National Park Service
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Natural Resource Program Center

Understanding the Science of Climate Change

Talking Points – Impacts to Alaska Maritime and Transitional

Natural Resource Report NPS/NRPC/NRR—2010/223

ON THE COVER

Alpenglow above the Harding ice field at Kenai Fjords National Park; NPS photo.

Understanding the Science of Climate Change

Talking Points – Impacts to Alaska Maritime and Transitional Bioregions

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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 Alaska Maritime and Transitional, 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)
- Cultural Resources (includes archeological, historical, anthropological and subsistence resources)
- Visitor Experience (includes human health, visitation, and infrastructure)

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 (IPCC). 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 Alaska Maritime and Transitional

The Maritime and Transitional Bioregion that is discussed in this section is shown in the map to the right. A list of parks and refuges for which this document 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

Alaska is a huge state spanning 375 million acres and occupying nearly one-fifth of the land area for the contiguous 48 states. More than half of the coastline of the entire United States is in Alaska. Due to the great size and geographically diverse nature of Alaska, two bioregional documents were produced: “Boreal and Arctic” and “Alaska Maritime and Transitional.” In Alaska, the vast majority of the land is public; with approximately 222 million acres (approximately 60%) designated federal lands and another 90 million acres (approximately 24%) in state ownership. There are 17 National Park Service (NPS) areas in Alaska covering over 54 million acres; this represents two-thirds of the land in the entire National Park system. Wrangell-St. Elias is the largest NPS unit at over 13 million acres in size. There are 16 National Wildlife Refuges in Alaska totaling over 76 million acres, representing approximately 80% of the entire National Wildlife Refuge system. The two national forests in Alaska encompass nearly 22 million acres; Tongass National Forest is the largest United States Forest Service unit, with nearly 17 million acres. The Bureau of Land Management manages almost 78 million acres in Alaska.

Summary Continued

Climate changes in the Alaska Maritime and Transitional bioregion include increased mean, minimum, and maximum annual temperatures, and increasing spring and wintertime temperatures that have resulted in a longer growing growing season and shifting plant distributions. Regional models project a wintertime shift in temperatures from below to above freezing by the mid to late 21st century, a decrease in the annual number of snow-free and frost-free days, and a mean increase in annual air temperatures. Observed hydrologic changes within the bioregion are profound, including significant decreases in the number, mass, and volume of glaciers; increased rates of glacial retreat and thinning; increased volume of glacial runoff; and increasing stream temperatures. Projections for the coming century include further changes in seasonal and annual precipitation patterns (both snow and rainfall), continued drying of existing wetlands, and sea level rise resulting from continued melting and retreat of glaciers. Observed and predicted bioregional changes in temperature and hydrology affect vegetation and wildlife through altered seasonality of runoff, increased wildfire and insect activity, movement of forests and shrublands into wetlands and recently deglaciated areas, phenological shifts (altered timing of reproductive events such as fish spawning and bud burst), and major directional and elevational shifts in plant distributions and community assemblages. Direct effects of bioregional climate changes on human populations and infrastructure are structure damage from thawing permafrost, altered soil conditions, and shifts in water and plant communities, which may, in turn, affect animal communities and alter fire regimes. Changes in terrestrial and marine wildlife distributions may affect visitor viewing opportunities and complicate subsistence hunting throughout the region.

List of Parks and Refuges

U.S. National Park Service Units

- Alagnak Wild River
- Aleutian World War II NHA
- Aniakchak NM & NPR
- Denali NP & NPR
- Glacier Bay NP & NPR
- Katmai NP & NPR
- Kenai Fjords NP
- Klondike Gold Rush NHP
- Lake Clark NP & NPR
- Sitka NHP
- Wrangell - St Elias NP & NPR (southen portion)

U.S. Fish & Wildlife Service Units

- Alaska Maritime NWR
- Alaska Peninsula NWR
- Becharof NWR
- Izembek NWR
- Kenai NWR
- Kodiak NWR
- Togiak NWR

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

Temperature
Water Cycle
Vegetation
Wildlife
Disturbance
Cultural Resources
Visitor Experience

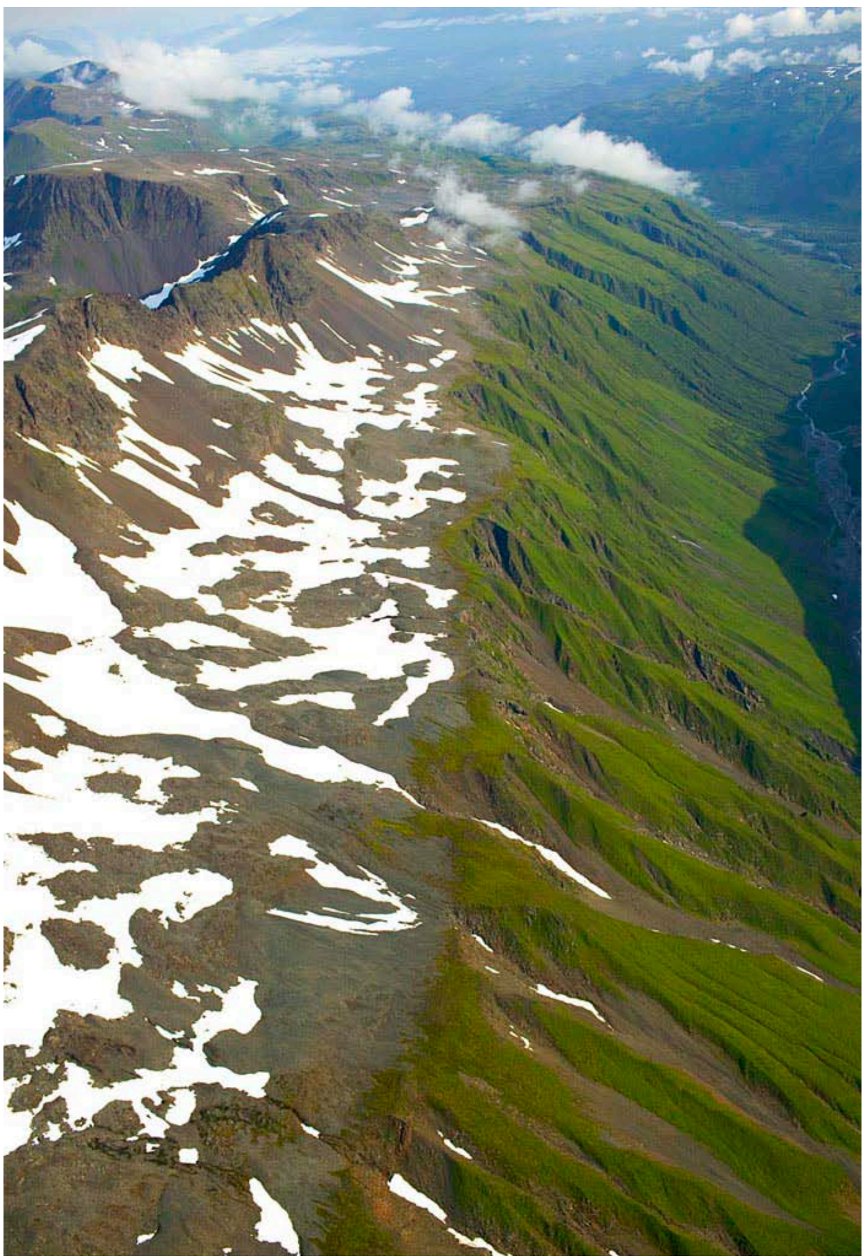
A. TEMPERATURE

What scientists know….

- Mean annual temperatures in Alaska increased an average 1.7°C over the last six decades, with a general warming rate of 0.16 to 0.37°C per decade from 1951 to 2001 (Alaska Climate Research Center et al. 2009; Hartmann and Wendler 2005).

- From 1949 to 2009, regional mean annual temperatures for the Arctic, Interior, and West Coast of Alaska increased by 1.4 to 2.5°C (2.5 to 4.5°F) and the greatest change in mean seasonal temperatures (2.3 to 4.9°C, 4.1 to 8.8°F) was observed in the winter (Alaska Climate Research Center 2010).

Aerial view of deglaciated mountains at Kodiak National Wildlife Refuge; USFWS photo.



- Maximum temperature increases were observed throughout Alaska; the greatest increases were observed during the spring with an average increase of 0.46°C (0.83°F) per decade (Keyser et al. 2000). Average maximum temperatures increased per decade 0.14°C (0.25°F) in the summer and 0.24°C (0.43°F) in the winter (Keyser et al. 2000).

- The greatest temperature increases in the Alaska Maritime and Transitional bioregion were observed during winter months. Air temperatures increased by 1.1 to 2.9° C (~ 2.0 to 5.2°F) between 1951 and 2001 (Hartmann and Wendler 2005). From the period 1948 to 2009, temperature increases throughout the region ranged from 0.5 to 2.7°C (0.1 to 4.9°F). The greatest temperature increases were observed in Talkeetna (+2.7°C, or 4.9°F), a community on the transitional area between maritime and boreal climate. Observed temperatures increased the least in the community of Kodiak (0.5°C, or 0.1°F), on the shores of Kodiak Island in the Gulf of Alaska, where temperatures are heavily moderated by ocean processes (Alaska Climate Research Center, Geophysical Institute et al. 2009).

- In southern and southeast Alaska the annual mean diurnal temperature range (difference between daily maximum and minimum temperatures) decreased by 0.9 °C (1.62 °F), and the winter diurnal temperature range decreased by 1.8 °C (3.24 °F), between 1949 and 1998 (Stafford et al. 2000). Four of the 25 locations used in the study showed significant decreases for all seasons: Anchorage, Juneau, Seward, and Talkeetna (Stafford et al. 2000).

- The majority of Alaskans polled anticipate that global climate change will result in more comfortable temperatures (Leiserowitz and Craciun 2006).

What scientists think is likely….

- Historical temperature trends for Seward, Alaska, the "jumping-off point" for Kenai Fjords National Park, indicate that from 1961 to 1990 average monthly temperatures were below freezing for five months of the year. In contrast, climate models based on mid-range emissions scenarios

At Kenai Fjords National Park an iceberg floats in Bear Glacier Lake. The glacier is undergoing a rapid retreat; NPS photo.

predict that by 2031 average monthly temperatures will be below freezing for three months of the year, and by 2061 average temperatures above freezing are predicted for all months of the year (Scenarios Network for Alaska Planning 2010b).

- In King Salmon, the community outside Katmai National Park and Preserve, the number of months with an average temperature below freezing will decrease by 50% by 2061, as compared to historical records (Scenarios Network for Alaska Planning 2010a).

- Models project an overall decrease in the number of frost days (days with a nighttime temperature below 0°C) by the end of the 21st century, with the most significant changes in the northwest U.S. (Meehl et al. 2004).

What scientists think is possible….

- Annual mean temperatures are predicted to increase at an average rate of 0.56°C (1.0°F) per decade for Alaska National Park units (Rupp and Loya 2009a, b, c, d, e, f, h), with the exception of Sitka National Historical Park where the rate of increase is predicted to be 0.34°C (0.61°F) per decade (Rupp and Loya 2009g).

- Average annual temperatures in Lake Clark National Park and Preserve and Wrangell-St. Elias National Park and Preserve are predicted to shift from below freezing to above freezing during the 21st century (Rupp and Loya 2009f, h).

- Average winter temperatures are predicted to shift from below freezing to above freezing (increases of 3.92 to 5.6°C, or 7.0 to 10.0°F) by 2080 for Aniakchak National Monument and Preserve, Glacier Bay National Park and Preserve, Katmai National Park and Preserve, and Kenai Fjords National Park (Rupp and Loya 2009a, b, c, d).

B. THE WATER CYCLE

What scientists know….

- All Alaskan glaciers below ~1,500 m (4,905ft) above sea level in elevation are melting, and many of Alaska's 100, 000 glaciers (including tidewater formations) are retreating and/or thinning (Molnia 2007, 2008).

- The melting rate of glaciers throughout Alaska has increased in recent decades, as has their contribution to sea level rise (Dyurgerov and Meier 2000; Larsen et al. 2007a). From the mid 1990s to the early 2000s, the rate of glacial thinning in Alaska tripled compared to the mid 1950s to mid-1970s time period; the loss of ice during this period was equivalent to nearly twice the estimated annual loss of ice from the Greenland Ice Sheet. Over the last half of the 20th century, Alaska glaciers contributed the largest single measured glaciological contribution to sea level, with a total annual volume change of –52 ± 15 km^3/year (12.3 ± 3.6 $miles^3$) water equivalent, which equates to a rise in sea level of 0.14mm ± 0.04 mm/year, (0.006 ± 0.002 in/year). (Arendt et al. 2002).

- The rate of thinning of glaciers in southeast Alaska, including some glaciers within Glacier Bay National Park, has increased in recent years (Arendt et al. 2002). The Mendenhall Glacier near Juneau has retreated a distance of 4.5 kilometers (2.8 miles) since the end of the Little Ice Age in the late 19th century, and its rate of retreat has increased since the late 1990s to a pace in excess of 50 meters per year (Kelly et al. 2007).

- Glaciers in the mountains around the Gulf of Alaska have lost a mass equivalent in volume to approximately 124 km^3 (29.5

miles^3)per year between 2002 and 2005 (Chen et al. 2006).

- Between 2003 and 2007, elevation change was observed in the glaciers of the St. Elias Mountains, several of which are within Wrangell-St. Elias National Park. The mass balance of these glaciers was reduced by approximately 21 gigatons per year, which equates to approximately 0.64m (2.1ft) per year water equivalent. Runoff from the melting ice makes its way to the ocean, where it contributes to sea level rise (Arendt et al. 2008).

- The estimated total volume change of the Harding Icefield and associated glaciers, more than 50% of which are contained in Kenai Fjords National Park, decreased by 34 km^3 (8.1 miles^3), with an average decrease in elevation of 21 m (68.7 ft), between the 1950s and the mid-1990s (Aðalgeirsdóttir et al. 1998); this rate of thinning increased by 1.5 times between the mid-1990s and 1999 (Vanlooy et al. 2006).

- The terminus of Exit Glacier, a main attraction in Kenai Fjords National Park, retreated a distance of 500m (1,635ft) and thinned by 80 to 90m (262 to 294ft) in the lower region between 1950 and 1990 (Aðalgeirsdóttir et al. 1998).

- Glacial recession in Southeast Alaska affects the physical and biochemical condition of streams and the land-to-ocean flux of organic and inorganic nutrients (Hood and Durelle 2008).

The rate of thinning of some glaciers in Glacier Bay has increased in recent years. Johns Hopkins Glacier at Glacier Bay National Park; NPS photo.

- In streams with a large glaciated area as part of their watershed, turbidity is higher and water temperatures and conductivity are lower as the proportion of glaciation increases. Glacial meltwater lowers stream temperatures and provides streams with a source of nitrogen rich dissolved organic matter and phosphorus via rock weathering. Lower stream temperatures, higher turbidity, and inputs of glacial meltwater all influence the timing and viability of salmon runs in coastal streams (Hood and Berner 2009).

- Between the months of May and October, stream temperatures in southcentral Alaska were coldest for streams with watershed containing more than 25% glacial influence (Kyle and Brabets 2001).

- Snow patterns in Alaska have changed in the past five decades. From 1972 to 2000, the duration of the snow-free period increased by 3 to 6 days per decade, and the first week in spring without snow cover shifted to 3 to 5 days earlier per decade (Dye 2002).

- In Juneau, average winter snowfall at sea-level decreased from 277 to 236 cm (109 to 93 inches) from 1943 to 2005, but overall precipitation increased by 6.6 cm (2.6 inches) (Kelly et al. 2007).

- In southern and southeast Alaska, timing and amount of annual and seasonal mean precipitation changed between 1949 and 1998. Annually, there was a 10% increase in precipitation, with the greatest increase (22%) in the winter and a 1% decrease in mean summer precipitation. A 17% annual increase was observed in Seward; Yakutat was the only station that showed increased precipitation during all seasons (Stafford et al. 2000).

- From 2001 to 2007, a study of the lake ice season of multiple lakes in Lake Clark National Park and Preserve, Katmai National Park and Preserve, and Kenai National Wildlife Refuge found that winter temperatures and weather conditions influence the timing of freeze-up and break-up and the duration of lake ice (Reed et al. 2009).

Temperature

Water Cycle

Vegetation

Wildlife

Disturbance

Cultural Resources

Visitor Experience

- Between 1950 and 1996, over 80% of wetland sites surveyed on the Kenai Peninsula had experienced some degree of drying and nearly 66% of wetland sites had decreased in area (Klein et al. 2005).

What scientists think is likely….

- Twentieth century climate warming on the northern margin of Bagley Icefield is more intense, and accompanied by more extensive glacier retreat, than the Medieval Warm Period or any other time in the last 1,500 years (Loso et al. 2007).

- As watersheds become deglaciated and plant succession occurs, the input of organic carbon and inorganic nitrogen into the streams will be altered, thereby changing the land-to-ocean fluxes of nutrients (Hood and Durelle 2008).

- High-latitude surface waters are expected to experience rapid ocean acidification, a process in which atmospheric CO_2 is absorbed into ocean water, forming carbonic acid. Cold water, shallow continental shelves, melting sea ice, and high productivity of Alaska's marine waters facilitate the increased absorption of CO_2, reduced deep water circulation, and decomposition; all contribute to increased acidification compared to other regions (Fabry et al. 2009).

- Models project that precipitation will increase in all national park units in this bioregion from 7 to 13% in the summers and 7 to 26% in the winter months. Due to increased evapotranspiration (the transport of water into the atmosphere from surfaces, including soils and vegetation) from temperature increases and lengthened growing seasons, the summer and fall seasons will be drier than they are currently (Rupp and Loya 2009a, b, c, d, e, f, g, h).

Visitors walk a trail at Exit Glacier, a main attraction in Kenai Fjords National Park. The terminus of Exit Glacier has retreated significantly in the last 50 years, NPS photo.

What scientists think is possible….

- Recent projections of the contribution of glaciers and ice caps to sea level rise are higher than were determined in previous assessments. Current projections suggest that glaciers and ice caps may exceed or equal the contribution of the Greenland and Antarctic ice sheets to sea level rise throughout the next century; the volume of the glaciers and ice caps will be decreased less than 35%, leaving substantial volume for additional future melting (Meier et al. 2007).

C. VEGETATION

What scientists know….

- Based on a meta analysis of studies examining phenological shifts (shifts in life cycle processes), species at higher latitudes are more sensitive to climatic change than species that exist at lower latitudes (Root et al. 2003).

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

- Between 1980 and 2000, a trend toward earlier spring budburst and increased maximum leaf area at high northern latitudes was observed, mainly due to changes in temperature (Lucht et al. 2002).

- Based on over 40 years of data collected across Alaska, the growing season has

Vegetation colonization has been observed in deglaciated areas throughout the Southwest Alaska Network. Above, photographs of Bear Glacier in Kenai Fjords National Park from 1909 (top) and 2005 (bottom) show a previously glaciated area now dominated by forest. NPS photos.

lengthened by an average of 2.6 days per decade. For the Maritime and Transitional bioregion, the growing season lengthened between 1.51 (Talkeetna) and 6.97 (Yakutat) days per decade (Keyser et al. 2000).

- On the Kenai Peninsula, wooded regions increased in area by 28% between 1950 and 1996,while open, wet, and watered areas decreased in size. Type shifts from wetlands to upland habitats were observed during the same time period (Klein et al. 2005).

- Comparisons of historical (ca. late 1800s to early 1900s) photographs with current (2004 to 2006) photos reveal that following glacial retreat in national parks in southwest Alaska, coastal areas experienced a striking level of vegetation colonization, but vegetation colonization in higher elevation areas was less marked (Jorgenson and Bennett 2006).

- Treeline expansion was documented from photo comparisons in Katmai National Park and Preserve and Lake Clark National Park and Preserve. In Katmai, white spruce (*Picea glauca*) and Kenai birch (*Betula papyrifera* Marsh. var. *kenaica*) cover has increased since 1919. White spruce forests have advanced in elevation in Lake Clark in the past 75 years; at most sites below 850 meters (2788 ft) in elevation, where Krummholz spruce were present in photos from 1928 to 1929, the size and number of these trees has increased (Jorgenson and Bennett 2006).

- Shrub expansion into uplands was documented along granitic ridges, where shrub cover increased from less than 50% between 1928 and 1929 to over 75% between 2004 and 2006 (Jorgenson and Bennett 2006). A preliminary comparison of aerial photographs from 1950 to 2005 in Kenai Fjords National Park documented conversion of two to 14% of barren areas to shrub cover, for all fjords studied. In Northwestern fjord, an area that is experiencing rapid glacial retreat, 39% of the areas that were once ice-covered have been converted to shrublands (Boucher et al. 2009).

What scientists think is likely….

- The decline in Alaskan yellow-cedar (*Callitropsis nootkatensis*), a widespread species across southeastern Alaska, may be due to lack of late season snow pack that helps to insulate the roots and protect them from spring freezes. The yellow cedars migrated to lower elevations during the Little Ice Age and have experienced declines as the temperatures have warmed (Hennon et al. 2006).

- Forest 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).

What scientists think is possible….

- Based on a model for lands directly adjacent to southeast Alaska in British Columbia, the majority of trees and vegetation classes are predicted to shift northward and upward in elevation. Mountain hemlock (*Tsuga mertensiana*), alpine tundra, and plants within the spruce-willow-birch zone are expected to shift more than 500m (1, 635ft) upward in elevation by 2085. The greatest shift northward is predicted for ponderosa pine (*Pinus ponderosa*) (614km, or 381 miles), by 2085 (Hamann and Wang 2006).

- By 2085, the spatial extent of alpine tundra, sthe Sub-Boreal Pine-Spruce Zone (composed mainly of dry lodgepole pine [Pinus contorta] forests and wetlands), and the Spruce-Willow-Birch Zone in areas adjacent to southeast Alaska in British Columbia, may decrease by 97%, 98%, and 99%, respectively. Within this region the species distributions of bunchgrass, ponderosa pine, and coastal Douglas-fir are expected to increase in spatial extent by 773%, 452%, and 336% (Hamann and Wang 2006).

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 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 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).

- The body size of masked shrews in Alaska increased significantly during the second half of the twentieth century. Evidence indicates that warmer winter weather conditions increased the survival rate of shrew's prey (small invertebrates that are sensitive to the cold), providing greater food availability for the shrew (Yom-Tov and Yom-Tov 2005).

- As glaciers retreat, new land and streams become available for colonization by fish and wildlife. In Glacier Bay National Park, salmon and Dolly Varden were captured in several recently deglaciated streams, including streams less than 50 years old (Milner et al. 2000).

- Average water temperatures during the incubation period of native pink salmon (*Oncorhynchus gorbuscha*) in Auke Creek, near Juneau, increased at a rate of 0.03 °C (0.05 °F) per year from 1972 to 2005. Over the same time period a trend of earlier migration of pink salmon fry was observed, at a rate of −0.5 days per year, and the migration timing of adult salmon into Auke Creek also showed a trend toward earlier timing (Taylor 2008).

- An 84% decline in Kittlitz's murrelets (Brachyramphus brevirostris), a diving seabird of relatively low abundance found only in Alaska and eastern Siberia, was observed in Prince William Sound from 1989 (6400 birds observed) to 2000 (1000 birds observed). During this period, bird distribution in the sound shifted from a fairly dispersed pattern to concentration in the northwest region. Fjords from which this species disappeared had receding glaciers as of the late 1980s, or had no direct glacial input, indicating a link between the decline of Kittlitz's murrelets and glacial recession (Kuletz et al. 2003).

Salmon are highly vulnerable to the effects of climate change due to their dependence on cold water for life cycle processes. Brown bears and other species that depend on salmon as a food source are directly affected by changes in salmon populations. NPS photos.

Harbor seals haulout on ice calved from glaciers at Glacier Bay. Harbor seals rest, give birth, and molt on calved ice. Glacier Bay was once home to one of the largest harbor seal breeding colonies in Alaska, but populations have declined significantly, coinciding with a reduction in ice calving in the bay. NPS photo.

Kittlitz's murrelets are losing habitat as glaciers retreat, and may disappear entirely from some areas of Alaska; NPS photos.

- In Glacier Bay National Park, Populations of Kittlitz's muurelets (Brachyramphus brevirostris) and marbled murrelets (Brachyramphus marmoratus) declined between 1991 and 2003, likely due to dramatic changes in glacial-marine habitats and alterations in terrestrial nesting habitats (Drew et al. 2007)

- The Audubon Christmas Bird count, a citizen science project, has documented that the center of the mean annual latitudinal center of abundance for over 300 bird species shifted northward nearly 35 miles (56.4 km) between 1966 and 2004. There is a significant correlation between temperature trends and shifts in the center of abundance. The mean latitudinal shift for the pine siskin, a small finch and year-round resident of southern Alaska, was approximately 288 miles (463.7km) north (Niven and Butcher 2009).

What scientists think is likely….

- Changes to the terrestrial and aquatic species compositions in parks and refuges are likely to occur as ranges shift, contract, or expand. Rare species and/or communities may be at further risk, and additional species could become rare (Burns et al. 2003).

- Parks and refuges may not be able to meet their mandate of protecting species that live 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).

- Models suggest that the distribution of the little brown bat will expand northward in Alaska in the next century in response to warming temperatures and shorter winters in its current range (Humphries et al. 2002).

- Coastal seabirds such as the arctic ivory gull, (*Pagophila eburnea*), aleutian tern (*Onychoprion aleuticus*), and Kittlitz's murrelet (*Brachyramphus brevirostris*) show medium or high vulnerability to climate change due to their low reproductive potential and their reliance on marine food webs that are also threatened by climate change (NABCI 2010).

- Kittlitz's Murrelet populations will continue to decline as glacial retreat results in the loss of more important habitats (USFWS 2006).

- Thawing permafrost may result in changes in the distribution and abundance of waterfowl, shorebirds, and gulls due to shifts in the types and locations of plant communities and changes in surface water availability; contaminants such as mercury and organic pollutants may also be released into the aquatic environment as the permafrost thaws, increasing contaminant exposure for birds that rely on the marine ecosystem for food (NABCI 2010).

- Ocean acidification will make shell building and carbonate skeletal development more difficult for pteropods, sea urchins, molluscs, and other marine organisms. It will also impact growth, reproduction, and survival of many marine organisms, including pteropods, which make up nearly half of the pink salmon's diet (Fabry et al. 2009).

- Changes in community organization in the Bering Sea caused by warming climate and associated loss of sea ice will alter availability of snow crab and other fisheries resources (Mueter and Litzow 2008)

What scientists think is possible….

- As temperatures increase in oceans and streams, salmon migration, spawning and incubation times may no longer match favorable environmental conditions, and habitat areas like Auke Creek, near Juneau, may become unsuitable for pink salmon (Taylor 2008).

- Stream temperature models for Cook Inlet Basin in south-central Alaska predict water-temperature changes of around 3 °C (5.4 °F) with a doubling of atmospheric CO_2, a magnitude of change that is considered significant for the incidence of disease in fish populations (Kyle and Brabets 2001).

- Because harbor seals in southeast and south central Alaska are dependent on tidewater glaciers for resting, molting, and calving sites, loss of glacial ice may limit recovery of already-diminshed harbor seal populations and force seals to move away from Glacier Bay, spend more time in the water, or use terrestrial habitat areas. Glacier Bay was once home to one of the largest harbor seal breeding colonies in Alaska, but between 1992 and 2008 the number of harbor seals and the harbor seal pup count declined significantly, and the long-term trend estimate for harbor seals at Johns Hopkins Inlet in Glacier Bay shows a population decline of 12.4% per year, with pup count decreasing by 5.0% per year (Womble 2010, Mathews and Pendleton 2007).

- An analysis of potential climate change impacts on mammalian species in U.S. national parks indicates that with a doubling of atmospheric CO_2, about 8% of current mammalian species diversity may be lost on average. The greatest losses across all parks occurred in rodent species (44%), bats (22%), and carnivores (19%). Species are projected to decline in direct proportion to their current relative representation within parks. (Burns et al. 2003).

Foresters examine a tree that has suffered infestation of spruce bark beetle; USFWS photos.

- Changing vegetation cover in many park areas will affect wildlife species dependent on those habitats. Animals will eventually occupy landscapes vacated by glacial ice, and utilize new alpine lakes after ice is gone (Burkett et al. 2005).

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

- Earlier onset of spring may initially increase productivity of nesting shorebirds, if they are able to change their migration and nesting schedules to coincide with the time when the most insects are available (NABCI 2010).

E. DISTURBANCE

What scientists know….

- Insect outbreaks increase in range and frequency with increased temperatures (Juday et al. 2004, Berg et al. 2006).

- In southcentral Alaska in the 1990s a spruce bark beetle (Dendroctonus rufipennis) outbreak, likely related to extremely high summer temperatures, affected two to three million trees, killing all spruce trees greater than 10 centimeters (3.9 inches) in diameter in some stands (Juday 1998, Berg et al. 2006).

- Tree-ring records indicate that spruce bark beetle outbreaks have occurred on the Kenai Peninsula approximately every 52 years for the past 250 years, following 5 to 6 years of warm summer temperatures and mild winters. These warm temperatures likely influence spruce beetle population size through a combination of increased overwinter survival, a doubling of the maturation rate from 2 years to 1 year, and regional drought-induced stress

Modeling shows that warming temperatures in the bioregion could lead to more fires, and that those fires may be larger than the fire events of the past. NPS photo.

of mature host trees; if the recent warming trend continues, endemic levels of spruce beetles will likely be high enough to perennially thin forests as soon as the trees reach susceptible size (Berg et al. 2006).

- Climate warming that results in rapid glacial melting ("wastage"), such as that observed in recent decades in southeast Alaska, can excite a very large solid earth response through the process of isostatic rebound (rise of land masses depressed by the weight of ice masses). This can impact regional faulting and seismic activity (Larsen et al. 2005). Land uplift since the late 18th century has been approximately 3.15 meters (10.5 feet) in Juneau, and up to 3.0 centimeters (1.2 inches) per year in areas around Glacier Bay National Park (Kelly et al. 2007).

What scientists think is likely….

- Due to ocean acidification, there has been a decrease in sound absorption. Based on current projections of future pH values for the oceans, a decrease in sound absorption of 40% is expected by mid-century (Hester et al. 2008).

- Glaciers melting and the associated rebound of the land (isostatic rebound) may produce a myriad of impacts including increased frequency of earthquakes. Based on evidence from former melting events, it is predicted that isostatic rebound may decrease fault stability margin and increase thrust faulting events such as earthquakes and aftershocks (Sauber and Molnia 2004).

- Glacier Bay National Park contains some of the fastest measured rates of uplift in the world. This uplift is occurring in direct relationship with glacial ice reduction and sea level rise, and has been caused primarily by these climatic changes rather than seismic factors. These changes in glacial ice loading can affect seismicity and regional tectonics and contribute to changes in hydrologic patterns, erosion, sedimentation, and changes to shorelines (Motyka et al. 2007).

- It may take decades for a spruce forest to recover from a spruce bark beetle outbreak and for there to be sufficient numbers of mature trees to sustain future beetle attacks (Berg et al. 2006).

- In the decades following a major tundra fire on a hillslope in the Seward Peninsula, vegetation population shifts, major permafrost thawing, soil decomposition, and surface subsidence were observed, suggesting that similar fire events in other permafrost areas could result in similar impacts (Racine et al. 2004).

What scientists think is possible….

- Land uplift in the Juneau area due to isostatic rebound may offset the impacts of rising sea levels in the area, as the land is expected to rise above the projected sea level (Kelly et al. 2007).

- *Ichthyophonus*, a parasite that causes mortality in fish populations and is easily and rapidly spread among fishes, infected 45% of Chinook salmon in the Yukon River and about 30% of the salmon in the Tanana River between 1999 and 2003. Warming water temperatures may have contributed to these levels of infection, as the parasite was not reported to affect salmon in these rivers before 1985 (Kocan et al. 2004).

- Model simulations suggest that a warming climate may result in greater number of fires and as much as a 22% increase in the regional area burned, as the result of both increased vegetation flammability in direct response to increased temperatures and expansion of forested areas into previously treeless tundra (Dale et al. 2001; Rupp et al. 2000).

- The majority of Alaskans polled anticipate that global climate change will cause increased flooding, worse storms, fewer salmon, and the extinction of the polar bear (Leiserowitz and Craciun 2006).

CULTURAL RESOURCES

What scientists know….

- Sea level rise, increased storm surges, and the impacts of permafrost erosion to infrastructure have begun to impact Native Alaskan communities, diverting resources from subsistence activities and in some cases requiring relocation of entire communities (Callaway 2007).

- The tribal community at Nelson Lagoon is facing increased threats to its village infrastructure from storm surges. For example, their shoreline breakwalls have been weakened by the melting shore ice and increasingly violent storms (ACIA 2004).

Remnant ice patch site discovered in Lake Clark National Park and Preserve in 2009 yielding the late prehistoric antler arrow point shown above. Photos courtesy of J. Schaaf.

- Relocating indigenous communities represents a large financial cost for governments, but also impacts the communities themselves, potentially resulting in loss of integral cultural elements such as access to traditional use areas for subsistence activities, loss of history and sense of intact community, and potential loss of social networks and extended kin support (Callaway 2007).

- Some traditional subsistence practices are more expensive and time-consuming than in the recent past, due to difficult hunting conditions associated with climate change impacts. These changes can place a strain on subsistence communities, and in some cases can be a deterrent to engaging in traditional hunting at all; for example, as sea ice conditions change, marine mammals may follow sea ice retreat, altering their distribution and taking them out of range for some hunters (Berman and Kofinas 2004; Callaway 2007; Hanna 2007).

- Aleut tribes have reported changes in local marine life populations that affect subsistence harvests, including increased presence of salmon sharks, reductions in eider populations, and changes in season for northern fur seals and Steller sea lion (ACIA 2004).

- According to the Alaska Department of Resources, Division of Lands, the winter tundra travel season on the Arctic North Slope has decreased from about 200 days in the 1970s to about 120 days in the early 2000s. Reliable travel over the frozen tundra enables natural resource development, access to subsistence sites, and travel between villages (Bradwell et al. 2004).

- The majority of Alaskans polled believe that global warming will seriously impact their families, communities, plants, and animals. Many believe that it will have serious impacts to Alaska within a decade (Leiserowitz and Craciun 2006).

What scientists think is likely....

- In Lake Clark National Park and Preserve, shoreline erosion in Chinitna Bay may threaten archeological sites near Clam Cove (Cusick and Bennett 2005).

- As glaciers and ice melt, cultural resources may be uncovered. Artifacts have been recovered from ice patches in Wrangell-St. Elias National Park. For example, five prehistoric sites were identified that contained artifacts ranging in age 370 to 2880 years before present. Such artifacts can provide unprecedented glimpses into the lives of ancient people (Dixon et al. 2007).

- Subsistence communities have expressed concerns about increased pollution and its potential effects on the natural environment's ability to respond to climate change. For example, because heavy met-

A hiker at False Summit, along the Chilkoot Trail at Klondike Goldrush National Historical Park (Top). Fishing has been an important part of the economic and cultural heritage of Alaska as shown in this historic photo from Lake Clark National Park and Preserve (Bottom). NPS Photos.

als and other contaminants bio-accumulate up the food chain, there are concerns that marine mammals and other animals harvested for subsistence could be sources of contaminants for hunters and their families as changes in circulatory patterns of water and air bring contaminants into the natural system (Callaway 1999). Researchers have found contaminants and heavy metals in animals harvested for subsistence in the Arctic (Cooper et al. 2000; Dehn et al. 2006).

What scientists think is possible....

- Migration patterns of terrestrial animals are predicted to change as temperatures, precipitation patterns, and vegetation availability change. An alteration in migration patterns will make hunting more challenging (Callaway 1999; ACIA 2004).

- Climate change may affect people's ability to conduct subsistence harvests due to changes in wildlife distribution and availability. Subsistence harvesting activities are linked to the health of rural residents in several ways, including the physical exertion of a hunt that promotes mental and physical well being, the nutritional value of harvested food items compared to store-bought food, and the value of maintaining a traditional diet (Callaway 1999).

VISITOR EXPERIENCE

What scientists know….

- A study of climate effects on tourism in King Salmon (near Katmai National Park and Preserve) and Anchorage shows climate warming has had both positive and negative effects on opportunities for tourism. The longer warm season has improved overall weather conditions for sightseeing in King Salmon, while weather conditions for skiing in Anchorage have deteriorated since the 1940s (Trainor et al. 2010).

- Glaciers, a main tourist attraction in many parks, are disappearing. This is happening throughout Alaska, including at national parks such as Wrangell St.-Elias and Kenai Fjords (Adema et al. 2007; Dyurgerov and Meier 2000; Larsen et al. 2007a; Molnia 2007; Rupp and Loya 2009).

- With increasing temperatures and more snow-free days, the length of the potential summer tourist season in Alaska is increasing (Alaska Climate Research Center 2009; Dye 2002).

What scientists think is likely....

- A study at Kenai Fjords National Park determined sea level rise and wave height increases could impact park resources through erosion and loss of gravel beaches along rocky coastlines. These pocket beaches are currently used recreationally by sea kayakers (Pendleton et al. 2006).

- The locations of climatically ideal tourism conditions are likely to shift toward higher latitudes under projected climate change, 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 these changes (Amelung et al. 2007).

What scientists think is possible....

- Damage to roads, buildings, and other infrastructure is predicted with climate change, due largely to permafrost thawing (ACIA 2004; Smith and Levasseur 2003). Damage could increase future costs for Alaska's public infrastructure from 3.6 to 6.1 billion dollars (10% to 20%) by 2030 to 5.6 to 7.6 billion dollars (10% to 12%) by 2080 (Larsen et al. 2007b).

- The majority of Alaskans polled believe that tourism will increase as a result of global climate change (Leiserowitz and Craciun 2006).

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, appliances 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 park Environmental Management System.
- Conduct an emissions inventory and set goals for CO_2 reduction.
- Provide alternative transportation options such as employee bicycles and shuttles for within-unit commuting.
- Provide hybrid electric or propane-fueled vehicles for official use, and impose fuel standards for park vehicles. Reduce the number and/or size of park vehicles and boats to maximize efficiency.
- Provide a shuttle service or another form of alternate transportation for visitor and employee travel to and within the unit.
- Provide incentives for use of alternative transportation methods.
- Use teleconferences and webinars or other forms of modern technology in place of travel to conferences and meetings.

Implement Management Actions

- Engage and enlist collaborator support (e.g., tribes, nearby agencies, private landholders) in climate change discussions, responses, and mitigation.
- Develop strategies and identify priorities for managing uncertainty surrounding climate change effects in parks and refuges.
- Build a strong partnership-based foundation for future conservation efforts.
- Identify strategic priorities for climate change efforts when working with partners.
- Incorporate anticipated climate change impacts, such as decreases in lake levels, rising sea levels, or changes in vegetation and wildlife, into management plans.
- Encourage research and scientific study in park units and refuges.
- Design long-term monitoring projects and management activities that do not rely

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.

solely on fossil fuel-based transportation and infrastructure.

- Incorporate products and services that address climate change in the development of all interpretive and management plans.

- Take inventory of the facilities/boundaries/species within your park or refuge that may benefit from or be vulnerable to climate change mitigation or adaptation activities.

- 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.

- Anticipate potential landscape and sea-level changes when designing new or replacement facilities and infrastructure, including positioning new facilities to avoid or mitigate impact from sea level rise or permafrost thawing.

- Work with native communities to identify climate refugia as special places for sustaining traditional subsistence living.

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 resilience.

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

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.

"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

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

Individuals can...

- In the park or refuge park their car and walk or bike. Use shuttles where available. Recycle and use refillable water bottles. Stay on marked trails to help further ecosystem restoration efforts.
- At home, walk, carpool, bike or use public transportation if possible. A full bus equates to 40 fewer cars on the road. When driving, use a fuel-efficient vehicle.
- Do not let cars idle - letting a car idle for just 20 seconds burns more gasoline than turning it off and on again.
- Replace incandescent bulbs in the five most frequently used light fixtures in the home with bulbs that have the ENERGY STAR® rating. If every household in the U.S. takes this one simple action we will prevent greenhouse gas emissions equivalent to the emissions from nearly 10 million cars, in addition to saving money on energy costs.

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. All statements in this section are synthesized from the IPCC report unless otherwise noted.

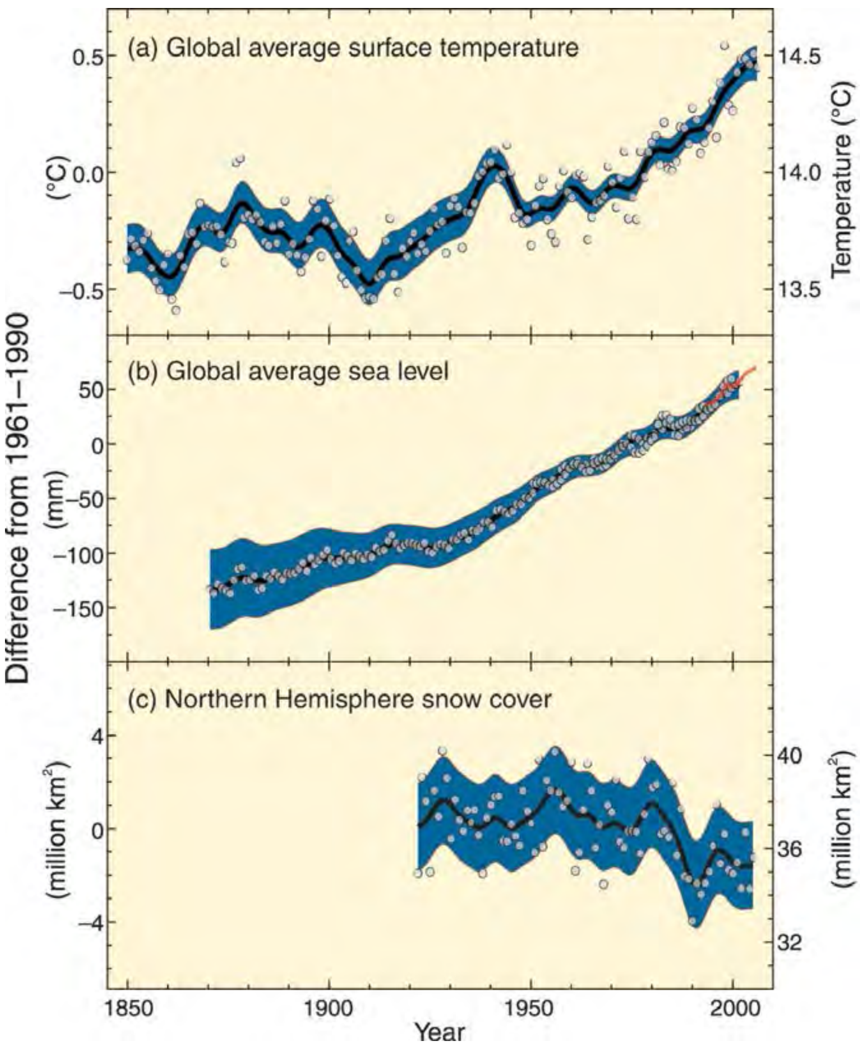


Figure 1. Observed changes in (a) global average surface temperature; (b) global average sea level from tide gauge (blue) and satellite (red) data and (c) Northern Hemisphere snow cover for March-April. All differences are relative to corresponding averages for the period 1961-1990. Smoothed curves represent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

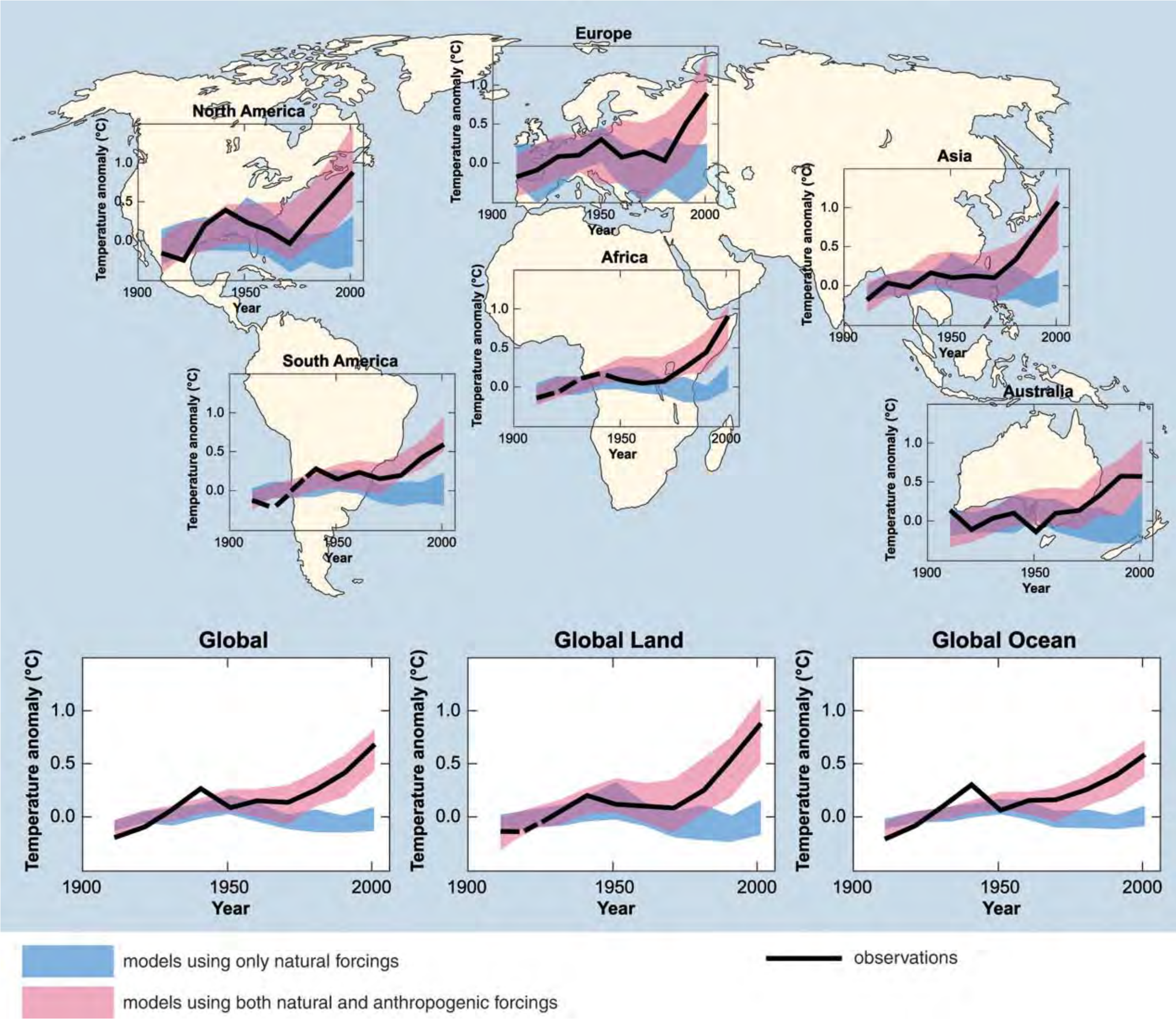


Figure 2. Comparison of observed continental- and global-scale changes in surface temperature with results simulated by climate models using either natural or both natural and anthropogenic forcings. Decadal averages of observations are shown for the period 1906-2005 (black line) plotted against the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

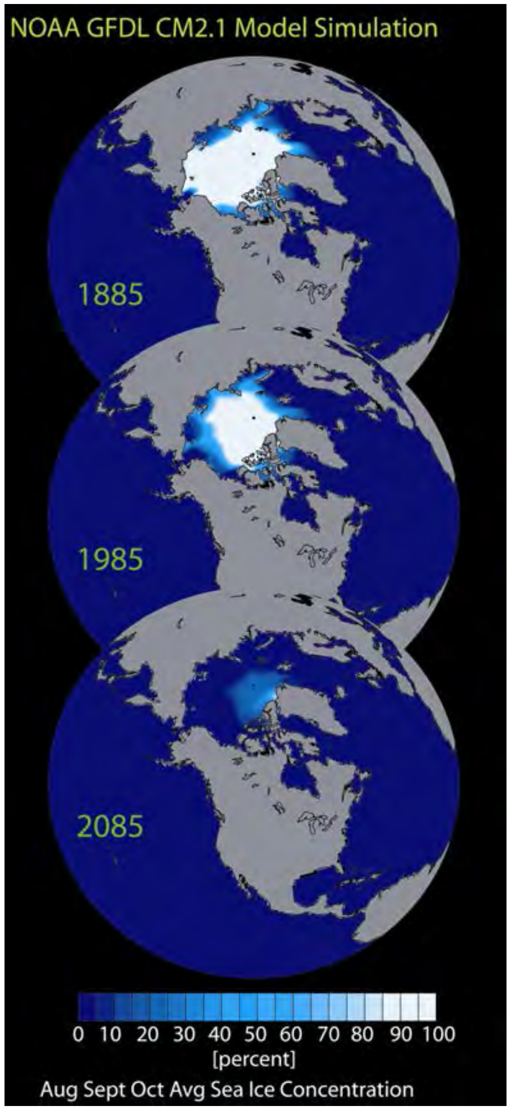
- Global temperatures are projected to increase in the future, and the magnitude of temperature change depends on specific emissions scenarios, and ranges from a 1.1ºC to 6.4ºC increase by 2100 (Table 1).

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.



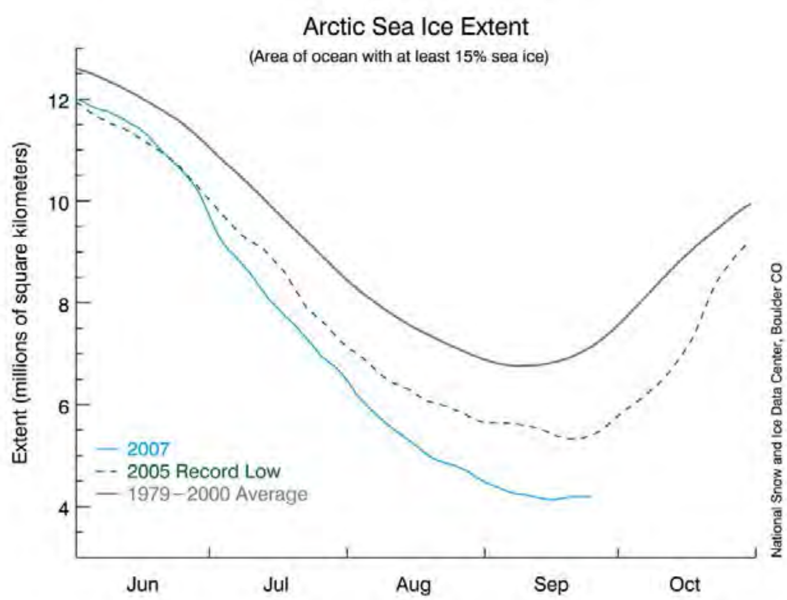


Figure 4. Arctic sea ice in September 2007 (blue line) is far below the previous low record year of 2005 (dashed line), and was 39% below where we would expect to be in an average year (solid gray line). Average September sea ice extent from 1979 to 2000 was 7.04 million square kilometers. The climatological 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 3ºC over pre-industrial levels.

B. Water, Snow, and Ice

What scientists know…

- Many natural systems are already being affected by increased temperatures, particularly those related to snow, ice, and frozen ground. Examples are decreases in snow and ice extent, especially of mountain glaciers; enlargement and increased numbers of glacial lakes; decreased permafrost extent; increasing ground instability in permafrost regions and rock avalanches in mountain regions; and thinner sea ice and shorter freezing seasons of lake and river ice (Figure 3).

- Annual average Arctic sea ice extent has shrunk by 2.7% per decade since 1978, and the summer ice extent has decreased by 7.4% per decade. Sea ice extent during the 2007 melt season plummeted to the lowest levels since satellite measurements began in 1979, and at the end of the melt season September 2007 sea ice was 39% below the long-term (1979-2000) average (NSIDC 2008)(Figure 4).

- Global average sea level rose at an average rate of 1.8 mm per year from 1961 to 2003 and at an average rate of 3.1 mm per year from 1993 to 2003. Increases in sea level since 1993 are the result of the following contributions: thermal expansion, 57%; melting glaciers and ice caps, 28%, melting polar ice sheets, 15%.

- The CO_2 content of the oceans increased by 118 ± 19 Gt (1 Gt = 109 tons) between A.D. 1750 (the end of the pre-industrial period) and 1994 as the result of uptake of anthropogenic CO_2 emissions from the atmosphere, and continues to increase by about 2 Gt each year (Sabine et al. 2004; Hoegh-Guldberg et al. 2007). This increase in oceanic CO_2 has resulted in a 30% increase in acidity (a decrease in surface ocean pH by an average of 0.1 units), with observed and potential severe negative consequences for marine organisms and coral reef formations (Orr et al. 2005: McNeil and Matear 2007; Riebesell et al. 2009).

- Oceans are noisier due to ocean acidification reducing the ability of seawater to absorb low frequency sounds (noise from ship traffic and military activities). Low-frequency sound absorption has decreased over 10% in both the Pacific and Atlantic over the past 200 years. An assumed additional pH drop of 0.3 (due to anthropogenic CO_2 emissions) accompanied with warming will lead to sound absorption below 1 kHz being reduced by almost half of current values (Hester et. al. 2008).

- Even if greenhouse gas concentrations are stabilized at current levels thermal expansion of ocean waters (and resulting sea level rise) will continue for many centuries, due to the time required to transport heat into the deep ocean.

- Observations since 1961 show that the average global ocean temperature has increased to depths of at least 3000 meters, and that the ocean has been taking up over 80% of the heat added to the climate system.

- Hydrologic effects of climate change include increased runoff and earlier spring peak discharge in many glacier- and snow-fed rivers, and warming of lakes and rivers.

- Runoff is projected to increase by 10 to 40% by mid-century at higher latitudes and in some wet tropical areas, and to decrease by 10 to 30% over some dry regions at mid-latitudes and dry tropics. Areas in which runoff is projected to decline face a reduction in the value of the services provided by water resources.

- Precipitation increased significantly from 1900 to 2005 in eastern parts of North and South America, northern Europe, and northern and central Asia. Conversely, precipitation declined in the Sahel, the Mediterranean, southern Africa, and parts of southern Asia (Figure 5).

What scientists think is likely….

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

- Model projections include contraction of snow cover area, widespread increases in depth to frost in permafrost areas, and Arctic and Antarctic sea ice shrinkage.

- The incidence of extreme high sea level has likely increased at a broad range of sites worldwide since 1975.

- Based on current model simulations it is very likely that the meridional overturning circulation (MOC) of the Atlantic Ocean will slow down during the 21st century; nevertheless regional temperatures are predicted to increase. Large-scale and persistent changes in the MOC may result in changes in marine ecosystem productivity,

Figure 5. Relative changes in precipitation (in percent) for the period 2090-2099, relative to 1980-1999. Values are multi-model averages based on the SRES A_1B scenario for December to February (left) and June to August (right). White areas are where less than 66% of the models agree in the sign of the change and stippled areas are where more than 90% of the models agree in the sign of the change (IPCC 2007a).

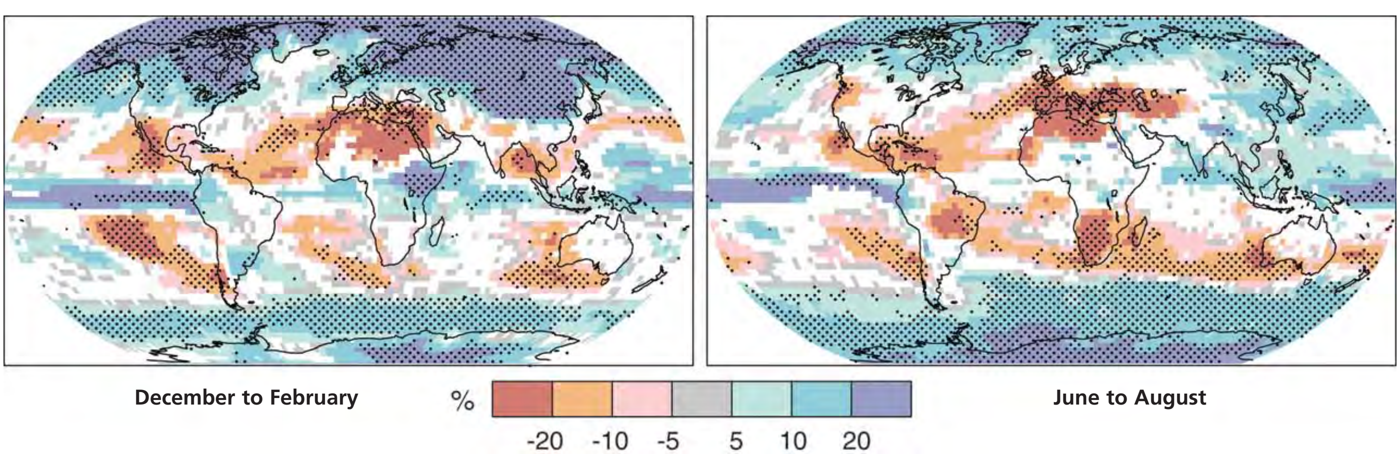


Table 2. Projected global average sea level rise at the end of the 21st century, adapted from IPCC 2007b.

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

Emissions Scenario	Sea level rise (m at 2090 – 2099 relative to 1980 – 1999)
	Model-based range (excluding future rapid dynamical changes in ice flow)
Constant Year 2000 Concentrations[a]	0.3 – 0.9
B_1 Scenario	1.1 – 2.9
B_2 Scenario	1.4 – 3.8
A_1B Scenario	1.7 – 4.4
A_2 Scenario	2.0 – 5.4
A_1F_1 Scenario	2.4 – 6.4

fisheries, ocean 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)

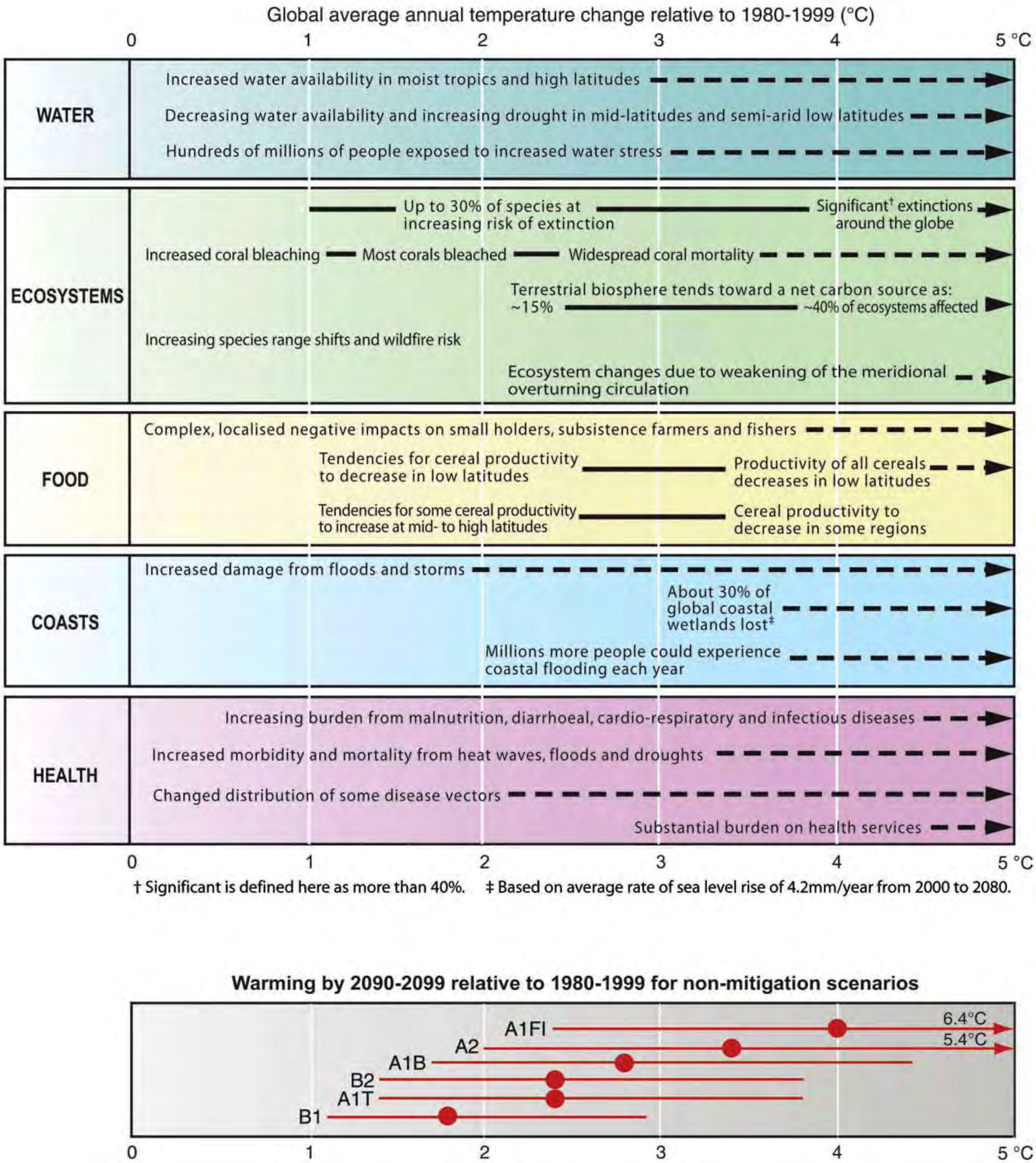


Figure 6. Examples of impacts associated with projected global average surface warming. Upper panel: Illustrative examples of global impacts projected for climate changes (and sea level and atmospheric CO_2 where relevant) associated with different amounts of increase in global average surface temperature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