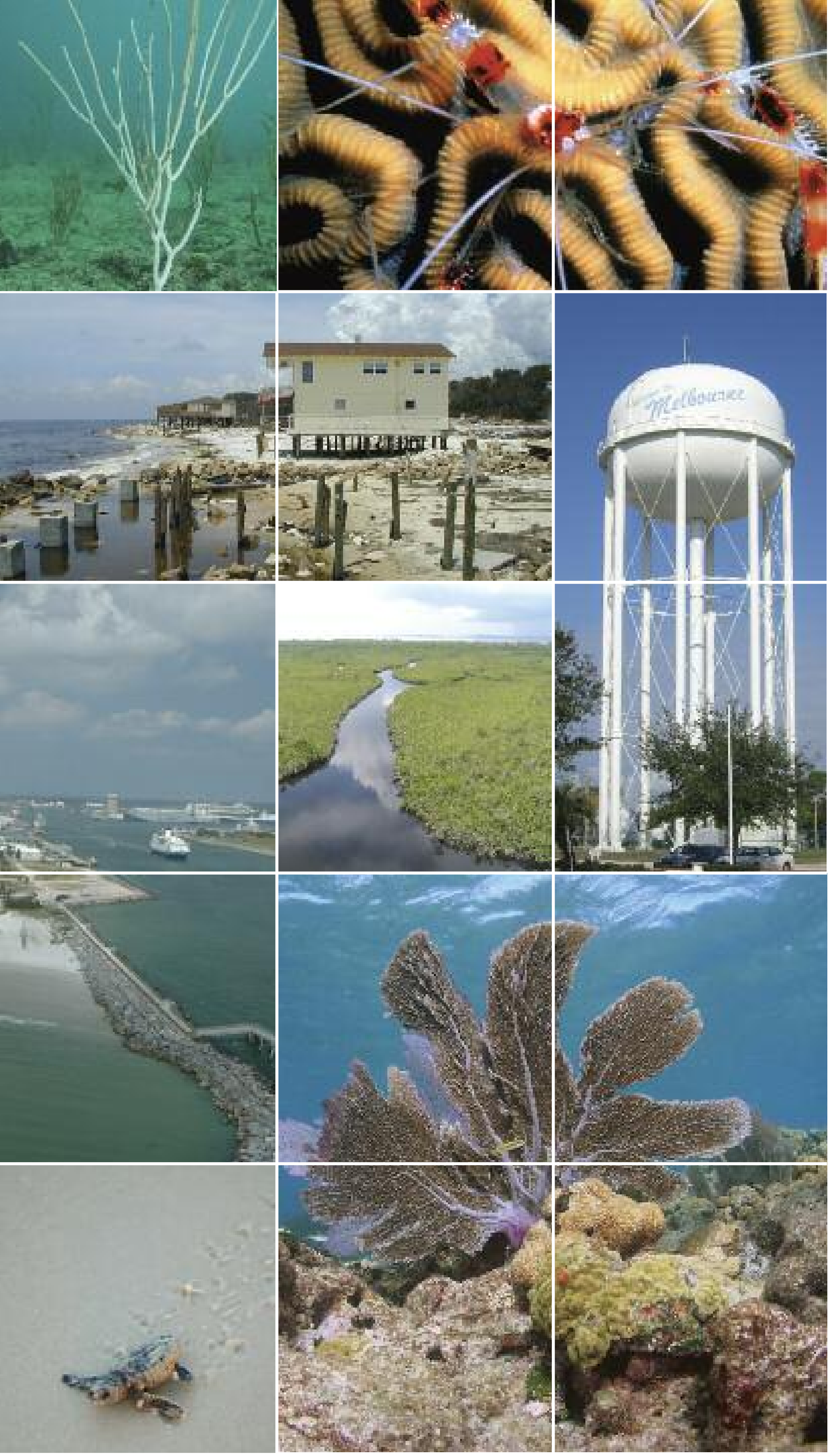

THE EFFECTS OF Climate Change ON FLORIDA'S Ocean & Coastal RESOURCES

A SPECIAL REPORT TO THE FLORIDA ENERGY AND CLIMATE COMMISSION AND THE PEOPLE OF FLORIDA

FLORIDA OCEANS AND COASTAL COUNCIL
TALLAHASSEE, FLORIDA

It is widely accepted that human activities can impact global climate patterns. While there are legitimate disagreements among scientists on the nature, magnitude, and impact of these changes, the potential risks to Florida's natural resources and our economy compel us to seek a thorough understanding of possible impacts and to provide current and future generations with the information necessary to adjust to them.

Florida Oceans and Coastal Council. Revised June 2009. The effects of climate change on Florida's ocean and coastal resources. A special report to the Florida Energy and Climate Commission and the people of Florida. Tallahassee, FL. 34 pp.

Photos on front and back cover courtesy of DEP, Bureau of Beaches and Coastal Systems; Paige Gill; Dave Gilliam; NASA; Guy Weeks & istockphoto.com.

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Acknowledgments

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Executive Summary

WHY THIS REPORT WAS WRITTEN

The Florida Oceans and Coastal Council prepared this report to provide a foundation for future discussions of the effects of global climate change on Florida's ocean and coastal resources, and to inform Floridians about the current state of scientific knowledge regarding climate change and how it is likely to affect Florida. It provides important information for legislators, policymakers, governmental agencies, and members of the public who are working to address, or who are interested in, issues related to climate change in Florida. The Council anticipates that the report will be updated periodically, and has recommended a number of research priorities for ocean and coastal research to improve levels of certainty about how climate change will affect Florida.

GLOBAL CLIMATE CHANGE AND FLORIDA

Global climate change is a reality. The scientific consensus presented in the 2007 report of the United Nations' Intergovernmental Panel on Climate Change is that warming of the Earth's climate system is unequivocally taking place (1). The report also concludes that most of the temperature increase since the mid-20th century is very likely caused by increased concentrations of greenhouse gases from human activities. These gases, which include carbon dioxide, are produced naturally and are also generated by human activities such as burning fossil fuels and widespread deforestation.

The question for Floridians is not whether they will be affected by global warming, but how much—that is, to what degree it will continue, how rapidly, what other climate changes will accompany the warming, and what the long-term effects of these changes will be. Florida is particularly vulnerable to the effects of climate change. It has over 1,200 miles of coastline, almost 4,500 square miles of estuaries and bays, more than 6,700 square miles of other coastal waters, and low-lying topography. In addition, most of its 18 million residents live within 60 miles of the Atlantic Ocean or Gulf of Mexico. Its diverse, productive coastal and marine ecosystems provide food and other products, valuable and irreplaceable ecological functions, and aesthetic and recreational opportunities. The state's life-support system, economy, and quality of life depend on preserving and sustaining these resources over the long term.

The four major aspects of climate change addressed in this document are **increasing greenhouse gases, increasing air temperature and water vapor, increasing ocean temperature,** and **increasing sea level**. In this report they are called "drivers," and for each driver the effects on Florida's ocean and coastal resources are described in terms of what is known, what is probable, and what is possible. "Probable" means that an effect is highly likely to occur in the future, while "possible" means that it may occur, but that predicted impacts must be carefully qualified to reflect the level of certainty.

Currently, none of the predicted effects is expected to benefit Florida's natural resources or human population (although this perspective may change as new knowledge becomes available). The potential impacts of climate change on the state's infrastructure, human health, and economy are significant.

Here is what is known and what is probable based on current scientific knowledge:

- Over the last 650,000 years, levels of atmospheric carbon dioxide have both increased and decreased.
- The rate of change in atmospheric carbon dioxide concentration has been about 100 times faster in recent decades than over the past 650,000 years. Concentrations of other greenhouse gases, such as methane and nitrous oxide, have also increased significantly.
- Atmospheric carbon dioxide will continue to increase at the rate of about 0.5 percent per year for at least the next few decades.
- As oceanic carbon dioxide has increased, the world's oceans have become more acidic, with pH declining by 0.1 standard units (representing a 30 percent increase in acidity) since 1750. A further decline is under way. The reduced pH (increased acidity) probably will have adverse impacts on corals, clams, shrimp, and other marine organisms with calcium carbonate shells or skeletons.
- Most of the increase in average air temperatures since the mid-20th century is due to increases in greenhouse gases.
- Water temperatures at the sea surface rose by an average of 0.5 degrees Fahrenheit (0.3 degrees Celsius) between the 1950s and 1990s in tropical and subtropical waters. Continued increases at this rate are probable.
- Over the past 30 years, increased sea-surface temperatures have led to episodic die-offs of sponges, seagrasses, and other important components of coastal and marine ecosystems. It is probable that the die-offs will become more frequent.
- Reef-building corals of Florida now are 1.8 to 2.7 degrees Fahrenheit (1 to 1.5 degrees Celcius) closer to their upper temperature limits than they were 100 years ago. In upcoming decades, as water temperature increases, the tolerance of some coral species will probably be exceeded.
- Corals that are stressed by high water temperature have displayed higher rates of disease, a situation that will probably become more widespread in upcoming decades. Coral bleaching events will also probably be more frequent.
- The geographic range of marine species will shift northward as sea-surface temperatures continue to rise. The species composition of Florida's native marine and estuarine communities will change, perhaps drastically.

- With further rises in water and atmospheric temperatures, conditions will probably be more favorable for exotic plant and animal species to invade Florida's coastal waters.
- Harmful algal blooms probably will increase if water temperatures continue to rise.
- Increased stormwater runoff in some parts of the state, coupled with human population increases, will increase the transport of nutrients to coastal waters, contributing to hypoxia (low oxygen).
- Sea levels around Florida have been slowly rising, at about 1 inch or less per decade.
- Sea levels around the state probably will continue to rise at historical to accelerated rates in upcoming decades, and could eventually threaten coastal development and the ecological integrity of natural communities in estuaries, tidal wetlands, and tidal rivers.
- As a result of increasing sea levels, Florida probably will become more vulnerable to coastal flooding and storm surges.
- Shoreline retreat and erosion are occurring now, and further rises in sea level will probably exacerbate this situation. Barrier islands probably will continue to erode and migrate towards the mainland.
- As sea levels rise, shallow coastal aquifers and associated public drinking water supplies are at risk from saltwater intrusion. The Pensacola and Miami-to-Palm Beach corridors are especially vulnerable to saltwater intrusion into public water supplies and reduced aquifer recharge.
- Climate change is likely to have a significant impact on coastal infrastructure such as roads and buildings. For example, buildings along the coast may experience catastrophic damage in upcoming decades if sea level continues to rise at the projected rate.

THE LONG-TERM SOLUTION

Some effects of climate change, such as ocean acidification, have already begun. Others will begin in the coming decades, and the time will come when Florida is simultaneously and continuously challenged by many of these effects. The long-term extent and severity of oceanic or coastal effects caused by climate change ultimately depend on how rapidly humanity can eliminate human sources of carbon dioxide and other greenhouse gases entering the atmosphere at harmful levels, now and in the future.

ABOUT THE FLORIDA OCEANS AND COASTAL COUNCIL

The 2005 Florida Legislature created the Florida Oceans and Coastal Council to annually establish a statewide agenda to prioritize ocean and coastal research, identify where research funding is needed, and coordinate public and private ocean research for more effective coastal management. The Council comprises 15 voting members and three nonvoting members. The Florida Department of Environmental Protection, Florida Fish and Wildlife Conservation Commission, and Florida Department of Agriculture and Consumer Services appoint five members each to the council. Additionally, one representative from each of these agencies serves as a nonvoting member. Additional information on the Council is available at: **http://www.floridaoceanscouncil.org**.

2008–2009 COUNCIL ACCOMPLISHMENTS

Sponsored the National Ocean Economics Program at California's Monterey Bay Aquarium Research Institute to complete Phase II: Florida Ocean and Coastal Economies Report:

- Made a presentation to the Governor and Cabinet on the economic impact of Florida's ocean and coastal economy; and
- Hosted the Florida Coastal and Ocean Economics Forum to present the work to the public and Florida's marine industries.

Completed eight coastal ocean observing systems projects through a contract with the Florida Coastal Ocean Observing System Consortium:

- Strategic Coastal Ocean Observing Implementation Plan and workshops (including the Ocean Tracking Network);
- Continuous remote sensing of nitrate using a moored instrument;
- A south Florida high-frequency radar array;
- An east-central Florida shelf array; deep ocean biological observatory station within the Oculina Habitat Area of Particular Concern;
- A moored buoy in data-sparse northeast Florida waters;
- A real-time high-resolution ocean and atmospheric modeling system for the Florida region;
- Florida-specific satellite remote sensing; and
- A northeast Florida shelf/estuary model.

Photo courtesy of University of South Florida

Continued work on the Resource Assessment for Florida.

Continued work on the Research Review for Florida.

Co-sponsored three conferences/workshops:

- 11th Annual International Coral Reef Symposium;
- Coastal Cities Summit; and
- Florida's Wildlife: On the Frontline of Climate Change (with the Florida Fish and Wildlife Conservation Commission).

Supported the Florida Water Resources Monitoring Council, enabling it to draft a Florida Coastal Monitoring Action Plan.

Co-sponsored the Gulf of Mexico Alliance's First Annual Monitoring Forum, which focused on data comparability and coastal nutrient criteria.

SECTION I.

Introduction

The Florida Oceans and Coastal Council prepared this report to provide a foundation for future discussions on the effects of climate change on Florida's ocean and coastal resources. The report addresses the aspects of climate change that are most important for Florida, its residents, and its coastal and ocean resources. It provides important information for legislators, policymakers, governmental agencies, and members of the public who are working to address, or who are interested in, climate change issues in Florida. The Council anticipates that the report will be updated periodically so that advances in science and policy can be communicated to Floridians.

WHY FLORIDIANS SHOULD CARE ABOUT CLIMATE CHANGE

Global climate change is not a science fiction scenario but a reality. The scientific consensus reached in 2007 by the United Nations' Intergovernmental Panel on Climate Change (see **Section II**) is that warming of the Earth's climate system is unequivocally taking place, and that most of the temperature increase since the mid-20th century is very likely caused by increased concentrations of greenhouse gases from human activities (see the sidebar) (1).

Thus, the question for Floridians is not whether they will be affected, but how much—that is, to what degree warming will continue, how rapidly, what other climate changes will accompany the warming, and what the long-term effects of these changes will be. Some detrimental effects, such as ocean acidification, are already well documented. Others will begin in the coming years and decades, and the time is coming when the state is simultaneously and persistently challenged by all of these effects.

WHAT ARE GREENHOUSE GASES?

Greenhouse gases, found in the Earth's atmosphere, are produced by natural and industrial processes. They absorb and emit heat, or infrared radiation, from the planet's surface, atmosphere, and clouds. While these gases are essential to maintaining the Earth's temperature, excess quantities can raise temperatures by radiating heat toward the surface. The most important greenhouse gases are water vapor (which causes 36 to 70 percent of the greenhouse, or warming, effect on Earth); carbon dioxide (9 to 26 percent); methane (4 to 9 percent); and ozone (3 to 7 percent). Other greenhouse gases include nitrous oxide, sulfur hexafluoride, hydrofluorocarbons, perfluorocarbons, and chlorofluorocarbons (2).

Florida is especially vulnerable to the effects of climate change. It has over 1,200 miles of coastline almost 4,500 square miles of estuaries and bays, and more than 6,700 square miles of other coastal waters (3). The entire state lies within the Atlantic Coastal Plain, with a maximum elevation less than 400 feet above sea level, and most of Florida's 18 million residents live less than 60 miles from the Atlantic Ocean or the Gulf of Mexico (3, 4).

In addition, Florida's coastal and marine resources comprise some of the nation's most diverse and productive ecosystems, supporting vast numbers of aquatic and terrestrial animals and plants—some of which exist nowhere else on Earth. These ecosystems include the coastal ocean, barrier islands, bays, estuaries, lagoons, sounds, tidal salt marshes and creeks, mangrove swamps, shellfish beds, seagrass beds, coral reefs, and oyster bars. They are an important source of food and other products; perform valuable and irreplaceable ecological functions at no cost; and provide significant aesthetic and recreational opportunities. Florida's life-support system, economy, and quality of life depend on preserving and sustaining these natural resources over the long term.

WHAT IS CLIMATE CHANGE?

Global climate comprises the atmosphere, land, snow and ice, the oceans and other bodies of water, and living organisms. The atmosphere is typically what we envision when talking about climate (which often is defined as the average weather) (5). However, the oceans are also a critical component of climate because of their ability to retain heat, their role in distributing heat globally, and their capacity as a reservoir for dissolved carbon dioxide.

According to the United Nations' Intergovernmental Panel on Climate Change, climate change is "a change in the state of the climate that can be identified (e.g., using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity" (1).

Currently, the composition of the Earth's atmosphere is changing as a result of both natural and human activities—including the burning of fossil fuels (which have caused the atmospheric buildup of carbon dioxide and other greenhouse gases) and large-scale deforestation. In recent decades, average air and ocean temperatures have increased; there is widespread melting of snow and ice at the poles; and average sea levels are rising. Because greenhouse gases remain in the atmosphere for a long time—from decades to hundreds of years—atmospheric levels of these gases will continue to increase during the 21st century (6).

> . . . The question for Floridians is not whether they will be affected, but how much that is, to what degree warming will continue, how rapidly, what other climate changes will accompany the warming, and what the long term effects of these changes will be. Some detrimental effects, such as ocean acidification, are already well documented. Others will begin in the coming years and decades, and the time is coming when the state is simultaneously and continuously challenged by all of these effects.

In the future, it is very likely that higher levels of greenhouse gases in the atmosphere will result in continued increases in average global temperatures and sea levels, and that patterns of rainfall will change as a result. However, a number of important scientific questions need additional study, including how much the Earth's temperature will rise, how rapidly, and how it will affect the global climate (6).

PRINCIPAL "DRIVERS" OF CLIMATE CHANGE AND HOW THEY WILL AFFECT FLORIDA

The following aspects, or "drivers," of climate change will affect Florida's ocean and coastal resources:

- Increasing greenhouse gases;
- Increasing air temperature and water vapor;
- Increasing ocean temperature; and
- Increasing sea level.

Global climate models currently available, including those used by the Intergovernmental Panel on Climate Change, are too broad to resolve issues about smaller, individual regions such as Florida. Thus, this report carefully identifies what is known about each of these drivers and describes its effects on Florida's ocean and coastal resources in terms of what is currently known, what is probable, and what is possible. "Probable" means that an effect is highly likely to occur in the future, while "possible" means that it may occur, but that predicted impacts must be carefully qualified to reflect the level of certainty. The report also examines some of the possible interactions among these drivers and their effects, as well as the potential consequences for Florida's infrastructure, human health, and economy.

The range of effects is imperfectly known and incomplete but could include the following:

Driver: Increasing greenhouse gases

- Increased ocean acidification.

Driver: Increasing air temperature and water vapor

- Altered rainfall and runoff patterns; and
- Changes in the frequency and intensity of tropical storms and hurricanes.

Driver: Increasing ocean temperature

- Increased coral bleaching and disease;
- Increased incidence of coral and fish diseases;
- Increased losses of sponges and other marine plants and animals;
- Decreasd biological diversity, or biodiversity;
- Changes in the distribution of native and invasive exotic marine species;
- Changes in nutrient supply, recycling, and food webs; and
- Increased incidence of harmful algal blooms, hypoxia (low oxygen), and water-borne diseases.

Driver: Increasing sea level

- Increased stresses on, or losses of, tidal wetlands;
- Changes to the landforms (or geomorphology) of estuaries, tidal wetlands, and tidal rivers;
- Greater instability of beaches, barrier islands, and inlets; and
- Increased threats to coastal fresh water supplies.

Currently, none of these effects is expected to benefit the state's natural resources or people. However, this perspective may change as new knowledge becomes available.

Florida will respond to the adverse effects of climate change in three ways:

1. **Some effects will have to be accepted,** meaning that no reasonable options will be found. For example, Florida may have to accept the loss of its coral reefs.
2. **Some effects can be mitigated,** meaning that strategies and actions will compensate for some of the adverse effects. For example, the state may set aside additional coastal lands so that tidal wetlands can migrate inland as sea level rises, preserving these essential coastal habitats.
3. **Floridians will adapt,** meaning that our way of life, infrastructure, and/or economy will have to change in order to maintain the same quality of life to which Floridians are accustomed. For example, buildings may need to be designed to new standards or located farther from vulnerable shorelines.

RESEARCH PRIORITIES

The Florida Oceans and Coastal Council has recommended a number of priorities for ocean and coastal research to improve levels of certainty about how climate change will affect Florida. These include designing and establishing real-time, interdisciplinary observing systems both for Florida waters and for -contiguous waters that affect the Florida coastline, as well as further investigating ocean and coastal ecosystems, water quality, and tools and technology. To accurately predict climate change, it is essential to develop and use models that couple the atmosphere and oceans, and to do so on appropriately fine spatial scales to address the changes relevant to Florida.

SECTION II.

Intergovernmental Panel on Climate Change: The 2007 Report Summary

The Intergovernmental Panel on Climate Change, a scientific intergovernmental body, was established in 1988 by the World Meteorological Organization and the United Nations Environment Programme. It is made up of a large, diverse group of scientists, governmental representatives, and individuals from around the world. It does not conduct research or monitoring, or make policy recommendations. Instead, the panel uses a scientific peer review process to assess the latest scientific, technical, and socioeconomic findings, providing decision makers and others with an objective source of information (7).

In 2007, both the Intergovernmental Panel on Climate Change and former U.S. Vice President Al Gore Jr. were awarded the Nobel Peace Prize *"for their efforts to build up and disseminate greater knowledge about man-made climate change, and to lay the foundations for the measures that are needed to counteract such change" (8).*

> "Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level."
>
> *Climate Change 2007: Synthesis Report (Inter governmental Panel on Climate Change, 2007)*

In 2007, the panel issued its fourth report on global climate change (previous reports were issued in 1990, 1992, 1995, and 2001) (1). Building on earlier work, the report presents the findings of three major working groups on the physical science of climate; impacts, adaptation, and vulnerability; and mitigation. Highlights are as follows:

Observed changes indicating global climate change:

- Eleven of the last 12 years have been subject to the warmest temperatures since 1850.
- Sea levels have been rising faster since 1993.
- Satellite data show Arctic sea ice, mountain glaciers, and snow cover have shrunk since 1978.

Causes of global climate change:

- Concentrations of greenhouse gases, especially carbon dioxide, have increased.
- Carbon dioxide emissions increased by 80 percent between 1970 and 2004.

Projected global climate change and impacts:

- Greenhouse gas emissions will continue to increase.
- This increase will induce greater climate change in the 21st century.
- Atomospheric warming of 0.4 degrees Fahrenheit (0.2 degress Celsius) per decade is projected.
- Warming will likely be greatest in the northern latitudes.
- Permafrost and icepacks will thaw at faster rates.
- Increases in temperature maxima will be associated with heavier precipitation.
- Storm intensity will likely increase; periods of drought may be longer.
- Ocean acidity will increase.
- Coastal flooding will increase due to sea-level rise and storms.
- Human health will be affected by increased heat, floods, drought, and disease.
- Some changes in climate could be abrupt and irreversible.

Available adaptations and steps to slow the pace of global climate change:

- Increase water reuse and rainwater harvesting.
- Create natural buffers against sea-level rise.
- Develop heat-health action plans.
- Develop renewable energy sources; reduce carbon dioxide emissions.

SECTION III.

Climate Change and Florida's Infrastructure, Human Health, and Economy

While all of the future impacts cannot be predicted, climate change has the potential to threaten every aspect of life in Florida, from essential infrastructure (such as buildings, roads, and fresh water supplies), to the health of residents and visitors, to the preservation of natural systems, to the state's economic well-being and long-term sustainability. The exact costs of dealing with these effects are not known, but they will be significant. However, the costs of inaction will be far greater, and some costs simply cannot be measured in dollars.

INFRASTRUCTURE IMPACTS

Florida could experience changes such as extreme winds, continued sea-level rise, increased flooding and storm surge, extreme and daily rainfall, and relative humidity and temperature fluctuations. Much of the state's infrastructure—water, power, telecommunications, transportation, and buildings – was constructed to last at least 75 years. Infrastructure longevity was thus based on past environmental design criteria and specifications, many of which may have been exceeded already by aspects of climate change (9, 10).

> Because current projections indicate that sea level may rise over six inches during the service life of a building, the risk for future catastrophic damage is high, not only near the coast (in large part due to Florida's flat terrain) but also in most inland regions.

Photo courtesy of Guy Weeks

HUMAN HEALTH IMPACTS

Changes in climate patterns and extreme climatic events have had a wide range of negative effects on human health and well-being in the United States and around the world. For example, severe heat waves, hurricanes, and floods have resulted in deaths and injuries (11, 12). With over 1,200 miles of coastline, Florida residents are particularly vulnerable to the effects of hurricanes and tropical storms.

In addition, stormwater discharges carry nutrients, toxins, and fecal contaminants from the land into coastal waterways. Pulses of fecal contaminants in stormwater runoff cause the closure of beaches and shellfish beds and affect humans through recreational exposure (13). Storm-induced increases in fertilizer runoff from agricultural and residential areas could affect the frequency, intensity, and duration of toxin-producing red tides or harmful algal blooms and promote the emergence of previously unknown toxic algae (14).

In other parts of the world, increases in water-borne diseases, such as cholera, have been directly linked to warming and extreme weather events. In the future, the potential exists for the reintroduction of mosquito-borne diseases, such as malaria and dengue fever, into areas where they do not currently exist, such as warmer regions of the United States, including Florida (15). Threats to ecosystems rich in biodiversity, such as coral reefs, mangroves, and seagrasses, will result in the loss of marine algae and invertebrates, some of which are sources of chemicals with disease-fighting properties (16).

> Changes in climate patterns and extreme climatic events have had a wide range of negative effects on human health and well being in the United States and around the world.

By monitoring a range of environmental factors such as sea-surface temperature and height, turbidity, chlorophyll concentration, and concentrations of the nutrients nitrogen and phosphorus, researchers can determine which factors are linked to disease outbreaks and harmful algal blooms (14). If outbreaks can be predicted, it may be possible to mitigate their harmful effects. Some of these measurements can be made using remote sensing data from satellites; other measurements can be taken by sensors placed in the oceans as part of the observing systems being established around the coast of the United States, including Florida.

ECONOMIC IMPACTS

Climate change will affect Florida's economy. The economic and financial costs associated with such change can be direct or indirect. Some costs are called "hidden" because they may be difficult to identify and quantify. Many environmental and human costs cannot be measured in dollars. These include the effects on human quality of life and the destruction of ecosystems that currently provide essential ecological functions at no cost.

Some sectors of the economy may benefit from climate change and some of the costs may be offset by taking actions to mitigate its effects. However, the net costs of climate change are likely to exceed the benefits.

A recent national study, sponsored by the Center for Health and the Global Environment at Harvard Medical School, indicates that the economic impacts of climate change will occur throughout the United States (17). These impacts will be unevenly distributed across regions and society, and negative impacts will outweigh benefits for most sectors that provide goods and services. The impacts will place immense strains on public sector budgets. The secondary impacts of climate change can include higher prices, reduced incomes, and job losses.

> . . . Negative impacts will outweigh benefits for most sectors that provide goods and services. The impacts will place immense strains on public sector budgets. The secondary impacts of climate change can include higher prices, reduced incomes, and job losses.

Photo courtesy of Guy Weeks – Alligator Point

The same study predicts that major impacts on the southeast United States (including Florida) will be felt most acutely in coastal infrastructure. Moreover, forests, agriculture and fisheries, water supplies, water quality, and energy sources may be subject to considerable change and damage. Many of these sectors are closely linked. For example, energy supply depends on cooling water availability; emergency preparedness on transportation, energy supply, water availability, and more. Only a few of these interrelationships typically enter economic impact and cost assessments. These indirect links need to be considered as well as the economic cost assessments.

Another recent study also estimates the costs of inaction for Florida, should the rate of greenhouse gas emissions continue unchecked (18). The study addresses both optimistic (rapid stabilization though greatly reduced emissions) and pessimistic scenarios (no change in the growth of emissions). The cost of inaction is the difference between these two scenarios. For just four categories of economic activity—tourism, hurricanes, electric power, and real estate—the cost of inaction ranged from $27 billion by 2025 (or 1.6 percent of the projected gross state product) to $354 billion in 2100 (about 5 percent of the projected gross state product). If estimates include other sectors, such as agriculture, fisheries, insurance, transportation, water systems, and ecosystem damages, the cost of inaction is even greater.

IV. "Drivers" of Climate Change and Their Effects on Florida's Ocean and Coastal Resources

The further Floridians look into the future, the more uncertain are the predicted consequences of climate change. This section identifies what is currently known, what is probable, and what is possible about the drivers of climate change and their effects on Florida.

DRIVER: Increasing Greenhouse Gases

Earth's temperature is rising because the levels of carbon dioxide and other greenhouse gases that retain atmospheric heat are increasing. This increase is largely a consequence of human activities that use energy, particularly fossil fuels such as oil and coal. All of these gases are absorbed by the oceans (19).

WHAT WE KNOW:

- From 1980 to 1989, the carbon content of the Earth's atmosphere is estimated to have risen by a rate of about 3.4 billion tons of carbon per year, with an estimated error of ± 0.2 billion tons (20, 21).
- Over the last 650,000 years, levels of atmospheric carbon dioxide have fluctuated between 180 to 280 parts per million by volume (5).
- The rate of change in increases in atmospheric carbon dioxide has been about 100 times faster in recent decades than over the past 650,000 years. Concentrations of other greenhouse gases, such as methane and nitrous oxide, have also increased significantly (5).
- Most of the increase in average atmospheric temperatures since the mid-20th century is due to increases in greenhouse gases.

WHAT IS PROBABLE:

- Atmospheric carbon dioxide will continue to increase at the rate of about 0.5 percent per year for at least the next few decades (22).
- Water quality will continue to change because of the absorption of increased greenhouse gases by the oceans (23).

Photo courtesy of Uwe Hermann

- Increases in pollutant emissions will result in the increased introduction of nutrients and toxins into surface waters.
- Continued greenhouse gas emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would very likely be larger than those observed during the 20th century.

WHAT IS POSSIBLE:

- Atmospheric carbon dioxide will stabilize if global emissions are reduced by 30 percent or more despite increases in global population (5).
- The rate of atmospheric greenhouse gas increase will markedly accelerate due to positive feedback processes not currently accommodated in model projections (5).

IV. "Drivers" of Climate Change and Their Effects on Florida's Ocean and Coastal Resources

EFFECT: Increases in Ocean Acidification

As levels of carbon dioxide in ocean waters increase, the oceans become more acidic. The average pH of the ocean has been approximately 8.3 units. A downward change in any pH value means an increase in acidity. A change of as little as 0.1 pH unit can have a large impact on organisms living in the sea because it repre sents a 30 percent increase in acidity.

WHAT WE KNOW:

- The average pH of the world's oceans has fallen by 0.1 pH unit since 1750 because of the uptake of carbon dioxide created by human activities (24).
- Marine organisms with calcium carbonate shells or skeletons, such as corals, clams, and some plankton at the base of the food chain, can be adversely affected by decreases in pH and carbonate saturation state (5, 26). A higher carbonate saturation state favors the precipitation of calcium carbonate, a mineral in their shells, while a lower state supports its dissolution into the water.
- Ocean chemistry is changing at least 100 times more rapidly today than at any time during the 650,000 years prior to the industrial era (22).

WHAT IS PROBABLE:

- An additional decrease in pH is under way (25, 27).
- With decreases in the pH of seawater, which is a measure of its relative acidity, some marine plants may show increases in production until a particular threshold is met, and then will decline.
- Some marine organisms will not be able to tolerate the predicted decreases in pH in the ocean.

Photo courtesy of Paige Gill – Florida Keys NMS

- Carbonate sediment dissolution will accelerate as pH decreases (28).

WHAT IS POSSIBLE:

- The average pH of the world's oceans may decrease by as much as 0.1 to 0.4 pH units over the next 90 years (29).
- Ocean acidification may lead to shifts in marine ecosystem structure and dynamics that can alter the biological production and export of organic carbon and calcium carbonate from the ocean surface (29).
- Important fisheries habitats, such as coral reefs, will markedly decline or disappear (22, 27).

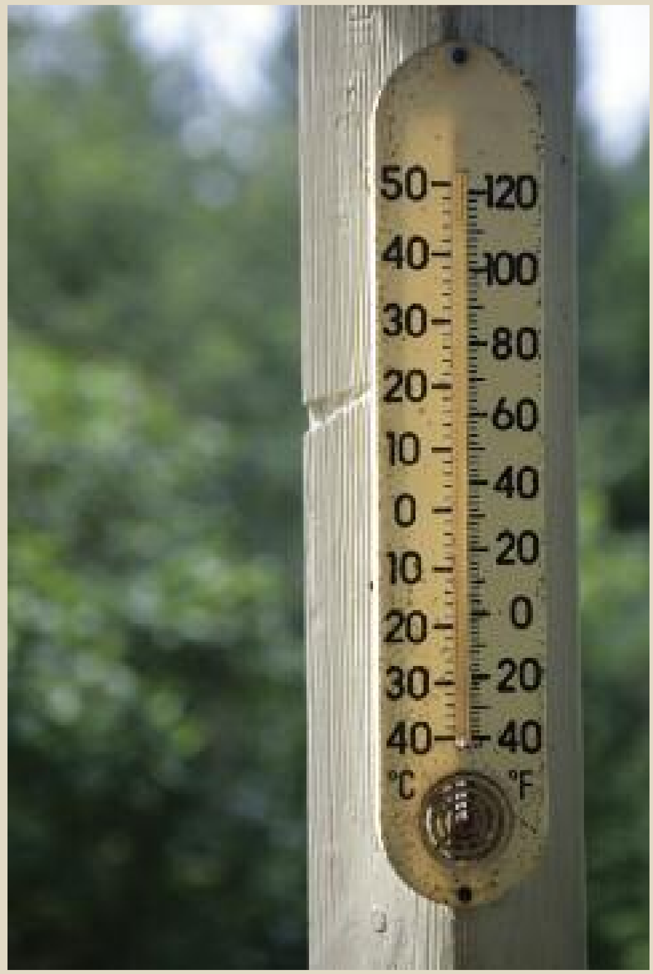
IV. "Drivers" of Climate Change and Their Effects on Florida's Ocean and Coastal Resources

DRIVER: Increasing Air Temperature and Water Vapor

Water vapor, the most abundant greenhouse gas, is an important factor causing uncertainty in climate prediction models. As air temperature increases, its capacity to hold water vapor increases. However, clouds may have a cooling or heating effect, and cloud processes are one of the largest sources of uncertainty in climate change pro jections. Our inability to correctly characterize the effects of water vapor greatly complicates climate forecasts.

WHAT WE KNOW:

- Mean global atmospheric temperature has increased by more than 1.1 degrees Fahrenheit (0.6 degrees Celsius) since 1901 (5).
- Since the 1980s, the atmospheric column average water vapor concentration has increased by 1.2 percent (5).



WHAT IS PROBABLE:

- Coastal air temperature observations around Florida since the 1830s do not show any statistically significant trend (30).
- Air temperature in south Florida may increase because of changes in land use and land cover, such as urbanization and the reduction of wetlands (31, 32).
- Global average air temperatures are projected to increase by 2.5 to 10.4 degrees Fahrenheit (1.4 and 5.8 degrees Celsius) by 2100 (5).

WHAT IS POSSIBLE:

- Florida may begin to experience increasing air temperatures.

IV. "Drivers" of Climate Change and Their Effects on Florida's Ocean and Coastal Resources

EFFECT: Altered Rainfall and Runoff Patterns

Rainfall over the Florida peninsula depends on the winds (e.g., sea breezes), especially in the summer, and on hurricanes and tropical storms. Rainfall variations are highly cyclical (33). Climate change, land use, and other factors may result in greater variations in observed patterns, conflicting trends, and regional differences within the state. Distinguishing Florida specific rainfall and runoff trends from future global trends is a critical research need.

WHAT WE KNOW:

- Annual rainfall in Florida is affected by tropical storms and variability over decades, such as the Atlantic Multidecadal Oscillation or the El Niño-Southern Oscillation warming phenomenon in the Pacific Ocean (33, 34, 35).
- Summer rainfall varies over periods of a few decades (36).
- Human alterations to freshwater inflow into estuaries, such as increased overland flow due to urbanization or decreased flow caused by dams and water withdrawals, have changed estuarine circulation patterns, salinity regimes, and patterns of animal use (37).

WHAT IS PROBABLE:

- Since 1979, there probably has been a change in the type of rainfall in the tropics, resulting in more frequent heavy and light rains, and less frequent moderate rains (38).
- If the frequency of extreme rainfall events increases, it will exacerbate already altered conditions in estuaries (39, 40).
- Rainfall in south Florida may be decreasing from changes in land use and land cover, such as urbanization and the reduction of wetlands (31).

WHAT IS POSSIBLE:

- Air pollution may cause more rainfall during weekdays (41).
- Based on models, reduced rainfall may accompany changes in land use such as urban development (31).
- If the frequency of extreme rainfall events increases (39), or river volume increases and the timing of freshwater flows to estuaries changes, it will exacerbate already-altered conditions in estuaries such as increased nutrient delivery and eutrophication (40, 42).

EFFECT: Altered Frequency and Intensity of Tropical Storms and Hurricanes

The development of tropical storms and hurricanes depends not only on sea surface temperature and water vapor content, but also on factors such as wind shear, which plays a significant role. Recent examples of rapid storm intensification are associated with storms passing over deep, warm ocean pools and through regions of low wind shear (43). Because of changes in methodology, it is difficult to obtain comparable data for tropical storms and hurricanes over the period of record, which dates from the mid 19th century.

WHAT WE KNOW:

- There is no clear, long-term trend in the number of tropical storms (5, 44).
- There are changes in storm frequency over a period of a few decades. We are currently in an active period and may eventually enter a less active period (45).
- Intense hurricanes and active seasons have occurred regardless of trends in sea-surface temperatures (46).
- Storms can occur at any time of year. Over 97 percent of North Atlantic tropical storm activity occurs from June to November (47).

Photo courtesy of NASA

WHAT IS PROBABLE:

- Storm frequency may decrease with increasing sea-surface temperatures (48).
- Wind shear will increase in a warming planet, thus reducing the intensity and frequency of storms (49, 50).

WHAT IS POSSIBLE:

- Severe hurricanes (Category 3 or higher) may become more frequent with increasing sea-surface temperatures (51).

IV. "Drivers" of Climate Change and Their Effects on Florida's Ocean and Coastal Resources

DRIVER: Increasing Ocean Temperature

Florida, situated between the Gulf of Mexico and Atlantic Ocean, is subject to contrasting environmental effects because each body of water has its own characteristic temperature regimes and patterns of change.

WHAT WE KNOW:

- There has been a cyclical rise in sea level and global ocean temperatures (52).
- Sea-surface temperatures have been steadily rising in tropical and subtropical waters. Between the 1950s and 1990, they rose by an average of 0.5 degrees Fahenheit (0.3 degrees Celsius) (53).
- The year 2005 was the warmest in the wider Caribbean than any in the last 100 years, and coincided with the Western Hemisphere Warm Pool being in an expanded state (52, 53).
- Global average sea-surface temperature has risen 1.1 degrees Fahrenheit (0.6 degrees Celsius) over the past 100 years (5).

WHAT IS PROBABLE:

- Sea-surface temperatures will continue to rise at least at the rate they have been rising for the past 100 years (5).
- As sea-surface temperatures continue to rise, the coastal and marine environments most stressed by nutrients from land-based sources of pollution will be most adversely affected (53).

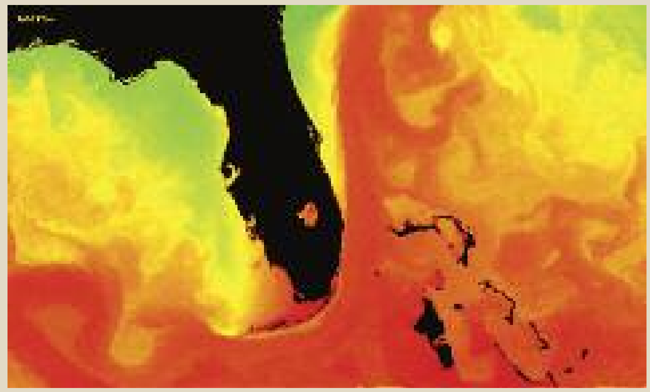


Photo courtesy of Roffer's Ocean Fishing Forecasting Service, Inc.

WHAT IS POSSIBLE:

- If the temperature of Florida's ocean waters increases at the same rate that the Intergovernmental Panel on Climate Change models predict for the Gulf of Mexico and Atlantic as a whole, they would increase by 3.6 degrees Fahrenheit (2 degrees Celsius) over the next 100 years (5).
- Ocean currents may shift (53).

EFFECT: Increases in Coral Bleaching and Disease

Corals are tropical animals already living close to their upper water temperature limits. These animals have a close association with single celled plants that live inside the cells of the coral and that provide energy to the coral by photosynthesis. Corals are said to bleach, or whiten, when they lose their plant cells. Bleaching events are correlated with local or regional increases in seawater temperature. In the early 1980s, during the first massive coral bleaching event in the Florida Keys, observations of increased coral diseases began to be reported (53).

WHAT WE KNOW:

- The reef-building corals of Florida are now 2.7 degrees Fahrenheit (1 to 1.5 degrees Celsius) closer to their upper thermal limits than they were 100 years ago (53).
- Corals stressed by temperature and bleaching are more vulnerable to pathogens on the outer surface of the coral, resulting in increases in coral disease (54, 55, 56).
- Coral diseases have increased substantially in the Florida Keys due to an increase in sea-surface temperatures (53).

Photo courtesy of Paige Gill – Florida Keys NMS

WHAT IS PROBABLE:

- The thermal tolerance limits of some coral species will be surpassed.
- The rates of sea-surface temperature change predicted by global climate models suggest that coral bleaching events will be more frequent and severe in the future (53).
- Current predictions of future coral bleaching events indicate that certain coral species will not be able to adapt to warmer water (53).
- Increasing sea-surface temperatures will increase microbial activity in coastal and marine environments, leading to increased algal blooms, coral diseases, and diseases of other coral reef organisms.
- Increases in sea-surface temperatures will continue to stress corals in the Florida Keys, and severe outbreaks of coral diseases will continue.

WHAT IS POSSIBLE:

- Coral reef community structure will shift toward coral species with a higher tolerance of changing conditions, resulting in major shifts in coral reef communities and a loss of biodiversity.

EFFECT: Increases in Fish Diseases, Sponge Die-offs, and Loss of Marine Life

Corals are not the only marine organisms adversely affected by increased sea surface temperatures. In the past 25 years, for example, tropical reef fish have suffered severe outbreaks of Brookynella, a marine disease caused by a protozoan, or single celled animal, that infects reef fish under stress. Massive die offs of sponges and blooms of cyanobacteria, which can produce biological toxins, have also been documented during extended periods of elevated sea surface temperatures (53).

WHAT WE KNOW:

- Increased sea-surface temperatures in coastal and marine environments, especially during slick calm periods in shallow and semi-enclosed embayments, lead to episodic die-offs of sponges, seagrasses, and other important components of coastal and marine communities.
- Massive die-offs of tropical reef fish, caused by infections of the organism *Brookynella*, occurred in 1980 in the Florida Keys and from 1997 to 1998 in the Florida Keys and the Caribbean (53).
- Massive sponge die-offs have occurred along the reef tract, which extends from Miami to the Dry Tortugas, and in Florida Bay during recent periods that coincided with elevated sea-surface temperatures and doldrum weather periods (53).
- The epidemic die-off of the black long spined sea urchin (*Diadema antillarum*) began on the Caribbean side of Panama in 1983 (57).
- A massive die-off of seagrasses occurred in Florida Bay in 1987, at the same time that a massive coral bleaching event was occurring throughout the Keys and Caribbean (53).

WHAT IS PROBABLE:

- As sea-surface temperatures continue to rise, die-offs of marine fauna incapable of moving to cooler water are likely to become more frequent. Other factors, such as low levels of dissolved oxygen, the addition of nutrients and other land-based sources of pollution, and harmful algal blooms, will exacerbate these die-offs.

WHAT IS POSSIBLE:

- The conditions that contribute to fish diseases and various die-offs in the Florida Keys may move to more northern latitudes. As sea-surface temperatures continue to increase, the impacts may begin to affect more northerly coastal and marine environments that have thus far escaped these problems.

EFFECT: Changes in the Distribution of Native and Exotic Species

As marine species shift northward with overall warmer ocean temperatures, this shift may have either negative or positive impacts. Some species may be able to survive farther north than in current ranges, but interactions among communities with new species compositions cannot be predicted. Moreover, reproduction in some fishes decreases in warmer temperatures, potentially resulting in population decreases.

WHAT WE KNOW:

- Geographic species ranges will shift northward as a result of increased water temperatures (58).
- Recent changes in the distribution and productivity of a number of fish species can, with high confidence, be ascribed to regional climate variability, such as the El Niño–Southern Oscillation warming phenomenon in the Pacific Ocean (57).
- Along with increasing sea temperatures, staghorn and elkhorn coral are now re-expanding their ranges northward along the Florida Peninsula and into the northern Gulf of Mexico (59).
- Abundant fossil evidence demonstrates that marine animals shifted toward the poles as sea-surface temperatures rose—for example, during the early Holocene (10,000 - 6,000 years ago) when cold-sensitive corals extended their range to the north (60).
- In addition to allowing natural range expansions, warming temperatures can facilitate the establishment and spread of deliberately or accidentally introduced species (62, 63).

WHAT IS PROBABLE:

- Florida's native marine and estuarine systems will change species composition, perhaps drastically (64).
- The impacts on living communities may stem from changing maximum and minimum water temperatures, rather than annual means.
- By giving introduced species an earlier start, and increasing the magnitude of their growth and recruitment compared with natives, global warming may facilitate a shift to dominance by non-native species, accelerating the homogenization of global animal and plant life (65).
- The frequency and intensity of extreme climate events are likely to have a major impact on future fisheries production in both inland and marine systems (5, 59).
- Non-native, larger-bodied bivalves—a group of mollusks that includes oysters and clams—will be the most successful invaders, while native, large-bodied bivalves may be more sensitive to environmental changes. Consequently, the native species may either shift their ranges or become locally extirpated as climate shifts (66).
- The effects of disease in marine organisms are likely to become more severe, because warmer temperatures generally favor the development of pathogens relative to their hosts (55).

WHAT IS POSSIBLE:

- Non-native, tropical invasive species could overwhelm Florida's native temperate marine and estuarine systems (67).
- Projections of future conditions portend further impacts on the distribution and abundance of fishes that are sensitive to relatively small temperature changes.
- Some species may not persist. Other, currently rare species may become dominant (58).

EFFECT: Changes in Nutrient Supply, Recycling, and Food Webs

The metabolism of marine and coastal ecosystems is affected by water temperature, nutrient supply, and volume of freshwater inputs. How efficiently or inefficiently nutrients move through the food web can affect the diversity, number, and economic value of living marine resources. A food web is the interconnected network through which energy, in the form of food, is transferred and stored among species in an ecosystem.

WHAT WE KNOW:

- Climate-related changes in freshwater runoff to coastal marine systems, coupled with changes in stratification (or layering) patterns linked to warming and altered salinity, will change the quantity and availability of nutrients in estuarine systems (68).

WHAT IS PROBABLE:

- Changes in the absolute and relative availability of nutrients will lead to changes in microscopic plants (phytoplankton) and microbial activity in the marine food web (69).

WHAT IS POSSIBLE:

- Induced changes may result in food webs that are less efficient in transferring energy to higher levels, thus affecting the productivity of economically important fish and other plant and animal life (69).

IV. "Drivers" of Climate Change and Their Effects on Florida's Ocean and Coastal Resources

EFFECT: Harmful Algal Blooms

Harmful blooms are caused by microscopic algae in the water column that can produce biological toxins, such as those generated by red tide in coastal marine waters; blue green algae in estuarine waters; or larger species of marine and estuarine algae that grow on the bottom, which can smother corals and other native plants and animals.

WHAT WE KNOW:

- Environmental factors, including light, temperature, and nutrient availability, set the upper limit to the accumulation of marine algae biomass (70). The algae that cause harmful algal blooms in coastal marine and estuarine waters are favored over other algae when water temperature is high and the water becomes thermally stratified (71, 72). Harmful algal blooms have been reported throughout Florida's coastal marine and estuarine waters (73).

Photo courtesy of Florida Fish and Wildlife Conservation Commission

WHAT IS PROBABLE:

- If climate change systematically increases nutrient availability and alters the amount of available light and the stability of the water column, there may be substantive changes in the productivity, composition, and biomass of marine algae, including the harmful species (74).
- If water temperatures increase due to climate change, harmful algal blooms probably will become more frequent and intense (71, 72, 75).

WHAT IS POSSIBLE:

- The increased occurrence, intensity, and toxicity of harmful algal blooms may result in the disruption of coastal marine and estuarine food webs, more frequent fish kills, and adverse impacts to people in or near an affected coastal area (70, 71, 75).

EFFECT: Hypoxia

Warm water holds less dissolved oxygen than cold water. Hypoxia, or low oxygen, occurs when the levels of oxygen dissolved in water fall below levels necessary to support ocean and coastal life, and can lead to what is called a "dead zone." Nutrients can cause or exacerbate hypoxic conditions by causing certain organisms to proliferate, leading to decreased oxygen when they decay. Terrestrial nutrients are introduced into the ma rine environment through precipitation and runoff.

WHAT WE KNOW:

- Hypoxia can occur as a natural phenomenon and also as a human-induced or exacerbated event (76).
- Precipitation and runoff amounts and distribution have changed over recent years and will continue to change as climate change progresses (77).

Photo courtesy of Florida Fish and Wildlife Conservation Commission

WHAT IS PROBABLE:

- Increased runoff in some areas, coupled with human population increases in Florida, will lead to the increased transport of nutrients to coastal waters, contributing to hypoxia (5).

WHAT IS POSSIBLE:

- Locations that have experienced hypoxia may also experience longer hypoxic episodes, or even the annual recurrence of hypoxia (78).
- Increased density stratification within estuaries could occur with increased precipitation and runoff (79).
- New locations with hypoxia may develop in coastal areas (78).
- There may be adverse impacts on bottom-feeding fish and sessile (attached to the bottom) organisms (5).

IV. "Drivers" of Climate Change and Their Effects on Florida's Ocean and Coastal Resources

DRIVER: Increasing Sea Level

The *rate* at which sea level rises is equally as important to coastal resources as how much it rises. Florida's geology, chemistry, biology, and human population have already been, and will continue to be, profoundly affected by rising sea level. For the past few thousand years, the sea level around Florida has been rising very slowly, although a persistent upturn in the rate of relative sea level rise may have begun recently (5). Geolog ical studies show that in the past, Florida and global sea level rose or fell much more rapidly than in recent times. Distinguishing Florida specific sea level trends from future global trends is a critical research need.

WHAT WE KNOW:

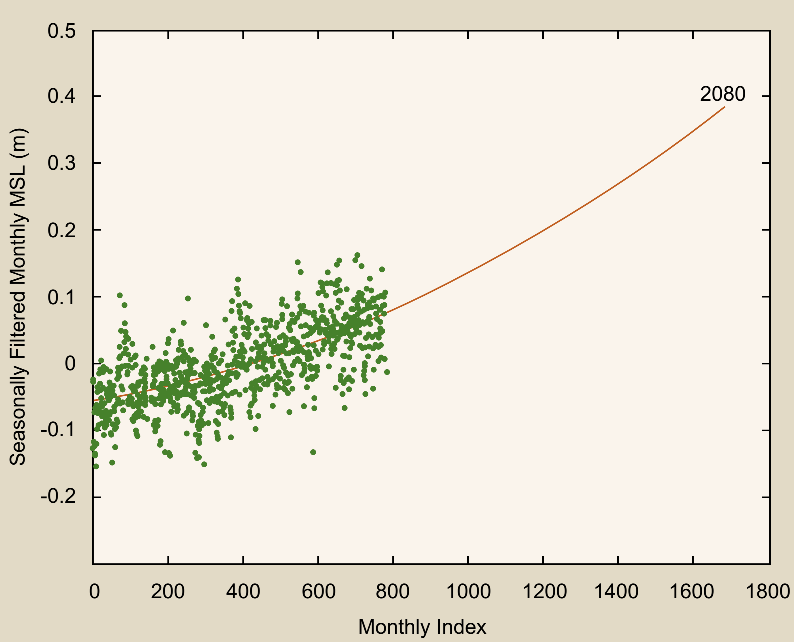
- Around Florida, relative sea level has been rising at a slow but constant rate, about an inch or less per decade (80).
- The rate of global sea rise increased from the 19th to the 20th century (5).

WHAT IS PROBABLE:

- The rate of global average sea-level rise has increased during the late 20th century (81).
- In time, the rate of global sea-level rise will accelerate because of ocean warming and contributions from land-based ice melt from glaciers and the ice sheets of Greenland and Antarctica (5).
- Sea-level rise will continue well after 2100 even if greenhouse gas concentrations are stabilized by then (5).

WHAT IS POSSIBLE:

- Major inputs of water from the melting of high-latitude and high-altitude ice reservoirs could cause several meters of sea-level rise over a period of centuries (82).



Key West, FL—forecasted sea level rise.

IV. "Drivers" of Climate Change and Their Effects on Florida's Ocean and Coastal Resources

EFFECT: Changes in Estuaries, Tidal Wetlands, and Tidal Rivers

Although Florida tide ranges are relatively small, tidal effects extend far inland because much of the state is so low and flat. Because sea level has been relatively constant for a long time, tidal wetlands such as mangrove forests and salt marshes have been able to grow into expansive habitats for estuarine and marine life. However, these tidal wetlands are sensitive to the rate of sea level rise and can perish if sea level rise exceeds their capacity to adapt. With rising sea levels, sandbars and shoals, estuarine beaches, salt flats, and coastal forests will be altered, and changes in freshwater inflow from tidal rivers will affect salinity regimes in estuaries and patterns of animal use. Major redistributions of mainland and barrier island sediments may have compensatory or larger benefits for wetland, seagrass, or fish and wildlife communities, but these processes cannot be forecast with existing models.

WHAT WE KNOW:

- Estuarine circulation, salinity, and faunal use patterns are changing (42).
- Many tidal wetlands are keeping pace with sea-level changes (83). Some are accreting vertically, migrating up-slope, or both (84, 85, 86). The rate of sea-level rise will be critical for tidal wetlands.
- Wetlands elsewhere are perishing as estuarine and coastal forests and swamps are retreating and being replaced by marsh vegetation (84, 85, 86).
- Open estuarine waters, some brackish marshes, and mangroves in south Florida estuaries are expanding (87, 88).
- Even at constant rates of sea-level rise, some tidal wetlands will eventually "pinch out" where their upslope migration is prevented by upland defenses such as seawalls (83, 89).

WHAT IS PROBABLE:

- Increased air temperatures and reductions in freeze events will result in mangrove habitat moving northward, replacing salt marsh in some areas (90, 91).
- Upland plant communities along tidal rivers and estuaries will be replaced by low-lying, flood-prone lands. Increased saline flooding will strip upland soils of their organic content (84, 92).
- Low-diversity wetlands will replace high-diversity wetlands in the tidal freshwater reaches of coastal rivers (93).
- Major spatial shifts in wetland communities, including invasions of exotic species, will occur (94).
- More lowland coastal forests will be lost during the next one to three centuries as tidal wetlands expand across low-lying coastal areas (95).
- Most tidal wetlands in areas with low freshwater and sediment supplies will "drown" where sea-level rise outpaces their ability to accrete vertically (96).

WHAT IS POSSIBLE:

- More than half of the salt marsh, shoals, and mudflats critical to birds and fishes foraging in Florida estuaries could be lost during the 21st century (87).
- Recreational and commercial fish species that depend on shallow water, or intertidal and subtidal plant communities, will be at risk (87).
- The loss of tidal wetlands will result in dangerous losses of the coastal systems that buffer storm impacts (97).

IV. "Drivers" of Climate Change and Their Effects on Florida's Ocean and Coastal Resources

EFFECT: Changes in Beaches, Barrier Islands, and Inlets

Beaches and inlets are regional systems of sediment deposition, erosion, and transport. These processes are profoundly affected by changes in sea level and rates of sea level change, as well as storm events. Scientists and resource managers will be challenged to separate the effects of sea level changes from the effects of storms and the alterations resulting from beach and inlet management actions.

WHAT WE KNOW:

- Shoreline retreat due to erosion and overwash is occurring now (98).
- There is an increase in the formation of barrier island inlets and in island dissection events, in which islands are eroded by wind and waves (98, 99).

WHAT IS PROBABLE:

- Continued sea-level rise will exacerbate erosion (100).
- Barrier islands will continue to erode, migrate landward, and be reduced in elevation (100).
- Coastal transportation infrastructure will be affected.

WHAT IS POSSIBLE:

- Increased overwash, breaching of coastal roads, and dissection of barrier islands will occur (98).
- Low barrier islands will vanish, exposing marshes and estuaries to open-coast conditions (100).

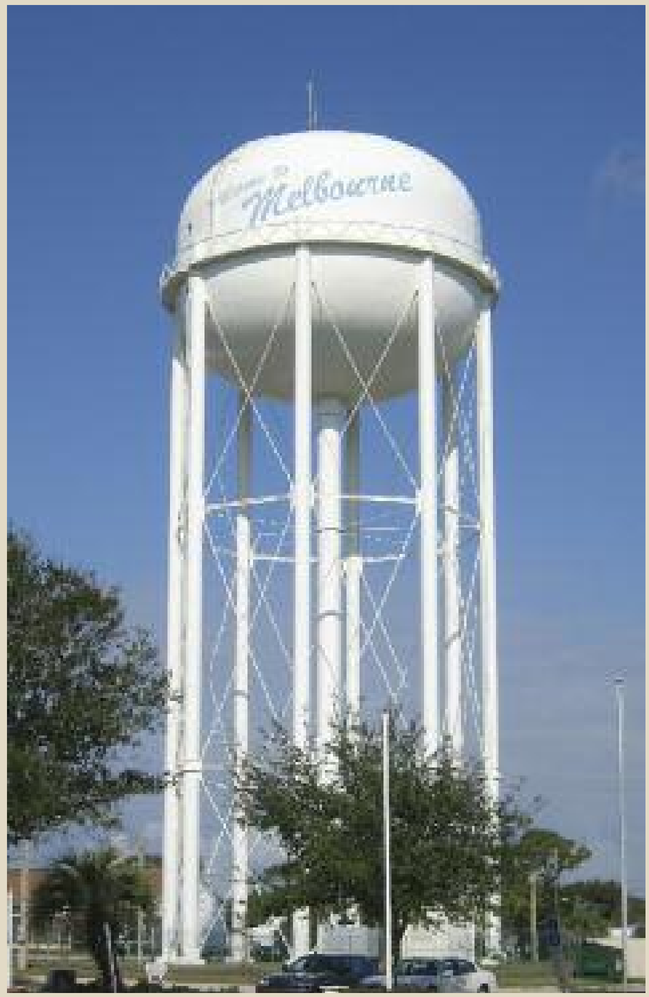
IV. "Drivers" of Climate Change and Their Effects on Florida's Ocean and Coastal Resources

EFFECT: Reduced Coastal Water Supplies

Sea levels in Florida are expected to eventually rise to the degree that saltwater intrusion will threaten the aquifers that currently supply much of Florida's drinking water in low lying areas. This problem will be exacer bated by increased withdrawals of water for the anticipated increase in Florida's population.

WHAT WE KNOW:

- Shallow coastal aquifers are already experiencing saltwater intrusion. The freshwater Everglades recharges Florida's Biscayne aquifer, the primary water supply to the Florida Keys. When rising water levels submerge the land, the low-lying portions of the coastal Everglades become more saline, decreasing the recharge area and increasing saltwater intrusion (101).
- The South Florida Water Management District already spends millions of dollars per year to prevent Miami's Biscayne aquifer from becoming brackish (102).



WHAT IS PROBABLE:

- A sea-level rise of about 6 inches would require greater cutbacks in water use by developed regions in order to prevent saltwater intrusion; however, the interior regional hydrologic system of south Florida would not be significantly affected (103).
- The Pensacola and Miami-Palm Beach corridors are especially vulnerable to saltwater intrusion into community fresh water supplies with rising sea levels (104, 105).

WHAT IS POSSIBLE:

- Eventually, if sea level continues to rise, surficial aquifers throughout the state will be threatened.

SECTION V.

Climate Change: Priorities for Florida's Ocean and Coastal Research

The climate-related effects identified in this document are expected to result in major changes to Florida's marine resources, as well as to its developed coastal areas. To sustain the quality of life of residents, the diversity and productivity of marine ecosystems, and the economy of the state in the face of these changes, residents, elected officials, resource managers, and university scientists must work together to find timely, responsible, and effective solutions. These often may involve difficult decisions that consider tradeoffs among the various sectors that depend on coastal resources, and as such, they will be politically as well as technologically challenging. Thus, it is imperative that decisions be based on sound science.

The Florida Oceans and Coastal Council will continue to address the critical information needs related to climate change for coastal and marine systems during its future deliberations. At this time, the following recommendations from the Council's 2009–2010 Research Plan directly support Florida's climate-based information needs:

CLIMATE CHANGE

The world's changing climate has the potential to dramatically impact Florida's marine resources, disrupt marine-based economies and cause significant damage to coastal development, thereby creating the need for mitigation and adaptive-management strategies. Providing guidance to minimize effects on Florida's population and natural resources must begin with investigation into three key areas outlined below.

Research Priorities—Climate Change:

1. Modeling of sea-level rise based on Intergovernmental Panel on Climate Change (IPCC) scenarios and development of cost estimates for resulting effects in terms of natural resource impacts and adaptation of existing coastal development. Emphasis is on collaborative, statewide efforts with peer review. These can include steps that may be necessary to improve model accuracy such as improved topography for coastal uplands.
2. Assessing the impact on fisheries productivity from changes in Florida's estuarine habitats due to climate change.
3. Monitoring, modeling, and mapping of natural system responses with an emphasis on predicting effects of climate change on coral reef communities. To establish baseline data, it will be necessary to map and characterize Florida's coral reef communities.

WATER QUALITY

Water quality is of critical importance to Florida—it determines what biological communities can live in a water body, whether the water is harmful to humans, and whether the water is suitable for other designated uses. With an economy driven by our environment, maintaining water quality to support coral reefs, grass beds, fishing, and beach activities must be a high priority.

Research Priorities—Water Quality:

1. Research and monitoring that examine effects of excess nutrients on living coastal resources and relate them to causes and sources and to human activities. The intent is to support cost-effective resource management programs to improve oceans and human health.
2. Statewide coastal observing that guides water quality management, marine resource management, and navigation and hazard response.
3. Harmful algal bloom (HAB) research to protect tourism, commercial and recreational fisheries, and inform watershed management for ocean health. The emphasis is on non-red tide HABs as red tide HABs are already being addressed.
4. Modeling of hydrodynamics, water quality, and coastal/ocean ecosystems to support better understanding of cause and effect between uplands activities, coastal freshwater discharges, and resulting effects on estuarine and marine biological communities.

OCEAN AND COASTAL ECOSYSTEMS

Florida's ocean and coastal ecosystems are critical to maintaining the economic activity they support, from beachgoing to fishing. It is also critical to maintain as sustainable natural systems. These resources are shaped by geology, water movement, and the plants and animals themselves interacting on a variety of scales from hundreds of kilometers to millimeters. Having a comprehensive understanding of these ecosystems through reliable baseline information is critical to supporting wise management decisions.

Research Priorities—Ocean and Coastal Ecosystems:

1. Map and characterize the seafloor and coast including the distribution and abundance patterns of coastal marine organisms. Emphasis is on the gaps in mapping identified by the state resource management agencies at the Florida Mapping Workshop in February 2007.[1]
2. Improve understanding of coastal and ocean hydrology, including the linkages between freshwater input and coastal waters. Emphasis should be on water budgets, hydrologic modeling, and factors affecting and controlling freshwater input to coastal and nearshore waters.
3. Research and modeling to understand and describe linkages between ocean and coastal habitats and the living marine resources they support. One area of emphasis is the effects of marine protected areas (MPAs) on surrounding populations. Fisheries and their linkages to habitats are an important area of these studies.
4. Increase understanding of ocean and coastal economics, including the values of non-market resources and the costs and benefits of beach nourishment and beach restoration.

TOOLS AND TECHNOLOGY

Fulfilling Florida's need to observe and predict environmental change and the ecosystem responses of its coastal waters provides abundant opportunity for the development and implementation of cost-effective tools and technologies to understand, monitor, and improve the health of Florida's resources.

Photo courtesy of Mike White, Florida Keys NMS

Research Priorities—Tools and Technology:

1. Integrated Coastal and Ocean Observing Systems—A mix of in-water platforms and buoys, shipboard surveys, remote sensing, and computer models is required for continuous monitoring of climate change, water quality, and status of marine resources. The goal is to create a sustained interdisciplinary observing system that spans all of Florida's waters from the outer shelf to coastal estuaries and rivers. Emphasis is on extending, integrating, and filling gaps in existing coastal observations.

2. Development of sensors to provide improved abilities to determine the status and trends of our coastal waters and their inhabitants. Emphasis is on sensor development for biological and chemical sensing, as well as tagging and tracking of wildlife.

3. Integrated Data Management and Prediction – Coordinated collection, handling, quality control, sharing, and interpretation of research and monitoring data are critical to improving the State's resource management capabilities. Centralized coordination of model development to provide prediction and user-friendly web-based posting of information and model predictions are needed to accommodate science-based decisions by management agencies and the general public.

4. Development of innovative tools and integration of data to cost-effectively map and monitor the State's coasts and oceans.

5. Development of assessment tools, particularly for assessments of biological community status and trends, for rapid assessments of natural resources, and for evaluation of management efforts.

Florida Department of Environmental Protection

Office of Coastal and Aquatic Managed Areas

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THE LONG-TERM SOLUTION

Some effects of climate change, such as ocean acidification, have already begun. Others will begin in the coming decades, and the time will come when Florida is simultaneously and continuously challenged by many of these effects. The long-term extent and severity of oceanic or coastal effects caused by climate change ultimately depend on how rapidly humanity can eliminate human sources of carbon dioxide and other greenhouse gases entering the atmosphere at harmful levels, now and in the future.