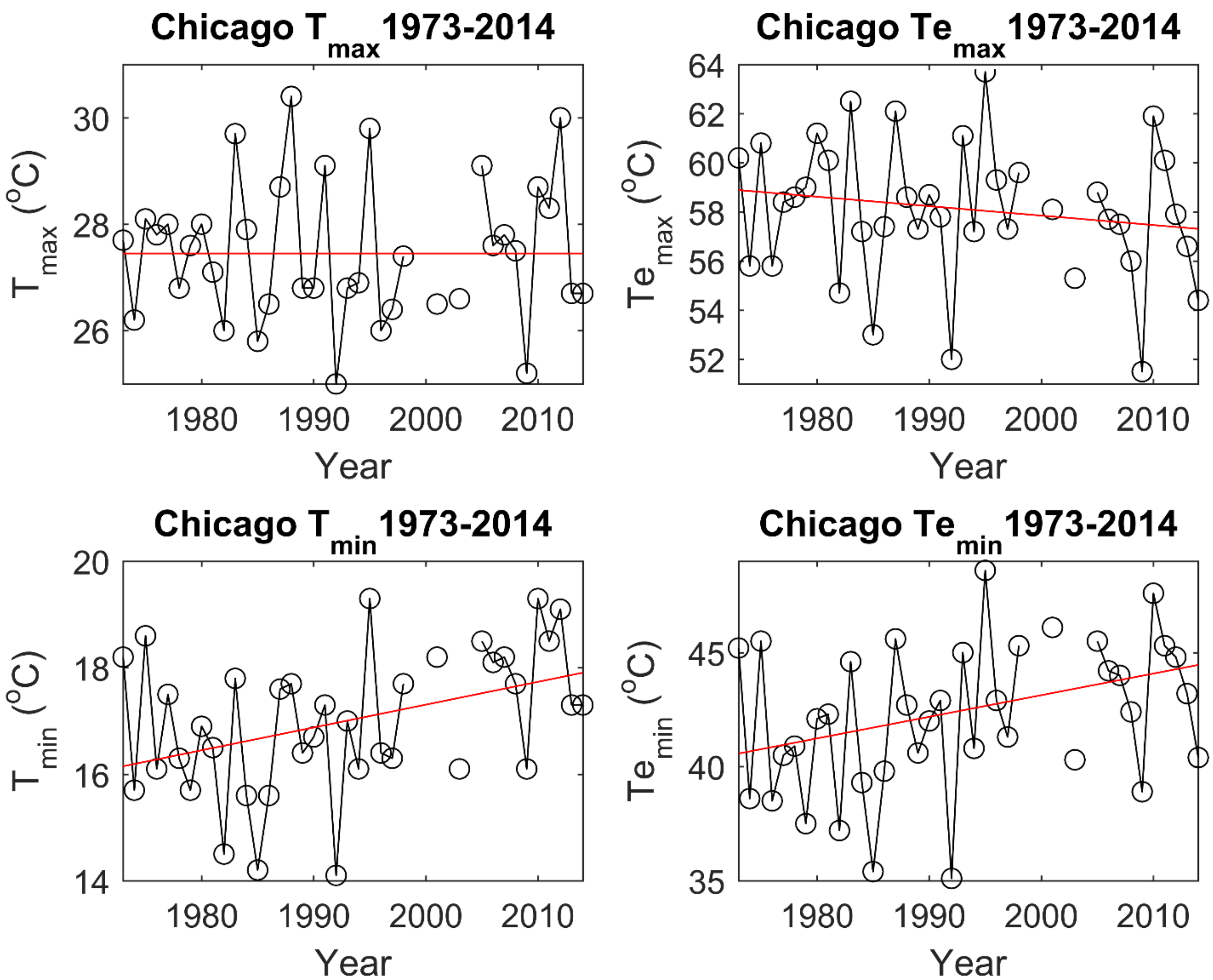






Fall-Sept, Oct, Nov	**Significance**	**Trend**	**P-Value**
T_max	not significant at 0.05	-0.1	0.39788
Te_max	not significant at 0.05	-0.18	0.21246
T_min	is significant at 0.05	0.27C°	0.001
Te_min	is significant at 0.05	0.47C°	0.00331

SUMMER 1973-2014



Summer-June, July,August	**Significance**	**Trend**	**P-value**
T_max	not significant at 0.05	0	0.85753
Te_max	not significant at 0.05	-0.38	0.2878
T_min	is significant at 0.05	0.43	0.02418
Te_min	is significant at 0.05	0.95	0.04561

Two Tailed T-Tests: Station moves, instrument changes, DTS1 installation

Chicago O'Hare	Dew Point			1960	Instrument change Max/min thermometer to Hygrothermometer	
T-Test	1956-1959	1961-1964				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.6622	-1.1156	0.7122	-0.4382	93	2.2427
Tdmax	0.2551	-0.3613	1.3458	1.1452	93	2.0946
Tmin	0.052	-0.0081	1.8767	1.9688	93	2.3127
Tdmin	0.5975	-0.8056	1.3919	0.5299	93	2.6963

Chicago O'Hare	Dew Point			1964	Estimated instrument change	
T-Test	1960-1963	1965-1968				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.8945	-0.8945	0.9957	0.133	94	2.3025
Tdmax	0.7542	-0.7432	1.0223	0.314	94	2.178
Tmin	0.2115	-1.4933	0.335	-1.258	94	2.2555
Tdmin	0.5087	-1.356	0.6768	-0.6634	94	2.5078

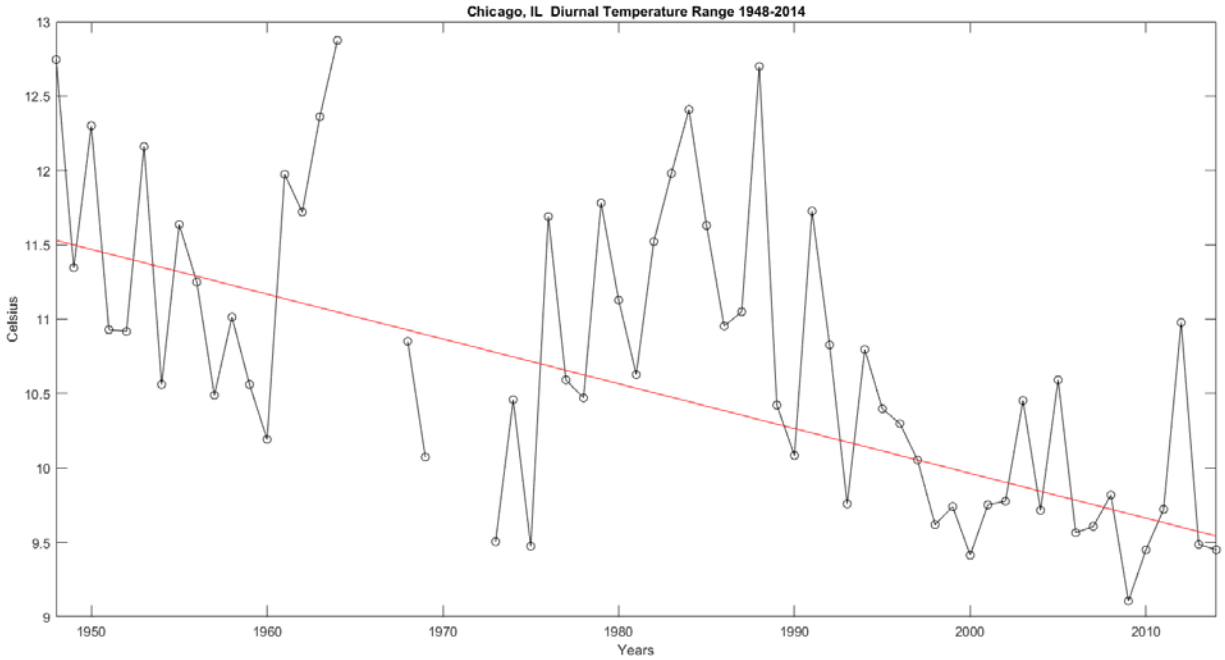
Chicago O'Hare	Dew Point			1985	Estimated instrument change and station move (0.75 miles east 03/11/1985)	
T-Test	1981-1984	1986-1989				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.1824	-1.5952	0.3077	-1.3434	94	2.3476
Tdmax	0.7165	-1.0484	0.7234	-0.3642	94	2.1858
Tmin	0.0643	-1.7431	0.0514	-1.8718	94	2.2138
Tdmin	0.6565	-1.249	0.7906	-0.4462	94	2.5162

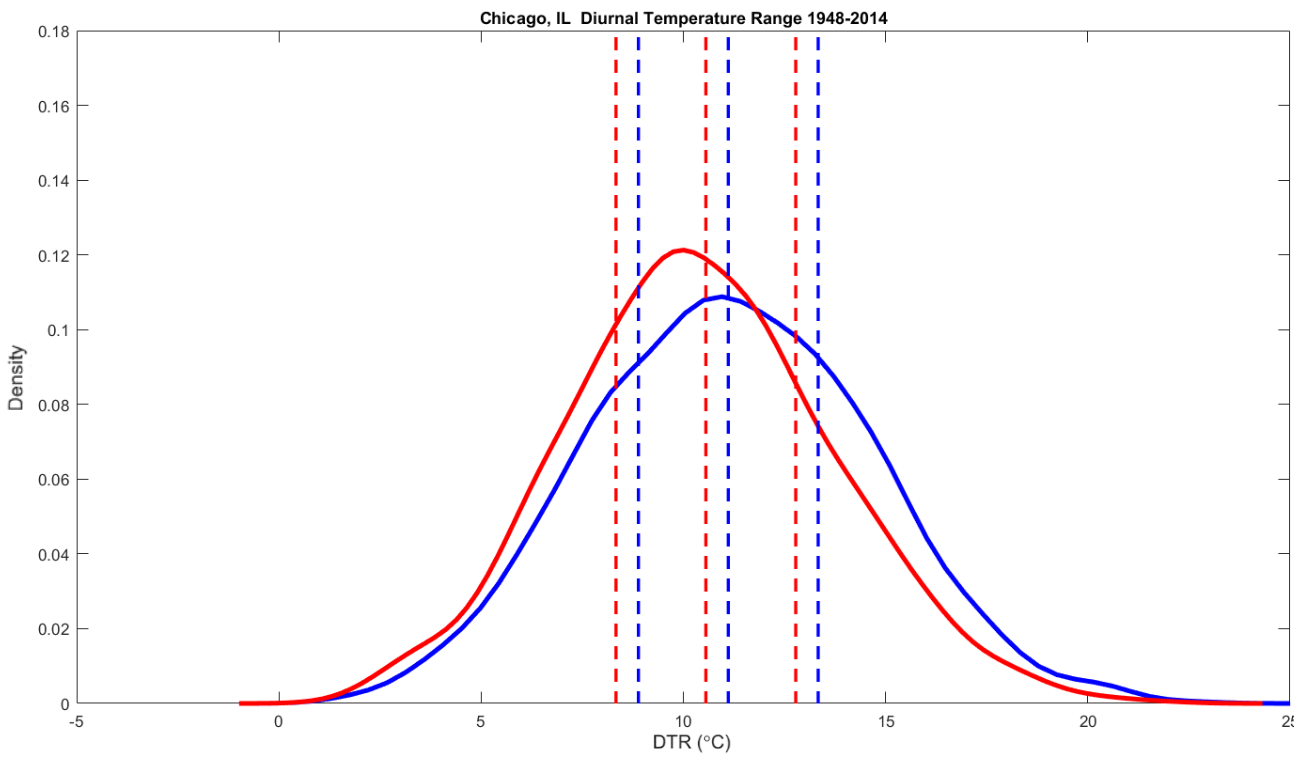
Chicago O'Hare	Dew Point			1989	Station move (1.2 miles NE 01/19/1989)

T-Test	**1985-1988**	**1990-1993**				
	P-value	**CI-Lower**	**CI-Upper**	**T-statistic**	**Degrees of Freedom**	**Standard Deviation**
Tmax	0.7599	-0.7416	1.0125	0.3066	94	2.164
Tdmax	0.0286	-1.6289	-0.092	-2.2231	94	1.8961
Tmin	0.1628	-1.4619	0.2494	-1.4619	94	2.1112
Tdmin	0.0313	-1.9799	-0.0951	-2.186	94	2.3251

Chicago O'Hare	**Dew Point**			**2004**	**Instrument change from Tempx to ATEMP**	
T-Test	**1999-2003**	**2005-2008**				
	P-value	**CI-Lower**	**CI-Upper**	**T-statistic**	**Degrees of Freedom**	**Standard Deviation**
Tmax	0.015	-2.1045	-0.2336	-2.4866	81	2.1152
Tdmax	0.5294	-1.1336	0.5873	-0.6316	81	1.9457
Tmin	0.5565	-0.6626	1.222	0.5906	81	2.1307
Tdmin	0.0879	-0.1325	1.8789	1.7276	81	2.274

Chicago O'Hare	**Dew Point**			**2005**	**DTS1 Installation 06/03/2005**	
T-Test	**2001-2004**	**2006-2009**				
	P-value	**CI-Lower**	**CI-Upper**	**T-statistic**	**Degrees of Freedom**	**Standard Deviation**
Tmax	0.3528	-1.3309	0.4801	-0.9345	82	2.0646
Tdmax	0.9283	-0.7898	0.8649	0.0903	82	1.8864
Tmin	0.0825	-0.1028	1.6646	1.758	82	2.0148
Tdmin	0.0076	0.3574	2.2546	2.7389	82	2.1628


Chicago, IL Diurnal Temperature Range 1948-2014
Celsius
Years
13
12.5
12
11.5
11
10.5
10
9.5
9
1950
1960
1970
1980
1990
2000
2010


Chicago, IL Diurnal Temperature Range 1948-2014
Density
DTR (°C)
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-5
0
5
10
15
20
25

APPENDIX C

Philadelphia

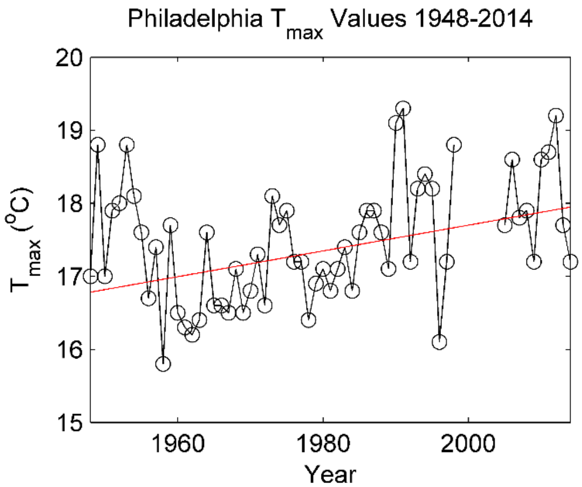
The station at the Philadelphia International Airport was moved in 1954, it was also lowered in elevation from 7.9 meters to 3 meters where it still stands today. T-tests showed changes in T_{max} and $T_{d\ max}$ for 1954, this could be due to the station being closer to the ground during this time. Only of the estimated instrument changes showed a possible error in the record in 1995 when many of the stations were changed to ASOS, T_{max} was affected here. After the installation for DTS1 in 2004, T_{max} and $T_{d\ min}$ were showing possible discontinuities. Philadelphia had a population of 1,526,006, with a land area of 134 and population density of 11,379 according to the 2010 US Census. The seasonal summer trend analysis shows significant increases for all variables except $T_{E\ max}$. T_{max} shows an increase of 0.13C°, T_{min} increased 0.37C° and $T_{E\ min}$ increased by 0.68C°. In the shorter time period starting at 1973 significant increases are present in T_{min} (0.48C°) and $T_{E\ min}$ (0.91C°). Annual trend analysis shows increases in T_{min} (0.31C°) and $T_{E\ min}$ (0.44C°).

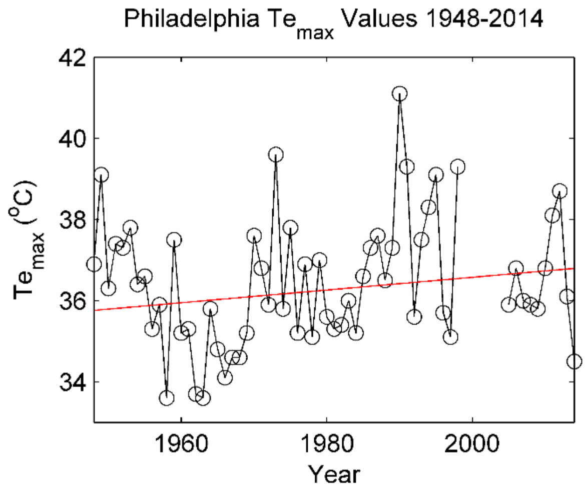
Philadelphia Int'l AP	**Station Metadata**	**Latitude: 39.8683**		
	WBAN# 13739	**Longitude: 75.2311**		
Year	**Site (m)**	**Instruments**		**Comments**
1948-1954	7.9 (1948-1954)	Hygrothermometer		Daily, obs times 2400
1954-2011	3 (1954-2003)	Hygrothermometer		Daily, obs times 2400. Instrument change from Hygrothermometer to ATEMP.
2011-Present	3 (2003-Present)	ATEMP: ASOS Hygrothermometer		Reporting method: ADP-ASOS-Era Data Downloaded to NCDC. No recorded change in observation times
Station Moves				
Latitude	**Longitude**	**Initial**	**Final Date**	
39.88333		7/1/1940	12/1/1995	
	75.23333	7/1/1940	12/22/1954	
	75.25	12/22/1954	12/1/1995	
39.86833		12/1/1995	9/15/2011	
	75.23111	12/1/1995	9/15/2011	
39.8683		9/15/2011	Present	
	75.2311	9/15/2011	Present	
T-test 1954	**Station move from old terminal bldg to new terminal bldg**			
T-test 1964	**estimated instrument change**			
T-test 1985	**estimated instrument change**			
T-test 1995	**estimated instrument change**			
T-Test 2004	**03/11/2004 DTS1 Installation**			
T-test 2011	**instrument change from Hygrothermometer to ATEMP (not enough data to conduct T-Test ends 2014)**			

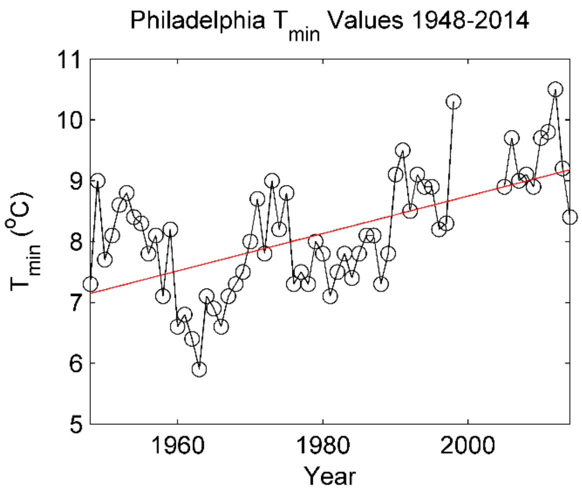
Philadelphia	**Median Pairwise Slopes 95% confidence**	**Degrees Celsius per decade**	
Seasonal Trends			
Winter-Dec, Jan, Feb	**Significance**	**Trend**	**P-value**
T_max	not significant at 0.05	0.12C°	0.36617
Te_max	not significant at 0.05	0.08C°	0.77934
T_min	not significant at 0.05	0.21C°	0.11302
Te_min	not significant at 0.05	0.25C°	0.25087
Spring-Mar, Apr, May			
T_max	is significant at 0.05	0.20C°	0.00978
Te_max	not significant at 0.05	0.23C°	0.18426
T_min	is significant at 0.05	0.26C°	0.00089
Te_min	is significant at 0.05	0.38C°	0.01456
Summer-June, July, August			
T_max	is significant at 0.05	0.13C°	0.02153
Te_max	not significant at 0.05	0.16C°	0.36672
T_min	is significant at 0.05	0.37C°	0
Te_min	is significant at 0.05	0.68C°	0.00013
Fall-Sept, Oct, Nov			
T_max	not significant at 0.05	0.05C°	0.35967
Te_max	not significant at 0.05	0.06C°	0.50478
T_min	is significant at 0.05	0.31C°	0.00001
Te_min	is significant at 0.05	0.46C°	0.00212

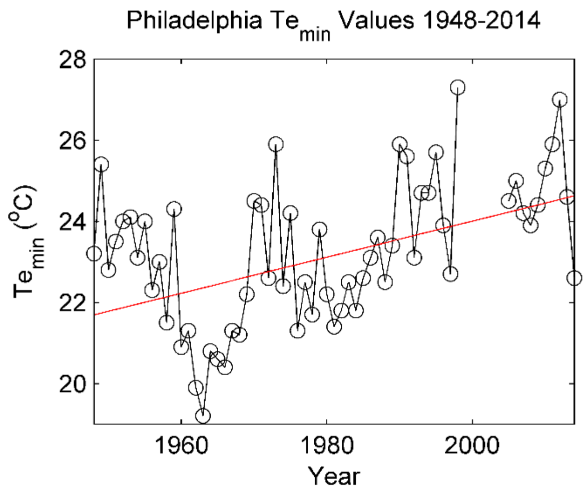
Philadelphia	**95% confidence**	**Degrees Celsius per decade**	
Annual Trend			
	Significance	**Trend**	**P-value**
T_max	is significant at 0.05	0.18C°	0.00728
Te_max	not significant at 0.05	0.16C°	0.21885
T_min	is significant at 0.05	0.31C°	0
Te_min	is significant at 0.05	0.44C°	0.00047

ANNUAL TREND





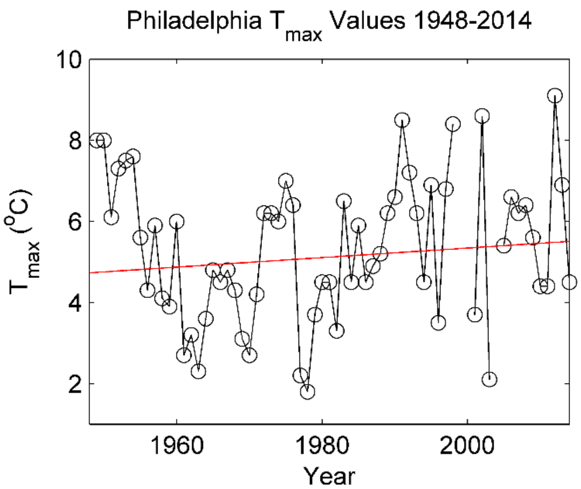


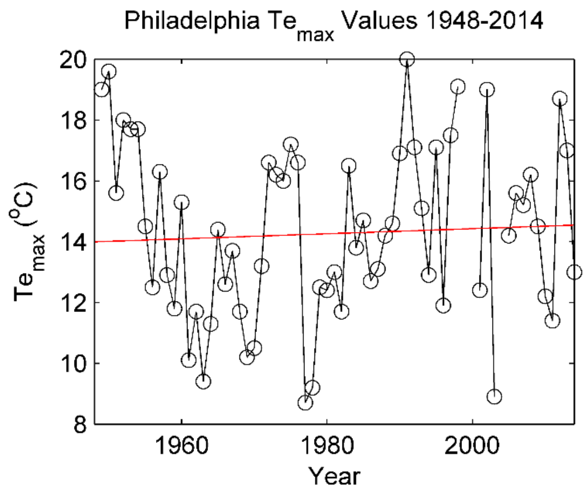


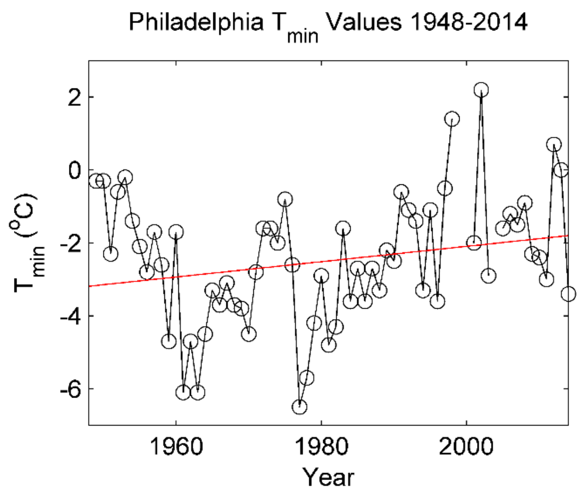
Philadelphia	**95% confidence**	**Degrees Celsius per decade**	
Annual			
	Significance	**Trend**	**P-value**
T_max	is significant at 0.05	0.18C°	0.00728
Te_max	not significant at 0.05	0.16C°	0.21885
T_min	is significant at 0.05	0.31C°	0
Te_min	is significant at 0.05	0.44C°	0.00047

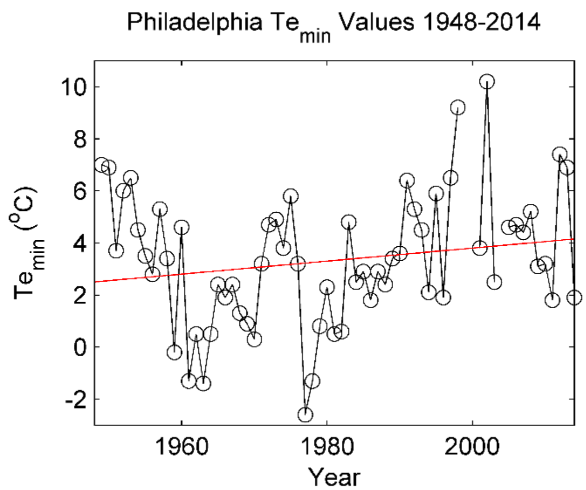
SEASONAL TRENDS

WINTER



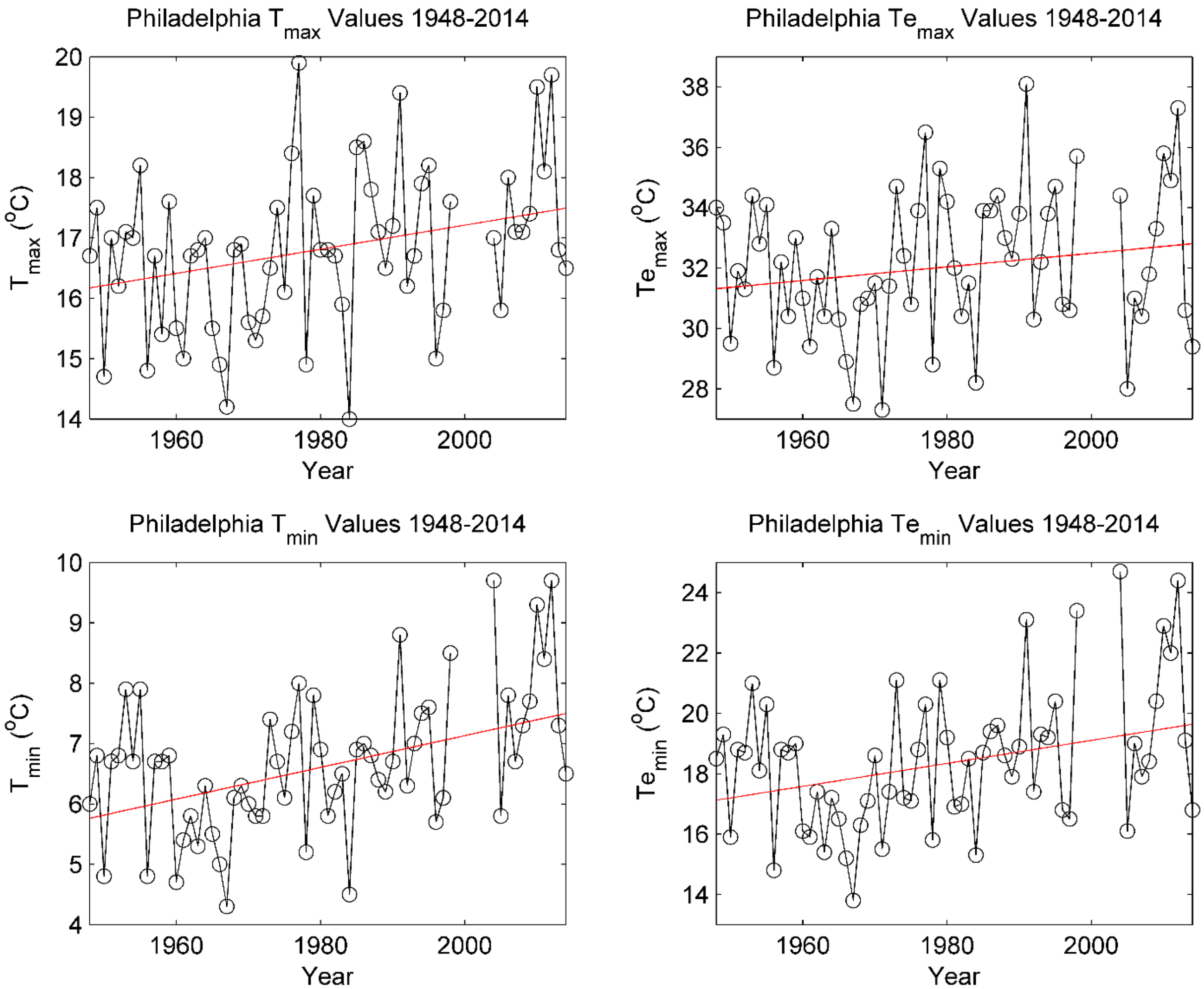






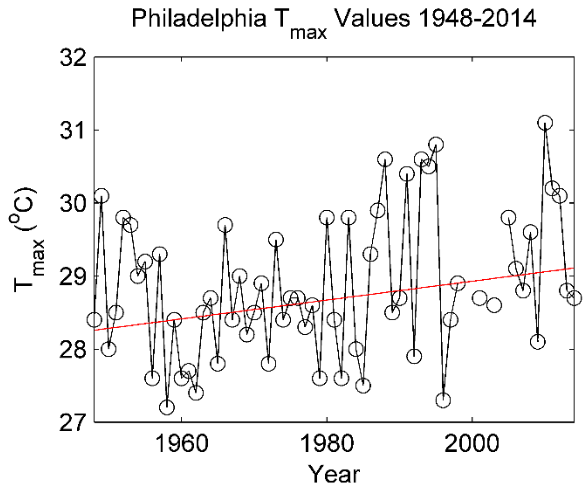
Winter-Dec, Jan, Feb	**Significance**	**Trend**	**P-value**
T_max	not significant at 0.05	0.12C°	0.36617
Te_max	not significant at 0.05	0.08C°	0.77934
T_min	not significant at 0.05	0.21C°	0.11302
Te_min	not significant at 0.05	0.25C°	0.25087

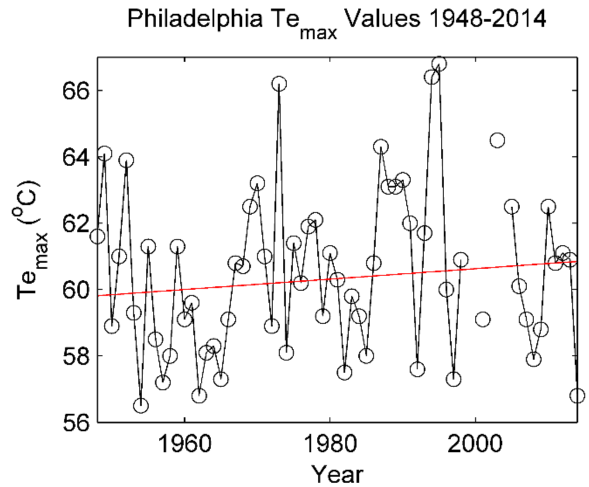
SPRING

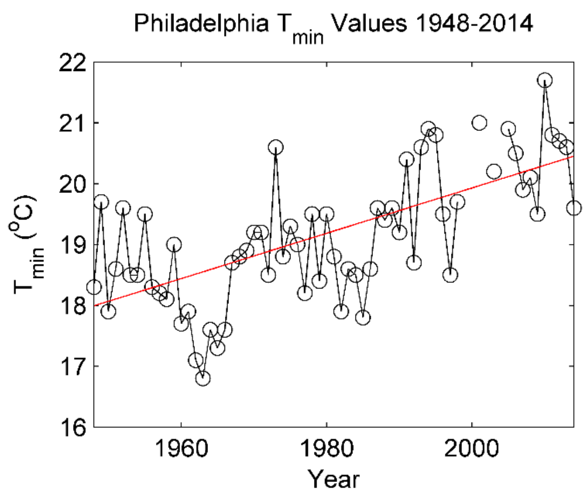


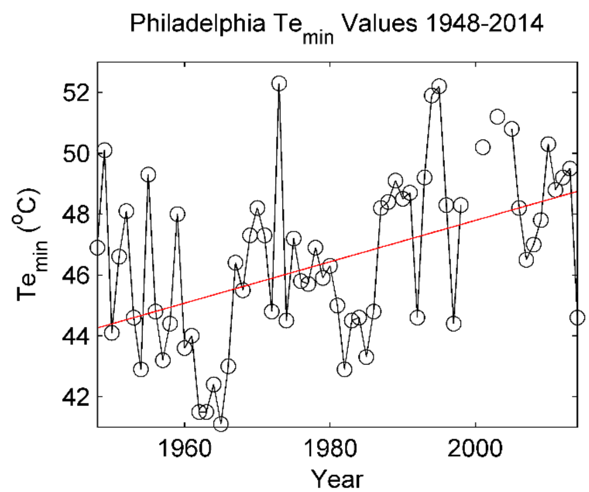
Spring-Mar,Apr,May	**Significance**	**Trend**	**P-value**
T_max	is significant at 0.05	0.20C°	0.00978
Te_max	not significant at 0.05	0.23C°	0.18426
T_min	is significant at 0.05	0.26C°	0.00089
Te_min	is significant at 0.05	0.38C°	0.01456

SUMMER



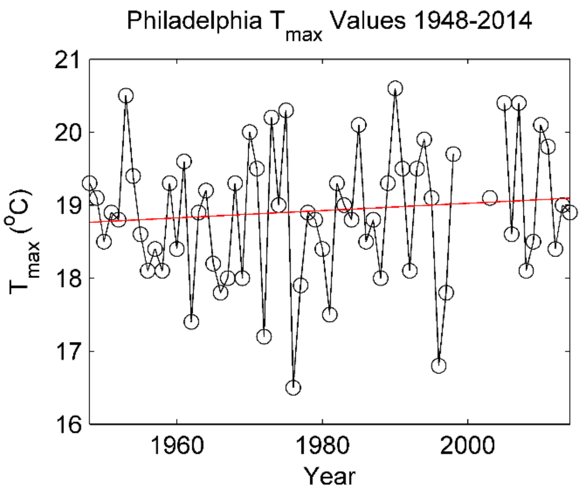


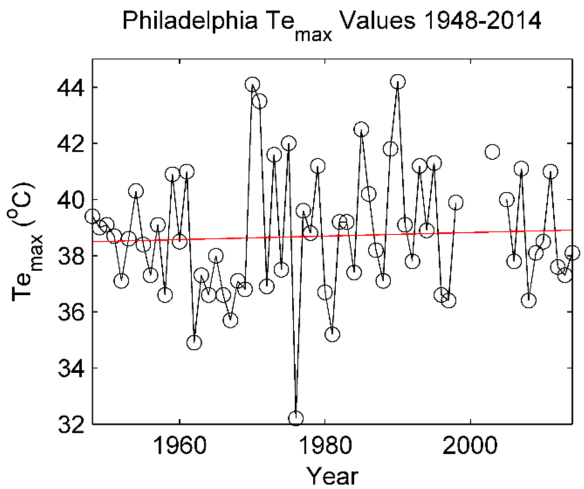


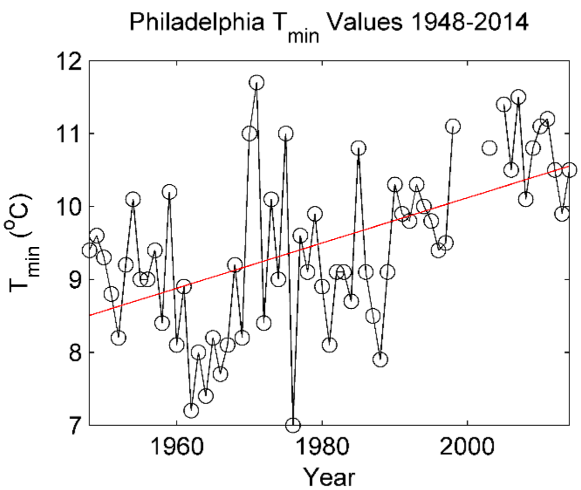


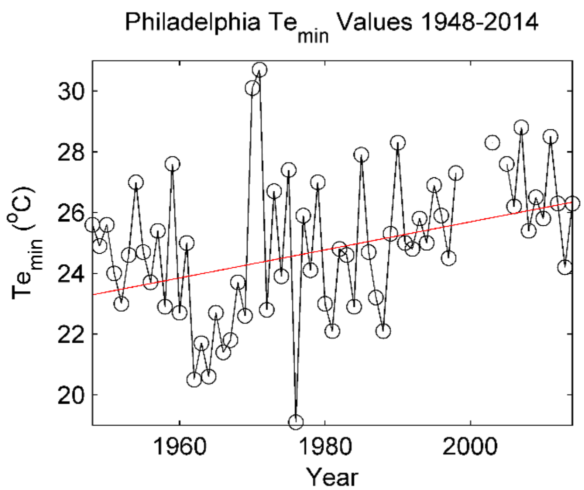
Summer-June, July, August			
T_max	is significant at 0.05	0.13C°	0.02153
Te_max	not significant at 0.05	0.16C°	0.36672
T_min	is significant at 0.05	0.37C°	0
Te_min	is significant at 0.05	0.68C°	0.00013

FALL



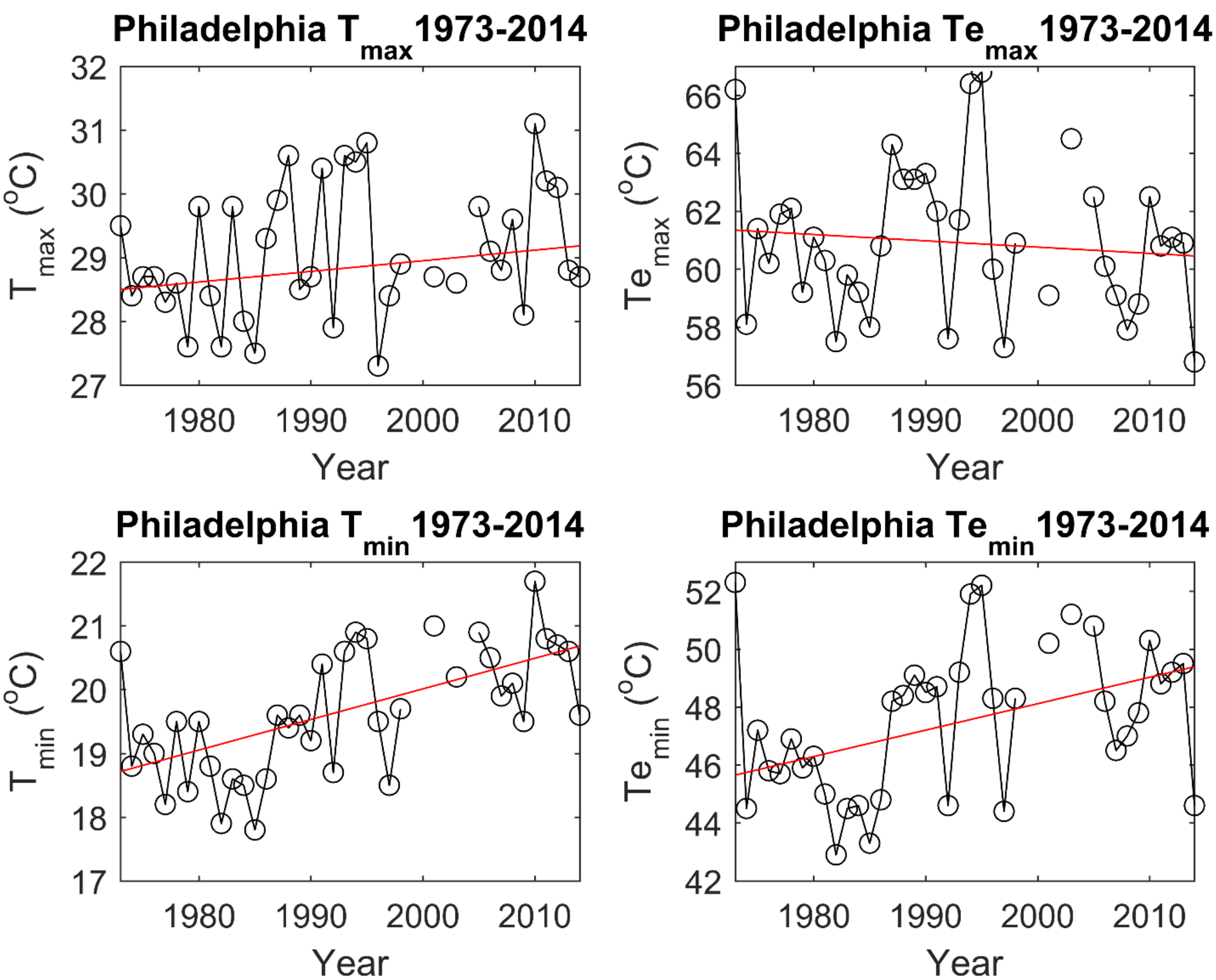






Fall-Sept, Oct, Nov			
T_max	not significant at 0.05	0.05C°	0.35967
Te_max	not significant at 0.05	0.06C°	0.50478
T_min	is significant at 0.05	0.31C°	0.00001
Te_min	is significant at 0.05	0.46C°	0.00212

SUMMER 1973-2014



Summer-June, July,August	Significance	Trend	P-value
T_max	not significant at 0.05	0.17C°	0.06767
Te_max	not significant at 0.05	-0.22C°	0.49783
T_min	is significant at 0.05	0.48C°	0.00005
Te_min	is significant at 0.05	0.91C°	0.01584

Two Tailed T-Tests: Station moves, instrument changes, DTS1 installation

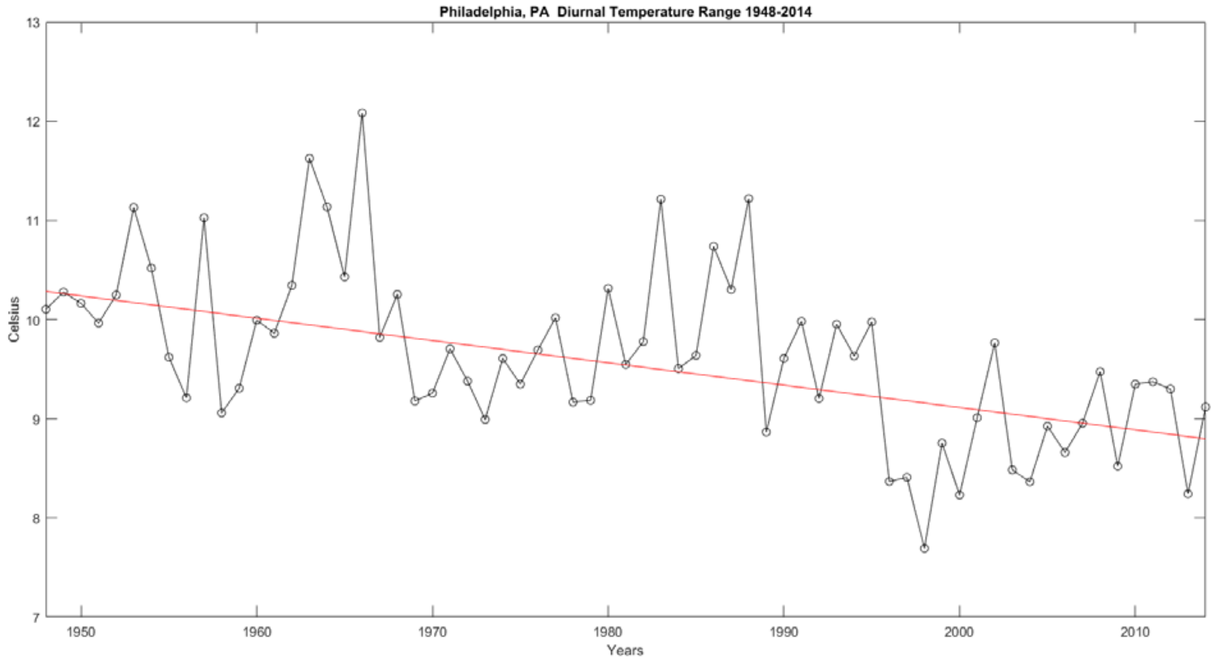
Philadelphia Int'l AP	Dew Point			1954	Station move from old terminal bldg to new terminal bldg.	
T-Test	1950-1953	1955-1958				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.0038	0.3377	1.7081	2.9642	94	1.6906
Tdmax	0.0271	0.1	1.625	2.2458	94	1.88140
Tmin	0.1501	-0.1689	1.0856	1.4509	94	1.5476
Tdmin	0.0541	-0.0148	1.669	1.9506	94	2.0773

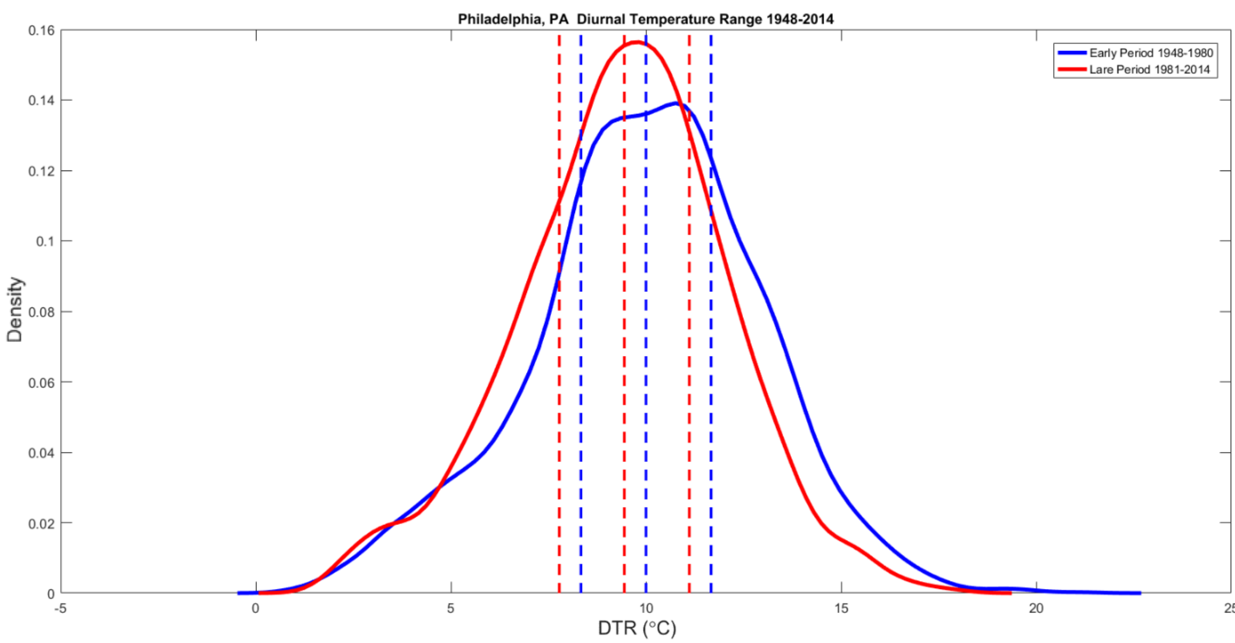
Philadelphia Int'l AP		Dew Point		1964	Estimated instrument change	
T-Test	1960-1963	1965-1968				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.3772	-1.0185	0.3893	-0.8873	94	1.7368
Tdmax	0.9858	-0.7031	0.6906	-0.0178	94	1.71930
Tmin	0.0575	-1.156	0.0185	-1.9229	94	1.449
Tdmin	0.4784	-0.4885	1.0344	0.7117	94	1.8787

Philadelphia Int'l AP		Dew Point		1985	Estimated instrument change	
T-Test	1981-1984	1986-1989				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.0863	-1.3097	0.0888	-1.7333	94	1.7253
Tdmax	0.0542	-1.4256	0.0131	-1.9495	94	1.7748
Tmin	0.2571	-0.9709	0.2625	-1.1402	94	1.5216
Tdmin	0.173	-1.3403	0.2445	-1.3729	94	1.9551

Philadelphia Int'l AP		Dew Point		1995	Estimated instrument change	
T-Test	1991-1994	1996-1999				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.0256	0.1087	1.6345	2.2715	85	1.7798
Tdmax	0.9108	-0.7735	0.6907	-0.1123	85	1.70800
Tmin	0.7936	-0.7396	0.5671	-0.2625	85	1.5242
Tdmin	0.1712	-1.4372	0.2595	-1.3801	85	1.9791

Philadelphia Int'l AP		Dew Point		2004	DTS1 Installation 03/11/2004	
T-Test	1999-2003	2005-2008				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.0451	-1.7715	-0.02	-2.0348	82	1.9966
Tdmax	0.5094	-0.5903	1.1801	0.6627	82	2.0183
Tmin	0.0664	-0.044	1.3171	1.8607	82	1.5516
Tdmin	3.65E-05	1.052	2.8119	4.3674	82	2.0063


Philadelphia, PA Diurnal Temperature Range 1948-2014
Celsius
Years
13
12
11
10
9
8
7
1950
1960
1970
1980
1990
2000
2010


Philadelphia, PA Diurnal Temperature Range 1948-2014
Early Period 1948-1980
Lare Period 1981-2014
Density
DTR (°C)
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-5
0
5
10
15
20
25

APPENDIX D

Jacksonville

Jacksonville is one of the fasters growing cities in the US (citation). With a population of 824,784, land area per square mile 747 and population density of 1,100. Station at Jacksonville International airport experienced a large move in 1971, the move was more than several miles, for this reason only data after 1971 was used. The most complete records began in 1973, this is where our analysis starts. T-tests for this station show a homogeneous time series for 1985, estimated instrument change as well as 1995 which experienced an estimated instrument change and station move 1.5 miles west. In 1996 the station was moved 1mile northeast, t-test for this move show no inconsistencies. In 2004 the station installed the Vaisala DTS1 station, according to t-tests, this could have caused some inhomogeneity in T_{max}, T_{min} and $T_{d\ min}$.

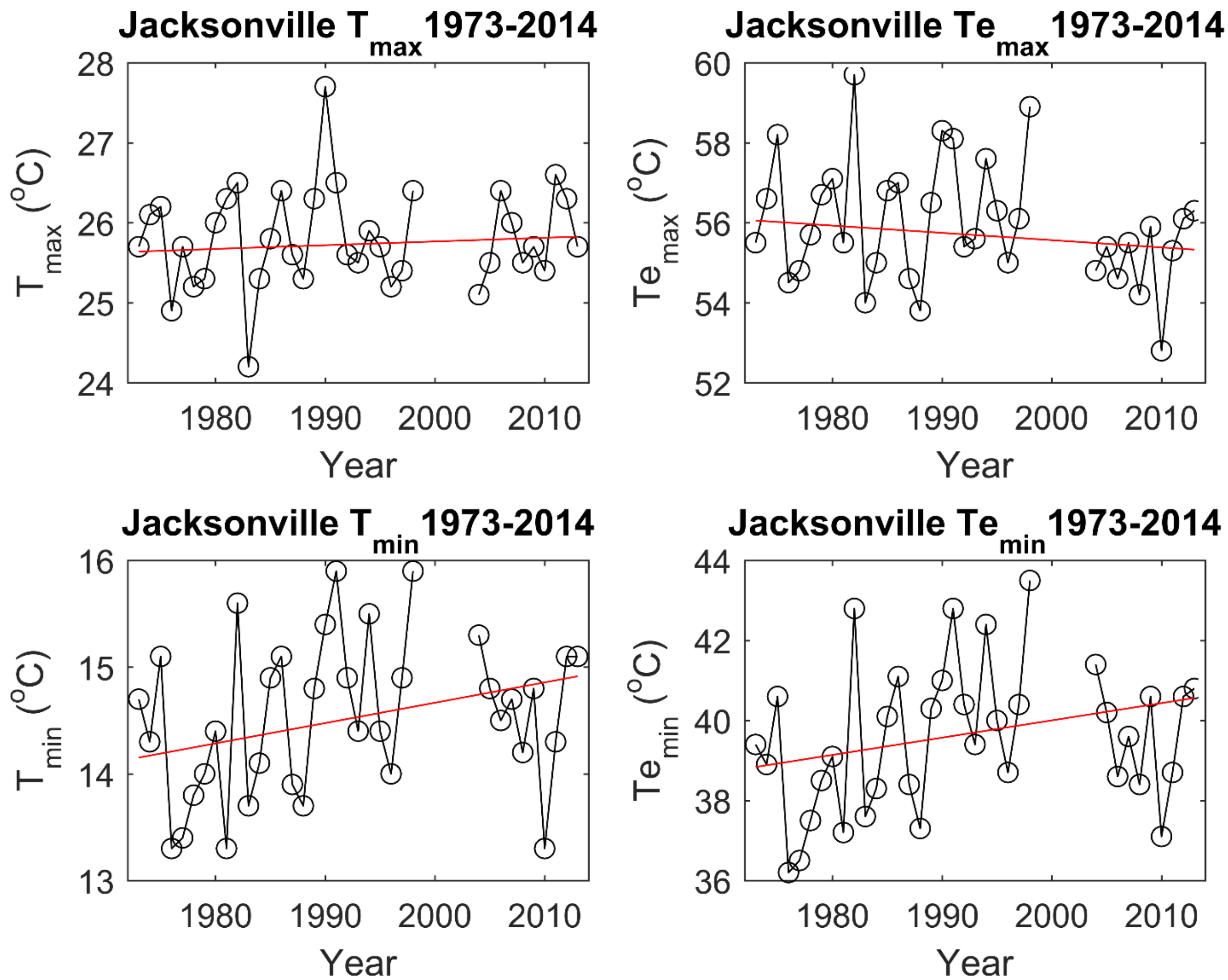
Jacksonville Int'l AP	Station Metadata	Latitude: 30.495	
	WBAN# 13889	Longitude: 81.6936	
Year	**Ground Elevation (m)**	**Instruments**	**Comments**
Data before 1971 unavailable			
1971-1974	7.9 (1971-1980)	unknown	Observations daily, 2400
1974-1980	9.1 (1980-1995)	unknown	Observations daily, 2400
1980-1995	9.4 (1995-1996)	Hygrometer (1995 official start date)	Observations daily, 2400. Instrument change from unknown to Hygrothermometer.
1995-1998	7.9 (1996-Present)	No temperature equipment listed	Observations daily, 2400. No instrument listed from 8/01/1995 to 4/01/1998.
1998-2008		Hygrothermometer	Observations daily, 2400. SOD Data Derived from DOB SFC Proc. Sys
2008-Present		Hygrothermometer	Observations daily, 2400. Reporting Method: ASOS-Era Data Downloaded to NCDC

Station	**Moves**			
Latitude	**Longitude**	**Initial**	**Final Date**	
30.495		1/19/1971	2/1/1995	
	81.6936	1/19/1971	3/1/1996	
30.48333		2/1/1995	3/1/1996	
	81.69353	3/1/1996	9/10/2002	
30.49511		3/1/1996	9/10/2002	
	81.69353	3/1/1996	9/10/2002	
30.496		9/10/2002	Present	
	81.69361	9/10/2002	12/14/2008	
	81.6936	12/14/2008	Present	
T-test 1985	**Estimated instrument change**			
T-test 1995	**Estimated instrument change (unknown to Hygrothermometer) and station move 1.5 miles W**			
T-test 1996	**Station move 1-mile NE (03/01/1996)**			
T-test 2004	**DTS1 Installation 1/16/2004**			

Jacksonville	Median of Pairwise Slopes 95% confidence	Degrees Celsius per decade	
Seasonal Trend			
Winter-Dec,Jan,Feb	**Significance**	**Trend**	**P-value**
T_max	not significant at 0.05	0.24 C°	0.54932
Te_max	not significant at 0.05	0.30 C°	0.67925
T_min	not significant at 0.05	0.42C°	0.13369
Te_min	not significant at 0.05	0.75 C°	0.18416
Spring-Mar,Apr,May			
T_max	not significant at 0.05	(-0.05C°)	0.53443
Te_max	not significant at 0.05	(-0.50C°)	0.09186
T_min	not significant at 0.05	(-0.06C°)	0.63753
Te_min	not significant at 0.05	(-0.06C°)	0.96017
Summer-June, July,August			
T_max	not significant at 0.05	(-0.00C°)	0.91058
Te_max	not significant at 0.05	(-0.17C°)	0.39576
T_min	is significant at 0.05	0.15C°	0.04695
Te_min	is significant at 0.05	0.82C°	0.00369
Fall-Sept, Oct, Nov			
T_max	not significant at 0.05	(-0.08C°)	0.35656
Te_max	not significant at 0.05	(-0.50C°)	0.05994
T_min	not significant at 0.05	0.12C°	0.45475
Te_min	not significant at 0.05	0.30C°	0.53789

Jacksonville	95% confidence	Degrees Celsius per decade	
Annual Trend			
	Significance	**Trend**	**P-value**
T_max	not significant at 0.05	0.00 C°	0.592
Te_max	not significant at 0.05	(-0.18C°)	0.29868
T_min	not significant at 0.05	0.19C°	0.10227
Te_min	not significant at 0.05	0.43C°	0.07889

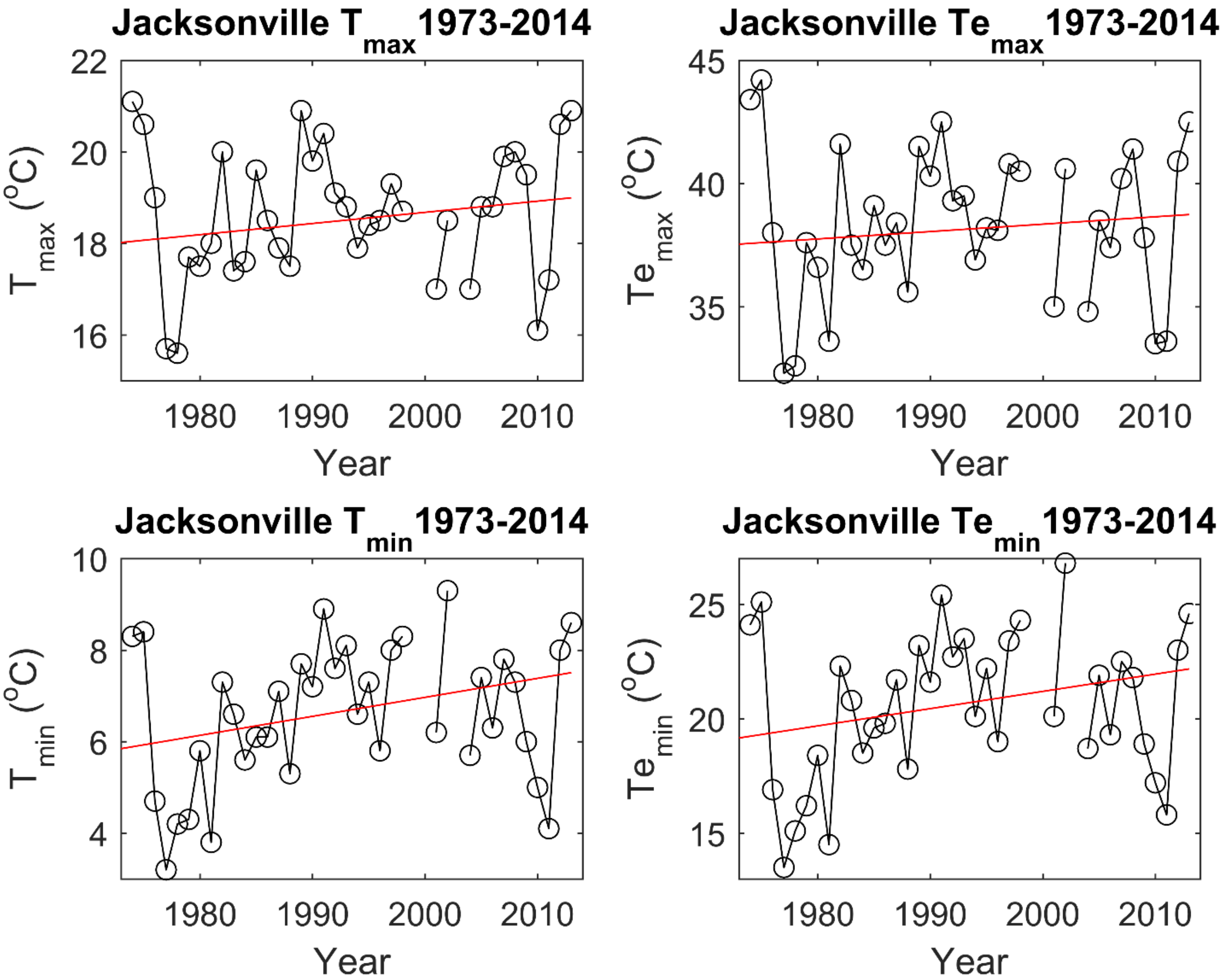
ANNUAL TREND



Jacksonville	**95% confidence**	**Degrees Celsius per decade**	
Annual Trend			
	Significance	**Trend**	**P-value**
T_max	not significant at 0.05	0.00 C°	0.592
Te_max	not significant at 0.05	(-0.18C°)	0.29868
T_min	not significant at 0.05	0.19C°	0.10227
Te_min	not significant at 0.05	0.43C°	0.07889

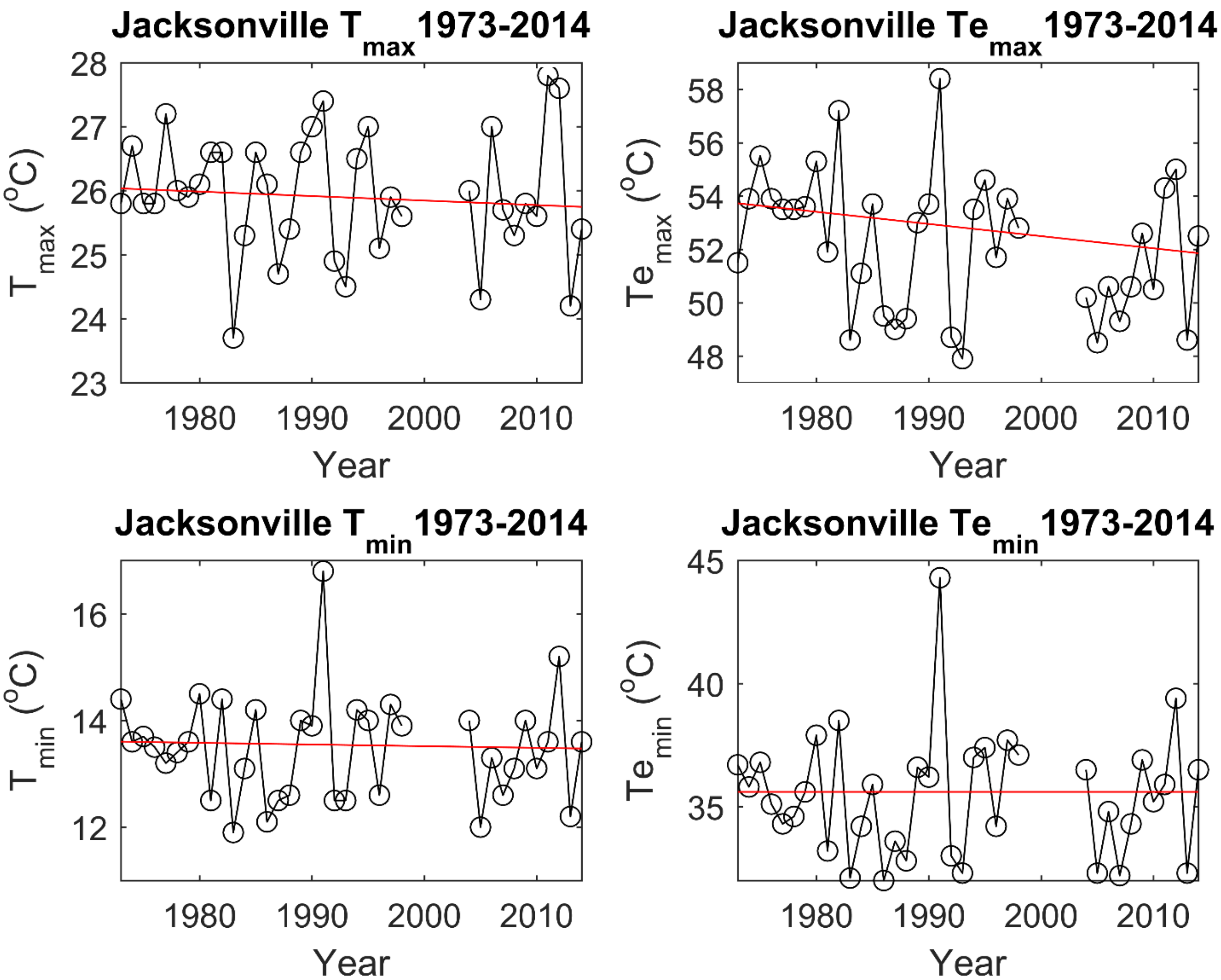
SEASONAL TRENDS

WINTER



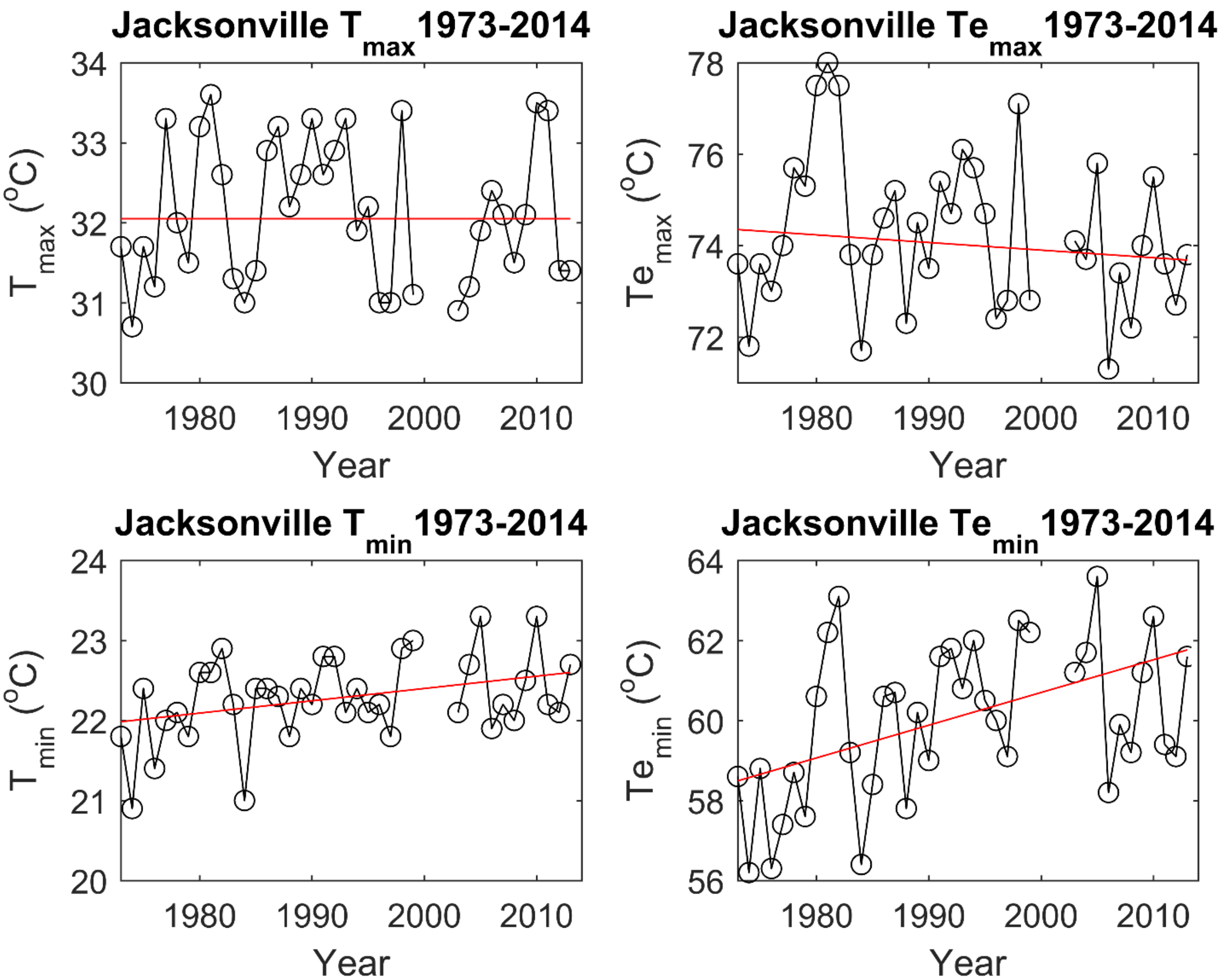
Winter-Dec, Jan, Feb	Significance	Trend	P-value
T_max	not significant at 0.05	0.24 C°	0.54932
Te_max	not significant at 0.05	0.30 C°	0.67925
T_min	not significant at 0.05	0.42C°	0.13369
Te_min	not significant at 0.05	0.75 C°	0.18416

SPRING



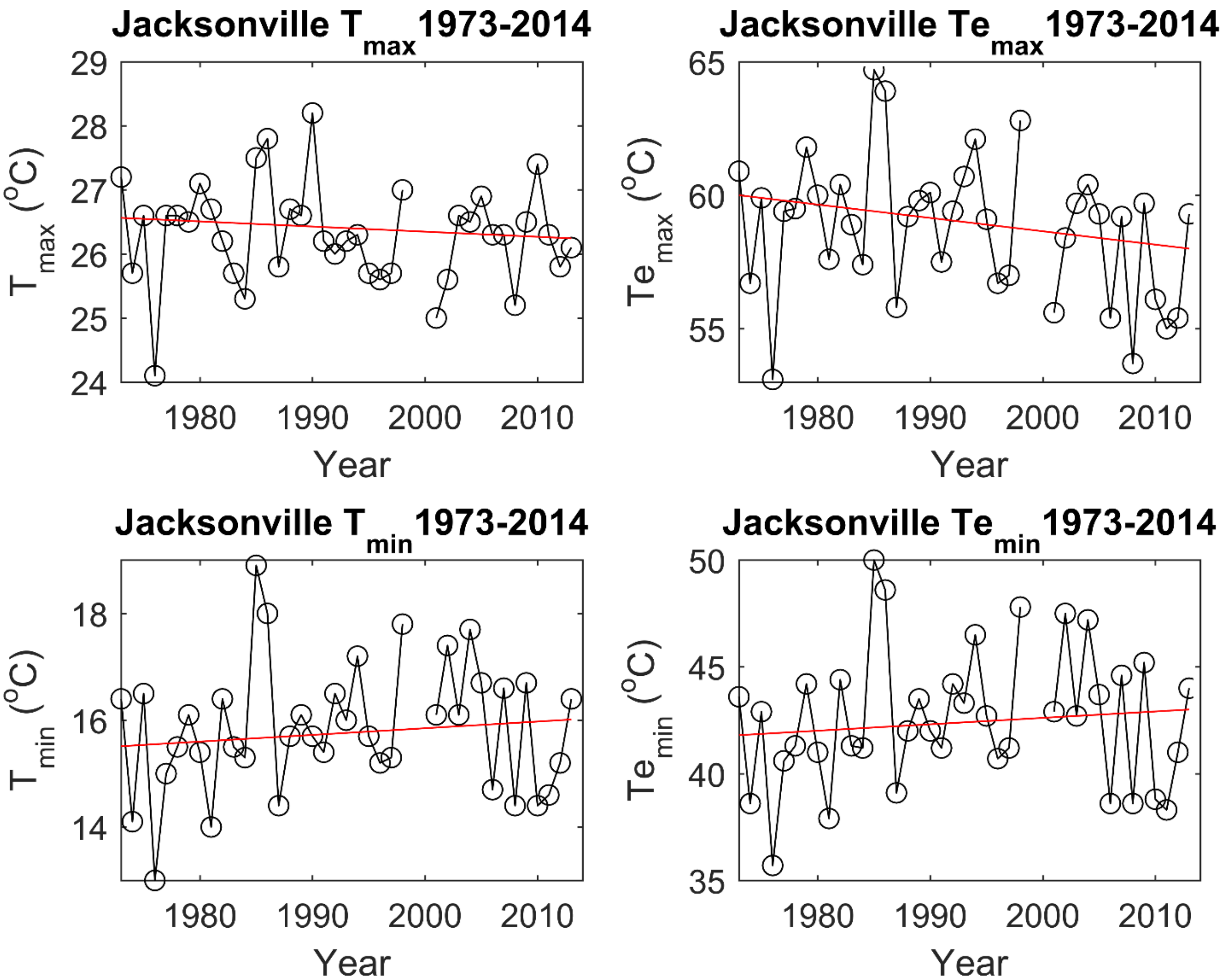
Spring-Mar, Apr, May	**Significance**	**Trend**	**P-Value**
T_max	not significant at 0.05	(-0.05C°)	0.53443
Te_max	not significant at 0.05	(-0.50C°)	0.09186
T_min	not significant at 0.05	(-0.06C°)	0.63753
Te_min	not significant at 0.05	(-0.06C°)	0.96017

SUMMER



Summer-June, July, August	**Significance**	**Trend**	**P-Value**
T_max	not significant at 0.05	(-0.00C°)	0.91058
Te_max	not significant at 0.05	(-0.17C°)	0.39576
T_min	is significant at 0.05	0.15C°	0.04695
Te_min	is significant at 0.05	0.82C°	0.00369

FALL



Fall-Sept, Oct, Nov	Significance	Trend	P-Value
T_max	not significant at 0.05	(-0.08C°)	0.35656
Te_max	not significant at 0.05	(-0.50C°)	0.05994
T_min	not significant at 0.05	0.12C°	0.45475
Te_min	not significant at 0.05	0.30C°	0.53789

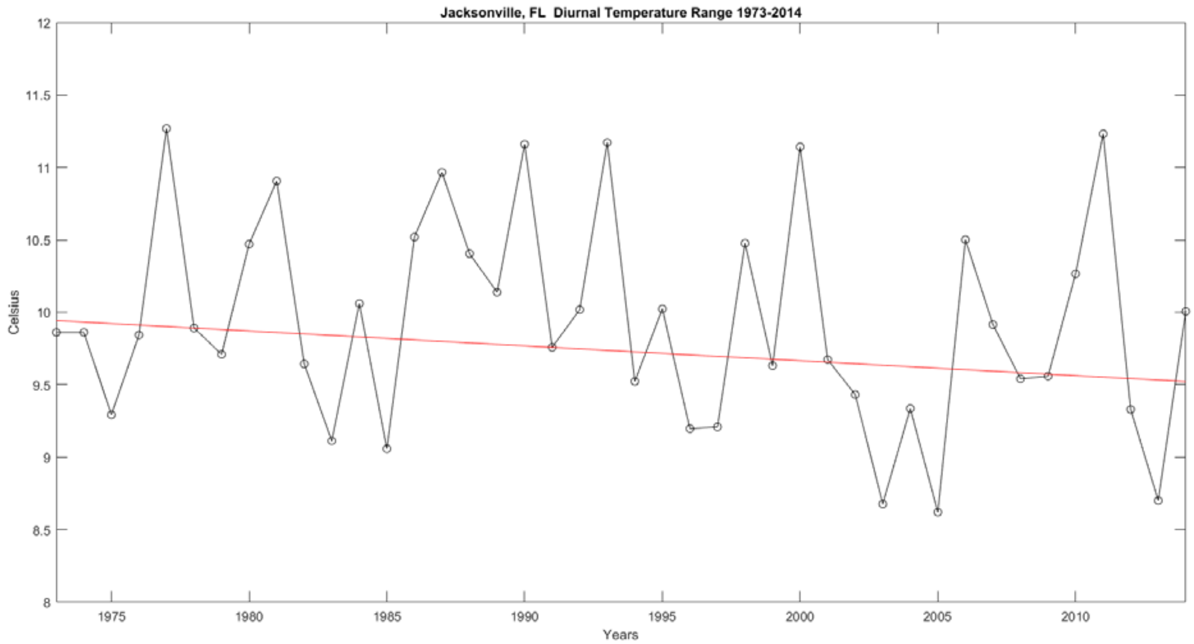
Two Tailed T-Tests: Station moves, instrument changes, DTS1 installation

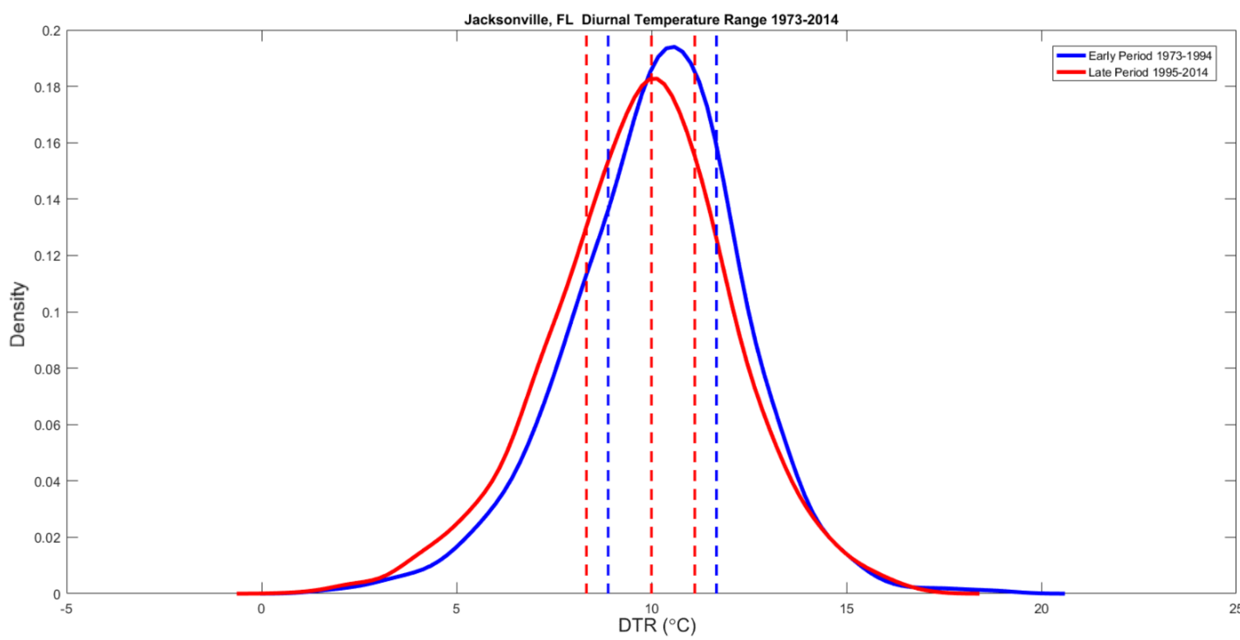
Jacksonville Int'l AP	**Dew Point**			**1985**	**estimated instrument changes**	
1981-1984	**1986-1989**					
T-Test						
	P-value	**CI-Lower**	**CI-Upper**	**T-statistic**	**Degrees of Freedom**	**Standard Deviation**
Tmax	0.3022	-0.9591	0.3008	-1.0374	94	1.5544
Tdmax	0.668	-0.5499	0.854	0.4302	94	1.7319
Tmin	0.527	-0.9372	0.483	-0.6349	94	1.7521
Tdmin	0.8974	-0.8372	0.9539	0.1293	94	2.2096

Jacksonville Int'l AP	**Dew Point**			**1995**	**estimated instrument change (unknown to Hygrothermometer) and station move 1.5 miles W**	
T-Test	**1991-1994**	**1996-1999**				
	P-value	**CI-Lower**	**CI-Upper**	**T-statistic**	**Degrees of Freedom**	**Standard Deviation**
Tmax	0.3331	-0.2788	0.8141	0.9733	89	1.3098
Tdmax	0.7882	-0.5044	0.6627	0.2695	89	1.39860
Tmin	0.502	-0.4159	0.843	0.6741	89	1.5087
Tdmin	0.7793	-0.893	0.6716	-0.2811	89	1.8751

Jacksonville Int'l AP	**Dew Point**		**1996**	**station move 1 mile NE (03/01/1996)**		
T-Test	**1991-1994**	**1996-1999**				
	P-value	**CI-Lower**	**CI-Upper**	**T-statistic**	**Degrees of Freedom**	**Standard Deviation**
Tmax	0.6599	-0.4673	0.7341	0.4416	84	1.3911
Tdmax	0.7533	-0.713	0.5179	-0.3153	84	1.42530
Tmin	0.1818	-1.0534	0.2028	-1.3464	84	1.4547
Tdmin	0.1482	-1.3758	0.2112	-1.4593	84	1.8376

Jacksonville Int'l AP				2004	DTS1 Installation 1/16/2004	
T-Test	2000-2003	2005-2008				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.0025	-1.4756	-0.326	-3.1153	86	1.3506
Tdmax	0.5227	-0.42	0.8205	0.6418	86	1.4575
Tmin	0.0366	0.0456	1.3886	2.1229	86	1.5778
Tdmin	0.0011	0.5773	2.2125	3.3915	86	1.9211


Jacksonville, FL Diurnal Temperature Range 1973-2014
Celsius
Years


Jacksonville, FL Diurnal Temperature Range 1973-2014
Early Period 1973-1994
Late Period 1995-2014
Density
DTR (°C)

APPENDIX E

Indianapolis

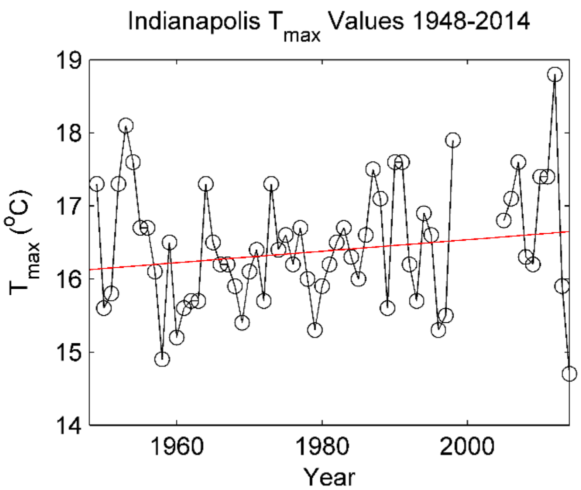
Indianapolis has a population of 820,445, land area per square mile is 361, and population density of 2270. The station had 6 instrument changes and one station move. T-tests reveal that an instrument change in 1962 had no effect on the time series. However, an estimated instrument change in 1964 may have affected T_{min}. In 1978 the station changed from a Hygrothermometer to a max/min thermometer, this change showed possible changes in dew point temperatures for both minimum and maximum. Estimated instrument changes in 1985 and 1995 showed no possible discontinuities, one more T-test was attempted for 1996 when the station changed from max/min thermometer to ATEMP/ASOS Hygrothermometer. The station was also moved 1.8 miles south in 1996, however no enough data was present for a T-Test, the results were inconclusive. The installation of Vaisala DTS1 in 2004 did show an inconsistency for T_{max} and $T_{d\ min}$. Seasonal trend analysis shows significant increases for T_{min} (0.22 C°) and $T_{E\ min}$ (0.41 C°). Significant increases for the same variables are also noticed in the Spring and Fall seasons. The analysis also shows a decrease of $T_{E\ max}$ in the summer, although not significant. Annual trend analysis also shows significant increases in T_{min} (0.18 C°) and $T_{E\ min}$ (0.30 C°). These results are very similar to one of the closest stations nearby in this study which is Columbus, OH.

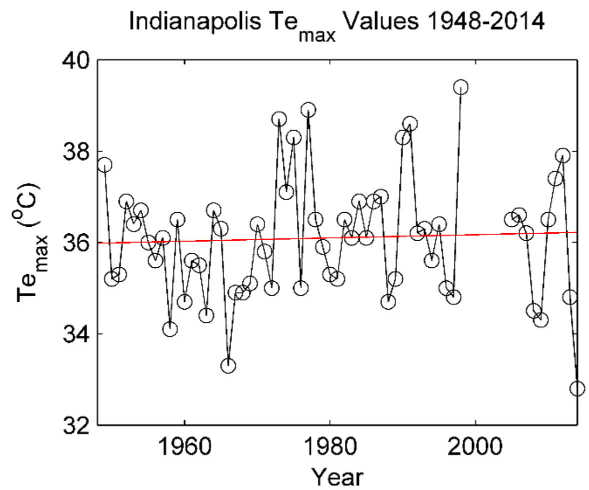
Indianapolis Int'l AP	**Station Metadata**		**Latitude: 39.7318**	
	WBAN# 93819		**Longitude: 86.2788**	
Year	**Ground Elevation(m)**	**Instruments**		**Comments**
1948-1962		unknown	temperature recorded daily, observation times unknown	
1962-1978	246.9 (1948-1966)	Hygrothermometer	temperature recorded daily, observation times 2400, Published flag CD, Receiver: NCEI only from (1962-1978)	
1978-1996	241.4 (1966-1996)	Max and min thermometers	Daily, Observation times 2400, Published flag CD, Receiver NCEI	
1996-2003		ATEMP/ASOS Hygrothermometer	Observation times 2400 from 1978-1988. Observation times from 1988-1996 daily 0700.	
2003-Present	240.8 (1996-present)	ATEMP/ASOS Hygrothermometer	Observation times 2400	
Station Moves				
Latitude	**Longitude**	**Initial**	**Final Date**	
39.73333		1/1/1931	1/1/1996	
	86.26667	1/1/1931	1/1/1966	
39.73333				
	86.28333	1/1/1966	9/30/1978	
39.7333				
	86.26667	9/30/1978	1/1/1996	
39.73167		1/1/1996	2/28/2006	
	86.27889	1/1/1996	2/28/2006	
39.7318		2/28/2006	5/12/2015	
	86.2788	2/28/2006	5/13/2015	
39.7318		5/12/2015	Present	
	86.2788	5/12/2015	Present	
T-test 1962	***instrument change from unknown to Hygrothermometer***			
T-test 1964	***estimated instrument changes***			
T-test 1978	***instrument change from Hygrothermometer to Max/min thermometer***			
T-test 1985	***estimated instrument changes***			
T-test 1995	***estimated instrument changes***			
T-Test 1996	***Instrument change from Max/min thermometer to ATEMP/ASOS Hygrothermometer. Station move 1.8 miles S (07/26/1996).***			
T-test 2004	**1/13/04 DTS1 Installation**			

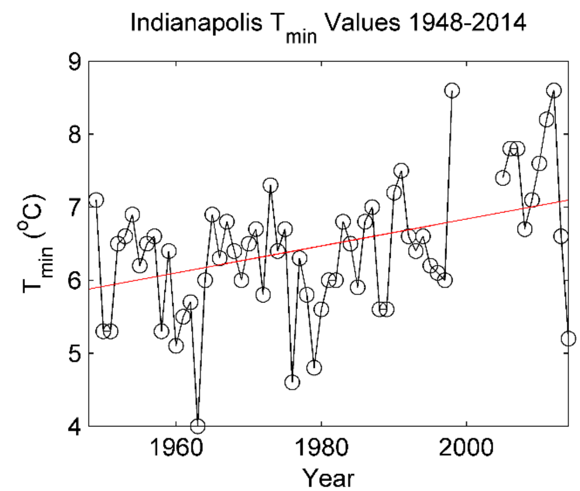
Indianapolis	Median Pairwise Slopes 95% confidence	Degrees Celsius per decade	
Seasonal			
Winter-Dec, Jan, Feb	**Significance**	**Trend**	**P-value**
T_max	not significant at 0.05	(-0.02C°)	0.74776
Te_max	not significant at 0.05	(-0.06C°)	0.74755
T_min	not significant at 0.05	0.06 C°	0.68196
Te_min	not significant at 0.05	0.09 C°	0.70778
Spring-Mar, Apr, May			
T_max	is significant at 0.05	0.22C°	0.03092
Te_max	not significant at 0.05	0.29C°	0.14052
T_min	is significant at 0.05	0.25C°	0.00724
Te_min	is significant at 0.05	0.39C°	0.01867
Summer-June, July, August			
T_max	not significant at 0.05	0.00C°	0.8632
Te_max	not significant at 0.05	(-0.10C°)	0.59802
T_min	is significant at 0.05	0.22C°	0.00179
Te_min	is significant at 0.05	0.41C°	0.01425
Fall-Sept, Oct, Nov			
T_max	not significant at 0.05	0.00C°	0.92642
Te_max	not significant at 0.05	(-0.05C°)	0.76046
T_min	is significant at 0.05	0.25C°	0.00195
Te_min	is significant at 0.05	0.36C°	0.02721

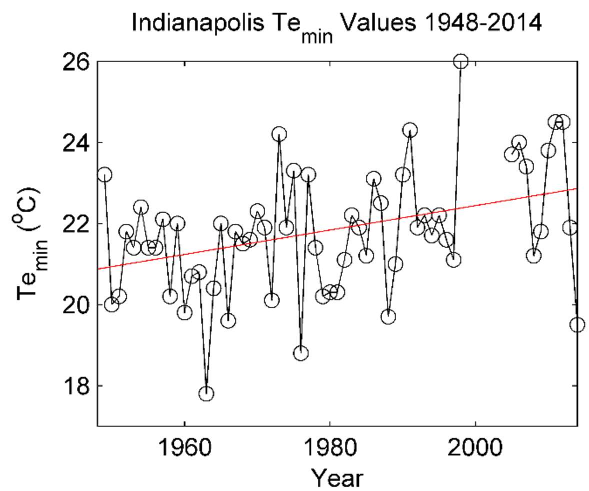
Indianapolis	95% confidence	Degrees Celsius per decade	
Annual Trend			
	Significance	**Trend**	**P-value**
T_max	not significant at 0.05	0.08C°	0.26625
Te_max	not significant at 0.05	0.04C°	0.67795
T_min	is significant at 0.05	0.18C°	0.0039
Te_min	is significant at 0.05	0.30C°	0.00589

ANNUAL TREND





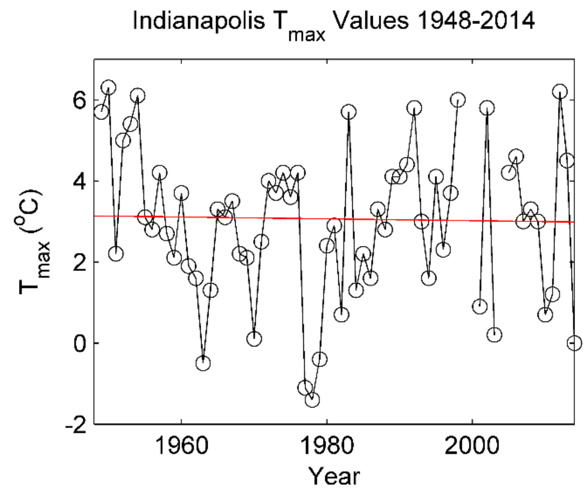


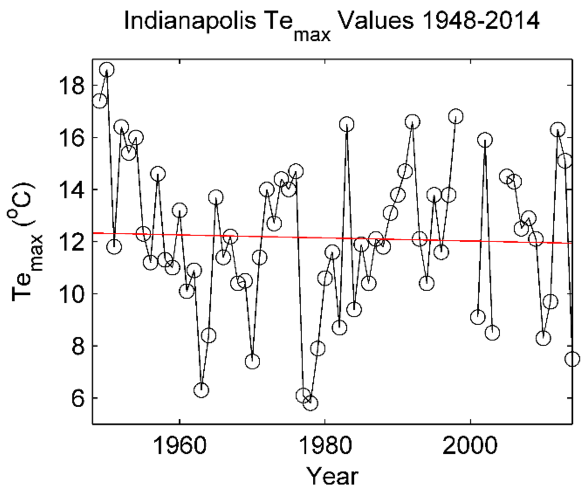


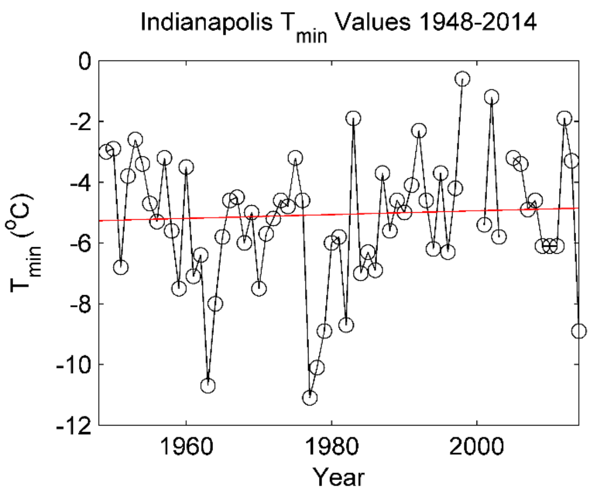
Indianapolis	**95% confidence**	**Degrees Celsius per decade**	
Annual Trend			
	Significance	**Trend**	**P-value**
T_max	not significant at 0.05	0.08C°	0.26625
Te_max	not significant at 0.05	0.04C°	0.67795
T_min	is significant at 0.05	0.18C°	0.0039
Te_min	is significant at 0.05	0.30C°	0.00589

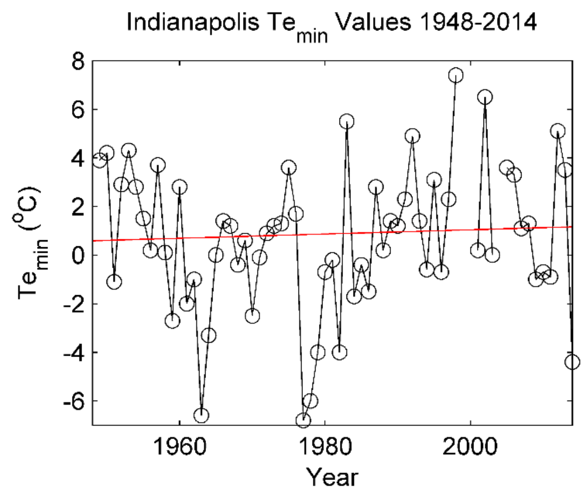
SEASONAL TRENDS

WINTER



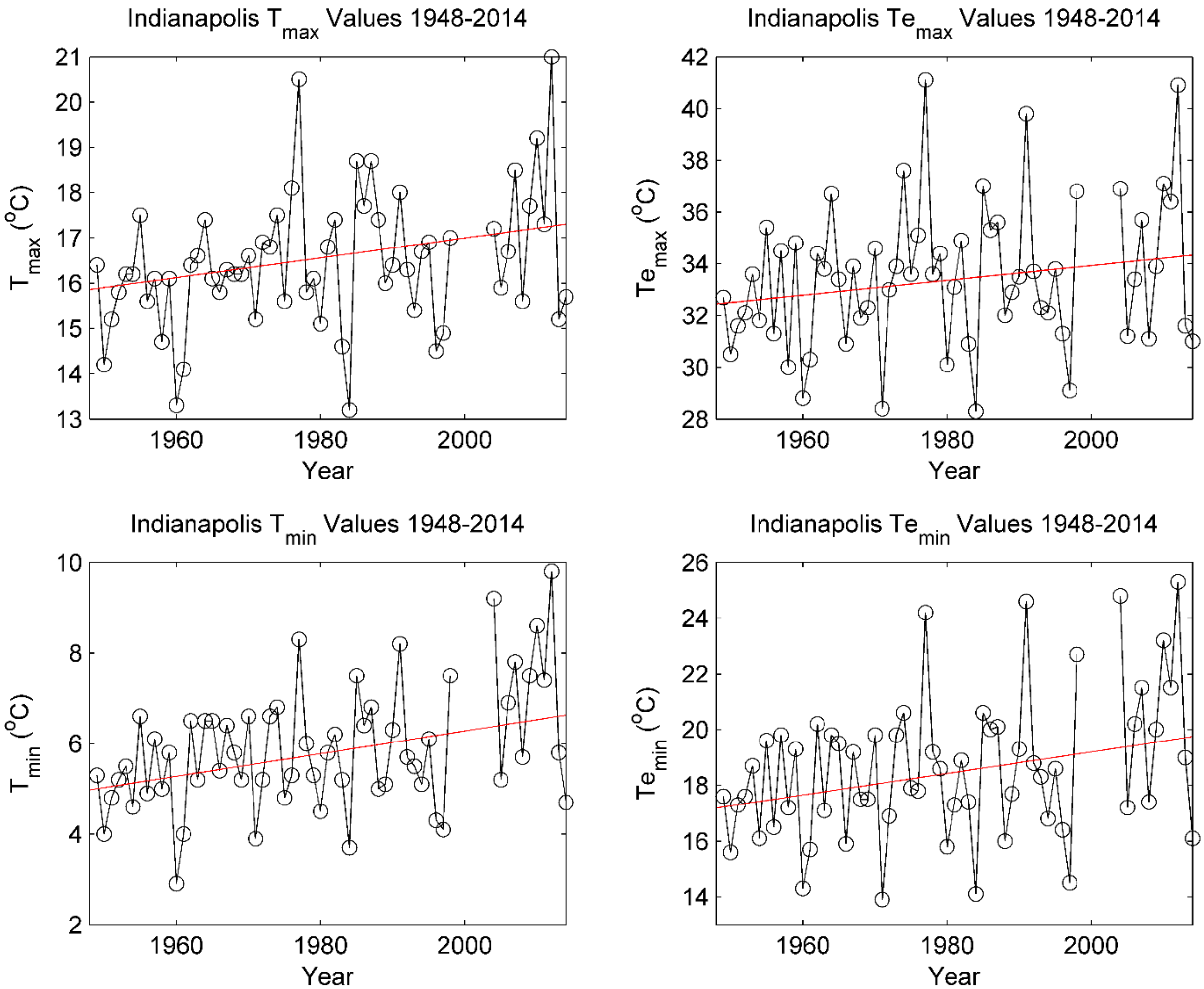






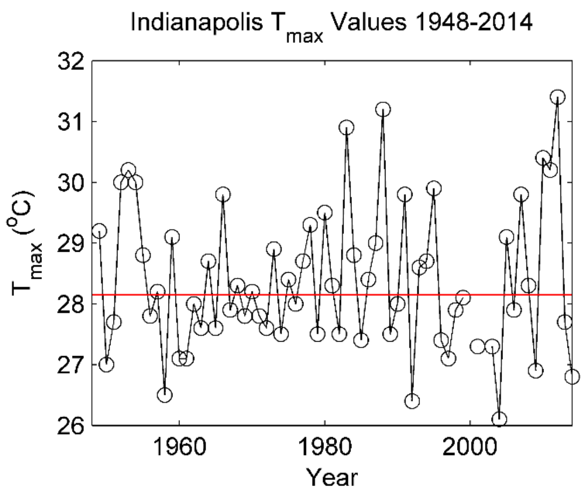
Winter-Dec, Jan, Feb	**Significance**	**Trend**	**P-value**
T_max	not significant at 0.05	(-0.02C°)	0.74776
Te_max	not significant at 0.05	(-0.06C°)	0.74755
T_min	not significant at 0.05	0.06 C°	0.68196
Te_min	not significant at 0.05	0.09 C°	0.70778

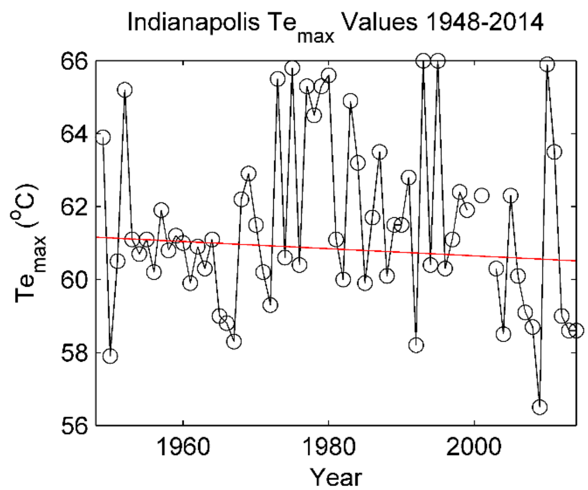
SPRING

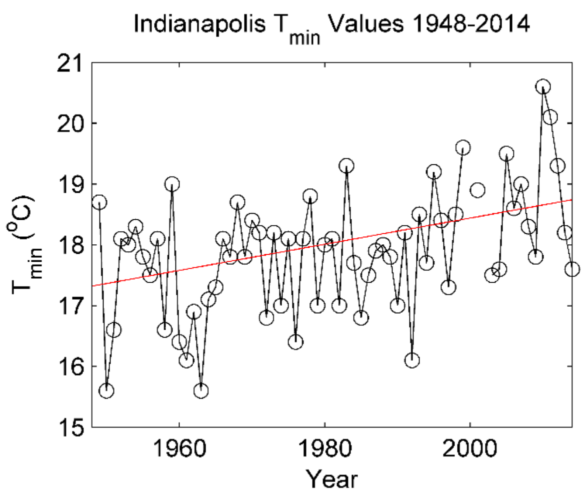


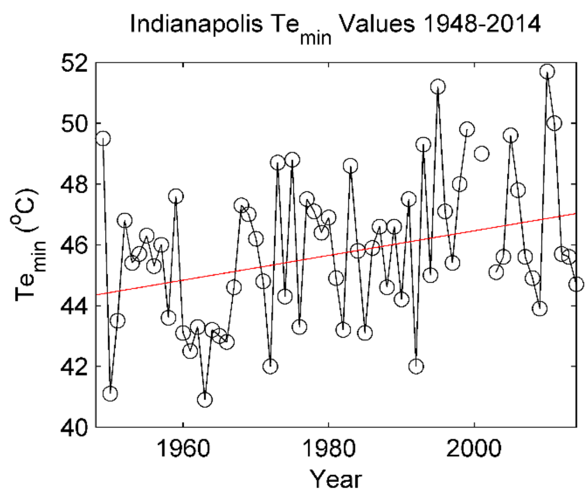
Spring-Mar, Apr, May	**Significance**	**Trend**	**P-Value**
T_max	is significant at 0.05	0.22C°	0.03092
Te_max	not significant at 0.05	0.29C°	0.14052
T_min	is significant at 0.05	0.25C°	0.00724
Te_min	is significant at 0.05	0.39C°	0.01867

SUMMER



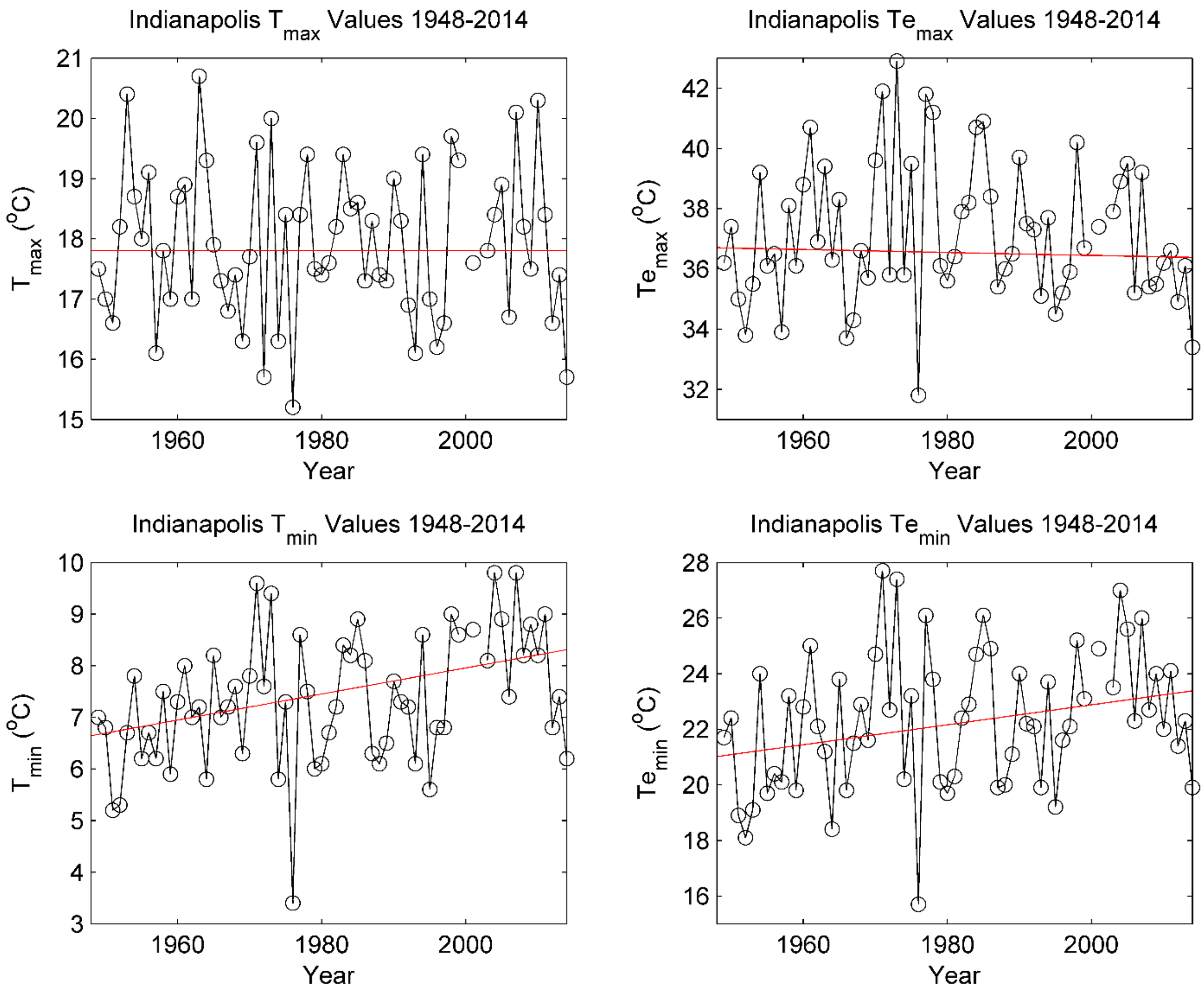






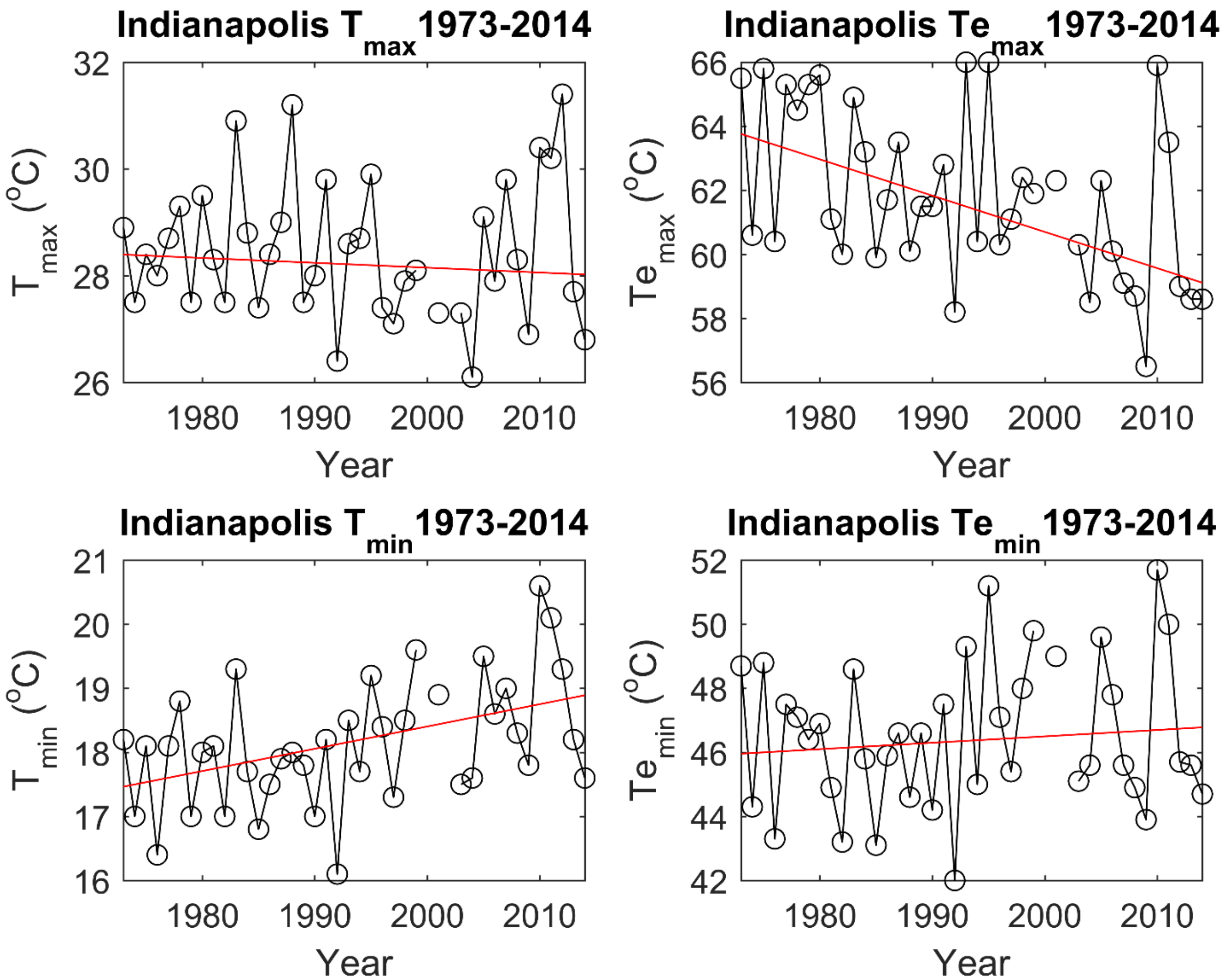
Summer-June, July, August			
T_max	not significant at 0.05	0.00C°	0.8632
Te_max	not significant at 0.05	(-0.10C°)	0.59802
T_min	is significant at 0.05	0.22C°	0.00179
Te_min	is significant at 0.05	0.41C°	0.01425

FALL



Fall-Sept, Oct, Nov	**Significance**	**Trend**	**P-value**
T_max	not significant at 0.05	0.00C°	0.92642
Te_max	not significant at 0.05	(-0.05C°)	0.76046
T_min	is significant at 0.05	0.25C°	0.00195
Te_min	is significant at 0.05	0.36C°	0.02721

SUMMER 1973-2014



Summer-June, July,August	Significance	Trend	P-Value
T_max	not significant at 0.05	-0.09	0.54543
Te_max	is significant at 0.05	-1.13	0.00396
T_min	is significant at 0.05	0.35	0.00833
Te_min	not significant at 0.05	0.2	0.53185

Two Tailed T-Tests: Station moves, instrument changes, DTS1 installation

Indianapolis	Dew Point		1962	*Instrument change from unknown to Hygrothermometer*		
T-Test	1960-1963	1965-1968				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.0674	-1.7406	0.0615	-1.8501	94	2.2232
Tdmax	0.1368	-0.2074	1.4907	1.5005	94	2.095
Tmin	0.6608	-1.1022	0.7022	-0.4402	94	2.226
Tdmin	0.1579	-0.2673	1.6214	1.4236	94	2.3301

Indianapolis	Dew Point		1964	Estimated instrument change		
T-Test	1960-1963	1965-1968				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.195	-1.4654	0.3029	-1.3053	94	2.1815
Tdmax	0.3866	-0.4703	1.2037	0.8698	94	2.06510
Tmin	8.59E-04	-2.286	-0.614	-3.4437	94	2.0627
Tdmin	0.5553	-1.2064	0.6522	-0.592	94	2.293

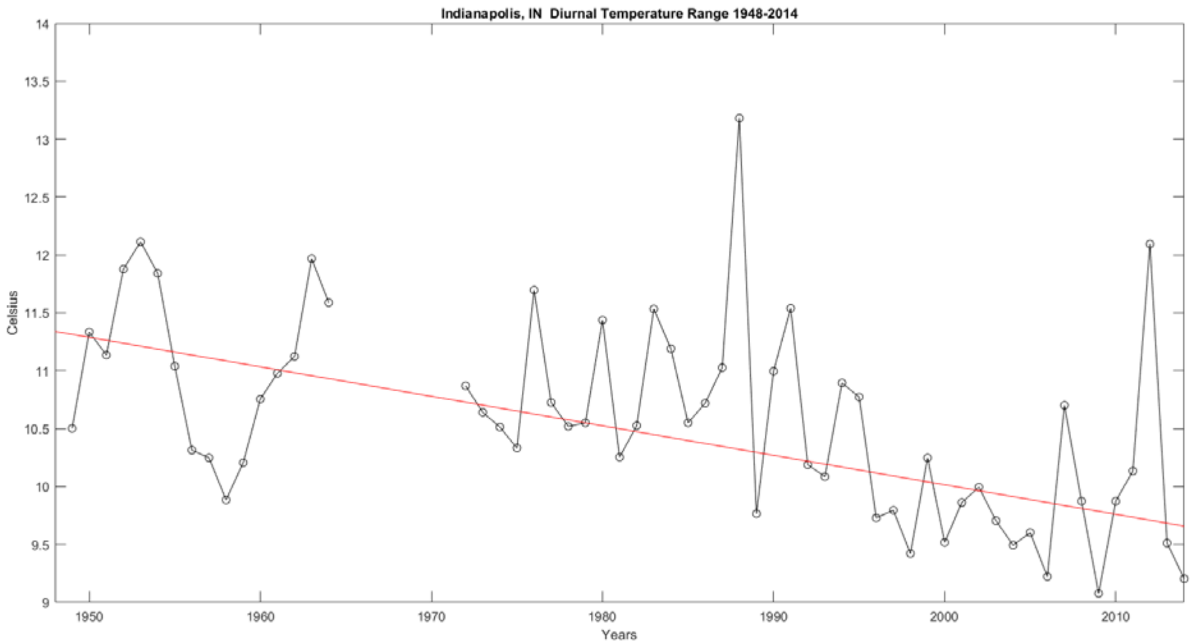
Indianapolis	Dew Point		1978		Instrument change from Hygrothermometer to Max/min thermometer	
1974-1977	1979-1982					
Two-Tailed T-Test						
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.2954	-0.4416	1.4374	1.0523	94	2.318
Tdmax	0.0093	0.3	2.0792	2.6551	94	2.1949
Tmin	0.4412	-0.5843	1.3302	0.7735	94	2.3619
Tdmin	0.0213	0.1794	2.1831	2.3411	94	2.4719

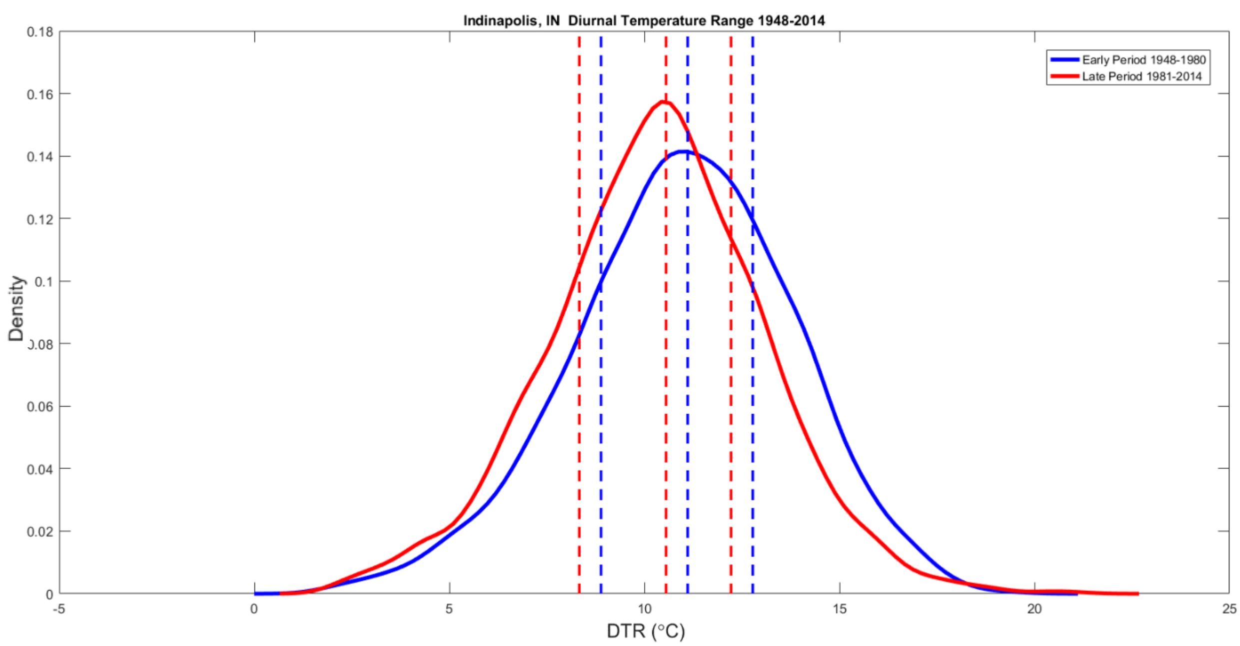
Indianapolis	Dew Point		1985	Estimated instrument change		
1981-1984	1986-1989					
Two-Tailed T-Test						
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.5814	-1.1949	0.6741	-0.5533	94	2.3057
Tdmax	0.8791	-0.7759	0.9051	0.1526	94	2.0739
Tmin	0.8614	-0.8186	0.9769	0.1751	94	2.215
Tdmin	0.8265	-1.0871	0.8704	-0.2198	94	2.4149

Indianapolis	Dew Point		1995	Estimated Instrument change		
T-Test	1991-1994	1996-1999				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.5251	-0.5289	1.0292	0.638	90	1.8788
Tdmax	0.7191	-0.6139	0.8864	0.3608	90	1.80920
Tmin	0.4134	-1.1157	0.4628	-0.8217	90	1.9034
Tdmin	0.6655	-1.0914	0.7002	-0.4337	90	2.1604

Indianapolis	Dew Point			1996	***Instrument change from Max/min thermometer to ATEMP/ASOS Hygrothermometer. Station move 1.8 miles S (07/26/1996).***	
T-Test	1992-1995	1997-2000				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	NaN	NaN	NaN	NaN	NaN	NaN
Tdmax	NaN	NaN	NaN	NaN	NaN	NaN
Tmin	NaN	NaN	NaN	NaN	NaN	NaN
Tdmin	NaN	NaN	NaN	NaN	NaN	NaN

Indianapolis	Dew Point		2004	01/13/2004 DTS1 Installation		
T-Test	1999-2003	2005-2008				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	**0.0431**	**-1.8649**	**-0.0303**	**-2.0519**	**91**	**2.2256**
Tdmax	0.8274	-0.7139	0.8906	0.2187	91	1.9465
Tmin	0.6238	-0.6218	1.0313	0.4921	91	2.0054
Tdmin	**0.0285**	**0.1072**	**1.8911**	**2.2252**	**91**	**2.164**


Indianapolis, IN Diurnal Temperature Range 1948-2014
Celsius
Years


Indianapolis, IN Diurnal Temperature Range 1948-2014
Early Period 1948-1980
Late Period 1981-2014
Density
DTR (°C)

APPENDIX F

Columbus

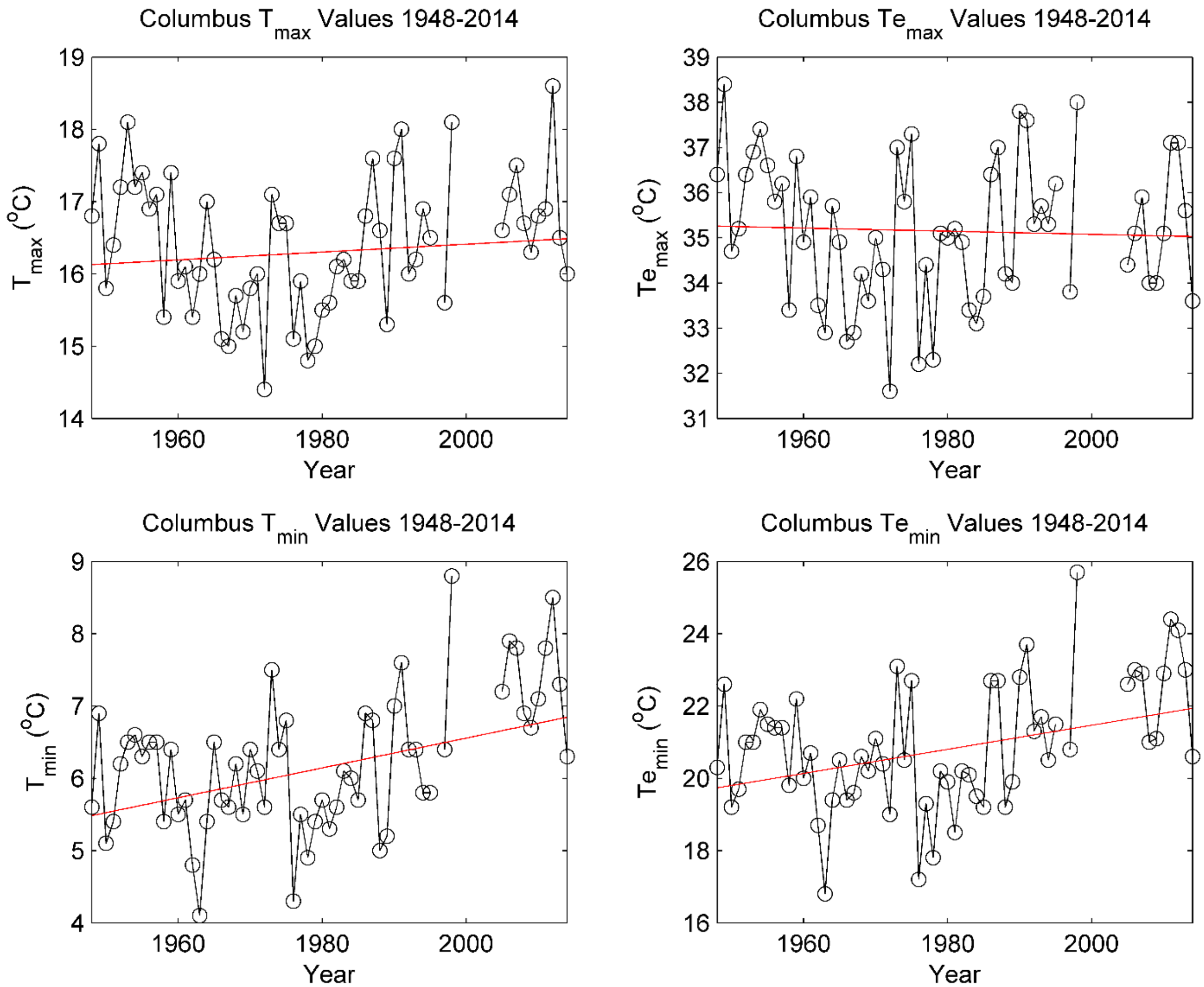
Columbus, Ohio has 787,033 residents, land area per square mile is 217, with a population density of 3,624 (US Census, 2010). The Columbus International Airport experienced 2 confirmed instrument changes, two estimated instrument changes and one move. In 1964 the station changed the max/min thermometer to a hygrothermometer, t-tests show a change in T_{min} for this year. An estimated instrument change in 1985 shows no effect on the time series, however a similar change in 1995 shows T_{min} being affected once again. In 1996 the station was moved 1.5 miles southeast, once again T_{min} shows a possible inhomogeneity. The station did not experience any other changes until the installation of the Vaisala DTS1 equipment in 2004, t-test show a possible inconsistency in T_{max} and $T_{d\ min}$. Seasonal trend analysis for summer shows significant increases in T_{min} (0.31C°) and $T_{E\ min}$ (0.62C°). Similar to Indianapolis these increases are also present in the spring and fall time series as well as the annual trend. In the shorter record from 1973 a significant decrease in $T_{E\ max}$ is present -1.13 C° along with a significant increase of T_{min} 0.35 C°.

Columbus Port Columbus Int'l AP	**Station Metadata**		**Latitude: 39.9942**	
	WBAN#14821		**Longitude : 82.8767**	
Year	**Site (m)**	**Instruments**		**Comments**
1948-1964	253.0 (1948-1959)	Max/min thermometer		Daily, reporting method unknown.
1964-1976	247.8 (1959-1998)	Hygrothermometer		Receiver NCEI, reporting method unknown.
1976-1996	246.9 (1998-Present)	Hygrothermometer		Receiver NCEI, reporting method: MF1-10
1996-2016		Hygrothermometer		Daily, obs times 2700, reporting method: ASOS-Era Data Downloaded to NCDC
2016-Present		ATEMP: ASOS Hygrothermometer		Daily, obs times 2400, reporting method: ASOS-Era Data Downloaded to NCDC
Station Moves				
Latitude	**Longitude**	**Initial**	**Final Date**	
39.98333		7/1/1929	1/1/1959	
	82.86667	7/1/1929	1/1/1959	
40		1/1/1959	2/1/1996	
	82.88333	1/1/1959	2/1/1996	
39.9942		2/1/1996	Present	
	82.8767	2/1/1996	Present	
T-test 1964	**Instrument change: Max/min thermometer to Hygrothermometer**			
T-test 1985	**estimated instrument change**			
T-test 1995	**estimated instrument change**			
T-test 1996	**station move 1.5 miles SSE (02/02/1996)**			
T-test 2004	**DTS1 installation 2/10/2004**			

Columbus Int'l AP	**Median Pairwise Slopes 95% confidence**	**Degrees Celsius per decade**	
Seasonal Trends			
Winter-Dec, Jan, Feb	**Significance**	**Trend**	**P-value**
T_max	not significant at 0.05	0.03C°	0.91473
Te_max	not significant at 0.05	(-0.00C°)	0.84851
T_min	not significant at 0.05	0.14C°	0.35402
Te_min	not significant at 0.05	0.16C°	0.44754
Spring-Mar, Apr, May			
T_max	not significant at 0.05	0.16C°	0.06095
Te_max	not significant at 0.05	0.04C°	0.79889
T_min	is significant at 0.05	0.22C°	0.00618
Te_min	is significant at 0.05	0.27C°	0.04076
Summer-June, July, August			
T_max	not significant at 0.05	(-0.02C°)	0.83949
Te_max	not significant at 0.05	(-0.08C°)	0.65188
T_min	is significant at 0.05	0.31C°	0
Te_min	is significant at 0.05	0.62C°	0.0002
Fall-Sept, Oct, Nov			
T_max	not significant at 0.05	(-0.06C°)	0.4335
Te_max	not significant at 0.05	(-0.13C°)	0.33348
T_min	is significant at 0.05	0.21C°	0.00231
Te_min	is significant at 0.05	0.29C°	0.02634

Columbus Int'l AP	**Median Pairwise Slopes 95% confidence**	**Degrees Celsius per decade**	
Annual Trend			
	Significance	**Trend**	**P-value**
T_max	not significant at 0.05	0.05C°	0.54346
Te_max	not significant at 0.05	(-0.03C°)	0.77704
T_min	is significant at 0.05	0.21C°	0.00048
Te_min	is significant at 0.05	0.33C°	0.00269

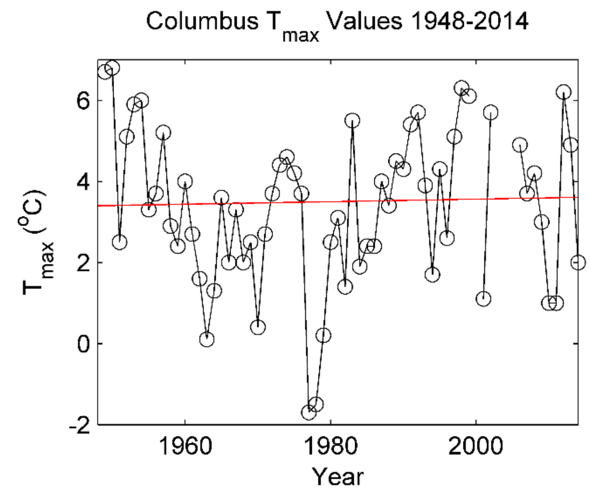
ANNUAL TREND

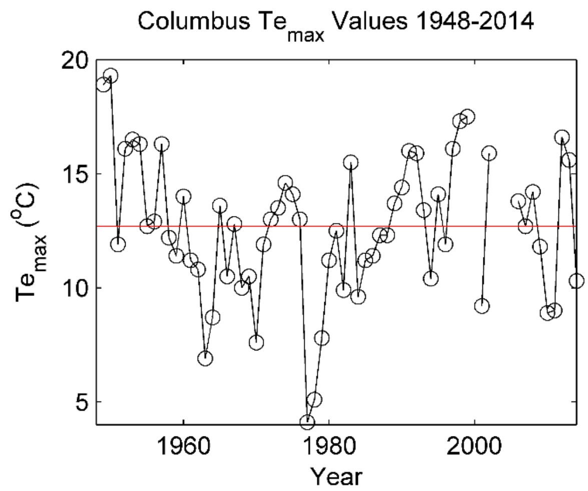


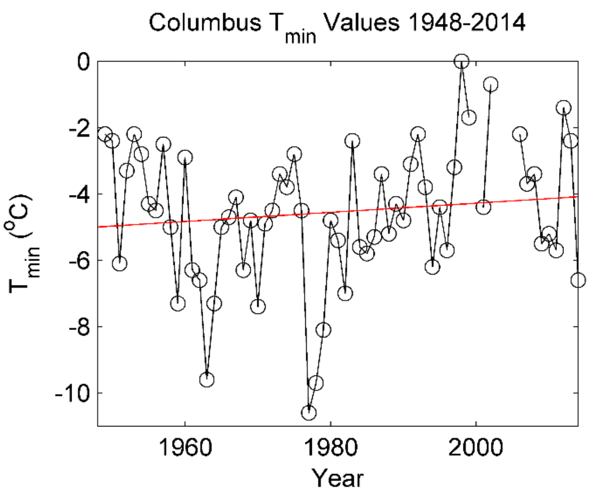
Columbus	**95% confidence**	**Degrees Celsius per decade**	
Annual Trend			
	Significance	**Trend**	**P-value**
T_max	not significant at 0.05	0.05C°	0.54346
Te_max	not significant at 0.05	(-0.03C°)	0.77704
T_min	is significant at 0.05	0.21C°	0.00048
Te_min	is significant at 0.05	0.33C°	0.00269

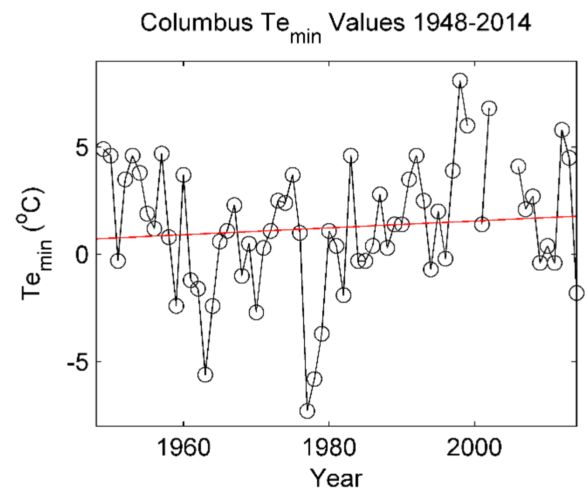
SEASONAL TRENDS

WINTER



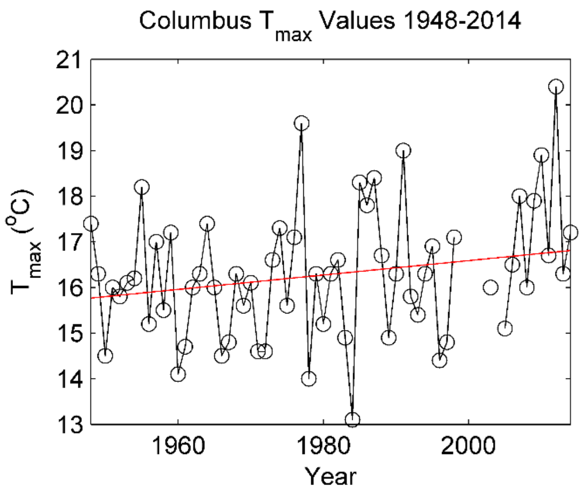


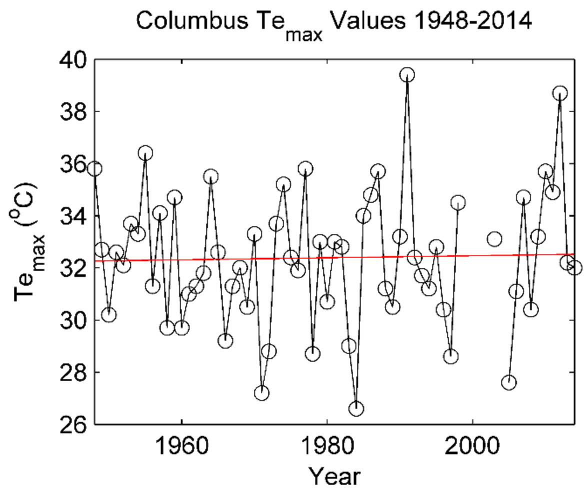


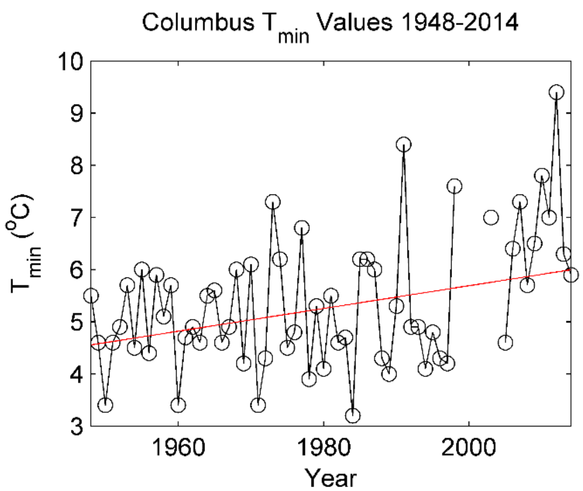


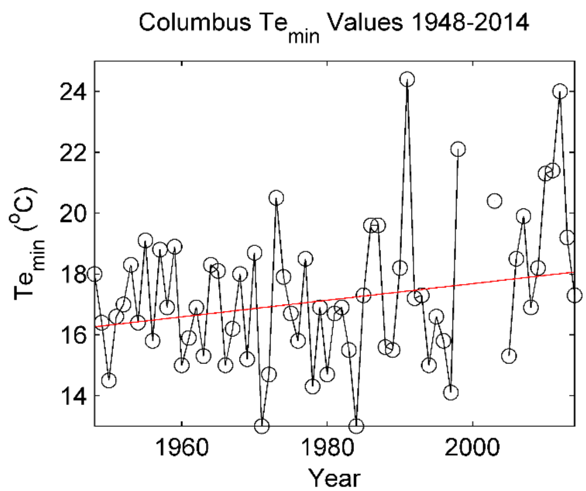
Winter-Dec, Jan, Feb	**Significance**	**Trend**	**P-value**
T_max	not significant at 0.05	0.03C°	0.91473
Te_max	not significant at 0.05	(-0.00C°)	0.84851
T_min	not significant at 0.05	0.14C°	0.35402
Te_min	not significant at 0.05	0.16C°	0.44754

SPRING



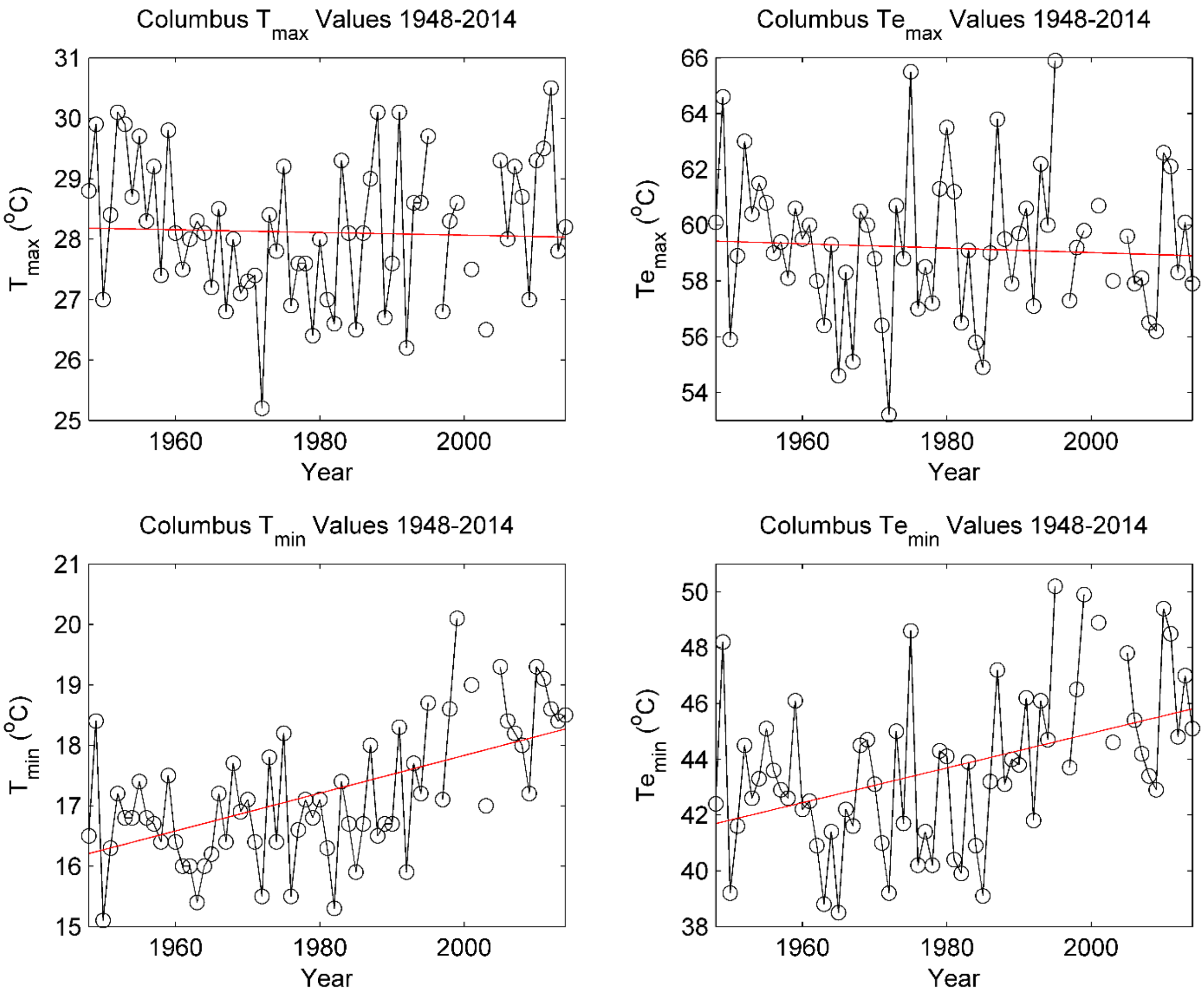






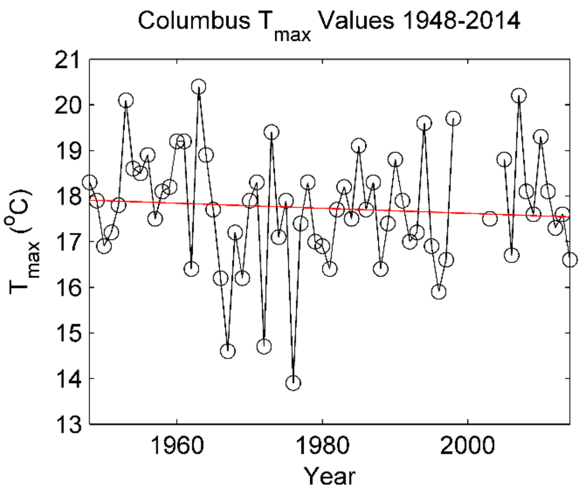
Spring-Mar, Apr, May	**Significance**	**Trend**	**P-value**
T_max	not significant at 0.05	0.16C°	0.06095
Te_max	not significant at 0.05	0.04C°	0.79889
T_min	is significant at 0.05	0.22C°	0.00618
Te_min	is significant at 0.05	0.27C°	0.04076

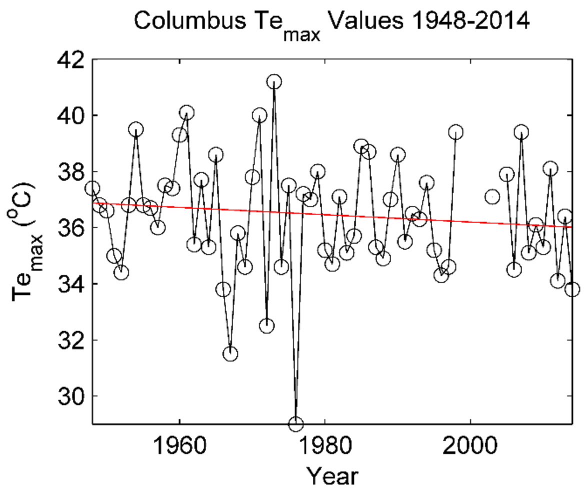
SUMMER

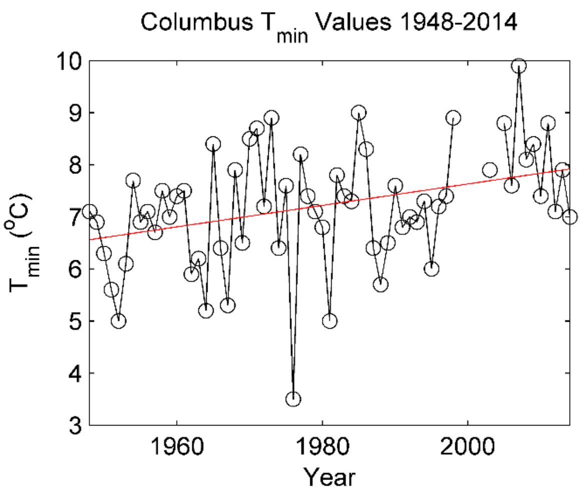


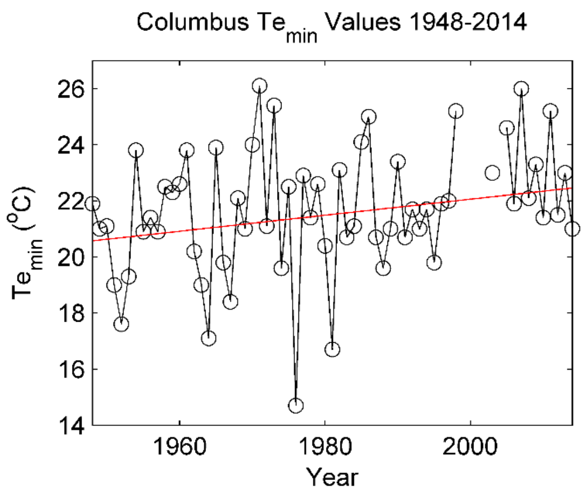
Summer-June, July, August			
T_max	not significant at 0.05	(-0.02C°)	0.83949
Te_max	not significant at 0.05	(-0.08C°)	0.65188
T_min	is significant at 0.05	0.31C°	0
Te_min	is significant at 0.05	0.62C°	0.0002

FALL



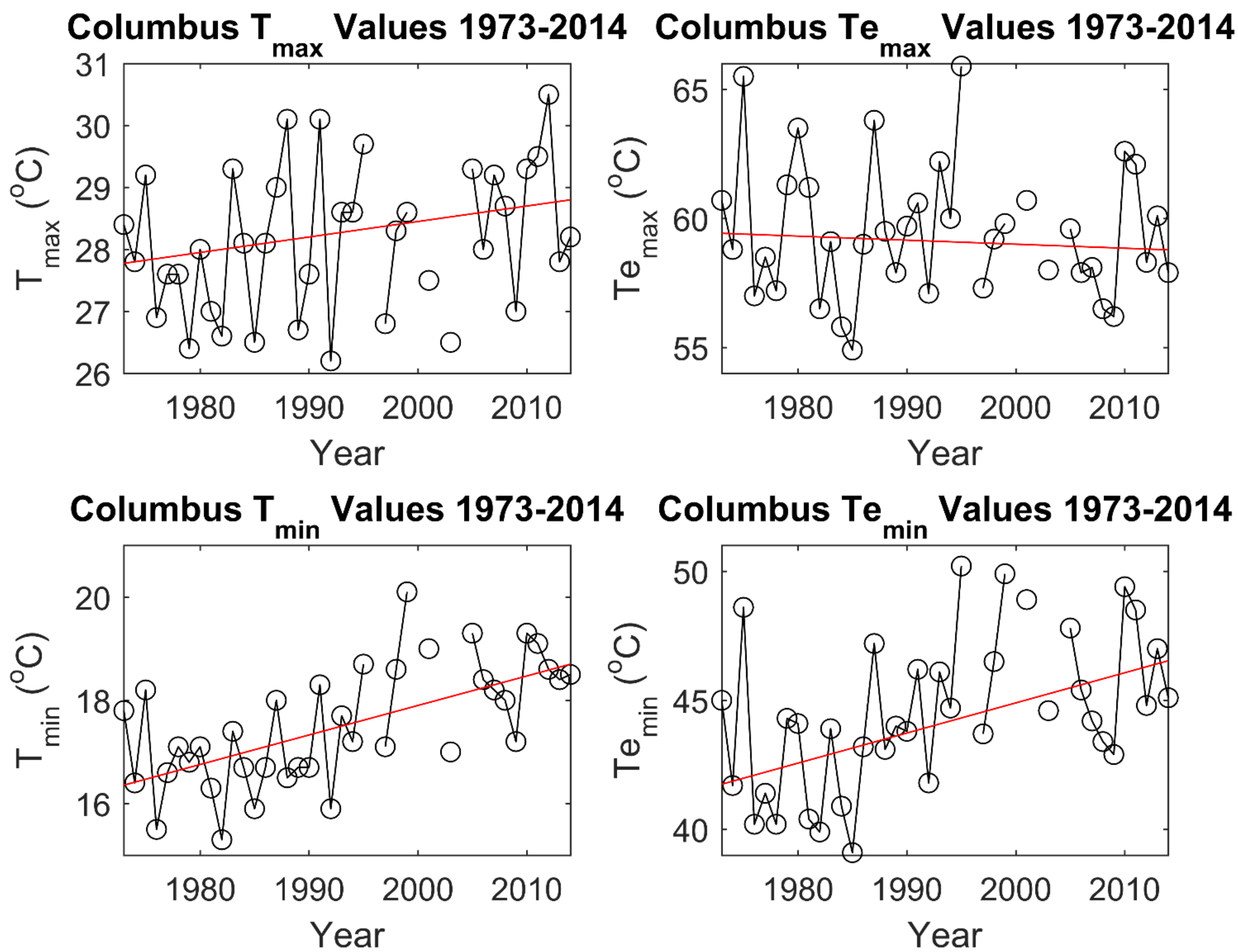






Fall-Sept, Oct, Nov	**Significance**	**Trend**	**P-value**
T_max	not significant at 0.05	(-0.06C°)	0.4335
Te_max	not significant at 0.05	(-0.13C°)	0.33348
T_min	is significant at 0.05	0.21C°	0.00231
Te_min	is significant at 0.05	0.29C°	0.02634

SUMMER 1973-2014



Summer-June, July,August	Significance	Trend	P-Value
T_max	not significant at 0.05	-0.09 C°	0.54543
Te_max	is significant at 0.05	-1.13 C°	0.00396
T_min	is significant at 0.05	0.35 C°	0.00833
Te_min	not significant at 0.05	0.2 C°	0.53185

Two Tailed T-Tests: Station moves, instrument changes, DTS1 installation

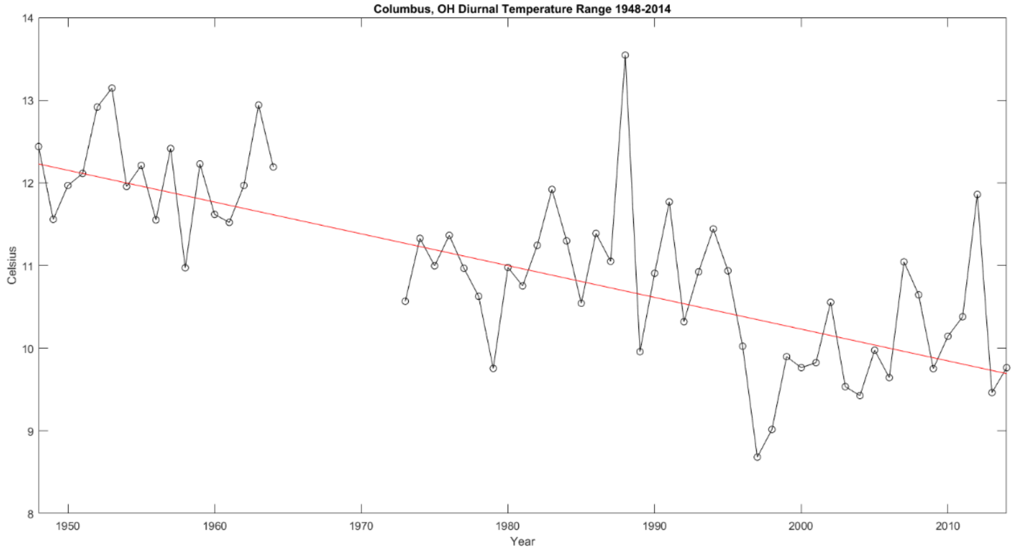
Columbus	Dew Point			1964	Instrument change: Max/min thermometer to Hygrothermometer	
T-Test	1960-1963	1965-1968				
Tmax	0.4131	-0.5308	1.2808	0.822	94	2.2349
Tdmax	0.4042	-0.4765	1.1723	0.8379	94	2.03410
Tmin	0.0188	-1.8155	-0.1679	-2.3901	94	2.0326
Tdmin	0.4427	-1.2738	0.5613	-0.7709	94	2.2639

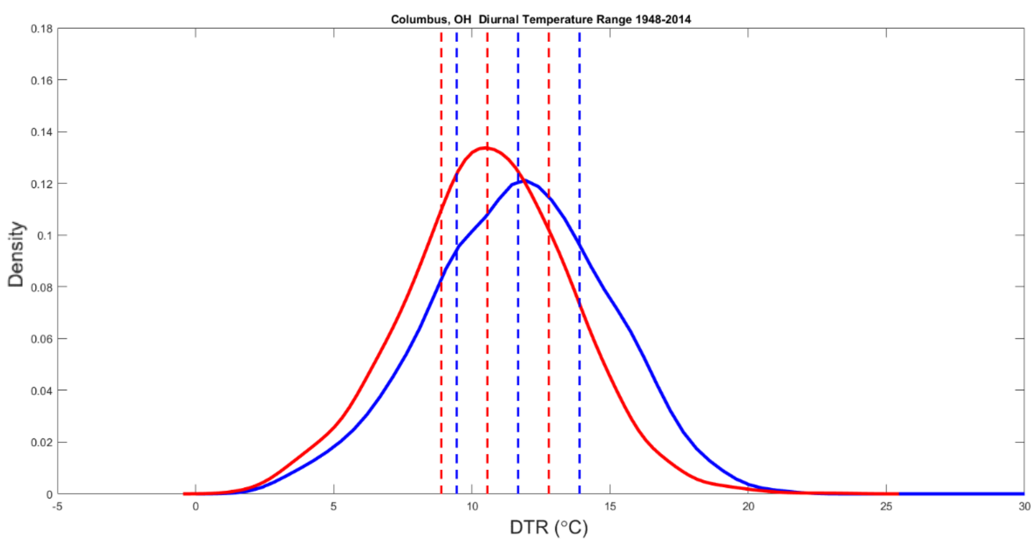
Columbus	Dew Point			1985	estimated instrument change	
Two-Tailed T-Test	1981-1984	1986-1989				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.1657	-1.5032	0.2616	-1.397	94	2.1772
Tdmax	0.0958	-1.4672	0.1213	-1.6822	94	1.9597
Tmin	0.5357	-1.066	0.5577	-0.6216	94	2.0031
Tdmin	0.0611	-1.7659	0.0409	-1.8955	94	2.2291

Columbus	Dew Point			1995	Estimated instrument changes	
T-Test	1991-1994	1996-1999				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.4975	-0.5428	1.1091	0.6813	88	1.9671
Tdmax	0.7525	-0.6079	0.838	0.3163	88	1.72160
Tmin	0.0375	-1.6501	-0.0502	-2.1119	88	1.9052
Tdmin	0.5812	-1.1148	0.629	-0.5536	88	2.0764

Columbus	Dew Point			1996	Station move 1.5 miles SSE (02/02/1996)	
T-Test	1992-1995	1997-2000				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.6738	-1.0838	0.7041	-0.4225	82	2.0381
Tdmax	0.9595	-0.7687	0.8091	0.051	82	1.79870
Tmin	3.08E-04	-2.4949	-0.7709	-3.7685	82	1.9653
Tdmin	0.0797	-1.7645	0.1008	-1.7744	82	2.1264

Columbus	Dew Point			2004	DTS1 installation 02/10/2004	
T-Test	2000-2003	2005-2008				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.0107	-2.2629	-0.3067	-2.6147	79	2.173
Tdmax	0.7446	-0.6883	0.9588	0.3269	79	1.8297
Tmin	0.4641	-0.5502	1.1953	0.7357	79	1.9389
Tdmin	3.89E-04	0.7434	2.4688	3.7057	79	1.9167


Columbus, OH Diurnal Temperature Range 1948-2014
Celsius
Year


Columbus, OH Diurnal Temperature Range 1948-2014
Density
DTR (°C)

APPENDIX G

Charlotte

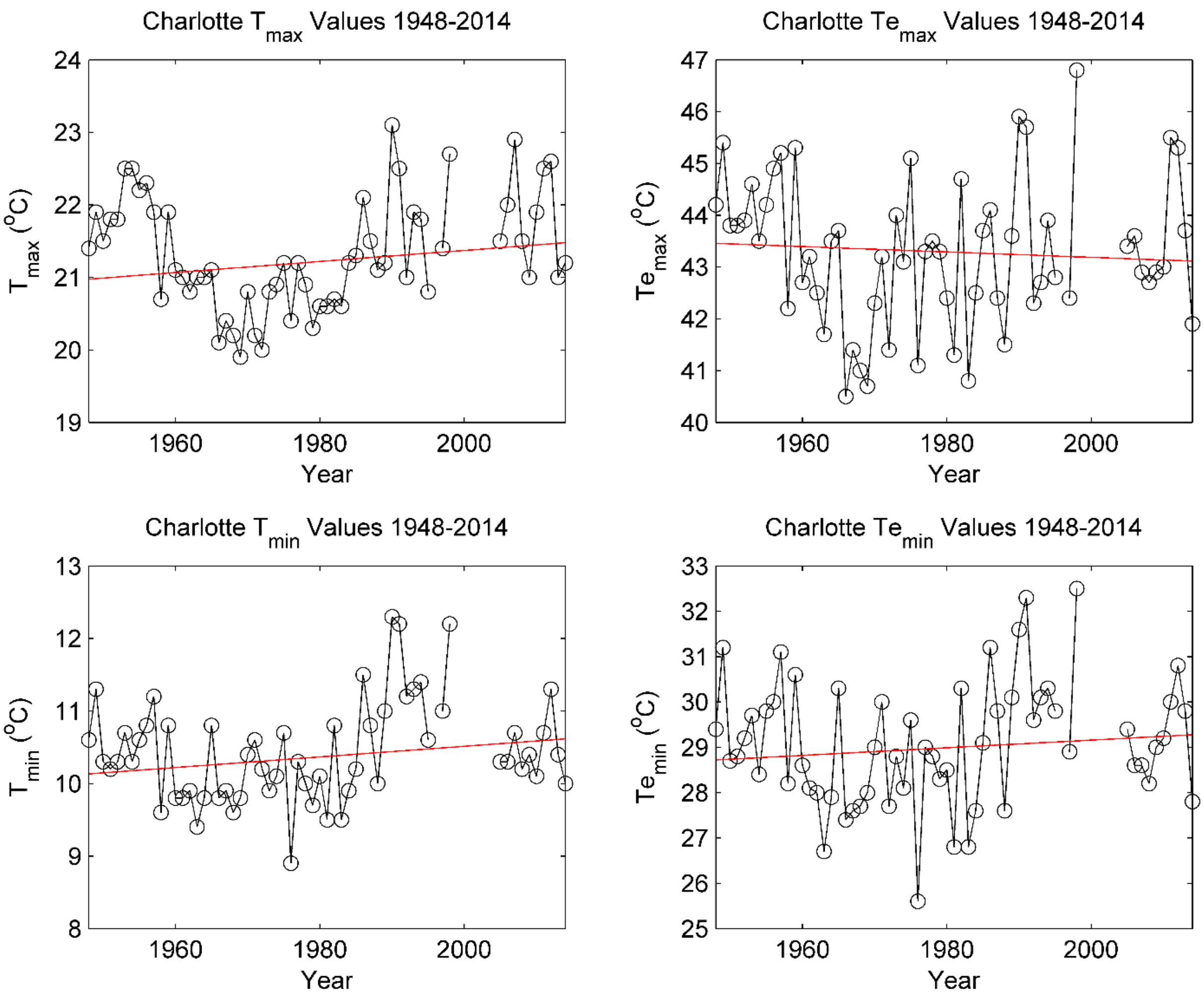
The city of Charlotte, NC is home to 731,424 people, it has a land area of 298 and population density is 2,457 (US Census, 2010). Seasonal summer trend analysis shows a significant increase in T_{min}, but no other variable. $T_{E\ min}$ showed an increase, but it was not significant. Interestingly, the similar results are present in in the annual trend, increases are noted, but they are not statistically significant. When looking at the shorter record starting in 1973, positive trends are noted, but none are significant. This station was never moved, it did experience 2 confirmed instrument changes and several estimated instrument changes. T-tests for estimated instrument changes in 1964 show no impacts, however 1985 seems to have affected the T_{min}. In 1989 the metadata entry changed from unknown instrument to Hygrothermometer, this also had an effect on T_{min}. An estimated instrument change in 1995, showed no significant results, however, the installation of the Vaisala DTS1 station in 2004 may have created an inhomogeneity in $T_{d\ min}$.

Charlotte Douglas AP	**Station Metadata**		**Latitude: 35.2236**	
	WBAN# 13881		**Longitude: 80.9552**	
Year	**Ground Elevation (m)**	**Instruments**		**Comments**
1948-1989	234.1 (1948-1954)	unknown		Observation times 2400
1989-1998	224.6 (1954-1982)	Hygrothermometer		Daily Observation 2400
1998-2007	219.5 (1982-1998)	Hygrothermometer		Daily observation times 2400-Reporting Method_FOS-SFC
2007-2016	221.9 (1998-Present)	Hygrothermometer		ASOS-Era Data Downloaded to NCDC
		** no station moves in any of the records		
Station Moves				
Latitude	**Longitude**	**Initial**	**Final Date**	
32.225		1/1/1937	1/1/1998	
	80.93333	1/1/1937	1/1/1998	
35.225		7/1/1998	5/15/2007	
	80.95417	7/1/1998	5/15/2007	
35.2236		5/15/2007	present	
	80.9552	5/15/2007	present	
T-test 1964	**Estimated instrument changes**			
T-test 1985	**Estimated instrument changes**			
T-test 1989	**Instrument change from unknown to hygrothermometer**			
T-test 1995	**Estimated instrument changes**			
T-test 2004	**DTS1-Installation (4/14/2004)**			

Charlotte-Douglas AP	Median Pairwise Slopes 95% Confidence		
Winter-Dec, Jan, Feb	**Significance**	**Trend**	**P-value**
Seasonal Trend			
T_max	not significant at 0.05	0.1C°	0.38008
Te_max	not significant at 0.05	0.05C°	0.90826
T_min	not significant at 0.05	0.15C°	0.28937
Te_min	not significant at 0.05	0.17C°	0.45127
Spring-Mar, Apr, May			
T_max	not significant at 0.05	0.08C°	0.26817
Te_max	not significant at 0.05	0.00C°	0.92245
T_min	not significant at 0.05	0.10C°	0.22242
Te_min	not significant at 0.05	0.03C°	0.7997
Summer-June, July, August			
T_max	not significant at 0.05	0	0.80784
Te_max	not significant at 0.05	0.04C°	0.88183
T_min	is significant at 0.05	0.10C°	0.00435
Te_min	not significant at 0.05	0.26C°	0.08037
Fall-Sept, Oct, Nov			
T_max	not significant at 0.05	0	0.84863
Te_max	not significant at 0.05	(-0.03)	0.8398
T_min	not significant at 0.05	0.05C°	0.37426
Te_min	not significant at 0.05	0.02C°	0.73918

Charlotte-Douglas AP	Median Pairwise Slopes 95% confidence	Degrees Celsius per decade	
Annual Trend			
	Significance	**Trend**	**P-value**
T_max	not significant at 0.05	0.08C°	0.27194
Te_max	not significant at 0.05	(-0.05C°)	0.57667
T_min	not significant at 0.05	0.07C°	0.0711
Te_min	not significant at 0.05	0.08C°	0.26699

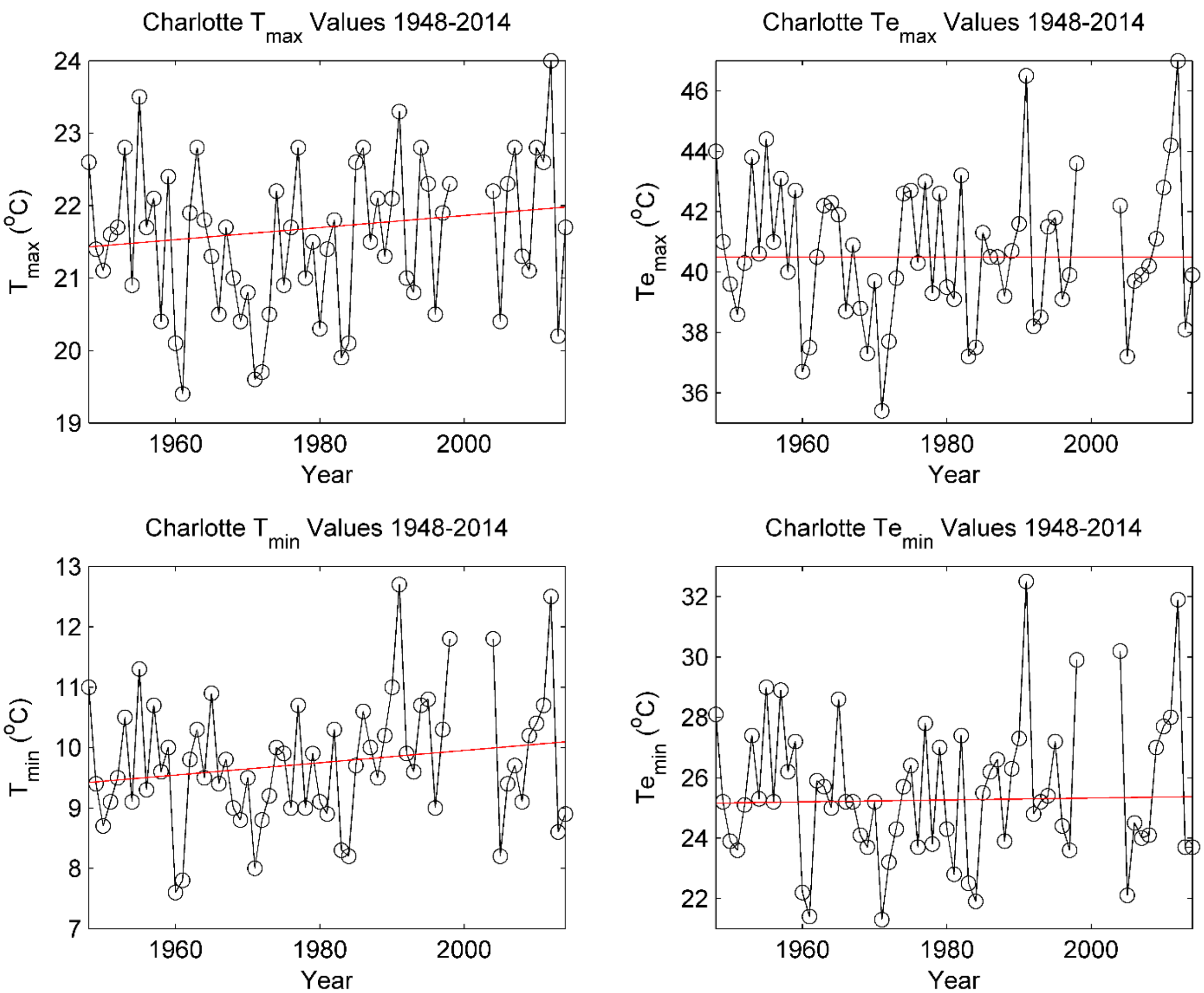
ANNUAL TREND



Charlotte	**Median Pairwise Slopes 95% confidence**	**Degrees Celsius per decade**	
Annual Trend			
	Significance	**Trend**	**P-value**
T_max	not significant at 0.05	0.08C°	0.27194
Te_max	not significant at 0.05	(-0.05C°)	0.57667
T_min	not significant at 0.05	0.07C°	0.0711
Te_min	not significant at 0.05	0.08C°	0.26699

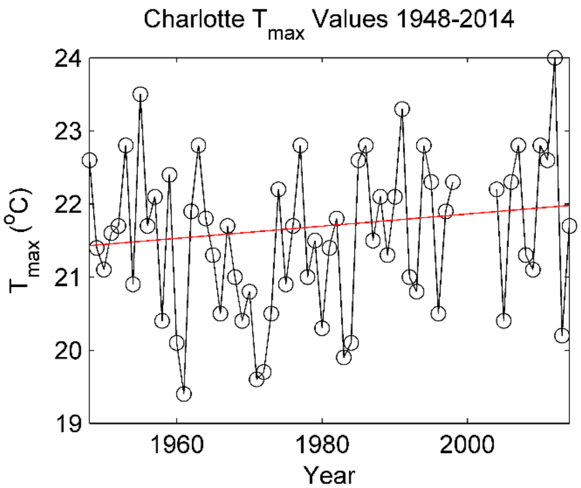
SEASONAL TRENDS

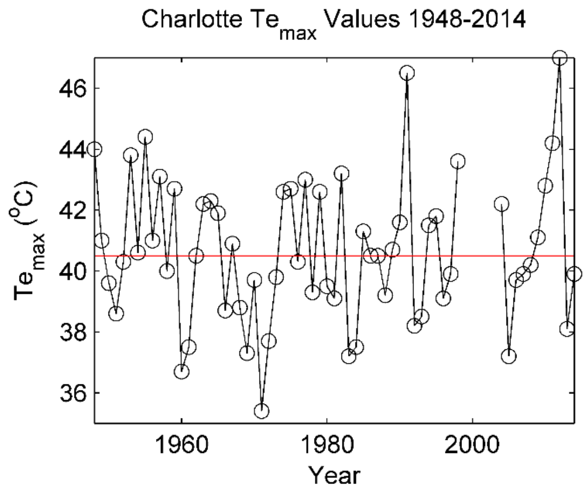
WINTER

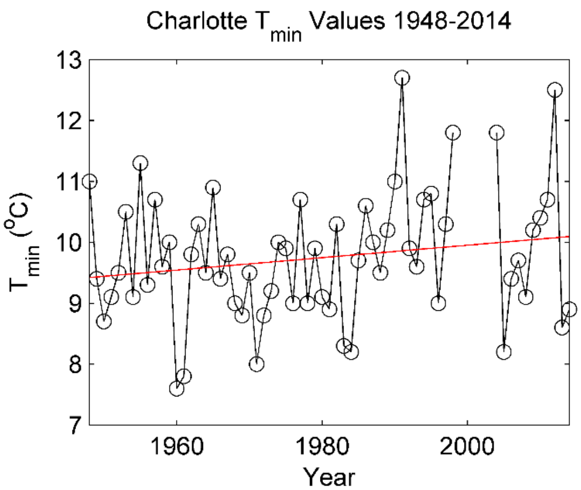


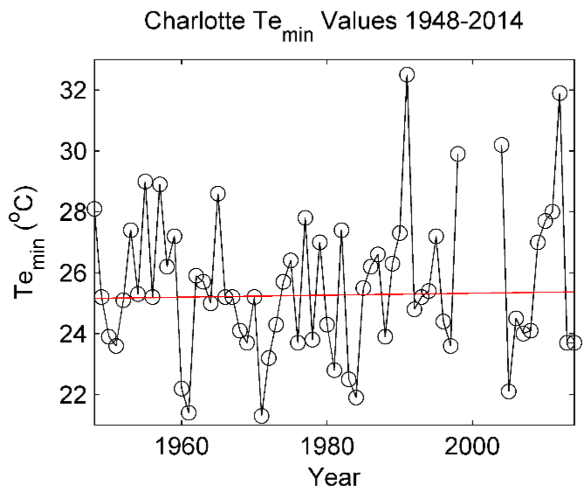
Winter-Dec, Jan, Feb	**Significance**	**Trend**	**P-value**
Seasonal Trend			
T_max	not significant at 0.05	0.1C°	0.38008
Te_max	not significant at 0.05	0.05C°	0.90826
T_min	not significant at 0.05	0.15C°	0.28937
Te_min	not significant at 0.05	0.17C°	0.45127

SPRING



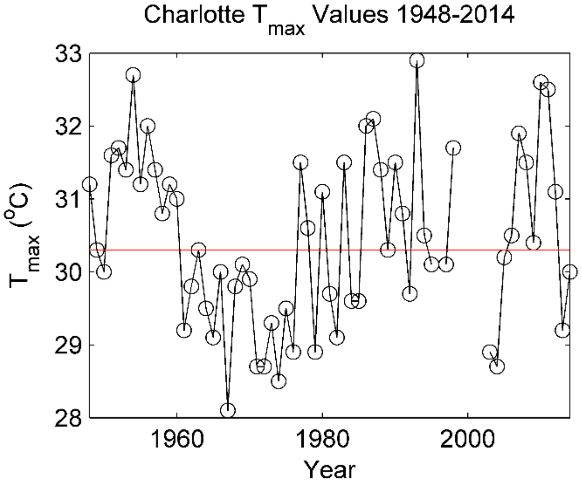


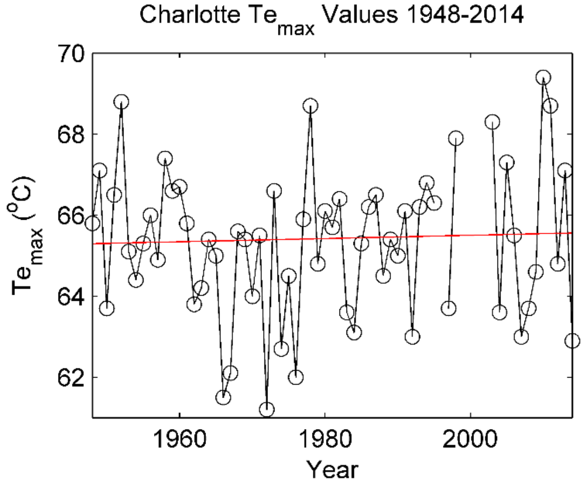


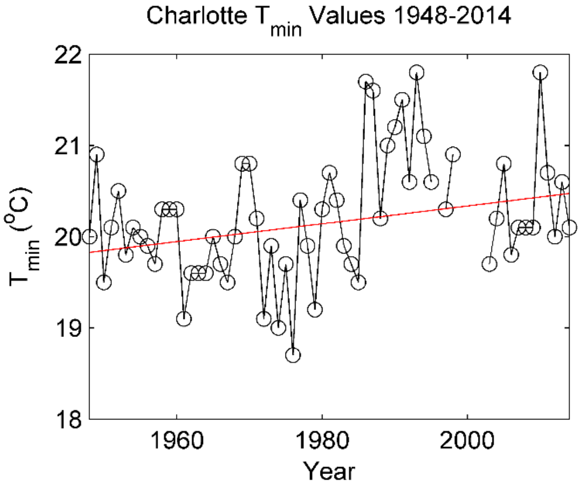


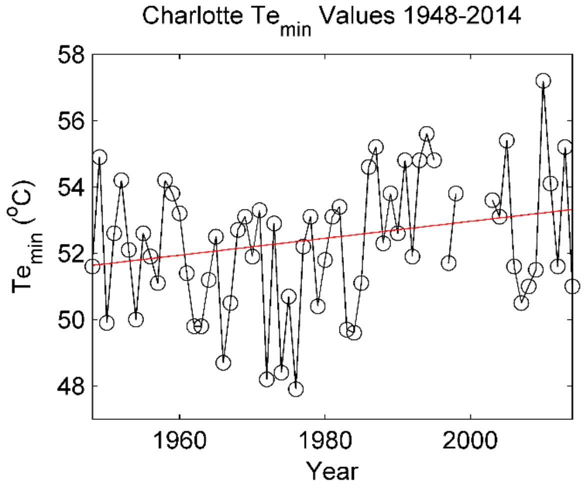
Spring-Mar, Apr, May	**Significance**	**Trend**	**P-value**
T_max	not significant at 0.05	0.08C°	0.26817
Te_max	not significant at 0.05	0.00C°	0.92245
T_min	not significant at 0.05	0.10C°	0.22242
Te_min	not significant at 0.05	0.03C°	0.7997

SUMMER



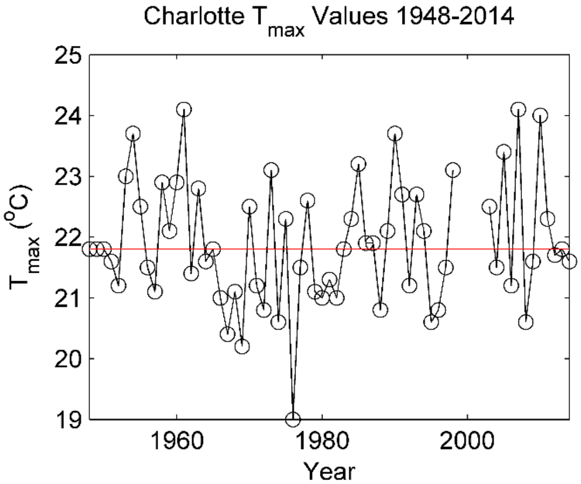


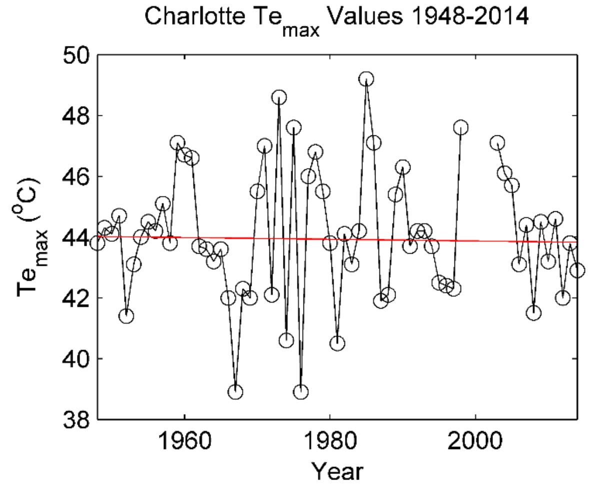


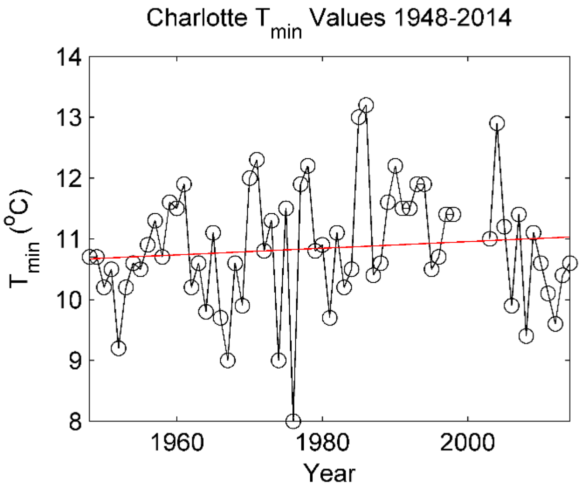


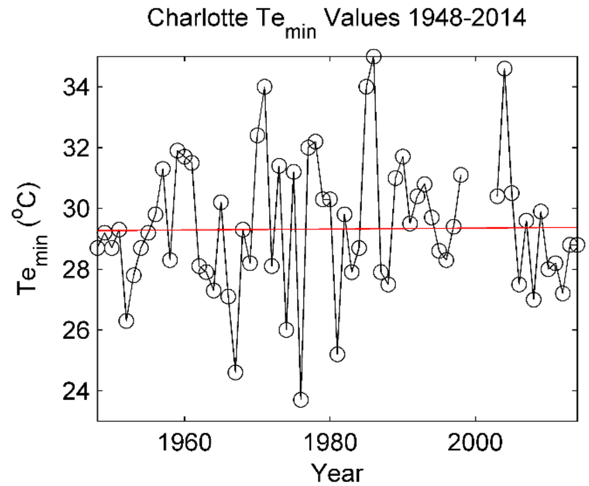
Summer-June, July, August	**Significance**	**Trend**	**P-value**
T_max	not significant at 0.05	0	0.80784
Te_max	not significant at 0.05	0.04C°	0.88183
T_min	is significant at 0.05	0.10C°	0.00435
Te_min	not significant at 0.05	0.26C°	0.08037

FALL



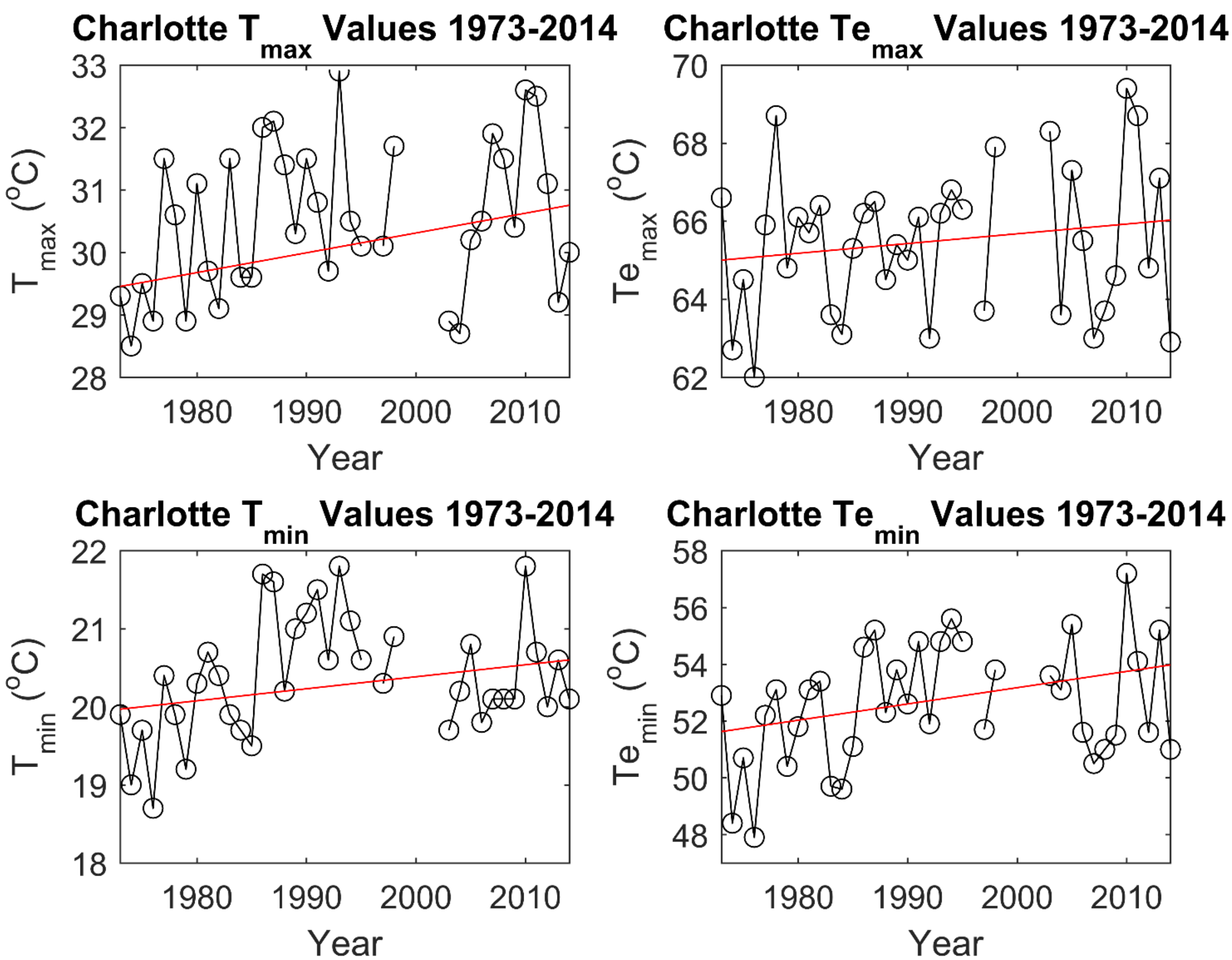






Fall-Sept, Oct, Nov	**Significance**	**Trend**	**P-value**
T_max	not significant at 0.05	0	0.84863
Te_max	not significant at 0.05	(-0.03)	0.8398
T_min	not significant at 0.05	0.05C°	0.37426
Te_min	not significant at 0.05	0.02C°	0.73918

SUMMER 1973-2014



Summer-June, July,August	Significance	Trend	P-Value
T_max	not significant at 0.05	0.32	0.0736
Te_max	not significant at 0.05	0.25	0.42908
T_min	not significant at 0.05	0.15	0.06378
Te_min	not significant at 0.05	0.57	0.06823

Two Tailed T-Tests: Station moves, instrument changes, DTS1 installation

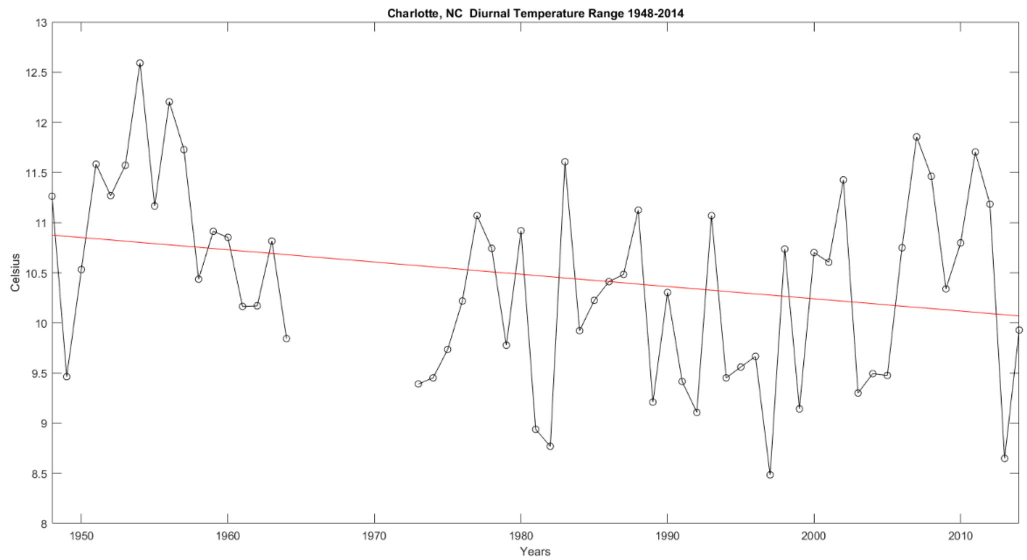
Charlotte	Dew Point			1964	Estimated instrument change	
T-Test	1960-1963					
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.1459	-0.1984	1.3193	1.4663	94	1.8723
Tdmax	0.3851	-0.433	1.1122	0.8727	94	1.9063
Tmin	0.3656	-0.922	0.3428	-0.9092	94	1.5604
Tdmin	0.1808	-1.3959	0.2667	-1.3484	94	2.0512

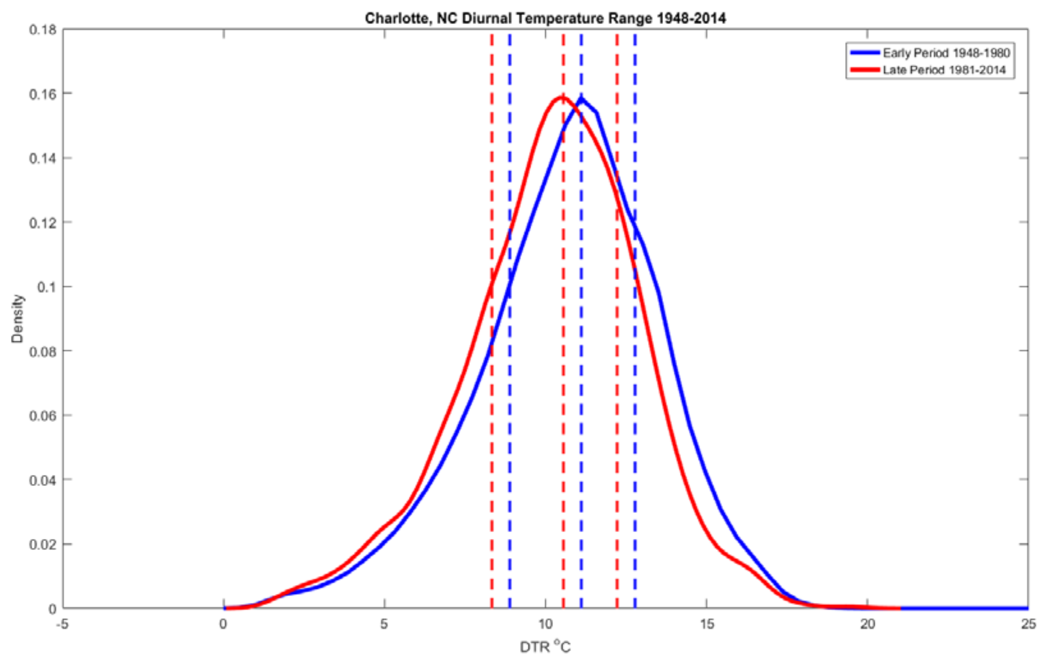
Charlotte	Dew Point			1985	Estimated instrument change	
T-Test	1981-1984	1986-1989				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.059	-1.3549	0.0257	-1.9115	94	1.7032
Tdmax	0.5569	-1.0555	0.5722	-0.5896	94	2.0081
Tmin	0.008	-1.5194	-0.2348	-2.7112	94	1.5848
Tdmin	0.8199	-1.0302	0.8177	-0.2283	94	2.2798

Charlotte	Dew Point			1989	Instrument change from unknown to hygrothermometer	
T-Test	1985-1988	1990-1993				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.0565	-1.2972	0.018	-1.9311	94	1.6225
Tdmax	0.0693	-1.4563	0.0563	-1.8377	94	1.8661
Tmin	7.25E-04	-1.7282	-0.476	-3.4949	94	1.5448
Tdmin	0.1337	-1.4984	0.2026	-1.5126	94	2.0984

Charlotte	Dew Point			1995		Estimated instrument change
T-Test	1991-1994	1996-1999				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.3742	-0.3935	1.0359	0.8931	88	1.7022
Tdmax	0.4433	-0.9619	0.4246	-0.7701	88	1.651
Tmin	0.3899	-0.3313	0.8412	0.8641	88	1.3962
Tdmin	0.1733	-1.3924	0.2547	-1.3727	88	1.9613

Charlotte	Dew Point			2004	DTS1 Installation 4/14/2004	
T-Test	1999-2003	2005-2008				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	4.64E-04	-2.3529	-0.6928	-3.6512	80	1.8607
Tdmax	0.4573	-0.529	1.1647	0.7469	80	1.8985
Tmin	0.1185	-0.1418	1.2279	1.5781	80	1.5352
Tdmin	4.26E-04	0.7589	2.5497	3.6767	80	2.0073


Charlotte, NC Diurnal Temperature Range 1948-2014
Celsius
Years


Charlotte, NC Diurnal Temperature Range 1948-2014
Early Period 1948-1980
Late Period 1981-2014
Density
DTR °C

APPENDIX H

Detroit

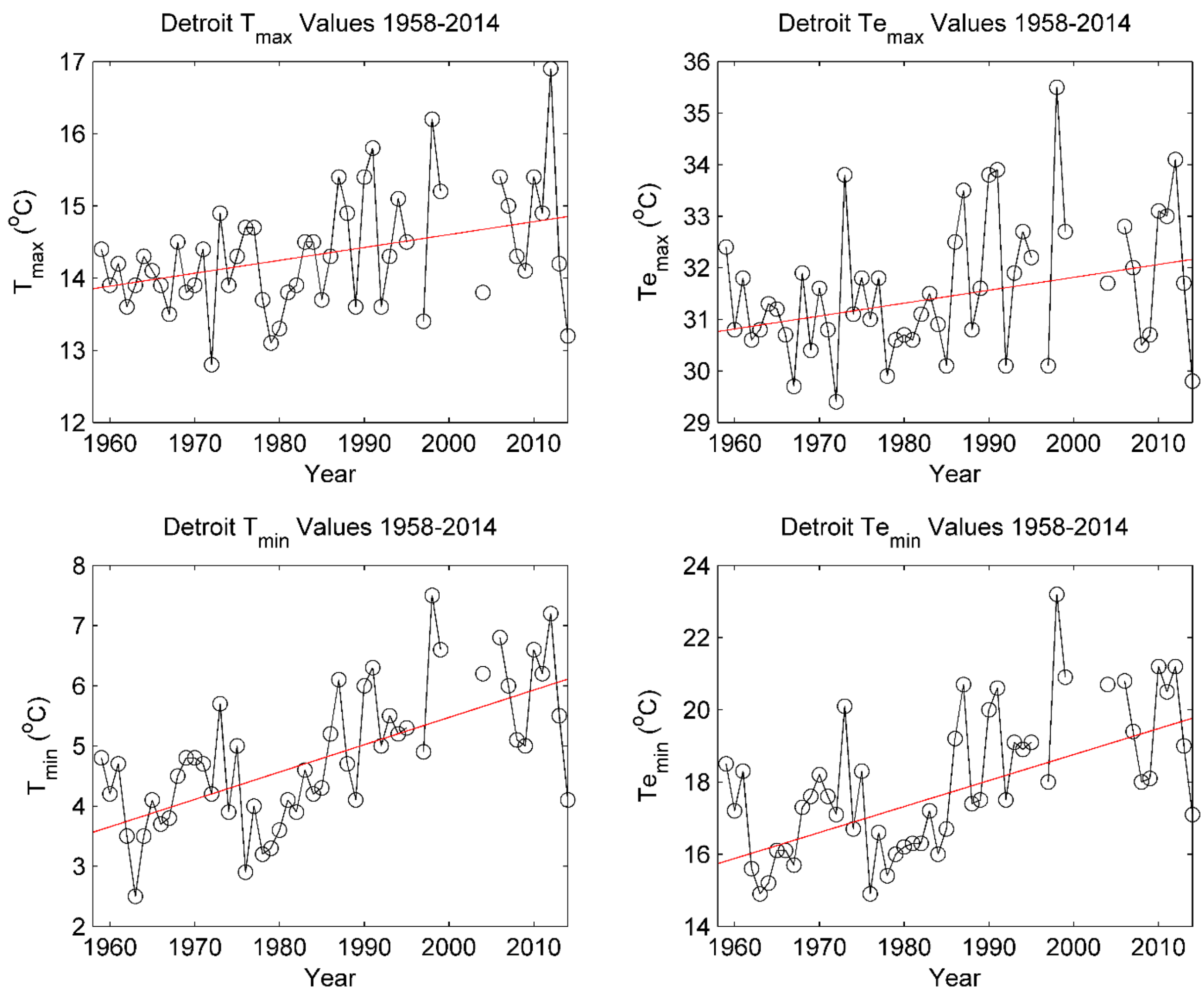
The city of Detroit, MI has a population of 713,777, with a land area per square mile of 139 and population density of 5,144 (US Census, 2010). The record for this station begins in 1958, a comprehensive record before then was not available. This station had a total of three estimated instrument changes, four confirmed instrument changes and it was moved twice during the study period. T-tests reveal possible discontinuities for two of the previously named changes, the first is an estimated instrument change in 1985 reflected in $T_{d\ max}$, T_{min}, $T_{d\ min}$. The second is in 2005 when the installation of the DTS1 happened, T_{max} and $T_{d\ min}$ may have been impacted. Annual trend analysis shows a significant increase for all 4 variables: T_{max} (0.18), $T_{E\ max}$ (0.25), T_{min} (0.45), $T_{E\ min}$ (0.72). Summer seasonal trend analysis shows significant increases in T_{min} (0.56) and $T_{E\ min}$ (1.10). Increases in T_{min} and $T_{E\ min}$ are also increasing in all 4 seasons, this is unique to the Detroit station. In the shorter period starting from 1973, significant increases are noted in T_{min} 0.65 and $T_{E\ min}$ 1.18, this suggests that more warming occurred in the more recent part of the record as opposed to the earliest.

Detroit Metro Airport	**Station Metadata**		**Latitude: 42.2313**	
	WBAN#94847		**Longitude : 83.3308**	
Year	**Site (m)**	**Instruments**		**Comments**
1958-1992	192.9 (1959-1995)	unknown		Daily, obs times 2400
1992-2000	194.2 (1995-2002)	Max and Min Thermometers		Daily, obs times 2400. From 1997-2000 reporting method: MF1-10C
2000-2002	192.3 (2002-Present)	Hygrothermometer		Daily, obs times 2400. Reporting method ADP: ASOS-Era Data Downloaded to NCDC
2002-Present		ATEMP: ASOS Hygrothermometer		Daily, obs times 2400. Reporting method ADP: ASOS-Era Data Downloaded to NCDC
Station Moves				
Latitude	**Longitude**	**Initial**	**Final Date**	
42.23333		1/1/1951	7/1/1995	
	83.33333	1/1/1959	4/17/1992	
	83.31667	4/17/1992	7/1/1995	
42.23139		7/1/1995	4/9/1998	
	83.33083	7/1/1995	4/9/1998	
42.21722		4/9/1998	9/25/2000	
	83.34333	4/9/1998	9/25/2000	
42.2313		9/25/2000	Present	
	83.3308	9/25/2000	Present	
T-test 1964	**estimated instrument changes**			
T-test 1985	**estimated instrument changes**			
T-test 1992	**instrument change from unknown to Max/min thermometer**			
T-test 1995	**estimated instrument change and station move .3 miles SW (07/01/1995)**			
T-test 1998	**Station move 1.5 miles S (04/09/1998)**			
T-test 2000	**instrument change from Max/Min thermometer to Hygrothermometer**			
T-test 2005	**DTS1 installation 06/03/2005**			

Detroit	Median Pairwise Slopes 95% confidence	Degrees Celsius per decade	
Seasonal			
Winter-Dec,Jan,Feb	**Significance**	**Trend**	**P-value**
T_max	not significant at 0.05	0.28C°	0.10681
Te_max	not significant at 0.05	0.50C°	0.09518
T_min	is significant at 0.05	0.55C°	0.00456
Te_min	is significant at 0.05	0.73C°	0.00745
Spring-Mar,Apr,May			
T_max	is significant at 0.05	0.32C°	0.01202
Te_max	not significant at 0.05	0.29C°	0.16518
T_min	is significant at 0.05	0.38C°	0.00031
Te_min	is significant at 0.05	0.50C°	0.00216
Summer-June, July,August			
T_max	not significant at 0.05	0.08C°	0.29409
Te_max	not significant at 0.05	0.29C°	0.17656
T_min	is significant at 0.05	0.56C°	0
Te_min	is significant at 0.05	1.10C°	0
Fall-Sept, Oct, Nov			
T_max	not significant at 0.05	0.01C°	0.79408
Te_max	not significant at 0.05	(-0.08C°)	0.68187
T_min	is significant at 0.05	0.29C°	0.00134
Te_min	is significant at 0.05	0.43C°	0.01341

Detroit	Median Pairwise Slopes 95% confidence	Degrees Celsius per decade	
Annual Trend			
	Significance	**Trend**	**P-value**
T_max	is significant at 0.05	0.18C°	0.02089
Te_max	is significant at 0.05	0.25C°	0.04265
T_min	is significant at 0.05	0.45C°	0
Te_min	is significant at 0.05	0.72C°	0

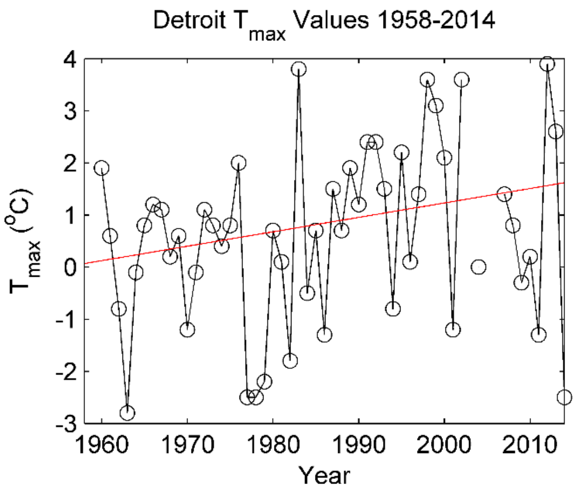
ANNUAL TREND

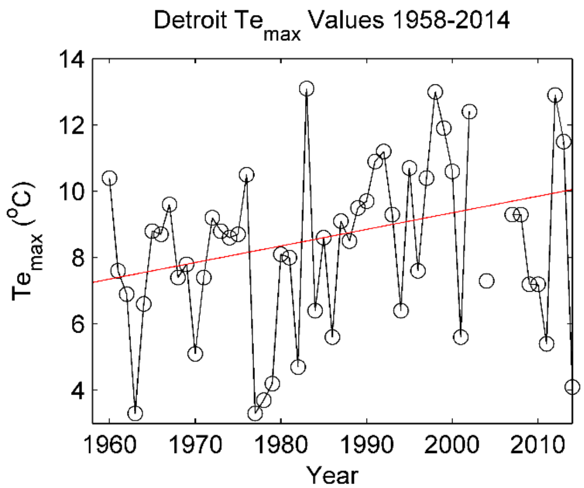


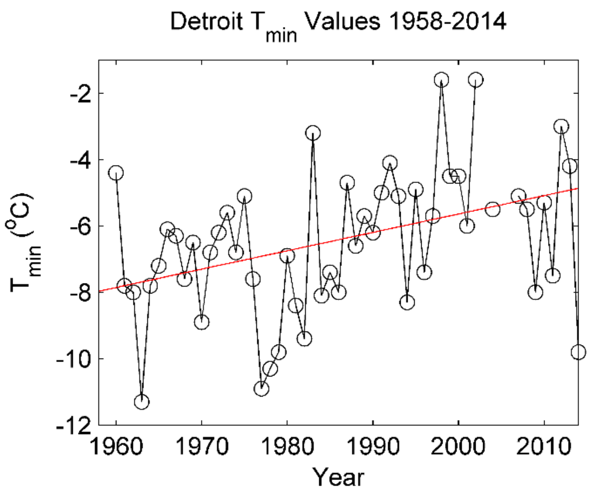
Detroit	**Median Pairwise Slopes 95% confidence**	**Degrees Celsius per decade**	
Annual Trend			
	Significance	**Trend**	**P-value**
T_max	is significant at 0.05	0.18C°	0.02089
Te_max	is significant at 0.05	0.25C°	0.04265
T_min	is significant at 0.05	0.45C°	0
Te_min	is significant at 0.05	0.72C°	0

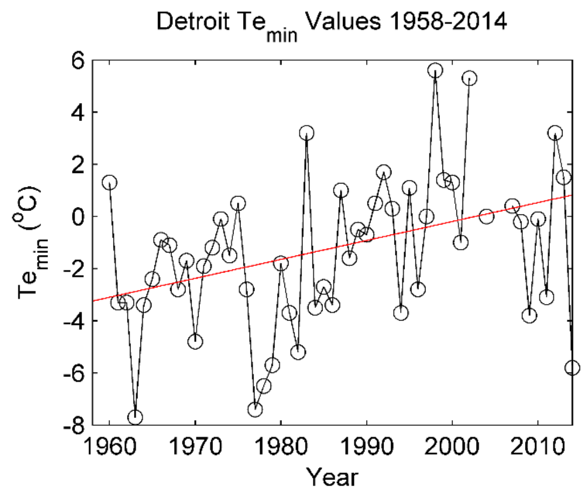
SEASONAL TRENDS

WINTER



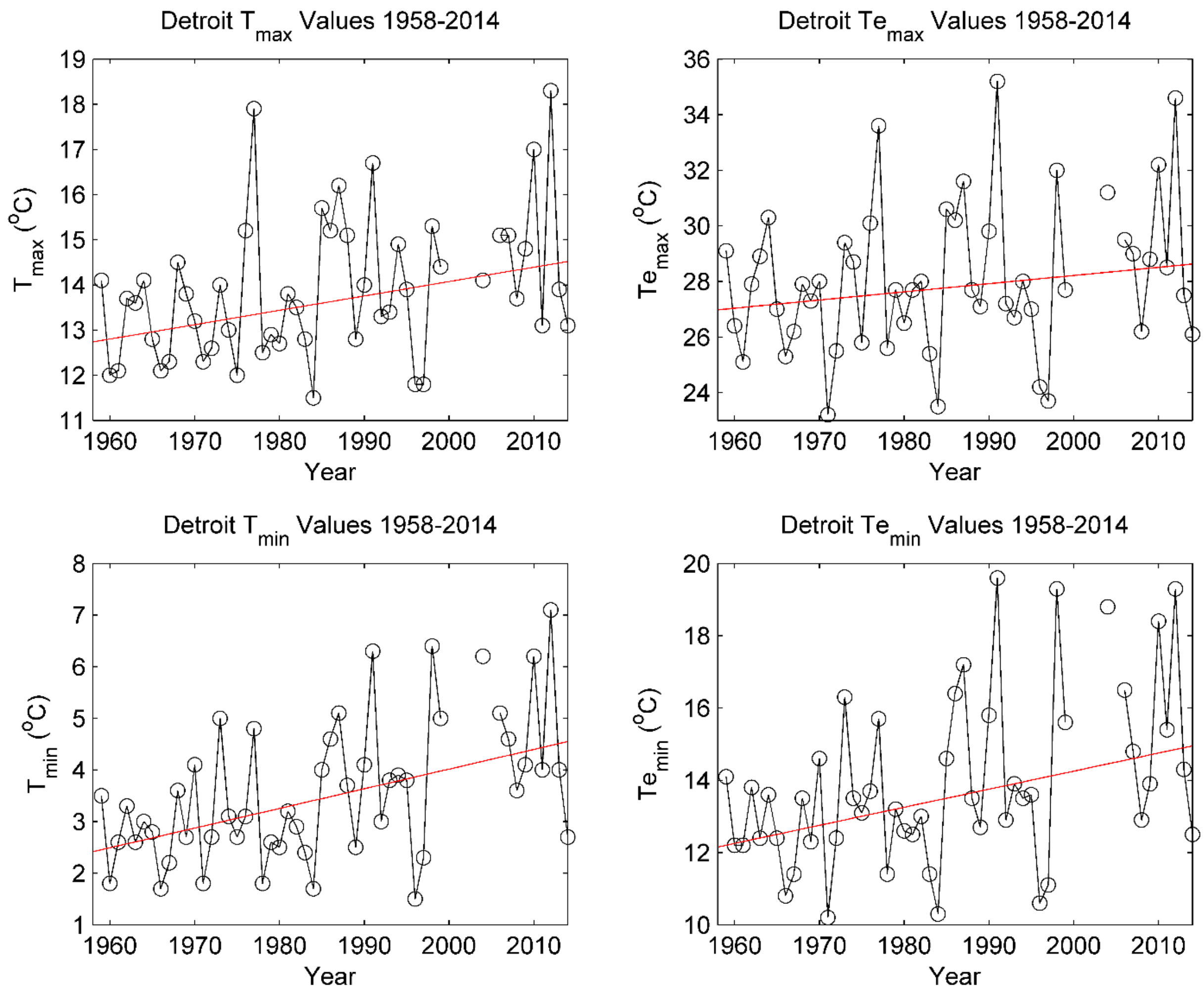






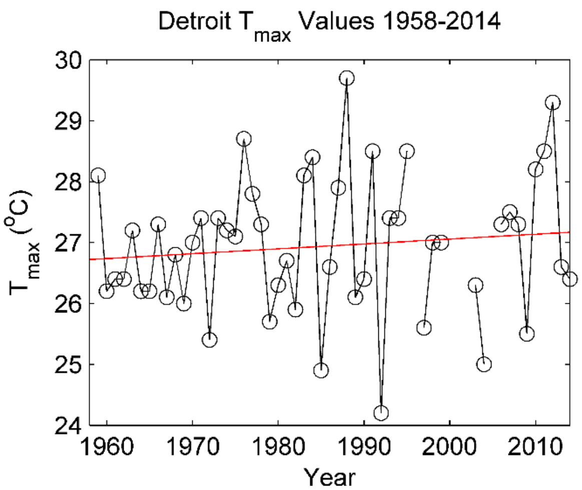
Winter-Dec,Jan,Feb	Significance	Trend	P-value
T_max	not significant at 0.05	0.28C°	0.10681
Te_max	not significant at 0.05	0.50C°	0.09518
T_min	is significant at 0.05	0.55C°	0.00456
Te_min	is significant at 0.05	0.73C°	0.00745

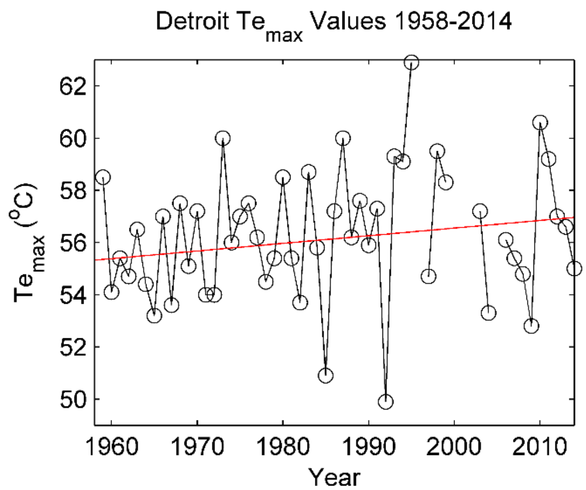
SPRING

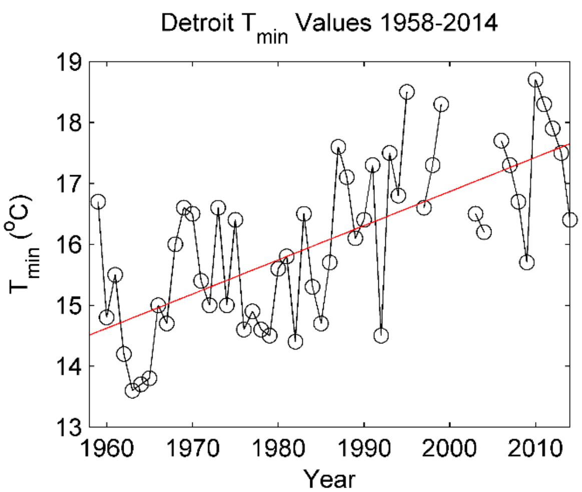


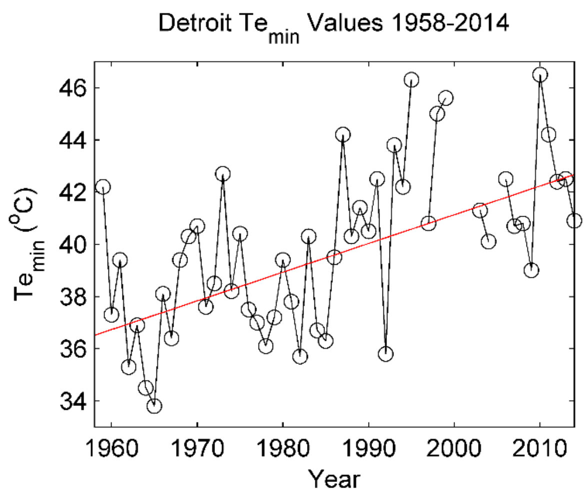
Spring-Mar,Apr,May	Significance	Trend	P-value
T_max	is significant at 0.05	0.32C°	0.01202
Te_max	not significant at 0.05	0.29C°	0.16518
T_min	is significant at 0.05	0.38C°	0.00031
Te_min	is significant at 0.05	0.50C°	0.00216

SUMMER



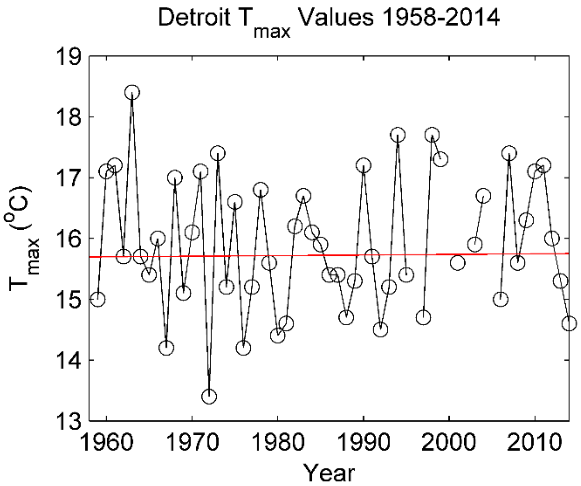


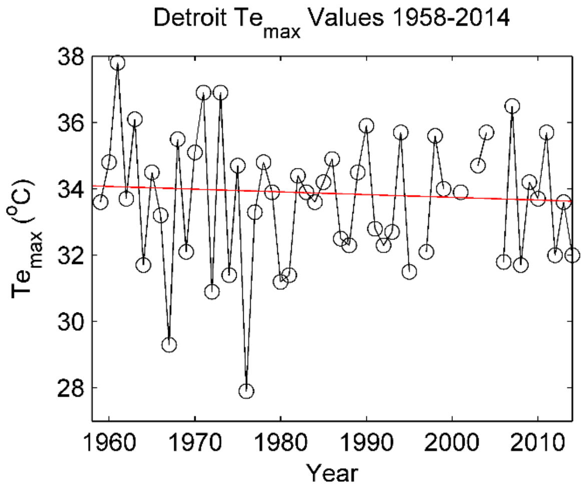


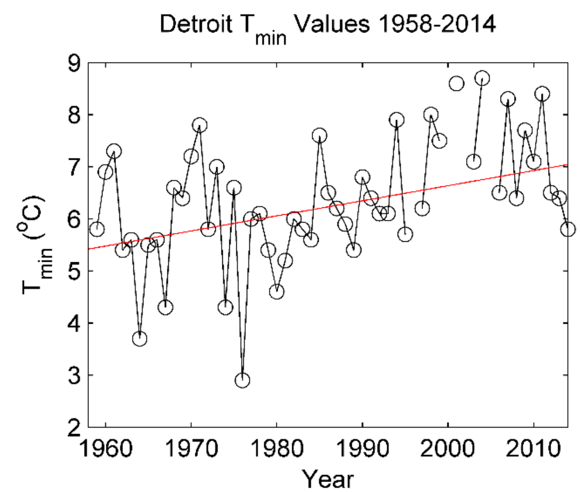


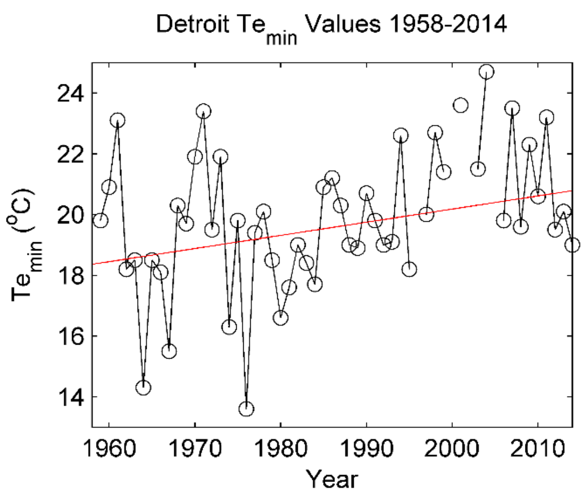
Summer-June, July,August	**Significance**	**Trend**	**P-value**
T_max	not significant at 0.05	0.08C°	0.29409
Te_max	not significant at 0.05	0.29C°	0.17656
T_min	is significant at 0.05	0.56C°	0
Te_min	is significant at 0.05	1.10C°	0

FALL



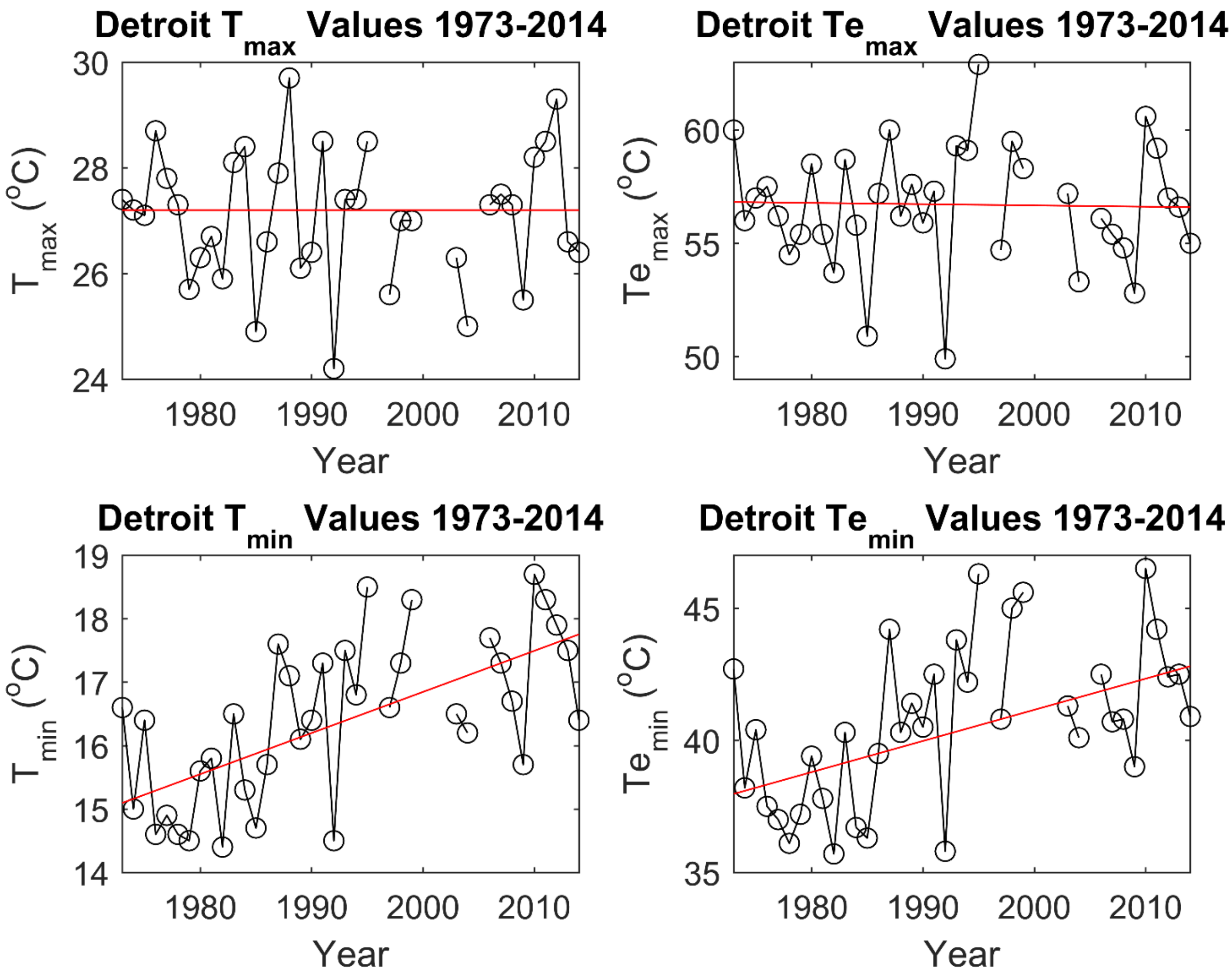






Fall-Sept, Oct, Nov	**Significance**	**Trend**	**P-Value**
T_max	not significant at 0.05	0.01C°	0.79408
Te_max	not significant at 0.05	(-0.08C°)	0.68187
T_min	is significant at 0.05	0.29C°	0.00134
Te_min	is significant at 0.05	0.43C°	0.01341

SUMMER 1973-2014



Summer-June, July,August	Significance	Trend	P-Value
T_max	not significant at 0.05	0	0.92
Te_max	not significant at 0.05	-0.06	0.93116
T_min	is significant at 0.05	0.65	0.00003
Te_min	is significant at 0.05	1.18	0.00053

Two Tailed T-Tests: Station moves, instrument changes, DTS1 installation

Detroit	Dew Point		1964	Estimated instrument changes		
T-Test	1960-1963	1965-1968				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.8636	-0.8613	0.7238	-0.1722	94	1.9555
Tdmax	0.3962	-0.4349	1.0891	0.8523	94	1.88010
Tmin	0.3718	-1.0976	0.4143	-0.8974	94	1.8652
Tdmin	0.8605	-0.7702	0.9202	0.1762	94	2.0853

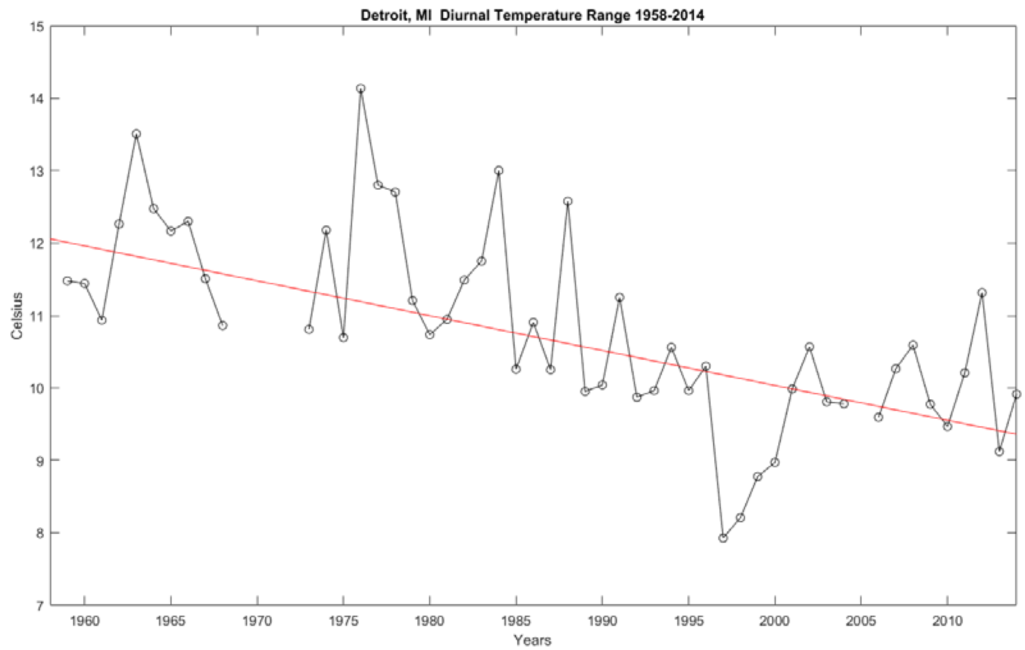
Detroit	Dew Point			1985	Estimated instrument changes	
	1981-1984	1986-1989				
T-Test						
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.4013	-1.2161	0.4911	-0.8432	94	2.1061
Tdmax	0.0348	-1.5857	-0.0601	-2.142	94	1.8821
Tmin	0.0411	-1.624	-0.0343	-2.0712	94	1.9612
Tdmin	0.023	-1.8976	-0.144	-2.3117	94	2.1634

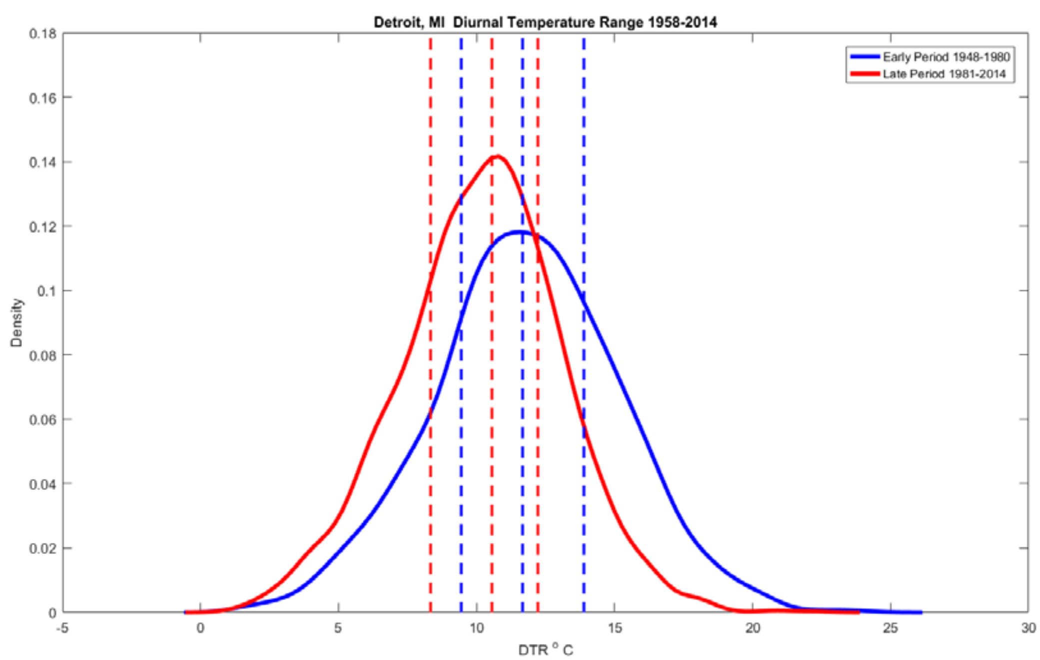
Detroit	Dew Point			1992	Instrument change from unknown to Max/min thermometer	
T-Test	1988-1991	1993-1996				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.1837	-0.2615	1.345	1.3396	92	1.9602
Tdmax	0.1786	-0.2476	1.3122	1.3556	92	1.90320
Tmin	0.7792	-0.6736	0.8958	0.2812	92	1.9148
Tdmin	0.4654	-0.5744	1.2464	0.733	92	2.2216

Detroit	Dew Point			1995	Estimated instrument change and station move .3 miles SW (07/01/1995)	
T-Test	1991-1994	1996-1999				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.8505	-0.7167	0.8675	0.189	92	1.933
Tdmax	0.9702	-0.7492	0.7215	-0.0375	92	1.79450
Tmin	0.2358	-1.2403	0.3093	-1.1933	92	1.8907
Tdmin	0.3206	-1.3081	0.4328	-0.9986	92	2.1241

Detroit	Dew Point			2000	Station move (possible, not clearly recorded). Instrument change from Max/Min thermometer to Hygrothermometer	
T-Test	1996-1999	2001-2004				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.0854	-0.1051	1.5796	1.7409	83	1.9456
Tdmax	0.6331	-0.5923	0.9683	0.4791	83	1.8023
Tmin	0.3102	-1.2487	0.4016	-1.021	83	1.9059
Tdmin	0.1949	-1.5243	0.3156	-1.3066	83	2.1249

Detroit	Dew Point			2005	DTS1 installation 06/03/2005	
T-Test	2001-2004	2006-2009				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.0372	-1.6488	-0.0515	-2.1166	85	1.8632
Tdmax	0.4661	-0.4662	1.0096	0.7322	85	1.7215
Tmin	0.1132	-0.1527	1.4143	1.6007	85	1.828
Tdmin	0.0014	0.5542	2.2256	3.3068	85	1.9497


Detroit, MI Diurnal Temperature Range 1958-2014
Celsius
Years


Detroit, MI Diurnal Temperature Range 1958-2014
Early Period 1948-1980
Late Period 1981-2014
Density
DTR ° C

APPENDIX I

Memphis

The city of Memphis, TN has a population of 646,889, with a land area per square mile of 315 and population density of 2,053 (US Census, 2010). The Memphis station was moved approximately 4 times according to station metadata, five instrument changes occurred during the period of study, we ran t-test for all except one of the changes in the record. $T_{d\ max}$ seems to have been affected by an estimated instrument change 1964 and a station move in 1973. A possible station move affected T_{min} in 1999. The move is marked on a map as a previous location, but the move is not documented in any other form of kept record. T_{max} shows a possible change in the series related to the DTS1 installation. Annual trend analysis shows a significant increase in both T_{min} (27) and $T_{E\ min}$ (37). Memphis' summers have been also increasing in both T_{min} (0.28) and $T_{E\ min}$ (0.33). In the earlier part of the record which begins in 1973 cooling occurs for T_{max}, $T_{E\ max}$ and $T_{E\ min}$, a slight warming is present for T_{min}, none of the observations are significant.

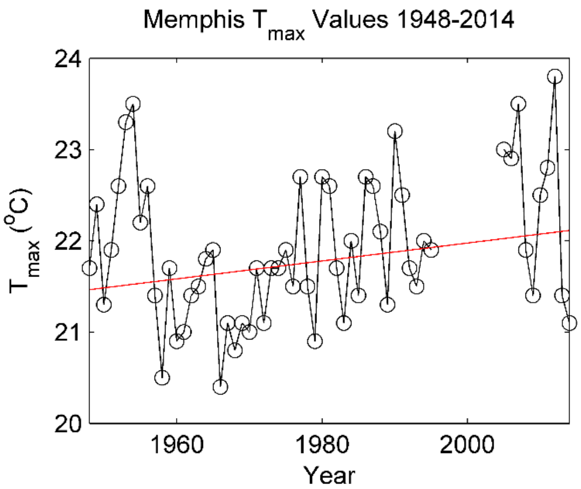
Memphis International Airport	Station Metadata		Latitude: 35.0564	
	WBAN# 13893		Longitude: 89.9865	
Year	**Site (m)**	**Instruments**		**Comments**
1948-1970	78.6 (1948-1987)	unknown		temperature recorded daily, obs times 2400
1970-1985		unknown		temperature recorded daily, obs times 2400
1985-1987		Max/min thermometer		temperature recorded daily, obs times 2400 (1985 temp. instrument from unknown to Max/min thermometer)
1987-2005	80.8 (1987-2001)	Hygrothermometer		temperature recorded daily, obs times 2400. Instrument change from Max/min thermometer to Hygrothermometer (1987). From 2001 -2005 Reporting method: FOSJ-SFC
2005-2006	77.4 (2001-Present)	unknown as written in NCDC (DTS1 installed 2003)		temperature recorded daily, obs times 2400, Receiver NCEI, Reporting Method: ADP
2006-2011		Hygrothermometer		temperature recorded daily, obs times 2400, Receiver NCEI, Reporting Method: ADP
2011-Present		ATEMP: ASOS Hygrothermometer		temperature recorded daily, obs times 2400, Receiver NCEI, Reporting Method: ADP
Station Moves				
Latitude	**Longitude**	**Initial**	**Final Date**	
35.05		7/1/1930	4/30/1999	
	89.9833	7/1/1930	4/1/1973	
	90	4/1/1973	4/30/1999	
35.0611		4/30/1999	10/2/2001	
	89.985	4/30/1999	10/2/2001	
35.05639		10/2/2001	11/15/2005	
	89.9864	11/15/2005	6/16/2011	

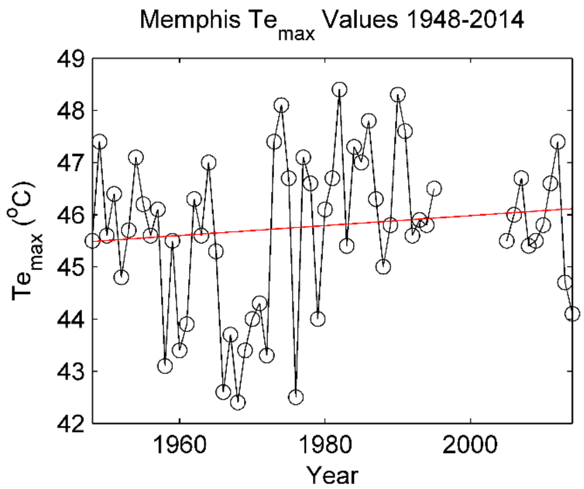
	Station Metadata
T-test 1964	Estimated instrument change
T-test 1973	Station move 0.3 miles NW (04/01/1973)
T-test 1985	Estimated instrument change (from unknown to Max/min thermometer) and station move 0.3 miles E (10/01/1985)
T-test 1987	Instrument change from Max/min thermometer to Hygrothermometer
T-test 1995	Estimated instrument change
T-test 1999	Station move, visible from "location data map (5)" 1999-2001.
T-test 2001	Station move, visible from "location data map (5)" 1999-2001.
T-test 2003	DTS1 Installation 12/15/2003 /Instrument change
T-test 2011	Station move and instrument entry changed from Hygrothermometer to ATEMP (T-Test can't be performed, data only goes to 2014, and 2015 would be needed to conduct test like all the others)

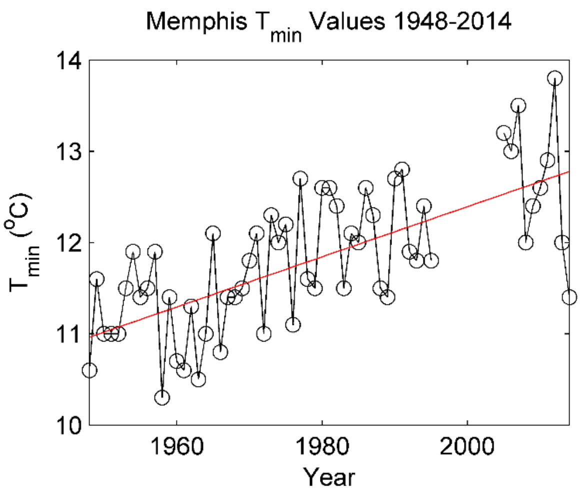
Memphis	Median Pairwise Slopes 95% confidence	Degrees Celsius per decade	
Seasonal			
Winter-Dec,Jan,Feb	**Significance**	**Trend**	**P-value**
T_max	not significant at 0.05	0.00C°	0.99597
Te_max	not significant at 0.05	(-0.11C°)	0.69667
T_min	not significant at 0.05	0.07C°	0.5138
Te_min	not significant at 0.05	(-0.00C°)	0.97861
Spring-Mar,Apr,May			
T_max	is significant at 0.05	0.14C°	0.046
Te_max	not significant at 0.05	0.24C°	0.18293
T_min	is significant at 0.05	0.25C°	0.00354
Te_min	not significant at 0.05	0.30C°	0.05611
Summer-June, July,August			
T_max	not significant at 0.05	0.09C°	0.36772
Te_max	not significant at 0.05	(-0.03C°)	0.93165
T_min	is significant at 0.05	0.28C°	0
Te_min	is significant at 0.05	0.33C°	0.01419
Fall-Sept, Oct, Nov			
T_max	not significant at 0.05	0.00C°	0.71402
Te_max	not significant at 0.05	0.10C°	0.54748
T_min	is significant at 0.05	0.35C°	0
Te_min	is significant at 0.05	0.53C°	0.00051

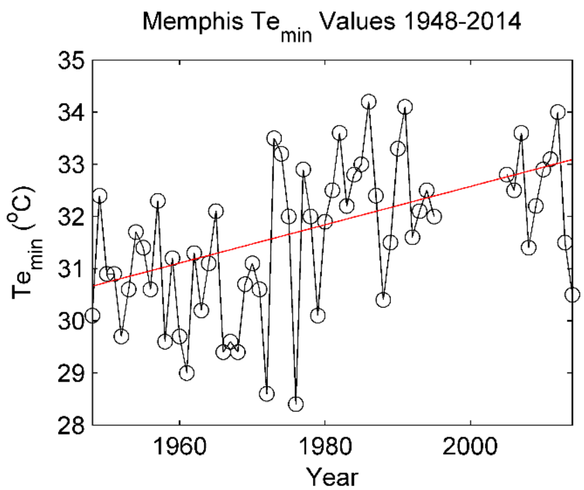
Memphis	95% confidence	Degrees Celsius per decade	
Annual			
	Significance	**Trend**	**P-value**
T_max	not significant at 0.05	0.10C°	0.09703
Te_max	not significant at 0.05	0.10C°	0.18908
T_min	is significant at 0.05	0.27C°	0
Te_min	is significant at 0.05	0.37C°	0.00003

ANNUAL TREND





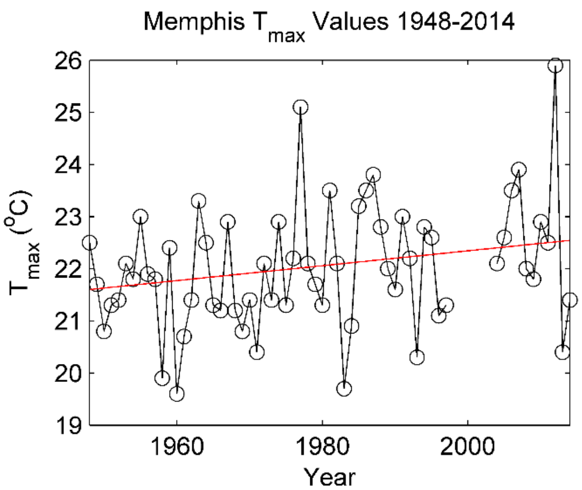


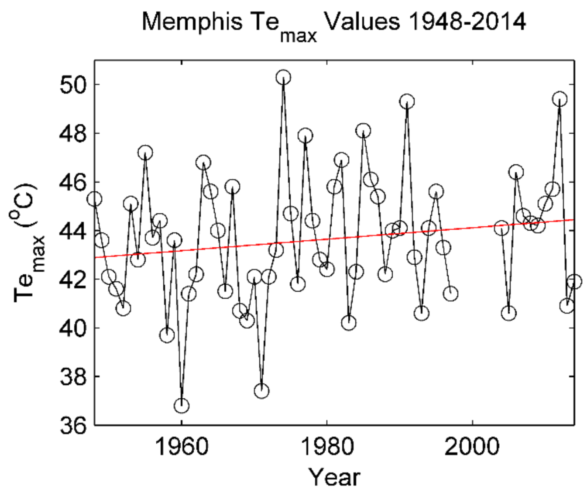


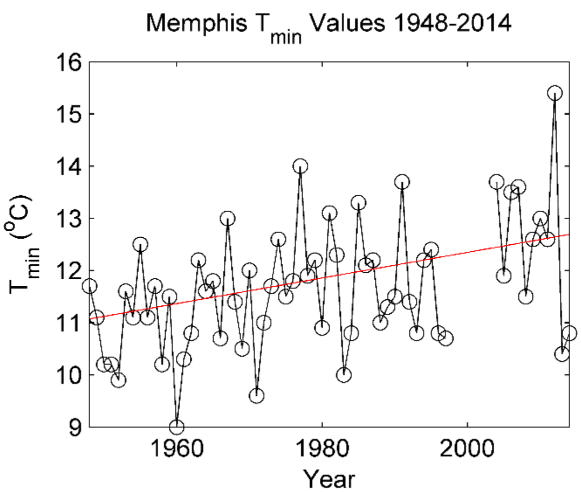
Memphis	**95% confidence**	**Degrees Celsius per decade**	
Annual			
	Significance	**Trend**	**P-value**
T_max	not significant at 0.05	0.10C°	0.09703
Te_max	not significant at 0.05	0.10C°	0.18908
T_min	is significant at 0.05	0.27C°	0
Te_min	is significant at 0.05	0.37C°	0.00003

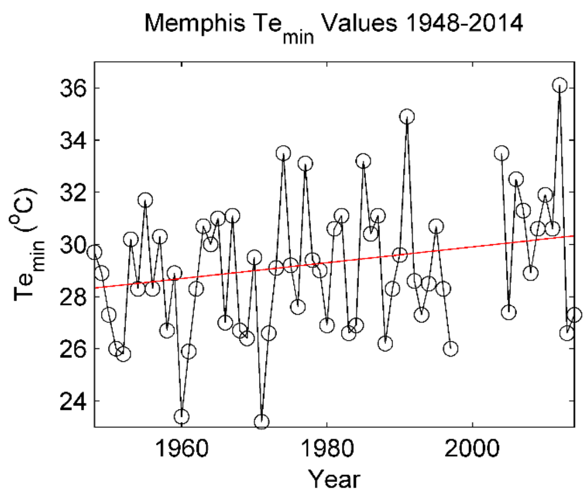
SEASONAL TRENDS

WINTER



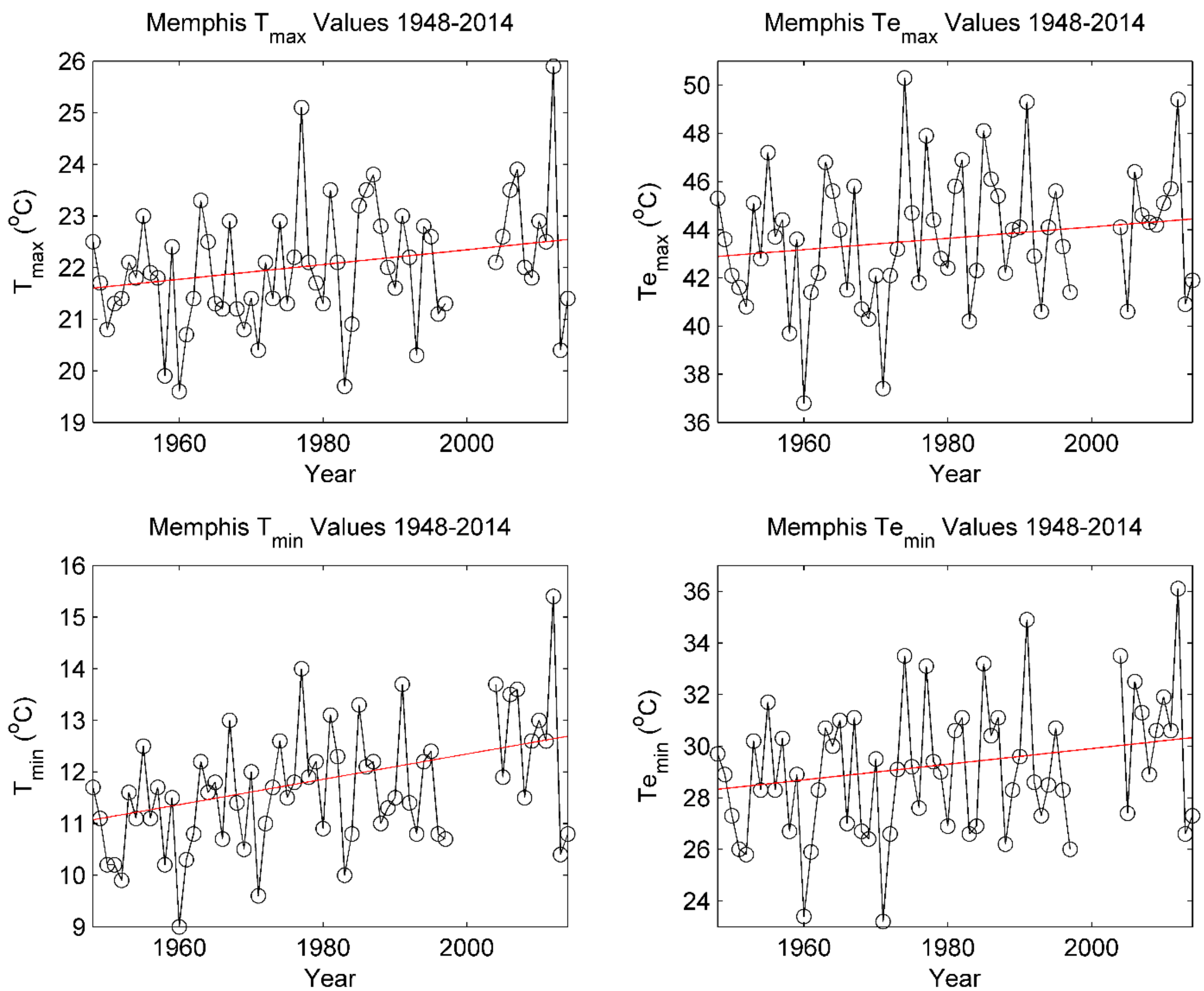






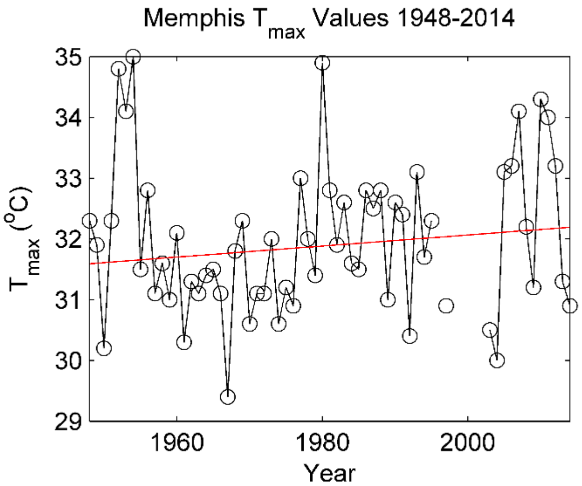
Winter-Dec,Jan,Feb	**Significance**	**Trend**	**P-value**
T_max	not significant at 0.05	0.00C°	0.99597
Te_max	not significant at 0.05	(-0.11C°)	0.69667
T_min	not significant at 0.05	0.07C°	0.5138
Te_min	not significant at 0.05	(-0.00C°)	0.97861

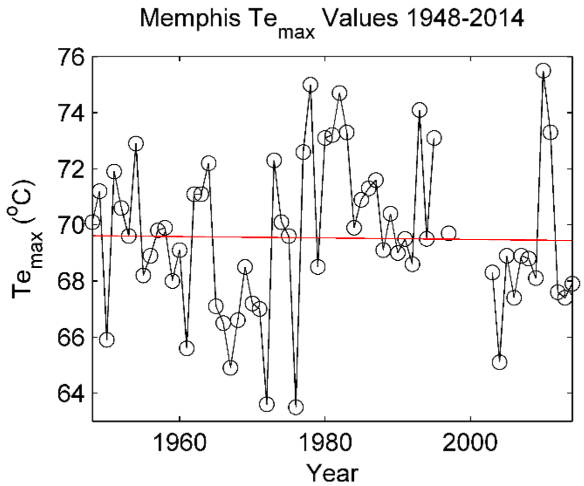
SPRING

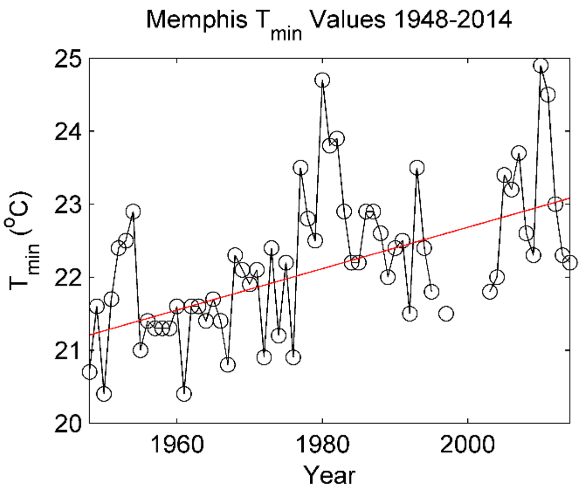


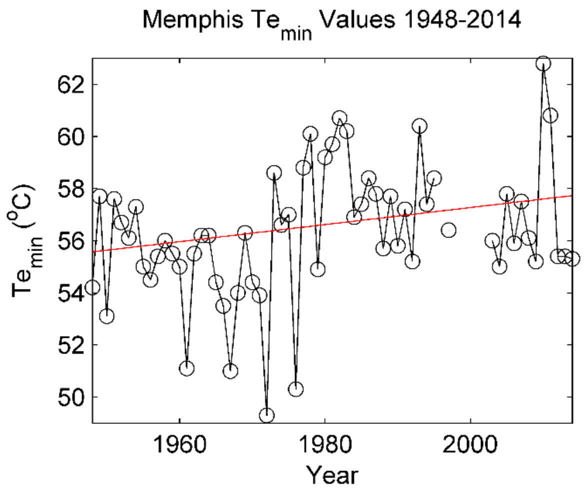
Spring-Mar,Apr,May	**Significance**	**Trend**	**P-value**
T_max	is significant at 0.05	0.14C°	0.046
Te_max	not significant at 0.05	0.24C°	0.18293
T_min	is significant at 0.05	0.25C°	0.00354
Te_min	not significant at 0.05	0.30C°	0.05611

SUMMER



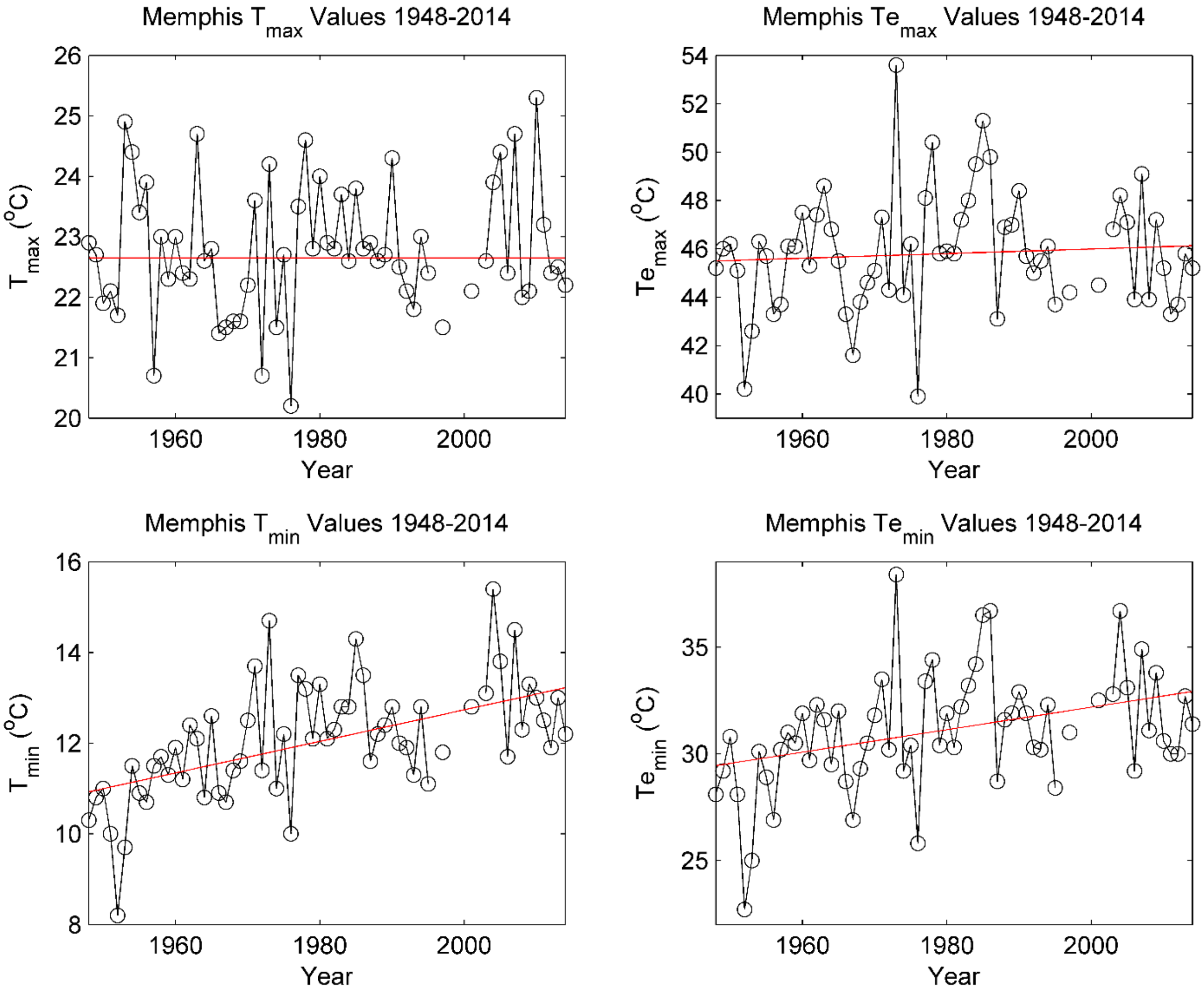






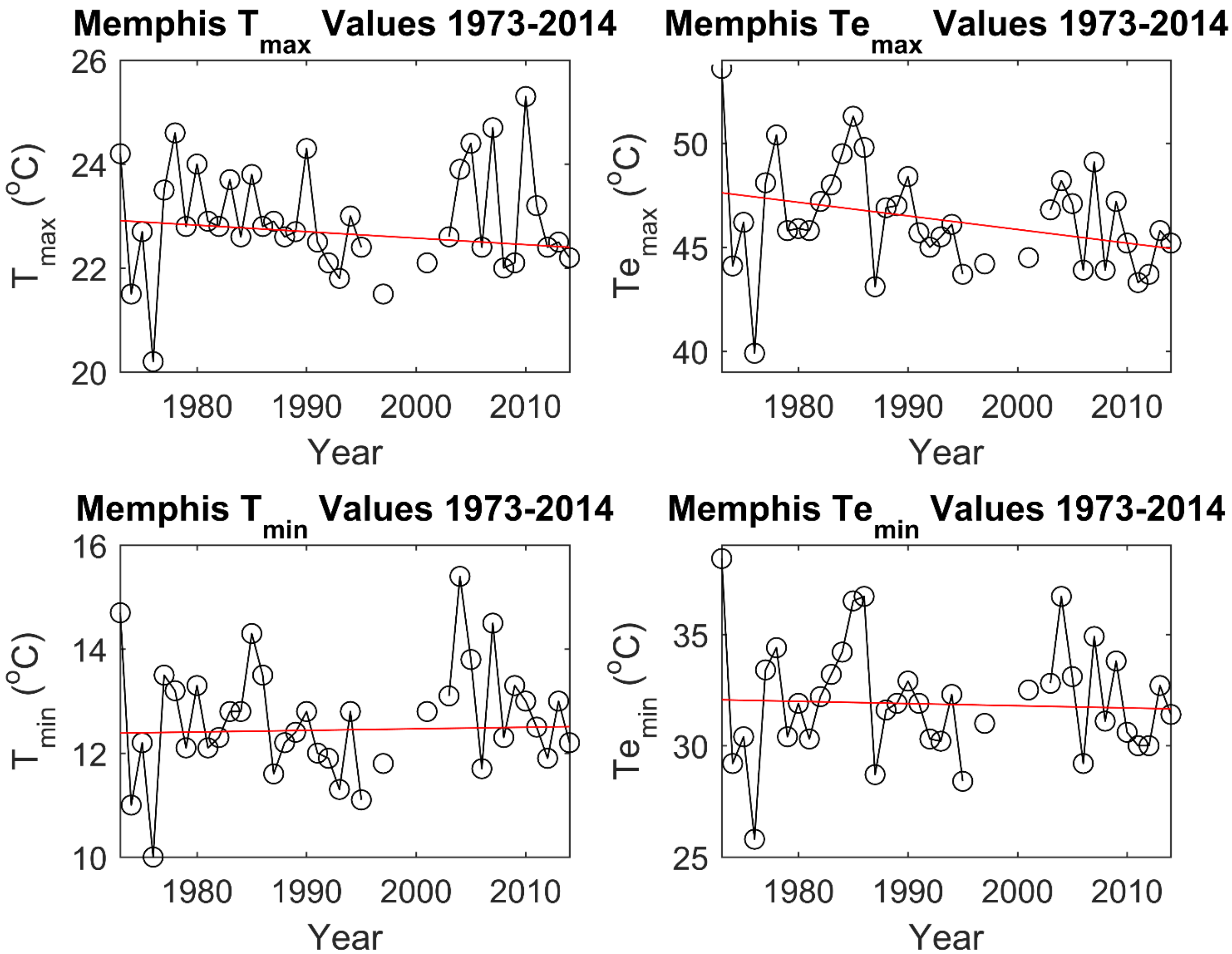
Summer-June, July,August	**Significance**	**Trend**	**P-Value**
T_max	not significant at 0.05	0.09C°	0.36772
Te_max	not significant at 0.05	(-0.03C°)	0.93165
T_min	is significant at 0.05	0.28C°	0
Te_min	is significant at 0.05	0.33C°	0.01419

FALL



Fall-Sept, Oct, Nov	Significance	Trend	P-value
T_max	not significant at 0.05	0.00C°	0.71402
Te_max	not significant at 0.05	0.10C°	0.54748
T_min	is significant at 0.05	0.35C°	0
Te_min	is significant at 0.05	0.53C°	0.00051

SUMMER 1973-2014



Summer-June, July,August	Significance	Trend	P-Value
T_max	not significant at 0.05	-0.12	0.37896
Te_max	not significant at 0.05	-0.65	0.0541
T_min	not significant at 0.05	0.03	0.70613
Te_min	not significant at 0.05	-0.1	0.69922

Two Tailed T-Tests: Station moves, instrument changes, DTS1 installation

Memphis International Airport	**Dew Point**			**1964**	**Estimated instrument changes**	
T-Test	**1960-1963**	**1965-1968**				
	P-value	**CI-Lower**	**CI-Upper**	**T-statistic**	**Degrees of Freedom**	**Standard Deviation**
Tmax	0.7296	-0.6993	0.9951	0.3467	94	2.0903
Tdmax	0.0166	0.1812	1.7688	2.4388	94	1.95860
Tmin	0.095	-1.3879	0.1129	-1.6867	94	1.8516
Tdmin	0.9609	-0.8617	0.82	-0.0492	94	2.0747

Memphis International Airport		**Dew Point**		**1973**	**station move 0.3 miles NW (04/01/1973)**	
1969-1972	**1974-1977**					
T-Test						
	P-value	**CI-Lower**	**CI-Upper**	**T-statistic**	**Degrees of Freedom**	**Standard Deviation**
Tmax	0.0635	-1.5472	0.043	-1.8781	94	1.9618
Tdmax	0.0038	-2.1596	-0.4279	-2.9668	94	2.1363
Tmin	0.2871	-1.1181	0.3348	-1.0705	94	1.7923
Tdmin	0.1685	-1.4989	0.2656	-1.3878	94	2.1768

Memphis International Airport	Dew Point			1985	Estimated instrument change (from unknown to Max/min thermometer) and station move 0.3 miles E (10/01/1985)	
T-Test	1981-1984	1986-1989				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.398	-1.0989	0.4406	-0.8491	94	1.8992
Tdmax	0.3798	-0.461	1.1985	0.8824	94	2.0473
Tmin	0.614	-0.536	0.9027	0.506	94	1.7749
Tdmin	0.1838	-0.3129	1.6087	1.3389	94	2.3707

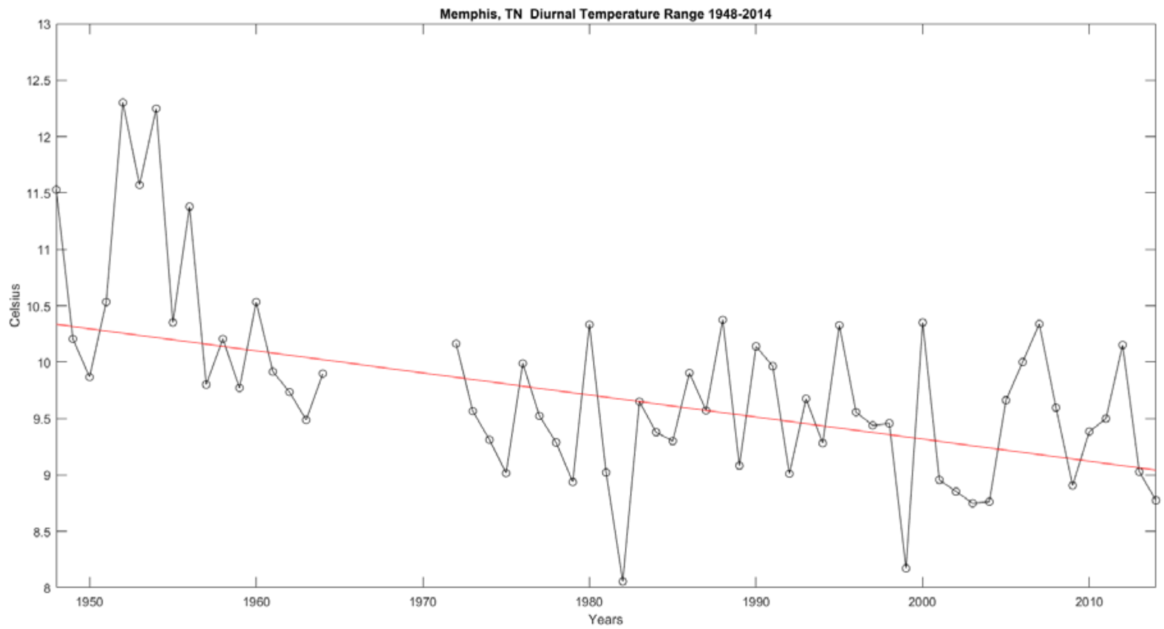
Memphis International Airport	Dew Point			1987	instrument change from Max/min thermometer to Hygrothermometer	
T-Test	1983-1986	1988-1991				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.2675	-1.2973	0.364	-1.1154	94	2.0496
Tdmax	0.815	-0.7773	0.9856	0.2346	94	2.1749
Tmin	0.9356	-0.7972	0.7347	-0.081	94	1.8898
Tdmin	0.1881	-0.3286	1.6494	1.3258	94	2.4402

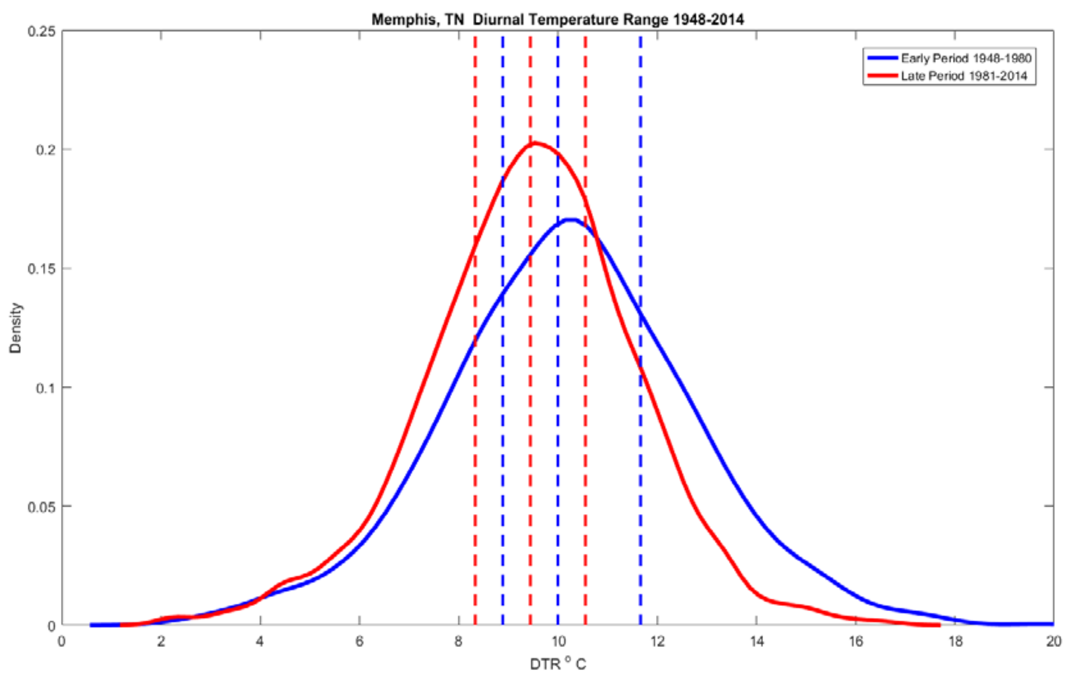
Memphis International Airport	Dew Point			1995	estimated instrument change	
T-Test	1991-1994	1996-1999				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.0733	-0.062	1.3399	1.8172	72	1.444
Tdmax	0.2062	-0.2785	1.2683	1.2757	72	1.59320
Tmin	0.2672	-0.3021	1.074	1.1183	72	1.4174
Tdmin	0.4386	-0.5664	1.2928	0.7789	72	1.9151

Memphis International Airport	Dew Point			1999	Station move, visible from "location data map (5)" 1999-2001.	
T-Test	1995-1998	2000-2004				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.2959	-0.4031	1.3052	1.053	71	1.8215
Tdmax	0.1458	-0.2289	1.5155	1.4707	71	1.8601
Tmin	0.0041	-1.9896	-0.3612	-2.9699	71	1.7044
Tdmin	0.0696	-1.841	0.0728	-1.8423	71	2.0406

Memphis International Airport	Dew Point			2001	station move, visible from "location data map (5)" 1999-2001.	
T-Test	**1997-2000**	**2002-2005**				
	P-value	**CI-Lower**	**CI-Upper**	**T-statistic**	**Degrees of Freedom**	**Standard Deviation**
Tmax	0.1682	-1.7535	0.3128	-1.3951	59	1.9544
Tdmax	0.814	-1.1848	0.9345	-0.2363	59	2.0046
Tmin	0.1046	-1.6391	0.1584	-1.6484	59	1.7001
Tdmin	0.8421	-1.2579	1.0292	-0.2001	59	2.1632

Memphis International Airport	Dew Point			DTS1 Installation 12/15/2003 /Instrument change		
T-Test	**1998-2002**	**2004-2007**				
	P-value	**CI-Lower**	**CI-Upper**	**T-statistic**	**Degrees of Freedom**	**Standard Deviation**
Tmax	0.0017	-2.6543	-0.6397	-3.261	70	2.0403
Tdmax	2.0403	-1.3102	0.7603	-0.5296	70	2.0969
Tmin	0.7444	-1.0274	0.7377	-0.3274	70	1.7876
Tdmin	0.0531	-0.0148	2.1759	1.9674	70	2.2187


Memphis, TN Diurnal Temperature Range 1948-2014
Celsius
Years


Memphis, TN Diurnal Temperature Range 1948-2014
Early Period 1948-1980
Late Period 1981-2014
Density
DTR ° C

APPENDIX J

Boston

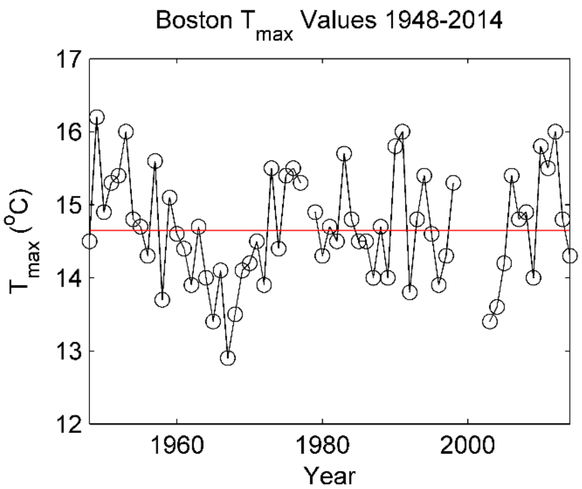
The city of Boston has a land area per square mile of 48, with population density of 12,793, in 2010 the population stood at 617,594 (US Census, 2010). This weather station did not experience any moves however; it did experience quite a large change in elevation for the period of study. T-test in 1964 for estimated instrument change along with a change in elevation shows a possible discontinuity in T_{max}, other t-tests show no changes until 1995. Estimated instrument changes in 1995 show a possible change in $T_{d\ min}$, the installation of Vaisala DTS1 in 2003 may have affected results in $T_{d\ max}$, T_{min} and $T_{d\ min}$. Annual trend analysis shows significant increases in T_{min} (0.11 C°) and $T_{E\ min}$ (0.20 C°). Seasonal summer trend analysis also shows significant increases in T_{min} (0.15 C°) and $T_{E\ min}$ (0.50 C°). $T_{E\ max}$ also shows a significant increase in the summer 0.30 C°. The later part of the record which begins in 1973 shows some cooling in T_{max} and $T_{E\ max}$ and some warming in T_{min} and $T_{E\ min}$ although none were significant.

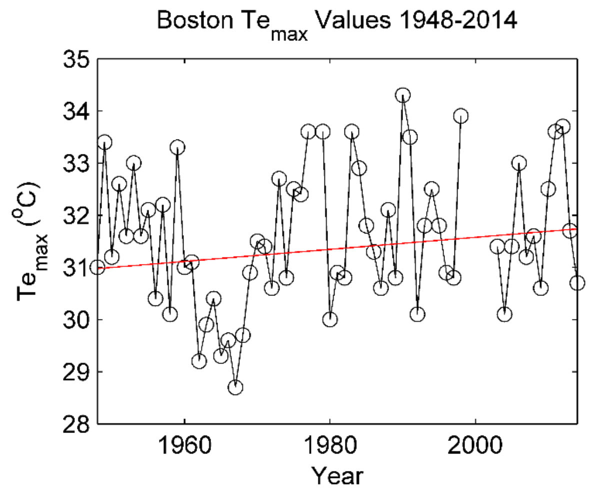
Boston Logan Int’l AP	**Boston Metadata**		**Latitude: 42.3606**	
	WBAN# 14739		**Longitude: 71.0106**	
Year	**Ground Elevation (m)**	**Instruments**	**Comments**	
1948-1987	13.1 (1948-1951)	unknown	Observations daily, 2400	
1987-1995	10.1 (1951-1964)	Hygrothermometer	daily/ observation times 2400. Instrument change from unknown to Hygrothermometer. Reporting Method_FOS-SFC	
1995-2009	6.1 (1964-2009)	Hygrothermometer	Observation times 2400, Reporting method: FOSJ-SFC	
2009-present	3.7 (2009-Present)	Hygrothermometer	Observation times 2400, Reporting method: ASOS-Era Data Downloaded to NCDC	
	*note changes in elevation		**No recorded station moves in any of the records	
Station Moves				
Latitude	**Longitude**	**Initial**	**Final Date**	
42.36667		1/1/1936	1/1/1951	
	71.03333	1/1/1936	1/1/1951	
42.36667		1/1/1951	1/1/1964	
	71.01667	1/1/1951	1/1/1964	
42.36667		1/1/1964	4/1/1996	
	71.03333	1/1/1964	4/1/1996	
42.36056		4/1/1996	10/9/2009	
	71.01056	4/1/1996	10/9/2009	
		2009-present		
T-test 1964	**estimated date for changes in instrumentation and equipment lowered 4 meters**			
T-test 1985	**estimated date for changes in instrumentation**			
T-test 1987	**instrument change from unknown to Hygrothermometer**			
T-test 1995	**estimated instrument changes**			
T-test 2003	**DTS1-Station Installation 10/28/2003**			

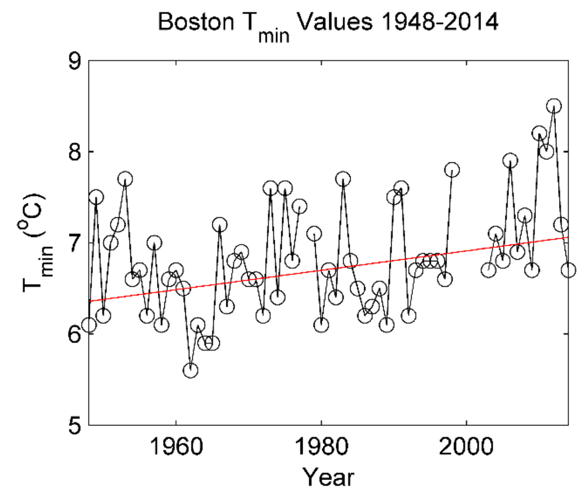
Boston Logan Int'l AP	Median Pairwise Slopes 95% confidence	Degrees C° per decade	
Seasonal Trend			
Winter-Dec,Jan,Feb	**Significance**	**Trend**	**P-value**
T_max	not significant at 0.05	(-0.00)	0.95665
Te_max	not significant at 0.05	-0.03	0.84876
T_min	not significant at 0.05	0.09C°	0.36102
Te_min	not significant at 0.05	0.10C°	0.54563
Spring-Mar,Apr,May			
T_max	not significant at 0.05	0C°	0.943
Te_max	not significant at 0.05	0.08C°	0.47296
T_min	not significant at 0.05	0.08C°	0.1774
Te_min	not significant at 0.05	0.16C°	0.13454
Summer-June, July,August			
T_max	not significant at 0.05	-0.03	0.62389
Te_max	is significant at 0.05	0.30C°	0.03171
T_min	is significant at 0.05	0.15C°	0.00206
Te_min	is significant at 0.05	0.50C°	0.00038
Fall-Sept, Oct, Nov			
T_max	not significant at 0.05	-0.03	0.60211
Te_max	not significant at 0.05	0.07C°	0.6189
T_min	not significant at 0.05	0.08C°	0.11304
Te_min	not significant at 0.05	0.17C°	0.23424

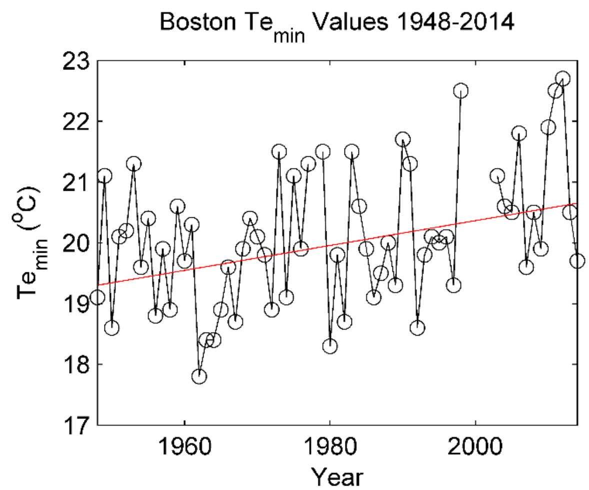
Boston Logan Int'l AP	95% confidence	Degrees C° per decade	
Annual Trend			
	Significance	**Trend**	**P-value**
T_max	is not significant at 0.05	0C°	0.89969
Te_max	is notsignificant at 0.05	0.12C°	0.19728
T_min	is significant at 0.05	0.11C°	0.00507
Te_min	is significant at 0.05	0.20C°	0.00613

ANNUAL TREND





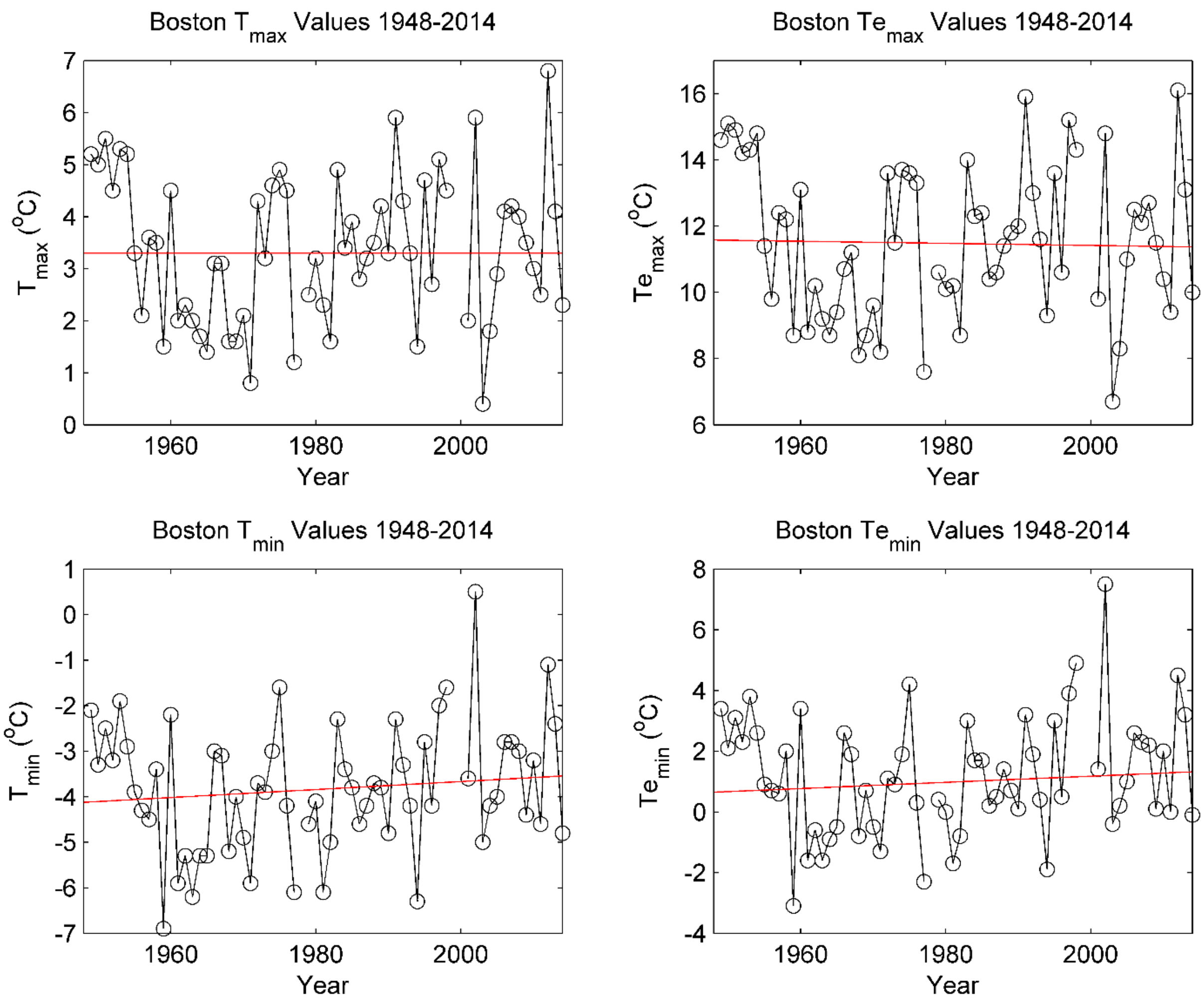




Boston Logan Int'l AP	**95% confidence**	**Degrees C° per decade**	
Annual Trend	**Significance**	**Trend**	**P-value**
T_max	is not significant at 0.05	0C°	0.89969
Te_max	is notsignificant at 0.05	0.12C°	0.19728
T_min	is significant at 0.05	0.11C°	0.00507
Te_min	is significant at 0.05	0.20C°	0.00613

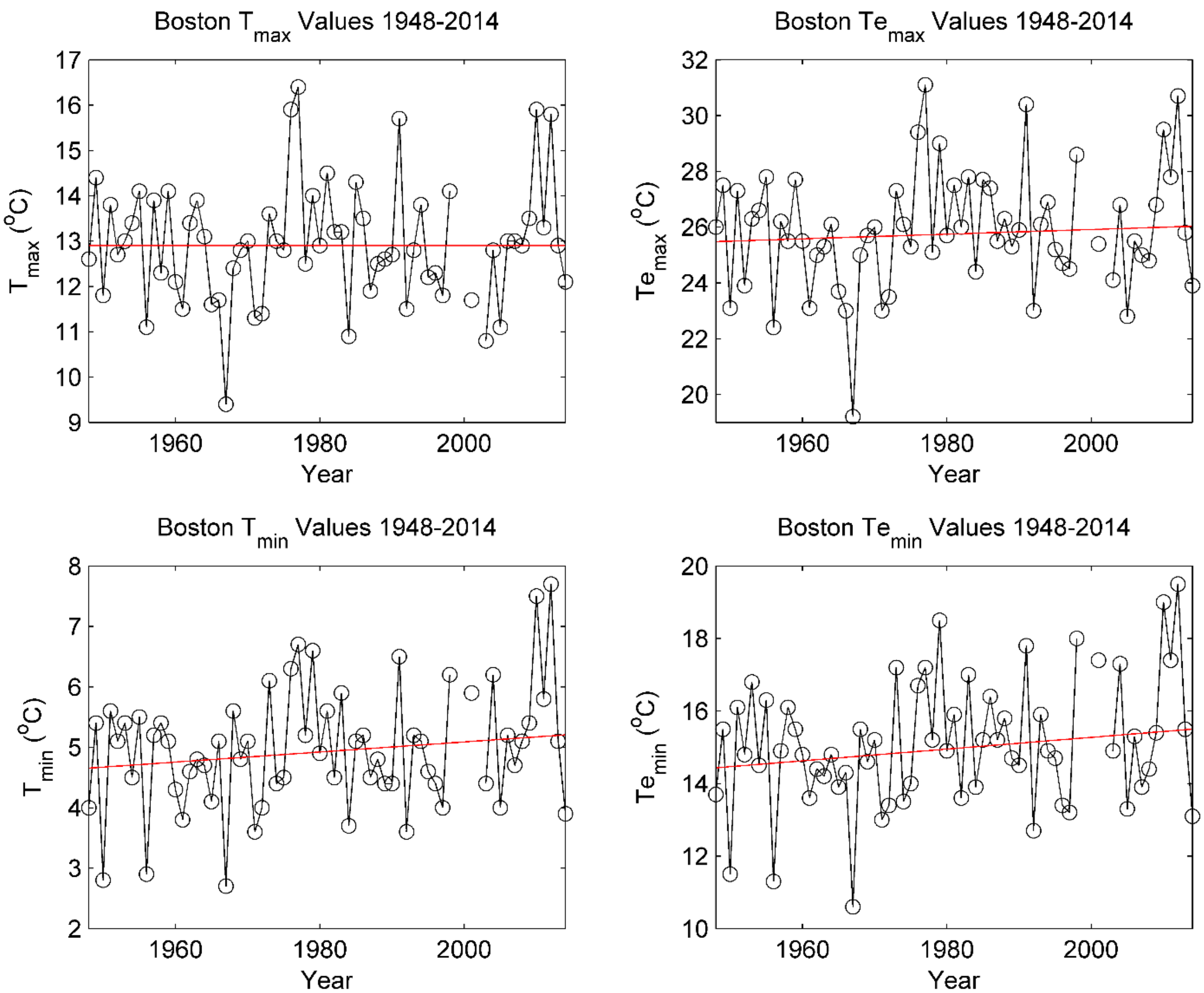
SEASONAL TRENDS

WINTER



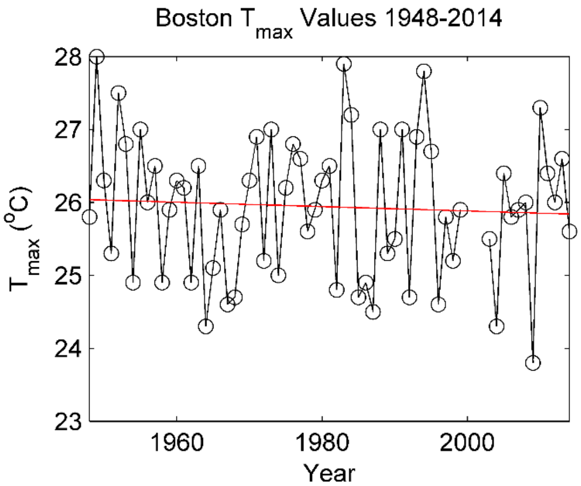
Winter-Dec,Jan,Feb	**Significance**	**Trend**	**P-value**
T_max	not significant at 0.05	(-0.00)	0.95665
Te_max	not significant at 0.05	-0.03	0.84876
T_min	not significant at 0.05	0.09C°	0.36102
Te_min	not significant at 0.05	0.10C°	0.54563

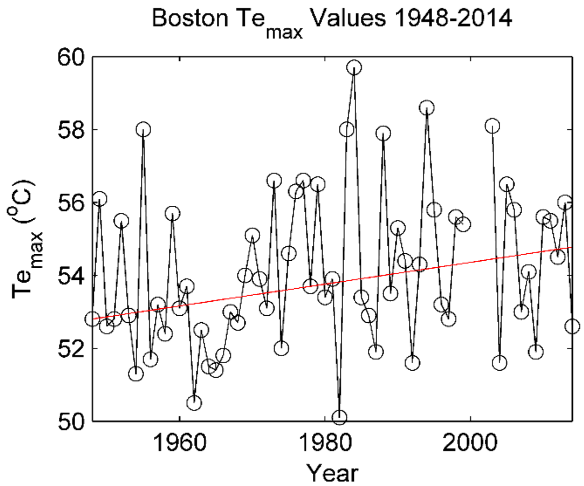
SPRING

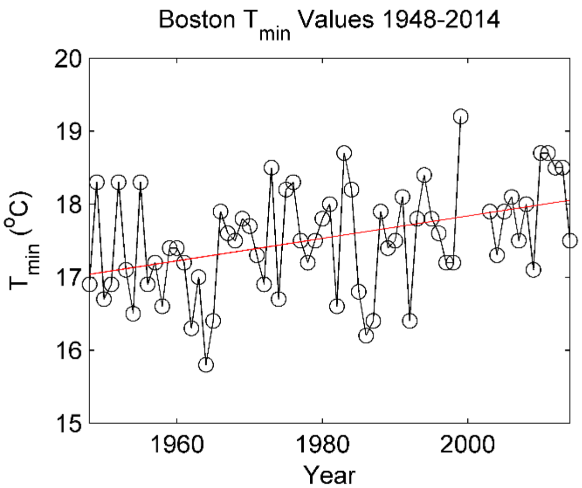


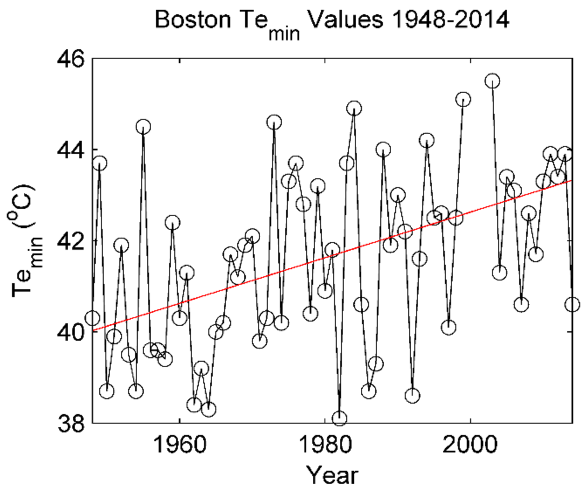
Spring-Mar,Apr,May	Significance	Trend	P-value
T_max	not significant at 0.05	0C°	0.943
Te_max	not significant at 0.05	0.08C°	0.47296
T_min	not significant at 0.05	0.08C°	0.1774
Te_min	not significant at 0.05	0.16C°	0.13454

SUMMER



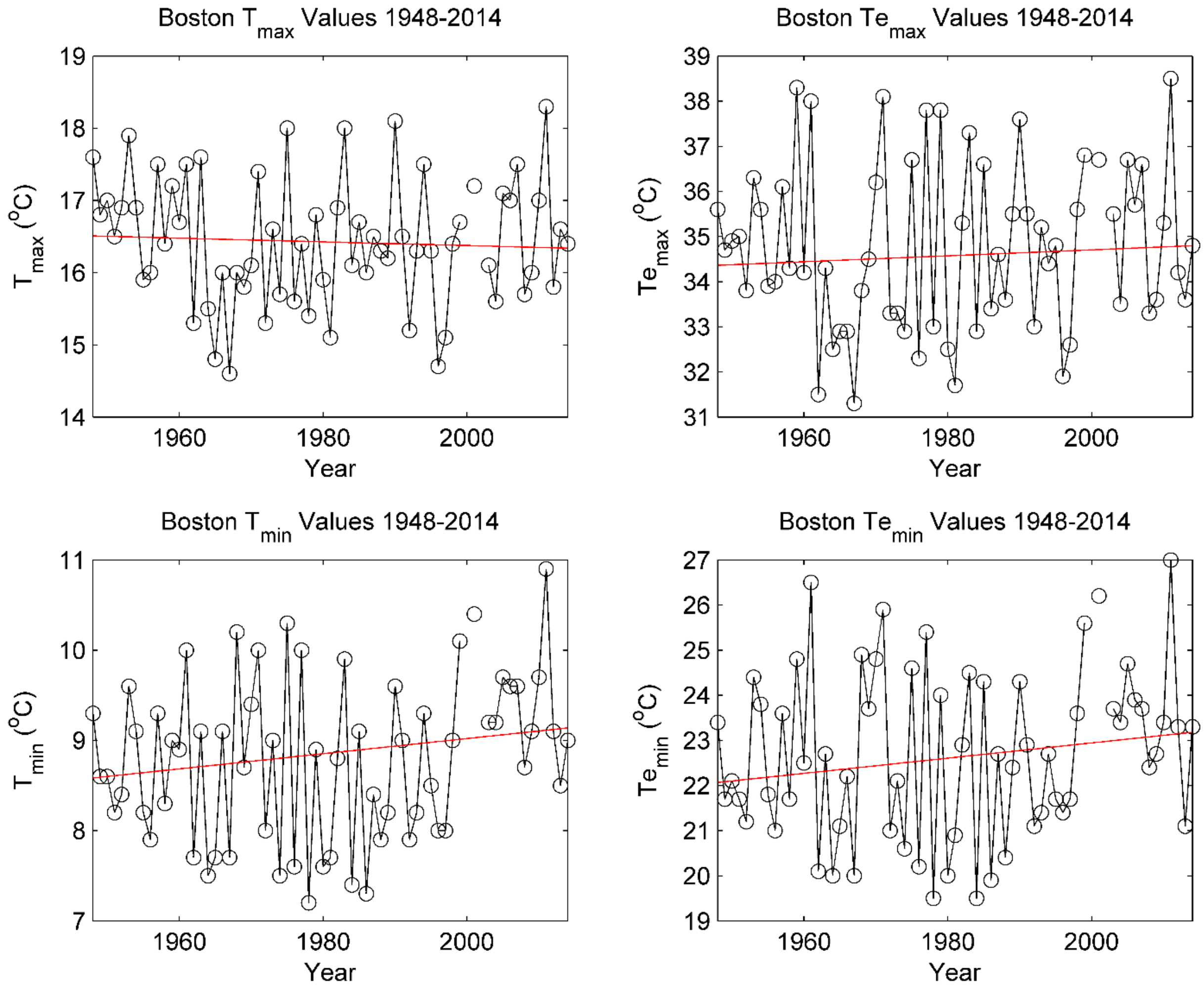






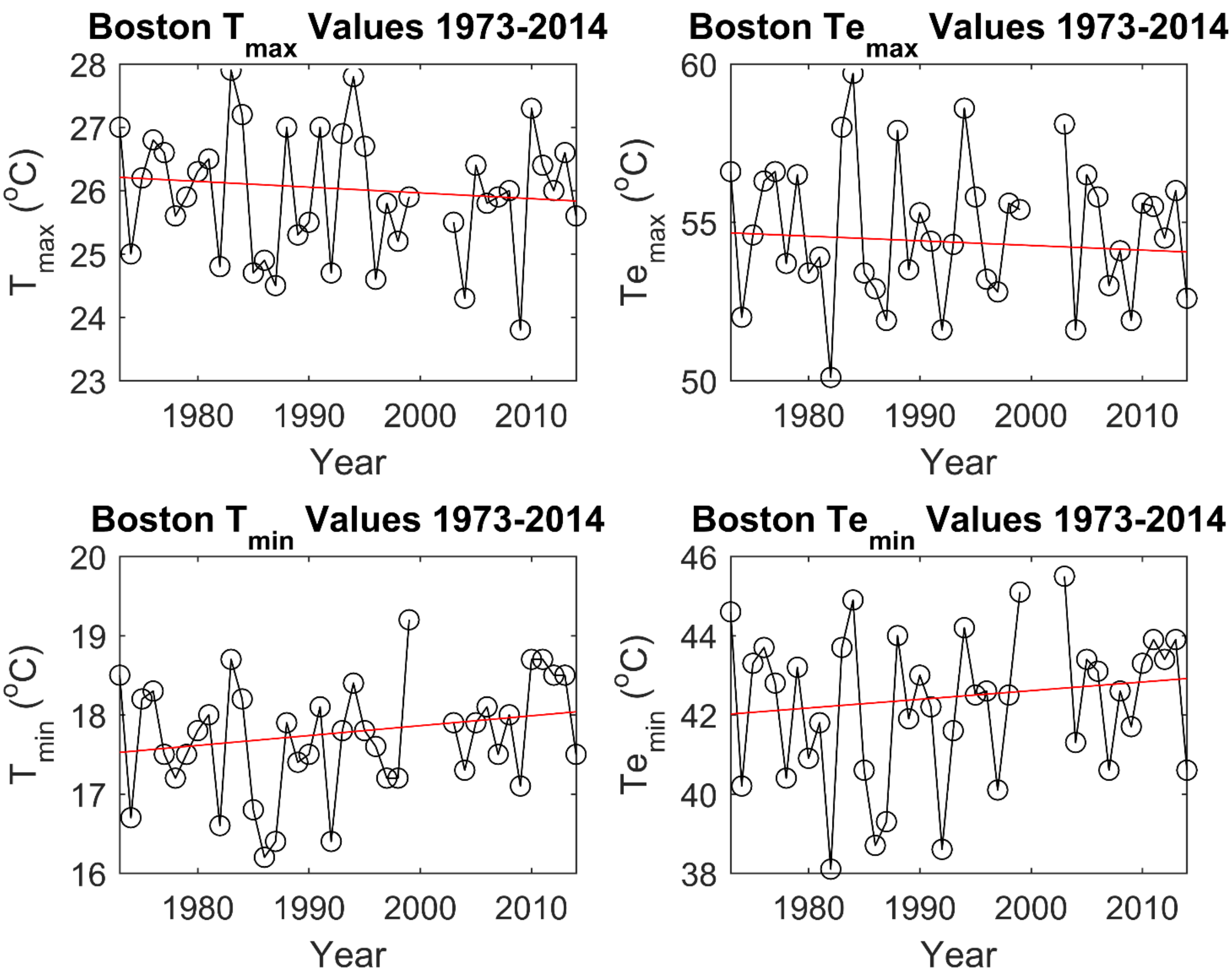
Summer-June, July,August	**Significance**	**Trend**	**P-value**
T_max	not significant at 0.05	-0.03	0.62389
Te_max	is significant at 0.05	0.30C°	0.03171
T_min	is significant at 0.05	0.15C°	0.00206
Te_min	is significant at 0.05	0.50C°	0.00038

FALL



Fall-Sept, Oct, Nov	**Significance**	**Trend**	**P-value**
T_max	not significant at 0.05	-0.03	0.60211
Te_max	not significant at 0.05	0.07C°	0.6189
T_min	not significant at 0.05	0.08C°	0.11304
Te_min	not significant at 0.05	0.17C°	0.23424

SUMMER 1973-2014



Summer-June, July,August	Significance	Trend	P-Value
T_max	not significant at 0.05	-0.09	0.52855
Te_max	not significant at 0.05	-0.15	0.61662
T_min	not significant at 0.05	0.12	0.22497
Te_min	not significant at 0.05	0.22	0.45293

Two Tailed T-Tests: Station moves, instrument changes, DTS1 installation

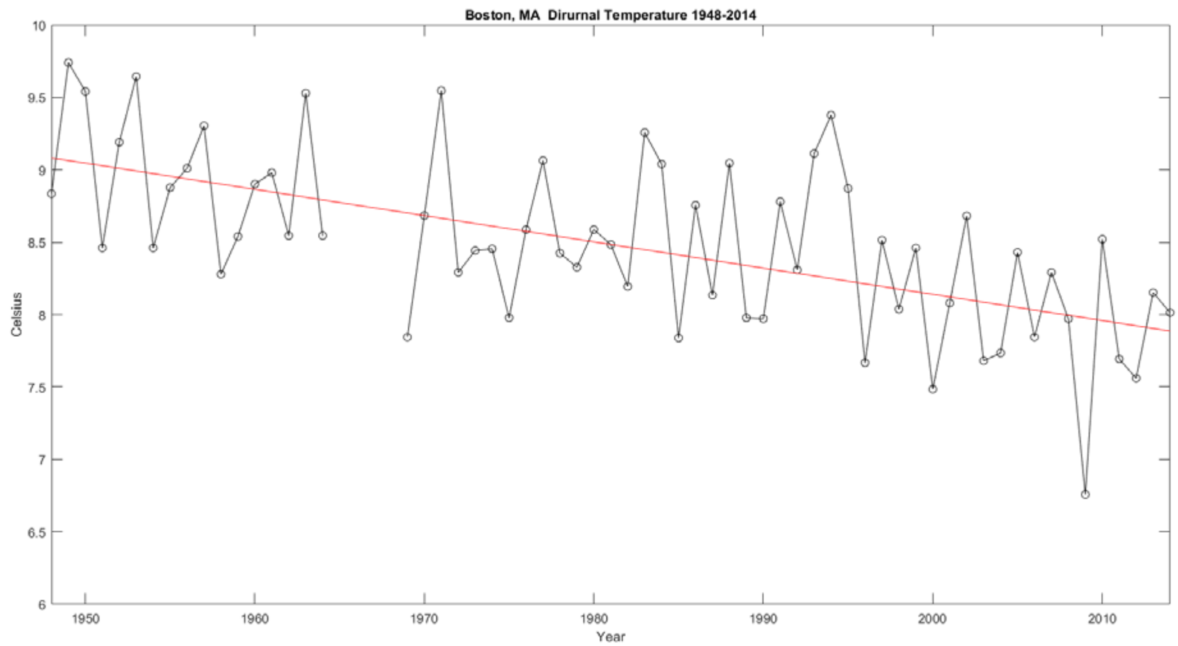
Boston	Dew Point			1964	Estimated instrument changes and elevation change	
T-Test	1960-1963	1965-1968				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.004	0.309	1.5785	2.9521	94	1.5661
Tdmax	0.0619	-0.0306	1.2306	1.8892	94	1.5559
Tmin	0.3012	-0.9033	0.2824	-1.0396	94	1.4627
Tdmin	0.2965	-1.2227	0.3769	-1.0499	94	1.9735

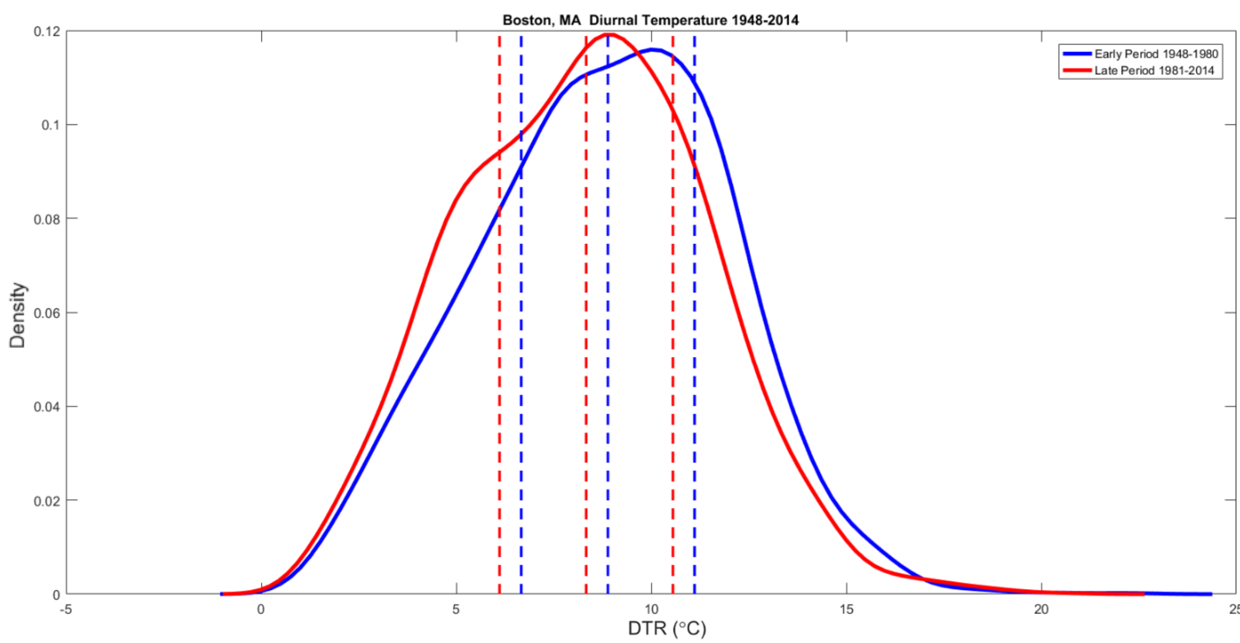
Boston	Dew Point			1985	Estimated instrument changes	
T-Test	1981-1984	1986-1989				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.1254	-0.1557	1.2515	1.5462	94	1.736
Tdmax	0.7919	-0.691	0.9035	0.2646	94	1.9672
Tmin	0.0607	-0.0273	1.2232	1.8987	94	1.5427
Tdmin	0.7131	-0.7579	1.1037	0.3688	94	2.2967

Boston	Dew Point			1987	Instrument change from unknown to Hygrothermometer	
T-Test	1983-1986	1988-1991				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.4115	-1.0363	0.428	-0.8248	94	1.8065
Tdmax	0.7784	-0.8537	0.6412	-0.2822	94	1.8442
Tmin	0.6539	-0.7557	0.4765	-0.4498	94	1.5202
Tdmin	0.9375	-0.8091	0.8758	0.8758	94	2.0786

Boston	Dew Point			1995	Estimated instrument changes	
T-Test	1991-1994	1996-1999				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.1268	-0.1386	1.097	1.5408	91	1.4988
Tdmax	0.3212	-0.918	0.3043	-0.9973	91	1.4827
Tmin	0.0926	-1.0336	0.0803	-1.6998	91	1.3514
Tdmin	0.0072	-1.8392	-0.2962	-2.7491	91	1.8717

Boston	Dew Point			2003	DTS1 installation 10/28/2003	
T-Test	1998-2002	2004-2007				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.7308	-0.5841	0.8299	0.3452	93	1.7349
Tdmax	0.013	0.2069	1.7107	2.5324	93	1.8451
Tmin	0.0023	0.3386	1.5017	3.142	93	1.4271
Tdmin	4.41E-05	0.9434	2.5714	4.2875	93	1.9975


Boston, MA Dirurnal Temperature 1948-2014
Celsius
Year


Boston, MA Dirurnal Temperature 1948-2014
Early Period 1948-1980
Late Period 1981-2014
Density
DTR (°C)

APPENDIX K

Washington DC

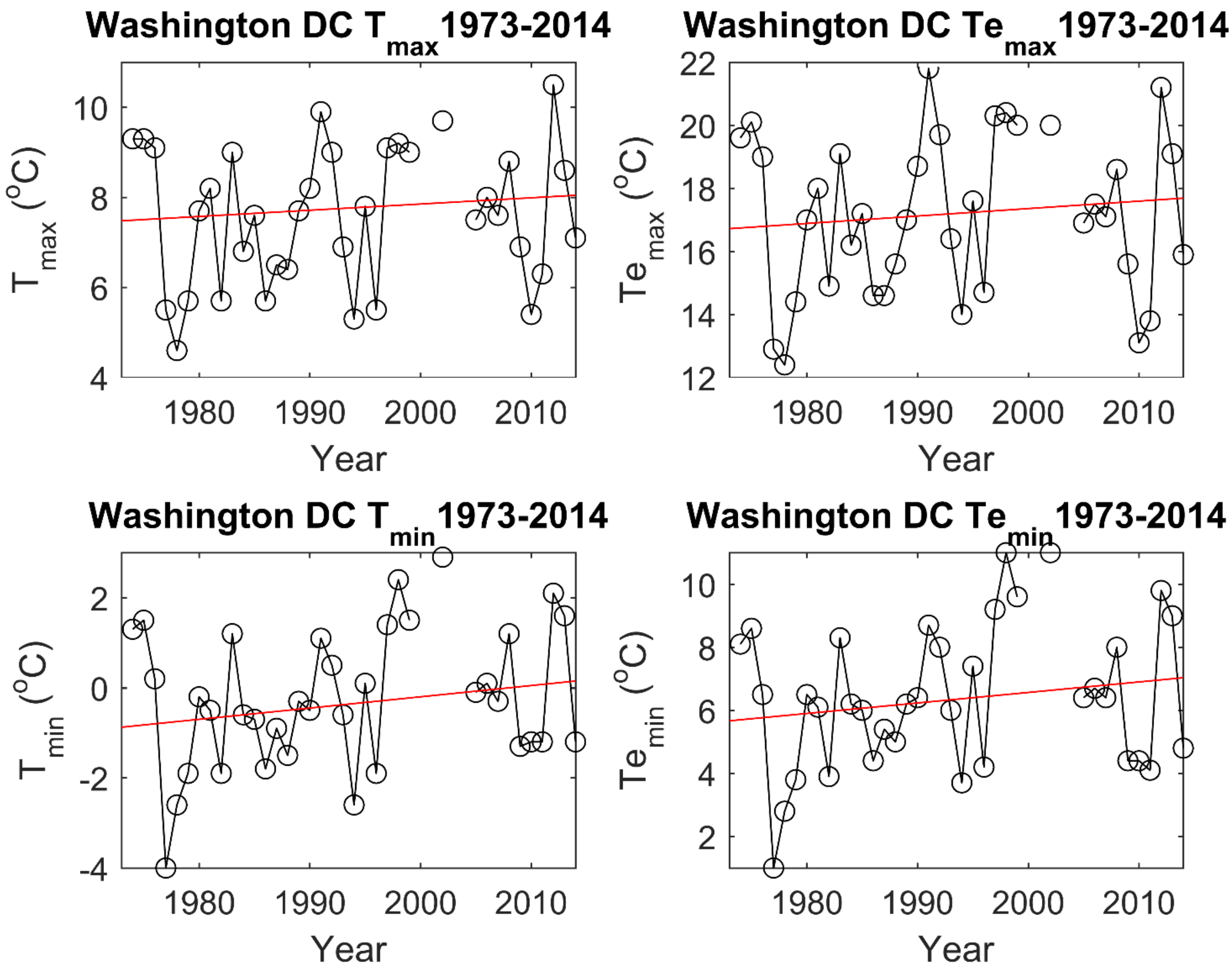
Population of 601, 723 land area per square mile 61, and population density of 9,856.60. No first order stations had records that were long enough to be used. The weather station at Washington Reagan National Airport did not experience any moves, but it did have three estimated instrument changes and three confirmed instrument changes including the installation of the DTS1 station. Reliable data was available for the more recent part of the time series, this station begins at 1973. T-tests show no possible in-continuities were present in the earlier part of the record however the estimated instrument change in 1985 may have affected T_{min}. In 1998 the station metadata shows a change from max/min thermometers to Hygrothermometer, t-test reveals significance for T_{min} and $T_{d\ min}$, the same result was present in 2003 when the ASOS Hygrothermometer was installed. Seasonal summer trend analysis shows a significant increase in T_{min} (0.24 C°) and $T_{E\ min}$ (0.34 C°). This station did not meet the threshold of having 90% available for analysis for the annual trend to be calculated.

Washington Reagan National AP, VA	**Station Metadata**		**Latitude: 38.8483**
	WBAN# 13743		**Longitude: -77.0341**
Year	**Site (m)**	**Instruments**	**Comments**
1948-1992		unknown	Observation times 2400
1992-1998		Max/min thermometer	Instrument change from unknows to Max/min thermometer
1998-2003		Hygrothermometer	Instrument change from Max/min thermometer to Hygrothermometer
2003-Present		ATEMP: ASOS Hygrothermometer	Observation times 2400
Station Moves: none			
Latitude	**Longitude**	**Initial**	**Final Date**
38.85			
	77.03333	7/1/1929	2/1/1998
38.84833			
	77.03417	2/1/1998	12/13/2003
38.84833			
	77.0341	12/13/2003	Present
T-test 1964	***Estimated instrument change***		
T-test 1985	***Estimated instrument change***		
T-Test 1992	***Instrument change from unknown to Max/min thermometer***		
T-test 1995	***Estimated instrument change***		
T-test 1998	***Instrument change from Max/min thermometer to Hygrothermometer***		
T-test 2003	***Instrument change from Hygrothermometer to ATEMP: ASOS Hygrothermometer***		

Washington Reagan National AP	Median of Pairwise Slopes95% confidence	Degrees Celsius per decade	
Seasonal			
Winter-Dec,Jan,Feb	**Significance**	**Trend**	**P-value**
T_max	not significant at 0.05	0.18C°	0.61406
Te_max	not significant at 0.05	0.30C°	0.44883
T_min	not significant at 0.05	0.40C°	0.11007
Te_min	not significant at 0.05	0.47C°	0.12326
Spring-Mar,Apr,May			
T_max	not significant at 0.05	(-0.20C°)	0.34555
Te_max	not significant at 0.05	(-0.32C°)	0.33613
T_min	not significant at 0.05	(-0.00C°)	0.74713
Te_min	not significant at 0.05	0.20C°	0.33806
Summer-June, July,August			
T_max	not significant at 0.05	0.08C°	0.64995
Te_max	not significant at 0.05	(-0.47C°)	0.07855
T_min	not significant at 0.05	0.18C°	0.07863
Te_min	not significant at 0.05	0.10C°	0.62562
Fall-Sept, Oct, Nov			
T_max	not significant at 0.05	(-0.25C°)	0.12702
Te_max	is significant at 0.05	(-0.75C°)	0.02275
T_min	not significant at 0.05	0C°	0.81767
Te_min	not significant at 0.05	(-0.11C°)	0.74403

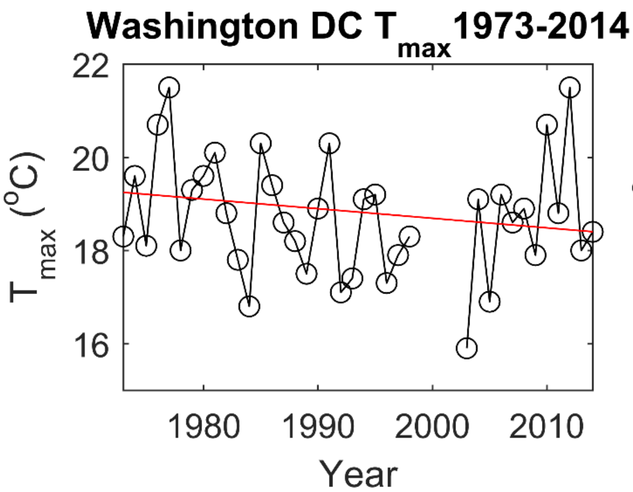
SEASONAL TREND

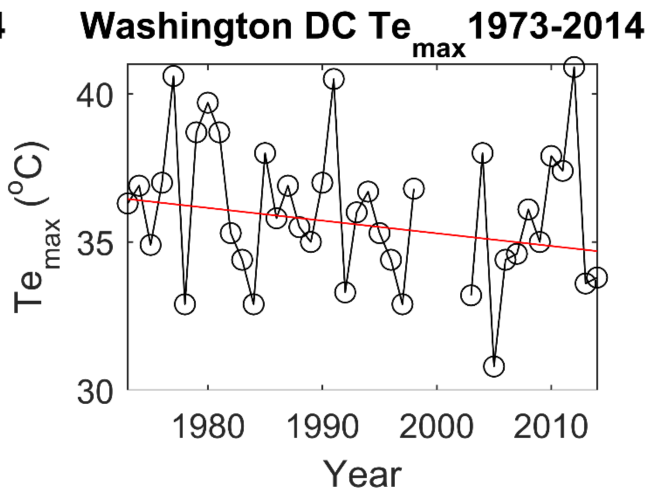
WINTER

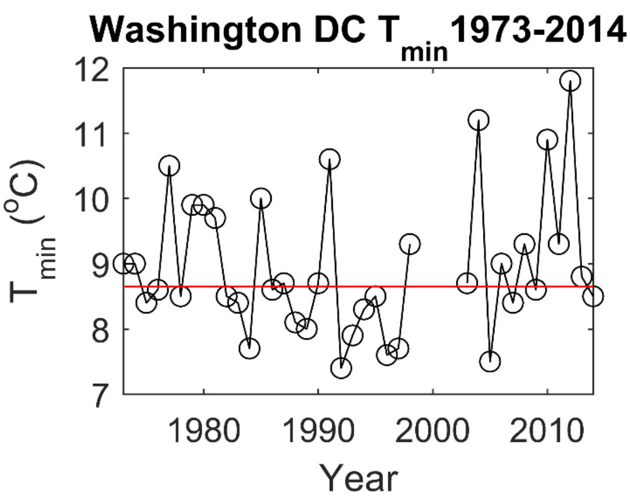


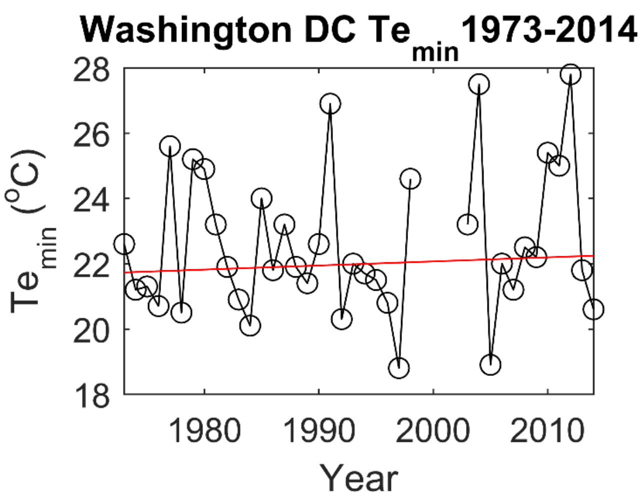
Winter-Dec,Jan,Feb	Significance	Trend	P-value
T_max	not significant at 0.05	0.18C°	0.61406
Te_max	not significant at 0.05	0.30C°	0.44883
T_min	not significant at 0.05	0.40C°	0.11007
Te_min	not significant at 0.05	0.47C°	0.12326

SPRING



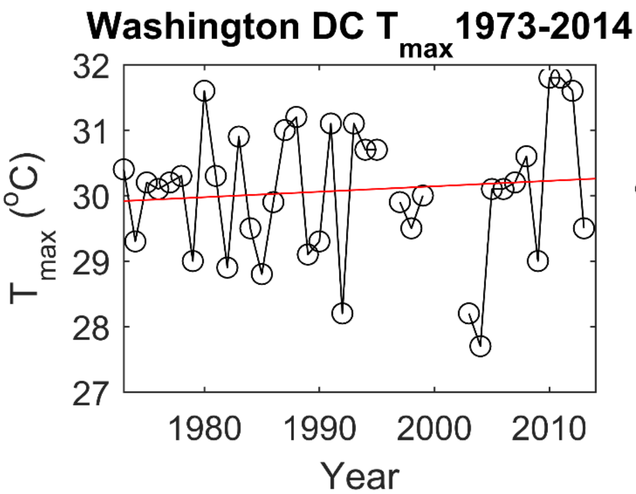


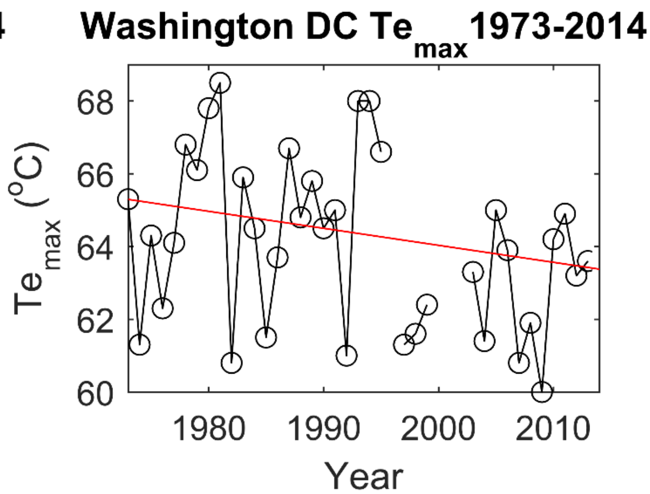


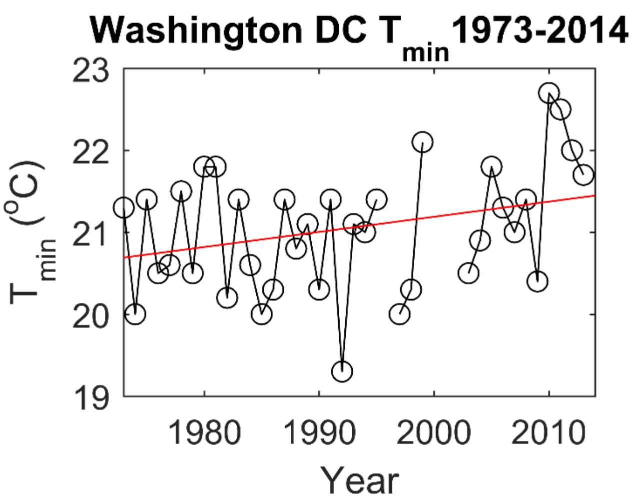


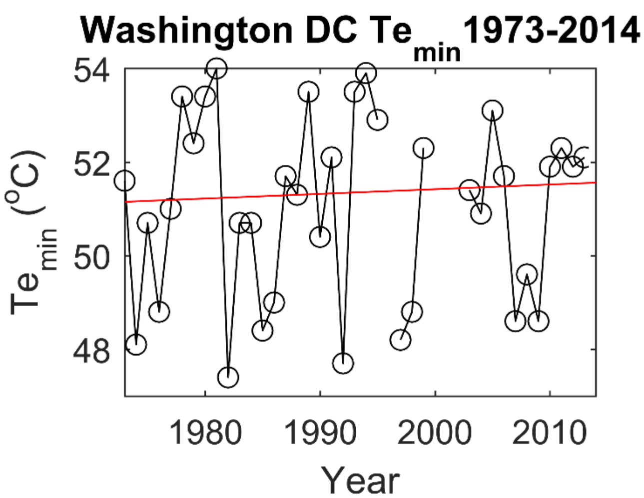
Spring-Mar,Apr,May			
T_max	not significant at 0.05	(-0.20C°)	0.34555
Te_max	not significant at 0.05	(-0.32C°)	0.33613
T_min	not significant at 0.05	(-0.00C°)	0.74713
Te_min	not significant at 0.05	0.20C°	0.33806

SUMMER



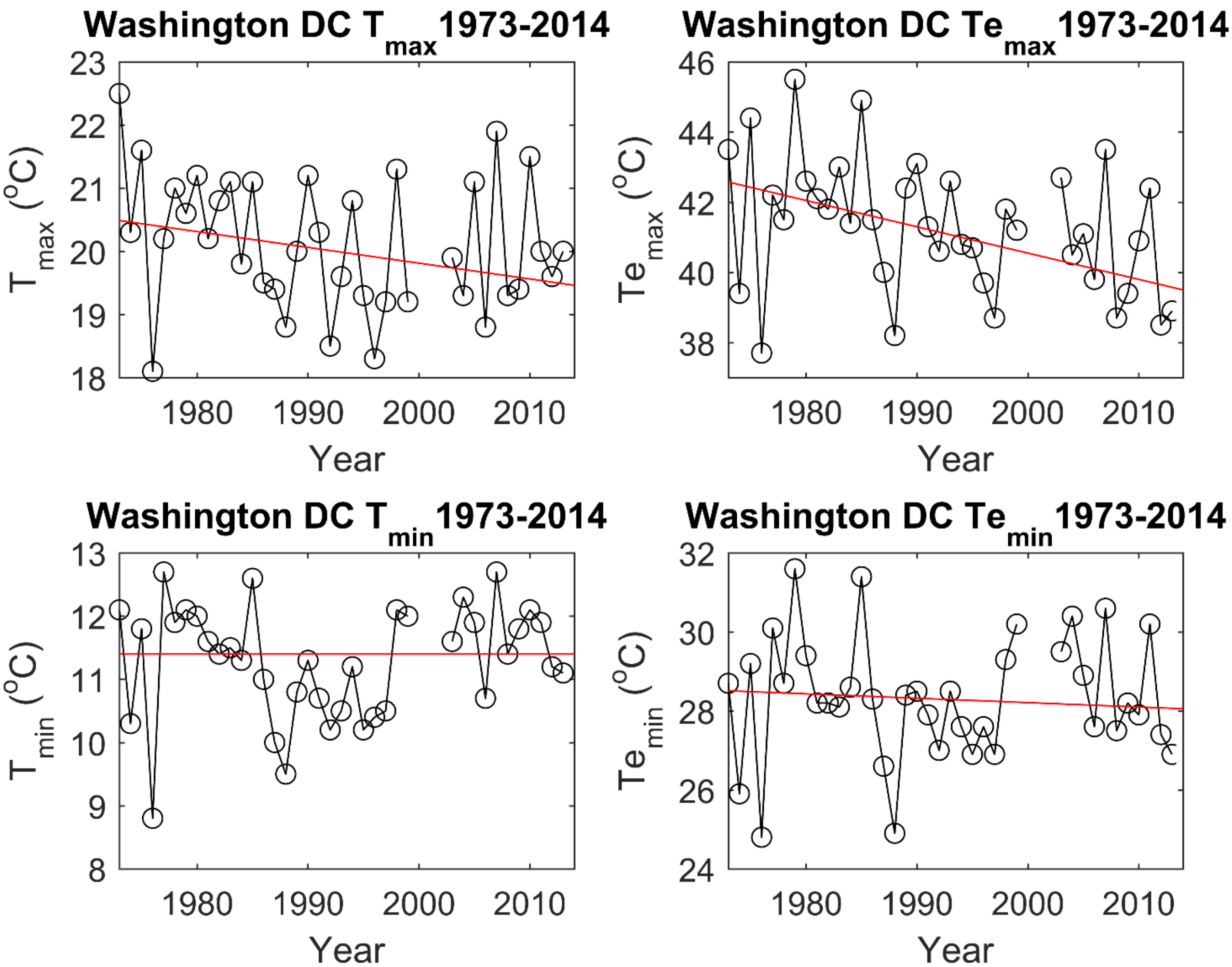






Summer-June, July,August	**Significance**	**Trend**	**P-value**
T_max	not significant at 0.05	0.08C°	0.64995
Te_max	not significant at 0.05	(-0.47C°)	0.07855
T_min	not significant at 0.05	0.18C°	0.07863
Te_min	not significant at 0.05	0.10C°	0.62562

FALL



Fall-Sept, Oct, Nov	**Significance**	**Trend**	**P-value**
T_max	not significant at 0.05	(-0.25C°)	0.12702
Te_max	is significant at 0.05	(-0.75C°)	0.02275
T_min	not significant at 0.05	0C°	0.81767
Te_min	not significant at 0.05	(-0.11C°)	0.74403

Two Tailed T-Tests: Station moves, instrument changes, DTS1 installation

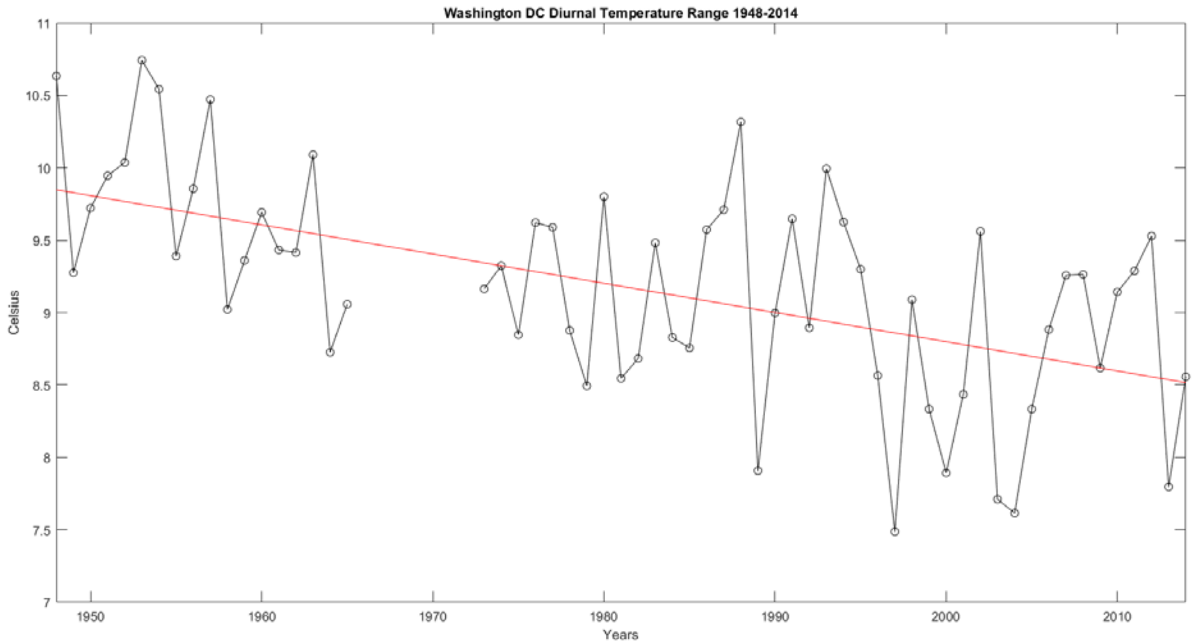
Washington Reagan National AP, VA	Dew Point		1985	Estimated instrument change		
T-Test	1981-1984	1986-1989				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.1444	-0.184	1.2382	1.4717	94	1.7545
Tdmax	0.9122	-0.7067	0.79	0.1106	94	1.8464
Tmin	0.0292	0.0721	1.3238	2.2142	94	1.5442
Tdmin	0.505	-0.5328	1.0744	0.6692	94	1.9828

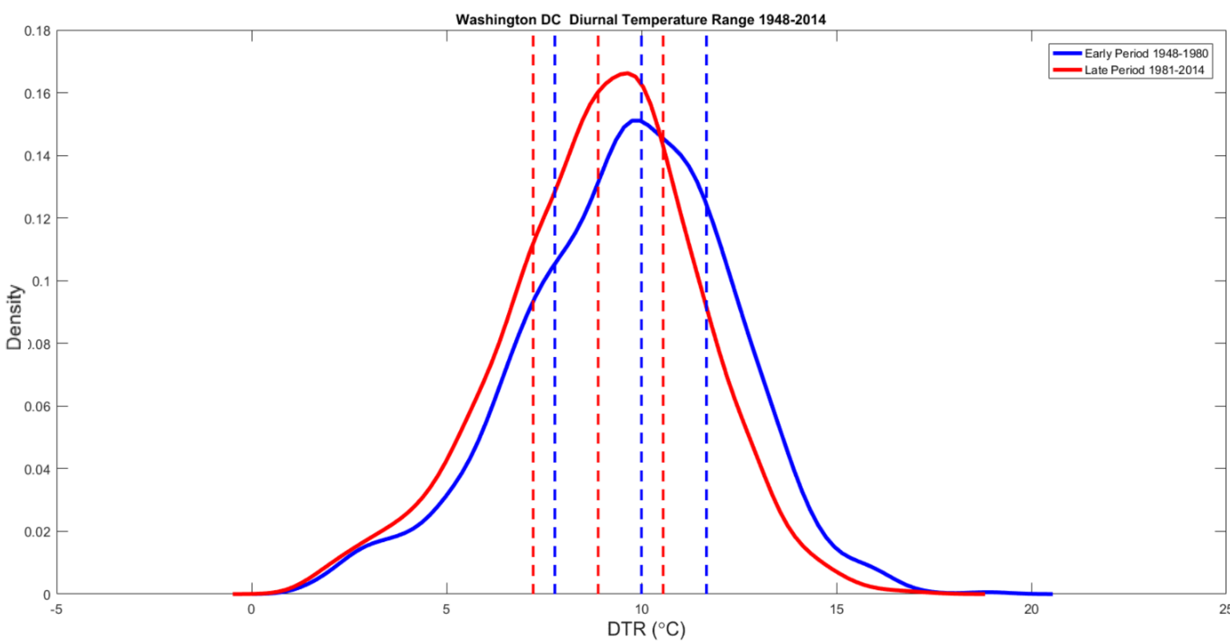
Washington Reagan National AP, VA	Dew Point		1992		Estimated instrument change	
T-Test	1988-1991	1993-1996				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.1365	-0.1932	1.392	1.5018	93	1.945
Tdmax	0.6575	-0.5935	0.9361	0.4448	93	1.87680
Tmin	0.2968	-0.3094	1.0026	1.0492	93	1.6099
Tdmin	0.9112	-0.7531	0.843	0.1119	93	1.9583

Washington Reagan National AP, VA	Dew Point		1995	Estimated instrument change		
T-Test	1991-1994	1996-1999				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.6627	-0.5424	0.849	0.4376	92	1.6977
Tdmax	0.1098	-0.1246	1.2082	1.6148	92	1.62620
Tmin	0.0765	-1.1968	0.0617	-1.7914	92	1.5355
Tdmin	0.8121	-0.6854	0.8723	0.2384	92	1.9006

Washington Reagan National AP, VA	Dew Point		1998	Change from Max/min thermometer to Hygrothermometer		
T-Test	1994-1997	1999-2003				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.2951	-0.3656	1.1902	1.0533	88	1.8549
Tdmax	0.4059	-0.4098	1.004	0.8351	88	1.68570
Tmin	1.76E-04	-1.859	-0.6077	-3.9175	88	1.4919
Tdmin	0.0028	-1.9676	-0.4231	-3.076	88	1.8415

Washington Reagan National AP, VA	Dew Point		2003	Instrument change from hygrothermometer to ATEMP: ASOS Hygrothermometer		
T-Test	1999-2002	2004-2007				
	P-value	CI-Lower	CI-Upper		Degrees of Freedom	Standard Deviation
Tmax	0.5411	-1.0868	0.5747		76	1.8119
Tdmax	0.9805	-0.7702	0.7895		76	0.0246
Tmin	0.0297	0.0723	1.3567		76	1.4008
Tdmin	0.41	0.4205	2.1492		76	1.8854


Washington DC Diurnal Temperature Range 1948-2014
Celsius
Years


Washington DC Diurnal Temperature Range 1948-2014
Early Period 1948-1980
Late Period 1981-2014
Density
DTR (°C)

APPENDIX L

Nashville

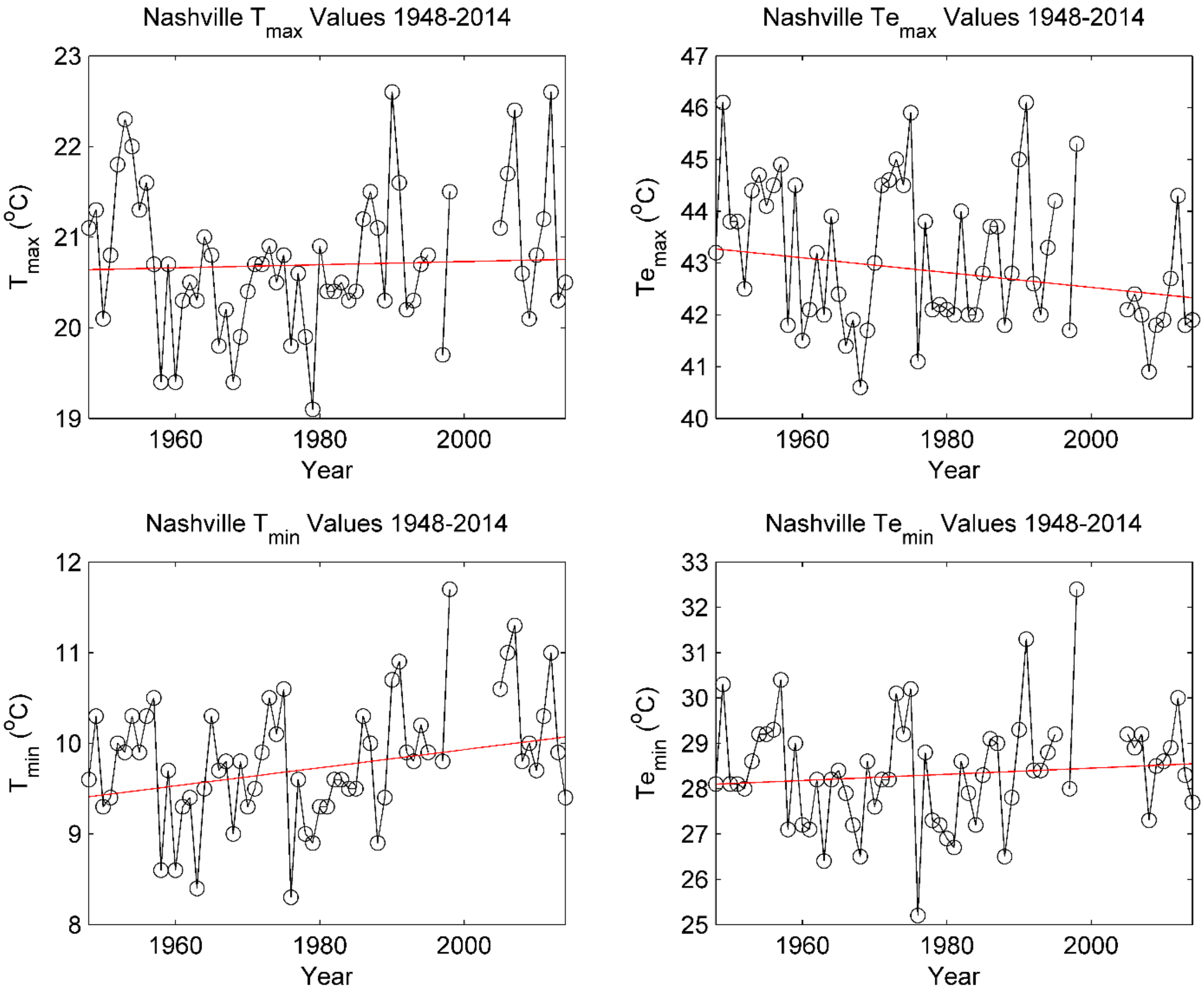
The city of Nashville, TN has a population of 601, 222, land area per square mile of 475 and population density stood at 1,265 in 2010 (US Census, 2010). The station at Nashville Int'l AP had 6 instrument changes and 1 station move. T-tests show a possible discontinuity in 1964 for $T_{d\ max}$, this was an estimated instrument change. In 1975 there was a noted instrument change from an unknown instrument to Hygrothermometer, this may have effected $T_{d\ max}$, T_{min}, and $T_{d\ min}$. In 2003 the DTS1 station was installed, t-test reveal changes in T_{max} and $T_{d\ min}$. The final change that may reflect in the record was a station move over 3000ft south may have affected $T_{d\ min}$. Summer trend analysis shows a significant increase in T_{min} (0.16 C°), an increase was also noted in $T_{E\ min}$, but it was not significant at (0.09 C°) Annual trend analysis shows significant decrease in $T_{E\ max}$ (-0.14 C°) (like Louisville) and a significance increase in Tmin (0.10C°). From 1973 there is a significant increase in T_{min} (0.29 C°), there is also an increase in $T_{E\ min}$, but it is not significant, $T_{E\ max}$ shows a decrease of -0.77C° with no significance.

Nashville Intl' AP	Station Metadata		Latitude: 36.11889	
	WBAN# 13897		Longitude: 86.68917	
Year	**Site (m)**	**Instruments**		**Comments**
1952-1975	177.1 (1948-1964)	unknown		unknown
1975-2001	182.9 (1964-1976)	Hygrothermometer		Daily, obs times 2400
2001-Present	179.8 (1976-1996)	ATEMP: ASOS Hygrothermometer		Daily, obs times 2400, Receiver NCEI, Reporting Method: ADP
	176.8 (1996-2001)			
	182.9 (2001-Present)			
Station Moves				
Latitude	**Longitude**	**Initial**	**Final Date**	
36.11667		12/1/1928	9/18/2001	
	86.68333	12/1/1928	9/18/2001	
36.12528		9/18/2001	8/18/2004	
	86.67639	9/18/2001	8/18/2004	
36.1252		8/18/2004	6/15/2006	
	86.6763	8/18/2004	6/15/2006	
36.11889		6/15/2006	Present	
	86.68917	6/15/2006	Present	
T-test 1964	**estimated instrument change**			
T-test 1975	**instrument change from unknown to hygrothermometer**			
T-test 1985	**estimated instrument change**			
T-test 1995	**estimated instrument change**			
T-Test 2001	**instrument change from Hygrothermometer to ATEMP**			
T-Test 2003	**09/11/2003 DTS1 Installation**			
T-Test 2009	**Station move 3612 ft South (7/23/2009)**			

Nashville	Median of Pairwise Slopes 95% confidence	Degrees Celsius per decade	
Seasonal Trend			
Winter-Dec,Jan,Feb	**Significance**	**Trend**	**P-value**
T_max	not significant at 0.05	0.05C°	0.91381
Te_max	not significant at 0.05	(-0.14C°)	0.41825
T_min	not significant at 0.05	0.12C°	0.49493
Te_min	not significant at 0.05	0.00C°	0.91074
Spring-Mar,Apr,May			
T_max	not significant at 0.05	0.07C°	0.33009
Te_max	not significant at 0.05	(-0.23C°)	0.22729
T_min	not significant at 0.05	0.08C°	0.21179
Te_min	not significant at 0.05	0.00C°	0.88359
Summer-June, July,August			
T_max	not significant at 0.05	(-0.00C°)	0.84256
Te_max	not significant at 0.05	(-0.28C°)	0.0929
T_min	is significant at 0.05	0.16C°	0.00141
Te_ min	not significant at 0.05	0.09C°	0.35694
Fall-Sept, Oct, Nov			
T_max	not significant at 0.05	0.00C°	0.85249
Te_max	not significant at 0.05	(-0.17C°)	0.25446
T_min	is significant at 0.05	0.14C°	0.00945
Te_min	not significant at 0.05	0.17C°	0.20936

Annual Trend	Significance	Trend	P-value
T_max	not significant at 0.05	0.02C°	0.71442
Te_max	is significant at 0.05	(-0.14C°)	0.04884
T_min	is significant at 0.05	0.10C°	0.03001
Te_min	not significant at 0.05	0.07C°	0.30607

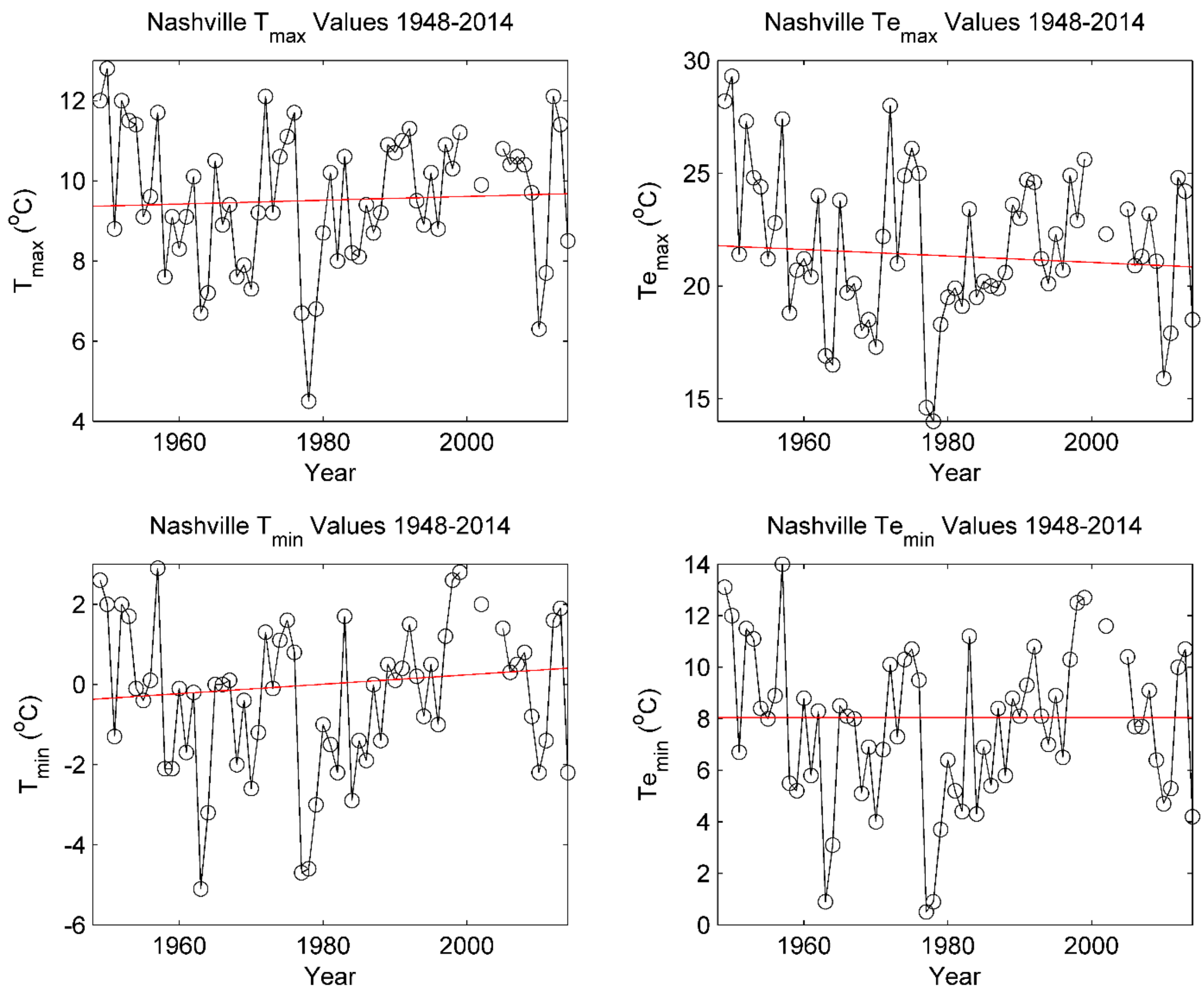
ANNUAL TREND



Annual Trend	Significance	Trend	P-value
T_max	not significant at 0.05	0.02C°	0.71442
Te_max	is significant at 0.05	(-0.14C°)	0.04884
T_min	is significant at 0.05	0.10C°	0.03001
Te_min	not significant at 0.05	0.07C°	0.30607

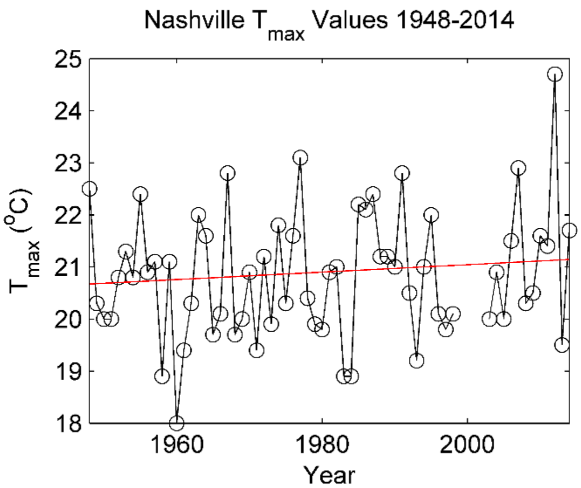
SEASONAL TRENDS

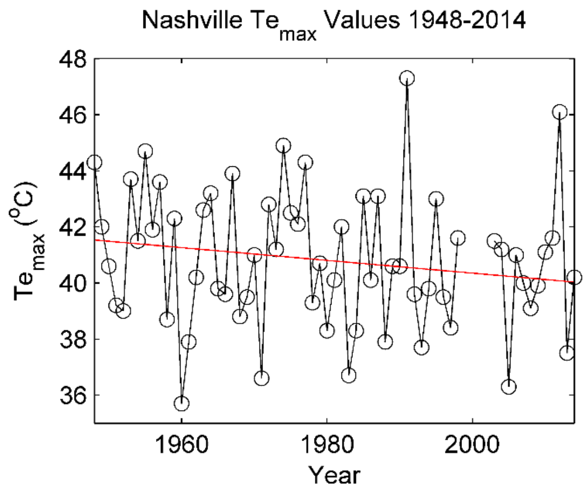
WINTER

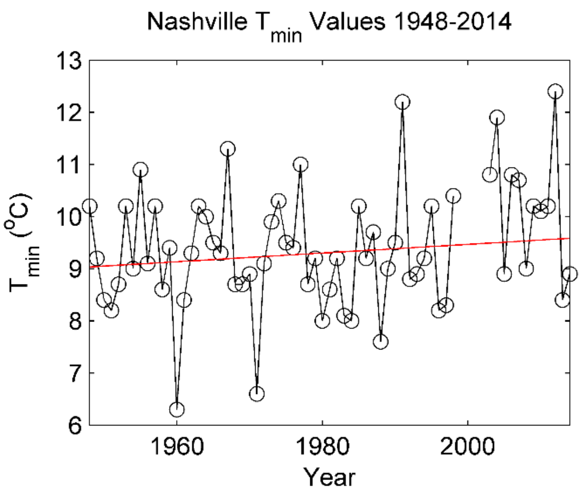


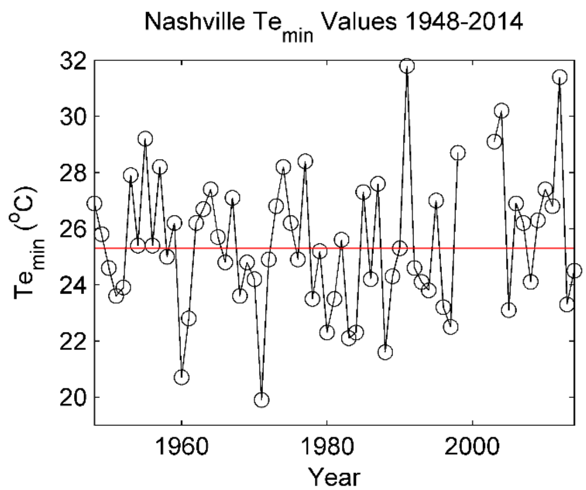
Winter-Dec,Jan,Feb	Significance	Trend	P-value
T_max	not significant at 0.05	0.05C°	0.91381
Te_max	not significant at 0.05	(-0.14C°)	0.41825
T_min	not significant at 0.05	0.12C°	0.49493
Te_min	not significant at 0.05	0.00C°	0.91074

SPRING



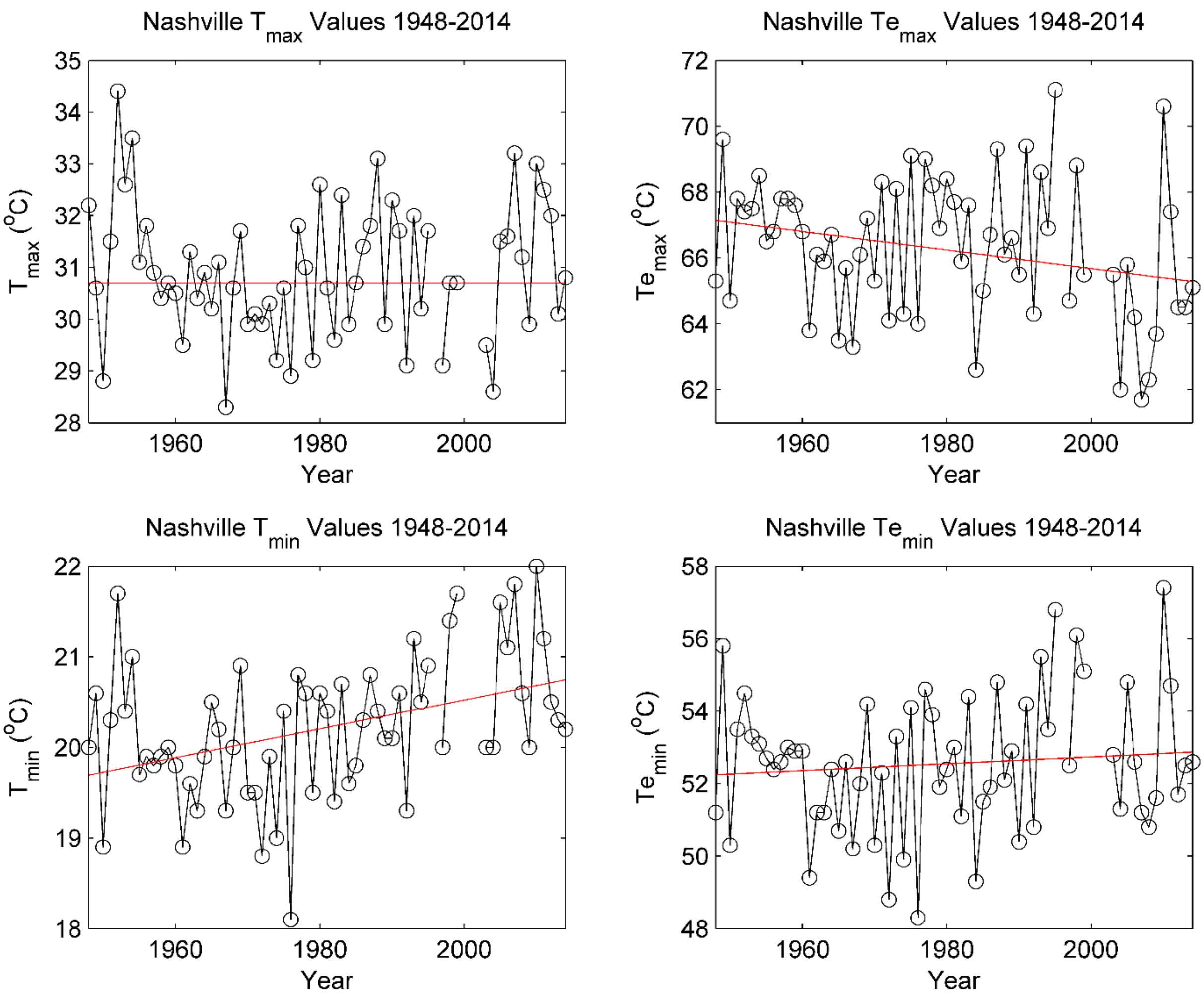






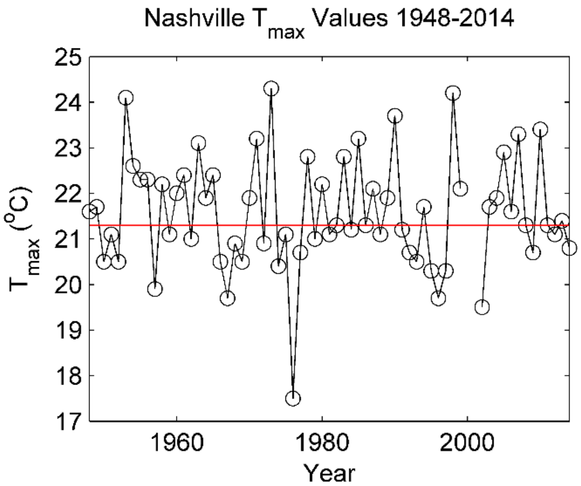
Spring-Mar,Apr,May	**Significance**	**Trend**	**P-Value**
T_max	not significant at 0.05	0.07C°	0.33009
Te_max	not significant at 0.05	(-0.23C°)	0.22729
T_min	not significant at 0.05	0.08C°	0.21179
Te_min	not significant at 0.05	0.00C°	0.88359

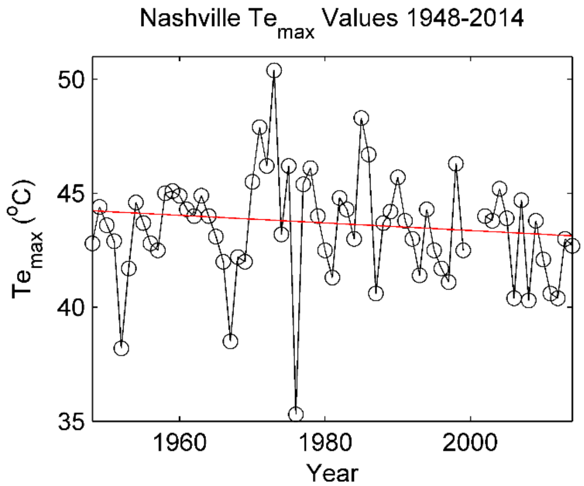
SUMMER

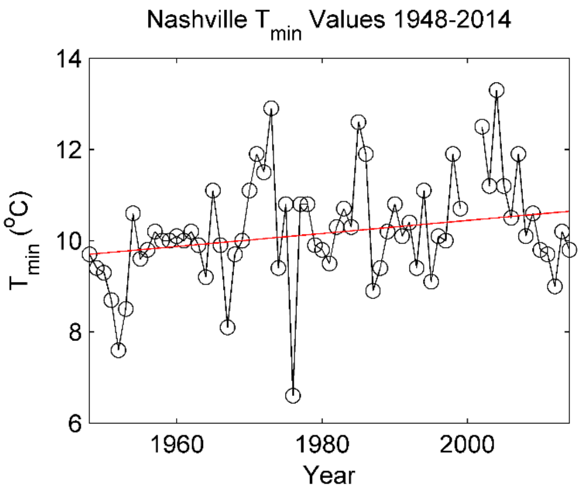


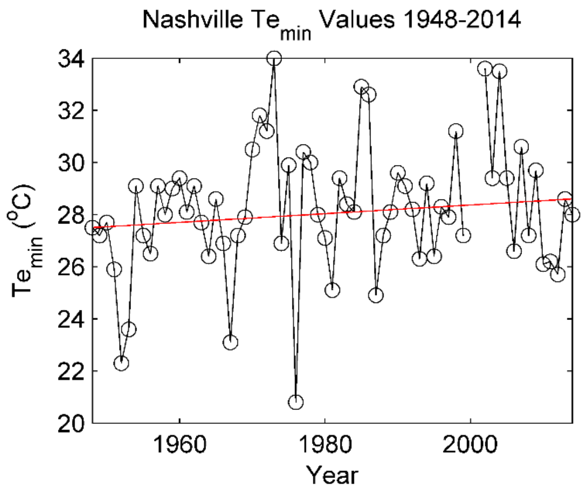
Summer-June, July,August	Significance	Trend	P-value
T_max	not significant at 0.05	(-0.00C°)	0.84256
Te_max	not significant at 0.05	(-0.28C°)	0.0929
T_min	is significant at 0.05	0.16C°	0.00141
Te_min	not significant at 0.05	0.09C°	0.35694

FALL



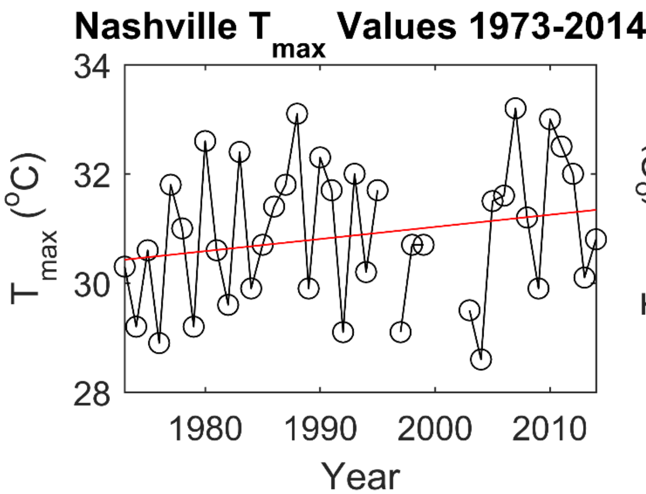


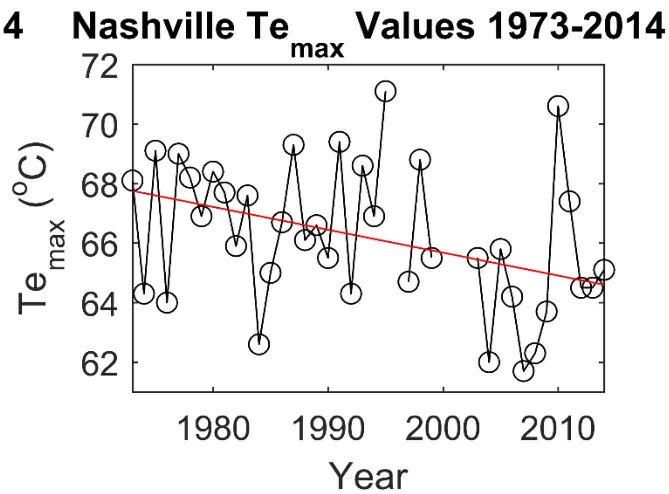


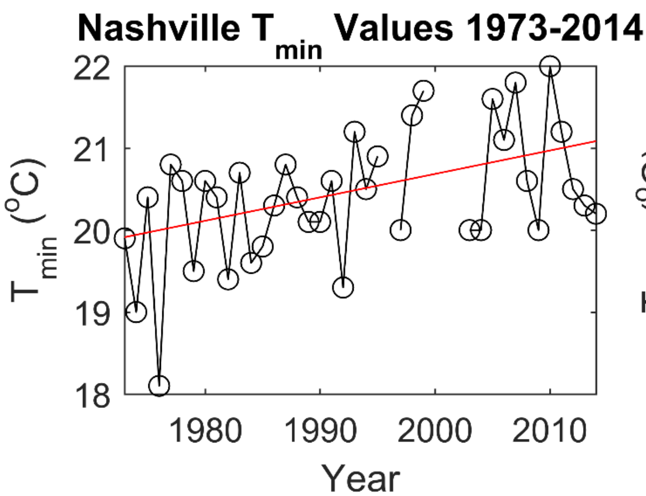


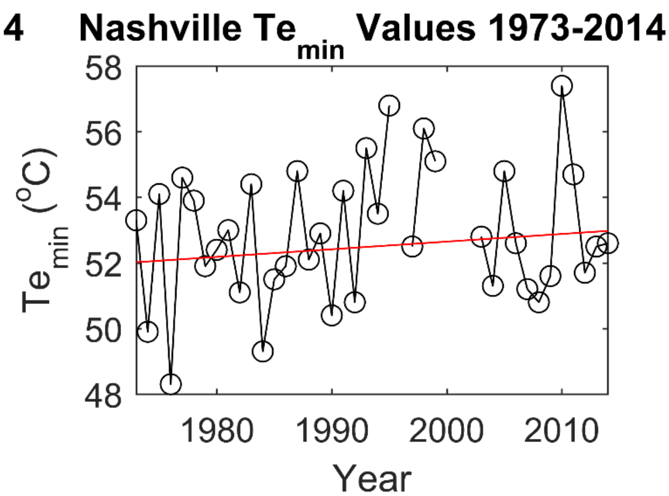
Fall-Sept, Oct, Nov	**Significance**	**Trend**	**P-value**
T_max	not significant at 0.05	0.00C°	0.85249
Te_max	not significant at 0.05	(-0.17C°)	0.25446
T_min	is significant at 0.05	0.14C°	0.00945
Te_min	not significant at 0.05	0.17C°	0.20936

SUMMER 1973-2014









Summer-June, July,August	**Significance**	**Trend**	**P-Value**
T_max	not significant at 0.05	0.22	0.21323
Te_max	not significant at 0.05	-0.77	0.05086
T_min	is significant at 0.05	0.29	0.01189
Te_min	not significant at 0.05	0.23	0.41691

Two Tailed T-Tests: Station moves, instrument changes, DTS1 installation

Nashville Int'l AP	Dew Point			1964	Estimated instrument change	
T-Test	1960-1963	1965-1968				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.9715	-0.9075	0.9408	0.0358	94	2.2803
Tdmax	0.0409	0.0349	1.6192	2.0731	94	1.95450
Tmin	0.056	-1.5703	0.0203	-1.9348	94	1.9623
Tdmin	0.5629	-0.5948	1.0865	0.5806	94	2.0742

Nashville Int'l AP	Dew Point			1975	Instrument change from unknown to Hygrothermometer	
T-Test	1971-1974	1976-1979				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.0825	-0.1108	1.7983	1.7551	94	2.3552
Tdmax	0.0015	0.6213	2.5412	3.2705	94	2.36860
Tmin	0.0223	0.1524	1.9393	2.3242	94	2.2044
Tdmin	0.0236	0.1608	2.1809	2.3017	94	2.4921

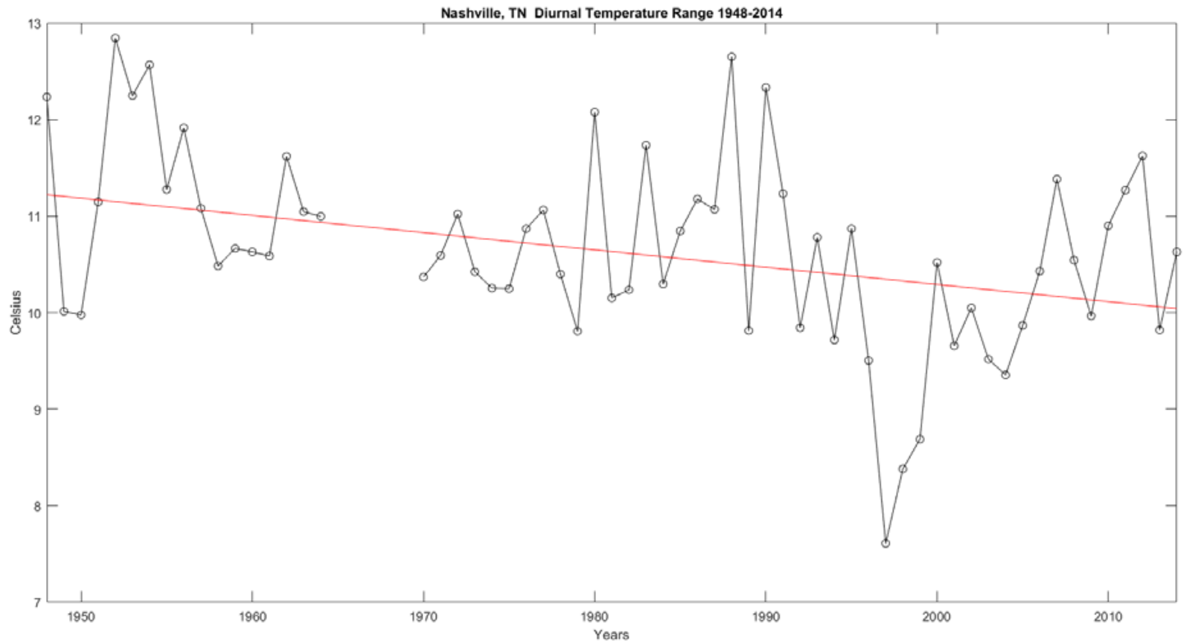
Nashville Int'l AP	Dew Point			1985	estimated instrument change	
T-Test	1981-1984	1986-1989				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.1345	-1.3892	0.1892	-1.5095	94	1.9473
Tdmax	0.9801	-0.8354	0.8146	-0.0251	94	2.0355
Tmin	0.7071	-0.9012	0.6137	-0.3768	94	1.8688
Tdmin	0.8576	-0.8781	1.0531	0.1799	94	2.3825

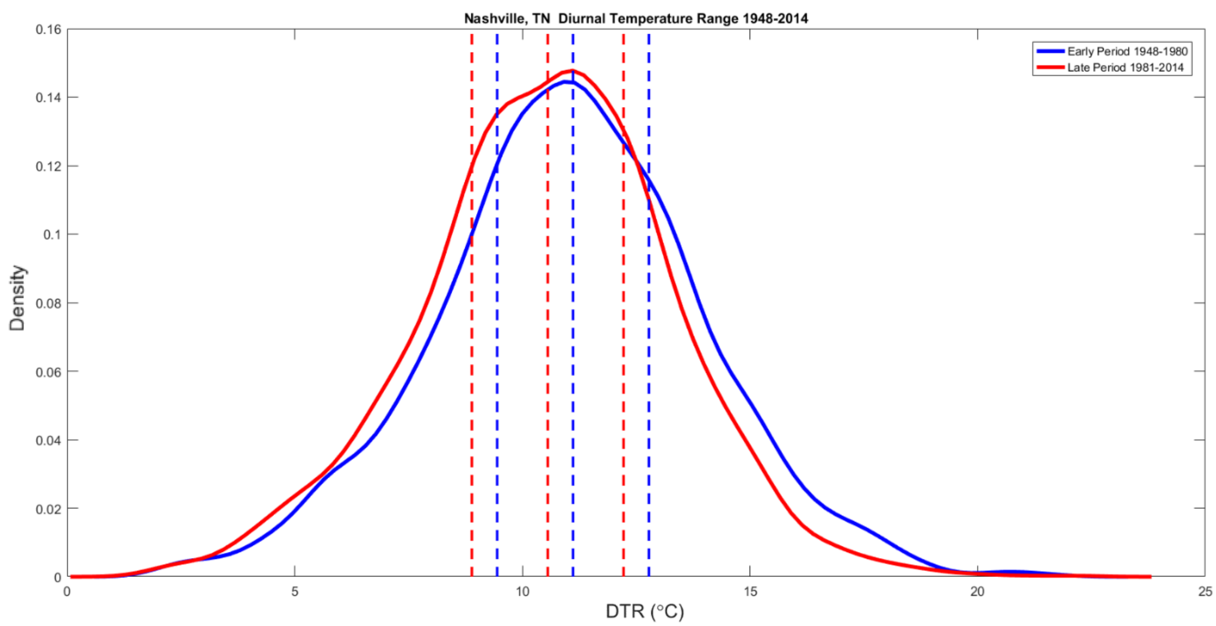
Nashville Int'l AP	Dew Point			1995	Estimated instrument change	
T-Test	1991-1994					
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.5615	-0.5132	0.9394	0.5828	92	1.7723
Tdmax	0.7204	-0.5352	0.7714	0.359	92	1.59430
Tmin	0.3158	-1.0079	0.329	-1.0085	92	1.6312
Tdmin	0.9665	-0.7957	0.7627	-0.0421	92	1.9014

Nashville Int'l AP	Dew Point		2001	Instrument change from Hygrothermometer to ATEMP		
T-Test	1997-2000	2002-2005				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.1281	-0.1734	1.3521	1.5368	83	1.7666
Tdmax	0.2555	-0.306	1.1366	1.1451	83	1.6708
Tmin	0.8535	-0.6325	0.7625	0.1853	83	1.6156
Tdmin	0.7713	-0.7394	0.9935	0.2916	83	2.0068

Nashville Int'l AP	Dew Point				09/11/2003 DTS1 Installation	
T-Test	1998-2002	2004-2007				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	1.69E-02	-1.7521	-0.1777	-2.4348	91	1.9108
Tdmax	0.0938	-0.1099	1.3795	1.6932	91	1.8077
Tmin	0.491	-0.4382	0.9062	0.6915	91	1.6317
Tdmin	2.94E-04	0.7855	2.5394	3.7656	91	2.1287

Nashville Int'l AP	**Dew Point**			**2009**	**Station move 3612 ft South (7/23/2009)**	
T-Test	**2005-2008**	**2010-2013**				
	P-value	**CI-Lower**	**CI-Upper**	**T-statistic**	**Degrees of Freedom**	**Standard Deviation**
Tmax	0.6115	-0.6093	1.0302	0.5097	94	2.0226
Tdmax	0.2271	-1.1959	0.2876	-1.2157	94	1.83020
Tmin	0.1976	-0.2341	1.1174	1.2977	94	1.6674
Tdmin	0.0415	-1.6829	-0.0337	-2.0668	94	2.0346


Nashville, TN Diurnal Temperature Range 1948-2014
Celsius
Years


Nashville, TN Diurnal Temperature Range 1948-2014
Early Period 1948-1980
Late Period 1981-2014
Density
DTR (°C)

APPENDIX M

Louisville

Louisville, KY has land area per square mile 325, population density is 1,837 and the city had 597,337 people in 2010 (US Census, 2010). The station at Louisville International Airport experienced five instrument changes and was moved four times. Station metadata was not as detailed as other stations for example, several station moves were logged in the text, but other moves were only visible on the maps provided along with changes in latitude and longitude. In 1960 there was a change from max/min thermometer to a Hygrothermometer, this may have affected T_{min}, this is consistent with an estimated instrument change in 1964. No other issues were present until a station move that occurred in 1994 where Tmax may have been affected. One of the moves which had an undefined distance and direction may have created an inhomogeneity in 2003, T_{max} and $T_{d\ min}$ (different directions). The installation of DTS1 in 2005 may have affected $T_{d\ max}$ and $T_{d\ min}$. Seasonal summer trend analysis shows significant increases for T_{min} (0.35C°) and $T_{E\ min}$ (0.59C°), significant increases for these same variables were also noted for spring and fall. Annual trend analysis shows a similar trend, increases in T_{min} (0.26C°) and $T_{E\ min}$ (0.41C°). For the shorter record that begins in 1973 as significant increase was noted for T_{min} (0.41 C°).

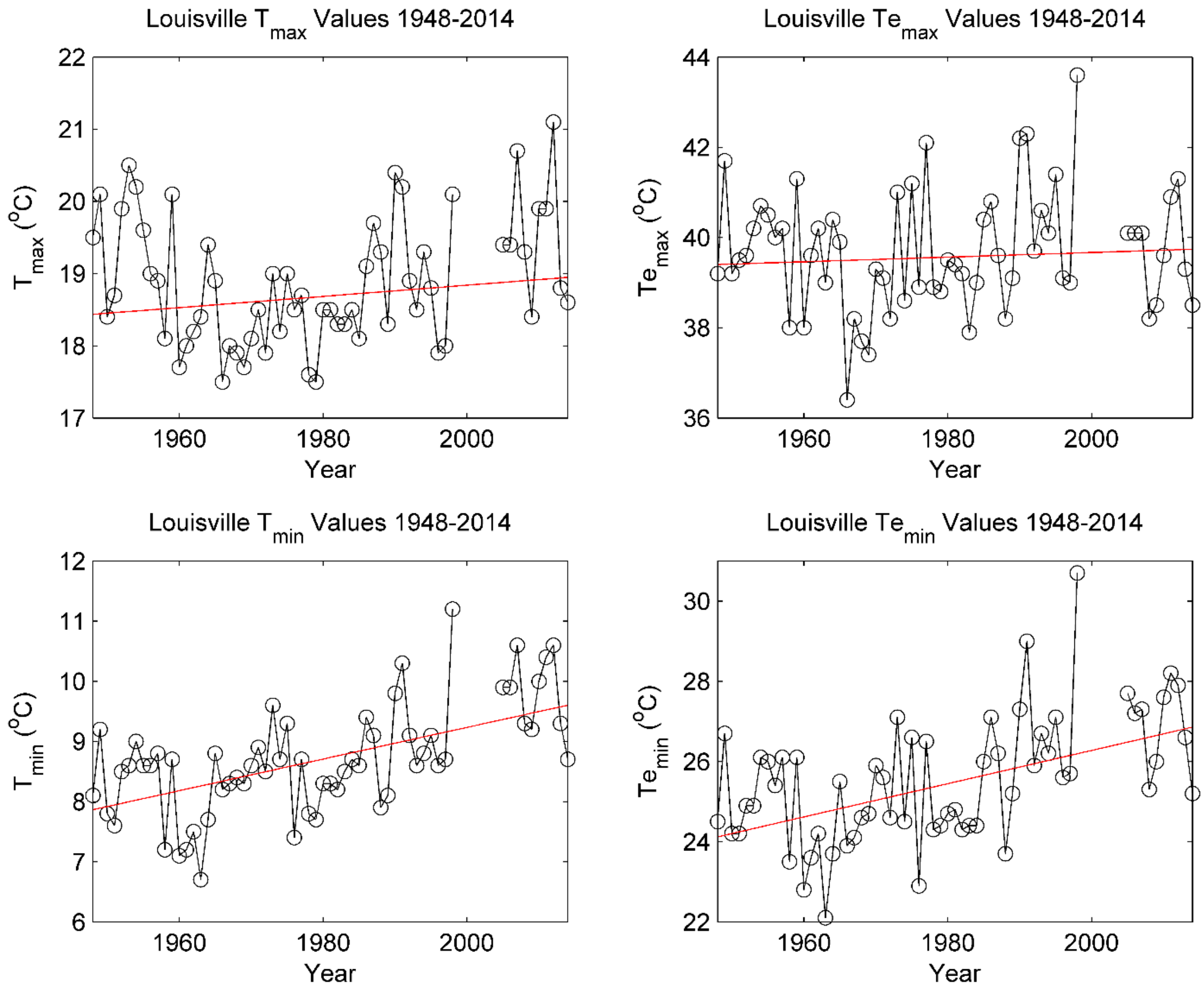
Louisville International Airport	**Louisville Station Metadata**		**Latitude: 38.18111**	
	WBAN# 93821		**Longitude: 85.73917**	
Year	**Site (m)**	**Instruments**	**Comments**	
1948-1960	147.8 (1947-1950)	Max/Min thermometer	temperature recorded daily, obs times 2400 (station moved 0.7 miles NW 9/19/1950) T-Test not possible, data does not go back to 1946.	
1960-1994	144.5 (1950-1981)	Hygrothermometer	temperature recorded daily, obs times 2400. Instrument change from Max/min thermo. To Hygrometer.	
1995-2009	145.4(1981-1994)	Hygrothermometer	temperature recorded daily, obs times 2400. Reporting method FOSJ-SFC	
2009-Present	146.6(1994-2003)	Hygrothermometer	temperature recorded daily, obs times 2400. Reporting method ADP_ASOS Era Data Downloaded to NCDC	
	148.7 (2003-Present			
Station Moves				
Latitude	**Longitude**	**Initial**	**Final Date**	
38.18333		11/15/1947	8/1/1994	
	85.73333	11/15/1947	8/1/1994	
38.17722		8/1/1994	11/1/2003	
	85.72972	8/1/1994	11/1/2003	
38.18111		11/1/2003	2/19/2009	
	85.73917	11/1/2003	2/19/2009	
38.1811		2/19/2009	Present	
	85.7391	2/19/2009	Present	
T-test 1960	**Instrument change from Max/min thermometer to Hygrothermometer**			
T-test 1964	**estimated instrument change**			
T-test 1981	**station move 0.9 miles SE (07/29/1981)**			
T-test 1985	**estimated instrument change**			
T-test 1994	**station move (visible in map as well as Lat. Long.)**			
T-test 1995	**estimated instrument change**			
T-test 2003	**station move (visible in map as well as Lat. Long.)**			
T-test 2005	**DTS1 Installation 3/30/2005**			
T-test 2009	**station move (visible in map as well as Lat. Long.)**			

Louisville	Median of Pairwise Slopes95% confidence	Degrees Celsius per decade	
Seasonal			
Winter-Dec,Jan,Feb	**Significance**	**Trend**	**P-value**
T_max	not significant at 0.05	0.00C°	0.97783
Te_max	not significant at 0.05	(-0.05C°)	0.73227
T_min	not significant at 0.05	0.15C°	0.34912
Te_min	not significant at 0.05	0.17C°	0.53239
Spring-Mar,Apr,May			
T_max	not significant at 0.05	0.15C°	0.06217
Te_max	not significant at 0.05	0.17C°	0.29065
T_min	is significant at 0.05	0.28C°	0.00085
Te_min	is significant at 0.05	0.37C°	0.00431
Summer-June, July,August			
T_max	not significant at 0.05	0.00C°	0.86318
Te_max	not significant at 0.05	0.00C°	0.67235
T_min	is significant at 0.05	0.35C°	0
Te_min	is significant at 0.05	0.59C°	0.00004
Fall-Sept, Oct, Nov			
T_max	not significant at 0.05	0.00C°	0.92083
Te_max	not significant at 0.05	0.03C°	0.8564
T_min	is significant at 0.05	0.32C°	0.00001
Te_min	is significant at 0.05	0.44C°	0.00061

Louisville	95% confidence	Degrees Celsius per decade	
Annual Trend			
	Significance	**Trend**	**P-value**
T_max	not significant at 0.05	0.08C°	0.31041
Te_max	not significant at 0.05	0.05C°	0.63519
T_min	is significant at 0.05	0.26C°	0
Te_min	is significant at 0.05	0.41C°	0.00001

ANNUAL TREND

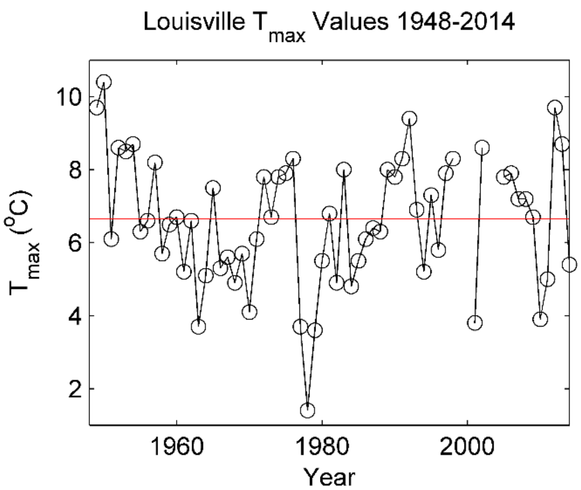
WINTER

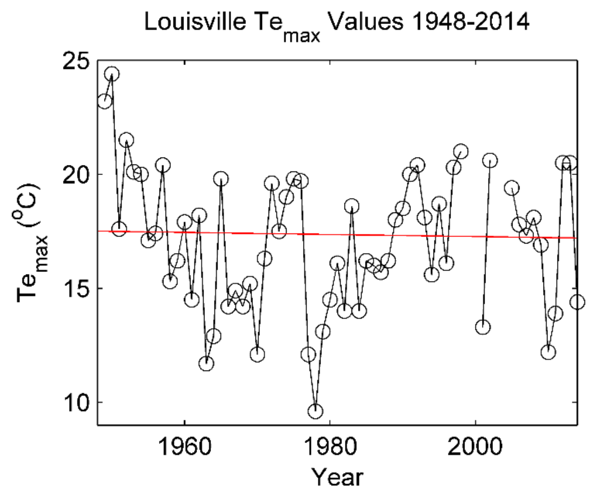


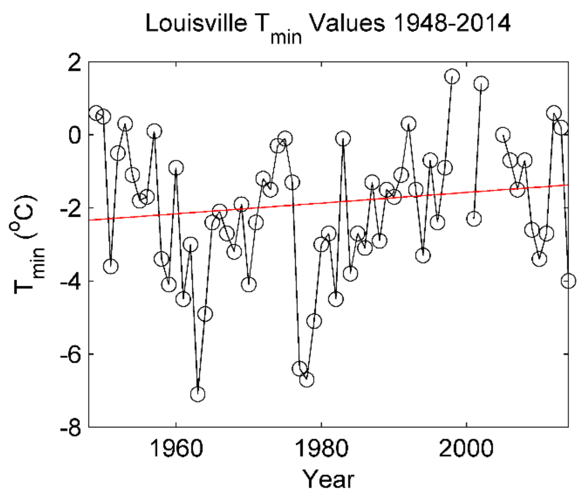
Annual Trend	Significance	Trend	P-value
T_max	not significant at 0.05	0.08C°	0.31041
Te_max	not significant at 0.05	0.05C°	0.63519
T_min	is significant at 0.05	0.26C°	0
Te_min	is significant at 0.05	0.41C°	0.00001

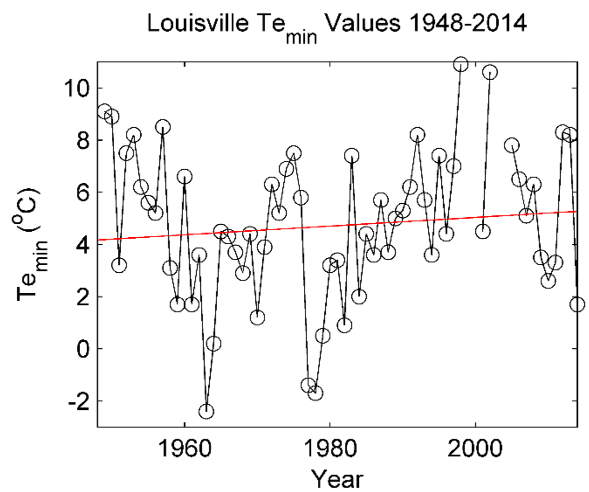
SEASONAL TREND

WINTER



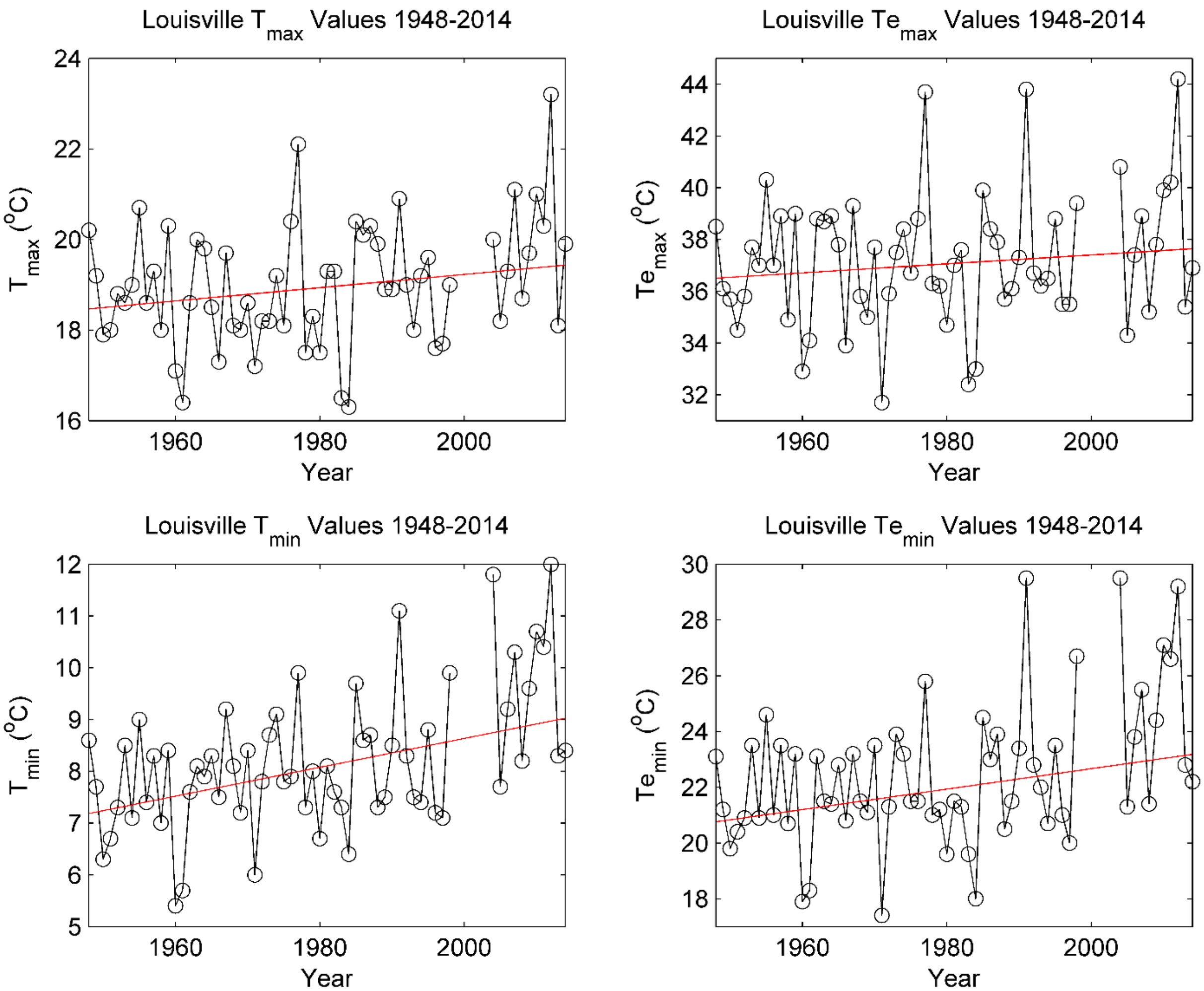






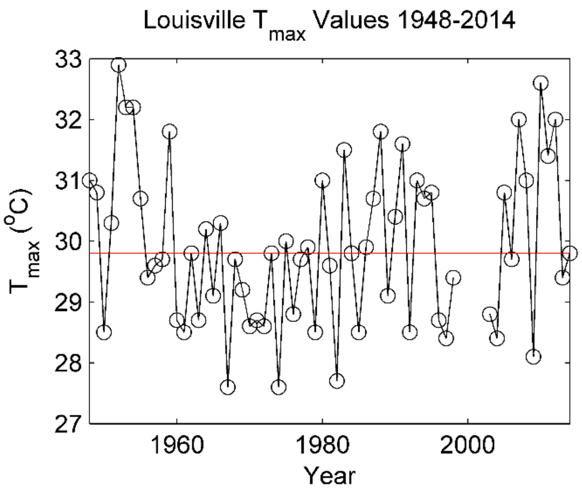
Winter-Dec,Jan,Feb	**Significance**	**Trend**	**P-value**
T_max	not significant at 0.05	0.00C°	0.97783
Te_max	not significant at 0.05	(-0.05C°)	0.73227
T_min	not significant at 0.05	0.15C°	0.34912
Te_min	not significant at 0.05	0.17C°	0.53239

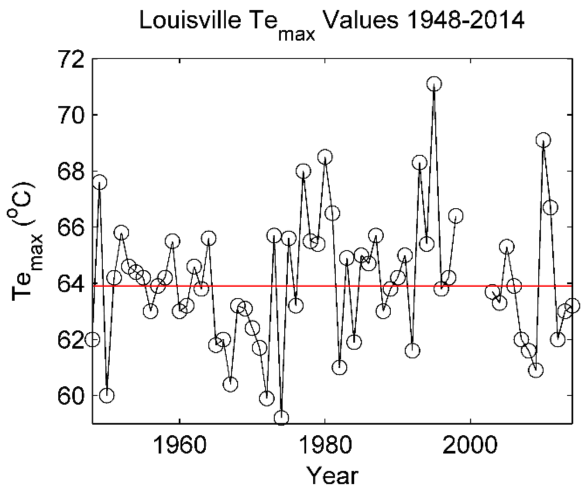
SPRING

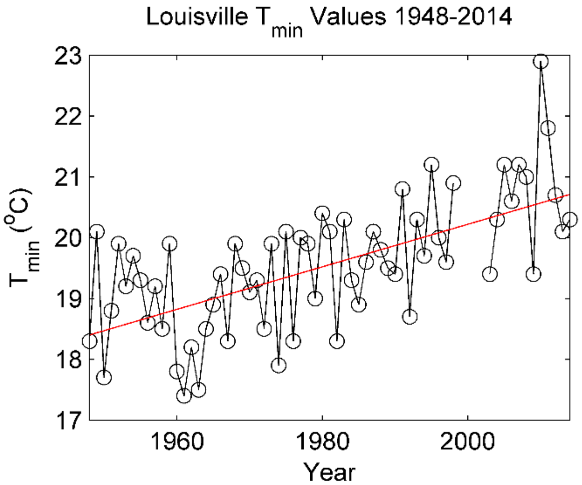


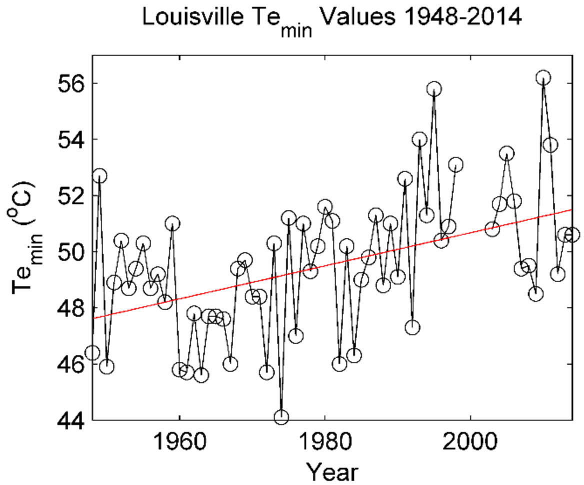
Spring-Mar,Apr,May	Significance	Trend	P-value
T_max	not significant at 0.05	0.15C°	0.06217
Te_max	not significant at 0.05	0.17C°	0.29065
T_min	is significant at 0.05	0.28C°	0.00085
Te_min	is significant at 0.05	0.37C°	0.00431

SUMMER



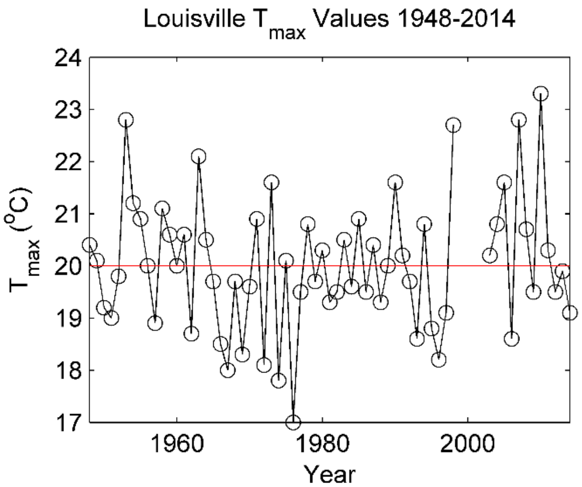


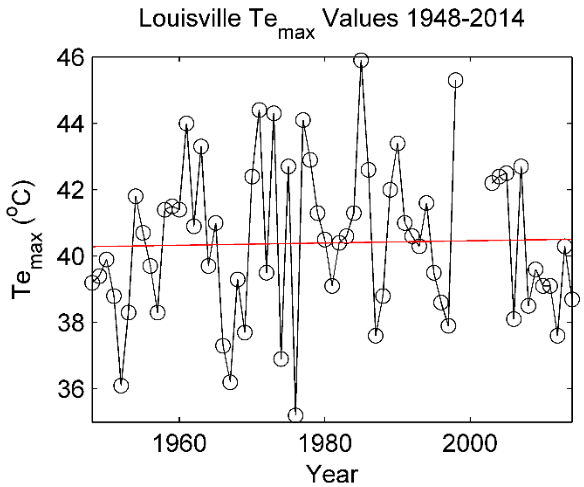


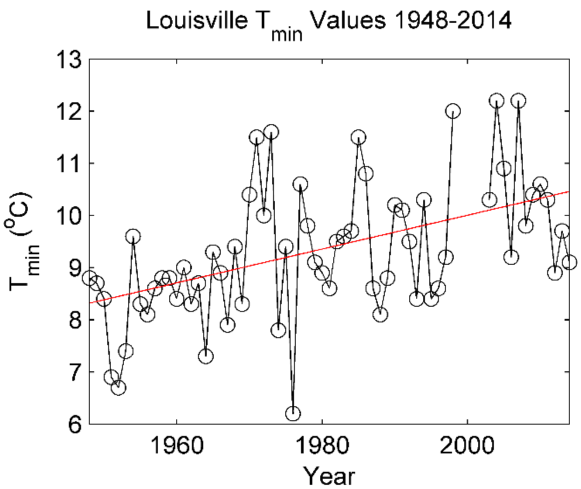


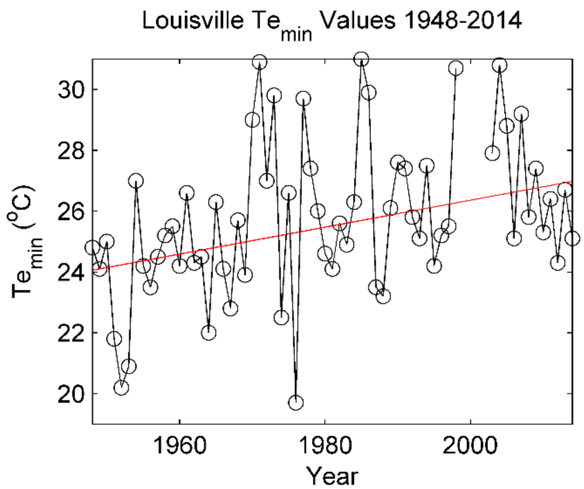
Summer-June, July,August	**Significance**	**Trend**	**P-value**
T_max	not significant at 0.05	0.00C°	0.86318
Te_max	not significant at 0.05	0.00C°	0.67235
T_min	is significant at 0.05	0.35C°	0
Te_min	is significant at 0.05	0.59C°	0.00004

FALL



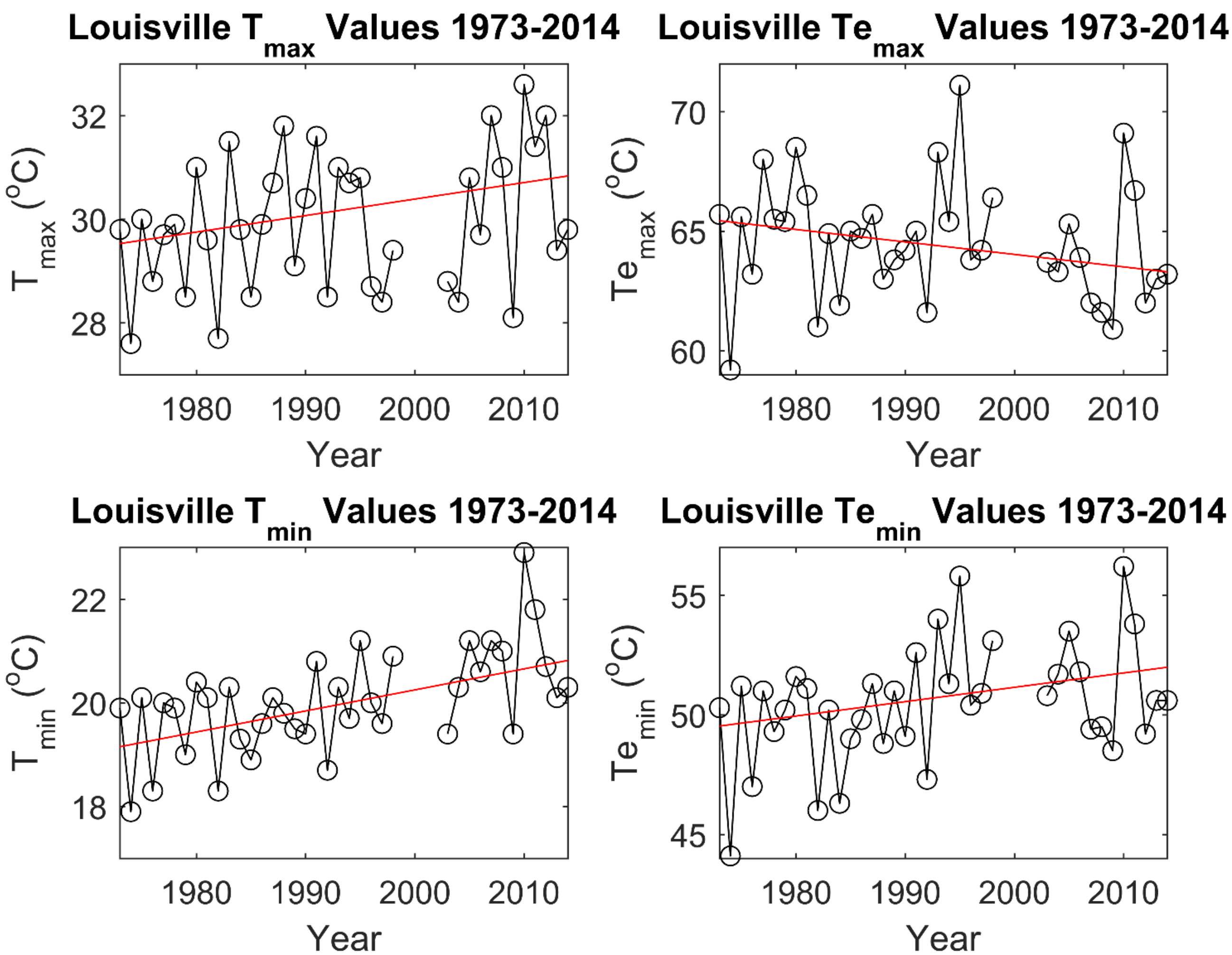






Fall-Sept, Oct, Nov	**Significance**	**Trend**	**P-value**
T_max	not significant at 0.05	0.00C°	0.92083
Te_max	not significant at 0.05	0.03C°	0.8564
T_min	is significant at 0.05	0.32C°	0.00001
Te_min	is significant at 0.05	0.44C°	0.00061

SUMMER 1973-2014



Summer-June, July,August	Significance	Trend	P-Value
T_max	not significant at 0.05	0.32 C°	0.17378
Te_max	not significant at 0.05	-0.52 C°	0.22782
T_min	is significant at 0.05	0.41 C°	0.0005
Te_min	not significant at 0.05	0.6 C°	0.05506

Two Tailed T-Tests: Station moves, instrument changes, DTS1 installation

Louisville	Dew Point		1960	Instrument change from Max/min thermometer to Hygrothermometer		
T-Test	1956-1959	1961-1964				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.1832	-0.2605	1.3438	1.3408	94	1.9791
Tdmax	0.484	-0.5249	1.0999	0.7026	94	2.0046
Tmin	0.0061	0.3113	1.8137	2.8082	94	1.8536
Tdmin	0.2219	-0.3343	1.4218	1.2296	94	2.1665

Louisville	Dew Point		1964	Estimated instrument changes		
T-Test	1960-1963	1965-1968				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.9849	-0.8662	0.8829	0.0189	94	2.1578
Tdmax	0.0659	-0.0536	1.6494	1.8606	94	2.10100
Tmin	0.0012	-2.05	-0.5208	-3.338	94	1.8865
Tdmin	0.8379	-0.9567	0.7775	-0.2051	94	2.1394

Louisville	Dew Point		1981	Station move 0.9 miles SE (07/29/1981)		
T-Test	1981-1984	1986-1989				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.6676	-1.2502	0.8044	-0.4308	94	2.5347
Tdmax	0.7905	-0.8201	1.0742	0.2664	94	2.3369
Tmin	0.4143	-1.34	0.5566	-0.8201	94	2.3398
Tdmin	0.6481	-0.7993	1.2785	0.4579	94	2.5633

Louisville	Dew Point		1985	Estimated instrument changes		
T-Test	1981-1984	1986-1989				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.1222	-1.5248	0.1832	-1.5596	94	2.1071
Tdmax	0.4894	-1.1019	0.5311	-0.6941	94	2.0146
Tmin	0.622	-0.9506	0.5715	-0.4946	94	1.8778
Tdmin	0.6903	-1.1065	0.7356	-0.3997	94	2.2726

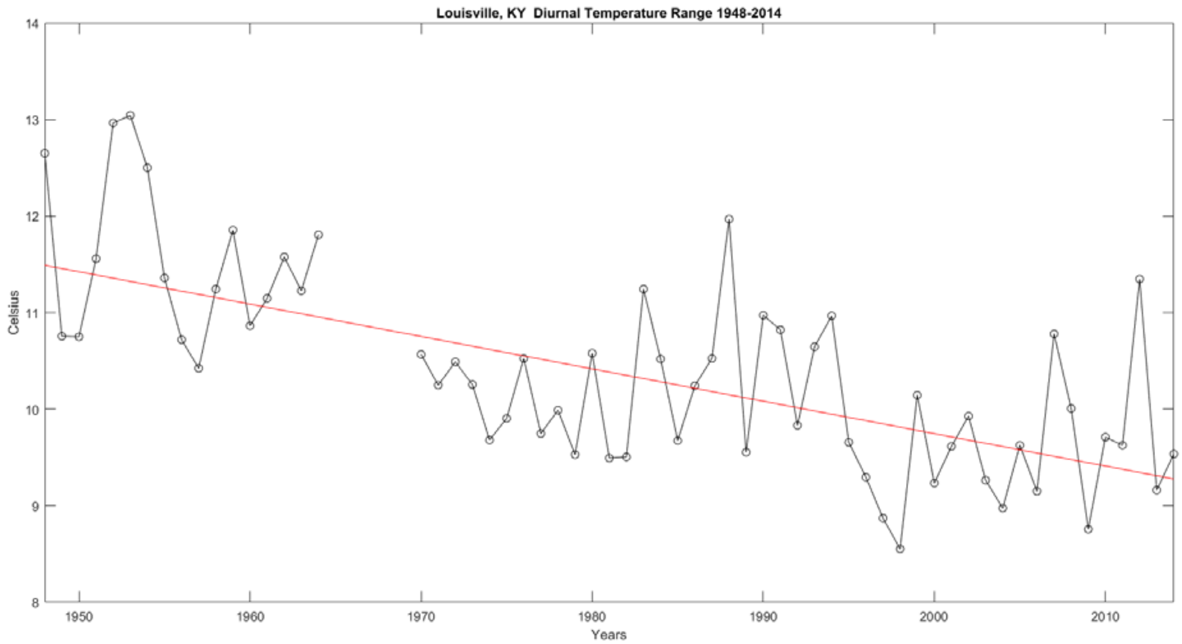
Louisville	Dew Point		1994	Station move-distance undefined		
T-Test	1990-1993	1995-1998				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.0374	0.0486	1.5764	2.1117	94	1.8849
Tdmax	0.9183	-0.6486	0.7194	0.1028	94	1.68770
Tmin	0.8131	-0.6147	0.7814	0.237	94	1.7223
Tdmin	0.7765	-0.6971	0.9304	0.2847	94	2.0079

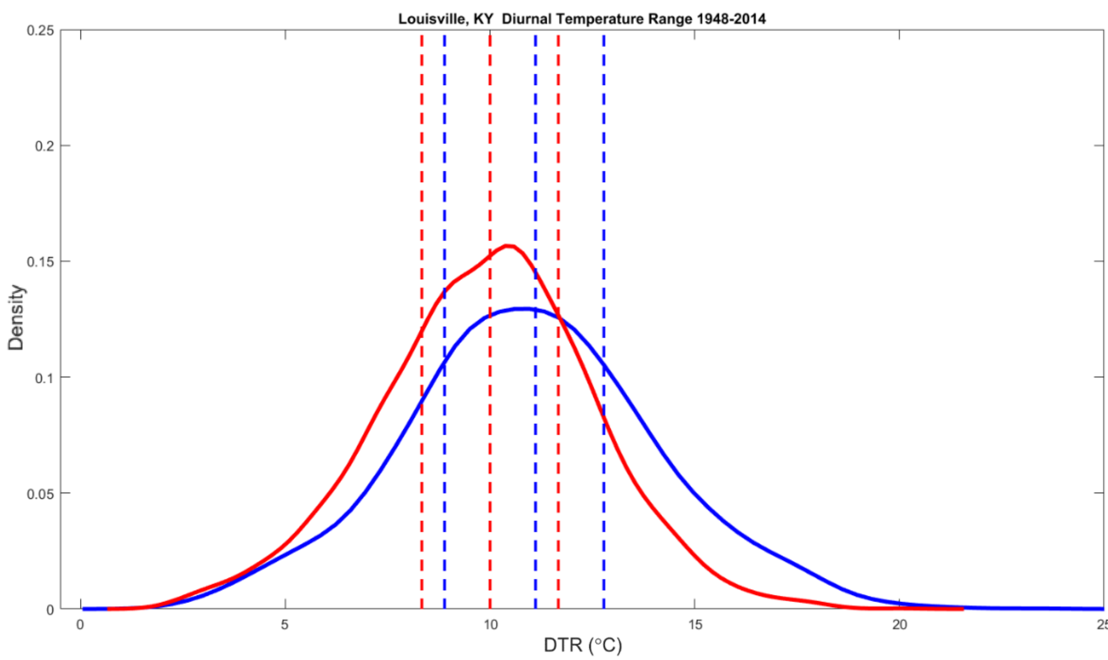
Louisville	Dew Point		1995	Estimated instrument change		
T-Test	1991-1994	1996-1999				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.2621	-0.3411	1.2373	1.1289	85	1.8413
Tdmax	0.5682	-0.9524	0.5263	-0.5729	85	1.72490
Tmin	0.2908	-1.1668	0.3539	-1.0629	85	1.7738
Tdmin	0.7032	-1.0495	0.711	-0.3822	85	2.0537

Louisville	Dew Point		2003	Station move (distance undefined)		
T-Test	1999-2002	2004-2007				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.0431	-2.446	-0.0396	-2.0623	66	2.2959
Tdmax	0.9556	-1.0464	1.1068	0.0559	66	2.05440
Tmin	0.9577	-1.0053	1.0604	0.0532	66	1.9708
Tdmin	0.048	0.0108	2.3463	2.015	66	2.2283

Louisville	Dew Point		2005	DTS1 Installation 03/30/2005		
T-Test	2001-2004	2006-2009				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.074	-1.7556	0.0831	-1.8106	79	2.0425
Tdmax	0.0376	0.0478	1.5716	2.1153	79	1.6927
Tmin	0.1407	-0.1981	1.3714	1.488	79	1.7435
Tdmin	8.97E-06	1.1449	2.7969	4.7493	79	1.8352

Louisville	Dew Point		2009	Station move (distance undefined)		
T-Test	2005-2008	2010-2013				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.6384	-1.1401	0.7026	-0.4714	94	2.2733
Tdmax	0.5634	-1.0139	0.5556	-0.5798	94	1.93620
Tmin	0.6102	-0.9357	0.5524	-0.5115	94	1.8359
Tdmin	0.1898	-1.3978	0.2811	-1.3206	94	2.0712


Louisville, KY Diurnal Temperature Range 1948-2014
Celsius
Years


Louisville, KY Diurnal Temperature Range 1948-2014
Density
DTR (°C)

APPENDIX N

Kansas City

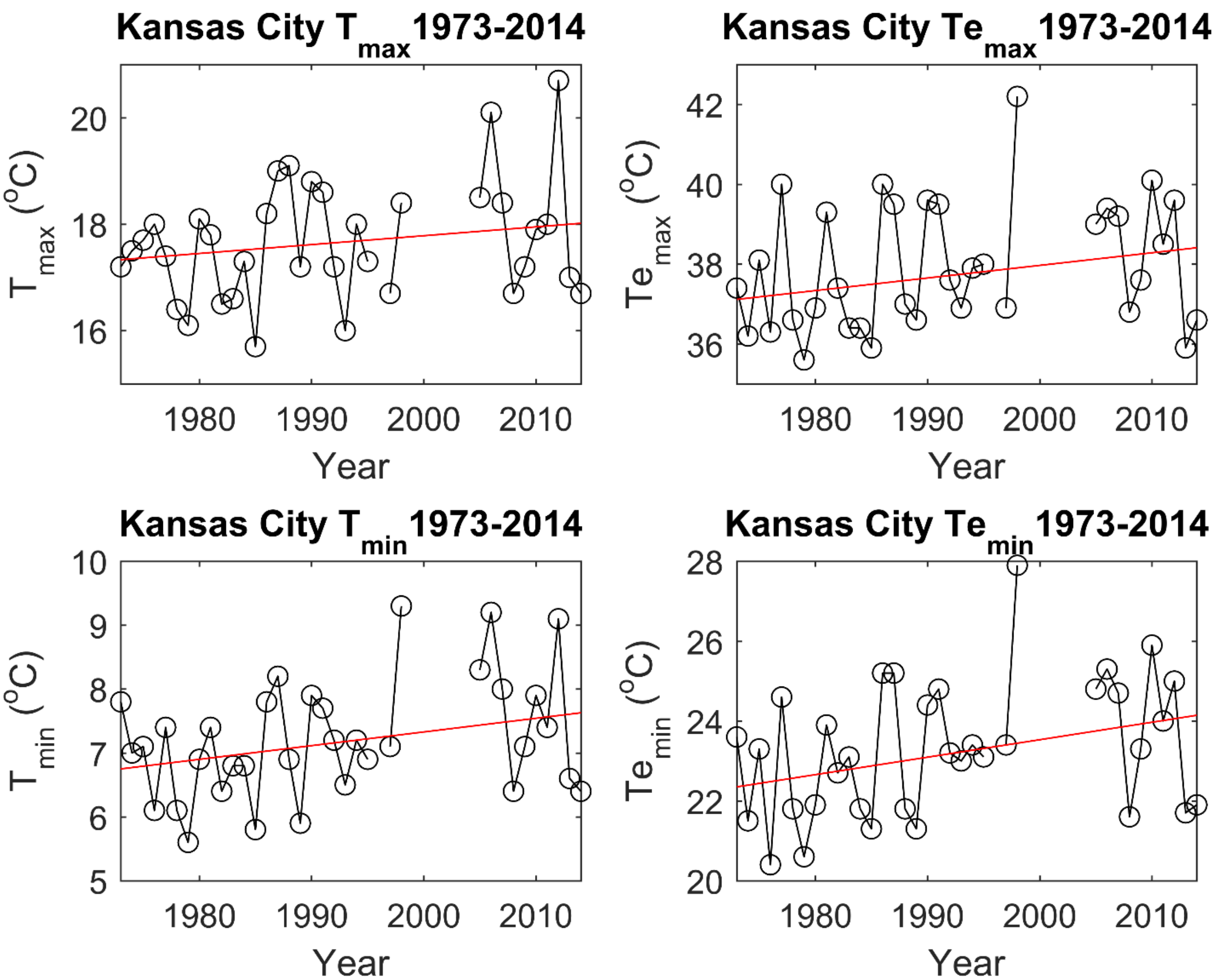
Kansas City, MO is home to 459, 787 people, it has a land area per square mile of 315 and population density stands at 1,460 (US Census, 2010). Record begins in 1973, the station was moved two times and had four instrument changes. Estimated instrument change in 1985 may have affected T_{max} values. In 2002 the max/min thermometer was replaced with a Hygrothermometer, there was also a station move that year, t-tests show that $T_{d\ min}$ may have been affected with these changes. DTS1 station was installed in 2005, these was another move for the station this year, this may have affected $T_{d\ max}$ and $T_{d\ min}$. Summer seasonal analysis shows warming for all variables except T_{max} which shows slight cooling, these results were insignificant. Annual trend analysis shows warming for all 4 variables, again without significance.

Kansas City Int'l Airport	**Station Metadata**		**Latitude: 39.2972**
	WBAN# 03947		**Longitude: 94.7306**
Year	**Site (m)**	**Instruments**	**Comments**
1972-1979	314.9 (1973-1979)	unknown	Observation times daily 2400
1979-1989	296.6 (1979-1995)	unknown	Observation times daily 2400
1989-2002	298.4 (1995-2002)	Max and Min Thermometers	Observations times daily 2400. 1989 instrument change from unknown to Max/min thermometer
2002-2011	306.3 (2002-Present)	Hygrothermometer	Observation times daily 2400. Instrument change from Max/min thermometer to Hygrothermometer.
2011-Present		ATEMP: ASOS Hygrothermometer	Observation times daily 2400
Station Moves			
Latitude	**Longitude**	**Initial**	**Final Date**
39.3		6/1/1957	1/1/1979
	94.71667	6/1/1957	7/1/1995
39.31667		1/1/1979	7/1/1995
	94.71667	6/1/1957	7/1/1995
39.29917		7/1/1995	9/4/2002
	94.71778	7/1/1995	9/4/2002
39.29722		9/4/2002	4/1/2005
	94.73056	9/4/2002	4/1/2005
39.2972		4/1/2005	Present
	94.7306	4/1/2005	Present
T-test 1985	**estimated instrument change**		
T-test 1989	**instrument change from unknown to Max/min thermometer**		
T-test 1995	**estimated instrument change**		
T-test 2002	**instrument change from Max/min thermometer to Hygrothermometer. Station move (noticeable in map and change in lat and long)**		
T-test 2005	**station move and DTS1 Installation 3/11/05**		

Kansas City	Median Pairwise of Slopes95% confidence	Degrees Celsius per decade	
Seasonal Trend			
Winter-Dec,Jan,Feb	**Significance**	**Trend**	**P-value**
T_max	not significant at 0.05	0.53C°	0.17615
Te_max	not significant at 0.05	0.73C°	0.16009
T_min	not significant at 0.05	0.50C°	0.26194
Te_min	not significant at 0.05	0.60C°	0.26391
Spring-Mar,Apr,May			
T_max	not significant at 0.05	0.18C°	0.52077
Te_max	not significant at 0.05	0.15C°	0.74745
T_min	not significant at 0.05	0.15C°	0.53314
Te_min	not significant at 0.05	0.21C°	0.58508
Summer-June, July,August			
T_max	not significant at 0.05	(-0.03C°)	0.79595
Te_max	not significant at 0.05	0.21C°	0.70689
T_min	not significant at 0.05	0.25C°	0.056
Te_min	not significant at 0.05	0.58C°	0.14228
Fall-Sept, Oct, Nov			
T_max	not significant at 0.05	0.12C°	0.40572
Te_max	not significant at 0.05	(-0.05C°)	0.85773
T_min	not significant at 0.05	0.04C°	0.51344
Te_min	not significant at 0.05	0.00C°	0.92103

Kansas City	95% confidence	Degrees C° per decade	
Annual Trend	**Significance**	**Trend**	**P-value**
T_max	not significant at 0.05	0.17C°	0.30211
Te_max	not significant at 0.05	0.32C°	0.13394
T_min	not significant at 0.05	0.21C°	0.09446
Te_min	not significant at 0.05	0.44C°	0.05039

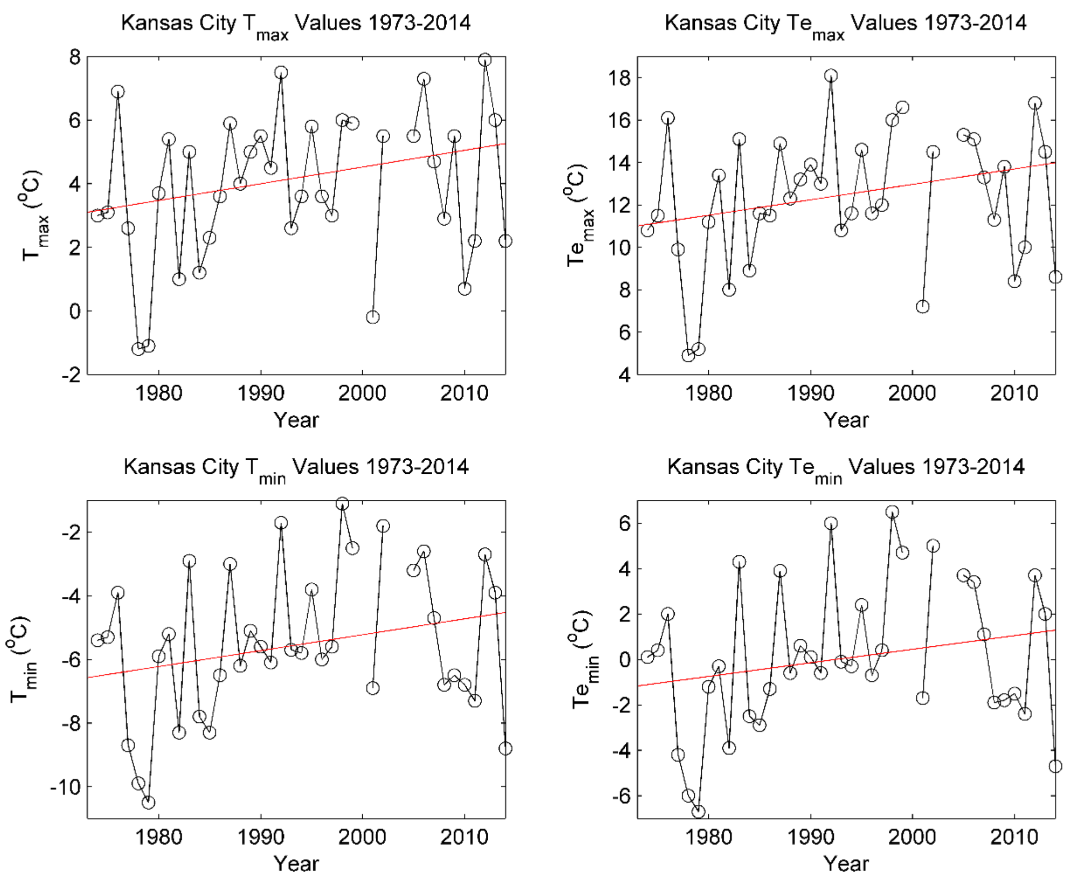
ANNUAL TREND



Kansas City	95% confidence	Degrees Celsius per decade	
Annual Trend	**Significance**	**Trend**	**P-value**
T_max	not significant at 0.05	0.17C°	0.30211
Te_max	not significant at 0.05	0.32C°	0.13394
T_min	not significant at 0.05	0.21C°	0.09446
Te_min	not significant at 0.05	0.44C°	0.05039

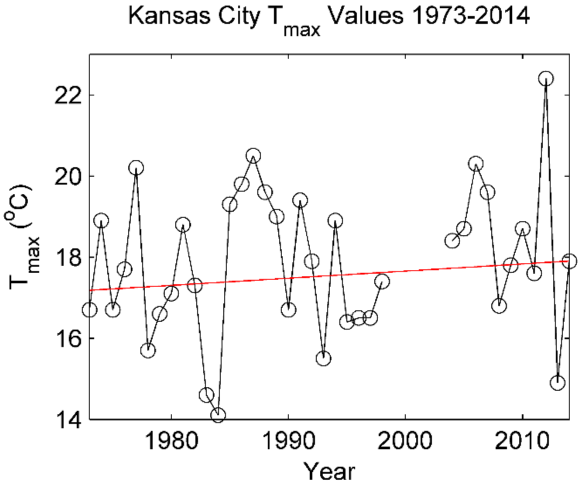
SEASONAL TRENDS

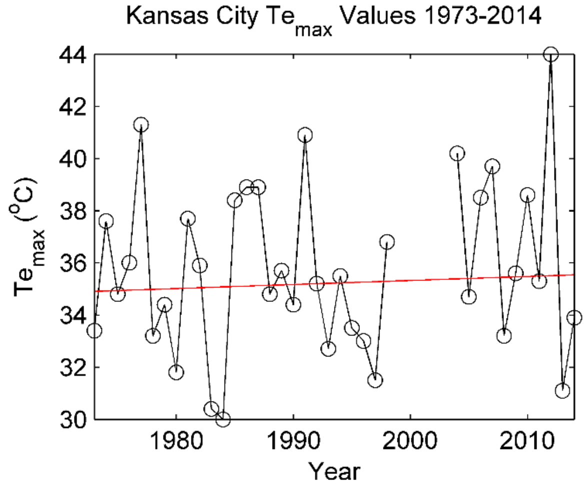
WINTER

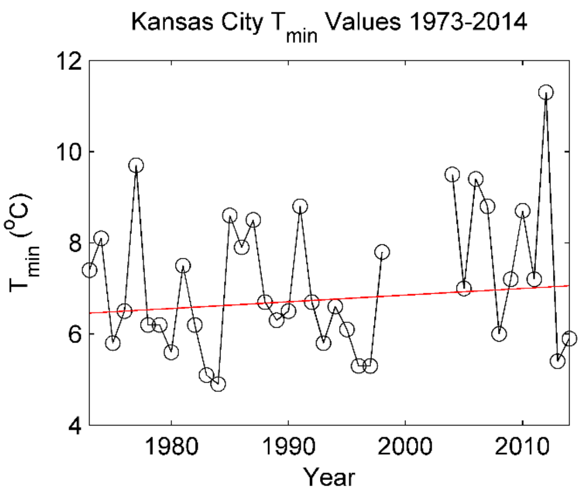


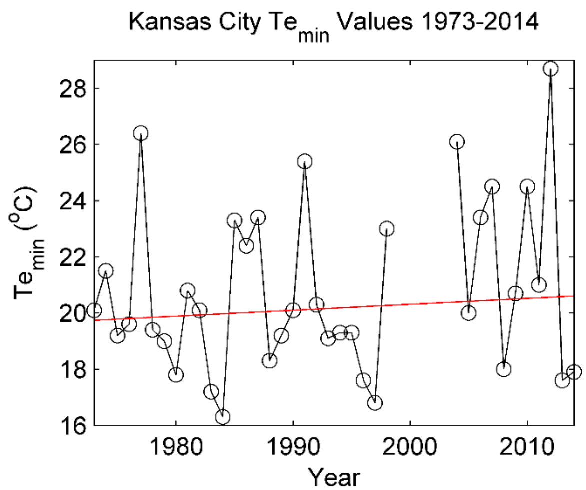
Winter-Dec,Jan,Feb	**Significance**	**Trend**	**P-value**
T_max	not significant at 0.05	0.53C°	0.17615
Te_max	not significant at 0.05	0.73C°	0.16009
T_min	not significant at 0.05	0.50C°	0.26194
Te_min	not significant at 0.05	0.60C°	0.26391

SPRING



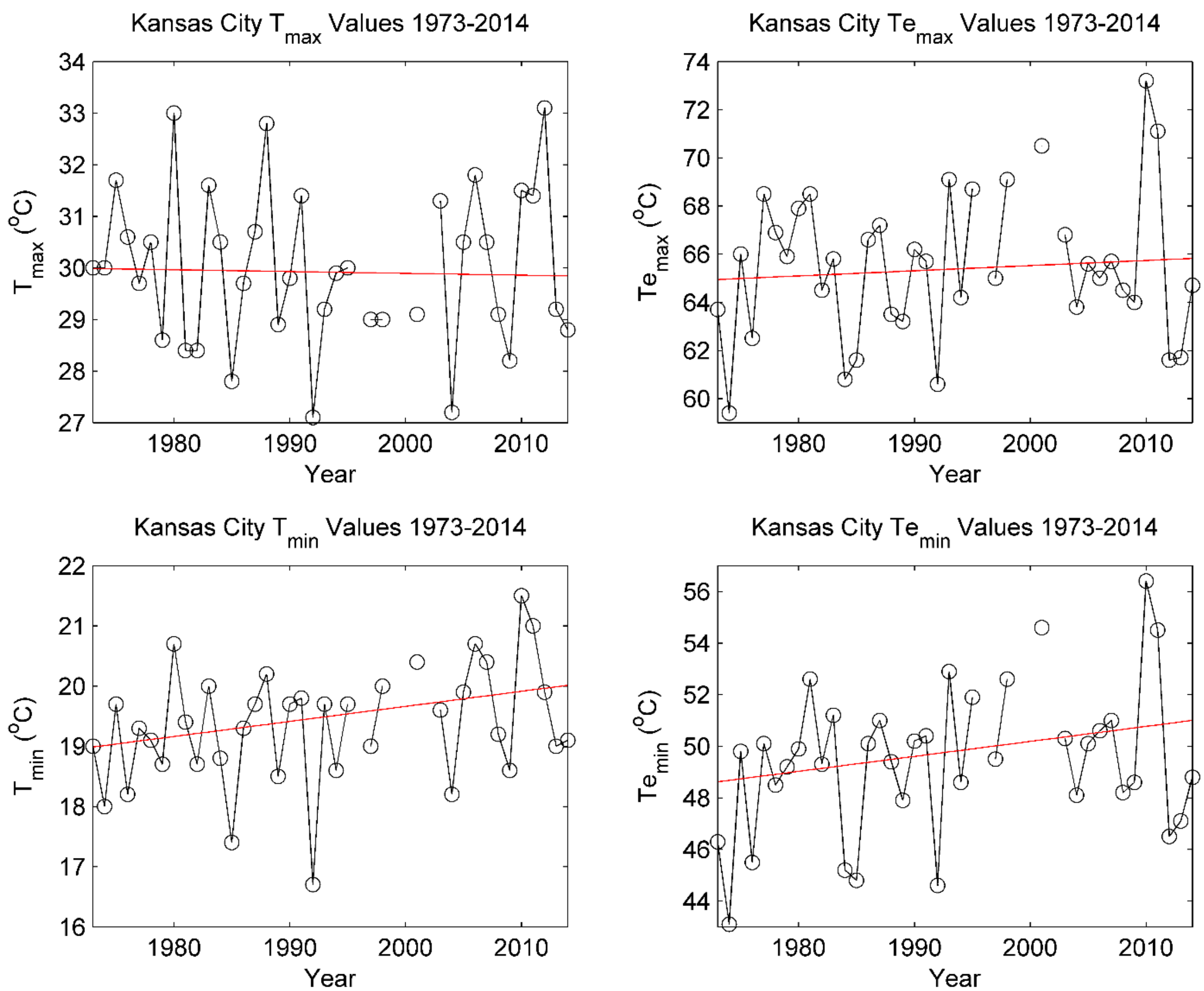






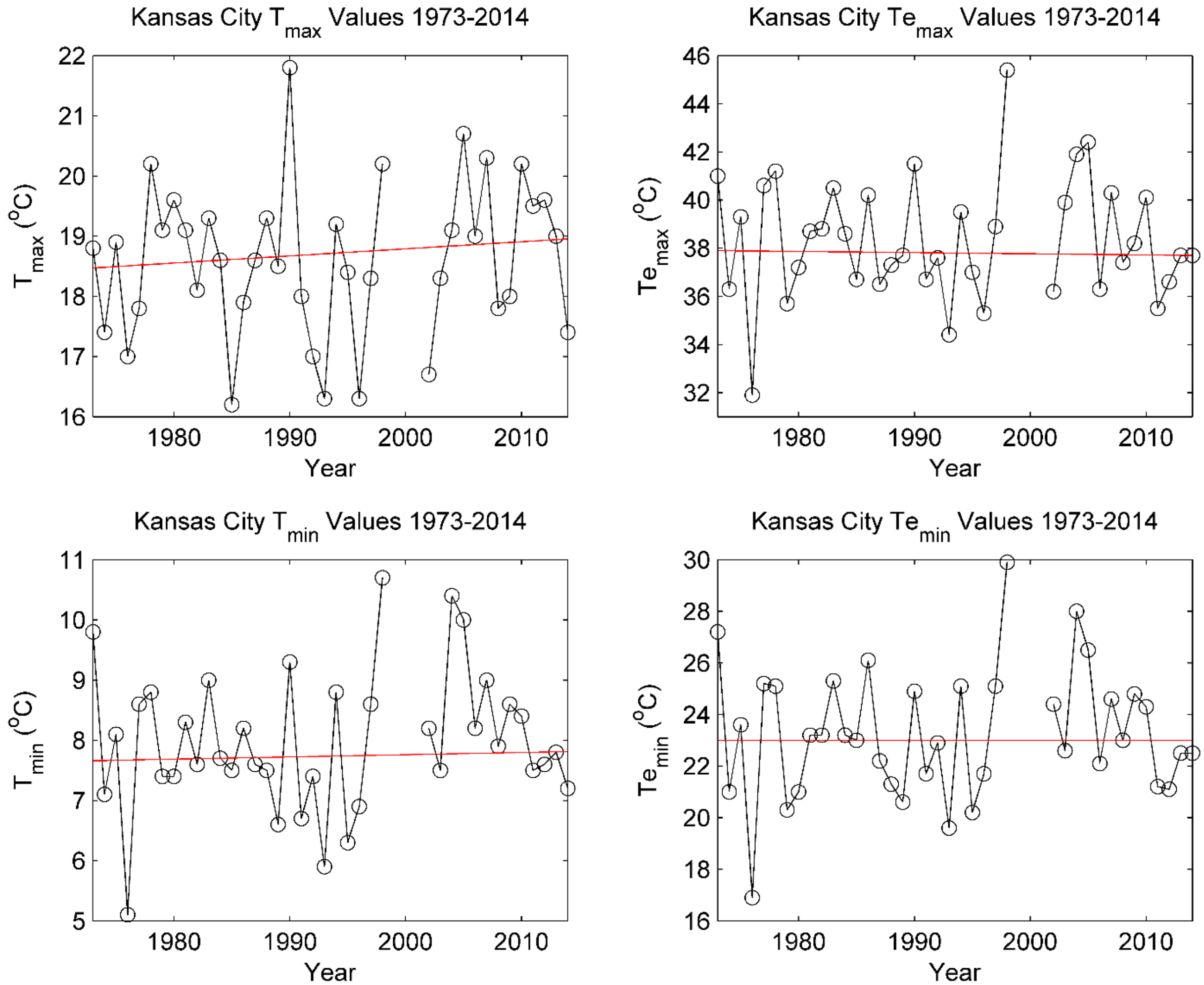
Spring-Mar,Apr,May	**Significance**	**Trend**	**P-Value**
T_max	not significant at 0.05	0.18C°	0.52077
Te_max	not significant at 0.05	0.15C°	0.74745
T_min	not significant at 0.05	0.15C°	0.53314
Te_min	not significant at 0.05	0.21C°	0.58508

SUMMER



Summer-June, July,August	**Significance**	**Trend**	**P-value**
T_max	not significant at 0.05	(-0.03C°)	0.79595
Te_max	not significant at 0.05	0.21C°	0.70689
T_min	not significant at 0.05	0.25C°	0.056
Te_min	not significant at 0.05	0.58C°	0.14228

FALL



Fall-Sept, Oct, Nov	Significance	Trend	P-Value
T_max	not significant at 0.05	0.12C°	0.40572
Te_max	not significant at 0.05	(-0.05C°)	0.85773
T_min	not significant at 0.05	0.04C°	0.51344
Te_min	not significant at 0.05	0.00C°	0.92103

Two Tailed T-Tests: Station moves, instrument changes, DTS1 installation

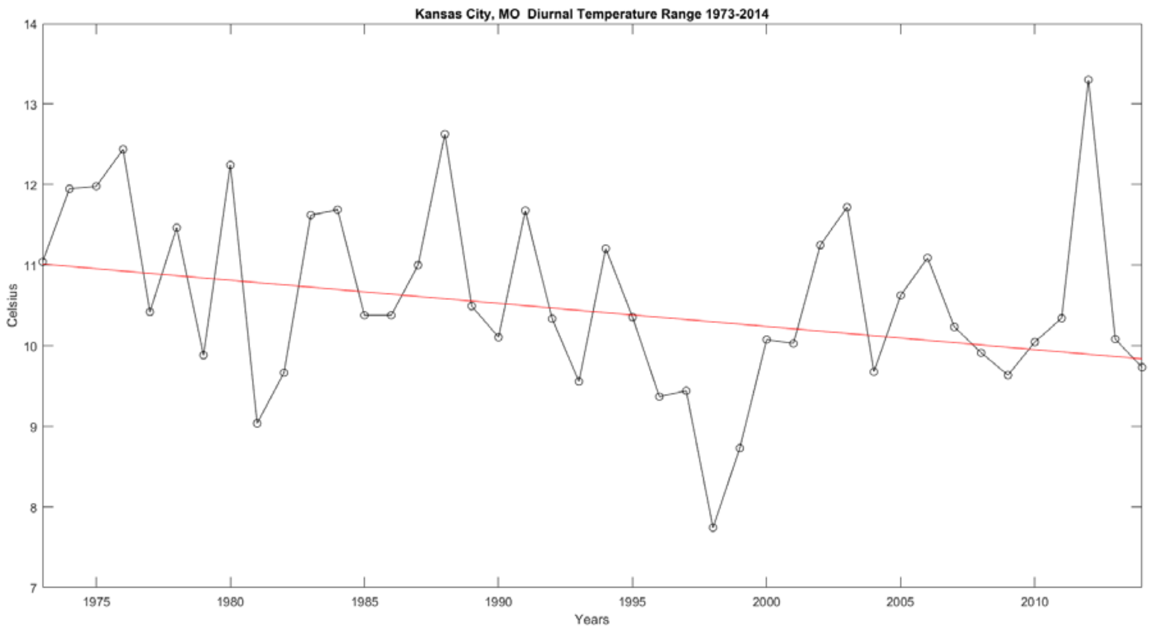
Kansas City	Dew Point			T-test 1985	Estimated instrument change	
T-Test	1981-1984	1986-1989				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.0153	-2.3783	-0.2592	-2.4712	94	2.6144
Tdmax	0.8912	-0.9674	0.8424	-0.1371	94	2.2327
Tmin	0.4081	-1.3135	0.5385	-0.8309	94	2.2847
Tdmin	0.8976	-1.0195	1.1611	0.129	94	2.6901

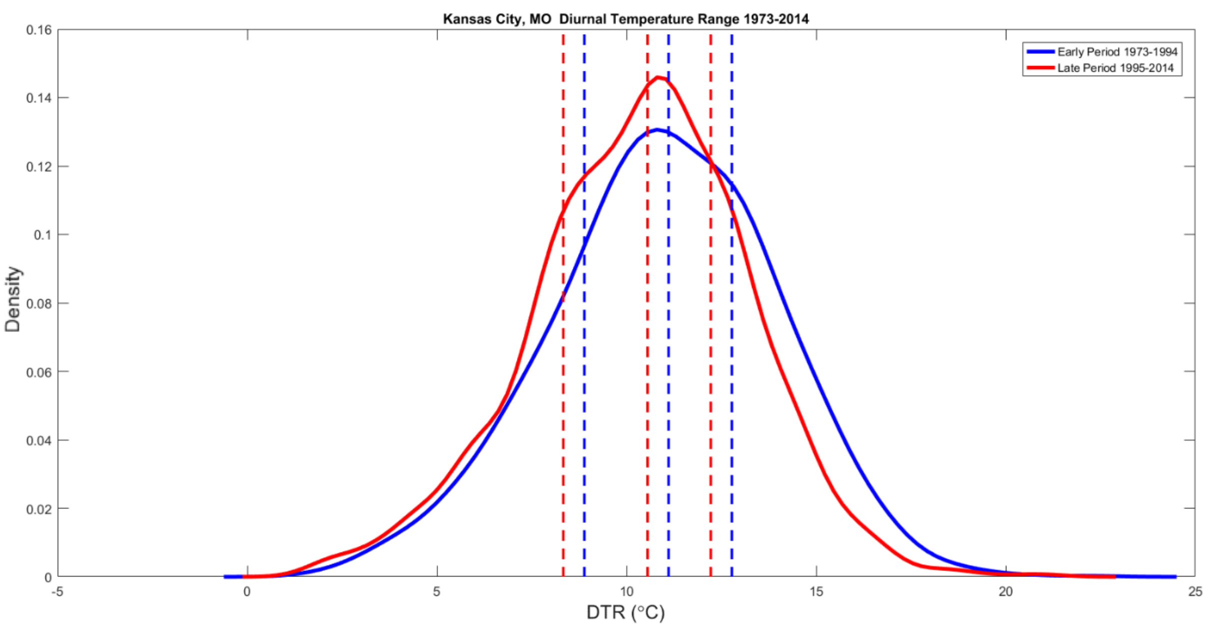
Kansas City	Dew Point			1989	Instrument change from unknown to Max/min thermometer	
T-Test	1985-1988	1990-1993				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.482	-0.6534	1.3743	0.7058	94	2.5015
Tdmax	0.1717	-1.2362	0.2237	-1.3771	94	1.80090
Tmin	0.8002	-0.9556	0.739	-0.2539	94	2.0906
Tdmin	0.1697	-1.5522	0.2772	-1.3839	94	2.2568

Kansas City	Dew Point			1995	estimated instrument change	
T-Test	1991-1994	1996-1999				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.9713	-0.9303	0.9647	0.036	86	2.2263
Tdmax	0.6024	-1.1084	0.6468	-0.5228	86	2.06210
Tmin	0.0949	-1.6357	0.1332	-1.6886	86	2.0781
Tdmin	0.3002	-1.6272	0.5078	-1.0423	86	2.5083

Kansas City	Dew Point			2002	Instrument change from Max/min thermo. To Hygrothermometer. Station move (noticeable in map and change in lat and long)	
T-Test	1998-2001	2003-2006				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.102	-2.0196	0.1862	-1.6554	76	2.4163
Tdmax	0.0762	-0.0904	1.7649	1.7977	76	2.0323
Tmin	0.3427	-0.4915	1.3966	0.9548	76	2.0682
Tdmin	0.0048	0.4522	2.4176	2.9081	76	2.1528

Kansas City	Dew Point			2005	DTS1 Installation 3/11/05 and Station move	
T-Test	2001-2004	2006-2009				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.0634	-1.8932	0.0525	-1.8813	84	2.253
Tdmax	0.0403	0.0336	1.4553	2.0827	84	1.6462
Tmin	0.1621	-0.247	1.4521	1.4103	84	1.9675
Tdmin	8.82E-05	0.8575	2.4572	4.1206	84	1.8523


Kansas City, MO Diurnal Temperature Range 1973-2014
Celsius
Years


Kansas City, MO Diurnal Temperature Range 1973-2014
Early Period 1973-1994
Late Period 1995-2014
Density
DTR (°C)

Virginia Beach

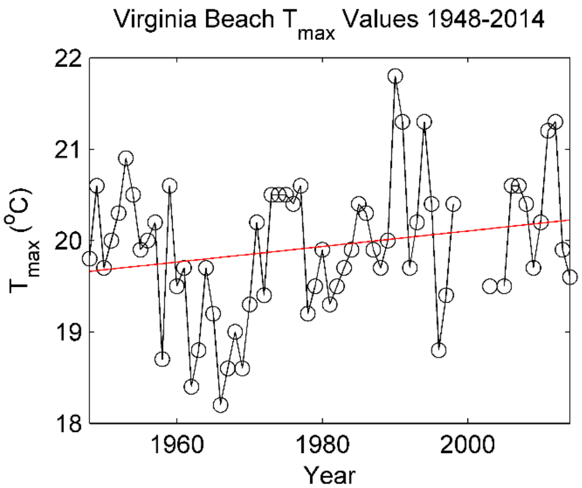
The city of Virginia Beach is home to 437,994 people, it has a land area per square mile of 249 and population density of 1,760 (US Census, 2010). The data for this station was taken from Norfolk International Airport, the station was moved two times and had six instrument changes. The first move was in 1950, however a t-test could not be performed as 4 years of data were needed before the date of the documented move. In 1952 the station was moved 0.3-mile north t-test reveals no inhomogeneity for this move. In 1964 was there an estimated instrument change and $T_{d\ max}$ may have been affected. Estimated instrument changes in 1985 may have affected both $T_{d\ max}$ and $T_{d\ min}$. Another estimated instrument change in 1995 shows that the series may have been impacted in regard to T_{max} and $T_{d\ min}$. The installation of Vaisala DTS1 in 2005 may have created an inhomogeneity in T_{max}, T_{min} and $T_{d\ min}$. Seasonal summer trend analysis shows significant increases in T_{min} (0.28C°) and $T_{E\ min}$ (0.62C°). Annual trend also analysis shows significant increases in T_{min} (0.20C°) and $T_{E\ min}$ (0.32C°). The shorter time series from 1973 is consistent with these results showing significant increases in T_{min} (0.39C°) and $T_{E\ min}$ (1.10 C°).

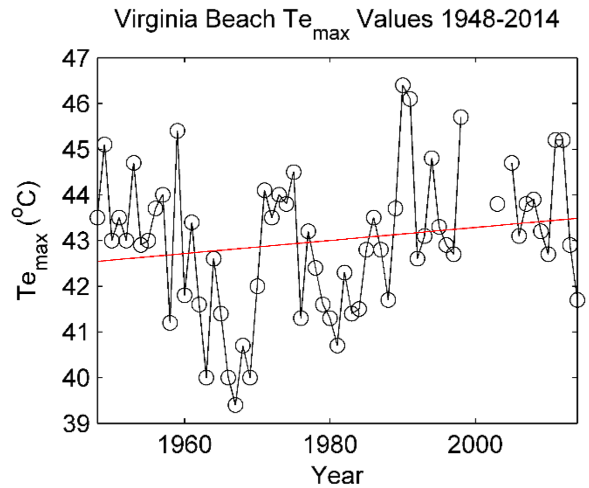
Virginia Beach/Norfolk Intl' AP	Station Metadata		Latitude: 36.9033
	WBAN# 13737		**Longitude: 76.1922**
Year	**Site (m)**	**Instruments**	**Comments**
1940-1992	11.9 (1948-1952)	unknown	Daily, obs times 2400
1992-1996	7.3 (1952-1996)	Hygrothermometer	Daily, obs times 2400. Instrument change 1992 from unknown to Hygrothermometer.
1996-2013	9.1 (1996-Present)	Hygrothermometer	Reporting method: ADP-ASOS-Era Data Downloaded to NCDC. No recorded change in observation times
2013-Present		ATEMP: ASOS Hygrothermometer	Reporting method: ADP-ASOS-Era Data Downloaded to NCDC. No recorded change in observation times
Station Moves			
Latitude	**Longitude**	**Initial**	**Final Date**
36.88333		1/1/1948	1/1/1952
	76.2	7/8/1938	3/1/1996
36.9		1/1/1952	3/1/1996
36.90333		3/1/1996	Present
	76.19222	3/1/1996	Present
T-test 1950	**Station move (900 ft WNW 05/01/1950) Not enough data to conduct T-Test, would need to go back to 1946)**		
T-test 1952	**Station move (.3 miles North, 03/05/1952)**		
T-test 1964	**Estimated instrument change**		
T-test 1985	**Estimated instrument change**		
T-test 1992	**Instrument change from unknown to Hygrothermometer**		
T-test 1995	**Estimated instrument change**		
T-Test 2005	**07/15/2005 DTS1 Installation**		

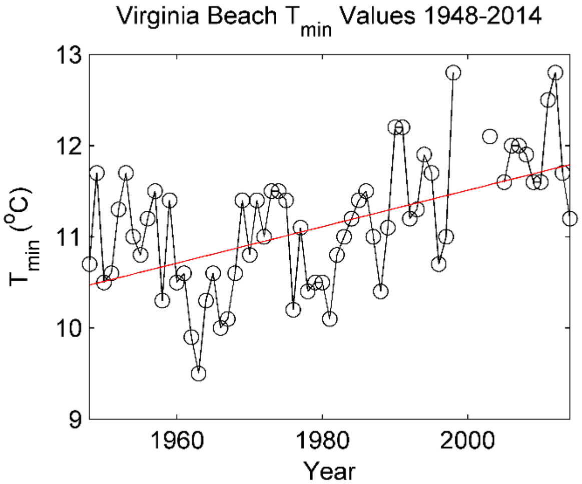
Virginia Beach	Median of Pairwise Slopes 95% confidence	Degrees Celsius per decade	
Seasonal Trend			
Winter-Dec,Jan,Feb	**Significance**	**Trend**	**P-value**
T_max	not significant at 0.05	0.08C°	0.63699
Te_max	not significant at 0.05	0.14C°	0.71157
T_min	not significant at 0.05	0.23C°	0.13618
Te_min	not significant at 0.05	0.30C°	0.17576
Spring-Mar,Apr,May			
T_max	not significant at 0.05	0.10C°	0.20225
Te_max	not significant at 0.05	0.16C°	0.33514
T_min	is significant at 0.05	0.19C°	0.00471
Te_min	is significant at 0.05	0.35C°	0.00963
Summer-June, July,August			
T_max	not significant at 0.05	0.11C°	0.05685
Te_max	not significant at 0.05	0.27C°	0.0663
T_min	is significant at 0.05	0.28C°	0
Te_min	is significant at 0.05	0.62C°	0.0001
Fall-Sept, Oct, Nov			
T_max	not significant at 0.05	0.10C°	0.17112
Te_max	not significant at 0.05	0.18C°	0.24359
T_min	is significant at 0.05	0.18C°	0.00151
Te_min	not significant at 0.05	0.25C°	0.06537

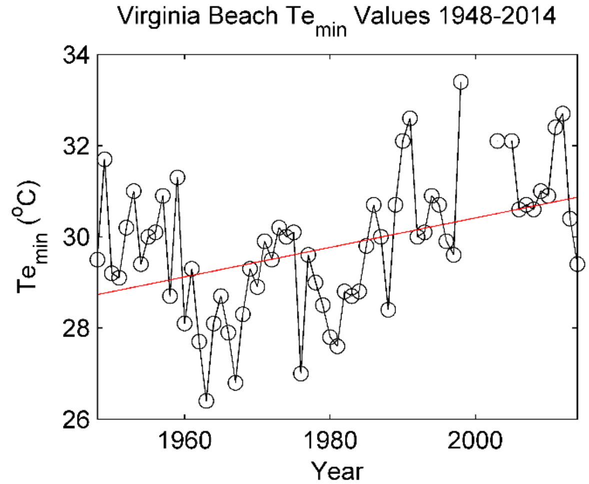
Virginia Beach	95% confidence	Degrees Celsius per decade	
Annual Trend	**Significance**	**Trend**	**P-value**
T_max	not significant at 0.05	0.09C°	0.14708
Te_max	not significant at 0.05	0.14C°	0.20209
T_min	is significant at 0.05	0.20C°	0.00001
Te_min	is significant at 0.05	0.32C°	0.00076

ANNUAL TREND





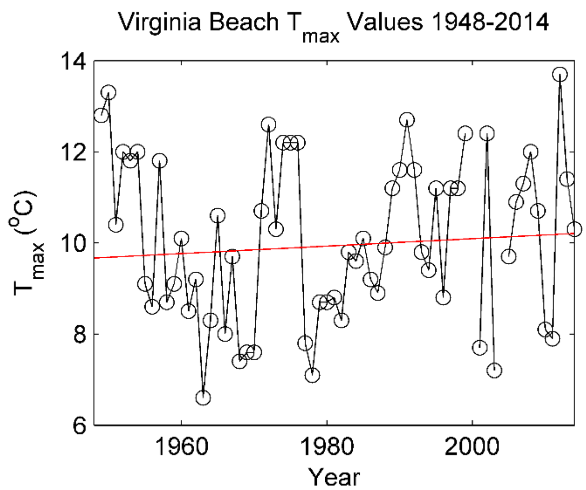


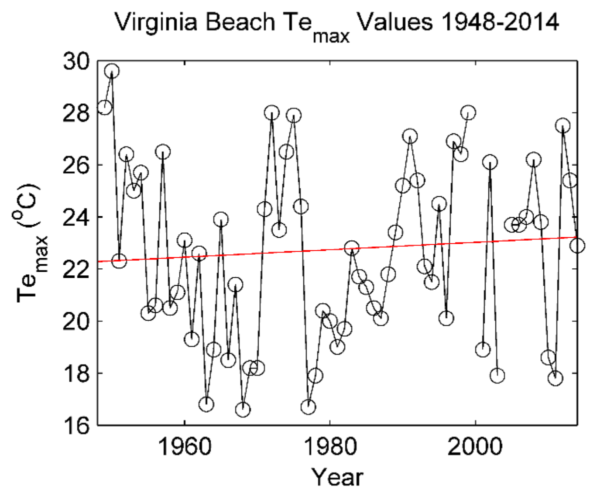


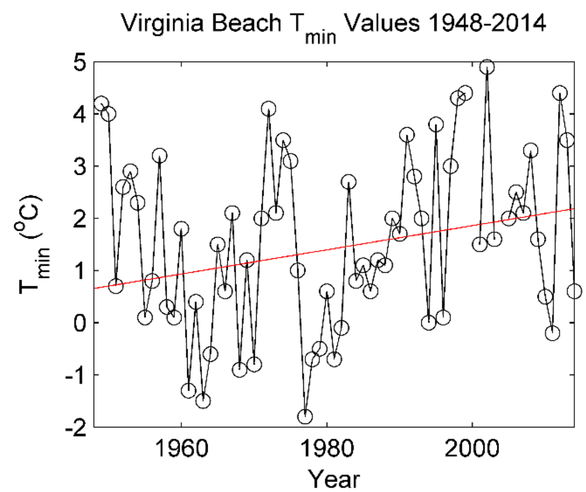
Virginia Beach	**95% confidence**	**Degrees Celsius per decade**	
Annual Trend	**Significance**	**Trend**	**P-value**
T_max	not significant at 0.05	0.09C°	0.14708
Te_max	not significant at 0.05	0.14C°	0.20209
T_min	is significant at 0.05	0.20C°	0.00001
Te_min	is significant at 0.05	0.32C°	0.00076

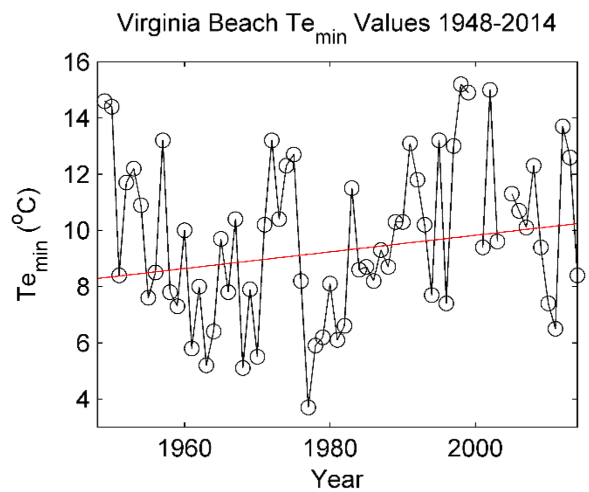
SEASONAL TRENDS

WINTER



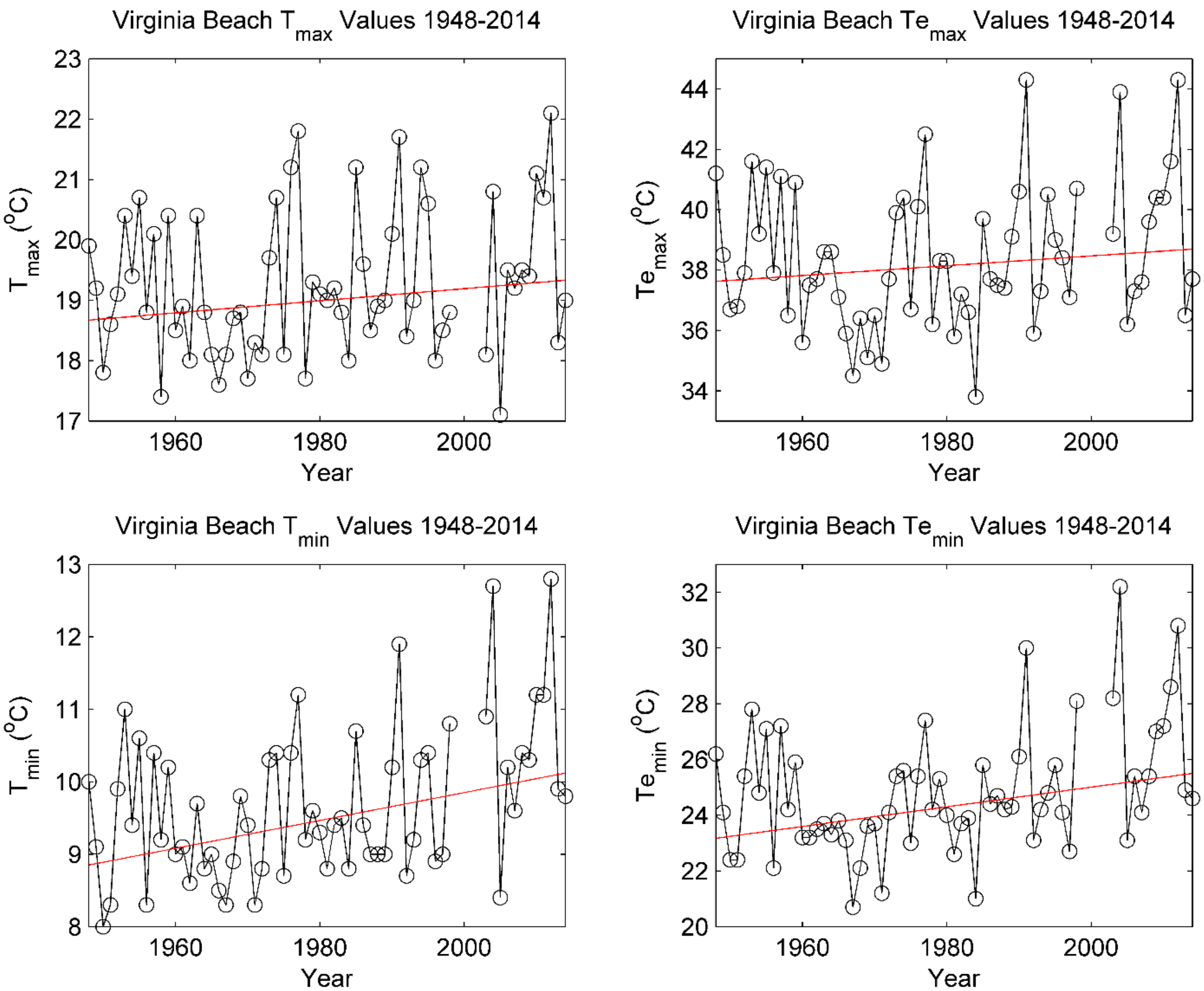






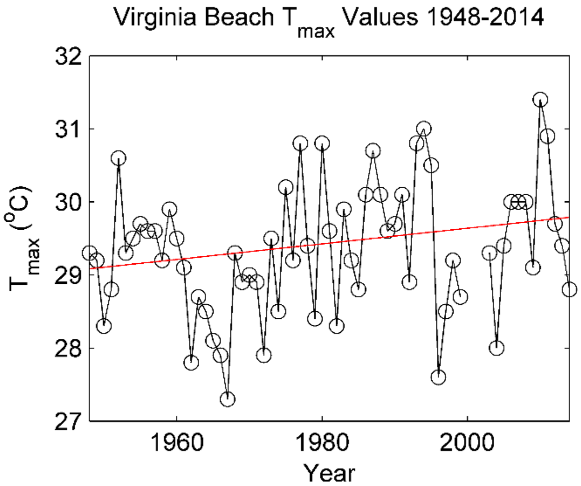
Winter-Dec,Jan,Feb	Significance	Trend	P-value
T_max	not significant at 0.05	0.08C°	0.63699
Te_max	not significant at 0.05	0.14C°	0.71157
T_min	not significant at 0.05	0.23C°	0.13618
Te_min	not significant at 0.05	0.30C°	0.17576

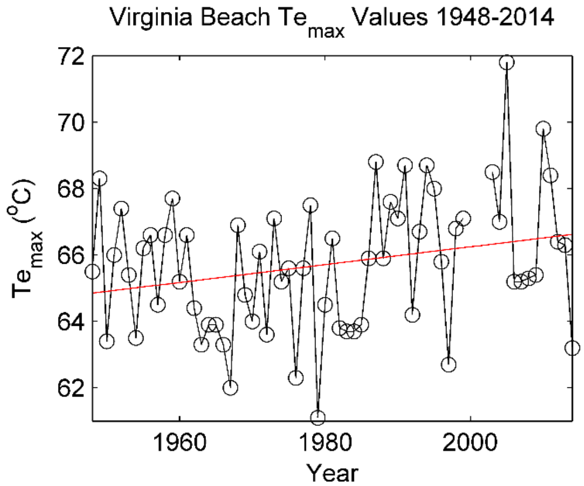
SPRING

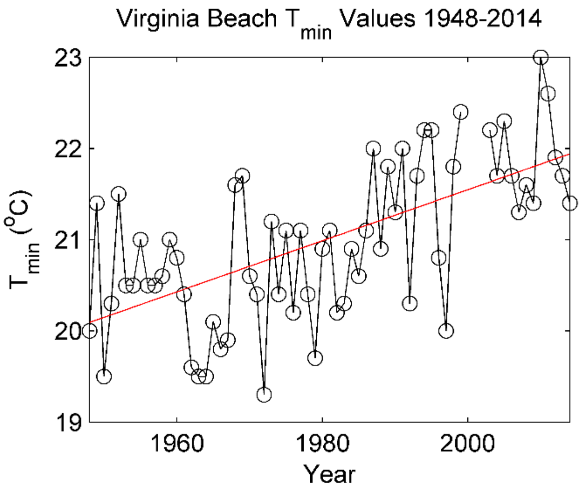


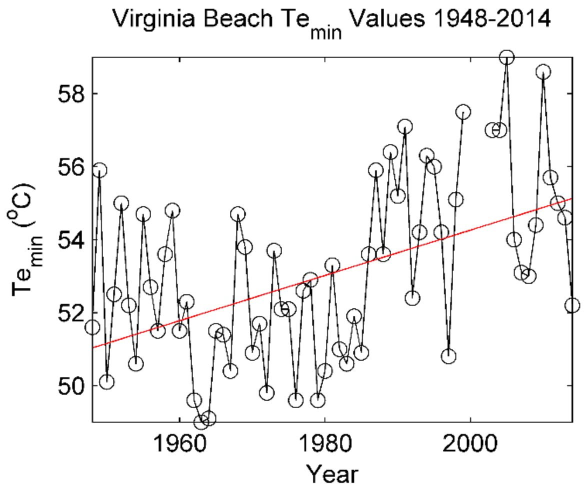
Spring-Mar,Apr,May	**Significance**	**Trend**	**P-Value**
T_max	not significant at 0.05	0.10C°	0.20225
Te_max	not significant at 0.05	0.16C°	0.33514
T_min	is significant at 0.05	0.19C°	0.00471
Te_min	is significant at 0.05	0.35C°	0.00963

SUMMER



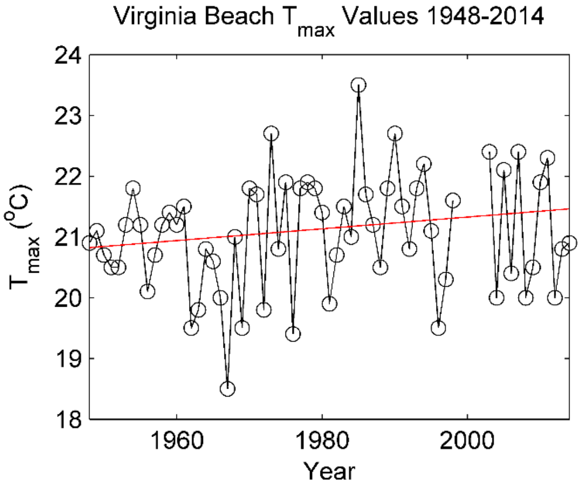


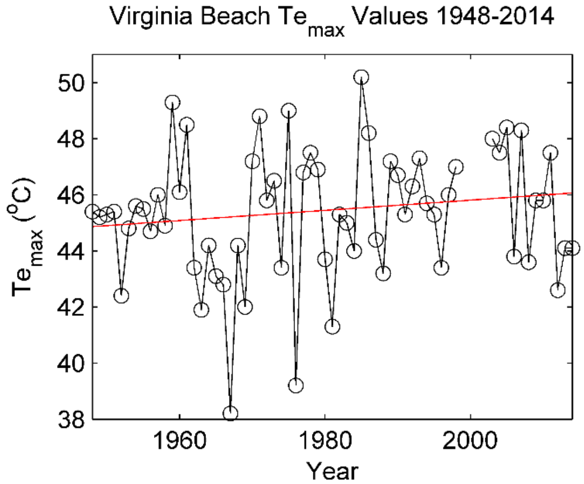


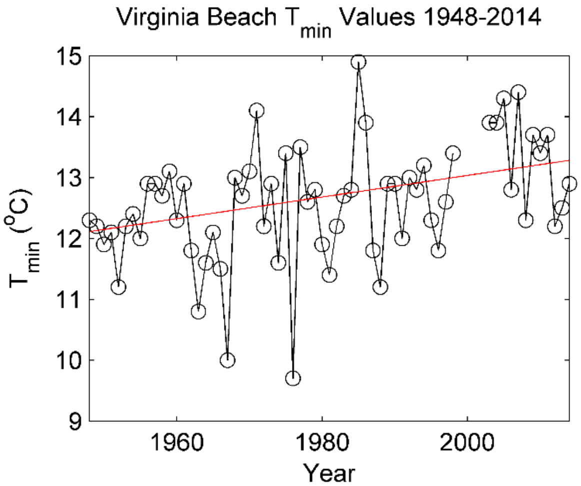


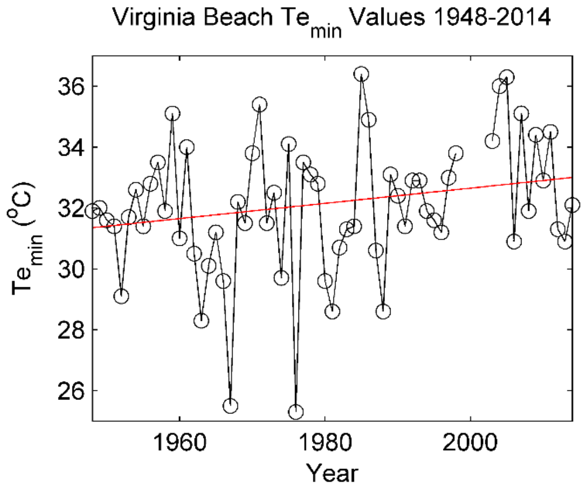
Summer-June, July,August	**Significance**	**Trend**	**P-Value**
T_max	not significant at 0.05	0.11C°	0.05685
Te_max	not significant at 0.05	0.27C°	0.0663
T_min	is significant at 0.05	0.28C°	0
Te_min	is significant at 0.05	0.62C°	0.0001

FALL



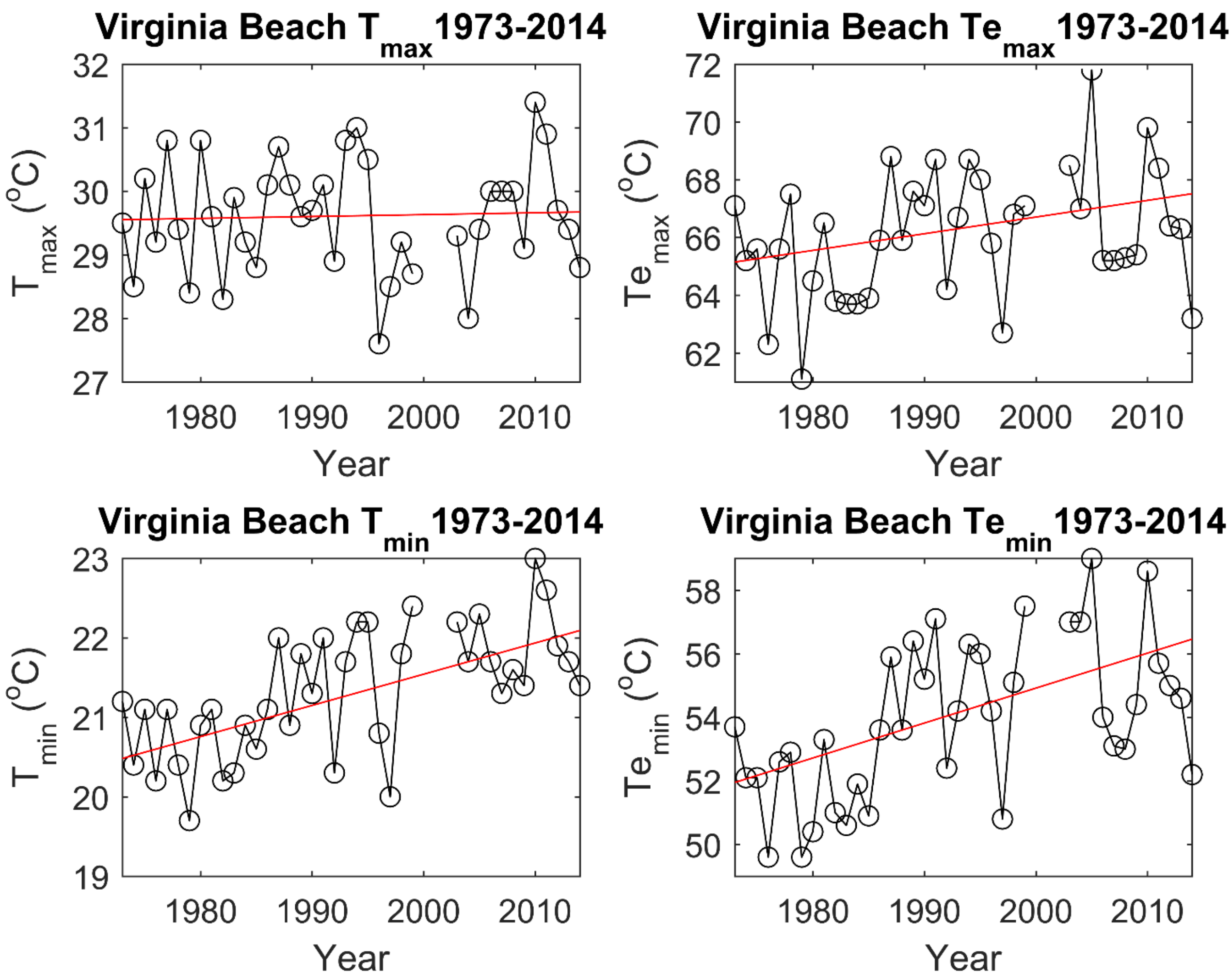






Fall-Sept, Oct, Nov	Significance	Trend	P-Value
T_max	not significant at 0.05	0.10C°	0.17112
Te_max	not significant at 0.05	0.18C°	0.24359
T_min	is significant at 0.05	0.18C°	0.00151
Te_min	not significant at 0.05	0.25C°	0.06537

SUMMER 1973-2014



Summer-June, July,August	Significance	Trend	P-Value
T_max	not significant at 0.05	0.03	0.86867
Te_max	not significant at 0.05	0.58	0.13066
T_min	is significant at 0.05	0.39	0.00002
Te_min	is significant at 0.05	1.1	0.00037

Two Tailed T-Tests: Station moves, instrument changes, DTS1 installation

Virginia Beach/Norfolk	Dew Point			1952	Station move (.3 miles North, 03/05/1952)	
T-Test	1948-1951	1953-1956				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.3715	-1.037	0.3911	-0.8979	94	1.7618
Tdmax	0.4064	-0.443	1.0847	0.834	94	1.8847
Tmin	0.3852	-0.9487	0.3695	-0.8724	94	1.6262
Tdmin	0.8141	-0.7267	0.9226	0.2358	94	2.0347

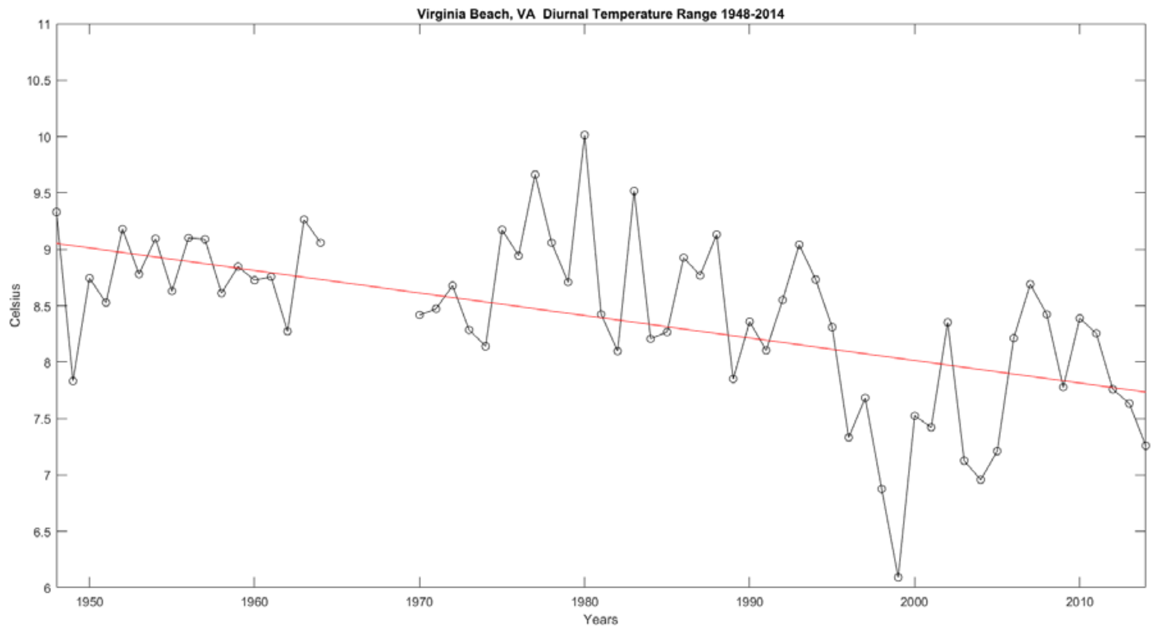
Virginia Beach/ Norfolk	Dew Point			1964	Estimated instrument changes	
T-Test	1960-1963	1965-1968				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.3004	-0.3457	1.1082	1.0413	94	1.7936
Tdmax	0.0171	0.1842	1.8366	2.4283	94	2.03850
Tmin	0.5257	-0.8149	0.419	-0.637	94	1.5222
Tdmin	0.6175	-0.6419	1.0753	0.501	94	2.1185

Virginia Beach/Norfolk	Dew Point			1985	estimated instrument changes	
T-Test	1981-1984	1986-1989				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.2716	-1.0425	0.2966	-1.1059	94	1.652
Tdmax	0.0359	-1.49	-0.0517	-2.1282	94	1.7744
Tmin	0.463	-0.8389	0.3848	-0.7369	94	1.5096
Tdmin	0.0498	-1.6616	-0.0009	-1.9877	94	2.0488

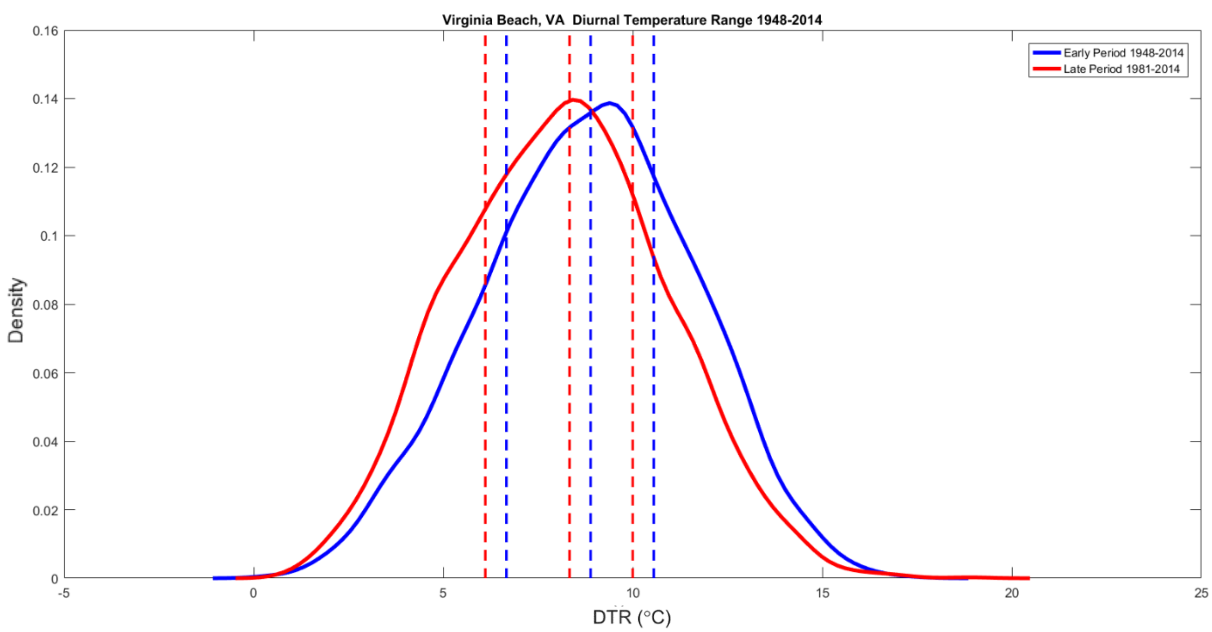
Virginia Beach/Norfolk	Dew Point			1992	instrument change from unknown to Hygrothermometer	
T-Test	1988-1991	1993-1996				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.1596	-0.2136	1.2803	1.4177	94	1.843
Tdmax	0.3222	-0.3628	1.092	0.9952	94	1.79470
Tmin	0.7788	-0.5419	0.7211	0.2817	94	1.5582
Tdmin	0.4828	-0.5076	1.0659	0.7046	94	1.9411

Virginia Beach/Norfolk	Dew Point			1995	Estimated instrument changes	
T-Test	1991-1994	1996-1999				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.0026	0.3557	1.6296	3.0952	92	1.5543
Tdmax	0.5435	-0.844	0.4475	-0.6098	92	1.57580
Tmin	0.5613	-0.7888	0.4307	-0.4307	92	1.488
Tdmin	0.0176	-1.7385	-0.1704	-2.4177	92	1.9134

Virginia Beach/Norfolk	Dew Point			2005	DTS1 Installation 07/15/2005	
T-Test	2001-2004	2006-2009				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.0218	-1.481	-0.1195	-2.3369	86	1.5996
Tdmax	0.7124	-0.5607	0.817	0.3699	86	1.6186
Tmin	0.0046	0.2454	1.3023	2.9112	86	1.2416
Tdmin	3.45E-06	1.14	2.6629	4.9644	86	1.7891



Virginia Beach, VA Diurnal Temperature Range 1948-2014
Celsius
Years



Virginia Beach, VA Diurnal Temperature Range 1948-2014
Early Period 1948-2014
Late Period 1981-2014
Density
DTR (°C)

APPENDIX P

Atlanta

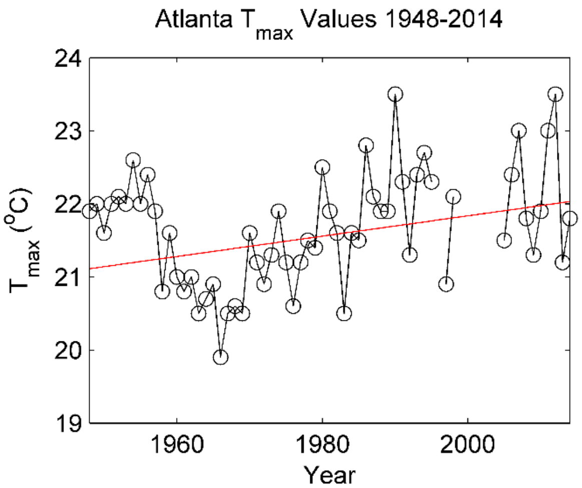
The station at Atlanta Hartsfield-Jackson Airport was moved only once and had six instrument changes. An estimated instrument change in 1985 may have altered the readings of T_{max} and T_{min}. In 1991 a metadata entry reads instrumentation from unknown to Hygrothermometer, this change may have affected $T_{d\ max}$ and $T_{d\ min}$. The DTS1 station was installed in 2004, t-test reveal that T_{max} and $T_{d\ min}$ may have some discontinuity. Seasonal summer trend analysis shows significant increases T_{min} (0.23 C°) and $T_{E\ min}$ (0.40C°). Annual trend analysis is also consistent with these findings as trend analysis shows significant increases T_{min} (0.20 C°) and $T_{E\ min}$ (0.29C°). The more recent trend from 1973 also shows significant increases T_{min} (0.38 C°) and $T_{E\ min}$ (0.62C°).

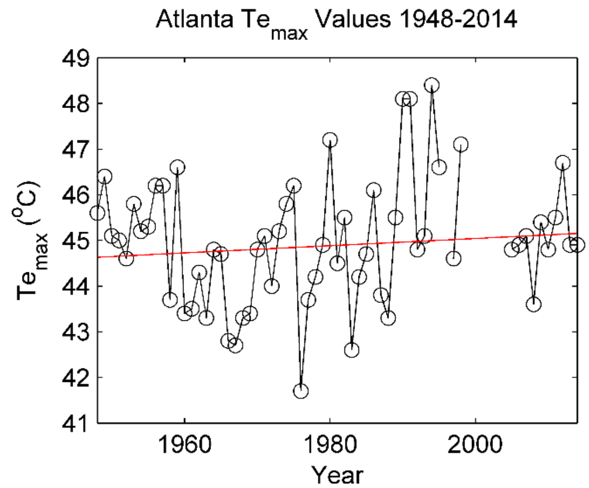
Atlanta Hartsfield-Jackson Int'l AP	**Station Metadata**		**Latitude: 33.6301**
	WBAN# 13874		**Longitude: 84.4418**
Year	**Ground Elevation (m)**	**Instruments**	**Comments**
1948-1991	306 (1948-1956)	unknown	Observations daily, times are unknown
1991-2001	303 (1956-1962	Hygrothermometer	Observations daily, obs times 2400. Instrument change from unknown to Hygrothermometer. Receiver NCEI, Reporting Method F6= NWS Form F6-Prelim.Local Clim. Data
2001-Present	307.8 (1962-Present)	ATEMP: ASOS Hygrothermometer	Reporting method: ADP-ASOS-Era Data Downloaded to NCDC. No recorded change in observation times
Station Moves			
Latitude	**Longitude**	**Initial**	**Final Date**
33.65		9/1/1928	8/1/1995
	84.41667	9/1/1928	1/1/1962
33.64028		8/1/1995	4/13/2001
	84.43333	1/1/1962	8/1/1995
33.63		4/13/2001	6/22/2004
	84.42694	8/1/1995	4/13/2001
33.6301		6/22/2004	Present
	84.4418	6/22/2004	Present
T-test 1964	**estimated instrument change**		
T-test 1985	**estimated instrument change**		
T-test 1991	**instrument change from unknown to Hygrothermometer**		
T-test 1995	**Station move (08/01/1995 0.5 miles WNW) and estimated instrument change**		
T-test 2001	**instrument changes: Hygrothermometer to ATEMP Hygrothermometer**		
T-test 2004	**DTS1 Installation 03/24/2004**		

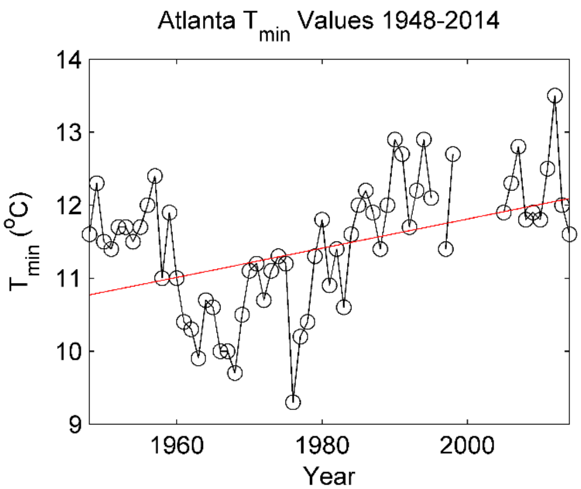
Atlanta Hartsfield-Jackson Airport AP	Median of Pairwise Slopes95% confidence	Degrees Celsius per decade	
Seasonal Trend			
Winter-Dec,Jan,Feb	**Significance**	**Trend**	**P-value**
T_max	not significant at 0.05	0.10C°	0.43349
Te_max	not significant at 0.05	0.05C°	0.90042
T_min	not significant at 0.05	0.20C°	0.19927
Te_min	not significant at 0.05	0.25C°	0.34866
Spring-Mar,Apr,May			
T_max	not significant at 0.05	0.11C°	0.19822
Te_max	not significant at 0.05	0.09C°	0.54118
T_min	is significant at 0.05	0.22C°	0.00379
Te_min	not significant at 0.05	0.33C°	0.06416
Summer-June, July,August			
T_max	not significant at 0.05	0.12C°	0.20214
Te_max	not significant at 0.05	0.11C°	0.37194
T_min	is significant at 0.05	0.23C°	0.00002
Te_min	is significant at 0.05	0.40C°	0.0018
Fall-Sept, Oct, Nov			
T_max	not significant at 0.05	0.10C°	0.10407
Te_max	not significant at 0.05	0.15C°	0.2304
T_min	is significant at 0.05	0.19C°	0.00034
Te_min	is significant at 0.05	0.30C°	0.04238

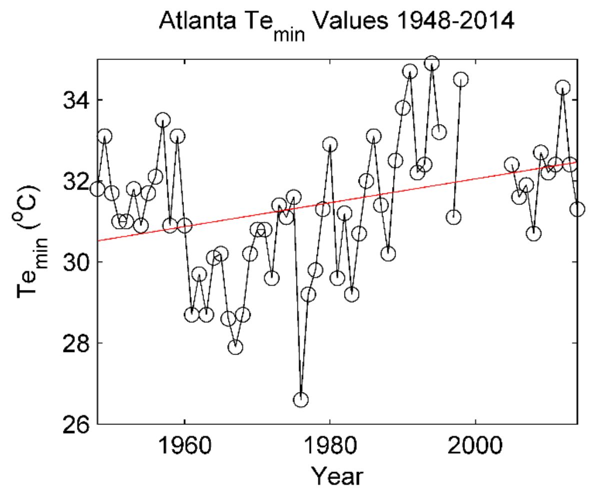
Atlanta Hartsfield-Jackson Int'l AP	95% confidence	Degrees Celsius per decade	
Annual Trend	**Significance**	**Trend**	**P-value**
T_max	is significant at 0.05	0.14C°	0.04519
Te_max	not significant at 0.05	0.08C°	0.38199
T_min	is significant at 0.05	0.20C°	0.00026
Te_min	is significant at 0.05	0.29C°	0.00562

ANNUAL TREND





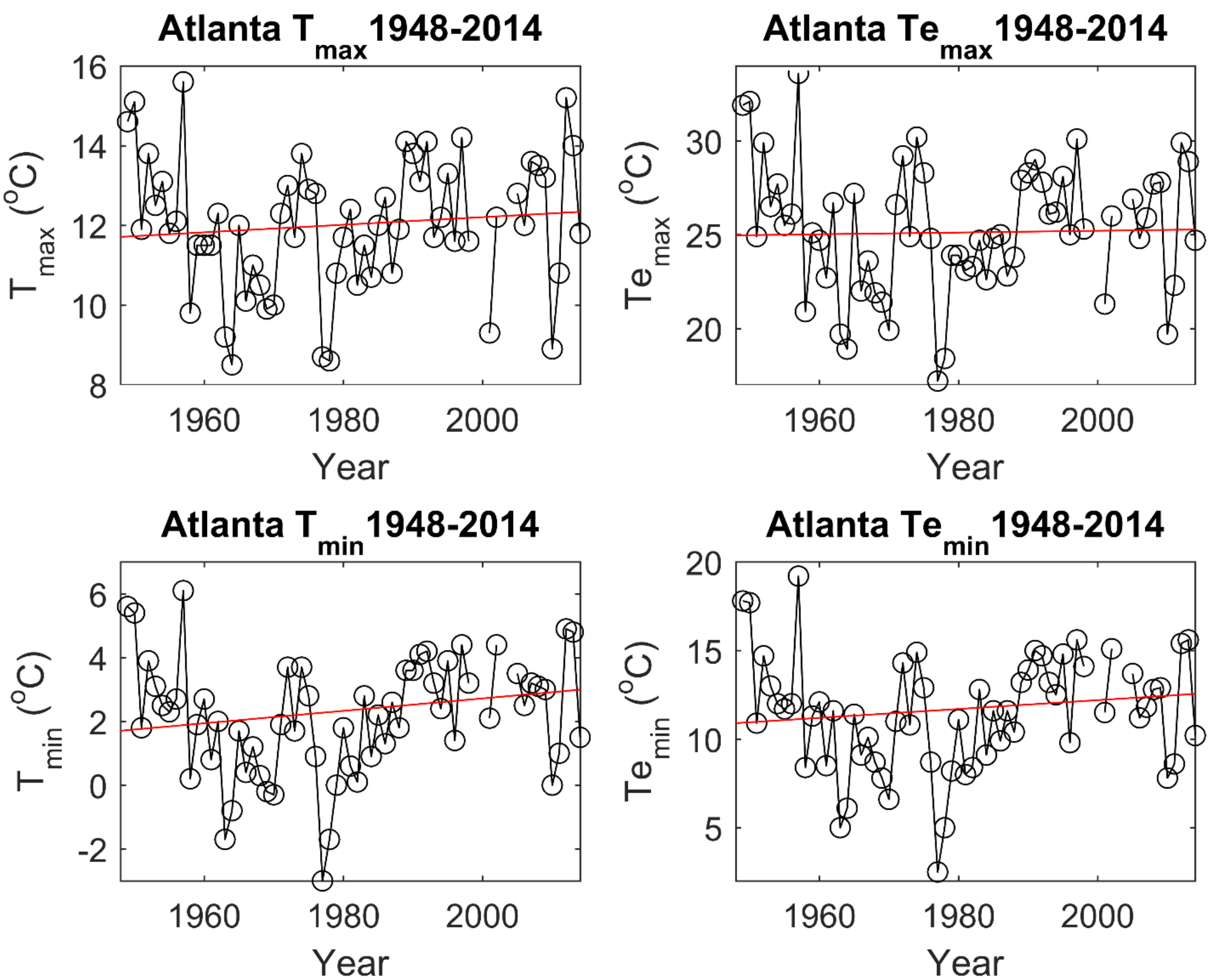




Atlanta Hartsfield-Jackson Int'l AP	**95% confidence**	**Degrees Celsius per decade**	
Annual Trend	**Significance**	**Trend**	**P-value**
T_max	is significant at 0.05	0.14C°	0.04519
Te_max	not significant at 0.05	0.08C°	0.38199
T_min	is significant at 0.05	0.20C°	0.00026
Te_min	is significant at 0.05	0.29C°	0.00562

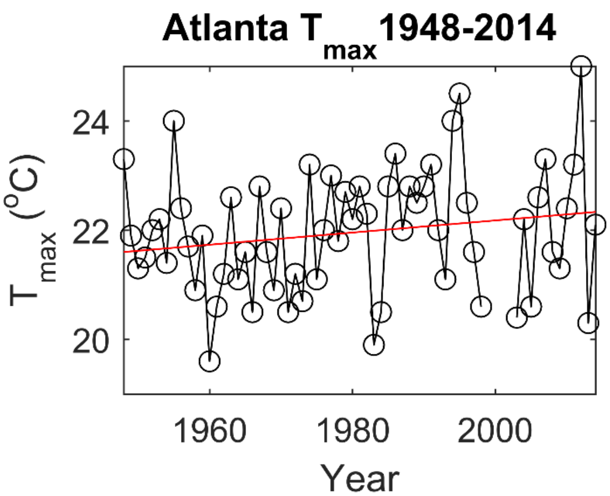
SEASONAL TREND

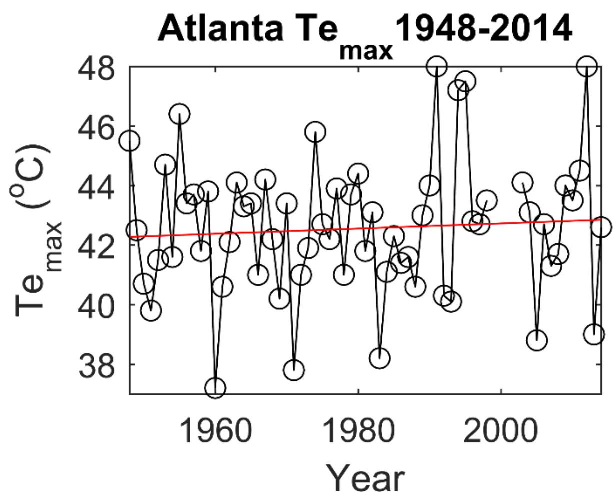
WINTER

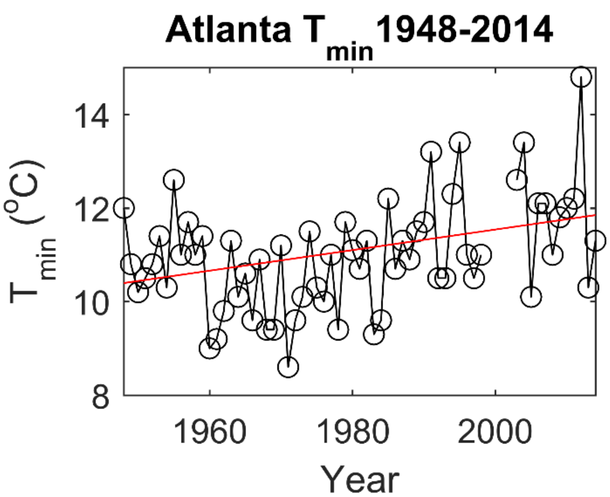


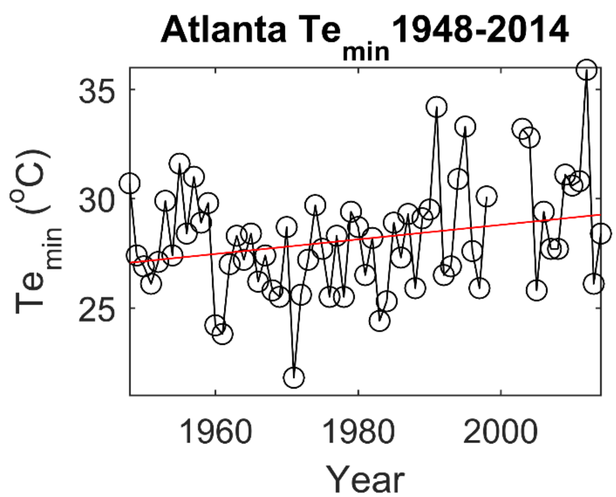
Winter-Dec,Jan,Feb	**Significance**	**Trend**	**P-value**
T_max	not significant at 0.05	0.10C°	0.43349
Te_max	not significant at 0.05	0.05C°	0.90042
T_min	not significant at 0.05	0.20C°	0.19927
Te_min	not significant at 0.05	0.25C°	0.34866

SPRING



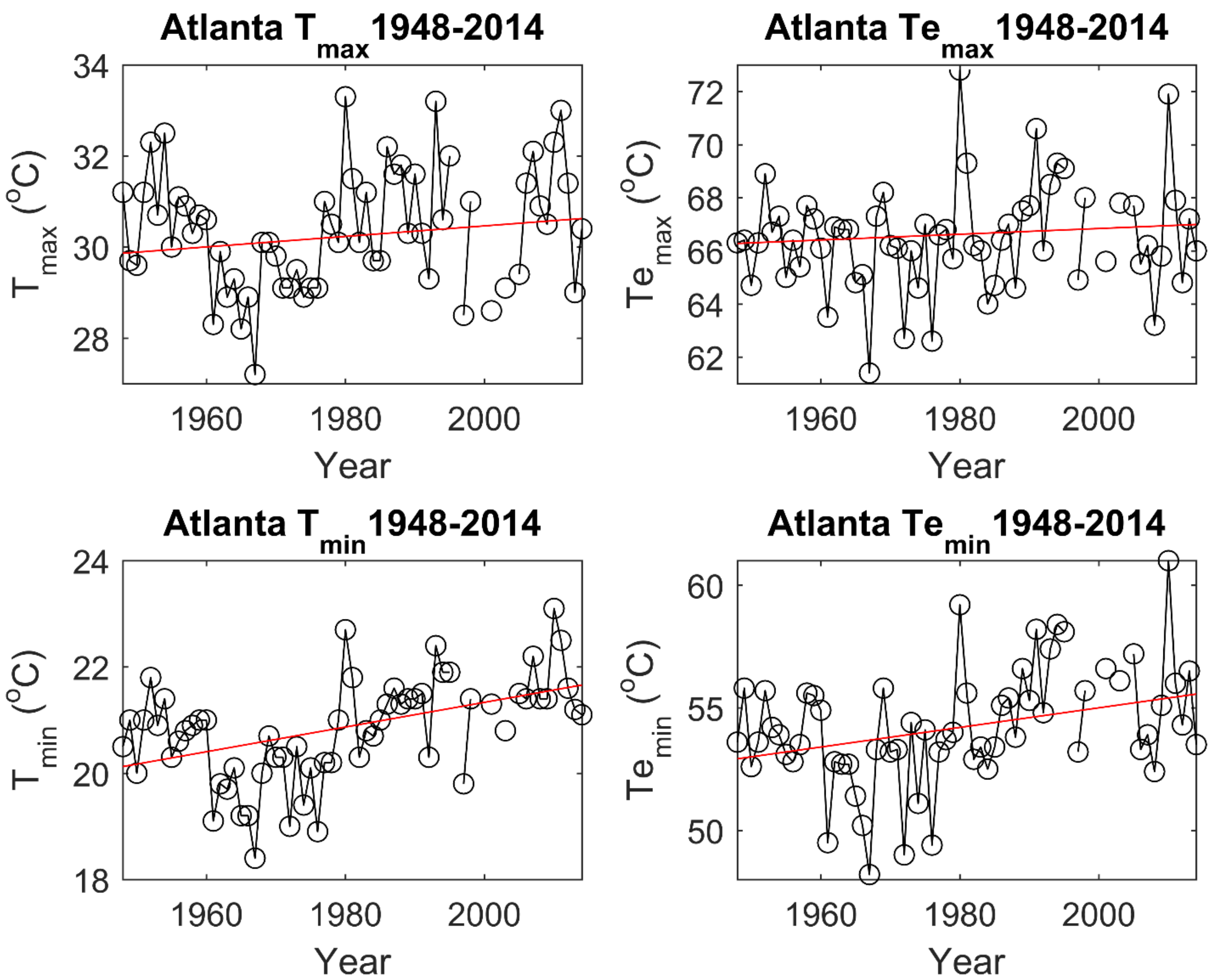






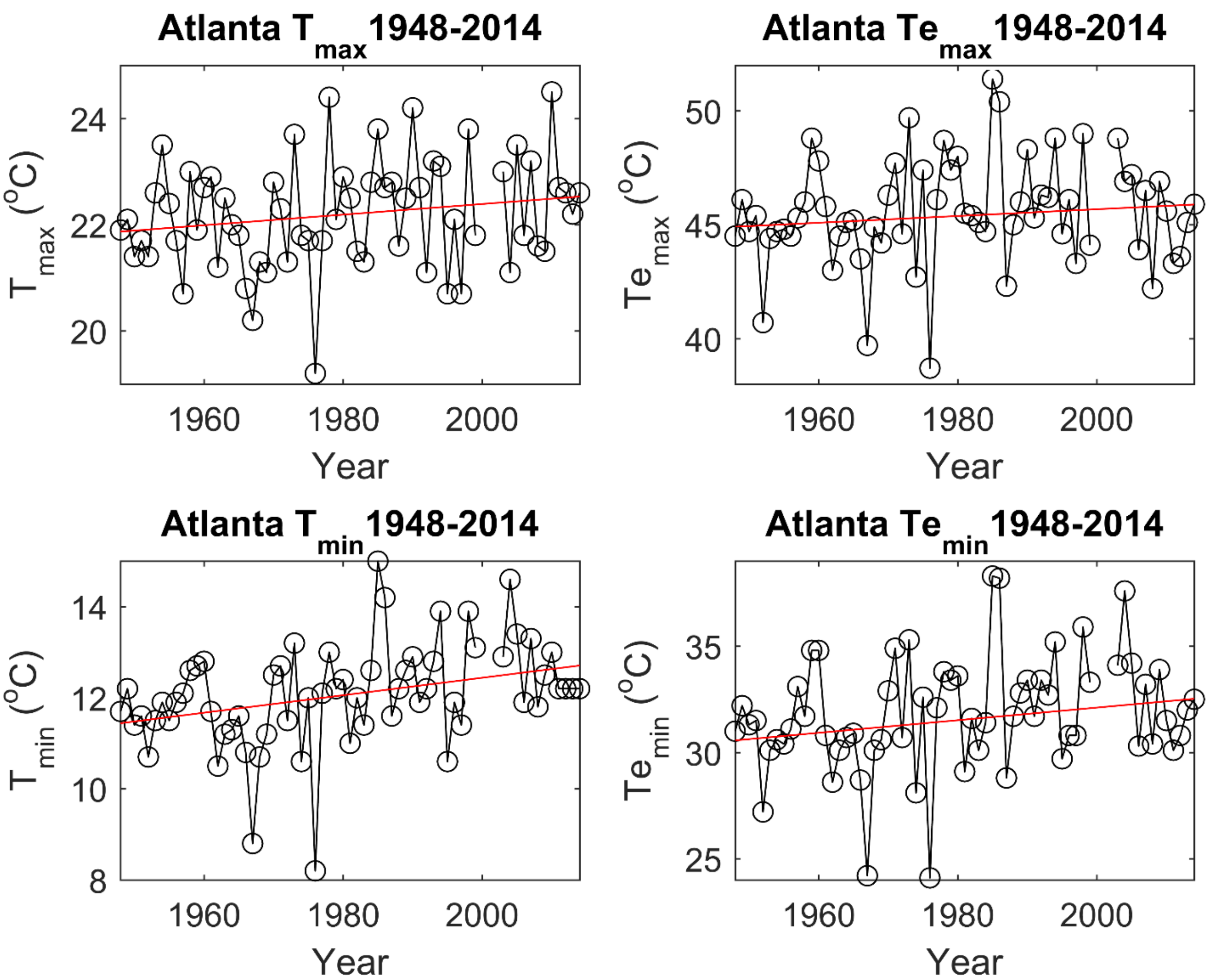
Spring-Mar,Apr,May	**Significance**	**Trend**	**P-Value**
T_max	not significant at 0.05	0.11C°	0.19822
Te_max	not significant at 0.05	0.09C°	0.54118
T_min	is significant at 0.05	0.22C°	0.00379
Te_min	not significant at 0.05	0.33C°	0.06416

SUMMER



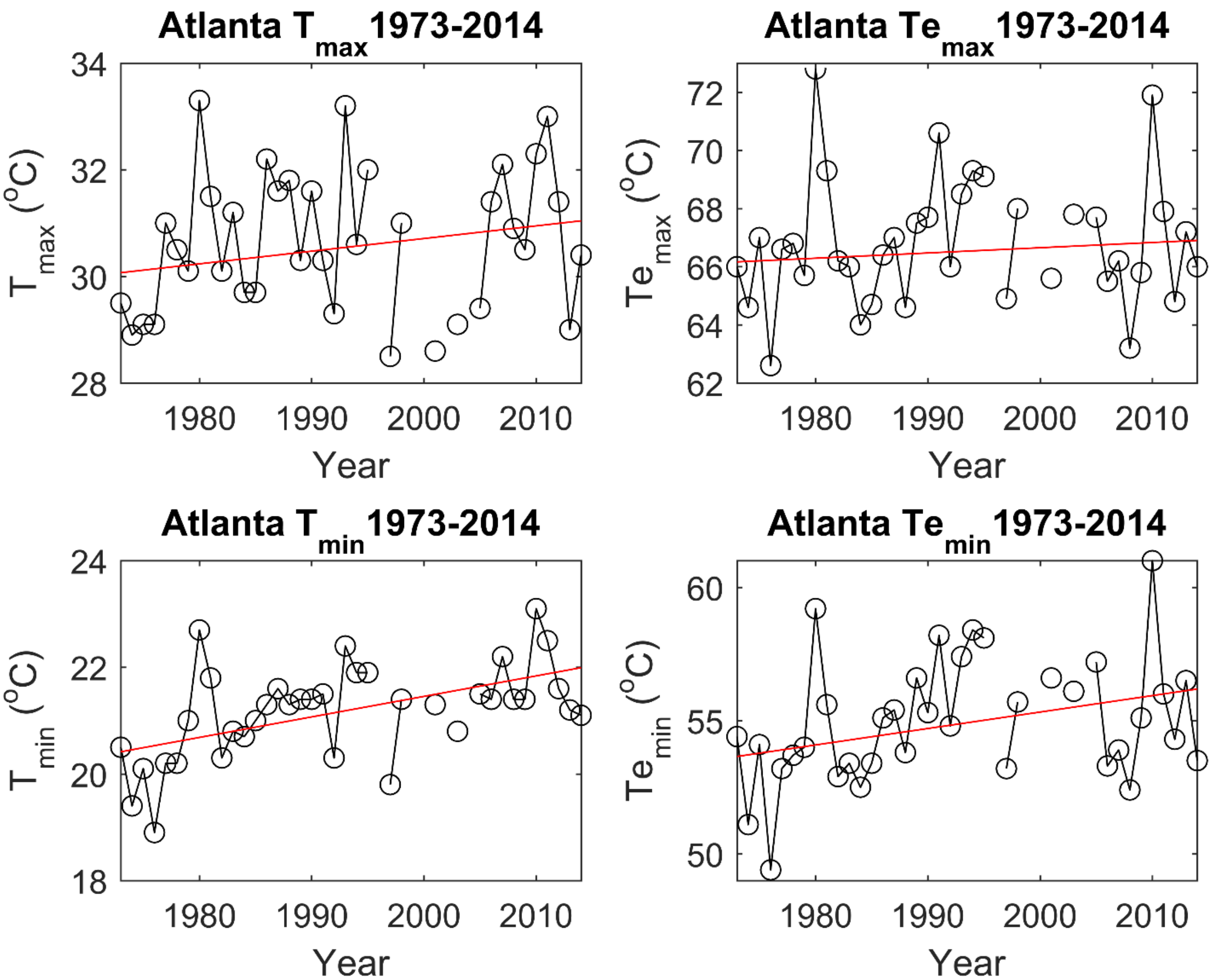
Summer-June, July,August	Significance	Trend	P-Value
T_max	not significant at 0.05	0.12C°	0.20214
Te_max	not significant at 0.05	0.11C°	0.37194
T_min	is significant at 0.05	0.23C°	0.00002
Te_min	is significant at 0.05	0.40C°	0.0018

FALL



Fall-Sept, Oct, Nov	**Significance**	**Trend**	**P-Value**
T_max	not significant at 0.05	0.10C°	0.10407
Te_max	not significant at 0.05	0.15C°	0.2304
T_min	is significant at 0.05	0.19C°	0.00034
Te_min	is significant at 0.05	0.30C°	0.04238

SUMMER 1973-2014



Summer-June, July,August	**Significance**	**Trend**	**P-Value**
T_max	not significant at 0.05	0.24	0.30771
Te_max	not significant at 0.05	0.18	0.48872
T_min	is significant at 0.05	0.38	0.00104
Te_min	is significant at 0.05	0.62	0.04769

__**Two Tailed T-Tests: Station moves, instrument changes, DTS1 installation**__

Atlanta Hartsfield-Jackson Int'l AP	**Dew Point**		**1964**	**Estimated instrument changes**		
T-Test	**1960-1963**	**1965-1968**				
	P-value	**CI-Lower**	**CI-Upper**	**T-statistic**	**Degrees of Freedom**	**Standard Deviation**
Tmax	0.335	-0.37805	1.0989	0.96906	94	1.822
Tdmax	0.99173	-0.8005	0.79216	-0.01039	94	1.96480
Tmin	0.3197	-0.3197	0.97628	1.0004	94	1.6018
Tdmin	0.66342	-1.0749	0.68742	-0.43657	94	3.1303

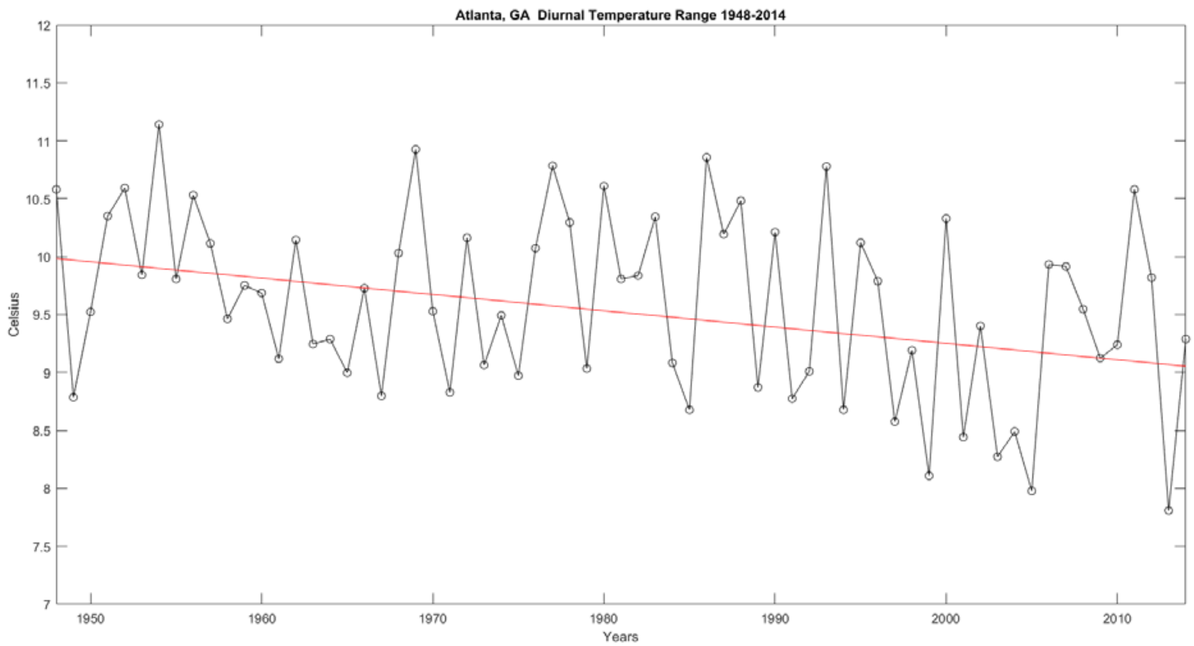
Atlanta Hartsfield-Jackson Int'l AP	**Dew Point**			**1985**	**Estimated instrument changes**	
T-Test	**1981-1984**	**1986-1989**				
	P-value	**CI-Lower**	**CI-Upper**	**T-statistic**	**Degrees of Freedom**	**Standard Deviation**
Tmax	0.026864	-1.475	0.091693	-2.2488	94	1.7065
Tdmax	0.5667	-1.0298	0.56735	-0.57495	94	1.9704
Tmin	0.023379	-1.4	-0.10418	-2.3048	94	1.5986
Tdmin	0.85554	-1.0144	0.84359	-0.18256	94	2.2922

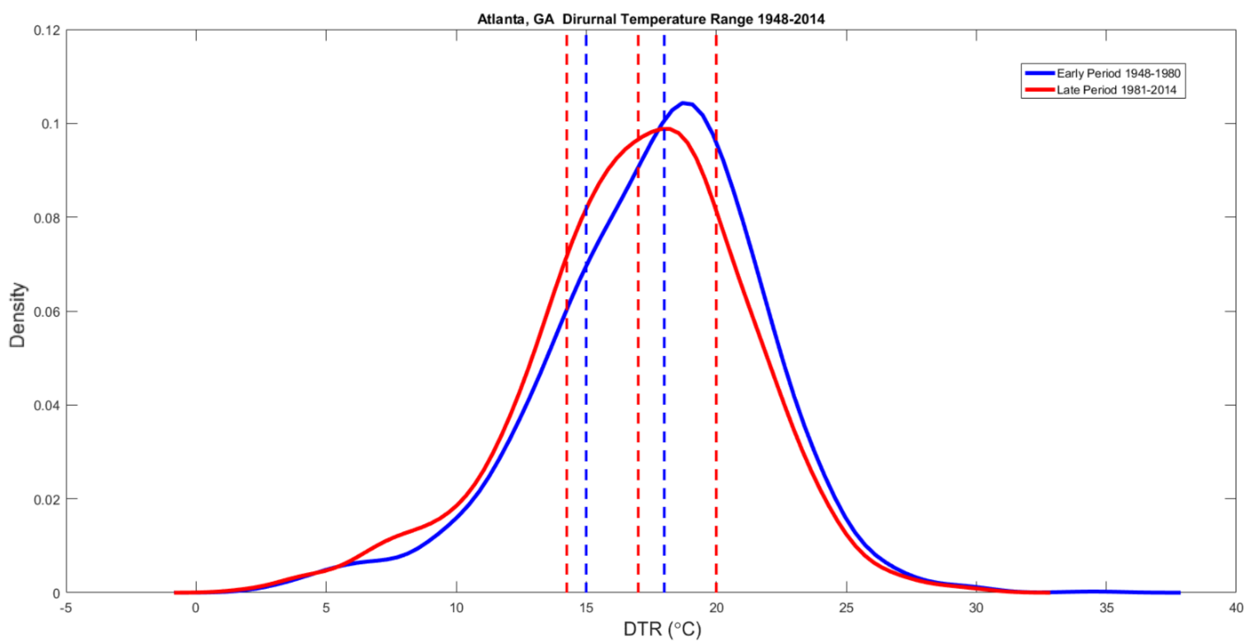
Atlanta Hartsfield-Jackson Int'l AP	**Dew Point**			**1991**	**Instrument change from unknown to Hygrothermometer**	
T-Test	**1987-1990**	**1992-1995**				
	P-value	**CI-Lower**	**CI-Upper**	**T-statistic**	**Degrees of Freedom**	**Standard Deviation**
Tmax	0.5732	-0.4919	0.8836	0.5654	94	1.6969
Tdmax	0.025	-1.5441	-0.1059	-2.278	94	1.77420
Tmin	0.5286	-0.7675	0.3967	-0.6324	94	1.4363
Tdmin	0.0174	-1.8508	0.1825	-2.4199	94	2.0582

Atlanta Hartsfield-Jackson Int'l AP	**Dew Point**			**1995**	**Station move (0.5 miles WNW 08/01/1995) and estimated instrument change**	
T-Test	**1991-1994**	**1996-1999**				
	P-value	**CI-Lower**	**CI-Upper**	**T-statistic**	**Degrees of Freedom**	**Standard Deviation**
Tmax	0.21846	-0.28306	1.2212	1.2396	87	1.7795
Tdmax	0.23988	-0.27265	1.0751	1.1834	87	1.59420
Tmin	0.29884	-0.29367	0.94505	1.0452	87	1.4653
Tdmin	0.60455	-0.62397	1.0659	0.51977	87	1.9989

Atlanta Hartsfield-Jackson Int'l AP	**Dew Point**			**2001**	**Instrument change: hygrothermometer to ATEMP Hygrothermometer**	
T-Test	**1997-2000**	**2002-2005**				
	P-value	**CI-Lower**	**CI-Upper**	**T-statistic**	**Degrees of Freedom**	**Standard Deviation**
Tmax	0.40254	-0.50223	1.237	0.84199	73	1.8879
Tdmax	0.64825	-0.60537	0.96671	0.45809	73	1.7064
Tmin	0.48436	-0.99931	0.47822	-0.70289	73	1.6038
Tdmin	0.68919	-1.082	0.71912	-0.40154	73	1.9551

Atlanta Hartsfield-Jackson Int'l AP	Dew Point			2004	DTS1 Installation 03/24/2004	
T-Test	**2000-2003**	**2005-2008**				
	P-value	**CI-Lower**	**CI-Upper**	**T-statistic**	**Degrees of Freedom**	**Standard Deviation**
Tmax	2.37E-05	-2.4155	-0.9325	-4.4934	79	1.6474
Tdmax	0.7141	-0.6149	0.8936	0.3677	79	1.6758
Tmin	0.8849	-0.5719	0.6619	0.1452	79	1.3706
Tdmin	2.49E-04	0.8093	2.5532	3.8379	79	1.9372


Atlanta, GA Diurnal Temperature Range 1948-2014
Celsius
Years


Atlanta, GA Dirurnal Temperature Range 1948-2014
Early Period 1948-1980
Late Period 1981-2014
Density
DTR (°C)

APPENDIX Q

Raleigh

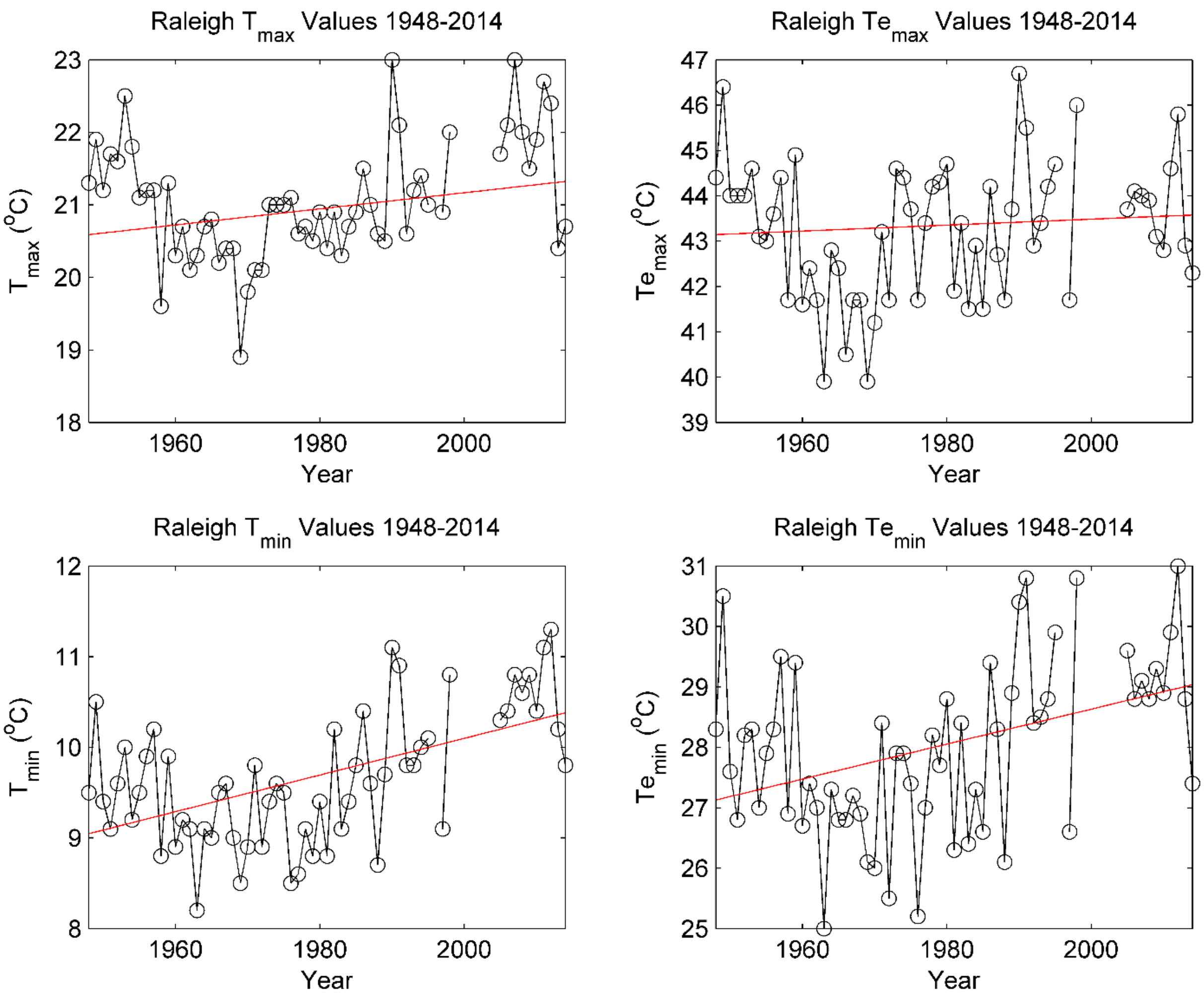
The station at Raleigh/Durham Airport was moved 3 times and had five instrument changes for the study period. T-tests were performed on all of the mentioned changes, the only change that may have affected the time series was the installation of Vaisala's DTS1 station in 2004, T_{max} and $T_{d\ min}$ reflect this. Seasonal summer trend analysis shows significant increases T_{max} (0.17 C°), T_{min} (0.25 C°) and $T_{E\ min}$ (0.49 C°). Annual trend analysis shows significant increases T_{min} (0.20 C°) and $T_{E\ min}$ (0.29C°). The trend analysis from 1973 also shows significant increases T_{min} (0.47 C°) and $T_{E\ min}$ (0.87C°).

Raleigh/Durham Airport	Dew Point		Latitude: 35.8923
	WBAN# 13722		Longitude: 78.7819
Year	**Ground Elevation (m)**	**Instruments**	**Comments**
1948-1991	135 (1948-1954)	unknown	Daily, obs times 2400
1991-2009	132.3 (1954-1979)		Daily, obs times 2400. Instrument change from unknown to Hygrothermometer. Receiver NCEI, Reporting Method: FOSJ-SFC
2009-Present	126.8 (1979-Present)	ATEMP: ASOS Hygrothermometer	Reporting method: ADP-ASOS-Era Data Downloaded to NCDC. No recorded change in observation times
Station Moves			
Latitude	**Longitude**	**Initial**	**Final Date**
35.86667		9/1/1930	2/1/1996
	78.78333	9/1/1930	2/1/1996
35.87056		2/1/1996	3/27/2009
	78.78639	2/1/1996	3/27/2009
35.86667		3/27/2009	6/22/2011
	78.78333	3/27/2009	6/22/2011
35.8923		6/22/2011	Present
	78.7819	6/22/2011	Present
T-test 1964	**estimated instrument change**		
T-test 1985	**estimated instrument change**		
T-test 1991	**instrument change from unknown to Hygrothermometer**		
T-test 1995	**estimated instrument change**		
T-test 1996	**Station move (#3 under location data). Visible on map.**		
T-Test 2004	**06/03/2004 DTS1 Installation**		
T-Test 2009	**Station move (#2 under location data). Visible on map.**		
T-Test 2011	**Station move (#1 under location data). Visible on map. Not enough data to conduct T-Test, ends 2014.**		

Raleigh/Durham	Median of Pairwise Slopes95% confidence	Degrees Celsius per decade	
Seasonal Trend			
Winter-Dec,Jan,Feb	**Significance**	**Trend**	**P-value**
T_max	not significant at 0.05	0.08C°	0.47813
Te_max	not significant at 0.05	0.15C°	0.66351
T_min	is significant at 0.05	0.28C°	0.03807
Te_min	not significant at 0.05	0.37C°	0.08143
Spring-Mar,Apr,May			
T_max	not significant at 0.05	0.10C°	0.25001
Te_max	not significant at 0.05	0.18C°	0.319
T_min	is significant at 0.05	0.16C°	0.04867
Te_min	not significant at 0.05	0.19C°	0.17453
Summer-June, July,August			
T_max	is significant at 0.05	0.17C°	0.04315
Te_max	not significant at 0.05	0.19C°	0.13575
T_min	is significant at 0.05	0.25C°	0
Te_min	is significant at 0.05	0.49C°	0.00106
Fall-Sept, Oct, Nov			
T_max	not significant at 0.05	0.04C°	0.53281
Te_max	not significant at 0.05	0.09C°	0.47622
T_min	is significant at 0.05	0.16C°	0.00162
Te_min	is significant at 0.05	0.22C°	0.03582

Raleigh/Durham AP	95% confidence	Degrees Celsius per decade	
Annual			
	Significance	**Trend**	**P-value**
T_max	not significant at 0.05	0.11C°	0.09121
Te_max	not significant at 0.05	0.07C°	0.42098
T_min	is significant at 0.05	0.20C°	0.00011
Te_min	is significant at 0.05	0.29C°	0.00162

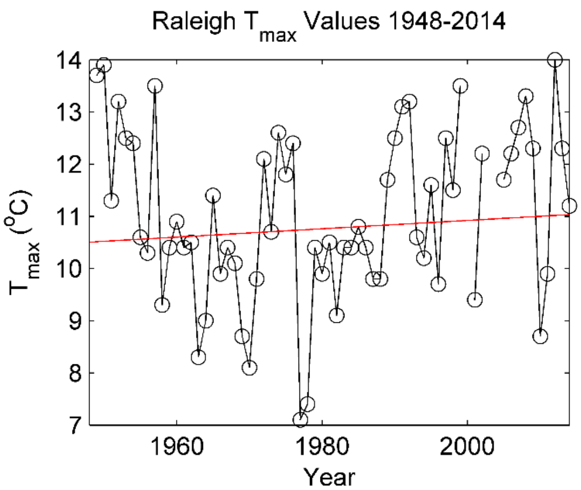
ANNUAL TREND

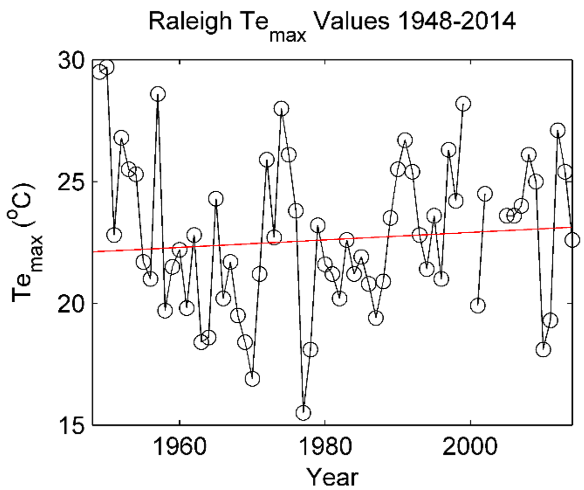


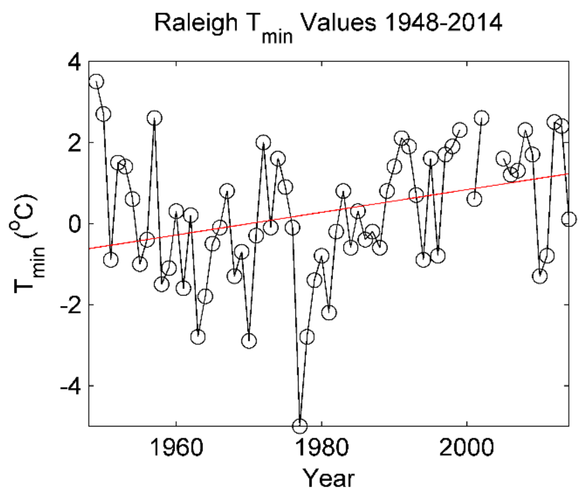
Raleigh/Durham AP	95% confidence	Degrees Celsius per decade	
Annual	**Significance**	**Trend**	**P-value**
T_max	not significant at 0.05	0.11C°	0.09121
Te_max	not significant at 0.05	0.07C°	0.42098
T_min	is significant at 0.05	0.20C°	0.00011
Te_min	is significant at 0.05	0.29C°	0.00162

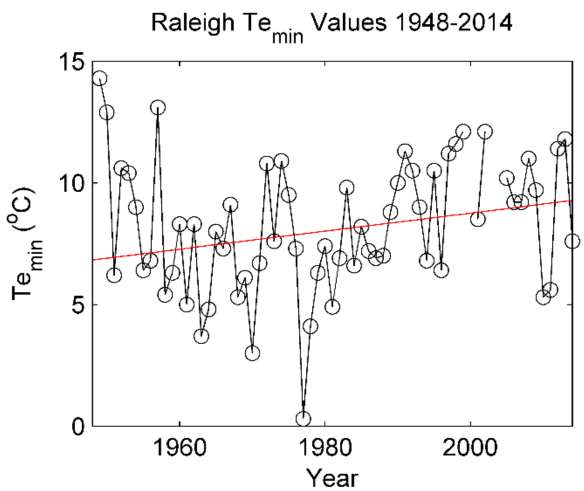
SEASONAL TRENDS

WINTER



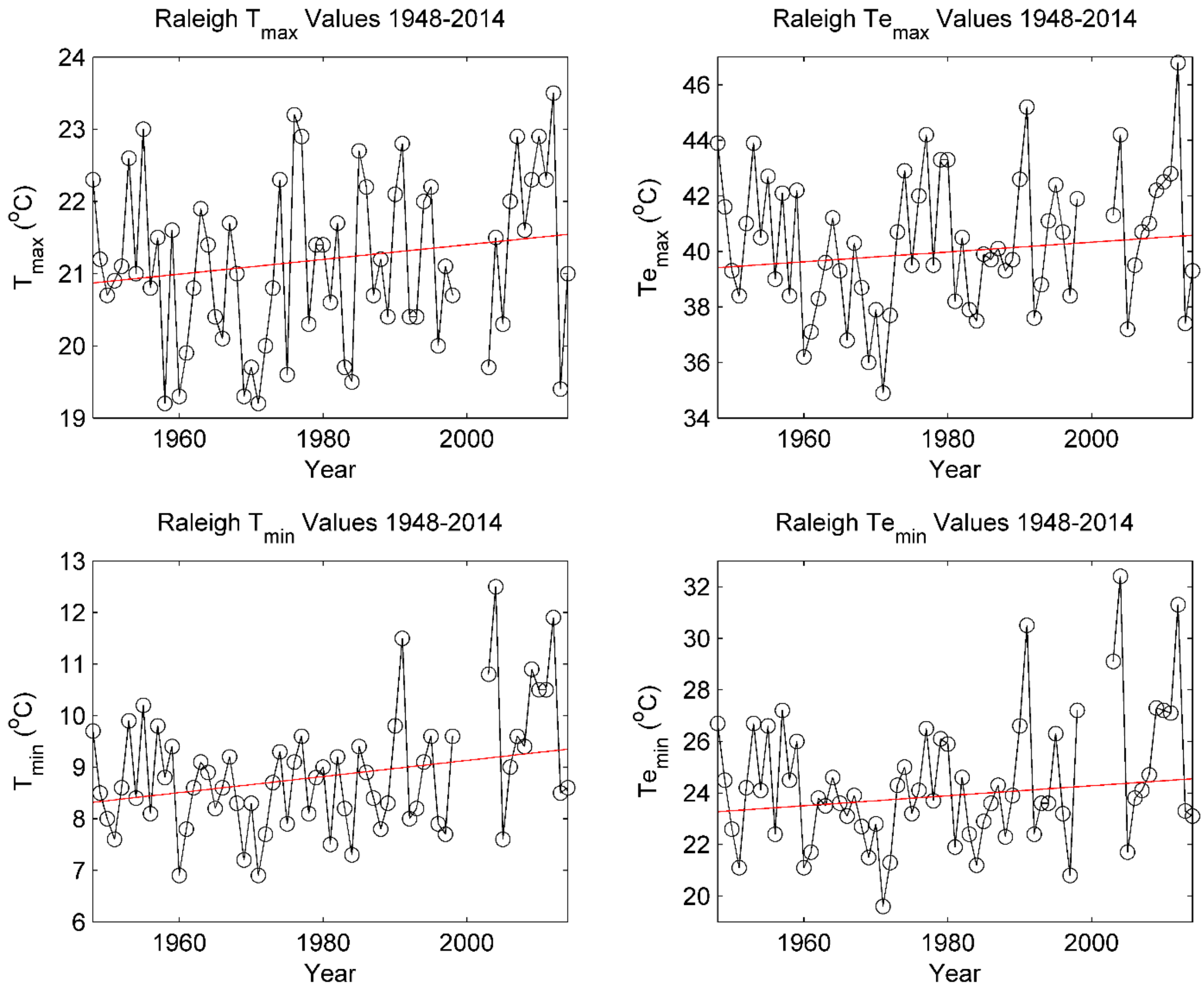






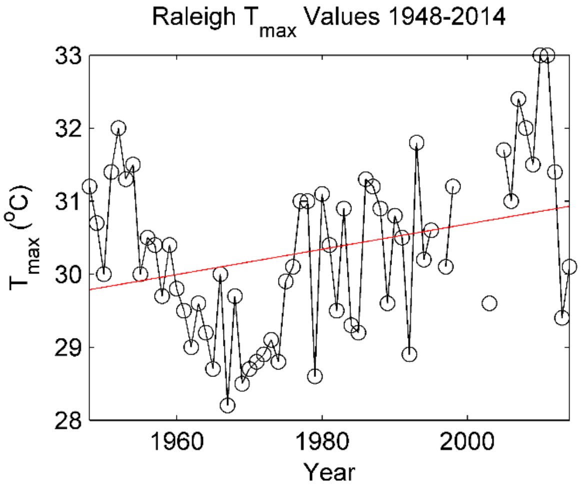
Winter-Dec,Jan,Feb	**Significance**	**Trend**	**P-value**
T_max	not significant at 0.05	0.08C°	0.47813
Te_max	not significant at 0.05	0.15C°	0.66351
T_min	is significant at 0.05	0.28C°	0.03807
Te_min	not significant at 0.05	0.37C°	0.08143

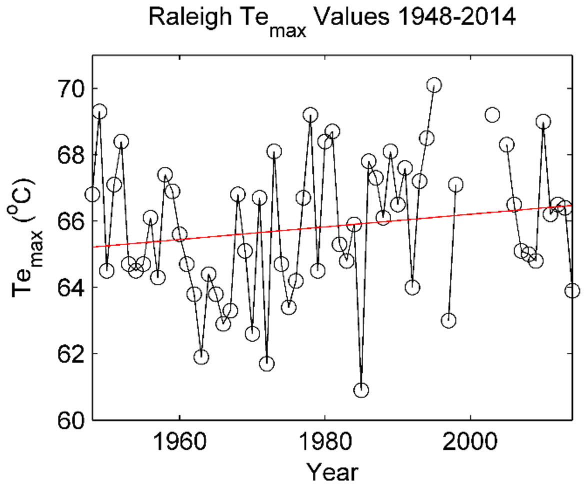
SPRING

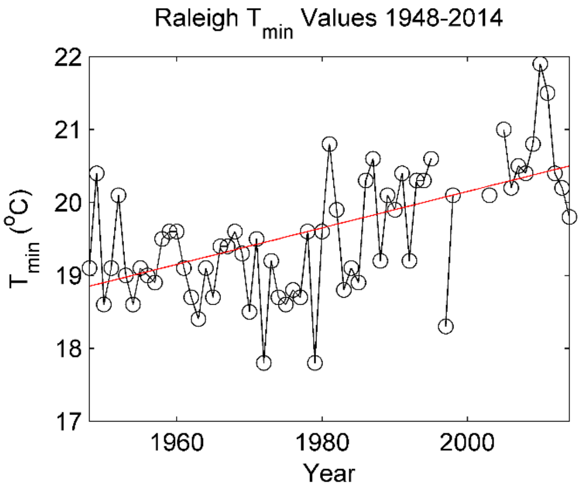


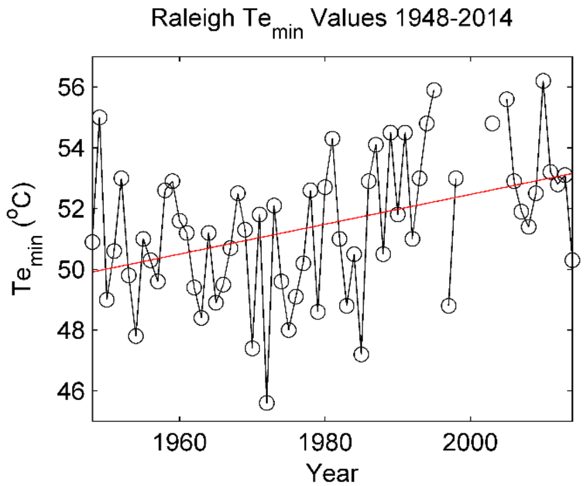
Spring-Mar,Apr,May	Significance	Trend	P-Value
T_max	not significant at 0.05	0.10C°	0.25001
Te_max	not significant at 0.05	0.18C°	0.319
T_min	is significant at 0.05	0.16C°	0.04867
Te_min	not significant at 0.05	0.19C°	0.17453

SUMMER



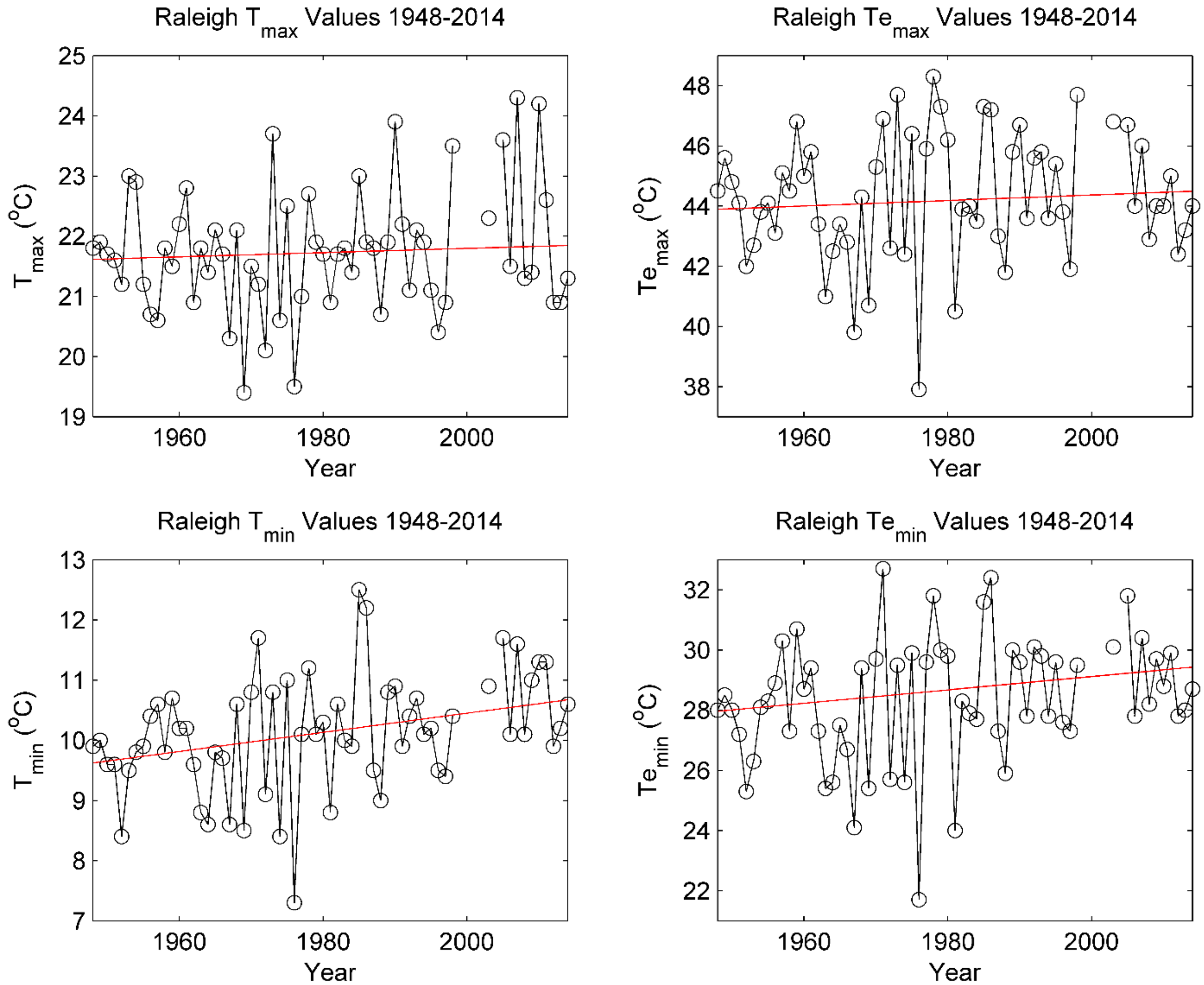






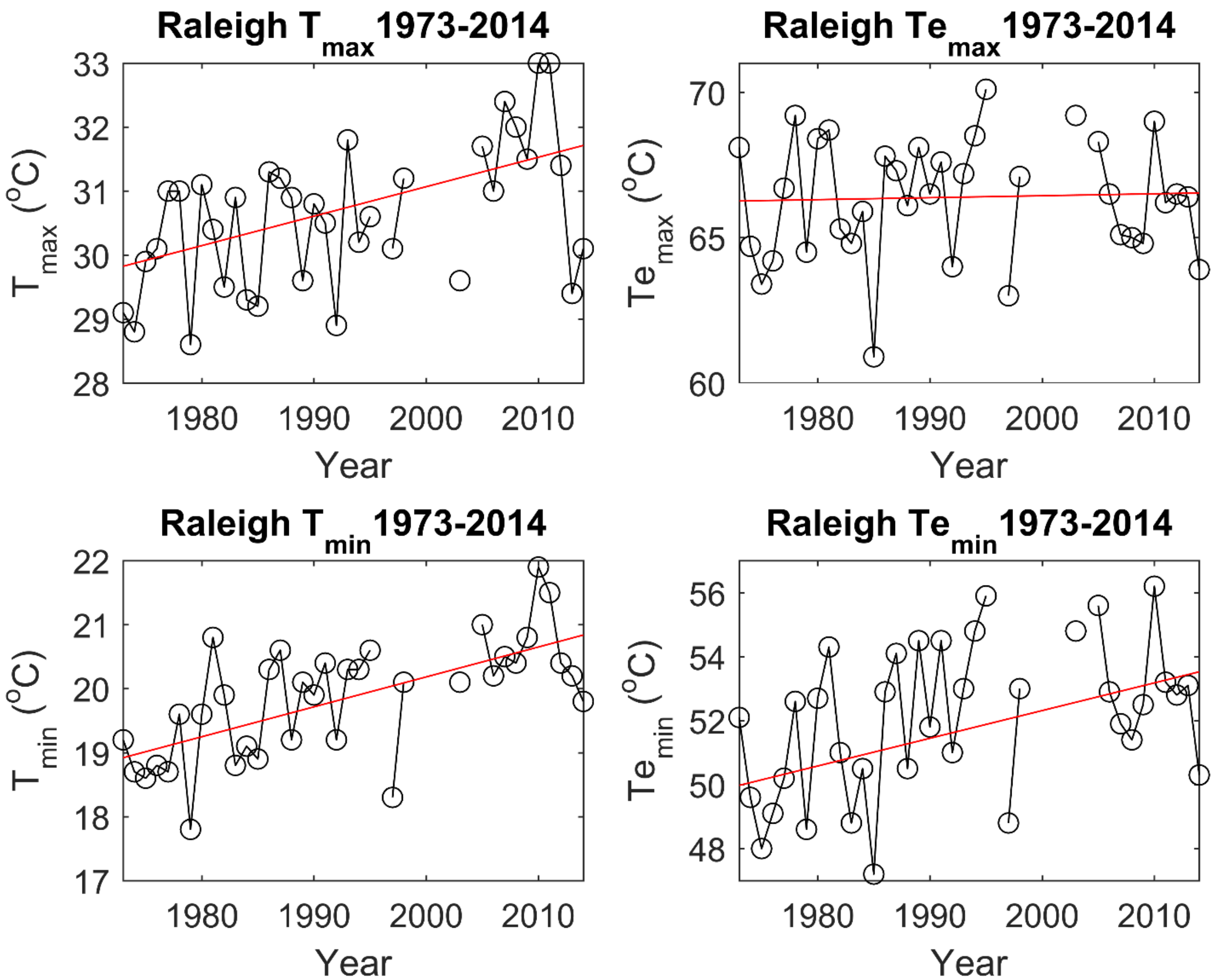
Summer-June, July,August	**Significance**	**Trend**	**P-Value**
T_max	is significant at 0.05	0.17C°	0.04315
Te_max	not significant at 0.05	0.19C°	0.13575
T_min	is significant at 0.05	0.25C°	0
Te_min	is significant at 0.05	0.49C°	0.00106

FALL



Fall-Sept, Oct, Nov	Significance	Trend	P-Value
T_max	not significant at 0.05	0.04C°	0.53281
Te_max	not significant at 0.05	0.09C°	0.47622
T_min	is significant at 0.05	0.16C°	0.00162
Te_min	is significant at 0.05	0.22C°	0.03582

SUMMER 1973-2014



Summer-June, July,August	Significance	Trend	P-Value
T_max	is significant at 0.05	0.46	0.00323
Te_max	not significant at 0.05	0.07	0.81953
T_min	is significant at 0.05	0.47	0.00003
Te_min	is significant at 0.05	0.87	0.00576

Two Tailed T-Tests: Station moves, instrument changes, DTS1 installation

Raleigh/Durham AP	Dew Point			1964	Estimated instrument change	
T-Test	**1960-1963**	**1965-1968**				
	P-value	**CI-Lower**	**CI-Upper**	**T-statistic**	**Degrees of Freedom**	**Standard Deviation**
Tmax	0.8046	-0.8252	0.6419	-0.2481	94	1.8099
Tdmax	0.3169	-0.3852	1.1769	1.0062	94	1.92710
Tmin	0.1854	-1.0628	0.2086	-1.3339	94	1.5685
Tdmin	0.1527	-1.4808	0.235	-1.4416	94	2.1168

Raleigh/Durham AP	Dew Point			1985	Estimated instrument change	
T-Test	**1981-1984**	**1986-1989**				
	P-value	**CI-Lower**	**CI-Upper**	**T-statistic**	**Degrees of Freedom**	**Standard Deviation**
Tmax	0.3657	-0.9752	0.3627	-0.909	94	1.6505
Tdmax	0.4698	-1.0818	0.5026	-0.7258	94	1.9547
Tmin	0.4438	-0.9328	0.412	-0.769	94	1.659
Tdmin	0.4891	-1.1978	0.577	-0.6945	94	2.1896

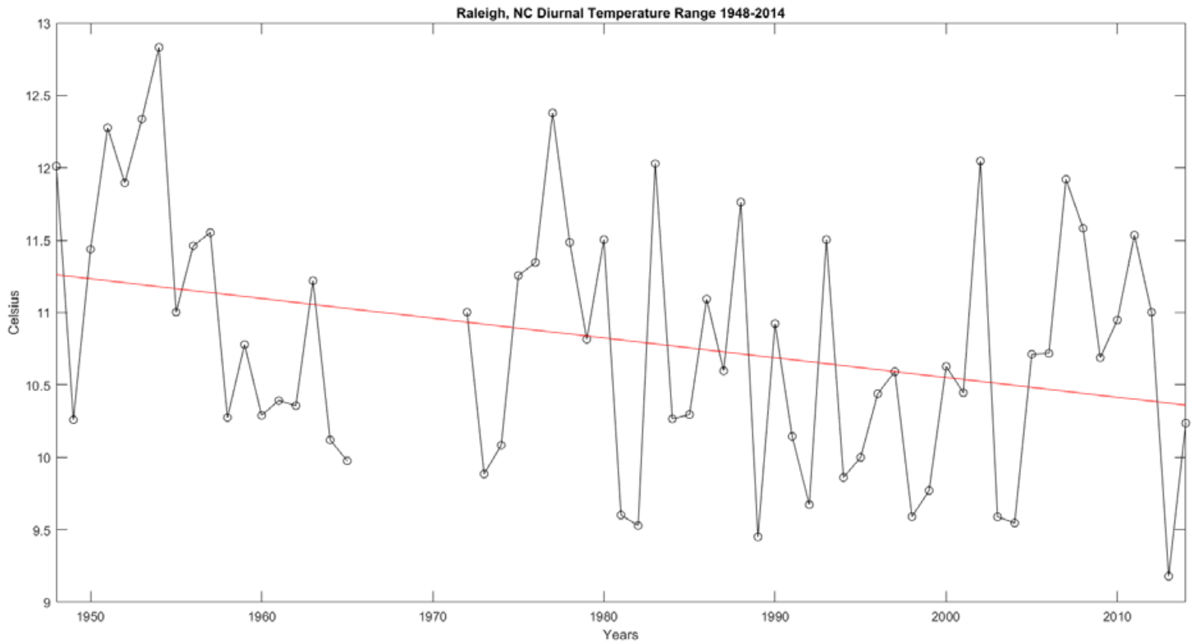
Raleigh/Durham AP	Dew Point			1991	instrument change from unknown to Hygrothermometer	
T-Test	**1987-1990**	**1992-1995**				
	P-value	**CI-Lower**	**CI-Upper**	**T-statistic**	**Degrees of Freedom**	**Standard Deviation**
Tmax	0.5087	-0.4692	0.9404	0.6633	94	1.7386
Tdmax	0.4284	-1.0198	0.4365	-0.7953	94	1.79650
Tmin	0.636	-0.7773	0.4773	-0.4773	94	1.5478
Tdmin	0.4523	-1.0741	0.4824	-0.7547	94	1.9203

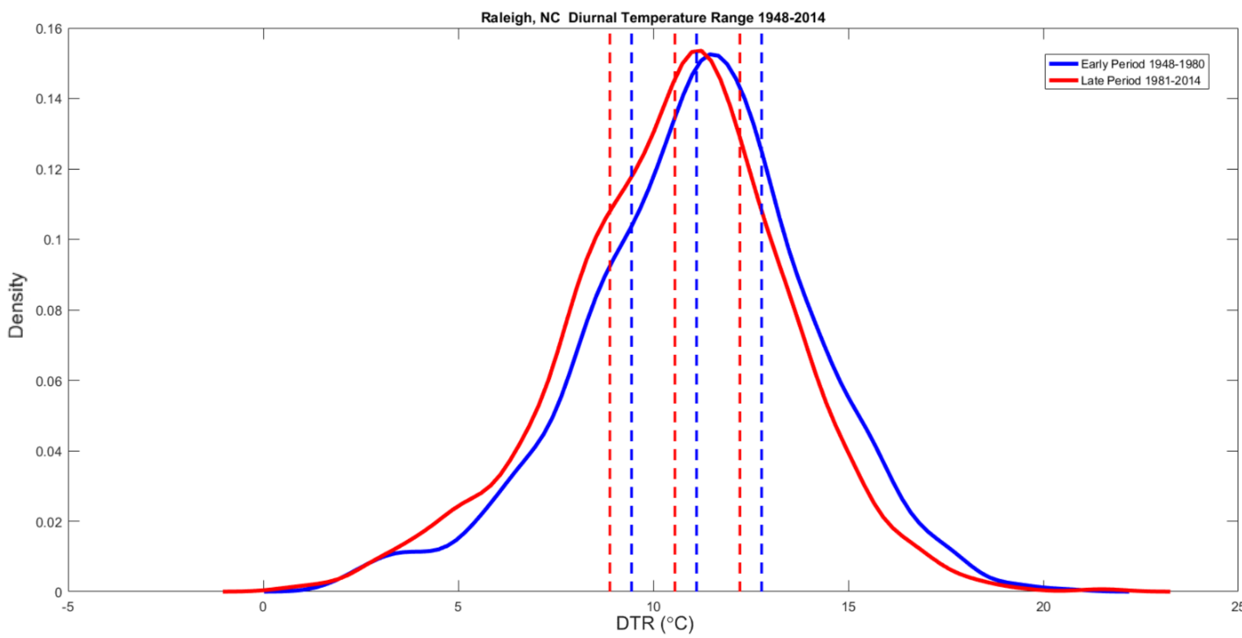
Raleigh/Durham AP	**Dew Point**			**1995**	**Estimated instrument change**	
T-Test	**1991-1994**	**1996-1999**				
	P-value	**CI-Lower**	**CI-Upper**	**T-statistic**	**Degrees of Freedom**	**Standard Deviation**
Tmax	0.5921	-0.4966	0.8651	0.5378	88	1.6215
Tdmax	0.8379	-0.6073	0.7472	0.2052	88	1.61290
Tmin	0.501	-0.4074	0.827	0.6756	88	1.4699
Tdmin	0.2965	-1.2157	0.3751	-1.0501	88	1.8942

Raleigh/Durham AP	**Dew Point**			**1996**	**Station move (#3 under location data). Visible on map.**	
T-Test	**1992-1995**	**1997-2000**				
	P-value	**CI-Lower**	**CI-Upper**	**T-statistic**	**Degrees of Freedom**	**Standard Deviation**
Tmax	0.7788	-0.8742	0.6572	-0.2818	83	1.7598
Tdmax	0.4763	-0.5036	1.0695	0.7155	83	1.80760
Tmin	0.5825	-0.8363	0.473	-0.552	83	1.5045
Tdmin	0.273	-1.356	0.3882	-1.1036	83	2.0043

Raleigh/Durham AP	**Dew Point**			**2004**	**DTS1 Installation 06/03/2004**	
T-Test	**1997-2000**	**2002-2005**				
	P-value	**CI-Lower**	**CI-Upper**	**T-statistic**	**Degrees of Freedom**	**Standard Deviation**
Tmax	1.13E-04	-2.4297	-0.8296	-4.0507	84	1.8528
Tdmax	0.547	-1.11	0.5924	-0.6047	84	1.9712
Tmin	0.7083	-0.5236	-0.7674	0.3755	84	1.4949
Tdmin	0.0046	0.4095	2.1696	2.914	84	2.0381

Raleigh/Durham AP	Dew Point			2009	Station move (#2 under location data). Visible on map.	
T-Test	**2005-2008**	**2010-2013**				
	P-value	**CI-Lower**	**CI-Upper**	**T-statistic**	**Degrees of Freedom**	**Standard Deviation**
Tmax	0.4119	-0.4756	1.1506	0.8242	94	2.0061
Tdmax	0.8236	-0.7227	0.9061	0.2235	94	2.00940
Tmin	0.5262	-0.8758	0.4508	-0.6361	94	1.6365
Tdmin	0.2512	-1.3429	0.3554	-1.1545	94	2.0951


Raleigh, NC Diurnal Temperature Range 1948-2014
Celsius
Years
13
12.5
12
11.5
11
10.5
10
9.5
9
1950
1960
1970
1980
1990
2000
2010


Raleigh, NC Diurnal Temperature Range 1948-2014
Early Period 1948-1980
Late Period 1981-2014
Density
DTR (°C)
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-5
0
5
10
15
20
25

APPENDIX R

Miami

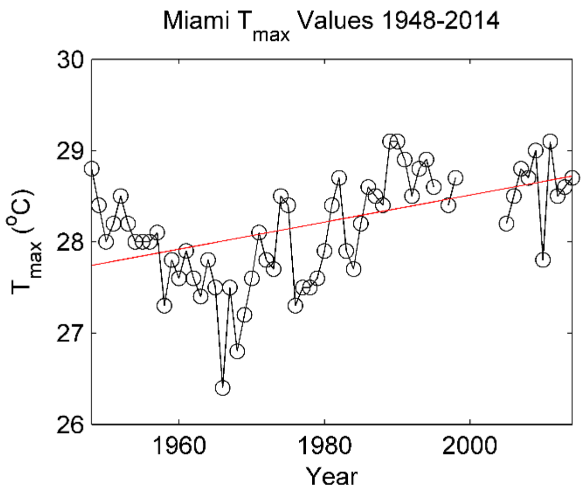
The station at Miami International Airport was moved approximately six times, the instrumentation was changed at least four times. One of the first moves estimated in the record happens in 1957, it is noted by a difference in latitude and longitude, a t-test shows that this change may have affected T_{max}. Estimated instrument changes in 1964 show a possible alteration of T_{max} and $T_{d\ min}$. A confirmed station move took it 2.2 miles northwest in 1977, t-tests for this change show that both T_{min} and $T_{d\ min}$ may have been affected. An estimated instrument change in 1985 may have altered T_{max}, the same result for the exact same change is present in 1995 t-tests. A station move and in instrument change produced results in a t-test that show that T_{min} and $T_{d\ min}$ have possible inhomogeneities. The installation of the Vaisala DTS1 occurred in 2005, t-tests indicate that T_{max} and $T_{d\ min}$ may be affected by this change. Finally, in 2010, the station was moved one last time, this is a change only reflected in latitude and longitude rather than an entry in the metadata, $T_{d\ max}$ and $T_{d\ min}$ show possible discontinuities. Summer trend analysis shows significant increases across all four variables T_{max} (0.14C°), T_{min} (0.38C°), $T_{E\ max}$ (0.28C°) and $T_{E\ min}$ (0.50C°). All four variables also showed significant increases in for the fall season. Winter also saw increases in all variables except T_{max}. Annual trend analysis also shows increases in all four variables: T_{max} (0.15C°), T_{min} (0.34C°), $T_{E\ max}$ (0.28C°) and $T_{E\ min}$ (0.45C°). Trend analysis for the shorter series which begins in 1973 shows significant increases in T_{max} (0.25 C°) and T_{min} (0.25 C°).

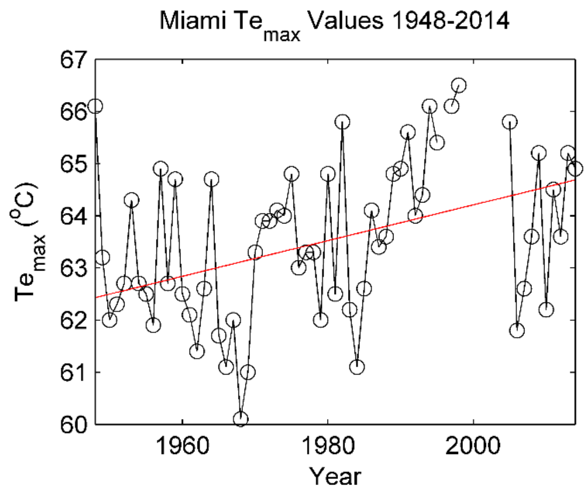
Miami International Airport	**WBAN# 12839**		**Latitude: 25.7905**
			Longitude: 80.3163
Year	**Site (m)**	**Instruments**	**Comments**
1948-1980	7 (1948-1957)	unknown	unknown
1980-1995	4 (1957-1977)	unknown	Daily, obs times 2400
1995-2002	3.7 (1977-1995)	Hygrothermometer	Daily, obs times 2400. Instrument change from unknown to Hygrothermometer. Receiver NCEI, Reporting Method: FOSJ-SFC
2002-2004	10.7 (1995-2002)	ATEMP: ASOS Hygrothermometer	Daily, obs times 2400, Receiver NCEI, Reporting Method: FOSJ-SFC
2004-Present	8.8 (2002-Present)	ATEMP: ASOS Hygrothermometer	Reporting method: ADP-ASOS-Era Data Downloaded to NCDC. No recorded change in observation times
Station Moves			
Latitude	**Longitude**	**Initial**	**Final Date**
25.91667		6/1/1932	1/1/1957
	80.28333	6/1/1932	1/1/1957
25.8		1/1/1957	1/24/1995
	80.2667	1/1/1957	3/1/1977
	80.3	3/1/1977	1/24/1995
25.78333		1/24/1995	7/1/1996
	80.28333	1/24/1995	7/1/1996
25.82389		7/1/1996	1/8/2002
	80.29972	7/1/1996	1/8/2002
25.79056		1/8/2002	11/6/2010
	80.31639	1/8/2002	11/6/2010
25.7905		11/6/2010	Present
	80.3163	11/6/2010	Present
T-test 1957	**Station move represented in Lat. Long.**		
T-test 1964	**estimated instrument change**		
T-test 1977	**Station move 2.2 miles NW (03/01/1977)**		
T-test 1985	**estimated instrument change**		
T-test 1995	**Station move 1mile South (1/24/1995) and instrument change from unknown to Hygrothermometer.**		
T-Test 1996	**Station move slight changes in Lat. Long. Visible in map**		
T-Test 2002	**Station move slight changes in Lat. Long. Visible in map. Instrument change from Hygrometer to ATEMP.**		
T-Test 2005	**10/13/2005 DTS1 Installation**		
T-Test 2010	**Station move Lat. Long. Change, visible in map**		

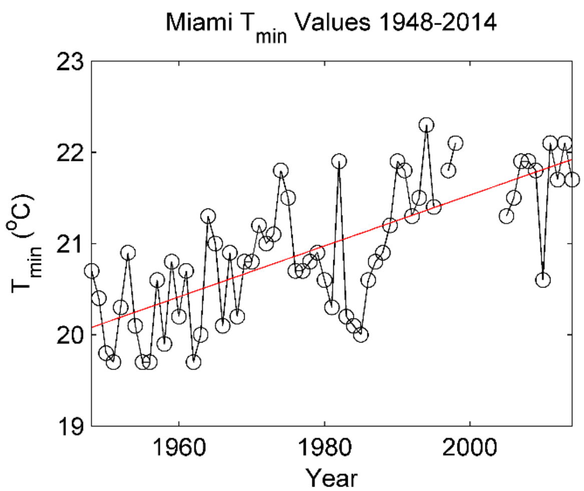
Miami International AP	Median of Pairwise Slopes95% confidence	Degrees Celsius per decade	
Seasonal Trend			
Winter-Dec,Jan,Feb	**Significance**	**Trend**	**P-value**
T_max	not significant at 0.05	0.14C°	0.05633
Te_max	is significant at 0.05	0.44C°	0.01824
T_min	is significant at 0.05	0.35C°	0.00208
Te_min	is significant at 0.05	0.69C°	0.01545
Spring-Mar,Apr,May			
T_max	not significant at 0.05	0.08C°	0.06417
Te_max	not significant at 0.05	0.00C°	0.94392
T_min	is significant at 0.05	0.23C°	0.00059
Te_min	not significant at 0.05	0.25C°	0.27831
Summer-June, July,August			
T_max	is significant at 0.05	0.14C°	0.00029
Te_max	is significant at 0.05	0.38C°	0.00009
T_min	is significant at 0.05	0.28C°	0
Te_min	is significant at 0.05	0.50C°	0
Fall-Sept, Oct, Nov			
T_max	is significant at 0.05	0.16C°	0.0001
Te_max	is significant at 0.05	0.35C°	0.03833
T_min	is significant at 0.05	0.30C°	0
Te_min	is significant at 0.05	0.53C°	0.00113

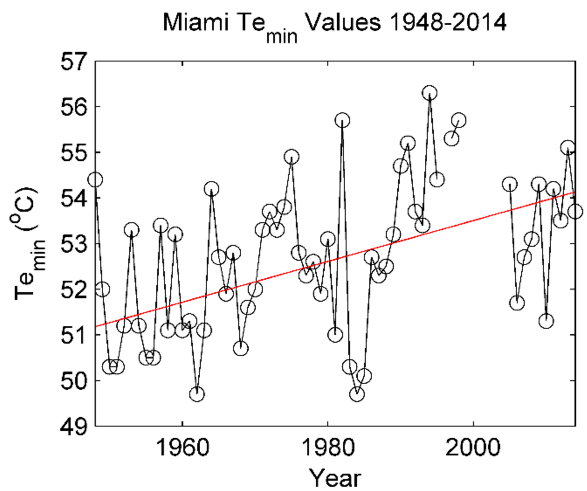
Miami International AP	95% confidence	Degrees Celsius per decade	
Annual Trend	**Significance**	**Trend**	**P-value**
T_max	is significant at 0.05	0.15C°	0.00001
Te_max	is significant at 0.05	0.34C°	0.00218
T_min	is significant at 0.05	0.28C°	0
Te_min	is significant at 0.05	0.45C°	0.00017

ANNUAL TREND





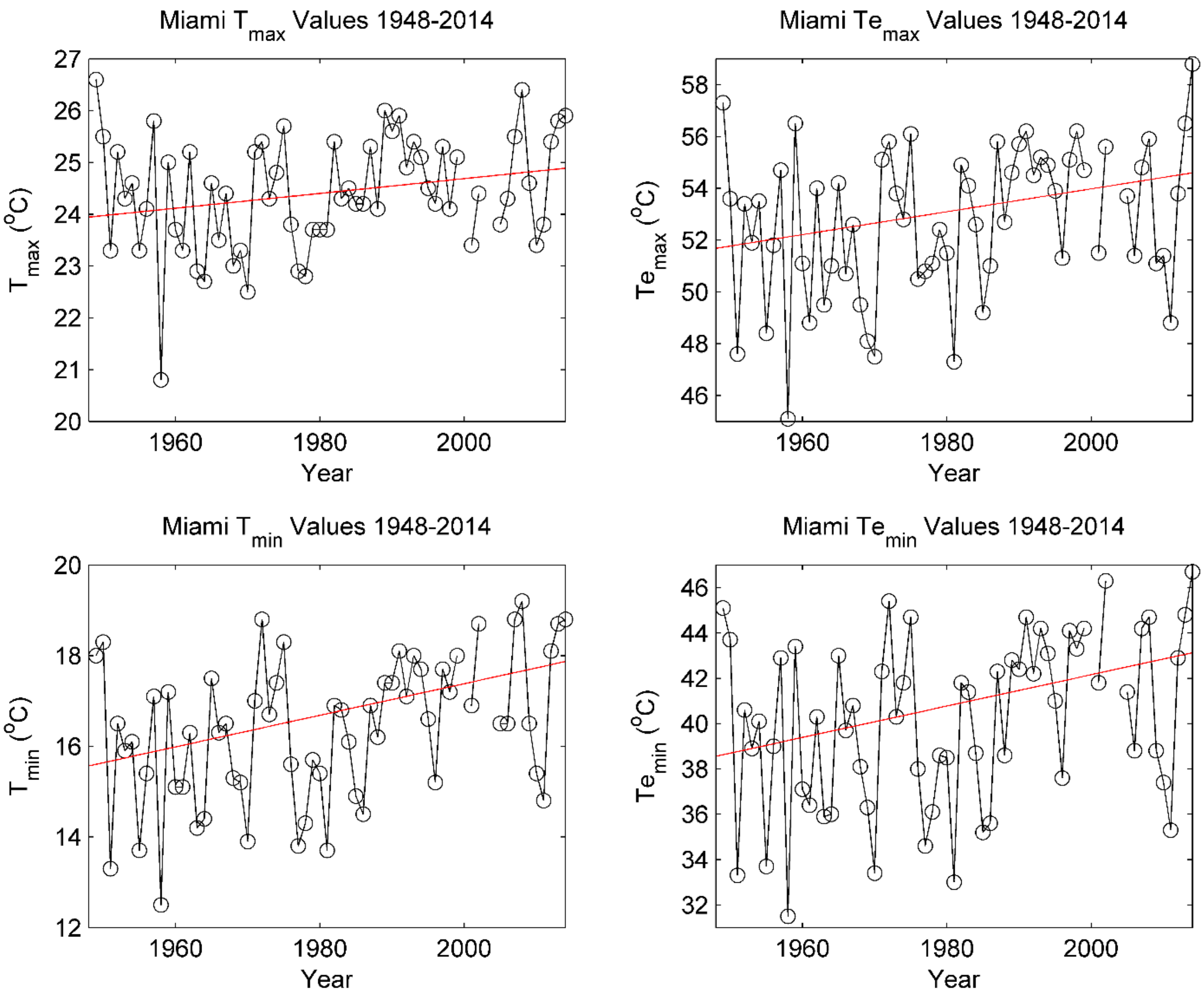




Miami	**95% confidence**	**Degrees Celsius per decade**	
Annual Trend	**Significance**	**Trend**	**P-value**
T_max	is significant at 0.05	0.15C°	0.00001
Te_max	is significant at 0.05	0.34C°	0.00218
T_min	is significant at 0.05	0.28C°	0
Te_min	is significant at 0.05	0.45C°	0.00017

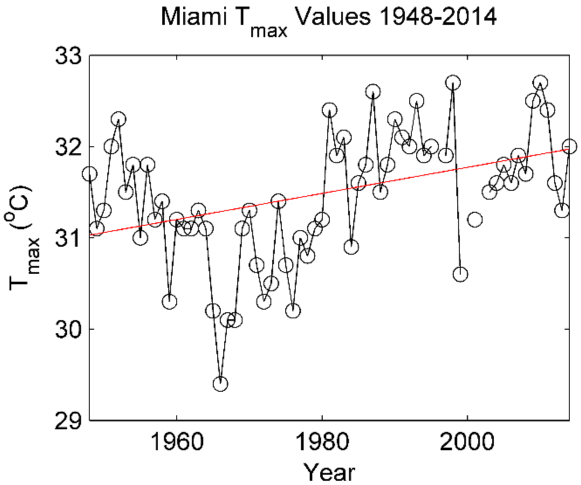
SEASONAL TRENDS

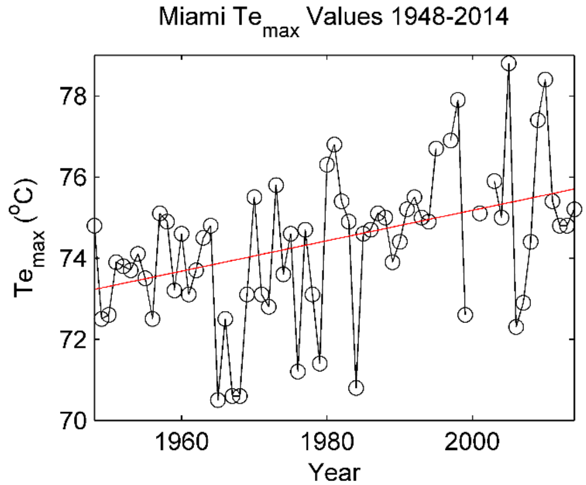
WINTER

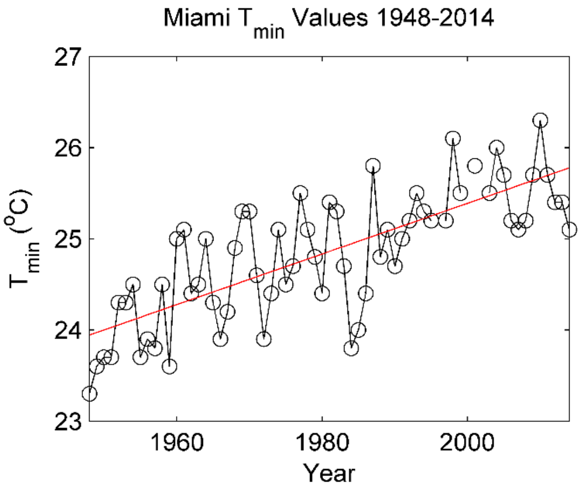


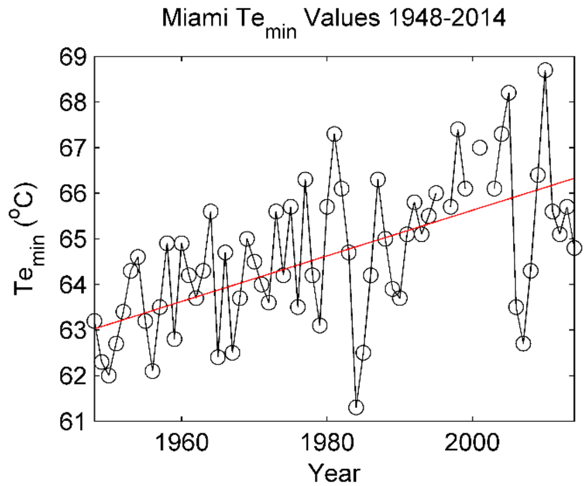
Winter-Dec,Jan,Feb	Significance	Trend	P-value
T_max	not significant at 0.05	0.14C°	0.05633
Te_max	is significant at 0.05	0.44C°	0.01824
T_min	is significant at 0.05	0.35C°	0.00208
Te_min	is significant at 0.05	0.69C°	0.01545

SPRING



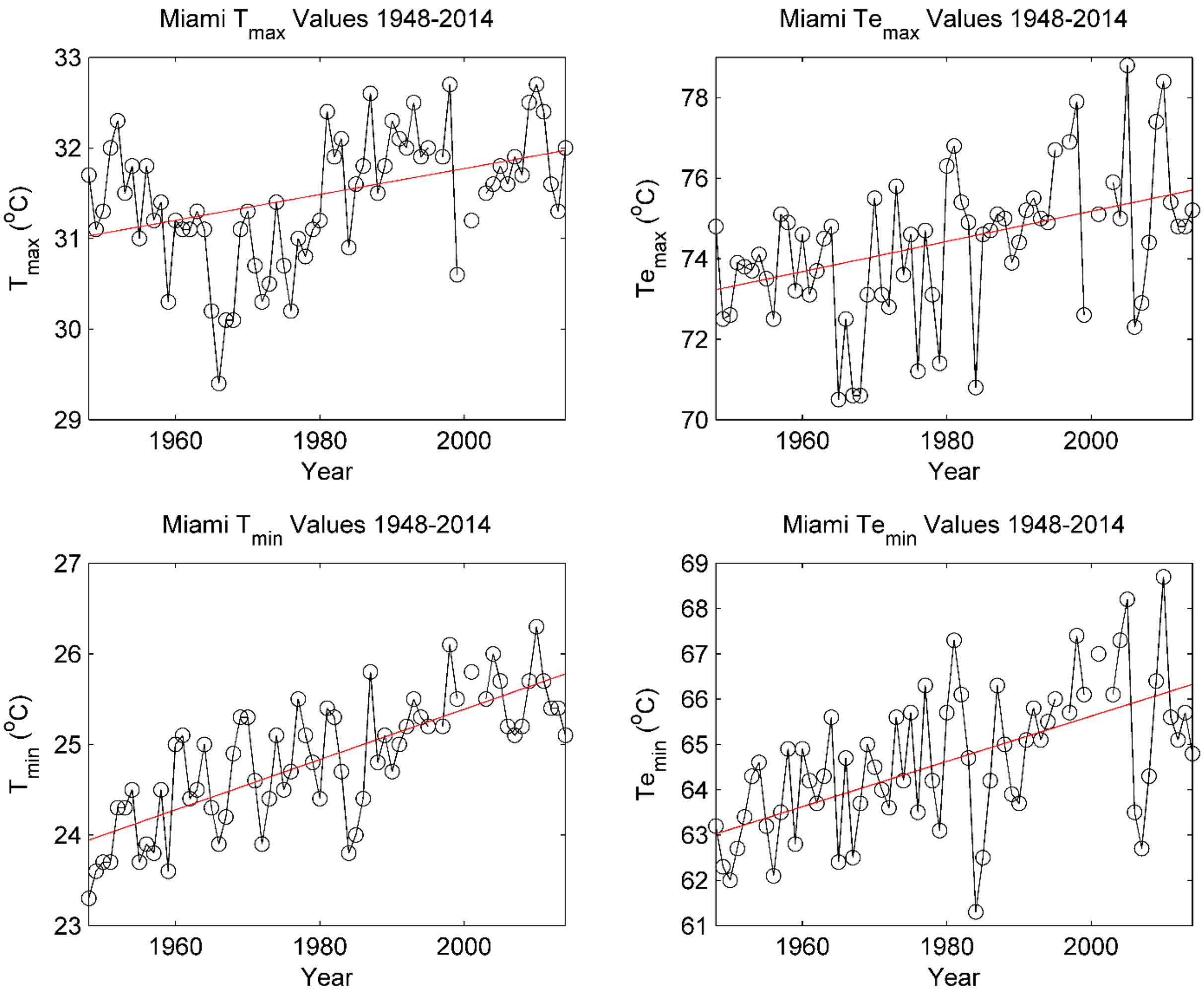






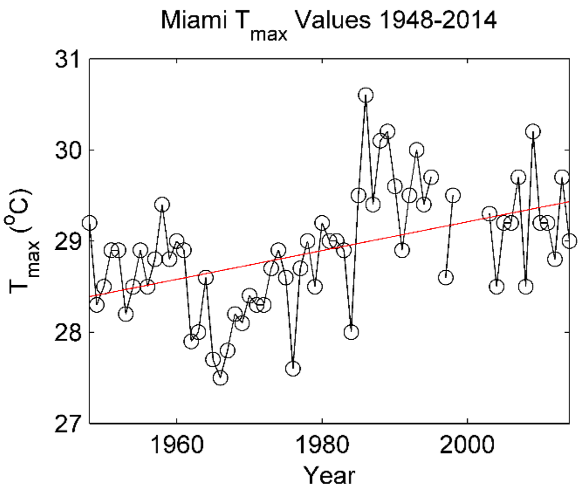
Spring-Mar,Apr,May	**Significance**	**Trend**	**P-Value**
T_max	not significant at 0.05	0.08C°	0.06417
Te_max	not significant at 0.05	0.00C°	0.94392
T_min	is significant at 0.05	0.23C°	0.00059
Te_min	not significant at 0.05	0.25C°	0.27831

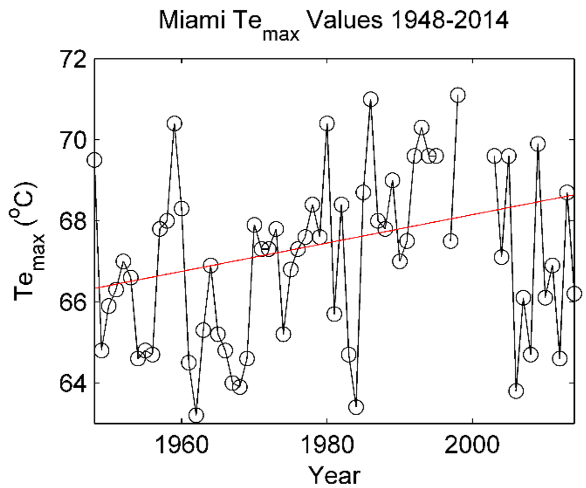
SUMMER

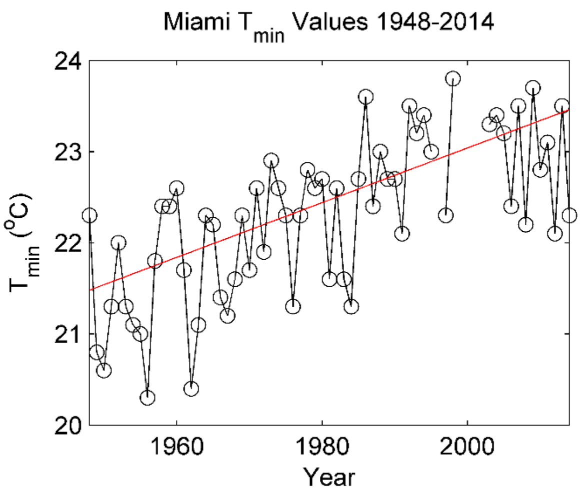


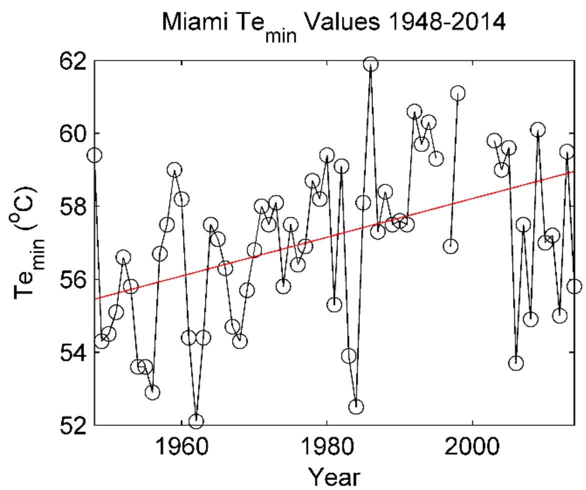
Summer-June, July,August	Significance	Trend	P-Value
T_max	is significant at 0.05	0.14C°	0.00029
Te_max	is significant at 0.05	0.38C°	0.00009
T_min	is significant at 0.05	0.28C°	0
Te_min	is significant at 0.05	0.50C°	0

FALL



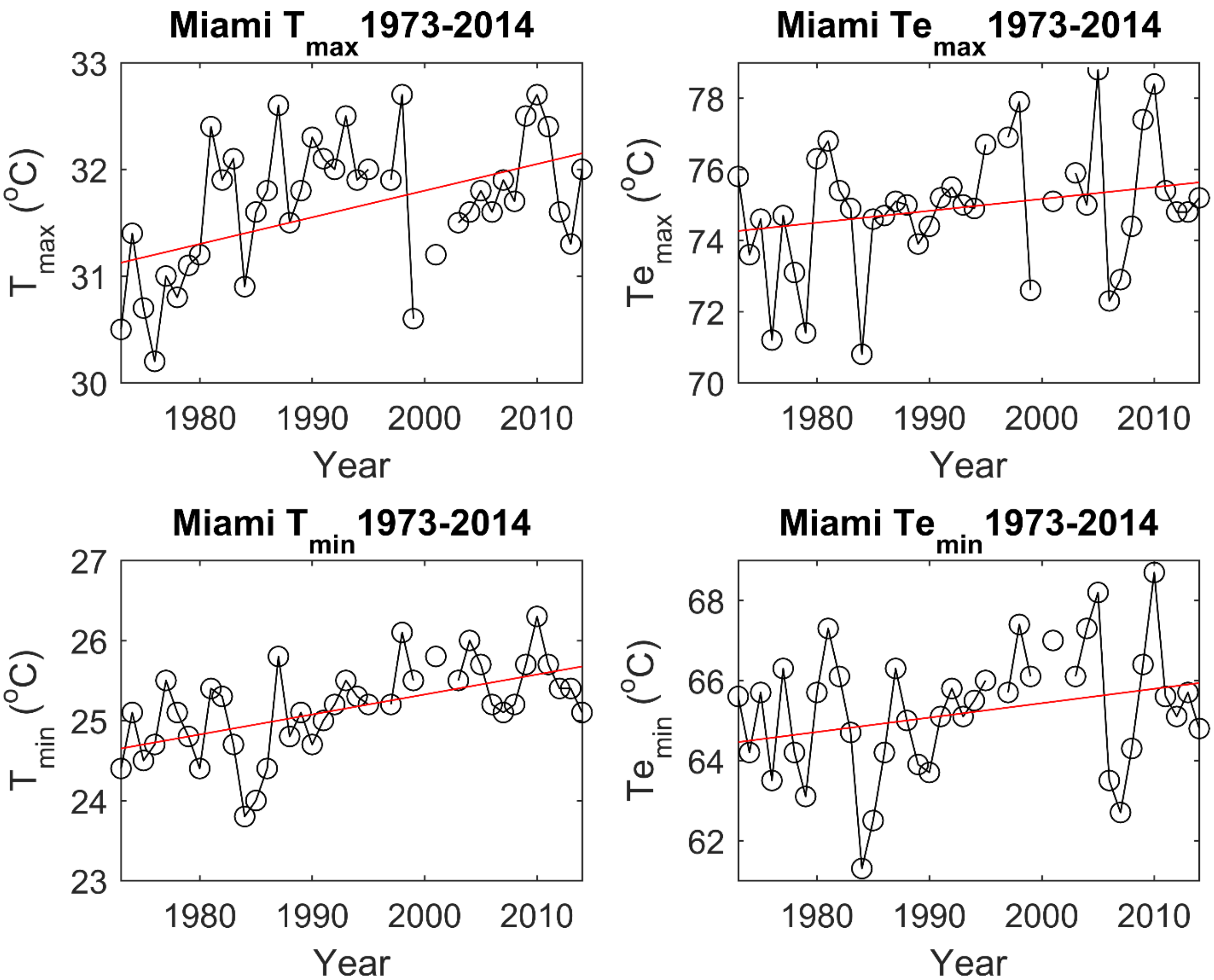






Fall-Sept, Oct, Nov	Significance	Trend	P-Value
T_max	is significant at 0.05	0.16C°	0.0001
Te_max	is significant at 0.05	0.35C°	0.03833
T_min	is significant at 0.05	0.30C°	0
Te_min	is significant at 0.05	0.53C°	0.00113

SUMMER 1973-2014



Summer-June, July,August	**Significance**	**Trend**	**P-Value**
T_max	is significant at 0.05	0.25	0.00855
Te_max	not significant at 0.05	0.33	0.08914
T_min	is significant at 0.05	0.25	0.00014
Te_min	not significant at 0.05	0.36	0.13284

Two Tailed T-Tests: Station moves, instrument changes, DTS1 installation

Miami Intl' AP	Dew Point			1957	Station move represented in Lat. Long.	
T-Test	1953-1956	1958-1961				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.0221	0.0673	0.0673	2.3272	94	0.9648
Tdmax	0.9221	-0.4413	0.4872	0.098	94	1.1454
Tmin	0.3203	-0.8091	0.2674	-0.9991	94	1.328
Tdmin	0.9696	-0.6625	0.6375	-0.0382	94	1.6038

Miami Int'l AP	Dew Point			1964	Estimated instrument change	
T-Test	1960-1963	1965-1968				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.0042	0.177	0.9188	2.9334	94	0.9151
Tdmax	0.2081	-0.1463	0.663	1.2676	94	0.99840
Tmin	0.0757	-0.9212	0.0462	-1.7959	94	1.1934
Tdmin	0.0018	-1.4551	-0.3449	-3.2193	94	1.3696

Miami Intl' AP	Dew Point			1977	Station move 2.2 miles NW (03/01/1977)	
T-Test	1973-1976	1978-1981				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.4811	-0.2711	0.5711	0.7073	94	1.0389
Tdmax	0.2089	-0.1803	0.8136	1.2652	94	1.2262
Tmin	0.0338	0.0513	1.2612	2.1538	94	1.4927
Tdmin	0.0288	0.0833	1.4958	2.2198	94	1.7426

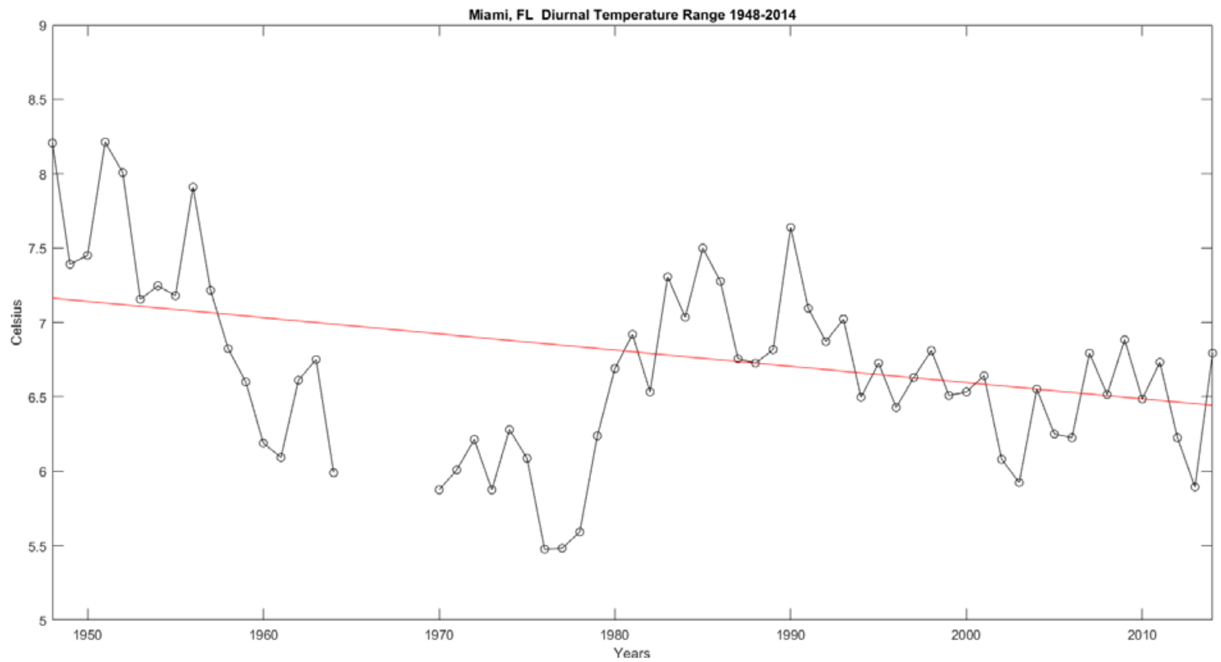
Miami Int'l AP	Dew Point			1985	Estimated instrument change	
T-Test	1981-1984	1986-1989				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.0161	-0.8861	-0.0931	-2.4516	94	0.9783
Tdmax	0.2218	-0.7788	0.183	-1.23	94	1.1866
Tmin	0.4218	-0.8581	0.3622	-0.8068	94	1.5055
Tdmin	0.2641	-1.1358	0.315	-1.1234	94	1.7898

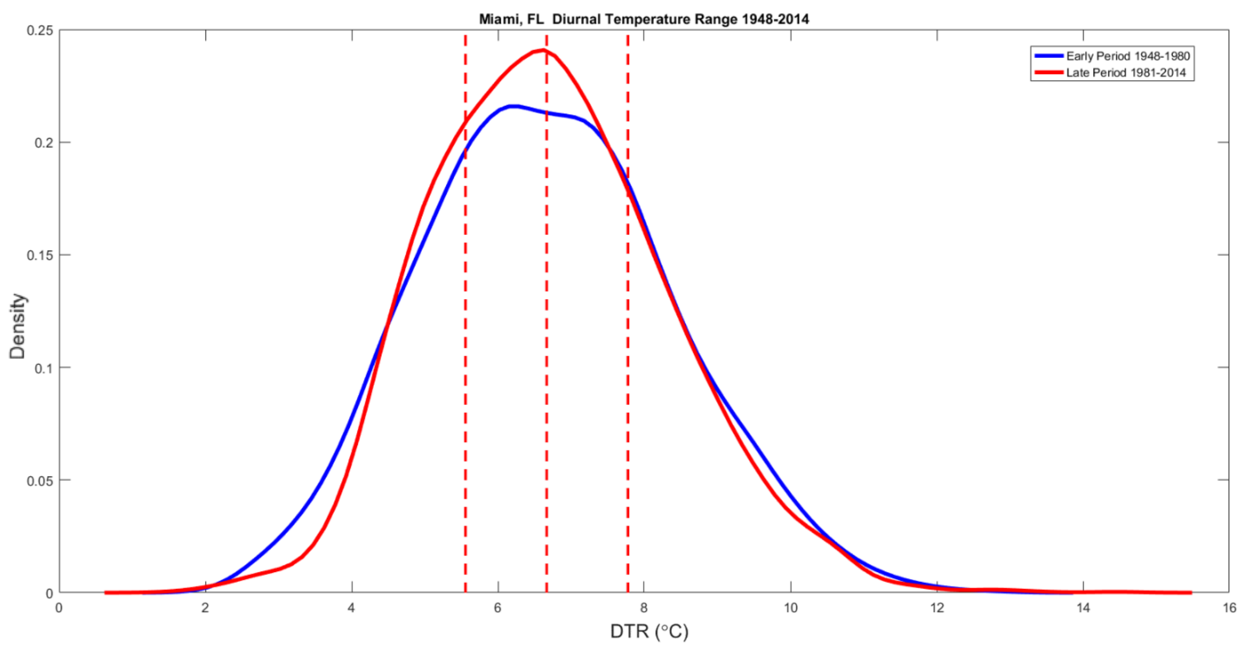
Miami Int'l AP	Dew Point			1995	Station move 1 mile South (1/24/1995) and instrument change from unknown to Hygrothermometer.	
T-Test	1991-1994	1996-1999				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.0042	0.1602	0.8316	2.935	90	0.8096
Tdmax	0.3401	-0.2222	0.637	0.9591	90	1.03610
Tmin	0.8167	-0.416	0.5262	0.2324	90	1.1361
Tdmin	0.8735	-0.5781	0.6792	0.1596	90	1.5161

Miami Int'l AP	Dew Point			2002	Station move sligth changes in Lat. Long. Visible in map. Instrument change from Hygrometer to ATEMP.	
T-Test	1998-2001	2003-2006				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	0.8231	-0.4641	0.3701	-0.2244	78	0.9322
Tdmax	0.5542	-0.3494	0.6466	0.594	78	1.1131
Tmin	0.0379	0.0314	1.0632	2.1119	78	1.1532
Tdmin	0.0018	0.3803	1.6044	3.2278	78	1.368

Miami Int'l AP	Dew Point			2005	10/13/2005 DTS1 Installation	
T-Test	2001-2004	2006-2009				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	4.18E-05	-1.2204	-0.4532	-4.3434	78	0.8442
Tdmax	0.0713	-0.0424	0.9981	1.8285	78	1.1451
Tmin	0.664	-0.459	0.7165	0.4361	78	1.2935
Tdmin	3.74E-05	0.8002	2.1375	4.3734	78	1.4717

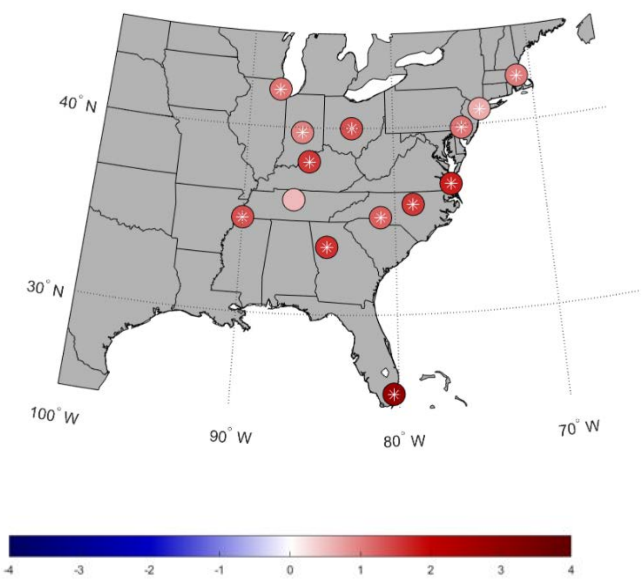
Miami Int'l AP	Dew Point			2010	Station move Lat. Long. Change, visible in map	
T-Test	2006-2009	2011-2014				
	P-value	CI-Lower	CI-Upper	T-statistic	Degrees of Freedom	Standard Deviation
Tmax	1	-0.321	0.321	2.75E-15	94	0.7921
Tdmax	0.0371	-0.9452	-0.0298	-2.1148	94	1.1293
Tmin	0.6822	-0.5956	0.3915	-0.4107	94	1.2178
Tdmin	0.0243	-1.3693	-0.0974	-2.2895	94	1.5692


Miami, FL Diurnal Temperature Range 1948-2014
Celsius
Years

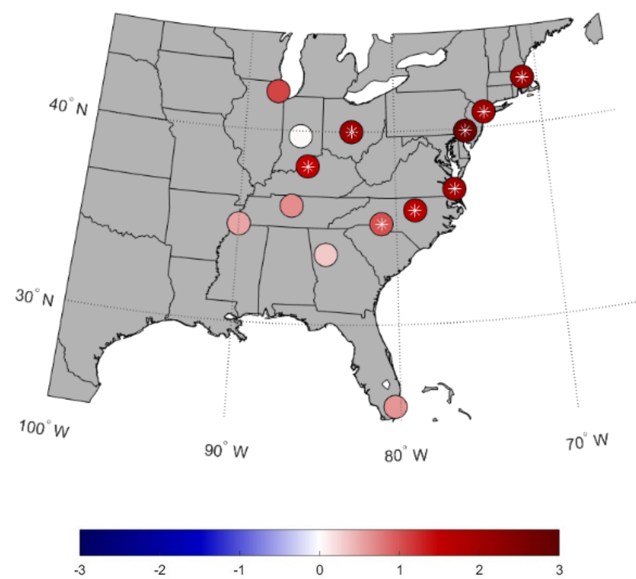

Miami, FL Diurnal Temperature Range 1948-2014
Density
DTR (°C)
Early Period 1948-1980
Late Period 1981-2014

APPENDIX S

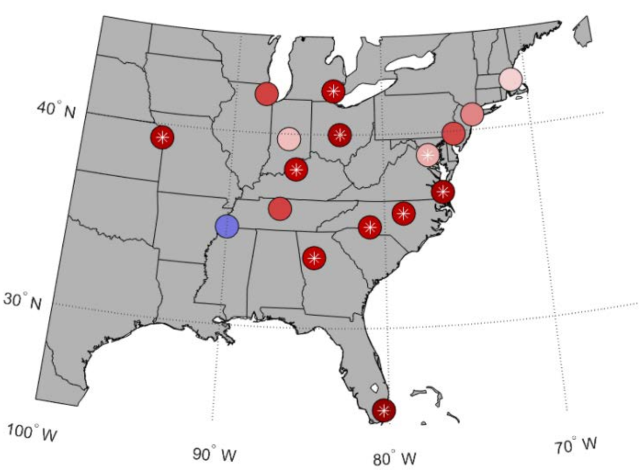
Linear Trend in $T_E$min HW Frequency 1948-2014 (days/decade)



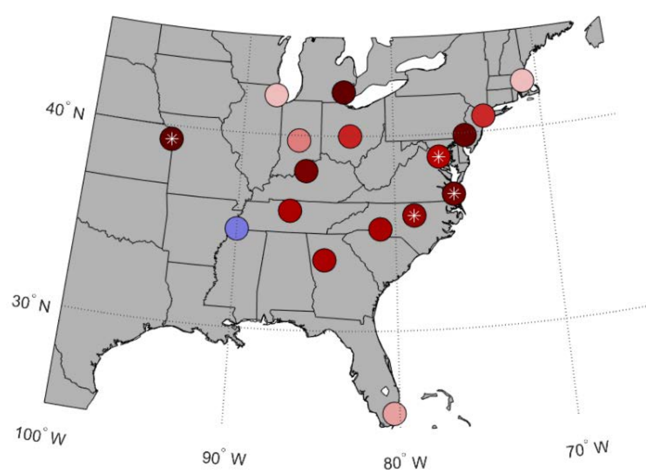
Linear Trend in $T_E$min HW Intensity 1948-2014 (^{o}C/decade)



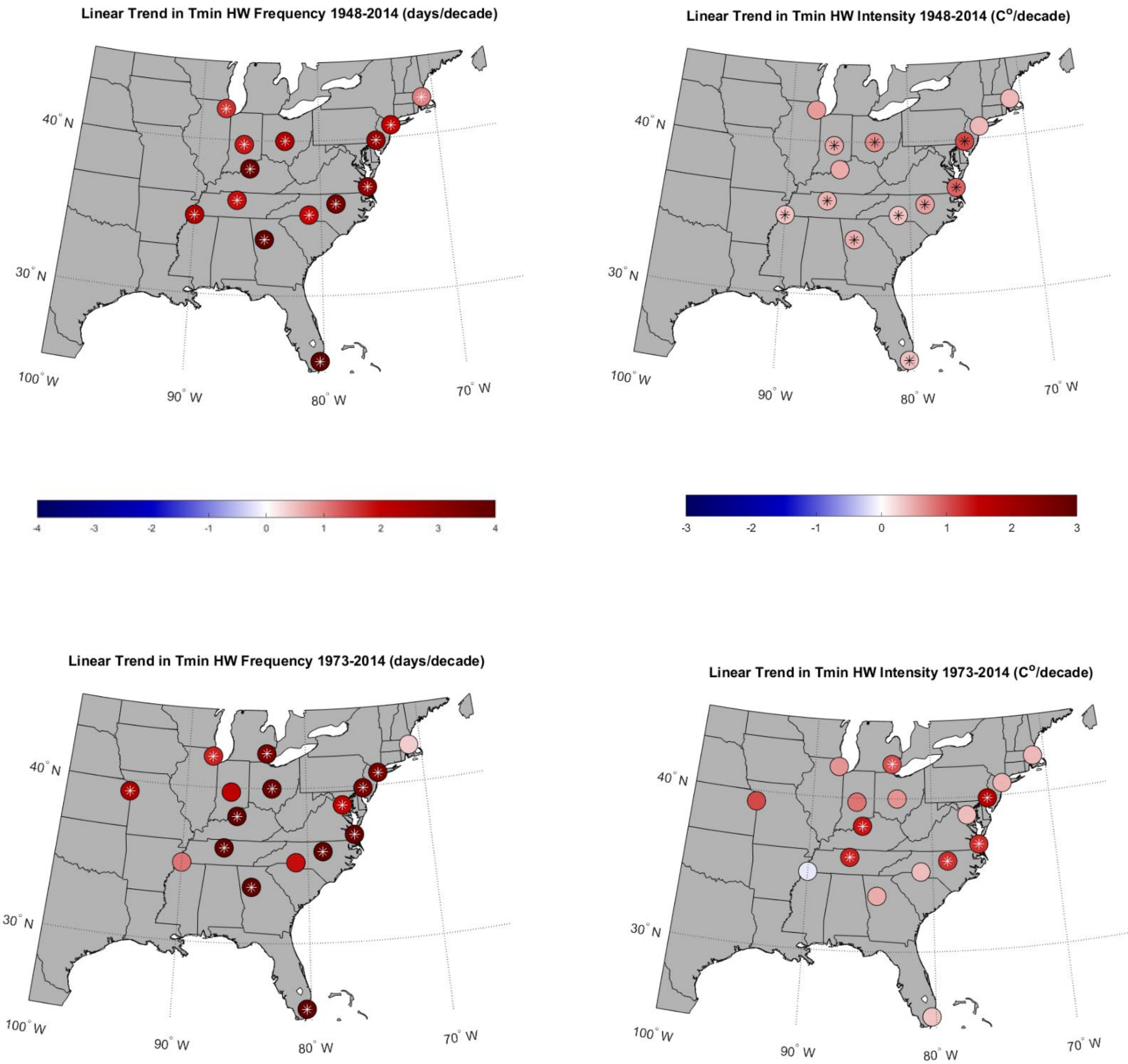
Linear Trend in $T_E$min HW Frequency 1973-2014 (days/decade)



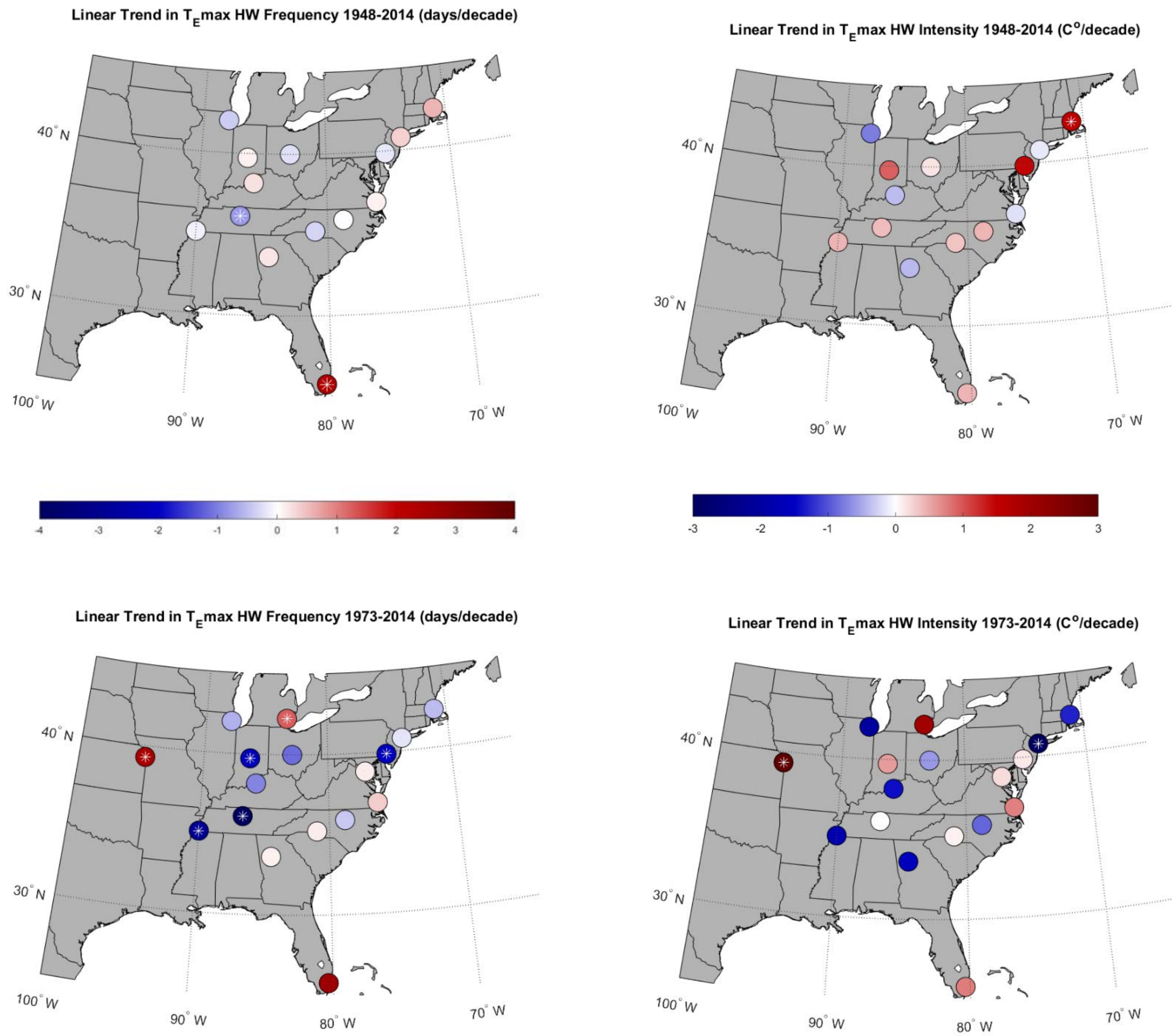
Linear Trend in $T_E$min HW Intensity 1973-2014 (C^{o}/decade)



APPENDIX T


Linear Trend in Tmin HW Frequency 1948-2014 (days/decade)
Linear Trend in Tmin HW Intensity 1948-2014 (C°/decade)
40° N
30° N
100° W
90° W
80° W
70° W
-4 -3 -2 -1 0 1 2 3 4
-3 -2 -1 0 1 2 3
Linear Trend in Tmin HW Frequency 1973-2014 (days/decade)
Linear Trend in Tmin HW Intensity 1973-2014 (C°/decade)

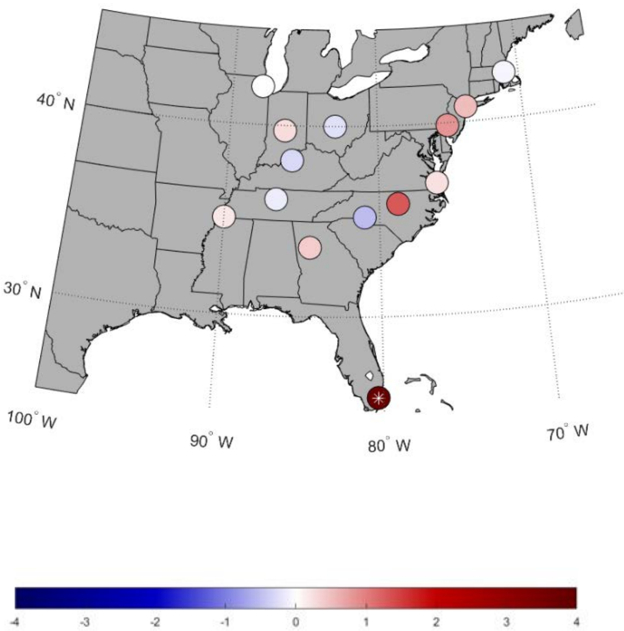
APPENDIX U



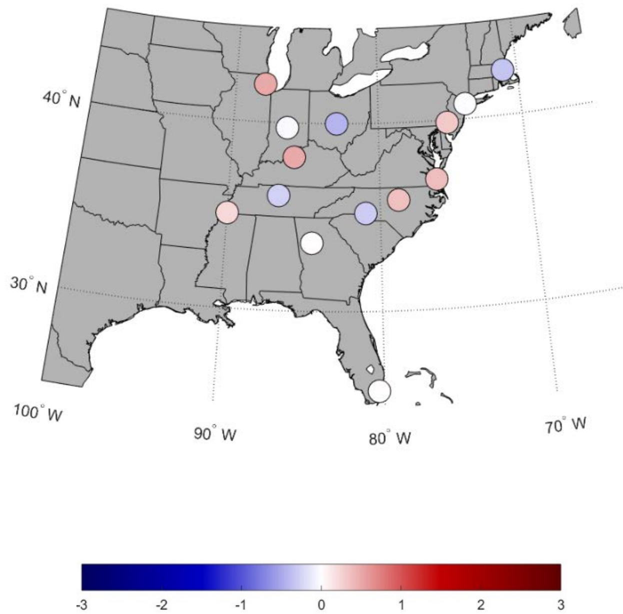
Linear Trend in T_E max HW Frequency 1948-2014 (days/decade)
Linear Trend in T_E max HW Intensity 1948-2014 (C°/decade)
Linear Trend in T_E max HW Frequency 1973-2014 (days/decade)
Linear Trend in T_E max HW Intensity 1973-2014 (C°/decade)
40° N
30° N
100° W
90° W
80° W
70° W
-4 -3 -2 -1 0 1 2 3 4
-3 -2 -1 0 1 2 3

APPENDIX V

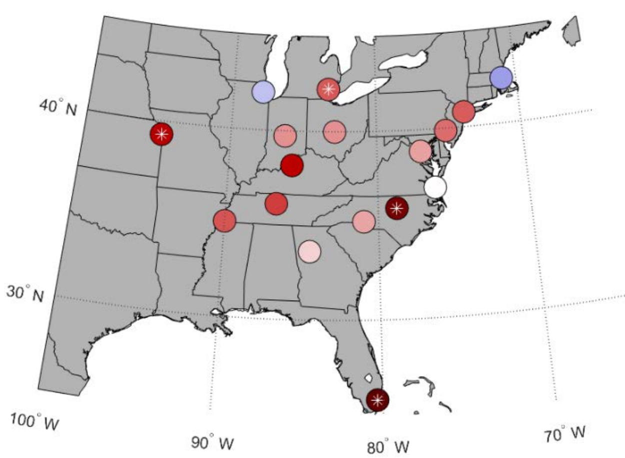
Linear Trend in Tmax HW Frequency 1948-2014 (days/decade)



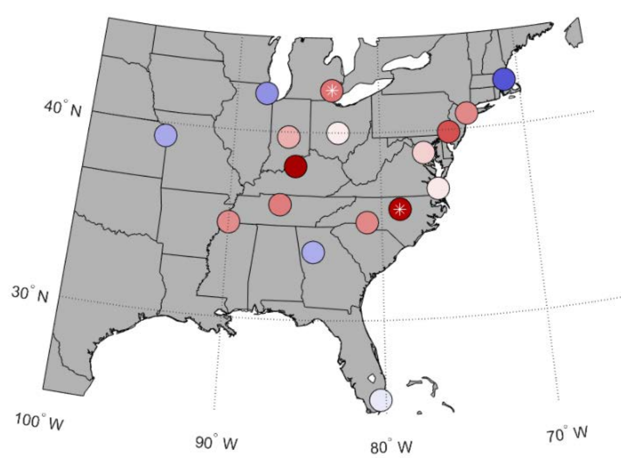
Linear Trend in Tmax HW Intensity 1948-2014 (C°/decade)



Linear Trend in Tmax HW Frequency 1973-2014 (days/decade)



Linear Trend in Tmax HW Intensity 1973-2014 (C°/decade)



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Assessing Equivalent Temperature Trends in the Eastern United States

Major Professor: Justin T Schoof