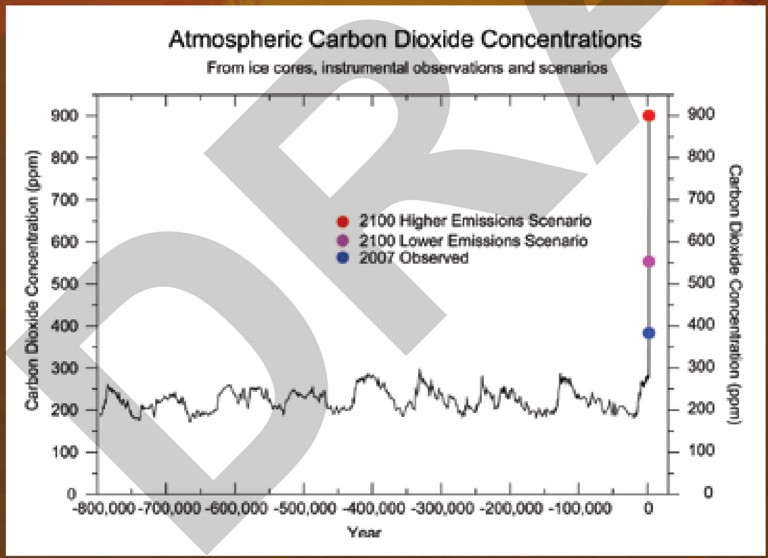
Global Climate Change

- Human-caused increases in the emissions of heat-trapping gases are responsible for most of the warming observed over the past 50 years.
- Changes in purely natural factors also influence climate, but cannot explain the warming of the past 50 years.
- Temperature and precipitation have increased over recent decades, along with some extreme weather events such as heat waves and heavy downpours.
- Warming is causing sea-level to rise as land-based ice melts and the warmer oceans expand.
- Arctic sea ice decline is accelerating.
- Many of these observed changes are occurring more rapidly than projected even a few years ago.
- The specific patterns of recent climatic change show that it is primarily human-induced.
- Global temperatures will continue to rise; how much depends on the amount of heat-trapping emissions and how sensitive the climate is to those emissions.
- Climate can also change abruptly, as is evident from ice core records of past climate.
- The human effect on climate can be minimized if emissions are sharply reduced.

This introduction to global climate change is a primer on what has been happening to global climate and why, and what is projected to happen in the future. While this report focuses on climate change impacts in the United States, understanding these changes necessarily requires an understanding of the Earth as a system, including the global climate. Impacts, while often local, arise from changes in this global system.

Some continued warming of the planet is inevitable over the next few decades. The amount of warming that we actually experience will be determined largely by the choices made now and in the near future. Lower amounts of heat-trapping emissions will yield less future warming, while higher amounts will result in more warming and more severe impacts on our society and economy as well as the natural world.

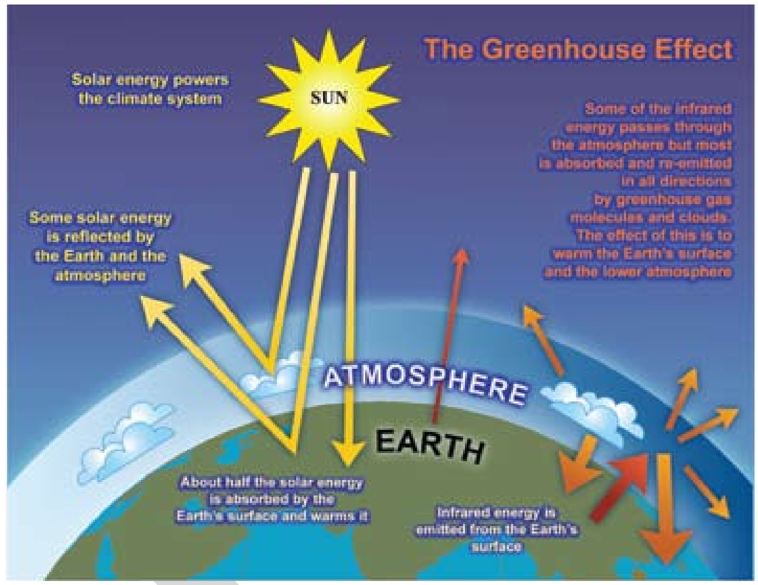


An Antarctic ice core provides a look at the past 800,000 years of Earth's carbon dioxide concentrations, a central factor in our planet's climate. Over this long period, atmospheric carbon dioxide levels varied within a range of 170 to 300 parts per million. Carbon dioxide concentration is now far outside of that range, 30 percent higher than the highest previous point, at over 380 parts per million. We are now in uncharted territory, and on a path that is moving us rapidly toward much higher levels.

The long record of temperature and carbon dioxide tells us something else as well: there is no natural cycle or process revealed in this long climate history that could have caused the global warming of the past 50 years.

Human-caused changes in the emissions of heat-trapping gases are responsible for most of the warming observed over the past 50 years.

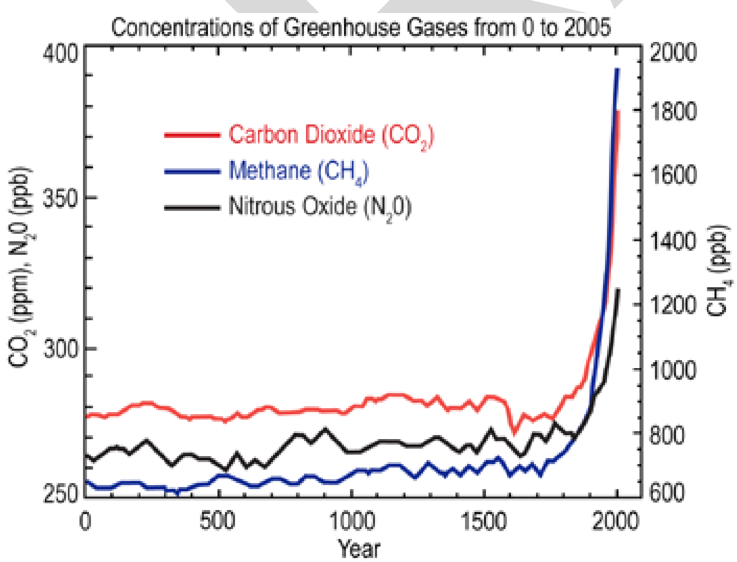
The Earth's atmosphere has a large natural "greenhouse effect." This arises because gases like water vapor, carbon dioxide, methane, and nitrous oxide, absorb heat radiated from Earth's surface. Without this natural greenhouse effect, the average surface temperature of the Earth would be about 60°F cooler. However, by burning fossil fuels (coal, oil and gas), we release additional heat-trapping gases into the atmosphere, thus intensifying the natural greenhouse effect, and changing the climate of our planet.



Earth's climate is influenced by a variety of factors, both human-induced and natural. Carbon dioxide, the principal driving factor in the warming of the past 50 years, has been building up in Earth's atmosphere since the beginning of the industrial era due to the burning of fossil fuels and the clearing of forests. Human activities have also increased the emissions of other greenhouse gases, such as methane, nitrous oxide, and halocarbons[1]. These emissions are thickening the blanket of heat-trapping gases in Earth's atmosphere, causing temperatures to rise.

Heat-trapping gases

Carbon dioxide has increased due to the use of fossil fuels in electricity generation, transportation, industrial processes, space and water heating, and in the manufacture of cement and other materials. Deforestation also releases carbon dioxide and also reduces its uptake by plants. Globally, over the past several decades, about 80 percent of human-induced carbon dioxide emissions come from the burning of fossil fuels, while about 20 percent results from deforestation. The concentration of carbon dioxide in the atmosphere has increased by 35 percent since the industrial revolution[2].



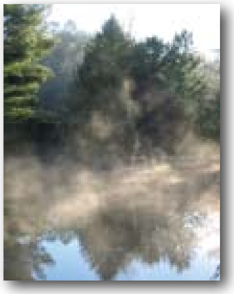
Increases in these gases since 1750 are due to human activities in the industrial era. Concentration units are parts per million (ppm) or parts per billion (ppb), indicating the number of molecules of the greenhouse gas per million or billion molecules of air.

Methane has increased as a result of the mining, transportation and use of coal, oil and natural gas, as well as from agriculture, raising livestock (which produce methane in their digestive tracts and from storage of manure under low oxygen conditions), and decomposing garbage in landfills.

Nitrous oxide is emitted from human activities such as fertilizer use and fossil fuel burning.

Halocarbon emissions come from the release of manmade chemicals such as chlorofluorocarbons (CFCs) like Freon®, which were used extensively in refrigeration and other industrial processes before their presence in the atmosphere was found to cause stratospheric ozone depletion. The abundance of these gases in the atmosphere is now decreasing as a result of international regulations designed to protect the ozone layer.
Ozone itself is a greenhouse gas, which is

continually produced and destroyed in the atmosphere by chemical reactions. In the troposphere, the part of the atmosphere closest to the surface, human activities have increased ozone through the release of gases such as carbon monoxide, hydrocarbons, and nitrogen oxides, which chemically react to produce ozone in the presence of sunlight. In addition to trapping heat, ozone in the troposphere causes respiratory illnesses and other human health problems. In the stratosphere, far above Earth's surface, ozone protects life on Earth from exposure to excessive ultraviolet radiation from the Sun. As mentioned above, halocarbons released by human activities destroy ozone in the stratosphere and have caused the ozone hole over Antarctica.

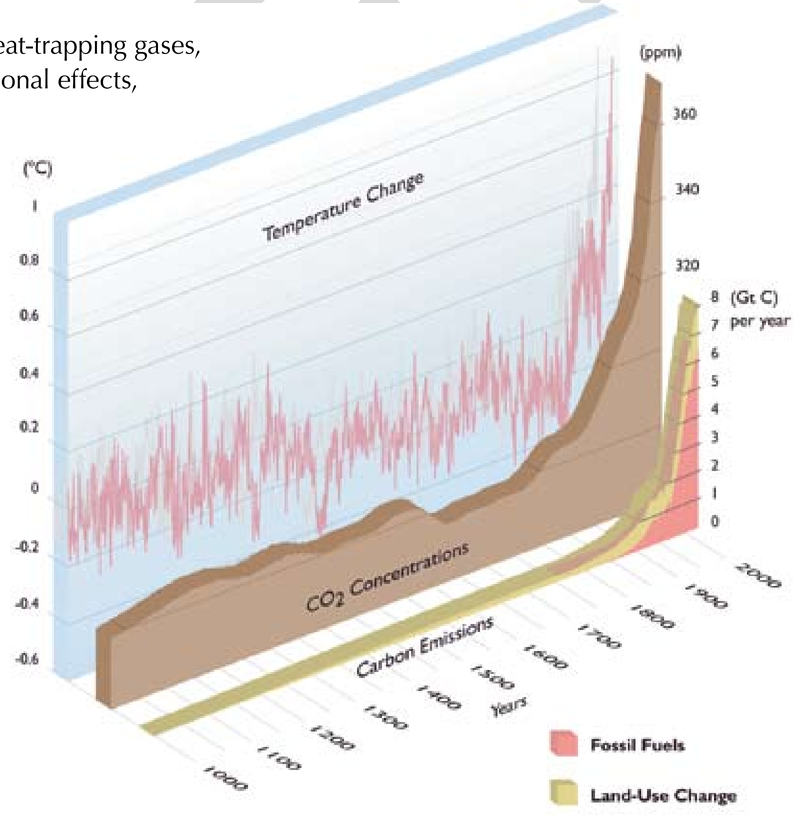


Water vapor is the most important and abundant greenhouse gas in the atmosphere. Human activities have only a small direct effect on water vapor, but a large indirect effect. The indirect effect occurs because the warming caused by human-produced increases in greenhouse gases leads to an increase in water vapor (a warmer climate increases evaporation and allows the atmosphere to hold more moisture), which in turn leads to more warming. This is referred to as a "feedback loop." Thus, human-induced warming is indirectly responsible for the significant observed increase in water vapor that is fueling much of the warming.

Other human influences

In addition to the global-scale climate effects of heat-trapping gases, human activities also produce more local and regional effects, which may partially offset or increase some of the warming caused by greenhouse gases. One such influence on climate is caused by tiny particles that scientists call "aerosols" (not to be confused with aerosol sprays). In particular, burning coal and vegetation results in emissions of sulfur-containing compounds that act to directly reflect some of the Sun's heat away from the Earth. These aerosols also affect clouds, causing them to reflect away more of the Sun's heat, causing an additional indirect cooling effect. Another type of aerosol, often referred to as "soot," absorb incoming sunlight and trap heat. Thus aerosols can either mask or increase the warming caused by increased levels of greenhouse gases.

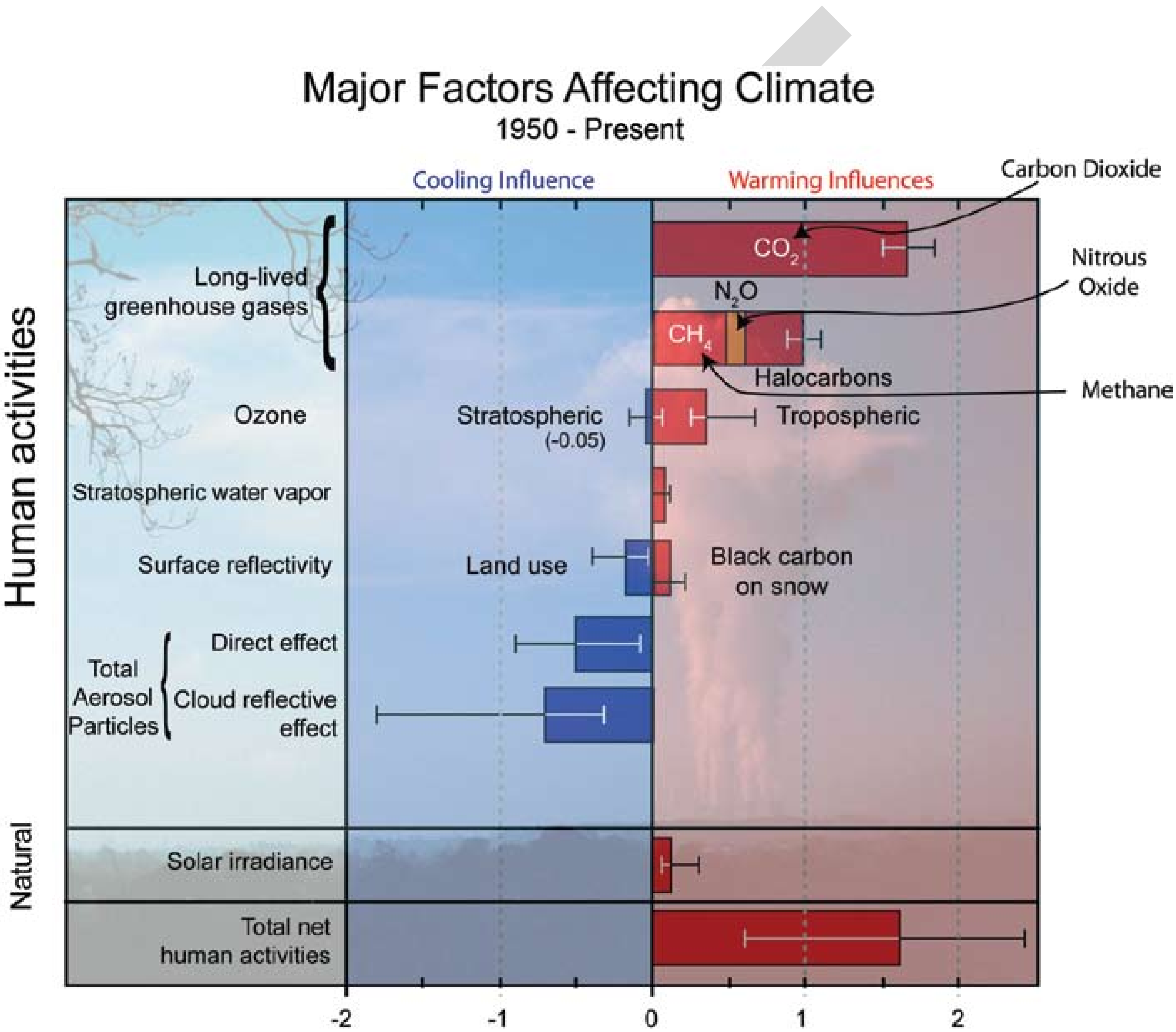
Human activities have also changed the land surface in ways that alter how much heat is reflected or absorbed by the surface. Such changes include the cutting and burning of forests and replacing wild lands with agriculture and cities. While these changes can have significant impacts locally, the net effect of these changes globally has probably been a slight cooling influence, as they have made the surface more reflective.



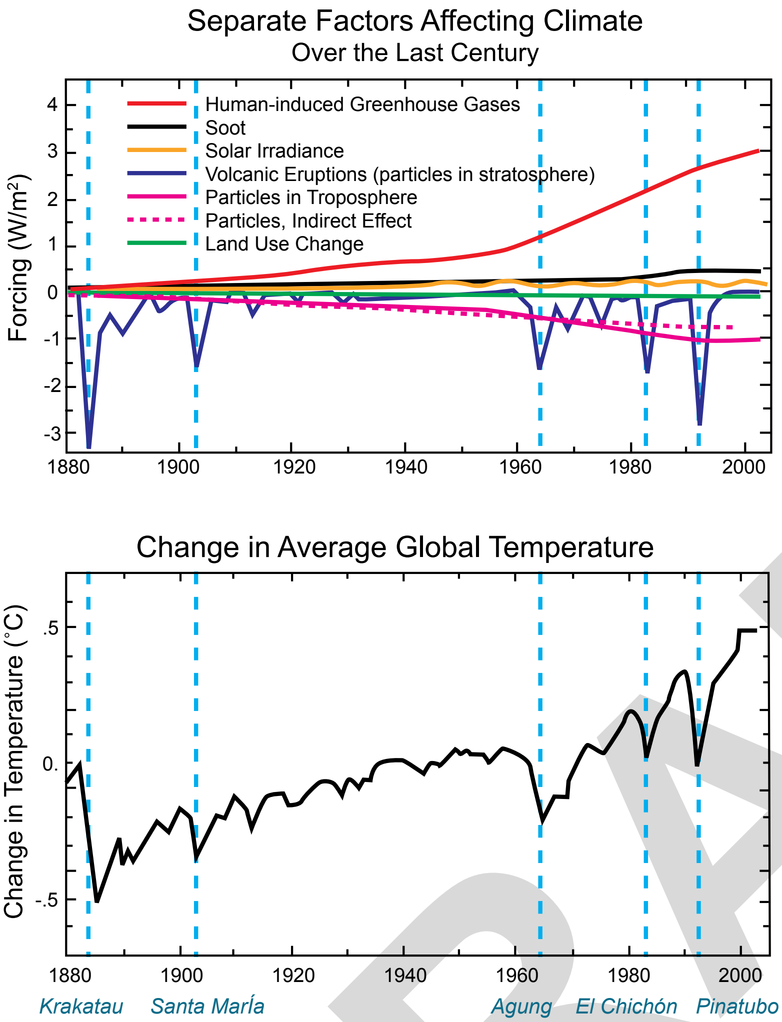
This 1000-year record tracks the rise in carbon emissions due to human activities (fossil fuel burning and land clearing) and the subsequent increase in atmospheric carbon dioxide (CO_2) concentrations and air temperatures. The earlier parts of the Northern Hemisphere temperature reconstruction shown here are derived from historical data, tree rings, and corals, while the later parts were directly measured. Measurements of CO_2 in air bubbles trapped in ice cores form the earlier part of the CO_2 record; direct atmospheric measurements of CO_2 began in 1957.

Changes in purely natural factors also influence climate, but cannot explain the warming of the past 50 years.

Two significant natural factors also influence climate: the Sun and volcanic eruptions. Over the past several decades, the time during which the human influence has become clear and global temperatures have risen sharply, the Sun's output, as measured by satellites, has followed its usual 11-year cycle of small ups and downs but with no net increase over the period. There have been several major volcanic eruptions that have had short-term cooling effects on climate lasting two to three years. These natural factors cannot explain the warming of recent decades; in fact, their net effect on climate has been a slight cooling influence over this period, which is small compared to the large warming influence of the human-caused increases in heat-trapping gases.



The figure above shows the amount of warming influence (red bars) or cooling influence (blue bars) each factor has had on Earth's climate in the industrial age (about 1750 to the present) in watts per square meter. The top box includes all the major human-induced factors while the second box includes the Sun, the only major natural factor with a long-term effect on climate. The cooling effect of individual volcanoes during the industrial age, which is also natural, is too short-lived (1 to 2 years) to significantly affect climate over the long term. The bottom box shows that the total net effect of human activities is a strong warming influence. The thin lines on each bar indicate an estimate of the range of uncertainty.



The influences of various factors as they have affected climate over the past 125 years shown separately (after Hansen *et. al.*, 2005, top[38]) and combined together to produce net temperature changes (NCDC/NOAA observed global temperature, bottom). The strong warming effect caused by the human-induced greenhouse gases (red line on top graph) more than compensated for the cooling caused by particle pollution and a series of volcanic eruptions that produced short-term cooling effects. Five prominent volcanic eruptions that caused temporary cooling are marked by the blue dashed lines and labeled at the bottom of the figure. Changes in the Sun's output over time are shown as the wiggly yellow line that reflects the 11-year solar cycle but no upward or downward trend.

Carbon release and uptake

Once carbon dioxide is emitted to the atmosphere, some of it is absorbed by the oceans and by vegetation on land; about 45 percent of the carbon dioxide emitted by human activities in the last 50 years has been taken up by these natural "sinks." The rest has remained in the air, increasing the atmospheric concentration[3]. It is thus important to understand not only how much carbon dioxide is emitted, but also how much is taken up, over what time scales, and how these sources and sinks of carbon dioxide might change as climate continues to warm. A significant fraction of the carbon dioxide emitted by human activities remains in the atmosphere for thousands of years, and some of it will be there for hundreds of thousands of years[4].

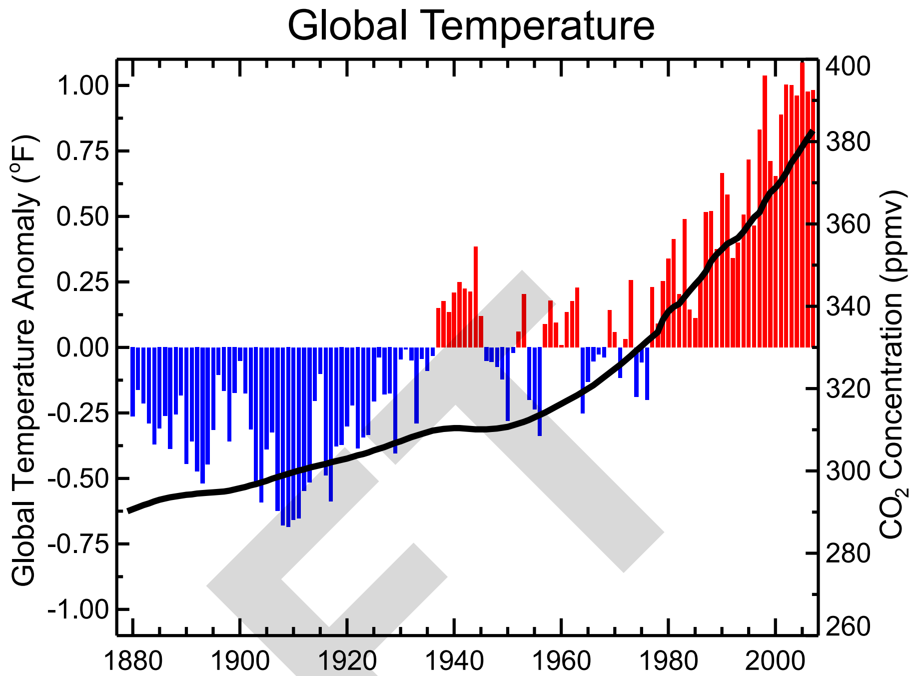
The rise in global emissions of carbon dioxide has been accelerating, with the growth rate increasing from 1.3 percent per year in the 1990s to 3.3 percent per year between 2000 and 2006[5]. This recent growth rate and the total emissions are higher than the highest emissions scenario developed by the Intergovernmental Panel on Climate Change for use in models that project future climate change.

While emissions are increasing, the rate of uptake of carbon dioxide by the oceans and vegetation on land appears to be decreasing in recent years. Both of these factors are contributing to an increased amount of carbon dioxide remaining in the atmosphere, thus raising atmospheric concentrations faster than before. Model simulations suggest that land and ocean carbon dioxide sinks would become less efficient as climate warms, but the magnitude of the observed reduction is larger than that projected by the models[6].

Temperature, precipitation and some extreme weather events have increased over the past century.

Temperatures are rising

Global average surface air temperature has been increasing, with the warming trend accelerating in recent decades. The record of temperature measurements comes from thousands of weather stations, ships, and buoys around the world; these measurements are independently compiled, analyzed, and processed by several different research groups. The warming trend that is apparent in all of these temperature records is confirmed by other observations such as the melting of Arctic sea ice, retreating mountain glaciers on every continent, earlier blooming of plants in spring, and increased melting of the polar ice sheets[7].



Global average temperature (as measured over both land and oceans) difference from twentieth century average. Red bars indicate above-average temperatures. Black line shows carbon dioxide concentrations.

Additionally, temperature measurements above the surface have been made by weather balloons since the late 1940s, and from satellite observations since 1979. These measurements show warming of the troposphere (the layer of the atmosphere just above the surface), consistent with the surface warming. They also reveal cooling in the stratosphere (the layer above the troposphere)[8]. This pattern of tropospheric warming and stratospheric cooling is consistent with our understanding of how atmospheric temperature should be changing in response to increasing greenhouse gas concentrations[9].

General Changes in Precipitation Patterns

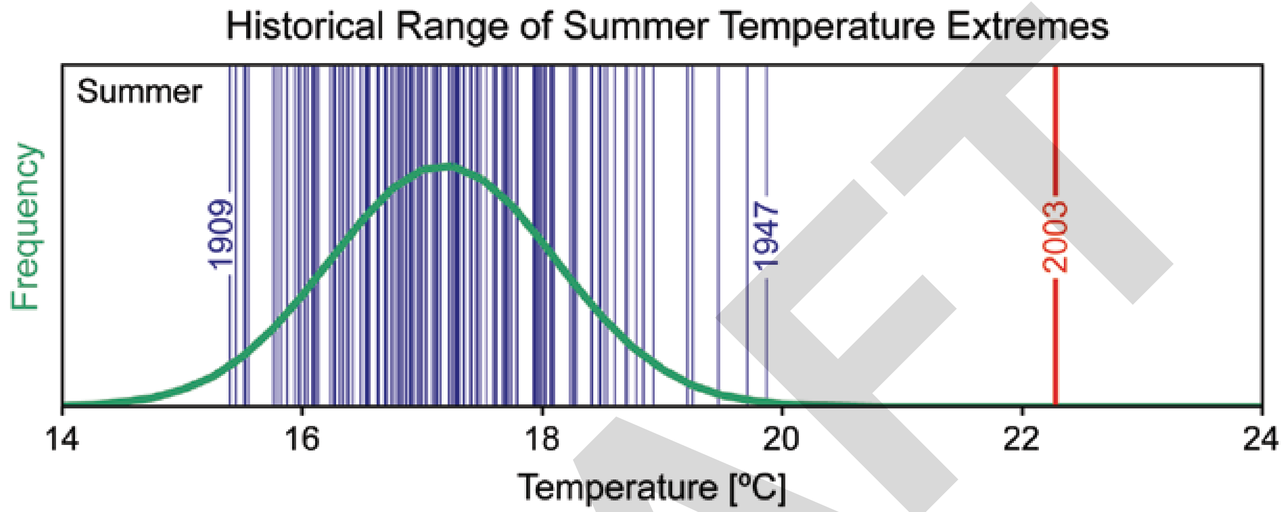
Broad scale patterns of precipitation change from 1925 to1999 show areas of increasing precipitation trends in green and decreasing trends in yellow. Areas in gray are mixed or uncertain[39].

Precipitation patterns are changing

Observations show that changes are occurring in the amount, intensity, frequency, and type of precipitation. Pronounced increases in precipitation over the past 100 years have been observed in eastern North America, southern South America, and northern Europe. Decreases were observed in the Mediterranean, most of Africa, and southern Asia (see figure at left). As the world warms, northern regions are experiencing more precipitation falling as rain rather than snow. Widespread increases in heavy precipitation events have occurred, even in places where total amounts have decreased. These changes are associated with the fact that warmer air holds more water vapor evaporating from the world's oceans and land surface. Increases in drought are not uniform, and some regions have seen increases in the occurrences of both droughts and floods[10].

Some extreme events are increasing

Over the past 50 years, the number of heatwaves has increased, as has the number of very warm nights. The extent of regions affected by droughts has also increased due to the combined effects of a small precipitation decrease over land and an increase in evaporation. Heavy precipitation events that lead to flooding have increased over many regions. Evidence suggests that there have been increases in the intensity of tropical storms and hurricanes since the 1970s[11,12].



In addition to becoming more frequent, heatwaves are also becoming more intense. For example, the temperature during the European summer of 2003 was far above the range of historical temperatures. Each vertical line on the graph above represents the average summer temperature for a single year from the average of four stations in Switzerland over the period 1864 through 2003. Temperature so far outside the historical range can have dramatic impacts, such as the enormous loss of life during that heatwave.

Global circulation patterns are changing

One reason for the variations of changes in temperature and precipitation over the globe is that as the world warms, the atmospheric circulation changes as well. For example, the equatorial region that experiences tropical climate is expanding four times faster than predicted; this tropical belt is now as wide as climate models suggested it would be at the end of this century[13]. Because the tropics drive much of the world's weather, this expansion is expected to cause shifts in weather patterns by pushing the jet stream and storm tracks northward[14], further drying out arid regions such as the U.S. Southwest and directing more intense storms toward the northern U.S. Some of these shifts already appear to be underway.

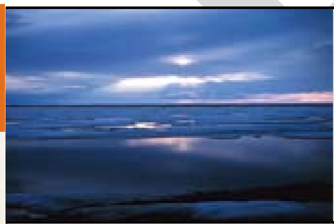
Warming is causing sea level to rise as land-based ice melts and the oceans expand.

After about 2000 years of little change, sea level rose about 8 inches over the past 100 years and is currently rising at an increasing rate. Global warming causes sea level to rise in two ways. As ocean water warms, it expands, taking up more space. In addition, the melting of glaciers and ice sheets due to warming adds water to the oceans.

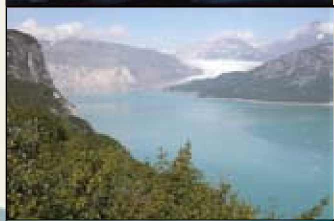
Glaciers have been retreating worldwide, especially since 1980, and at an increasing rate in the past decade[15]. While a few glaciers are not retreating (in locations where increased precipitation has outpaced melting), the vast majority of glaciers are in strong retreat, and the total volume of glaciers on Earth is declining sharply. This has major implications for water supplies in some regions and for sea-level rise globally.

The Earth has two major ice sheets: the Greenland Ice Sheet, near the north pole, which contains enough water to raise sea level by about 20 feet, and the Antarctic Ice Sheet, near the South Pole, which holds enough to raise sea levels over 200 feet. Both of these ice sheets are currently melting around some of their edges and losing ice mass at increasing rates. The Greenland Ice Sheet has also been experiencing record amounts of surface melting in recent years. Studies suggest that the surface melt water is flowing down to the base of the ice sheet, providing lubrication that causes the ice to flow more easily to the sea, speeding the loss of ice. The most recent studies of West Antarctic Ice Sheet melting show very large increases in the rate of mass loss in the past decade[16].

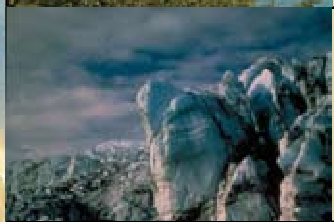
An Ice Primer



Sea Ice is formed as ocean water freezes. It is less dense than water, so it floats on top of the ocean. As sea ice forms, it rejects most of its salt to the surrounding ocean.



Glaciers and Ice Caps are land-based ice, with ice caps topping hills and mountains, and glaciers filling the valleys, although the term glacier is often used to refer to both ice caps and glaciers.



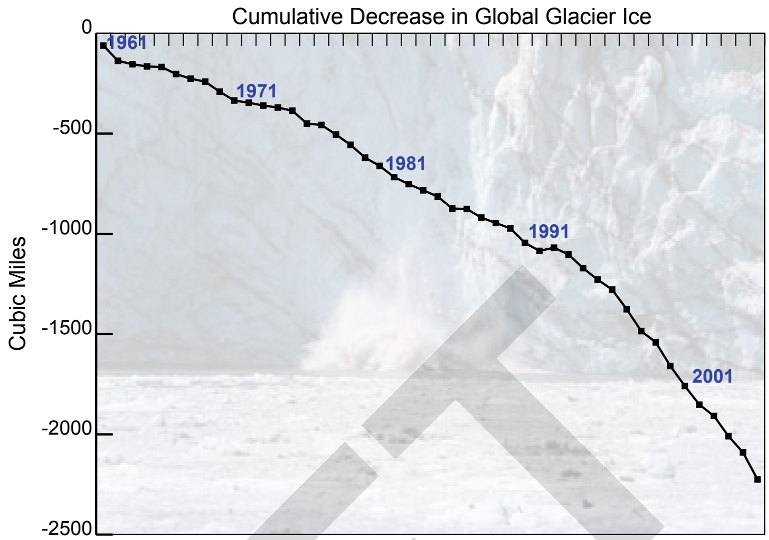
An **Ice Sheet** is a collection of ice caps and glaciers that form one large mass, such as currently found on Greenland and Antarctica.

An **Iceberg** is a chunk of ice that breaks off of a glacier, ice sheet, or **ice shelf** (an extension of ice from land out on the ocean) and floats on the ocean's surface.

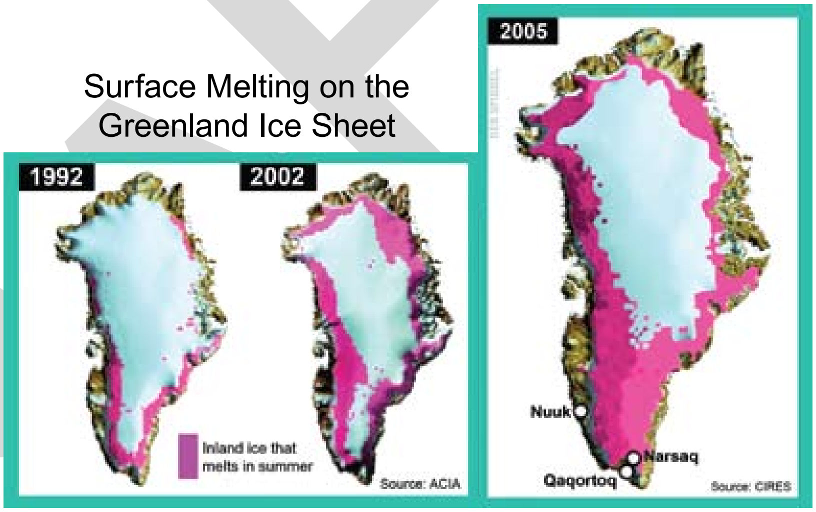
When glaciers, ice caps, and ice sheets melt, they cause sea level to rise by adding to the amount of water in the oceans. Melting sea ice and ice shelves do not cause sea level to rise.

In addition to land-based ice like glaciers and ice sheets, the polar regions also have ice on the surface of their oceans. The amount of this sea ice varies with the seasons, growing more extensive in winter and melting back in summer.

Earth's two poles are responding differently to human influences on climate for several reasons. The northern polar region, known as the Arctic, is warming very rapidly across the region. In Antarctica, the cooling influence of stratospheric ozone depletion over the South Pole is likely to be masking the effect of global warming. In addition, the temperatures are so cold in Antarctica, initial warming does not necessarily lead to melting of snow and ice. The slightly increasing trend in Antarctic sea ice over the past 30 years is also likely to have been influenced by the way stratospheric ozone depletion has affected atmospheric circulation: westerly winds have increased by an average of 15 percent across the Southern Ocean and Antarctica, effectively blocking warmer air from reaching the continent. This phenomenon has not affected the area around the West Antarctic Peninsula, which has experienced significant reductions in sea ice consistent with the strong warming in that region.

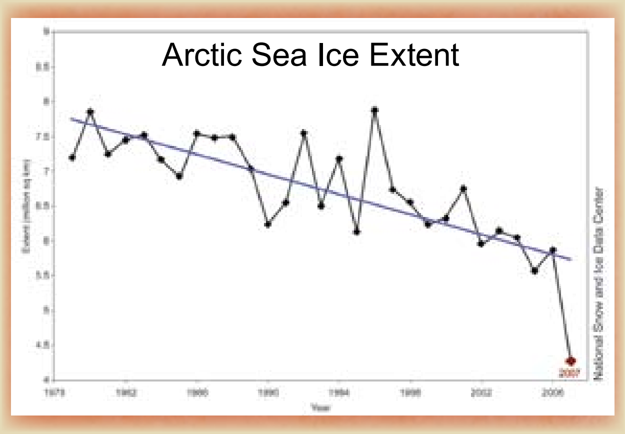


(see endnote 40)



Arctic sea ice decline is accelerating

In the northern polar region, the sea ice on the Arctic Ocean has been declining for the last three decades, with declines in both thickness and extent becoming quite dramatic in recent years. Sea ice is a very important part of the climate system, affecting surface reflectivity, cloudiness, humidity, exchanges of heat and moisture at the ocean's surface, and ocean currents. For example, melting of sea ice makes the ocean surface darker, which allows it to absorb more of the Sun's heat, which increases warming. As in the case of warming increasing water vapor, this is another example of a "feedback loop." Changes in sea ice have enormous environmental, economic, and societal implications[17].



Arctic sea ice extent in September (the annual minimum) since satellite observations began.

The specific patterns of climatic change show that it is primarily human-induced.

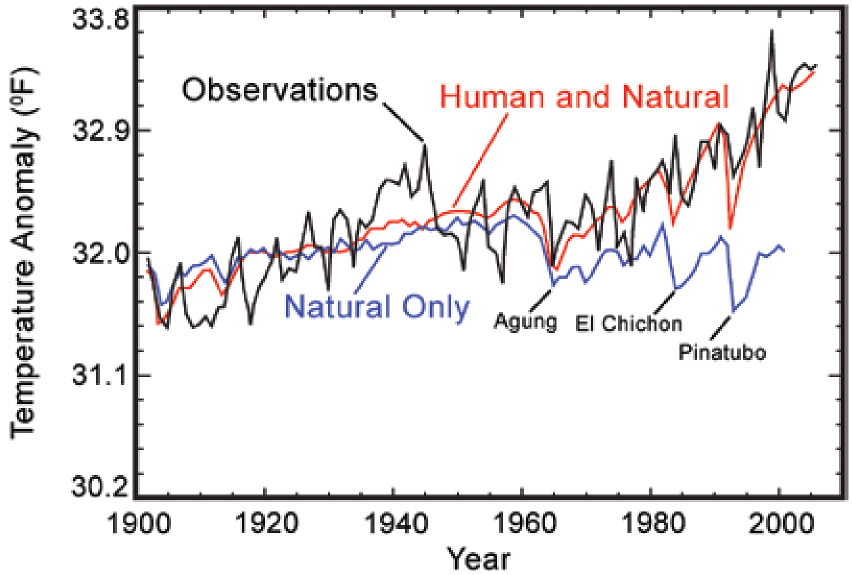
Each factor that affects climate produces a unique pattern of climate response, much as each person has a unique fingerprint. We can thus use detailed pattern analyses called fingerprint studies to determine cause and effect relationships in the climate system. Climate scientists rely on such studies to attribute observed changes in climate to particular causes. Each fingerprint study includes estimates of the natural variations (or "noise") in climate, and tests whether these natural variations could explain the observed climate changes.

Attribution studies generally involve comparing observed changes with simulations from climate models in which specific factors are varied. The benefit of using models in this way is that we can do what we can't do in the real world: add and remove particular factors and see how climate responds to these factors individually and together[18].

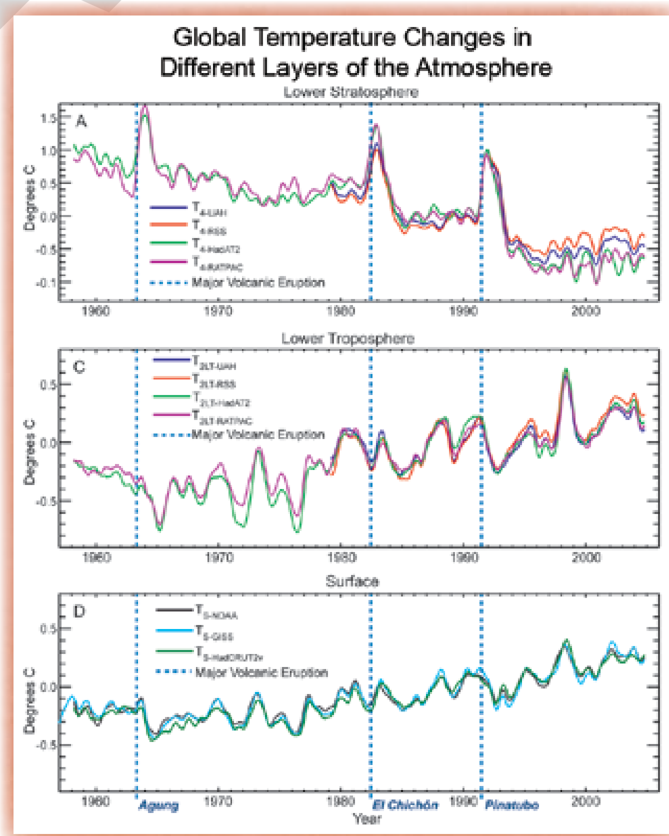
For example, climate model simulations of the last century that include all of the major influences on climate, both human-induced and natural, reproduce many important features of observed climate change patterns. When the human influences are removed from the models, the result shows that climate would actually have first warmed and then cooled slightly over the last century. The clear message from fingerprint studies is that the observed warming could not have been caused by natural factors alone[19].

Similarly, the pattern of temperature changes vertically through the layers of the atmosphere, from the surface up through the stratosphere, indicates that the most likely cause of the warming is the human-induced build-up of heat-trapping gases. All climate models show that heat-trapping greenhouse gases cause warming at the surface and in the layer just above the surface (the troposphere) but lead to cooling in the stratosphere. The observed pattern of climate change matches the model fingerprint, and also shows warming of the troposphere and cooling of the stratosphere. If most of the observed surface and tropospheric warming

Separating Human and Natural Influences on Climate



The blue line shows how global average temperatures would have changed due to natural forces only. The red line shows the effect of human and natural forces as simulated by climate models. The black line shows actual observed global average temperatures. As the blue line indicates, without human influences, temperature over the past century would actually have first warmed and then cooled slightly.

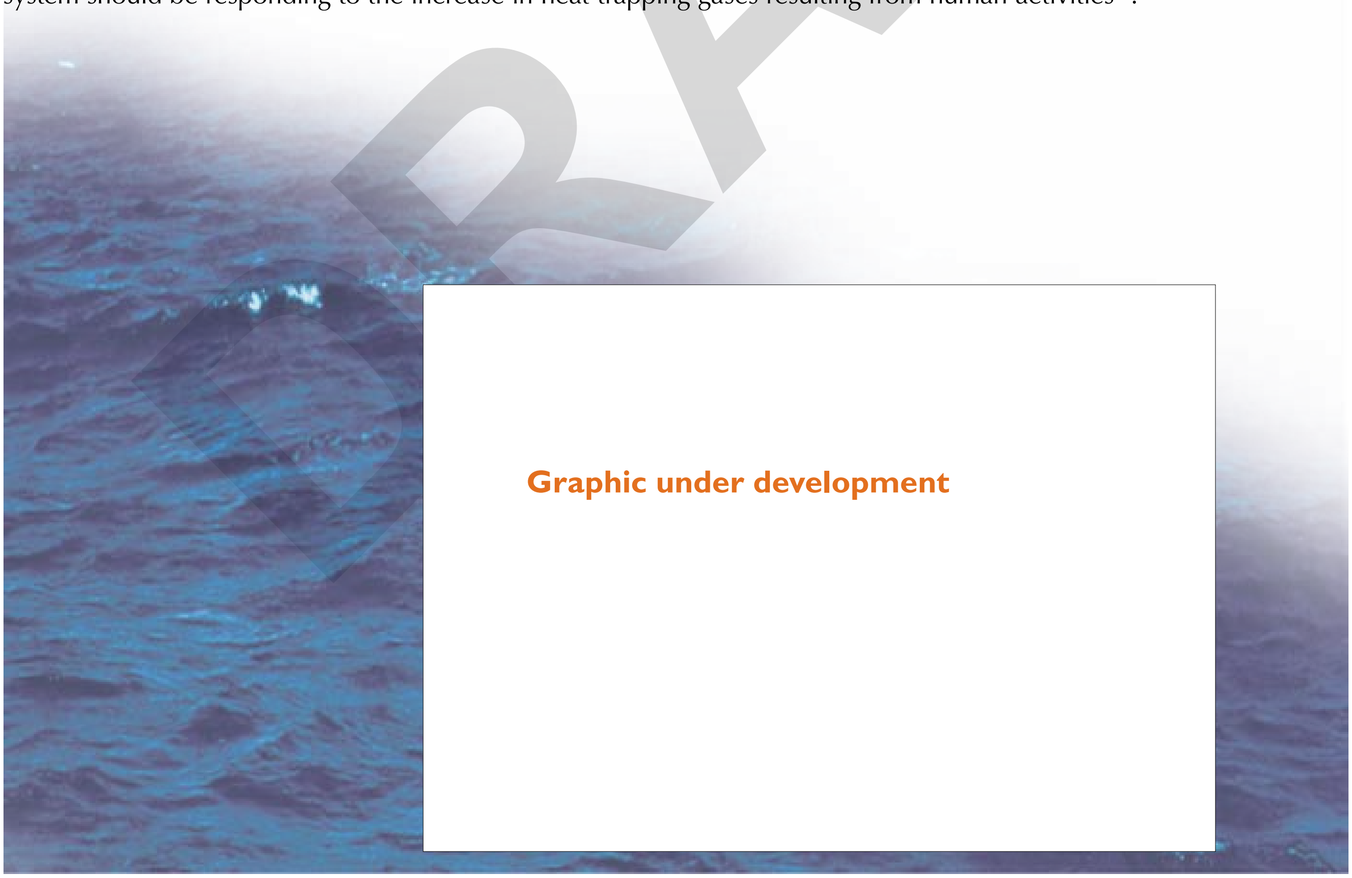


had been caused by an increase in solar output rather than by greenhouse gases, we should have observed warming throughout most of the atmosphere, including the stratosphere[20]. Observed climate change is therefore inconsistent with the hypothesis that changes in the Sun can explain the warming of recent decades.

Other fingerprint analyses have looked at changes in the heat content of the oceans, the height of the tropopause (the boundary between the troposphere and stratosphere, which has shifted upward by hundreds of feet in recent decades), the geographic redistribution of precipitation, surface pressure patterns, the humidity close to Earth's surface, and the moisture content of the atmosphere over the oceans. Fingerprint studies have also been used to analyze how much human-induced warming has increased the risk of occurrence of certain types of extreme weather events. For example, an analysis of the European summer heat wave of 2003 found that the risk of such a heat wave is now roughly four times as great due to human influences on climate[21].

On the question of hurricanes, analyses have found a strong correlation between sea surface temperatures and hurricane power, with both showing increasing trends in the Atlantic in recent decades. Observations indicate that sea surface temperatures have increased in the regions of the Atlantic and Pacific where hurricanes are born. Fingerprint analysis used to determine the cause of the increased ocean temperature in these key regions found that most of the increase was due to human influences and not natural variations. The authors concluded that the human-induced increase in heat-trapping gases was the main driver of the rise in sea surface temperatures in these key ocean regions[23].

The fingerprint studies described above analyze different climatic variables. Each study has concluded that human influences are the primary driver of recent climatic changes, and that natural factors cannot account for these changes. All of the observed changes are consistent with each other and with our scientific understanding of how the climate system should be responding to the increase in heat-trapping gases resulting from human activities[24].

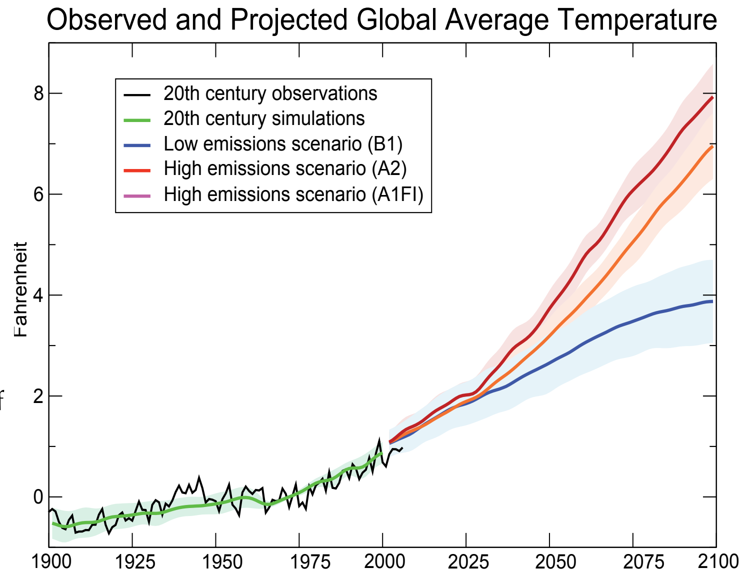


Graphic under development

Climate will warm more in the future; how much depends on the level of emissions and how sensitive the climate will be to those emissions.

Rising global temperature

All climate models project that human-caused emissions of heat-trapping gases will cause further warming in the future, with global average temperature projected to rise by 3 to 11.5°F by the end of this century. About 1.5°F of this total warming has already occurred over the past century, so the additional warming would be in the range of 1.5 to 10°F above today's level. Whether the warming will be nearer the low or the high end of this range depends on two factors: first, the future level of emissions of heat-trapping gases, and second, how sensitive climate will be, that is, how much climate will change in response to those emissions. The range of possible outcomes has been explored using a range of different emissions scenarios, and a variety of climate models, each with a different sensitivity.

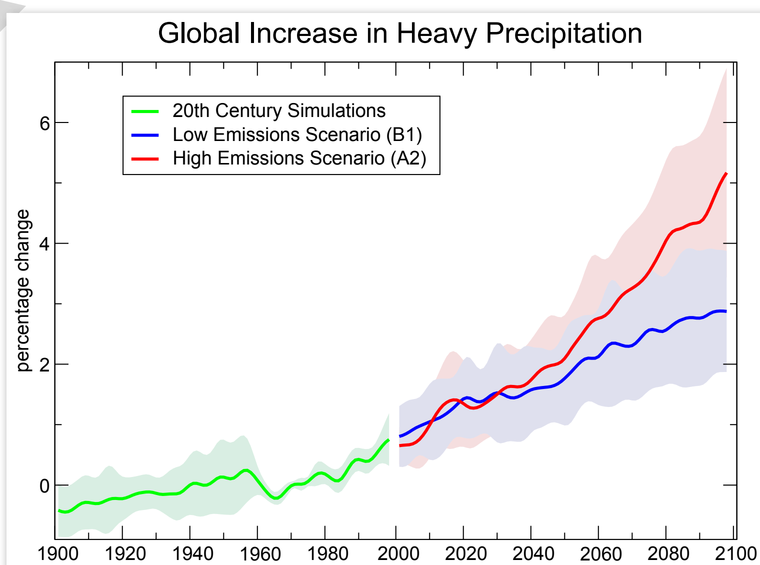


Observed and projected changes in the global average temperature under three emissions scenarios. The shaded areas show the possible ranges while the lines show the central projections from a set of climate models.

The IPCC developed a set of scenarios in a Special Report on Emissions Scenarios (SRES)[25]. These have been extensively analyzed by scientists to understand future climate change. None of these scenarios include explicit policies to limit climate change. Rather, emissions in these scenarios vary based on different assumptions about changes in population, adoption of new technologies, economic growth, and other factors. None of them involve stabilizing atmospheric concentrations of heat-trapping gases at a level that would avoid dangerous human interference with the climate system as required by the Framework Convention on Climate Change.

Changing precipitation patterns

Projections of future changes in precipitation largely follow recently observed patterns of change, with overall increases in the global average but substantial shifts in where and how precipitation falls. Generally, higher latitudes are projected to become wetter while the sub-tropics become drier. Increases in tropical precipitation are projected during rainy seasons (such as monsoons), and especially over the tropical Pacific. Certain regions, including the U.S. West and Southwest and the Mediterranean, are expected to become drier. The trend towards more heavy downpours is expected to continue, with precipitation becoming less frequent but more intense[26]. More precipitation is expected to fall as rain rather than snow.



Observed and projected changes in the heaviest 5 percent of precipitation events. The shaded areas show the possible ranges while the lines show the central projections from a set of climate models.

Currently rare extreme events become more common

In a warmer future climate, there will be an increased risk of more intense, more frequent and longer-lasting heat waves. The European heat wave of 2003 is an example of the type of extreme heat event that is likely to become more common[27], with the likelihood of such a heat wave projected to increase 100-fold in the next 40 years. If greenhouse gas emissions continue to increase as projected, by the 2040s more than half of European summers will be hotter than the summer of 2003, and by the end of this century, a summer as hot as that of 2003 will be considered unusually cool[28].

Increased extremes of summer dryness and winter wetness are projected for much of the globe, meaning a generally greater risk of droughts and floods. This has already been observed and is projected to continue, because in a warmer world, precipitation tends to be concentrated into more intense events, with longer periods of little precipitation in between. Therefore, heavy downpours would be interspersed with longer relatively dry periods[29].

Models project a general tendency for more intense but fewer storms overall outside the tropics, with more extreme wind events and higher ocean waves in several regions in association with those storms. Models also project a shift of storm tracks toward the poles in both hemispheres[30].

Changes in hurricanes are difficult to project because there are countervailing forces. Higher ocean temperatures lead to stronger storms with higher wind speeds and more rainfall. But changes in wind speed and direction with height are also projected to increase in some regions, and this tends to work against storm formation and growth. It currently appears that stronger tropical storms and hurricanes are likely in some regions, though more research is required on these issues.

Sea level will continue to rise

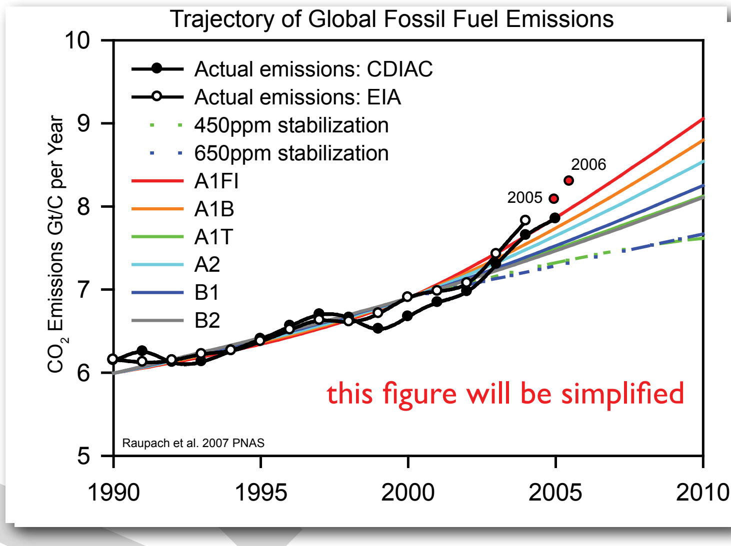
Projecting future sea-level rise presents special challenges. Scientists have a well-developed understanding of the contributions of thermal expansion and glacier-melt to sea-level rise, so the models used to project sea-level rise include these processes. However, recent observations on Greenland and Antarctica show that additional processes are at work which affect the dynamic responses of ice sheets to warming. Although these processes are not yet well understood or included in current climate models, they are probably already producing substantial additional loss of ice mass and are thus contributing to sea-level rise (see further discussion under "Abrupt climate change" on next page).

Thus, most current models can give us only a lower bound for future sea-level rise projections, with a highly uncertain upper bound. The 2007 assessment by the Intergovernmental Panel on Climate Change set the range of this lower bound at about two thirds of a foot to 2 feet of sea-level rise by the end of this century. Various methods of estimating future sea-level rise suggest increases of 2 to almost 5 feet by the end of this century, but even larger numbers cannot be ruled out.

The human effect on climate can be minimized if emissions are sharply reduced.

The scenarios described on the previous page do not encompass the full range of possible futures: climate can change less than those scenarios imply, or it can change more. Current carbon dioxide emissions are, in fact, above the highest emissions scenario developed by the Intergovernmental Panel on Climate Change (IPCC), implying that if we stay the current course, we're heading for even larger warming than the highest projections from the IPCC.

There are also lower possible emissions paths than those put forth by the IPCC. The Framework Convention on Climate Change, to which the United States and most other countries are signatories, calls for stabilizing concentrations of greenhouse gases in the atmosphere at a level that would avoid dangerous human interference with the climate system. What exactly constitutes such interference is subject to interpretation. Some argue, based on a number of criteria, including already observed impacts, that we have already crossed into "dangerous" territory and that what we must now seek to avoid is catastrophic climate change.



Given that global temperature has already risen 1.5°F above pre-industrial levels and significant impacts are already apparent, it has been suggested that avoiding more severe, widespread, and irreversible impacts would require limiting the total temperature rise to no more than 3.5°F above pre industrial levels. To have a good chance (but not a guarantee) of avoiding temperatures above those levels, it has been estimated that atmospheric concentrations of carbon dioxide would need to stabilize in the long-term at around today's levels. There is not one precise number for the carbon dioxide "stabilization target" because the sensitivity of the climate system to greenhouse gases is not known precisely; different models show different temperature changes for the same stabilization target.

A further complication is that carbon dioxide is not the only greenhouse gas of concern. Concentrations of other greenhouse gases like methane and nitrous oxide would also have to be stabilized at low enough levels to prevent global temperatures from rising above the level mentioned above. When these other gases are added, including the offsetting cooling effects of certain aerosol particles, analyses suggest that stabilizing concentrations around 400 parts per million of CO_2 would yield about an 80 percent chance of avoiding exceeding the 3.5°F threshold. This would be true even if concentrations temporarily peaked as high as 475 parts per million and then stabilized at 400 roughly a century later[33,34,35,36,37].

Climate can also change abruptly, as is evident from ice core records of past climate.

Figure under development

Abrupt climate change

At the other end of the spectrum is the possibility of even larger climate change than current scenarios and models project, including possible abrupt climate change. Not all climate changes are gradual. The long record of climate found in ice cores, tree rings, and other natural records show that Earth's climate has undergone abrupt shifts from one stable state to another. Such changes occur so rapidly that they would challenge the ability of human and natural systems to adapt. Examples of such changes are abrupt shifts in drought frequency and duration. Ancient climate records suggest that in the U.S., the Southwest may be at greatest risk for this kind of change, but that other regions including the Midwest and Great Plains have also had these kinds of abrupt shifts in the past and could experience them in the future.

Small grains of sand ground out by glaciers and carried far out across the North Atlantic by icebergs, deposited over intervals from a few decades to a few centuries, provide evidence that the Northern ice sheets have melted abruptly in the past (Photo credit: J. Andrews, U. of Colorado)

Rapid ice sheet collapse and related sea-level rise is another type of abrupt change that is not well understood or modeled and poses a risk for the future. Recent observations show that melting on the surface of an ice sheet produces water that flows down through large cracks that create conduits through the ice to the base of the ice sheet where it lubricates ice previously frozen to the rock below. Further, the interaction with warm ocean water where ice meets the sea, this can lead to sudden losses in ice mass and accompanying rapid global sea-level rise. Observations indicate that ice loss has increased dramatically over the last decade, though scientists are not yet confident that they can project how the ice sheets will respond in the future. Recent studies suggest that sea level could rise as much as 3 to 5 feet per century over the next several centuries[32].