National Park Service
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Natural Resource Program Center

Understanding the Science of Climate Change

Talking Points – Impacts to Arid Lands

Natural Resource Report NPS/NRPC/NRR—2010/209

ON THE COVER

The view through Mesa Arch in Canyonlands National Park; NPS photo by Neil Herbert.

Understanding the Science of Climate Change

Talking Points – Impacts to Arid Lands

Natural Resource Report NPS/NRPC/NRR—2010/209

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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 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 bioregional 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 Arid Lands, 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 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
- Cultural Resources

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:

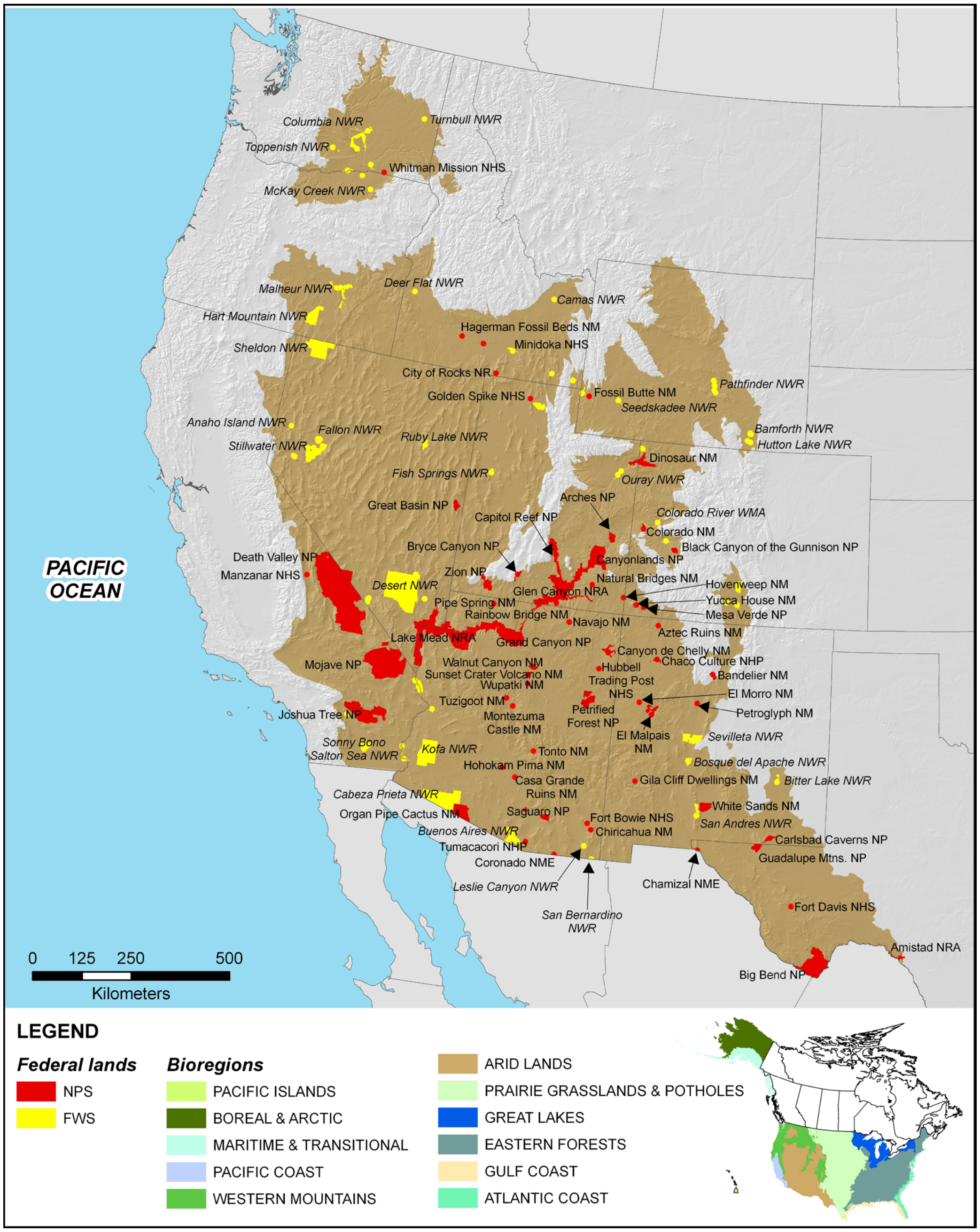
- "What scientists know" are statements based on measurable data and historical records. These are statements for which scientists generally have high confidence and agreement because they are based on actual measurements and observations. Events under this category have already happened or are very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

The Arid Lands 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

Arid ecosystems are particularly sensitive to climate change and climate variability because organisms in these regions live near their physiological limits for water and temperature stress. Slight changes in temperature or precipitation regimes, or in magnitude and frequency of extreme climatic events, can significantly alter the composition, abundance, and distribution of species. Observed climate changes in the southwestern U.S. include increased seasonal and annual average temperatures, increased minimum temperatures, and decreases in the length of the frost-free period and number of frost days. In general the region has become more arid over the past few decades, with a significant decrease in regional snowpack and a broad-scale shift in the timing of snowmelt runoff to earlier in the season. Projected climate changes include continued increases in temperature, potentially at rates faster than observed rates of change, and a large reduction in the volume and persistence of mountain snowpacks. Precipitation and flooding events are projected to become more extreme, even as drought conditions intensify. Observed and projected climate changes will likely alter plant species ranges; shift the geographic and elevational boundaries of the Great Basin, Mojave, Sonoran, and Chihuahuan deserts; cause major changes in vegetation composition and cover, increase rates of erosion and sediment transport to streams; result in increased tree mortality from synergistic associations between drought stress and insect outbreaks; increase the frequency, size, and duration of wildfires; and increase the probability of extinctions in plant and animal species.

List of Parks and Refuges

U.S. National Park Service Units

- Amistad NRA
- Arches NP
- Aztec Ruins NM
- Bandelier NM
- Big Bend NP
- Black Canyon of the Gunnison NP
- Bryce Canyon NP
- Canyon de Chelly NM
- Canyonlands NP
- Capitol Reef NP
- Carlsbad Caverns NP
- Casa Grande Ruins NM
- Chaco Culture NHP
- Chamizal NME
- Chiricahua NM
- City of Rocks NR
- Colorado NM
- Coronado NME
- Death Valley NP
- Dinosaur NM
- El Malpais NM
- El Morro NM
- Escalante NM
- Fort Bowie NHS
- Fort Davis NHS
- Fossil Butte NM
- Gila Cliff Dwellings NM
- Glen Canyon NRA
- Golden Spike NHS
- Grand Canyon NP
- Great Basin NP
- Guadalupe Mountains NP
- Hagerman Fossil Beds NM
- Hohokam Pima NM
- Hovenweep NM
- Hubbell Trading Post NHS
- Joshua Tree NP
- Lake Mead NRA
- Manzanar NHS
- Mesa Verde NP
- Minidoka NHS
- Mojave NPR
- Montezuma Castle NM
- Natural Bridges NM
- Navajo NM
- Organ Pipe Cactus NM
- Petrified Forest NP
- Petroglyph NM
- Pipe Spring NM
- Rainbow Bridge NM
- Saguaro NP
- Sunset Crater Volcano NM
- Tonto NM
- Tumacacori NHP
- Tuzigoot NM
- Walnut Canyon NM
- White Sands NM
- Whitman Mission NHS
- Wupatki NM
- Yucca House NM
- Zion NP

U.S. Fish & Wildlife Service Units

- Alamosa NWR
- Anaho Island NWR
- Ash Meadows NWR
- Baca NWR
- Bamforth NWR
- Bear Lake NWR
- Bear River MBR
- Big Boggy NWR
- Bill Williams River NWR
- Bitter Lake NWR
- Bosque del Apache NWR
- Browns Park NWR
- Buenos Aires NWR
- Cabeza Prieta NWR
- Camas NWR
- Cibola NWR
- Coachella Valley NWR
- Cokeville Meadows NWR
- Cold Springs NWR
- Colorado River WMA
- Columbia NWR
- Deer Flat NWR
- Desert NWR
- Desert NWR
- Fallon NWR
- Fish Springs NWR
- Hart Mountain NWR
- Havasu NWR
- Hutton Lake NWR
- Imperial NWR
- Kofa NWR
- Leslie Canyon NWR
- Malheur NWR
- McKay Creek NWR
- McNary NWR
- Minidoka NWR
- Moapa Valley NWR
- Monte Vista NWR
- Mortenson Lake NWR
- Ouray NWR
- Oxford Slough WPA
- Pahranagat NWR
- Pathfinder NWR
- Ruby Lake NWR
- Saddle Mountain NWR
- San Andres NWR
- San Bernardino NWR
- Seedskadee NWR
- Sevilleta NWR
- Sheldon NWR
- Sonny Bono Salton Sea NWR
- Stillwater NWR
- Toppenish NWR
- Turnbull NWR
- Umatilla NWR

Acronym	Unit Type
MBR	Migratory Bird Refuge
NHP	National Historic Park
NHS	National Historic Site
NM	National Monument
NME	National Memorial
NP	National Park
NPR	National Preserve
NR	National Reserve
NRA	National Recreation Area
NWR	National Wildlife Refuge
WMA	Wildlife Management Area
WPA	Waterfowl Production Area

A. Temperature

What scientists know….

- Winter and spring temperatures increased in western North America during the 20th century (Mote et al. 2005). The rate of change varied with location, but the central tendency is a warming of 1°C per century from 1916 to 2003 (Hamlet et al. 2007).

- Regionally averaged spring and summer temperatures for 1987 to 2003 were 0.87°C 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).

- A region-wide temperature increase of 0.3 to 0.6ºC has been observed in the Great Basin over the 20th century. Minimum temperatures increased more than maximum temperatures, variability in interannual temperatures declined, the probability of very warm years increased, and the probability of very cold years declined during this period (Wagner 2003, Chambers 2008).

- An analysis of climate trends in the Sonoran Desert from 1960 to 2000 shows widespread winter and spring warming trends, a decrease in the frequency of freezing temperature days, a lengthening of the frost-free season, and increased minimum temperatures (Weiss and Overpeck 2005).

All the plants of the Sonoran Desert lay hidden under three inches of snow as seen through an Ocotillo plant. Events like this will become more rare as temperature increases due to climate change. NPS photo.

- Most areas in New Mexico have experienced temperature increases in recent decades. Warming has been greatest in the southwestern, central, and northern parts of the state, especially in the Jemez Mountains. In addition, most of New Mexico's mid- to high-elevation forests and woodlands experienced consistently warmer and drier conditions or greater variability in temperature and precipitation from 1991 to 2005 (Enquist and Gori 2008).

- A strong spring warming and an earlier spring onset (by 2 to 3 weeks during the past 50 years) has been documented in the western United States, based on temperature, snow cover, and phenological records (Groisman et al. 2004).

- The combined paleo-modern climate record (tree-ring data and modern instrumental records) of the southwest has at least three occurrences of multi-decadal variation (50 to 80 years) of alternating dry and wet periods. The amplitude of this variation (amount of change) has increased since the 1700s, and the current increase in temperatures is unprecedented in the last 400 years of climate history (Sheppard et al. 2002).

What scientists think is likely….

- Temperatures during the 21st century are very likely to increase throughout the southwest at a rate faster than that observed in past decades (Smith et al. 2001).

- Extreme cold temperatures are projected to increase faster than extreme warm temperatures during the 21st century (Kharin et al. 2007).

- Temperatures in the Great Basin are expected to warm by 5 to 10ºC during the 21st century (Wagner 2003).

- Analysis of 19 climate models provides strong evidence for an imminent transition to a more arid climate in the southwestern U.S., due to increased air subsid-

The Mojave Desert is an area that is likely to see large increases in temperature, which will decrease the available habitat for the Joshua Tree; FWS photo.

ence in the sub-tropics and intensified equatorial convection (Seager et al. 2007).

- Rising temperatures are likely to shorten the snowpack season by delaying the autumnal change from rainfall to snow, and advancing spring snowmelt (Smith et al. 2001).

What scientists think is possible….

- Model simulations predict that temperatures that are currently considered unusually high (e.g., 20-year return interval) will become very frequent in the desert southwest, occurring every couple of years, and unusually low temperatures will also become increasingly uncommon. As a result, winters will be warmer, leading to higher evapotranspiration and lower snowfall (Kharin et al. 2007).

- Two general circulation models project increases of 2.5 to 4.5ºC and 5.0 to 8.0ºC in seasonal temperatures in the Great Basin/Rocky Mountain region by 2080 to 2100, based on the assumption of a doubling in the concentration of atmospheric CO_2 (Wagner 2003).

- Regional climate models predict that extreme temperature events (heat waves) may increase in frequency (increase of up to 100 days per year, or 560%), intensity, and duration (up to 15 days per event, or 550%) by the end of the 21st century, mainly as the result of increased atmospheric concentration of greenhouse gases (Diffenbaugh et al. 2005).

- Models identify southern California, northern Mexico, and western Texas as climate change 'hotspots,' areas that are predicted to be especially sensitive to 21st century anthropogenic (human caused) climate forcings (e.g. increased CO_2 emissions) (Diffenbaugh et al. 2008).

B. THE WATER CYCLE

What scientists know….

- The current severe, multi-year drought in the western U.S. is the most extreme in 500 years, and has drastically reduced available water resources for people and wildlife (Cook et al. 2004, Glick 2006).

- The timing of snowmelt runoff has shifted to earlier in the snowmelt season for 84 rivers in the western U.S. This shift has not been gradual, but appears to have occurred as a step change (significant difference in value) during the mid-1980's, related to a regional increase in spring-summer temperatures (McCabe and Clark 2005).

- Daily observations from automated snowpack telemetry (SNOTEL) stations from within the drainage basin of the Great Salt Lake over the period from 1982 to 2007 show a shift toward an earlier date of peak snow water equivalent (SWE) by around fifteen days and reductions in the amounts of peak SWE and April 1 SWE (Bedford 2008).

- April 1 snow pack has on average decreased at most monitoring sites in the Great Basin since about 1950. Snowpack

Isolated summer monsoon thunderstorm at Guadalupe Mountains National Park (Top); Manzanita Spring, a wetland spring, provides essential habitat for plants and animals (Bottom); NPS photos.

decline in the dry interior U.S. (including the Great Basin) has been among the largest observed, with the exception of central and southern Nevada (Baldwin et al. 2003).

- The onset of snow runoff in the Great Basin is currently 10–15 days earlier than 50 years ago, with significant impacts on the downstream utilization of this water (Ryan et al. 2008).

- Water supply in the Colorado River basin is unsustainable under current environmental and management conditions due to a combination of currently scheduled depletions (loss of water from consumptive use), water losses due to evaporation/infiltration, and reductions in runoff due to climate change (Barnett and Pierce 2008).

- Approximately 85% of the water used by humans in the Great Basin and Rocky Mountain region flows from spring melt of mountain snowpacks. Warmer wintertime temperatures and earlier melt dates will deplete this virtual reservoir, leaving much less available water for natural systems and human uses. Water resources in the region are totally allocated, with 80% of available water used for agriculture. Regional human populations and water needs are expected to double in the next 40 years, taxing resources even further (Wagner 2003, Service 2004).

- The majority of the observed low-frequency changes in the hydrological cycle (river flow, temperature, and snow pack) over the western U.S. from 1950 to 1999 are due to human-caused climate changes from greenhouse gases and aerosols (Barnett et al. 2008).

What scientists think is likely….

- There is broad consensus among climate models that the arid regions of the southwestern U.S. will become drier in the 21st century, and that a transition to a more arid climate is already underway. This forecast reverses earlier projections that the southwest might receive more rainfall as the climate warms (Lenart et al. 2007, Backlund et al. 2008).

- Projected future warming trends will significantly impact water resources, including a large reduction in the volume and persistence of mountain snowpacks, and a commensurate reduction in natural water storage. Current demands on water resources in many parts of the West will not be met under plausible future climate conditions, including water supplies for natural and anthropogenic systems (Barnett et al. 2004, Knowles et al. 2006).

- Warming in the western states is expected to increase the fraction of precipitation that falls as rain rather than snow and hasten the onset of snowmelt once snowpacks have formed. Snow deposition is sensitive to wintertime (November-March) warming trends, whereas snowmelt is sensitive to changes in springtime temperatures (Knowles et al. 2006).

- Reduced snowpack and earlier runoff will mean less available water for summer irrigation needs, higher water temperatures, and increased conflict between agricultural users and those whose principal concern is sustaining fish populations. These effects will be especially profound in smaller, snowmelt-driven rivers (Barnett et al. 2004).

- A water budget analysis shows that under current onditions there is a 10% chance that live storage (the reservoir space from which water can be evacuated by gravity) in Lakes Mead and Powell will be gone by about 2013, and a 50% chance that it will be gone by 2021 if no changes in water allocation from the Colorado River system are made. These projections are driven by climate changes, the effects of natural climate variability, and the current operating status of the reservoir system. There us a 50% chance that minimum power pool levels in both Lake Mead and Lake Powell could be reached under current conditions by 2017 (Barnett and Pierce 2008).

Stella Lake and snowpack on Wheeler Peak in Great Basin National Park; NPS photo.

- Early season spring runoff, a consequence of increased spring temperatures, is likely to increase risk of spring flooding, complicate seasonal water allocation schedules, and create difficulties in matching summer instream flow requirements (Smith et al. 2001).

- Decreased late-season runoff will likely result in reduced water quality unless stronger pollution control measures are applied. Lower streamflows will concentrate pollutants in water bodies, and higher temperatures will decrease dissolved oxygen levels, with negative implications for fish and wildlife (Smith et al. 2001).

- River and riparian ecosystems in arid lands are likely to be negatively impacted by decreased streamflows, increased water removal, and competition from nonnative species (Backlund et al. 2008).

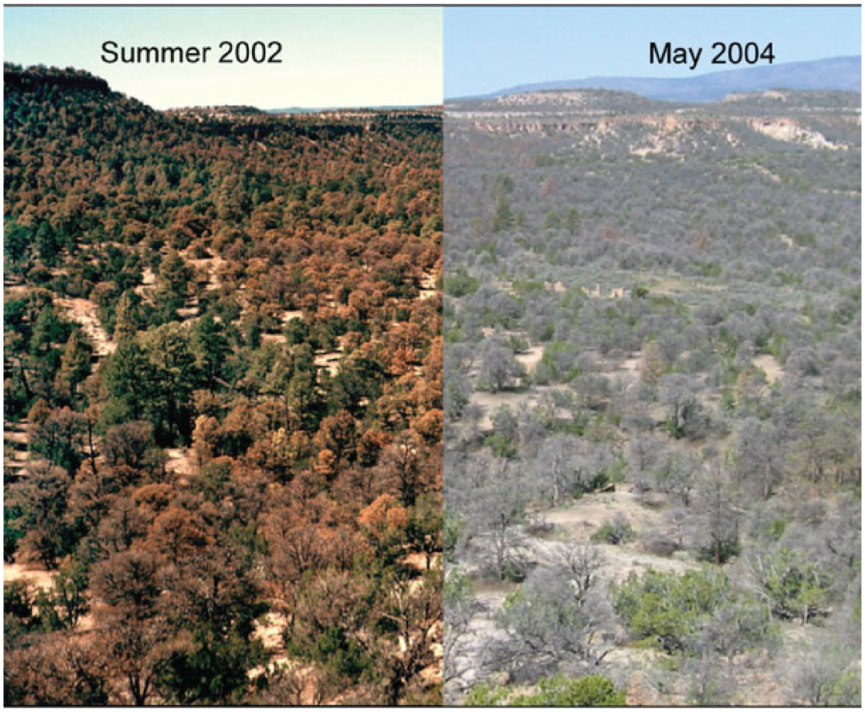
- Changes in runoff patterns and river flows resulting from decreased precipitation and increasing seasonal temperatures may disrupt biological communities and sever ecological linkages. For example, as the result of earlier spring runoff aquatic species' life histories (e.g. spawning) may be temporally out of synch with flow regimes in warming climates (Palmer et al. 2009).

What scientists think is possible….

- Future drought conditions are predicted to far exceed the severity of any drought in living memory, including the 1930's "Dust Bowl' period, and the immediate future in the southwest could look much like the peak drought years of 2000 to 2003 (Lenart et al. 2007, Seager et al. 2007, Schwinning et al. 2008).

- Elevated aridity in the western U.S. occurs in response to climate warming, as demonstrated by drought-temperature patterns during the Medieval Warm Period in AD 900 to 1300, and any trend toward warmer temperatures in the future could lead to a serious long-term increase in aridity over western North America (Cook et al. 2004).

- Model simulations predict that precipitation events that are currently considered extreme (20-year return interval) are ex-



In 2002 pinon trees in the forest around Los Alamos New Mexico suffered a severe die off due to drought and pine beetle outbreak. Photos courtesy of Craig Allen, USGS.

pected to occur roughly twice as often as they currently do, consistent with general increases in rainstorm intensity (Kharin et al. 2007).

- Evaporation rates are expected to increase as a consequence of increasing temperatures, an effect that may increase the intensity of precipitation events and flooding. Changes in rainfall patterns may affect human systems (water storage, agricultural production, human mortality, seasonal energy demands) and ecosystem dynamics (plant communities, extinction, invasive species, and diseases) (Diffenbaugh et al. 2005).

- Simulation models project that total water storage for the Colorado River basin will decrease by 36% for the period 2010-2039 under a business-as-usual (no emissions reduction) scenario, resulting in a situation in which total system demand (water deliveries plus reservoir evaporation) will exceed (decreasing) reservoir inflows (Christensen et al. 2004).

- Multiple climate model projections suggest that groundwater recharge in the San Pedro Basin, a riparian river corridor in southeastern Arizona, will decrease by 26% with 21st century climate changes, resulting in loss of some or all riparian habitat and associated species (Serrat-Capdevila et al. 2007).

C. VEGETATION

What scientists know….

- Arid ecosystems of the western U.S. are particularly sensitive to climate change and climate variability because organisms in the region live near their physiological limits for water and temperature stress. Slight changes in temperature or precipitation regimes, or in magnitude and frequency of extreme climatic events, can significantly alter the composition, abundance, and distribution of species (Archer and Predick 2008).

- An extreme drought accompanied by unusually high temperatures in the southwest in 2002 resulted in widespread mortality of dominant plants in multiple community types, including manzanita, quaking aspen, ponderosa pine, Fremont cottonwood, Engelmann spruce, white fir, Douglas-fir, and piñon pine. By 2003, 12,000 km2 of piñon and ponderosa pine had died across the region (Burkett et al. 2005, Gitlin et al. 2006).

- Most of New Mexico's mid- to high-elevation forests and woodlands experienced consistently warmer and drier conditions or greater variability in temperature and precipitation from 1991 to 2005. Should these trends continue, these habitats will experience increased vulnerability and susceptibility to ongoing climate changes (Enquist and Gori 2008).

- Recent drought, and in particular decreases in cool-season precipitation, has been linked with significant shrub mortality in parts of the Sonoran and Mojave deserts. Small, drought-deciduous shrubs such as Ambrosia deltoidea (triangle-leaf bursage) and Ambrosia dumosa (white bursage) experienced nearly 100% mortality, while larger, drought-enduring evergreen Larrea tridentata (creosote bush) showed somewhat lower mortality (McAuliffe and Hamerlynck 2010).

- The basic driver of recent tree mortality in the southwest has been climate-induced stress. Climate can act synergistically with insect outbreaks (e.g. bark beetles) to greatly amplify tree mortality, especially

Temperature

Water Cycle

Vegetation

Wildlife

Disturbance

Visitor Experience

under climatic conditions that promote large scale outbreaks through modification of insect life cycle dynamics (Allen 2007).

- Extreme drought conditions in the southwest in 1996 and 2002 led to widespread mortality of piñon pines across northern Arizona, and a vegetation shift such that piñon-juniper woodlands are becoming dominated by juniper, a species that is typical of lower elevations and more arid conditions (Mueller et al. 2005).

- Forests in the western United States sequester 20 to 40% of U.S. carbon emissions from fossil fuels, an amount equal to about one-half of the carbon absorbed by terrestrial ecosystems in the conterminous U.S. Changes in forest productivity, structure, and composition will result in changes in the rate of carbon sequestration and amount of carbon stored as biomass (Pacala et al. 2001, Westerling et al. 2006, Brown 2008).

Saguaro National Park is home to the iconic saguaro cactus which is a species that is likely to be strongly affected by climate change; NPS photo.

- Widespread bleaching of desert moss in the northern Mojave Desert in the winter of 2002 and 2003 has been attributed to physiological stress resulting from lower than average rainfall during winter growing seasons and an extended period of drought in the region. Physiological stress reduces plant productivity, increases regeneration time, and reduces the overall health of biological crust communities, which perform valuable ecosystem functions such as nitrogen fixation, erosion control, and water retention (Barker et al. 2005).

- Water availability greatly influences vegetation growth and composition in the Mojave Desert. For example, intense droughts (1989 to 1991 and the current drought) caused widespread mortality of chenopods and perennial grasses, and a wet period from 1976 to 1998 resulted in an increase in the size and cover of creosote bush (Hereford et al. 2006).

- Timing of precipitation is important for germination, establishment, and productivity of desert vegetation. Cool season precipitation is the most important and dependable source of rainfall for most vascular plants, although the extent and magnitude of warm-season rainfall is important for many species of cacti, yuccas, agaves, and leguminous trees (Hereford et al. 2006).

- Field experiments in a Sonoran Desert grassland demonstrated that changes in the timing and amount of precipitation can significantly impact soil carbon storage through effects on autotrophic (plant) and heterotrophic (soil microbe) respiration. Specific response depends on a number of ecological properties including soil texture, soil type, and spatial distribution of vegetation (Cable et al. 2008).

- Climate is the most important factor controlling saguaro populations in the Sonoran Desert. In particular, saguaros require adequate summer rainfall for establishment and survival, and maximum July temperatures appear to limit the number of young saguaros such that fewer are observed in areas characterized by higher temperatures (Drezner 2004).

Desert Agave plant at Saguaro National Park (Top); NPS photo. Yucca plant in the desert of New Mexico (Bottom); USFWS photo.

- The average elevation of plant species in the Santa Rosa mountains of southern California, including desert ceanothus, Muller oak, canyon live oak, Jeffrey pine, white fir, sugar sumac, creosote bush, and desert agave increased by an average of 65 meters from 1977 to 2007, probably because of increased temperature and length of frost-free period, upward movement of the snowline, and occurrence of severe drought (Kelly and Goulden 2008).

- Field experiments show that semi-arid grasslands are capable of immediate and substantial responses to shifts in precipitation patterns that include changes in the magnitude (larger) and frequency (fewer) of rainfall events. Larger, less frequent rainfall events resulted in higher rates of aboveground net primary productivity over historical conditions, likely because of greater soil water content and deeper soil moisture penetration (Heisler-White et al. 2008).

What scientists think is likely….

- Climate-induced vegetation mortality can occur much faster than regeneration, with profound ecological effects such as feedbacks to disturbance processes (e.g. wildfire and erosion, insect invasions), loss of sequestered carbon, changes in nutrient cycling, altered landscape composition and biodiversity, changes in hydrology, decreased wildlife habitat, and impacts to ecological services (Dale et al. 2001, Allen 2007).

- Geographic boundaries of the southwestern deserts (e.g. Sonoran Desert) will likely expand to the north and east with a predicated decrease in the frequency of frost days, lengthening of the frost-free season, and increased minimum temperatures. In addition, climate changes will likely alter bioclimatic zones and shift distributions of arid land communities upward in elevation in response to warmer and drier conditions (Weiss and Overpeck 2005, Archer and Predick 2008).

- Increased fire activity in arid regions where ecosystems have not co-evolved with fire cycles will very likely result in the loss of iconic, charismatic megaflora such as saguaro cacti and Joshua trees (Backlund et al. 2008).

- Vegetation response to changing climate will depend on the factors that limit productivity at a particular site; for example, changes in growing season length may affect annual productivity, and increased nitrogen and CO_2 inputs strongly influence forest productivity if other factors (water, temperature, radiation) are less limiting (Ryan et al. 2008).

- Extensive, recent piñon pine mortality in the southwest may represent a threshold-type response to warming mean, maximum, minimum, and summer (June-July) temperatures. Ecological thresholds are points at which there are abrupt changes in ecosystem properties or processes in response to external conditions such as climate changes. Combined with fire and erosion, climate-induced forest die-back

Drought conditions are especially hard on Willow Flycatchers (Top); USFWS photo. Yellow-Bellied Marmot making a living at 11,000 feet in Cedar Breaks National Monument. Marmots have already gone extinct in some ranges; NPS photo.

may be causing permanent type-conversions in some southwestern ecosystems (CCSP: Fagre et al. 2009).

- High-elevation areas in New Mexico are potentially very vulnerable to climate changes, due to their large number of drought-sensitive species and evidence of susceptibility to recent warmer-drier conditions. Three areas that may be particularly vulnerable are the Sierra San Luis/ Peloncillo Mountains, the Jemez Mountains, and the Southern Sangre de Cristo Mountains (Enquist and Gori 2008).

- Drought-caused reductions in the number of piñon pines present in piñon-juniper woodlands are likely to be long-term, because piñons are slow-growing species and changes in stand dynamics and community interactions (e.g. maintenance of seed-dispersing birds) may prevent or delay a return to pre-drought stand conditions (Mueller et al. 2005).

What scientists think is possible….

- Significant portions of the current species range are projected to become climatically unfavorable for Joshua trees under climate change conditions. However, because elevated atmospheric CO_2 concentrations enhance the low-temperature tolerance of Joshua tree seedlings, anthropogenic increases in CO_2 may allow for range expansion into regions with cooler climates than current range limits (Dole et al. 2003).

- A comparison of satellite-derived land cover response to drought in the Great Basin suggests that valley ecosystems may be more resilient and montane ecosystems more susceptible to prolonged drought, including decreased growth and increased mortality, and increased susceptibility to invasion by exotic weeds (Bradley and Mustard 2008).

- Predictive modeling of the potential distribution of plant communities in Saguaro National Park East, Arizona, suggests that increasing temperatures will lead to upslope movement of communities and increase the area of desert scrub at the expense of montane conifer forests. Increased precipitation may mitigate some effects of temperature changes, depending on the timing and magnitude of rainfall events (Kupfer et al. 2005).

- Models suggest that populations of the federally endangered Arizona cliffrose in the central Arizona upper Sonoran Desert are slowly declining, and will be at greater risk of extinction with increased aridity. Favorable local site conditions (high soil moisture, low sand content, northern aspects) can mitigate extinction risk, suggesting important conservation strategies under climate change conditions (Maschinski et al. 2006).

- The potential ranges of arid plant species in the southwest are predicted to shift in response to increases in mean temperatures of the coldest month (the physiological parameter that commonly limits the range of North American tree species) Shifts include: big sagebrush - northward shift and contraction of current range; Joshua tree - fragmentation of current range and northward and eastward shift; saguaro - expansion and divergence of range, with new habitat west and east of current range; and creosote bush - expansion throughout the intermountain west into areas currently dominated by sagebrush (Shafer et al. 2001).

D. WILDLIFE

What scientists know….

- A consistent temperature-related shift has been observed across a broad range of plant and animal species (80% of species from 143 studies), including changes in species density, northward or poleward range shifts, changes in phenology, and shifts in genetic frequencies (Root et al. 2003).

- A retrospective analysis of desert bighorn sheep population dynamics from 1941 to 1976 on the San Andres National Wildlife Refuge, New Mexico indicates that below-average precipitation limited population size through regulation of forage and production and survival of lambs. When total annual precipitation was <28.2 cm, carrying capacity for desert bighorn sheep on

Below average precipitation results in lower population for the Desert Bighorn Sheep, such as this one at Dinosaur National Monument; NPS photo.

the refuge was zero (Bender and Weisenberger 2005).

- At least 26 populations of desert bighorn sheep have gone extinct from mountain ranges in the desert regions of California. These extinctions occurred in conjunction with a 20% decrease in precipitation and 1°C increase in average temperature during the last half of the 20th century (Epps et al. 2004, Epps et al. 2006).

- A severe drought in central Arizona in 2002 resulted in a reduced insect prey base and near total reproductive failure for the Southwestern Willow Flycatcher, an insectivorous Neotropical migratory bird that is restricted in its breeding sites to riparian habitats in the southwestern U.S. This suggests that events such as regional droughts that influence the overall abundance of insects may also be critical drivers of productivity for Willow Flycatchers (Durst et al. 2008).

- Drought-related physiological stress has been observed to impair immune function in cavity-nesting Western Bluebirds, Ash-throated Flycatchers, and Violet-green Swallows in New Mexico. Specifically, decreases in adult weight, reduced clutch sizes, reduced nestling body mass, and lower overall survival were observed (Fair and Whitaker 2008).

- Water availability can be a limiting factor for egg production in desert tortoises, and dry and drought periods may result in reduced reproductive behavior, low feeding and activity levels, and increased adult mortality for both male and female tortoises (Henen et al. 1998, Longshore et al. 2003).

- Warming temperatures are raising lower elevations of habitable sites for pygmy rabbits in the Great Basin, while higher-elevation sites are being increasingly impacted by piñon-juniper encroachment. These changes have resulted in extirpations of pygmy rabbits at lower-elevation sites and a 157 meter increase in the elevation of occupied locations (Larrucea and Brussard 2008).

What scientists think is likely….

- Warmer temperatures are likely contributing to losses of pika populations in the Great Basin. Changes in population have occurred at a pace significantly more rapid than that suggested by paleontological records; for example, extirpations have occurred in three lower elevation areas since 1956 (Beever et al. 2003, Grayson 2005).

- Marmots may have gone extinct in some Great Basin mountain ranges during the 20th century, potentially as the result of climate changes that force montane vegetation zones further upslope and reduce habitat area (Floyd 2004).

- Restoration of population connectivity may be necessary to buffer the effects of climate change on desert bighorn sheep in southeastern California, particularly in low-elevation habitats within which populations have already experienced range contractions and extinctions as the result of decreased precipitation and increased temperatures (Epps et al. 2006).

- Drought-caused loss of piñon pines from piñon-juniper woodlands is likely to result in reductions in the numbers of avian seed dispersers, as birds abandon stands with reduced cone crops (Mueller et al. 2005).

Fire rages through the Joshua Trees in July 2006 at Mojave National Preserve. Increased drought gives opportunities for invasive plants to invade, which then increase the fire cycle. NPS photo.

- Climate change poses the greatest future threat to the persistence of the Colorado River cutthroat trout, because changes in temperature and precipitation will affect stream temperature, steam flows, the distribution of habitat areas, and decrease connectivity among populations (Young 2008).

- Changes in minimum and mean temperatures and amount and timing of precipitation may increase prevalence of hantavirus, plague, and West Nile virus in wildlife populations through changes in phenological development, increased rates of reproduction and survival, altered geographic distributions, and expansion of favorable habitats of disease vector, host, and reservoir species (Patz et al. 2000, Epstein 2001, Field et al. 2007).

What scientists think is possible….

- An analysis of potential climate change impacts on mammalian species in U.S. national parks indicates that on average about 8% of current mammalian species diversity may be lost. The greatest losses across all parks occurred in rodent species (44%), bats (22%), and carnivores (19%) (Burns et al. 2003).

- Shifts in vegetation communities and increased wildfire frequencies, both resulting from temperature and precipitation changes, may exacerbate habitat loss and increase local extirpation for the Great Basin pygmy rabbit, a sagebrush obligate species (Larrucea and Brussard 2008).

- Big sagebrush habitats throughout the western U.S. could decrease in area by 59% before the end of the 21st century, with devastating consequences for sage grouse, mule deer, pronghorn and other species that depend on these habitats (Glick 2006).

- Predicted future drought conditions in the southwest may impact trout by confining populations to smaller, upstream habitat with perennial flows, including some streams that are currently uninhabitable because of cold water temperatures. The overall effect may be a reduction in trout abundance and distribution, and an increase in susceptibility to small-population phenomena such as inbreeding and disturbance vulnerability (Young 2008).

E. DISTURBANCE

What scientists know….

- Drought and warm temperatures (1996 to 2002) in combination with outbreaks of the Piñon Engraver bark beetles (2002 to 2004) have resulted in widespread mortality of piñon pine at stand, landscape, and regional scales throughout the southwest, including about 2,500,000 acres of substantial piñon dieback across the region (Burkett et al. 2005, Allen 2007).

- The current insect outbreak among Ponderosa and piñon pines in the Pinaleño Mountains of southern Arizona is an order of magnitude larger (millions of acres affected) and more severe than an outbreak in 1957 (490,000 acres affected) that followed an extreme drought from 1955 to 1957. Probable causes are increasingly warm maximum, winter, and annual average temperatures that stress trees and increase the length of the beetle breeding season and a drop in the number of frost days that decreases opportunities to kill off overwintering insect populations (Lenart et al. 2007).

- Soil dryness and air temperatures increased in the southwest over the 20th century, making the region more susceptible to forest fires (Groisman et al. 2004).

- There is strong synchrony between climate and wildfires in forested ecosystems of western North America; changes in temperature and precipitation will result in longer fire seasons and more frequent episodes of extreme fire weather (Ryan et al. 2008).

- The forested area burned in the western U.S. from 1987 to 2003 was more than six and a half times the area burned from 1970 to 1986. Other observed trends include more frequent large wildfires (greater than 400 ha in size), longer wildfire durations, and longer wildfire seasons (Westerling et al. 2006).

- A large area (approximately 120,000 km2) of California and western Nevada experienced a notable increase in the extent of forest stand-replacing (high severity) fire and increases in mean and maximum fire size and area burned annually between 1984 and 2006. These changes in fire severity and activity are attributed to a regional increase in temperature and a long-term increase in annual precipitation (Miller et al. 2008).

- Climate change in arid lands will create physical conditions conducive to wildfire, and the proliferation of exotic grasses will provide fuel, resulting in a self-reinforcing increase in fire frequencies (Backlund et al. 2008).

Saguaro National Park's iconic species, the saguaro cactus, is severely threatened by the invasion of buffelgrass; NPS photo.

- Increased fire frequency and fire size in the Mojave Desert between 1980 and 2004 has been linked to invasion of non-native grasses. Changes in fire history are especially evident in middle elevation shrublands dominated by creosotebush, Joshua tree, and/or blackbrush, where high rainfall years result in rapid and dense growth of non-native annual grasses (Brooks and Matchett 2006).

- Wetter conditions and increased periodicity of high rainfall events facilitate the spread of the invasive Sahara mustard throughout the Mojave and lower Sonoran deserts, at the expense of native plant populations. Drier conditions limit spread of Sahara mustard, but may have other negative consequences for native flora and fauna (Barrows et al. 2009).

What scientists think is likely….

- Increases in frequency, size, and duration of wildfires in the western U.S. observed within the past three decades are attributed to a 78-day increase in the length of the wildfire season, increases in spring-summer temperatures of 0.87ºC, and earlier spring snowmelt (Westerling et al. 2006).

- Climate changes have very likely increased the size and number of forest fires, insect outbreaks, and tree mortality in the interior West and the Southwest, and will continue to do so as climate changes continue (Backlund et al. 2008).

- By 2070 the length of the fire season could be increased by two to three weeks in the northern Rockies, Great Basin, and Southwest as the result of increases in summer temperature and decreases in summer humidity (Barnett et al. 2004).

- Analysis of a twenty-year time series of satellite imagery for the Gila National Forest, New Mexico, suggests that burned area and severity of wildfires is related to the timing and intensity of rainfall events during the fire season, such that longer rain-free periods increase the likelihood that fires will burn as high-severity crown fires (Holden et al. 2007).

- Large outbreaks of forest insects are likely influenced by observed increases in temperature because temperature controls life cycle development rates, influences synchronization of mass attacks required to overcome tree defenses, and determines winter mortality rates. Climate also affects insect populations indirectly through effects on hosts; for example, drought stress reduces the ability of a tree to mount a defense against insect attacks (Logan and Powell 2001, Ryan 2008).

- Climate change is likely to lead to a northern migration of weeds. Many weeds respond positively to increasing CO2, and recent research also suggests that glyphosate, the most widely used herbicide in the U.S., loses its efficacy on weeds grown at the increased CO2 levels likely in the coming decades (Backlund et al. 2008).

- Interactions between climate change and non-native invasive species may increase invasion risk to native ecosystems through expansion of habitat areas climatically suitable for invasion. Climate change may also create opportunities for ecosystem restoration on invaded lands that become climatically unsuitable for invasive species (Bradley 2009).

What scientists think is possible….

- Predicted trends in climate will reinforce the tendency toward longer fire seasons and accentuate conditions favorable to the occurrence of large, intense wildfires (e.g. increased storminess, higher fuel loads, drier conditions late in the season) (Lenihan et al. 2003, Whitlock et al. 2003, Westerling et al. 2006).

- Changes in relative humidity, especially drying over much of the West, are projected to increase the number of days of high fire danger at least through the year 2089, as compared to a 1975 to 1996 base period, under a business-as-usual emissions scenario. The regions most affected are the northern Rockies, Great Basin and the Southwest (Brown et al. 2004).

- Variable projections in the amount and timing of precipitation strongly influence prediction models for invasive species. For example, a bioclimatic envelope model indicates that decreased precipitation, particularly in the summer, may result in an expansion of suitable land area for invasive cheatgrass by up to 45%, elevating invasion risk in parts of Montana, Wyoming, Utah, and Colorado. Conversely, increased precipitation reduces suitable habitat by as much as 70%, decreasing invasion risk (Bradley 2009).

- Despite the uncertainty in future climate conditions, prediction models show consistent areas that maintain climate suitability for cheatgrass invasion, including parts of Nevada, the Snake River plain in Idaho, western Utah, and eastern Oregon. Under most future climate conditions, these areas will continue to be at risk of cheatgrass invasion (Bradley 2009).

F. VISITOR EXPERIENCE

- The tourism industry in the western U.S. is particularly sensitive to climate change because it is so strongly oriented towards outdoor activities. Climate changes will likely reduce the seasonal period for winter activities such as skiing, but may increase winter visitation for activities such as hiking and sight-seeing. The period for summer activities may increase because of an increase in the number of warm shoulder season days, but could also decrease due to increasing aridity and high temperatures in mid-summer (Smith et al. 2001, Wagner 2003).

- Climate simulations for 2045 to 2055 suggest that warming, increased solar radiation, reduced rainfall frequency, increased stagnation occurrence, and reduced ventilation may negatively affect air quality in the western U.S., especially during the fall season (Leung and Gustafson 2005).

- Direct 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).

Hikers in Capitol Reef National Park; NPS photo.

- Climate changes may favor zoonotic disease transmission to humans through altered distributions of pathogens and disease vectors, increased populations of reservoir or host species, and increased prevalence of diseases within host and reservoir populations. Diseases likely to increase in scope and/or incidence in the region include hantavirus pulmonary syndrome, plague, and West Nile virus (Epstein 2001, Confalonieri et al. 2007).

- Increasing water demands combined with decreasing supply are very likely to result in over-allocation of water resources for humans and ecosystems. Higher temperatures and growth of southwestern cities may result in additional demands for agricultural and home users, higher water prices, and water shortages (Lenart et al. 2007).

- Increased summer temperatures will 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.

- Reduced runoff, particularly when combined with higher demands due to hotter and drier conditions, will very likely make allocation of water supplies a critical issue for the West. It is likely that instream uses such as hydropower and recreation will be among those most affected by a reduction in runoff (Smith et al. 2001).

G. CULTURAL RESOURCES

- Cultural resources such as pueblos, cliff dwellings, churches, and forts, already susceptible to damage from natural erosive forces, may be at additional risk from increased wildfires and extreme precipitation events likely to occur with climatic change. The following have been identified as resources in "immediate, imminent danger": Grand Canyon National Park and Canyon de Chelly, Casa Grande, and Navajo national monuments (AZ); Bandelier, Gila Cliff Dwellings, and Fort Union national monuments and Chaco Culture National Historical Park (NM); Canyonlands and Zion national parks and Glen Canyon National Recreation Area (UT); Mesa Verde National Park and Colorado, Dinosaur, and Hovenweep national monuments(CO); Mojave National Preserve and Death Valley National Park (CA); Fort Laramie National Historic Site (WY); and Big Bend National Park and San Antonio Missions National Historical Park (TX) (Saunders et al. 2007).

- Increasing frequency and 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.

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.

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

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 emmisions 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.

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 nonmotorized 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 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.

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- 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/

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.

CLIMATE *Friendly* PARKS

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.

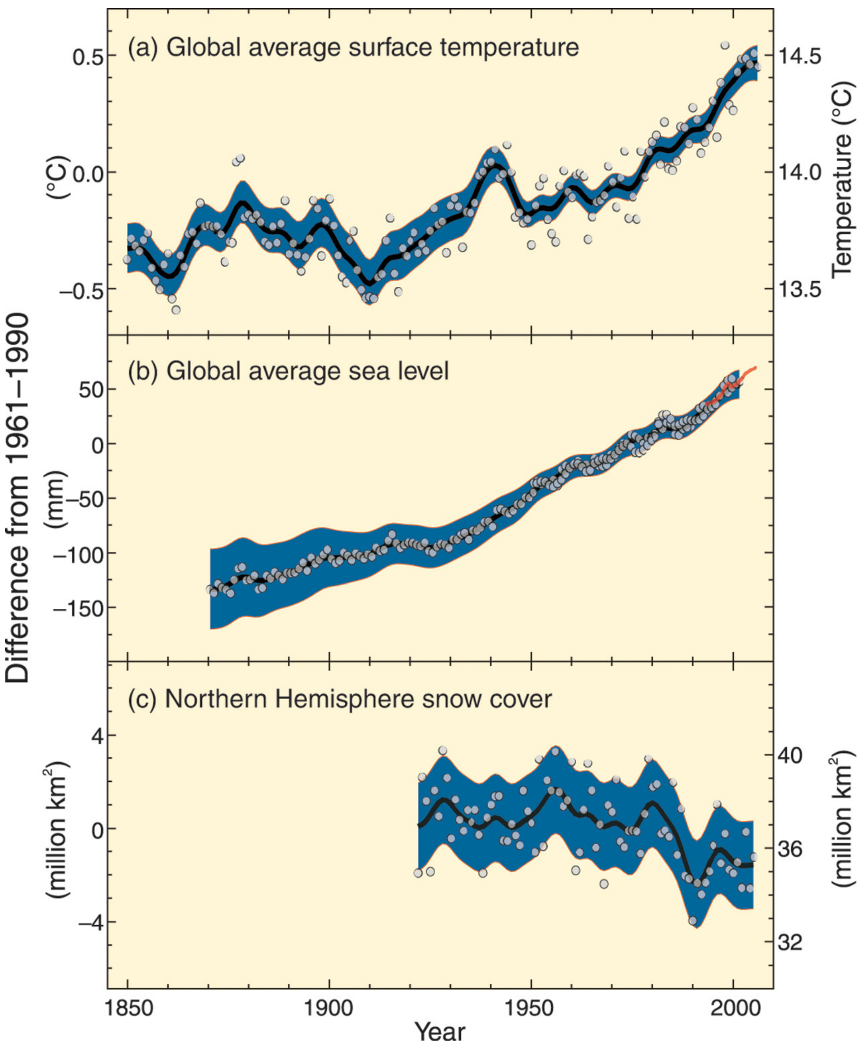


Figure 1. Observed changes in (a) global average surface temperature; (b) global average sea level from tide gauge (blue) and satellite (red) data and (c) Northern Hemisphere snow cover for March-April. All differences are relative to corresponding averages for the period 1961-1990. Smoothed curves represent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

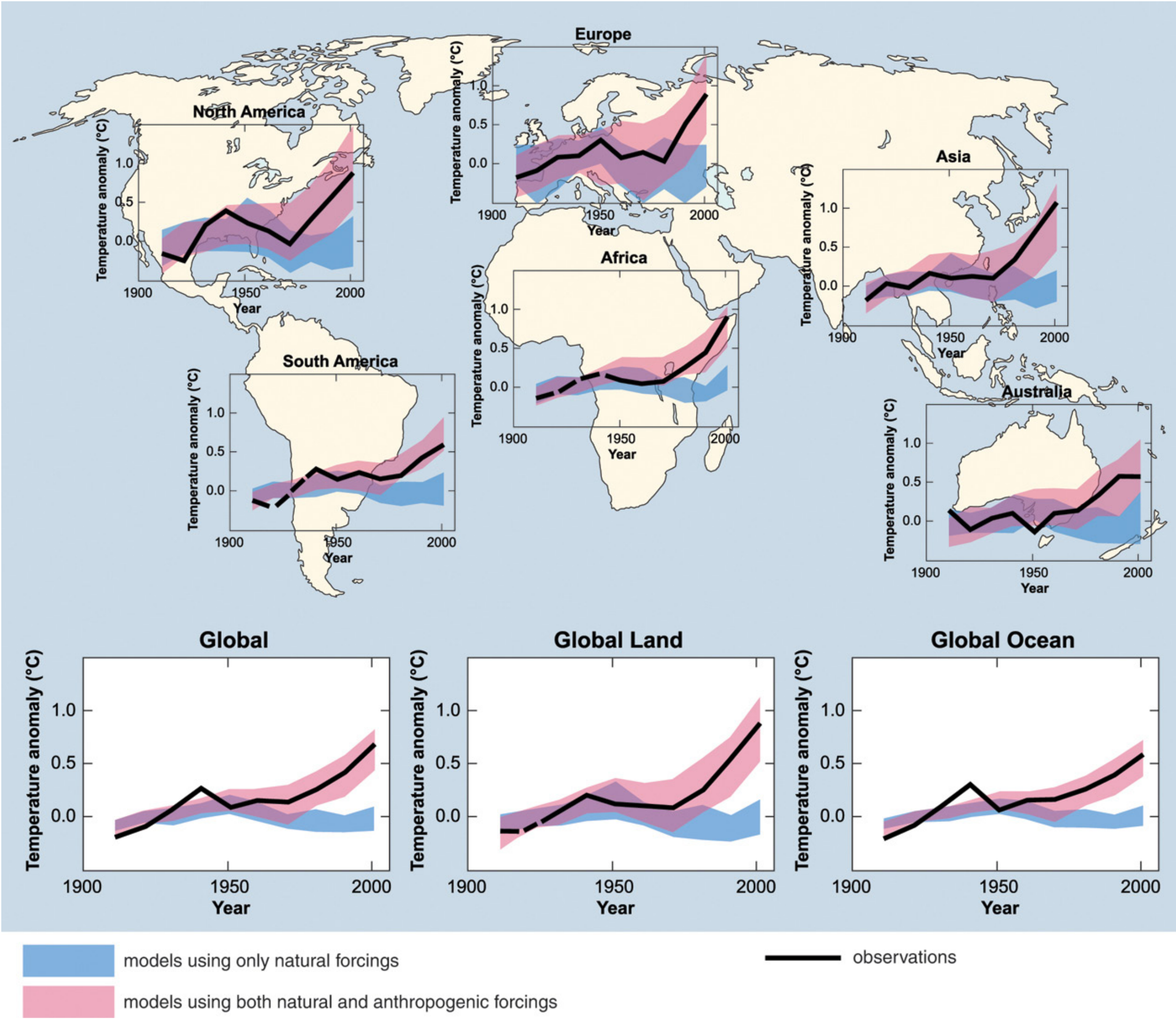


Figure 2. Comparison of observed continental- and global-scale changes in surface temperature with results simulated by climate models using either natural or both natural and anthropogenic forcings. Decadal averages of observations are shown for the period 1906-2005 (black line) plotted against the 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 0.2ºC 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…

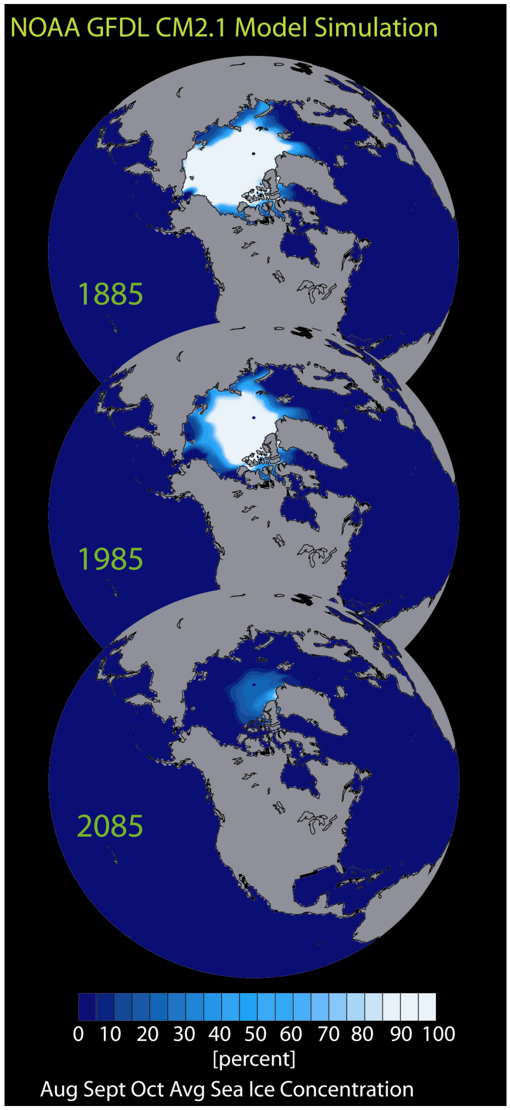
- Global temperatures are projected to increase in the future, and the magnitude of temperature change depends on specific emissions scenarios, and ranges from a 1.1ºC to 6.4ºC increase by 2100 (Table 1).

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.



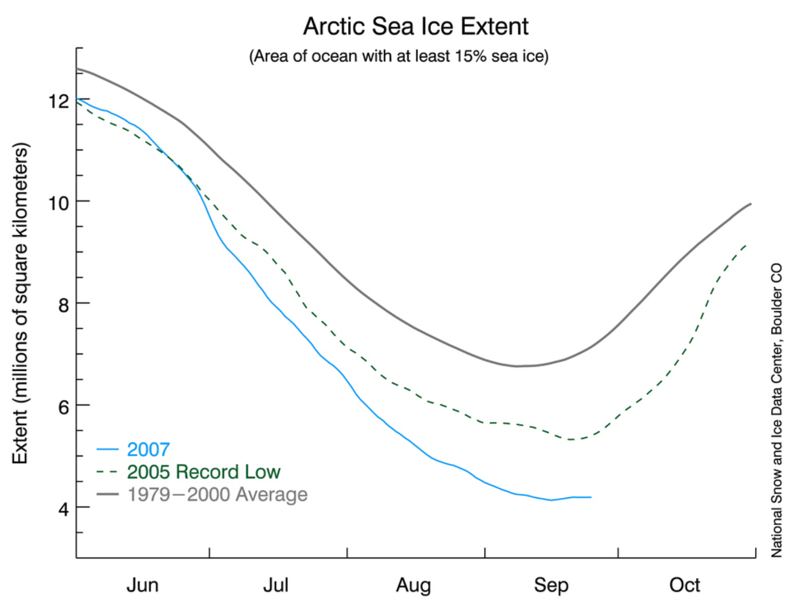


Figure 4. Arctic sea ice in September 2007 (blue line) is far below the previous low record year of 2005 (dashed line), and was 39% below where we would expect to be in an average year (solid gray line). Average September sea ice extent from 1979 to 2000 was 7.04 million square kilometers. The climatological 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 CO2 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 CO2 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 produc-

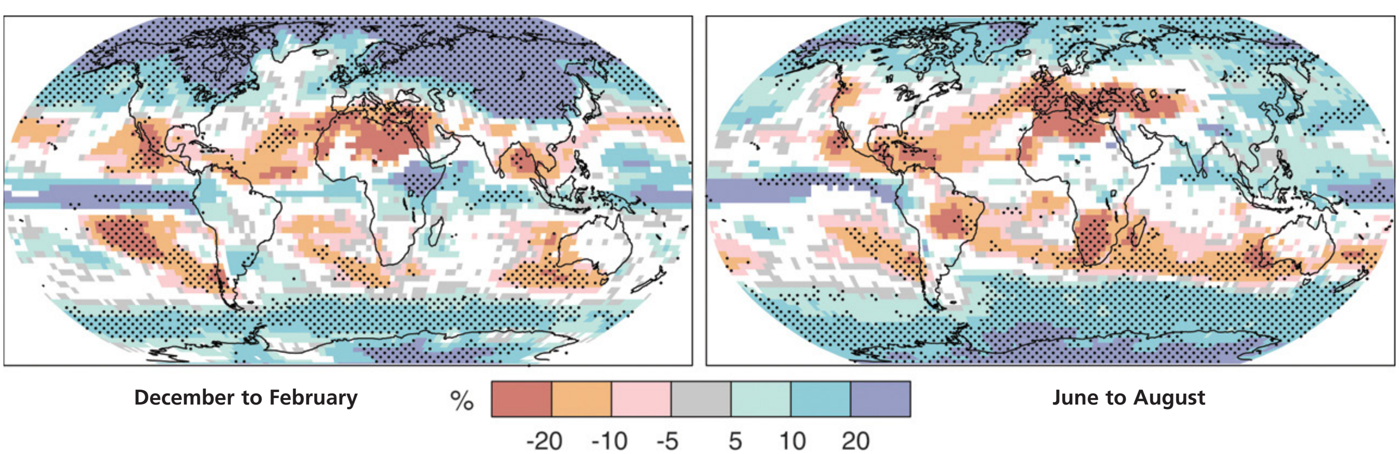


Figure 5. Relative changes in precipitation (in percent) for the period 2090-2099, relative to 1980-1999. Values are multi-model averages based on the SRES A_1B scenario for December to February (left) and June to August (right). White areas are where less than 66% of the models agree in the sign of 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

tivity, fisheries, ocean CO2 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 CO2 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 CO2 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)

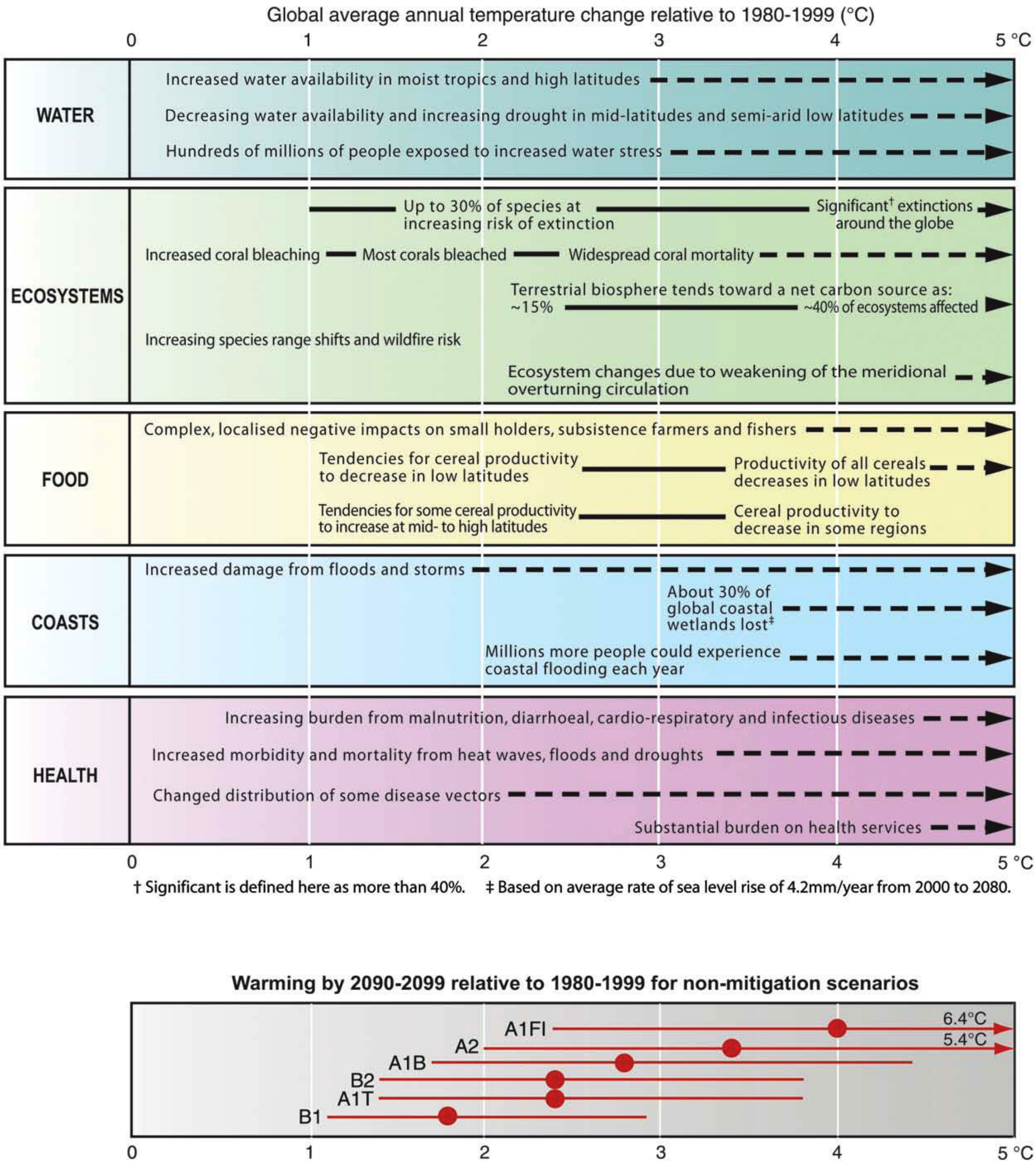


Figure 6. Examples of impacts associated with projected global average surface warming. Upper panel: Illustrative examples of global impacts projected for climate changes (and sea level and atmospheric CO_2 where relevant) associated with different amounts of increase in global average surface temperature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