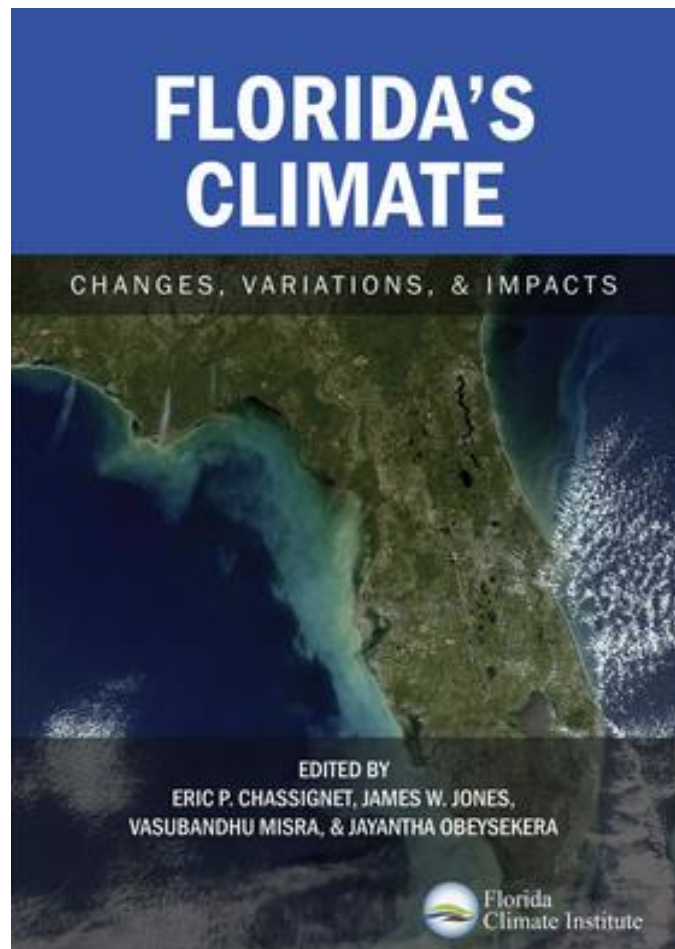


# Florida's Climate Changes, Variations, & Impacts:

Summary and Key Messages



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## Executive Summary

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*Eric P. Chassignet, James W. Jones, Vasubandhu Misra, Jayantha “Obey” Obeysekera*

Florida’s climate has been and continues to be one of its most important assets. It has enabled the growth of many major industries, including tourism and agriculture, which both rank at the top of Florida’s diverse economic activities. Florida’s weather and the natural beauty of its native ecosystems—including more than 11,000 miles of rivers, streams, and waterways and 663 miles of beaches—attract visitors and new residents from other states and around the world. The Sunshine State’s dependency on climate is widely recognized and generally taken for granted. However, as we observe climate around the world changing, questions arise about whether or not Florida’s climate is changing as well, how rapidly these changes might occur, how Florida might adapt to anticipated changes, and how Floridians might support efforts to reduce the rates of change. This includes questions about how the state’s major economic activities might be affected by climate change, how they might adapt, and how they might contribute to reducing human activities’ influence.

Although many scientific papers and books have been written on climate trends and changes at global, national, or regional scales, this book focuses on Florida—its climate, changing sea levels, the impacts of these changes, and how our societal and natural systems may adapt to anticipated changes. It addresses the unique conditions in our state and provides a thorough review of the current state of research on Florida’s climate, including physical climate benchmarks; climate prediction, projection, and attribution; and the impacts of climate and climate change on the people and natural resources in the state. Over ninety researchers from universities across the state and beyond have contributed to this volume, summarizing important topics such as sea level rise, water resources, and how climate affects various sectors, including energy, agriculture, forestry, tourism, and insurance. Authors of each chapter summarize key messages to help readers understand important risks associated with climate change and societal responses that would be beneficial to Florida’s economy, its natural resources, and the well-being of its citizens.

The purpose of this book is to provide accessible, accurate information to a broad audience, to serve as a reference on Florida’s climate and its influences on important sectors, and to introduce the various approaches that Floridians are considering for adapting to pending changes in climate and sea levels. It is intended for use by a broad audience that includes: students and educators, both at the secondary school level and at universities; policymakers; business and industry planners; and the general public. It focuses on the unique characteristics of Florida’s natural and built environments, including its peninsular features and highly active economic activities, how these characteristics are influenced by our climate systems, how changes have influenced these current and past features, and how they are likely to affect these features in the future. Furthermore, it provides information on how various components of our state’s natural and built systems may be able to adapt to future changes.

Climate change poses significant challenges to a wide range of economic activities in Florida, some of which are more critical to our state’s economy than others; for example, tourism, agriculture, forestry, fisheries and the infrastructures that support those activities. The

science that addresses these changes in climate and oceans is offered, not as an afterthought, but rather as key evidence that supports the societal impacts and responses to the anticipated changes presented in earlier chapters. The book is therefore divided in three sections: societal challenges associated with climate and climate change, economic activity challenges associated with climate change, and past, current and future physical climate.

### **Societal Challenges Associated with Climate and Climate Change in Florida**

There are many societal challenges associated with climate variability and climate change in Florida. These challenges include human health impacts, the availability of and access to essential resources such as water and energy, changes in land use, and the need for new laws and policies associated with all of these issues. Although many direct effects of climate change on Florida are of major concern, it is clear that sea level rise, and its impacts on coastal communities, infrastructure, ecosystems, and businesses, is the state's most immediate climate-related threat.

The interaction between Florida's climate and societal systems is bidirectional: climate change affects social systems and social systems influence climate change. Furthermore, communicating this can instigate social action and facilitate (or obstruct) adaptive responses. But unfortunately, while scientists develop skills for communicating with other scientists, many lack the necessary skills to effectively communicate with the broader public. This is particularly true and problematic in scientists' discussions of climate change, in part due to the complexity and potential impacts of the issue. In particular, there is a nationwide organized effort embraced by some Florida politicians to reject climate change science, which makes it difficult to consider practical and rational policies at the state level. However, as this book points out, Florida has a wide array of response capabilities for imminent threats, and they must be improved if we are to address longer-term challenges such as climate change and sea level rise.

Although there are many specific areas where climate change will impact the daily lives of Floridians across different sectors, several are of concern to all residents of the state. For instance, the chapters in this section address connections between climate change and human health. Research has demonstrated that increased risks to human health are likely to occur due to heat waves and temperature-related illnesses, waterborne and vector-borne diseases, and direct human exposure to stronger hurricanes, storm surge, intensive rainfall and flooding, and other extreme events. There are also societal challenges associated with land use, particularly those related to population growth and the possible inward migration from coastal areas due to climate change and sea level rise.

The availability and accessibility of essential resources are likely to become more limited as our climate continues to change. For example, competition for water and energy resources will continue to increase, intensified by greater demands under expected temperature increase. Policies and investment decisions will be essential to address these growing needs. Another key societal issue affecting property, infrastructure, and businesses is the changing risk levels, particularly along the coasts where vulnerabilities to climate change and sea level rise are highest. Climate change and sea level rise increase the risks of losses, thus increasing the cost of insurance and making it very likely that consumers will see substantial changes in the insurance products available to them; some of these modifications are already being made. Finally, the

authors in this section point out that some policies and laws, which were developed under more stable climate and sea level conditions, have now become obsolete. New policies and laws are needed to ensure that our social support systems adapt to climate change and sea level rise and to address these societal challenges in order to make communities and infrastructure more resilient to anticipated changes.

## **Economic and Environmental Challenges Associated with Climate Change in Florida**

Florida has one of the most vibrant state economies in the US, and all its economic sectors benefit from the pleasant climate and abundant natural resources in the state. Economic growth in Florida is predicted to outpace national trends. However, Florida's economic activities may be severely impacted by higher sea levels and projected climate conditions, including the potential for more powerful hurricanes. To achieve the predicted economic growth, business leaders must address the serious threats associated with climate change and sea level rise and develop technological and policy solutions that ensure that the state's potential is achieved. Fortunately, Florida has highly educated scientists backed by nationally acclaimed research universities as well as political and business leaders, and we have the human, physical, and natural resources necessary to address these threats.

Currently, the state's two largest economic sectors are tourism and agriculture. Both are highly dependent on climate conditions and both are vulnerable to the projected changes. The tourism industry in Florida accounts for about 2.5 million jobs, either directly or indirectly, and serves more than 106 million tourists per year, generating nearly \$90 billion in economic impact annually. Because much of the state's economic activity and projected growth are in coastal areas, solutions to overcome risks associated with sea level rise, storm surge, wind damage, and other detrimental events must be developed. And, if projected increases in temperature and the frequency of intense rainstorms disrupt many tourism activities, these risks must also be addressed.

Similarly, Florida's agricultural and forestry industries are highly vulnerable to climate, most notably to the availability of water and energy resources that are likely to be negatively impacted by climate change. Together, these two industries contribute more than \$120 billion to the state's economic revenues and support more than 2 million jobs. Fortunately, Florida agriculture has a successful history of adapting to the vagaries of weather. But climate change is occurring at an unprecedented rate, thus increasing the challenges of continuing or increasing the economic contributions of the state's agriculture sector. In the case of forestry, projected increases in temperature and atmospheric CO<sub>2</sub> concentration in Florida may actually result in increased plantation production if, as projected, rainfall remains constant or increases slightly.. Forestry provides a number of positive ecosystem services and withdraws more carbon dioxide from the atmosphere than it requires for production. Thus, this "carbon sequestration" could contribute even more to a reduction in greenhouse gases in the atmosphere. That said, science-based management approaches are essential for society to fully benefit from forest ecosystem services in the future.

Urban infrastructure is also crucial to our economic activity, supporting many businesses and contributing to the state's economic activity through construction, revitalization, and maintenance. Similar to agriculture and tourism, Florida's urban development and populations are concentrated in the coastal areas. This means that infrastructure is also highly vulnerable to sea level rise and climate change, particularly near the coasts, where we continue to see increasing coastal development and population densities. Thus, a large portion of Florida's urban infrastructure is susceptible to damage due to storm surge, flooding, and wind. New technologies, policies, and strategies are needed at the individual and community-level that will lead to the development of a more resilient and sustainable urban infrastructure.

Florida's biodiversity and ecology are central to most of the state's economic activities and valued greatly by its residents. The rich biodiversity of Florida is the product of climate conditions, geographic position, and geology, all of which contribute to the unique ecosystems that exist. This biodiversity and the resulting ecosystems are highly vulnerable to changes in climate and local hydrology; they are dependent upon society's willingness and ability to protect them. They may disappear if coastal populations continue to grow, causing development that displaces coastal habitats, and if projected increases in sea level lead to coastal habitat inundation. Some of this is already happening. Migration of wildlife from affected areas may also be threatened due to loss of habitats, making the biodiversity of coastal ecosystems extremely vulnerable. Adaptive capacity to climate change must be improved to avoid unwanted losses in these critical areas.

Florida's extensive shorelines support a diverse marine life that contributes significantly to the economy of the state in a variety of ways. This section also deals with potential impacts of climate change on the vast marine habitat of Florida, such as coral bleaching, warming of the Gulf of Mexico, and ocean acidification, which can affect larval and nutrient transport and fisheries production and lead to harmful algal blooms.

Finally, marine and freshwater fisheries and other large aquaculture industries contribute about \$15 billion annually to Florida's revenue. These types of industries are also highly vulnerable to higher temperatures, more frequent severe storms, and sea level rise. The interactions between climate change and fish production/catches are complex, making it difficult to accurately assess the impacts. However, it is likely that there will be negative effects from climate change in Florida that will need to be addressed to help sustain the viability of these industries.

### **Florida's Physical Climate: Past, Current, and Future**

The peninsular geography of Florida is an outcome of tectonic movements that took place some ~200 million years ago with the simultaneous creation of the Gulf of Mexico and the Caribbean Sea. Consequently, Florida, surrounded by water, has a unique climate characterized by sea breezes that bring moist air to both the east and west coasts and by a strong seasonality in rainfall. The cyclic growth and retreat of huge ice sheets in the Northern Hemisphere lead to strong fluctuations in sea level, alternatively exposing or covering the Florida Peninsula. A paleoclimate analysis of Florida reveals clearly the interglacial cycles punctuated by the glacial periods, which make detection of regional climate change trends non-trivial. To compound this intricate entanglement, Florida's climate is dependent upon phases of the El Niño and the

Southern Oscillation (ENSO), the Atlantic Multi-decadal Oscillation (AMO), and the Pacific Decadal Oscillation (PDO).

Despite this complexity of regional climate variations, significant progress has been achieved in the seasonal prediction of winter climate over Florida on the basis of the persistence of large-scale variations of ENSO. However, regional climate predictions are daunting and challenge our current understanding and state-of-the-art climate models to account for the correct balance of influences including remote large-scale climate drivers (e.g., ENSO), local feedback (e.g., land-biosphere-atmosphere interactions), and climate change.

There is undeniable evidence linking increased greenhouse gas emissions to sea level rise. The discussion of sea level rise presents this evidence and shares an in-depth discussion on the challenges of arriving at quantitative sea level rise estimates for Florida. There is also the issue of climate and weather extremes affecting Florida that increases the vulnerability profile of the state and makes it a focus of the risk insurance market. This section gives a thorough review of events such as droughts, land-falling tropical cyclones, tornadoes, severe thunderstorms, and lightning, which cause collateral damage and human fatality periodically across Florida. Finally, the variations and triggers of such extreme events are discussed in this book, providing a complete picture of the physical (earth, ocean, and atmosphere) climate system of Florida.

## **Conclusion**

There is no doubt that development, climate change, vulnerability, and risk go hand in hand, particularly in Florida. These vulnerabilities and risks exist in all segments of Florida, but they are particularly severe along our coastline where negative impacts are already being felt. Understanding these linkages is important and will help in the development of effective mitigation and adaptation strategies to address the impacts of climate change. The purpose of this book is to share knowledge about this linkage that has been gathered over years of research from experts around the state, and to provide candid views on the known, unknown, and the unknowable. There is no silver bullet to eliminate the risks imposed on Florida by climate change. But making informed decisions in light of potential future climate evolution would go a long way toward mitigating at least some of future vulnerabilities and risks. It is our sincere hope that the contents of this book will help move us in this direction.



# Societal Challenges Associated with Climate and Climate Change in Florida

## 1. Human Dimensions and Communication of Florida's Climate

*Peter J. Jacques, Kenneth Broad, William Butler, Christopher Emrich, Sebastian Galindo, Claire Knox, Keith W. Rizzardi, and Kathryn Ziewitz*

Florida's climate system, which is nested within regional and global climate systems, cannot be fully understood without including human dimensions that interact with the climate systems in two principal ways: 1) where social systems facilitate or dominate causes of climate change, and 2) where climate change affects social systems. These aspects include complex social interactions and feedbacks, but can be broken down into the impacts, risks, and causes of climate change specific to Florida. Further, communication of these elements can interact with social in/action and facilitate or obstruct adaptive responses. It is important to view the organization of these interactions through social structure, where essential drivers of social forces include the political-economy, demographic, and attitudinal architecture of Florida social systems. In this chapter, we review key social drivers of specific impacts, risks, and causes of climate change within Florida.

### Key Messages

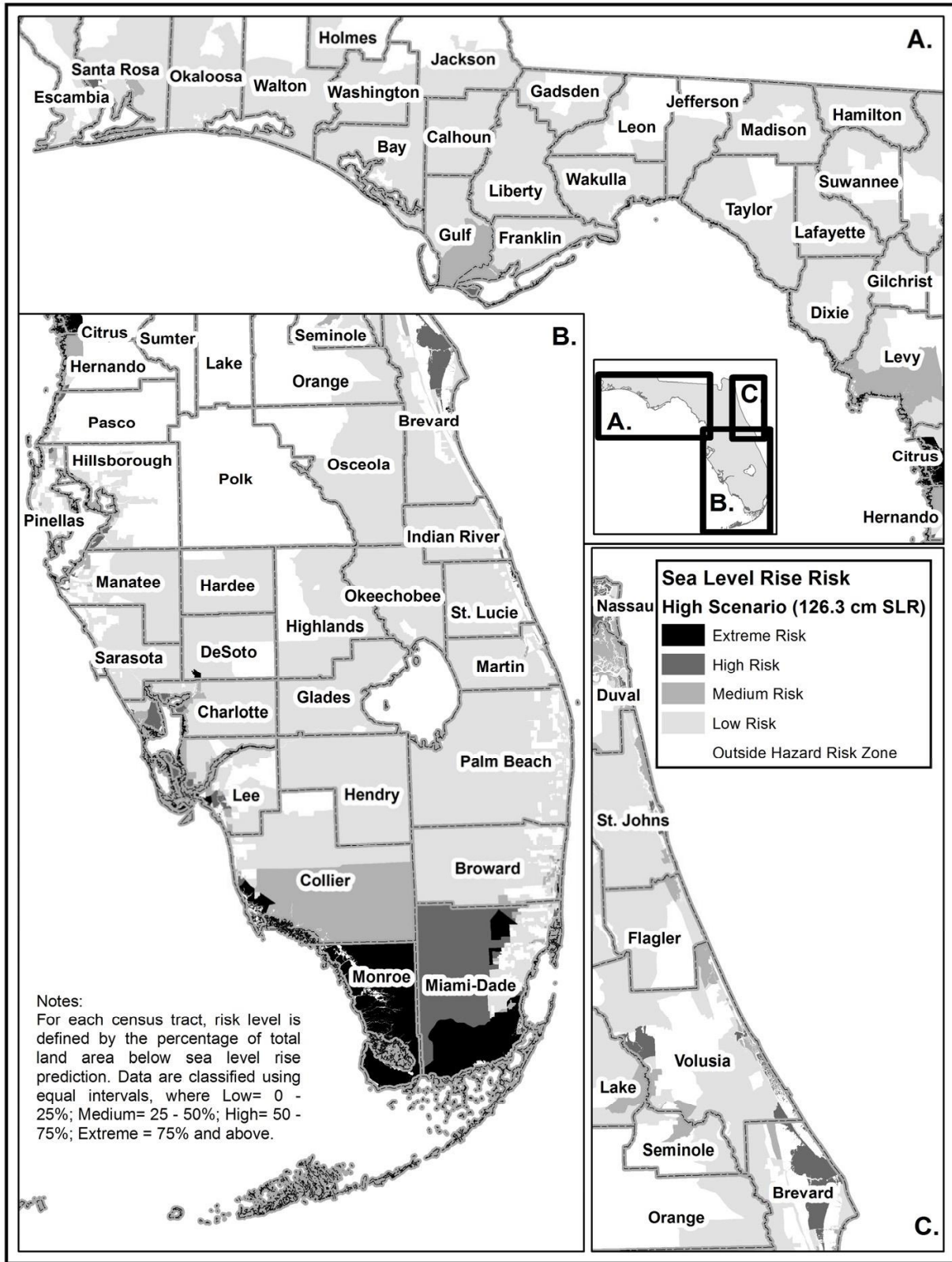
#### Mitigation

- Florida faces a series of threats from climate change that will affect social groups and geographic areas differently. Florida's future depends critically on global reductions of greenhouse gases (GHGs). Florida itself is the 27th largest GHG emitter across all states and other countries. This makes it essential that Florida contribute to global reductions.
- To understand how to reduce GHGs, one needs to be familiar with the development of land and energy in the state that determines sources of power for buildings, transportation infrastructure, and the institutions (rules and laws) that ultimately guide the consumption of hydrocarbon-based energy. Florida has been guided heavily by land and highway development, with almost all the energy consumed in the state coming from sources that directly emit GHGs, with the exception of nuclear power plants.
- There are important macro and micro obstacles to change that must be understood. At the macro level, social structures guide the behavior of large groups, and individuals acting alone are less effective in reducing GHGs than changing these social structures, including institutions. A significant obstacle has been a national organized effort to reject climate change science that some Florida politicians have reproduced at the state level, making policy efforts in this area difficult to even discuss.

- At the micro level (the individual), communication does not necessarily consist of what people say, but instead what is heard. Improvements in reaching out to different target audiences will require engaging creative approaches to communication.
- And providing information is only one step in the process. Sustaining motivation for change remains one of the biggest challenges and will require collaboration among academics, practitioners, and community leaders to ensure that we continue to move forward.

## Impacts and Adaptation

- Effective change strategies will require the coordinated collaboration of multiple sectors of society.
- GHG emissions have already exceeded the mid-scenario emission posed by the IPCC 2005 reports and are expected a continued increase in carbon emissions associated with SLR.
- The most realistic SLR estimates place Florida's shoreline 4 ft higher in 2100 than it was in 1990. However, potential impacts from SLR go beyond inundation in coastal and near-coastal areas, and include decreases in potable water for consumption and fresh water for crop growth.
- Sea level hazards have far-reaching implications beyond near-shore areas including loss of tax bases, changes in vector-borne illnesses associated with standing water, and water system failures leading to polluted waters entering the water supply.
- We can identify those areas where populations are least able to adequately prepare for, respond to, and rebound from disasters. When overlaid with potential impacts, we can create a clear path forward for adaptation, mitigation, and resilience building.
- Focusing efforts on those areas designated highly vulnerable will ensure that their respective populations will have more opportunities to increase their resilience to disasters.
- Social vulnerability results from the dynamic interaction of many socio-demographic characteristics and is specific to distinct places, beyond any one factor such as race or economic class. This means that the drivers of vulnerability are different across the landscape and policies for improving resilience need to be aware of what issues and specific drivers exist at the local level.
- Florida has a bipartisan history of funding conservation, a critically important component of both climate mitigation and adaptation efforts so long as funding is used for acquiring land and setting it aside for conservation—which does not always occur in the state.
- Florida has an array of planning tools at its disposal to mitigate imminent future threats but there is significant room for improvement in these plans, which are often incremental and disconnected from other planning documents. Efforts such as the Southeast Florida Climate Change Compact are among the most promising models for regional collaboration geared toward adapting to climate risks.



**Figure 1.2.** Sea level rise risk in Florida (126.3cm by 2100). Areas included are contiguous from the shore.

## 2. Florida Land Use and Land Cover Change in the Past 100 Years

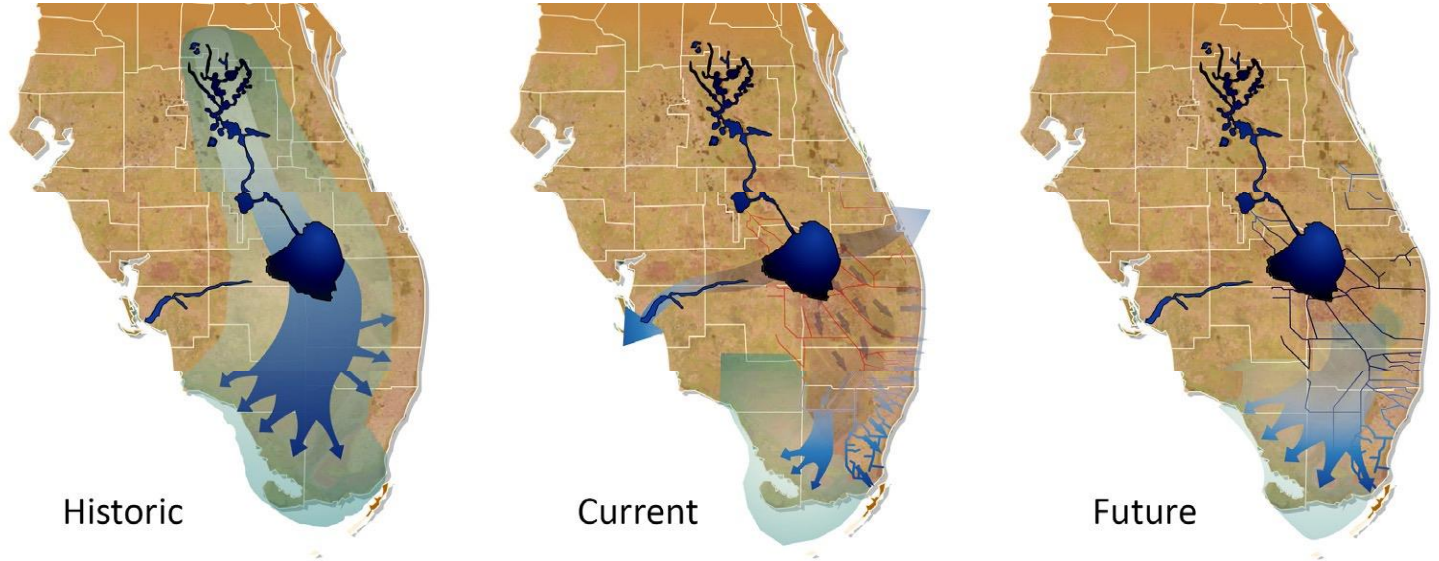
*Michael I. Volk, Thomas S. Hoctor, Belinda B. Nettles, Richard Hilsenbeck, Francis E. Putz, and Jon Oetting*

This chapter provides an overview of land use and land cover change in Florida over the past 100 years and a summary of how it may change in the future. We begin by providing a baseline description of Florida's pre-1900 land cover, natural resource distribution, and biodiversity. This is followed by a description of major land use changes and trends related to transportation, agriculture, mining, urbanization, tourism, disruption of natural processes, and conservation from 1900 to the present. We also describe changes in land use and land cover caused by climate change. The chapter concludes with a discussion of current land use and land cover patterns, and the potential impacts of climate change and continued human population growth on the remaining natural and rural landscapes in Florida. Much has changed in Florida over the last century due to a combination of wetland draining, agriculture conversion, urban development, and establishment of several dominant exotic plant species, as well as accelerating sea level rise and shifting climate zones due to climate change.

### Key Messages

- Land cover and land use within Florida have changed dramatically since pre-settlement times, primarily due to human activities, with significant impacts on ecosystems and biodiversity.
- Climate-related impacts on land cover, resulting from human-caused climate change, have also been documented in Florida.
- Patterns of historic land use and land cover change are important to quantify and visualize so that we can assess the degree to which natural systems have been impacted and changed by human activities.
- Florida still has highly significant cultural and natural landscapes, which provide important services to people, in addition to possessing intrinsic values separate from their value to humans.
- As future changes continue to occur as a result of climate change and population growth, it will be more important than ever to conduct careful land use planning and management so that we can preserve natural and cultural resources, and maintain the qualities that make Florida the special place that it is today.

## Florida Land Use and Land Cover Change in the Past 100 Years



**Figure 2.1.** Historic, current, and future hydrologic patterns in the Everglades watershed. Future hydrologic patterns are those anticipated under the Comprehensive Everglades Restoration Plan (CERP). Primary flow patterns are shown by blue arrows, with canals indicated by blue and red lines. Image credit: Jacksonville District, U.S. Army Corps of Engineers.

### 3. Implications of Climate Change on Florida's Water Resources

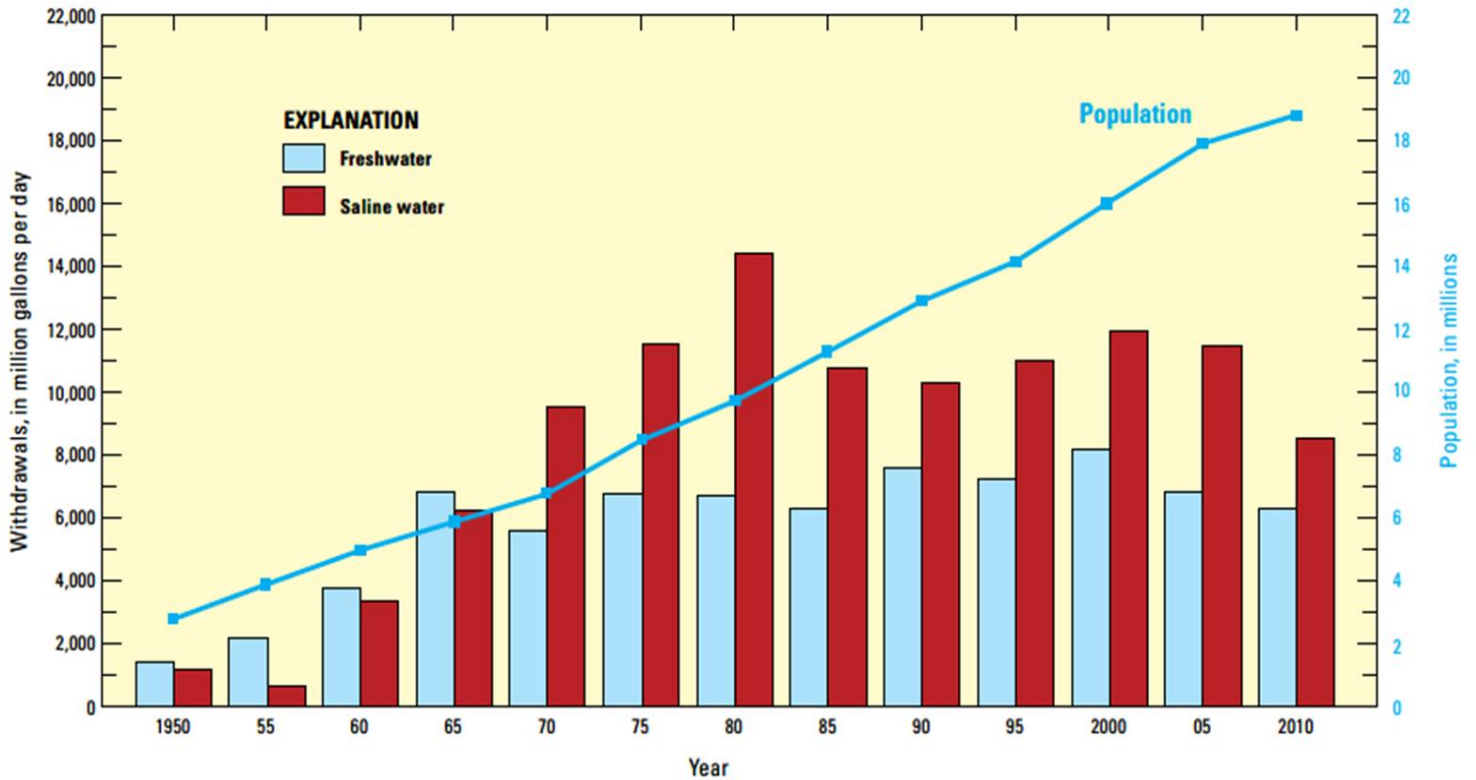
*Jayantha Obeysekera, Wendy Graham, Michael C. Sukop, Tirusew Asefa, Dingbao Wang, Kebreab Ghebremichael, and Benjamin Mwashote*

Water resources systems in Florida are unique and exhibit significant diversity in hydrogeologic characteristics and in rainfall and temperature patterns. In many parts of the state, both surface and groundwater systems are complex, highly interconnected, and any change in hydrologic drivers such as rainfall or temperature has the potential to impact the water resources of the urban, agricultural, and ecological systems. Because of this diversity, it is not possible to present a single overall outlook regarding the implications of climate change on the water resources of the state. This chapter presents brief summaries of individual studies that are available for major water resources systems in the state, which include the Everglades, the Tampa Bay region, the St. Johns River watershed, and the Suwannee River and Apalachicola River basins. Available climate models and their downscaled versions have varying degrees of bias and lack of skill that need to be considered in impact analyses. In all regions, projected changes in rainfall, temperature, and sea level may have significant impacts on water supply, water levels in environmentally sensitive areas, flood protection, and water quality.

#### Key Messages

- Water resources are an integral contributor to Florida's economy, but there is increasing competition for water supply among the urban, agricultural, and environmental sectors due to population growth in the state.
- Climate change along with rising sea levels will exacerbate the competition for water and it is extremely important to understand the potential impacts on this vital resource through actionable science that is relevant to this region.
- Although different climate models predict a consistent increase in future temperatures, future precipitation is not yet consistently predicted and could be higher or lower. Differences in precipitation propagate into significant differences in future streamflow, groundwater levels, and ET predictions.
- The range of future hydrologic conditions predicted by climate models allows an evaluation of the spectrum of possible future risks, but does not provide actionable information because the uncertainty is so high. Improvement in the ability of the climate models to simulate both retrospective and future rainfall patterns will be required before their projections can reliably be used for water resource planning and management
- Impact assessment to date on large-scale, regional basins in the state demonstrates that future climate change has a significant potential to impact both water quantity and quality, and as a consequence, additional research is necessary to develop standardized climate projections and conduct impact assessment on the water resources systems on a statewide basis.

- Potential increases in temperature, and the variations in precipitation patterns may degrade water quality, exacerbate algae problems, and cause eutrophication of important water bodies.



**Figure 3.1.** Historic total population, freshwater, and saline water withdrawals in Florida 1950–2010 (Marella 2014).

## 4. Climate Change Impacts on Human Health

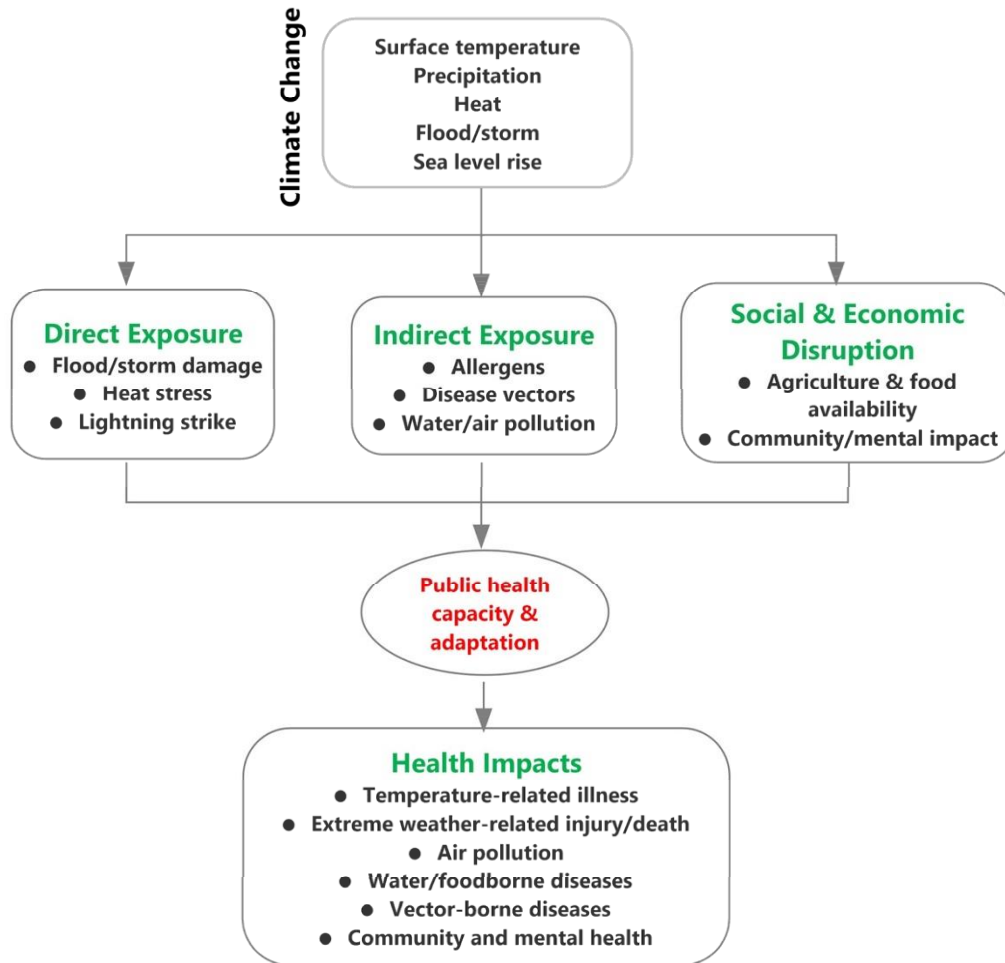
*Song Liang, Kristina Kintziger, Phyllis Reaves, and Sadie Ryan*

Climate change poses major challenges to human society and to Earth systems, influencing the functioning of many ecosystems and thereby affecting human health. Many climate change/variability- and extreme weather-associated events, such as sea level rise, hurricanes, and storm surge, as well as other weather extremes, including excessive precipitation and heatwaves, have direct and/or indirect impacts on human health. These impacts include death/injury, cardiovascular and respiratory diseases, environmentally-mediated infectious diseases, and mental health, among others. Due to its unique geography, Florida is particularly vulnerable to these environmental impacts, which have important health implications for the state's more than 20 million residents. In this chapter, we review the health impacts of climate change and associated weather events, with an emphasis on those relevant to Florida, and environmental hazards, including hurricanes and storms, lightning, sea level rise, excessive precipitation, extreme heat, and drought. There is clear evidence for significant climate-sensitive hazards and human health impacts in the state, despite uncertainties associated with the assessment of some effects. To address health impacts and challenges, policies focused on mitigation and adaptation strategies, health surveillance, and research that could close knowledge gaps on human exposures to the climate-sensitive hazards and health impacts are needed.

### Key Messages

- Florida is highly vulnerable to climate-sensitive hazards (e.g. sea level rise, heat waves, storm surge, and hurricanes), which have a wide range of human health effects.
- The health effects can be direct, such as storm/temperature related illnesses, injuries, and deaths; or indirect, such as waterborne, food-borne, and vector-borne diseases; or take social and economic pathways, such as stress and mental illness.
- The health effects exhibit substantial regional disparities across the state.
- Policies focused on health surveillance and research on knowledge gaps between human exposure to the hazards and health effects are much needed.





**Figure 4.1.** Impact pathways by which climate change and variability and related weather events affect human health.

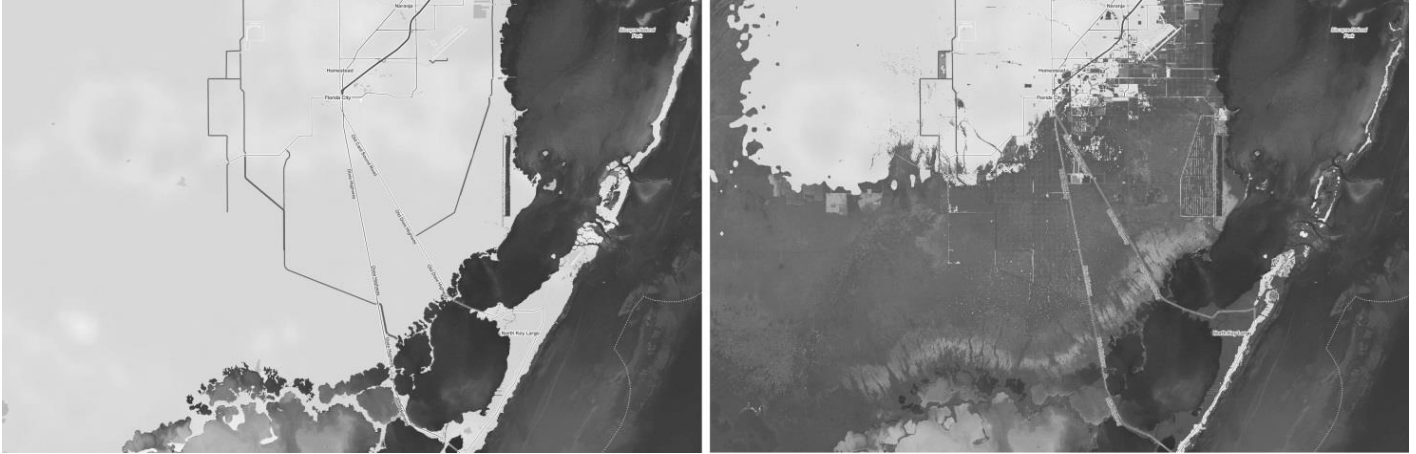
## 5. Climate Change Impacts on Florida's Energy Supply and Demand

*Wendell A. Porter and Hal Knowles III*

Florida's unique location in the contiguous United States ensures that the effects of climate change will be significant and persistent across the state. Florida's current economy and its population have developed energy use patterns based on fully developed fossil fuel industries. These industries and Florida's consumption patterns are presented and analyzed. Location of Florida's electricity generating facilities are shown and a significant proportion of these facilities are literally at the water's edge. Future actions to protect the state's energy supply may need to include costly moving of significant fossil fueled facilities and/or outright replacement by newer, cheaper renewable energy power plants. The current status of energy consumption in Florida is presented in this chapter, along with disruptive technologies in energy efficiency, renewable energy, and the electrical grid. World photovoltaic (PV) and wind power adoption rates are used to explore the possible time frames for renewable energy transformation.

### Key Messages

- Currently, Florida has very few sources of energy within its borders. There are no appreciable coal mines, natural gas fields, or oil fields.
- Florida has very little diversity in its sources of energy. More than two-thirds of Florida's electricity is produced from natural gas, and almost all of the oil used in Florida is used for transportation.
- Significant portions of Florida's energy infrastructure are located at the water's edge and may be exposed to the effects of sea level rise much sooner than we expect.
- Florida's dependence on electricity to run its economy is inefficient and not competitive in comparison with leading U.S. states and other fully developed countries.
- A significant push to incorporate energy efficiency and renewable energy into Florida's energy mix can rapidly make the state more competitive and bring down the cost of energy for all of Florida residents.



**Figure 5.1.** Existing Florida coastline compared to a future coastline scenario with a three foot rise in sea level (Harrison, adapted from Surging Seas 2016).

**Table 5.1.** Energy consumption benchmarks for selected states and countries.

Country/State	Population, millions	GDP, Trillions (\$ ppp)	Electricity consumption, Billion MWh/yr	MWh/yr, ca	\$GDP/MWh
California	39.1	2.45	0.261	6.68	9,387
United Kingdom	64	2.68	0.335	5.23	8,000
Germany	81	3.84	0.585	7.23	6,560
Japan	126	4.83	0.960	7.62	5,031
USA	321	17.95	4.05	12.62	4,432
Florida	20.3	0.89	0.237	11.69	3,768

## 6. Climate Change Impacts on Insurance in Florida

*Lorilee Medders*

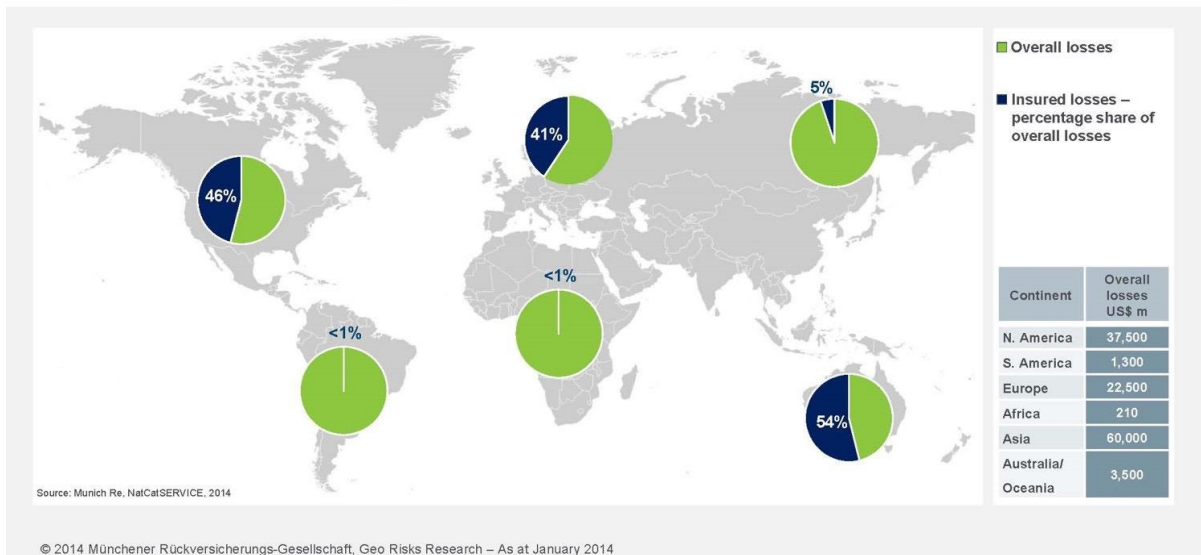
Climate change presents added risks as well as related opportunities for the insurance industry and financial sector. Implications must be evaluated for property, casualty and life insurance industry segments as well as for the financial sector more broadly. While climate change exacerbates the existing volatility of these markets, it also inherently creates opportunities for product development. Florida is a unique contributor to both the risk and opportunity since the state is the world's largest insured catastrophe region. The state of Florida itself is heavily leveraged as insurer for much of the cost of extreme weather in the form of hurricanes and other tropical storms. Unlike other insurance risk bearers, however, this state cost of risk cannot be offset by commensurate market opportunity. Increased volatility in insurance, reinsurance, and capital markets are all challenges for Florida, with potentially adverse collateral effects on residual insurance market pressures, policyholder assessments, state debt, and tax strategies. Insurance industry initiatives, to the extent they are successful, can have a balancing effect on these challenges.

### Key Messages

- The potential for substantial changes in the climate make the risk assessment, underwriting, and pricing of insurance and insurance-linked securities more complex.
- Catastrophe loss models incorporate scientific assumptions about climate change into the risk assessment capabilities for multiple disaster perils, including hurricane, flood, and wildfire, among others.
- Insurers and reinsurers are at the forefront of research regarding the effects of climate and climate change on future loss costs, loss uncertainty, and opportunity.
- Florida is and will continue to be one of the world's largest insured, catastrophe markets, and as such is highly vulnerable to changes in the climate as well as changes in the markets for protecting against financial risk.
- It is especially important for Florida and Floridians to implement smart ways of adapting to climate change and its effects in order to protect our economic sustainability.

# Loss events worldwide 2013

## Overall and insured losses per continent



**Figure 6.1.** The best measures to close the gap address the root causes of underinsurance.

**Table 6.1.** Probable Maximum Loss Estimates for the State of Florida Due to 2016 Hurricanes.

Return Period (in Years)	Critical Probability	Aggregate Gross PML (in Billions)
250	0.004	\$80.6
100	0.01	\$53.9
50	0.02	\$36.0

**Interpretation:** A one-in-hundred loss year (associated with a one% probability) would produce estimated \$53.9 billion or greater in gross loss to all Florida residential policyholders, including loss adjustment expenses. Source: State of Florida Financial Services Commission 2016b.

## 7. Climate Change Impacts on Law and Policy in Florida

*Thomas Ruppert and Erin L. Deady*

Climate change and sea level rise have made obsolete the notion that law and policy develop in the context of a relatively stable natural environment. The need of communities to adapt to climate change and sea level rise reflects the need for laws and policies governing those communities to facilitate rather than undermine such adaptation. This chapter provides an overview of law and policy issues at three levels of government—state, local, and federal. It highlights changes in state law and policy in Florida that relate to climate change and sea level rise. The chapter also focuses on local governments, and includes sections about regional collaborations of local governments, financial issues and climate change/sea level rise at the local level, examinations of impacts on infrastructure, and impacts on the public's use of beaches in Florida. The chapter concludes with discussion of a policy change related to climate change and sea level rise at the federal level that impacts local governments.

### Key Messages

- The state of Florida engagement with climate change began early, with energy law in 2006. Since then the focus of engagement in climate and sea level rise has shifted from energy to disaster planning and flooding. This shift to focus on flooding and resilience resulted from local government experience of roads and drainage being the first types of infrastructure to suffer from rising seas.
- Local governments, with much of their focus on infrastructure, have been some of the greatest centers of action on climate change, with many adopting extensive comprehensive plan policies that are increasingly being implemented through ordinances. Collaboration among local governments has resulted in increased focus on climate change and sea level rise as well as harmonized approaches to the challenges.
- Among the challenges that Florida faces is protecting the state's beaches, which are the lifeblood of Florida's tourism industry.
- Federal actions (from federally-supported research and data to federal policy changes to the National Environmental Protection Act and the new Federal Flood Risk Management Standard) have been both drivers and supporters of state and local activities on climate change and sea level rise, though recent changes at the federal level have eliminated some of these drivers.

# Economic and Environmental Challenges Associated with Climate Change in Florida

## 8. Climate Change Impacts and Adaptation in Florida's Agriculture

*Young Gu Her, Kenneth J. Boote, Kati W. Migliaccio, Clyde Fraisse, David Letson, Odemari Mbuya, Aavudai Anandhi, Hongmei Chi, Lucy Ngatia, and Senthold Asseng*

In this chapter, we describe Florida's agriculture, the vulnerability of its crops and livestock to climate change and possible adaptation strategies. Much of Florida's agricultural success is linked to its moderate climate, which allows vegetable and fruit crop production during the winter/spring season as well as the production of perennial crops such as citrus and sugarcane. In addition, there is a substantial livestock industry that uses the extensive perennial grasslands. While rising CO<sub>2</sub> is generally beneficial to crop production but detrimental to nutritional quality, increase in temperature will cause mostly negative effects on yield. Florida's agriculture faces additional challenges from climate change characterized by sea level rise and intensified extreme climate events, affecting land and irrigation water availability, livestock productivity and pest and disease pressure. New technologies and adaptation strategies are needed for sustainable agricultural production in Florida, including increased water and nutrient use efficiency in crops, crop and livestock breeding for heat stress, pest and disease resistance and reduced exposure of livestock to high temperature. Irrigation is a favored adaptation, but places an even greater burden or potential conflict between agriculture and community use of water resources.

### Key Messages

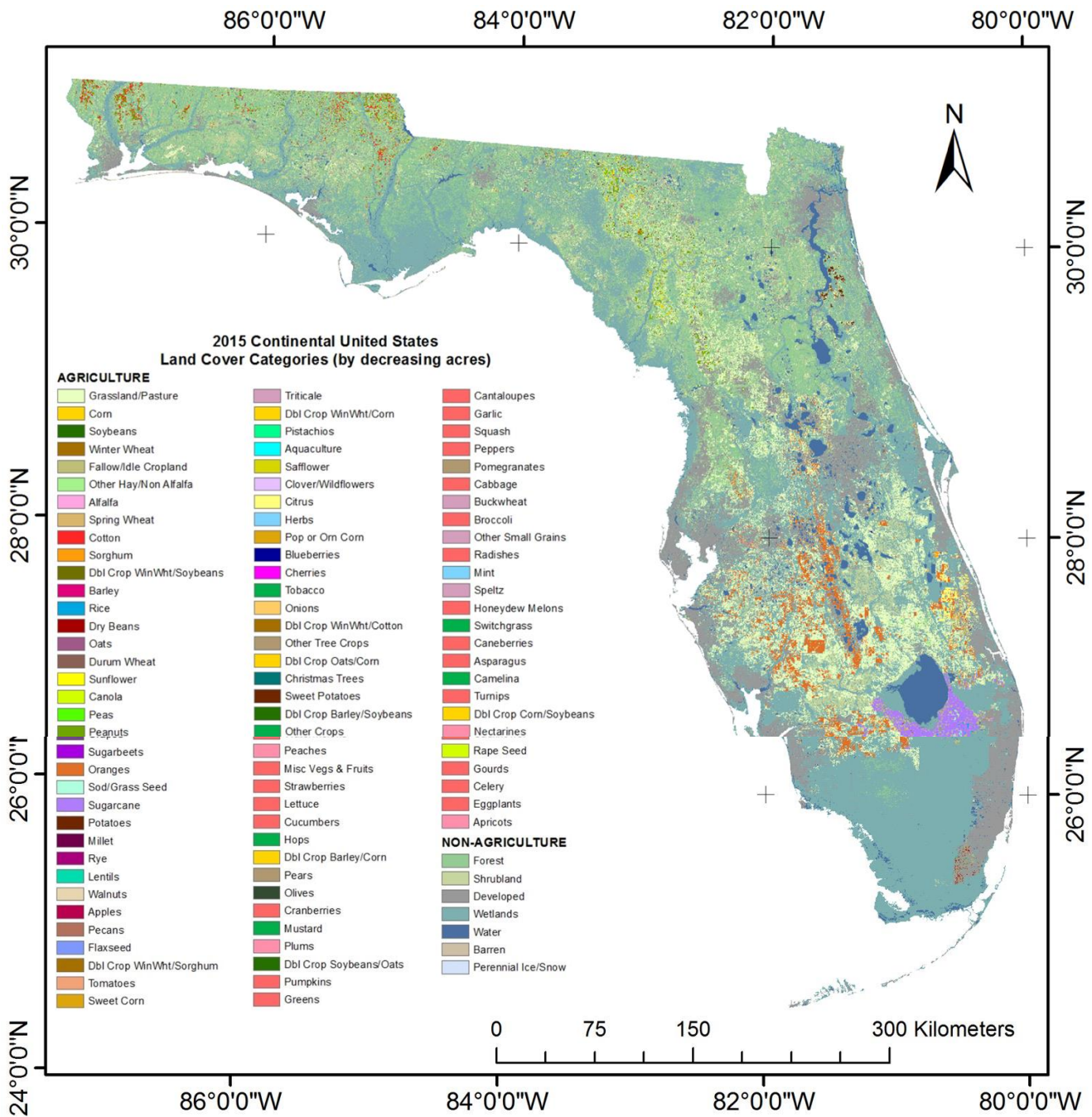
- Florida's agricultural industries provide over \$120 billion in economic revenue to the state, second only to tourism, and support more than two million jobs.
- Florida's diverse climate conditions make it suitable for many crops, fruits, livestock, and seafood, although these are vulnerable to climate variations that occur from year to year.
- Florida's agriculture has a long history of successful adaptations to the vagaries of weather and climate, but climate change poses a challenge that is unprecedented in magnitude and rates of change.
- Although current temperatures are near optimal for growing many of our crops, yields are lower during the hotter seasons that occur now, and additional increases in future temperatures will lead to lower crop yields, creating challenges to the competitiveness of current production systems.
- Florida's agriculture faces additional challenges from climate change characterized by sea level rise and intensified extreme climate events, affecting land and irrigation water availability, crop yield and quality, livestock productivity, as well as pest and disease pressures.

- The known increases in atmospheric CO<sub>2</sub> concentration can stimulate growth in some crops but will reduce the nutritional value of many food crops. Higher atmospheric CO<sub>2</sub> concentration will also increase canopy temperatures and could add to the adverse effects of temperature.
- New technologies and adaptation strategies needed for sustainable agricultural production in Florida include increased water and nutrient use efficiency in crops, crop and livestock breeding for heat stress, pest and disease resistance, and reduced exposure of livestock to high temperatures.
- Knowledge gaps include an understanding of climate change impacts on growth and nutritional value of vegetable and fruit crops, the dynamics of pests and diseases, and direct and indirect effects (the latter via pasture growth) on livestock and livestock-crop systems.
- New experiments and development of modeling and analysis tools are needed for many of the economically-important agricultural systems in order to better estimate climate change impacts on Florida’s diverse agricultural production systems.

**Table 8.1.** Climate change impacts on crops.

Changes	Positive Impacts	Negative Impacts
Elevated CO <sub>2</sub> concentration	Increased growth rate Increased water use efficiency	Increased weeds Decreased nutritive products Warmer canopies
Increased temperature	Less frost damage Improved winter growth Earlier planting	Faster phenology Reduced chill hours Increased heat stress Increased water use Increased pest/disease Increased risk of freeze if early flowering  Crop water-logging/flooding Decreased arable lands (due to salt water intrusion induced by sea level rise)
Intensified rainfall and prolonged dry period		Increased runoff Increased erosion Increased irrigation requirement Increased chemical leaching





**Figure 8.1.** Distribution of crop areas in Florida (USDA-NASS 2016).

## 9. Managing Florida's Plantation Forests in a Changing World

*Timothy A. Martin, Damian C. Adams, Matthew J. Cohen, Raelene M. Crandall, Carlos A. Gonzalez-Benecke, Jason A. Smith, and Jason G. Vogel*

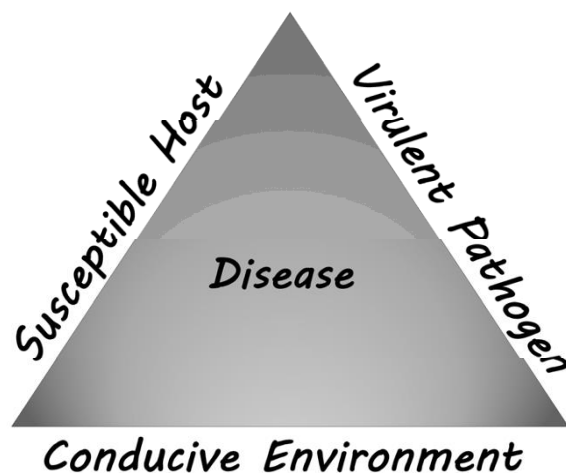
Production forestry provides substantial benefits to the state of Florida, including the provision of ecosystem services, such as regulation of water quantity and quality, provision of wildlife habitat and carbon sequestration, and supporting 80,000 jobs and \$16.34 billion/year in economic activity. Climate through the end of the century in the production forestry regions of northern Florida and southern Georgia is predicted to result in substantial increases in potential loblolly pine and slash pine plantation productivity, ranging from 5–35% depending on emissions scenario, species, and location. Climate change is likely to affect the timing and frequency of abiotic disturbances, such as wildfire and windstorms, and will also change the dynamics of forest pests, pathogens, and forest water resources. But predictions about the nature of these impacts remains uncertain. Regardless, the fact is that plantation forests have been a vital part of protecting regional water quantity and quality, and they will continue to be essential features of healthy productive landscapes, as climate changes and the potential for adverse climate impacts on water resources increases. The key to adapting forest management to changing climate will be the considered application of silvicultural tools, such as competition control, density and fertility management, and proper choice of species for each site. Keeping abreast of research advances related to these tools will be increasingly important for forest managers as climate conditions change. In addition, the development of viable policy options focused primarily on privately owned forests can help protect Florida's existing forests and the benefits they provide, and encourage investment in reforestation of existing forestland and planting new forests on previously unforested land.

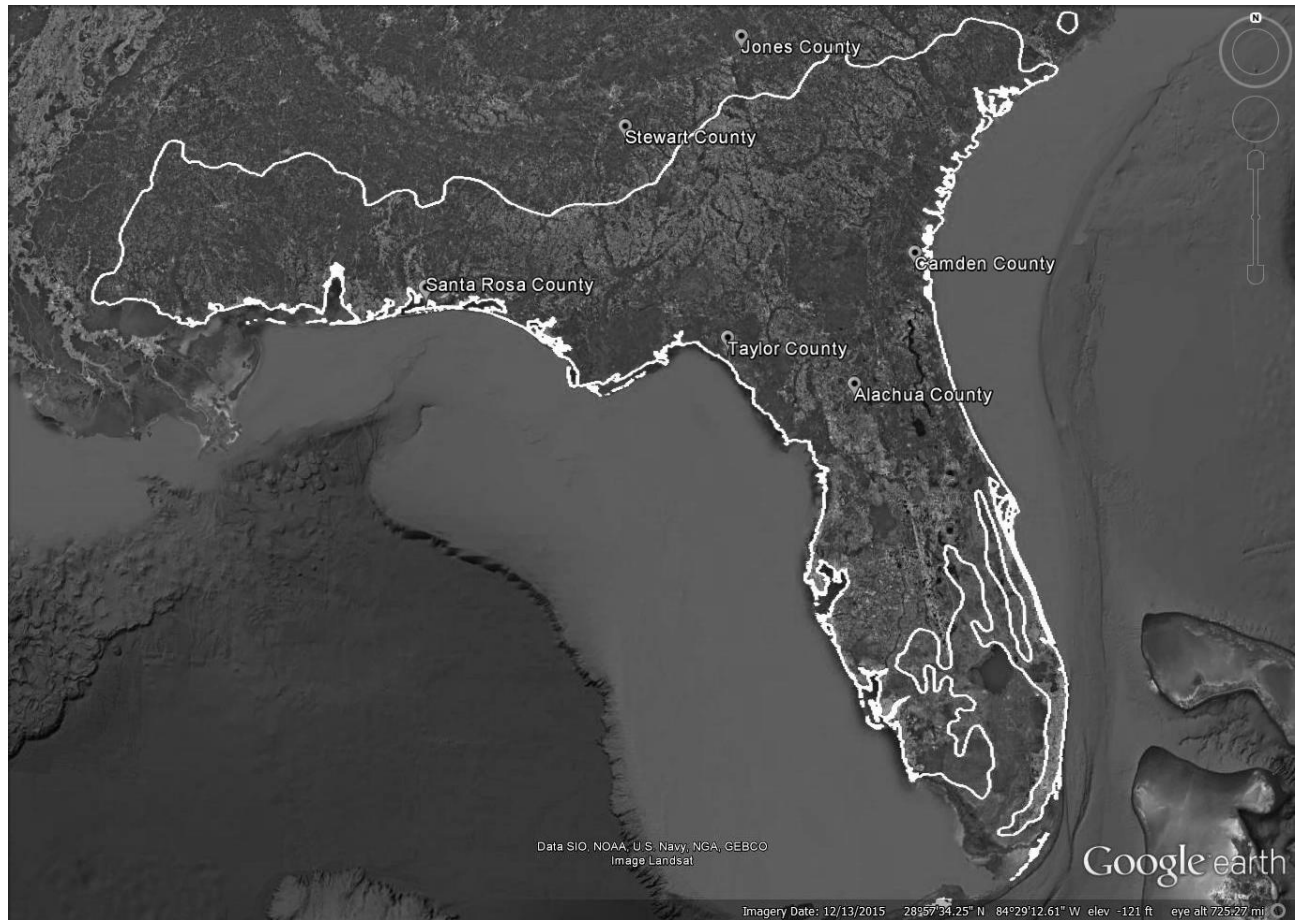
### Key Messages

- Production forestry provides substantial benefits to the state of Florida, including the provision of ecosystem services, such as regulation of water quantity and quality, provision of wildlife habitat and carbon sequestration, and supporting 80,000 jobs and \$16.34 billion/year in economic activity.
- Climate through the end of the century in the production forestry regions of northern Florida and southern Georgia is predicted to warm from 1.5 °C to almost 3.5 °C, with small increases in annual precipitation, and elevated atmospheric CO<sub>2</sub> concentration. Models predict that these changes will result in substantial increases in potential loblolly pine and slash pine plantation productivity, ranging from 5–35% depending on emissions scenario, species, and location.
- Forestry is unique in that it is one of the few industries that sequesters more carbon than it emits. There are opportunities to increase carbon sequestration for mitigation of atmospheric CO<sub>2</sub> through retention or expansion of forested areas, altered forest management, and the use of woody biomass for power generation in place of fossil fuels.

- The frequency and intensity of abiotic disturbances, such as wildfire and windstorms, are likely to be affected by climate change; but predictions remain uncertain about the magnitude of change and their effects on the forest resource.
- Research is underway to better understand how native forest pests and pathosystems may respond to changing climate. The movement of pests or pathogens into previously non-impacted areas is of particular concern.
- Plantation forests have been a vital part of protecting regional water quantity and quality, and they will continue to be essential features of healthy, productive landscapes as climate changes and the potential for adverse climate impacts on water resources increases.'
- The key to adapting forest management to changing climate will be the considered application of silvicultural tools, such as competition control, density and fertility management, and proper choice of species for each site. Keeping abreast of research advances related to these tools will be increasingly important for forest managers as climate conditions change.
- There are several viable policy options for harnessing forests to mitigate climate change and increasing forest resilience and adaptation to climate change. However, since 71% of Florida's forests are privately owned, policy options must align well with landowner needs to have adequate impact. Broadly speaking, policies that improve market conditions, reduce burdens (regulatory and economic), and increase economic sustainability for forest landowners would help protect Florida's existing forests and the benefits they provide, and would encourage investment in reforestation of existing forestland and planting new forests on previously unforested land.

**Figure 9.4.** The disease triangle showing the three factors necessary for the development of disease. Note that timespans for a conducive environment are skewed for long-lived plants, such as trees.





**Figure 9.1.** Map of the six locations (labeled by counties) in Florida and Georgia used for climate projections and productivity simulations. Current slash pine range is outlined in white.

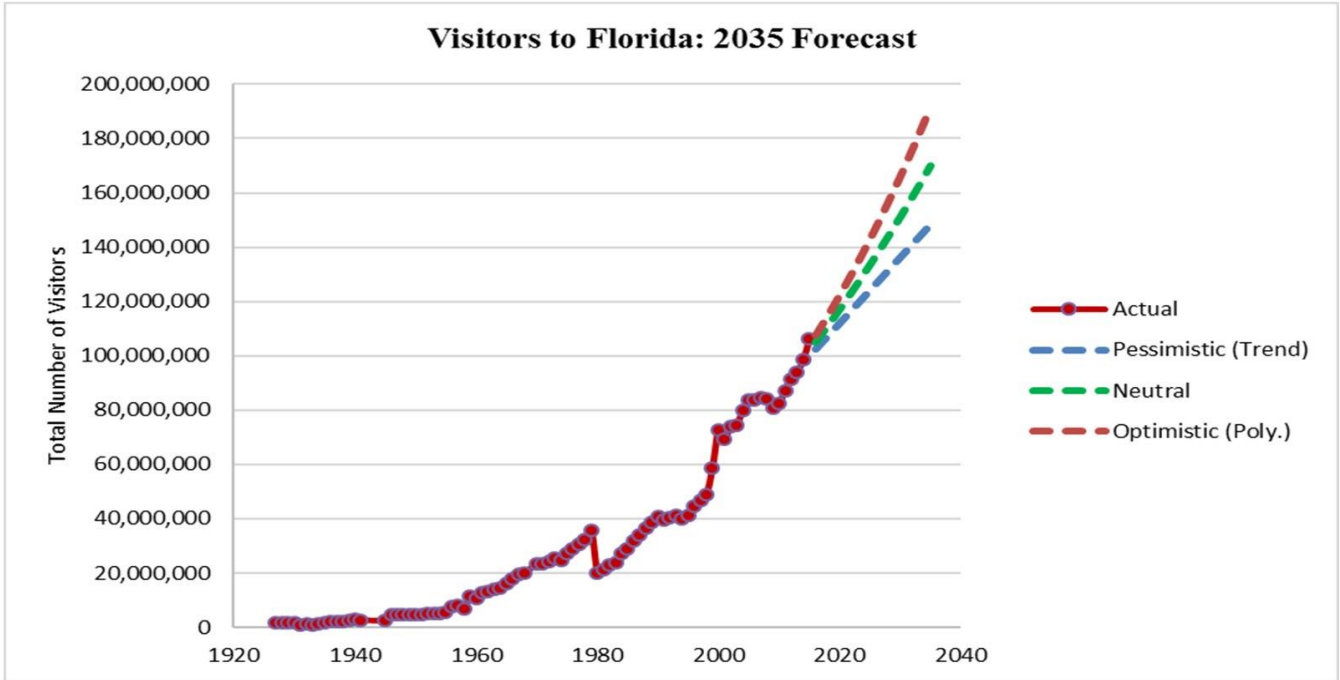
## 10. Florida Tourism

*Julie Harrington, Hongmei Chi, and Lori Pennington Gray*

Tourism is one of the largest economic industries in Florida. In 2015, a record 106.3 million tourists visited Florida (about five visitors per resident), with an economic impact of about \$90 billion. Tourism also provides additional benefits for federal, state, and local governments in the form of taxes (e.g., excise, sales, income, and property taxes). In Florida, tourism accounts for over one million direct jobs and an additional 1.5 million indirect and supply chain jobs. The three industries or business sectors most impacted by tourism and currently experiencing substantial growth in the state, include: leisure and hospitality (e.g., hotels, restaurants, museums, amusement parks, entertainment), transportation (e.g., cruise ships, taxis, airports), and retail trade (e.g., gas stations, retail stores). The 106.3 million tourists comprise approximately 91.2 million out-of-state visitors, 3.9 million Canadian visitors, and 11.2 million overseas visitors. The domestic visitors are anticipated to grow by 20% in 2018. Tourism and the associated industries in Florida are highly vulnerable to climate change over time. The state population and real estate markets continue to grow in the coastal areas, with corresponding increases in property values at risk. In addition, there are losses associated with the properties used to mitigate the effects of climate change. In summary, indicators of climate change, such as higher sea levels and more frequent and powerful hurricanes and other extreme weather events, have the potential to severely impact the tourism industry in Florida.

### Key Messages

- In 2015, a record 106.3 million tourists visited Florida, with an economic impact of ~\$90 billion. Over the last five years, tourism has averaged about 6% growth annually.
- The 106.3 million tourists are comprised of 91.2 million out-of-state (or domestic) visitors, 3.9 million Canadian visitors, and 11.2 million overseas visitors.
- Tourism accounts for more than one million direct jobs and an additional 1.5 million indirect jobs.
- The three business sectors most impacted by tourism in the state are leisure and hospitality, transportation, and retail trade.
- Climate change presents significant uncertainties in future Florida tourism and economics.
- The state's population and real estate markets continue to grow in the coastal areas, along with corresponding increases in property values at risk to sea level rise and inundation, storm surge, land subsidence, and wind damage among other things.
- The authors discuss the relationship between tourism's impacts of climate change, vulnerability and adaptation.
- The vulnerability of Florida tourism will decrease if we improve our adaptive capacity with respect to climate change.



**Figure 10.2.** Visitors to Florida: Forecasted numbers to years, 2035.

## 11. Adaptation of Florida's Urban Infrastructure to Climate Change

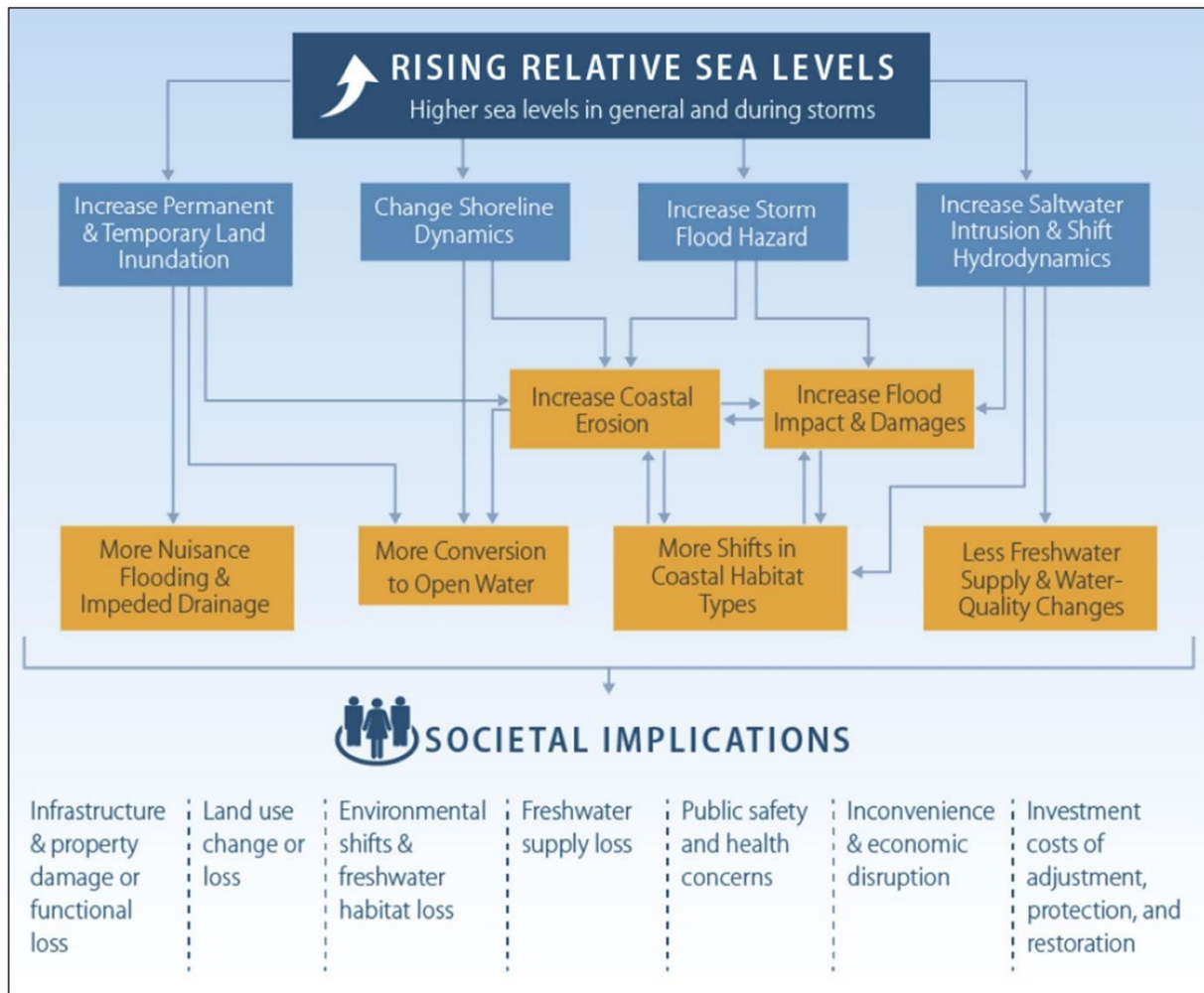
*Frederick Bloetscher, Serena Hoermann, and Leonard Berry*

This chapter looks at how the impacts of climate change affect different parts of Florida. With more than 1500 miles of coastline that contains numerous differences in character between the state's southern-most point in the Florida Keys to the northwest Florida Panhandle and northeast Florida in Jacksonville, it is easy to see why areas across the state are not all the same; temperature, rainfall rates, and even the potential for sea level rise can vary significantly depending on what part of the state one is in. For example, southeast Florida and the Tampa Bay area are already dealing with sea level rise issues, but there is much work to be done in order to assess the risks and help identify potential solutions. Efforts to adapt to rising seas will need to draw upon prior research and current work to develop tool box strategies that involve the hard and soft components. A background of impacts to water resources (less rainfall has been detected) will be discussed.

### Key Messages

- Climate changes, along with population continuing to increase, makes the water supply planning and management a critical challenge for the state.
- Climate change factors in Florida impact different areas differentially, making it unfeasible to develop one-size-fits-all policies. This makes it essential to tailor climate adaptation management strategies to each community's unique needs.
- Storm surge in coastal areas will increase flooding and property damage.
- Flooding is not just a coastal issue, but an inland issue, leading to lower capacity for soil to absorb precipitation, thereby increasing the risk of flooding because aquifers are full and groundwater has no place to go.
- Climate change, especially sea level rise, will have adverse impacts on water, sewer, transportation and stormwater infrastructure. The risk of failure from these systems put private property and economic prosperity at risk.
- The development of a framework to evaluate the impacts of climate change on infrastructure and urban development (as they are intrinsically intertwined) requires (1) identification of vulnerable areas, and (2) the development of successful flood mitigation scenarios to address community vulnerability and cost effectiveness.
- A set of strategies to combat or mitigate climate impacts on a community will be community-specific and usually require significant engineering and planning to determine the best mix.
- Longer-term development policies will need to include the 50- and 100-year vision for development. This vision will address hard and green infrastructure, policy and development objectives and funding needs.

### Selected Coastal Effects of Relative Sea-Level Rise



**Source:** Congressional Research Service, September 12, 2016.

**Notes:** This illustration depicts how rising higher sea levels may influence a number of coastal processes and affect coastal terrestrial and estuarine ecosystems and society. Each process and impact shown also is affected by other factors in addition to sea-level rise. For example, coastal shoreline dynamics are influenced not only by sea-level rise but also by climate and weather patterns; nearshore hydrodynamics and geomorphology; coastal land development and use; infrastructure projects such as seawalls and dredging; and other factors.

**Figure 11.3.** Selected coastal effects of sea level rise.



## 12. Climate Change Impacts on Florida’s Biodiversity and Ecology

*Beth Stys, Tammy Foster, Mariana M.P.B. Fuentes, Bob Glazer, Kimberly Karish, Natalie Montero, and Joshua S. Reece*

Florida’s rich biodiversity is the product of climatic conditions, geographic position, and underlying geology. Interactions of these factors over time have led to the state’s unique biota, with Florida ranking fourth in the nation for total number of endemic species. The ability of Florida’s ecosystems to support plants and animals is intimately tied to its geographic location, climatic and hydrologic variables, including timing and amount of precipitation, the frequency and intensity of storms, the range and duration of temperature extremes, and water chemistry. The ecosystems and species of Florida have adapted to past periods of climatic change. However, these ecosystems are now under stress and less resilient due to past and existing human-caused alterations and impacts, affecting their ability to withstand and adapt to additional stressors such as climate change. The overall vulnerability of some systems and species is primarily driven by the severity and extent of these non-climate stressors. Florida’s biodiversity may be very different in the future, with some species and ecosystems affected to a greater extent than others. Community-level changes will occur as plant and animal species move and adapt at different rates. There are tools available to assist in determining relative vulnerability (vulnerability assessments) and potential impacts (scenario planning) that can aid in developing adaptation strategies. Awareness that change is likely to happen is critical to planning for the future and allowing for adaptation in management practices that will maximize Florida’s biodiversity for future generations.

### Key Messages

#### Climate Change Impacts on Biodiversity and Ecology

- Climate change has differential impacts on: coastal ecosystems, freshwater wetlands, and upland ecosystems. Coastal ecosystems, in particular, are subject to the “squeeze” of human impacts, changing climate, and rising sea levels.
- The Florida Keys and the Everglades are particularly vulnerable to sea level rise over the next 50 to 100 years due to their low elevation (typically less than 1 m).
- Out of 1,200 species tracked by the Florida Natural Areas Inventory, 25% are likely to lose at least half of their current habitat due to sea level rise alone.
- Florida’s species have migrated and adapted to climate change in the past, but that ability is severely compromised now due largely to human modification of the landscape. Up to 76% of 236 surveyed species were deemed unlikely to be able to relocate inland in response to rising sea level.
- Several keystone species are particularly vulnerable to the impacts of climate change and the loss of these species can have cascading impacts on natural communities.

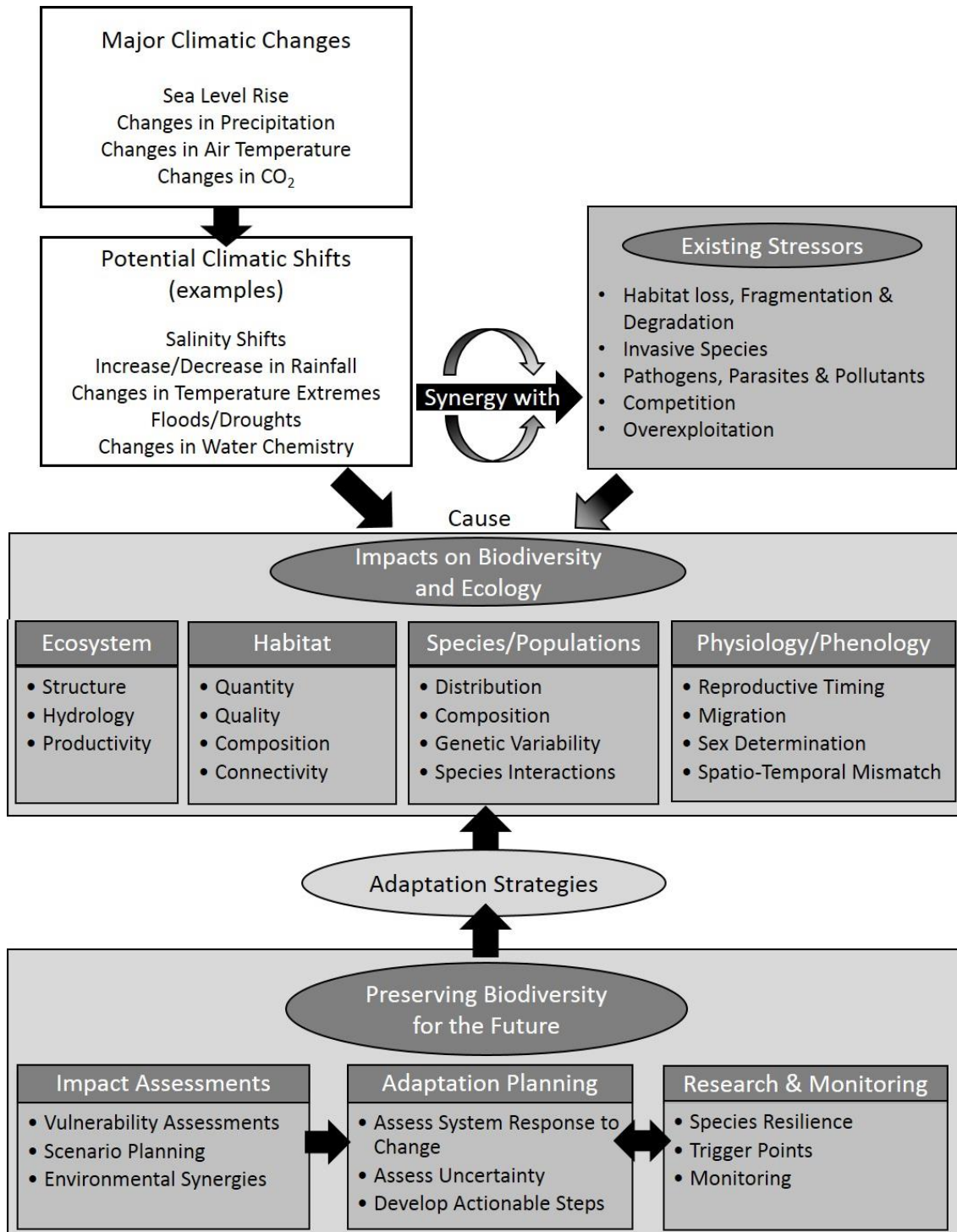
- Sea turtles are likely to respond to climate change through altered sex ratios of hatchlings, northward movements of rookeries, decreased reproductive output due to storm events, and potential shifts in foraging ground locations.
- Phenology, or the timing of life history events, are likely to change in response to climate shifts, both as the climate becomes warmer but also as it becomes more variable. This is particularly true for plants and can cause major disruptions to co-evolutionary relationships, such as those between pollinators and the plants they pollinate.

#### Existing Stressors and Climate Change

- Habitat loss and degradation are the leading causes of extinctions in Florida and globally. The impacts of climate change on species and natural communities are greatly magnified by decreased adaptive capacity due to habitat loss and degradation.
- Many invasive species are projected to have enhanced fitness under future climate change scenarios, potentially causing greater disruption to natural communities.
- Climate change is projected to increase the vulnerability of native species to foreign and domestic pathogens and parasites.
- Overexploited species have diminished capacity to adapt to climate change, making them especially vulnerable.

#### Preserving Biodiversity for the Future

- Planning for climate change involves impact assessments, adaptation scenario planning, and research and monitoring.
- While many of the ways in which species and natural communities respond to climate change are gradual, other changes can be abrupt and non-linear. These so-called thresholds, trigger points, or paradigm shifts are harder to predict, but are often more consequential than linear patterns of change through time.



**Figure 12.1.** Diagrammatic illustration of this chapter showing simplified connections between major components (chapter sections). The grey boxes include overview of the chapter content, the white boxes are described in other chapters, but form the foundation of content in this chapter.

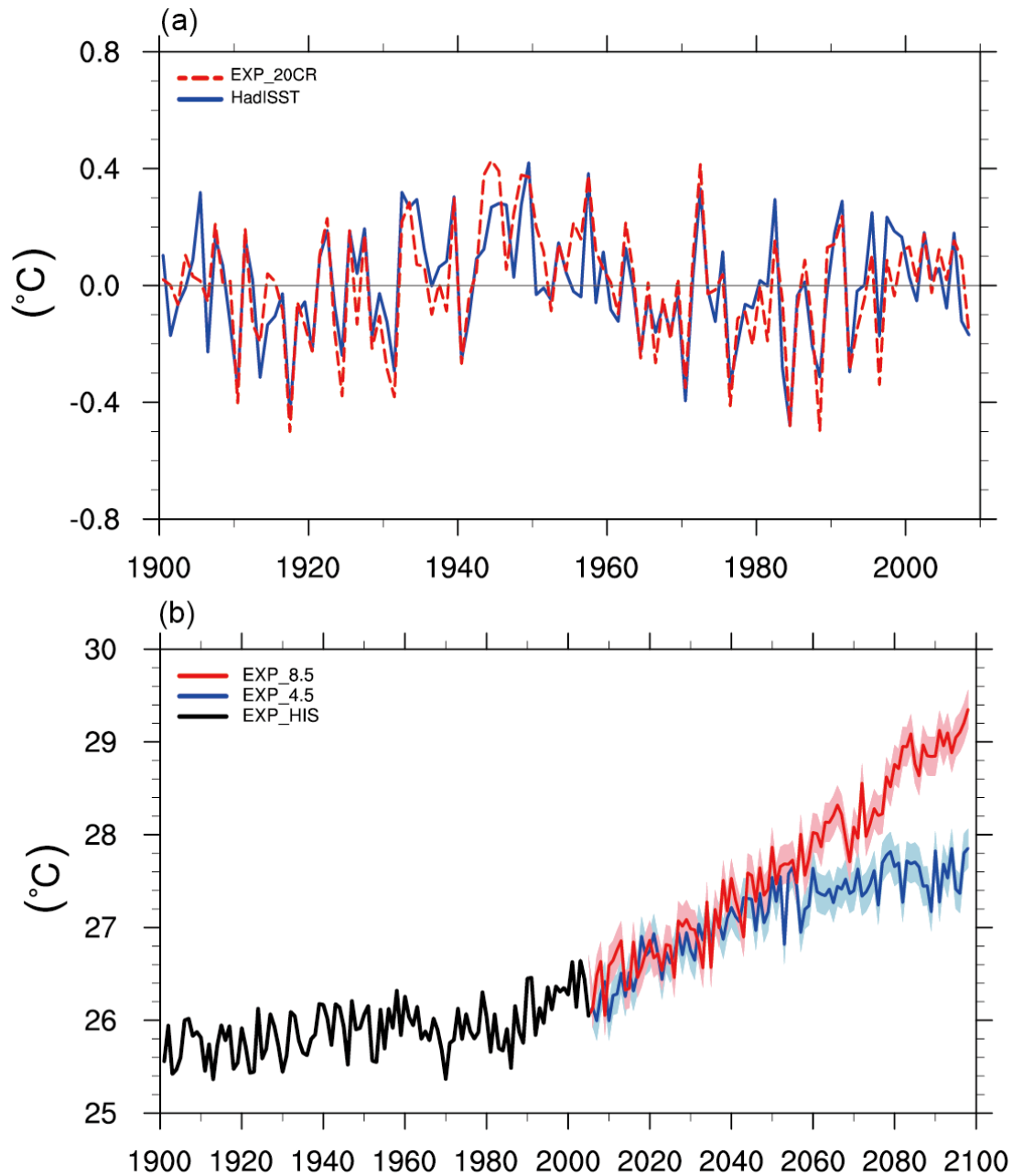
## 13. Florida's Oceans and Marine Habitats in a Changing Climate

*Steven Morey, Marguerite Koch, Yanyun Liu, and Sang-Ki Lee*

Florida's peninsula extending ~700 km north-to-south, extensive shoreline (2,100 km), and broad carbonate platform create a diversity of marine habitats (estuaries, lagoons, bays, beach, reef, shelf, pelagic) along the coast, shelf, and deep ocean that are influenced by continental, oceanographic, and atmospheric processes all predicted to shift with a rapidly changing climate. Future changes of the global ocean circulation could result in a 25% reduction in the Atlantic Meridional Overturning Circulation (AMOC), leading to a subsequent slowing of Florida's regional/local current systems (Yucatan, Loop, Florida and Gulf Stream) and eddies. While downscaled climate models suggest that slowing of the Loop Current by 20-25% during the 21st century will moderate the increase in surface temperatures in the Gulf of Mexico to 1.4oC - 2.8oC, this warming is predicted to have wide-ranging consequences for Florida's marine habitats (e.g., enhanced coral bleaching, lower O<sub>2</sub> in surface waters, increased harmful algal blooms, reduced phytoplankton and fisheries production, and lower sea turtle reproduction). The reduction in the AMOC is also predicted to reduce hurricane frequency, albeit with increased intensity (2-11%) due to ocean warming. Climate projections affecting Florida's oceans include rises in sea level, changes in coastal circulation impacting larval and nutrient transport, changes in marine biogeochemistry including ocean acidification, and loss of coastal wetlands that protect Florida's coastline. Understanding the consequences of these projected climate impacts and gaining a more complete understanding of complex changes in atmospheric processes (e.g., ENSO, AMO, convection, wind shear), air-sea interaction, currents, and stratification under a changing climate is critical over the next few decades to prepare and protect the state of Florida.

### Key Messages

- Florida has a unique peninsular geography that creates an extensive shoreline with a diversity of marine habitats along the coast, shelf, and deep ocean influenced by continental, oceanographic, and atmospheric processes all predicted to shift with a rapidly changing climate.
- Climate projections affecting Florida's oceans include rise in sea level, warmer sea surface temperatures, changes in coastal circulation impacting larval and nutrient transport, changes in marine biogeochemistry including ocean acidification, and loss of coastal wetlands and reefs that protect Florida's coastline.
- Downscaled ocean models have proven successful for understanding future changes for the region given climate projections, and their continued revision and improvement will result in a more complete understanding of complex changes in air-sea interaction, large-scale currents, and the rates of climate change impacts, a critical research need over the next few decades to prepare and protect the state of Florida.



**Figure 13.4.** (a) Time series of annual mean sea surface temperature (SST) anomalies averaged over the Gulf of Mexico ( $100^{\circ}\text{W}$ - $82^{\circ}\text{W}$ ,  $21^{\circ}\text{N}$ - $30^{\circ}\text{N}$ ) during 1900-2008 obtained from a downscaled model (EXP\_20CR, red) and HadISST (blue). (b) Time series of the annual mean SSTs averaged over the Gulf of Mexico during 1900-2098 obtained from downscaled MOM4.1 simulations (20<sup>th</sup> century simulation [black], RCP4.5 forcing [blue] and RCP8.5 forcing [red]). The standard deviation (STD) of the SST anomalies in the Gulf of Mexico for the period of 1900-2008 is calculated ( $\text{STD} = 0.21^{\circ}\text{C}$ ) and the  $\pm 0.21^{\circ}\text{C}$  is added to each time point of the future SST projections (light color regions). From Liu et al. (2015).

## 14. Climate Changes Impacts on Florida's Fisheries and Aquaculture Sectors and Options for Mitigation

*Kai Lorenzen, Cameron Ainsworth, Shirley Baker, Luiz Barbieri, Edward Camp, Jason Dotson, and Sarah Lester*

Florida supports diverse marine and freshwater fisheries and a significant aquaculture industry with a combined economic impact of approximately 15 billion US\$. We begin by describing the characteristics of the different fisheries and aquaculture sectors. This is followed by a description of the relevant climate change and confounding drivers. We then present an integrated social-ecological systems framework for analyzing climate change impacts and apply this framework to the different fisheries and aquaculture sectors. We highlight how the characteristics of each sector gives rise to distinct expected climate change impacts and potential adaptation measures. We conclude with general considerations for monitoring and adaptation.

### Key Messages

- Sea level rise, more frequent severe storms, coastal habitat loss associated with both factors, changes in nutrient dynamics, and ocean acidification are likely to impact the productivity of Florida's marine fisheries. Some of these factors will also affect fisheries access.
- Florida's freshwater fisheries will be impacted by increased hydrological variability, increased temperatures, and more frequent severe storms. Shallow lakes may respond by switching from a clear to a turbid, phytoplankton-dominated state that provides poor sport fishing. Greater hydrological variability will also exacerbate fishing access issues.
- Among the aquaculture sectors, shellfish aquaculture is particularly sensitive to multiple drivers including sea level rise, coastal habitat loss, increased frequency of harmful algal blooms and ocean acidification. Ornamental fish culture and other forms of intensive aquaculture under controlled conditions will be relatively insensitive to climate change.
- Key adaptation options for marine fisheries include switching of species, locations and fishing methods, while adapting catch limits to changes in productivity. In freshwater fisheries, on the other hand, water and habitat management will be key to adaptation. Change in farming methods will be important in aquaculture, along with species and location changes, particularly in the shellfish industry. Aquaculture for fisheries enhancement and ecological restoration can aid adaptation in both marine and freshwater fisheries. Adaptation will benefit from awareness of drivers and impact pathways, monitoring of a broad suite of impact indicators, and adaptive decision-making.

**Table 14.1.** Economic impact, employment, and participation in Florida’s fisheries and aquaculture sectors and subsectors.

Sector	Economic Impact or Value (\$ Million)	Employment	Participation (Thousands)	Harvest
<b>Marine fishing</b>				
Recreational	12,249 <sup>(1)</sup>	70,109 <sup>(1)</sup>	6500 <sup>(1)</sup>	
Commercial	1,060 <sup>(1)</sup>	12,241 <sup>(1)</sup>	12 <sup>(1)</sup>	99 million lbs <sup>(1)</sup>
Commercial (marine life)	7 <sup>(2)</sup>			12 million individuals
<b>Freshwater fishing</b>				
Recreational	1,689 <sup>(3)</sup>	14,040 <sup>(3)</sup>	3100 <sup>(3)</sup>	
Commercial	5 <sup>(4)</sup>			10 million lbs <sup>(4)</sup>
Aquaculture	69 <sup>(5)</sup>	2000 <sup>(5)</sup>	2 <sup>(5)</sup>	
Ornamental	27 <sup>(5)</sup>	400 <sup>(5)</sup>	< 1 <sup>(5)</sup>	
Shellfish	12 <sup>(5)</sup>	400 <sup>(5)</sup>	< 1 <sup>(5)</sup>	
Other	30 <sup>(5)</sup>	1000 <sup>(5)</sup>	1 <sup>(5)</sup>	

Sources: (1) NMFS 2016; (2) Larkin et al. 2001; FWC 2017 (3) Southwick Associates 2012; (4) FWC 2011; (5) USDA 2013.

# Florida's Physical Climate: Past, Present, and Future

## 15. Paleoclimate of Florida

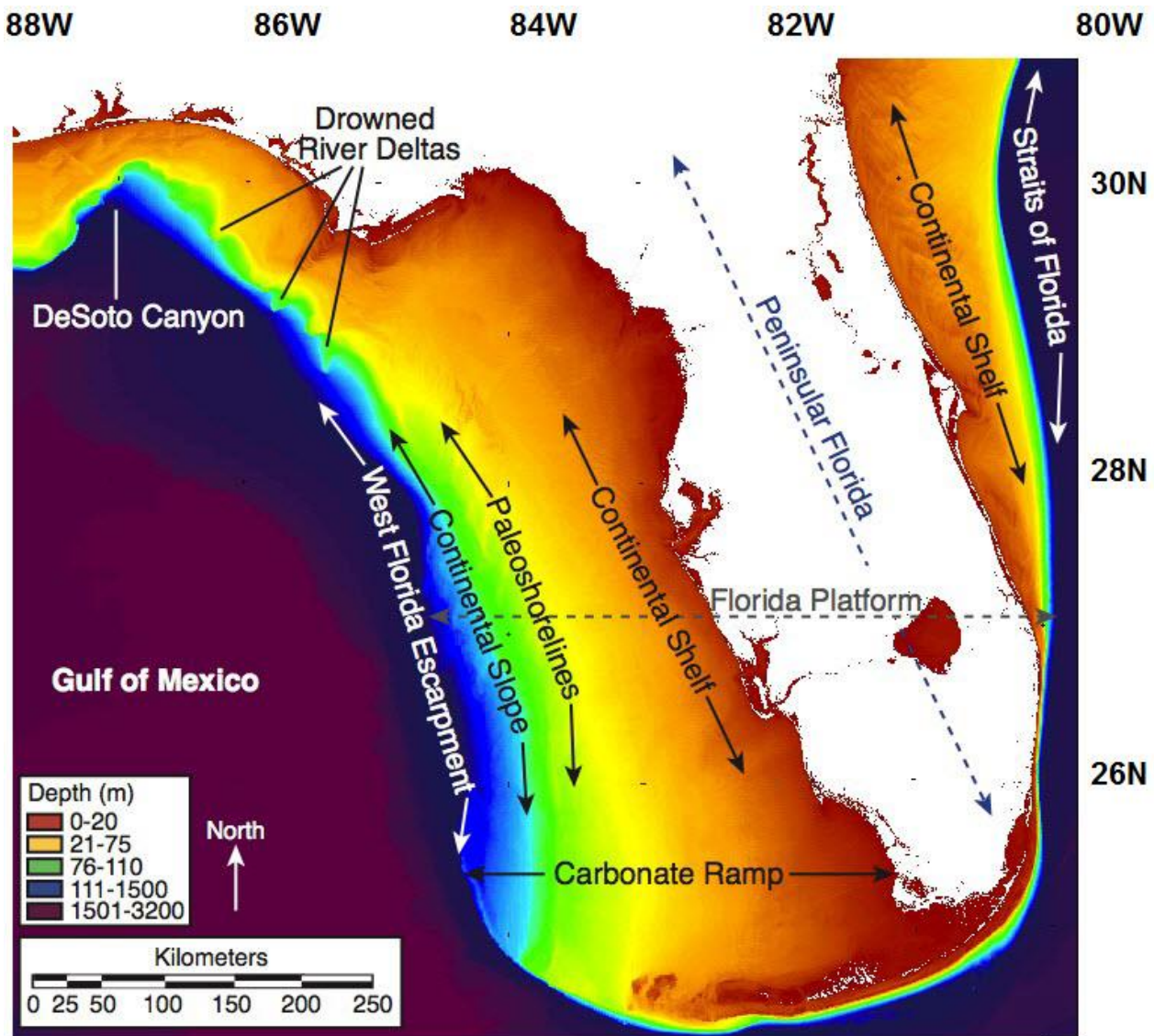
*Albert C. Hine, Ellen E. Martin, John M. Jaeger, and Mark Brenner*

We present our understanding of Florida's paleoclimate for the past ~50 million years (Myr). The paleoclimate of the Florida Platform is closely linked to global paleoclimate. Global climate change over the past 50 Myr is a record of declining atmospheric carbon dioxide, decreasing temperature, and progressive addition of ice sheets. The overall global climate narrative is one of transition from a greenhouse Earth (warm temperatures with higher sea levels) to an icehouse Earth (colder temperatures with lower sea levels). The early 21st century has been a period of extreme climate conditions in Florida, in that we have already seen very low lake levels, including complete drying of some water bodies for the first time in recorded history. Such complete drying was never reported previously and suggests that we have entered a new climate regime in this millennium.

### Key Messages

- The peninsular morphology of Florida, created during the near-simultaneous tectonic opening of the Gulf of Mexico, Caribbean Sea, and western North Atlantic Ocean starting ~200 million years ago has always played a fundamental role in Florida's climate. When a large fraction of the peninsular land mass was exposed during sea level lowstands, huge thunderstorms formed thus defining a unique component of Florida's climate.
- The topographically low and flat morphology of the Florida Platform has also allowed climate-driven sea level changes to leave a robust stratigraphic record. From these rocks and sediments the paleoceanography and, to a lesser extent, the paleoclimate of the Florida Platform has been reconstructed.
- Over the past 50 Myr the climate of the Florida Platform followed the global climate change of declining atmospheric carbon dioxide (CO<sub>2</sub>) and cooling, i.e., a transition from a greenhouse (warm) to an icehouse (cooler with cyclical glaciations and deglaciations) Earth. There were three major warming events that occurred during this prolonged cooling that impacted Florida's paleoclimate.
- Pleistocene data reveal a terrestrial climate comparable to the modern climate, with evidence of cool climate episodes that may have been influenced by regional upwelling of cold marine waters. As climate in Florida warmed after the Last Glacial Maximum and early Holocene (~18–~11.7 ka), there were profound consequences for Florida's terrestrial environment, as vast areas that had served as habitat for Pleistocene land plants and animals, some now extinct (e.g., mammoths, horses, giant sloths, tapirs), were inundated by rising seawater.
- Shortly after the onset of the Holocene Epoch (11.7 ka), rainfall increased contributing to rising groundwater tables and initial filling of Florida's more than 8,000 shallow lakes.





**Figure 15.2.** Exposed and submerged portions of the Florida Platform. Geologists consider the Florida Platform to be a single entity that includes the emerged state of Florida, as well as the vast area that today lies under water. The size of the exposed portion of the Platform changed dramatically over geologic time as sea level rose and fell (from Hine 2013; *Geologic History of Florida: Major Events That Formed the Sunshine State* by Albert C. Hine. Gainesville: University Press of Florida, 2013. Reprinted by permission; modified from USGS Open File Report 2007-1397; courtesy of Dr. L. Robbins).

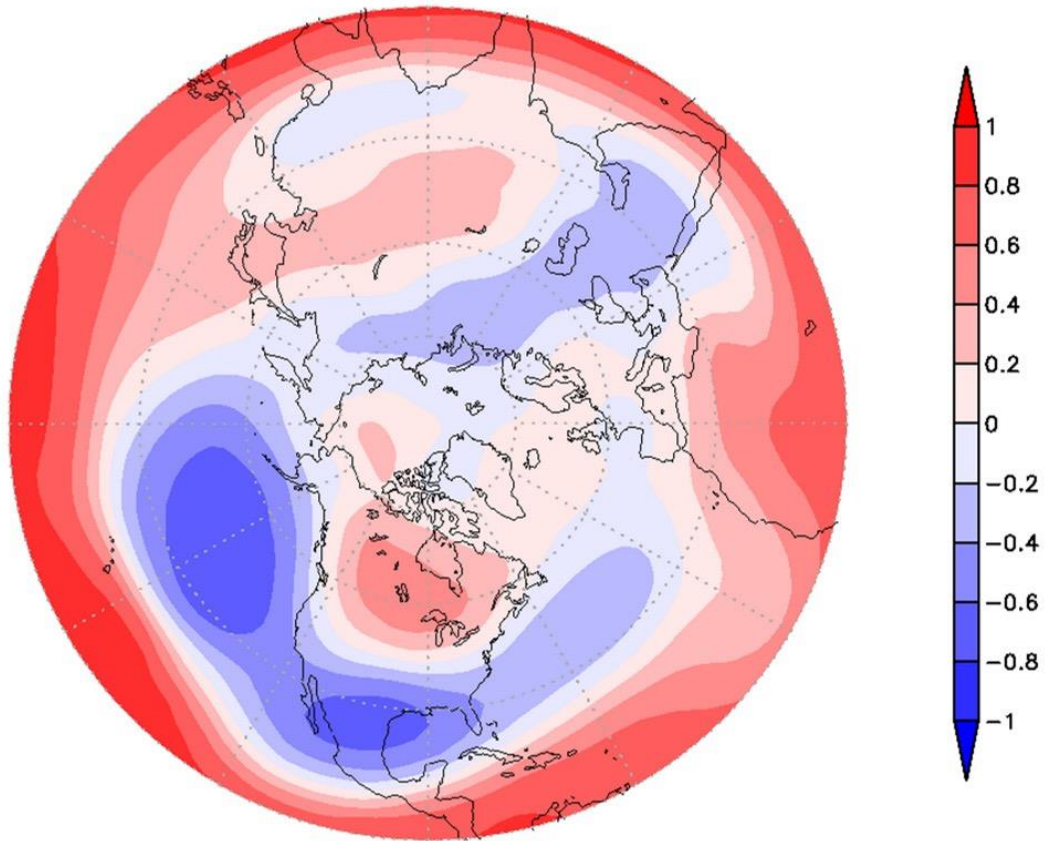
## 16. Terrestrial and Ocean Climate of the 20th Century

*Vasubandhu Misra, Christopher Selman, Amanda J. Waite, Satish Bastola, and Akhilesh Mishra*

The Florida peninsula, with its close proximity to the equator surrounded by robust surface and deep water ocean currents, has a unique climate. Generally, its climate is mild with variations on numerous time scales, punctuated by periodic extreme weather events. In this chapter, we review the mechanisms by which some well-known natural variations impact the regional climate and modulate the occurrence of extreme weather over Florida and its neighboring oceans. In addition, we explore the role of land cover and land use changes on the regional climate over the same area. It is made apparent from the review that remote variations of climate have an equally important impact on the regional climate of Florida as the local changes to land cover and land use.

### Key Messages

- Florida is a unique region to the east of the Rocky Mountains with a very distinct monsoonal type of wet season in the summer that distinguishes it from the rest of the seasons.
- Florida's climate is as much affected by remote climate variations as local variability over land and its neighboring water bodies. Florida's climate is affected by more global scale natural variations like ENSO, AMO, PDO. Similarly, there is a discernible impact of local land cover and land use change on surface temperatures in Florida.
- There are important interactions of the observed climate across time and spatial scales to consider. For example, the sea breeze over the Florida Panhandle is shown to be affected by the subtle variations of the Bermuda High. Similarly, ENSO forcing on Florida's winter climate is affected by decadal variations such as the PDO and the AMO.



**Figure 16.6.** The contemporaneous correlation of the mean December-January-February Niño3.4 SST index with corresponding seasonal mean 500 hPa geopotential heights from NCEP-DOE reanalysis (Kanamitsu et al. 2002).

## 17. Florida Climate Variability and Prediction

*Ben P. Kirtman, Vasubandhu Misra, Robert J. Burgman, Johnna Infanti, and Jayantha Obeysekera*

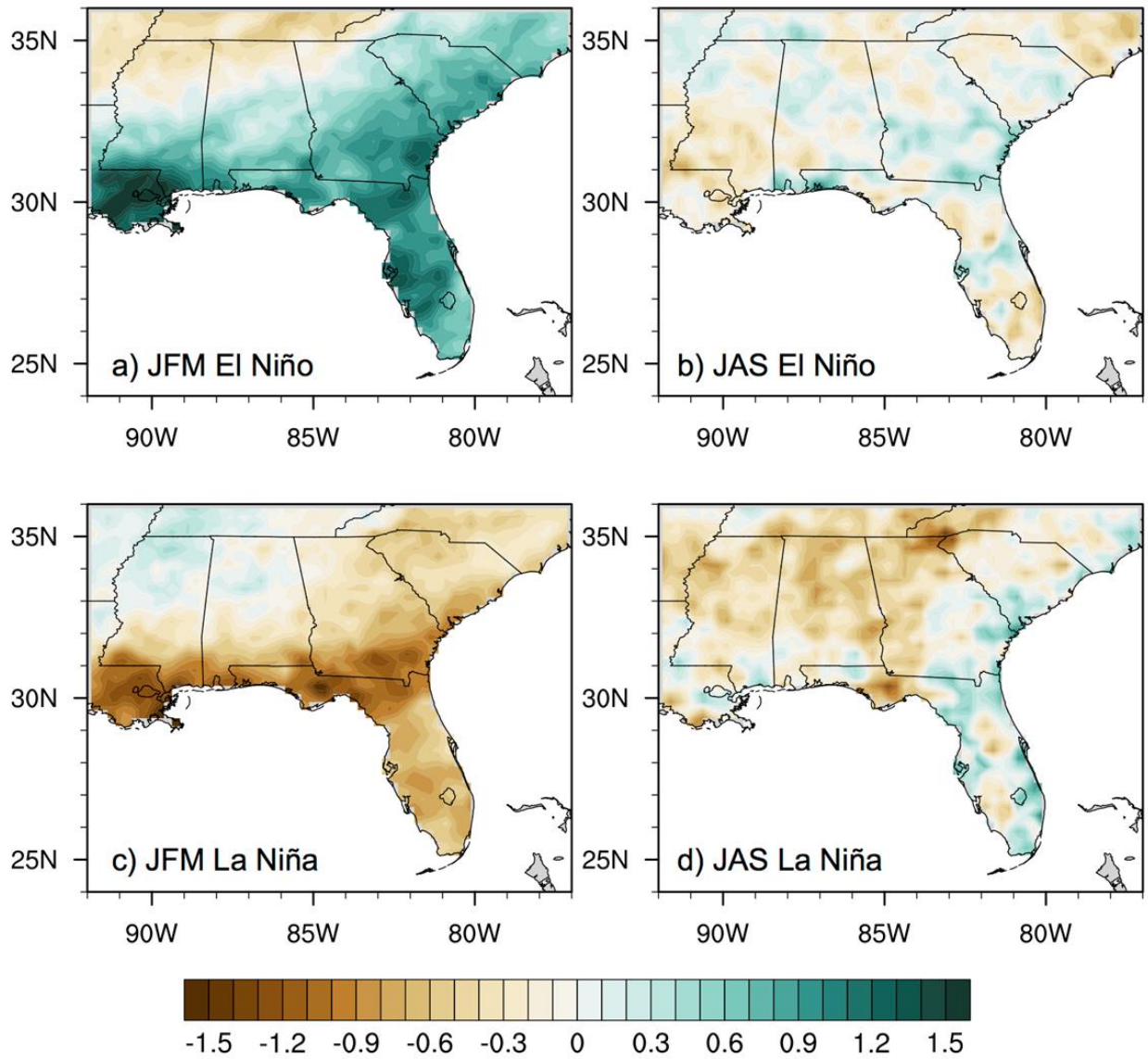
This chapter describes the sources and mechanisms for climate variability in Florida across timescales (i.e., seasonal-to-decadal) and how they are used to make predictions. Current capabilities in terms of prediction quality, with an emphasis on precipitation and land surface temperature on seasonal timescales, are introduced as well as challenges and opportunities for the future. The longer decadal time scales are discussed in the next chapter in conjunction with climate change associated with anthropogenic forcing.

### Key Messages

- There is known large-scale climate variability (e.g., El Niño) that affect Florida’s local climate.
- While this large-scale climate variability can be predicted several months in advance, correctly capturing the regional impacts remains challenging.

**Table 17.1.** El Niño, La Niña impacts for the four seasons (OND, JFM, AMJ and JAS) in Florida. Adapted from the Florida Climate Center Office of the State Climatologist (<https://climatecenter.fsu.edu/topics/climate-variability>).

Phase	Region	OND	JFM	AMJ	JAS
El Niño	Peninsular Florida	Wet Cool	Very Wet Cool	Slightly Dry	Slightly Dry or No Impact
	Western Panhandle	No Impact	Wet	Slightly Dry	No Impact
La Niña	Peninsular Florida	Dry Slightly Warm	Very Dry Warm	Slightly Wet	No Impact
	Western Pan-handle	Slightly Dry	Dry	Dry	No Impact
Neutral	All Regions	No Impact	No Impact	No Impact	No Impact



**Figure 17.1.** 1982–2009 precipitation anomalies (mm/day) during (a) JFM El Niño events, (b) JAS El Niño events, (c) JFM La Niña events, and (d) JAS La Niña events.

## 18. Future Climate Change Scenarios for Florida

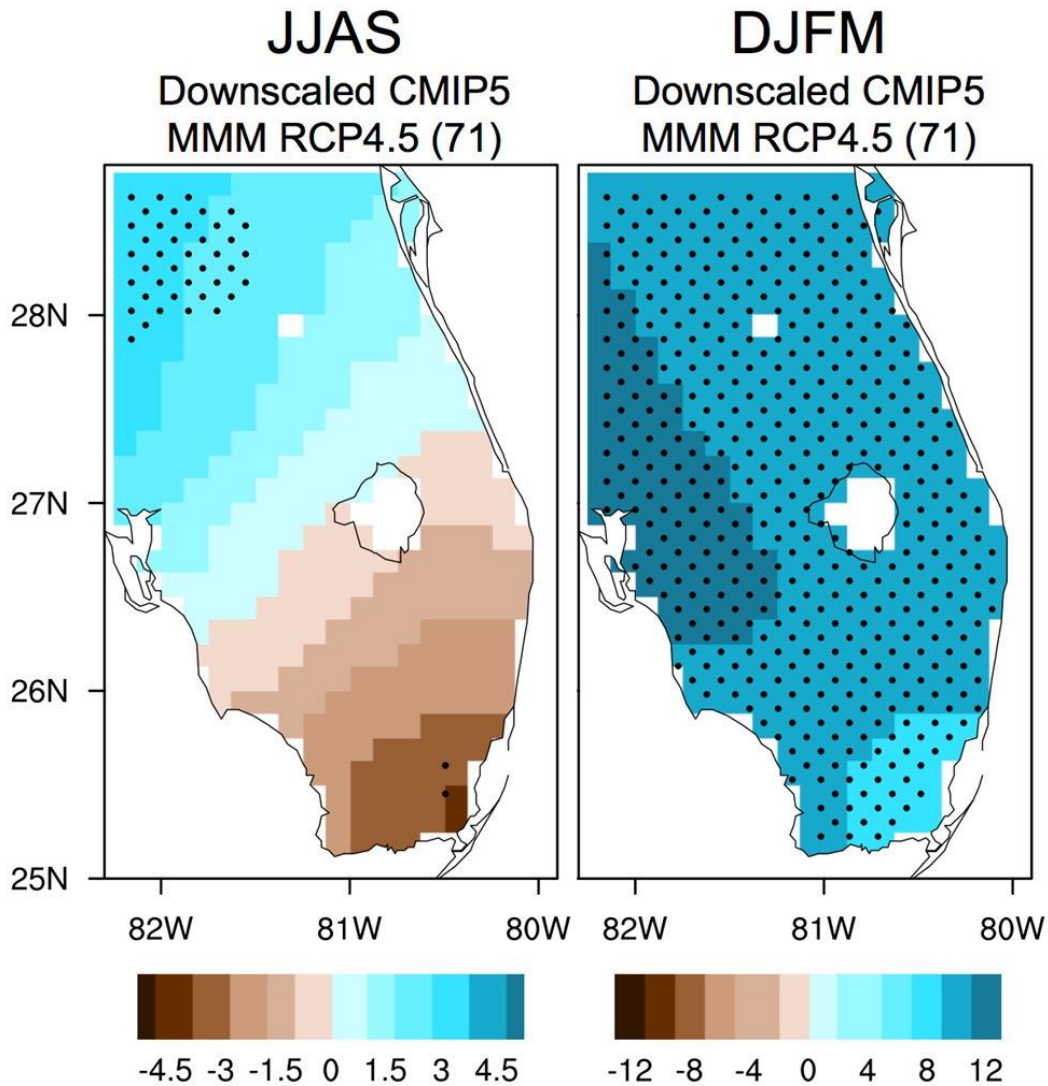
*Ben P. Kirtman, Vasubandhu Misra, Aavudai Anandhi, Diane Palko, and Johnna Infanti*

This chapter describes both the nature of and anthropogenic mechanisms for climate change, as well as how scenarios and projections of future climate change are made. Specific emphasis is placed on understanding the changes over the near-term (i.e., adaption timescale) where the emission scenario has little impact vs. changes beyond the mid-century where the projections are conditional on the emission scenario. The various tools and models used to assess climate change are also summarized, and projections from global and regional models are presented. Finally, the new science of decadal prediction is presented as it has the potential to improve climate information in the near-term.

### Key Messages

- The climate science community clearly understand that adaptation decision support needs robust regional information, and that the current generation of global models are not sufficient in this regard.
- Efforts to downscale the global models are promising but much remains to be done.





**Figure 18.9.** Maps of downscaled precipitation changes for peninsular Florida in 2080–2099 with respect to 1986–2005 in June through September (JJAS, left) and December through March (DJFM, right) in the RCP4.5 scenario with 71 CMIP5 models and ensemble members, from DHCP data. Precipitation changes are given as percent change in JJAS or DJFM from 1986–2005. Stippling denotes where more than 66% of models have the same sign with the ensemble mean changes.

## 19. Sea Level Rise

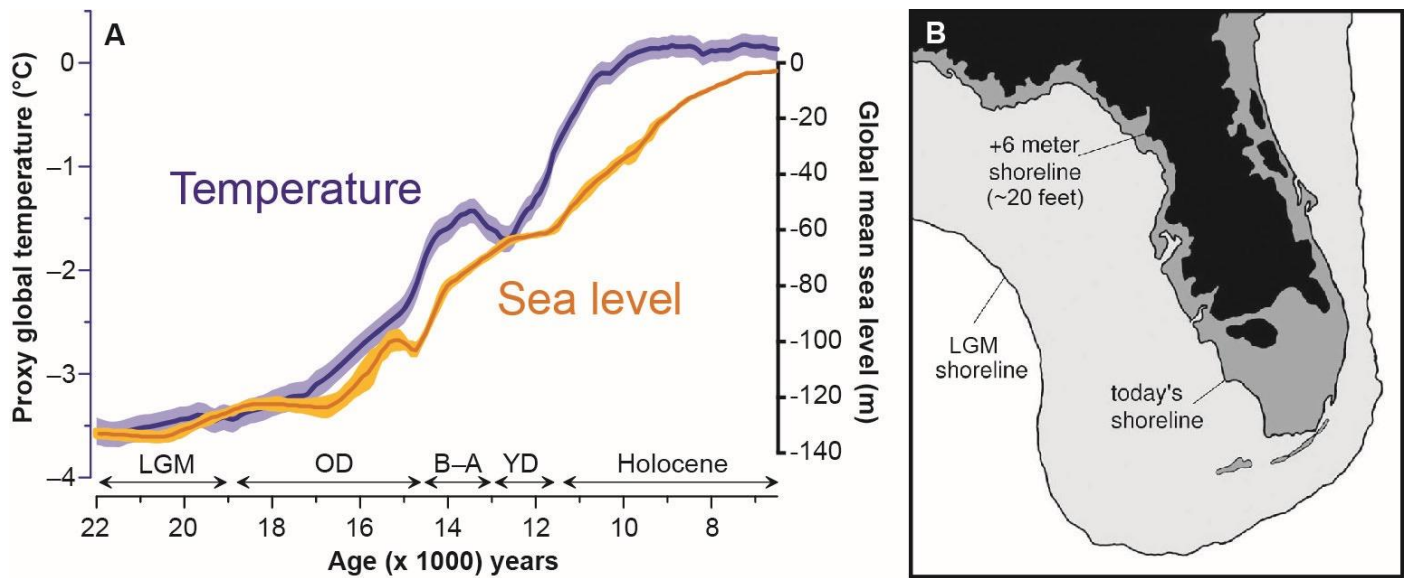
*Gary Mitchum, Andrea Dutton, Don P. Chambers, and Shimon Wdowinski*

Sea level rise is naturally a topic of concern to many Floridians. Our intention in this chapter is to give the reader enough information on this topic to inform decisions about future adaptation strategies. We begin by reviewing how we measure sea level and the reasons that sea level can change. At the global level, the problem is relatively simple in that globally averaged sea level can only increase if water is added to the ocean or the ocean warms. The situation is more complicated at the local level, where variations can occur (e.g., due to changes in wind and ocean current patterns, and differences in vertical land motion rates). We present summaries of global sea level change over several time scales, ranging from the modern day to the geological records. Although we have confidence in estimates of the rate of global mean sea level change, determining from observations whether the rate is increasing, or accelerating, is more challenging. Over the next century, sea level change in Florida is expected to follow the global trend reasonably closely, but on shorter time scales and in different localities some variations are inevitable. We end with a discussion of the future sea level rise projections for Florida that should form the basis for efforts to plan adaptation strategies.

### Key Messages

- Unless greenhouse gas emissions are reduced, sea level will most likely increase by 1-2 meters over the next 50 to 100 years. The time scale is not certain, but the ultimate rise of sea level is. The only way to mitigate this risk is to reduce greenhouse gas emissions as soon as possible and to commit to lowered emissions in the future.
- The linkage between greenhouse emissions and sea level rise is incontrovertible. Sea level rise projections are often misinterpreted due a lack of understanding of this point. We cannot invoke any particular sea level rise projection without committing to the emission scenario associated with that sea level rise projection. The scatter seen in charts projecting sea level rise is due to the differing emission scenarios assumed, and is not due to uncertainty in the climate science that underlies the projections.
- On shorter time scales of a few years to a few decades, sea level rise fluctuations due to oceanic and atmospheric changes and vertical land motion can substantially increase the frequency of nuisance flooding events. Although these smaller sea level changes are likely ephemeral, these events can have large economic impacts.
- Sea level rise impacts in coming decades will be felt differently in different communities. Regional to local adaptations should be developed based on the best available science, and to support these efforts, scientists need to be involved at the local level. We do not discuss this point in our chapter, but would argue that an important outcome of this book is that local scientists, practitioners, and decision makers will have the information needed to inform at the local level.





**Figure 19.4.** (A) Change in global mean temperature relative to the pre-Industrial Era (blue, Shakun et al. 2012), and in sea level (orange, Lambeck et al. 2014) from the LGM to 6,000 years ago. Abbreviations denoted on time axis represent climate intervals: Older Dryas (OD), Bolling-Allerod (B-A), Younger Dryas (YD). (B) Comparison of the shoreline during the LGM, today, and for a position representing ~ +6 meters (~ 20 feet) higher than present.

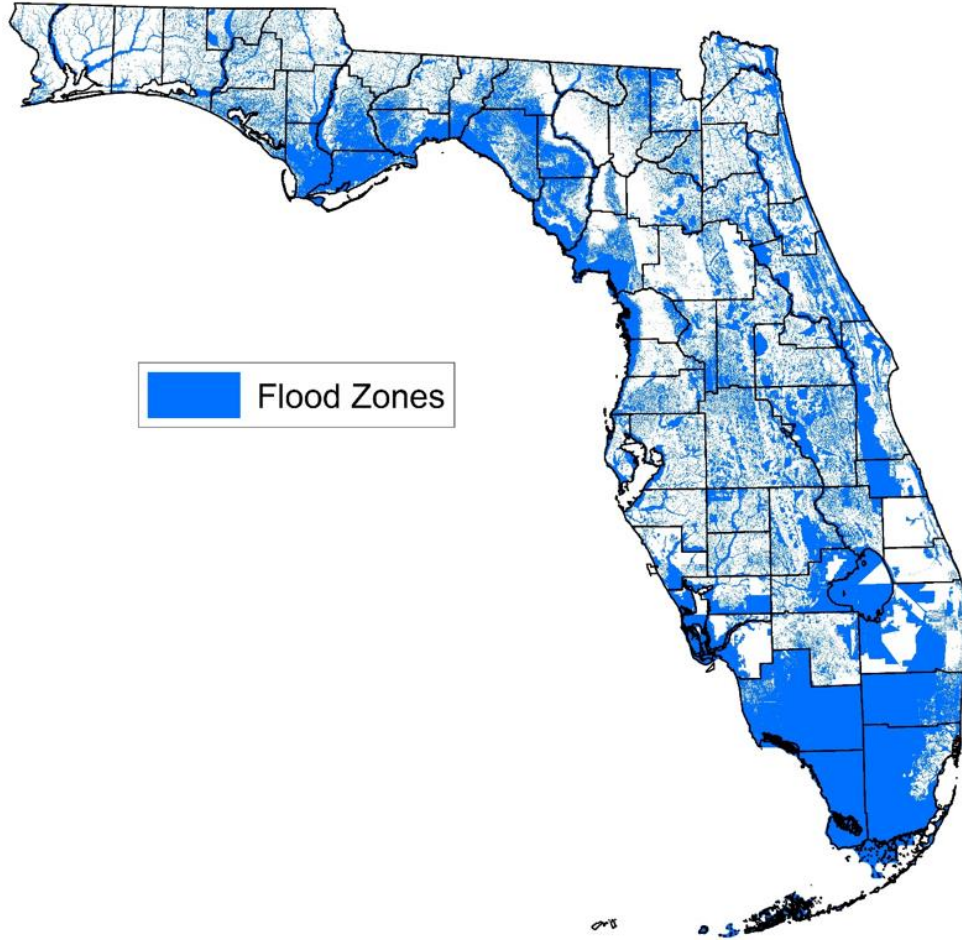
## 20. Climate and Weather Extremes

*Jennifer M. Collins, Charles H Paxton, Thomas Wahl, and Christopher T. Emrich*

This chapter examines Florida's extreme weather hazards: 1) why they happen, 2) their relation to interannual to multidecadal climate variability, and 3) the potential of each hazard and spatial variability across the state. The weather hazards indicated are under these broad categories: precipitation (rainfall, flooding, droughts), thunderstorms (lightning, hail, convective wind, tornadoes), tropical weather (tropical storms and hurricanes), and temperatures (extreme highs and lows). The conclusions section mainly addresses the challenge of attributing extreme events to human-induced climate change.

### Key Messages

- The state of Florida is prone to various types of weather extremes, with tropical cyclones being the most dangerous in terms of impact potential.
- Most types of extreme events exhibit a seasonal cycle making it more likely for them to occur at certain times of the year. Many of them are also sensitive to large-scale climate variation resulting in strong interannual to multidecadal variability. The most important climate indicator for extreme weather in Florida is the El Niño Southern Oscillation (ENSO).
- Strong spatial variability of extreme events and related hazards exists across the state, with certain areas more susceptible to particular weather hazards than others. Maps of observed frequencies of the different types of events in the past can help identify hot spots.
- Attribution of climatic extremes is challenging because of insufficient observational records (with strong variability) and limitations in models with regards to resolution and complexity of the processes involved in the genesis of extreme events. This is also the reason for large uncertainties in future projections of most types of extreme events.
- There is, however, agreement that changes in the mean, which are better represented in climate models, will also affect the extremes (e.g., increasing mean sea level will affect storm surge heights and frequency).



**Figure 20.3.** Flood potential.