17. Southeast and the Caribbean

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Key Messages

1. **Sea level rise poses widespread and continuing threats to both natural and built environments, as well as the regional economy.**
2. **Rising temperatures and the associated increase in frequency, intensity, and duration of extreme heat events will affect public health, natural and built environments, energy, agriculture, and forestry.**
3. **Decreased water availability, exacerbated by population growth and land-use change, will continue to increase competition for water and impact the region's economy and unique ecosystems.**

Introduction

The Southeastern region is exceptionally vulnerable to sea level rise, extreme heat events, and decreased water availability. The spatial distribution of these impacts and vulnerabilities is uneven, since the region encompasses a wide range of natural-system types, from the Appalachian Mountains to the coastal plains. It is also home to more than 80 million people, and draws hundreds of million visitors every year (U.S. Census Bureau 2010) .

The region has one of the most populous metropolitan areas in the country (Miami) and four of the ten fastest-growing such areas (U.S. Census Bureau 2010). Three of these (Palm Coast, FL, Cape Coral-Fort Meyers, FL, and Myrtle Beach area, SC) are along the coast and vulnerable to sea level rise and storm surge.

The Gulf and Atlantic coasts are major producers of seafood and home to seven major ports (Ingram et al. 2012) that are also vulnerable. The Southeast is a major energy producer of coal, crude oil, and natural gas, and the highest energy user of any of the National Climate Assessment regions (Ingram et al. 2012).

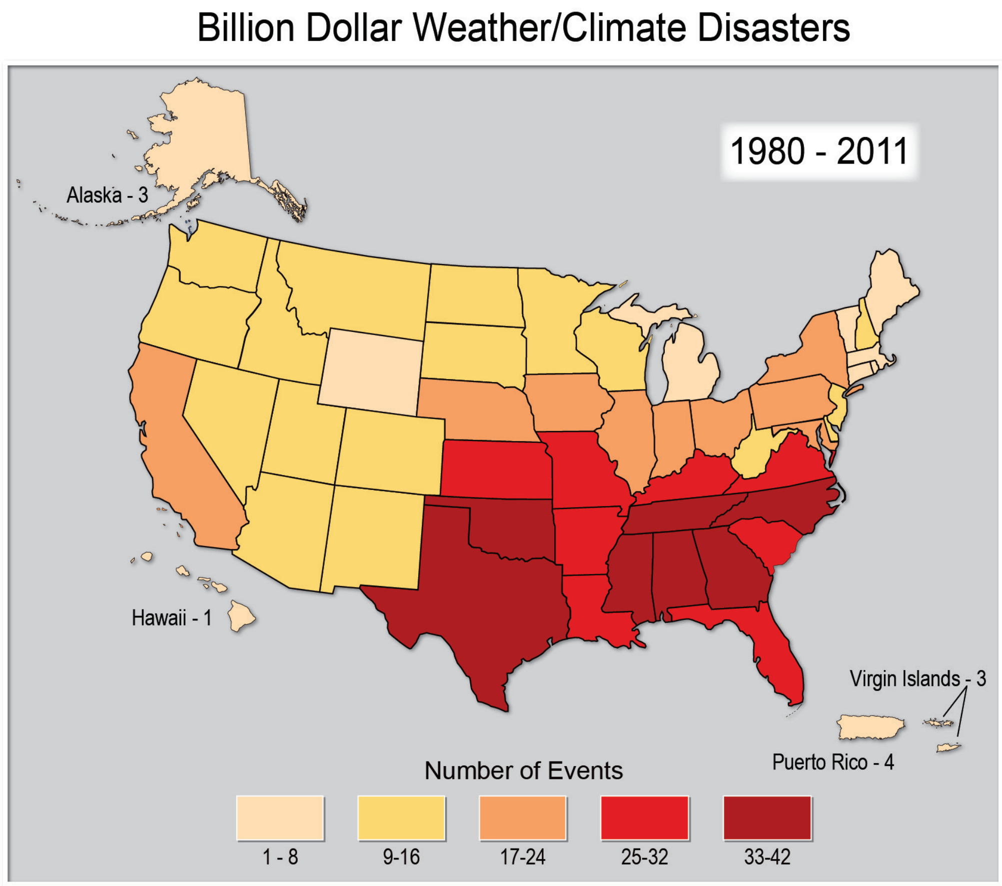


Figure 17.1: Billion Dollar Weather/Climate Disasters 1980-2011.

Caption: This map summarizes the number of weather and climate disasters over the past 30 years that have resulted in more than a billion dollars in damages. The Southeast has experienced more billion-dollar disasters than any other region.

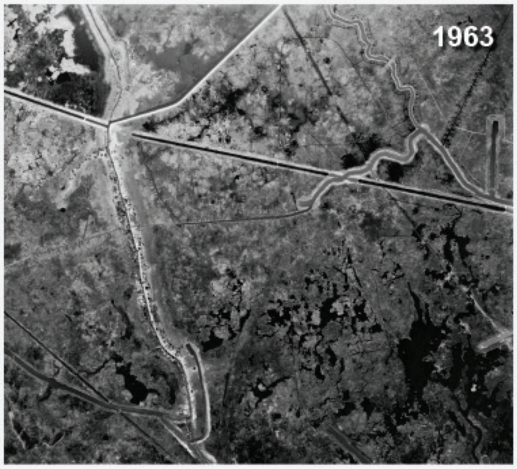
http://www.ncdc.noaa.gov/billions/Population Distribution and Change: 2000 to 2010, summary statistics

The Southeast's climate is influenced by many factors, including latitude, topography, and proximity to large bodies of water like the Atlantic Ocean and the Gulf of Mexico. Temperatures generally decrease northward and into mountain areas, while precipitation decreases with distance from the Gulf and Atlantic coasts. Its climate also varies considerably over seasons, years, and decades, largely due to natural cycles such as the El Niño-Southern Oscillation (ENSO, periodic changes in ocean surface temperatures in the Tropical Pacific Ocean), the semi-permanent high pressure system over Bermuda, differences in atmospheric pressure among key areas of the globe, and land-falling tropical weather systems (Katz et al. 2003; Kunkel et al. 2006; Kutzman and Scanlon 2007; Li et al. 2011; Misra et al. 2011). These cycles contribute to occurrences of droughts, flooding, freezing winters, hurricane wind damage, and property damage from tornadoes.

Box: Stories of Change: Coastal Louisiana Tribal Communities

Four Native Communities in Southeast Louisiana (Grand Bayou Village, Grand Caillou/Dulac, Isle de Jean Charles, and Pointe-au-Chien) have already experienced land loss from river management that has deprived the coastal wetlands of the freshwater and sediment that it needs to survive. As a result of this and other natural and man-made problems, Louisiana has lost 1,880 square miles of land in the last 80 years (Louisiana's 2012 Coastal Master Plan). Numerous other impacts from increases in temperature, sea level rise, land loss, erosion, subsidence, and salt-water intrusion amplify this main problem. This combination of changes has resulted in a cascade of losses of sacred places, healing plants, habitat for important wildlife (such as eagles), food security (from lack of land and water to grow food), and of connectivity with the mainland. Additional impacts include increased inundation of native lands, further travel to reach fishing grounds, reduced connections among family members as their lands have become more flood-prone, and declining community cohesiveness as heat requires more indoor time (Coastal Louisiana Tribal Communities 2012).

Isle de Jean Charles



1963 aerial photograph of Isle de Jean Charles, LA - not retouched or recolored. Island Road, the lone roadway that leads to the narrow Isle de Jean Charles, was built ten years prior to this photograph. Families have lived on the ridge of higher ground since the 19th century, but in this photo a significant amount of marsh still remains.

2008 aerial photograph of Isle de Jean Charles, LA. By the time this image was taken, Louisiana and the surrounding Gulf Coast had been pummeled by four major Hurricanes- Katrina, Rita, Ike and Gustav. With marshland weakened by the loss of water and sediment, development, canals, erosion, and higher sea levels, the storms surged further inland. The Terrebonne Basin didn't bear the brunt of these storms, but it still experienced damage with little time to recover between the disasters.

Figure 17.2

Photos courtesy of USGS.

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Observed and Projected Climate Change

Average annual temperature during the last century across the Southeast cycled between warm and cool periods (see figure below, black line), with a warm peak occurring during the 1930s and 40s followed by a cool period in the 60s and 70s, and warming again from 1970 to the present by an average of 2°F, with more warming on average during summer months. There have been increasing numbers of days above 95°F and nights above 75°F, and decreasing numbers of extremely cold days since 1970 (Kunkel et al. 2012). Daily and five-day rainfall intensities have also increased (Ingram et al. 2012), as summers have been either increasingly dry or extremely wet (Kunkel et al. 2012). Better reporting of major tornados makes it appear that they have increased over the last 50 years; however there has been no actual statistically significant trend (Verbout et al. 2006). The number of Atlantic-basin hurricanes has increased slightly during the last 130 years, and Category 4 and 5 hurricanes have increased since the 1970s (Knutson et al. 2010; Ch. 2: Our Changing Climate; Key Message 8). This can be attributed to both natural variability and climate change.

Southeast Temperature: Observed and Projected

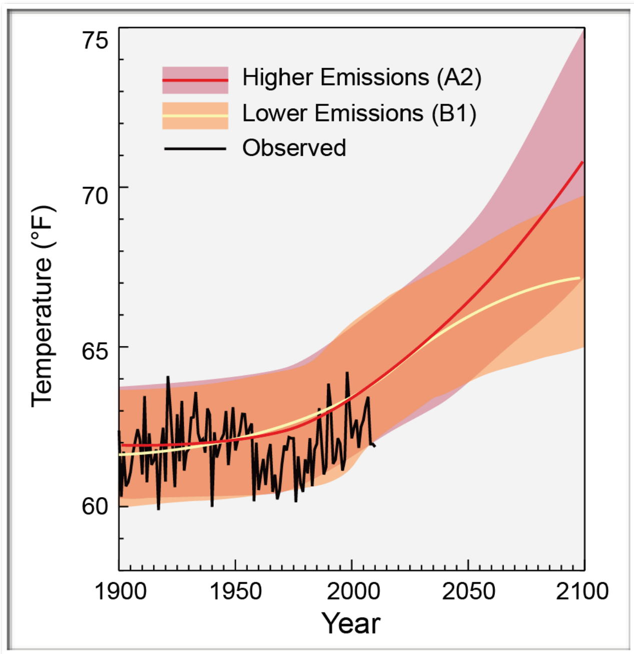

Figure 17.3: Southeast Temperature: Observed and Projected

Caption: Observed annual average temperature for the Southeast (black) and projected assuming substantial emissions reductions (lower emissions, B1) and assuming continued growth in emissions (higher emissions, A2) (Kunkel et al. 2012). For each emissions scenario, shading shows the range of projections and the line shows a central estimate.

Temperatures across the Southeast are expected to increase during this century, fluctuating over time because of natural climate variability (annually and decade-to-decade) (Ch. 2: Our Changing Climate, Key Message 3). Major consequences of warming include significant increases in the number of hot days (95°F) and decreases in freezing events. Projections for the region by 2100 include increases of 10°F for interior states of the region, 2°F to 4°F for the Caribbean, and a regional average range of 2°F to 6°F (Kunkel et al. 2012).

Projections of future precipitation patterns are less certain than projections for temperature increases (Kunkel et al. 2012). Average changes in annual precipitation under a higher emissions scenario (A2) by later this century range from a nearly 10% reduction in the far southern and western portions of the region – with most of that reduction in the summer – to about 5% increases in the northeastern part of the region (Kunkel et al. 2012);(Ch. 2: Our Changing Climate, Key Message 5). Projections further suggest that warming will cause tropical storms to be fewer in number globally, but stronger in force, with more category 4 and 5 storms (Knutson et al. 2010).

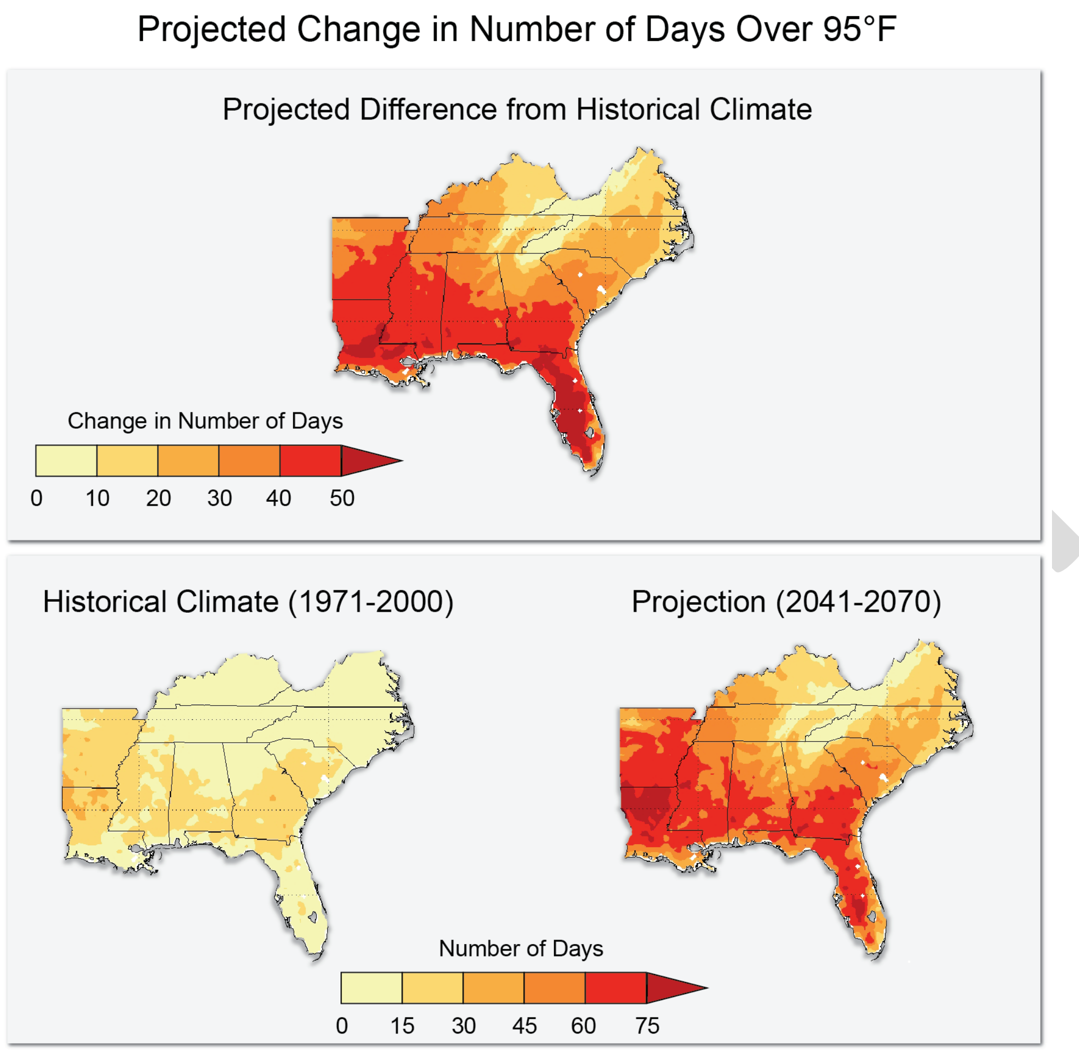

Figure 17.4: Projected Days Over 95°F

Caption: Projected number of days per year with maximum temperatures above 95°F for 2041-2070 compared to 1971-2000, assuming emissions continue to grow (A2 scenario) (Kunkel et al. 2012).

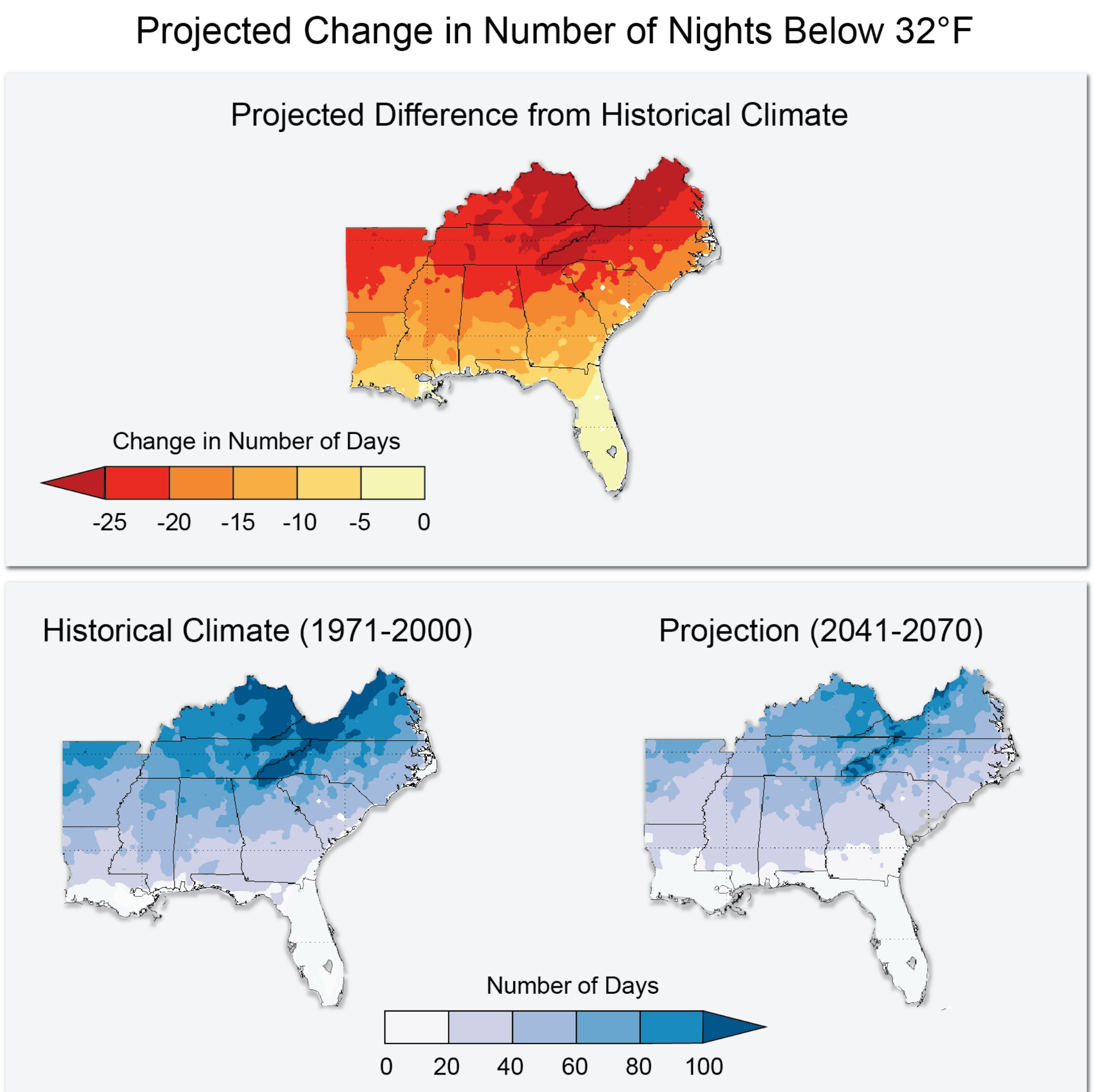

Figure 17.5: Projected Nights Below 32°F

Caption: Projected annual number of days with temperatures less that 32°F for 2041-2070 compared to 1971-2000, assuming emissions continue to grow (A2 scenario). (Kunkel et al. 2012).

Sea Level Rise Threats

Sea level rise poses widespread and continuing threats to both natural and built environments, as well as the regional economy.

Global sea level rise over the 20th century averaged approximately eight inches (Karl et al. 2009; Mitchum 2011; Ch. 2: Our Changing Climate; Key Message 9), and that rate is expected to accelerate through the end of this century (Parris et al. 2012). Portions of the Southeast are highly vulnerable to sea level rise, although how much sea level rise is experienced in any particular place depends on whether and how much the local land is sinking (also called subsidence) or rising, and changes in offshore currents (Sallenger et al. 2012).

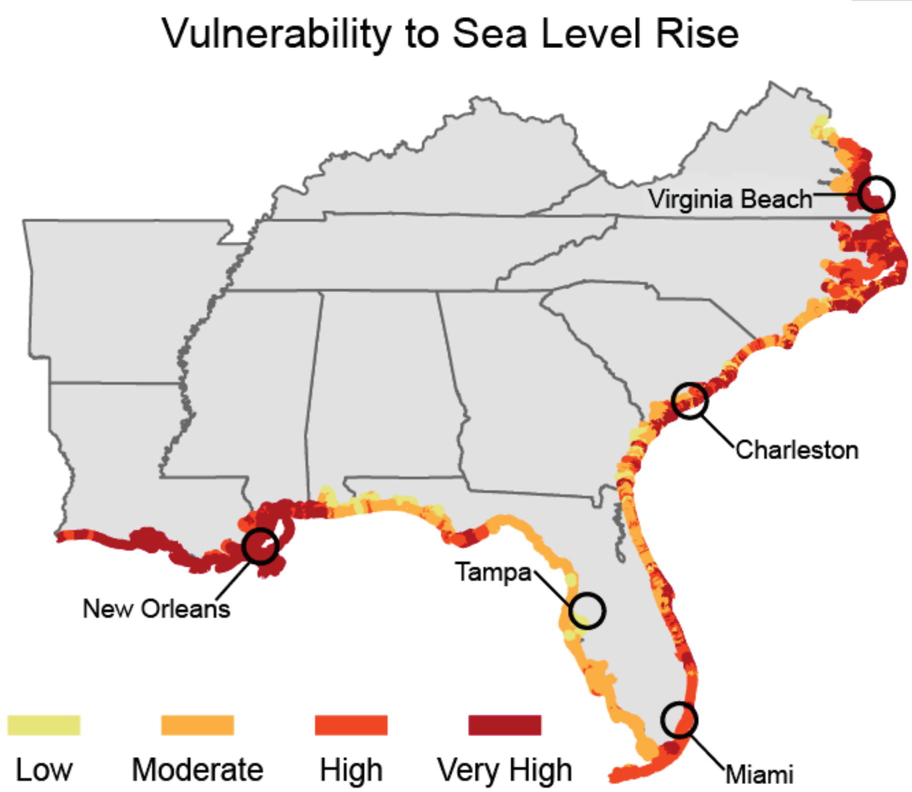

Figure 17.6: Vulnerability to Sea Level Rise

Caption: The map shows the relative risk that physical changes will occur as sea level rises. The Coastal Vulnerability Index used here is calculated based on tidal range, wave height, coastal slope, shoreline change, landform and processes, and historical rate of relative sea level rise. The approach combines a coastal system's susceptibility to change with its natural ability to adapt to changing environmental conditions, and yields a relative measure of the system's natural vulnerability to the effects of sea level rise (Hammar-Klose and Thieler 2001).

Large numbers of cities, roads, railways, ports, airports, oil and gas facilities, and water supplies are at low elevations and potentially vulnerable to the impacts of sea level rise. Major cities like

New Orleans, with roughly half of its population living below sea level (Campanella 2010), Miami, Tampa, Charleston, Virginia Beach, and San Juan, Puerto Rico are among those most at risk (Strauss et al. 2012). According to a recent study by the regional utility, Entergy, coastal counties and parishes in Alabama, Mississippi, Louisiana, and Texas, with a population of approximately 12 million, assets of about $2 trillion, and producers of $634 billion in annual GDP, already face significant losses that annually average $14 billion from hurricane winds, land subsidence, and sea level rise. Future losses for the 2030 timeframe could reach $18 billion (with no sea level rise or change in hurricane wind speed) to $23 billion (with nearly 3% increase in hurricane wind speed and just under 6 inches of sea level rise). Approximately 50% of the increase in the estimated losses is related to climate change. Entergy identified $7 billion in cost-effective adaptation investments that could reduce the 2030 losses by about 30% (Entergy et al. 2010).

The North Carolina Department of Transportation is raising the roadbed of U.S. Highway 64 by four feet, which includes 18 inches to allow for higher future sea levels (Devens 2012; Henderson 2011; Titus 2002). Louisiana State Highway 1, heavily used for delivering critical oil and gas resources from Port Fourchon, is “literally sinking” and now increasingly floods during high tides and low-level storms (Louisiana Department of Transportation and Development ; Louisiana’s 2012 Coastal Master Plan 2012). The Department of Homeland Security (July 2011) estimated that a 90-day shutdown of this road would cost the nation $7.8 billion.

Highway 1 to Port Fourchon:
Vulnerability of a Critical Link for U.S. Oil

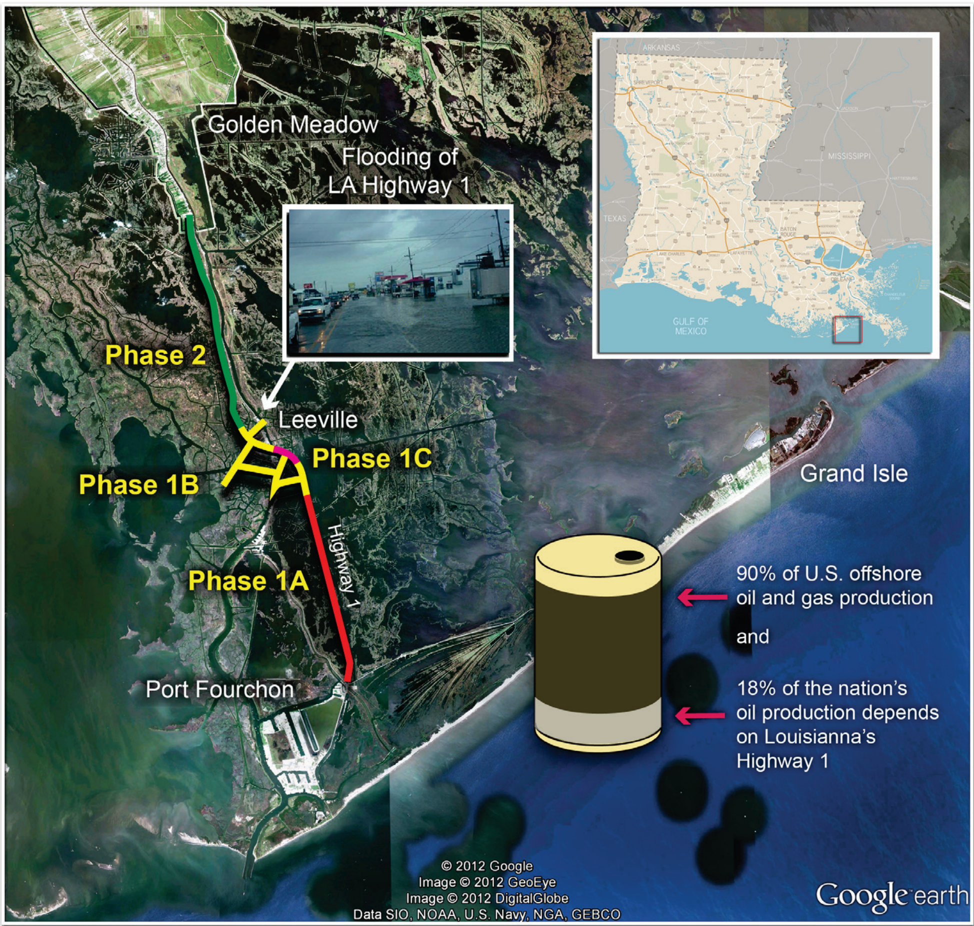

Figure 17.7: Highway 1 to Port Fourchon: Vulnerability of a Critical Link for U.S. Oil

Caption: Highway 1 in southern Louisiana is the only road to Port Fourchon, whose infrastructure supports 18% of the nation's oil and 90% of the nation's offshore oil and gas production. Flooding is becoming more common on Highway 1 in Leeville, (photo from flooding in 2004) on the way to Port Fourchon.

(Sources: Louisiana Department of Transportation and Development ; Louisiana's 2012 Coastal Master Plan 2012)

Sea level rise increases pressure on utilities, water, and energy, for example, by contaminating potential freshwater supplies with salt water, and such problems are amplified during extreme dry events with little run-off. Although uncertainties in the scale, timing, and location of climate change impacts can make decision-making difficult, response strategies can be effective with early planning. Some utilities in the region are already taking sea level rise into account in the construction of new facilities and are seeking to diversify their water sources (Heimlich et al. 2009).

As temperatures and sea levels increase, changes in marine and coastal systems are expected to affect the potential for energy resource development in coastal zones and the outer continental shelf. Oil and gas production infrastructure in embayments that are protected by barrier islands, for example, are likely to become increasingly vulnerable to storm surge as sea level rises and barrier islands deteriorate along the central Gulf coast. The capacity for expanding and maintaining onshore and offshore support facilities and transportation networks is also apt to be affected (Burkett 2011).

Sea level rise and storm surge can have impacts far beyond the area directly affected. Homes and infrastructure in low areas are increasingly prone to flooding during tropical storms. As a result, insurance costs will increase and people will move from vulnerable areas, stressing the social and infrastructural capacity of surrounding areas. This migration also happens in response to extreme events such as Hurricane Katrina, when more than 200,000 migrants were temporarily housed in Houston and 42% indicated they would try to remain there (Coker 2006).

Ecosystems of the Southeast are exposed to and at risk from sea level rise, especially tidal marshes and swamps. Some tidal freshwater forests are already retreating, while mangrove forests (adapted to coastal conditions) are expanding landward (Doyle et al. 2010). The pace of sea level rise will increasingly lead to inundation of coastal wetlands in the Southeast. Such a crisis in land loss has occurred in coastal Louisiana for several decades (Couvillion et al. 2011), with 1,880 sq. miles having been lost since the 1930s as a result of natural and man-made factors (Louisiana's 2012 Coastal Master Plan 2012). With tidal wetland loss, protection of coastal lands and people against storm surge will be compromised.

In some southeastern coastal areas, changes in salinity and water levels due to sea level rise can happen so fast that local vegetation cannot adapt quickly enough and those areas become open water (Nicholls et al. 2007). Fire, hurricanes, and other disturbances have similar effects, causing ecosystems to cross thresholds at which dramatic changes occur over short time frames (Burkett 2008; Burkett et al. 2005).

The impacts of sea level rise on agriculture derive from decreased freshwater availability, land loss, and saltwater intrusion. Salt-water intrusion is projected to reduce the availability of groundwater for irrigation, thereby limiting crop production in some areas (Ritschard et al. 2002). Agricultural areas around Miami-Dade County and southern Louisiana with shallow groundwater tables are at risk of enhanced inundation and future loss of cropland with a projected loss of 37,500 acres in Florida with a 27-inch sea level rise (Stanton and Ackerman 2007), which is well within a 1 to 4 foot range of sea level rise by 2100 (Ch. 2: Our Changing Climate, Key Message 9).

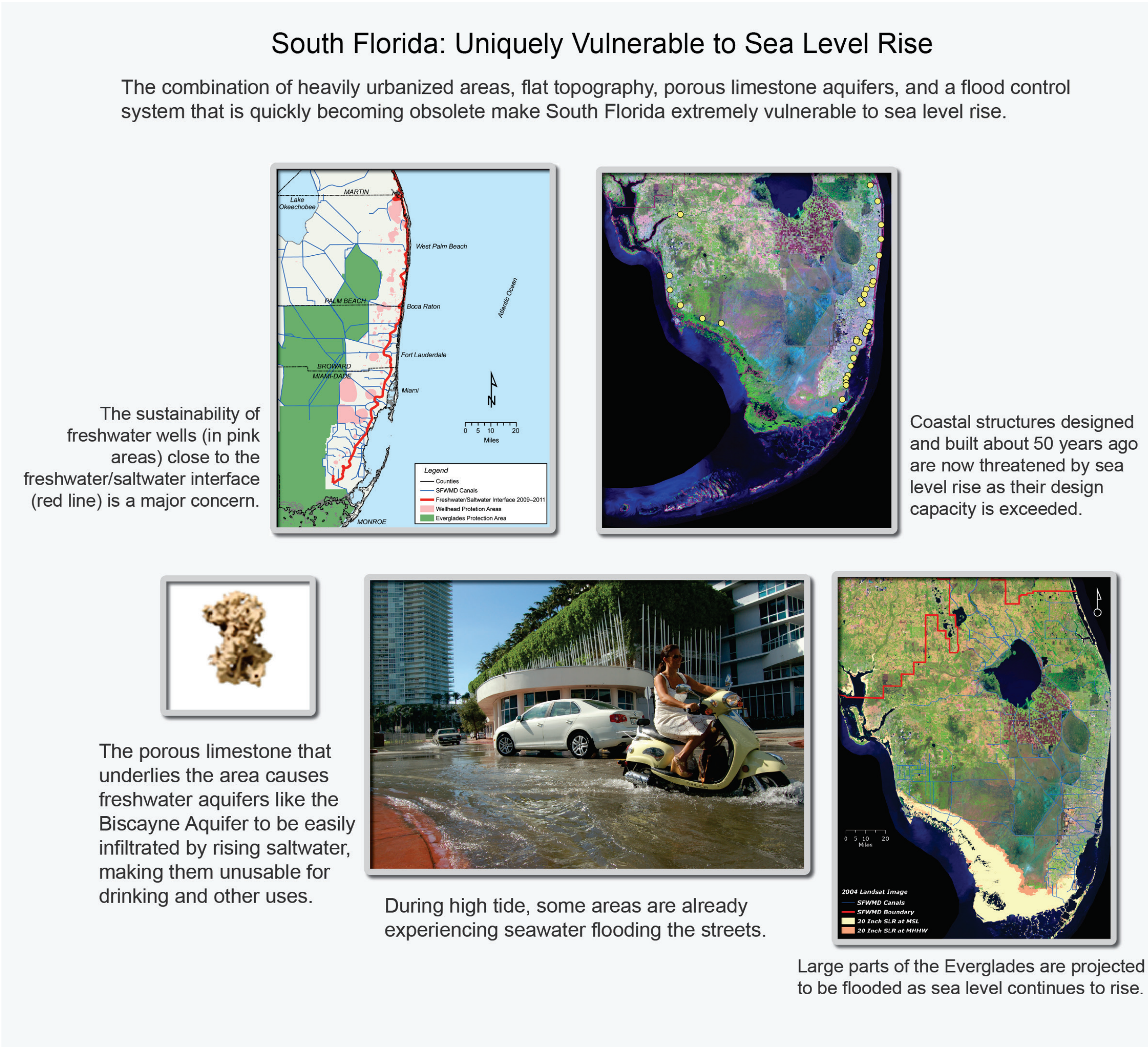

Figure 17.8

There are basically three types of adaptation options to rising sea levels: protect, accommodate, and retreat (Karl et al. 2009; Nicholls et al. 2007). Individuals and communities are using all of these strategies. However, regional cooperation among local, state, and federal governments can greatly improve the success of adapting to impacts of climate change and sea level rise. An excellent example is the Southeast Florida Regional Compact. Through collaboration of county, state, and federal agencies, a comprehensive action plan was developed that includes hundreds of actions and special Adaptation Action Areas (SFRCCC 2012).

Local Planning

Figure 17.9: Local Planning

Caption: Miami-Dade County staff leading workshop on incorporating climate change considerations in local planning. (Photo credit: Armando Rodriguez/Miami-Dade County)

Extreme Heat

Rising temperatures and the associated increase in frequency, intensity, and duration of extreme heat events will affect public health, natural and built environments, energy, agriculture, and forestry.

The negative effects of heat on human cardiovascular, cerebral, and respiratory systems are well established (e.g., Kovats and Hajat 2008; O'Neill and Ebi 2009). Atlanta, Miami, New Orleans, and Tampa have already had increases in the number of days with temperatures exceeding 95ºF, during which the number of deaths is above average (Sheridan et al. 2009). By 2100, the Southeast is expected to have the highest increase in heat index (a measure of comfort that combines temperature and relative humidity) of any region of the country (Burkett et al. 2001). Higher temperatures also contribute to the formation of harmful air pollutants and allergens (Portier et al. 2010). Ground-level ozone is projected to increase in the 19 largest urban areas of the Southeast, leading to an increase in deaths (Chang et al. 2010). A rise in hospital admissions due to respiratory illnesses, emergency room visits for asthma, and lost school days is expected (Tagaris et al. 2009).

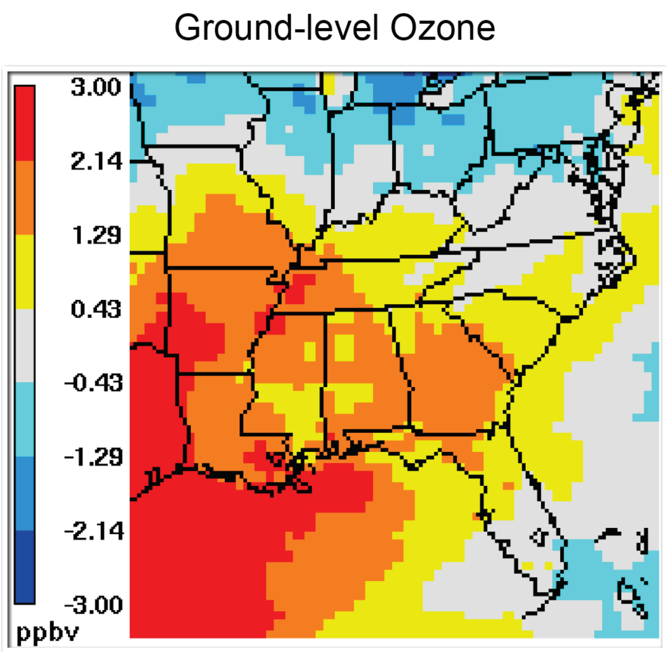

Figure 17.10: Ground-level Ozone

Caption: Ground-level ozone is an air pollutant that is harmful to human health and which generally increases with rising temperatures. The map shows projected increases in ground level ozone pollution in 2050 as compared to 2001, using a mid-range emissions scenario (A1B, assuming some decrease from current emissions growth trends). (Adapted from Tagaris et al. 2009)

The climate in many parts of the Southeast is suitable for mosquitoes carrying malaria, and yellow and dengue fevers. It is still uncertain how regional climate changes will impact vector-borne and zoonotic (animal to human) disease transmissions. While higher temperatures are likely to shorten both development and incubation time (Watts et al. 1987), vectors also need the right conditions for breeding (water), for dispersal (vegetation and humidity), and access to susceptible vertebrate hosts to complete the disease transmission cycle (Ingram et al. 2012). While these transmission cycles are complex, increasing temperatures have the potential to result in an expanded region with more favorable conditions for transmission of these diseases (CDC 2010; Filler et al. 2006; Mali et al. 2012).

Climate change is expected to increase harmful algal blooms and several disease-causing agents in inland and coastal waters, which were not previously problems in the Southeast (Hallegraeff 2010; Moore et al. 2008; Tester et al. 2010; Tirado et al. 2010; Wiedner et al. 2007). For instance, higher sea surface temperatures are associated with higher rates of ciguatera fish poisoning (Hales et al. 1999; Tester et al. 2010), one of the most common hazards from algal blooms in the region (Landsberg 2002). The algae that causes this food-borne illness is moving northward, following increasing sea surface temperatures (Litaker et al. 2010; Villareal et al. 2006). Certain species of bacteria (*Vibrio,* for example) that grow in warm coastal waters and are present in Gulf Coast shellfish can cause infections in humans. Infections are now frequently reported both earlier and later by one month than traditionally observed (Martinez-Urtaza et al. 2010).

Coral reefs in the Southeast, as well as worldwide, are susceptible to climate change, especially warming waters and ocean acidification, whose impacts are exacerbated when coupled with other stressors including disease, runoff, over-exploitation, and invasive species (Ingram et al. 2012). The region's aquaculture industry is also expected to be compromised by climate-related stresses (Twilley et al. 2001).

An expanding population and regional land-use changes have affected land available for agriculture and forests faster in the Southeast than in any other region (Loveland et al. 2012). Climate change is also expected to change the unwanted spread and locations of some nonnative plants, which will result in new management challenges (Hellmann et al. 2008).

Heat stress adversely affects dairy and livestock production (West 2003) – optimal temperatures for milk production are between 40ºF and 75ºF – and additional heat stress could shift dairy production northward (Fraisse et al. 2009). A 10% decline in livestock yield is projected across the Southeast with a 9ºF increase in temperatures (applied as an incremental uniform increase in temperature between 1990 and 2060), related mainly to warmer summers (Adams et al. 1999).

Summer heat stress is projected to reduce crop productivity, especially when coupled with increased drought. The 2007 drought cost the Georgia agriculture industry $339 million in crop losses (CIER 2009), and the 2002 drought cost North Carolina $398 million (Ingram et al. 2012). A 2.2ºF increase in temperature would likely reduce overall productivity for corn, soybeans, rice, cotton, and peanuts across the South – though rising CO_2 levels could partially offset these decreases (Hatfield et al. 2008), based on a crop yield simulation model. In Georgia, climate projections indicate corn yields could decline by 15% and wheat yields by 20% through 2020 (Alexandrov and Hoogenboom 2000). In addition, many fruits from long-lived trees and bushes require chilling periods and may need to be replaced in a warming climate (Hatfield et al. 2008).

Adaptation for agriculture involves decisions at many scales, from infrastructure investments (like reservoirs) to management decisions (like cropping patterns) (Howden et al. 2007). Dominant adaptation strategies would include altering local planting choices to better match new climate conditions (Howden et al. 2007) and developing heat-tolerant crop varieties and breeds of livestock (Fraisse et al. 2009; Ingram et al. 2012). Most critical for effective adaptation is the delivery of climate risk information to decision-makers at appropriate temporal and spatial scales (Fraisse et al. 2009; Howden et al. 2007), and focus on cropping systems that increase water use efficiency, shifts toward irrigation, and more precise control of irrigation delivery (Fraisse et al. 2009; Ingram et al. 2012).

The Southeast (includes Texas and Oklahoma, not Puerto Rico) leads the nation in number of wildfires, averaging 45,000 fires per year (Gramley 2005), and this number continues to increase (Morton et al. 2012; Stanturf and Goodrick 2012). Increasing temperatures contribute to increased fire frequency, intensity, and size (Gramley 2005). Lightning, a frequent initiator of wildfires, is expected to increase (Wu et al. 2008). Drought often correlates with large wildfire events, as seen with the Okeefenokee (2007) and Florida fires (1998). The 1998 Florida fires led to losses of more than $600 million (Butry et al. 2001). Wildfires also affect human health through reduced air quality and direct injuries (Albrecht et al. 2007; Butry et al. 2001; Ebi et al. 2008). Expanding population will result in restrictions on prescribed burning, constraining deployment of a useful adaptive strategy (Stanturf and Goodrick 2012).

Forest disturbances caused by insects and pathogens are altered by climate changes due to factors such as increased tree stress, shifting phenology, and altered insect and pathogen lifecycles (Vose et al. 2012). Current knowledge provides limited insights into specific impacts on epidemics, associated tree growth and mortality, and economic loss in the Southeast, though the overall extent and virulence of some insects and pathogens have been on the rise (for example, Hemlock Woolly Adelgid in the Southern Appalachians) while recent declines in southern pine beetle (*Dendroctonus frontalis* Zimmerman) epidemics in Louisiana and East Texas have been attributed to rising temperatures (Friedenberg et al. 2007). Due to forests' vast extent and high cost, adaptation strategies are limited, except through post epidemic management responses – for example, sanitation cuts and species replacement.

The Southeast has the existing power plant capacity to produce 32% of the nation's electricity (U.S. Energy Information Administration 2011). Energy use is approximately 27% of the U.S. total, more than any other region (Ingram et al. 2012). Net energy demand is projected to increase, largely due to higher temperatures and increased use of air conditioning. This will potentially stress electricity generating capacity, distribution infrastructure, and energy costs. This is of particular concern for lower income households, the elderly, and other vulnerable communities (Ingram et al. 2012). Long periods of extreme heat could damage roadways by softening asphalt and cause deformities of railroad tracks, bridge joints, and other transportation infrastructure (FTA 2011).

Increasing temperatures will impact many facets of life in the Southeast. For each impact there could be many possible responses. Many adaptation responses are described in other chapters in this document. For examples, please see the sector chapter of interest and the Adaptation chapter.

Water Availability

Decreased water availability, exacerbated by population growth and land-use change, will continue to increase competition for water and impact the region's economy and unique ecosystems.

Water resources in the Southeast are abundant and support heavily populated urban areas, rural communities, unique ecosystems, and economies based on agriculture, energy, and tourism. The region also experiences extensive droughts, such as the 2007 drought in Atlanta, Georgia that created water conflicts among three states (Kunkel et al. 2012; Manuel 2008; Pederson et al. 2012; Seager et al. 2009). In northwestern Puerto Rico, water was rationed for more than 200,000 people during the winter and spring of 1997-1998 because of low reservoir levels (Larsen 2000). Droughts are one of the most frequent climate hazards in the Caribbean, resulting in economic losses and anxiety (Farrell et al. 2010). Water supply and demand in the Southeast are influenced by many changing factors, including climate (for example, temperature increases that contribute to increased transpiration from plants and evaporation from soils and water bodies), population, and land use (Ingram et al. 2012).

With projected increases in population, conversion of rural areas, forestlands, and wetlands into residential, commercial, industrial, and agricultural zones is expected to intensify (Loveland et al. 2012). The continued development of urbanized areas will increase water demand, exacerbate saltwater intrusion into freshwater aquifers, and threaten environmentally sensitive wetlands bordering urban areas (Heimlich et al. 2009).

Additionally, higher sea levels will accelerate saltwater intrusion into freshwater supplies from rivers, streams, and groundwater sources near the coast. Porous aquifers in some areas make them particularly vulnerable to salt water intrusion (Obeysekera et al. 2011; SFWMD 2009). For example, officials in the City of Hallandale Beach, Florida have already abandoned six of their eight drinking water wells (Berry et al. 2011).

With increasing demand for food and rising food prices, irrigated agriculture will expand in some states. Also, population expansion in the region is expected to increase domestic water demand. Such increases in water demand by the energy, agricultural, and urban sectors will increase the competition for water, particularly in situations where environmental water needs conflict with other uses (Ingram et al. 2012).

Box: Water Recycling

Because of Clayton County, Georgia's, innovative water recycling project during the 2007-2008 drought, they were able to maintain reservoirs at near capacity and an abundant supply of water while neighboring Lake Lanier, the water supply for Atlanta, was at record lows. Clayton County developed a series of constructed wetlands used to filter treated water that recharges groundwater and supplies surface reservoirs. They have also implemented efficiency and leak detection programs. (American Rivers et al. 2009).

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Net water supply in the Southeast is expected to decline over the next several decades, particularly in the western part of the region (based on Caldwell et al. 2012). Analysis of current and future water resources in the Caribbean shows many of the small islands would be exposed to severe water stress under all climate change scenarios (UNEP 2008).

Trends in Water Availability

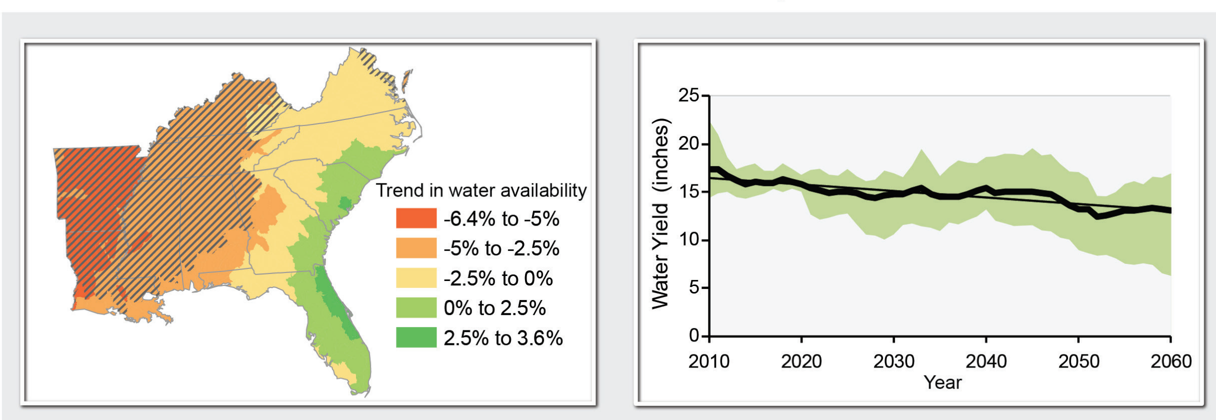

Figure 17.11: Trends in Water Availability

Caption: Left: Average annual water yield (equivalent to water availability) trends projected for 2010-2060 (based on A1B & B2 emissions scenarios) compared to the average from 2001-2010. Statistical confidence in the projected changes is highest in the hatched areas. **Right:** Projected Southeast-wide 10-year moving-average annual water yield. The green area represents the range in predicted water yield from four climate model projections based on the A1B & B2 emissions scenarios. As shown on the map, the western part of the Southeast region is expected to see the largest reductions in water availability. Figure source: based on (Caldwell et al. 2012).

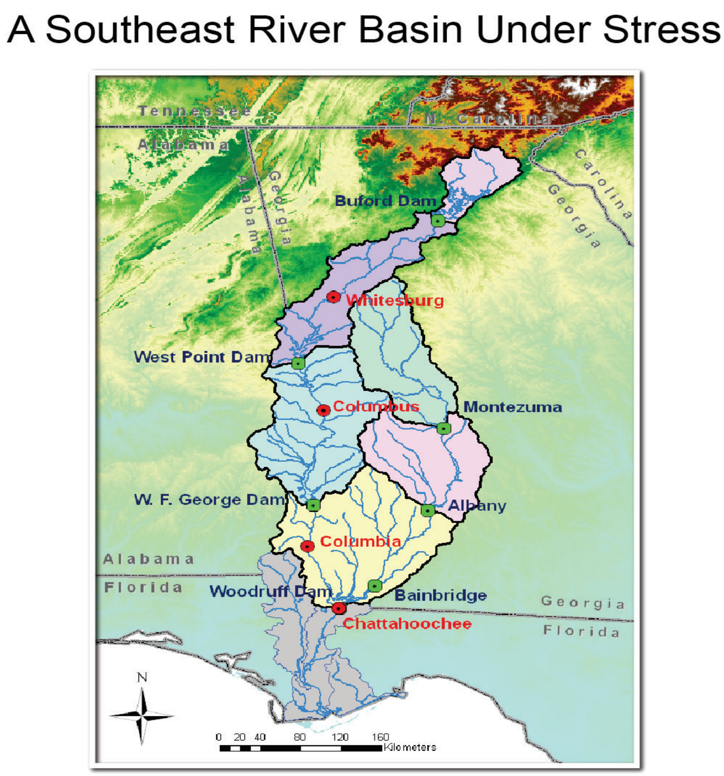

Figure 17.12: A Southeast River Basin Under Stress

Caption: The Apalachicola-Chattahoochee-Flint River Basin in Georgia exemplifies a place where many water uses are in conflict, and this conflict is expected to be exacerbated by future climate change (Georgakakos et al. 2010). The basin drains 19,600 square miles in three states and supplies water for multiple, often competing, uses, including irrigation, drinking water and other municipal uses, power plant cooling, navigation, hydropower, recreation, and ecosystems. Under future climate change, this basin is likely to experience more severe water supply shortages, more frequent emptying of reservoirs, violation of environmental flow requirements, less energy generation, and more competition for remaining water. Adaptation options include changes in reservoir storage and release procedures, and possible phased expansion of reservoir capacity (Georgakakos and Zhang 2011; Georgakakos et al. 2011; Georgakakos et al. 2010).

New freshwater well fields may have to be established inland to replenish water supply lost from existing wells closer to the ocean once they are compromised by salt water intrusion. Programs to increase water-use efficiency, reuse of waste water, and water storage capacity are options that can help alleviate water supply stress.

The Southeast, which has a disproportionate number of the fastest growing metropolitan areas in the country and important economic sectors located in low-lying coastal areas, is particularly vulnerable to some of the expected impacts of climate change. The most severe and widespread impacts are likely to be associated with sea level rise and changes in temperature and precipitation, which ultimately affect water availability. Changes in land use and land cover, more rapid in the Southeast than most other areas of the country, often interact with and serve to amplify the effects of climate change on southeastern ecosystems.

Traceable Accounts

Chapter 17: Southeast and Caribbean

Key Message Process: A central component of the process was the SE Regional Climate assessment workshop that was held on September 26-27, 2011 in Atlanta, with approximately 75 attendees, to begin the process leading to a foundational Technical Input Report (TIR). That 344-page foundational "Southeast Region Technical Report to the National Climate Assessment" (Ingram et al. 2012) comprised 14 chapters from over 100 authors, including all levels of government, NGOs, and business.

The writing team held a 2-day meeting in April, 2012 in Ft. Lauderdale, engaged in multiple technical discussions via teleconferences and webinars, which included careful review of the foundational TIR (Ingram et al. 2012)., of nearly 60 additional technical inputs provided by the public, and other published literature and professional judgment. Discussions were followed by expert deliberation of draft key messages by the authors, and targeted consultation with additional experts by the SE chapter writing team and lead author of each key message.

Key message #1/3	**Sea level rise poses widespread and continuing threats to both natural and built environments, and the economy.**
Description of evidence base	The key message and supporting text summarizes extensive evidence documented in the SE Technical Input (Ingram et al. 2012). A total of 57 Technical Input Reports (TIR's) on a wide range of sea level rise topics were also received and reviewed as part of the Federal Register Notice solicitation for public input. Evidence that the rate of sea level rise has increased is based on satellite altimetry data and direct measurements such as tide gauges. Numerous peer-reviewed publications describe increasing hazards associated with sea level rise and storm surge, heat waves, and intense precipitation for the Southeast. For sea level rise, the authors relied on the NCA SLR scenario (Parris et al. 2012) and detailed discussion in Ingram et al. (2012). Evidence that sea level rise is a threat to natural and human environments is documented in detail within Ingram et al. (2012) and other TIR's, as well as considerable peer-reviewed literature, with examples of areas that are being flooded more regularly, salt water intrusion into fresh water wells, and changes from fresh to salt water in coastal ecosystems (e.g. fresh water marshes) causing them to die, and increases in vulnerability of many communities to coastal erosion is well documented in field studies. Economic impacts are seen in the cost to avoid flooded roads, buildings, ports, the need to drill new fresh water wells, and the loss of coastal ecosystems and their storm surge protection.
New information and remaining uncertainties	Tremendous improvement has been made since the last IPCC evaluation of sea level rise in 2007, with strong evidence of mass loss of Greenland icecap and glaciers worldwide. Improved analyses of tide gauges, coastal elevations, and circulation changes in offshore waters have also provided new information on accelerating rates of rise. These have been documented in the NCA Sea Level Change Scenario document (Parris et al. 2012). Uncertainties in the rate of sea level rise through the 21st century stems from a combination of large differences in projections between different climate models, natural climate variability, uncertainties in the melting of land based glaciers and the Antarctic and Greenland ice sheets especially, and future rates of fossil fuel emissions. A second key uncertainty is the rate of vertical land movement at specific locations. The two factors – sea level rise and subsidence, when combined, increase the impact of global sea level rise in any specific area. A third area of uncertainty is where and what adaptive plans and actions are being undertaken to avoid flooding and associated impacts in areas that affect people, communities,

	facilities, infrastructure, and ecosystems.
Assessment of confidence based on evidence	Nearly all studies to date published in the peer-reviewed literature agree that sea level rise will continue if greenhouse gas concentrations continue to rise. Because sea levels determine the locations of human activities and ecosystems along the coasts, increases in sea level and the rate of rise will nearly certainly have substantial impacts on natural and human ecosystems along the coastal area. What specific locations will be impacted under what specific levels of sea level rise need to be determined location-by-location. However, since many locations are already being impacted by rising seas, more and more locations will be impacted as the sea levels continue to rise. Confidence in this key message is therefore judged to be **very high**.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

Chapter 17: Southeast and Caribbean

Key Message Process: See key message #1.

Key message #2/3	**Rising temperatures and the associated increase in frequency, intensity, and duration of extreme heat events are already and will continue to affect public health, the natural and urban environments, energy, agriculture, and forestry.**
Description of evidence base	The key message and supporting text summarizes extensive evidence documented in the SE Technical Input (Ingram et al. 2012). Technical Input reports (57) on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input. Numerous peer-reviewed publications describe increasing hazards associated with heat events and rising temperatures for the Southeast. For temperature and associated heat events, Kunkel et al. (2012) worked closely with the region's state climatologists on both the climatology and projections. Evidence of rising temperatures and current impacts is based on an extensive set of field measurements. There is considerable evidence of high air temperature effects across a wide range of natural and managed systems in the SE. Increased temperatures affect human health and hospital admissions (Kovats and Hajat 2008; O'Neill and Ebi 2009; Portier et al. 2010; Tagaris et al. 2009). Rising water temperatures also increase risks of bacterial infection from eating Gulf Coast shellfish (Martinez-Urtaza et al. 2010) and increase algal blooms that have negative human health effects (Hallegraeff 2010; Moore et al. 2008; Tester et al. 2010; Tirado et al. 2010). There is also evidence that there will be an increase in favorable conditions for mosquitos that carry diseases (CDC 2010). Higher temperatures are detrimental to natural and urban environments, through increased wildfires in natural areas and managed forests (Delfino et al. 2009; Gramley 2005; Morton et al. 2012; Stanturf and Goodrick 2012) and invasiveness of some nonnative plants (Hellmann et al. 2008). High temperatures also contribute to more roadway damage and deformities of transportation infrastructure such as railroad tracks and bridges (FTA 2011). In addition, high temperature increases net energy demand and costs, placing more stress on electricity generating plants and distribution infrastructure. Increasing temperatures in the SE causes more stresses on crop and livestock agricultural systems. Heat stress reduces dairy and livestock production (West 2003) and also reduces yields of various crops grown in this region (corn, soybean, peanuts, rice, cotton) (Alexandrov and Hoogenboom 2000; Hatfield et al. 2008).
New information and remaining uncertainties	Since 2007, studies on impacts of higher temperatures have increased in many areas. Most of the publications cited above concluded that increasing temperatures in the SE will result in negative impacts on human health, the natural and urban environments, energy, agriculture and forestry. A key issue (uncertainty) is the detailed mechanistic responses, including adaptive capacities and/or resilience, of natural and urban environments, the public health system, energy systems, agriculture, and forests to rising temperatures and extreme heat events. Another uncertainty is how combinations of stresses, in addition to extreme heat for example, water availability, will impact the outcomes. There is a need for more monitoring to document the extent and location of vulnerable areas (natural and human), and then research to assess how those impacts will affect productivity of

	key food and forest resources and human livability as well as research that develops or identifies more resilient, adapted systems.
Assessment of confidence based on evidence	**Temperature Rise:** There is **high** confidence in documentation that projects increases in air temperatures (but not in the precise amount) and resulting changes in extreme heat events. Projections for increases in temperature are more certain in the SE than those for changes in precipitation. Rising temperatures and the substantial increase in duration of high temperatures (for either scenario) above critical thresholds will have significant impacts on the population, agricultural industries, and ecosystems in the region. There is **high** confidence in documentation that increases in temperature in the SE will result in higher risks of negative impacts in human health, agricultural and forest production, on natural systems, on the built environment, and on energy demand. There is **lower** confidence in the magnitude of these impacts, partly due to lack of information on how these systems will adapt or be adapted to higher temperatures and partly due to the limited knowledge base on the wide diversity that exists across this region in terms of climates and systems.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

Chapter 17: Southeast and Caribbean

Key Message Process: See key message #1.

Key message #3/3	**Decreased water availability exacerbated by population growth and land-use change will continue to increase competition for water and impact the region's economy and unique ecosystems.**
Description of evidence base	The key message and supporting text summarizes extensive evidence documented in the SE Technical Input (Ingram et al. 2012). Technical Input reports (57) on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input. Chapter 2, Our Changing Climate, describes evidence for drought and precipitation in its key messages, and numerous salient literature leading to decreased water availability is also summarized for the Southeast in Ingram et al. (2012) Evidence for the impacts on the region's economy and unique ecosystems is also detailed in Ingram et al. (2012) and the broader literature surveyed by the authors.
New information and remaining uncertainties	Many studies have been published since 2007 documenting increasing demands for water in the SE due to increases in populations and irrigated agriculture in addition to water shortages due to extensive droughts (Ingram et al. 2012; Kunkel et al. 2012). There is also more evidence of losses in fresh water wells near coastlines due to salt- water intrusion (Berry et al. 2011; Obeysekera et al. 2011), and continuing conflicts among states for water use, particularly during drought periods (Georgakakos et al. 2010; Ingram et al. 2012). It is a virtual certainty that population growth in the SE will continue in the future and will be accompanied by a significant change in land-use patterns, which is projected to include a larger fraction of urbanized areas, reduced agricultural areas, and reduced forest cover. With increasing population and human demand, competition for water among agriculture, urban, and environment sectors is expected to continue to increase. However, the projected population increases between the low (B1) and high (A2) emission scenarios differ significantly (33% versus 151%). Consequently the effect of climate change on urban water demand for the low emission scenario is expected to be much lower than that of the high emission scenario. Land-use change will also alter the regional hydrology significantly, and unless measures are adopted to increase water storage, availability of freshwater during dry periods will decrease, partly due to drainage and other activities. Projected increase in temperature will increase evaporation, and in areas where precipitation is projected to decrease in response to climate change, the net amount of water supply for human and environmental uses may decrease significantly. Along the coastline of the SE, accelerated intrusion of saltwater due to sea level rise will impact both freshwater well-fields and potentially freshwater intakes in rivers and streams connected to the ocean. Although sea level rise (SLR) corresponding to the high emission scenario is much higher (twice as much), even the SLR for the low emission scenario will increasingly impact water supply availability in low-lying areas of the region as they are already being impacted by sea level rise and land subsidence. Projections of specific spatial and temporal changes in precipitation in the SE remain highly uncertain and it is important to know with a reasonable confidence the sign and the magnitude of this change in various parts of the large Southeast

	region. There are no reliable projections of evapotranspiration for the SE, another major factor that determines water yield and adds to uncertainty in water availability. There are inadequate regional studies at basin scales to determine the future competition for water supply among sectors (urban, agriculture, environment). There is a need for more accurate information on future changes in drought magnitude and frequency.
Assessment of confidence based on evidence	**High** confidence in each aspect of the key message: It is virtually certain that the water demand for human consumption in the SE will increase as a result of population growth. The past evidence of impacts during droughts and the projected changes in drivers suggest that there is a **high** confidence of the above assessment of future water availability. However, without additional studies, the resilience and the adaptive capacity of the socio-economic and environmental systems are not known with confidence. Water supply is critical for sustainability of the region, particularly in view of increasing population and land-use changes. Although climate models' precipitation projections are uncertain, the combined effects of possible decreases in precipitation, increasing evaporation losses due to warming, and increasing demands for water due to higher populations, under either scenario, will have a significant impact on water availability for all sectors.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
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