Chapter 5

Climate Interactions with the Built Environment in the Southeast USA

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The built environment in the Southeast (SE) United States comprises components influenced by human alteration of the landscape, and subsequent physical, environmental, and socio-economic systems related to landscape modification. Thus, the built environment is manifested at spatial scales ranging from small (e.g., offices, houses, hospitals, shopping malls, schools), to larger scales (e.g., transportation networks, communities), or as highly modified landscapes such as cities (Younger et al., 2008). The impacts of climate change on the built environment, therefore, may have a multitude of affects on humans and the land, and the impact of climate change may be exacerbated by the interaction of different events that singularly may be minor, but together, may have a synergistic set of impacts that are quite significant. As a consequence, climate change impacts will affect many aspects of the built environment in the southeastern US.

Key Findings

- Areas of the built environment likely to be affected by climate change include human health (from a specifically urban perspective primarily as related to air quality); the urban heat island effect, precipitation, urban flooding, the urban-wild land interface, tourism, energy, poverty and socio-economic vulnerability, migration, the coastal environment, and even have implications on national security.
- Development of adaptation plans to maintain built environment infrastructure and its natural milieu are imperative to cope with the effects of climate change and to ensure built environment sustainability.
- Because of the complexity of the built environment and its supporting ecosystems, we must operate at a component-by-component level to assess various types of adaptability measures needed to make the individual systems sustainable and resilient.
- Good stewardship of the resources that comprise the subcomponents of systems related to the built environment, as well as climate change adaptation planning, are primary requirements of success in dealing with these challenges.

5.1 Background

In this report, the "built environment" refers to the part of the overall landscape that is distinct from the natural environment, that part where humans have in some way transformed or imprinted non-natural features across the landscape. The impact of climate change has the potential to be exacerbated by the interaction of different events that singly could be minor, but together could have a synergistic set of impacts that are significant. Also, there are possible feedback mechanisms wherein the built environment, particularly cities, could affect weather and the climate on local and regional scales. The impacts of climate change on built environments in the Southeast (SE) will have a collective impact on the overall urban ecosystems for cities in the region. An urban ecosystem can be defined as a composite of (1) the natural environment, (2) the built environment, and (3) the socioeconomic environment (Clark 2008).

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

This section of the technical report focuses on the potential impacts that a changing climate is likely to have on several key aspects of the built environment in the southeastern USA: air quality; the urban heat island effect; precipitation; urban flooding; urban forestry and the urban-wild land interface; tourism; energy, poverty, and socioeconomic vulnerabilities; and urban migration. There are significant and definitive ways to mitigate and/or adapt to the effects of climate change on the built environment, and there are numerous example of actions being planned or undertaken in the SE, which are discussed in Chapter 13. The key to successfully implementing such strategies is to educate policy and decision makers, planners, and the general public. In this era of widespread usage of digital technology, there are numerous ways to communicate both the potential impacts of climate change on the built environment and subsequent methods for adapting to, or mitigating, these impacts. Establishment of publically accessible websites, blogs, and Wiki's that clearly articulate the nature of climate cause and effect impacts, and indicators that definitely point to the onset and progression of climate change are of critical importance within the overall scope of climate change education and communication. Such communications should be geared towards users of this information, such as metropolitan county and municipal governments, nonprofit or nongovernmental entitites, and the interested general public. This information must also be conveyed through online magazines, newspapers, and trade magazines, as well as the print and broadcast media. Additionally, there is an emerging industry of communication and engagement technology, especially in gaming and risk communications, that use relational databases similar to climate indicators that could be used to reach broad audiences, including interacting with K-12 and higher education (NCA 2011).

The impact of climate change on urban areas in the USA can potentially have far-reaching effects on the local and regional environment and in cities and their adjacent surroundings, sometimes referred to as the "periurban" environment. These impacts likely will affect the atmosphere above and around cities through alteration of the physical parameters that govern the land-atmosphere interface over urban areas. In turn, this may have broader impacts on atmospheric phenomena and regional interactions that encompass large-scale physical and environmental processes. Feedback mechanisms in urban areas have potential effects on physical parameters and interactions that can influence local and regional meteorology, and, in the long-term, the climate (World Bank 2010, Lankao 2008). Three impacts are of concern: (1) degradation of air quality; (2) an increase in the size and extent of the urban heat island (UHI) effect; and (3) changes in precipitation, including increases or decreases in amount or intensity.

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

5.2 Air Quality

Air quality in the SE, particularly over cities, is currently problematic and is projected to be even more so in the future (Stone 2008, Levy 2009). Purturbations that contribute to increases in stagnant air in many regions include (1) effects of increased temperatures on atmospheric reactions; (2) effects of increased temperature on atmospheric reaction rates; (3) effects of increased water vapor concentrations; and (4) effects of increased pollutant levels at the inflow boundary layer (Millstein and Harley 2009). An observed correlation between surface ozone and temperature in polluted regions suggests a detrimental effect of warming (Sillman and Samson 1995, Jacob and Winner 2006, Stone 2011). Studies of global climate models (GCMs) coupled with chemical transport models (CTMs) show that climate change alone will increase summertime surface ozone in polluted regions by 1 to 10 parts per billion (ppb) over the coming decade, with the largest effects in urban areas and during pollution episodes (Jacob and Winner 2006). Ozone (O_3), which is emitted at ground level, is created by a chemical reaction between oxides ($NO_{x)}$ and volatile organic compounds (VOCs) in the presence of sunlight (Figure 5.1). Motor vehicle exhaust and industrial emissions, gasoline vapors, and chemical solvents also contribute to ozone formation. Sunlight and hot weather cause ground-level O_3 to form harmful concentrations in the air. Peak O_3 levels typically occur during hot, dry, stagnant summertime conditions that are exacerbated by the urban heat island effect. The length of the ozone season varies from region to region. Southern and southwestern cities could have an ozone season that lasts for several months.

The effect of increased temperatures on particulate matter is more complicated and uncertain than are the effects on ozone. Course particulate matter also contributes to air pollution. Particles with diameters between 2.5 and 10 micrometers (μg) are referred to as "coarse." Sources of coarse particles include crushing or grinding operations, and dust from paved and unpaved roads. Other types of particles may be formed in the air from chemical changes that are indirectly created when gases from burning fuels react with sunlight and water vapor. These particles can result from fuel combustion in motor vehicles, at power plants, and other industrial processes (EPA 2011). Studies illustrate that increased temperatures are likely to increase particulate matter in polluted environments by ± 0.1-1 μg m^{-3} over the coming decades (Jacob and Winner 2006).

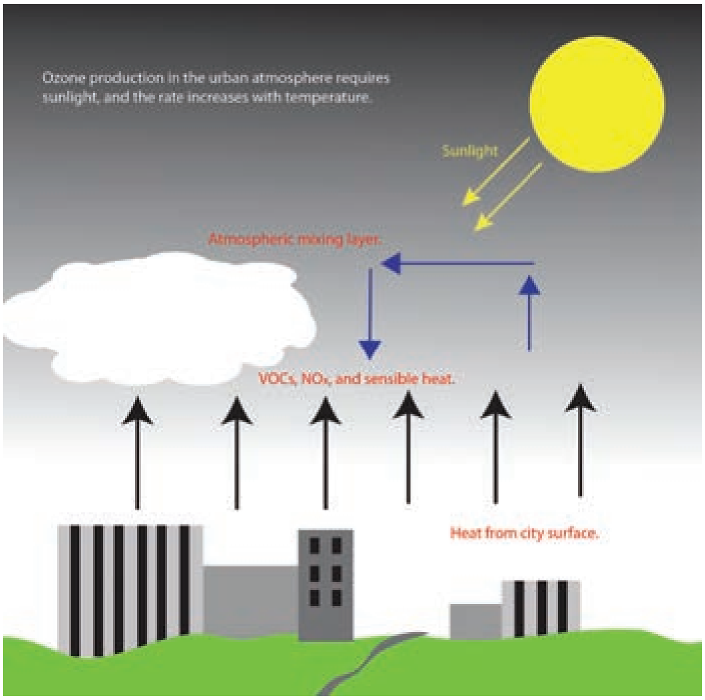

Figure 5.1 Ozone formation in the urban atmosphere (Quattrochi et al. 2006).

5.3 The Urban Heat Island Effect

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

As urbanization continues and forest, agricultural, and natural open lands are consumed as part of urban growth, changes in land cover around cities lead to an urban heat island (UHI). A UHI is a dome of elevated air temperatures over cities. They arise as a result of the transition from pervious to impervious surfaces increase (Landsberg

1981, Voogt 2002, Souch and Grimmond 2006, Grimmond 2010, Weng et al. 2004, Hua and Weng 2008). Development of the UHI is generated by a number of causes related to the land and atmosphere interactions that occur over cities. These include surface geometry, surface thermal properties, surface conditions, anthropogenic heat, and the urban greenhouse effect (Voogt 2002). Research using historical meteorological and satellite data illustrate that the UHI size and dimension is associated with urban growth (Oke 1973, Remar 2010, ELI 2011). This relationship is expected to continue in cities in both developed and developing countries (Goldman 2004, Dodman 2009, Zhang et al. 2011, Zhou et al. 2011, Peng et al. 2012). Moreover, it is becoming clear that the amplitude of thermal intensity of the UHI has an effect on biomes surrounding cities (Imhoff et al. 2010). As cities continue to grow, more research will be required to determine how cities will affect and be affected by climate changes locally and regionally.

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

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

The increased pace of warming in urban environments in the USA is likely to amplify the intensity of heat waves in the present period as well as enhance the magnitude of future warming trends. For example, recent studies have found the UHI effect is contributing to the increasing number of extreme heat events in SE cities (Stone et al. 2010), as well as to an amplification of heat-wave events in large cities such as Atlanta (Zhou and Shepherd 2010). Increased rates of extreme heat are more evident in sprawling cities than in more spatially compact urban areas–a relationship that is independent of where the city is located from a climate perspective, metropolitan population size, or rate of population growth (Stone et al. 2010). Another study has pointed to the likelihood that global heat waves of the future will be more intense, greater in frequency, and longer lasting (Meehl and Tebaldi 2004).

Urban-scale climate change suggests potential for health threats associated with extreme heat events. Methods to mitigate the UHI effect are necessary to abate such threats. Over the last two decades, a large number of studies have found that variable combinations of tree planting and vegetative cover, albedo enhancement, and reductions in waste heat emissions reduce urban temperatures by a minimum of 1°C to more than 6°C (Kikegawa et al. 2006, Lynn et al.2009, Rosenzweig et al. 2006, Taha 2007, Zhou and Shepherd 2010). Of the various approaches to heat island mitigation, tree planting and other vegetative strategies where water resources are sufficient are generally found to be effective. Surface reflectivity and waste heat management typically account for somewhat lower reductions of near surface air temperatures, depending upon the spatial extent of coverage and the regional landscape type (Akbari and Konopacki 2005, Hart and Sailor 2009, Lynn et al. 2009, Zhou and Shepherd 2010).

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

5.4 Effects on Precipitation

While urban heat islands and urban air pollution are fairly common in the public and scientific vernacular, the "urban rainfall effect" (Shepherd et al. 2010a) is not. Yet, the literature is fairly conclusive on urban land cover and pollution altering components of the hydroclimate, such as clouds, precipitation, and surface runoff. Historical perspectives, global confirmation of urban precipitation effects and societal implications are discussed in Ashley et al. 2012, Shepherd et al. 2011, Niyogi et al. 2011, Shepherd et al. 2010b. We present a few examples here with relevance to the SE region.

Ashley et al. (2012) conducted a climatological synthesis of how the urban environment modifies convection in various cities in the SE. Researchers used lightning and high-resolution radar to study precipitation in the cities and adjacent control regions during June through August over a 10-year period. The results confirmed positive urban amplification of thunderstorm activity (frequency and intensity) for larger SE cities such as Atlanta. Figure 5.2 illustrates that Atlanta's convective frequency counts and occurrences slope from the central business district to relatively lower values in rural areas, a conclusion that is consistent with numerous findings in the literature. Results vary as a function of size and geometry of various cities.

On the other hand, Rosenfeld et al. (2008) discussed the apparent conflicting role of aerosols in the precipitation processes. Aerosols may enhance or suppress convection under certain atmospheric conditions. While research into urban aerosol effects on precipitation has been conducted globally (Lin et al. 2011, Stjern et al. 2011, Jin and

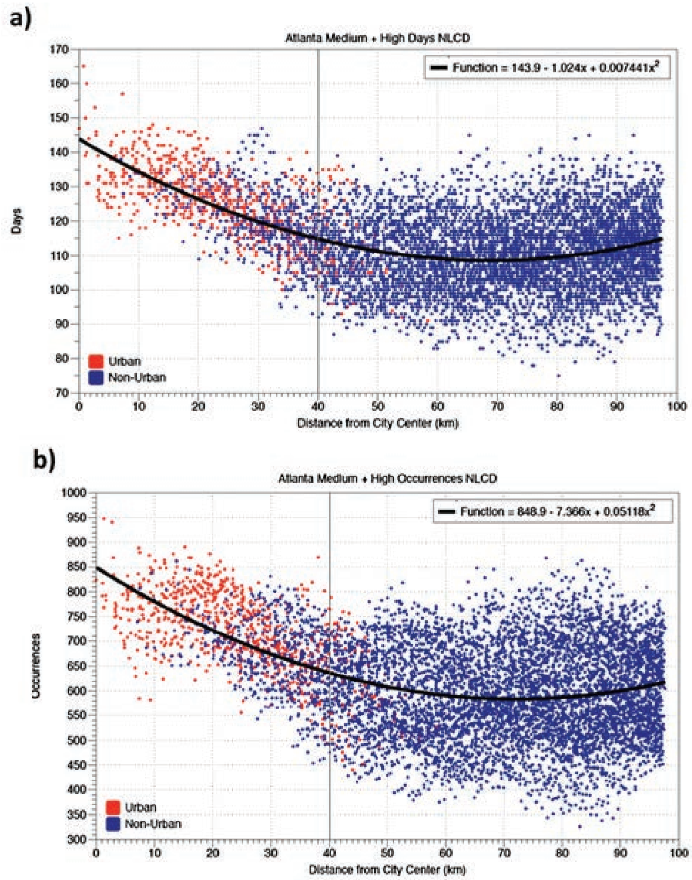

Figure 5.2 Composite radar analysis for Atlanta, GA: (a) The total number of days ≥ 40 dBZ and (b) the total number of 5-minute occurrences ≥ 40 dBZ for each 2-km grid cell versus distance from city center in the Atlanta domain for the 10-year, June through August. National Land Cover Database urban delineated cells are colored red/grey, whereas nonurban cells are blue/black. (Ashley et al. 2012).

Shepherd 2008), more research is needed in the USA. Although uncertainty remains regarding supporting details driving change in precipitation, the literature confirms the influence of the built, urban environment on precipitation. Both observational and numerical modeling research (Shepherd et al. 2010b) have indicated that one or a combination of the following processes contribute to urban precipitation effects: (1) atmospheric destabilization related to the heat island and thermal mixing, (2) enhanced convergence from building-induced mechanical turbulence and mixing, (3) modified dynamic and microphysical processes related to urban aerosols, and (4) bifurcation-physical modification because of physical or thermodynamic barriers. More research is needed to determine the relative contributions of these processes while considering other factors such as topography, urban geometry, seasonality, diurnal effects, and moisture.

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

Urban Flooding

The Intergovernmental Panel on Climate Change (IPCC 2007) notes that instances of hydrological extremes such as flooding and drought have increased markedly in the last three decades with more intense and longer episodes (Trenberth et al. 2007). Analysis by the National Oceanic and Atmospheric Administration's (NOAA) National Climatic Data Center (NCDC 2009) suggests that in the SE an increasing trend is detectable in the extreme precipitation record (Figure 5.3). Increased urban flooding has been noted in several global regions including SE cities such as Atlanta and Nashville. The southeastern USA will be increasingly vulnerable to extreme hydroclimate events because of increasing populations and population density (Seager et al. 2009). While many urban-related floods are explained by large scale meteorological and hydrological forcing (Shepherd et al. 2011), it is also clear that an urban environment may modify or increase the likelihood of flooding. Ntelekos et al. (2007) suggested that urban land cover and aerosols could have assisted in the meteorological set-up for a flood event in the Baltimore-Washington DC area. Shepherd et al. (2011) speculated that the urban landscape, through urban-enhanced precipitation, discussed elsewhere in this report, could have explained various regions of enhanced flooding around Atlanta during the historic North Georgia floods of 2009 (Figure 5.4) even as large-scale hydro-meteorological processes governed the main flooding event.

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

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

Hydrological modeling systems are important tools for assessment and prediction of hydrological flows (Poelmans et al. 2010). Urban impervious surface areas and morphological parameters are represented in such models using various technologies, such

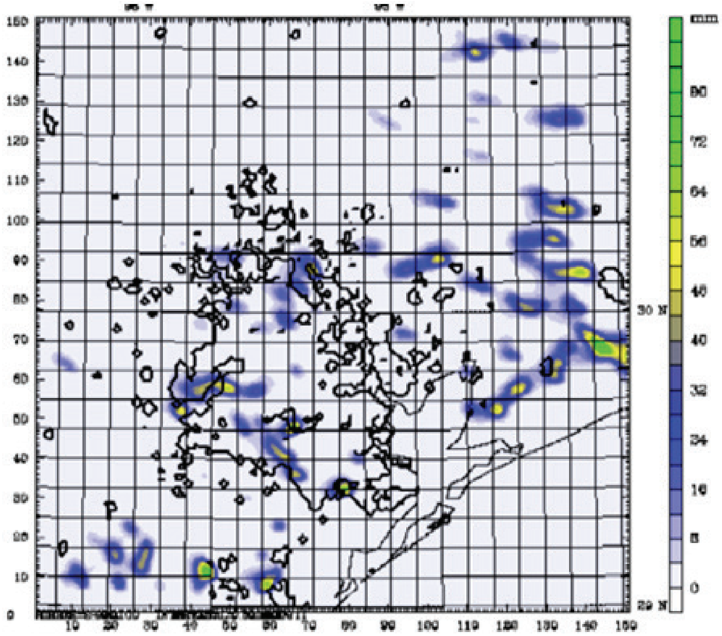

Figure 5.3 Difference (2025 Current Land Cover) in simulated rainfall amount for a typical case day in Houston, Texas. Black outline represents 2025 urban land cover. Rainfall amounts illustrated in the image correspond to the bar graph on the right hand side of the figure (Shepherd et al. 2010a).

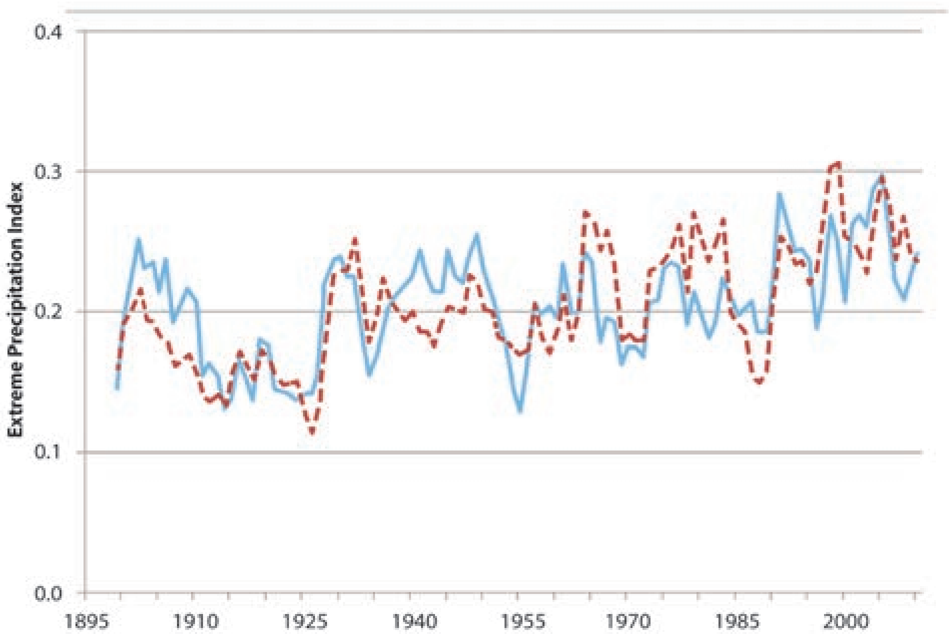

Figure 5.4 Trends in the extreme precipitation index for the southeastern USA. Red dotted line is 1 day, 1 in 5-year event. Blue line is 5-day, 1 in 5-year event Kunkel et al. 2013).

as remote sensing, aerial photography, high-resolution optical imagery, and LIDAR. However, Coon and Reddy (2008) noted that hydrological modeling still suffers from uncertainties related to input precipitation data, calibration errors, assumptions and parameterizations, land cover classification errors, and catchment scale-transfer errors. Reduction of such errors is required as increasingly complex urban landscapes and processes become explicitly represented in models.

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

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

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

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

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

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

5.6 Vulnerability and Risks to Tourism

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

Climate change is likely to create distinct and unique changes in the tourism industry in the southeastern USA. Potential impacts to the SE include droughts, floods, water quality problems, sea level rise, storm surge, heat stress, poor air quality, extreme weather events, increases in heavy downpours, rising temperatures, lengthening growing seasons, and alterations in river flows (USGCRP 2009). The effects of some of these climate changes will impact consumer travel tourism and potentially create new markets while collapsing others (Scott and Lemieux 2009). For example, having prolonged warmer days in the spring and fall would extend the golfing season, whereas such days would cut short the snow skiing season. Coastal areas that rely on tourism will likely experience the physical effects of climate change in a variety of ways from ecosystem stress and habitat loss to saltwater intrusion, drought, and flooding. Direct economic losses may include higher insurance costs, lower property values, and a decrease in tourism. However, local or regional factors, such as projected changes in population and economic growth, as well as specific weather events, may cause some of these direct economic losses (Bin et al. 2007).

Tourism and attendant recreational sectors could adapt to a changing climate in various ways, for example, alternative sources or recycled water available for golf courses, water-saving measures for the hospitality industry, or changes in a business model for ski slopes—more summer activities (Becken and Hay 2007, Curtis et al. 2011). As noted by Scott and Lemieux (2009), climate change will constitute an increasing risk for tourism operators in many destinations. Many tourism activities are heavily dependent on the climate and insurance policies that are increasingly affected by natural hazards. Thus, accurate weather information and forecasting of extreme climatic events are becoming ever more important for tourism businesses (Scott and Lemieux 2009).

Vacation and Second Homes

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

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

Second homes represent a substantial part of the vacation rental market. In 2009 vacation rentals in the USA represented a $24.3 billion market, which at the time represented 22% of the hotel market and 8% of the travel and tourism market (PhoCusWright 2009). The vacation rental market is a significant part of the economy in the SE. The PhoCusWright study found that Florida, North Carolina, and South Carolina represented 34% of the total vacation rental market. The Outer Banks Visitors Bureau also found that 43% of overnight visitors used vacation rental homes (Outer Banks 2005-2006).

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

5.7 Impacts on Energy, Poverty, and Socioeconomic Vulnerability

Climate models for the Southeast project substantial increases in days above 90°F and in numbers of consecutive very warm days. (See regional projections being finalized by Chip Konrad and Chris Furman. Also see Table 2, Kunkel et al. 2013). Comparisons of 1971 to 2000 records with 2041 to 2070 projections from dynamic and statistically downscaled models show increases of 44% to 49% in the number of cooling degree days. There is less consistency in projections of the maximum run days for high temperatures. Mean projected increases range from 97% to 234% for maximum runs of days greater than 95°F and 132% to 575% for maximum runs of days greater than 100° Fahrenheit (Table 2.2 in Chapter 2).

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

The Low Income Home Energy Assistance Program (LIHEAP) administered by the US Department of Health and Human Services serves a subset of low-income households (USDHS 2011). Table 5.1 provides more information on the number of households eligible for LIHEAP assistance, the distribution by state within the SE, and the numbers of household members who could be particularly stressed due to other vulnerabilities. There are approximately 11.5 million households in the National Climate Assessment SE region that are eligible for assistance to cover energy costs (Table 5.1). The largest number of households and households with a member over 60 years old are in Florida, where the greatest increases in heating-degree days are projected (Figure 2.12, Chapter 2).

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

Low-Income Home Energy Assistance Program (LIHEAP) Home Energy Notebook for FY 2009: Appendix B: Income Eligible Household Estimates

State-level estimates of the number of LIHEAP income eligible households using the Federal maximum LIHEAP income standard of 75 percent of SMI by vulnerability category [1,2]

Three-Year American Community Survey (ACS) 2007-2009

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

Data for this table are summarized from "Administration for Children and Families LIHEAP Home Energy Notebook for Fiscal Year 2009" (USDHHS 2011).

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

[2] The greater of 75% of state median income estimates or 150% of the US Health and Human Services (HHS) Poverty Guidelines. For "All States," 75% of state median income is greater than 150% of the HHS Poverty Guide lines.

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

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

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

5.8 Impacts on National Security

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

5.9 Impacts on Urban Migration

Throughout history, people have frequently migrated because of climate, moving from coastal areas because of flooding or from drought-stricken areas in search of water and better growing conditions. In contemporary times, the USA has seen a migration to the Sunbelt during the past several decades as many people, particularly retirees, sought more temperate weather (Svart 1976, Graves 1980). Climate change, however, can greatly affect shifts in populations when severe weather events, such as Hurricane Katrina or droughts, devastate SE regions. A significant portion of the population of New Orleans, for instance, has chosen not to return to that city after Hurricane Katrina (Grier 2005, Groen and Polivka 2009, Fussell, Sastry, VanLandingham, 2010). In other cases migration may be due to physical conditions such as property inundation due to sea-level rise or lifestyle choices such as a desire for cooler weather.

Potable water supply for urban areas has the potential to be affected directly and indirectly by climate change (Cromwell, Smith, and Raucher 2007). Regional climate change impacts that include increased frequency of drought, greater evaporation as a result of higher temperatures, saltwater intrusion, reduced groundwater recharge, and flooding threaten ground and surface water supplies. As water supply options become more limited, technological and economic water treatment challenges may emerge as more polluted water sources or saltwater sources are pressed into service. Higher temperatures could result in algae and microbe growth. Additionally, water treatment plants, transmission lines, pump stations, and other infrastructure that are located in areas vulnerable to flooding, temporary or permanent inundation, or extreme weather events will likely be at risk. Constraints in water supply and treatment options may result in limits to future growth, including an inability to meet the needs of industry or even relocation of existing residents. Communities that want to grow—or simply maintain current population—must secure stable future water supplies, which could be more difficult due to climate change challenges. Communities that cannot find adequate potable water supplies could be subject to outmigration and economic difficulties.

Regions of the USA projected to experience less severe climate change impacts, stand to gain population and economic development. (Shuford et al. 2010) The SE USA is particularly vulnerable to climate change impacts along coastal areas, and up to 46,000 km^2 (17,760 mi^2) of land could be lost in the region from a sea level rise of 1.5 meters. (Titus and Richman 2000) The Miami, FL, metropolitan area is projected to have 4,795,000 people exposed to coastal flooding by 2070, ranking ninth in the world's coastal metropolitan regions for such exposure (Nicholls et al. 2008).

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

5.10 Impacts on Coastal Environments

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

5.11 Summary of Climate Change Impacts on the Built Environment

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

The outlook, however, is not entirely gloomy. Adaptation strategies within the built environment are numerous. For example, increased tree planting, albedo enhancement (e.g., white roofs), and green roofs (e.g., plants on the roof) have the potential to moderate some effects of climate change especially related to the urban heat island. Such actions could create opportunities for reduced energy consumption, reduced heat impacts on people, and reduced GHG emissions, thus contributing both adaptations and mitigation actions. More pervious surfaces (e.g., porous paving) result in less runoff, which will decrease the magnitude of flooding during heavy precipitation events and contribute to aquifer recharge. An important aspect to successfully meeting the challenges of future climate changes is the inclusion of policy and decision makers, planners, and the general public in the planning, education efforts, and discussions. The discussions should embrace many aspects of the issues including the long-term cost benefits of adaptation strategies and how and when to apply practical strategies for implementation

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