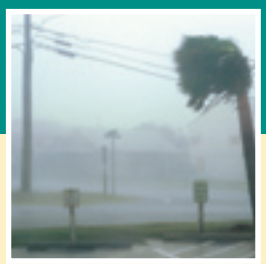


CLIMATE CHANGE 101
The Science and Impacts

Scientists now know for certain that the earth has been warming for the past century. They know that human activities, mainly the burning of coal and oil, have dramatically increased concentrations of heat-trapping gases in the atmosphere. And they understand the science of how these gases are causing the observed warming. As a result, they predict that the world will continue to warm in the centuries ahead, with significant impacts on sea levels and weather patterns, and consequences for human health, ecosystems, and the economy. Avoiding the most severe impacts, scientists say, will require substantial reductions in emissions of the greenhouse gases that are contributing to climate change.

GLOBAL TEMPERATURES: THE EARTH IS WARMING

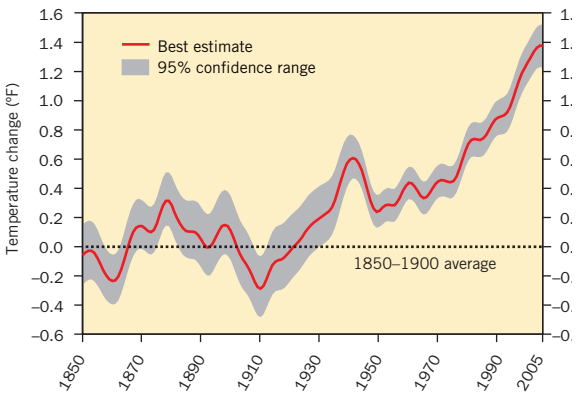
The world is getting warmer. Average global temperatures have risen by more than 1 degree Fahrenheit over the last century, with average warming of as much as 4 degrees Fahrenheit in some regions (see Figure 1).[1]

According to scientists, this warming trend has accelerated in recent years. The ten warmest years since thermometer records became available in 1860 all occurred between 1995 and 2005.[2] The World Meteorological Organization has reported that 2005 was the second hottest year on record, surpassed only by 1998, when El Niño conditions in the Pacific Ocean contributed to above-average temperatures worldwide. For the United States, the first six months of 2006 were the warmest such period on record.[3] No U.S. state was cooler than average for the six-month period; five states—Texas, Oklahoma, Kansas, Nebraska and Missouri—experienced record warmth.

Accompanying the increased temperatures at the earth's surface has been a significant rise in ocean temperatures to a depth of 700 meters. Scientists from the U.S. National Oceanic and Atmospheric Administration have demonstrated that the ocean as a whole has been warming for the past

Figure 1

Global Surface **Temperature Trend** 1850-2005



five decades.[4] The highest level of warming was recorded at the upper levels of the oceans, evidence that the oceans are absorbing most of the increased heat from the earth's surface (see Figure 2).[5]

Even if greenhouse gas concentrations were stabilized today, the heat that is already in the ocean will warm the atmosphere over time, bringing an additional 1 degree Fahrenheit of warming by the end of the twenty-first century.[6]

PEW CENTER ON Global CLIMATE CHANGE

PEW CENTER on the STATES

This brief is part of a series called *Climate Change 101: Understanding and Responding to Global Climate Change*, published by the Pew Center on Global Climate Change and the Pew Center on the States.

The increases in global temperatures will continue in the decades ahead, scientists say. According to the Intergovernmental Panel on Climate Change (IPCC), which includes more than 2,000 scientists from the United States and other countries, over the next century, average global temperature will rise by two-and-a-half to ten degrees Fahrenheit.[7] Regional increases may be greater or less than the global average, according to the IPCC. For example, the level of warming in the United States is projected to be higher than the global average.[8] The Arctic is likely to experience the greatest warming.

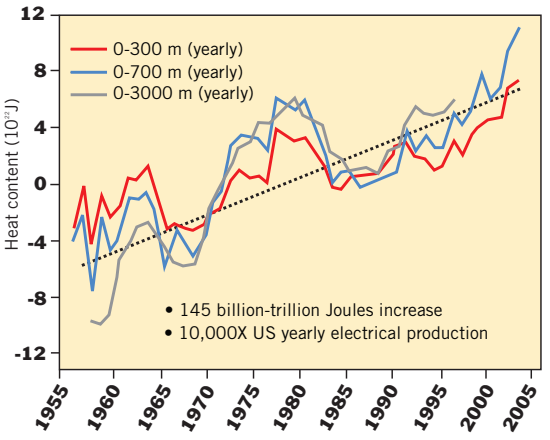
The problem is not just changing temperatures; it is a changing climate—or a change in the weather patterns that people and ecosystems have become accustomed to over time.[9] In fact, "climate change" and "global warming" often are used interchangeably to describe the same phenomenon.

GREENHOUSE GASES: MAKING THE CONNECTION

Global temperatures have experienced natural shifts throughout human history. For example, the climate of the Northern Hemisphere varied from a relatively warm period between the eleventh and fifteenth centuries to a period of cooler temperatures between the seventeenth century and the middle of the nineteenth century.

Figure 2

Ocean Heat Content



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However, scientists studying the rapid rise in global temperatures during the late twentieth century say that natural variability cannot account for what is happening now.[10] The main culprit, they say, is emissions of carbon dioxide and other greenhouse gases from human activities, primarily the

Figure 3

The Greenhouse Effect

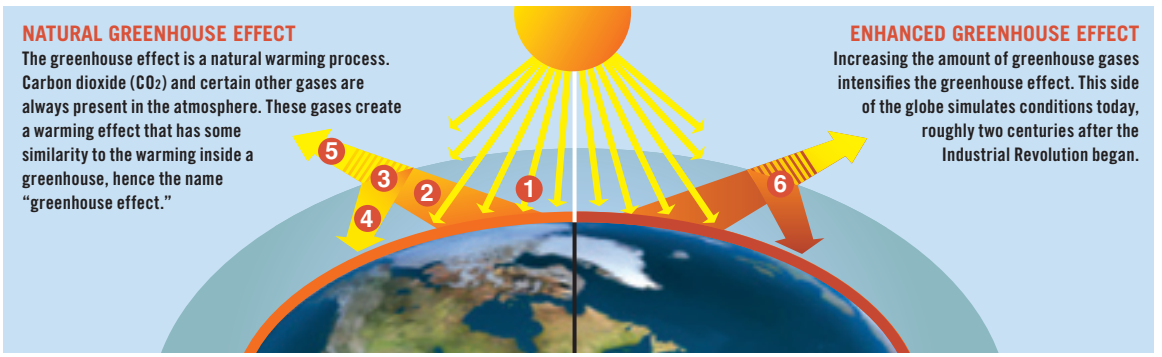


Illustration of the greenhouse effect (courtesy of the Marian Koshland Science Museum of the National Academy of Sciences). Visible sunlight passes through the atmosphere without being absorbed. Some of the sunlight striking the earth ❶ is absorbed and converted to heat, which warms the surface. The surface ❷ emits heat to the atmosphere, where some of it ❸ is absorbed by greenhouse gases and ❹ re-emitted toward the surface; some of the heat is not trapped by greenhouse gases and ❺ escapes into space. Human activities that emit additional greenhouse gases to the atmosphere ❻ increase the amount of heat that gets absorbed before escaping to space, thus enhancing the greenhouse effect and amplifying the warming of the earth.

burning of fossil fuels such as coal and oil. Other human sources of these gases include deforestation, agriculture and industrial processes.

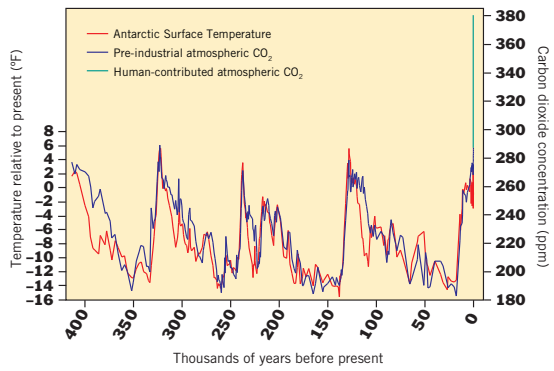
Scientists refer to what has been happening in the earth's atmosphere over the past century as the "enhanced greenhouse effect." By pumping man-made greenhouse gases into the atmosphere, humans are altering the process by which naturally occurring greenhouse gases trap the sun's heat before it can be released back into space.

The greenhouse effect keeps the earth warm and habitable; without it, the earth's surface would be about 60 degrees Fahrenheit colder on average. Since the average temperature of the earth is about 45 degrees Fahrenheit, the natural greenhouse effect is clearly a good thing. But the enhanced greenhouse effect means even more of the sun's heat is trapped, causing global temperatures to rise (see Figure 3).

Among the many scientific studies providing clear evidence that an enhanced greenhouse effect is under way was a 2005 report from NASA's Goddard Institute for Space Studies. Using satellites, data from buoys, and computer models to study the earth's oceans, scientists concluded that more energy is being absorbed from the sun than is emitted back to space, throwing the earth's energy out of balance and warming the globe.[12]

Figure 4

Global Temperature: The Last 400,000 Years



IPCC TAR, 2001

Through the cycle of ice ages, atmospheric CO_2 closely tracks the surface temperature. As temperatures rise, biological activity produces more CO_2, which increases the warming and stimulates more CO_2 production. During the past 400,000 years, CO_2 concentrations never exceeded 300 ppm (parts per million) until industrialization occurred. Current concentrations now exceed that historical maximum by about 80 ppm due to human contributions.

At Issue:
Measuring Satellite vs. Surface Temperatures

For many years, skeptics of climate change have pointed to differences between temperature increases recorded at the earth's surface and those recorded by satellites as a way to challenge scientific claims about climate change. However, a May 2006 report from the U.S. Climate Change Science Program corrected errors in the satellite data and other temperature observations, concluding that "(t)he previously reported discrepancy between surface and atmospheric temperature trends is no longer apparent on a global scale."[11]

How much of a jump have we seen in greenhouse gases? In its first *Greenhouse Gas Bulletin*, issued in March 2006, the World Meteorological Organization said average global concentrations of the three main greenhouse gases—carbon dioxide, methane, and nitrous oxide—continued their year-after-year climb in 2004. Compared to pre-industrial times, concentrations of the most abundant greenhouse gas, carbon dioxide, were up by 35 percent, while methane levels had increased by 155 percent and nitrous oxide by 18 percent.[13]

Looking back even further, scientists say the world is entering largely uncharted territory as atmospheric levels of greenhouse gases continue to rise. Today's carbon dioxide levels are substantially higher than anything that has occurred for more than 400,000 years. And, even over all those millennia, there has been a clear correlation between carbon dioxide levels and global temperatures (see Figure 4).

There is no doubt among scientists that the recent spike in carbon dioxide and other greenhouse gases in the atmosphere is the result of human activities. The World Meteorological Organization and many other scientific organizations have confirmed this relationship. While there are natural processes that produce these gases, they are balanced out by other

natural processes that consume them. Therefore, the current rise in atmospheric greenhouse gases can only be explained by human activities that pump additional gases into the atmosphere at a rate of billions of tons each year. A recent review of more than 900 journal articles on climate change revealed that not one of the authors disagreed with the evidence showing that human greenhouse gas emissions impact the climate.[14]

Many of the predictions that scientists have made in the past about the impacts of global warming are already upon us.

In 2005, the United States National Academy of Sciences joined a group of 10 other science academies from around the world in a statement calling for "prompt action" on global warming by world leaders. The statement could not have been more explicit about the connection between human activity and climate change. It stated: "Action taken now to reduce significantly the build-up of greenhouse gases in the atmosphere will lessen the magnitude and rate of climate change."

THE CHANGING CLIMATE: FROM THEORY TO REALITY

It is not just rising average global temperatures that concern scientists but also their effects on weather extremes, declining global ice cover and sea level rise. In fact, many of the predictions that scientists have made in the past about the impacts of global warming are already upon us, including disappearing glaciers, loss of sea ice, more extreme heat waves, accelerated sea level rise, and stronger hurricanes. Scientists say these effects are likely to worsen in the decades ahead.

RISING SEA LEVEL

Among the most serious and potentially catastrophic effects of global warming is sea level rise, caused by a combination of melting glaciers all over the world and the "thermal expansion" of the seas as oceans warm. By the end of the century, if nothing is done to rein in emissions of greenhouse gases, global sea level may be three feet higher than today and rising.[15]

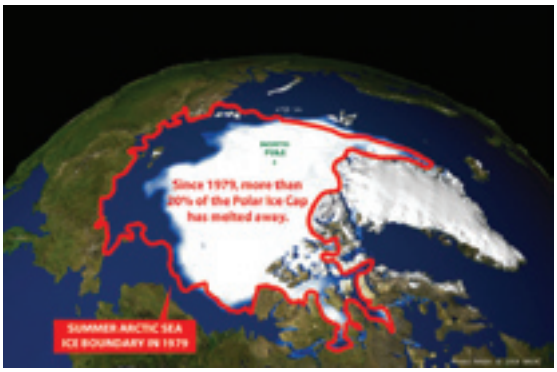
Rising sea level will have severe impacts in low-lying coastal communities throughout the world. In Bangladesh, for example, even a one-meter rise would inundate 17 percent of the country. In the United States, where 54 percent of the population lives in close proximity to the ocean, the most vulnerable areas are the Southeast and Mid-Atlantic coasts. Also at risk are low-lying areas and bays such as North Carolina's Outer Banks, the Florida Coast, and much of southern California.

Melting Polar Ice. In November 2004 an international team of 300 scientists from 15 countries, including the United States, issued a report on the impacts of climate change in the Arctic. In addition to painting a stark picture of how climate change already is affecting the region, the report of the Arctic Climate Impact Assessment predicted that at least half the summer sea ice in the Arctic will melt by the end of this century, along with a significant portion of the Greenland Ice Sheet (see Figure 5).[16]

The decline of the Greenland Ice Sheet was the focus of a February 2006 article in the journal *Science*.[17] Using new satellite-based measurements, researchers showed that the second largest land-based ice sheet in the world is losing ice twice as fast as scientists had estimated. A complete melting of this ice sheet could raise global sea level by almost 20 feet

Figure 5

Summer Arctic Sea Ice Extent



NASA* and *Natural Resources Defense Council

within a few hundred years, a level that would permanently flood virtually all of America's major coastal cities.

Ice cover loss is not limited to the northern hemisphere. Another *Science* article in March 2006 revealed that Antarctica also is losing massive amounts of ice to the melting and slipping of glacier ice into the ocean, a natural process that has been accelerated by global warming.[18] The result is a net loss of polar ice that is adding billions of tons of water each year to the world's oceans.

In addition to causing sea level rise, the disappearance of polar ice actually will intensify global warming. Because water absorbs more solar radiation than ice, as the poles lose ice cover, more heat from the sun will be absorbed at the earth's surface instead of being reflected back into space by the snow and ice.

Loss of Mountain Glaciers and Snow Pack. In addition to the loss of polar ice, climate change is causing a worldwide loss of mountain glaciers at all latitudes. Scientists have observed that glaciers are in retreat in all regions of the world, from the Himalayas to tropical South America to the western United States. By mid-century, scientists say, most mountain glaciers may be gone. If the current rate of global warming continues, there will be no glaciers left in Glacier National Park by 2030.[19]

In addition to contributing to sea level rise, the melting of mountain glaciers also poses a threat to global water supplies. Billions of people around the world depend solely on glaciers for irrigation and drinking water.

Expansion of the Oceans. Another cause of sea level rise is what scientists refer to as the "thermal expansion" of the oceans—put simply, as the oceans continue to warm, they will expand. Even if no more greenhouse gases are added to the atmosphere, global sea level will rise by four inches over the next century because of thermal expansion alone, according to researchers at the National Center for Atmospheric Research.[20]

Even if no more greenhouse gases are added to the atmosphere, global sea level will rise by four inches over the next century because of thermal expansion alone.

CHANGING WEATHER PATTERNS

Scientists predict that climate change will have a significant effect on global weather patterns, causing both more floods and more droughts. Extended heat waves, more powerful storms, and other extreme weather events have become more common in recent years and will continue on this trend. These changes in weather patterns will have serious—and potentially severe—impacts on human societies and the natural world.

Stronger Hurricanes. The 2005 hurricane season in the Atlantic Ocean, with four Category 5 storms for the first time in recorded history, raised questions in many Americans' minds about the potential connections between hurricanes and climate change. Now, scientists have confirmed that hurricanes are becoming more intense—not just in the Atlantic but in all oceans where they occur.[21]

Why would climate change make hurricanes stronger? The answer, scientists say, is because hurricanes draw their strength from the heat in ocean surface waters. Therefore, as ocean waters grow warmer, hurricanes will become more powerful on average, a trend that is already evident over the past 35 years.

At Issue: Twentieth-Century Temperature Trends

Scientists have noted a distinct pattern of warming during the twentieth century, with a large warming between 1910 and 1940, moderate cooling from 1940 to 1975, and a large warming again starting in 1975. The most likely reason for the cooling during the middle of the century: a surge in sun-blocking aerosols, or very fine particles, resulting from volcanic eruptions, human pollution, and other sources.[22] Scientists expect that these causes are on the decline, while greenhouse gas emissions are on the rise, and that both trends will continue.

While there is no way to link one hurricane directly to climate change, Hurricane Katrina, which wreaked havoc along the U.S. Gulf Coast in August 2005, showed the potential of warm ocean waters to contribute to stronger storms. At the same time that Katrina was exploding from a tropical storm to a Category 5 hurricane while still at sea, the surface waters in the Gulf of Mexico were unusually warm—about 2 degrees Fahrenheit warmer than normal for that time of year. With global warming causing ocean temperature to rise, we should expect hurricanes like Katrina to become more and more common.

More Droughts and Flooding. Other weather impacts from climate change include a higher incidence of drought and flooding and changes in precipitation patterns. According to the Intergovernmental Panel on Climate Change, future changes in weather patterns will affect different regions in different ways. In the short term, for instance, farms and forests may be more productive in some regions and less productive at others. Among the reasons: precipitation will increase in high-latitude regions of the world in summer and winter, while southern Africa, Australia and Central America may experience consistent declines in winter rainfall.[23] As a result of these changes, agriculture in developing countries will be especially at risk. Wheat, for example, may virtually disappear as a crop in Africa, while experiencing substantial declines in Asia and South America.[24]

Two reports released by the Pew Center on Global Climate Change in 2004 looked at the likely impact of climate change on the United States. The U.S. areas most at risk, according to the reports, will be the Southeast and southern Great Plains because of the low-lying coasts in the Southeast and the long-term impacts of warmer temperatures on agriculture in both regions. The reports also warned of the potential impacts of climate change on long-lived infrastructure in the United States, especially the nation's water resources.[25]

Climate change holds the potential of inflicting severe damage on the ecosystems that support all life, from hazards to coral reefs due to warmer and more acidic ocean waters to threats to polar bears because of declines in sea ice

Effects on Human Health. A recent United Nations report blamed climate change, along with worsening air and water quality and poor disposal of solid waste, for an increase in malaria, cholera and lower respiratory tract infections in African societies. Africans also are suffering from the effects of reduced crop yields and decreased availability of water.[26] The U.N. report on Africa provides an early glimpse of some of the ways in which scientists say climate change will affect people's health in the decades to come, no matter where they live. Climate change can affect human health directly (for example, because of extreme temperatures and heat waves) and indirectly (for example, by contributing to the spread of infectious disease or threatening the availability and quality of food and water). The elderly, the infirm and the poor will be especially at risk.[27]

Effects on Ecosystems. Climate change holds the potential of inflicting severe damage on the ecosystems that support all life, from hazards to coral reefs due to warmer and more acidic ocean waters to threats to polar bears because of declines in sea ice. Ecosystems around the world already are reacting to a warming world.

For example, one study found that 130 species, including both plants and animals, have responded to earlier spring warming over the last 30 years. These organisms have changed their timing of flowering, migration and other spring activities. The changes occurred regardless of regional difference and were linked directly to enhanced greenhouse warming.[28]

Researchers also have established that climate change is driving some species to extinction. For instance, in the past 20 years dozens of species of mountain frogs in Central America have disappeared because of a disease that formerly did not occur where they live. In 2006, a paper in the journal *Nature* revealed that the disease-causing organism, a fungus, has spread to higher elevations as a result of human-induced climate change.[29]

In other scientific findings, biologists have observed changes in Arctic ecosystems as a result of sea ice loss, including changes in fish populations in southern reaches of the Arctic seas.[30] And researchers predict that if ocean warming continues (along with ocean acidification from rising atmospheric concentrations of carbon dioxide), the world's coral reefs will be at risk from an increase in "coral bleaching," which can ultimately kill the corals and endanger the fish and other creatures that depend on the reefs.[31]

WHAT CAN BE DONE?

The greenhouse gases that are already in the atmosphere because of human activity will continue to warm the planet for several centuries. In other words, some level of continued climate change is inevitable, meaning that humanity is going to have to take action to adapt to a warming world.

However, scientists say it is still possible—and necessary—to reduce the magnitude of climate change by "stabilizing" atmospheric concentrations of greenhouse gases. This means stopping these concentrations from rising further, chiefly by achieving substantial reductions in emissions of carbon dioxide and other greenhouse gases from human sources.

The consensus among climate scientists is that worldwide emissions of greenhouse gases need to start a long-term decline within the next decade or two. According to the Intergovernmental Panel on Climate Change, the world needs to reduce total emissions by about 50 to 80 percent (compared to a business-as-usual scenario) in order to stabilize atmospheric greenhouse gas concentrations and avoid dangerous climatic change.[32]

The science makes it abundantly clear: the time to act is now. The world is already facing severe consequences; we must respond to the overwhelming scientific evidence and take strong action to reduce the greenhouse gas emissions that cause climate change.

Pew Center on Global Climate Change

For more information on the science and impacts of climate change visit www.pewclimate.org.

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