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Climate extremes in the Southeast United States : variability, spatial classification, and related planning

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CLIMATE EXTREMES IN THE SOUTHEAST UNITED STATES: OBSERVED VARIABILITY, SPATIAL CLASSIFICATION, AND RELATED PLANNING

A Dissertation

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by
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LIST OF ABBREVIATIONS

C2ES	Center for Climate and Energy Solutions
CISA	Carolinas Integrated Sciences and Assessments
CLIVAR	Climate Variability and Predictability
COOP	Cooperative Observer Network
CSC	Coastal Services Center
ENSO	El Niño Southern Oscillation
EPA	U.S. Environmental Protection Agency
ETCCDI	Expert Team on Climate Change Detection and Indices
FEMA	Federal Emergency Management Agency
HUD	U.S. Department of Housing and Urban Development
IPCC	Intergovernmental Panel on Climate Change
NCA	National Climate Assessment
NCDC	National Climatic Data Center
NFIP	National Flood Insurance Program
NOAA	National Oceanic Atmospheric Administration
NWS	National Weather Service
OECD	Organization for Economic Cooperation and Development
PDSI	Palmer Drought Severity Index
RISA	Regional Integrated Sciences and Assessments
SCIPP	Southern Climate Impacts Planning Program
SECC	Southeast Climate Consortium
SERCC	Southeast Regional Climate Center

SRCC	Southern Regional Climate Center
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
USGCRP	United States Global Change Research Program
USGS	United States Geological Survey
USHCN	United States Historical Climate Network
WMO	World Meteorological Organization

ABSTRACT

Spatial and temporal trends in temperature and precipitation extremes were investigated for the Southeast United States for the period 1948 to 2012 using 27 extreme indices developed by Working Groups headed by the World Meteorological Organization. Results show region-wide warming in extreme minimum temperatures and cooling in extreme maximum temperatures. As a result, diurnal temperature ranges are decreasing for most stations. The intensity and magnitude of extreme precipitation events appear to be rising overall, though eastern sites are experiencing increasing dryness in some indices. Seasonal trends suggest that warming in minimum temperatures is most pronounced in summer and least pronounced in winter. Fall is becoming significantly wetter, while spring and summer are getting drier, on average.

Principal component analysis (PCA) was used to develop a regionalization of extremes for the Southeast. Results based on temperature extreme indices divided the Southeast into roughly equal western and eastern regions, suggesting that western and eastern stations tend to covary but in opposite directions. This likely reflects synoptic scale weather patterns that frequently affect the region throughout the year. A PCA based on precipitation extreme indices resulted in a greater number of small groups exhibiting similar modes of variability. A seasonality of extremes was further characterized for the Southeast. Extreme seasons tend to follow traditional 3-month definitions of seasons. An extended winter season may be defined as November to March, while summer occurs from June to August, peaking in July.

Based on analysis of state and local planning and policy from six case study sites across the Southeast, this research suggests that many existing efforts may contribute to climate mitigation and adaptation. Similarities appear in sector-based planning, largely in response to federal mandates, though levels of engagement differ between sites. Threats from changing temperature and precipitation extremes are addressed only to a limited extent. Leadership priorities, federal actions, wealth, population, and experience with hazards seem to influence state and local actions. Recommendations are offered to guide future climate planning and policy. Findings can benefit planners, policy analysts, decision makers, and hazards specialists engaged in climate adaptation and hazard mitigation in the Southeast and beyond.

Keywords: climate extremes, climate change, temperature extremes, precipitation extremes, Southeast climate, principal component analysis, climate adaptation, climate mitigation

CHAPTER 1. INTRODUCTION

1.1 Overview

Climate change is expected to alter the frequency and intensity of weather extremes that have primary impacts on societies, including extreme heat, severe storms, freezes, floods, and drought (Brown and Katz 1995, IPCC 2007, USGCRP 2009, Trenberth 2011). Extremes in temperature and precipitation are key indicators of climate and are inherently linked to the development of weather events and natural hazards. Increases in air temperatures and atmospheric water vapor content are likely to generate more extremes in temperature and accelerate the water cycle, leading to increases in precipitation magnitudes and intensities (Huntington 2006, Griffiths and Bradley 2007, dos Santos et al. 2011, Peterson et al. 2012). More intense precipitation may be compounded by the likelihood of more severe drought episodes. In a warmer climate, added heat is expected to accelerate evaporation and increase the potential for severe or prolonged droughts (Trenberth 2012). Thus, while precipitation may become more intense, these precipitation events will likely be shorter, less frequent, and/or interjected by longer dry spells (Groisman and Knight 2008). Increases in average temperatures may continue to lengthen the average frost-free season, which has increased by two weeks since the beginning of the 20th century in the United States (Kunkel et al. 2004). Such changes in the strength and variability of extremes will become a primary area of focus for governments, stakeholders, and the general public as they make decisions regarding future growth and management of key resources.

The likelihood of more extreme weather and climate, coupled with increased vulnerability, highlights a need for more research on extreme event behavior and responses at regional and sub-regional scales. Losses from weather and climate extremes have been rising nationally since about the mid-1900s and peaking in the most recent decades since the 1990s (Gall et al. 2011). Losses have been largely attributed to increases in wealth, development, and population in vulnerable areas (Pielke and Landsea 1998, Changnon et al. 2000, Pielke et al. 2008), as well as a combination of changes in natural hazard activity and societal resilience (Gall et al. 2011). Regardless of the primary reason for increased losses, climate change will only compound socioeconomic factors that contribute to increased risk and vulnerability.

The Southeast United States has experienced more billion-dollar disasters than any other region in the country since 1980 (NCADAC 2013). Additionally, the Southeast is already feeling the effects of a changing climate. Average temperatures in the region have risen since 1970 by 2°F, particularly in summer (NCADAC 2013). While long-term trends in precipitation are generally more difficult to discern, trends in the magnitude of heavy rainfall events have increased in the Southeast during much of the 20th century (Keim 1999), and extreme precipitation events have become more frequent in recent decades (Kunkel 2003). Upward trends in precipitation have been most pronounced for stations along the northern Gulf Coast (Faiers and Keim 2008, Kunkel et al. 2013), where highest average and median annual precipitation values typically occur (Godschalk 2007).

Response and preparedness to extreme events will be of utmost importance in determining how the region is impacted by future changes in extremes. Adaptation to climate change is a new area of focus for all levels of government (NCADAC 2013). Given that impacts are felt at the local level, local governments are the most crucial players in implementing measures on the ground and increasing local adaptive capacity

(Hansen et al. 2013). In addition, economic and environmental sectors that are particularly susceptible to the risks of climate change will play crucial roles in increasing overall resilience. A lack of a region-wide climate initiative in the Southeast (C2ES 2011), coupled with the fact that this is the most weather active region in the country (NWS 2012), makes an analysis of extreme behavior in this region particularly important. This study attempts to provide a more comprehensive assessment of observed changes in climate extremes for the Southeast than previous studies that have focused on individual parameters of extremes or that have analyzed only a subset of parameters. In addition, this research attempts to group locations together based on similar extreme variability to inform regional and local planning and preparedness efforts.

1.2 Study Region

This research investigates spatial and temporal patterns in extreme temperature and precipitation for the Southeast United States. The Southeast is defined as the 11-state region that includes Texas, Louisiana, Arkansas, Oklahoma, Mississippi, Tennessee, Alabama, Georgia, Florida, North Carolina, and South Carolina (Figure 1-1). This region was chosen because it receives a large number and variety of extreme weather and climate events and is highly vulnerable to a changing climate (Keim 1999, NWS 2012, Kunkel et al. 2013).

This region overlaps with service areas of established climate research institutes. It encompasses the 6-state region of the Southern Climate Impacts Planning Program (SCIPP), the 3-state region of the Southeast Climate Consortium (SECC), and the 2-state region of the Carolinas Integrated Sciences and Assessments (CISA), whose work partially provided the foundation and impetus for this research. These institutes are part

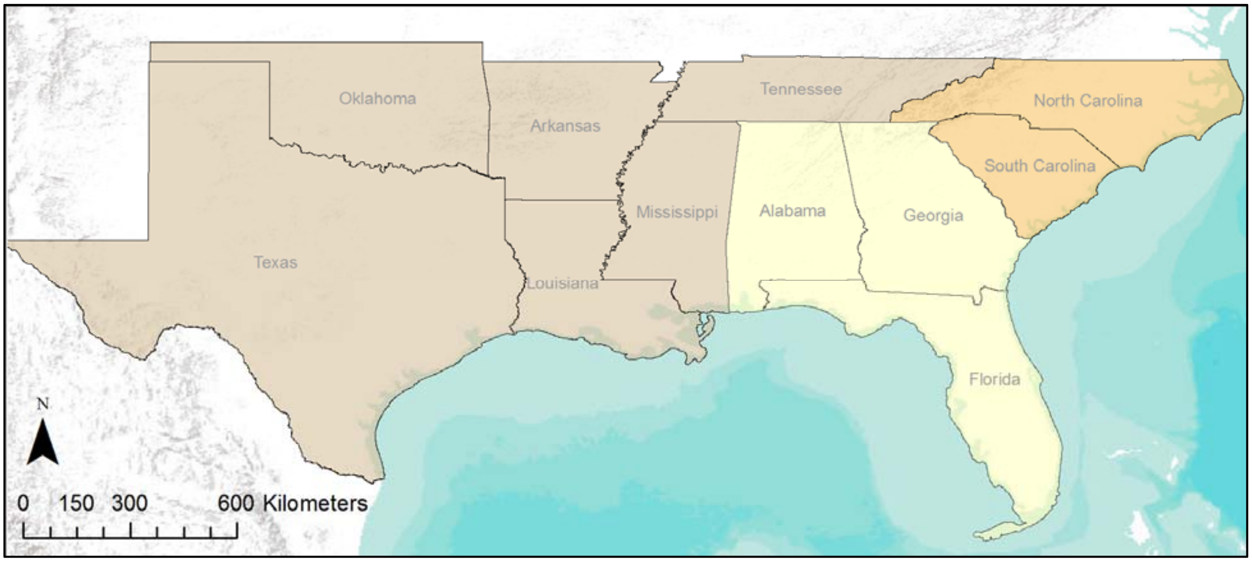

Figure 1-1. The 11 states encompassing the Southeast United States and study area. SCIPP states are shaded in brown, SECC states in yellow, and CISA states in orange.

of the National Oceanic and Atmospheric Administration's (NOAA) Regional Integrated Sciences and Assessments (RISA) programs, which include a total of eleven projects around the United States. These RISA programs overlap with the service areas of the Southern Regional Climate Center (SRCC) and Southeast Regional Climate Center (SERCC). This study area also encompasses states included in the domains of the Southeast and South Central Climate Science Centers (CSCs). These regional climate centers conduct applied climate research and develop data support and services for industry and the public aimed at increasing awareness and knowledge of climate impacts and adaptation. This study will be of particular interest to these centers.

The Southeast is in large part a climatically homogeneous region; however, weather patterns can vary considerably across the region (Kunkel et al. 2013). The majority of the Southeast has a humid subtropical climate according to the Köppen climate classification, with the exception of the western portions of Texas and

Oklahoma, which are classified as arid and semi-arid, and southern Florida, which is tropical savanna and tropical monsoon. The Southeast is largely influenced by the strength and position of the Atlantic Subtropical High and moisture-laden air from the Gulf of Mexico (Henderson and Robinson 1994, Henderson and Muller 1997). Rossby wave flow acts as an important driver of daily extreme temperature frequency in winter, and subtropical flow is generally more important for temperature extremes during summer (Henderson and Muller 1997). The region is also susceptible to extremes in precipitation due to its proximity to both the Gulf of Mexico and Atlantic Ocean, which influence rainfall regimes through moist air advection from the south and east. The region receives heavy rainfall from mid-latitude systems tracking in from the west during winter and early spring. Heavy precipitation events are also caused by cyclogenesis in the Gulf, as well as from tropical storms and hurricanes, with return periods for major landfalling hurricanes (category 3-5) averaging between 13 and 52 years for many parts of the Gulf Coast and southern portions of the East Coast (Keim et al. 2007).

1.3 Research Objectives

Previous studies have addressed extremes for the Southeast related to temperature (Henderson and Muller 1997, DeGaetano and Allen 2002, USCCSP 2008, Kunkel et al. 2013), precipitation (Keim 1996, 1999, Kunkel et al. 1999a, Kunkel 2003, USCCSP 2008, Kunkel et al. 2013), and storm events (Keim et al. 2007, USCCSP 2008, Nogueira et al. 2012, Kunkel et al. 2013); however, they are generally independent studies that have defined extremes in various, often inconsistent ways. While independent analyses such as by (Henderson and Muller 1997) or (Kunkel et al. 1999a) have provided invaluable information about specific indicators of climate change, they do not offer a complete picture of how temperature and precipitation extremes are changing across the region. Without comprehensive, detailed information on climate extremes, planning efforts cannot adequately address future risks associated with climate change and extreme variability. Recent synthesis reports and studies have begun to assess extremes for the Southeast in greater detail (Kunkel et al. 2013, NCADAC 2013). This research expands upon such reports by examining a greater number of climate extreme indicators that have not yet been examined in detail for the region. Thus, this contributes to these synthesis reports and is guided by three main research questions:

1. How have extremes in temperature and precipitation changed spatially and temporally in the Southeast?
2. Can a regionalization of extremes be defined for the Southeast based on temporal variability in extreme temperature and precipitation?
3. What is the level and focus of state- and local-level policy and planning efforts related to extremes and how do they compare with extreme event behavior?

This dissertation is structured as following. Chapter Two analyzes temporal and spatial trends in temperature and precipitation extremes for the Southeast since the mid-20th century from 1948 to 2012. The aim of this first analysis is to comprehensively assess extremes in the region using a global set of extreme indices developed by the World Meteorological Organization (WMO) Expert Team on Climate Change Detection and Indices (ETCCDI) Working Group (Linkage Project LP100200690). This chapter will further examine seasonal trends in temperature and precipitation extremes using a subset of extreme temperature and precipitation indices. A total of 107 United States

Historical Climate Network (USHCN) stations are analyzed and mapped to show direction and significance of trends for each index across the region.

Utilizing the results from Chapter Two, Chapter Three develops a regionalization of climate extremes for the Southeast. A principal component analysis (PCA) is applied on standardized extreme data to identify groups of stations that exhibit similar temperature and precipitation extreme variability and to determine how these sub-groups are distributed across the region. In particular, it investigates whether spatially homogeneous groups exist or whether stations with similarity are dispersed throughout the region. The classification scheme resulting from the PCA will be compared with a k-means clustering method to further investigate possible sub-regions that may exist. Lastly, a PCA is used to develop a seasonality of extremes based on a sub-set of the extreme indices.

Chapter Four compares state and local policy and planning activities related to climate change and extreme events for locations across the Southeast. Climate change and adaptation planning have increased at all levels of government in recent years (Hansen et al. 2013); however, implementation of plans is still largely lacking (Wheeler 2008, IPCC 2012, Bierbaum et al. 2013) and more research is needed to determine the effectiveness of plans (Millard-Ball 2012a, Millard-Ball 2012b). To this aim, the study uses the classification scheme resulting from the regionalization analysis to select several locations as case studies in which to compare historical climate extreme data with climate policy and planning activities. By examining local planning efforts and comparing these efforts across sites that exhibit different temporal variability in extremes, this analysis tests a possible relationship between extreme event behavior and local action.

1.4 Background

1.4.1 Defining and measuring climate extremes

Measuring extremes in climate is a common approach to detecting and monitoring climate change. Various metrics of climate extremes exist, with definitions typically dependent on their intended applications. Extreme climate events can be thought of as the accumulation of several weather events (IPCC 2012); however, they may span both short and long timeframes, on the order of days to months or even years. Defined broadly, extreme climate is unusual climate experienced over large areas and long periods of time (Easterling et al. 2000). Extremes may be represented in the tails of statistical distributions, as well as through time-of-year- and region-dependent measures of temperature and precipitation. Socioeconomic factors can also drive definitions of extremes (Landsea 1999, Easterling et al. 2000, Landsea 2007). For instance, an event may not meet statistical definitions of extremes but may be considered extreme if it produces exceptionally high losses to property, infrastructure, business, or crops. Lastly, the likelihood of an extreme event occurring may be described using return periods or quantile estimates that characterize the average rate of occurrence for certain events of given magnitudes, such as floods, hurricanes, and storm surges of varying heights (Keim et al. 2007, Tank et al. 2009). Changes in the frequency and/or magnitude of these quantiles can describe how climate and weather events are changing, though the long recurrence intervals of extremes can make their estimations less reliable (IPCC 2012).

Statistical approaches are commonly used to investigate changes in temperature and precipitation extremes (Kunkel et al. 1999a, DeGaetano and Allen 2002, Kunkel 2003, Kunkel et al. 2004). Extreme value theory (EVT) is an approach used to estimate extreme values for extreme events with long recurrence intervals. It can help resolve sampling issues inherent in more rare events, such as those that occur 5 percent or less of the time (IPCC 2012). Its main objective is to derive a probability distribution from events in the tails of a distribution that occur less frequently in a given time period (IPCC 2012). Thus, EVT creates a new probability distribution for low probability events that lie in the far tails of the distribution. It is particularly useful for estimating events that do not occur in the available record, such as events that occur once in a hundred years or more (Tank et al. 2009). Two general statistical approaches to EVT exist that are used in climate research: peaks-over-threshold (POT) and block maximum methods (IPCC 2012). The POT method is used to identify extremes over a high threshold, resulting in a generalized Pareto (GP) distribution, which is used as a probability distribution for exceedences over some threshold (Smith 2002). The block maximum method selects the maximum value observed during a defined block of time (e.g. one year, one season, etc.) using a generalized extreme value distribution (Tank et al. 2009).

The Intergovernmental Panel on Climate Change (IPCC) defines climate extremes as the occurrence of a value of a weather or climate variable above (below) a threshold value near the upper (lower) end of a range of observed values of that variable (IPCC 2012). The upper and lower tails of statistical distributions are where the largest changes can occur percentage-wise, making extremes ideal for climate change detection (Trenberth 2011, IPCC 2012). Estimating extreme values under a changing climate must consider how a shift in the temperature or precipitation distribution will affect extremes at the tails of the distribution. In particular, projections of extremes must consider how the mean, variance, and distributions are changing. A change in global mean temperatures would not necessarily lead to a rise in extremes (Frich et al. 2002). According to the IPCC (2012), an overall shift in the distribution and mean toward a warmer (colder) climate results in more warm (cold) extremes and less cold (warm) extremes (Figure1-2a). If variability changes but the mean remains unchanged, the result may be more extreme weather on both tails of the distribution (i.e. more warm and cold extremes) (Figure 1-2b). Finally, a change in the shape of the distribution can lead to an asymmetrical distribution with more, less, or no change in extremes at either end of the distribution (Figure 1-2c).

Research suggests that extremes in temperature track changes in mean temperatures in some regions (Griffiths et al. 2005). In addition, DeGaetano and Allen (2002) found a correlation between mean summer and extreme warm temperatures, whereby if the mean summer temperature increased by 0.5°C over a 50-year period, the 95th percentile exceedence would increase by six events per year. A similar, albeit weaker, relationship was found between mean winter temperature and cold exceedences (DeGaetano and Allen 2002).

Despite these relationships, changes in the variance of exceedence rates do not always follow overall changes in mean values. For example, the second half of the 20th century was a period of general warming (Easterling et al. 2000, DeGaetano and Allen 2002, Groisman et al. 2004). However, Robeson (2002) found that the variance in daily maximum and minimum temperatures was negative or near zero for most of the

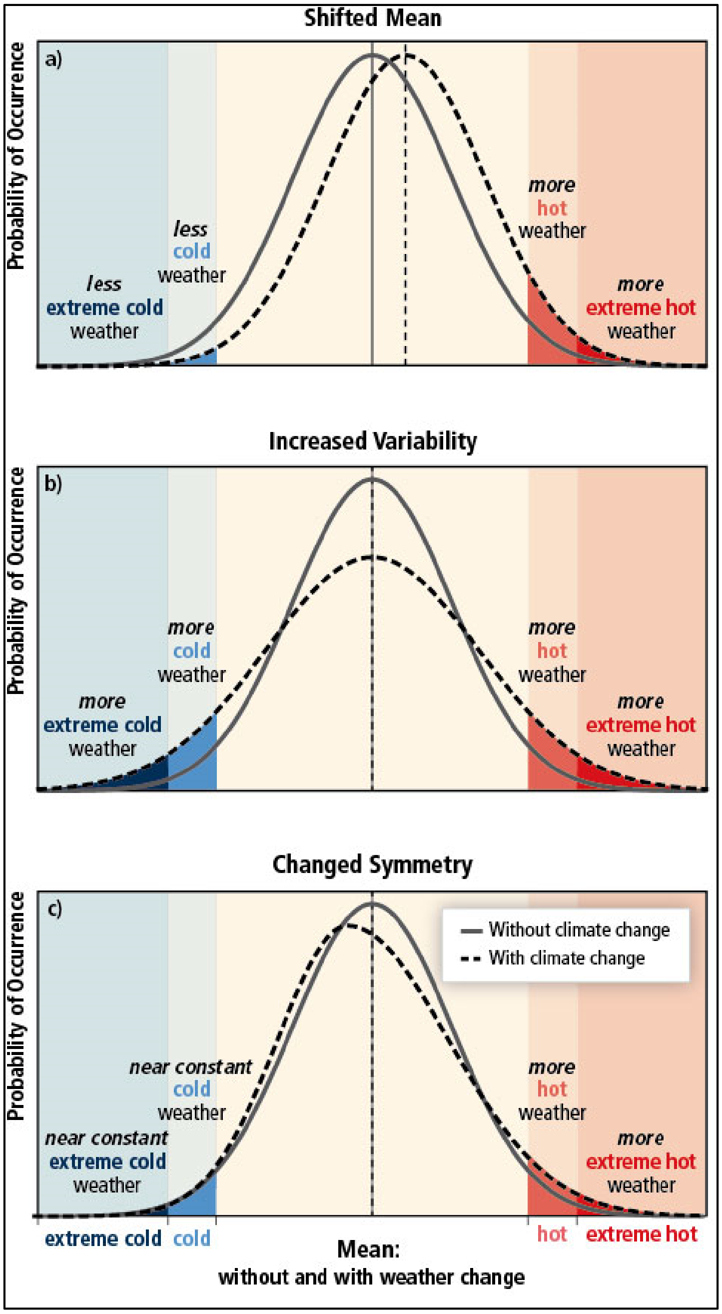

Figure 1-2. The effects of changes in temperature distributions on extreme occurrences, as shown by the IPCC (2012). Changes demonstrate a) the effects of a shift in the mean, b) the effects of an increase in variability with no shift in the mean, and c) the effects of a change in the shape of the distribution.

contiguous United States during this period. Based on his results, Robeson (2002) concluded that as the mean temperature rises, a negative variance response could mitigate some of the adverse impacts of an increasing mean temperature, such as heat stress on crops and humans. Additionally, temperatures in the lower tail of the distribution may rise even more than would be expected with no change in variance, which could produce both beneficial and harmful impacts to agriculture, humans, and the environment. These studies aforementioned demonstrate some of the complexities inherent in defining and understanding extremes under a changing climate.

Region and time-of-year dependent measurements make comparison between regional climate studies complicated. For instance, many methods based on thresholds often limit analysis to certain times of year for which those values make the most sense. Percentiles are useful for measuring changes in extremes across seasons and regions. The choice of threshold will create a new or expected extreme distribution. For instance, Gleason et al. (2008) and Karl et al. (1996) investigated the Palmer Drought Severity Index (PDSI) outside the 90th and 10th percentiles to yield an expected extreme value distribution averaging 20 percent. Temperature extremes are often measured as the number, percentage, or fraction of days with temperatures above the 90th, 95th, or 99th percentiles or below the 1st, 5th, or 10th percentiles with respect to a common base, or reference period, such as the WMO's climate normal period of 1961-1990 (IPCC 2012). For example, maximum and minimum temperatures above the 90th percentile are used to denote warm days and warm nights, respectively, and those below the 10th percentile denote cool days and cool nights, respectively. In addition, the number, percentage, or fraction of days with precipitation above certain thresholds is often used to describe the occurrence of heavy, very heavy, or extremely heavy precipitation days (Tank et al. 2009, IPCC 2012). Similarly, DeGaetano and Allen (2002) computed warm and cold temperature extremes for the United States using temperature exceedences above the 90th, 95th, and 99th percentiles and below the 1st, 5th, and 10th percentiles for 361 USHCN daily stations.

Oftentimes, studies of extremes are based on exceedences over certain thresholds or probabilities of certain magnitudes occurring (IPCC 2012). Unlike percentiles, exceedences over absolute threshold values, or POT, are sensitive to the time of year and spatial characteristics of the region (Tank et al. 2009). Kunkel et al. (2004) used a threshold-based approach to measure changes in the frost-free season, measuring days above 0°C for daily minimum temperatures. Conventional temperature and precipitation extremes may be further altered for more robust statistical analysis and to remove temporal and spatial sensitivities inherent in many climate extreme measures. Henderson and Muller (1997) developed a method to calculate an ‘extreme temperature day’ across all seasons for the South Central United States by defining an extreme warm (cold) day as a daily maximum (minimum) that exceeded one standard deviation above (below) the average daily maximum (minimum) for that day. By comparison, the WMO has indices that define summer (ice) days as the annual count of days when the maximum (minimum) temperature is greater (less) than 25°C (0°C) (Tank et al. 2009). While these indices are easy to interpret, such threshold exceedences may not make sense for all locations and seasons. For example, monthly average maximum temperatures for Dallas, Texas exceed 25°C for seven months of the year, and monthly average minimum temperatures stay above 0°C throughout the year. Lastly, durations may be used in addition to exceedences to analyze extremes. Kunkel et al. (1999a) and Kunkel (2003) analyzed several durations of extreme precipitation, such as 1-, 5-, 7-, and 30-day events, to explain how the magnitudes and intensities of events are changing.

Oftentimes, highly technical analyses of climate change do not translate well for wider audiences or more general application. In addition, the complex nature of climate processes and feedback mechanisms make identifying the point at which conditions become critical (i.e. extreme) more complicated. Indicators and indices are increasingly used in climate studies to compute, assess, monitor, and communicate changes in temperature and precipitation extremes. Indicators and indices can provide a mechanism by which to more easily detect, monitor, and communicate extremes in climate. According to the Organization for Economic Cooperation and Development (OECD), indicators should have relevance for policy and other users, analytical soundness, measurability, and accessibility (OECD 2003). While there are different definitions of indicators and indices, such as defined by the OECD, this research does not distinguish between indicators and indices and uses these two terms interchangeably.

Indices that measure conventional temperature and precipitation extreme parameters provide a more uniform perspective on observed weather and climate extremes between and within countries (Tank et al. 2009). A study by Frich et al. (2002) used a set of ten indices that can be applied to a large variety of climates to measure global changes in temperature and precipitation extremes during the second half of the 20th century. The ten indices identify extremes in daily temperatures and daily precipitation totals. They are: frost days, intra-annual extreme temperature range, growing season length, heat wave duration, warm nights (≥ 90th percentile), heavy precipitation days (≥ 10 mm), consecutive dry days, maximum 5-day precipitation, precipitation on very wet days (≥ 95th percentile), and daily intensity. These ten indices were created through working groups headed by the WMO and Climate Variability and Predictability (CLIVAR) program. The ETCCDI has since expanded these indices by developing more indices and identifying a core set that has been adapted for use in global, continental, and regional analyses. These indices are conventional climate extreme indices that were chosen largely based on their relevance and applicability around the world. They encompass many conventional climate extreme indices used in other studies (ETCCDI 2012). Most of them do not fall within traditional definitions of climate indices; rather, they act more as variables that measure different extreme parameters based on absolute values, percentiles, durations, and thresholds that are deemed important for most regions.

To monitor extremes across the United States, Karl et al. (1996) developed a more traditional index by combining a subset of conventional climate extreme parameters into a single value, called the Climate Extreme Index (CEI). The CEI is used as a monitoring and communications tool to help policymakers, stakeholders, and the broader nonscientific community better understand climate change across the country. The CEI has undergone subsequent updates since its creation (Gleason et al. 2008) and is now available for regions within the United States through the National Climatic Data Center's (NCDC) CEI website (*www.ncdc.noaa.gov/extremes/cei*). The CEI is defined as the annual arithmetic average of five climate extreme indicators based on temperature, precipitation, and the PDSI. These five indicators are defined as the sum of the area of the country with: 1) maximum temperatures much below and above normal; 2) minimum temperatures much below and above normal; 3) severe drought and severe moisture surplus based on the PDSI; 4) much greater-than-normal proportion of precipitation derived from extreme 1-day precipitation events; and 5) much greater-than-normal number of days with and without precipitation (Gleason et al. 2008). These values are represented as percentages of the conterminous United States; thus, they also provide information about the area of the country impacted by each individual indicator. The CEI has been calculated for eight periods, including all four seasons, the year-to-date, cold, and warm periods, as well as for nine U.S. regions that have been defined by the NCDC for purposes of CEI calculation.

Limitations are inherent with any definition of an extreme. Overall, there is no single best way to define a climate extreme; however, the choice of definition largely influences how we come to understand these events. What lies outside ‘normal’ climate variability, which includes fluctuations in temperatures and rainfall patterns, for instance? The definition of a climate extreme will greatly influence how its impacts are measured and perceived. As the IPCC discussed in their report on extremes (IPCC 2012), an event may be considered extreme from a statistical perspective but not in terms of impact. The reverse may also be true. In addition, extremes in temperature and precipitation can vary temporally (i.e. seasonally) and spatially (i.e. by climate division or region). These considerations make comparing extremes across regions and studies especially complicated. Therefore, this research applies the core set of ETCCDI indices to analyze extremes in temperature and precipitation in the Southeast. While defining extremes in ways that make sense to a particular location has advantages with respect to local impacts and adaptive capacity, indices enable comparisons of extreme behavior across regions and across multiple scales. Their wide applicability and relative ease of interpretation also makes them useful for informing strategic approaches to mitigation and adaptation at various scales.

1.4.2 Eigenvector techniques for climate analysis

Eigenvector techniques are often used to simplify large spatial and temporal records of complex data arrays to uncover underlying patterns or structures (Vega and Henderson 1996). More specifically, eigenvector analysis, a term used to collectively refer to eigenvector techniques, reduces temporal and spatial data to facilitate their physical interpretation by expressing the variance of the data through a fewer number of variable dimensions (White et al. 1991). Eigenvector techniques have been commonly used in climatological and meteorological studies to simplify large amounts of data and explain patterns in various parameters (Dyer 1975, Jolliffe 1986, 1990, Green et al. 1993, Vega and Henderson 1996, Nogueira et al. 2012). There are many types of eigenvector techniques. Examples include common Factor Analysis (FA), Canonical Correlation Analysis (CCA) and Empirical Orthogonal Functions (EOF). Principal component analysis (PCA) is among the most popular eigenvector technique employed in climatological research (Vega and Henderson 1996). Moreover, it has been commonly used to describe patterns of meteorological variables, such as temperature, pressure, and precipitation, over large areas (Jolliffe 1986).

PCA is rooted in matrix algebra and is a data transformation or reduction technique. Pearson originally defined PCA in statistical terms (Jolliffe 1990). According to Pearson (1901), if observations are plotted as points along a dimensional space, principal components are defined by successively finding a line or plane of dimension from which the sums of squared perpendicular distances to the points are minimized (Figure 1-3). A less statistical definition of PCA was given by Hotelling (1933) as the successive maximization of variance explained by a new set of variables from an original set of variables. In practice, PCA attempts to reduce the number of variables by creating a subset of variables, called components, that explain most of the variance in the original variables. It does this by looking for a subset of variables that are highly correlated with each other but that are uncorrelated with others (Hamilton 1992). The set of components that explain most of the variance are retained while the remaining components are discarded. PCA assumes that the variables under scrutiny are correlated. Thus, PCA techniques can help to reduce the complexity inherit in multivariate analysis by helping to reduce multicollinearity. The resultant components of a PCA, therefore, remove the collinearity (and correlation) in the variables (Vega and Henderson 1996).

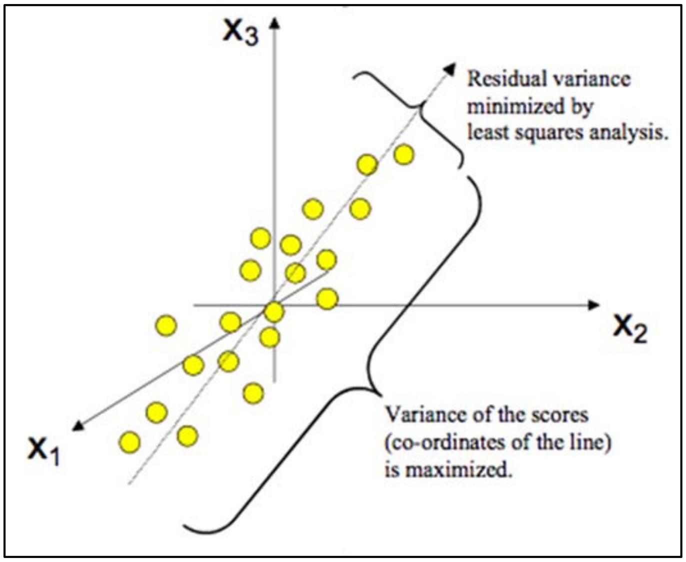

Figure 1-3. Illustration showing how a PCA model finds lines or planes that are the best fit of the data according to the least squares approximation, from Eriksson et al. 2006.

The resulting components of a PCA capture the variation in a data set. The number of components produced by PCA equals the number of initial variables. The first component accounts for as much of the variance as possible; the second component accounts for as much of the remaining variance as possible while being uncorrelated with the first component; the third component accounts for as much of the remaining variance as possible while being uncorrelated with the first two components; and so on (Vega and Henderson 1996). Eigenvalues are defined as the variances corresponding to original components (Wang 2006). Thus, in a PCA, the first principal component has the highest eigenvalue, or variance; the second component has the second highest variance, and so forth.

EOF and CCA may be considered generalizations of PCA (Cheng and Dunkerton 1995), and EOF may be defined as eigenvectors that define principal components (Jolliffe 1986). PCA can be compared closely to FA, and the two are often used together for data reduction (Wang 2006). Nonetheless, several differences between the two techniques have been noted in the literature. One simple distinction involves their use of components. PCA uses the same number of components as the number of original variables in a data set to conduct a simple mathematical transformation of the original data (although all components are not necessarily retained); whereas, FA uses fewer variables to capture most of the variation in the original data using a statistical analysis process (Wang 2006). In addition, PCA attempts to explain the variance of observed variables, while FA explains their intercorrelations. Finally, PCA does not assume uniqueness of data, whereas FA does, which is one reason PCA is often preferred in applications of climatology, given that station data typically do not show unique qualities (Vega and Henderson 1996).

Several specifications must be made in PCA. First, PCA can be based on a covariance or correlation matrix of the variables. Correlations are more often used in practice (Jolliffe 1990). Use of a correlation matrix standardizes the variables by dividing each by its standard deviation. This gives all variables equal weight, since the original variables may have very different variances and variables with the highest variances will dominate the first few principal components (Jolliffe 1990). In addition, use of standardized variables in PCA allows comparison of variables with different units of measure. Second, different modes of PCA exist, depending on the parameters that are used as the variables and individuals for input into the analysis (Green et al. 1993). A spatial, or S-mode, PCA attempts to isolate subgroups of stations with similar temporal characteristics, and the input matrix uses location as the variable index and time as the individual index (Green et al. 1993). The temporal, or T-mode, PCA isolates subgroups of observations with similar spatial patterns, with time being the variable index and location the individuals (Green et al. 1993). Other modes of PCA exist, such as R-mode PCA that examines the correlations or covariations among variables, and Q-mode PCA that focuses on correlations or covariances among samples of the data (Holland 2008). A third specification involves the number of components to retain. This choice is oftentimes subjective, such as using the squared deviations of the eigenvalues or scree plots to make the decision. There must be sufficient separation between eigenvalues to decide the number of components to retain (Richman 1987). Alternatively, the choice may rely on *a priori* knowledge of the data. Lastly, a rotation technique may be applied to the retained components so that they fall closer to the axes. Rotation is often included in PCA to make interpretation of the components easier (Jolliffe 1986).

Rotations are linear transformations of the data (Richman 1986). Research has suggested that rotated variables generally provide more meaningful results than unrotated variables (Richman 1986, White et al. 1991), though Jolliffe (Jolliffe 1990) suggested that unrotated variables are not necessarily less useful than the rotated counterparts. The intent of rotating variables in a PCA is to isolate subsets of variables that covary similarly or that have similar spatial patterns (Richman 1986). Richman (1986) showed that unrotated variables tend to exhibit characteristics that can limit their ability to uncover individual modes of variation. Among these characteristics is domain shape dependence. Originally identified and described by Buell (1975, 1979), domain shape dependence can occur when the topographies of unrotated EOFs are largely determined by the shape of the domain (i.e. physical features) and not by the covariation of the variables and components. As a result, a predictable sequence emerges on unrotated EOFs for different geographical areas, resulting in lower confidence of any real physical meaning of the data (Buell 1975, 1979). Richman suggests that rotation can resolve issues associated with domain shape dependence (Richman 1986, 1987). In particular, the first principal component of rotated variables may be more likely to yield patterns that occur in nature compared to their unrotated counterparts (Richman 1987). Conversely, Legates (1991) found this ‘overdependence’ on rectangularly shaped domains to not hold true. Using a PCA on global precipitation and surface air temperature data, Legates (1991) found that the patterns of the loadings on the first four components were very dissimilar and only minimally influenced by the domain shape, mostly through spatial autocorrelation.

The choice of whether to apply rotation lies largely in the structure of the data. A primary goal of rotation is to align points so that they lie close to one of the axes such that their loadings on the factors that represent the other axes are near zero (Jolliffe 1986). Points that lie close to the axes exhibit simple structures, and points that lie randomly and largely in between axes have weak simple structure. According to Richman (1986), when variables are correlated and clustered along hyperplanes or axes (i.e. strong simple structure), rotation should be used to aid interpretation of components. Conversely, if a highly random configuration of variables exists with little to no clustering along hyperplanes, then rotation will not help to reduce the number of variables to explain the variance. In this latter case, rotation will not be of much use, because any principal component position would be equally valid. Richman (1986) goes on to explain that while meteorological data are generally not random, if they are random, eigenanalysis would be inappropriate. The choice of rotation is only relevant, however, if interpretation of each mode is desired. If PCA/EOF is used strictly for data reduction, rotation is unnecessary (Richman 1987).

There are many types of rotations available in eigentechniques, which fall into two categories: orthogonal and oblique rotations. Orthogonal rotations find planes or lines of best fit at right angles to the initial pairwise plot of variables. Varimax is a commonly used orthogonal rotation technique that attempts to simplify the columns of the matrix as a way to achieve simple structures (Richman 1986). While Richman (1986) found evidence that Varimax may not work as well as other oblique rotations, Varimax is widely accepted as being the most accurate technique when applied to known data sets, i.e. when *a prior* knowledge of the data exists. Thus, a rotation using Varimax was used in the present research to aid in the interpretation of components. Other orthogonal rotation techniques that are readily available in statistical software packages include Equimax and Quartimax. Commonly available oblique rotations, which do not find planes at right angles, include Direct oblimin, Harris-Kaiser Class II and III, and Procrustes, among others (Richman 1986).

1.4.3 National climate and disaster mitigation trends

Hazard mitigation and climate adaptation planning both seek to lessen the adverse impacts from climate and weather extremes. Hazard mitigation refers to efforts to reduce loss of life and property by lessening the impact of disasters, with emphasis on proactive measures that reduce losses long term (FEMA 2013). While hazard mitigation planning is now a common practice among state and local governments, climate adaptation is a more recent area of planning. Adaptation is defined as an adjustment in natural or human systems in response to a new or changing environment that moderates harm or exploits beneficial opportunities (IPCC 2012). In contrast to hazard mitigation, climate mitigation refers to actions that enhance carbon sinks and reduce carbon sources from human induced greenhouse gas (GHG) emissions that contribute to earth’s greenhouse effect (NCADAC 2013). Climate mitigation is often implemented through technological changes or substitutions that reduce emissions.

Gaining a better understanding of the effects of climate change can help facilitate more effective planning to mitigate adverse impacts, such as to agriculture, natural and artificial water systems, infrastructure, and utilities. In addition, an understanding of how climate extremes are changing is a prerequisite for effective policy and planning. The NOAA Coastal Services Center (CSC 2010) identified several barriers to resilience planning in the United States. First, hazard mitigation planning and long-range climate adaptation planning often compete with economic development and more short-term needs, with an exception possibly being when disaster events occur. Because planning tends to favor growth through economic development and hazard mitigation planning restricts growth in high-risk areas, there is often a lack of support for hazard planning. Additionally, once plans are developed and adopted, they are often not implemented (Wheeler 2008, Bierbaum et al. 2013), particularly if plans are politically driven, such as for federal funds and disaster assistance (CSC 2010). In addition, federal mandates can lead to increased planning but often do not include implementation; thus, mandates can lead to communities producing their first plans, but many communities may not implement these plans post development (CSC 2010).

Ineffective policies can act to worsen existing problems. In the early to mid-1900s, a focus on federal flood control structures provided an increasing sense of security that attracted new development in floodplains (Burby 2006, Rubin 2012), yet despite increased protection, monetary losses continued to rise (Rubin 2012). The National Flood Insurance Program (NFIP) was established in 1968 in response to a failure of physical structures alone to provide adequate protection against floods. The NFIP was designed by Congress to mitigate flood losses through community-enforced building and zoning ordinances and to provide affordable, federally backed flood insurance to property owners (FEMA 2011). However, the availability of flood insurance, coupled with the availability of federal disaster relief funds through the Disaster Relief

Act, further contributed to development in high-risk areas. The increasing amount of federal disaster money likely discouraged more careful planning and responsible community growth patterns (TheHeinzCenter 2002). In 1988, the Robert T. Stafford Disaster Relief and Emergency Assistance Act (Stafford Act) authorized post-disaster federal assistance to both states and local governments for disaster mitigation projects. However, it was not until the Disaster Mitigation Act of 2000 (DMA) that hazard mitigation planning became a priority. The DMA amended the Stafford Act to provide the legal basis for the Federal Emergency Management Agency's (FEMA) mitigation planning requirements of State, Local, and Indian Tribal governments. Thus, the DMA represents a much more proactive approach and an increased emphasis on pre-disaster planning at the state and local levels (Berke et al. 2009).

An overall lack of building code enforcement before the early 2000s (Pielke et al. 2008) has also been a contributing factor to poor development choices. Building code requirements have varied largely from state to state and even county to county, as responsibility of code enforcement was largely deferred by states to local governments (TheHeinzCenter 2002). The issue of building code enforcement holds true for the high-risk and vulnerable coastal states within the Southeast. In particular, none of the Gulf Coast states, including Alabama, Mississippi, Louisiana, and Texas, required local government code enforcements or local comprehensive plans before 2002 (Burby 2006). Building code requirements were also absent in Georgia and South Carolina. Only Florida and North Carolina had both local building code and comprehensive plan requirements before the early 2000s, with Florida requiring local comprehensive plans as early as 1975 (Burby 2006).

Climate adaptation is a nascent area of focus that has begun under the Obama Administration in recent years. Currently, many sectors and all levels of government, as well as the private sector, are engaging in some level of adaptation planning (Bierbaum et al. 2013). In 2009, President Obama signed Executive Order (EO) 13514, titled “Federal Leadership in Environmental, Energy, and Economic Performance,” to serve as the foundation for a coordinated approach to climate change preparedness and resilience at the Federal level. It established the Interagency Climate Change Adaptation Task Force, an interdepartmental council charged with developing a set of policy and planning recommendations on how to better prepare the country for climate change (ICCATF 2011). In November 2013, Obama signed an EO titled “Preparing the United States for the Impacts to Climate Change” to further increase the nation’s preparedness for the impacts of climate change. It established an interagency Task Force on Climate Preparedness and Resilience made up of State, Local, and Tribal leaders. The EO is expected to help guide federal agencies and assist states to build infrastructure that will withstand the impacts of climate change.

1.4.4 Southeast climate planning trends

Barriers to planning have inhibited more proactive action in the Southeast. Godschalk (2007) suggested that a lack of collaboration between agencies has been a problem and has led to a failure to follow through with and implement land use and comprehensive plans among government agencies. The CSC (2010) similarly concluded that a common deficiency in growth management planning efforts existed in Florida, Georgia, South Carolina, North Carolina, and Alabama, whereby government agencies were unable to follow through in carrying out the recommendations outlined in growth management plans. A report by The Heinz Center (2002) highlighted 18 locations that were engaged in climate adaptation planning across the United States, with Miami-Dade County, Florida representing the only location in the Southeast. In addition, the Georgetown Climate Center's current database of state and local adaptation plans identifies 16 states engaged in adaptation planning, with Florida being the only state in the Southeast that has completed or begun work on a statewide adaptation plan (GeorgetownClimateCenter 2013b). Thus, while there has been an increased focus on climate change and climate adaptation efforts at the Federal level, the Southeast has made limited progress with respect to climate adaptation planning. Once exception is Florida, which has taken progressive action for climate adaptation and comprehensive planning in response to intense development in its high-hazard coastal areas. For instance, the state passed a statute in 2006 requiring local governments to establish comprehensive planning that includes coastal zone protection and hazard mitigation elements (Emmer et al. 2007).

Integrating mitigation and adaptation within existing community planning efforts will become increasingly important as communities plan to grow their local economies while preparing for the impacts of changing temperature and precipitation patterns. According to Berke et al. (2010), states can enhance stand-alone hazard mitigation plans by integrating these plans with land use planning, ecosystem management, economic development, and climate change adaptation. In addition, a study prepared by the Louisiana Sea Grant suggests that the effectiveness of comprehensive planning, which often incorporates risks from natural hazards, is greatly increased when it considers a community's overall vision for future development (Emmer et al. 2007).

Lackstrom et al. (2012) found that sectors within the Carolinas are increasingly engaged in adaptation but additional data needs, resources, and support are needed to increase adaptation planning. Historically, hazard mitigation, comprehensive resilience, and adaptation planning happened in silos. While this is beginning to change, there is still much work to be done to better integrate planning efforts and increase preparedness for changing risks (Babcock 2013).

CHAPTER 2. TRENDS IN DAILY TEMPERATURE AND PRECIPITATION EXTREMES FOR THE SOUTHEAST UNITED STATES

2.1 Introduction

Changes in climate extremes and natural disasters are among the most serious challenges in coping with climate change (USCCSP 2008). Extreme events impact human populations and natural systems on which they depend. Extremes in temperature can increase energy demand (Henderson and Muller 1997), stress crops, and endanger human health (Henderson and Muller 1997, Kunkel et al. 1999a, Kunkel et al. 2013), while precipitation extremes can result in flooding and damages to crops (USCCSP 2008) and infrastructure (Brown et al. 2010). The vulnerability of communities and ecosystems to future climate will likely be due to changes in the intensity and frequency of extreme events rather than changes in overall mean climate (Katz and Brown 1992, Lynch and Brunner 2007). Thus, measuring changes in temperature and precipitation extremes is important for assessing the impacts of climate change on human and natural systems (Tebaldi et al. 2006).

There has been a growing body of research measuring national trends in extreme climate in recent years, including extremes in temperature (Henderson and Muller 1997, DeGaetano and Allen 2002, Kunkel 2003, Kunkel et al. 2004, Gleason et al. 2008, Peterson et al. 2008, IPCC 2012), precipitation (Kunkel 2003, Faiers and Keim 2008, Gleason et al. 2008, Peterson et al. 2008), and severe storms (Emanuel 2005, Keim et al. 2007, Knight and Davis 2009). Studies have concluded that much of North America has seen more hot days and nights and fewer cold days and nights, as well as fewer frost days (USCCSP 2008). In addition, heavy rainfall events appear to be increasing in frequency and intensity, and droughts are more severe in some regions

(USCCSP 2008). Extreme precipitation has been increasing in the United States over roughly the last century, with increases in extreme precipitation from tropical cyclones in more recent decades (Knight and Davis 2009). The impacts of climate extremes are generally most salient at regional and local scales (Alexander et al. 2009). Much of the aforementioned research contributed to the U.S. NCAs and synthesis products, which have generated more regional analyses of climate since 2000. However, more information regarding regional patterns of climate change and ongoing monitoring of changes in climate extremes is needed (Griffiths and Bradley 2007, IPCC 2007).

The impacts of extreme weather and climate events are noticeably increasing. Direct losses from natural hazards are rising (Changnon et al. 2000, Pielke et al. 2008), particularly as a result of hurricanes and floods over the past fifty years (Gall et al. 2011). According to FEMA loss statistics, the number of presidentially declared disasters has clearly increased over the past sixty years since 1953 (Figure 2-1). Many factors play a role in determining the number of disaster declarations, such as institutional changes, a president’s view of federal-state relationships, policy positions on disasters, and presidential priorities (Rubin 2012), as well as increased social vulnerability due to more people and property in harm’s way (Changnon et al. 2000, Pielke et al. 2008). However, direct losses from natural disasters cannot be explained solely by growth in population and wealth, and the increasing trend is likely influenced by changes in disaster frequency, magnitude, and/or social resilience as well (Gall et al. 2011).

Extremes are particularly important elements of climate in the Southeast U.S. The South experiences more weather extremes than any other National Weather

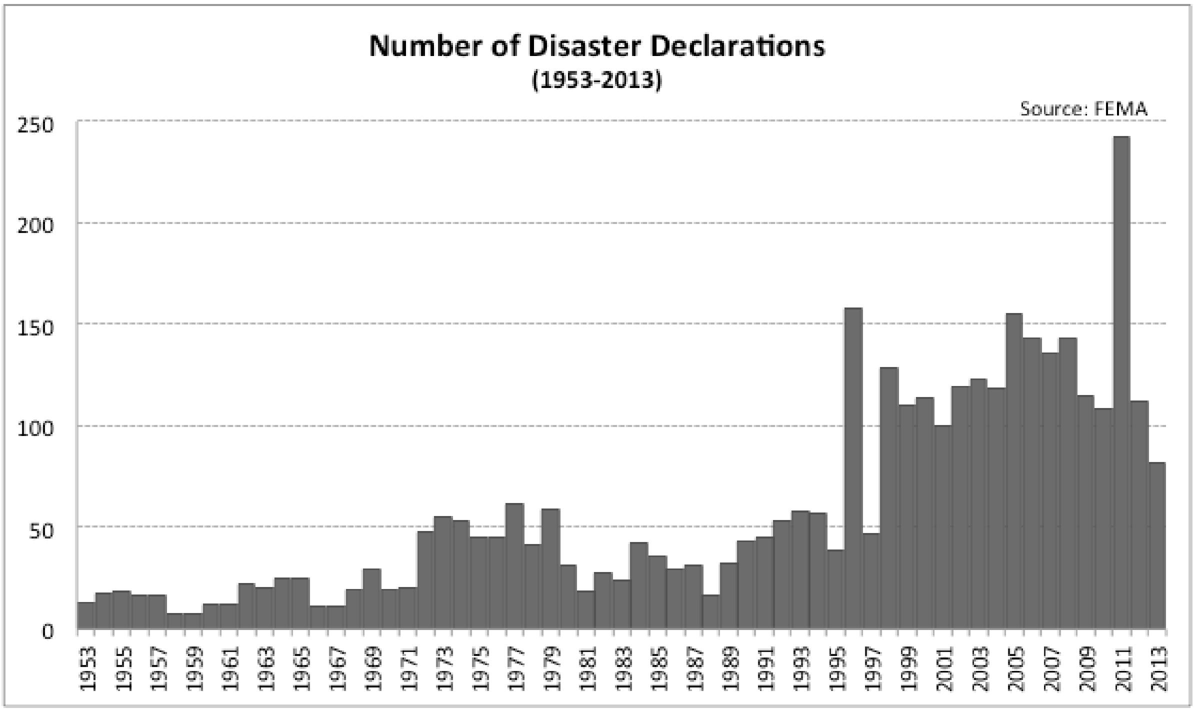

Figure 2-1. Number of disaster declarations in the United States from 1953 to 2013 (Source: FEMA).

Service (NWS) region in the country (NWS 2012). Since 1980, the Southeast has experienced more billion-dollar weather disasters than any other region in the United States, mostly due to hurricanes, floods, and tornadoes (NOAA 2013). The Southeast is susceptible to a wide variety of weather and climate extremes that impact natural and man-made environments (Kunkel et al. 2013). The Bermuda High (BH), a semi-permanent high pressure system off of the Atlantic Coast, contributes to the generation of heat waves, droughts, and poor air quality in the Southeast, as well as steering hurricane tracks in the region (Kunkel et al. 2013). The Southeast's proximity to large sources of moisture influences the occurrence of heavy rainfall events. Changes in the flow of the jet stream are responsible for creating stormy weather at the boundary of cold, drier air from the north and warm, moist air from the south, which is particularly common in the spring. Strong meridional flow can result in cold-air outbreaks as far south as central Florida (Kunkel et al. 2013). The variability of extreme weather in the Southeast, combined with its diverse population comprised of dense urban centers, coastal populations, and rural towns, make a more detailed analysis of extreme event behavior particularly important to the region's capacity to adapt and mitigate adverse impacts.

2.1.2 Research objectives

While many studies have investigated extreme events in the Southeast (Faiers et al. 1994, Henderson and Robinson 1994, Keim et al. 1995, Henderson and Muller 1997, Keim 1999, Faiers and Keim 2008, Knight and Davis 2009), they are generally independent studies that define extremes in various, perhaps even disparate, ways. Perhaps one recent exception to this was a study by Kunkel et al. (2013) who assessed Southeast climate for the Third National Climate Assessment (NCA) report. Comprehensive assessments of extremes in temperature and precipitation have been conducted for other parts of the United States, including for the Northeast Region (Griffiths and Bradley 2007, Brown et al. 2010), the state of New York (Insaf et al. 2012), and the state of Utah (dos Santos et al. 2011). These studies offer a more detailed analysis of the spatial and temporal variability in climate extremes and the types of extremes most important to each region.

A comprehensive assessment of how climate extremes are changing across the Southeast can provide important information for stakeholders and decision makers, particularly as a region that experiences a wide range of extreme weather and climate. For instance, information about the number of frost days, extreme wet days, warm spells, and growing season length are important to agriculture, local infrastructure, and public health (Brown et al. 2010). Additional benefits of monitoring extremes in climate include the ability to place the magnitude and frequency of extreme events in a regional, national, and global context, as well as to assess anomalous changes in temperature and precipitation extremes that may have particularly severe local impacts (Donat et al. 2013). This study assessed changes in temperature and precipitation extremes for the Southeast United States to provide a more detailed assessment of extreme behavior for this region.

The main objectives of this study are as follows:

1. to assess annual spatial and temporal trends since the mid-20th century in temperature and precipitation extremes for the Southeast, and
2. to examine seasonal trends in temperature and precipitation extremes for the same region.

2.2 Data and Methods

2.2.1 Station data

Analysis of extreme events is often restricted by a lack of high-quality, long-term climatic data (Easterling et al. 2000). However, the NCDC produced a long-term dataset for use in regional extreme climate change detection, known as the USHCN. The USHCN has undergone a high level of quality control and quality assurance testing, resulting in a high quality dataset. USHCN data include daily and monthly records of maximum and minimum temperatures, precipitation amount, snowfall amount, and snow depth. These data were derived from various digital and non-digital sources and have been subjected to extensive manual and automated quality assurance testing, with the first daily database release in 1992, referred to as H92 (Menne et al. 2011, Menne et al.

2012). While subsequent updates to daily data have not adhered to as strict of requirements as the H92 to allow for better spatial coverage, the USHCN daily dataset is generally considered to be of high quality with most station record lengths complete for at least 60 years. This study uses daily maximum and minimum temperatures and daily precipitation amounts from the USHCN daily dataset to calculate extremes in climate.

The current version of the USHCN database contains data from three main sources, namely the U.S. Cooperative Summary of the Day, Climate Data Modernization Program, and U.S. First Order Summary of the Day datasets. Many USHCN stations are U.S. Cooperative Observer Network (COOP) data operated by the NWS. COOP stations are generally located in more rural areas. Other USHCN stations are NWS First-Order stations that are more often located at airports or more urbanized locales. Extensive quality control efforts were made by the NCDC to the USHCN dataset to minimize bias due to length of record, percent of missing data, and factors affecting homogeneity. Quality control procedures have included internal consistency, frequent-value, outlier, and spatial consistency checks, as well as subsequent temperature- and precipitation-specific checks (Menne et al. 2012). In addition, stations are generally checked for completeness, reasonableness, and accuracy. Completeness is often represented as less than ten percent missing data for a period of record (Gleason et al. 2008, Insaf et al. 2012).

The USHCN includes 1,218 stations across the contiguous United States, chosen for their overall quality relative to other COOP stations. The number of USHCN stations in the Southeast, as defined in this study (Figure 1-1), totals 290. These stations include 173 in the 6-state SRCC region, including 15 stations each in Arkansas and Tennessee, 18 stations in Louisiana, 32 stations in Mississippi, 44 stations in Oklahoma, and 49 stations in Texas. In addition, there are 177 stations in the remainder of the Southeast, including 14 in Alabama, 22 in Florida, 23 in Georgia, and 29 stations each in North and South Carolina. When analyzing extreme climate using daily data, it is important that records be complete, or near complete, for the given period under investigation (Moberg and Jones 2005, Griffiths and Bradley 2007). Of the 290 USHCN stations available in this study region, 200 stations were initially selected based on a ten percent missing data criterion for the period 1910-2012. However, years with missing data should not be clustered together in certain intervals or blocks within the record, which could lead to spurious trends (Moberg and Jones 2005, Griffiths and Bradley 2007). Therefore, more strict criteria were needed for the selection of stations included in this study.

Final station inclusion was based on a more thorough assessment of the number and cluster of missing values throughout the period of record. The method applied in this study closely followed methods used previously by Moberg and Jones (2005) and Griffiths and Bradley (2007). Moberg and Jones (2005) used a missing data threshold of two missing days in one month for determining whether a month was complete; whereas, Griffiths and Bradley (2007) used a threshold of five missing days in one month to define a ‘complete’ month. The same threshold of five or less missing days in one month was initially used for a subset of the 200 stations in this analysis. However, it was clear that this criterion needed to be relaxed slightly to incorporate a greater number of stations in the analysis. Therefore, a threshold of seven days was tested for a subset of stations and determined to be sufficient to allow for the incorporation of more stations while not compromising the ‘completeness’ of the data substantially. For instance, relaxing the criteria from a threshold of five days to seven days brought the number of stations that could be included in this study up from two to five stations in Alabama; from three to six stations in Georgia; and from five to eight stations in Louisiana.

The final methodology used to select stations with reasonable completeness included the following criteria: 1) a month was considered to have sufficiently complete data if there were seven or less missing days within that month; 2) a year was considered to have sufficiently complete data if all months were complete according to (1); and 3) a station was considered to have sufficiently complete data if all three of the following blocks had less than or equal to seven missing years: 1910-1944, 1945-1978, and 1979-2012. This methodology closely follows that used by Moberg and Jones (2005) and Griffiths and Bradley (2007).

Based on these criteria, results revealed that the first block, 1910-1944, was the most problematic, with few stations having sufficiently complete data to be considered for inclusion. Therefore, it was decided to truncate the period of record to 1948-2012 to include a sufficient number of stations in the analysis. This start date was chosen based on the fact that most daily Cooperative Summary of the Day station records began in 1948 (Menne et al. 2012). Furthermore, based on the threshold of seven missing days described above, changing the start date from 1910 to 1948 substantially improved the total number of stations included in the analysis, from 38 to 107 stations total. Appendix A provides basic information on all 107 stations used in this study, including state, climate division, latitude and longitude, and elevation. Figure 2-2 shows the distribution of stations across the study region. It is clear that these stations do not cover all areas within the study region equally, with gaps particularly in western Texas, the Florida panhandle, and southeastern portions of Georgia and Florida. However, nearby and somewhat distant stations in the south central region have been shown to display similar daily patterns of extremes (Henderson and Muller 1997). In addition, the objective of this study is to describe general trends in climate extremes for the region as a whole. Thus, this distribution of stations should provide a reasonable representation of extreme events for purposes of this study.

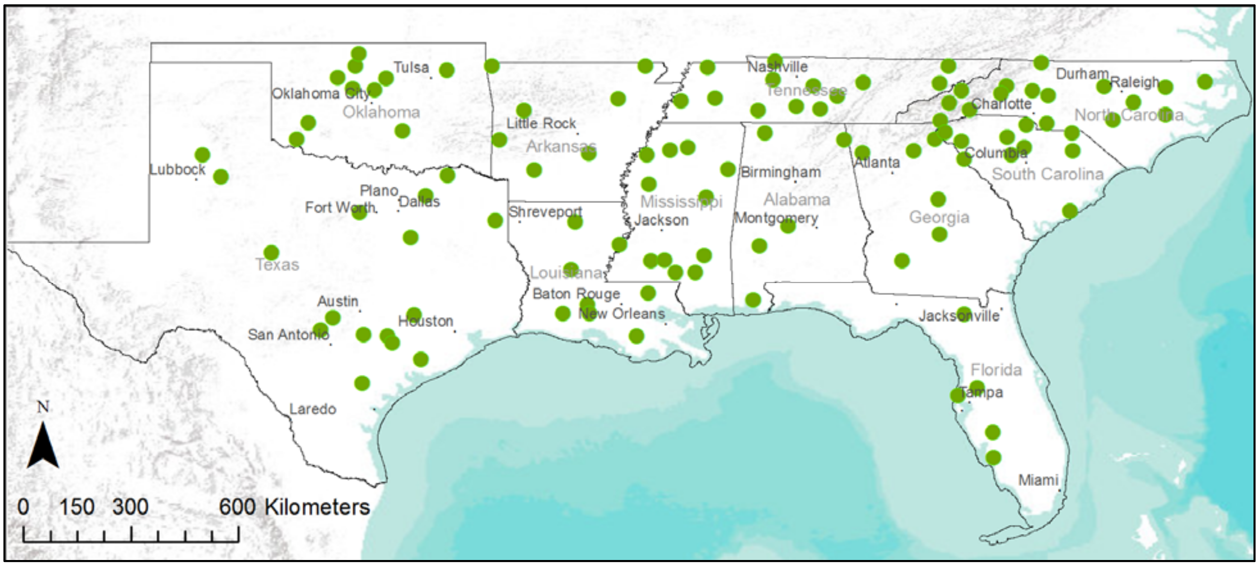

Figure 2-2. Distribution of USHCN stations within the Southeast included in this analysis.

2.2.2 Extreme indices

Studies have expressed a need for more robust extreme indicators to detect changes in climate extremes (Frich et al. 2002). The ETCCDI working group approved a set of extreme climate definitions as guidance for measuring and monitoring extremes, as well as related software packages for their calculations. The goals of the ETCCDI are to promote international collaboration on climate change detection, increase monitoring of extremes between and within countries, and encourage comparison of observations to modeled data. The ETCCDI created and continue to maintain a core set of extreme indices for global application to address the characterization of climate variability and change. These indices reflect extreme aspects of climate by characterizing intensity, duration, and frequency of events (Donat et al. 2013); however, they assess more moderate extremes that can occur several times a year, rather than high-impact, low probability events that may only occur once per decade or less often.

The ETCCDI is comprised of the Commission for Climatology (CCI) of the WMO's World Climate Data and Monitoring Program (WCDMP), the CLIVAR program of the World Climate Research Program (WCRP), and the Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM). Together, the joint CCI, CLIVAR, and JCOMM ETCCDI continue to maintain and recommend climate extreme indices for use in global datasets through the CLIMDEX project (*www.climdex.org*). The CLIMDEX project is maintained by a group of researchers at multiple organizations: the Climate Change Research Centre, The University of New South Wales (funded by the Australian Research Council and the Australian Department of Climate Change and Energy Efficiency through the Linkage Project LP100200690), in collaboration with the University of Melbourne, Climate Research Division of Environment Canada, and NOAA's NCDC in the United States. The overall goals of the CLIMDEX project are to produce *in situ*, gridded land-based global datasets of extreme indices; increase access to these data for research purposes; assess variability in climate extremes; assess uncertainties in representing extreme climate; evaluate climate model output; and provide traceability for methods of computation.

The origins of the ETCCDI began with a meeting of the WMO and CCI/CLIVAR Working Group in 1998, which led to subsequent meetings held around the world to discuss development of a global daily dataset for inclusion in the IPCC Third Assessment Report (Frich et al. 2002). While time constraints did not allow sufficient time to produce, analyze, and publish findings for the Third Assessment Report, this joint effort resulted in the compilation of data files of daily temperature and precipitation series for many locations around the world.

ETCCDI indices were developed to provide a common method by which to measure and monitor extremes in climate across regions. The ETCCDI developed their set of extreme indices primarily based on daily temperatures and precipitation amounts. The CCI/CLIVAR Working Group has now approved 40 indices in all, which includes a core set of 27 indices These indices do not meet traditional definitions of an index, and only a few can be assumed to follow extreme value distributions (ETCCDI 2012).

This study used the core set of 27 indices developed by the ETCCDI. These core indices include 20 temperature indices, which are 16 core indices and four user-defined indices (Table 2-1a), and 11 precipitation indices (Table 2-1b). Temperature indices include nine warm and seven cold indices, and these can be further grouped according to their method of calculation as four percentile, four threshold, one absolute, and three duration indices. Precipitation indices include ten wet indices and one dry index, which are further grouped as two percentile, three threshold, two absolute, two duration, and two other indices (see Table 2-1 for units). Appendix C includes the full definitions and formulas for each indicator.

Several studies have used these WMO standard indices to describe trends in temperature and precipitation extremes in the United States (Frich et al. 2002, Alexander et al. 2006, Peterson et al. 2008), as well as for other parts of the world (Zhang et al. 2005a, Tank et al. 2006, Tebaldi et al. 2006, Alexander and Arblaster 2009, Sen Roy 2009). Studies conducted for other regions of the world were largely in areas where less information was previously available. For instance, Rahimzadeh et al. (2009) computed the 27 core indices to assess climate variability in Iran, and Roy (2009) analyzed a subset of these indices to detect trends in extreme hourly precipitation patterns across India, both historically data-sparse regions. Within the United States, these WMO indices have been used to investigate extremes in climate for particular states and regions, including for the Northeast (Griffiths and Bradley 2007, Brown et al. 2010), New York (Insaf et al. 2012), and Utah (dos Santos et al. 2011).

The ETCCDI approach has also been used among the climate modeling community to improve regional climate projections (Alexander and Arblaster 2009, Fowler and Ekström 2009). These studies used the WMO indices to assess how well climate models represent observed trends in extremes and how well multiple simulations of future trends agree. These countrywide studies build on the work by Frich et al. (2002), who were the first to use the ETCCDI approach to conduct a global analysis of temperature and precipitation extremes. They calculated ten extreme indices, including five temperature and five precipitation indices, which were later used to verify global model projections of these same extremes (Tebaldi et al. 2006). Model

Table 2-1. (a) A list of the 16 core ETCCDI extreme temperature indices and their definitions, and (b) a list of the 11 extreme precipitation indices and their definitions, available online at: *www.climdex.org/indices.html*.

(a) Temperature Indices			
Index Name	ID	Definition	Units
Percentile			
Warm days	TX90p	% of days when Tmax is > 90th percentile	%
Warm nights	TN90p	% of days when Tmin is > 90th percentile	%
Cool days	TX10p	% of days when Tmax is < 10th percentile	%
Cool nights	TN10p	% of days when Tmin is < 10th percentile	%
Threshold			
Summer days	SU25	Annual count when Tmax > 25 °C	Days
Summer days	SU35	Annual count when Tmax > 35 °C	Days
Tropical nights	TR20	Annual count when Tmin > 20 °C	Days
Tropical nights	TR24	Annual count when Tmin > 24 °C	Days
Ice days	ID0	Annual count when Tmax < 0 °C	Days
Ice days	ID-2	Annual count when Tmax < -2 °C	Days
Frost days	FD0	Annual count when Tmin < 0 °C	Days
Frost days	FD-2	Annual count when Tmin < -2 °C	Days
Absolute			
Warmest day	TXx	Annual maximum value of daily max temp	Deg C
Warmest night	TNx	Annual maximum value of daily min tem	Deg C
Coldest day	TXn	Annual minimum value of daily max temp	Deg C
Coldest night	TNn	Annual minimum value of daily min temp	Deg C
Diurnal temp range	DTR	Daily Tmax - Daily Tmin	Deg C
Duration			
Growing season length	GSL	Annual count between first span of at least 6 days with Tmean>5C and first span after July 1 of 6 days with Tmean<5°C	Days
Warm spell duration	WSDI	Annual count of days with at least 6 consecutive days when Tmax > 90th percentile	Days
Cold spell duration	CSDI	Annual count of days with at least 6 consecutive days when Tmin < 10th percentile	Days

simulations projected changes in climate extremes under various emission scenarios to the end of the 21st century. Results indicated positive trends in growing season length,

(Table 2-1 continued)

(b) Precipitation Indices			
Index Name	ID	Definition	Units
Percentile			
Precipitation on very wet days	R95pTOT	Annual total PRCP when RR > 95th percentile	mm
Precipitation on extremely wet days	R99pTOT	Annual total PRCP when RR > 99th percentile	mm
Threshold			
Number of heavy precip days	R10mm	Annual count of days when PRCIP >= 10mm	Days
Number of very heavy precip days	R20mm	Annual count of days when PRCP >= 20 mm	Days
Number of days above *nn* mm	Rnnmm	Annual count of days when PRCP >= nn (user-defined threshold)	Days
Absolute			
Max 1-day precip	Rx1day	Annual max 1-day precip	mm
Max 5-day precip	Rx5day	Annual max consecutive 5-day precip	mm
Duration			
Consecutive wet days	CWD	Max number of consecutive days when RR >= 1mm	Days
Consecutive dry days	CDD	Max number of consecutive days with RR < 1 mm	Days
Other			
Annual total wet day precip	PRCPTOT	Annual total PRCP in wet days (RR >= 1mm)	mm
Simple daily intensity index	SDII	Annual total precip divided by the number of wet days (PRCP >= 1mm)	mm/day

heat waves, and warm nights, as well as negative trends in frost days and diurnal temperature range, all consistent with a warming climate. Models also agreed with observed precipitation extremes, indicating a trend toward more intense precipitation, including a greater frequency of heavy precipitation and high quantile events, though with much greater spatial variability (Tebaldi et al. 2006).

The ETCCDI's core set of 27 extreme temperature and precipitation indices provides an objective method by which to measure and characterize variability in climate extremes between and within regions. They can provide important information for the Southeast, particularly as a region that experiences a wide range of extreme weather and climate events. Many of these indices have applicability and relevance to specific sectors as well. For instance, frost days, ice days, growing season length, extreme wet days, and warm spells are important to agriculture, local infrastructure, and public health (Brown et al. 2010). Key advantages to using this suite of indices to assess climate change include the ability to place the magnitude and frequency of extreme events in a regional, national, and global context, as well as to assess anomalous changes in temperature and precipitation extremes (Donat et al. 2013).

2.2.3 Computation of extreme indices

The ETCCDI indices are currently maintained through the CLIMDEX project, which provides access to global, *in situ* gridded datasets of these indices, as well as software for their computation. The CLIMDEX project maintains several software packages for use in different platforms. Two versions of the software were initially released, the first for use in Excel and the second for use in Fortran. The latest version of the software, called RClimDex, runs in R, a language and environment for statistical computing and graphing. This version reflects updates that have been made to the program since the release of the two former versions. This study uses the R version of the software for calculating extreme indices. Daily temperature data were converted to degrees Celsius and daily precipitation amounts to millimeters, and input station files were converted to ASCII text files for use in the RClimDex software. In addition to the

31 core and user-defined indices, the RClimDex program calculates monthly and annual mean maximum and minimum temperatures.

Threshold indices are computed from a common 30-year base period to allow for comparison of trends between stations with different record lengths. The base period used in this study was 1981-2010 to reflect the most recent ‘normal’ period. While similar studies use a base period of 1971-2000 for comparison with the WMO operational climatology base period, it is assumed that the standard use of this base period will be updated eventually for all regions (Insaf et al. 2012). While choice of base period may affect the number of exceedences in any given year, it has no effect on the magnitude or direction of any temporal trends present in the time series (DeGaetano and Allen 2002).

The RClimDex program uses a bootstrapping technique to address any discontinuities in the expected rates for the years on the boundaries of the base period, thereby making estimations of threshold exceedence rates for both the in-base and out-of-base periods comparable and temporally consistent (Zhang et al. 2005b). A detailed description of the bootstrapping procedure used to calculate the base period thresholds is provided by Zhang et al. (2005b) and Zhang and Yang (2004), and a brief description is provided here. The base period ‘normal’ is computed by taking the 30-year base period and dividing it into one out-of-base year, which is the year for which exceedence is to be estimated. The remaining 29 years become the base period from which the thresholds are estimated. A 30-year block is used by taking the 29-year base period and adding an additional year of data from the out-of-base period (the one year removed from the 30-year block). The out-of-base year is compared with the thresholds and the exceedence rate for the out-of-base year is obtained. This is repeated 28 times by repeating each of the remaining 28 in-base years in turn to construct the final 30-year block. The final index for the out-of-base year is obtained by averaging the 29 estimates (Hyndman and Fan 1996).

The RClimDex program allows for several user-defined inputs when calculating indices. In addition to the first and last years of the base period, user-defined parameters include the upper and lower thresholds of daily maximum temperature, upper and lower thresholds of daily minimum temperature, and daily precipitation threshold. Default temperature thresholds are automatically computed for summer days (25°C), tropical nights (20°C), frost days, (0°C), and ice days (0°C). In addition to these default values, user-defined thresholds produce additional estimates of these same indices based on threshold values that better reflect the region under investigation.

The following thresholds were used in this study in addition to the defaults:

1. an upper threshold of daily maximum temperature of 35 ˚C (95˚F),
2. upper threshold of daily minimum temperature of 24 ˚C (75˚F),
3. lower threshold of daily maximum temperature of -2 ˚C (28˚F),
4. lower threshold of daily minimum temperature of -2 ˚C (28˚F), and
5. daily precipitation threshold of 102 mm (4 in).

The upper thresholds of daily maximum temperature of 35˚C and daily minimum temperature of 24˚C are commonly used thresholds for examining warm temperature extremes in the Southeast (Kunkel et al. 2013). Thus, these values were chosen for consistency with other work and because they more appropriately analyze extremes in the climate of this region, which is generally warmer than much of the United States.

The lower threshold of daily maximum and minimum temperatures of -2°C was chosen to assess the occurrence of hard freezes in addition to frost days and ice days, which are based on minimum and maximum temperature thresholds of 0°C, respectively. The daily precipitation threshold of 102 mm, or four inches, was based on previous work developed to inform regional descriptions of climate extremes for the latest National Climate Assessment (NCADAC 2013). In addition, the RClimDex default values for extreme precipitation events are relatively low in magnitude, i.e. 10 mm (0.4 in) and 20 mm (0.8 in), and a much higher threshold was desired here to reflect heavy rainfall events more characteristic of the region that can exceed 100 mm in a 24-hour period (Keim 1999, Faiers and Keim 2008). These user-defined values were held consistent across the study region to more easily compare and analyze spatial variations in these indices.

In addition to the quality control measures that are part of the USHCN daily dataset, further quality control tests are embedded in the RClimDex program. The RClimDex program calculates annual values for each index, as well as monthly values for a subset of indices. Monthly values are calculated for all months with no more than three missing days, and annual values are calculated for years with no more than 15 days of missing data. For threshold indices, data must be at least 70 percent complete (Zhang and Yang 2004). The software also identifies outliers in daily maximum and minimum temperatures. Outliers are represented as the mean plus or minus n times the standard deviation of the value for the day (e.g. $\mu - n^*\sigma$ and $\mu + n^*\sigma$). A default value of three standard deviations is used for calculating outliers; however, the RClimDex user manual recommends a threshold of four standard deviations to identify outliers, since a value of three may flag a large number of values (Zhang and Yang 2004). In addition, Brown et al. (2010) used a value of four standard deviations to identify outliers when calculating these same indices for the Northeast U.S. Therefore, this study used a value of four to apply more strict criteria in identifying outliers. In general, any outliers that were identified in the data were not changed, since this study was interested in detecting extreme values. The program further identifies all unreasonable values in the daily data. Unreasonable values are defined as negative daily precipitation amounts and daily maximum temperatures that are less than the daily minimum temperatures. Log files are produced listing the occurrences of all unreasonable values for each station. The user then has an opportunity to review and replace any unreasonable value as missing. Negative precipitation values and minimum temperatures that were less than maximum temperatures were changed to missing values. If the difference between the daily maximum and minimum temperature was zero, the values were left unchanged. No daily negative precipitation amounts were flagged in the station data, and only one station was flagged as having two days when the daily maximum temperature was less than the daily minimum temperature.

Despite the quality control measures embedded within the USHCN daily datasets and the RClimDex software, checks for homogeneity are not yet included in the daily data. In this study, daily precipitation data were not adjusted for inhomogeneities due to the complexities involved and a lack of reliable methods in correcting precipitation data (Brown et al. 2010). Additionally, the number of stations included in this study makes correcting temperature data for inhomogeneities unfeasible. However, Appendix B provides information about station changes that occurred during the period of record since 1948 for those stations included in the study. Information about station changes was obtained from the NCDC Historical Observing Metadata Repository.

2.2.4 Trend calculations

The RClimDex program uses linear regression to calculate trends in these extreme indices. Previous studies that applied these same ETCCDI indices to other regions of the country used ordinary least squares (OLS) regression, in particular, to assess trends in these extremes (Griffiths and Bradley 2007, Brown et al. 2010, Insaf et al. 2012). While the OLS method of trend fitting is the most widely used and accepted method for linear regression in the literature (Griffiths and Bradley 2007), it is sensitive to outliers and non-Gaussian (i.e. non-normal) distributions (Brown et al. 2010). Despite its limitations, the OLS regression was used in this study to remain consistent with previous work and the RClimDex method for index calculation. Least squares fit trends were plotted on the time series to show long-term trend in certain indices. The linear least squares fitting procedure finds the best straight fit to the data points by minimizing the sum of the squares of the residuals, i.e. the distance of points from the curve. Significance of trends was based on the *t* test for the estimate of the slope at the 95 percent level. Two-tailed tests of significance were used, since a priori knowledge about the direction of trends for each index was unknown.

Trends in all indices shown in Table 2-1 were calculated for every station in the study region that had records of sufficient length and data of adequate quality, as described above. The RClimDex program calculates and outputs annual values for all 27 core indices, five user-defined indices, and mean maximum and minimum temperatures, yielding a total of 33 indices. In addition to the log and index calculation output files, the RClimDex program produces several other output files. These include time series graphs for each index with trend lines computed by linear least squares and locally weighted linear regression using a loess smoother function in R (Zhang and Yang 2004). The time series also display statistics of the linear trend fitting, including the slope estimate, slope error, p-value, and R^2 value. A summary output file includes the slope, standard of the slope, and p-value estimates for all indices.

Annual trends in each index were produced for each individual station, and the resulting p-values were used to determine trend significance. Annual averages were computed across stations for each state and index, as well as average trends over the entire record. Annual anomalies were calculated to determine periods of elevated extremes, or periods when extreme values were above their long-term mean. Anomalies are based on the differences between annual index values and the long-term (1948-2012) mean for that index and station. Average annual anomalies were grouped according to indices with common units of measure (e.g. days, degrees Celsius, and percent) and time series graphs were produced for each state with 5-year moving averages overlayed. All index calculations and statistical analyses were conducted in R open-source software. Thematic maps were produced in ArcMap 10 to reflect spatial trends in each index. Thematic maps were based on the slopes and p-values of each index to produce a scaled symbology reflecting the direction, size, and significance of trends for each station.

Impacts of temperature and precipitation extremes often have particular relevance in a given season or time of year. Therefore, seasonal trends were calculated for a subset of the indices where both monthly and annual values are computed by the

RClimDex program. There are thirteen monthly indices for which seasonal trends were calculated. These included: average maximum temperature (TMAXmean), average minimum temperature (TMINmean), diurnal temperature range (DTR), maximum 1-day precipitation (RX1day), maximum consecutive 5-day precipitation (RX5day), cool nights (TN10p), cool days (TX10p), warm nights (TN90p), warm days (TX90p), coldest night (TNn), coldest day (TXn), warmest night (TNx), and warmest day (TXx). Seasonal trends were calculated using OLS regression for consistency with annual trend calculations. Significance of trends was assessed at the 95 percent level (p-value < 0.05), unless otherwise indicated.

Since this study is interested in changes in the variability of extremes, annual residual values were extracted from the RClimDex program for all indices and stations. Slopes of trends in the residuals were calculated for a subset of indices and stations to further assess how variability in extremes may be changing. Based on results from 22 stations and four indices, the overall range in the slopes of the residuals was generally very small and similar to values observed from the raw index values. Thus, it was determined that the residuals did not provide much additional information than that provided from the raw values themselves, and the overall range was too small to be able to say anything conclusively about how variability differs between stations. Therefore, this approach was not pursued.

2.3 Results

This section describes observed changes in temperature and precipitation extremes for the Southeast since 1948, based on indices calculated using the RClimDex program defined in Table 2-1. Results are described in terms of warm and cool extremes or indices. Warm indices are those that depict changes toward a warmer climate and include both maximum- and minimum-temperature related indices. Positive trends in warm indices reflect a change toward a warming climate, while negative trends reflect a change toward a cooling climate. For instance, the summer day (SU) index is defined as the annual count of days when the maximum temperature exceeds 25°C. Thus, a positive trend would mean the region is experiencing more days with maximum temperatures above 25°C. Cold indices describe changes in extremes toward a cooler climate. These also include changes in both maximum and minimum temperatures. The direction of the trend may reflect a cooling or warming trend, depending on the particular index. For instance, the cool days (TX10p) index is defined as the percent of days when the maximum temperature is less than the 10th percentile. Here, a positive trend denotes a cooling climate. By contrast, the coldest day (TXn) index is defined as the monthly minimum value of daily maximum temperatures. Here, a negative trend reflects a change toward a cooling climate as the temperature of the lowest monthly maximum temperature decreases over time. This analysis also includes ten wet indices and one dry index. Wet indices describe changes in extremes toward a wetter climate, and the dry index describes changes toward a drier climate (i.e. longer periods without rainfall). Positive trends in wet (dry) indices reflect increasing (decreasing) wetness, and negative trends in wet (dry) indices suggest increasing dryness (wetness).

2.3.1 Comparison of indices

Table 2-2 summarizes the information presented in Table 2-3. It shows the number of indices with a majority of significant trends for the Southeast as a whole. The majority of stations show negative trends in warm indices that measure changes in maximum temperatures (Table 2-3). This includes summer days (SU) above 25°C and

35°C, warm days (TX90p), warm spells (WSDI), and diurnal temperature range (DTR). However, positive trends are generally seen in warm indices that measure changes in minimum temperatures, including tropical nights (TR) above 20°C and 24°C, warmest nights (TNx), and warm nights (TN90p). This suggests that warming in the Southeast can largely be attributed to increases in nighttime rather than daytime temperatures. The majority of stations (57%) show decreasing significant trends in diurnal temperature range, which may be explained by minimum temperatures that are rising more than maximum temperatures. Duration indices (WSDI, CSDI, CWD, and CDD) exhibit more significant negative trends than positive trends. In particular, 39 percent of stations showed significant decreasing trends in warm spells (WSDI) and 33 percent of stations had significant decreasing trends in cold spells (CSDI). This suggests that weather may be more variable and that temperature extremes are becoming shorter in duration, which could help to counteract any increases in their intensity.

Table 2-2. Total number of indices with a majority of stations showing significant negative and positive trends, at the 0.05 level, for the Southeast from 1948 to 2012.

	Total	Warm	Cool	Wet/Dry
Negative	13	7	4	2
Positive	17	4	5	8

Figure 2-3 shows the percentage of stations exhibiting significant and non-significant trends in each extreme index for the Southeast. There are more significant trends in temperature extremes than precipitation extremes overall. Positive trends in indices representing nighttime temperatures were evident. For example, about 87 percent of stations showed increases in tropical nights above 20°C (68°F), with about 52percent of these being significant (Table 2-3). In addition, about 96 percent of stations

Table 2-3. Percentage of stations in the southeast United States with significant trends at the 0.05 level by index from 1948 to 2012. Indices are grouped as warm (red), cool (blue), wet (green), and dry (brown).

Index	Index Description	Positive (%)	Negative (%)
SU25	Summer day > 25°C	6	34
SU35	Summer day > 35°C	4	16
TR20	Tropical night > 20°C	52	3
TR24	Tropical night > 24°C	45	3
GSL	Growing season length	3	5
TXx	Warmest day	6	8
TNx	Warmest night	37	4
TX90p	Warm days > 90th percentile	6	35
TN90p	Warm nights > 90th percentile	39	14
WSDI	Warm spell duration	1	39
DTR	Diurnal temperature range	7	57
ID0	Ice day < 0°C	5	0
ID-2	Ice day < -2°C	1	0
FD0	Frost day < 0°C	14	18
FD-2	Frost day < -2°C	12	19
TXn	Coldest day	4	1
TNn	Coldest night	28	0
TX10p	Cool days < 10th percentile	28	11
TN10p	Cool nights < 10th percentile	4	53
CSDI	Cold spell duration	1	33
RX1Day	Maximum 1-day precipitation	4	1
RX5Day	Maximum 5-day consecutive precip	3	0
SDII	Simple daily intensity index	25	2
R10mm	No. of heavy precip days > 10mm	7	7
R20mm	No. of very heavy precip days > 20mm	9	2
R102mm	No. of days above 102mm	8	0
CWD	Consecutive wet days	1	17
R95p	Total precip on very wet days > 95th percentile	10	0
R99p	Total precip on extremely wet days > 99th percentile	4	0
PRCPTOT	Annual total precipitation on wet days > 1 mm	5	2
CDD	Consecutive dry days	1	5

displayed increases in temperatures for the coldest night of the month. Negative trends are predominantly seen for indices describing changes in maximum temperatures. In particular, roughly 71 percent and 67 percent of stations showed decreases in the number of days above 25°C (77°F) and 35°C (95°F), with about 34 percent and 16 percent of these being significant, respectively.

Results of wet indices suggest greater frequency and intensity of rainfall events in the Southeast. Most precipitation indices showed upward trends in wetness, with the exception of consecutive wet days, where about 72 percent of stations displayed downward trends (17% significant). In addition, about 75 percent of stations showed upward trends in the simple daily intensity index and 77 percent of stations displayed increases in the amount of rainfall on very wet days above the 95th percentile.

2.3.2 Average state and regional trends

Trends in each index were averaged for all individual stations in each state and then for the region as a whole to reflect the direction and strength of statewide and regional trends. Results are shown by category as follows: eleven warm indices (Table2-4), nine cool indices (Table 2-5), and eleven wet and dry indices (Table 2-6). Evidence of warming was seen in certain indices. In particular, the number of tropical nights (TR20 and TR24) and warm nights (TN90p) increased for most states. In addition, most states saw a decline in number of cold spells (CSDI) and hard freezes (FD-2). By contrast, certain warm indices showed negative trends, including summer days (SU), warmest days (TXx), and warm days (TX90p), and warm spells (WSDI).

While some indices showed evidence of warming, results shown in Table 2-4 reveal that warming is not a universal component of the Southeast. All eleven states experienced downward trends in warm days (TX90p), warm spells (WSDI), and diurnal temperature range (DTR). In addition, every state is experiencing a declining number of days above 25°C and 35°C, with the exception of Florida and Louisiana (for summer

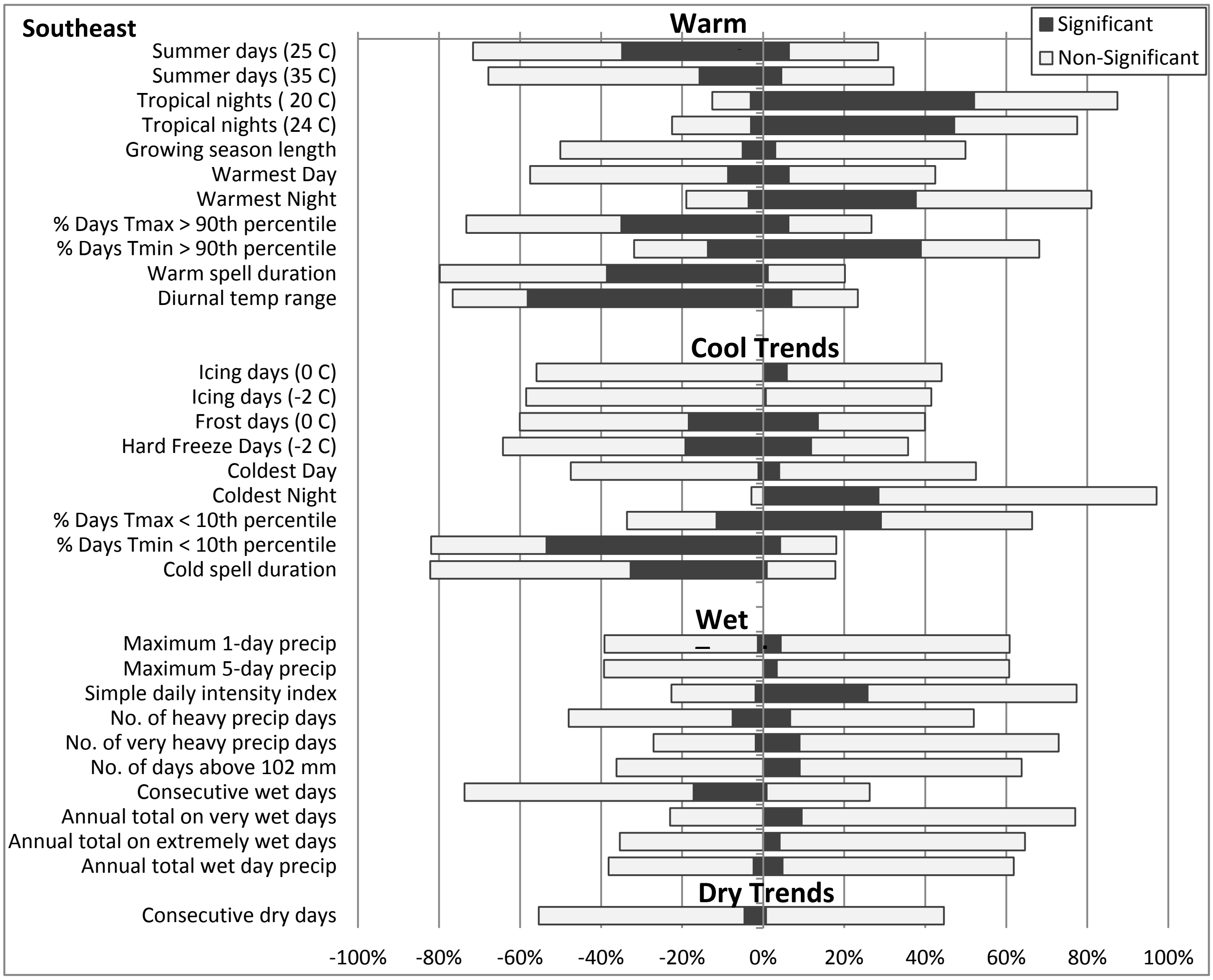

Figure 2-3. Proportion of stations in the Southeast showing positive and negative trends in extreme indices from 1948 to 2012; image concept from Insaf et al. (2012).

days above 35°C). These results are consistent with previous studies that have observed cooling trends in the Central Great Plains (Pan et al. 2004) and Southeast (Lund et al. 2001, Groisman et al. 2004, Lu et al. 2005, Rogers 2013) regions of the U.S. during much of the 20th century. It is clear from this set of indices that the cooling observed in the Southeast is due more to decreases in extreme daytime temperatures versus nighttime temperatures. This is further reflected in the cool extreme indices

(Table 2-5). For example, annual absolute temperatures of the coldest nights (TNn) increased in all states and the percent of cool nights (TN10p) decreased, on average.

Table 2-4. Average trends in warm-related extreme indices by state from 1948 to 2012.

	SU25	SU35	TR20	TR24	GSL	TXx	TNx	TX90p	TN90p	WSDI	DTR
AL	-0.066	-0.024	0.176	0.028	0.019	-0.006	0.007	-0.037	0.011	-0.125	-0.003
AR	-0.206	-0.074	0.229	0.095	-0.100	0.000	0.009	-0.080	0.034	-0.199	-0.022
FL	0.062	0.024	0.370	0.337	-0.015	-0.001	0.018	-0.006	0.097	-0.053	-0.012
GA	-0.066	-0.037	0.279	0.015	0.129	-0.006	0.010	-0.050	0.008	-0.106	-0.009
LA	-0.059	0.032	0.263	0.270	-0.014	0.012	0.016	-0.025	0.043	-0.065	-0.010
MS	-0.139	-0.101	0.267	0.066	-0.055	-0.003	0.009	-0.073	0.013	-0.166	-0.014
NC	-0.076	-0.039	0.132	0.021	0.018	-0.005	0.010	-0.032	-0.017	-0.049	-0.007
OK	-0.129	-0.089	0.033	0.032	-0.146	-0.008	-0.003	-0.046	-0.009	-0.146	-0.007
SC	-0.053	-0.035	0.307	0.081	0.119	-0.009	0.013	-0.043	0.054	-0.034	-0.014
TN	-0.079	-0.057	0.162	0.008	0.035	-0.007	0.006	-0.037	0.018	-0.119	-0.010
TX	-0.043	-0.141	0.302	0.170	0.021	-0.007	0.011	-0.047	0.083	-0.113	-0.017
Total	**-0.077**	**-0.049**	**0.229**	**0.102**	**0.001**	**-0.004**	**0.010**	**-0.043**	**0.030**	**-0.107**	**-0.011**

Table 2-5. Average trends in cool-related extreme indices by state from 1948 to 2012.

	ID0	ID-2	FD0	FD-2	TXn	TNn	TX10p	TN10p	CSDI
AL	-0.008	-0.005	0.028	-0.011	0.006	0.037	0.010	-0.039	-0.032
AR	0.032	0.015	-0.037	-0.058	-0.010	0.033	0.048	-0.057	-0.049
FL	0.000	0.000	-0.010	-0.007	0.006	0.011	-0.002	-0.087	-0.063
GA	0.003	0.002	-0.021	-0.047	0.001	0.036	0.015	-0.056	-0.062
LA	-0.006	-0.002	-0.031	-0.029	0.004	0.032	0.005	-0.077	-0.054
MS	-0.002	-0.001	0.015	-0.002	0.000	0.031	0.033	-0.068	-0.060
NC	0.013	0.008	0.093	0.050	-0.011	0.022	0.031	-0.056	-0.057
OK	-0.001	-0.009	-0.015	-0.022	-0.002	0.017	0.024	-0.015	-0.013
SC	-0.001	-0.001	-0.080	-0.071	0.007	0.032	-0.005	-0.071	-0.066
TN	0.000	0.000	-0.035	-0.039	0.012	0.051	0.012	-0.065	-0.049
TX	-0.008	-0.009	-0.141	-0.131	0.018	0.050	0.001	-0.084	-0.084
Total	**0.002**	**0.000**	**-0.021**	**-0.033**	**0.003**	**0.032**	**0.015**	**-0.061**	**-0.054**

Overall trends in precipitation indices reveal that wet and dry spells are becoming shorter across the Southeast (Table 2-6). Texas and Oklahoma are the wettest states, with upward trends in all wet indices (excluding duration indices). Oklahoma in particular has been experiencing more intense rainfall since 1948. For instance, it has the highest trends in the amount of rainfall on very wet days (R95p) and annual total rainfall (PrcpTot). South Carolina has been the driest state in the region. It is the only state in the Southeast that has experienced downward trends in every wet index since 1948. It also experienced an increase in the length of dry spells (CDD). These state differences are further illustrated in Figures 2-4 and 2-5 for Oklahoma and South Carolina, respectively.

Table 2-6. Average trends in wet- and dry- related indices by state from 1948 to 2012.

	RX1d	**RX5d**	**SDII**	**R10mm**	**R20mm**	**R102mm**	**R95p**	**R99p**	**Prcp Tot**	**CWD**	**CDD**
AL	0.137	0.103	0.013	-0.002	0.023	0.002	0.885	0.502	0.783	-0.008	0.006
AR	-0.058	-0.092	0.004	0.012	0.017	0.001	0.513	0.179	0.744	-0.004	-0.010
FL	-0.081	0.180	0.029	-0.018	0.026	-0.002	0.334	-0.300	0.125	-0.008	0.002
GA	0.079	0.148	0.016	-0.049	0.000	0.001	0.775	0.169	-0.750	-0.011	-0.007
LA	-0.025	0.204	0.018	0.021	0.032	-0.001	0.373	-0.302	0.987	-0.003	-0.029
MS	0.253	0.212	0.029	-0.004	0.023	0.005	0.695	0.641	0.606	-0.005	-0.014
NC	0.126	0.135	0.000	-0.032	-0.003	0.002	0.611	0.244	-0.308	-0.009	-0.008
OK	0.154	0.069	0.035	0.081	0.050	0.002	1.404	0.266	2.669	-0.006	-0.108
SC	-0.042	-0.080	-0.005	-0.085	-0.019	-0.001	-0.349	-0.370	-1.864	-0.013	0.011
TN	0.141	0.151	0.015	-0.004	0.013	0.002	0.785	0.431	0.393	-0.007	0.008
TX	0.080	0.192	0.022	0.054	0.036	0.002	0.659	0.217	1.778	-0.004	-0.031
Total	**0.070**	**0.111**	**0.016**	**-0.002**	**0.018**	**0.001**	**0.608**	**0.153**	**0.469**	**-0.007**	**-0.016**

There is some support in the literature to suggest that under a warming climate, the Bermuda High will expand and shift westward (Coleman 1988, Keim 1997). The result would be relatively dry, more stable conditions along the East Coast and wetter conditions with greater instability occurring in the central Gulf Coast region (Keim 1997). Minimum warming found in the central United States may be associated with changes in

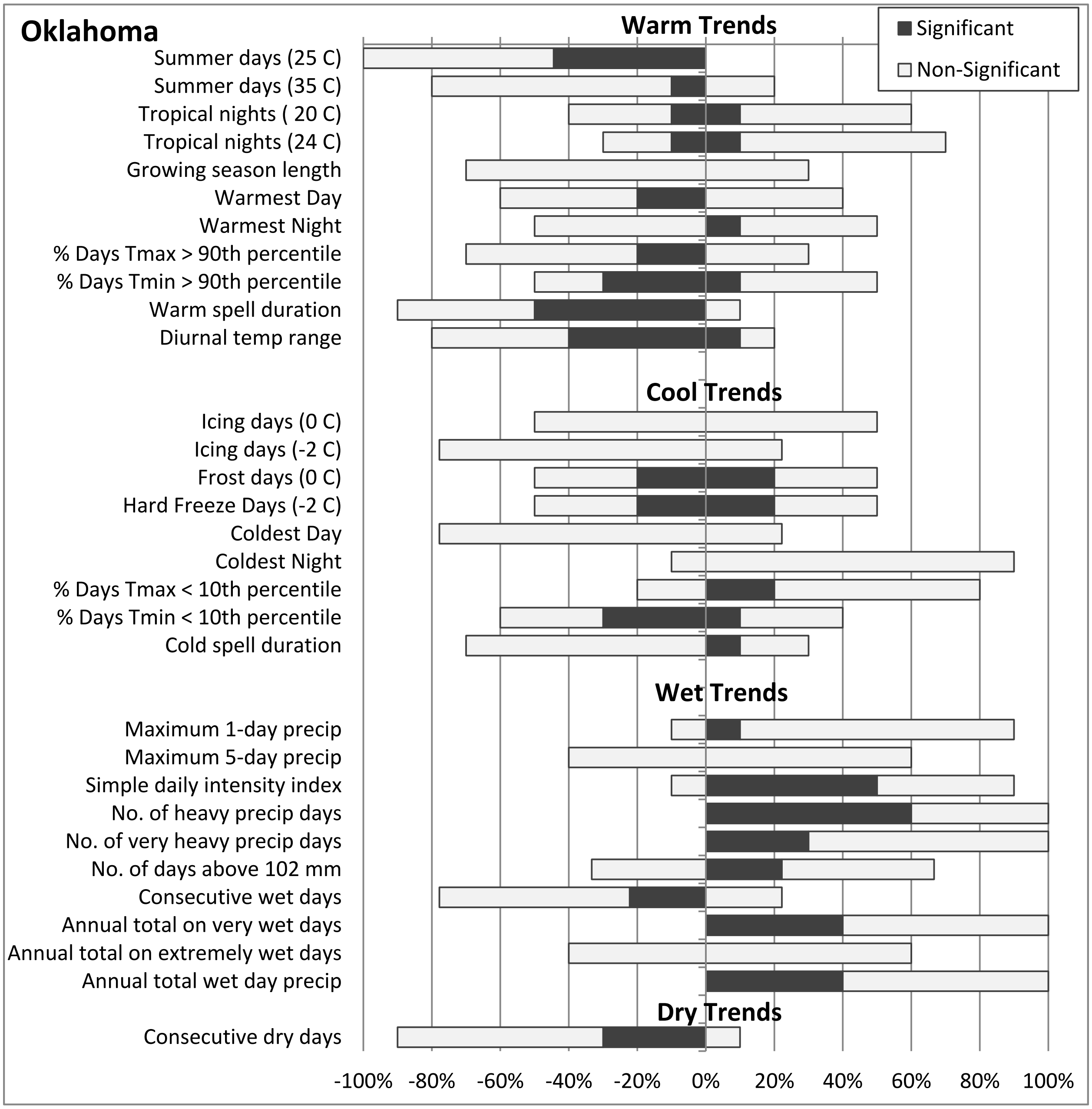

Figure 2-4. Proportion of stations in Oklahoma showing positive and negative trends in extremes indices from 1948 to 2012; image concept from Insaf et al. (2012).

low-level circulation patterns that lead to increased rainfall and replenishment of soil moisture, which may be increasing summer evapotranspiration and lowering daytime temperatures (Pan et al. 2004). Given that the Southeast has experienced increasing wetness, this explanation may make sense for the broader Southeast region as well.

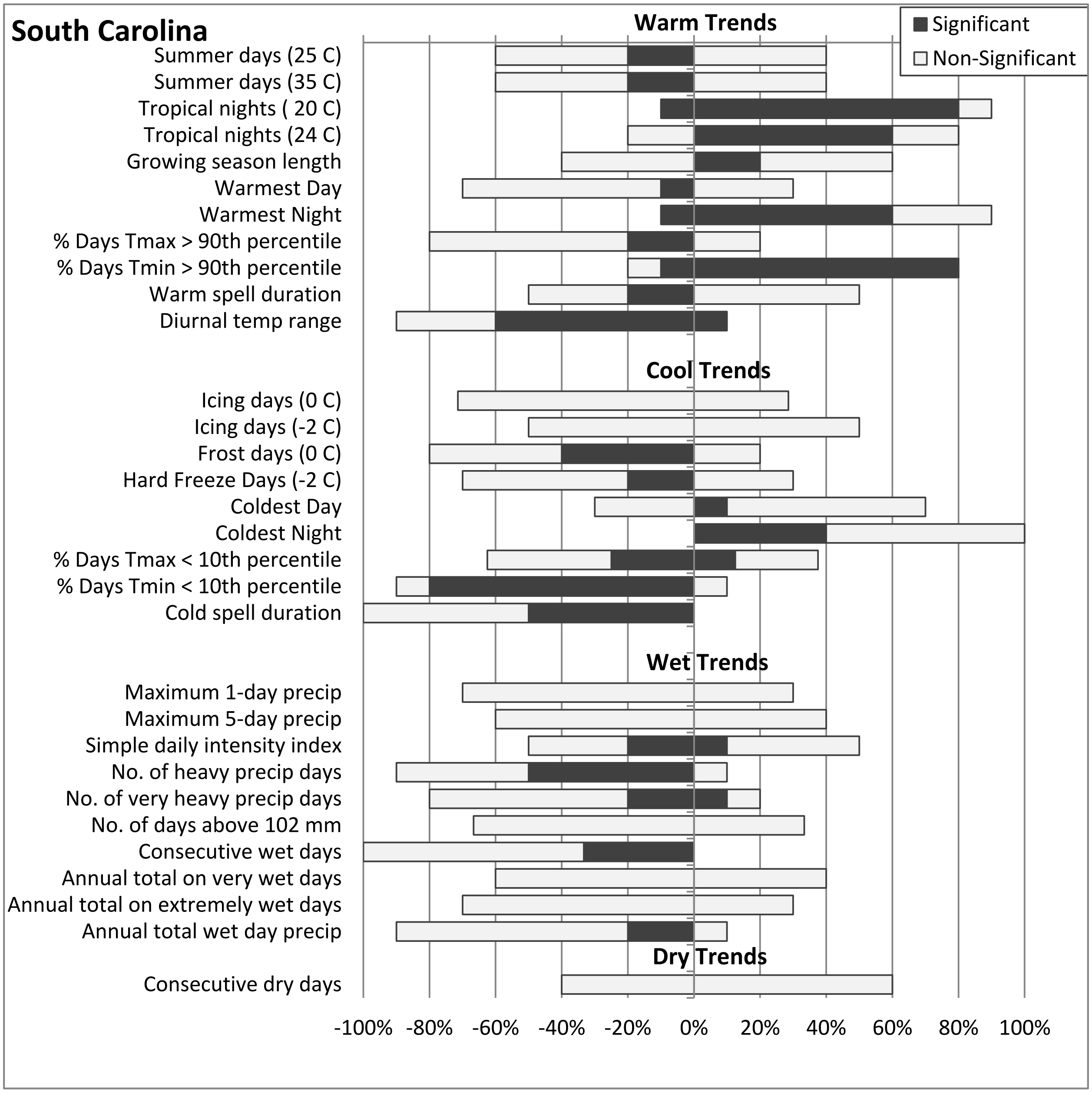

Figure 2-5. Proportion of stations in South Carolina showing positive and negative trends in extreme indices from 1948 to 2012; image concept from Insaf et al. (2012).

2.3.3 Spatial trends in temperature extremes

Annual trends in each temperature index were mapped to investigate spatial patterns in these extremes for the Southeast. A red scale was used to represent warming trends, and a blue scale was used to represent cooling trends. A red symbol represents a trend toward a warmer climate, while a blue symbol denotes a trend toward a cooler climate. These may be positive or negative depending on the given index. Larger circles indicate significance at the 5 percent (largest) and 10 percent (medium) levels; the smallest circles represent non-significant trends. Figure 2-6 shows results of trends for the warm-related temperature indices. Appendix C provides the full definitions and formulas for all 27 core indices.

Region-wide trends in warm temperature-related indices showed good spatial coherence overall. In particular, region-wide decreases in extreme highs were evident since 1948, as reflected in several indices. Figure 2-6c shows decreases in the number of summer days above 35°C (95 °F) for most locations, with exceptions in Louisiana, Florida, and Georgia. Further evidence of daytime cooling was observed in the warm days index (Figure 2-6a), defined as the percent of days when the maximum temperature exceeded the 90th percentile for a given calendar day, as well as in the annual absolute value of the warmest days (Figure 2-6e). Given that the number of warm days declined over much of the region, it follows that there were region-wide decreasing trends in the warm spell duration index (WSDI), which is defined as number of days, in intervals of six days, when the daily maximum temperature was greater than the 90th percentile for that calendar day (Figure 2-6h).

Warming in the Southeast is largely attributed to nighttime heat. Figure 2-6d shows region-wide increases in the number of tropical nights above 24°C (75°F), with many of these trends significant at either the 5 or 10 percent level. Most stations exhibit more warm nights above the 90th percentile for a calendar day (Figure 2-6b), and increases in the annual absolute value of minimum temperatures, or warmest nights

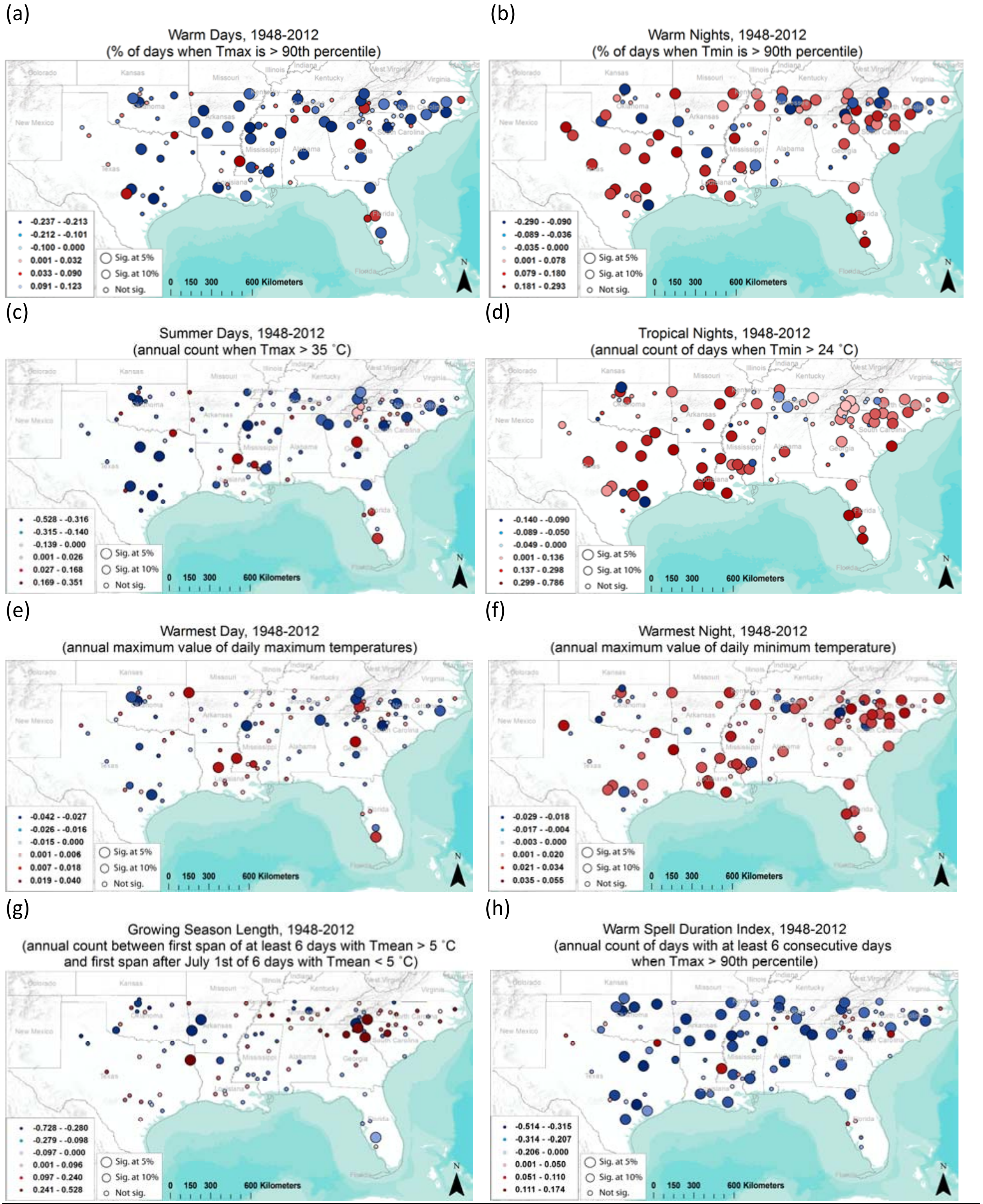

Figure 2-6. Trends in warm temperature extreme indices for the Southeast from 1948 to 2012. The largest sized circles are significant at the 0.05 level, medium sized circles are significant at the 0.10 level, and the smallest circles are non-significant.

(Figure 2-6f). Increases in nighttime temperatures, coupled with decreases in extreme daytime temperatures, appear to be decreasing overall diurnal temperature ranges in the Southeast. In fact, region-wide decreases in diurnal temperature range (DTR) since 1948 are apparent (Figure 2-7h), with just a few exceptions in more northerly parts of the region, including parts of Oklahoma, northern Mississippi, Alabama, central Tennessee, and western North and South Carolina with increasing trends in DTR. Here, DTR is calculated as the mean difference between daily maximum and minimum temperatures. The growing season length (GSL) showed greater spatial variability than other indices, with few significant trends (Figure 2-6g). Overall, GSL trends are inconsistent with those expected under a warming climate. Extreme western parts of South Carolina and southwestern North Carolina show significant increases in GSL, and western Arkansas and western Oklahoma show significant decreases in GSL.

Figure 2-7 shows results for the cold-related temperature indices. Daytime cooling and nighttime warming are apparent in several of the cold temperature-related indices as well. For instance, the region has seen an increasing number of cool days (Figure 2-7a) since 1948, defined as maximum temperatures below the 10th percentile for a calendar day. Most stations show significant warming trends in cool nights, with fewer occurrences when the minimum temperature was below the 10th percentile for a calendar day (Figure 2-7b). Region-wide significant upward trends are observed in coldest nights, barring the extreme southeast portion of the region and Oklahoma (Figure 2-7f). This index shows that the absolute coldest nighttime temperatures are getting warmer. Other cold temperature extremes showed less spatial coherence across the region. Few significant trends were seen in ice days for the region overall, though some northerly locations showed significant increases in the number of ice days, particularly in Arkansas and North Carolina (Figure 2-7c). Frost day trends show mixed patterns but many stations are seeing fewer frost days, with many trends significant at the 0.05 level, except in Georgia and Florida (Figure 2-7d). Despite cooling observed in maximum temperature-related indices, cold spells are becoming shorter in duration (Figure 2-7g). Cold spells (Figure 2-7g) are defined here as the annual number of days when the minimum temperature is below the calendar day 10th percentile for at least six days. Negative trends in both the warm and cold spell duration indices reflect a greater variability in extremes that are shorter lived. Appendix E shows results for the default thresholds of 25°C (77°F) for summer days and 20°C (68°F) for tropical nights, as well as hard freeze and ice days below a threshold of -2°C, not discussed here.

2.3.4 Spatial trends in precipitation extremes

Precipitation indices were also mapped to investigate spatial patterns in wetness and dryness over the latter half of the 20th century for the Southeast. Figure 2-8 shows the results of precipitation-related indices that are in units of millimeters, which include percentile and absolute indices. Figure 2-9 shows precipitation-related indices in units of days, which include threshold and duration indices. Overall, many parts of the Southeast are seeing significantly more extreme precipitation events, reflected in multiple indices. Drying trends are largely restricted to extreme eastern portions of the region. However, less spatial coherence is observed in precipitation indices compared to temperature indices, and it is not uncommon for nearby locations to show opposite trends in the same precipitation indices.

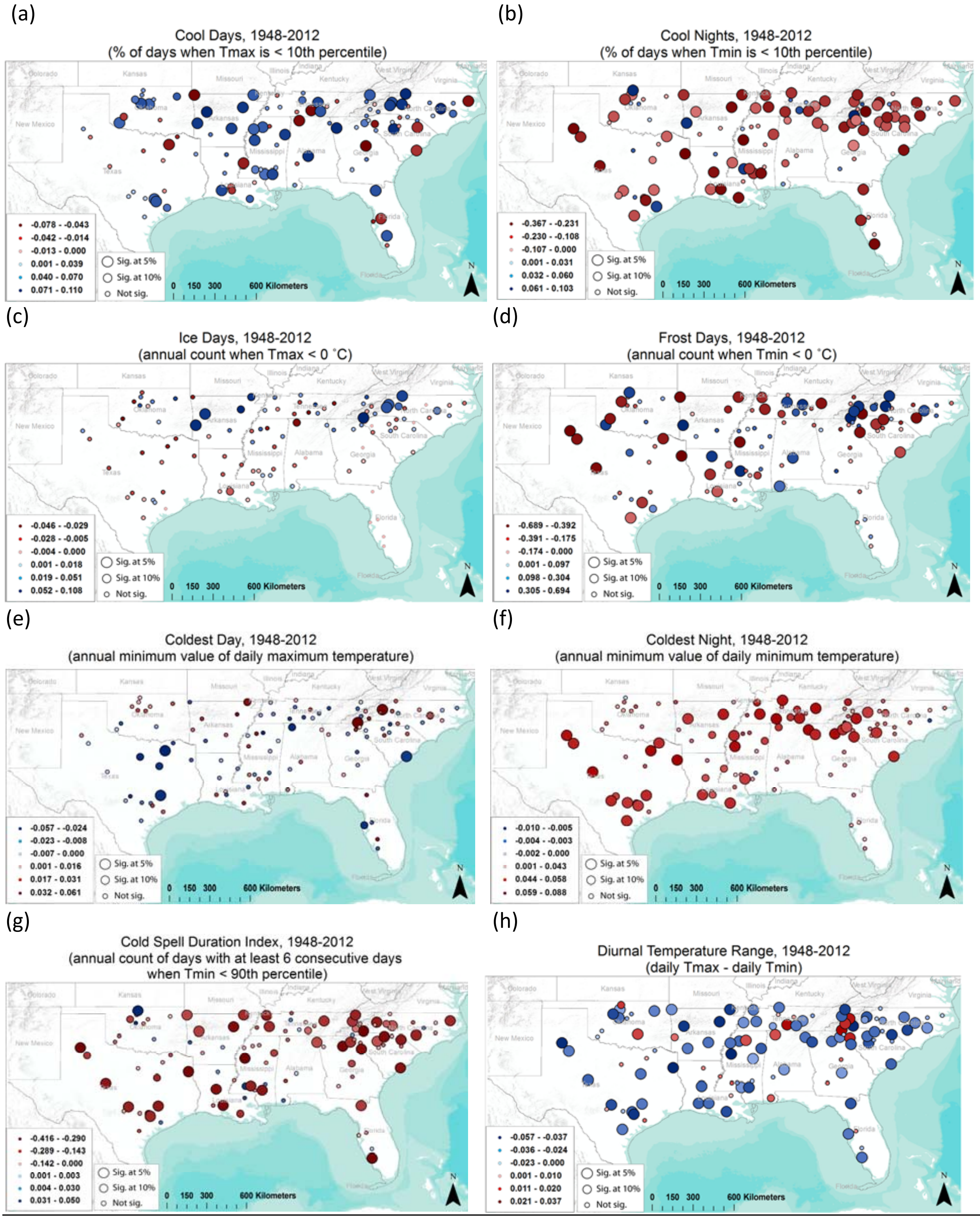

Figure 2-7. Trends in cold temperature extreme indices for the Southeast from 1948 to 2012. The largest sized circles are significant at the 0.05 level, medium sized circles are significant at the 0.10 level, and the smallest circles are non-significant.

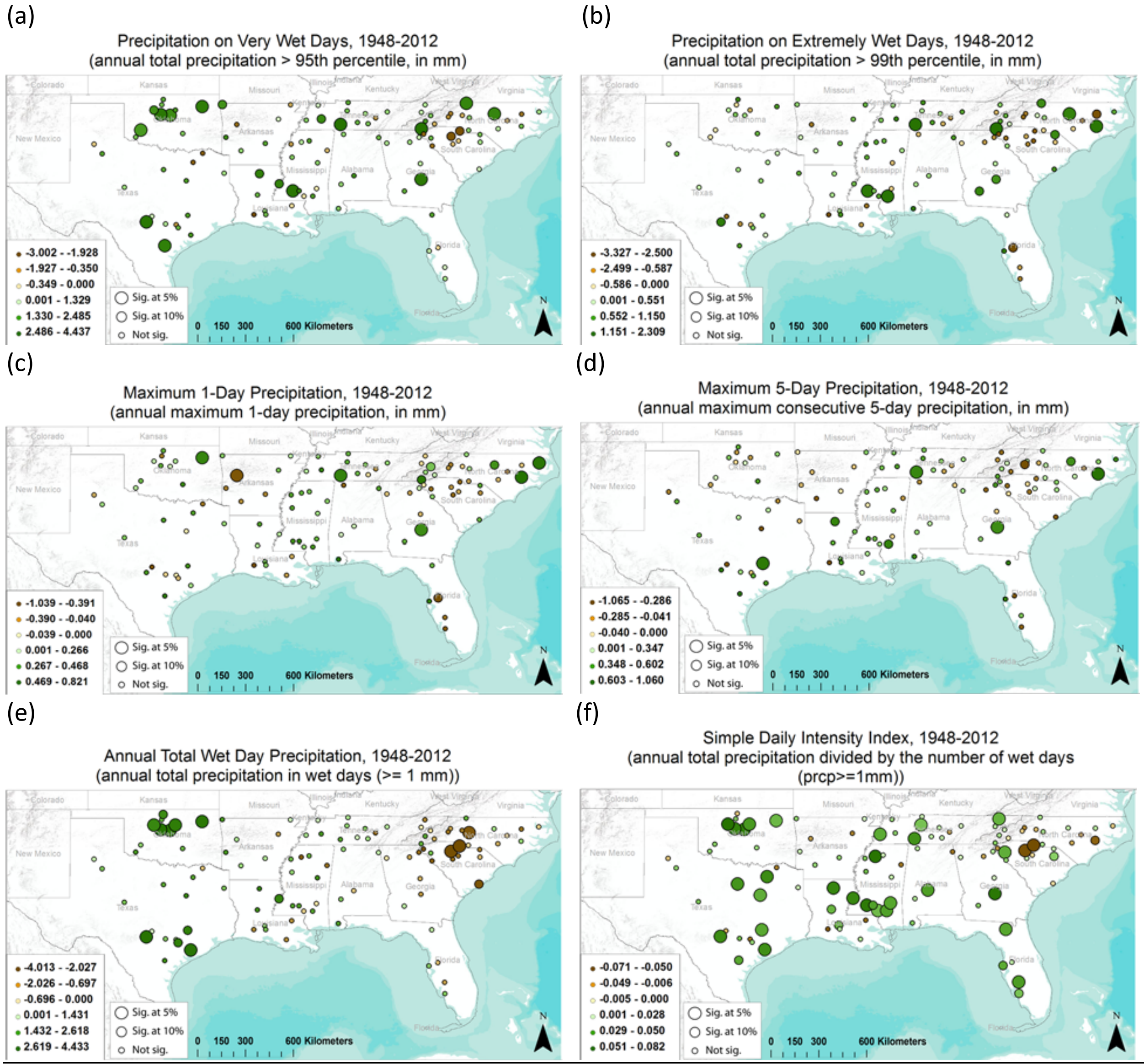

Figure 2-8. Trends in percentile and absolute precipitation extreme indices, in units of mm (mm/day for the Simple Daily Intensity Index), for the Southeast from 1948 to 2012. The largest sized circles are significant at the 0.05 level, medium sized circles are significant at the 0.10 level, and the smallest circles are non-significant.

A distinct east-west pattern is evident in several precipitation extreme indices in the region, whereby increasing dryness was observed in the east and increasing wetness was observed in central and western portions of the region. This pattern was particularly evident in the following indices: annual total precipitation (Figure 2-8e) and

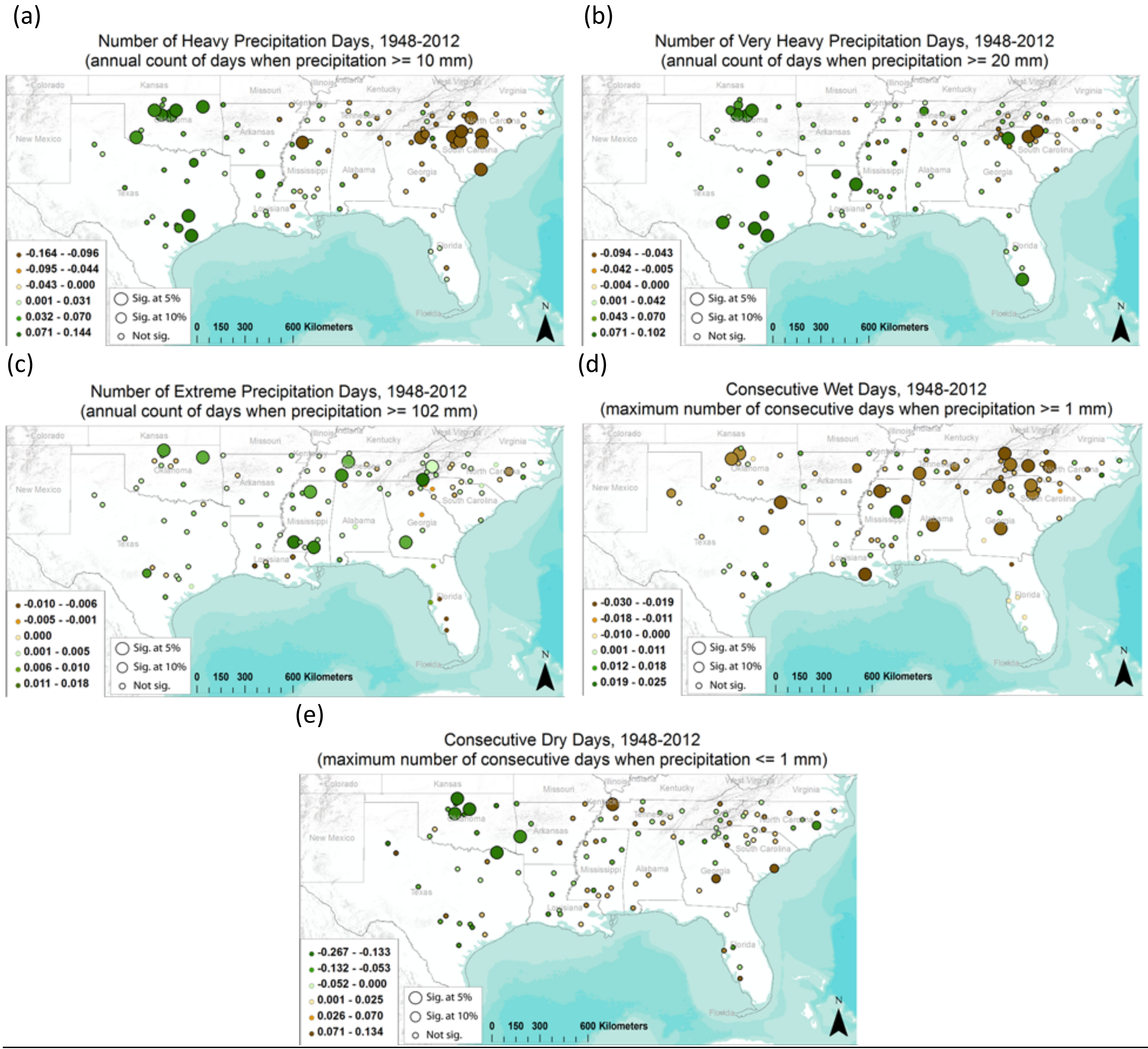

Figure 2-9. Trends in threshold and duration precipitation extreme indices, in units of days, for the Southeast from 1948 to 2012. The largest sized circles are significant at the 0.05 level, medium sized circles are significant at the 0.10 level, and the smallest circles are non-significant.

number of heavy and very heavy precipitation days (Figures 2-9a and b), and to a lesser extent the simple daily intensity index (SDII) (Figure 2-8f). According to the SDII, which is defined as the annual total precipitation divided by the number of days with precipitation (greater than 1 mm), precipitation events are becoming more efficient. In other words, the SDII does not indicate changes in the frequency of events but when precipitation does occur, it is more intense. This is especially true for eastern Texas, much of Louisiana and Mississippi, southern Georgia, Florida, and many parts of Tennessee.

Fewer significant trends are observed in other wet indices. Significantly increasing precipitation on very wet days, defined as the annual total precipitation above the base period 95th percentile, is observed for select locations in the west, central and northeastern parts of the region, while significantly increasing precipitation on extremely wet days (defined as the annual total precipitation above the base period 99th percentile) is restricted to southern Mississippi, parts of Tennessee and North Carolina (Figure 2-8a and b). Only a few significant trends in annual maximum 1-day and consecutive 5-day precipitation are observed across the region, with no clear spatial pattern (Figure 2-8c and d, respectively). Significant upward trends in extreme precipitation days (defined as days with precipitation greater than 102 mm or 4 in) are largely restricted to central portions of the region, particularly Mississippi and central Tennessee, as well as northern Oklahoma and extreme western North Carolina (Figure 2-9c). Increases in the efficiency of precipitation events seen in the SDII may be partially explained by shorter wet spells observed for much of the region (Figure 2-9d). Significant increases in consecutive dry days (CDD) were largely absent, suggesting that the region is not seeing longer drought episodes, defined here as the annual maximum number of days with no precipitation (≤ 1 mm). While the CDD index lacked overall spatial coherence, significant negative trends exist in Oklahoma and the surrounding locations of western Arkansas and northern Texas, further reflecting shorter dry spells. The Southeast showed region-wide decreases in wet spells, with significant decreasing trends mostly in the central and northern portions of the region (Figure 2-9).

The strength and position of the Bermuda High (BH) likely play a role in driving the spatial variability observed in these precipitation indices for the Southeast. In fact, the seasonal shift of the BH has been found to exert the strongest influence on daily temperature and precipitation in the Southeast, more so than variations in El Niño Southern Oscillation (ENSO) (Henderson and Robinson 1994, Katz et al. 2003). The BH is generally positioned more eastward over the central part of the North Atlantic Ocean during winter and more westward during summer, contributing to extremes in precipitation in winter and summer months, respectively (Katz et al. 2003, Li et al. 2012).

There is some conflicting research regarding changes in the BH in the literature. Li et al. (2012) suggested that the BH has intensified in recent years, resulting in a westward shift in the western ridge in summer. Normally, its more westerly position in summer results in the transport of warm, moist air from the North Atlantic over the Southeast, increasing the probability of rainfall along the East Coast. A shift further west than its normal position would bring the western edge of the BH closer to land areas of the Southeast, with areas of subsiding air closer to land, inhibiting rainfall (Katz et al. 2003). Furthermore, anticyclonic airflow associated with the BH would have a greater impact on areas further west by bringing warm, moist air from the Gulf of Mexico over the central and western portions of the Southeast and increasing precipitation in these areas. Diem (2013) found that increased interannual variability in the Western Bermuda High Index (WBHI) appears to explain the increased variance in rainfall in the

Southeast, and that the WBHI is an important predictor of rainfall magnitudes, duration and days. However, he found that the western ridge of the BH has not shifted westward over the past few decades as Li et al. (2012) suggested. Instead, Diem (2013) hypothesized that an increase in atmospheric humidity is responsible for an increase in rainfall days in recent decades. Trends observed in these indices seem to reflect a pattern consistent with that described by Li et al. (2012), whereby a westward shift in the BH may be inhibiting precipitation in the east but increasing instability and precipitation further west. However, this is not to say that atmospheric humidity does not play a role in extreme precipitation patterns in the region.

2.3.5 Temporal trends in temperature extremes

Several indices that exhibited significant trends for stations across the region were selected to investigate temporal variability from 1948 to 2012. Figure 2-10 shows time series for summer days (SU) and tropical nights (TR) for the region as a whole. SU is defined again as the annual total number of days when the maximum temperature was above 35°C (95°F), and TR is the annual total number of nights when the minimum temperature was above 24°C (75°F). The least squares trend line shows little change or a slightly decreasing trend in the frequency of extremely hot days since 1948. For the region overall, the frequency in hot days was greatest in the 1950s, corresponding to a period of extremely dry weather (Kunkel et al. 2013).

The frequency of extremely warm nights has clearly increased for the Southeast since 1948, and especially since the late 1970s. DeGaetano and Allen (2002) attributed the rise in the frequency of minimum temperatures above 24°C over the past few decades to urbanization. It is worth noting that the majority of stations included in this

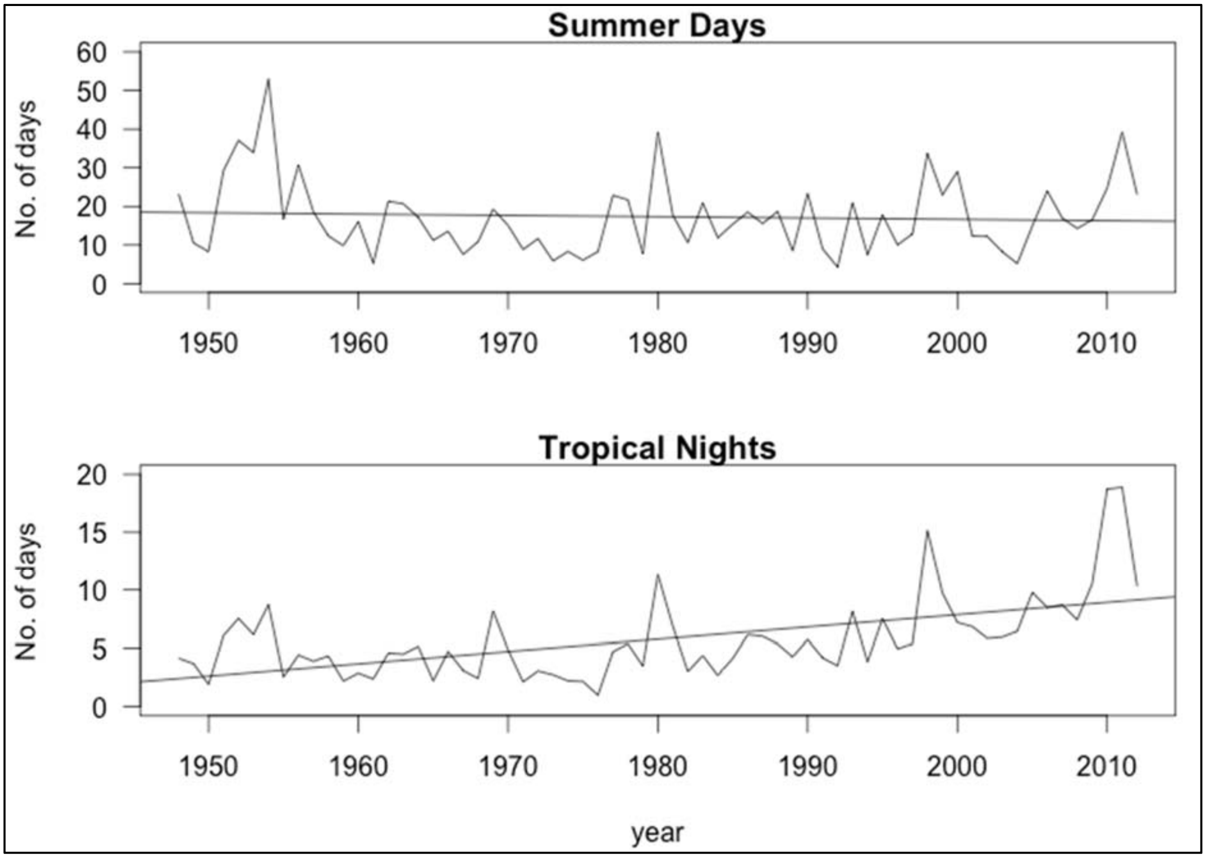

Figure 2-10. Annual time series for summer days (Tmax > 35°C) and tropical nights (Tmin > 24°C) for the Southeast from 1948 to 2012, with the least fit trend line plotted.

study are rural locations; whereas, the rise in maximum and minimum temperature extremes observed by DeGaetano and Allen (2002) were most prominent for urban locations. Thus, urbanization may not play as large of a role in the trends observed in these warm indices. More frequent warm nights were also evident during the period of dry, hot weather in the 1950s, though to a much lesser extent than seen for maximum temperatures.

Similar long-term trends were observed in indices related to cold extremes. For example, Figure 2-11 shows time series for the coldest days and coldest nights, defined as the annual absolute lowest maximum and minimum temperatures, respectively, with the least fit trend line plotted. The total range in both the coldest days and coldest nights for the entire 65-year record is about 10°C. The annual absolute lowest maximum temperatures have not changed much since 1948. However, the lowest maximum temperatures were higher during the early and latter part of the record, while a cooler period marked by particularly colder days occurred in the 1980s. Annual temperatures of the coldest nights have exhibited an overall increasing trend since 1948, consistent with the rise in tropical nights. This suggests that the coldest nighttime temperatures are not as cold on average as they were in the middle of the 20th century. Similarly, the coldest nighttime temperatures were observed in the 1980s, and the warmest temperatures occurred in the early part of the record and more recently in the last decade.

Anomalies relative to the long-term mean (1948-2012) were analyzed to further assess temporal variability in extreme temperature indices. Investigating anomalies in extreme indices can reveal periods of particularly active weather, or periods of elevated extremes above average. Patterns of temperature-related extreme anomalies revealed an overall U-shaped curve for most states, though the beginning and end dates of elevated regimes varied between locations.

Overall, two periods marked by excessive heat were apparent when examining statewide anomalies, namely the 1950s that were characterized by extreme drought and record heat across much of the United States and the 2000s that experienced several years with extreme weather. For example, the extreme heat and drought of 2011 that plagued the Southern Plains and Texas, in particular (Peterson et al. 2012), were apparent for stations in Texas and, to a lesser extent, Oklahoma. In 2011, stations

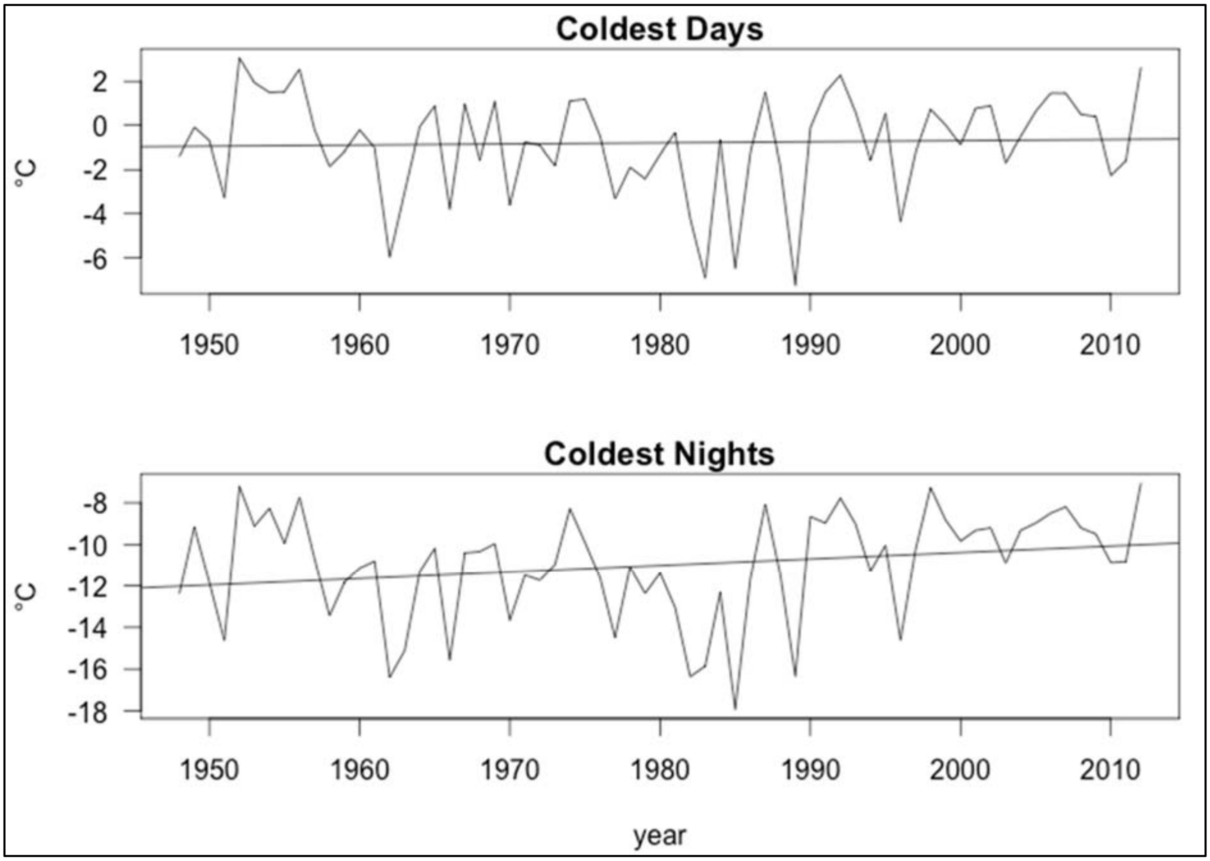

Figure 2-11. Southeast annual time series of coldest days (temperature of the annual absolute lowest maximum temperature) and coldest nights (temperature of the annual absolute lowest minimum temperature) from 1948 to 2012, with least fit trend lines plotted.

in Texas experienced nearly 100 days with maximum temperatures exceeding 35°C (95°F) (Figure 2-12). In addition, nearly 15 percent of days were above the long-term average for maximum and minimum temperatures exceeding the 90th percentile in 2011 for stations in Texas. Oklahoma experienced particularly warm weather in the 1950s and again in the 2000s. For instance, years that had the greatest number of days with above-average warmth (i.e. summer days, tropical nights, and warm spells) relative to the 1948-2012 average, were 2011, 1954 and 1956, with 32, 31 and 30 days, respectively. These results are consistent with previous studies that showed peaks in warm maximum and minimum temperatures in the 1950s due to widespread drought that extended as far east as 90° longitude, affecting Texas and Oklahoma in particular (DeGaetano and Allen 2002). Warm extremes were apparent in the 1950s for many other states in the region as well, including Alabama, Arkansas, Georgia, Mississippi, North Carolina, South Carolina, and Tennessee. However, stations in Florida did not show similar elevated warm extremes during this time. For example, the percent of warm days above the 90th percentile peaked in the 1980s and 1990s, and have since been near average (Figure 2-13).

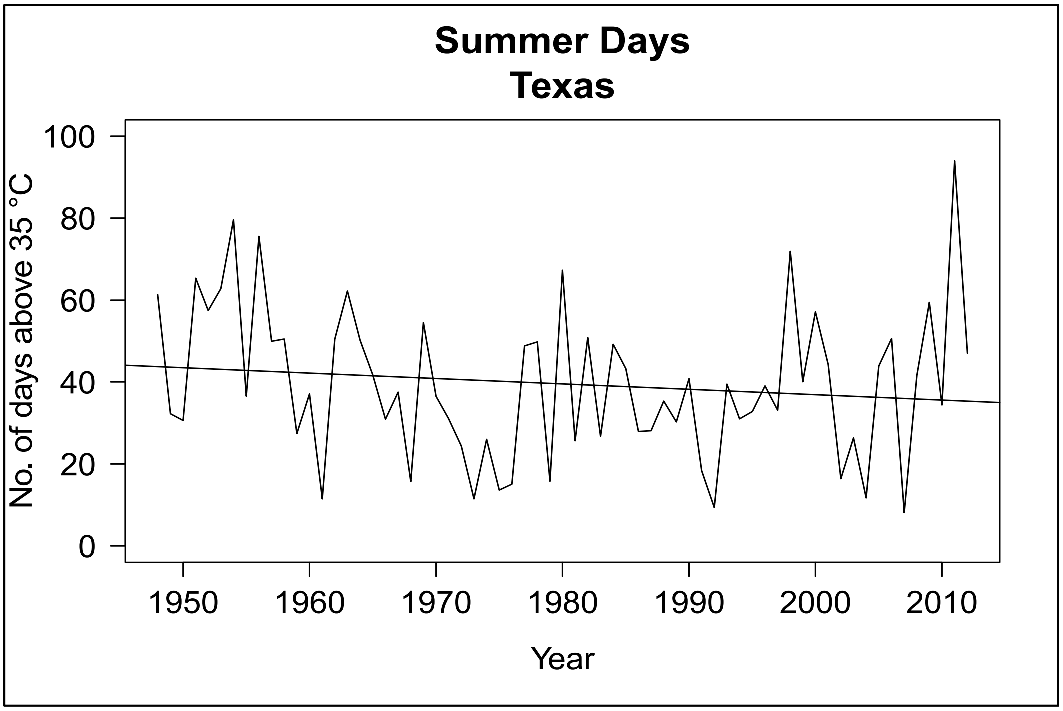

Figure 2-12. Texas annual time series of average summer days (annual count of days with maximum temperatures above 35°C) from 1948 to 2012, with the least fit trend line plotted.

In general, periods of particularly cold extremes occurred in the 1960s and 1970s for more easterly locations and in the 1970s and 1980s for more westerly locations in the region. In South Carolina, four of the top five years with above-average number of

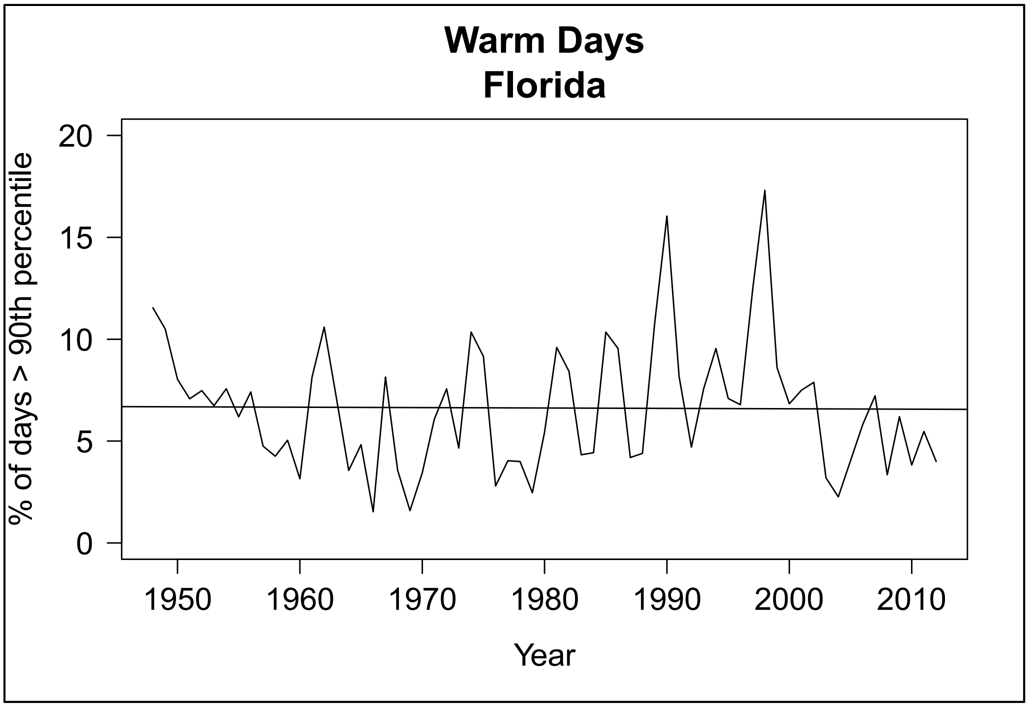

Figure 2-13. Florida annual time series of warm days (percent of days above the 90th percentile for a calendar day) from 1948 to 2012, with the least fit trend line plotted.

frost days occurred in the 1960s, particularly 1968, 1963, 1969, and 1960, in order from greatest to least number of days (Figure 2-14). Similar cooling during the 1960s and 1970s was observed for locations in Alabama, Florida, Georgia, Mississippi, North Carolina, and Tennessee. Cold extremes were apparent in the 1980s for locations in Texas, Oklahoma, Arkansas, and Alabama. Figure 2-15 shows this cooling period in the 1980s, as reflected in the average minimum temperatures for stations in Arkansas.

2.3.6 Temporal trends in precipitation extremes

The Southeast as a whole appears to be getting wetter, though there are important differences in individual indices and for particular parts of the region. Figure 2-16 shows time series graphs for two wet indices: the simple daily intensity index (SDII) and consecutive wet days (CWD). The SDII is defined as the annual total amount of

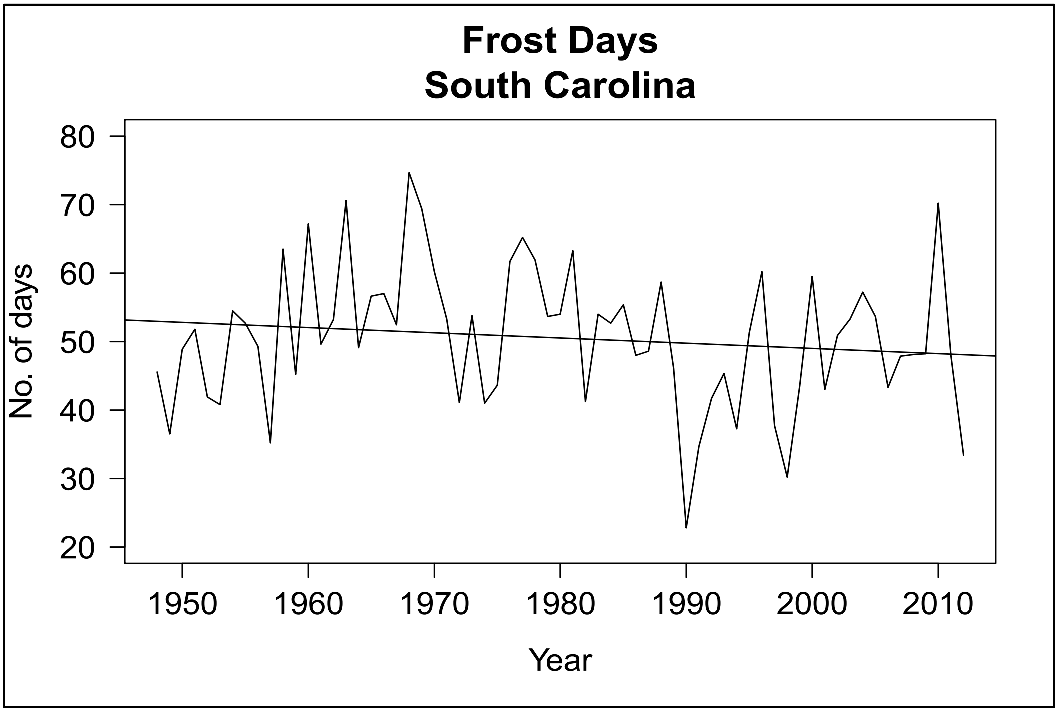

Figure 2-14. South Carolina annual time series of frost days (annual count of days with minimum temperatures below 0°C) from 1948 to 2012, with the least fit trend plotted.

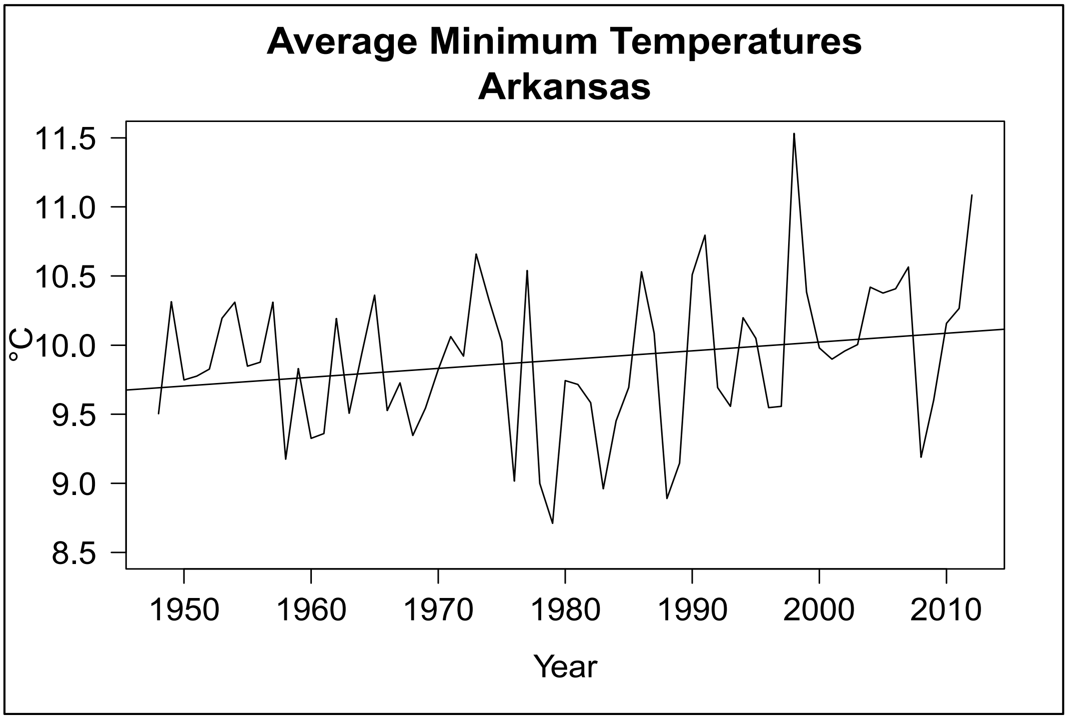

Figure 2-15. Arkansas annual time series of average minimum temperatures (in degrees Celsius) from 1948 to 2012, with the least fit trend plotted.

precipitation divided by the number of days with precipitation greater than or equal to 1 mm. The CWD is the annual maximum number of consecutive days when precipitation was greater than or equal to 1 mm. There is a slight increasing trend in the amount of precipitation that occurs on wet days, as observed in the SDII. However, the CWD index shows a clear decreasing trend since 1948. These trends suggest that extreme precipitation events may be getting shorter in duration for the Southeast; however, when precipitation does occur, it may be more efficient and of greater magnitude.

Trends in wet and dry indices were not consistent across the region. For instance, stations in Oklahoma are experiencing precipitation events of greater magnitude, as reflected by the SDII (Figure 2-17). South Carolina, on the other hand, has experienced increasing dryness, on average, since 1948, as reflected for instance in annual maximum consecutive 5-day precipitation events (Figure 2-18). The 1950s drought is apparent in precipitation-related indices for Oklahoma, Texas, and Arkansas, in particular. For example, the two driest years since 1948 in Oklahoma occurred in 1956 and 1951, with 27 and 25 consecutive days with no rainfall (days with < 1 mm), respectively. Figure 2-19 shows annual total precipitation from 1948 to 2012 for stations in Oklahoma, with depressed precipitation totals in the 1950s. Increasing dryness was apparent in the 2000s for more easterly states, particularly locations in Florida, South Carolina, and North Carolina.

2.3.7 Seasonal trends in extremes

Changes in extremes that occur during certain times of year can have different implications for various sectors. For instance, increases in extreme temperatures during

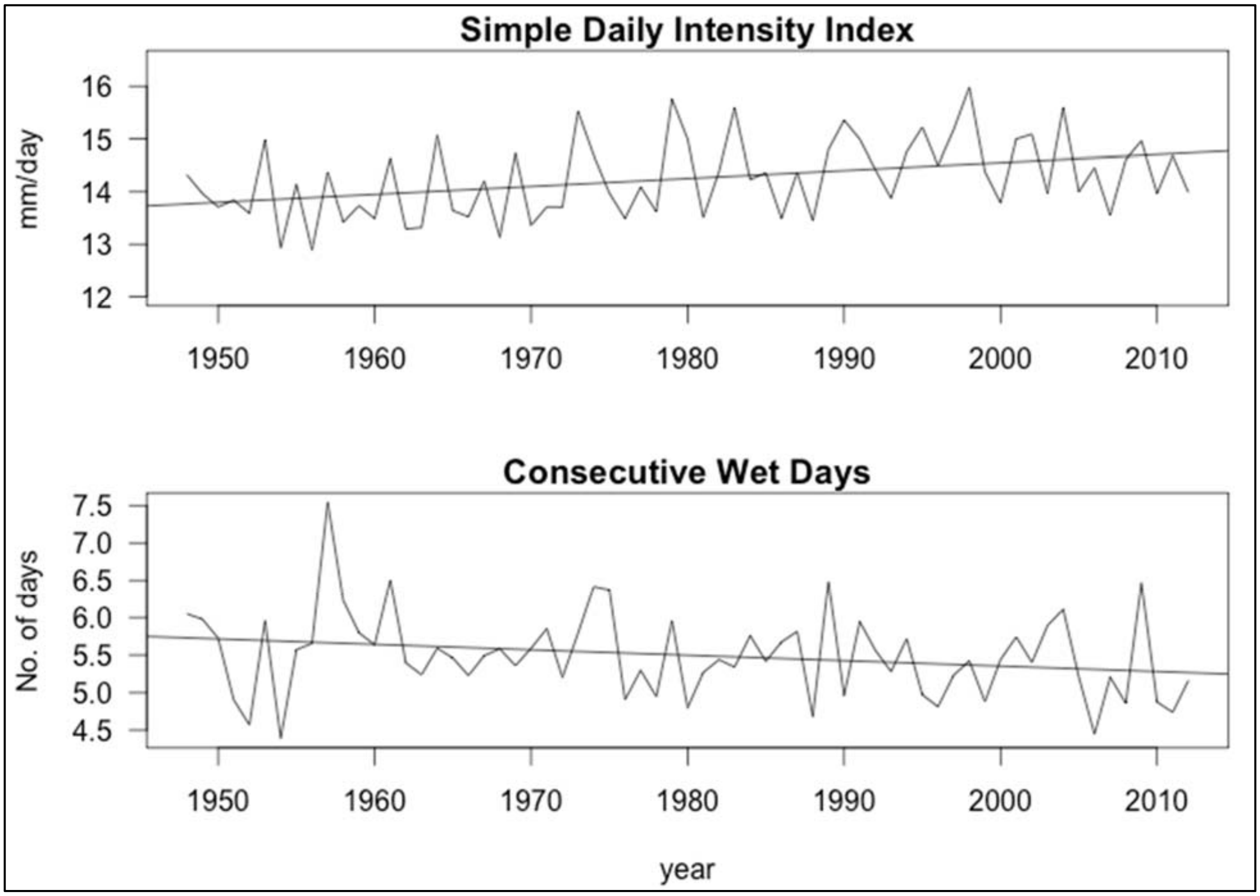

Figure 2-16. Southeast annual time series of the simple daily intensity index (total annual precipitation divided by the number of days with precipitation of at least 1 mm) and consecutive wet days (maximum number of consecutive days with precipitation of at least 1 mm) from 1948 to 2012, with least fit trend lines plotted.

summer months may have a larger impact on the energy sector, while increases in cold extremes during spring months may be more relevant to agriculture. Seasonal trends in certain indices are discussed in this section to provide more detail about intraannual extreme event behavior in the Southeast.

The thirteen extreme indices and their seasonal trends are shown in Table 2-7. Extreme indices do not display a distinct seasonality for the Southeast as a whole, though there are a few notable patterns. The majority of stations show downward trends in warm indices during winter. Fall shows increasing wetness region-wide. Conversely,

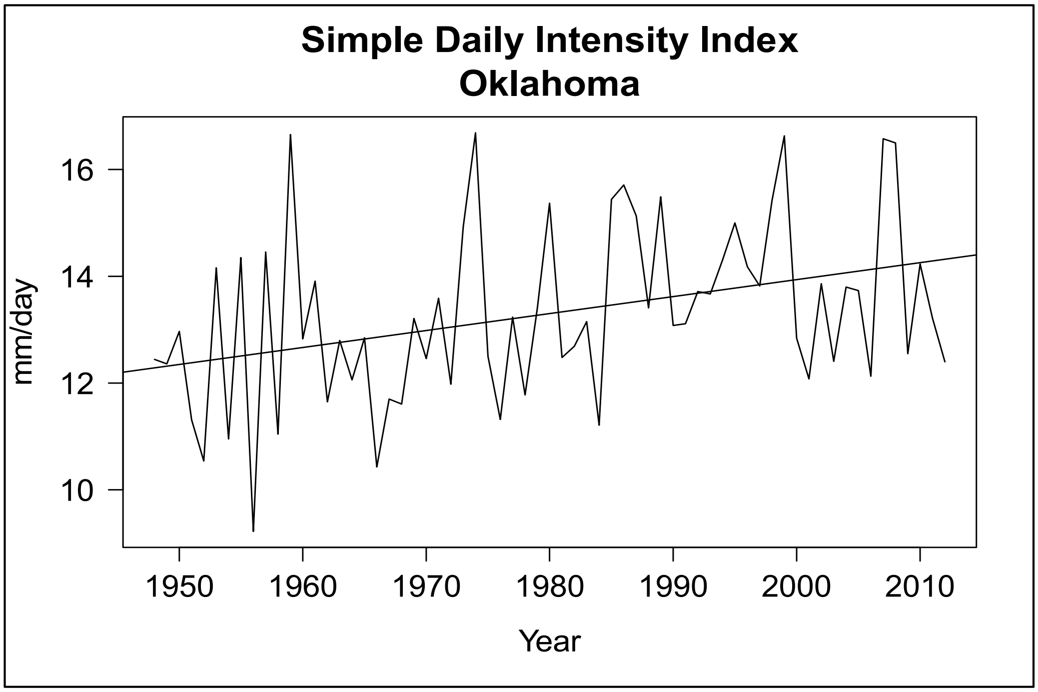

Figure 2-17. Oklahoma annual time series of the simple daily intensity index (total annual precipitation divided by the number of days with precipitation ≥1mm), in mm/day, from 1948 to 2012, with the least fit trend plotted.

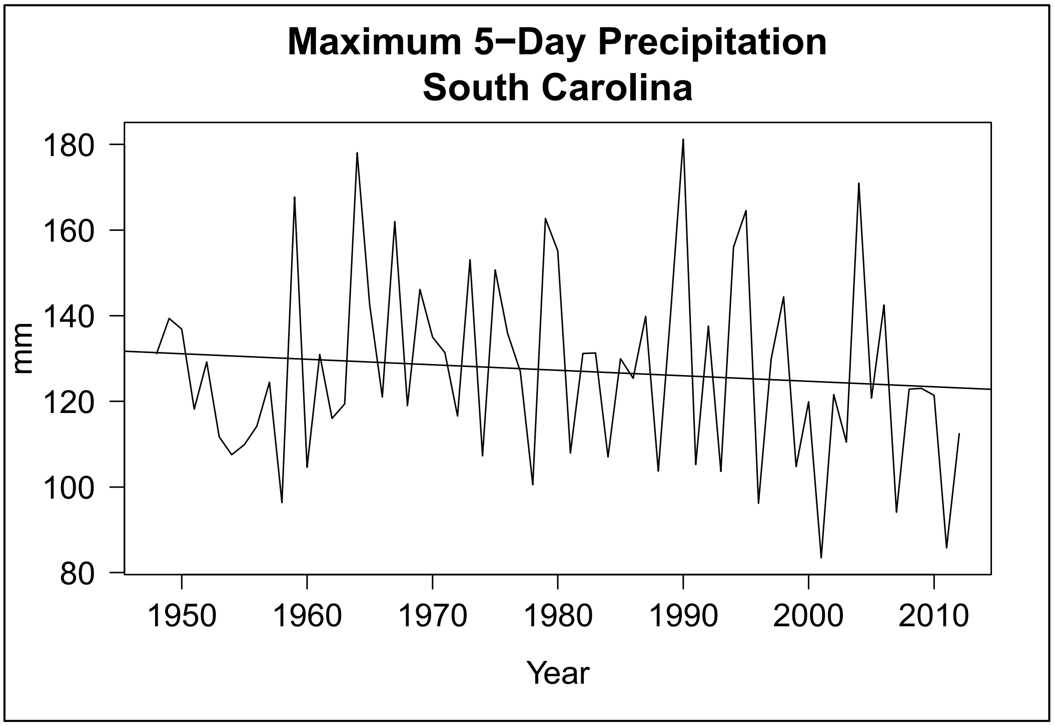

Figure 2-18. South Carolina annual time series of the average maximum 5-day consecutive precipitation totals in mm, from 1948 to 2012, with the least fit trend plotted.

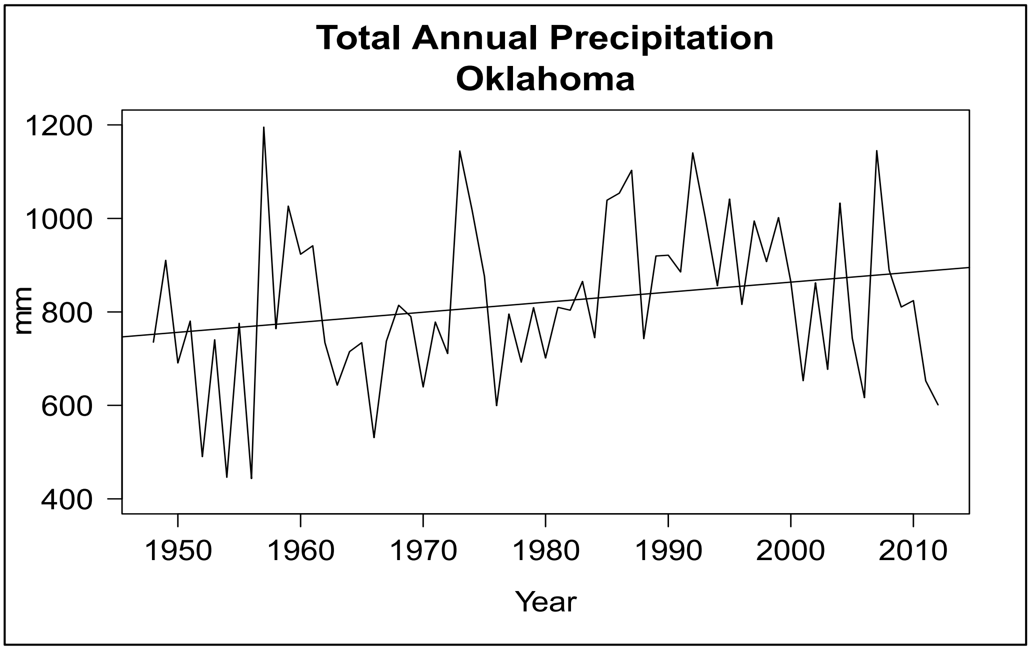

Figure 2-19. Oklahoma annual time series of average precipitation totals, in mm, from 1948 to 2012, with the least fit trend plotted.

spring is becoming drier for most states in the region, except Oklahoma, which shows strong, significant increasing trends in extreme 1- and 5-day rainfall. Tennessee has seen increasing wetness as well, though these trends were non-significant. While cool indices did not show clear, region-wide seasonal differences, certain states show notable patterns. For instance, Louisiana has clearly experienced cooling in winter and warming in summer since 1948. Fall is becoming wetter in Alabama, Arkansas, Louisiana, Mississippi, and Tennessee, on average (with significant trends at the 5 or 10% levels). Spring is becoming wetter in Oklahoma but drier for South Carolina and Georgia (again, with significant trends at the 5 or 10% levels). Summers are becoming drier in Arkansas, Louisiana, North Carolina, and South Carolina (though trends are not generally significant). Conversely, summers are becoming wetter in Florida, Mississippi, Tennessee, and Texas (with significant trends only in Florida and Mississippi).

Table 2-7. Total count of states with average negative and positive trends for the Southeast by season and index category, as follows: warm indices (TXmean, DTR, TX90p, TN90p, TXx, and TNx), cold indices (TNmean, TX10p, TN10p, TXn, and TNn), and wet indices (RX1day and RX5day).

	Warm		**Cold**		**Wet**	
	Negative	Positive	Negative	Positive	Negative	Positive
Fall	43	23	22	33	2	20
Winter	60	6	26	29	10	12
Spring	45	21	27	28	16	6
Summer	36	30	21	34	9	13

Seasonal trends for all states and seasons are provided in Table 2-8. Results reveal widespread decreases in average maximum temperatures, particularly in winter, and widespread increases in average minimum temperatures in fall, spring, and especially summer. Decreasing annual, summer, and winter trends in mean air temperatures occurred in the Southeast between 1895 and 2007 (Rogers 2013). Results from this study reveal that overall decreases in mean temperatures can be attributed to decreases in maximum temperatures, particularly in winter. In addition, most locations have seen slight decreases in diurnal temperature ranges in most seasons due to the disproportionate increases in minimum versus maximum temperatures. Trends in diurnal temperature range are consistent with those found for the Northeast by Brown et al. (2010). Significant trends in minimum temperatures and diurnal temperature range are largely restricted to summer months, with the exception of Oklahoma.

The occurrence of significant trends also varies somewhat by season. In general, fall and summer have the greatest number of significant trends, particularly in the temperature indices. For example, significant trends in nights below the 10th percentile (TN10p) and coldest nights (TNn) are largely restricted to fall and summer. Maximum 1-

Table 2-8. Seasonal trends in average monthly indices by state from 1948 to 2012. Bold values indicate significance at the 0.05 level and an asterisk denotes significance at the 0.10 level.

		TXmean	TNmean	DTR	RX1day	RX5day	TX90p	TN90p	TX10p	TN10p	TXn	TNn	TXx	TNx
AL	fall	0.003	0.005	-0.003	**0.192**	**0.327**	-0.023	0.061 *	-0.047	-0.036	0.018 *	0.016 *	-0.006	0.010
	winter	-0.008	-0.013	0.006	0.029	-0.091	-0.059	-0.072 *	0.000	-0.005	0.006	0.019	-0.007	-0.007
	spring	0.006	0.001	0.004	-0.017	-0.172	-0.005	0.010	-0.013	-0.024	-0.004	0.004	-0.001	-0.011
	summer	-0.001	**0.012**	**-0.013**	0.066	0.111	-0.017	**0.102**	0.009	-0.067 *	-0.004	**0.022**	-0.003	**0.010**
AR	fall	**-0.021**	0.009	**-0.030**	**0.158**	**0.304**	**-0.123**	0.018	0.043	**-0.080**	-0.023 *	**0.020**	**-0.019**	0.000
	winter	**-0.024**	-0.005	**-0.018**	0.008	0.004	**-0.068**	-0.034	0.062 *	0.002	-0.012	0.026	**-0.029**	-0.011
	spring	-0.006	0.009	**-0.016**	-0.013	-0.030	-0.058	0.052	0.045	-0.051 *	-0.010	0.017 *	-0.010	-0.002
	summer	-0.009	**0.014**	**-0.023**	-0.071	-0.137	-0.087	0.085 *	0.039	**-0.087**	-0.003	**0.030**	-0.011	**0.010**
FL	fall	0.004	**0.014**	**-0.010**	-0.112	-0.226	0.008	**0.103**	-0.026	-0.049	0.007	0.013	0.000	**0.014**
	winter	-0.007	0.005	**-0.013**	0.040	0.074	-0.033	0.047	0.018	-0.041	-0.012	0.003	-0.003	**0.014**
	spring	0.000	0.011 *	**-0.011**	-0.048	-0.049	-0.030	**0.074**	-0.010	**-0.077**	-0.011	0.010	-0.005	**0.010**
	summer	0.000	**0.018**	**-0.018**	0.112 *	**0.295**	0.019	**0.164**	0.019	**-0.206**	-0.005	**0.026**	0.003	**0.019**
GA	fall	-0.004	0.007	-0.010	0.131 *	0.172	-0.043	0.034	-0.004	-0.065 *	0.012	**0.023**	-0.013 *	0.003
	winter	-0.010	-0.010	0.000	0.030	-0.032	-0.041	**-0.101**	0.021	-0.035	-0.009	0.027 *	-0.008	-0.014
	spring	-0.004	-0.001	-0.003	-0.080	-0.204 *	-0.047	-0.002	0.033	-0.032	-0.013	0.011	-0.010 *	-0.010
	summer	-0.001	**0.015**	**-0.016**	0.004	-0.030	-0.026	**0.103**	-0.007	**-0.088**	-0.005	**0.032**	0.001	0.009 *
LA	fall	-0.001	0.012	-0.012	**0.176**	**0.384**	-0.004	0.057 *	-0.021	**-0.082**	-0.008	0.017	0.001	0.010
	winter	-0.018	-0.013	-0.004	0.012	-0.069	-0.070 *	-0.056	0.012	-0.040	-0.003	**0.023**	-0.009	-0.012
	spring	0.002	0.007	-0.005	-0.094	-0.184	0.009	0.024	0.010	-0.037	-0.011	0.005	-0.004	-0.003
	summer	0.000	**0.016**	**-0.015**	-0.030	-0.023	0.000	**0.153**	0.008	**-0.133**	-0.001	**0.027**	0.005	**0.015**
MS	fall	-0.008	0.011	**-0.018**	**0.160**	**0.310**	-0.049	0.057 *	0.000	**-0.076**	-0.009	**0.026**	-0.009	0.010
	winter	**-0.023**	-0.016	-0.008 *	0.010	-0.082	**-0.093**	**-0.098**	0.029	-0.029	-0.007	0.025 *	**-0.018**	-0.023 *
	spring	-0.004	0.004	-0.007	-0.022	-0.163	-0.055	-0.005	0.045 *	-0.041	-0.016	0.009	-0.009	-0.010
	summer	-0.011	**0.013**	**-0.024**	**0.131**	**0.181**	-0.093	0.068	0.052	**-0.109**	-0.018 *	**0.030**	-0.010	0.007 *
NC	fall	-0.007	0.002	-0.010	0.071	0.093	-0.034	-0.009	0.024	**-0.076**	0.000	**0.027**	-0.012 *	-0.003
	winter	-0.012	-0.012	0.000	-0.017	-0.075	-0.041	**-0.105**	0.029	-0.055	-0.012	0.024 *	-0.003	-0.021 *
	spring	-0.007	-0.004	-0.003	0.007	-0.002	-0.024	-0.024	0.050 *	-0.024	**-0.029**	0.005	-0.006	**-0.014**
	summer	-0.002	**0.013**	**-0.014**	-0.013	-0.089	-0.015	**0.072**	0.003	**-0.082**	-0.002	**0.029**	-0.005	**0.008**
OK	fall	-0.014	-0.003	-0.012	0.119	0.153	-0.068	-0.008	0.032	-0.016	-0.026 *	0.004	-0.012	0.000
	winter	-0.008	-0.007	-0.001	0.072	0.135 *	0.000	**-0.053**	0.016	-0.012	0.002	0.020	-0.004	**-0.033**
	spring	-0.002	0.000	-0.002	**0.165**	**0.236**	-0.028	0.022	0.008	-0.016	-0.006	0.018	-0.008	0.000
	summer	-0.002	0.006	-0.007	0.057	0.126	-0.005	0.049	0.008	-0.035	0.002	**0.019**	-0.004	0.002
SC	fall	-0.011 *	0.010	**-0.021**	0.059	0.008	-0.065	0.063	0.006	**-0.082**	0.003	**0.027**	**-0.023**	0.005
	winter	-0.008	0.001	**-0.009**	-0.040	-0.093	-0.046	-0.036	-0.004	-0.054	0.002	**0.028**	-0.008	-0.001
	spring	0.000	0.007	-0.006	-0.099 *	**-0.195**	-0.018	0.043	0.007	-0.055 *	-0.010	0.010	-0.007	0.002
	summer	0.000	**0.018**	**-0.018**	-0.014	-0.044	-0.015	**0.137**	-0.039	**-0.102**	0.008	**0.028**	-0.004	**0.014**
TN	fall	-0.004	0.010	-0.015 *	**0.129**	0.156 *	-0.041	0.025	0.007	**-0.090**	0.007	**0.029**	-0.013 *	0.002
	winter	-0.010	-0.005	-0.005	-0.037	-0.193	-0.042	-0.059 *	0.019	-0.034	0.001	0.029	-0.009	-0.011
	spring	0.002	0.004	-0.004	0.070	0.113	0.003	0.027	0.016	-0.052	-0.010	0.004	-0.002	-0.004
	summer	-0.007	**0.014**	**-0.021**	0.025	0.085	-0.082	**0.070**	0.020	**-0.098**	-0.005	**0.030**	-0.010	0.006
TX	fall	-0.004	**0.015**	**-0.019**	0.049	0.084	-0.065	**0.075**	0.003	-0.064 *	-0.010	0.009	-0.009	**0.016**
	winter	-0.003	0.006	-0.010	0.064	0.073	-0.019	0.002	-0.021	-0.057	0.016	**0.035**	-0.007	0.004
	spring	0.005	**0.016**	-0.011 *	0.006	-0.040	-0.004	**0.097**	-0.025	-0.043	0.011	0.014	-0.003	**0.014**
	summer	-0.009	**0.015**	**-0.024**	0.058	0.128	-0.074	**0.121**	0.038	**-0.111**	0.003	**0.024**	-0.013 *	**0.011**

day (RX1day) and consecutive 5-day (RX5day) precipitation indices generally display significant increases during fall, with significance at the 5 or 10 percent level. Downward trends in springtime wetness are observed overall, but these trends are not generally significant. Summer and winter wet extremes are more varied. For instance, maximum 1-day precipitation events generally increase in summer and winter; whereas, maximum 5-day precipitation events display more significant positive trends in summer and more negative, though insignificant, trends in winter.

2.4 Discussion

The set of ETCCDI indices reflect increasing trends in warm and wet extremes for much of the Southeast, with drier conditions evident in the eastern part of the region, particularly South Carolina. Threats from excessive heat are due more to increases in minimum temperatures than maximum temperatures. Minimum temperature-related extreme indices showed widespread increases across the region since 1948. The lack of relief at night from increasing minimum temperatures may have severe implications for human health. In particular, the number of tropical nights above 20°C (68°F) has increased by 0.23 days per year on average since 1948, and tropical nights above 24°C are also increasing for most locations. Consistent with overall warming, the number of frost days has decreased by 1.4 days since 1948. Similar results in these same temperature indices were found for New York State (Insaf et al. 2012), Utah State (dos Santos et al. 2011), and to a lesser extent in the Northeast (Brown et al. 2010).

Periods of extreme warm weather are observed throughout the 65-year period. Based on 95th percentile exceedences, DeGaetano and Allen (2002) found that the U.S. is experiencing a significantly increasing trend in warm thresholds that outnumber decreasing trends in these same thresholds. Yet, increasing trends are not apparent until the 1950-1996 period for much of the country, and the most recent two decades virtually lacked significant decreasing trends altogether (DeGaetano and Allen 2002).

Similarly, many locations in the Southeast show increasing warm extremes in the most recent two decades; however, time series of warm indicators and anomalies show that the early part of the record experienced extremes comparable to, if not greater than, those experienced in more recent years. In other words, extreme events in more recent years may not be outside the range of 'normal' for extremes during much of the 20th and early 21st centuries.

Despite warming seen many indices, maximum temperature-related indices are not increasing uniformly in the Southeast. In fact, average annual trends since 1948 show that the number of summer days and days above the 90th percentile are declining for the region as a whole. Results of maximum temperature-related indices from this study are consistent with previous studies that observed a 'warming hole' over much of the eastern and southeastern regions of the United States observed in maximum (Donat et al. 2013) and mean temperatures (Rogers 2013). In fact, the Southeast is one of few regions globally to not show an overall warming trend in surface temperatures over the 20th century (IPCC 2007). Kunkel et al. (2013) summarize the hypotheses that have been made regarding the lack of warming in the Southeast, which have included increased cloud cover and precipitation, increased aerosols and biogenic production, changes in sensible heat flux due to irrigation, and changes in North Atlantic and tropical Pacific sea surface temperatures.

Increases in the length of the growing season would be expected under a warming climate. Brown et al. (2010) and Griffiths and Bradley (2007) found a strong increasing trend in the growing season length for the Northeast, with some stations seeing about 2.2 days per decade increase in the growing season (Griffiths and Bradley

2007). Dos Santos et al. (2011) also found general increases in the growing season length across Utah since 1930. In the Southeast, trends in growing season length are more variable and not as strong. Five states (Arkansas, Florida, Louisiana, Mississippi, and Oklahoma) show negative trends in the growing season length, while six states have positive trends, on average (Alabama, Georgia, North Carolina, South Carolina, Tennessee, and Texas). Trends for the entire Southeast are near zero, on average, and only 8 percent of the stations exhibit significant trends in this index overall. This makes conclusions about changes in the length of the growing season for this region less clear.

Much of the Southeast has experienced more extreme wet days since 1948, particularly in far western and central portions of the region. Increases in the number of heavy and very heavy precipitation days are largely restricted to western portions of the study region, namely Texas, Oklahoma, and Louisiana; whereas, increases in extreme precipitation days over four inches occur mostly in the central portion of the region, particularly in parts of Mississippi, Tennessee, and western North Carolina. Evidence suggests that precipitation events are becoming more intense as well, as seen in the simple daily intensity index. In addition, extreme precipitation events are becoming shorter, with a decline in the number of consecutive wet days in most locations. Increases in precipitation extremes were previously observed in eastern portions of North America (Donat et al. 2013) and the United States (Kunkel 2003, Knight and Davis 2009). In the United States, Kunkel (2003) found an increase in extreme precipitation event frequency since the early 1900s, and Knight and Davis (2009) found that extreme precipitation has been increasing over roughly the last century, with increases in extreme precipitation from tropical cyclones in more recent decades. These trends are similarly reflected for the Southeast using these ETCCDI indices. However, there are fewer significant trends in precipitation extremes compared to temperature extremes, which was also true for these same indices in Utah (dos Santos et al. 2011).

Periods of elevated warm extremes tend to coincide with periods of drought. In particular, peaks in extremes are observed during the 1950s when roughly 80 percent of the Southeast and South (as defined by NCDC's Climate Extreme Index) were affected by severe or extreme drought and again in the 2000s when roughly 40 percent of the Southeast and South were in drought (Easterling et al. 2000). These results are consistent with DeGaetano and Allen (2002) who found that century-long trends in warm temperature extremes for both maximum and minimum temperatures peaked in the 1930s, 1950s, and 1980s, coinciding temporally and spatially with widespread drought episodes. Despite an enhanced hydrologic cycle leading to more intense rainfall events, a rise in temperatures is expected to increase evapotranspiration rates and lead to more drought conditions in the country (Easterling et al. 2000). Based on results in this study, extreme western and eastern portions of this region may be at greatest risk to increased drought in the future.

2.5 Future Research

The direction and strength of annual trends in extremes are influenced by the length of record and number of stations available with data of adequate quality and completeness. To minimize the occurrence of missing values that can affect index and trend results, it was necessary to truncate the period of record by pushing the start year up from 1910 to 1948. The USHCN includes 1,218 stations across the U.S., chosen for their overall quality relative to other COOP stations. It was decided to limit stations in this study to the USHCN daily dataset to ensure all stations had undergone consistent data quality measures. Future work could incorporate more stations in the analysis from other available daily datasets, such as the COOP network that contains more temperature and precipitation stations than that available through the USHCN. In addition, an analysis of extreme indices over a longer period of record should be conducted on a subset of stations identified as having adequate quality and completeness of data as far back as the late 1800s. Century-long trends in extremes would provide a valuable comparison with trends observed in this study during the latter half of the 20th century, helping to place more recent trends in a broader context of climate variability in the Southeast.

Understanding the drivers behind extreme weather and climate is important for projecting future climate change and understanding potential impacts. The Bermuda High and ENSO are two important teleconnection patterns that exert strong influences on temperature and precipitation variability in the Southeast. Further investigations into the relationship between extreme indices and the strength and signal of these and other modes of atmospheric patterns would be an important and logical next step in this research. For instance, Griffiths and Bradley (2007) investigated the relationship between two precipitation (CDD and R95p) and two temperature (FD and TN90) ETCCDI indices with the Arctic Oscillation, Pacific-North American, and ENSO patterns. They found that the AO is a good predictor of warm nights in winter, and the ENSO is a good predictor of consecutive dry days for the Northeast. However, Brown et al. (Brown et al. 2010) conducted a preliminary investigation of the association between extreme indices and six teleconnection patterns, namely the AO, ENSO, PNA, North Atlantic Oscillation, Pacific Decadal Oscillation, and the North Pacific patterns. Using a multiple linear regression, these six patterns were used as predictors of each of the 27 ETCCDI indices for a 53-year period, from 1951-2002, and a 103-year period, from 1900 to 2002. They found little explanatory power in the Multiple Linear Regression model over the 103-year period, concluding that large-scale modes of climate variability did not appear to exert much influence on these extreme indices for the Northeast, though they recommended a more thorough analysis be performed on the interactions of these six patterns for more conclusive results. A similar analysis would be worthwhile for the Southeast to assess which, if any, atmospheric circulation patterns exert the greatest influence on extremes in temperature and precipitation and which are the best predictors during different times of year.

A recent series of interviews conducted by SCIPP assessed climate-related needs of stakeholders and decision makers in Oklahoma (Riley et al. 2012) and along the Gulf Coast (Needham and Carter 2012). Among the needs and priorities participants identified were locally relevant climate information, improved seasonal forecasts, and projections of changes in extremes. Tebaldi et al. (2006) found a need for more regional-scale projections of climate change among researchers and stakeholders in general. One of the primary objectives of the ETCCDI Working Group and CLIMDEX project are to encourage comparison of observational data to climate models and to evaluate model output. Results from this study could be used to evaluate the robustness and accuracy of regional climate models (RCMs) and help improve projections of climate extremes for the Southeast U.S. The opportunities, and burdens, of adapting to climate change and mitigating the adverse impacts of extreme events are largely the responsibility of local governments. Therefore, regional and local projections of climate change can provide crucial information to assist local governments and communities in taking hazard mitigation and climate adaptation measures. Improved regional models would provide more reliable information about extreme variability for incorporation into hazard mitigation planning, land use planning, climate adaptation planning, and stormwater management.

Lastly, future work could combine these 27 extreme indices with other environmental indicators of climate change important to the region for a much more thorough analysis of risks posed by climate change. This work could include observations of sea level rise, sea surface temperatures, drought indices, and timing of peak river flow, as well as other important environmental factors that may exacerbate climate change, such as land subsidence and coastal erosion rates. In addition to assessing changes in these indices, it is imperative to incorporate changes in their impacts on the region’s economy, environment, and human populations. Information about the impacts of extreme events on specific sectors and how they may be changing is a prerequisite for proper planning and adaptation.

CHAPTER 3. CLASSIFICATION OF CLIMATE EXTREMES IN THE SOUTHEAST UNITED STATES USING PRINCIPAL COMPONENT ANALYSIS

3.1 Introduction

Traditional classifications of climate delineate the boundaries of regions with similar climate characteristics. In 1900, Köppen significantly advanced efforts of climate classification when he identified climatic boundaries based on vegetation regimes (Thornthwaite 1948). The majority of the Southeast is characterized as humid subtropical (Cfa) under the Köppen climate classification, with the exception of the western portions of Texas and Oklahoma, which are classified as semi-arid (BSh and BSk), and southern Florida, which is tropical savanna (Aw) and tropical monsoon (Am). Despite its widespread use, the Köppen climate classification has been criticized as defining climatic limits that are too theoretical, grouping spatially diverse locations into the same climate group (Ackerman 1941). For instance, southern Connecticut and central Florida are both classified as humid subtropical (Cfa) and Spokane, Washington and Fresno, California are hot summer Mediterranean (Csa) climates. Conversely, Thornthwaite's classification scheme, developed in 1931, mapped climatic boundaries by comparing rates of precipitation and evapotranspiration, regarding vegetation as simply the physical mechanism that transports water from the ground to the atmosphere (Thornthwaite 1948). General knowledge of climate is typically the description of mean temperature and precipitation, including the seasonality and type of precipitation.

Similar to detecting shifts in hardiness zones, climate classifications provide a benchmark against which climate change may be measured. Understanding how climate change is influencing traditional notions of climatic zones can contribute invaluable information about the broader repercussions of climate change. Evidence suggests that climate change may indeed be altering traditional definitions of climate zones. Grundstein (2008) investigated how traditional climate regimes have expanded or contracted with climate change over the last century. He found statistically significant changes in the spatial extents of different climate types, based on Thornthwaite’s climate classification scheme, from 1895 to 2005. In particular, he found that the eastern half of the U.S. has changed to a wetter regime, which is particularly pronounced in the Deep South (Grundstein 2008). Climate classification schemes have also been used in climate modeling studies to visualize impacts of climate change and empirically evaluate climate shifts on regional to global scales (Grundstein 2008).

Climate change may be altering patterns of temperature and precipitation (USGCRP 2009). In particular, climate change is expected to manifest itself most as changes in temperature and precipitation extremes (Peterson et al. 2012). Changes in the frequency and intensity of extremes are often the subject of climate change research that aims to better understand and anticipate the impacts of climate change. Temperatures and precipitation patterns are not expected to change uniformly across the country. Overall trends suggest that areas with higher average precipitation are expected to become wetter, and dry areas will likely become drier (IPCC 2007, USCCSP 2008). However, while much of the U.S. is experiencing warmer and wetter extremes, regional differences exist (USCCSP 2008). For instance, changes in precipitation extremes are expected to be larger than changes in mean precipitation (IPCC 2007), and temperature changes have differed in the Southeast than for the rest of the country (Groisman et al. 2004, Rogers 2013).

Grundstein (2008) argued that studies based on temperature and precipitation trends across large areas may mask important differences that exist on sub-regional scales. With respect to extremes in temperature and precipitation, in particular, the Southeast may be less spatially homogeneous compared to overall mean climate. Firstly, changes in extremes may occur in both tails of statistical distributions (IPCC 2012), suggesting increasing variability in overall climate due simply to an increasing range in specific climate parameters. Secondly, extreme events are stochastic in nature and, therefore, are likely to exhibit more spatial and temporal variability. Because of their stochastic nature, uncertainty remains over whether more frequent and intense storms are likely, despite strong evidence that the water cycle accelerated throughout much of the 20th century (Huntington 2006). Lastly, climate extremes may exhibit more spatial variability, particularly at local to regional scales, than overall mean climate due to land use changes and other environmental factors that can drive and/or exacerbate extreme events.

Due to the more serious impacts associated with extremes, a classification based on extremes in climate is worthwhile to further understand climate change and its implications. A classification of climate extremes may in fact be different from traditional classification schemes that are based on long-term measures of precipitation, evapotranspiration rates and vegetation regimes. This ‘geography of climate extremes’ would be beneficial to climate-related research, as well as decision makers, policy shapers and local governments planning and developing climate adaptation and hazard mitigation strategies.

A regionalization of extremes can contribute to a better understanding of the geographic nature of climate change. Eigenvector techniques are often employed in geographical research to classify and simplify large amounts of data, including in climatological and meteorological studies (Jolliffe 1986, 1990, Vega and Henderson 1996). Principal component analysis (PCA) is a commonly used method for describing patterns of meteorological variables, like temperature, pressure and precipitation, over large areas (Jolliffe 1986). In fact, PCA has been identified as the most popular eigenvector technique employed in climatological research (Vega and Henderson 1996). Several climate studies have effectively used PCA for classification purposes, such as for the characterization of sea-level atmospheric pressure patterns over North America (Jolliffe 1986); spatial patterns of tropical cyclone precipitation for the eastern U.S. (Nogueira et al. 2012); seasonal periods of wind, temperature and precipitation for Southern California (Green et al. 1993); and annual precipitation totals over southern Africa for forecasting purposes (Dyer 1975), to name a few.

3.1.2 Research objectives

The main objective of Study One in this research was to measure spatial and temporal changes in temperature and precipitation extremes in the Southeast during the last half-century using a set of indices developed by the WMO ETCCDI working group. Results showed large variability in some indices, while other indices displayed trends that were largely consistent across the study region. Knowledge of extreme event behavior is paramount to adequate planning and preparedness, even considering uncertainty inherent in future climate change. A regionalization of temperature and precipitation extremes for the Southeast would provide additional information regarding areas that have experienced similar variability in extremes, enabling local governments and resource managers to draw from the experiences and actions of others facing similar issues, not necessarily based on proximity alone.

This study uses the WMO indices calculated in Study One to develop a classification of climate extremes for the Southeast. Three main classification regimes are produced, one each for temperature extremes, precipitation extremes, and seasonal periods of extremes. The purpose of these classifications is to identify locations that have experienced similar patterns in temperature and precipitation extremes over a 65-year record, from 1948 to 2012. The classification scheme will then be used to inform an analysis of climate-related policy and planning efforts in Study Three. This study has two main objectives:

1. to group stations together with similar temporal patterns in extreme temperature and precipitation indices to develop a regionalization of extremes for the Southeast United States, and
2. to characterize a seasonality of extremes based on extreme temperature and precipitation indices.

3.2 Data and Methods

3.2.1 ETCCDI data

This study uses the core set of ETCCDI indices that were calculated in Study One to define a regionalization of climate extremes in the Southeast in this study. These indices characterize the intensity, duration and frequency of extremes in temperature and precipitation. They were developed by the ETCCDI working group to assess extreme events that generally occur several times a year to facilitate better measuring and monitoring of extremes (Tank et al. 2009). A complete list of the 27 core indices and their definitions are provided in Table 2-1. The RClimDex program was used in Study One to calculate these indices for stations in the Southeast for the period 1948 to 2012. All 107 USHCN stations within the Southeast region included in Study One are also used in this study (see Appendix I for station IDs and names). The calculations resulted in annual values for all indices for each station, as well as monthly values for a subset of indices. Annual values of all temperature-related indices (20 indices, as well as mean maximum and minimum temperatures) are used in the classification of temperature extremes. Similarly, annual values of all precipitation-related indices (11 total) are used in the classification of precipitation extremes.

Monthly indices are used to identify seasonal periods of extremes for the Southeast. A list of the monthly indices and their definitions are provided in Table 3-1. They include 11 temperature indices: mean maximum and minimum temperature (TMAXmean and TMINmean), diurnal temperature range (DTR), cool days (TX10p), cool nights (TN10p), warm days (TX90p), warm nights (TN90p), coldest day (TXn), coldest night (TNn), warmest day (TXx), and warmest night (TNx). In addition, there are two monthly precipitation indices: maximum 1-day precipitation (RX1day) and maximum 5-day consecutive precipitation (RX5day).

3.2.2 S-mode PCA

This study aims to classify extremes in both temperature and precipitation to spatially characterize extremes and group stations that have experienced similar temporal patterns in extremes over the 65-year record. An S-mode PCA is used for both the temperature and precipitation classifications; whereby, the input matrix consists of stations as the variables (i.e. columns) and years as the individuals (i.e. rows). This

Table 3-1. The thirteen monthly extreme indices and their definitions, as provided by the CLIMDEX project, used to calculate seasonal periods of extremes.

Monthly Indices	
Index	*Definition*
TMAXmean	Mean of maximum temperature
TMINmean	Mean of minimum temperature
DTR	Diurnal temperature range
TN10p	% of days when Tmin is < 10th percentile
TX10p	% of days when Tmax is < 10th percentile
TN90p	% of days when Tmin is > 90th percentile
TX90p	% of days when Tmax is > 90th percentile
TNn	Monthly minimum value of daily min temp
TXn	Monthly minimum value of daily max temp
TNx	Monthly maximum value of daily min tem
TXx	Monthly maximum value of daily max temp
RX1day	Monthly maximum 1-day precipitation
RX5day	Monthly max consecutive 5-day precipitation

produced two, but similar, input matrices. The temperature (precipitation) matrix consisted of 107 columns by 66 rows, with the common variable under investigation being average temperature (precipitation) index values. All data analysis and PCA models were conducted in R, an open-source language and environment for statistical analysis (*www.r-project.org*). Maps were produced in R and ArcMap 10.

Raw index values were first standardized for use in the PCA models. Use of standardized values (i.e. z-scores) enabled the synthesis of multiple indices with different units, and it ensured that each index was represented equally in the PCA model. For each index, annual z-scores were calculated by subtracting the mean from the annual value and dividing the result by the standard deviation. The mean and standard deviations were determined from the annual values for the entire period of record (1948-2012) for that particular index. The formula may be written as:

$$Z_{ij} = \frac{(index_{ij} - \mu_i)}{\sigma_i}$$

where Z is the standardized value, or z-score, for index i and year j; index is the raw annual value for index i and year j; μ is the mean for the period of record and index i; and *σ* is the standard deviation for the period of record and index i. This formula was applied to all 107 stations and 33 indices. Finally, for each station, annual z-scores for all temperature and precipitation indices were averaged together to derive a single value for each station and year. Thus, final values were based on the average of 22 temperature indices and the average of 11 precipitation indices. These averages were used to create the final matrices for input into the PCA to develop temperature and precipitation classifications.

PCA assumes that variables are well correlated and attempts to reduce the dimensionality of a data set consisting of many interrelated variables (Jolliffe 1986). To test the suitability of a PCA model on these data, scatterplots were created between various stations, chosen at random, to easily visualize how well stations correlate with each other. The scatterplots represent the relationship of annual average standardized values for the temperature (or precipitation) indices for the period 1948 to 2012 between two stations. While the degree of correlation obviously varies, many stations are highly correlated with respect to temperature extremes. Figure 3-1 shows an example of a station in Texas that is highly correlated with a station in Oklahoma with respect to annual averages of standardized temperature extreme indices. Unsurprisingly, stations closer together seem to be better correlated than stations farther apart; however, this is not necessarily true. For instance, Figure 3-2 shows fairly good correlation between a station in South Carolina and one in Mississippi.

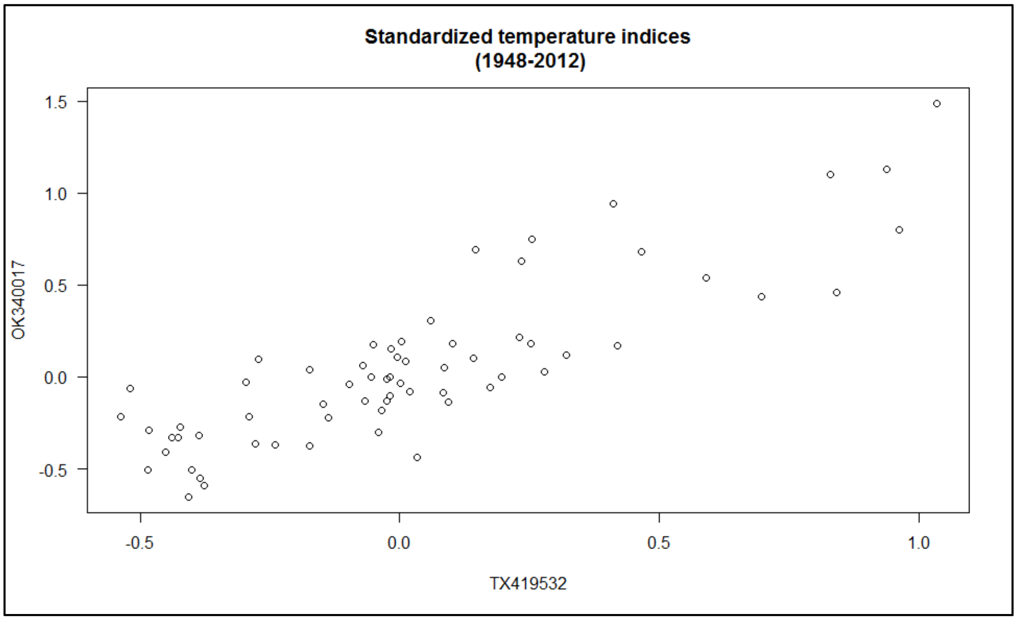

Figure 3-1. Scatterplot demonstrating the correlation between a station in Oklahoma (340017) and Texas (419532) for annual average standardized temperature extremes.

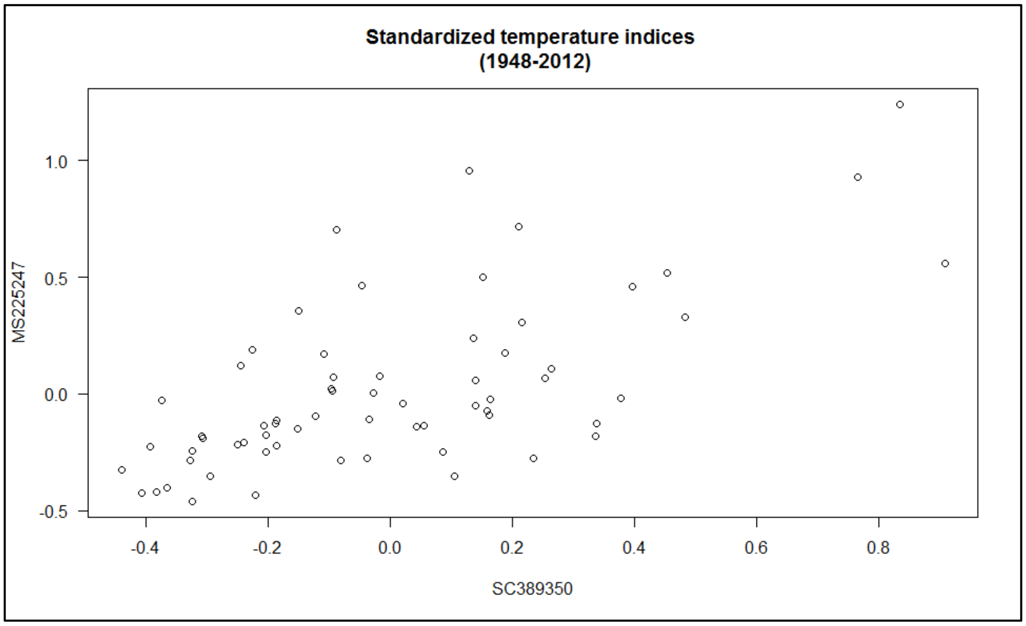

Figure 3-2. Scatterplot demonstrating the correlation between a station in South Carolina (389350) and Mississippi (225247) for annual average standardized temperature extremes.

Stations were similarly chosen at random to test their interrelatedness with respect to precipitation extreme indices. As expected, some stations are more highly correlated than others, but compared to temperature extremes, precipitation data are not as well correlated overall. This is likely due to the fact that precipitation extremes tend to be more variable across the study region, as was observed in the precipitation indices in Study One. Nonetheless, collinearity exists between many stations. Figure 3-3 shows an example of a station in Georgia and one in Alabama that are moderately correlated with respect to annual average standardized precipitation extreme indices.

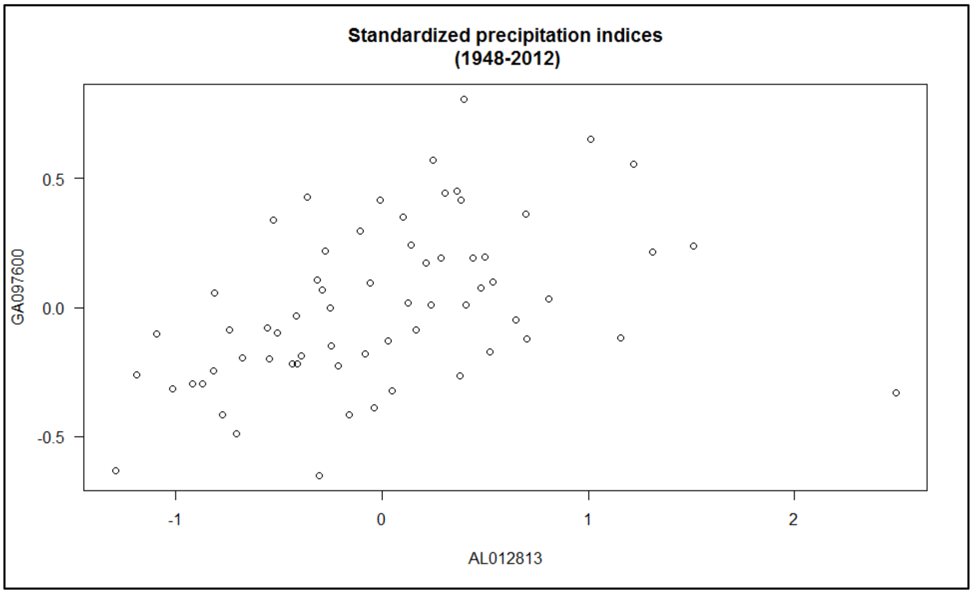

Figure 3-3. Scatterplot demonstrating the correlation between a station in Georgia (097600) and Alabama (012813) for annual average standardized precipitation extremes.

3.2.2.1 Missing values

The RClimDex program used to calculate the indices allows for some missing data. The program requires that daily data files be at least 70 percent complete. In addition to this criterion embedded within the RClimDex program, Study One applied more strict criteria on the raw station data files before input into the RClimDex program. Despite these criteria, resulting annual index files outputted from the RClimDex program contained years, or months, with missing values. In fact, many stations had at least one or more missing years in the 65-year period of record.

Missing values pose a problem in most statistical analyses and must be accounted for in some way. In R, the PCA function typically removes entire rows of data (i.e. independent variables) if one of the cells in that row is recognized as a missing value. Obviously, the removal of many rows (i.e. years) from the PCA analysis was undesirable. To resolve the issue of missing values in the data set and avoid the removal of data used in the PCA, missing values were imputed using functions available in the ‘missMDA’ package in R. The ‘estim_ncpPCA’ function in R was first used to estimate the number of dimensions or components that should be used to replace missing values with predicted ones. The generalized cross-validation method provides a more straightforward way to estimate the number of dimensions without being computationally intensive (Josse and Husson 2011). Thus, the generalized cross-validation criteria was used to identify the number of components that produces the smallest mean square error of prediction that should be used in the imputation procedure. This value was then used as input to the imputation procedure, using the ‘imputePCA’ function.

The imputation function in R initially imputes missing values using the mean of each variable. While the mean substitution or imputation method is a common approach for handling missing values (Karhunen 2011), it is often criticized because it substitutes the same value for each missing data point. Thus, in using mean substitution, it is possible to artificially reduce the variance in the variable by creating the same value for every missing value. However, if the data set contains only a limited number of missing data points, and those missing data points are spread out, then the replacement of missing values with the mean or median should not matter too much. In fact, when the percentage of missing data is small, replacing the missing values with the mean or an extreme value is a common strategy in multivariate statistics (Dodge 1985). Both temperature and precipitation data sets contained roughly 6 percent missing data. This was considered to be a relatively small percentage and mean substitution method non-problematic. The imputed (i.e. complete) data set was then used as input to the PCA.

3.2.3 T-mode PCA

This study characterizes seasonal periods for temperature and precipitation extremes. A temporal, or T-mode, PCA is used to group months into seasons using monthly values from 13 ETCCDI indices (Table 3-1). For the T-mode PCA, the input data matrix was structured such that months represented the variables and stations represented the individuals, producing a matrix consisting of 12 columns (months) and 107 rows (stations). To prepare the data for analysis, raw monthly values were first standardized using a similar approach as that used for the S-mode PCAs. For each station, monthly averages were calculated for the entire period of record for each index and then converted to z-scores. The standardization was based on the difference between the monthly average index value and the annual average for the period of record for that same index, using the following formula:

$$Z_{ij} = \frac{(index_{ij} - \mu_{annual})}{\sigma_{annual}}$$

where Z is the z-score for index i and month j; index is the average index value for month i and index j; μ is the average annual value for index i over the period of record; and σ is the standard deviation of the annual values for index i over the period of record. Lastly, the 13 z-scores were averaged together to produce a single value for each station and month. This approach may be summarized as follows:

For a given station, the following steps were performed on the data:

1. Monthly averages for the 65-year period were calculated for each of the 13 indices, creating 12 average values for each index.
2. These monthly averages were transformed into z-scores based on the formula above.
3. The z-scores were averaged together by month across all 13 indices – yielding one average z-score for each month and station.

Missing values were omitted from the calculation of monthly averages over the period of record before transforming averages into z-scores. Therefore, the final z-scores did not contain missing values and the imputation procedure to predict missing values was not necessary on these data. However, it is worth noting that some stations' monthly averages and, thus, z-scores used as input to the PCA are based on shorter periods of records where stations had one or more months with missing values. All other specifications for the PCA model were the same as those used in the S-mode PCA described above.

3.2.4 Interpreting PCA results

Several factors can affect the results and interpretation of a PCA model. In particular, there is inherent subjectivity in using PCA to classify variables into a new set of components or groups. Choices must be made in a PCA pertaining to the structure of the matrix used as input into the model, the number of components that are retained, whether components are rotated, and the method used to rotate components (Green et al. 1993). Arguably, the greatest subjectivity lies in the decision of the number of components to retain for analysis and interpretation. Eigenvalues can serve as a basis for deciding how many components to retain. A common rule of thumb is to retain only eigenvalues greater than one (Hamilton 1992, Wang 2006). Since the standardized variables will have a variance of one, a component with variance less than one accounts for less than a single variable's variation, making it less useful for data reduction (Hamilton 1992). Another common approach for determining the number of components is to analyze the scree and bar plots of eigenvalues and look for the point at which the slope begins to level off. Lastly, the retention of components may be based largely on *a priori* knowledge of the data and which components have the highest interpretability. All of these methods have advantages and limitations. The eigenvalue threshold of PCs above one may be too strict and somewhat arbitrary, particularly in cases when a value of 1.01 is retained and the next value of 0.99 is removed. Visual analysis of scree plots, however, is also subjective, though it can show where more natural cutoffs occur in the data that may be overlooked when applying a strict threshold criterion. This study used a correlation matrix in the PCA and the eigenvalue threshold criteria for determining the number of components to retain, though also using the scree plots and *a priori* knowledge of the data to support the threshold criteria.

Two different techniques were employed to facilitate interpretation of PCA results and identify similar regions of temperature and precipitation extremes. The first method assigned each station to the component with the highest loading, a method similar to that used by Nogueira et al. (2012). The stations and their 'assignments' were then mapped to visualize results and identify stations in the study region that displayed similar temporal characteristics. An interpolation method was used to further visualize geographic areas and boundaries of each component. Both inverse distance weighting (IDW) and kriging interpolation techniques were tested and compared for the temperature-based principal components. Results between the two interpolation techniques were very similar and the small differences observed between the two were not believed to alter much of the overall interpretation of the PCA components. Therefore, IDW was chosen to help visually represent and interpret results.

The second approach used k-means cluster analysis of the resulting components to similarly partition the study region into geographic areas with similar temporal characteristics. This approach was used by Green et al. (1993) to identify seasonal periods in temperature, precipitation and wind data for southern California. The k-means method does not attempt to form groups of similar size to better reflect natural processes. In addition, this method attempts to minimize variance within groups, or the within-cluster sum of squared deviations from the cluster means (Green et al. 1993). In other words, this method aims to partition points into a specified number of groups, k, so that the sum of squares from points to the assigned cluster centers is minimized (RCoreTeam 2012). The k-means clustering method was chosen here to form groups of stations exhibiting similar variability in temperature and precipitation extremes for comparison with the first method based on the assignment of each station to its component of maximum loading.

Rotating variables so that they fall closer to the axes can make interpretation of components easier. In an S-mode PCA, the rotation of variables attempts to identify a subset of variables that covary in a similar way, and in a T-mode PCA, rotation attempts to identify subgroups of observations with similar spatial patterns, essentially simplifying the station time series (Richman 1986). Despite the fact that orthogonally rotated solutions (i.e. at right angles) may be less stable than oblique rotations (i.e. not at right angles), thereby producing less consistent results (White et al. 1991), most climatological studies employ a correlation matrix and Varimax rotation when conducting PCA (Green et al. 1993, Vega and Henderson 1996, Nogueira et al. 2012). Varimax rotation is a widely used orthogonal rotation method that attempts to polarize loadings so that they are high or low, making it easier to connect factors with variables for interpretation (Hamilton 1992). Moreover, while Richman (1986) showed that Varimax rotation did not work as well as other oblique rotations, Varimax rotation is widely accepted as being the most accurate analytic technique for orthogonal rotation when a prior knowledge of a data set exists (Richman 1986). As a result, Varimax rotation technique was used in this study to compare with results based on unrotated components.

3.3 Results

3.3.1 Temperature extremes

Classification of temperature extremes is based on 21 indices calculated for 107 stations for a period from 1948 to 2012. Index values were standardized before use in the PCA to reduce skewness and enable the cross comparison of extreme indices that have differing units. Use of standardized variables also ensured normality of data, though this is not an essential requirement of PCA. The PCA used a correlation matrix and Varimax rotation, which maximized component loadings and between-type spatial coherence of regions (Nogueira et al. 2012).

The PCA model returned 65 components that together explain all of the variance in the original set of stations. While there are 107 variables (i.e. stations), a PCA returns a maximum of either the number of columns or rows (row-1), whichever is smaller. The 65 rows of data represent the 65-year record; thus, the PCA returned 65 components. Table 3-2 shows the standard deviations of the eigenvalues, the proportion of variance and cumulative proportions of variance for the first 30 components. Strictly following the ‘above one’ criteria, only the first two components need to be retained. In addition to this criterion, the scree and bar plots of eigenvalues were analyzed to look for the point at which the slope begins to level off. Figure 3-4 shows the scree plot that was used as a visual aid in deciding the number of components to retain. The bar graph of the standard deviations of the eigenvalues for all components is also shown in Figure 3-5 for comparison with the scree plot.

Upon examination of the scree plot of eigenvalues and standard deviations of eigenvalues for all 65 components, two principal components were retained for analysis. These first two components together explain 65 percent of the total variance in temperature extremes for these stations in the Southeast. Values of the coefficients for the first component (PC1) are all small and negative, with the exception of two stations. This implies that most of the temperature extremes over the Southeast are equally, though poorly, correlated with the new variable. Coefficients for the second component (PC2) are slightly larger for some stations, suggesting they correlated somewhat well with the second new variable, and roughly half of stations were of opposite signs.

Table 3-2. Standard deviations, proportional variance, and cumulative variance for the first 30 components representing the standardized temperature extreme indices. Standard deviations above one are retained for analysis.

	Standard deviation	**Proportion of Variance**	**Cumulative Proportion**
PC1	2.442	0.507	0.507
PC2	1.287	0.141	0.648
PC3	0.840	0.060	0.707
PC4	0.643	0.035	0.743
PC5	0.591	0.030	0.772
PC6	0.561	0.027	0.799
PC7	0.449	0.017	0.816
PC8	0.393	0.013	0.829
PC9	0.370	0.012	0.841
PC10	0.362	0.011	0.852
PC11	0.346	0.010	0.862
PC12	0.325	0.009	0.871
PC13	0.311	0.008	0.879
PC14	0.302	0.008	0.887
PC15	0.287	0.007	0.894
PC16	0.279	0.007	0.901
PC17	0.272	0.006	0.907
PC18	0.260	0.006	0.913
PC19	0.257	0.006	0.918
PC20	0.247	0.005	0.924
PC21	0.242	0.005	0.929
PC22	0.238	0.005	0.933
PC23	0.228	0.004	0.938
PC24	0.223	0.004	0.942
PC25	0.217	0.004	0.946
PC26	0.204	0.004	0.950
PC27	0.197	0.003	0.953
PC28	0.187	0.003	0.956
PC29	0.180	0.003	0.959
PC30	0.178	0.003	0.961

Keeping only PC1 and PC2, each station was assigned to its component of maximum loading. The ‘assignment’ of stations to their component of maximum loading resulted in three distinct regions, shown in Figure 3-6, as western, central, and eastern

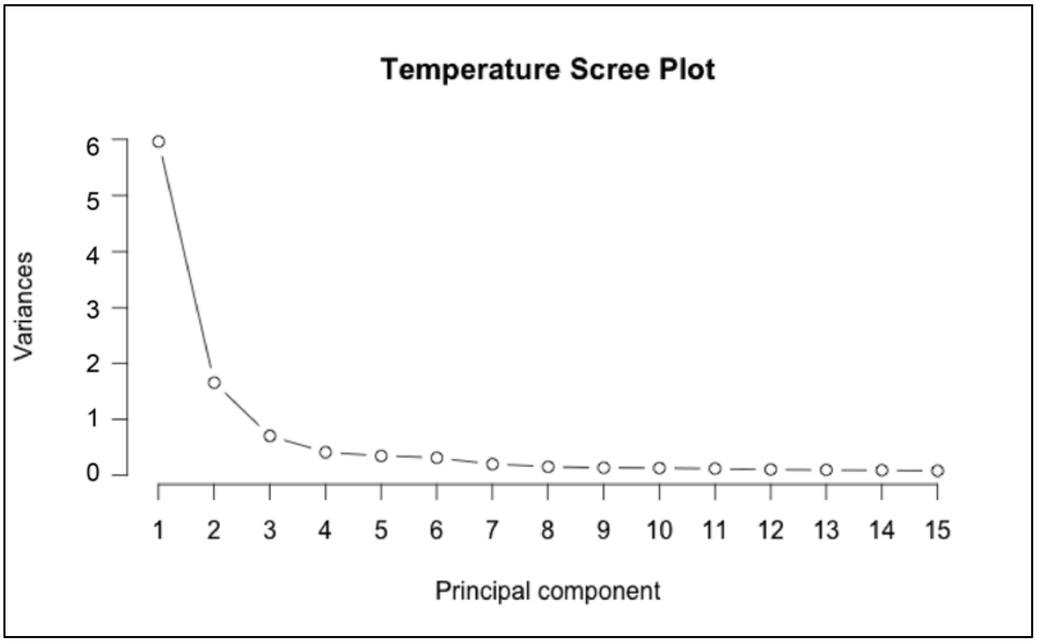

Figure 3-4. Scree plot of the principal components and variances (eigenvalues) resulting from the PCA based on extreme temperature indices.

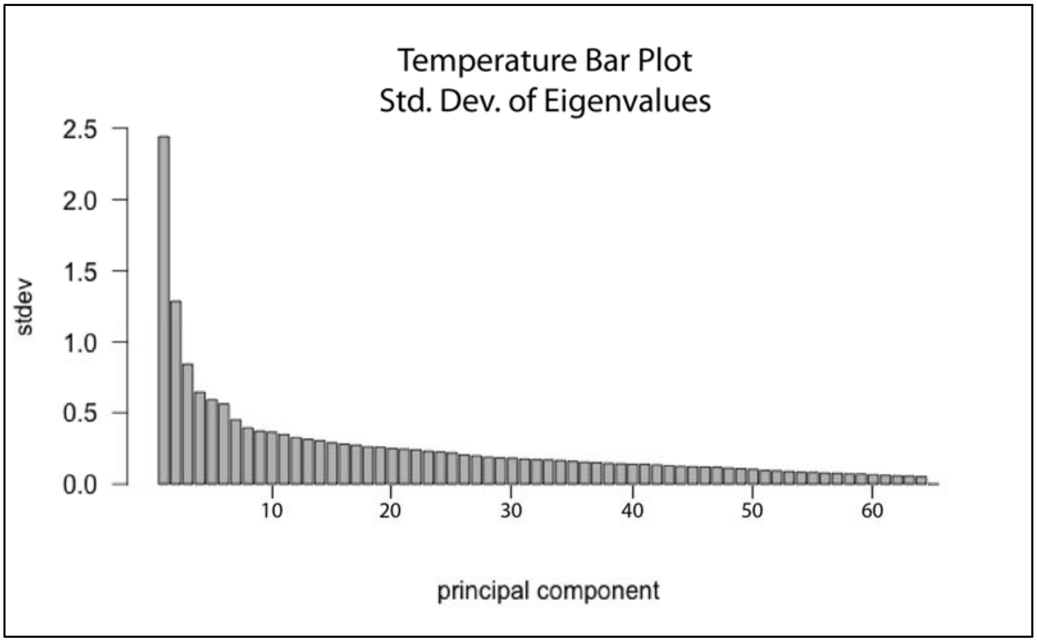

Figure 3-5. Bar plot of the standard deviations of eigenvalues and principal components shown in Table 3-2 resulting from the PCA based on extreme temperature indices.

sub-regions. PC1 represents 51 percent of the variance in all stations. This first component loads highest in the central Southeast, extending from eastern Oklahoma, through Arkansas and Louisiana to western Georgia and parts of Florida. Nearly all stations' values for PC1 are negative and small (near zero). Thus, PC1 may represent the average of the temperature extremes for all stations over the period of record.

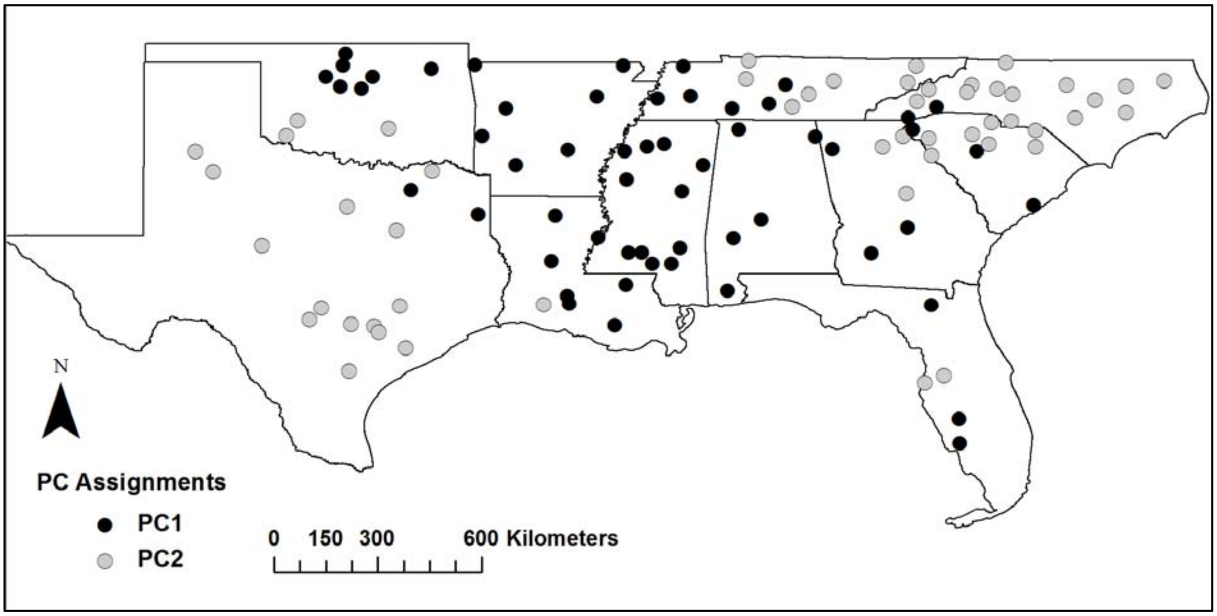

Figure 3-6. Assignment of stations to their component of highest loading for temperature extreme indices, retaining the first two principal components. A map of the stations and their IDs are provided in Appendix I.

PC2 explains 14 percent of the variance in all stations. This component shows a distinct east-west pattern, whereby there exists a center of action in Texas and another in the far east-northeast area, specifically in the Carolinas and eastern Tennessee. Just over half of the coefficients for this second component are negative (60 stations). Stations in South Carolina, North Carolina, and Tennessee have values of opposite sign from those in Oklahoma and Texas. These results suggest that extremes in temperature do not generally occur simultaneously in the eastern and western portions of the Southeast and that these two regions exhibit different temporal variability in temperature extremes. Furthermore, these two areas likely have two distinct sources of variability in extremes in temperature. Extremes in the east may be explained by the maritime influence of the Atlantic Ocean and the track of the Bermuda High, contrasted by the more westerly portion of the Southeast where continentinality and tracks of frontal systems that drive precipitation and drought patterns may play greater roles in generating temperature extremes.

To better visualize results and identify regions of maximum loadings, the coefficients of unrotated components were mapped across the study region using IDW to interpolate values across stations. The magnitudes of the coefficients, and not the signs, are used here to show the spatial patterns of each of the two components that were retained in the analysis. The loading maps in Figure 3-7 show that neither component is entirely spatially coherent, though clear regions emerge between the two components. PC1 clearly loads highest in the north and central portions of the region and is concentrated in Oklahoma, Arkansas, northeastern Texas, northern Louisiana, and northern Mississippi. PC2 loads highest in the extreme western part of the region, specifically western Texas, as well as eastern regions, namely in parts of North and South Carolina. Lowest coefficients for PC2 (i.e. values near zero) are concentrated in the central part of the region, suggesting that the variance of stations in this part of the region do not account for much of the variance explained by PC2.

Clustering analysis was performed on the coefficients of the first two components using the k-means method for comparison with the assignment of highest loadings shown in Figure 3-6. For the k-means cluster analysis, two groups were specified for consistency with the assignment method, which placed each station into one of two groups based on the coefficients of the first two components. The results of

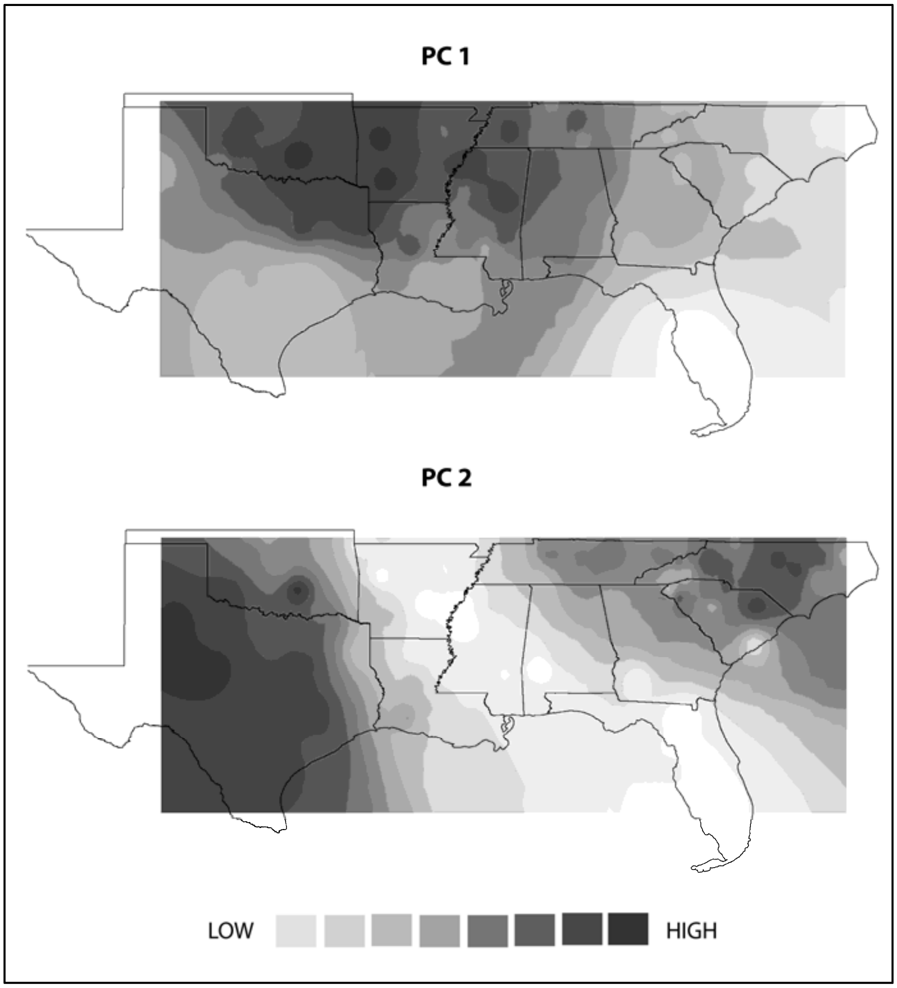

Figure 3-7. Loading maps of the first (PC1) and second (PC2) unrotated principal components of standardized temperature extremes in the Southeast, mapped using inverse distance weighting. Darker areas represent higher values. Concept borrowed from Nogueira et al. (2013).

the clustering reveals two spatially coherent groups with a clear divide between eastern and western regions (Figure 3-8). The first cluster consists of stations in the western half of the region, including those in Texas, Oklahoma, western Arkansas, Louisiana, southern Mississippi, and extreme southern Alabama. The second cluster consists of stations in the eastern half of the region, including those in eastern Arkansas and northern Mississippi eastward. The total variance explained for by the clustering is 71.4 percent. Figure 3-9 is a plot of the resulting clusters against the first two principal components, and Figure 3-10 is a plot of the centroids against the first two discriminant functions.

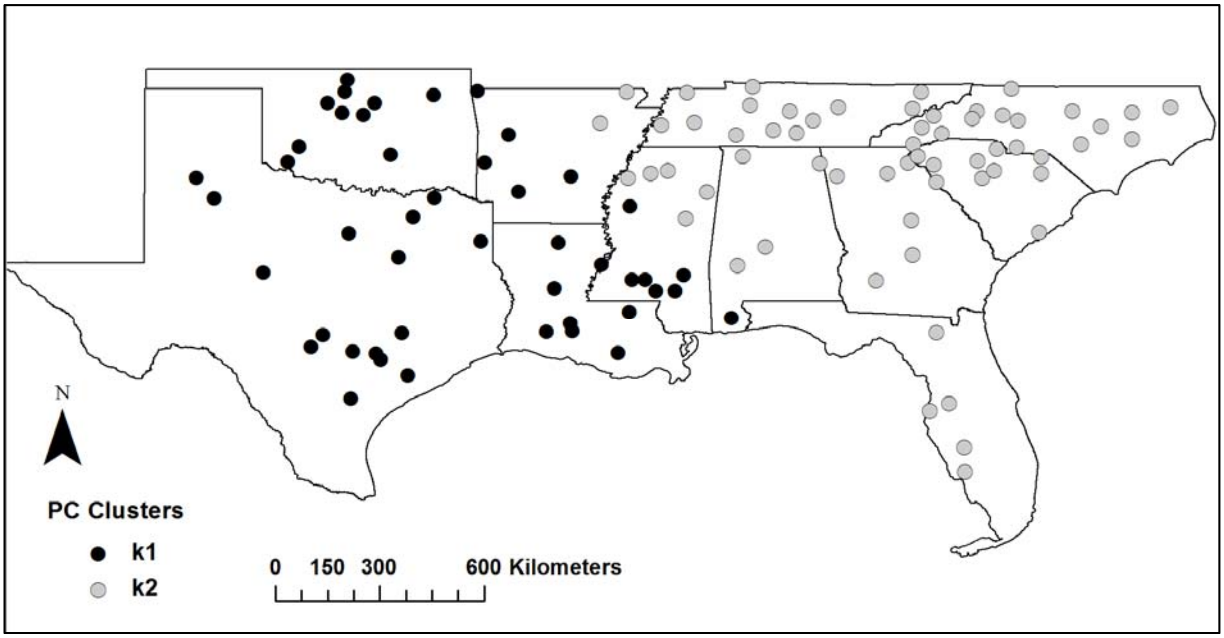

Figure 3-8. Results of the k-means clustering (k=2) on the first two unrotated principal components for standardized temperature extremes in the Southeast.

To further explore a regionalization of temperature extremes for the Southeast, the third principal component (PC3) was included for comparison with PCs 1 and 2. Stations were reassigned according to their highest loading on PC 1, 2, or 3 (Figure 3-11). In addition, a k-means clustering was conducted on all three components (Figure 3-12). Results produced by both methods are again in agreement. In addition to the east-west partitioning of the study region defined by the first two components, PC3 loads highest along the Gulf Coast and in more northerly locations of the region. Thus, while PC3 alone did not account for much of the total variance (6 percent), this additional component seems to identify stations most influenced by Gulf-induced moisture,

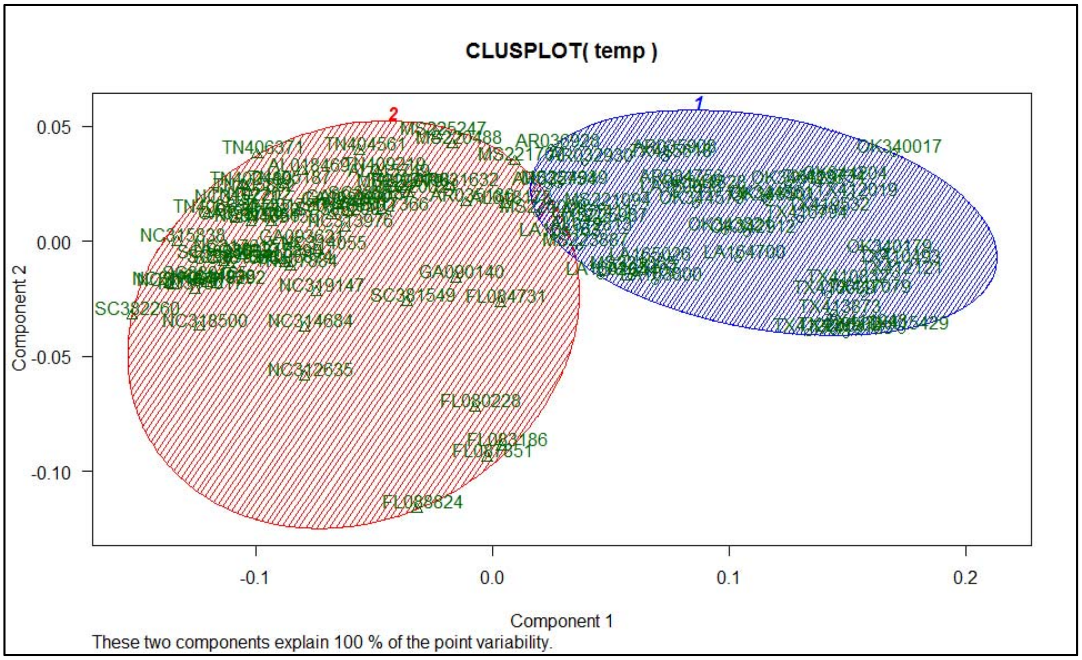

Figure 3-9. K-means cluster plot based on the first two unrotated components representing the temperature extreme indices.

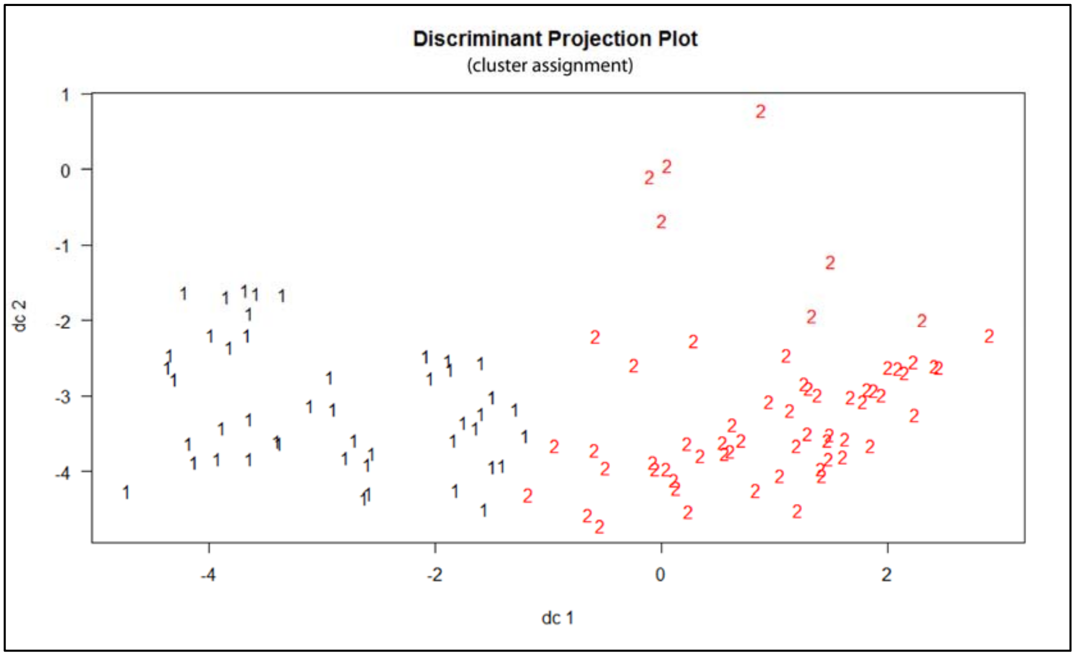

Figure 3-10. Discriminant projection plot based on the first two unrotated components representing the temperature extreme indices.

particularly from higher humidity and rainfall, against stations less influenced by moisture from the Gulf of Mexico.

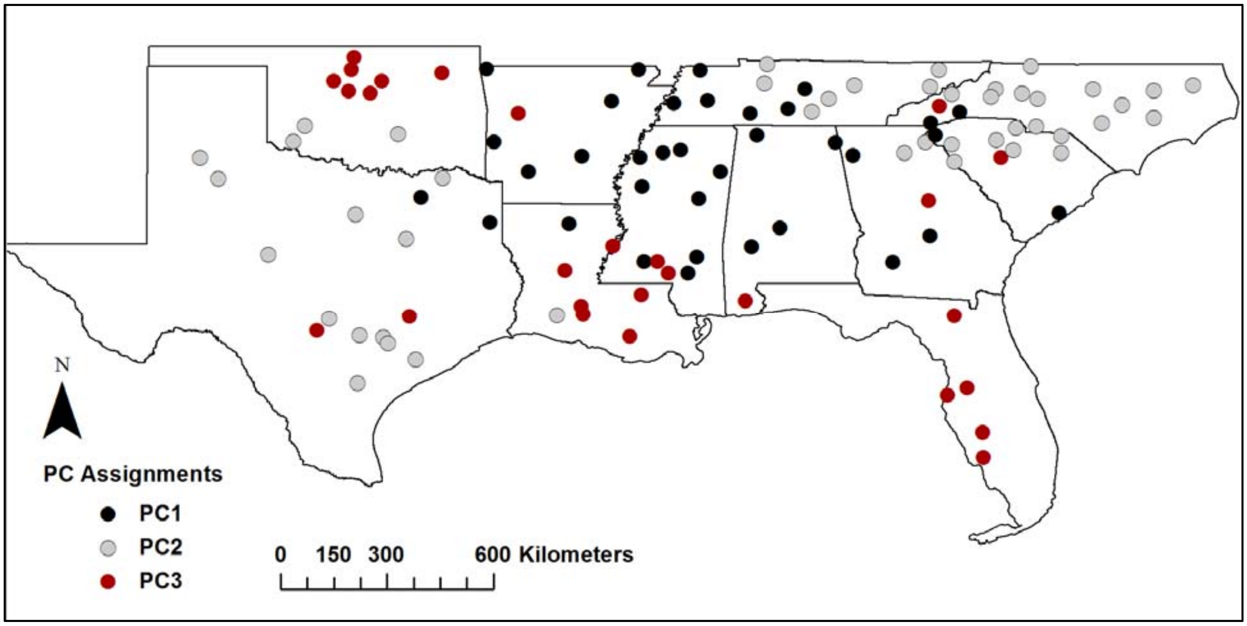

Figure 3-11. Assignment of stations to their component of highest loading for temperature extreme indices, retaining the first three components.

Figure 3-13 shows the signs of the unrotated coefficients for PCs 1 and 2. According to PC1, a common mode of variability may exist across all stations in the region over the period 1948-2012. Previous research suggests that the same sign and small coefficients typically found in the first PC may be indicative of region-wide changes in average values (Green et al. 1993). However, the presence of domain shape dependence cannot be ruled out, whereby the topographies of unrotated components may be largely determined by the shape of the domain (i.e. physical features) and not by the covariation of the variables and components. PC2 identifies a common mode of variability for western sites that differs from eastern sites, such that stations in the West and East covary but in opposite directions.

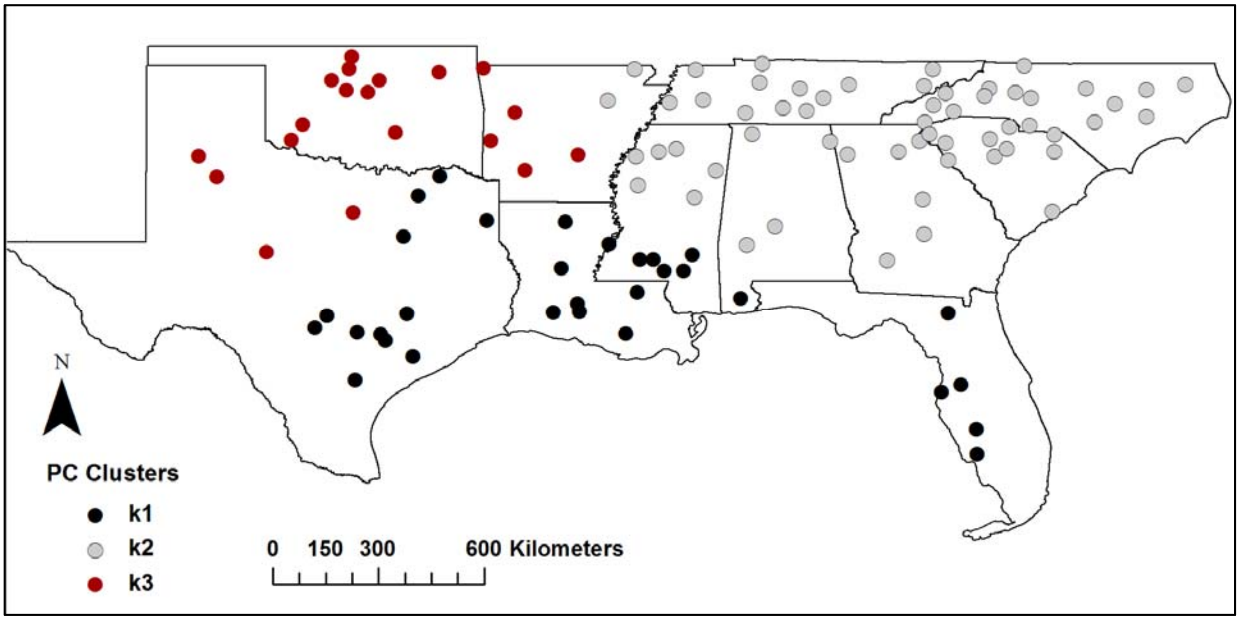

Figure 3-12. Results of the k-means clustering (k=3) on the first three unrotated components for standardized temperature extremes in the Southeast.

Rotation has been shown to produce more physically meaningful results, aid in the interpretation of components, and resolve issues found in unrotated variables (Richman 1985, 1987). The first two components that were retained in this analysis were rotated using Varimax rotation. Figure 3-14 shows the coefficients of the rotated components. Rotation tends to maximize loadings on a particular component. Thus, stations without positive or negative signs were either zero or near zero for that component. Results show that eastern stations load strongly on PC1 and western stations load strongly on PC2, reinforcing the east-west bimodal pattern.

At a most basic level, the maximum loadings and clusters grouped stations in the western half of the study area together, suggesting that these stations have exhibited similar variability in temperature extremes. A second group of stations exist for the eastern half of the region. This spatial characterization may be driven most by the position and strength of the Bermuda High. When the third component was retained in

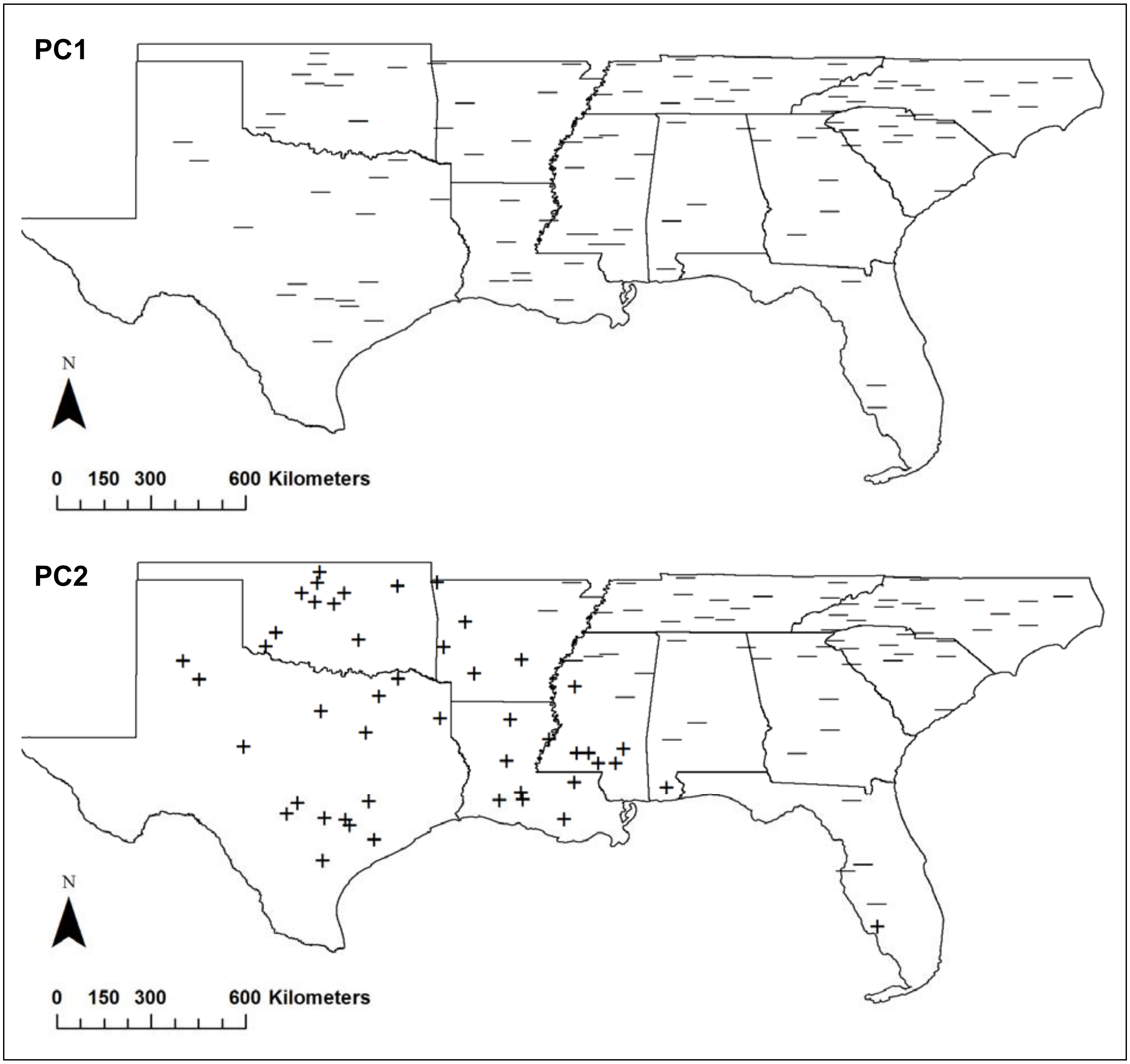

Figure 3-13. Signs of the coefficients for the first (PC1) and second (PC2) principal components, based on unrotated components of extreme temperature indices.

the analysis, the influence of the Gulf of Mexico on temperature extremes emerged. The Gulf of Mexico acts to suppress extremely high temperature extremes for locations near the Gulf Coast. These regionalizations may be particularly useful for stakeholders, policy makers, and decision makers addressing climate adaptation and risk reduction strategies on a regional scale.

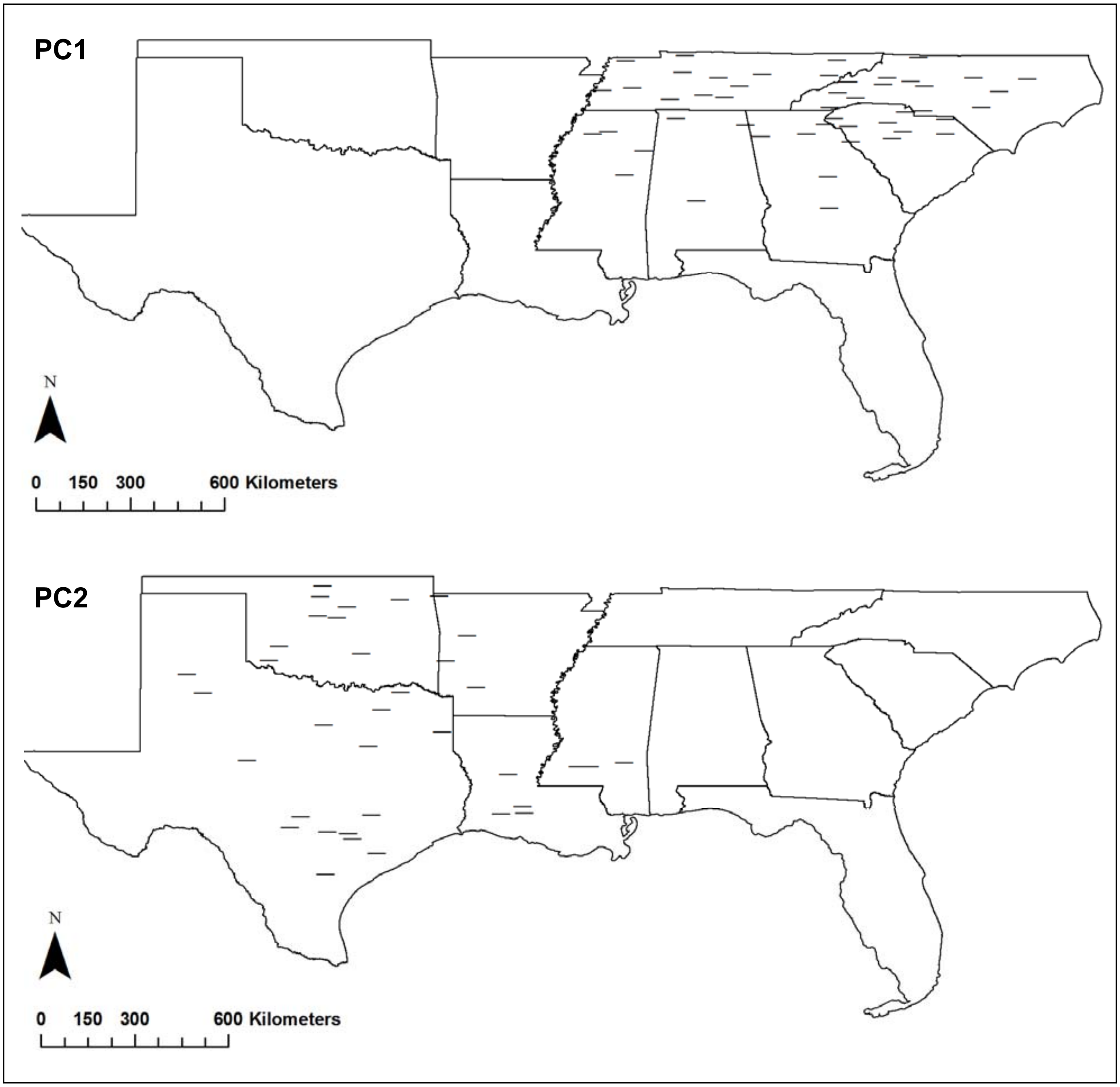

Figure 3-14. Signs of the coefficients for the first (PC1) and second (PC2) principal components, based on Varimax rotation of extreme temperature indices.

3.3.2 Precipitation extremes

An S-mode PCA was performed on precipitation extreme indices to classify extremes into similar regions of variability. The decision of how many components to retain was more ambiguous than for temperature extremes. Table 3-3 shows the standard deviations from the PCA, as well as the proportion of variance and the cumulative variance of each component. Unlike temperature-related components, a few components could not account for most of the variance in the precipitation data, as the first three components only accounted for 37 percent of the total variance. Following the more strict criteria of retaining only components with standard deviations greater than one, ten components should be retained. This criterion was compared against the scree and bar plots (Figures 3-15 and 3-16, respectively). While it could be argued that the greatest break in the line (and bars) occurs after PC4, there is no major cutoff in the data after PC1. In addition, very little change in the amount of variance explained by each additional component is observed for components greater than PC10. I decided to keep the first ten principal components to explain the majority (62%) of variance in the original data, as four components only explained 42 percent. It would require keeping 30 components to explain 88 percent of the total variance.

Analysis of the ten components was done using the same two methods used in the temperature PCA: 1) assignments of maximum loadings, and 2) clustering analysis of principal components. Figure 3-17 shows the component of maximum loading for each station, based on the maximum value of the coefficients for PCs 1-10. No obvious regions emerge from the assignment of each station to its component of maximum loading. However, while loadings are not spatially homogenous, small clusters do emerge. For instance, PC6 (light blue) is mostly concentrated in eastern North Carolina and central Georgia, while PC3 (yellow) is concentrated in South Carolina. The spatial pattern of maximum loadings suggests that precipitation extremes do not follow the same regionalization as temperature extremes. Moreover, locations in very different

Table 3-3. Standard deviations, proportional variance, and cumulative variance for the first 30 components representing the standardized precipitation extreme indices. Standard deviations above one are retained for analysis.

	Standard deviation	**Proportion of Variance**	**Cumulative Proportion**
PC1	2.878	0.194	0.194
PC2	2.025	0.096	0.289
PC3	1.830	0.078	0.368
PC4	1.476	0.051	0.418
PC5	1.446	0.049	0.467
PC6	1.260	0.037	0.504
PC7	1.221	0.035	0.539
PC8	1.080	0.027	0.567
PC9	1.039	0.025	0.592
PC10	1.031	0.025	0.617
PC11	0.943	0.021	0.637
PC12	0.924	0.020	0.657
PC13	0.895	0.019	0.676
PC14	0.884	0.018	0.694
PC15	0.879	0.018	0.712
PC16	0.834	0.016	0.729
PC17	0.827	0.016	0.745
PC18	0.795	0.015	0.759
PC19	0.761	0.014	0.773
PC20	0.732	0.013	0.785
PC21	0.716	0.012	0.797
PC22	0.698	0.011	0.809
PC23	0.688	0.011	0.820
PC24	0.678	0.011	0.830
PC25	0.661	0.010	0.841
PC26	0.647	0.010	0.850
PC27	0.626	0.009	0.860
PC28	0.620	0.009	0.869
PC29	0.616	0.009	0.877
PC30	0.580	0.008	0.885

parts of the study region appear to exhibit similarity in precipitation extremes. For instance, stations loading highest on PC1 include stations in Alabama, Georgia, Mississippi, North Carolina, and Tennessee, with the same signs in their coefficients.

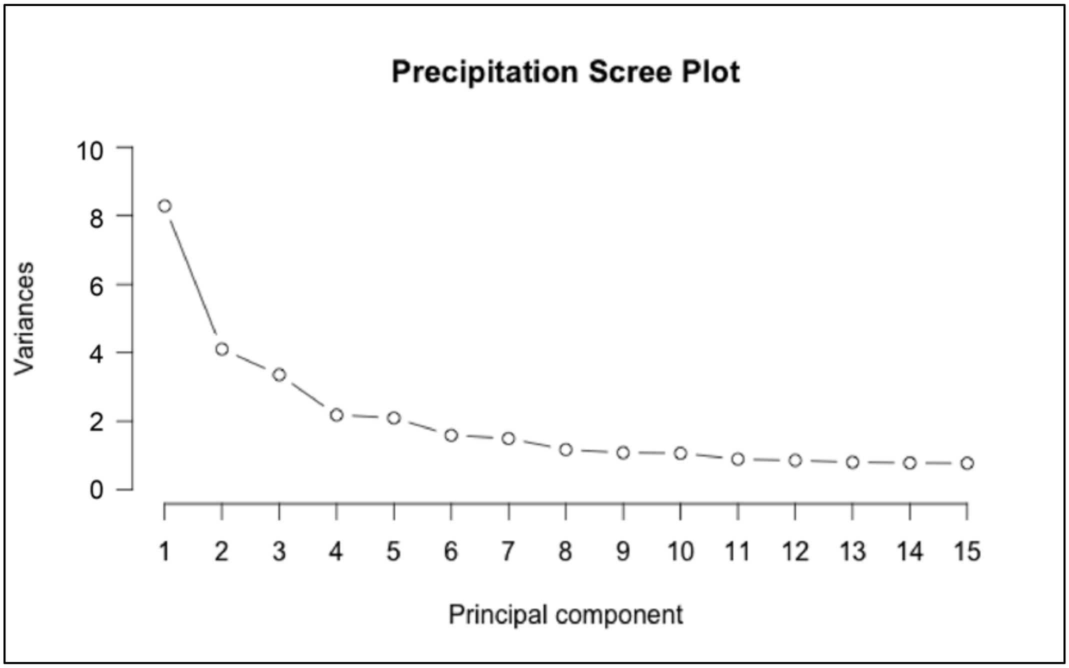

Figure 3-15. Scree plot of variances and the first 15 principal components resulting from the PCA based on standardized extreme precipitation indices.

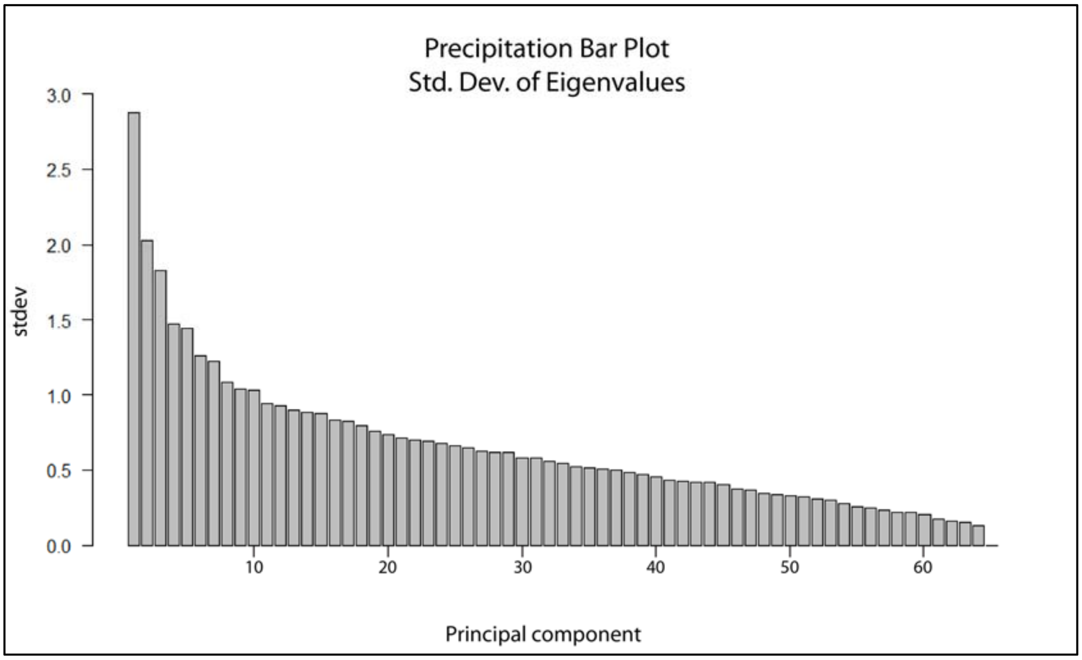

Figure 3-16. Bar plot of the standard deviations of the eigenvalues and all precipitation components representing the extreme precipitation indices.

Thus, these stations have similar variability in precipitation extremes, experiencing periods of extreme wetness/dryness at the same time. This heterogeneous geographic distribution implies that addressing extremes in precipitation may require more localized approaches.

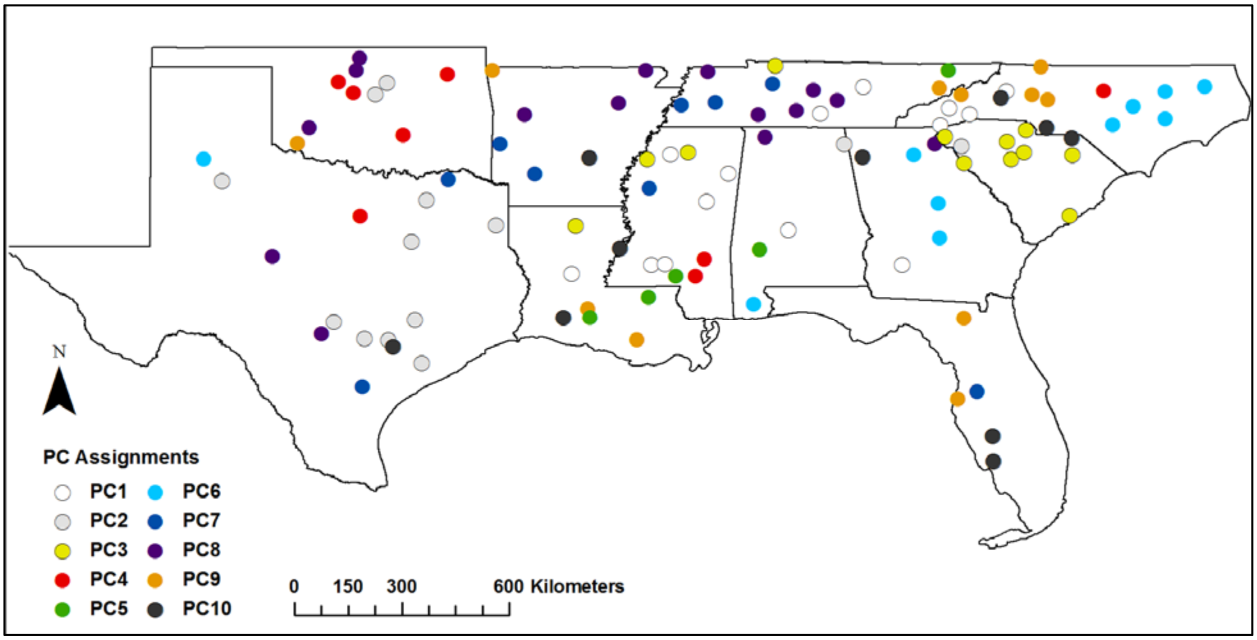

Figure 3-17. Assignment of stations to their component of highest loading for precipitation extreme indices, retaining the first ten principal components. A map of the stations and their IDs are provided in Appendix I.

Overall, precipitation extremes appear to lack the overall spatial coherence seen in the temperature extreme indices. Based on unrotated components, the coefficients of the first component are all relatively small and negative, with the exception of a few stations. Like that seen in the first component for temperatures, this suggests that all stations correlate equally with the first new variable, albeit poorly. Greater values are observed for the remainder of the components, PCs 2-10, with roughly half of stations in each component having opposite sign. Table 3-4 shows the stations that loaded highest on each of the ten components along with the value of the coefficients (see appendix I for a list of all station IDs and names). This table illustrates the spatial diversity in each component or group. Each group is a different size and consists of stations from across the region. PC1 had 14 stations, with coefficients of similar size and with stations in several different states. PC2 had 13 stations, nine of which were in Texas. Twelve stations are assigned to PC3, seven of which are in South Carolina. PC 5 is the smallest group with only five stations, while PC8 is the largest with 15 stations.

Mapping the highest loadings across the study region reveals clear spatial patterns in the first few components. Figure 3-18 shows the loading maps for the ten components, again using IDW to interpolate values between stations for greater visual representation. PC1, which accounts for 19 percent of the variance in the data, is centered over the central part of the study region, with maximum loadings occurring in southern Mississippi. PC2 explains an additional 10 percent of the total variance and is centered over Texas and Oklahoma, with a second center of action in the east, over parts of north Georgia and western Carolinas. PC3 explains 8 percent of the total variance with similar centers of action in southern Texas and South Carolina, but with a third center of action in the upper central part of the region along the border of Tennessee, Arkansas, and Mississippi. The coefficients of stations in the western and eastern regions denoted by PC2 and PC3 are of opposite sign, suggesting that precipitation extremes manifest themselves differently in these two regions such that when the western region is experiencing wetter conditions, the eastern region may be much drier. From Study One, a similar east-west pattern is observed in specific precipitation indices, namely in annual total wet day precipitation (PRCPTOT), heavy precipitation days (R10mm), and very heavy precipitation days (R20mm), whereby

Table 3-4. Station groupings based on unrotated coefficients loading highest on the first ten principal components retained for analysis. Station IDs, latitude and longitude, and coefficients are provided.

	State	Station ID	Longitude	Latitude	Coefficient
PC1	AL	17366	-87.014	32.411	-0.12
	GA	90140	-84.149	31.534	-0.13
	LA	160098	-92.461	31.321	-0.14
	MS	220021	-88.521	33.830	-0.13
	MS	220488	-89.981	34.306	-0.13
	MS	221094	-90.458	31.545	-0.15
	MS	225247	-89.071	33.136	-0.15
	MS	225987	-90.106	31.552	-0.16
	NC	313976	-82.449	35.330	-0.15
	NC	314055	-83.198	35.057	-0.15
	NC	314938	-81.538	35.915	-0.11
	NC	319147	-82.968	35.487	-0.14
	TN	402202	-85.131	36.015	-0.14
	TN	409155	-86.209	35.345	-0.14
PC2	AL	18469	-85.613	34.567	-0.12
	OK	343821	-97.395	35.816	0.17
	OK	348501	-97.095	36.118	0.19
	SC	380165	-82.661	34.528	-0.13
	TX	410832	-98.429	30.106	0.20
	TX	411048	-96.397	30.159	0.20
	TX	412019	-96.487	32.123	0.16
	TX	412121	-101.245	33.652	0.15
	TX	412266	-96.232	29.057	0.17
	TX	413183	-97.064	29.634	0.22
	TX	413734	-96.098	33.168	0.17
	TX	415429	-97.658	29.676	0.17
	TX	415618	-94.351	32.540	0.17
PC3	LA	161411	-92.349	32.513	0.18
	MS	221707	-90.557	34.186	0.20
	MS	229079	-89.531	34.373	0.19
	SC	381277	-82.588	34.091	-0.17
	SC	381549	-79.932	32.780	-0.11
	SC	382260	-79.877	34.301	-0.14
	SC	385200	-81.415	34.194	-0.16
	SC	387722	-81.521	34.635	-0.20

(Table 3-4. continued)

	State	Station ID	Longitude	Latitude	Coefficient
	SC	388887	-83.075	34.754	-0.15
	SC	389327	-81.093	34.374	-0.19
	SC	389350	-81.032	34.938	-0.19
	TN	401790	-87.335	36.547	0.15
PC4	MS	223887	-89.339	31.255	-0.21
	MS	224939	-89.124	31.676	-0.16
	NC	311677	-79.079	35.909	0.15
	OK	340017	-96.685	34.786	0.17
	OK	341828	-95.581	36.323	0.15
	OK	344861	-97.929	35.858	0.23
	OK	346629	-98.315	36.122	0.23
	TX	419532	-97.770	32.748	0.14
PC5	AL	18178	-87.735	31.917	0.15
	LA	160205	-90.525	30.709	0.17
	LA	165026	-91.988	30.205	0.15
	MS	221865	-89.836	31.250	0.21
	TN	407884	-82.984	36.416	-0.16
PC6	AL	12813	-87.881	30.547	-0.03
	GA	92966	-83.206	32.200	-0.13
	GA	93621	-83.860	34.301	-0.15
	GA	95874	-83.250	33.083	-0.18
	NC	312635	-76.552	36.016	0.29
	NC	313017	-78.858	35.058	0.21
	NC	314684	-77.543	35.197	0.22
	NC	317994	-78.346	35.516	0.25
	NC	318500	-77.539	35.885	0.34
	TX	417079	-101.702	34.189	0.13
PC7	AR	34756	-94.249	34.573	-0.18
	AR	35908	-93.388	33.820	-0.18
	FL	87851	-82.260	28.338	0.29
	MS	226009	-90.510	33.452	-0.18
	TN	402108	-89.700	35.550	0.23
	TN	402489	-87.396	36.075	0.18
	TN	404561	-88.846	35.621	0.20

(Table 3-4. continued)

	State	Station ID	Longitude	Latitude	Coefficient
	TX	410639	-97.706	28.458	-0.16
	TX	416794	-95.559	33.674	-0.26
PC8	AL	15749	-87.600	34.744	-0.19
	AR	31632	-90.586	36.420	0.17
	AR	35186	-91.274	35.604	0.16
	AR	36928	-93.637	35.303	0.18
	GA	98740	-83.332	34.579	0.15
	OK	342912	-97.875	36.419	0.18
	OK	344204	-99.053	34.989	-0.13
	OK	344573	-97.790	36.722	0.20
	TN	405187	-86.809	35.414	-0.16
	TN	405882	-85.781	35.672	-0.13
	TN	406371	-86.373	35.920	-0.16
	TN	409219	-89.032	36.393	0.20
	TN	409502	-87.759	35.304	-0.17
	TX	410493	-99.976	31.741	-0.15
	TX	410902	-98.735	29.799	-0.24
PC9	AR	32930	-94.448	36.426	0.21
	FL	84731	-82.594	30.185	-0.19
	FL	88824	-82.754	28.152	-0.23
	LA	163800	-92.044	30.419	-0.17
	LA	164407	-90.816	29.641	-0.29
	NC	315356	-82.666	35.804	-0.12
	NC	315890	-80.651	36.499	0.14
	NC	317615	-80.482	35.684	0.19
	NC	318292	-80.881	35.810	0.16
	OK	340179	-99.334	34.590	-0.13
	TN	406534	-83.201	35.983	-0.24
PC10	AR	35754	-92.019	34.226	-0.20
	FL	80228	-81.874	27.218	-0.17
	FL	83186	-81.861	26.585	-0.28
	GA	97600	-85.151	34.245	-0.09
	LA	164700	-92.664	30.200	0.21
	LA	168163	-91.234	31.950	-0.19
	NC	315771	-80.523	34.980	-0.18

(Table 3-4. continued)

	State	Station ID	Longitude	Latitude	Coefficient
	NC	315838	-81.673	35.730	-0.15
	SC	381588	-79.883	34.732	-0.18
	TX	413873	-96.940	29.471	0.19

significant positive trends are observed for stations in Texas and Oklahoma and significant negative trends are observed in South Carolina and North Carolina over the 65-year record. Thus, PC2 and PC3 may explain the variance in these particular indices. PC4 explains 5 percent of the total variance in the data and is centered on the Gulf Coast, particularly the south central Gulf Coast, with a smaller area of focus in Oklahoma. After inspection of the coefficients observed for PC4, the signs between stations along the Gulf Coast are of opposite sign to those in Oklahoma, suggesting PC4 contrasts the behavior of precipitation extremes between these two regions. It highlights the region most likely to be impacted by moisture from the Gulf of Mexico from stations least likely to be impacted by this source of moisture.

The remaining PCs are much more limited in spatial extent and display much less spatial coherence. The additional amount of variance explained by each component beyond PC5 is also negligible. PCs 5-10 explain 4.9, 3.7, 3.5, 2.7, 2.5, and 2.5 percent of the remaining variance, respectively. These remaining components suggest more localized variability in the data and overall regionalization of the data becomes much more difficult.

The ten components retained for analysis were rotated using Varimax rotation for comparison with the unrotated results. Figure 3-19 shows in the left column the signs of the coefficients based on unrotated components and in the right column the signs of the coefficients based on the Varimax rotation. In examining the signs of the coefficients,

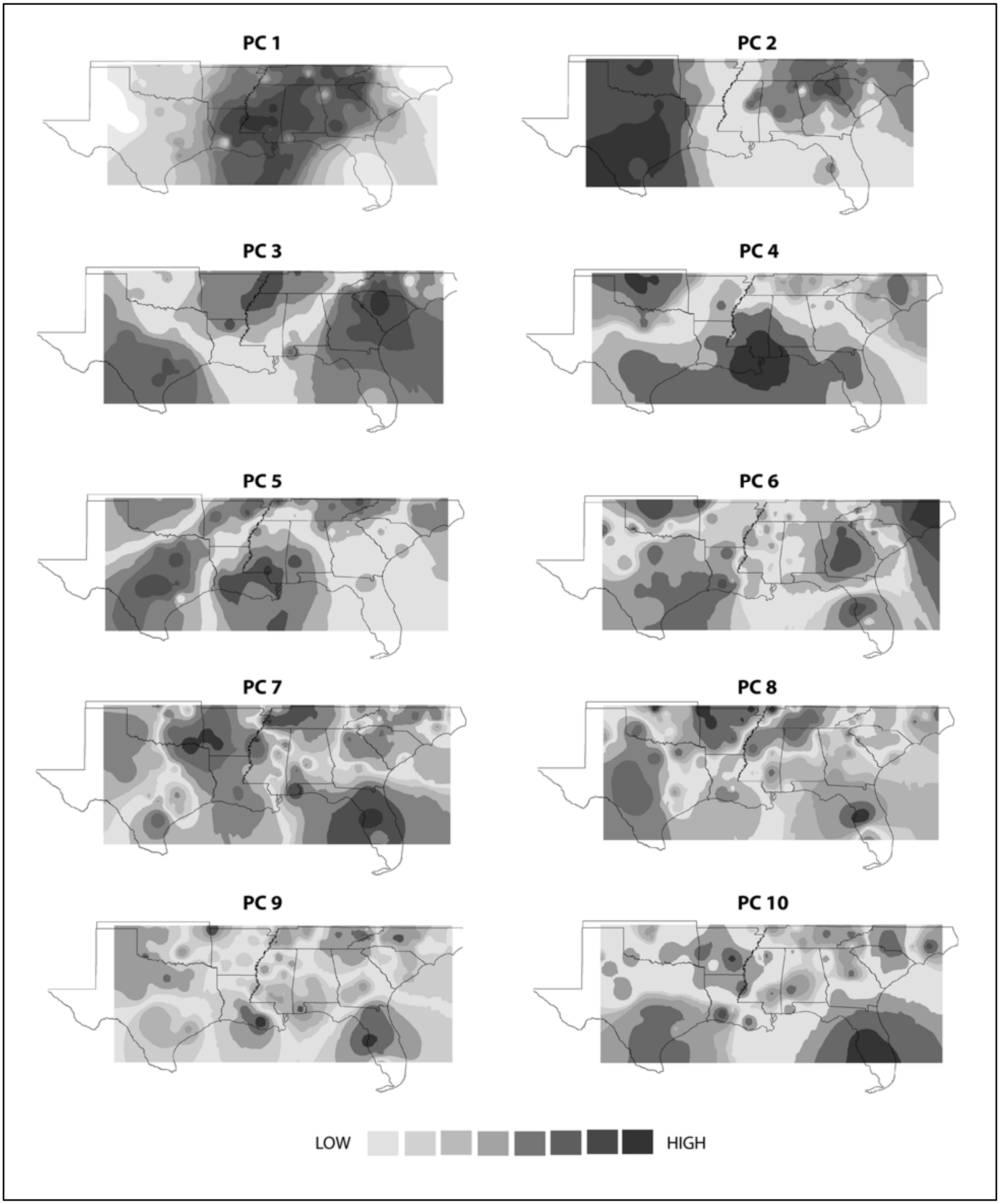

Figure 3-18. Loading maps of the ten unrotated principal components (PC 1-10) of standardized precipitation extremes in the Southeast, mapped using inverse distance weighting. Darker areas represent higher values. Concept borrowed from Nogueira et al. (2013).

the unrotated components show geographic patterns similar to the sequences identified by Buell. The first unrotated PC (PC1) shows a common mode of variability seen as the same sign across all stations, in this case all negative coefficients. PC2 identifies a clear east-west bimodal pattern of variability, similar to that seen in the temperature extremes. PC3 shows an alternating positive-negative-positive pattern. PC4 depicts a mode of variability that differs between southerly and northerly sites. Lastly, PC5 shows an alternating north-south pattern of variability across the western, central, and eastern sites.

Rotating the components produces very different results. In particular, small clusters or groupings of stations emerge for each component. Stations without coefficients on any given component are either zero or near zero. Each cluster or group of stations loading onto a particular component consist of stations in proximity to one another, suggesting that stations closest together exhibit similar modes of variability in extreme precipitation and stations further apart exhibit different modes of variability. Thus, extreme precipitation is much more variable and localized than temperature extremes across the Southeast.

To further explore the classification of precipitation extremes, a k-means clustering analysis was conducted for comparison with the maximum loading maps. Using ten groups (k=10) for consistency with the assignment of stations to their maximum loadings, the resulting cluster assignments for each station are shown in Figure 3-20. Cluster analysis results in more spatially coherent groups. The first group (white circles) is centered mainly on Florida, with a few other stations included in this group that are scattered across the region. The second group (gray) consists of stations

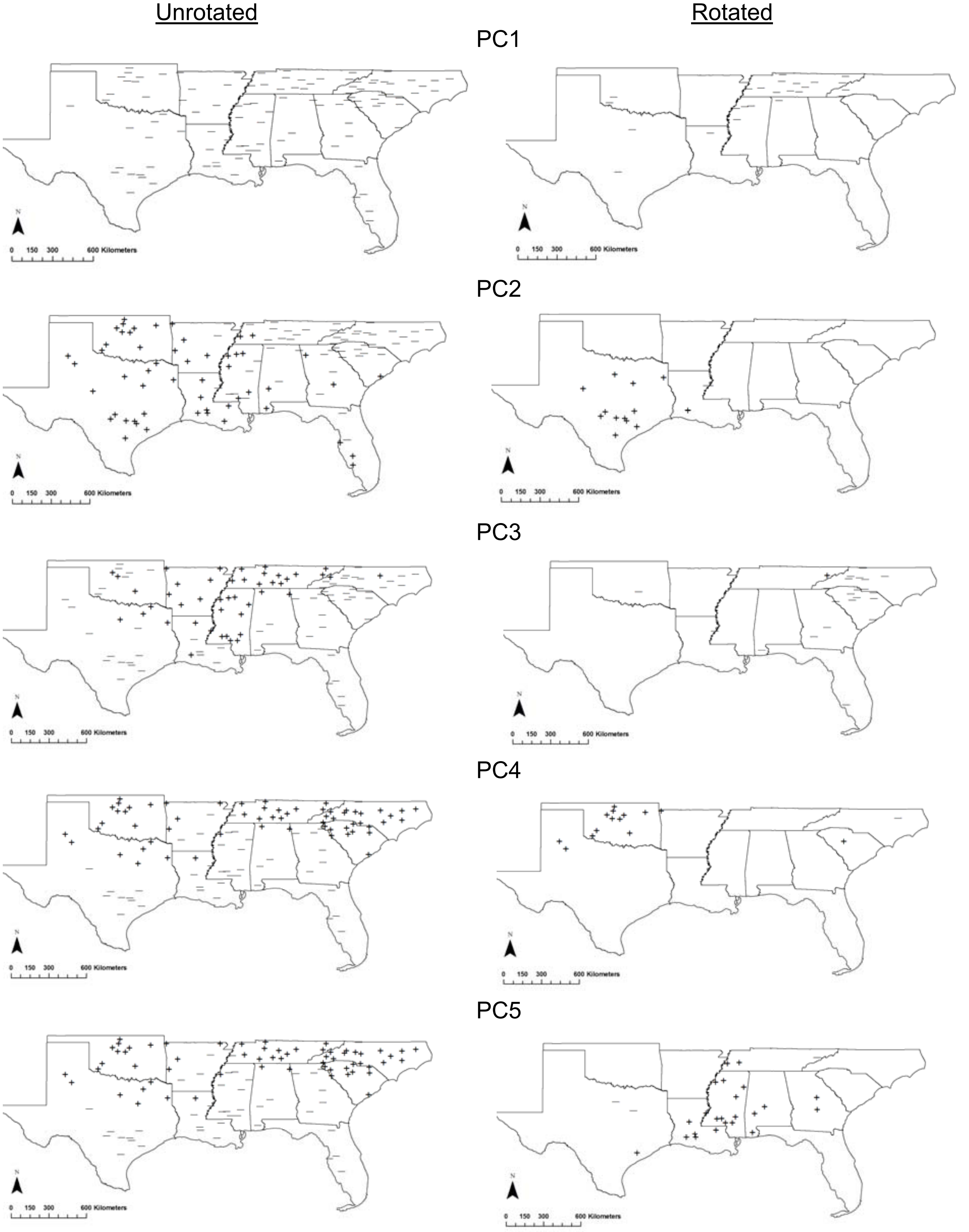

Figure 3-19. Signs of the coefficients for the first five principal components, PC1-5, of extreme precipitation indices in the Southeast, with unrotated components shown in the left column and rotated components in the right column.

predominantly in the eastern part of North Carolina. Group three (yellow) represents stations in Oklahoma. Stations in the fourth group (red) are mostly in the west-central portion of the region, forming a box around southern Arkansas, northeastern Texas, northern Louisiana, and northwestern Mississippi. Group five (green) is observed in the Carolinas (western North Carolina and South Carolina), as well as Georgia. The sixth group (light blue) represents stations in southeastern Texas. Group seven (dark blue) includes the central Gulf stations, mostly stations in Louisiana, Mississippi, and southern Alabama. Group eight (purple) is almost exclusively in central and eastern Tennessee. Group nine (orange) is defined as the extreme northern part of Arkansas and western Tennessee. Lastly, group ten (black) includes stations in south-central Texas.

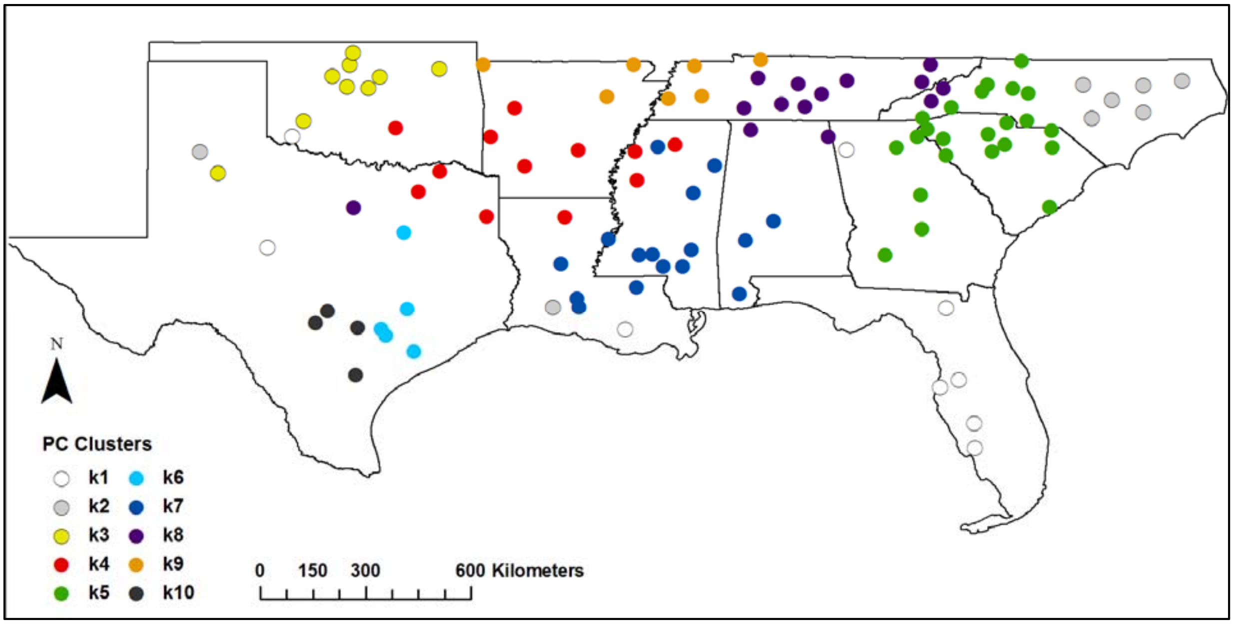

Figure 3-20. Results of the k-means clustering (k=10) on the first ten unrotated principal components for standardized precipitation extremes in the Southeast.

Compared to the assignments of maximum loadings based on unrotated PCs, clustering analysis results in much more spatially homogeneous groups. The clustering results are similar to the rotated components shown in Figure 3-19. Despite more coherent groupings, results suggest that stations in very different parts of the region can display similar variability in precipitation extremes. In particular, locations in Florida show similarity with stations in Texas, Oklahoma, Georgia, and Louisiana. Stations in eastern North Carolina display similar patterns with stations in Texas and Louisiana. Stations in Tennessee, northern Alabama, western North Carolina, and north-central Texas all display similar variability. Figure 3-21 shows a cluster plot of the k-means clusters against the first two principal components, which explains 27 percent of the variance. The total variance in the data that is explained by the clustering was smaller than that for temperature indices, at just 59.3 percent. Overall, these results have implications for climate-related planning and policy, whereby regional coordination and collaboration to address the impacts of climate change could happen using a much more targeted, strategic approach.

3.3.3 Seasonal periods

Climatological patterns do not always have annual temporal patterns that correspond to conventional definitions of seasons, defined as winter (DJF), spring (MAM), summer (JJA), and fall (SON) (Green et al. 1993). Moreover, extreme weather events do not necessarily follow typical seasons, such as severe storms that can occur during any time of year and hurricanes that have a clear June to November season. This section explores use of PCA to determine temporal patterns of climate extremes (as defined by the ETCCDI indices) in the Southeast. A T-mode PCA was performed on the monthly indices to identify and group months exhibiting similar patterns in extremes to better reflect the seasonality in climate extremes in the Southeast. The input matrix

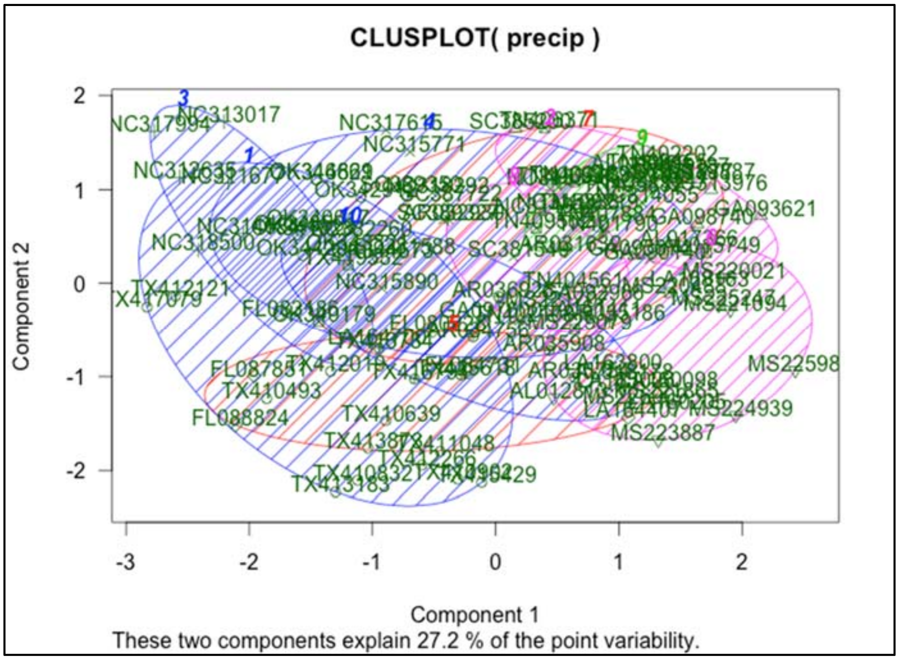

Figure 3-21. Cluster plot of stations in the Southeast on the first two unrotated components resulting from the k-means clustering of standardized precipitation extremes.

for the PCA consisted of 12 variables, representing all 12 months in a year, and 107 stations as the individuals. The PCA resulted in 12 new components. Adhering to the strict criterion of retaining only those components with standard deviations above one, only the first component would be kept and the remaining eleven components discarded. Table 3-5 shows that the first component indeed accounts for 83 percent of the total variance in the original data. However, with inclusion of the second component, an additional 10 percent of the variance is explained, bringing the total explained variance up to 93 percent. Upon investigation of the scree and bar plots (Figures 3-22 and 3-23, respectively), the additional variance explained by PCs 3-12 are minimal and the scree plot levels off almost entirely beyond PC3. Therefore, the first two components are retained, though arguably only the first component may suffice for capturing most of the variability in the precipitation extremes, as supported by the values in Table 3-5 and Figure 3-22.

Table 3-5. Standard deviation of eigenvalues, proportional variance, and cumulative proportion of variance for each principal component representing monthly extreme indices.

	Standard deviation	**Proportion of Variance**	**Cumulative Proportion**
PC1	1.09	0.83	0.83
PC2	0.38	0.10	0.93
PC3	0.19	0.03	0.96
PC4	0.13	0.01	0.97
PC5	0.12	0.01	0.98
PC6	0.10	0.01	0.99
PC7	0.08	0.00	0.99
PC8	0.06	0.00	1.00
PC9	0.05	0.00	1.00
PC10	0.04	0.00	1.00
PC11	0.04	0.00	1.00
PC12	0.03	0.00	1.00

A definition of seasons may be initially detected using the PCA variables factor map, which is a standard output of a PCA. Figure 3-24 shows the factor map of the variables (i.e. months) plotted on the first two dimensions or hyperplanes. The clustering of months reveals moderately strong simple structures and seasons begin to emerge. June, July, and August appear to be well correlated. These months contrast with December, January, and February. Transitional months also correlate well, including the following pairs: May and September, October and April, and November and March. The coefficients of the first and second components are shown in Tables 3-6 and 3-7, respectively. Months that loaded highest on each component are boxed in each table. November, December, January, and February all loaded highest on PC1, as well as July. November through February negatively load on PC1, contrasting with July, which

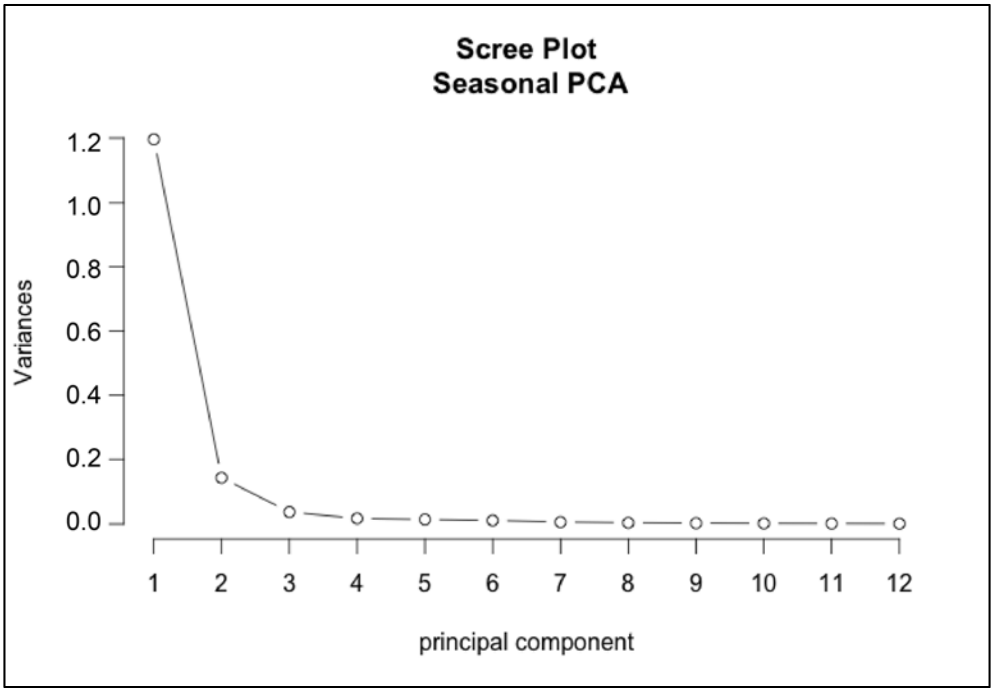

Figure 3-22. Scree plot of the twelve principal components and variances (eigenvalues) resulting from the PCA base on monthly extreme indices.

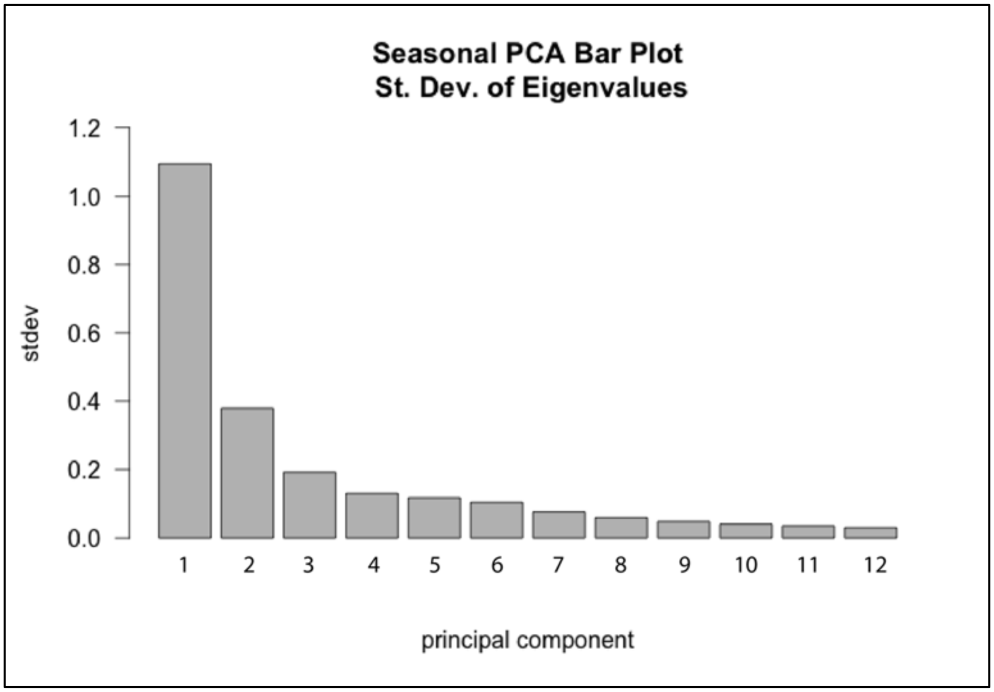

Figure 3-23. Bar plot of the standard deviations of eigenvalues and twelve principal components representing the monthly extreme indices.

loads positively on PC1. This indicates that areas experiencing low extremes in winter tend to have high summer extremes, specifically in July. June and August also load high (and positively) on PC1. According to these results, PC1 suggests a clear winter-summer seasonality to extremes, with an extended winter season. Table 3-7 shows that March through June and August through October load highest on PC2. Thus, PC2 defined transitional periods as a slightly extended spring and fall consisting of the months of August, September, and October.

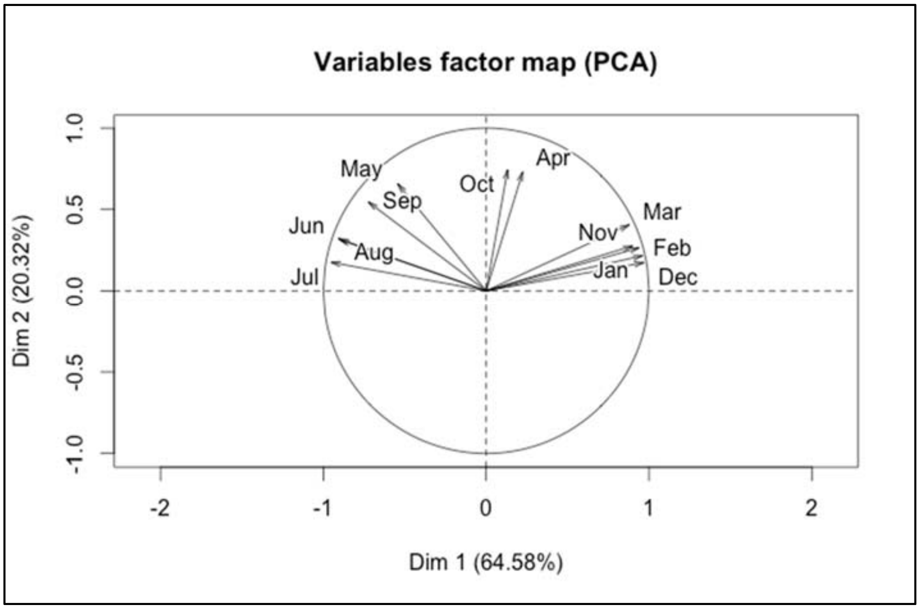

Figure 3-24. Factor map resulting from the t-mode PCA on monthly extreme indices. Variables (i.e. months) are mapped on the first two dimensions (Dim 1 and Dim 2).

Monthly index values were correlated with the first two principal components to further interpret seasonal periods defined in these two components (Table 3-8). This explains which variables (i.e. months) contribute most to each principal component. The correlations reinforce the coefficients of components shown in Tables 3-6 and 3-7. November through March correlate well and negatively with PC1, and June to August

Table 3-6. Coefficients of loadings for the first two components; boxes indicate the months loading highest on PC1.

Month	PC1	PC2
Jan	-0.46	0.24
Feb	-0.4	0.28
Mar	-0.22	0.24
Apr	-0.03	0.2
May	0.07	0.26
Jun	0.25	0.31
Jul	0.38	0.31
Aug	0.32	0.45
Sep	0.13	0.35
Oct	-0.03	0.35
Nov	-0.25	0.18
Dec	-0.43	0.17

Table 3-7. Coefficients of loadings for the first two components; boxes indicate the months loading highest on PC2.

Month	PC1	PC2
Jan	-0.46	0.24
Feb	-0.40	0.28
Mar	-0.22	0.24
Apr	-0.03	0.20
May	0.07	0.26
Jun	0.25	0.31
Jul	0.38	0.31
Aug	0.32	0.45
Sep	0.13	0.35
Oct	-0.03	0.35
Nov	-0.25	0.18
Dec	-0.43	0.17

also correlate well but positively with PC1. Monthly values do not correlate as well with PC2, though September, October, and April correlate moderately well and positively with PC2. While June and August load highest in PC2, this table shows that these months contribute to and correlate well with PC1.

Table 3-8. Correlation coefficients between monthly indices and the first two components.

Month	PC1	PC2
Jan	-0.98	0.18
Feb	-0.96	0.23
Mar	-0.90	0.32
Apr	-0.24	0.58
May	0.49	0.59
Jun	0.88	0.37
Jul	0.94	0.26
Aug	0.88	0.42
Sep	0.68	0.63
Oct	-0.17	0.75
Nov	-0.91	0.23
Dec	-0.98	0.13

Table 3-9 shows the correlation matrix for the monthly indices. The months November, December, January, February and March correlate well with each other, with correlation coefficients greater than 0.9 for all monthly pairs. In addition, June, July, and August correlate well with each other, with correlation coefficients above 0.9 for June and July and 0.88 for June and August. November through March correlates negatively with May through September. October correlates only moderately with September (0.44) and does not correlate well with other months. April also does not correlate well with other months, except moderately with March (0.55).

PCA was useful overall in grouping months into seasonal periods of extreme indices. PC1, which explains 83 percent of the total variance in the data, identifies the winter-summer seasonality in extreme indices. Winter is defined as November, December, January, and February. Summer is defined as June, July, and August, though July seems to dominate summer extremes in the region. PC2 appears to explain the transitional periods during the year, including September and October in fall and

Table 3-9. Correlation matrix of monthly extreme indices.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Jan	1.00											
Feb	0.99	1.00										
Mar	0.93	0.95	1.00									
Apr	0.33	0.37	0.55	1.00								
May	-0.38	-0.33	-0.17	0.43	1.00							
Jun	-0.78	-0.75	-0.65	0.06	0.79	1.00						
Jul	-0.87	-0.84	-0.75	-0.05	0.60	0.93	1.00					
Aug	-0.78	-0.74	-0.68	-0.05	0.56	0.88	0.93	1.00				
Sep	-0.56	-0.53	-0.45	0.05	0.64	0.79	0.76	0.88	1.00			
Oct	0.28	0.31	0.33	0.29	0.21	0.01	-0.03	0.22	0.44	1.00		
Nov	0.92	0.89	0.85	0.32	-0.36	-0.73	-0.80	-0.70	-0.43	0.37	1.00	
Dec	0.99	0.96	0.90	0.28	-0.41	-0.81	-0.89	-0.80	-0.57	0.26	0.95	1.00

March, April, and May in spring. A biplot of the rotated individuals on PC1 and PC2 is shown in Figure 3-25, and a similar biplot of the monthly loadings on PC1 and PC2 is shown in Figure 3-26. These graphs help to determine variables that are similar and well correlated, as well as identify any outliers in the data. Figure 3-25 indicates that many stations in the analysis are well correlated, with a few possible outliers in Oklahoma, Tennessee, and Texas. It further shows moderately strong simple structures in the data, as the stations tend to cluster together; however, there are several stations that exhibit a more random complex structure that do not cluster along the axes. Figure 3-26 suggests that December, January, and February behave similarly, while March and November behave very similarly. August may be an outlier when extremes behave somewhat differently than during the rest of the year.

3.4 Discussion

A regionalization of temperature and precipitation extremes was produced to describe areas with similar variability. The majority of the variance in temperature extreme indices is explained by the first two principal components (65%), effectively reducing the number of variables from 107 stations to just two new components. The

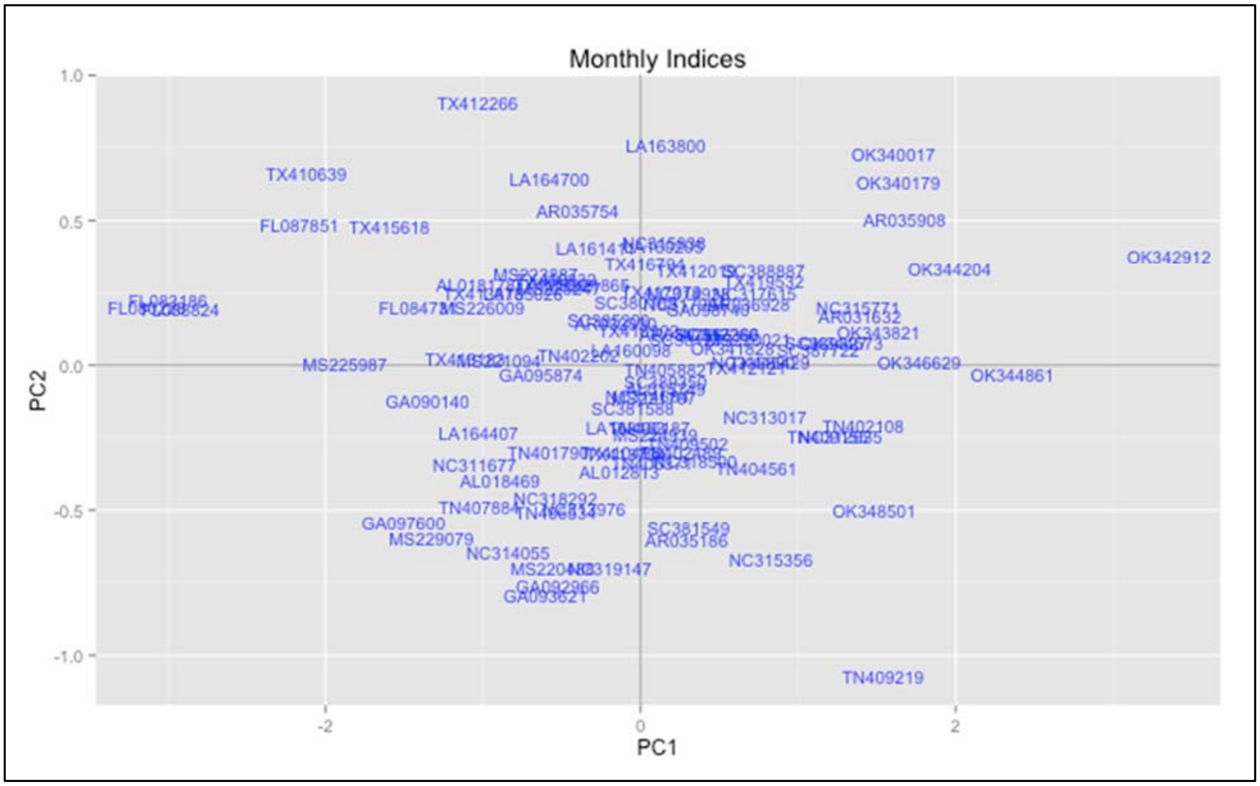

Figure 3-25. Biplot of the individuals and the first two principal components, based on the t-mode PCA of monthly extreme indices. Each point represents a station in the Southeast.

coefficients of the first principal component are relatively small and of the same sign for all stations. Thus, this first component seems to be an overall 'size' component. Several of the temperature indices mapped in Study One have consistent trends, of the same sign, across the study region. For instance, most locations across the Southeast showed significant warming trends in warm nights, cool nights, coldest nights, and tropical nights from 1948 to 2012. Likewise, most stations have significant cooling trends in warm spell duration, diurnal temperature range, and summer days. PC1 may represent region-wide trends in these extreme indices.

The second component, PC2, essentially divides the Southeast into east and west sub-regions, with a transition area in the central part of the study area. This

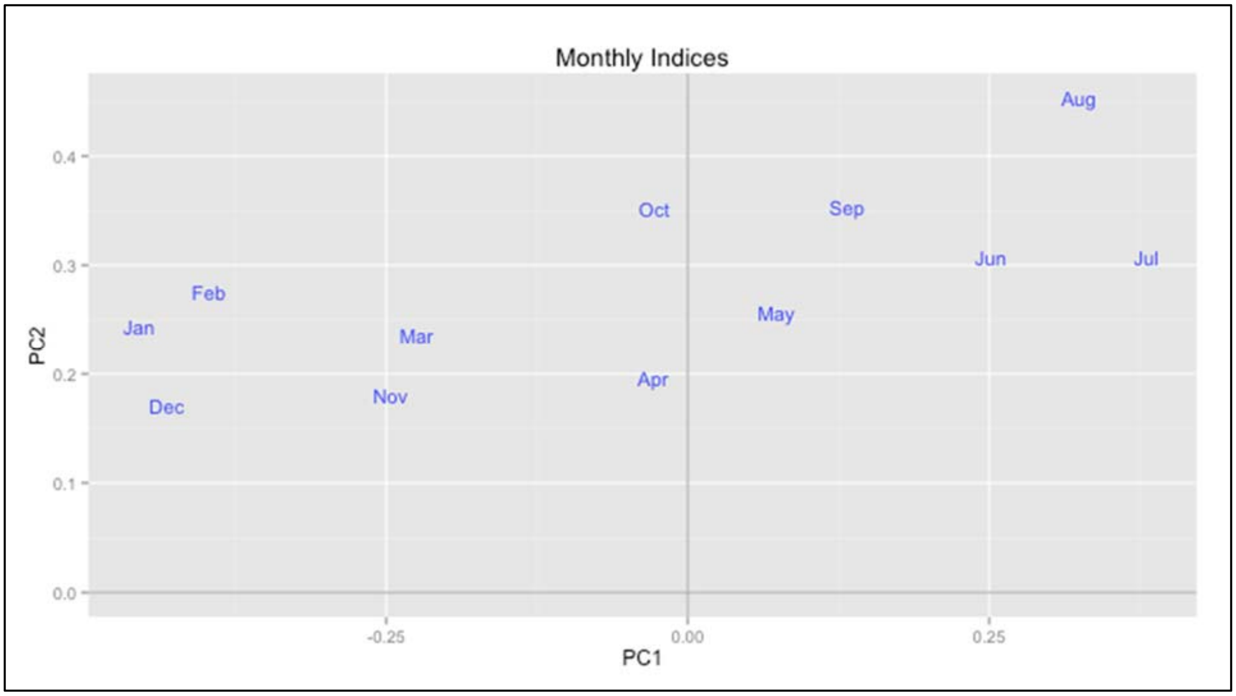

Figure 3-26. Biplot of monthly variable loadings on the first two principal components, based on the t-mode PCA of monthly extreme indices.

suggests that as locations in the west experience elevated extremes in temperature, more easterly locations have suppressed temperature extremes. Rotating the first two components using Varimax similarly partitions the Southeast into a western and an eastern region. A similar east-west pattern is evident in a few of the temperature extreme indices, namely coldest days, ice days, and frost days, where westerly locations have significant trends of opposite sign to locations in the extreme eastern part of the region. Thus, the retained PCs may reflect the variability in these three extreme indices, which are all winter-related indices. Results of the k-means clustering analysis are generally consistent with the assignments of maximum loadings. The clusters similarly partitioned the Southeast into east and west sub-regions. This classification regime can likely be explained through the issue of scale. The Southeast region as defined in this study closely matches the scale at which synoptic weather patterns occur (i.e. on the order of 1000’s of kilometers). At this scale, temperature extremes are largely controlled by the positioning of the Bermuda High and increased meridional flow of the jet stream that can create large swings in temperatures as cold air from the north plunges southward and warm, Gulf air is carried further north. In particular, as low pressure and associated frontal system move through the region from the west, warm extremes may develop under a ridge of high pressure ahead of the cold front to the east, and cold extremes can occur near the trough behind the cold frontal boundary further west. Thus, this east-west dichotomy may be explained by this typical synoptic weather pattern that can impact the region throughout the year.

A second PCA yielded ten new components to describe precipitation extreme variability for the same set of stations in the Southeast. More components are needed to explain roughly the same amount of variance in the precipitation indices, with ten components explaining 62 percent of the variance. In addition, trends in precipitation extremes are much more spatially variable over the 65-year period, making a regionalization of these stations based on extreme precipitation more difficult. The second unrotated component, which loads highest in parts of Texas and Oklahoma with a second center of action over the Carolinas (and of opposite sign), suggests that as western sites experience elevated precipitation extremes, sites in the Carolinas experience suppressed extremes. Differences between sites in the West and the Carolinas are especially evident in a few precipitation indices, namely annual total wet day precipitation and days with heavy (≥ 10mm) and very heavy (≥ 20mm) precipitation. An example time series is provided in Figure 3-27, which compares the temporal variability in the number of heavy precipitation days for a station in South Carolina and a station in Texas. The opposing trends as reflected in these two stations are most apparent in the beginning and latter parts of the record. Another center of action is evident in the precipitation classification for stations near the Gulf Coast, as contrasted from stations further inland in the northern part of the region, suggesting the importance of proximity to the Gulf of Mexico in generating extreme precipitation events. However, interpretation of results based on the unrotated components should be made with caution, as the unrotated signs of the coefficients are symptomatic of Buell sequencing patterns, whereby the signs of the resulting components may not display any real physical meaning.

While it is important to examine results based on the unrotated components, rotated components are more likely to yield patterns that occur in nature (Richman 1987). When Varimax rotation was applied to the ten components retained for analysis, the regionalization of precipitation extremes looked very different. Instead of a partitioning between eastern and western sites and between Gulf and more northerly sites, rotation maximizes loadings on one component and yields a greater number of groups made up of a smaller number of stations close to one another. Based on rotation, stations in different parts of the study region exhibit different modes of precipitation extreme variability. Only nearby stations have experienced similar changes in precipitation extremes since 1948, according to the 11 precipitation extreme indices included in Study One. Overall, the pattern of smaller, coherent regions that emerges suggests that stations with similar variance in precipitation extremes tend to be tightly clustered together over the Southeast. However, much of the variance in the data remains unaccounted for by the PCA (roughly 38%). As a result, PCA may be less

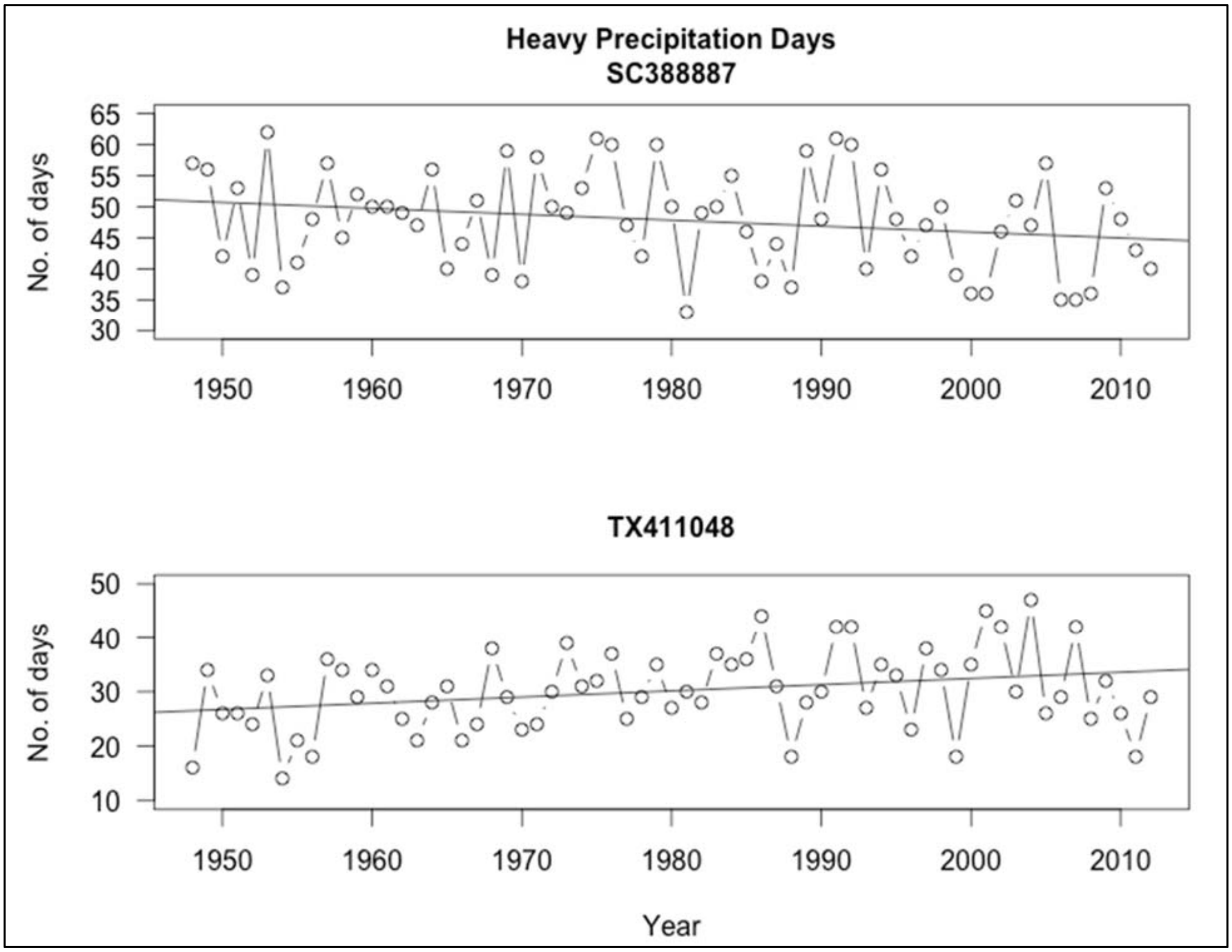

Figure 3-27. Time series of heavy precipitation days (number of days with precipitation ≥ 10 mm) for a station in South Carolina and a station in Texas from 1948 to 2012, with the least squares trend lines plotted.

successful, or useful, in its ability to explain the variability in precipitation extremes in this region. The k-means clustering of components, based on Euclidean distances, creates small, spatially homogenous groups that closely mirror the results of the rotated components. Given the similarity in results, rotated components may be more reliable in describing a regionalization of precipitation extremes for the Southeast.

Results from these two S-mode PCAs reveal considerable differences existing on a sub-regional scale in temperature and precipitation extreme indices, particularly for precipitation extreme indices. Temperature extremes suggest a region from Texas and Oklahoma extending east to Mississippi and half of Tennessee, and a second region extending from Mississippi and Tennessee eastward. The western region defined by the temperature classification closely resembles the 6-state South Central region managed by SCIPP and the SRCC. In addition, the second sub-region defined as the East Coast states roughly corresponds to the area managed by the SERCC and Carolina Integrated Sciences Assessment. Precipitation extremes further sub-divide the Southeast into multiple smaller regions. These sub-regions may be defined as sites in the northern region of Tennessee, a second northern region of Arkansas, a southwestern region encompassing sites in Texas and southern Louisiana, an eastern region that includes sites in the Carolinas and Georgia, a northwestern region with sites in Oklahoma and northern Texas, and a central region made up of sites in Louisiana, Mississippi and Alabama. Some differences emerge between southern sites closer to the Gulf with sites further inland to the north. These results suggest that extremes vary greatly across the region, even within the SRCC and SERCC regions, as well as the larger NWS's Southern region. These results have important implications for these regional climate centers, whose regions may contain large variation in extremes. Thus, this regionalization may be used to inform strategies for identifying focus areas with respect to extremes, as well as how to target the delivery of information based on more homogeneous regions that exhibit similar extreme behavior.

A third PCA performed on monthly index values attempted to define a seasonality of extremes for the Southeast. Most of the monthly indices are temperature-related indices, with eleven temperature and just two precipitation indices. Therefore, the resulting seasonality may apply more to temperature rather than precipitation extremes. Overall, these monthly indices exhibit a seasonality very close to conventional definitions of seasons. The PCA classifies the 12 individual months into two new components, or variables. Based on the magnitudes and signs of the coefficients, PC1 contrasts the winter and summer months. Winter is dominant from November to February. Summer extremes are most pronounced in July, though a summer season may be defined as June through August. Transition months generally correspond to conventional definitions of fall and spring, though they may be slightly longer in duration. Spring is defined as March through June, with June being a transition month between spring and summer. Fall is defined as August through October, with August representing a transition month between summer and fall. April and May contribute most to spring, while September and October contribute most to fall.

Overall, this seasonal classification results in longer and shorter seasonal periods that differ somewhat from the conventional 3-month seasons throughout the year, though not by much. An extended winter season may reflect the importance and frequency of frontal systems in much of the region, including enhanced winter cyclogenesis in the Gulf (Whittaker and Horn 1981), as well as patterns of mid-tropospheric air flow that drive the occurrence of both temperature and precipitation extremes in the region (Keim 1996). July particularly stood out as the peak of when summer extremes occur, when the Bermuda High exerts its greatest influence on extreme rainfall in this region (Keim 1996). Based on their maximum loadings, an extended spring season may occur from March to June, influenced by frontal systems that mark boundaries between dry, cooler continental air masses from the north and wet, warmer moist air from the Gulf that drive heavy precipitation events and swings in temperatures.

This research presents a ‘geography of climate extremes’ for the Southeast United States. Results illuminate underlying spatial patterns in temperature and precipitation extremes across the region. In addition, it reveals a seasonality of extremes that varies somewhat from conventional 3-month seasonal definitions. This research furthers knowledge of the underlying physical patterns in extreme variability for the Southeast. It will be of further interest and use to policy and decision makers. As will be discussed in Study Three, communities continue to need case study examples and precedents for climate-related planning to help ensure plans are implemented and, more importantly, effective in reaching communities’ climate mitigation and adaptation goals. Communities can use such a regionalization of extremes presented in this study to help build pilot programs and target ‘lessons learned’ to specific locations experiencing similar temporal variability in extreme events in other parts of the Southeast. A regionalization of extremes may also help inform the work of climate research centers in the Southeast and to possibly inform new boundaries that make more sense for their respective regions of interest and charge.

3.5 Conclusions and Future Research

Based on PCAs of standardized extreme index values, this study conducted a regionalization of temperature and precipitation extremes. The PCA approach was successful in classifying temperature extremes for the Southeast into distinct east and west sub-regions, with the majority of variance in the original data explained by retaining two components. While precipitation extremes could be classified into several groups using PCA, coherent regions were less obvious than for temperature extremes and less overall variance could be explained with just a handful of components. Results between the two grouping methods were also very different. Thus, this research suggests that precipitation extremes are much more variable than temperature extremes for the stations included in this analysis. Extremes in the Southeast exhibit a clear seasonality, with extended winter and spring seasons and a summer peak in July. The fall season was defined as August, September, and October, which is slightly earlier than the typical 3-month definition of fall.

As aforementioned, the interpretation of PCA involves some subjectivity and will depend on decisions that are made when setting up the analysis. The classifications themselves depend on the number of components that are retained. In addition, the choice of rotation and which rotation method to use in the PCA may yield different results. For the k-means clustering analysis, the number of groups specified in the k-means test will obviously play a role in resulting station assignments. Despite limitations inherent in these two approaches, they present a new, and generally successful, way of classifying extremes.

This study classified extremes for the Southeast using a set of indices developed by the WMO ETCCDI Working Group. Future research should incorporate more stations to further refine a regionalization of these extreme indices. Increasing station density across the study region would produce a more accurate regionalization and improve interpolation methods for visualizing the boundaries of coherent spatial regions. In addition to the Varimax rotation, other orthogonal and oblique rotations should be tested and compared to verify the regionalization and identify the most physically meaningful results. Additional regionalization methods could be incorporated for comparison with the PCA and clustering methods to further verify results and possibly improve the classification of precipitation extremes, in particular. This might include using other eigenvector techniques, such as discriminant analysis, as well as statistical methods, such as ANOVA or other variance tests.

Overall, stations located in very different parts of the region have seen similar variability in extremes, particularly with respect to precipitation-related indices. While it is necessary to develop an understanding of trends in each individual index, which was the focus of Study One, a classification of extremes helped to reveal underlying patterns that exist on smaller spatial scales. This classification can also be helpful in producing a simplified description of extreme variability for use by decision makers, stakeholders, policy makers, and the general public. A key takeaway is that counties and municipalities should think beyond their immediate jurisdictions for opportunities to collaborate with other locales experiencing similar extreme variability. The next study will use the results from the classifications to compare climate-related planning and policy across the Southeast, using stations with similar and different extreme behavior.

CHAPTER 4. STATE AND LOCAL ACTIONS ON CLIMATE CHANGE: CASE STUDIES IN THE SOUTHEAST UNITED STATES

4.1 Introduction

Communities across the country are already feeling the effects of climate change, particularly from extreme precipitation, wildfire, extreme heat, reduced snowpack, and rising sea levels (USGCRP 2009). State and local governments are beginning to respond by taking proactive steps to adapt (Hansen et al. 2013). Substantial adaptation planning is occurring at all levels of government, as well as in the public and private sectors (Hansen et al. 2013). Until recently, planning for local impacts was limited in large part by a lack of sufficient local-level climate data and associated effects (IPCC 2007, CSC 2010). As of the IPCC's 2007 Fourth Assessment Report, adaptation planning for climate change was occurring only on a limited basis. Thus, for many states and local entities, adaptation planning is a nascent effort, beginning within the past several years under the Obama Administration.

Impacts of climate change are commonly addressed using climate mitigation and adaption strategies that reduce risk. The NCA (2013) defines climate mitigation as actions that enhance carbon sinks and reduce carbon sources from human induced greenhouse gas (GHG) emissions that contribute to earth's greenhouse effect. Climate mitigation is often implemented through technological changes or substitutions that reduce emissions. Over the past couple of decades, focus has shifted from climate mitigation to reduce greenhouse gas emissions to climate change adaptation in more recent years to reduce the impacts of climate change (Hansen et al. 2013). The IPCC defines adaptation as an adjustment in natural or human systems in response to a new or changing environment that moderates harm or exploits beneficial opportunities (IPCC

2012). As of 2013, 17 states have or will soon have adopted adaptation plans, many of which are coastal states (Hansen et al. 2013). About half of these plans also include strategies to mitigate climate change. Hansen et al. (2013) further found that some states are engaged in sector- or impact-specific adaptation planning to address specific hazards or threats. Hazard mitigation is synonymous with climate adaptation in that they both seek to reduce the adverse impacts from extreme events. FEMA defines hazard mitigation as efforts to reduce loss of life and property by lessening the impact of disasters, with emphasis on proactive measures that reduce losses long term (FEMA 2013). Hazard mitigation and climate adaptation have congruent goals and provide complementary information (i.e. past and future risk); however, these planning efforts generally have separate processes and outcomes. For instance, a recent report stressed that only five of 30 coastal state hazard mitigation plans explicitly address climate change adaptation, none of which were southern states (CSC 2010).

The increase in adaptation planning in recent years has not been widespread (Hansen et al. 2013). Climate change planning began to accelerate among U.S. states and cities in the mid-1990s (Wheeler 2008); however, adaptation is much newer and implementation of plans overall is still largely lacking (Wheeler 2008, IPCC 2012). Areas that are lagging behind may be the most vulnerable to risk. According to the Center for Climate and Energy Solutions (C2ES), several multi-state regional climate initiatives have been established across the country in recent years. Five regional initiatives exist, as of 2013: 1) the North America 2050 (NA2050), 2) the Western Climate Initiative, 3) the Regional Greenhouse Gas Initiative; 4) the Midwest Greenhouse Gas Reduction Accord; and 5) the Transportation and Climate Initiative (Figure 4-1). None of these five collaborations includes states within the Southeast, and the Southeast lacks a comparable region-wide climate initiative. This is particularly important given that the Southeast is the most weather-active region of the country (NWS 2012, Kunkel et al. 2013). Furthermore, Hansen et al. (2013) point out that the Southwest and Southeast regions are the most vulnerable in the country and the least likely to plan for climate change.

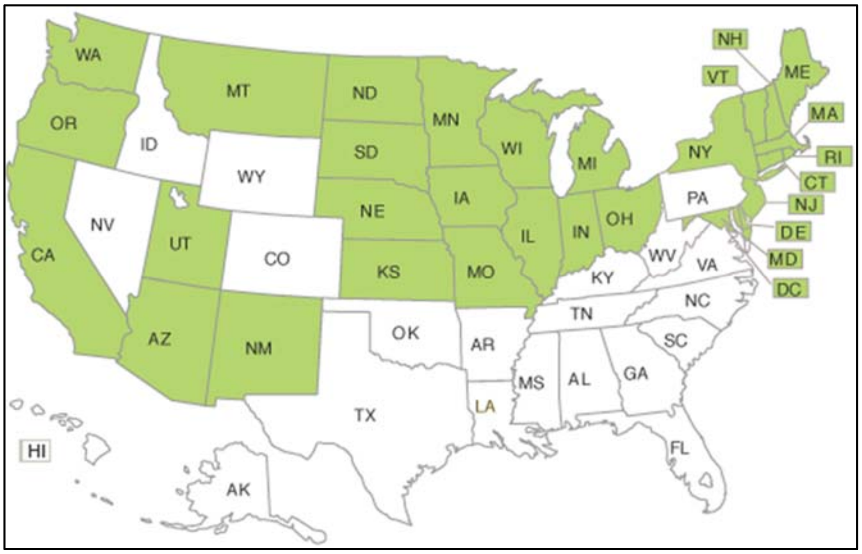

Figure 4-1. Map of states that are part of a regional initiative related to climate mitigation or adaptation (shaded in green), according to the C2ES (2011).

Previous research has shown that public opinion regarding climate change differs among political parties (Hamilton 2010, Hamilton et al. 2010, Leiserowitz et al. 2011, Leiserowitz et al. 2012, GeorgetownClimateCenter 2013a). In particular, the majority of Republicans (56%) view global warming as a low national priority compared to only 15 percent of Democrats (Leiserowitz et al. 2011). Furthermore, while an overwhelming majority (75%) of Americans thinks there is solid evidence that average temperatures are rising, 29 percent of Republicans feel that this increase in average temperatures is due to human activity, compared to 55 percent of Democrats (GCC 2013). Among individuals in rural counties around the U.S., Hamilton et al. (2010) similarly found that concern for the environment increased with education among Democrats but not Republicans. A large percentage of people in the South are classified as dismissive (39%), doubtful (30%), or unconcerned (26%) about climate change (Leiserowitz et al. 2012). These groups tend to be Republican and politically conservative compared to those that are more concerned about climate change (Leiserowitz et al. 2012). Thus, the fact that the Southeast is largely Republican likely contributes to a reduced emphasis on climate-related issues and planning. Furthermore, the limited amount of state adaptation planning that has occurred in the Southeast has been in response to recent executive orders issued by state governors, such as in Florida and South Carolina, and support for such efforts often disappears with changes in leadership (Hansen et al. 2013).

Climate mitigation and adaptation happen largely at the state and local levels, rather than at the Federal level (ICCATF 2011). This is due partly to the fact that local governments are typically responsible for planning, with implementation occurring through zoning, subdivision regulations, and related actions (Emmer et al. 2007). Additionally, more jurisdictions are adopting comprehensive plans to reduce emissions (Wheeler 2008). This study investigates state and local actions related to climate and natural hazards in the Southeast to examine the types of actions that are occurring and the substance of these efforts. Information about the types of planning and policy actions and the focus of resulting documents can provide particular insight for stakeholders, policy makers, and governments at all scales that are working to increase the region's preparedness to climate change.

4.1.2 Research objectives

A primary objective of this research is to assess communities' efforts to reduce the effects of extreme events and increase resilience to climate change. Several counties and municipalities in the Southeast exemplify proactive, innovate planning and actions related to climate change, both in the region and nationally. For example, the Miami Climate Action Plan (CityofMiami 2008) for Miami, Florida indicated that the city will plan for the impacts of climate change by incorporating climate change scenarios into long-term planning. Tulsa, Oklahoma serves as a national precedent for its long and active history in floodplain management, which has included the use of acquisition programs to remove more than 900 flood-prone properties out of floodplains (ASFPM 2004). The latest NCA adaptation report (NCADAC 2013) also provides several local and regional examples of adaptation efforts taking place within the Southeast. For instance, the city of Satellite Beach, Florida partnered with the Indian River Lagoon National Estuary Program to use sea level rise projections and policies in the city's comprehensive growth management plan. Also in Florida, the Southeast Florida Climate Compact is a joint commitment between Broward, Miami-Dade, and Monroe Counties in southeast Florida to reduce GHG emissions and adapt to climate impacts (NCADAC 2013). It is valuable to highlight the cities and regions that have hitherto led climate adaptation and mitigation actions to serve as examples and precedents for others looking to take similar action. However, restricting analysis to only these communities may paint a misleading picture of the extent and ability to which communities are considering climate change in their planning efforts. In addition, larger cities are at a natural advantage in terms of their capacity to tackle climate change impacts, with larger budgets, staff, and greater expertise.

This study assesses state and local actions related to climate change and hazards in the Southeast using six locations as case studies. The aim of the study is to improve understanding of the level and types of actions taking place in smaller communities in the Southeast, using data on extreme events as context for both the impetus and focus of actions. This study includes actions that have occurred over the past several decades, though emphasis is placed on the most recent decade, since hazard mitigation and adaptation planning have emerged mostly within this timeframe.

Extreme event data are used in this study as context for examining the focus of climate change actions. Climate-based plans have been criticized for lack of substance and causality of effect (Millard-Ball 2012a, Millard-Ball 2012b). The intent of incorporating historical extreme event data in this study is to help assess whether the focus of state and local efforts reflect actual risks and whether communities are incorporating relevant climate change information needed to reduce their risk. Past studies have linked experiences with extreme events to related planning efforts (Burby and Dalton 1984, Clary 1985, Neil Adger et al. 2005, Hamilton and Keim 2009). According to Burby and Dalton (1984), areas that experienced repeated hazards were more likely to adopt land use plans. Extremes likely raise awareness and concern over climate change within policy making and, therefore, are more likely to lead to adaptation through governmental action (Neil Adger et al. 2005). In addition, Clary (1985) showed that when a low frequency of natural hazards existed, elected officials felt it necessary to allocate limited resources elsewhere and gave lower priority to hazard planning activities. Lastly, Hamilton and Keim (2009) suggest that climate itself seems to influence perceptions about climate change, particularly if climate trends have newsworthy impacts on important sectors or daily life. In these ways, vulnerability to extreme events is dictated by social and political factors, as well as by physical ones (TheHeinzCenter 2002, Sullivan and Meigh 2005, CSC 2010). Incorporating site-specific hazard profiles helps place recent planning efforts into context, which can then inform future efforts.

This study builds on earlier research aforementioned by looking beyond climate adaptation planning to assess the types of actions taking place in the Southeast that can help reduce impacts of and increase preparedness for climate change. It will determine whether communities in different parts of the Southeast demonstrate similar behavior with respect to their approaches to planning for climate change risks. The research objectives of this study are to:

1. assess the level and type of state- and local-level hazard and climate-related planning efforts for six locations across the Southeast United States, and
2. compare the focus and content of such efforts to assess their relevance and effectiveness in preparing communities for climate change.

4.2 Data and Methods

4.2.1 Station selection

This study uses six sites in the Southeast as case studies to investigate actions that communities are taking to prepare for the impacts of climate change. This research builds on results from Studies One and Two. These six sites represent stations that were included in Study Two, which used principal components analysis (PCA) to develop a classification of extremes in temperature and precipitation for the Southeast. The methodology for choosing the six sites for this study is largely based on results from Study Two and outlined below.

The PCA analysis in Study Two created groups of stations based on similar variability in extreme temperatures and precipitation. Extremes in temperature and precipitation were initially calculated in Study One for 107 stations in the Southeast using 27 core extreme indicators developed through the WMO ETCCDI Working Group and available through the CLIMDEX Project (*www.climdex.org*). Site selection was based on results from the temperature PCA than on the precipitation PCA, though the temperature extreme indices yielded a simpler regionalization. Based on PCA results for the temperature extreme indices, the first two principal components revealed two distinct groups of stations. The sign of the loading coefficients contrasted stations in the western part of the region with stations in the eastern portion, meaning that these sets of stations covary but in opposite directions. When the first three components were retained, however, an additional group emerged that generally contrasted northern, interior stations with stations near the Gulf Coast. In particular, stations in southern Texas, Louisiana, Mississippi, Alabama, and Florida were contrasted with stations in Oklahoma, as well as a few in Arkansas, South Carolina, North Carolina, and Georgia. Results from the extreme precipitation PCA analysis supported a classification scheme whereby stations in proximity to one another exhibit a similar mode of variability that differs from all other stations in the region.

The PCA classification schemes in Study Two revealed several distinct sub-regions: west and east, as well as several small regions across the Southeast. Three main criteria were used to determine which stations to include in the present study. These station selection criteria were:

1. to select at least one station from different regions defined by the temperature and precipitation PCA analyses,
2. to select stations with significant trends in extreme indices (precipitation or temperature), and
3. to represent areas with historically different types of hazards and threats and, thus, with various levels of engagement in climate/hazard-related planning (i.e. coastal versus agricultural land; progressive vs. more conservative).

Based on the above criteria, the six locations that were chosen for final inclusion are: 1) Okeene, Oklahoma; 2) Brenham, Texas; 3) Hattiesburg, Mississippi; 4) Corning, Arkansas; 5) Little Mountain, South Carolina; and 6) Tarpon Springs, Florida. They cover each of the four regions described above, with two stations in the west, one in the central/Gulf, one in the upper interior region, and two in the east. Figure 4-2 shows a map of these six stations. All six stations have at least ten indices with significant trends for the period 1948-2012. In addition, these stations are thought to be diverse in terms of threats and previous planning activity (i.e. Florida as a more active state focused on coastal issues versus Arkansas as a less active state focused on agriculture).

4.2.2 Extreme event losses

SHELDUS^{TM} data were used to provide historical documentation on the number and amount of damaging climatological events that have occurred in the six sites and corresponding counties included in this study. SHELDUS^{TM} is a county-level hazard database for the United States developed and maintained by the Hazards &

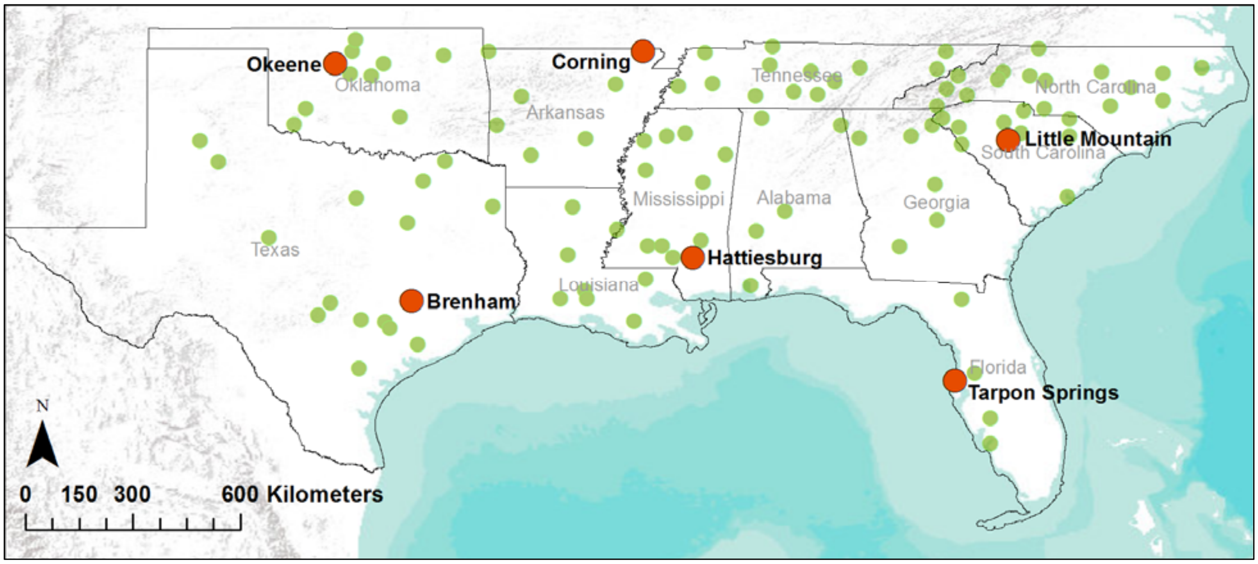

Figure 4-2. Map of the six case study sites in the Southeast selected as the focus of this study.

Vulnerability Research Institute at the University of South Carolina. SHELDUS™ includes data for 18 natural hazard types. Only events that generated direct losses, whether in the form of damages, injuries, or fatalities, are included in the database. For each event, a hazard ID, beginning and end dates, location (property or state), property losses, crop losses, injuries, and fatalities are included. Data on losses can be adjusted to a certain year and queried data can be downloaded in various formats for further analysis. Data extend back to 1960, and all counties included in this study were queried for the period 1960 to 2012.

The counties for which hazard data were downloaded include: Blaine County, Oklahoma (Okeene); Washington County, Texas (Brenham); Forrest County, Mississippi (Hattiesburg); Clay County, Arkansas (Corning); Newberry County, South Carolina (Little Mountain); and Pinellas County, Florida (Tarpon Springs). One query was used to find the climate-related disasters that occurred in each of these six counties. Six climatological disasters were searched for each county: 1) drought, 2) flooding, 3) heat, 4) wildfire, 5) severe storm/thunderstorm, and 6) winter weather.

SHELDUS^{TM} consolidates data from the NCDC's Severe Storms Database, the U.S. Geological Survey (USGS), and other sources. To provide county-level data, SHELDUS^{TM} distributes loss estimates equally across counties and reports only the lowest loss estimate if loss ranges are provided (Gall et al. 2011). For instance, if an event affected two counties and caused between \$50,000 and \$500,000 in losses, then SHELDUS^{TM} divides the losses as \$25,000 for each county. Thus, SHELDUS^{TM} provides conservative loss estimates. In 1995, the NWS changed its loss reporting procedures from a logarithmic loss estimate approach to actual dollar amounts. As a result, the NCDC's Storm Database switched from using categorical estimates to actual, whole dollars (Gall et al. 2009). Thus, SHELDUS^{TM} uses two temporal thresholds over its period of record. From 1960 through 1995, the database includes any event with losses equal to or greater than \$50,000, as well as any with at least one reported fatality. From 1996 onwards, it includes every loss-causing event (producing crop or property losses), every fatality, and every injury, regardless of the amount of monetary losses (Gall et al. 2009).

The NCDC storms publication provides definitions for each of these types of disasters (NCDC 2007). Drought is defined as a deficiency of moisture that adversely impacts people, animals, and/or vegetation over a sizeable area. A drought event is included in the NCDC Storm Data publication if the drought is a D2 classification (severe drought), or higher, as indicated by the U.S. Drought Monitor (NCDC 2007). A flood is any high flow, overflow, or inundation by water that causes or threatens damage. It includes river flooding, flash flooding, and other non-coastal flooding events. Excessive heat events, caused by a combination of high temperatures and humidity, are entered into the database if the heat index value meets or exceeds locally or regionally established heat warning thresholds. Wildfire is any significant (i.e. causing one or more fatalities, one or more injuries, and/or property damage) forest, grassland, rangeland, or wildland-urban interface fire. Severe storms and thunderstorms include storm events that caused damages as a result of heavy rain, hail, or wind. Lastly, winter weather events are those that include more than one significant hazard that meet or exceed locally or regionally defined 12- and/or 24-hour warning criteria for at least one of the precipitation elements on a widespread or localized basis. Winter weather events can include such hazards as blizzards, heavy snow, ice storms, lake-effect snow, sleet, winter storms, and extreme cold. In addition, winter precipitation events that cause death, injury, or significant impact to commerce or transportation but that do not meet locally/regionally defined warning criteria are also included in the data set.

Damage estimates reported in the NCDC storms publication and included in SHELDUS^{TM} are entered in actual dollar amounts. All damage estimates for this study were adjusted for inflation, to 2012 dollars, to enable comparison from year to year. Property damage generally refers to damage inflicted to private property, including structures, objects, and vegetation, as well as public infrastructure and facilities (NCDC 2007). Property damage estimates commonly come from emergency managers, the USGS, United States Army Corps of Engineers (USACE), power utility companies, and newspaper articles (NCDC 2007). Crop damage estimates are commonly obtained from the U.S. Department of Agriculture (USDA), the county agricultural extension agent, state departments of agriculture, crop insurance agencies, and other reliable sources (NCDC 2007). This study uses damage estimates only for contextual purposes to help assess the focus and content of climate-related policy and planning actions for each particular location. Thus, losses are not compared or analyzed across locations.

4.2.3 Trends in extreme indices

The ETCCDI, comprised of the Commission for Climatology (CCI) of the WMO's World Climate Data and Monitoring Program (WCDMP), the CLIVAR program of the World Climate Research Program (WCRP), and the Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM), created and continue to maintain a core set of climate extreme indices for global application to address the characterization of climate variability and change. ETCCDI indices were developed to provide a common method by which to measure and monitor extremes in climate across regions. They developed a set of 27 core indices that were used to investigate the spatial and temporal variability in extremes for 107 stations in the Southeast. Definitions of these 27 core indices and available software for their calculation are available through the CLIMDEX project (*www.climdex.org*), developed by the WMO ETCCDI under the Australian Research Council's Linkage Project (LP100200690). Appendix C includes the full definitions and formulas for each index.

This study examines trends in extreme indices for each site, focusing on indices with particularly significant and/or interesting trends. These data were included to provide context for how climate extremes are changing at each site and whether actions are in line with threats. Time series of several temperature and precipitation extreme indices are included for each site to illustrate how extremes are changing. Indices were calculated in R, a language and environment for statistical computing and graphing, using a program called RClimDex from the CLIMDEX project. Time series were also produced in R, and trends were plotted using least squares regression. Significance was determined at the $p \leq 0.10$ level.

4.2.4 State and local climate actions

A primary goal of this research is to compare the type of activity related to climate change for these six locations in the Southeast. Particular comparisons are made according to the PCA classification schemes defined in Study Two, namely between actions in Arkansas and Mississippi, and between Oklahoma, Texas, Florida, and South Carolina. For each state, county, and city, a range of policy and planning actions are included to represent the efforts being made by state and local government entities. State level actions are any statewide legislation, plans, studies, and programs. The local level is defined here as the county and/or municipality, as well as regional entities within a state that span multiple counties or jurisdictions.

National and local examples of climate change mitigation and adaptation efforts are well documented by organizations interested in climate change planning and policy. Several clearinghouses have been developed in recent years that inventory national, state, and local climate adaptation activities. The following national databases were searched for relevant climate mitigation and adaptation actions within the states and locales included in this study: the EcoAdapt's Climate Adaptation Knowledge Exchange, Georgetown Climate Center's Adaptation Clearinghouse, the U.S. Environmental Protection Agency's (EPA) State and Local Climate and Energy Program, and C2ES' U.S. States and Regions Climate Action site.

Several types of plans were included. First, this study includes all climate-related plans at state and local levels. This includes, for instance, state Climate Action Plans, which are Governor-led planning initiatives focused heavily on climate mitigation that identify policy recommendations for reducing emissions and mitigating climate change. Many state and local climate mitigation and adaptation approaches to climate change have relied on integrating climate information and related strategies into existing frameworks or sector-based plans (Bierbaum et al. 2013). Therefore, this study searched sector-based plans to identify state and local efforts related to climate change. Planning within certain sectors often addresses the specific climate change issues most pertinent to the particular sector. The following sectors were included to determine whether climate change issues were incorporated into existing plans or strategies: hazard mitigation, environmental management and conservation, drought and wildfire management, agriculture and water management, and energy. Third, hazard mitigation plans were included for each state, as these plans address the range of natural hazards that can impact a state or county and they may include hazard mitigation measures that can contribute to adaptation. This study did not include disaster response or emergency preparedness plans, since these plans generally focus on preparedness, response, and immediate recovery from disasters. Exceptions include drought response plans that addressed long-term drought trends and impacts. Fourth, local comprehensive plans that integrate climate mitigation and/or adaptation measures are included. Comprehensive plans define a community's vision for future growth, typically over a 20 to 30 year timeframe, in terms of its social fabric, economy, and environment. These plans outline strategies to direct growth and development in optimal areas. Thus, they can act as important tools for integrating a community's development goals with adaptation and other risk-reduction strategies to ensure long-term resilience to hazards. In addition to planning, this study includes examples of relevant policy actions. Political activities included Acts, legislative reports or major documents, executive orders, and programs/initiatives that pertained to climate change and/or that influenced and impacted the ability to plan for the impacts of extreme events in a given location.

A variety of sources were used to find an adequate number and variety of relevant planning and policy documents. Sources for climate- and hazard-related planning activities were compiled from state and county planning departments and commissions through online government websites, government databases (e.g. Oklahoma's state database, Digital Prairie, available at *documents.ok.gov*), organizations' databases, and through existing clearinghouses aforementioned. Policy and sector-based plans were identified and gathered from a variety of sources, including State, county, and city government websites, state government databases, and from the literature, including peer-reviewed papers and "grey" literature. Grey literature included government reports, sector-specific department websites, private sector websites and reports, and other agency documents. In addition, the contents of identified sector-based plans were used to determine whether a specific event or policy prompted development of the plan. National private and public sector initiatives and programs were included if one of the states, counties, or cities within this study was a part of the program. This systematic approach used to find relevant documents closely follows that used by Lackstrom et al. (2012) in their analysis of planning in the Carolinas. While this study aimed to be representative of the level and types of action taking place across multiple scales, the final set of documents reviewed in this study is not intended to be a comprehensive analysis of all climate-related planning and policy that may be taking place within these study sites.

While efforts were made to include policy and planning actions that occurred as far back as the mid-20th century to correspond to extreme indices and loss data, the majority of actions identified at the state and local level have occurred since 2000. While activities to mitigate and adapt to climate change have certainly increased in recent years, this study does not make any assumptions about the level of state and local government actions related to climate impacts in earlier decades. Rather, this study should be considered as a snapshot in time that provides an overview of the types of actions that have recently taken place across the Southeast.

This analysis compares actions across multiple scales, from statewide climate-related actions to those actions taking place at the county and/or municipality level. Obviously larger sized cities have greater capacity for planning in general, particularly with respect to funding, expertise, and staff resources. However, most of the locations included in this study are rural towns where less activity may be occurring. As such, actions taking place in surrounding cities and counties are considered to reflect actions in the immediate region by larger communities. Actions by larger communities may have an impact on the capacity of rural towns to respond to climate change, such as by sharing planning process strategies, lessons learned, data, etc.

Additional criteria were used to determine whether a document should be included. First, documents were scanned to assess their focus and contents. Second, an action or document must address at least one of the six climate-related hazards included in the SHELDUS^{TM} database. These six climate hazards (as well as variants on these terms) were used as key words to search documents and determine whether the particular state or local action addressed these issues. Table 4-1 lists the key words that were used as search criteria. If a key word was identified, that part of the document was further analyzed for context and clarity before final inclusion. Third, the document must discuss impacts or strategies for addressing impacts associated with hazards. In addition, reports, programs, and projects were limited to those being conducted and/or funded by a state or local government entity. Thus, scientific research projects and studies are not included. In summary, final document selection includes those that met at least one of the following:

1. pertained to the state, county, or city of interest,
2. addressed some aspect of climate variability or change,
3. addressed climate mitigation or adaptation,
4. discussed at least one of the six climate-related hazards, or
5. included actions or strategies for addressing a climate-related issue.

Table 4-1. List of key words used to search document contents for determination of document inclusion in final analysis.

Key Words	heat, severe storms, drought, flooding, winter weather, wildfire, climate, climate change, variability, temperature, precipitation, mitigation, adaptation, impact, conservation, dry, wet, cold spell, ice, heavy rainfall

Once all documents were systematically identified, a table was created of all documents and key attributes that summarized the following information: entity responsible for document; summary of climate-related information and topics of focus; climate hazards that are addressed; type of document (e.g. report, plan, law, etc.);

mitigation or adaptation processes; climate scope (e.g. extremes, impacts, mitigation, adaptation, etc.); temporal focus (current, past, future); needs and/or impediments related to climate; and impetus for action, if appropriate. Many of these attributes were borrowed from those used by Lackstrom et al. (2012). Final tables summarizing state and local actions for each site were created and are included in the results section below. The organization of these tables closely mirrors Bierbaum et al. (2013).

NVivo software was used to assess the substance of documents' contents and identify the themes and topics of focus for each location. NVivo is a qualitative research tool developed and maintained by QSR International. To assess the substance of the documents and the extent to which they addressed climate extremes and impacts, three unique text search queries were run for state and local level actions separately for each site to find content related to three categories: climate change, temperature extremes, and precipitation extremes. Table 4-2 provides a list of words and phrases used for each categorical search. Variants of these words were included using special characters where appropriate (e.g. "flood*" to capture floods and flooding, and "*heat*" to capture extreme heat, heat waves, etc.).

To illustrate the focus of actions by state and local governments included in this analysis, word frequency queries were conducted to show the 50 most commonly occurring words. Queries were run for each of the six sites for both state and local actions, as well as for state and local actions separately. Results were generated as word clouds to more easily visualize the most frequent concepts for each site. NVivo automatically removes non-substance words, called 'stop words,' in these queries,

Table 4-2. List of words and phrases used to search documents for content related to climate change, temperature extremes, and precipitation extremes.

Climate Change	climate change, global warming, emissions, climate impacts, climate variability, mitigation, adaptation, greenhouse
Temperature Extremes	temperature, *heat*, extreme temperature, high temperature, warm spells, cold spell, cold snap, cold*, ice*, hot
Precipitation Extremes	heavy precipitation, heavy rainfall, extreme precipitation, stronger storms, *storms*, *rain*, flood, drought, dry

including conjunctions and articles. Users can also add additional stop words to remove them from queries. I added all place names, numbers (except dates), units of measure, and miscellaneous words (e.g. also, tables, however, etc.) as stop words to exclude them from results. Only words with a minimum of three letters in length are included.

4.3 Results

This section presents socioeconomic characteristics, hazards, and planning and policy efforts for each of the six case study sites. Table 4-3 summarizes socioeconomic characteristics and profiles hazards, including loss estimates for six climate-related disasters, for the six counties that correspond to each case study site. Socio-economic characteristics based on Census QuickFacts include population, based on 2012 estimates, as well as median household income, homeownership rates, and poverty level, all over the 5-year period from 2007-2011. Population ranges from a low of just less than 10,000 in Blaine County, Oklahoma to a high of over 921,000 in Pinellas County, Florida. Median household income is similar across all sites, with the wealthiest counties being Pinellas and Washington Counties. Homeownership rates are similar, near 70 percent, though Forrest County, Mississippi is somewhat lower at 59 percent. Political affiliation is based on the latest 2012 Presidential election results (source: *www.politico.com/2012-election*) and not voter registration data. It is believed that election polling results provides a better indication of people's behavior compared to how they are registered to vote. All counties corresponding to the six sites are majority Republican, with the exception of Pinellas County, Florida, where Democrats represent a slight majority.

Table 4-3 further provides hazard profiles for each county. The hazards listed are those that pose a medium to high risk for the corresponding county, as indicated in state Hazard Mitigation Plans (HMP). Most places focus on the same set of hazards, though the Mississippi HMP does not specify as many hazards by county overall. In addition, erosion and sinkholes are issues that emerge for the eastern counties in South Carolina and Florida but are not a concern for the western sites. SHELDUS^{TM} data include the number of disasters that produced losses or injuries, the amount of property and crop losses, and total losses per capita for six disaster types from 1960 to 2012. All values are adjusted to 2012 dollars. These data are described in detail in subsequent sections.

4.3.1 Clay County, Arkansas

Corning, Arkansas is located in Clay County in the extreme northeastern part of the state (Figure 4-3). Corning, Arkansas is included here to represent an interior location within the Southeast. This region was generally contrasted with Gulf Coast locations with respect to temperature and precipitation extremes in Study Two. Clay County is a small county of less than 16,000 people, and its population declined by 2.5 percent in recent years from 2010 to 2012. Agriculture is the largest industry in the state (EAPDD 2009, Chou et al. 2012), making variability of extremes particularly acute for the agricultural, economic, and environmental sectors within the state. In fact, the

Table 4-3. Socio-economic, hazard, and disaster data from 1960-2012, adjusted to 2012 dollars, by county for each case study site. Data sources include U.S. Census QuickFacts (2013), state hazard mitigation plans, and SHELDUS^{TM}.

		Blaine Co., OK	Washington Co., TX	Clay Co., AR	Forrest Co., MS	Newberry Co., SC	Pinellas Co., FL
Socio-economic	Population (2012)	9,785	34,093	15,684	76,894	37,576	921,319
	Med HH Income (2007-2011)	$41,306	$45,320	$31,135	$35,805	$42,866	$45,891
	Homeownership rate (2007-2011)	70%	68%	74%	59%	73%	70%
	Below poverty (2007-2011)	16%	14%	18%	27%	16%	13%
Political Party	Republican (2012 elec.)	74%	76%	63%	55%	57%	47%
Hazards	Medium - High Risk outlined in HMP	Flooding, Tornadoes, Extreme Heat, Earthquakes, Drought, Winter Weather	Riverine Flooding, Drought, Wildfire, Extreme Heat, Hurricane Winds, Winter Weather	Flooding, Tornado, Earthquake, Drought, Severe Storms, Hail	Flooding, Tornadoes, Hurricanes	Flooding, Tornadoes, Hurricanes, Severe Storms, Wildfire, Extreme Heat, Drought, Winter Weather, Hail, Earthquakes, Sinkholes	Flooding, Hurricanes, Severe Storms, Wildfire, Tornadoes, Drought, Extreme Heat, Erosion, Sinkholes
Winter Weather	No. of Events	24	16	28	16	77	10
	Property Losses	$14,696,559	$570,511	$3,950,389	$1,303,551	$2,349,140	$37,943,542
	Crop Losses	$142,329	$1,510,747	$2,804,349	$713,171	$17,237,009	$9,252,077
	Total Per Capita Losses	$1,516	$61	$431	$26	$521	$51
Drought	No. of Events	3	4	4	3	11	0
	Property Losses	$4,132,421	$2,707,680	$6,792,847	$1,318	$9,357,960	$0
	Crop Losses	$18,635,549	$26,022,873	$20,112,340	$2,020,457	$5,134,396	$0
	Total Per Capita Losses	$2,327	$843	$1,715	$26	$386	$0
Severe Storms	No. of Events	53	29	68	156	96	120
	Property Losses	$2,215,270	$684,544	$7,220,691	$27,609,295	$1,740,561	$47,889,715
	Crop Losses	$1,480,813	$160,164	$7,102,449	$3,432,320	$1,507,853	$32,964
	Total Per Capita Losses	$378	$25	$913	$404	$86	$52
Flooding	No. of Events	10	25	23	63	24	34
	Property Losses	$6,522,533	$2,874,572	$10,931,988	$31,715,666	$1,258,784	$11,660,511
	Crop Losses	$8,091,594	$168,869	$5,161,417	$15,687,903	$1,366,869	$11,857
	Total Per Capita Losses	$1,494	$89	$1,026	$616	$70	$13
Heat	No. of Events	2	1	4	3	6	0
	Property Losses	$8,438	$14,821	$4,205,144	$0	$9,123,762	$0
	Crop Losses	$7,237,234	$1,482,093	$20,124,051	$115,120	$2,379,008	$0
	Total Per Capita Losses	$740	$44	$1,551	$1	$306	$0
Wildfire	No. of Events	0	0	0	0	3	2
	Property Losses	$0	$0	$0	$0	$100,449	$4,001,068
	Crop Losses	$0	$0	$0	$0	$255,125	$0
	Total Per Capita Losses	$0	$0	$0	$0	$9	$4
Total	No. of Events	92	75	127	241	217	166
	Property Losses	$27,575,221	$6,852,129	$33,101,058	$60,629,830	$23,930,657	$101,494,836
	Crop Losses	$35,587,519	$29,344,746	$55,304,606	$21,968,972	$27,880,261	$9,296,898

agricultural supply in much of eastern Arkansas is in crisis due to depletion of aquifers (EAPDD 2009).

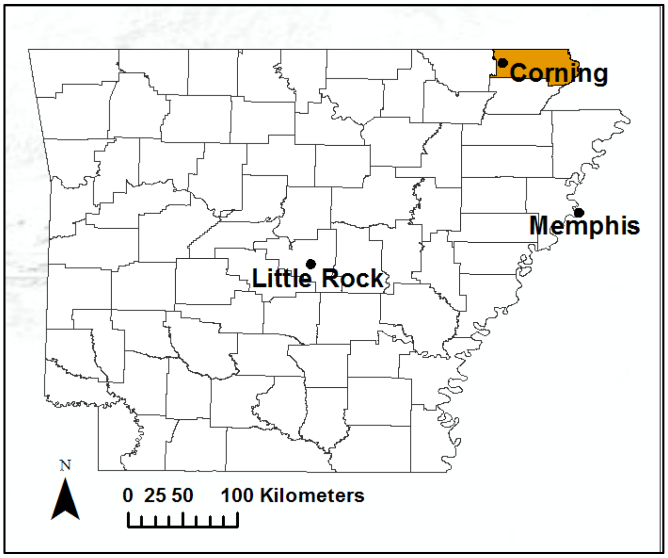

Figure 4-3. Location of Clay County (shaded), Corning, and major nearby cities.

<u>4.3.1.1 Temperature and precipitation extremes</u>

Since 1948, Corning has experienced increasing warmth in minimum temperatures, but maximum temperatures display general cooling. Figure 4-4 shows time series for warm nights, cool days, and warm spells, all with trends significant at the 0.05 level. There is a decreasing percent of warm days above the 90th percentile for a calendar day, but a significant increase in annual absolute warmest nighttime temperatures. The duration of temperature extremes appear to be getting shorter, as observed in warm spells (Figure 4-4c) and cold spells (Figure 4-5b). Cold-related indices further support increasing warmth in minimum temperatures and cooling in maximum temperatures. For instance, frost days are becoming less frequent (Figure 4-5a), yet the percent of cool days below the 10th percentile is rising (Figure 4-5c).

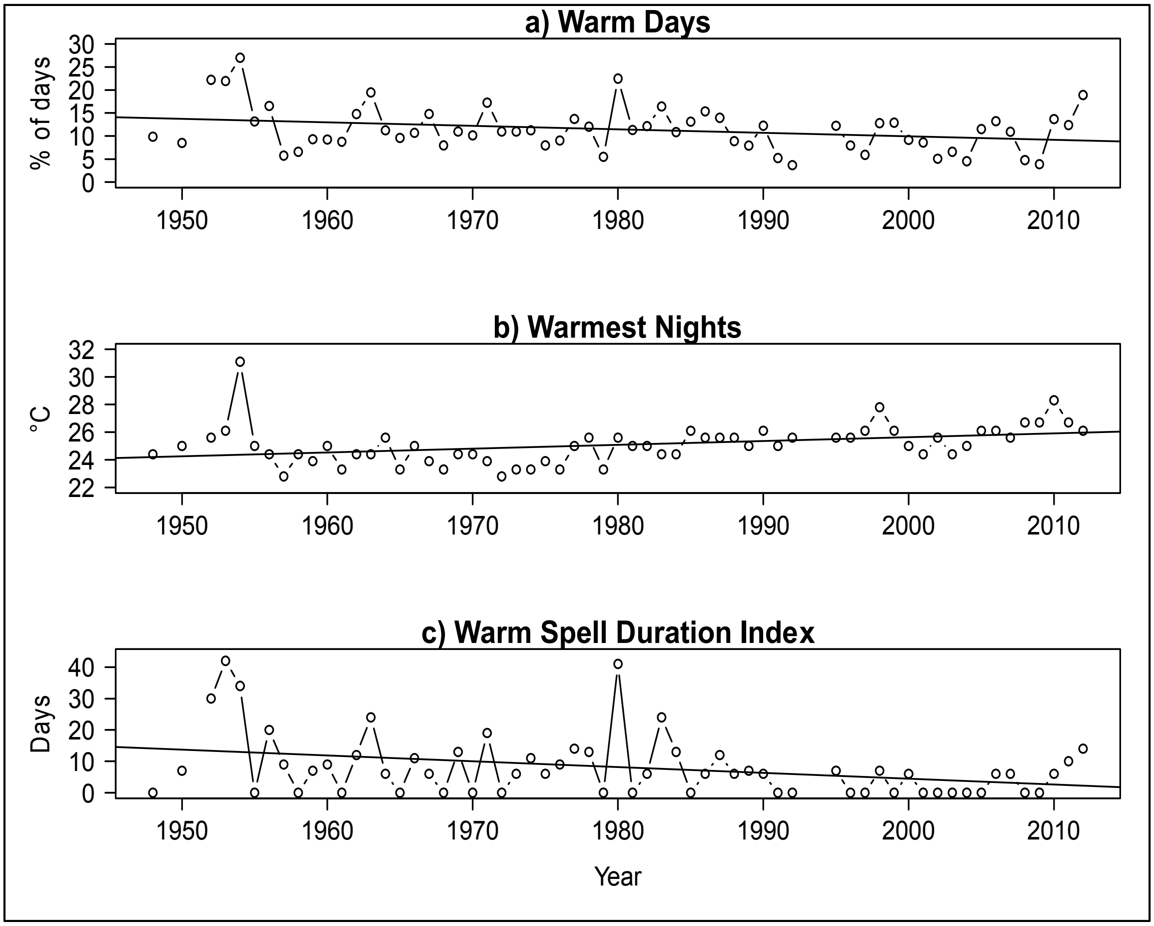

Figure 4-4. Time series of warm-related temperature extreme indices for Corning, Arkansas, including a) warm days (days with Tmax greater than the calendar day 90th percentile), b) warmest nights (absolute annual Tmax), and c) warm spells (annual count of days with at least six consecutive days when Tmax is above the calendar day 90th percentile). Trends significant at the $p \leq 0.05$ level.

Figure 4-6 shows time series of three precipitation indices for Corning. Trends in precipitation-related indices were insignificant for Corning overall. Despite this lack of significance, indices suggest that precipitation events are becoming more intense. For instance, Figure 4-6a shows a trend toward heavier 1-day precipitation events, and Figure 4-6b shows that the annual total precipitation above the 99th percentile (for a calendar day) is increasing. The duration of extreme precipitation appears to be getting

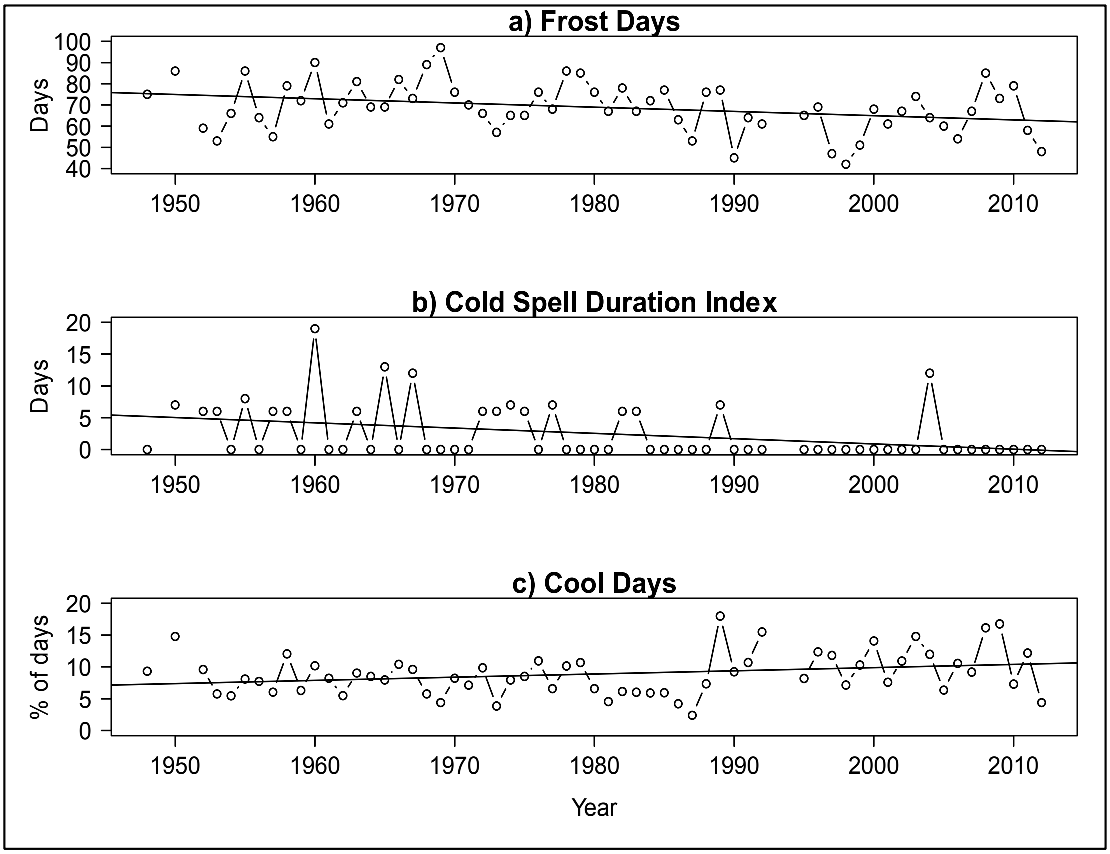

Figure 4-5. Time series of cold-related temperature extreme indices for Corning, Arkansas, including a) frost days (annual count of days when Tmin was below 0°C), b) cold spells (annual count of days with at least six consecutive days when Tmin is below the calendar day 10th percentile), and c) cool days (percent of days when Tmax is below the calendar day 10th percentile). Trends significant at the $p \leq 0.05$ level.

longer and/or more variable, as reflected by an increasing trend in consecutive wet days (Figure 4-6c) and dry days (not shown).

While fall is generally the driest season in Arkansas, Study One showed that 1-day and consecutive 5-day precipitation events are becoming significantly more intense in fall for Arkansas. This is in agreement with the U.S. Global Change Research Program (USGCRP) that also found average fall precipitation to have increased by 30 percent since 1901 (USGCRP 2009). Conversely, spring and summer may be experiencing less intense 1- and 5-day precipitation events, as well as a decrease in

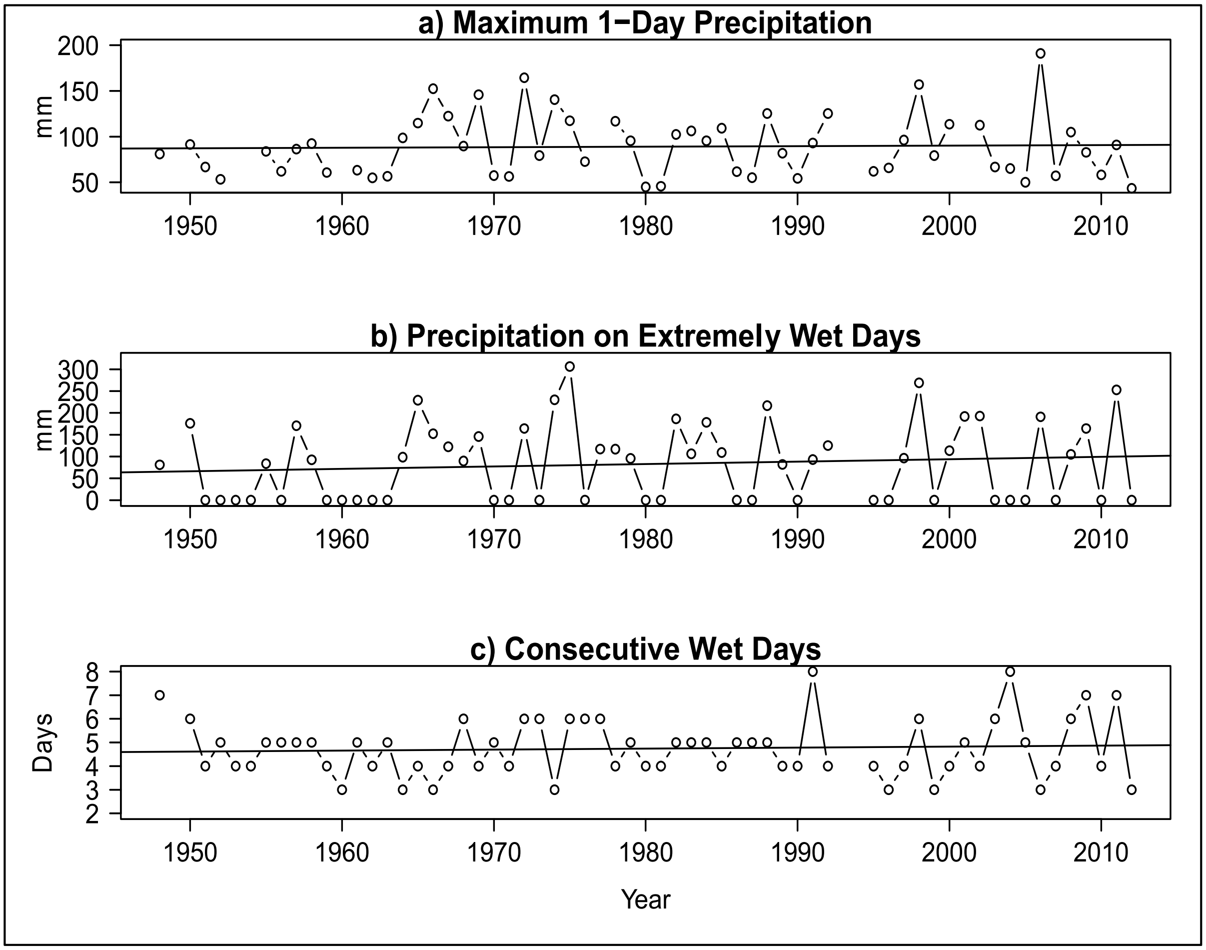

Figure 4-6. Time series of extreme precipitation indices for Corning, Arkansas, including a) maximum 1-day precipitation (annual maximum 1-day precipitation), b) precipitation on extremely wet days (annual total precipitation when precipitation was greater than the calendar day 99th percentile), and c) consecutive wet days (maximum number of consecutive days when precipitation was greater than or equal to 1 mm). Trends are not significant.

average summer precipitation (USGCRP 2009). Higher temperatures, coupled with declining summer precipitation in Arkansas, will have implications specifically for agriculture (Chou et al. 2012).

4.3.1.2 Extreme events and losses

Arkansas experiences a variety of extreme weather and climate. The state All-Hazard Mitigation Plan (AHSPA 2010) focuses on several weather and climate-related hazards, including floods (riverine, flash, and dam failure), severe winter weather, tornadoes, thunderstorms, wildfires, drought, and earthquakes. Clay County has taken steps to address risks from natural disasters by developing a FEMA-approved local hazard mitigation plan (AHSPA 2010). In addition, the county was one of four Arkansas communities that participated in Project Impact, a FEMA-led national program that ran from 1997 to 2001 to promote disaster-resistant communities through local hazard mitigation efforts.

Between 1960 and 2012, Clay County experienced 127 climate-related disasters that produced losses to property and/or crops (Table 4-3). Severe storms were responsible for generating the greatest number of damaging events during this period, with winter weather and floods competing for second place. Similarly, severe storms and flooding have caused the majority of emergency and major disaster declarations in the state since 1957, at 43 and 39 declarations, respectively (FEMA 2013). While the number of damage-producing events has steadily risen each decade since 1960, this may reflect an increase in reporting and improved documentation over time and not necessarily a rise in the frequency of events.

The number of events is not necessarily indicative of the amount of damages they cause. For instance, there were only four drought and four heat-related events that produced losses reported between 1960 and 2012; however, these generated the greatest amount of damages both to crops and overall (Table 4-3). In addition, floods generated the greatest amount in property damages. While the county has experienced a relatively high number of damaging winter weather events, estimated losses have been more moderate, peaking at $2.3 million over a 10-year period from 1970 to 1979.

Clay County falls in a low-risk wildfire zone, with the greatest threats from wildfire existing in the southern and southwestern parts of the state (AHSPA 2010). Accordingly, the county has not experienced damaging wildfires since 1960.

Clay County has been directly affected by climate-related extreme events in recent decades. The 2010 Arkansas All-Hazard Mitigation Plan identifies Clay County as having medium to high risk to severe storms, flooding, and drought, with heat waves only discussed in relation to droughts. Notable drought coupled with simultaneous heat waves are a recurring hazard, having affected much of Arkansas in 1953, 1954, 1980, 2000, 2005, and 2006 (AHSPA 2010). The drought and heat of 1980 was particularly devastating, with an estimated $18.5 million in crop-related losses. Arkansas has suffered from devastating floods in recent years, particularly in 2008 and 2011, and the spring floods along the White and Mississippi Rivers in 2011 were followed by drought conditions that affected nearly the entire state (Chou et al. 2012). In addition, extreme heat has the potential to directly impact the county. For example, extreme heat in the summer of 1995 was blamed for warping train tracks and causing the derailment of 21 cars in Corning (AHSPA 2010).

4.3.1.3 Policy and planning actions

The importance of agriculture to the state's economy has led unsurprisingly to a focus on water resources and forest management. There has been approximately $55 million in crop-related losses due to extreme events since 1960 just in Clay County. Tables 4-4 and 4-5 summarize state and local actions that address climate-related risks and issues, respectively. Many of these actions, including sector-based plans, focus on water concerns at both the state and local levels. The state's first Water Plan was developed in 1975. Following this initial plan, Clay County and the surrounding area experienced substantial losses in the 1980s as a result of drought and heat, more than in any other decade since 1960 in Clay County.

As a result of severe drought, the Arkansas General Assembly enacted Section 2 of Act 1051 in 1985, which expanded the role of the Arkansas Soil and Water Conservation Commission (ASWCC 1988). In particular, it required the ASWCC to determine instream flow requirements for a variety of water uses in the state; surface water needs of public water supplies, industry and agriculture; minimum stream flows; safe yields of streams and rivers; and identify critical water areas (ASWCC 1988). The Act also included provisions to help the state address current and future water needs for the next thirty years by requiring periodic updates to the state water plan that would thereafter incorporate twelve new basin water plans. These twelve new basin-level water plans were developed and incorporated into the state's 1990 update of its developed in 1988, determined present and future water requirements for different uses comprehensive water plan (ASWCC 1990). The Eastern Arkansas Basin Water Plan for a 16-county study area, which includes Clay County. However, the plan does not specifically consider climate change impacts on water quality or quantity.

The severe drought of 1980 prompted additional studies to ascertain water resources for the future. In response to the 1980 drought, farmers in several eastern county conservation districts requested assistance to alleviate water shortages. This prompted a study, called the Eastern Arkansas Water Conservation Project, which began in 1986 as a multi-year project to investigate irrigation management practices and improve efficiency in the Eastern Arkansas Basin, which included a 26-county

Table 4-4. Summary of state-level actions related to climate mitigation, adaptation, or hazards in Arkansas.

Year	Entity	Action	Description	Climate Focus
1969	Arkansas Legislature	Act 217: Arkansas State Water Planning	Established and authorized the Arkansas Soil and Water Conservation Commission to be the designated agency responsible for water resources planning at the state level, mandating a comprehensive state water plan.	Flooding, runoff and drought
1985	Arkansas Legislature	Act 1051: Updates to Arkansas State Water Plans	Prompted by recent drought, this Act mandated that updates be made to the state water plans, including development of twelve new basin reports.	Flooding, runoff and drought
1993	Arkansas Legislature	Arkansas Pollution Prevention Act	Prompted by the federal Pollution Control Act of 1990, this Act mandated development and implementation of a comprehensive pollution prevention and waste minimization plan for the state.	Reduction of pollutants through conservation and energy efficiency
1995	Arkansas Legislature	Private Wetland Riparian Zone Creation and Restoration Act	An incentive-based program designed to encourage private landowners to restore and enhance existing wetlands and riparian zones and, when possible, create new wetlands and riparian zones.	Mitigate flooding impacts and enhance natural environment
2007	Arkansas Legislature	Act 696 (HB 2460)	Established the Governor's Commission on Global Warming to study the impacts of climate change on the state's environment and economy; study the carbon market; and recommend pollutant reduction goals and strategies for achieving it.	Sets pollutant reduction goals to combat global warming
2007	Arkansas Soil and Water Conservation Commission	Arkansas Wetland Mitigation Bank Program	A state-sponsored initiative to provide off-site mitigation opportunities to recipients that are required to provide compensatory mitigation for impacts of approved wetland projects.	Helps to manage and conserve wetlands, which contributes to flood mitigation and filtering of excess nutrients and pollutants
2008	Commission on Global Warming	Governor's Commission on Global Warming Report	As directed by HB 2460, the Commission recommended a 20% emissions reduction level below 2000 levels by 2020, and 50% by 2035. To achieve these goals, it recommends adoption of a comprehensive set of 54 policies to address climate, energy, and commerce related issues.	Emphasizes strategies to mitigate impacts of global warming; some goals relate to adaptation measures.
2010	Arkansas Homeland Security and Preparedness Agency	All-Hazard Mitigation Plan, State of Arkansas	This 3-year plan update was approved by FEMA under requirements of the Disaster Mitigation Act of 2000 and through ongoing planning support from the Governor's Executive Order 10-13. The first hazard mitigation plan was developed in 2004.	Encourages state drought planning, floodplain management, and historical wildfire data

(Table 4-4. continued)

Year	Entity	Action	Description	Climate Focus
2010	Arkansas Forestry Commission	Arkansas Statewide Forest Resources Assessment & Strategy	Prepared in order to receive federal forestry assistance funds. This assessment identifies climate change as one of six main issues. It discusses the effects on forest health, species compositions, as well as forests' ability to help mitigate and adapt to global climate change. Objectives for adapting and/or mitigating effects include improving air quality through urban tree planting, managing open spaces, and promoting education and outreach with communities and the public.	Includes climate change effects on forests, specifically wildfires, insect outbreaks, and wildlife distributions; climate mitigation; and conservation
2012	Arkansas Forestry Commission, Arkansas Agriculture Department	Forestry Commission 2011-2012 Annual Report	The Commission was established in 1931 by passage of Act 234 to work with agencies, organizations, and residents to prevent and control wildfires, forest health, and manage forest resources.	Considers impacts of drought, heat, and ice storms on insect infestation, disease, forest health and wildfire
2012	Arkansas Natural Resources Commission	Update to the State Water Plan	This update to the 1990 State Water Plan has begun as a multiyear process, which is expected to include strategies for addressing water excess and shortage from demographic changes and climate change impacts (ANRC).	Drought, flooding, precipitation changes

region that included Clay County. The project was to develop a series of models for use by state and federal agencies to assess impact of future irrigation demands and alternative systems (ASWCC 1988). Another study was conducted in 1982 as a direct result of excessive water shortages in eastern Arkansas, called the Eastern Arkansas Region Comprehensive Study (ASWCC 1988). Authorized by a resolution adopted by the U.S. House of Representatives Committee on Public Works and Transportation, the study investigated water conservation and management practices in eastern Arkansas to develop a water balance for the region based on current and future water uses; formulate solutions to address needs; and develop recommendations for implementing specific projects (ASWCC 1988). According to the Eastern Arkansas Basin Plan (1988), water conservation was not a priority before the 1980 drought. An update to the state's

Table 4-5. Summary of local- and regional-level actions related to climate mitigation, adaptation, or hazards in Corning, AR and the surrounding region.

Year	Entity	Action	Description	Climate Focus
1988	Arkansas Soil and Water Conservation Commission	State Water Plan: Eastern Arkansas Basin	As one of the twelve basin water plans, which includes Clay County, this plan determined present and future requirements of water uses in the region.	Impacts of extreme precipitation and drought on agriculture, water quality, and water quantity issues
2009	East Arkansas Planning and Development District	Comprehensive Economic Development Strategy	Serving a 12-county region in eastern Arkansas, the strategy emphasizes the importance of agricultural production in the area, despite a water supply crisis. It outlines goals to grow the district's economy and improving quality of life, while protecting prime agricultural lands.	Considers risks from natural hazards and hazard mitigation, but not climate change impacts
2011	East Arkansas Planning and Development District	ReNEW East Arkansas: Regional Plan for Sustainable Development	Includes a 12-county area in eastern Arkansas, funded by a $2.6 million Regional Sustainability Planning Grant from HUD. It aims to address the interrelated challenges of community revitalization, job access, education, energy and other resource conservation, and environmental impact.	Sustainability and local food, environmental restoration, and emergency management; it does not include strategies for climate adaptation or mitigation

1990 Water Plan is currently underway. The draft vision report for this update re-iterates efficiency of water use, water conservation, and improved water resource management; however, it will identify important data gaps and needs, which can help the state respond to climate change impacts. It is also expected to include impacts of population and climate change for the first time (ANRC 2012, Chou et al. 2012).

Impacts of extreme events are further addressed within sector-based plans. For instance, the Arkansas Forestry Commission prepared the Statewide Forest Resources Assessment and Strategy in 2010 to fulfill requirements for federal forestry assistance funds. This strategy identifies climate change as one of six main threats, as well as options for mitigating and adapting to climate change. The Forestry Commission's 2012 annual report further outlined climate-related threats to forest health, including the effects of drought, heat, and ice storms on insect infestations, disease, wildfire, and overall health. The economic development sector has also taken a role in promoting overall resilience to risk. One example is a newly established regional plan called ReNEW East Arkansas, which promotes sustainable development for a 12-county region in eastern Arkansas funded through a Regional Sustainability Planning grant from the U.S. Department of Housing and Urban Development (HUD). While it does not include strategies for climate change directly, it includes measures that will support climate mitigation and resilience to risk, such as environmental restoration, energy conservation, and support of local agriculture.

The state has taken more direct steps to tackle climate change in recent years. In 2007, Arkansas Governor Mike Beebe signed Act 696 (HB 2460) to place Arkansas as a leader in global climate and to take advantage of clean, renewable energies. The Act established the Governor's Commission on Global Warming (GCGW) and charged the Commission to study the impacts of climate change on the state's environment and economy. The Act aimed to determine whether global warming is an immediate threat to the people of Arkansas and to assess the potential future impacts on people, natural resources, and the economy (AGCGW 2008). To fulfill the requirements of the Act, the Arkansas GCGW developed a set of 54 policy recommendations to reduce greenhouse gas emissions. Of these 54 policies, the GCGW approved 28 policy actions unanimously, 23 by super majority, and three by a majority. The policies outlined in the report emphasize climate change mitigation by reducing greenhouse gases and opportunities to engage in the carbon market. However, the GCGW report does not include adaptation strategies to address climate variability or impacts of climate extremes on certain sectors. As of 2012, the state had not formally adopted the policy recommendations included in the report, nor other greenhouse gas pollution goals (Chou et al. 2012). Lastly, the report does not identify needs or impediments related to climate. In fact, very few actions in the state address needs related to climate change. Based on historic extreme data for the county and trends in extremes in Corning, state and local entities should plan more aggressively for the potential impacts from severe storms and flooding, in addition to future drought.

Figure 4-7 shows the most commonly occurring words in all state and local documents included in Tables 4-4 and 4-5 for further illustration. While not reflective of all actions and their focus, it provides an overview of the content of these documents. Among the most commonly occurring words are ‘water,’ ‘energy, and ‘data,’ and ‘ghg.’ For local documents only, results further included ‘streams,’ ‘streamflow,’ ‘aquifer,’ and ‘irrigation,’ reinforcing the importance of water-related concerns by local governments.

Figure 4-7. The top 50 most commonly occurring words found within all state and local actions in Arkansas that were included in this study.

4.3.2 Forrest County, Mississippi

Hattiesburg, Mississippi was included to represent a location near the Gulf Coast. Hattiesburg sits at the confluence of the Leaf and Bouie Rivers. While it straddles Forrest and Lamar Counties, the majority of the city lies in Forrest County, where it is the county seat. Forrest County is located in the far southern part of the state near the coast (Figure 4-8). The county's southern location makes it vulnerable to hurricanes and related high winds, heavy rain, and flooding (MEMA 2010). Since 1965, nine hurricanes and tropical storms have affected Forrest County (MEMA 2010). The county was one of 26 in the state affected by Hurricane Katrina in 2005, which caused widespread flash flooding (MEMA 2010). As a result, the county has since reduced the number of repetitive and severe repetitive loss properties and related losses (MEMA 2010).

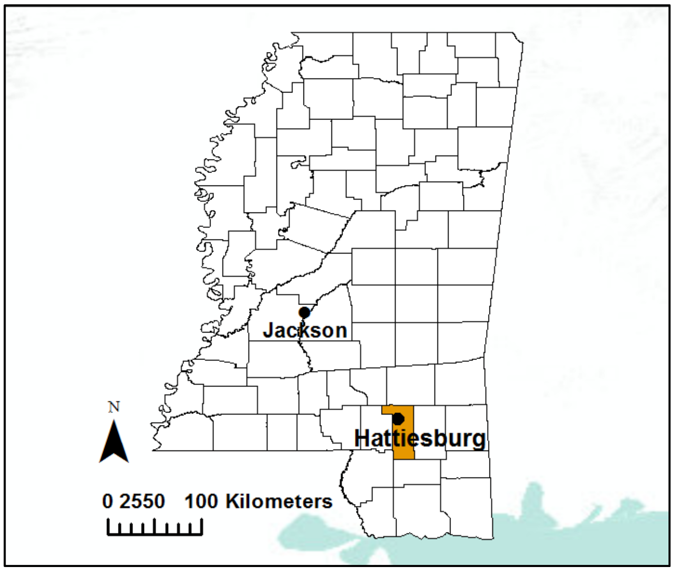

Figure 4-8. Map showing the location of Forrest County (shaded), Hattiesburg, and major cities nearby in Mississippi.

Forrest County has a population of nearly 77,000, and it saw a small rise in population of 2.6 percent from 2010 to 2012. Hattiesburg is one of the fastest growing areas in southern Mississippi (HCC 2008). Roughly 59 percent of residents own their homes, and the median household income is $36,000 (Table 4-3). The median value of owner-occupied households in the county is higher than that for the state as a whole.

4.3.2.1 Temperature and precipitation extremes

Temperature-related extremes exhibit similar trends in Hattiesburg as observed for Corning and the broader Southeast region. Warm-related indices suggest that extremely high maximum temperatures are becoming less frequent, while extremely warm minimum temperatures are occurring more often (Figure 4-9). Warm spells are becoming significantly shorter in Hattiesburg. Like Corning, Hattiesburg has also experienced fewer frost days (Figure 4-10a) and shorter cold spells (Figure 4-10b), and the percentage of cool days has been increasing significantly since 1948 (Figure 4-10c).

Extreme precipitation indices show that Hattiesburg is getting significantly wetter overall. In particular, the city is experiencing more intense extreme precipitation events (Figure 4-11 a and b) and more frequent extremely heavy wet days (Figure 4-11c). While not shown, the number of consecutive dry days has been increasing for Hattiesburg since 1948, while consecutive wet days have been declining. These trends were insignificant, yet they suggest that the duration of intense precipitation events may be getting shorter. If trends continue, the impacts of heavy rainfall and flood events will likely increase in Hattiesburg. These results are particularly important given that severe storms and flooding historically represent the greatest threats to the county in terms of losses (Table 4-3).

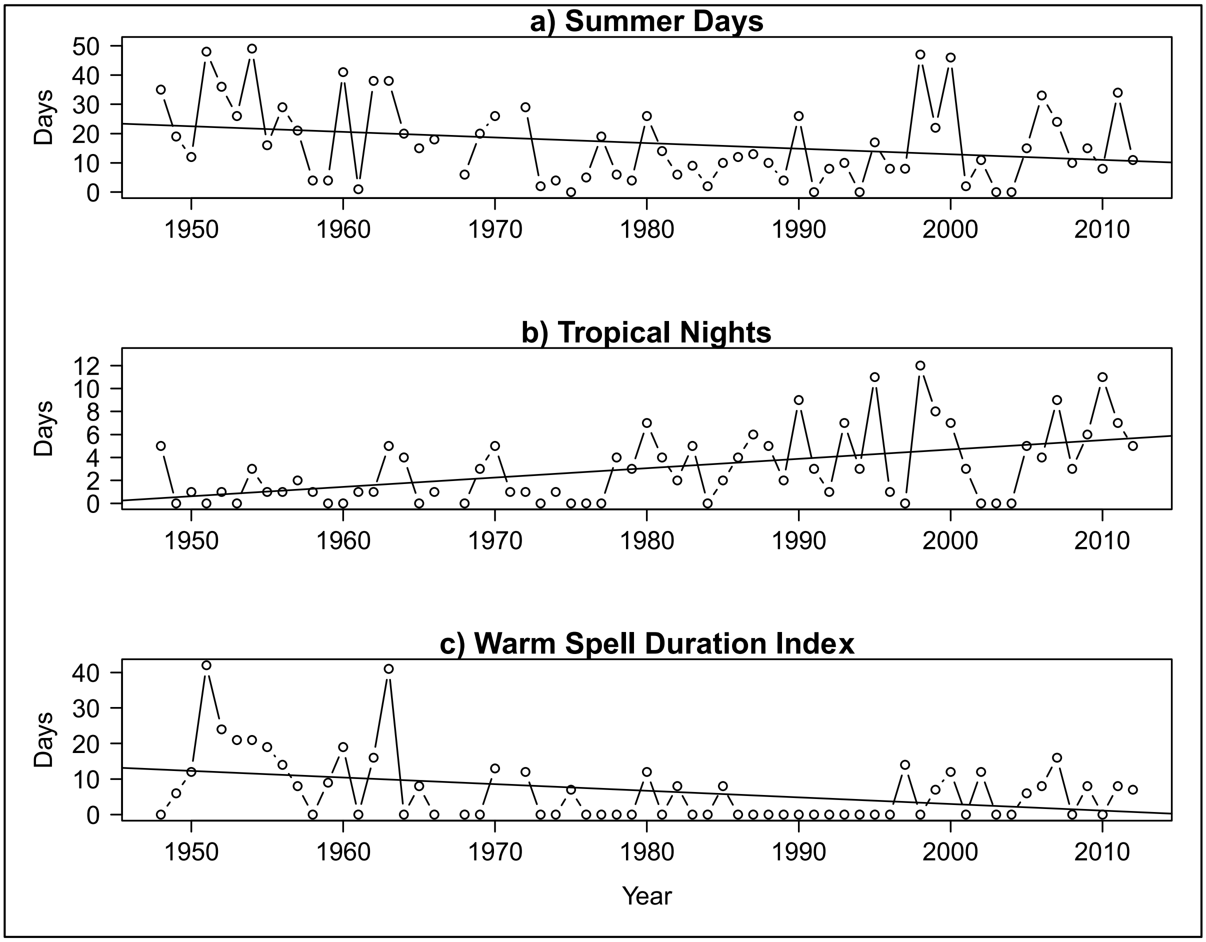

Figure 4-9. Time series of warm-related temperature extreme indices for Hattiesburg, Mississippi, including a) summer days (number of days when Tmax exceeded 35°C), b) tropical nights (number of days when the Tmin exceeded 25°C), and c) warm spells (annual count of days with at least six consecutive days when Tmax is above the calendar day 90th percentile). Trends are significant at the $p \leq 0.05$ level.

4.3.2.2 Property and crop losses

Forrest County experienced nearly twice as many damaging climate-related disasters from 1960 to 2012 compared to Clay County, with a total of 241 events. In addition, total property damages in Forrest County were considerably more than those experienced in Clay County, roughly $28 million more; however, Clay County had approximately $33 million more in crop-related damages. According to FEMA (2013), tornadoes, floods, severe storms, and hurricanes have made up the majority of

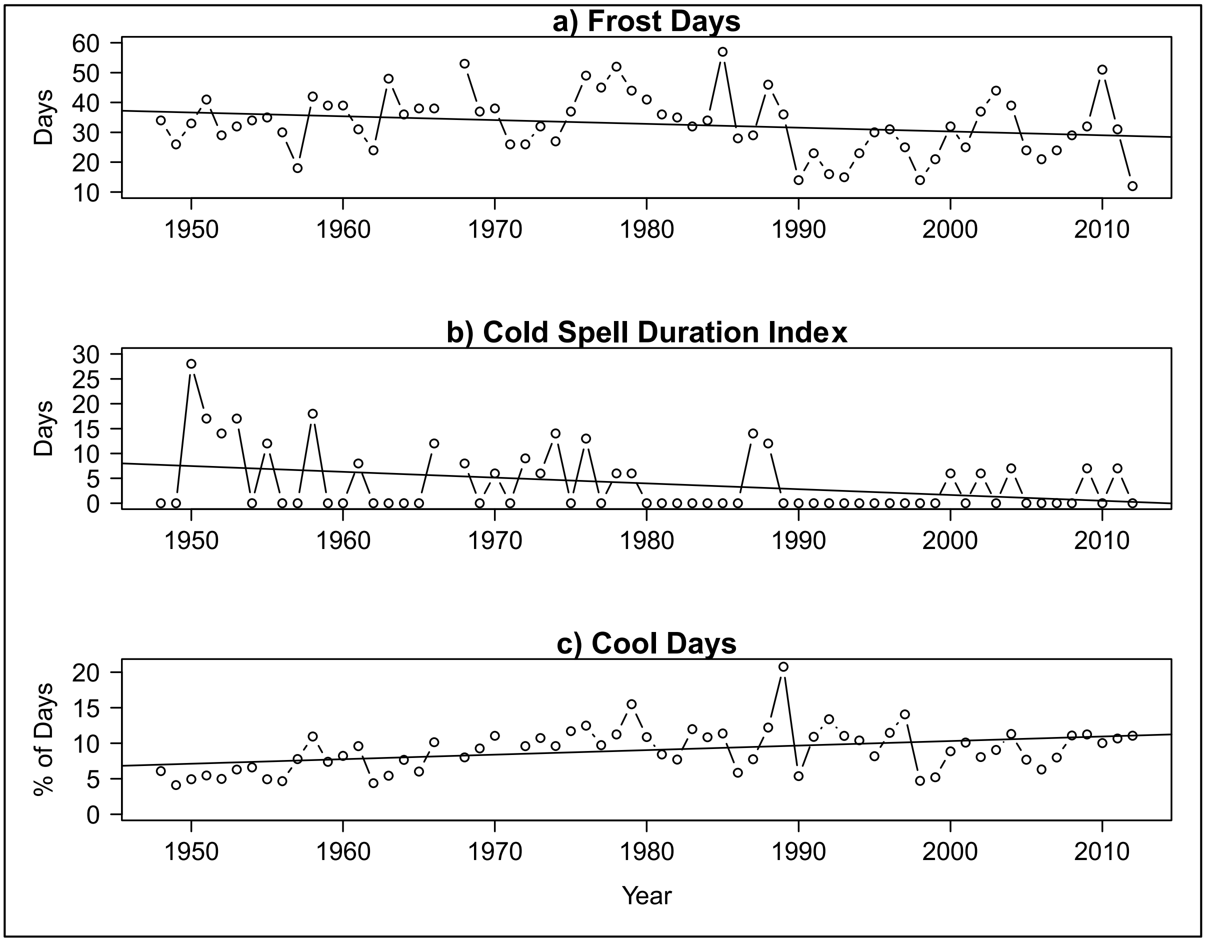

Figure 4-10. Time series of cold-related temperature extreme indices for Hattiesburg, Mississippi, including a) frost days (annual count when Tmin is below 0°C), b) cold spells (annual count with at least six consecutive days when Tmin is below the calendar day 10th percentile), and c) cool days (percent of days when Tmax is below the calendar day 10th percentile). Trends significant at the $p \leq 0.10$ level.

emergency and major disaster declarations since 1957 in Mississippi. Forrest County has seen a relatively high number of damage-producing severe storms since 1960. Flooding and winter weather have also been important in terms of losses, with floods generating the greatest losses to both property and crop (Table 4-3). While there were 156 severe storms that caused damages to property and/or crops, these events have not had as great of an impact as flooding events. Since 1960, losses from severe storms totaled approximately $28 million in property damages and $3 million in crop

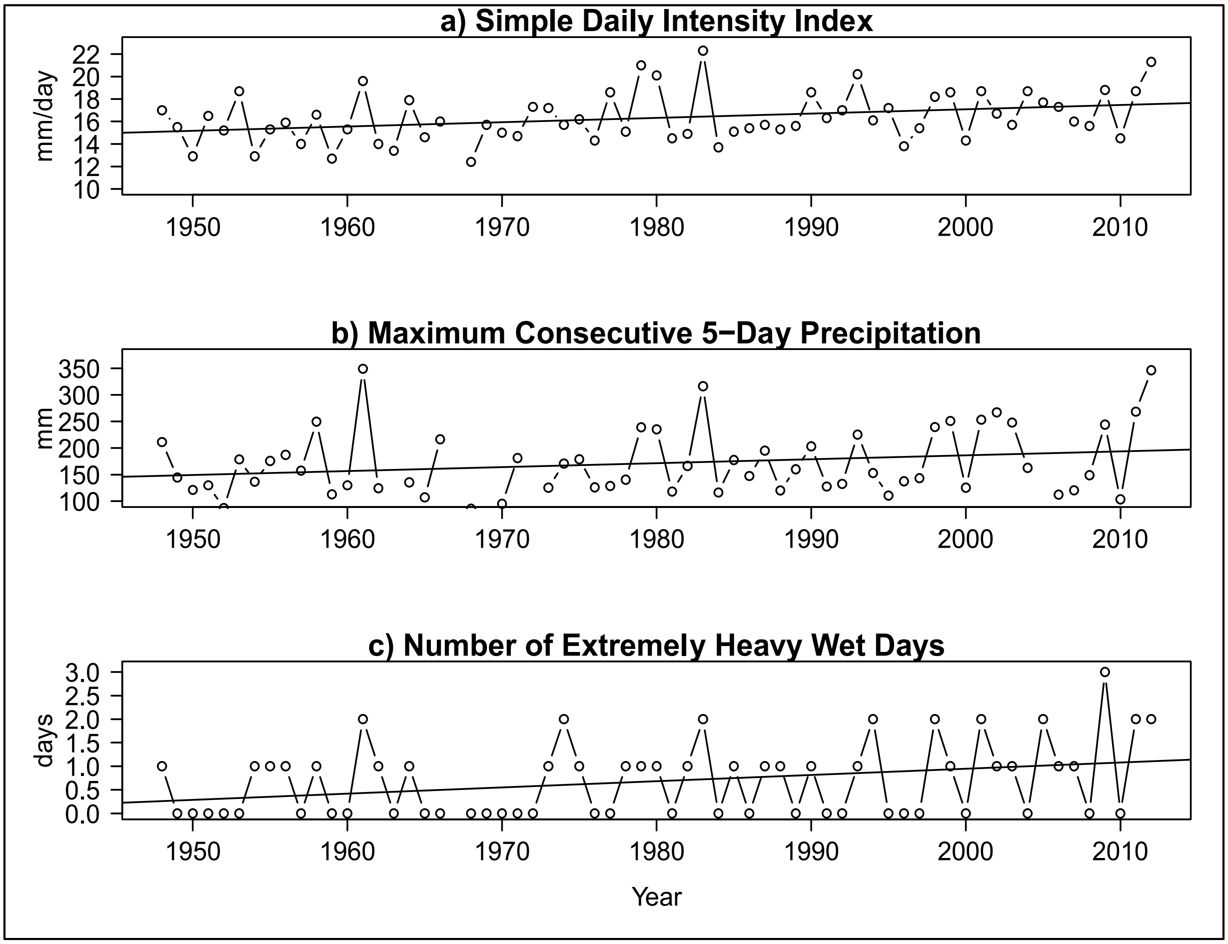

Figure 4-11. Time series of extreme precipitation indices for Hattiesburg, Mississippi, including a) simple daily intensity index (annual total precipitation divided by the number of wet days ≥ 1 mm), b) maximum 5-day precipitation (annual maximum consecutive 5-day precipitation), c) extremely heavy wet days (number of days ≥ 102 mm), and d) extremely wet days (annual total precipitation when precipitation was greater than the calendar day 99th percentile). Trends significant at the $p \leq 0.10$ level.

damages, while flooding caused $32 million in property damages and $16 million in crop damages.

4.3.2.3 Policy and planning actions

Mississippi state-level actions are summarized in Table 4-6. Hazard mitigation and emergencies appear to be an area of focus in the state overall. As a Gulf Coast state affected by frequent storms and flooding, many actions in Mississippi are addressing coastal risks through the protections of wetlands to mitigate the impacts of coastal flooding and storms (Table 4-6). For instance, the Mississippi Department of Marine Resources (MDMR) established the National Estuarine Research Reserve in 1999 to promote wetlands research and education. MDMR's 2012 annual report emphasized the importance of coastal management issues related to climate change, which was not a part of their 2010 annual report (MDMR 2012). However, Mississippi has not engaged in any planning efforts to address potential impacts of climate change. It has not conducted a greenhouse gases inventory report or set a plan for reducing pollution; however, several actions may help the state mitigate the effects of climate change. For instance, Governor Bryant released an *Energy Roadmap Report* for the state in 2012, which recognized the need to improve energy efficiency and conservation. However, the report does not discuss climate mitigation options or pollution reduction goals. Thus, this represents an opportunity whereby climate mitigation and/or pollution reduction goals could be readily incorporated into existing efforts. In 2013, the Mississippi Legislature passed a set of bills that address energy conservation and renewable energy technologies that may promote increased climate mitigation measures in the state.

The Mississippi Forestry Commission completed a Forest Assessment and Resource Strategy in 2010 to become eligible for federal forestry assistance funds. The Strategy recognizes climate change as one of eight key issues related to forest health (MFC 2010). Despite the fact that Forrest County has not experienced damages from wildfires in recent decades, Hurricane Katrina prompted the Southern Mississippi Planning and Development District to develop Wildfire Protection Plans for the 15

Table 4-6. Summary of state-level actions related to climate mitigation, adaptation, or hazards in Mississippi.

Year	Entity	Action	Description	Climate Focus
2010	Mississippi Emergency Management Agency	State of Mississippi Standard Mitigation Plan	Prepared by the Governor's Office and the Hazard Mitigation Council as an update to the 2007 state hazard mitigation plan.	Flooding, extreme winter weather, wildfires, and hurricanes
2010	Mississippi Forest Commission	Forest Assessment and Resource Strategy	Prepared as required by the 2008 Farm Bill, the strategy identifies climate change as one of eight key issues. It discusses both beneficial and adverse impacts of climate change on forest health, and opportunities for forests to provide ecosystem services by mitigating warming temperatures and atmospheric carbon dioxide.	Impacts on forest health, climate mitigation, ecosystem services
2012	State of Mississippi	Energy Works: Mississippi's Energy Roadmap	Released by Governor Bryant, this report aims to capitalize on the state's energy strengths and increase energy jobs. It recognizes the need to expand energy conservation and efficiency in some policy changes, but does not mention greenhouse gases or climate mitigation.	Energy conservation and efficiency
2013	Mississippi Legislature	HB 1296, 1266, 1281, 1685	As part of Gov. Bryant's economic development plan, this set of bills promotes energy efficiency within state agencies and the private sector and renewable technologies in the state. They strengthen energy efficiency standards for newly constructed state-owned buildings and commercial buildings and establish a $2.75 million revolving loan fund administered by the Mississippi Development Authority for municipalities and school districts.	Climate change mitigation through energy efficiency and renewable technologies

counties in southern Mississippi. While not all counties have developed their plan as of this study, including Forrest County, the goal of these plans is to address wildlife-urban interface changes caused by Hurricane Katrina, as well as changes from increased development.

Local-level actions show promising strides toward addressing hazards and climate-related risks (Table 4-7). Hattiesburg represents a city whereby a specific event has led to greater planning and hazard mitigation efforts. For instance, the City of Hattiesburg updated its Comprehensive Plan for the period 2008-2028 to reflect changes resulting from Hurricane Katrina (HCC 2008). While the plan does not explicitly address climate change, it includes strategies for increasing the city's overall resilience to hazards and climate change impacts, such as tree planting, 'green design' standards, environmental protection, and alternative energy (HCC 2008). In addition, regional entities have recently made efforts to synthesize their planning efforts to encourage risk reduction. For instance, the Southern Mississippi Planning and Development District's (SMPDD) 2012 Comprehensive Economic Development Strategy emphasizes the importance of considering hazards and hazard mitigation measures in the context of economic development. The SMPDD is considering how hazard mitigation can be incorporated into comprehensive plans through a study funded by the Mississippi-Alabama Sea Grant Consortium and NOAA's Gulf of Mexico Coastal Storms Program (SMPDD 2013).

Figure 4-12 summarizes the words that occur most frequently in state and local actions included in Tables 4-6 and 4-7 to further illustrate the concepts that are emphasized in these actions. 'Mitigation,' 'hazards,' and 'emergency' occurred frequently, while climate-related terms are nearly absent. This frequency query further suggests that hazard mitigation continues to be emphasized, while the threats from climate change are not yet an area of focus for state and local governments in Mississippi. In addition, many process words, including 'development,' 'management,' 'planning,' and 'facilities,' appear frequently. It is possible that actions are more bureaucratic in nature, which can complicate policy and planning efforts.

Table 4-7. Summary of local- and regional-level actions related to climate mitigation, adaptation, or hazards in Hattiesburg, MS and the surrounding region.

Year	Entity	Action	Description	Climate Focus
1999	Department of Marine Resources	National Estuarine Research Reserve	The annual 2012 report describes National Estuarine Research Reserve programs as prioritizing coastal management issues related to wetlands conservation, habitat protection, climate change, and water quality.	Wetland protection and climate change impacts in general
2006	Southern Mississippi Planning and Development District	Wildfire Protection Plan	The Mississippi Forestry Commission and The Nature Conservancy commissioned the preparation of wildfire protection plans for the 15-county region to address changes to the wildlife-urban interface as a result of Hurricane Katrina and increased development.	Changes to wildfire risks due to extreme storms and development
2008	City of Hattiesburg	Comprehensive Plan 2008-2028	This Plan updates the 1988 comprehensive plan to reflect changes in the city and region as a result of Hurricane Katrina, population changes, technology changes, and others. It defines long-range goals and policies for future growth and development. Strategies include tree planting, recycling, energy usage, environmental protection, and natural resource management. It calls for 'green design' standards in the Land Development Code and the expanded use of solar energy and fuel efficiency.	Energy conservation and efficiency, environmental conservation, green infrastructure
2012	Southern Mississippi Planning and Development District	Comprehensive Economic Development Strategy, 2013-2017	A required update to the 2007-2012 strategy, prepared with support from the U.S. Dept. of Commerce, Economic Development Administration, it emphasizes the importance of hazard mitigation planning to economic resilience and suggests that hazard impacts and coastal resilience must be incorporated into comprehensive planning and other planning efforts.	Integration of hazard mitigation with comprehensive planning; coastal resilience
2013	Southern Mississippi Planning and Development District	Integrating Hazard Mitigation into Local Planning to Support Community Resiliency	With funding from the MS-AL Sea Grant Consortium and NOAA's Gulf of Mexico Coastal Storms Program, this addresses how hazard mitigation and comprehensive plans can be integrated to improve planning for, response to, and recovery from costal hazards and climate risks.	Costal hazards and climate risks

Figure 4-12. The 50 most commonly occurring words found within all state- and local-level actions in Mississippi included in this study.

4.3.3 Washington County, Texas

Brenham, Texas is a small town located in Washington County in the southeastern part of the state (Figure 4-13). It lies approximately 113 kilometers (70 miles) northwest of Houston and 145 kilometers (90 miles) east of Austin, in the middle of the tri-city area formed by Houston, San Antonio, and Dallas/Ft. Worth. Brenham has not seen as much growth as other cities near the tri-city area, and Washington County saw only a slight rise in population of 1.1 percent from 2010 to 2012. However, the city is beginning to feel the effects of growth around the Houston metro area, and future growth is expected due to its location within this tri-city area (COB 2008). Because of this slow, steady growth, Brenham has retained a rural, small town character. The county has actually seen higher growth since 1990 than Brenham, which is thought to be a result of retirees from other cities buying large properties or ranches in more rural parts of the county (COB 2008).

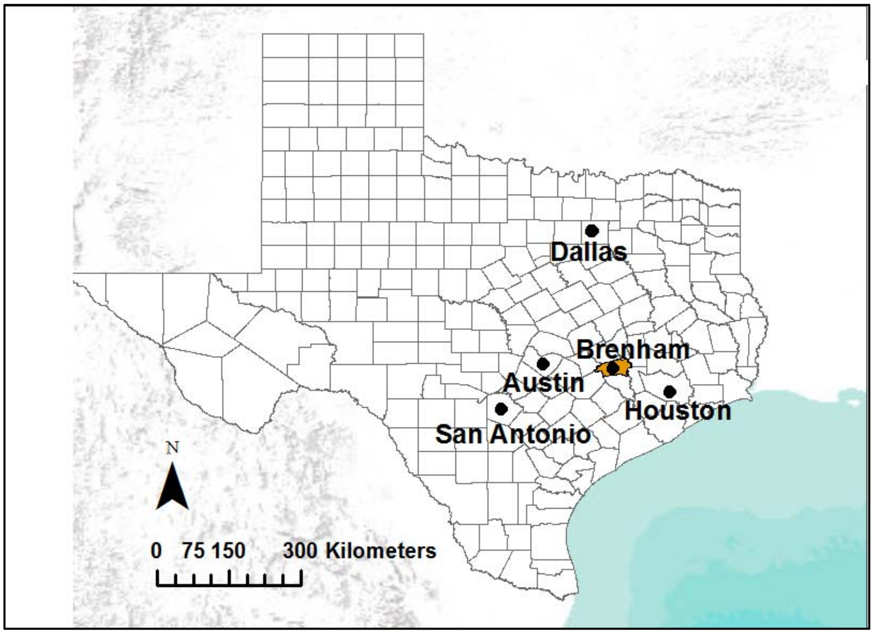

Figure 4-13. Map of Washington County (shaded), Brenham, and surrounding major cities in Texas.

4.3.3.1 Trends in climate extremes

Trends in temperature extremes for Brenham are consistent with those observed for much of the Southeast. Namely, Brenham has experienced increasing warm extremes in minimum temperatures but cooling in maximum temperatures. Figures 4-14 and 4-15 show times series of temperature extreme indices. Exceedences of extremely high maximum temperatures above 35°C have been decreasing since 1948 (Figure 4-14a), while the annual absolute warmest minimum temperature has significantly increased (Figure 4-14b). Minimum temperature exceedences above 20°C are significantly increasing (not shown), reinforcing a trend toward increasingly warm nights. The net result of these opposing trends in maximum and minimum temperatures is an increasingly smaller range in diurnal temperatures (Figure 4-14c). However, despite fewer days above 35°C, trends in the annual absolute lowest maximum temperature are significantly rising (Figure 4-15a). Thus, Brenham may be experiencing decreasing variability in daytime temperatures in particular, with fewer occurrences of both extremely hot and extremely cold days.

Overall, Brenham is susceptible to more intense and frequent precipitation extremes. Exceedences of days over 20 mm have significantly risen (Figure 4-16a), and the intensity of maximum 5-day precipitation events has increased (Figure 4-16b). The simple daily intensity index suggests that precipitation events are becoming more efficient as well (Figure 4-16c). Despite increases in extreme wetness, Brenham is also susceptible to extreme dry spells. While no clear trend was observed in consecutive dry days (defined here as at least six days with precipitation ≤ 1 mm), this index shows that extended dry periods have coincided with statewide drought episodes. For instance, the longest dry spell in Brenham since 1948 occurred in 2011 with 58 consecutive dry days, coinciding with a drought that had affected 99 percent of the state by September 2011 (TWDB 2012). The second longest dry spell occurred in 1953 with 49 consecutive dry days. This coincided with a seven-year drought that ended in 1957 and resulted in 253 of the 254 counties in Texas being declared disaster areas (TWDB 2012).

4.3.3.2 Property and crop losses

The Texas State Hazard Mitigation Plan identifies four hazards as posing the most serious threats to the state: riverine flooding, hurricanes and tropical storms, tornadoes, and drought (TDEM 2010). Since 1960, severe storms and floods have been the most recurring types of climatological disasters resulting in losses in Washington

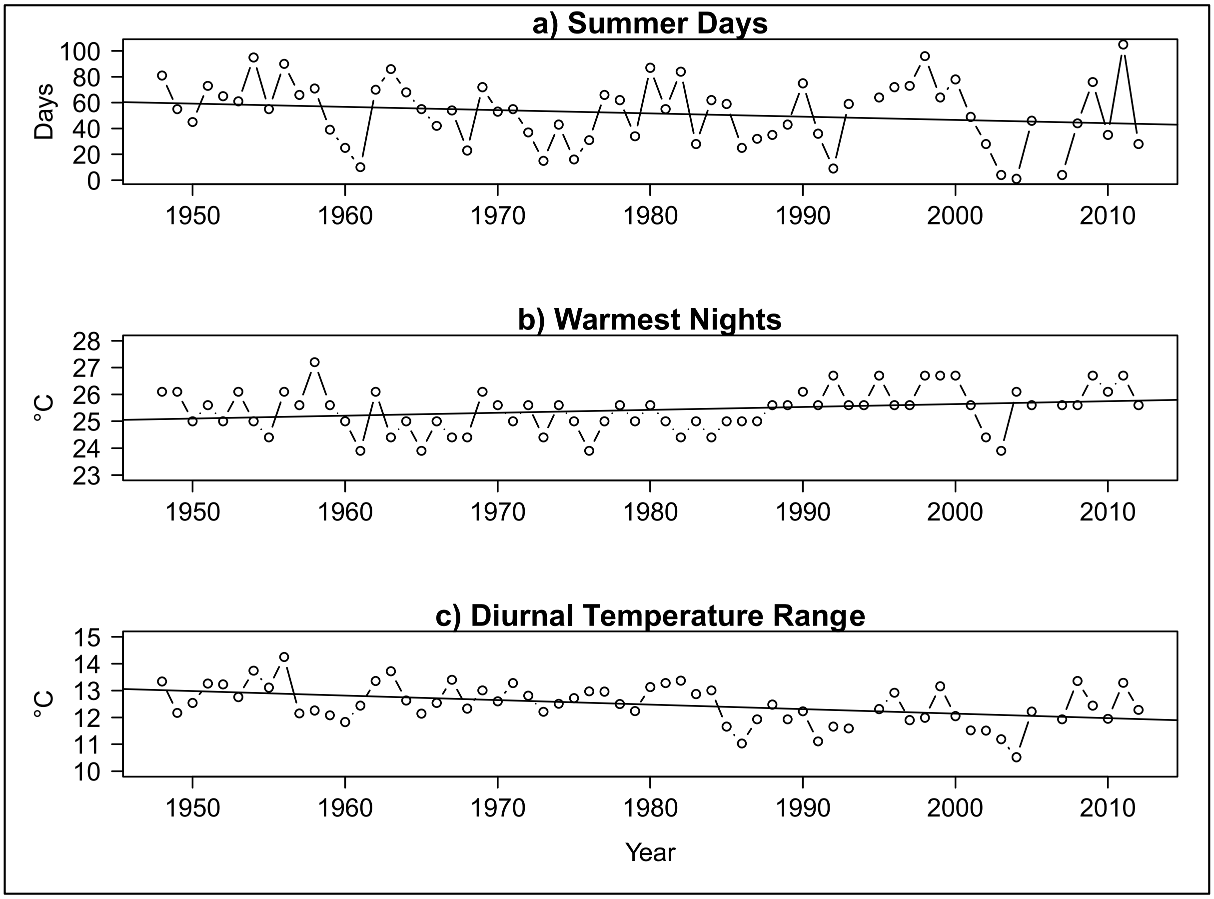

Figure 4-14. Time series of warm-related temperature extreme indices for Brenham, Texas, including a) summer days (number of days when Tmax exceeded 35°C), b) warmest nights (annual absolute highest minimum temperature), and c) diurnal temperature range (average Tmax - Tmin). Trends significant at the $p \leq 0.05$ level, except (a).

County, followed by winter weather events (Table 4-3). There have been far fewer damaging drought and heat events and no damaging wildfires in the county since 1960, though the state HMP identifies wildfires as being of medium to high risk for the county. Damages from severe storms are minimal compared to damages from floods, winter weather, drought, and heat. The 1990s saw the highest amount of damages than any other decade since 1960. The county experienced losses to property and/or crops from severe storms, drought, winter weather, and floods. Losses in this decade totaled $5

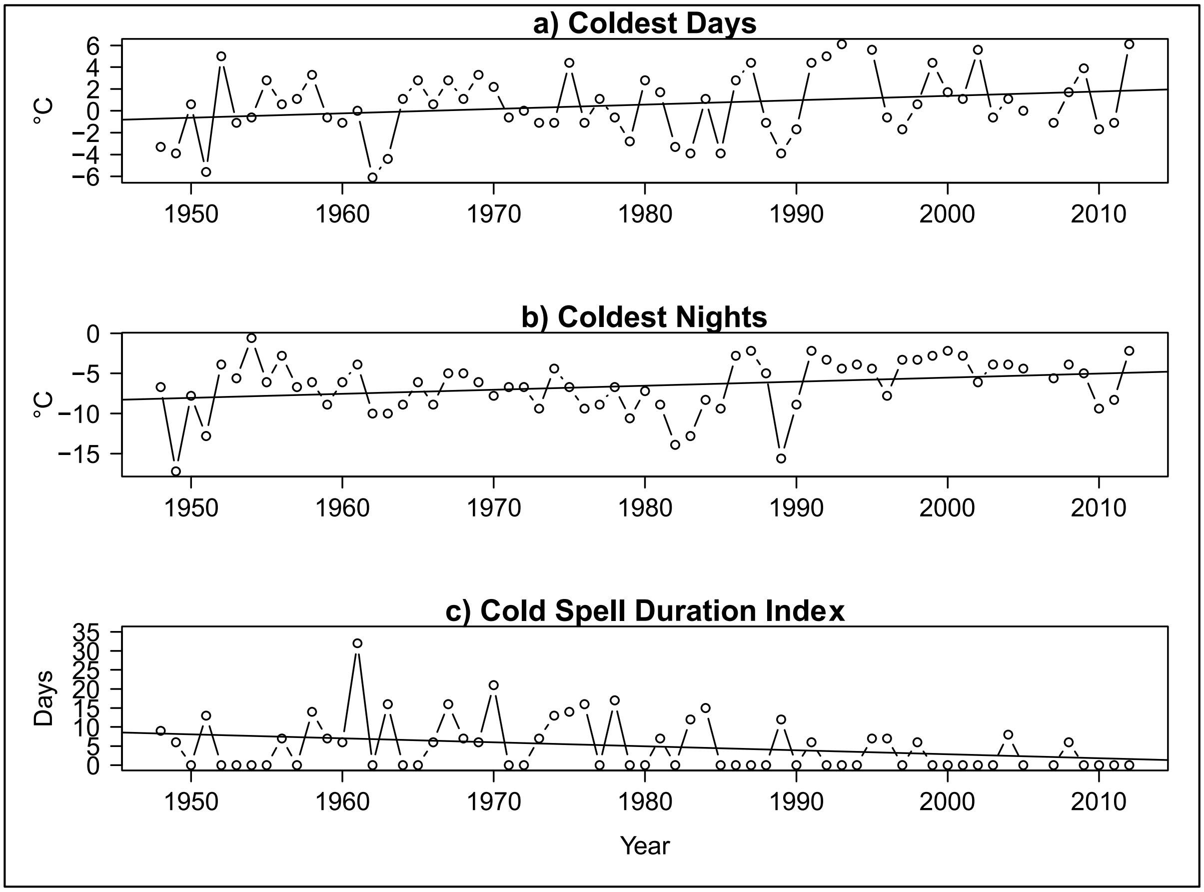

Figure 4-15. Time series of cold-related temperature extreme indices for Brenham, Texas, including a) coldest days (annual absolute lowest maximum temperature), b) coldest nights (annual absolute lowest minimum temperature), and c) cold spell duration index (count of days with at least six consecutive days when Tmin < 10th percentile). Trends significant at the $p \le 0.05$ level.

million to property and nearly $20 million to crops. While there have been fewer damaging drought events, they have had the greatest impact in Washington County, particularly to crops. Drought was responsible for $19.8 million in damages to crops in the 1990s and another $5.9 million between 2000 and 2012, with a total of over $26 million since 1960.

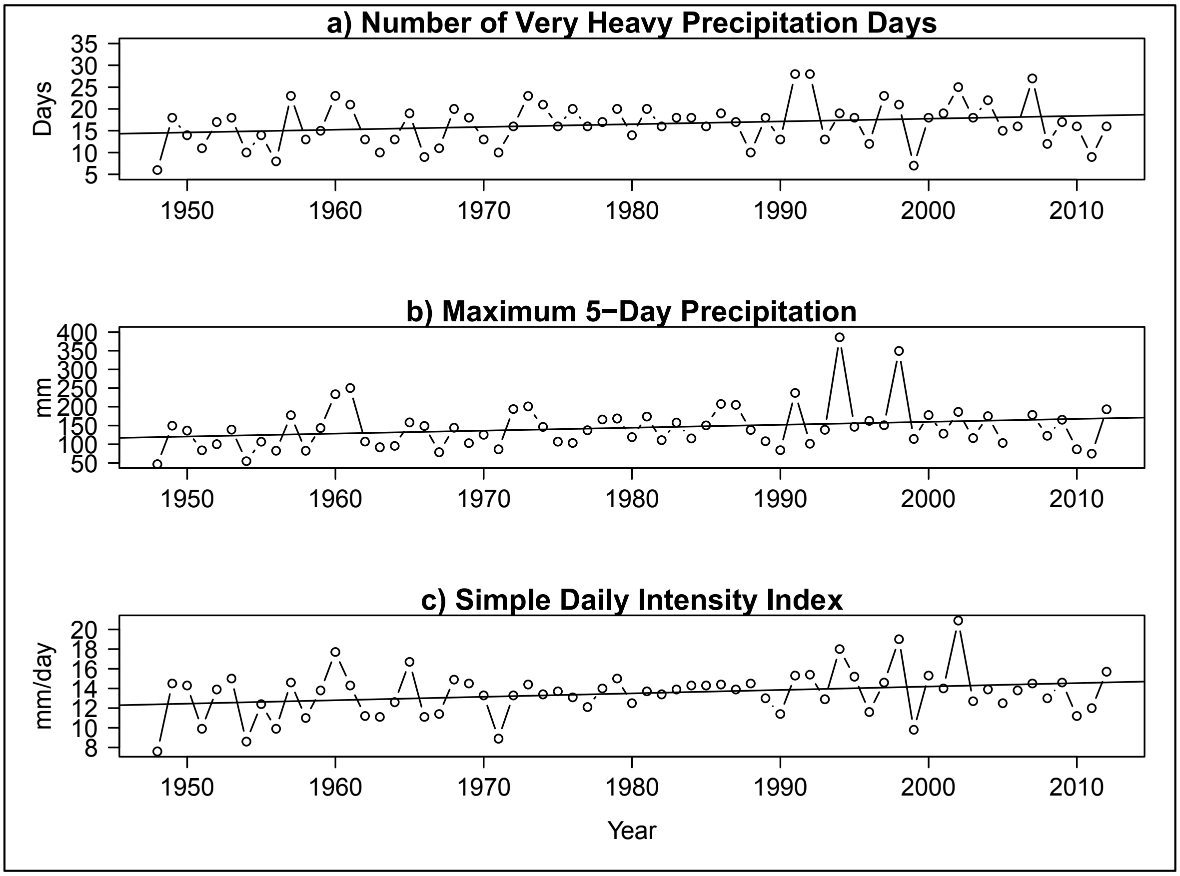

Figure 4-16. Time series of extreme precipitation indices for Brenham, Texas, including a) very heavy precipitation days (number of days with precipitation ≥ 20mm), b) maximum 5-day precipitation (annual maximum consecutive 5-day precipitation), and c) simple daily intensity index (annual total precipitation divided by the number of wet days ≥ 1 mm). Trends significant at the $p \leq 0.05$ level.

4.3.3.3 Policy and planning actions

Tables 4-8 and 4-9 provide examples of state- and local-level actions, respectively, to address risks from natural hazards and climate change. While not comprehensive of all efforts the state and region are engaged in, the majority of actions tend to relate to water resources and energy efficiency. Given the impacts of past drought, drought has triggered many policy and planning actions in Texas. The importance of drought in the state is reflected in its long history with water planning, which is only partially represented in Table 4-8. The first state water plan was developed in 1961, yet water management in the state dates back even further to the late 1800s (TWDB 2012). The 1950s drought remains the worst in Texas' recorded history and continues to serve as a benchmark against which all water planning is based (TWDB 2012). In addition to the 1950s drought of record, Texas has experienced devastating droughts in more recent years. As aforementioned, much of Texas experienced some degree of drought in 2011 and 2012. In addition, severe drought occurred in the 1990s, peaking in 1996, which did not end officially until the summer floods of 2007 when most of Texas was declared drought free (TDEM 2010).

Drought impacts in Texas have prompted specific legislative actions that have led to organizational changes to better address water-related needs and issues, as well as planning to mitigate drought impacts. In 1953, the Texas Legislature passed House Bill 487 to establish the Texas Water Resources Committee in direct response to the recurrent drought of the 1950s. The 1996 drought prompted the state to pass Senate Bill 1 to establish regional water plans to be incorporated into the state water plan. The 2012 State Water Plan mentions the uncertainty in future water supplies due to climate change; however, as reflected in this latest plan, the state will continue to rely on the 1950s drought of record for planning purposes until more climate information becomes available (TWDB 2012).

In addition to drought, many of the actions that may help the state mitigate climate change impacts center on energy efficiency and conservation. Texas has passed several bills and established incentive-based programs to encourage more efficient energy use, expand the role of renewable energy supplies, and conserve energy supplies. While these bills do not specifically address climate change, they can

Table 4-8. Summary of state-level actions related to climate mitigation, adaptation, or hazards in Texas.

Year	Entity	Action	Description	Climate Focus
1953	Texas Legislature	HB 487	Established the Texas Water Resources Committee for four years in direct response to recurrent drought to survey the state's water problems and develop a long-range water policy and conservation program.	Drought
1957	Texas Legislature	Water Planning Act	This created the Texas Water Resources Planning Division of the Board of Water Engineers in response to the prolonged drought. The Act led to the development of state and eventually regional water resources planning.	Drought
1988	Texas State Energy Conservation Office	Texas LoanSTAR Saving Taxes and Resources Program	This statewide energy efficiency program provides low-interest loans to finance energy conservation in public facilities. The program had funded projects in 191 facilities as of April 2006, with energy savings averaging 15 percent, an average payback period of 5.6 years, and three percent annual interest rates.	Climate mitigation through energy efficiency and conservation
1997	Texas Legislature	SB 1	As a result of the 1996 drought, this bill established the regional water planning process as a new framework, charging local entities with preparing regional water plans every five years that are to be incorporated in the statewide comprehensive water plan.	Drought
2005	Texas Legislature	SB 20	This bill increased the amount of renewable generation required by the state by 2015 and a cumulative target of installing renewable generation capacity by 2025.	Climate mitigation through renewable energy
2010	Texas Division of Emergency Management	State of Texas Hazard Mitigation Plan	This most recent update was adopted in 2010, describing the goals, strategies, and specific measures to reduce the occurrence or severity of natural hazards. This plan focuses on the "big four" most serious threats: riverine flooding, hurricanes and tropical storms, tornadoes, and drought mitigation.	Hazard mitigation, with emphasis on drought, wildfire, precipitation; climate change and sea level rise over next 100 years
2011	Texas Legislature	SB 898	Amends the Health and Safety Code to require energy efficiency programs in political subdivisions, institutes of higher education, and state agency facilities to reduce electric consumption by at least five percent each year for ten years beginning 2011.	Climate mitigation through energy efficiency and conservation

(Table 4-8. continued)

Year	Entity	Action	Description	Climate Focus
2011	Texas State Energy Conservation Office	Schools and Local Government Program	This program helps public school districts, colleges, universities, and nonprofit hospitals establish and maintain energy efficiency programs. The first round of the program awarded grants through funds from the American Recovery and Reinvestment Act of 2009.	Climate mitigation through energy efficiency and conservation
2012	Texas Forest Service	Texas Statewide Forest Resource Strategy	Completed in response to the Cooperative Forestry Assistance Act enacted by the 2008 Farm Bill, the strategy includes several climate-related goals. These goals are to reduce the impacts of climate change on forests; mitigate climate and conserve energy; consider climate resilient species; investigate changing ecosystem services in response to climate; and promote carbon markets for private landowners.	Climate mitigation, impacts, ecosystem services
2012	Texas Water Development Board	Water for Texas 2012 State Water Plan	Adopted in 2011 and signed in January 2012 as the state's ninth water plan since 1961, this is the third update that has incorporated Regional Water Plans. It emphasizes uncertainty of future water supplies due to demand, supply, and climate change, as well as funding needs for implementation.	Drought, climate change, variability, uncertainty

contribute to climate mitigation, such as by reducing greenhouse gas emissions, increasing carbon sequestration, and reducing the urban heat island effect.

The examples of local-level actions included in Table 4-9 reflect differences between actions in Brenham and Houston in recent years. As a larger, metropolitan city, Houston has taken more climate-progressive steps. For instance, it appears that the city is integrating measures to reduce impacts of climate change into existing city planning efforts. The Houston-Galveston Area Council produced a report to address the effects of climate change on the area’s environment, economy, and public health (HGAC 2008). This report recommends development of heat wave management plans; stricter emission controls to improve air quality; green building standards; incorporation of climate change projections into planning; and development of water conservation plans;

among others (HGAC 2008). While its study area does not include Washington County, the study proposes a set of adaptation strategies that would have a beneficial impact on the surrounding region and, at the very least, can serve as an example of possible adaptation approaches local governments like Brenham can take to safeguard risks from climate. Austin has also taken progressive steps to address climate change. The City Council passed a resolution in 2007 calling for the development of departmental Climate Action Plans and identifying several goals related to climate mitigation. By comparison, recent planning efforts made by the City of Brenham (i.e. the city's 2008 Comprehensive Plan and 2012 Downtown Master Plan) fail to incorporate or mention climate change risks or adaptation strategies. However, the city may benefit from these regional-level efforts. For instance, the Regional Summaries Report of the 2012 State Water Plan looked ahead to future needs and found that the Brazos Regional Water Planning Area, which lies within the Brazos River Basin and includes Washington County, will need additional water supplies by the year 2060 (TWDB 2012).

Figure 4-17 shows the word cloud of the 50 most commonly occurring words within all state- and local-level actions included in Tables 4-8 and 4-9. The importance of water is clearly reflected in these actions, at both the state and local levels. In addition to water, the concept of mitigation is heavily emphasized, similar to that seen for Arkansas and Mississippi. In addition, process-based words are common, such as 'planning,' 'building,' 'development,' 'program,' and 'management.' Specific extremes or threats are represented as well, including 'drought,' 'flood,' 'risk,' and 'hazard.'

Table 4-9. Summary of local- and regional-level actions related to climate mitigation, adaptation, and hazards in Brenham, TX and the surrounding region.

Year	Entity	Action	Description	Climate Focus
2007	Houston-Galveston Area Council	Bridging Our Communities: The 2035 Houston-Galveston Regional Transportation Plan	The plan incorporated beach and wetland protection into transportation and sewer planning, and it identified potential impacts of climate change and variability on the region's transportation system to adapt to future change. It is currently being updated to extend to the year 2040.	Future climate change, climate variability, climate mitigation through wetland protection
2007	Austin City Council	Resolution No. 20070215-023	Established the Climate Program and directed the City to take specific actions through 2020 to reduce greenhouse gas emissions. The program is run by the city’s Office of Sustainability.	Climate change, extremes, climate mitigation
2008	Houston-Galveston Area Council	Houston-Galveston Area Council Foresight Panel on Environmental Effects Report	The Expert Panel was established in 2007 to develop recommendations for local governments to adapt to potential changes in climate and associated environmental effects. This report focuses on adaptation strategies that local governments can employ to reduce the adverse impacts produced by climate change on energy, economy, industry, and food production.	Climate adaptation, future climate projections
2008	City of Houston	City of Houston Commercial Energy Conservation Code	This code includes provisions for mandatory cool roofing on all new commercial buildings.	Climate mitigation through green infrastructure
2008	City of Brenham	City of Brenham Envision 2020 Comprehensive Plan	The Plan focuses on economic development needed to accommodate future growth expected with proximity to major cities. The plan only considers limiting development in floodplains and discusses the general climate. However, it does not discuss issues related to climate, nor does it address climate mitigation or adaptation.	Hazard mitigation only
2012	City of Brenham	Brenham Downtown Master Plan	Prepared by consultants for the City of Brenham, the plan focuses on keeping the downtown area competitive and vibrant. However, it does not mention hazards or climate-related risks.	None

4.3.4 Blaine County, Oklahoma

Okeene, Oklahoma is a rural town in the west central part of the state, roughly 145 kilometers (90 miles) northwest of Oklahoma City (Figure 4-18). Agriculture is an important industry in the state, and the area in and around Blaine County is cropland,

Figure 4-17. The 50 most commonly used words found within all state- and local-level actions in Texas included in this study.

particularly wheat fields (ODEM 2011, NODA 2012). Oklahoma is part of the Great Plains region, with relatively flat terrain and strong continental influences from the west and north, while the southeast part of the state is influenced more by the Gulf of Mexico with higher annual average precipitation (ODEM 2011). As of 2012, Oklahoma is the third most disaster-prone state in the country based on annual numbers of disaster declarations (OSEO 2013), with droughts being the costliest natural hazard in the state (ODEM 2011).

While Oklahoma's population has been increasing steadily since 1950 (ODEM 2011), Blaine County's population declined by 18 percent from 2010 to 2012, with an estimated population of nearly 9,800 in 2012 (Table 4-3). As a result, Blaine County has not seen much commercial or housing development in recent years (NODA 2012). Blaine County's homeownership rate was roughly 70 percent and the median household income was approximately $41,000 for the 5-year period from 2007 to 2011.

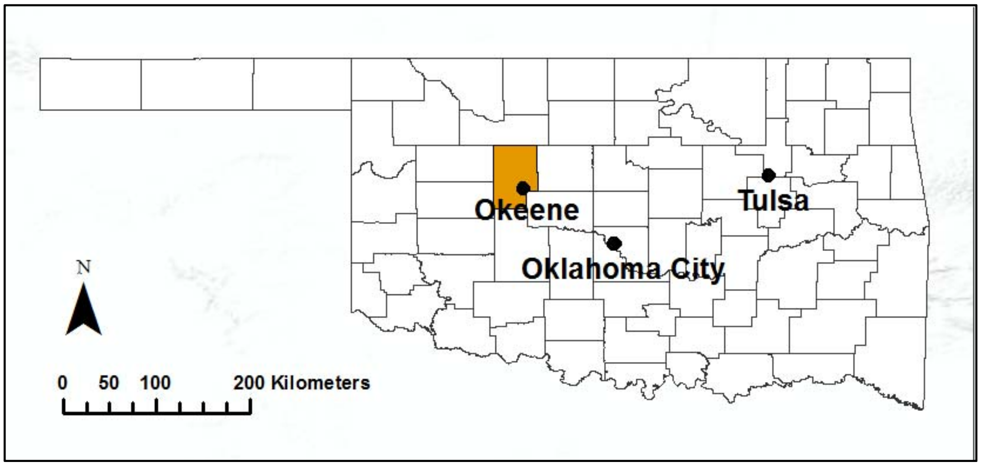

Figure 4-18. Blaine County (shaded), Okeene, and surrounding major cities in Oklahoma.

4.3.4.1 Trends in climate extremes

Similar to the other locations in Texas, Mississippi, and Arkansas, extremes in maximum temperatures reflect cooling in Okeene since 1948. There is a decreasing percent of days with maximum temperatures above the 90th percentile (Figure 4-19a), and a corresponding increase in the percentage of days with maximum temperatures below the 10th percentile (Figure 4-20b). In addition, annual absolute maximum temperatures are significantly decreasing (Figure 4-19c). Conversely, warming is apparent in minimum temperatures. The percentage of days with minimum temperatures above the 90th percentile calendar day has significantly increased (Figure 4-20b). Warmer nights have also led to significantly fewer frost days and less frequent cold spells (Figure 4-20 a and c, respectively). Warm spells have also decreased in duration since 1948 (not shown), particularly since the drought in the earlier part of the record when Brenham observed a peak in consecutive warm days (above the 90th percentile) in 1953 and 1954, with 35 and 42 consecutive warm days, respectively.

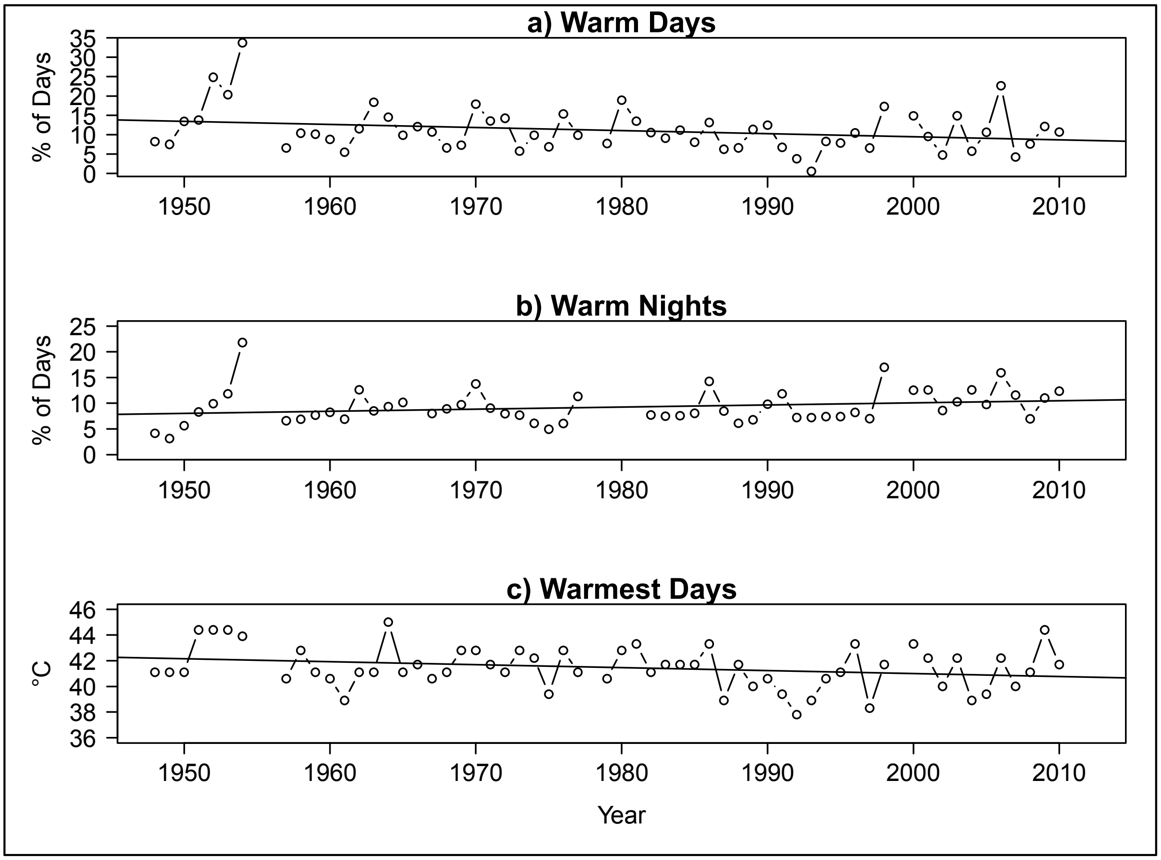

Figure 4-19. Time series of warm-related temperature extreme indices for Okeene, Oklahoma, including a) warm days (percent of days when Tmax exceeded the 90th percentile), b) warm nights (percent of days when Tmin exceeded the 90th percentile), and c) warmest days (annual absolute highest Tmax). Trends significant at the $p \leq 0.10$ level.

Oklahoma experienced unusually wet weather from the early 1980s to around 2000, shifting to a much drier period since 2000 (OWRB 2011). This shift was noticeable in Okeene, which experienced a peak in consecutive dry days in 2000, at 83 days. This 2000 peak was followed by a second maximum in 1980 with 67 dry days, followed by 1951 with 59 dry days, both coinciding with periods of drought in the region. In addition to drought, Okeene is susceptible to heavy precipitation events. Trends in precipitation extremes suggest that precipitation events are becoming more intense. For example, the simple daily intensity index shows significantly greater precipitation per

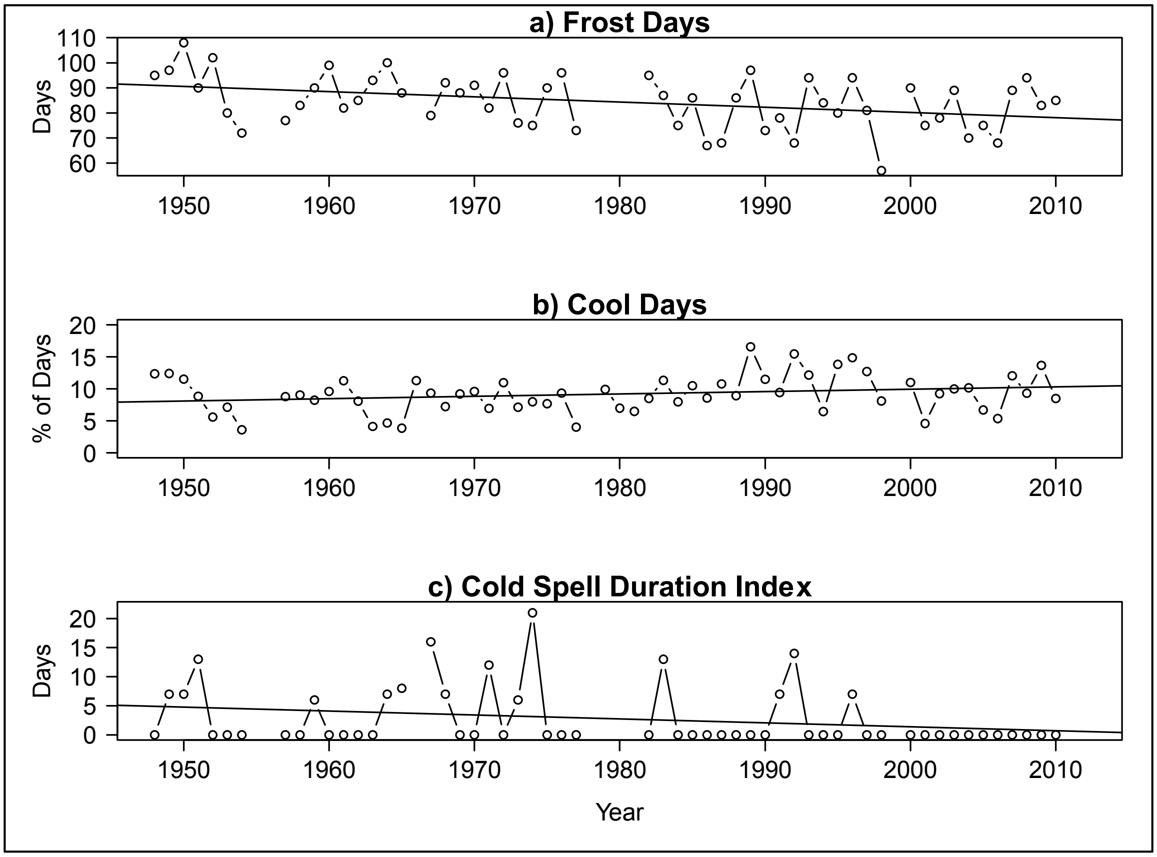

Figure 4-20. Time series of cold-related temperature extreme indices for Okeene, Oklahoma, including a) frost days (number of days when Tmin < 0°C), b) cool days (percent of days when Tmax < the 10th percentile), and c) cold spell duration index (annual count of days with at least 6 consecutive days when Tmin < 10th percentile). Trends significant at the $p \leq 0.10$ level.

day (Figure 4-21a), and the amount of precipitation on very wet days is significantly rising (Figure 4-21b). Despite increasing intensity, the duration of precipitation events has been decreasing over time in Okeene (Figure 4-21c).

4.3.4.2 Property and crop losses

Oklahoma has had more major disaster declarations since 2000 than any other state in the country (OWRB 2010). Among the hazards identified as highest priority in terms of risk to the state are tornadoes, winter weather, flooding, wildfires, high winds, drought, and extreme heat (ODEM 2011). Blaine County has observed losses as a

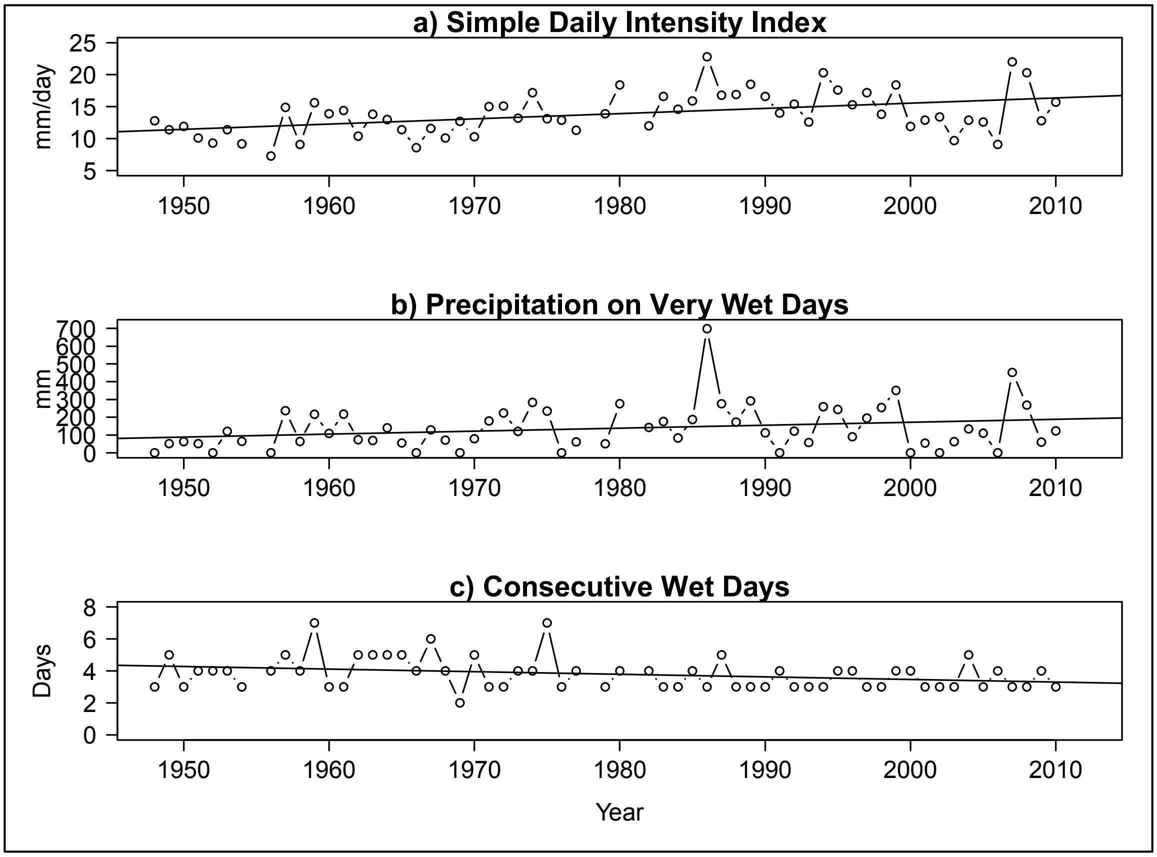

Figure 4-21. Time series of extreme precipitation indices for Okeene, Oklahoma, including a) simple daily intensity index (annual total precipitation divided by the number of wet days ≥ 1 mm), b) precipitation on very wet days (annual total precipitation above the 95th percentile), and c) consecutive wet days (maximum number of wet days ≥ 1mm). Trends significant at the $p \leq 0.05$ level.

result of climate-related disasters in every decade since 1960, with a total of 92 damage-producing events between 1960 and 2012 (Table 4-3). Severe storms, winter weather, and floods were the most recurring damage-producing events during this period. For instance, in December 2007, a severe ice storm caused an estimated 600,000 homes and business in the state to be without power for several days and outages lasted a week or more for some (OSEO 2013).

While there have been relatively few damage-causing disasters in Blaine County since 1960, their impacts have not been insubstantial. The 1960s and 2000s saw the highest number of events, with 26 and 25 events, respectively. However, total damages by decade were highest in the 1980s and since 2000, both in terms of property and crop losses. While only three droughts produced damages in the county since 1960, these events have had the greatest impact on the county, similar to Washington County, Texas. Droughts, which are due mostly to local rainfall patterns in Oklahoma (OWRB 2010), have caused a total of $4.1 million in property damages and $18.6 million in crop damages since 1960 in Blaine County alone. Winter weather events have also resulted in considerable losses, with a total of over $14.8 million since 1960. Floods in the 1980s were also particularly devastating, causing $5.1 million in property damages and $7.9 million in crop damages.

4.3.4.3 Policy and planning actions

Oklahoma has engaged in several initiatives to address climate change in recent decades, as well as several environmental mitigation measures that can benefit overall risk reduction in the state. Tables 4-10 and 4-11 show actions at the state and local levels, respectively. At the state level, climate mitigation actions have sought to increase the efficiency of energy and support the expansion of renewable energy sources. For instance, the Governor's First Energy Plan seeks to improve air quality through energy efficiency and renewable technologies (Fallin and Ming 2011). The Oklahoma Conservation Commission has partnered with other institutions in the state to develop and capitalize on market-based solutions to greenhouse gases. In addition, the Commission has outlined a wetlands management strategy to promote conservation of wetlands for pollution control and hazard mitigation (OCC 1996).

Table 4-10. Summary of state-level actions related to climate mitigation, adaptation, or hazards in Oklahoma.

Year	Entity	Action	Description	Climate Focus
1996	Oklahoma Conservation Commission	Oklahoma's Comprehensive Wetlands Conservation Plan	Funded by grants through the EPA, the goal of the plan was to develop a wetlands management strategy for the state coinciding with national efforts to promote development of comprehensive state wetlands conservation plans. This plan calls for the protection and construction of wetlands to control pollution and to serve as a mitigation solution.	Climate mitigation and environmental protection to control pollutants and mitigate flooding hazards
1996	Oklahoma Legislature	Executive Order 96-24	Spurred by the 1995-1996 drought, this Order created the Oklahoma Drought Management Team and recommended that the team develop drought response, recovery, and mitigation initiatives for conditions that are deemed detrimental to the state's economy and public health.	Climate impacts from drought
1997	Oklahoma Drought Management Team	Oklahoma Drought Management Plan	The Plan outlines the impacts of drought to the state, as well as mitigation measures to reduce impacts.	Drought and hazard mitigation measures
2002	Oklahoma Dept. of Environmental Quality, Air Quality Division	Inventory of Oklahoma Greenhouse Gas Emissions and Sinks: 1990 and 1999	Funded by a grant from the EPA, this report inventories greenhouse gas emissions for the state as a whole. Separate reports were produced for Oklahoma City and Tulsa in 1988.	Climate mitigation
2010	Oklahoma Climatological Survey	Climate Issues and Recommendations Report	This report was produced as a supplemental report to the 2012 Update of the Oklahoma Comprehensive Water Plan to describe the climate of the state and extreme events since 2000.	Extremes, variability, global warming
2010	Oklahoma Forestry Services	Oklahoma Forest Resource Strategy 2010 to 2015 and Beyond	Developed to meet requirements in the 2008 Farm Bill, this report considers the impacts of climate change, particularly to wildfires, as outlined in the accompanying Assessment report. The goals stated in this report include restoring forests to mitigate and adapt to climate change; maintaining forest health to adapt to climate change; and increase public awareness and knowledge of climate change.	Climate change impacts, climate, adaptation
2011	State of Oklahoma Department of Emergency Management	Standard Hazard Mitigation Plan Update for The Great State of Oklahoma	This update to the state’s hazard mitigation plan profiles all the hazards that threaten the state. It only discusses the general climate across the state.	Hazard mitigation

(Table 4-10. continued)

Year	Entity	Action	Description	Climate Focus
2011	Office of the Governor	Oklahoma First Energy Plan	The plan aims to take advantage of economic opportunities of new energy technologies and sources. It includes strategies to decrease emissions and improve air quality through greater energy efficiency and renewable energy sources, particularly wind and solar.	Climate mitigation; impacts of drought and precipitation on water supplies
2012	Oklahoma Water Resources Board	Oklahoma Comprehensive Water Plan	Considers local and regional water use and management through the year 2060 and beyond. It commissioned the OCWB to conduct a study on the research and outreach needs related to climate and future water. The first Water Plan was adopted in 1981 with emphasis on projects. An update in 1997 focused more on policy.	Future climate impacts, particularly with reduced precipitation and higher temperatures
2012	Oklahoma Legislature	Water for 2060 Act (HB 3055)	This Act made Oklahoma the first state in the nation to establish a goal of consuming no more freshwater in 2060 than is consumed today. It established a new Water for 2060 Advisory Council, and the U.S. Army Corps of Engineers has partnered with the OWRB to begin work supporting the Council.	Climate mitigation, conservation

Oklahoma has not adopted ordinances that regulate population growth or future development, as areas for future growth and development, particularly as they relate to hazards, are generally managed at the local level (ODEM 2011). However, it appears that local planning efforts in Okeene have not yet addressed the impacts of climate change on development and related sectors. Okeene has developed a Wildfire Protection Plan for the city in 2012, despite the fact that wildfires have not been particularly damaging to the county in recent decades. In addition, the Wildfire Protection Plan addresses hazard mitigation measures only and does not include climate change impacts or adaptation options (NODA 2012). Larger cities are taking more progressive action compared to Okeene. In 2009, Oklahoma City established an Office of Sustainability to enhance energy efficiency efforts and reduce emissions.

Table 4-11. Summary of local- and regional-level actions related to climate mitigation, adaptation, or hazards in Okeene, OK and the surrounding region.

Year	Entity	Action	Description	Climate Focus
2009	City of Oklahoma City	Office of Sustainability	Funded by the DOE's Energy Efficiency and Conservation Block Grant Program, the City established the Office to enhance the city's energy efficiency efforts and promote sustainability. They provide technical recommendations, planning, and outreach services to City Departments and the public to encourage communities to implement projects to improve energy efficiency and reduce energy use and fossil fuel emissions.	Climate mitigation, sustainability
2010	Oklahoma Conservation Commission	North Canadian River Watershed Carbon Pilot Program	The program is an expansion of a carbon sequestration program in the state. Funded by EPA through a North Canadian River Water Quality Project, the program's goal is to improve water quality, reduce polluted runoff from land, and encourage improved land management practices that store carbon dioxide. Blaine County is included in the watershed and part of the program.	Climate mitigation
2011	City of Oklahoma City. Oklahoma City Planning Department	PlanOKC	Oklahoma City's Comprehensive Plan addresses issues and concerns related to the impacts of climate change, including to wildlife, as well as how ozone levels will impact water pollution and public health. Goals include minimizing urban heat island effects, improving air quality, and other goals to protect the environment.	Climate mitigation, local impacts of climate change to the environment and public health
2011	Oklahoma Water Resources Board	Oklahoma Comprehensive Water Plan Report on the Central Watershed Planning Region	This water plan addresses water use and quality for central Oklahoma, including Blaine County, to promote safe, dependable water and improved management and planning. It discusses climate in general, including extreme events, with the impacts of climate addressed in supplemental reports.	Climate, general and extremes
2012	Northern Oklahoma Development Authority	Okeene Community Wildfire Protection Plan	This local action plan addresses wildfire emergency response and mitigation measures. It does not discuss future climate concerns, needs, or adaptation strategies.	Wildfires, hazard mitigation

In addition, Oklahoma City's 2011 Comprehensive Plan, titled PlanOKC, represents an example of a local land use planning effort that has considered climate change. The plan considers the potential local impacts of climate change on wildlife and the environment, and it emphasizes the reduction of ozone levels to minimize water pollution and improve public health (OCPD 2011). Specific goals outlined in the plan include reducing the urban heat island effect, improving air quality, and serving as a model of energy efficiency and conservation. Regional entities are also taking action to mitigate climate change, such as the Oklahoma Conservation Commission’s North Canadian River Watershed Carbon Pilot Program that includes Blaine County and aims to take specific actions to store atmospheric carbon dioxide.

Like Texas, drought episodes have led to increased water planning. As such, water issues have been a main focus of action, including for state and local governments (Figure 4-22). Among the most commonly occurring words in state and local documents are: ‘water,’ ‘basin,’ ‘groundwater,’ ‘demand,’ ‘use,’ and ‘storage,’ among others. The state and regional watershed plans have addressed the impacts of extreme climate on water resources, and the Oklahoma Water Resources Board (OWRB) developed a plan for the Central Watershed Planning Region that considers the impacts of climate change for the region including Blaine County (OWRB 2011). State water planning has also focused on reducing the impacts of extreme precipitation on water quality and quantity. As such, drought and flood also appear in the top 50 most frequent words.

4.3.5 Newberry County, South Carolina

Little Mountain is a small, rural town in the eastern part of Newberry County, roughly 48 kilometers (30 miles) northwest of Columbia (Figure 4-23). Newberry County lies in the Central Midlands Region of South Carolina within the Piedmont-Blue Ridge area of the state. The northern half of the county is largely forested, and agriculture is

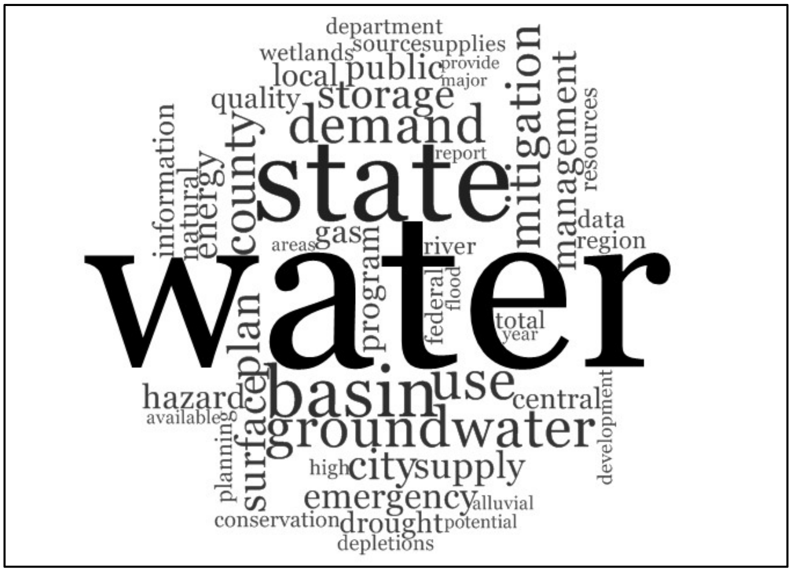

Figure 4-22. The 50 most commonly used words found within all state- and local-level actions for Oklahoma included in this study.

an important sector in the county (CMCOG 2013). The county seat is Newberry, about 24 kilometers (15 miles) west of Little Mountain. Newberry County and the surrounding area have experienced steady growth in the past 30 years, increasing in population by 35 percent from 1980 to 2010 (CMCOG 2012). While, Newberry County's population rose only slightly by 0.2 percent in recent years from 2010 to 2012, the broader four-county Central Midlands Region is expected to continue to grow over the next two decades, possibly reaching one million (CMCOG 2012).

4.3.5.1 Trends in climate extremes

Unlike most locations in the Southeast, Little Mountain appears to be seeing fewer warm extremes. Warm extreme indices exhibit significantly downward trends since 1948, for both maximum- and minimum-related extreme temperature indices. Figure 4-24 shows time series of three warm-related temperature extreme indices. Trends in annual absolute warmest days (Figure 4-24a) and nights (Figure 4-24b) have

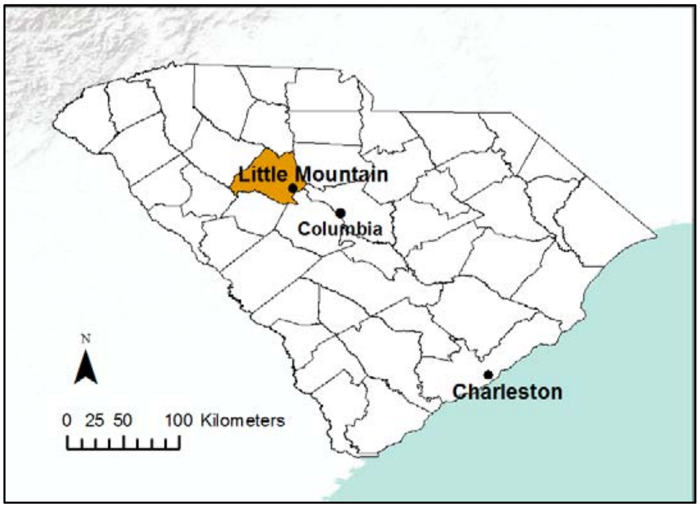

Figure 4-23. Newberry County (shaded), Little Mountain, and surrounding major cities in South Carolina.

been significantly decreasing. In addition, warm spells appear to be getting shorter and less variable, with the warmest period since 1948 occurring in the 1950s (Figure 4-24c).

Trends in cold-related temperature extremes further support a cooling climate for Little Mountain. For instance, ice days are becoming somewhat more frequent (Figure 4-25a), and annual absolute coldest daytime temperatures are getting colder (Figure 4-15b), though these trends were insignificant. However, cool days, defined as the percent of days when maximum temperatures are below the 10th percentile for a calendar day, are significantly rising (Figure 4-25c). While many cold-related indices showed insignificant trends, they are consistent with trends in warm-related extremes that are significant at the 0.05 level. Overall, these findings indicate that extreme heat may not be as much of a concern here as it is for much of the Southeast, particularly with respect to extremely warm minimum temperatures.

Little Mountain also differs from much of the Southeast with respect to extremes in precipitation. Overall, extreme precipitation events are becoming less severe, less

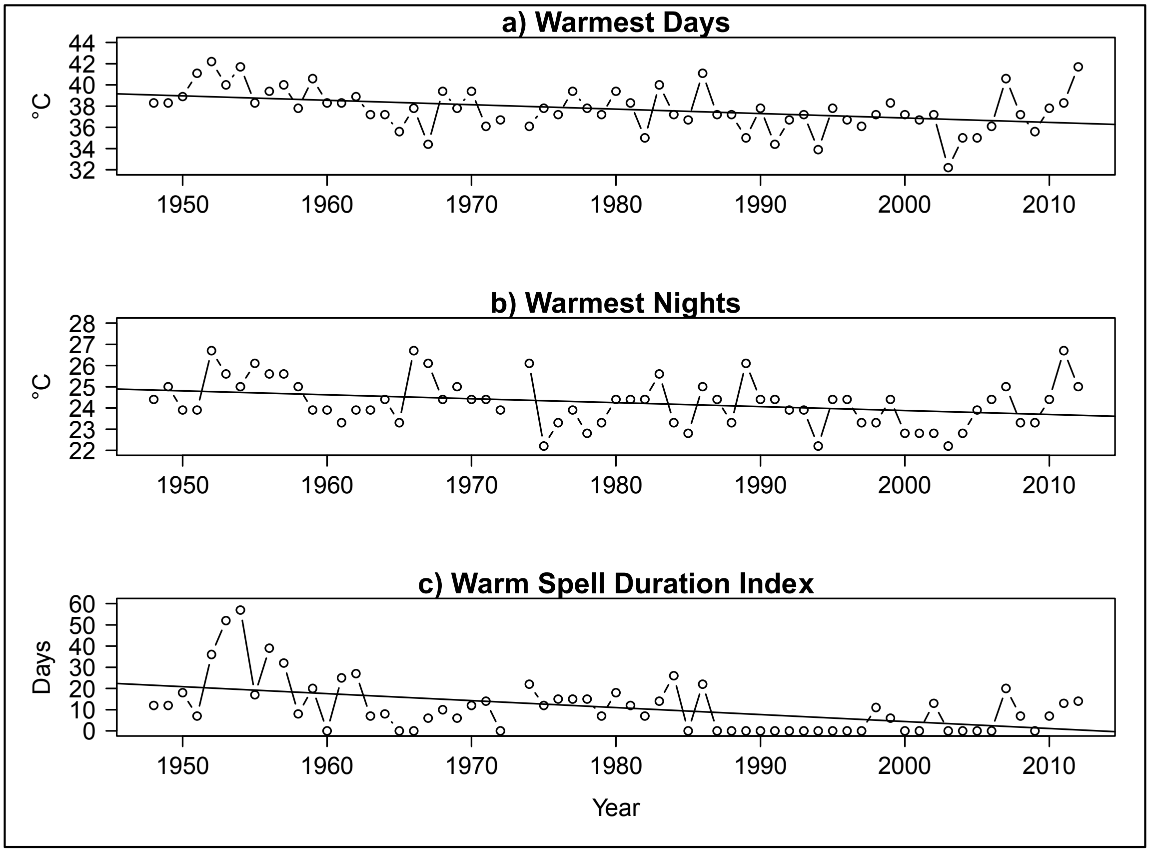

Figure 4-24. Time series of warm-related temperature extreme indices for Little Mountain, South Carolina, including a) warmest days (annual absolute highest maximum temperature), b) warmest nights (annual absolute highest minimum temperature), and c) warm spell duration index (annual count of days with at least six consecutive days when Tmax is above the calendar day 90th percentile). Trends significant at the p ≤ 0.05 level.

frequent, and shorter in length. Figure 4-26 shows times series for three wet-related extreme indices as evidence for decreasing wetness. Namely, the intensity of heavy 1-day precipitation events has been significantly decreasing since1948, and heavy precipitation days (≥ 10 mm) are becoming significantly less frequent. Wet spells are clearly becoming shorter in duration, though this trend was insignificant.

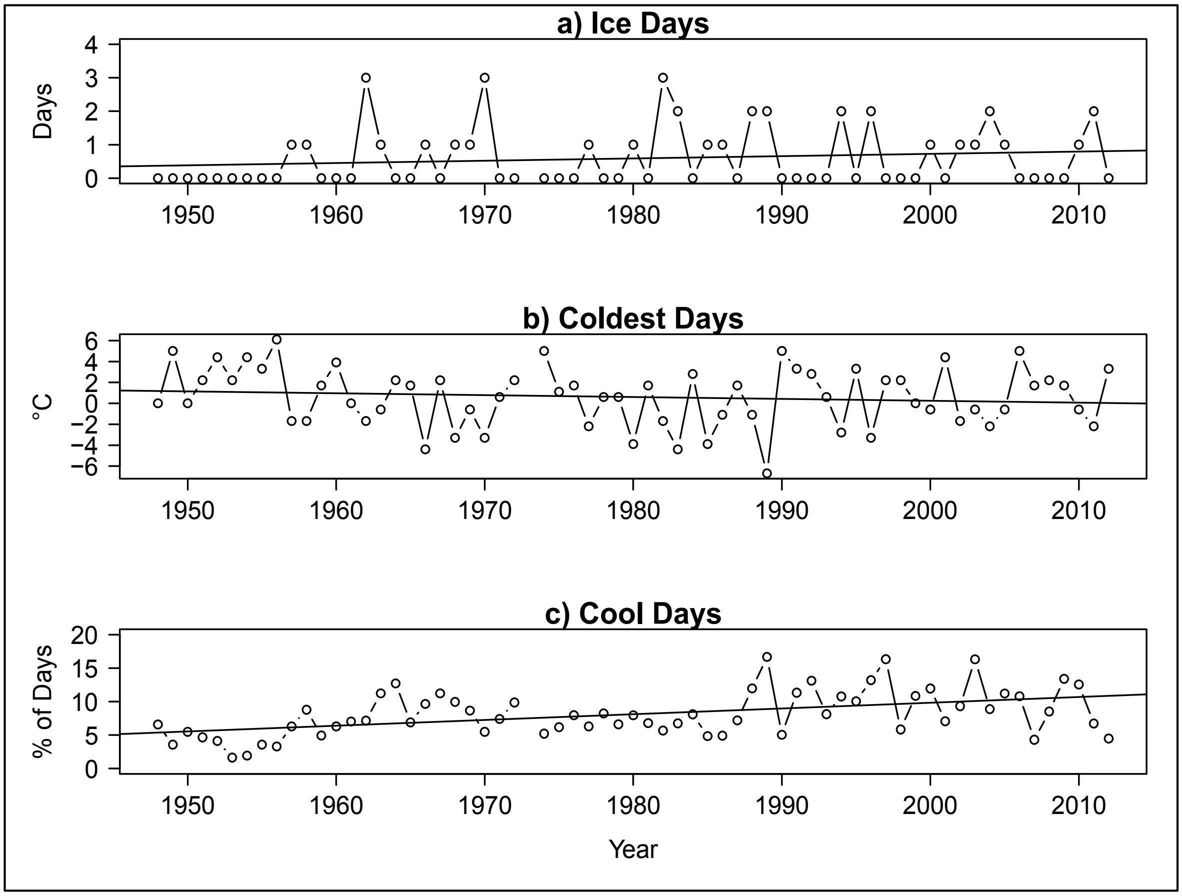

Figure 4-25. Time series of cold-related temperature extreme indices for Little Mountain, South Carolina, including a) ice days (annual count of days when Tmax < 0°C), b) coldest days (annual absolute lowest maximum temperature), and c) cool days (percent of days when Tmax < 10th percentile). Trends significant at the $p=0.05$ level for (c) only.

4.3.5.2 Property and crop losses

For the Central Midlands Region of South Carolina, severe thunderstorms, wind, tornadoes, hurricanes, winter snow, ice storms, and floods are the most recurring types of hazards in the region (CMCOG 2010). In Newberry County in particular, severe storms, wildfires, and hail have occurred most frequently compared to other natural hazards, and the annual probability of future hazards in the county is highest for wildfires (SCSEMD 2013). Winter weather and drought also commonly impact Newberry County (CMCOG 2010).

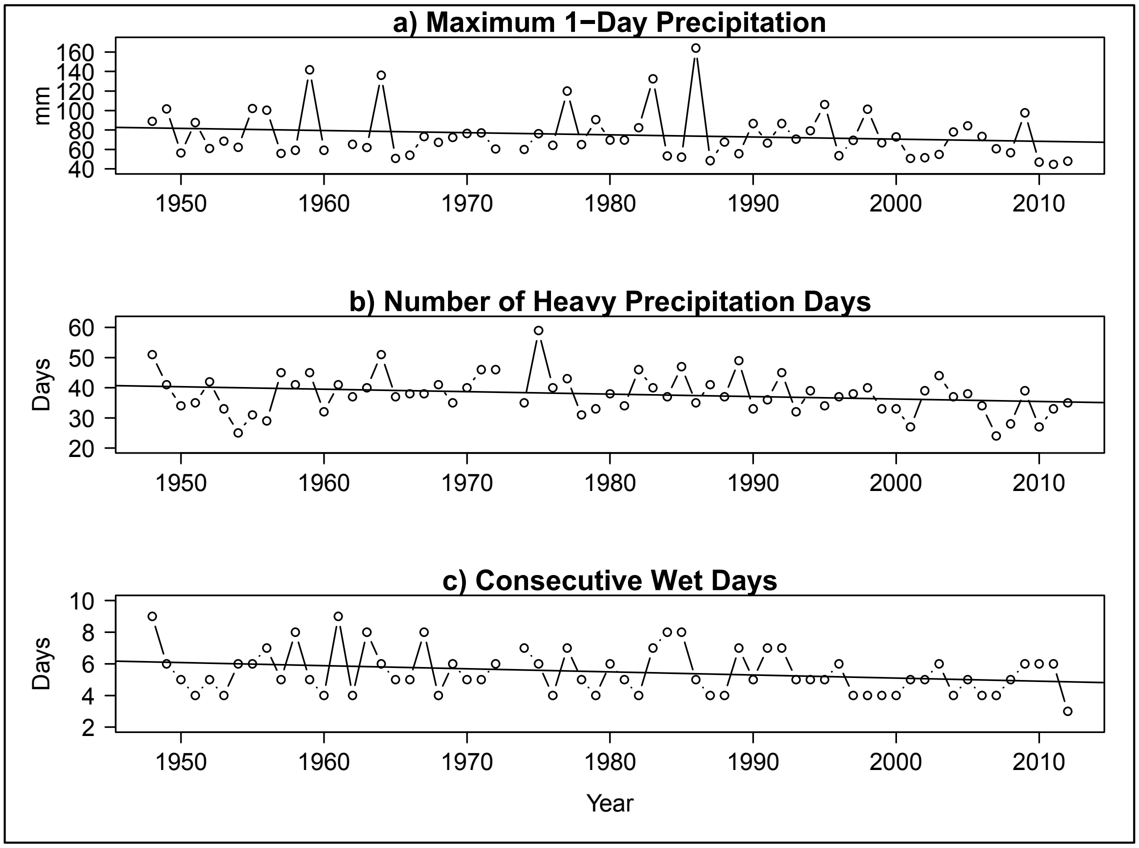

Figure 4-26. Time series of extreme precipitation indices for Little Mountain, South Carolina, including a) maximum1-day precipitation (annual maximum 1-day precipitation), b) heavy precipitation days (number of days with precipitation ≥ 10mm), and c) consecutive wet days (maximum number of consecutive days with precipitation ≥ 1 mm). Trends significant at the p ≤ 0.10 level for a) and b) only.

Winter weather, drought, and heat have generated the highest amount of damages in the county since 1960 (Table 4-3). Crop losses due to winter weather were particularly high in the 1960s during a relatively cool period, with a second devastating period in the 1980s. As cold extremes appear to be increasing for Little Mountain, the area should prepare for the potential for more damaging winter weather events in the future. Drought losses were highest in the 1990s, particularly in 1993, 1994, and 1995. Just a few years later, South Carolina experienced one of its worst droughts on record from 1998 to 2002, when average precipitation was 10-30 percent below normal (Badr et al. 2004). Given that the intensity, frequency, and duration of precipitation extremes appear to be decreasing in Newberry County, future changes in precipitation extremes will be particularly important to the region's capacity to mitigate future drought hazards and flooding impacts.

4.3.5.3 Policy and planning actions

South Carolina has addressed climate adaptation and mitigation at the state level through legislative, planning, and research-based efforts (Table 4-12). Several statewide plans and reports that address climate change impacts and adaptation relate to sea level rise. For instance, the State Department of Health and Environmental Control issued a report in 2010 on adapting to shoreline changes (SCAC 2010), and the South Carolina Sea Grant released an adaptation report that focuses heavily on strategies and implementation related to coastal and marine issues (SCSGC 2010). The state's Hazard Mitigation Plan also addresses coastal issues, among other natural hazards (SCSEMD 2013). In addition to climate adaptation and mitigation planning, the South Carolina state legislature issued an executive order in 2007 to establish the Governor's Climate, Energy & Commerce Advisory Committee to develop a Climate Action Plan to reduce greenhouse gases. The plan, completed the following year, recommends a set of 51 policies to address climate-related issues, which include setting a target to reduce gross greenhouse gas emissions by 2020 and development of a state adaptation plan (CECAC 2008). Also in 2008, the state completed a statewide inventory of greenhouse gases intended to inform future policy.

South Carolina has taken specific actions at the state level directly aimed to mitigate the effects of drought to the economy and environment, through both policy and

Table 4-12. Summary of state-level actions related to climate mitigation, adaptation, or hazards in South Carolina.

Year	Entity	Action	Description	Climate Focus
1985	South Carolina Legislature	South Carolina Drought Response Act	Established the Drought Response Committee, which includes state and local representatives, and gave the Committee the authority to declare drought in the state. The Act further calls on the Department of Natural Resources to formulate and execute a drought mitigation plan consistent with the Water Resources Planning and Coordination Act.	Drought mitigation
1988	South Carolina Legislature	South Carolina Beachfront Management Act	Established a comprehensive statewide beachfront management program, which included several conservation measures to protect the coastal area from storms. It also included adaptation policy guidelines that promote a gradual retreat from the beach/dune system over a 40-year period.	Adaptation, hazard mitigation, conservation
2004	South Carolina Department of Natural Resources' Land, Water, and Conservation Division	South Carolina Water Plan	This update to the State Water Plan was prompted in part by the recent multiyear drought to address future water needs in the state. The first water plan was published in 1998, with this being the second edition. While the plan does not specifically discuss climate change, it includes several strategies to mitigate impacts of drought and flood, as well as to promote water conservation.	Mitigation of drought and flood, conservation
2005	South Carolina Department of Natural Resources	2005 Comprehensive Wildlife Conservation Strategy	This strategy identifies wildlife species of high priority and conservation strategies that protect habitats and promote effective land management strategies. It does not mention climate change or related hazards, however.	Environmental protection and conservation
2007	South Carolina Legislature	Executive Order 2007-04	This order was signed by Governor Mark Sanford to establish the Governor's Climate, Energy & Commerce Advisory Committee to develop a Climate Action Plan to reduce greenhouse gas emissions.	Climate mitigation
2008	Climate, Energy, & Commerce Advisory Committee	Climate Energy and Commerce Action Plan	The plan recommends a set of 51 specific policies to address climate, energy, and commerce related issues at the state, regional, and national levels. It recommended that the state reduce gross greenhouse gas emissions to 5% below 1990 levels by 2020, and to develop a state adaptation plan.	Climate mitigation, adaptation

(Table 4-12. continued)

Year	Entity	Action	Description	Climate Focus
2008	Center for Climate Strategies for the Climate, Energy & Commerce Advisory Committee	Final Draft South Carolina Greenhouse Gas Inventory and Reference Case Projections, 1990-2020	Assesses the state's greenhouse gas emissions from anthropogenic sources, as well as sinks, from 1990 to 2020 to inform development of policy options for mitigating these emissions.	Climate Mitigation
2009	South Carolina Emergency Management Division	South Carolina Drought Response Plan	Identifies policies and procedures for responding to drought. It emphasizes response and management of drought periods but includes mitigation options aimed to improve water storage and collection; coordination between water basins and across regions; conservation; industry and public works plans; and monitoring. It includes the use of long-range, climate-scale predictions for the state.	Drought mitigation, water conservation, future climate
2010	South Carolina Department of Health and Environmental Control's Shoreline Change Advisory Committee	Adapting to Shoreline Change: A Foundation for Improved Management and Planning in South Carolina	Through financial assistance provided by NOAA's Office of Ocean and Coastal Resource Management, the report was prepared to propose policies for shoreline management and provide guidance for future coastal planning in response to current and projected sea level rise.	Climate mitigation and adaptation to sea level rise and storms
2010	South Carolina Forestry Commission	South Carolina's Statewide Forest Resource Assessment and Strategy	Prepared to receive federal forestry assistance, this report identifies climate change threats to forests and encourages sustainable management. It discusses emerging markets of carbon credits, biomass, and other forest products to promote energy independence and tackle climate change. Specific strategies include tree restoration; forest management and arboriculture practices that will address increased risks of insect attacks; wildfire mitigation efforts particularly in wildland-urban interface areas; increased monitoring of invasive species; and increased urban tree canopy to mitigate urban heat island effects.	Climate change impacts to forest resources; climate mitigation
2013	South Carolina Emergency Management Division	South Carolina Hazard Mitigation Plan	Formally adopted in 2004, this update identifies many natural hazards that are likely to affect the state. Among those related to climate are coastal issues, floods, thunderstorms, sea level rise, wildfires, drought, winter weather, and extreme heat.	Hazard mitigation of extreme events and sea level rise

(Table 4-12. continued)

Year	Entity	Action	Description	Climate Focus
2010-2013	South Carolina Sea Grant	Strategic Plan for Adapting to Change	This strategy and implementation plan identifies programs to effectively address sea level rise issues in the state. This is an update to the previous 2010-2013 plan. It outlines a plan of action for the next four years to address contemporary coastal and marine resource issues facing the state.	Sea level rise

planning. South Carolina published its first state Water Plan in 1998 at a time when it was entering into a multiyear drought, which subsequently prompted the latest 2004 plan update. The State's Drought Response Plan, developed in 2009, is included here because, while it is a plan to outline procedures during emergency situations, it includes the use of long-range climate-scale drought predictions. This exemplifies the potential to readily incorporate climate change projections within existing frameworks where appropriate, even emergency management plans that focus on more short-term, immediate needs and issues.

Most local-level actions in Little Mountain and surround areas focus on environmental conservation and hazard mitigation (Table 4-13). While local planning efforts have not addressed climate change directly, plans have incorporated many measures that would help to mitigate the effects of climate change and/or extreme events. For instance, the CMCOG promoted open space preservation and green infrastructure in the region to improve air quality, filter stormwater runoff, and support greater biodiversity (CMCOG 2007). In addition, the City of Newberry's Comprehensive Plan 2010-2020 outlines many similar climate mitigation measures, such as protecting open spaces, urban forests, and wetlands (CNPDSD 2010). However, the Comprehensive Economic Development Strategy for the Central Midlands Region

(CMCOG 2012) does not consider impacts from climate change and does not integrate hazard mitigation planning, illustrating important gaps and missed opportunities to better integrate planning efforts among these regional councils and planning commissions.

Table 4-13. Summary of local- and regional-level actions related to climate mitigation, adaptation, or hazards in Little Mountain, SC and the surrounding region.

Year	Entity	Action	Description	Climate Focus
2007	Central Midlands Council of Governments	Keeping it Green in the Midlands: Preserving Open Space in South Carolina's Capital Region	This plan promotes green infrastructure to create open space preservation in the area. Promoting green infrastructure is expected to ensure ecosystems can function properly by removing pollutants from the air, carry and filter stormwater runoff, and support diverse plant and wildlife species.	Climate mitigation, environmental conservation
2008	Central Midlands Council of Governments	Midlands Tomorrow: 2035 Long Range Transportation Plan	Developed based on a Columbia Area Transportation Study (COATS) and adopted in 2008, this transportation plan covers the 4-county area of the CMCOG, though its focus is for the Columbia metro area. While the plan does not address climate change, it emphasizes the importance of environmental mitigation with respect to development and transportation to reduce the impacts of development on natural systems.	Environmental mitigation
2010	Central Midlands Council of Governments	An All Natural Hazard Risk Assessment and Hazard Mitigation Plan for the Central Midlands Region of South Carolina 2010 Update	This plan outlines the hazards most important to each county in the Council's 4-county jurisdiction, and it identifies a list of hazard mitigation measures to reduce their impacts to the region.	Hazard mitigation
2010	City of Newberry's Planning and Development Services Department	City of Newberry Comprehensive Plan 2010-2020	Adopted in 2010, the plan does not discuss climate change; however, the strategies and goals outlined in the Natural Resources Element include measures that would help to mitigate impacts of climate change and extreme events. These include protecting air quality, wildlife habitats, parks, natural areas, urban forests, water resources, and wetlands.	Climate and hazard mitigation, environmental conservation

A word frequency query was conducted to illustrate the issues and concepts that appear in these state and local level documents. Figure 4-27 shows the 50 most commonly occurring words for all state and local actions included in Tables 4-12 and 4-13. Climate-related words, such as ‘mitigation’ and ‘emissions,’ are represented in these documents, unlike previous locations. In addition, despite the effects of drought and heat, water is not as prominent as it was for most other locations in the analysis. Words associated with winter weather events are not reflected in these documents. Many process or bureaucratic words appear, including ‘development,’ ‘management,’ and ‘program.’ Indeed, many actions included in this analysis focus on policies or programs to manage resources and mitigate the impacts of climate change and natural disasters.

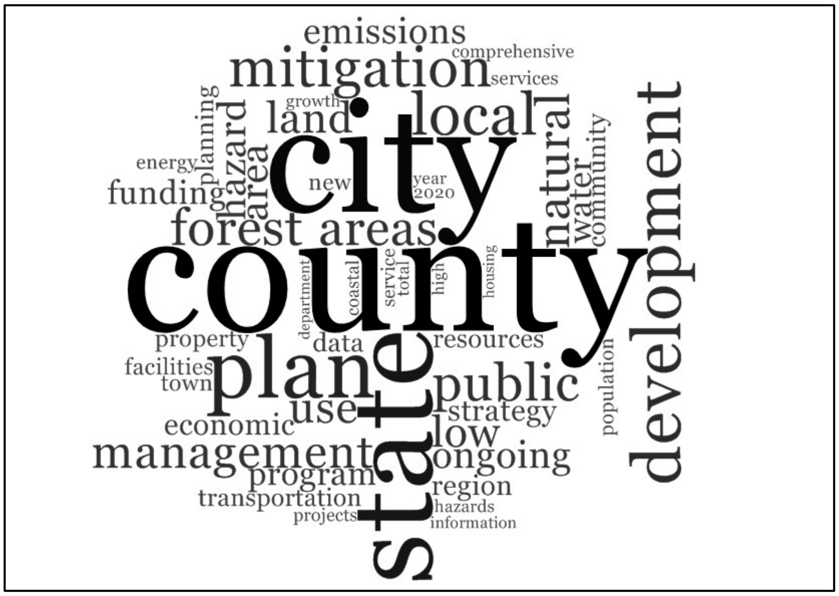

Figure 4-27. The 50 most commonly occurring words found within all state and local actions for South Carolina included in this study.

4.3.6 Pinellas County, Florida

Florida is highly vulnerable to the effects of climate change (FAU 2007, NRDC 2012). Climate change impacts of particular relevance to the state include sea level rise, hurricane activity, drought, and heavy rainfall (Murley et al. 2007). The city of Tarpon Springs is located in Pinellas County, a coastal county in west central Florida (Figure 4-28). The city is roughly 45 kilometers (28 miles) northwest of Tampa and 48 kilometers (30 miles) north of St. Petersburg. Roughly 75 percent of Florida's population resides in coastal counties (FOCC 2010), and Pinellas County has one of the highest coastal populations in the state (FDEM 2013). Tarpon Springs is bounded by Lake Tarpon and the Salt Lakes to the east and the Gulf of Mexico to the west. In addition, the Anclote River runs through the northern part of the city. Approximately 75 percent of the city lies within the 100-year floodplain, much of which is heavily urbanized, and the area is susceptible to flooding from heavy rainfall coupled with high tides (CTS 2010).

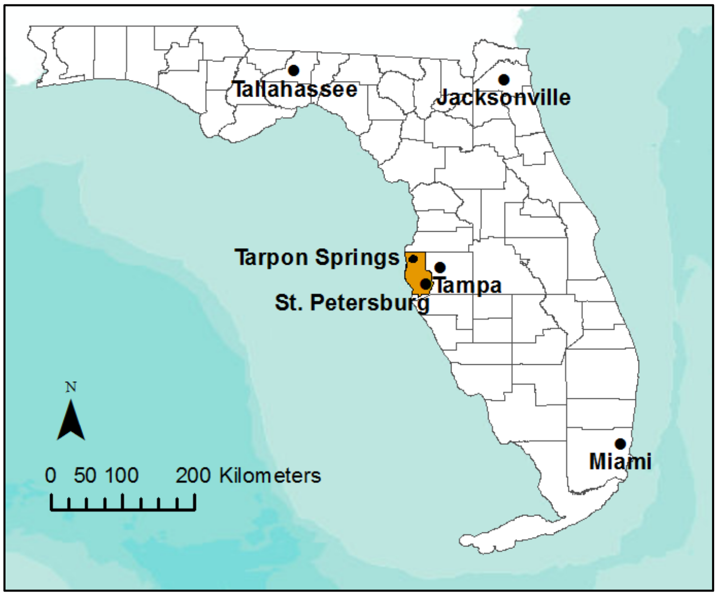

Figure 4-28. Pinellas County (shaded), Tarpon Springs, and surrounding major cities in Florida.

The city's economy benefits from the area's temperate climate, attracting tourists, permanent residents, and retirees. The city's population has experienced an estimated growth of 2.1 percent per year from 2000 to 2010, and projections suggest continued growth to 2025 (CTS 2010). Pinellas County has also grown slightly in recent years by 0.5 percent from 2010 to 2012. Pinellas County has the largest population and highest median household income of all other sites in this analysis (Table 4-3). As a retiree community, 22 percent of its population is at or over the age of 65, based on U.S. Census Bureau QuickFacts data.

4.3.6.1 Trends in climate extremes

Extreme temperature indices show that Tarpon Springs is experiencing more warm extremes. Unlike other locations in this study and the Southeast in general, the city is experiencing increasing warm extremes in both maximum and minimum temperatures. Moreover, temperature extreme trends are generally of opposite direction to those observed for Little Mountain, South Carolina. Figure 4-29 shows time series for the percent of warm days (a), number of tropical nights (b), and diurnal temperature range (c) for the city. Since 1948, the city has seen a significantly higher percent of warm days (above the 90th percentile for a calendar day) and more nights above 24°C, with a net decrease in mean annual diurnal temperature range.

Trends in cold-related extremes are consistent with warming trends. The number of frost days and the percent of cool days (below the 10th percentile for a calendar day) are decreasing (Figure 4-30 a and b), though trends in these indices were insignificant. The percent of cool nights (below the 10th percentile for a calendar day) has been significantly decreasing (Figure 4-30c), reiterating a trend toward warmer nights in Tarpon Springs. Despite long-term warming, daytime temperatures have undergone a recent cooling period in the 2000s, with fewer warm days (Figure 4-30a) and a corresponding elevated percent of cool days (Figure 4-30b).

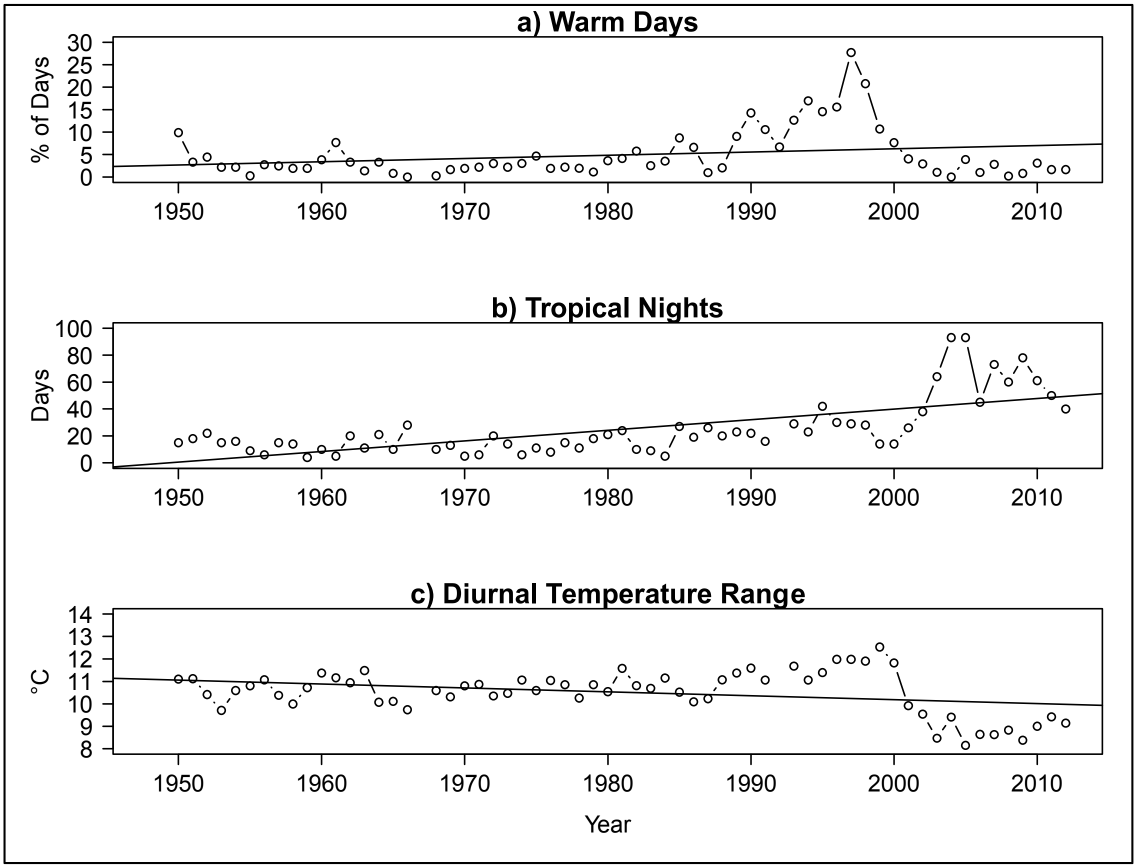

Figure 4-29. Time series of warm-related temperature extreme indices for Tarpon Springs, Florida, including a) warm days (percent of days when Tmax > the 90th percentile), b) tropical nights (number of nights when Tmin exceeded 24°C), and c) diurnal temperature range (avg. Tmax - Tmin). Trends significant at the $p \leq 0.10$ level.

Trends in precipitation extremes suggest that Tarpon Springs is seeing increases in the magnitude of precipitation events (Figure 4-31). For instance, precipitation events are becoming significantly more intense as indicated by the simple daily intensity index (Figure 4-31a). While trends in other precipitation extreme indices were insignificant, they also suggest a trend toward greater magnitude events, including increasingly heavy 1-day precipitation events (Figure 4-31b) and more precipitation falling on extremely wet days (Figure 4-31c). It is more difficult to draw conclusions regarding the

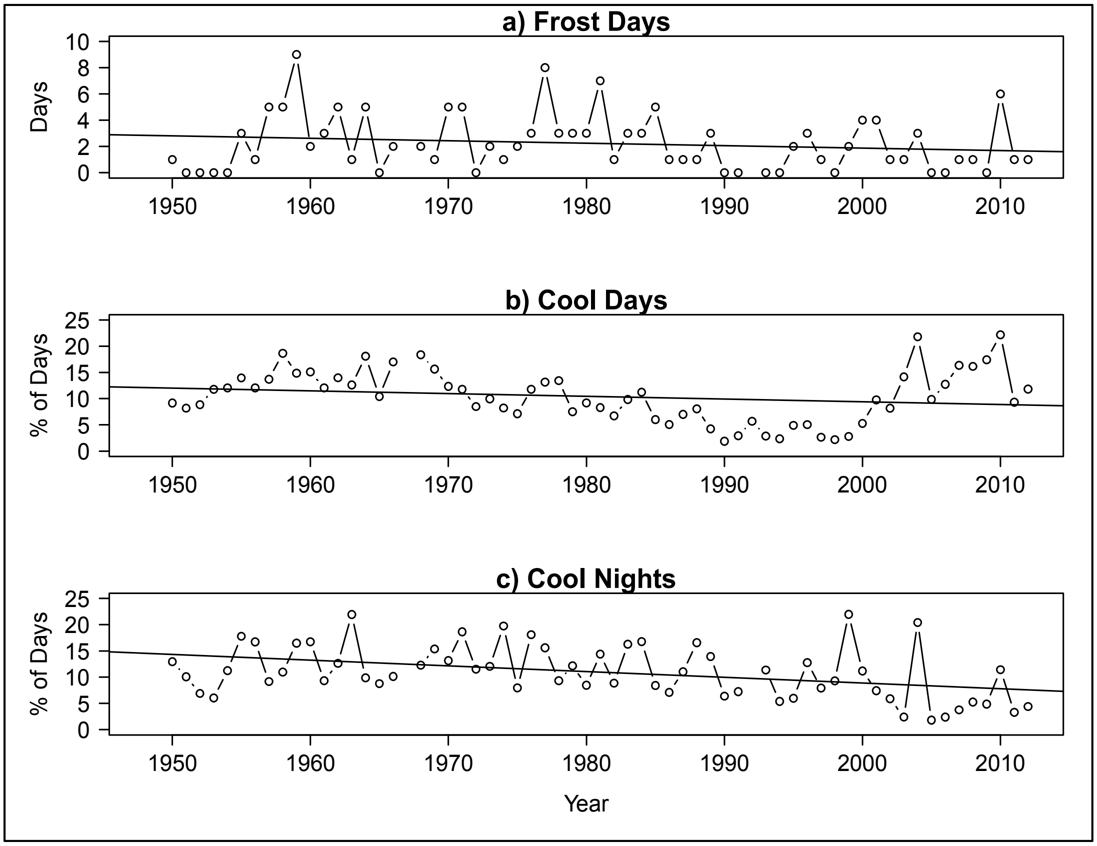

Figure 4-30. Time series of cold-related temperature extreme indices for Tarpon Springs, Florida, including a) frost days (annual count when Tmin is below 0°C), b) cool days (percent of days when Tmax is below the calendar day 10th percentile), and c) cool nights (percent of days when Tmin is below the calendar day 10th percentile). Trends significant at the $p \leq 0.05$ level for (c) only.

frequency of heavy precipitation days or their durations given a lack of significance in related trends.

4.3.6.2 Property and crop losses

Losses resulting from climatological hazards in Pinellas County indicate that severe storms are the most recurring damaging hazard (Table 4-3). Flooding was common in the 1990s; however, many of these events were small stream floods in localized urban areas. Astronomical high tides and flash flooding caused many damaging flooding events, particularly since 2000. Despite fewer damaging winter

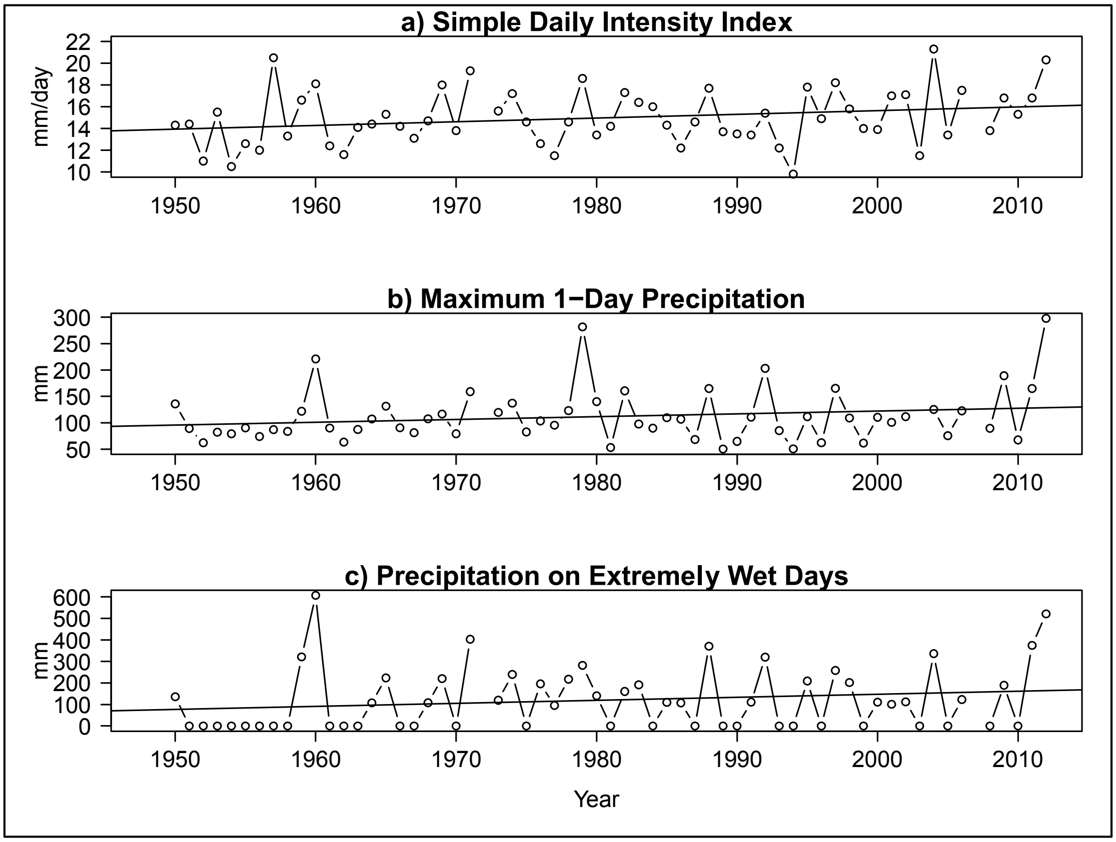

Figure 4-31. Time series of extreme precipitation indices for Tarpon Springs, Florida, including a) simple daily intensity index (annual total precipitation divided by the number of wet days ≥ 1 mm), b) maximum 1-day precipitation (annual maximum 1-day precipitation), and c) extremely wet days (annual total precipitation on days when precipitation > 99th percentile). Trends significant at the $p \leq 0.10$ level for (a) only.

weather events between 1960 and 2012, the county has the capacity to experience relatively high losses from these events, to both property and crops. Severe storms and flooding tend to cause substantial damages to property in particular. Although extreme heat has not generated losses in the county during the past five decades, trends in extreme indices suggest that warmer weather may be a concern in the future (Figure 4-29). Furthermore, the state's Hazard Mitigation Plan identifies extreme heat as one of four hazards for which Pinellas County is particularly vulnerable, the other three being hurricanes, severe storms, and erosion (FDEM 2013).

4.3.6.3 Policy and planning actions

Given its high vulnerability to climate change, Florida is one of the most progressive states in the Southeast and country in terms of policy and planning actions to address climate change. Table 4-14 shows examples of actions at the state level related to climate. These documents demonstrate that the state has taken many efforts to combat and prepare for specific impacts of climate change, particularly in the last decade. Given the state's large coastal population, many of these actions focus on coastal issues with emphasis on coastal adaptation, coastal and ocean resources, and sea level rise. In addition to climate-specific actions, climate change is being integrated into existing planning efforts. For instance, the goals within the state's most recent Enhanced Hazard Mitigation Plan (FDEM 2013) include conducting more research on climate change and sea level rise to prepare the state and local governments in planning for and mitigating adverse impacts. In addition, the state has developed reports to better prepare for the effects of sea level rise (FOCC 2009, 2010). Florida's Hazard Mitigation Plan (HMP) has also been shown to lead other coastal state HMPs in terms of plan development and quality, particularly in linking hazard mitigation with land use planning to promote more effective policies and decision making (Berke et al. 2009). Risks to other types of extremes may be contributing to increased action in the state. In 2002, Florida developed a Water Conservation Initiative in response to drought and growing water demands. This initiative identified 51 recommendations for increased water efficiency in the state, many of which have been implemented through multiple programs, such as the Conserve Florida Program and Water Protection and Sustainability Program (FDEP 2002).

Table 4-14. Summary of state-level actions related to climate mitigation, adaptation, and hazards in Florida.

Year	Entity	Action	Description	Climate Focus
1974	Florida Legislature	Florida Energy Conservation in Buildings Act	Mandated the use of energy efficient equipment and design. It required use of solar energy devices for heating and cooling state buildings where life-cycle cost analysis determines that the solar systems will be cost-effective over the building's lifetime.	Climate mitigation through renewable energy
2002	Florida Department of Environmental Protection	Florida Water Conservation Initiative	Prepared in response to growing water demands, water supply issues, and severe drought from 1999 to 2001, the focus is on long-term strategies leading to permanent water sources and use. The initiative resulted in 51 recommendations for increased water use efficiency. Many of these have been implemented in the Conserve Florida Program, the Landscape Irrigation and Florida-Friendly Design Committee, the Water Protection and Sustainability Program, and other programs.	Water conservation, drought mitigation
2005	Florida Legislature	Executive Order 05-241	Called for the continued reduction in the state's energy demands and encourages all state agencies, departments, and local governments to be models for citizens by engaging in energy conservation practices that include investing in energy-saving equipment.	Climate mitigation through energy conservation
2006	Florida Legislature	Florida Renewable Energy Technologies & Energy Efficiency Act (SB 888)	Promoted energy efficiency and the sale of energy-efficient products, and it created incentive programs for renewable energy.	Climate mitigation through energy efficiency and renewable energy
2006	Department of Environmental Protection	Florida's Energy Plan	Prepared as directed by EO 05-241, the plan aims to ensure energy supply is met for the state and for he speedy recovery of operations following natural disasters. It promotes more energy efficient technologies to minimize greenhouse gas emissions.	Climate mitigation through energy efficiency
2007	Florida Legislature	Executive Order 07-127	Set new building standards that were to increase the energy performance of new buildings 15% by 2009 from the 2007 energy code.	Climate mitigation through energy efficiency

(Table 4-14. continued)

Year	Entity	Action	Description	Climate Focus
2007	Florida Legislature	Executive Order 07-128	Created the Action Team on Energy and Climate Change to develop a comprehensive Energy and Climate Change Action Plan for the state and called for recommendations for mitigation and adaptation strategies to combat adverse impacts from climate change.	Climate mitigation and adaptation
2007	Center for Urban and Environmental Solutions - Florida Atlantic University, National Commission on Energy Policy	Florida's Resilient Coasts: A state policy framework for adaptation to climate change	Written in recognition of the threats of climate change to the state, including the likelihood of sea level rise, more intense hurricanes, drought, and torrential rainfall. This report outlines strategies for policy makers to more effectively address climate change impacts.	Extremes, sea level rise, hurricanes
2007	Florida Legislature	Executive Order 07-126	Required the Department of Management Services to only approve the purchase of new vehicles with the greatest fuel efficiency in a given class to minimize greenhouse gas emissions. Among other things, it sets near-term emissions goals for state agencies, and directs the Department to set leadership in Energy and Environmental Design (LEED) green building standards for the state's new and existing state-owned buildings.	Climate mitigation through energy conservation
2007	Florida Department of Environmental Protection, Division of Emergency Management; Department of Agriculture and Consumer Services; and South Florida Water Management District	Florida Drought Action Plan	Prepared in reaction to recent drought, the plan identifies short- and mid-term actions, which include implementing any of the steps considered in the 2002 Florida Water Conservation Initiative; developing alternative water supplies; pursuing water conservation; considering more ways to convert water disposal into reuse; considering implementing water supply and growth management linkages in the 2005 legislative reforms; and having local governments adopt local ordinances.	Climate mitigation, water conservation

(Table 4-14. continued)

Year	Entity	Action	Description	Climate Focus
2008	Action Team on Energy and Climate Change	Florida's Energy & Climate Change Action Plan	The Plan was developed to secure Florida's energy future, reduce greenhouse gas emissions, and support and sustain economic development in the emerging "green tech" sectors. It includes 50 policy recommendations to reduce greenhouse gas emissions that, if implemented, would exceed the state's targets for 2017 and 2025. Recommendations and strategies are divided by sector and include adaptation strategies.	Climate mitigation through energy conservation, adaptation
2008	Florida Legislature	The Florida Climate Protection Act (HB 7135)	Created the Florida Energy and Climate Commission (which replaced the Florida Energy Commission) and the Florida Energy Systems Consortium, which will develop and implement a "comprehensive, long-term, environmentally compatible, sustainable, and efficient energy strategic plan for the state." The bill also required the Building Commission to prepare a 2010 edition of the state Energy Efficiency Code for Building Construction that increases the energy performance of new buildings by at least 20% relative to 2007 and 50% by 2019.	Climate mitigation through energy efficiency, sustainability
2008	Florida State Government	Final Florida Greenhouse Gas Inventory and Reference Case Projections 1990-2025	Pursuant to EO 07-126 and part of the Governor's Action Team on Energy and Climate Change, this is a comprehensive assessment of greenhouse gas emissions. The state has since produced quarterly updates of its State Greenhouse Gas Reduction Scorecard. The first inventory was completed in 2001.	Climate mitigation through conservation
2009 & 2010	Florida Oceans and Coastal Council	The Effects of Climate Change on Florida's Ocean and Coastal Resources	Prepared for the Florida Energy and Climate Commission, this report addresses climate change impacts on ocean and natural resources, such as ocean acidification, altered rainfall and runoff patterns, air temperatures, ocean temperatures, coral bleaching, and marine health, as well as climate change impacts on infrastructure, human health, and the economy. A 2010 update provided current up-to-date information regarding sea level rise and identified future priorities for policy, planning and management.	Climate impacts, oceans, coasts, public health, economy, sea level rise

(Table 4-14. continued)

Year	Entity	Action	Description	Climate Focus
2010	Florida Department of Agriculture & Consumer Services	Forest Resources – 2010: Florida’s Statewide Strategies	Prepared in response to the 2008 Farm Bill, the report includes a section on meeting climate change challenges. It integrates the policies outlined in the 2008 Climate Change Action Plan related to “Agriculture, Forestry, and Waste Management.”	Climate mitigation, adaptation, impacts (incl. invasive species and species migration)
2013	Florida Division of Emergency Management	State of Florida Enhanced Hazard Mitigation Plan	Adopted in 2013, the plan is an update to the 2010 plan and incorporates local information where appropriate. All 67 counties in the state have approved local mitigation strategies. Pinellas County faces high risk to hurricanes, severe storms, extreme heat, and erosion.	Hazard mitigation

Florida is one of few states to have developed a climate adaptation plan (as of 2013). Completed in 2008, this Energy & Climate Change Action Plan recommends 50 policy actions aimed to secure Florida’s energy future by reducing greenhouse gases and supporting new green sector technologies (GATECC 2008). Florida shows further leadership in the region as one of only two states in the Southeast designated as a Center for Disease Control Climate-Ready State, a national public health initiative to increase the capacity of state and city health departments to study, prepare for, and respond to the health effects of climate change. (The other state in the Southeast a part of this program is North Carolina.)

Several local-level actions in Pinellas County and the surrounding region have integrated measures into land use plans that support climate mitigation and adaptation to climate change. Table 4-15 shows examples of local-level actions for Tarpon Springs, Pinellas County, and the surrounding region. Tarpon Springs and the broader southwest region of Florida are taking active steps to reduce climate impacts than other locations in this analysis, which may be partially attributed to having two major cities in proximity.

The Countywide Plan for Pinellas County includes strategies for conserving wetlands, improving air quality, and preserving vegetated areas (PPC 2005). The City of St. Petersburg's Comprehensive Plan identifies greenhouse gas reduction strategies, and it was the first community in Florida to be designated a "green city" by the Florida Green Building Coalition in 2007 due to the city's focus on sustainable land development, water conservation, environmental purchasing practices, and others (CSP 2013). The Southwest Florida Water Management District developed a regional water plan for the Tampa Bay Region that identifies climate change as a threat to water supplies and a need for infrastructure adaptation.

While not in the immediate vicinity of Tarpon Springs, the City of Punta Gorda, located approximately 160 kilometers (100 miles) south of Tarpon Springs, is included here as an example of a progressive city, both in the state and nationally, that has addressed climate change through climate mitigation and adaptation to reduce adverse economic and environmental impacts. The city developed an Adaptation Plan in 2009 that outlines vulnerabilities and specific adaptation strategies to climate issues, and their comprehensive plan includes language to address sea level rise and strategies to reduce coastal effects (SWFRPC 2009). In addition, Lee County, which is a neighboring county to the city of Punta Gorda, developed a Climate Change Resiliency Strategy, which also focuses on strategies to address the potential impacts of climate change in the county.

At both the state and local levels, climate and climate-related issues seem to be a greater focus overall than for the other locations in this study. Figure 4-32 shows the word cloud of the top 50 most frequently occurring words in all state and local

Table 4-15. Summary of local- and regional-level actions related to climate mitigation, adaptation, or hazards in Tarpon Springs, FL and the surrounding region.

Year	Entity	Action	Description	Climate Focus
1984	City of St. Petersburg (with consultants)	St. Petersburg Downtown Urban Design Plan	Identifies energy conservation as a priority, promoting energy conservation through the "use of alternative fuel sources other than oil or coal generated electricity for providing at least one-half of the building's space heating or cooling needs or all hot water needs."	Climate mitigation through energy conservation
2002	City of St. Petersburg City Council, Planning Commissioners, neighborhood activists	Vision 2020 Plan	Developed by a cohort of volunteers consisting of citizens, businesses, and other stakeholders, along with the City Council, the plan calls for a healthy environment based on application of best practices that include restored tree canopy, water quality and conservation, energy conservation, and habitat protection.	Climate mitigation, environmental restoration, energy conservation
2005	Tampa Bay Regional Planning Council	Future of the Region: A Strategic Regional Policy Plan for the Tampa Bay Region	Initially adopted in 1995 but amended in 2005, the plan outlines a set of policies to guide water quality, air quality, wetlands and other sensitive areas, floodplain management, stormwater management, and other measures to protect the natural environment and improve hazard mitigation.	Conservation, hazard mitigation
2005	Pinellas Planning Council	The Updated Countywide Plan for Pinellas County	Outlines several actions that would make Pinellas County more resilient to hazards and climate change impacts, such as conserving open space and wetlands, using energy efficiency and conservation where possible, and improving air quality. The Land Use Component also includes measures to increase bicycle and pedestrian pathways and preserve open space and vegetated areas.	Climate mitigation, conservation
2006	Southwest Florida Regional Planning Council	Sea Level Rise in the Tampa Bay Region	The Project was completed with funds from grants by the U.S. EPA and coordinated with the State of Florida. It discusses future sea level rise projections for the area and the three main adaptation strategies: protect, accommodate, and retreat.	Adaptation, sea level rise
2009	Southwest Florida Regional Planning Council	City of Punta Gorda Adaptation Plan	Funded through grants from the U.S. EPA, this report is both an assessment of economic and physical vulnerabilities the city faces from climate change, as well as an adaptation plan to respond to the highest priority vulnerable areas.	Adaptation, climate impacts

(Table 4-15. continued)

Year	Entity	Action	Description	Climate Focus
2010	Lee County	Lee County Climate Change Resiliency Strategy	Builds on the climate change vulnerability assessment for Lee County and includes a process for identifying potential climate change resiliency strategies through consultation with local government leadership.	Climate impacts, adaptation
2010	City of Tarpon Springs	City of Tarpon Springs Comprehensive Plan	The Land Use element recognized energy efficient land use patterns and called for the reduction of greenhouse gas emissions to mitigate negative impacts to public health, particularly for its older population. The Coastal Planning Area and Conservation Element discussed the need to protect and construct wetlands as a flood protection mechanism, as well as the need to protect property and people in the coastal high hazard area.	Climate mitigation, impacts, hazard mitigation
2010	City of Tampa, University of South Florida, University of Florida (UF), and UF's Hillsborough County IFAS Extension	City of Tampa Urban Ecological Analysis and Management Plan 2010-2012	An ecological analysis of the City's urban forest was completed for 2006-2007, which examined the temporal change in tree canopy coverage from 1975-2006 and concluded that the potential existed to substantially increase tree cover on most land uses within the city. It outlined the beneficial ecosystem services provided by trees in Tampa with an annual economic value in the tens of millions of dollars. This project re-examined the city's urban forest, as required by the Tampa tree ordinance, and developed a long-term urban forest management plan.	Climate mitigation, environmental restoration
2011	Southwest Florida Water Management District	2010 Regional Water Supply Plan: Tampa Bay Planning Region	This Plan assesses projected water demands for the southwest region, including Pinellas County, to meet demands to 2030. It addresses climate change as a threat to water supply sources and the potential need for infrastructure adaptation. It assumes a 'monitor and adapt' approach to climate change.	Water conservation, adaptation

(Table 4-15. continued)

Year	Entity	Action	Description	Climate Focus
2011	City of St. Petersburg	City of St. Petersburg Comprehensive Plan	The Plan's Future Land Use Element identifies energy conservation and greenhouse gas reduction strategies as a priority. The city has been recognized for supporting strategies related to electrical energy, parks, sustainable land development, environmental purchasing practices, water conservation, and recycling. The City encourages 'green' construction practices and renewable energy sources as part of its economic development effort.	Climate mitigation through renewable energy, sustainability, environmental conservation,

documents. The words ‘water,’ ‘energy,’ and ‘climate’ occur within the top 10 most common words. Other frequently occurring words related to climate include ‘emissions,’ ‘mitigation,’ and ‘GHG.’ Similar word clouds were generated for just state-level actions and again for just local-level actions. Water remained an important topic at all levels; however, climate occurred more frequently within state documents, including the topics of emissions and energy. While climate change has been a clear focus in recent years, actions may not adequately address pertinent future risks. Aside from sea level rise and coastal concerns, other threats are not well represented. While some actions have considered threats from more intense hurricanes and torrential rainfall (Murley et al. 2007), severe storms that have historically produced considerable losses in the region do not appear as a commonly occurring concept in these documents. Also absent are words related to heat extremes, which may become a greater threat in the future based on trends in extreme indices.

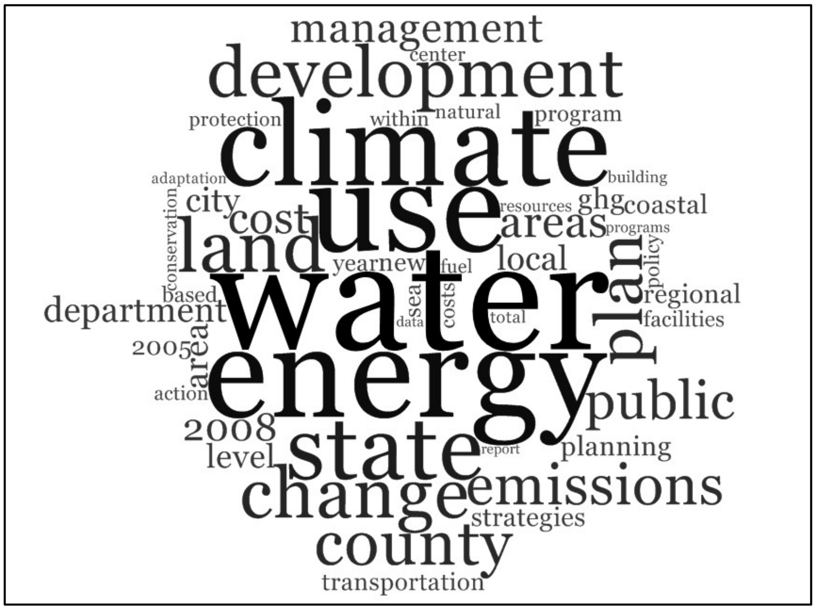

Figure 4-32. Word cloud showing the 50 most commonly occurring words found within all state- and local-level actions in Florida included in this study.

4.4 Discussion

Analysis of climate-related actions for these six case studies reveals overarching themes across the Southeast. Overall, these locations show similar levels and types of actions at both the state and local levels. Figure 4-33 shows the overarching themes that emerged in state-level documents for each state represented by these six sites. State-level actions emphasize environmental protection, energy efficiency and conservation, and hazard mitigation measures, particularly related to drought. Commonly occurring sub-themes include water conservation, wetlands restoration, green space, and renewable technology. Energy efficiency/conservation and renewable technology are most likely emphasized in anticipation of growing economic opportunities through carbon markets and federal initiatives related to alternative energy sources. Drought management and related water resource planning have been a major area of focus largely in response to periods of devastating drought. In addition, every state has developed a state Forest Assessment and Strategy report in compliance with the Cooperative Forestry Assistance Act (CFAA), enacted by the 2008 Farm Bill, to be eligible for federal forestry assistance. These documents are similar across states, as they closely follow the guidelines outlined in the national guidance documentation (USDA 2008). Most of these forestry reports address forests' role in helping to mitigate climate change, as well as adaptation strategies for addressing the impacts of climate change on forests. Lastly, leadership appears to be an important differentiation between states that have addressed climate change issues directly, such as through development of Climate Action Plans (e.g. South Carolina, Florida, and Arkansas) and those that have only addressed climate change on a limited or tangential basis (e.g. Mississippi, Texas, and Oklahoma).

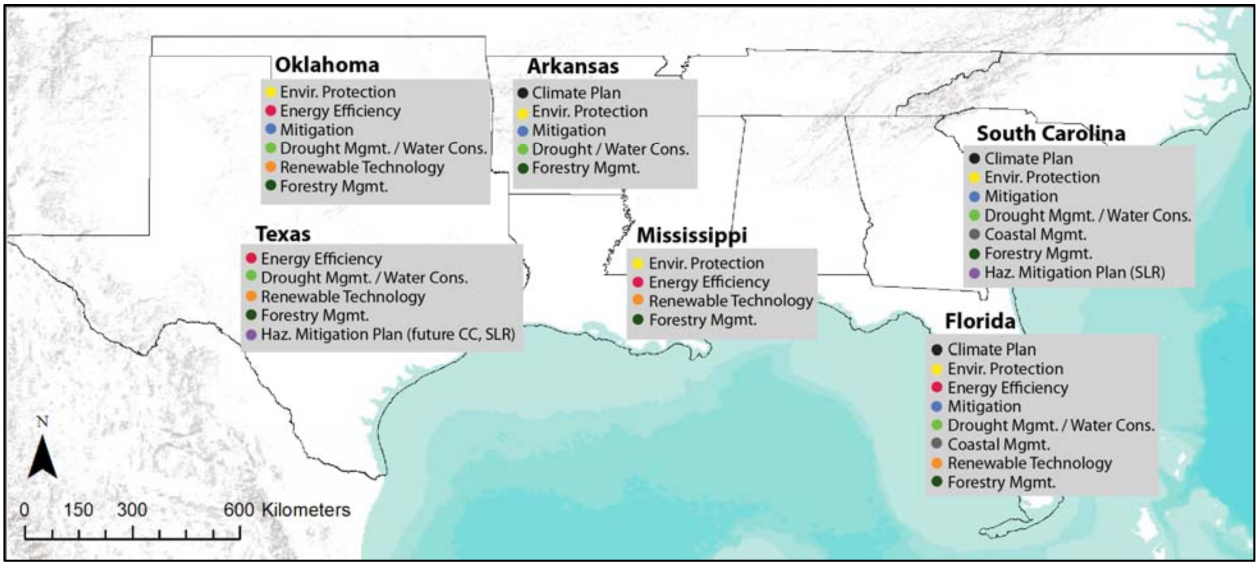

Figure 4-33. Overarching themes found within state-level documents for each state corresponding to the six case study sites in the Southeast.

Figure 4-34 shows the themes that emerged in local-level documents for each site and their surrounding areas. Environmental protection is a main area of focus for local governments overall. Half of the cities and counties focus specifically on sustainability in many plans and local initiatives. In addition, Pinellas and Washington Counties address or recommend adaptation strategies in their planning efforts. Okeene, Brenham, and Tarpon Springs (and surrounding areas) are incorporating targeted climate mitigation measures, such as improved land management practices to reduce the urban heat island effect, installing cool roofing, and restoring and increasing tree canopy cover.

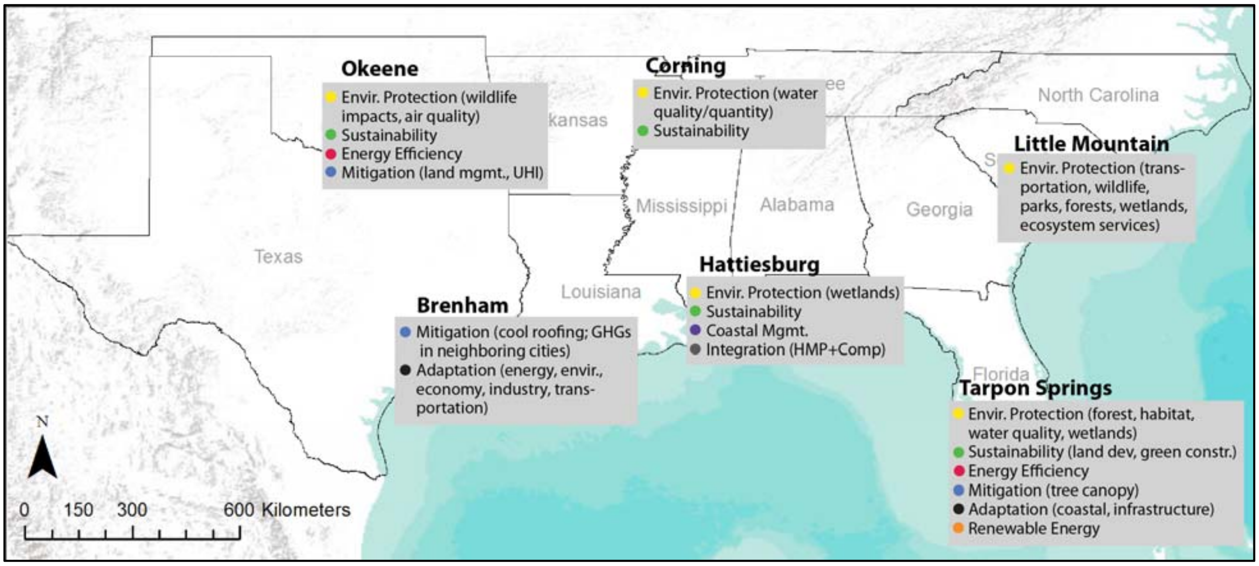

Figure 4-34. Overarching themes found within local-level documents for each of the six case study sites in the Southeast.

The themes that emerged in these state- and local-level documents reflect an emphasis on strategies that have the potential to provide multiple benefits to communities, such as wetland restoration to filter pollution and mitigate storm impacts or the enhancement of green spaces to reduce urban heat island effects while improving quality of life for citizens. While many of these actions do not directly address climate change, a majority could be used to help mitigate and/or alleviate adverse effects of climate change when taken together. As such, many of the actions that are taking place can be beneficial in terms of climate mitigation and long-term adaptive capacity, as similarly concluded by Bierbaum et al. (2013) in their review of adaptation actions across all levels of government. Despite the benefit of such actions and advancements made by local governments, these local actions should not be considered solutions to climate change and must be implemented in addition to more aggressive, innovative solutions that can produce more effective and lasting solutions, across all scales.

Despite similarities, important differences emerged between sites. Four of the six sites focus heavily on water-related issues, including Arkansas, Florida, Texas, and Oklahoma. The impetus behind this focus may differ somewhat between states. In Arkansas, the importance of agriculture to the state's economy, coupled with the fact that Clay County had the highest crop-related damages of all six sites, likely explains its focus on water-related issues. Conversely, Pinellas County, Florida had the lowest crop-related damages of all sites, and the emphasis here is likely due more to threats from severe storms, flooding, and sea level rise. Many actions taking place for the western sites in Texas and Oklahoma have been largely in response to the impacts from drought and concerns over water resources. As a result, these two western sites are beginning to consider climate change impacts largely in relation to state water planning. It is important to note that crop losses and indirect effects of heat, drought, and wildfire tend to be underreported in NCDC's Storm Database (Gall et al. 2011). As such, it is likely that the impacts from drought and heat are even higher than that shown in Table 4-3.

The eastern sites in South Carolina and Florida appear to focus on climate change more than the two western sites, as coastal issues, climate mitigation, drought, and adaptation are addressed in many of the South Carolina and Florida documents. South Carolina and Florida have also developed state climate action plans. In Texas, local governments appear to be addressing climate change issues more than the State government. Interestingly, Pinellas, Newberry, and Washington Counties had the highest median household incomes of the six counties included in the analysis. By comparison, Arkansas, Mississippi, and Oklahoma have addressed climate-related concepts on a more limited basis. While not necessarily linked, this suggests that factors unrelated to extremes likely play important roles in driving climate-related action.

Further differences exist between the Gulf Coast (Mississippi) and northern, interior locations (Arkansas). While both Mississippi and Arkansas are addressing climate-related issues through water planning, forest management, and wetlands, only Arkansas has passed climate mitigation measures to set pollution and emissions reduction goals. Conversely, Mississippi has focused only on energy efficiency without setting any pollution or emissions reduction targets. Distinct differences exist between the two Gulf Coast sites as well. While Mississippi has included some measures related to coastal issues, Florida has been much more active in addressing the coastal impacts of climate change. In fact, Florida has passed legislation and adopted a variety of plans that directly address climate change impacts, mitigation, and adaptation, at both the state and local levels. Mississippi lags far behind in this regard.

While states and local governments are increasingly engaged in adaptation planning, few plans are actually implemented (Bierbaum et al. 2013) or may not produce the intended effects (Millard-Ball 2012b). In addition, policies and programs often generate funds for planning, but rarely incorporate support for subsequent implementation. Berke et al. (2009) found that implementation and monitoring represented the weakest sections of coastal state hazard mitigation plans, and only five of 30 coastal states have incorporated climate change into the risk assessments within their hazard mitigation plans. In general, recommended climate mitigation and adaptation strategies outlined in legislative reports and planning documents are implemented through specific planning projects and/or policies. While implementation was not the focus of this analysis, most documents examined for these six locations are recent efforts, suggesting that few states and local entities have implemented specific climate-related strategies. Thus, while the level of climate and risk-based planning has increased considerably during the last few years, it will likely be several more years before comparable increases occur in implementation and even longer still before the benefits are realized. This is particularly important given that the pace and extent of adaptation activities have not been proportional to the risks from climate change (NCADAC 2013). Despite a lack of implementation, state and local governments in the Southeast may be better positioned to increase adaptation activities moving forward given existing planning efforts within different sectors that have promoted environmental conservation, energy efficiency, and hazard mitigation, for instance. Many of these actions can help reduce local impacts of extremes and contribute to climate mitigation. In addition, some sector-based plans are incorporating strategies to reduce the effects of climate extremes. Nevertheless, few sector-based plans have readily incorporated climate mitigation and/or adaptation outright into their planning efforts. As suggested by

Berke et al. (2009) in their analysis of coastal state hazard mitigation plans, more work will be needed to increase links between land use, hazard mitigation, and climate adaptation planning. The integration and implementation of climate-related actions will likely remain a key challenge in this region, given that the majority remain skeptical about climate change (Leiserowitz et al. 2012).

This analysis suggests that local governments are proactively seeking ways to reduce risk and promote climate mitigation and adaptation solutions, consistent with Hansen et al. (2013) and Bierbaum et al. (2013). As local governments are typically responsible for planning (Emmer et al. 2007), they have often taken the lead on climate policy ahead of state and national governments (Betsill 2001, Betsill and Bulkeley 2006). Given a lack of federal mandate or guidance before the mid- to late-2000s, these community-level actions to reduce risks from natural hazards and climate change represent proactive steps (Hansen et al. 2013). This is especially important in the Southeast, given the region's political climate, which has been less supportive of climate policies. The lack of Federal leadership until recent years may further help to explain why community efforts have been more closely tied to their experience with larger natural disaster events. In addition, although long-term hazard mitigation planning was not incentivized until the early 2000s following the DMA of 2000, hazard risk assessments are the strongest and most thorough components of state hazard mitigation plans (Berke et al. 2009), providing communities with more information and data related to hazards on which to base planning efforts.

Several factors have been associated with higher rates of climate change policy and planning at the local level. Bedsworth and Hanak (2013) found that population size, household income, and support from local leaders and the public were all positively associated with high levels of adoption of climate policy in California. Results from this analysis suggest that similar factors may play a role for states in the Southeast. Counties with higher populations and median household incomes appear to be more active in climate change planning and/or policy. For instance, sites with the highest number of documents addressing climate mitigation and/or adaptation are Washington, Newberry, and Pinellas Counties, which have the highest median household incomes. In addition, the most progressive site in terms of climate-related state and local actions in this study is Pinellas County, which has the highest population and median household income of all sites. In general, nearby larger cities were much more engaged in climate-related issues than each of the six case study sites (e.g. Houston and Austin versus Brenham). These findings are unsurprising given that larger cities generally have greater capacity for planning, including larger staffs, larger budgets, and greater expertise. Furthermore, larger cities may feel obligated to take more aggressive climate mitigation measures given that they generally have larger relative contributions to greenhouse gases.

Smaller communities may benefit from actions happening at the regional scale and from neighboring communities. This study provides evidence that regional entities in parts of the Southeast are more engaged in climate-related issues than municipalities within their jurisdictions (e.g. Central Midlands Council of Governments versus Little Mountain, SC). Bedsworth and Hanak (2013) found that regional approaches to climate-related issues, i.e. those that span a county and/or multi-county jurisdiction, are more effective at overcoming barriers faced by local governments in small and less wealthy communities. Thus, it will be important for larger cities and regional entities to maximize transfer of knowledge and coordinate regional approaches with nearby towns and rural communities to help them prepare for the impacts of climate change.

The extent to which state and local actions have addressed extremes in temperature and precipitation varies widely by site and type of action. Results indicate that, barring state hazard mitigation plans, few documents have directly addressed variability and/or impacts of extremes in temperature or precipitation. Actions that have incorporated extremes are generally limited to climate action or adaptation plans. For instance, temperature extremes are heavily emphasized in the Arkansas Governor’s Commission on Global Warming Report (AGCGW 2008), and temperature and precipitation extremes are well represented in the Florida Energy and Climate Change Action Plan (GATECC 2008). Exceptions to this include plans that address specific risks. For instance, words related to precipitation extremes tend to occur frequently in drought plans, with particularly heavy emphasis in the Oklahoma Drought Management Plan (ODMT 1997), the South Carolina Drought Response Plan (SCEMD 2009), and Texas’ State Drought Preparedness Plan (TDPC 2005). However, the term ‘winter weather’ appeared almost exclusively in hazard mitigation plans, despite winter weather having generated considerable losses historically for most sites. At the local level, extremes in temperature and precipitation appear to be an even lesser focus. The types of documents that do focus on extremes range in scope. In Florida, the City of Punta Gorda and Lee County have prepared climate adaptation and resilience plans, respectively, that contain a relatively high degree of language pertaining to both temperature and precipitation extremes. Temperature extremes occur frequently in the

Oklahoma Comprehensive Water Plan Report on the Central Watershed Planning Region (OWRB 2011). In addition, language contained within the City of Houston's Commercial Energy Conservation Code heavily emphasizes extremes in temperature (CityofHouston 2008).

Despite increased attention and information on climate in recent years, Godschalk et al. (2009) emphasized that planners need more data and evidence to support the case for mitigation. Few documents investigated in this study specify any particular data and information needs or impediments related to climate. The few documents that do identify needs relate to: 1) environmental management resources and planning, 2) public attention, outreach, and education, 3) local examples and pilot programs for new energy/carbon markets, 4) increased monitoring, monitoring tools, and inventories, 5) regional climate projections, 6) research on future climate impacts, 7) long-range policies for extreme drought, and 8) coastal restoration activities.

4.4.1 Recommendations

Climate adaptation is an emerging area of focus at all levels of government. The findings from this study and conclusions drawn from these six case study sites provide insights into the types of activities state and local governments are engaging in related to climate mitigation and adaptation. Although the documents included in this analysis are not comprehensive, they represent the variety and breadth of approaches being taken by state and local governments in the Southeast. Many of these actions, particularly at the local level, represent proactive approaches that local government entities have taken to address risk in recent years, largely in the absence of federal guidance or direction. This section offers specific recommendations for Federal, State, Local, and Tribal governments to consider in planning for the risks and impacts from climate change.

Integration of extremes into existing efforts

1. Integrate adaptation into existing planning efforts, rather than developing stand-alone adaptation plans only.
2. Consider changing extremes in maximum and minimum temperatures in addition to threats from natural disasters in sector-based planning efforts, particularly the implications of changes in minimum temperatures for the energy/utility, agricultural, and public health sectors.
3. Adapt new and existing infrastructure to better withstand both cold and warm extremes, as well as increased intensity and magnitude of precipitation events.

Expansion of existing knowledge and resources

4. Maximize the transfer of knowledge from regional planning entities and large cities to nearby small, rural towns and cities to increase local capacity for adaptation to climate change.
5. Develop strong outreach and education campaigns about the impacts of climate change and benefits of adaptation geared for specific sectors and the general public.

Plan implementation and effectiveness

6. Identify and prioritize existing measures that can contribute to mitigating climate change and/or reduce adverse impacts of climate change in adaptation planning.

7. Develop locally relevant metrics for monitoring the effectiveness of climate action plans and adaptation strategies.
8. Incorporate local and regional climate change data and information to the best extent possible.

Increased coordination and compliance

9. Increase integration of climate adaptation, hazard mitigation, and land use planning efforts to maximize effectiveness of policies.
10. Align sector-based plans with climate mitigation and adaptation goals.
11. Ensure that federally driven state plans and assessments are in line with land use planning and vice versa. For instance, State Forest Assessments and Strategies should coordinate with land use plans and zoning ordinances to identify optimal areas for tree densification and green space development or preservation.

4.5 Future Research

Findings from this study provide insight into the types of actions taken by small communities throughout the Southeast to reduce risk from extremes and climate change impacts. Several studies have shown that society's vulnerability to extreme events appears to be increasing as a whole (Kunkel et al. 1999b, Lynch and Brunner 2007, Pielke et al. 2008). According to an NRDC report that assessed state-level climate change preparedness on water-related impacts of climate change, all states but one in the Southeast (North Carolina) were said to be lagging behind other states in the country as the least engaged on climate change preparedness (Chou et al. 2012). The findings from this study can help inform new actions or augment existing ones at the state, regional, and local levels so as to enhance local capacity and ensure that smaller communities benefit from actions by larger jurisdictions.

This research should be expanded to assess the factors that typically drive and prohibit action in the region. First, future work should incorporate a greater number and variety of sites within the Southeast to enable a more thorough assessment of the breadth of activity at the state and local levels. Second, a longer period should be considered to better understand how actions have changed over time and why. Third, federal actions should be incorporated to determine the contribution of federal mandates versus incentive-based programs and the response of state and local governments. For instance, political, social, and economic factors should be considered to measure the relative contributions of certain variables on climate actions. This would build upon the findings by Bedsworth and Hanak (2013) who conducted a similar analysis of factors affecting local actions in California. This information can be used in subsequent work to build a more complete regional comparative analysis in the country to help shape and guide public- and private-led programs related to climate change at all levels of government. Lastly, data on major weather and climate events could be used and compared with sector-based planning efforts to determine the effectiveness of these plans in responding to and reducing threats from extreme events.

More research is needed to understand the effectiveness of risk-based plans and barriers to implementation. This research could benefit by using surveys for distribution to state and local governments, as well as private and nonprofit organizations that have been engaged in climate mitigation and adaptation programs. Surveys questions should focus on priority issues and projects, reasons for past action or lack thereof, data and information needs, past successes and challenges, and continued impediments to preparing for climate change. In addition, information about if and how local governments are implementing climate mitigation and adaptation measures is of particular interest, given that the local effects of climate change may be most severe and planning is largely the responsibility of local governments. Finally, this research could be synthesized with additional research to formulate a set of local climate policy recommendations, along with supporting local precedents, to guide future planning efforts.

CHAPTER 5: CONCLUSIONS AND FUTURE RESEARCH

This dissertation was organized into three distinct, yet connected, journal-style chapters. Each of these chapters had specific objectives. These objectives were as follows:

Chapter Two (study one)

1. to assess annual spatial and temporal trends since the mid-20th century in temperature and precipitation extremes for the Southeast,
2. to examine seasonal trends in temperature and precipitation extremes for the Southeast,

Chapter Three (study two)

1. to group stations together with similar temporal patterns in extreme temperature and precipitation indices to develop a regionalization of extremes for the Southeast,
2. to characterize a seasonality of extremes based on extreme temperature and precipitation indices,

Chapter Four (study three)

1. to assess the level and type of state- and local-level hazard and climate-related planning efforts for locations across the Southeast United States, and
2. to compare the focus and content of efforts to assess their relevance and effectiveness in preparing communities for the impacts of climate change.

5.1 Study One Conclusions

An increasing amount of information exists regarding extreme weather and climate variability and the impacts of extreme events on society. Synthesis reports produced for the USGCRP’s NCAs offer increasingly detailed regional information on extremes; however, more information and data on climate change and impacts are needed to inform effective strategies for climate mitigation and adaptation. This study offers a more comprehensive assessment of extremes in the Southeast than any previous known research using a pre-defined set of 27 extreme temperature and precipitation indices developed by the ETCCDI Working Group and maintained through the CLIMDEX project. Temporal and spatial patterns in extremes were assessed for 107 stations in the Southeast from 1948 to 2012. Given that the Southeast is a hazard-prone region vulnerable to climate change, a detailed analysis of extremes is particularly important for this region. Moreover, investigating extremes using an international set of indices can be useful for assessing the benefits and limitations of various climate extreme indices.

Results suggest that the Southeast is becoming warmer and wetter overall. Much of the warming seen in the Southeast is due more to increases in extremely warm minimum temperatures rather than extremely warm maximum temperatures. While much of the country and globe are seeing increasingly high maximum temperatures, this set of temperature-related indices reveals that most Southeast stations show significantly decreasing trends in warm daytime temperatures. This analysis reaffirms widespread increases in nighttime temperatures coupled with decreases in daytime temperatures, thus narrowing diurnal temperature ranges across the region. This ‘warming hole’ has been well documented in previous research (Pan et al. 2004, IPCC 2007, Rogers 2013). Rogers (2013) found that soil moisture, cloud cover, and teleconnections, particularly the Arctic Oscillation, that are important drivers of temperature in the Southeast only partially account for the cooling observed in the region during the last century. Increasing wetness is largely reflected through more intense and more efficient precipitation events; however, the duration of precipitation appears to be getting shorter overall. While increasing wetness is evident for much of the region, easterly locations appear to be getting drier with negative trends in many wet-related indices, particularly in the Carolinas.

Results from this analysis reflect periods of elevated extremes in the 1950s and 2000s for the Southeast, consistent with other research on climate extremes. According to the Climate Extreme Index (CEI), the United States has seen much above-normal maximum and minimum temperatures and heavy daily precipitation, particularly over the latter half of the 20th century (Gleason et al. 2008). Elevated CEI values were particularly apparent in the South in the 2000s (Gleason et al. 2008). Other studies similarly show periods of elevated extremes in the 1930s, 1950s, and since the early 1970s (DeGaetano and Allen 2002, Gleason et al. 2008).

This analysis used a subset of extreme indices to assess seasonal trends in temperature and precipitation. In fall, average maximum temperatures are decreasing and average minimum temperatures are increasing for the region as a whole. In particular, there are fewer nights below the 10th percentile and fewer days above the 90th percentile. Annual absolute warmest daytime temperatures are decreasing for much of the region in fall as well. The fall is becoming significantly wetter, as reflected by increasing 1- and 5-day consecutive precipitation trends. Spring temperatures are warming, but to a lesser extent than in other seasons. This warming is reflected most in nighttime temperatures. Unlike fall, spring is generally becoming drier in most states, with the exception of Oklahoma and Tennessee. In summer, mean maximum temperatures are decreasing for all states except Florida, Louisiana, and South Carolina, where average maximum temperatures have not changed much since 1948. Conversely, mean minimum temperatures are increasing everywhere. Parts of the central and eastern portions of the region show increasing dryness in summer, particularly Arkansas, Louisiana, North Carolina, and South Carolina. The Southeast is experiencing more cold extremes in winter. Annual absolute maximum daytime temperatures are decreasing, and there are fewer days and nights above the 90th percentile for a given day. In addition, absolute coldest nighttime temperatures are getting colder across much of the region in winter. Winter precipitation patterns are more mixed, but overall the magnitude of 1- and 5-day precipitation events are decreasing, particularly in the north and east. These seasonal trends have particular implication for various sectors that are sensitive to fluctuations in cold and warm extremes, as well as heavy or prolonged precipitation events.

5.2 Study Two Conclusions

This study used results from the extreme temperature and precipitation indices calculated in Study One to present a ‘geography of extremes’ for the Southeast using PCA. The dataset used for input to the PCA consisted of annual standardized index values that averaged together all temperature and precipitation indices separately. Thus, two classification schemes were produced – one for temperature extremes and one for precipitation extremes. A third PCA was performed on the monthly indices to develop a seasonality of extremes for the Southeast. No known previous research has developed such a regionalization of climate extremes in the Southeast or examined how extreme seasons compare to traditional 3-month seasons. A regionalization and seasonality of extremes can increase understanding of extreme behavior in the region by unmasking differences that exist at the sub-regional level and by helping communities and policy makers target specific strategies at the local level.

Results from the temperature-based PCA showed that the majority of variance (65%) in these indices could be explained by retaining the first two principal components. By assigning stations to their component of maximum loading, two sub-regions emerged. Results divided stations into east and west sub-regions, whereby stations in the east and west tend to covary together but in opposite directions. The k-means clustering results similarly partitioned the region into east and west sub-regions. This grouping of stations can likely be explained by synoptic-scale patterns that influence weather regimes in the region. The area is frequented by frontal systems that track eastward, shifting the pattern of the jet stream from a zonal to more meridional flow. Thus, as a system moves eastward, more westerly locations that are behind the system are influenced by troughing and experience reversals in temperatures and wind directions, compared to eastern locations in front of the system that are influenced by ridging and high pressure.

Results from the precipitation-based PCA suggest that precipitation extremes are much more variable, making a regionalization more difficult to discern. More components were needed to explain the majority of variance in the original data. Ten components were retained to explain 62 percent of the variance. As stations were assigned to their component of maximum loading, only the first four components displayed coherent spatial patterns, which may be described as east, west, central/upper and Gulf Coast regions. However, after a Varimax rotation was applied, a greater number of smaller groups of stations emerged. This suggests that precipitation extremes tend to be much more variable across the Southeast, particularly compared to temperature extremes. The k-means clustering analysis similarly resulted in small, coherent groups of stations across the region.

Extreme seasonality in the Southeast varies somewhat from standard 3-month definitions of extremes, though not by much. The seasonality was largely based on temperature extremes, with nine temperature indices and only two precipitation indices used in the PCA. Results showed that 93 percent of the variance in the original monthly extreme indices could be explained by the first two components. The first component seemed to contrast winter and summer months, while the second component represented transitional seasons. Winter may be defined as November to February, while summer may be defined as June to August, with extremes being most pronounced in July and August being more of a transition month. Based on maximum loadings, April and May contribute most to spring, while September and October contribute most to fall.

5.3 Study Three Conclusions

The third study analyzed state and local planning and policy related to climate change and extreme events. Little research exists on climate-related planning at the local level, though adaptation planning has increased significantly in recent years. By analyzing six sites as case studies, climate-related planning efforts were compared for smaller communities in the Southeast to illustrate the type, level, and content of actions taking place to prepare communities for the risks associated with climate change. Results from the first two studies were used to select sites in different sub-regions that exhibit different patterns of extreme variability. The six case study sites were: 1) Corning, Arkansas, 2) Brenham, Texas, 3) Hattiesburg, Mississippi, 4) Okeene, Oklahoma, 5) Little Mountain, South Carolina, and 6) Tarpon Springs, Florida. Trends in temperature and precipitation extremes from Study One, as well as historical hazards and associated losses, were used to place state and local planning and policy efforts into context. While not a comprehensive review of state- and local-level planning in this region, this analysis provides new information about local actions addressing the risks from climate change, with implications for the country and beyond.

An increasing amount of research and survey-based reports have shown that climate-related planning has increased nationally in recent decades (Betsill 2001, Betsill and Bulkeley 2006, Lackstrom et al. 2012, Bierbaum et al. 2013, Hansen et al. 2013); however, more work is needed in the evaluation of plans (Millard-Ball 2012a, Millard-Ball 2012b, Bierbaum et al. 2013). Florida, South Carolina, and Arkansas are the only states in the Southeast that have developed climate adaptation and/or action plans. Results from this study show that state and local governments are taking a more diffused approach by integrating measures into existing plans, many of which can help communities mitigate and adapt to climate change. For instance, the focus of many sector-based plans and comprehensive plans included goals related to environmental conservation, energy efficiency, resource management, renewable technologies, and reduction of greenhouse gases.

Florida, Texas, and South Carolina are leading the Southeast in terms of climate-related mitigation and adaptation. Common areas of focus across the region included water-related planning linked to drought, as well as energy and emissions. Sector-based planning that incorporates threats from natural hazards and climate change is being done in response to specific threats and/or events, as well as in response to federal mandates. Changes in the frequency, intensity, or duration of extremes associated with temperature and precipitation, such as heat waves, icing events, and heavy rainfall, are not well represented in existing plans or policies. In addition, while many sector-based plans have considered existing threats, oftentimes using an 'event of record' as a benchmark for planning, few of the plans included in this analysis have readily incorporated climate mitigation and/or adaptation into their planning efforts. Only a few documents identified specific needs related to climate change data or information. Lastly, this analysis suggests that state and local governments may be well positioned to incorporate climate change risks into existing planning efforts and increase adaptation measures already outlined in existing plans. Future studies on state and local actions should bear in mind that many communities and sectors may integrate measures related to climate mitigation, adaptation, and hazard mitigation into existing planning efforts, as well as impacts from extreme events, without using these terms and or placing them into a broader context.

5.4 Future Work

Extreme variability and associated impacts will continue to be an important area of research as communities take greater action to mitigate the negative effects of weather and climate extremes. The Southeast is vulnerable to a wide variety of extremes, and the region will need to use more aggressive, strategic approaches to prepare for future changes in extreme activity. Study One limited the number of stations to USHCN stations with data of sufficient quality and length. Future research should incorporate more stations with records of greater length and sufficient quality to assess century-term trends in temperature and precipitation extremes. Incorporating a greater number and density of stations would fill gaps in coverage in this study. Adding a greater number of stations to the analysis would further help to refine a regionalization and seasonality of extremes for the region. This research used ordinary least squares regression to assess trends to more easily compare with similar studies that investigated these same indices for other regions of the United States. Investigating other types of trends in these data would be beneficial to better reflect changes in the variability of extremes. Research has suggested extremes may not track changes in the overall mean under a changing climate. For instance, Robeson (2002) found that as global mean temperatures rise, a negative variance response exists, which could mitigate some of the adverse impacts of increasing mean temperatures. Michaels et al. (1998) similarly found that, despite an increasing occurrence of extremes between 1897 and 1996, as global mean temperatures warmed, the intra-annual variance decreased at a significant rate. This study could add to such work by comparing trends in the variability of extremes to changes in the mean.

Understanding the factors that drive extreme weather and climate variability is important for climate change research. Results from Study One should be compared to teleconnection patterns that influence temperature and precipitation patterns in the Southeast to investigate the relationship between these 27 extreme indices and the strength and signal of various modes of teleconnection patterns, such as ENSO, the Bermuda High, Atlantic Multidecadal Oscillation, and Arctic Oscillation. Such research would help to identify the best predictors of climate extremes and may help to decipher the relative contributions of natural and anthropogenic drivers of climate change. Such research would be of added interest to the climate modeling community, as well as to stakeholders and decision makers interested in extreme event behavior.

Extreme regionalizations developed in Study Two have particular use for policy makers, state and local governments, regional research centers, and other entities engaged in hazards and climate change action in the region. PCA methods used in Study Two should be expanded upon to verify the interpretation of resulting components and possibly refine the regionalization. In particular, additional research could compare the Varimax results with other orthogonal and oblique rotation techniques. Additional eigenvector techniques could be employed for comparison with results in this study, such as discriminant analysis, as well as other statistical methods, such as ANOVA or other variance tests.

To expand upon the results from Study Three, future research should focus on how communities are addressing the impacts of extreme events, rather than extremes themselves. For instance, this research suggests that communities are largely moving forward with climate mitigation and adaptation approaches without discussing issues of climate change and/or specific risks. Thus, this research may benefit by incorporating more documents, either through similar systematic research methods and/or surveys, and analyzing them for language pertaining to the impacts of climate extremes to more fully determine the extent to which state and local governments are addressing climate. In addition, an analysis of anticipated or planned future implementation would be beneficial to help guide effective policies and strategies. Future work should incorporate a more comprehensive set of documents across a greater range of sectors. Lastly, future work should consider a greater variety of sites with respect to socio-economic characteristics to better assess factors that drive and inhibit action in the region.

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APPENDIX A: STATION METADATA

Table A-1. Station metadata information for all USHCN stations included in this study.

State	COOP ID	Name	Climate Division	Lat	Lon	Elevation (ft)
AL	AL012813	Fairhope	AL-08: Gulf	30.5467	-87.8808	23
	AL015749	Muscle Shoals Rgnl AP	AL-01: Northern Valley	34.7442	-87.5997	540
	AL017366	Selma	AL-06: Prairie	32.4111	-87.0144	147
	AL018178	Thomasville	AL-07: Coastal Plain	31.9172	-87.7347	390
	AL018469	Valley Head	AL-02: Appalachian Mountains	34.5667	-85.6128	1062
AR	AR031632	Corning	AR-03: Northeast	36.4197	-90.5858	300
	AR032930	Gravette	AR-01: Northwest	36.4261	-94.4481	1260
	AR034756	Mena	AR-04: West Central	34.5731	-94.2494	1130
	AR035186	Newport	AR-03: Northeast	35.6042	-91.2744	228
	AR035754	Pine Bluff	AR-09: Southeast	34.2256	-92.0189	215
	AR035908	Prescott	AR-08: South Central	33.8203	-93.3878	308
	AR036928	Subiaco	AR-04: North Central	35.3028	-93.6369	500
FL	FL080228	Arcadia	FL-04: South Central	27.2181	-81.8739	30
	FL083186	Ft. Myers Page Fld AP	FL-05: Everglades and SW Coast	26.5850	-81.8614	15
	FL084731	Lake City	FL-02: North	30.1853	-82.5942	195
	FL087851	Saint Leo	FL-03: North Central	28.3378	-82.2600	190
	FL088824	Tarpon Springs SWG PLT	FL-04: South Central	28.1522	-82.7539	8
GA	GA090140	Albany	GA-07: Southwest	31.5339	-84.1489	180
	GA092966	Eastman	GA-05: Central	32.2003	-83.2058	400
	GA093621	Gainesville	GA-02: North Central	34.3006	-83.8600	1170
	GA095874	Milledgeville	GA-05: Central	33.0831	-83.2497	368
	GA097600	Rome	GA-01: Northwest	34.2453	-85.1514	659
	GA098740	Toccoa	GA-03: Northeast	34.5786	-83.3319	1012
LA	LA160098	Alexandria	LA-05: Central	31.3206	-92.4611	87
	LA160205	Amite	LA-08: East Central	30.7094	-90.5250	170
	LA161411	Calhoun	LA-02: North Central	32.5133	-92.3486	180
	LA163800	Grand Coteau	LA-05: Central	30.4192	-92.0439	55
	LA164407	Houma	LA-09: Southeast	29.6408	-90.8161	8
	LA164700	Jennings	LA-07: Southwest	30.2003	-92.6642	25
	LA165026	Lafayette Rgnl AP	LA-08: South Central	30.2050	-91.9875	42
	LA168163	St. Joseph	LA-03: Northeast	31.9497	-91.2336	78
MS	MS220021	Aberdeen	MS-06: East Central	33.8300	-88.5214	198
	MS220488	Batesville	MS-02: North Central	34.3061	-89.9806	220
	MS221094	Brookhaven City	MS-07: Southwest	31.5447	-90.4581	435

(Table A-1. continued)

State	COOP ID	Name	Climate Division	Lat	Lon	Elevation (ft)
	MS221707	Clarksdale	MS-01: Upper Delta	34.1864	-90.5572	173
	MS221865	Columbia	MS-08: South Central	31.2503	-89.8361	150
	MS223887	Hattiesburg	MS-09: Southeast	31.2547	-89.3392	385
	MS224939	Laurel	MS-09: Southeast	31.6756	-89.1236	225
	MS225247	Louisville	MS-06: East Central	33.1356	-89.0711	581
	MS225987	Monticello	MS-08: South Central	31.5519	-90.1058	191
	MS226009	Moorhead	MS-04: Lower Delta	33.4517	-90.5097	117
	MS229079	University	MS-02: North Central	34.3725	-89.5308	408
NC	NC311677	Chapel Hill	NC-03: Northern Piedmont	35.9086	-79.0794	500
	NC312635	Edenton	NC-08: Northern Coastal Plain	36.0164	-76.5517	10
	NC313017	Fayetteville	NC-06: Southern Coastal Plain	35.0583	-78.8583	96
	NC313976	Hendersonville	NC-01: Southern Mountains	35.3297	-82.4492	2160
	NC314055	Highlands	NC-01: Southern Mountains	35.0567	-83.1983	3850
	NC314684	Kinston	NC-07: Central Coastal Plain	35.1967	-77.5433	24
	NC314938	Lenoir	NC-02: Northern Mountains	35.9150	-81.5378	1200
	NC315356	Marshall	NC-01: Southern Mountains	35.8036	-82.6658	2000
	NC315771	Monroe	NC-05: Southern Piedmont	34.9797	-80.5233	550
	NC315838	Morgantown	NC-01: Southern Mountains	35.7297	-81.6728	1160
	NC315890	Mt. Airy	NC-02: Northern Mountains	36.4992	-80.6508	1041
	NC317615	Salisbury	NC-04: Central Piedmont	35.6836	-80.4822	700
	NC317994	Smithfield	NC-07: Central Coastal Plain	35.5164	-78.3458	150
	NC318292	Statesville	NC-04: Central Piedmont	35.8100	-80.8808	950
	NC318500	Tarboro	NC-08: Northern Coastal Plain	35.8847	-77.5386	35
	NC319147	Waynesville	NC-01: Southern Mountains	35.4867	-82.9683	2658
OK	OK340017	Ada	OK-08: South Central	34.7864	-96.6850	1015
	OK340179	Altus Irig Rsch Stn	OK-07: Southwest	34.5903	-99.3344	1380
	OK341828	Claremore	OK-03: Northeast	36.3225	-95.5808	588
	OK342912	Enid	OK-02: North Central	36.4194	-97.8747	1245

(Table A-1. continued)

State	COOP ID	Name	Climate Division	Lat	Lon	Elevation (ft)
	OK343821	Guthrie	OK-05: Central	35.8161	-97.3950	1110
	OK344204	Hobart Muni AP	OK-07: Southwest	34.9894	-99.0525	1556
	OK344573	Jefferson	OK-02: North Central	36.7222	-97.7903	1045
	OK344861	Kingfisher	OK-05: Central	35.8583	-97.9294	1050
	OK346629	Okeene	OK-04: West Central	36.1217	-98.3150	1215
	OK348501	Stillwater	OK-05: Central	36.1175	-97.0950	895
SC	SC380165	Anderson	SC-02: Northwest	34.5283	-82.6606	800
	SC381277	Calhoun Falls	SC-05: West Central	34.0906	-82.5883	530
	SC381549	Charleston City	SC-07: Southern	32.7800	-79.9319	10
	SC381588	Cheraw	SC-04: Northeast	34.7319	-79.8833	140
	SC382260	Darlington	SC-04: Northeast	34.3011	-79.8767	150
	SC385200	Little Mountain	SC-05: West Central	34.1942	-81.4150	711
	SC387722	Santuck	SC-02: Northwest	34.6350	-81.5206	520
	SC388887	Walhalla	SC-02: Northwest	34.7544	-83.0750	980
	SC389327	Winnsboro	SC-03: North Central	34.3739	-81.0928	560
	SC389350	Winthrop Univ.	SC-03: North Central	34.9381	-81.0317	690
TN	TN401790	Clarksville Sewage Pl	TN-03: Middle	36.5472	-87.3353	402
	TN402108	Covington	TN-04: Western	35.5497	-89.7000	385
	TN402202	Crossville Exp Stn.	TN-02: Cumberland Plateau	36.0147	-85.1314	1810
	TN402489	Dickson	TN-03: Middle	36.0750	-87.3958	780
	TN404561	Jackson Exp Stn	TN-04: Western	35.6214	-88.8456	400
	TN405187	Lewisburg Exp Stn	TN-03: Middle	35.4139	-86.8086	787
	TN405882	MC Minnville	TN-02: Cumberland Plateau	35.6722	-85.7811	940
	TN406371	Murfreesboro	TN-03: Middle	35.9203	-86.3728	535
	TN406534	Newport	TN-01: Eastern	35.9833	-83.2008	1036
	TN407884	Rogersville	TN-01: Eastern	36.4161	-82.9839	1355
	TN409155	Tullahoma	TN-02: Cumberland Plateau	35.3453	-86.2089	1022
	TN409219	Union City	TN-04: Western	36.3925	-89.0317	350
	TN409502	Waynesboro	TN-03: Middle	35.3042	-87.7592	750
TX	TX410493	Ballinger	TX-02: Low Rolling Plains	31.7414	-99.9764	1755
	TX410639	Beeville	TX-07: South Central	28.4575	-97.7061	255
	TX410832	Blanco	TX-06: Edwards Plateau	30.1061	-98.4286	1380
	TX410902	Boerne	TX-06: Edwards Plateau	29.7986	-98.7353	1445
	TX411048	Brenham	TX-07: South Central	30.1592	-96.3972	313
	TX412019	Corsicana	TX-03: North Central	32.1225	-96.4867	449
	TX412121	Crosbyton	TX-01: High Plains	33.6517	-101.2450	3010

(Table A-1. continued)

State	COOP ID	Name	Climate Division	Lat	Lon	Elevation (ft)
	TX412266	Danevang	TX-08: Upper Coast	29.0567	-96.2319	70
	TX413183	Flatonia	TX-07: South Central	29.6339	-97.0644	470
	TX413734	Greenville KGVL Radio	TX-03: North Central	33.1678	-96.0983	545
	TX413873	Hallettsville	TX-07: South Central	29.4706	-96.9397	275
	TX415429	Luling	TX-07: South Central	29.6756	-97.6578	400
	TX415618	Marshall	TX-04: East Texas	32.5403	-94.3508	352
	TX416794	Paris	TX-03: North Central	33.6744	-95.5586	542
	TX417079	Plainview	TX-01: High Plains	34.1892	-101.7022	3370
	TX419532	Weatherford	TX-03: North Central	32.7483	-97.7700	955

APPENDIX B: STATION RELOCATIONS

Table B-1. Historical station relocations by state and climate division from 1948 to 2012. Station relocation information obtained from the NCDC Historical Observing Metadata Repository (http://www.ncdc.noaa.gov/homr/).

State	Climate Division	Station	Station Changes	Year
AL	AL-01: Northern Valley	AL015749	1.1 mi W	1997
	AL-06: Prairie	AL017366	150 ft W	2005
			120 ft N	2003
			16 ft ENE	2002
	AL-07: Coastal Plain	AL018178	0.3 mi NE	2005
	AL-02: Appalachian Mountains	AL018469	0.2 mi E	1992
			0.2 mi S	1986
AR	AR-03: Northeast	AR031632	1.2 mi NW	1994
			0.5 mi S	1988
	AR-01: Northwest	AR032930	0.6 mi NE	1978
	AR-04: West Central	AR034756	1.4 mi E	1980
	AR-03: Northeast	AR035186	1.2 mi W	1986
			1.2 mi E	1986
	AR-08: South Central	AR035908	100 Yds NE	2001
FL	FL-04: South Central	FL080228	1.5 mi SW	1999
			10 ft N	1997
	FL-05: Everglades and SW Coast	FL083186	0.8 mi NE	1993
	FL-02: North	FL084731	200 ft NW	2004
GA	GA-07: Southwest	GA090140	250 ft NW	1993
	GA-05: Central	GA095874	1.4 mi NE	1984
	GA-01: Northwest	GA097600	0.4 mi S	1999
	GA-03: Northeast	GA098740	1.2 mi SW	1998
LA	LA-06: East Central	LA160205	2 mi SW	1987
	LA-05: Central	LA163800	500 ft N	2006
	LA-07: Southwest	LA164700	0.1 mi S	1983
	LA-08: South Central	LA165026	0.3 mi SW	1986
	LA-03: Northeast	LA168163	50 ft NW	1986
MS	MS-06: East Central	MS220021	2 mi NE	1991
			200 ft W	1993
			15 ft NW	2002
	MS-02: North Central	MS220488	100 ft SE	1985
	MS-07: Southwest	MS221094	300 ft NW	1992
	MS-01: Upper Delta	MS221707	0.25 mi N	2001
	MS-09: Southeast	MS223887	~2.3 mi S	1967
			0.8 mi NE	1984
			0.5 mi SW	1996

(Table B-1. continued)

State	Climate Division	Station	Station Changes	Year
	MS-08: South Central	Monticello	50 ft N	1989
			4 mi NE	1997
			4 mi SSE	2005
	MS-02: North Central	MS229079	0.6 mi SE	2005
			0.6 mi SE	2009
NC	NC-08: Northern Coastal Plain	NC312635	3.94 mi SE	2007
	NC-01: Southern Mountains	NC313976	30 ft S	1986
	NC-01: Southern Mountains	NC314055	~1.9 mi N	1978
			0.5 ft WNW	2010
	NC-07: Central Coastal Plain	NC314684	1.5 mi SE	2002
	NC-02: Northern Mountains	NC314938	350 ft S	1985
	NC-01: Southern Mountains	NC315356	1.1 mi E	1990
	NC-05: Southern Piedmont	NC315771	100 Yd W	1985
			1.6 mi W	2003
	NC-02: Northern Mountains	NC315890	2.3 mi SW	1993
	NC-04: Central Piedmont	NC318292	~4.2 mi NE	1956
			30 ft N	1986
	NC-01: Southern Mountains	NC319147	0.2 mi N	1986
OK	OK-07: Southwest	OK340179	~4.5 mi NNW	1966
			150 ft SE	1995
	OK-05: Central	OK343821	4.5 mi S	1995
			150 ft N	2000
	OK-07: Southwest	OK344204	0.1 mi ESE	1996
	OK-05: Central	OK344861	1.8 mi NW	2002
	OK-04: West Central	OK346629	0.4 mi NE	1986
			12 ft N	1992
			100 ft WSW	2000
	OK-05: Central	OK348501	0.3 mi S	1986
			480 ft NE	1998
SC	SC-02: Northwest	SC380165	90 ft S	1989
	SC-05: West Central	SC381277	200 ft NW	1984
	SC-07: Southern	SC381549	0.25 mi S	2003
	SC-04: Northeast	SC381588	75 ft S	1986
	SC-04: Northeast	SC382260	0.9 mi S	1986
			600 ft S	2004
	SC-05: West Central	SC385200	110 ft SW	1999
	SC-02: Northwest	SC388887	100 ft S	2001
	SC-03: North Central	SC389327	100 Yd NW	1984
			300 ft NW	1988

(Table B-1. continued)

State	Climate Division	Station	Station Changes	Year
TN	TN-03: Middle	TN401790	100 ft S	1985
			160 ft NE	2010
	TN-03: Middle	TN406371	~2.5 mi N	1968
			600 ft N	2007
	TN-02: Cumberland Plateau	TN409155	200 ft E	1985
TX	TX-02: Low Rolling Plains	TX410493	~2.5 mi SSW	1963
			~0.5 mi NW	1986
			4.5 mi SW	1986
			4.3 mi NE	1993
			120 ft NW	2005
	TX-07: South Central	TX410639	300 yd SE	1993
	TX-06: Edwards Plateau	TX410832	0.4 mi NW	2007
	TX-06: Edwards Plateau	TX410902	~1.2 mi SSW	1968
			0.3 mi SW	1983
	TX-03: North Central	TX412019	1.4 mi NNW	1997
			2.8 mi NNW	2010
	TX-01: High Plains	TX412121	1.1 mi SW	1982
	TX-07: South Central	TX413183	150 ft. NE	1996
			4 mi SE	2009
	TX-03: North Central	TX413734	4 mi NW	1964
			5.7 mi E	1992
			0.8 mi NE	1994
			30 ft. S	2006
	TX-07: South Central	TX413873	4 mi N	1987
	TX-07: South Central	TX415429	~2.1 mi NNW	1949
			0.6 mi W	1995
	TX-03: North Central	TX419532	1.2 mi SE	1995
			0.8 mi NE	1996
			2.5 mi SSE	1998

APPENDIX C: DEFINITIONS OF THE 27 CORE INDICES

1. Frost Days (FD)

   Number of frost days: Annual count of days when TN (daily minimum temperature) < 0°C.

   Let TN_{ij} be daily minimum temperature on day *i* in year *j*. Count the number of days where:

   $TN_{ij} < 0^{o}C$.

2. Summer Days (SU)

   Number of summer days: Annual count of days when TX (daily maximum temperature) > 25°C.

   Let TX_{ij} be daily maximum temperature on day *i* in year *j*. Count the number of days where:

   $TX_{ij} > 25^{o}C$.

3. Ice Days (ID)

   Number of icing days: Annual count of days when TX (daily maximum temperature) < 0°C.

   Let TX_{ij}be daily maximum temperature on day *i* in year *j*. Count the number of days where:

   $TX_{ij} < 0^{o}C$.

4. Tropical Nights (TR)

   Number of tropical nights: Annual count of days when TN (daily minimum temperature) > 20°C.

   Let TN_{ij} be daily minimum temperature on day *i* in year *j*. Count the number of days where:

   $TN_{ij} > 20^{o}C$.

5. Growing Season Length (GSL)

Growing season length: Annual (1st Jan to 31st Dec in Northern Hemisphere (NH), 1st July to 30th June in Southern Hemisphere (SH)) count between first span of at least 6 days with daily mean temperature TG>5°C and first span after July 1st (Jan 1st in SH) of 6 days with TG<5°C.

Let TG_{ij} be daily mean temperature on day *i* in year *j*. Count the number of days between the first occurrence of at least 6 consecutive days with:

$TG_{ij} > 5^{o}C$.

and the first occurrence after 1st July (1st Jan. in SH) of at least 6 consecutive days with:

$TG_{ij} < 5^{o}C$.

6. Warmest Day (TX_x)

   Monthly maximum value of daily maximum temperature:

   Let TX_x be the daily maximum temperatures in month *k*, period *j*. The maximum daily maximum temperature each month is then:

   $TX_{xkj}=\max(TX_{xkj})$

7. Warmest Night (TN_x)

   Monthly maximum value of daily minimum temperature:

   Let TN_x be the daily minimum temperatures in month *k*, period *j*. The maximum daily minimum temperature each month is then:

   $TN_{xkj}=\max(TN_{xkj})$

8. Coldest Day (TX_n)

   Monthly minimum value of daily maximum temperature:

   Let TX_n be the daily maximum temperatures in month *k*, period *j*. The minimum daily maximum temperature each month is then:

   $TX_{nkj}=\min(TX_{nkj})$

9. Coldest Night (TN_n)

   Monthly minimum value of daily minimum temperature:

Let TN_n be the daily minimum temperatures in month *k*, period *j*. The minimum daily minimum temperature each month is then:

$TN_{nkj}=\min(TN_{nkj})$

10. Cool Nights (TN10p)

Percentage of days when TN < 10th percentile:

Let TN_{ij} be the daily minimum temperature on day *i* in period *j* and let $TN_{in}10$ be the calendar day 10th percentile centered on a 5-day window for the base period 1961-1990. The percentage of time for the base period is determined where:

$TN_{ij} < TN_{in}10$

To avoid possible inhomogeneity across the in-base and out-of-base periods, the calculation for the base period (1961-1990) requires the use of a bootstrap procedure. Details are described in Zhang *et al.* (2005).

11. Cool Days (TX10p)

Percentage of days when TX < 10th percentile:

Let TX_{ij} be the daily maximum temperature on day *i* in period *j* and let $TX_{in}10$ be the calendar day 10th percentile centered on a 5-day window for the base period 1961-1990. The percentage of time for the base period is determined where:

$TX_{ij} < TX_{in}10$

To avoid possible inhomogeneity across the in-base and out-base periods, the calculation for the base period (1961-1990) requires the use of a bootstrap procedure. Details are described in Zhang *et al.* (2005).

12. Warm Nights (TN90p)

Percentage of days when TN > 90th percentile:

Let TN_{ij} be the daily minimum temperature on day *i* in period *j* and let $TN_{in}90$ be the calendar day 90th percentile centered on a 5-day window for the base period 1961-1990. The percentage of time for the base period is determined where:

$TN_{ij} > TN_{in}90$

To avoid possible inhomogeneity across the in-base and out-base periods, the calculation for the base period (1961-1990) requires the use of a bootstrap procedure. Details are described in Zhang *et al.* (2005).

13. Warm Days (TX90p)

    Percentage of days when TX > 90th percentile:

    Let TX_{ij} be the daily maximum temperature on day *i* in period *j* and let $TX_{in}90$ be the calendar day 90th percentile centered on a 5-day window for the base period 1961-1990. The percentage of time for the base period is determined where:

    $TX_{ij} > TX_{in}90$

    To avoid possible inhomogeneity across the in-base and out-base periods, the calculation for the base period (1961-1990) requires the use of a bootstrap procedure. Details are described in Zhang *et al.* (2005).

14. Warm Spells (WSDI)

    Warm spell duration index: Annual count of days with at least 6 consecutive days when TX > 90th percentile

    Let TX_{ij} be the daily maximum temperature on day *i* in period *j* and let $TX_{in}90$ be the calendar day 90th percentile centered on a 5-day window for the base period 1961-1990. Then the number of days per period is summed where, in intervals of at least 6 consecutive days:

    $TX_{ij} > TX_{in}90$

15. Cold Spells (CSDI)

    Cold spell duration index: Annual count of days with at least 6 consecutive days when TN < 10th percentile

    Let TN_{ij} be the daily maximum temperature on day *i* in period *j* and let $TN_{in}10$ be the calendar day 10th percentile centered on a 5-day window for the base period 1961-1990. Then the number of days per period is summed where, in intervals of at least 6 consecutive days:

    $TN_{ij} < TN_{in}10$

16. Diurnal Temperature Range (DTR)

    Daily temperature range: Monthly mean difference between TX and TN

    Let TX_{ij} and TN_{ij} be the daily maximum and minimum temperature respectively on day *i* in period *j*. If *I* represents the number of days in *j*, then:

$$DTR_j = \frac{\sum_{i=1}^{I}\left(Tx_{ij} - Tn_{ij}\right)}{I}$$

17. Maximum 1-Day Precipitation (Rx1day)

    Monthly maximum 1-day precipitation:

    Let RR_{ij} be the daily precipitation amount on day i in period j. The maximum 1-day value for period j are:

    $Rx1day_j$ = max (RR_{ij})

18. Maximum 5-Day Precipitation (Rx5day)

    Monthly maximum consecutive 5-day precipitation:

    Let RR_{kj} be the precipitation amount for the 5-day interval ending $_k$, period j. Then maximum 5-day values for period j are:

    $Rx5day_j$ = max (RR_{kj})

19. Simple Daily Intensity Index (SDII)

    Simple precipitation intensity index: Let RR_{wj} be the daily precipitation amount on wet days, w $(RR \geq 1mm)$ in period j. If W represents number of wet days in j, then:

$$SDII_j = \frac{\sum_{w=1}^{W} RR_{wj}}{W}$$

20. Heavy Precipitation Days (R10mm)

    Annual count of days when PRCP≥ 10mm: Let RR_{ij} be the daily precipitation amount on day i in period j. Count the number of days where:

    $RR_{ij} \geq 10mm$

21. Very Heavy Precipitation Days (R20mm)

Annual count of days when PRCP≥ 20mm: Let RR_{ij} be the daily precipitation amount on day i in period j. Count the number of days where:

$RR_{ij} \geq 20mm$

22. Extremely Heavy Precipitation Days (Rnnmm)

    Annual count of days when PRCP≥ nnmm, nn is a user defined threshold:
    Let RR_{ij} be the daily precipitation amount on day i in period j. Count the number of days where:

    $RR_{ij} \geq nnmm$

23. Consecutive Dry Days (CDD)

    Maximum length of dry spell, maximum number of consecutive days with RR < 1mm: Let RR_{ij} be the daily precipitation amount on day i in period j. Count the largest number of consecutive days where:

    $RR_{ij} < 1mm$

24. Consecutive Wet Days (CWD)

    Maximum length of wet spell, maximum number of consecutive days with RR ≥ 1mm: Let RR_{ij} be the daily precipitation amount on day i in period j. Count the largest number of consecutive days where:

    $RR_{ij} \geq 1mm$

25. Precipitation on Very Wet Days (R95pTOT)

    Annual total PRCP when RR > 95p. Let RR_{wj} be the daily precipitation amount on a wet day w $(RR \geq 1.0mm)$ in period i and let$RR_{wn}95$ be the 95th percentile of precipitation on wet days in the 1961-1990 period. If W represents the number of wet days in the period, then:

    $$R95p_j = \sum_{w=1}^{W} RR_{wj} \text{ where } RR_{wj} > RR_{wn}95$$

26. Precipitation on Extremely Wet Days (R99pTOT)

    Annual total PRCP when RR > 99p: Let RR_{wj} be the daily precipitation amount on a wet day w $(RR \geq 1.0mm)$ in period i and let$RR_{wn}99$ be the 99th percentile of precipitation on wet days in the 1961-1990 period. If W represents the number of wet days in the period, then:

$$R99p_j = \sum_{w=1}^{W} RR_{wj} \text{ where } RR_{wj} > RR_{wn}99$$

27. Annual Total Wet Day Precipitation (PRCPTOT)

    Annual total precipitation in wet days: Let RR_{ij} be the daily precipitation amount on day *i* in period *j*. If *I* represents the number of days in *j*, then

$$PRCPTOT_j = \sum_{i=1}^{I} RR_{ij}$$

APPENDIX D: THE PERCENT OF STATIONS WITH SPECIFIC TRENDS IN EXTREME INDICES FOR 1948-2012 BY STATE

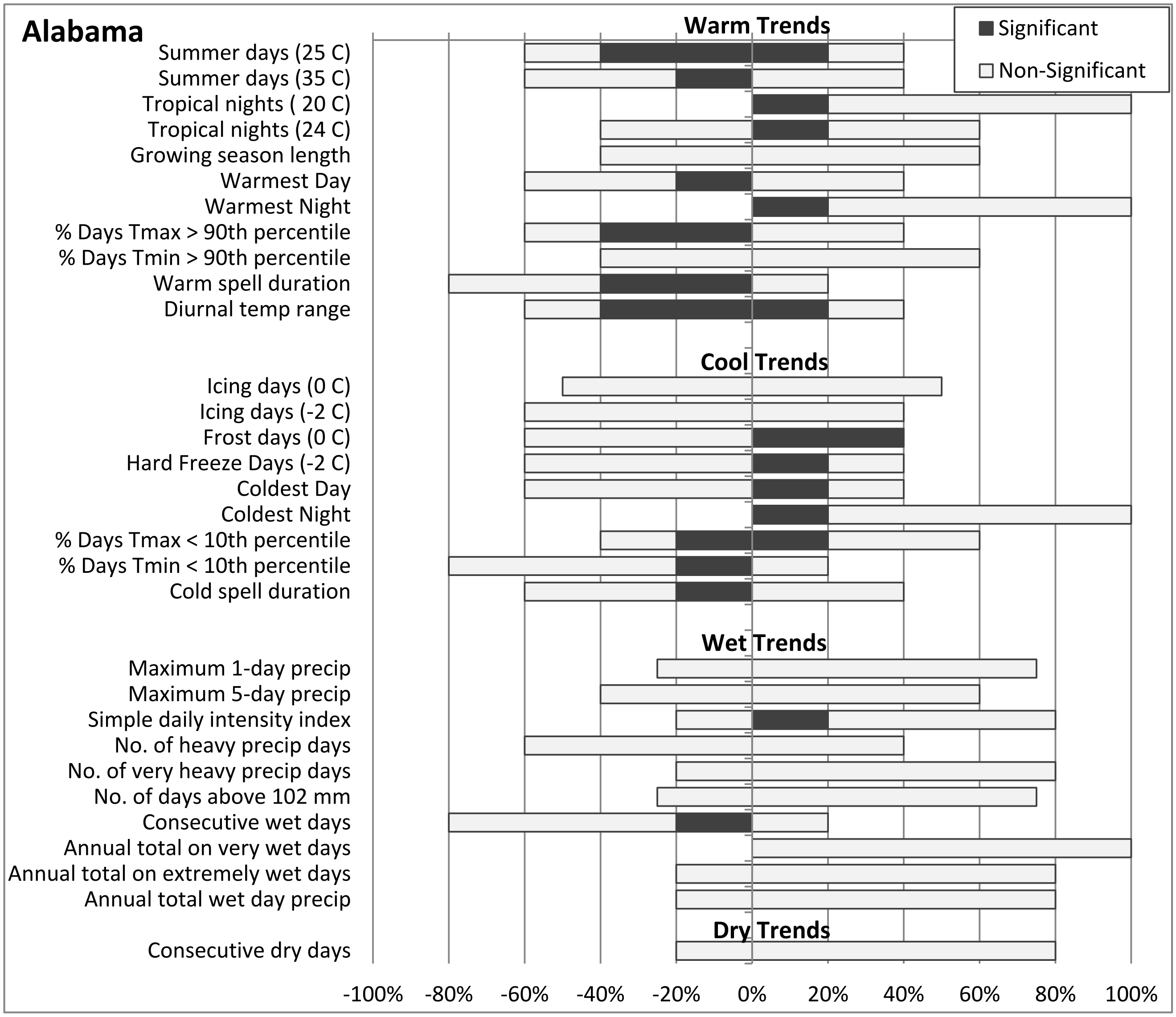


Figure D-1. Proportion of stations in Alabama showing positive and negative trends in extreme indices from 1948 to 2012.

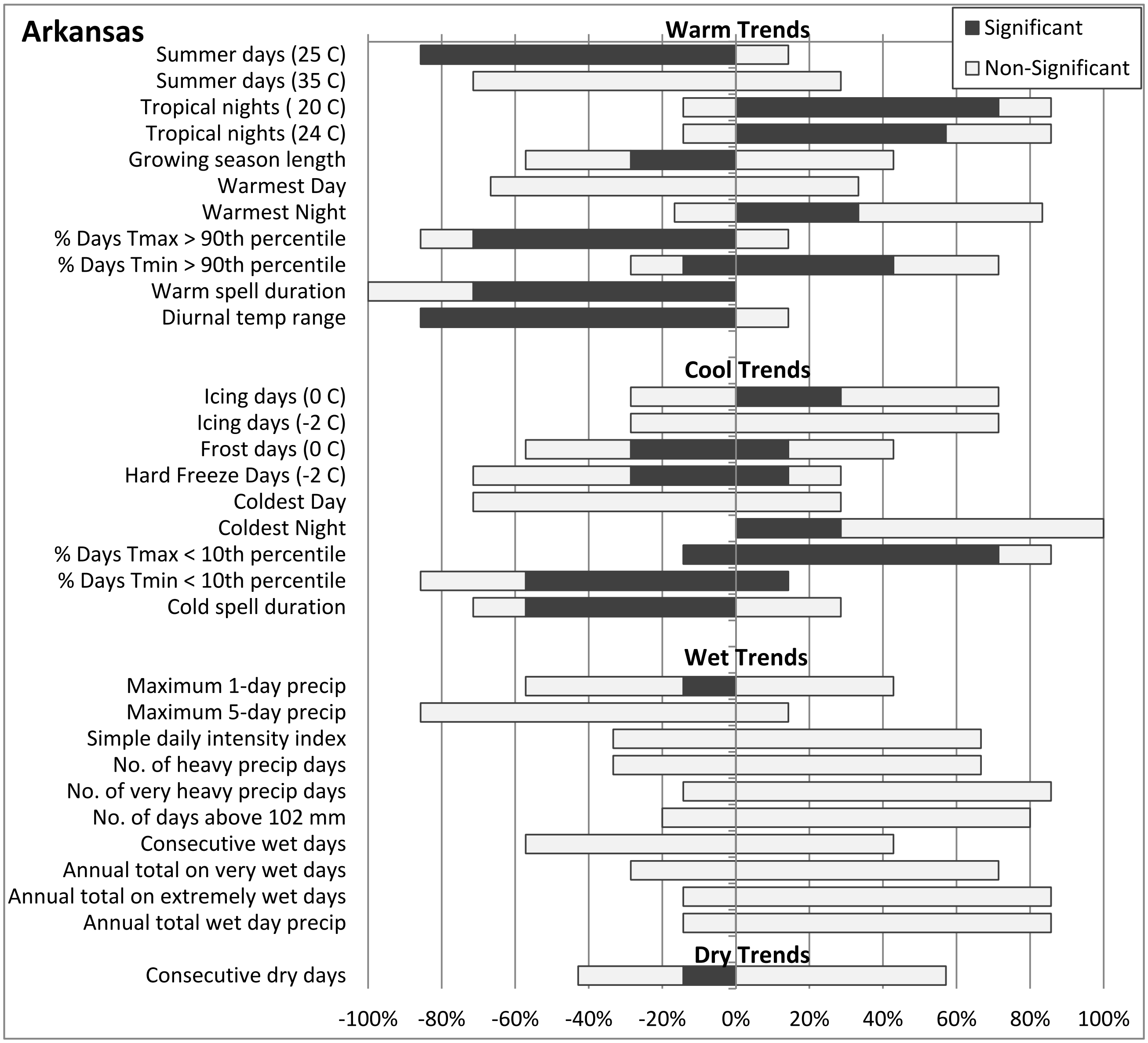


Figure D-2. Proportion of stations in Arkansas showing positive and negative trends in extreme indices from 1948 to 2012.

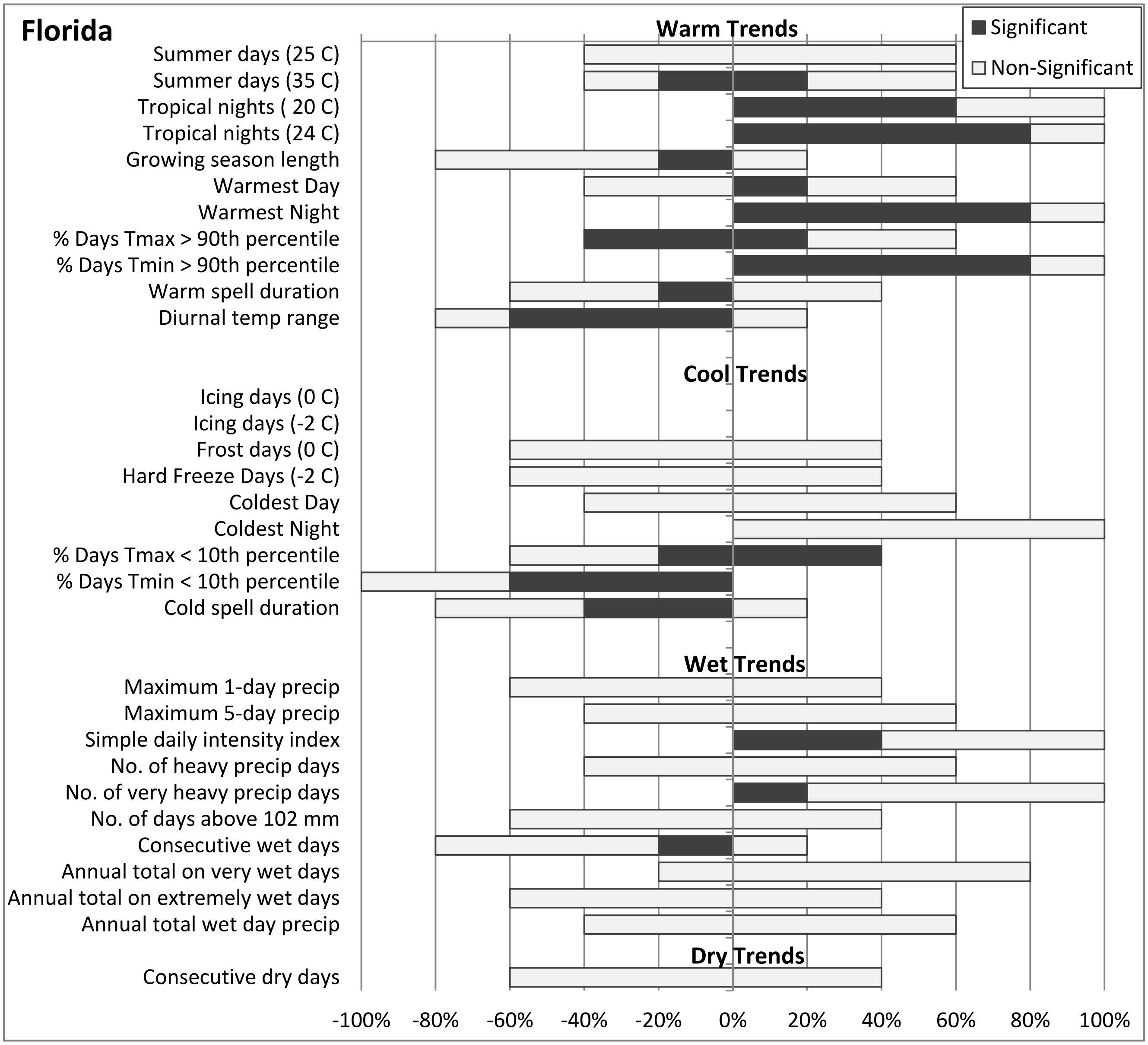


Figure D-3. Proportion of stations in Florida showing positive and negative trends in extreme indices from 1948 to 2012.

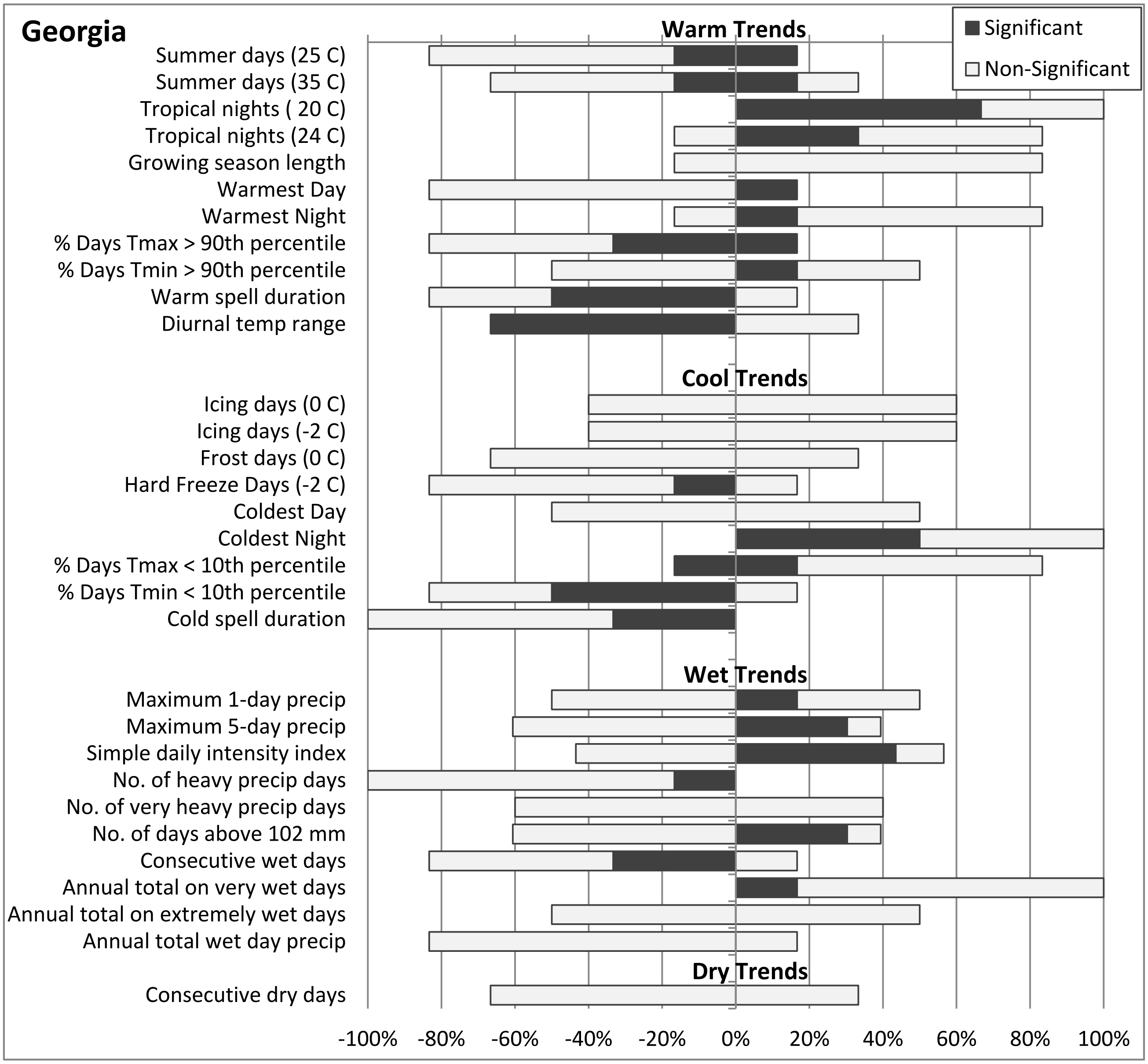


Figure D-4. Proportion of stations in Georgia showing positive and negative trends in extreme indices from 1948 to 2012.

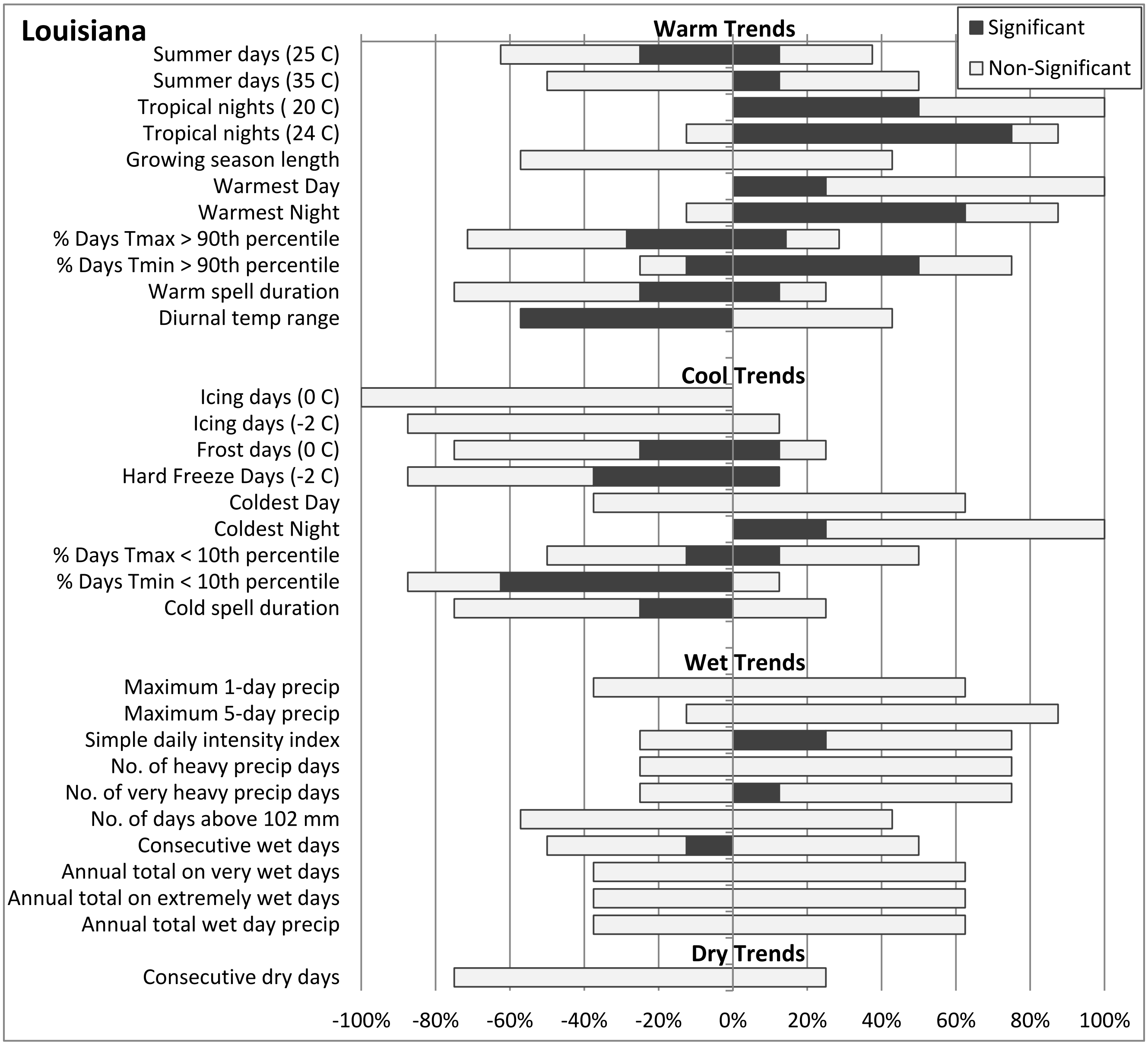


Figure D-5. Proportion of stations in Louisiana showing positive and negative trends in extreme indices from 1948 to 2012.

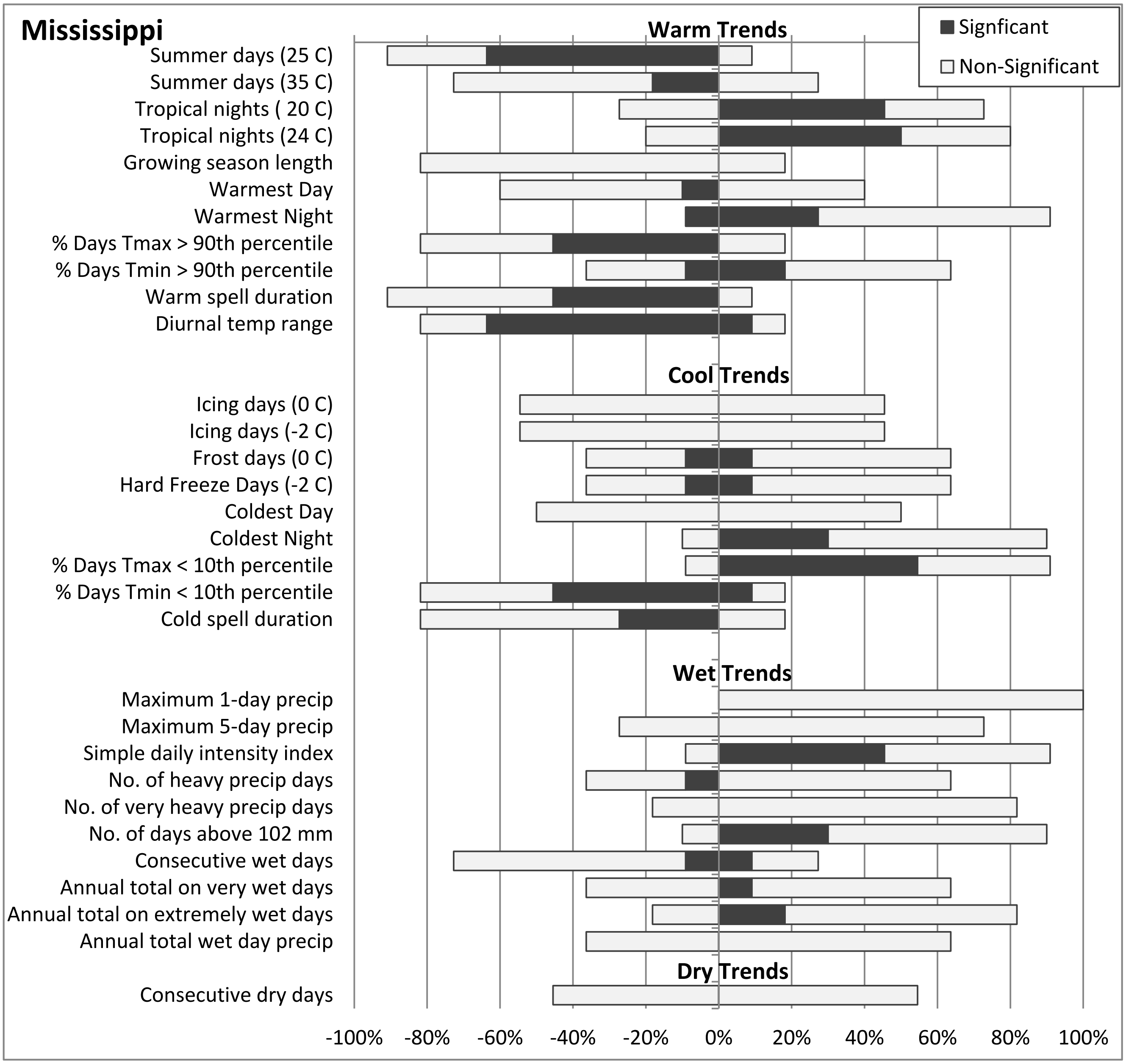


Figure D-6. Proportion of stations in Mississippi showing positive and negative trends in extreme indices from 1948 to 2012.

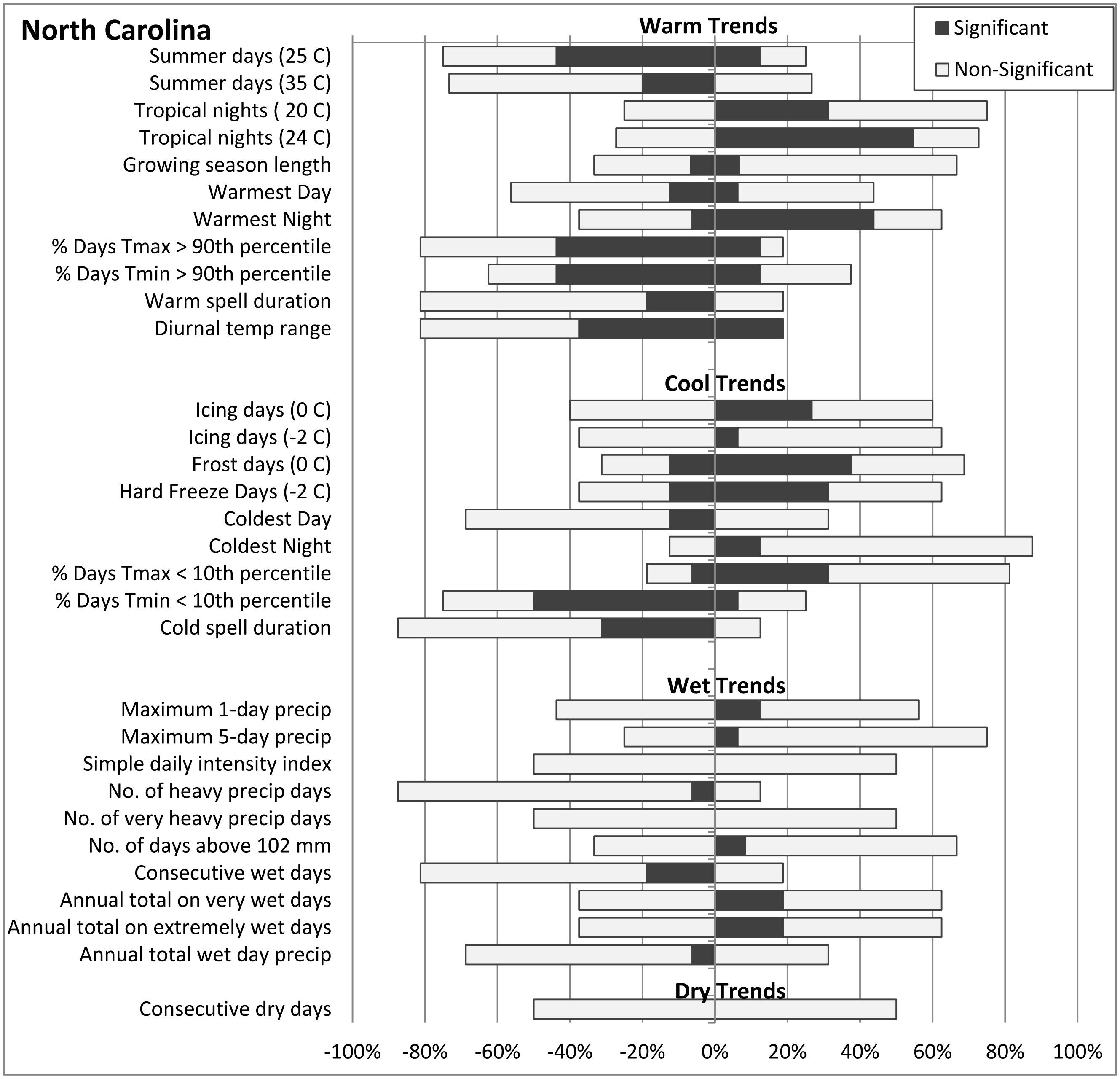


Figure D-7. Proportion of stations in North Carolina showing positive and negative trends in extreme indices from 1948 to 2012.

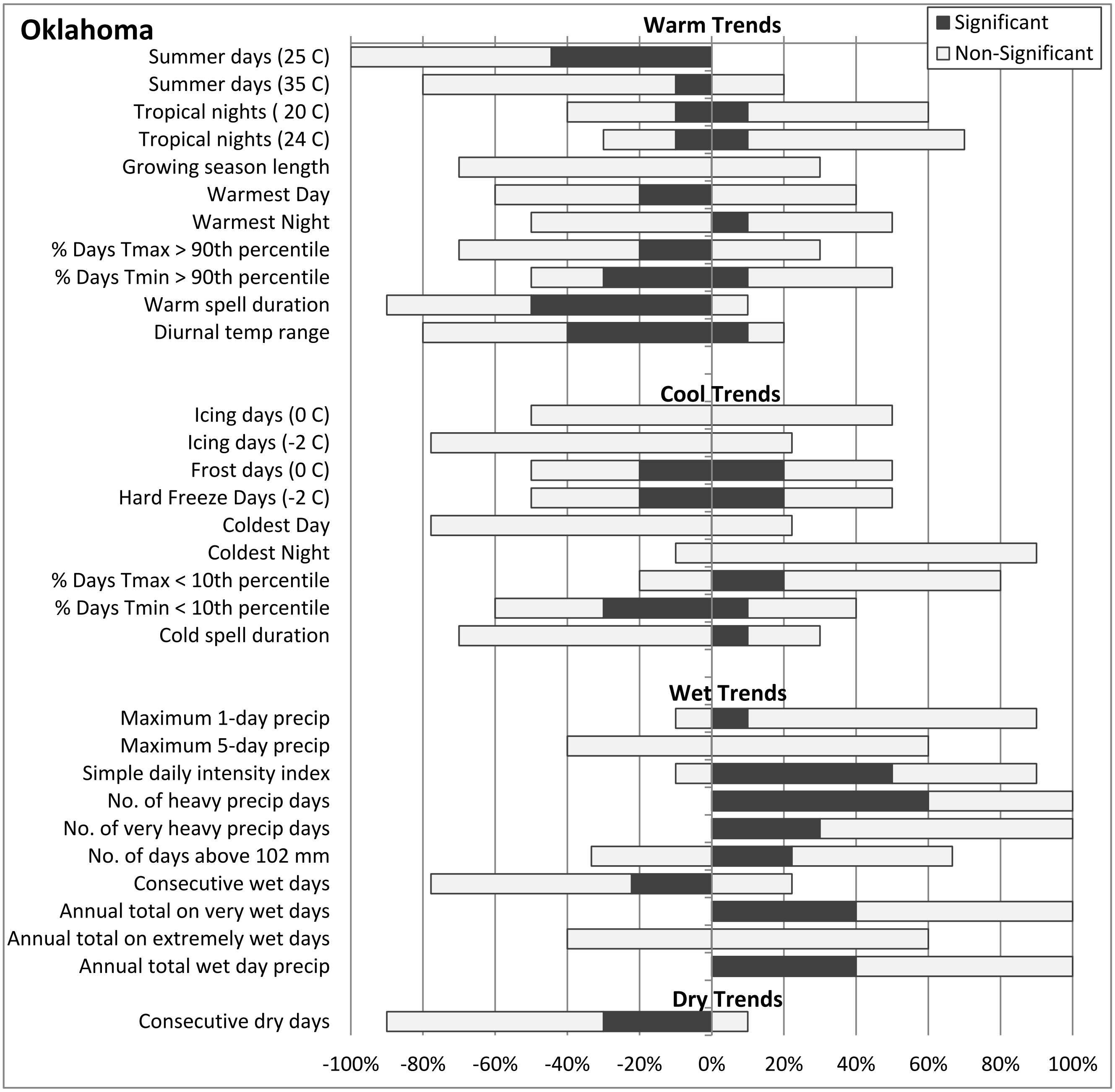


Figure D-8. Proportion of stations in Oklahoma showing positive and negative trends in extreme indices from 1948 to 2012.

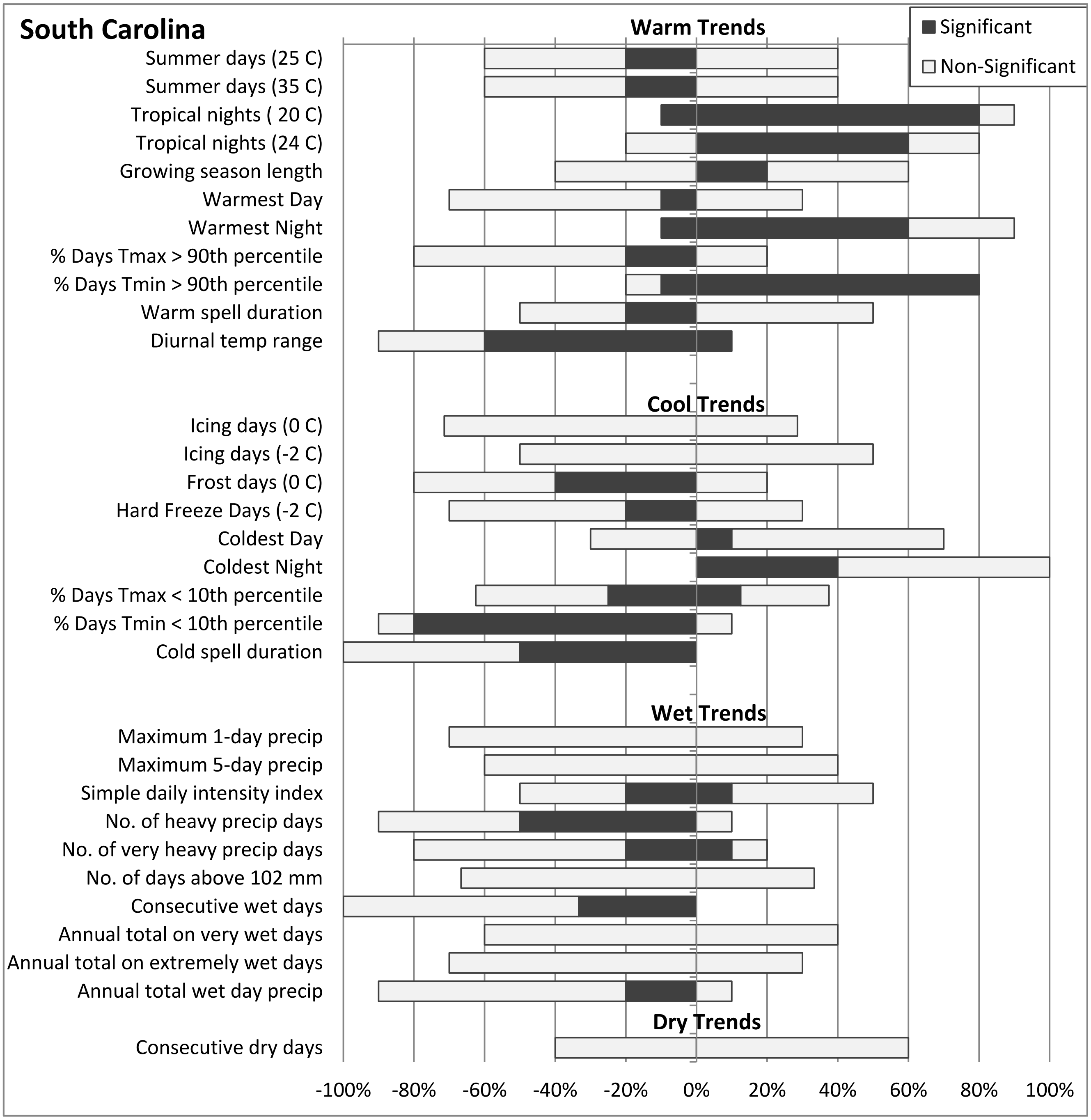


Figure D-9. Proportion of stations in South Carolina showing positive and negative trends in extreme indices from 1948 to 2012.

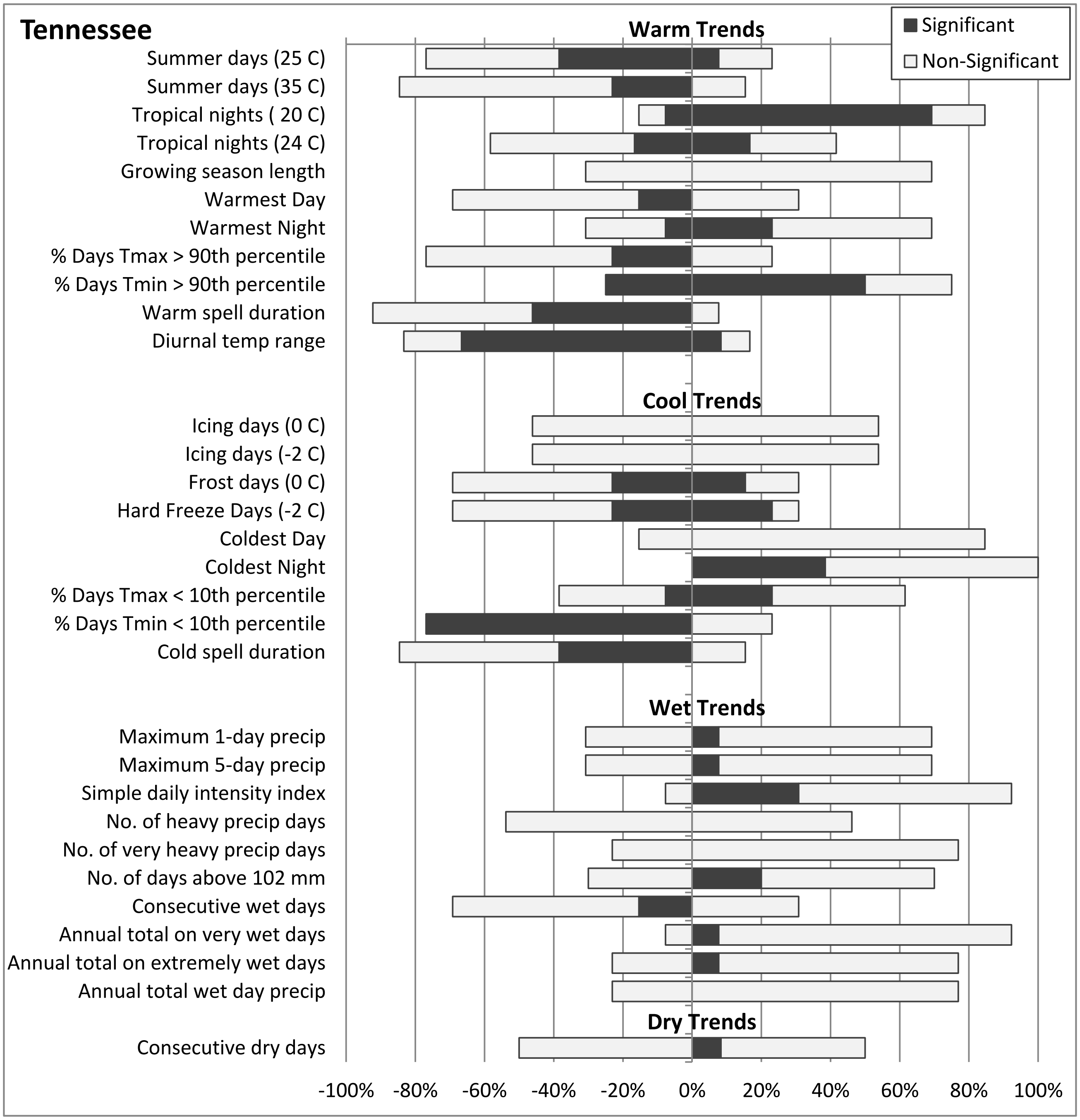


Figure D-10. Proportion of stations in Tennessee showing positive and negative trends in extreme indices from 1948 to 2012.

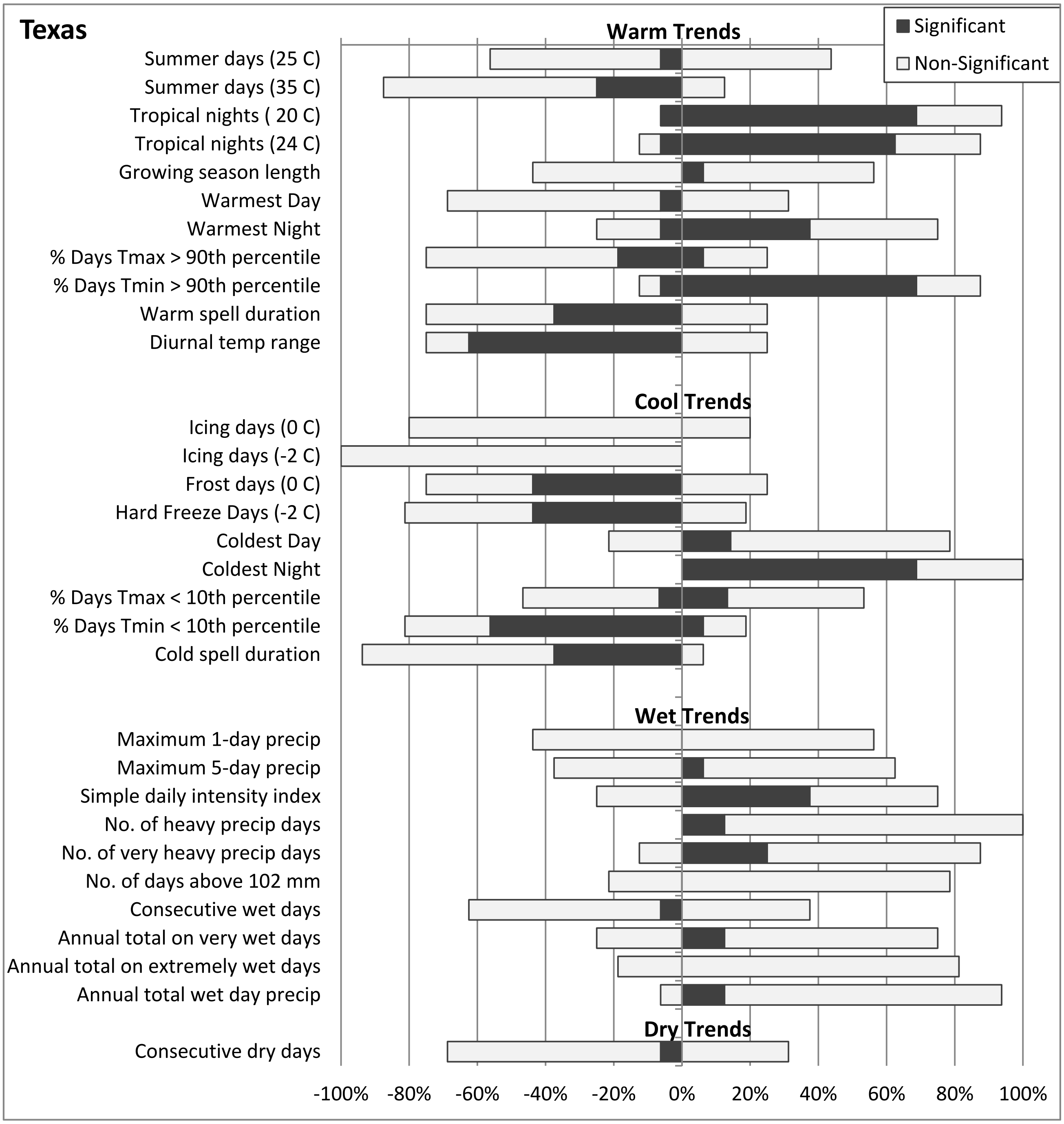
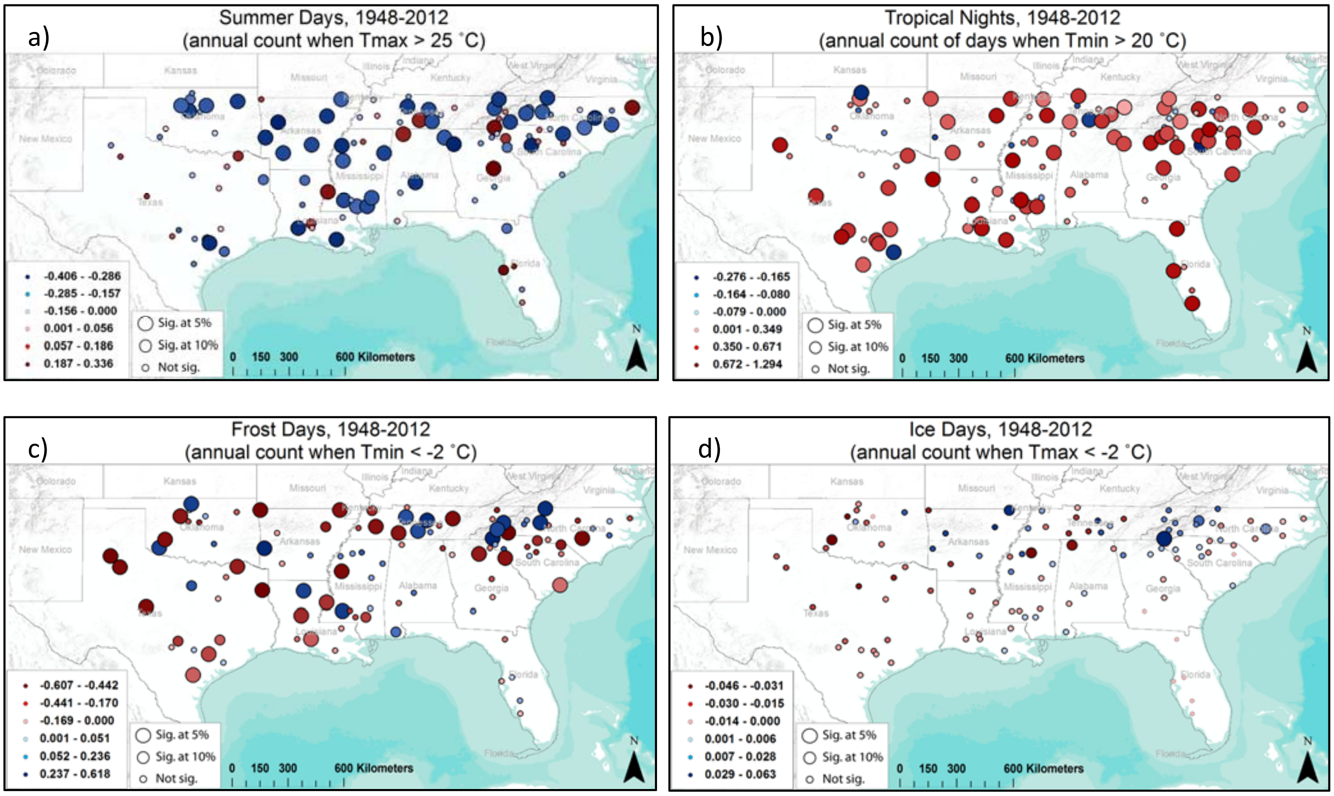


Figure D-11. Proportion of stations in Texas showing positive and negative trends in extreme indices from 1948 to 2012.

APPENDIX E: ADDITIONAL TEMPERATURE INDEX MAPS



a) Summer Days, 1948-2012 (annual count when Tmax > 25 ˚C)

b) Tropical Nights, 1948-2012 (annual count of days when Tmin > 20 ˚C)

c) Frost Days, 1948-2012 (annual count when Tmin < -2 ˚C)

d) Ice Days, 1948-2012 (annual count when Tmax < -2 ˚C)

Figure E-1. Maps of temperature extreme indices for a) summer days (annual count of days when Tmax ≥ 25˚C, b) tropical nights (annual count of days when Tmin ≤ 20˚C), c) frost days (annual count of days when Tmin ≤ -2˚C), and d) ice days (annual count of days when Tmax ≤ -2˚C).

APPENDIX F: STATION DISTRIBUTION AND KEY

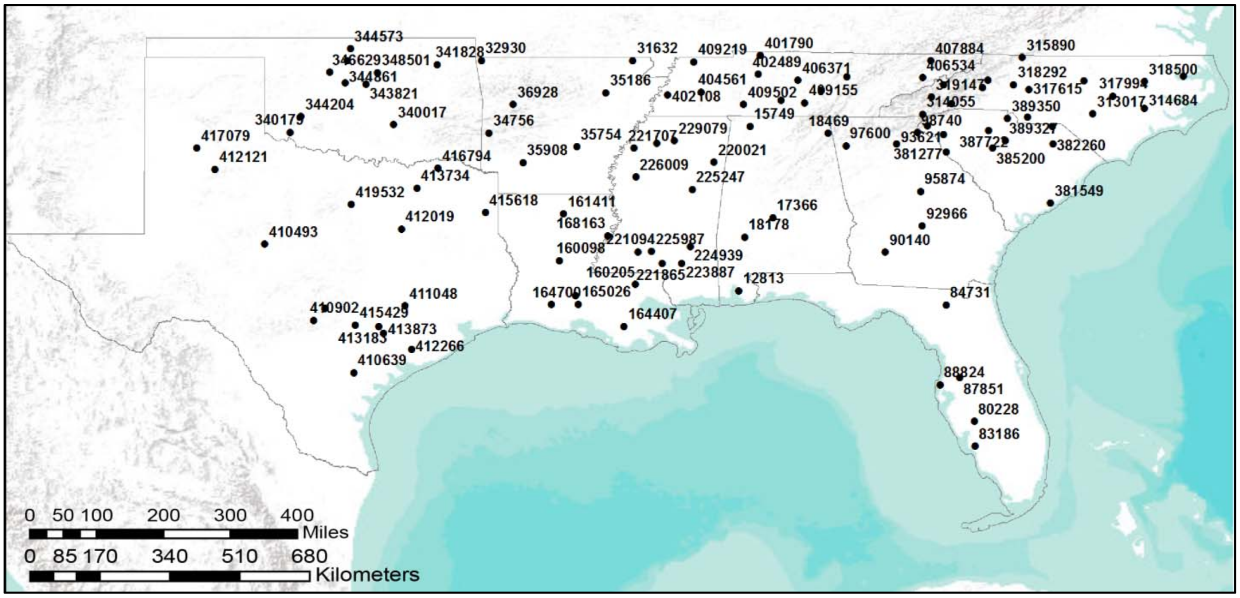


Figure F-1. USHCN IDs for the Southeast stations used in this study.

Table F-1. Key for station IDs and station names for all 107 stations used in this study.

State	Station	Name	Latitude	Longitude
Alabama	12813	Fairhope	30.547	-87.881
	15749	Muscle Shoals Rgnl AP	34.744	-87.600
	17366	Selma	32.411	-87.014
	18178	Thomasville	31.917	-87.735
	18469	Valley Head	34.567	-85.613
Arkansas	31632	Corning	36.420	-90.586
	32930	Gravette	36.426	-94.448
	34756	Mena	34.573	-94.249
	35186	Newport	35.604	-91.274
	35754	Pine Bluff	34.226	-92.019
	35908	Prescott	33.820	-93.388
	36928	Subiaco	35.303	-93.637
Florida	80228	Arcadia	27.218	-81.874
	83186	Ft. Myers Page Fld AP	26.585	-81.861
	84731	Lake City	30.185	-82.594
	87851	Saint Leo	28.338	-82.260
	88824	Tarpon Springs SWG PLT	28.152	-82.754
Georgia	90140	Albany	31.534	-84.149
	92966	Eastman	32.200	-83.206
	93621	Gainesville	34.301	-83.860

(Table F-1. continued)

State	Station	Name	Latitude	Longitude
	95874	Milledgeville	33.083	-83.250
	97600	Rome	34.245	-85.151
	98740	Toccoa	34.579	-83.332
Louisiana	160098	Alexandria	31.321	-92.461
	160205	Amite	30.709	-90.525
	161411	Calhoun	32.513	-92.349
	163800	Grand Coteau	30.419	-92.044
	164407	Houma	29.641	-90.816
	164700	Jennings	30.200	-92.664
	165026	Lafayette Rgnl AP	30.205	-91.988
	168163	St. Joseph	31.950	-91.234
Mississippi	220021	Aberdeen	33.830	-88.521
	220488	Batesville	34.306	-89.981
	221094	Brookhaven City	31.545	-90.458
	221707	Clarksdale	34.186	-90.557
	221865	Columbia	31.250	-89.836
	223887	Hattiesburg	31.255	-89.339
	224939	Laurel	31.676	-89.124
	225247	Louisville	33.136	-89.071
	225987	Monticello	31.552	-90.106
	226009	Moorhead	33.452	-90.510
	229079	University	34.373	-89.531
North Carolina	311677	Chapel Hill	35.909	-79.079
	312635	Edenton	36.016	-76.552
	313017	Fayetteville	35.058	-78.858
	313976	Hendersonville	35.330	-82.449
	314055	Highlands	35.057	-83.198
	314684	Kinston	35.197	-77.543
	314938	Lenoir	35.915	-81.538
	315356	Marshall	35.804	-82.666
	315771	Monroe	34.980	-80.523
	315838	Morgantown	35.730	-81.673
	315890	Mt. Airy	36.499	-80.651
	317615	Salisbury	35.684	-80.482
	317994	Smithfield	35.516	-78.346
	318292	Statesville	35.810	-80.881
	318500	Tarboro	35.885	-77.539
	319147	Waynesville	35.487	-82.968
Oklahoma	340017	Ada	34.786	-96.685
	340179	Altus Irig Rsch Stn	34.590	-99.334

(Table F-1. continued)

State	Station	Name	Latitude	Longitude
	341828	Claremore	36.323	-95.581
	342912	Enid	36.419	-97.875
	343821	Guthrie	35.816	-97.395
	344204	Hobart Muni AP	34.989	-99.053
	344573	Jefferson	36.722	-97.790
	344861	Kingfisher	35.858	-97.929
	346629	Okeene	36.122	-98.315
	348501	Stillwater	36.118	-97.095
South Carolina	380165	Anderson	34.528	-82.661
	381277	Calhoun Falls	34.091	-82.588
	381549	Charleston City	32.780	-79.932
	381588	Cheraw	34.732	-79.883
	382260	Darlington	34.301	-79.877
	385200	Little Mountain	34.194	-81.415
	387722	Santuck	34.635	-81.521
	388887	Walhalla	34.754	-83.075
	389327	Winnsboro	34.374	-81.093
	389350	Winthrop Univ.	34.938	-81.032
Tennessee	401790	Clarksville Sewage Pl	36.547	-87.335
	402108	Covington	35.550	-89.700
	402202	Crossville Exp Stn.	36.015	-85.131
	402489	Dickson	36.075	-87.396
	404561	Jackson Exp Stn	35.621	-88.846
	405187	Lewisburg Exp Stn	35.414	-86.809
	405882	MC Minnville	35.672	-85.781
	406371	Murfreesboro	35.920	-86.373
	406534	Newport	35.983	-83.201
	407884	Rogersville	36.416	-82.984
	409155	Tullahoma	35.345	-86.209
	409219	Union City	36.393	-89.032
	409502	Waynesboro	35.304	-87.759
Texas	410493	Ballinger	31.741	-99.976
	410639	Beeville	28.458	-97.706
	410832	Blanco	30.106	-98.429
	410902	Boerne	29.799	-98.735
	411048	Brenham	30.159	-96.397
	412019	Corsicana	32.123	-96.487
	412121	Crosbyton	33.652	-101.245
	412266	Danevang	29.057	-96.232
	413183	Flatonia	29.634	-97.064

(Table F-1. continued)

State	Station	Name	Latitude	Longitude
	413734	Greenville KGVL Radio	33.168	-96.098
	413873	Hallettsville	29.471	-96.940
	415429	Luling	29.676	-97.658
	415618	Marshall	32.540	-94.351
	416794	Paris	33.674	-95.559
	417079	Plainview	34.189	-101.702
	419532	Weatherford	32.748	-97.770

VITA

Emily J. Powell, born in Atlanta, Georgia, is pursuing her Doctor of Philosophy in Geography, with a minor in Disaster Science Management, at Louisiana State University. She received her Bachelor of Science in Geography from the University of Georgia, with an emphasis in atmospheric science. Emily began her career in meteorology product development at The Weather Channel, Inc. shortly after graduating from UGA. While at The Weather Channel, Emily pursued a Master of Science in Geography from the University of Georgia.

Emily gained diverse research experience during her graduate studies at UGA in the areas of atmospheric science. Her thesis investigated surface mass balance changes of the Greenland ice sheet using scatterometer and model data to delineate the boundaries of snow facies and measure interannual changes in the equilibrium line altitude. She also worked on a research project to measure precipitation contributions from mesoscale convective complexes in the United States.

After completing her master's degree, Emily moved to the United Kingdom and began working for a weather company in Birmingham as a meteorologist in the media production team building weather shows for distribution to European clients. After traveling and working in the field of science writing for several years, she decided to return to school to pursue interests in natural hazards and climate science. At LSU, she first worked as a research assistant studying the socio-economic impacts of changing flood insurance rate maps on individuals and businesses in coastal Louisiana. Currently, Emily works as a Research Fellow at LSU's Coastal Sustainability Studio on the Louisiana Resiliency Assistance Program to assist communities seeking to address risks from natural hazards through resilience planning efforts.