National Park Service
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Natural Resource Stewardship and Science

Understanding the Science of Climate Change

Talking Points – Impacts to the Pacific Coast

Natural Resource Report NPS/NRSS/CCRP/NRR—2012/513

ON THE COVER

Nidever Canyon at Channel Islands National Park; NPS photo.

Understanding the Science of Climate Change

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Contents

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 significantly 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 from 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 Pacific 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 seven types of changes or impacts, while the Global Section is arranged around four topics.

Regional Section

- Temperature
- The Water Cycle (including precipitation, snow, ice, and lake levels)
- Vegetation (plant cover, species range shifts, and phenology)
- Wildlife (aquatic and terrestrial animals, range shifts, invasive species, migration, and phenology)
- Disturbance (including range shifts, plant cover, plant pests and pathogens, fire, flooding, and erosion)
- Cultural Resources
- 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:

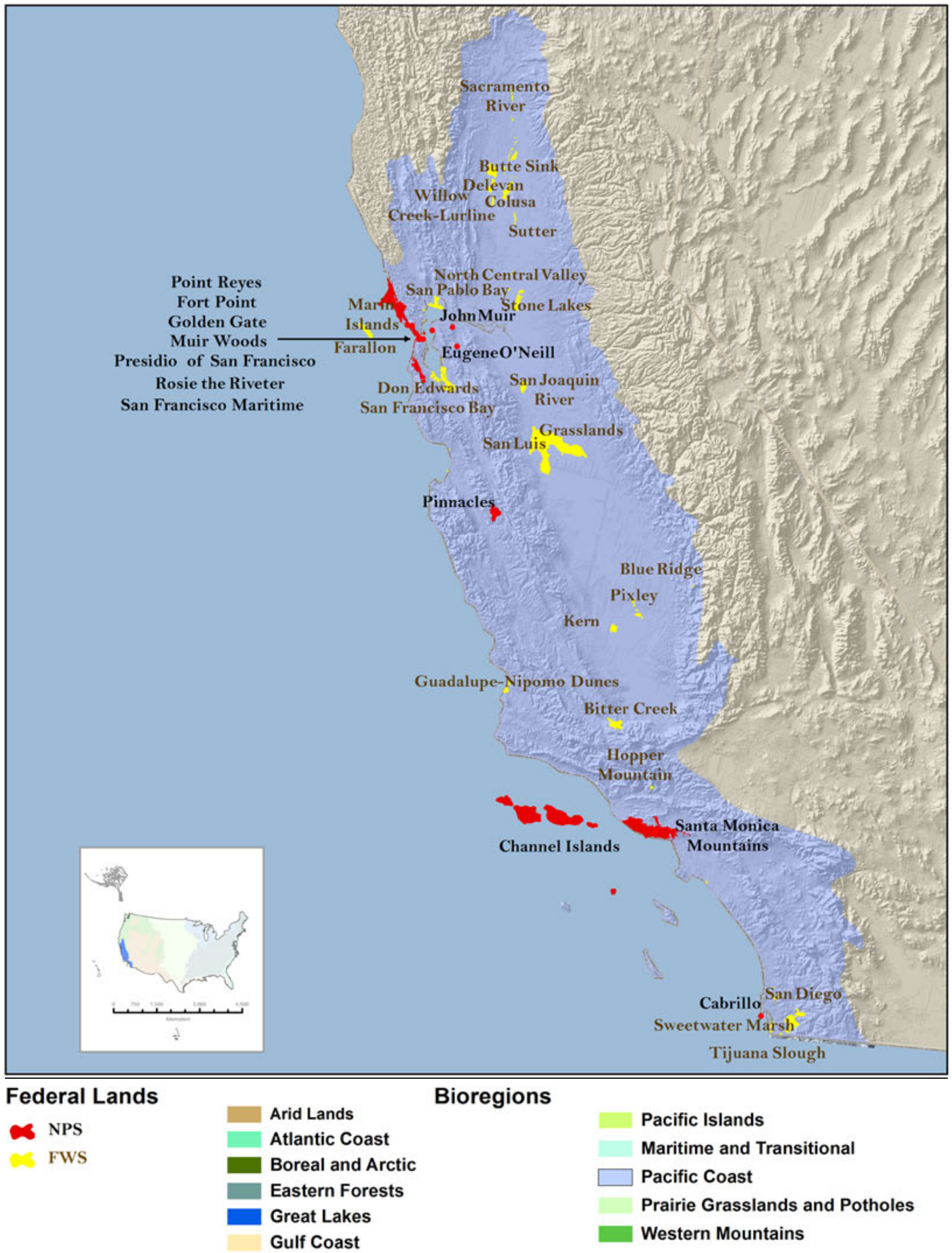
- "What scientists know" are statements based on measurable data and historical records. These are statements for which scientists generally have high confidence and agreement because they are based on actual measurements and observations. Events under this category have already happened or are very 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 Pacific Coast

The Pacific Coast bioregion discussed in this section is shown in the map to the right. A list of parks, refuges and sanctuaries 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

The Pacific Coast is an area of incredible biodiversity and diverse landscapes that are subject to a range of effects as regional climates shift. Changes that have already been observed within this bioregion include warmer average temperatures, earlier runoff season, rising sea levels, coastal erosion, species migration, and a longer growing season. In the next century, sea level rise is expected to threaten human communities, natural areas, and cultural resources with erosion and flooding. Developing seawalls and other infrastructure to protect developed areas from inundation may have negative consequences for coastal wetlands that will be blocked from migrating inland as the seas encroach. Groundwater sources may prove unable to meet water demands, and the quality of groundwater may be compromised as seawater infiltrates aquifers. Overall conditions are likely to be drier, though uncertainty exists over whether winter precipitation will trend higher or lower. Summer temperatures will rise more dramatically than winter temperatures, resulting in more frequent and longer-lasting heatwaves. Summer recreational seasons may lengthen due to a longer warm season.

Temperature
Water Cycle
Vegetation
Wildlife
Disturbance
Cultural Resources
Visitor Experience

List of Parks, Refuges and Sanctuaries

U.S. National Park Service Units

- Alcatraz Island
- Cabrillo NM
- California NHT
- Channel Islands NP
- Eugene O'Neill NHS
- Fort Point NHS
- Golden Gate NRA
- John Muir NHS
- Juan Bautista de Anza NHT
- Muir Woods NM
- Old Spanish NHT
- Pinnacles NM
- Point Reyes NS
- Pony Express NHT
- Port Chicago Naval Magazine NME
- Presidio of San Francisco
- Redwood National and State Parks
- Rosie the Riveter WWII Home Front NHP
- San Francisco Maritime NHP
- Santa Monica Mountains NRA
- World War II Valor in the Pacific NM

U.S. Fish & Wildlife Service Units

- Antioch Dunes NWR
- Bitter Creek NWR
- Castle Rock NWR
- Don Edwards San Francisco Bay NWR
- Ellicott Slough NWR
- Farrallon NWR
- Guadalupe-Nipomo Dunes NWR
- Hopper Mountain NWR
- Humboldt Bay NWR
- Marin Islands NWR
- Salinas River NWR
- San Diego NWR
- San Diego Bay NWR
- San Joaquin River NWR
- San Pablo Bay NWR
- Seal Beach NWR
- Stone Lakes NWR
- Tijuana Slough NWR

National Oceanic and Atmospheric Administration (NOAA) National Marine Sanctuaries

- Channel Islands NMS
- Cordell Bank NMS
- Gulf of the Farallones NMS
- Monterey Bay NMS

Acronym	Unit Type
NHP	National Historical Park
NHS	National Historic Site
NHT	National Historic Trail
NM	National Monument
NME	National Memorial
NMS	National Marine Sanctuary
NP	National Park
NRA	National Recreation Area
NWR	National Wildlife Refuge

A. TEMPERATURE

What scientists know...

- Winter and spring temperatures increased in western North America during the twentieth century. The rate of change varies with location, but the median tendency is a warming of 1°C (1.8°F) per century from 1916 to 2003 (Hamlet et al. 2007).

- Observational evidence shows that spring temperatures over western North America have undergone significant warming over the past half century, while autumn temperatures have shown relatively little change; however, recent research suggests that after accounting for seasonally opposite effects of atmospheric circulation, similar warming trends of around +0.2°C (0.36°F) per decade exist for both seasons (Abatzoglou and Redmond 2007).

- Regionally averaged spring and summer temperatures for 1987 to 2003 were 0.87°C (1.6°F) higher than those for 1970 to 1986, and spring and summer temperatures for 1987 to 2003 were the warmest since the beginning of the record in 1895 (Westerling et al. 2006).

- The rate of temperature increase for the western United States from 1947 to 2003 is roughly double that of the period from 1916 to 2003, largely attributable to the fact that much of the observed warming occurred from 1975 to the present. The largest warming trends occurred between January and March (Hamlet and Lettenmaier 2007).

- Average temperatures in the Napa and Sonoma Valleys increased 1.13°C (2.03°F) between 1951 and 1997, primarily due to increases in night minimum temperature (Nemani et al. 2000).

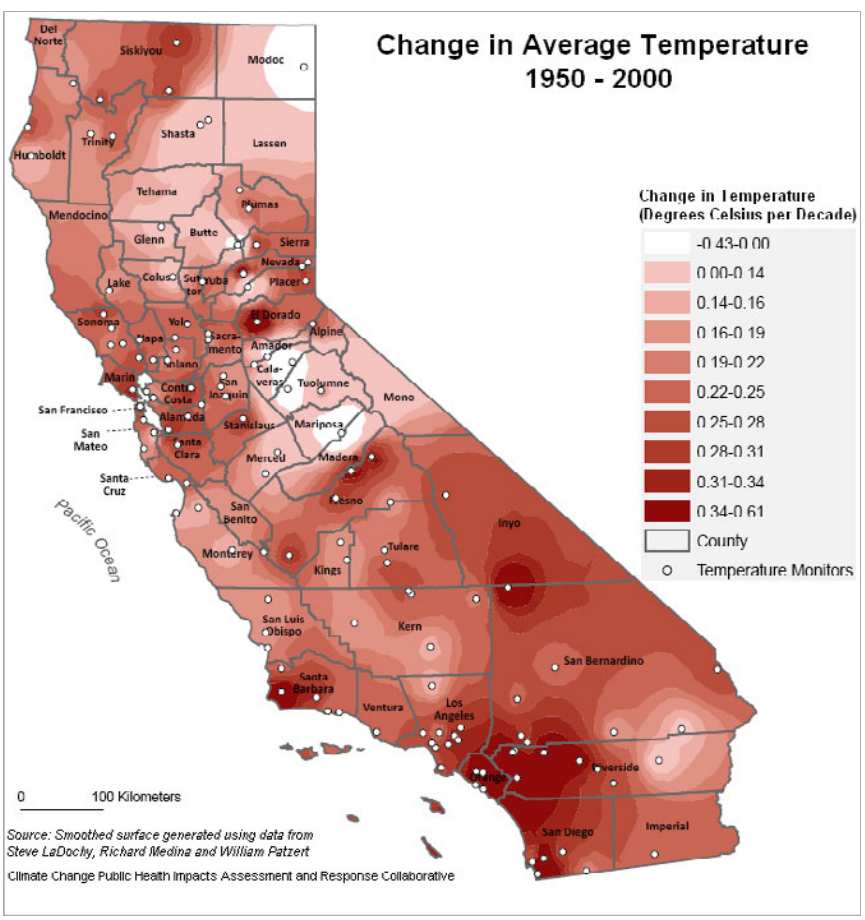
- Pacific sea surface temperatures along the California coast increased by 0.7°C (1.26°F) between 1951 and 1997, mostly occurring after the pacific climate shift during 1976-77. Coastal dewpoint temperatures increased by 0.9°C (1.62°F) during the same time period (Nemani et al. 2000).

- In addition to a rise in sea surface temperature, the deep ocean (between 700-3,000m, or 2,296-9,840ft) has experienced significant warming during the past several decades (Chen et al. 2006; Fletcher 2009).

- The rise in average global sea surface temperature has been accompanied by an increased frequency of El Niño-Southern Oscillation events (events of warm Pacific ocean surface temperature coupled with high air surface pressure that affect global weather patterns) (Bettencourt et al. 2006).

- Between the early 1930s and the late 1990s, the annual mean inshore water temperature at Monterey Bay increased by about 0.8°C (1.44°F), and mean summer maximum temperatures increased by approximately 1.9°C (3.42°F). By 1996, the populations of 10 of the 11 southern-distribution (warm water) intertidal species had increased compared to the early 1930s. At the same time, the populations of 5 of 7 northern (cooler water) species declined (Kennedy et al. 2002).

The image below depicts changes in average temperature for the state of California between 1950 and 2000. Image courtesy of the California Public Health Tracking Program.



What scientists think is likely...

- Both air and ocean surface temperatures are expected to increase in the Pacific by the end of the century (USGCRP 2009).

- Studies released since publication of the 2007 IPCC Fourth Assessment on Climate Change have shown that measured and modeled effects of climate change, including sea surface temperature, rate of glacial melting, and sea level rise are even greater than projected by the IPCC (Füssel 2009).

- Regional climate projections for the northwestern United States for the late 21st century include increased frequency of extreme hot events, decreased frequency of extreme cold events, and decreased severity of cold events (Diffenbaugh et al. 2005).

- All natural ecosystems of California are likely to be affected by changes in temperature and precipitation, including altered structure, composition, and productivity of vegetation communities; more frequent and intense wildfires; non-native species invasions; and a significant rise in the number of threatened and endangered species (Lenihan et al. 2003).

What scientists think is possible...

- Factoring in volcanic and solar activity and El Niño-Southern Oscillation events along with projections of anthropogenic (human-caused) influences, modeling projects global temperature rises of 0.12 to 0.13°C (0.22 to 0.23°F) from 2009 to 2014, at a rate 50% greater than projected by IPCC. However, the same models show that between 2014 and 2019, the rate of warming may slow (an increase of only 0.02 to 0.04°C, or 0.036 to 0.072°F) as a result of declining solar activity (Lean and Rind 2009).

- Summer temperature projections for the state of California show about 0.5 to 2°C (0.9 to 3.6 °F) warming on average between the year 2000 and 2030. By the last 30 years of the 21st century, average temperatures are expected to increase by 1.5 to 5.8 °C (2.7 to 10.5 °F). The high end of this temperature range is a much greater warming rate than the historical rates estimated from observed temperature records in California. Overall, summer temperatures are expected to increase more than winter temperatures (CAT 2010).

- By the year 2100, temperature modeling for California projects up to 100 more days per year with temperatures above 90°F in Los Angeles and above 95°F in Sacramento under the higher warming range. By the middle of the 21st century, extreme heat events in cities like Sacramento, Los Angeles, and San Bernardino could cause two to three times more heat-related deaths compared to 2006 (Cayan et al. 2006).

California, like much of the western United States, suffered intense droughts in the late 20th and early 21st centuries. Below, 2009 drought conditions at Lake Oroville. Photo courtesy of California Department of Water Resources.

B. THE WATER CYCLE

What scientists know...

- The timing of peak spring season flows in the western United States has advanced over the past 50 years to occur earlier in the season. In addition, snow water equivalent has decreased in many western states. In recent decades more of the precipitation is coming as rain rather than snow (Regonda et al. 2004).

- California is particularly vulnerable to reduced water availability due to early snowmelt because summer rains that could replenish water stores are rare (CCSP 2008).

- Areas of drought correspond to changes in sea surface temperature. In the western United States, reduction in snowpack and associated loss of soil moisture are also factors. This region suffered intense, multi-annual droughts in the late 20th and early 21st centuries (IPCC 2008).

- About 25% to 30% of anthropogenic (human-caused) carbon dioxide (CO_2) emissions in the atmosphere are absorbed by the earth's oceans, where the CO_2 reacts with the water to form carbonic acid in a process known as "ocean acidification" (Kleypas et al. 2006; Hoegh-Guldberg et al. 2007; Jokiel et al. 2008).

- Availability of calcium carbonate in ocean waters is essential for marine organisms like coral and pteropods that use it for building their shells and calcium carbonate skeletons. Ocean acidification is resulting in a net loss of calcium carbonate saturation, which translates to slower calcification (inhibited reef-building capacity) and faster dissolution for coral. This represents a major reversal of the previous trend of calcium carbonate increase in shallow-water ocean environments, which has been in effect worldwide for thousands of years (Kleypas et al. 1999; Orr et al. 2005; Andersson et al. 2009).

- Ocean areas with low surface chlorophyll are the least productive areas of the ocean. These areas expanded by about 15% between 1998 and 2006. A rise in mean sea surface temperature was experienced in the same areas during this period. Expansion of these low-chlorophyll areas is consistent with global warming models that predicted increasing stratification of ocean waters as sea surface temperatures rise (Polovina et al. 2008).

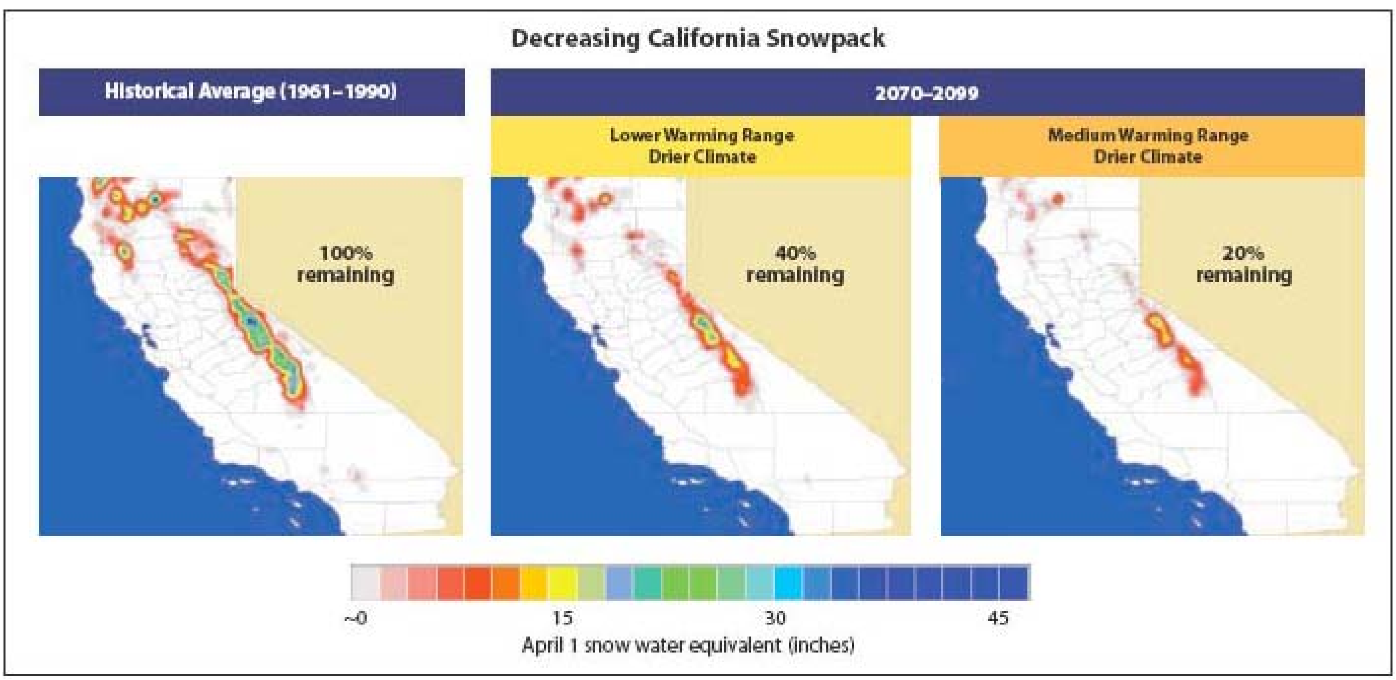
- Global mean sea level is estimated to rise by approximately 3mm (0.12 inches) per year (Fletcher 2009). A rise between 0.34-0.39 ± 0.05mm (0.13-0.15 ± 0.02 inches) per year that occurred between 1955 and 2003 is attributable to "steric effect" (thermal expansion and salinity-density compensation of sea water) (Chen et al. 2006).

- Historical tide-gauge measurements show that the rates of global sea level rise over the past 100 years are ten times greater than rates over the past 5,000 years (Field et al. 2008).

- Historically, the coast south of La Jolla, California has experienced sea level rise at a rate of approximately 8 inches (20 cm) per century. The coast from Los Angeles to San Francisco has experienced a 6 inch (15 cm) per century sea level rise, and the coast in far northern California has experienced a relative reduction in sea level of 2-6 inches (5-16 cm) per century (Smith et al. 2001).

- The California coast has experienced a 33% reduction in fog frequency since the early 20th century (Johnstone and Dawson 2010).

Models show a reduction in April 1st snow water equivalent in the Sierra under a warming climate. Image courtesy of California Climate Change Center.



The Sacramento River is subject to flooding during winter storms or high runoff events; USFWS Photo.

- The western United States experienced a decline in frost frequency of approximately 3 days per decade during the second half of the 20th century (Feng and Hu 2004).

- Warming in the Napa and Sonoma valleys between 1951-1997 translated to a 71% decline in frost frequency, from 28 days to 8 days per year. At the same time, the valleys experienced a 25% increase in frost-free growing season length, from 254 days to 320 days per year (Nemani et al. 2000).

What scientists think is likely...

- California's Mediterranean seasonal precipitation pattern, with most precipitation falling during winter, is expected to continue. Climate models diverge on whether future precipitation may trend wetter or drier (Cayan et al. 2006). However, future conditions in California are expected to be drier overall, when changes in precipitation patterns and increased evapotranspiration due to warmer temperatures are both taken into account (CAT 2010).

- Projections from a suite of model emissions scenarios show a decrease in California's average streamflow from April to October, with the greatest drop in June and July. Changes in streamflow have implications for commercial fisheries, recreational fishing, recreational boating, municipal and industrial use, irrigation, hydropower and flood mitigation (Shaw et al. 2009).

- Sea level rise in California is expected to contribute to an increased rate of high sea level events as high tides combine with winter storms. This may be further exacerbated by El Niño events which often cause sea levels to rise substantially (CAT 2010).

- Climate change is expected to cause changes in ocean currents such as the California Current, which spans from British Columbia to Baja Mexico. Effects could include oxygen depletion events such as the growing "dead zone" off the coasts of Washington and Oregon (USGCRP 2009).

- If trends in declining frost frequency continue, Napa and Sonoma wine country will become a frost-free climate (Nemani et al. 2000).

What scientists think is possible...

- Some regional climate models indicate that on average California may experience substantially warmer and wetter winters, somewhat warmer summers, and an enhanced El Niño Southern Oscillation (ENSO) during the 21st century (Lenihan et al. 2003). Enhanced ENSO could be characterized by more frequent or more intense El Niño events, or both (Kennedy et al. 2002).

- Overall winter precipitation is projected to decrease by 15%-30% by the year 2100, with reductions concentrated in the Central Valley and along the north Pacific Coast (Hayhoe et al. 2004).

- Modeling projects that a temperature increase of 7°F (4°C) and a 20% increase in precipitation could increase winter runoff by 75% and decrease the summer runoff by 49% (Wilkinson 2002).

- A reduction in snowpack in the Sierra Nevada Mountains, combined with earlier runoff and reduced spring and summer streamflows, will likely affect surface water supplies and shift reliance to groundwater resources. This could impact 85% of California's population in the Central Valley, San Francisco Bay Area, and the South Coast, about half of whose water is supplied by rivers of the Central Valley (Hayhoe et al. 2004).

Coast redwoods could be affected positively or negatively by changes in summer fog frequency; NPS photo.

- By 2050, sea-level rise in California could range from 30-45 cm (11-18 inches) higher than in 2000. By 2100, sea level could be 60-140 cm (23-55 inches) higher than in 2000 (Cayan et al. 2009; CAT 2010).

- The oceans may absorb as much as 90% of atmospheric CO_2 over the next millennium. Ocean acidification is projected to reduce oceanic pH by as much as 0.4 pH units by the end of this century. By 2050, ocean carbonate saturation levels may drop below the levels required to sustain coral reef building activity (Hoegh-Guldberg et al. 2007; Kleypas et al. 2006).

- The western United States experienced an epic drought during the Medieval Warm Period, 900 to 1300 AD. Assuming that increased aridity is a direct natural response to climate warming, a trend toward warmer temperatures in the western U.S. could lead to serious long-term drought conditions (Cook et al. 2004).

- Under most global warming scenarios, higher temperatures in polar regions will reduce the thermal gradient between the poles and equator, potentially resulting in a weakening of the ocean's overall wind-driven circulation. Weaker winds would reduce upwelling off California, causing lowered phytoplankton production and reducing transport of oxygen from the sea surface to the deep ocean. Over time, this could render deep ocean areas hypoxic (low in oxygen) or anoxic (without oxygen) (Kennedy et al. 2002).

C. VEGETATION

What scientists know...

- Climate has demonstrably affected terrestrial ecosystems through changes in the seasonal timing of life-cycle events (phenology), plant-growth responses (primary production), and biogeographic distribution (Parmesan 2006; Field et al. 2007). Statistically significant shifts in Northern Hemisphere vegetation phenology, productivity, and distribution have been observed and are attributed to 20^{th} century climate changes (Walther et al. 2002; Parmesan and Yohe 2003; Parmesan 2006).

- In the last few decades, spring bloom dates of lilac and honeysuckle have trended toward earlier occurrence in western North America, signaling an earlier onset of the spring season. Between the 1950 and 2000, bloom dates and spring pulses occurred 5–10 days earlier in the last half of the study period. This corresponds to a spring 1–3°C (1.8°-5.4°F) temperature increase over western North America since the 1970 (Cayan et al. 2001).

- Warmer winter sea surface temperatures, on average, correspond to higher quality wine grape production in the Napa and Sonoma wine growing areas, and higher quality wine vintages for the year. Wine quality is related to temperature variability and temperature extremes measured by a "temperature variability index" (TVI). Lower TVIs favor production of high-quality wines, and TVI values under 30 are suitable for any variety of table wine. In Napa and Sonoma wine country, the TVI declined from 36.1 to 31.4 between 1951 and 1997 (Nemani et al. 2000).

What scientists think is likely...

- Health of the coast redwood (*Sequoia sempervirens*) is closely associated with the presence of summer marine fog along the California coast, which affects the trees' transpiration and sap flow. Reduced summer fog frequency would cause coast redwood and other ecosystems along the west coast to be increasingly drought stressed (Johnstone and Dawson 2010).

- Under various climate warming scenarios, models project a 15%-70% increase in California's shrublands and a consistent decline in conifer woodland, conifer forest, and herbaceous cover through the end of the century. This includes expansion of the hardwood forest into the North Coast ecoregion and the Sacramento Valley, and coastal shrublands expanded northward into the Central Coast (Shaw et al. 2009).

- Climate modeling shows southern California shrublands, including Chaparral and coastal sage, moving to higher elevations with cooler climates and greater precipitation in response to rising temperatures and reduced precipitation in their current environments (Messner et al. 2009).

- Non-native grasses are projected to increase in shrublands, which, along with increased wildfire frequency, may substantially reduce their range and proficiency (Messner et al. 2009).

- By the end of the 21st century (2070–2099), cattle grazing forage production is projected to decline dramatically, ranging from a 14%-58% decline in annual mean production across a range of models and emissions scenarios (Shaw et al. 2009).

What scientists think is possible...

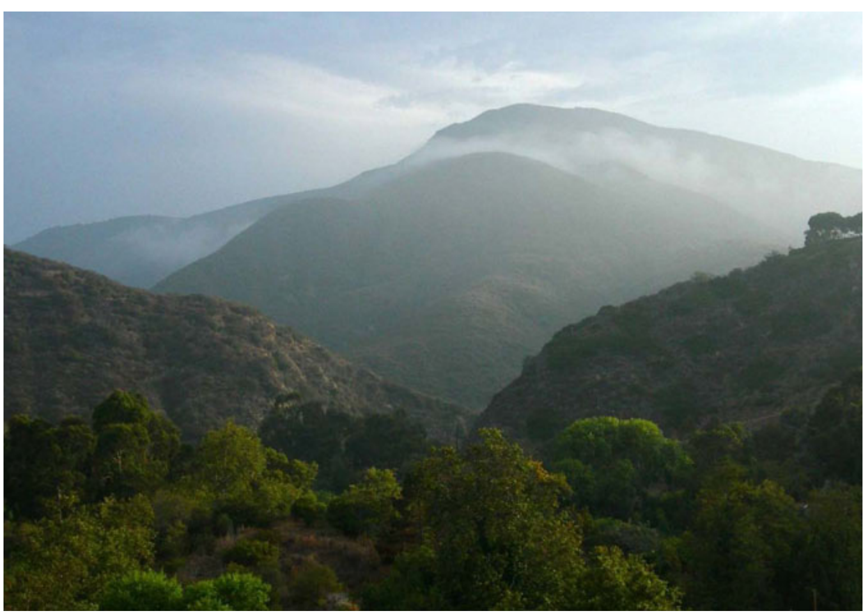
- Studies of the Beach Evening Primrose (*Camissoniopsis cheiranthifolia [Onagraceae]*), a Pacific coastal dune plant, have shown that the plant can exhibit a high level of fitness outside its existing geographic range. It is possible that habitat changes due to climate warming might present conditions allowing the primrose to increase its northern limit (Samis and Eckert 2009).

- Warmer temperatures could enhance coast redwood productivity given adequate moisture availability. The highest monthly mean temperatures along the north-central coast are currently lower than the optimal mean summer temperature for coast redwood forest productivity and seedling growth (Lenihan et al. 2003).

- If fire events become longer and more severe, the distribution and abundance of dominant plant species may shift significantly. Species that are sensitive to fire may decline, while other species may benefit (McKenzie et al. 2004).

- Warmer winter temperatures may lead to an increase in occurrences of forest diseases such as pitch canker, which are limited by low temperatures and are more successful when attacking drought-stressed trees. Pitch canker has been known to affect trees such as Monterey pine (*Pinus radiate*). Warming may also increase habitat quality for *Phytophthora cinnamomi* in northern California. This disease affects the root and stem-base of a wide range of broad-leaved and coniferous species. *P. cinnamomi* infections have already been reported among coast live oaks (*Q. agrifolia Nee.*) in San Diego County (Kliejunas et al. 2009).

(Top): Warmer temperatures may lead to an earlier growing season for California wine grapes. USDA Photo by Stephen Ausmus. (Bottom): Southern California shrublands could shift to higher elevations as suitable conditions become scarce in their current environments. Photo courtesy of California Department of Parks and Recreation.



In recent years, gray whales have been observed delaying their southbound migration, and expanding their feeding range along the migration route; NPS photo.

- Climate models show that by the end of the 21st century, warmer temperatures may lead to a reduction in alpine and subalpine forest cover and cause mixed conifer forest to displace evergreen conifer forest in the Sierra Nevada Mountains and the North Coast. In the South Coast, the same models show an expansion of mixed conifer forest because of increased humidity and reduced fire frequency (Hayhoe et al. 2004).

- Warmer temperatures may lead to an earlier growing season for California wine grapes. Models show average ripening occurring 1–2 months earlier and at higher temperatures over the 21st century, leading to degraded quality and impaired conditions for all growing areas except the cool coastal region (Hayhoe et al. 2004)

D. WILDLIFE

What scientists know...

- A meta-analysis of climate change effects on range boundaries in Northern Hemisphere animal and plant species shows an average shift of 6.1 km per decade northward (3.8 miles 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) by 2.3 days per decade (Parmesan and Yohe 2003).

- Sooty Shearwaters, a type of seabird, have shifted their summer migration pathway from the coastal California current to a more central Pacific pathway, corresponding to a warming-induced shift in regions of high fish abundance (CCSP 2008).

- Changes in distributions of marine species along the Pacific coast have been observed in connection with climate warming. Between 1930-1990, Monterey Bay experienced an increase in abundance of southern species of gastropods, anthozoans and barnacles and a decrease in abundance of northern anthozoan and limpet species (Cheung et al. 2009).

- In the past 40 years, marine copepods have exhibited range shifts up to 1,000 meters northward (Parmesan and Yohe 2003).

- The California coast is home to both polar and temperate species of marine fish and intertidal invertebrates (snails, barnacles, anemones, copepods and limpets). These two species react differently to the effects of climate change. Whereas polar species tend to be stable or decline in abundance, temperate species have increased in abundance and/or expanded their distributions over time (Parmesan and Yohe 2003).

- In recent years, gray whales have been observed to delay their southbound migration and to expand their feeding range along the migration route. Some have even remained in polar waters over winter (Moore 2009).

- Warming of up to 1.5°C (2.7°F) between 1951-1993 led to a 70% decline in zooplankton abundances off the California coast (Kennedy et al. 2002).

- Pacific salmon disappeared from about 40% of their historical breeding range in the Pacific Northwest and California during the 20th century, and many remaining populations are severely depressed. Populations in coastal streams have fared better than others (Parson et al. 2001).

- In the 31 years leading up to the year 2003, the average first spring flight of 23 butterfly species in the Central Valley of California occurred an average of 24 days earlier. Changes in climatic conditions such as winter temperature and precipitation are found to explain a large part of the variation (Forister and Shapiro 2003).

Temperature
Water Cycle
Vegetation
Wildlife
Disturbance
Cultural Resources
Visitor Experience

What scientists think is likely...

- Results from a range of model and scenario combinations suggest that California's rare and imperiled terrestrial species will migrate poleward, coastward, and upslope in response to climate warming, and will experience negative biodiversity impacts. Potential future refugia (areas with stable, suitable climates) will diminish rapidly. The transition of habitat areas from suitable to unsuitable conditions is consistent across all major taxonomic groups, regardless of geographic and ecological differences (Shaw et al. 2009).

- All 67 ocean bird species in U.S. waters are considered to have a medium or high vulnerability to climate change; 43 species are considered highly vulnerable (NABCI 2010).

- Rising sea levels are expected to inundate or fragment existing low-lying seabird habitats such as salt marshes, barrier islands, and mudflats. The Pacific coast is particularly vulnerable to this type of activity, which is expected to be most pronounced in areas with steep topography or seawalls that limit the ability of coastal wetlands to move. Models project that sea level rise will lead to reductions of 20% to 70% of intertidal foraging habitat for shorebirds. More than half of the tidal flats and over 60% of intertidal foraging areas may be lost by the year 2100 if current rates of sea level rise continue (Galbraith et al. 2002).

- The reproductive success of the endangered San Clemente Loggerhead shrike (*Lanius ludovicianus mearnsi*) is closely related to pre-breeding precipitation levels (November to March). During exceptionally dry years, a high degree of human management is needed to ensure effective breeding (Heath et al. 2008).

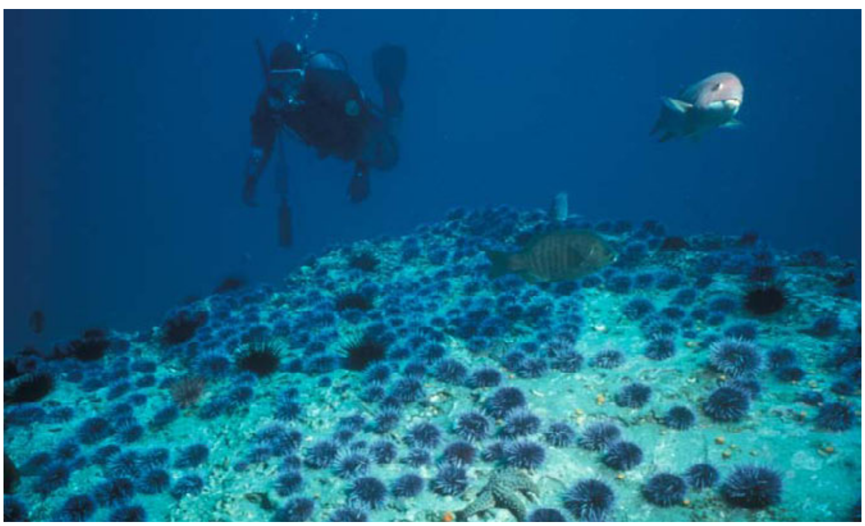
- Isolated, fragmented populations of checkerspot butterflies and other species may become increasingly susceptible to extinctions due to the effects of climate change. This has implications for both species diversity and critical ecosystem services. The changes in precipitation amplified population fluctuations, leading to rapid extinctions (McLaughlin et al. 2002).

- Intertidal communities are especially sensitive to the effects of climate change due to their exposure to a wide range of environmental conditions at the extreme edge of both the marine and terrestrial environments (Blanchette et al. 2008).

- Studies of intertidal communities of the California mussel (*Mytilus californianus*) along the west coast of the United States showed that the organism's body temperature is affected by both large-scale and regional-level climate patterns. These studies demonstrate that the role of "hot spots" and "cold spots" can have significant effects, including population changes and local extinctions, for organisms well within their species ranges as well as those at range edges (Helmuth et al 2006).

- The productivity of endangered Pacific loggerhead sea turtles has an inverse relationship with sea surface temperature

Ocean acidification inhibits the ability of shell-building marine creatures, like urchins and the spiny lobster, to develop carbonate shells and skeletons; NPS photos.



(Top): Changes in precipitation could challenge the reproductive success of endangered San Clemente Loggerhead Shrike; USFWS photo by David Menke. (Bottom): The body temperature of California mussels is affected by both large-scale and regional-level climate patterns; NPS Photo.

in core foraging areas. As oceans warm, Loggerhead populations could decrease unless the turtles are able to shift their foraging habitat to cooler locations (Chaloupka et al. 2008).

- Echinoderms such as sea stars, sea cucumbers, and sea urchins have bodies that are largely made up of calcium carbonate, and their populations capture an estimated 0.1 gigatons of carbon per year from oceans worldwide. These species may be highly susceptible to ocean acidification, with effects such as failure of planktonic larvae recruitment, larval death, and impairments to growth and development (Lebrato et al. 2009).

- The upwelling of carbonate-deficient deep ocean water that has been observed along the west coast of the U.S. could be detrimental to pteropods, an essential part of the food chain for juvenile salmon (Feely et al. 2008).

- In Channel Islands National Marine Sanctuary, several species are considered vulnerable to ocean acidification, including sea urchins and other echinoderms, crustaceans, abalone, corals, coralline algae, foraminifera, and pteropods (Polefka and Forgie 2008).

- Climate warming may contribute to an increase in cases of "summer mortality syndrome," a condition in cultivated Pacific oysters that is associated with high temperatures and results in oyster die-off (Kennedy et al. 2002).

What scientists think is possible...

- The combination of rapid temperature rise and stresses such as habitat destruction may disrupt connectedness among species, lead to reformulation of species communities, and result in numerous extirpations (localized extinctions) and/or large-scale extinctions (Root et al. 2003).

- If current carbon dioxide emission trends continue, ocean acidification may become intense enough that corals do not survive this century (Caldeira 2007).

- More than 50% of some coastlines in California have replaced natural habitats with artificial hard surfaces. Development of infrastructure such as seawalls in response to coastal erosion and sea level rise may have unintended consequences for intertidal communities, including blocking species from inland migration or connecting communities that had previously been isolated, leading to species homogenization (Bulleri and Chapman 2010). Coastal wetlands may be lost entirely in areas where they cannot migrate inland with the sea (Smith et al. 2001).

- Changes in marine species productivity have been documented to affect seabird reproduction. Warmer waters in the California Current region have resulted in diminished West Coast salmon productivity and other fish population decreases, which could, in turn, lead to a decline in the abundance of fish-eating birds. If catastrophic events increase in frequency, intensity, or length, the likelihood of population recovery will be diminished (NABCI 2010).

- Future warming could alter the temperature regime of the Sacramento River, an important spawning habitat for California Chinook salmon. Winter and spring runs are most at risk from spawning and rearing temperature exceedences, particularly in drought years, because of the timing of their reproduction. Temperature disruptions at these critical times could further reduce already fragmented Chinook habitat (Yates et al. 2008).

Changes in sea surface temperature are linked to wildfire activity, and future scenarios for California project an increase in total annual area burned of 9 to 15% above the historical norm by 2100. Above, fire fighters combating the 1995 Vison Fire at Point Reyes National Seashore; NPS photo.

E. DISTURBANCE

What scientists know...

- A vulnerability assessment of 22 coastal national parks found that these parks are moderately vulnerable to sea level rise overall. Average sea level rise rates were calculated at 2.74 mm/year at Channel Islands National Park, 2.16 mm/year at Golden Gate National Recreation Area, and 2.51 mm/year at Point Reyes National Seashore. Each of these parks contains areas of high to very high vulnerability to sea level rise. All beaches on the west side of Point Reyes, as well as coastal estuaries, are threatened. At Golden Gate, one of the largest urban parks in the world, 24% of the coastline is considered to have very high vulnerability and 26% is categorized as high vulnerability. All of San Miguel Island at Channel Islands National Park is in the high to very high vulnerability category, and most of Santa Rosa Island is also considered high to very high vulnerability (Pendleton et al. 2010; Pendleton et al. 2005)

- A vulnerability assessment of United States counties found that the San Francisco Bay Area is highly vulnerable to coastal erosion, and is, in fact, the most vulnerable coastal area on the Pacific coast due to both physical landscape and social composition of communities (Boruff et al. 2005).

- Approximately 100 billion dollars of property and 475,000 people are located in Bay and open coastal areas that are expected to be vulnerable to coastal inundation by the end of the 21st century due to sea level rise (CAT 2010).

- Increased precipitation variability and systematic warming associated with late 20th century climate has increased flood risks in rain-dominant basins and in many near-coastal areas in California (Hamlet and Lettenmaier 2007).

- Agricultural lands in the Sacramento-San Joaquin Delta are vulnerable to flooding due to sea level rise. Some of these lands are already as much as 25 feet below sea level (Smith et al. 2001).

- High-volume runoff events have become so much more common that water capture infrastructure in the Folsom Basin, once thought to be "500-year" flood protection for American River runoff, is now estimated to be adequate for only 75-80 year intervals (Wilkinson 2002).

- Erosion can increase by nearly 20% for one meter of sea level rise when waves are large, of long period, and from westerly directions (similar to El Niño events) (CAT 2010).

- In the Southern California Bight (including the southern California coast, the Channel Islands and part of the Pacific Ocean), El Niño storm waves under warmer water conditions (warm phase PDO) are higher, have a longer period, and approach from a more westerly direction than El Niño storm waves that occur during a cool phase PDO (Adams et al. 2008).

- Pierce's disease, a bacterial disease fatal to grapevines, is increasing in Napa and Sonoma valleys. The disease is transmitted by sharpshooter beetles and typically limited by frost occurrence, which has become less frequent in the region (Nemani et al. 2000).

- Changes in sea surface temperature are linked to wildfire regimes. Warm phases of the Atlantic Multidecadal Oscillation (AMO) correspond to synchronous wildfire events across the western United States (Kitzberger et al. 2007).

What scientists think is likely...

- Sea level rise will encroach into coastal groundwater aquifers, contaminating freshwater supplies (Smith et al. 2001).

- Without protective measures, California beaches, hundreds of acres of low-lying land, and even agricultural lands in the Sacramento-San Joaquin Delta could be flooded due to sea level rise (Smith et al. 2001). The Delta is particularly vulnerable to flooding, as a combination of sea waters and river flows would contribute to the water level. Inundation in the Delta would put severe pressure on Delta levees in areas that have experienced breaches in the past (Cayan et al. 2006).

- Many coastal areas vulnerable to flooding from sea level rise either include wetland areas that are currently only occasionally inundated by high tides, or are currently protected by levees and would only be inundated if the levees breached. In the North Bay, the most prominent areas subject to inundation are the wetlands surrounding San Pablo and Suisun Bays, municipal and industrial areas along the Martinez-Pittsburg corridor, the Richmond-Pinole peninsula, and areas in eastern Marin. In the Central and South Bays, sea level rise is expected to pose a new threat to some developed areas that currently have levees, as rising sea levels could greatly increase pressure on the levees and increase the risk of breaching. Other areas that currently do not have levee protection, such as the San Francisco airport, may require levee protection to avoid inundation (CAT 2010).

- Ocean acidification has caused a decrease in sound absorption. Based on current projections of future pH values for the oceans, a decrease in sound absorption of 40% is expected by mid-century, resulting in increased ocean noise within the critical auditory range for environmental, military, and economic interests, and with unknown implications for acoustically sensitive marine mammals (Hester et al. 2008).

- Warmer temperatures are likely to lead to longer fire seasons in the western United States, with fire season beginning earlier and ending later than is currently typical. The area burned may also increase in some locations (McKenzie et al. 2004).

What scientists think is possible...

- A higher frequency of El Niño-like conditions could occur as a result of climate change. As a result, divergence of longshore sediment (change in the locations or pattern of coastal sediment deposits) at exposed sites could increase by as much as 300%, increasing erosion or turning previously accreting (sand depositing) sections of beach into erosion hotspots (CAT 2010).

- Modeling that uses a time-scaled linkage between sea level rise and global mean temperature projects a future rise in sea level of 75-190 cm by the year 2100, com-

At Golden Gate NRA, 24% of the coastline is considered to have very high vulnerability to sea level rise, and 26% is categorized as high vulnerability; NPS photo.

(Top): Young visitors to San Francisco Maritime NHP; NPS photo. (Bottom): The Chumash traveled by canoe to Anacapa Island, now a part of Channel Islands NP. Archeological evidence of human settlements dating back over 10,000 years can be found in the park. Rising sea levels pose a threat to these resources; NPS photo.

pared to 1990 levels. This represents a rise in sea level as much as three times greater than projected by the IPCC (Vermeera and Rahmstorfb 2009).

- As sea level rises, the rate of extreme high sea level events is expected to increase. These events occur during high tides, often in tandem with winter storms and sometimes exacerbated by El Niño events. Over time, models show heightened sea level events persisting for longer durations, implying a greater threat of coastal erosion and other damage (Cayan et al. 2009).

- Sea level rise models for the San Diego area project several areas of beach and wetland loss and high-tide-range inundation on existing beaches, urban streets, and the parking lot of the famous Hotel Del Coronado (Messner et al. 2009).

- With warmer temperatures, the average cyclone track trends northward, along with a decrease of winter storm wind forcing and a decline in winter wave energy along the California coast. The lower wave heights and decreased extreme waves could potentially reduce coastal erosion potential due to sea level rise (Cayan et al. 2009).

- Trends toward increasing humidity and air temperature could increase the risk of fungal and vector borne disease outbreaks that could affect wine grapes in the Napa and Sonoma valleys (Nemani et al. 2000).

- Modeling projects a reduction in intensity of the Santa Ana winds in the 21st century. These winds contribute positively to coastal ecosystems and improve air quality in the South Coast Basin, but are also associated with wildfire hazards (CAT 2010).

F. CULTURAL RESOURCES

What scientists know...

- Coastal archeological sites are threatened by erosion and storm surges. Coastal cyclonic activity has been known to destroy entire archeological assemblages and to rework coastal midden areas (Spennemann 2004).

- At Channel Islands National Park, erosion caused by sea level rise is damaging some of the best evidence of how the Americas were settled dating back over 10,000 years. Rock shelters are being inundated, and coastal middens that contain numerous artifacts are rapidly disappearing (Curry 2009).

- Benefits of using local knowledge and traditional practices in resource management can help facilitate adaptation to climate change (IPCC 2008; Finucane 2009).

- Climate change poses a threat to water supply in California and much of the American west. Native American tribes have reserved water rights that represent up to 45-60 million acre-feet, but most of those claims have not been clearly quantified or developed. In many cases, nontribal water users have already fully appropriated and used the sources of water that would potentially fulfill tribal rights (Smith et al. 2001).

- Areas of high to very high coastal vulnerability along the northern California coast include the locations of historic structures and archeological sites, including San Francisco's Fort Mason and Presidio, and numerous Coast Miwok Indian cultural sites at Point Reyes National Seashore (Pendleton 2005).

What scientists think is likely...

- Land use areas that are fixed in place, like national parks and Native American reservations, are particularly vulnerable to the effects of climate change because they cannot adapt by relocating in response to changes in natural conditions (Smith et al. 2001).

G. VISITOR EXPERIENCE

What scientists know...

- Drought conditions can have a significant effect on recreational activity. During the drought that affected California from 1987-1991, visits to California state parks declined by 20%, and water-based recreational activities also declined (Kiparsky and Gleick 2003).

What scientists think is likely...

- The locations of climatically ideal tourism conditions are likely to shift toward higher latitudes under projected climate change, and as a consequence redistribution in the locations and seasons of tourism activities may occur. The effects of these changes will depend greatly on the flexibility of institutions and tourists as they react to climate change (Amelung et al. 2007).

- The tourism industry in California and the western U.S. is particularly sensitive to climate, as it is very outdoor-oriented. Climate warming is expected to reduce the period for winter recreation, while increasing the length of the summer recreation season (Smith et al. 2001).

- Sport anglers fish for salmon in the coastal waters of California, as well as in the streams and rivers where the fish reproduce. Climate change threatens the health of salmon populations, and will likely make it more difficult to restore salmon fisheries that contribute to this recreational activity (Shaw et al. 2009).

What scientists think is possible...

- 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 designated. 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).

- Increased frequency of wildfires resulting from a hotter, drier climate in the west could deter visitors from coming to parks, or could lead to park closures (Saunders et al. 2007).

- Excessive surface water from streamflow and runoff could lead to flooding and/or coastal and freshwater pollution that could affect beach recreation and other water-based recreation (Shaw et al. 2009).

A young birder searches the landscape at Humboldt Bay NWR. The static boundaries of wildlife refuges and national parks may not be adequate to provide the same level of species protection as habitat areas shift; USFWS photo.

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

Individuals, businesses, and agencies release carbon dioxide (CO_2), 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_2 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_2 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. Conserve water.
- 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_2 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, adaptation and mitigation.
- Develop strategies and identify priorities for managing uncertainty surrounding climate change effects in parks and refuges.
- Dedicate funds not only to sustainable actions but also to understanding the impacts to the natural and cultural resources.
- 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 or changes in vegetation and wildlife, into management plans.

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

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.

- Encourage climate change research and scientific study in park units and refuges.

- 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 climate change mitigation or adaptation activities.

- 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

- 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 and conserve connectivity within habitats, protect and enhance instream flows for fish, and maintain and develop access corridors to climate change refugia.

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

- Address climate change impacts to cultural resources by taking actions to document, preserve, and recover them.

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.

- 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.

"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

- 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 or boats idle - letting a car idle for just 20 seconds burns more gasoline than turning it off and on again.

- Replace incandescent bulbs in 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 action we will prevent greenhouse gas emissions equivalent to the emissions from nearly 10 million cars, in addition to saving money on energy costs.

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 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.

- 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.

- Conserve water.

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- Climate Change Response Program: http://www.nps.gov/climatechange

NPS- Climate Friendly Parks Program: http://www.nps.gov/climatefriendlyparks/

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/

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.

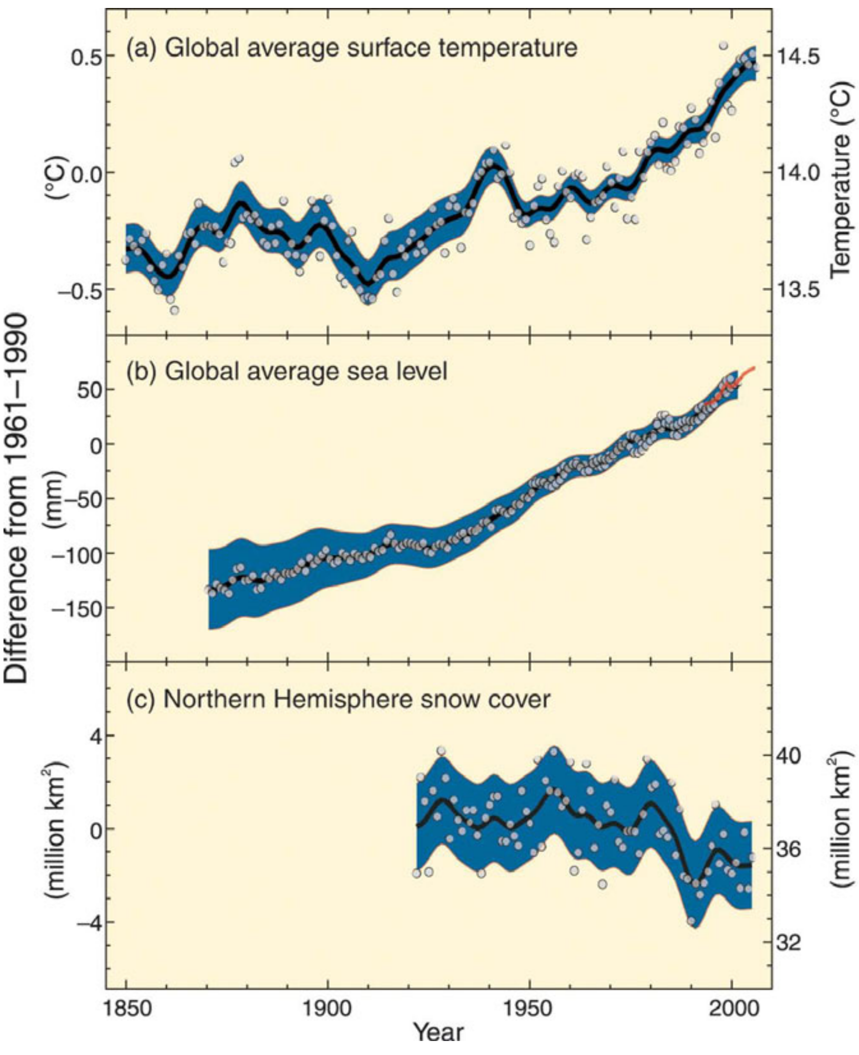


Figure 1. Observed changes in (a) global average surface temperature; (b) global average sea level from tide gauge (blue) and satellite (red) data and (c) Northern Hemisphere snow cover for March-April. All differences are relative to corresponding averages for the period 1961-1990. Smoothed curves represent 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

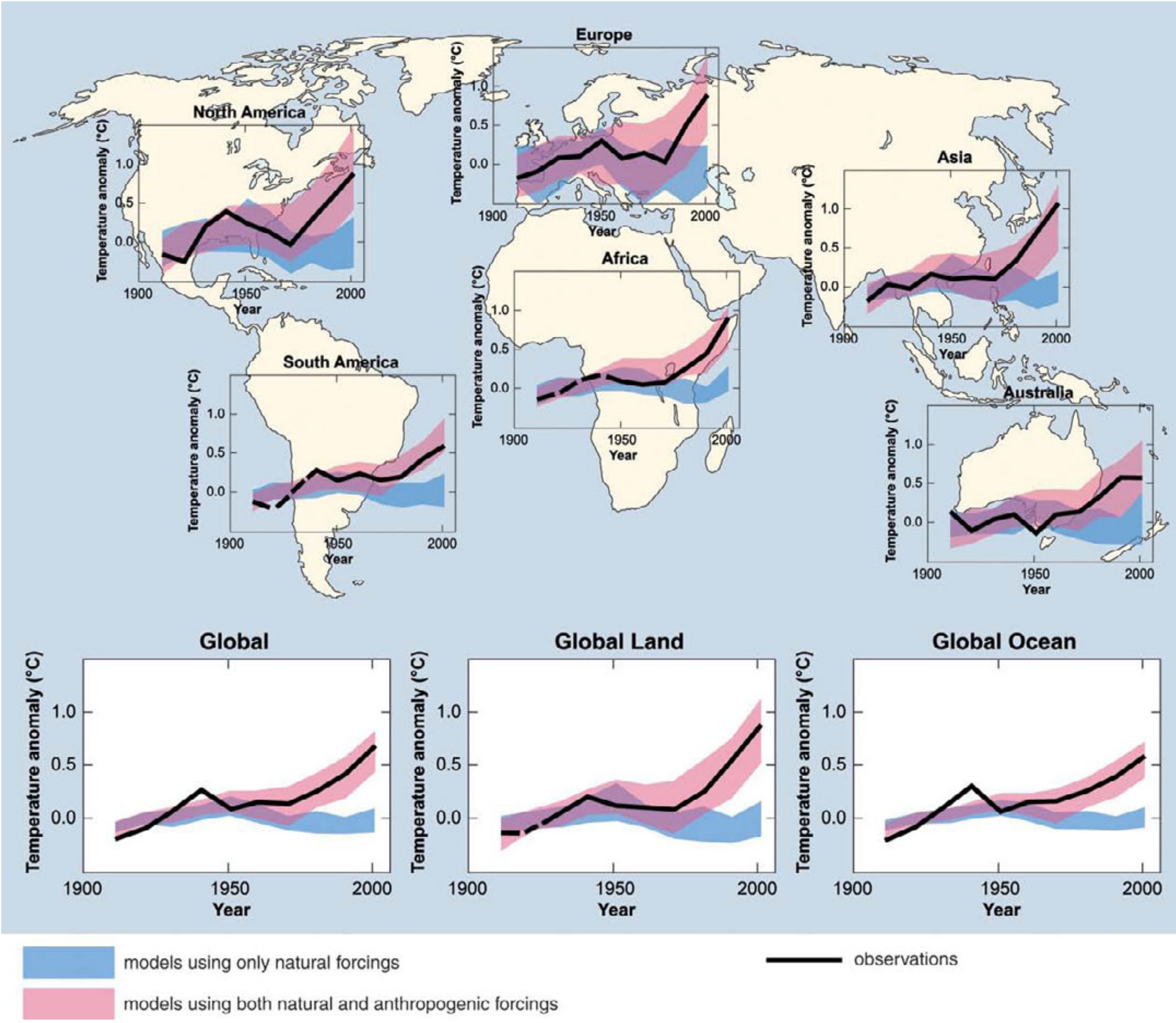


Figure 2. Comparison of observed continental- and global-scale changes in surface temperature with results simulated by climate models using either natural or both natural and anthropogenic forcings. Decadal averages of observations are shown for the period 1906-2005 (black line) plotted against the 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_2), primarily from fossil fuel use and land-use change; methane (CH_4) and nitrous oxide (N_2O), 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_2 and CH_4 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_2 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_2, increasing the fraction of anthropogenic emissions remaining in the atmosphere. This positive carbon cycle feedback results in increasingly greater accumulation of atmospheric CO_2 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).

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 20th 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-20th 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).

- 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 20th century.

- 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 21st 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)[a,b]	
Emissions Scenario	**Best Estimate**	**Likely Range**
Constant Year 2000 Concentrations[a]	0.6	0.3 – 0.9
B_1 Scenario	1.8	1.1 – 2.9
B_2 Scenario	2.4	1.4 – 3.8
A_1B Scenario	2.8	1.7 – 4.4
A_2 Scenario	3.4	2.0 – 5.4
A_1F_1 Scenario	4.0	2.4 – 6.4

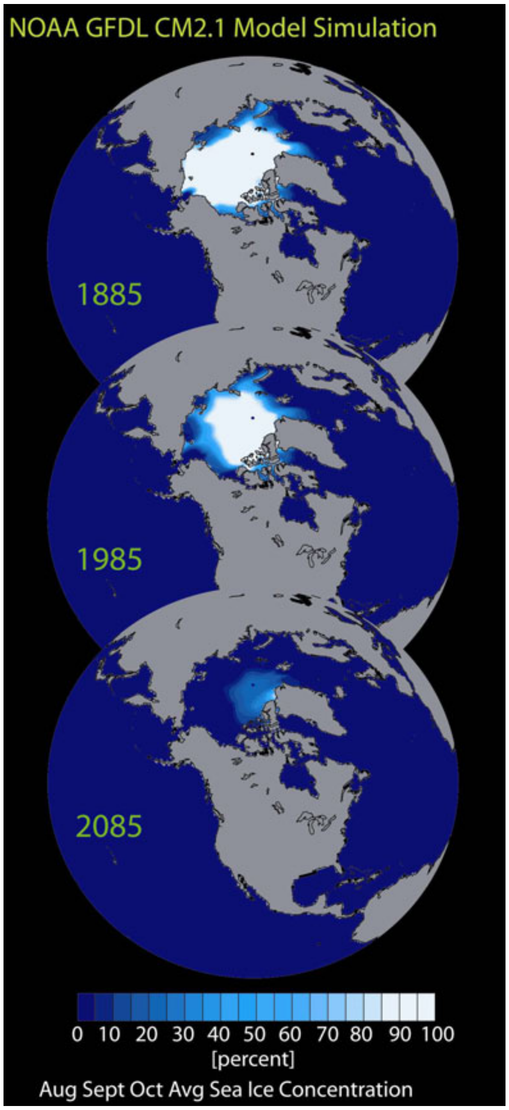


Figure 3. Sea ice concentrations (the amount of ice in a given area) simulated by the GFDL CM2.1 global coupled climate model averaged over August, September and October (the months when Arctic sea ice concentrations generally are at a minimum). Three years (1885, 1985 & 2085) are shown to illustrate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

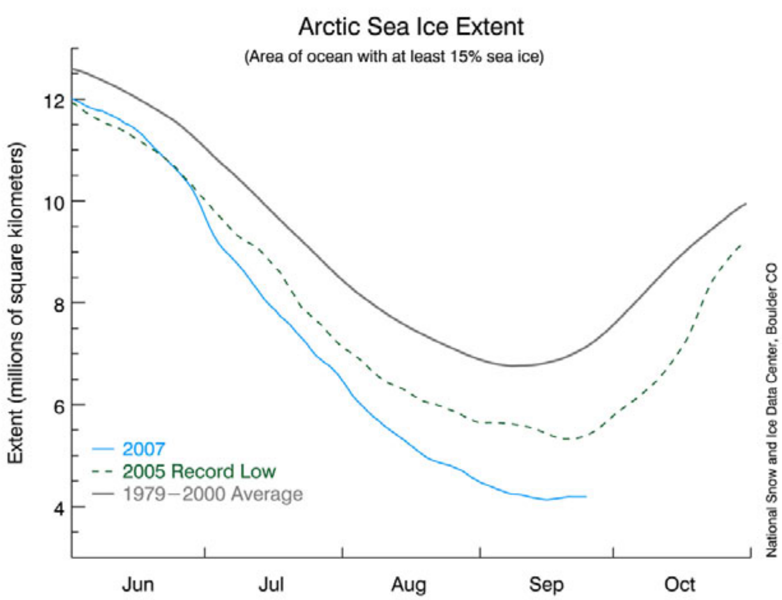


Figure 4. Arctic sea ice in September 2007 (blue line) is far below the previous low record year of 2005 (dashed line), and was 39% below where we would expect to be in an average year (solid gray line). Average September sea ice extent from 1979 to 2000 was 7.04 million square kilometers. The climatological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

- 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_2 content of the oceans increased by 118 ± 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_2 emissions from the atmosphere, and continues to increase by about 2 Gt each year (Sabine et al. 2004; Hoegh-Guldberg et al. 2007). This increase in oceanic CO_2 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_2 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 21st 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 21st century; nevertheless regional temperatures are predicted to increase. Large-scale and persistent changes in the MOC may result in changes in marine ecosystem productivity,

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_1B 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).

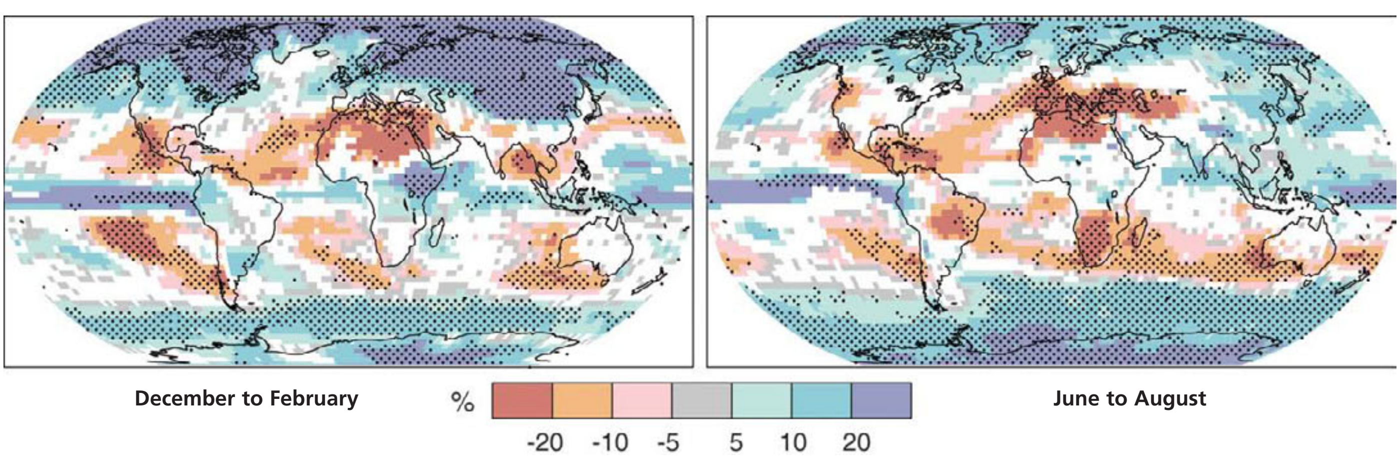


Table 2. Projected global average sea level rise at the end of the 21st century, adapted from IPCC 2007b.

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[a]	0.3 – 0.9
B_1 Scenario	1.1 – 2.9
B_2 Scenario	1.4 – 3.8
A_1B Scenario	1.7 – 4.4
A_2 Scenario	2.0 – 5.4
A_1F_1 Scenario	2.4 – 6.4

fisheries, ocean CO_2 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 21st 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.

- Model-based projections of global average sea level rise at the end of the 21st 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_2 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_2 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 21st 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)

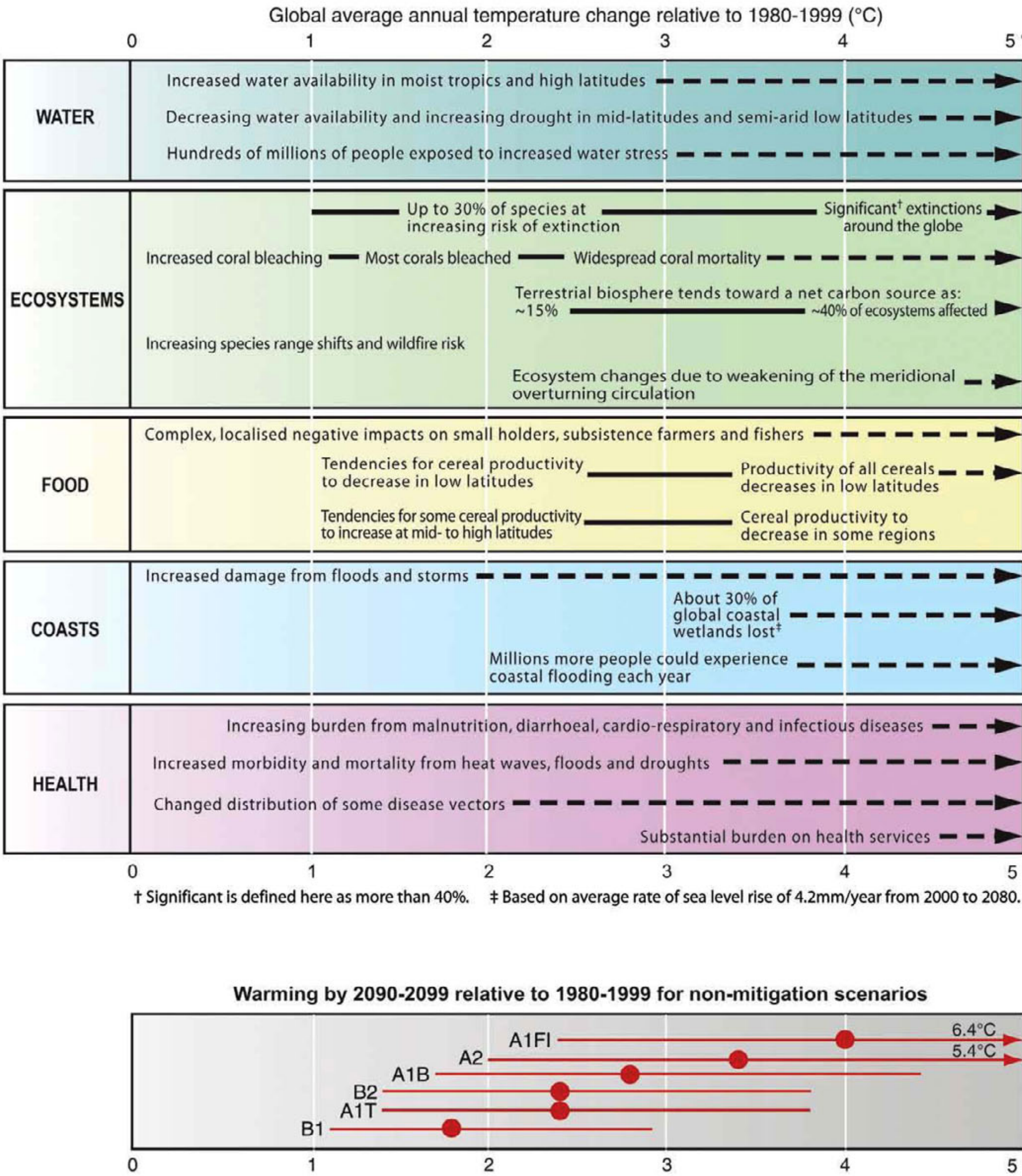


Figure 6. Examples of impacts associated with projected global average surface warming. Upper panel: Illustrative examples of global impacts projected for climate changes (and sea level and atmospheric CO_2 where relevant) associated with different amounts of increase in global average surface temperature in the 21st 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_2, 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_2 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_2 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_2 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 quality, 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 cardiorespiratory 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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