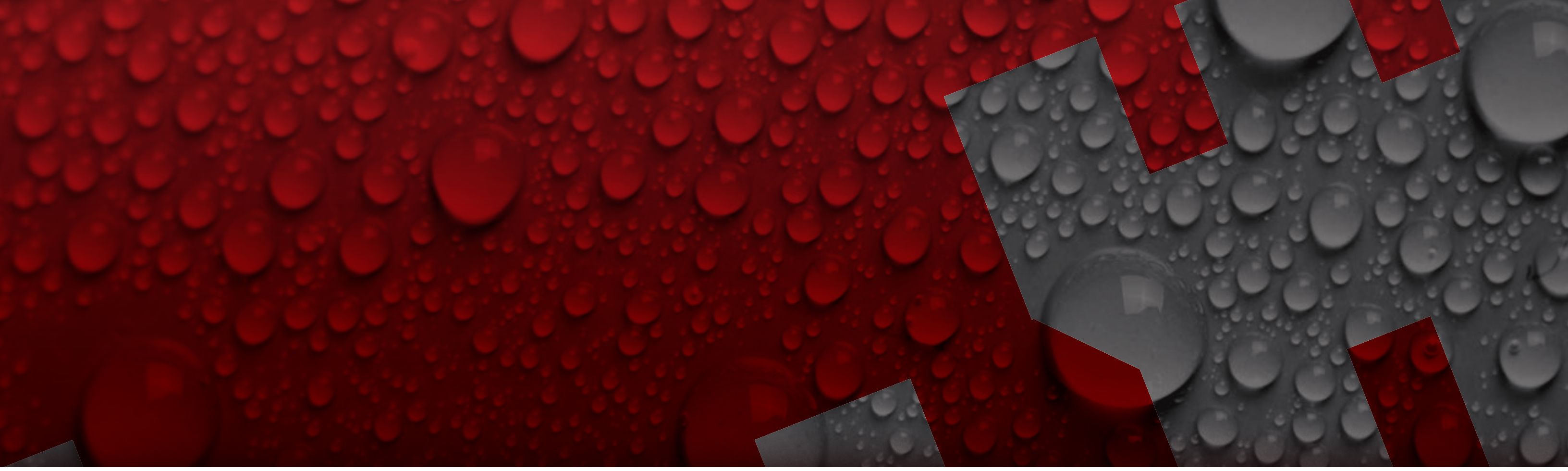

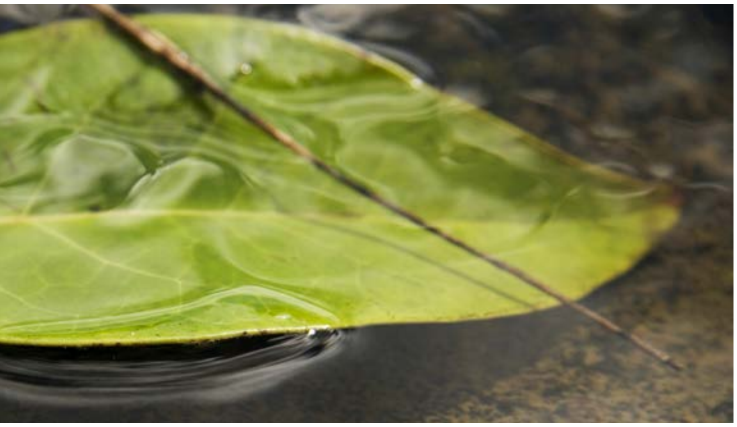

Recent US Climate Change and Hydrology Literature Applicable to US Army Corps of Engineers Missions

SOUTH ATLANTIC-GULF REGION 03

FINAL

January 2015

USACE CLIMATE PREPAREDNESS AND RESILIENCE

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14. ABSTRACT
To help the US Army Corps of Engineers (USACE) staff in meeting the requirements of the 2011 and 2014 policy statements on climate change adaptation by the Assistant Secretary of the Army for Civil Works, the USACE Climate Change Adaptation Plans, and agency policy and guidance, this report presents concise and broadly-accessible summaries of the current climate change science with specific attention to USACE missions and operations. This report, focused on the South Atlantic-Gulf Region, is part of a series of twenty one (21) regional climate syntheses prepared by the USACE under the leadership of the Response to Climate Change Program at the scale of 2-digit Hydrologic Unit Code (HUC) Water Resources Regions, across the continental United States, Alaska, Hawaii, and Puerto Rico. Each of these regional reports summarize observed and projected climate and hydrological patterns cited in reputable peer-reviewed literature and authoritative national and regional reports, and characterize climate threats to USACE business lines.

15. SUBJECT TERMS

South Atlantic-Gulf Region	Observed Hydrology	Business Line
Water Resources Region 03	Projected Climate	Climate Vulnerability
Observed Climate	Projected Hydrology	Regional Climate Synthesis

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CLIMATE CHANGE AND HYDROLOGY LITERATURE SYNTHESIS FOR THE US ARMY CORPS OF ENGINEERS MISSIONS IN THE UNITED STATES

SOUTH ATLANTIC-GULF REGION 03

January 9, 2015

CDM Smith
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Water Resources Region 03: South Atlantic-Gulf Region

1. Introduction

U.S. Army Corps of Engineers (USACE) staff are increasingly considering potential climate change impacts when undertaking long-term planning, setting priorities, and making decisions that affect resources, programs, policies, and operations, consistent with the 2011 and 2014 policy statements on climate change adaptation by the Assistant Secretary of the Army for Civil Works, the USACE Climate Change Adaptation Plans, and agency policy and guidance. USACE is undertaking its climate change preparedness and resilience planning and implementation in consultation with internal and external experts using the best available – and actionable – climate science and climate change information. This report represents one component of actionable science, in the form of concise and broadly-accessible summaries of the current science with specific attention to USACE missions and operations. This report is part of a series of twenty one (21) regional climate syntheses prepared by the USACE under the leadership of the *Response to Climate Change Program* at the scale of 2-digit U.S. Geological Survey (USGS) Hydrologic Unit Codes (HUC) across the continental United States, Alaska, Hawaii, and Puerto Rico. The twenty one Water Resources Regions included in this series of reports is shown in **Figure 1.1** along with USACE division boundaries. Each of these regional reports summarizes observed and projected climate and hydrological patterns cited in reputable peer-reviewed literature and authoritative national and regional reports, and characterizes climate threats to USACE business lines. They also provide context and linkage to other agency resources for climate resilience planning, such as sea level change calculation and coastal risk reduction resources, downscaled climate data for subregions, and watershed vulnerability assessment tools.

This report focuses on Water Resources Region 03, the South Atlantic-Gulf, the boundaries for which are shown in **Figure 1.2**. The Wilmington, Charleston, Savannah, Jacksonville, Atlanta, and Mobile USACE districts and a relatively small section of the Mississippi Valley Division are within the region.

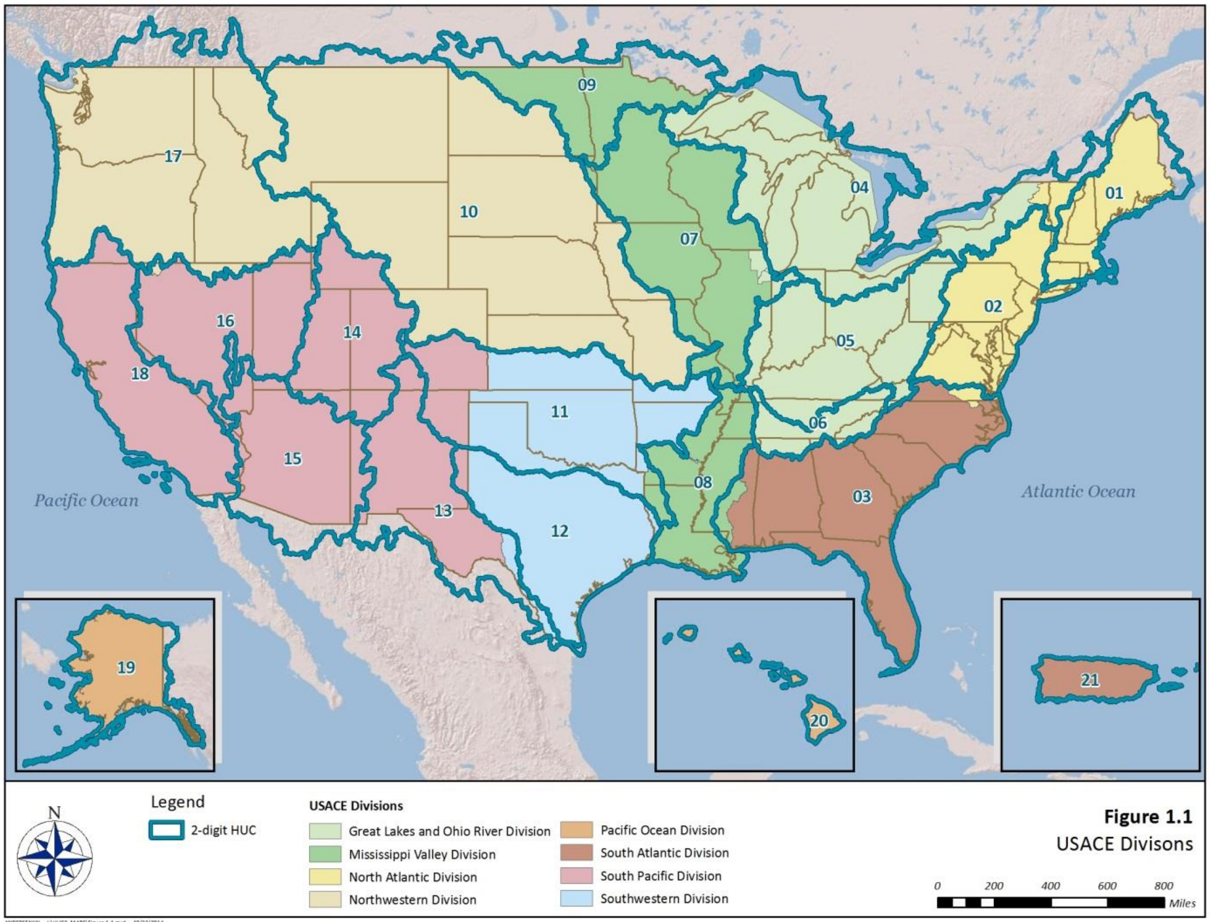

Figure 1.1. 2-digit Hydrologic Unit Code Boundaries for the Continental United States, Alaska, Hawaii, and Puerto Rico.

Figure 1.2. Water Resources Region 03: South Atlantic-Gulf Region Boundary.

1.1 A Note on the Water Resources Region Scale

USACE and other resource management agencies require reliable, science-based methods for incorporating climate change information into the assessments that support water resources decisions and actions. Such planning assessments must quantify projections of future climate and hydrology. One common practice is to begin by developing relationships between the currently observed climate and the projected future possible climate over the assessment region.

However, the numerical models producing these multiple projections of future possible climate were not designed to support these assessments for local-to-regional scale operations. This means that intervening steps have to be taken to correct obvious biases in the models' outputs and to make the outputs relevant at the scales where hydrologic resource assessments can take place. The commonly used name for these post-processing steps is "downscaling" because one step is using one or another method to spatially (and temporally) disaggregate or interpolate (or other) the results produced at the numerical climate models' native scale to the scale of the water resources assessment. The current generation of climate models, which includes the models used to generate some of the inputs described in this work, have a native scale on the order of one to two hundred kilometers on each side of the grids used to simulate climate for Earth, substantially too coarse for the watershed assessments needed to inform resource assessment questions and decisions.

On the other hand, these questions and decisions should not be addressed with model inputs at scales so fine that they impart false precision to the assessment. False precision would appear by suggesting that the driving climate model information can usefully be downscaled, by any method, to individual river reaches and particular project locations, for example.

The approach at USACE is to consider the questions in need of climate change information at the geospatial scale where the driving climate models retain the climate change signal. At present, USACE judges that the regional, sub-continental climate signals projected by the driving climate models are coherent and useful at the scale of the 2-digit USGS HUC (Water Resources Region), and that confidence in the driving climate model outputs declines below the level of a reasonable trade-off between precision and accuracy for areas smaller than the scale of the 4-digit HUC (Water Resources Subregion). Hence, these summaries group information at the Water Resources Region scale both to be guides into the climate change literature and to support the informational analyses USACE is conducting at the Water Resources Subregion scale. For Water Resources Region 03, both the 2-digit and 4-digit HUC boundaries are shown in Figure 1.2.

2. Observed Climate Trends

Observed climate trends within the Water Resources Region 03 are presented in this section to generally characterize current, or past, climate in the study region. While the primary cause for global warming is attributed by the scientific community to human-induced increases in atmosphere levels of heat-trapping gases (Walsh et al., 2014) this section is not focused on attribution or cause (either natural or unnatural). Rather, it is specifically focused on the identification and detection of climate trends in the recent historical record. The interrelationships of Earth's climate system are complex and influenced by multiple natural and unnatural (i.e., anthropogenic greenhouse gas emissions) forcings. When additional detail is needed the reader is referred to the specific references cited, including the third National Climate Assessment (NCA), which includes not only regional assessments, but also foundational resources related to climate science literacy.

The climate trends presented in this section are based on peer-reviewed literature on the subject of observed climate. To the extent possible, studies specific to the South Atlantic-Gulf Region or its sub-watersheds were relied upon. A focus is placed on identified primary variables including:

- mean temperature
- extreme temperatures
- average precipitation
- extreme precipitation events
- mean streamflow

In addition to primary variables, peer-reviewed literature addressing climate change within the geographic region or inclusive of the Water Resources Region revealed additional, secondary, climatic variables that have been studied such as the spring index (SI), drought indices, and soil moisture.

The results presented below indicate a mild upward trending in temperature and a mild downward trending in streamflow in the South Atlantic-Gulf Region, particularly since the 1970s. However, clear consensus does not exist for either. Studies on precipitation show mixed results but with more findings showing an upward, rather than downward, pattern over the past 50 to 100 years.

2.1. Temperature

A number of studies focusing on observed trends in historical temperatures were reviewed for this report. These include both national scale studies inclusive of results relevant to Water Resources Region 03 and regional studies focusing more specifically and exclusively on the area. Results from both types of studies are discussed below.

A 2009 study by Wang et al. examined historical climate trends across the continental United States. Gridded (0.5 degrees x 0.5 degrees) mean monthly climate data for the period 1950 – 2000 were used. The focus of this work was on the link between observed seasonality and regionality of trends and sea surface temperature variability. The authors identified positive statistically significant trends in recent observed mean air temperature for most of the U.S. (**Figure 2.1**). For the South Atlantic-Gulf Region, mixed results are presented. A positive, but mild, warming trend is identified for most of the area in the spring and summer. For the fall months, the southern portion of the area is shown to be warming while mild cooling is shown in the northern portion of the area. For the winter months, the divide appears to be more east-west, with warming in the east and cooling in the western portion of the area. A later study by Westby et al. (2013), using data from the period 1949 – 2011, moderately contradicted these findings, presenting a general winter cooling trend for the entire region for this time period. The third NCA report (Carter et al., 2014) presents historical annual average temperatures for the southeast region. Their southeast study region is larger than, but inclusive of the South Atlantic-Gulf

Region. For this area, historical data generally shows mild warming of average annual temperatures in the early part of the 20th century, followed by a few decades of cooling, and is now showing indications of warming. However, though a seasonal breakdown is not presented, the NCA report cites an overall lack of trend in mean annual temperature in the region for the past century. Details on statistical significance are not provided.

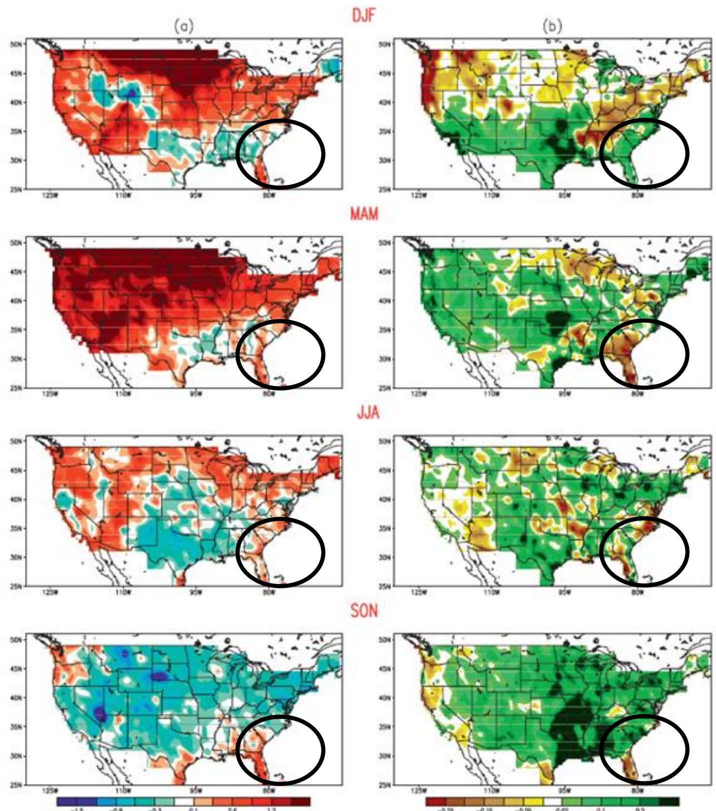

Figure 2.1. Linear trends in surface air temperature (a) and precipitation (b) over the United States, 1950 – 2000. The South Atlantic-Gulf Region is within the black oval (Wang et al., 2009).

Grundstein and Dowd (2011) investigated trends in one-day extreme maximum and minimum temperatures across the continental U.S. The study was based on daily temperature data compiled by the National Climatic Data Center (NCDC) for 187 stations across the country for the period 1949 – 2010. For the South Atlantic-Gulf Region, they found a statistically significant increasing trend in the number of one-day extreme minimum temperatures. However, only in the southern portion of the region (Florida) were significant trends in the number of one-day extreme maximum temperatures identified. This appears to generally agree with the findings of Wang et al. (2009), two years earlier and described above, which indicated a mix of warming versus cooling trends in recent historical temperature data for the region.

Schwartz et al. (2013) investigated changes in spring onset for the continental U.S. Their particular focus was on changes in the seasonality of plant growth as dictated by changing temperature regimes. The authors used historical data from over 22,000 stations across the United States, obtained from the NCDC with periods of record extending through 2010. Their findings indicate that for most of the South Atlantic-Gulf Region, spring onset is occurring at least a few days later for the current period (2001 – 2010) compared to an earlier baseline reference decade (1951 – 1960) (**Figure 2.2**). This is particularly evident for the north and west portions of the area. In other words, an apparent small shift in seasons has been identified for most of the South Atlantic-Gulf Region, with spring warming occurring later than in the past.

Figure 2.2. Change in spring onset (first leaf date), in days for 2001 – 2010 compared to 1951 – 1960. The South Atlantic-Gulf Region is within the red oval (Schwartz et al., 2013).

A 2011 study by Obeysekera et al. focused on identifying climate (temperature and precipitation) trends for South Florida using historical data. This study examined a number of climate metrics with data extending back to the 1890s. For all of the metrics, including average and maximum daily temperatures, number of hot days, and extreme temperature events, no discernible trends were found for their study region. While some climate stations showed an increasing trend, just as many displayed a decreasing trend, and even more showed no trend at all. Two years later, many of these same authors conducted a similar study of climate stations distributed across the entire state of Florida (Irizarry-Ortiz et al., 2013). They found similar results, although focused on slightly different metrics. Based on the same historical observation period as the 2011 study, no consistent, discernible trend in daily average temperature was found. However, the authors present evidence of increasing trends in the number of extreme heat days and in daily minimum temperature, with many stations exhibiting statistically significant increasing trends in one or both of these metrics.

A 2012 study by Patterson et al. focused exclusively on historical climate and streamflow trends in the South Atlantic region. Monthly and annual trends were analyzed for a number of stations distributed throughout the South Atlantic-Gulf Region for the period 1934 – 2005. Results (**Figure 2.3**) identified a largely cooling trend for the first half of the historical period and the period as a whole. However, the second half of the study period (1970 – 2005) exhibits a clear warming trend with nearly half of the stations showing statistically significant warming over the period (average increase of 0.7 ºC). The circa 1970 "transition" point for climate and streamflow in the U.S. has been noted elsewhere, including Carter et al. (2014). Trends in overnight minimum temperatures (T_{min}) and daily maximum (T_{max}) temperatures for the southeast U.S. were the subject of a study by Misra et al. (2012). Their study region encompasses nearly the full extent of the South Atlantic-Gulf Region and used data from 1948 to 2010. Results of this study show increasing trends in both T_{min} and T_{max} throughout most of the study region. The authors attribute at least a portion of these changes to the impacts of urbanization and irrigation.

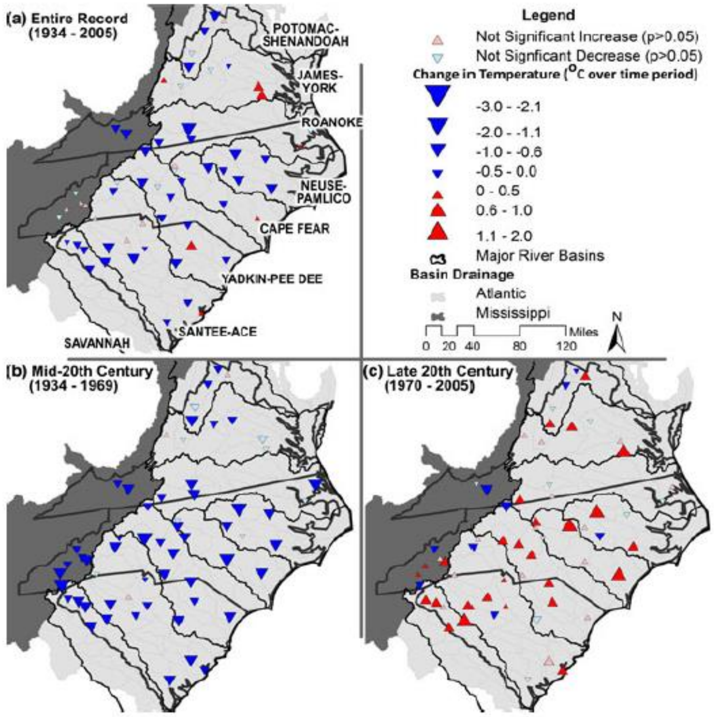

Figure 2.3. Historical annual temperature trends for the South Atlantic Region, 1934 – 2005. Triangles point in the direction of the trend, size reflects the magnitude of the change. Blue indicates a decreasing temperature trend. Red indicates an increasing temperature trend (Patterson et al., 2012).

Laseter et al. (2012) present a continuous historical climate data set for the Coweeta Laboratory in North Carolina (northern portion of the region). This data shows significant warming since the late 1970s (**Figure 2.4**) in terms of annual average, maximum, and minimum air temperatures. They report that 1999 was the hottest year on record for their study site. Similar results are presented by Dai et al. (2011) for a climate station in South Carolina (Santee Experimental Forest). They quantified a statistically significant increasing trend in annual average air temperature (at a rate of 0.19 ºC per year) going back to 1946.

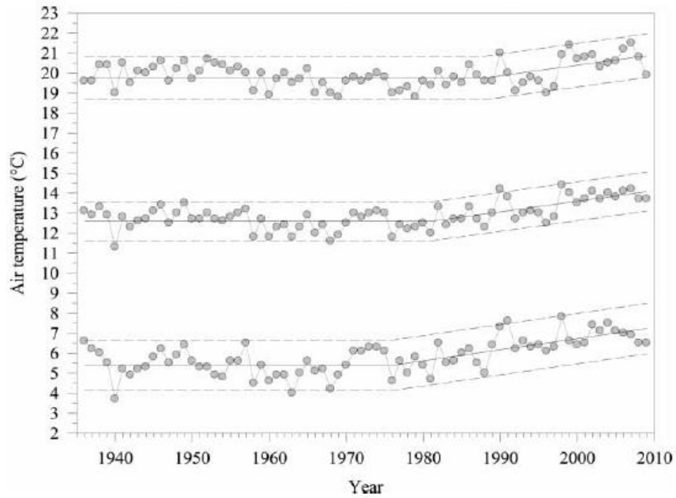

Figure 2.4. Annual maximum, average, and minimum historical air temperatures, 1940 – 2010, Coweeta Laboratory, North Carolina. (Laseter et al., 2012).

Key point: There has been an apparent warming in the region since the 1970s. The overall trend since the early 1900s, however, is unclear.

2.2. Precipitation

Palecki et al. (2005) examined historical precipitation data from across the continental United States. They quantified trends in precipitation for the period 1972 – 2002 using NCDC 15-minute rainfall data. For the South Atlantic-Gulf Region, statistically significant increases in winter storm intensity (mm per hour) and fall storm totals were identified for the southernmost portion of South Atlantic-Gulf Region. Additionally, a statistically significant decrease in summer storm intensity was identified for the northern portion of the area.

Multiple authors have identified significant increasing trends in total annual precipitation in recent historical records for the study region. Grundstein (2009) presented little evidence of significant trends (1895 – 2006) in either annual precipitation or soil moisture for the majority of the area (**Figure 2.5**), except for Alabama. Soil moisture is a function of both supply (precipitation) and demand (evapo-transpiration [ET]), and therefore is an effective proxy for both precipitation and ET. A number of sites in Alabama (southwest portion of the HUC) exhibit significant increasing trends in both annual precipitation and soil moisture over the past century.

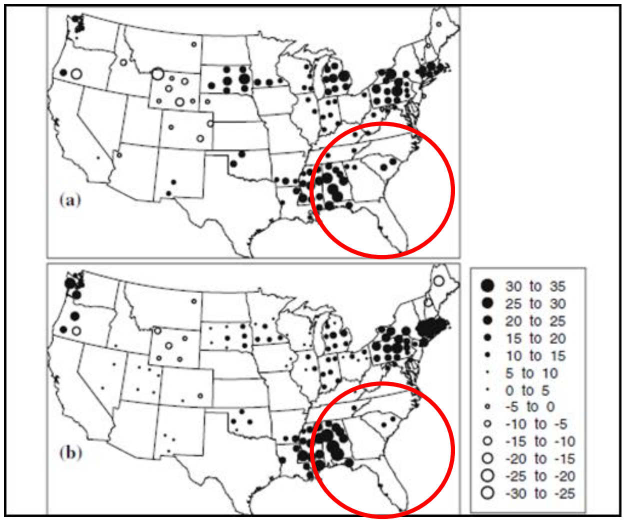

Figure 2.5. Statistically significant linear trends in (a) soil moisture index (unitless) and (b) annual precipitation (cm) for the continental U.S., 1895 – 2006. The South Atlantic-Gulf Region is within the red oval (Grundstein, 2009).

As described in Section 2.1, a similar study by Wang et al. (2009) also focused on historical climate trends across the continental U.S. using gridded climate data and a shorter period of record (1950 – 2000). The authors identified generally positive significant trends in annual precipitation for most of the U.S. For the South Atlantic-Gulf Region, the authors identified a mild increasing trend in winter precipitation for most of the area (**Figure 2.1**). Results were mixed for the other seasons, with some areas showing increasing precipitation and others showing decreasing precipitation.

A 2011 study by McRoberts and Nielsen-Gammon used a new continuous and homogenous data set to perform precipitation trend analyses for sub-basins across the United States. The extended data period used for the analysis was 1895 – 2009. Linear positive trends in annual precipitation were identified for most of the U.S (**Figure 2.6**). For the South Atlantic-Gulf Region, results were mixed with some areas showing mild decreases in precipitation and others showing mild increases. No clear trend for the area is evident from these results.

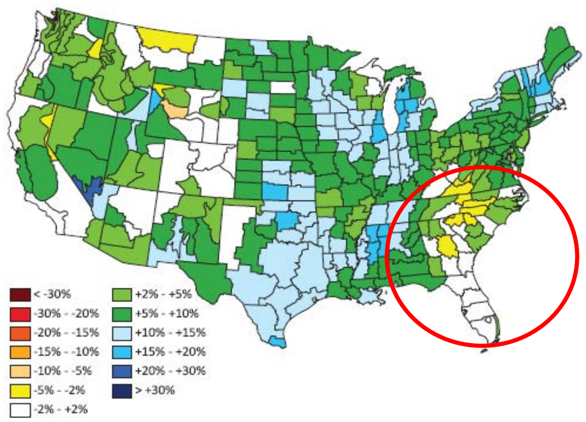

Figure 2.6. Linear trends in annual precipitation, 1895 – 2009, percent change per century. The South Atlantic-Gulf Region is within the red oval (McRoberts and Nielsen-Gammon, 2011).

Changes in extreme precipitation events observed in recent historical data have been the focus of a number of studies. Studies of extreme events have focused on intensity, frequency, and/or duration of such events. Wang and Zhang (2008) used recent historical data and downscaled Global Climate Models (GCMs) to investigate changes in extreme precipitation across North America. They focused specifically on the changes in the frequency of the 20-year maximum daily precipitation event. The authors looked at both historical trends in observed data and trends in future projections. Statistically significant increases in the frequency of the 20-year storm event were quantified across the southern and central U.S., in both the recent historical data and the long-term future projections (described below). For the South Atlantic-Gulf Region, significant changes in the recurrence of this storm were identified for the period 1977 – 1999 compared to the period 1949 – 1976. An increase in frequency of approximately 25 to 50% was quantified.

Pryor et al. (2009) performed statistical analyses on 20th century rainfall data to investigate for trends across a range of precipitation metrics. They used data from 643 stations scattered across the continental U.S. For the South Atlantic-Gulf Region, the analysis showed generally increasing, and statistically significant, trends in the number of precipitation days per year (**Figure 2.7 d**). However, no clear trends for the region were evident for total annual precipitation, extreme high precipitation events (90th percentile daily), or precipitation intensity (**Figure 2.7 a – c**). The authors note that the trends identified are not necessarily linear, with an apparent increase in the rate of change in the latter part of the century for most of the trends.

a) Annual precipitation

b) 90th percentile daily precipitation

c) Precipitation intensity (annual total / number of precipitation days)

d) Number of precipitation days per year

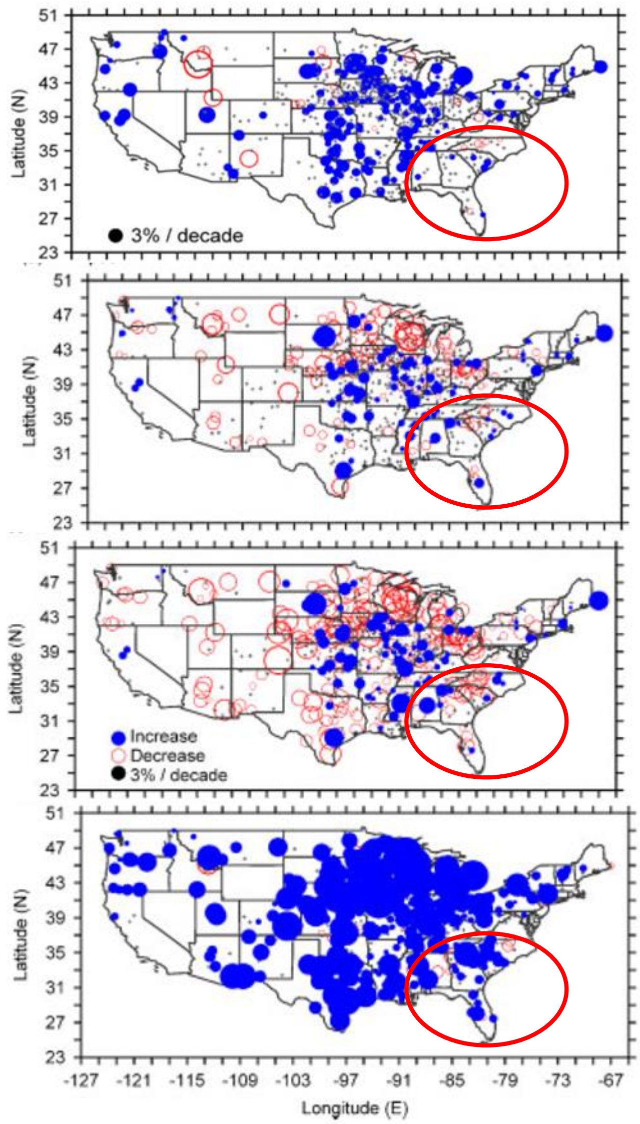

Figure 2.7. Historical precipitation trends in the 20th century. a.) annual totals, b.) 90th percentile daily, c.) precipitation intensity (annual total/number of precipitation days), and d.) number of precipitation days per year. Note that blue dots indicate positive trend, red circles indicate negative trend, and symbol sizes are scaled to 3% change per decade. The South Atlantic-Gulf Region is within the red oval (Pryor et al., 2009).

Brommer et al. (2007) investigated changes in long duration precipitation events over the past century. This study found no significant changes for the South Atlantic-Gulf Region during the 20th century, despite such changes quantified for many other areas in the U.S.

A number of recent studies have focused more specifically on the southeast region of the U.S., including the South Atlantic-Gulf Region. As above, regional investigations have targeted trends, or changes, in annual precipitation and the occurrence of extreme events. The work of Small et al. (2006) included analysis of the South Atlantic-Gulf Region specifically. These authors investigated for significant trends in various precipitation and flow metrics based on USGS Hydroclimatologic Data Network (HCDN) climate data from 1948 to 1997. Statistically significant increasing trends were identified for the region in annual and fall precipitation for multiple locations in the area (**Figure 2.8**). There were even more locations within the HUC, however, where no statistically significant trends in precipitation were identified.

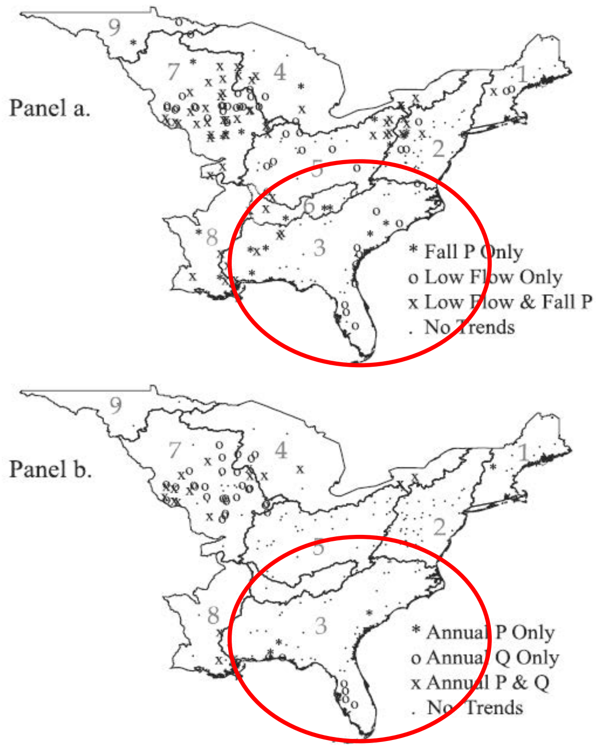

Figure 2.8. Historical trends in precipitation (P) and streamflow (Q), 1948 – 1997. The South Atlantic-Gulf Region is within the red oval (Small et al., 2006).

Li et al. (2011) investigated the occurrence of anomalous summer precipitation in the southeast U.S., including the South Atlantic-Gulf Region, as defined by deviation from the mean. They attribute apparent trends in anomalies to changes in the North Atlantic Subtropical High (NASH), which in turn is attributed to climate change. As above, results indicate a general increase in the frequency and magnitude of anomalous summer precipitation (**Figure 2.9**). These results are generally supported by the findings of Villarini et al. (2013). These authors identified statistically significant ($p \leq 0.05$) increasing trends in the frequency of occurrence of heavy rainfall in a region inclusive of the western edge of the South Atlantic-Gulf Region (Mississippi and Alabama) for multiple climate stations with at least 50 years of historical record. While significant trends were identified for a number of stations in the region, an even greater number of stations in the South Atlantic-Gulf Region exhibited no significant trends.

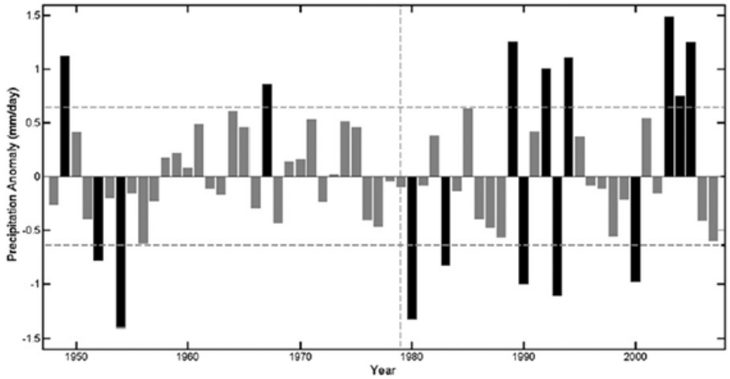

Figure 2.9. Summer precipitation anomalies, southeast USA, 1900 – 2000. (Li et al., 2011).

Wang and Killick (2013) also investigated both high and low extreme precipitation anomalies, as well as non-stationarity in historical monthly data. These authors targeted 56 watersheds in the southeast U.S., nearly all of which are located in the South Atlantic-Gulf Region. Quantile regression analysis was applied to detect trends in different quantiles of monthly historical precipitation data (1900 – 2009). For the 10th quantile (low precipitation), the vast majority of sites showed no trend at all, while a small number exhibited a negative (decreasing) trend in monthly precipitation (**Figure 2.10).** For high precipitation months (90th quantile), approximately 20% of the sites showed a significant increasing trend. These results point toward an increasing frequency of extreme storm events. It is also worth noting that non-stationarity in monthly precipitation totals for the same period of record was detected in 8 of the 56 study watersheds.

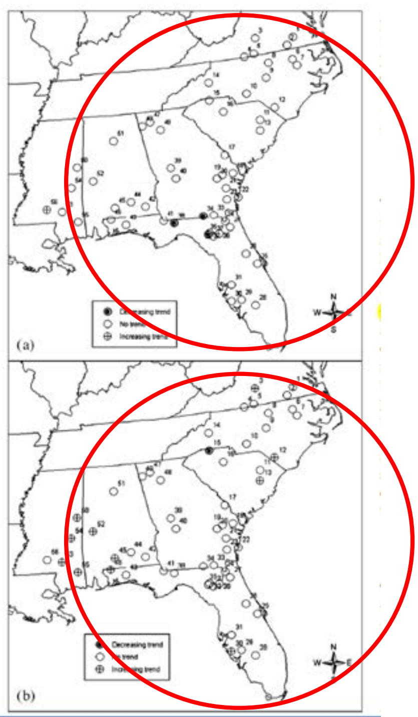

Figure 2.10. Trends in 10th (a) and 90th (b) quantile monthly precipitation, 1900 – 2009. The South Atlantic-Gulf Region is within the red oval. (Wang et al., 2013a).

A 2011 study by Obeysekera et al. focused on identifying climate (temperature and precipitation) trends for South Florida using historical data. This study examined a number of climate metrics with data extending back to the 1890s. For all of the metrics, including total annual precipitation and the occurrence of temperature extremes, no discernible trends were found for their study region. Two years later, Irizarry-Ortiz et al. (2013) quantified an overall decreasing trend in wet season (most evident in the month ofMay) precipitation for the state of Florida using an extended data set (1892 – 2008). In contrast, they also found evidence of an increase in the number of dry season (November – January) precipitation days in Florida.

In North Carolina (at the Coweeta Laboratory), changes in precipitation variability have been observed (Laseter et al., 2012) (**Figure 2.11**). These changes include wetter wet years and dryer dry years compared to the middle of the 20th century. As an example, the wettest year on record occurred in 2009 at Coweeta, and only two years earlier (2007) the driest year on record was observed. This pattern of change is supported by the NCA report (Carter et al., 2014), which states that, "summers have been either increasingly dry or extremely wet" in the southeast region. This assessment is based on analysis of data dating back to the turn of the 20th century.

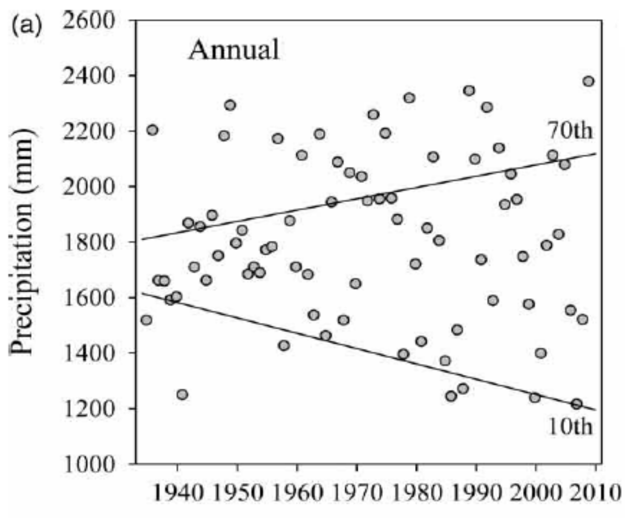

Figure 2.11. Total annual precipitation at Coweeta Laboratory (North Carolina). Lines show modeled 10th and 90th quantiles as a function of time, 1940 – 2010. (Laseter et al., 2012).

A study by Dai et al. (2011), for a climate station in South Carolina (at the Santee Experimental Forest), identified a generally increasing, but not statistically significant, pattern in the number of extreme storm events over the past 60 years. Similarly, they demonstrate a generally increasing trend in total annual precipitation at their study site, but without statistical significance.

A 2012 study by Patterson et al. focused exclusively on the South Atlantic Region, investigating historical climate and streamflow trends. Monthly and annual trends were analyzed for a number of stations distributed throughout the South Atlantic-Gul Region for the period 1934 – 2005. Results identified little, if any, patterns of precipitation change in the area over this period. Some sites showed increasing trends, others showed decreasing trends. Overall, and for the full period of record, more sites exhibited mild increases in precipitation than decreases.

Trends in the frequency and severity of droughts in the Southeast U.S. were the subject of studies by Chen et al. (2012) and Cook et al. (2014). In the first study, historical data (1895 – 2007) for the southern USA, including the South Atlantic-Gulf Region, were used to identify trends in drought, as defined by the standard precipitation index (SPI). The SPI is a metric of precipitation only and neglects the impacts of ET on droughts (Chen et al., 2012). The authors were not able to identify significant trends in either the frequency or intensity of droughts in the study region. The second set of authors used tree ring data to assess the frequency and severity of droughts over the past millennium (1000 – 2005), across the U.S. For the southeast region, which includes the South Atlantic-Gulf Region, the authors identified a statistically significant decline in drought frequency (droughts per century) over the past 1,000 years and a general increase in soil moisture, as defined by the Palmer Drought Severity Index (PDSI), over the same period (**Figure 2.12**).

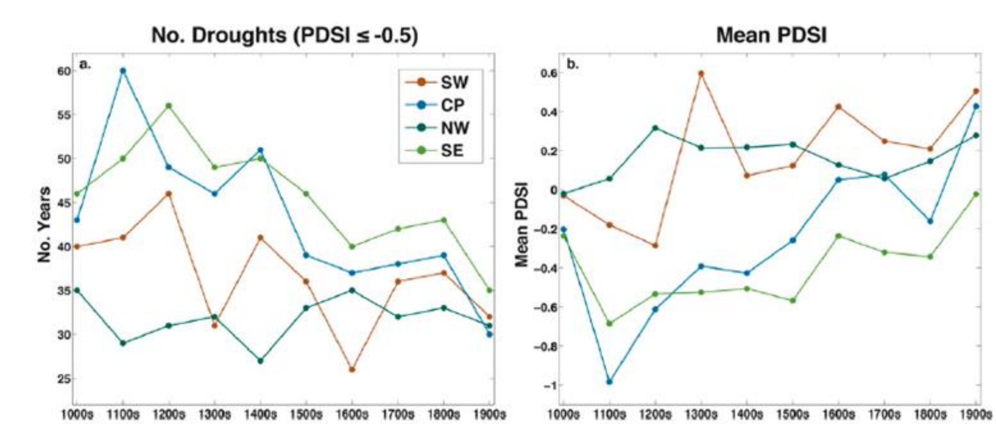

Figure 2.12. Drought frequency and severity for southeast USA (light green), based on Palmer Drought Severity Index (PDSI), 1000s – 1900s. (Cook et al., 2014).

Key point: A mild upward trend in precipitation in the study region, in terms of both annual totals and occurrence of storm events, has been identified by multiple authors but a clear consensus is lacking. Evidence has also been presented indicating an increase in the year-to-year variability in precipitation.

2.3. Hydrology

Studies of trends and non-stationarity in streamflow data collected over the past century have been performed throughout the continental U.S., some of which include the South Atlantic-Gulf Region. In 2013, Xu et al. investigated trends for multiple stream gages in the South Atlantic-Gulf Region. This study used the Model Parameter Estimation Experiment (MOPEX) data set for the period 1950 – 2000. Additional information on the MOPEX can be found in Duan et al. (2006). Statistically significant negative trends in both annual streamflow and baseflow were identified for two stations in Florida. The vast majority of stations, distributed throughout the HUC, show no significant trend in streamflow in either direction.

In contrast to the findings described above, Kalra et al. (2008) found statistically significant negative trends in annual and seasonal streamflow for a large number of stream gages in the South Atlantic-Gulf Region, analyzed in aggregate, for the historical period 1952 – 2001. This study also identified a statistically significant stepwise change occurring in the mid-1970s, concurrent with the warming climate "transition" period previously noted in Section 2.1, Temperature. These findings are supported by a regional study by Small et al. (2006). This study, using HCDN data for the period 1948 – 1997, identified statistically significant negative trends in annual low flow for multiple stations distributed throughout the South Atlantic-Gulf Region (but even more stations exhibited no significant trend at all).

The Patterson et al. (2012) study also observed a "transition" period occurring around 1970, as well as identified significant decreasing trends in streamflow in the South Atlantic-Gulf Region for the period 1970 – 2005 (**Figure 2.13**). Results were mixed for an earlier time period (1934 – 1969), with some decreasing and some increasing trends. These results again highlight the noted transition period of the 1970s.

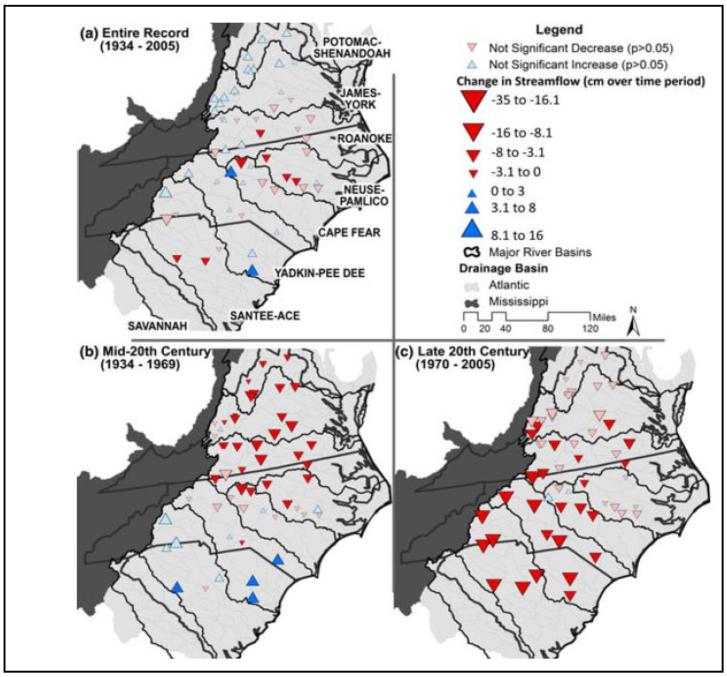

Figure 2.13. Observed changes in annual streamflow, South Atlantic Region, 1934 – 2005. Triangles point in the direction of the trend, size reflects the magnitude of the change. Blue indicates a decreasing streamflow trend. Red indicates and increasing streamflow trend. (Patterson et al., 2012).

Key point: A mild downward trend in mean streamflow in the study region, particularly since the 1970s, has been identified by multiple authors.

2.4. Summary of Observed Climate Findings

The general consensus in the recent literature points toward mild increases in annual temperature in the South Atlantic-Gulf Region over the past century, particularly over the past 40 years. While much of the area is located within the so-called "warming hole" identified by various researchers (including Carter et al., 2014), recent studies have demonstrated significant warming for other parts of the area (particularly northern portions) since the 1970s.

Annual precipitation totals have become more variable in recent years compared to earlier in the 20th century. Evidence has also been presented, but with limited consensus, of mildly increasing trends in the magnitude of annual and seasonal precipitation for parts of the study area. These results are seemingly contradicted by a number of studies that have shown decreasing trends in streamflow throughout the area, particularly since the 1970s. This paradox is discussed by Small et al. (2006), who attribute it largely to seasonal differences in the timing of the changes in precipitation vs. streamflow. The study authors evaluated watersheds that experienced minimal water withdrawals and/or transfers. Results presented here also suggest that increasing temperatures may also play a role in decreasing streamflows, despite the lack of corresponding precipitation decline.

3. Projected Climate Trends

While historical data is essential to understanding current and future climate, non-stationarity in the data (i.e., a changing climate) dictates the use of supplemental information in long-term planning studies. In other words, the past may no longer be a good predictor of the future (Milly et al., 2008). Consequently, the scientific and engineering communities are actively using computer models of the Earth's atmosphere and associated thermodynamics to project future climate trends for use in water resources planning efforts. Although significant uncertainties are inherent in these model projections, the models, termed global climate models (GCMs), are widely accepted as representing the best available science on the subject, and have proven highly useful in planning as a supplement to historical data. A wealth of literature now exists on the use of GCMs across the globe.

This section summarizes projected climate trends, as projected by GCMs, within the South Atlantic-Gulf Region identified in a review of recent peer-reviewed literature. The information presented should be considered an overview and, similar to Section 2 on observed climate trends, does not focus on attribution or causation of the projected climate trends or the causal relationships between climate variables. These relationships are complex and influenced by multiple natural and unnatural (i.e., anthropogenic greenhouse gas emissions) forcings that influence the Earth's climate system. Typical of projected climate studies, often specific (and sometimes multiple) greenhouse gas emission scenarios (or representative concentration pathways) are modeled by a single GCM (or ensemble of GCMs). The spectrum of scenarios offer a wide range of "climate futures" so each study's assumed emission scenario(s) are noted. When additional detail is needed, the reader is referred to the specific references cited, including the third NCA, which includes not only regional assessments, but also foundational resources related to climate science literacy, GCMs, and emission scenarios.

Results of this review indicate a strong consensus in the scientific literature that air temperatures will trend sharply upward over the next century in the South Atlantic-Gulf Region. There is much less consensus on the future trending, or lack thereof, in precipitation and streamflow in the region.

3.1. Temperature

GCMs have been used extensively to project future climate conditions across the country. At a national scale, model projections generally show a significant warming trend throughout the 21st century, with a high level of consensus across models and modeling assumptions. There is much less consensus on future patterns of precipitation. Results of studies inclusive of the South Atlantic-Gulf Region typically fall in line with both of these generalizations.

Maximum air temperature projections were investigated by Liu et al. (2013) using a single GCM and assuming an A2 greenhouse gas emissions scenario (worst case). The results of their study, specific to the South Atlantic-Gulf Region, show a projected increase in winter and spring maximum air temperature of about 2 ºC for a 2055 planning horizon compared to a baseline period of 1971 – 2000 (**Figure 3.1**). They show projected increases of up to 3.5 ºC for summer and fall temperatures.

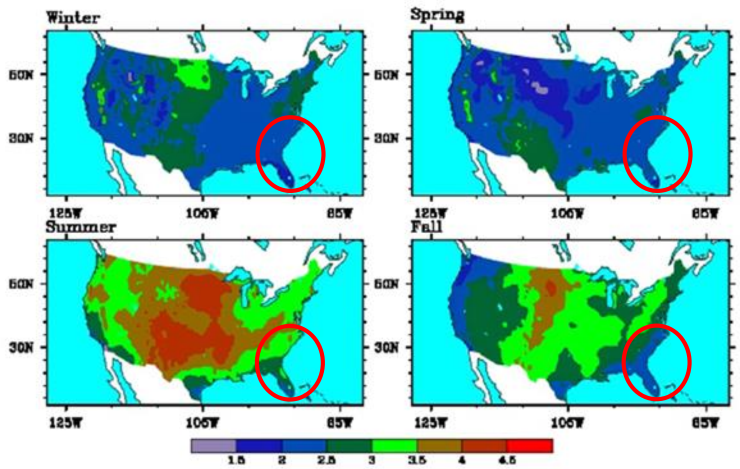

Figure 3.1. Projected changes in seasonal maximum air temperature, ºC, 2041 - 2070 vs. 1971 - 2000. The South Atlantic-Gulf Region is within the red oval (Liu et al., 2013).

Similar results are presented by Scherer and Diffenbaugh (2014). These authors apply a multi-member ensemble GCM, assuming an A1B (middle of the road) emissions scenario, to the continental U.S. For the southeast portion of the country, including the South Atlantic-Gulf Region, model projections indicate steadily increasing air temperatures throughout the 21st century for both summer and winter seasons (**Figure 3.2**). By 2090, projections show an increase of 3.9 ºC in the summer and 3.2 ºC in the winter, compared to a 1980 – 2009 baseline period. These results agree well with those described previously for Liu et al., (2013).

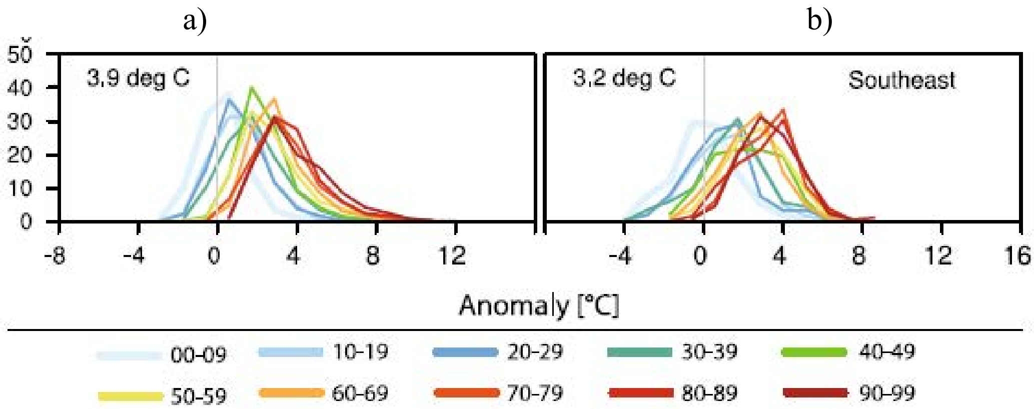

Figure 3.2. Probability distributions of GCM Projections of daily maximum temperatures for Years 2000 – 2100 by decade, southeast region (a. summer months: Jun – Aug, b. winter months: Dec – Feb). (Scherer and Diffenbaugh, 2014).

Elguindi and Grundstein (2013) present results of regional climate modeling of the U.S. focused on the Thornthwaite climate type – a measure of the combination of relative temperature and precipitation projections. For the South Atlantic-Gulf Region, results show a shift from primarily warm wet or warm moist climate type in the latter decades of the 20th century to a much larger proportion of hot moist or hot dry climate type areas by the period 2041 – 2070 (**Figure 3.3**).

a) Historical observed (1971 – 2000)

b) GCM projections (2041 – 2070)

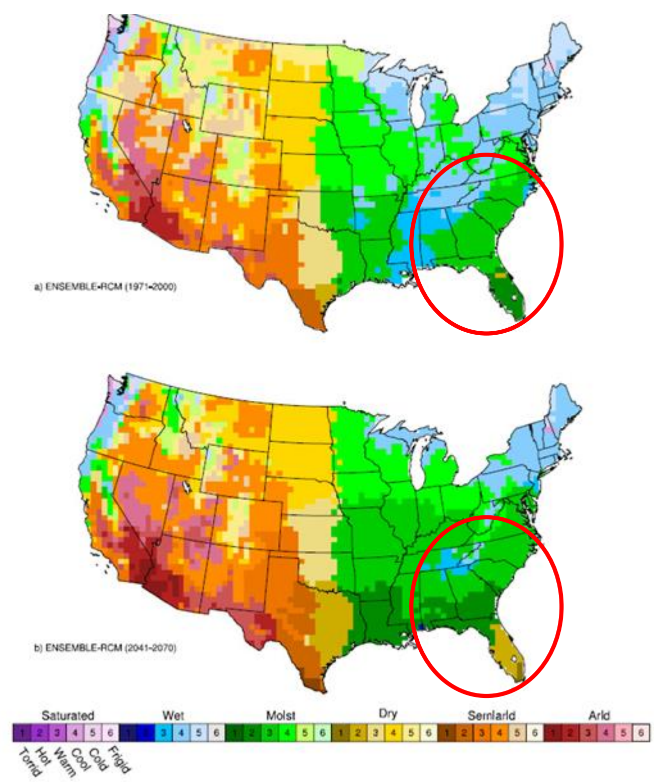

Figure 3.3. Revised Thornthwaite climate types projected by regional climate models. The South Atlantic-Gulf Region is within the red oval (Elguindi and Grundstein, 2013).

Projections of changes in temperature extremes have been the subject of many recent studies performed at a national scale. A 2006 study by Tebaldi et al. applied nine GCMs at a global scale focused on extreme precipitation and temperature projections. Model projections of climate at the end of the century (2080 – 2099) were compared to historical data for the period 1980 – 1999. For the general southeastern U.S., inclusive of the South Atlantic-Gulf Region, the authors identified small increases in the projected extreme temperature range (annual high minus annual low temperature), a moderate increase in a heat wave duration index (increase of 3 to 4 days per year that temperatures continuously exceeds the historical norm by at least 5 ºC), and a moderate increase in the number of warm nights (6 to 7% increase in the percentage of times in the year when minimum temperature is above the 90th percentile of the climatological distribution for the given calendar year), compared to the baseline period.

Similar results are presented by Kunkel et al. (2010). In this study, two different downscaled GCMs were applied to the continental U.S., assuming high greenhouse gas emissions scenarios (A2 and A1F), with a focus on summer heat wave occurrence and intensity. For the South Atlantic-Gulf Region, projections indicate a 3 to 5 ºC increase in three-day heat wave temperatures and a 50 to 80 day increase in the annual number of heat wave days for a 2090 planning horizon compared to a recent historical baseline.

At a regional scale, Qi et al. (2009) used two GCMs (CGC1 and HadCMSul2) in combination with hydrologic modeling to project streamflow changes in the Trent River (North Carolina). Temperature projections from these two climate models (**Figure 3.4**) show increases of approximately 2 to 4 ºC by the end of the 21st century for their study area.

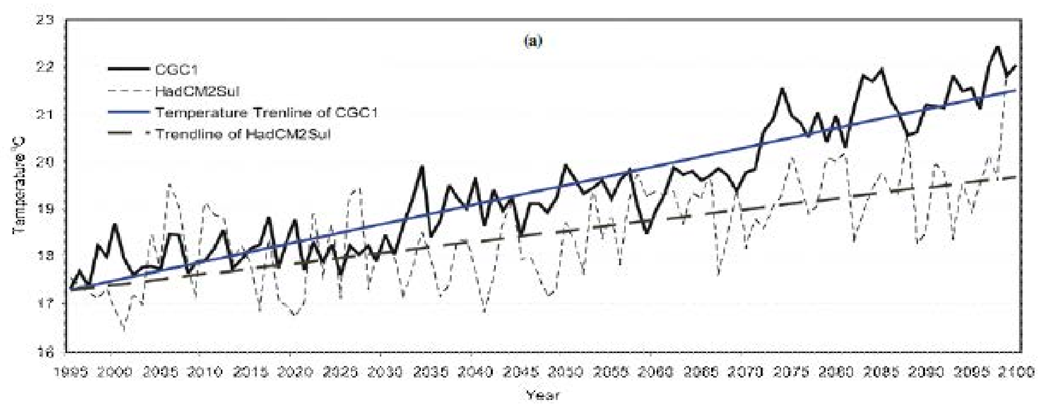

Figure 3.4. Figure 3.4. Projected annual average air temperature, Trent River basin, North Carolina, 1995 – 2100. (Qi et al., 2009).

As part of a water quality study of the Upper Pearl River watershed in Mississippi, Jayakody et al. (2013) applied a single GCM, across three different emissions scenarios (A2, B1, and A1B), to project future climate and potential impacts on water quality. The Upper Pearl watershed is located at the western edge of the South Atlantic-Gulf Region. Climate projections presented in this study show an increase in maximum and minimum annual air temperature in the watershed of c. 2 to 3 ºC for their 2050 and 2075 planning horizons. Projections also point toward an extended summer peak temperature period (moving from July – August to June – September).

Gao et al. (2012) focus on future extreme climate events in the eastern U.S., as forecast by GCMs. They applied a single GCM downscaled to a high resolution grid (4 km x 4 km) that included the entire South Atlantic-Gulf Region and a single planning horizon centered on 2058. A single representative concentration pathway was simulated, representative of intensive future fossil fuel use and high greenhouse gas emissions. Results (**Figure 3.5**) show projected increases in heat wave intensity, duration, and frequency for the study region. Extreme heat wave temperatures are projected to increase by up to 4 ºC in the South Atlantic-Gulf Region and the frequency of heat waves is projected to increase by 2 to 7 days per year, compared to the baseline period (2001 – 2004). Heat wave durations are also predicted to increase for most of the South Atlantic-Gulf Region, by up to 4 days per event.

a) Intensity (ºC)

b) Duration (days/event)

c) Frequency (events/year)

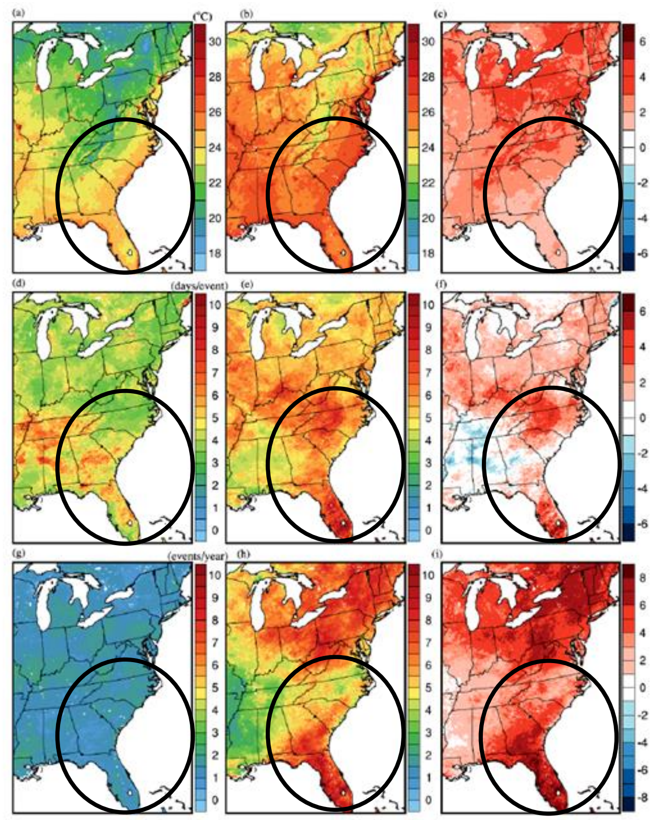

Figure 3.5. GCM Projections of heat wave patterns in eastern USA (intensity, duration, frequency) for a 2058 planning horizon (compared to 2002 baseline); first column = baseline, second column = future, third column = difference between the two. The South Atlantic-Gulf Region is within the black oval (Gao et al., 2012).

The third NCA report (Carter et al., 2014) generally supports the findings presented above. Climate model projections for the southeast region of the U.S. presented in this report indicate a sharp, and statistically significant, increase in both annual average temperature and the number of extreme heat days over the next century (**Figure 3.6**). Additionally, projections are presented showing a decrease in the number of nights below freezing (**Figure 3.7**).

a) Annual average temperature b) Extreme heat days

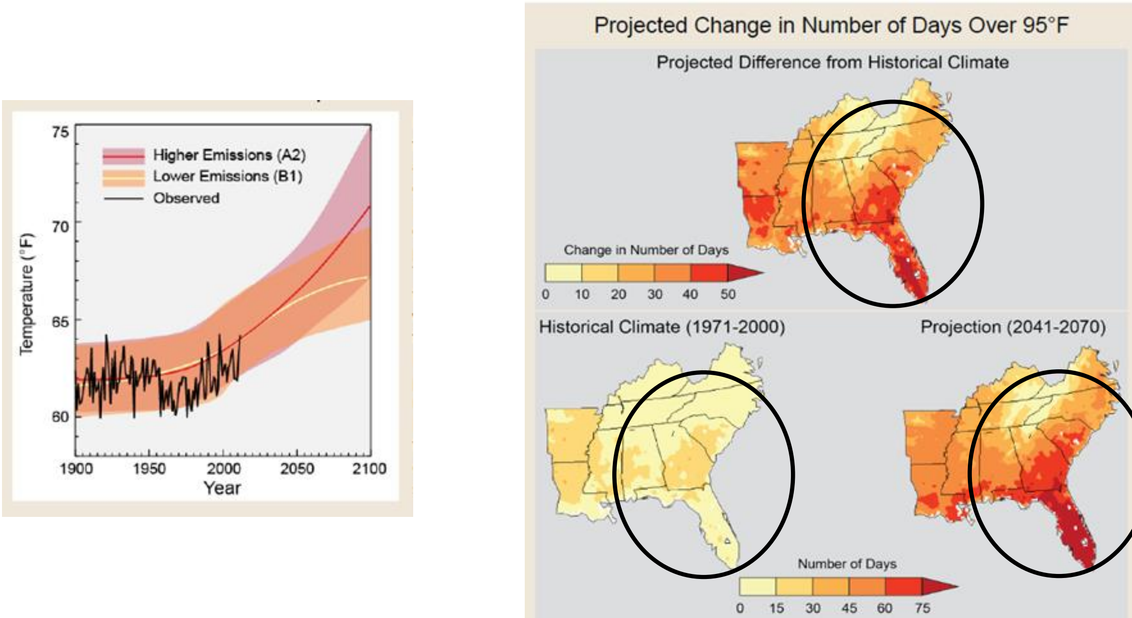

Figure 3.6. GCM projections of temperature change in the southeast USA. The South Atlantic-Gulf Region is within the black oval (Carter et al., 2014).

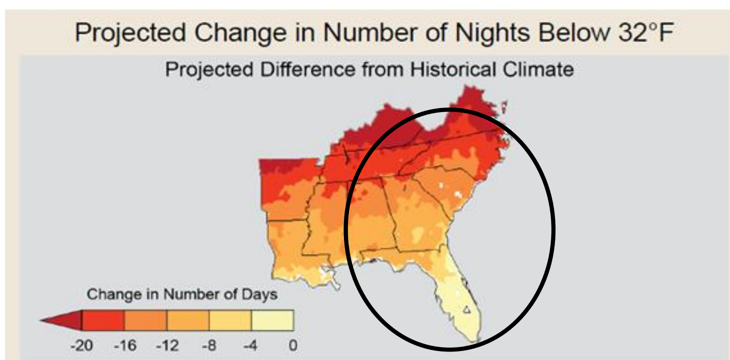

Figure 3.7. GCM projections of change in overnight minimum temperatures in the southeast USA. The South Atlantic-Gulf Region is within the black oval (Carter et al., 2014).

Key point: Strong consensus exists in the literature that projected temperature in the study region show a sharp increasing trend over the next century.

3.2. Precipitation

In line with projections for the rest of the country, projections of future changes in precipitation in the South Atlantic-Gulf Region are variable and generally lacking in consensus among studies or across models. The Liu et al. study (2013), described above, quantified significant increases in winter and spring precipitation associated with a 2055 planning horizon, relative to a recent historical baseline (1971 – 2000, centered around 1985), for the South Atlantic Region (**Figure**

3.8). Smaller increases, or even slight decreases, are projected for the other seasons. However, the authors also project increases in the severity of future droughts for the region, as projected temperature and ET impacts outweigh the increases in precipitation. The study by Jayakody et al. (2013) on the Upper Pearl River watershed (Mississippi) revealed a low consensus on precipitation change projections for their three GCMs and more focused study region. There was, however, general consensus across their three sets of GCM projections of overall dryer summers for their future planning horizons, compared to historical baseline. These results appear to mildly disagree with those presented by Liu et al. (2013).

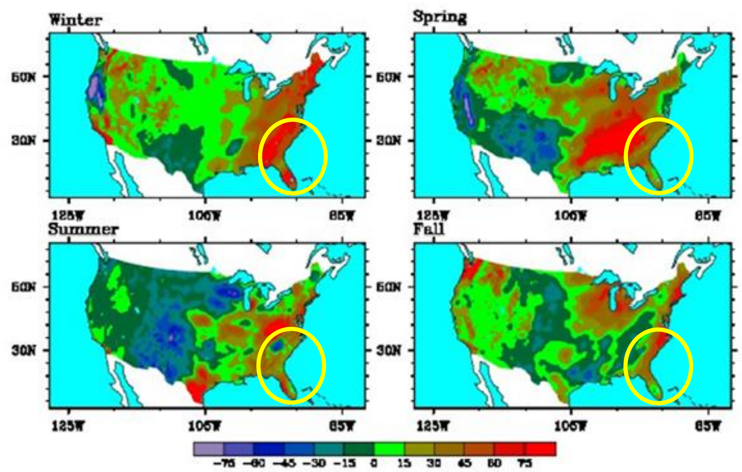

Figure 3.8. Projected changes in seasonal precipitation, 2055 vs. 1985, mm. The South Atlantic-Gulf Region is within the yellow oval (Liu et al., 2013).

More regionally, Wang et al. (2013b) present a study focused on the Wolf Bay watershed in southern Alabama. Results from this study highlight the uncertainty in climate model precipitation projections (**Figure 3.9**). Projected changes in annual precipitation (2016 – 2040), compared to historical baseline (1984 – 2008), range from an approximate 5% decrease to a 10% increase, across an ensemble of four GCMs applied for different assumed greenhouse gas emissions scenarios. Seasonally, results show an increase in fall precipitation for nearly all scenarios, while results are mixed for other seasons. Model uncertainty is also apparent in the results presented by Bastola (2013). For grid cells located primarily in Florida and Georgia, projected changes in seasonal precipitation in the 2070s, compared to historical baseline, range from a 50% increase to a 50% decrease across a large range of GCMs and emissions and concentration pathway scenarios. The median projected changes appear to be in the -10% to +10% range. Similarly, Qi et al. (2009) present two differing GCM projections for their coastal North Carolina watershed (**Figure 3.10**). One projects an approximate 15% increase in precipitation by the end of the 21st century, while the other projects an approximate 20% decrease.

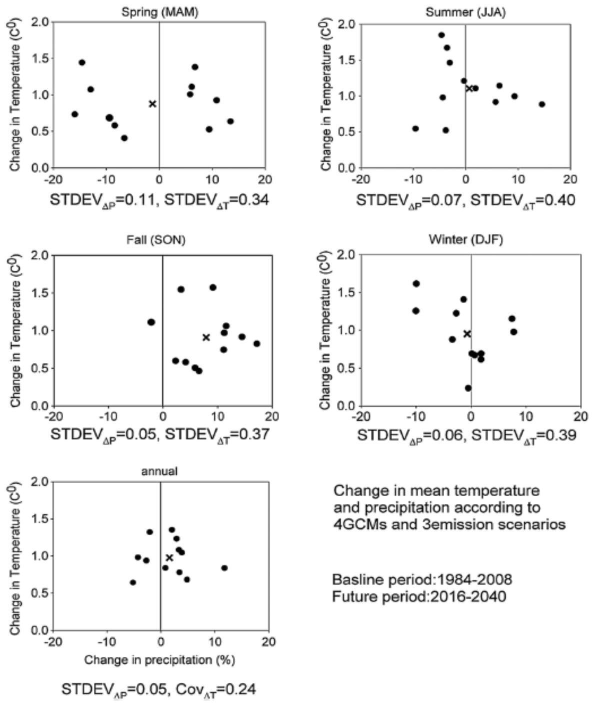

Figure 3.9. Projected changes in seasonal and annual precipitation in Alabama, baseline period, 1988 – 2008 and future period, 2016 – 2040. (Wang et al., 2013b)

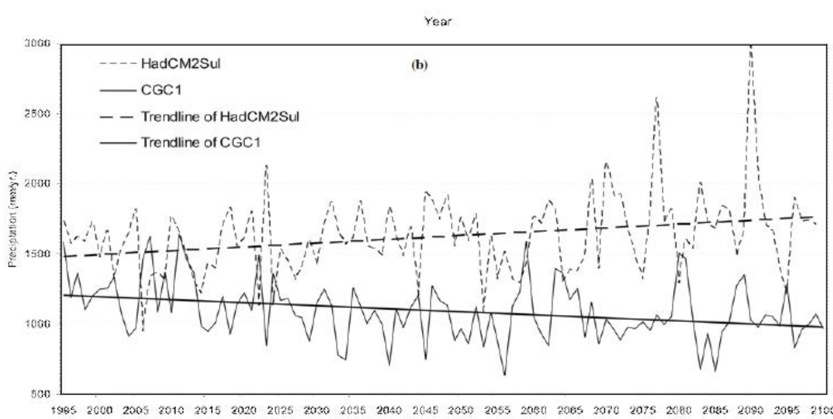

Figure 3.10. Projected changes in annual precipitation, North Carolina, 1995 – 2100. (Qi et al., 2009).

Future projections of extreme events, including storm events and droughts, are the subject of studies by Tebaldi et al. (2006), Wang and Zhang (2008), Gao et al. (2012), and Wang et al. (2013a). The first authors, as part of a global study, compared an ensemble of GCM projections for the southeast U.S. and a 2090 planning horizon with historical baseline data (1980 – 1999). They report small increases in the number of high (> 10 mm) precipitation days for the region, the number of storm events greater than the 95th percentile of the historical record, and the daily precipitation intensity index (annual total precipitation divided by number of wet days). In other words, the projections forecast small increases in the occurrence and intensity of storm events by the end of the 21st century for the general study region. In addition to the historical data trend analyses by Wang and Zhang (2008) described above, these authors also used downscaled GCMs to look at potential future changes in precipitation events across North America. They used an ensemble of GCMs and a single high emissions scenario (A2) to quantify a significant increase (c. 30 to 50%) in the recurrence of the current 20-year 24-hour storm event for their future planning horizon (2075) and the general South Atlantic-Gulf Region (**Figure 3.11**). The projected increases in storm frequency presented by Wang and Zhang appear to be more significant than those projected by Tebaldi et al. (2006), but there is agreement on the general trend.

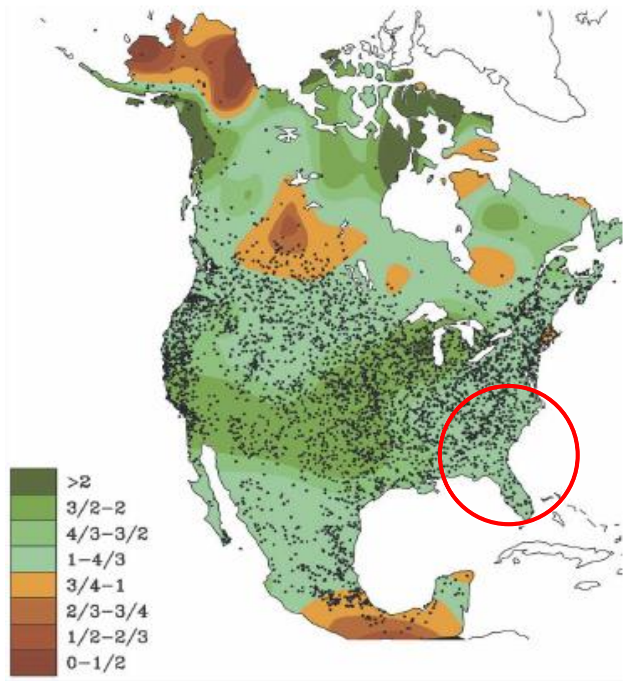

Figure 3.11. Projected risk of current 20-year 24-hour precipitation event occurring in 2070 compared to historical (1974). A value of 2 indicates this storm will be twice as likely in the future compared to the past. Black dots show the locations of stations. The South Atlantic-Gulf Region is within the red oval (Wang and Zhang, 2008).

The GCM applied in the Gao et al. (2012) study for the eastern U.S. generally projects increases in the magnitude of annual total (up to 200 mm yr^{-1}) and daily (up to 20 mm day^{-1}) extreme (95th percentile) storm events and in the frequency of storm events (up to 5 days yr^{-1}), for their 2058 planning horizon compared to current conditions (2001 – 2004) (**Figure 3.12**). The authors use a downscaled GCM to reproduce extreme weather events including hurricanes. Changes in the frequency and intensity of storm events were also the focus of a study by Wang et al. (2013a). These authors applied two GCMs to project future (2046 – 2069) design storm characteristics for the Florida panhandle. Results, in agreement with Gao et al. (2012), show a general shift upward of intensity-duration-frequency (IDF) curves, compared to historical baseline, for their three study sites (**Figure 3.13**). In other words, storm events are projected to be more intense and more frequent in the future compared to the past in northern Florida.

a) Annual total of extreme events (mm/yr)

b) Daily extreme storms (mm/day)

c) Frequency of storm events (days/yr)

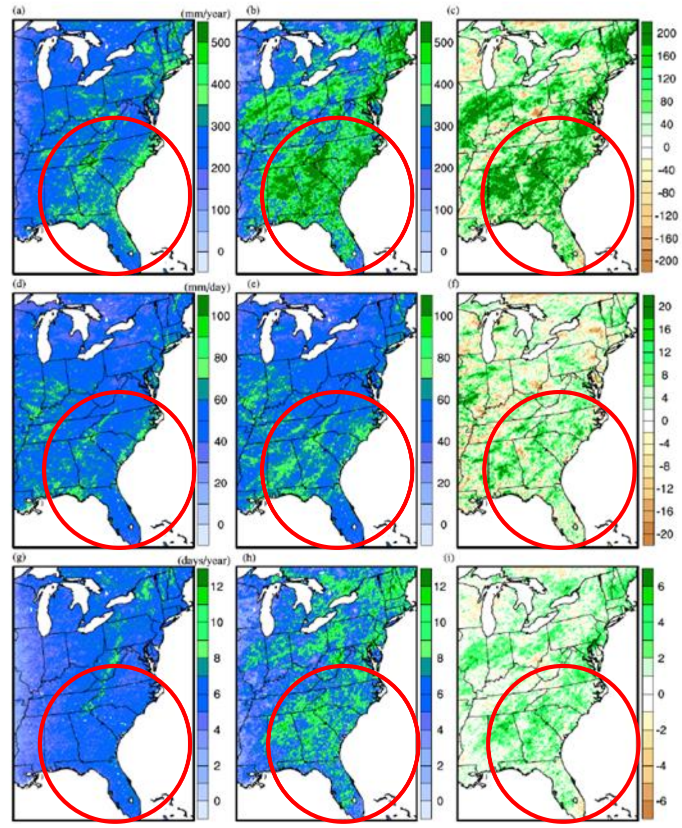

Figure 3.12. GCM projections of future precipitation patterns in eastern USA (annual extreme totals, daily extremes, frequency of events) for a 2057 - 2059 planning horizon (compared to 2002 baseline); first column = baseline, second column = future, third column = difference between the two. The South Atlantic-Gulf Region is within the red oval (Gao et al., 2012).

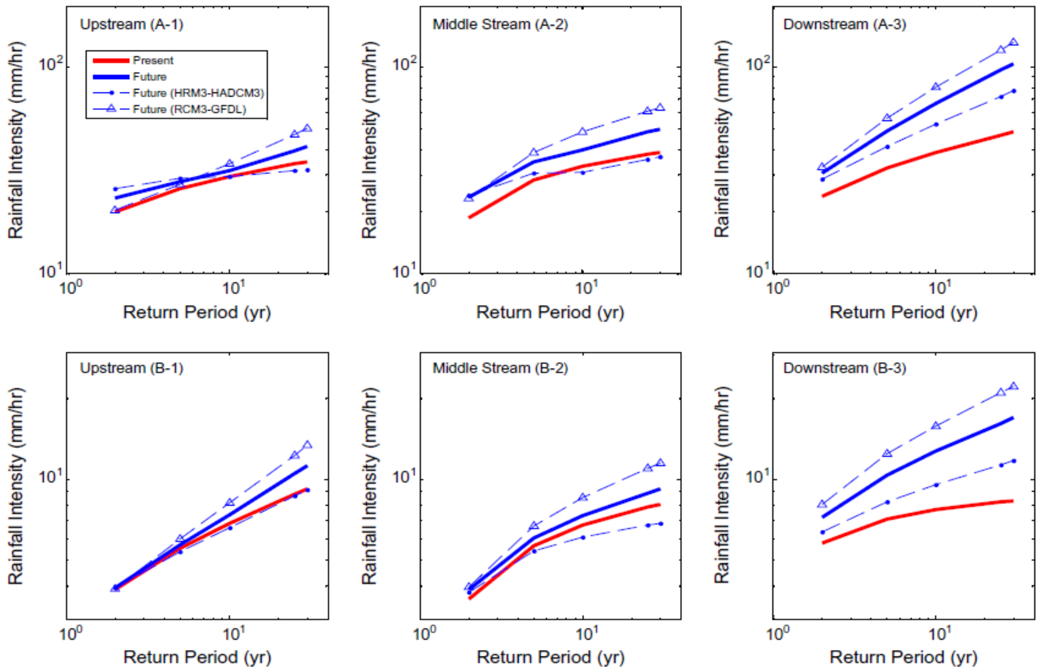

Figure 3.13. Projected changes in storm intensity and frequency, Florida Panhandle. The top row is the 3-hour storm. The bottom row is the 24-hour storm. The columns correspond to three different locations in the study area. Blue lines are future GCM projections. Red lines are the historical baseline (1970 – 1999). (Wang et al., 2013a).

Key point: Reasonable consensus exists in the literature that the intensity and frequency of extreme storm events will increase in the future for the South Atlantic-Gulf Region. Low consensus exists with respect to projected changes in total annual precipitation for the region.

3.3. Hydrology

A number of global and national scale studies have attempted to project future changes in hydrology, relying primarily on a combination of GCMs and macro-scale hydrologic models. These studies include projections of potential hydrologic changes in the South Atlantic-Gulf Region. Thomson et al. (2005) applied two GCMs, across a range of varying input assumptions, in combination with the macro-scale Hydrologic Unit Model to quantify potential changes in water yield across the United States. Results are presented for both continuous spatial profiles across the country (**Figure 3.14**) and for individual HUCs. For the South Atlantic-Gulf Region, contradictory results are generated by the two GCMs. For the same set of input assumptions, one model predicts significant decreases in water yield, the other projects significant increases in water yield.

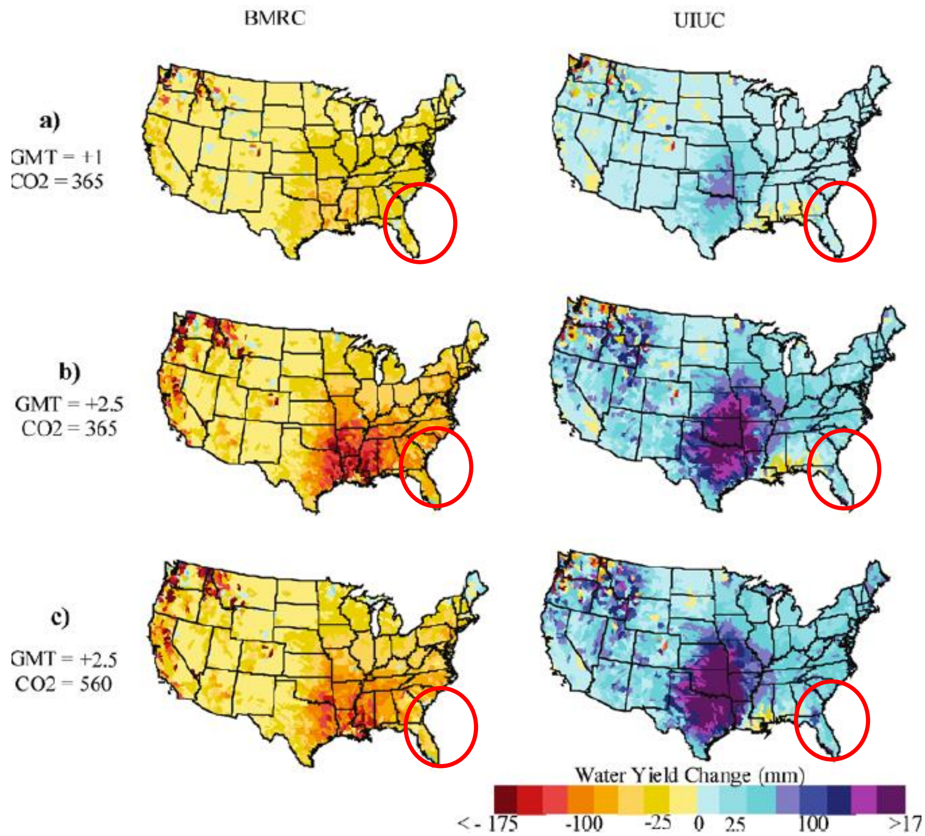

Figure 3.14. Projected change in water yield (from historical baseline), under various climate change scenarios based on 2 GCM projections. The South Atlantic-Gulf Region is within the red oval (Thomson et al., 2005).

The results presented by Thomson et al. (2005), described above, highlight the significant uncertainties associated with global climate modeling, particularly with respect to hydrologic parameters. Additional uncertainty is generated when these climate models are combined with hydrologic models that carry their own uncertainty. This comparison and quantification of uncertainty is the subject of a 2013 study by Hagemann et al. In this study, the authors apply three GCMs, across two emission scenarios to seed eight different hydrologic models for projecting precipitation, ET, and runoff on a global scale. Their findings, in agreement with CDM Smith (2012), indicate that the uncertainty associated with macro-scale hydrologic modeling is as great, or greater, than that associated with the selection of climate models. Study projections from Hagemann et al. (2013) for the general South Atlantic-Gulf Region show an overall decrease in runoff by approximately 200 mm per year for their future planning horizon (2071 – 2100) compared to the recent historical baseline (1971 – 2000) (**Figure 3.15**), assuming an A2 emissions scenario.

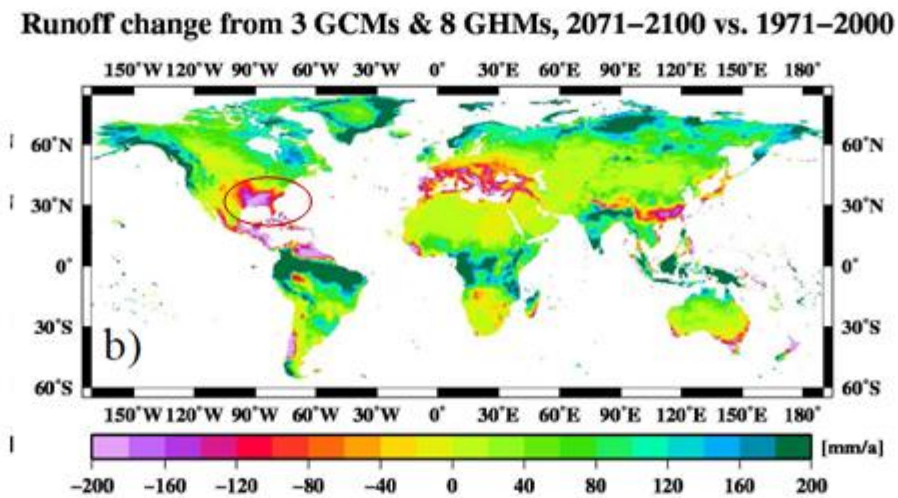

Figure 3.15. Ensemble mean runoff projections (mm/year) for A2 greenhouse gas emissions scenario, changes in annual runoff, 2085 vs. 1985. The South Atlantic-Gulf Region is within the red oval (Hagemann et al., 2013).

One method for addressing uncertainty in climate change projections is to use probabilistic modeling approaches (CDM, 2011). Such studies are described by Wang et al. (2013a) and Wu et al. (2014). In the first study, the authors apply four GCMs across three greenhouse gas emission scenarios, in combination with a mechanistic hydrologic model, to quantify future changes in streamflow as a result of climate change. Results are presented in the form of a cumulative distribution function (**Figure 3.16**) and show a high likelihood of higher flows in the future compared to the past, particularly for the wetter projection scenarios. The driest scenarios, however, show a nearly equal likelihood of decreasing flows as increasing flows. In the Wu et al. (2014) study, the full suite of CMIP3 GCM projections were used, in combination with a lumped rainfall-runoff model, within a probabilistic framework to project future changes in streamflow for a watershed in North Carolina (Coweeta Laboratory). They compared future (2070 – 2099) projections with historical (1961 – 1990) data.

Probabilistic results (**Figure 3.17**) suggest a likely increase in winter streamflow (up to c. 30%) across a range of assumed greenhouse gas emission scenarios. Results are mixed for the other seasons. Summer flows are projected to likely decrease under the A2 (worst case) scenario but likely increase (slightly) under the B1 (best case) scenario. Spring flows appear just as likely to be lower as higher for the A2 and A1B scenarios but more likely to be higher under the B1 scenario. The value of probabilistic approaches is evident when comparing this study with a deterministic study by Qi et al. (2009), also focused on North Carolina streamflow changes. The Qi et al. study presented projections from only two GCMs and a single hydrologic model. One set of results predicts a small and gradual increase in streamflow through the 21st century, while the other predicts a small decrease in streamflow for the same time period.

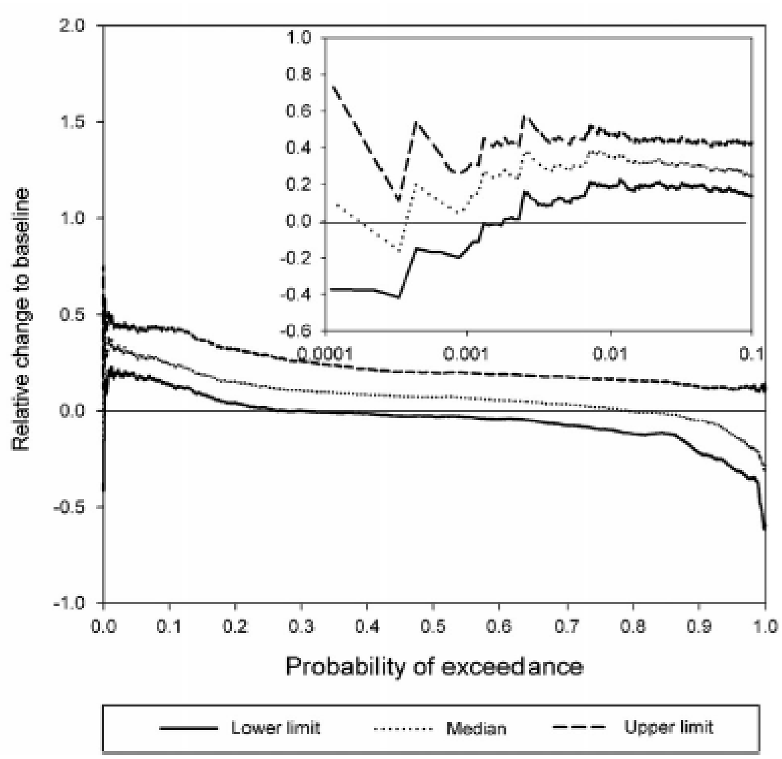

Figure 3.16. Projected changes in streamflow, Southern Alabama: 2016 – 2040 vs. 1984 – 2008. (Wang et al., 2013b).

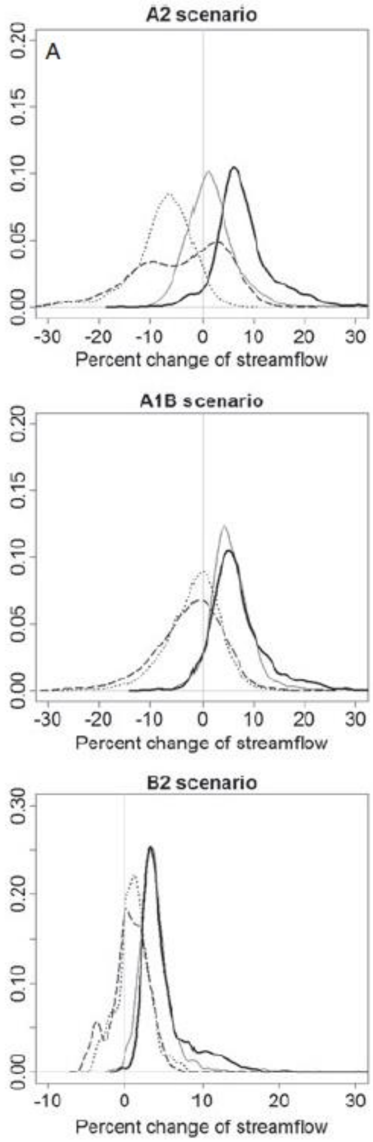

Figure 3.17. Projected changes in streamflow, Coweeta Laboratory (North Carolina): 2070 – 2099 vs. 1961 – 1990. Winter = thick black line, spring = thin black line, summer = dotted line, fall = dashed line. (Wu et al., 2014).

Stronger consensus is seen in the results presented by Bastola (2013) for the southeast region (primarily Georgia and Florida), based on the latest climate model projections (CMIP5). These results (**Figure 3.18**) show a clear majority of the utilized GCM simulations projecting small increases in average spring and summer streamflow (on the order of 1 – 10%) across a range of models and representative concentration pathways (RCPs). Uncertainty is still evident, however, as a number of projections indicate decreased flows in the future.

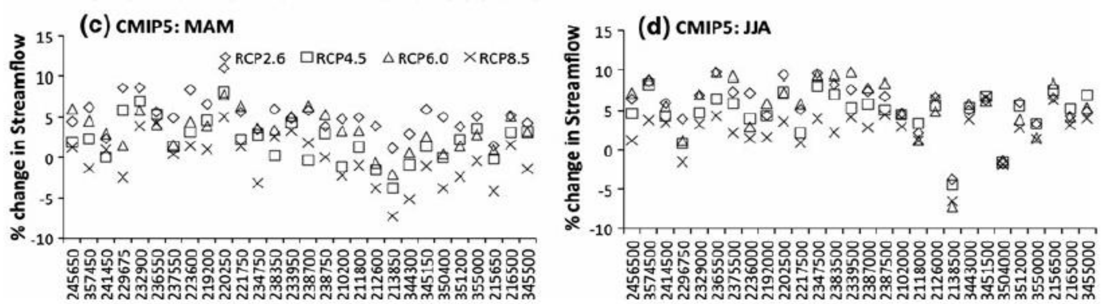

Figure 3.18. Projected change in streamflow, southeast USA (Georgia and Florida): 2061 – 2080 vs. 1960 – 1990. (Bastola, 2013).

Lastly, the third NCA (Carter et al., 2014) presents projections of a mild decrease in water availability for the southeast region of the country through the next century in agreement with only some of the study results presented above.

Key point: No clear consensus was found in projected streamflow changes in the South Atlantic-Gulf Region. Some studies point toward mild increases in flow, others point toward mild decreases in flow.

3.4. Summary of Future Climate Projection Findings

There is strong consensus in the literature that air temperatures will increase in the study area, and throughout the country, over the next century. The studies reviewed here generally agree on an increase in mean annual air temperature of approximately 2 to 4 ºC by the latter half of the 21st century for the South Atlantic-Gulf Region. The largest increases are projected for the summer months. Reasonable consensus is also seen in the literature with respect to projected increases in extreme temperature events, including more frequent, longer, and more intense summer heat waves in the long term future compared to the recent past.

Projections of precipitation in the study area are less certain than those associated with air temperature. Results of the studies reviewed here are roughly evenly split with respect to projected increases vs. decreases in future annual precipitation. This is not unexpected as, according to the recently released NCA (Carter et al., 2014); the southeast region of the country (inclusive of the South Atlantic-Gulf Region) appears to be located in a "transition zone" between the projected wetter conditions to the north and dryer conditions to the west. There is, however, moderate consensus among the reviewed studies that future storm events in the region will be more intense and more frequent compared to the recent past.

Similarly, clear consensus is lacking in the hydrologic projection literature. Projections generated by coupling GCMs with macro-scale hydrologic models in some cases indicate a reduction in future streamflows but in other cases indicate a potential increase in streamflows in the study region. Of the limited number of studies reviewed here, results are approximately evenly split between the two.

A number of studies reviewed here employed probabilistic modeling methods to capture and quantify some of this projection uncertainty, resulting from both climate and runoff modeling steps. These methods frame output in the form of probability distributions that can be viewed as characterizations of likelihood of occurrence (risk) or levels of consensus among modeling scenarios.

The trends and literary consensus of observed and projected primary variables noted above are summarized for reference and comparison in **Figure 3.19**.

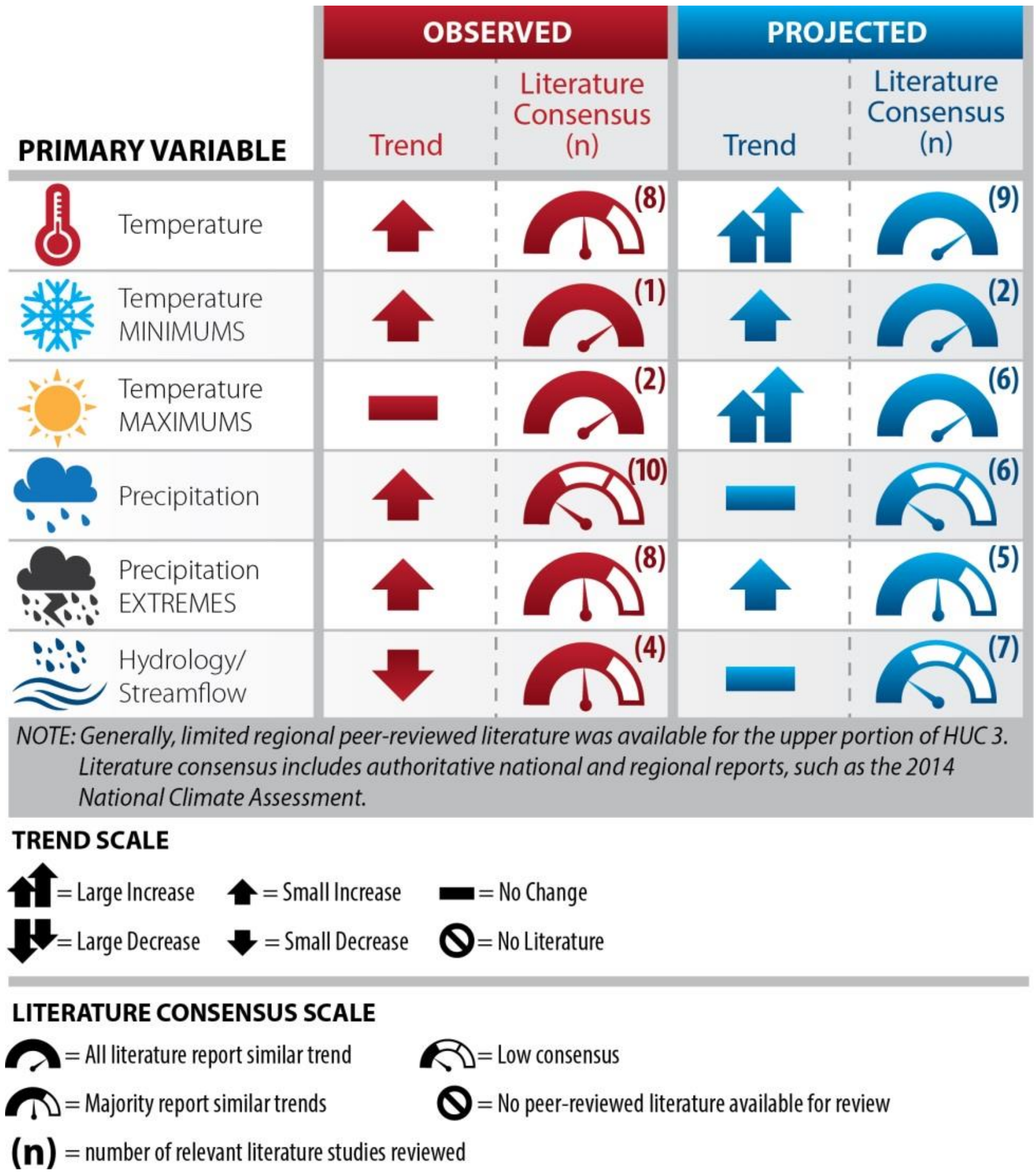

Figure 3.19. Summary matrix of observed and projected climate trends and literary consensus.

4. Business Line Vulnerabilities

The South Atlantic-Gulf Region encompasses a vast area in the south/southeastern region of the United States, including the coasts from Southern Virginia to Mississippi. The projected changes in climate conditions within the entire South Atlantic-Gulf Region Region may influence future USACE planning, engineering and operational activities as well as those of other users of lands and waters within these river basins. Unlike other HUCs, the inland waterways begin and end within the South Atlantic-Gulf Region, making the climatic conditions beyond this HUC less important. USACE recognizes the potential impacts of future climate considering the exposure and dependency of many of its projects on the natural environment. To assess the potential vulnerabilities that climate change may pose on USACE's missions, a set of primary USACE business lines were identified. They include:

- Navigation
- Flood Risk Management
- Water Supply
- Ecosystem Restoration
- Hydropower
- Recreation
- Emergency Management
- Regulatory
- Military Programs

Navigation is one of the primary missions of USACE in the South Atlantic-Gulf Region and the 25 major harbors and 6,300 miles of inland waterways and ports are essential for the regional and national economy. These waterways are not influenced by tides, thus rely on dredging efforts to maintain appropriate depths. The expected increases in air temperatures, especially in the summer, may impede USACE's ability to maintain the approved navigation depths on these waterways.

Flood risk management projects in the region include structural projects which regulate the flows in many of the river basins to avoid flooding. Uncertainty exists with regard to impacts of climate change on flood-risk management needs due to the lack of consensus for future precipitation patterns. However, flood risk management projects may be very important for reducing the residual flooding impacts due to extreme storm events, which are predicted to be more frequent and intense.

USACE also maintains and operates several fresh water supplies for aquifer replenishment for agricultural uses. Managing competing water needs can be a challenge, especially when water demand is high and water supply is low. While this report does not highlight the impacts of sea level change, changes in coastal conditions can have impacts which penetrate to inland water bodies. Sea levels along the southeastern coastline of the United States are projected to increase and may exacerbate salt water intrusion into freshwater water supply. Tools and information related to sea level change can be found on the USACE Responses to Climate Change website (USACE, 2014). Water supplies may also be strained due to increased temperatures and heat waves in the summer months. These conditions lead to increase ET, lowering surface water and groundwater supplies. Maintaining necessary flows for competing sources such as hydropower generation, navigation and ecosystem management, may present some significant, additional challenges to an already complex water resource system.

USACE implements several ecosystem restoration projects in the South Atlantic-Gulf Region, such as examining existing ecosystems, developing watershed management plans, performing restoration feasibility studies, executing comprehensive river restoration, and preserving and maintaining natural habitats. Increased air temperatures, particularly in the summer months, will result in increased water temperatures. This may lead to water quality concerns, particularly for the dissolved oxygen levels, which are an important water quality parameter for aquatic life. Increased air temperatures are associated with the growth of nuisance algal blooms and influence wildlife and supporting food supplies.

The hydropower facilities in the South Atlantic-Gulf Region provide over five billion kilowatt-hours of electricity, mainly as "peaking power" to supplement fossil fuel plants. Uncertainty exists with regard to impacts of climate change on potential hydropower output, due to the lack of consensus for future precipitation patterns. However, increased air temperatures may cause seasonal drought situations, especially in the summer, and may reduce the amount of power that may be generated by the hydropower plants.

Recreational facilities in the region offer several benefits to visitors as well as positive economic impacts. Increases in air temperature along extended heat waves in the summer months and the increased frequency of extreme storm events have the potential to decrease the number of visitors to USACE's recreational facilities. Periods of extreme high heat poses human health concerns and higher water temperatures can result in algal blooms and other water quality issues which may cause health risks for those involved in aquatic activities. Increased extreme storm events may make recreational activity difficult, dangerous, or impossible.

USACE has extraordinary capabilities to respond to natural disasters and other emergency situations throughout the country, and it is a top priority. There are designated emergency managers and assigned staff in each region and subregion that are able to quickly mobilize. Extreme storm events are capable of creating emergency situations in which USACE would be needed to provide assistance in the South Atlantic-Gulf Region. These types of storms are capable of intense precipitation, winds, and storm surge in coastal areas. Since these may occur more frequently, USACE can expect an increased need for their assistance in disaster response and recovery.

USACE's regulatory mission has a serious commitment to protecting aquatic resources while allowing reasonable development. The climate projections may have indirect implications for permitting in the region, and may result from modifications in federal laws and guidance. This may spur stricter regulation or increase the permitting breadth and depth. While most of the permitting processes may not change, the volume and frequency of the permitting requirements may increase – thus increasing the permitting costs for projects.

In addition, USACE provides engineering, construction, real estate, environmental management, disaster response, and other support or consulting services for the Army, Air Force, other assigned U.S. Government agencies, and foreign governments. Environmental management services include rehabilitation of active and inactive military bases, formerly used defense sites, or areas that house excess munitions. Expected changes in climate may necessitate adjustments in rehabilitation approaches, engineering design parameters, and potential types of military construction/infrastructure projects that USACE may be asked to support.

USACE projects are varied, complex, and at times, encompass multiple business lines. The relationships among these business lines, with respect to impacts from climate change, are complicated with cascading effects. Such interrelationships must be recognized as an essential component of future planning efforts when considering the best methods or strategies to adapt. **Figure 4.1** summarizes the projected climate trends and impacts on each of the USACE business lines.

CLIMATE VARIABLE	VULNERABILITY
Increased Ambient Temperatures	Increased ambient air temperatures throughout the century, and over the next century are expected to create the following vulnerabilities on the business lines in the region: • Loss of vegetation from increased periods of drought and reduced streamflows may have impacts on vegetation within the region, which is important for sediment stabilization in the watershed. Loss of non-drought resistant vegetation may result in an increase in sediment loading, potentially causing geomorphic changes in the tributaries to the river system. • Decrease in flows may result from periods of drought and reduced streamflow has implications for maintain water levels in the rivers. • Risk of wildfires during hot and dry conditions may cause an increased risk of wildfires, especially in heavily forested and dry areas. Flora and fauna that are not drought resistant can also be impacted by longer drought conditions, which may reduce opportunities for recreational wildlife viewing. **BUSINESS LINES IMPACTED:**
Increased Maximum Temperatures	Air temperatures are expected to increase 2-4°C in the latter half of the 21st century, especially in the summer months. This is expected to create the following vulnerabilities on business lines in the region: • Increased water temperatures leading to water quality concerns, particularly for the dissolved oxygen (DO) levels, growth of nuisance algal blooms and influence wildlife and supporting food supplies. • Increased evapotranspiration. • Human health risk increases from extended heat waves, impacting recreational visitors and increasing the need for emergency management. **BUSINESS LINES IMPACTED:**
Increased Storm Intensity and Frequency	Extreme storm events may become more intense and frequent over the coming century which are expected to influence the following vulnerabilities on business lines in the region: • Increased flows and runoff, which may carry pollutants to receiving water bodies, decreasing water quality. • Increased erosion with subsequent changes in sediment accumulation rates and creating water quality concerns. • Increased groundwater recharge rates, as residence times are shortened within areas where evapotranspiration takes place during high intensity events. • Increased flooding, which may have negative consequences for all infrastructure, habitats, and people in the area. **BUSINESS LINES IMPACTED:**
Sea Level Rise	Sea level rise may exacerbate saltwater intrusion into fresh water supplies. **BUSINESS LINES IMPACTED:**

NOTE: The Regulatory and Military Program business lines may be impacted by all climate variables

= Navigation = Flood Risk Management = Ecosystem Restoration = Hydropower = Recreation = Water Supply = Emergency Management

Figure 4.1. Summary of projected climate trends and impacts on USACE business lines

Appendix A: References Climate/Hydrology Summary Table

	Observed										Projected									
References	Mean Temperature	Temperature Minimums	Temperature Maximums	Precipitation	Precipitation Extremes	Hydrology/Streamflow	Drought Indices	Soil Moisture	Spring Onset Index	Climate Classification	Mean Temperature	Temperature Minimums	Temperature Maximums	Precipitation	Precipitation Extremes	Hydrology/Streamflow	Drought Indices	Soil Moisture	Spring Onset Index	Climate Classification
Bastola et al., (2007)														X		X				
Brommer, D.M., Cerveny, R.S., Balling Jr, R.C. (2007)				X																
Carter, L.M., J W. Jones, L. Berry, V. Burkett, J. F. Murley, J. Obeysekera, P. J. Schramm, and D. Wear, (2014)	X			X						X		X	X			X	X			
CDM, (2011)																X				X
CDM Smith, (2012)																X				X
Chen, G., Tian, H., Zhang, C., Liu, M., Ren, W., Zhu, W., . . . Lockaby, G. B. (2012)				X			X													
Cook, B. I., Smerdon, J. E., Seager, R., & Cook, E. R. (2014).				X			X													
Dai, Z., Amatya, D.M., Sun, G., Trettin, C.C., Li, C., Li, H. (2011)	X			X																
Elguindi, N., & Grundstein, A. (2013).	X										X									X
Gao, Y., J. S. Fu, J. B. Drake, Y. Liu and J. F. Lamarque (2012).													X		X					
Grundstein, A. (2009).				X			X	X												
Grundstein, A., & Dowd, J. (2011).		X	X																	
Hagemann, S., Chen, C., Clark, D. B., Folwell, S., Gosling, S. N., Haddeland, I., . . . Wiltshire, A. J. (2013).																X				
Irizarry-Ortiz, M.M., Obeysekera, J., Park, J., Trimble, P., Barnes, J., Park-Said, W., Gadzinski, E. (2013)	X			X																
Jayakody et al. (2013)												X	X	X		X				
Kalra, A., T. C. Piechota, R. Davies and G. A. Tootle (2008).						X														
Kunkel, K. E., Liang, X.-Z., & Zhu, J. (2010).													X							
Laseter, S.H., Ford, C.R., Vose, J.M., Swift, L.W. (2012)	X	X	X	X																
Li W, Li L, Fu R, Deng Y, Wang H (2011)				X																
Liu, Y., Goodrick, S. L., & Stanturf, J. A. (2013).													X	X			X	X		
McRoberts, D. B., & Nielsen-Gammon, J. W. (2011).				X																
Obeysekera, J., Irizarry, M., Park, J., Barnes, J., Dessalegne, T. (2011)	X		X	X																
Palecki et al. (2005)				X																
Patterson, L.A., Lutz, B., Doyle, M.W. (2012)	X			X		X														
Pryor, S. C., Howe, J. A., & Kunkel, K. E. (2009).				X	X															
Qi, S., Sun, G., Wang, Y., McNulty, S.G., Myers, J.A.M. (2009)											X			X		X				
Scherer, M., & Diffenbaugh, N. (2014).													X							
Schwartz, M. D., Ault, T. R., & Betancourt, J. L. (2013).	X			X					X											
Small, D., S. Islam and R. M. Vogel (2006).					X	X														
Tebaldi C (2006)												X	X		X					
Thomson AM, Brown RA, Rosenberg NJ, Srinivasan R, Izaurralde RC (2005)																X				
Villarini, G., Smith, H.A., Vecchi, G.A. (2013)				X	X															
Wang and Killick (2013)				X	X															
Wang, H., Schubert, S., Suarez, M., Chen, J., Hoerling, M., Kumar, A., & Pegion, P. (2009).	X	X	X	X																
Wang, J., & Zhang, X. (2008).					X										X					
Wang, D., Hagen, S.C., Alizad, K. (2013a)				X												X				
Wang, R., Kalin, L., Kuang, W., Tian, H. (2013b)				X												X				
Westby, R.M., Lee, Y.-Y., Black, R.X. (2013)	X																			
Wu, W., Clark, J.S., Vose, J.M. (2014)																X				
Xu, X., Liu, W., Rafique, R., Wang, K. (2013)						X														

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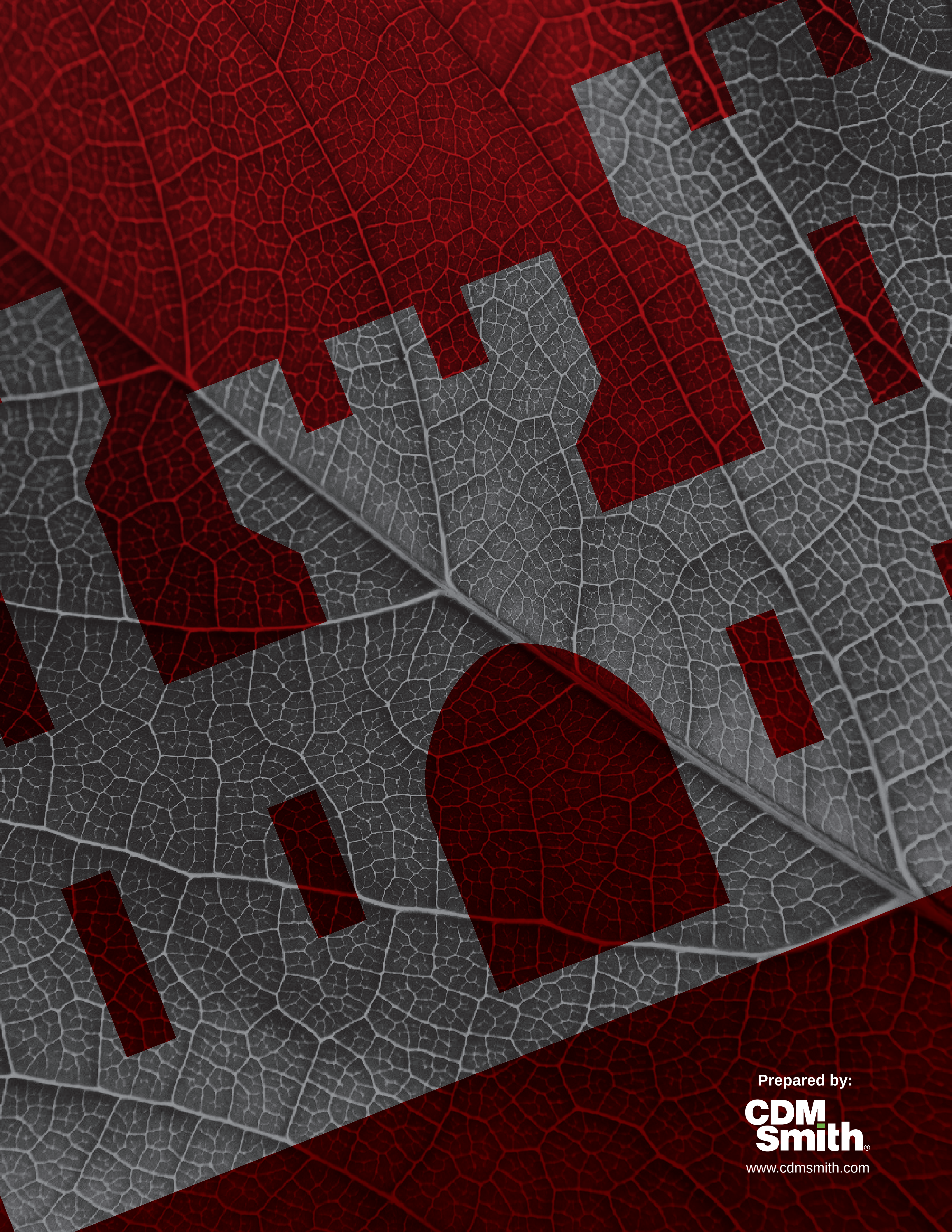

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