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, and to the regional economy.**
2. **Increasing 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 affect the region's economy and unique ecosystems.**

Introduction

The Southeast and Caribbean is exceptionally vulnerable to sea level rise, extreme heat events, hurricanes, and decreased water availability. The geographic 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[1] and draws millions of visitors every year. In 2009, Puerto Rico hosted 3.5 million tourists who spent $3.5 billion.[2] In 2012, Louisiana and Florida alone hosted more than 115 million visitors.[3]

The region has two of the most populous metropolitan areas in the country (Miami and Atlanta) and four of the ten fastest-growing metropolitan areas.[1] Three of these (Palm Coast, FL, Cape Coral-Fort Myers, FL, and Myrtle Beach area, SC) are along the coast and vulnerable to sea level rise and storm surge. Puerto Rico has one of the highest population densities in the world, with 56 percent of the population living in coastal municipalities.[4]

The Gulf and Atlantic coasts are major producers of seafood and home to seven major ports[5] that are also vulnerable. The Southeast is a major energy producer of coal, crude oil, and natural gas, and is the highest energy user of any of the National Climate Assessment regions.[5]

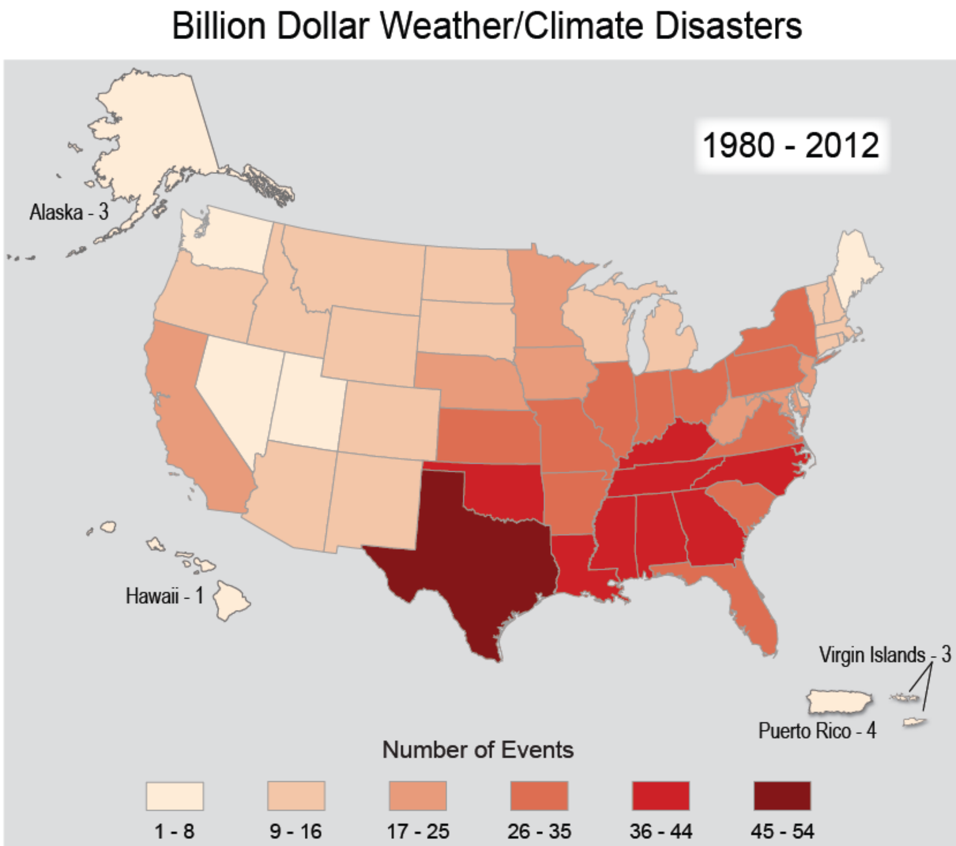

Figure 17.1: Billion Dollar Weather/Climate Disasters

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. The primary disaster type for coastal states such as Florida is hurricanes, while interior and northern states in the region also experience sizeable numbers of tornadoes and winter storms. For a list of events and the affected states, see: http://www.ncdc.noaa.gov/billions/events.[6] (Figure source: NOAA NCDC).

The Southeast's climate is influenced by many factors, including latitude, topography, and proximity to 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. The region's 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 over key areas of the globe, and land-falling tropical weather systems.[7] These cycles alter the occurrences of hurricanes, tornadoes, droughts, flooding, freezing winters, and ice storms, contributing to climate and weather disasters in the region that have exceeded the total number of billion dollar disasters experienced in all other regions of the country combined (see Figure 17.1).

Box: Stories of Change: Coastal Louisiana Tribal Communities

Climate change impacts, especially sea level rise and related increases in storm surges pulsing further inland, will continue to exacerbate ongoing land loss already affecting Louisiana tribes. Four Native communities in Southeast Louisiana (Grand Bayou Village, Grand Caillou/Dulac, Isle de Jean Charles, and Pointe-au-Chien) have already experienced significant land loss. Management of river flow has deprived the coastal wetlands of the freshwater and sediment that they need to replenish and persist. Dredging of canals through marshes for oil and gas exploration and pipelines has led to erosion and intense saltwater intrusion, resulting in additional land loss. Due to these and other natural and man-made problems, Louisiana has lost 1,880 square miles of land in the last 80 years.[8] This combination of changes has resulted in a cascade of losses of sacred places, healing plants, habitat for important wildlife, food security,[9] and in some cases connectivity with the mainland. Additional impacts include increased inundation of native lands, further travel to reach traditional fishing grounds, reduced connections among family members as their lands have become more flood-prone and some have had to move, and declining community cohesiveness as heat requires more indoor time.[10] (For more specifics, see Ch. 12: Indigenous Peoples). Numerous other impacts from increases in temperature, sea level rise, land loss, erosion, subsidence, and saltwater intrusion amplify these existing problems.

Shrinking Lands for Tribal Communities

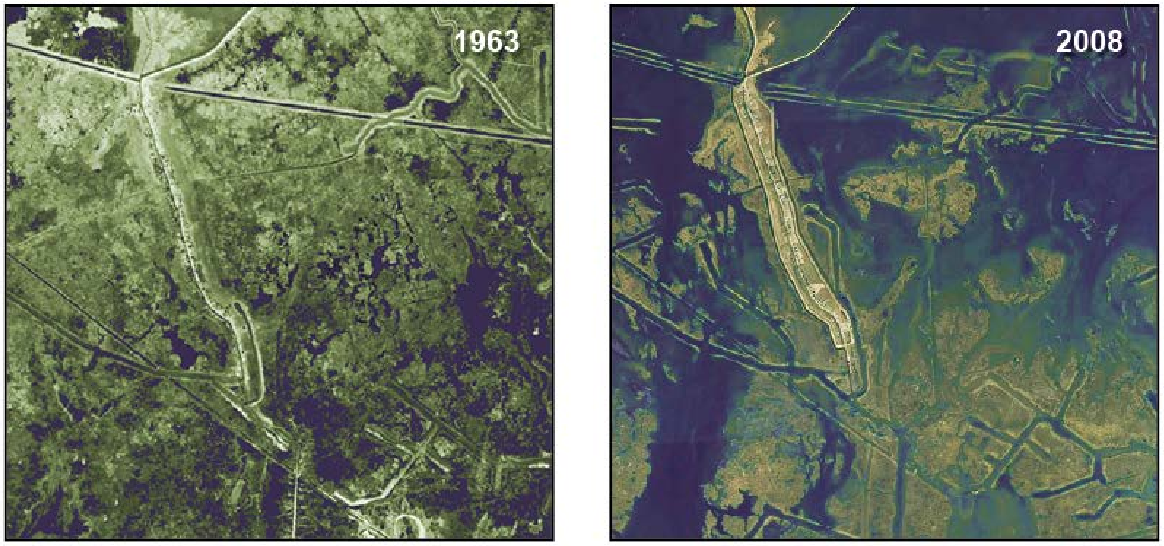

Figure 17.2: Shrinking Lands for Tribal Communities

Caption: Aerial photos of Isle de Jean Charles in Louisiana taken 25 years apart shows evidence of the effects of rising seas, sinking land, and human development. The wetlands adjacent to the Isle de Jean Charles community (about 60 miles south of New Orleans) have been disappearing rapidly since the photo on the left was taken in 1963. By 2008, after four major hurricanes, significant erosion, and alteration of the surrounding marsh for oil and gas extraction, open water surrounds the greatly reduced dry land. See Ch. 25: Coasts for more information. (Photo credit: 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 17.3, black line). A warm peak occurred during the 1930s and 40s followed by a cool period in the 60s and 70s. Temperatures increased again from 1970 to the present by an average of 2°F, with higher average temperatures 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.[11] The Caribbean also exhibits a trend since the 1950s, with increasing numbers of very warm days and nights, and with daytime maximum temperatures above 90°F and nights above 75°F.[4] Daily and five-day rainfall intensities have also increased.[5] Also, summers have been either increasingly dry or extremely wet.[11] For the Caribbean, precipitation trends are unclear, with some regions experiencing less annual amounts of rainfall and some increasing amounts.[4] Although the number of major tornadoes has increased over the last 50 years, there is no statistically significant trend (Ch 2: Our Changing Climate, Key Message 9).[11,12] This increase may be attributable to better reporting of tornadoes. The number of Category 4 and 5 hurricanes in the Atlantic basin has increased substantially since the early 1980s compared to the historic record that dates back to the mid-1880s (Ch. 2: Our Changing Climate; Key Message 8). This can be attributed to both natural variability and climate change.

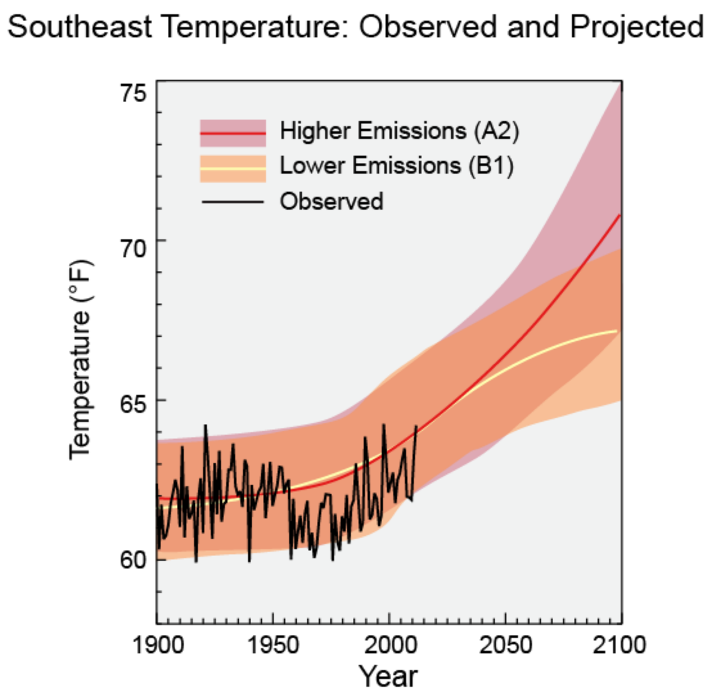

Figure 17.3: Southeast Temperature: Observed and Projected

Caption: Observed annual average temperature for the Southeast and projected temperatures assuming substantial emissions reductions (lower emissions, B1) and assuming continued growth in emissions (higher emissions, A2) (Kunkel et al. 2013). For each emissions scenario, shading shows the range of projections and the line shows a central estimate. The projections were referenced to observed temperatures from 1901-1960. The region warmed during the early part of last century, cooled for a few decades, and is now warming again. The lack of an overall upward trend over the entire period of 1900-2012 is unusual compared to the rest of the U.S. and the globe. This feature has been dubbed the "warming hole" and has been the subject of considerable research, although a conclusive cause has not been identified. (Figure source: adapted from Kunkel et al. 2013[11]).

Temperatures across the Southeast and Caribbean are expected to increase during this century, with shorter-term (year-to-year and decade-to-decade) fluctuations over time due to natural climate variability (Ch. 2: Our Changing Climate, Key Message 3).[4] Major consequences of warming include significant increases in the number of hot days (95°F or above) and decreases in freezing events. Although projected increases for some parts of the region by the year 2100 are generally smaller than for other regions of the U.S., projected increases for interior states of the region are larger than coastal regions by 1°F to 2°F. Regional average increases are in the range of 4°F to 8°F (combined 25th to 75th percentile range for A2 and B1 emissions scenarios) and 2°F to 5°F for Puerto Rico.[11]

Projections of future precipitation patterns are less certain than projections for temperature increases.[11] Because the Southeast is located in the transition zone between projected wetter conditions to the north and drier conditions to the southwest, many of the model projections show only small changes relative to natural variations. However, many models do project drier conditions in the far southwest of the region and wetter conditions in the far northeast of the region, consistent with the larger continental-scale pattern of wetness and dryness (Ch. 2: Our Changing Climate, Key Message 5).[11] For the Caribbean, it is equally difficult to project the magnitude of precipitation changes, although the majority of models show future decreases in precipitation are likely, with a few areas showing increases. In general, annual average decreases are likely to be spread across the entire region.[4] 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 (Ch. 2: Our Changing Climate, Key Message 8).[13] On top of the large increases in extreme precipitation observed during last century and early this century (Ch. 2: Our Changing Climate, Figures 2.16, 2.17, and 2.18,), substantial further increases are projected as this century progresses (Ch. 2: Our Changing Climate, Figure 2.19).

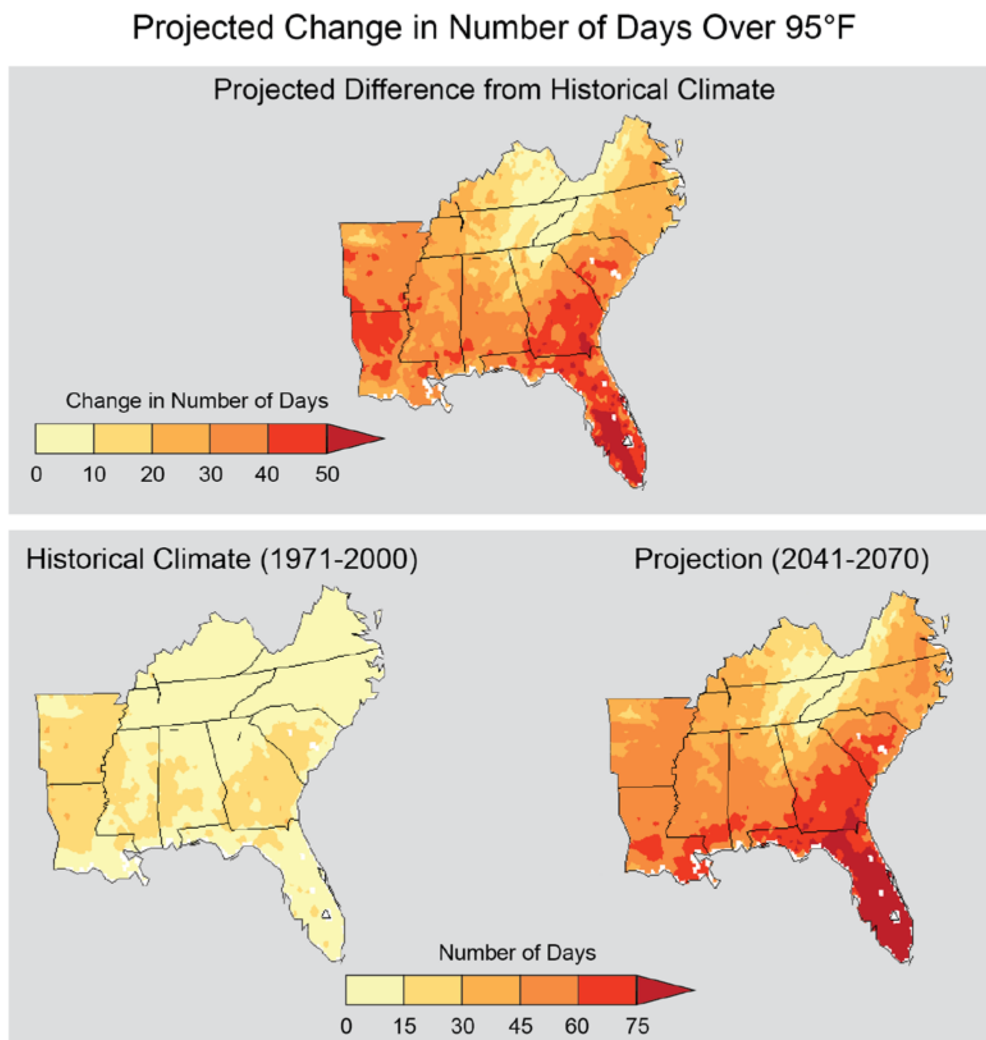

Figure 17.4: Projected Change in Number of Days Over 95°F

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). Patterns are similar, but less pronounced, assuming a reduced emissions scenario (B1). (Figure source: NOAA NCDC / CICS-NC).

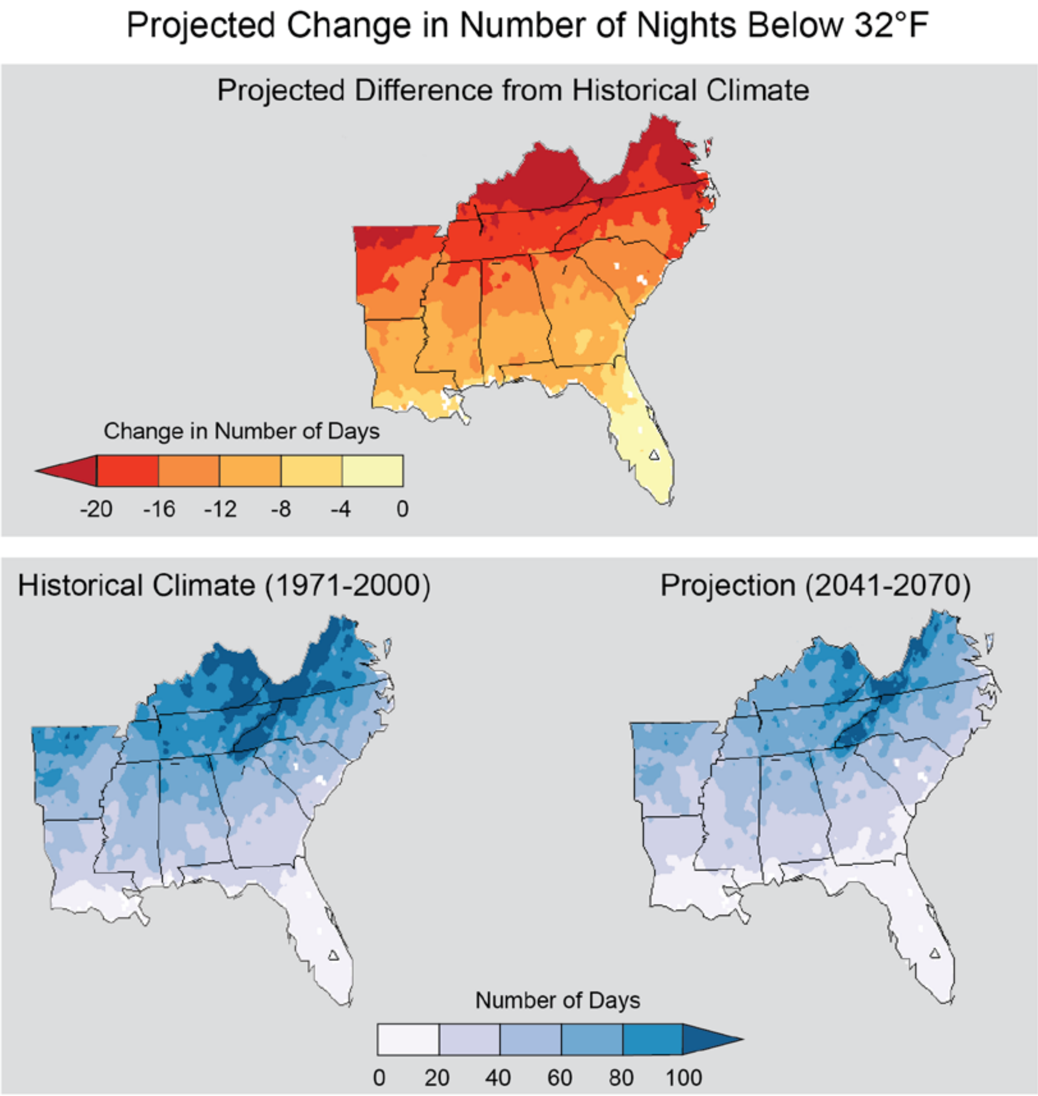

Figure 17.5: Projected Change in Number of Nights Below 32°F

Caption: Projected annual number of days with temperatures less than 32°F for 2041-2070 compared to 1971-2000, assuming emissions continue to grow (A2 scenario). Patterns are similar, but less pronounced, assuming a reduced emissions scenario (B1). (Figure source: NOAA NCDC / CICS-NC).

Sea Level Rise Threats

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

Global sea level rise over the past century averaged approximately eight inches (Ch. 2: Our Changing Climate, Key Message 10),[14,15] and that rate is expected to accelerate through the end of this century.[16] Portions of the Southeast and Caribbean are highly vulnerable to sea level rise.[4,5] 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.[16,17]

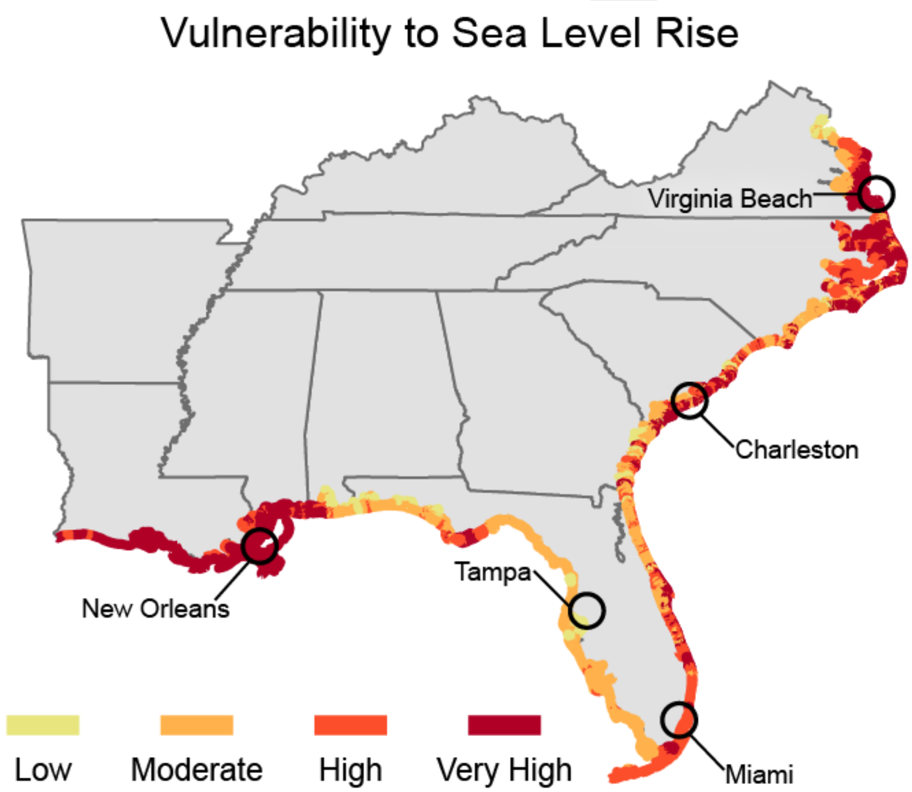

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Figure 17.6: Vulnerability to Sea Level Rise

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. (Data from Hammar-Klose and Thieler 2001[18]).

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. New Orleans (with roughly half of its population living below sea level[19]), Miami, Tampa, Charleston, and Virginia Beach are among those most at risk.[20] As a result of current sea level rise, the coastline of Puerto Rico around Rincón is being eroded at a rate of 3.3 feet per year.[4]

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 a 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 estimated 2030 losses by about 30%.[21]

The North Carolina Department of Transportation is raising the roadbed of U.S. Highway 64 across the Albemarle-Pamlico Peninsula by four feet, which includes 18 inches to allow for higher future sea levels.[22] Louisiana State Highway 1, heavily used for delivering critical oil and gas resources from Port Fourchon, is "literally sinking," resulting in more frequent and more severe flooding during high tides and storms.[8] The Department of Homeland Security estimated that a 90-day shutdown of this road would cost the nation $7.8 billion.[23]

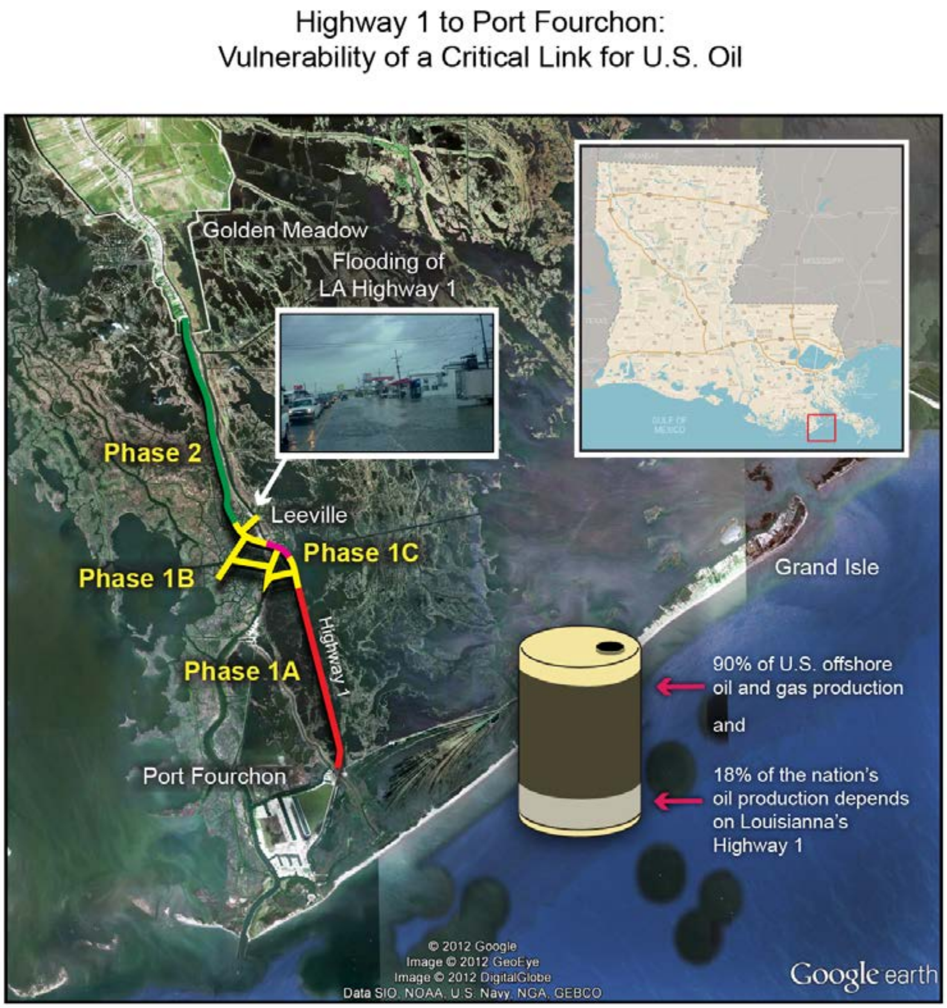

Figure 17.7: Highway 1 to Port Fourchon: Vulnerability of a Critical Link for U.S. Oil

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, (inset photo from flooding in 2004) on the way to Port Fourchon. See also Ch. 25: Coasts, Figure 25.5. (Figure and photo sources: Louisiana Department of Transportation and Development; State of Louisiana 2012[8]).

Sea level rise increases pressure on utilities – such as water and energy – by contaminating potential freshwater supplies with salt water. Such problems are amplified during extreme dry periods with little run-off. Uncertainties in the scale, timing, and location of climate change impacts can make decision-making difficult, but response strategies, especially those that try to anticipate possible unintended consequences, can be more 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.[24]

There is an imminent threat of increased inland flooding during heavy rain events in low-lying coastal areas such as southeast Florida, where just inches of sea level rise will impair the capacity of storm water drainage systems to empty into the ocean.[24] Drainage problems are already being experienced in many locations during seasonal high tides, heavy rains, and storm surge events. Adaptation options that are being assessed in this region include the redesign and improvement of storm drainage canals, flood control structures, and storm water pumps.

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 bays and coves 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.[25]

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 may increase or coverage may become unavailable[26] and people may 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 (Ch. 9, Human Health, Figure 9.10).[27]

Furthermore, because income is a key indicator of climate vulnerability, people that have limited economic resources are more likely to be adversely affected by climate change impacts such as sea level rise. In the Gulf region, nearly 100% of the “most socially vulnerable people live in areas unlikely to be protected from inundation,” bringing equity issues and environmental justice into coastal planning efforts.[28]

Ecosystems of the Southeast and Caribbean 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.[29] The pace of sea level rise will increasingly lead to inundation of coastal wetlands in the region. Such a crisis in land loss has occurred in coastal Louisiana for several decades, with 1,880 square miles having been lost since the 1930s as a result of natural and man-made factors.[8,30] With tidal wetland loss, protection of coastal lands and people against storm surge will be compromised.

Reduction of wetlands also increases the potential for losses of important fishery habitat. Additionally, ocean warming could support shifts in local species composition, invasive or new locally viable species, changes in species growth rates, shifts in migratory patterns or dates, and alterations to spawning seasons.[4,31] Any of these could affect the local or regional seafood output and thus the local economy.

In some southeastern coastal areas, changes in salinity and water levels due to a number of complex interactions (including subsidence, availability of sediment, precipitation and sea level rise) can happen so fast that local vegetation cannot adapt quickly enough and those areas become open water.[32] Fire, hurricanes, and other disturbances have similar effects, causing ecosystems to cross thresholds at which dramatic changes occur over short time frames.[33]

The impacts of sea level rise on agriculture derive from decreased freshwater availability, land loss, and saltwater intrusion. Saltwater intrusion is projected to reduce the availability of fresh surface and groundwater for irrigation, thereby limiting crop production in some areas.[34] Agricultural areas around Miami-Dade County and southern Louisiana with shallow groundwater tables are at risk of increased inundation and future loss of cropland with a projected loss of 37,500 acres in Florida with a 27-inch sea level rise,[35] which is well within the 1- to 4-foot range of sea level rise projected by 2100 (Ch. 2: Our Changing Climate, Key Message 10).

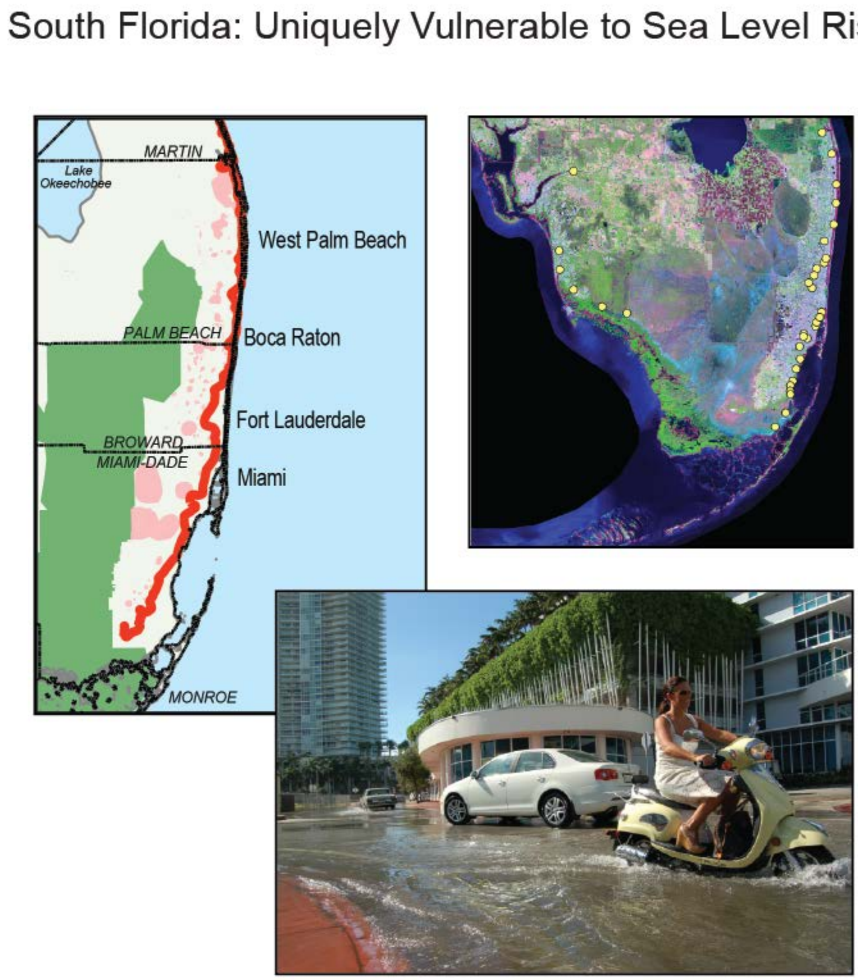

Figure 17.8 South Florida: Uniquely Vulnerable to Sea Level Rise

Caption: Sea level rise (SLR) presents major challenges to South Florida's existing coastal water management system due to a combination of increasingly urbanized areas, aging flood control facilities, flat topography, and porous limestone aquifers. For instance, South Florida's freshwater well field protection areas (left map: pink areas) lie close to the current interface between saltwater and freshwater (red line), which will shift inland with rising sea level, affecting water managers' ability to draw drinking water from current resources. Coastal water control structures (yellow circles) that were originally built about 60 years ago at the ends of drainage canals to keep salt water out and to provide flood protection to urbanized areas along the coast, are now threatened by sea level rise (right map). Even today, residents in some areas such as Miami Beach are experiencing seawater flooding their streets (lower photo). (Maps from The South Florida Water Management District.[36] Photo credit: Luis Espinoza, Miami-Dade County Department of Regulatory and Economic Resources).

There are basically three types of adaptation options to rising sea levels: protect (such as building levees or other "hard" methods), accommodate (such as raising structures or using "soft" or natural protection measures such as wetlands restoration), and retreat.[15,32] 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.[37]

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).

Increasing Temperatures

Increasing 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 (Ch. 9: Human Health)(for example:[38]). 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.[39] Higher temperatures also contribute to the formation of harmful air pollutants and allergens.[40] Ground-level ozone is projected to increase in the 19 largest urban areas of the Southeast, leading to an increase in deaths.[41] A rise in hospital admissions due to respiratory illnesses, emergency room visits for asthma, and lost school days is expected.[42]

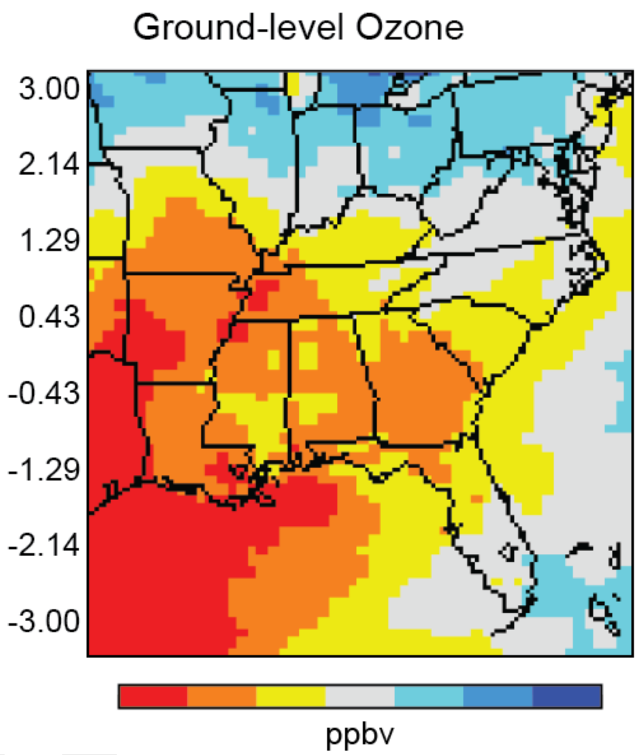

Figure 17.10: Ground-level Ozone

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 changes in average annual ground level ozone pollution concentration in 2050 as compared to 2001, using a mid-range emissions scenario (A1B, assuming some decrease from current emissions growth trends). (Figure source: adapted from Tagaris et al. 2009[42]).

The climate in many parts of the Southeast and Caribbean is suitable for mosquitoes carrying malaria, and yellow and dengue fevers. The small island states in the Caribbean already have a high health burden from climate-sensitive disease, including vector-borne and zoonotic (animal to human) diseases.[43] It is still uncertain how regional climate changes will affect vector-borne and zoonotic disease transmissions. While higher temperatures are likely to shorten both development and incubation time,[44] vectors (like disease-carrying insects) 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.[5] 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.[45,46]

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 region.[47,48,49] For instance, higher sea surface temperatures are associated with higher rates of ciguatera fish poisoning,[48,50] one of the most common hazards from algal blooms in the region.[51] The algae that causes this food-borne illness is moving northward, following increasing sea surface temperatures.[52] 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.[53]

Coral reefs in the Southeast and Caribbean, 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.[4,5] The region's aquaculture industry is also expected to be compromised by climate-related stresses.[54]

An expanding population and regional land-use changes have reduced land available for agriculture and forests faster in the Southeast than in any other region in the contiguous United States.[55] Climate change is also expected to change the unwanted spread and locations of some nonnative plants, which will result in new management challenges.[56]

Heat stress adversely affects dairy and livestock production.[57] Optimal temperatures for milk production are between 40ºF and 75ºF, and additional heat stress could shift dairy production northward.[58] 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.[59]

Summer heat stress is projected to reduce crop productivity, especially when coupled with increased drought (Ch. 6: Agriculture). The 2007 drought cost the Georgia agriculture industry $339 million in crop losses,[60] and the 2002 drought cost the agricultural industry in North Carolina $398 million.[5] 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 based on a crop yield simulation model.[61] In Georgia, climate projections indicate corn yields could decline by 15% and wheat yields by 20% through 2020.[62] In addition, many fruit crops from long-lived trees and bushes require chilling periods and may need to be replaced in a warming climate.[61]

Adaptation for agriculture involves decisions at many scales, from infrastructure investments (like reservoirs) to management decisions (like cropping patterns).[63] Dominant adaptation strategies include altering local planting choices to better match new climate conditions[63] and developing heat-tolerant crop varieties and breeds of livestock.[5,58] Most critical for effective adaptation is the delivery of climate risk information to decision-makers at appropriate temporal and spatial scales,[58,63] and a focus on cropping systems that increase water use efficiency, shifts toward irrigation, and more precise control of irrigation delivery (See also Ch. 28: Adaptation, Table 28.7).[5,58]

The southeastern U.S. (data include Texas and Oklahoma, not Puerto Rico) leads the nation in number of wildfires, averaging 45,000 fires per year,[64] and this number continues to increase.[65,66] Increasing temperatures contribute to increased fire frequency, intensity, and size,[64] though at some level of fire frequency, increased fire frequency would lead to decreased fire intensity. Lightning is a frequent initiator of wildfires,[67] and the Southeast currently has the greatest frequency of lightning strikes of any region of the country.[68] Increasing temperatures and changing atmospheric patterns may affect the number of lightning strikes in the Southeast, which could influence air quality, direct injury, and wildfires. 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.[69] Wildfires also affect human health through reduced air quality and direct injuries.[69,70,71] Expanding population and associated land use fragmentation will limit the application of prescribed burning, a useful adaptive strategy.[66] Growth management could enhance the ability to pursue future adaptive management of forest fuels.

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.[72] 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.[73] Due to southern forests' vast size and the high cost of management options, 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.[74] Energy use is approximately 27% of the U.S. total, more than any other region.[5] 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. Energy costs are of particular concern for lower income households, the elderly, and other vulnerable communities, such as native tribes.[5,10] Long periods of extreme heat could also damage roadways by softening asphalt and cause deformities of railroad tracks, bridge joints, and other transportation infrastructure.[75]

Increasing temperatures will affect many facets of life in the Southeast and Caribbean region. 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 Ch. 28: Adaptation.

Water Availability

Decreased water availability, exacerbated by population growth and land-use change, will continue to increase competition for water and affect 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.[11,76] 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.[77] Droughts are one of the most frequent climate hazards in the Caribbean, resulting in economic losses.[78] Water supply and demand in the Southeast and Caribbean 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.[4,5] While change in projected precipitation for this region has high uncertainty (Chapter 2: Our Changing Climate), there is still a reasonable expectation that there will be reduced water availability due to the increased evaporative losses resulting from rising temperatures alone.

With projected increases in population, the conversion of rural areas, forestlands, and wetlands into residential, commercial, industrial, and agricultural zones is expected to intensify.[55] The continued development of urbanized areas will increase water demand, exacerbate saltwater intrusion into freshwater aquifers, and threaten environmentally sensitive wetlands bordering urban areas.[24]

Additionally, higher sea levels will accelerate saltwater intrusion into freshwater s

upplies from rivers, streams, and groundwater sources near the coast. Porous aquifers in some areas make them particularly vulnerable to salt water intrusion.[36,79] For example, officials in the city of Hallandale Beach, Florida, have already abandoned six of their eight drinking water wells.[80]

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.[5]

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[81] (for additional specific information see the Clayton County Water Authority website at: http://www.ccwa.us/).

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As seen from Figure 17.11, the net water supply availability in the Southeast is expected to decline over the next several decades, particularly in the western part of the region.[82] 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.[83]

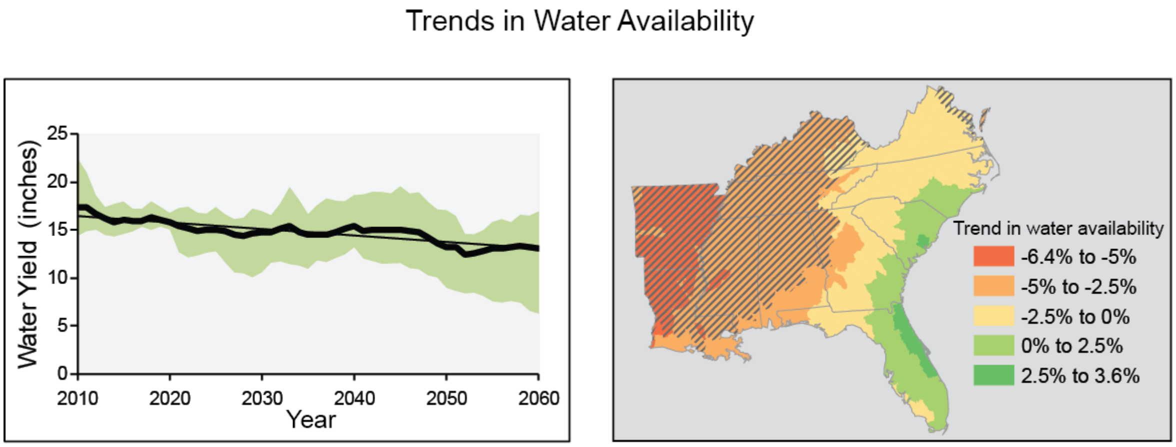

Figure 17.11: Trends in Water Availability

Caption: Left: Projected trend in Southeast-wide annual water yield (equivalent to water availability) due to climate change. The green area represents the range in predicted water yield from four climate model projections based on the A1B & B2 emissions scenarios. **Right:** Spatial pattern of change in water yield for 2010-2060 (decadal trend relative to 2010). The hatched areas are those where the predicted negative trend in water availability associated with the range of climate scenarios is statistically significant (with 95% confidence). As shown on the map, the western part of the Southeast region is expected to see the largest reductions in water availability. (Figure source: adapted from Sun et al. 2013[82]).

A Southeast River Basin Under Stress

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 future climate change is expected to exacerbate this conflict.[84] 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 (with possible impacts to fisheries at the mouth of the Apalachicola), 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.[84,85] Additional adaptation options could include water conservation and demand management. (Figure source: Georgakakos et al. 2010.[84])

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 wastewater, and water storage capacity are options that can help alleviate water supply stress.

The Southeast and Caribbean, 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 and Caribbean than most other areas of the country, often interact with and serve to amplify the effects of climate change on regional ecosystems.

Traceable Accounts

Chapter 17: Southeast and Caribbean

Key Message Process: A central component of the process was the Southeast Regional Climate Assessment Workshop that was held on September 26-27, 2011 in Atlanta, with approximately 75 attendees. This workshop began the process leading to a foundational Technical Input Report (TIR). That 344-page foundational "Southeast Region Technical Report to the National Climate Assessment"[5] 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 teleconference and webinar technical discussions, which included careful review of the foundational TIR,[5] 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 Southeast 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, as well as the regional economy.**
Description of evidence base	The key message and supporting text summarize extensive evidence documented in the Southeast Technical Input Report.[5] A total of 57 technical inputs on a wide range of southeast-relevant topics (including sea level rise) 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 (Ch. 2 Key Message 10). Numerous peer-reviewed publications describe increasing hazards associated with sea level rise and storm surge, heat waves, and intense precipitation for the Southeast.[5] For sea level rise, the authors relied on the NCA Sea Level Change Scenario[16] and detailed discussion in the foundational TIR.[5] Evidence that sea level rise is a threat to natural and human environments is documented in detail within the foundational TIR[5] and other technical inputs, as well as considerable peer-reviewed literature (for example, Campanella 2010).[19] Field studies document examples of areas that are being flooded more regularly, salt water intrusion into fresh water wells,[80] and changes from fresh to salt water in coastal ecosystems (e.g. fresh water marshes) causing them to die,[32] and increases in vulnerability of many communities to coastal erosion. Economic impacts are seen in the cost to avoid flooded roads, buildings, and ports;[23] the need to drill new fresh water wells;[80] and the loss of coastal ecosystems and their storm surge protection.
New information and remaining uncertainties	Tremendous improvement has been made since the last Intergovernmental Panel on Climate Change evaluation of sea level rise in 2007,[86] with strong evidence of mass loss of Greenland icecap and glaciers worldwide (Chapter 2: Our Changing Climate). Improved analyses of tide gauges, coastal elevations, and circulation changes in offshore waters have also provided new information on accelerating rates of rise (Ch. 2: Our Changing Climate, Figure 2.26). These have been documented in the NCA Sea Level Change Scenario publication.[16] Uncertainties in the rate of sea level rise through this century stems from a combination of large differences in projections among different climate models, natural climate variability, uncertainties in the melting of land-based glaciers and the Antarctic and Greenland ice sheets especially, and uncertainties about future rates of fossil fuel emissions. A further 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 on people, communities, facilities, infrastructure, and ecosystems.
Assessment of confidence based on evidence	Sea level is expected to continue to rise for several centuries, even if greenhouse gas emissions are stabilized, due to the time it takes for the ocean to absorb heat energy from the atmosphere. Because sea levels determine the locations of human activities and ecosystems along the coasts, increases in sea level and in the rate of rise will nearly certainly have substantial impacts on natural and human systems 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, given that many locations are already being affected by rising seas, more and more locations will be impacted as 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

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Key Message Process: See key message #1.

Key message #2/3	**Increasing 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.**
Description of evidence base	The key message and supporting text summarize extensive evidence documented in the Southeast Technical Input Report.[5] Technical inputs (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. The authors of a report on the Southeast climate[11] worked closely with the region's state climatologists on both the climatology and projections for temperature and associated heat events. Evidence of rising temperatures and current impacts[38,39] is based on an extensive set of field measurements. There is considerable evidence of the effects of high air temperatures across a wide range of natural and managed systems in the Southeast. Increased temperatures affect human health and hospital admissions.[38,40,42] Rising water temperatures also increase risks of bacterial infection from eating Gulf Coast shellfish[53] and increase algal blooms that have negative human health effects.[47,48] There is also evidence that there will be an increase in favorable conditions for mosquitoes that carry diseases.[46] Higher temperatures are detrimental to natural and urban environments, through increased wildfires in natural areas and managed forests[64,65,66,71] and increased invasiveness of some nonnative plants.[56] High temperatures also contribute to more roadway damage and deformities of transportation infrastructure such as railroad tracks and bridges (Ch. 5: Transportation).[75] In addition, high temperatures increase net energy demand and costs, placing more stress on electricity generating plants and distribution infrastructure. Increasing temperatures in the Southeast cause more stresses on crop and livestock agricultural systems. Heat stress reduces dairy and livestock production[57] and also reduces yields of various crops grown in this region (corn, soybean, peanuts, rice, cotton).[61,62]
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 Southeast will result in negative impacts on human health, the natural and built environments, energy, agriculture and forestry. A key issue (uncertainty) is the detailed mechanistic responses, including adaptive capacities and/or resilience, of natural and built environments, the public health system, energy systems, agriculture, and forests to increasing temperatures and extreme heat events. Another uncertainty is how combinations of stresses, for example lack of water in addition to extreme heat, will impact 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 well-being. There is also a need for research that develops or identifies more resilient, adapted systems.

Assessment of confidence based on evidence	**Increasing Temperatures:** There is **high** confidence in documentation that projects increases in air temperatures (but not in the precise amount) and associated increases in the frequency, intensity, and duration of extreme heat events. Projections for increases in temperature are more certain in the Southeast than projections of changes in precipitation. **Impacts of increasing temperatures:** Rising temperatures and the substantial increase in duration of high temperatures (for either the low [B1] or high [A2] emission scenarios) 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 Southeast will result in higher risks of negative impacts on 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 (without human intervention) or be adapted (by people) to higher temperatures, and partly due to the limited knowledge base on the wide diversity that exists across this region in climates and human and natural 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

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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 affect the region's economy and unique ecosystems.**
Description of evidence base	The key message and supporting text summarize extensive evidence documented in the Southeast Technical Input Report (TIR).[5] Technical inputs (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. Numerous salient studies support the key message of decreased water availability, as summarized for the Southeast in the TIR.[5] Evidence for the impacts on the region's economy and unique ecosystems is also detailed in the TIR[5] and the broader literature surveyed by the authors.[78]
New information and remaining uncertainties	Many studies have been published since 2007 documenting increasing demands for water in the Southeast due to increases in populations and irrigated agriculture, in addition to water shortages due to extensive droughts.[5,11] There is also new evidence of losses in fresh water wells near coastlines due to saltwater intrusion,[79,80] and of continuing conflicts among states for water use, particularly during drought periods.[5,84] It is a virtual certainty that population growth in the Southeast will continue in the future and will be accompanied by a significant change in patterns of land-use, which is projected to include a larger fraction of urbanized areas, reduced agricultural areas, and reduced forest cover.[55] With increasing population and human demand, competition for water among the agriculture, urban, and environment sectors is projected to continue to increase. However, the projected population increases for the low (B1) versus high (A2) emission scenarios differ significantly (33% versus 151%).[11] Consequently, the effect of climate change on urban water demand for the low emission scenario is projected to be much lower than for that of the high emission scenario. Land-use change will also alter the regional hydrology significantly. Unless measures are adopted to increase water storage, availability of freshwater during dry periods will decrease, partly due to drainage and other human activities. Projected increase in temperature will increase evaporation, and in areas (the western part of the region[87]) 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 Southeast, 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 these areas are already being impacted by SLR and land subsidence. Projections of specific spatial and temporal changes in precipitation in the Southeast 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. For the Southeast, there are no reliable projections of evapotranspiration, another major factor that determines water yield. This adds to uncertainty about 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	There is **high** confidence in each aspect of the key message: It is virtually certain that the water demand for human consumption in the Southeast will increase as a result of population growth. The past evidence of impacts during droughts and the projected changes in drivers (land use change, population growth, and climate change) 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. Water supply is critical for sustainability of the region, particularly in view of increasing population and land-use changes. Climate models' precipitation projections are uncertain. Nonetheless, 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 low [B1] or high [A2] emission scenarios), will have a significant impact on water availability for all sectors.

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

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