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This project used climate and soil data to determine if significant relationships between soil type and air temperature trends in the North Carolina Piedmont area occurred during 1988 to 2017. In pursuit of that, this project examined the average maximum and minimum monthly temperatures of 26 weather stations and their annuals with near-complete records located across the Piedmont region. Temperature data from each station were grouped by season, (winter: December, January, February; spring: March, April, May; summer: June, July, August; fall: September, October, November) and annually. Trends for maximum and minimum temperatures during 1988–2017 were calculated (n= 260) using regression analyses. For the total analyses 110 (42%) observations were significant, of which, 74 (67%) were associated with minimum temperature trends, while 36 (33%) were associated with maximum temperature trends. Spring and fall seasons contained the largest number of significant observations.

Temperature trends were affected by soil separate conditions, as percentage sand found within the soil was associated with larger positive temperature trends. Sandier soils had a 65% chance of having a station that was significant versus nonsandy soils that only had a 35% chance. Finally, a difference-of- means test between significant slopes and non- significant slopes soils showed that percentage sand content was significant higher for those stations with significant temperature trends. These results suggest that soil texture content affects temperature trends and that sandier soils will experience

increasing temperature trends at higher rates than non-sandy soils within the same geographical area

INFLUENCE OF EDAPHIC CONDITIONS ON SEASONAL AND ANNUAL TEMPERATURE TRENDS IN THE NORTH CAROLINA PIEDMONT REGION: 1988-2017

by

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APPROVAL PAGE

This thesis written by JAMES RODERICK BLOUNT has been approved by the following committee of the Faculty of The Graduate School at The University of North Carolina at Greensboro.

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CHAPTER I

INTRODUCTION

Considerable variability in soil type—thus soil texture composition— can exist across small spatial scales (i.e., < 300 m) depending on topography with some locations (e.g., mountainous regions) characterized by dozens of soil textures (Crowther 1930; USGS 2018). Likewise, local-scale (i.e., the size of a small town such as Kernersville NC, 45.1 km^2) variability in atmospheric conditions also exist (NOAA, 2018). Weather forecasts of the Piedmont region will show various temperatures with any given localized area and while there are numerous possible factors, (i.e.; wind speed, elevation, proximity to water, bordering air masses, infrastructure, etc..) that would explain such a phenomenon, it is the focus of this study to determine if soil texture can effectively be considered a significantly influential factor as well. There are numerous factors that influence the state of the atmosphere including, time of day, climate, or moving parcels of air; but what about the actual soil conditions (Godefroid et al., 2006; Fields et al., 2012; Key et al., 2017)? Soils with higher sand content heat more rapidly than less sandy soil because sandier soils have lower water carrying capacities. Water has a high specific heat which means it takes more energy to the temperature of soils that has more water contained within them and air parcels that form over wetter soils will have more water vapor in them which affects heat rates (Weih & Karlsson, 2001; USGS, 2018). Thus, it is not surprising that the warmest temperatures in North Carolina are associated with sites with sandy soils (e.g., Fayetteville and Lafayette). While certain large amount of areas within a land mass can all experience the same climate, microclimatic factors that alter how that shared climate is portrayed (Harrison & Bairner, 1998) are well known and typically cited as causes for local variability. Elevation differences across a spatial plane can create unique microclimates on their own and shading can create microclimates that are relatively different from the immediate nearby locations (Harrison & Bairner, 1998; Boyles & Raman, 2003).

In the UK, Suggitt et al. (2011) wanted to show what impact habitat has on the development of microclimate with a focus on the variations of extreme temperature between the high and low readings with different environments. Their study looked at three textures of landscapes categorized based on vegetation differences (heartlands, plains and deciduous forests). The researchers examined temperature ranges out the three different habitats based on nine different locations within Skipwith Common in North Yorkshire. They found that due to variations in direct sunlight that significant differences can be found between shaded woodlands and open plain grass and heath lands.

For example, they (Suggitt et al., 2011) found that due to the shading provided by trees that the woodlands showed lower maximum temperature averages than their counterparts due to lower direct solar radiation. They wanted to look at the “fine-scale microclimates”, which they defined as less than 1000 km2. They believed that such a narrowed land area of focus would consider the nature of the habitat as a factor in determining what impacts the temperature variation seen in a microclimate. This was not done before scholarly due to the inability of a low number of climate stations to accurately record temperatures of small (i.e. < 100km2) areas of land within a wide range of land, such as the North Carolina Piedmont. One method Suggitt et al. (2011) used to get a sense of the relevant literature surrounding “fine-scale microclimates” was conducting web searches on academic databases where they found the number of related articles to be insufficient to determine the scientific value of the local microclimates. A similar experiment was done for this study on soil textures using the JSTOR database. I found the number of articles related to “microclimates” and “temperature variation” was 2,081 with most of those articles focusing on either larger-scale microclimate (>1000 km^2) or discussing the vegetation of a habitat. When the additional search factor of “soil texture” was included the search dropped to 171 with only 38 of those results taking place since 2011. Even among the 38 only two used soil texture as a possibility of influencing the nature of microclimates as the other 36 focused on vegetation, soil respiration, weather and regional ecology. (Suggitt et al., 2011). Still no article found a direct study testing the correlation of soil texture and temperature variation within a homogeneous landscape. Here I wish to address this void in research by addressing the potential role of soil texture in influencing temperature trends.

Daily air temperature measurements at most stations record lows, highs and averages. Since the 1980s, one common climatic phenomenon that is seen nearly worldwide is a warming trend (Wanju Shi et al., 2017; Chang-qing Chen et al., 2018) with nights warming faster than days (Chang-qing Chen et al., 2018). More locally, a study (Patterson 2014) of the North Carolina climate divisions from 1895–2013 found that overall North Carolina is experiencing a warming trend similar to the other parts of the mid-latitude Northern Hemisphere (Wanju Shi et al., 2017; Chang-qing Chen et al., 2018), but that significances of those trends differed depending on climate division (i.e., spatially) and season (i.e., temporally). Boyles & Raman (2003) examined temperature trends across all of North Carolina during 1949–1998 and found minimum temperature trends significantly increased in select regions of the Piedmont during the summer and spring but decreased in the in northern part of the Piedmont during the winter. The same cooling trend patterns are seen in the Piedmont for maximum temperatures, which is believed to due to increased rain and cloud cover (Boyles & Raman, 2003; Patterson, 2014).

It is true that air temperature can affect the soil's temperature but what if there were times where that relationship was reversed? Different soils also will have different temperature change rates due to the already existing climates and the agricultural history of the land (Waggoner, 1950; Spomer, 1976); however, there have been few studies attempting to directly link soil texture with air temperature and thus, potential temperature trends. Several studies peripherally examine a direct soil texture to atmospheric status, but these studies tend to focus on how soils affect the growth rate of vegetation that in turn can create a microclimate of their own depending on leaf size and coverage (Peacock, 1957; Robeson, 1995; Weih & Karlsson, 2001). In terms of soil content, the most prominent factor in determining air temperature is water capacity (Sindelar, 2015; Ismangil et al. 2016). North Carolina State and NOAA each maintain records of a climate division's temperature trend by plotting the historical data in a graph and determining a "best-fit" regression line (NOAA). Both sources show rising temperature trends (NOAA); so, it is important to address if a geographic location's soil profile could have had any influence in the station records. That examination could help determine if some other factor, such as soil texture, might have influenced the trends.

Soils that can retain higher water capacity in their profile (i.e. soils with lower sand content) produce higher localized humidity levels. In turn, these conditions cause air temperature to warm and cool more slowly than would occur in drier, sandier soils (Sindelar, 2015). Given that, wetter soils are also more resistant to temperature change as the high specific heat of water helps to normalize soil temperature drier soils also will have a greater range of variation in high and low extremes for recorded temperatures. For example, the highest temperature (43.3˚C) recorded in North Carolina was from the Fayetteville Airport on August 21, 1983 (Historical Heat Waves in North Carolina, 2017). Conversely, record high temperatures for the more clayey soils found in the Piedmont are considerably lower (e.g., 39.4 C for Greensboro). A soil's ability to absorb water is dependent upon the makeup of the soil texture (Ismangil, 2016) as clay-rich soils with good structure can hold more water than the sandy soils with more permeability (Poppick, 2008; Obi, 2014; Ismangil, 2016). Soils with higher water capacity also show a natural resistance to extreme variations in air temperature as water has a particularly high specific heat (Ismangil, 2016). The spatial extent of the soil texture can impact how influential any soil texture can have on a microclimate (Poppcick, 2008; Sindelar, 2015)) as large parcels of consistent soil texture will have a bigger impact than smaller areas.

Soil is form based on five environmental factors: the original parent material the soil weathered from; the type of climate in which the weathering took place; the topography of the land; the impact of organisms on the land and the amount of time allotted for the soil to form (Key et al., 2017; Obi, 2014; NCRS, 2019). Soil derives from rock weathering and those sediments retain the same chemical properties as that parent material. However; that does not mean all soils derive from their surrounding area, as wind and water will often erode the fragments away from the source material (Key et al., 2017; Obi, 2014; NCRS, 2019). Climate factors are linked to soil formation because the temperature and humidity of a climate will greatly impact the type and rate of erosions a rock will experience. Soils eroded from arid locations are more subjectable to wind erosion while moisture found in humid atmospheres will bind the weathered sediment together (Key et al., 2017; Obi, 2014; NCRS, 2019). Meanwhile, humid areas are more likely to have chemical weathering caused by organic matter and are likely to experience erosion via waterways. The availability of water and biotic compost impacts the abundance of vegetation, whose roots and ability to absorb water further impacts weather and erosion rates (Key et al., 2017; Obi, 2014; NCRS, 2019). The rate at which it can take for soil to form naturally depends, again, on the type of climate where it develops. Colder, drier climates will have slower formation than hotter, tropical climates and on average will take around one hundred years for one inch of upper layer soil to form. All these varying individual factors are considered when determining how to classify soil type. Soil type is dependent on the location and its composition (Key et al., 2017; Obi, 2014; NCRS, 2019).

North Carolina has three main topographical profiles: mountainous from the western border to the east side of the Blue Ridge escarpment, undulating topography (up to 150 m elevation variability) of the Piedmont region in central third of the state and the minimal-terrain variation (e.g., < 50 m) of the coastal plain (USGS, 2018). The Piedmont region is a plateau of eroded slate that weathered down to a relatively flat surface stretching from southern United States from Alabama to New Jersey (NCPEDIA, 2019). The bedrock of the North Carolina Piedmont is home to several different varieties of igneous and metamorphic rocks including schist, gravel and clay. Towards the southeastern section of the North Carolina Piedmont is home to sandier soils than the clay-rich north and western section of the Piedmont (USGS, 2018; NCPEDIA, 2019).

This study examines seasonal maximum and minimum temperature trends in the Piedmont region of North Carolina to determine: 1) if soil texture is associated with these trends; and, 2) if there is an association; what is the impact of geographic variability in soil texture on temperature trends. I performed a statistical analysis based on 26 climate stations located in the Piedmont region of North Carolina and determined if any spatial patterns in trends were linked to different soil textures. All the stations selected for analysis were chosen because they were located within the North Carolina Piedmont region. They were not separated based on soil texture prior to being involved in the study because their location was chosen to provide the most accurate weather readings possible under normal conditions. For example, stations are often placed in wide-open areas to avoid inaccurate anemometer readings caused by the wind- tunnel effect. With that in mind, it appears that when determining appropriate locations for stations “soil texture” was not taken into consideration during their original placement, therefore; it was not a consideration when initially searching for stations to use in this study. The location of the weather stations is varied across the Piedmont as some cities, such as Greensboro and Raleigh, have multiple stations while less populated towns, like Siler City, only have one. The uneven pattern of weather station distribution is normalized, in terms of gathering climate data, by obtaining the average temperatures of singular station within any given division. Even if the stations are spread apart, an average of their temperatures provide clues into the nature of a sectioned division. That sporadic distribution of stations would not be seen if the soil texture of an area was the sole determining factor of where weather stations are placed, which means the soils found around stations are figuratively random with respect to soil texture. A goal of this study is to examine that apparent randomness for any distinguishable patterns across different stations and their temperature trends.

CHAPTER II

METHODS

Climate Data

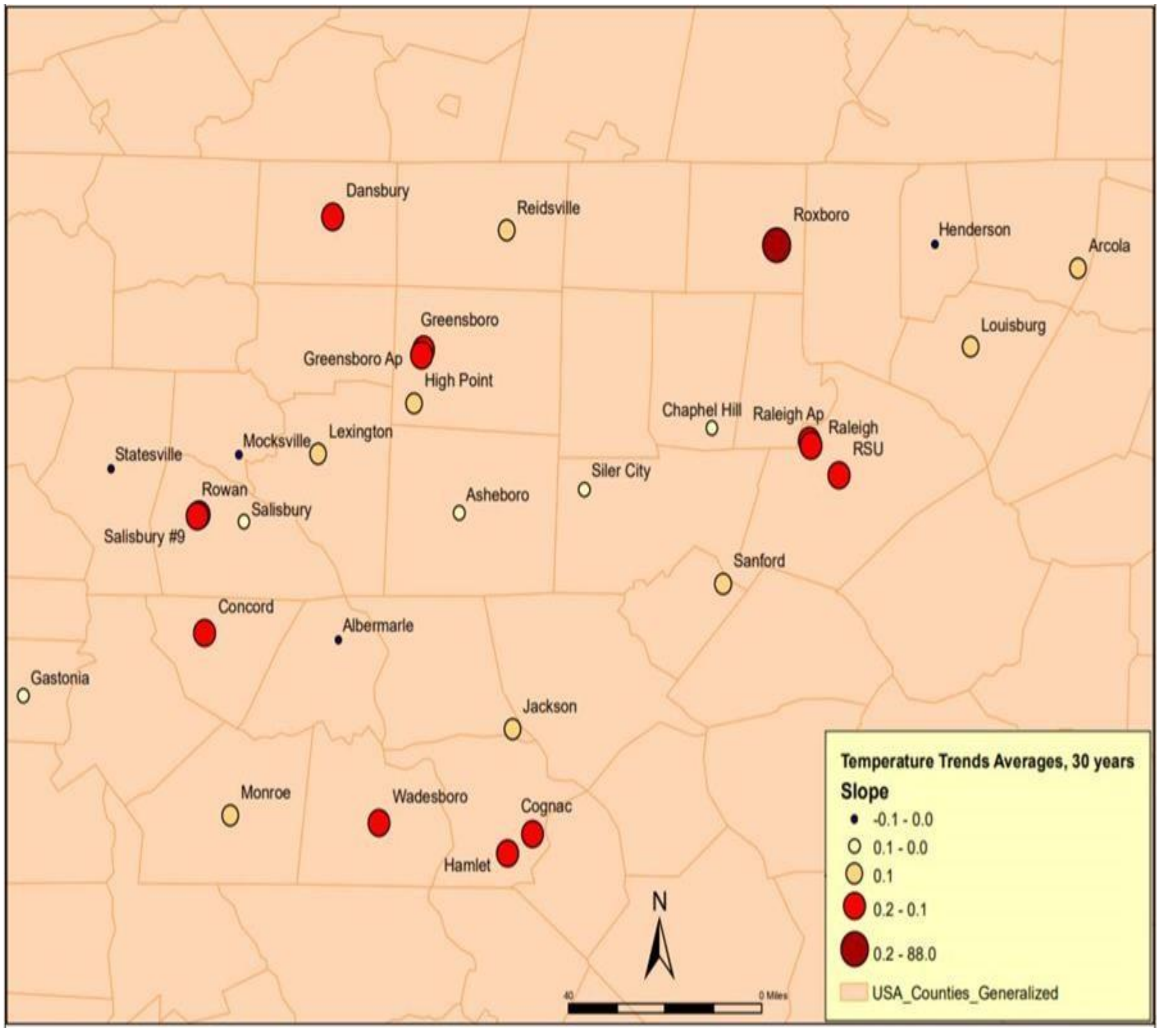
I collected data from the National Oceanic and Atmospheric Administration (NOAA) and North Carolina State University Climate lab (NCSU) for monthly records of maximum and minimum temperatures during 1988–2017 for 26 climate stations located in the North Carolina Piedmont. This time period is coincident with both national (NOAA, 2019) and global-scale (NOAA, 2019) trends in warming temperatures. In determining which weather station would be tested, there were certain criteria that had to be met:

1. Stations had to be within any county that is in the Piedmont region of North Carolina and fall within the North (CD3), Central (CD4) and South Piedmont (CD5) climate divisions (Table 2.1).
2. Exact coordinates of the station location had to be listed to get accurate soil texture data.
3. Stations had to maintain at least 324 out of 360 observations (90%) within a 30-year period ranging from 1988–2017 (Figure 2.1).
4. The time span selected for this study was obtained by comparing the best available continuous monthly data between all 26 stations within the NOAA and NC State databases.

Looking for climate data prior to 1988 within the Piedmont area severely limited the number of stations useable for this study due to incomplete data. 2017 was the most recent complete year of data.

The stations and climate divisions chosen for the project are shown in Figure 2.

Figure 2.1. The 26 Stations as Seen in the Map as Graduated Circles Used in This Study are Displayed for a 3o Year Period for the Piedmont North Carolina. The larger the circle the higher the slope for the temperature change rate in that location. Blue circle represents a cooling trend; beige circles represent neutral trends; and red represents a warming trend.



To get a better analysis, it was important to find stations that had as many similar variables as possible with the only noticeable difference being soil texture. Since several outside factors including: air front passage, jet stream placement, seasonal climates, daylight hours, shading, and even human error can determine air temperature recordings at any given station, stations within local spatial proximity of each other were chosen in an effort the minimalize some of that uncontrollable variables (Robeson, 2005). Additionally, variations in station elevation (< 150 m) and latitude (< 0.5 degrees) were minimal. Data were requested form the NOAA and NCSU databases for all stations matching the criteria stated above resulting in 26 different stations across all three sections of the Piedmont met the requirements (Table 2.1). For each soil texture the percent sand and clay were compared to further determine how soil texture could influence the weather above it.

Table 2.1. Stations Included for Temperature Trend Analysis in North Carolina Grouped by Climate Division. (*) Greensboro Airport and PTI, as with Raleigh Airport and Raleigh Durham International Airport, are different stations, but located close (i.e., <1000 m) to each other.

CD 3--North (*n* = 9)	**CD 4--Central (*n* = 10)**	**CD 5--South (*n* =7)**
Chapel Hill	Asheboro	Albemarle
Danbury	Lexington	Cognac
Henderson	*Raleigh Airport	Gastonia
High Point	Raleigh State University	Hamlet
*Greensboro Airport	Rowan	Jackson
*Piedmont Airport (PTI)	Salisbury	Monroe
Louisburg	Salisbury # 2	Wadesboro
Reidsville 2	Sandford	
Roxboro	Siler	
	*RDI- Airport	

Figure 2.2**.** Methods for Mathematically Calculating “Missing Data” within Individual Weather Station Databases. The mathematical average of the climate regional data for any month and year was obtained from NCSU’s Climate Division website. The monthly information from the sites were separated into four seasons (winter: DJF; spring: MAM; summer: JJA; fall: SON.

1. Find the quotients of the Climate Division Average by the any non-missing data of individual weather stations

$$\frac{\boldsymbol{Climate\ Division\ Average}}{\boldsymbol{Non\ missing\ data\ of\ individual\ weather\ stations}} = \boldsymbol{Quotient}$$

2. Find the average of those quotients by taking their sum and dividing it by 30 years

$$\frac{\boldsymbol{Quotients}}{\boldsymbol{30}} = \boldsymbol{Calculated\ Quotient\ Average}$$

3. The calculated average was multiplied with the Climate Division Average of the missing data of individual stations to get an estimated product of what the absent data would reasonable be.

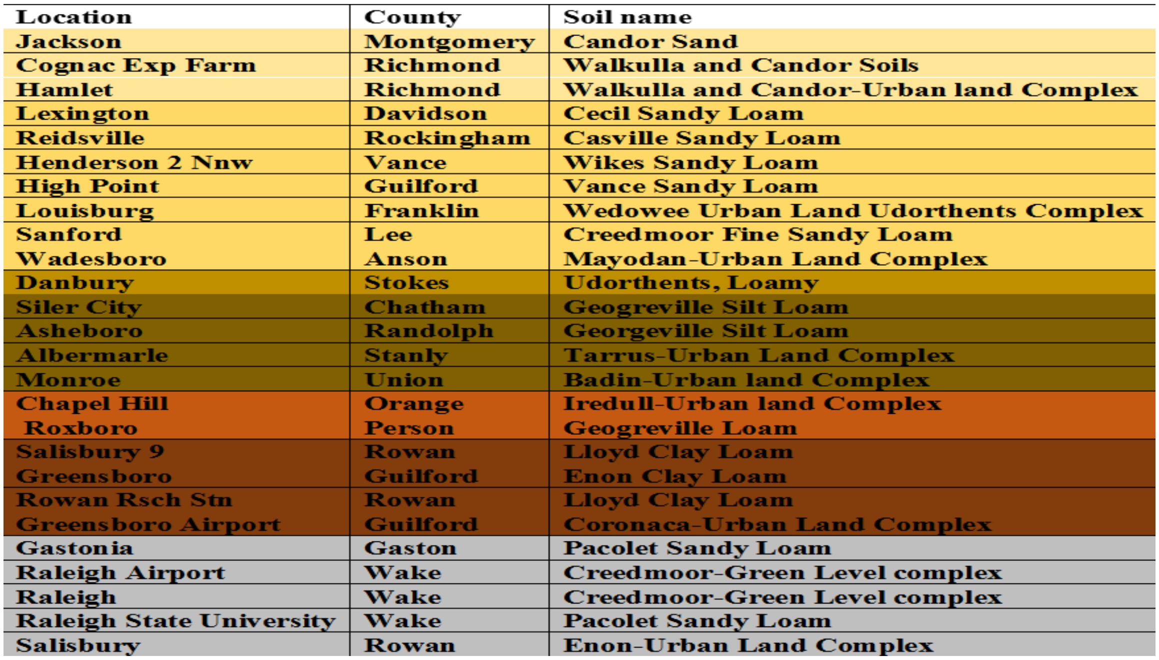
$$\boldsymbol{Climate\ Division\ Data} \times \boldsymbol{Calculated\ Quotient\ Average} = \boldsymbol{Esitimated\ Missing\ Data}$$

Once the missing data were filled, a regression analysis for each station was run to determine if any station showed a significant upward (warming) or downward (cooling) trend during the 30-year period. The data were loaded on SPSS to perform regression on each station’s maximum and minimum records and to examine their respective *p*-values. A one-tailed test was used in determining significance: If the “*p*-value” was greater than 0.05 the site did not show a significant trend. If “*p*-value” was less than or equal to 0.05 than the site did show a significant trend. For the sites that showed significance, an examination of the regression analysis revealed the slope value and trend direction.

Soils Data

To aid in determining soil texture characteristics among the stations, the United States Geological Survey's (USGS) online surveyor tool provided weather station soil texture based on the coordinates of station retrieved from the NOAA and NCSU databases. The stations were grouped by the soil type their A-horizon layer of their soil profile. For stations with substantial surround development (i.e., Gastonia, Raleigh, Raleigh Airport, Raleigh State University and Salisbury) the USGS labeled these sites as "Urban", which does not include a soil profile. To substitute for that lack of information, the soil profile of the closest adjacent soil plot was used which all happened to be sandy loam; therefore, in this study, all "Urban" soil profiles were changed to "Sandy Loam" (Tables 2.2 and 2.3).

Table 2.2. A Listing of the 26 Stations Used in this Project Grouped by Soil Type. The classification of the soil type was based on the A-Horizon.



Location	County	Soil name
Jackson	Montgomery	Candor Sand
Cognac Exp Farm	Richmond	Walkulla and Candor Soils
Hamlet	Richmond	Walkulla and Candor-Urban land Complex
Lexington	Davidson	Cecil Sandy Loam
Reidsville	Rockingham	Casville Sandy Loam
Henderson 2 Nnw	Vance	Wikes Sandy Loam
High Point	Guilford	Vance Sandy Loam
Louisburg	Franklin	Wedowee Urban Land Udorthents Complex
Sanford	Lee	Creedmoor Fine Sandy Loam
Wadesboro	Anson	Mayodan-Urban Land Complex
Danbury	Stokes	Udorthents, Loamy
Siler City	Chatham	Geogreville Silt Loam
Asheboro	Randolph	Georgeville Silt Loam
Albermarle	Stanly	Tarrus-Urban Land Complex
Monroe	Union	Badin-Urban land Complex
Chapel Hill	Orange	Iredull-Urban land Complex
Roxboro	Person	Geogreville Loam
Salisbury 9	Rowan	Lloyd Clay Loam
Greensboro	Guilford	Enon Clay Loam
Rowan Rsch Stn	Rowan	Lloyd Clay Loam
Greensboro Airport	Guilford	Coronaca-Urban Land Complex
Gastonia	Gaston	Pacolet Sandy Loam
Raleigh Airport	Wake	Creedmoor-Green Level complex
Raleigh	Wake	Creedmoor-Green Level complex
Raleigh State University	Wake	Pacolet Sandy Loam
Salisbury	Rowan	Enon-Urban Land Complex

Table 2.3 Stations Classified by Soil Type. This chart displays the A, E and B-horizons in inches. *[p] indicates that the soil was plowed.

Location	A Horizon	E Horizon	B Horizon
Jackson	**Sand (0 to 8 in)**	**Sand (8 to 27 in)**	**[t] Loamy Sand (27 to 39 in)**
Cognac Exp Farm	**Sand (0 to 7 in)**	**Sand (7 to 24 in)**	**[t] Loamy Sand (24-42 in)**
Hamlet	**Sand (0 to 7 in)**	**Sand (7 to 24 in)**	**[t] Loamy Sand (24-42 in)**
Lexington	**Sandy Loam (0 to 6 in)**		**[t] Clay (6 to 50 in)**
Reidsville	**[p] Sandy Loam (0 to 6 in)**	**Sandy Loam (6 to 10 in)**	**[t] Clay (10 to 38 in)**
Henderson 2 Nnw	**Sandy Loam (0 to 3 in)**	**Sandy Loam (3 to 6 in)**	**[t] Clay (6 to 10 in)**
High Point	**[p] Sandy Loam (0 to 6 in)**		**[t] Clay (6 to 36 in)**
Louisburg	**[p] Sandy Loam (0 to 5 in)**		**[t] Sandy Clay Loam (5 to 10 in)**
Sanford	**[p] Fine Sandy Loam (0 to 14 in)**		**[t] Silty Clay Loam (14 to 29 in)**
Wadesboro	**[p] Fine Sandy Loam (0 to 6 in)**	**Sandy Clay Loam (6 to 9 in)**	**[t] Clay (9 to 33 in)**
Danbury	**Sandy Clay Loam**		
Siler City	**Silt Loam (0 to 9 in)**	**Silt Loam (9 to 14 in)**	**[t] Silty Clay Loam (14 to20 in)**
Asheboro	**Silt Loam (0 to 12 in)**		**[t] Silt Clay (12 to 50 in)**
Albermarle	**[p] Gravelly Silt Loam (0 to 7 in)**		**[t] Silt Clay Loam (7 to 42 in)**
Monroe	**[p] Channery Silt Loam (0 to 6 in)**		**[t] Silt Clay (6 to 35 in)**
Chapel Hill	**[p] loam (0 to 6 in)**		**[t] Clay (6 to 25 in)**
Roxboro	**[p] loam (0 to 8 in)**		**[t] Clay (8 to 45 in)**
Salisbury 9	**[p] Clay Loam (0 to 7 in)**		**[t] Clay (7 to 58 in)**
Greensboro	**[p] Clay Loam (0 to 8 in)**	**[BE] Clay Loam (8 to 11 in)**	**[t] Clay (11 to 33 in)**
Rowan Rsch Stn	**[p] Clay Loam (0 to 7 in)**		**[t] Clay (7 to 58 in)**
Greensboro Airport	**[p] Clay Loam (0 to 8 in)**		**[t] Clay (8 to 71 in)**
Gastonia	**0 to 6 in Sandy Loam**		**[t]6 to 38 in Clay**
Raleigh Airport	**[p] 0 to 10 Sandy Loam**		**[t]10 to 45 in Clay**
Raleigh	**[p] 0 to 10 Sandy Loam**		**[t]10 to 45 in Clay**
Raleigh State University	**[p] 0 to 8 Sandy Loam**		**[t] 8 to 27 in Clay**

All soil data used in this study comes from the USGS online soil surveyor, which is a free collection of American county survey formatted for accessible only usage. The engineering data for the counties used in this study uses information obtained December 2013 and last updated for the online surveyor on September 2018 (USGS, 2019). I correlated the percent soil separate content data obtained from the engineering data from USGS for sand, silt, clay plus Available Water Capacity (AWC) at different horizons (Table 3.1) of the 26 stations per season and annually for both maximum and minimum temperatures. For all stations, data representing the values within 1 inch within the ground was gathered for the properties of AWC, clay, sand and silt. In addition, all the percentages within the A and B horizons were found and was labeled as “Mix”. In total there were 260 correlations between temperature slopes and soil characteristics (n = 26 stations x 5 “seasons” including annual x 2 observations of maximum and minimum temperature).

An example of all the slopes used in the correlation and the percent content of Mix A/B-sand horizons are shown in Table 3.1. After all the correlations were identified, the findings were added to Table 3.2 to show which slopes had significant correlations amounts the four variables of soil content at various depth levels. The last step taken in this project was to compare soil characteristics of those stations with significant trends with soil characteristics of stations with non-significant trends using an independent-sample t test for sand and silt.

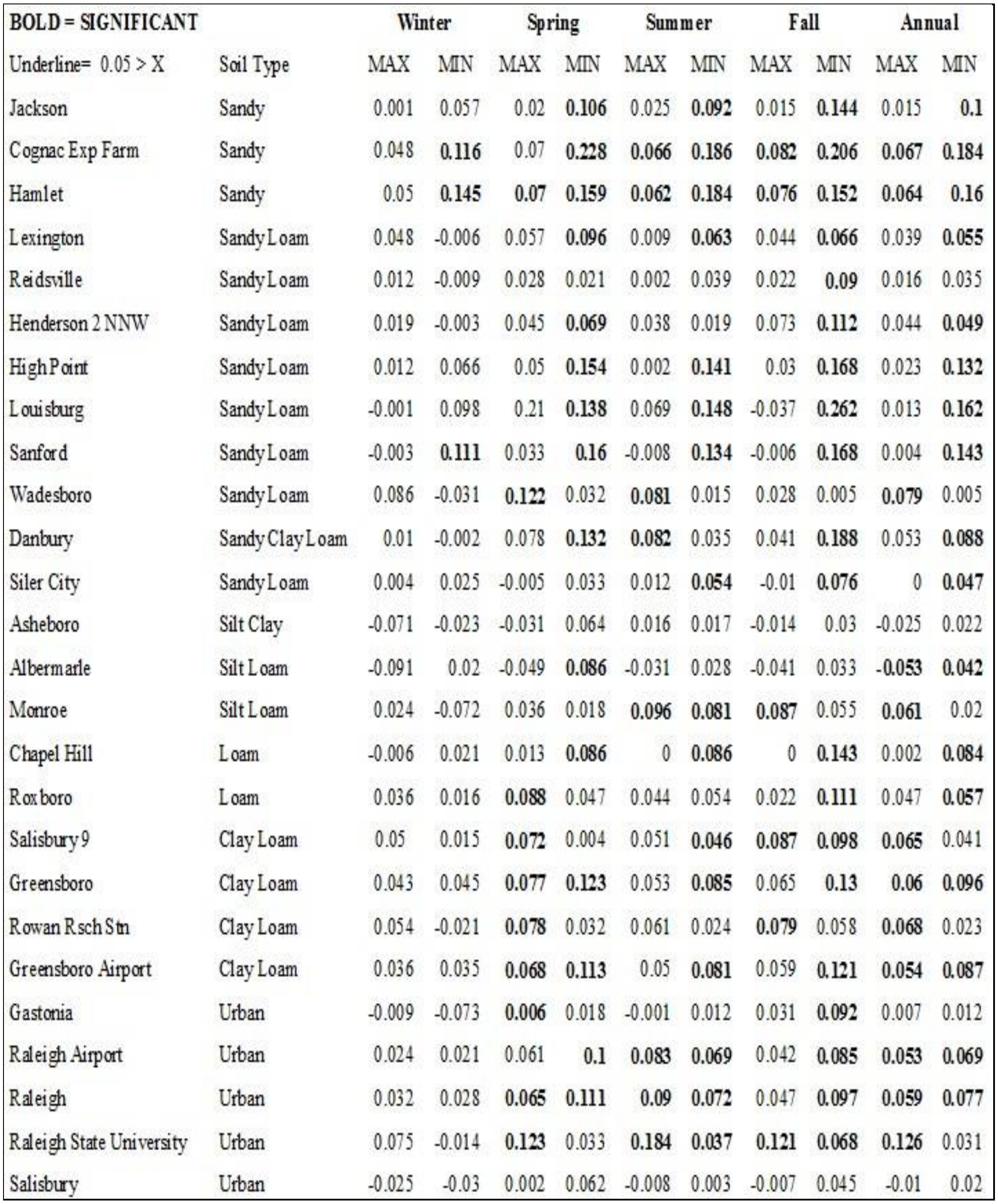
CHAPTER III

RESULTS

Minimum and Maximum Temperature Trends

This study consisted of examining the 30-year maximum and minimum temperature slopes of 26 different stations for four seasons and annual values. The total number of slopes observed was n= 260 with 110 (42%) steepest slopes associated with sandy-based soils (Table 3.1). Seventy of 110 (64%) significant trends had sand as some part of their classification name and had an average of 3.3 out of a total of 8 significant trends, annual regression trends are excluded to limit redundancy, per station for 16 stations associated with sand (Tables 3 and 4). In comparison, non-sandy soils represented 36 (33.6%) of the 110 significant trends with the remainder associated with urban soils. The 10 non-sandy stations had an average of 2.5 out if 8 significant trends per station (Tables 3 and 4). In addition, of the total of 24 observations classified as "sandy" soil, 16 (66.7%) were significant (Table 3.1). Soils absent the term either "sand", "sandy", or "urban" represented a total of 80 observations with 24 (30.0%) significant (Table 3.1).

Table 3.1. A List of the Stations’ Slope Trends Separated by Season (Winter, Spring, Summer, Fall and Annual) and Maximum and Minimum. The percent content of [AB] mix horizons is correlated to the annual slope observations. The bold typed slopes indicate that the slope is significant ($p < 0.1$) and an underline slope indicates as significance of $p < 0.05$.



BOLD = SIGNIFICANT		**Winter**		**Spring**		**Summer**		**Fall**		**Annual**	
Underline= 0.05 > X	Soil Type	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN
Jackson	Sandy	0.001	0.057	0.02	**0.106**	0.025	**0.092**	0.015	**0.144**	0.015	**0.1**
Cognac Exp Farm	Sandy	0.048	**0.116**	0.07	**0.228**	**0.066**	**0.186**	**0.082**	**0.206**	**0.067**	**0.184**
Hamlet	Sandy	0.05	**0.145**	**0.07**	**0.159**	**0.062**	**0.184**	**0.076**	**0.152**	**0.064**	**0.16**
Lexington	Sandy Loam	0.048	-0.006	0.057	**0.096**	0.009	**0.063**	0.044	**0.066**	0.039	**0.055**
Reidsville	Sandy Loam	0.012	-0.009	0.028	0.021	0.002	0.039	0.022	**0.09**	0.016	0.035
Henderson 2 NNW	Sandy Loam	0.019	-0.003	0.045	**0.069**	0.038	0.019	0.073	**0.112**	0.044	**0.049**
High Point	Sandy Loam	0.012	0.066	0.05	**0.154**	0.002	**0.141**	0.03	**0.168**	0.023	**0.132**
Louisburg	Sandy Loam	-0.001	0.098	0.21	**0.138**	0.069	**0.148**	-0.037	**0.262**	0.013	**0.162**
Sanford	Sandy Loam	-0.003	**0.111**	0.033	**0.16**	-0.008	**0.134**	-0.006	**0.168**	0.004	**0.143**
Wadesboro	Sandy Loam	0.086	-0.031	**0.122**	0.032	**0.081**	0.015	0.028	0.005	**0.079**	0.005
Danbury	Sandy Clay Loam	0.01	-0.002	0.078	**0.132**	**0.082**	0.035	0.041	**0.188**	0.053	**0.088**
Siler City	Sandy Loam	0.004	0.025	-0.005	0.033	0.012	**0.054**	-0.01	**0.076**	0	**0.047**
Asheboro	Silt Clay	-0.071	-0.023	-0.031	0.064	0.016	0.017	-0.014	0.03	-0.025	0.022
Albermarle	Silt Loam	-0.091	0.02	-0.049	**0.086**	-0.031	0.028	-0.041	0.033	**-0.053**	**0.042**
Monroe	Silt Loam	0.024	-0.072	0.036	0.018	**0.096**	**0.081**	**0.087**	0.055	**0.061**	0.02
Chapel Hill	Loam	-0.006	0.021	0.013	**0.086**	0	**0.086**	0	**0.143**	0.002	**0.084**
Roxboro	Loam	0.036	0.016	**0.088**	0.047	0.044	0.054	0.022	**0.111**	0.047	**0.057**
Salisbury 9	Clay Loam	0.05	0.015	**0.072**	0.004	0.051	**0.046**	**0.087**	**0.098**	**0.065**	0.041
Greensboro	Clay Loam	0.043	0.045	**0.077**	**0.123**	0.053	**0.085**	0.065	**0.13**	**0.06**	**0.096**
Rowan Rsch Stn	Clay Loam	0.054	-0.021	**0.078**	0.032	0.061	0.024	**0.079**	0.058	**0.068**	0.023
Greensboro Airport	Clay Loam	0.036	0.035	**0.068**	**0.113**	0.05	**0.081**	0.059	**0.121**	**0.054**	**0.087**
Gastonia	Urban	-0.009	-0.073	**0.006**	0.018	-0.001	0.012	0.031	**0.092**	0.007	0.012
Raleigh Airport	Urban	0.024	0.021	0.061	**0.1**	**0.083**	**0.069**	0.042	**0.085**	**0.053**	**0.069**
Raleigh	Urban	0.032	0.028	**0.065**	**0.111**	**0.09**	**0.072**	0.047	**0.097**	**0.059**	**0.077**
Raleigh State University	Urban	0.075	-0.014	**0.123**	0.033	**0.184**	**0.037**	**0.121**	**0.068**	**0.126**	0.031
Salisbury	Urban	-0.025	-0.03	0.002	0.062	-0.008	0.003	-0.007	0.045	-0.01	0.02

More significant trends of seasonal temperature occurred during the spring, summer and fall seasons than winter and more significant trends were associated with minimum temperatures than maximum temperatures. Of the 110 significant trends 74 (67%) were associated with minimum temperatures and 36 (33%) were associated with maximum temperatures.   Annual trends were more equally split between maximum and minimum temperatures than the seasonal data.

Table 3.2. The Number of Significant Trends per Season for Maximum and Minimum Temperatures.

Season	WINTER		SPRING		SUMMER		FALL		Annual	
Type	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN
# Significant	0	3	10	16	8	17	6	21	12	17

Correlations between Temperature Trends and Soil Characteristics

Table 3.3 shows the correlation of the temperature trends and the composition of the soil at various depths. The engineering data of the components of water, clay, sand and silt examined at different depths for each station. Starting at depths of 1in, all of A horizon for that site, and a mixture depth which was the all of A and B horizons, which was is labeled as “Mix”. Underneath each correlation is the *p* value and those that are labeled significant ($p < 0.05$) are in bold and ($p < 0.01$) are underlined as well. Table 3.3 shows 120 observations of correlation and of those only 17 were significant or about 14%. Of those that were significant 13 (76%) were minimum correlations and four (24%) were maximum. Every composition besides sand had a correlation that was negative while all the sand correlations were positive. In terms of season, most of the significant trends occurred during spring, fall and summer found no significance in any category. Within the depths, 11 out of the 17 (65%) significant trends were found in the mixed horizons.

The results of the difference of means test were significant for both sand and silt soils. This test did not include the annual observations and only focused on the measured trends, which is $n = 208$. This test compared the engineering data of sand (silt) content between for at each site with a significant trend (n=110) to the sand (silt) content at sites with non-significant trends (n=150). An independent sample means test was done using sand and silt soil types and found when the groups were separated based on significant temperature trends, the mean sand value was 6% higher (p <0.01) than from soils at sites with non-significant trends. Conversely, the difference of means test showed that percent silt was 6% lower (p <0.01) for sites with non-significant trends compared to the soil composition of those sites with significant temperature trends.

Table 3.3. A List of Correlations Between Minimum and Maximum Temperature Trend Lines (beta) with Either Soil Texture Content Available Water Capacity (AWC) at Different Horizons

	Correlation of minimum trends per texture					**Correlation of maximum trends per texture**				
	Winter	**Spring**	**Summer**	**Fall**	**Annual**	**Winter**	**Spring**	**Summer**	**Fall**	**Annual**
AWC 1in	-0.225	-0.376	-0.092	-0.369	-0.291	-0.144	-0.167	-0.009	-0.16	-0.21
p-value	0.269	0.058	0.654	0.064	0.149	0.484	0.416	0.967	0.434	0.302
AWC A	-0.217	-0.367	-0.079	-0.368	-0.285	-0.106	-0.131	0.028	-0.122	-0.172
p-value	0.287	0.065	0.7	0.065	0.159	0.606	0.525	0.892	0.554	0.4

AWC Mix	-0.318	**-0.436**	-0.194	-0.348	-0.345	**-0.472**	**-0.519**	-0.351	**-0.435**	**-0.517**
p-value	0.113	**0.026**	0.342	0.082	0.084	**0.015**	**0.007**	0.079	**0.026**	**0.007**
Clay 1in	-0.348	**-0.415**	-0.383	-0.185	-0.336	-0.061	0.04	-0.07	0.018	-0.012
p-value	0.082	**0.035**	0.054	0.365	0.094	0.768	0.847	0.732	0.93	0.954
Clay A	-0.348	**-0.415**	-0.383	-0.185	-0.336	-0.061	0.04	-0.07	0.018	-0.012
p-value	0.082	**0.035**	0.054	0.365	0.094	0.768	0.847	0.732	0.93	0.954
Clay Mix	-0.172	-0.271	-0.108	-0.117	-0.156	0.327	0.198	0.021	0.37	0.243
p-value	0.4	0.181	0.601	0.57	0.446	0.103	0.332	0.919	0.062	0.232
Sand 1in	0.288	0.338	0.254	**0.434**	0.341	0.055	0.156	0.026	0.037	0.092
p-value	0.154	0.092	0.21	**0.027**	0.089	0.789	0.447	0.899	0.858	0.655
Sand A	0.286	0.334	0.249	**0.431**	0.339	0.064	0.168	0.032	0.039	0.098
p-value	0.157	0.095	0.219	**0.028**	0.091	0.758	0.413	0.878	0.851	0.633
Sand Mix	0.312	**0.482**	0.236	**0.419**	**0.391**	-0.066	0.119	0.031	-0.091	0.009
p-value	0.12	**0.013**	0.246	**0.033**	**0.048**	0.748	0.563	0.881	0.66	0.965
Silt 1in	-0.215	-0.326	-0.121	**-0.481**	-0.317	-0.018	-0.156	-0.059	-0.101	-0.122
p-value	0.292	0.104	0.556	**0.013**	0.115	0.929	0.447	0.776	0.623	0.551
Silt A	-0.202	-0.325	-0.118	**-0.47**	-0.309	-0.04	-0.174	-0.078	-0.129	-0.149
p-value	0.322	0.105	0.566	**0.015**	0.125	0.884	0.396	0.704	0.531	0.469
Silt Mix	**-0.404**	**-0.567**	-0.359	**-0.57**	**-0.525**	-0.041	-0.198	-0.067	-0.142	-0.111
P-value	**0.041**	**0.003**	0.072	**0.002**	**0.006**	0.844	0.333	0.744	0.489	0.588

CHAPTER IV

DISCUSSION

Seasonal and annual temperature trends of 26 climate stations in the Piedmont region of North Carolina were examined to answer two questions: 1) if edaphic conditions as defined by soil texture are associated with temperature trends; and, 2) the impact of geographic variability in soil texture on temperature trends. The results suggest that the percentage sand (clay) content in soils is associated with positive (negative) temperature trends for all seasons and annually except for winter (Table 3.1). Sandy soils lack the ability to retain water like silt or clay-based soil, thus are drier and more porous by comparison. Due to the lack of water, sandier soil is more likely to experience higher levels of temperature change as due as seen, for example, in the bigger temperature slopes found in Cognac (0.288 ◦ F/year) and Hamlet (0.184 ◦ F/year) (Table 3.1). Conversely, the data shows that AWC and silt content are associated with negative significant temperature trends.

Significant temperature trends occurred predominantly in the spring and fall seasons. Table 3.2 shows the number of significant observations found during different season for both maximum and minimum trends. Of the 260 observations measured 74 (67%) were associated with minimum temperature trends, while 36 (33%) were associated with minimum trends. This information suggests that the impacts of edaphic factors will be more noticeable while measuring minimum trends than maximum.

The discrepancy between the frequency of minimum and maximum in the North Carolina Piedmont is consistent with other studies within the U.S. A possibility for this could be the time at which maximum and minimum are recorded by NOAA weathering stations as maximum are measured in the afternoon around 3:00 pm and minimums are recorded around 6:30 to 7:00 am. During the day, the heating of the earth's surface prompts an increase in water vapor concentration that leads to the formation of clouds which act at limiters to how high the daytime temperatures can rise (e.g., Vose et al. (2005)). Another potential reason for skewed maximum trends and be traced back an error in monitoring the weather station according to NOAA. A bias is formed by under reporting from poorly monitored location sites that can lead to artificial cooling trends along the maximum temperature trends and a false warming trends along minimum temperatures (NOAA, 2018). In the morning, the earth is releasing heat it absorbed during the day, sandy soils can allow heat to transfer easily through it an escape into the atmosphere at night. At night there are less limiters than during the day due to a lack of cloud formation and less humid air.

When considering the location of land-based climate monitoring, there are approximately 50 factors to consider according the Global Climate Observing System (GCOS, 2019; NOAA, 2019). Fast development of urban zone in favor of rural locations has led to an unbalanced calculation in urban/rural weather station monitoring. There had been an increase in weather monitoring stations being closer to urban area as more people are choosing there to live. This development might skew the analysis of trends because the urban index inflates actual temperatures by 0.0054 ◦ F/year (Watts, 2011).

In terms of edaphic factors in climate monitoring, soil temperature, moisture and vegetation are often considered key areas of focus, but few studies have directly attempted to link soil type as another factor (Crowther, 1930; Ács, Mihailović, & Rajković, 1991; Maynard, Paré, Thiffault, Lafleur, Hogg, & Kishchuk, 2014; Obi, 2014; Key et al., 2017; NCRS, 2019). Soil type can determine the variability of all three of those factors since soil type can impact the land's ability to hold store water; the rate of temperature change over a period and what kind of plant life is dominate in a regional area (Key et al., 2017; Obi, 2014; NCRS, 2019). Since there has been ample research conducted of the impact of surface temperature trends from soil temperature, moisture and vegetation which are all dependent on soil type; directly analyzing the impact soil type can have on climate could be considered redundant. However, the purpose of this project exerts unique correlations along soil types and temperatures trends. These correlations are important in the development of new ways of considering important factor in determining temperature monitoring.

Considerable spatio-temporal variability in temperature patterns in North Carolina exist as Patterson (2014) found variability in the timing and location of these trends during 1895–2014. For example, the Coastal climate divisions saw significant warming trends for all seasons while a similar pattern occurred within the Piedmont divisions with the only exception being fall. When comparing the Piedmont and Coastal division, Patterson found that coastal areas had repeated warming trends thought the 120-year study with the exception of the southern coastal region, while the Piedmont region was more varied in trends. This study and Patterson's both suggest that monitoring temperature trends in sandy soils would show mostly higher than average warming trends during all times of the year.

Several caveats exist in assessing these data. First, this project was principally dependent upon the information provided the United States Geological Survey (USGS) and the National Oceanic and Atmospheric Administration (NOAA). The information provided was reliable but incomplete and estimations and assumptions were made in terms of calculation for missing data and choosing the soil type of weathering station listed as "Urban" by the USGS surveyor. The unavoidable limitations of gathering complete information prevents the findings in this study from being as conclusive as possible. Further, studies with more complete data are needed to help support the evidence found in this study. Second, environmental conditions surrounding the weather stations are not static as local changes (e.g., nearby development, growth of vegetation causing shading, development of more impervious ground cover) have the potential to affect the temperature conditions at the station

CHAPTER V

CONCLUSION

This project explored if edaphic conditions may play a role in the geographic variability of temperature trends and found that patterns of temperatures can be linked to soil type. Each soil type has certain properties, such their ability to hold water, which contribute to their ability to impact surface temperatures. The results showed that temperature trends are likely affected by soil type and that the influence of this may vary by season. Spring and fall season across all climate divisions saw a considerable increase in significance than the winter and summer. In particular, the results suggest that sandier soils can be linked to a high number of significant warming trends and at higher rates across the Piedmont region than soils that have a higher percentage of either clay or silt.

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