



# Understanding the Science of Climate Change

## *Talking Points – Impacts to the Gulf Coast*

Natural Resource Report NPS/NRPC/NRR—2010/210



**ON THE COVER**

Great Egret in front of cypress trees, Everglades National Park; NPS photo.

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# I. Introduction

## Purpose

Climate change presents significant risks to our nation's natural and cultural resources. Although climate change was once believed to be a future problem, there is now unequivocal scientific evidence that our planet's climate system is warming (IPCC 2007a). While many people understand that human emissions of greenhouse gases have contributed to recent observed climate changes, fewer are aware of the specific impacts these changes will bring. This document is part of a series of bio-regional summaries that provide key scientific findings about climate change and impacts to protected areas. The information is intended to provide a basic understanding of the science of climate change, known and expected impacts to resources and visitor experience, and actions that can be taken to mitigate and adapt to change. The statements may be used to communicate with managers, frame interpretive programs, and answer general questions to the public and the media. They also provide helpful information to consider in developing sustainability strategies and long-term management plans.

## Audience

The Talking Points documents are primarily intended to provide park and refuge area managers and staff with accessible, up-to-date information about climate change and climate change impacts to the resources they protect.

## Organizational Structure

Following the Introduction are three major sections of the document: a Regional Section that provides information on changes to the Gulf Coast, a section outlining No Regrets Actions that can be taken now to mitigate and adapt to climate changes, and a general section on Global Climate Change. The Regional Section is organized around six types of changes or impacts, while the Global Section is arranged around four topics.

### *Regional Section*

- Temperature
- The Water Cycle (including snow, ice, lake levels, sea levels and sea level rise, and ocean acidification)
- Vegetation (plant cover, species range shifts, and phenology)
- Wildlife (aquatic, marine, and terrestrial animals, range shifts, invasive species, migration, and phenology)
- Disturbance (including range shifts, plant cover, plant pests and pathogens, fire, flooding, and erosion)
- Visitor Experience

### *Global Section*

- Temperature and Greenhouse Gases
- Water, Snow, and Ice
- Vegetation and Wildlife
- Disturbance

Information contained in this document is derived from the published results of a range of scientific research including historical data, empirical (observed) evidence, and model projections (which may use observed or theoretical relationships). While all of the statements are informed by science, not all statements carry the same level of confidence or scientific certainty. Identifying uncertainty is an important part of science but can be a major source of confusion for decision makers and the public. In the strictest sense, all scientific results carry some level of uncertainty because the scientific method can only “prove” a hypothesis to be false. However, in a practical world, society routinely elects to make choices and select options for actions that carry an array of uncertain outcomes.

The statements in this document have been organized to help managers and their staffs differentiate among current levels of uncertainty in climate change science. In doing so, the document aims to be consistent with the language and approach taken in the Fourth Assessment on Climate Change reports by the Intergovernmental Panel on Climate Change. However, this document discriminates among only three different levels of uncertainty and does not attempt to ascribe a specific probability to any particular level. These are qualitative rather than quantitative categories, ranked from greatest to least certainty, and are based on the following:

- “What scientists know” are statements based on measurable data and historical records. These are statements for which scientists generally have high confidence and agreement because they are based on actual measurements and observations. Events under this category have already happened or are very likely to happen in the future.
- “What scientists think is likely” represents statements beyond simple facts; these are derived from some level of reasoning or critical thinking. They result from projected trends, well tested climate or ecosystem models, or empirically observed relationships (statistical comparisons using existing data).
- “What scientists think is possible” are statements that use a higher degree of inference or deduction than the previous categories. These are based on research about processes that are less well understood, often involving dynamic interactions among climate and complex ecosystems. However, in some cases, these statements represent potential future conditions of greatest concern, because they may carry the greatest risk to protected area resources.

## II. Climate Change Impacts to the Gulf Coast

The Gulf Coast bioregion that is discussed in this section is shown in the map to the right. A list of parks and refuges for which this analysis is most useful is included on the next page. To help the reader navigate this section, each category is designated by color-coded tabs on the outside edge of the document.



### Summary

Predicted climate changes in the Gulf Coast bioregion include increased air and sea surface temperatures, altered fire regimes and rainfall patterns, increased frequency of extreme weather events, rising sea levels, increased hurricane intensity, and potential destruction of coastal wetlands and the species that reside within them. Prolonged drought conditions, storm surges, and rising sea levels may reduce availability of freshwater resources, alter river and wetland hydrology, increase erosion, and induce changes in the distribution of coastal plant and animals species. For example, intense hurricane activity may decrease survival of endangered Florida manatees, and sea level rise may allow mangrove habitats to expand at the expense of upland habitat areas. Coastal development, dredging, reservoir construction, diversion of surface water, and groundwater pumping may exacerbate the effects of climate changes on biotic communities.

# List of Parks and Refuges

Temperature

Water Cycle

Vegetation

Wildlife

Disturbance

Visitor Experience

## U.S. National Park Service Units

- Big Cypress NPR
- Big Thicket NPR
- De Soto NME
- Dry Tortugas NP
- Everglades NP
- Gulf Islands NS
- Jean Lafitte NHP&NPR
- New Orleans Jazz NHP
- Padre Island NS
- Palo Alto Battlefield NHP

## U.S. Fish & Wildlife Service Units

- Anahuac NWR
- Aransas NWR
- Bayou Sauvage NWR
- Bayou Teche NWR
- Big Boggy NWR
- Big Branch Marsh NWR
- Bogue Chitto NWR
- Bon Secour NWR
- Brazoria NWR
- Breton NWR
- Caloosahatchee NWR
- Cameron Prairie NWR
- Cedar Keys NWR
- Chassahowitzka NWR
- Crystal River NWR
- Delta NWR
- Egmont Key NWR
- Florida Panther NWR
- Grand Bay NWR
- Great White Heron NWR
- Island Bay NWR
- J.N. "Ding" Darling NWR
- Key West NWR
- Lacassine NWR
- Laguna Atascosa NWR
- Lake Wales NWR
- Lower Refuge Grande Valley NWR
- Lower Suwannee NWR
- Mandalay NWR
- Matlacha Pass NWR
- McFaddin NWR
- Mississippi Sandhill Crane NWR
- Moody NWR
- National Key Deer Refuge
- Passage Key NWR
- Pine Island NWR
- Pinellas NWR
- Sabine NWR
- San Bernard NWR
- Santa Ana NWR
- Shell Keys NWR
- St. Marks NWR
- St. Vincent NWR
- Ten Thousand Islands NWR
- Texas Point NWR
- Trinity River NWR

Acronym	Unit Type
NHP	National Historical Park
NME	National Memorial
NP	National Park
NPR	National Preserve
NS	National Seashore
NWR	National Wildlife Refuge



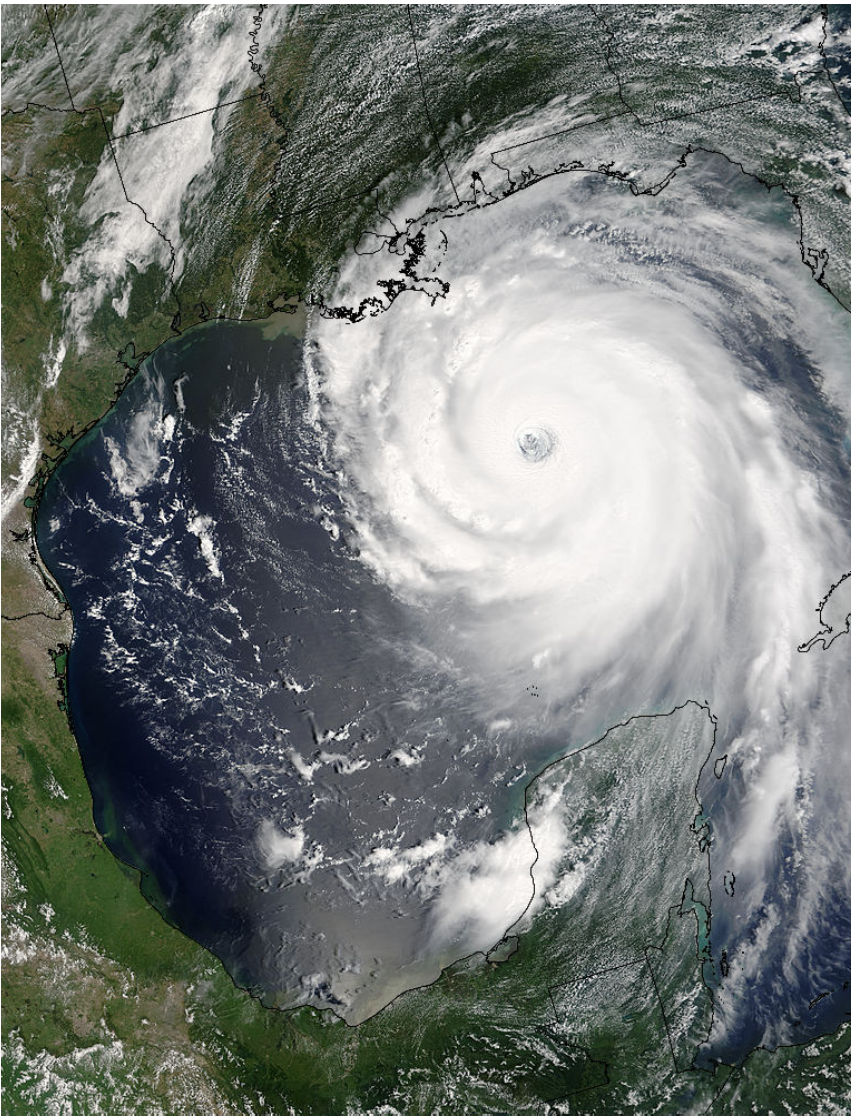
## A. TEMPERATURE

### *What scientists know....*

- Southeastern temperature trends have varied over the past 100 years, with a warm period during the 1920s-1940s followed by a cooling trend through the 1960s. Since the 1970s, temperatures have been increasing, with much of the warming occurring in winter months (Burkett et al. 2001, Ning et al. 2003).
- Regional temperature changes are several times larger than the global average, there has been a decrease in the daily temperature range, and daily minimum temperatures are increasing at twice the rate of maximum temperatures. Minimum temperatures have increased by 0.83°C since 1950 (Ning et al. 2003).
- Recent studies show that the mean temperature of the oceans between depths of 0 and 300 meters increased by 0.31°C between 1948 and 1998 and that this warming signal is observable to depths of 3000 meters (Levitus et al. 2000).
- Tropical oceans have warmed about 0.6°C over the instrumental record, including about 0.5°C since 1970. Tropical cyclones, which form only over warm oceans from which they gain energy, (mainly from the latent heat of condensation) have increased in intensity since the 1970s (Anthes et al. 2006).
- In confined coastal bays and estuaries, especially along the southern coast, water temperature will be directly influenced by changes in air temperature. Consequently, the temperatures of these shallow waters are expected to closely track the projections for changes in regional air temperatures, and will be especially vulnerable to increasing warming (Twilley et al. 2001).

### *What scientists think is likely....*

- Some models predict a twofold increase in the number of days that fall above the present-day high-temperature thresholds, resulting in increased mean seasonal temperatures and shifts in daily temperatures (Hayhoe et al. 2007).



The Gulf Coast is prone to hurricanes as thunderstorm complexes approaching from the east develop into low pressure systems that can quickly intensify. Hurricane Katrina approaches the Gulf Coast (Top); NASA photo. Katrina flooded Bayou Sauvage NWR with saltwater (Bottom). Most of the saltwater was pumped out through the levee system that protects the refuge. USFWS photo.





The Davis Bayou salt marsh at Gulf Islands National Park; NPS photo.

- Increasing seasonal and annual average temperatures will increase the July heat index, decrease winter cold spells, and cause a northward shift in the frost line (Twilley et al. 2001).

#### ***What scientists think is possible....***

- Average air temperatures in Florida will continue to increase in the coming decades, with average low temperatures in winter increasing by 1.7-5.6°C and average high temperatures in summer increasing by 1.7-3.9°C by 2100 (Harwell et al. 2001).
- The heat index (measure of human comfort based on temperature and humidity) is projected to rise by as much as 4 to 8°C across the entire southeastern U.S. by 2100. (Twilley et al. 2001).
- An ensemble of regionally downscaled general circulation models indicate that the average annual temperature in the Gulf Coast region is likely to increase by 1-2°C by 2050. Extreme high temperatures (above 37.8°C [100°F]) are also expected to increase in the region (Keim et al. 2008).

## **B. THE WATER CYCLE**

#### ***What scientists know....***

- Annual rainfall trends show very strong increases of 20-30% or more over the past 100 years across Mississippi, Arkansas,

South Carolina, Tennessee, Alabama, and parts of Louisiana, with mixed changes across most of the remaining area. The percentage of the Southeast landscape experiencing severe wetness (periods in which the PDSI averages more than +3) increased approximately 10% between 1910 and 1997 (Burkett et al. 2001).

- Much of the increase in precipitation observed in the region over the past 100 years was associated with intense rainfall events (rainfall amounts greater than 5 cm per day). Moderate rainfall events, generally beneficial to agriculture and water supply, contributed to only a small percentage of the increased precipitation (Burkett et al. 2001).
- There is evidence for an enhanced hydrologic cycle in the Gulf Coast region, including a decreased daily temperature range, more atmospheric water vapor, increased precipitation, more intense precipitation events, and stronger extratropical storms (Ning et al. 2003).
- Aquatic ecosystems are especially vulnerable to extreme climatic changes such as drought because these disturbances alter the flow regime, water chemistry and, ultimately, the biotic community. During extreme drought streams typically form a series of disconnected pools and surface flow ceases, a response that can potentially reset the aquatic community (Griswold et al. 2008).
- Accumulation of nutrients and toxic waste, coupled with increased temperature and lowered dissolved oxygen, stress aquatic species. Survival after drought depends on specific life-history traits including resistance to desiccation and the ability to colonize habitats rapidly through drift, aerial migration and /or oviposition (Griswold et al. 2008).

#### ***What scientists think is likely....***

- A recent study predicted a net increase during the late 21st century in the number of days in which severe thunderstorm environmental conditions occur. The largest increases in storm activity are during the summer season, in proximity to the Gulf

of Mexico and Atlantic coastal regions (Trapp et al. 2007).

- Climate changes are predicted to increase water supply stress in Florida by the year 2020 by as much as 34%, depending on precipitation patterns projected by climate models. Population increase will likely amplify climate-induced water supply stress across the region (Sun et al. 2008).
- Large river system (e.g., Mississippi) discharges are expected to increase. Water flows will be determined by rainfall trends in watersheds far upstream of the Gulf Coast, as well as by massive human-engineered flood control structures. Smaller, local river systems are expected to experience decreased discharge due to increased evaporation and droughts (Twilley et al. 2001).

#### *What scientists think is possible....*

- Regional climate projections for the Gulf Coast for the late 20th century include increases in both extreme precipitation events and in the frequency of dry days, suggesting that climate change could result in simultaneous enhancement of both wet and dry conditions (Diffenbaugh et al. 2005).
- More frequent or longer lasting droughts and reduced freshwater inflows may increase the incidence of extreme salt concentrations in coastal ecosystems, resulting in a decline of valuable habitats such as the mangroves, baldcypress, water tupelo,

and seagrasses in Florida Bay and South Texas lagoons (Krauss et al. 2000; Twilley et al. 2001).

- Estuaries in the southeast/Gulf of Mexico region tend to have lower freshwater turnover times (higher flushing rates) than other U.S. estuaries, and climate change may increase these flushing rates. Alternatively, introduced chaotic and episodic climate changes (e.g. droughts and floods) may result in loss of wetlands and decreased flushing rates, as open water habitat increases and estuaries deepen. A lower flushing rate could lead to more harmful algal blooms (because of a longer residence time) or higher salinities (because of increased seawater mixing). It is not known whether these factors will compensate for each other so that equilibrium is maintained (Ning et al. 2003).
- Permanent reductions of freshwater flows in rivers from both human activities and climate change may substantially reduce biological productivity in Mobile Bay, Apalachicola Bay, Tampa Bay, and the lagoons of Texas (Twilley et al. 2001).
- The oxygen-poor (hypoxic) waters in the Gulf of Mexico off of Louisiana now extend across as many as 20,480 square kilometers, depending on the amount of nitrate-laden fresh water discharged by the Mississippi River. A 20% increase in discharge, as predicted by some climate models, could increase the risk of hypoxia and expand the oxygen-poor “dead zone” (Twilley et al. 2001).

The J.N. “Ding” Darling National Wildlife Refuge is one of the largest mangrove ecosystems in the United States; USFWS photo.



## C. VEGETATION

#### *What scientists know....*

- In wild plants and animals, climate-induced extinctions, distributional and phenological changes, and species range shifts are being documented at a growing rate (Parmesan 2006).
- Changes in climate significantly affect vegetation phenology, morphology, distribution, growth, and reproduction. Most observed changes are linked with temper-



ature change either directly or indirectly (i.e. altered moisture availability) (Root et al. 2003).

- Harmful algal blooms (red tides) have become more extensive in recent years. Warmer coastal waters, especially in combination with nutrient pollution, can also increase the intensity, duration, and extent of blooms of harmful algae and cyanobacteria. Red tides, considered a natural phenomenon and not dependent on pollution, are already a chronic problem in many areas and thrive in warmer waters (Harvell et al. 1999).
- Sea level rise and drought interactions have accelerated forest decline on the Gulf Coast of Florida, including dramatically increased mortality and increased water stress in Southern red cedar and cabbage palm. In addition, increased frequency of

Mangrove maze; USFWS photo.



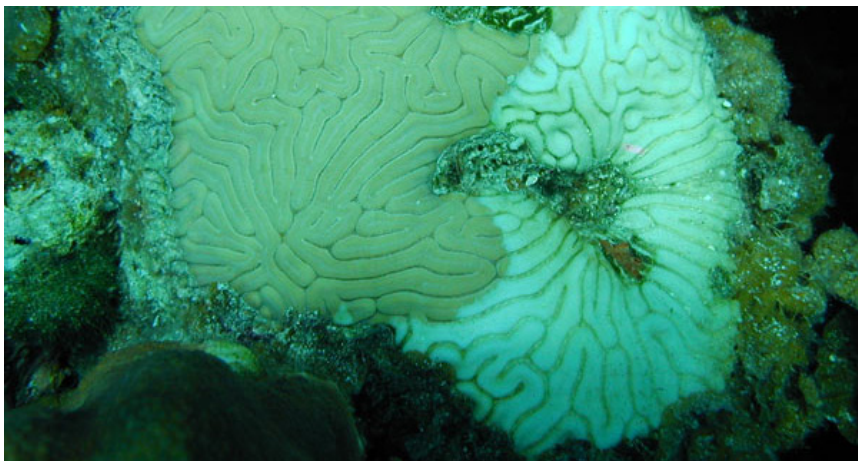
tidal flooding has resulted in decreased species richness in coastal forest stands (Desantis et al. 2007).

- Mangrove systems and other tidal wetlands are threatened by climate change effects, especially sea level rise. Other climate change components that threaten these ecosystems include high water events, storminess, temperature and precipitation, and ocean circulation patterns. Loss of mangroves will result in reduced coastal water quality, reduced biodiversity, loss of fish and crustacean nursery habitat, and loss of ecosystem services for human populations (Gilman et al. 2008).
- Experimental long-term exposure to elevated atmospheric CO<sub>2</sub> caused an increase in above ground shoot biomass of a Florida scrub-oak ecosystem, in particular of Myrtle oak, the dominant species. Growth stimulation was sustained throughout the experiment, although there was significant variability between years resulting from variations in total annual rainfall. The absolute stimulation of above ground biomass generally declined over time, reflecting increasing environmental limitations to long-term growth response (Seiler et al. 2008).

#### ***What scientists think is likely....***

- Land-use change models for Waccasassa Bay State Preserve Park in Florida predict a 17.5% reduction in coastal forest due to conversion to salt marsh. The models estimate that 50% of the forests that were present in the Preserve in 1973 will disappear between 2108 and 2228, and all forests will be gone by 2273–2393. In addition, faunal and floral migration into upland areas on private land adjacent to the Preserve is likely to be impeded by development in the region (Castaneda and Putz 2007).
- Although salt marshes may be able to survive rates of sea level rise as high as 50 centimeters, an estimate that is lower than the expected rise in sea level for much of the coastal U.S. over the next 100 years, local subsidence or hydrologic changes could increase the rate of relative sea level at individual marshes, potentially exceeding





A healthy coral reef environment (Top); Bleached coral reef (Bottom); NASA photos.

the ability of some salt marshes to adapt (Boesch et al. 2000).

- In general, coastal wetlands will survive if the increase in sediment surface elevation equals the rate of relative sea level rise, or if they are able to migrate inland or to areas of higher elevation; however, if soil accumulation does not keep pace with sea level rise, or if bluffs, coastal development, or shoreline protective structures (dikes, sea walls, jetties) block wetland migration, wetlands may be excessively inundated, reduced in area, and replaced by open water (Scavia et al. 2002, Gilman et al. 2008).

#### ***What scientists think is possible....***

- Warmer winter temperatures projected for the southeastern U.S. may make northward expansion of the range of mangroves possible (Boesch et al. 2000).
- Heavy storm surges that completely saturate the vadose (unsaturated) zone at 30 parts per thousand (ppt) for 1 day could lead to a regime shift in which mangroves dominate areas previously dominated

by hardwood hammocks. Lighter storm surges that saturated the vadose zone at less than 7 ppt, the tolerance level of hardwood hammocks, did not cause vegetation shifts in model simulations. Rate of mangrove domination is determined by the residence time of high salinity in the vadose zone, dependent on the thickness of the vadose zone and precipitation (Teh et al. 2008).

- Elevated atmospheric CO<sub>2</sub> concentrations may mitigate some of the effects of droughts on Florida scrub-oak ecosystems through increased photosynthetic capacity under dry-air conditions (Li et al. 2007).
- Modeled effects of sea level rise on a forest-open water transition zone in Terrebone Basin, Louisiana predict dramatic loss of marsh and increasing interface between open water and relatively resistant forest. Results suggest that coastal stability structures may be initially effective in facilitating marsh reestablishment, but that additional management efforts are necessary to sustain marshlands (Shirley and Battaglia 2008).

## **D. WILDLIFE**

### ***What scientists know....***

- Many tropical species are moving into the United States as climates warm in southern regions. For example, Florida has five new species of tropical dragonfly, and many tropical butterflies that are normally confined to Mexico are starting to breed as far north as Austin, Texas. Although such species migrations may increase overall species diversity, there are also potentially negative implications including competition with native species and introduction of new diseases (NRC 2008).
- Hurricanes can affect breeding activity of colonially nesting wading birds through destruction of nesting habitat by wind and storm surges, intrusion of saltwater into freshwater wetlands, and reduced resource availability (e.g. freshwater invertebrates) in foraging habitats (Leberg et al. 2007).



- In regions of the low-lying southeastern U.S. coast that are undergoing subsidence, a projected relative sea level rise of 0.6 to 1.2 meters over the next 100 years will re-configure shorelines and fragment barrier islands. Animal species that depend on coastal marshes and mangroves, including fish species, migratory waterfowl, and wading birds will be adversely affected (NRC 2008).
- Loss of late-succession dune plants, projected to occur with sea level rise and resulting changes in coastal habitat, will result in loss of dependent animal species such as the endangered Kemp's ridley sea turtle and the endangered Choctawatchee beach mouse (Feagin et al. 2005).
- Reefs off the Florida Keys are to varying degrees already in degraded condition due to the effects of overfishing, land-based pollution by nutrients and sediments, and coastal development (Pandolfi et al. 2005).
- Episodes of coral reef bleaching and mortality are due primarily to climate-induced ocean warming. By far the most significant cause of coral bleaching in the past 25 years has been sea surface temperatures that exceed the normal summer maxima by 1 or 2°C for at least 4 weeks. The most severe events typically accompany coupled ocean-atmosphere phenomena, such as the El Niño-Southern Oscillation (ENSO), which result in sustained regional elevations of ocean temperature (Baker et al. 2008, Wilkinson and Souter 2008).
- Rising atmospheric CO<sub>2</sub> concentrations will result in slower growth of corals that are trying to recover from bleaching and other disturbances. Such interactions of multiple disturbance agents will continue to challenge the survival of coral reefs (Wilkinson and Souter 2008).
- Bleaching episodes have resulted in catastrophic loss of coral cover in some locations and have changed coral community structure in many others, with a potentially critical influence on the maintenance of biodiversity in the marine tropics. Bleaching also sets the stage for other declines in reef health such as increased coral diseases, the breakdown of reef framework by bioeroders, and the loss of critical habitat for associated reef fishes and other biota (Baker et al. 2008).
- Staghorn and elkhorn corals, important cold-sensitive reef building species historically restricted to warm waters in Biscayne Bay, are expanding their ranges northward along the Florida peninsula and into the northern Gulf of Mexico, coincident with increasing ocean temperatures (Precht and Aronson 2004). These corals were recently listed as Threatened on the Federal list of endangered and threatened species.
- Adult survival for the endangered Florida manatee is high (~97%) in years with no or low intensity storms in the northern Gulf of Mexico, and decreases (~81-93%) in years with intense hurricane activity. Decreased survival may be due to direct mortality, indirect mortality, and/or emigration from the region as a consequence of storms (Langtimm and Beck 2003).
- Storm surges significantly decrease reproductive output in sea turtles by lowering the number of nests that hatch and the number of hatchlings that emerge, with species-specific variations in severity: leatherback turtles, early nesters, are least affected by storms because most offspring hatch before the arrival of the tropical cyclone season; loggerhead turtles, intermediate nesters, suffer losses of some nests; and green turtles, with a late nesting season that overlaps the tropical cyclone season, are most severely affected (Pike and Stiner 2007).

Florida panther at Everglades National Park (Top); NPS photo. West Indian Manatee (Bottom); USFWS photo.





A reddish egret (Top), dowitchers (Center), and a nesting Kemp's Ridley sea turtle (Bottom) at Padre Island National Seashore; NPS photos.

#### ***What scientists think is likely....***

- Higher air temperatures may result in a shift in sex ratio of sea turtles, with more female offspring produced at higher temperatures (Booth 2006, Hawkes et al. 2007). Populations of turtles in southern parts of the United States are currently highly female biased and are likely to become ultra-biased with as little as 1°C of warming, and experience extreme levels of mortality if warming exceeds 3°C. For example, at modeled temperature increases of 7.5°C, loggerhead turtles show 100% female hatchling production and lethally high incubation (Hawkes et al. 2007).
- A single catastrophic hurricane, series of smaller hurricanes, or increased hurricane activity associated with climatic change could increase the probability of extinction for Florida manatees (Langtimm and Beck 2003).
- Important Florida gamefish species vulnerable to sea level rise include bonefish, flounder, gag grouper, gray snapper, permit, pompano, redfish, snook, spotted seatrout, and tarpon. Rising sea levels will negatively impact habitat areas for these fishes, and reduce habitat for important prey species such as shrimp, crabs, and smaller fish (Click and Clough 2006).

#### ***What scientists think is possible....***

- Specific changes in mammal populations and movements may be hard to predict due to the complexity of interactions with their environment and the rapid pace of change that is expected. However, U.S. national parks could lose on average 8.3% and up to 20% of current mammalian species diversity. The greatest loss of species is expected to occur in the most southerly national parks where ecosystem types will become more limited (Burns et al. 2003).
- Warming temperatures may drive complex shifts in ocean circulation, nutrient supplies, plankton production, and other factors that shape marine ecosystems, in ways that are difficult to predict (Frumhoff et al. 2007).

- There is particular concern for individual animal species that are already stressed and have greatly reduced ranges, such as manatees, Cape Sable sparrow and Florida panther. Additional stress resulting from higher temperatures could put those populations at increased risk for extirpation or extinction (Harris and Cropper 1992).
- The construction of sea-wall defenses and other protective measures for coastal habitats against rising sea levels could potentially negatively impact coastal marine species; for example, in Florida between 1974 and 1996 approximately 4% of manatee deaths were caused by crushing or drowning in flood gates and canal locks (Reynolds and Powell 2002).
- Simulated landscape-level changes (increasing water levels or decreasing habitat availability) were associated with dramatic population declines and increases in extinction risk for the endangered Cape Sable seaside sparrow of the South Florida Everglades. The sparrows are dependent on the plant community structure of the Everglades' marl and mixed-marl prairies and the timing of seasonal floods within these prairies, which may be altered due to a combination of shrub and tree invasions, sea level rise, and hydrologic changes (Elder and Nott 2008).
- A comparison of median capture dates for 15 bird species between the Gulf Coast of Louisiana and stations approximately 2,500 km to the north suggests that Neartic-Neotropical migratory birds may be able to adjust their rate of migration to match annual variations in ambient temperatures or associated factors such as leaf emergence and resource availability (Marra et al. 2005).
- In GIS-based simulations, potential habitat for the endangered Lower Keys marsh rabbit decreased across its geographic distribution with modeled sea level rise of 0.3 to 0.9 meters. Simulated upslope migration of vegetation, protection of natural areas, and abandonment of developed areas slightly offset habitat loss resulting from sea level rise (LaFever et al. 2007).

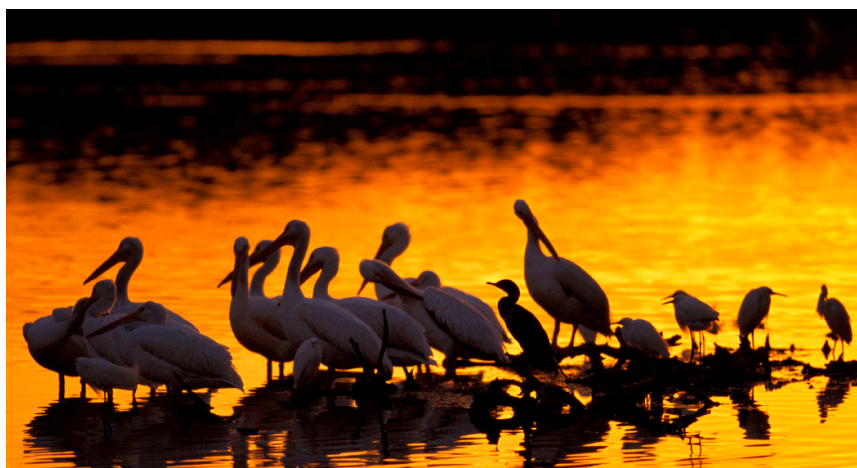


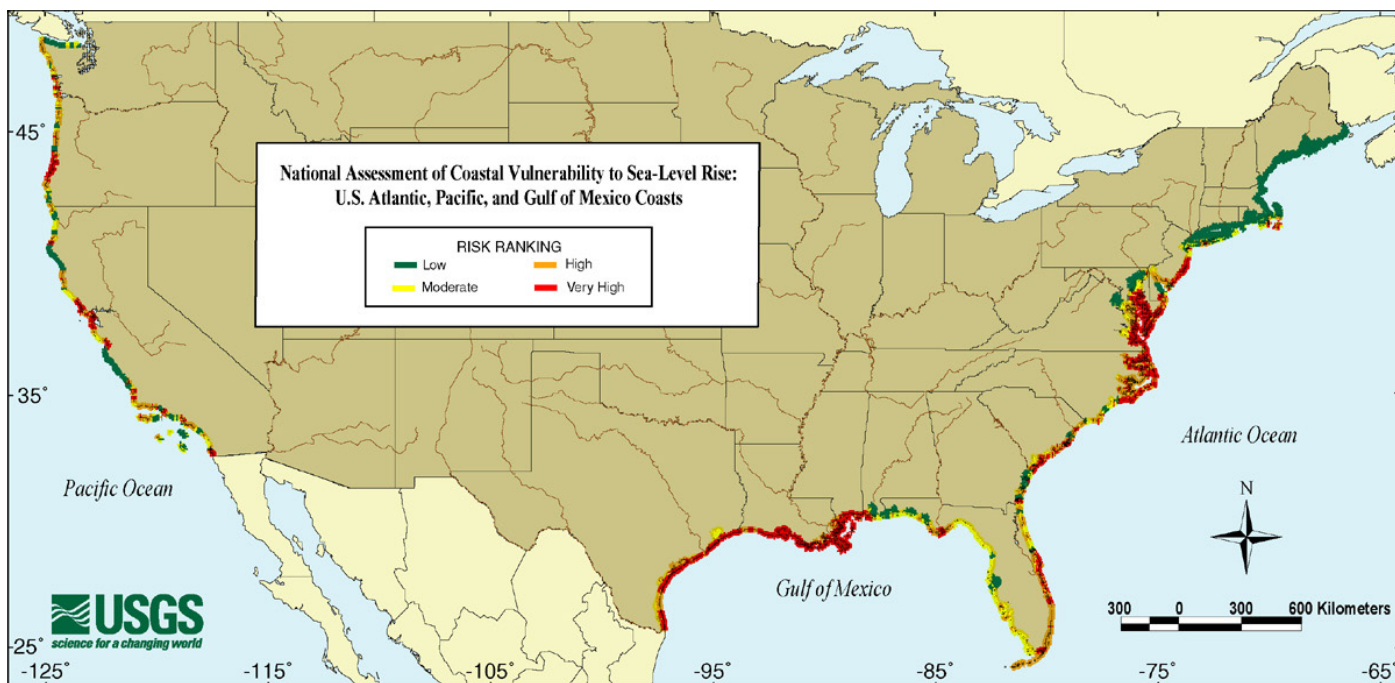
## E. DISTURBANCE

### *What scientists know....*

- In Louisiana alone more than one third of the deltaic plain that existed in the beginning of the 20th century has been lost to a combination of sea level rise and local subsidence. In the Gulf of Mexico and the South Atlantic, the ecological processes that lead to accretion of wetlands and continued productivity have not been able to keep pace with the physical processes that lead to relative rising sea level (Burkett et al. 2005).
- Most of the U.S. Gulf of Mexico coastline has experienced rates of relative sea level increase that are significantly greater than those observed on the U.S. Pacific coast or farther north on the Atlantic Coast (Scavia et al. 2002).
- Rates of relative sea level rise along the Gulf Coast are higher than global average rates due to local subsidence (sinking). Relative sea level rise rates range from 0.20 cm per year along some parts of the Texas coast to around 1 cm per year in the Mississippi River delta plain. The average rate of regional sea level rise began to increase significantly around 1930 (Twilley et al. 2001).
- A Coastal Vulnerability Index, developed by the USGS, identifies areas that are likely to be most affected by future sea level rise. Much of the Gulf Coast region along the Louisiana-Texas coast has been assessed as highly vulnerable. The highest-vulnerability areas are typically lower-lying beach and marsh areas with less than a meter of tidal range ; their susceptibility is primarily a function of geomorphology, coastal slope and rate of relative sea level rise (Thieler and Hammar-Klose 2000).
- Coastal vulnerability assessments for Dry Tortugas National Park, Gulf Islands National Seashore and Padre Island National Seashore show significant areas of shoreline classified as having high vulnerability to sea level rise (Pendleton et al. 2004a, Pendleton et al. 2004c, Pendleton et al. 2005).
- Storms, hurricanes, and typhoons produce high winds which in turn generate large waves and currents. The storms may also produce storm surges that temporarily raise water levels far above normal. These surges are a primary cause of beach erosion in the U.S., and usually move near-shore and beach sand seaward where it may be stored in offshore bars or lost from the active system when deposited in very deep water (Boesch et al. 2000).
- Hurricanes, typhoons, and their related impacts affect societies directly through acute damage on human settlements, often with major loss of life, and indirectly through their impact on coastal ecosystems such as coral reefs, seagrass beds, and mangroves that support local societies and economies (Adger et al. 2005).
- Hurricanes are a significant factor in reducing short-term carbon storage in U.S. forests. Single storms can convert the equivalent of 10% of the total annual carbon sequestered by U.S. forests into dead and downed biomass, and because forests require at least 15 years to recover from severe storms, a large amount of forest carbon is indirectly lost through reduced carbon sequestration capacity (McNulty 2002).
- The La Niña phase of the El Niño Southern Oscillation climatic cycle is associated with decreased dry-season rainfall, lowered surface water levels, increased lightning strikes, more fires, and large areas burned in Everglades National Park. In contrast, the El Niño phase is associated with increased dry-season rainfall, raised

Subsidence along the Texas coast decreases the land area available for certain water birds to nest; USFWS photo.





Coastal vulnerability in the U.S. is most pronounced along the gulf and Atlantic coasts; USGS image.

surface water levels, decreased lightning strikes, fewer fires, and smaller areas burned (Ebi et al. 2007).

- The spread of invasive species has been on the rise over the past 50 years due to a number of factors including climatic conditions. For example, the Chinese tallow tree has been invading coastal prairies from the Carolinas to south Texas, where periods of decreased flooding have allowed for its wide-spread establishment. The northward spread of tallow is limited only by low winter temperatures (Twilley et al. 2001, Burkett et al. 2005).
- Field studies at salt marshes along the coasts of Georgia and Louisiana show that drought-induced stress and grazing snails act synergistically to cause plant death and conversion of marshes to exposed mudflats. More frequent droughts, resulting from increasing climatic extremes, may increase system susceptibility to intense and prolonged vegetation loss and large-scale collapse (Silliman et al. 2005).
- Estimates of Hurricane Katrina's effect on Gulf Coast forests indicate mortality and severe structural damage to 320 million large-diameter trees, and a total biomass loss of 105 Tg C, an amount equivalent to 50 to 140% of the net annual U.S. carbon sink in forest trees (Chambers et al. 2007).

#### What scientists think is likely....

- Even if greenhouse gas emissions are stabilized, the rate of sea level rise will likely continue to increase beyond 2100 because of the time it takes for oceans and ice sheets to approach equilibrium conditions with the atmosphere (Scavia et al. 2002).
- Relative sea level is likely to rise between 0.3 to 1.8 meters by the end of the 21st century, depending upon model assumption and geographic location. The highest rate of relative sea level rise will very likely be in the central and western parts of the Gulf Coast (Louisiana and East Texas) where subsidence rates are highest (Keim et al. 2008).
- Rising relative sea level will increase vulnerability to storm surges and flooding. Depending on the trajectory and scale of individual storms, facilities at 9 meters above sea level or below could be subject to direct storm surge impacts (Keim et al. 2008).
- A rise in sea level or changes in storms or storm surges may result in the increased erosion of shores and associated habitat, altered tidal ranges in rivers and bays, increased salinity of estuaries and freshwater aquifers, changes in patterns of chemical and microbiological contamination in coastal areas, and a change in sediment and nutrient transport (Boesch et al. 2000).



- Secondary impacts associated with sea level rise include inundation of waste disposal sites and landfills and the subsequent release of toxins and pollutants; and increased siltation of subtidal habitats due to shoreline erosion (Boesch et al. 2000).
- Future projections of tropical cyclone activity consistently indicate that greenhouse warming will cause the intensity (mean maximum wind speed) of tropical cyclones to increase by 2-11% by 2100. It is likely that the frequency of tropical cyclones will either decrease or remain unchanged, with high variability at the scale of individual basins (Knutson et al. 2010).

#### ***What scientists think is possible....***

- Decreased runoff coupled with increasing sea-levels could lead to increased salt-water intrusion in some areas, affecting vegetation, fish, and water resources (Twilley et al. 2001, IPCC 2007a).
- A drier climate along the Gulf Coast, combined with such activities as dredging, reservoir construction, surface water diversions, and groundwater pumping, could accelerate local subsidence and sinkhole formation in areas underlain by limestone (Twilley et al. 2001).
- Sea level rise may increase beach erosion along shorelines, constraining coastal plants to narrow stretches of beach and resulting in a breakdown of the succes-

sional process. Late-succession species are important for dune building, sediment binding, and reduction of erosion (Feagin et al. 2005).

- Model projections indicate that the invasive Chinese tallow tree has the potential to spread 500 kilometers northward beyond its current distribution in coastal areas of eastern Texas, Louisiana, Mississippi, Alabama, and Florida, as the result of increased minimum temperatures and decreased aridity in the eastern and western U.S. (Pattison and Mack 2008).
- Sea level rise on Key Deer National Wildlife Refuge may allow mangrove habitats to expand at the expense of upland and transitional habitats. A sea level rise of about 0.2 meters may result in the loss of most of the upland and transitional habitat in the central portion of Sugarloaf Key, and as sea level rise approaches 0.5 meters about 95% of Sugarloaf will become mangrove forest and mudflat, leaving only a small amount of remnant upland habitat in the southeast portion of the Key (Ross et al. 2008).
- Model simulations results suggest that heavy storm surges that completely saturate saline-intolerant areas in southern Florida could result in vegetation regime shifts from hardwood hammocks to saline-tolerant mangroves (Teh et al. 2008).
- A 38 cm rise in average sea level is projected to result in the loss of 50% (9,294 ha) of critical saltmarsh, 84% (67,438 ha) of tidal flats, 14% (70,680 ha) of dry land, 30% (405 ha) of ocean beaches, and 60% (2,380 ha) of estuarine beaches at nine areas along Florida's coast, including Pensacola Bay, Apalachicola Bay, Tampa Bay, Charlotte Harbor, Ten Thousand Islands, Florida Bay, Biscayne Bay, St. Lucie Estuary and Indian River Lagoon (Click and Clough 2006).
- Forest fire seasonal severity rating is projected to increase from 10 to 30% in the Southeast by 2060. In addition, model projections simulate a large increase in fire activity and biomass loss, sufficient to convert the southernmost closed-canopy forests to savannas (Backlund et al. 2008).

Goat's-foot morning glory grows on a dune field in Padre Island National Seashore; NPS photos.

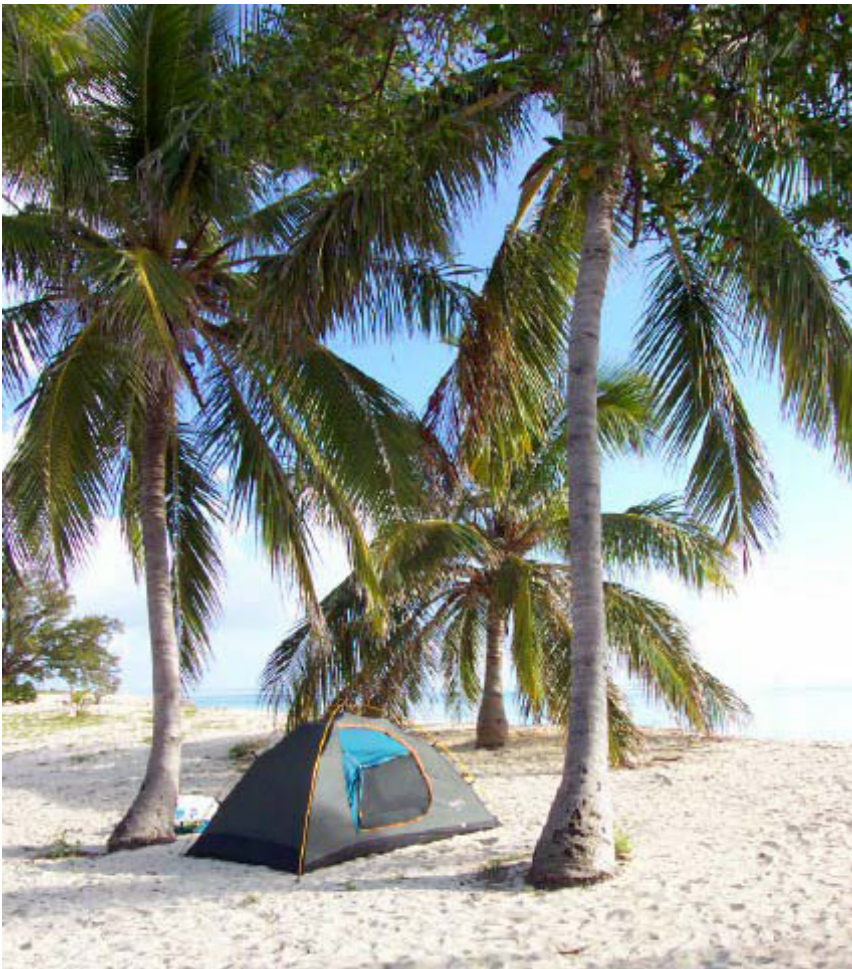




## F. VISITOR EXPERIENCE

- The locations of climatically ideal tourism conditions are likely to shift toward higher latitudes under projected climate change, and as a consequence spatial and temporal redistribution of tourism activities may occur. The effects of these changes will depend greatly on the flexibility demonstrated by institutions and tourists as they react to climate change (Amelung et al. 2007).
- Changes to the terrestrial and aquatic species compositions in parks and refuges are likely to occur as ranges shift, contract, or expand (Burns et al. 2003).
- Parks and refuges may not be able to meet their mandate of protecting current species within their boundaries, or in the case of some refuges, the species for whose habitat protection they were designed. While wildlife may be able to move northward or to higher elevations to escape some effects of climate change, federal boundaries are static (Burns et al. 2003).

A campsite among the palm trees at Dry Tortugas National Park; NPS photo.



- More intense hurricane activity may result in increased damages to structures and property along the Gulf Coast (Peterson et al. 2008).
- Economic and social vulnerability to hurricane damage is increasing rapidly, predominantly because of the rise in population and property values near coastlines (Anthes et al. 2006).
- Sea level rise poses threats to cultural and historic resources and infrastructure (Pendleton et al. 2004b). For example, Fort Massachusetts of the Gulf Islands National Seashore may be lost to the rising waters of the Mississippi Sound and Gulf of Mexico if it is not protected (Caffrey and Beavers 2008).
- Effects of projected climate changes on human health include increased incidence of heat stress and heat stroke, respiratory distress from pollutants released during wildfires, cardio-respiratory morbidity and mortality associated with ground-level ozone, and injury and death from floods, storms, fires, and droughts (Epstein 2001, Confalonieri et al. 2007).
- Increases in maximum temperatures, precipitation, and sea surface temperature are linked with increased transmission of dengue fever, a mosquito-borne disease, on the Texas-Mexico border (Brunkard et al. 2008).
- Increasing intensity of severe storms and floods may pose threats to historic structures, roads and trails, archeological sites, administrative facilities, and other park resources and infrastructure.
- Increased summer temperatures will likely lead to increased utility expenditures in parks in the summer and, potentially, decreases in the winter.
- Potentially poorer visibility due to smoke from increased wildland fire activity will likely cause a negative impact on visitor experiences.

### III. No Regrets Actions: How Individuals, Parks, Refuges, and Their Partners Can Do Their Part

Individuals, businesses, and agencies release carbon dioxide (CO<sub>2</sub>), the principal greenhouse gas, through burning of fossil fuels for electricity, heating, transportation, food production, and other day-to-day activities. Increasing levels of atmospheric CO<sub>2</sub> have measurably increased global average temperatures, and are projected to cause further changes in global climate, with severe implications for vegetation, wildlife, oceans, water resources, and human populations. Emissions reduction – limiting production of CO<sub>2</sub> and other greenhouse gases – is an important step in addressing climate change. It is the responsibility of agencies and individuals to find ways to reduce greenhouse gas emissions and to educate about the causes and consequences of climate change, and ways in which we can reduce our impacts on natural resources. There are many simple actions that each of us can take to reduce our daily carbon emissions, some of which will even save money.

#### Agencies Can...

##### *Improve sustainability and energy efficiency*

- Use energy efficient products, such as ENERGY STAR® approved office equipment and light bulbs.
- Initiate an energy efficiency program to monitor energy use in buildings. Provide guidelines for reducing energy consumption.
- Convert to renewable energy sources such as solar or wind generated power.
- Specify “green” designs for construction of new or remodeled buildings.
- Include discussions of climate change in the park Environmental Management System.
- Conduct an emissions inventory and set goals for CO<sub>2</sub> reduction.
- Provide alternative transportation options such as employee bicycles and shuttles for within-unit commuting.

- Provide hybrid electric or propane-fueled vehicles for official use, and impose fuel standards for park vehicles. Reduce the number and/or size of park vehicles and boats to maximize efficiency.
- Provide a shuttle service or another form of alternate transportation for visitor and employee travel to and within the unit.
- Provide incentives for use of alternative transportation methods.
- Use teleconferences and webinars or other forms of modern technology in place of travel to conferences and meetings.

##### *Implement Management Actions*

- Engage and enlist collaborator support (e.g., tribes, nearby agencies, private landholders) in climate change discussions, responses, and mitigation.
- Develop strategies and identify priorities for managing uncertainty surrounding climate change effects in parks and refuges.
- Build a strong partnership-based foundation for future conservation efforts.
- Identify strategic priorities for climate change efforts when working with partners.
- Incorporate anticipated climate change impacts, such as decreases in lake levels, rising sea levels, or changes in vegetation and wildlife, into management plans.
- Encourage research and scientific study in park units and refuges.

An interpretive brochure about climate change impacts to National Parks was created in 2006 and was distributed widely. This brochure was updated in 2008.

#### Climate Change in National Parks







Park Service employees install solar panels at San Francisco Maritime National Historical Park (Top); At the National Mall, Park Service employees use clean-energy transportation to lead tours; NPS photos.

- Design long-term monitoring projects and management activities that do not rely solely on fossil fuel-based transportation and infrastructure.
- Incorporate products and services that address climate change in the development of all interpretive and management plans.
- Take inventory of the facilities/boundaries/species within your park or refuge that may benefit from or be vulnerable to climate change mitigation or adaptation activities.
- Limit development on or adjacent to beaches. This dynamic habitat will be needed by many species and serves as a critical buffer with adjacent rising waters.
- Participate in gateway community sustainability efforts.
- Recognize the value of ecosystem services that an area can provide, and manage the area to sustain these services. Conservation is more cost-effective than restoration and helps maintain ecosystem integrity.
- Provide recycling options for solid waste and trash generated within the park.

#### ***Restore damaged landscapes***

- Restoration efforts are important as a means for enhancing species' ability to cope with stresses and adapt to climatic and environmental changes. Through restoration of natural areas, we can lessen cli-

mate change impacts on species and their habitats. These efforts will help preserve biodiversity, natural resources, and recreational opportunities.

- Strategically focus restoration efforts, both in terms of the types of restoration undertaken and their national, regional, and local scale and focus, to help maximize resilience.
- Restore human altered sediment supplies to increase resilience of sandy coasts (e.g. barrier island ability to survive storm impacts, overwash, etc.).
- Restore and conserve connectivity within habitats, protect and enhance instream flows for fish, and maintain and develop access corridors to climate change refugia.
- Restore natural hydrologic functions of coastal wetlands to help protect coastal areas against hurricanes and flooding.

#### ***Educate staff and the public***

- Post climate change information in easily accessible locations such as on bulletin boards and websites.
- Provide training for park and refuge employees and partners on effects of climate change on resources, and on dissemination of climate change knowledge to the public.
- Support the development of region, park, or refuge-specific interpretive products on the impacts of climate change.
- Incorporate climate change research and information in interpretive and education outreach programming.
- Distribute up-to-date interpretive products (e.g., the National Park Service-wide Climate Change in National Parks brochure).
- Develop climate change presentations for local civic organizations, user and partner conferences, national meetings, etc.
- Incorporate climate change questions and answers into Junior Ranger programs.

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“Humankind has not woven the web of life. We are but one thread within it. Whatever we do to the web, we do to ourselves. All things are bound together. All things connect.”  
—Chief Seattle

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- Help visitors make the connection between reducing greenhouse gas emissions and resource stewardship.
- Encourage visitors to use public or non-motorized transportation to and around parks.
- Encourage visitors to reduce their carbon footprint in their daily lives and as part of their tourism experience.

### Individuals can...

- In the park or refuge park their car and walk or bike. Use shuttles where available. Recycle and use refillable water bottles. Stay on marked trails to help further ecosystem restoration efforts.
- At home, walk, carpool, bike or use public transportation if possible. A full bus equates to 40 fewer cars on the road. When driving, use a fuel-efficient vehicle.
- Do not let cars idle - letting a car idle for just 20 seconds burns more gasoline than turning it off and on again.
- Replace incandescent bulbs in the five most frequently used light fixtures in the home with bulbs that have the ENERGY STAR® rating. If every household in the U.S. takes this one simple action we will prevent greenhouse gas emissions equivalent to the emissions from nearly 10 million cars, in addition to saving money on energy costs.
- Keep an energy efficient home. Purchase ENERGY STAR® appliances, properly insulate windows, doors and attics, and lower the thermostat in the winter and raise it in the summer (even 1-2 degrees makes a big difference). Switch to green power generated from renewable energy sources such as wind, solar, or geothermal.
- Buy local goods and services that minimize emissions associated with transportation.
- Encourage others to participate in the actions listed above.

able products (Starbucks uses more than 1 billion paper cups a year).

- Carry reusable bags instead of using paper or plastic bags.
- Recycle drink containers, paper, newspapers, electronics, and other materials. Bring recyclables home for proper disposal when recycle bins are not available. Rather than taking old furniture and clothes to the dump, consider “recycling” them at a thrift store.

For more information on how you can reduce carbon emissions and engage in climate-friendly activities, check out these websites:

EPA- What you can do: <http://www.epa.gov/climatechange/wycd/index.html>

NPS- Do Your Part! Program: <http://www.nps.gov/climatefriendlyparks/doyourpart.html>

US Forest Service Climate Change Program: <http://www.fs.fed.us/climatechange/>

United States Global Change Research Program: <http://www.globalchange.gov/>

U.S. Fish and Wildlife Service Climate change: <http://www.fws.gov/home/climatechange/>

### Reduce, Reuse, Recycle, Refuse

- Use products made from recycled paper, plastics and aluminum - these use 55-95% less energy than products made from scratch.
- Purchase a travel coffee mug and a reusable water bottle to reduce use of disposable

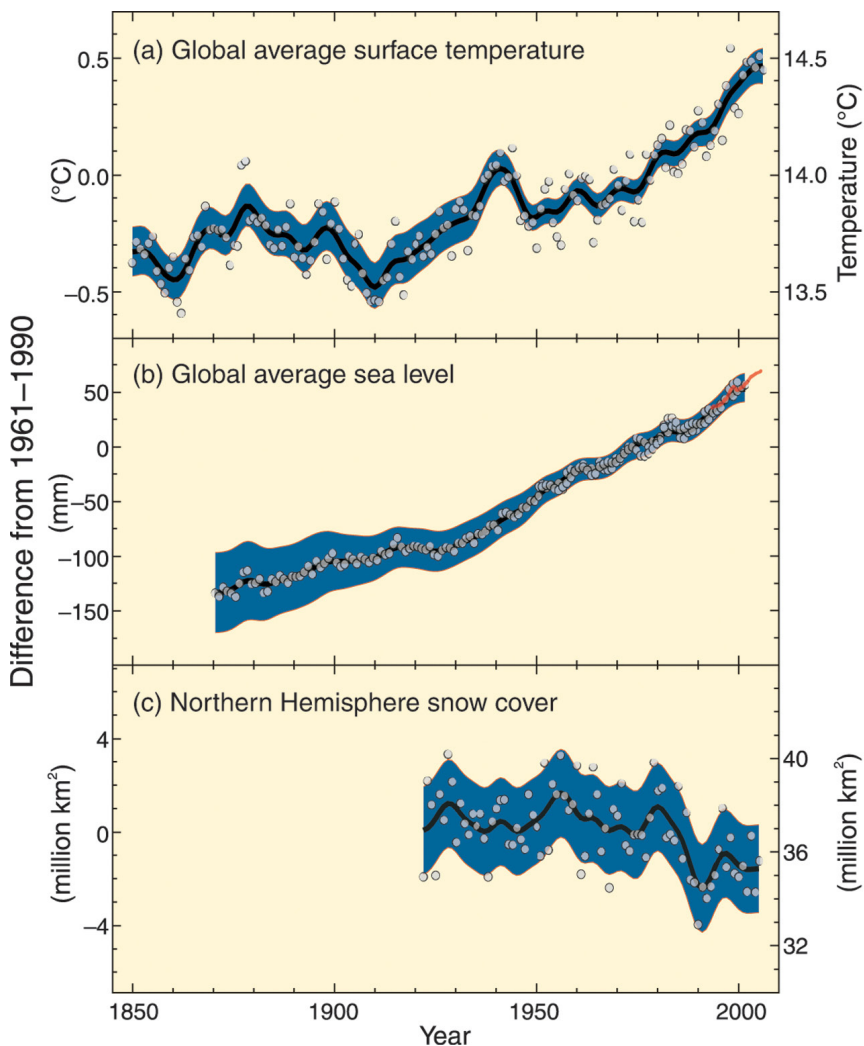
The Climate Friendly Parks Program is a joint partnership between the U.S. Environmental Protection Agency and the National Park Service. Climate Friendly Parks from around the country are leading the way in the effort to protect our parks' natural and cultural resources and ensure their preservation for future generations; NPS image.



## IV. Global Climate Change

The IPCC is a scientific intergovernmental, international body established by the World Meteorological Organization (WMO) and by the United Nations Environment Programme (UNEP). The information the IPCC provides in its reports is based on scientific evidence and reflects existing consensus viewpoints within the scientific community. The comprehensiveness of the scientific content is achieved through contributions from experts in all regions of the world and all relevant disciplines including, where appropriately documented, industry literature and traditional practices, and a two stage review process by experts and governments.

**Definition of climate change:** The IPCC defines climate change as 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. All statements in this section are synthesized from the IPCC report unless otherwise noted.



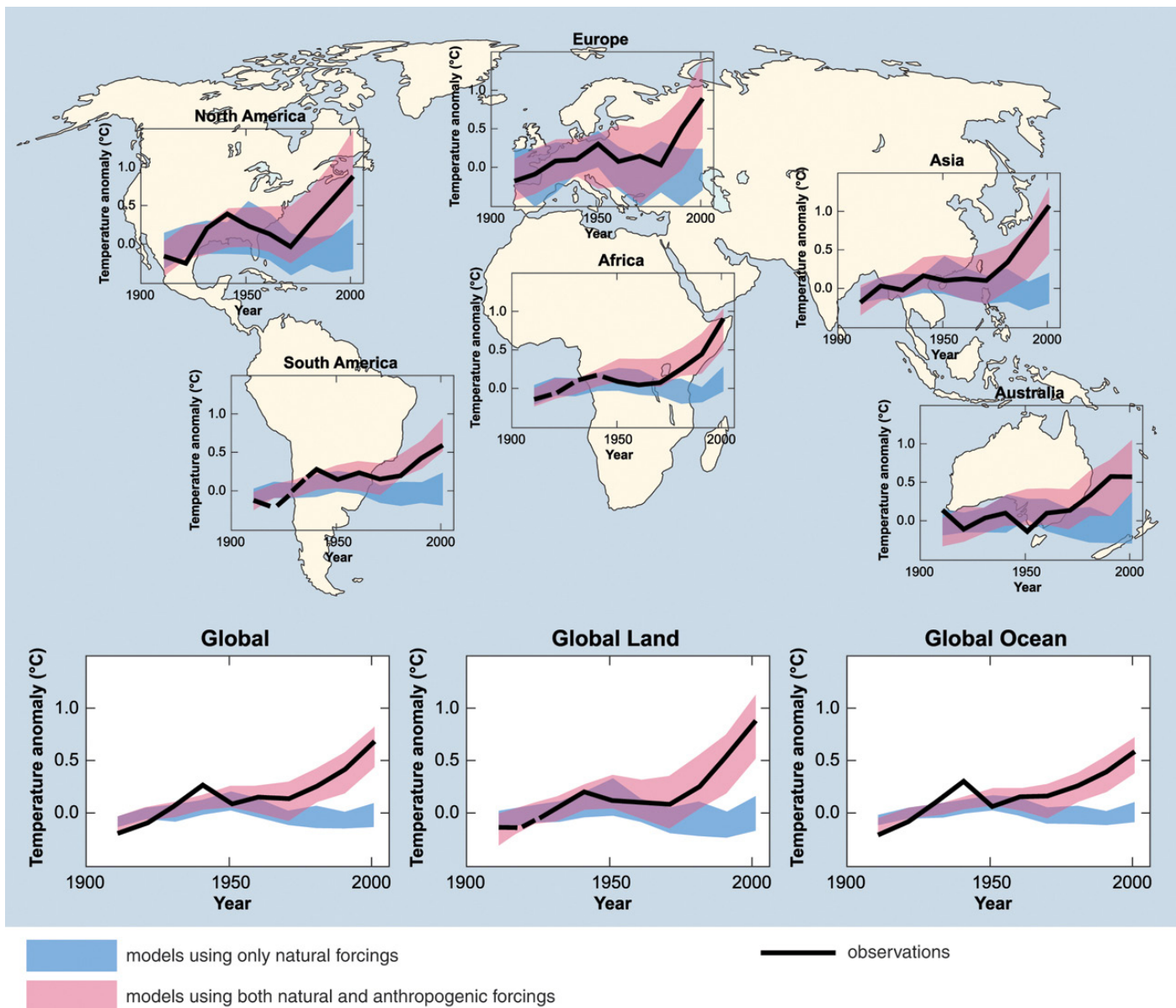
**Figure 1.** Observed changes in (a) global average surface temperature; (b) global average sea level from tide gauge (blue) and satellite (red) data and (c) Northern Hemisphere snow cover for March-April. All differences are relative to corresponding averages for the period 1961-1990. Smoothed curves represent decadal averaged values while circles show yearly values. The shaded areas are the uncertainty intervals estimated from a comprehensive analysis of known uncertainties (a and b) and from the time series (c) (IPCC 2007a).

### A. Temperature and Greenhouse Gases

#### *What scientists know...*

- Warming of the Earth's climate system is unequivocal, as evidenced from increased air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level (Figure 1).
- In the last 100 years, global average surface temperature has risen about 0.74°C over the previous 100-year period, and the rate of warming has doubled from the previous century. Eleven of the 12 warmest years in the instrumental record of global surface temperature since 1850 have occurred since 1995 (Figure 1).
- Although most regions over the globe have experienced warming, there are regional variations: land regions have warmed faster than oceans and high northern latitudes have warmed faster than the tropics. Average Arctic temperatures have increased at almost twice the global rate in the past 100 years, primarily because loss of snow and ice results in a positive feedback via increased absorption of sunlight by ocean waters (Figure 2).
- Over the past 50 years widespread changes in extreme temperatures have been observed, including a decrease in cold days and nights and an increase in the frequency of hot days, hot nights, and heat waves.
- Winter temperatures are increasing more rapidly than summer temperatures, particularly in the northern hemisphere, and





**Figure 2.** Comparison of observed continental- and global-scale changes in surface temperature with results simulated by climate models using either natural or both natural and anthropogenic forcings. Decadal averages of observations are shown for the period 1906-2005 (black line) plotted against the centre of the decade and relative to the corresponding average for the period 1901-1950. Lines are dashed where spatial coverage is less than 50%. Blue shaded bands show the 5 to 95% range for 19 simulations from five climate models using only the natural forcings due to solar activity and volcanoes. Red shaded bands show the 5 to 95% range for 58 simulations from 14 climate models using both natural and anthropogenic forcings (IPCC 2007a).

there has been an increase in the length of the frost-free period in mid- and high-latitude regions of both hemispheres.

- Climate change is caused by alterations in the energy balance within the atmosphere and at the Earth's surface. Factors that affect Earth's energy balance are the atmospheric concentrations of greenhouse gases and aerosols, land surface properties, and solar radiation.
- Global atmospheric concentrations of greenhouse gases have increased significantly since 1750 as the result of human activities. The principal greenhouse gases are carbon dioxide (CO<sub>2</sub>), primarily from fossil fuel use and land-use change; methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O), primarily from agriculture; and halocarbons (a group of gases containing fluorine, chlorine or bromine), principally engineered chemicals that do not occur naturally.
- Direct measurements of gases trapped in ice cores demonstrate that current CO<sub>2</sub> and CH<sub>4</sub> concentrations far exceed the natural range over the last 650,000 years and have increased markedly (35% and 148% respectively), since the beginning of the industrial era in 1750.
- Both past and future anthropogenic CO<sub>2</sub> emissions will continue to contribute to warming and sea level rise for more than a millennium, due to the time scales required for the removal of the gas from the atmosphere.

- Warming temperatures reduce oceanic uptake of atmospheric CO<sub>2</sub>, increasing the fraction of anthropogenic emissions remaining in the atmosphere. This positive carbon cycle feedback results in increasingly greater accumulation of atmospheric CO<sub>2</sub> and subsequently greater warming trends than would otherwise be present in the absence of a feedback relationship.
  - There is very high confidence that the global average net effect of human activities since 1750 has been one of warming.
  - Scientific evidence shows that major and widespread climate changes have occurred with startling speed. For example, roughly half the north Atlantic warming during the last 20,000 years was achieved in only a decade, and it was accompanied by significant climatic changes across most of the globe (NRC 2008).
- house gas concentrations. Furthermore, it is extremely likely that global changes observed in the past 50 years can only be explained with external (anthropogenic) forcings (influences) (Figure 2).
- There is much evidence and scientific consensus that greenhouse gas emissions will continue to grow under current climate change mitigation policies and development practices. For the next two decades a warming of about 0.2°C per decade is projected for a range of emissions scenarios; afterwards, temperature projections increasingly depend on specific emissions scenarios (Table 1).
  - It is very likely that continued greenhouse gas emissions at or above the current rate will cause further warming and result in changes in the global climate system that will be larger than those observed during the 20<sup>th</sup> century.

#### ***What scientists think is likely...***

- Anthropogenic warming over the last three decades has likely had a discernible influence at the global scale on observed changes in many physical and biological systems.
  - Average temperatures in the Northern Hemisphere during the second half of the 20<sup>th</sup> century were very likely higher than during any other 50-year period in the last 500 years and likely the highest in at least the past 1300 years.
  - Most of the warming that has occurred since the mid-20<sup>th</sup> century is very likely due to increases in anthropogenic greenhouse gas concentrations. Furthermore, it is extremely likely that global changes observed in the past 50 years can only be explained with external (anthropogenic) forcings (influences) (Figure 2).
- It is very likely that hot extremes, heat waves and heavy precipitation events will become more frequent. As with current trends, warming is expected to be greatest over land and at most high northern latitudes, and least over the Southern Ocean (near Antarctica) and the northern North Atlantic Ocean.

#### ***What scientists think is possible...***

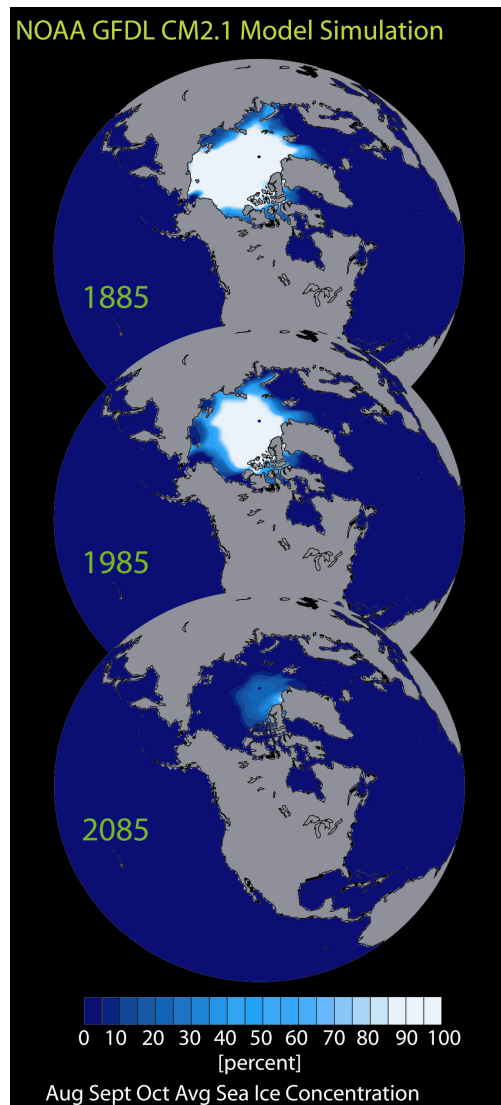
- Global temperatures are projected to increase in the future, and the magnitude of temperature change depends on specific emissions scenarios, and ranges from a 1.1°C to 6.4°C increase by 2100 (Table 1).

**Table 1. Projected global average surface warming at the end of the 21<sup>st</sup> century, adapted from (IPCC 2007b).**

Notes: a) Temperatures are assessed best estimates and likely uncertainty ranges from a hierarchy of models of varying complexity as well as observational constraints. b) Temperature changes are expressed as the difference from the period 1980-1999. To express the change relative to the period 1850-1899 add 0.5°C. c) Year 2000 constant composition is derived from Atmosphere-Ocean General Circulation Models (AOGCMs) only.

	Temperature Change (°C at 2090 – 2099 relative to 1980 – 1999) <sup>a,b</sup>	
Emissions Scenario	Best Estimate	Likely Range
Constant Year 2000 Concentrations <sup>a</sup>	0.6	0.3 – 0.9
B <sub>1</sub> Scenario	1.8	1.1 – 2.9
B <sub>2</sub> Scenario	2.4	1.4 – 3.8
A <sub>1</sub> B Scenario	2.8	1.7 – 4.4
A <sub>2</sub> Scenario	3.4	2.0 – 5.4
A <sub>1</sub> F <sub>1</sub> Scenario	4.0	2.4 – 6.4

Figure 3. Sea ice concentrations (the amount of ice in a given area) simulated by the GFDL CM2.1 global coupled climate model averaged over August, September and October (the months when Arctic sea ice concentrations generally are at a minimum). Three years (1885, 1985 & 2085) are shown to illustrate the model-simulated trend. A dramatic reduction of summertime sea ice is projected, with the rate of decrease being greatest during the 21<sup>st</sup> century portion. The colors range from dark blue (ice free) to white (100% sea ice covered); Image courtesy of NOAA GFDL.



- Anthropogenic warming could lead to changes in the global system that are abrupt and irreversible, depending on the rate and magnitude of climate change.
- Roughly 20-30% of species around the globe could become extinct if global average temperatures increase by 2 to 3°C over pre-industrial levels.

## B. Water, Snow, and Ice

### *What scientists know...*

- Many natural systems are already being affected by increased temperatures, particularly those related to snow, ice, and frozen ground. Examples are decreases in snow and ice extent, especially of mountain glaciers; enlargement and increased numbers of glacial lakes; decreased permafrost extent; increasing ground instability in permafrost regions and rock avalanches in mountain regions; and thinner sea ice and shorter freezing seasons of lake and river ice (Figure 3).
- Annual average Arctic sea ice extent has shrunk by 2.7% per decade since 1978, and the summer ice extent has decreased by 7.4% per decade. Sea ice extent during the 2007 melt season plummeted to the lowest levels since satellite measurements began in 1979, and at the end of the melt season September 2007 sea ice was 39% below the long-term (1979-2000) average (NSIDC 2008)(Figure 4).
- Global average sea level rose at an average rate of 1.8 mm per year from 1961 to 2003 and at an average rate of 3.1 mm per year from 1993 to 2003. Increases in sea level since 1993 are the result of the following contributions: thermal expansion, 57%; melting glaciers and ice caps, 28%, melting polar ice sheets, 15%.
- The CO<sub>2</sub> content of the oceans increased by  $118 \pm 19$  Gt (1 Gt = 109 tons) between A.D. 1750 (the end of the pre-industrial period) and 1994 as the result of uptake of anthropogenic CO<sub>2</sub> emissions from the atmosphere, and continues to increase by about 2 Gt each year (Sabine et al. 2004; Hoegh-Guldberg et al. 2007). This

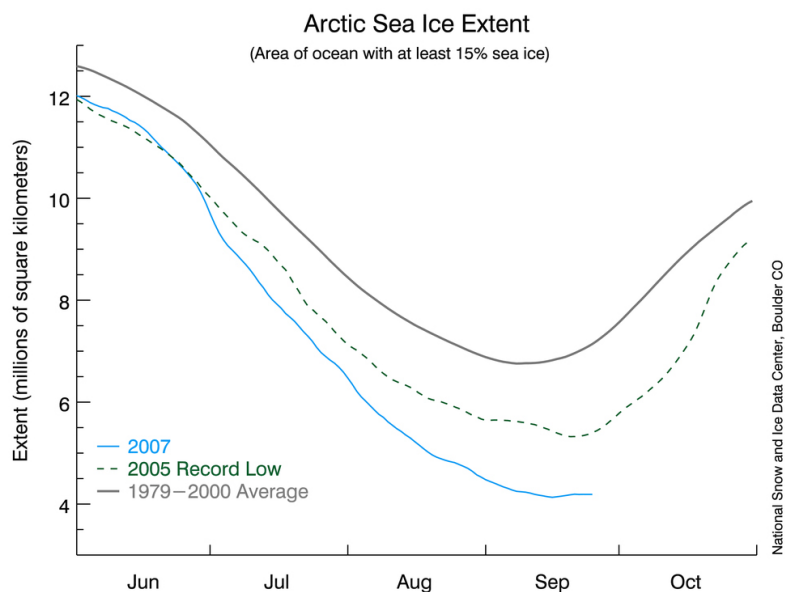


Figure 4. Arctic sea ice in September 2007 (blue line) is far below the previous low record year of 2005 (dashed line), and was 39% below where we would expect to be in an average year (solid gray line). Average September sea ice extent from 1979 to 2000 was 7.04 million square kilometers. The climatological minimum from 1979 to 2000 was 6.74 million square kilometers (NSIDC 2008).



increase in oceanic CO<sub>2</sub> has resulted in a 30% increase in acidity (a decrease in surface ocean pH by an average of 0.1 units), with observed and potential severe negative consequences for marine organisms and coral reef formations (Orr et al. 2005; McNeil and Matear 2007; Riebesell et al. 2009).

- Oceans are noisier due to ocean acidification reducing the ability of seawater to absorb low frequency sounds (noise from ship traffic and military activities). Low-frequency sound absorption has decreased over 10% in both the Pacific and Atlantic over the past 200 years. An assumed additional pH drop of 0.3 (due to anthropogenic CO<sub>2</sub> emissions) accompanied with warming will lead to sound absorption below 1 kHz being reduced by almost half of current values (Hester et. al. 2008).
- Even if greenhouse gas concentrations are stabilized at current levels thermal expansion of ocean waters (and resulting sea level rise) will continue for many centuries, due to the time required to transport heat into the deep ocean.
- Observations since 1961 show that the average global ocean temperature has increased to depths of at least 3000 meters, and that the ocean has been taking up over 80% of the heat added to the climate system.
- Hydrologic effects of climate change include increased runoff and earlier spring peak discharge in many glacier- and snow-fed rivers, and warming of lakes and rivers.
- Runoff is projected to increase by 10 to 40% by mid-century at higher latitudes and in some wet tropical areas, and to decrease by 10 to 30% over some dry regions at mid-latitudes and dry tropics. Areas in which runoff is projected to decline face a reduction in the value of the services provided by water resources.
- Precipitation increased significantly from 1900 to 2005 in eastern parts of North and South America, northern Europe, and northern and central Asia. Conversely, precipitation declined in the Sahel, the Mediterranean, southern Africa, and parts of southern Asia (Figure 5).

#### ***What scientists think is likely....***

- Widespread mass losses from glaciers and reductions in snow cover are projected to accelerate throughout the 21<sup>st</sup> century, reducing water availability and changing seasonality of flow patterns.
- Model projections include contraction of snow cover area, widespread increases in depth to frost in permafrost areas, and Arctic and Antarctic sea ice shrinkage.
- The incidence of extreme high sea level has likely increased at a broad range of sites worldwide since 1975.
- Based on current model simulations it is very likely that the meridional overturning circulation (MOC) of the Atlantic Ocean will slow down during the 21<sup>st</sup> century; nevertheless regional temperatures are predicted to increase. Large-scale and persistent changes in the MOC may result in changes in marine ecosystem produc-

**Figure 5. Relative changes in precipitation (in percent) for the period 2090-2099, relative to 1980-1999. Values are multi-model averages based on the SRES A,B scenario for December to February (left) and June to August (right). White areas are where less than 66% of the models agree in the sign of the change and stippled areas are where more than 90% of the models agree in the sign of the change (IPCC 2007a).**

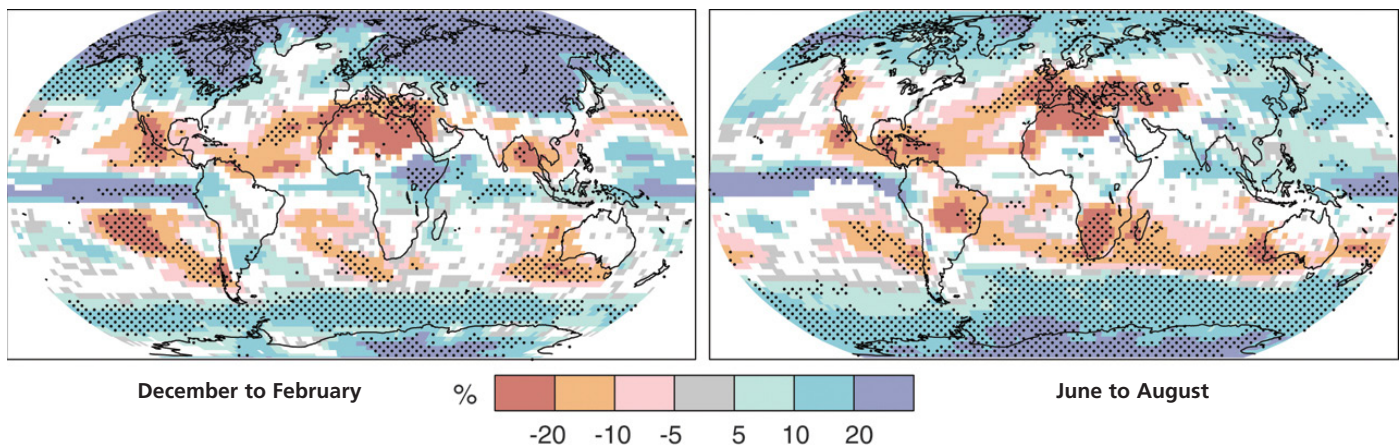


Table 2. Projected global average sea level rise at the end of the 21<sup>st</sup> century, adapted from IPCC 2007b.

Notes: a) Temperatures are assessed best estimates and likely uncertainty ranges from a hierarchy of models of varying complexity as well as observational constraints.

Emissions Scenario	Sea level rise (m at 2090 – 2099 relative to 1980 – 1999)
	Model-based range (excluding future rapid dynamical changes in ice flow)
Constant Year 2000 Concentrations <sup>a</sup>	0.3 – 0.9
B <sub>1</sub> Scenario	1.1 – 2.9
B <sub>2</sub> Scenario	1.4 – 3.8
A <sub>1</sub> B Scenario	1.7 – 4.4
A <sub>2</sub> Scenario	2.0 – 5.4
A <sub>1</sub> F <sub>1</sub> Scenario	2.4 – 6.4

tivity, fisheries, ocean CO<sub>2</sub> uptake, and terrestrial vegetation.

- Globally the area affected by drought has likely increased since the 1970s and the frequency of extreme precipitation events has increased over most areas.
- Future tropical cyclones (typhoons and hurricanes) are likely to become more intense, with larger peak wind speeds and increased heavy precipitation. Extra-tropical storm tracks are projected to move poleward, with consequent shifts in wind, precipitation, and temperature patterns.
- Increases in the amount of precipitation are very likely in high latitudes and decreases are likely in most subtropical land regions, continuing observed patterns (Figure 5).
- Increases in the frequency of heavy precipitation events in the coming century are very likely, resulting in potential damage to crops and property, soil erosion, surface and groundwater contamination, and increased risk of human death and injury.

#### ***What scientists think is possible...***

- Arctic late-summer sea ice may disappear almost entirely by the end of the 21<sup>st</sup> century (Figure 3).
- Current global model studies project that the Antarctic ice sheet will remain too cold for widespread surface melting and gain mass due to increased snowfall. However, net loss of ice mass could occur if dynamical ice discharge dominates the ice sheet mass balance.

cal ice discharge dominates the ice sheet mass balance.

- Model-based projections of global average sea level rise at the end of the 21<sup>st</sup> century range from 0.18 to 0.59 meters, depending on specific emissions scenarios (Table 2). These projections may actually underestimate future sea level rise because they do not include potential feedbacks or full effects of changes in ice sheet flow.
- Partial loss of ice sheets and/or the thermal expansion of seawater over very long time scales could result in meters of sea level rise, major changes in coastlines and inundation of low-lying areas, with greatest effects in river deltas and low-lying islands.

## **C. Vegetation and Wildlife**

### ***What scientists know...***

- Temperature increases have affected Arctic and Antarctic ecosystems and predator species at high levels of the food web.
- Changes in water temperature, salinity, oxygen levels, circulation, and ice cover in marine and freshwater ecosystems have resulted in shifts in ranges and changes in algal, plankton, and fish abundance in high-latitude oceans; increases in algal and zooplankton abundance in high-latitude and high-altitude lakes; and range shifts and earlier fish migrations in rivers.
- High-latitude (cooler) ocean waters are currently acidified enough to start dissolving pteropods; open water marine snails



which are one of the primary food sources of young salmon and mackerel (Fabry et al. 2008, Feely et al. 2008). In lower latitude (warmer) waters, by the end of this century Humboldt squid's metabolic rate will be reduced by 31% and activity levels by 45% due to reduced pH, leading to squid retreating at night to shallower waters to feed and replenish oxygen levels (Rosa and Seibel 2008).

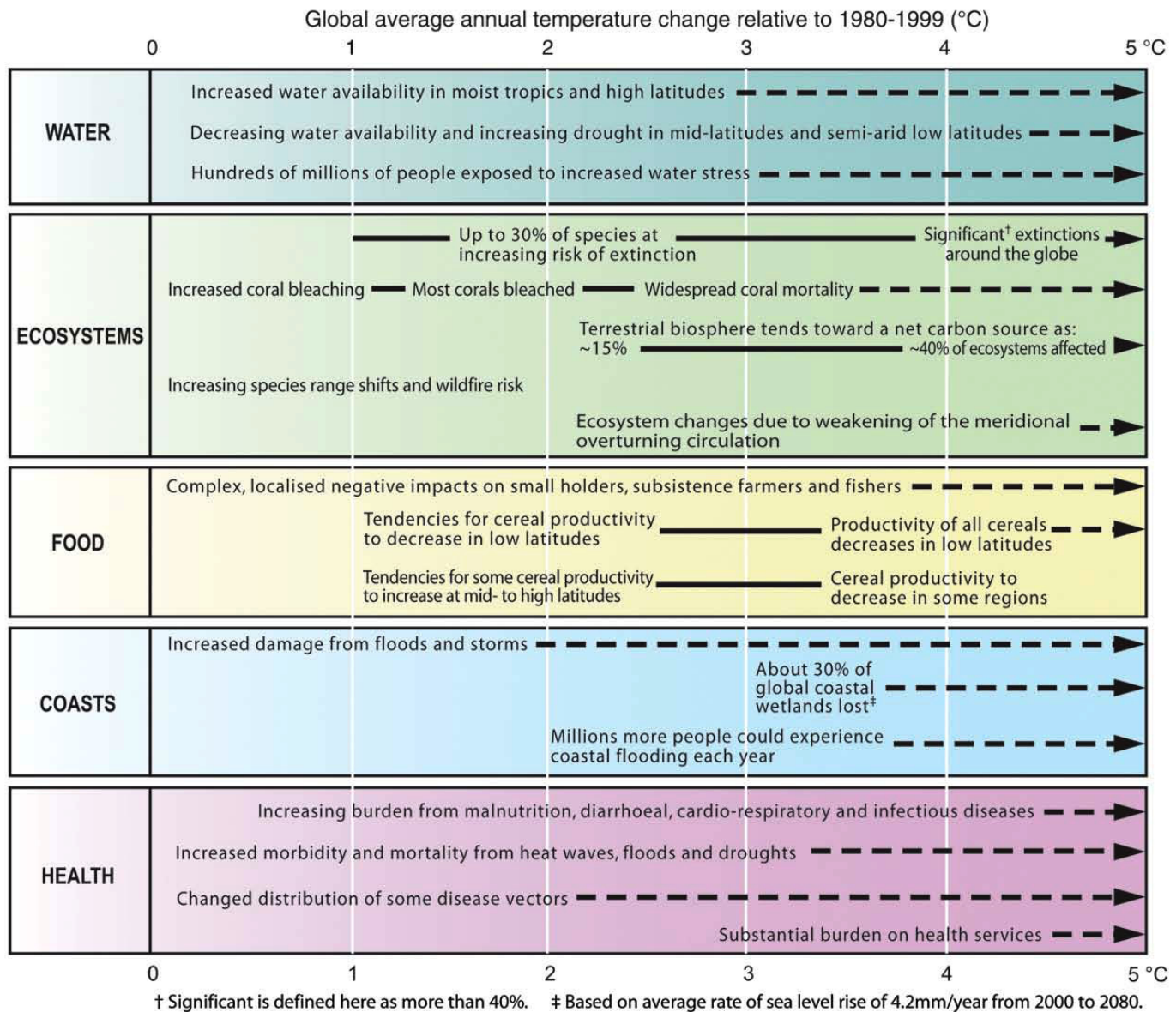
- A meta-analysis of climate change effects on range boundaries in Northern Hemisphere species of birds, butterflies, and alpine herbs shows an average shift of 6.1 kilometers per decade northward (or 6.1 meters per decade upward), and a mean shift toward earlier onset of spring events (frog breeding, bird nesting, first flowering, tree budburst, and arrival of migrant butterflies and birds) of 2.3 days per decade (Parmesan and Yohe 2003).
- Poleward range shifts of individual species and expansions of warm-adapted communities have been documented on all continents and in most of the major oceans of the world (Parmesan 2006).
- Satellite observations since 1980 indicate a trend in many regions toward earlier greening of vegetation in the spring linked to longer thermal growing seasons resulting from recent warming.
- Over the past 50 years humans have changed ecosystems more rapidly and extensively than in any previous period of human history, primarily as the result of growing demands for food, fresh water, timber, fiber, and fuel. This has resulted in a substantial and largely irreversible loss of Earth's biodiversity
- Although the relationships have not been quantified, it is known that loss of intact ecosystems results in a reduction in ecosystem services (clean water, carbon sequestration, waste decomposition, crop pollination, etc.).

#### ***What scientists think is likely...***

- The resilience of many ecosystems is likely to be exceeded this century by an unprecedented combination of climate change,

associated disturbance (flooding, drought, wildfire, insects, ocean acidification) and other global change drivers (land use change, pollution, habitat fragmentation, invasive species, resource over-exploitation) (Figure 6).

- Exceedance of ecosystem resilience may be characterized by threshold-type responses such as extinctions, disruption of ecological interactions, and major changes in ecosystem structure and disturbance regimes.
- Net carbon uptake by terrestrial ecosystems is likely to peak before mid-century and then weaken or reverse, amplifying climate changes. By 2100 the terrestrial biosphere is likely to become a carbon source.
- Increases in global average temperature above 1.5 to 2.5°C and concurrent atmospheric CO<sub>2</sub> concentrations are projected to result in major changes in ecosystem structure and function, species' ecological interactions, and species' geographical ranges. Negative consequences are projected for species biodiversity and ecosystem goods and services.
- Model projections for increased atmospheric CO<sub>2</sub> concentration and global temperatures significantly exceed values for at least the past 420,000 years, the period during which more extant marine organisms evolved. Under expected 21<sup>st</sup> century conditions it is likely that global warming and ocean acidification will compromise carbonate accretion, resulting in less diverse reef communities and failure of some existing carbonate reef structures. Climate changes will likely exacerbate local stresses from declining water quality and overexploitation of key species (Hoegh-Guldberg et al. 2007).
- Ecosystems likely to be significantly impacted by changing climatic conditions include:
  - i. Terrestrial – tundra, boreal forest, and mountain regions (sensitivity to warming); Mediterranean-type ecosystems and tropical rainforests (decreased rainfall)



#### Warming by 2090-2099 relative to 1980-1999 for non-mitigation scenarios

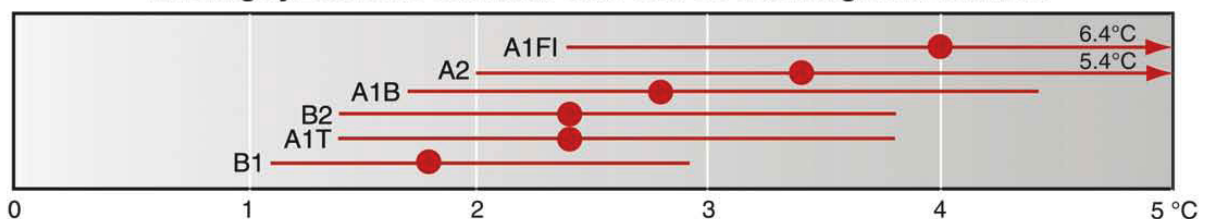


Figure 6. Examples of impacts associated with projected global average surface warming. Upper panel: Illustrative examples of global impacts projected for climate changes (and sea level and atmospheric CO<sub>2</sub>, where relevant) associated with different amounts of increase in global average surface temperature in the 21<sup>st</sup> century. The black lines link impacts; broken-line arrows indicate impacts continuing with increasing temperature. Entries are placed so that the left-hand side of text indicates the approximate level of warming that is associated with the onset of a given impact. Quantitative entries for water scarcity and flooding represent the additional impacts of climate change relative to the conditions projected across the range of SRES scenarios A1FI, A2, B1 and B2. Adaptation to climate change is not included in these estimations. Confidence levels for all statements are high. Lower panel: Dots and bars indicate the best estimate and likely ranges of warming assessed for the six SRES marker scenarios for 2090-2099 relative to 1980-1999 (IPCC 2007a).

- ii. Coastal – mangroves and salt marshes (multiple stresses)
- iii. Marine – coral reefs (multiple stresses); sea-ice biomes (sensitivity to warming)

#### ***What scientists think is possible...***

- Approximately 20% to 30% of plant and animal species assessed to date are at increased risk of extinction with increases in global average temperature in excess of 1.5 to 2.5°C.
- Endemic species may be more vulnerable to climate changes, and therefore at higher risk for extinction, because they may have evolved in locations where paleo-climatic conditions have been stable.
- Although there is great uncertainty about how forests will respond to changing climate and increasing levels of atmospheric CO<sub>2</sub>, the factors that are most typically predicted to influence forests are increased fire, increased drought, and greater vulnerability to insects and disease (Brown 2008).
- If atmospheric CO<sub>2</sub> levels reach 450 ppm (projected to occur by 2030–2040 at the current emissions rates), reefs may experience rapid and terminal decline worldwide from multiple climate change-related direct and indirect effects including mass bleaching, ocean acidification, damage to shallow reef communities, reduction of biodiversity, and extinctions. (Veron et al. 2009). At atmospheric CO<sub>2</sub> levels of 560 ppmv, calcification of tropical corals is expected to decline by 30%, and loss of coral structure in areas of high erosion may outpace coral growth. With unabated CO<sub>2</sub> emissions, 70% of the presently known reef locations (including cold-water corals) will be in corrosive waters by the end of this century (Riebesell, et al. 2009).

## **D. Disturbance**

#### ***What scientists know...***

- Climate change currently contributes to the global burden of disease and premature death through exposure to extreme events and changes in water and air qual-

ity, food quality and quantity, ecosystems, agriculture, and economy (Parry et al. 2007).

- The most vulnerable industries, settlements, and societies are generally those in coastal and river flood plains, those whose economies are closely linked with climate-sensitive resources, and those in areas prone to extreme weather events.
- By 2080-2090 millions more people than today are projected to experience flooding due to sea level rise, especially those in the low-lying megadeltas of Asia and Africa and on small islands.
- Climate change affects the function and operation of existing water infrastructure and water management practices, aggravating the impacts of population growth, changing economic activity, land-use change, and urbanization.

#### ***What scientists think is likely...***

- Up to 20% of the world's population will live in areas where river flood potential could increase by 2080-2090, with major consequences for human health, physical infrastructure, water quality, and resource availability.
- The health status of millions of people is projected to be affected by climate change, through increases in malnutrition; increased deaths, disease, and injury due to extreme weather events; increased burden of diarrheal diseases; increased cardio-respiratory disease due to higher concentrations of ground-level ozone in urban areas; and altered spatial distribution of vector-borne diseases.
- Risk of hunger is projected to increase at lower latitudes, especially in seasonally dry and tropical regions.

#### ***What scientists think is possible...***

- Although many diseases are projected to increase in scope and incidence as the result of climate changes, lack of appropriate longitudinal data on climate change-related health impacts precludes definitive assessment.



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