Southeast Region Technical Report

to the

National Climate Assessment

Revised July 23, 2012

Submitted by

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1 Introduction

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1.1 Background

This report is a technical reference for the National Climate Assessment document that will be prepared for submission to the President of the United States and the United States Congress in 2013. The document summarizes the scientific literature with respect to climate impacts on the Southeast USA, in particular the literature that has been published since the 2004 assessment. A national assessment was produced in 2009; however, no technical report was developed in support of that document.

For the U.S. National Climate Assessment 2013, the Southeast region includes 11 southern states to the east of the Mississippi River (Figure 1), Puerto Rico, and the US Virgin Islands. This region differs slightly from the previous National Climate Assessment (NCA) in that it follows state borders and does not include the Gulf Coast of Texas.

1.2 Diversity and Vulnerabilities

The SE USA is characterized by great diversity in terms of climate, natural and managed ecosystems, social and political attitudes, and vulnerabilities. While most of the SE is classified as humid, temperatures vary widely across the regions, with a transition from tropical rainforests in Puerto Rico and the US Virgin Islands to temperate forests in the southern Appalachian Mountains. This climatic diversity, which is described in detail in Chapter 2, results from a range of weather patterns that affect the region, including frontal systems that dominate during fall and winter, convective systems that dominate during the spring and summer, tropical systems that are important during the summer and fall, and sea breeze systems that are important for the coastal regions. In addition, the region is prone to other extreme weather phenomena, including droughts, floods, winter storms, and tornadoes.

Figure 1.1. Map of the states in the Southeast region for the US National Climate Assessment. Note that the region and report also covers Puerto Rico and the US Virgin Islands though they are not included in the map.

The region also is subject to related risks that interact with climate variability and change. For example, sea level change and salt water intrusion already threaten many coastal communities (Chapter 5) and ecosystems (Chapters 9 and 11). Sea level change, which includes both sea level rise and land subsidence in parts of Louisiana, Mississippi, and Alabama, makes the region more vulnerable to storm surges produced by tropical storms or winter storms in the Gulf of Mexico (Mitchum 2011). Increasing atmospheric carbon dioxide concentrations might benefit agricultural (Chapter 7) and forest systems (Chapter 8) of the region through increasing photosynthesis, but benefits are likely to be offset by losses of productivity that would result from increased temperatures. Increasing atmospheric carbon dioxide concentrations are also projected to acidify surface waters, which would likely inhibit the growth of corals, shellfish, and crustaceans (Chapter 9). Finally, increasing atmospheric carbon dioxide increases pollen production by many plant species, which has been linked with increased levels of asthma and respiratory illnesses (Chapters 3 and 7).

Climate also interacts with social conditions in the Southeast, which has experienced unprecedented population growth during recent decades. All states in the region had positive growth from 2000 through 2010, with overall population growing by 8.9 million people, or about 13% (Table 1). Population grew fastest in North Carolina (18.5%), Georgia (18.3%), Florida (17.6%), and South Carolina (15.3%), and most of the population growth has been in urban and peri-urban areas (Mackun and Wilson 2011). In the region, only Puerto Rico had negative growth of about 2.2% (Mackun and Wilson 2011). States with the fastest growing populations on a percentage basis were mostly states that already had relatively large populations. This trend indicates widening differences in population density among states in the Southeast. Population growth likely will compound climate related risks for most sectors. Increasing competition for water resources (Chapter 10) will likely affect the energy (Chapter 4), agriculture (Chapter 7), fisheries and aquaculture (Chapter 9), natural ecosystems (Chapter 11), and built environment (Chapter 5) sectors.

Table 1. Population of the Southeast USA and Puerto Rico in 2000 and 2010.

State	2000	2010	Change (%)
Alabama	4,447,100	4,779,736	7.5
Arkansas	2,673,400	2,915,918	9.1
Florida	15,982,378	18,801,310	17.6
Georgia	8,186,453	9,687,653	18.3
Kentucky	4,041,769	4,339,376	7.4
Louisiana	4,468,976	4,533,372	1.4
Mississippi	2,844,658	2,967,297	4.3
North Carolina	8,049,313	9,535,483	18.5
South Carolina	4,012,012	4,625,364	15.3
Tennessee	5,689,283	6,346,105	11.5
Virginia	7,078,515	8,001,024	13.0
Total	67,473,856	76,350,620	13.2

Source: Mackun and Wilson, 2011.

The diversity of people, natural and managed ecosystems, and resources of the Southeast provide the region with great richness. With coastlines along the Gulf of Mexico and South Atlantic seaboard, the SE has a wealth of estuaries (Chapter 12) with associated fishing industry (Chapter 9), ports with associated transportation hubs (Chapter 6), and beaches with associated tourism (Chapter 13). Inland forests constitute an important carbon sink (Chapter 8), which mitigate greenhouse gas effects on climate (Chapter 12). Its relatively humid, high rainfall environment provides the SE sufficient water resources (Chapter 10) to be a major exporter of energy (Chapter 4) to other regions at present, though future increases in competition for water resources might diminish the region's energy production capacity. Climate change threatens all of these natural resources and the industries that depend on them. Thus, it is not surprising that there are numerous efforts already underway in the Southeast to mitigate and adapt to climate change (Chapters 12 and 13). In addition there are ongoing programs to educate people about climate variability, climate change, and ways society can manage climate related risks (Chapter 14).

1.3 Time-scales of Interest to Southeast Decision Makers

Decision makers in the Southeast have the greatest interest in seasonal and decadal time-scales (Bartels et al. 2011). Typically, the time-scale of interest matches the time-scale of investments and expenditures, most of which are 20 years or less. In order to engage decision makers in the use of climate information, it is important to provide information at time-scales that are relevant to the decisions for which they need information. If the science community can provide useful information at these shorter timescales, as decision makers use that information to manage seasonal and near term climate risks, they also begin to adapt to and mitigate climate change (Fraisse et al. 2009).

An advantage to providing climate information at shorter time-scales in the Southeast is that seasonal climates of the Florida peninsula and coastal plains from Louisiana to North Carolina are affected by sea surface temperatures in the equatorial Pacific, or El

Niño/Southern Oscillation phenomenon (Chapter 2). For these areas, El Niño conditions typically result in cool, wet fall and winter conditions whereas La Niña conditions typically result in dry, warm fall and winter conditions. To the north of the coastal plains, seasonal climate does not typically exhibit an El Niño/Southern Oscillation signal.

1.4 Future Scenarios

In this report, we use the term “projection” to describe how future climate is expected to respond to various scenarios of population growth, greenhouse gas emissions, land development patterns, and other factors that might affect climate change. The report uses two of the IPCC scenarios for climate projections, A2 and B1. It is important to recognize that these scenarios describe potential situations for both greenhouse gas (GHG) emissions and societal development alternatives.

The A2 scenario is the most pessimistic in that it assumes that nations will have little or no response to anticipated adverse effects of climate change (EPA 2012). The A2 storyline and scenario describes a heterogeneous world with an underlying theme of self-reliance and preservation of local identities. Birth rates across regions converge slowly, which results in continuously increasing population. This scenario is often called “business as usual.”

The B1 storyline and scenario describes a convergent world with the same global population as in the A1 storyline, but with rapid change in economic structures toward a service and information economy (EPA 2012). This scenario includes a reduction in material intensity and the introduction of clean and resource-efficient technologies. It emphasizes global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives. The B1 scenario is the most optimistic in that it generally reflects a concerted, global effort to mitigate human impacts that would further warm the planet.

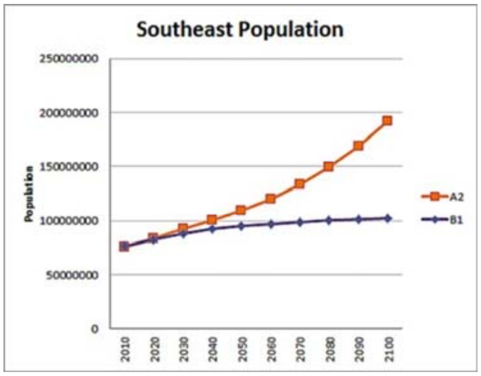

Figure 1.2. Population projections for the Southeast USA for the A2 (greatest climate change) and B1 (least climate change) scenarios.

An important feature of these scenarios is the difference in population growth for the region (Figure 1.2). In the A2 scenario the population of the SE nearly triples from 2010 through 2100 whereas in the B1 scenario, population increases about one-third over the same period. If population growth follows trends similar to those simulated in the A2 scenario, the SE will experience far more cross-sectoral competition for land and water resources, which will compound climate change impacts. On the other hand, the B1 scenario with its more modest population growth provides more opportunities for adaptation and mitigation.

Another important factor for the Southeast will be changes in land use and land cover. As population grows, development is inevitable. How that development proceeds, however, will have great impact on regional climate (Shin and Baigorria 2012).

1.5 Process for Developing this Report

This document has been produced through collaboration among three Regional Integrated Sciences and Assessments Centers (RISAs): the Southeast Climate Consortium; the Carolinas Regional Sciences and Assessments; and the Southern Climate Impacts Planning Program; and with contributions from numerous local, state, federal, and non-governmental individuals and agencies. We established a leadership committee that was charged with the design of the overall report and the organization of a two-day workshop with about 90 participants that was held in Atlanta, GA, in September 2011. From September 2011 through February 2012, contributors provided information to lead authors, who drafted the chapters, which were reviewed and revised to the extent possible given the time constraints. The March 1, 2012 draft report to the NCA was not fully reviewed, so the editors and authors will continue preparation of the document to assure that all information has been fully vetted.

1.6 Report Organization

Three sections of the report follow this introduction: (1) Climate of the Southeast, which has one chapter that reviews the historic climate, current climate, and projected future climate of the region; (2) Climate interactions with important sectors of the Southeast, which includes nine chapters loosely organized from most to least anthropocentric; and (3) Cross-sectoral issues, namely climate change mitigation, adaptation, and education and outreach.

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2 Climate of the Southeast United States: Past, Present, and Future

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2.1 General Description

The climate of the Southeast (SE) is quite variable and influenced by a number of factors, including latitude, topography, and proximity to large bodies of water. The topography of the region is diverse. In the southern and eastern portions of the region, extensive coastal plains stretch from Louisiana eastward to southeastern Virginia, while rolling low plateaus, known as the Piedmont, are present from eastern Alabama to central Virginia. North and west of these areas, mountain ridges are found, including the Ozarks in Arkansas (1500 to3000 ft) and the Appalachians, which stretch from Alabama to Virginia (2000 to 6600 ft). Finally, elevated, dissected plateaus lie from northern Alabama to Kentucky. Temperatures generally decrease with increasing latitude and elevation, while precipitation decreases away from the Gulf-Atlantic coasts, although rain is locally greater over portions of the Appalachian Mountains.

A semi-permanent high pressure system, known as the Bermuda High, is typically situated off the Atlantic Coast. Depending on its position, the Bermuda High commonly draws moisture northward or westward from the Atlantic and Gulf of Mexico, especially during the warm season. As a result, summers across the SE are characteristically warm and moist with frequent thundershower activity in the afternoon and early evening hours. Day-to-day and week-to-week variations in the positioning of the Bermuda High can have a big influence on precipitation patterns. When the Bermuda High builds to the west over the region, hot and dry weather occurs, although humidity often remains relatively high. This pattern can cause heat waves and poor air quality, both of which negatively affect human health. When the Bermuda High persists over or immediately south of the area for extended periods, drought conditions typically develop. This places stress on water supplies and agricultural crops and can reduce hydroelectric energy production. Variations in the positioning of the Bermuda High also affect how hurricanes move across the region.

During cooler months of the year, the Bermuda High shifts southeastward as the jet stream expands southward. Accompanying the jet stream are extratropical cyclones and fronts that cause much day-to-day variability in the weather. As the jet stream dives southward, continental air can overspread the SE behind extratropical cyclones, leading to cold-air outbreaks. Sometimes subfreezing air reaches as far south as central Florida, causing major damage to citrus crops. Extratropical cyclones also draw warm and humid air from the Atlantic Ocean and Gulf of Mexico northward over frontal boundaries and this can lead to potentially dangerous snowstorms or ice storms. These winter storms are generally confined to the northern tier of the region (35°N latitude and greater) where temperatures are cold enough to support frozen precipitation. In the spring, the sharp contrast in temperature and humidity in the vicinity of the jet stream can promote the development of severe thunderstorms that produce damaging winds, large hail, and tornadoes.

Temperature contrasts are especially great across the region in the wintertime. Average daily minimum temperatures in January range from 60°F in South Florida to 20°F across the southern Appalachians and northern Kentucky (Figure 2.1). In contrast, average daily maximum temperatures in July range from 95°F across the lower Mississippi River Valley and southeast Georgia to 75°F across the higher elevations of the southern Appalachians (Figure 2.2). Seasonal variations in temperature are relatively modest across the Caribbean due to its tropical climate. In Puerto Rico, these variations relate to both elevation and soil wetness. For example, minimum winter temperatures drop to as low as 50°F in the Cordillera Central mountain range (above 4,000 ft), while maximum summer temperatures reach 95°F across the drier southwestern part of the island.

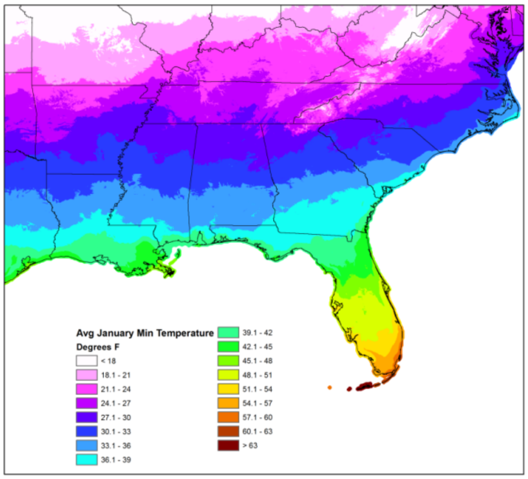


Figure 2.1. Map of average daily January minimum temperature using the Parameter-elevation Regressions on Independent Slopes Model (PRISM) (http://www.prism.oregonstate.edu/).

Average annual precipitation across the region shows variations that relate both to the proximity to moisture sources (e.g., Gulf of Mexico and Atlantic Ocean) and the influences of topography, such as orographic lifting and rainshadows (dry areas on lee side of a mountain) (Figure 2.3). The Gulf Coast regions of Louisiana, Mississippi, Alabama, and the Florida Panhandle receive more than 60 in of precipitation, while much of Virginia, northern Kentucky, and central sections of the Carolinas and Georgia receive between 40 in and 50 in of precipitation annually. Higher amounts of precipitation are found along the Atlantic coast and across the Florida Peninsula due in part to the lifting of the air associated with the sea breeze circulation. Tropical cyclones can also contribute significantly to annual precipitation totals in the region, especially over the Southeast Atlantic coast (Knight and Davis 2009). The wettest locations in the SE are found in southwestern North Carolina and across the eastern (i.e., windward) slope of Puerto Rico, where average annual totals exceed 100 in. Across the northern tier of the region, average annual snowfall ranges from 5 in to 25 in, except at the

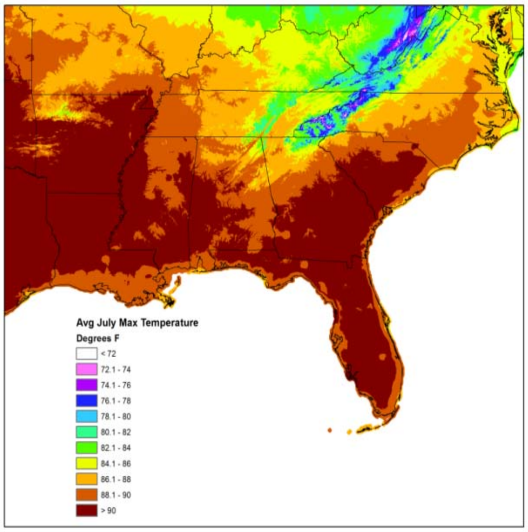


Figure 2.2. Map of average daily July minimum temperature using the Parameter-elevation Regressions on Independent Slopes Model (PRISM) (http://www.prism.oregonstate.edu/).

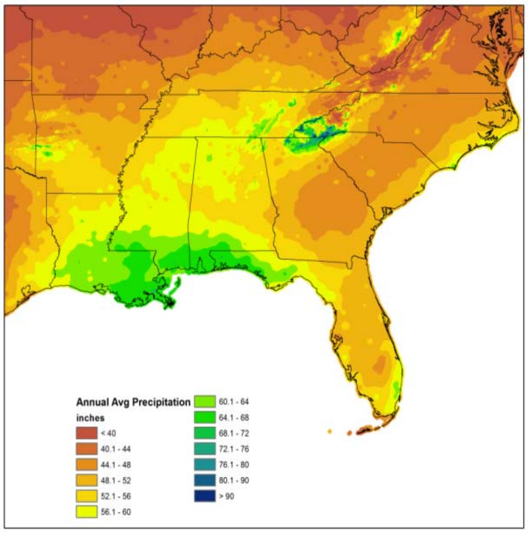


Figure 2.3. Map of annual average precipitation using the Parameter-elevation Regressions on Independent Slopes Model (PRISM) (http://www.prism.oregonstate.edu/).

higher elevations of the southern Appalachians in North Carolina and Tennessee (Figure 2.4). These locations can receive up to 100 in of snowfall annually, which is comparable to annual snowfall amounts experienced across portions of New England (Perry et al. 2010). The southern tier of the region (35°N latitude and lower) experiences very little snowfall (i.e., less than 1 in per year) and may not record any measurable snowfall for several years.

Although the SE is mostly in a humid subtropical climate zone, the seasonality of precipitation varies considerably across the region (see Figure 5 in Kunkel et al. 2012). Along the coast, as well as some areas in the interior, a summer precipitation maximum is found, especially across the Florida Peninsula. This can be related to the daytime thunderstorm activity associated with the heating of land surface and lifting of air along the sea breeze front. Many locations in the interior SE have nearly the same amount of precipitation in the cool season as in the warm season. In the cool season, extratropical cyclones and associated fronts frequently traverse much of the region and bring with them precipitation. Cool season precipitation totals, however, show much regional scale variability. The northern Gulf coast is especially wet as mid-latitude cyclones frequently transport (advect) high levels of moisture northward from the Gulf of Mexico along frontal systems (Keim 1996). In contrast, the Florida Peninsula is often positioned south and east of cyclones and fronts and, therefore, displays a winter precipitation minimum (Trewartha 1981). Locations along the Atlantic Coast are situated in the path of mid-latitude cyclones in winter and spring. However, the fast motion of these systems frequently limits the deep transport of moisture and the duration of the associated precipitation (Keim 1996). Precipitation in the Caribbean is influenced primarily by the Bermuda High. In the winter, as the Bermuda High shifts southward, easterly trade winds increase while sea-surface temperatures (SSTs) and humidity decreases across the Caribbean, resulting in a winter precipitation minimum. The opposite occurs during the summer when the Bermuda High shifts northward, the easterly trade winds decrease, and summer precipitation maximizes (Taylor and

Alfero 2005). A reduction in precipitation in July, known as the Caribbean midsummer drought, occurs when the Bermuda High temporarily expands southwestward across the Caribbean (Gamble et al. 2008). Tropical cyclones also contribute significantly to precipitation totals across the Caribbean in the summer and fall seasons.

2.2 Extreme Events

The southeastern region experiences a wide range of extreme weather and climate events that affect human society, ecosystems, and infrastructure. Since 1980, the SE has experienced more billion-dollar weather disasters than any other region in the USA (NCDC 2011). This section summarizes the climatology of these events across the region.

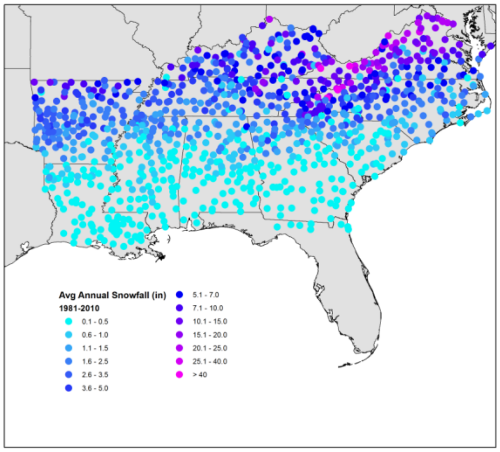


Figure 2.4. Annual average snowfall from 1981 to 2010 using data from the Global Historical Climatology Network (GHCN) (http://www.ncdc.noaa.gov/oa/climate/ghcn-daily/).

2.2.1 Heavy Rainfall and Floods

Heavy rainfall can produce short-lived flash floods and long-duration river floods that have enormous impacts on property and human life. These events result from a variety of weather systems that show much seasonality in their occurrence. In the winter and spring, slow-moving extratropical cyclones can produce large areas of very heavy rainfall, and during the late spring and summer slow-moving or training thunderstorms can generate excessive rainfalls over local areas. During the later summer and fall, tropical cyclones can produce extremely heavy rainfall, both locally and regionally, especially when they interact with frontal systems (Konrad and Perry 2010). Major rivers in the SE are susceptible to flooding, which can have a big impact on transportation and utility and industrial plants, as well as population interests along the major river basins (e.g., Mississippi and Ohio Rivers). Additional impacts include increased incidence of waterborne disease, contamination of water supplies, as well as property and agricultural losses. Most flood-related deaths result from flash floods associated with extratropical cyclones and tropical cyclones (Ashley and Ashley 2008). Of those deaths associated with tropical cyclones from 1970 to 1999, nearly 60% resulted from inland freshwater floods (Rappaport 2000). As air passes over mountains. the very moist air in tropical cyclones rises quickly, which can produce extraordinary precipitation totals, resulting in flash and river flooding as well as landslides on the steeper slopes of the southern Appalachians (Fuhrmann et al. 2008).

2.2.2 Droughts

Despite the abundance of moisture, the SE is prone to drought as deficits of precipitation lead to a shortage of freshwater supplies. Rapid population growth and development has greatly increased the region’s demand for water and vulnerability to drought. In the SE, droughts typically display a relatively shorter duration (i.e., one to three years) as compared to the multidecadal droughts experienced in the western and central parts of the USA (Seager et al. 2009). This may be due in part to the periodic occurrence of tropical cyclones, which can ameliorate the effects of drought during the peak water demand months of the late summer and fall (Maxwell et al. 2011). In contrast, the absence of tropical cyclones combined with high variability in warm season rainfall, increased evapotranspiration, and increased water usage can lead to the rapid development of drought conditions across the SE. Recent examples include the 1998-2002 drought, which resulted in record low lake, reservoir, and groundwater levels across parts of the Carolinas (Carbone et al. 2008), and the 2007-2008 drought, which resulted in over $1 billion in losses in Georgia alone and led to federal lawsuits over control of water releases from Lake Lanier in northern Georgia (Manuel 2008). In some cases, flooding and drought can occur simultaneously as was the case in early summer of 2011 (see Box 1). Severe droughts can also lead to forest fires and degraded air quality.

Box 2.1 Extreme Drought During a Record Flood

In the early summer of 2011, the lower Mississippi Valley experienced something very unusual: the simultaneous occurrence of both flooding and drought. People were piling sandbags to hold back the floodwaters and the Morganza Spillway in Louisiana was opened for the first time since 1973 to relieve pressure on the swollen river downstream in Baton Rouge and New Orleans. As the swollen river meandered across this region, however, much of the south Louisiana landscape was in extreme drought according to the USA Drought Monitor (http://www.drought.gov). As such, the region was experiencing both flood and drought at the same time.

Interestingly, both the flood and the drought were tied La Niña conditions in the equatorial Pacific Ocean. La Niña's tend to dry out the Gulf Coast region by shifting storm tracks to the north across the Ohio River Valley. As storms tracked across the central portion of the United States, they bypassed Texas, Oklahoma, Louisiana, and Mississippi leaving them high and dry and producing drought conditions. However, excessive rainfall in the Midwest associated with the northward-displaced storm track, compounded by a large volume of spring snowmelt, and subsequently produced a flood wave that moved downstream into drought stricken Tennessee, Arkansas, Mississippi, and Louisiana.

On May 14, 2011, the U.S. Army of Corps of Engineers opened the first gate on the Morganza Floodway in Louisiana to relieve flooding on the Mississippi River. Photo Credit: U.S. Army Corps of Engineers. Found at: http://www.flickr.com/photos/30539067@N04/5722952407

2.2.3 Extreme Heat and Cold

Due to its mid-latitude location, the SE often experiences extreme heat during the summer months and is occasionally prone to extreme cold during the winter months (see Figures 6 and 7 in Kunkel et al. 2012). Periods of extreme heat, particularly when combined with high humidity, can cause heat-related illness among vulnerable individuals as well as place stress on agriculture, water supplies, and energy production. Periods of extreme heat across the interior of the southeastern region have been tied to an upper-level ridge of high pressure centered over the Mississippi River Valley (Fuhrmann et al. 2011). There are significant local-scale variations in extreme heat and humidity related to adiabatic warming associated with downsloping winds off of the Appalachian Mountains, daytime mixing and draw-down of dry air from aloft, and the presence and strength of the sea-breeze circulation (Fuhrmann et al. 2011).

Outbreaks of extreme cold can have devastating effects on agriculture, particularly in the southern tier of the region. For example, a severe cold outbreak lasting more than a week in January 2010 resulted in more than $200 million in losses to the Florida citrus crop industry. Periods of extreme cold can also lead to cold-water anomalies that result in coral mortality. The cold outbreak of January 2010 resulted in the death of nearly 12% of corals along the Florida Reef Tract in the lower Florida Keys, marking the worst coral mortality on record for the region (Lirman et al. 2011). Outbreaks of extreme cold (e.g., deep freezes) in the SE are generally associated with a strong anticyclone moving southward from the Great Plains (Rogers and Rohli 1991). The most severe freezes occur when the anticyclone tracks into the Gulf coast region, transporting cold polar air and promoting strong radiational cooling at night. Extreme cold can also have an adverse effect on river transportation, as was the case in January 1994 when sections of the Ohio River froze following a period of record cold temperatures across the eastern USA, including an all-time state record low temperature of -37°F in Kentucky.

2.2.4 Winter Storms

Winter storms, including snowstorms and ice storms, occur most frequently across the northern tier of the southeastern region. These storms have significant impacts on society, including property damage, disruption of utilities and transportation, power outages, school and business closings, injury, and loss of life. Snowstorms exceeding 6 inches occur one or two times per year on average across Tennessee, Kentucky, and northern Virginia, and two or three times per year on average across the southern Appalachians (Changnon et al. 2006). In contrast, snowstorms exceeding 6 inches occur only once every 100 years on average across the Gulf coast region (Changnon et al. 2006).

Ice storms occur when a shallow dome of subfreezing air near the ground causes rain to freeze on surfaces. This cold air is sometimes supplied by a high pressure system located over New England. In this case, the Appalachian Mountains act as a dam by helping transport (advect) low-level cold and dry air from New England southward across Virginia and the Carolinas. The resulting glaze of ice can bring down tree limbs and power lines and cause widespread power outages. These events are most common across west-central portions of Virginia and North Carolina, which experience three to four days with freezing rain per year on average, and least common along the Gulf Coast (i.e., one day with freezing rain every 10 years on average)

(Changnon and Karl 2003). Damaging ice storms can also occur across the mid-South from Arkansas to South Carolina. In February 1994, a major ice storm struck much of the southern tier of the USA, resulting in over $3 billion in damage as well as power outages exceeding one month in parts of Mississippi. The previous month, a major ice storm shut down the entire interstate highway system in Kentucky for nearly a week. A major ice storm in December 2002 produced more than one inch of ice accretion across parts of the Carolinas. Though monetary losses from this event were lower than the 1994 storm, more than 1.8 million customers lost power, eclipsing the previous record for power outages in the region from a single storm set by Hurricane Hugo in 1989 (Jones et al. 2004).

Severe Thunderstorms and Tornadoes

Thunderstorms are frequent occurrences across the SE during the warmer months of the year. Severe thunderstorms, which are defined by the occurrence of winds in excess of 58 mph, hail at least 1 inch in diameter, or a tornado, occur most frequently in the late winter and spring months. Damaging winds and large hail occur most frequently across Alabama, Mississippi, Arkansas, western Tennessee, and northern Louisiana. These states also experience the highest number of strong tornadoes (F2 and greater) and experiences more killer tornadoes than the notorious “Tornado Alley” of the Great Plains (Ashley 2007) (see Figure 8 in Kunkel et al. 2012). The high death tolls can be attributed to increased mobile home density, longer path lengths, and a greater number of cool season and nocturnal tornadoes (Brooks et al. 2003; Ashley 2007; Ashley et al. 2008; Dixon et al. 2011). Cloud-to-ground lightning is also a significant hazard. The greatest frequencies of lightning strikes in the USA are found across the Gulf Coast and the Florida Peninsula. Moreover, eight of the eleven SE states rank in the top 20 for lightning-related fatalities from 1959 to 2006 (Ashley and Gilson 2009). Cloud-to-ground lightning also starts many house fires during the warm season and in rare instances can ignite wildfires.

2.2.5 Tropical Cyclones

Since 1980, tropical cyclones (tropical storms and hurricanes) have contributed to more billion-dollar weather disasters in the region than any other hazard (NOAA 2011). The Atlantic hurricane seasons of 2004 and 2005 were especially active and included seven of the top 10 costliest hurricanes to affect the USA since 1900 (Blake et al. 2011). Tropical cyclones produce a wide variety of impacts, including damaging winds, inland flooding, tornadoes, and storm surge (see Box 2). While their impacts are the greatest along the coast, significant effects are often observed several hundred miles inland. Wind gusts exceeding 75 mph occur every five to 10 years across portions of the coastal plain of the region and every 50 to 75 years across portions of the Carolina Piedmont, central Alabama, Mississippi, and northern Louisiana (Kruk et al. 2010). Tropical cyclones also contribute significantly to the rainfall climatology of the SE (Knight and Davis 2007) and relieve short-term droughts by providing a replenishing supply of soil moisture and rainfall for water supplies across the region. However, the heavy rainfall periodically results in deadly inland flooding, especially when the tropical cyclone is large or interacts with a stalled front (Konrad and Perry 2010).

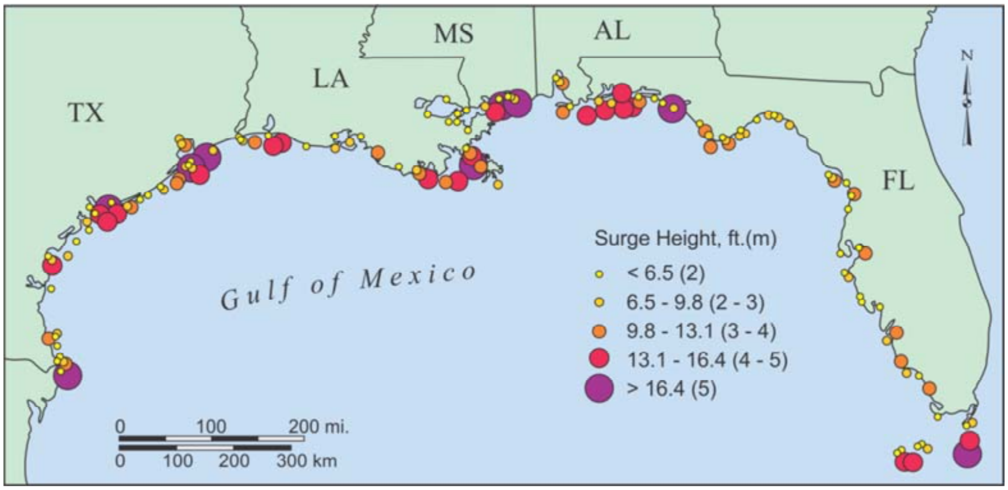
Tropical cyclones make landfall most frequently along the Outer Banks of North Carolina (i.e., once every two years), southern Florida, and southeastern Louisiana (i.e., once every three years) (Keim et al. 2007). They are least frequent along concave portions of the coastline, including the western bend of Florida and the Georgia coast (Keim et al. 2007). Major hurricane landfalls (i.e., categories 3 to5) are most frequent in South Florida (once every 15 years) and along the northern Gulf Coast (once every 20 years) (Keim et al. 2007).

Box 2.2 Gulf Coast Storm Surge Database (SURGDAT)

SURGEDAT provides the world's most comprehensive archive of maximum observed storm surge data. This dataset has identified the magnitude and location of peak storm surge for more than 500 tropical cyclone-generated surge events around the world since 1880. Prior to the creation of this dataset, such information was not archived in one central location.

Spatial analysis along the Gulf Coast reveals that the greatest storm surge activity, for both surge magnitudes and frequencies, generally occurs along the northern and western Gulf Coast, as well as the Florida Keys. Florida's west coast, from the eastern Panhandle to the Everglades, has generally observed less storm surge activity (see following map). Although storm tracks may help determine this pattern, offshore water depth (bathymetry), storm size, and duration of maximum sustained winds also play important roles (Chen et al. 2008; Irish et al. 2008).

The complete dataset and map are hosted by the Southern Regional Climate Center at http://srcc.lsu.edu. Points on the map are interactive, enabling users to click on a peak surge location and obtain information about that surge event. These data are supported by robust metadata files that provide documentation of all surge observations. This website also hosts a blog, which compares active and historic cyclones, incorporating historic surge observations into a discussion about surge potential in an active cyclone. Such discourse brings storm surge history to life, potentially enhancing surge forecasts, hurricane research, and public awareness.



The location and height of the 195 peak storm surges along the US Gulf Coast identified in SURGEDAT. From Needham and Keim (2011), Figure 1 (in press).

2.3 Trends

2.3.1 Precipitation

No long-term trends are revealed in the times series of annual or summer season precipitation across the SE during the last 100 years, except along the northern Gulf Coast where precipitation has increased (Figure2. 5 and see Figures 9 and 10 in Kunkel et al. 2012). Inter-annual variability has increased during the last several decades across much of the region with more exceptionally wet and dry summers observed as compared to the middle part of the 20th century (Groisman and Knight 2008; Wang et al. 2010). This precipitation variability is related at least partly to the mean positioning of the Bermuda High. For example, when the western ridge of the Bermuda High shifts to the southwest precipitation tends to increase in the southeastern region, and likewise when it shifts northwest, precipitation tends to decrease (Li et al. 2011). This broad scale relationship, however, is modulated in coastal areas by precipitation variations that relate to the strength of the sea breeze circulation. An intensification and westward expansion of the Bermuda High, for example, has been shown to correspond to a stronger sea breeze circulation and increased precipitation along the Florida Panhandle (Misra et al. 2011). Similar increases in precipitation are noted along much of the northern Gulf Coast (Keim et al. 2011). In addition, anthropogenic land-cover change may also be influencing the pattern and intensity of sea breeze forced precipitation along the Florida Peninsula (Marshall et al. 2004).

The strength and position of the Bermuda High has been tied to sea surface temperature (SST) anomalies in the North Pacific (i.e., the Pacific Decadal Oscillation; Li et al. 2011) and the subtropical western North Atlantic (i.e., Atlantic warm pool; Misra et al. 2011). Summer precipitation variability in the SE also shows some relationship with Atlantic SST anomalies and the Atlantic Multidecadal Oscillation (AMO). In general, warmer than average SSTs in the North Atlantic lead to increased warm-season precipitation across the southeastern region (Curtis 2008) as well as the Caribbean (Winter et al. 2011).

Sea-surface temperature anomalies in the equatorial Pacific such as El Nino-Southern Oscillation (ENSO) are correlated with precipitation totals across all seasons in South Florida and the Caribbean (Jury et al. 2007; Mo et al. 2009). This influence extends across much of the rest of the SE during the winter and spring months. Specifically, a warm anomaly in the equatorial Pacific (El Niño) is associated with wetter and cooler than normal conditions across most the SE, while a cold anomaly (La Niña) is tied to unseasonably dry and warm conditions (New et al. 2001), except across portions of the Appalachian plateau, including Kentucky and Tennessee (Budikova 2008). The influence of ENSO on precipitation diminishes during the warmer months and is restricted to southern portions of the region (e.g., Florida) where El Niño conditions typically lead to a dry weather pattern. The persistence of El Niño conditions can lead to significant impacts, as was the case during the unusually strong El Niño event of 1997-1998. For instance, numerous wildfires broke out across Florida in June, which were fueled by a dense growth of vegetation caused by heavy winter rainfall (Changnon 1999).

The severity of recent droughts across the southeastern region raises the possibility of a long-term shift in the precipitation regime. However, climate reconstructions using tree rings reveal significant multidecadal variability in precipitation and soil moisture across the SE over the past millennium with no discernible long-term trend (Stahle and Cleaveland 1992, 1994; Doublin and Grundstein 2008; Seager et al. 2009; Ortegren et al. 2011). In particular, the reconstructions suggest that the severity and duration of several prominent 20th and early 21st century droughts are not unusual in the longer-term context and that decade-long droughts have occurred periodically in the SE during the past 1000 years. The disappearance of the Lost Colony of Roanoke in the late 16th century, as well as the abandonment of the Jamestown Colony in the early 17th century, were likely tied to food shortages and poor water quality resulting from severe and persistent drought that covered much of the southern tier of the USA—the 16th century "megadrought" (Stahle et al. 1998; Stahle et al. 2000; Stahle et al. 2007). In addition to this drought, prolonged dry periods are also evident in the middle 18th century (Stahle and Cleaveland 1994) and early-to-middle 19th century (Seager et al. 2009), after which conditions transitioned to a persistent wet regime that is largely unmatched in the region over the past millennium (Fye et al. 2003; Kangas and Brown 2007; Seager et al. 2009).

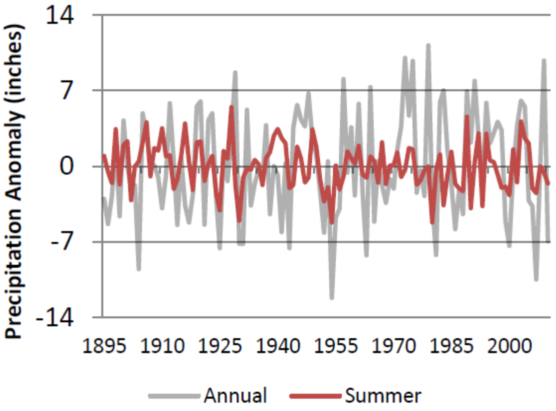


Figure 2. 5. Annual and summer season precipitation anomalies for the SE based on cooperative observer data from the National Climatic Data Center.

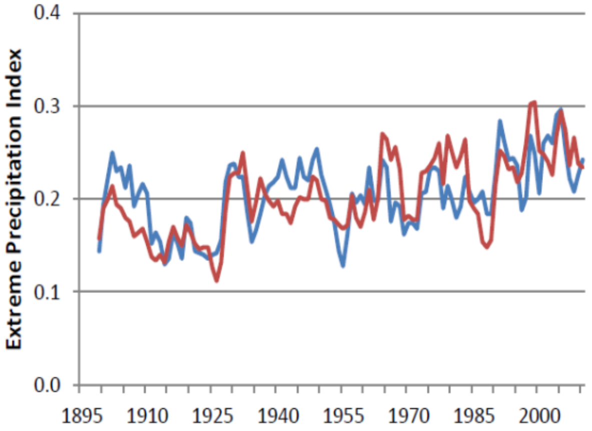


Figure 2.6. Time series of the extreme precipitation index (using a 5-year running average) for the SE for the occurrence of 1-day, 1 in 5 year extreme precipitation events (red) and 5-day, 1 in 5 year events (blue). Based on cooperative observer data from the National Climatic Data Center and updated from Kunkel et al. (2003).

Both instrumental and proxy records indicate significant multidecadal variability in Caribbean precipitation dating back over 800 years that appears to be linked to variations in the North Atlantic Oscillation (NAO) (Malmgren et al. 1998) and the AMO (Winter et al. 2011), as well as variations in the character of the Intertropical Convergence Zone (Kilbourne et al. 2010). Trends beginning in the early 20th century indicate a drying of the Caribbean over time associated with an accelerated Hadley circulation (Jury and Winter 2009). The drying trend is more pronounced over tropical landmasses than over water and is presumed to be the result of land-surface interactions modulated by large-scale circulation patterns (Kumar et al. 2004).

2.3.2 Heavy Rainfall and Floods

The frequency of extreme precipitation events has been increasing across the southeastern region, particularly over the past two decades (Figure 2.6). Increases in extreme precipitation events are most pronounced across the lower Mississippi River Valley and along the northern Gulf Coast (see Figures 13 and 14 in Kunkel et al. 2012). Despite a long-term increase in extreme precipitation events, there is no discernible trend in the magnitude of floods along ex-urban, unregulated streams across the region (Hirsch and Ryberg 2011). The increase in extreme precipitation, coupled with increased runoff due to the expansion of impervious surfaces and urbanization, has led to an increased risk of flooding in urban areas of the region, for example, the record-breaking Atlanta, GA flood in 2009 (Shepherd et al. 2011). Time series of extreme precipitation events are available at the climate division level from the following website: http://charts.srcc.lsu.edu/ghcn/.

2.3.3 Temperature

The southeastern USA is one of the few regions globally that did not exhibit an overall warming trend in surface temperature during the 20th century (IPCC 2007). Annual and summer season temperatures across the region exhibited much variability during the first half of the 20th century, though most years were above the long-term average (Figure 2.7). This was followed by a cool period in the 1960s and 1970s. Since then, temperatures have steadily increased, with the most recent decade (2001 to 2010) being the warmest on record. The recent increase in temperature is most pronounced during the summer season, particularly along the Gulf and Atlantic coasts, while winter season temperatures have generally cooled over the same areas (see Figures 16 and 17 in Kunkel et al. 2012). The overall increase in temperatures over the past several decades is also related at least partially to increasing daily minimum temperatures due to human development of the surface, including urbanization and irrigation (Christy 2002; Christy et al. 2006).

The observed lack of warming during the 20th century (i.e., "warming hole," Pan et al. 2004) also includes parts of the Great Plains and Midwest regions, and several hypotheses have been put forward to explain it, including increased cloud cover and precipitation (Pan et al. 2004), increased aerosols and biogenic production from forest re-growth (Portmann et al. 2009), decreased sensible heat flux due to irrigation (Puma and Cook 2010), and multidecadal variability in both North Atlantic SSTs (Kunkel et al. 2006) and tropical Pacific SSTs (Robinson et al. 2002).

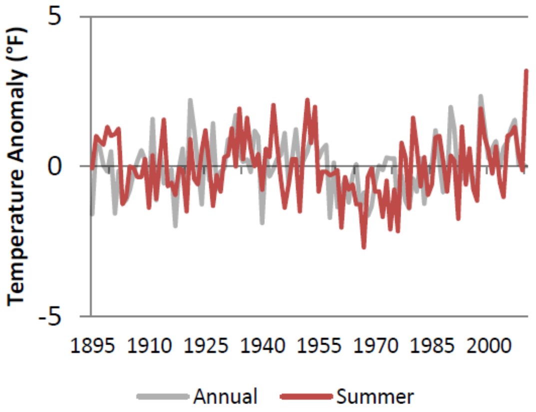


Figure 2.7. Annual and summer season temperature anomalies for the SE based on cooperative observer data from the National Climatic Data Center.

In the Caribbean, no long-term trend has been identified in temperatures from the mid-18th to the mid-20th centuries (Kilbourne et al. 2008) but significant multidecadal variability is evident in the time series. Since then, a significant warming trend has occurred, which is consistent with the overall global trend (Campbell et al. 2011) and is positively correlated with both the AMO and ENSO (i.e., warmer Atlantic SSTs, more El Niño events) (Malmgren et al. 1998).

2.3.4 Extreme Heat and Cold

The frequency of maximum temperatures exceeding 95°F has been declining across much of the SE since the early 20th century, particularly across the lower Mississippi River Valley (see Figure 18 in Kunkel et al. 2012). Higher frequencies of extreme maximum temperatures are noted in the 1930s and 1950s and correspond to periods of exceptionally dry weather. Following a period of relatively few extreme maximum temperatures in the 1960s and 1970s, there has been an upward trend over the last three decades, particularly across the northern Gulf Coast, Florida Peninsula, and northern Virginia. The frequency of minimum temperatures exceeding 75°F has generally been increasing across most of the SE region. This increase is most pronounced over the past few decades (see Figure. 19 in Kunkel et al. 2012) and has been attributed largely to human development of the surface (Christy 2002; DeGaetano and Allen 2002). Time series of extreme heat and cold are available at the climate division level from the following website: http://charts.srcc.lsu.edu/ghcn/.

Similar to trends in extreme heat, the number of days with extreme cold has generally been declining across most locations in the SE, though there is much decadal and intraregional variability (see Figures 20 and 21 in Kunkel et al. 2012). For example, major Florida freezes tend to be clustered in time, particularly in the late 19th and early 20th centuries and from the late 1970s to the late 1980s (Rogers and Rohli 1991). These clusters are tied to decadal-scale periods in which the PNA (NAO) pattern was predominantly positive (negative) (Downton and Miller 1993) and ENSO neutral conditions prevailed across the equatorial Pacific (Goto-Maeda et al. 2008). Recent cold winters across the eastern USA have also been associated with a persistent negative phase of the NAO (Seager et al. 2010). The occurrence of several strong freezes beginning in the 19th century have gradually forced the citrus industry and other industries, for example, winter vegetables and sugarcane, to migrate from northern Florida into South Florida. To accommodate this shift, substantial areas of wetlands were drained and converted to agricultural land, reducing the moisture in the atmosphere above these former wetlands, which increased the risk of freezes (Marshall et al. 2004).

2.3.5 Winter Storms

Average annual snowfall totals across the northern tier of the southeastern region have declined at a rate of approximately 1% per year since the late 1930s (Kunkel et al. 2009). Additionally, snowstorms exceeding 6 in have been declining in frequency since the start of the 20th century (Changnon et al. 2006). This trend, however, is punctuated by an increase in frequency of snowstorms in the 1960s (Changnon et al. 2006). Snowfall trends across the SE southern tier are less certain due to the relative lack of snowfall (see Figure 2.4) and possible inconsistencies in the snowfall data. The decline in snowfall and snowstorms across the northern tier of the region corresponds to low-frequency variability in the NAO, which reveals a positive trend (i.e., warmer winters) over the latter half of the 20th century (Durkee et al. 2007). It is worth noting that this decline stands in contrast to a positive trend in snowfall and snowstorms over much of the 20th century (Changnon et al. 2006; Kunkel et al. 2009) across the northeastern and Midwest regions of the USA. The frequency of days with freezing rain has shown little overall change since the middle of the 20th century but more interdecadal variability relative to snowstorms (Changnon and Karl 2003).

2.3.6 Severe Thunderstorms and Tornadoes

There has been a marked increase in the number of severe thunderstorm reports, including tornadoes over the last 50 years; however, this increase is associated with a much-improved ability to identify and record storm damage. In the case of tornadoes, improved radar technology (Doppler) has allowed meteorologists to resolve storm circulations and identify where to anticipate storm damage (Verbout et al. 2006). The annual frequencies of strong tornadoes (F1 and greater) have remained relatively constant nationally over the last 50 years (Brooks and Doswell 2001). Preliminary statistics suggest that the 2011 storm season was one of the most active and deadliest on record; however, this is not part of an upward trend. Due to increased public awareness as well as improved weather forecasting and technology, tornado fatalities have declined dramatically since the 1930s (Ashley 2007) in spite of the fact that the population has increased in tornado-prone areas.

2.3.7 Hurricanes

Many of the hurricanes that affect the United States make landfall in the SE. The decadal frequencies of both hurricane and major hurricane (category 3 and greater) landfalls have declined slightly over the last 100 years (Blake et al 2011); however, there is much inter-decadal variability in the record that relates to the AMO (Keim et al 2007; Klotzbach 2011) and ENSO (Klotzbach 2011). The AMO was most positive between 1930 and 1950, and 27 major hurricanes made landfall. In contrast, only 13 major hurricanes made landfall during the AMO negative phase between 1970 and 2000. During the last 10 years, there has been an increase in hurricanes as the AMO has shifted back to a positive phase. Tropical cyclone activity and landfall frequencies are typically lower during El Niño years, though this relationship is somewhat weaker during AMO positive phases (Klotzbach 2011).

Analyses of hurricanes and tropical cyclones over the entire Atlantic Basin provide differing perspectives regarding secular trends in activity. Holland and Webster (2007) and Mann and Emmanuel (2006) found increasing trends in tropical cyclone activity in the Atlantic basin extending back to 1900 and 1880, respectively. Landsea (2007), however, points out that the pre-satellite era (prior to the late 1960s) record of tropical activity is likely missing numerous storms and that the record may be worse before airplane reconnaissance began in the mid-1940s. Prior to the 1940s, storms were largely detected through landfalls and/or encounters with ships at sea. Even when a ship route intersected a hurricane, the intensity of the storm was likely underestimated (Landsea et al. 2004). Landsea et al. (2010) also suggest that there has been a significant increase in the number of short-lived storms detected since the introduction of satellites that were likely missed in the earlier portions of the hurricane records.

When adjusted for these reporting and monitoring biases, the time series of Atlantic basin tropical cyclone frequency shows only a slight upward trend from 1878 to 2008 (Landsea et al.

2010). Examination of the accumulated cyclone energy (ACE) index, a metric that incorporates cyclone intensity (wind speed) and duration, reveals that, while global hurricane activity since 2006 has been at its lowest level since the 1970s, hurricane activity across the Atlantic basin has remained high over the past two decades (Maue 2011). Klotzbach (2011) examined the ACE index across the Atlantic basin and found an increasing trend from 1900 to 2009. Earlier work by Webster et al. (2005) and Klotzbach (2006) showed that the frequency of Category 4 and 5 hurricanes has increased across the Atlantic basin during the satellite era. These studies attribute increasing trends in ACE and major Atlantic basin hurricanes to anthropogenic global warming, multidecadal climate variability, and improved monitoring technology.

Trends in Atlantic basin tropical cyclone frequency and landfalls dating back 1500 years have been estimated using various proxy reconstructions that include the use of sediment records of storm surge over-wash (Mann et al. 2009). Results indicate a peak in tropical cyclone activity during the Medieval Period more than 1000 years ago with an overall declining trend into the mid-20th century. This result is also supported by Nyberg et al. (2007), who used coral and marine sediment cores in the Atlantic basin and found a declining trend in tropical cyclone frequencies from the mid-18th century to the early 1990s.

2.3.8 Sea Level Rise and Sea-Surface Temperatures

Sea levels have slowly risen across the extensive coastline of the southeastern region. Satellite altimetry records, however, reveal spatial and temporal variations in the rates of sea level rise that relate to land motion (e.g., subsidence) as well as short-term climate variability (e.g., ENSO) (Mitchum et al. 2010). Trends in global sea level dating back nearly 500,000 years have been assessed using coastal sediment cores. These records indicate variations in global sea level of as much as 100 meters that correspond with glacial and inter-glacial cycles (Church et al. 2010). Variations in sea level since the mid-19th century have been assessed using tidal gauge records, which indicate a rate rise of approximately 1.7 mm per year over most the 20th century (see Figure 22 in Kunkel et al. 2012) (Church et al. 2010). However, satellite altimetry data indicate a rate rise of between 3.0 and 3.5 mm per year since the early 1990s, or nearly double the average rate experienced over the 20th century (Prandi et al. 2009; Church et al. 2010). Variations in sea level rise are driven primarily by thermal expansion due to the warming of ocean waters and glacial melt (Domingues et al. 2008; Pritchard et al. 2009). Recent analysis of glacial melting on Greenland shows that the melt rate from 1996 to 2007 was above the long-term average (1973 to 2007), with 2007 exhibiting the highest melt rate on record by more than 60% (Mote 2007).

Trends in SSTs during the 20th century reveal a cooling over the North Atlantic near Greenland. This cooling may be related to an infusion of melt water as well as an increase in wind speed and heat loss from the ocean surface connected with the upward trend in the NAO circulation during the latter half of the century (Deser et al. 2010). A marked warming trend in SST (1.6°C per century) has been noted off of the East Coast of North America; globally only the east coast of China exhibits a comparable trend (Deser et al. 2010).

2.4 Future Projections

This section provides a summary of future climate projections for the southeastern USA based on recently published studies and an independent analysis of model output from statistically and dynamically downscaled datasets. These include global climate model output and statistically downscaled monthly and daily climate projections from phase 3 of the Coupled Model Inter-comparison Project (CMIP3) as well as dynamically downscaled output from the North American Regional Climate Change Assessment Program (NARCCAP). The reader is directed to Kunkel et al. (2012) for a detailed description of the model datasets and methods used as well as measures of model uncertainty and agreement.

2.4.1 Precipitation

Model simulations of future precipitation patterns using the A2 and B1 emissions scenarios from the IPCC AR4 reveal both increases and decreases in precipitation across the SE by the mid-21st century. Average annual precipitation is projected to decrease by 2% to 4% over Louisiana and South Florida, while increases in precipitation of up to 6% are projected across North Carolina and Virginia (Figure 2.8). Precipitation is expected to increase across most of the SE in all seasons except summer, where a decrease of as much as 15% is noted across parts of Arkansas, Louisiana, and South Florida (see also Keim et al. 2011). An increase in interannual precipitation variability is noted across the region through the first half of the 21st century, with the greatest variability projected during the summer season and in line with recent trends in the observational record. The continued intensification and westward expansion of the Bermuda High will likely increase summer season precipitation variability across most of the SE and is a robust feature in several of the IPCC AR4 models (Li et al. 2011).

Short-range projections (i.e., by 2035) reveal changes in annual precipitation across the SE that are smaller than typical year-to-year variations seen in the observed record (see Figure 36 in Kunkel et al. 2012). In contrast, by the end of the 21st century, annual precipitation is projected to decrease by as much as 12% across Louisiana and Arkansas, with increases of up to 6% noted across the far northeastern part of the region. These changes are significantly larger than the year-to-year variations seen over most of the 20th century. Moreover, individual model ranges by 2085 are rather large compared to the multimodel mean difference in precipitation from the 1971-2000 baseline period, indicating much uncertainty in precipitation projections by the end of the 21st century (Kunkel et al. 2012).

The annual number of days with extreme precipitation is expected to increase across most of the region by the mid-21st century, particularly along the southern Appalachians as well as parts of Tennessee and Kentucky (Figure 2.9). Little change in the annual frequency of extreme precipitation is projected across the southern tier of the region, with more consecutive dry days expected across the northern Gulf Coast (see also Keim et al. 2011). These trends are projected to continue throughout the 21st century. The projected drying across the southern tier of the region extends into the northern Caribbean and is a robust feature in all of the IPCC AR4 models (Rauscher et al. 2008; Biasutti et al. 2009). This drying trend across the Caribbean, which is most pronounced during the summer and winter months (Campbell et al. 2011), may be associated with projected increases in atmospheric stability and decreases in convection. These trends are tied to a mean warming of the tropical atmosphere (Lee et al. 2011; Rauscher et al. 2011), as well as variations in the strength of the trade winds and Caribbean low-level jet stream (Gamble et al. 2008; Campbell et al. 2011). This broad drying pattern may lead to an increase in the frequency and severity of hydrologic drought (Biasutti et al. 2009). Overall, there is much uncertainty in these projections because of inadequacies in model resolution, which is often too coarse to resolve regional and local-scale processes (e.g., sea-breeze circulation), and internal variability in the climate system (e.g., AMO, NAO, ENSO), which is also less successfully simulated by climate models (Ting et al. 2009; Stefanova et al. 2011; Kunkel et al. 2012).

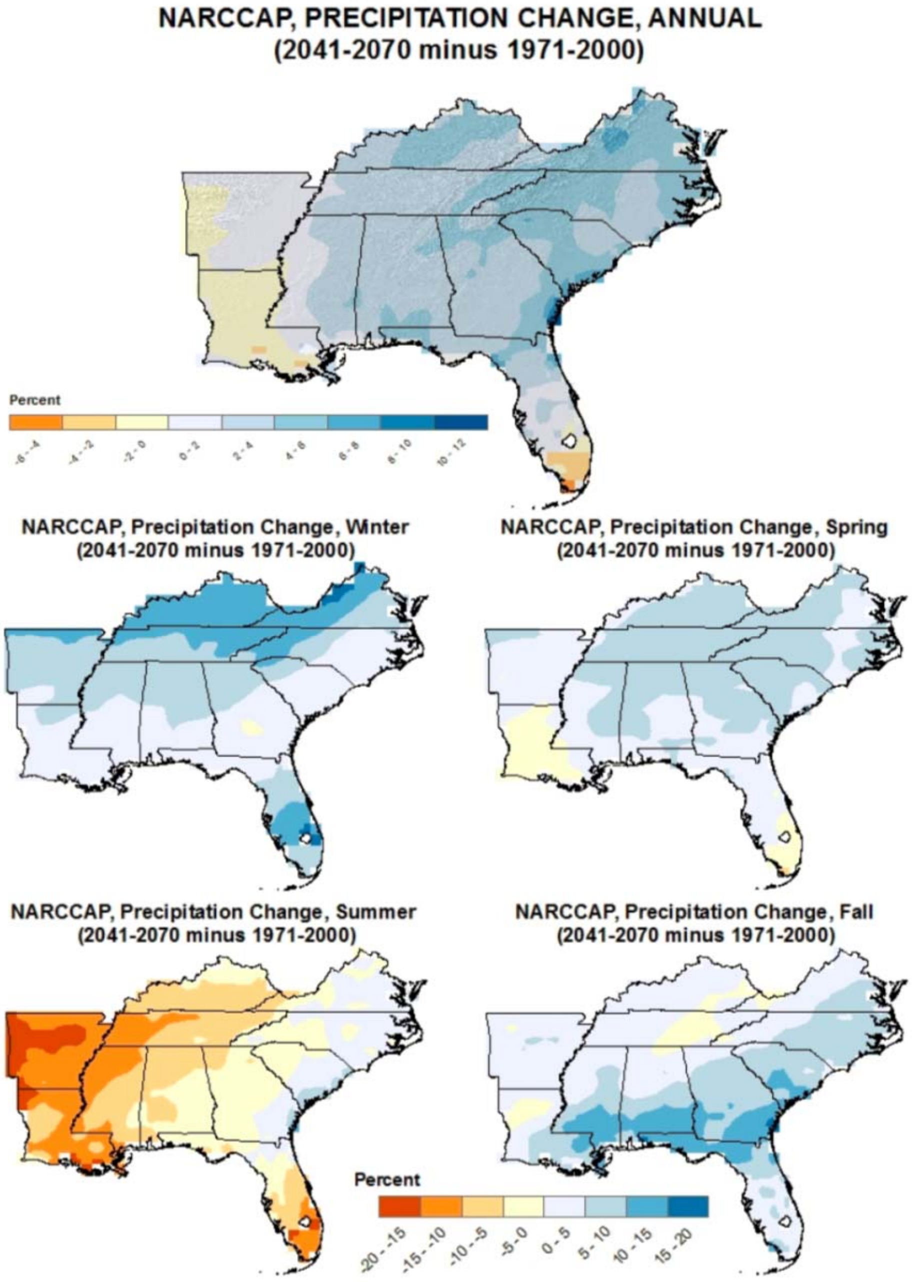


Figure 2.8. Annual and seasonal difference in precipitation (percent) between 2041-2070 and 1971-2000 derived from eight regional climate model simulations from the North American Regional Climate Change Assessment Program (NARCCAP).

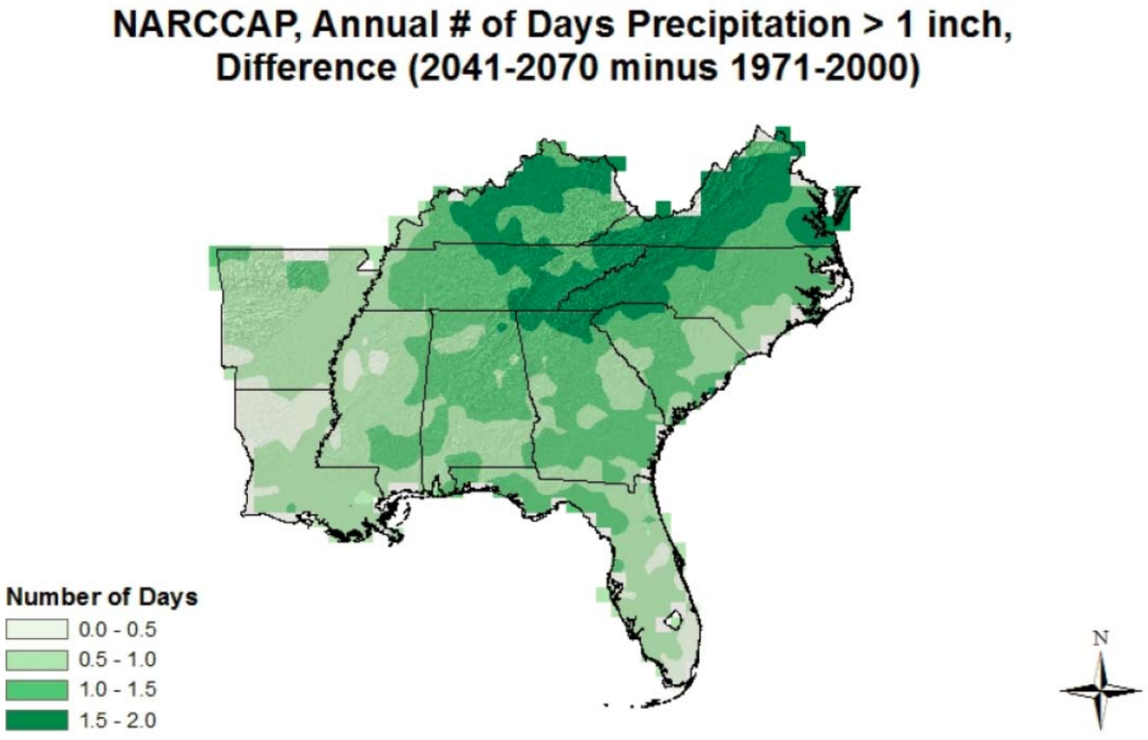


Figure 2.9. Mean change in annual number of days with precipitation exceeding 1 inch between 2041-2070 and 1971-2000.

Another measure of model uncertainty involves the comparison between model simulations and observations of 20th century climate conditions. Figure 2.10 shows the observed and simulated mean decadal average precipitation changes for the SE from 1900 to 2100, expressed as deviations from the 1901 to 2000 average. Observed precipitation was derived from the National Weather Service's Cooperative Observer Network, while model simulated precipitation was derived from 15 different CMIP3 simulations for the high (A2) emissions scenario (see Kunkel et al. 2012). Simulation of 20th century conditions were based on estimated historical forcings of the climate system, including greenhouse gas emissions, solar variations, and aerosols. As seen in Figure 2.10, the observed trends and variations in decadal average precipitation are small and are within the envelopes of the model simulations. However, model projections into the 21st century indicate increased decadal variability in precipitation compared to the 20th century observations (see also Figure 40 in Kunkel et al. 2012). Moreover, there is

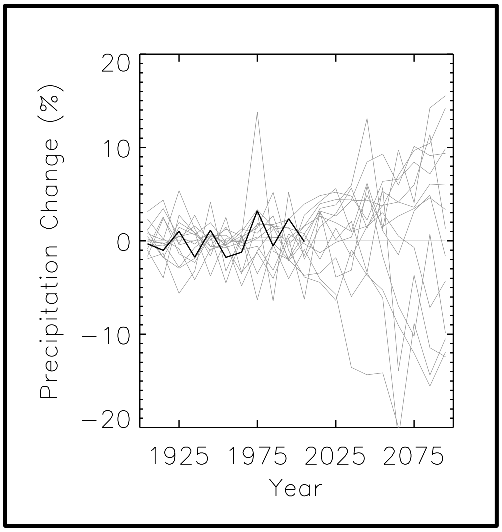


Figure 2.10. Observed decadal mean annual precipitation change (percent change from the 1901 to 2000 average) for the southeastern U.S. (black lines) and the 20th and 21st century simulations from 15 CMIP3 models for the high (A2) emissions scenario (gray lines). *Source: Kunkel et al. 2012, Figure 45.*

significant spread in projected precipitation among individual model simulations and an overall lack of agreement on the sign (i.e., an increase or decrease) of the projected change. When examined by season, the 21st century portions of the time series indicate an overall increase in precipitation in all seasons except summer (see Figure 46 in Kunkel et al. 2012).

2.4.2 Temperature

Mean annual temperatures are projected to increase across the SE through the 21st century. By 2050, the largest increases (3°F to 5°F) are projected over the interior of the region with the smallest increases observed over South Florida (Figure 2.11). By the end of the 21st century, the interior of the region is projected to warm by as much as 9°F while temperatures across the Caribbean are projected to be between 2°F and 4°F warmer than the late 20th century average (Biasutti et al. 2009; Campbell et al. 2011). These changes are generally consistent between the CMIP3 and NARCCAP simulations (see Figures 24 and 25 in Kunkel et al. 2012). The greatest warming is projected to take place during the summer months, while the winter months exhibit the least amount of warming (Figure 2.11). Additionally, the seasonal changes exhibit more spatial variability than the mean annual temperature change. It is important to note that the range of temperatures across the model simulations is large, particularly through the middle of the 21st century as internal climate variability contributes significantly to the temperature uncertainties in each model simulation over shorter time scales (Hawkins and Sutton 2009). Therefore, these projections should not be interpreted as precise quantitative predictions, but instead as broadly indicative of the kinds of changes that are likely to occur in the SE as the global climate warms.

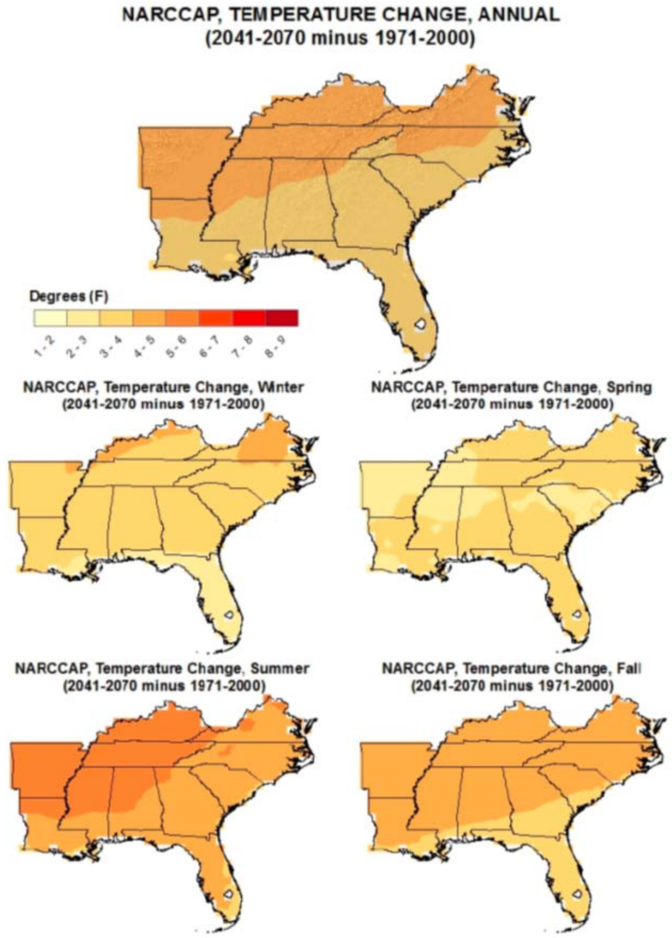


Figure 2.11. Annual and seasonal difference in temperature (°F) between 2041-2070 and 1971-2000 derived from eight regional climate model simulations from the North American Regional Climate Change Assessment Program (NARCCAP).

Maximum temperatures exceeding 95°F are expected to increase across the SE, with the greatest increases (35 additional days annually) found across the southern half of Florida by the mid-21st century (Figure 2.12). In general, more warm temperature extremes are predicted in the southwest part of the region, which has seen an increasing trend in such temperatures during the 20th and early 21st centuries (Diffenbaugh and Ashfaq 2010). In addition, the number of consecutive days exceeding 95°F, a metric used as a measure of heat waves, is expected to increase between 97% and 234%, depending on the model and emissions scenario (see Table 3 in Kunkel et al. 2012). An increase in the number of warm nighttime temperatures is projected across the Caribbean, with the warmest nights over the 20th century becoming four times more frequent by the end of the 21st century (Biasutti et al. 2009). Minimum temperatures below 10°F are expected to decrease in frequency by as much as 10 days in the northern tier of the region by the mid-21st century (Figure 2.13). Overall warming in the northern tier of the region is projected to increase the length of the freeze-free season by as much as 30 days in the mid-21st century. The length of the freeze-free season is defined as the period of time between the last spring frost, or daily minimum temperature less than 32°F, and first fall frost. In addition, the number of growing degree days (with a base of 50°F) is expected to increase by nearly 25%. Depending on the model and emissions scenario, the number of heating degree days in expected to decrease by 19% to 22%, while the number of cooling degree days is expected to increase by 44% to 49% by the mid-21st century (see Table 3 in Kunkel et al. 2012). The areas expected to have a larger increase in cooling degree days (e.g., south Florida and the northern Gulf Coast) will have a smaller increase in heating degree days, and vice versa.

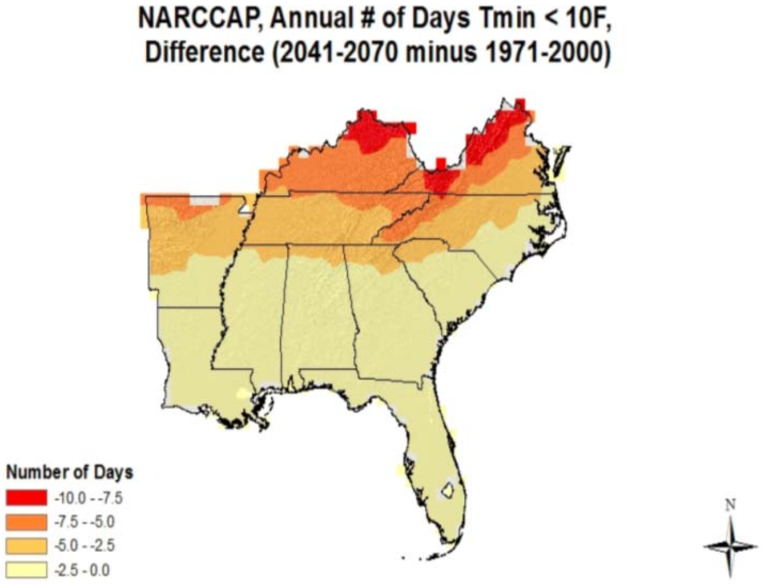


Figure 2.12. Mean change in annual number of days with a maximum temperature exceeding 95°F between 2041-2070 and

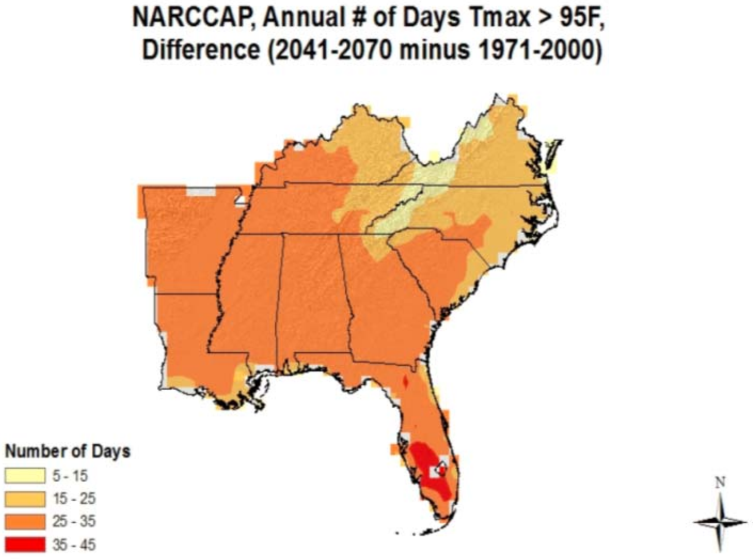


Figure 2.13. Same as Figure 2.11, but for minimum temperatures below 10°F.

Projections of mean annual and seasonal temperature variability across the SE were calculated for each future period (2035, 2055, and 2085) using monthly data from CMIP3 for the high (A2) emissions scenario (see Kunkel et al. 2012). Variability in these projections is defined as the standard deviation of mean annual or seasonal temperature. Secular changes in the temperature variability are calculated as a percent change in standard deviation between the future periods and a 1971 to 2000 baseline period. The models reveal a trend of increasing annual variability of temperature across all periods in the future, especially the latter 21st century. Projections of temperature variability at the seasonal scale, however, are more varied. Small changes of less than 5% are seen during winter and spring, while summer exhibits the greatest increase in variability of 24% by the end of the 21st century.

A comparison between model simulations and observations of 20th century mean annual temperatures across the SE shows that the models do capture the observed rate of warming since the 1960s. However, the models currently do not simulate interdecadal variability, which is a key aspect of the observed temperature record across the SE region. Specifically, the rate of warming from 1900 to the 1930s as well as the rate of cooling from the 1930s to the 1960s was not simulated by any of the CMIP3 models (Figure 2.14). Moreover, while the rate of warming since the 1960s was captured by the models, the observed decadal temperatures during this period were slightly cooler than those reproduced by the models. For the winter and summer seasons, observed temperatures in the 1930s are higher than any model simulation, while observed temperatures in the 1960s and 1970s are lower than any model simulation. Observed spring and fall temperatures generally fall within the envelope of the model simulations and do not show a marked change in temperature over the 20th century.

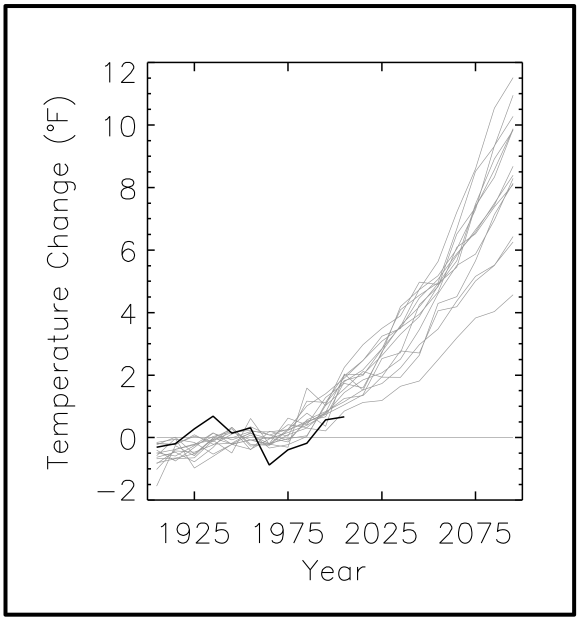


Figure2.14. Observed decadal mean annual temperature change (percent change from the 1901 to 2000 average) for the southeastern USA (black lines) and the 20th and 21st century simulations from 15 CMIP3 models for the high (A2) emissions scenario (gray lines). *Source: Kunkel et al. 2012, their Figure 43.*

2.4.3 Droughts

There is much uncertainty regarding future drought frequency and intensity across the SE (Seager et al. 2009). Hydrological drought is expected to increase across most of the country through 2050, with the largest increases in drought frequency observed across the southwestern USA and Rocky Mountains (Strzepek et al. 2010). While this is shown across a range of higher greenhouse gas emissions scenarios, there is much uncertainty because of variations in the projections of future precipitation patterns and evaporation rates across the region (Seager et al. 2009). Recent models project a greater likelihood of increased drought across the lower Mississippi River Valley and Gulf Coast, with fewer droughts across the northern tier of the region and in the mid-Atlantic (Strzepek et al. 2010).

2.4.5 Severe Thunderstorms and Tornadoes

Future projections in the frequency and intensity of severe thunderstorms and tornadoes are uncertain. This is especially the case for tornadoes, which cannot be resolved by global or regional climate models (Diffenbaugh et al. 2008). Severe thunderstorms, including those that produce tornadoes, require large amounts of convective available potential energy (CAPE), which is tied to atmospheric warming and moistening. Indeed. CAPE is projected to increase throughout the 21st century, thereby providing additional energy for severe thunderstorms (Trapp et al. 2007). However, global climate model simulations indicate significant inter-annual variability in CAPE due to internal climate dynamics, such as ENSO (Marsh et al. 2007). Tornadoes also require strong vertical wind shear, but this is projected to decrease over much of the mid-latitudes due to a weakening of the pole-to-equator temperature gradient (Diffenbaugh et al. 2008).

2.4.6 Hurricanes

Recent modeling studies suggest that the frequency of major hurricanes (categories 3 to 5) likely will increase in the future, while the overall number of tropical cyclones will likely decrease (Bender et al. 2010; Knutson et al. 2010). These studies project the greatest increase in major hurricanes over the western Atlantic basin, where increases in SSTs and decreases in vertical wind shear are expected (Wu and Tao 2011). Conversely, hurricane frequency is projected to decrease in the Caribbean and Gulf of Mexico sub-basins due to increased vertical wind shear (Biasutti et al. 2009; Bender et al. 2010). The observed positive trend in sea-surface temperatures (Trenberth 2005), which may be partly attributed to anthropogenic forcings (Mann and Emanuel 2006), has been strongly correlated with hurricane intensity in the Atlantic basin (Emanuel 2005; Webster et al. 2005). However, no definitive connections have been established between greenhouse gas emissions and hurricane activity (Pielke et al. 2005).

2.4.7 Sea-Level Rise and Sea-Surface Temperatures

The southeastern region displays an extensive and complex coastline that is especially vulnerable to sea level rise. As the sea level rises, storm surge and coastal erosion from tropical cyclones and other extreme events will likely increase in magnitude. Sea level rise models from the IPCC AR4 project a mean rise of between 18 and 59 cm by the end of the 21st century. An additional rise of between 10 and 20 cm is possible from a rapid dynamic melting episode of the Greenland or West Antarctic ice sheets (Mitchum et al. 2010). Such an event could result in complete inundation of various low-lying areas in the Caribbean and along the Gulf Coast (Milliken et al. 2008). Of particular importance to coastal communities and ecosystems is the rise in relative sea level, which accounts for changes in ocean volume and land motion. For example, coastal areas currently subsiding due to natural and human-induced processes (e.g., groundwater extraction, sediment redistribution), including portions of the northern Gulf Coast, will be most affected by sea level rise (Ericson et al. 2006).

North Atlantic sea surface temperatures are expected to increase by the end of the 21st century, with the greatest increases (3°C) noted in a region extending eastward across the subtropics from South Florida and the Bahamas (Figure 2.15). Smaller increases are projected across the higher latitudes of the North Atlantic as well as the Caribbean Sea and Gulf of Mexico (Biasutti et al. 2009; Leloup and Clement 2009). However, there is significant uncertainty in SST projections in these regions, as recent studies indicate significant model errors and biases in the IPCC AR4 projections, for instance, a cold bias in sea surface temperatures across the Gulf od Mexico (Richer and Xie 2008; Misra et al. 2009).

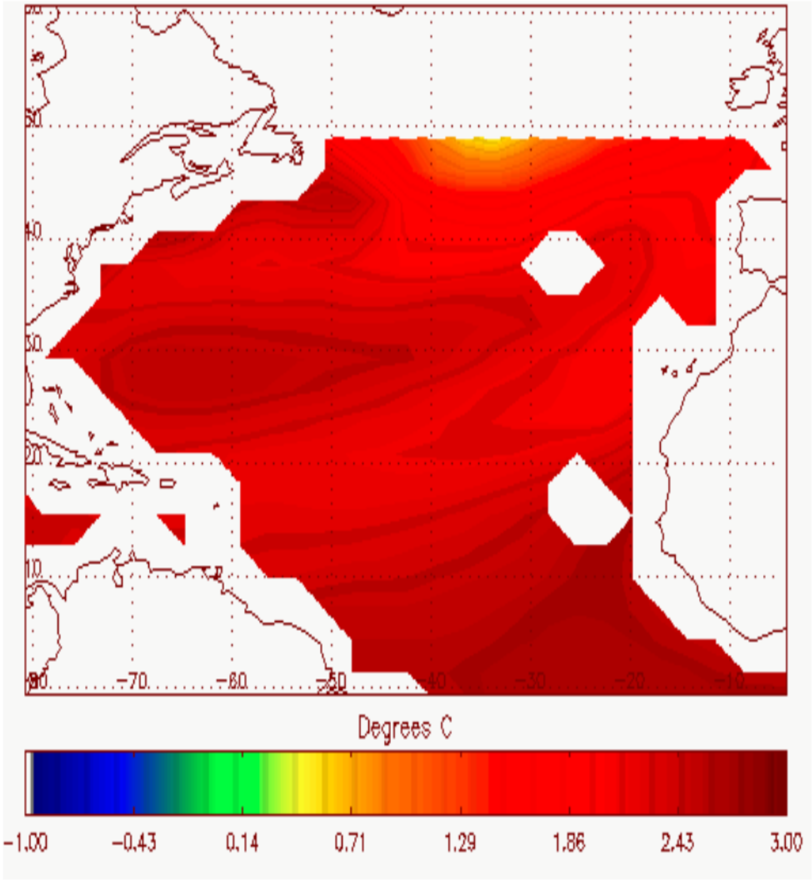


Figure 2.15. Mean difference in SST (°C) for the North Atlantic region between 2071 and 2100 and between 1971 and 2000. SSTs for the 1971 to 2000 period were computed from the Coupled Model Inter-comparison Model Project Phase 3 (CMIP3) suite of 16 climate model simulations. For the 2071 to 2100 period, simulations of SSTs were constructed from the SRES A2 and B1 scenarios from the IPCC AR4.

2.4.8 Air Quality

Poor air quality, especially high ozone levels, is known to be harmful to ecosystems, agriculture, and human health. Atmospheric conditions that promote poor air quality—such as increased temperatures, increased solar radiation, reduced precipitation, increased air stagnation, and decreased atmospheric ventilation—are expected to become more frequent across the western and southern USA by the mid-21st century (Leung and Gustafson 2005). By the mid-21st century, average summer season ground-level ozone concentrations are projected to increase by 4.5 to 7.5 ppb across the northern tier of the region, with locations along the Ohio River and in the vicinity of Atlanta, GA, exhibiting increases of as much as 12 ppb (Hogrefe et al. 2004). Conversely, projections of summer season ozone concentrations in the southern tier of the region are projected to show little change (Hogrefe et al. 2004). However, it is probable that future changes in ozone concentrations may be driven as much or more by mitigation practices than by changes in atmospheric conditions.

2.5 Acknowledgements

We thank Kevin Robbins, David Sathiaraj, and Luigi Romolo of the Southern Regional Climate Center, and Ryan Boyles and Ashley Frazier of the North Carolina State Climate Office, for producing many of the figures that accompany this document (Kunkel et al. 2012). We also thank those individuals who reviewed earlier versions of this document, including John Christy, Bill Murphey, Stu Foster, and Keith Ingram.

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3 Human Health in the Southeast Region

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Acknowledgements
Thanks to Janet Gamble, Winston Liao, John Thayer, and Karin Yeatts for providing additional comments.

3.1 Introduction

Climate change is projected to affect human health in the Southeast (SE) USA in a variety of ways, both directly and indirectly. Increasing temperatures, shifts in weather patterns, and variations in sea level and water composition have the potential to exacerbate existing public health problems in the region while also leading to the introduction of novel diseases. The SE has a wide variety of ecosystems, ranging from the subtropical wetlands of the Everglades to the temperate forests of the Great Smoky Mountains, as well as diverse human development patterns including rural farmlands and large dense cities. In addition, the SE experiences a wide range of weather events that can affect health and could be influenced by climate change. These factors complicate the assessment of climate-related health issues in the region.

Identifying the underlying health risks and vulnerabilities from climate change to the population of the SE is essential. By taking steps to reduce vulnerability to these events through improved monitoring, prediction, education, communication, engagement, and planning, the southeastern USA can become more resilient to climate-related health impacts. Developing tools and products that translate weather and climate information into a form that is useful for public health can also help in managing and reducing vulnerability. There exists a dense network of weather stations in the SE, as well as a significant amount of health data from sources such as the North Carolina Disease Event Tracking and Epidemiologic Collection Tool (NC DETECT), various CDC tracking programs, and other federal, local, state, citizen-based and academic research programs. Opportunities to link disease surveillance systems with available climate and environmental data should be explored.

This chapter discusses current and potential regional human health effects from climate change in seven major categories: heat and cold; air quality and respiratory/airway diseases; storms, extreme weather, and sea-level rise; harmful algal blooms and marine toxins; vector-borne and zoonotic disease; water quality and quantity; and human migration/displacement and healthcare disruption. Health impacts in other areas, such as mental health and food security may also occur, but more research is needed to determine the potential effects in the SE.

3.2 Heat and Cold

As a result of global climate change, global mean temperatures have been rising and are predicted to continue rising. In the southeastern USA, average temperatures have already risen by 2°F since 1970. Climate models predict continued warming, with average annual temperatures rising by 4.5°F to as much as 9°F by the 2080s, depending on the emissions scenario used. Climate models project continued warming in all seasons across the SE and an increase in the rate of warming through the end of this century. Summer temperatures alone could rise by as much as 10.5°F on average (Karl et al. 2009, EPA 2010). In addition, according to the previous National Climate Assessment by 2100 the SE is expected to experience a greater increase in heat index than any other region of the country (Burkett et al. 2001).

The relationship between temperature and human health is well established, and the negative effects of heat on the cardiovascular, cerebral, and respiratory systems have been further described in recent years (Kovats and Hajat 2008, O'Neill and Ebi 2009). Extreme heat events cause more deaths annually in the USA than all other extreme weather events combined (Luber 2008). As with other USA regions, rising temperatures in the Southeast are expected to have an impact on human health. In addition to the direct health effects of heat exposure, increasing temperatures can also exacerbate preexisting chronic conditions and contribute to formation of harmful air pollution and allergens (Portier et al. EHP 2010).

Despite the increase in average temperatures in the SE over the past several decades, heat-related mortality overall has been decreasing. Improvements in health care and the prevalence of air-conditioning are likely the two main factors affecting the relationship between heat and mortality (Sheridan et al. 2009). Human biophysical acclimatization to higher temperatures in the region could also reduce mortality rates (Davis et al. 2003). However, the decline in heat-related mortality appeared to abate from the mid-1990s to the mid-2000s, and population increase and demographic shifts in the SE could expand the vulnerable population in the future. Vulnerable and high-exposure populations such as the elderly, athletes, and outdoor laborers could be particularly at risk from increasing heat (Luber and McGeehin 2008). For example, of 68 heat-related deaths among crop workers from 1992 to 2006 in the USA, 13 occurred in North Carolina and 6 in Florida (MMWR 2008). Urban areas are also at risk, as several of the largest cities in the SE (Atlanta, Tampa, Miami, and New Orleans) have already seen significant increases in the number of hot days per year in which mean mortality is significantly above the summer baseline (Sheridan et al. 2009). Rising spring heat vulnerability was seen in Atlanta (Sheridan 2010), and increasing temperatures in the SE are projected to lead to increased ozone concentrations in the 19 largest urban areas in the region, causing an increase in mortality (Chang et al. 2010).

Expanding and improving the surveillance of heat-related illness throughout the warm season can significantly reduce the overall burden on the public health system. Improving education and communication, particularly among at-risk groups and communities, may best be accomplished through collaborative efforts between local meteorologists and public health officials. Moreover, designing and utilizing collaborative models for engaging at-risk citizens in building heat resilience may prove an effective tool for reducing vulnerability and raising awareness to heat-related threats.

Rising temperatures could also affect food quality and security. Expanding population and land use changes have already reduced the existing land available for agriculture in the SE more rapidly than any other area of the country (Loveland et al. 2012). In addition, and summer average temperatures are already at or above the optimal temperature ranged for major crops including corn, peanuts, soy, rice, and wheat (Hatfield et al., 2008). Moderate temperature increases may result in lower crop yields, with potential implications for food security and human health (Boote et al. 2005).

One potential benefit of increased temperatures is the potential for a reduction in cold-related deaths in the SE, although this has not been fully explored in the literature. The total number of freezing days in the SE has declined by four to seven days per year for most of the region since the mid-1970s (EPA 2010). However, the human health response to cold temperatures is much less pronounced than the response to high temperatures, making direct relationships between cold weather and mortality more difficult to predict (Laschewski and Jendritzky 2002). More research is needed on this topic.

3.3 Air Quality Effects on Respiratory and Airway Diseases

Climate changes impact air quality via several mechanisms, including changes in ozone production due to higher temperatures or a shift in cloud cover; changes in rates of precipitation scavenging, the process by which precipitation removes particulates from the atmosphere; shifts in vertical mixing due to changes in stability and wind speeds; and changes in the frequency of tropical and extra-tropical cyclones and cold fronts which vent pollutants. Impacts on air quality can also result from variation in vegetation type and amount, which affects biogenic emissions, and higher temperatures leading to higher fossil fuel consumption. In turn, atmospheric chemistry impacts climate, primarily via radiative effects of aerosols. The many feedbacks are not yet fully understood or simulated by current models (Denman et al. 2007).

Studies of climate change impacts on air quality in the southeastern USA have focused on ozone and small particulate matter ($PM_{2.5}$). In estimating future ozone and $PM_{2.5}$ levels, both air quality modeling simulations driven by downscaled global-climate model projections and empirical models linking future meteorological parameters with pollution levels have been reported in the literature. Although daily maximum 8-hour ozone levels in the SE have been generally estimated to rise in the 2040s and 2050s as compared to early 2000s, the magnitude of change varies among different studies, from less than 1 ppbv (Chang et al. 2010) to as much as 3 ppbv (Avise et al. 2009). The uncertainty in estimated daily maximum 8-hour ozone concentrations has been found to be approximately 2.5 ppbv in the SE (Liao et al. 2009). The resulting estimate of premature deaths that are attributable to climate change in the region ranges from a few dozen to a few hundred per year. Less research has been done on projected ozone-related morbidity, although a rise in outcomes such as hospital admissions due to respiratory illnesses, emergency room visits for asthma, and lost school days is expected (Tagaris et al. 2009). Associations between pollutants and health outcomes are different under different air masses. Projections for North Carolina indicate moister air mass patterns and increased ozone, which likely would trigger asthma attacks and result in more emergency room visits (Hanna 2011).

There is less consensus in estimated $PM_{2.5}$ concentration trends in the SE. A small increase of 1 mcg/m^3 has been reported in one study, as increased future emissions under the business-as-usual scenarios offset the air pollution reduction effects of increased precipitation and wet deposition (Avise et al. 2009). Another study projects a slight decrease of $PM_{2.5}$ levels by 2050, resulting in fewer cases of related premature mortality as well as morbidity outcomes (Tagaris et al. 2009). In addition, current air quality models such as Congestion Mitigation and Air Quality (CMAQ) can underestimate $PM_{2.5}$ by as much as 30% (Tagaris et al. 2007). Another study found that uncertainty in estimated $PM_{2.5}$ concentrations is moderate in the SE (< 1 mcg / m^3) (Liao et al. 2009).

Wildfires reduce air quality and therefore also affect human health. Predicted temperature increases coupled with anticipated precipitation changes in the SE could lead to increased evapotranspiration and lower vegetation water content. Lightning, a frequent initiator of wildfires, is expected to increase (Wu et al. 2008). Together, these factors indicate an increasing risk of wildfires, which continues a recent trend (Ebi et al. 2008). Particulate matter (PM) emitted by wildfires poses a serious health risk and increases asthma incidence in particular. Studies have demonstrated that PM is associated with increases in hospital admissions and occurrences of acute asthma exacerbations (Zanobetti and Schwartz 2006). In the Carolinas, peat bog wildfires pose a health hazard, and even brief exposure to smoke associated with these types of wildfires has been associated with negative respiratory and cardiovascular outcomes (Rappold et al. 2011).

Climate change can also affect human health through shifts in air-borne allergens. Recent changes in both carbon dioxide concentrations and temperature may be responsible for the observed trend of the earlier onset of the spring pollen season in the USA. (Confalonieri et al. 2007). It is reasonable to expect that this trend will continue, and that allergies and other respiratory illnesses related to airborne pollens will continue to increase.

3.4 Storms, Extreme Weather, and Sea Level Rise

Climate change may increase the probability of extreme weather events such as heat waves, floods, drought, and the intensity of tropical cyclones in the SE. Greenough et al. (2001) and the International Panel on Climate Change (IPCC) note that extreme weather events will be more frequent, costly, and likely raise the morbidity and mortality rate across the USA. The country's aging population will be more vulnerable to extreme heat events especially in cities where the urban heat island effect can raise temperatures by 2°F to10°F (Luber and McGeehin 2008; IPCC 2007). In addition, by 2030, several southeastern states, such as Florida, North Carolina, and Georgia are projected to have some of the largest numbers of older Americans (Administration on Aging 2011).

Tropical cyclones that make landfall will also impact public health systems in the southeastern USA, especially on coastal population centers. The incidence of longer-lived tropical cyclones in the North Atlantic is correlated with increased sea-surface temperatures consistent with a warming climate (Mann and Emanuel 2006). Tropical cyclone intensity can be measured by the power dissipation index (PDI) as defined by Emmanuel (2005). The annual PDI has increased significantly in the North Atlantic basin since the mid-1970s and is attributed to an increased trend in longer tropical cyclone lifetimes and frequencies. Although there has not been an associated increase in North Atlantic tropical cyclone PDI (Wu et al. 2008), the increased likelihood of tropical cyclones in the North Atlantic could lead to more frequent tropical cyclones along the southeastern coastline.

In the aftermath of Hurricanes Katrina and Rita in 2005, coastal and inland populations along the SE USA suffered from breakdowns of various societal and infrastructure systems including governance and public health systems. Storm surge, high winds and falling trees, and rising and receding floodwaters led directly to deaths and injuries and also impeded transportation and prevented many people from obtaining emergency medical services. The lack of potable water was a major concern, as human beings require water for hydration, food preparation, and washing. Raw sewage and industrial contaminated waters disrupted the water distribution system and became a major environmental and health issue (Goldman and Coussens 2007). Survivors showed a higher prevalence of serious mental illness (Kessler et al. 2006). The havoc that these storms wreaked is emblematic of the potential public health impacts that future powerful storms may inflict in the SE.

Sea level rise is another potential consequence of both the Earth's warming from an accumulation of anthropogenic greenhouse gases and natural climate variability. Changes in Mean Sea Level (MSL) are of major interest to public health in the northern Gulf of Mexico (nGOM) due to the large extent of coastal wetlands, productive fisheries, and large resident populations. Changes in MSL are being recorded in NOAA observation stations from south Texas to the Florida Keys in the nGOM. These data have been collected for more than 150 years through the National Water Level Observation Network. The MSL changes consistently show a rise in sea level with the most severe changes in coastal Louisiana. The rate of MSL rise can be generally categorized as from 0 mm to 3 mm/yr off the coast of west Florida, Alabama, and Mississippi coasts. In North Carolina, the rate of MSL rise has been observed at a rate of 2 mm to 4 mm/yr (North Carolina 2010), and MSL rise has been 9 mm to 12 mm/yr in coastal Louisiana. The Eugene Island station in south central Louisiana has recorded a MSL trend of 9.65 mm/yr (Figure 3.1), the fastest rate of MSL rise in the nGOM.

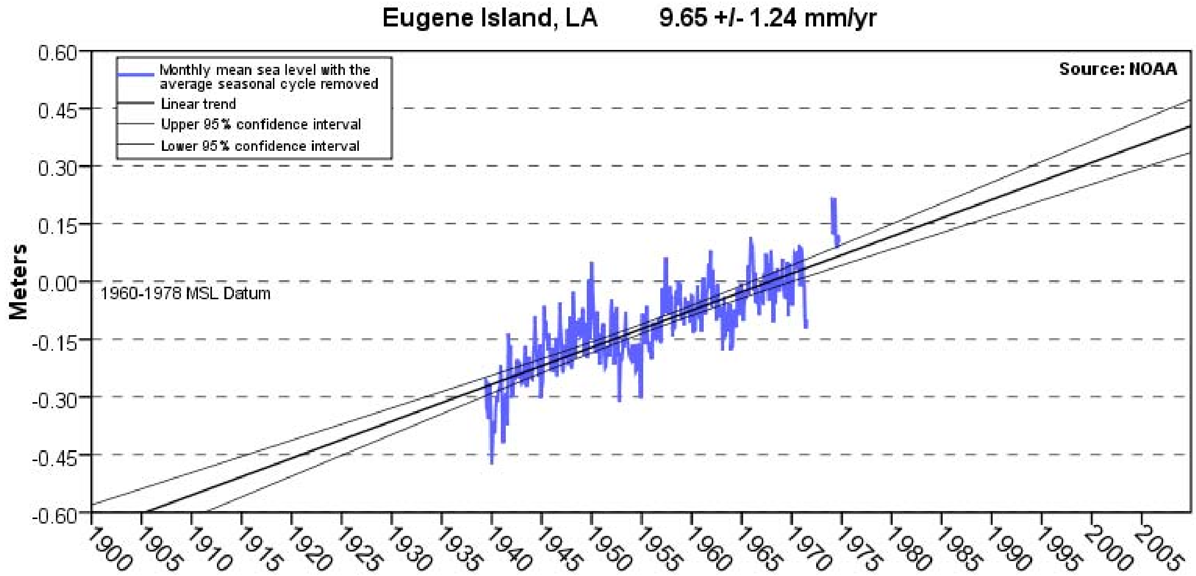

Figure 3.1. MSL at Eugene Island, LA

The major impacts from MSL rise cited in the IPCC 2007 report are inundation, flood and storm damage, erosion, saltwater intrusion, rising water tables, impeded drainage, and wetland loss. Changes in MSL exacerbate coastal erosion, flood highly productive marsh and wetland ecosystems, and change salinity levels that affect fisheries and food sources. Varying degrees of land loss currently are occurring among hydrologic basins, ranging from 0.1 square miles (64 acres) per year in the Atchafalaya Basin to 11.1 square miles (7,104 acres) per year in the Barataria Basin (Louisiana Coastal Wetlands 1997). Barrier islands and other low lying areas are subject to increased frequency and levels of flooding, which have human health implications from direct injury and disruption of emergency response. MSL rise and coastal erosion may affect nearshore ecosystems including seagrasses and oyster reefs, which degrade habitats essential for commercial fisheries, possibly leading to shellfish contamination (Hagen et al. 2011).

Adaptation strategies for sea level rise include changes in construction rules for structure elevation in local and regional comprehensive plans. Locations of health-related infrastructure should be carefully planned to meet the needs of communities while providing maximum protection from rising sea level. Some adaptation strategies being used in the nGOM provide short and long-term benefits include the use of natural breakwaters such as oyster reefs or other man-made and natural materials to dissipate wave action and protect shorelines; creation of dunes along the backshore of beaches with dune grasses and sand fencing to induce settling of wind-blown sand; introduction of submerged aquatic vegetation to stabilize sediment and erosion and protect critical fisheries habitat; replacement of shoreline armoring with living shorelines through beach nourishment and vegetation planting; and promotion of wetland accretion through the introduction of sediment (Eco-Systems 2011). All of these strategies could protect critical infrastructure to prevent health impacts from flood events and ensure a resilient public health response after a disaster.

3.5 Harmful Algal Blooms and Marine Toxins

Harmful algal blooms (HABs) are toxin-producing blooms of algae including cyanobacteria that can endanger human health (Landsberg 2002). HABs have caused mass mortalities of fish and marine mammals in the ocean, killed domestic animals on land, and sickened people through exposure to the toxins by consumption of contaminated seafood or through recreational exposure (Backer and McGillicuddy 2006). In the eastern USA, the major toxin producers are dinoflagellates and cyanobacteria. These organisms have life cycles that can be influenced by climatic patterns; changes in climate may increase the effects of HABs and consequently concern for food safety and public health (Tirado et al. 2010).

A variety of climate changes can be expected to cause changes in the frequency, distribution, and intensity of toxic algal blooms in inland and coastal waters. These include warmer temperatures and changes in the timing of lake warming, changes in the duration of calm winds, as well as changes in frequency and intensity of hurricanes. Over the past decade significant strides have been made in understanding how climate affects HABs (Moore et al. 2008, Tester al. 2010, Hallegraeff 2010), which should improve predictions of these blooms in the future.

In the SE and Caribbean the most common coastal hazards from HABs are ciguatera fish poisoning (CFP) and neurotoxic shellfish poisoning (NSP), although potential risks of diarrhetic shellfish poisoning (DSP) and paralytic shellfish poisoning (PSP) exist (Landsberg 2002). CFP results from eating fish carrying ciguatoxin, a neurotoxin produced by species of the tropical dinoflagellate *Gambierdiscus*. With the exception of scombroid fish poisoning (associated with mishandling of fish after harvest), ciguatoxin is the most common foodborne illness associated with fish, affecting an estimated 50,000 to 500,000 people per year globally. In the USA, CFP illness is concentrated in the Virgin Islands, Puerto Rico, South Florida, and Hawaii. A subset of patients develops chronic symptoms, which may be associated with long-term disability (Litaker et al. 2010). NSP results from brevetoxin, produced by the dinoflagellate *Karenia brevis* and some related species. *K. brevis* produces the well-known “red tide” in Florida. Brevetoxin is unusual in that it can become aerosolized, leading to respiratory distress in humans. During a bloom, hospital admissions for respiratory illness increase, and asthmatics are especially at risk (Kirkpatrick et al. 2006). An economic byproduct of red tide is changes in tourism plans that can lead to millions of dollars in losses to coastal communities (Larkin and Adams 2007; see Chapter 5).

Cyanobacteria also produce a variety of health risks (Backer 2002) including the hepatotoxin *Microcystin*. In addition, cyanobacteria produce several other toxins that pose health risks. Dermatitis as a result of recreational exposure is an additional risk to humans. *Cylindrospermopsis raciborskii* is a cyanobacterium of subtropical origin that appeared in Florida in the early 1990s and has established itself in the eastern USA and has also bloomed the Midwest. The cause of the spread is uncertain but earlier onset of the warm season favors its growth (Wiedner et al. 2007). Changes in climate that affect the timing of the warm season in these areas may favor development of *Cylindrospermopsis* blooms.

As climate change affects water temperature and rainfall, shifts in phytoplankton populations are expected (Moore et al. 2008; Hallegraeff 2010). As a particular water body changes with climate, a niche shift is likely to provide the opportunity for new species to populate. Changes in rainfall and the subsequent nutrient shifts likely will alter the dynamics of the population. In October 1987, *Karenia brevis* (Florida "red tide") was transported in the Gulf Stream to North Carolina, resulting in closures of shellfisheries in both Carolinas from October until late winter 1988 (Tester et al. 1991). *Dinophysis*, which has not been a problem in the USA, appeared in the Gulf of Mexico in March 2008, causing a closure of shellfish beds, as well as a recall of oysters. Blooms of tropical *Pyrodinium* sp. have appeared in Florida in the last decade, and have caused PSP through consumption of fish containing saxitoxin (Landsberg et al. 2006).

Climate change can lead to the expansion of CFP in tropical areas as well as more temperate zones. While higher sea surface temperatures are associated with higher rates of CFP (Hales et al. 1999, Tester et al. 2010), studies also have suggested that there may be a maximum temperature at which the toxin responsible for CFP can grow, with risk declining above this temperature (Llewellyn 2010). The preferred substrate of *Gambierdiscus* is macroalgae, which may spread as a result of coral bleaching (Tester et al., 2010). In the Caribbean, longer duration of warm temperatures favors development of *Gambierdiscus* spp*.* potentially allowing ciguatera to bio-accumulate in reef fish over a longer period of time (Tester et al. 2010). This will also cause a decrease in the amount of time available for the toxin to depurate. In the past decade, CFP has been documented from fish caught in South Carolina and in the Flower Garden Banks National Marine Sanctuary on the Texas/Louisiana border. These observations suggest that the disease is moving northward, possibly in association with increasing sea surface temperatures (CDC 2006; Villareal et al. 2007; Litaker et al. 2010).

The frequency and intensity of other events, such as hurricanes, may result from climate change and may play a role in the spreading of blooms. The first documented *K. brevis* bloom in Mississippi and Louisiana occurred in 1996 when Tropical Storm Josephine transported a Florida bloom westward (Maier Brown et al. 2006). Hurricane Katrina in 2005 transported a *K. brevis* bloom from southwest Florida to the north Florida coast (Carlson and Clarke 2008). While the full effect of hurricanes on HABs is not clear, these storms have contributed to the spread or relocation of blooms in the past and it is likely this trend will continue in the future.

3.6 Vector-borne and Zoonotic Disease

The subtropical climate in Florida and parts of the SE is attractive to mosquitoes, including vectors for the most important mosquito-borne diseases. These diseases include malaria, vectored by *Anopheles* sp. mosquitoes; and yellow fever, chikungunya, and dengue fever vectored by *Aedes aegypti* and *Aedes albopictus*. Outbreaks of dengue occurred regularly in Florida before the 1950s, when mosquito control efforts were implemented across the state. The vector, *A. aegypti*, also called the house mosquito, lives in close proximity to people, in and around homes. Mosquitoes prefer warm environments with high humidity so modern homes with air conditioning and screens help interrupt transmission by separating the vectors from susceptible hosts. Local transmission of dengue and malaria in the southeastern USA is now rare, primarily due to the actions of the Centers for Disease Control and Prevention, which was created to help with the control and prevention of malaria and related diseases. However, as the 2003 malaria outbreak in West Palm Beach (MMWR 2004) and the 2009 and2010 dengue fever outbreak in Key West (MMWR 2010) showed, when people open their houses and spend time on unscreened porches or in other places outdoors, disease transmission is still possible.

How climate change will impact vector-borne and zoonotic disease transmission in the southeastern USA is still uncertain. Vector-borne disease transmission cycles are complex and influenced by many factors. An increase in temperature is likely to shorten the development time of immature vectors to adults and also shorten the extrinsic incubation period of the pathogen in an infected vector (Watts et al. 1987). However, vectors also require access to water to breed, vegetation and humidity to disperse, and susceptible vertebrate hosts to propagate the disease transmission cycle. Regardless of the complexity of these transmission cycles, it is important to note that with climate change, it is likely the SE tropical wet-dry climate zone will expand. This is the climate zone where the most intense vector borne disease transmission occurs around the world. It is possible that the expansion of the wet-dry tropical climate zone in the SE USA will result in more favorable ecologic conditions for vector-borne disease transmission.

The greatest climate change related vector-borne disease concerns are associated with the expansion of habitats or accessible hosts for *A. aegypti*. The human population in the SE USA is growing fast and the demand for drinking and irrigation water is increasing. *A. aegypti* is known to readily adapt to urban environments with high host densities. As energy prices increase, the cost of running air-conditioning may result in increased disease transmission due to higher prevalence of open windows. In addition, climate change is predicted to increase the severity of tropical storms and hurricanes. During the many months required to repair homes damaged by such storms, residents are potentially vulnerable to mosquitos. In addition, debris from the storms creates mosquito breeding habitats thus increasing mosquito populations.

Zoonotic disease transmission is dependent on contact between infected animals and susceptible human hosts, and it is possible that any climate associated ecological changes that facilitate such contact will result in an increased risk for zoonotic diseases. For example, the anticipated water shortages during periods of drought may facilitate zoonotic disease transmission by attracting raccoons, a rabies vector species, and other wildlife to human water supplies. By 2055, changing temperature and precipitation patters could shift the zoonotic disease tularemia northward, resulting in reduced infections in the central-south area of the USA (Nakazawa et al. 2007).

3.7 Water Quality and Quantity

Worldwide, climate change is expected to increase diarrheal incidence by 10% by 2030 (Shuman et al. 2010), much of which will be associated with the water-borne disease transmission route. In the USA, while widely underreported (Blackburn et al. 2004), waterborne diseases continue to cause significant morbidity; exposure patterns and illness rates may change alongside climate and weather patterns (Semenza et al, 2012).

Human exposure to climate sensitive pathogens occurs by ingestion of water intended for drinking; incidental ingestion during swimming; or by direct contact with eyes, ears, or open wounds. Pathogens in water also can be concentrated by bivalve shellfish, such as oysters or pathogens in irrigation water can be deposited on produce; both food sources can then serve as vehicles for water-associated bacteria and viruses. Pathogens of concern for waterborne exposure may be either enteric and transmitted by the fecal-oral route (enteric viruses, bacteria and protozoa) or may occur naturally in aquatic systems (bacteria and protozoa), where they may cause a range of diseases. Climate may act on these pathogens directly by influencing growth, survival, persistence, transmission, or virulence. Changing climate or environments may likewise alter or facilitate transmission of the pathogens or affect the ecology and/or habitat of zoonotic reservoirs.

Climatological drivers, especially those affecting the hydrologic cycle, can influence how contaminants are introduced, transported, and processed in coastal ecosystems. Climate change in the SE USA has manifested itself most dramatically through the regional hydrologic cycle, with little change in overall temperatures for the region (Portmann et al. 2009). Climate change is projected to have a significant effect on water resources in the SE (Sun et al. 2008). Annual precipitation has decreased significantly, more than 20%, over the past 50 years (Karl et al. 2009) while at the same time the intensity of rainfall has *increased* by 20% (Groisman et al. 2004). In particular, there has been a significant shift in summer precipitation patterns over the SE, with a move toward higher variability in recent years (Wang et al. 2008). Exceptionally dry and exceptionally wet summers will be more likely during the 21st century, due to the North Atlantic Subtropical High (Li et al. 2011). Recent summer precipitation patterns show multiple shifts from drought to extreme precipitation. This severe combination of more frequent drought with episodes of intense rainfall alters overland and groundwater flow, changing mobilization patterns of inorganic and organic nutrients and contaminants (Boxall et al. 2009). There is also current evidence for the role of climate change and variability on water quality and waterborne disease in the SE including (1) expansion in temporal (seasonal) ranges of certain disease and pathogens related to moderate changes in temperature, (2) increased loading of enteric pathogens due to intense precipitation events, and (3) periodic exposure to multiple pathogens during hurricanes and extreme events.

There is a commonly noted correlation between general diarrheal disease (irrespective of agent) and ambient temperatures. This phenomenon has been documented in both the northern and southern hemispheres and across geographical areas (Hall et al. 2005, Singh et al. 2001. The enteric pathogens that cause a high burden of illness in the USA, especially the SE include more than 2,000 serovars of *Salmonella enterica*. *Salmonella* are carried by a wide range of domestic, agricultural, and wild animals. This feature allows *Salmonella* infections to be widespread. Outbreaks are generally associated with food, including consumption of undercooked poultry, beef, eggs, and contaminated produce but may also be associated with direct contact with animals and contaminated water, which may contribute to a high burden of sporadic cases that occur outside of defined outbreaks (Clarkson et al. 2009). Infections with *Salmonella enterica* serovars continue to be among the top sources of foodborne disease in the USA, and the SE reports the highest rates in the nation (MMWR 2010). Worldwide, including the USA, *Salmonella* cases peak with the highest annual temperatures (D'Souza et al. 2003, Kovats et al. 2004, Fleury et al. 2006, Naumova et al. 2006) although the specific mechanism for this trend is not clear. One study in southern Georgia showed that maximum waterborne prevalence of *Salmonella* and diversity of serovars, especially those associated with human clinical cases, are most common in summer months (Haley et al. 2009). Increased risk of waterborne exposure may be driving many of the sporadic cases of *Salmonella* infections that are currently driving regional and national trends in increasing disease incidence (Clarkson et al. 2009).

Naturally occurring pathogens, including the marine bacteria *Vibrio* spp*.,* are directly associated with warm temperatures. While the genus is commonly found in coastal waters worldwide, four species are commonly associated with human disease: *V. parahaemolyticus*, *V. vulnificus*, *V. cholerae* non-O1 and *V. alginolyticus*. *Vibrio* spp. are the most common bacteria associated with shellfish disease in the USA and a common cause of wound, eye, and ear infections. *Vibrio* illnesses are common in the coastal states of the SE, especially along the Gulf coast, where most cases of *V. vulnificus* arise (Yoder et al. 2008).

Pathogenic *Vibrio* spp*.* are well-adapted to coastal waters and proliferate at warm temperatures, particularly above 15^{o}C (Martinez-Urtaza et al. 2009), and human infections are more frequently observed in warm climates (Dechet et al. 2008, Iwamoto et al. 2010, Weis et al. 2011). Reported human cases also peak during summer months, corresponding with warm temperatures and increased human exposures through seafood and recreational water use (Dechet et al. 2008, Dziuban et al. 2006, Iwamoto et al. 2010, Yoder et al. 2008). Additionally, in the USA, human reports from Gulf Coast states and southeastern Atlantic states include a greater overall diversity of *Vibrio* spp. associated with infections (Dechet et al. 2008). Recent analyses on *Vibrio* infections associated with consumption of Gulf Coast shellfish indicates that cases are expanding temporally, with cases now frequently reported in April, one month earlier and in November, one month later than traditionally observed (Martinez-Urtaza et al. 2010). This trend is associated with an increase in the number of days in each month where water temperature is greater than 20^{o}C. From the decade between 1997 and 2007 compared to the decade between 1987 and 1997 there were water temperatures reaching more than 20^{o}C for five days in April with a 300% increase in the number of *V. vulnificus* illnesses (Martinez-Urtaza et al. 2010). Across the USA, rates of *Vibrio* spp*.* infections have grown by more than 115% since 1996 (MMWR 2011).

Changes in precipitation leading to increased flooding may have the greatest potential impact on food and waterborne disease, especially those associated with the fecal-oral route. A retrospective analysis of waterborne outbreaks associated with drinking water in the USA between 1948 and 1994 revealed that 51% of outbreaks occurred following a daily precipitation event in the 90th percentile and 68% occurred when precipitation levels reached the 80th percentile (Curriero et al. 2001). Waterborne pathogens associated with point and nonpoint sources of pollution include *Cryptosporidium* spp., *Giardia* spp., *Salmonella* spp., *Campylobacter* spp., and a range of enteric viruses, such as noroviruses, hepatitis A viruses, and enteric viruses.

High levels of precipitation may cause the spread of pathogens in a number of ways: overloading of waste-water treatment plants leading to diversion of waste-water to combined sewer overflows, increased run off of pesticides and other contaminants from agricultural or urban lands, or the failure of septic systems. Such events may expose people to significant quantities of enteric pathogens as has been documented with storm events in the SE (Lipp et al. 2001a, Shehane et al. 2005, Vereen et al. 2007, Stumpf et al. 2010, Parker et al. 2010).

The specific effects of climate variability on water quality in the SE have been determined using ENSO events as a model for interannual variability in retrospective studies. Tidally influenced rivers in the SE respond to increased precipitation and streamflow associated with El Niño events with significantly higher levels of fecal contamination, that are measured using fecal coliform bacteria (Lipp et al. 2001b, Chigbu et al. 2004). Moreover, specific enteric pathogens, such as enteric viruses, are also more likely to occur with high precipitation and streamflow associated with El Niño winters (Lipp et al. 2001a).

Water quality is also impaired during extreme events, specifically hurricanes, which are projected to increase in frequency and/or strength under various climate change scenarios. Hurricanes associated with large storm surges and tidal inundation may increase exposure for *Vibrio* spp. in affected populations as was seen in Gulf Coast states following the 2005 hurricanes, Katrina and Rita, in the SE. The incidence of *Vibrio* spp. infection increased relative to previous periods, with 22 wound infections and 5 deaths in slight more than a one-month period (CDC 2005). Flooding can also result in contamination from fecal sources and associated increase in enteric illnesses. In 1999, Hurricane Floyd flooded much of eastern North Carolina, including farm and livestock operations. This massive flooding event resulted in high levels of fecal contamination (Bales et al. 2000). The number of people seeking treatment for gastrointestinal illness doubled (Setzer and Domino 2004).

3.8 Human Migration and Displacement and Healthcare Disruption

Past disasters have identified problems associated with medical surge capacities during disaster events. Not only are the medical services within a disaster area often overtaxed (Franco et al. 2006), but in many instances populations evacuating from impact zones to safe areas can overwhelm medical services in the safe zone (Sheppa et al 1993, Gagnon et al. 2005, Gavagan et al. 2006, Stratton and Tyler 2006, Allen et al. 2007). Figure 2 shows the displacement pattern of Mississippians to other parts of the nation after Hurricane Katrina. These disaster diaspora populations often need more than food, water, and shelter during the transition from victims to survivors. One of the least understood aspects of this additional need is related to medical surge and the need to create accurate plans for the accommodation of increased patient volumes both inside and outside of the disaster impact zone (Hick et al. 2004, Bonnett et al 2006, Barbisch and Koeing 2008). With climate change likely to increase extreme weather events in the SE, including storm intensity, increased health implications associated with this type of migration will be expected to increase in the future. Mental health impacts could result from traumatic stress and deterioration of community wellbeing (Berry at al. 2010), especially for the disadvantaged communities in the SE (Wilson et al. 2010).

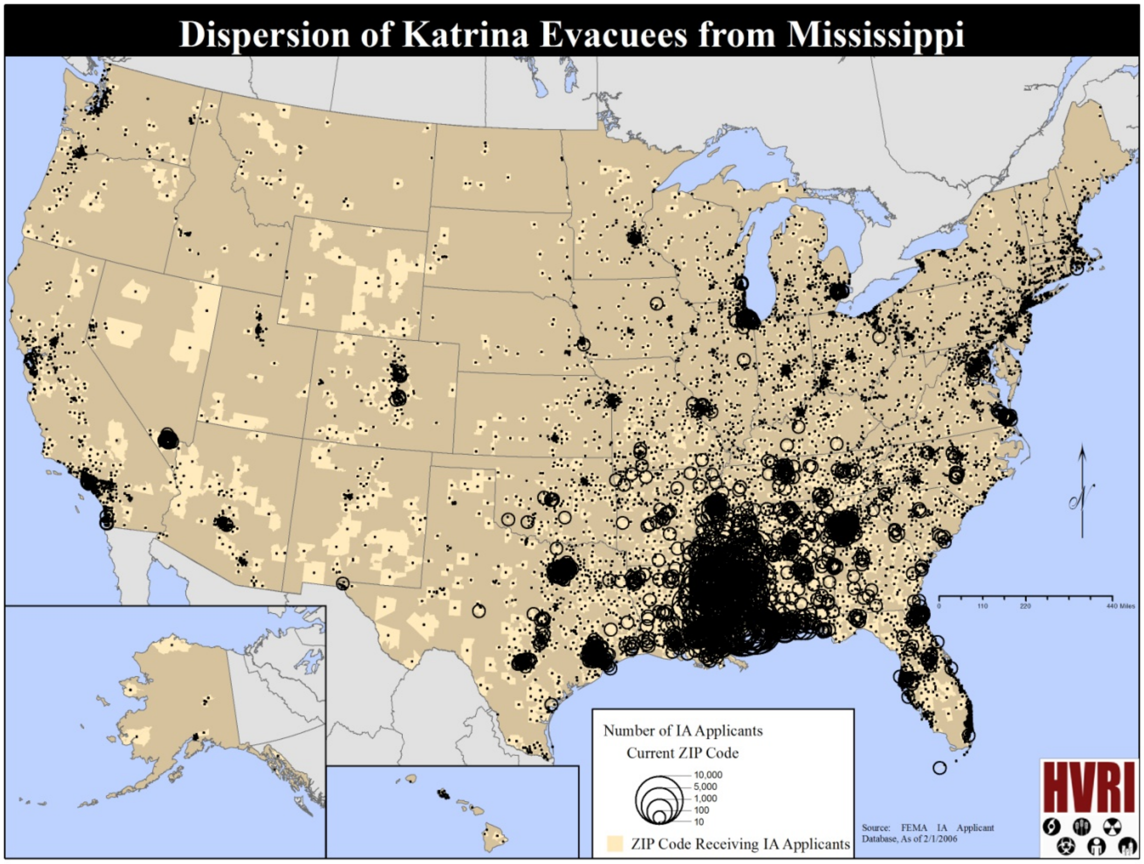

Figure 3.2. Disaster Diaspora populations from Mississippi by evacuation location.

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4 Southeastern Energy Production, Use, and Vulnerability to Climate Change

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Key Vulnerabilities

Impact of extreme weather events on energy production and distribution infrastructure

- Change in water supplies for hydropower and/or thermal power plant cooling
- Impact of temperature increases on overall thermoelectric power generation efficiencies
- Changed conditions affecting facility siting decisions
- Most effects are likely to be modest except for possible regional effects of extreme weather events and water shortages.

4.1 Status and Outlook for Energy Production and Use in the Southeast

The southeastern USA is one of the most important domestic producers and users of energy in the United States.[1] In 2010, states in the Southeast (SE) produced 15%of the coal and approximately one quarter of nation's domestic crude oil.[2],[3] In 2009, three SE states ranked in the top ten nationally in renewable energy installed or cumulative capacity in millions of watts (MW) in one or more resource types: Alabama (fifth in biopower), Florida (fourth in biopower and fifth in in solar photovoltaic or PV), and Louisiana (second in biopower), and North Carolina (tenth in annual solar PV capacity additions).[4] However, no southeastern state ranked in the top ten in wind or geothermal development.[5] In addition to being a major supplier of energy, the region is also a large consumer of electricity and other fuels. Of the eleven states in the SE USA., six have an electricity import/export deficit as a percent of total generation (two with greater than 20% deficit and four between 20% and 0% deficit).[6] Puerto Rico and the U.S. Virgin Islands have few conventional energy sources and make most of their electricity from imported fossil fuels.[7]

This chapter explores the status of the SE as a source and user of energy in the USA. It also looks at how a changing climate may impact the ’region’s ability to supply energy into the future and identifies key uncertainties in the understanding of these issues.

4.1.2 Existing Energy Resources in the Southeast

The SE is home to large and varied, though unevenly concentrated, energy resource reserves. Approximately 10% to 11% of the national hydroelectric power comes from the SE (more than half from Alabama and Tennessee) with some additional future potential still available.[8] Coal deposits are distributed throughout Appalachia and beyond. Natural gas and oil finds exist both onshore and offshore. Solar insolation is above average for the eastern part of the nation. Significant amounts of biomass energy are available. In specific locations, wind and geothermal resources are also potential sources of energy, but mostly offshore and via co-produced fluids in the oil and gas industry respectively.[9] In the ongoing development of these various energy resources, a number of issues will have to be considered, including permitting requirements, costs, distance to transmission, environmental impacts, and the number of projects needed to reach generation goals.

Coal

Coal deposits in the SE are concentrated in several states including Kentucky, Virginia, and Alabama. Approximately 10% of the USA coal reserves are located in four key states in the SE, including Kentucky, with 1,303 million tons and Virginia with 294 million tons. In 2009, recoverable coal reserves in the SE were estimated at 1,896 million short tons out of 17,474 million short tons (approximately 10.9%) of the USA total.[10] About 71% of coal in the USA is transported by train for at least part of its trip to market. Coal can also be transported by barge, ship, truck, and even pipeline.[11]

There are also lignite resources available in Arkansas, Mississippi, and Louisiana that could play a role in future electric generation. Mississippi Power Company’s 582 MW Integrated Gasification Combined Cycle (IGCC) power plant (which will also include carbon capture and sequestration technology) in Kemper County, for example, is set to burn lignite as its fuel supply beginning in 2014.[12]

Oil and Natural Gas

Figure 4.1 shows natural gas production in the USA from 1990 through 2009 with forecasts through 2035. While onshore and offshore conventional supplies make up a significant portion of historical production, shale gas is forecast to play a key role in future supply due to improved exploration and production technologies.[13] Key shale finds include the Fayetteville shale in Arkansas and the Haynesville/Bossier in Louisiana. Of the 61 trillion cubic feet (Tcf) of shale play reserves in the USA, 20 Tcf are found in the Haynesville/Bossier and Fayetteville plays.[14]

The distribution of natural gas occurs in a major pipeline network (Figure 4.2) with significant pipeline capacity in the SE.[15] Several of the liquefied natural gas (LNG) terminals in the nation are in Louisiana and Elba Island Georgia.[16]

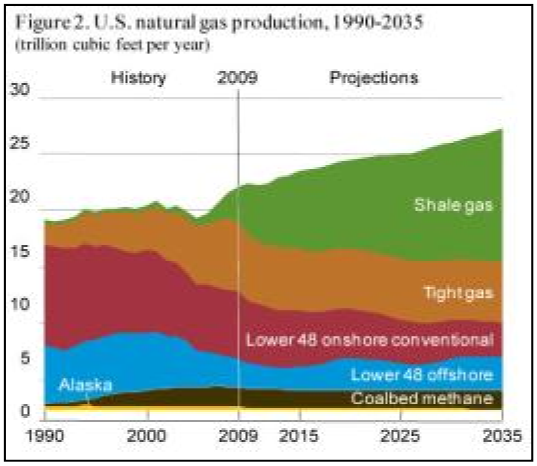


Figure 4.1. Natural gas production, 1990 to 2005, (trillion cubic feet).

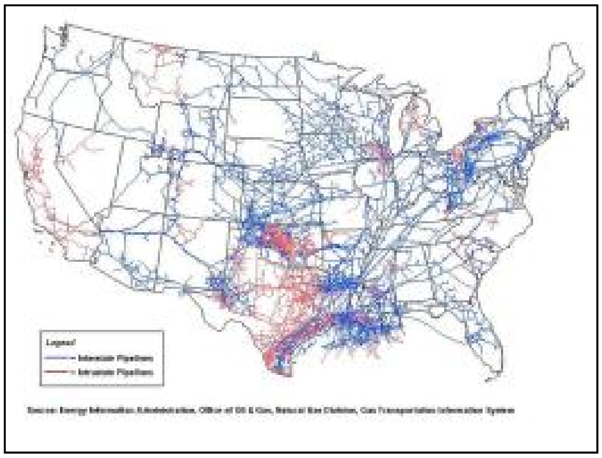


Figure 4.2. Natural gas pipelines.

Biomass

One estimate of the biomass resource in SE is 106,710 thousand tons of material per year (25% of the USA total).[17] Wood pellet mills are among the most successful group of new woody biomass consumers, with pellet mills currently consuming 6.2 million tons of wood per year, and producing 3.1 million tons of export quality wood pellets.[18] This is largely due to demand for biomass co-firing in European countries that have opted to use wood pellets because of increasing fossil fuel prices and environmental concerns.[19]

Nuclear

Of the 104 nuclear reactors in the USA, 37 (36%) are located in the SE and account for more than 36,400 MW of electrical power. In 2010, these units generated some 285 billion Kwh, operating at a capacity factor slightly less than 90%.[20]

Hydro and Marine Hydrokinetic

Every SE state except Mississippi generates some electricity via hydroelectric power. In 2008, the SE produced 11% of the total USA hydroelectric power and had 14,310 MW of net summer hydroelectric capacity, or over 18% of the USA total.[21,22] Tennessee, Arkansas, and Mississippi each have approximately 4 GW of developable hydroelectric resources remaining. North Carolina, Georgia, Alabama, and Louisiana have between 2 to4 GW of developable hydroelectric resources remaining. South Carolina, Kentucky, and Florida contain around 1 GW of hydroelectric potential each.[23] These resources are mostly available from retrofitting and upgrading existing hydroelectric dams, or installing small or microscale hydroelectric systems.

The U.S. Department of the Interior estimates that 0.1% of the Florida Straits Current could supply 35% of Florida's electrical demand via marine hydrokinetic electric generation.[24] Some energy potential also exists for Georgia[25] and North Carolina[26] and likely in similar fashion for South Carolina from wave, tidal, and currents using marine hydrokinetic technology.

Solar

Solar resources in the 11 states of the SE are not as robust as those found in the western USA, but resources near or in excess of 5 watts per square meter, are significantly better than in much of the country east of the Mississippi River. Among SE states, Florida has the best solar resources.[27] Puerto Rico and the U.S. Virgin Islands both have high solar resource potential.[28,29]

Wind

In the SE wind energy resources are less robust than resources in the Plains states; however, wind resources do exist in specific mountainous, coastal, and offshore areas. A scenario outlined by the National Renewable Energy Lab estimated that as part of a national strategy to generate 20% of the nation's electricity from wind energy by 2030, the SE could provide between 17 GW and 32 GW of wind energy capacity, including onshore and offshore resources.[30] North Carolina, for example, has the best shallow water offshore wind resource in the country.[31]

Geothermal

The SE has few viable opportunities for geothermal power generation sites. However, co-produced fluids (water from oil and gas production) could provide up to 771 MW of geothermal energy using existing wells in Alabama, Arkansas, Florida, Louisiana, and Mississippi.[32]

Energy Efficiency

Energy efficiency initiatives in the SE are a powerful way to reduce per capita energy consumption, conserve fuels, and reduce the need for new generating capacity into the future. Additional energy efficiency resources and initiatives are discussed in chapters 5 (Built Environment) and 12 (Mitigation).

Case Study: Louisiana

Louisiana is an important state for both the production and distribution of fuel in the United States. For example, the Louisiana Offshore Oil Port (LOOP) is the only port in the United States capable of accommodating deep draft tankers, two of the U.S. Strategic Petroleum Reserve's four storage facilities are located in Louisiana, and the Henry Hub is the largest centralized point for natural gas spot and futures trading in the United States, providing access to major markets throughout the country. In addition, the liquefied natural gas (LNG) import terminal at Sabine is the largest of nine existing LNG import sites in the United States.

4.1.3 Landscape of Energy Production, Delivery, and Use in the Southeast

Electricity Production
Peak demand for electricity in the SE, which was more than 238 GW in 2010, represents around 32% of the total demand in the nation. Likewise, generating capacity in the SE is approximately 32% of the total nationwide. Nationally, fossil fuel based capacity represents some 71 % of the total generating capacity while nuclear, hydro, and other renewables make up around 25%. In the SE, traditional fossil-based generating capacity is some 235 GW or 78% of the total generating capacity of 300 GW. In addition to fossil fuels, nuclear power provided (in 2009) 36 GW and renewables and pumped storage 28 GW of generating capacity (Table 1).[33]

Table 4.1. Southeastern States Generation Capacity (2009)

Fuel	GW	Percent
Coal	94	31.3
Petroleum	19	6.3
Natural Gas	122	40.5
Nuclear	36	12.1
Renewables	19	6.3
Pumped Storage	9	3.1
Total	**300**	

The SE has a balanced portfolio of resources from an operational perspective. Traditional base load resources such as nuclear and coal provide power around the clock. Pumped storage, along with gas turbine units, provides energy during peak load conditions. The generation of electricity on an hourly basis, measured in kilowatt-hours, provides a different picture with nuclear power providing around 292 billion Kwh of electricity, some 25% of the electrical needs of the SE in 2009. In contrast, coal generation in 2009 delivered 491 billion Kwh, while natural gas combined cycle units produced some 277 billion Kwh of electricity. From 2005 to 2009, coal fired generation dropped from 50% to 43% of the total generation, while natural gas picked up the majority of that difference.[34]

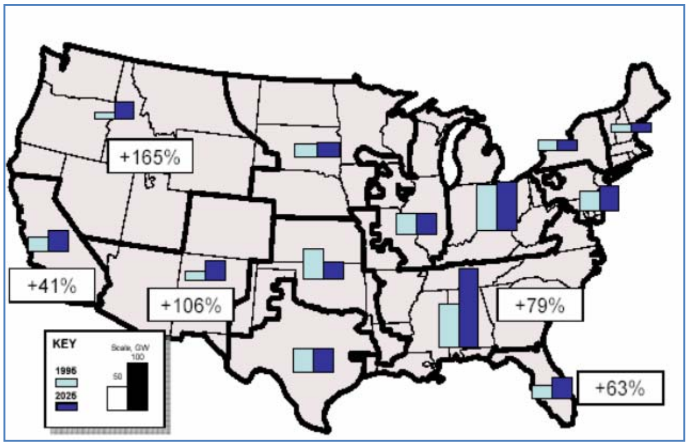


Figure 4.3. Comparison of regional thermoelectric generation capacity by North American Electric Reliability Council Region, 1995-2025.

With regard to growth in electric power sector, a 2004 study by the Department of Energy projects a 63% to 79% increase in thermoelectric capacity by year 2025 for much of the Southeast (Figure 4.3).[35] Updated estimates for growth in the electric power sector (all fuel types) indicates more modest growth in electric generating capacity between 2010 and 2035 of 23% for Florida and 15% for the rest of the region.[36] [37]

With regard to renewables, including conventional hydro, the SE produced 67 billion Kwh in 2009[38] with this value expected to grow over time. For example, 29 MW of generation capacity from wind turbines currently exist in the SE,[39] and at least five utility-scale wind farms have recently been proposed in the following locations: Invenergy, North Carolina, 80MW; Iberdrola, North Carolina, 300MW; Invenergy, North Carolina, 300MW; Next Era, Kentucky, 100 MW; and Wind Capital Group, Florida, 150 MW.[40], [41], [42], [43], [44]

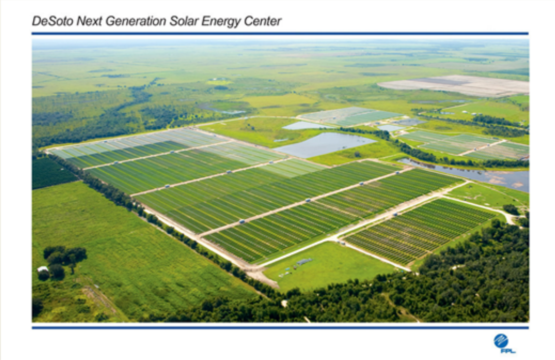
Case Study: DeSoto Next Generation Solar Energy Center

When opened in October 2009, Florida Power and Light's DeSoto County Next Generation Solar Energy Center was the largest solar photovoltaic plant in the United States.

The facility's 90,500 solar panels have an annual estimated generation of approximately 42,000 MWh - enough power to serve about 3,000 homes.

Over 30 years, the solar facility will prevent emission of more than 575,000 tons of GHGs, equivalent of removing over 4,500 cars from the road every year for the entire life of the project.

The project is also estimated to decrease fossil-fuel usage by approximately 7 billion cubic feet of natural gas and 277,000 barrels of oil.



http://www.fpl.com/environment/solar/desoto.shtml

As another example, Tennessee Valley Authority (TVA) has 300 kW of solar photovoltaic capacity installed, an additional 16 MW under contract, and 34 MW approved under the *Generation Partners* program.[45] Duke Energy owns, purchases, or has installed up to 24 MW of solar capacity in North Carolina and South Carolina.[46] Georgia Power is soliciting 50 MW of large-scale solar capacity to be added to the Georgia system by 2015,[47] and a solar company, National Solar Power, has announced its plans to develop a 400 MW solar power plant in Florida.[48] Florida Power and Light's existing three solar power plants generate 110 MW of clean energy for 4.5 million customers throughout the state, preventing the emission of more than 3.5 million tons of greenhouse gases--equivalent to removing 25,000 cars from the road every year.[49]

The Caribbean also has significant renewable energy resources. For example, a recent study estimated available resources for electricity production on the island of Puerto Rico (Table 2).[50] In 2010, the U.S. Virgin Islands signed a memorandum of understanding with both the U.S.

Department of Energy (DOE) and U.S. Department Interior (DOI) to establish a deployment strategy for the islands' significant renewable energy resources. The plan includes transportation, electricity generation and transmission, energy efficiency, tourism and industry, and a public education campaign.[51] As of March 2012, several utility-scale wind and solar projects were under construction in Puerto Rico, according to information provided by the Puerto Rico Energy Affairs Administration.[52]

Table 4.2. Estimated Renewable Energy Potential for Electricity Production in Puerto Rico

Renewable Resource/Technology*	Electric Energy Production Estimate MWh/year if 10% of Resource is Used to Produce Electricity	Percent of the 2006 Electric Energy Demand**
Wind	2,977,052	14.4
Ocean	16,935,360	82.2
Solar (photovoltaic)	3,900,000	18.9
Biomass – Agricultural	1,200,000 (traditional) 24,000,000 (microalgae)	5.8 to 116.5
Biomass – Waste	~90,000	0.4
Micro Hydro	2.628	0.01

*Fuel Cells were also considered in the source paper for this table, but not shown here.
**According to the Banco de Desarrollo Economico de Puerto Rico, the island had an electricity demand of 20,600,000 MWh in 2006.

Electrical Transmission System

The electrical transmission system in the SE is widely interconnected throughout the Eastern Interconnection, essentially states east of the Rockies except Texas, with more than 280,000 miles of transmission lines more than 100 kilovolts (kV). The SE grid consists of almost 110,000 miles of transmission lines above 10 kV and includes the two regional reliability corporations, SERC and FRCC (Figure 4.4).[53] As of 2009, this represented 35% of the transmission found in the Eastern Interconnection and 26% of the entire USA transmission of 372,340 miles. In 2009, approximately 8,800 circuit miles of new transmission were added to the North American bulk power system with some 2,600 miles greater than 200kV. More than 5,000 miles of that new transmission was added in the SE, particularly in Florida. The bulk transmission system (more than 100kV) is forecast to consist of over 115,000 miles by 2018 with the Eastern Interconnection totaling 296,000 miles within a national system of 407,000 miles.[54]

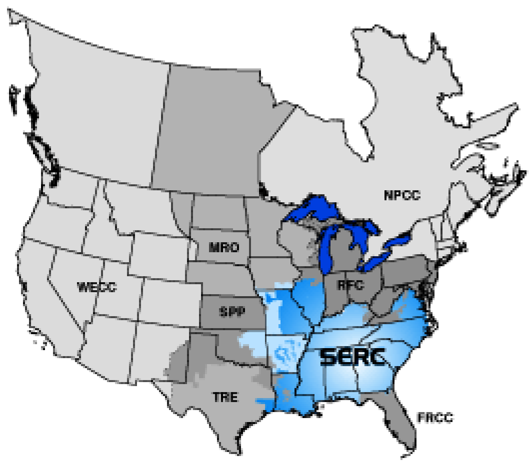


Figure 4.4. North American Reliability Corporations

Some energy sources have special transmission considerations. For example, DOE has noted that the rapid development of wind power requires substantial additions to the nation's transmission infrastructure due to the geographically-dependent nature of wind resources. The relatively low capacity factor of wind plants and the short time it typically takes to build a new wind project versus the longer time required develop new transmission infrastructure add to the challenge.[55] That said, wind energy-related projects are moving forward to provide electricity for the SE. TVA signed contracts in 2010 for more than 1,300 MW of wind energy from projects throughout the Midwest;[56] and Alabama Power, a subsidiary of Southern Company, has signed a power purchase agreement for 202 MW of wind energy from Oklahoma.[57] Pattern Energy has proposed its Southern Cross long-distance transmission project that would connect up to 3,000 MW of Texas wind farm energy to an offloading location in Northeastern Mississippi by 2016[58] and Clean Line Energy has proposed its Plains & Eastern project that would provide up to 7,000 MW of wind energy capacity from farms in Kansas, Oklahoma, and Texas to an offloading point in Memphis, Tennessee (TVA territory).[59]

Electricity Assets in the Southeast

The nation's current fleet of electric power generators has a wide range of sizes and ages. Of the nation's 1,266 coal steam electric generating units, for example, the largest (250 MW) represents 36% of the fleet and have been in service an average of 34 years. The smallest units (0 to 25 MW), which make up 15% of the fleet have been in service an average age of 45 years.[60] In the SE, there have been numerous coal fleet retirement announcements, including 269 MW at 4 units by Dominion Power; 800 MW at four Cliffside units in North Carolina by Duke Power; 1,481 MW at 14 units, also by Duke, each of which was built between 1941 and 1958. Progress Energy is retiring 11 units of 1951 to1972 vintage in North Carolina totaling 1,513 MW; Southern Company is retiring over 1,094 MW units built in the 1960s. TVA has announced plans to retire 21 coal-fired generating units in Tennessee and Alabama, totaling 3,231 MW at plants built between 1952 and 1959. In total, this represents around 8,388 MW of electrical generating capacity that will eventually be replaced with more efficient, cleaner electrical supply options.[61]

In the American Society of Civil Engineers (ASCE) *Report Card for America's Infrastructure 2009*, energy sector received a grade of D+, a grade that is consistent with other segments of USA infrastructure, such as water, roads and bridges, and transit. ASCE has noted that "while progress has been made in grid reinforcement since 2005 and substantial investment in generation, transmission and distribution is expected over the next two decades, demand for electricity continues to grow (25% since 1990) and permitting for much needed modernization has been difficult. Projected electric utility investment needs could be as much as $1.5 trillion by 2030."[62]

Energy Use in the Southeast

At approximately 27% of the USA total, the SE consumes more energy than any other NCA Region (Figure 4.5). That consumption in 2009 was dominated by the industrial sector (31%) and transportation (28%), both of which are higher than the national average. Among industrial energy consumption, Louisiana is substantially higher than other southeastern states. Residential use accounted for 23% of SE energy consumption while commercial activity consumed 18%, both of which are lower than the national average.[63] Of the southeastern states, Florida dominates in terms of consumption (Figure 4.6). It is noteworthy that among residential users, the per capita consumption of energy in the SE has risen steadily since the 1960, with southeastern residences now consuming the highest amount of energy per person of any other NCA Region (Figure 4.7).

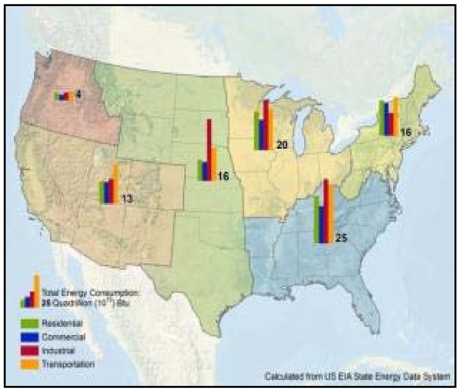


Figure 4.5. Energy consumption by NCA region.

With regard to petroleum, the SE is the largest consumer of petroleum products in the USA, with one quarter of all petroleum consumed by the region's eleven states (Table 3).[64] For example, about 28% of all motor gasoline consumed in the USA was purchased in the SE in 2009, reflecting both the high population and the number of vehicle miles traveled (VMT) in this region. It is also noteworthy that in addition to having the highest VMT among all NCA regions (Figure 4.8), the per capita VMT in the SE is also the highest.[65,66]

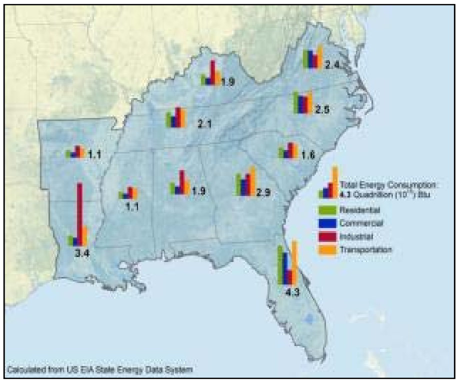


Figure 4.6. Energy consumption by state.

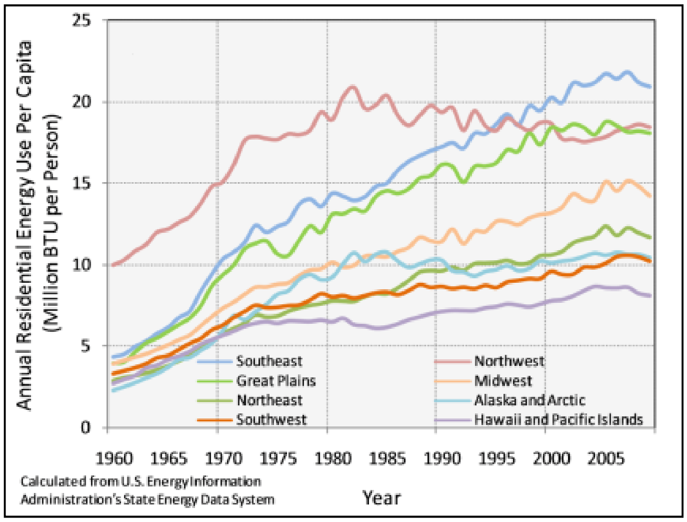


Figure 4.7. Per capita energy use by NCA region.

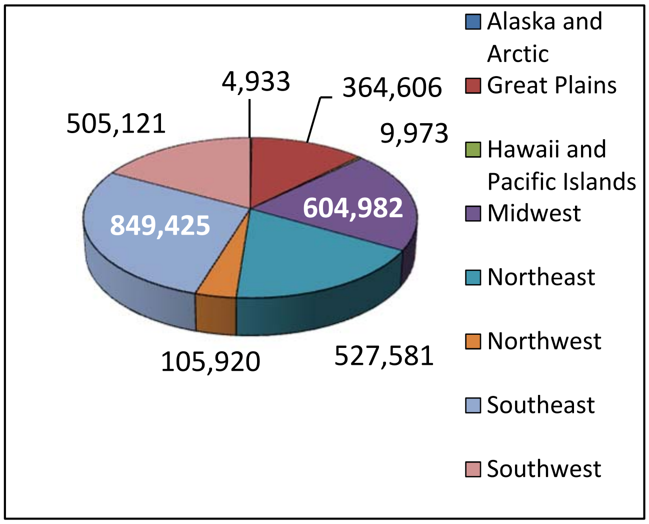


Figure 4.8. Annual VMT by NCA region (millions).

Table 4.3.
Energy Consumption Estimates for Petroleum Energy Sources in Physical Units, 2009

	Petroleum							**Fuel Ethanol[e]**
	Distillate Fuel Oil	**Jet Fuel[a]**	**LPG[b]**	**Motor Gasoline[c]**	**Residual Fuel Oil**	**Other[d]**	**Total**	
	Million Barrels							
Alabama	24.4	1.7	3.7	62.8	0.9	16.1	109.7	2.6
Arkansas	22	0.8	2.9	34.8	0.1	4.1	64.8	1.7
Florida	46.4	31.5	5.5	200.6	13.8	13	310.8	17
Georgia	38.2	18	5.4	117.8	7.3	9.4	196.1	9.9
Kentucky	27.7	9.8	8.6	53.4	0.1	25.6	125.3	4.9
Louisiana	32.7	16.1	58.5	54.7	16.4	86.2	264.6	3.1
Mississippi	19.9	4.9	3.4	37.6	0.8	9.4	75.9	2
North Carolina	31.3	1.9	12.2	105.9	2.7	11.1	165	9
South Carolina	19	1.1	2.7	65.6	2.9	12.5	103.7	5.4
Tennessee	25.2	11.2	3.3	75.4	(s)	28.6	143.8	7.6
Virginia	34.3	15.7	5.6	94.5	3	7.1	160.3	8.6
Southeast	**321.1**	**112.7**	**111.8**	**903.1**	**48**	**223.1**	**1720**	**71.8**
United States	**1325.3**	**508.5**	**748.7**	**3283.7**	**186.6**	**798.7**	**6851.6**	**262.8**
Southeast as a % of U.S. Total	**24**	**22**	**15**	**28**	**26**	**28**	**25**	**27**

[a] Includes kerosene-type jet fuel only; naphtha-type jet fuel is included in "Other Petroleum"

[b] Liquefied petroleum gases

[c] Motor gasoline as it is consumed; includes fuel ethanol blended into motor gasoline

[d] Includes asphalt and road oil, aviation gasoline, kerosene, lubricants, and the 16 other petroleum products

[e] Includes denaturant

Where shown, (s) = Value less than 0.05.

4.2 Impact of Climate Change on Energy Supply and Demand in the Southeast

Climate change is of concern for energy services in the SE due to the potential for changing patterns of demand, such as more air conditioning during warm months, as well the potential impacts on electricity generating capacity and energy distribution infrastructure. For example, concerns exist for energy supply facilities and systems in vulnerable parts of the region, such as the oil and gas supply systems along the Gulf Coast. The U.S. Climate Change Science Program has summarized this issue as follows:[67]

How might climate change affect energy consumption in the United States? The research evidence is relatively clear that climate warming will mean reductions in total U.S. heating requirements and increases in total cooling requirements for buildings. These changes will vary by region and by season, but they will affect household and business energy costs and their demands on energy supply institutions. In general, the changes imply increased demands for electricity, which supplies virtually all cooling energy services but only some heating services. Other effects on energy consumption are less clear.

How might climate change affect energy production and supply in the United States? The research evidence about effects is not as strong as for energy consumption, but climate change could affect energy production and supply (a) if extreme weather events become more intense, (b) where regions dependent on water supplies for hydropower and/or thermal power plant cooling face reductions in water supplies, (c) where temperature increases decrease overall thermoelectric power generation efficiencies, and (d) where changed conditions affect facility siting decisions. Most effects are likely to be modest except for possible regional effects of extreme weather events and water shortages.

How might climate change have other effects that indirectly shape energy production and consumption in the United States? The research evidence about indirect effects ranges from abundant information about possible effects of climate change policies on energy technology choices to extremely limited information about such issues as effects on energy security. Based on this mixed evidence, it appears that climate change is likely to affect risk management in the investment behavior of some energy institutions, and it is very likely to have some effects on energy technology R&D investments and energy resource and technology choices. In addition, climate change can be expected to affect other countries in ways that in turn affect U.S. energy conditions through their participation in global and hemispheric energy markets, and climate change concerns could interact with some driving forces behind policies focused on U.S. energy security.

In most cases, the availability of peer-reviewed published literature on these issues is quite limited, including at the regional level, although there is a broad consensus about the general vulnerabilities and risks based partly on reputable expert group assessments.

As discussed in chapter 2, the climate of the SE is variable and influenced by a number of factors, including latitude, topography, and proximity to large bodies of water. Although the SE is mostly of a humid subtropical climate type, climate characteristics such as temperature and precipitation are variable, including on a seasonable basis, across the region.

The SE region currently experiences a wide range of extreme weather events that affect human society, ecosystems, and infrastructure, including energy infrastructure. Since 1980, the SE has experienced more billion-dollar weather disasters than any other region in the USA Most of these were associated with hurricanes, floods, and tornadoes. A summary of extreme weather in the SE follows. Chapter 3 provides additional detail about historical climate trends in the SE and projections of future climate. Please see that chapter for a more complete description of the existing climate, climate trends, and climate projections for the SE, along with citations to that information.

- Heavy rainfall can produce short-lived flash floods and long-duration river floods. Major rivers in the SE, for example, the Mississippi and Ohio are susceptible to flooding, which can have an impact on transportation; utility and industrial plants; and population interests.
- Despite an abundance of moisture, the SE region is prone to drought in which deficits of precipitation lead to a shortage of freshwater supplies. Rapid population growth and development greatly increase the region's demand for water thus increasing its vulnerability to drought.
- Due to its mid-latitude location, the SE region often experiences extreme heat during the summer months and also is prone to extreme cold during the winter months.
- Winter storms, including snow and ice storms, occur most frequently across the northern tier of the SE region and have the potential to impact society, including disruption of utilities and transportation as well as school and business closings. A December 2002 ice storm, for example, resulted in more than 1.8 million customers losing power, eclipsing the previous record for power outages in the region from a single storm set by Hurricane Hugo in 1989.
- Thunderstorms are frequent occurrences across the region with damaging winds and large hail occurring most frequently across Alabama, Mississippi, Arkansas, western Tennessee, and northern Louisiana.
- The region sees the highest number of strong tornadoes (F2 and greater) and experiences more killer tornadoes than the Tornado Alley of the Great Plains.
- The greatest frequencies of lightning strikes in the USA are found across the Gulf Coast and the Florida Peninsula.
- Tropical cyclones (tropical storms and hurricanes) have contributed to more billion-dollar weather disasters in the region than any other hazard since 1980. Tropical cyclones make landfall most frequently along the Outer Banks of North Carolina, southern Florida, and southeast Louisiana. (Puerto Rico and the U.S. Virgin Islands have also had numerous major disaster declarations due to tropical storms and hurricanes.)[68,69]

In addition to extreme weather events under current climate conditions, other climate-related issues, such as sea level rise, are relevant to energy production, distribution, and use in the SE. For example, about one-third of USA refining and gas processing facilities are situated in the coastal plain of the Gulf of Mexico. Rising sea levels, which primarily result from warming ocean water and melting ice, could lead to direct loses of these assets from flooding and erosion. One response might be to raise vulnerable assets to higher ground, or build new facilities further inland at correspondingly higher transportation costs.[70,71]

The remainder of this section provides brief examples of some of the potential climate risks and vulnerabilities to SE energy production and use. As noted previously, chapter 3 of this report provides additional detail about historical climate trends in the SE and projections of future climate (along with citations for this information).

4.2.1 Climate Impacts on Energy Demand

The SE already experiences high heat and humidity, resulting in elevated heat indices, eks-2-27 in summer months with higher temperatures projected for the future. Higher temperatures raise demands for electricity to cool homes, work places, commercial spaces, and indoor recreational spaces. Urban heat island effects may further increase demands for cooling. In cooler seasons, energy demands for space warming will likely decrease, possibly reducing net annual demands for non-electricity fuels for interior heating. Overall, the net change for energy demand (cooling and heating) in the SE is expected to be an increase. This is a particular concern for lower income households in the SE that may already be unable to weatherize their homes and install and operate air conditioning systems.[72,]

For example, a 2006 analysis looked at heating energy, cooling energy, and net changes, by Region, under two climate projections. The study estimated that increases in cooling demands in the SE would be considerable even in the relatively near term for either a high or a low temperature-change scenario (Figure 4.9).[73]

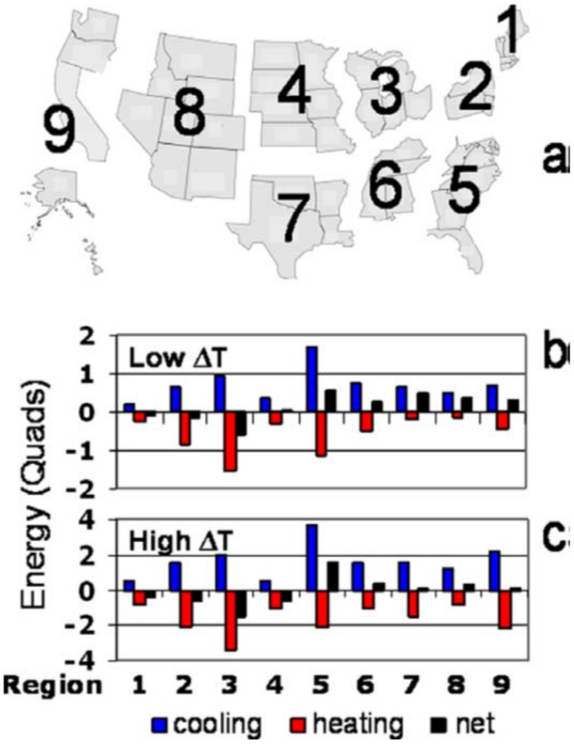


Figure 4.9. (a) The nine U.S. Census Divisions and projected cumulative (2003-2025) changes in primary heating energy, cooling energy, and net changes, as departures from the reference case, for (b) the low DT scenario and (c) the high DT scenario. The Census Divisions are: (1) Northeast, (2) Middle Atlantic, (3) East North Central, (4) West North Central, (5) South Atlantic, (6) East South Central, (7) West South Central, (8) Mountain, and (9) Pacific including Alaska and Hawaii.

Other climate effects on energy demand are less clear (e.g., lower fuel mileage from increased vehicle air conditioning use or more use of lawn irrigation systems in response to droughts). While some of these changes may not be large, they may contribute to increases in regional energy demands overall.

Climate-related demographic shifts are another consideration for energy needs in the SE. For example, the American Planning Association has noted that shifts in migration in the SE may occur in response to climate-related risks in coastal areas and rising heat indexes.[74] Such shifts in population and economic activities would change patterns of energy demand within the region.

4.2.2 Climate Impacts On Energy Production And Distribution (Supply)

Critical SE regional infrastructure, such as energy, transportation, and hospitals, already experience the effects of extreme events such as floods, hurricanes, high ambient temperatures, and tornados. Damage to these assets can cause disruption of services lasting from days to months.

Of these risks, one which has received substantial attention in recent years is coastal infrastructure exposure to hurricanes, sea-level rise, and land subsidence along the Gulf Coast.[75] In the near term, the effects are risks of major temporary disruptions in energy supply activities, including both coastal and offshore facilities, involving oil/gas systems as well as electricity production systems. Over the longer term, effects could include increased capital expenditures to harden existing facilities, build more robust new facilities, or move facilities and activities to less vulnerable locations.

Case Study: Browns Ferry Nuclear Plant

Browns Ferry Nuclear Plant is on the north shore of Wheeler Reservoir in north Alabama and was the largest in the world when it opened in 1974. It was also the first nuclear plant in the world to generate more than 1 billion watts of power.

Browns Ferry has had to operate at reduced power production for significant periods of time during hot summer months and low water flow conditions in order to maintain the plant discharge within environmental limits. In 2010, for example, existing climate conditions resulted reduced plan operations that resulted in $50 million in additional costs to TVA customers.

TVA is currently working on a project to expand their cooling tower capacity in order to continue operating during high river temperatures.

http://www.tva.gov/sites/brownsferry.htm
http://www.tva.gov/abouttva/board/pdf/11-4-2010_board_final.pdf

The impact of existing climate factors on oil and gas production and refining was demonstrated in 2005 when hurricanes Katrina and Rita hit the Gulf. Figure 4.10 shows the large magnitude of impact and slow recovery of production following the two storms (note that Katrina made landfall on Day 1 and Rita on about day 28).[76] To put these numbers into a national perspective, Katrina alone resulted in the shut-in of more than 95% of offshore Gulf crude oil production, approximately 27% of total U.S. crude production. This local domestic production could not be rapidly replaced by imports since major oil import terminals were also interrupted, resulting in an estimated 32% reduction of total USA crude oil import capacity. In addition, Katrina and Rita forced the shutdown of about 32 refineries representing a loss of up to 26% of USA refining capacity. According to the Federal Trade Commission, these interruptions were largely responsible for

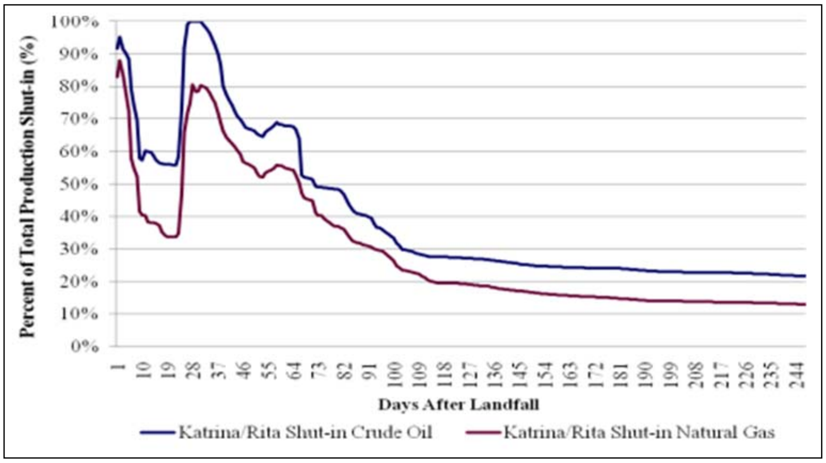


Figure 4.10. Time history of offshore oil and gas production in the Gulf following Katrina and Rita.

gasoline price increases of about 17%, increases which did not disappear until several months after the storms.[77]

Based on climate projections discussed in the chapter 2, other potentially important considerations for certain areas of the SE may include (a) increased droughts that reduce the availability of water for power generation; (b) higher temperatures, particularly during summer months, that cause electricity demands to rise over periods that are long enough to exceed supply and that could jeopardize electricity availability; (c) reductions in thermal power plant capacities due, for example, to higher water temperatures (see the Browns Ferry case study above); and (d) possible effects on renewable energy beyond hydropower, such as biopower, are generally thought to be more sensitive to climate variability than fossil or nuclear energy systems).[78,79]

4.2.3 Indirect Effects of Climate Change on Energy Production and Use

Climate change may have important indirect implications for energy supply and use. Indirect effects may include impacts on specific economic sectors that, in turn, may have implications for energy supply and demand. Other areas of potential indirect effects include energy technology development and choice, energy prices, and energy security.[80] The following discussion illustrates this concept using agricultural and tourism energy needs in the SE as examples.

For any crop there is an optimum range of environmental conditions relative to maximum yield. Most crops cultivated in the SE are at, or near, their optimal growing temperatures for the CO_2 and water conditions that currently prevail. A rise in temperature and CO_2 concentration in the SE is expected to have a direct effect on the agricultural yield and may, consequently, have an impact on related energy needs.

Specifically, warmer temperatures will speed annual crops through their developmental phases but at a cost of increased water requirements and lower grain number, size, and quality.[81] Increased water requirements result in greater water pumping and transportation needs, all at a significant energy cost. Periods of drought may necessitate additional irrigation, further increasing electric pump loads. Overall, the southern tier of the SE is expected to increase its need for irrigation water whereas the northern tier is expected to decrease its relative need, with expected increased energy and decreased energy demands, respectively. [82]

Similar to crops, the effects of climate change on livestock are likely to be variable, based on the magnitude of temperature rise, animal feed prices, and the cost of electricity for cooling. Dairy cows, for example, produce milk at an optimum temperature of between 40°F and 75°F. Areas with increasing temperatures will consequently pose a cooling issue for livestock owners.[83]

Another SE economic sector that has an important link to energy is tourism, a complex and multifaceted industry that includes a variety of operating sectors such as transportation, accommodations, food service, attractions and events, and outdoor recreation. Within the 11 state NCA SE region, tourism spending exceeds $181 billion, including $28.6 billion in tax receipts, and over two million jobs with a payroll of $48 billion.[84,85]

The important connection of tourism to energy is illustrated by vacation rentals which, in 2007 in the USA, represented a $24.3 billion market, equaling more than 22% of the USA hotel market and 8% of the entire travel and tourism market. The vacation rental market is particularly strong in the south Atlantic region where fully one-third of the nation's vacation accommodations were rented in just three states: 22% in Florida, 7% In North Carolina and 5% in South Carolina.[86]

Each year, the average energy expenditure on American hotel rooms is $2,196, representing about 6% of all operating costs.[87] This relatively high level of energy consumption, along with water consumption, waste levels, and the use of potentially hazardous chemicals, has made this industry a focus of pollution prevention efforts. As such, the availability, type, and cost of energy, and its associated greenhouse emissions, are important considerations for the climate change issues and the tourism sector in the SE.

4.3 Key Issues and Uncertainties

The U.S. Climate Change Science Program has articulated a core set of research priorities to better understand the relationship between energy and climate change.[88] In general, the areas of research articulated at the national level are equally relevant to the SE USA and are briefly reiterated here.[89]

- Improved capacities to project climate change and its effects on a relatively fine-grained geographic scale, especially of precipitation changes and severe weather events;
- Research on and assessments of implications of extreme weather events for energy system resiliency, including strategies for both reducing and recovering from impacts;
- Research on and assessments of potentials, costs, and limits of adaptation to risks of adverse effects, for both supply and use infrastructures;
- Research on efficiency of energy use in the context of climate warming, with an emphasis on technologies and practices that save cooling energy and reduce electrical peak load;
- Research on and assessments of implications of changing regional patterns of energy use for regional energy supply institutions and consumers;
- Improvements in the understanding of effects of changing conditions for renewable energy and fossil energy development and market penetration on regional energy balances and their relationships with regional economies;
- Attention to linkages and feedbacks among climate change effects, adaptation, and mitigation; to linkages between effects at different geographic scales; and relationships between possible energy effects and other possible economic, environmental, and institutional changes.
- Improving information about interactions among water demands and uses where the quantity and timing of surface water discharge is affected by climate change;

- Improving the understanding of potential climate change and localized variability on energy production from wind and solar technologies;
- Developing strategies to increase the resilience of coastal and offshore oil and gas production and distribution systems to extreme weather events;
- Pursuing strategies and improved technology potentials for adding resilience to energy supply systems that may be subject to stress under possible scenarios for climate change;
- Improving understandings of potentials to improve resilience in electricity supply systems through regional intertie capacities and distributed generation; and
- Research on and assessments of the impacts of severe weather events on sub-sea pipeline systems, especially in the Gulf of Mexico, and strategies for reducing such impacts.

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[1] The Southeastern U.S. does not have an official U.S. Census delineation and varies in boundary as expressed by different entities related to the energy sector (see NREL, EIA, SEEA, NERC, and other organizations as examples). Sometimes Florida is recognized independently from the rest due to its size. Sometimes, but not always, Virginia and/or Missouri are included. For purposes of this chapter, the Southeastern U.S. is comprised of Alabama (AL), Arkansas (AR), Florida (FL), Georgia (GA), Kentucky (KY), Louisiana (LA), Mississippi (MS), North Carolina (NC), South Carolina (SC), Tennessee (TN), Virginia (VA), Puerto Rico, and the U.S. Virgin Islands. Unless otherwise note, the statistics presented are focused on the 11 continental states.

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[3] U.S. Energy Information Administration, Petroleum Explained Data Tables, accessed 12/14/11, http://www.eia.gov/energyexplained/index.cfm?page=oil_home#tab2

[4] http://www.nrel.gov/applying_technologies/state_local_activities/state_data_book.html

[5] http://www.nrel.gov/applying_technologies/state_local_activities/state_data_book.html

[6] http://www.nrel.gov/applying_technologies/state_local_activities/state_data_book.html

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[9] See www.eia.gov and www.nrel.gov for data on energy statistics for the United States.

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[89] Note that these important areas for further evaluation are not meant to be a comprehensive list.

5 Climate Interactions with the Built Environment in the Southeast USA

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5.1Introduction

In this report, the “built environment” refers to the part of the overall landscape that is distinct from the natural environment, that part where humans have in some way transformed or imprinted non-natural features across the landscape. The built environment consists of components that have been made by humans at a range of scales from small (such as offices, houses, hospitals, shopping malls, and schools) to large (such as transportation networks and communities) to highly modified landscapes such as cities (Younger et al. 2008). The impacts of climate change on the built environment, therefore, may have a multitude of effects on humans and the land. The impact of climate change may be exacerbated by the interaction of different events that singly may be minor, but together may have a synergistic set of impacts that are significant. Also, there may be feedback mechanisms wherein the built environment, particularly in the form of cities, may affect weather and the climate on local and regional. This section of the technical report focuses on the potential impacts that climate change likely will have on several key aspects of the built environment in the southeastern USA: air quality; the urban heat island effect; precipitation; urban flooding; urban forestry and the urban-wild land interface; tourism; energy, poverty, and socio-economic vulnerabilities; and urban migration. There are significant and definitive ways to mitigate and/or adapt to the effects of climate change on the built environment. The key to successfully implementing such strategies is to educate policy and decision makers, planners, and the general public.

The impact of climate change on urban areas in the USA can potentially have far-reaching effects on the local and regional environment and in cities and their adjacent surroundings, sometimes referred to as the “periurban” environment. These impacts likely will affect the atmosphere above and around cities through alteration of the physical parameters that govern the land-atmosphere interface over urban areas. In turn, this may have broader impacts on atmospheric phenomena and regional interactions that encompass large-scale physical and environmental processes. Feedback mechanisms in urban areas have potential effects on physical parameters and interactions that can influence local and regional meteorology, and, in the long-term, the climate (World Bank 2011, Lankao 2011). Three impacts are of concern: (1)

degradation of air quality; (2) an increase in the size and extent of the urban heat island (UHI) effect; and (3) changes in precipitation, including increases or decreases in amount or intensity.

It must also be mentioned here that the impacts of climate change on built environments in the Southeast (SE) will have a collective impact on the overall urban ecosystems for cities in the region. An urban ecosystem can be defined as a composite of (1) the natural environment, (2) the built environment, and (3) the socio-economic environment (Clark 2008). This chapter describes some of the key impacts that climate change will have on the urban ecosystems of the SE. The urban ecosystem is complex, encompassing interactions that occur between the urban atmosphere (e.g., urban-atmosphere interrelationships); the urban biosphere (e.g., vegetation, animal life); urban hydrosphere (e.g., water use); the urban lithosphere (e.g., soils/bedrock); and the urban fabric, of which the built environment is a fundamental part. Thus, the exchanges that occur within the urban ecosystem are highly intermingled wherein the disruption of one of the key elements can have cascading impacts throughout the entire ecosystem. How climate change may impact the built environment via alteration of inputs and outputs to the urban ecosystems in the southeastern USA are described in this section and threaded throughout the various chapters in this report. Moreover, the National Climate Assessment (NCA) technical report, *U.S. Cities and Climate Change: Urban Infrastructure, and Vulnerability Issues,* has as its foundation, the assessment of how climate change will impact urban ecosystems in the USA, including extensive examples on impacts specific to SE, and has one chapter dedicated entirely to ecosystems and the built environment" (Chapter 3.6).

Many of the examples of how climate change will affect the built environment are focused on the Atlanta, GA, metropolitan area only because several contributors to this report have extensively investigated key climate change impacts within this geographical area. The examples given in this section provide insight into how climate change will impact specific elements relevant to Atlanta in order to identify how key impacts will affect the largest urban/built environment within the SE. This certainly is not to the purposeful exclusion of examples for other cities across the southeastern USA, particularly those located on the Atlantic and Gulf of Mexico coasts. Many of the impacts that will affect coastal and inland cities in the southeastern USA are described in other sections of this report, as well as in the NCA technical reports on U.S. Cities and Climate Change: Urban, Infrastructure, and Vulnerability Issues, and Climate Change and Infrastructure, Urban Systems, and Vulnerabilities.

5.2 Air Quality

Air quality in the SE particularly over cities, is currently problematic and is projected to be so in the future (Stone 2008, Forbes 2011, TNGE 2011). Weaker global atmospheric circulation and increased temperatures contribute to more stagnant air in many regions (Millstein and Harley 2009). An observed correlation between surface ozone and temperature in polluted regions suggests a detrimental effect of warming (Stillman and Samson 1995; Jacob and Winner 2009; Stone 2011). Studies of global climate models (GCMs) coupled with chemical transport models (CTMs) show that climate change alone will increase summertime surface ozone in polluted regions by 1 to 10 ppb over the coming decade, with the largest effects in urban areas and during pollution episodes (Jacob and Winner 2009). In addition, course particulate matter also contributes to air pollution. Particles with diameters between 2.5 and 10 micrometers are referred to as “coarse.” Sources of coarse particles include crushing or grinding operations, and dust from paved and unpaved roads. Other types of particles may be formed in the air from chemical changes that are indirectly formed when gases from burning fuels react with sunlight and water vapor. These can result from fuel combustion in motor vehicles, at power plants, and other industrial processes (EPA 2011). GCM-CTM studies illustrate that increased temperatures likely will affect particulate matter in polluted environments by $\underline{+}0.1\text{-}1\ \mu g\ m^{-3}$ over the coming decades (Jacob and Winner 2009).

The effect of increased temperatures on particulate matter, however, is more complicated and uncertain than are the effects on ozone. Ozone (O_3), which is emitted at ground level, is created by a chemical reaction between oxides ($NO_{x)}$ and volatile organic compounds (VOCs) in the presence of sunlight (Figure 5.1). Motor vehicle exhaust and industrial emissions, gasoline vapors, and chemical solvents also contribute to ozone formation. Sunlight and hot weather cause ground-level O_3 to form harmful concentrations in the air. Peak O_3 levels typically occur during hot, dry, stagnant summertime conditions that are exacerbated by the urban heat island effect. The length of the ozone season varies from region to region. Southern and southwestern cities may have an ozone seasons that last for several months.

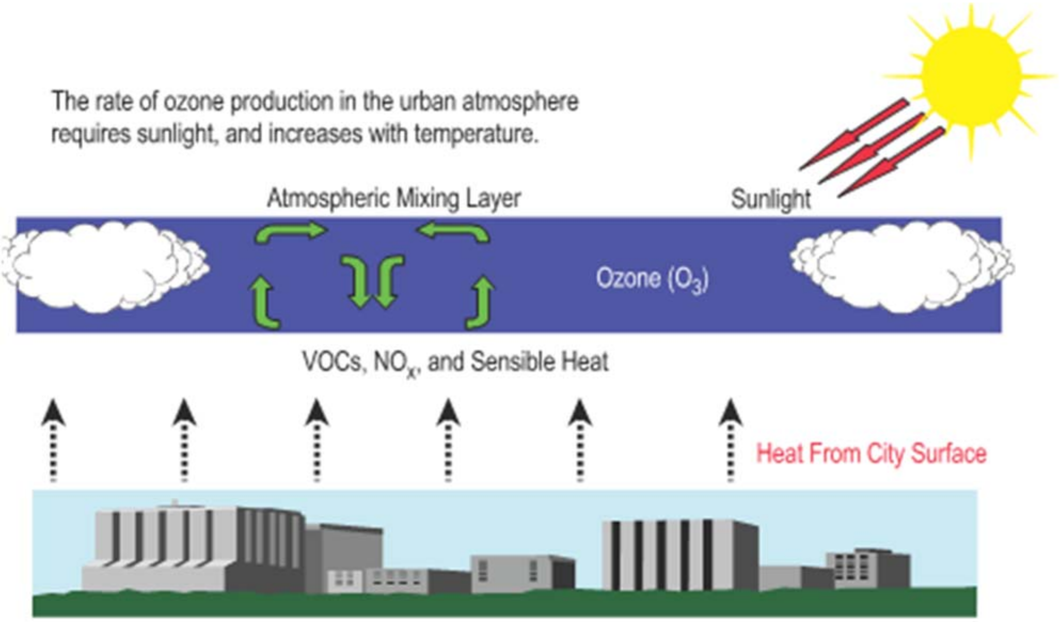

Figure 5.1. Ozone formation in the urban atmosphere (from Quattrochi, et al., 2006).

5.2 The Urban Heat Island Effect

The urban heat island effect is the term used when temperatures in urban environments surpass those seen in the surrounding rural areas. (Landsberg 1981). The most significant effects have been observed in mid-latitude urban centers where the difference in temperatures is typically 2°C to 3°C or more higher than surrounding rural areas (Oke 1987). Initial research on urban heat island issues has been on large megacity environments such as Mexico City (Oke et al. 1999) and New York City (Jin et al. 2005). However, temperature increases have also been observed in midscale urban areas such as Atlanta and other major urban centers in the southeastern USA (Stone 2007).

As urbanization continues and forest, agricultural, and natural open lands are consumed as part of urban growth, changes in land cover around cities lead to an urban heat island, which exists as a dome of elevated air temperatures over cities as a result of transition from pervious to impervious surfaces increases (Landsberg 1981; Voogt 2002; Souch and Grimmond 2006; Grimmond 2007; Weng et al. 2004; Liu and Weng 2008). Development of the UHI is forced by a number of causes related to the land and atmosphere interactions that occur over cities. These include surface geometry, surface thermal properties, surface conditions, anthropogenic heat, and the urban greenhouse effect (Voogt 2002). Research using historical meteorological and satellite data illustrate that the UHI size and dimension is associated with urban growth (Oke 1973, Remar 2010, ELI 2011). This trend is expected to continue in cities in both developed and developing countries (Goldman 2004, Dodman 2009, Zhang et al. 2011, Zhou 2011, Peng et al. 2012). Moreover, it is becoming clear that the amplitude of thermal intensity of the UHI has an effect on biomes surrounding cities (Imhoff et al. 2011). As cities continue to grow, more research will be required to determine how cities will affect and be affected by climate changes locally and regionally.

The most comprehensive study of urbanization and climate change in the USA focuses on 50 of the most populous metropolitan regions, including 13 cities in the SE. Through this study, monthly temperature records dating back to the 1950s were obtained for urban and proximate rural weather stations to assess the extent to which the UHI effect has increased in these regions over time. Urban temperature trends in the majority of the cities studied had increased at a rate of 0.31°C per decade compared to a rural rate of increase of 0.12°C per decade. These findings suggest that most large USA cities are warming at a rate more than double that of the planetary warming rate (Stone 2007).

Studies of temperatures in Atlanta, GA, show typical UHI effects characterized by differences in nighttime temperatures, which represent the main difference in heat loads, due primarily to increased heat trapped by various gases that were at higher levels in the lower nighttime boundary layer (Zhou and Shepard 2010). These higher levels of gases were due to increased energy use, such as air conditioning and motor vehicle traffic in the urban area. In addition, the emission of reactive biogenic hydrocarbons from conifers and deciduous trees in nearby forested areas interacted with nitrogen oxide emissions in the urban area to form ozone, which like nitrogen dioxide, is a potent heat-trapping gas. Increases in regional background levels of ozone have been a major issue in the SE USA, particularly in urban centers such as Atlanta and Knoxville, which are located near heavily forested regions (Stone 2007 and 2008).

The increased pace of warming in urban environments in the USA is likely to amplify the intensity of heat waves in the present period as well as enhance the magnitude of future warming trends. For example, recent studies have found the UHI effect is contributing to the increasing number of extreme heat events in SE cities (Stone, Hess, and Frumkin 2010), as well as to an amplification of heat-wave events in large cities such as Atlanta (Zhou and Shepherd

2010). Increased rates of extreme heat are more evident in sprawling cities than in more spatially compact urban areas--a relationship that is independent of where the city is located from a climate perspective, metropolitan population size, or rate of population growth (Stone et al. 2010). Another study has pointed to the likelihood that global heat waves of the future will be more intense, greater in frequency, and longer lasting (Meehl and Tebaldi 2004).

Urban-scale climate change suggests potential for health threats associated with extreme heat events. Methods to mitigate the UHI effect are necessary to abate such threats. Modeling as well as experimental studies have found land-use strategies, such as the enhancement of urban tree canopy and surface albedo, measurably slow warming trends when implemented extensively throughout urbanized regions. Over the last two decades, a large number of studies have found that variable combinations of tree planting and vegetative cover, albedo enhancement, and reductions in waste heat emissions reduce urban temperatures by a minimum of 1°C to more than 6°C (Kikegawa et al. 2006, Lynn et al.2009;, Rosenzweig, Solecki, and Slosberg 2006; Taha 1997; Zhou and Shepherd 2010). Of the various approaches to heat island mitigation, tree planting and other vegetative strategies where water resources are sufficient are generally found to be the most effective. . Surface reflectivity and waste heat management typically account for somewhat lower reductions of near surface air temperatures, depending upon the spatial extent of coverage and the regional landscape type (Akbari and Konpacki 2005; Hart and Sailor 2009; Lynn et al. 2009; Zhou; Shepherd 2010).

Many synergies exist between strategies designed to control greenhouse gas emissions and strategies designed to mitigate the urban heat island effect. For instance, a direct cooling of the ambient air through vegetation and albedo enhancement carries benefits for reduced energy consumption in the summer. While such strategies may serve to increase energy consumption during winter heating, studies have found the net benefits of reduced cooling for greenhouse emissions to be greater for mid- to low-latitude settings, a geographic region encompassing most large cities in the USA (Akbari, Konopacki, and Pomerantz 1999). When implemented extensively throughout a metropolitan region, such approaches have been shown to reduce energy consumption by as much as 10%, suggesting the potential for emission reductions and surface heat abatement to be managed concurrently (Akbari, Pomerantz, and Taha 2001).

5.3 Effects on Precipitation

While urban heat islands and urban air pollution are fairly common in the public and scientific vernacular, the “urban rainfall effect” (Shepherd et al. 2010a) is not. Yet, the literature is fairly conclusive on urban land cover and pollution altering components of the hydroclimate, such as clouds, precipitation, and surface runoff. Historical perspectives, global confirmation of urban precipitation effects and societal implications are discussed in Ashley et al. 2011, Shepherd et al. 2011, Niyogi et al. 2011, Shepherd et al. 2010b. We present a few examples here with relevance to the SE region.

Ashley et al. (2011) conducted a climatological synthesis of how the urban environment modifies convection in various cities in the SE. Researchers used lightning and high-resolution radar to study precipitation in the cities and adjacent control regions over a 10-year period

(June through August). The results confirmed positive urban amplification of thunderstorm activity (frequency and intensity) for larger SE cities such as Atlanta. Figure 5.2 illustrates that Atlanta's convective frequency counts and occurrences slope from the central business district to relatively lower values in rural areas, a conclusion that is consistent with numerous findings in the literature. Results vary as a function of size and geometry of various cities.
On the other hand, Rosenfeld et al. (2008) discussed the apparent conflicting role of aerosols in the precipitation processes. Aerosols may enhance or suppress convection under certain atmospheric conditions. While research into urban aerosol effects on precipitation has been conducted globally (Lin et al. 2011, Stjern et al. 2011, Jin and Shepherd 2008), more research is required in the USA. Although uncertainty remains regarding supporting details driving change in precipitation, the literature conclusively confirms the influence of the built, urban environment on precipitation. Both observational and numerical modeling research (Shepherd et al. 2010b) have indicated that one or a combination of the following process contribute to urban precipitation effects: (1) atmospheric destabilization related to the heat island and thermal mixing (2) enhanced convergence from building-induced mechanical turbulence and mixing, (3) modified dynamic and microphysical processes related to urban aerosols, and (4) bifurcation-physical modification because of physical or thermodynamic barriers. Research must continue to extract the relative contributions of these processes while considering other factors such as topography, urban geometry, seasonality, diurnal effects, and moisture.

While the urban rainfall effect is an important scientific issue in its own right, there are also vital connections of this effect on contemporary research and prediction problems in climatology, meteorology, hydrology, and geographic systems. Precipitation issues in a built, urban environment present significant challenges for key societal processes and potential vulnerabilities related to urban flooding, urban planning, public health, water resources, agricultural systems and hazard management. Some of these are discussed in the following sections.

5.3.1 Urban Flooding

The International Panel on Climate Change (IPCC) notes that instances of hydrological extremes such as flooding and drought have increased markedly in the last three decades with more intense and longer episodes (Trenberth et al. 2007). Analysis by NOAA's National Climatic Data Center (NCDC) suggests that in the SE an increasing trend is detectable in the extreme precipitation record (Figure 5.3). Increased urban flooding has been noted in several global regions including SE cities such as Atlanta and Nashville. The southeastern USA will be increasingly vulnerable to extreme hydroclimate events because of increasing populations and population density (Seager et al. 2009). While many urban-related floods are explained by large scale meteorological and hydrological forcing (Shepherd et al. 2001), it is also clear that an urban environment may modify or increase the likelihood of flooding. Ntelekos et al. (2007) suggested that urban land cover and aerosols may have assisted in the meteorological set-up for a flood event in the Baltimore-Washington, DC, area. Shepherd et al. (2011) speculated that the urban landscape, through urban-enhanced precipitation, discussed elsewhere in this report, could have explained various regions of enhanced flooding around Atlanta during the historic

North Georgia floods of 2009 (Figure 5) even as large scale hydro-meteorological processes governed the main flooding event.

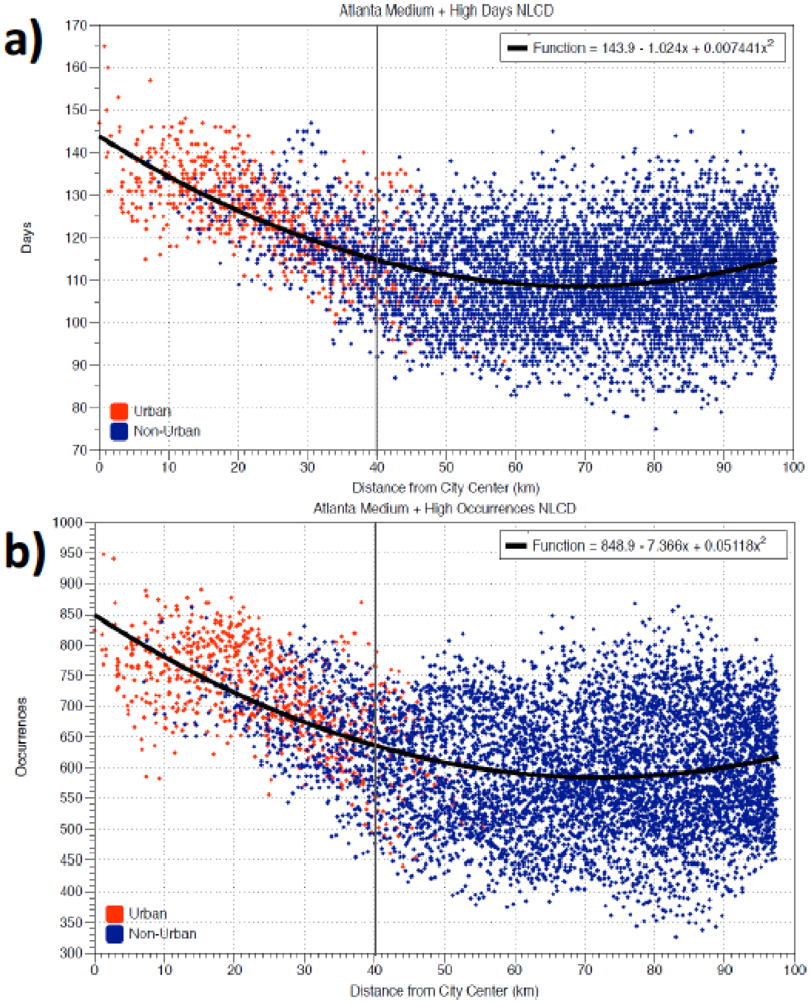

Figure 5.2. Composite radar analysis for Atlanta, GA: (a) The total number of days ≥ 40 dBZ and (b) the total number of 5-minute occurrences ≥ 40 dBZ for each 2-km grid cell versus distance from city center in the Atlanta domain for the 10-year, June through August. NLCD urban delineated cells are colored red, whereas nonurban cells are blue. Source: Ashley et al. 2011).

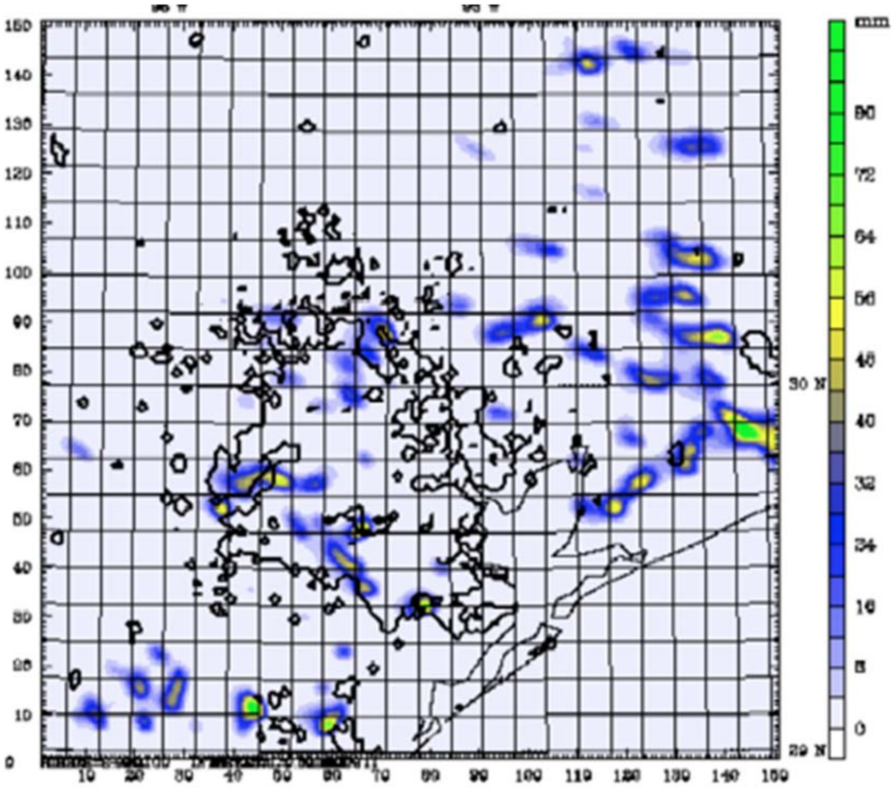

Figure 5.3. Difference (2025 Current Land Cover) in simulated rainfall amount for a typical case day in Houston, Texas. Black outline represents 2025 urban land cover. Rainfall amounts illustrated in the image correspond to the bar graph on the right hand side of the figure. (Shepherd et al. 2010).

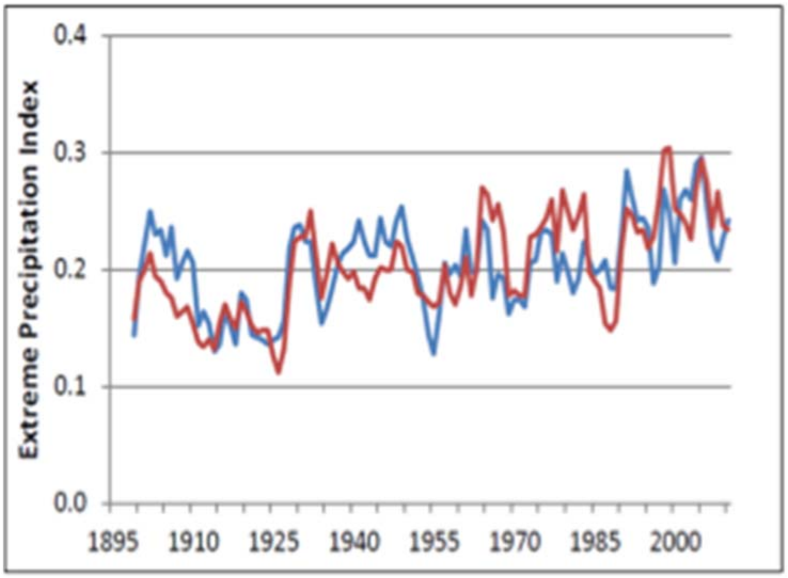

Figure 5.4. Trends in the extreme precipitation index for the southeastern USA. Red line is 1 day, 1 in 5-year event. Blue line is 5-day, 1 in 5-year event. Source: K. Kunkel (2012).

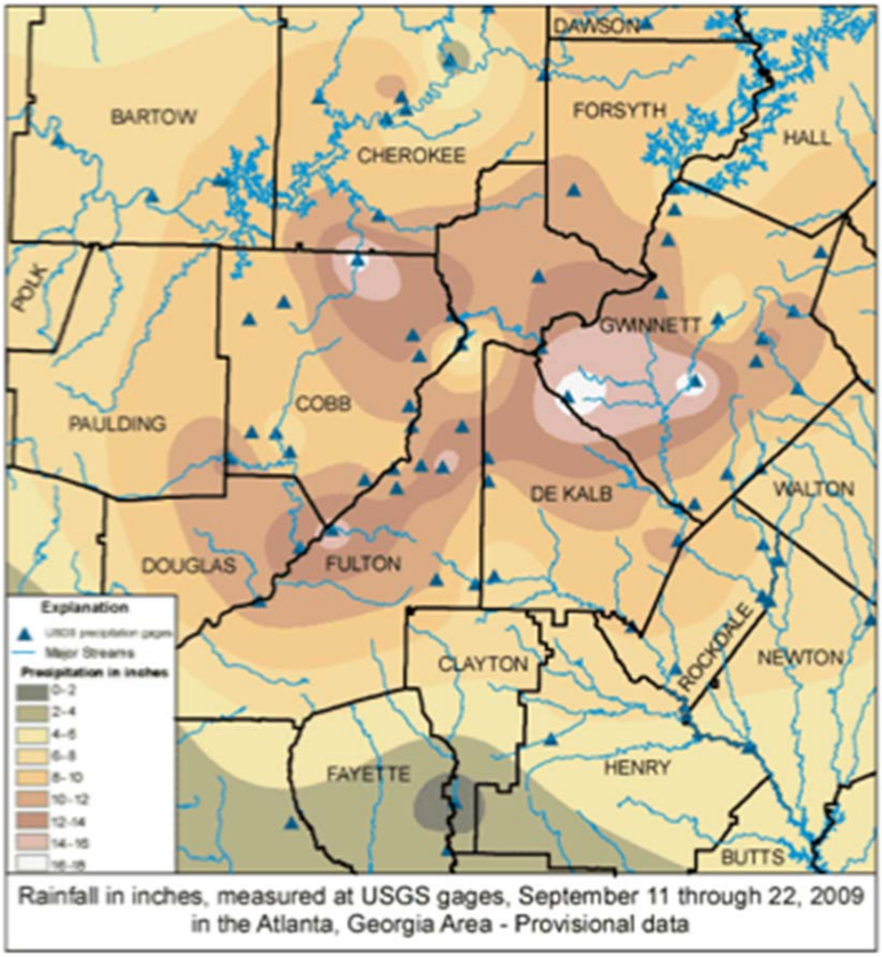

Figure 5.5. Flood totals from the Atlanta floods of 2009. Note the areas of significantly higher rainfall in Gwinnett and Cobb counties (right and upper middle side of the figure, respectively) (USGS 2009).

The conversion of natural landscapes to built, urban environments changes various water cycle components including evapotranspiration, surface runoff, infiltration, precipitation, and groundwater recharge. In discussing the Atlanta floods, Shepherd et al. (2011) noted that urban impervious surfaces increased the land surface hydrological response in Atlanta in a similar manner observed in other urban locations. They document that previous studies have noted the role that the urban environment has on the hydrologic cycle, including runoff, infiltration, evapotranspiration, and precipitation. Reynolds et al. (2008) found that impervious surfaces in Houston distributed stormwater to conveyance systems with more volume over a shorter amount of time, which increases the risk of overwhelming the capacity of the system.

Urban areas are increasingly affected by the complex hydrometeorological-urban interactions. Scholars and stakeholders are beginning to question whether urban planners have properly considered shifting precipitation regimes (intensity and/or frequency) associated with urban hydroclimate changes, land use changes and expanding areas of impervious surfaces, and climate change (Burian et al. 2004). Hydrometeorological scientists have warned that current urban flood assessment is based on outdated assumptions concerning rainfall intensity, frequency, and stability. Modeling tools and methodologies must be updated with current data that reflect changing urban landscapes, population density, and climate predictions in order for mitigation and adaptation plans to be successful.

Hydrological modeling systems are important tools for assessment and prediction of hydrological flows (Poelmans et al. 2010). Urban impervious surface areas and morphological parameters are represented in such models using various technologies, such as remote sensing, aerial photography, high resolution optical imagery, and LIDAR (Jacobson 2011). However, Coon and Reddy (2008) noted that hydrological modeling still suffers from uncertainties related to input precipitation data, calibration errors, assumptions and parameterizations, land cover classification errors, and catchment scale-transfer errors. Mitigation of such errors is required as increasingly complex urban landscapes and processes become explicitly represented in models.

Weather, climate, and hydrological systems are linked. Researchers and stakeholders must work collaboratively to understand what aspects of and in what ways the built environment modifies water cycle processes.

5.4 Effects on the Wild Land-Urban Interface (WUI)

The population of the SE is increasing at one of the fastest rates in the USA (U.S. Census Bureau 2010)). As a result there are unique forest-management challenges associated with climate change and population interactions. Land managers are developing adaptation and mitigation strategies, but the implementation of these plans could be significantly hampered by ownership fragmentation associated with population growth. Historically, private landowners controlled large parcels of forest land, but the size of these ownerships has been steadily decreasing for decades (Wear and Greis 2002). As the parcel size decreases below levels that are commercially viable to manage, the cost and complexity of management increases and activities such as wild-fire fuel reductions, selective harvesting to encourage more climate-change adaptive species such as hickory and oak, or the removal of trees in insect outbreak areas are less likely to occur (Wear and Greis 2002). Increased drought events (Seager et al. 2009), longer insect breeding seasons (Ayres and Lombardero 2000), and increased potential for hurricanes (Mann and Emanuel 2006) could synergistically combine with reduced management options to significantly reduce forest health (McNulty and Boggs 2010).

In addition to the challenges associated with managing SE ecosystems, urban and WUI dwellers will likely face new challenges associated with climate variability. General circulation models universally predict increasing air temperature and increases or decreases in precipitation across the region (see Chapter 2). As air temperature increases, forest water use increases. Given that forests represent approximately 40% of the total land area within the SE (Fry et al. 2009), future forests may provide less water for metropolitan areas even if precipitation increases (Sun et al. 2008). While the southeastern USA is considered a “water rich” region, water limitations in metropolitan areas could impact current and future economic development (Apex 2012) . As with other areas of the country, water disputes have already caused intense legal battles in the SE. Most notable is the cross-state dispute that formed around Atlanta’s population increases subsequent draw-downs of water Lake Lanier, which affects flow into the Chattahoochee River, which serves the neighboring states Alabama and Florida. As a consequence, there has been sustained litigation against Georgia by these neighboring states. (Moore 1999, Governing 2010, The Economist 2010).

Climate change may also affect recreational activities due to altered ecosystems and unusual weather patterns, extreme weather events, and fire. Fisheries may decline, adequate snow for winter sports may decrease, and inclement weather might keep people from enjoying outdoor activities (Wear and Greis 2002, Scholze et al. 2006, Dale et al. 2001)~~.~~

Despite being affected by climate change, urban and WUI areas also have the potential to help mitigate these effects. Heavily wooded SE cities provide plenty of trees that cool the air through evapotranspiration and sequester carbon dioxide in their trunks as they grow. City parks, lawns, and green spaces have the potential to sequester carbon when properly managed and might become climate change regulators as urban land managers learn how to utilize the unique conditions present in urban and WUI ecosystems.

5.5 Vulnerability and Risks to Tourism

Tourism is a complex and multifaceted industry that includes a variety of operating sectors such as transportation, accommodations, food service, attractions, entertainment, events, travel trade, tourism services, and adventure and outdoor recreation. In the USA as of 2010, business and leisure travel accounts for $758.7 billion of travel expenditures, $188.4 billion of travel-generated payroll and 7.4 million jobs, $117.6 billion of travel-generated tax revenue, and $31.7 billion of travel trade surplus. International travelers paid a total of $31.3 billion to domestic air carriers on international passenger fares, with additional spending on international passenger fares totaling $134.4 billion (US Travel Association 2010a). Tourism spending in the SE exceeds $181 billion in sales, garner $28.6 billion in tax receipts, and create 2.06 million jobs with a payroll of about $48 billion (US Travel Association 2010b).

Climate change is likely to create distinct and unique vulnerabilities in the tourism industry in the southeastern USA. Potential impacts to the SE include droughts, floods, water quality problems, sea level rise, storm surge, heat stress, poor air quality, extreme weather events, increases in heavy downpours, rising temperatures, lengthening growing seasons, and alterations in river flows (USGCRP 2009). The effects of climate change likely will affect consumer travel tourism and potentially create new markets while collapsing others (Scott and Lemieux 2009). Coastal areas that rely on tourism will likely experience the effects of climate change in a variety of ways from ecosystem stress and habitat loss to saltwater intrusion, drought, and flooding. Direct economic losses may include higher insurance costs, lower property values, and a decrease in tourism. However, local or regional factors, such as projected changes in population and economic growth, as well as specific weather events, may cause some these direct economic losses (Bin et al. 2008).

Tourism and attendant recreational sectors must react to changing climate with various adaptations that might include, for example, less water available for golf courses, water-saving measures for the hospitality industry, or changes in a business model for ski slopes. (Curtis et al. 2011). As noted by Scott and Lemieux (2009), climate change will constitute an increasing risk for tourism operators in many destinations. Many tourism activities are heavily dependent on the climate and insurance policies that are increasingly affected by natural hazards.Thus, accurate weather information and forecasting of extreme climatic events are becoming ever more important for tourism busineses (Scott and Lemieux 2009.

5.5.1 Vacation and Second Homes

Vacation and second homes are a substantive part of the built environment highly susceptible to the effects of climate change in the SE. These properties are most often found in coastal or mountain environments that are highly desirable places to live and vacation due to their natural beauty and recreational amenities (Long et. al 2012). The 2010 U.S. Census Data for General Housing Characteristics reports more than 1.4 million housing units in the “Seasonal, Recreational or Occasional Use” category across the 11-state SE region, representing just over 4% of the housing stock (General Housing Characteristics, 2011). Collateral expenditures increase the value of vacation and secondary homes to the communities they are in and include economic benefits from construction and related services, enhanced retail trade, real estate services, and leisure and hospitality services (Long and Hao 2009).

Dare County, North Carolina, provides an example of how climate change affects such communities. The county represents significant part of the state’s Outer Banks tourism trade and more than 70% of the housing stock consists of second homes. The Outer Banks is increasingly susceptible to rising sea level and more frequent and severe storms. For example, the cost of building one bridge over a storm-created inlet that severed NC Highway 12 just north of Rodanthe was $12 million (Associated Press 2011). In another study (Long and Hao 2009), full-time and second home property owners were asked about perceived effects on future property values of sea level rise; coastal flooding; number and intensity of coastal storms; availability of fresh water; and changes in temperature, humidity, and precipitation.The study was conducted just prior to the impact of Hurricane Irene in 2011 that affected the coastal county of Currituck, North Carolina, located just north of Dare County. The study found significant statistical differences between the concerns expressed by resident property owners. These statistical differences were primarily a function of education level. People who perceived that climate and weather would affect both their current property ownership and future property values had a comparatively high level of education. Property owners that perceived climate and weather would not affect their current property ownership, but would nevertheless affect their future property values, were the most educated. Respondents who perceived that climate and weather would not affect their current property ownership or their future property values had the lowest level of education.

Second homes also represent a substantial part of the vacation rental market. In 2009 vacation rentals in the USA represented a $24.3 billion market, which at the time represented 22% of the hotel market and 8% of the travel and tourism market (PhoCusWright 2009). The vacation rental market is a significant part of the economy in the SE. The PhoCusWright study found that

Florida, North Carolina, and South Carolina represented 34% of the total vacation rental market. Additionally, the Outer Banks Visitors Bureau found that 43% of overnight visitors used a vacation rental homes (2006).

Extreme weather events in the SE caused by climate change would likely impact the tourism economy in various direct or indirect ways. For example, people may choose other locations for second homes; storms may cause severe damage to vacation properties, transportation infrastructure, and utilities; erosion may endanger coastal vacation homes; and erratic weather patterns may deter vacationers. More research is needed to investigate adaptation and mitigation strategies for the tourism industry. Research might include developing databases for the industry to assess prediction models and respond appropriately depending upon location and circumstances, for instance coastal versus mountain areas; looking at how various tourist-related businesses have responded to disasters and why some fared better than others; and analyzing market concerns and solutions for tourism with regard to climate change impact.

5.6 Impacts on Energy, Poverty, and Socio-economic Vulnerability

Climate models for the SE predict substantial increases in the number of days above 90°F and in numbers of consecutive very warm days (see Table 2.2, Chapter 2). Comparisons of 1971 to 2000 records with 2041 to 2070 projections from dynamic and statistically downscaled models shows increases of 44% to 49% in the number of cooling degree days. There is less consistency in projections of the maximum run days for high temperatures. Mean projected increases range from 97% to 234% for maximum runs of days greater than 95°F and 132% to 575% for maximum runs of days greater than 100°F (see Figure 2.2, Chapter 2)

The potential impacts of increased cooling costs are significant because meeting energy costs is already a burden for many in the SE. Nationwide in 2009, home cooling costs represented approximately 12% of residential energy expenditures (DHSS 2011). In the southern USA, according to U.S. Census regions data, 98% of households overall have means to cool their home including central and room air conditioning, and other cooling devices such as ceiling fans, or evaporative coolers. Southern low-income households spent approximately 10% of their income on energy costs (DHSS 2011). Low income households are defined as those households with incomes at or below 150 percent of HHS poverty guidelines. Of that 10% total for low-income households in this broadly defined southern region, almost 4% is related to home cooling (DHSS 2011). A narrower focus on southeastern states is needed because of the greater temperature stresses.

The Low Income Home Energy Assistance Program (LIHEAP) administered by the U.S. Department of Health and Human Services serves a subset of low-income households (DHSS 2011). Table 1 provides more information on the number of households eligible for LIHEAP assistance, the distribution by state within the SE, and the numbers of household members who may be particularly stressed due to other vulnerabilities. There are approximately 11.5 million households in the National Climate Assessment SE region that are eligible for assistance to cover energy costs (Table 1). The largest number of households and households with a member over 60 years old are in Florida, where the greatest increases in heating degree days are projected (see Figure 2.10, Chapter 2).

Table 5.1. Households in the Southeastern United States Eligible for Energy Assistance

LIHEAP Home Energy Notebook for FY 2009: Appendix B: Income Eligible Household Estimates					
State-level estimates of the number of LIHEAP income eligible households using the Federal maximum LIHEAP income standard of 75 percent of SMI by vulnerability category1/ 2/					
(Three-Year ACS 2007-2009)					
			LIHEAP eligible households by vulnerability category		
	Total number of LIHEAP eligible households/3/4	at least one person 60+	At least one child less than 6 years old	At Least one person with a disability/5	LIHEAP eligible households with no vulnerable members
Alabama	730,898	270,669	126,992	107,911	270,852
Arkansas	409,926	152,575	80,822	59,225	141,515
Florida	2,562,971	1,099,474	415,284	209,177	951,745
Georgia	1,308,090	422,644	277,853	132,709	542,440
Kentucky	675,932	248,033	125,256	121,642	227,068
Louisiana	649,385	234,254	122,056	84,046	247,838
Mississippi	437,229	160,342	85,644	69,730	153,240
Missouri	839,453	310,617	152,937	100,394	313,575
North Carolina	1,304,413	461,248	253,120	136,434	513,727
South Carolina	629,722	234,882	116,713	70,706	240,890
Tennessee	914,211	339,673	168,986	117,288	341,212
Virginia	1,025,078	378,297	186,910	98,574	406,974
SE states total	11,487,308	4,312,708	2,112,573	1,307,836	4,351,076
All States	41,767,370	15,379,522	7,990,905	4,187,416	16,155,505
	27.5%	28.0%	26.4%	31.2%	26.9%

Data in this table are summarized from DHSS 2011 (DHSS 2009, 2011.)

1/State estimates are subject to sampling error and may not sum to All States total due to rounding.

2/The greater of 75% of state median income estimates or 150% of the HHS Poverty Guidelines. For All States, 75% of state median income is greater than 150% of the HHS Poverty Guidelines.

3/The three-year ACS estimate of the total number of all USA households is 113,104,074.

4/A household can be counted under more than one vulnerability category.

5/The U.S. Census Bureau changed the questions on disability in ACS in 2008. Since the new questions were not comparable to those in previous years, all disability questions were removed from the 2007-2009 ACS data file. The definition only includes individuals ages 15 through 64 who received Supplemental Security Income in the past year and nonwidowed individuals ages 19 through 61 who received Social Security income in the past year. The reader should exercise caution in comparing these estimates with those in previous LIHEAP Notebooks.

5.7 Impacts on National Security

Recently, the U.S. Department of Defense and other national security agencies in the USA have released key reports addressing aspects of climate change impacts on national security (Defense Science Task Board 2011, National Research Council 2011). These reports highlight key issues related to how changing climate events such as sea level rise, declining sea ice, and extreme weather likely will affect the built infrastructure supporting national security. The reports provide information on the complex national and international security issues that arise in a stressed climate system. These security issues include, for example, food and water supply, humanitarian aid, and climate refuges and migration. The SE region is home to several military installations and assets (SERDP 2012). This unique built environment can be particularly vulnerable and so national policymakers must continue to monitor the implications, study climate changes carefully, and plan mitigation and adaptation strategies.

5.8 Impacts on Urban Migration

Throughout history, people have frequently migrated because of climate, moving from coastal areas because of flooding or from drought-stricken areas in search of water and better growing conditions. In contemporary times, the USA has seen a migration to the Sunbelt during the past several decades as many people, particularly retirees, sought more temperate weather (Svart 1976; Graves 1980). Climate change, however, can greatly affect shifts in populations when severe weather events, such as Hurricane Katrina, devastate SE regions. A significant portion of the population of New Orleans, for instance, has chosen not to return to that city after Hurricane Katrina (Grier 2005). In other cases migration may be due to physical conditions such as property inundation due to sea-level rise or lifestyle choices such a desire for cooler weather.

Potable water supply for urban areas is likely to be affected directly and indirectly by climate change. Regional climate change impacts that include increased frequency of drought, greater evaporation a result of higher temperatures, saltwater intrusion, reduced groundwater recharge, and flooding threaten ground and surface water supplies. As supply options become more limited, technological and economic water treatment challenges may emerge as more polluted water sources or saltwater sources are pressed into service. Higher temperatures may result in algae and microbe growth. Additionally, water treatment plants, transmission lines, pump stations, and other infrastructure that is located in areas vulnerable to flooding, temporary or permanent inundation, or extreme weather events will likely be at risk. Constraints in water supply and treatment options may result in limits to future growth, an inability to meet the needs of industry, or even evacuation of existing residents. Communities that want to grow—or simply maintain current population—must secure stable future water supplies, which will likely be more difficult due to climate change challenges. Communities that cannot find adequate potable water supplies will be subject to outmigration and thus further economic difficulties.

Regions of the USA projected to experience less severe climate change impacts, stand to gain population and economic development. (Shuford et al. 2010) The SE USA is particularly vulnerable to climate change impacts along coastal areas, and up to 46,000 km^2 of land could be lost in the region from a sea level rise of 1.5 meters. (Titus and Richman 2000) The Miami, FL, metropolitan area is projected to have 4,795,000 people exposed to coastal flooding by 2070, ranking ninth in the world's coastal metropolitan regions for such exposure (OECD 2007).

Rapid population growth may strain infrastructure, cause tension between new residents and established ones, influence changes in community character, and create significant stress on social services. These effects may be compounded if there are USA humanitarian efforts to relocate noncitizens from severely impacted areas of the world. Some changes, though, may be perceived as positive for some urban residents. For instance, rapid population decline in communities may create more affordable housing, less congestion, and more open space (Shuford et. al, 2010). Additionally population increases as people move away for vulnerable areas may result in economic booms for areas less affected by climate change effects.

5.9 Impacts on Coastal Environments

Although built environments throughout the southeastern USA are subject to the impacts previously discussed in this section, perhaps the most vulnerable areas affected by climate change are built environments located in coastal areas. Given the extensive area of the coastal SE that is urbanized, there are numerous examples in this report of what the impacts climate change will have on coastal cities in the region. These impacts are far-ranging and include storm surges from tropical storms (Chapter 2, section 2.2.5), heavy precipitation events (Chapter 2, section 2.3.2), and sea level rise (Chapter 2, section 2.3.8). Specific aspects of climate change impacts on coastal built environments, such as human health and transportation, are described throughout this report (see Chapters 3, 4, 6, and 13). An even more thorough examination of climate change impacts on coastal cities in the U.S. is presented in the NCA technical report "U.S. Cities and Climate Change: Urban, Infrastructure, and Vulnerability Issues" (Chapter 3.7).

5.10 Summary of Climate Change Impacts on the Built Environment

It is apparent that the impacts of climate change on the built environment will be local and regional, direct, and indirect and potentially will range from mild to severe. These impacts may be single events such as hurricanes, but likely will be interrelated; for example, heavy precipitation events that create regional flooding will synergistically have a series of cascading impacts, such as effects on transportation and utilities, residential and business infrastructure, land use, and population. Moreover, the built environment potentially will impact climate via mechanisms related to physical exchanges with the lower atmosphere, such as an increase in the intensity and size of the urban heat island effect or an increase or decrease in precipitation over urban areas. Climate changes caused by circumstances external to the built environment, such as global increase in greenhouse gases, or directly related to the built environment, such as increase in impervious versus pervious surfaces. Although these impacts will be felt at different spatial and temporal scales, they likely will have significant effects on the socio-economic and demographic structure of the built environment. In the SE, population fluctuations, economic decline including a potential decline in tourism, vulnerability of energy supplies, and challenges to built infrastructure as well as natural areas are likely to be a result of climate change in the coming decades.

The outlook, however, is not entirely gloomy. Adaptation strategies within the built environment such as increased tree planting or albedo enhancement have the potential to moderate some effects of climate change. This likely will reduce waste heat emissions which, in turn, can create opportunities for reduced energy consumption. Other adaptation measures such as green roofs or porous paving can further reduce the climate change impacts, particularly those caused by the feedback mechanism that the built environment has with the lower atmosphere. More pervious surfaces result in less runoff, which will decrease the magnitude of flooding during heavy precipitation events. The primary key to successfully meeting the challenges of climate change is to educate policy and decision makers, planners, and the general public on the long-term cost benefits of adaptation strategies and to set in motion practical strategies for implementation.

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6 Climate Change and Southeast Transportation

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(*Note: This chapter contains a dissenting opinion written by Kevin Moody that appears in an appendix following the references.*)

Key Findings

All transportation networks in the southeastern USA are vulnerable to weather-related phenomena and climate change. The most significant threats, in addition to disruptions to local community access, are to low lying areas where sea level rise may inundate major transportation systems and where severe weather threatens coastal ports and transportation systems. While potentially catastrophic, storm damage is temporal in nature as opposed to the permanent threat posed by sea level rise. Warmer temperatures are forecast along with more intense rainfall events, which will require re-engineering of transportation surfaces and storm water collection and disposal. Permitting for disposal of storm water may pose a significant challenge to an area where nutrients create significant eutrophication problems in slow moving and coastal waterways. Outside the box thinking will be required to deal with the problem of too much water.

Ongoing efforts to identify vulnerable infrastructure, and measuring the risk and disruption posed by those risks from an economic and societal perspective are needed. Such efforts are generally in their infancy, if they have been initiated at all. There is a general lack of awareness and in some cases resistance on the part of the public and some state agencies and local municipalities to address or support planning in regard to transportation and climate change in the Southeast (SE). Transportation planning in terms of climate and weather impacts on the economics of the coastal regions should be incorporated into larger policy frameworks. For example, 5.5 million Floridians are at risk in southeast Florida where sea level rise is projected to affect nearly $4 trillion worth of property and more than $300 billion per year in economic enterprises, including three airports, three major sea ports, as well as rail and highway facilities. In the case of southeast Florida, it is mostly local officials and citizens who are creating strategies and making plans rather than state or federal agencies.

6.1 Current Sea Level Predictions

Current projections and timing of sea level rise are shown in Figure 1 using the methodology of Heimlich et al. (2009) and updated for recent peer-reviewed publications (Vermeer and Rahmstorf 2009; Jevrejeva, Moore, and Grinsted 2010; Bloetscher, Heimlich, and Romah 2011; Bloetscher et al. 2010). Years are on the x-axis; sea level rise from 2010 is on the y-axis. The purple line is the midrange scenario chosen for this study. This is not to say that sea level may rise faster or slower. The red horizontal bars indicate the range of times when a given sea level rise milestone may occur faster than the average scenario, which is three feet by 2100.) The blue bars are the range of times if sea level rises more slowly. If sea level rise actually occurs faster than the midrange scenario case, the timing of infrastructure improvements can be adjusted accordingly. The light blue vertical bars on the right are the sea level ranges of recent, published articles and reports. The green vertical bars indicate the Southeast Florida Regional Climate Compact (SFRCC) guidelines for 2030 and 2060 (**). The projected range of two to five feet by 2100 was derived from the average of the published projections. With such a projection, coastal areas in southeast Florida with elevations below five feet NGVD are vulnerable to inundation regardless even if they are located immediately along the coast since mean high tide with a 3 foot sea level rise is approximately 2 feet above mean tide.

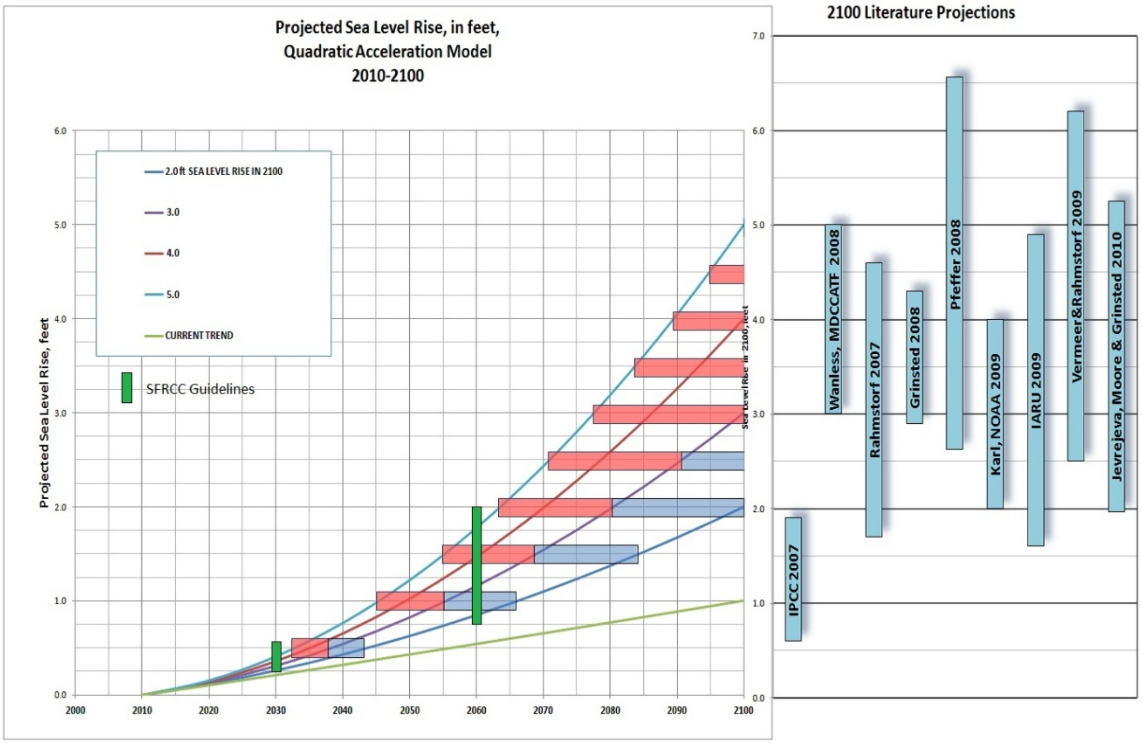


Figure 6.1 Sea Level Rise projection diagram (Heimlich et al. 2009).

6.2 Transportation Sustainability

Transportation networks in the SE are directly and indirectly vulnerable to climate change and weather. The key to economic sustainability is the consistent ability of transportation systems and operations to provide mobility and access that is safe and reliable for the long-term. The National Research Council (NRC 2009) suggests evaluating transportation and other infrastructure performance through the following five 21st century categories: (1) economic competitiveness, (2) global climate change, (3) energy supplies, (4) disaster resilience, and (5) environmental sustainability. Environmental sustainability encompasses natural, built, and socio-cultural environments that would include, for example, ecosystem integrity, community health, environmental justice, and livable communities.   The U.S. Environmental Protection Agency (USEPA 200**) notes that there is no single definition of what constitutes a sustainable transportation system. However, the Transportation Research Board Sustainable Transportation Indicators Subcommittee defines a sustainable transport system as follows:

- Allows the basic access and development needs of individuals, companies, and society to be met safely and in a manner consistent with human and ecosystem health, and promotes equity within and between successive generations.

- Is affordable, operates fairly and efficiently, offers a choice of transport mode, and supports a competitive economy, as well as balanced regional development.
- Limits air, water, and noise emissions, waste, and resource use. Limits emissions and waste within the planet's ability to absorb them, uses renewable resources at or below their rates of generation, and uses non-renewable resources at or below the rates of development of renewable substitutes, while minimizing the impact on the use of land and the generation of noise.

Creating a sustainable transportation system will require a change in the current model of cooperative working relationships. The Transportation Research Board (TRB 2008) and NRC (2009) suggest that the institutional arrangements that delivered the 20th century transportation network are inadequate in the face of climate change and other weather driven events. Past storm experience bears this out. In order to create leadership for cooperative sustainable transportatio,n the federal government created the Interagency Partnership for Sustainable Communities (IPSC) to reinforce the importance of environmental, economic, and social sustainability. In June 2009, the U.S. Department of Housing and Urban Development (HUD), the U.S. Department of Transportation (DOT), and EPA agreed to coordinate housing, transportation, and environmental policies and investments to increase transportation options, improve accessibility to jobs and other destinations, and lower the combined cost of housing and transportation while protecting the environment in communities nationwide (USEPA 20**). These federal working relationships need to trickle down to state and regional officials in order to address local needs, including those in the built and natural environments.

6.3 Climate Change and Infrastructure

Economic development requires appropriate management of water, sewer, stormwater and transportation networks (Heimlich et al 2009). Bloetscher (2012) developed a framework to evaluate the impacts of climate change on infrastructure and water resources and economic development, as they are intrinsically intertwined. The first step of the multiple-step framework focused on topography, economic drivers, and population with regard to likely climate change events such as precipitation, temperature, and sea level rise. Figure 2 shows a simplified flow chart is used as a basis for the evaluation. Topographic and Light Detection and Ranging (LIDAR) data can be used for the terrestrial characteristics. Topographic, census, and economic activity data were evaluated to determine how climate changes would affect the population and economy.

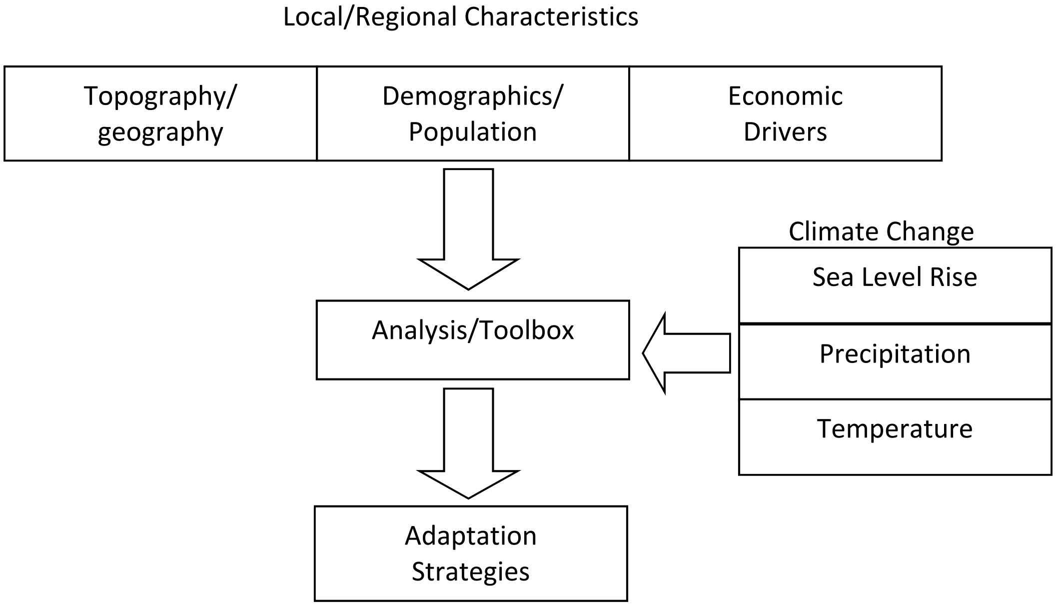


Figure 6.2. Analysis tool (Bloetscher 2012)

Local and regional efforts are required to integrate current data sources to develop methods for assessing and mitigating the potential impacts of sea level rise (SLR) and storm impacts on transportation infrastructure to assist transportation planning. The approach integrates the U.S. Department of Transportation (DOT) information systems with existing state and national topographical and geological data to facilitate (1) evaluation of current and projected SLR impacts on coastline and low-lying terrain areas, (2) downscaling of statewide data bases to local jurisdictions, and (3) identification of the physical transportation infrastructure that are most likely to be affected by frequent to continuous flooding due. A projection of SLR level and timing was outlined using a benchmark approach that brackets time intervals rather than specific times to make improvements.

6.3.1 Impacts of Climate Change Parameters on Transportation Systems

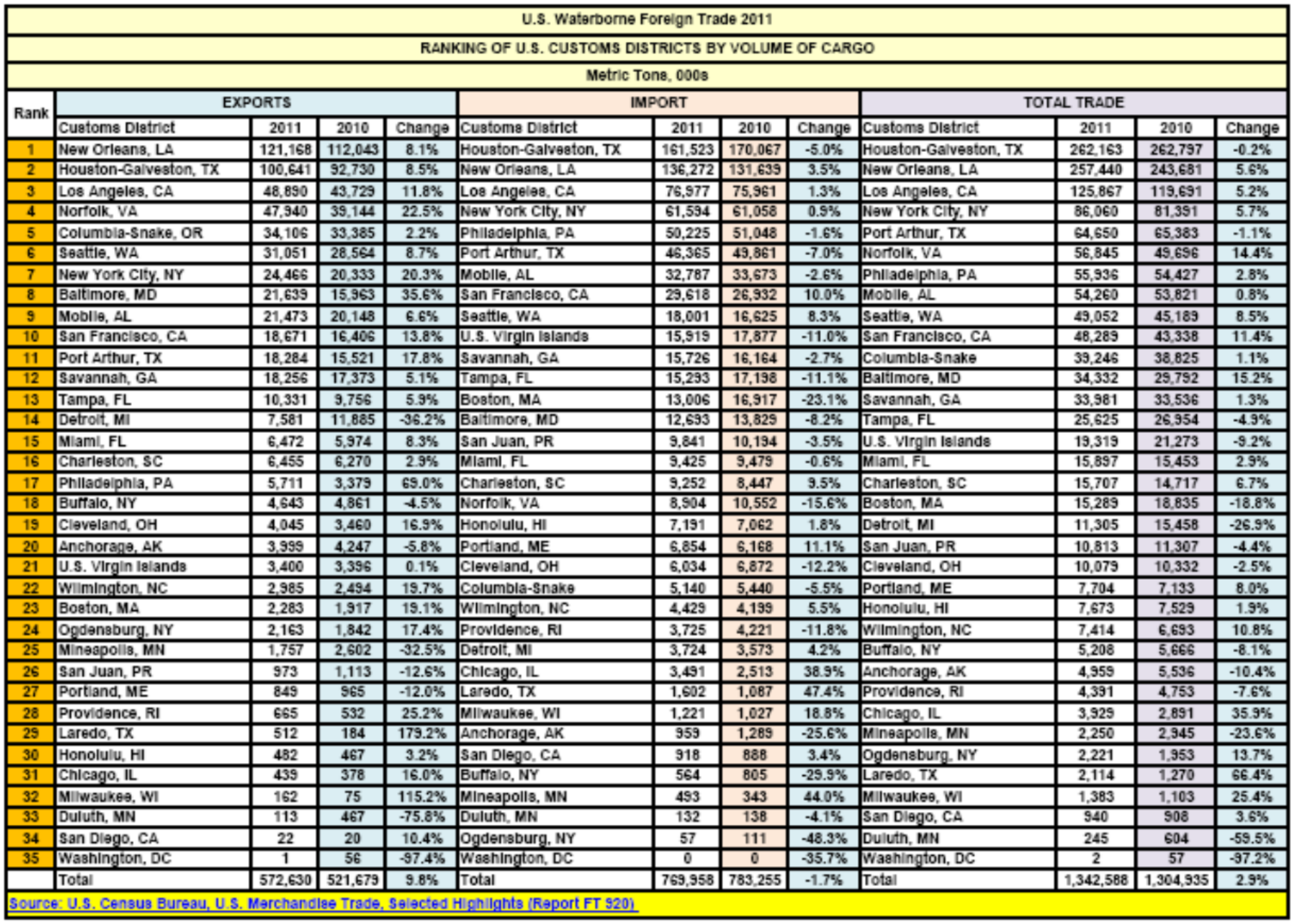
Transportation in the Southeast is directly affected by a suite of climate-related risks. Transportation infrastructure along the coastline and low lying areas is vulnerable to sea level rise. Access to roads, bridges, rail and rail transit are all at risk of flooding or damage to the base layer of ground components of all transportation system, which would ultimately create failure of the system. Sea level rise can also indirectly affect transportation systems. For example, when a critical road is flooded traffic will be shifted and cause congested conditions in other roadways. If the roadway network is unable to carry the traffic demand, the system would experience operational failure including delays and longer travel times. Moreover, inundation of a critical access would cause connectivity problems by blocking access to some areas—some of which might be critical such as hospitals or areas served by bridges.

In addition to sea level rise, other climate change events likely will impact transportation in the SE. For instance, extreme heat events can soften asphalt, causing damage to roads; or affect concrete, which can rupture and warp steel rails. Heat, therefore can affect various types of transportation systems and cause slow-downs and rerouting of various transportation services. Other effects of climate change include changes in hydrology that may dramatically increase the consequences of highway runoff on ecosystems; droughts and floods that may directly interfere with inland waterway operations; drought that leads to wildfires that can create unsafe driving conditions; and snow and ice events that can create landslide and slope failures near or on roadways. The following paragraphs outline the challenges facing each transportation sector.

***Marine and Inland Ports*.** The SE supports an array of marine and inland shipping ports. Table 1 identifies those that rank highest in the USA in terms of tonnage transferred. Of the 35 customs districts in the USA, nine are in the Southeast, and of those three, New Orleans, LA; Norfolk, VA; and Mobile, AL, are in the top 10 ranked by tonnage transferred. Other SE ports include those in Savannah, GA; Tampa and Miami, FL; and Charleston, NC—all in the top 20. These ports account for more than half the total tonnage entering or leaving the USA in a given year. These ports are in low-lying coastal areas that are subject to disruption through inundation from storm water as well as sea level rise. In addition, port facilities may be damaged by extreme weather events such as powerful hurricanes that result from climate change.

In addition to damage directly to shipping lanes and port facilities, import and export activities can be affected by disruption to intermodal links. Thriving marine ports are linked to distribution centers, and importers and exporters benefit from accessible, efficient, and reliable rail and roadway systems that connect to regional and national transportation networks. Severe climate change events, especially those near coastal low-lying areas, may cause damage to these transportation networks.

Table 6.1. Southeast Ports, Ranked for USA by Tonnage (NOAA)



U.S. Waterborne Foreign Trade 2011

RANKING OF U.S. CUSTOMS DISTRICTS BY VOLUME OF CARGO

Metric Tons, 000s

Rank	EXPORTS				IMPORT				TOTAL TRADE			
	Customs District	2011	2010	Change	Customs District	2011	2010	Change	Customs District	2011	2010	Change
1	New Orleans, LA	121,168	112,043	8.1%	Houston-Galveston, TX	161,523	170,067	-5.0%	Houston-Galveston, TX	262,163	262,797	-0.2%
2	Houston-Galveston, TX	100,641	92,730	8.5%	New Orleans, LA	136,272	131,639	3.5%	New Orleans, LA	257,440	243,681	5.6%
3	Los Angeles, CA	48,890	43,729	11.8%	Los Angeles, CA	76,977	75,961	1.3%	Los Angeles, CA	125,867	119,691	5.2%
4	Norfolk, VA	47,940	39,144	22.5%	New York City, NY	61,594	61,058	0.9%	New York City, NY	86,060	81,391	5.7%
5	Columbia-Snake, OR	34,106	33,385	2.2%	Philadelphia, PA	50,225	51,048	-1.6%	Port Arthur, TX	64,650	65,383	-1.1%
6	Seattle, WA	31,051	28,564	8.7%	Port Arthur, TX	46,365	49,861	-7.0%	Norfolk, VA	56,845	49,696	14.4%
7	New York City, NY	24,466	20,333	20.3%	Mobile, AL	32,787	33,673	-2.6%	Philadelphia, PA	55,936	54,427	2.8%
8	Baltimore, MD	21,639	15,963	35.6%	San Francisco, CA	29,618	26,932	10.0%	Mobile, AL	54,260	53,821	0.8%
9	Mobile, AL	21,473	20,148	6.6%	Seattle, WA	18,001	16,625	8.3%	Seattle, WA	49,052	45,189	8.5%
10	San Francisco, CA	18,671	16,406	13.8%	U.S. Virgin Islands	15,919	17,877	-11.0%	San Francisco, CA	48,289	43,338	11.4%
11	Port Arthur, TX	18,284	15,521	17.8%	Savannah, GA	15,726	16,164	-2.7%	Columbia-Snake	39,246	38,825	1.1%
12	Savannah, GA	18,256	17,373	5.1%	Tampa, FL	15,293	17,198	-11.1%	Baltimore, MD	34,332	29,792	15.2%
13	Tampa, FL	10,331	9,756	5.9%	Boston, MA	13,006	16,917	-23.1%	Savannah, GA	33,981	33,536	1.3%
14	Detroit, MI	7,581	11,885	-36.2%	Baltimore, MD	12,693	13,829	-8.2%	Tampa, FL	25,625	26,954	-4.9%
15	Miami, FL	6,472	5,974	8.3%	San Juan, PR	9,841	10,194	-3.5%	U.S. Virgin Islands	19,319	21,273	-9.2%
16	Charleston, SC	6,455	6,270	2.9%	Miami, FL	9,425	9,479	-0.6%	Miami, FL	15,897	15,453	2.9%
17	Philadelphia, PA	5,711	3,379	69.0%	Charleston, SC	9,252	8,447	9.5%	Charleston, SC	15,707	14,717	6.7%
18	Buffalo, NY	4,643	4,861	-4.5%	Norfolk, VA	8,904	10,552	-15.6%	Boston, MA	15,289	18,835	-18.8%
19	Cleveland, OH	4,045	3,460	16.9%	Honolulu, HI	7,191	7,062	1.8%	Detroit, MI	11,305	15,458	-26.9%
20	Anchorage, AK	3,999	4,247	-5.8%	Portland, ME	6,854	6,168	11.1%	San Juan, PR	10,813	11,307	-4.4%
21	U.S. Virgin Islands	3,400	3,396	0.1%	Cleveland, OH	6,034	6,872	-12.2%	Cleveland, OH	10,079	10,332	-2.5%
22	Wilmington, NC	2,985	2,494	19.7%	Columbia-Snake	5,140	5,440	-5.5%	Portland, ME	7,704	7,133	8.0%
23	Boston, MA	2,283	1,917	19.1%	Wilmington, NC	4,429	4,199	5.5%	Honolulu, HI	7,673	7,529	1.9%
24	Ogdensburg, NY	2,163	1,842	17.4%	Providence, RI	3,725	4,221	-11.8%	Wilmington, NC	7,414	6,693	10.8%
25	Minneapolis, MN	1,757	2,602	-32.5%	Detroit, MI	3,724	3,573	4.2%	Buffalo, NY	5,208	5,666	-8.1%
26	San Juan, PR	973	1,113	-12.6%	Chicago, IL	3,491	2,513	38.9%	Anchorage, AK	4,959	5,536	-10.4%
27	Portland, ME	849	965	-12.0%	Laredo, TX	1,602	1,087	47.4%	Providence, RI	4,391	4,753	-7.6%
28	Providence, RI	665	532	25.2%	Milwaukee, WI	1,221	1,027	18.8%	Chicago, IL	3,929	2,891	35.9%
29	Laredo, TX	512	184	179.2%	Anchorage, AK	959	1,289	-25.6%	Minneapolis, MN	2,250	2,945	-23.6%
30	Honolulu, HI	482	467	3.2%	San Diego, CA	918	888	3.4%	Ogdensburg, NY	2,221	1,953	13.7%
31	Chicago, IL	439	378	16.0%	Buffalo, NY	564	805	-29.9%	Laredo, TX	2,114	1,270	66.4%
32	Milwaukee, WI	162	75	115.2%	Minneapolis, MN	493	343	44.0%	Milwaukee, WI	1,383	1,103	25.4%
33	Duluth, MN	113	467	-75.8%	Duluth, MN	132	138	-4.1%	San Diego, CA	940	908	3.6%
34	San Diego, CA	22	20	10.4%	Ogdensburg, NY	57	111	-48.3%	Duluth, MN	245	604	-59.5%
35	Washington, DC	1	56	-97.4%	Washington, DC	0	0	-35.7%	Washington, DC	2	57	-97.2%
	Total	572,630	521,679	9.8%	Total	769,958	783,255	-1.7%	Total	1,342,588	1,304,935	2.9%

Source: U.S. Census Bureau, U.S. Merchandise Trade, Selected Highlights (Report FT 920)

Railroads. As Figure 6.3 indicates, the SE is heavily crisscrossed with freight railroads. Most railroads in the USA were constructed 100 years ago and as a result they may be somewhat more resilient to climate change effects. This resilience is partially due to location--most were constructed on relatively high ground. However, vintage railroads were built for lighter and slower traffic and as a result base failure and loosening of spikes holding down rails could create long term safety concerns. Base failure may contribute to the $1 million per mile for maintenance costs. As sea level or groundwater levels rise, base saturation and deterioration may become a structural integrity concern. So while higher in elevation than roadways, coastal railroads may nevertheless be vulnerable to the effects of climate change (see Figures 6.4 and 6.5).

Table 6.2. Class I Freight Railroads in the Southeast.

Railroad	**States**
Union Pacific	Louisiana; Arkansas
Norfolk Southern	Louisiana; Mississippi; Alabama; Georgia; Florida; Tennessee; Kentucky; South Carolina; North Carolina; Virginia
Kansas City Southern	Louisiana; Arkansas; Mississippi; Alabama
CSX	Louisiana; Mississippi; Alabama; Georgia; Florida;

	Tennessee; Kentucky; South Carolina; North Carolina; Virginia
Canadian National	Louisiana; Mississippi; Alabama; Tennessee
BSNF	Louisiana; Mississippi; Alabama; Arkansas; Tennessee

Figure 6.3 Class I Railroads in North America

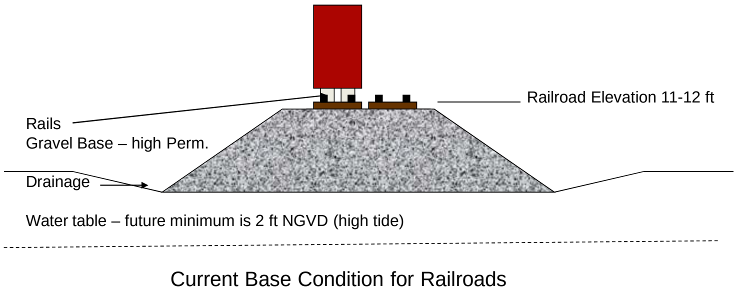


Figure 6.4 : Railroads are built on high ground – current situation.

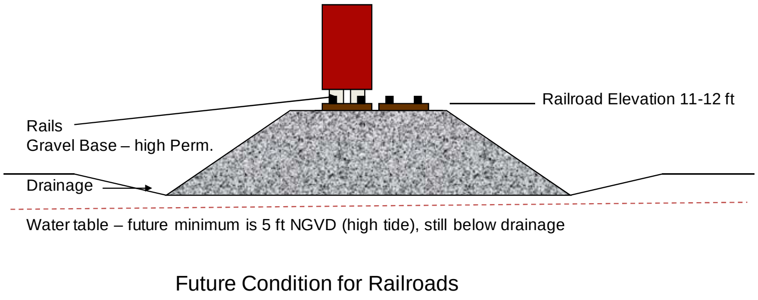


Figure 6.5: Future railroad condition.

Airports. There are hundreds of airports in the southeastern USA, but only a handful that are significant. Atlanta dominates foreign trade and passenger traffic, followed by Miami, Fort Lauderdale, and New Orleans (see Table 6.4). Miami International Airport (17 million passengers) is eight feet above sea level (Bureau of Transportation Statistics webpage, accessed 2/29/12). Fort Lauderdale-Hollywood International Airport (10 million passengers, projected to 32 million by 2030) is five feet above sea level and located in the coastal hazard zone. The Louis Armstrong Airport in New Orleans (4.07 million passengers in 2010) is four feet above sea level.

http://www.transtats.bts.gov/DatabaseInfo.asp?DB_ID=640andLink=0). Most of these coastal airports are in the process of expanding or have recently completed expansions. Similar to the construction of railroad tracks, the runways are on higher ground than the surrounding areas, but long-term base failure would likely be caused by rising groundwater levels (see Figures 6.6 and 6.7) Although ongoing upgrades can potentially protect runway structures from sea level rise damage, access roads to airports may be compromised (for example, see Figure 6.8).

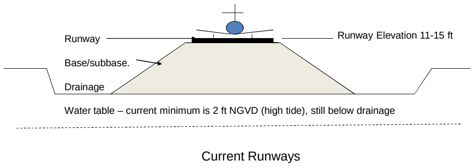


Figure 6.6 Airport runways are generally elevated.

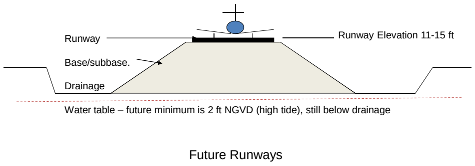


Figure 6.7 If sea level rises, it may take longer for runways to be impacted by flooding.

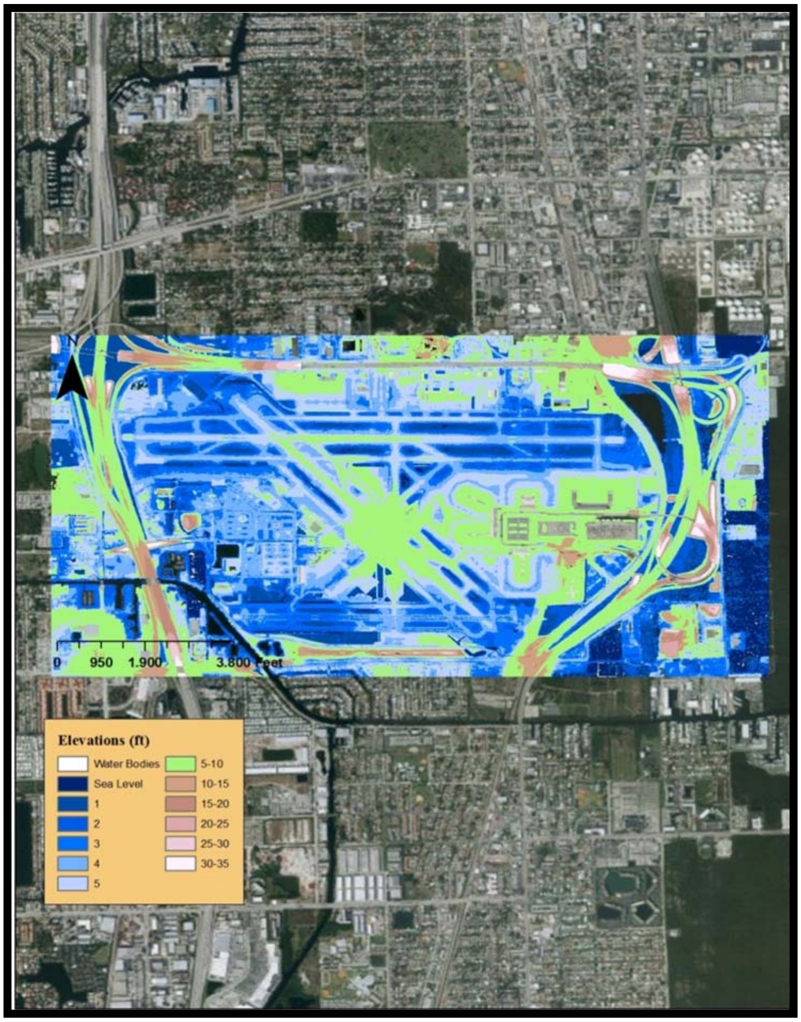


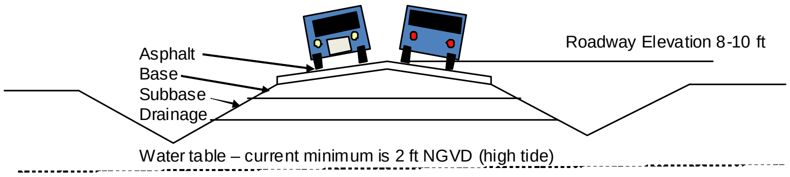
Figure 6.8 Illustration of Fort Lauderdale-Hollywood International Airport. LiDAR map shows that runways are currently above SLR projections; however drainage areas are not. Areas in dark blue color are less than one foot above SLR projections and medium blue color are less than three feet above SLR projections.

6.3.4 Roadways

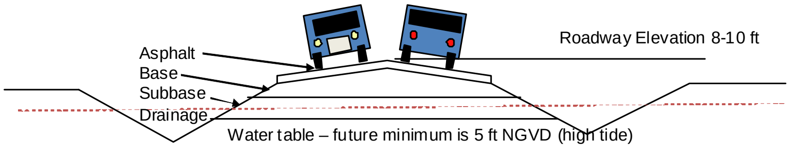
By far the greatest transportation infrastructure system is roadways. The network of highways and roads to in the SE are owned by state and local transportation agencies. Roadways account for $250 billion in freight movement, five times as railroads (see Figure 6.11). Most freight moves on the interstate highway system, which is also used by billions of individuals each year.

Protection of transportation infrastructure is related to the effectiveness of flood control and storm water drainage systems within transportation corridors. Severe flooding in low-lying terrain can adversely affect transportation infrastructures along the coastline, inundating roadways and damaging the substrate. Sea level rise also is likely to cause increased water table levels, which likely would compound flooding in low lying areas since soil storage capacity would be reduced. Road bases below five feet NVGD would become saturated under this scenario, causing premature base failure. In addition, because soil water storage capacity is diminished, frequently flooding of roadways would likely damage pavements.

Figure 6.9 illustrates properly constructed roads that are main arteries for transport as well as emergency routes. Many local roads that do not meet these standards would be more vulnerable to failure. Figure 6.10 shows the LiDAR image for a community with areas below five feet NAV 88. The blue areas are those vulnerable to sea level rise and flooding, and show that roadways, as opposed to property, would be disrupted.



Current Base Condition for Low lying Roads



Future Condition for Low lying Roads

Figure 6.9 Impact to roadbeds from sea level rise.

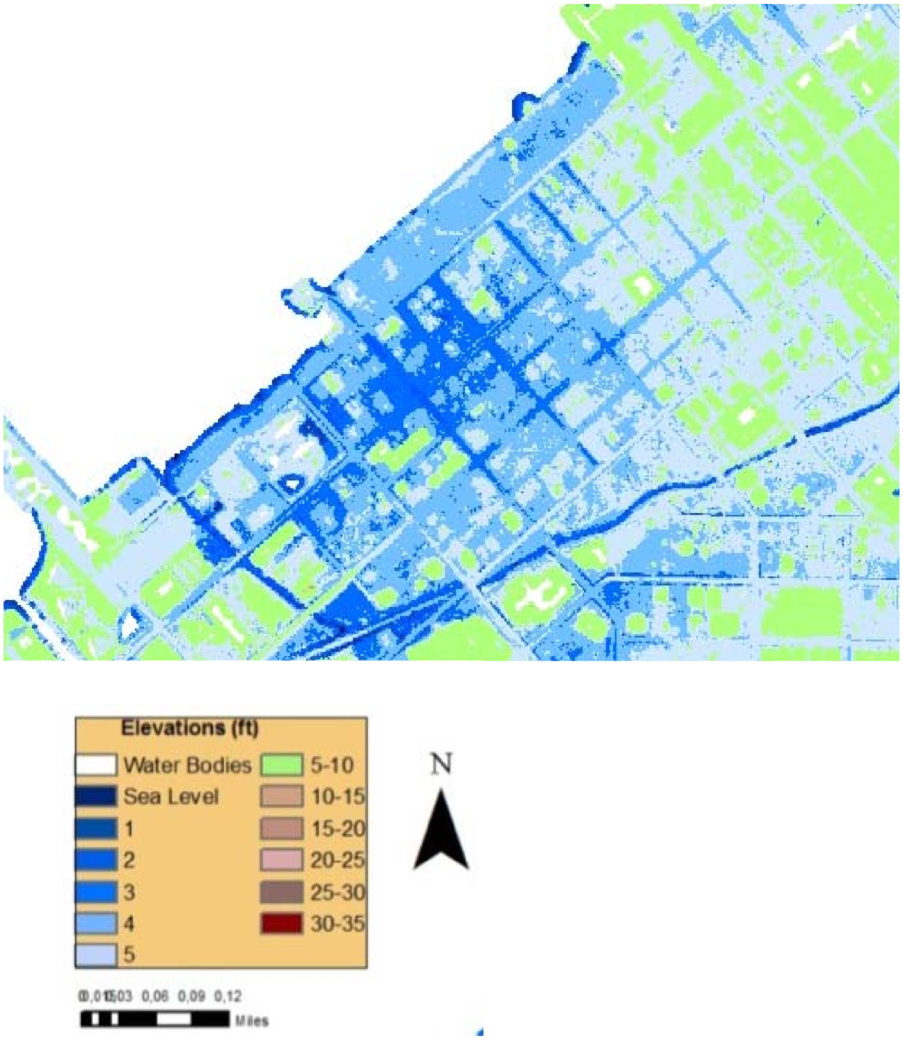


Figure 6.10: Impact of flooding in a downtown coastal community.

6.4. Transportation System Performance and Protection

Economic Impact. The movement of goods and people across various transportation corridors represents substantial economic value for a number of businesses and individuals in the SE including truckers, agriculture, manufacturing, vacation and business, and various types of freight. Adequate data on the value of goods shipped into, out, or through the SE are not currently available. Generally, however, costs have historically ranged from $2 per pound for air freight to $0.1 per pound for truck freight, $0.01 per pound for rail freight, and $0.005 per pound for boat freight.

Marine Ports. Seven marine ports-- Norfolk, VA; Charleston, NC; Savannah, GA; Jacksonville, Miami, and Tampa, FL; and, New Orleans, LA—represent $XXX in value of imports and exports . Climate change issues may put these coastal ports, and the economy they provide, at risk. Two climate risk issue bear review: sea level rise and changes in traditional shipping routes.

First, changes in sea level are expected to have two general effects. (1)Altered hydrology and sea level likely will affect sedimentation rates, in turn affecting operational costs and even the long term sustainability of some marine ports. In addition, sea level change has a cumulative effect on spring high tides and storm surge levels. In most of the SE, countermeasures likely will be necessary to maintain levels of service during all conditions. However, such plans may take 20 years to develop. (2) An indirect effect of warmer climate and greater variability in rainfall would be through their effects on agricultural businesses in the SE. Inundation, repetitive storm damage, or long-term drought may result in large growers moving to, and thus accessing ports, in other regions

The expansion of the Panama Canal to accommodate wide-beamed, post-Panamax ships and potentially ice-free Northwest Passage will make new ports available to shippers. Currently, only Norfolk can accommodate post-Panamax sized ships; although several SE marine ports are in the planning stages or in the process of increasing channel dimensions to accommodate ships. Expansion of the Panama Canal means that wide beamed ships that currently operate through the Suez Canal may be competitive in areas opened up by the Panama Canal expansion. Vulnerability without adaptation to climate impacts may force port operations to relocate to more protected, environments.

Airports. The Southeast has many economically important airports that are subject to delays due to weather locally or in other locations. Both situations disrupt inbound and outbound flights. Hartsfield-Jackson Atlanta International Airport, for example, is a main hub for the southeast and weather events and temperature inversions that likely will be exacerbated by climate change would adversely affect passenger and freight traffic. 2007 demonstrated that Atlanta could be adversely impacted by water problems.

Atlanta would not be affected by sea level rise; however, other coastal SE airports such as Miami, New Orleans, and Fort Lauderdale-Hollywood likely will need to make adaptations. These three airports are undergoing various upgrades. Fort Lauderdale, for example, has invested in to move its runway 65 feet above sea level. NAV88. However, without a solution to the surrounding areas, these coastal airports could be isolated from intermodal opportunities.

Other economic issues for SE airports also include reduction of agricultural freight due to regional drought or water inundation, infrastructure damage from intense hurricanes or wind or runway damage from extreme heat that could result in closures or partial closures of air service.

Waterways. Coastal waterways in the SE are vulnerable to hydraulics and sedimentation, sea level change and storm surge, and tropical storms. Severe drought that lowers water levels to a point where boat traffic is not possible is the only real limitation but is unlikely to pose a threat in the next 100 years.

Highways. Protecting roadway base structures is crucial to insure that ground transportation is not disrupted by extreme weather or long-term climate change. Adequate drainage systems are also needed to meet future conditions. At present most base courses are installed above the water table. As long as the base stays dry, the roadway surface will remain stable. As soon as the base is saturated, the roadway can deteriorate. Additional storm water systems can protect against sea level rise in the short term as long as adequate means for discharging increased storm water are provided.

Sea level rise may require various constructions and methods for removing water from highways. For instance, wellpoint systems, used at construction sites can filter water as it is moved to a discharge zone. Wellpoint pump stations would need to be regularly spaced along an affected roadway. Because wellpoints do not function when flooded, additional drainage measures will be needed during heavy rainfall events. The costs for such systems, which should be designed as well as sanitary sewer systems, could exceed $1 million per lane-mile.

Exfiltration trenches or French drains, perforated pipes located about the water table, are used by state and municipal transportation departments to drain highways . However, exfiltration systems do not work when they become submerged and so are not practical for low-lying areas or sea level rise. These trenches could be replaced by stormwater gravity wells or Class V injection wells. Stormwater gravity wells are a useful option where saltwater underlies the surface. Such drainage wells along the southeast Florida coast can drain 1 MGD under certain conditions. However as sea level rises, the potential differential may be altered if the saltwater wedge migrates inland as a result of surficial drainage efforts. Also, increased head due to water table rise will alter pump characteristics. Depending on local conditions, these wells may or may not be appropriate. Wells of this type generally cost about $150,000 each for a 24-inch diameter well. Obtaining permits remains a challenge and it is likely that wells would have to be deeper than current gravity wells. Gravity wells require regular maintenance, which would raise transportation system budgets.

Class V injection wells, which may be hundreds of feet deep in some locations, might be required for areas that. Permitting Class V injection wells must be done under the rules of the Underground Injection Control program of the Safe Drinking Water Act, something that is not currently considered in most transportation jurisdictions. Permitting and consistent monitoring of Class V wells is required.

Raising the elevation of roadways may be an option in some areas; however, there are two significant issues: (1) determining the proper roadway elevations and (2) impacts on adjacent properties. Roadways are designed to last 50 to 100 years. As a result, transportation agencies should design roadway bases to be above the mean high water table of five feet NGVD. Such roads would likely have surface elevations at or above 10 ft NGVD, above many of today’s low lying roads. Such elevated roadways would be well above adjacent properties (for example, people will be looking at the side of the road from their windows), so local roadway elevations will be limited by the elevations of adjacent buildings. For example, in Dania Beach, FL, the typical elevation of houses east of US 1 is between six and eight feet NGVD and so raising a roadbed to ten feet would create depressions that have no outlets and would be prone to prolonged flooding. While runoff from private property would not reach the roadbed, runoff from the roads would flood the adjacent land areas. As a result, local neighborhoods would need pumping systems to remove stormwater. Neighborhoods in the SE, especially those prone to storm water surges and sea level rise will need to deal with protecting roadways as well as adjacent properties.

Also of concern are sanitary sewers, water mains, and other utilities that underlie these pavements. Elevating roads would require manholes to be reconstructed and water lines and underground utilities to be replaced. Costs for these improvements could be $4 million per mile of roadway.

Elevation of roadways, estimated to cost $1 million per lane-mile, likely will exceed the cost of new roads. With the added improvements, additional rights-of-way required to control runoff, and extensive fill, the cost is more likely to be $2 to $3 million per lane-mile. In addition, modifications to adjacent properties, such as pumps to remove their stormwater, could add another half million dollars per property. Such improvements likely would change the character of neighborhoods and may also displace residents.

Moving traffic off of vulnerable or inundated roadways will create congestion elsewhere, which would mean longer travel times, increased costs, and less reliable pick-up and delivery times for truck operators. To compensate, motor carriers typically add vehicles and drivers and extend their hours of operation. Over time, most of these costs are passed along to shippers and consumers. The Federal Highway Administration (FHWA) estimates that increases in travel time cost shippers and carriers an additional $25 to $200 per hour depending on the product carried. The cost of unexpected truck delays can add another 50 percent to 250 percent.[4] Figure 6.14 show peak congestions points that disrupt the smooth flow of goods and traffic. Miami, Fort Lauderdale, Tampa, Atlanta, Houston and New Orleans are all in the red areas.

6.5 Conclusions

Transportation infrastructure in SE coastal areas is increasingly vulnerable to sea level rise. Given the high population density near the coasts, the potential exposure of transportation infrastructure to flooding is immense (NOAA 2010). The SE transportation system is extremely weather dependent for the two NRC imperatives considered--economic competitiveness and disaster resilience. Transportation is strongly interconnected with other infrastructure systems and is highly susceptible to natural hazards.

In order to build strategies for adaptation, high priority must be given to encouraging government agencies to collaborate (National Research Council 2010). Adaptation may not be successful if agencies and governments continue to use 20th century processes, practices, technologies, and materials, which tend to cause increasing instances of service disruptions, higher operating and repair costs, and the possibility of catastrophic, cascading failures. To meet the challenges of 21st century climate change, a new paradigm for the renewal of critical infrastructure systems is needed for the SE and for the entire country. Transportation systems are not independent: ports, roadways, airports, and waterways represent complex interconnected networks that rely on each other. A disruption in one place or system can cause disruptions in other systems or locations. In addition climate change effects, for instance heat, that may not seem related to roadways specifically, might affect the transportation of poultry, which could succumb to extreme conditions during transport. In addition, impacts, such as sea level rise, may affect the transportation network for years at a time.

Engineering options are already available for strengthening and protecting transportation infrastructure such as bridges, ports, and railroads from coastal storms and flooding, but inundation from sea level rise is a different issue. The former are temporal in nature; SLR likely will be permanent—or at least permanent for the foreseeable future. The development and implementation of technologies that monitor major transportation facilities and infrastructure, as well as the updates and re-evaluations of design standards, are required sea level rise adaptations for coastal areas. However, little attention has been given to evaluation approaches for where and when such new technology and strategies should be pursued, or to the potential co-benefits or unintended consequences (The National Academy of Sciences National Research Council 2010).

Planning for sea level rise adaptation in transportation infrastructure will require new approaches to engineering analysis including the development and use of risk analysis based on uncertain SLR and the development of new engineering standards to reflect future climate conditions (The National Academy of Sciences National Research Council 2010). The U.S. Climate Change Science Program has recommended the following approaches to incorporate climate information into transportation decision-making (source**):

- Planning time frames

- Risk assessment approach
- Integrated climate data and projections
- Risk analysis tools
- Region-based analysis
- Interdisciplinary research
- Identification of vulnerable assets and locations
- Identification of opportunities for adaptation of specific facilities
- Understanding changes in the life span of facilities caused by SLR
- Understanding the modes and consequences of failure
- Assessing the risks, costs, and benefits of adaptation

As sea level rises, populations at low elevations areas along southeast coastline may move inland, thereby changing travel patterns. As a result, re-routing of current transit, roadways, and non-motorized systems may be necessary, along with the relocation of pipelines, freight, seaports and airport facilities. Travel patterns maybe adversely affected, including reduced operational efficiency as well as reduced capacity and level of service of the current systems. When any transportation sector or roadway becomes permanently or temporarily unusable, others will become congested. Traffic delays will affect the reliability, efficiency, and capacity of the remaining transit systems. Such transportation issues potentially may affect the safety and quality of life of the communities served by these transportation systems. Traffic safety plans, which would include warning systems that address the changes in environment conditions, need to be developed and implemented. In addition emergency response plans need to be modified with new evacuation routes, accessibility, and mobility plans based on the updated data on sea level rise, storm surge, and other climate-related hazards.

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Appendix: Dissenting Opinion

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In the years since the last National Climate Assessment (NCA), much research and planning have been conducted to support local and state-level climate change adaptation and mitigation. This chapter provides some great examples. It is clear that locally generated problems, especially congestion or development in low-lying and other areas vulnerable to extreme weather, can arguably rise to become regional and national level concerns.

The objective of this chapter is to deliver a concise summary of new information about SE transportation and climate change that is relevant to the 2013 iteration of the National Climate Assessment. The guidance to authors identifies eight priority topics: (1) risk-based framing; (2) confidence characterization; (3) documentation information quality, and traceability; (4) engagement, communications, and evaluation; (5) adaptation; (6) international context; (7) scenarios; and, (8) sustained assessment and research needs.

The design-level material in this chapter distracts readers from the core regional and national level information the authors were charged with providing. Readers should clearly understand that the best available information suggests (1) that the institutional arrangements that so successfully built our 20th century infrastructure systems appear unable to address our 21st century challenges; (2) that our transportation system is dependent on, and vulnerable to cascade effects from other systems; and (3) that we cannot appreciate the risk climate change poses until we understand how climate and weather drive financial viability and reliability.

To that end, information relevant to the national discussion needs to be presented more clearly for this technical analysis. For instance, although Bloetscher's 2012 article and risk assessment tool identified and prioritized threats posed by climate change to the transportation network in the SE, the co-authors of this chapter have focused perhaps too much on a subset of direct effects rather than on indirect effects and regional level independent variables.

The institutional arrangements for delivering effective infrastructure solutions, including transportation, are ineffective in the face of climate change and other challenges. Current program delivery processes are legacies of a different suite of challenges and budget realities (Government Accountability Office, 2012; Transportation Research Board, 2008; National Research Council 2009). Specifically, the present institutional arrangements provide acceptable levels of operational effectiveness and predictable costs, but are not suited to problems that require high levels of adaptiveness and integration (or, complexity; Heckscher 2007).

The regionally important elements of transportation in the SE include marine and inland ports; spaceports, airports, rail yards, truck terminals, urban centers, linear connections and intermodal hubs, and critical inter-related systems for telecommunications, power supply, stormwater, and water supply. The financial viability and reliability of each of these elements is dependent on a suite of independent variables. These independent variables are key to assessing the consequences of climate and weather-related exposure-response profiles, system adjustments, feedbacks, and cascade effects (Varis and Kuikka 1999; Keeney 1994).

Weather is generally a co-stressor affecting the financial viability and reliability of the SE transportation systems. Changing weather trends and accelerating rates of change are expected to drive the aforementioned consequences as well as the financial viability and reliability of transportation and related infrastructures that determine quality of life. At the SE regional level, nationally significant weather-related stressors are (1) geological hazards that transect freight corridors, such as karst zones and mountains; (2) the tolerance of critical materials such as steel rails and pavements to extreme heat and cold; and (3) economic health of agriculture and other industries that underpin financial viability of key transportation modes.

In addition, a challenging analytic problem is raised by the expectation of an ice-free Northwest Passage. Warming trends will open the Arctic Circle for year-round maritime freight in the foreseeable future, which is likely to have profound, but currently unpredictable effects on the economic viability of ports in the SE USA. The impacts will cascade through other dependent infrastructures.

This chapter is meant to help guide regional and national level discussions and decisions about transportation legislation, research, and investments. The SE transportation systems are mostly built-out, as are other lifeline infrastructure systems. Current and future legislation, research, and investments target renewal of these aging and deteriorating infrastructure systems in a cost conscious, adaptive, and integrative manner. Renewal, repair, and replacement is budget-constrained, but must provide robust solutions that improve the quality of life of future generations despite challenges related to climate change, economic competitiveness, energy supplies, national security, and disaster resilience (see, for example, National Research Council 2009).

Although this author does not agree with the focus and analysis of much of this chapter, specifically as some local issues might be considered irrelevant to the regional and national purpose, the chapter does contain three critical points. First, improving the institutional arrangements that deliver the transportation program is a pre-requisite to meaningful climate change mitigation and adaptation. Second, climate change is principally an indirect threat to the financial viability and reliability of SE transportation systems, which are part of larger interconnected complex systems. Third, the key information gaps are predictive tools that (1) assist management of inter-system connections, (2) describe the elasticity of the key independent variables that drive economic viability and reliability for each element of the transportation system, and (3) provide governance alternatives that would improve the adaptive and integrative aspects of program delivery.

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7 Agriculture

Impact of climate change on agriculture in the Southeast USA, including key climate vulnerabilities, uncertainties, adaptation, assessment and research needs.

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Introduction

For the southeastern agricultural sector, this chapter summarizes key vulnerabilities and impacts; describes the characteristics and importance; analyzes current and potential climate sensitivities and vulnerabilities; discusses uncertainties, summarizes subregion-specific impacts and opportunities as referred to in the literature; explores adaptation needs and opportunities; and concludes with recommendations for further assessment and research needs. We have taken into consideration a range of studies from within and outside the region to describe major impacts and likely projections for climate change in this region, which covers the 11 southeastern states, but does not specifically assess Puerto Rico and the Virgin Islands.

Summary of Key Vulnerabilities and Impacts

Changes in precipitation extremes

- Drought is already a major stress for rain-fed crops in the Southeast (SE), and drought impacts are predicted to become more frequent and severe, especially in the western part of the region. Both dryland and irrigated agriculture will be further affected by drought as a result of greater irregularity of rainfall distribution and increasing competition with other sectors for water resources.
- Flood frequency likely will increase as a result of predicted increased numbers and intensity of storms in some areas of the region. Floods cause direct damage to crops, especially if they occur during fruit set or near crop maturity, as well as indirect damage through soil erosion, leaching of nutrients, and loss of future productivity.

Changes in temperature extremes

- High temperature stresses are predicted to become more frequent and damaging to crops. Warm temperatures during the winter months reduce fruit set on blueberry, peach, and other crops that have a chilling requirement. These adverse impacts can be partly offset through the application of growth regulators, but such methods increase costs of production.
- Increasing summer heat stress will reduce crop productivity, especially if it occurs during flowering and seed set and if it is combined with drought.
- Heat stress already limits production of dairy and livestock, especially during summer months. An increased frequency of heat stress events will have the potential to force some dairy and livestock production northward.

Changes in tropical storm strength

- Projected increases in strength of tropical storms likely will cause extensive damage to nearly all agricultural systems, particularly when storms occur during maturation and harvest. Wind damage to perennial crops is particularly expensive and long lasting.
- Storm damage will negatively impact crops by reducing yield and crop quality. In addition storms also damage agricultural land; product handling, storage, and distribution systems; and equipment and buildings.

Increased atmospheric carbon dioxide

- Atmospheric carbon dioxide concentrations have a direct benefit to photosynthesis, especially for plants with a C_3 metabolism such as legumes, cotton, some cereals and most vegetable and tree crops particularly when under drought conditions. Many weeds also will benefit from increases in atmospheric carbon dioxide concentrations resulting in increased production costs associated with weed management.

Major research needs

- Agricultural simulation models are the main tools for quantifying climate change impact on crop and animal production. However, these models require significant improvements to deal appropriately with the complexity of climate change. Most important are needs to improve their ability to simulate heat impacts and interactions between temperature and atmospheric CO_2 concentration that are based on field research. In addition, their application to the study of climate impacts is limited by the lack of suitable climate datasets for historical and projected climates. These climate datasets need to provide daily data that include maximum and minimum temperatures, precipitation, and solar radiation. To date, attempts to produce datasets through dynamical or statistical downscaling of global climate models (GCMs) have not been successful.
- The other critical need for climate technology adoption is for deeper and broader social science research. In addition to economics, ethnographic and cognitive approaches to decision making science also must be addressed. The dearth of policy research and applications to date is largely due to limited funding for the social science in agriculture and a lack of understanding of the socioeconomic, cultural, and political systems within which climate-based decisions will be made.

7.1 Agriculture in the Southeast USA

The Southeast (SE) USA includes the Delta States, the Southeastern and Appalachian regions (USDA Farm Production Regions). States specific to this region are Arkansas, Louisiana, Mississippi, Kentucky, Tennessee, Virginia, North Carolina, South Carolina, Alabama, Georgia, and Florida (Figure 7.1). The region includes the Southern Seaboard, the Mississippi Portal, part of the Eastern Uplands, and Florida's Fruitful Rim. It represents one of the most diverse agricultural production regions in the USA as defined by the USDA Farm Resource Regions. Agriculture is a major economic contributor to the region's economy and communities. Seasonal and spatial variability of climate conditions, including rainfall and temperature distributions, soil types, and access to water for irrigation have led to the development of a diverse and intensive agricultural sector.

The SE has a land area of 135 million ha, which is 14.9% of the USA total. Although land use differs widely by county in the SE, 60% (about 79 million ha) is designated as forest, which is about 30% of the total forest land in the USA. Cropland in the SE totals about 21 million ha, which is about 15.7% of the region's landmass and 13% of the total cropland of the nation (Figure 7.1). Grassland pasture and ranges total about 11 million ha, which is 8.3% of the land in the region and 4.5% of the grassland pasture and ranges of the nation (USDA Land-Use 2011)

Diverse climate conditions, land-use options, access to water, availability of farm labor, proximity to urban markets, distribution systems, and financial farm income have led to large structural differences among the states and subregions. Beef cattle, most of which is grazed on improved pastures; poultry; and swine are raised throughout most of the SE. Georgia, Arkansas, and Alabama are the top three poultry producing states in the nation and North Carolina is the number 2 swine producing state in the nation. Crops grown in the SE include soybean, corn, fruits, and vegetables. Peanut and cotton are produced through most of the coastal plain from Mississippi to Virginia. Florida is the nation’s largest producer of citrus and an important producer of sugar cane and winter vegetables. In addition to the products already mentioned, the Delta States also produce rice, sugarcane, and small grains. The Appalachian States are the nation’s major producers of tobacco-and horses as well as major producers of peanuts, cattle and dairy (USDA - ARS 2012).

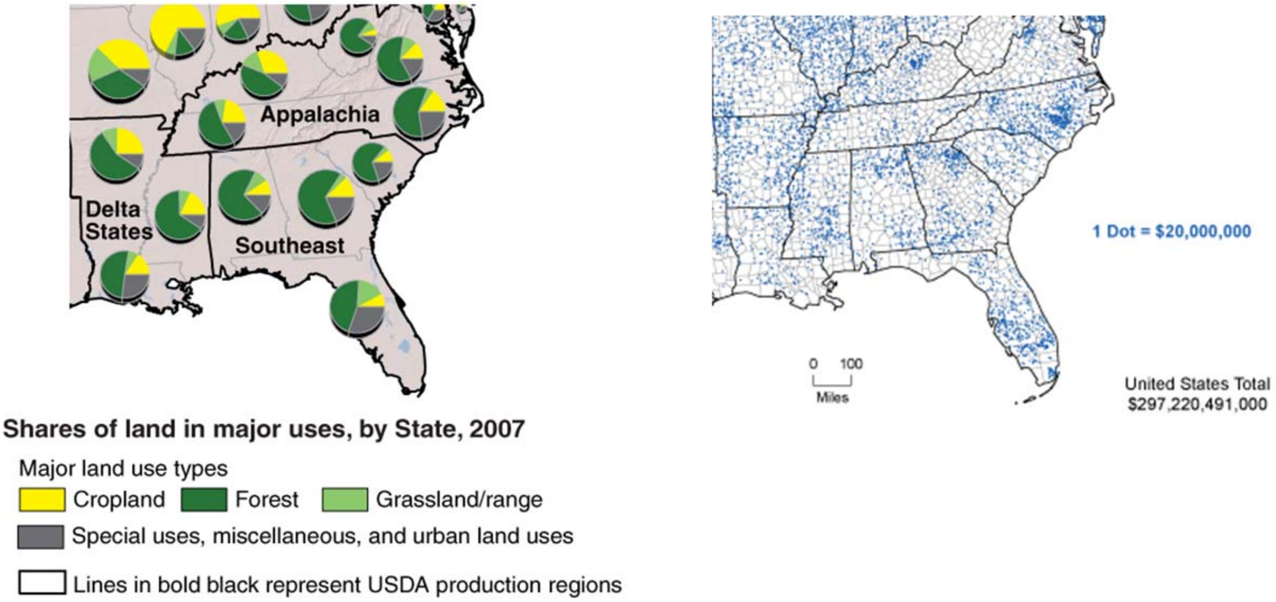

Figure 7.1. Maps show (a) shares of land use in the Southeast and (b) distribution of market value of agricultural products sold. Sources: (a) USDA Census 2007 and (b) ARS USDA 2011.

Within the SE, Alabama, Georgia, and Florida have the largest share of urban land use, which is well above the national average. Kentucky, Tennessee, Virginia, and North Carolina also have urban shares of urban land use above the national average (USDA Land-Use 2011).

The SE produces more than $55 billion in agricultural products annually, accounting for more than 17% of the total annual USA production (Figure 7.1). Of the total SE annual sales, more than 50% are derived from animal production with the top five commodities consisting of broilers, eggs and chicken products, cattle and calves, hogs, and dairy products (Table 7.1). Crops represent 40% of the annual production, and include fruits and vegetables, soybeans, greenhouse and nursery products, corn and cotton. The SE produces 66% of the nation’s broilers, 29% of the chicken eggs, 27% of the turkeys, 50% of the aquaculture, 37% of the cotton, 62% of the peanuts, and 33% of the tomato production (ARS USDA 2011).

Table 7.1. Regional population and agricultural sales in the Southeast. Source: USDA-ERS (2010).

Population	
Urban	59,600,000
Rural	16,900,000
Farms	528,800
Annual Sales	
Crop (Billion $)	25.6
Animal (Billion $)	31.1
Total (Billion $)	56.7

Since 1985, agricultural land used for cropping, pasture, and ranges has consistently decreased as a consequence of expansion in nonagricultural land uses. Between the 1985 and the 2007 census the region recorded combined losses of agricultural land greater than 18% (7 million ha). Nationwide, cropping areas for the same period declined by more than 24 million ha, with the SE accounting for 36% of this loss. For the SE, there is a greater decrease in cropping land than in pastures. The states with the biggest net agricultural land loss were Georgia, Mississippi, Louisiana, and Florida (USDA Land-Use 2011). These long-term trends are linked to a number of factors, including changes in farm policies, commodity price fluctuation, crop insurance, land ownership, and urban encroachment as a result of population growth.

Agriculture consumes more than 80% of the water used in the USA (Schaible 2004). Competing demands for water from population growth, energy sector growth, and environmental needs have intensified. The development and maintenance of irrigation technology is an important factor to successful and optimal agriculture. In 2007, about 23 million ha (17% of all cropland) in the SE was irrigated. Since 1982 growth rates in irrigation have slowed down nationwide and in most parts of SE, except for large expansions in the Delta Region and Arkansas (Nickerson 2011). The region accounts for about 15% of the total USA water used for agriculture: Arkansas is ranked second after California (USDA Land-Use 2011).

Agriculture is a large contributor to CO_2 emissions. However agriculture also provides opportunities for carbon sequestration and increased storage that have the potential to offset high emission rates, while providing economic value to landholders and farming businesses. For the region, conversion to restorative land use and adoption of carbon sequestration practices can help to achieve a positive carbon balance in agriculture (Lal 2011). Many practices that farmers implement as part of adaptations to climate changes will also mitigate carbon emissions. For example, carbon losses associated with grazing systems could be reduced through proactive management to conserve vegetative cover and to store soil carbon through integration of crop, pasture, and livestock production systems (Shepherd, 2011). This topic will also be addressed in the up-coming 2012 ARS GRACEnet assessment.

The diverse and intensive agricultural sector in the SE is highly affected by climate conditions and requires appropriate, continuously improving management practices. Climate impacts on agriculture profits, spill over into the broader agribusiness sector. Severe climate events such as floods and droughts have large impacts on the financial performance of agricultural businesses. For instance, the 2011 floods in the Mississippi River area were estimated to cost the Arkansas agricultural industry more than $500 million (Arkansas Farm Bureau 2011). The risks associated with such events are comparatively higher than in other industry sectors and require more intense risk management strategies. Relatively few of the crops grown in the SE are covered by government risk management programs, which tend to favor the major agronomic crops such as corn, soybean, and wheat, which are relatively less important in the SE.

Land and water are the most important production resources in the agricultural sector. The costs for using these resources in agricultural production are affected by a number of factors including urban encroachment, competition for water from other sectors, sea level rise, effects of weather and climate, and land degradation. Major input costs that influence agricultural production include fuels, chemicals, seeds, labor, resource management, and marketing. Between 2002 and 2007, farm-related production expenses have increased 39%. Individually, costs for fuel and fertilizers increased more than 80% during this time (USDA-ERS 2012).

The complexity of the agriculture sector requires management decisions that maximize production and minimize environmental impact on soils and water resources, in addition to mitigation of climate change and the adaptation to its likely effects (Lal 2011).

7.2 Climate Sensitivities and Vulnerabilities

Agriculture is highly sensitive to climate variability and change. Increasing temperatures, changes in rainfall, and higher atmospheric CO_2 concentration affect agricultural production through various physiological mechanisms. In combination, these factors will increase or reduce agricultural production; the net effect will depend on interactions among these factors. Sea level rise and increased frequency of hurricanes and tornados will have direct and indirect negative impacts on agriculture in coastal areas. Climate sensitivities and vulnerabilities also will affect productivity and production costs feed for animal production, under both free-range and confined conditions.

Adverse impacts of climate change on other economic sectors may increase the vulnerability of agriculture. For example, tourism and real-estate are important parts of the economy in most areas of the SE that have coastlines. With rising sea levels and the degradation of vulnerable coastal areas by storms and floods, the tourism industry is predicted to be substantially affected (ASP 2011). A study by Luscombe (2010) estimates that property values in the Florida Keys alone could be reduced by $11 billion by 2100 through the impact of sea level rise (see also Borisova et al. 2008). A negative growth in the tourism and real estate industries will affect the region's important food service sector through reduced demand for locally produced food, representing an important market for many agricultural businesses in the region.

7.2.1. Potential Impact of Rainfall Variability and Change

Changes in rainfall amounts can have both negative and positive effects on agricultural production. For example, in low rainfall environments higher rainfall will increase growth, where less rainfall will further limit plant production. In contrast, in high rainfall zones, too much rainfall can result in waterlogging, which damages crop growth (Dracup et al. 1993, Jiang et al. 2008) or result in nutrient leaching in sandy soils (Anderson et al. 1998). Additionally, reduced rainfall on these same soils will limit the negative impacts of waterlogging and nutrient leaching.

Rainfall distribution also plays an important role for determining crop yields. Rainfall around the time of anthesis ensures water supply during the grain-filling period and is particularly critical for grain yield in annual crops (Fischer 1979, Hatfield et al. 2011). Future changes in growing-season rainfall distribution therefore will have an impact on crop growth and yield. Balancing growth and water use before and after anthesis is one of the tools to manage uneven rainfall distribution. Options for managing the seasonal water use by crops include sowing time, nutrient management, plant density, and cultivar choice (Fischer 1979, Hatfield et al. 2011).

Extreme events are predicted to include a higher drought frequency leading to reduced crop production and yields below what is expected based on the average climate change (Easterling 2007). Particularly critical are changes in rainfall intensity and the distribution of small versus large rainfall events (Hayhoe et al. 2007), which can have significant consequences for crop production via the impact on soil infiltration depth, water balance, soil mineralization, and crop water use efficiency (Sadras and Rodriguez 2007).

The greatest impact of rainfall variability on livestock and poultry systems will be the indirect consequences of higher feed costs for purchased inputs. The impacts of changes in rainfall on forage production have not been as thoroughly researched as those for crop production but prolonged droughts could significantly alter these systems as very little forage land is irrigated. Selection of drought tolerant forages and improvements in grazing management to buffer against drought could aid producers in adapting to more frequent drought conditions.

7.2.2. Potential Impact of Temperature Change

Temperature affects plant and crop-level process that determine yield for all crops. Where crops are grown near their genotype specific limits of maximum temperature tolerance (Hatfield et al. 2011), heat spells can be particularly detrimental (Ferris et al. 1998). Conversely, in cooler regions such as the northeast of China, increased annual mean temperature since the 1980s has contributed to the reported increase in agriculture production (Yang et al. 2007).

Higher temperatures can negatively affect plant production indirectly as accelerated phenology (Menzel et al. 2006, Sadras and Monzon 2006a;) provides less time for accumulating biomass

(Amthor 2001, Asseng et al. 2002). Menzel et al. (2006) analyzed phenological data from 125,000 time series for 542 plants in 21 European countries. For the period 1971 to 2000, researchers found that 78% of all leafing, flowering, and fruiting events occurred earlier (Menzel et al. 2006). Sadras and Monzon (2006b) modeled in detail the effect of recently realized changes in temperature on phenological development of wheat, and found earlier flowering. However, unexpectedly, no changes were noted in the duration from flowering to maturity due to the shift of flowering to cooler parts of the season.

Extreme temperature events can have large negative impacts on plant growth and yield as shown for wheat (van Herwaarden et al. 1998). Temperatures of below 9^oC and above 31^oC around anthesis can reduce potential grain weight and therefore yield (Calderini et al. 2001). Higher average temperatures can reduce the frequency of frost, and frost damage (Baethgen et al. 2003). However, indirect effects of temperature may lead to the paradox of increasing frost risk in some systems (Sadras and Monzon 2006a). Sadras and Monzon (2006b) showed that shifting of flowering to “cooler” parts of the season due to accelerated phenology with higher temperatures could potentially increase the risk of frost at flowering.

The impact of increasing temperatures can vary widely between crop species. Optimum temperature for leaf photosynthesis and plant growth is higher for C4 than for C3 plants (Goudriaan and Van Laar 1994, Hatfield et al. 2011). Species with a high base temperature for crop emergence such as maize, sorghum, millet, sunflower and some of the legumes (e.g. mung bean and cowpea) (Angus et al. 1981, Hatfield et al. 2011) might benefit from increasing temperatures in cool regions. For most of the cereals; legumes such as field pea and lentil; linseed and oilseed crops with a low base temperature (Angus et al. 1981), a warming climate will result in an advanced phenology. For example Sadras and Monzon (2006a) showed that the date of wheat flowering in different environments is advanced about seven days per degree increase in temperature.

Climate change is not likely to have greater impacts on minimum than on maximum temperatures (Nicholls 1997), and such changes in diurnal temperature range can have different effects on various crops. Lobell (2007) analyzed historical yield data of wheat, rice, and maize from the leading global producers and showed that an increase in diurnal temperature range was associated with reduced yields of rice and maize in several agricultural regions worldwide. This reflects the nonlinear response of yield to temperature, which likely results from greater heat stress during hot days (Lobell 2007). Peng (2004) suggested that rice yields declined by 15% per degree Centigrade in minimum temperature due to wasteful night respiration, but this interpretation was challenged in subsequent studies (Sheehy et al. 2006a, Sheehy et al. 2006b). Baker et al. (1995) observed 10% loss in rice yield per degree above 25^oC mean daily temperature, based on extensive experiments in sunlit, controlled environment chambers.

An indirect effect of increasing temperatures due to climate change likely will be higher water demand by plants due to increased transpiration, which can potentially reduce plant production

(Lawlor 2000; Peng et al. 2004b). In dry-land agriculture, this will directly limit plant growth, while in irrigated systems increased temperatures could result in higher irrigation demands in combination with increased losses through evaporation. However, if future temperature changes are similar to the changes in the last 50 years, where global minimum temperatures have generally increased twice as fast as maximum temperatures, resulting in a reduced diurnal temperature range (Folland et al. 2001), the impact of increasing temperatures on vapor pressure deficit and therefore on atmospheric evapotranspiration would be very small (Farquhar et al. 1978). In addition, higher atmospheric CO_2 concentrations can partially compensate for the increased water demands due to higher temperatures, through lower stomatal conductance, which reduces transpiration (Kimball 2011). Reduced leaf transpiration as a consequence of higher CO_2 will also increase leaf temperature with an increased chance of plant damage due to heat stress. Plants grown at higher atmospheric CO_2 tend to have a higher leaf water potential, which results in reduced drought stress (Wall 2001).

Higher temperatures can also adversely affect grain quality as shown for grain protein content (Triboi et al. 2003; Zhao et al. 2008) and dough quality of wheat (Randall and Moss 1990; Wrigley et al. 1994). For some crops, night temperatures are critical for grain quality, as shown for fatty acid composition in sunflower (Izquierdo et al. 2002).

Increasing temperatures could have profound impacts on livestock and poultry producers. Heat stress in particular may lead to significant detrimental effects on production and reproduction of some livestock species. Heat stress in dairy cattle can have a long-term effect (weeks to months) on both milk production and birthing rates (Klinedinst et al. 1993). Dairy cows perform best under cool temperatures, with the temperature optimum for maximum milk production between 4 ^{o}C and 24^{o}C. At high relative humidity (>80%) heat stress in dairy cows can begin at temperatures as low as 23 ^{o}C, and stress becomes severe at 34^{o}C. Dairy farmers could adapt to warmer temperatures by renovating barns to improve their cooling systems, but these costs would have to be weighed against potential risks and benefits. Poultry animals are primarily grown in housed operations, so the effect of climate change more directly affects the energy requirements for building operation rather than a direct effect on the animal. Similar statements can be made for swine production as the vast majority of the animals are housed. Temperature affects animals being moved from buildings to processing plants, but because these animals are moved quickly from production to processing, this is a problem only in extreme conditions (Hatfield et al. 2008).

7.2.3. Potential Impact of Elevated Atmospheric CO_2 Concentrations

Elevated CO_2 has two main effects on crop growth. It increases the intercellular CO_2 concentration leading to increased net photosynthesis rates, and at the same time reduces stomatal conductance resulting in reduced transpiration and improved water use efficiency (Farquhar et al. 1978). Many experiments have shown that higher CO_2 concentrations increase plant biomass production and yield (Drake et al. 1997, Garcia et al. 1998, Ma et al. 2007; Morison 1985, Tubiello et al. 2007, Kimball 2010, Hatfield et al. 2011). However, C3 species respond differently to elevated CO_2 than do C4 species (Allen et al. 2011; Prasad et al. 2005; Kimball 2010; Hatfield et al. 2011) (see Table 7.2)

Table 7.2 Examples of C3 and C4 Species

C3 Species	C4 Species
• Small grains such as wheat, barley, oats, and rye • Grain legumes such as soybean, peanuts, various beans and peas • Root and tuber crops such as potato, sweet potato • Most oil, fruit, nut vegetable and fiber crops; and cool climate forage and grassland species, wheat, soybean, potato, sunflower	• Maize, sorghum, sugarcane • Many warm-climate grass species grown

Increases in CO_2 concentration increase photosynthesis more than crop yield; at 500 to 550 ppm, yields of C3 crops will yield 15% to 30% more, whereas C4 crops will yield up to 25% more (Kimball 2011; Tubiello et al. 2007; Long et al. 2006; Hatfield et al. 2008, Hatfield et al. 2011). On average, doubling CO_2 concentrations increases photosynthesis from 30% to 50% in C3 species, and from 10 to 30% in C4 species (Kimball 2011, Tubiello et al. 2007). Lobell (2007) summarized CO_2 effects from a number of open-top chambers and Free Air Carbon-Dioxide Enrichment (FACE) experiments with 0.07% grain yield increase in wheat per ppm CO_2 increase for up to 550 ppm.

The response of pasture species to elevated CO_2 is consistent with the general response of C3 and C4 vegetation to elevated CO_2. Pasture species with C3 metabolism increase their photosynthetic rates by up to 40%, but not those with a C4 pathway (Hatfield 2008). Unlike croplands, the literature for pasturelands is sparse in providing quantitative information to predict the yield change of pastureland species. Current information indicates forage yield responses of C3 versus C4 perennial forages to be similar to corresponding C3 or C4 annual crops (Newman et al. 2001). The projected increases in temperature and the lengthening of the growing season should be, in principle, beneficial for livestock by increasing pasture productivity and reducing the need for forage storage during the winter.

The impact of elevated CO_2 on plant production depends on water and nutrient availability. The greatest response to elevated CO_2 is found under water limiting conditions (Kang et al. 2002; Manderscheid and Weigel 2007, Kimball 2010) because higher CO_2 concentrations increase leaf and plant level water use efficiency (WUE) (Wu et al. 2004, Kimball 2010; Allen et al. 2011). Low nutrient availability can reduce the positive impact of elevated CO_2 on yield (Kimball 2011). The impacts of elevated CO_2 at field and farm levels are probably lower than those estimated in well-controlled experimental conditions because, due to production limiting factors such as low nutrient availability, pests, and weeds (Tubiello et al. 2007). An important indirect effect of higher atmospheric CO_2 is reduced plant nutrient concentrations, which can result in lower grain quality (Kimball et al. 2001; Rogers et al. 1996).

An indirect effect of elevated atmospheric CO_2 is an increase on canopy temperatures via the reduction in stomatal conductance (Kimball 2010; Hatfield et al. 2011). There is evidence in C3 plants, as found in experiments with wheat and cotton, that selection for improved grain yields in breeding programs is more successful when selecting for high stomatal conductance, resulting in heat avoidance through evaporative cooling in hot environments (Amani et al. 1996, Lu 1994; Radin et al. 1994). Reduced stomatal conductance in response to increased atmospheric CO_2 might therefore have additional effects on crop growth and development similar to an increase in temperatures (Allen et al. 2011).

7.2.4. Potential Impact of Tornados, Hurricanes, and Sea Level Rise

High wind speeds of tornados and hurricanes can destroy most summer crops, particularly at later growth stages where it could result in lodging. The impacts on confined poultry or livestock can be devastating if facilities are destroyed resulting in long periods without production and considerable animal mortality. Heavy rainfall from hurricanes can lead to soil water-logging, delays in harvesting, degraded crop quality and overall yield losses. Sea level rise will affect ground water availability for irrigation near the coast due to salt water intrusion. In addition, retreating urban populations from the current coast line will put pressure on agricultural areas (Spechler 2001).

7.2.5. Potential Combined Impact of Climate Change

Rainfall, temperature, and CO_2 concentrations do not change independently but interact with each other and are highly complex (Hatfield et al. 2011). To develop climate change adaptation strategies so that crop production can remain stable in a changing climate, it is important to sufficiently understand the complexity of natural systems and how these are affected by changing climatic factors (Boote et al. 2011). Wheeler et al. (1996) showed that a positive yield effect in wheat from 700 ppm elevated CO_2 in the UK could be offset by an increase in mean seasonal temperatures of 1°C to 1.8^{o}C. It is important to understand the interactions before developing climate change adaptation strategies because, for example, adaptations to higher temperatures may be different from adapting to reduced rainfall (Ludwig and Asseng 2008, Tubiello et al. 2007).

Another study by Allen et al. (2011) based on experiments with maize and sorghum, suggests that drought stress in C4 crop plants can be ameliorated at elevated CO_2 as a result of lower stomatal conductance and sustaining of intercellular CO_2 concentration. Furthermore the study suggests, that C4 crops may require less water under future higher atmospheric CO_2.

In livestock and poultry production, Reynolds et al. (2010) stated that changing climate would affect the following: (1) the suitability of land, (2) availability of land due to sea level rise, (3) water availability and quality, and (4) production efficiencies under drought conditions. As local environmental conditions change, so too will the spread of livestock diseases in response to the changes in prevalence of the host species and the suitability of environmental conditions for pathogen transfer. Van Dijk et al. (2010) found clear evidence that climate change has already changed the overall abundance, seasonality, and spatial spread of endemic helminthes (parasitic worms in cattle) in the UK. Warming and changes in rainfall distribution may lead to changes in spatial or temporal distributions of those diseases sensitive to moisture such as anthrax, blackleg, *haemorrhagic septicaemia*, and vector-borne diseases (Hatfield et al. 2008). Pastureland response to climate change will likely be complex because, in addition to the main climate drivers, other plant and management factors might also influence the response (e.g., plant competition, perennial growth habits, seasonal productivity, and plant-animal interactions).

7.2.6. Climate Change Impact in the Southeast USA

A previous SE regional climate change assessment report summarized impacts of climate change on agriculture, forestry, air, and water quality (Ritschard et al. 2002. The effect of climate change on the crops studied in the report could be positive or negative, depending on location and crops. Dryland crops are expected to be more sensitive to climate change: a decline of 20% rainfall and an increase of 2^{o}C temperature will cause yield losses from 10 to 15% by 2030 (Ritschard et al. 2002). Irrigated crop yields will decrease by 10%, except for rice, peanut, and soybean, which will increase 10% to 20% by 2030. The agriculture sector will likely be able to adapt to mild increase of temperatures of 1°C by 2030 provided rainfall increases. An increase in temperature will cause row crops growing in Alabama, north Florida, and southwest Georgia to shift north towards central Georgia, South Carolina, and North Carolina. Access to water for irrigation has been identified as the largest challenge to adapt to declining rainfall. Although some regions in the SE have access to shallow groundwater tables for irrigation, these areas are at risk of salt water intrusion projected sea level rise (Ritschard et al. 2002). Also, competition for freshwater between agricultural industry, urban communities, and ecological sectors will continue to increase. Recommended strategies to adapt to climate variability and change include improved seasonal forecasts, drought and heat stress resistant crops and livestock, adjustments of planting dates, and improved water management and fertilization practices to keep water reserves clean and available for the growing demands (Ritschard et al. 2002).

Hatfield et al. (2011) showed how future climate change likely will affect crops differently across the USA, due to different crops responses (e.g., C3 versus C4 plants), but also different base conditions (warmer and drier south versus cooler and wetter Midwest). For example, yields of maize and soybean likely will be less negatively affected in the Midwest than in SE, where increasing CO_2 (440 ppm) and temperatures (+0.8^{o}C) will be more detrimental because of the fundamentally warmer climate in the South (Hatfield et al. 2011).

Higher temperatures will increase the atmospheric evaporative demand for water, thereby increasing evapotranspiration (ET). The effect of warmer temperatures on evaporative demand might be offset in part if warmer temperatures increase cloud cover. Higher atmospheric CO_2 is predicted to stimulate crop growth but also increase water use efficiency. Increasing temperature and CO_2 effects are of the same magnitude by 2040 in the USA (440 ppm, +0.8^{o}C) but act in the opposite direction. The combined impacts of these effects will mean that the net changes to evapotranspiration likely will be minimal (Hatfield et al. 2011).

Climate changes will adversely affect the economic viability of livestock production systems. Surrounding environmental conditions directly affect mechanisms and rates of heat gain or loss by all animals. Lack of prior conditioning to extreme weather events often results in catastrophic losses in the domestic livestock industry. In the central USA in 1992, 1995, 1997, 1999, 2005, and 2006, some intensive cattle feeding operations lost in excess of 100 head each during severe heat episodes (Hatfield, 2008). Economic losses from reduced cattle performance (morbidity) likely exceed those associated with cattle death losses by several-fold (Mader 2003). The risk potential associated with livestock production systems due to climate variability can be characterized by levels of vulnerability, as influenced by animal performance and environmental parameters (Hahn 1999). When combined performance level and environmental influences create a low level of vulnerability, there is little risk. As performance levels (e.g., rate of gain, milk production per day, eggs per day) increase, the vulnerability of the animal increases and, when coupled with an adverse environment, the animal is at greater risk. Combining an adverse environment with high performance pushes the level of vulnerability and consequent risk to even higher levels. At very high performance levels where much of the highly efficient production in the SE is, any environment other than near-optimal may increase animal vulnerability and risk.

The potential impacts of climatic change on overall performance of domestic animals can be estimated using defined relationships between climatic conditions and voluntary feed intake, climate data, and GCM output. Because ingestion of feed is directly related to heat production, any change in voluntary feed intake or energy density of the diet will change the amount of heat produced by the animal (Mader et al. 1999). Ambient temperature has the greatest influence on voluntary feed intake. Body weight, body condition, and level of production affect the magnitude of voluntary feed intake and ambient temperature at which changes to voluntary feed intake begin to be observed. Based on predicted climate outputs from GCM scenarios, production and response models for growing confined swine and beef cattle, and milk-producing dairy cattle, have been developed (Frank et al. 2001). The goal in the development of these models was to utilize climate projections, primarily average daily temperature, to estimate direct climate-induced changes in daily voluntary feed intake and subsequent performance across the entire country. The production response models were run for one current (pre-1986 as baseline) and two future climate scenarios: doubled CO_2 (~2040) and tripled CO_2 (~2090) levels. This database employed the output from two GCMs—the Canadian Global Coupled (CGC) Model, Version I, and the United Kingdom Meteorological Office/Hadley Center for Climate Prediction and Research model—for input to the livestock production and response models. Across the entire USA, days to market for swine increased 1.2% for the CGC and 0.9% for the Hadley model; days to market for beef increased 2.0% for the CGC and 0.7% for the Hadley model; and dairy milk production decreased 2.2% for CGC and 2.1% for the Hadley model. Swine and beef production were affected most in the south-central and SE USA. Dairy production was affected the most in the Midwest and Northeast. In the east-central USA, per animal milk production declined 388 kg (~4%) for a July through April production cycle, and 219 kg (~2.2%) for an October through July production cycle as a result of global warming. Swine growth rate in this same region was found to decline 26% during the summer months, but increased nearly 12% during the winter months as a result of climate changes. Approximately one-half of these summer domestic livestock production declines are offset by improvements in productivity during the winter.

Amundson et al. (2005) reported a decrease in pregnancy rates of cattle of 3.2% for each increase in average Temperature Heat Index (THI) above 70, and a decrease of 3.5% for each increase in average temperature above 23.4°C. These data were obtained from beef cows in a range or pasture management system. Minimum temperature had the greatest influence on the percent of cows getting pregnant. Clearly, increases in temperature or humidity have the potential to affect conception rates of domestic animals not adapted to those conditions.

A range of reviewed subregional and state-based assessments and impact studies predicting direct and indirect impacts on the agricultural sector in the SE region are summarized in the following sections.

Virginia. Increased storm surges and flooding are projected from higher sea levels on 5,335 km Virginia tidal shoreline. The state is highly susceptible to damage from hurricanes, storms, and water surges that are forecast to intensify and are likely to result in increasing economic damages and losses.

Virginia can play an important role in reducing fossil C emissions as it has an abundance of required resources for biomass combustion, including mill and crop residues (Commonwealth of Virginia; ASP 2011).

North Carolina. An increase in global temperature likely will shrink North Carolina's booming $70.8 billion agricultural industry by nearly 23% by the end of the century. Between 1996 and 2006, 14 tropical storms and hurricanes caused more than $2.4 billion of damage to the state's agricultural Industry (CIER 2009). The state's 2002 drought cost the industry $398 million and affected over 4,300 jobs (NCSL 2008). The Appalachian region livestock industry is projected to lose 10% of its yield through heat stress due to projected temperature changes (CIER 2009).

Tennessee. Impacts of climate change are predicted to negatively affect Tennessee soybean and corn industry. Temperature increases will reduce corn and soybean yields (USDA 2010).Higher temperatures could impact the lifespan of the Kentucky-bluegrass, an important turf grass (Texas Cooperative Extension, Kentucky Bluegrass 2010).

South Carolina. Agriculture accounts for 14.8% of South Carolina's GDP. One-quarter of the state's 17.7million ha has been converted to farmland; and agriculture accounts for around $17 billion annually. Expected temperature increases are likely to hasten the maturation of plants, thus reducing total yield potential. The U.S. Environmental Protection Agency projects that South Carolina's soybean and wheat yields will fall by 42%, and its corn yields by 32%, with predicted rising temperatures (ASP 2011). Climate change will lower agricultural productivity in the long term for South Carolina due to increasing extreme weather events, pest infestations, and a northward shift of optimal production areas (Van Lehe 2008).

Alabama. A study by Davenport (2007) suggested that in Alabama traditional crops such as peach, apple, soybean, and wheat will suffer from climate change. In addition, more pesticides and herbicides will be required under any of the projected climate scenarios. However, increasingly favorable conditions are likely for cotton, corn, and new citrus crops. The predicted impact of sea level rise on the Gulf Coast region's integrated network of roads, ports, and rail lines will impact Alabama through its central location in this network. The Union of concerned Scientist notes that 27% of the major roads, 9% of rail lines and 72% of ports within the region are built at or below sea level. Alabama's interconnectedness threatens its economy, inclusive of the agricultural sector (ASP 2011). Of the 70 natural disasters between 1980 and 2007 that caused $1 billion or more in damage nationally, at least 21 affected Alabama (CIER 2007).

Georgia. A study by the Center for Integrated Environmental Research suggests that by 2020, corn yields will drop by 15% and winter wheat yields will drop by 20% in parts of Georgia. However, soybean and peanut yields could increase as much 25% in northern Georgia and drop by 5% in the southern part of the state (CIER 2009). The 2007 drought cost Georgia $1.3 billion in damages including crop losses of $83.8 million in hay, $160.1 million in cotton, $92.5 million in peanuts, and $63.1 million in corn (CIER 2009).

Florida. Sea level rise, in combination with increased frequency and intensity of storms, hurricanes, and associated seawater surges, is predicted to be the largest threat to Florida. A Natural Resources Defense Council report estimates for instance that by 2060 16% of the Miami Dade County will be inundated with water. Miami Dade County produces more than $661 million annually in agricultural produce (2007), and is the second largest agricultural producing county in Florida. (Hauserman 2007; Stanton and Ackerman 2007; USDA 2010).

Hurricanes are predicted to cost the state economy, including agriculture, $6 billion annually in 2025, jumping to $25 billion by 2050 (Hauserman 2007; Stanton and Ackerman 2007). Florida's agricultural industries are predicted to be affected by higher temperatures, water scarcity, flooding of farmland that will cause crop losses and erosion, increased water demands, and increased costs for irrigation. Higher temperatures might lessen the likelihood of crop damaging winter freezes. By 2060, floods are predicted to claim 10,400 ha of farmland, 1800 ha of pasture, and 2800 ha of Florida's citrus crop (Stanton and Ackerman 2007, Borisova et al. 2008). Preserving a sustainable citrus production in Florida could provide opportunities to expand the production of ethanol from citrus waste (USEIA 2010).

Mississippi. Warmer temperatures and less rainfall will require additional irrigation to maintain the $4.8 billion agricultural industry in Mississippi (EPA 2010). Higher temperatures are also predicted to increase pests and weeds and reports suggest that one of the most used and cost-effective herbicides, glyphosate, will be less effective under conditions of higher concentration of carbon dioxide (ASP 2011). The state's vulnerable aquaculture industry will be under threat as a result of shrinking freshwater supplies, increasing salinization, warmer water temperatures, and contaminated runoff from high precipitation events (Twilley and Miller 2001). Opportunities exist for increased soybean-based biodiesel production, cellulosic ethanol made from crop residues, and renewable energy production from swine, poultry and dairy industries. Mississippi already has the nation's first methane producing system from poultry waste (ASP 2011).

Arkansas. The agricultural industry in Arkansas contributes $16.3 billion to the state's economy (DOA 2010), and the impacts of climate change are predicted to lead to increased industry costs of production and reduced yields, causing a decrease in the sector's profitability according to an analysis of effects of 2009 weather conditions on crop production (Hignight et al. 2009). Twenty-two percent of the state's agricultural land lies in flood zones. Soil erosion from increased flooding will need to be managed (America 2010). Abnormal weather events, predicted to increase in the future, caused an estimated loss of revenues close to $397 million in 2009-- $204 million for soybeans and $46 million for rice. Production levels of rice are expected to drop in the Mississippi Delta by 10% to 20% (Hignight 2009). Agriculture has great potential to help Arkansas reduce its carbon emissions through production of biodiesel and cellulosic ethanol using crop residues, which has the potential to replace 40% of the gasoline used in the state (ASP 2011; Cohen 2009).

Louisiana. The low-lying coast of Louisiana, including New Orleans, could be entirely under water by 2100 due to sea level rise. The state currently loses wetlands at rate of 6200 ha annually. Impacts of climate change include increased occurrences of storms, hurricanes, and floods (Wilbanks 2010) and also increased droughts that are expected to impact the state's agricultural industry (ASP 2011).

7.3 Adaptation to Climate Change and Variability in the Southeast USA

Climate change effects clearly will have impact on agriculture in the Southeast. Various types of adaptation can protect and even improve farm productivity. Adaptation has the potential to help farmers minimize negative effects or take advantage of positive effects of a changing climate. In most cases, adaptation to climate change in agriculture will occur locally, at the farm level, in response to and as preparation for local impacts of local or regional changes in rainfall and temperature and global changes in atmospheric CO_2 concentrations. Therefore, understanding the local impacts of regional climate change is a prerequisite for any adaptation strategy, since adaptations are devised at the local level in response to local conditions (Figure 7.2).

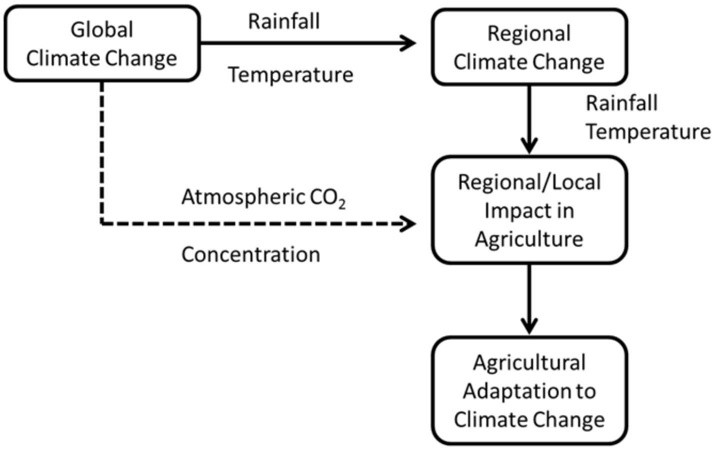

Figure 7.2

Most recent adaptations in agriculture in the SE USA relate to improved management in dealing with climate variability that includes frequent droughts, heat, frost, and high wind speeds. Recently, a better understanding of seasonal variability has emerged from climate-related agricultural research in the SE USA (Alexandrov and Hoogenboom 2001, Garcia y Garcia et al. 2006, Persson et al. 2011), the forecasting of seasonal climate (Bannayan and Hoogenboom 2008, Garcia y Garcia et al. 2010b, Olatinwo et al. 2010, Olatinwo et al. 2011, Royce et al. 2011), managing anticipated seasonal variability (Alexandrov and Hoogenboom 2001, Garcia y Garcia et al. 2006) and the management of climate-related pest and diseases (Boote at al. 2008). Studies on managing seasonal climate variability include research on farm-level risk management using irrigation (Lin et al. 2008), alternative crop insurance indices (Deng et al. 2008), optimizing crop insurance (Cabrera et al. 2006), spatial drought stress assessments (McNider et al. 2011), and the development of weather research and forecasting decision support tools (Olatinwo et al. 2011). Management tools for adaptation are available through AgroClimate. This widely-used climate-based decision support system, includes tools for seasonal forecast for the SE, planting date scheduler, growing degree days and chill units tools, drought indices, and a host of other decision aids delivered via the Internet (www.agroclimate.org) (Fraisse et al. 2006b).

Due to the relatively small changes in past climatic factors (rainfall, temperature, and CO_2), little adaptation has occurred that is exclusively related to historically experienced climate change. A number of researchers have studied the potential effects of changing climate and atmospheric CO_2 on agriculture (Bannayan et al. 2009, Ben-Asher et al. 2008, Garcia y Garcia et al. 2009, Garcia y Garcia et al. 2010a, Yoon et al. 2009) to prepare for climate change. Others have investigated these impacts on the future of agriculture assessing the potential for adaptation

(Crane et al. 2011, Persson et al. 2011, White et al. 2011, Furman et al. 2011). For instance, alternative crops for ethanol production, as an important strategy for climate change mitigation, have been investigated in a number of studies (Persson et al. 2010a, Persson et al. 2009a, Persson et al. 2009b, Persson et al. 2010b).

7.3.1 Current Adaptation Strategies in Crop Production

Several possible adaptation strategies have been suggested to optimize crop production to local climate and to adapt to climate variability. Such methods will also assist in adapting crops to future climate change trends. Farmers in the SE have been testing a number of these new technologies, including sod-based rotation, conservation tillage, the usage of high biomass cover crops in combination with strip tillage and precision nutrient placement, optimum irrigation and fertilizing strategies, and decision support systems such as AgroClimate.

Sod-based rotation. A sod-based rotation is a four-year rotation that includes two years of bahiagrass pasture/hay, followed by peanut, a winter cover crop, and cotton. The system has greater water-use efficiency as a result of increased soil organic matter and increased root activity at greater depths. The root mass produced by perennial grass is 20 mg/ha, compared with annual cover crops that produce only 3 to 4 mg/ha root mass. In addition, this system achieves greater efficiency of nutrient with less nitrate leached into ground water, greater soil cover for moderation of high temperature extremes, and reduced erosion. Other benefits include slower decomposition of crop residues that enhance opportunities for C sequestration and better yields at lower than conventional rates of fertilizer N, potentially mitigating greenhouse gas emissions (Wright et al. 2012).

Sustainable soil management strategies. Conservation tillage is one of the sustainable soil management strategies adopted in the SE. Conservation tillage is defined by USDA-NRCS as a system that leaves enough crop residues on the soil surface after planting to cover at least 30% of the soil area. Conservation tillage reduces climate risks through: reduced runoff, increased water infiltration, increased plant-available water, reduced soil water evaporation, and reduced diurnal temperature fluctuations (Smith et al. 2011).

High biomass cover crops with strip tillage, and precision nutrient placement. The use of high biomass cover crops and limited tillage reduces impacts from weather extremes such as intense rainfall events, short-term spring/summer droughts, and extreme soil temperature during critical crop reproduction periods. Keeping the soil covered year round with crop residue, cover crops, or cash crops reduces soil erosion, improves water infiltration, reduces evaporative moisture loss, and moderates soil temperature. Precise nutrient placement improves nutrient efficiency during weather extremes.

Variable-rate irrigation. Variable-rate irrigation (VRI) is an innovative technology that retrofits existing center pivot systems and integrates GPS positioning with a control system that cycles individual sprinklers or groups of sprinklers on and off and varies travel speed to achieve desired irrigation rates within management zones. VRI reduces climate-related risks through reduction of total irrigation water volume required to grow field crops, exclusion of non-crop areas from water application; enhanced ability to tailor water application to varying crop needs across the field; better matching of irrigation application to site-specific soil types, textures, and topography reduction of nutrient leaching by application of optimal irrigation volumes; and reduction or elimination of runoff by better managing water application.

Micro-irrigation. Micro-irrigation is the slow, frequent application of water directly to relatively small areas adjacent to individual plants through emitters placed along a water delivery line, for example, drip irrigation. Micro-irrigation can help farmers adapt to climate changes through improving water use efficiency and reducing irrigation water volume required to grow crops, flexible irrigation based on the difference between potential and actual crop evapotranspiration, reduced nutrient leaching, optimal timing of nutrient applications, and application of fertilizer directly in the root zone. In addition, micro-irrigation is compatible with plastic mulch, which helps soil water conservation and protects fertilizer from leaching. Micro-irrigation via micro-sprinklers also provides freeze protection for small, high-value crops, such as strawberries. Information on these various methods is available through publications from IFAS (www.edis.ifas.ufl.edu).

Sensor-based, variable-rate nitrogen management. A sensor-based, variable-rate nitrogen application (SVNA) system for irrigated and dry land cotton reduce, production costs through the use of a nitrogen-rich calibration strip (NRCS) that guides mid-season nitrogen fertilization. The NRCS guidelines are adjusted for seasonal climate variability that arises in response to El Niño and La Niña events. Although the system will not mitigate risks from drought, excess rainfall, and temperature extremes, the technology can significantly reduce the nitrogen footprint for crop production to reduce greenhouse gas emissions.

AgroClimate: Information and tools for climate-smart agriculture in the SE USA. AgroClimate is a Web-based climate information system that includes seasonal forecasts and numerous management options for different crops/climate scenarios and tools that help producers plan for the season ahead. Users can also monitor variables of interest such as growing degree days, chill hours, disease risks for selected crops and drought conditions. Growers can use AgroClimate to reduce climate-related risks through tracking seasonal climate outlooks to better understand how climate conditions might affect crops, learn how El Niño and La Niña events affect the local climate, to explore how El Niño and La Niña phases affected crop production in the SE USA, to help determine optimal planting dates for predicted climate, to select crops and varieties better suited for the expected climate, and to improve monitoring of disease risks for selected crops. In addition growers can monitor soil moisture conditions using several drought indices and be alerted via e-mail and mobile phones about detrimental soil conditions for specific crops (Fraisse et al. 2006).For more information and to use AgroClimate, go to www.agroclimate.org.

Livestock and Poultry Adaption Strategies. Livestock production systems have adapted slowly over a long period of time to suit local environmental conditions, such as water and forage availability. In animal agriculture, adaptation technologies have been studied far less than mitigation options (Thomas et al. 2011). Priorities include (1) use of species-rich mixtures, legumes, and better adapted forage species and cultivars adaptation in forage lands; (2) permanent pasture management by changes in grazing frequency to favor the maintenance of high-digestibility species and to increase tolerance to drought stress; (3) use of intercropping with legumes and use of C_3 and C_4 species of feed crop mixes; (4) integrated control options to reduce the spread and impacts of gastrointestinal parasites, especially in ruminant production systems; (5) provision of more shade or water in extensive grazing systems and development of improved technologies for reducing heat stress impacts in confined systems; (6) changes in livestock and poultry breed selection and selection to favor animals that are more tolerant of local conditions; and (7) development of improved tools to provide producers with warnings of when temperature heat indexes are nearing threshold levels so that producers can take action to avoid losses.

7.3.1 The Capacity for Agricultural Stakeholders to Adapt to Climate Change

The capacity for agricultural stakeholders to adapt to climate change is determined by more than their access to appropriate technologies or management practices. Social, political, and economic factors also shape adaptive responses. These include, but are not limited to, the degree to which farmers are concerned about the impacts and risks of long-term climate change, their access to and use of climate information; the ways in which they are actively connected within knowledge and community networks; and their capacity to address problems at household and farming system levels, in addition to those infrastructural, market, and policy barriers that limit also options for adaptation.

A politicized struggle to shape public understanding of climate change in the USA has polarized the debate in the media. The scientific consensus is framed through elements of dread and uncertain risk, while climate change deniers portray climate change as natural, familiar, and improbable (Weber and Stern 2011, Lieserowitz et al., 2008). Within this context, many agricultural stakeholders in the SE USA find it difficult to assess the risks that climate change presents. Furthermore, because farmers manage many different types of risks on a day-to-day basis, the potential impacts of long-term climate change might not always motivate immediate concern (Ingram et al. 2012). Studies have shown that political ideologies also correlate strongly with belief in climate change as seen among organic farmers (Furman, 2009) and African farmers in the southeastern states (Bartels, at al. 2012a, b). Another study demonstrated, for instance, that conservative white males are more likely to be climate skeptics (McCright 2010). In the SE, only one-eighth of the farm operators are women, with an average age from 56 to 58. The majority of farmers in the SE who are likely to make management decisions in the agricultural sector are older, more conservative, white men (AgCensus 2007).

The challenge of communicating about climate change with more skeptical audiences is being addressed within the SE Climate Consortium (SECC) by focusing initial discussions on climate-related issues that are of more urgent concern to growers. The manner in which scientists begin to engage with farmers about climate change can influence their receptiveness to exploring adaptation options. By focusing on climate issues that resonate strongly with growers, researchers can open the door to future discussions about longer-term changes (Bartels et al. 2012). For example, due to the strong influence of La Niña and El Niño on agricultural production in the SE USA, seasonal variability and extreme events are areas where scientists have the best potential to engage with farmers in implementing on-farm adaptation strategies (Ingram et al. 2012). In surveys conducted with row crop farmers, extension specialists, and researchers, respondents indicated that weather or seasonal forecasts were more useful to them than longer-term projections (Figure 7.3; Bartels et al. 2012). This was also demonstrated in studies by Crane at al. (2010) and Furman et al. (2011). A large body of research and extension within the SECC has centered on providing farmers and extension professionals with seasonal climate forecasts and coproduction of decision support tools to reduce climate-related risks (Breuer et al. 2008, Breuer et al. 2009, Cabrera et al. 2008, Fraisse et al. 2009, Fraisse et al. 2006a, Ingram et al. 2012, Furman et al. 2009). Approaches developed and knowledge gained from these projects to help farmers manage risks from seasonal climate variability are now being applied to new projects concerning to help farmers adapt climate change.

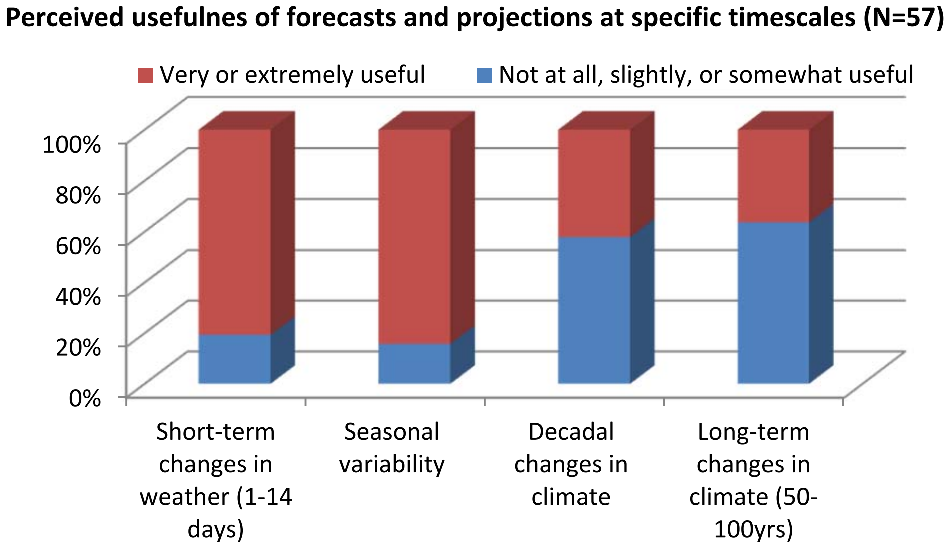

Figure 7.3. Perceived usefulness of forecasts and projections at specific timescales among row crop stakeholders (N=57) in the SE USA (Bartels et al. 2012).

Enhancing farmer use of climate information also requires an understanding of the social nature of risk management and information processes. For instance, social networks are important for processing information (Crane et al. 2010). Farmers discuss weather and climate at social gatherings, when doing business with buyers and brokers, or at meetings with extension agents (Crane et al. 2010, Furman et al.2011). The extension systems within the land-grant universities provide boundary organizations that link scientists to farmers for information diffusion and decision support. A survey of Florida extension agents found that between 2005 and 2009, knowledge and willingness to use and provide climate information to end users increased on average, and extension agents had refined their understanding of the types of climate information that are most useful (Breuer et al. 2010). These findings highlight the importance of receiving feedback from stakeholders about technologies. Participatory methods can be used to understand farmers' perceptions, attitudes, long-term goals, and other cognitive and decision-making information before and during the development of decision support tools and systems (Breuer et al. 2008. Breuer et al. 2009; Cabrera et al. 2008, Fraisse et al. 2006a). Fraisse et al. (2009) provide a framework for developing an extension program that combines climate variability and climate change (Figure 7.4).

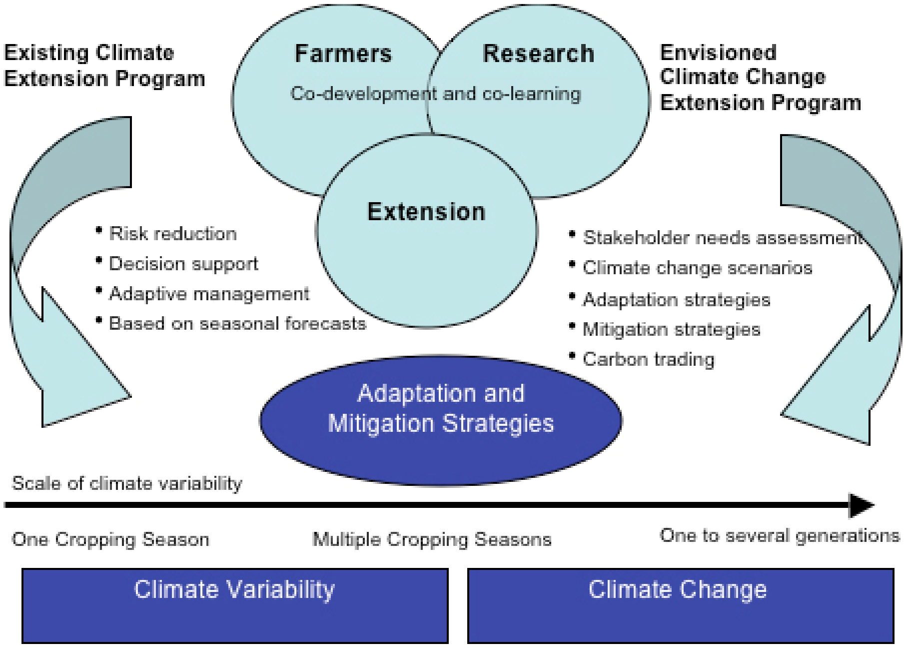

Figure 7.4. Framework for a combined climate variability and change extension program (Fraisse et al. 2009).

Interactive venues in which farmers can exchange knowledge about adaptation technologies can enhance learning among all stakeholders. In this way, the thoughtful design of stakeholder engagement processes becomes a powerful social tool for improving adaptation decision support (Bartels et al. 2012). A regional climate working group in the SE that includes farmers, extension agents, and researchers from Alabama, Florida, and Georgia meets biannually to foster knowledge exchange about climate and adaptation among scientists, farmers, and extension professionals. Historical timelines and storytelling have revealed the many ways in which growers have adapted to past changes and seasonal variability in climate. In assessing the barriers and opportunities for adapting farming systems these workshops reveal that farmers are familiar with several farm-and-field level management practices and planning decisions that can reduce climate-related risks. They are able to change crops or varieties, planting dates, tillage practices, or pesticide and irrigation schedules. However, they perceive a lack of control over other factors, such the federal farm bill, access to industrial infrastructure such as peanut shellers and cotton gins, and changes in commodity prices that drive planting decisions. One grower, for instance, reported that "as far as what crops were going to be grown 20 years from now, the farm bill probably impacts what farmers are gonna' grow more than anything." These findings point to the importance of moving discussions beyond farm-level decision making to embrace other scales of influence, for example, policy making circles that can influence the availability of potential adaptation options such as irrigation systems, crop insurance, or credit services (Bartels et al. 2012).

Farmers constantly navigate and negotiate biophysical and socio-economic processes. Values, norms, meanings, and goals affect the way farmers perceive and respond to climate information. In addition, some livelihood systems are more flexible than others in terms of the ease with which farmers can integrate new technologies (Crane et al. 2010). For example, although awareness has grown among organic farmers in Georgia about the potential economic incentive offered by emerging markets for carbon credits, these farmers are not always able to implement practices that reduce emissions and sequester carbon. Smaller farms, including most organic farms, are easier to manage with manual tools than larger farms and new farmers might be less likely to afford the extra labor and costs required by strategies that seek to reduce carbon emissions (Furman et al. 2011). Farmers in central and northern Florida, who have more diversified and smaller operations, tend to place more importance on seasonal climate variability and are better positioned to respond to climate predictions (Breuer et al. 2010). Similarly, dryland farmers face very different adaptation challenges than do farmers who have irrigation systems. Therefore, to be effective, climate communication and education strategies must be designed to target specific commodity audiences, farming systems, and household types rather than a one-size-fits-all approach to adaptation (Bartels et al. 2012, Furman et al. 2011, Crane et al. 2011). When viewing agriculture as a complex system of practices, climate information should be integrated gradually and experimented with over time. In this way, farmers will learn to employ these new technologies and adapt them to their own particular circumstances (Crane et al. 2010). For example, an Alabama extension professional and member of the row-crop climate working group reported that long term changes in agriculture are needed but that such changes are difficult. "It's about like trying to turn a cruise ship, you know. You don't turn a sharp left or a sharp right, ok, but you can start bending in one direction or another...I think that this kind of climate data and information can help make those minor shifts in one direction or another" (Bartels et al. 2012).

7.4 Assessment and Research Needs

7.4.1. General Research Needs

Mechanistic crop simulation models have been important tools in efforts to extrapolate how future climate will affect future crops. These models use knowledge gained from experiments conducted in fields, controlled-environments, across climate zones, rainfall regions, soil types, management regimes, crops, in order to project how crops will perform under different climate change scenarios. The impact of individual climate change components and the combined effects of climate change scenarios on crop production and externalities have been explored with such models. These models allow us to test various management options and, to a lesser extent, varietal traits that can counteract the negative impacts of climate change and to maximize potential benefits of climate change. While these models are simplifications of reality, they allow a first assessment of the complexity of climate change impact and adaption options in agriculture. However, there are a number of gaps in the global knowledge that apply to the SE USA that are needed to improve mechanistic crop models and their application in climate adaptation studies. These gaps include a better understanding of how combinations of various climate change factors affect crops, how specific climate change factors affect plant-water relations, how climate change effects on internal crop feedbacks such as sink-source relations, and how extreme events will affect crops. These needs are briefly discussed in the following paragraphs.

Temperature and CO_2. Effects of elevated CO_2 and temperature are often not considered in crop models. For example, reduction of transpiration canopy cooling as a result of elevated CO_2 and stomata closure can increase pollen sterility in rice (Ziska and Bunce 2007). As the frequency of extreme high temperatures (>32°C) during the growing season increases, interactions with elevated CO_2 need to be understood and considered (Attri and Rathore 2003). Amthor (2001) indicated a reduction of yield with elevated CO_2 in combination with warming for wheat, compared with elevated CO_2 alone. Alonso and Perez (2008) found a higher photosynthetic temperature optimum in cereals under elevated CO_2. No such beneficial interactive effects have been reported for rice, soybean, peanut, dry bean, or sorghum, although independent main effects of temperature or CO_2 were present (Boote et al. 2005; Hatfield et al., 2008).

Crop models need to be tested with data sets of interactive effects to ensure validity for climate change scenarios as suggested by Boote et al. (2010). Similarly, interaction effects of elevated CO_2 and flooded conditions; salinity (Ziska and Bunce 2007); or soil constraints such as compactions, sub-soil toxicity, or transient waterlogging are unknown, but need to be considered (Probert and Keating 2000). Due to the interactive effects and feedbacks that emerge when climate factors are combined, experiments in which only single factors are manipulated are likely to be inadequate to fully predict the impacts of future climate change (Dermody 2006).

Warming, reduced water, and elevated CO_2. Studies have simulated elevated CO_2 and warming with reduced water supply, specific rainfall patterns, and a range of soil water holding capacities under various climate impact scenarios. Elevated CO_2 and increased temperatures will have different effects on physiological processes (Triboi et al. 2006), such as sink-source relationships of grain yield, whether they are correctly or incorrectly represented in crop models (Fischer 2008; Sinclair and Jamieson 2006). For example, wheat grain yield has been reported to be reduced under elevated CO_2 in sink-manipulated shoots, implying that a high source-sink ratio might down-regulate photosynthetic capacity to an extent that more than offsets the stimulating effect of elevated CO_2 (Uddling et al. 2008). However, these models have never been tested with experimental data with such interactions as treatments even though the combined effects could be very different to the sum of single factor effects. For example, in one study, the net primary production response of grasslands to increased atmospheric CO_2, temperature, rainfall, and nitrogen deposition differed greatly from simple combinations of single factor responses (Shaw et al. 2002). In addition, simulation studies generally ignore genotype by CO_2 interactions (Manderscheid and Weigel 1997, Slafer and Rawson 1997), mainly because of the lack of experimental data. Boote et al. (2011) conducted model simulations of genetic improvements in soybean and found certain traits gave a greater response under elevated CO_2 than under ambient CO_2 and that heat-tolerance traits for grain set were more beneficial under elevated temperature conditions. Such analysis gives plant breeders a chance to target genetics to adapt to future climate change. Linking crop models with the underlying genetic structure of crops (Hammer et al. 2006) might help identify and incorporate genetic traits that will help crops adapt to future climates. Little is known about CO_2 acclimatization of crops and hence this is ignored in simulation studies.

Potassium and phosphorus. Most crop models consider nitrogen (N). Other nutrients such as potassium and phosphorus can also limit growth under elevated CO_2 conditions (Hungate et al. 2003; Ziska and Bunce 2007), but models do not usually consider them in climate impact studies. Both model simulations and field experiments indicate that response to CO_2 is less under N-limitation while response to CO_2 under water limitation is greater in field experiments and model simulations (Boote et al. 2010, Kimball 2010). Nutrients could also limit crop growth when climate change alters soil factors or restricts root growth needed for nutrient uptake (Brouder and Volenec 2008).

Yield quality. Climate factors often affect yield quality, such as protein composition and oil content (Kimball et al. 2001), but models do not simulate these effects as well as they simulate yield. Simulation studies on climate change impacts will require a better understanding of the physiology of yield quality and its incorporation into crop models.

Minimum temperatures. Changes in specific climate thresholds could become critical. For example, changes minimum temperatures are likely to have greater importance than changes in mean temperatures for grain yields of wheat and rice, so crop models may require modifications to respond appropriately to changes in minimum temperatures (Fischer 2007).

Modeling growth events. In developmental stages of growth, crops can be sensitive to various climate-related stresses. For example, cereals are highly sensitive to frost during flowering. Models still face challenges in representing and quantifying impacts from extreme events such as heat stress, frost, and flooding.

New cultivars and farming systems. In addition to improved modeling capacities and adaptation options in agriculture, research is needed to investigate new cultivars and better adapted species for the projected climate change scenarios (Tester and Langridge 2010). In particular, crop varieties are needed that take advantage of elevated atmospheric CO_2 concentrations, resist heat stress and frost events, and are more water-use efficient. Also needed are drought-tolerant farming systems (Katsvairo et al. 2006) as well as methods for sequestering more carbon in soils (Lal 2004). For many agricultural regions, new crop varieties, cropping systems, and agricultural management strategies are needed to provide options to farmers to counterbalance climate changes (Boote 2011).

Livestock and poultry. Livestock and poultry production have many similar research needs to those of crops, though there has been less research to improve understanding of climate change effects on livestock and poultry production systems that for crops. Developing new breeds and genetic types, improving animal health, and enhancing water and soil would support adaptation measures in the long term. An improved understanding of the impacts of climate change on pastureland should be sought through comprehensive studies that include grazing regimes, mutualistic relationships (e.g., plant roots-nematodes; nitrogen-fixing organisms), as well as the balance of carbon, nutrients and water (Hatfield et al., 2008). Studies addressing the impacts of climate changes on parasites and pathogens that impact livestock and poultry are needed. Interactions exist among temperature, humidity, and other environmental factors which, in turn, influence energy exchange. Indices or measures that reflect these interactions remain ill-defined, but research to improve them is underway.

Extreme event models. As rainfall in the SE USA is variable and likely to become more variable, skillful seasonal rainfall forecasts also will be crucial. Similar seasonal forecasting systems are needed for extreme events, including heat, frost, hurricanes, and tornados to improve planning and adaptation to seasonal climate variability and change.

7.4.2. Specific Research Needs for the SE USA

With its diversity and production of specialty crops, the SE USA has specific research needs unique to the region in addition to those mentioned in the previous section. Such research is essential for agriculture to remain socially, economically, and environmentally sustainable in light of a changing climate and growing population. Following are some of the research needs specific to the Southeast.

Climate datasets and collaboration between agricultural and climate modelers. Agricultural simulation models, as the main tool for climate impact studies, require significant improvements in heat impact and temperature by CO_2 interactions to deal appropriately with the complexity of climate change in the Southeast. For appropriate application to conditions in the SE climate datasets that provide daily data including maximum and minimum temperatures, precipitation, and solar radiation are required.

Initial efforts to include daily information in SE regional climate models (RCMs) to crop simulation models were unsuccessful because the RCMs simulated small amounts of rainfall daily rather than as discrete storm-related events (Jagtap 2005, pers. comm.). Efforts to use statistically downscaled GCM outputs for the SE also failed because the datasets included freeze events during summer months (Baigorria 2011, pers. comm.), a condition that does not currently exist and is not projected to occur in the future.

Climate modelers do not generally evaluate the performance of models based on daily data outputs; they generally analyze seasonal or annual averages. To be used in simulation models for other sectors, especially agriculture and hydrology, GCM and downscaled outputs must be evaluated at a daily time-step. Clearly, enhanced collaboration between climate and agricultural simulation modelers would benefit both parties and would help identify anomalous events such as a freeze during the summer, thereby helping climate scientists improve their methods.

Integrated, participatory, systems research approaches. Traditional agricultural research has followed a linear approach from research scientist to extension agent to farmer. To address the complex issues of sustainability in the face of changing and variably climate, research must follow a new paradigm—one that emphasizes the integration of research, teaching, and extension; that invites the participation of decision makers throughout the research process; and that assembles the diverse elements of agriculture through a systems approach (e.g., Breuer et al. 2009 and 2010; Bartels et al. 2012, Roncoli 2006). Plant and livestock breeding and management research also are important elements to the overall agricultural research portfolio regarding climate change, but they should be incorporated into integrated approaches to assure that they contribute to agricultural sustainability.

Water and land resource policies. Population increases in the SE have led the nation for several decades and are likely to continue. As a result, urban sprawl and demands for water from municipal, energy, and other sectors will increasingly conflict with agricultural sustainability. Initial research shows that there is a strong interaction between changes in agricultural land use/land cover and regional climate (Baigorria et al. 2012). Policy research will be essential to balance these competing demands for land and water resources. Research of water resource issues should evaluate agricultural competitiveness in the SE both for its ability to meet food, fiber, and fuel needs of the region as well as to contribute to similar national and global production (Marcus 2008).

Mitigation and adaptation technologies and systems. While researchers already are working with farmers in the SE to develop and assess technologies to mitigate and adapt to climate variability and change, additional albeit similar research is needed to identify and incorporate adaptive technologies into agricultural systems. Though such analyses are rarely applied to agricultural research and development, these technologies should be evaluated based on their carbon, energy, water, and nutrient balances as well as life cycle, risk, and economic analysis.

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Key Findings

- Warming air temperatures will likely increase regional drying regardless of changes in precipitation, and this drying will likely increase wildfire risk across southeastern USA forests.
- Longer growing seasons will likely increase the risk of insect outbreak and very likely will expand the northern range of some species such as the southern pine beetle.
- Continued increases in metropolitan populations coupled with increase water use by forests will likely cause more frequent and severe regional and local water shortages.
- Despite climate and demographic derived changes, forests in the southeastern USA will likely continue to provide a sink of atmospheric carbon dioxide (CO_2).

8.1 Historical Perspective

The forests of the Southeast (SE) USA have seen extensive change during the past century. Currently, 60% of the SE landscape is forested (Wear and Greis 2002). In 1860, about 43% of the SE land area was reported as farmland, but a substantial part of the farm holdings that remained in forest were used for grazing livestock (USDA 2009). Timberland continued to decline until the early 1920s due to the continued expansion of settlements. Significant changes in agriculture took place after 1920 that resulted in abandonment of large areas of crop and pasture lands. Some of the abandoned land was planted with trees, but most of the land reverted naturally to forest, leading to increases in timberland acreage (Wear et al. 2007). By the late 1950s and early 1960s, decline of timberland began again in the SE, caused primarily by the clearing of forests for soybean and other crop production. Much of this timberland reduction occurred in bottomland hardwood forest areas of the Mississippi Delta.

Throughout the 1970s, timberland was cleared for agricultural use and for an expanding export market. In the decade beginning in 1982, the National Resources Inventory reported roughly a half million-acre loss (less than 1%) in forestland in the SE. That trend has continued into the

21^{st} century as softwood pulp prices have fallen by 50% since 1998, and the forest products industry divested approximately 75% of its timberland holdings (Butler and Wear 2011). Although market prices will likely continue to be a driving factor in forest land area, other ecosystem services such as climate change, wildlife protection, drinking water supply, and recreation, may increasingly influence the distribution and composition of SE forests.

8.2 Southeastern Forest Types

The southeastern USA is not comprised of a single forest type, but of many. This assessment of forests and climate change focuses on six distinct forest areas within the SE: the Atlantic and East Gulf Coastal Plain, Piedmont, Appalachian/Cumberland, Mid-South, Coastal, and the Mississippi Alluvial Valley. Current inventory data shows that more than 30 million hectares of upland hardwood forests dominate the SE, followed by more than 15 million hectares of planted pine, approximately 13 million hectares of natural pine and bottomland hardwoods, and more than 3 million hectares oak-pine forest types (Wear et al. 2011). These forest ecosystems provide a multitude of goods and services including clean water and air, wildlife habitat, recreation and aesthetics, timber and fiber production, and CO_2 sequestration. This chapter reviews current and future stresses on and services provided by SE forests, and examines how forest management could be used to cope, adapt, or mitigate negative impacts.

Atlantic and East Gulf Coastal Plain. Historically, most of the southeastern Coastal Plain was dominated by fire-dependent longleaf pine (*Pinus palustris*) savannas (Christensen 2000). However, upland closed-canopied forests occur in mesic areas protected from frequent fire or where fire suppression has occurred. Notable examples of old-growth mesophytic beech-magnolia forests are present in the Apalachicola National Forest of the Florida panhandle. Other Coastal Plain broadleaved forests include those dominated by southern oak species such as swamp chestnut oak (*Quercus michauxii*), cherry bark oak (*Quercus pogoda*), and live oak (*Quercus virginiana*), as well as hickories (*Carya spp.*) and loblolly pine (*Pinus taed*a). American holly (*Ilex opaca*), spice bush (*Lindera benzoin*), and pawpaw (*Asimina triloba*) are common in the understory and subcanopy (Christensen 2000). Several dendrochronological analyses of Coastal Plain longleaf pine trees demonstrate the impact of growing season drought severity in relationship to reduced tree growth rates, as well as positive impacts of warmer winter temperatures (Bhuta et al. 2009, Henderson and Grissins-Mayer 2009). Less climatic research has been conducted in closed-canopied upland forests, but increasing fire frequencies in these Coastal Plain forests due to ongoing and future drought may be a major impact on forests of this region. Additionally, a recent study by Grun and White (2011) examined the northward range expansion of southern magnolia by comparing establishment success with climatic and topographic variables. Although minimum winter temperatures and the number of frost-free days were important determinants of establishment success, precipitation was not.

In addition to fire, Coastal Plain forests and other ecosystems are also particularly vulnerable to hurricanes. Hurricane Isabel in September 2003 damaged 15% of trees, particularly canopy trees, in a maturing hardwood forest of the Virginia Coastal Plain (Prengaman et al. 2008). Hurricane Isabel was only a Category 2 storm, so increased frequencies of Category 4 and 5 hurricanes as a consequence of climate change) likely will have even more profound effects

(Webster et al. 2005). Hurricanes Katrina is an example of the damage caused by a strong hurricane (MIFI 2005).

Southern Appalachians. These forests cover much of the high elevation areas of the north-central southern region that includes eastern Tennessee and Kentucky, western North Carolina and Virginia, and northern Georgia. The southern Appalachian forests are some of the most diverse in North America (Clark et al. 2011). Both unique species and commercially important species can be found within the region. The diversity of these forests is controlled by regional and local weather patterns that can be highly variable due to the mountainous terrain (Clark et al. 2011). As with other mountain systems, the high elevation forests of the southern Appalachian ecosystems are at particular risk from a warming climate. A 3^{o}C increase in July temperature would raise climate-elevation bands by about 480 m, resulting in the extirpation of the rare red spruce-Fraser fir (*Picea rubens* and *Abies fraseri*) alpine forests growing at the highest elevations in North Carolina and harboring federally threatened animal species including the North Carolina flying squirrel (Delcourt and Delcourt 1998). Many of the mid-elevation “cove” forests currently dominated by mesic, fire-intolerant tree species are extremely diverse in terms of canopy trees, spring ephemeral wildflowers, and amphibians. A recent study by Laseter et al. (in press) suggests that since the early 1980s the region has warmed significantly and precipitation variability has increased. If these trends continue, they could lead to substantial change in the structure and function of future southern Appalachian forests.

In addition to determining biodiversity, climate variability also controls forest growth. For example, the annual growth rate of five dominant oak species can be severely affected by growing season drought intensity (Speer et al. 2009). During drought years, observed oak forests showed diminished productivity and accumulated 40% less carbon compared to a year of average precipitation (Noormets et al. 2008). Increased temperatures and decreased growing season precipitation may reduce the competitiveness of oaks in the southern Appalachians and elsewhere in the SE (Ibáñez et al. 2008).

Wildfires also shape the structure and function of forests within the southern Appalachians. A recent study suggested that fires occurred fairly frequently over the past 4000 years in a variety of southern Appalachian forest types including those now dominated by mesic hardwoods including tulip poplar (*Liriodendron tulipifera*) (Fesenmyer and Christiansen 2010). Fire return intervals appear to have been of centuries-scale duration in the time period 4000 to 1000 years before present, and were likely often severe. Fires became more frequent approximately1000 years ago and were thus likely less severe due to less accumulated fuels build-up. The increased frequency of fire coincided with the occupation by Woodland Tradition Native Americans. If drought-induced fires become more common in the southern Appalachians, fire-tolerant oak and hickory species may become more abundant over less-tolerant tulip poplar, maple (*Acer spp.*), basswood (*Tilia americana*), birch (*Betula* spp.) and magnolia (*Magnolia* spp.) species, potentially reducing diversity in currently highly-diverse mesic forests.

Piedmont. The Piedmont region lays southeast of the Appalachian region and stretches from east-central Alabama through central Georgia, northwestern South Carolina, and central North Carolina and Virginia. These forests are dominated by mixture of pine and deciduous species (Figure 8.1) of high commercial importance (Van Lear et al. 2004). Dale et al. (2010) used ecosystem models and an ensemble of global climate model (GCM) scenarios to predict that in the southeastern Piedmont and Appalachians, southern mixed hardwoods and pine forests on Piedmont were the most susceptible to changes induced by warmer, and particularly drier, climates. Under the driest of the three climate scenarios considered by Dale et al. (2010), a southern mixed forest transitioned from very high tree species diversity with 14 commonly co-dominant species to very low forest diversity, dominated by loblolly pine, southern red oak (*Quercus falcata*), and Shumard's oak (*Quercus shumardii*). Dale et al. (2010) also found that the less-diverse forests may be more susceptible to insect and pathogen pests, and that hickory (*Carya spp.*) species tended to increase in relative importance under the climate change scenarios. Conversely, the biomass of chestnut (*Quercus prinus*) and black oaks (*Quercus velutina*) tended to decline across Tennessee, as the hickories appeared to be better able to grow in the warmer, drier climate relative to the oak species.

Figure 8.1. Mixed conifer and deciduous Piedmont forest in the southeastern USA.

Research from the Duke Free-Air CO_2 Enrichment (FACE) experiment and the Oak Ridge FACE experiment in the southern Appalachians suggests that an approximate doubling of atmospheric CO_2 increases the productivity of the canopy loblolly pine and sweet gum

(*Liquidambar styraciflua)* trees by 23% to 27% (DeLucia et al. 2005, Norby et al. 2005). However, when examining the juvenile tree species most likely to comprise the future forests, elevated CO_2 conditions favored the population biomass growth of less productive, shade-tolerant tree species southern sugar maple (*Acer saccharum*), red maple (*Acer rubrum*), and black cherry (*Prunus serotina*) as well as woody vines such as poison ivy (*Toxicodendron radicans*) (Mohan et al. 2006, 2007, and 2008) and exotic Japanese honeysuckle (*Lonicera japonica*) (Belote et al. 2004).

Coastal Forests. Coastal wetlands exist in the transition between Coastal Plain and maritime ecosystems and are responsive to changes in climate and freshwater outflow resulting from varying patterns and frequencies of freeze, drought, storm, sea level, and runoff events. Because saltmarshes and mangroves thrive in the intertidal zone between land and sea, these systems are expected to undergo the most severe changes from marine effects, such as sea-level rise and salinity; freshwater drainage effects, such as flooding, nutrients, and pollutants; and extreme climate events, such as freeze, droughts, and hurricanes. For example, mangroves (*Rhizophora* spp.) are halophytes that thrive along tropical coastlines reaching latitudinal limits along the northern Gulf Coast in Texas, Louisiana, and Florida. Lapses in freeze events and extreme drought events related perhaps to global warming may account for mangrove establishment and expansion into subtropical saltmarsh ecosystems. Warming sea and surface temperatures under predicted climate change scenarios will likely increase the frequency and severity of drought episodes while decreasing the periodicity of hard freezes that cause dieback of frost-intolerant tropical plant species. Mangrove populations have persisted in fringe populations along subtropical coastal settings of Texas, Louisiana, and Florida but have been undergoing recent expansion in latitudes above the tropical Everglades region, where mangroves traditionally have dominated the coastal land margin (Michot et al. 2010, Doyle et al. 2010). Local populations of black mangrove *(Avicennia germinans)* in coastal Louisiana have expanded in area, density, and stature since the last damaging freeze two decades ago (Michot et al. 2010). As the period between severe freeze events lengthens, mangrove expansion is expected to succeed landward and poleward along the northern Gulf Coast changing the proportion of saltmarsh area (Krauss et al. 2008). Mangroves have the added benefit of possessing unique root structures that may help stabilize coastal areas from erosion (McKee et al. 2007, Cherry et al. 2009). A shift from saltmarsh dominated coastlands to mangrove dominated shores, due to climatic changes, may also lead to shifts in fish species present (Ley et al. 1999), and reductions in some bird populations (e.g., brown pelican, *Pelecanus occidentalis*) (Visser et al. 2005).

Climate change poses some immediate and long-term threats to the health, function, and biodiversity of tidal freshwater wetlands along the coastal margin of the SE USA. Tidal freshwater forests of the Gulf Coast and elsewhere have been undergoing dieback and retreat from sea-level rise over the last century. This will continue or be exacerbated under projected increases of global eustacy. Coastal ecosystems of the western Gulf of Mexico are even more vulnerable due to the high rates of land subsidence that drive relative sea level rates that equal or exceed high IPCC projections for accelerated global eustacy expected with climate warming over the next century (Doyle et al. 2007 and 2010). In all coastal counties and region-wide, sea level rise of any rate or origin, relative or eustatic, is expected to cause widespread loss or retreat of coastal forests as dictated by local environmental settings (Doyle et al. 2010). Mangrove forests that dominate tropical shores of southern Florida are expected to migrate inland with increasing sea level and increase the proportion of forested habitat in coastal areas.

Mississippi Alluvial Plain and Adjacent Regions. The Mississippi Alluvial Plain (MAP) forests, which extend up to southern Illinois; north to Kentucky, west to Tennessee; and into the western gulf Coastal Plain, are similar to those of the Atlantic and Eastern Gulf Coastal Plain forests but can include different levels of nutrients and soil types. Alfisol soils, which are more fertile than highly-weathered clay Ultisol soils or sandy Entisols, are common along the alluvial plain of the Mississippi River as well locations in Alabama (Christenson 2000). Seasonal temperature variations increase away from the coast and frost-free growing season durations decline appreciably from south to north. Although covered more extensively in Natural Ecosystems (Chapter 11), the freshwater swamp forests of the MAP in Louisiana are particularly threatened by a combination of drought and intrusion of salt water triggered by drought conditions (Hoeppmer et al. 2008). Drought also has been linked to increased fire frequency and size in Mississippi, particularly in counties dominated by pines in the southern part of the state (Grala and Cook 2010). The importance of drought for this region is underscored by paleo-ecological work examining extended drought impacts during the mid- to late-Holocene period including the Medieval Warm Period (approximately 800 to 1200 CE) that characterized much of the Northern Hemisphere. During these times, vegetation loss was severe enough to coincide with the formation of low mounds and dunelike features that characterize much of the currently forested regions in the south-central USA today (Seifert et al. 2009).

8.3 Changes in Forest Type Across the South

The forests of the SE USA are highly diverse but not necessarily stable under a changing climate. The IPCC (2007) projected that average annual air temperatures will increase 3°C to 5°C, and that summer precipitation will remain almost unchanged within the region under a doubling of atmospheric CO_2 concentrations. Although the total amount of precipitation is not predicted to change very much, the intensity and timing of the rain could change significantly. Increased frequency of extreme precipitation events are predicted, bringing both more droughts as well as more intense storms (O'Gorman and Schneider 2009). Savannafication of the SE, in which forests are converted into more open woodlands, could be one of the most profound potential climate change impacts in the USA. Predictions for the SE include emergence of savanna ecosystems (Hansen et al. 2001, Bachelet et al. 2001), with expansion of Coastal Plain species into the Piedmont and Appalachians (Iverson et al. 2008). However, the SE is expected to have future climates and vegetation compositions that are currently not found within the region (Williams and Jackson 2007). The combination of future climate, soils, and land cover may not resemble anyplace currently within vegetation dispersal distances (Williams and Jackson 2007). Current Coastal Plain climates are most similar to those expected for the Piedmont, but this region differs in soils, hydrology, and historical fire frequencies (Christensen 2000). Clay soils of the southeastern mountains and Piedmont are more similar to each other than those of the sandy Coastal Plain, and it is unclear how species may shift distributions in response to changes in SE climates.

Climate envelope models use the climate where a species occurs today to predict where suitable climates will likely occur in the future. However, climate envelop models themselves do not predict the future locations of tree species, as they do not account for rates of migration, habitat fragmentation, and other issues (Iverson et al. 2008). Genetic evidence suggests late Quaternary and early Holocene migration of trees species following the last ice age likely occurred at much slower rates than what would be required to track current and future climate change (McLachlan et al. 2005, Anderson et al. 2006, Mohan et al. 2009). Molecular work using chloroplast DNA suggests these paleo-rates were much less than 100 m per year, yet current temperatures are shifting poleward at rates exceeding 1 km per year (McLachlan et al. 2005, Anderson et al. 2006). Migration rates of plant populations depend largely on rare long-distance seed dispersal events (LDD) which may not be frequent enough to result in the rapid migrations needed to keep track with species' current climates. Successful seedling recruitment and colonization after LDD is further limited by successful germination, growth, and survival (Ibáñez et al. 2007, Mohan et al. 2009). Recent work suggests that 59% of the 92 tree species examined were exhibiting range contractions at both the northern and southern boundaries (Zhu et al. 2011). Only 21% of eastern temperate tree species were shifting ranges northward, and 16% were shifting ranges southward. This is in contrast to the expectation that juvenile trees of the eastern USA may currently be expanding northward in response to warming over the last several decades.

Climate effects on canopy tree mortality rates are highlighted in work by Lines et al. (2010). Using data from across the eastern USA they found that tree mortality was 6 to 9 times lower at intermediate temperatures (8°C to 10^{o}C) compared with higher or lower temperatures. Mean annual temperatures of more than 15^{o}C, which defines much of the southeastern Piedmont and most of the Coastal Plain, exhibited much higher rates of tree mortality, suggesting that overall tree survivorship may decline with warmer southeastern temperatures. In addition, mortality increased with increasing temperatures for species that currently exist in a range where average annual air temperature ranges between 10^{o}C to 15^{o}C. Therefore, northern parts of the SE may also see strong rates of forest decline with increasing annual temperatures. Tree mortality was similarly minimized at intermediate amounts of annual precipitation, and increases in mortality rates were much greater where annual precipitation was lowest.

8.4 Current and Projected Forest Stresses

Expansion and contraction in forest range and survivorship are often not directly a function of climate or climate change, but indirectly a function of climate impacts on other stressors such as insect populations and wildfire. Drought may weaken a forest, but it may be another biotic or abiotic factor that is the actual cause of death (McNulty and Boggs 2010). Forests in the southeastern USA are characterized by frequent natural disturbances such as fire, wind and ice storms, drought, insects and disease (Dale et al. 2001). Under a changing climate, many of these disturbances are projected to continue and may be amplified by climate change, and a series of disturbances may be required to significantly impact forest mortality (Fig. 2). The major types of disturbance across the southeastern USA are outlined in the following sections.

Wildfires. The SE contains some of most productive forest land in the USA (Wear et al. 2007). As forest productivity increases so does fuel for wildfire. The combination of favorable climate and abundant fuel loads create a high fire-return rate of 3 to 5 years (Stanturf et al. 2002). The SE leads the nation in number of wildfires per year. The region averaged approximately 45,000 fires per year from 1997 through 2003 (Gramley 2005). Climate change may increase the frequency and intensity of wildfires. In addition, the southeastern USA has been experiencing increased droughts. In 2007 the worst drought in more than a century occurred in the southeastern USA and severe wildfires broke out that spring in the southern Georgia and northern Florida around the Okefenokee National Wildlife Refuge. More than 600,000 acres, approximately 243,000 hectares, were burned.

Wildfires can lead to severe environmental consequences. Emissions from wildfires are an important source of atmospheric carbon. Furthermore, smoke particles are a source of atmospheric aerosols, which affect atmospheric radiative transfer through scattering and absorbing solar radiation and through modifying cloud microphysics (Charlson et al. 1992). These processes can further modify clouds and precipitation and atmospheric circulation (Ackerman et al. 2000, Liu 2005a and 2005b). In addition, wildfires release large amounts of particulate matter (PM) and other air pollutants that can degrade air quality (Riebau and Fox 2001). Wildland fires contribute an estimated 15% of total PM and 8% of CO_2 emissions over the southeastern USA (Barnard and Sabo 2003).

Weather and climate are determinants for wildfires along with fuel properties and topography (Pyne et al. 1996). Fire activities vary from one fire season to another. Fire weather and climate influence wildfire behavior and account for fire variability at various time scales. Under warm and dry conditions, a fire season becomes longer, and fires ignite more easily and spread more quickly. There is evidence that wildfires, especially catastrophic wildfires, have increased in recent decades in both the USA and other parts of the world (Piñol et al. 1998, Westerling et al. 2006). Among the converging factors were extreme weather events such as extended drought and climate change (Goldhammer and Price 1998, Stocks et al. 2002). Many climate models have projected significant climate change by the end of this century due to the greenhouse effect (IPCC 2007), including an overall increase in temperature worldwide and a drying trend in many subtropical and mid-latitude regions. Thus, wildfires likely will increase in these regions. Fire potential will increase significantly in several global geographic regions, including some areas in the USA (Liu et al. 2009).

Climate change may have various impacts on fires in the SE. Temperature is projected to increase across the South and would contribute to increased fire frequency and intensity, total burned area and longer fire seasons. In addition, temperature change can indirectly impact fires by changing fuel conditions. Increased temperature will reduce fuel moisture due to increased evaporation and, therefore, increase the threat of wildfires. The impact of climate change on fuel loading is more complex. Increased air temperature can increase fuel loading due to a longer growth season, but decrease fuel loading due to reduced water availability and a reduction in biomass production.

The contributions of precipitation and humidity are also complex. Precipitation is projected to decrease in many subtropical and mid-latitude ecosystems. This would reduce fuel moisture and therefore increase fire potential in these regions. However, precipitation reduction would reduce available water for plant growth, leading to less fuel and therefore lower fire potential. Projections for precipitation are less certain than those for air temperature. Projected precipitation change often shows no clear trends even over large areas, including the southeastern USA (McNulty et al. 2012). Nevertheless, most GCMs also project more frequent precipitation anomalies such as drought, that in turn could increase fire risk.

Hurricanes. Hurricanes, which are tropical cyclones with sustained winds equal to or greater than 119 km per hour, can cause massive economic damage to forests. In 2005, Hurricane Katrina heavily damaged forests along the Louisiana and Mississippi Gulf coasts (Chambers et al. 2007, Kupfer et al. 2007, and Stanturf et al. 2007). McNulty (2002) estimated that a single hurricane can destroy the equivalent gain of 10% of the annual carbon sequestered in the USA. Owing to its size, intensity and trajectory, Hurricane Katrina may have had 6 to 14 times that impact (Chambers et al. 2007). In 2005, winds from Hurricane Katrina damaged 22 million m^3 of timber estimated at a value of $1.4 billion to $2.4 billion dollars. Impacts are not limited to loss of wood volume and quality, ecosystem services provided by these forests also can also be impaired. Although not necessarily linked to climate change, hurricane activity has increased since the mid-1990s and this higher activity has been projected to last for the next 10 to 40 years (Goldenberg et al. 2001).

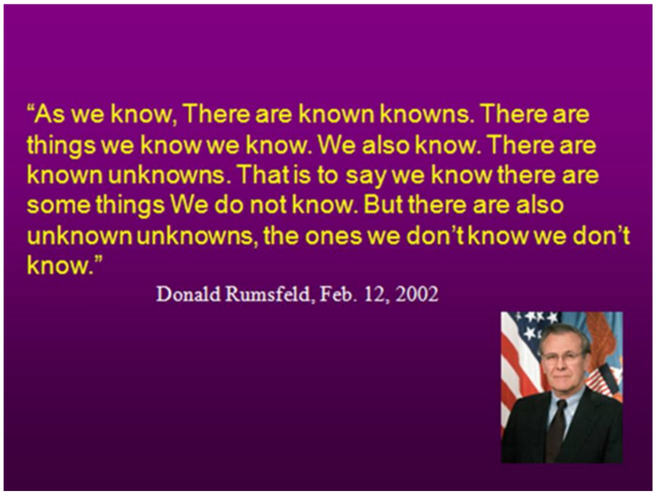
There are four main factors that determine the extent and severity of wind damage on forests: climate, soils, topography, and stand conditions (Wilson 2004). Hurricanes obviously represent an extreme climatic event. Soil conditions that restrict root growth and depth are consistently more prone to uprooting. Variation in wind-throw along topographical gradients is more complicated and is often confused with damage due to species and soil variation. There are many stand attributes that help determine tree susceptibility to wind-throw. These include height to diameter ratios, height, spacing, recent thinning, and impacts of previous disturbance on creating exposed edges that contain trees more vulnerable to wind-throw. Tree species composition may also impact the degree of damage from hurricanes. Therefore, stand composition and stocking levels represent stand attributes that can be manipulated by forest managers to reduce hurricane impacts.

Some evidence suggests that longleaf pine (*Pinus palustris*) might also be more tolerant to high winds than either slash pine (*P. elliottii*) or loblolly pine (*P. taeda*). In a study of the Hobcaw Forest, in coastal South Carolina after Hurricane Hugo, Gresham et al. (1991) reported that longleaf pine suffered less damage than loblolly pine. It was noted that species native to the Coastal Plain may be adapted better to the disturbance regimes found there. For example, longleaf pine, baldcypress (*Taxodium distichum*), and live oak (*Quercus virginiana*) suffered less damage than forest species with broad distribution ranges.

Johnsen et al. (2009) found that following hurricane Katrina, longleaf pine suffered less mortality (7%) than loblolly pine (26%). In addition to being potentially more resistant to wind-throw, longleaf pine is also more drought and fire resistant than the commonly planted loblolly pine (Landers et al. 1995). Wind damage increases with tree size, but the frequency and severity varies with species, site, wind parameters, and stand characteristics, specifically canopy evenness and age distribution, making it difficult to distinguish those tree species that appear to be more or less susceptible to wind damage (Gresham et al. 1991). The southeastern USA Coastal Plain is highly prone to hurricane events (Stanturf et al. 2007), and intense hurricanes occur two out of every three years across the region (McNulty 2002). Similar to historical natural fire regimes, the selection pressure of frequent high velocity winds has been a driving factor.

Insects. There are many types of insects that damage southeastern forests, but the southern pine beetle *(Dendroctonus frontalis Zimm.)* is the most commercially destructive. Southern pine beetles caused more than $900 million in damage to SE pine forests between 1960 and 1990. The impact of climate change on the distribution and impact of forest pests and diseases remains uncertain. Higher winter air temperatures will increase over-wintering beetle larva survival rate, and higher annual air temperatures will allow the beetles to produce more generations per year (Ayres and Lombardero 2000). Both of these factors could increase beetle populations. On the one hand, field research has demonstrated that *moderate* drought stress can increase pine resin production and, therefore, reduce the colonization success rate of the beetle. However, *severe* drought stress reduces resin production and greatly increases the susceptibility of trees to beetle infestation. Insufficient evidence currently exists to predict which of these factors will control future beetle populations and impacts (McNulty et. al. 1998, McNulty and Boggs 2010).

In addition to length and timing of the breeding season, other factors will likely impact the amount of insect caused damage under future climate conditions including; the minimum winter air temperature (Michael 1984) and the prompt removal and destruction of infected timber (Rodriguez 1966). However, another factor closely linked to climate change may also impact insect success. Although it is one of the principle drivers of rising global air temperatures, CO_2 also increases forest productivity. Gan (2004) used an ecosystem model in conjunction with climate scenarios to predict that climate change would increase forest production by more than 7% during this century. The increase in productivity was a function of increased air temperature, longer growing season, and elevated atmospheric CO_2. However, southern pine beetle damage is also projected to increase by 4 to 7 times current levels, which would cause damage estimated at $500 to $800 million year per year (Gan, 2004).



"As we know, There are known knowns. There are things we know we know. We also know. There are known unknowns. That is to say we know there are some things We do not know. But there are also unknown unknowns, the ones we don't know we don't know."

Donald Rumsfeld, Feb. 12, 2002

Figure 8.2. Former Defense Secretary Donald Rumsfeld was referring to unknown contingencies associated with the middle-eastern conflict, but the same concerns regarding the unknown also pertain to climate change.

Potentially, some of the challenging impacts of climate change will be those conditions for which we have not considered or prepared for, such as previously unobserved combinations of environmental conditions that interact in new and unique ways. This concern is not unique to science. Former U.S. Secretary of Defense Donald Rumsfeld expressed the importance of looking for unique situations during a press briefing on the Middle East conflict (Figure 8.2). One such event occurred in western North Carolina about a decade ago. From 1999 until 2002, the area around Mt. Mitchell was in a period of extended heat wave and drought (McNulty and Boggs 2010). This southerly section of the Appalachian Mountains received some of the highest rates of acidic deposition in the eastern USA. In 2001 red spruce (*Pica rubens Sarg.*) trees in the area began to die in large numbers (Figure 8.3). An examination of the sites indicated that affected trees were killed by southern pine beetles, which does not normally inhabit that elevation (Williams and Liebhold 2002). Foliar, soil, and basal area growth measurements revealed that long-term nitrogen deposition may have altered red spruce forest structure and function in this area. Those stands that prior to the drought had the highest foliar and soil nitrogen concentrations and fast basal area growth rates were more likely to be killed by beetles during the drought period compared to slower growing red spruce stands (McNulty and Boggs 2010). The authors suggested that those factors which allowed stands to have the most vigorous growth under average climatic conditions also made these stands the most susceptible to mortality once those conditions changed. In combination, insects, drought, and nitrogen deposition ultimately combined to cause the observed forest mortality. If any one of these factors were not present, the trees may not have died. While in retrospect, the mechanisms

Figure 8.3. Red spruce (*Picea rubens* Sarg.) mortality in western North Carolina due to a combination of drought, southern pine beetles, and acid rain.

for decline seem clear, forest managers have historically not been taught to consider vigorous forest stands as unhealthy. However, under a changing climate the definition of forest health, resilience, and resistance may need to be reevaluated (Thompson et al. 2009).

Elevated Atmospheric CO_2. Although CO_2 is not considered a disturbance factor for forests, atmospheric CO_2 could impact forest structure and function. Atmospheric carbon dioxide (CO_2) levels have increased nearly 35% since preindustrial times, from about 280 ppm to more than 380 ppm (IPCC 2007). Depending on the growth and emissions scenario used, atmospheric CO_2 may rise as high as 850 ppm by 2100 (IPCC 2007).

While carbon dioxide is the primary driver of anthropogenic climate change, it is also the basis of plant photosynthesis. Given that plant photosynthesis is not saturated at current CO_2 levels, anthropogenic increases in CO_2 will almost certainly lead to higher rates of photosynthesis. However, greater photosynthesis may not translate to significantly greater forest productivity and plant carbon storage, and gains in productivity may not be sustainable over the long term (Norby et al. 2010).

8.5 Ecosystem Services

Southeastern forests have always been a major source of ecosystem goods and services dating back thousands of years (Anderson and Sassaman 1996). Current changes in demographics and climate may change the value and need for some ecosystem services, but an overall reliance on southeastern ecosystems for societal and economic purposes remains. In addition to traditional products such as timber and water supply, southeastern forests are considered important sinks for atmospheric CO_2, and part of a strategy to slow global warming. These services are outlined in the next section.

Forest Productivity and Carbon Sequestration. Large areas in the southeastern USA are actively managed for wood production at varying levels of intensity. For example, site preparation, weed control, fertilization; stocking, such as planting density and thinning, and genetic improvement can all impact forest productivity. Attention is being focused on the role forests play in sequestering some of the anthropogenic carbon inputs to the atmosphere in biomass and soils, while conserving existing carbon stocks through informed resource management.

The role of southeastern forests in providing a steady supply of timber and fiber is of particular importance in meeting current and future timber and fiber needs across the USA because forest harvests have substantially decreased across the other regions. As a whole, the South's forest sector produces approximately 60% of the total wood production in the USA (Prestemon and Abt 2002).

Climate change has the potential to impact forest productivity and carbon sequestration. Increases in forest carbon sequestration (a result of forests storing carbon in soils and woody tissues) can slow down the rate of atmospheric CO_2 increase and therefore help to slow down global warming. Land occupied by forests represent 30% of the total forestland in the in the southern USA (Han et al. 2007). Southeastern forests also have been estimated to account for

36% of the carbon sequestered in the conterminous United States (Turner et al. 1995). Han et al. (2007) estimated forests in the SE sequester 13% of regional greenhouse emissions in soils and long-lived forest products, such as lumber. Southeastern forests also contain about 30% of the nation's carbon stock (Mickler et al. 2004) and play a prominent role in the regional and global carbon cycle (Turner et al. 1995).

Forest Water Resources. When compared with other land uses, managed and unmanaged forests provide the cleanest and most stable water supplies for drinking water, recreation, power generation, aquatic habitat, and groundwater recharge. (Jackson et al. 2004). Large acres of forestland in the Appalachians and Piedmont are the headwaters of many river systems in the SE (Sun et al. 2011). These watersheds provide disproportionally higher water supply than the Coastal Plain because these forests occupy areas with relatively high precipitation and cool climate, (Brown et al. 2008).

The impacts of climate change on forest structure and functions are likely to result in negative consequences on water quantity and quality of forested watersheds through altering key hydrologic fluxes including precipitation and evapotranspiration (ET), and the biogeochemical processes (Sun et al. 2011). An increase in air temperature means an increase in energy availability and atmospheric water demand. Thus for the humid southeastern USA, water shortages are expected to increase. For example, Walter et al. (2004) concluded ecosystem ET has been increasing at a rate of 10.4 mm per decade across six major basins that cover a majority of the watersheds in the USA. Shifts in tree species due to changes in climate, fire regime, and invasive species are likely to increase ecosystem transpiration rates and alter the carbon and nutrient balances. An increase in frequency of high intensity storm events will increase rainfall erosivity thus the potential for increased soil erosion and sedimentation (Marion et al. 2011). An example of this increased soil erosion potential was forecast for the Uwharrie National Forest where severe soil erosion was predicted to increase significantly under future climate (Figure 8.4). This is of particular concern in the SE where land conversions from traditional agricultural use to urban development and intensive agriculture practices are on the rise. Droughts, caused by lack of precipitation

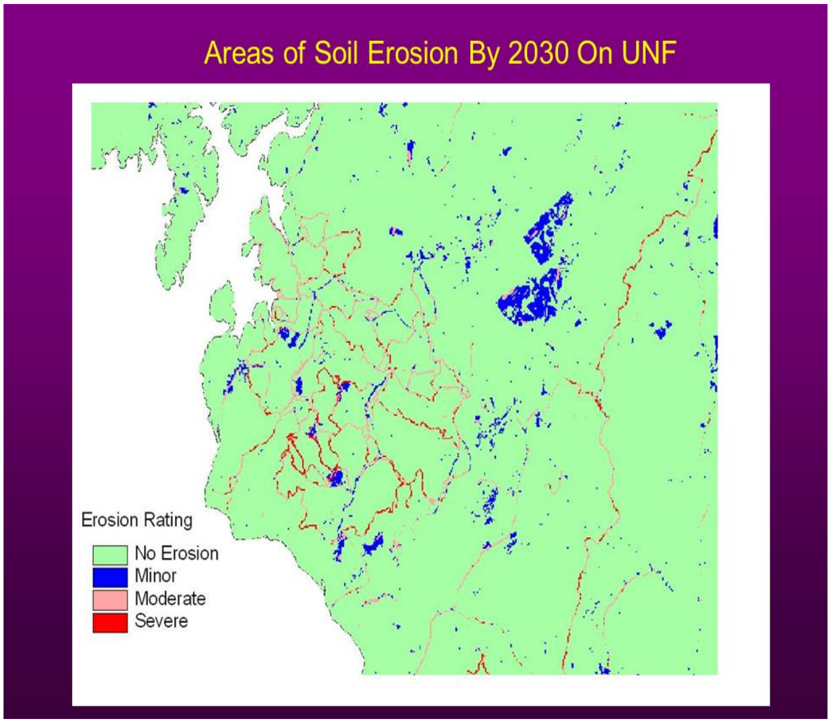


Figure 8.4. Revised Universal Soil Loss Equation predictions of soil erosion areas within the Uwharrie National Forest by 2030

or increased water use by humans in the humid, water rich SE, are becoming more common. Droughts are likely to cause land degradation, raise stream water temperature, and threaten sensitive aquatic species such as cold water fish in the Appalachians.

Ecosystem model simulations and multiple watershed vegetation manipulation experiments suggest that activities that do not result in a forest type conversion or a coppice stand structure will not substantially alter streamflow responses to extreme precipitation events (Ford et al. 2011). However, based on forest conversion experiment studies, the conversion of deciduous forests (either naturally or by forest management) to pine monocultures in the Appalachians substantially altered the streamflow response to extreme annual precipitation. Thus, forest management may reduce flood risk but also exacerbate drought. Tradeoff between managing forests for opposite extremes should be carefully considered by water resource managers for contingency land use planning (Ford et al. 2011).

Increased frequency of large storms will likely impact forest communities and increase flood occurrence. Increased spring and summer droughts will likely make forest vegetation vulnerable to stresses due to high ET demands in the Coastal Plain region. Forests can also modulate regional climate by controlling energy and water transfers between the atmosphere and forested land-surface (Liu 2011, Chen et al. 2011). Forest restoration, afforestation, or both are expected to play important roles in mitigating the impacts of climate change on water resources in these regions.

Regional modeling with a monthly scale water supply and demand model called the Water Supply Stress Index (WaSSI) suggests ecosystem water stress across the eastern USA will likely increase in the next 50 years, especially during the summer and fall seasons, due to increase water demand and reduced water yield (Caldwell et al. 2011).

8.6 Adaptation Options

In general, the biological productivity of SE forests will likely be enhanced by atmospheric carbon enrichment, as long as precipitation does not decline or air temperature does not increase soil moisture stress to a level that would offset potential CO_2 benefits on productivity. For instance, a northward shift in forest productivity (Figure 8.5) is projected to lead to relative increases in the proportion of regional timber harvests that come from the northern reaches of the region. This may compensate for the reduction harvests in the southeastern parts, which will be more negatively affected by the biophysical effects of climate change. In addition, landowners are projected to shift land between forests and agriculture in places and at times

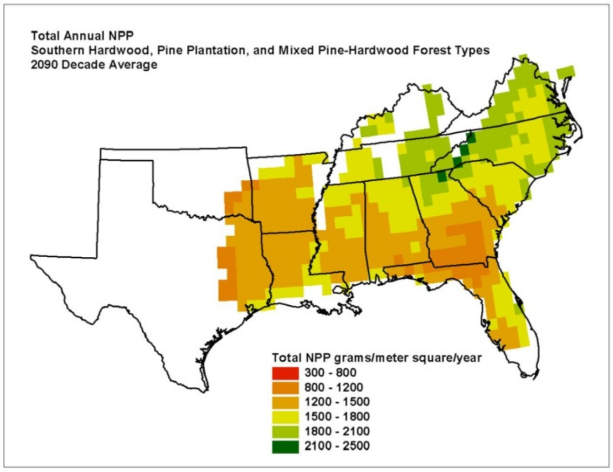


Figure 8.5. Forest model predictions of increased carbon sequestration (measured at net primary productivity, NPP) in the northern sections of the southern USA due to increasing air temperature by the end of this century.

where the change in relative productivity warrants it.

Other potential adaptation strategies include genetic and silvicultural system improvements that increase water use efficiency or water availability. Increasing knowledge of the role of fire, hurricanes, droughts, and other natural disturbances will be important in developing forest management regimes and increasing stand productivity in ways that are sustainable over the long term. Under a hotter, drier climate, an aggressive fire management strategy may prove important in this region. Timber productivity associated with increased temperature, growing season length, and CO_2 enrichment may be further enhanced by improved genetics, bioengineering, use of marginal agricultural land for tree production, and more intensive forest management. Reduction of air pollutants, such as ozone and nitrogen oxides, may also be an important strategy for increasing forest productivity due to the potential for synergistic stress impacts (Figure 8.6).

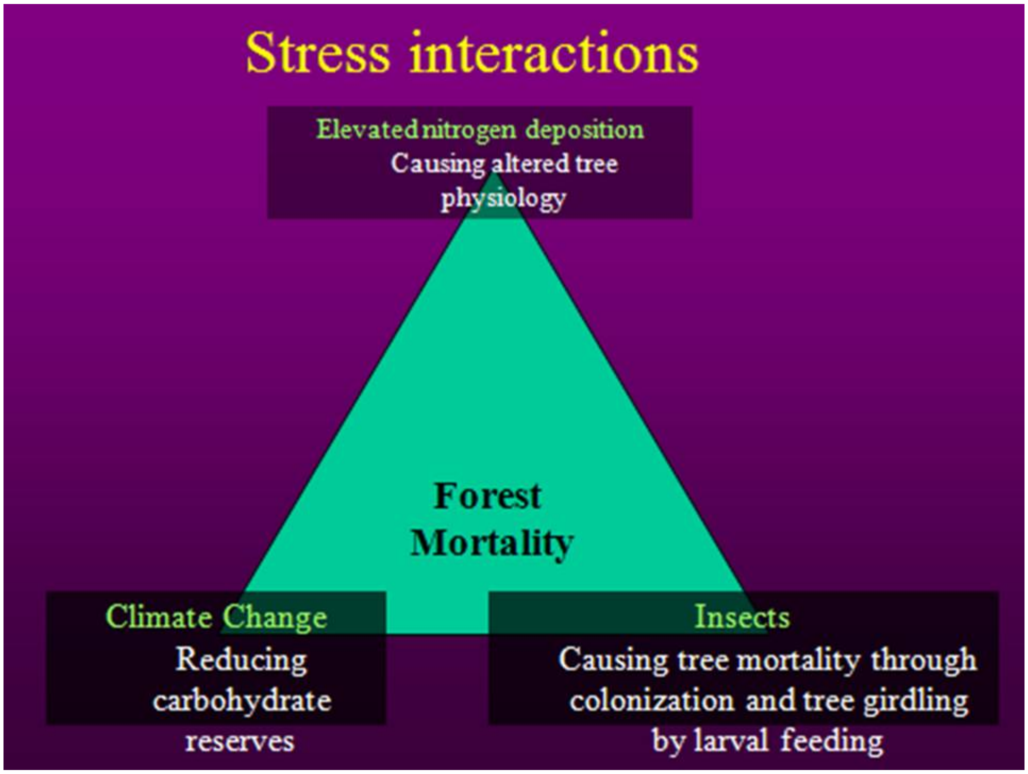


Figure 8.6. Interactions of climate (e.g., drought), biological (e.g., insects) and abiotic (e.g., fire or acid rain) can combine to cause forest mortality. The interactive stresses may be related (e.g., drought and fire) or unrelated (e.g., drought and acid rain). Any single stress may not have caused the mortality, but as climate change continues the potential for more frequent and more severe stress increases.

More than 400,000 ha of pine plantations are now fertilized each year with nitrogen which increases forest productivity (Albaugh et al. 2007). Fertilization can also decrease carbon losses by reducing soil respiration, and thus increasing forest carbon sequestration (Butnor et al. 2003). Other management tools that directly impact carbon sequestration include species selection, modification of initial planting density, and rotation length and thinning.

The effects of silvicultural treatments, such as planting density, thinning and rotation length, on carbon sequestration were analyzed by simulating carbon flux under different climate and management scenarios for loblolly pine and slash pine plantations established in the southeastern USA Lower Coastal Plain (Gonzalez-Benecke et al. 2010 and 2011). Increasing the rotation length increased carbon stock in both species. Other reports for different conifer species (Liski et al 2001 and Harmon et al 2002) indicated similar effects of rotation length on carbon storage; that is, extended rotations increased carbon sequestration in conifer forest plantations. Canadell and Raupach (2008) cited longer harvesting cycles as a major management strategy for increasing forest carbon stocks.

Improved understanding of climate change impacts and adaptation options are only useful if this information can be conveyed to the land manager. New web-based models and tools are being developed allow for easier, more site specific climate change assessments. For example, the web-based Distrib/Shift forest species distribution model gives users the ability to examine which tree and bird species will likely become more and less dominant in that area over the coming years and decades (Iverson et. 2011). Similarly, the web-based WaSSI (Water Supply Stress Index) hydrologic model gives land managers the ability examine the impacts of climate, population and land use change on water supply and demand on their watersheds. Finally, Web-based tools like TACCIMO (Template for Assessing Climate Change Impacts and Management Options) allow the user to search scientifically reviewed literature on climate change impacts for their area, and then to further use TACCIMO to search for management options to address or adapt to these changes. Significantly improved graphic user interfaces (Figure 8.7), data storage, and internet access speeds have greatly improved the application of these tools.

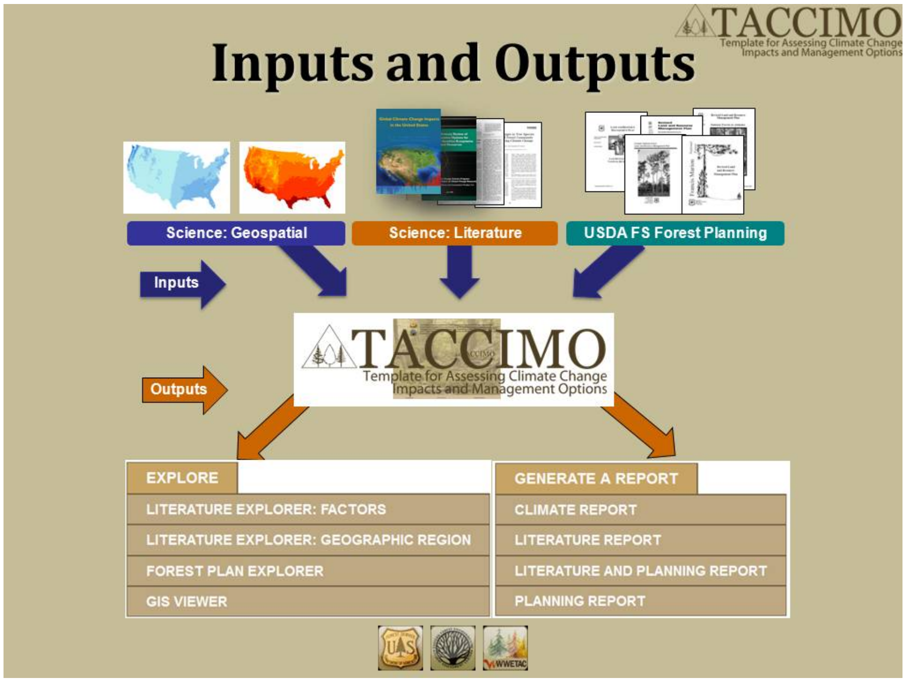


Figure 8.7. Web-based tools such as TACCIMO (Template for Assessing Climate Change Impacts and Management Options) are increasingly being used to easily translate scientific knowledge into the hands of the land manager.

8.7 Conclusions

Southeastern forests are as diverse as the cultures that exist within them. The wide range of tree, plant, and animal species make the region both resistant and susceptible to change. Some species will not be able to adapt to rapidly changing climatic conditions; other species will fill vacated niches that develop. Protecting the overall integrity of the ecosystem will be less of a challenge than protecting all of the parts. Several independent studies suggest that remnant species present from the last glaciation, such as red spruce or hemlock may be most at risk of extirpation. The more drought-tolerant species such as oaks and long-leaf pine may thrive in the drier, warmer world.

Land managers will need to develop new strategies or modify existing management practices to address the changing stressors in the future. The continued sustainability of forests for water, recreation, timber, and wildlife resources is possible but will require new practices to achieve desired goals. Federal, state, and private forest research organizations should work together to use the limited funding currently available to develop coping strategies for future forest management.

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9 Effects of Climate Change on Fisheries and Aquaculture in the Southeast

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Key Concepts

- As land loss continues from sea level rise and coastal inundation, vital habitat for juvenile estuarine finfish and crustacean shellfish such as shrimp, fisheries production will also decrease.
- Most fish species have a fairly narrow range of optimum temperatures. Depending on the species, the area occupied may expand, shrink, or be relocated with changes in ocean temperatures. Extinctions are predicted to occur where dispersal ability is limited or suitable northward habitat is unavailable.
- Chronic exposure to hypoxia and fluctuating oxygen concentrations impairs reproduction, immune responses, and growth. Hypoxic events are predicted to increase from increased run-off, droughts, and increased temperatures.
- Severe tropical storms negatively affect fishery species through increased pollution run-off, direct storm damage, flooding, saltwater intrusion from storm surge, and habitat loss. In addition the fishing and aquaculture industries can be devastated by the damage and loss of infrastructure including boats, docks, marinas, equipment, processing plants, and distribution centers.
- The potential effects on molluscan shellfish fishing and aquaculture are significant and complex. Changes in distribution could occur on longer time periods based on multiple parameter including temperature, ocean pH and local acidification, sea level rise, and saltwater intrusion.
- Warming water temperatures may lead to an increase in foodborne and waterborne pathogens associated with molluscan shellfish harvest and consumption.
- Designing adequate mitigation and adaptation strategies for fisheries management will require continued monitoring, research, and predictive modeling. Existing practices such as gear technology, direct marketing, monitoring, diversified effort, and carbon sequestration options exist and need to be encouraged.

9.1 Introduction and Background

This chapter covers major fishery and aquaculture systems in the SE region beginning with the value and importance of existing systems, the predicted effect from climate change, and adaptions currently underway or that may be taken in the future. Information includes the research needs necessary to increase human society's resiliency to climate change. Not all fisheries and sectors in the region are discussed; those highlighted are known to be vulnerable to climate change. Many of the ecosystem impacts are covered more thoroughly in the natural ecosystem chapter. Some of these gaps in coverage are addressed in the research needs portion, and these topics should be included in future assessments.

In the SE, commercial fishing, recreational fishing, and aquaculture sectors are diverse and widespread. They provide a large economic benefit to the SE as well as providing sources of food, baitfish, and ornamental organisms for the rest of the nation. Many of the species and infrastructure are likely to be heavily affected by climate change as has already been seen throughout the region.

9.1.1 Commercial Fishing

Commercial fishing in the SE consists of freshwater fisheries in reservoirs, lakes, and river systems for sport fish (Florida Fish and Wildlife Conservation Commission, personal communication). Commercial fishing for marine species using seines, hook-and-line, cast nets, gill nets, tongs, and other gear types are conducted in state and federally managed waters. The SE includes 12 of the top 50 commercial fishery ports for landings and value in the United States (Lowther 2011). Primary commercial marine species include blue crab, stone crab, crawfish, shrimp, scallops, oysters, clams, menhaden, flounder, groupers, mackerels, mullets, red snapper, striped bass, and tunas. Commercial fishing in the SE has been valued at $787 million in dockside sales with more than 800,000 metric tons landed in 2010 (National Marine Fisheries Service 2010).

Commercial fishing is a major economic enterprise in the SE and specifically in the Gulf of Mexico. According to National Ocean Service (NOS 2011), four of the top ten ports by poundage are in Louisiana (three) and Mississippi (one) for a combined 1,024 million pounds annually. Louisiana also has three of the top fifteen ports by value. Gulf of Mexico coastal wetlands produce an annual shellfish harvest worth $474 million (NOS 2011). These areas are expected to be heavily affected by climate change in the SE (NOS 2011).

9.1.2 Recreational Fishing

The combined marine and freshwater recreational fishing industry in the USA was valued at $42 billion in 2006 (U.S. Department of Interior et al. 2006). Total marine fishing trip and durable equipment expenditures across the Mid-Atlantic, South Atlantic, and Gulf of Mexico regions in 2009 totaled approximately $19 billion (National Marine Fisheries Service 2010). Florida has the largest freshwater fishing industry of any state. Combined, the saltwater and freshwater sectors contributed more than $6.1 billion to the state's economy in 2006 (Florida Fish and Wildlife Conservation Commission 2011).

Primary marine recreational species in the SE are striped bass, bluefish, black sea bass, spotted seatrout, yellowfin tuna, dolphin fish, red grouper, red snapper, yellowtail snapper, sheephead, flounder, Spanish mackerel, and Atlantic croaker. The most sought after freshwater recreational species are largemouth bass, sunfishes, trout, and catfish. Recreational fishing occurs in most natural bodies of water and many constructed impoundments. The SE has thousands of kilometers of rivers and streams and thousands of hectares of natural lakes and constructed impoundments.

9.1.3 Aquaculture

The most recent estimate of farm-gate sales of freshwater and marine aquaculture in the 11-state SE is approximately $740 million (Census of Aquaculture 2005). The primary food species farmed in the SE include clams, crawfish, oysters, soft-shell crawfish and crabs, alligators, catfish, striped bass, tilapia, and trout. The production of food organisms is the most common form of aquaculture practiced in the USA. However, all SE states also have bait farms, sometimes known as minnow or crawfish farms. Species of fish and crustaceans produced include golden shiners, fathead minnows, shrimp, goldfish, suckers, and crawfish.

In addition to those species already mentioned, more than 800 species of ornamental fish are cultured for the aquarium trade, primarily in Florida (Hill and Yanong 2010). The ornamental fish, aquatic plant, and snail industry may be divided into two types: tropical and cool-water species. The tropical fish and aquatic plant industry originated in South Florida where annual temperatures are similar to those of the plant or animal's native range. Other varieties of ornamental fish cultured are the goldfish and the koi carp, which are cool-water species. In addition to growing ornamental fish, some farmers grow fish for use as “feeders” for larger aquarium fish. In addition, raising aquaculture products for educational and research biological supply houses covers a broad range of organisms from algae to turtles. Louisiana also has a thriving pet turtle aquaculture industry.

The production of sportfish to stock the farm, city, and county ponds and lakes in the SE is another aquaculture sector. Many combinations of fish are suitable for stocking in ponds and lakes. Some of the more commonly cultured species are largemouth bass, bluegill, redear sunfish, hybrid sunfish, channel catfish, bullhead, trout, crappie, walleye, yellow perch, fathead minnow, bluntnose minnow, and golden shiner.

Production methods. When describing aquatic production systems, names of systems refer to the type of water-holding facility in which the organisms are grown. Several kinds of water facilities are used for growing fish in the SE, including ponds, cages, raceways, and recirculating systems (Swann 1992). The most common production system in use is the earthen pond and may include simple small farm ponds in addition to those specifically designed and built for aquaculture. Cage culture of fish uses existing water resources, lakes or ponds, with the fish enclosed in cages or baskets, which allows water to pass freely between the fish and the water body. A raceway production facility requires large quantities of inexpensive high quality water. The water is normally obtained from a spring or stream and is passed through the raceways using gravity. Recirculating raceway facilities reduces water consumption.

All four types of facilities will face challenges due to climate change. Ponds will likely face threats from saltwater intrusion, sea level rise, extreme temperatures, drought, and flooding. Drought and increased temperatures will likely threaten cage production because they increase the need for adequate circulation to compensate for reduced levels of dissolved oxygen. Both raceways and recirculating systems will be affected by conflicting water uses.

9.2 Climate Change Effects

The metabolism of fish, crustaceans, and bivalves is influenced by a variety of water quality parameters including temperature, salinity and pH. Aquatic organisms have evolved to adapt to daily fluctuations in these parameters (Willmer et al. 2000); however, future climate variation of temperature, for example, may have a significant influence on the metabolism of these organisms. Most freshwater and marine fish, crustaceans, and bivalves are non-thermoregulating ectotherms; they are unable to regulate their body temperature and, therefore, their internal temperatures match the environment. On an acute time scale, the metabolic rate of ectotherms increases approximately exponentially with temperature (Willmer et al. 2000). For example, the metabolic rate of a clam may double with every 7°C to 10°C increase in water temperature. This increase in metabolic rate has important implications for energy use, growth efficiency, and upper lethal limits (Gosling 2003). Temperature, photoperiod, and in the case of marine organisms, salinity also regulate reproduction. Many of these factors are linked, and altering temperature at different times of year (photoperiod) could drastically affect spawning, mating, and growth of many species (Munro et al 1990).

Observed changes in species distributions begin at the base of the food web: primary producers. Long-term studies begun in 1958 indicate that climate change has altered primary production in the North Atlantic Ocean. Phytoplankton abundance has increased in the cooler regions (north of 55°N) and decreased in warmer regions (south of 50°N) (Richardson and Schoeman 2004; Sarmiento et al. 2005). Although both regions have experienced warming, reductions in primary productivity in the southern region of the North Atlantic Ocean are due to a warming-induced reduction in vertical mixing and the resulting nutrient limitation (Richardson and Schoeman 2004, Sarmiento et al. 2005). Impacts on phytoplankton have likely moved up through the food web. The planktonic phases of fish life cycles are particularly vulnerable to impacts of unsuitable or insufficient food. Therefore climate-induced changes in productivity may alter the distribution and phenology of fish larvae and, ultimately, recruitment and production of fish stocks through impacts on growth, survival, and reproduction (Beaugrand et al. 2002 and 2003). Given these potential impacts on stock distributions, more data on the effects of climate change on primary productivity in the Mid-Atlantic Ocean and the Gulf of Mexico are needed.

Species and systems will be impacted by other concurrent pressures such as overfishing including age truncation and loss of genetic diversity, increased coastal storm activity, precipitation and runoff, habitat destruction, pollution, invasive species, and pathogens, making populations less resilient to unfavorable conditions related to climate (Knutson et al. 1998; Wolock and McGabe 1999; Brander 2005, 2007 and 2010; Planque et al. 2010). Some projections show that climate change may lead to many local extinctions of exploited species, particularly in subpolar and tropical regions (Cheung et al. 2009). Designing adequate mitigation and adaptation strategies for fisheries management will require continued monitoring, research, and predictive modeling. Continued development of aquaculture production may contribute to future food security.

9.2.1 Finfish and Crustacean Shellfish

Wetland loss and sea level rise. Sea level rise will be a significant factor of climate change effects. The Southeast Atlantic and Florida experience an increase of 2.5 mm per year while Louisiana has rates of 9.5 mm per year. Climate change could increase sea level rise 0.5 m to 1 m over the next 100 years (NOAA 2011). Currently Louisiana's wetland loss represents about 90% of coastal wetland loss nationally, yet Louisiana has still seen a 6.4% per year increase in marine commercial landings since 1930. However, this is most likely due to the increasing land-water interface as a result of land loss. As large land masses are splintered, the total surface area increases due to the combined surface area of all the smaller pieces. However, continued erosion, subsidence, and sea level rise eventually result in the total loss of these splintered islands. Fisheries production will likely decrease as land loss continues and the scale tips to shrinking land-water interface, vital habitat for juvenile estuarine finfish and crustacean shellfish such as shrimp (Caffey and Schexnayder 2002; Browder et al. 1985). While well-documented in Louisiana, all the SE coastal states face these threats. Menhaden, for example, depend on coastal wetlands or estuaries for part of their life cycle, spawning all along the USA Atlantic coast and Gulf of Mexico in different months at different locations. After two months in the ocean the larvae are carried into the bays and estuaries by ocean currents, and from there they move into the rivers for several months before migrating back to the ocean. Most mature at two to three years and can live to age ten. Changes in ocean currents could disrupt larval transport into bays and estuaries. Additionally, salt water intrusion, coastal inundation, and land loss due to sea level rise in the Gulf of Mexico states may increase nursery habitat while sea level associated with global warming could flood nursery habitats in northern areas of the region such as the Carolinas and Virginia where spawning occurs in protected bays rather than on the shelf. In addition to being a fishery species, menhaden are an important food fish for many larger fish, and their reduced abundance and distribution would likely affect the populations of fish that prey on them (Aubrey and Emery 1993; Houde and Rutherford 1993; Jones 1994).

Temperature. A number of researchers have hypothesized the effect of climate change on fishes. Effects range from simple extension of native ranges migrating northward in response to the gradual warming of water to total year class failure and disappearance of populations due to interruption of reproductive cycles and offset of timing between predator and prey. Most fish species have a fairly narrow range of optimum temperatures related to specific basic metabolism per species, and in addition the availability of food organisms have their own optimum temperature ranges. Depending on the species, the area it occupies may expand, shrink, or be relocated with changes in ocean temperatures. For example, warmer temperatures would change menhaden adult migration patterns and spawning locations. Warmer temperatures in estuaries would be associated with lower dissolved oxygen levels for larvae (Aubrey and Emery 1993; Houde and Rutherford 1993 Jones 1994). Research indicates that within and near oxygen-depleted waters, finfish and mobile macroinvertebrates, such as crustacean shellfish, experience negative effects that range from mortality to altered trophic interactions. Chronic exposure to hypoxia and fluctuating oxygen concentrations impairs reproduction, immune responses, and growth (Breitburg et al. 2009). Changes in species distributions occur much more rapidly in the marine environment than in terrestrial systems (Rosenzweig et al. 2007), and there are many examples of distribution changes and migration phenology associated with climate change (Ware and Tanasichuk 1989; Sims et al. 2004; Perry et al. 2005; Pörtner and Knust 2007). For example, a number of tropical and subtropical fish species have shifted northwards along the continental slope of England, at rates matching plankton shifts of50 km y^{-1} (Quero et al. 1998; Stebbing et al. 2002). The southern boundary of one North Sea species, the blue whiting (*Micromesistius poutassou*), has moved by as much as 816 km (ICES 2004, Perry et al. 2005). It should be noted that not all species move northward at the same rate or at all. These disconnected shifts may have unpredictable consequences on, for example, trophic interactions of predators and prey (Murawski 1993; Edwards and Richardson 2004). Extinctions are predicted to occur where dispersal ability is limited or suitable northward habitat is unavailable (Thomas et al. 2004). Local extinctions have already occurred at the edges of some current fish ranges (Friedland et al. 2003). These species shifts and extinctions in other parts of the world suggest that similar changes in distribution could be occurring in the SE USA; more research is needed in this area.

Shifts in fish stock distributions are likely having social and economic consequences (Brander 2010). One economic impact of distributional shifts in some fishery species is the displacement of fishing pressure to other species. For example, as cod fisheries have declined, landings of shrimp, crab, and lobsters have risen (Parsons and Lear 2001). In fact, northern shrimp (*Pandalus borealis*) and lobster (*Homarus americanus*) populations have actually increased, possibly as a result of increased water temperatures and subsequent improvements in recruitment (Parsons and Colbourne 2000; Mann and Drinkwater 1994). The long-term impact of climate change on fisheries in the SE is likely to be great. The rate of future warming is predicted to be more rapid than previous changes.

***Storm severity**.* Some climate change projections indicate an increase in the frequency and severity of tropical storms in the western Atlantic (Emmanuel et al. 2008). An increase in tropical storm activity could have large impacts on the fishing and aquaculture industries. Many fished and cultured species are negatively affected by severe tropical storms through increased pollution run-off, direct storm damage, flooding, saltwater intrusion from storm surge, and habitat loss. In addition the fishing and aquaculture industries can be devastated by the damage and loss of infrastructure including boats, docks, marinas, equipment, processing plants, and distribution centers. This loss has already been documented throughout the SE after major storms and may only increase with climate change.

9.2.2 Molluscan Shellfish

Molluscan shellfish include bivalves such as clams, oysters, scallops, and mussels that are fished or cultured for human consumption. These species are predominately sessile and face different effects from climate change than finfish and crustacean shellfish. Clams and oysters are of particular importance in the SE. For example, shellfish aquaculture products sold in 2005 from SE states were valued at $42 million--Louisiana and Florida were the largest contributors (USDA 2005). The effects of climate change on molluscan shellfish fisheries and aquaculture are expected to be complex; some potential aspects are considered in the following sections.

Climate change can be expected to affect the reproduction, health, and distribution of commercially harvested bivalve species within the Gulf of Mexico, as expected in other coastal marine systems (Harley et al. 2006; Hollowed et al. 2011). The potential effects of increased water temperature on molluscan shellfish fishing and aquaculture, in particular, are significant, potentially complex and highly variable (Allison et al. 2011). Bivalve ranges shift locally on a seasonal basis as freshwater flows ebb and flow. However, changes in range could occur on longer time periods based on multiple parameters. Among these are temperature, ocean pH and local acidification, and sea level rise that may move coastal estuaries inland. Here the potential aspects of climate change that could influence molluscan shellfish are considered.

Increases in water temperature. Warmer water temperatures are expected to have effects on the physiology of species, leading to possible impacts on metabolism, reproduction, and species distribution in both marine and estuarine environments (Fields et al. 1993; Lubchenco et al. 1993). Sea-surface temperatures are expected to increase 3°C by the end of the 21st century (see Chapter 2). Increased temperatures may allow tropically distributed species, including nonindigenous species such as the green mussel, *Perna viridis*, (currently established in Florida) to expand their ranges northward. Additionally, warming water temperatures may lead to an increase in foodborne and waterborne pathogens associated with molluscan shellfish harvest and consumption (Rose et al. 2001). Moreover, increased water temperatures may be associated with an increase in hypoxia events, which pose a significant threat to commercially harvested shellfish in the coastal waters of the Gulf of Mexico (Fogelson et al. 2011; Vaquer-Sunyer and Duarte 2008).

Sea level rise. Sea level rise is expected to have the greatest impacts on fisheries and aquaculture in areas of shallow water, such as Louisiana and much of the Gulf coast, as estuarine locations could shift significantly. Blum and Roberts (2009) suggest the loss of tens of thousands of square kilometers of delta surface area in Louisiana alone. Rises in sea level may affect the distribution of established oyster reefs as well as the productivity and accessibility of privately leased oyster beds and clam farms.

Freshwater inputs and increased precipitation. . Increased precipitation, predicted for parts of the SE. is likely to increase freshwater inputs to estuarine and coastal areas, decreasing salinity. On the other hand, diversion of freshwater sources for human and agricultural uses may reduce freshwater inputs and increase salinity. Studies of El Niño Southern Oscillation (ENSO) events support observations that salinity is a major factor affecting distribution of molluscan shellfish, and any changes in salinity are predicted to have significant consequences. Soniat et al. (2006) found that the oyster pathogen, *Perkinsus marinus* or Dermo, was associated with ENSO-driven increases in salinity. Conversely, Kim et al. (1999) suggested that ENSO-driven cycles can lead to increased levels of contaminants, such as pesticides and trace metals, with increased freshwater input. Studies of ENSO events can provide a model of what precipitation changes from climate change could mean to the region.

Ocean acidification. The effect of increased CO_2 concentrations in water and the resulting lower pH decreases the saturation state of calcium carbonate and leads to decreased calcification in marine organisms (Raven et al. 2005). Therefore, ocean acidification is expected to have major effects on molluscan shellfish fisheries and aquaculture (Porter 2007; Kraines et al. 1996; Miller et al. 2009) and has already been linked to failures of shellfish spawning at Pacific coast hatcheries in the USA. Estuarine waters are less buffered than marine waters and are more susceptible to ocean acidification (Waldbusser et al. 2011). Experimental studies of larval growth and survival have indicated that predicted levels of acidification (pCO_2 up to 560 and 800 µatm) would lead to decreased growth and survival (Miller et al. 2009; Parker et al. 2009; Talmage and Gobler 2010). Miller et al. (2009) studied the Atlantic oyster (*Crassostrea virginica*) and found modest decreases in shell area and calcium content in specimens treated with two expected future CO_2 concentrations (up to approximately three times preindustrial CO_2 levels), compared to controls. However, oysters were able to continue to accrue some new shell, even in situations with limited amounts of aragonite, the most soluble form of calcium carbonate (Miller et al. 2009).

Severity of storms. The potential increase in the severity of tropical storms in the western Atlantic (Emmanuel et al. 2008), if such change occurs, could have devastating effects on both molluscan shellfish fisheries and aquaculture, as evidenced by the catastrophic effects of recent hurricanes within the Gulf of Mexico. Not only are animals directly affected, but fisheries and aquaculture infrastructure can be completely destroyed. The depression of oyster harvests in the northern Gulf of Mexico by Hurricane Katrina is one well-documented example of the effect of severe storms (NMFS Statistics Office, personal communication). Research is needed to assess the potential impacts of increased storm frequency and severity on molluscan fisheries and aquaculture.

9.2.3 Freshwater Fisheries and Aquaculture

All aquaculture species may face harmful effects from climate change. Increased temperatures may result in hypoxia in outdoor systems (see production methods in this chapter). Surface temperatures are predicted to increase 1°C to 5°C (IPCC 2001). Outdoor systems near the coast face threats from sea level rise and inundation. Crawfish and alligators are important fishery and aquaculture species in the SE facing negative impacts by climate change. Sea level rise, reduced rainfall, or seasonal flooding would all have effects. Although crawfish are fairly tolerant to saltwater, saltwater intrusion will negatively affect production. Tolerance to salinity is directly proportional to crawfish size. Salinity affects crawfish reproduction at much lower concentrations but the effect of continuous exposure to low salinity on crawfish reproduction is not fully known. If salinities higher than 3 ppt occur through most of the crawfish season, production will likely be negatively affected (McClain 2007).

Alligator farmers depend on the collection of eggs from nests found in coastal or inland wetland habitats. Nesting efforts by female alligators are negatively affected by elevated salinity as well as high water levels during the spring prior to egg laying time. Stress levels increase as salinity increases causing female alligators to abort nesting when salinity reaches 8 to 10 ppt. Droughts along the coast and saltwater intrusion also may result in higher salinities. Nesting female alligators respond to high water events prior to nesting by building higher nests or moving to a higher site. High water events following egg laying result in drowning of the embryos should the eggs be submerged (Joanen and McNease 1989). The SE is predicted to see an increase in extreme precipitation events which could lead to the submerging of nests (IPCC 2007).

Droughts, expected to increase in the summers throughout much of the SE, might decrease water levels, increase water temperature, and decrease dissolved oxygen. An extreme drought like that in Texas and western Louisiana in the summer of 2011 resulted in large fish kills as reservoirs dried up and oxygen levels dropped. Nearly 124,000 fish were killed in just one lake, Lake Grapevine, a few miles northwest of Dallas (Texas Parks and Wildlife Department, personal communication). Other SE states could easily witness similar droughts. Additionally, reservoirs, farm ponds, aquaculture ponds and streams are all vulnerable to these climate change conditions.

9.3 Complicating Factors

SE fisheries and aquaculture are not closed systems. Many factors, some discussed in this section, likely will influence the effects of climate change on these sectors.

***The Gulf of Mexico Dead Zone*.** The Mississippi River captures runoff from 41% of the continental United States. As climate changes throughout the USA, changes in flows of the Mississippi River will affect the Gulf of Mexico. Climate changes likely will result in higher water temperatures, stronger stratification, and increased inflows of freshwater and nutrients to coastal waters. Since the 1970s a large hypoxic zone has been documented off the coast of Louisiana related to the Mississippi River's drainage. The oxygen levels in the are water so low that fish and shellfish often do not survive or must leave the area if possible. As flooding events increase and agricultural practices are adapted to climate change, the extent of the yearly dead zone is expected to increase. In 2010, the Dead Zone size was one of the largest ever recorded. However, an increase in severe tropical storms could help offset this hypoxic zone with additional mixing of water (NOS 2011; Rabalais et al. 2009).

Harmful Algal Blooms. Harmful Algal Blooms (HABs) result from a rapid growth of *Karenia brevis* and other "red tide" organisms. An increase in nutrients from human-caused nutrient pollution often increases the prevalence of HABs resulting in fish kills, sea bird mortality, and human illness from contaminated shellfish. In Florida alone, HABs are estimated to cost $19 million to $32 million per year in economic damage (NOS 2011). These HAB events likely will increase as a result of increased precipitation, runoff, and nutrient pollution, directly killing fish, affecting human and wildlife populations, and impacting the economics of the region.

Restoration Conflicts. In areas where fishers have already relocated, such as in the upper reaches of the estuary in response to saltwater intrusion, restoration efforts to return natural tidal flows and salinity regimes can be in direct opposition to these fishers' adaptations. In coastal Louisiana, freshwater diversions are designed to increase freshwater flow and return sediment to the wetlands. However, this freshwater lowers salinity detrimental to oyster leases and results in possible relocation of adult blue crabs and shrimp, forcing fishers and producers to adapt again to changes. Oyster lease relocation programs have, therefore, also been considered as part of the restoration (Caffey and Schexnayder 2002). Florida's clam industry faces these same challenges if there are shifts in salinity regimes due to climate change.

Water Use. Water is an essential resource for communities and for aquaculture. In Louisiana alone, $326 million is contributed to Louisiana's economy from aquaculture. However, this economic contribution requires a water investment, usually freshwater. As droughts are expected to increase in frequency, conflicts may arise over water use between communities and aquaculture producers throughout the SE. Best management practices will need to be encouraged for the most efficient use of water resources by all groups involved (Romaire et al. 2011).

9.4 Adaptation and Mitigation

Designing adequate mitigation and adaptation strategies for fisheries management will require continued monitoring, research, and predictive modeling. Existing adaption and mitigation practices exist which may help fisheries and aquaculture adjust to or even offset climate change factors. This section highlights specific concerns for adaptation and mitigation related to aquaculture and fisheries in the SE USA.

Monitoring. To adapt to climate change, fishers and farmers can check weather and water conditions in order to fish and harvest at optimal times. Offshore fishers can receive satellite weather and water conditions to help them decide if it is cost-effective to stay out on the water or head to port. In Florida, clam farmers can use a water quality website (http://shellfish.ifas.ufl.edu/water_quality.html) to check wind speed, air and water temperature, and salinity prior to planting or harvest. This results in decreased fuel use and costs and, therefore, lower emissions (University of Florida 2011).

***Gear Efficiency*.** As fisheries face impacts from climate change, increased gear efficiency is a vital adaption. Reducing drag on gear, and thereby fuel consumption, is one option to make the shrimp-trawl fishery more adaptable to a changing future. Reducing fuel expense and extending the intervals for various preventive maintenance activities may enable remaining operators to begin improving economic performance in the shrimp fishery. Efforts to reduce fuel use have also led to the ability to document a reduced carbon footprint. Experimental gear technology such as vented, cambered trawl doors; small-diameter, braided high-density, polyethylene (HDPE) webbing called Sapphire®; and Kaplan-style propellers allow the industry to adapt to and mitigate effects of climate change. Results generated by co-operators across the Gulf and South Atlantic suggest that other fishers can expect somewhere between a 20% and 28% reduction in fuel use with the experimental fishing gear. Fuel conservation and the reduction in fuel expense is, unequivocally, the largest saving attributable to the new gear, and it is immediate (Graham and Haby 2010).

***Shifting Effort*.** The development of the hard clam aquaculture industry in Florida and other parts of the Gulf Coast is an excellent example of the efforts to shift from fishing to aquaculture. Former gillnet fishers were trained in shellfish aquaculture and the industry has become successful (Colson and Sturmer 2000). In selecting aquaculture species, however, an important consideration must be the degree of dependence on products from fisheries, such as fish meal and fish oil, for food supply (Naylor et al. 2000).

***Carbon Sequestration*.** Use of bivalves for carbon sequestration (Hall et al. 2011 and 2009; Lee et al. 2011) may be plausible. Some discussion of the impacts of carbonate concentration on shellfish biology (Spero et al. 1997) is worthy of consideration, and a complete analysis of mollusk shell evolution (Furuhashi et al. 2009) reveals a complex story. Mollusk shells do sequester carbon, albeit in a way derived from indirect solar energy (including algae consumption) and with input from the water column. Dehon (2010) studied the issue and concluded that oyster reefs could sequester geologically significant amounts of carbon. Use of artificial reefs for multiple functions has been explored by Hall et al. (2011) and many others. Natural or artificial reefs can become dominated by native oysters and can produce food and habitat, provide protection from erosion, aid in sedimentation, and be useful sustainable tools for estuarine management as well as carbon sequestration.

The commercial culture of northern hard clams, *Mercenaria mercenaria*, in Florida is conducted in high-density lease areas, designated by the state in waters that were previously determined to be unproductive for shellfish. Clams grow rapidly in this environment and typically reach commercial size after about one year of growth in the leased areas. Clams are cultured in semi-rigid mesh bags, which provide hard substrata for fouling organisms on an otherwise soft-bottom environment. Market clams, however, accounted for only 70% of the bags. Nonharvested clams, oysters (*Crassostrea virginica* and *Ostrea equestris*), mussels (*Brachidontes* sp.) and barnacles (*Balanus* spp.), among other shell-bearing fauna, were recovered from both on and within the clam bags. With this material added, carbon sequestration estimates rose to 2.2-6.8 Mg ha^{-1} y^{-1} (Baker 2011).

Local Markets. By utilizing local markets, fishers and producers can reduce their fuel costs and emissions. Additionally, they can yield a high price per unit to adapt to lower catch, increased fuel costs, and variable weather from climate change. For example, Delcambre Direct Seafood, Delcambre, Louisiana, uses the Internet to connect fishers with buyers who want to purchase directly off the boat. By the end of 2010, more than 20 vessels were enrolled and profiled in the Delcambre Direct network and buyer participation had risen to 675 subscribed individuals. Suppliers were reporting a steady and increasing number of requests for product and in many cases fishers reported having most or all of their catch sold prior to leaving port. On average, prices received via Delcambre Direct were 2.5 times greater than average dockside prices for commodity shrimp. Direct sales netted these fishers a $6,000 premium over dock prices annually (Hymel 2011). In South Carolina, the interactive web-based tool MarketMaker, featuring a searchable database that connects consumers of South Carolina products with suppliers, was redesigned to include seafood and seafood products. The seafood component of MarketMaker serves all elements of the seafood industry (fishers, retail, distributor, and wholesaler) allowing each to create an online business profile highlighting the uniqueness of their products and businesses, and to choose from a nationally compiled list of seafood species and attributes to characterize their products on the sellers' side and specify their needs on the buyers' side (see http://www.scseagrant.org/content/?cid=532#award).

9.5 Research Needs

Aquaculture and fisheries are important economic drivers in the SE USA. For these industries to continue to grow and contribute to national food security, strategies must be adopted to mitigate the harmful impacts of climate change, such as sea level rise, coastal storm activity, freshwater inflow events, ocean temperature increase, and ocean circulation alteration (Scavia et al. 2002). However, interactions between climate change processes and anthropogenic factors, such as fishing pressure, are complex and may be unpredictable at our current level of understanding (Harley et al. 2006). Therefore, an active collaboration of ecologists, physiologists, geneticists, engineers, climatologists, oceanographers, economists, resource managers, and members of the fishery and aquaculture industries must be developed. Working together these groups can help prioritize and direct research efforts and policies of relevance to the aquaculture and fishery industries in the SE USA. All climate change predictions need to include ocean currents, sea-surface and air temperatures, ocean acidification, land loss, sea level rise, oxygen concentrations, precipitation changes in frequency and intensity, and storm frequency and intensity. Some of the identified research needs are discussed in the following sections.

Impacts of Freshwater Inflow. There is great uncertainty regarding future rainfall and runoff patterns. For example, the Hadley model projects a much wetter USA climate over the next 100 years, with a 34% increase in total runoff along the Atlantic and Gulf coasts. The Canadian global climate model predicts a drier and hotter climate, with a decrease in runoff of 32%. Both models, however, predict an increase in extreme rainfall events (Wolock and McCabe 1999; NAST 2001). Either scenario has important implications for the volume of freshwater delivered to coastal systems (Scavia et al. 2002). Additionally, as human populations grow or migrate, water use conflicts are likely to escalate.

Estuaries are particularly important for fisheries and aquaculture production, for example, serving as nursery grounds for larval fish or as the appropriate habitat for suspension-feeding shellfish. Physical impacts of inflow changes likely will include modified salinity regimes and estuarine stratification; increases in nutrient, sediment, and pollutant load to estuaries; and reduced freshwater availability for inland aquaculture (Kennedy 1990; Najjar et al. 2000). Potential biological impacts include changes in phytoplankton communities and increased eutrophication, resulting in expanded hypoxic or dead zones (Cloern 2001; Rabalais et al. 2002). Both physical and biological impacts of changes in freshwater inflow will interact with fisheries and aquaculture in the SE in complex ways and will require adaptation in the industries. Research examining possible coping strategies is important. In addition, developing reliable precipitation and inflow models for the SE, including the Gulf of Mexico, is imperative.

***Aquaculture Development*.** As capture fishery production moves northward or species go extinct at the southern edges of their ranges (Ware and Tanasichuk 1989; Friedland et al. 2003; Sims et al. 2004; Perry et al. 2005; Pörtner and Knust 2007), continued development of aquaculture may contribute to future food security. Local extinctions may be a particular problem in the Gulf of Mexico, where northward shifting species have nowhere to go. As a result, place-bound fishers may displace their activities to remaining species, resulting in their decline as well (Parsons and Lear 2001). Therefore, aquaculture development may be particularly important in the SE USA. Research examining methods of culturing new food fish and shellfish species, development of more efficient culture methods, and development of alternative feeds is needed.

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10 Impacts of Climate Change and Variability on Water Resources in the Southeast

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Key Findings

- Climate change is affecting the southeastern USA, particularly increases in rainfall variability and air temperature, which have resulted in more frequent hydrologic extremes, such as high-intensity storms (tropical storms and hurricanes), flooding, and drought events.
- Future climate warming likely will increase water loss through evapotranspiration (ET) due to increased evaporative potential and plant species shift. Greater ET can decrease total streamflow, groundwater recharge, flow rate, and regional water supplies.
- Water supply stress is projected to increase significantly by 2050 due to hydrologic alteration caused by climate change and increased water use by key economic sectors, such as domestic water supply, irrigation agriculture, and power plants. Water supply stress will become most severe in the summer season when normal rainfall is typically not sufficient to meet evaporative demand of the atmosphere

- Declining runoff and increasing demands for water resources are likely to increase the pressure on the existing reservoirs, leading to deeper and longer lasting drawdowns.
- Runoff and soil erosion potential are projected to increase in some areas due to changes in rainfall that either increase rainfall erosivity or decrease vegetative cover protection.
- Inland water temperature is projected to increase with increases in air temperature, resulting in possible adverse impacts on coldwater fish habitat in the Appalachians.
- Salinity intrusion in coastal fresh water systems likely will increase in response to sea level rise and decrease of fresh water inputs from uplands due to climate change. Flooding related to sea level rise may also threaten coastal infrastructure in low lying areas.
- Ecosystem restoration, including afforestation, has the potential to mitigate or reduce adverse impacts of hydrologic extremes (droughts or floods) and water quality caused by climate change.
- Best management practices (BMPs) should be adjusted and enhanced to increase watershed resilience to likely adverse impacts of climate change on water quantity and quality.
- Programs to increase water-use efficiency, to use recycled water, and to increase water storage capacity should be developed to help alleviate water supply stress.
- Large knowledge gaps exist about how future climate change and other stressors--such as human population growth, land use change, energy security, and policy shifts--will interactively affect both surface and ground water availability.
- Consequences of proposed adaptation management options, such as increase in irrigated agriculture and bioenergy development, must be carefully evaluated to maximize their effectiveness and cost-benefit.

Executive Summary

The specific objectives of this chapter are (1) to document the consequences of climate change and variability in altering the quantity, quality, and timing of water supplies at multiple scales during the past and the next 50 years; (2) to present case studies showing how climate change has affected regional water resources; and (3) to discuss water resource management strategies to mitigate and adapt to climate change across the southeastern region.

10.1 Water Resources in the Southeast

The 11 states in the Southeast (SE) are known for warm climate, abundant water resources, rich ecosystems including large forested areas (60% of all land area), and high quality of life. Many areas of the SE have seen population increases between 45% and 75% during the past three decades. The population is projected to increase 50% in the next 50 years, representing one of the most dynamic economies in the nation (Wear and Greis 2011). The region relies on water resources to maintain this growing economy that is largely based on forestry, recreation, manufacturing, tourism, irrigated agriculture, power generation, fisheries, and navigation.

In recent decades the SE region has experienced water stress due to recurring severe droughts and the increasing levels of consumptive water use from multiple sources (Sun et al. 2008). Water stress is especially critical in the large metropolitan areas such as Atlanta and Charlotte.

Thus, any additional stresses implied by climate change are beginning to concern all economic sectors. The 2009 National Climate Change Assessment suggests that droughts, floods, and water quality problems are likely to be amplified by climate change in the SE (Easterling et al. 2000a, Karl et al. 2009). Projected demographic and socioeconomic changes associated with rapid population growth further threaten water resources (Lockaby et al. 2011, Marion et al. 2011). Recent drought experience in many areas of the USA indicate that even small changes in drought severity and frequency will have major impact on agricultural production and ecosystem services, including drinking water supplies (Easterling et al. 2000b). Unique to the SE are the 8000 km long, mostly populated, low-lying coastal areas that are vulnerable to salt water intrusion, flooding, erosion, water quality degradation, and wetland losses in addition to projected sea level rise and intensified tropical storms (Amatya et al. 2006, Lockaby et al. 2011). The devastating consequences of Hurricane Katrina in 2005 indicate the severity of what extreme climate impacts might be on coastal zones. The large range of hydrometeorological and socioeconomic characteristics across the region implies that responses to climate change in the SE require a multifaceted adaptation and mitigation management strategy (Marion et al. 2011).

10.2 Key Constraints to Water Resources in the Southeast

Changing climate. Climate change alters stream water quantity and quality by altering hydrometeorological patterns, elevating evapotranspiration (ET) potential, and disrupting biological processes. Climate variability, growing water demands, and limited storage capacity exacerbate the risk of water shortages during droughts. In addition, buildup of dissolved phosphorus and cyanobacteria in drinking water reservoirs and rivers is a major threat to public health (Meybeck 2004, Osidele and Beck 2004). Damage from tropical and winter storms has also increased dramatically. As a result, the region is faced with the need to develop new infrastructure, such as reservoirs and water treatment facilities; management strategies; and planning policies to respond to these challenges. Climate-related hazards, particularly tropical storms and drought, are the most frequently occurring natural hazards in the Caribbean. Projected increase of drought frequency is of vital concern for the Caribbean islands, which already have limited freshwater sources (Farrell et al. 2011).

Sea level rise. If global temperatures continue to increase, sea levels are expected to rise as much as two feet by 2050 in the coastal areas in the SE (Cahoon et al. 2009). Coastal areas in Louisiana, Mississippi, Alabama, Florida, and the Caribbean Islands are vulnerable to saltwater intrusion and flooding. Some of the major economic and environmental consequences of saltwater intrusion into freshwater aquifers and drainage basins include the degradation of natural ecosystems and the contamination of municipal, industrial, and agricultural water supplies (Bear et al. 1999). Coastal flooding events may increase damage to forests and wetlands, and property and infrastructure (Obeysekera et al. 2009, Heimlich et al. 2009). In addition, sea level rise will have significant effects on river form and processes and may alter channel behavior far upstream of the estuaries and coastline.

Rising water use for energy generation. The relationship between water and energy, called the “water-energy nexus,” represents a critical business, security, and environmental issue (Glassman et al. 2011). The growing population and irrigated agriculture in the SE has increased the demand for energy by orders of magnitude over the past decades. Power production by nuclear, coal, gas, and hydropower is the largest overall user of water resources in the region. Water availability is a large concern in the SE, especially during drought conditions when cumulative effects of thermal discharges reduce the assimilative capacity of streams and the sensitivity of aquatic organisms during periods of high temperatures and low dissolved oxygen. Loss of dissolved oxygen for aquatic species is further accelerated by eutrophication and the accumulation of nutrients from outdated wastewater treatment plants and agricultural fertilizer runoff from feed lots and eroding farmlands. Competition between water use for energy and other water uses, such as drinking water and irrigation, are most severe during droughts. During the 2007-2008 drought, water providers from Atlanta, GA, to Raleigh, NC, urged residents to conserve water while power plants struggled to avoid blackouts. In North Carolina, water woes forced Duke Energy to reduce output at its G. G. Allen and Riverbend coal plants on the Catawba River (Averyt et al. 2011). In Alabama, the Browns Ferry nuclear plant had to drastically reduce its output (as it has in three of the past five years) to avoid exceeding the river temperature limit and killing fish in the Tennessee River (Averyt et al. 2011).

Increasing water use for irrigation. The 2008 U.S. Farm Bill established the Agricultural Water Enhancement Program (AWEP) to encourage more efficient and effective irrigation and water conservation measures. Evidence from climate research indicates that frequent drought conditions may continue to plague the region and may even be exacerbated (IPCC 2007). In order to maintain a robust agricultural economy and food prices, there is a large potential to expand irrigated agriculture in the SE, especially in South Carolina and Alabama. Florida, Georgia, and Mississippi have substantially expanded irrigation in the last 40 years, but irrigation withdrawals impair summer stream flows and threaten riverine ecosystems. Increasing existing water storage is being considered as a potential strategy to restore environmental flows. For example, Alabama farmers have recently begun to build off stream reservoirs to store water during the winter, when streamflows are greatest, for use during the spring and summer crop season.

Changing land use and land cover. The conversion of forest lands and wetlands to residential, commercial, industrial, and agricultural uses likely will exacerbate the impacts of climate change (Lockaby et al. 2011, Sun et al. 2012). For example, large areas of the North Carolina Pocosin system in the Atlantic Coastal Plain region have been modified into an extensive network of drainage canals to make agricultural production feasible in the normally hydric soils. These canals have altered the hydrology, lowered the water table, and increased the vulnerability of the system to long-lived fires. As the climate warms, droughts likely will be more severe, more frequent, or both, thus increasing the exposure to fires that can burn for many weeks (Poulter et al. 2006). Climate change influences streamflows differently from land use change. In the Appalachian region, the influence of recent climatic trends is larger than the influence of direct human impacts from urbanization or agriculture. However, in the Piedmont and Coastal Plain regions, direct human impacts on streamflow have generally been larger than the impacts of recent climatic trends (Wang and Hejazi 2011).

Insufficient water storage. Unlike the western USA, most of the water supply systems, primarily reservoirs, in the SE are within-year systems that store water during the high-flow fall and winter season and release it during the low-flow spring and summer season. Thus, any substantial increase or decrease in annual runoff due to climate change will increase the vulnerability of these water supplies, as these systems are smaller in size than multi-year systems. Detailed uncertainty analyses of climate change impact on the vulnerability of water supply systems are important tools for adaptation and mitigation. The current level of uncertainty in precipitation and runoff projections does not warrant application of projections for critical investment decisions; for example, building a new reservoir to respond to drought or flood over the next 50 years. However, it is important to develop strategies to reduce the vulnerability of systems if projected climate change does occur.

Unique biodiversity. Native ecosystems in the SE are among the most diverse and unique in the world. Few areas on the planet have such biodiversity and few face as great a threat of destruction. Trying to reconcile regional development against the backdrop of fragile and fragmented ecosystems is a key sustainability issue (Richter et al. 2006). Allocating proper environmental streamflows is essential to protect the aquatic resources.

Unique cultures. The racial legacy in the SE has left an imprint on educational institutions both from segregation and desegregation, and environmental perceptions. Trying to bridge the old versus the new South will require the development of communication and collaboration mechanisms that are relevant to important subcultures, not only the existing African-American and rural communities, but also the emerging Latin-American communities. In addition, there is increasing evidence that the poor and elderly in the SE have unequal access to natural resources, including water (Wisner et al. 2004).

10.3 Historical Climate Trends

Observed and projected climate change in the SE is spatially complex due to the interacting influences of global climate change *and* natural large scale climate oscillations including El Niño-Southern Oscillation (ENSO) (Li et al., 2011), Atlantic Multi-decadal Oscillation (AMO) and the Pacific Decadal Oscillation (PDO) (Obeysekera et al., 2009). Across the region, mean air temperature increased 0.9^{o}C between 1970 and 2008 (Karl et al. 2009). Average annual temperatures in the region are expected to increase by an additional 2.5°C to 3.5°C over the next 50 years (McNulty et al. 2012). During the 20th century, annual rainfall amounts increased 20% to 30% or more for some portions of the SE, although other portions experienced declines in rainfall amounts. The amount of very heavy rainfall (more than 2 inches per event) increased 15% to 20% from 1958 to 2007. The SE summer rainfalls have exhibited higher interannual variability with more frequent and intense summer droughts and anomalous wetness in the recent 30 years (1978 to 2007) than earlier in the 20th century (1948 to 1977) (Karl et al. 2009; Wang et al. 2010). The intensification of the SE summer rainfall variability is primarily associated with higher Atlantic sea surface temperature variability in the last three decades. Strong seasonal and year-to-year variations in precipitation seen in the SE were partially caused by strong El Niño-Southern Oscillation (ENSO) effects. The number of abnormally wet and dry summers in the SE region doubled over the last few decades (Li et al. 2011). As anthropogenic forcing continues to increase and the North Atlantic Subtropical High (NASH) climate system continues to intensify, the SE will experience more frequent wet and dry summers during positive Pacific Decadal Oscillation phases (Li et al. 2011, Li et al. 2010).

10.4 Uncertainty in Predicting Future Climate and Hydrologic Impacts

Most global climate models (GCMs) predict that as the climate warms, the frequency of extreme precipitation will increase across the globe (O'Gorman and Schneider 2009). However, less than two-thirds of GCMs agree on the predicted change in direction of future precipitation events for the eastern USA (IPCC 2007). The uncertainty of predicting local and regional precipitation patterns stems from the fact that clouds, evaporative flux from surface (either land or ocean), advection of moisture and diffusion of moisture in the atmosphere are imperfectly modeled. Seasonally, the uncertainty is greatest in the summer when the moisture-holding capacity of the warmer air is greatest. In the summer, the SE exhibits the greatest variance of the seasonal mean precipitation relative to the rest of the continental USA (Chan and Misra 2010). Furthermore, Chan and Misra (2010) found that an apparent difference between a wet and a dry summer for the SE is the result of the presence or absence of a remote moisture source, particularly the atmospheric river from northwest subtropical Atlantic Ocean, as well as quantitative differences in the local recycling of moisture. The atmospheric river from the remote northwestern subtropical Atlantic Ocean, which leads to wet summers, is a major source of uncertainty for the SE climate projections because most IPCC AR4 models have significant bias in sea surface temperatures (SST) over this region (Misra et al. 2009).

Climate change impacts hydrologic processes and water resources directly through precipitation, evapotranspiration, groundwater recharge, peak flow, and water yield; and indirectly through water quality and water use by irrigation. Many of the responses are not unidirectional and can be additive or cancel each other. For example, increase in atmospheric CO_2 concentration may increase plant water use efficiency and reduce ET demand. But increase in air temperature is likely to increase potential water loss through ET and stimulate plant growth when soil moisture and nutrients are not limited. So the net hydrologic effects can be uncertain. Similarly, agricultural abandonment followed by reforestation tends to increase ET and reduce streamflows (Wu et al. 2007, Cruise et al. 2010), thus mitigating the impacts of extreme climate and hydrology (e.g., flooding) (Ford et al. 2011). Consequently, projections of timing and spatial distribution of climatic variables, such as radiation and cloudiness, and climate impacts on ET and precipitation remain difficult.

10.5 Water Resources Impacts of Climate Change

10.5.1 Drought

Drought is one of the most common disasters in the USA. Drought can increase a location's vulnerability to other hazards such as salt water intrusion, wildfire, wind-induced soil erosion, and natural ecosystems' capacity to capture atmospheric carbon dioxide (Zhao and Running 2010). Despite its disruptive impact, drought often does not receive as much attention as other natural disasters such as hurricanes, tornadoes, or floods.

Droughts are common to the SE and the Caribbean regions. During the past 10 to 18 years, on average, each state reported about five drought events every year, with Florida and North Carolina topping the list. The most recent severe drought occurred during 2009-2010 in most

Caribbean countries (Farrell et al. 2011) and currently in Florida. Karl et al. (2009) illustrate the observed trend in droughts over North America for the period spanning 1958 to 2007. The results point to a slight increasing trend in drought in the SE, which is commensurate with the trends of increasing temperature over the observed period of record and corroborated by other studies (Burke et al. 2006; Wehner et al. 2011; Dai 2011). Dramatic spatial and inter-annual variations also exist in the region. For example, from eastern Georgia to northwestern Florida, precipitation differences can be as much as 20 inches, exceeding the total rainfall in many parts of the country. The region also exhibits a distinctive seasonal climatology (Keim and Faiers 1996). In southern Georgia, May and June are pronounced dry periods as the Bermuda high expands inland. October tends to be dry in most areas in the region as air masses stagnate with high pressure dominating the SE. Alabama and Georgia generally have two dry periods: one April through June and the other in September and October due to the precipitation and ET patterns (SERAT 2002).

Localized droughts have occurred frequently throughout history in the SE. Recent drought periods (2000-2002, 2005-2008) and the large extent of the 2010-2012 droughts have received much attention. The most recent droughts were not unusual when compared with the geologic record. Seager et al. (2009) used historic instrumented data, tree ring reconstructions, and model simulations to analyze drought over the SE USA since 1000 CE (Figure 10.1). Much more severe drought conditions can and have occurred in the past. Instrumental records since 1895 shows that there were at least five periods during the 20th century when seasonally adjusted rainfall was below the 2005-2006 levels for at least a two-year period. In fact, there were sustained periods of at least five years during the decades of the 1920s, 1930s, and 1950s when average rainfall was below that of both the 2000 through 2002 and 2005 through 2007 drought years in Alabama and Mississippi where positive precipitation trends have been identified. Georgia's rainfall does not exhibit a positive trend, but the records suggest that the 20th century was anomalously wet for the region overall by the standards of the past millennium.

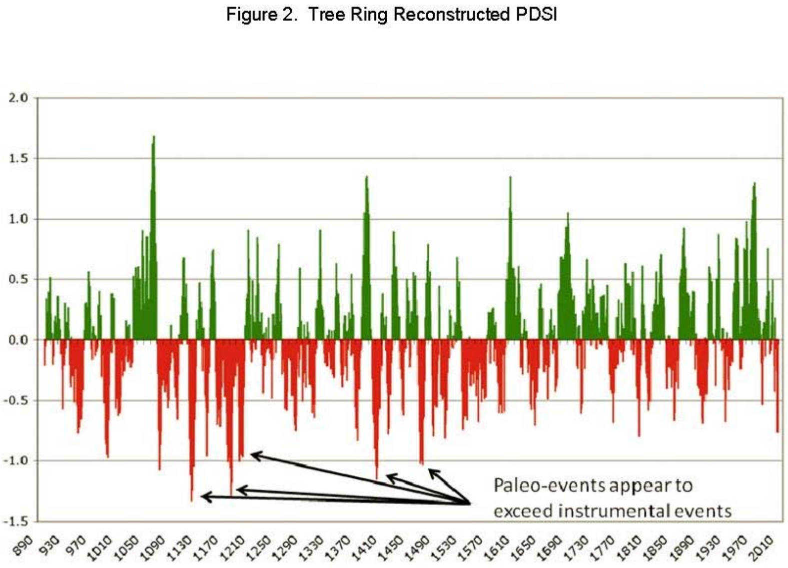


Figure 10.1. Reconstructed Palmer Drought Severity Index (PDSI) using tree ring data suggest that much more severe drought events have occurred in the past than those recorded during the past century (Seager et al. 2009).

Alabama and Mississippi climate division precipitation records demonstrate that the early 1940s period was among the driest since 1895, even exceeding the great 1954 drought as well as the 2007 drought (in Mississippi). Consequently, hydrologic droughts are prominent in the streamflow records of the region for the last century. The region as a whole had abnormally low minimum flows in 1931, 1954, 1986, 2000, and 2007. However, the severity of these droughts varied spatially over the region, and other drought years even appear in specific areas. For example, from 1943 to 1945 a localized drought in the headwaters area of the Black Warrior River in western Alabama and northeastern Mississippi approached the severity of many recognized regional drought periods but was confined spatially. However, in eastern Alabama or Georgia, or even south into the Tombigbee basin in Alabama, that period does not appear to have been abnormally dry.

***Future Trends**.* Because drought is difficult to quantify, it is also inherently difficult to model. A recent study by Wehner et al. (2011) evaluated 19 climate models from the Coupled Model Intercomparison Project database. Each model was evaluated on its ability to simulate drought over North America from 1950 through 1999. The authors noted that raw model outputs tended to overestimate precipitation, and therefore underestimate drought. Model deficiencies notwithstanding, the current literature suggests that a warming climate may lead to a fundamental change in the drought climatology of the SE USA during the next century. This change appears to be driven by warmer temperatures, which in turn may result in more ET and less soil moisture. Though some areas of the SE are projected to receive more precipitation during certain seasons and for different modeled periods, results from modeling studies such as Wehner et al. (2011) indicate that projected increases in precipitation may not be enough to offset the higher values of ET. The results from both Dai (2011) and Wehner et al. (2011) suggest that moderate drought may become the new normal state altered drought climatology for the SE whereby. In addition, Dai (2011) indicates that droughts in the next 20 to 50 years may become more persistent. This finding is critical when considering that the severity of drought impacts is typically directly correlated to drought length.

***Economic Impacts of Drought**.* One of the most critical impacts of drought to the study region is that on the agriculture sector. In the western parts of the region, the lush Mississippi River basin is home to one of the most fertile landscapes in the country. In Louisiana, droughts reduce sugar cane production and crawfish harvesting. Cotton, soybean, and sweet potato are often affected by drought in Arkansas, Alabama, and Mississippi. In Florida, droughts strongly affect sugarcane production and force citrus farmers to pursue aggressive irrigation strategies. In North Carolina and Kentucky, drought can have a major impact on tobacco, cotton, corn, and soybean. In addition to agriculture, droughts in the SE cause water levels in lakes and rivers to drop drastically, subsequently affecting tourism and recreational activities. In the case of low river flows, drought also has serious consequences on the shipping industry. The Mississippi river is the largest river system in the USA, draining runoff from 31 individual states and with the drainage divide extending into southern Canada. The river is one of the world's most commercial rivers, transporting a large bulk of goods. According to the national park service, the port of south Louisiana and the port of New Orleans shipped more than 250 million tons of goods in 2010 alone, making the Mississippi River one of the world's most prolific shipping arteries. The drought of 1988 caused extremely low water levels on the Mississippi river, stranding approximately 4000 barges (Karl et al. 2009). In Louisiana, droughts in the summer of

1998 and in the summer and winter of 2000 caused more than $100 million in crop damage. In Arkansas, a drought in the summer of 2010 caused an estimated $500,000 in crop damage. In Florida, a drought in the late spring of 2001 caused approximately $100 million in crop damage. While a “typical” period of drought might last from months to a year or two, the SE occasionally experiences multiyear droughts; for instance the one from the winter of 2005-2006 through the summer of 2008. This exceptional drought (D4), the highest level according to the U.S. Drought Monitor’s classification, resulted in widespread crop and pasture losses; higher than usual fire risk; and shortages of water in reservoirs, streams, and wells, creating water emergencies. According to Manuel (2008), crop losses in 2007 alone totaled more than $1.3 billion.

10.5.2 Groundwater and Low Flows

Surface water and groundwater are connected. Climate change and human influences on surface water also affect groundwater. This is especially true in regions such as Florida where a unique hydrogeology exists. There are many issues to consider for a comprehensive review of climate change and watershed management including groundwater withdrawal for domestic use and irrigation, inland wetland and coastal habitats, storm water management, and salt water intrusion (Heimlich et al. 2009).

Low flows levels are an integral component of a flow regime of any river and can occur seasonally or during drought (Smakhtin 2001). Low flows affected by climate change likely will have serious consequences for water supply to reservoirs, transportation, power generation, water quality, for example, dissolved oxygen concentration, water temperature, salinity, and nutrient levels, as well as the quality of aquatic habitat.

Previous studies suggested that the low flow characteristics have been changing in the South. For example, Lins and Slack (1999, 2005) reported significant increasing trends in annual minimum and 10th percentile flows between 1940 and 1999 at most sites in the Appalachian-Cumberland (AC), Mississippi Alluvial Valley (MAV), and Mid-South (MS) subregions of the SE while many sites in the Coastal Plain (CP) and Piedmont (PD) subregions exhibited significant decreasing trends in low flows. McCabe and Wolock (2002) found that the observed increasing trends in streamflow occurred as a result of a steep increase in precipitation beginning around 1970. A case study on three forest-dominated headwater watersheds in the Lower Mississippi River Basin suggested that low flows were occurring more frequently over time as the watersheds have become drier in the past 60 to 90 years. A continental watershed hydrologic simulation study with the Water Supply Stress Index (WaSSI) model (Sun et al. 2008) showed that monthly mean low flows were projected to decrease 6.1% per decade across the southern USA into the first half of the 21st century under various climate change scenarios; the largest decreases in flow magnitude in the study were in the Appalachian-Cumberland and Mississippi Alluvial Valley subregions. The large decrease in the MAV was partially due to decreasing flows from streams outside of the study region (Marion et al. 2012).

10.5.3 Water Supply for Humans and Ecosystems

Significant increasing trends of streamflow rates from 1940 to 1999 have been detected in the Appalachians and Mississippi Alluvial Valley regions, and to a lesser extent in the Coastal Plain and Piedmont regions (Lins and Slack 1999, 2005). Groisman et al. (2003) and McCabe and Wolock (2002) found that the increasing trends in streamflow occurred as a result of a steep increase in precipitation beginning around 1970.

The uncertainty of future climate and the interactive relationship between hydrological cycle and land use change and human water demand means the future of water supplies in the SE cannot be precisely predicted at this time (Sun et al. 2008). Krakauer and Fung (2008) argued that climate change will ultimately decrease future streamflows across the USA due to increased ET. The Apalachicola-Chattahoochee-Flint (ACF) river basin in the three-state area of Alabama, Florida, and Georgia is one example of how climate change will interact with other factors such as land use changes. For example, for the Flint River Basin in Georgia, modeling results suggest a declining streamflow trend relative to current conditions (Viger et al. 2011; Walker et al. 2011; Georgakakos et al. 2010). However, under a "business-as-usual" scenario of continued urbanization, some of these streamflow declines may be reduced due to increasing surface runoff from impervious surfaces. Recently, Moreau (2007) provided an excellent review on the projected climate changes by various coupled global circulation models (CGCMs) over the SE. Moreau compared the change in precipitation suggested by various models from 1980 to 1999 and concluded that there is no agreement between the CGCMs on both the magnitude and the direction of change in precipitation over the SE. Most importantly, the review shows that the differences among CGCMs are largest during the summer season, which is the most critical for the SE water supply. Sankarasubramanian et al. (2001) found that streamflow in the SE would increase 2% for every 1% increase in precipitation, which was estimated based purely on the observed records of precipitation and temperature over the last 50 years. Bates et al. (2008) reported that the changes in runoff over many watersheds are not consistent with changes in precipitation. Milly et al. (2005) combined runoff downscaled from different climate models and also found that the streamflow over the SE is expected to increase 2% for a 1% increase in precipitation. Multiple CGCMs and multiple scenarios are required to quantify the uncertainty in projections. For instance, it has been shown that combining multiple models optimally reduces model uncertainty and improves seasonal climate and streamflow forecasts (Devineni et al. 2008). Multimodel combination algorithms for reducing model uncertainty in atmospheric general circulation models (AGCMs) also has improved seasonal climate forecasts (Barnston et al. 2003; Devineni and Sankarasubramanian 2010). Greene et al. (2006) show that developing multimodel combinations of atmospheric-ocean global circulation models (AOGCMs) using Bayesian hierarchical modeling provide better correspondence with regional air temperature under climate change projections. Thus, importance should be given to reducing model uncertainty so that future climate change projections can be utilized for decision making in the water resources sector.

To understand water resource issues, both water supply and water demand must be examined simultaneously at a basin scale (Sun et al. 2008). The same study defined Water Supply Stress Index (WaSSI) as the ratio of human related water use by all economic sectors (for example, thermoelectric, irrigation, domestic water withdrawal) to the total water supply, such as surface and groundwater. Climate change affects both water supply and demand dynamics, thus greatly influences WaSSI values. The importance of integrated climate assessments for water planning and management is exemplified in the Apalachicola-Chattahoochee-Flint case study presented later in this chapter (Georgakakos et al. 2010).

Future projections for water yield. Using the mean water yield response under the CSIRO-A1B, CSIRO-B2, HAD-B2, and MIROC-A1B climate projections, WaSSI model results indicate that annual water yield across the SE as a whole will decline in the first half of the 21st century. The decrease is predicted to be approximately 10 mm per decade (3.7% of 2001 to 2010 mean annual water yield) per decade or 50 mm (18% of 2001 to 2010 levels) by 2060 (Figure 10.2). There is considerable interannual variability in the projected water yield, but the general trend is a statistically significant decrease ($p < 0.05$). Likewise, there is considerable variability in the magnitude of water yield changes among the four climate projections; however, all four projections considered in this study exhibited decreasing trends.

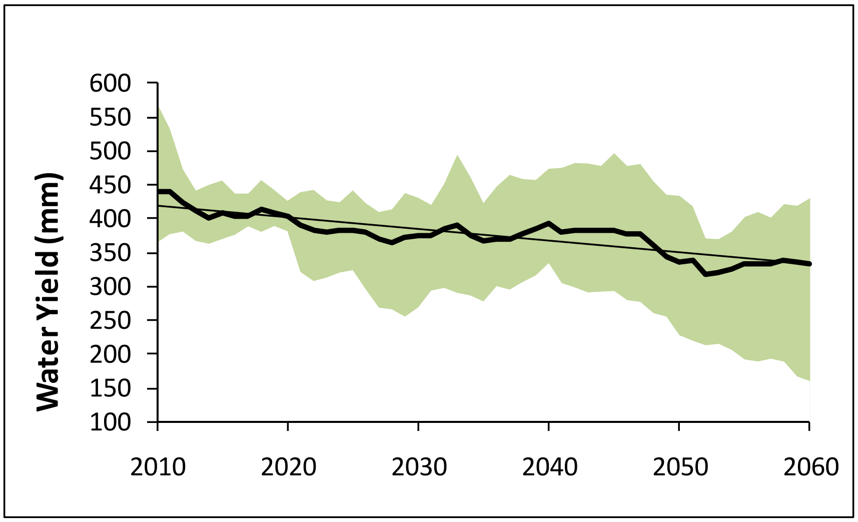


Figure 10.2. Predicted Southeast-wide 10-year moving-mean annual water yield. The green area represents the range in predicted water yield over the four climate projections (Marion et al. 2012).

The trend in the mean water yield varies considerably across the SE as well, with most watersheds exhibiting statistically significant declining trends in water yield of more than 2.5% per decade (Figures 10.2 and 10.3). Across the region, the water yield trend is projected to decline between 2010 and 2025, level off between 2025 and 2045, and decline again after 2045 (Figure 10.2).

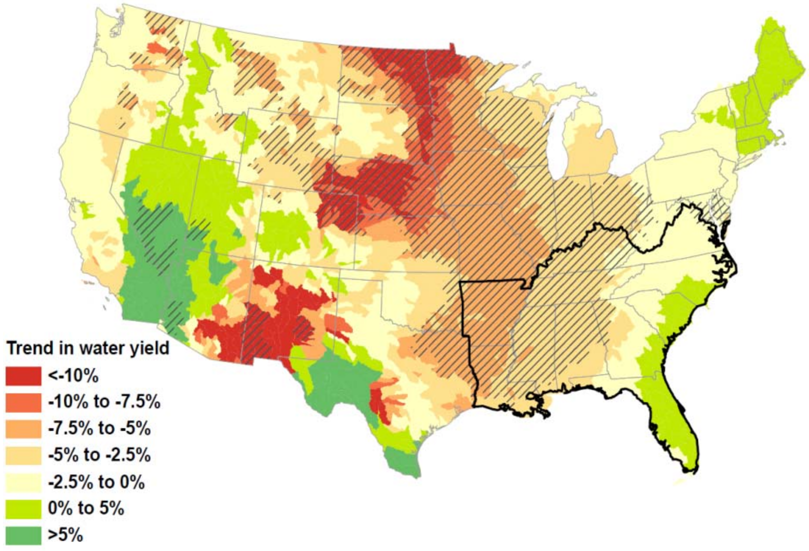
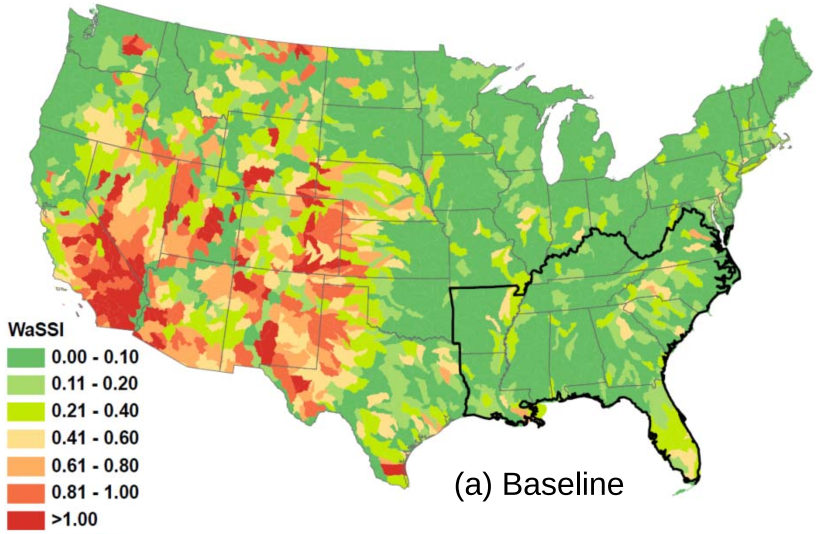


Figure 10.3. Mean trends predicted for 2010 to 2060 in mean annual water yield, normalized by the 2001 to2010 mean annual water yield. Hatched area represents locations where the predicted trend in water yield is statistically significant ($p < 0.05$) (Marion et al. 2012).

Impacts on water stress. Population growth impacts water demand due to domestic water use, while land use and climate change affect water supply through alteration of the watershed water balances. The impact of declining water yield and increasing population is projected to increase water supply stress by 2060 in much of the SE, particularly in developing watersheds (Figure 10.4). For example, the Upper Neuse River watershed, which provides water supply for the Raleigh-Durham, NC metropolitan area, is projected to experience a 14% decline in water yield due to climate change; at the same time, population growth likely will increase water demand by 21%. This simulation suggests an increase in WaSSI from 0.30 from 2001 to 2010 to 0.44 from 2051 to 2060. A WaSSI value of 0.40 has been used as a general threshold at which a watershed begins to experience water supply stress (Alcamo et al. 2000; Vörösmarty et al. 2000), although stress may occur at lower or higher values depending on local water infrastructure and management protocols.



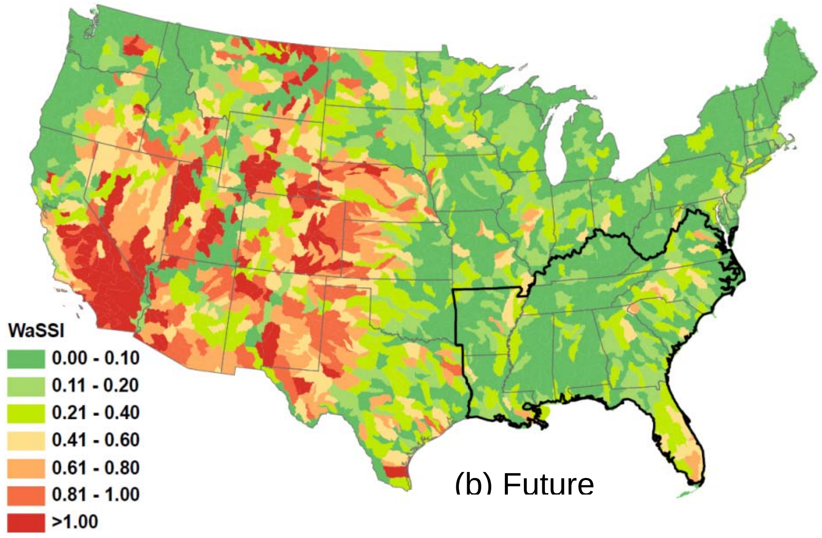


Figure 10.4. Mean annual Water Supply Stress Index (a ratio of water demand/water supply) based on four climate projections for (a) Baseline (2001 to 2010), and (b) Future (2051 to 2060) (Marion et al. 2012).

10.5.4 Water Quality

Water Temperature. Climate change affects water quality as well as water quantity (Cruise et al. 1999; Whitehead et al. 2009; Murdoch and Baron 2000). A warming climate may elevate water temperature and decrease in-stream dissolved oxygen concentrations, which would adversely affect aquatic life (Mohseni and Stefan 1999; Webb et al. 2008; Kaushal et al. 2010). Warmer water is of particular concern for coldwater fish habitats in the southern Appalachians. Coldwater streams in the southern Appalachian Mountains provide crucial habitat for Eastern Brook Trout (*Salvelinus fontinalis*) and other coldwater species. The lethal limit for such species is approximately 25°C (Meisner 1990; Matthews and Berg 1997). Several natural factors influence the extent to which changes in air temperature impact stream temperature, including total stream flow, the relative groundwater contribution to flow (Sullivan et al. 1990; Matthews and Berg 1997; Webb et al. 2008), and canopy cover over the stream. In addition, human-related factors that influence the air-water temperature relationship include runoff from impervious surfaces (Nelson and Palmer 2007), thermal discharges (Webb and Nobilis 2007), and reservoir releases (Webb and Walling 1993). A recent analysis using a monthly air-water temperature models for 91 low-impact sites in the SE was reported in Marion et al. (2012). This modeling study suggested that 62 of the 91 sites showed significant trends, where mean annual stream water temperature (T_s) increased between 1960 and 2007. The mean increase in annual stream water temperature across the 62 sites with significant trends was 0.14°C per decade, ranging from 0.08°C to 0.29°C per decade. The largest increasing trends were found in the Appalachian region. More relevant to aquatic ecosystems than mean annual T_s are the extreme temperature conditions, such as the annual maximum monthly T_s. Of the 91 sites 71 show significant trends in annual maximum monthly T_s between 1960 and 2007. The mean trend in annual maximum monthly T_s for the 71 sites was 0.20°C per decade, ranging from 0.04°C to 0.37°C per decade. Under four future climate change scenarios, all 91 sites were predicted to have significant warming trends in mean annual T_s (0.21°C to 0.35°C per decade) from 2011 to 2060. The mean significant warming trend in annual maximum T_s over all sites and climate projections was 0.25°C per decade.

Soil Erosion and Sedimentation. Sediment is one of the primary pollutants affecting water quality in the SE (West 2002). Changes in precipitation amount or storm intensity can affect surface soil erosion potential by changing the runoff magnitude or kinetic energy of rainfall or by changing vegetation cover resisting erosion. Increased erosion results in increased sediment delivery to streams and lakes. Increases in T_s and sediment concentrations may occur in combination with decreased flow rates and velocities, magnifying the individual impacts of these factors on fish and other aquatic animals. The rainfall-runoff erosivity factor (R-factor) provides an index of the intensity and amount of rainfall occurring at a given location over a long period of time, and as such is directly affected by climate. The R-factor provides a useful surrogate for assessing potential changes in future surface erosion related to climate change. Predicted precipitation based on GCMs and emission scenarios have been used to assess how future climate change may affect R-factor values within the conterminous 48 states. In general, the R-factor value changes showed little consistency for the South (Phillips et al. 1993; Nearing, 2001). Overall, past work evaluating potential R-factor changes provides inconclusive results for the SE. A recent study by Marion et al. (2012) provides a new examination using a somewhat more conservative emission scenario (Hadley GCM and the B2 emission scenario) and a still finer-scale climate projection than past studies. This study suggests that large future changes in soil erosion potential concentrate in three major geographic clusters including the Central Gulf Coast, Blue Ridge Mountains, and South Florida. The effect of R-factor increases on surface erosion within the Blue Ridge Mountains may be amplified by the steeper terrain where landslides are of particular concern.

10.5.5 Aquatic Biota

Changes in water quantity and quality due to climate change in turn affect aquatic systems. Species richness and biodiversity rates are sensitive to hydrologic changes, and transformation into altered or qualitatively different states can occur (Kwak and Freeman 2010; Spooner et al. 2011). Degraded ecosystem functions and services that are the product of past human actions that have altered the landscape can also be exacerbated by climate change.

Climate change has cascading effects in the SE and the Caribbean. For example, in Puerto Rico, large runoff rates result in both periodic and intense sediment discharges and chronic elevated nutrient levels. As in conterminous SE, elevated runoff rates and nutrient levels are related to human land use activities. Sediment discharge in these watersheds is highly episodic and spatially variable. In Puerto Rico, small watersheds with large channel gradients combine with intense rainfall events to transport large amounts of sediment directly to the coast that threats coral reef systems (Larsen and Webb 2009). The largest sediment transport events occur when tropical systems pass over the islands and deposit multiple centimeters of rain in one event. Although much uncertainty remains about future trends in precipitation, hurricane frequency, and hurricane intensity, these results suggest that increases in future extreme precipitation events will result in large sediment and nutrient discharges into reef systems. Other reef stressors such as increasing salinity, acidity, and ocean temperatures will compound sediment and nutrient stress.

10.5.6 Salinity Intrusion

Saltwater intrusion into freshwater aquifers and drainage basins can degrade natural ecosystems and the contamination of municipal, industrial, and agricultural water supplies (Bear et al. 1999). The balance between hydrologic flow conditions within a coastal drainage basin and sea level governs the magnitude, duration, and frequency of salinity intrusion into coastal rivers. Future changes in precipitation patterns have the potential of decreasing streamflow to the coast, which favors salinity intrusion, especially combined with sea level rise.

A case study reported by Marion et al. (2012) examines how future sea level rise can potentially affect salinity intrusion threatening the municipal water supply from two municipal intakes, on the Atlantic Intracoastal Waterway (AIW) and the Waccamaw River near Myrtle Beach along the Grand Strand of the South Carolina Coast. Results show an increase in number of days that specific conductance values, which measure salinity level, exceeded the threshold level of 2,000 $\mu S\ cm^{-1}$ with historic sea level rises and decreases of streamflow. For example, a 1 ft sea level rise combined with a 10% decrease in historical streamflow would increase the days that the intake is unavailable by 25%, or an additional 100 days. A 25% reduction of low streamflows increases the number of days of unavailability to more than 700 days.

10.5.7 Climate Change Implications for River Basin Management: A Case Study of the Apalachicola-Chattahoochee-Flint River Basin

The Apalachicola-Chattahoochee-Flint (ACF) River Basin drains 19,600 sq mi and receives an average annual rainfall of 114 cm. The basin long-term runoff coefficients, which are computed as the average annual streamflow divided by average annual rainfall, vary from about 0.45 in for the north to about 0.25 in for the south, and the historical monthly river flows exhibit a distinct seasonality. The principle water uses include the following:

Irrigation: at 2.9/0.2 (summer/winter) billion gallons per day (bgd).

Municipal and industrial: 1.8/1.4 bgd.

Thermoelectric: 2.5/2.2 bgd. The ACF includes one nuclear and six fossil fuel power plants.

Navigation: The ACF River system is navigable from the mouth of the Apalachicola in Florida up to Columbus, GA, and is used to transport construction materials. The economic significance of this activity is waning, but it continues to require the maintenance of navigation drafts and reservoir releases.

Hydropower: The ACF includes four federal (369 MW) and five private (276 MW) hydroelectric plants. Federal power is marketed by the South East Power Administration (SEPA). Private hydropower facilities are operated by Southern Company Services.

River and estuary ecology: The basin sustains rich ecosystems, including the Apalachicola Bay, which supports 131 freshwater and estuarine fish species and serves as a nursery for many significant Gulf of Mexico species (e.g., the Gulf sturgeon). It produces 90% of Florida’s oyster harvest and the third largest shrimp catch. River and estuary ecology depend on historical hydrological conditions including magnitude, variability, frequency, and persistence of floods, droughts, and normal flows. Significant climate, land, and water use changes in the upstream watersheds affect the estuary freshwater quantity, quality, and nutrients and are bound to impact the estuary ecosystem.

Recreation: According to the U.S. Army Corps of Engineers (US ACE), in 2003 Lake Lanier and West Point Lake registered more than 15,000,000 visitor days with an economic benefit exceeding $300 million. The Apalachicola Bay is a major ecotourism attraction valued at $73 billion per year.

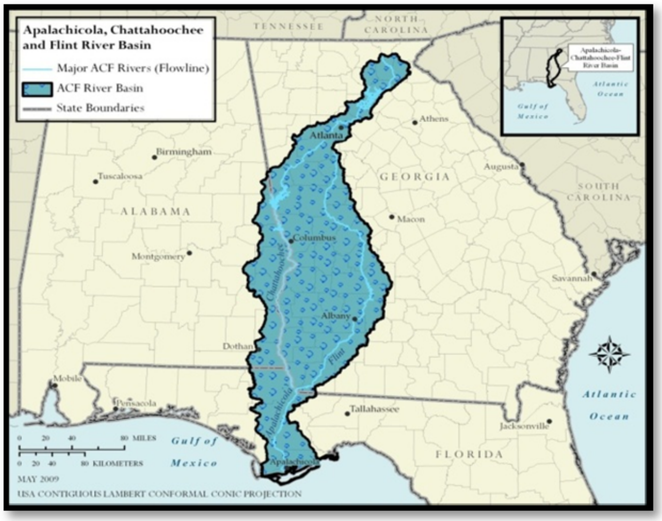
The amount of surface water withdrawals returned to the hydrologic system varies by water use. For example, more than 90% of thermoelectric withdrawals are returned, whereas less than 10% of irrigation withdrawals are returned. The basin is underlain by productive groundwater resources, including the Upper Floridan Aquifer, primarily pumped for irrigation but also for domestic and industrial water supply. Groundwater provides approximately 62% of the region’s irrigation.

Case Study: The Apalachicola-Chattahoochee-Flint (ACF) River Basin

Authors: Alan Covich, Mary Freeman, and Steve Golladay

The Apalachicola-Chattahoochee-Flint (ACF) River Basin extends from the Blue Ridge Mountains across the Piedmont and Southeastern Coastal Plains to the Gulf of Mexico and drains approximately 50,000 square kilometers of land. The headwaters in the upper ACF basin provide essential water supply for several million people where access to groundwater aquifers is geologically constrained. The main-stem rivers support hydroelectric, thermoelectric, and nuclear power production; waste assimilation; recreation; and in lower half of basin, navigation. These flows are managed by 3 federal and 12 state or privately operated main-stem dams. Many small impoundments, such as lakes, ponds, and wetlands, occur throughout much of the drainage area and provide some degree of flood protection, sediment storage, and local water supplies during prolonged droughts. The lower ACF basin intersects the extensive Floridan aquifer, which provides groundwater for irrigated agriculture over large areas of southwest Georgia.

The ACF contains one of the longest remaining free-flowing rivers in the lower 48 United States. The Upper Flint and Chattahoochee rivers are highly valued for recreational fishing and boating. Lake Lanier, on the upper Chattahoochee, north of Atlanta, provides multimillion dollar recreational opportunities for bass fishing and boating. The outflows from Lake Lanier provide valuable trout fishing to people from throughout the region, especially from metro Atlanta. The Flint River flows from headwaters south of metro Atlanta, across the Piedmont and onto Coastal Plain before reaching Lake Seminole, a main-stem impoundment noted for its bass fishing and duck hunting. The Apalachicola River flows out of Lake Seminole and affects a diverse floodplain known for exceptional habitat and species diversity. The river flows from a dam at the Georgia-Florida border to the Apalachicola Bay on the Gulf of Mexico, a barrier island estuary designated as a National Estuarine Research Reserve. The Apalachicola River provides approximately 90% of the freshwater discharge to the Bay. The estuary supports a multimillion dollar production of shellfish (oysters, crabs, shrimp) and finfish. These fisheries depend on a specific salinity range maintained by freshwater inflow from the ACF rivers and groundwater from the Floridan aquifer. Oyster mortality in particular is dependent on an optimal range of salinity (16 to 26 ppt) for growth. Lower salinity values are associated with high river discharges and are thought to reduce mortality from salt-water fish predators. High river flows also bring nutrients into the bay that contribute to planktonic food production used by oysters.



Decades of discussion among water users in the three states that comprise the ACF basin are ongoing and continue to deal with competing water needs: municipal supply, especially in upper basin;, power plants; irrigated agriculture in the lower basin; reservoir recreation and land values; fish and wildlife conservation (river and stream species that include federally protected species in middle and lower basin); and estuarine fisheries. Major issues include municipal water supplies for upstream users, especially metro Atlanta, and sufficient environmental flows to sustain endangered species, while also providing the necessary nutrients and optimal range of salinity within the Apalachicola Bay needed for oyster production. Consequently, long-term combinations of prolonged droughts, high storm flows from the river and wind-driven wave action generated by hurricanes are significant variables that influence coastal fisheries.

Photo by Andrea Fritts (UGA student)

Climate change impacts in the ACF will likely exacerbate conflicts among water users and anthropogenic stresses on these interconnected natural systems. Floods throughout the ACF basin are associated with intense, hurricane-derived rainfall. Higher evaporation and evapotranspiration by plants in the freshwater ecosystems will decrease water availability and river discharge. Projected increases in extreme variability of rainfall and increased demands for water for irrigation and municipal supplies by rapidly growing regional populations will also likely continue to transform the ACF drainage network. Extremely low flows during prolonged droughts and high temperatures combine to concentrate the effects of excessive nutrients from waste-water treatment plants and agricultural runoff that threaten local extinctions. These reduced flows will further threaten the high biodiversity of the freshwater biota. Spring Creek, an inflowing stream to Lake Seminole in southwest Georgia, is a recent example of a perennial stream that has dried up in the last decade for first time ever recorded.

The aquatic species diversity in the ACF includes approximately 125 freshwater fishes, 33 unionid mussels, 30 crayfishes, and hundreds of less-well inventoried invertebrates. At least 30 species of fish, mussels and crayfish are endemic to the system, and new species continue to be discovered. In general, freshwater invertebrates are the most endangered groups of organisms. Of the nearly 300 native unionid species of freshwater mussels in North America, 278 of them live only in the Southeast USA, and 33 are in the ACF. Four mussel species in the Lower Flint River and the Apalachicola River are federally listed as endangered (*Medionidus penicillatus, Pleurobema pyriforme, Amblema neislerii, Hamotia subangulata*) and one species (*Elliptoideus sloatianus*) is federally listed as threatened. Most freshwater mussels require sufficient flows of high-quality water as well as the presence of particular species of fish that serve as hosts to complete larval development and dispersal within river drainages. These species provide important ecosystem services throughout the SE. For example, mussels filter as much as six gallons of water a day and feed on suspended microalgae, bacteria, and other organic particles. This biofiltration helps to improve water clarity and quality. Mussels are also good sentinels that indicate increases in contaminants such as ammonia because they are among the most sensitive, long-lived species to complete life cycles completely in freshwaters.

Integrated Water Resources Assessment and Planning Framework. The ACF climate change assessment is carried out following the integrated water resources assessment and planning framework (Figure 10.6, Georgakakos et al. 2010 and 2011a). The assessment process begins with the development and selection of consistent climate, demographic, socioeconomic, and land use and land cover scenarios, which are depicted across the top of Figure 10.6. Historical scenarios and responses are analyzed first to establish baseline conditions. Future climate scenarios are based on GCMs available through the IPCC. Downscaling of GCM outputs through statistical, dynamic, or both methods is applied to generate high resolution (12x12 km) atmospheric forcing, such as rainfall, temperature, and ET demand, over the ACF River Basin watersheds (Zhang and Georgakakos 2011). Physically based watershed, aquifer, and estuary models are used to quantify the hydrologic and water quality response to alternative climate and land use and land cover scenarios at a basin scale. Water demand assessments are carried out for all water users including environmental and ecological flow and lake level requirements. The goal is to establish desired water use targets, performance metrics, and management and adaptation options. Adaptive optimization methods are used to generate system-wide management policies conditional on inflow forecasts. Subsequently, environmental and socioeconomic impact assessments are carried out to quantify the relative merits, risks, vulnerabilities, and tradeoffs of alternative adaptation and management strategies across the

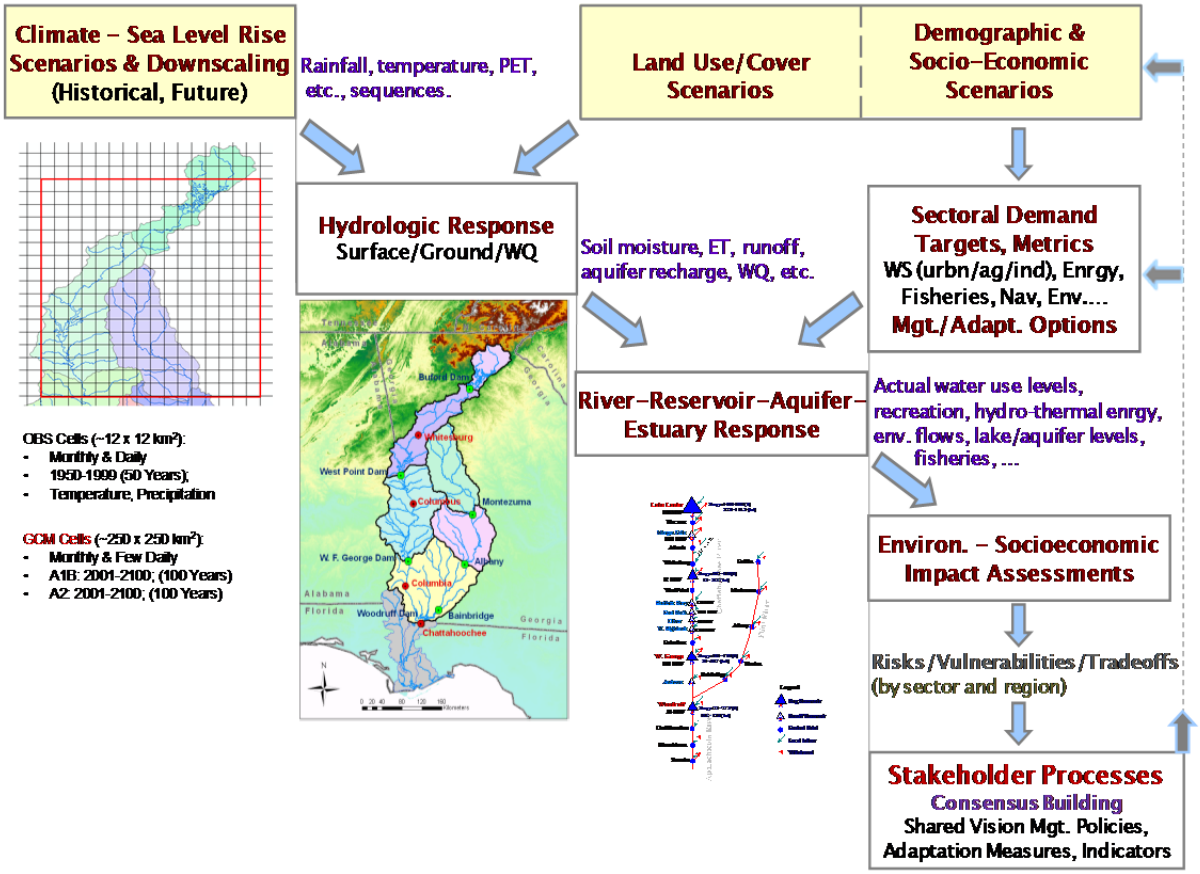


Figure 10.6. Integrated Water Resources Assessment and Planning Framework (Georgakakos et al. 2010 and 2011a)

various water sectors and users. The generated information is used to inform stakeholder planning and decision processes aimed at developing consensus on adaptation measures, management strategies, and performance monitoring indicators. The assessment and planning process is driven by stakeholder input and is iterative and sequential.

Historical Climate Assessments (1960 to 2009). Hydrologic characteristics of six ACF watersheds (Buford, West Point, George, Woodruff, Montezuma, and Albany) were examined under unimpaired conditions where applicable consumptive water uses and reservoir losses from these basins were considered (Figure 10.7). The results indicate that, across all watersheds, during the 1960 to 2009 period, (1) precipitation declined about 9% to 16%; (2) Potential evapotranspiration increased about 1% to 3% (except for George where it decreased by about 0.8%); (3) soil moisture declined by about 3% to 6%; and (4) runoff declined by about 16% to 27%.

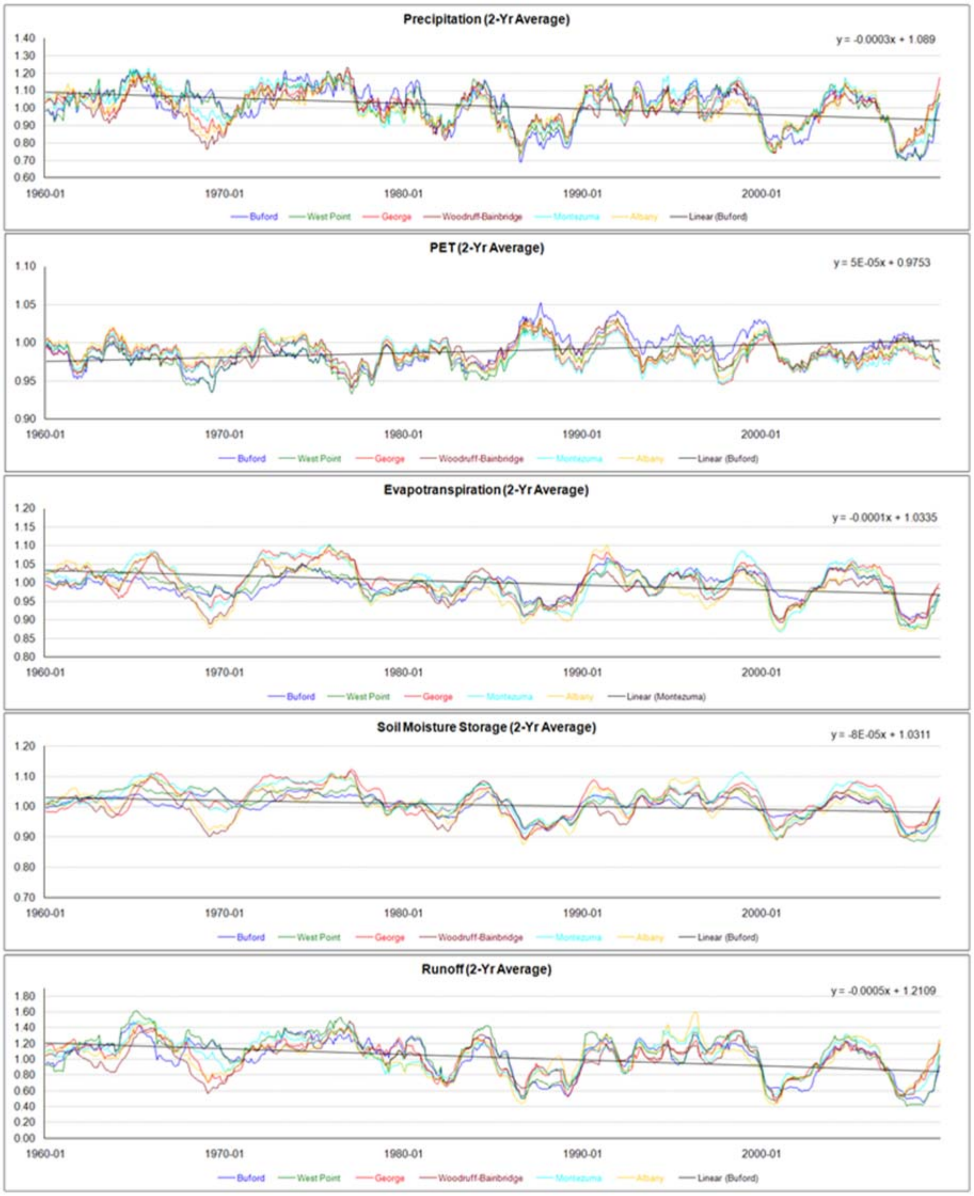


Figure 10.7. Historical ACF two-year average hydrologic response (1960 to 2009). Each sequence is normalized by the respective 50 year mean value.

A longer historical analysis (1901 to 2009) demonstrated that the most recent drought (2006 to 2008) was the worst two-year drought on record. The most severe two-year droughts (in order of decreasing severity) occurred in 2006 to 2008, 1980s, 1940s, 1950s, 1930s, 1998 to 2002, 1920s, and 1900s. Furthermore, the last three major droughts (1980 to 1988, 1998 to 2002, and 2006 to 2008) were the most persistent. The declining trend of total runoff is due to the declining trend of the subsoil moisture storage. This trend implies that the watershed ability to sustain base river flows is diminishing. Across the ACF watersheds, the ratio of total annual average runoff to annual average precipitation is between 0.27 and 0.42, distinctly decreasing from north to south. These findings clearly suggest that climatic change is already occurring in the ACF River Basin.

Future Climate Assessments (2000 to 2099). The future climate assessments were carried out by running the ACF watershed models for all A1B and A2 emissions scenarios generated by 13 GCMs for the period from January 2000 through December 2099 (100 years) in monthly time steps. Results are herein presented for the Buford watershed (Upper ACF) and support the following findings:

- Buford average annual precipitation is near the 50th percentile, and thus not expected to change significantly. The precipitation distribution, however, is expected to "stretch," becoming wetter and drier than the historical climate. This assertion holds for both the A1B and A2 scenarios, with the latter (Figure 10.8) stretching the distribution farther.
- Almost all future scenarios result in higher potential evapotranspiration (PET) and ET and lower soil moisture storage. This effect is especially pronounced in dry years, falling below 75% of the distribution values.
- In the upper 15th percentile of wettest years, runoff is expected to greater than historical. However, the rest of the future ensemble distributions indicate drier than historical runoff conditions. Thus, the coming decades are likely to usher in more severe floods and droughts than in the past.

The previous results and conclusions are typical of all watersheds. However, they are based on frequency comparisons with all data. Box plots of the historical and future scenarios for each month of the year, watershed, climate scenario type (A1B or A2), and hydrologic process (precipitation, PET, soil moisture storage, and runoff) show that climate change impacts are not uniform across the months of the year. The following observations are noted (see Figure 10.9 for Buford and the A2 scenario).

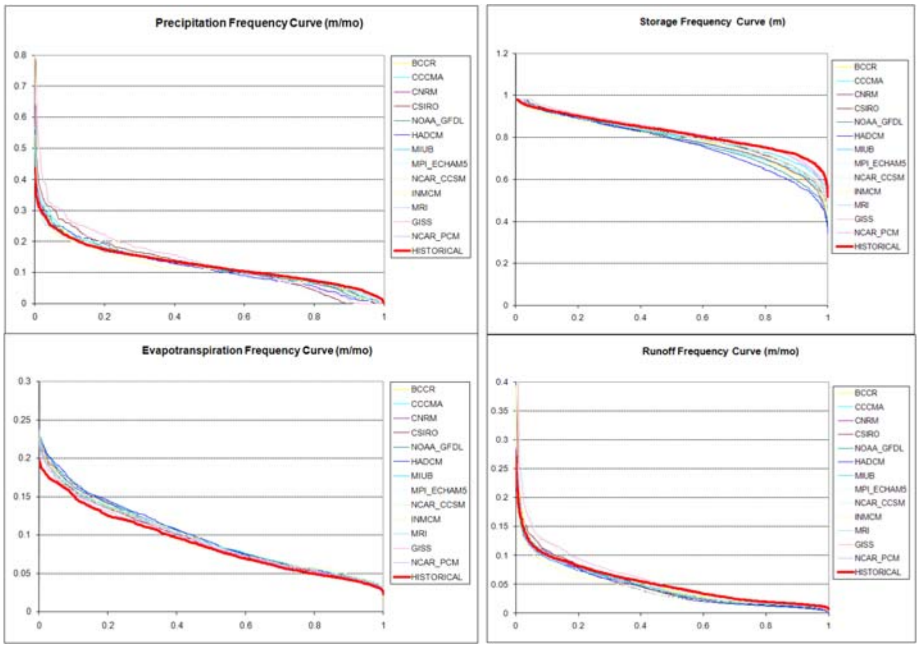


Figure 10.8. Probabilities of exceedance curves using A2 Climate Scenarios (2000 to 2099) for the Buford watershed. Historical frequencies are depicted in thick red lines

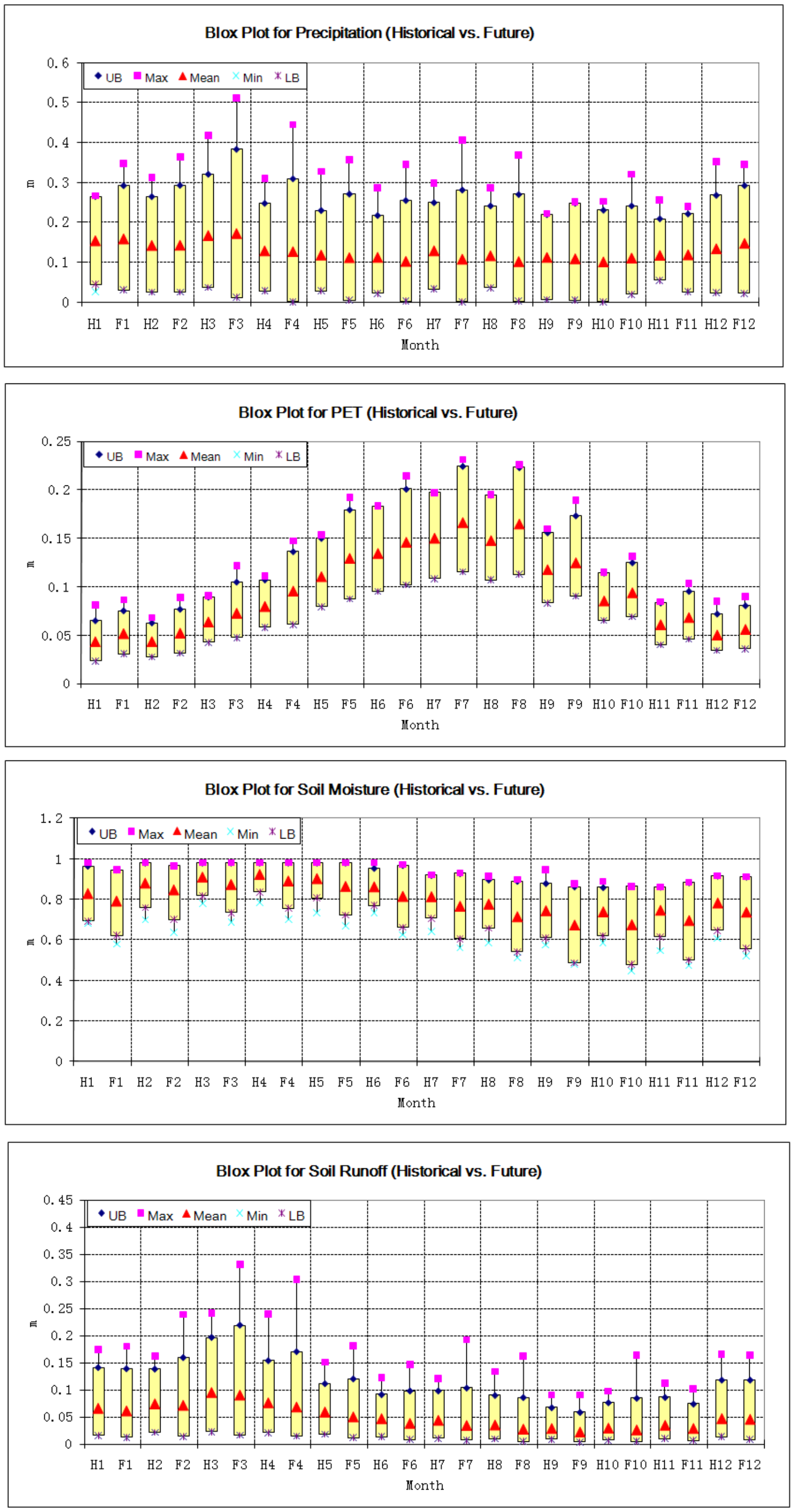


Figure 10.9. Monthly historical (H) versus future (F) watershed response for Buford watershed using A2 climate scenarios. (Unit: precipitation in meter/month, PET in meter/month, soil moisture in meter, and runoff in meter/month

- Mean watershed precipitation shows clear declining trends in June, July, and August, but it does not show appreciable change for the other months of the year. However, precipitation distributions for January through September are considerably extended (toward both ends) in comparison with historical distributions. This relative change is observed for both A1B and A2 scenarios.
- Future PET exhibits a higher mean and wider range than historical PET from February to September, with the largest change observed in July and August. For these two months, the future mean PET is higher than the historical PET by as much as 12%, while the quartile range of the future distribution exceeds that of the historical by nearly 20%.
- Future soil moisture is clearly lower than its historical levels in almost all months. The decline is more pronounced under the A2 scenarios in late summer and fall months (exhibiting a 6% to 10% declining trend).
- Future runoff at Buford is wetter (in the mean and the 75% percentile) than historical in February, March, and April, and drier than historical in June, July, August, and September under A1B scenarios. By comparison, under the A2 scenarios, the future Buford runoff is drier that historical in all months of the year, a finding with critical water supply implications for Atlanta.

These trends are observed for all ACF watersheds, becoming more intense in the lower ACF. For example, future soil moisture of the Woodruff-Bainbridge watershed is less than historical in most months. This change is more pronounced for summer and fall, and the decreasing percentage is larger than the Buford watershed. The average soil moisture reduction reaches as much as 11% under A2 scenarios. Even more critical is the significant decline of the lowest soil moisture levels as indicators of agricultural droughts. Soil moisture during summer months is most likely to be reduced in the southern watersheds, which is precisely the time when soil moisture is critical for agriculture. Lower soil moisture content would lead to higher surface and groundwater irrigation withdrawals, adding more stress to the declining supplies and more tension among the basin stakeholders.

Water Resources Assessments. Historical and future basin inflow sequences corresponding to A1B and A2 climate change scenarios were used to drive the ACF river basin model that incorporates the river network, all storage projects and hydroelectric facilities, water withdrawals and returns, in-stream flow requirements, and management procedures (Georgakakos et al. 2010). The impact assessment criteria include reliability of water supply for municipal, industrial, and agricultural users; lake levels; environmental and ecological flow requirements; navigation; and hydropower generation. Following is a summary of the assessment conclusions:

- Under the climate change scenarios and with current management procedures that follow rule curve based releases, the ACF River Basin is likely to experience more severe than historical stresses including deeper reservoir drawdowns (Figure 10.10), greater water supply deficits (Figure 10.11), less firm energy generation, and more frequent and severe violations of environmental flow requirements. The A2 climate scenario impacts are considerably more severe than those of the A1B.
- Adaptive management procedures and modified operation rules as proposed and tested by Georgakakos et al. (2010) and Georgakakos et al. (2011b) prove to be useful to mitigate the impacts of climate change (Figure 10.10). However, adaptive management procedures and tools have yet to be adopted and made operational by federal and state agencies.

ACF assessments include estuary salinity assessments, agricultural assessments, and hydro-economic assessments, with critical findings for all sectors. The ACF decision support system and assessments are currently used by the Georgia Water Resources Institute to support the nonprofit, 88-member ACF Stakeholders, an organization founded in 2009 to develop and adopt water development, sharing, and management plans in the face of a changing climate and increasing demands.

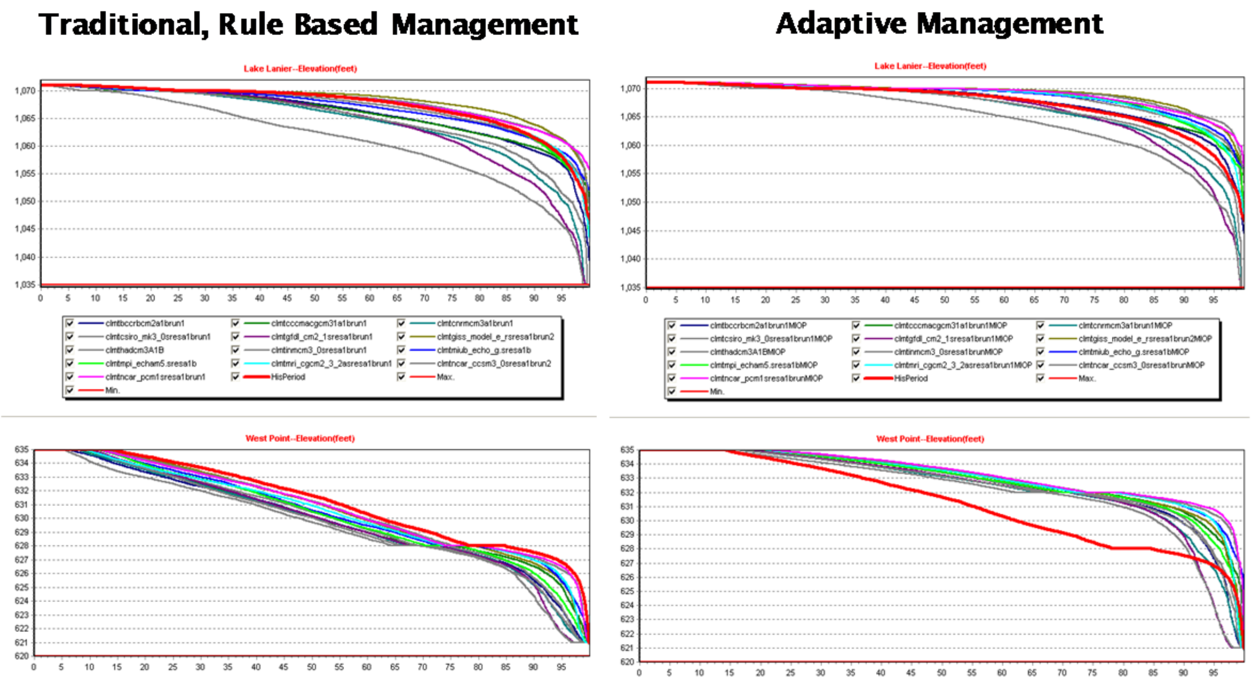


Figure 10.10. Comparison of reservoir elevation frequency curves for Lake Lanier and West Point Lake under A1B climate change scenario, future demands, and traditional or adaptive operation policies. Thick red lines represent historical climate response and thinner lines represent lake response under 13 future A1B climate scenarios. The figures in the left column show that future lake levels most likely will be lower than historical levels. Comparisons of the left and right columns show that adaptive management policies maintain higher lake levels than traditional (rule based) policies, thereby reducing the risk of shortages for all water users. The findings are qualitatively similar, albeit more striking, for the A2 climate scenarios.

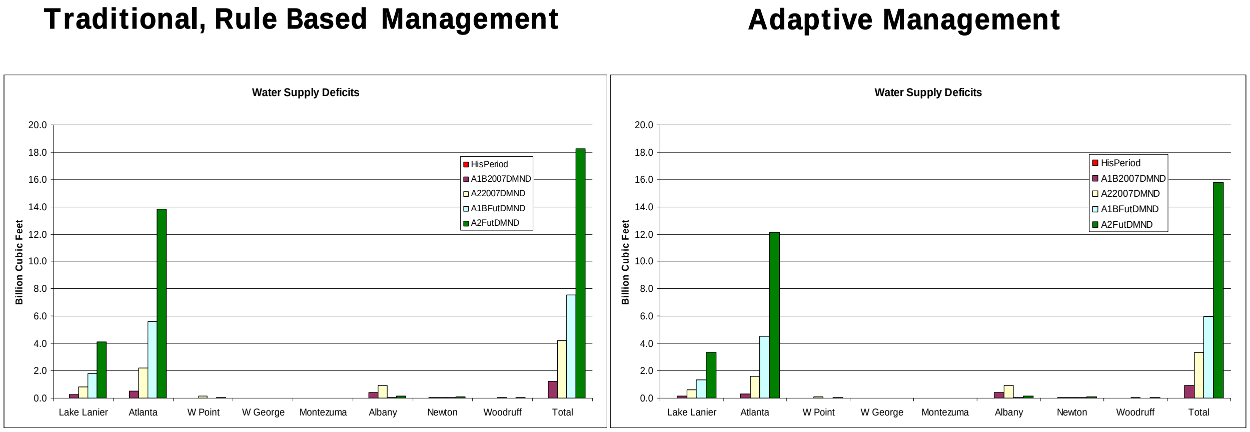


Figure 10.11. Mean water supply deficits (cumulative over the assessment horizon) at various ACF nodes under (1) historical and future (A1B and A2) climate scenarios, (2) 2007 and 2050 water demands, and (3) traditional and adaptive reservoir management policies. No historical deficits are noted. The largest deficits occur under the A2 climate scenarios and 2050 demand targets in the upper Chattahoochee. Deficits under the A1B climate and 2007 demand scenarios are approximately half of the A2/2050 deficits. Adaptive management leads to fewer and less severe deficits while maintaining higher lake levels than traditional reservoir management practices.

10.6 Mitigation and Adaptation Options

Although global climate model projections for the next several decades do not agree in terms of magnitude or direction of the expected changes for some variables, they all point towards a new climatic regime that the region previously has not experienced (Milly et al. 2008). Climate change already has affected water quantity and quality in several regions in the SE and likely will impact natural ecosystems (Carlisle et al. 2010) and society (Table 1). Innovative adaptation options are needed to reduce or adapt to the severe consequences of climate changes, such as water supply shortages, habitat loss, and increased forest wildfires. For example, watershed manipulation experiments show that converting a deciduous forest cover to a conifer evergreen forest in the Appalachians can reduce flood risk in extreme wet years (Ford et al. 2011). Adaptation to intensified extreme storms may require future land planning to consider alternative forest covers. Best management practices that have been found to be most effective in reducing nonpoint source pollution should be enhanced and revisited to best reflect future hydrologic and management conditions. Integrated watershed management that aims at enhancing ecosystem resilience to climate disturbances and maintaining ecosystem services including climate moderation and mitigation is recommended as the best general adaptation approach. The large area of forests in the SE will have an increasing role to modulate regional climate, maintain water quality, and sequester carbon (Liu 2011; Chen et al. 2012; Lockaby et al. 2011). There is large potential to increase water use efficiency from all major water users, such as the agriculture and energy sectors, including power plants that produce bioenergy.

Facing the uncertainty of climate change, water planning and management organizations and stakeholders must create adaptive frameworks for solutions, re-evaluate past decisions in light of the changing climate, and identify the most effective policies based on the current scientific research and understanding. Rosenhead (2001) views planning under deep uncertainty as sequential and adaptive decisions made over time. Such an approach helps identify robust solutions, which may not be the best but provide more options for the decision makers in making decisions. Robustness could be thought of as making decisions between optimality and minimizing solutions (Groves, 2006). For example, using a stochastic dynamic programming model, Chao and Hobbs (1997) revisit the decision of protecting the Great Lakes shoreline every year in such a way that the expected cost of sand nourishment is minimized under the anticipated probability of lake level change due to global warming. Given that projections of climate are represented probabilistically, it is important that the water management framework explicitly quantify the reservoir yield and releases by assigning reliabilities (Sankarasubramanian et al. 2009a). Sankarasubramanian et al. (2009b) and Georgakakos et al. (2011b) also show that updating climate forecasts on a monthly basis, and utilizing the updated forecasts within the seasonal reservoir operation, benefited the system more than an operational policy derived purely based on the climate forecasts at the beginning of the season. Thus, addressing climate variability utilizing seasonal to interannual climate forecasts will partially improve yields, which could reduce the future vulnerability of water supply systems under climate change and population growth.

Table 10.1. Potential adaptation options for managing hydrologic impact and risks from climate change.

Hydrologic Impacts	Risks to Ecosystems and Society	Adaptation Options
Water supply stress increase	Water shortage; drying up of drinking wells; Consequences to aquatic ecosystems, socioeconomics, and business	Reduce groundwater and surface water use for agriculture and lawns; enhance water conservation; increase water use efficiency and storage; recycle water; institute adaptive management.
Evapotranspiration increase	Hydrologic droughts; wildfires; insect, disease outbreaks	Use native tree species; reduce tree stocking; reduce water use by crops
Increase of peak flow, Storm flow volume, floods	Flooding; increased soil erosion and sedimentation	Reduce impervious areas; increase stormwater retention ponds; increase evapotranspiration by increasing forest coverage; increase water storage capacity
Low flow decrease; drought	Water quality degradation; fish habitat loss; reduced transportation capacity	Increase water storage; reduce off-stream water withdrawal
Wetland hydroperiod change	Wildlife habitat loss; greenhouse gas (CO_2 , CH_4, NO_x) emissions	Plug ditches; adjust outflows from reservoirs
Stream water temperature increase	Water quality degradation; loss of cold fish habitat	Maintain riparian buffers and shading
Soil erosion, sedimentation increase	Water quality degradation; siltation of reservoirs; increase cost of water treatment	Enhance best management practices (BMPs); redesign riparian buffers; minimize direct discharge of runoff from roads to streams
Chemical loading increase	Water quality degradation; higher cost of water treatment	Maintain streamflow quantity; applications of BMPs

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11 The Effects of Climate Change on Natural Ecosystems of the Southeast

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Key Findings

Three very different aspects of climate change are very likely to affect natural ecosystems of the Southeast. Those aspects are (1) ocean acidification, especially for hard bottom reefs and coral reefs, (2) sea-level rise, especially for tidal fresh to saline marshes and swamps, and (3) warming and hydrology (rainfall and evapotranspiration).

For all the natural ecosystems considered in this chapter, it is difficult to isolate the effects of climate change from the many other threats to these systems, including, for example, invasive species and disease, land use change, water withdrawals, and atmospheric deposition. A unique characteristic of many natural wetland ecosystems of the SE is that the combined effects of sea-level rise, associated increase in salinity, and altered dry-wet cycles likely will enhance the fluxes of potent greenhouse gases (GHGs), especially nitrous oxide (CH_4) and nitrous oxide (N_2O), into the atmosphere. This increase in GHG emissions has implications for the USA carbon balance of and its net contribution to the global increase in effective CO_2 concentrations in the atmosphere.

- For aquatic ecosystems in the SE two important aspects of climate change will be warmer water temperatures that are expected to put organisms closer to the threshold temperature for their thermal tolerance and exacerbate low dissolved oxygen conditions, which already characterize many blackwater streams draining the SE coastal plain.
- More frequent droughts coupled with increasing water demands from greater evapotranspiration (ET) and growing human consumption will result in more frequent stream drying, even in systems historically considered perennial, which will increase the frequency of local species extirpations.
- Non-native, invasive species will increase due to less frequent and shorter durations of cold temperatures caused by climate change.
- Climate change is expected to have major harmful impacts in the increasingly rare longleaf pine savannas of the SE.

- More frequent droughts and higher rates of ET are predicted in the SE, where fire is the greatest threat to millions of acres of freshwater peat wetlands. CO_2 emissions during fire can reverse centuries of CO_2 sequestration and ultimately convert these systems from being net C sinks to significant C sources.
- In the SE tidal wetlands, the higher predicted rates of SLR likely will outpace the ability of wetlands to build elevation. As a result wetlands will become vulnerable to coastal erosion and increased inundation, eventually converting to open water. Such changes have been apparent in coastal Louisiana for several decades. With the loss of tidal wetlands, upland human settlements will lose important protection form storm surges, which could result in significant economic loss to coastal communities.
- Coral reefs and other hard-bottom reefs of the SE are also susceptible to climate change, especially due to warming waters, acidification, and sea level rise. Effects of ocean acidification and warming can be exacerbated when present with other stressors in reef systems, such as disease, coastal runoff, overexploitation, vessel damage, marine debris, and exotic species.

Climate effect on hydrology in SE is perhaps the single most important impact on natural ecosystems during the coming century. This aspect may also have the greatest policy relevance because humans have the ability to control or regulate precipitation runoff, river flow, water storage, and water use. To some extent warming of aquatic systems can be moderated by water management that insures adequate flow during summer months. Likewise, salinity intrusion and the upstream shifting of brackish habitats can be controlled, though not prevented, by water management that buffers the effects of droughts. Loss of river and noncoastal wetlands might also be moderated or controlled by water management policy that limits drainage, maintains connection to the river network, and meets minimal flow requirements of the various types of wetlands of the SE.

How natural ecosystems of the SE will respond to climate change is the subject of ongoing research. How climate change will interact with other anthropogenic activities, such as land use change and human water use, are also important avenues of study. Thus future policy and management activities should be adaptive by design and changed as knowledge expands.

11.1 Background

In this chapter, the major ecosystems of the SE and Caribbean region are discussed, excluding those discussed in other chapters, namely natural and managed forests, agriculture, and the systems supporting major commercial fisheries and mariculture operations. This review begins with the aquatic systems of the SE, the lakes, reservoirs, streams, and rivers. The chapter then transitions down elevation to review the effects of climate change on savannas, then freshwater wetlands and swamps, tidal wetlands and swamps, and finally offshore coral reefs and hard-bottom reefs.

Not all natural ecosystems of the SE are discussed, only those that are considered to be most vulnerable to changes in the hydrologic cycle as a result of changes in temperature, precipitation, and evapotranspiration. Two types of systems that are uniquely vulnerable to other aspects of climate change, sea-level rise and ocean acidification, are also discussed. Important systems not examined include maritime forests on barrier islands (Figure 11.1), other barrier island ecosystems, and southern Appalachian bogs. These should be included in future assessments of climate change in the SE.

Figure 11.1. Maritime forests on some of the few remaining, relatively intact barrier islands of the Southeast, for example on Ossawbaw Island, GA, are vulnerable to climate change through the devastating impact of winds, surge, salt spray, and shoreline erosion from hurricanes and sea level rise. This artistic rendering by Philip Juras (*Passing Storm*, 2009, oil on canvas) shows remnants of the maritime forest now in the intertidal beach zone.

Climate projections considered in this chapter were developed for the 2012 Southeast Climate Assessment report (Konrad et al. 2012), and are based on regional downscaling of the National Climate Assessment using the IPCC A2 and B1 scenarios for climate projections. The A2 scenario is somewhat pessimistic in that it assumes many nations will change behaviors only modestly. For the SE, it assumes population will triple by 2100. The B1 scenario in contrast is optimistic that nations will mitigate human activities that can further warm the planet. For the SE, it assumes population will increase about one-third by 2100. With respect to climate, all scenarios suggest there will be marked warming across the SE, especially during summer. Temperature is likely to increase 2ºF to 4ºF in the Caribbean to as much as 8ºF in interior regions of the SE. Warming will be pronounced in urban areas, because of the urban heat island effect. There likely will be increases in annual net precipitation, but with decreased rainfall during summers. There is increased likelihood for the number of extreme precipitation events to increase as well as for interannual variability to increase. Thus we can expect to see increased frequency and severity of drought with consequent effects on hydrology and river flow. Sea level rise (SLR) is expected to increase between 0.2 m and 2 m by the end of the century.

11.2 Southeastern Freshwater Aquatic Ecosystems

The aquatic systems of the SE are diverse and include the largest river system of the USA, the Mississippi and Atchafalaya Rivers; first order mountain streams of the Smokey Mountains in Tennessee and North Carolina; man-made ponds and reservoirs so common on farms and throughout the Tennessee River Valley; the blackwater rivers of coastal Georgia, Florida and South Carolina; and to the freshwater Everglades of Florida. The ecosystem services provided by these environments are unrivaled in the SE, perhaps matched only by the wetland systems through which most are linked.

11.2.1 Streams, Rivers, Lakes and Reservoirs

Many freshwater ecosystems in the SE increasingly are subject to changing climatic conditions (Cook et al. 2007; Karl et al. 2009; Kaushal et al. 2010). Warmer waters, more frequent and severe droughts, and floods from more extreme storm events such as hurricanes, will continue to alter freshwater ecosystems and will stress a wide range of freshwater species (Emanuel 2005; Gibson et al. 2005; Elsner and Jagger 2006; Shepherd et al. 2007; Parisi and Lund 2008; Kaushal et al. 2010; Dai 2011). Long-term (more than 100 years) decreases in rainfall have been observed for warmer months of the year for Georgia, North Carolina, and South Carolina (Alexandrov and Hoogenboom 2001). In some coastal plain regions of the SE, decreases in summer rainfall combined with increased groundwater withdrawals for irrigation are resulting in significant decreases in stream discharge (Rugel et al. 2012). These declines have been linked to decreased carbon exports as suspended organic matter to coastal areas with potential increases in local mineralization rates and corresponding release of CO_2 from streams (Mehring et al. in prep 2011).

Long-term trends of increasing temperatures and extremes in rainfall (droughts and floods) are likely to alter distributions and abundance of freshwater algae, zooplankton, benthic invertebrates, and fish as well as ecosystem processes. In general, the effects of increased temperatures will decrease dissolved oxygen and increase rates of respiration for freshwater species. For example, many cold-water fish such as trout in southern Appalachian headwater streams are near their upper thermal limits during extreme summer heat waves. Even warm water species can be limited by extremely high water temperatures in shallow ponds and pools where cool, deep waters or spring-fed inflows are not available as thermal refugia. Of particular concern are largemouth bass, a large component of the multimillion-dollar recreational fishing industry in southeastern waters.

There are many direct and indirect ways in which warming can impact aquatic systems of the SE. Higher temperatures in shallow lakes and reservoirs can increase growth rates for warm-water species but only to thresholds of thermal tolerance (Rypel 2009). Higher water temperatures are also expected to exacerbate low dissolved oxygen conditions, which already characterize many blackwater streams that drain the southeastern coastal plain (Mulholland et al. 1997; Utley et al. 2008). Moreover, the prolonged droughts often associated with these warmer waters can also lower water levels and eliminate essential habitats for completion of life cycles and effective foraging. Fishes that disperse within large drainage basins can adjust to warmer temperatures by moving northward to find cooler waters if their routes for dispersal are unimpeded by dams, diversions, or dry-river channels (Matthews and Marsh-Matthews 2003; Ficke et al. 2007). However, when record warm temperatures are coupled with increased frequencies and intensities of droughts, many species are at risk over wide regions. Warmer waters also increase the exposure of freshwater fish and other species to diseases and parasites that diminish survivorship (Ficke et al. 2007). The increase in risk from toxic cyanobacteria that are extending their geographic ranges and causing massive fish kills is also associated with warmer waters where high nutrient loading can provide a competitive advantage to these harmful algae (Paerl et al. 2011). Warmer waters associated with droughts and floods are also linked to increases in various species of mosquitoes. Expanding ranges and pulsed population increases in these vectors that reproduce in temporary waters and wetlands can result in disease outbreaks among wildlife and humans (Shaman et al. 2003).

Rare species of fish and mussels are of particular concern in a changing climate. For example, Atlantic and Gulf sturgeon (*Acipenser oxyrinchus oxyrinchus, A. oxyrinchus desotol*) use marine and estuarine habitats as adults but reproduce in coastal rivers along the Atlantic and Gulf of Mexico (Freeman et al. 2003; Grunwald et al. 2007). Their populations have declined previously due to overfishing, reduction in spawning sites by dam construction, and river pollution. These large, slow growing species require specific water depths, temperatures, and substrata for spawning in the remaining coastal waters available for sustaining their complex life histories. During summer months the adults move upstream to occupy deep, relatively cool pools (2 m to 4 m), some of which receive groundwater inflows. However, reduced flows from groundwater, lower river-water levels, and generally warmer waters during drought are further stresses. These fish historically supported fisheries but are now considered imperiled. Shortnose sturgeon (*A. brevirostrum*), which remain in rivers their entire life, are also of particular concern as their southern range, limited by temperature, is likely to shift northward out of Georgia as warming proceeds in this century. This species is also vulnerable to impacts associated with salt water intrusion, as oligohaline tidal waters are a critical habitat during their multidecadal adult years.

Despite comprising the highest aquatic diversity of any temperate system, the ecological relationships and life histories of many SE species are not yet well understood within the constraints of current climatic variability. In addition, sustaining this exceptionally high regional biodiversity is difficult because emerging cumulative effects are creating novel habitats and dynamics that have not previously been observed. Currently, many species declines are associated with widespread alteration of stream habitats and flow regimes, and these effects are expected to be exacerbated by climate change. Specifically, more frequent droughts coupled with increasing water demands will result in more frequent stream drying, even in systems historically considered perennial, and thus increasing the frequency of local species extirpations. Greater short-term flow variability, particularly during warmer seasons, is expected to lower reproductive success of many fish that require periods of stable flow during nesting, spawning, and juvenile development. Decreased base flows will reduce habitat availability and lower survival for species requiring flowing-water habitats. Freshwater mussel reproduction may fail if temperatures exceed tolerance levels or if low flows limit the effectiveness of mechanisms for attracting host fish. Decreased base flows in combination with nutrient loading from agricultural and urban areas may result in algal blooms that alter food webs and benthic habitats, shifting biotic communities as well as threatening water supplies. The net expected result is faunal homogenization, in which communities become dominated by species most capable of re-colonizing or surviving in stream systems affected by more frequent drought and unpredictable flow conditions. Faunal homogenization is currently seen in the spread of the invasive red shiner (Walters et al. 2008), loss of highland endemic fishes from southern Appalachian streams (Scott and Helfman 2001, Scott 2006; Walters et al. 2003), and reduced diversity in fragmented and flow-altered systems.

Climate change is also expected to facilitate establishment of non-native and invasive species by lessening constraints imposed by frequency and duration of cold temperatures. Non-native subtropical and tropical species, including many species already established in Florida, and potentially spread by use in aquaculture (e.g., Tilapia, *Oreochromis* spp.), aquaria, or as live food (e.g., swamp eel, *Monopterus* spp.) (Collins et al. 2002) may increase with warmer and milder winters. Higher stream temperatures and greater streamflow variability may also favor invasive species, which often have wider environmental tolerances than native species (Rahel and Olden 2008). The spread of invasive zooplankton such as *Daphnia lumholtzi* is expected to increase in response to warmer waters (Fey and Cottingham 2011).

In every region, it is difficult to isolate the effects of climate change from the other aspects that threaten freshwater species. For example, accelerated erosion from climate change or land use change induced flooding diminishes habitat quality for many species. Although rivers and reservoirs fill with sediment during floods and water levels decline during droughts, the subsequent dredging of rivers to maintain shipping channels can have a longer-lasting effect on many freshwater species than the shorter term climate-related impacts. Moreover, there is greater societal demand for additional freshwater during warmer summers. Heat waves require more cooling waters for energy production to meet the increased use of air-conditioning and for pumping water to irrigate crops. Increasing population diverts additional water from natural ecosystems. The rapid increase in construction of water storage reservoirs and ponds in the SE have created relatively permanent changes in the region's hydrology. Reservoirs are also associated with increased introductions of invasive species (Rahel and Olden 2008). Freshwater habitats have lost critical characteristics of their natural flow regimes (Gibson et al. 2005; Poff et al. 2007). In many cases, the past connectivity among headwater streams, groundwater, rivers, and their floodplains has been modified or lost completely (Freeman et al. 2007). These changes and losses of habitats may continue or even increase as solutions are devised for increasing water storage to mitigate droughts and regulate floods.

11.3 Southeastern Savannas

Fire-dependent longleaf pine (*Pinus palustris*) savannas historically covered much of the southeastern Coastal Plain, but are now less than 5% of the landscape (Christenson 2000; Keddy 2009). Remnant examples of these savannas (Figure 11.2) classified hydrologically as wet, mesic (moist), or dry--are some of the most species-rich terrestrial communities ever measured at small spatial scales, ranging to more than 50 species per square meter (Walker and Peet 1983). Diversity is particularly high on frequently burned mesic and wet savannas, and is exemplified by abundant orchids and carnivorous plants such as pitcher plants (*Sarracenia* spp.), sundews (*Drosera* spp.), and the native range of Venus fly trap (*Dionaea muscipula*). East of the Mississippi River, longleaf pine savannas contain abundant wiregrass (*Aristida* spp.) in the understory; west of the Mississippi wiregrass is replaced by little bluestem (*Schizacharium scoparium*), a grass also common in the tallgrass prairies of the Midwest. A recent study in the western Gulf Coastal Plain using fire scars on longleaf pine trees growing in mesic longleaf-bluestem savannas suggested an average fire frequency of 2.2 years during the period from1650 to1905 CE—one of the most frequent fire histories ever documented (Stambaugh et al. 2011). These fires typically occur in the growing season, with important consequences for plant reproduction. Wiregrass and other savanna species only flower after growing season fires and not after managed fires set in the dormant season (Platt et al. 1988). In wet savannas, abundant *Sphagnum* peat moss and dead peat have accumulated and currently store significant amounts of carbon.

Figure 11.2. Longleaf pine savanna of the southeastern Coastal Plain. This forest is managed actively through controlled burns on the Fort Stewart Military base in Georgia. Species diversity is particularly high in these ecosystems. While warmer winter temperatures may benefit the longleaf pine ecosystem in the northern range margin, the majority of longleaf pine savannas likely will fare less well due to increasing summertime droughts. (*Photo by Charles Hopkinson.*)

With warmer temperatures, diminished summer precipitation, and an increase in frequency and severity of drought predicted for the Southeast over the remainder of the century, the likelihood of fire will increase as well (Mearns et al. 2003; Liu et al. 2010). The combined effects of drought, warmer temperatures, and fire probability likely will increase the flow of carbon to the atmosphere by the decomposition and burning of drier vegetation and peat, as in other peatland ecosystems throughout the world (Ise et al. 2008; Taylor 2010; Hergoualc'h and Verchot 2011).

In addition to fire, the composition and function of these ecosystems are strongly influenced by drought frequency. In most of the longleaf pine range, spring and summer precipitation are the most important climatic variables associated with growth. While warmer winter temperatures may benefit the longleaf pine ecosystem in the northern margin of its range, most longleaf pine savannas will likely fare less well due to increasing summertime droughts.

Wet longleaf pine savannas often grade into swamps dominated by cypress tree species (*Taxodium distichum* and *T. ascendens*) and swamp gums (*Nyssa biflora* and *N. aquatica*). A 10-year study in coastal South Carolina analyzed tree growth and ecosystem productivity in forests across a range of soil moisture types and found that severe drought affected wet swamp forests more than mesic oak-pine forests or dry longleaf ecosystems (Conner et al. 2011). Another study found that spring and summer precipitation and temperatures were the most important environmental variables explaining tree growth in swamps of the Congaree National Park (Doyle 2009). In both cypress-gum swamps and longleaf pine savannas increases in hurricane intensity likely will increase forest damage and create biophysical feedbacks to climate through temporary increase**s** in surface albedo (reflectivity) and reductions in evapotranspirative cooling (Juárez et al. 2008).

11.4 Southeastern Freshwater Marshes and Swamps

Freshwater marshes and swamps of the SE are found throughout the region, but are especially prevalent along low gradient river systems (e.g., Mississippi and Atchafalaya Rivers) and the extensive coastal plain physiographic province that lies between the Atlantic and Gulf coasts and the fall-line adjacent to the Piedmont province. While many of these wetlands are perennially connected to the river network, others are continually isolated or connected via ephemeral streams. Land use changes for urbanization or agriculture significantly affect the integrity of these systems and must be considered along with climate change for future assessments.

As with the stream, river, lake, and reservoir aquatic systems of the SE, freshwater marshes and swamps are also highly vulnerable to warming, changes in precipitation quantity and severity of storms, and the frequency and severity of drought. The combined effects of warming and changes in precipitation likely will alter overall hydrology including increased evapotranspiration and reduced stream base flows (IPCC 2001; Mulholland et al. 1997; Schindler 1997; Vörösmarty et al. 2000). Temperature regimes of freshwater ecosystems are projected to change in parallel with shifts in air temperature because of the tight relationships between air and water temperature (Mohseni and Stefan 1999; Allan et al. 2005). Alterations of regional and catchment hydrology predicted by global climate models include increasing frequency and intensity of extreme precipitation events driven by increased temperature (Easterling et al. 2000), although increased water inputs may be offset by increased evapotranspiration and runoff, and these effects may exhibit high regional variability (Todd et al. 2010; Todd et al. 2011). Resulting impacts of climate change on riverine wetland ecosystems are predicted to include increased periods of water drawdown, greater frequency and intensity of high flow events, and increased water temperature (IPCC 2001; Alcamo et al. 2003; Carpenter et al. 2005; Webster et al. 2005; IPCC 2007; Erwin 2009; Mulholland and Sale 2011).

Wetland ecosystems will play a critical role in determining climate change feedbacks, as shifts in hydrology and increased soil temperature will enhance GHG emissions at catchment and regional scales (Erwin 2009) further contributing to climate change. The vast amount of carbon stored in the peat soils of the Pocosins and Everglades makes them especially important there is danger of an autocatalytic reaction between climate change and drought because as climate change leads to more drought, it also leads to more oxidation of peat soil, which releases GHGs and further speeds the rate of GHG induced atmospheric warming and more drought. Drainage of these wetlands has also caused large carbon losses from soil and slower rates of carbon storage, contributing to global climate change (Bridgham et al. 2006).

Ecosystem fluxes of greenhouse gasses, including CO_2, N_2O, and CH_4, depend not only on hydrologic position and flow paths within wetland complexes (Pennock et al. 2010), but also exhibit considerable temporal variation with changes in hydroperiod, including hydrologic pulsing from surface water inputs (Altor and Mitsch 2008; Mander et al. 2011). The responses of biogeochemical cycling of carbon and nitrogen to climate change impacts in southeastern wetlands ecosystems are particularly understudied, and represent a critical source of uncertainty in projecting future climates (Clough et al. 2007). The types of wetlands addressed in this assessment represent known and predicted climate change effects on freshwater wetlands in the southeastern USA. They include the Carolina Bays and Pocosins, mountain bogs, riverine floodplain swamps, coastal wetland forests, and the Florida Everglades.

Fire is the greatest threat to these wetland ecosystems under climate-induced drought. For example, a recent study estimated carbon emissions for a large peatland fire in North Carolina using remote sensing to reconstruct burn severity and topographic Light Detection and Ranging (LiDAR) to estimate peat burn depths (Poulter et al. 2006). This study estimated that total carbon emissions for a 40,000-ha (98,842-acre) 1985 fire was from 1 to 3.8 Tg (1.1 to 4.2 million tons), with spatially heterogeneous patterns of carbon fluxes from 0.2 to 11 kg C m^{-2} (4.7 to 258 lb C ft^{-2}) depending on vegetation type, peat burn depth, soil substrate (mineral or organic), and fire severity. A more recent fire in the Pocosins Lakes Wildlife Refuge during the severe drought of 2008 burned 16,500 ha (40,772 acres) of abandoned drained peatlands, releasing an estimated 22 million metric tons (24.3 trillion tons) of carbon to the atmosphere (USFWS 2008). These two events show the potential for massive releases of carbon from fires in Pocosin peatlands under lower water tables resulting from climate-induced droughts.

Carolina Bay. Southern wetlands are vulnerable to changes in precipitation and warmer temperatures, especially as these changes are likely to result in more frequent droughts and higher rates of evapotranspiration (Mulholland and Sale 2011). Wet and dry cycles are thought to drive plant community dynamics in Carolina Bay wetlands, with wet periods characterized by larger areas of aquatic and emergent species and dry periods leading to the expansion of grasses and woody species. Increased drought frequency is likely to drive a shift to communities dominated by less flood tolerant woody species, especially in smaller bays that are more prone to drying (Stroh et al. 2008). Future cycling between wet and dry conditions likely will be driven by a balance between changes in precipitation, and increased evapotranspiration by increased temperature (Pyzoha et al. 2008). In southern mountain bogs, predicted increases in evapotranspiration in concert with anthropogenic increased nitrogen deposition might lower water tables and accelerate peat decomposition leading to a shift to alternative ecosystems (such as ephemeral wetlands or dry land ecosystems) and local extinction of several bog species (Schultheis et al. 2010).

Pocosins. Pocosins, also known as southeastern shrub bogs; are characterized by a very dense growth of mostly broadleaf evergreen shrubs with scattered pond pine. The typically thick layer of peat soils 1 m to 3 m (histosols) underlying Pocosin soils store nearly 300 Mt (330.7 million tons) of carbon in North Carolina alone (Richardson 2012). Under normal saturated hydrologic conditions, decomposition in organic soils is minimized due to a lack of oxygen, allowing for accumulation of organic carbon. Bridgham and Richardson (1992) incubated peat from pocosins in anaerobic conditions and found very low CH_4 production potentials relative to other peatlands. However, they also found that CO_2 increased greatly in aerobic soils under drought conditions--a climate scenario predicted to happen in the southeastern USA under climate change (IPCC 2007). A recent field study by Morse (2010) in restored and natural Pocosin soils also found very low levels of CH_4 release to the atmosphere in comparison with CO_2 and N_2O under dryer conditions. Morse found increases in CH_4 gas under higher water levels, more CO_2 release from dryer soils and seasonal fluxes of CO_2 to the atmosphere, further supporting the earlier findings of Bridgham and Richardson (1992) and suggesting that climate induced drought will change the magnitude and form of GHG fluxes. Further research is needed to establish how these GHG fluxes will change.

Southern Bottomland Swamp Communities. In southern bottomland swamp communities, alteration of growing season length and water regime could influence the ability of dominant canopy species to regenerate. Middleton (2009) found a distinct shift in species that germinate under flood and nonflood conditions within bald cypress (*Taxodium distichum*) swamps, and concluded that with the already low regeneration potential of dominant tree species, the range of bald cypress swamps may be compressed from the South in future climate scenarios. Stallins et al. (2010) found the interplay of lower baseflow on Apalachicola River, floodplain geomorphology, and canopy gap dynamics was associated with shifts in species composition of the floodplain forest canopy. This trend was most pronounced in backwater swamps where obligate wetland tree species, such as water tupelo (*Nyssa aquatica*), ogechee tupelo (*N. ogeche*), and Carolina ash (*Fraxinus caroliniana*), have undergone marked reductions in stem densities and there has been a muddling of the compositional contrasts between plant communities along the wet to dry gradient that typifies riparian floodplains.

The hydrology of coastal forested wetlands is expected to be very responsive to changes in both precipitation and temperature with declines in floodplain water table elevations and stream base flows expected under many future model scenarios (Dai et al. 2010; Dai et al. 2011). Similar results are seen in pine flatwoods where these effects are expect to be most pronounced in depression wetlands during dry cycles (Lu et al. 2009). Conner et al. (2011) examined the effects of drought on ecosystem productivity along a moisture gradient within coastal plain wetland forests in South Carolina and found that, both in terms of trunk diameter and aboveground net primary productivity (ANPP), wet sites were more sensitive to drought conditions than drier sites.

Figure 11.3. Nymphaea open water slough surrounded by Sawgrass (*Cladium jamaicense*) in the central Everglades. The peat depths are 1.8 m at this site. Wetland prairies such as these are highly vulnerable to changes in the hydrologic cycle. While these systems are currently strong carbon sinks, under a warmer and drier climate they could become carbon sources emitting powerful greenhouse gases such as CH_4, in addition to CO_2.

Everglades. The successional dynamics of the Everglades are mainly controlled by the interaction of climatic patterns (droughts and rainfall) and human alterations of hydroperiod, which in turn influence fire frequency and the degree of fire intensity as well as the transfer and release of carbon and nutrients on the landscape (Richardson 2008). In the Everglades, the dominant sawgrass (*Cladium mariscus,* spp. *jamaicense*) communities (Figure 11.3) growing typically on one to three meters of peat are thought to be resilient to a wider range of inundation durations and depths than other species, although prolonged periods of flooding cause problems (Richardson 2008). However, other communities such as pine savanna, red mangrove scrub, bay-hardwood, and muhly grass have more pronounced physiological limitations to inundation depth, duration, or both, and are more restricted in their distribution (Richardson 2008; Todd et al. 2010). Within the context of more extreme cycling between wet and dry conditions, this suggests that these plant communities may undergo a contraction of spatial extent under future climate scenarios. Knowledge of long-term climatic patterns is important to understand changes within the Everglades. With impending sea level rise due to global climate change, saltwater becomes even more of a factor as it invades farther into the southern Everglades and alters freshwater communities (Bartlett et al. 1995). It is unclear whether freshwater flow can counteract or prevent saltwater intrusion associated with sea-level rise. A sudden change from freshwater to saltwater conditions may accelerate oxidization of organic substrate leaving large areas of thin substrate or bare limestone bedrock with a greatly reduced potential for plant community shifts in response to climate change (Pearlstine et al. 2010; Willard and Bernhardt 2011).

11.5 Southeastern Tidal Marshes and Swamps

The greatest expanse of tidal wetlands in the continental USA is found in the Southeast. More than half of all tidal marshes are associated with the Mississippi River delta in coastal Louisiana. Because of their location at the land-sea interface, these areas are impacted by changes occurring in the sea as well as throughout the upland watersheds that drain to the coast. The magnitude of ecosystem services provided by these systems is unrivaled and nursery grounds that support the vast majority of recreational and industrial fisheries, water quality amelioration, storm surge abatement that protects hundreds of billion dollars of coastal real estate, and carbon sequestration (Barbier et al. 2011).

Coastal wetlands, sentinel ecosystems for environmental change and human-induced degradation of natural systems, are predicted to disappear at an accelerating rate (Nicholls et al. 1999; Nicholls et al. 2007). The distribution of coastal wetland habitats is determined predominantly by land elevation relative to sea level, freshwater, and climate. Climate change is predicted to cause widespread degradation of the coastal wetlands of the southeastern USA due to sea level rise (SLR), changes in freshwater flows, and increased frequency of extreme weather events (Meehl et al. 2007; Karl et al. 2009). Human activities, including hydrologic alterations (e.g., dams and levee construction), coastal development, and pollution likely will interact with climate change and further degrade coastal systems (Gedan et al. 2009). The most pressing issues for wetlands facing climate change and how they will alter the coastal landscape are discussed in the following paragraphs.

Sea level is the overriding factor determining the existence of tidal wetlands (Figure 11.4). Tidal wetlands have existed in a state of equilibrium with sea level rise (~ 0.2 mm/year) over the past 4,000 years by accumulating mineral sediment and organic matter produced by marsh vegetation (Morris et al. 2002; Mudd et al. 2009). Rates of SLR along the southeastern Atlantic and Florida coasts at2.5 mm/year are comparable to the current global average of 2 to 3 mm/year (Meehl et al. 2007; NOAA 2011). Rates of SLR in the Louisiana Gulf Coast are much higher (9.5 mm/year) due to a combination of human activity and tectonic subsidence (NOAA 2011). Climate change is predicted to accelerate SLR in the coming century resulting in a sea level increase of up to 2 m or more by 2100 (NCA 2012; Meehl et al. 2007: Rahmstorf 2007: Rahmstorf et al. 2007: Richardson et al. 2009: Vermeer and Rahmstorf 2009). As rates of SLR outpace the ability of wetlands to build, they will become vulnerable to coastal erosion and increased inundation rates, eventually resulting in a conversion of coastal wetlands to open water (Day and Templet 1989: Donnelly and Bertness 2001: Craft et al. 2009: Kirwan et al. 2010).

Figure 11.4. Tidal salt water marshes and swamps, such as this *Spartina alterniflora* marsh near Sapelo Island, GA, are particularly vulnerable to sea level rise. If they are unable to build in elevation as rapidly as sea level rises, they will revert to open-water areas. Salt marshes are critical habitats for most of the commercial fisheries of the SE USA.

Anthropogenic activities will reduce the ability of coastal wetlands to adapt to SLR. Increased freshwater and fossil fuel withdrawals increase local subsidence rates (Yuill et al. 2009). The construction of dams and other freshwater control devices reduce sediment delivery to the coast (Slattery et al. 2002: Graff et al. 2005). Large scale disappearance of wetlands in Louisiana has already been observed as sea level rises and sediment supply is restricted by large scale river alterations (Blum and Roberts 2009). At the same time, development has restricted the ability of coastal wetlands to migrate inland and upland with SLR via shoreline hardening and the placement of fill in the immediate coastal zone (Feagin et al. 2010).

Increasing average sea temperatures over the past 40 years have been correlated with increased intensity of hurricanes, which in turn have been correlated with an increase in average summer wave heights in the Atlantic (Komar and Allan 2008; Kunkel et al. 2008). Increased storm and wave intensity cause erosion and shoreline retreat of coastal wetlands. Coastal wetlands are important for dissipating storm energy and their loss leads to the increased vulnerability of human structures on coastlines to wave erosion (Gedan et al. 2011). Storm surges can also introduce saltwater into sensitive freshwater ecosystems increasing wetland degradation.

Climate models predict greater interannual variability in temperature and precipitation with the potential for greater frequency of droughts and floods that, in combination with increased temperatures and accelerated rates of evapotranspiration across terrestrial landscapes, will alter the availability of freshwater to the coast. Increased human demands for freshwater and changes in seasonal precipitation patterns have and likely will continue to alter the timing and magnitude freshwater delivery to the coast. Changes in precipitation regimes, storms and anthropogenic alterations of freshwater flows are predicted to compound the effects of SLR, resulting in saltwater intrusion into freshwater wetlands (Smith et al. 2005; Hilton et al. 2008; Craft et al. 2009).

Saltwater intrusion into coastal freshwater wetlands will accelerate the release of organic carbon by stimulating microbial decomposition, especially sulfate reduction, and negatively affect plant productivity and alter species composition (Craft 2007: Weston et al. 2006: Spalding and Hester 2007: Neubauer and Craft 2009: Neubauer 2011: Weston et al. 2011). Increased decomposition will lead to a reduced capacity to sequester carbon, increased greenhouse gas production (CO_2 and CH_4), and a reduced capacity to build elevation against SLR (Neubauer and Craft 2009; Neubauer 2011). Nitrogen cycling (e.g., denitrification, nitrification, and nitrogen accumulation) will be negatively affected by salinity, reducing nitrogen removal from coastal waters and increasing coastal eutrophication (Rysgaard et al. 1999; Giblin et al. 2010; Weston et al. 2010).

Plant metabolic processes will be stressed by the interaction of increased flooding and salinity as well as increased temperature. Saltwater intrusion and increased evapotranspiration caused by elevated temperatures will elevate soil salinities, thus coastal wetland plant communities will shift towards species with greater salinity tolerance (Craft et al. 2009; Neubauer and Craft 2009). Increased inundation can stimulate plant growth at limited water depths (40 to 60 cm below mean high tide), beyond which it will cause mortality (Morris et al. 2002; Kirwan et al. 2010). Increased temperatures and longer growing seasons might increase net primary productivity (Kirwan et al. 2009). Increased CO_2 concentrations might also stimulate plant growth, thereby helping coastal wetlands build elevation against SLR (Pendall et al. 2004; Langley et al. 2009). However, increased CO_2 concentrations favor plants with a C3 metabolism over those with a C4 metabolism, indicating that large-scale shifts in plant community compositions may occur, which will have implications for habitat use and food resources for fish, birds, and other fauna (Rasse et al. 2005). Coastal eutrophication as well as increases in temperature that increase litter decomposition may limit or negate the positive effects of increased temperature and CO_2 concentrations on productivity (Langley and Megonigal 2010; Kirwan and Blum 2011). The complex interactions between these factors are poorly understood, but will determine how plant communities respond to climate change.

Unpredictable nonlinear interactions may increase susceptibility of marsh ecosystems to drought and increased salinity. For example, Silliman et al. (2005) found that drought and salinity induced die-off of salt marsh vegetation was exacerbated by herbivore grazing. Large-scale diebacks of salt marsh vegetation, called “brown marsh,” occurred along the southeastern and Gulf coasts between 2002 and 2004, affecting more than 250,000 acres (McKee et al. 2004;

Silliman et al. 2005). These diebacks may accelerate salt marsh conversion to open water (McKee et al. 2004).

Figure 11.5. Tidal fresh forest along the Satilla River in coastal Georgia. These forests are particularly vulnerable to salt water intrusion that occurs with sea level rise. Vegetation likely will be replaced by salt tolerant marsh species, such as *Zizaniopsis* sp. During the transition these environments can emit high rates of greenhouse gases,

Tidal freshwater forests are extremely vulnerable to climate change (Figure 11.5). More than 80% of tidal wetland forests occur in the SE USA and dieback and retreat of these systems has been observed over the past several decades (Connor et al. 2007). Saltwater intrusion stunts the growth of the dominant species, such as bald cypress (Krauss et al. 2009), and extended periods of chronic saltwater exposure caused by SLR lead to forest dieback (Connor et al. 2007). These systems are also sensitive to increased flooding associated with SLR, not just salt water exposure as rising sea levels will cause river water to backup and increasingly flood oligohaline wetlands (conner et al. 2007.)While herbaceous marshes can adapt to climate change by building elevation and rapid community shifts, tidal freshwater forests are less able to adapt via vertical accretion or migration due to their slow growth and development, low sedimentation rates, and adjacency to upland areas. They are often replaced by herbaceous freshwater and brackish marshes that alter habitat and decrease overall potential for carbon sequestration as woody biomass (Connor et al. 2007). Desantis et al. (2007) report that exposure to salinity stress as little as a few times a year reduces species diversity in Florida Gulf Coast tidal freshwater forests, converting communities with more than 20 species to low-diversity stands of cabbage palm (*Sabal palmetto*) and southern red cedar (*Juniperus virginiana*). At low elevations, increased frequency of saltwater intrusion causes these systems to convert to herbaceous marsh (Desantis et al. 2007; Geselbracht et al. 2011).

Climate change will facilitate the expansion of invasive species by altering climatic constraints and transport of invasive species (Hellmann et al. 2008). Cold weather is one of the primary factors limiting the abundance of the invasive semi-aquatic rodent nutria (*Myocastor coypus*; Dedah et al. 2010 and references therein). Nutria burrowing and feeding activities destroy root systems and depress soil accretion leading to erosion and submergence of wetlands (Gedan et al. 2009). The invasive tree Chinese tallow (*Triadica sebifera*) is predicted to move 300 to 700 km north of its current range with a 2°C increase in temperature (Pattison and Mack 2008; Wang et al. 2011) and *Melaleuca quinqueneria* is predicted to similarly expand its range northward. Hurricanes and other storm events may aid in the spread of invasive propagules, and frequent hurricane disturbance has been shown to favor certain invasive species over their native counterparts, for instance *Iris pseudocorus* over *I. hexagona* (Pathikonda et al. 2009).

Direct human actions could also enhance invasive potential for two highly productive and aggressive invasive species, *Arundo donax* and *Phalaris arundinacea,* which are being explored for biofuel production (Hellmann et al. 2008).

Warming may also facilitate the expansion of certain native species at the expense of others. Mangrove wetlands are limited by periodic freezes to southern Florida and the Louisiana and Texas coasts (Sherrod and Mcmillan 1981 and 1985; Mcmillan and Sherrod 1986; Sherrod et al. 1986; Pickens and Hester 2011). Multiple observations confirm the northward advance of mangrove species over the last 20 years due to the lack of freezes in the Gulf and South Atlantic regions (Zomlefer et al. 2006; Michot et al. 2010). Sea level rise is facilitating mangrove encroachment on the salt marsh dominant species *Spartina alterniflora* and allowing mangroves to move inland with saltwater intrusion to replace freshwater marshes on the Florida coast (Doyle et al. 2010; Krauss et al. 2011). Though there is some evidence that mangroves may build elevation in response to SLR more readily than salt marsh and may be more resilient to storm surges (Mckee et al. 2007; Kumara et al. 2010), increased mangrove dominance has implications for coastal food webs, economically important fisheries (e.g., fish, shrimp, and other shellfish) and recreational activities.

Changes in the extent and productivity of wetland plant communities will have cascading impacts on fisheries, migratory birds, and bird breeding habitat (Craft 2007; Craft et al. 2009). Wetlands provide refuge and food for fish, crustaceans, and mollusks, and to maintain viable commercial and recreational fisheries (UNEP 2006). These systems provide habitat for migratory resident and migratory water birds that are important to hunters and bird watchers. Many of these species rely on the preservation of an entire estuarine landscape because they feed in salt marshes but breed and nest preferentially in freshwater wetlands or upland edge habitat (e.g., the wood stork, painted bunting) (Winn et al. 2008; Brittain et al. 2011). Other species (e.g., rails) select nesting locations in relation to tide levels, putting them in danger as sea level rises and storm surges intensify (Rush et al. 2010; van de Pol et al. 2010). Delivery of ecosystem services associated with water quality improvement and carbon sequestration likely will decline as tidal wetland habitat is lost or altered (Craft et al. 2009).

Recent model simulations suggest the combined impacts of accelerated SLR and saltwater intrusion will drastically alter the estuarine landscape over the next century through submergence and landward migration of estuarine systems (Craft et al. 2009; Neubauer and Craft 2009). The greatest losses likely will occur at both ends of the estuarine spectrum, namely salt marshes and tidal freshwater forests (Donnelly and Bertness 2001; Craft et al. 2009; Geselbracht et al. 2011). Climate change impacts on both terrestrial and marine systems also affect wetlands, the future survival of which will depend on management of an entire continuum of landscapes from the headwaters of rivers to the ocean.

11.6 Coral Reefs of the Southeast USA

Coral reefs and hard bottom reefs are some of the most biologically diverse ecosystems in the temperate, subtropical, and tropical oceans (Veron 2000). In the southeastern USA, stony corals exist in the shallow waters of the western Atlantic, the Gulf of Mexico, as well as U.S. territories in the Caribbean including Puerto Rico, the U.S. Virgin Islands, and Navassa Island (Figure 11.6). Most of these reefs are within managed areas including three national parks (Biscayne, Dry Tortugas, and Virgin Islands); national monuments and national historical parks (Buck Island and Salt River Bay); national marine sanctuaries (Flower Garden Banks, Florida Keys, and Gray's Reef); and a state park (John Pennekamp in Florida). Other coral reefs are found along the SE coast of Florida from Martin County to Dade County, Florida. Middle Grounds and Pulley Ridge in the Gulf of Mexico contain some of the deepest stony corals in the USA. Detailed assessment and status reports for coral reefs in the USA have been produced by NOAA, Global Coral Reef Monitoring Network, and Reef and Rainforest Research Center. Following, some aspects of these reports are summarized as they relate to the effects of global climate change (Waddell and Clarke 2008, Wilkinson 2008, Wilkinson and Souter 2008).

Coral reefs worldwide are in decline as a result of multiple stressors, including climate change (Wilkinson 2008). In the Florida Keys and U.S. Caribbean reefs, once structurally complex, have declined with few reefs exhibiting a mean live coral coverage greater than 10% (Waddell and Clarke 2008) and with 21% of the reefs destroyed are unlikely to recover (Wilkinson 2008). The largest changes documented since the 1970s indicate that the most prevalent branching corals, the acroporid corals, have experienced population declines of greater than 90% (Team 2005). Two of these corals, *Acropora palmata* and *A. cervicornis*, were listed in 2006 as threatened under the Endangered Species Act (Hogarth 2006). In 2010, the National Marine Fisheries Service found sufficient evidence to list 82 additional coral species as threatened, including eight Caribbean species (NOAA 2010). The majority of coral reefs in the Caribbean-Atlantic-Gulf of Mexico region are reported to be in poor or fair condition with Flower Garden Banks having the fewest threats (Waddell and Clarke 2008). However, the 2010 Deepwater Horizon oil leak occurred to the east of Flower Garden Banks and monitoring continues to assess any impacts from the accident.

Figure 11. 6. Location of coral reefs in the southeast USA including Flower Garden Banks (FGB), Florida Middle Grounds (FMG), Pulley Ridge (PR), Dry Tortugas (DT), Florida Keys (FK), Biscayne (B), southeast Florida reefs (SEFL), Gray's Reef (GR), Navassa Island (NI), Puerto Rico (PRR), and U.S. Virgin Islands (USVI). Orange areas are coral reefs from ReefBase (http://reefgis.reefbase.org/).

The major direct climate change threats to coral reefs are increases in water temperature, ocean acidification, and sea level rise (IPCC 2007). Effects of ocean acidification and warming can be exacerbated when coupled to other stressors in reef systems, including disease, coastal runoff, overexploitation, vessel damage, marine debris, and exotic species (Carilli et al. 2009). In 1983, 93% of a sea urchins species, *Diadema antillarum,* died in the Caribbean (Lessios 1988). Sea urchins are important because they graze on algae thereby providing suitable habitat for coral settlement. Diseases of coral reef organisms can be expected to increase in the future as climate change stressors increase (Richardson 1998; Waddell and Clarke 2008). Coral diseases include coral bleaching, black-band disease, dark-spots disease, red-band disease, white-band disease, white-plague disease, white pox, and yellow-blotch disease (Richardson 1998).

There is active investigation and research of climate change impact on corals and their capacity to adapt. While some studies report declining coral growth rates (De'ath et al. 2009; Cantin et al. 2010; Manzello 2010), others show some species having greater elongation rates but with decreased skeletal density (Helmle et al. 2011). Additionally some studies suggest that changes in temperature may offset changes in pH for some corals (Cooper et al. 2012; McCulloch et al. 2012), while others suggest the opposite (Rodolfo-Metalpa et al. 2011). There has been concern that high CO_2 levels (Veron et al. 2009; Veron 2011) may lead to the demise of corals, but some studies suggest corals may adapt or survive in refugia (Hughes et al. 2003; Fabricius et al. 2011; Howells et al. 2012; Karnauskas and Cohen 2012).

Prolonged events of abnormal water temperatures lead to coral bleaching, when corals expel the symbiotic zooxanthellae that provide the coral with nutrients (Muscatine 1973; Jokiel and Coles 1977). Corals can recover from short duration bleaching events (i.e., days); however, prolonged or drastic temperature changes for weeks can result in bleaching that leads to coral death (Jokiel and Coles 1977). Such events are occurring with increased frequency and currently bleaching events take place each summer somewhere is the USA coral reef system (Wilkinson and Souter 2008). A massive regional coral bleaching event affected virtually the entire Caribbean basin in the late summer and fall of 2005. Following this bleaching event, a coral disease epidemic resulted in about a 50% decline in live coral cover and in places up to 90% mortality (García-Sais et al. 2006; Miller et al. 2006; Wilkinson and Souter 2008). Conversely, cold water events can also lead to bleaching and coral death, such as the anomalous cold event in 2010 that killed numerous near-shore corals in the Florida Keys and southeast Florida (NOAA 2011; Colella et al. 2012).

Changes in tropical storm frequency and intensity (Trenberth and Shea 2006; Bender et al. 2010; Mousavi et al. 2011) can have damaging effects on coral reefs by overturning colonies, altering the habitat, increasing turbidity, and increasing nutrient concentrations from land runoff (Wilkinson and Souter 2008). During the 2005 hurricane season, extensive damage to coral reefs occurred in the Flower Garden Banks, the Dry Tortugas, and the Florida Keys; however, these reefs were spared from bleaching as the passing hurricanes reduced water temperatures (Stone et al. 2005; Gierach and Subrahmanyam 2008; Wilkinson and Souter 2008).

Much remains to be learned concerning the effects of ocean acidification in coral reef systems from the physiological scale to ecosystem level (Fabricius et al. 2011; Pandolfi et al. 2011). Decreases in pH reduce growth rates of organisms that have calcified skeletons, such as corals; mollusks; and some plankton, echinoderms, and crustaceans (Veron et al. 2009). Changes in ocean pH have been documented for the Caribbean and Gulf of Mexico (Gledhill et al. 2008; Gledhill et al. 2009) and ocean acidification models predict pH may drop another 0.3 pH units with business-as–usual climate change scenarios (Caldeira and E.Wickett 2003; Feely et al. 2009, Academies 2010). Future projections that model continued warming and ocean acidification reveal increased coral bleaching and coral disease result in widespread morality (Hoegh-Guldberg et al. 2007; IPCC 2007, Veron et al. 2009; Pandolfi et al. 2011).

Sea level rise is a concern in reef systems primarily as it affects water depth and light penetration (IPCC 2007). Coral reefs can respond to slow rates of sea level rise as they have during past glacial-interglacial cycles (Lidz 2006); however, coral reefs may not be able to keep up with the rates of sea level rise that are possible by the end of the 21st century, especially when considering other stressors on coral health.

Finally, increased precipitation associated with climate change may impact coral reefs by increasing runoff of contaminants, sediments, and nutrients into oceans thus further reducing coral health and contributing to the decline of coral reefs (Weber et al. 2006; Deslarzes and Lugo-Fernández 2007; Waddell and Clarke 2008).

11.7 Summary

For all the natural ecosystems considered in this chapter, it is difficult to isolate the effects of climate change from the many other threats to these systems, including for example invasive species, disease, land use change, water withdrawals, and atmospheric deposition.

Sea level rise and ocean acidification are two additional aspects of global climate change that uniquely affect the natural ecosystems considered in this chapter, especially coastal tidal wetlands, and coral reefs. It is likely that acidification effects also will be experienced in freshwater stream, lake, reservoir, and river systems. Another unique aspect of many natural ecosystems of the SE is that the combined effects of sea level rise, associated increase in salinity, and alternating wet and dry cycles likely will enhance the fluxes of potent GHGs, CH_4 and N_2O, into the atmosphere.

In the SE, higher water temperatures are expected to put organisms closer to their thermal temperature limits and exacerbate low dissolved oxygen conditions, which already characterize many blackwater streams draining the southeastern coastal plain. Fish that disperse within basins can adjust to warmer temperatures by moving northward to find cooler waters, but only if their routes for dispersal are unimpeded by dams, diversions, and dry-river channels. Freshwater mussel reproduction may fail if temperatures exceed tolerance levels or if low flows limit the effectiveness of mechanisms for attracting host fish.

More frequent droughts coupled with increasing water demands, from of greater evapotranspiration and growing human consumption, likely will result in more frequent stream drying, even in systems historically considered perennial, which will increase the frequency of local species extirpations. The net result is faunal homogenization, in which communities become dominated by a smaller number of species that are most capable of recolonizing or surviving in stream systems affected by more frequent drought and unpredictable flow conditions.

Climate change is expected to further the establishment of non-native, invasive species by lessening constraints imposed by frequency and duration of cold temperatures.

Climate change is expected to have major impacts in the increasingly rare longleaf pine savannas of the SE. The combined effects of drought, warmer temperatures, and fire probability will increase the flow of carbon to the atmosphere by the decomposition and burning of drier vegetation and peat. While warmer winter temperatures may benefit the longleaf pine ecosystem in the northern range margin, the majority of longleaf pine savannas will likely fare less well due to increasing summertime droughts.

Southeastern freshwater wetlands are vulnerable to climate driven changes in precipitation and temperature, where more frequent droughts and higher rates of ET are predicted. Most of the SE freshwater wetlands experience shifts in seasonal fluxes of greenhouse gases, with more CH_4 under wet conditions, and more CO_2 and N_2O under dry conditions.

Fire is the greatest threat to millions of acres of freshwater peat-based wetlands in the SE under climate-induced drought. CO_2 emissions during fire can reverse centuries of CO_2 sequestration and ultimately convert these systems from being net C sinks to important C sources. Wet and dry cycles drive plant community dynamics in freshwater wetlands and increased drought frequency is likely to drive a shift to communities dominated by less flood tolerant woody species.

For tidal wetlands of the SE, rates of sea level rise could outpace the ability of wetlands to build elevation. As a result wetlands likely will become vulnerable to coastal erosion and increased inundation rates, eventually converting to open water, as has been experienced in coastal Louisiana for several decades now. The construction of dams and other freshwater control devices reduce sediment delivery to the coast further exasperating wetland loss. Increased storm and wave intensity cause erosion and shoreline retreat of coastal wetlands. Tidal freshwater forests are less able to adapt either via vertical accretion or migration due to their slow growing time, low sedimentation rates and their adjacency to upland areas.

Warming will likely facilitate the expansion of certain native species at the expense of others. For example mangrove wetlands, which are limited in their northern limits by periodic freezes, are advancing northward in the Gulf and South Atlantic coastal regions of the SE.

Coral reefs and other hard bottom reefs of the SE are also susceptible to climate change, especially because of warming waters, acidification, and sea level rise. Effects of ocean acidification and warming can be exasperated when coupled to other stressors in reef systems, including disease, coastal runoff, overexploitation, vessel damage, marine debris, and exotic species. Warm water temperatures lead to coral bleaching and when prolonged can lead to death of corals. Changes in tropical storm frequency and intensity will impact coral reefs as many forms of coral are susceptible to wave damage.

Much remains to be learned about the effects of acidification on coral reef systems, from the physiology to the entire ecosystem. Sea level rise affects light transmission to the reef, especially so if the reef has limited ability to build vertical elevation. In addition most reef building is via calcification, which is highly sensitive to ocean pH.

Southeast aquatic and coastal systems are also sensitive to climate changes that may increase freshwater runoff from land as well as carry contaminants and nutrients that can degrade these environments.

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12 Mitigation of Greenhouse Gases in the Southeast

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Key Issues

- Continued investment in clean energy, including energy efficiency and clean energy supply options, including for transportation.
- Maintenance of carbon sinks in the face of development pressures.

12.1 Introduction

For the purpose of this chapter, “mitigation” refers to activities that avoid or decrease the release of greenhouse gas (GHG) emissions from new and existing sources, or decrease atmospheric GHG concentrations by GHG emissions sinks (e.g., carbon storage in forests) as compared to a specific historical point in time across a specific spatial boundary. This chapter briefly reviews the emissions of GHGs from sources in the Southeast, along with some recent efforts being undertaken to reduce emissions by southeastern businesses, governments, homeowners, and others. The ability of natural systems in the SE to sequester carbon is also reviewed.[1]

12.2 Overview of GHG Emissions and Sinks in the Southeast

12.2.1 Greenhouse gas emissions

The southeastern USA is only one of eight NCA regions, but is home to over 81 million people (26% of the USA population, including Puerto Rico and the U.S. Virgin Islands).[2,3] Likewise, at 25% of national emissions, the SE outpaces all other NCA regions as the largest emitter of anthropogenic carbon dioxide (CO_2) through combustion of fuels in the United States (Figure 12.1). In 2009, southeastern sources alone were responsible for over 1,444 million metric tons (MMt) of CO_2 combustion emissions. The electric power sector accounted for 41% of these emissions, followed by the transportation sector (35%) and industrial sources (18%) as the largest contributors.[4] (A more comprehensive emissions inventory of greenhouse gas (GHG) emissions, for a limited number of SE states, is provided in the next section).[5]

Among the southeastern states, all but Louisiana produce the greatest share of their combustion CO_2 emissions from the electric power and transportation sectors. Louisiana is anomalous with industry contributing the greatest share of emissions. Florida leads all the southeastern states with the greatest total amount of emissions (234 MMt CO2 in 2009), with the majority of its emissions almost equally split between the electricity and transportation sectors (Figure 12.2).

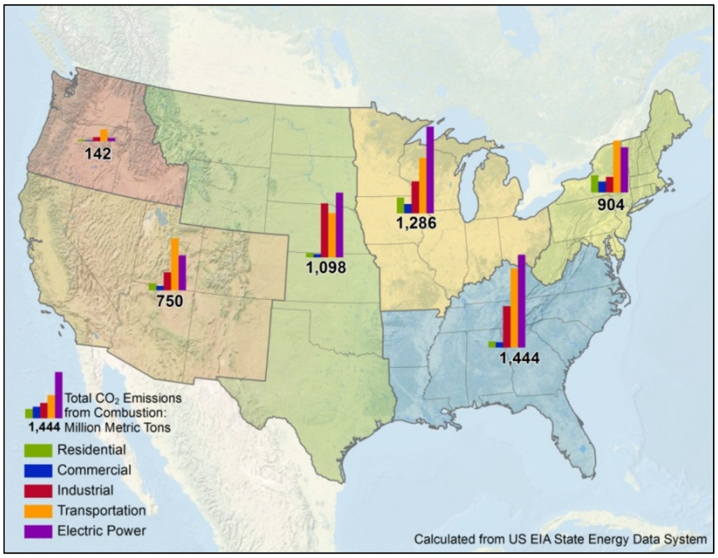


Figure 12.1. Total CO2 emissions from combustion by sector by NCA region in 2009.

12.2.2 Regional Trajectory for GHG Emissions

Of the eleven states in the SE, six Arkansas, Florida, Kentucky, North Carolina, South Carolina, and Virginia)[6] have undertaken a process to develop a climate change plan for their state, including an inventory of emissions and projections of emissions into the future (typically, for the 2020 to 2030 timeframe). In most cases, these states developed estimates of both gross emissions as well as net emissions that attempt to account for forestry and land use sinks. The emission sources and GHGs evaluated extend beyond those captured by DOE combustion CO_2 emission estimates discussed above. For example, the state-specific estimates may have considered and included emissions of methane (CH_4) from livestock operations and nitrogen dioxide from forest wildfires, collectively reported as carbon dioxide equivalents or CO_{2e}.[7]

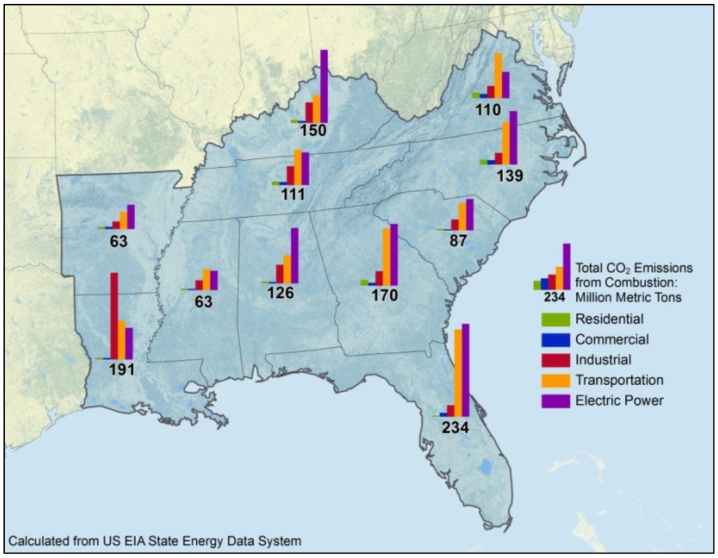


Figure 12.2. Total CO_2 emissions from combustion by sector by in SE states.

Most of these plans were developed with the assistance of the Center for Climate Strategies and a collection of these plans is available on their website.[8] A summary of the estimated out-year GHG emissions for these six states is provided in Table 1 and indicates an expected increasing trend in emissions over time.[9] It should be noted that estimates of future emissions are dependent upon a host of variables, ranging from changes in technology and policy to how the economy develops.

12.2.3 Carbon Sinks

Generally speaking, carbon sequestration measures the rate of carbon removed from the atmosphere over a finite period of time (e.g., a month or a year) within a finite unit of space (e.g., an individual plant or an acre of land), while carbon storage measures the total mass of carbon accumulated within that finite space. For example, if something sequesters at a rate of 2 Mt CO$_2$/year but emits at a rate of 1 Mt CO$_2$/year via its natural processes, then its carbon storage is only 1 Mt CO$_2$ the first year, then 2 Mt CO$_{2e}$ the next year and then 3 Mt CO$_{2e}$, and so on, until it reaches some internal saturation point or until it is released in a pulse from a disturbance like a fire.

Table 12.1. GHG Inventory and Reference Case Projections (1990 – 2030)[10,11,12,13,14,15]

MMtCO$_2$e	1990	2000	2005	2010	2015	2020	2025	2030
Gross Emissions on a Consumption Basis, Excluding Sinks (Increase relative to 1990)*								
Arkansas	65.8	86.8 *(32%)*	85.4 *(30%)*	93.5 *(42%)*	101.3 *(54%)*	107.5 *(63%)*	114.2 *(74%)*	n/c
Florida	248.8	315.0 *(27%)*	336.6 *(35%)*	362.6 *(46%)*	n/c	424.9 *(71%)*	463.3 *(86%)*	n/c
Kentucky	136.7	165.9 *(21%)*	183.1 *(34%)*	191.6 *(40%)*	205.1 *(50%)*	217.7 *(59%)*	232.3 *(70%)*	247.7 *(81%)*
North Carolina	136	180 (33%)	192 (42%)	214 (58%)	n/c	256 (88%)	n/c	n/c
South Carolina	67.2	87.8 *(31%)*	93.5 *(39%)*	102.2 *(52%)*	n/c	125.4 *(87%)*	n/c	n/c
Virginia	n/c	162.63	n/c	n/c	n/c	n/c	229.84 (41%)	n/c
Net Emissions on a Consumption Basis, Includes Forestry and Land Use Sinks (Increase relative to 1990)								
Arkansas	27.3	66.0 (141%)	64.6 (136%)	72.6 (166%)	80.4 (194%)	86.6 (217%)	93.4 (242%)	n/c
Florida	230.9	288.3 *(25%)*	309.4 *(34%)*	335.3 *(45%)*	n/c	397.8 *(72%)*	436.2 *(89%)*	n/c
Kentucky	126.8	158.2 *(25%)*	175.5 *(38%)*	184.0 *(45%)*	197.6 *(56%)*	210.1 *(66%)*	224.8 *(77%)*	240.2 *(89%)*
North Carolina	112	156 (39%)	169 (50%)	191 (70%)	n/c	232 (106%)	n/c	n/c
South Carolina	34.0	56.8 (67%)	62.3 (83%)	71.0 (109%)	n/c	94.1 (177%)	n/c	n/c
Virginia	n/c	n/c	n/c	n/c	n/c	n/c	n/c	n/c

*The Virginia baseline is 2000. MMtCO$_2$e - Million metric tons of carbon dioxide equivalentn/c – Not Calculated

Table 12.2. Total Terrestrial Carbon (C) Storage in Southeast

State	Soil Organic C	Biomass C			Total Terrestrial C
		Forest	Crop*	Pasture*	
	Tg C	Tg C	Tg C	Tg C	Tg C
AL	535	489	1.3	1.3	1,027
AR	814	482	22	2.9	1,321
FL	3,504	252	0.3	0.7	3,757
GA	1,232	514	3.7	1.6	1,751
LA	1,100	376	8.7	0.7	1,485
MS	457	450	7	1.3	915
NC	1,761	517	7.4	1.8	2,287
SC	888	262	1.9	0.7	1,153
TN	408	389	5.2	4.7	807
VA	516	455	6.3	3.2	981
Total	**11,215**	**4,186**	**63.8**	**18.9**	**15,483.7**

*On an annual basis

A 2007 study of terrestrial carbon storage in the SE and South-Central USA estimated the state-level terrestrial carbon storage as teragrams of carbon (Tg C) in Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, Texas, and Virginia.[16] The study also projected the potential for terrestrial carbon sequestration in the region. The estimates of carbon storage for the SE are provided in Table 2. The estimate of annual terrestrial carbon sinks (or annual sequestration) in the SE is provided in Table 12.3. Of the southeastern states evaluated, Florida leads at nearly 25% of carbon storage, largely due to soil storage. In contrast, Arkansas leads with more than 20% of annual biomass carbon sink due to its high level of crop production.

Table 12.3. Annual Terrestrial Biomass C Sinks in the Southeast

State	Biomass C (Tg C/year)			Total Terrestrial C as Biomass (Tg C/year)
	Forest	Crop	Pasture	
	Tg C	Tg C	Tg C	Tg C
AL	8.7	1.3	1.3	11.3
AR	6.5	22	2.9	31.4
FL	5.4	0.3	0.7	6.4
GA	11	3.7	1.6	16.3
LA	5.9	8.7	0.7	15.3
MS	7.8	7	1.3	16.1
NC	8.5	7.4	1.8	17.7
SC	3.7	1.9	0.7	6.3
TN	4.3	5.2	4.7	14.2
VA	6.3	6.3	3.2	15.8
Total	**68.1**	**63.8**	**18.9**	**150.8**

Note that Kentucky was not included in this evaluation, and estimates of storage and annual sinks were not available for the commonwealth by the same methodology used for the other southeastern states. That said, approximately 10% of Kentucky is used for cultivated crops and 47% is covered by deciduous forests,[17] indicating that terrestrial systems in Kentucky are expected to add substantively to the totals shown in Tables 2 and 3. Other estimates of terrestrial sequestration for select Southeastern states, including Kentucky, are discussed in the preceding section on regional trajectories of GHG emissions.

While coastal wetlands have been estimated to contain about 10% of the total soil carbon,[18,19,20] no comprehensive studies estimating the carbon sequestration and storage capabilities for the coastal areas of the NCA SE could be located.

A recent study found that the ability of SE ecosystems to act as a net carbon sink (also called Net Ecosystem Productivity or NEP) varied greatly across the region (Figure 12.3) due to differences in ecosystem types and climate. NEP can be approximated by net ecosystem exchange (NEE), a term used by the eddy flux research community that focuses on field measurements of ecosystem carbon sequestration. By convention, NEE equals minus-NEP; thus, negative values of NEE represent a carbon sink, while positive values represent a carbon source. The ability to act as a net carbon sink can have large inter-annual variability due to fluctuations in precipitation and drought patterns in the region. The mean regional NEP is about 0.3 petagrams of carbon per year in which about 60% is from forests and the rest from lands classified as savannas.[21]

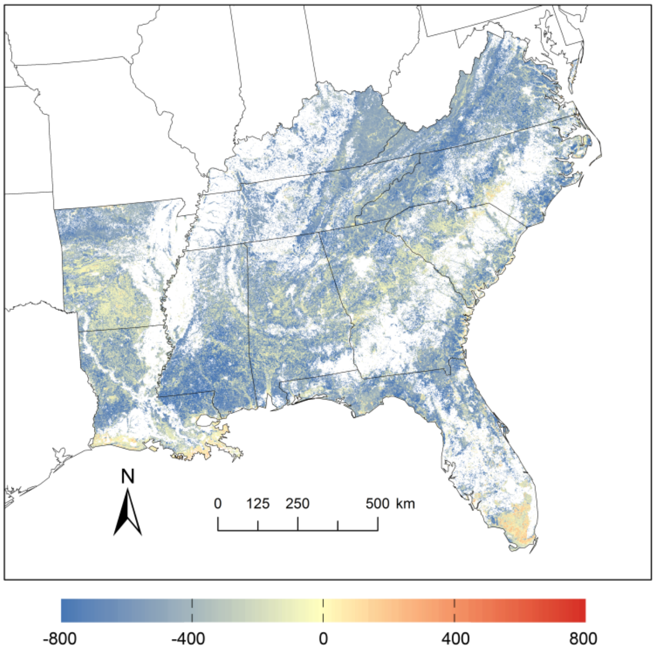


Figure 12.3. Mean annual NEE for the Southeastern USA for the period 2001 to 2006. Units are gCm^{-2} yr^{-1}. Positive *values indicate carbon release, and negative values indicate carbon uptake (croplands, urban areas, water bodies,* and non-vegetated areas excluded).

12.3 GHG Emission Reduction Activities

The largest share of southeastern GHG emissions comes from the production and use of energy (including energy for transportation). Fortunately, southeastern businesses and consumers increasingly have the interest and ability to invest in cleaner energy options. Energy efficient home appliances, highly efficient combined heat and power (CHP) technology, increasingly more stringent building energy codes, improved fuel efficiency and alternative fuel infrastructure for cars and trucks, clustered and transit oriented development, and renewable energy sources are only a few of the ways the SE is working to modernize its energy landscape and cut its GHG emissions. In addition, federal and state policy makers, electric and gas utilities, research institutions, and others are working to identify, design and implement clean energy policy and technology solutions that deliver important environmental and economic benefits. This section discusses some of the many activities that are helping to reduce GHG emissions in the SE over time.

12.3.1 Transportation

As noted in chapter 4 (Energy), the SE uses more petroleum fuel and has more vehicle miles traveled than any other NCA region in the country. The SE has an extensive network of highway, rail, and navigable transportation corridors and is home to 5 of the top 30 busiest airports in the USA by passenger boarding[22] and seven of the top 30 freight gateways in the USA handling international merchandise by either water, air, or land.[23] Transportation alone makes up 35% of combustion-related CO2 emissions in the SE.

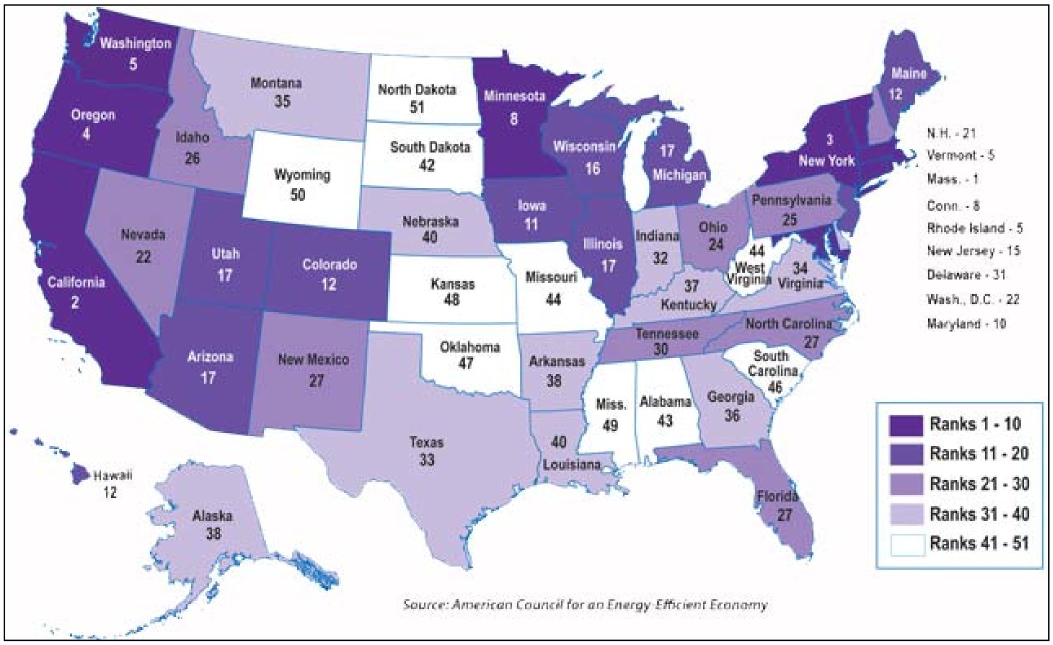
A wide array of government and other stakeholders in the SE are working to improve the efficiency of the region's transportation network through such efforts as smart growth, congestion relief and commuter programs. In Georgia, for example, citizens will soon vote on a regional sales tax to help provide funding for transportation efficiency improvements including both congestion relief for roadways as well as increased transit solutions, improved walkability and bikeability, and educational services.[24]

A noteworthy effort to reduce petroleum use in the SE is the Southeast Diesel Collaborative (SEDC). [25] The SEDC focuses on reducing the impacts of diesel emissions through strategies such as replacing older vehicles with newer, more fuel efficient vehicles, repowering existing engines to improve emissions and fuel usage, encouraging strategies to eliminate wasteful idling, and retrofitting long haul trucks with aerodynamic improvements to increase fuel economy. SEDC also works to reduce the impact of freight movement at ports and airports. For example, an SEDC project in Tennessee is engaged in installing auxiliary power units on tractor trailers to reduce fuel usage when idling. The effort is projected to save over 9 million gallons of fuel over the life of the project and eliminate over 100,000 tons of CO_2.[26]

SEDC is also working to create "green corridors" along interstates to promote the availability of less carbon intensive fuels and "idle-free" options for truckers during rest periods (e.g., truck stop electrification). SEDC is promoting this effort nationally and is working with other regional diesel collaborative organizations along the east coast to develop Interstate I-95 into a green corridor. To date, the SE hosts over 1,500 alternative fuel locations, including biodiesel, compressed natural gas, propane, and E85 options.[27]

12.3.2 Energy Efficiency in Buildings and Manufacturing

Energy efficiency is one of the most cost-effective ways to reduce GHG emissions of various end-use sectors, such as residential, commercial, and industrial. Innovative, climate specific building designs, such as passive solar orientation, daylighting, high quality thermal and air barriers along the building envelop, and improved building occupant conservation behaviors can complement energy efficiency and help avoid new GHG emissions. While barriers to energy efficiency projects do exist, such as the upfront costs, many energy efficiency projects have a negative cost per ton of CO_2 avoided due to reduced expenditures on fuel or electricity, though this depends on the temporal boundary of cost analysis and the useful life of the particular efficiency measure.[28] Unfortunately, the reliable flows, estimated future stocks, high densities, and low costs of the Southeast's fossil fuel derived energy sources has made it difficult to promote energy conservation and efficiency improvements in the region. Market penetration data for energy efficient products such as Energy Star® appliances are lower-than-average and polling data suggests a weak conservation ethic in the SE.[29] According to the American Council for an Energy Efficient Economy's (ACEEE) 2011 State Energy Efficiency Scorecard, states in the SE consistently rank towards the bottom of the list based on policies promoting energy-efficiency (Figure 12.4).[30] This is illustrated by electric utility energy efficiency program spending per capita in the SE which was just one-fifth the national average as of 2002.[31]



Source: American Council for an Energy Efficient Economy

Figure 12.4. 2011 ACEEE energy efficiency scorecard rankings.

An exception is the ongoing implementation of the October 2009 Presidential Executive Order 13514 on Federal Leadership in Environmental, Energy, and Economic Performance. This order directs federal agencies to reduce greenhouse gas pollution, eliminate waste, improve energy and water performance, and leverage federal purchasing power to support innovation and entrepreneurship in clean energy technologies and environmentally-responsible products.[32] The General Services Administration, along with its Federal Agency Partners is working to implement this order in more than 140 federally owned buildings comprising more than 17 million rentable square feet of space in the southeastern USA.[33]

As another example, some states in the SE have outdated or non-existent energy code policies to govern the energy efficiency of new buildings. This is changing, in part due to a provision of the 2009 American Recovery and Reinvestment Act (ARRA)[34] requiring states receiving ARRA funds to adopt updated energy codes. It should be noted that some states in the SE have already adopted fairly progressive energy codes. According to ACEEE's Scorecard, Georgia ranks fifth in the nation and Florida in the top 15 for both the stringency of their energy codes and energy code compliance efforts. Additionally, in April 2010, the Southeast Energy Efficiency Alliance (SEEA) was granted $20 million in funding from the U.S. Department of Energy Better Buildings Program to "partner with cities in eight southeastern states and the U.S. Virgin Islands to dramatically increase the effectiveness of building energy efficiency improvements across the region."[35]

An upside to these generally low energy efficiency rankings across the SE is the large untapped potential for energy saving gains through cost-effective measures. This was illustrated in a recent study on the effect of implementing key energy efficiency polices in the industrial, residential, and commercial sectors in the SE. The study found that policies promoting process improvements, utility plant upgrades, CHP in the industrial sector, equipment standards and retrofits in the commercial sector, and home energy retrofits, building energy codes, energy-efficient appliances and an expanded residential weatherization allocation program are estimated to save 2,100 trillion BTUs (Tbtu) in 2020 (an 11% reduction in total energy consumption from a reference year of 2010) and 3,376 Tbtu in 2030 (a 16% reduction in total energy consumption from a reference year of 2010). In 2030, these energy savings are estimated to mitigate the emissions of approximately 100 MMt of CO_2. These policies would also have a net positive impact on the economy in the region, generate an estimated 220,000 jobs, avoid $24 billion of utility bills, and save 5 billion gallons of freshwater in 2020.[36] For an example of one important energy efficiency technology that is already being used to some extent in the SE, see the following case study on CHP.[37,38,39,40,41,42,43]

Several southeastern states are leading in specific energy efficiency areas even though the SE as a region is lagging in overall energy-efficiency policies. According to U.S. Green Building Council's 2010 ranking, four of the southeastern states (Florida, Virginia, Georgia and North Carolina) rank in the top 11 of all 50 states for total number of Leadership in Energy and Environmental Design (LEED) projects.[44] Georgia and Virginia are also among the top states in the country for promoting green affordable housing. Their qualified allocation plan (QAP) policy incentivizes energy-efficiency, smart growth, resource conservation and health.[45,46] Organizations in several southeastern states are active in the areas of research, development and demonstration for energy efficiency, including the Florida Solar Energy Center (FSEC), the Florida Energy Systems Consortium (FESC), the North Carolina Solar Center, the Southeast Energy Efficiency Alliance (SEEA), and Southface Institute which conducts research and training on energy efficient housing and communities.

12.3.3 Renewable Portfolio Standards

A Renewable Portfolio Standard (RPS) provides states with a mechanism to increase renewable energy generation using a market-based approach that is administratively efficient. An RPS requires electric utilities and other retail electric providers to supply a specified minimum amount of customer load with electricity from eligible renewable energy sources. The goal of an RPS is to stimulate market and technology development so that renewable energy will eventually be economically competitive with conventional forms of electric power. States create RPS programs because of the energy, environmental (including GHG reductions), and economic benefits of renewable energy and sometimes other clean energy approaches, such as energy efficiency and combined heat and power (CHP).[47]

In the SE NCA Region, only North Carolina, Puerto Rico, and the U.S. Virgin Islands have legally binding RPSs.[48,49,50] Several solar electricity facilities have subsequently been built, including a 17 MW solar farm in Davidson County.[51] Two states (Virginia and Florida) have established renewable portfolio goals and Florida's Public Service Commission has approved inclusion of 110 MW of solar capacity in its ratemaking plan.[52] The remaining southeastern states have not established either a mandatory or voluntary RPS. Additional renewable energy and energy efficiency policies and programs have likewise been established unevenly across SE. Programs such as public benefit funds, net metering and green pricing programs, decoupling policies, energy efficiency resource standards, and various financial incentives vary from state to state.[53]

12.3.4 Carbon Capture and Storage

Carbon capture and storage (CCS) is the process of capturing and storing CO_2 emissions from stationary sources that would otherwise accumulate in the atmosphere. Although currently expensive and in the early stages of development, CCS technologies offer one technological solution to mitigating CO_2 emissions from stationary sources. For example, Mississippi Power's advanced integrated gasification combined cycle power plant being built in Kemper County, Mississippi, will allow an initial capture of 65% of generated CO_2, much of which will be sold for enhanced oil recovery (EOR).[54]

It should be noted that CCS has an associated "energy penalty" defined as the fraction of fuel that must be dedicated to CCS for a fixed quantity of work output. One recent study the energy penalty associated with pulverized coal power plants provided an absolute lower bound for the energy penalty of 11%, with an easily achievable value of 40% and 29% as a "decent target value".[55]

DOE is investigating a variety of cost-effective technological approaches for CCS including geologic carbon storage. Of particular interest is storage in saline formations, oil and gas reservoirs, coal areas that cannot be mined, organic-rich shales, and basalt formations. An example of potential geologic formations for CCS in the SE (deep saline formations) is shown in Figure 12.5.[56]

DOE's Carbon Sequestration Program is comprised of three key elements for CCS technology development and research: (1) Core R&D, (2) Infrastructure, and (3) Global Collaborations. The primary component of the infrastructure element is the Regional Carbon Sequestration Partnerships, a government/academic/industry cooperative effort tasked with characterizing, testing, and developing guidelines for the most suitable technologies, regulations, and infrastructure for CCS in different regions of the United States and several provinces in Canada.

For the NCA SE region, the Southeast Regional Carbon Sequestration Partnership (SECARB), managed by the Southern States Energy Board (SSEB), is the primary Partnership investigating Regional CCS opportunities.[57] SECARB represents a 13-State region (AL, AR, FL, GA, LA, MI, NC, SC, TN, TX, and VA, as well as portions of KY and WV.) The primary goal of SECARB is to develop the necessary framework and infrastructure to conduct field tests of carbon storage technologies and to evaluate options and potential opportunities for the future commercialization of carbon storage in the region. Estimates of storage capacity in the SECARB Region are provided in Table 4.

SECARB is currently designing and operating four small-scale and two large-scale CCS demonstration projects across the Region. In addition, SECARB continues to characterize the region's on- and off-shore geologic storage options, identify barriers and opportunities for the wide-scale construction of CO_2 pipelines to storage areas, enhanced oil recovery, and other commercial uses, monitor Federal and State regulatory and legislative activities, and support local, regional, national, and international education and outreach efforts related to the SECARB and the regional carbon sequestration partnership initiative.

12.3.5 Sustainability Plans

In addition to individual projects aimed at reducing emissions of GHGs from a particular source (such as CCS for a large power plant or switching that plant to fuels with lower carbon intensities per unit of output as energy or goods), many corporations and cities are developing and instituting plans to reduce their overall direct and indirect impact on the environment. Energy efficiency, renewable energy, and GHG emission reductions are frequently central themes in corporate and local government sustainability plans.

Table 4 . Estimates of CO_2 Storage Capacity in the SECARB Region

Estimated Years of Storage						
State	**CO_2 Sources (Million Metric Tons)**	**CO_2 Storage Resource (Million Metric Tons)**				**Years Storage****
	Total	**Oil and Gas**	**Coal and Shale***	**Saline***	**Total**	
AL	80	344	1,944	12,900	15,188	190
AR	35	250	15,675	4,304	20,229	572
FL	143	109	1,275	16,725	18,109	127
GA	90			4,909	4,909	55
KY	94	14	68	400	482	N/A
LA	102	6,781	8,325	139,497	154,603	1,520
MS	34	399	5,400	46,427	52,226	1,546
NC	77			1,352	1,352	18
SC	40			1,995	1,995	49
TN	66			500	500	8
VA	46	10	231	159	400	9
†Federal OffShore		17,754		484,996	502,750	N/A
Total	**807**	**25,661**	**32,918**	**714,164**	**772,743**	

*Low estimates used **Years of CO_2 storage at the current emission rates (State CO_2 storage resource/State annual emissions)

†Includes storage in the Gulf of Mexico off the coast of TX

A number of southeastern cities have also developed sustainability plans to help save energy and reduce their carbon footprint. For example, 186 southeastern mayors have signed on to the U.S. Conference of Mayor's Climate Protection Agreement. Among other things, signatories strive for a 7% reduction in GHG emissions by 2012 (from 1990 levels) through actions ranging from anti-sprawl land-use policies to urban forest restoration projects to public information campaigns.[58]

As another example, ICLEI – Local Governments for Sustainability, is working with more than 50 local governments in the SE to develop GHG emission inventories, set realistic goals for GHG reductions, develop and implement an action plan to achieve those reductions, and measure results.[59] The National Association of Counties, through its Green Government Initiative, is also providing assistance to cities and counties through seminars, best practices, modeling and analytical tools to increase local government plans for reducing GHG emissions.[60] A number of private sector firms are helping governments and businesses get on a path toward more quantifiable and accountable sustainability planning.

Other types of organizations, such as universities, are also engaged in developing and implementing GHG reduction programs. For example, 104 southeastern colleges and universities are signatories to the American College and University Presidents' Climate Commitment (ACUPCC) which works to "eliminate net greenhouse gas emissions from specified campus operations, and to promote the research and educational efforts of higher education to equip society to re-stabilize the earth's climate."[61] Some leaders include the University of Florida (UF),[62] in Gainesville, Florida, and Emory University in Atlanta, Georgia.

In 2006, UF was the first institution in the United States to sign the ACUPCC. Since 2001, UF has required all new buildings and major renovations to meet USGBC LEED [63] certification, increasing the minimum certification threshold to Silver in 2006, and more recently to a minimum of Gold. UF now has 21 USGBC LEED certified buildings including the first Platinum and Gold certified buildings within Florida. In 2009, UF recycled 50% of its waste including construction debris and ambitiously aims for zero waste by 2015. Over 95% of all UF campus outdoor irrigation is supplied by reclaimed water from the university's on-campus treatment plants. UF was also named one of the nation's "Best Workplaces for Commuters" by the U.S. Environmental Protection Agency. Approximately 29% of all UF students, faculty, staff, and visitors travel to campus as pedestrians or bicyclists with another 39% arriving on the public bus system which runs on a 20% biodiesel fuel blend and is partially subsidized by student fees which allows free access to UF card holders. By 2011, UF earned the honor as the top school on the Roberts Environmental Center's sustainability reporting of the top U.S. universities. Other aspects of the UF sustainability vision include research, curriculum, and engagement.

Emory University requires all new buildings to meet USGBC LEED or Energy Star® [64] or equivalent standards; they have an active compost program to reduce the need to transport and landfill food wastes; and they use recycled grease to power on-campus fleet service vehicles. Emory has set a goal of reducing energy usage by the year 2015 (on a square foot basis) by 25 % from a 2005 baseline. As of 2010, their per-square-foot energy use had decreased by over 15%.[65]

Universities are also using creative financing mechanisms such as Green Revolving Funds to promote energy efficiency improvements on campus. One example in the SE is the revolving fund at Georgia Tech which has enabled the school to update physical plant infrastructure including boiler upgrades, efficient lights and variable-speed motors and pumps, and high-efficiency upgrades to chillers.[66]

Additional activities

In addition to the activities discussed above, a number of additional and varied projects are in place and planned throughout the SE to reduce GHG emissions. Southeastern states, for example, currently have 167 active landfill projects under EPA's Landfill Methane Outreach Program (LMOP), a voluntary assistance program that helps to reduce methane emissions from landfills by encouraging the recovery and beneficial use of landfill gas as an energy resource. In addition to the active projects, 131 additional landfills in the SE have been identified as possible candidates for methane capture projects.[67] Other examples include efforts by farmers to convert animal waste to useable energy (16 anaerobic digester systems are currently operating at southeastern commercial livestock farms)[68] and efforts by municipalities, such as Hoover, Alabama, and St. Johns County, Florida, to collect waste grease for conversion to biodiesel.[69,70,71]

12.4 Research Needs and Uncertainties

Some ongoing focus areas for research on GHG mitigation include the following:[72]

- Renewable electricity conversion and delivery systems.
- Renewable fuels formulation and delivery (including storage).
- Efficient and integrated energy systems.
- Strategic energy analysis.
- Carbon capture and storage.
- Vehicle electrification.
- Personal and organizational behavior amongst the diversity of energy consumption end-use sectors.
- Approaches to making substantial investments in ways that do not lead to technology lock-in, given the uncertainties in technology development pathways and future conditions of climate, economic growth, and other factors.

For example, as the country moves from fossil fuels to renewable fuels, such as ethanol/gasoline blends and biodiesel, the resulting changes and impacts of radiative forcing agents need to be examined. Note that EPA has been mandated by the U.S. Congress to evaluate, on a three-year cycle, the current and potential future environmental and resource conservation impacts associated with increased biofuel production and use. The first report is due in 2012.[73]) As another example, the impact of emissions from biomass burning is an important consideration.[74,75,76,77,78,79]

12.5 References

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[1] For purposes of this chapter, the Southeast is comprised of LA, AL, MS, FL, GA, SC, NC, VA, TN, KY, AR, Puerto Rico, and the U.S. Virgin Islands. Unless otherwise note, the statistics presented are focused on the 11 continental states.

[2] U.S. Census Bureau 2011 Population Estimate, State and County Quick Facts. http://quickfacts.census.gov/qfd/index.html

[3] U.S. Census Bureau. 2012 Statistical Abstract, The National Data Book, Puerto Rico and the Island Areas. http://www.census.gov/compendia/statab/cats/puerto_rico_the_island_areas.html

[4] Calculated from State Energy Data System, 1960-2009 Estimates, U.S. Department of Energy, Energy Information Administration. Release Date June 30, 2011. http://www.eia.gov/state/seds/seds-data-complete.cfm

[5] In 2009, EPA issued the Mandatory Reporting of Greenhouse Gases Rule which requires reporting of greenhouse gas (GHG) data and other relevant information from large sources and suppliers of GHGs in the United States. The purpose of the rule is to collect accurate and timely GHG data to inform future policy decisions. Data for the first year of reporting (covering calendar year 2010) is not yet available. For updates, see: http://epa.gov/climatechange/emissions/ghgrulemaking.html

[6] Alabama completed a climate change action plan in 1997 with GHG projections only to 2010 and, so, is not included here.

[7] CO_2e is a measure used to compare the emissions from various greenhouse gases based upon their global warming potential (GWP). The carbon dioxide equivalent for a gas is derived by multiplying the tons of the gas by the associated GWP, thus:
Million metric tons of CO_2e = (million metric tons of a gas) * (GWP of the gas)

[8] http://www.climatestrategies.us/policy_tracker/state/

[9] Note that the trends shown in this table may not be directly comparable from state to state because of state-specific assumptions used in the development of emissions estimates. The source document for each state should be consulted to evaluate these differences.

[10] Strait, Randy et al. Final Arkansas Greenhouse Gas Inventory and Reference Case Projections, 1900-2025. Center for Climate Strategies. October 2008. http://www.arclimatechange.us/ewebeditpro/items/O94F20293.PDF

[11] Strait, Randy et al. Final Florida Greenhouse Gas Inventory and Reference Case Projections, 1900-2025. Center for Climate Strategies. October 2008. http://www.flclimatechange.us/ewebeditpro/items/O12F20490.pdf

[12] Strait, Randy et al. Final Kentucky Greenhouse Gas Inventory and Reference Case Projections, 1900-2025. Center for Climate Strategies. June 2010. http://www.kyclimatechange.us/ewebeditpro/items/O122F24903.pdf

[13] Recommended Mitigation Options for Controlling Greenhouse Gas Emissions; Final Report. Climate Action Plan Advisory Group. October 2008. http://www.ncclimatechange.us/ewebeditpro/items/O120F19990.pdf

[14] Strait, Randy et al. Final Draft South Carolina Greenhouse Gas Inventory and Reference Case Projections, 1900-2020. Center for Climate Strategies. June 2008. http://www.scclimatechange.us/ewebeditpro/items/O60F19091.pdf

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[16] Terrestrial Carbon Pools in Southeast and South-central United States. Fengxiang X. Han & M. John Plodinec & Yi Su & David L. Monts & Zhongpei Li. Climatic Change (2007) 84:191–202. DOI 10.1007/s10584-007-9244-5. Texas data is not included in Tables 2 or 3 since it is outside the NCA Southeast Region.

[17] Kentucky Forum on Carbon Sequestration Through Agriculture and Forestry Management. Kentucky Renewable Energy Consortium. Forum Summary. September 10, 2009. https://louisville.edu/kppc/krec/krec-publications/CarbonForumSummaryweb2012-17-09.pdf

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[22] http://www.faa.gov/airports/planning_capacity/passenger_allcargo_stats/passenger/

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[25] http://southeastdiesel.org/

[26] APU Rebate Program-Final report, Table 2. Actual Results, Tennessee Department of Environment and Conservation Grant 2D-95422009. June 30, 2011.

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13 Climate Adaptations in the Southeastern USA

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Executive Summary

Climate adaptation activities are currently under way around the Southeast (SE). Efforts by local, state, and federal agencies include identification of relevant climate impacts, assessment of significant risks and vulnerabilities, and the creation of partnerships to support planning. In addition to specific projects, adaptive capacity also is being established through monitoring, research, and outreach. This analysis draws on multiple efforts to inventory adaptation in the SE. The authors of this chapter identified few advanced examples of plans and projects that have been implemented. However because of the number of efforts, diversity of groups involved, the mainstreaming of efforts, and the differences in how those efforts disseminated, this review may not fully represent adaptation activity in the SE.

The majority of current efforts are aimed at identification of relevant climate risks and assessment of risk and vulnerability. Coastal areas, where risks of severe storms and sea level rise (SLR) are highly salient, are frequently the focus of attention. Efforts to bring climate change adaptation strategies and methods into mainstream activities often are done through projects that focus on resilience and sustainability. The adaptation process is complex and must

include partnerships for cross-disciplinary coordinated response from many sectors including financial, technical, governance, and social.

In the future, groups move from risk and vulnerability assessments to strategic adaptation planning and implementation, the authors anticipate a shift in activities and information needs that place great emphasis on costs, benefits, and co-benefits of adaptations. As efforts advance, evaluation of adaptation efforts will become important in decision making.

13.1 Introduction

The southeastern USA currently experiences a wide range of climate variability including extreme heat, drought, heavy rain, ice, and tropical storms and hurricanes and related threats such as flooding and wildfires. These events have the potential for losses to life, property, and economic activity. Climate model projections indicate increases in frequency or intensity of these events as well as threats from sea level rise and ocean acidification (Konrad et al. 2012). The multiple regional vulnerabilities to climate change are summarized in Karl et al. (2009) and several sectoral risks are explored in more detail in the noted documents (CCSP 2008; CCSP 2009). Given the existing level of climate variability, human-environment systems in the region are, to varying degrees, already adapted to many forms of climate variability and potential impacts. However, growing population, particularly in the coastal areas, is placing more people and property at risk to hurricanes, SLR, and land subsidence. The associated increases in water demand and periodic droughts already place significant stress on water resources. Projections of increases in the magnitude, frequency, and intensity of many of these familiar threats suggest that they might challenge existing adaptive strategies and could exceed limits of present adaptation efforts or cross over "tipping points" where the state of the system will be altered dramatically and potentially irreversibly (NRC 2011; Konrad et al. 2012, this volume).

This review of climate adaptation programs and activities in the SE begins with an introduction to broad adaptation research questions and then introduces major stresses currently confronting regional adaptation needs. Existing stresses likely will increase the potential negative impacts of future climate changes. This summary picks up from the 2009 National Assessment report (Karl et al. 2009) that included some discussion around adaptation efforts in this region and the nation and provides an overview of recent adaptation activities and example case studies.

Definition of adaptation. Climate adaptation can be defined as the "adjustment in natural or human systems to a new or changing environment that exploits beneficial opportunities or moderates negative effects" (NRC 2010a: 19). Questions that lead to an understanding of the adaptation process initially are descriptive: Who is adapting or not? To what are they adapting? How, when, and why are they adapting? Answers to these questions provide a foundation for further questions including the following:

- How does the understanding of climate change and potential consequences or opportunities motivate a response?
- How do other stresses interact with potential climate impacts and influence adaptation options?

- How do individuals, sectors, groups, and governments differ in their capacity to adapt?
- How are adaptation options being evaluated?
- What are the barriers, constraints, and limits to adaptation and how can they be overcome?

Adaptive responses can vary in several ways, including by what motivates them. Some responses are “anticipatory” or planned in response to real or perceived information about expected climate changes. Other responses are “autonomous” adaptations taken in response to indirect signals such as changes in regulations or markets.

The process of adaptation can be conceptualized as a series of steps moving from developing an understanding of current and future climate changes related to the system of interest, assessing vulnerabilities and risks, evaluating management options, implementing strategies, monitoring outcomes, and reevaluating those analyses and decisions (Figure 13.1). The process generally prescribes multiple iterations to incorporate new information and changing conditions. The emphasis on risk management and identification of opportunities and co-benefits differs among frameworks, but there is good consistency at the conceptual level that this is a critical piece to adaptation (e.g. NRC 2011; NRC 2010b; UKCIP 2011).

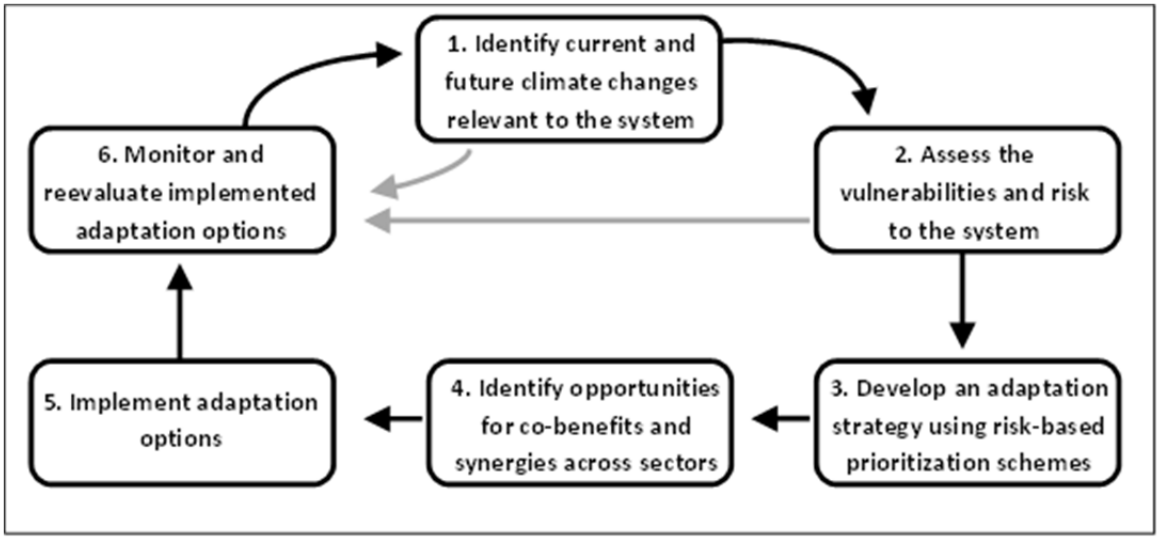

Figure 13.1. Adaptation planning is envisioned as a cyclical, iterative process incorporating these six steps. Source: NRC 2010a.

Practical applications of adaptation rarely proceed in the tidy, sequential manner of a concept diagram such as Figure 13.1. Rather because multiple groups of people are involved steps must be repeated to account for differences in planning schedules, organizational timelines, and priorities. Some activities may be out of step with others at any specific time. Examples of the ongoing processes for these steps are outlined later in this chapter.

While not focused on the southeastern USA, there is a substantial research literature associated with each of these six steps (for example, NRC 2010a). However, because interest in climate adaptation is relatively recent, for each subsequent step in the process, the fraction of empirical work on climate change adaptation becomes substantially thinner and that of conceptual contributions and insights garnered from related or analogous topics swell.

Efforts are ongoing to engage stakeholders of all types in assessing the significance of climate to their areas of interests. Information about stakeholder needs is integral for research projects as well for making decisions about adaptation to climate change effects.

When making risk and vulnerability assessments, researchers and planners need to consider other stresses, such as population growth and land development, which likely will interact with climate change in shaping vulnerabilities. Identification of relevant impacts and analysis of risks and vulnerabilities are important foundations to setting risk-based priorities. In addition, processes for risk-based priority setting and analysis of opportunities for co-benefits frequently require information from socioeconomic scenarios and climate projections as well as institutional and economic analyses. While several studies have considered potential losses to SLR, there is less consideration of economic evaluations of adaptation alternatives (Bin et al. 2011).

Other research addresses the arrows connecting the steps highlighted in Figure 13.1. These projects seek to understand the processes that influence the pace, difficulty, and resources required to move from one step to the next. For example, some of the practical complexity is related to the diversity of actors and sectors working at different social and geographical scales and institutional needs for coordination (NRC 2010a and 2010b). Another significant body of work focuses on understanding the factors that increase the capacity to adapt. These include governance, financial, technological, and social resources, and are sometimes expressed through the creation of networks.

Some prominent strategies emphasize the value of incorporating new adaptation activities and policies into existing planning and management efforts, a process called mainstreaming. Mainstreaming is especially valuable when climate change may exacerbate extant stresses. In the Southeast, mainstreaming might include strategies that address population growth, hurricanes, tropical storms, SLR, land subsidence, and drought. Mainstreaming is often recommended because it offers the option to reduce current risks while increasing preparedness for potential future risks. Benefits also include using existing institutions to avoid duplication of efforts, to increase coordination, and to build on existing support and networks across levels of organizations and governments. Note though, that mainstreaming faces the challenges and limitations of that existing institutions face. The following section provides a brief review of the current climate and related stresses in the Southeast and situates the subsequent discussion of adaptation efforts.

13.2 Major Stresses on the Southeast

The Southeast and Caribbean are vulnerable to a number of direct and indirect impacts from the current range of climate variability and the significant challenges posed by climate change (Karl et al. 2009; Konrad et al. 2012; and also see Chapter 2 of this report). Adaptation is complicated by other changes within the region and internationally, such as population issues, agricultural markets, changes to natural ecosystems, and economic fluctuations. Four major regional challenges facing multiple sectors are discussed in the following paragraphs.

Population growth. The southeastern region's moderate climate has been a population-growth driver since the development of air conditioning (Svart 1976; Graves 1980). The region is vulnerable to rising summer temperatures that will increase energy demand, which is already high during summer months due to demands for residential and commercial cooling (Karl et al. 2009; also see Chapter 2). The population is also at risk to potential spread of disease vectors with changing climate conditions (e.g., Morens and Fauci 2008; Karl et al. 2009; also see Chapter 3).

Residential and business development has typically increased populations in coastal areas and major metropolitan centers (U.S. Census Bureau 2011). These areas are vulnerable to climate change effects, such as sea level rise, droughts, floods, stronger hurricanes, and unstable weather patterns (Karl et al. 2009). Miami, according to one set of climate predictions, ranks internationally as the number one metropolitan area likely to be exposed to coastal flooding by 2070 (Hanson et al. 2011). In the same analysis, New Orleans is ranked number 12 and Virginia Beach number 19. For coastal areas, retreat from SLR may prove difficult. For example, retreat by the City of Satellite Beach, Florida, will be restrained because 98% of the land is developed and there is no room for expansion away from encroaching sea level (Parkinson 2011).

Research on land use planning along the Atlantic coast indicates that many state and local governments already experience high development pressures in low lying coastal areas, which is unlikely to change as coastal regions are desirable locations for residents and businesses (Table 1). In addition, local governments benefit from the higher property taxes of coastal properties, so there is little financial incentive to curtail development.

Table 13.1.

	Likelihood of shore protection High ↔ low						
	Per cent of dry land, by land use type[a]				Area		
State	Developed (%)	Intermediate (%)	Undeveloped (%)	Conservation (%)	Dry land (km^2)	Nontidal Wetlands (km^2)	Tidal Wetlands (km^2)
MA	26	29	22	23	110	24	325
RI	36	11	48	5	8	1	29
CT	80	8	7	5	30	2	74
NY	73	18	4	6	165	10	149
NJ	66	15	12	7	275	172	980
PA	49	21	26	4	24	3	6
DE	27	26	23	24	126	32	357
MD	19	16	56	9	449	122	1116
DC	82	5	14	0	4	0	1
VA	39	22	32	7	365	148	1272

NC	28	14	55	3	1362	3050	1272
SC	28	21	41	10	341	272	2229
GA	27	16	23	34	133	349	1511
FL	65	10	12	13	1286	2125	3213
Total	42	15	33	9	4665	6314	12882

[a] Calculated as the statewide area of a given land use category divided by the area of dry land in the study area. Percentages may not add up to 100% due to rounding. Titus et al. 2009.

Tourism. The economic importance of tourism in the Southeast and the Caribbean complicates adaptation efforts (e.g., Evans 2004; Murley et al. 2005; North Carolina Department of Commerce 2012). In the Gulf Coast region, for example, 8% of jobs are in the tourism and recreation industry. Consequently, public infrastructure and private investment are geared toward a combination of permanent and seasonal populations along the coastline. Such investment increases exposure to losses due to SLR, storm surge, and wind damage from tropical storm systems. Exposure to risk is also increased due to the geomorphic characteristics of the most populated coastal areas. The majority of Atlantic coastline areas that experienced the greatest population increase are historically rapidly shifting and highly dynamic barrier island systems (Culver et al. 2011). The large investment in infrastructure and employment tied to coastal tourism could hinder the ability to adapt rapidly to tipping points and threshold responses in the climate system (Frazier et al. 2010).

Sea-level rise and Land Subsidence. The geomorphic setting and the length of the coastline in the SE and Caribbean mean that SLR is likely to be one of the most immediate, widespread, and potentially damaging impacts of climate change (Thieler and Hammar-Klose 1999; Titus and Richman 2001). Many of the southeastern coastal areas are low in elevation and vulnerable to SLR. Additionally, many areas are prone to land subsidence due to the presence of organic soils and water soluble rock substrates (USGS 2001). Extensive withdrawals of groundwater for drinking and for industrial processes exacerbate hydrologic conditions. Withdrawal of oil and gas promote further subsidence, which enhances the vulnerability to present and future sea level rise. In some cases, subsidence is the primary cause of relative changes between land surface elevation and sea level (Dixon et al. 2006).

Vulnerability to SLR is also enhanced by storm surge from tropical cyclones. As sea level rises, storm surge likely will move further inland along low-lying coastal areas (Mousavi et al. 2011). Many communities along the southeastern coast are built on soils that are highly porous and permeable, which means that hard barriers, such as levees and seawalls, will not be effective because SLR will increase hydrostatic pressure and force water to flow beneath or behind the structures (Parkinson and McCue 2011). Barriers also potentially create a false sense of security that could encourage continued building and place more people and property at risk from events that may exceed infrastructure design as we saw when Hurricane Katrina broke the levees in New Orleans.

Advance warning systems and improved evacuation procedures and infrastructure are crucial for human safety. Under climate change projections, property and infrastructure damages likely will increase substantially, affecting cost and availability of insurance; energy, property; as well as changes in local, state, and federal policies (Irish et al. 2010; Bin et al. 2011; Neumann et al. 2011). Increases in storm intensity as opposed to frequency have been projected by recent climate models (Knutson et al. 2010). Overall storm intensity is projected to increase by 2% to 11% by 2100 and rainfall by roughly 20%. The frequency of intense hurricanes also is expected to increase (Knutson et al. 2010).

Drought and Water Supply. Climate-related issues likely will threaten water supplies in the SE. Many large metropolitan areas depend on surface water supplies to meet potable and industrial water needs. Metro Atlanta obtains 99% of its water from surface sources, primarily from the Chattahoochee River and Lake Lanier (ARC 2011). All of Charlotte-Mecklenburg's public water supply comes from two lakes, Lake Norman and Mountain Island Lake, which are fed by the Catawba River (City of Charlotte 2012). Groundwater resources are also at risk. For example, the Southeast Florida Regional Climate Change Compact includes threats to drinking water supply due to salinity intrusion among its priorities (http://www.southeastfloridaclimatecompact.org/).

Drought conditions exacerbated by climate change likely will affect the reliability of all water sources. In addition regional competition for surface water resources, which has already erupted between Georgia, Florida, and Alabama over water from Lake Lanier and the Apalachicola-Chattahoochee-Flint (ACF) River Basin, may become more problematic (Gibson et al. 2005; Marella and Fanning 2011). The National Integrated Drought Information System (NIDIS) has been working with stakeholders, including state and federal agencies, to pilot a drought early warning system for the ACF basin (NIDIS 2012). Other strategies will need to be developed in the SE to appropriate water fairly and efficiently.

13.3. Adaptation in the Southeast

Adaptation efforts in the SE either focus on the early stages of identifying climate risks relevant to communities, ecosystems, and businesses or on assessing risks and vulnerabilities. Much activity focuses on coastal areas and existing stresses. Despite the review and search efforts undertaken and described in Box 1, we believe that the identified information is an indicative, rather than comprehensive, summary of overall trends in the Southeast.

Box 13.1. Process for Identifying Adaptation Activities in the Southeast

These observations are based on an extensive investigation to identify adaptation activities taking place in the Southeast. The following summary is based on a compilation of adaptation actions identified by the Georgetown Climate Center Adaptation Clearinghouse, (Georgetown Climate Center 2012); the NOAA Coastal Services Center database of Coastal Climate Adaptation/Action Plans (NOAA CSC 2012), case studies in the CAKE database (Climate Adaptation Knowledge Exchange 2012), the Gulf of Mexico Climate Change Adaptation Inventory (NOAA Gulf Coast Services Center 2012), contributions from researchers contributing to the Southeastern Region Technical Input to the National Climate Assessment, and additional research conducted by RISA teams in the Southeast. The types of documents represented included planning documents, government reports, workshop reports, peer-reviewed publications, research reports (not peer reviewed), and website reports.

This body of information represents the triangulation of efforts across the groups of researchers mentioned above. The cases presented represent publicly available information and are likely to under-represent actual adaptive efforts on-going in the region for at least three reasons. First, the documents reviewed are publicly available they likely under represent efforts undertaken by private entities or organizations, such as energy or manufacturing businesses. A second reason is that the cases represented are biased towards planned rather than autonomous forms of adaptation. Finally, reluctance of some groups to publicly engage with the climate change controversies is a potential source of under representing of adaptation activities in the Southeast. Research by CISA (2012 draft in preparation for NCA) indicates that while some entities are undertaking climate adaptation activities, they consciously avoid publicly identifying these activities as adaptation actions in order to avoid political controversy around climate change. Instead, some highlight co-benefits, such as reduction of risks to current hazards, which might build resilience, water efficiency, and energy efficiency.

This review of adaptation activities in the Southeast uses the 6 step process of adaptation (Figure 13.1) as an organizational framework for assessing the current status of efforts. In the figure, the boxes mark a step in the process while the arrows represent the efforts needed to achieve each step. Our assessment provides numerous case study examples of the projects that mark achievement of a step as well as the process-related activities represented by the arrows. In the absence of a significant body of peer-reviewed research or other broad adaptation assessments, case studies are used extensively to illustrate the types of activities taking place. Various efforts are also underway to support the development of adaptive capacity in the region by developing educational outreach programs (Chapter 14), tools, and organizational resources. Along with the case studies are descriptions of a few of the many tools that have been developed by researchers and practitioners that are applicable to the southeast region. This section concludes with short descriptions of some organizations located in the region whose goals include assisting the region to adapt better to a changing climate. The review of tools and organizations is not exhaustive but indicative of the diversity of actors and efforts.

13.3.1 Step1: Identify current and future climate changes relevant to the system

Many entities in the region have recognized that current climate variability and future climate changes will require adaptation planning, although the planning may be in a very early stage or not yet formally underway. A wide variety of entities are involved in organizing conferences, workshops, listening sessions, and other forums for identifying concerns. For example, the National Conference of State Legislatures published a series of reports on potential risks to states, including Georgia, North Carolina, and Tennessee (National Conference of State Legislatures, 2008a; National Conference of State Legislatures, 2008b; National Conference of State Legislatures, 2008c). Listening sessions held along the Albemarle Sound elicited concerns of residents about climate change impacts on culture and livelihoods as well as physical changes (Brown et al. 2010).

Ongoing monitoring together with associated outreach and research efforts by federal agencies such as the National Weather Service, the National Atmospheric and Oceanic Administration, and the United State Geological Survey support the identification of current trends and risks. EPA Region 4 convened a workshop on adaptation in the Southeast which brought together over 200 representatives of federal government; state, tribal, and local governments; academia; the private sector; and nongovernmental organizations (NGOs) in February 2010 (Stratus Consulting, 2010b). Other examples of federal efforts are included in the following sections.

Among the twelve states, Puerto Rico and U.S. Virgin Islands, six have completed climate action plans (The Center for Climate Strategies 2012). Five of the six with climate action plans, Arkansas, Kentucky, North Carolina, South Carolina, and Virginia, have been recommended to start adaptation planning as part of their comprehensive climate action plan (The Center for Climate Strategies 2012). Florida’s climate action plan included a section on adaptation (The Center for Climate Strategies 2012).

An analysis of 48 cities in the Southeast with populations greater than 100,000 found that six of these large cities have also recommended adaptation planning as a part of their climate change plans although those plans were not complete (Morsch 2010; Table 2). These cities included Miami and St. Petersburg, FL; Atlanta, GA; Louisville, KY; New Orleans, LA; and Greensboro, NC. Since the time of that study, Greensboro, NC has integrated climate issues into their sustainability plan (Community Sustainability Council, 2010); Miami is a member of the Southeast Florida Climate Change Compact and has completed a city plan that calls for adaptation planning (Community Sustainability Council, 2010). It is likely that there are other communities whose actions are not yet integrated. For example, the comprehensive plan for Beaufort, SC calls for addressing SLR (Beaufort County South Carolina, 2010).

Table 13.2. Southeastern cities with populations over 100,000 in 2006. Cities in bold, italicized font have climate action plans that recommend adaptation planning. The study region consisted of the states of Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, and Tennessee. (Morsch 2010).

Birmingham,	Fort	Pembroke	Augusta, GA	Shreveport, LA	Winston-

AL	Lauderdale, FL	Pines, FL			Salem, NC
Huntsville, AL	Gainesville, FL	Pompano Beach, FL	Columbus, GA	Jackson, MS	Charleston, SC
Mobile, AL	Hialeah, FL	Port St. Lucie, FL	Savannah, GA	Cary, NC	Columbia, SC
Montgomery, AL	Hollywood, FL	***St. Petersburg, FL***	Lexington, KY	Charlotte, NC	Chattanooga, TN
Little Rock, AR	Jacksonville, FL	Tallahassee, FL	***Louisville, KY***	Durham, NC	Clarksville, TN
Cape Coral, FL	***Miami, FL***	Tampa, FL	Baton Rouge, LA	Fayetteville, NC	Knoxville, TN
Clearwater, FL	Miramar, FL	Athens, GA	Lafayette, LA	***Greensboro, NC***	Memphis, TN
Coral Springs, FL	Orlando, FL	***Atlanta, GA***	***New Orleans, LA***	Raleigh, NC	Nashville, TN

A 2008 survey of experts and decision-makers working in the Florida Keys reported widespread concern about climate-related impacts. At that time only 5% of those surveyed reported that their organization or agency had a climate adaptation plan and less than 1% reported having participated in community discussions, state, or federal climate change initiatives (Mozumder et al. 2011). Since the time of that study, other initiatives, including the Southeast Florida Climate Change Compact (see discussion below) and the Climate Action Plan for Florida Reef (The Nature Conservancy 2010) have increased engagement in this area.

13.2.2 Step 2: Assess the vulnerabilities and risk to the system

Several efforts are underway to conduct risk and vulnerability assessments to inform adaptation processes. Multi-sectoral vulnerability analyses to inform adaptation are underway in Puerto Rico (discussed below) and North Carolina (in Step 4). Many efforts reflect existing pressures on coastal areas and give particular attention to tropical storms and SLR (Stratus Consulting Inc., 2010). Louisiana is updating its Coastal Master Plan to incorporate both planning and action-ready projects that among other things address resilience to rising sea levels 50 years into the future (http://www.coastalmasterplan.louisiana.gov). The Southeast Florida Regional Climate Change Compact addresses water resources and includes a substantial effort to develop a shared regional understanding of local SLR scenarios to underpin developing adaptation plans.

Other efforts include work by government agencies, private sector, and non-governmental organizations. For example, America's Energy Coast, Entergy, and America's Wetland Foundation undertook the development of a framework and a fact base that allowed the quantification of the climate risks for energy infrastructure in the US Gulf Coast. They also developed an economic analysis of the costs to secure/adapt that energy infrastructure (America's Energy Coast 2010). Work by the Department of Defense illustrates a case-based approach designed to inform a broader vulnerability assessment of military facilities in the SE to be conducted in the future. NASA is assessing local risks and vulnerabilities to inform adaptation at five facilities in the Southeast. Both of these federal efforts recognize the substantial facilities along the coast. There are several conservation-oriented efforts including the USGS Southeast Regional Assessment Project, the Florida Reef action plan, the North Carolina Coastal Habitat plan, and the Kentucky wildlife plan (Dalton 2010, The Nature Conservancy 2010, Kentucky Department of Fish and Wildlife Resources 2010, North Carolina Department of Environment and Natural Resources 2010).

The Puerto Rico Coastal Adaptation Project and the Puerto Rico Climate Change Council. *The* Puerto Rico Coastal Adaptation Project, PRCAP, is a two-year effort from 2010 to 2012 that was initiated to collect and synthesize information about climate change risks to Puerto Rico through increasing coordination of efforts and compiling all best available scientific and local knowledge (Programa de Manejo de la Zona Costanera, Departamento de Recursos Naturales y Ambientales 2011). PRCAP is a partnership of the Puerto Rico Department of Natural and Environmental Resources and Coastal Zone Management Division (PRCZMP), and involves more than 130 scientists, planners, practitioners, and communication experts. It is developing a comprehensive climate change vulnerability assessment and recommended adaptation strategies for Puerto Rico. The project supported the establishment of the Puerto Rico Climate Change Council (PRCCC) in November 2010. The PRCCC is working to accurately assess vulnerability of life and property and to identify and assess feasible adaptation strategies for government, the private sector, non-profit organizations, and civil society.

The PRCCC collaboration is working towards the following objectives:

- To use the best available scientific knowledge to identify the communities and ecosystems most at risk from coastal hazards and climate change.
- To identify, assess, develop, and prioritize effective adaptation strategies and policies that could be implemented in Puerto Rico.
- To communicate findings, consensuses, and recommendations to government, civil society, the media, and the private sector.
- To cultivate a well-informed Puerto Rican society about coastal hazards, climate change adaptation, and mitigation.

The PRCCC identified communication and sharing of information as an early priority. Their newly created Puerto Rico Climate Research Library has more than 480 documents related to climate change and the Caribbean and they have established a PR-CC-Listserv for announcements and sharing of relevant publications.

***Southeast Florida Regional Climate Change Compact*.** The Southeast Florida Regional Climate Change Compact (referred to as the Compact) (http://www.southeastfloridaclimatecompact.org/) was signed in 2009 by Broward, Miami-Dade, Palm Beach, and Monroe Counties and is an example of the development of a regional resilience perspective and response to issues of climate concern that will impact the region as a whole and not just a particular county or community. The Compact has four major purposes: (1) to develop a regional cooperative response strategy to climate changes; (2) to encourage federal funding to support regional action plans; (3) to respond to proposed state and federal climate policies and legislation; and (4) to devote resources including staff time to support the development of the Southeast Florida Regional Climate Change Action Plan, including both mitigation and adaptation strategies.

Managing water resources is a primary focus of the Compact and that includes freshwater supply (considering changes in rainfall patterns) and storm water management (especially under the potential for stronger storms). SLR is also a critical stressor for the cooperating counties.

There are numerous successes as a result of the Compact in the areas of governance, policy, planning, and communication, as well as in unified positions on state and federal legislation and appropriations. Also a new amendment to Florida Statues now allows for the creation of “Adaptation Action Areas” where local governments may implement special policies for areas that are particularly vulnerable to SLR and coastal flooding.

Another success was achieved through a series of consultations and technical input resulting in the four cooperating counties agreeing to a unified SLR projection out to 2060 that they will use for planning and communications. They have also established a suggested trend and range of future SLR projections out to 2110 and while these further projections are not being put up for immediate adoption they will provide a sense of future trends for longer term and large scale investments in the region.

The white paper discussing the unified SLR projections can be found online at:
http://www.broward.org/NaturalResources/ClimateChange/Documents/SE%20FL%20Sea%20Level%20Rise%20White%20Paper%20April%202011%20ADA%20FINAL.pdf

Adaptation Efforts by the Department of Defense. The Department of Defense (DoD) recognizes that climate change presents increased challenges for current and future missions, built infrastructure, and natural ecosystems on military lands. The 2010 Quadrennial Defense Review (DoD 2010) states that "…the Department (of Defense) must complete a comprehensive assessment of all installations to assess the potential impacts of climate change on its missions and adapt as required." DoD increasingly is focusing on the need to develop adaptation approaches for identified climate change vulnerabilities and impacts. Several research projects are currently underway on southeastern U.S. installations that will support vulnerability and impact assessment and adaptation planning for climate change. Current adaptation research and planning initiatives for the SE NCA region are administered by the DoD Strategic Environmental Research and Development Program (SERDP). These efforts consider both built and natural infrastructure. More information is available through SERDP (2012), USACE (2010), and U.S. Navy (2012).

Climate Adaptation at NASA Centers in the Southeastern U.S. The National Aeronautics and Space Administration (NASA) is concerned about the possible impacts that climate change will have on NASA Centers across the USA and has many facilities of concern in the SE. As a proactive measure, NASA has implemented a Climate Adaptation and Science Investigation (CASI) wherein each NASA Center is assessing its risk and vulnerability to climate change, and developing adaptation measures and plans for potential climate-induced threats. The five NASA Centers in the SE are: Stennis Space Center (SSC), MS; Kennedy Space Center (KSC), FL; Langley Research Center (LaRC), VA; Wallops Flight Facility WFF), VA; and Marshall Space Flight Center (MSFC), AL. Three of these Centers, KSC, LaRC, and WFF, are located on the Atlantic Ocean; SSC is located very near the Gulf of Mexico. Consequently, the major climate change threats to these Centers are SLR, flooding caused by severe storms (principally hurricanes), and in the case of LaRC and WFF, land subsidence. For each Center, CASI efforts have developed projections for the 2020s, 2050s and 2080s—these projections include average temperature, average precipitation, SLR, SLR under a rapid ice melt scenario, days with maximum temperatures over 90°F and days with minimum temperatures at or below 40°F or 32°F (Rosenzweig and Brown, 2009; Rosenzweig et al, 2011).

Given these projections, each Center is developing plans for implementation of adaptation strategies to mitigate the overall effect of climate change impacts on facilities, property, the workforce and the environment. Personnel at the five Southeast NASA Centers are conducting research under the aegis of CASI that further elucidates the potential impacts that climate change will have on the respective Centers as a foundation for constructing adaptation strategies.

Southeast Regional Assessment Project (SERAP). The Southeast Regional Assessment Project (SERAP) is a prototype for the type of studies that the Department of Interior Climate Science Centers will develop to explore and project ecological responses to climate change and inform natural resource managers on strategies for conserving wildlife and cultural resources. SERAP is working in the southeastern USA in an area that includes all or parts of 15 states. Work began in 2009 and SERAP is scheduled to complete most products during 2012. This section summarizes a report by on SERAP Dalton and Jones (2010).

SERAP takes a multi-disciplinary approach that includes modeling of key physical, ecological, and socio-economic processes to aid the development of robust adaptation strategies. Improving the robustness of decisions is primarily achieved by identifying and quantifying the sources of uncertainty in model projections, and propagating this uncertainty through to the different modeling components. Physical processes that are modeled include local climate change impacts, shoreline change due to SLR, fire frequency, and streamflow conditions. Social and economic changes are simulated by modeling urban growth. Ecological responses are simulated through projections of vegetation dynamics that are used to predict species specific habitat changes through time and models of species distributions for birds, fish, and mussels. The end product for managers will be the development of spatially explicit, conservation strategies that are more robust to a range of future climatic changes.

Downscaled climate projections of temperature and precipitation will be used as inputs to ecological process models. Avian range dynamics are being developed for the entire study area, SLR modeling is focused in the Gulf coast of Alabama, Florida, and Mississippi, and aquatic ecosystem responses will be evaluated in the Apalachicola-Chattahoochee-Flint River Basin in Alabama, Florida, and Georgia. All the assessments will project changes through 2100.

Climate adaptation strategies developed through SERAP will be provided to interested stakeholder groups including federal, state, and local agencies and NGOs. A primary stakeholder is the U.S. Fish and Wildlife Service (USFWS) Landscape Conservation Cooperatives (LCCs). The conservation strategies are being developed through an interactive process with wildlife management agencies and will include a diverse portfolio of actions. The goal is to provide information that can help decision-makers and managers to plan for the potential impacts of climate and landscape changes using strategic habitat conservation and a process of adaptive management.

North Carolina Sea Level Rise Risk Management Study and iRisk Tool for the Integrated Hazard Risk Management. North Carolina has significant vulnerability to SLR. In recognition of this hazard, the North Carolina Office of Geospatial and Technology Management Floodplain Mapping Program received a $5 million grant from FEMA to develop a comprehensive study on climate change effects on risks to built and living systems and to develop science-based mitigation and adaptation strategies that will pro-actively reduce future risk. The NC Sea Level Rise Risk Management Study (SLRRMS) will evaluate the potential changes in coastal flooding hazards due to SLR and changes in storm frequency and intensity on a system-wide basis inclusive of societal and economic impacts. This assessment will include future vulnerability to both temporary and permanent flooding, land loss, and account for dynamic interactions and feedback between receptor systems.

The Integrated Hazard Risk Management (IHRM) program is designed to complement the SLRRMS by helping the public, private sector, and governments (local, state, and federal) manage their risk from natural hazards. IHRM damage assessment methods extend and enhance calculations and data from several commonly used models, including FEMA's HAZUS-MH and benefit-cost analysis. In particular, IHRM focused on collecting asset information for buildings and other critical infrastructure at the parcel or individual asset level. Methods to define qualitative hazard ratings as High, Medium, or Low were defined at both the building level and the county level. Hazard ratings consider risk as well as the individual components of risk: hazard probability, consequences, and vulnerability.

IHRM provides this information through a web-based visualization tool, iRISK, so users can educate themselves about their risk and make informed decisions that will help save lives, decrease property damage, and improve resiliency to natural disasters. Four pilot counties in North Carolina will be the first to demonstrate the revised planning approach and the associated computer-based tools, including Durham, Edgecombe, Macon, and New Hanover.

13.2.3 Step 3: Develop an adaptation strategy using risk-based prioritization schemes. Adaptation efforts furthest advanced in developing and implementing plans are often at smaller scales, individual communities or a system, such as Spartanburg's water system in South Carolina (U.S. Environmental Protection Agency, 2011a). The Hampton Roads area of

Virginia has also undertaken several efforts (see the discussion of Wetlands Watch). These include the communities of Wilmington and Greensboro, NC (Community Sustainability Council 2010; Prete 2010). At the state level, the Florida climate action plan gives explicit consideration to adaptation strategies and options (Governor's Action Team on Energy and Climate Change 2008).

Some research is assessing the value of different types of community engagement for adaptation planning. Broad outreach supported advancing adaptation activities on Bald Island, NC. Frazier et al. (2010) report positive outcomes from using scenarios in a day-long workshop setting. A number of efforts support increasing community resilience to hazards and integrating climate change issues in their guidance. For example, the *Louisiana Coastal Hazard Mitigation Guidebook* suggests strategies that, if implemented, would reduce but not completely eliminate the risks from coastal natural hazards including subsidence and SLR, storm surge, and other flooding (Wilkins et al. 2008). The approaches are designed to address current stresses and to provide additional protection from those hazards. The guidebook also demonstrates methods that communities can use to adopt a flexible approach to hazard planning and include a wide range of attitudes around restricting the use of property when necessary to mitigate hazards.

Lee County, FL has completed a vulnerability assessment that assessed potential impacts of climate stability, sea level, hydrology, geomorphology, natural habitats and species, land use changes, economy, human health, human infrastructure, and variable risk projects with respect to multiple goals, including implementation of a comprehensive plan, perceived current impacts, habitat loss, and proximity in time (Beever et al. 2009). Rankings were used to create a priority matrix for climate change vulnerabilities, which placed alterations to hydrology as the top priority followed by climate variability and changes in storm severity (Beever et al. 2009).

Several regional efforts to develop climate adaptation strategies have been undertaken with significant support from federal agencies. The U.S. Environmental Protection Agency (EPA) and the Federal Emergency Management Agency (FEMA) are partnering to explore the intersection of climate change adaptation and local planning in North Carolina through technical assistance to two coastal communities facing impacts from SLR, more intense coastal storms, and changes in precipitation. New Orleans recovery efforts are increasing the resilience of the city to hurricanes (Natural Resources Defense Council, 2011). Terrebonne Parish, LA has established a plan to develop a strategic decision-making tool to help guide their response to wetlands loss and restoration, including the threats of SLR (Suazo 2010).

Two other efforts were supported by the Climate Ready Estuaries program (described below). In 2008, Charlotte Harbor National Estuary Program (CHEP) collaborated with the City of Punta Gorda, FL to develop a climate change adaptation plan. CHNEP and the Southwest Florida Regional Planning Council also prepared a Southwest Florida Climate Change Vulnerability Assessment (Beever et al. 2009). In order to support the adaptation plan, they are working to develop climate change indicators and a monitoring plan for estuarine systems. Indian River Lagoon NEP and the City of Satellite Beach, FL began collaboration in 2009 on a SLR vulnerability assessment, which helped identify options for reducing risk, planning for adaptation, and educating local decision makers (Parkinson and McCue 2011).

There are also many efforts underway to support the development of adaptation plans, such as assessment of existing regulatory authorities (Silton and Grannis 2010; Farber 2009) and development of methods for decision-making (Julius et al. 2010). These efforts assemble substantial resources from local, private, non-governmental, and federal while synchronizing tasks and decisions that allow the process to move quickly. Several of the following case studies point to the importance and value of building new forms of regional coordination and organizational authority in support of climate adaptation (Sheffer 2010).

Climate Ready Estuaries. The Climate Ready Estuaries program within the US Environmental Protection Agency is a partnership among the National Estuary Programs (NEPs) and other EPA divisions to address climate change in coastal areas. The NEP is a network of voluntary community-based programs focused on the conservation and management of estuaries. NEP is a place-based effort and each NEP has a Management Conference made up of stakeholders including citizens, local, state, and Federal agencies, as well as non-profit and private sector entities. Since 2008, Climate Ready Estuaries has been assisting NEPs and coastal communities in becoming "climate ready" by providing tools and assistance to assess climate change vulnerability and to plan for adaptation. Activities are taking place at the Albemarle-Pamlico Estuary Program (EP), Charlotte Harbor EP, Indian River Lagoon EP, Tampa Bay EP, and the City of Satellite Beach, Florida, in conjunction with an EP in the Southwest region, the Coastal Bend Bays and EP in Texas.

Two programs in particular are strongly oriented to transferring knowledge from these place-based efforts. Sarasota Bay EP developed an adaptation plan that includes public outreach and participation in updates to local comprehensive plans to integrate adaptation measures. Associated research to support this effort includes the use of LiDAR (Light Detection and Ranging) data, the development of a web-based SLR visualization tool, development of a technical report including maps, and a guide with tips and early lessons. In 2011, Tampa Bay EP and Coastal Bend Bays and EP focused on publication and distribution of the “Gulf Coast Community Handbook” for incorporating resiliency into habitat restoration and protection plans to communities around the Gulf of Mexico.

Wetlands Watch, Norfolk, Virginia. Wetlands Watch, a nonprofit environmental advocacy group, based in Norfolk, VA, has been working with local governments on SLR adaptation for five years (Wetlands Watch 2012). Their adaptation work grew out of a session held with the Center for Coastal Resources Management at the Virginia Institute of Marine Sciences, after which they realized the benefits of their conventional wetlands advocacy work would be overwhelmed by SLR impacts to the coastal ecosystem (S. Stiles, personal communication).

In 2007 Wetlands Watch began a campaign focused on making local government long-range planning, floodplain and post-hazard mitigation planning, zoning and ordinance codes, capital improvement funding, and permitting processes to account for SLR. Wetlands Watch has formed partnerships with academic institutions, government agencies, military programs, businesses, and faith communities to address these issues (Wetlands Watch 2012).

Gulf of Mexico Climate Change Adaptation Inventory. The Climate Change Adaptation Inventory is a compilation of climate adaptation activities and research initiatives taking place at the federal, state, and local levels in communities adjacent to the Gulf of Mexico. The inventory focuses specifically on those projects and efforts that address climate change or SLR. Research activities captured by the inventory are limited to those projects that have applications to coastal communities, particularly planning and development, land management, and socioeconomic initiatives. Currently available online as a document with links to a variety of websites and online resources, the inventory will be upgraded to an interactive database so users can input their own adaptation efforts.

The inventory's intended audience includes National Oceanic and Atmospheric Administration (NOAA) staff members and other stakeholders. It is a living document that will be maintained by the NOAA Gulf Coast Services Center. Addenda to listed project information and new project suggestions for the inventory are encouraged (NOAA Gulf Coast Services Center 2011).

Template to Assess Climate Change Impact and Management Options (TACCIMO). Since its creation in 1905, the USDA Forest Service has overseen the care of US public forests and grasslands. That area now exceeds 193 million acres (USDA Forest Service 2009) and 13.1 million acres in the Southern region (the southeastern states considered in this report plus Oklahoma and Texas). The Forest Service has faced many challenges in its 100+ year history and like other federal agencies is now attempting to address the management issues created or amplified by a changing climate with a goal of identifying options to assure ecosystem sustainability (USDA Forest Service 2009).

All National Forests operate under management plans specifically designed for each National Forest. The National Forest Management Act of 1976 requires that all National Forests are managed for multiple uses (NFMA 1976), but each forest has unique challenges and attributes. These goals are called the *desired future conditions* of the forest. Periodically, these management plans are re-evaluated to see if desired future conditions have or should be modified. During the past two years, Forest Service scientists and land planners have collaborated to develop a web-based management and adaptation tool called the Template to Assess Climate Change Impact and Management Options (TACCIMO) is a result of that collaboration (http://www.sgcp.ncsu.edu:8090/, Solomon et al. 2009).

TACCIMO has been parameterized with National Forest Plans for Region 8 (southern region) and can be used for state and private forest use. In the Southern region, the user can select their location (county, state, or region) for an assessment of general climate change impacts and management options. The core of TACCIMO is hundreds of scientifically reviewed papers on climate change impacts and management options. TACCIMO compares the desired future conditions outlined in each forest plan with the cataloged climate change impacts to assess whether various aspects of climate change (e.g., wildfire risk, drought, SLR) could pose a new or enhanced threat to the National Forest desired future conditions. TACCIMO cross references the climate change impacts with cataloged management options to provide land managers with potential choices to minimize negative change. Finally, TACCIMO generates a report that includes the forest plan, potential climate change impacts and management options.

Figure 13.2. Members of the Southeast Natural Resource Leaders Group

Leveraging Federal Programs for Natural Resource Protection in the Albemarle-Pamlico Estuary. Adaptation to climate change along the North Carolina coast is the focus of an interagency pilot project to build resilience into the natural landscape, integrate partnership priorities and leverage existing Federal resources. The project is being directed through the Southeast Natural Resource Leaders Group (SENRLG) (U.S. EPA 2011b). SENRLG is comprised of regional Federal agency leaders across the SE with natural resource mission responsibilities (Figure 13.2). The SENRLG Landscape Conservation and Restoration Pilot Project (LCRPP) identified the Albemarle-Pamlico estuary (Figure 13.3) as the initial location to illustrate the co-benefits of targeting Federal program resources and to outline an innovative approach to address environmental challenges in long-term natural resource protection. The outcomes of the LCRPP are designed to demonstrate that collaborative, on-the-ground climate risk-related conservation, restoration, and resilience-building work produces results that exceed those that could be achieved through individual agency efforts.

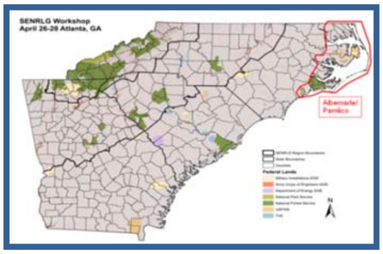

Figure 13.3. Albemarle-Pamlico Estuary.

Public access to the Targeted Resource Implementation Plan (TRIP) and online decision support tools is scheduled for October 2012. The tools will include a web portal to access the documents and a Geographical Information System viewer to access the data used during the project. When complete, the TRIP will do the following:

- Identify a landscape where agencies may collaborate and leverage resources that promote resilience of the landscape and improved capacity to adapt to climate change within the estuary.
- Support collaboration with external stakeholders that obtain co-benefits through targeted funding of restoration and conservation projects.
- Provide a set of performance metrics to evaluate co-benefits of resource accomplishments for on-the-ground work.
- The decision support tools will identify Federal resources available to support locally driven landscape conservation efforts that address climate change adaptation. The TRIP products will be transferable to other internal and external partnerships across the SE.

13.2.4 Step 4: Identify opportunities for co-benefits and synergies across sectors

Many current planning efforts focus on identification of risks and vulnerabilities in order to inform adaptation strategies. Some vulnerability assessment and adaptation planning processes, such as the Puerto Rico example given earlier, are being conducted as one integrated effort. Still, reports of efforts to identify co-benefits and synergies across sectors are sparse. A reef restoration project off the coast of Alabama is one example of implementing an adaptation strategy that provides protection from storm surge and increases habitat (TNC 2010). A guidebook aimed at helping governments assess the economic value of adaptation is available that comments on the potential to incorporate additional societal benefits in cost-benefit analyses, but the treatment is very brief (The Economics of Climate Change Adaptation Working Group, 2009: 51). The North Carolina effort described below illustrates one effort to identify adaptation strategies with broad benefits across sectors.

Using Vulnerability Assessment to Inform Adaptation Strategies. The North Carolina Interagency Leadership Team, (ILT) led by the North Carolina Department of Environment and Natural Resources, assessed North Carolina's vulnerability to the impacts of climate change in order to inform adaptive strategies that will reduce risk and increase resilience to projected future changes. Federal agencies involved include EPA, USACE, NOAA, Federal Highway Administration, and U.S. Fish and Wildlife Service. North Carolina state agencies include Departments of Transportation, Environment and Natural Resources, Commerce, Cultural Resources, and Agriculture and Consumer Services; as well as the Wildlife Resources Commission.

The effort focused on major climate change threats to North Carolina including increased air and water temperatures, inundation from SLR, more frequent and intense heat waves, increased tropical cyclone intensity, and altered rainfall patterns resulting, paradoxically, in more droughts and more floods.

A Climate Change Working Group developed a prototype for climate vulnerability assessments across multiple sectors and statewide and regional scales. Sectors assessed included: Transportation, Natural Ecosystems, Water Resources, Coastal and Marine Resources, Human Health and Welfare, Agriculture and Forestry, Energy Production and Use, Human Social Systems, Land Resources, and Air Quality. This vulnerability assessment phase was critical to inform adaptation responses, within and across sectors and regions of the state.
The NC Climate Adaptation Framework initially focuses on broad overarching strategies that emphasize cross-sector, integrated efforts within three major categories: (1) policy integration and creation; (2) promotion and facilitation of adaptive behaviors; and (3) research and education.

The ILT agencies and their partners are concentrating early efforts on adaptive responses that can make progress within 3 to 5 years. To leverage limited resources, initial strategies will focus on no- or low-cost actions that address multiple or particularly vulnerable systems. Early efforts emphasize "no-regrets" actions that provide multiple benefits and are good to do for reasons beyond climate adaptation.

These strategies provide common themes designed to guide future efforts to prepare for climate impacts across multiple levels – state, regional, or local:

- Collaborate with partners to provide information that informs decisions.
- Promote comprehensive adaptation planning among state agencies.
- Facilitate communication and education to support local, regional, and state planning efforts.
- Refine adaptation strategies as science advances and tools improve.
- Encourage broad collaboration and partnerships to leverage resources.
- Partner with communities to facilitate local climate adaptation efforts.

13.2.5 Steps 5 and 6: Implement, monitor, and re-evaluate implemented adaptation options.

The implementation, monitoring, and regular re-evaluation of adaptation options are steps of adaptive management strategies incorporated into climate adaptation recommendations. The approach is intended to support ongoing social learning in the context of uncertainty. In practice, the process of adaptive management confronts several challenges in application (Gregory et al. 2006) including tolerance for delay during the experiment. One example of applying adaptive management strategies to coastal conservation management that is well documented and advanced is that of the Alligator River National Wildlife Refuge.

Adaptive Management in the Alligator River National Wildlife Refuge. The Alligator River National Wildlife Refuge encompasses about 154,000 acres in the Albemarle-Pamlico Estuary, Dare and Hyde Counties, NC. The US Fish and Wildlife Service (USFWS) and North Carolina Chapter of The Nature Conservancy (TNC) are working together to evaluate the effects of different adaptive management strategies that might contribute to the resilience and stability of wetland ecosystems on areas affected, or likely to be affected, by SLR. Successes would include reductions in the rates of ecosystem change, shoreline erosion, saltwater intrusion, land subsidence, and an increase in the growth and survival of salt-tolerant vegetation.

Adaptation strategies include the following:

- Using oyster reefs to dissipate wave energy, slow currents, and reduce shoreline erosion. Added benefits are that these reefs sequester carbon and provide habitat for a variety of species.
- Using ditch plugs or water control structures equipped with flashboard risers and tide gates to restore the hydrologic regime and prevent saltwater intrusion.
- Planting salt-tolerant vegetation, such as bald cypress and brackish marsh grasses, to enhance future shoreline stability and combat expected biodiversity and habitat loss.

In addition, the project aims to establish migration corridors for species to move inland and upland from low lying areas. TNC and USFWS have already implemented these strategies in several locations. Marl, a calcium carbonate fossil rock, and oyster shell bags have been used to construct oyster reefs to buffer the shoreline, ditch plugs and water control structures have been strategically placed in areas to restore the region back to a sheet flow system, and 40 acres of salt-tolerant vegetation have been planted. Monitoring is underway to track the progress each project. The projects have begun adaptation efforts in other nearby conservation areas, including the Swan Quarter National Wildlife Refuge, and plan to expand efforts to all nine North Carolina Coastal Plain refuges.

13.3 Supporting Adaptive Capacity

The many specific adaptation efforts in the SE are supported more generally by an expanding set of programs and centers that support adaption planning at all stages. The expertise and resources provided by these groups ranges from original research on the climate of the SE, to development of climate datasets, geospatial datasets, and analysis tools, to direct assistance with adaptation planning. Some programs engage with many sectors while others focus on specific needs, such as coasts, forestry, water resources, or conservation. Though not exhaustive, below is a sample list of the existing and developing programs in the region.

Climate Ready Estuaries (www.epa.gov/cre/live.html). Five of the EPA's Climate Ready Estuary Programs are located in the SE USA. The Climate Ready Estuaries program together with the EPA National Estuary Programs works with coastal managers and others: 1) to determine vulnerabilities to climate change; 2) to create and apply adaptation strategies; 3) to interact and educate stakeholders; and 4) to disseminate the lessons learned. The Climate Ready Estuaries website contains information on climate change impacts to various estuary regions, provides resources and tools important to monitor changes, and material to support development of adaptation plans for coastal communities and their related estuaries.

Climate Science Centers *(www.doi.gov/csc/southeast/index.cfm).* Two (southeast and south central) of the newly developing Department of Interior Climate Science Centers will serve the SE/Gulf Coast region of the USA. The mission for all of the Science Centers is to make scientific information, tools, and techniques available to assist wildlife managers and others to anticipate, observe and measure, and adapt to a changing climate.

CSC: Coastal Services Center (www.csc.noaa.gov). The Coastal Services Center (CSC) of NOAA assists local and state organizations responsible for coastal resource management by providing technology, information, management strategies, tools, data, publications, training, and a wide variety of options that address today's complex coastal issues. The CSC offerings support the economic, social, and environmental well being of the coast by linking information, people, and technology.

National Estuarine Research Reserves (NERRs) (www.nerrs.noaa.gov; gulfalliancetraining.org). There are 10 National Estuarine Research Reserves (NERRs) sites in the SE. These reserves are living laboratories to investigate coastal concerns, including climate change and building resilience. The five Gulf Coast NERRs Coastal Training Programs established a partnership in 2007 that addresses adaptation through the framework of the Gulf of Mexico Alliance. This regional collaboration supports adaptation-planning workshops hosted by each Gulf NERR. Intended for local decision-makers, workshops have and will feature regional climate-science experts and highlight local climate efforts.

Regional Integrated Science Assessment (RISA), National Oceanic and Atmospheric Administration (NOAA)

There are three RISA teams serving the SE.

- CISA: Carolinas Integrated Science and Assessments (www.cisa.sc.edu)
  For North and South Carolina, the CISA program focuses on improving the quality, range, relevance, and accessibility of climate information that is used for resource management and other decision-making efforts, particularly related to coastal and water resources, human health and adaptation. In collaboration with regional stakeholders, CISA researchers work to identify and create effective methods of providing climate data, science, and education.
- SCIPP: Southern Climate Impacts Planning Program (www.southernclimate.org)
  The SCIPP focus is on research, education, and tool development around climate change and hazards in the south central USA through interaction with a wide variety of regional efforts. The mission of SCIPP is to build resiliency in the region and increase preparedness for present and future weather extremes. The SCIPP region includes: Oklahoma, Texas, Arkansas, Louisiana, Tennessee, and Mississippi.
- SECC: Southeast Climate Consortium(seclimate.org)
  The Southeast Climate Consortium's mission is to use progress in climate sciences, including improved climate forecast capabilities - both seasonal and long-term climate change - to develop scientifically sound information and tools for decision-making. These tools are for application to a variety of ecosystems in the SE US including: agricultural, forests and other terrestrial ecosystems, and coastal. The most advanced of these decision support systems is AgroClimate (AgroClimate.org), which focuses on the agricultural and forest sectors but also includes climate information at the county level that is valuable to many other sectors.

Sea Grant Programs (www.seagrant.noaa.gov). There are 32 Sea Grant Programs nationwide that address issues and create products and tools for the coastal region of the USA. The Texas, Louisiana, Mississippi/Alabama, and Florida Sea Grant programs have developed individually as well as cooperated on developing a variety of outreach, education, and tools that focus on building resilience in the coastal zone. North and South Carolina Sea Grant programs were the first to place a full time regional climate extension specialist on staff. There are many tools and educational resources developed and in process through the various Sea Grant programs.

13.4 Summary

Adaptation efforts are underway in the SE. Work to understand the relevant climate impacts, to assess the significant risks and vulnerabilities, and to build partnerships and resources to support planning is taking place at all levels – from small communities to NGOs, states, and federal agencies. Many of these groups are supporting broad efforts to build adaptive capacity as well as individual projects. Given the growing numbers and diversity of groups involved, the mainstreaming of adaptation planning, and the rapid advancement of adaptation efforts, this review and the existing catalogs and databases are likely to be incomplete representations of the full scope of effort.

Currently, most efforts aim to identify the relevant climate risks and conduct risk and vulnerability assessments. Coastal areas, where risks of severe storms and SLR are highly visible, are the focus of much of this attention. Many of the efforts are working to mainstream climate adaptation into existing institutions and processes. Partly as a consequence of that mainstreaming approach, adaptation efforts are being conducted under a variety of different names and terminologies, including resilience and sustainability. The adaptation process is much more complex and less linear than conveyed by basic models. Significant effort is going into building necessary partnerships for coordinated response of the authorities and resources.

In the future, as more entities move from risk and vulnerability assessment to strategic adaptation planning and implementation, we anticipate a greater demand for more information on the costs, benefits and co-benefits of adaptations. As efforts advance, support for evaluation of adaptation efforts will need to increase.

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14 Southeast Regional Climate Extension, Outreach, Education, and Training

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Executive Summary

Extension, outreach, education, and training (EOET) programs have been and will continue to be essential in addressing the climate change needs facing the Southeast (SE) United States. This chapter, developed by professionals working in the EOET field as practitioners, provides an introduction and details for planning, delivering, and evaluating climate change programs.

Connecting science to societal problems is a difficult task, especially with respect to the implications that climate change education seeks to change behaviors. From a human behavior perspective, "global warming" implies a cataclysmic ending while "climate change" conveys something more manageable. Both are true and EOET programs must be tailored to fit the desired behavior change whether it is reduction of greenhouse gas emissions or climate adaptation strategies for a coastal community. Using the best available science delivered by credible and trusted educators is critical for successful implementation of mitigation and adaptation strategies.

Because climate change science has become highly politicized in the policy arena and in education, programs must be thoughtfully created to inform without alienating. Often people's willingness to learn depends on attitudes toward an issue and perceived trustworthiness of the information provided through EOET programs as well as trust in the people delivering the programs. Climate scientists and EOET professionals will benefit from collaboration with each other to craft simple, clear, and consistent messages necessary to build trust and encourage behavior changes that result in mitigation of and adaptation to climate change Climate change education has a broad range of goals and achieving them will require a cross-disciplinary approach, combining instruction with education, social, behavioral, and economic sciences as well as earth systems science.

The SE has a strong contingent of EOET professionals familiar with effective program planning and implementation. Though efforts vary among the states, EOET professionals in several states

also conduct,comprehensive program evaluation. Programs for youth and adults in the SE use formal, nonformal, and informal instructional methods. Initial steps have been taken to begin to coordinate existing EOET programs with climate science topics; however, more efforts toward program coordination could be achieved through an updatable directory of climate programs that could increase awareness of climate programs and the audiences, goals, and objectives. New partnerships can be forged among programs and institutions to create programs aimed at improving communications regarding climate change education.

Climate change programs must be designed for specific audiences and should include formal, nonformal, and informal options for all student grade levels. Programs also need to be established for state and local governments, nongovernmental organizations, industry, and the general public. Programs designed to reach specific audiences are more likely to improve climate literacy, adaptation strategies, and/or climate-friendly behavior changes. Existing and nascent climate EOET programs should be inventoried and evaluated against local, regional, and national climate program goals and objectives to determine ways to improve effectiveness and to establish best practices for future EOET programs.

Coordination among federal agencies, nongovernmental organizations, and businesses invested in climate change education will avoid duplicate efforts that waste limited resources. The current EOET programs in the SE have good relationships with target audiences and will be even more effective with increased performance-based funding. Coordination, funding, and open communication between agencies and people across levels are required to build strong climate change education programs in the SE.

14.1 Introduction

A study by Karl et al. (2009) is among the overwhelming number of studies which report that warming of the climate is unequivocal." In addition, the "global warming observed over the past 50 years is due primarily to human-induced emissions of heat-trapping gases." (The human activities causing climate changing gases are complex and are influenced by both psychological (internal), social (external), and physical (external) factors (Carter 1998). Education influences environmental choices and behaviors through internal and external mechanisms (Carter 1998; Coyle 2005; Knowles 1980; Tyson and Hurd 2009). The stabilization of the planetary systems requires a large proportion of the population to change their behavior and support critical mitigation and adaptation policies and regulations. Because the climate issue is complex and long-lived and likely will produce even more impacts in the future, it is critical that human behaviors change and that those changes are sustainable. Research shows that permanent change depends largely upon internal factors such as personal insight, commitment, confidence, a feeling of control, and personal responsibility (Carter 1998). All of these can be built through gaining knowledge about an issue in ways that resonate with a specific audience (Carter 1998, McCright and Dunlap 2011).

According to a recent study by the American Psychological Association (APA 2010), "people's understandings of climate change underlie their willingness to act, and to support public policies, in response." Logically then increasing the public's understanding in a way that personalizes climate change impacts should lead to an increase in willingness to make the necessary changes in behavior and support for mitigation (such as limits on greenhouse gas emissions) and individual, business, and governmental adaptation strategies (). The following are useful in developing programs to educate people about climate and corresponding appropriate action:

1. What are the audience's motivations/attitudes?
2. How will their viewpoints be addressed?
3. What information do people need and for what purposes?
4. Does everyone need or want the same information?
5. How will the target audiences be approached?
6. Who do different audiences trust when delivering information?
7. How will the content be delivered?
8. How will the success of a program be measured?

In other words, public education involves the right information, in the right communication format, at the right time to the right audience.

Research on the various interpretations of and responses to a changing climate has identified six "publics" in the USA (Leiserowitz et al. 2011). They are categorized along a continuum of acceptance of the reality and critical nature of a changing climate. The continuum ranges from those seriously concerned (Alarmed and Concerned), to those who doubt (Doubtful) or completely deny it is occurring (Dismissive). There are two categories of publics in between these extremes: Cautious and Disengaged. The Knowledge of Climate Change Across Global Warming's Six Americas study found a great deal of public uncertainty on the issue of a changing climate. Many members of the identified publics said they needed more information. If such information could be provided it might help "more than a third of Americans . . . change their minds about global warming--especially those in the Disengaged (73%) and Cautious (58%) segments." (Editor's note: Numbers in parentheses refer to the portion of people within the category that changed their mind from one survey to the next.) One explanation for the lack of broad public acceptance of the science around climate change is the failure of scientists to craft simple, clear, and consistent messages and repeat them often (Somerville and Hassol 2011). The excessive detail and unfamiliar language of science communications make it difficult for nonscientists to sort out what is important and relevant to them (Leiserowitz et al. 2011).

Many respondents in the Six Americass study identified a number of specific questions about climate, which include the following:

1. How do the experts know human activities are the problem rather than natural variability?
2. How do they know what they know?
3. What are the likely impacts?
4. What can we do in response?

In addition, many members of the public believe there is still major disagreement among the science community about the reality of climate change. They do not know that 100% of the climatologists believe climate is changing and 97% of publishing climate scientists are convinced that human induced activities are responsible for recently detected climate trends (Shah, 2012).

14.2 A Starting Point for Climate Education: Climate versus Weather

A person who has lived in a single place for many years develops an organic awareness of the local climate, as well as an appreciation for the inherent variability of the climate from year to year. Depending on the region, one may experience combinations of heat and cold waves, droughts and floods, hurricanes, snow and ice storms, severe thunderstorms that tornadoes, and other types of hazardous weather that characterize a region's climate. With time, expectations emerge about the types of weather typical for the various seasons of a year. This composite view, which includes both a sense of what type of weather is typical and an awareness of the variability of weather, is a representation of *climate*.

Climate typically is summarized using simple statistics. Average temperatures and precipitation amounts are most commonly referenced when describing a region's climate. Official averages are based on 30 years of observations. These averages are compiled for daily, monthly, seasonal, and annual time scales. Averages of other weather factors that characterize climate, such as snowfall, wind speed and direction, humidity, frequency of thunderstorms, heavy precipitation events, and other weather events are reported as well.

The climate of any particular place is naturally variable. On average some years are warmer or, some are wetter or drier, and some result in more or fewer storms. Recognizing this inherent variability, climate averages are updated periodically, typically every ten years. If the underlying influences that shape climate are unaltered, then the averages, though they may fluctuate slightly upward or downward, do not indicate a meaningful change in climate.

Climate change refers to a sustained drift in climate averages over an extended period of time. Given the magnitude of noise that reflects the natural variability of climate, the signal of climate change embedded in the drift of climate averages is initially difficult to detect. Drift is difficult to detect because the climate system has enormous momentum, and drift can persist for years or decades or longer. Hence, the initial detection of small, seemingly inconsequential change may reasonably be viewed as a leading indicator of more pronounced change. Current climate change projections suggest that meaningful, perhaps radical impacts on both natural and human systems will become increasingly apparent within the current century.

14.3 Context for Climate Extension, Outreach, Education, and Training

14.3.1 Three Classifications of Education

Understanding classifications of educational methods and the intended audiences are essential to effectively design, deliver, and evaluate climate EOET programs. There are three classifications of education: formal, nonformal, and informal.

- **Formal education** is normally associated with kindergarten through twelfth grade (K-12) and higher education where there is a hierarchically structured, chronologically graded educational system (Coombs 1973).

- **Nonformal education** is any intentional and systematic educational enterprise, usually outside of a traditional school, in which content is adapted to the unique needs of the audiences or unique situations in order to maximize learning (Etllng 1993). Nonformal education is more learner-centered than most formal education. In general, nonformal education has less structure and therefore more flexibility than formal education.
- **Informal education** is the third classification and deals with everyday experiences which are not planned and do not have formal learning objectives (Etllng 1993). The unstructured approach of informal education lends itself well to incidental learning through aquaria, zoos, and other settings with passive learning opportunities.

Adult education often uses nonformal methods, as does youth education is some cases, for example, 4-H programs. Successful implementation of adult education programs requires an effective instructor who understands how adults learn best. Compared with youths, adults have special needs and requirements as learners. Malcom Knowles, who pioneered the field of adult learning using nonformal methods, identified the following characteristics of adult learners:

1. Adults are autonomous and self-directed. They need to be free to direct themselves. Their teachers must actively involve adult participants in the learning process and serve as facilitators for them. Specifically, teachers must get participants' perspectives about what topics to cover and let them work on projects that reflect their interests. Teachers should allow the participants to assume responsibility for presentations and group leadership. Teachers should act as facilitators, guiding participants to their own knowledge rather than supplying them with facts. Finally, teachers should show participants how the education program will allow them reach their goals.
2. Adults have accumulated a foundation of life experiences and knowledge that includes work-related activities, family responsibilities, and previous education. They need to connect learning to this knowledge and experience base. To help them do so, teachers should draw out participants' experience and knowledge relevant to the topic. Teachers must relate theories and concepts to the participants and recognize the value of experience in learning.
3. Adults are goal-oriented. Upon enrolling in an education program, they usually know what goal they want to attain. Adults, therefore, appreciate an educational program that is organized and has clearly defined elements. Instructors must show adult participants how an education program will help them attain their goals. This classification of goals and course objectives must be done early in the course.
4. Adults are relevancy-oriented. They must see a reason for learning something. Learning has to be applicable to their work or other responsibilities to be of value to them. Therefore, instructors must identify objectives for adult participants before the course begins. This need for relevance also means that theories and concepts must be related to a setting familiar to participants. This need can be fulfilled by letting participants choose projects that reflect their own interests.

5. Adults are practical, focusing on the aspects of a lesson most useful to them in their work. They may not be interested in knowledge for its own sake. Instructors should tell participants explicitly how the lesson will be useful to them on the job.
6. As with all learners, adults need to be shown respect. Instructors must acknowledge the wealth of experiences that adult participants bring to an education program. These adults should be treated as equals in experience and knowledge and allowed to voice opinions freely.

Understanding why and how adults learn is a prerequisite to any program for adult audiences described later in this chapter.

14.3.2 Engagement in the Climate Discussion

Organizations that implement EOET programs at the community level will be more effective when they engage constituents and respond to their needs. Sustained community engagement by EOET professionals lays the foundation for climate change discussions with communities. Ultimately, meaningful engagement will lead to planning efforts with desired outcomes to mitigate against and adapt to climate change. The Kellogg Commission's report "Returning to Our Roots: The Engaged Institution" (APLU 1999) includes a seven-part test through which universities and other adult education programs can measure engagement with constituents.

The seven standards to measure constituent engagement are as follows:

1. Responsiveness – Does the organization listen to its constituents and respond to their needs?
2. Respect for Partners – Does the organization understand that it can improve its services and learn from its partners? Does it respect the skills and capacities of its partners in collaborative projects?
3. Intellectual Neutrality – Does the organization's research present data and analysis that informs constituents about important and controversial issues in a factual and timely manner?
4. Accessibility – Does the organization help constituents and partners find appropriate personnel or solutions within the organization? Is the organization's expertise accessible to those who can best utilize it?
5. Integration – In addressing opportunities with its partners, has the organization developed ways of integrating its diverse areas of expertise to address the multi-disciplinary problems of society?
6. Coordination – Is the organization prepared to maximize its internal resources and capabilities? Do the organization's employees understand and appreciate all of the products and services of the organization?
7. Resource Partnerships – Does the organization make a serious effort to partner with other organizations to address the problems of society in the interest of fulfilling its mission and achieving its vision?

14.3.3 EOET and Downscaling of Climate Information

Numerous educational and informational groups have identified the public's need for and request of climate change information (Carter 1998; Culver et al., 2010; Hamilton 2010; National Ocean Council 2012; NOAA 2008a; National Research Council 2011). Requested information includes basic climate literacy, basics of climate change, suggested adaptation options for specific sectors (e.g. farmers, foresters, human health, infrastructure, dwellings), and projections of climate impacts for which communities might need to prepare. The Southern Climate Impacts Planning Program (SCIPP) at Louisiana State University (SCIPP, in press) recently conducted 62 one-hour interviews along the Gulf Coast focused on coastal climate information needs. The number one request from the respondents for what SCIPP could provide to assist participants was climate information applicable to their local areas. SCIPP interprets this as a need to provide climate projections that are down-scaled to be appropriately useful for residents of specific locations in creating mitigation and adaptation strategies. The next most common requests were for instructions on where to find trustworthy climate information and for training on how to interpret climate information products. Climate EOET needs are complex and by necessity will vary with audience. For example, a farmer in central Florida will have different needs than a commercial fisherman in south Louisiana or a beach front community in North Carolina.

14.3.4 Who are the Current Audiences?

Climate EOET programs can and should encompass all audiences. These audiences include internal training for EOET professionals and outreach for K-12 and adult audiences, including focus on the general public, industry, governmental planners, and resources managers.
As part of the process to design effective EOET programs, the four Gulf of Mexico Sea Grant Programs are undertaking a survey to determine climate perceptions of more than 3,000 Gulf of Mexico coastal residents to determine how they perceive climate is affecting community resilience (Goidel and Swann, underway). The results of the survey will be used to refine EOET through the Gulf of Mexico Climate Outreach Community of Practice, which is described further below (Capps et al. 2010). Among other potential applications, these data will be used to establish a climate perception baseline dataset among Gulf of Mexico residents for use with data from qualitative methods to create and implement a community-based social marketing (CBSM) campaign (Pickens, 2002). The CBSM will aide planners in building broad community support for local governments to include climate adaptation strategies in hazard mitigation plans.

In 2010, the Coastal Services Center of the National Oceanic and Atmospheric Administration studied the perceived benefits and barriers in hazard and resiliency planning. The study results are useful in planning climate information needs because some impacts from climate change will be reflected as increased strength or frequency of present hazards (Hamilton, 2010). The initial recommendation called for working with local planners and community leaders to identify specific data and information needs that would help communities organize and take action to adapt to or mitigate climate change impact. For instance, data needs for Gulf coast audience might include maps of projected relative sea level rise overlaying vulnerable infrastructure and neighborhoods.

Another important audience is K-12 teachers and their students. Improving climate literacy in K-12 education programs lays the foundation for long-term improvements in understanding the consequences of individual choices. NOAA (2008a and 2009) defined a climate literate person as someone who has the following expertise:

1. Understands the essential principles of all aspects of the Earth system governing climate patterns.
2. Knows how to gather information about climate and weather, and how to distinguish credible from non-credible scientific sources on the subject.
3. Communicates about climate and climate change in a meaningful way.
4. Makes scientifically informed and responsible decisions regarding climate.

14.3.5 What Is Success and How Should It Be Measured

Climate change education programs must be evaluated in order to be responsive to and useful for individuals, communities, and organizations impacted by climate change. Regardless of the audience (youth or adult) and classification (formal, nonformal, or informal), an evaluation plan is necessary to measure its effectiveness in reaching program goals and objectives (Dick et al. 2011; Friedman 2008). Program assessments should include formative and summative evaluations and when possible a confirmative evaluation, as described in the following paragraphs (Russell and Hellebrandt 1993).

The purpose of formative evaluation is to validate or ensure that the instruction goals are achieved and to improve the instruction through identification and remediation of any problems (Friedman 2008). Instructional content developed for climate education programs should undergo a formative evaluation to determine age-appropriateness and to ensure that the content is valid and reliable. Formative evaluations also used to improve instructor skills and to correct management procedures such as audience accessibility. The return on the instructional investment should be calculated during the formative stage of the program.

Summative evaluations provide information on the program's efficacy and its ability to do what it was designed to do (Dick et al. 2011). Summative evaluations are typically conducted by an external evaluator. A widely used tool for summative evaluation is the pretest/posttest design, which assumes that changes in the audience's reflexive control are due to the instruction. In practice a posttest only design is common, but is only useful with reflexive controls that assume little variation between treatment groups receiving the instruction and the control group not receiving the instruction.

Implementation of adaptation plans, changes in behavior, policy changes, and climate literacy are just a few indicators that might be used to measure the success of climate education programs. Resiliency and adaptation to climate change and ocean acidification, for example, is one of the nine national priorities set forth in the National Ocean Policy (NOP) draft implementation plan (National Ocean Council, 2012). This plan requires the development and implementation of adaptation strategies for coastal communities to reduce vulnerability to sea level rise based on climate change projections and vulnerability assessments. The NOP implementation plan also recognizes the importance of organizations, such as Sea Grant

Extension agents, to translate and communicate the science and adaptation-relevant information to practitioners.

14.3.6 Role of Credible Science in EOET

Joint fact finding (JFF) is a collaborative process that adds insight in solving a problem by including an additional component; local knowledge. JFF refers to a procedure or set of best practices that have evolved over the past decade or so for ensuring that science and politics are appropriately balanced in environmental decision making at the federal, state, and local levels (Karl 2007). Because JFF promotes and improves constituent engagement through shared learning, it helps create knowledge that is technically credible, publicly legitimate, and especially relevant to policy and management decisions. JFF involves people affected by policy decisions in a continual process of generating and analyzing information needed to shape scientific inquiry and to make sense of scientific findings. Local and cultural knowledge as well as expert knowledge are considered relevant components of JFF.

EOET practitioners can help scientists become more comfortable when engaging with constituents through internal training programs that define collaborative JFF, how it works, why scientists should be involved in JFF, and how scientists can effectively contribute to JFF without losing their credibility (Karl 2007; Hinkey 2007). For example, the scientific process frames a question as a test of significant difference between two alternatives. Possible answers through the scientific method can only be that results did or did not differ from the hypothesis tested. The scientific method does not conclude with a "right" answer but with an answer that is either not wrong or different from the proposed answer (hypothesis). The collaborative JFF process asks "*How* do we solve this problem?" Through JFF science, logic, and reasoning are combined to inform solutions and actions rather than just to define a single right or wrong hypothesis.

14.3.7 Trust, Risk, and Credible Science Climate Education and Communication

One definition of risk is the probability or threat of damage, injury, liability, loss, or other negative occurrence that is caused by external or internal vulnerabilities. Risk management can be based on either quantitative or qualitative representations of likelihood and consequence. However, a written, traceable account to sources used to establish quantitative judgments and the rationale behind qualitative judgments must be provided. In order to ensure a transparent, traceable account of recommended actions, it is important to have a guideline that accounts for uncertainty in estimates of the likelihood of various outcomes. Risk management actions typically progress from observation to implementation of mitigation of or adaptation to climate change impacts.

As a tool for risk management and communication, trust is important in judging appropriate conclusions about the acceptability of the hazard and management policies (Siegrist et al. 2007). Judgments of trustworthiness are based on representations of salient value similarities among similar groups. Strategic trust in climate EOET programs has the potential for mutual gains as groups work together to solve a problem. Strategic trust can be defined as “A trusts B to the extent that A will do X; where A is an individual, industry, or planner, B is a scientist, educator, risk communicator, or policy makers, and X is a recommended action or change of behavior (Hardin 1996; Siegrist et al., 2007). Strategic trust is built on experience and goodwill, and reduces transaction costs needed to take action in response to new information.

Education broadens people's perspectives on the world by providing new information to increase knowledge, awareness, skills, and motivation. Increased learning can sharply increase trust through the establishment of a similar value system among EOET professionals and EOET program participants (Uslaner 2002). The average American adult, regardless of age, income, or education, generally does not grasp essential aspects of environmental science, important cause-effect relationships, or concepts such as runoff pollution, power generation and fuel use, or water flow patterns (Coyle, 2005). Moreover, Coyle found, the opinions of 80% of Americans are heavily influenced by incorrect or outdated information and only 12% of Americans can pass a basic quiz on awareness of energy topics.

Social trust refers to willingness to rely on others whose values are compatible with our own main goals (Siegrist et al. 2007). There is no significant correlation between social trust and judged risks and benefits for hazards with which people are familiar, whereas there is strong correlation between these variables with people who have little familiarity of the hazard (Siegrist and Cvetkovich 2000). A mental model proposed by Morgan et al. (2002) suggests that solutions for some risk management problems may be identified by comparing the understanding of a risk among different groups of people, such as the general public, scientific experts, risk managers, and EOET practitioners. The mental model approach offers a method for understanding self-assessed knowledge and how to design EOET programs to correct any gaps or errors in the self-assessed knowledge (Siegrist et al., 2007). Morgan explained further that laypeople rank the degree of risk from a hazard based on how well the risk is distributed across the population, how well an individual can control the risk they face, and whether the risk is assumed to be voluntary or imposed on people without their approval.

14.3.8 Needs Based Content

Effective EOET programs are built around program planning models (Dick et al. 2011), for which audience needs assessment or gap analysis is central. Many state and regional EOET programs have conducted needs assessments and market analysis to identify educational and informational needs (Culver et al.; SCIPP, in press; Capps et al. 2010). One example by Culver et al. (2010) identified an exhaustive list of needs for climate education. Needs relevant to this discussion include the following:

1. Establish climate education inventories that can be used to develop an inventory of plans, lessons learned, and best management practices.
2. Establish a clear vocabulary on climate science that is understandable by disparate audiences.
3. Develop reliable and consistent information to frame messages.
4. Set standards for what a climate-literate citizen should know.
5. Develop transparent and participatory approaches to the selection of materials for educational programs.
6. Support ongoing information clearinghouses.

7. Address gaps in climate change projections with specific education, outreach, extension and training programs.
8. Perform additional socioeconomic impact, risk, and cost-benefit analyses.
9. Sustain mechanisms for regional collaboration.
10. Address issues of scale.
11. Facilitate cooperation among states, federal agencies, and regional associations.

More than half of USA citizens live in a jurisdiction that has enacted a greenhouse gas (GHG) emissions reduction goal (National Research Council 2010). Growing numbers of people and organizations responding to climate change have increased demands for climate information and justify the need for an effective national capacity to respond to climate change. The National Research Council (2010) report, "Informing an Effective Response to Climate Change" identified three key lessons from these GHG reduction experiences:

1. A broad range of tailored information and tools is needed for the diversity of decision makers and to engage new constituencies.
2. Most decision makers will need to make climate choices in the context of other responsibilities, competing priorities, and resource constraints.
3. There is a critical need to coordinate a national response that builds on existing efforts, provides a heuristic approach to successes and failures, reduces burdens on any one region or sector, and ensures the credibility and comprehensiveness of information and policy.

Data from needs assessments conducted with target audiences are used to determine if the identified needs can be solved through EOET program. Needs that can be addressed through an EOET program undergo an instructional design process beginning with instructional goals and desired outcomes, and culminating with a summative evaluation of the instructional strategy used to reach the identified goals. Through the needs assessments that have been conducted (e.g. SCIPP 2012), organizations are implementing instructional programs to present an understandable, acceptable, and effective climate EOET programs to constituents in ways that draws participation from partners and the public. These partnerships include to federal, state, and county agencies as well as academia, nongovernmental, private, and community groups.

14.3.9 State STEM Education Standards

Science, technology, engineering, and mathematics (STEM) initiatives started as a way to promote education in physical sciences so that students would be prepared to study STEM fields in college and pursue STEM-related careers (Jones 2008). Schools with a strong emphasis on STEM education often integrate science, technology, engineering, and mathematics into the entire curriculum. Jones provided five recommendations for strengthening STEM education:

1. Obtain societal support for STEM education.
2. Expose students to STEM careers.
3. Provide ongoing and sustainable STEM professional development.
4. Encourage STEM pre-service teacher training.
5. Recruit and retain STEM teachers.

Though a consensus process, federal agency and nongovernmental organizations concluded that climate is an ideal interdisciplinary theme for education (National Research Council 2011). Incorporating climate change into state education science standards is increasing and provides early evidence of success (National Research Council 2011). To support STEM, the NOAA 2009-2029 Education Strategic Plan (NOAA 2009) recommended an environmentally literate public be supported by a continuum of lifelong formal and informal education and outreach opportunities in ocean, coastal, Great Lakes, weather, and climate sciences.

14.4 Delivery Methods

Program delivery is the mechanism to meet EOET goals and objectives. Organizations providing EOET use various delivery methods to reach their target audiences. This section describes some key delivery mechanisms for EOET (NOAA 2008b; Baker et al. 2001; Etllng 1993).

14.4.1Traditional delivery

Traditional delivery methods such as newsletters, publications, field tours, video, workshops, seminars, symposia, evening meetings, short courses, and formal classes have been extremely effective as an education tool. State Land Grant and Sea Grant Extension programs have historically used these delivery methods for programs since their inception. Designers of these nonformal education programs understand the need to develop delivery methods that are most appropriate for adult and youth learners and adopt methods. For example, Seger (2011) recommended a blend of delivery methods in learning opportunities by mixing new technology with traditional on-site educational activities

14.4.2 Role of Media in Climate Education Delivery

Media in any form provide a powerful tool for climate education. A study conducted by Pew Internet and American Life Project found that, when asked specifically about news habits on a “typical day,” 99% of American adults surveyed said they get news from a local or national print newspaper, a local or national television news broadcast, radio, or the Internet. The Internet has surpassed newspapers and radio in popularity as a news platform and now ranks just behind television (Purcell et al. 2011

Cooperative Extension organizations have identified Internet social media as a diverse online tool for reaching audiences—especially for adult education. Such programs are easily accessible and often provided free through a personal computer, smartphone, or web-enabled television. In 2010, Americans spent 23% of their Internet time using social media (O'Neill et al. 2011). Social media sites, such as Facebook, Twitter, YouTube, Flicker, and Blogger, are popular sources of news and communications. Facebook, for instance, had more than 800 million subscribers in 2011 (O'Neill et al. 2011). The accessibility of social media tools and the ability to share across platforms creates an environment primed for quick and widespread distribution of information (Cornelisse et al. 2011). A social media post theoretically can be spread worldwide and viewed by millions within minutes, if not seconds. The use of social media as a delivery platform for formal and nonformal education programs for adults and youth offers tremendous potential for climate education when programs are based on the best available climate science.

The downside of the explosive growth in the use of social media for education is the low level of credibility of information often provided by such the sites. Credibility of an information source can be evaluated with metrics from the University of Oregon Libraries (http://libweb.uoregon.edu/guides/findarticles/credibility.html):

1. Authority of the author and the publisher: Are they well qualified to speak to the topic at hand?
2. Objectivity of the author.
3. Quality of the work.
4. Coverage of the work.
5. Currency: How recently is the research and publication?

14.5 Program Integration

Many state and local agencies, professional organizations, and other groups in the SE are becoming increasingly aware of the importance and the crucial value of partnerships and program integration. For this chapter program integration is defined as the intra- and interagency integration of scientists and EOET professionals with the public. The National Oceanic Atmospheric Administration (NOAA) Coastal Services Center has created a central hub for information and reports (http://www.csc.noaa.gov/climate/). The Gulf of Mexico Climate Community of Practice (CoP) is another example of collaborative program integration (Capps et al. 2010), which recognizes the value in leveraging the diverse set of assets among federal, state, and local partners when working with local communities to develop and implement climate adaptation strategies. Efforts like these address key impediments to effective delivery of climate education programs such as a tight coupling between science and policy; improved federal, regional, and state coordination; and funding (Culver et al. 2010; National Research Council 2010 and 2011)

14.5.1 Mandates

The America COMPETES Act assigns NOAA responsibility for advancing and coordinating mission-related STEM education and stewardship efforts and for participating in interagency education efforts. At the local level, however, there are few mandates for climate education. Most mandates are driven at the federal level. NOAA 2009-2029 acknowledges that NOAA has a climate education mandate through its climate literacy program.

The National Aeronautics and Space Administration (NASA), NOAA, and the National Science Foundation (NSF) have formed a partnership to streamline climate education into a program that is relevant, recognizable, and effective. With mandates from the U.S. Congress to increase global climate change literacy among educators and students, federal agencies have begun the process of implementing programs and awarding cooperative agreements and grants to further climate science education.

14.6 Barriers to Extension, Outreach, Education, and Training Regarding Climate Change

The National Research Council (2011) identified various barriers to climate change education including the following:

1. Resistance to the behavior change model. Connecting science with society is a difficult task, especially with respect to the implications that climate change education is currently aimed solely at changing people's behavior.
2. Lack of technical support provided at the right time and in the right format to implement mitigation and adaptation strategies.
3. Overcoming distrust of those identified in the Six Americas study as being doubtful, disengaged, or dismissive of climate change (Leiserowitz et al. 2011).
4. The need for a cross-disciplinary approach, blending education with the learning, social, behavioral, and economic sciences as well as earth systems science.
5. The lack of a forum for coordination, cooperation, and alignment of overall education strategies among myriad federal agencies, nongovernmental organizations, and businesses invested in climate change education might duplicate efforts and waste limited resources.
6. Climate change science has become highly politicized in the policy arena and in education institutions in some regions and sectors. Often people's willingness to learn depends on their attitude toward the issue itself (Gardner and Stern 2008; Leiserowitz and Smith 2010).

Cluver et al. (2010) identified the lack of research funding to investigate local impacts, create adaptation plans, and then implement those plans as barriers to EOET at the community level. As a result, Cluver et al. recommended case studies and partnerships with practitioners knowledgeable in developing frameworks to overcome barriers previously identified in. In addition, the inclusion of participants from federal, regional, and local agencies would create broad ownership in the planning process. Finally, a communication strategy and outreach plan was suggested as a way to open doors, engage stakeholders, and obtain funding to implement actions from the plan.

14.7 Ongoing Education, Outreach, Extension and Training Programs

In response to these and other expressed climate EOET needs, many groups within the SE have developed a wide range of education and communication programming, hands-on activities, online tools for decision makers, short and long courses, teacher training, publications, websites, online programs, handouts, topical brochures, and other outreach efforts through a variety of mechanisms. Programs include formal K-12 and university level courses; informal training and topic specific options; options for businesses, such as insurance information; and federally supported programs. This section provides examples of climate education outreach extension and training programs in the SE. These programs were identified during October and November 2011 through an online survey (http://surveymonkey.com/s/climate_education_outreach) that was disseminated to members of the Southeast Regional Technical Report team and other groups known to deliver climate EOET programs. The survey is a step forward in developing and an inventory of these types of services.

Name: Southern Climate Impacts Planning Program (SCIPP)

Description: The Southern Climate Impacts Planning Program (SCIPP) is one of the NOAA RISA (Regional Integrated Science Assessment) programs. The SCIPP focus is on research, education, and tool development around climate change and hazards in the south central United States. The mission of SCIPP is to build resiliency in the region and increase preparedness for present and future weather extremes. SCIPP efforts are aimed at the six states of: Oklahoma, Texas, Arkansas, Louisiana, Tennessee, and Mississippi. SCIPP interacts with a wide variety of regional efforts through working with emergency managers, planners at many levels, community government officials, and other regional stakeholders to support a multi-hazard mitigation planning process. The SCIPP focus includes development of new information, data tools and other planning products, education, and outreach on weather and climate, as well as new research to increase understanding around social vulnerabilities, perceptions of hazards and extreme events, climate variability now and in the future, and information needs. SCIPP offers educational webinars on current issues such as drought and on climate and adaptation issues among others. The tools/data products on the SCIPP website at present include: Southern US drought tool; Average Monthly Temperature and Precipitation tool; Historical Climate Trends tool; Climograph tool; and Historical Gulf Coast surge map.
Web site: http:// www.southernclimate.org
Point of Contact
Lynne Carter
Louisiana State University
lynne@srcc.lsu.edu
(225) 578-8374

Name: Sapelo Island National Estuarine Research Reserve (SINERR) Coastal Training Program
Description: The SINERR Coastal Training Program provides support and information to elected officials and professionals so they can better manage the coastal resources so vital to their economies and way of life. The program responds to individuals, businesses and communities by providing information on topics ranging from waste removal systems to shoreline erosion and shellfish habitat. The program targets the entire coastline of Georgia with partners and collaborators from many agencies and organizations.
Web site: http://www.sapeloislandnerr-ctp.org/
Point of Contact
Suzanne VanParreren
Sapelo Island NERR Coastal Training Program
Suzanne.vanparreren@dnr.state.ga.us
912-485-2251

Name: State Climate Office of North Carolina
Description: The office mission has three components: research, extension, and education. The outreach and education goals are to increase public and professional understanding of climate science, monitoring, and prediction and to build capacity for sectoral professionals to better use climate information and science.
Website: http://nc-climate.ncsu.edu
Point of Contact

Ryan Boyles
State Climate Office of North Carolina
ryan_boyles@ncsu.edu
919-513-2816

Name: Climate Literacy Education and Research
Description: This program combines climate information with information from the natural, built, human and economic sectors and relays this information to decision makers. Rather than one-way web communication, the program starts with outreach and active listening, improves prototypes, and provides true tools to support decision making at a variety of scales.
Website: http://nemac.unca.edu/climate-literacy
Point of Contact
James Fox
University of North Carolina - Asheville's NEMAC
jfox@unca.edu
828-301-2075

Name: Climate Change in the Gulf of Mexico
Description: The program goal is to educate K-16 teachers and informal educators about various aspects of climate change and to explore activities with them that they can use in their classroom or laboratory to help communicate these topics to their students.
Website: http://dhp.disl.org/teachertraining.htm
Point of Contact
Tina Miller-Way
Dauphin Island Sea Lab
tmiller-way@disl.org
251-861-2141

Name: King Tide Photo Documentary Project
Description: This project raises awareness of sea-level rise in the local community through the opportunity to be part of a photo documentary activity. Community members take pictures of areas receiving higher than usual water during the King Tides each year and submit them to on-line sharing websites.
Website: http://www.tbep.org
Point of Contact
Misty Cladas
Tampa Bay Estuary Program
misty@tbep.org
727-893-2765

Name: Gulf Coast Community Handbook, Tampa Bay Estuary Program
Description: This program will develop and distribute a Gulf Coast Community Handbook for incorporating resiliency into habitat restoration and protection plans to communities around the Gulf of Mexico. The Handbook will incorporate “case studies” of habitat restoration

resiliency examples from communities around the Gulf. This effort will contribute to climate change adaptation in the estuary by providing on-the-ground examples of how local communities around the Gulf area incorporating resiliency into habitat restoration and protection strategies, including a summary of best practices.
Website: http:://www.tbep.org
Point of Contact
Lindsay Cross
Tampa Bay Estuary Program
lcross@tbep.org
(727) 893-2765

Name: CHARM--Community Health and Resource Management
Description: Addresses climate adaptation issues through a no-regrets approach of good planning for existing coastal hazards.
Website: http://www.urban-nature.org
Point of Contact
John Jacob
Texas Sea Grant
jjacob@tamu.edu
281-461-6099

Name: Alabama Office of the State Climatologist
Description: The office provides information to legislative, governmental, industrial, agricultural, educational etc. institutions regarding all aspects of climate. The office performs fundamental climate research from local to global aspects, and provides solicited testimony before numerous state legislative bodies, U.S. Congress, Federal Agencies, and Federal Courts regarding climate and climate change issues.
Website: http://vortex.nsstc.uah.edu/aosc/
Point of Contact
John Christy
University of Alabama - Huntsville
christy@nsstc.uah.edu

Name: Tennessee Climatological Service
Description: Although we are not a designated State Climate Office, this outreach effort by three universities (UTK, UTM, and TTU) provides climate data and services to the state of Tennessee.
Website: http://climate.tennessee.edu/
Point of Contact
Joanne Logan
University of Tennessee - Knoxville
loganj@utk.edu
865-974-8803

Name: Kentucky Climate Center
Description: The center serves as the State Climate Office for Kentucky. Our main outreach education and outreach activities include hosting a website with a database for Kentucky's climate, filling individual requests for data and advice regarding climate, and operating a mesonet to support both operational and research needs.
Website: http://www.kyclimate.org
Point of Contact
Stuart Foster
Western Kentucky University
stuart.foster@wku.edu
270-745-5983

Name: Georgia Interfaith Power & Light
Description: The organization’s goal is to educate and engage communities of faith across Georgia with respect to our responsibility as people of faith to care for the planet as well as to communicate the realities of climate change and how we can make a difference.
Website: http://www.gipl.org
Point of Contact
Alexis Chase
Executive Director - GIPL
achase@gipl.org
404-588-9978

Name: Public Water Supply Utilities Climate Impacts Working Group (PWSU-CIWG)
Description: The PWSU-CIWG focuses on making climate science more useable for planning and operational needs related to both the supply of and demand for water. It provides a collaborative forum for public water suppliers, water resource managers, climate, hydrologic and social scientists to promote shared knowledge, data, models, decision-making tools, strategies and adaptations relevant to the dynamic and changing conditions affecting water supply reliability. The working group is interested in opportunities to support the collaborative development of new industry-relevant tools that have been vetted through the academic, public water supply and regulatory communities in Florida.
Website: http://waterinstitute.ufl.edu/workshops_panels/PWSU-CIWG.html
Point of Contact
Lisette Staal
University of Florida Water Institute
lstaal@ufl.edu
352-392-5893 ext 2116

Name: Climate Resilient Communities
Description: The program goal is to help local governments build more resilient communities, through greater resilience of social, enviornmental, and economic systems. The program aggregates and develops information needed for local governments to understand climate change, to understand their vulnerabilities, to identify strategies appropriate for their unique

vulnerabilities and opportunities from a changing climate, to assist them with implementing the actions, and then to assist with monitoring and verifying success.

Website: http://www.icleiusa.org/adaptation

Point of Contact

Brian Holland
ICLEI
brian.holland@iclei.org

Name: Climate Literacy Partnership in the Southeast (CLiPSE)

Description: The goals of CLiPSE are: 1) To improve the understanding of climate science implications in the SE US through respectful dialog, critical thought, and effective communication among and through a vibrant network of leading theologians, agricultural groups, scientists, businesses, outdoor enthusiasts, and educators; and 2. To create an easily searchable database of peer-reviewed, science based, formal education resources matched to state science and math benchmark standards throughout the SE US.

Website: http://www.clipse-project.org

Point of Contact

Julian Carroll
Project Coordinator
Mississippi State University
julian.carroll@cobilan.msstate.edu
662-871-6416

Name: Pine Integrated Network: Education, Mitigation, and Adaptation project (PINEMAP)

Description: This program conducts research, education, and outreach on climate change and pine – both pine adaptations to climate change and using pine to mitigate change. Our education activities include a graduate course, an undergraduate internship program, a secondary project learning tree module, and a host of extension materials and programs to reach SE forest landowners. Each project will have specific objectives, of course.

Website: http://pinemap.org

Point of Contact

Tim Martin
University of Florida
tamartin@ufl.edu
352-846-0866

Name: Center for Coastal Ecology

Description: The center works primarily in outreach to working scientists, agency staff, NGOs, and the general public on Florida-specific issues relating to sea level and sea-level rise.

Point of Contact

Ernest Estevez
Mote Marine Laboratory
estevez@mote.org
9413884441

Name: Gulf of Mexico Climate Community of Practice
Description: The Climate Outreach Community of Practice brings together extension, outreach and education professionals to learn how coastal communities along the Gulf can adapt to sea-level rise and other climate-related issues. Through participation in the community, extension, outreach, and education professionals become better equipped to provide community leaders with reliable information and science-based guidance regarding the level of risk to their communities and strategies they can use to adapt to climate change.
Website: masgc.org/cop
Point of Contact
LaDon Swann
Mississippi-Alabama Sea Grant Consortium
swanndl@auburn.edu
251-438-5690

Name: Southeast Climate Consortium (SECC)
Description: The consortium includes about 70 participating research and extension members from 8 universities and 5 southeastern states. The SECC conducts research and extension to develop and apply climate information in partnership with information users and other education and outreach programs. Target audiences of the SECC currently emphasize agricultural and water resource managers.
Websites: SEClimate.org; AgroClimate.org
Point of Contact: Keith T. Ingram
SECC, Agricultural and Biological Engineering Department, University of Florida
ktingram@ufl.edu
352-392-1864 x 283

Name: Climate Variability and Change Focus Group (CVCFG)
Description: Within the Institute of Food and Agricultural Sciences of the University of Florida, the CVCFG coordinates climate extension activities of the Cooperative Extension Services for the State of Florida. The overall objective of the CVCFG is to prepare Floridians to face the challenges posed by climate variability and change by increasing relevant knowledge and motivation of citizens, professionals, and agency personnel to collaborate on the development of solutions and take actions that reduce impacts on Florida's natural and build environment.
Point of Contact: William Sheftall
Leon County Extension Service, University of Florida
sheftall@ufl.edu
850-606-5202

Name: Climate Change and Animal Agriculture in the Southeast
Description: This integrated extension and research program is part of a national effort that aims to understand the interactions between climate and animal agriculture in the SE and to provide support to extension agents in the development of materials and programs to inform

producers, particularly for cattle, swine, and poultry, how they can adapt to and mitigate climate change.
Point of Contact: Mark Risse
Biological and Agricultural Engineering Department, University of Georgia
mrisse@engr.uga.edu
706-542-9067

Name: Climate Literacy for Agriculture in the Southeast
Description: This project works in partnership with other complementary projects in the SE to improve climate literacy, particularly for corn growers, through workshops, farm trials, field days, and other events.
Point of Contact: Clyde Fraisse
Agricultural and Biological Engineering Department, University of Florida
cfraisse@ufl.edu
352-392-1864 x 239

14.8 CONCLUSIONS

Climate Extension, outreach, education and training (EOET) programs have been and will continue to be essential in addressing the climate change needs facing the SE region of the United States. EOET program design, delivery, and evaluation must be tailored to the audience needs, whether through formal, nonformal, or informal programs for K-12 education, higher education, state or local governments, or for the general public. Targeted programs are essential to reach the desired program goals or outcomes including improving climate literacy, adaptation strategies, or climate-friendly behavior changes. Existing and nascent climate EOET programs should be inventoried and evaluated against local, regional and national climate program goals and objectives to determine ways to improve their effectiveness and establish best practices for future EOET programs. Inadequate funding is always an issue, regardless of the type of EOET program. In the absence of increased funding better integration among existing climate EOET programs and sponsors of climate education should encourage.

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