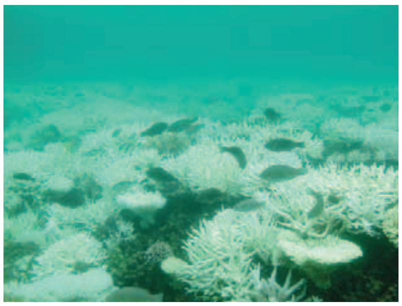
Global Warming's Increasingly Visible Impacts



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Global Warming's Increasingly Visible Impacts

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Our mission
Environmental Defense is dedicated to protecting the environmental rights of all people, including the right to clean air, clean water, healthy food and flourishing ecosystems. Guided by science, we work to create practical solutions that win lasting political, economic and social support because they are nonpartisan, cost-effective and fair.

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Executive summary

Global warming will not only be felt many decades from now—it is already happening and its impacts are clearly visible. This paper gathers examples from the peer-reviewed scientific literature of recent impacts around the world. These include increases in extreme weather events, rising sea level, disappearing glaciers and polar ice, damaged coral, changes in wildlife distributions and health, and increased activity and abundance of disease vectors. Although a direct link to global warming is difficult to establish for some of these phenomena in isolation, the multitude of changes collectively provide clear evidence of the immediate and growing danger that global warming poses to the economy, human health, and the ecosystems upon which humans and other species depend. Since greenhouse gas pollution stays in the atmosphere for decades or centuries, humanity may have no more than a decade left to begin stabilizing the climate to avert devastating and irreversible impacts. Such an achievement will require a concerted effort among all nations.

The following are highlights of the global warming impacts described in this report. For readers particularly interested in the United States, we include, preceding this Executive Summary, a listing of domestic impacts by region. (For a comprehensive rebuttal of skeptics' claims regarding the science of global warming, see our earlier report, *The Latest Myths and Facts on Global Warming*, available at http://www.undoit.org/what_is_gb_myth.cfm.)

In brief, this is what the scientific studies show:

• Killer heat waves

Human-caused global warming may have already doubled the chance of "killer" heat waves like the one that hit Europe in July and August of 2003. That summer was very likely the continent's hottest in 500 years. The relentless heat killed at least 27,000 people, breaking all records worldwide for heat-induced human fatalities. The heat and associated drought and wildfires cost European economies more than $14.7 billion (13 billion euros) in losses in the agriculture, forestry, and electric power sectors.

Records have been shattered in other parts of the world as well in recent years. In April-June 1998, 3,028 people died in the most disastrous heat wave to ever hit India. In 1995, a five-day heat wave caused 525 deaths in Chicago, with the 106°F (41°C) reading on July 13 the warmest July temperature ever measured.

• Torrential rains and flooding

According to the available data, global warming has increased the intensity of precipitation events over recent decades. In December 1999, for instance, Venezuela saw its highest monthly rainfall in 100 years, with massive landslides and flooding that killed approximately 30,000 people. On two days in the city of Maiquetia, rains fell with an intensity normally experienced just once in 1,000 years.

• Drought, forest pests, and wildfires

From 1998 to 2002, below-normal precipitation and high temperatures resulted in droughts covering wide swaths of North America, southern Europe, and southern and central Asia. Drought continued in some regions through 2004, including the western U.S., which endured the most severe drought in 80 years and one of the most severe in 500 years. The worldwide drought has been linked to unusually warm waters in the Indian Ocean and western Pacific, which many scientists believe to be caused in part by global warming.

Insect pests are spreading to forests previously too cold for their survival; Alaska, for instance, had in the 1990s the world's largest recorded outbreak of spruce bark beetles.

Drought, heat, and insect attacks promote severe forest fires. In 2004, Alaska had its warmest and third driest summer, resulting in its worst fire year on record, with fires consuming an area of forest the size of Maryland. All told, over the past 30 years, the area burned annually by wildfires in the Arctic region of western North America has doubled. In Russia, the area of forest burned annually more than doubled in the 1990s compared to the previous two decades.

• Rising sea level

Sea-level rise is one of the most certain impacts of global warming. During the 20th century, sea levels around the world rose by an average of 4 to 8 inches (10 to 20 cm), ten times the average rate over the last 3,000 years. That rise is projected to continue or accelerate further, with possible catastrophic increases of many meters if the ice sheets on Greenland and/or Antarctica collapse. Already, one-third of the marsh at Blackwater National Wildlife Refuge in the Chesapeake Bay has been submerged under the sea, and the edges of mangrove forests in Bermuda are lined with recently drowned trees. If sea level continues to rise, thousands of square miles of land in densely populated areas such as the eastern U.S. and Bangladesh may be lost, and flooding during storm surges will worsen. Construction of physical barriers such as seawalls would be expensive and in some cases unfeasible.

• Shrinking snowpack and vanishing glaciers

Mountain snowpack constitutes a critical reservoir of fresh water, as well as the basis for the four-and-a-half billion dollar U.S. ski industry. Over the past 50 years, spring snowpack has diminished by 16% in the Rocky Mountains and 29% in the Cascade Range, due mainly to rising temperatures. Furthermore, springtime snowmelt in the western U.S. now begins 9 days earlier on average, lowering stream levels during the dry summer months. It will be extremely difficult to solve the problem of crippling, long-term water shortages in the West without addressing global warming.

In almost every mountainous region across the world, glaciers are retreating in response to the warming climate. The shrinkage of glaciers is already creating water shortages, and threatening tourism in scenic parks. In one basin in Glacier National Park in Montana, for instance, two-thirds of the ice has disappeared since 1850; with uncontrolled warming, the remaining glaciers could disappear by 2030. In the European Alps, ice that had hidden and preserved the remains of a Stone Age man melted for the first time in 5,000 years. Venezuela had six glaciers in 1972, but now has only two; these too will melt away in the next ten years. In the Peruvian Andes, glacial retreat has accelerated sevenfold over the past four decades. In Africa, 82 percent of the ice on Mt. Kilimanjaro has disappeared since 1912, with about one-third melting in just the last dozen years. In Asia, glaciers are retreating at a record pace in the Indian Himalaya, and two glaciers in New Guinea will be gone in a decade.

• Disintegrating polar ice and melting permafrost

Since 1950, the Antarctic Peninsula has warmed by 4°F (2°C), four times the global average increase. In 2002, a Rhode Island-sized section of the Larsen B ice shelf, which sits offshore of the Peninsula, disintegrated in only 35 days. The ice shelf acts as a dam for glaciers on land; its break-up is causing a worrisome speed-up of glacier flow into the ocean, which could raise global sea level.

In 2003 the Ward Hunt Ice Shelf, the largest in the Arctic, broke in two, draining a unique freshwater lake that was home to a rare microbial ecosystem. Since the 1950s, the surface area of the Arctic's sea ice has shrunk by 10 to 15% in spring and summer, and the ice has thinned by about 40% in late summer and early autumn. In a turn for the worse, the years 2002–2005 have all seen record or near-record low ice coverage. The Hudson Bay has been particularly hard hit, with the sea-ice season shortened by three weeks. The reduced time for hunting ice-dwelling seals is seriously damaging the health of the bay's polar bears and causing them to have 15% fewer cubs. At present rates of shrinkage, Arctic sea ice could soon pass a point of no return, disappearing completely each summer by the end of this century and pushing polar bears to the brink of extinction everywhere. Shrinking and thinning ice has also made hunting of seals and other food sources more challenging and accident-filled for humans. Continued warming could destroy traditional societies.

Because the permafrost on which they are built is melting, buildings and roads in Alaska have been sinking and breaking up. The 4,000 year-old Eskimo village of Shishmaref has been so severely eroded by ocean waves that the entire community was forced to relocate.

• Damage to coral reefs

The past 25 years have witnessed a higher incidence around the world of large-scale coral "bleaching" events, which can lead to coral death. In 1997–98 alone, the largest bleaching event on record seriously damaged 16% of the reefs in the world and killed 1,000-year-old corals. Mass bleachings are usually caused by excessively high temperatures. Scientists therefore attribute the increase in bleaching events to the rise in average surface ocean temperatures in many tropical regions by almost 2°F (1°C) over the past century. Within the next few decades, continued warming could cause mass bleachings to become an annual event, wiping out some reef species and ecosystems along with the food, tourism income, and coastline protection they provide. Corals are also directly threatened by increasing atmospheric concentrations of carbon dioxide, which is acidifying seawater and making it more difficult for corals to build their calcium carbonate skeletons.

• Shifting species ranges and yearly cycles

Of over 1,400 species analyzed, ranging from fish and mammals to grasses and trees, over 80% are migrating to higher latitudes or higher elevations and altering their annual routines in response to global warming. Over time, this could cause disruptive ecological and economic changes, such as the disappearance of entire fisheries. Amphibians have shown particular vulnerability: In mountains around the globe, many species, including the golden toad and most of the 70-odd species of harlequin frogs, have vanished or declined because of diseases spurred by climatic changes.

• Disease outbreaks

Higher temperatures accelerate the maturation of disease-causing agents and the organisms that transmit them, especially mosquitoes and rodents. Higher temperatures can also lengthen the season during which mosquitoes are active, as has already been observed in

Canada. Warming has also been linked to the recent spread of tropical diseases, including malaria, dengue fever and yellow fever, into high-altitude areas in Colombia, Mexico, and Rwanda that had never seen the diseases before.

The increase in El Niño events since the mid-1970s—a change consistent with global warming model predictions—has also contributed to new outbreaks of disease. In the past decade, heavy rains associated with El Niño events have caused explosive population growth in the rodents that transmit hantavirus, which can lead to severe and often fatal illness in humans. As a consequence, record outbreaks of hantavirus have been occurring in the U.S.

Introduction

Global warming is no longer just a prediction—it is actually happening. It is undisputed that the average temperature at the surface of the Earth has increased over the past century by about 1°F (0.6°C), with both the air and the oceans warming.[1] Since 1880, when people in many locations first began to keep temperature records, the 25 warmest years have all occurred within the last 28 years.[2] Scientists know with absolute certainty that the observed dramatic increase in the atmospheric concentrations of greenhouse gases since pre-industrial times (to levels higher than at any other time in at least the last 420,000 years) has been caused by human activities, mostly the burning of fossil fuels (coal, oil, and natural gas), and to a lesser extent, deforestation.[3] The ability of greenhouse gases, such as carbon dioxide, methane, and nitrous oxide, to trap heat at the Earth's surface is also scientifically well understood. While it has not yet been precisely determined how much of the recent warming was caused by human activities, the consensus among climate scientists is that most of the warming over the past 50 years was probably caused by human-produced greenhouse gases. (See statements issued by the National Academy of Sciences, the American Meteorological Society, the American Geophysical Union, the Intergovernmental Panel on Climate Change, and the national academies of eleven countries.)[4] Recent precise measurements of the heat content of the world's oceans, which show an increase close to the amount expected from warming by greenhouse gases, strengthen the consensus view.[5,6]

Many among the public may have the misconception that global warming is a distant threat, with consequences that will only be felt many decades from now. The fact is, many widely accepted, peer-reviewed scientific studies have found evidence that global warming has already had major impacts on ecosystems and societies across the world. Glaciers all around the world and Arctic sea ice have been shrinking and disappearing; sea level has been rising and flooding low-lying areas; life-threatening heat waves, flooding rainstorms, droughts, and forest fires have become more intense and frequent over recent decades; corals are "bleaching" and dying in response to higher ocean temperatures; and numerous animal and plant species are migrating away from the higher temperatures, toward the poles and higher elevations. While a direct causal link to global warming has been established for some observed changes, such as sea-level rise and worldwide glacial retreat, such a link is difficult to definitively establish for other changes, such as the increased incidence of droughts or the migration of a particular species. However, the multitude of changes collectively provides a consistent and clear body of evidence of the immediate and growing danger that global warming brings. Using the terminology of those tasked with protecting public health, "the weight of the evidence," or information compiled from all available studies, points strongly to global warming as a force behind the observed changes. At risk are the health of the global economy, of human individuals and communities, and of the ecosystems upon which we depend for food, clean water, other resources, and spiritual sustenance.

Carbon dioxide and other greenhouse gases stay in the atmosphere for a

Humanity may have only a narrow window of time left, perhaps a decade or so, to begin the long process of stabilizing greenhouse gas concentrations at a level that can avert devastating and irreversible impacts from climate change.

century or longer after being emitted.[7] The greenhouse gases we have already added to the atmosphere since the Industrial Revolution have therefore committed the globe to a certain amount of continued warming over the coming decades no matter what we do with future emissions.[8,9,10] Humanity may have only a narrow window of time left, perhaps a decade or so, to begin the long process of stabilizing greenhouse gas concentrations at a level that can avert devastating and irreversible impacts from climate change.[11,12]

This report summarizes some of the major impacts that global warming has already had across the world, including some that have been observed since the publication of major assessments by the Intergovernmental Panel on Climate Change (IPCC) and the National Academy of Sciences in 2001.[13] Our goal is to provide policymakers, journalists, and the public with facts so that they can make informed decisions on the measures needed to stem the global-warming tide. We have made every effort to ensure that the document is scientifically rigorous, noting where the link between a particular phenomenon and global warming may not be fully established or where other causative factors may be involved. We have relied almost exclusively on information from peer-reviewed scientific publications and government websites; the few exceptions include a Munich Re company report, a *National Geographic* article, and a BBC News article.

There are many more examples of global warming impacts than can fit into an easily digestible report like this. For more comprehensive information, the reader may want to refer to other recent reports, such as the 2004 *Arctic Climate Impact Assessment; Status of Coral Reefs of the World: 2004;* the 2000 *National Assessment of Climate Change Impacts on the United States;* and the IPCC *Third Assessment Report*.[14] For a comprehensive rebuttal of skeptics' claims regarding the science of global warming, see an earlier report of ours, *The Latest Myths and Facts on Global Warming,* available at http://www.undoit.org/what_is_gb_myth.cfm. Occasional updates to the present report are planned. Suggestions for improvements and additions are welcome. Please send suggestions to: Dr. James Wang, Environmental Defense, 257 Park Avenue South, New York, NY 10010; jwang@environmentaldefense.org

PART I

Extreme events

A warmed world, in other words, is like a loaded die that comes up "Heat Wave" or "Intense Rainstorm" more often than an unperturbed world.

It is difficult to blame a particular extreme weather event (such as a heat wave, flood-producing storm, or drought) on global warming, since weather fluctuates naturally. However, climate theory and models predict that global warming will increase the frequency and/or intensity of some types of extreme events. A warmed world, in other words, is like a loaded die that comes up "Heat Wave" or "Intense Rainstorm" more often than an unperturbed world.[15] Thus, scientists can estimate the fraction of the risk of a particular kind of event for which humans are responsible. This section of the report presents examples of extreme events observed during recent decades that are consistent with the effects of global warming and may be harbingers of greater changes to come if we allow global warming to continue unabated.

Killer heat waves

Human-caused global warming may have already doubled the chance of "killer" heat waves like the one that scorched Europe in July–August 2003.[16] Strong evidence indicates that the summer was the hottest in Europe in at least the past 500 years.[17] All-time high temperature records were broken in many countries. In the United Kingdom, the mercury hit 100.6°F (38.1°C) at Gravesend-Broadness, Kent on August 10, exceeding 100°F for the first time in that country since records began.[18] In Germany, an all-time record of 104.4°F (40.2°C) was set on August 8.[19]

At least 27,000 people died as a result of the relentless heat, breaking all records worldwide for heat-induced human fatalities.[20] (The figure refers to the number of deaths in excess of the typical number during the summer period.) In France alone, over 14,000 people died. In addition to the emotional trauma and medical costs, the heat and associated drought and wildfires cost European economies over $14.7 billion (13 billion euros)* in losses in the agriculture, forestry, and electric power sectors.[21] Specific damages included a 60% reduction in fodder production in France, an 18% decrease for wine in Italy, an 11% fall in grain production for Europe as a whole, livestock deaths (for example, millions of chickens died in France and Spain, reducing the flock by 15–20% in Spain),[22] and cuts in power generation due to shortages of river water for cooling the plants. France, Europe's main electricity exporter, cut its power exports by more than half to preserve an adequate domestic supply. By the 2040s, the risk of a similar heat wave could increase 100-fold if civilization doesn't restrain the growth of greenhouse gases, **with one out of every two years being hotter than 2003** (as compared to the current one out of every 200).[23]

India was also hit in 2003 by a severe heat wave. Temperatures reached as high as 122°F (50°C) in May across the worst hit areas and over 1,200 people died.[24] Just five years earlier, the most disastrous heat wave to ever hit India took place during April–June of 1998, with an estimated 3,028 fatalities.[25] The temperature rose as high as 113–121.6°F (45–49.8°C) in several Indian states. Disruptions to the electricity supply due to excessive demand wreaked havoc on

* We obtained the U.S. dollar value from the value in euros by applying the 2003 conversion rate.

A ship on the river Rhine in Duesseldorf, Germany, July 25, 2003, during the extreme heat wave that scorched Europe for much of the summer. Low water levels meant bigger ships could transport only 30 to 50 percent of their normal cargo. (AP Photo/Martin Meissner)

hospital services and on refrigerated supplies of vaccines and medicines.[26]

In the United States, Chicago experienced one of the worst weather-related disasters in Illinois history when a heat wave resulted in 525 deaths during a 5-day period in July of 1995.[27] The 106°F (41°C) reading on July 13 set a record for the warmest July temperature since measurements began. The combination of high humidity and high nighttime temperatures meant little respite from the heat could be found, especially for such vulnerable populations as the elderly and people with low incomes. Studies indicate that the increase in death rate from more frequent heat waves in the future will probably outweigh any decrease in death rate due to less severe winter cold in the U.S., because cold-related mortality is more complex and not so strongly tied to the severity of the cold.[28,29]

Torrential rains and flooding

According to the available data, a significant increase in the intensity of precipitation events occurred over the second half of the 20th century.[30] This increase is consistent with the predicted effects of global warming, since higher temperatures speed up evaporation and increase the amount of water vapor in the air, leading to heavier downpours. Heavier rainfall in turn increases the risk of flooding.

Another factor contributing to more intense precipitation in some regions is the increase in frequency and intensity of El Niño events since the mid-1970s. An El Niño is a phase of warmer-than-average waters in the eastern Pacific and weaker-than-average tropical trade winds, usually lasting around a year and occurring once every two to seven years. El Niños typically bring unusually heavy rains to the southern tier of the U.S. and Peru, while causing below-normal precipitation in the northwestern U.S., northeastern Brazil, Southeast Asia, Australia, and southern Africa. Several recent El Niños may have been more intense or long-lasting than any in the last three centuries.[31] Some climate simulations have indicated that further

Devastation in coastal Venezuela caused by the December 1999 flows of mud and rocks. (Lawson Smith, U.S. Army Corps of Engineers)

warming of the planet will produce more frequent and longer-lasting El Niños in the future, thus causing extreme floods and droughts to occur more often.

One of many extreme flooding events that may have been exacerbated by global warming occurred in December 1999, when Venezuela experienced its highest monthly rainfall in 100 years, with massive landslides and flooding that killed approximately 30,000 people.[32] Total December rainfall in the coastal city of Maiquetia, near Caracas, was almost 4 feet (1.2 m), more than 5 times the previous December record. During one particularly intense period, 2.8 inches (72 mm) of rain fell in one hour. Rainfall on two of those December days were "1,000-year events"—in other words, that daily amount of rainfall is expected to occur in that location on average only once in 1,000 years. Rainfall amounts in the neighboring mountains are estimated to have been twice as high, or around 8 feet over the month.

The rainfall was unusual not only for its intensity, but also because it occurred outside of the normal rainy season (May to October) and was not produced by a hurricane or other tropical cyclone. The ensuing flows of mud and boulders are thought to have been among the largest worldwide in at least a century. It is worth noting that the high death toll was partly due to the building of large numbers of homes on steep slopes prone to landslides and low-lying areas susceptible to floods. Discouraging development in these kinds of vulnerable locations, in addition to reducing worldwide greenhouse gas pollution, would help mitigate future damages from global warming.

Drought

Paradoxically, although flooding events are very likely to increase with global warming, droughts are also expected to be more frequent and severe. Higher temperatures tend to increase the rate of evaporation; if precipitation doesn't soon replenish the lost moisture, soils grow drier. In drier soils, less solar energy is used up in evaporating water, meaning more energy is available to raise the temperature of the soil and the overlying air, leading to even more desiccating conditions; this kind of self-amplifying cycle can lead to a lengthy and severe drought.[33] Dry soils can drive another kind of self-amplifying cycle as well: when there is less evaporation to the air because soil moisture is depleted, there can be less moisture in the atmosphere locally to form precipitation, potentially resulting in yet drier soils.[34] The drought that accompanied the devastating heat waves of 2003 in Europe, for instance, is thought to have been intensified by global warming.[35] (See the section "Killer Heat Waves" in Part I.) Models predict that the vulnerability to summer droughts will be especially high in many mid-continental areas, which are often important grain-producing and/or grazing regions. The reasons for their vulnerability are that their climate isn't cooled by the ocean and that a large portion of their precipitation is derived from continental moisture.[36]

In addition to increasing evaporation and prolonging periods with deficient rainfall, a warmer climate can reduce water supplies in arid and semi-arid regions (such as the western U.S.) by decreasing the proportion of precipitation that falls as snow rather than rain in the mountains, and by accelerating the rate of snow melt in the spring. A reduced snowpack and earlier and quicker melts make for lower stream flows in the summer, when water can be in short supply. (See "Disappearing Snowpack" in Part III.)

Lowering water level during severe drought at Lake Powell on the Colorado River, at the confluence with the Dirty Devil River (entering from left). Top: June 29, 2002. Bottom: December 23, 2003. (John C. Dohrenwend, USGS files)

Warmer ocean temperatures due to global warming may also increase the severity of droughts. The Indian Ocean and the western Pacific were exceptionally warm between 1998 and 2002,* in part because of the overall warming trend in the world's oceans.[37] In the same period, unusually persistent atmospheric flow patterns resulted in below normal precipitation, high temperatures, and drought conditions across wide swaths of North America, southern Europe, and southern and central Asia. Drought continued through 2004 in some areas, including the western U.S., where according to stream flow records and tree ring studies the drought was the **most severe in 80 years and one of the most severe in 500 years.**[38,39,40] During the peak, more than 50% of the area of the coterminous U.S. suffered from moderate to severe drought, with much of the area experiencing record or near-record low precipitation.[41] The average annual flow of the Colorado River at Lees Ferry, Arizona during the 2001–2003 period was 5.4 million acre feet (6.7 cubic kilometers), just half of the 10.2 million

* While the geographic pattern of the warmth can be explained by a La Niña event (the opposite of an El Niño, or in other words, a phase of warmer-than-average waters in the *western* Pacific and cooler-than-average waters in the *eastern* Pacific), scientists studying the 1998–2002 event believe that an overall warming trend in the world's oceans over the past few decades contributed to the unusual extremeness of the warmth.

Example of a recent severe wildfire in the West: In Glenwood Springs, Colorado, on June 8, 2002, the evening sun barely penetrates the smoke and ash as evacuees flee West Glenwood because of the spreading wildfires in Garfield County. (Bryan Dahlberg/FEMA News Photo)

acre feet (12.6 cubic kilometers)* that flowed during the Dust Bowl years (1930–1937).[42]

A number of researchers have used climate models to examine the underlying causes of the recent drought.[43,44] Their model simulations produced a climate pattern very similar to that observed, and suggested that the warmth in the Indian Ocean and western Pacific caused the persistent atmospheric flow patterns, which in turn produced the drought conditions across the wide expanse of mid-latitude regions. In short, there is mounting evidence that global warming contributed to the vast extent and severity of the recent drought.

* This comparison of streamflow is adjusted for changes caused by the Glen Canyon Dam, which was constructed in the early 1960s. The streamflow figures are not corrected for increases in water consumption upstream of Lees Ferry over time; but even after applying an extremely large correction, the estimated flow during the recent period would still be 1.3 million acre feet (1.6 cubic kilometers) lower than during the Dust Bowl.

Forests and wildfires

Scientists expect global warming to contribute to an increase in wildfire in several ways. As discussed in the previous section, droughts are expected to become more common and severe in some regions. Desiccating heat and lack of precipitation create ideal conditions for major wildfires. In addition, longer warm seasons often translate into longer fire seasons. Warmer temperatures also promote outbreaks of insects that feed on trees, killing many of the hosts and creating large amounts of dry fuel for forest fires. Insects are even spreading to areas that until recently were too cold for their survival. In south-central Alaska in the 1990s, the world's largest recorded outbreak of spruce bark beetles damaged more than 4 million acres (1.6 million hectares) of forest, an area nearly the size of the state of New Jersey.[45] Since 1994, Canada has been afflicted with its largest and most northerly spruce bark beetle outbreak ever, affecting 750,000 acres (300,000 hectares) in the Yukon.[46]

Aerial view of a white spruce forest severely damaged by spruce bark beetles, Canada. (Courtesy of Natural Resources Canada, Canadian Forest Service, Laurentian Forestry Centre/Luc Jobin)

With this combination of heat, drought and pests, wildfires have become increasingly destructive in recent decades. Among the regions hit hard are the huge tracts of Arctic spruce and pine forest spanning Alaska, northern Canada, Scandinavia, and Siberia (which despite their northerly latitude are susceptible to fires in the summertime, especially during warm, dry years). In the Arctic region of western North America, the area burned annually has doubled over the past thirty years.[47] In the Russian Arctic, fire damage increased sharply in the 1990s, with the area of forest burned annually being more than twice as large as during the previous two decades.[48] The risk of catastrophic fires has been exacerbated in the Arctic as well as other parts of the world by decades of fire suppression by humans, which has allowed dead, flammable plant material to accumulate. But even remote parts of the Arctic, which have seen little fire suppression, have experienced an increase in wildfire, suggesting that suppression by itself cannot completely explain the increase in wildfire around the world, and that global warming has played an important role.[49]

The summer of 2004 was particularly fierce: Alaska's warmest and third driest summer on record made for its worst fire year ever.[50,51] A total of 703 fires consumed 6,517,200 acres (2.6 million hectares) of forest, an area the size of Maryland. Evacuations of threatened communities reached record levels, and for the first time ever, fire engines were shipped from the lower 48 states to deal with the conflagration. Because of the fires, air quality in the interior and the northeast of the state was reported as unhealthy or hazardous on 52 days. On June 28 in Fairbanks, health-threatening airborne particulates registered 1,000 micrograms per cubic meter, the highest ever recorded in Alaska; normal is 65.

Regions outside of the Arctic have seen many severe fires in recent decades as well. For example, severe drought and high temperatures in the western U.S. in 2000 resulted in over 122,000 fires, which burned approximately 8.5 million acres (3.44 million hectares), the worst wildfire season in the last 50 years.[52] The first seven months of that year were the warmest in 106 years of records in New Mexico, Utah, and Texas, while Arizona, Colorado, Nevada, Wyoming, and Idaho had their 2nd or 3rd warmest January–July. In 1998, Mexico experienced its worst fire season ever, when 1.25 million acres (506,000 hectares) burned during a severe drought.[53] Smoke reaching Texas triggered a statewide health alert.

As with drought, wildfire can set off a self-amplifying cycle. If, as climate models predict, wildfires continue to increase in frequency and intensity,[54] the amount of carbon dioxide released into the atmosphere from burning vegetation and soil organic matter could outstrip the amount absorbed by regrowing forests, strengthening the greenhouse effect and global warming and possibly leading to even more fires in a worsening cycle.

PART II

Sea level rise and coastal flooding

Sea-level rise is one of the most certain impacts of global warming. Sea level rose around the world by an average of 4 to 8 inches (10 to 20 cm) over the course of the 20th century, ten times the average rate over the previous three thousand years.[55] The rise in sea level is due to the expansion of ocean water as it warms, and to the addition of water from melting glaciers and ice sheets, both of which are consequences of global warming.

The effects of global sea-level rise are amplified in some places due to local geologic and man-made factors. For example, about one-third of the marsh at Blackwater National Wildlife Refuge in the Chesapeake Bay in the eastern U.S. has become submerged since 1938. Half of the marsh loss is attributed to the sinking of land due to groundwater extraction, and the rest is attributed to global warming.[56] Elsewhere in the Chesapeake Bay, Bloodsworth Island is 590 acres (235 hectares) smaller than it was in 1942, a loss of more than 10% of its original land area.[57]

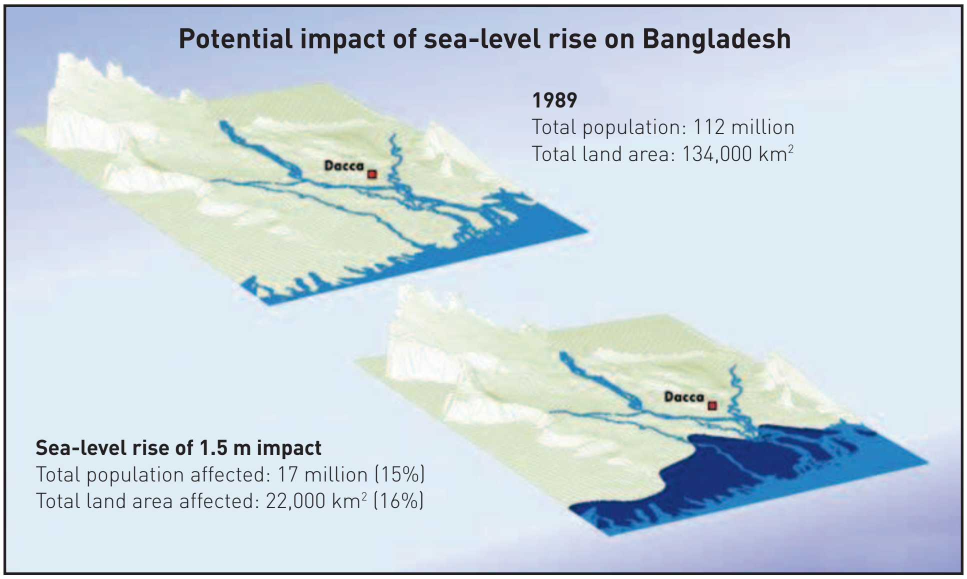
In Louisiana, nearly a million acres (400,000 hectares) of biologically-rich marsh, 28% of the original marsh area in the state, has been lost to the encroaching sea since 1932. Many factors have contributed, including the sinking of land along geologic fault-lines, compaction of loose soil, and a decrease in the supply of soil-replenishing sediments due to the construction of dams and levees. However, global sea-level rise has contributed at least one-eighth of the flooding, even at the sites that are sinking most rapidly.[58] In Bermuda, rising sea level is leading to saltwater inundation of coastal mangrove forests.[59] The edges of the forests are now lined with trees that have recently drowned or whose roots have been exposed due to erosion, making them susceptible to being blown over by the wind. Mangrove forests provide habitat for many birds and economically important marine species including shrimp, oysters, and fish; these forests also filter the water, keeping it clean and clear, and protect the coast from storm surges and waves. (A storm surge is a sharp, localized rise in sea level lasting hours or days, caused by a storm.) These forests, like other coastal ecosystems, are not able to build up sediment fast enough to keep up with the current rate of sea-level rise, and could completely disappear in places where natural or man-made barriers prevent landward migration.

On the other side of the Atlantic, the Thames Flood Barrier, which protects the city of London from storm surges coming up from the mouth of the river, was used less than once a year in the 1980s; in the 1990s it was used on average more than six times a year.[60] Although this increase is attributable mainly to a combination of natural variations in storm surge intensity and increased occurrence of high runoff from rainstorms, it illustrates a potential impact of rising global sea level. If the barrier were to break during a flood, the resulting damage to London could cost about $54 billion in 2004 dollars (30 billion pounds), roughly 2% of the current U.K. GDP. In addition to the Thames, more frequent and extreme flooding due to sea-level rise threatens low-lying areas near the mouths of the Nile in Egypt, the Mekong in Vietnam and Cambodia, the Ganges and Brahmaputra in Bangladesh, and other rivers around the world.[61]

Scientists project that sea level will continue to rise as a result of human-produced greenhouse gas pollution and

This map highlights the areas along the U.S. Atlantic and Gulf coasts that are vulnerable to inundation resulting from sea-level rise. This is a simple elevation map and does not include additional future impacts from erosion and local sinking of land. Altogether, 22,400 square miles (58,000 square kilometers) of land, an area more than twice the size of Maryland, lie within 5 feet (1.5 m) of sea level; sea level could rise by this amount within the next few centuries. More than 80% of this low land is found in just four states: Louisiana, Florida, Texas, and North Carolina. (Source: Titus, J.G. and C. Richman. 2001. Maps of lands vulnerable to sea level rise: modeled elevations along the U.S. Atlantic and Gulf coasts, Climate Research. Available at http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsSLRMapsIndex.html)

could reach an additional 3.5 inches to 3 feet (9–88 cm) by the end of the century, with even further rises in subsequent centuries as sea level gradually adjusts to the warmer climate.[62] (The large range for projected sea level rise reflects differences among models and emission projections, with the lower end reflecting possible growth in ice sheets in parts of Antarctica due to increased precipitation.) Some studies have even suggested the possibility that warming over the next several centuries would lead to the complete, irreversible disappearance of the Greenland ice sheet, which would raise sea level by an extra *23 feet (7 m)*; there is also a slight chance that the West Antarctic Ice Sheet could collapse, further raising sea level by *13–20 ft (4–6 m)*.[63,64]



This graphic, based on an analysis conducted in 1989, illustrates the potential impact of sea-level rise on Bangladesh, a low-income nation with a very large population living within a few feet of sea level. With a 5 feet (1.5 m) sea-level rise, approximately 8,500 square miles (22,000 square km), or 16% of the country's land area, would be submerged, displacing 17 million people. That figure is based on the estimated population in 1989. Given that the nation's population has grown rapidly since 1989 and is projected to continue growing, a much higher number of people could actually be affected. (Source: UNEP/GRID Geneva; University of Dacca; JRO Munich; The World Bank; World Resources Institute. Washington, D.C. http://www.grida.no/climate/vital/33.htm.)

In the absence of expensive man-made physical barriers such as seawalls, even a moderate sea-level rise would submerge large portions of island nations and densely populated coastal areas, displacing millions of people. (See the accompanying figures for examples of vulnerable areas in the eastern U.S. and Bangladesh.) Adaptation to sea-level rise could cost several percent of GDP for certain developing countries, and for many small island nations would simply be infeasible.[65] Sea-level rise not only inundates land, but also causes additional land loss due to erosion by ocean waves. A foot of sea level rise would result in approximately 50-1000 feet of horizontal shoreline retreat in many parts of the U.S., varying according to location.[66] In addition, higher sea levels would exacerbate the flooding risk associated with storm surges during hurricanes and other storms.[67] Increased loss of coastal property due to shoreline retreat and flooding could be costly to taxpayers as well as property owners in the U.S., since the federal government subsidizes flood insurance for much coastal property.[68] Another impact of rising sea level is contamination of fresh surface water and groundwater supplies by salty water. Communities that obtain water from sections of rivers that are currently just upstream from the point where the water becomes salty include Philadelphia, New York City (as an emergency supply during droughts) and much of California's Central Valley.[69]

It takes even more time to stabilize rising sea levels than it does to stabilize rising atmospheric temperatures, due to the slow rate at which water is circulated and heat distributed throughout the depth of the ocean.[70] We need to put the brakes on rising greenhouse gas concentrations now to avoid an increasingly disastrous rise in sea-level down the road.

PART III

Snow, land ice and sea ice

Shrinking snowpack

Over the past 30 years, scientists around the world have recorded a steady decline in mountain snowpack, an important reservoir of fresh water, as well as the basis for the ski industry and other winter tourism. In the western United States, where water is scarce, 75% of the water in streams and rivers comes from snowmelt, providing a crucial supply for farms, hydroelectric power plants, aquatic life, and 60 million people—one-fifth of the U.S. population.[71] Spring snowpack has been decreasing in the region: measurements recorded declines in three-quarters of the mountainous areas between 1950 and 1997.[72] In the Rockies, snowpack decreased an average of 16%; the Cascades lost an average of 29%, with many sites in Washington, Oregon, and Northern California losing more than 50%. Model simulations indicate that temperature increases are the main culprit in the snowpack decline. Even precipitation increases in some areas have generally not been sufficient to overcome the impact of strong regional warming. In the Swiss Alps, rising nighttime temperatures and an increase in the percentage of precipitation falling as rain rather than as snow were to blame for a reduction in snowpack of 12–45% between the 1960s and the 1990s at low- to mid-elevation sites.[73]

Assessments of global warming impacts on ski resorts in North America, Europe, and Australia all project negative consequences.[74] Assuming current snowmaking technology, the ski season in the province of Ontario in Canada is projected to shorten by 0–16% in the 2020s (11–50% in the 2080s), even with an increase in snowmaking of 36–144% in the 2020s.[75] Snowmaking is expensive; for example, it currently makes up 20% of the operating costs of the Attitash Mountain resort in New Hampshire.[76] Warming thus threatens the ability of ski resorts to stay in business and remain a vital contributor to regional economies. U.S. ski resorts bring in approximately $4.5 billion in revenues annually (including tickets, rentals, retail, and food and beverages).[77]

Records also show that the springtime pulse, when a large amount of snow suddenly begins to melt and fill streams, has shifted over the last two decades across the western U.S., beginning 9 days earlier on average than it did 40 years ago.[78] Earlier snowmelt means that streamflow reaches its maximum earlier in the season; throughout California's Sierra Nevada it now peaks 3 weeks earlier than it did in 1948.[79] Capturing higher streamflows earlier in the year is difficult in places such as California and the Columbia River Basin. Existing man-made reservoirs are nearly filled to capacity at that time; to avoid flooding, extra runoff must be allowed to drain into the ocean.[80] By the time summer arrives, streamflow has greatly diminished, reducing the water supply all through the hottest, driest months. The West already faces water shortages in times of drought: it will be extremely difficult to prevent still more crippling water shortages without addressing global warming.

Vanishing glaciers

Glaciers are slow-moving "rivers" of ice formed over many years from compacted snow on sloping land. In almost every mountainous region across the world, long-term monitoring has revealed that the vast majority of glaciers are retreating upslope in response to a warming climate;[81] the glaciers' lower reaches are melting faster than ice flowing down from above can replenish them. Since glaciers, like snowpack, serve to store water and release it steadily over the year, their continued disappearance will have a severe impact on water supplies in some regions.

In Montana's Glacier National Park, the retreat of the glaciers has been dramatic. Between 1850 and 1979, glaciers in the Blackfoot-Jackson Glacier Basin decreased in area by about 65%, from 8.3 square miles (21.6 square kilometers) to 2.8 square miles (7.4 square kilometers).[82] More recent observations show that the retreat and thinning of glaciers in the park continues: For example, between 1979 and 1993, Grinnell Glacier shrank by 22% and Sperry Glacier by 11%.[83] The shrinkage has been driven by both an increase in regional temperatures and a decrease in precipitation. Using climate models, scientists project that all the glaciers in Glacier National Park could disappear completely by 2030, eliminating one of the park's main tourist attractions.[84]

The Pacific Northwest is witnessing similarly rapid retreats. The South Cascade Glacier in Washington State may currently be at its smallest size ever in the last 6,000 years. Between 4000 BC and A.D. 1958, its length had always stayed within the range of 2.24 to 2.88 miles (3.60 to 4.63 km). By 1995, it had dropped to 1.81 miles (2.92 km).[85]

Across the Atlantic, in the European Alps, glacial retreat has exposed well-preserved remains, including the 5,000-year-old Stone Age Oetzal "ice man." Having survived in the ice for so long due to the absence of ice flow in the flat

In the European Alps, glacial retreat has exposed well-preserved remains, including the 5,000-year-old Stone Age Oetzal "ice man."

Grinnell Glacier in Glacier National Park, Montana, viewed from the top of Mount Gould during late summer 1938 (left) and 1981 (right). In just 43 years, a dramatic response to warming is evident, including loss of volume and formation of a lake at the foot of the glacier. Between 1850 and 1993, the glacier shrank 63% in area and the foot receded about 0.7 miles (1.1 km). Debris marks the 1850 glacier boundary, right. (Courtesy of Carl H. Key (originally published in Key et al., 1998. Glacier retreat in Glacier National Park, Montana. In R.S. Williams and J.G. Ferrigno, eds. Satellite image atlas of glaciers of the world, Chapter J, Glaciers of North America. U.S. Geological Survey Professional Paper 1386-J.)


Left: In 1978, the Qori Kalis Glacier looked like this, flowing out from the Quelccaya Ice Cap in the Peruvian Andes Mountains. Right: In 2002, the view of Qori Kalis has changed dramatically with a massive 10-acre lake forming at the ice margin. (Courtesy of Professor Lonnie G. Thompson, Byrd Polar Research Center, The Ohio State University)

areas where they were found, these remains only now have been exposed for the first time in thousands of years—evidence that the recent glacial retreat is highly unusual.[86]

At the opposite end of the Earth, glaciers in the Patagonia region of southern South America have been retreating over the past several decades.[87] Chile's San Rafael Glacier—a World Heritage Site and a popular tourist attraction where boats can pull right up to the towering edge of the ice on the water—has retreated 0.6 miles (1 km) in just the last decade.[88] If this continues, the glacier will terminate over land instead of water in the near future.

Even in tropical mountain areas, where the climate is generally more stable than in high-latitude regions, glaciers are receding at an accelerating rate.[89,90] Venezuela had six glaciers in 1972. Now it has only two and, if present trends continue, those too will be completely melted in the next 10 years.[91] Glacial retreat has accelerated sevenfold in the Peruvian Andes:[92] The edge of the Qori Kalis glacier retreated 13 feet (4.0 m) annually between 1963 and 1978; by 1995, the rate had stepped up to 99 feet (30.1 m) per year. Shrinkage of the Zongo Glacier in the Bolivian Andes has created water shortages for downstream communities.[93]

Tropical regions in Africa and Southeast Asia are showing similar patterns. 82% of the ice on Mt. Kilimanjaro has disappeared since 1912, with about one third melting in just the last dozen years.[94,95] Kilimanjaro's remaining ice is projected to disappear by 2020. A glacier on Mount Kenya has shrunk by 40% since 1963. Two glaciers in Irian Jaya (the Indonesian portion of the island of New Guinea) are disappearing and should be gone in a decade.

In the subtropics, glaciers are also retreating at a record pace. The Dokriani Bamak Glacier in India retreated 66 ft (20.1 m) in 1998, and an annual average of 54 ft (16.5 m) over the preceding 5 years; the Gangotri Glacier is retreating 98 ft (30 m) per year.[96] Both are in the Himalayan range, which has the world's largest concentration of glaciers outside of the polar regions and has been called the "Water Tower of Asia."[97] Seven of the continent's great rivers originate here and supply water to hundreds of millions of people: the Ganges, Indus, Brahmaputra, Salween, Mekong, Yangtze, and Huang Ho. Initially, continued warming is projected to swell those rivers with more extensive melting of glaciers and snowpack and increased precipitation.[98] This will worsen the already high flood risk. In a few decades, after the most vulnerable portions of the glaciers are gone, river flow will get dangerously low in summer.[99] The loss of glacial meltwater would reduce summer flows on the Ganges by two thirds, creating water shortages for several hundred million people and up to 37% of India's irrigated farmland.[100]

Global warming skeptics have actually claimed that the majority of glaciers across the world are advancing rather than retreating. In fact, in only a very few areas, specifically western Norway, Iceland, and New Zealand, have a significant fraction of the glaciers been expanding during the past few decades.[101,102] That expansion is a result of regional increases in storm frequency and snowfall amounts rather than colder temperatures, and is therefore compatible with a global warming trend. But in *all* other regions of the world, the retreat of glaciers has been pronounced;[103] the total net loss in volume across all of the world's glaciers between 1961 and 1997 is about 3 billion acre feet (890 cubic miles, or 3,700 cubic km).[104] Skeptics have also argued that the glacial retreat is unconnected to global warming by focusing on the isolated case of Kilimanjaro, for which scientists have offered alternative explanations, including a drop in precipitation beginning in the late 1800s, a decrease in cloud cover, and the drying effect of regional deforestation.[105] The consensus among scientists remains, however, that rising air temperatures are the most important factor behind the retreat of glaciers on a global scale over long time periods.[106,107]

Polar ice disintegration

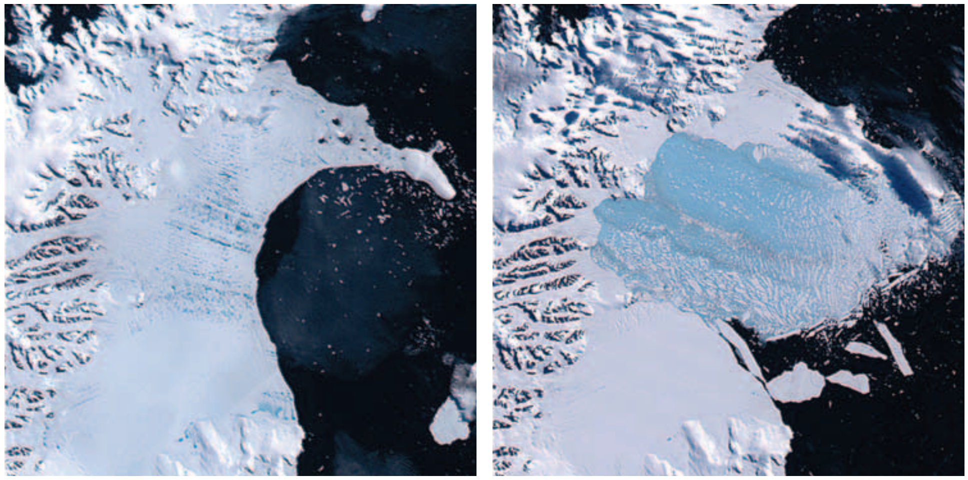
Polar regions have two kinds of floating ice. *Ice shelves* are thick plates of ice that form where glaciers flow into the sea. *Sea ice* forms when seawater gets cold enough to freeze. Unlike land-based glaciers and ice sheets, floating ice does not raise sea level when it melts. It does, however, have serious consequences.

One of the most dramatic melting events so far has occurred on the Antarctic Peninsula, the part of that continent that juts out towards South America. While a slight cooling occurred in the interior of Antarctica over the past century, the Peninsula has warmed by around 4°F (2°C) since 1950, four times the global average of 0.9°F (0.5°C).[108] The retreat of ice shelves on both the eastern and western sides of the Peninsula since 1995 has been attributed to this regional warming.[109] That retreat took a surprising turn in 2002, when the northern section of the Larsen B ice shelf, a large floating ice mass on the eastern side of the Peninsula, shattered and separated from the continent. In just 35 days, beginning on January 31, 2002, a total of about 1,250 square miles (3,250 square kilometers) of shelf, an area bigger than the state of Rhode Island, completely disintegrated.

An ice shelf acts as a dam for glaciers on land. So although its break-up did not directly contribute to sea-level rise, observations show that the removal of the Larsen B ice dam has caused a worrisome acceleration of glacier flow into the ocean (as much as eight-fold), which could in time raise global sea level.[110,111]

A similar event occurred in the Arctic in the spring and summer of 2003, when the Ward Hunt Ice Shelf, the Arctic's largest ice shelf, broke in two.[112] The ice shelf had been acting as a dam for a unique freshwater lake, the largest of its kind in the northern hemisphere and home to a rare microbial ecosystem that was only discovered in 1999. Researchers believe that rising temperatures caused the weakening of the ice shelf. When it broke, the lake drained and disappeared.

Sea ice has been faring no better. In 2000 and again in 2001, people were



Sudden break-up of the Larsen B ice shelf in Antarctica. Left: At the beginning of the break-up, January 31, 2002; Right: At the end of the break-up, March 7, 2002. (Ted Scambos, National Snow and Ice Data Center, University of Colorado, Boulder, based on data from MODIS. http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=8257)

Like drought and other climatic changes, sea ice shrinkage sets in motion a worsening cycle, amplifying global warming.

astounded by the appearance of a gaping hole of ice-free water at the North Pole, a stark demonstration that Arctic sea ice is no longer as extensive and solid as it used to be. Spring and summer Arctic sea ice has decreased in surface area by 10 to 15% since the 1950s.[113] Furthermore, in late summer to early autumn, sea ice has thinned by about 40% in many parts of the Arctic. (By comparing identical parts of the year, these numbers account for seasonal fluctuations and therefore represent real, long-term changes.) While for much of the past few decades the downward trend fluctuated between record-low years and closer-to-normal years, the ice took a turn for the worse from 2002 to 2005, which have all seen record or near-record low ice coverage.[114] Like drought and other climatic changes, sea ice shrinkage sets in motion a worsening cycle, amplifying global warming. Light colored ice reflects a significant portion of the energy from the sun back into space. If that sea ice is gone, the darker water absorbs the solar energy and the climate heats up faster. At present rates of shrinkage, Arctic sea ice could soon pass a point of no return, disappearing completely each summer by the end of this century; that situation would be unprecedented in the last one million years.[115]

The implications for many inhabitants of the Arctic are grim. The shrinking of sea ice, especially during the warmer part of the year, has resulted in population declines among animals such as polar bears and ice-dwelling seals, which require a sufficiently long sea-ice season for hunting and rearing young.[116] (A detailed discussion on Arctic wildlife can be found in Part IV of this report.) This in turn makes it more difficult for native peoples to hunt for seals and other food sources.[117] Hunters' lives are also endangered by the increasing risk of falling through thin ice. If we allow global warming to continue, traditional societies in the Arctic could be destroyed.

Melting permafrost and damage to infrastructure

In cold regions around the world, large reaches of land have been frozen year-round. That permafrost is now melting rapidly in places like the Arctic of North America, Siberia, and the Himalayan/Tibetan region of Asia.[118]

GARY BRAASCH 2001, HTTP://WWW.BRAASCHPHOTOGRAPHY.COM

Coastline next to the village of Shishmaref, Alaska, eroding as rising temperatures cause the permafrost underneath the land to melt.

The impacts on Alaskan infrastructure have been particularly striking. Alaska has experienced the largest warming trend of any state; since the 1950s, temperatures have increased about 4°F (2.2°C) on an annual average, and as much as 7°F (3.9°C) in the interior in winter.[119] Climate models project that Alaskan temperatures will rise by an additional 9–18°F (5–10°C) by 2100. In addition to the increase in catastrophic forest fires described earlier, Alaska's warming has caused buildings to sink and break into pieces and roads to buckle, as the underlying permafrost liquefies.[120] In the Mackenzie Basin, thawing permafrost has destabilized slopes, causing landslides, erosion and local flooding, and threatening roads and bridges. Meat stored in traditional ice cellars dug into the ground has begun to rot.[121] The residents of Shishmaref, an Eskimo village that had existed for 4,000 years on an island off the coast of Alaska, were recently forced to relocate their entire community to the mainland.[122] The ground under their feet had weakened as the permafrost melted and been eroded by ocean waves, which are amplified when disappearing sea ice is replaced by open water. Many other villages are dangerously close to a similar fate.

Beyond these immediate impacts, scientists are concerned that thawing permafrost may increase atmospheric levels of carbon dioxide and methane, which are both greenhouse gases. Because of the slow rates of decomposition of dead plant material in the cold, waterlogged environment, Arctic soils contain vast stores of carbon. In fact, 25% of the global reservoir of soil carbon can be found in this region.[123] Permafrost also contains large quantities of frozen methane.[124] With continued thawing, large amounts of carbon and methane could be released, raising atmospheric levels significantly and warming the planet further.[125] Ironically, the melting of permafrost will also make oil and natural gas exploration more difficult, since the heavy equipment required can only be transported over solidly frozen ground.[126] This could mean the reduction of one source of greenhouse gases.

PART IV

Ecological impacts

Damage to coral reefs

Around the world, the incidence of large-scale coral "bleaching" events has increased since 1979, and most evidence indicates that this increase in mass bleachings is linked to global warming.[127,128] The normally brilliant colors of corals are provided by photosynthetic algae, called zooxanthellae, which live inside the corals in a mutually beneficial relationship. Under certain stressful conditions, especially when the surrounding water temperature rises at least 1.8°F (1°C) above the long-term average summer maximum, corals cope by expelling their zooxanthellae guests. This results in the loss of color that gives rise to the term "bleaching." Prolonged bleaching often leads to death of the coral.

Average surface ocean temperatures in many tropical regions rose by almost 2°F (1°C) over the past century. From mid-1997 to mid-1998, the warmest 12-month period on record, the largest bleaching event on record affected every region of the world. About 16% of the reefs in the world were seriously damaged in that one event.[129] Corals which had survived for as long as a thousand years perished. In the Florida Keys, significant bleaching in consecutive years was observed for the first time; the damaged reefs have shown little recovery since. A year earlier, in 1996, the first bleaching event ever documented in Hawaii occurred, affecting several islands.[130] Although bleaching events in Hawaii may have occurred previously, no evidence has been found of such an extensive one across the island chain.

Continued warming could cause mass bleachings to become an annual event within the next few decades. While there is some evidence that corals can cope with excessive heat by forming new relationships with heat-tolerant zooxanthellae, it is currently unknown whether this adaptation mechanism could occur widely and rapidly enough to prevent loss of some reef ecosystems or species.[131] The extensive loss of corals during the 1997–1998 bleaching event and the projected further warming of tropical oceans by 1–3°C (1.8–5.4°F) over the next century do not bode well.

Increases in atmospheric carbon dioxide pose a more direct danger to corals as well. When carbon dioxide gas dissolves in seawater, it changes ocean chemistry, making it more difficult for corals to produce calcium carbonate, the main building material in their skeletons.[132] Such a change in seawater chemistry has in fact been observed.[133]

Left: Healthy corals (iStockphoto).Right: bleached corals (Ray Berkelsman, CRC Reef, Townsville).

Coupled with other human-induced stresses, including water pollution, increased runoff of dirt from disturbed land areas, mining and blasting of reefs, and destructive fishing practices, coral reefs could soon be wiped out across many parts of the world, an irreparable loss of one of the world's ecological treasures.

The loss of coral ecosystems would also have severe economic repercussions in regions that depend on reefs for food and tourism income, and for the protection of coastal land from destructive waves. Coral reefs provide an estimated $3.1–4.6 billion (U.S.) in economic benefits to the Caribbean region each year.[134] The Great Barrier Reef directly contributes around $1 billion to the economy of Australia each year. Saving these beautiful, wondrous ecosystems may require rapid, worldwide cuts in greenhouse gas emissions, as well as mitigation of other human disturbances to reefs.

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Shifting species ranges and yearly cycles

Recent research provides strong evidence that global warming is already having measurable impacts on many wild animal and plant species worldwide. Two different research groups, each of whom synthesized numerous studies of shifts in the geographic range and yearly cycles of over 1,400 species, found a discernible "fingerprint" of global warming on the web of life.[135] **Over 80% of the species, ranging from fish to mammals and from grasses to trees, are changing in the direction expected for a warming climate.**

In one strong indication of global warming, the researchers found an average range shift of 3.8 miles (6.1 km) per decade towards the poles, and 20 feet (6.1 m) per decade upward in altitude, across a large number of diverse species. Among 36 butterfly species in North America and Europe, eight expanded their range northward while dying out at the southern end of their range; no species showed the opposite pattern. Of 36 species of fish in the North Sea (between Great Britain and Norway), the populations of 13 shifted northward over the past 25 years in response to warming waters, while only 2 shifted southward.[136] The average distance moved was a remarkable 107 miles (172 km). An additional 6 species moved into deeper, cooler waters. Pressure from fishing does not appear to explain the shifts in distribution. It is projected that two kinds of commercial fish could move completely out of the North Sea by 2050, with profound ecological and economic consequences.

In another indication of global warming, springtime events such as migration of birds and butterflies, bird nesting, frog breeding, tree leafing, and flowering are starting an average of 2.3–5.1 days earlier every decade across all observed species.[137] The authors of one analysis conclude that continued rapid climate change combined with other man-made stresses, such as habitat destruction, could result in numerous disruptive changes to ecosystems, including extinctions.

Declining Arctic animal populations

The disproportionate warming in the Arctic has had detrimental effects on many Arctic species. The health of polar bears, in particular, is declining due to decreasing ice coverage in the Hudson Bay, at the southern end of the species' range.[138] As the total area of Arctic sea ice has declined by close to 6% over the last 20 years, the sea ice season in the Hudson Bay has shortened by three weeks. Polar bears depend on sea ice thick enough to walk on to travel

A polar bear in its natural sea ice habitat. (NOAA Photo Library)

between their dens (which can be on the shore or out on the ice), and their main food source: ice-dwelling ringed seals. As the ice in the Bay forms later each autumn and breaks up earlier each spring, polar bears have less time to hunt, and return to land at the end of the season in poorer condition. Less accumulated weight makes it more difficult for females to successfully give birth in the winter, when they must hole up inside their dens and go for months without eating. Insufficient sea ice in the spring can also prevent the mothers from hunting food for their cubs. Scientists found a 15% decline in both the average weight of adult bears and the number of cubs born during the last 20 years.

Further jeopardy is posed to the bears by increasingly frequent and intense spring rains— yet another consequence of global warming— which cause some snow dens to collapse, killing the mothers and cubs.[139] In 2005, a scientific petition was filed in the U.S. to list polar bears as a threatened species under the Endangered Species Act. Ongoing environmental changes due to global warming were cited as the primary threat.[140] If summer sea ice disappears across the entire Arctic, as is projected for the end of this century in the absence of action to limit warming, polar bears are likely to be pushed to the brink of extinction.

Other Arctic animals are also showing population declines in response to warming. For caribou, an earlier spring means that their food plants have passed their prime by the time the caribou migrate back from their winter home to the south.[141] The range of the

Left: Caribou (NOAA Photo Library. Photographer: Captain Budd Christman, NOAA Corps).
Right: Arctic fox (U.S. Fish and Wildlife Service).

Arctic fox is shrinking as the animals retreat toward the North Pole and are replaced by more common red foxes, which are adapted to warmer climates.[142]

Declining amphibian populations

Amphibian populations in highland areas around the globe are declining still more precipitously. In Central and South America, many mountain amphibians, including the golden toad and most of the 70-odd species of harlequin frogs, have vanished or declined markedly.[143] In the Pacific Northwest of the United States, embryo mortality rates are increasing for species like the western toad and the Cascades frog, which lay their eggs in mountain lakes: fewer of those eggs ever hatch.[144]

Research suggests that changing cloud and/or precipitation patterns associated with global warming could be affecting how amphibians respond to disease. In the mountains of the tropics, two specific climate-related causes of amphibian declines have been identified.[145,146] First, amphibians typically escape the effects of a lethal fungal parasite of the skin that thrives in cool, moist conditions by basking temporarily in sunny, warm microclimates. Global warming increases the amount of water vapor in the atmosphere, producing more clouds when moisture-laden trade winds in the tropics are forced upward against mountains and cooled. The increased cloud cover reduces the occurrence of sunny microclimates, preventing the amphibians from ridding themselves of the fungus.

Second, global warming may raise the altitude at which clouds and mist form; with warmer temperatures, moisture-containing air must in some circumstances rise higher up the mountains to cool sufficiently for condensation to occur. That possibility has been demonstrated in climate models, especially for the winter dry season, which is when tropical mountain forests are the most dependent for their water supply on direct contact with clouds and mist.[147] A decrease in water availability can further promote fungal attack, since amphibians are forced to spend prolonged periods in cool, moist spots in order to maintain body moisture. A decrease in the amount of mist, along with an increase in the occurrence of higher clouds, has in fact been observed since the early 1970s in Costa Rica in Central America.

In the Pacific Northwest, the rise in embryonic mortality may be linked to the increase in El Niño events associated with global warming.[148] Years with

Left: Golden toads in the mountains of Costa Rica are believed to have gone extinct in recent years. Right: Harlequin frog in the mountains of Costa Rica. (Michael and Patricia Fogden) unusually low rainfall in the region have become more common in recent decades, corresponding to the increase in El Niño events. (For more on El Niño, see the section “Torrential Rains and Flooding” in Part I.) As a result lake levels have been low. Without water sufficiently deep to filter out some sunlight, amphibian eggs in high-altitude lakes may be exposed to high levels of UV radiation. The embryos within exposed eggs, experiments have found, are more vulnerable to infection by a deadly fungus.

PART V

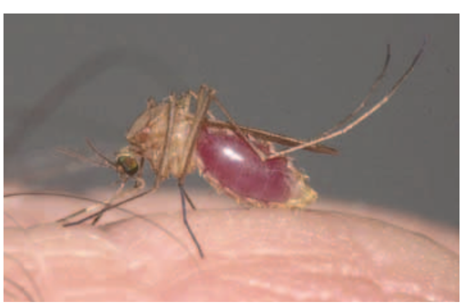
Outbreaks of vector-borne diseases

Many infectious diseases are spread by organisms such as mosquitoes and rodents, known as disease vectors, whose distributions and behavior are sensitive to temperature and moisture. Global warming can increase the risk of vector-borne disease in a number of ways:

1. Higher temperatures accelerate the maturation of certain disease-causing agents and their vectors. For example, the incubation period required for a mosquito to be able to transmit dengue fever virus after it has been infected falls from 12 days at 30°C to 7 days at 32–35°C; this translates into a potential threefold increase in the transmission rate of disease.[149]

2. Higher annual average temperatures can lengthen the season during which vectors are active. For example, in Canada, ecologists have found that present-day mosquitoes wait nine days more than their ancestors did 30 years ago before they begin their winter dormancy, with warmer autumns being the most likely cause.[150]

3. A warmer climate can expand the geographic range of tropical mosquito-borne diseases, such as malaria, dengue fever, and yellow fever, to higher altitudes and latitudes. Especially vulnerable are less developed countries that have fewer resources to combat disease. Malaria, the most prevalent vector-borne disease, kills 1 to 2 million people annually.[151] The disease is generally limited to areas with winter temperatures above 16°C, since the parasite is not able to grow below this temperature. Dengue viruses are generally limited to the tropics between the latitudes of 30° north and 20° south, since frosts or prolonged cold weather kill the vector, adult *Aedes aegypti* mosquitoes, as well as their overwintering eggs and larvae.[152]



Mosquito feeding on human hand. (Courtesy of Dr. Gary Alpert, Environmental Health and Safety Dept., Harvard University)

Nighttime and winter temperatures are increasing faster than daytime and summer temperatures in many regions of the world.[153] This decrease in the occurrence of cold weather means that areas at high latitudes or altitudes that were previously unsuitable for the transmission of tropical diseases may become suitable due to global warming. *This has, apparently, already started to happen.* In the South American country of Colombia, the mosquitoes that carry dengue fever and yellow fever viruses were previously limited to altitudes below 3,300 ft (1,000 m), but have been recently found at 7,200 ft (2,200 m).[154] To the north in Mexico, dengue fever has spread above its former limit of 3,300 ft (1,000 m), appearing at 5,600 ft (1,700 m).[155] An ocean and half a continent away in Rwanda, malaria was unheard of above 5,600 feet (1,700 m) until the early 1980s.[156] Higher nighttime temperatures are strongly correlated with the spike in malaria cases. The spread of the disease to higher altitudes has also been facilitated by heavy rainfall, which creates more pools of water in which mosquitoes can breed.

There are factors in addition to global warming that can influence the spread of tropical diseases, as skeptics often emphasize. For example, there has been a resurgence of malaria all over the tropics since 1973, influenced more by the appearance of insecticide-resistant mosquitoes and by the malaria parasite's growing resistance to antibiotics than by global warming.[157] But the correlation between rising temperatures and the spread of diseases to high-altitude areas previously free of disease provides strong evidence that global warming has actually expanded the range of tropical diseases.

4. Increasing climate variability associated with global warming, especially increases in the frequency of heavy precipitation events and floods, can promote explosive growth in the populations of disease vectors. Outbreaks of hantavirus, which is carried by wild rodents and can lead to severe and often fatal illness in humans, have in the past decade been occurring in parts of the U.S. These record outbreaks appear to be a result of episodes of unusually heavy precipitation associated with El Niño events, which as noted in Part I may increase in frequency and intensity with global warming. In the Southwest, six years of drought followed by heavy spring rains in 1993 produced a burst of vegetation growth that resulted in a ten-fold increase in the population of deer mice, a known carrier of hantavirus.[158] Despite public education campaigns after an outbreak in 1993-1994 to spread awareness of the disease and preventive measures, another outbreak hit the Southwest in the wake of the 1997–1998 El Niño.

Conclusion

- Although individual events or phenomena may not always be easy to link to global warming, the increase in frequency and intensity of such phenomena, and their simultaneous occurrence around the world, provides stronger evidence for such a linkage.
- Many of the recently observed events have been the worst or unprecedented in 100, 500, 1,000 years or more. This suggests that something highly unusual is happening to our planet.
- Many of the impacts we have seen so far are likely just "the tip of the iceberg"—scientists predict more dramatic, severe and, in some cases, irreversible impacts if we allow warming to continue unabated in the future.
- Other effects of human activity, such as the spread of homes and infrastructure into vulnerable locations, sinking of coastal land, and degradation of wildlife habitat, can compound the damage caused by global warming.
- Global warming has wide-ranging effects on many aspects of human life. It threatens economies, lives and traditional ways of life.

The facts gathered in this report present society with a choice: We can make no serious effort to combat global warming, and instead try to cope with its increasingly devastating impacts on our livelihoods and the natural world we cherish. Or we can act now to stabilize the climate and mitigate future damages.

Progress in combating global warming has already been made at the international, state, and local levels. But national action by the U.S.—the world's most powerful and technologically advanced nation and its biggest emitter of greenhouse gas pollution—is urgently needed as well. National legislation that sets a mandatory cap on emissions, as well as a renewed engagement by the U.S. with the international community, would be transformative steps towards solving the problem of global warming.

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