

# Common Questions about Climate Change

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United Nations Environment Programme  
World Meteorological Organization

*This document answers some of the most commonly asked questions about climate change.*

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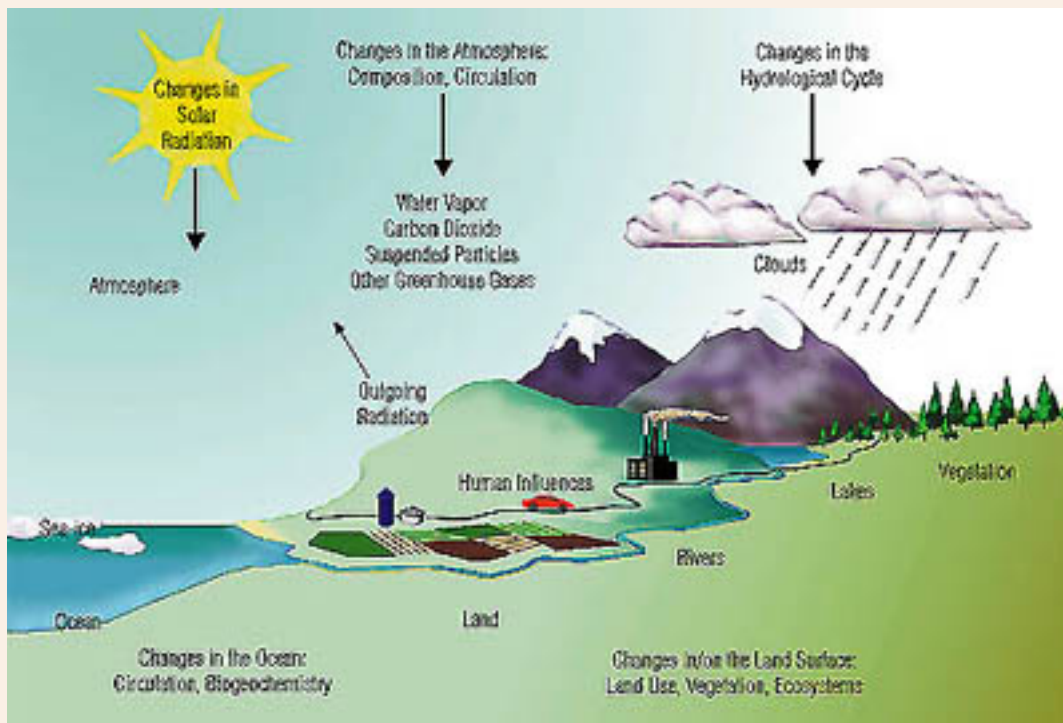
# Introduction

This document answers some of the most commonly asked questions about climate change, including whether the Earth has warmed, which human activities are contributing to climate change, what further climatic changes are expected to occur, and what effects these changes may have on humans and the environment. First, however, several issues are clarified: what the Earth's climate is, how climate differs from weather, and what processes influence climate.

Climate is the average weather, including seasonal extremes and variations, either locally, regionally, or across the globe. In any one location, weather can change very rapidly from day to day and from year to year, even within an unchanging climate. These changes involve shifts in, for example, temperatures, precipitation, winds, and clouds. In contrast to weather, climate is generally influenced by slow changes in features like the ocean, the land, the orbit of the Earth about the sun, and the energy output of the sun.

Fundamentally, climate is controlled by the long-term balance of energy of the Earth and its atmosphere. Incoming radiation from the sun, mainly in the form of visible light, is absorbed at the Earth's surface and in the atmosphere above. On average, absorbed radiation is balanced by the amount of energy returned to space in the form of infrared "heat" radiation. Greenhouse gases such as water vapor and carbon dioxide, as well as clouds and small particles (called aerosols), trap some heat in the lower part of the Earth's atmosphere. This is called the greenhouse effect. If there were no natural greenhouse effect, the average surface temperature would be about 34°C (61°F) colder than it is today.

Winds and ocean currents redistribute heat over the surface of the Earth. The evaporation of surface water and its subsequent condensation and precipitation in the atmosphere redistribute heat between the Earth's surface and the atmosphere, and between different parts of the atmosphere.



**Figure 1.1**

*Schematic view of components of the global climate system, some of their processes and interactions, and some aspects that can cause climate change.*

Natural events cause changes in climate. For example, large volcanic eruptions put tiny particles in the atmosphere that block sunlight, resulting in a surface cooling of a few years' duration. Variations in ocean currents change the distribution of heat and precipitation. El Niño events (periodic warming of the central and eastern tropical Pacific Ocean) typically last one to two years and change weather patterns around the world, causing heavy rains in some places and droughts in others. Over longer time spans, tens or hundreds of thousands of years, natural changes in the geographical distribution of energy received from the sun and the amounts of greenhouse gases and dust in the atmosphere have caused the climate to shift from ice ages to relatively warmer periods, such as the one we are currently experiencing.

Human activities can also change the climate. The atmospheric amounts of many greenhouse gases are increasing, especially that of carbon dioxide, which has increased by 30% over the last 200 years, primarily as a result of changes in land use (e.g., deforestation) and of burning coal, oil, and natural gas (e.g., in automobiles, industry, and electricity generation). If current trends in emissions were to continue, the amount of carbon dioxide in the atmosphere would double during the twenty-first century, with further increases thereafter. The amounts of several other greenhouse gases would increase substantially as well.

The accumulation of greenhouse gases in the atmosphere due to human activities will change the climate by enhancing the natural greenhouse effect, leading to an increase in the Earth's average surface temperature. This warming may be partially offset in certain regions where air pollution leads to high concentrations of small particles in the atmosphere that block sunlight.

The current best estimate of the expected rise of globally averaged surface temperature relative

to 1990 is 1 to 3.5°C (about 2 to 6°F) by the year 2100, with continued increases thereafter. Because most greenhouse gases remain in the atmosphere for a long period of time, even if emissions from human activities were to stop immediately, effects of accumulated past emissions would persist for centuries.

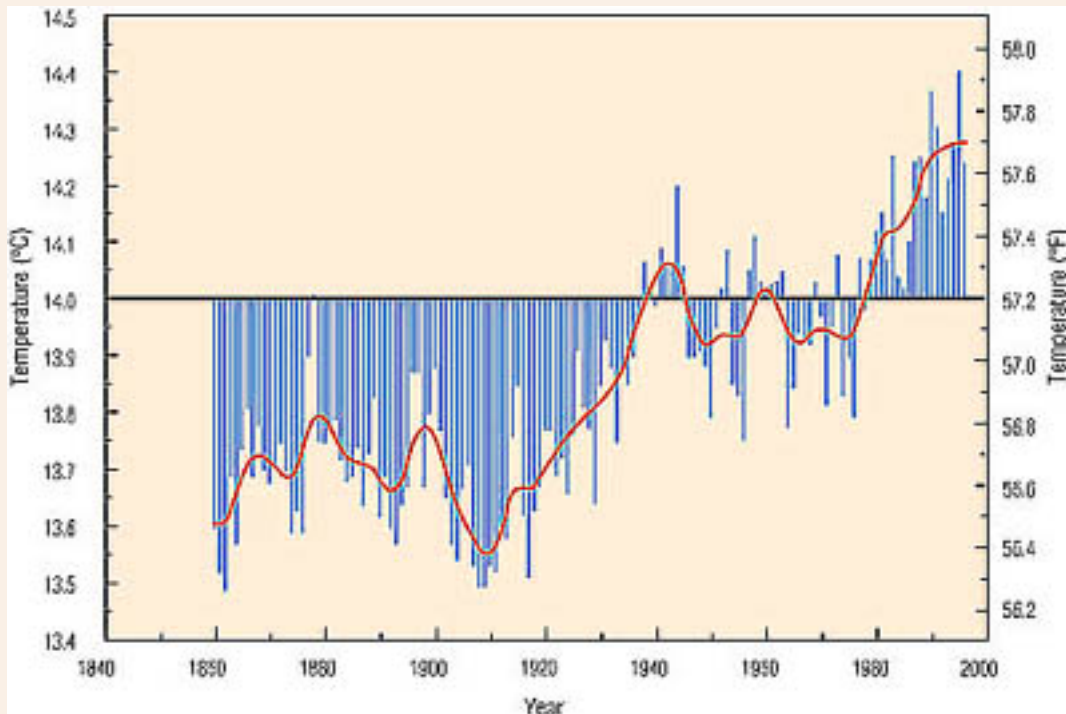
The Intergovernmental Panel on Climate Change (IPCC), cosponsored by the United Nations Environment Programme and the World Meteorological Organization and made up of over 2000 scientific and technical experts from around the world, published its First Assessment Report in 1990 and its Second Assessment Report in 1996. The Second report contains over 10,000 references and is over 2000 pages in length. Although our understanding of some details of climate change is still evolving, the IPCC report is the most comprehensive and scientifically authoritative account of our understanding of climate change, the potential impacts on humans and the natural environment, the technology currently available to reduce human influences on climate, and the socio-economic implications of possible measures to mitigate these changes. The document that follows has been written and reviewed by scientists who participated in the IPCC process, and it attempts to answer some of the most commonly asked questions about these issues, based upon information contained in the IPCC reports. A list of the scientists who prepared this document is provided inside the front cover.

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# Has the World Warmed?

The globally averaged temperature of the air at the Earth's surface has warmed between 0.3 and 0.6°C (about 0.5 and 1°F) since the late nineteenth century ([Figure 2.1](#)).

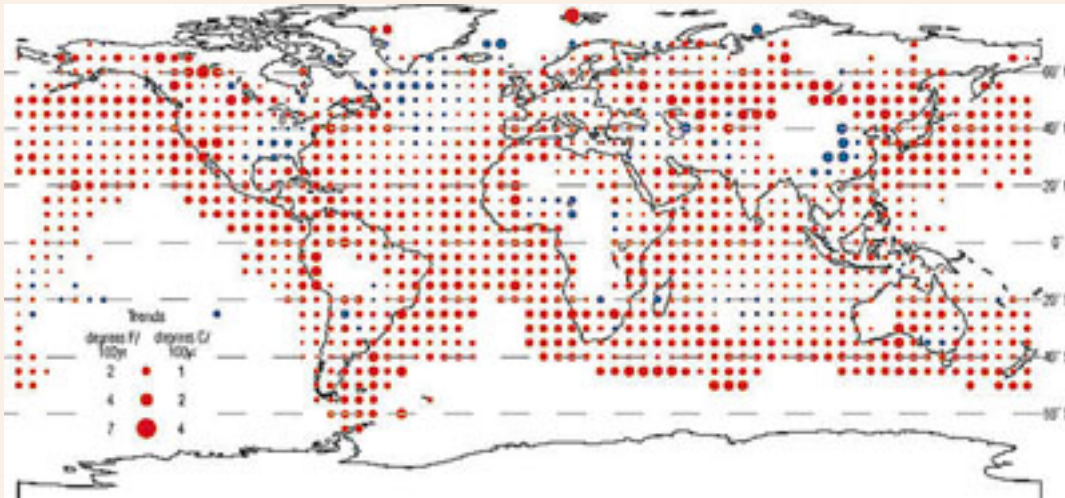


**Figure 2.1**

*Measured global surface temperatures relative to the average for the 30-year period 1961 to 1990 (the horizontal line).*

The four warmest years on record since 1860 have all occurred since 1990. The warming has been greatest at night over land in the mid-to-high latitudes of the northern hemisphere. The warming during the northern winter and spring has been stronger than at other seasons. In some areas, primarily over continents, the warming has been several times greater than the global average. In a few areas, temperatures have actually cooled, e.g., over the southern Mississippi Valley in North America ([Figure 2.2](#)).





**Figure 2.2**

*Trends in measured surface air temperature over the past century. Red circles represent warming; blue circles represent cooling. No data are available for the large areas with no circles.*

Other evidence of global temperature increases since the nineteenth century includes the observed rise in sea level of 10 to 25 centimeters (about 4 to 10 inches), the shrinkage of mountain glaciers, a reduction of northern hemisphere snow cover (1973 to present), and increasing sub-surface ground temperatures. Data derived from measurements of tree rings, shallow ice cores, and corals, and from other methods of indirectly determining climate trends, suggest that global surface temperatures are now as warm as or warmer than at any time in the past 600 years.

Data from a few locations can be used to trace temperatures even further into the past. For example, deep ice cores and North Atlantic deep sea sediments suggest that the recent warming stands out against a record of relatively stable temperatures over the past ten thousand years, with century-to-century variations of temperature seldom approaching the observed increase of global mean temperatures of about 0.3 to 0.6°C (about 0.5 to 1°F) over the last century.

Satellite-based instruments have recently measured temperatures at higher altitudes (2 to 6 kilometers, or about 1 to 4 miles above the Earth's surface), rather than at the surface. These observations indicate that this portion of the atmosphere may have cooled slightly, by about 0.1°C (about 0.2°F), since 1979 when the measurements began. Although apparently at variance with the surface temperature measurements, they are not. Significant differences in short-term trends are to be expected between the surface and atmospheric temperatures at higher altitudes, because of the different factors affecting the variability and persistence of climate patterns at different altitudes. Furthermore, questions have recently arisen concerning the consistency of calibrations of the satellite-based instruments, suggesting that what was believed to be a small cooling may actually be a slight warming.

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# Are Human Activities Contributing to Climate Change?

A comprehensive assessment by the IPCC of the scientific evidence suggests that human activities are contributing to climate change, and that there has been a discernible human influence on global climate.

Climate changes caused by human activities, most importantly the burning of fossil fuels (coal, oil, and natural gas) and deforestation, are superimposed on, and to some extent masked by, natural climate fluctuations. Natural changes in climate result from interactions such as those between the atmosphere and ocean, referred to as internal factors, and from external causes, such as variations in the sun's energy output and in the amount of material injected into the upper atmosphere by explosive volcanic eruptions.

Studies that aim to identify human influences on climate attempt to separate a human-caused climate-change factor (the signal) from the background noise of natural climate variability. Such investigations usually consist of two parts: detection of an unusual change, and attribution of all or part of that change to a particular cause or causes.

The concepts of detection and attribution may be understood in terms of a simple medical analogy. Measurement of a body temperature of 40°C (104°F) detects the presence of some abnormal condition or symptom, but does not in itself give the cause of the symptom. To attribute the symptom to an underlying cause often requires additional and more complex tests, such as chemical analyses of blood and urine, or even x-rays and CAT scans. Early work on climate-change detection examined changes in the globally averaged surface temperature of the Earth over the last century. Most studies of this type concluded that the observed increase of roughly 0.5°C (about 1°F) was larger than would be expected as a result of natural climate variability alone. Observed globally averaged temperature changes have also been analyzed away from the Earth's surface. The observations used come from conventional weather observing instruments (radiosondes) and from satellites. As expected, because of the different factors affecting the variability of and persistence of temperatures at different altitudes, there are noticeable differences between short-term trends at the surface and those at higher altitudes. The record of temperatures away from the Earth's surface, which spans only the past 40 years compared with the much longer surface record, is too short for globally averaged values to provide any definitive information about the extent of human influences.

The further step of attributing some part of observed temperature changes to human influences makes use of climate models, which have been employed to estimate the climatic effects of a range of human-induced and natural factors. The human factors include recent changes in the atmospheric concentrations of both greenhouse gases and sulfate particles (called "aerosols"). The natural factors considered include solar variability, the effects of volcanic eruptions, and internal variability of the climate system resulting from interactions among its individual

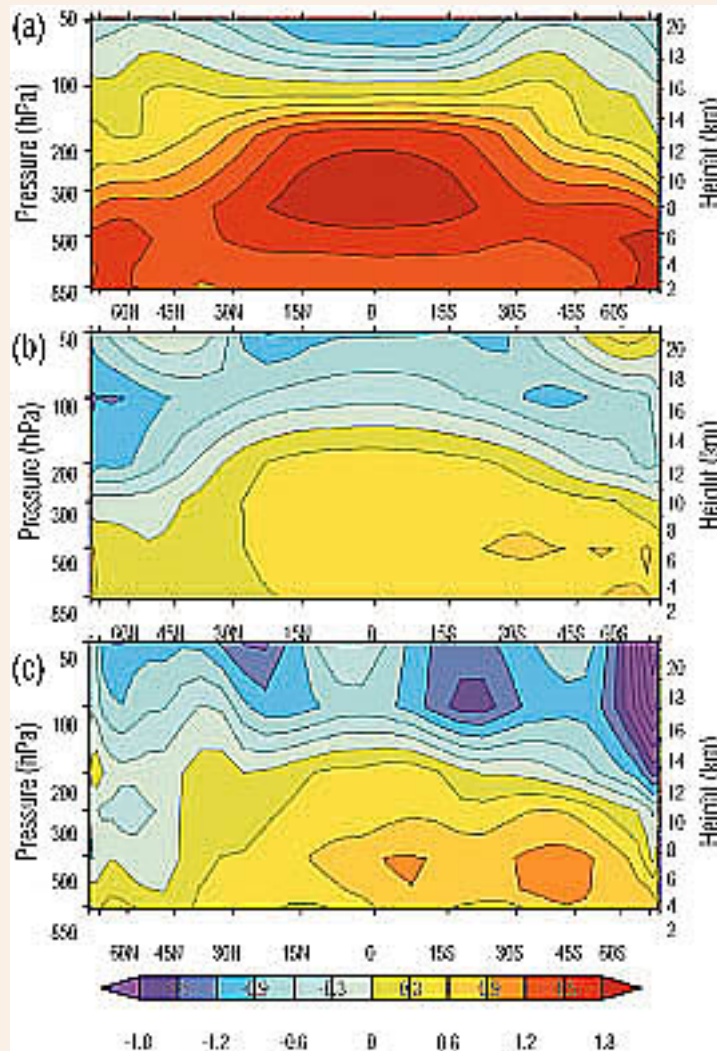
components.

The changes in globally averaged temperature that have occurred at the Earth's surface over the past century are similar in size and timing to those predicted by models that take into account the combined influences of human factors and solar variability. To probe the question of attribution requires the application of more powerful and complex methods, beyond the use of global averages alone. New studies have focused on comparing maps or patterns of temperature change in observations and in models. Pattern analysis is the climatological equivalent of the more comprehensive tests in the medical analogy mentioned previously, and makes it possible to achieve more definitive attribution of observed climate changes to a particular cause or causes.

The expected influence of human activities is thought to be much more complex than uniform warming over the entire surface of the Earth and over the whole seasonal cycle. Patterns of change over space and time therefore provide a more powerful analysis technique. The basic idea underlying pattern-based approaches is that different potential causes of climate change have different characteristic patterns of climate response or fingerprints. Attribution studies seek to obtain a fingerprint match between the patterns of climate change predicted by models and those actually observed.

Comparisons between observed patterns of temperature change and those predicted by models have now been made at the Earth's surface and in vertical sections through the atmosphere ([Figure 3.1](#)). Model predictions show increasing agreement with changes observed over the past 30-50 years. The closest agreement occurs when the combined effects of greenhouse gases and sulfate aerosol particles are considered. Statistical analyses have shown that these correspondences are highly unlikely to have occurred by chance.





**Figure 3.1**

*Modelled and observed changes in atmospheric temperature, from close to the Earth's surface to the lower stratosphere. Model results are from two sets of experiments: with "present-day" levels of atmospheric CO<sub>2</sub> (panel a), and with present-day CO<sub>2</sub>, sulfur emissions, and stratospheric ozone depletion (panel b). They are given as changes relative to a pre-industrial state of the atmosphere. Observed changes (panel c) are temperature trends over the period 1963 to 1988, as estimated from weather balloons. All results are for annually averaged data and are in units of °C (panels a, b) and °C/25 years (panel c). The patterns of change in panels b and c are similar.*

The agreements between the patterns of change predicted by models and those actually observed are due to similarities at large spatial scales, such as contrasts between the temperature changes in the northern and southern hemispheres or between different levels of the atmosphere. It is at these large scales that we have most confidence in model performance. More importantly, many of the results of these studies agree with our physical understanding of the climate system, and do not depend solely on numerical models or statistical techniques.

There are still uncertainties in these detection and attribution studies. These are due primarily to

our imperfect knowledge of the true climate-change signal due to human activities, to our incomplete understanding of the background noise of natural climatic variability against which this signal must be detected, and to inadequacies in the observational record. Such uncertainties make it difficult to determine the exact size of the human contribution to climate change. Nevertheless, the most recent assessment of the science suggests that human activities have led to a discernible influence on global climate and that these activities will have an increasing influence on future climate.

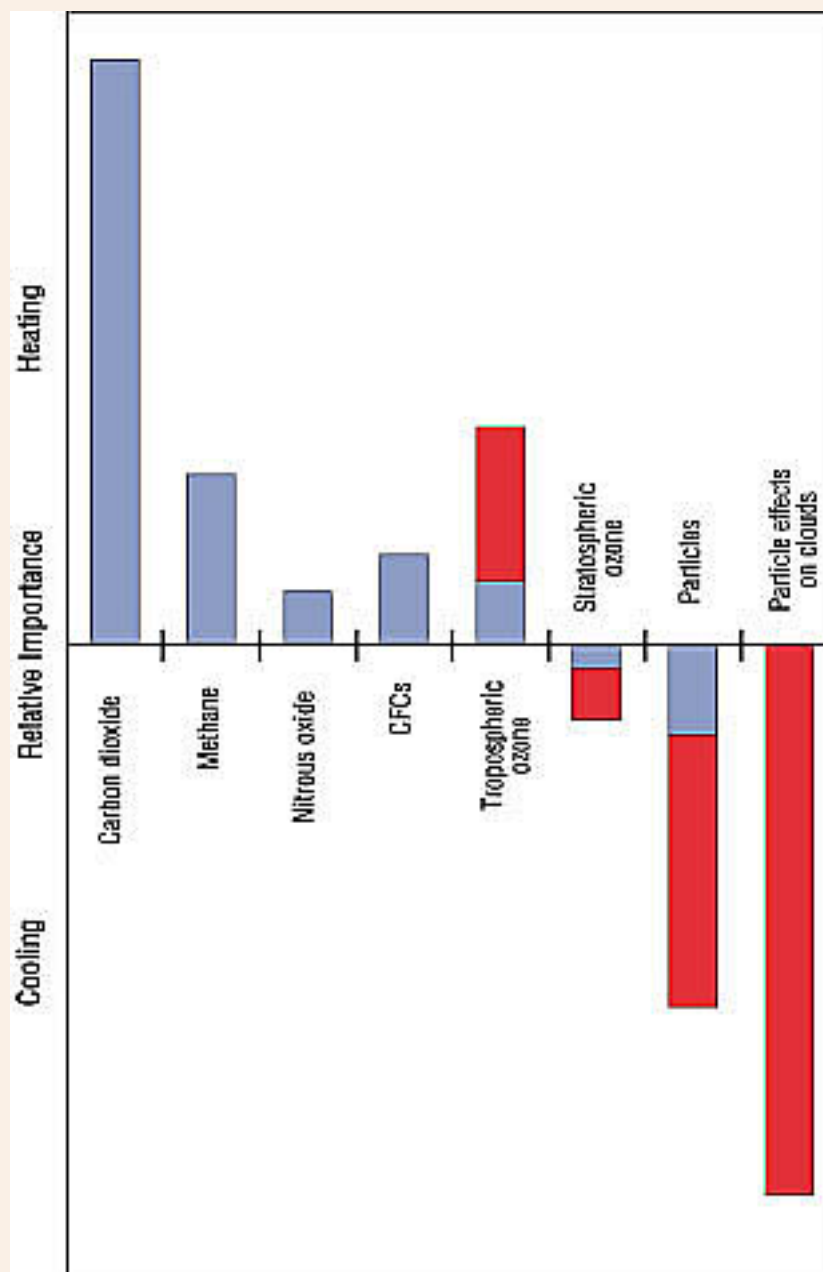
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# What Human Activities Contribute to Climate Change?

The burning of coal, oil, and natural gas, as well as deforestation and various agricultural and industrial practices, are altering the composition of the atmosphere and contributing to climate change. These human activities have led to increased atmospheric concentrations of a number of greenhouse gases, including carbon dioxide, methane, nitrous oxide, chlorofluorocarbons, and ozone in the lower part of the atmosphere. The relative importance of these gases is shown in [Figure 4.1](#).

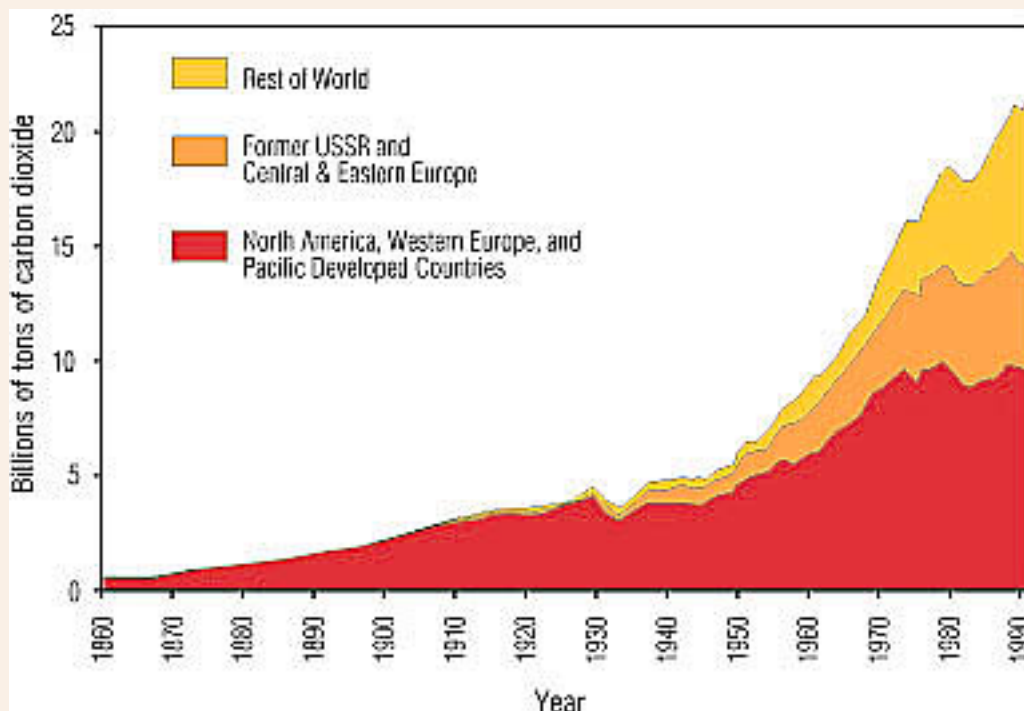


## Figure 4.1

*Relative importance of the various greenhouse gases and small particles currently in the atmosphere. Bars extending above the horizontal line indicate a warming effect. Bars extending below the horizontal line indicate a cooling effect. The impacts of tropospheric ozone, stratospheric ozone, and particles are quite uncertain. The range of possible effects for these gases is indicated by the red bar; i.e., the effect is in the range of one end of the red bar to the other.*

Carbon dioxide is produced when coal, oil, and natural gas (fossil fuels) are burned to produce energy used for transportation, manufacturing, heating, cooling, electricity generation, and other applications. The use of fossil fuel currently accounts for 80 to 85% of the carbon dioxide being added to the atmosphere.

Land use changes, e.g., clearing land for logging, ranching, and agriculture, also lead to carbon dioxide emissions. Vegetation contains carbon that is released as carbon dioxide when the vegetation decays or burns. Normally, lost vegetation would be replaced by re-growth with little or no net emission of carbon dioxide. However, over the past several hundred years, deforestation and other land use changes in many countries have contributed substantially to atmospheric carbon dioxide increases. Although deforestation is still occurring in some parts of the northern hemisphere, on the whole, re-growth of vegetation in the north appears to be taking some carbon dioxide out of the atmosphere. Most of the net carbon dioxide emissions from deforestation are currently occurring in tropical regions. Land use changes are responsible for 15 to 20% of current carbon dioxide emissions.



**Figure 4.2**

*Carbon dioxide emissions from the burning of coal, oil, and natural gas are shown for the period 1860 to 1992 for three groups of countries.*

Methane (natural gas) is the second most important of the greenhouse gases resulting from human activities. It is produced by rice cultivation, cattle and sheep ranching, and by decaying material in landfills. Methane is also emitted during coal mining and oil drilling, and by leaky gas pipelines. Human activities have increased the concentration of methane in the atmosphere by about 145% above what would be present naturally.

Nitrous oxide is produced by various agricultural and industrial practices. Human activities have increased the concentration of nitrous oxide in the atmosphere by about 15% above what would be present naturally.

Chlorofluorocarbons (CFCs) have been used in refrigeration, air conditioning, and as solvents. However, the production of these gases is being eliminated under existing international agreements because they deplete the stratospheric ozone layer. Other fluorocarbons that are also greenhouse gases are being used as substitutes for CFCs in some applications, for example in refrigeration and air conditioning. Although currently very small, their contributions to climate change are expected to rise.

Ozone in the troposphere, that is, in the lower part of the atmosphere, is another important greenhouse gas resulting from industrial activities. It is created naturally and also by reactions in the atmosphere involving gases resulting from human activities, including nitrogen oxides from motor vehicles and power plants. Based on current data, tropospheric ozone is an important contributor to the enhanced greenhouse effect. However, in part because ozone is also produced naturally, and because of its relatively short atmospheric lifetime, the magnitude of this contribution is uncertain.

Contrary to popular perception, the Antarctic ozone hole does not cause global warming. Instead, the global depletion of stratospheric ozone caused by CFCs and other gases has resulted in a small cooling effect as shown in [Figure 4.1](#).

Human activities, such as the burning of fossil fuels and changes in land use, have increased the abundance of small particles in the atmosphere. These particles can change the amount of energy that is absorbed and reflected by the atmosphere. They are also believed to modify the properties of clouds, changing the amount of energy that they absorb and reflect. Intensive studies of the climatic effects of these particles began only recently and the overall effect is uncertain. It is likely that the net effect of these small particles is to cool the climate and to partially offset the warming of increasing concentrations of greenhouse gases.

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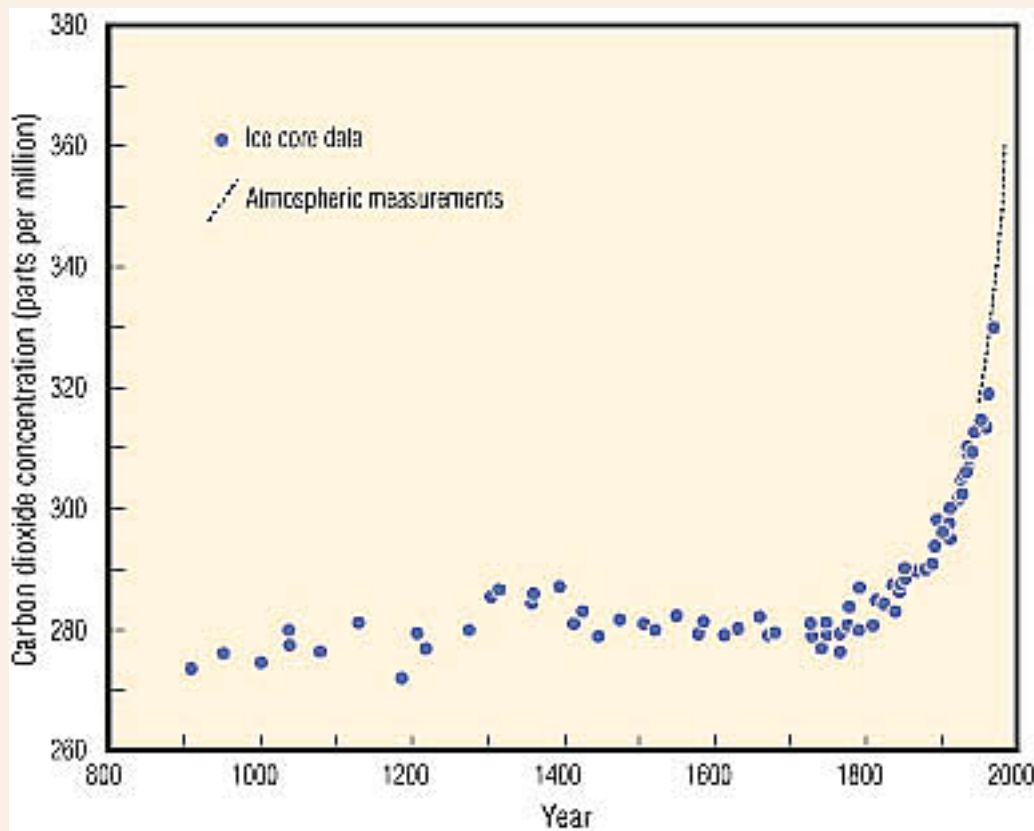
# How Do We Know that the Atmospheric Build-up of Greenhouse Gases Is Due to Human Activity?

Four lines of evidence prove conclusively that the recent buildup of carbon dioxide arises largely from human activities.

The nuclei of carbon atoms in carbon dioxide emitted by burning coal, oil, and natural gas (fossil fuels) differ in their characteristics from the nuclei of carbon atoms in carbon dioxide emitted under natural conditions. Coal, oil, and natural gas were formed deep underground tens of millions of years ago, and the fraction of their nuclei that were once radioactive has long ago changed to non-radioactive carbon. But the carbon dioxide emitted from natural sources on the Earth's surface retains a measurable radioactive portion. As carbon dioxide has been emitted through fossil fuel combustion, the radioactive fraction of carbon in the atmosphere has decreased. Forty years ago scientists provided the first direct evidence that combustion of fossil fuels was causing a buildup of carbon dioxide and thereby diluting radioactive carbon in the atmosphere by measuring the decreasing fraction of radioactive carbon-14 captured in tree rings, each year between 1800 and 1950.

Secondly, scientists began making precise measurements of the total amount of carbon dioxide in the atmosphere at Mauna Loa, Hawaii, and at the South Pole in the late 1950s. They have since expanded their observations to many other locations. Their data show convincingly that the levels of carbon dioxide have increased each year worldwide. Furthermore, these increases are consistent with other estimates of the rise of carbon dioxide emissions due to human activity over this period.

A third line of evidence has been added since 1980. Ice buried below the surface of the Greenland and Antarctic ice caps contains bubbles of air trapped when the ice originally formed. These samples of fossil air, some of them over 200,000 years old, have been retrieved by drilling deep into the ice. Measurements from the youngest and most shallow segments of the ice cores, which contain air from only a few decades ago, produce carbon dioxide concentrations nearly identical to those that were measured directly in the atmosphere at the time the ice formed. But the older parts of the cores show that carbon dioxide amounts were about 25% lower than today for the ten thousand years previous to the onset of industrialization, and over that period changed little ([Figure 5.1](#)).



**Figure 5.1**

*Measured amounts of carbon dioxide in the atmosphere.*

The final line of evidence comes from the geographic pattern of carbon dioxide measured in air. Observations show that there is slightly more carbon dioxide in the northern hemisphere than in the southern hemisphere. The difference arises because most of the human activities that produce carbon dioxide are in the north and it takes about a year for northern hemispheric emissions to circulate through the atmosphere and reach southern latitudes.

Carbon dioxide is released to the atmosphere by a variety of sources, and over 95% percent of these emissions would occur even if human beings were not present on Earth. For example, the natural decay of organic material in forests and grasslands, such as dead trees, results in the release of about 220 billion tons of carbon dioxide every year. But these natural sources are nearly balanced by physical and biological processes, called natural sinks, which remove carbon dioxide from the atmosphere. For example, some carbon dioxide dissolves in sea water, and some is removed by plants as they grow.

As a result of this natural balance, carbon dioxide levels in the atmosphere would have changed little if human activities had not added an amount every year. This addition, presently about 3% of annual natural emissions, is sufficient to exceed the balancing effect of sinks. As a result, carbon dioxide has gradually accumulated in the atmosphere, until at present, its concentration is 30% above pre- industrial levels.

Direct atmospheric measurements of other human-produced greenhouse gases have not been made in as many places or for as long a period as they have for carbon dioxide. However,

existing data for these other gases do show increasing concentrations of methane, nitrous oxide, and chlorofluorocarbons over recent decades. In addition, ice core data are available for methane and for nitrous oxide that demonstrate that the atmospheric concentrations of these gases began to increase in the past few centuries, after having been relatively constant for thousands of years. Chlorofluorocarbons are absent from deep ice cores because they have no natural sources and were not manufactured before 1930.

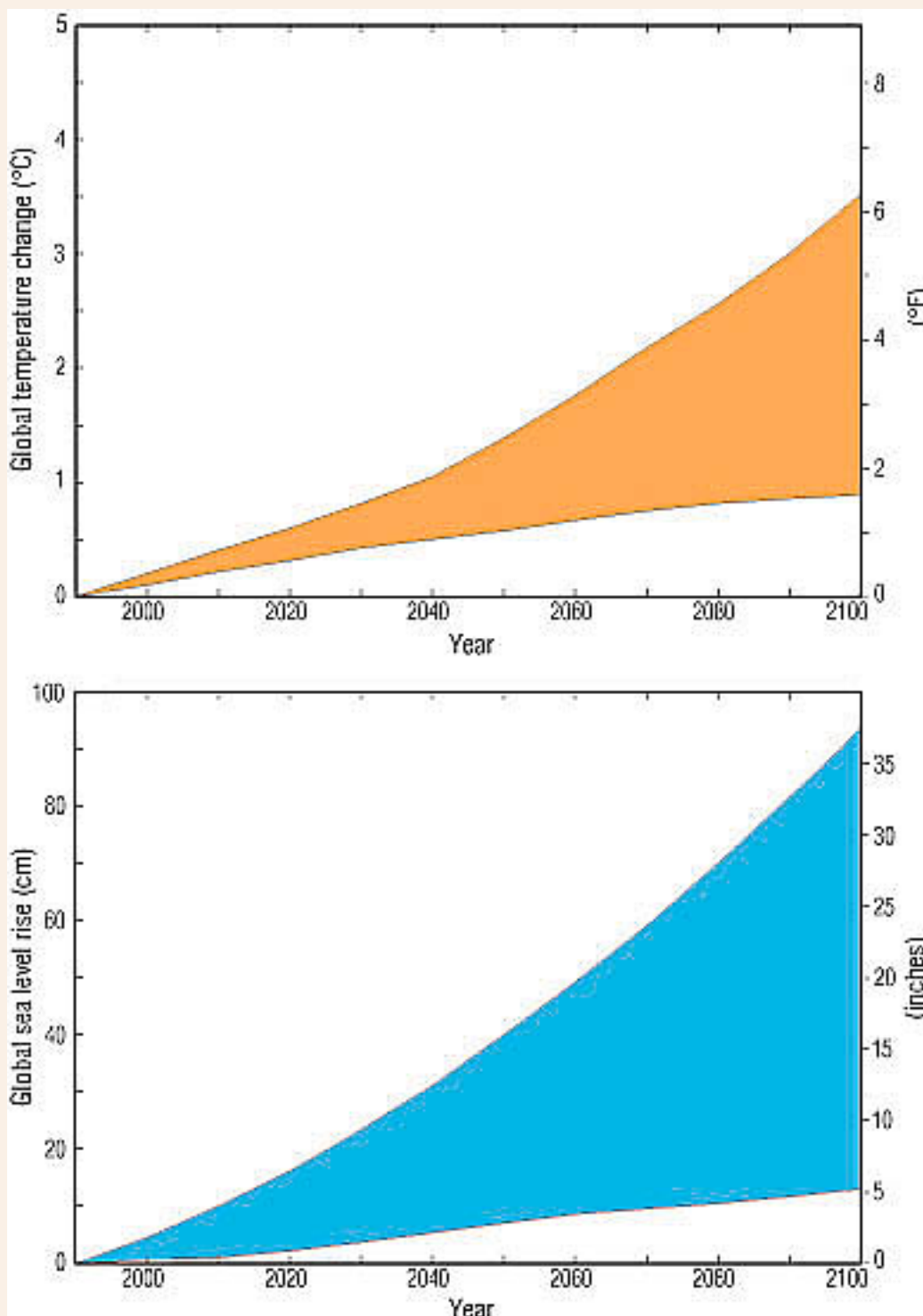
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## What Climate Changes Are Projected?

The IPCC has projected further increases in globally averaged surface temperatures of 1 to 3.5°C (about 2 to 6°F) by the year 2100, as compared with 1990 ([Figure 6.1](#)). This projection is based on estimates of future concentrations of greenhouse gases and sulfate particles in the atmosphere.



## Figure 6.1

*(top) The possible range of globally average surface temperature increase is shown for the period 1990 to 2100.*

*(bottom) The possible range of globally averaged sea level rise is shown for the period 1990 to 2100.*

The average rate of warming of the Earth's surface over the next hundred years will probably be greater than any that has occurred in the last 10,000 years, the period over which civilization developed. However, specific temperature changes will vary considerably from region to region.

As a result of the warming, global sea level is expected to rise by a further 15 to 95 cm (about 6 to 37 inches) by the year 2100, because sea water expands when heated and some glacial ice will melt.

Although globally averaged surface temperature increases and sea level rise are the most certain of the IPCC projections, other effects can be projected with some confidence. Greater warming is expected to occur over land than over the oceans. The maximum warming is expected to occur in the Arctic in winter. Nighttime temperatures are expected to increase more than daytime temperatures. In general, there will probably be an increase in the number of very hot days at mid-latitude locations in summer, such as in most of North America, Europe, and parts of South America, with a decrease of very cold days in the same locations in winter.

Extreme events such as heavy rains and droughts are the most destructive forms of weather, and the frequency and duration of these events are likely to increase as the climate continues to change. Increases in the global averages of both evaporation and precipitation are expected. In winter at mid-latitudes, higher surface temperatures are expected to cause an increased portion of the precipitation to fall in the form of rain rather than snow. This is likely to increase both wintertime soil moisture and runoff, leaving less runoff for summer. In spring, faster snow melt is likely to aggravate flooding. In the summer, increased heating will lead to increased evaporation, which could decrease the availability of soil moisture needed both for natural vegetation and agriculture in many places, and increase the probability of severe drought. Droughts and floods occur naturally around the world, for example in association with El Niño events, but are likely to become more severe, causing water management to become an even more critical problem in the future.

The most uncertain projections of future climate relate to changes in particular locales, as well as how weather events such as tropical storms, including hurricanes, typhoons, and cyclones, will be affected. This uncertainty results from the existence of large natural regional variations, as well as limitations in computer models and the understanding of the relationship between local and global climate at the present time.

The range of estimated warming of 1 to 3.5°C (about 2 to 6°F) by the year 2100 arises from uncertainties about the response of climate to the buildup of greenhouse gases and particles, as well as the total amount of future emissions of these gases. Factors such as estimates of human



population growth, land use changes, life styles, and energy choices yield a range of plausible greenhouse gas emissions. For example, concerted efforts to reduce emissions of greenhouse gases would lead to a significantly lower projected temperature rise.

All of these predictions are based on the assumption that the global climate will change gradually. However, there is evidence to suggest that the Earth's climate has occasionally changed rather rapidly in the distant past. There may be similarly abrupt transitions due to human-induced climate change. These abrupt transitions raise the possibility of significant surprises as the world warms over the next century, perhaps with rapid and unexpected changes in ocean currents and regional climate. The likelihood that such rapid changes could occur increases with increasing emissions of greenhouse gases.

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# How Reliable Are Predictions of Future Climate?

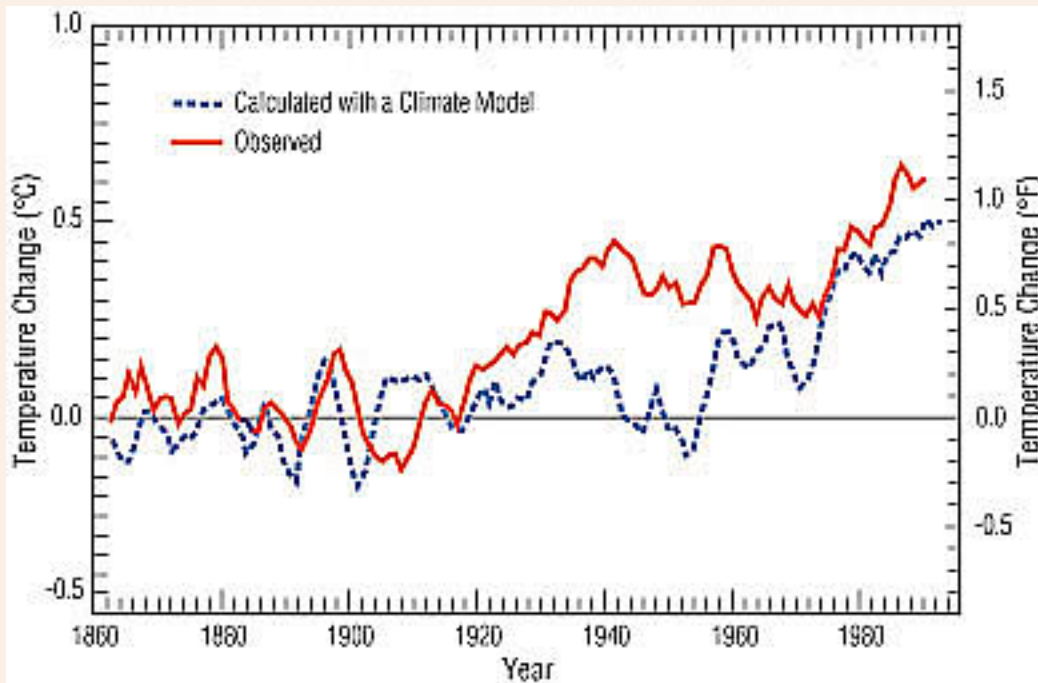
Predictions of climate change are calculated by means of computer models that mathematically simulate the interactions of the land, sea, and air, which together determine the Earth's climate. Our confidence in these models rests largely on their basis in accepted physical laws, their ability to describe many aspects of current climate accurately, and their skill at reproducing some of the important features of past climates.

Climate models are based on a wealth of scientific observations and well established laws of physics, including the laws of gravity and fluid motion, and the conservation of energy, momentum, mass, and water. It is this reliance on basic physical laws that lends high confidence to the prediction that a buildup of greenhouse gases will eventually lead to a significant alteration in the Earth's climate.

A second important reason for having confidence in climate models is because of their ability to reproduce many of the observed features of the atmosphere and ocean. For the purposes of predicting the behavior of the atmosphere for only a few days ahead, an atmosphere-only model, with no simulation of the ocean, can be used. This is the method employed in making short-term weather forecasts, whose relative accuracy demonstrates the ability of this sort of model to reproduce some of the important details of the atmosphere's behavior.

While reliable weather forecasts can only be made for periods up to ten days, predictability for greater lengths of time can be obtained for averages of weather, i.e., the climate. For example, with regard to longer periods (several years or more), climate models in which both the oceans and the atmosphere are represented are able to simulate the main features of current climate and its variability, including the seasonal cycle of temperature, the formation and decay of the major monsoons, the seasonal shift of the major rain belts and storm tracks, the average daily temperature cycle, and the variations in outgoing radiation at high elevations in the atmosphere as measured by satellites. Similarly, many of the large-scale features observed in the ocean circulation have been reproduced by climate models.

It is possible for a model to simulate current climate well but still fail in its prediction of climate change. So another test of models is to compare their simulations of earlier climates to historical data, including the climate of the past century ([Figure 7.1](#)). These efforts have been hampered by our imprecise knowledge of a variety of factors, including how humans have changed the amounts of small particles in the atmosphere and variations in the energy output of the sun.



**Figure 7.1**

*Calculated globally averaged surface air temperature is compared to observed values over the period 1860 to 1994.*

Nevertheless, using estimates of some of these factors, climate models can reproduce many changes observed over the last century, including the global mean surface warming of 0.3 to 0.6°C (about 0.5 to 1°F), the reduction in temperature differences between day and night, the cooling in the atmosphere above about 14 km (about 9 miles), the increases in precipitation at high latitudes, the intensification of precipitation events in some continental areas, and a rise in sea level. Moreover, a climate model has correctly predicted broad features of the globally averaged surface cooling and subsequent recovery associated with the eruption of Mt. Pinatubo in 1991.

Climate models can also be used in attempts to reproduce the main features of prehistoric climates, but this effort has been limited by the scarcity and the indirect nature of the evidence available from sediment cores, tree rings, preserved pollen, and ice core data used to infer earlier climates. Even so, the models have reproduced some of the general features of reconstructed past climates, such as the enhanced North African monsoon 6000 to 9000 years ago, and the approximate level of cooling during the last ice age.

The major weakness of models is their reliance on approximations of some aspects of climate. It takes too much computer time, or is simply beyond the capacity of even supercomputers, to represent some of the key smaller-scale processes that affect climate. Even if adequate computers were available, scientists' understanding of the detailed physics of such processes is limited. So, some aspects of climate are approximated, based on a combination of physical laws, laboratory experiments, and direct observations of climate. For example, it is not possible to represent the details of the formation and dissipation of clouds. So, approximations are used. The approximation of cloud behavior is a major source of uncertainty in climate models.

In summary, the fact that models are based upon the known physical laws of nature and can reproduce many features of the current climate and some general aspects of past climates gives us increasing confidence in their reliability for projecting many large-scale features of future climate. However, there remains substantial uncertainty in the exact magnitude of projected globally averaged temperature rise caused by human activity, due to shortcomings in the current climate models, particularly in their representation of clouds. Furthermore, scientists have little confidence in the climate changes they project at the local level. Other uncertainties, not arising from specific limitations in the climate models, such as estimates of the rate of future greenhouse gas emissions, also restrict the ability to predict precisely how the climate will change in the future.

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# Are Recent Extreme Weather Events, Like the Large Number of Atlantic Hurricanes in 1995, Due to Global Warming?

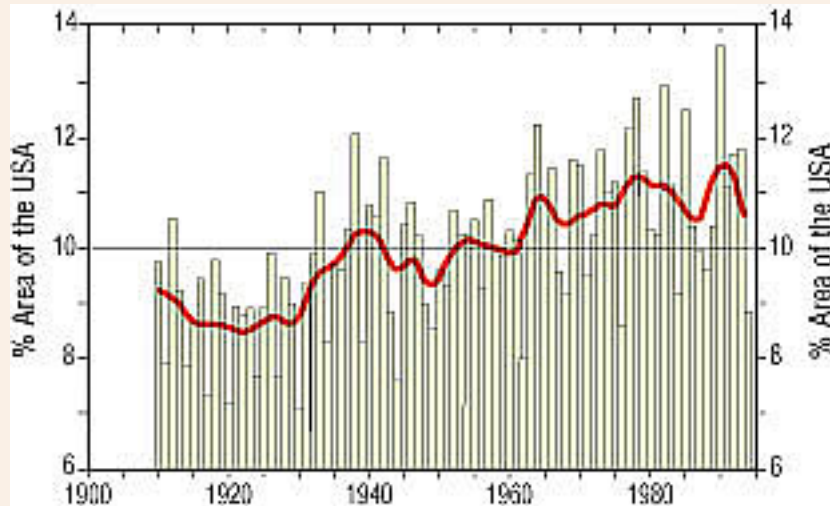
As the world warms, some extreme climate events, like the frequency of heat waves and very heavy precipitation, are expected to increase, but it remains uncertain whether or not to expect changes in the frequency of some other extremes. Moreover, it is important to note that it is not possible to link any particular weather or climate event definitively to global warming. The causal linkage, if any, between the frequency of extreme events and global warming only can be determined through statistical analyses of long-term data, because the natural climate system can produce weather and climate events that often appear to be uncharacteristic of the recent climate.

Data on climate extremes in many regions of the world are inadequate to draw definitive conclusions about possible changes that may have occurred on a global scale. However, in some regions where good data are available, there have been some significant increases and decreases in extreme events over time. For example, there has been a clear trend to fewer extremely low minimum temperatures in several widely separated areas in recent decades (e.g., Australia, the United States, Russia, and China). The impact of such changes can manifest itself in fewer freezing days and late season frosts, such as have been documented in Australia and the United States. Indeed, we expect that the number of days with extremely low temperatures should continue to decrease as global temperatures rise.

Widespread, extended periods of extremely high temperatures are also expected to become more frequent with continued global warming, such as the unprecedented high nighttime temperatures during the 1995 heat wave in Chicago, Illinois, and the midwestern United States that caused an estimated 830 deaths. However, the global frequency of such heat waves has not been analyzed at this time.

Higher temperatures lead to higher rates of evaporation and precipitation. As the Earth warms, we expect more precipitation and it is likely to fall over shorter intervals of time, thereby increasing the frequency of very heavy and extreme precipitation events. Analyses of observed changes in precipitation intensity have been conducted only for a few countries. Perhaps the best evidence of increases in extreme and very heavy precipitation events comes from data in North America as depicted for the United States in [Figure 8.1](#). In Australia, which is historically prone to heavy precipitation, an increase in rainfall amount from major storms has also been observed. Analyses for South Africa also show increases in extreme precipitation rates. In another area, China, where data have been analyzed for the last several decades, no obvious trends are apparent, but high concentrations of air pollution (such as sulfate particles that can cool the climate) may be counteracting such changes in this region.





**Figure 8.1**

*The area (expressed in percentage) of the United States, excluding Alaska and Hawaii, with an unusually large amount of total annual precipitation coming from extreme precipitation events (those with more than 5.08 cm {2 inches} of rainfall {or equivalent if precipitation is snowfall} in 24 hours) is displayed. The smooth curve shows the same data, but averaged over periods of about 10 years.*

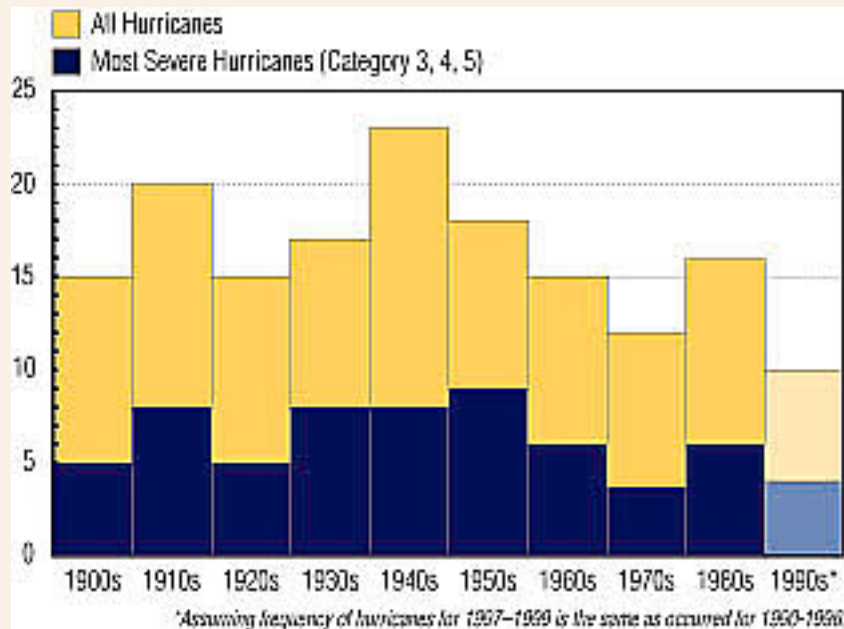
There is as yet no evidence for a worldwide rise in the frequency of droughts. In the future, however, it is expected that many regions will experience more frequent, prolonged, or more severe droughts, primarily due to the more rapid evaporation of moisture from plants, soils, lakes, and reservoirs. This is expected to occur even as precipitation increases and heavy precipitation events become more common.

Blizzards and snow storms may actually increase in intensity and frequency in some colder locations as atmospheric moisture increases. In more temperate latitudes, snowstorms are likely to decrease in frequency, but their intensity may actually increase, as the world warms. Observations show that snowfall has increased in the high latitudes of North America, but snow accumulations have melted faster because of more frequent and earlier thaws.

There is evidence of an increase in the frequency of intense extra-tropical storms in the northern North Atlantic and adjacent areas of Europe, such as the British Isles, but there has been a decrease in such events in the southern North Atlantic (south of 30°N) over the past few decades. It remains uncertain as to whether these changes are natural fluctuations or relate to global warming, because there is little consensus about how global warming will affect these non-tropical, yet powerful storms.

There is little evidence to support any significant long-term trends in the frequency or intensity of tropical storms, or of hurricanes in the North Atlantic during the past several decades. Although the hurricane frequency was high during 1995 and 1996, an anomalously low number of hurricanes occurred during the 1960s through the 1980s, including those hitting the United States during that period ([Figure 8.2](#)). Reliable data from the North Atlantic since the 1940s indicate that the peak strength of the strongest hurricanes has not changed, and the mean maximum intensity of all hurricanes has decreased. There is also some evidence for a decrease

in the frequency of cyclones in the Indian Ocean during the past two decades relative to earlier records and an increase in the frequency of typhoons in the western Pacific. Wide variations in the total number of tropical storms including hurricanes, typhoons, and cyclones occurring per decade have been observed, with no apparent long-term trends in most ocean basins. There is little consensus about how global warming will affect the intensity and frequency of these storms in the future.



**Figure 8.2**

*Number of all hurricanes and the most severe hurricanes making landfall in the United States, excluding Alaska and Hawaii.*

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# Why Do Human-made Greenhouse Gases Matter When Water Vapor Is the Most Potent Greenhouse Gas?

The Earth's surface temperature would be about 34°C (61°F) colder than it is now if it were not for the natural heat trapping effect of greenhouse gases like carbon dioxide, methane, nitrous oxide, and water vapor. Indeed, water vapor is the most abundant and important of these naturally occurring greenhouse gases. In addition to its direct effect as a greenhouse gas, clouds formed from atmospheric water vapor also affect the heat balance of the Earth by reflecting sunlight (a cooling effect), and trapping infrared radiation (a heating effect).

However, just because water vapor is the most important gas in creating the natural greenhouse effect does not mean that human-made greenhouse gases are unimportant. Over the past ten thousand years, the amounts of the various greenhouse gases in the Earth's atmosphere remained relatively stable until a few centuries ago, when the concentrations of many of these gases began to increase due to industrialization, increasing demand for energy, rising population, and changing land use and human settlement patterns. Accumulations of most of the human-made greenhouse gases are expected to continue to increase, so that, over the next 50 to 100 years, without control measures, they will produce a heat-trapping effect equivalent to more than a doubling of the pre-industrial carbon dioxide level.

Increasing amounts of human-made greenhouse gases would lead to an increase in the globally averaged surface temperature. However, as the temperature increases, other aspects of the climate will alter, including the amount of water vapor in the atmosphere. While human activities do not directly add significant amounts of water vapor to the atmosphere, warmer air contains more water vapor. Since water vapor is itself a greenhouse gas, global warming will be further enhanced by the increased amounts of water vapor. This sort of indirect effect is called a positive feedback.

It has been suggested that as greenhouse gases accumulate, the atmospheric events that generate cumulus clouds in tropical areas would cause a drying rather than moistening of the upper layers of the troposphere (the lowest region of the atmosphere). However, observations of the current atmosphere provide evidence for the conclusion that on a global scale, a warmed atmosphere will moisten and this will enhance greenhouse warming.

Clouds are another important factor in determining climate. The increased levels of water vapor in the atmosphere, as well as changes in temperatures and winds, will also cause changes in clouds that will alter the amount of energy from the sun that is absorbed and reflected by the Earth, at some locations enhancing and at others diminishing the warming due to greenhouse gases. The response of clouds to global warming is a major uncertainty in determining the magnitude and distribution of climate change.

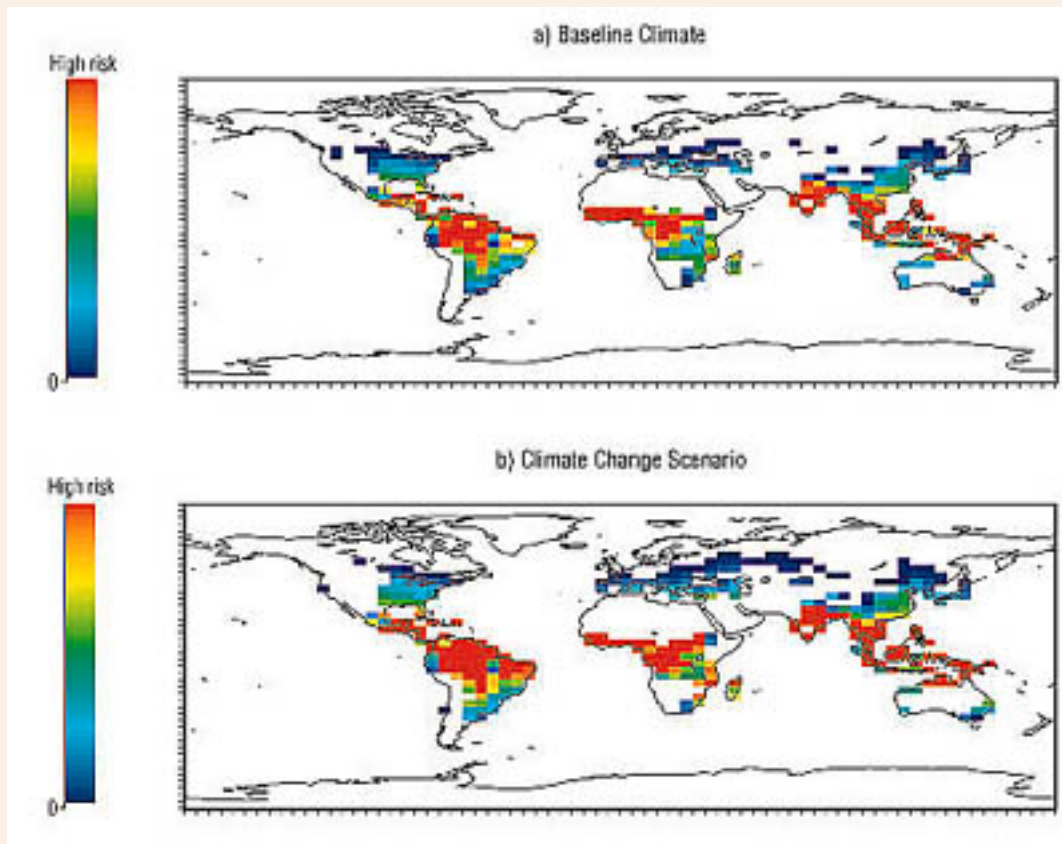
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# Why Should a Few Degrees of Warming Be a Cause for Concern?

The most recent IPCC scientific assessment of climate change estimated that the globally averaged surface temperature will increase by 1 to 3.5°C (about 2 to 6°F) by the year 2100, with an associated rise in sea level of 15 to 95 cm (about 6 to 37 inches). These changes may lead to a number of potentially serious consequences. For example, mid- and high-latitude regions, such as much of the United States, Europe, and Asia, could experience an increase in the incidence of heat waves, floods, and droughts as the global climate changes. The impacts of such extreme events on human welfare as well as natural ecosystems could be significant.

Climate change is likely to have wide-ranging and mostly adverse impacts on human health. The projected increase in the duration and frequency of heat waves is expected to increase mortality rates as a result of heat stress, especially where air conditioning is not available. To a lesser extent, increases in winter temperatures in high latitudes could lead to decreases in mortality rates. Climate change is also expected to lead to increases in the potential transmission of many infectious diseases, including malaria, dengue, and yellow fever, extending the range of organisms such as insects that carry these diseases into the temperate zone, including parts of the United States, Europe, and Asia. For example, projections indicate that the zone of potential malaria transmission, in response to global surface temperature increases at the top of the projected range, may enlarge from an area containing about 45% of the world population to about 60% by the end of the twenty-first century, resulting in 50-80 million additional cases of malaria per year ([Figure 10.1](#)).



**Figure 10.1**

*The figures show model-calculated potential malaria risk areas for the most dangerous type of malaria (*P. falciparum*). Panel a) shows the average annual 'epidemic potential' (EP), a measure of risk of contracting malaria, for baseline climate conditions (1931-1980) and panel b) shows EP for a mean global temperature increase of about 1.2 °C. This temperature increase is projected to occur somewhere in the time frame of 2040 to 2100. Both the magnitude of risk in current transmission areas and the area of potential transmission are projected to increase.*

It may be possible for global agricultural production to keep pace with increasing demand over the next 50-100 years if adequate adaptations are made, but there are likely to be difficulties in some regions. This conclusion takes into account the beneficial effects of carbon dioxide fertilization, i.e., given sufficient water and nutrients, plant growth will be enhanced by an increased concentration of carbon dioxide in the atmosphere. Changes in the spread and abundance of agricultural pests and the effects of climate variability were not reflected in this assessment. Regional changes in crop yields and productivity are expected to occur in response to climate change. There is likely to be an increased risk of famine, particularly in subtropical and tropical semi-arid and arid locations.

With 50-70% of the global human population currently living in coastal areas, future sea level rises, alterations in storm patterns, and higher storm surges could have significant effects. About 46 million people are currently at risk by flooding in coastal areas as a result of storm surges. In the absence of measures to adapt, even with current populations, a 50 cm (about 20 inches) sea level rise would increase the number of people whose land will be at risk from serious flooding



or permanent inundation to about 92 million, while a 100 cm (about 40 inches) rise would increase this number to 118 million. If expected population growth is incorporated into the projections, these estimates increase substantially.

Other projected changes include a disappearance of between one- third and one-half of existing mountain glacier mass by 2100. Alpine glaciers are already observed to be in rapid retreat and many cities between 30°N and 30°S depend on these natural reservoirs for their water supply. For example, in Lima, Peru, the entire water supply for 10 million people depends on the summer melt from a glacier that is now in rapid retreat, for reasons that may or may not be related to global climate change. In the future, climate change could also lead to shifts in river flow and water supply, with serious implications for human settlements and agriculture.

Climate change is also likely to affect human infrastructure, including transportation, energy demand, human settlements (especially in developing countries), the property insurance industry, and tourism.

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# Why Can't Ecosystems Just Adapt?

Climate change has the potential to alter many of the Earth's natural ecosystems over the next century. Yet, climate change is not a new influence on the biosphere, so why can't ecosystems just adapt without significant effects on their form or productivity? There are three basic reasons.

First, the rate of global climate change is projected to be more rapid than any to have occurred in the last 10,000 years. Second, humans have altered the structure of many of the world's ecosystems. They have cut down forests, plowed soils, used rangelands to graze their domesticated animals, introduced non-native species to many regions, intensively fished lakes, rivers and oceans, and constructed dams. These relatively recent changes in the structure of the world's ecosystems have made them less resilient to further changes. Third, pollution, as well as other indirect effects of the utilization of natural resources, has also increased since the beginning of the industrial revolution. Consequently, it is likely that many ecosystems will not be able to adapt to the additional stress of climate change without losing some of the species they contain or the services they provide, such as supplying sufficient clean water to drink, food to eat, suitable soils in which to grow crops, and wood to use as fuel or in construction.

For millions of years, species have been shifting where they grow and reproduce in response to changing climate conditions. Over the next century, global warming could result in approximately one-third of the Earth's forested area undergoing major transitions in species composition. From the fossil record we have an indication of the maximum rate at which various plant species have migrated to more suitable areas; from 0.04 km/yr (about 0.03 miles/yr) for the slowest to 2 km/yr (about 1.3 miles/yr) for the fastest. However, the projected rate of surface temperature change in many parts of the world could require plant species to migrate at faster rates (1.5 to 5.5 km/yr or about 1 to 3.5 miles/yr). Thus, many species may not be able to move rapidly enough to prosper. These changes in vegetation and ecosystem structure may in turn give rise to additional releases of carbon into the atmosphere, further accelerating climate change.

Moreover, as the old vegetation dies in areas most affected by climate change, such as forests in northern latitudes, it is likely to be replaced by fast growing, often non-native species. These species commonly yield less timber, provide lower quality forage for domesticated animals, supply less food for wild animals, and furnish poorer habitat for many native animals. The prevalence of pest species, such as weeds, rats, and cockroaches, may also increase.

Humans actively and productively use and manipulate large portions of the land surface of the Earth, whether it be for agriculture, housing, energy, or forestry. These practices have created a mosaic of different land uses and ecosystem types, resulting in fewer remaining large and contiguous areas of a single type of habitat than existed in the past. Therefore it will often be difficult for plants and animals to move to a location with a more suitable climate even if a species was able to migrate quickly enough. This was not the case thousands of years ago, when

ecosystems last experienced rapid climate change. Now, many of the world's ecosystems are essentially trapped on small islands, cut off from one another, only capable of travel over a limited and shrinking number of bridges. As this increasingly occurs, more species are likely to be stranded in an environment in which they cannot survive and/or reproduce.

Further complicating the response of many of the Earth's terrestrial and aquatic ecosystems to climate change is the prevalence of stress from other disturbances associated with resource use. In the case of trees, for example, many species are already weakened by air pollution. Increased concentrations of carbon dioxide in the atmosphere will raise the photosynthetic capacity of many plants, but the net effect on ecosystem productivity is unclear, particularly when combined with higher air temperatures or where soil nutrients are limiting.

Among the ecosystems that are most likely to experience the most severe effects from climate change are those that are at higher latitudes, such as far northern (Boreal) forests or tundra, as well as those where different habitat types converge, such as where grasslands meet forests, or forests give way to alpine vegetation. Coastal ecosystems are also at risk, particularly saltwater marshes, mangrove forests, coastal wetlands, coral reefs, and river deltas. Many of these ecosystems, already under stress from human activities, may be significantly altered or diminished in terms of their extent and productivity as a result of future climate change.

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The scientists listed below have volunteered their time to write and review this brochure. The brochure is cosponsored by the [United Nations Environment Programme](#) and the [World Meteorological Organization](#). In addition, the [United Nations Environment Programme](#), the [National Oceanic and Atmospheric Administration](#), the [U.S. Global Change Research Program](#), and the [Rockefeller Brothers Fund](#) contributed funds for the layout and printing of the brochure. Leonie Haimson and Christine Ennis assisted in editing and Elizabeth C. Johnston and Julianne Snider designed the layout of the brochure.

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