National Park Service
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Natural Resource Program Center

Understanding the Science of Climate Change

Talking Points: Impacts to Prairie Potholes and Grasslands

Natural Resource Report NPS/NRPC/NRR—2009/138

ON THE COVER

Squirreltail grassland at Wind Cave National Park; NPS photo.

Understanding the Science of Climate Change

Talking Points - Impacts to Prairie Potholes and Grasslands

Natural Resource Report NPS/NRPC/NRR—2009/138

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I. Introduction

Purpose

Climate change presents significant risks to our nation's natural and cultural resources. Although climate change was once believed to be a future problem, there is now unequivocal scientific evidence that our planet's climate system is warming (IPCC 2007a). While many people understand that human emissions of greenhouse gases have caused 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 changes in 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 the 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 Prairie Potholes and Grasslands, a section outlining No Regrets Actions that can be taken now to mitigate and adapt to climate changes, and a general section on Global Climate Change. The Regional Section is organized around six types of changes or impacts, while the Global Section is arranged around four topics.

Regional Section

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

Global Section

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

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

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

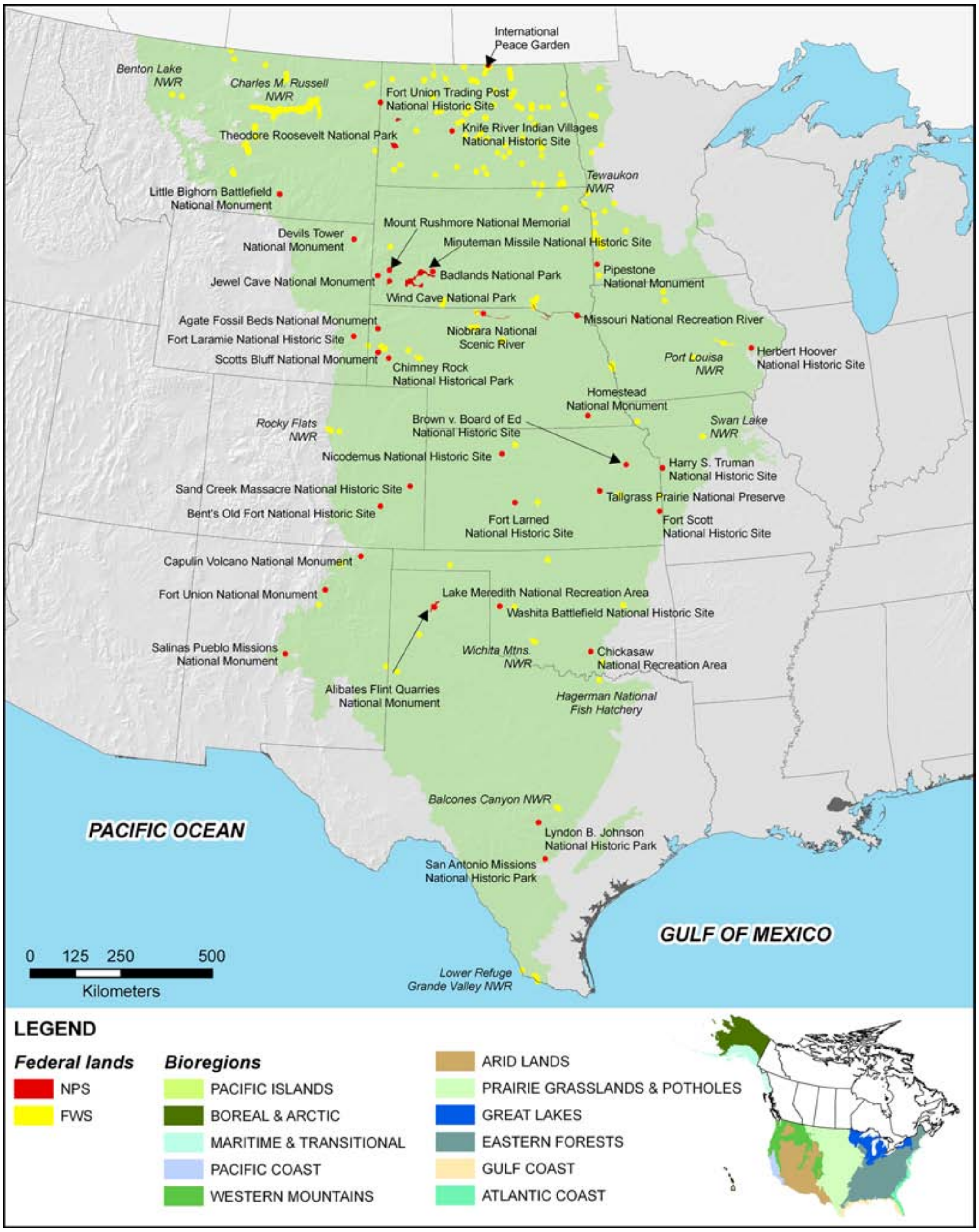
- "What scientists know" are statements based on measurable data and historical records. These are statements for which scientists generally have high confidence and agreement because they are based on actual measurements and observations. Events under this category have already happened or are very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

The Prairie Potholes and Grasslands 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

Climate changes in the Prairie Potholes and Grasslands bioregion include increased seasonal, annual, minimum, and maximum temperature and changing precipitation patterns. Because the region is relatively dry with a strong seasonal climate, it is sensitive to climatic changes and vulnerable to changes in climatic regime. For example, model simulations show that regional drought in the Prairie Pothole Region may result in loss of valuable habitat for breeding waterfowl, from an area that historically has produced 50-80% of the continent's ducks. Other impacts include potential vegetation shifts from C3 to C4 grassland communities, increased wildfires, changes in wetland hydrology, altered carbon balance, and phenological shifts.

List of Parks and Refuges

U.S. National Park Service Units

- Agate Fossil Beds NM
- Alibates Flint Quarries NM
- Badlands NP
- Bent's Old Fort NHS
- Brown v. Board of Education NHS
- Capulin Volcano NM
- Chickasaw NRA
- Chimney Rock NHP
- Devils Tower NM
- Fort Laramie NHS
- Fort Larned NHS
- Fort Scott NHS
- Fort Union NM
- Fort Union Trading Post NHS
- Herbert Hoover NHS
- Homestead NM
- International Peace Garden
- Jewel Cave NM
- Lake Meredith NRA
- Little Bighorn Battlefield NM
- Lyndon B. Johnson NHP
- Minuteman Missile NHS
- Mount Rushmore NME
- Nicodemus NHS
- Salinas Pueblo Missions NM
- Sand Creek Massacre NHS
- Scotts Bluff NM
- Tallgrass Prairie NPR
- Theodore Roosevelt NP
- Washita Battlefield NHS
- Wind Cave NP

Acronym	Unit Type
MP	Memorial Parkway
NB	National Battlefield
NHP	National Historic Park
NHR	National Historical Reserve
NHS	National Historic Site
NM	National Monument
NP	National Park
NR	National Reserve
NRA	National Recreation Area
NWR	National Wildlife Refuge
WMA	Wildlife Management Area

U.S. Fish & Wildlife Service Units

- Ankeny NWR
- Agassiz NWR
- Appert Lake NWR
- Ardoch NWR
- Arrowwood NWR
- Audobon NWR
- Balcones Canyonlands NWR
- Bear Butte NWR
- Benton Lake NWR
- Big Stone NWR
- Black Coulee NWR
- Bowdoin NWR
- Boyer Chute NWR
- Brumba NWR
- Buffalo Lake NWR
- Camp Lake NWR
- Canfield Lake NWR
- Chase Lake NWR
- Cottonwood Lake NWR
- Creedman Coulee NWR
- Crescent Lake NWR
- Dakota Lake NWR
- Des Lacs NWR
- Desoto NWR
- Flint Hills NWR
- Florence Lake NWR
- Glacial Ridge NWR
- Grulla NWR
- Hailstone NWR
- Halfbreed Lake NWR
- Half-Way Lake NWR
- Hamden Slough NWR
- Hewitt Lake NWR
- Hiddenwood NWR
- Hobart Lake NWR
- Hobart Lake NWR
- Hutchinson Lake NWR
- J. Clark Salyer NWR
- John W. and Louise Seier NWR
- Johnson Lake NWR
- Karl E. Mundt NWR
- Kellys Slough NWR
- Kirwin NWR
- Lacreek NWR
- Lake Alice NWR
- Lake Andes NWR
- Lake George NWR
- Lake Ilo NWR
- Lake Mason NWR
- Lake Nettie NWR
- Lake Otis NWR
- Lake Patricia NWR
- Lake Thibadeau NWR
- Lake Zahl NWR
- Lambs Lake NWR
- Lamesteer NWR
- Las Vegas NWR
- Little Goose NWR
- Lords Lake NWR
- Lost Lake NWR
- Lostwood NWR
- Lower Refuge Grande Valley NWR
- Maple River NWR
- Marais Des Cygnes NWR
- Maxwell NWR
- McLean NWR
- Medicine Lake NWR
- Muleshoe NWR
- Neal Smith NWR
- North Platte NWR
- Northern Tallgrass Prairie NWR
- Optima NWR
- Pleasant Lake NWR
- Port Louisa NWR
- Pretty Rock NWR
- Quivira NWR
- Rabb Lake NWR
- Rock Lake NWR
- Rocky Flats NWR
- Rocky Mountain Arsenal NWR
- Rose Lake NWR
- Rydell NWR
- Salt Plains NWR
- Sand Lake NWR
- School Section Lake NWR
- Shell Lake NWR

List of Parks and Refuges Continued

U.S. Fish & Wildlife Service Units Cont'd

- Sheyenne Lake NWR
- Sibley Lake NWR
- Silver Lake NWR
- Slade NWR
- Snyder Lake NWR
- Springwater NWR
- Squaw Creek NWR
- Stewart Lake NWR
- Stoney Slough NWR
- Storm Lake NWR
- Stump Lake NWR
- Sully's Hill NGP
- Tewaukon NWR
- Tishomingo NWR
- Tishomingo NWR
- Tomahawk NWR
- Two Ponds NWR
- UL Bend NWR
- Union Slough NWR
- Upper Mislssippi River NWFR
- Upper Souris NWR
- Valentine NWR
- War Horse NWR
- Washita NWR
- Waubay NWR
- White Lake NWR
- Wichita Mountains NWR
- Wild Rice Lake NWR
- Willow Lake NWR
- Wintering River NWR
- Wood Lake NWR

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NWR	National Wildlife Refuge
WMA	Wildlife Management Area

Bison at Wind Cave National Park; NPS photo.

A. TEMPERATURE

What scientists know….

- The Northern and Central Great Plains have warmed by about 1.1°C over the last century, with larger increases in minimum than in maximum temperatures and more pronounced winter warming (Ojima and Lackett 2002).

- Other changes in regional climate, observed in the last few decades, include a decrease in the diurnal temperature range (difference between day and night), less frequent cold days, and more frequent hot days (Karl et al. 2009; Millet et al. 2009).

What scientists think is likely….

- By the mid-21st century year-round temperatures across North America will likely be outside the range of present-day natural variability (Field et al. 2007).

- 21st century temperature increases are expected to be larger in the northern portion of the region. In the southern and central portions of the region summer temperature increases are projected to be larger than those in winter (Karl et al. 2009).

What scientists think is possible….

- Air temperatures in northern and central parts of the Prairie Pothole Region may warm 3-6°C by the end of this century. Longer growing seasons, milder winters, earlier springs, and warmer and drier summers are expected (USGS 2006).

- General circulation model projections for the Great Plains include annual temperature increases of +1.6 to +2.2°C by 2030 and +3.7 to +6.1°C by 2090; an increase in heat events (3 or more days ≥ 41°C); more hot days (number of days ≥ 41°C); and an increase in the number of growing degree days, as compared with the period from 1961-1990 (Ojima and Lackett 2002).

Summer thunderhead developing at Lacreek National Wildlife Refuge; USFWS photo.

Aerial view of prairie potholes (wetlands) at Waubay National Wildlife Refuge; USFWS photo.

B. THE WATER CYCLE

What scientists know….

- Climate records for the Prairie Pothole Region indicate that the strong west-to-east moisture gradient across the region steepened during the 20th century, with weather stations in the west becoming drier and stations in the east becoming wetter. The greatest drying occurred in the Canadian Prairies (USGS 2006).

- Average annual precipitation in the Prairie Pothole Region increased by 49mm, or 9%, over the 20th century, with the largest increases along the eastern and northeastern fringe of the tall grassland ecoregions (Millet et al. 2009).

- Precipitation patterns in the Great Plains region are notoriously extreme, punctuated by both severe droughts and deluges. These weather extremes are important for the long-term productivity and biodiversity of semi-permanent prairie wetlands (Johnson et al. 2005).

- The Northern Great Plains region is characterized by an annual deficit of precipitation, making it highly sensitive to changes in moisture regime (Brown et al. 2005).

- In the last century, annual precipitation has increased by 5-20% in South Dakota, Oklahoma, Texas, and in parts of Kansas (Joyce et al. 2001).

- Because wetlands exist in the transition zone between aquatic and terrestrial environments, they are vulnerable to changes in surface and ground water hydrology. These hydrologic shifts may push wetland species beyond their limits of adaptation and tolerance. Wetlands that depend upon precipitation as their primary water source are the most vulnerable to climate variation and change (Burkett and Kusler 2000).

- Northern prairie wetlands are at risk from losses due to changes in land use and climate. Consequences of wetlands losses, besides habitat fragmentation, include disruption of normal hydrological flow within watersheds, increased risk of downstream water quality impairment, and losses to waterfowl populations (Beeri and Phillips 2007).

What scientists think is likely….

- A warmer climate and changes in precipitation patterns are likely to strongly affect wetland ecological functions through changes in hydrology, biogeochemistry, and biomass accumulation. Because wetlands play an important global role in reducing the amount and rate of increase in atmospheric carbon dioxide, destruction of wetland habitats can enhance global warming through the release of stored carbon to the atmosphere (Burkett and Kusler 2000).

- Prairie potholes are considered particularly vulnerable to climate change because they cannot migrate to escape changing climatic conditions or environmental stressors. Their vulnerability is further exacerbated by human development and agriculture in surrounding areas. (Ojima and Lackett 2002).

- Wetlands may be affected by any changes in temperature, precipitation, and evaporation/evapotranspiration that alter the water supply to the wetland through changes in runoff, streamflows, and groundwater

Tallgrass Prairie with Yellow Coneflowers at Herbert Hoover National Historic Site (Top); NPS photo. Much of the remaining tallgrass prairie habitat is highly fragmented and dominated by human activity, prairie paintbrush (Bottom); USFWS photo.

recharge. Both the seasonal patterns and intensity of precipitation events are important: in the northern prairies, if evapotranspiration increases and snowmelt runoff decreases as some scenarios project, a dramatic loss of meadow and shallow marshlands could result (Ojima and Lackett 2002).

- Reductions in wetland size and the disappearance of some wetlands can be expected with increases in temperatures and/or reduced precipitation in the Prairie Pothole Region, which provides habitat for about half of the Nation's waterfowl (Burkett and Kusler 2000).

- More extreme rainfall regimes, characterized by larger events and longer intervals between events, can reduce stress in typically anoxic (oxygen depleted) wetland systems, and increase the rates of some aerobic ecosystem processes (e.g. organic matter decomposition, soil respiration, net primary production) (Knapp et al. 2008).

What scientists think is possible….

- Climatologists forecast increased drought in the Prairie Pothole Region under most climate scenarios (USGS 2006).

- Model projections suggest that precipitation in the Great Plains region may increase by as much as 12cm per year by 2090. Despite this increase, water resources may be severely impacted because moderate precipitation gains may be offset by large increases in temperature. Other hydrologic changes may include an intensified hydrologic cycle with increases in evaporation, evapotranspiration, and precipitation, heavy snowmelt runoff, heavy rains, and early fall and late spring snows (Ojima and Lackett 2002).

- Model simulations determined that climate warming of only a few degrees Centigrade increased evaporation, shortened wetland hydroperiod, increased drought frequency and duration, and produced less favorable vegetation conditions in semi-permanent wetlands for most of the Prairie Pothole Region, as compared with historic conditions. Unfavorable wetland conditions developed more often in the historically drier western portions of the Prairie Pothole Region under a simulated warmer climate (USGS 2006).

- Reduced streamflows on the Great Plains are causing many Federal reservoirs to become profoundly inefficient, and may lead to eventual failure as negative annual reservoir water budgets become more common. Historically, reduced streamflows were related to groundwater mining; since the mid-1980s, however, declines correlate increasingly with climate. Predictions of streamflow and reservoir performance based on climate change models indicate a 70% chance of steady decline after 2007, and a very high likelihood of severely reduced surface water resources between 2007 and 2050 (Brikowski 2008).

C. VEGETATION

What scientists know….

- Manipulative experiments, modeling exercises, and long-term observations of rangeland vegetation over the past two centuries provide indisputable evidence that warming, altered precipitation patterns, and rising atmospheric CO_2 are vir-

Native Butterfly Weed at Herbert Hoover National Historic Site; NPS photo.

tually certain to have profound impacts on rangeland ecology and agricultural utility, including shifts in plant community species composition, changes in the frequency and timing of wildfires, and altered watershed catchment (Hatfield 2008).

- Tallgrass prairies of North America are threatened by an increase in the abundance of native woody species. This increase is attributed to changes in climate, increased atmospheric carbon dioxide, nitrogen deposition, grazing pressure, and altered disturbance regimes (e.g. fire frequency and intensity) (Briggs et al. 2005).

- In an experiment at the Konza Prairie Biological Station, increased variability in precipitation without concurrent changes in total rainfall quantity enhanced plant community diversity and was accompanied by increased turnover of rare and uncommon species (Knapp et al. 2002).

- Productivity of native grasslands in the Northern Great Plains is highly dependent on early spring soil moisture and winter/early spring precipitation patterns, and changes in the seasonality of precipitation will have large impacts on these vegetation communities (Hatfield 2008).

- Long-term demographic data from a native mixed-grass prairie in Kansas demonstrated that interannual climate variability promotes the coexistence of three common perennial grass species: sideoats grama, hairy grama, and little bluestem, because favorable climatic conditions increased the ability of all three grass species to recover from low densities, while minimizing the effects of intra- and interspecific competition (Adler et al. 2006).

- An experiment at the Konza Prairie Biological Station in northeast Kansas demonstrated that grassland ecosystem responses to extreme rainfall patterns expected with climate change are likely to be variable, but will result in changes in ecosystem carbon cycling. For example, an increase in total rainfall quantity increased mean soil moisture and leaf photosynthetic carbon gain, aboveground net primary productivity, and soil respiration by 20-55%; and a 3-15 days increase in the interval between rainfall events increased leaf photosynthetic carbon gain but decreased soil respiration (Fay et al. 2008).

- Increased temporal variability in precipitation patterns and soil moisture in grasslands will, in the short term, increase plant water stress and alter key carbon cycling processes such as net photosynthesis, aboveground productivity, and soil CO_2 flux, with long-term consequences for carbon storage and biotic-atmospheric feedbacks (Knapp et al. 2002).

- Wetlands can sequester over twice the organic carbon as no-till cropland; therefore, restoration of prairie wetlands in North America has potential to sequester 378 Tg of organic carbon over a 10-year period, offsetting 2.4% of the annual fossil CO_2 emission reported for North America in 1990 (Euliss et al. 2006).

- A recent study found that competition between C_3 (forbs, woody plants, legumes) and C_4 plants (grasses, sedges) in North American grasslands is particularly sensitive to daily high temperatures and monthly rainfall in July. Specifically, mixed C_3 and C_4 systems persist in Great Plains grasslands where the July average temperature is $21.5 \pm 3^{\circ}C$; systems are C_3 dominated (<33% C_4) below this range and C_4 dominated (>66% C_4) above it (von Fischer et al. 2008).

Bison at Wind Cave National Park, NPS photo.

- Field experiments in the shortgrass steppe of northern Colorado indicate that a doubling of atmospheric CO_2 above current levels stimulates increased productivity, apparently due to improved soil-plant water relations. Results also show that C3 grasses were more responsive (showed higher productivity) to CO_2 enrichment than C4 grasses and herbaceous dicots (Morgan et al. 2004).

- Experimentally increasing daily minimum air temperature and mean soil temperature by 2°C increased aboveground net primary productivity (NPP) of tallgrass prairie in Oklahoma by 0-19% during the first three years of study, largely by increasing NPP of C4 grasses (Wan et al. 2005). Additional effects included a three-week extension of the growing season, shifts in the timing and duration of reproductive events among plant species, and earlier spring flowering (Sherry et al. 2007).

- An increase in spring season daily minimum temperatures over the past 70 years has resulted in a consistent trend of earlier flowering dates for winter wheat at six locations in the U.S. Great Plains (Hu et al. 2005).

What scientists think is likely....

- Analysis of long-term demographic data for ten forb species in a native mixed-grass prairie in Kansas suggests that 1) climate had a greater influence than species composition on historical population dynamics; 2) predicted increases in mean temperatures are likely to impact population growth more than changes in precipitation or composition; and 3) the significant effects of both climate and species composition on recruitment suggest that range shifts will be particularly difficult to forecforecast (Adler and HilleRisLambers 2008).

- CO_2 enrichment (increasing atmospheric CO_2 concentration) will stimulate net primary productivity on most rangelands, with the amount of increase dependent on precipitation and soil water availability (Hatfield 2008).

- In tallgrass prairie, shifts in plant species composition toward more diverse communities, and toward communities characteristic of more xeric environments, may result from predicted climatic regimes that include changes in both precipitation variability and quantity (Knapp et al. 2002).

- Plants with the C3 photosynthetic pathway (e.g. forbs,woody plants, and legumes) seem likely to be favored by rising CO_2 levels over C4 species (grasses and sedges), because C3 plants can assimilate more CO_2 than C4 grasses when temperatures are relatively cool. However, interactions of species responses with rising temperature and altered precipitation patterns may affect these responses: for example, warmer temperatures and drier conditions will tend to favor C4 species, which may cancel out the CO_2 advantage of C3 plants (Hatfield 2008, von Fischer et al. 2008).

What scientists think is possible....

- Vegetation models predict an eastward shift in the east-west forest-grass ecotone, resulting in a reduction in forest cover and an increase in grass cover, for the central United States under climate change condi-

Birds and insects with prairie habitats, from top to bottom: American Bittern, Monarch Butterfly, Greater Sage-Grouse; USFWS photo, NPS photo, USFWS photo respectively.

tions. This shift is primarily due to interannual precipitation variability (Notaro 2008).

- More extreme rainfall regimes are expected to increase the duration and severity of soil water stress in mesic ecosystems, as intervals between rainfall events increase. In contrast, xeric ecosystems may exhibit the opposite response to extreme events: larger but less frequent rainfall events may result in proportional reductions in evaporative losses, and thus may lead to greater soil water availability (Knapp et al. 2008).

- Modeling exercises suggest that increases in CO_2 and temperature projected for the next 30 years will result in generally increased net primary productivity in Great Plains native grasslands, although these increases in productivity may be accompanied by reduced digestibility of forage grasses (Morgan et al. 2004, Pepper et al. 2005, Parton et al. 2007).

D. WILDLIFE

What scientists know….

- The projected drying of the Prairie Pothole Region—the single most important duck production area in North America—will significantly affect the ability of the U.S. National Wildlife Refuge System to maintain migratory species in general and waterfowl in particular (Scott et al. 2008).

- A study in the J. Clark Salyer National Wildlife Refuge in North Dakota, a mixed-grass prairie region, found that breeding grassland birds are negatively impacted by habitat fragmentation resulting from encroaching woody vegetation. For example, the probability of occurrence decreased markedly for 11 of 15 bird species (including three endemic to the northern Great Plains) as percent woodland, tall shrub, or brush cover increased; bird species were increasingly affected as the height of woody plants increased from brush to tall shrubs to trees; and grasslands became largely unsuitable for nine species as woodland cover exceeded 25% (Grant et al. 2004).

- A study examining the effects of long-term temperature change on the laying dates and clutch sizes of North American birds demonstrated that laying dates for four species (American robin, killdeer, Eastern bluebird, red-winged blackbirds) were earlier when spring temperatures were warmer, and that laying dates advanced over time for two species (red-winged blackbirds, eastern bluebirds) (Torti and Dunn 2005).

- A comparison of recent with historical survey data from upland wetlands and riparian areas in Theodore Roosevelt National Park, North Dakota indicates that herpetofauna (reptiles and amphibians) populations appear relatively unchanged during the last half-century (Hossack et al. 2005).

What scientists think is likely….

- Climate changes will likely alter future rangeland community structure, thereby impacting faunal species that depend on plants for important stages of their life-cycles (Hatfield 2008).

- Although increasing spring temperatures are positively correlated with nest success for dabbling duck species in Saskatchewan, Canada, any positive effect of temperature increases may be offset by loss of wetlands from drought, agriculture, and land use change (Drever and Clark 2007).

- Bats, as hibernating animals, are expected to be directly affected by climate changes. Bat populations overwintering in northern prairie environments may become dehydrated under conditions of decreased humidity and increased temperatures; may awake more frequently from hibernation throughout the winter and take more winter flights,reducing stored fat reserves; and may shift their ranges northward in areas where higher altitude refugia are unavailable (Lausen and Barclay 2006).

What scientists think is possible….

- Reduced spring precipitation may affect critical bird migration or nesting, even if

Gunnison Prairie Dog at Curecanti NRA (Top); NPS photo. Black Hills American Dipper (Bottom); USFWS photo.

mean annual precipitation and water levels remain constant (Burkett and Kusler 2000).

- Model simulations for the Prairie Pothole Region of North America suggest that the most productive habitat for breeding waterfowl will shift under a drier climate from the center of the region (the Dakotas and southeastern Saskatchewan) to the wetter eastern and northern fringes, areas that are currently less productive or where most wetlands have been drained. Unless these wetlands are protected and restored, there is little insurance for waterfowl against future climate warming (Johnson et al. 2005).
- Climate changes are predicted to result in loss of wetlands in the western Prairie Pothole Region, causing extirpation of some amphibian species and an eastward shift of favorable wetland habitat to a region where most wetlands have been drained for agricultural production. The eastern region is dominated by crops, and therefore likely subjected to fertilizer and pesticide loads, compounding the potential impacts (Johnson et al. 2008).
- Wetlands in the central flyway in Nebraska could be adversely affected by a drop in river water levels during migration periods. However, wetlands could be enhanced if increased precipitation exceeds evapotranspiration, consistently providing increased streamflow and groundwater supply (Ojima and Lackett 2002).
- The health of the prairie potholes for waterfowl habitat depends on whether future precipitation increases sufficiently enough to offset warmer temperatures. A combination of higher temperatures and lower rainfall could dry up potholes in a region covering six U.S. states and three Canadian provinces, home to the world's most productive waterfowl habitat (Johnson et al. 2005).
- Predicted increased temperatures in the Northern Great Plains over the next 50 years may result in more frequent droughts and a 40% or more decline in numbers of both prairie wetlands and ducks (Sorenson et al. 1998). If human response is considered, the numbers of ponds would be even lower, because scarce water resources may be diverted to agricultural use unless water is secured for wetland conservation (Burkett and Kusler 2000).
- Models based on distributional data of Great Plains bird species suggest that plains species are heavily influenced by climate changes, which may result in drastic area reductions and dramatic spatial movements of appropriate habitats (Peterson 2003).
- Two species of rodents, Coues' rice rats and the Mexican vole, are predicted to go extinct in Texas under warmer and drier climatic conditions because of severe reductions in suitable habitat. Model results suggest that rodents are more adaptable to climate changes than other mammals (e.g.

lagomorphs and insectivores), although significant range shifts may occur in addition to the extinctions predicted above (Cameron and Scheel 2001).

- Climatically drier portions of the Prairie Pothole Region are especially vulnerable to climate warming because they may become critically dry in most years under predicted climate change scenarios. Ongoing efforts to protect wetlands and improve waterfowl nesting cover in the region's historic "duck factory" could be maximized to increase duck production when wet years do occur. Restoration of wetlands in the eastern portion of the region could help diminish the effects of increased drought in a drier west (USGS 2006).

- Reduced incidence of plague in black-tailed prairie dogs, resulting in an increase the number of prairie dog colonies, may occur with climate change. The assumed underlying mechanism is an inhibiting effect of high temperatures on fleas (dispersal vector) and on flea-mediated transmission of the disease-causing bacterium (Snall et al. 2009).

A fire burns on the priarie (Top); USFWS photo. Bison cow and calf on the plains of Wind Cave National Park (Bottom); NPS photo.

E. DISTURBANCE

What scientists know….

- Nearly all freshwater ecosystems in the Great Plains have been modified by human activities and land uses, including alteration of thermal regimes; habitat destruction resulting from dams, diversions, and channelization; altered groundwater flow patterns as a result of pumping and erosion; point and non-point pollution sources; introduction of non-native plant and animal species; and over-harvesting of native species (Ojima and Lackett 2002).

- Plains island forests - refugia of trees and tree-dependent species isolated in a grassland matrix - are at significant risk from climate changes because they are ecotone systems (borderline between grassland and forest ecosystems) and therefore sensitive to relatively small changes in environmental conditions. In addition, because island forests are relatively small ecosystems, they may exhibit reduced genetic diversity and greater vulnerability to catastrophic disturbance such as wildfire, pathogen attack or severe drought (Henderson et al. 2002).

- Analyses of a late Holocene core from Kettle Lake in northwestern North Dakota showed that climate–fuel–fire cycles have persisted on the northern Great Plains for most of the last 4,500 years, and that fire has not been a constant process on the prairies through time, but has oscillated with short-term climatic cycling. Fire is more prevalent during moist periods, when grass cover is extensive, compared with drier intervals with less dense vegetation cover (Brown et al. 2005).

- Fire regime is critically important in determining the cover and extent of woody vegetation in mesic grasslands, and the interaction of fire and livestock grazing can exacerbate the expansion of woody vegetation within tallgrass prairie. For example, after a 20-year period woody plant density Konza Prairie Biological Station in Kansas increased by two- to tenfold, except in those watersheds that were burned annually (Briggs et al. 2005).

- Four years after the addition of native bison herbivores to watersheds in the Konza Prairie Biological Station in Kansas, woody plant abundance increased significantly as compared with ungrazed watersheds. Thus, the presence of large ungulate grazers in tallgrass prairie greatly accelerated the increase in woody plant abundance (Briggs et al. 2005).

- Prescribed fire experiments on fossil specimens from Badlands National Park, South Dakota suggest that low to moderate fire conditions have minimal impact on fossil resources except in areas where the fossils are in contact with fuel; and that significant fire effects on fossils would be found under high spread rate and high intensity conditions even without direct fuel contact (Benton and Reardon 2006).

What scientists think is likely….

- Studies suggest that while different pathways characterize the conversion of C4 grass–dominated systems to those co-dominated by grass and woody plant growth forms, only a single pathway exists by which the plant community characteristic of a mesic grassland ecosystem can be maintained. This pathway involves frequent fire and the absence of grazing or grazing at low intensity. It is important to note that once shrubs establish and a state of co -dominance is reached, frequent fire will maintain this state, but a return to a C4-dominated grassland is no longer possible (Briggs et al. 2005).

What scientists think is possible….

- Summer increases in temperature and precipitation may impact fire management through increased fuel loads from altered temperature and precipitation regimes, and an increase in the number of ignitions resulting from increased convective storm activity (Ojima and Lackett 2002).

- Models predict that the invasive swede midge, an insect pest that affects agricultural and non-agricultural plants in the Brassicaceae family, may spread from its current initial invasion in southern Ontario and northwestern New York State to all the Great Lakes states, into midwestern states as far south as Colorado, and west into Washington State by the 2080s (Mika et al. 2008).

- Climate changes may increase the area in Oklahoma suitable for invasion by red imported fire ants by 26 to 36%, an increase in land area of around 35,000 to 47,000 km2. These aggressive ants cause extensive crop damage, prey on newborn white-tailed deer fawns, attack other young animals (e.g. reptiles and hatchlings), and can threaten endangered species by modifying food webs (Levia and Frost 2004).

- Insect pests that were historically unable to survive in cooler areas within the region are expected to spread northward. Milder winters and earlier springs resulting from increasing seasonal temperatures will likely result in the emergence of additional generations of insects each year, earlier emergence, and larger overall insect populations (Karl et al. 2009; Diffenbaugh et al. 2008).

- Warmer temperatures and lower soil moistures, especially during severe multi-year droughts, may restore wildfire as a significant disturbance process in prairie grasslands. Increased fire disturbance may limit encroachment of woody vegetation into grasslands, but may also stimulate conversion of native grasslands to exotic-dominated ecosystems, because many exotic invasive grasses respond more rapidly and successfully to fire disturbance than native grass and shrub species (Matthews 2008).

- Simulation modeling experiments of the interactions among climate changes, natural fire regimes, and livestock grazing at Wind Cave National Park, South Dakota, predict that temperature increases will limit the growth of trees that rely on availability of deep water, favor shrub and grass development, and promote a shift from forests to woodlands. In the simulation, woody encroachment of shrubs in grasslands areas, enhanced by grazing, was only held in check by frequent natural fires (Bachelet et al. 2000).

F. VISITOR EXPERIENCE

- In North Dakota, conservation reserve program habitat has positively affected game and non-game species populations, and these thriving wildlife populations have in turn influenced the number of individuals participating in hunting and wildlife viewing activities. Accordingly, expenditures related to those recreational activities have also increased (Bangsund et al. 2004).
- The locations of climatically ideal tourism conditions are likely to shift toward higher latitudes under projected climate change, and as a consequence spatial and temporal redistribution of tourism activities may occur. The effects of these changes will depend greatly on the flexibility demonstrated by institutions and tourists as they react to climate change (Amelung et al. 2007).
- Changes to the terrestrial and aquatic species compositions in parks and refuges are likely to occur as ranges shift, contract, or expand (Burns et al. 2003).
- Parks and refuges may not be able to meet their mandate of protecting current species within their boundaries, or in the case of some refuges, the species for whose habitat protection they were designed. While wildlife may be able to move northward or to higher elevations to escape some effects of climate change, federal boundaries are static (Burns et al. 2003).
- Lakeshore levels and stream depths will increasingly fluctuate, potentially making fixed docks and boat ramps unusable for much of the year. Navigational hazards and new sand bars may be exposed (Scavia et al. 2002).
- 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).
- 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 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.
- 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.

A park ranger leads a guided walk in the tallgrass prairie at Herbert Hoover National Historic Site; NPS photo.

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

Individuals, businesses, and agencies release carbon dioxide (CO2), 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 CO2 have measurably increased global average temperatures, and are projected to cause further changes in global climate, with severe negative implications for vegetation, wildlife, oceans, water resources, and human populations. Emissions reduction – limiting production of CO2 and other greenhouse gases - is an important step in addressing climate change. It is the responsibility of agencies and individuals to find ways to reduce greenhouse gas emissions and to educate about the causes and consequences of climate change, and ways in which we can reduce our impacts on natural resources. There are many simple actions that each of us can take to reduce our daily carbon emissions, some of which will even save money.

Agencies Can...

Improve sustainability and energy efficiency

- Use energy efficient products, such as ENERGY STAR® approved office equipment and light bulbs.
- Initiate an energy efficiency program to monitor energy use in buildings. Provide guidelines for reducing energy consumption.
- Convert to renewable energy sources such as solar or wind generated power.
- Specify "green" designs for construction of new or remodeled buildings.
- Include discussions of climate change in the park Environmental Management System.
- Establish an in-park sustainability team and develop sustainability Best Management Practices. Request and hold Climate Friendly Park workshops in cooperation with the EPA.
- Provide alternative transportation options such as employee bicycles and shuttles for within-park 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 travel to and within the park.
- Provide incentives for use of alternative transportation methods.
- Use teleconferences or other forms of modern technology in place of travel to conferences and meetings.

Management Actions

- Engage and enlist collaborator support (e.g., tribes, nearby agencies, private landholders) in climate change discussions, responses, and mitigation.
- Develop strategies and identify priorities for managing uncertainty surrounding climate change effects in parks and refuges.
- Build a strong partnership-based foundation for future conservation efforts.
- Identify strategic priorities for climate change efforts when working with partners.
- Incorporate anticipated climate change impacts, such as decreases in lake levels 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.

Climate Change in National Parks

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

- Encourage 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

- 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.
- 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 resources.
- Restore and conserve connectivity within habitats, protect and enhance instream flows for fish, and maintain and develop access corridors to climate change refugia.
- Restore natural hydrologic functions of coastal wetlands to help protect coastal areas against hurricanes and flooding.

Educate staff and the public

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

> “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 use public or non-motorized transportation to and around parks.

- Encourage visitors to reduce their carbon footprint in their daily lives and as part of their tourism experience.

Individuals can...

- In the park or refuge park your 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. 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.

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.

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.

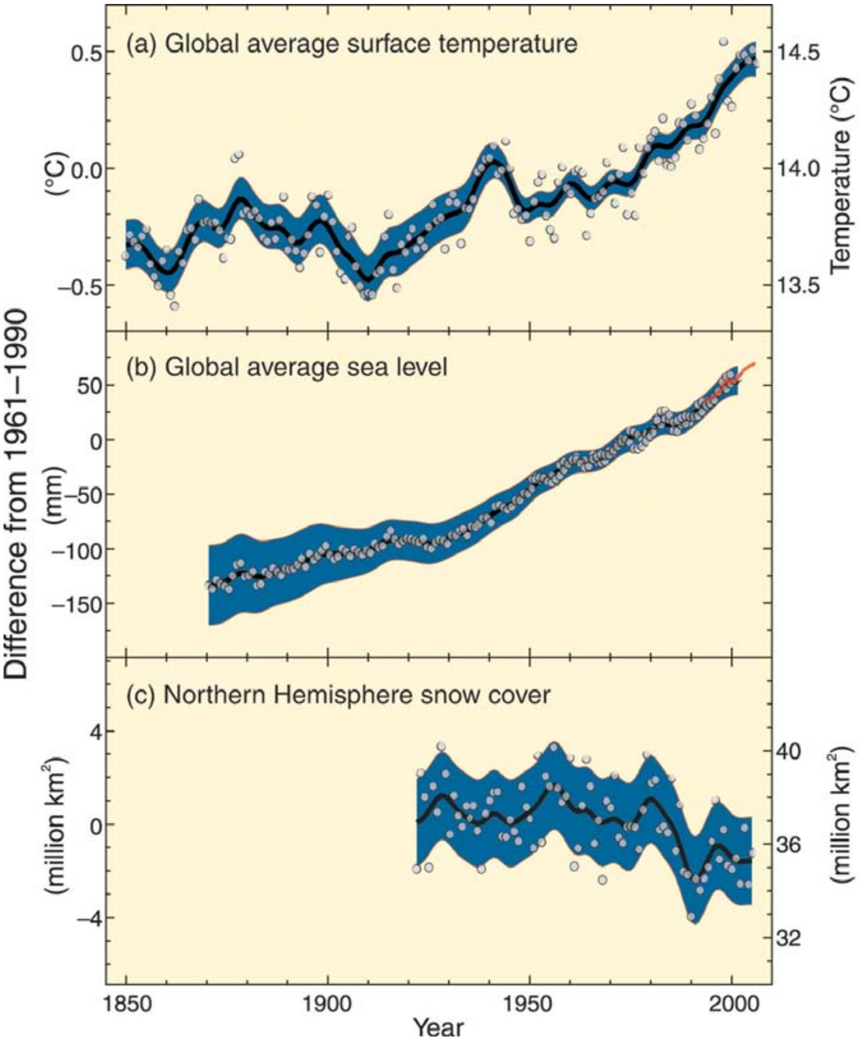


Figure 1. Observed changes in (a) global average surface temperature; (b) global average sea level from tide gauge (blue) and satellite (red) data and (c) Northern Hemisphere snow cover for March-April. All differences are relative to corresponding averages for the period 1961-1990. Smoothed curves represent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

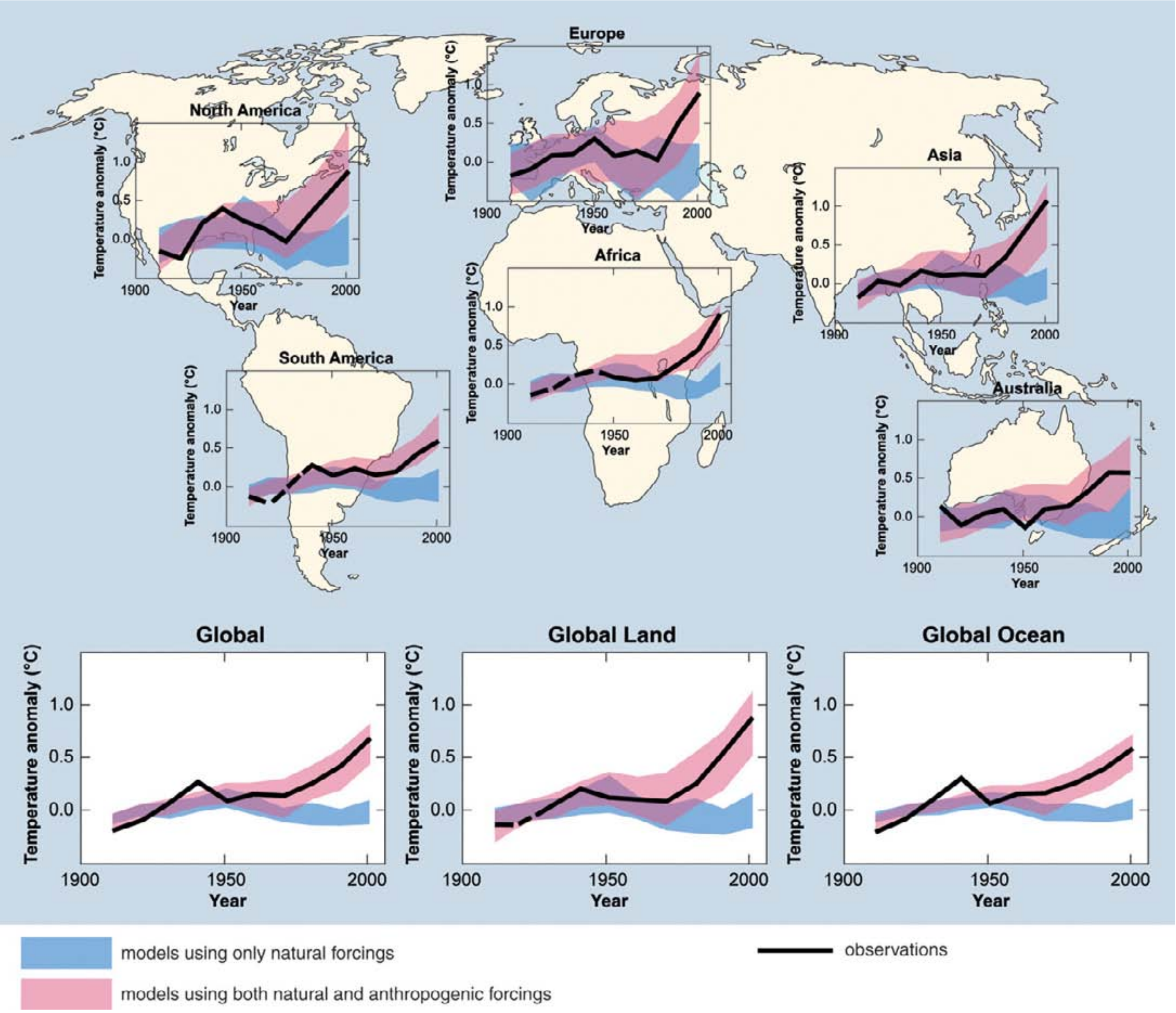


Figure 2. Comparison of observed continental- and global-scale changes in surface temperature with results simulated by climate models using either natural or both natural and anthropogenic forcings. Decadal averages of observations are shown for the period 1906-2005 (black line) plotted against the 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 (CO2), primarily from fossil fuel use and land-use change; methane (CH4) and nitrous oxide (N2O), 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 CO2 and CH4 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 CO2 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 CO2, increasing the fraction of anthropogenic emissions remaining in the atmosphere. This positive carbon cycle feedback results in increasingly greater accumulation of atmospheric CO2 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 (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

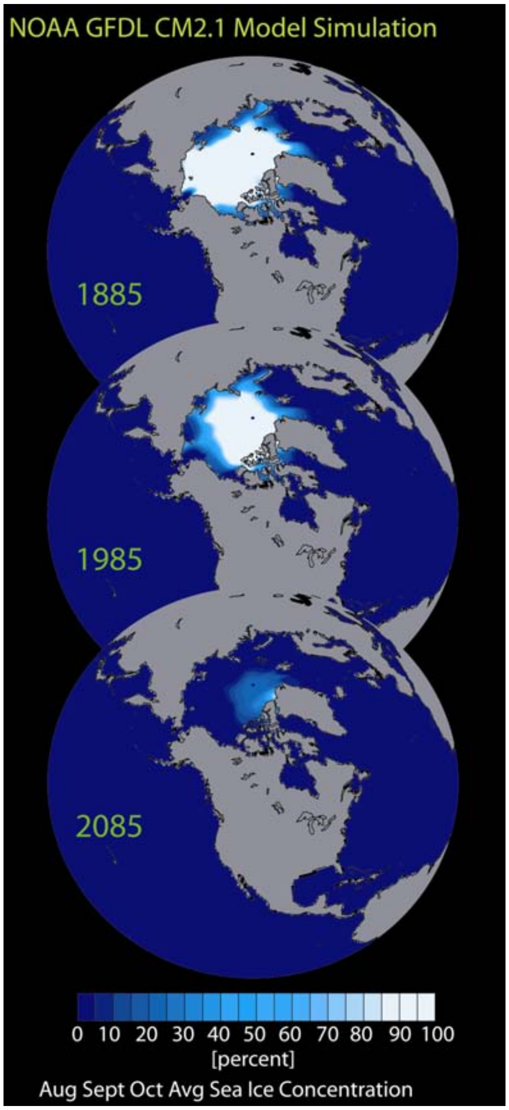


Figure 3. Sea ice concentrations (the amount of ice in a given area) simulated by the GFDL CM2.1 global coupled climate model averaged over August, September and October (the months when Arctic sea ice concentrations generally are at a minimum). Three years (1885, 1985 & 2085) are shown to illustrate 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.

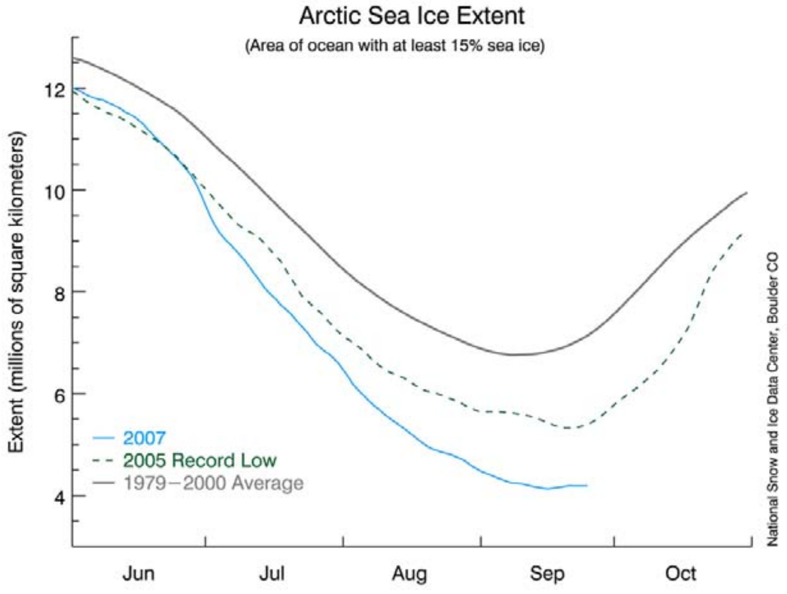


Figure 4. Arctic sea ice in September 2007 (blue line) is far below the previous low record year of 2005 (dashed line), and was 39% below where we would expect to be in an average year (solid gray line). Average September sea ice extent from 1979 to 2000 was 7.04 million square kilometers. The climatological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

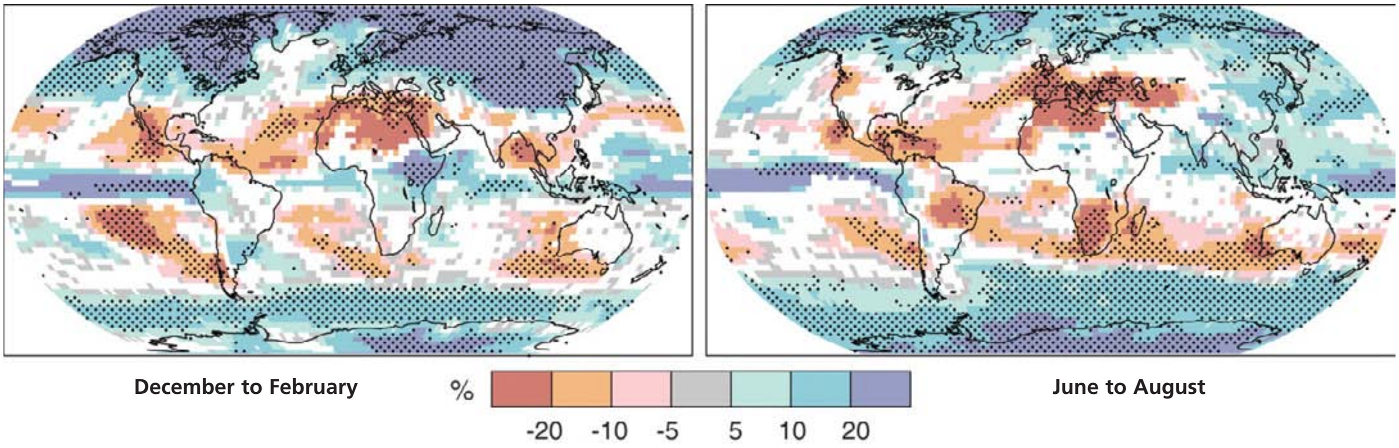
- Widespread mass losses from glaciers and reductions in snow cover are projected to accelerate throughout the 21st century, reducing water availability and changing seasonality of flow patterns.

- 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 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).



December to February

June to August

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 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)

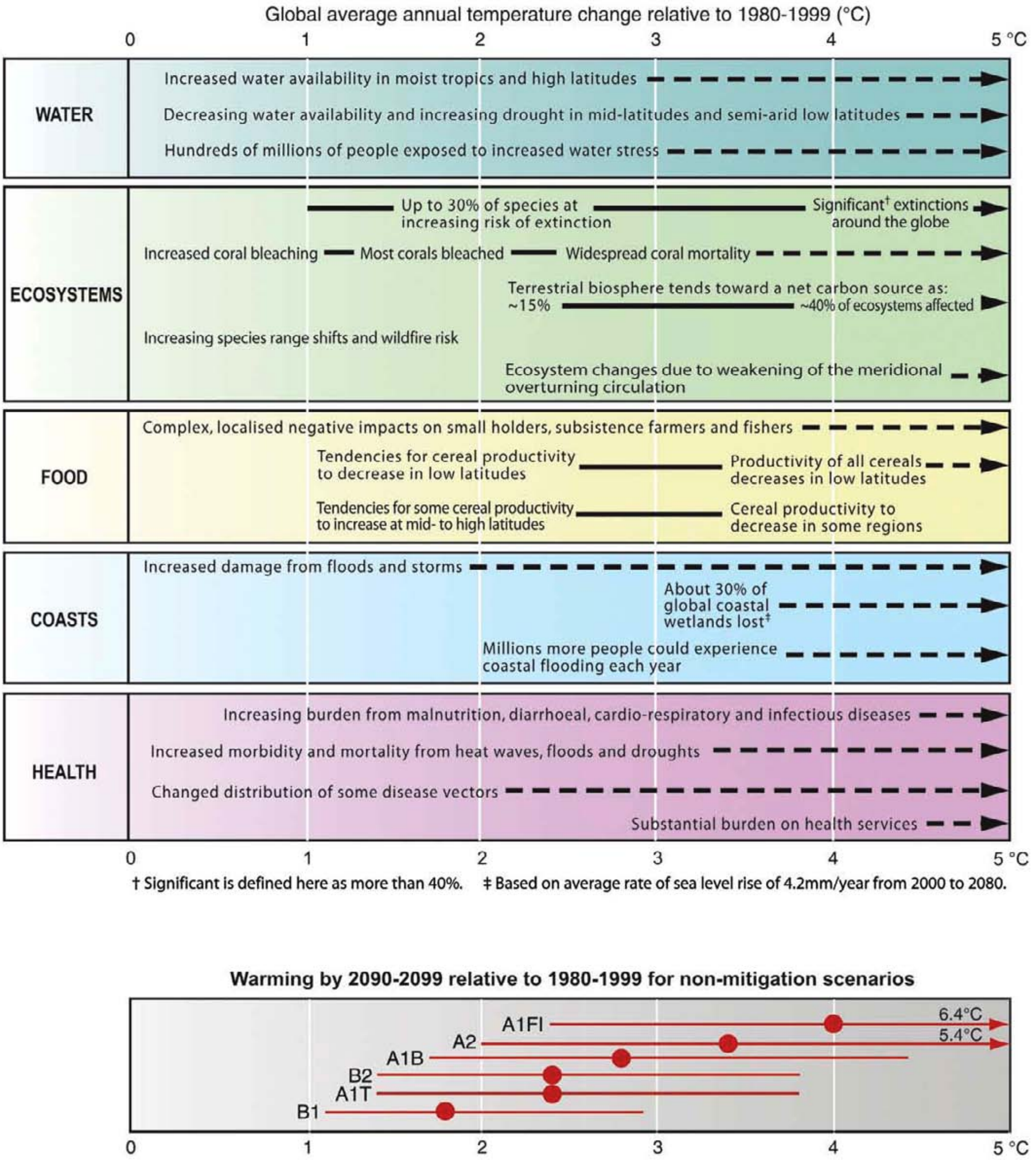


Figure 6. Examples of impacts associated with projected global average surface warming. Upper panel: Illustrative examples of global impacts projected for climate changes (and sea level and atmospheric CO_2 where relevant) associated with different amounts of increase in global average surface temperature 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 CO2, 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 CO2 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 CO2 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 CO2 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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