Appendix 4: Climate Science: Frequently Asked Questions

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Introduction

This section answers some frequently asked questions about climate change. The questions addressed range from those purely related to the science of climate change to those that extend to some of the issues being faced in consideration of mitigation and adaptation measures. The author team selected these questions based on those often asked in presentations to the public. The answers are based on peer-reviewed science and assessments and have been confirmed by multiple analyses.

Outline of the Questions addressed

A. How can we predict what climate will be like in 100 years if we can't even predict the weather next week?

B. Is the climate changing? How do we know?

C. Climate is always changing. How is recent change different than in the past?

D. Is the globally averaged surface temperature still increasing? Isn't there recent evidence that it is actually cooling?

E. Is it getting warmer at the same rate everywhere? Will the warming continue?

F. How long have scientists been investigating human influences on climate?

G. How can the small proportion of carbon dioxide in the atmosphere have such a large effect on our climate?

H. Could the sun or other natural factors explain the observed warming of the past 50 years?

I. How do we know that human activities are the primary cause of recent climate change?

J. What is and is not debated among climate scientists about climate change?

K. Is the global surface temperature record good enough to determine whether climate is changing?

L. Is Antarctica gaining or losing ice? What about Greenland?

M. Weren't there predictions of global cooling in the 1970s?

N. How is climate projected to change in the future?

O. Does climate change affect severe weather?

P. How are the oceans affected by climate change?

Q. What is ocean acidification?

R. How reliable are the computer models of the Earth's climate?

S. What are the key uncertainties about climate change?

T. Are there tipping points in the climate system?

U. How is climate change affecting society?

V. Are there benefits to warming?

W. Are some people and ecosystems more vulnerable than others?

X. What can be done? Are there solutions?

Y. Are there advantages to acting sooner rather than later?

Z. Can we reverse global warming?

Questions and Answers

A. How can we predict what climate will be like in 100 years if we can't even predict the weather next week?

Predicting how climate will change in future decades is a different scientific issue from predicting weather a few weeks from now. Weather is short term and chaotic, largely determined by whatever atmospheric system is moving through at the time, and thus it is nearly impossible to predict day-to-day changes beyond about two weeks into the future. Climate, on the other hand, is a long-term statistical average of weather and is determined by larger-scale forces, such as the level of heat-trapping gases in the atmosphere and the energy coming from the sun. Thus it is actually easier to project how climate will change in the future. By analogy, while it is impossible to predict the age of death of any individual, the *average* age of death of an American is possible to calculate. In this case, weather is like the individual, while climate is like the average. To extend this analogy into the realm of climate change, we can also calculate the life expectancy of the average American who smokes. We can predict that on average, a smoker will not live as long as a non-smoker. Similarly, we can project what the climate will be like if we emit less heat-trapping gas, and what it will be like if we emit more.

Weather is the day-to-day variations in temperature, precipitation, and other aspects of the atmosphere around us. Weather prediction using state-of-the-art computer models can be very accurate for a few days to about a week in advance. Because weather forecasts are based on the initial conditions of the atmosphere and ocean at the time the prediction is made, accuracy decays over time. After about two weeks, small errors in defining these initial conditions grow so large that meteorologists can no longer discern what the weather will be like on any specific day or place.

Climate is long-term average weather – the statistics of weather over time scales of 30 years or more. Climate is primarily the result of the effects of local geography, such as distance from the equator, distance from the ocean, and local topography and elevation, combined with larger scale climate factors that can change over time. These include the amount of energy from the sun and the composition of the atmosphere, including the amount of greenhouse gases and tiny particles suspended in the atmosphere. Knowing all these factors enables scientists to quantify the climate at a given place and time. Climate change occurs when these large-scale climate factors change over time.

Using our understanding of the physics of how the atmosphere works, we can estimate how climate will change in the future: in response to human activities, which are now changing Earth's atmospheric composition faster than at any time in at least the last 800,000 years. It is also possible to estimate changes in the statistics of certain types of weather events, such as heat waves or heavy precipitation events, especially when we know what is causing them to change.

We know how climate has changed in the recent past, and often we know why those changes have occurred. For example, the increase in global temperature, or global warming, that has occurred over the last 150 years can only be explained if we include the impact of increasing levels of heat-trapping gases in the atmosphere caused by human activities. The present generation of climate models can successfully reproduce the past warming and therefore provide an essential tool to peer into the future.

The role of human activities in driving recent change is discussed in FAQ I. (In the context of a changing climate, the term "human activities" is used throughout these frequently asked questions to refer specifically to activities, such as extracting and burning fossil fuels, deforestation, agriculture, waste treatment, and so on, that produce heat-trapping gases like carbon dioxide, methane, and nitrous oxide and/or emissions of black carbon, sulfate, and other particles.) Other human activities, like changes in land use, can also alter climate, especially on local or regional scales, such as that which occurs with urban heat islands.

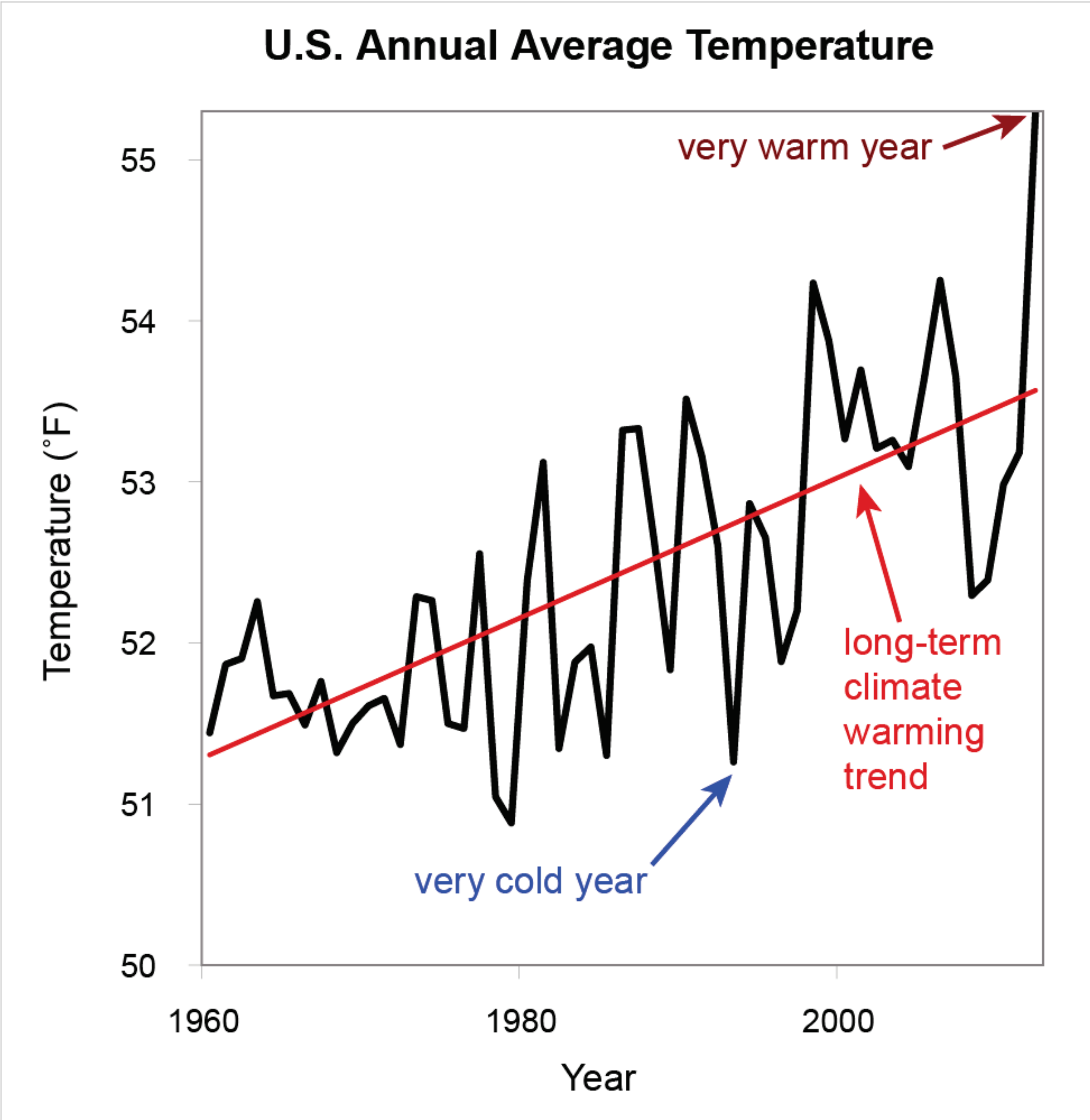

Figure 1: U.S. Annual Average Temperature

Caption: Climate change refers to the changes in average weather conditions that persist for an extended period of time, over multiple decades or even longer. Year-to-year and even decade-to-decade conditions do not necessarily tell us much about long-term changes in climate. One cold year, or even a few cold years in a row, does not contradict a long-term warming trend, even as one hot year does not prove it. (Figure source: adapted from Kunkel et al. 2013[1]).

B. Is the climate changing? How do we know?

Yes. The world has warmed over the last 150 years, and that warming has triggered many other changes to the Earth's climate. Evidence for a changing climate abounds, from the top of the atmosphere to the depths of the oceans. Changes in surface, atmospheric, and oceanic temperatures; melting glaciers, snow cover, and sea ice; rising sea level; and increase in atmospheric water vapor have been documented by hundreds of studies conducted by thousands of scientists around the world. Rainfall patterns and storms are changing and the occurrence of droughts is shifting.

Documenting climate change often begins with global average temperatures recorded near Earth's surface, where people live. But these temperatures, recorded by weather stations, are only one indicator of climate change. Additional evidence for a warming world comes from a wide range of consistent measurements of the Earth's climate system. It is the sum total of these indicators that lead to the conclusion that warming of our planet is unequivocal.

Ten Indicators of a Warming World

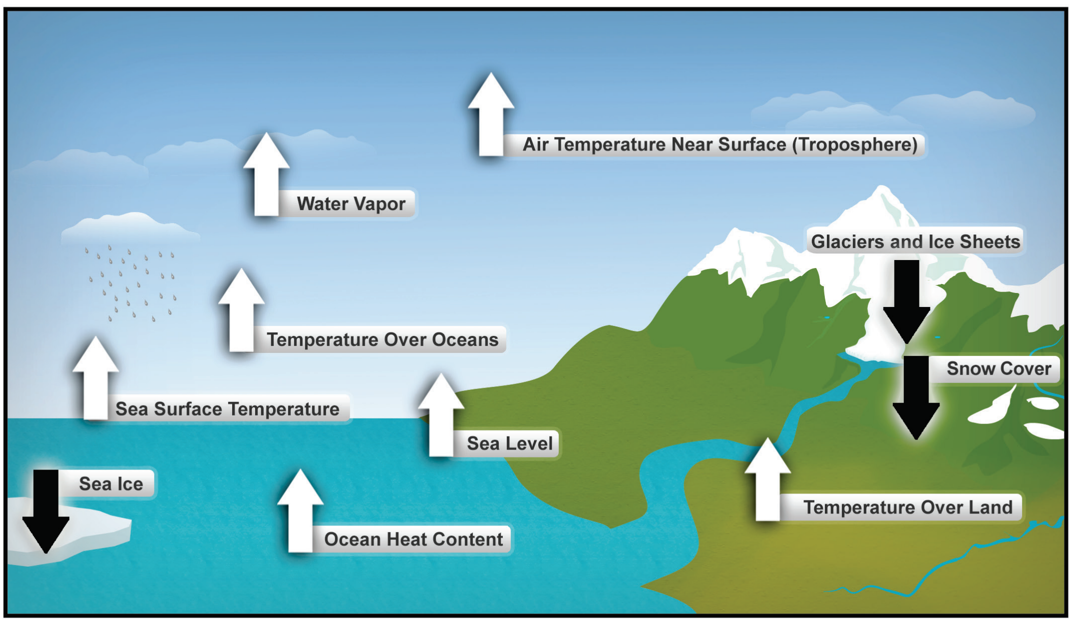

Figure 2: Ten Indicators of a Warming World

Caption: These are just some of the many indicators measured globally over many decades that demonstrate that the Earth's climate is warming. White arrows indicate increases, and black arrows show decreases. All the indicators expected to increase in a warming world are increasing, and all those expected to decrease in a warming world are decreasing. See Figure 3 for measurements showing these trends. (Figure source: NOAA NCDC; based on data updated from Kennedy et al. 2010[2]).

Evidence for a changing climate is not confined to the Earth's surface. Measurements by weather balloons and satellites consistently show that the temperature of the troposphere, the lowest layer of the atmosphere, has increased. The temperature of the upper atmosphere, particularly the stratosphere, has cooled, consistent with expectations of changes due to increasing concentrations of CO_2 and other greenhouse gases. The upper ocean has warmed, and more than 90% of the additional energy absorbed by the climate system since the 1960s has been stored in the oceans. As the oceans warm, seawater expands, causing sea level to rise.

As the troposphere warms, Arctic ice and glaciers melt, also causing sea level to rise. About 90% of the glaciers and land-based ice sheets worldwide are melting as the Earth warms, adding further to the sea level rise. Spring snow cover has decreased across the Northern Hemisphere since the 1950s. There have been substantial losses in sea ice in the Arctic Ocean, particularly at the end of summer when sea ice extent is at a minimum (See FAQ L for discussion of Antarctic sea ice).

Warmer air, on average, contains more water vapor. Globally, the amount of water vapor in the atmosphere has increased over the land and the oceans over the last half century. In turn, many parts of the planet have seen increases in heavy rainfall events.

All of these indicators and all of the independent data sets for each indicator unequivocally point to the same conclusion: from the ocean depths to the top of the troposphere, the world has warmed and the climate has reacted to that warming.

In summary, the evidence that climate is changing comes from a multitude of independent observations. The evidence that climate is changing because of human activity, as discussed in FAQ I and in more detail in Chapter 2 and the Climate Science Appendix, comes from observations, basic physics, and analyses from modeling studies.

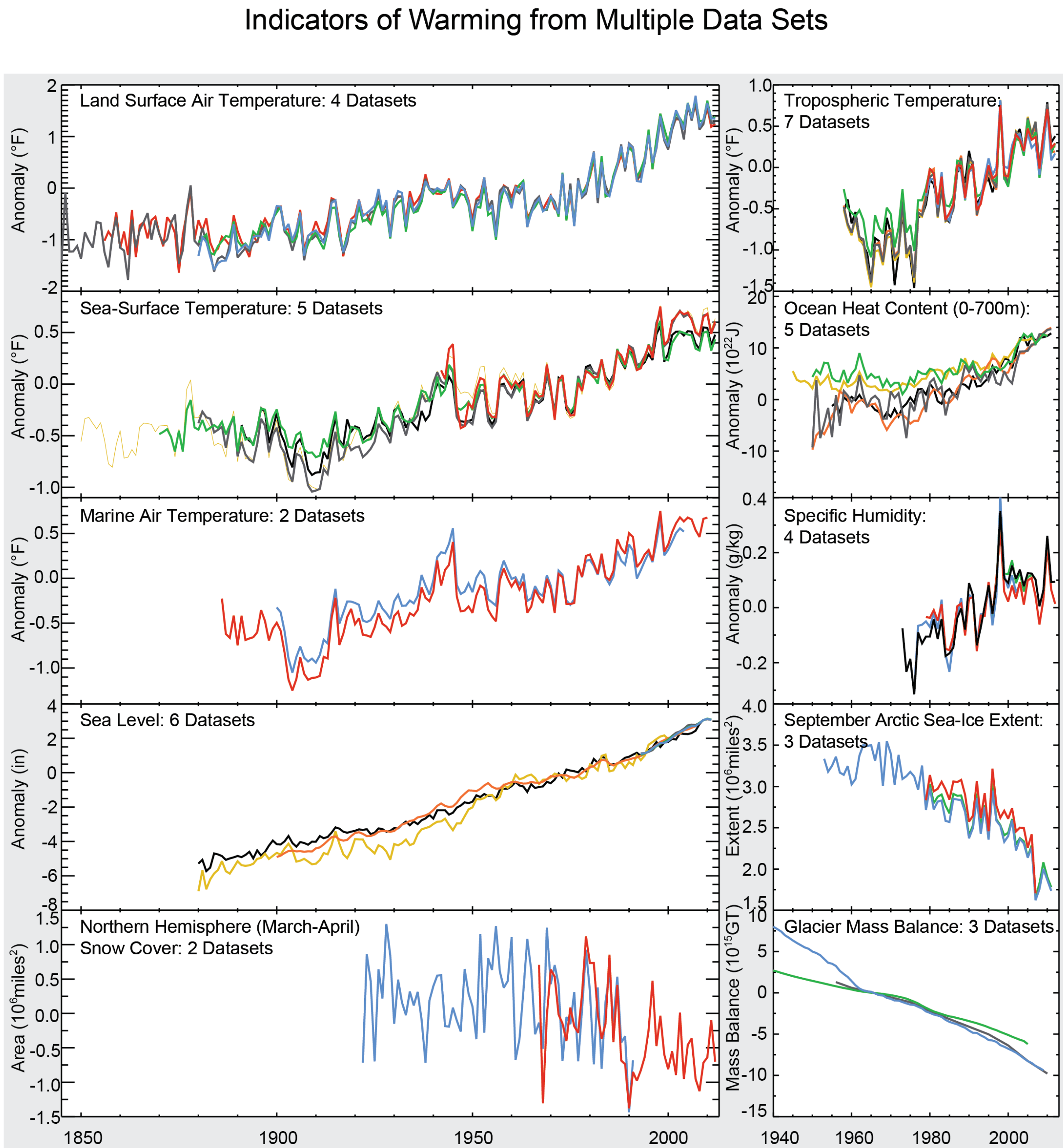

Figure 3: Indicators of Warming from Multiple Data Sets

Caption: This figure summarizes some of the many datasets documenting changes in the Earth's climate, all of which are consistent with a warming planet. In all figures except the lower two in the right column, data are plotted relative to averages over the period 1960-1999 (Figure source: updated from Kennedy et al. 2010[2]).

C. Climate is always changing. How is recent change different than in the past?

The Earth has experienced many large climate changes in the past. However, current changes in climate are unusual for two reasons: first, many lines of evidence demonstrate that these changes are primarily the result of human activities (see Question I for more info); and second, these changes are occurring (and are projected to continue to occur) faster than many past changes in the Earth's climate.

In the past, climate change was driven exclusively by natural factors: explosive volcanic eruptions that injected reflective particles into the upper atmosphere, changes in energy from the sun, periodic variations in the Earth's orbit, natural cycles that transfer heat between the ocean and the atmosphere, and slowly changing natural variations in heat-trapping gases in the atmosphere. All of these natural factors, and their interactions with each other, have altered global average temperature over periods ranging from months to thousands of years. For example, past glacial periods were initiated by shifts in the Earth's orbit, and then amplified by resulting decreases in atmospheric levels of carbon dioxide and subsequently by greater reflection of solar radiation by ice and snow as the Earth's climate system responded to a cooler climate. Some periods in the distant past were even warmer than what is expected to occur from human-induced global warming. But these changes in the distant past generally occurred much more slowly than current changes.

Natural factors are still affecting the planet's climate today. The difference is that, since the beginning of the Industrial Revolution, humans have been increasingly affecting global climate, to the point where we are now the primary cause of recent and projected future change.

Records from ice cores, tree rings, soil boreholes, and other forms of "natural thermometers," or "proxy" climate data, show that recent climate change is unusually rapid compared to past changes. After a glacial maximum, the Earth typically warms by about 7ºF to 13ºF over thousands of years (with periods of rapid warming alternating with periods of slower warming, and even cooling, during that time). The observed rate of warming over the last 50 years is about eight times faster than the average rate of warming from a glacial maximum to a warm interglacial period.

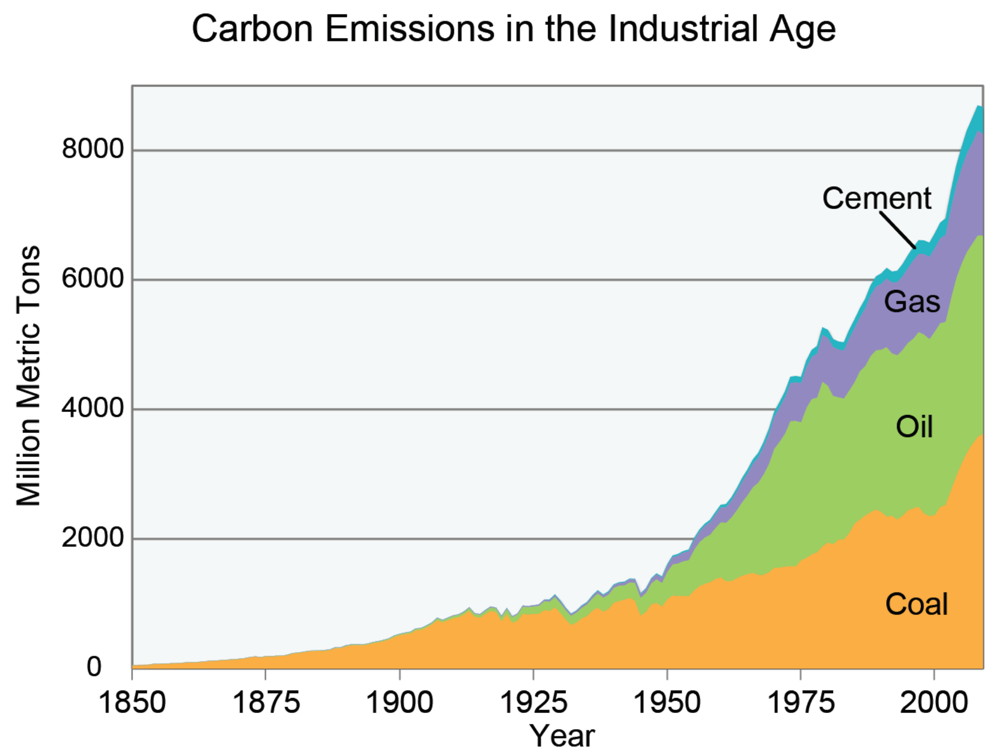

Figure 4: Carbon Emissions in the Industrial Age

Caption: Global carbon emissions from burning coal, oil, and gas and from producing cement (1850-2009). These emissions account for about 80% of the total emissions of carbon from human activities, with land-use changes (like cutting down forests) accounting for the other 20% in recent decades. (Data from Boden et al. 2012[3]).

Global temperatures over the last 100 years are unusually high when compared to temperatures over the last several thousand years. Atmospheric carbon dioxide levels are currently higher than any time in at least the last 800,000 years. Paleoclimate studies indicate that temperature and atmospheric carbon dioxide levels have been higher in the distant past, millions of years ago, when the world was very different than it is today. But never before have such rapid, global-scale changes occurred during the history of human civilization.

Our societies have not been built to withstand the changes that are anticipated in the relatively near future, and thus are not prepared for the effects they are already experiencing: higher temperatures, sea level rise, and other climate change-related impacts.

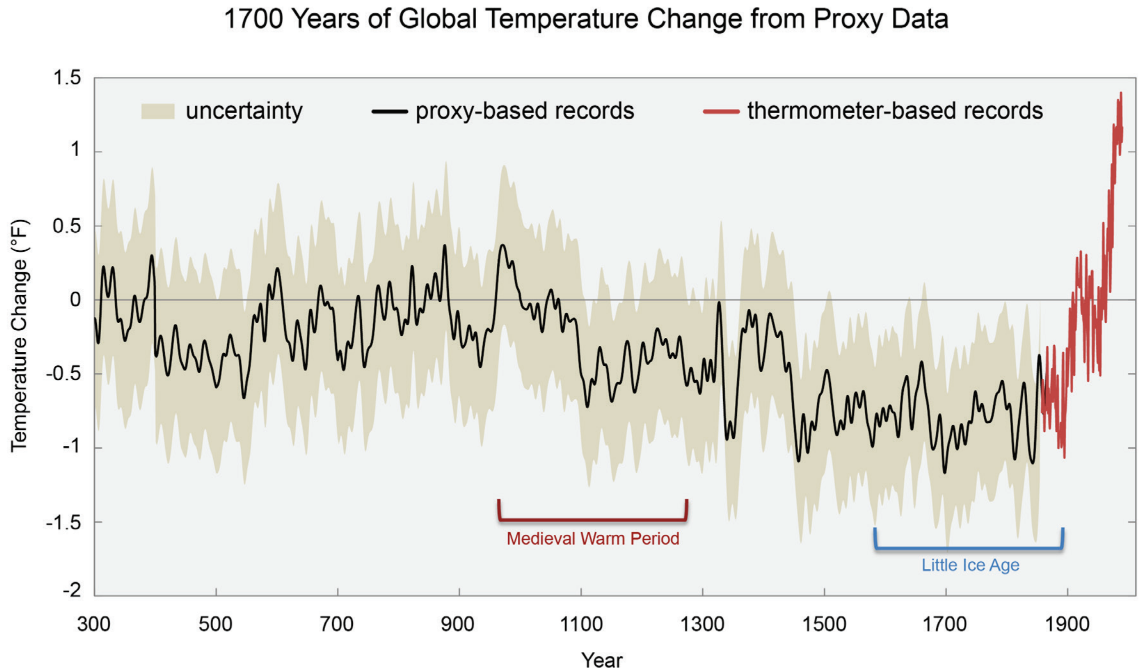

Figure 5: 1700 years of Global Temperature from Proxy Data

Caption: Changes in the temperature of the Northern Hemisphere from surface observations (in red) and from proxies (in black; uncertainty range represented by shading) relative to 1961-1990 average temperature. These analyses suggest that current temperatures are higher than seen globally in at least the last 1700 years, and that the last decade (2001 to 2010) was the warmest decade on record. (Figure source: adapted from Mann et al. 2008[4]).

D. Is the globally averaged surface air temperature still increasing? Isn't there recent evidence that it is actually cooling?

Global temperatures are still rising. Climate change is defined as a change in the average conditions over periods of 30 years or more (see FAQ A). On these time scales, global temperature continues to increase. Over shorter time scales, natural variability (due to the effects of El Niño and La Niña events in the Pacific Ocean, for example, or volcanic eruptions or changes in energy from the sun) can reduce the rate of warming or even create a temporary reduction in average surface air temperature. These short-term variations in no way negate the reality of long-term warming. The most recent decade was the warmest since instrumental record keeping began around 1880.

From 1970 to 2010, for example, global temperature trends taken at five-year intervals show both decreases and sharp increases. The five-year period from 2005 to 2010, for example, included a period in which the sun's output was at a low point, oceans took up more than average amounts of heat, and a series of small volcanoes exerted a cooling influence by adding small particles to the atmosphere. These natural factors are thought to have contributed to a recent slowdown in the rate of increase in average surface air temperature caused by the buildup of human-induced greenhouse gases. But while there has been a slowdown in the rate of increase, temperatures are still increasing.

In addition, satellite and ocean observations indicate that most of the increased energy in the Earth's climate system from the increasing levels of heat-trapping gases has gone into the oceans. These observations indicate that the Earth-atmosphere climate system has continued to gain heat energy.

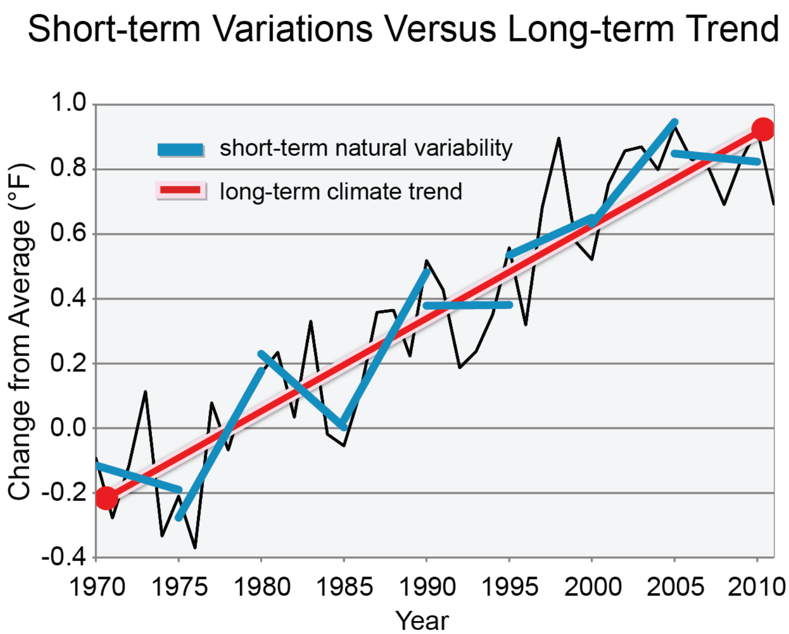

Figure 6: Short-term Variations Versus Long-term Trend

Caption: Short-term trends in global temperature (blue lines show temperature trends at five-year intervals from 1970 to 2010) can range from decreases to sharp increases. The evidence of climate change is based on long-term trends over 20-30 years or more (red line). (Data from NOAA NCDC).

In the U.S., there has been considerable decade-to-decade variability superimposed on the long-term warming trend. In most seasons and regions, the 1930s were relatively warm and the 1960s/1970s relatively cool. The most recent decade of the 2000s was the warmest on record throughout the U.S. and globally.

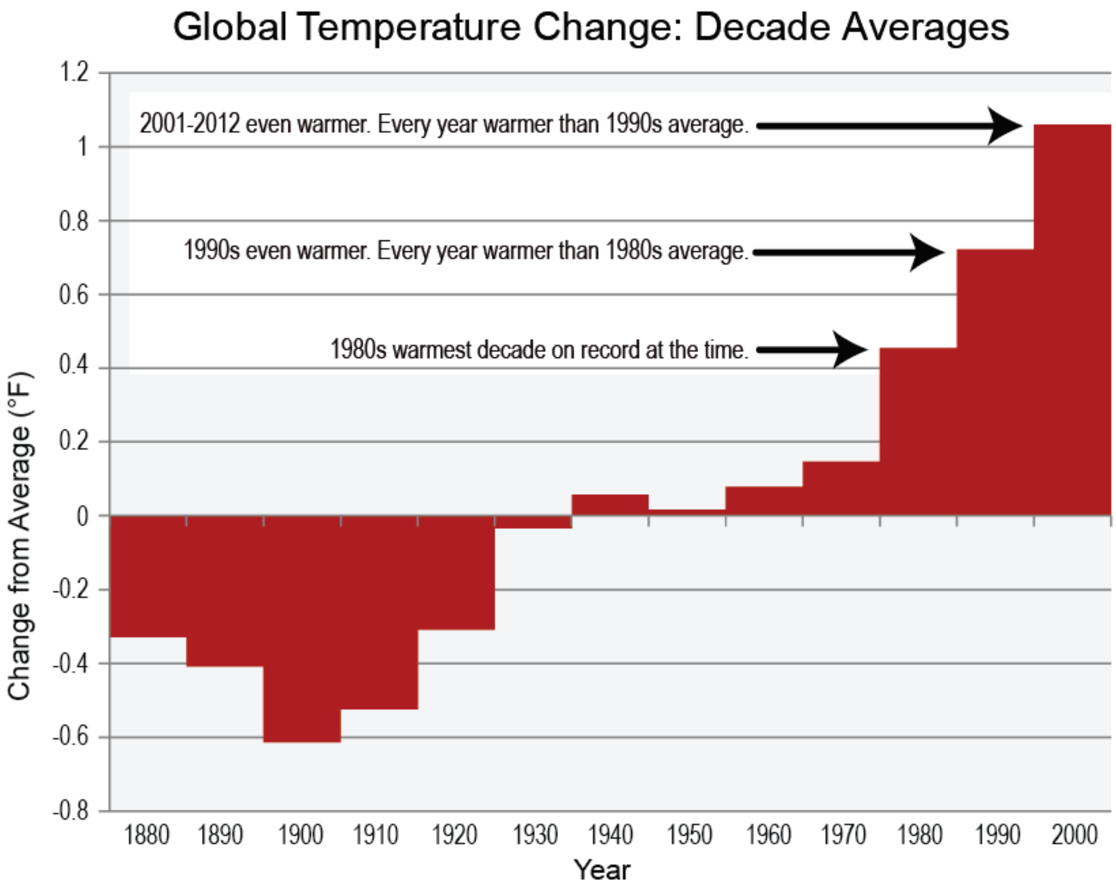

Figure 7: Global Temperature Change: Decade Averages

Caption: The last five decades have seen a progressive rise in Earth's average surface temperature. Bars show the difference between each decade's average temperature and the overall average for 1901 to 2000. The far right bar includes data for 2001-2012. (Figure source: NOAA NCDC).

E. Is it getting warmer at the same rate everywhere? Will the warming continue?

Temperatures are not increasing at the same rate everywhere, because temperature changes in a given location depend on many factors. However, average global temperatures are projected to continue increasing throughout the remainder of this century due to heat trapping gas emissions from human activities.

The planet is warming overall (see FAQ I), but some locations could be cooling due to local factors. Temperature changes in a given location are a function of multiple factors, including global and local forces, and both human and natural influences. In some places, including the U.S. Southeast, temperatures actually declined over the last century as a whole (although they have risen in recent decades). Possible causes of the observed lack of warming in the Southeast during the 20th century include increased cloud cover and precipitation,[5] increases in the presence of fine particles called aerosols in the atmosphere, (including those produced by burning fossil fuels and by natural sources), expanding forests in the Southeast over this period,[6] decreases in the amount of heat conducted from land to the atmosphere as a result of increases in irrigation,[7] and multi-decadal variability in sea surface temperatures in both the North Atlantic[8] and the tropical Pacific[9] oceans. At smaller geographic scales, and during certain time intervals, the relative influence of natural variations in climate compared to the human contribution is larger than at the global scale. An observed decrease in temperature at an individual location does not negate the fact that, overall, the planet is warming.

In terms of impacts, "global warming" is probably not the most immediate thing most people would notice. A changing climate affects our lives in many more obvious ways, for example, by increasing the risk of severe weather events such as heat waves, heavy precipitation events, strong hurricanes, and many other aspects of climate discussed throughout this report.

For these reasons, many scientists prefer the term "climate change," which connotes a much larger picture: broad changes in what are considered "normal" conditions. This term encompasses both increases and decreases in temperature, as well as shifts in precipitation, changing risk of certain types of severe weather events, and other features of the climate system.

At the global scale, some future years will be cooler than the preceding year; some decades could even be cooler than the preceding decade (though that has not happened for more than six decades; see Figure 7). Brief periods of faster temperature increases and also temporary decreases in global temperature can be expected to continue into the future. Nonetheless, each successive decade in the last 30 years has been the warmest in the period of reliable instrumental records (going back to 1850). Based on this historical record and plausible scenarios for future increases in heat-trapping gases, we expect that future global temperatures, averaged over climate timescales of 30 years or more, will be higher than preceding periods as a result of carbon dioxide and other heat-trapping gas emissions from human activities. A portion of the carbon dioxide emissions from human activities will remain in the atmosphere for hundreds of years, and continue to affect the global carbon cycle for thousands of years. Year-to-year projections of regional and local temperatures are more variable than global temperatures, and even at a particular location, future warming becomes increasingly likely over longer periods of time.[1]

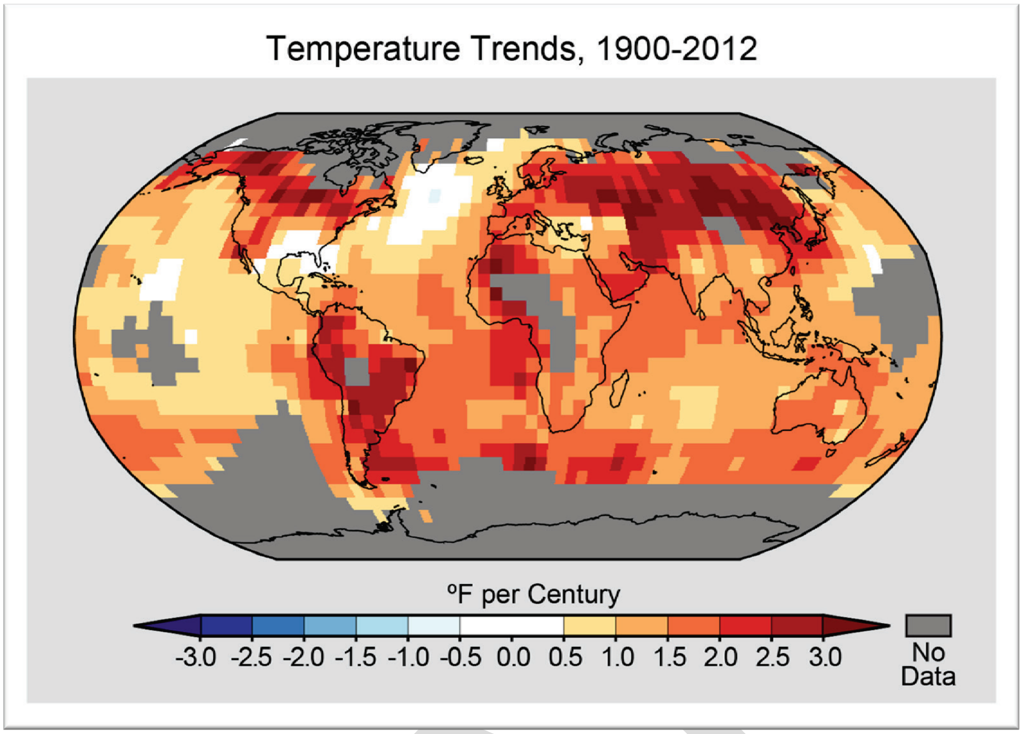

Figure 8: Temperature Trends, 1900-2012

Caption: Observed trend in temperature from 1900 to 2012; yellow to red indicates warming, while shades of blue indicate cooling. Grey indicates areas for which there are no data. There are substantial regional variations in trends across the planet, though the overall trend is warming. (Figure source: NOAA NCDC).

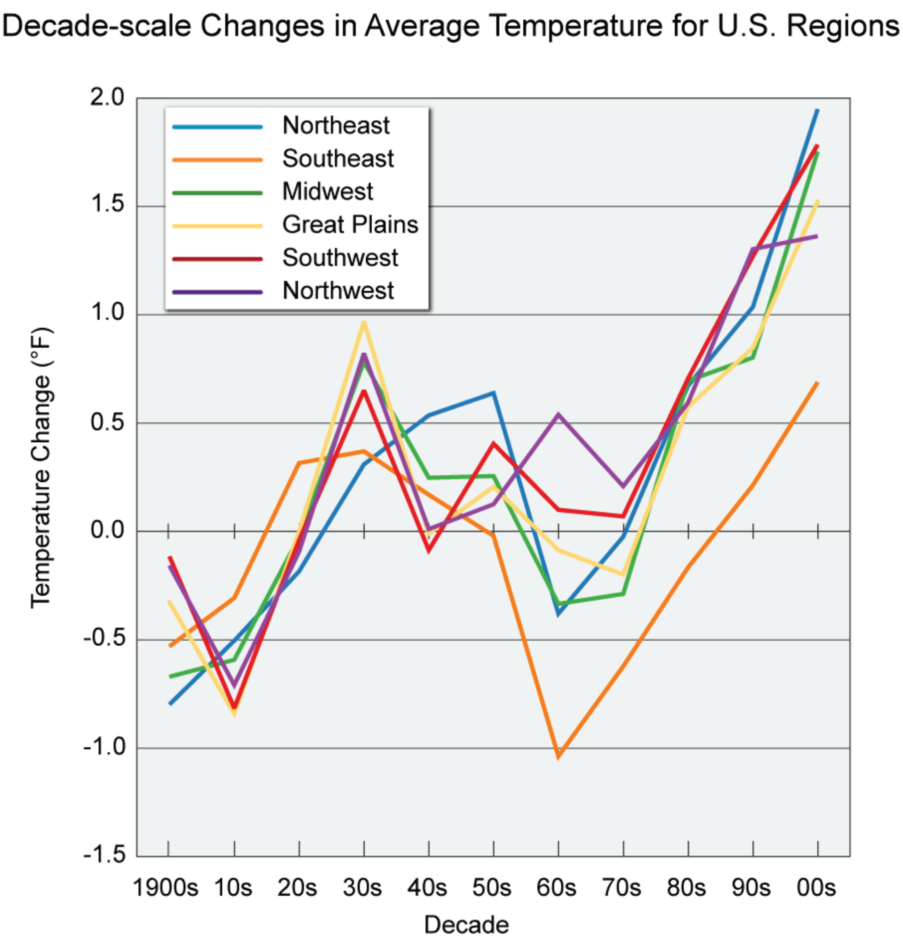

Figure 9: Decade-Scale Changes in Average Temperature for U.S. Regions

Caption: Change in decadal-averaged annual temperature relative to the 1901-1960 average for the six National Climate Assessment regions in the contiguous United States. This figure shows how regional temperatures can be much more variable than global temperatures, going up and down from decade to decade; all regions, however, show warming over the last two decades or more. In the figure, 00s refers to the 12-year period of 2001-2012. (Figure source: NOAA NCDC / CICS-NC).

F. How long have scientists been investigating human influences on climate?

The scientific basis for understanding how heat-trapping gases affect the Earth's climate dates back to the French scientist Joseph Fourier, who established the existence of the natural greenhouse effect in 1824. The heat-trapping abilities of greenhouse gases were corroborated by Irish scientist John Tyndall with experiments beginning in 1859. Since then, scientists have developed more tools to refine their understanding of human influences on climate, from the invention of the thermometer, to the development of computerized climate models, to the launching of Earth observing satellites that, together, provide global data coverage.

The greenhouse effect is caused by heat-trapping gases, such as water vapor, carbon dioxide, and methane, in the Earth's atmosphere. These gases are virtually transparent to the visible and ultraviolet wavelengths that comprise most of the sun's energy, allowing nearly all of it to reach Earth's surface. However, they are relatively opaque to the heat energy the Earth radiates back outward at infrared wavelengths. Other more abundant gases in the atmosphere like nitrogen and oxygen are largely transparent to the Earth's infrared energy. Greenhouse gases trap some of the Earth's energy inside the atmosphere and prevent it from escaping to space by absorbing and re-emitting that energy in all directions, rather than just upwards. Some of the trapped energy is re-radiated back down to the Earth's surface. This natural trapping effect makes the average temperature of the Earth nearly 60°F warmer than what it would be otherwise. On other planets, like Venus, where there are much higher concentrations of heat-trapping gases in the atmosphere, the greenhouse effect has a much stronger influence on surface temperature, making conditions far too hot for life as we know it.

By the late 1800s, scientists were aware that burning coal, oil, or natural gas produced carbon dioxide, a key heat-trapping gas. They were also aware that methane, another heat-trapping gas, was released during coal mining and other human activities. And they knew that, since the Industrial Revolution, humans were producing increasing amounts of these gases. It was clear that humans were increasing the natural greenhouse effect and that this would warm the planet.

In 1890, Svante Arrhenius, a Swedish chemist, calculated the effect of increasing fossil fuel use on global temperature. This climate model, computed by hand, took two years to complete. Arrhenius' results were remarkably similar to those produced by the most up-to-date global climate models today, although he did not anticipate that atmospheric levels of carbon dioxide would increase as quickly as they have.

In 1938, a British engineer, Guy Callendar, connected rising carbon dioxide levels to the observed increase in the Earth's temperature that had occurred to date. In 1958, Charles David Keeling began to precisely measure atmospheric levels of carbon dioxide in the relatively unpolluted location of Mauna Loa on Hawaiʻi. Today, those data provide a clear record of the effect of human activities on the chemical composition of the global atmosphere. Many more sources of data corroborate the work of these early pioneers in the field of climate science.

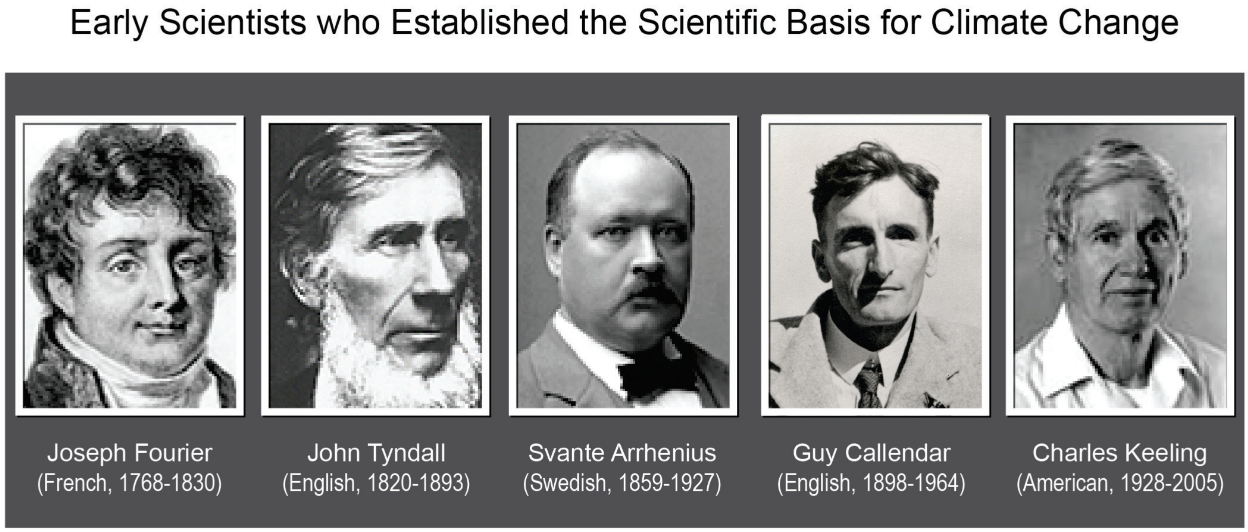

Figure 10: Early Scientists who Established the Scientific Basis for Climate Change

Caption: Scientists whose research was key to understanding the greenhouse effect and the impact of human activities on climate.

G. How can the small proportion of carbon dioxide in the atmosphere have such a large effect on our climate?

The reason why heat-trapping gases like carbon dioxide, methane, and nitrous oxide have such a powerful influence on Earth's climate is their potency: although they are transparent to visible and ultraviolet solar energy, allowing the sun's energy to come in, they are very strong absorbers of the Earth's infrared heat energy, blanketing the Earth and not allowing some of the energy to escape to space.

Before the Industrial Revolution, natural levels of carbon dioxide in the atmosphere averaged around 280 parts per million (ppm), that is, 280 molecules of CO_2 per million molecules of air (which is mostly nitrogen and oxygen). In other words, carbon dioxide made up about 0.028% of the volume of the atmosphere. Methane and nitrous oxide, other heat-trapping gases, made up even less, about 700 parts per billion (ppb) and 270 ppb, respectively. Over the last few centuries, emissions from human activities have increased carbon dioxide levels to about 400 ppm, or more than 3,000 billion tons – more than a 40% increase. Over the same time period, methane and nitrous oxide levels in the atmosphere have risen to around 1800 ppb and 320 ppb, respectively.

As the concentrations in the atmosphere of these heat-trapping gases increase due to human activities, they are absorbing greater and greater amounts of infrared heat energy emitted from the Earth's surface. As discussed in FAQ F, the gases then radiate some of this heat back to the surface, effectively trapping the heat inside the Earth's climate system and warming the Earth's surface.

These heat-trapping gases do not absorb energy equally across the infrared spectrum. Carbon dioxide absorption is very strong at certain wavelengths of infrared radiation, whereas water vapor absorbs more broadly across most of the spectrum. Water vapor is the most important naturally occurring heat-trapping greenhouse gas, but small increases in heat energy absorption by carbon dioxide and other heat-trapping gases trigger increases in water vapor that amplify the infrared trapping, leading to further warming. As a result, water vapor is considered a "feedback" rather than a direct forcing on climate.

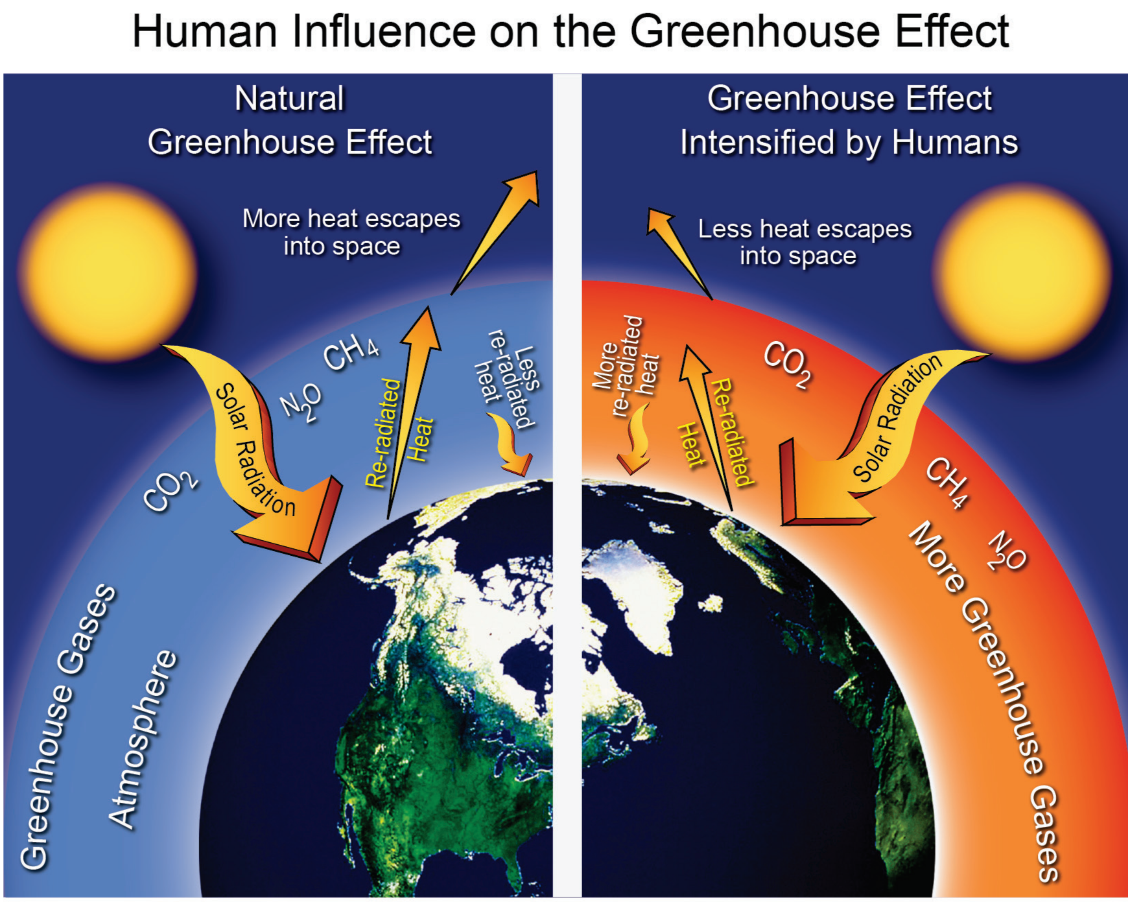

Figure 11: Human Influence on the Greenhouse Effect

Caption: (left) A stylized representation of the natural greenhouse effect. Most of the sun's radiation reaches the Earth's surface. Naturally occurring heat-trapping gases, including water vapor, carbon dioxide, methane, and nitrous oxide, do not absorb the short-wave energy from the sun but do absorb the long-wave energy re-radiated from the Earth, keeping the planet much warmer than it would be otherwise. (right) In this stylized representation of the human-intensified greenhouse effect, human activities, predominantly the burning of fossil fuels (coal, oil, and gas), are increasing levels of carbon dioxide and other heat-trapping gases, increasing the natural greenhouse effect and thus Earth's temperature. (Figure source: modified from National Park Service[10]).

H. Could the sun or other natural factors explain the observed warming of the past 50 years?

No. Since accurate satellite-based measurements of solar output began in 1978, the amount of the sun's energy reaching Earth has slightly decreased, which should, on its own, result in slightly lower temperatures; but the Earth's temperature has continued to rise. The sun can explain less than 10% of the increase in temperature since 1750, and none of the increase in temperature since 1960.

Patterns of vertical temperature change (from the Earth's surface to the upper atmosphere) provide further evidence that the sun cannot be responsible for the observed changes in climate. An increase in solar output would warm the atmosphere consistently from top to bottom. Warming from increasing heat-trapping gases, on the other hand, should be concentrated in the lower atmosphere (troposphere), while the upper atmosphere (stratosphere) would cool. Satellite measurements and weather balloon records reveal that the troposphere has warmed, and the stratosphere has cooled. This observed pattern of vertical temperature change matches what we would expect from the increase in heat-trapping gases, not that of the sun.

Changes in the sun's magnetic field are known to affect the intensity of cosmic rays reaching Earth's atmosphere and there is some suggestion that this could affect cloud formation; however, observations indicate that the magnitude of this effect is much smaller than the effects from the human-related changes in heat-trapping gases and from particle emissions on clouds and the changes in climate.

Large explosive volcanic eruptions can cool climate for a few years after an eruption, if the eruption is powerful enough to send particles far up into the atmosphere. In the atmosphere, sulfur dioxide from volcanoes is converted into sulfuric acid particles that can scatter sunlight, cooling the Earth's surface. Particles from exceptionally large eruptions like Pinatubo in 1991 or Krakatoa in 1883 can reach all the way into the stratosphere, where they can stay for several years. Eventually, they fall back into the troposphere where they are rapidly removed by precipitation. Volcanoes also emit carbon dioxide, but this amount is less than 1% annually of the emissions occurring from human activities.

Thus, natural factors cannot explain recent warming. In fact, observed solar and volcanic activity would have tended to slightly cool the Earth, and other natural variations are too small to account for the amount of warming over the last 50 years.

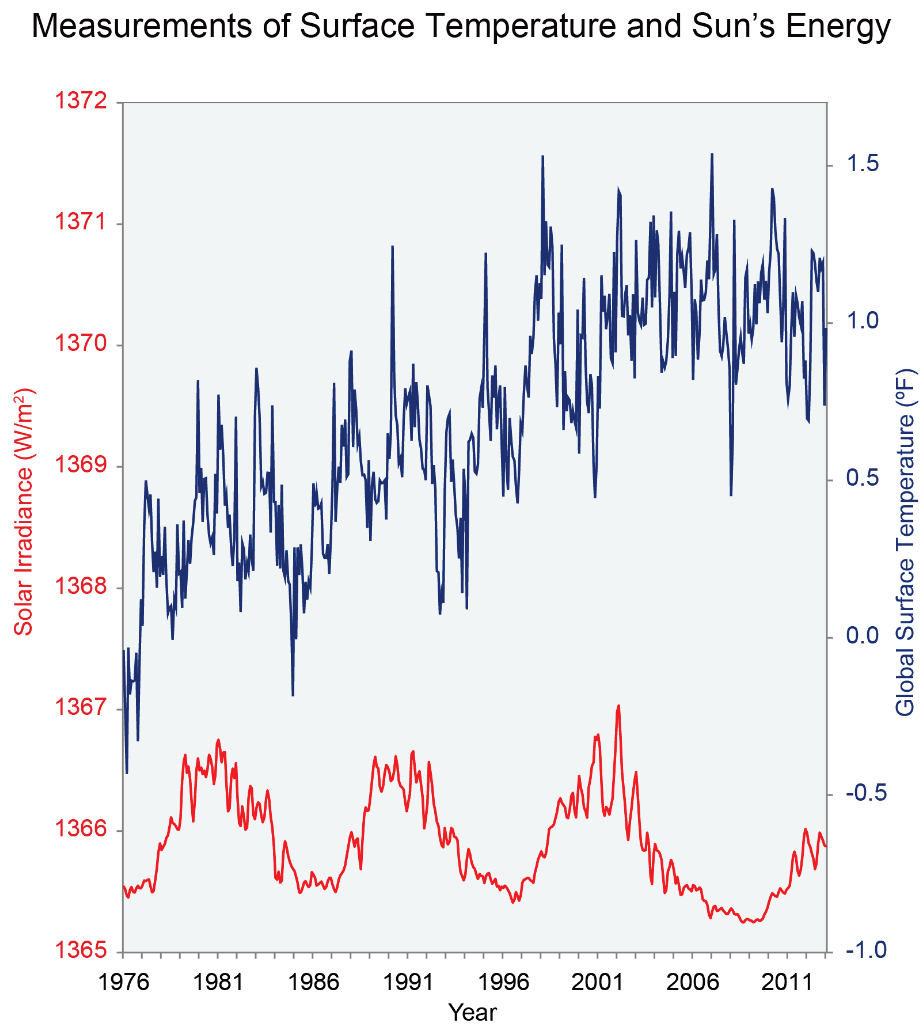

Figure 12: Measurements of Surface Temperature and Sun's Energy

Caption: Changes in the global surface temperature (top) and the solar flux (bottom) since 1900 (temperatures are relative to 1961-1990; solar flux is relative to the total average irradiance from the sun of about 1360 watts per square meter). The temperatures are based on thermometer observations of the Earth's surface temperature, while the solar flux at the top of Earth's atmosphere is based on satellite observations starting in 1978 and on proxy observations before then. (Figure source: NOAA NCDC / CICS-NC).

I. How do we know that human activities are the primary cause of recent climate change?

Many lines of evidence demonstrate that human activities are primarily responsible for recent climate changes. First, basic physics dictates that increasing the concentration of CO_2 and other heat-trapping gases in the atmosphere will cause the climate to warm. Second, modeling studies show that when human influences are removed from the equation, climate would actually have cooled slightly over the past half century. And third, the pattern of warming through the layers of atmosphere demonstrates that human-induced heat trapping gases are responsible, rather than some natural change.

Scientists are continually designing experiments to test whether observed climate changes are unusual and then to determine their causes. This field of study is known as "detection and attribution." Detection involves looking for evidence of changes or trends. Attribution attempts to identify the causes of these changes from a line-up of "suspects" that include changes in energy from the sun, powerful volcanic eruptions – and today, human-induced emissions of heat-trapping gases.

Detection and attribution analyses have confirmed that recent changes cannot have been caused either by internal climate system variations or by solar and volcanic influences (see FAQs C and H). Human influences on the climate system – including heat-trapping gas emissions, atmospheric particulates, land-use and land-cover change – are required to explain recent changes (see Figure 14).

Detection and attribution has been used to analyze the contribution of human influences to changes in global average conditions, in extreme events, and even in the change in risk of specific types of events, such as the 2003 European heat wave. Such analyses have found that it is virtually certain that observed changes in many aspects of the climate system are the result of influences of human activities. Scientific analyses also provide extensive evidence that the likelihood of some types of extreme events (such as heavy rains and heat waves) is now significantly higher due to human-induced climate change.

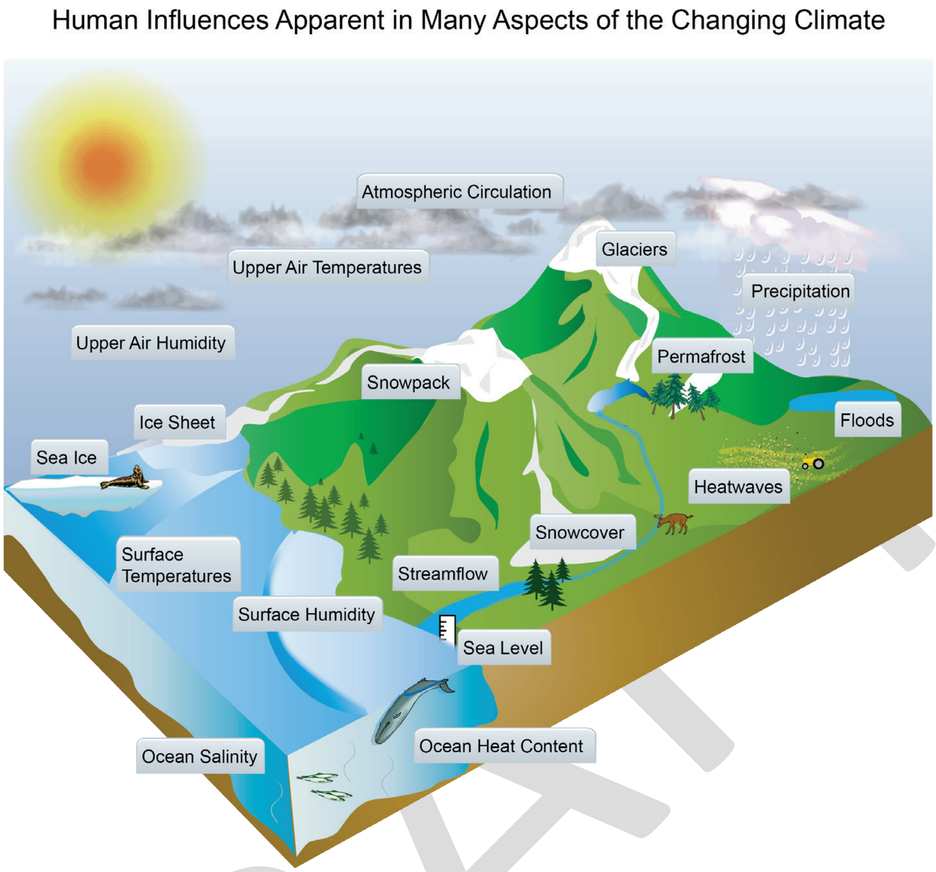

Figure 13: Human Influences Apparent in Many Aspects of the Changing Climate

Caption: Figure shows examples of the many aspects of the climate system in which changes have been formally attributed to human emissions of heat-trapping gases and particles by studies published in peer-reviewed science literature. For example, observed changes in surface air temperature at both the global and continental levels, particularly over the past 50 years or so, cannot be explained without including the effects of human activities. While there are undoubtedly many natural factors that have affected climate in the past and continue to do so today, human activities are the dominant contributor to recently observed climate changes. (Figure source: NOAA NCDC).

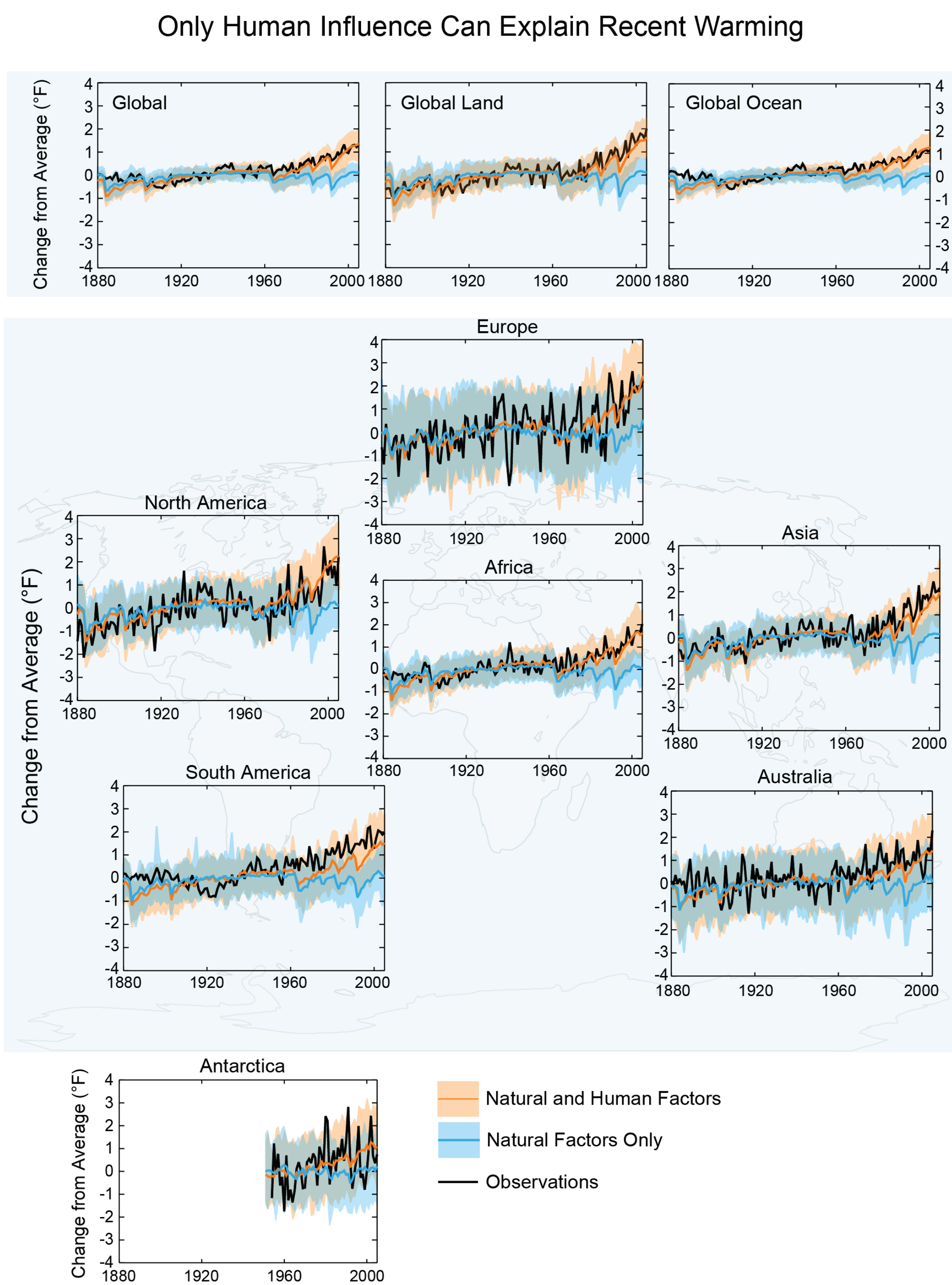

Figure 14: Only Human Influence Can Explain Recent Warming

Caption: Changes in surface air temperature at the continental and global scales can only be explained by the influence of human activities on climate. The black line depicts the annually averaged observed changes. The blue shading represents estimates from a broad range of climate simulations including solely natural (solar and volcanic) changes in forcing. The orange shading is from climate model simulations that include the effects of both natural and human contributions. These analyses demonstrate that the observed changes, both globally and on a continent-by-continent basis, are caused by the influence of human activities on climate. (Figure source: updated from Jones et al. 2013[11]).

J. What is and is not debated among climate scientists about climate change?

Multiple analyses of the peer-reviewed science literature have repeatedly shown that more than 97% of scientists in this field agree that the world is unequivocally warming and that human activity is the primary cause of the warming experienced over the past 50 years. Spirited debates on some details of climate science continue, but these fundamental conclusions are not in dispute.

The scientific method is built on scrutiny and debate among scientists. Scientists are rigorously trained to conduct experiments to test a question, or hypothesis, and submit their findings to the scrutiny of other experts in their field. Part of that scrutiny, known as "peer review," includes independent scientists examining the data, analysis methods, and findings of a study that has been submitted for publication. This peer review process provides quality assurance for scientific results, ensuring that anything published in a scientific journal has been reviewed and approved by other independent experts in the field, and that the authors of the original study have adequately responded to any criticisms or questions they received.

However, peer review is only the first step in the long process of acceptance of new ideas. After publication, other scientists will often undertake new studies that may support or reject the findings of the original study. Only after an exhaustive series of studies over many years, by many different research groups, are new ideas widely accepted.

Given that new scientific understanding emerges from this exhaustive process, the widespread agreement in the scientific community regarding the reality of climate change and the leading role of human activities in driving this change is striking. This consensus includes agreement on the fundamental scientific principles that underlie this phenomenon, as well as the weight of empirical evidence that has been accumulated over decades, and even centuries, of research (see FAQ F).

The conclusion that the world is warming, and that this is primarily due to human activity, is based on multiple lines of evidence, from basic physics to the patterns of change through the climate system (including the atmosphere, oceans, land, biosphere, and cryosphere). The warming of global climate and its causes are not matters of opinion; they are matters of scientific evidence, and that evidence is clear. Scientists do not "believe" in human-induced climate change; rather, the widespread agreement among scientists is based on the vast array of evidence that has accumulated over the last 200 years. When all of the evidence is considered, the conclusions are clear.

There is more work to be done to fully understand the many complex and interacting aspects of climate change, and important questions remain. Scientific debate continues on questions such as: Exactly how sensitive is the Earth's climate to human emissions of heat-trapping gases? How will climate change affect clouds? How will climate change affect snowstorms in Chicago, tornadoes in Oklahoma, and droughts in California? How do particle and soot emissions affect clouds? How will climate change be affected by changes in clouds and the oceans? These detailed questions and more serve as healthy indicators that the scientific method is alive and well in the field of climate science. But the fact that climate is changing, that this is primarily in response to human activities, and that climate will continue to change in response to these activities, is not in dispute (see FAQ I).

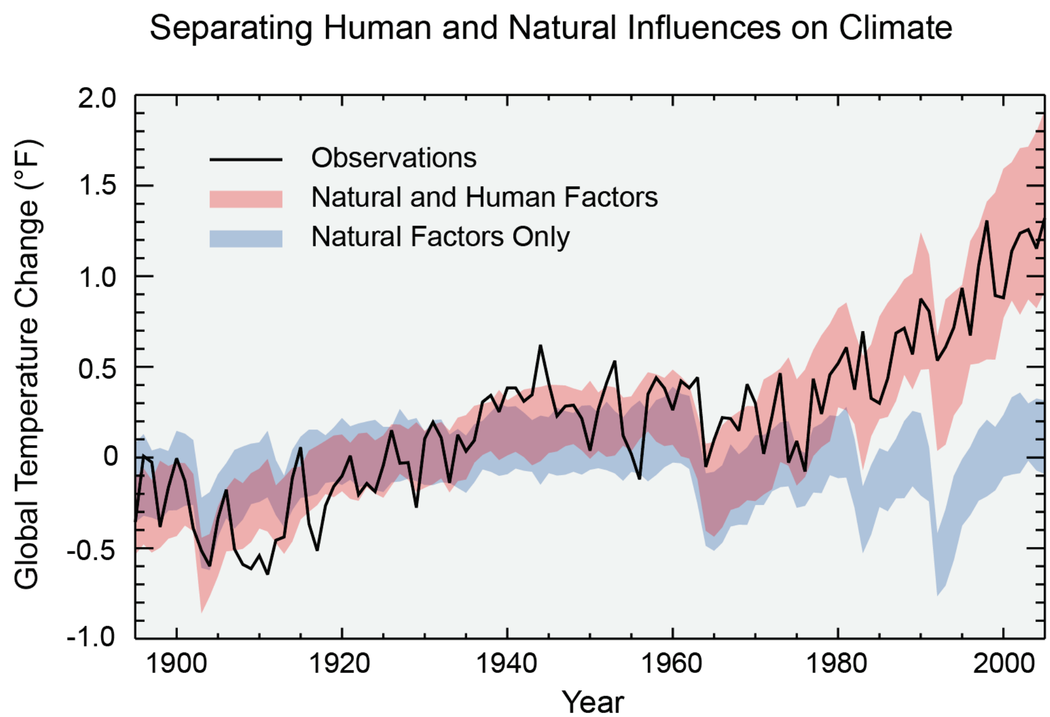

Figure 15: Separating Human and Natural Influences on Climate

Caption: The blue band shows how global average temperature would have changed due to natural forces only, as simulated by climate models. The red band shows model simulations of the effects of human and natural factors combined. The black line shows observed global average temperatures. As indicated by the blue band, without human influences, temperature over the past century would actually have cooled slightly over recent decades. The match up of the red band and the black line illustrate that only the inclusion of human factors can explain the recent warming. (Figure source: adapted from Huber and Knutti, 2012[12]).

K. Is the global surface temperature record good enough to determine whether climate is changing?

Yes. There have been a number of studies that have examined the U.S. and global temperature records in great detail. These have used a variety of methods to study the effects of changes in instruments, time of observations, station siting, and other potential sources of error. All studies reinforce high confidence in the reality of the observed upward trends in temperature.

Global surface temperatures are measured by weather stations over land, and by ships and buoys over the ocean. These records extend back regionally for over 300 years in some locations and near-globally to the late 1800s.

Scientists have undertaken painstaking efforts to obtain, digitize, and collate these records. Because of the way these measurements have been taken, many of the records contain results that are skewed by, for example, a change of instrument or a station move. It is essential to carefully examine the data to identify and adjust for such effects before the data can be used to evaluate climate trends.

A number of different research teams have taken up this challenge. Some have spent decades carefully analyzing the data and continually reassessing their approaches and refining their records. These independently produced estimates are in very good agreement at both global and regional scales.

Scientists have also considered other influences that could contaminate temperature records. For example, many thermometers are located in urban areas that could have warmed over time due to the urban heat island effect (in which heat absorbed by buildings and asphalt makes cities warmer than the surrounding countryside). At least three different research teams have examined how this might affect U.S. temperature trends. All have found that this effect is adequately accounted for by the data corrections. At the global scale, if all of the urban stations are removed from the global temperature record, the evidence of warming over the past 50 years remains intact. Other studies have shown that the temperature *trends* of rural and urban areas in close proximity essentially match, even though the urban areas may have higher temperatures overall.

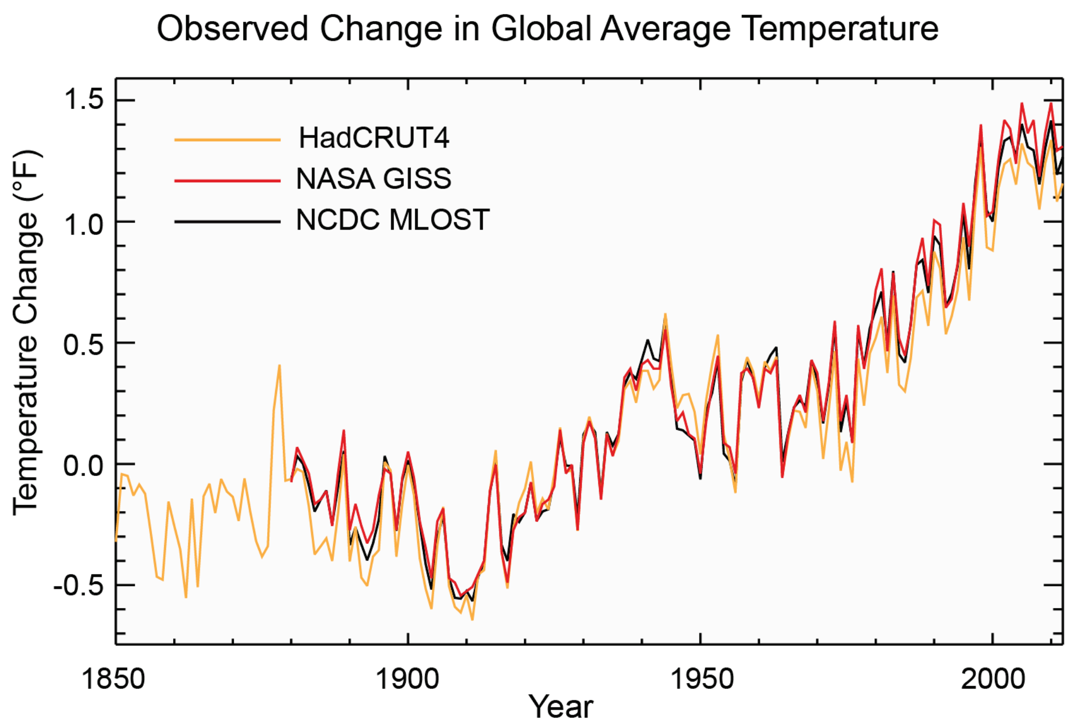

Figure 16: Observed Change in Global Average Temperature

Caption: Three different global surface temperature records all show increasing trends over the last century. The lines show annual differences in temperature relative to the 1901-1960 average. Differences among data sets, due to choices in data selection, analysis, and averaging techniques, do not affect the conclusion that global surface temperatures are increasing. (Figure source: NOAA NCDC / CICS-NC).

L. Is Antarctica gaining or losing ice? What about Greenland?

The ice sheets on both Greenland and Antarctica, the largest areas of land-based ice on the planet, are losing ice as the atmosphere and oceans warm. This ice loss is important both as evidence that the planet is warming, and because it contributes to rising sea levels.

One way that scientists are evaluating ice loss is by observing changes in the gravitational fields over Greenland and Antarctica. Fluctuations in the pull of gravity over these major ice sheets reflect the loss of ice over time. Over the last decade, the GRACE (Gravity Recovery and Climate Experiment) satellites have measured changes in the gravitational pull of the continents and revealed that, on the whole, both Greenland and Antarctica are losing ice. It is clear that these ice sheets are already losing mass as a result of human-induced climate change, and the evidence suggests that Greenland and Antarctica are likely to continue to lose ice mass for centuries. How rapidly the Greenland and Antarctic ice sheets will melt as warming continues represents the largest uncertainty in projections of future sea level rise.

Paleoclimate records show that the giant ice sheets of Greenland and Antarctica (as well as others, such as the Laurentide Ice Sheet that covered much of North America during the last glacial maximum) have expanded and contracted as the Earth cooled or warmed in the past. As temperature increases and precipitation patterns shift in response to human-induced climate change, scientists expect the ice sheets of Greenland and Antarctica to continue responding in a similar way. Over time horizons of hundreds to thousands of years, a general melting and reduction in the extent of both of these ice sheets is expected to occur in response to global warming. Over shorter time frames of years to decades, however, the response of these ice sheets is more complicated.

The Antarctic ice sheet is up to three miles deep and contains enough water to raise sea level about 200 feet. Because Antarctica is so cold, there is little melt of the ice sheet in the summer. However, the ice on the continent slowly flows down the mountains and through the valleys toward the ocean. Some parts of the ice sheet extend out into the ocean as “ice shelves.” Here, above-freezing ocean water speeds up the process called “calving” that breaks the ice into free floating icebergs. Melting and calving and the flow of ice into the oceans around Antarctica has accelerated in recent decades and is now contributing about 0.005 to 0.010 inches per year to sea level rise. It is possible that the West Antarctic Ice Sheet, which contains enough ice to raise global sea levels by 10 feet, could begin to lose ice much more quickly if ice shelves in the region begin to disintegrate at the edges.

Greenland contains only about one tenth as much ice as the Antarctic ice sheet, but if Greenland’s ice were to entirely melt, global sea level would rise 23 feet. Greenland is warmer than Antarctica, so unlike Antarctica, melting occurs over large parts of the surface of Greenland’s ice sheet each summer. Greenland’s melt area has increased over the past several decades. Satellite measurements indicate that the Greenland ice sheet is presently thinning at the edges (especially in the south) and slowly thickening in the interior, increasing the steepness of the ice sheet, which causes the ice to flow toward the ocean. Several of the major outlet glaciers that drain the Greenland ice sheet have sped up in the past decade. Recent scientific studies suggest that warming of the ocean at the edges of the outlet glaciers may contribute to this speed-up. Greenland’s ice loss has increased substantially in the past decade or two, and is now contributing 0.01 to 0.02 inches per year to sea level rise (about twice the rate of Antarctica’s mass loss). This increased rate of ice loss means that Greenland's contribution to global sea level rise is now similar to the effect from smaller glaciers worldwide and from Antarctica.

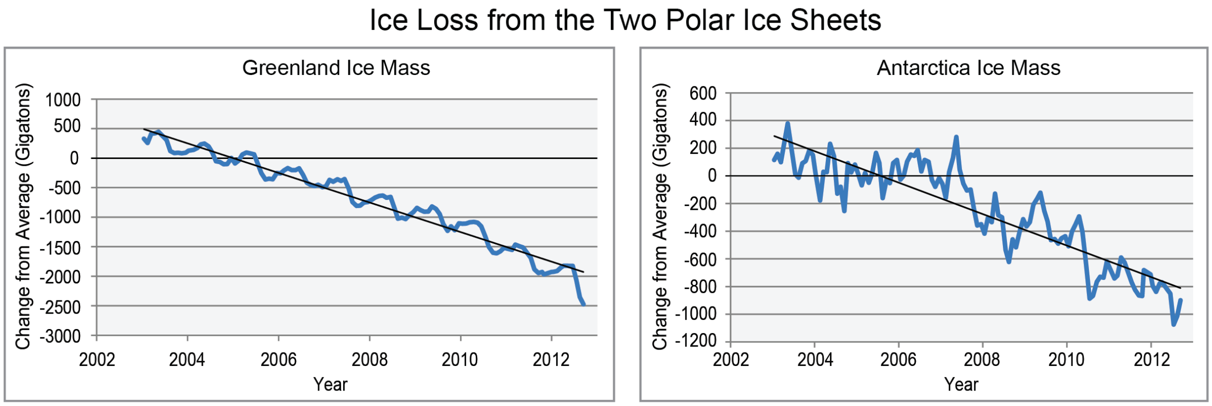

Figure 17: Ice Loss from the Two Polar Ice Sheets

Caption: GRACE (Gravity Recovery and Climate Experiment) satellite measurements show that both Greenland and Antarctica are, on the whole, losing ice as the atmosphere and oceans warm. (Figure source: adapted from Wouters et al. 2013[13]).

M. Weren't there predictions of global cooling in the 1970s?

No. An enduring myth about climate science is that in the 1970s the climate science community supposedly predicted "global cooling" and an "imminent" ice age. A review of the scientific literature shows that this was not the case. On the contrary, even then, discussions of human-related warming dominated scientific publications on climate and human influences.

Where did all the discussion about global cooling come from? First, temperature records from about 1940 to 1970 showed a slight global cooling trend, intensified by temporary increases in snow and ice cover across the Northern Hemisphere. Short-term natural variations in the Earth's climate (see FAQ A) and increasing emissions of sulfur and other particles from coal-burning power plants, which reflect solar energy and have a net cooling effect on the Earth, likely contributed to cooler temperatures during that time period. Several unusually severe winters in Asia and parts of North America in the 1970s raised people's concerns about cold weather. The popular press, including *Time*, *Newsweek*, and *The New York Times*, carried a number of articles about cooling at that time.

Second, climate scientists study both natural and human-induced changes in climate. Over the last century, scientists have learned a great deal about what drives Earth's ice ages. Scientific understanding of what are called the Milankovitch cycles (cyclical changes in the Earth's orbit that can explain the onset and ending of ice ages) led a few scientists in the 1970s to suggest that the current warm interglacial period might be ending soon, plunging the Earth into a new ice age over the next few centuries. Scientists continue to study this issue today; the latest information suggests that, if the Earth's climate were being controlled primarily by natural factors, the next cooling cycle would begin sometime in the next 1,500 years. However, humans have so altered the composition of the atmosphere that the next glaciation has now been delayed.

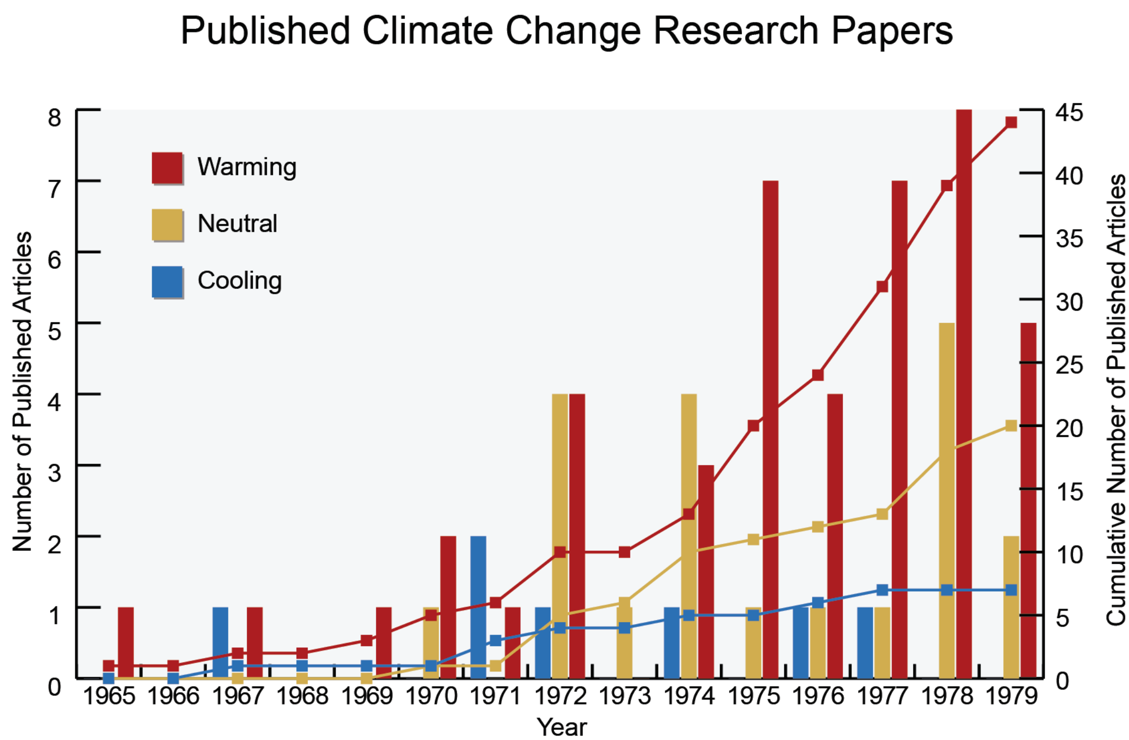

Figure 18: Published Climate Change Research Papers

Caption: The number of papers classified as predicting, implying, or providing supporting evidence for future global cooling, warming, and neutral categories. Bars indicate number of articles published per year. Squares indicate cumulative number of articles published. For the period 1965 through 1979, the literature survey found seven papers suggesting further cooling, 20 neutral, and 44 warming. Even in the early years of the study of climate change, more science studies were discussing concerns about global warming than global cooling. (Figure source: Peterson et al. 2008[14]).

N. How is climate projected to change in the future?

Climate is projected to continue to warm, with the amount of future warming ranging from another 3ºF to another 12ºF by 2100, depending primarily on the level of emissions from human activities, principally the burning of fossil fuels. For precipitation, wet areas are generally projected to get wetter while dry areas get drier. More precipitation is expected to fall in heavy downpours. Natural variability will still play a role in year-to-year changes. Details follow.

Future climate cannot be "predicted" because human activities are currently the most important driver of climate change and we cannot predict what society will choose to do with regard to emissions. Rather, we can *project* the climate change that would result from a given set of assumptions, or future scenarios, regarding human activities (including changes in population, technology, economics, energy, and policy). Future changes also have some uncertainty due to natural variability, particularly over shorter time scales (see FAQ A) and limitations in scientific understanding of exactly how the climate system will respond to human activities (see FAQ S).

The relative importance of these three sources of uncertainty changes over time. Which type of uncertainty is most important also depends on what type of change is being projected: whether, for example, it is for average conditions or extremes, or for temperature or precipitation trends (see FAQ S).

Over the next few decades, global average temperature over 30-year climate timescales is expected to continue to increase (see FAQ D), while natural variability still plays a significant role in year-to-year changes (see FAQ A). The amount of climate change expected over this time period is unlikely to be significantly altered by reducing current heat-trapping gas emissions alone or even by stabilizing atmospheric levels of carbon dioxide and other gases. This is because near-term warming will be caused primarily by emissions that have already occurred, due to the lag in the temperature response to changes in atmospheric composition. This lag is primarily the result of the very large heat storage capacity of the world's oceans and the length of time required for that heat to be transferred to the deep ocean. At smaller geographical scales, temperatures are projected to increase in most regions in the next few decades, but a few regions could experience flat or even decreasing temperatures. Any climate change always represents the net effect of multiple global and local factors, both human-related and natural (see FAQ E).

Beyond the middle of this century, global and regional temperature will be determined primarily by the rate and amount of various emissions released by human activities, as well as by the response of the Earth's climate system to those emissions. Efforts to rapidly and significantly reduce emissions of heat-trapping gases can still limit the global temperature increase to 3.6ºF (2ºC) relative to the 1901-1960 time period. However, significantly greater temperature increases are expected if emissions follow higher scenarios associated with continuing growth in the use of fossil fuels; in that case, the increase in U.S. average air temperature is likely to exceed 11ºF by the end of this century. This amount of temperature increase would reshape human societies in ways that are almost unthinkable to us today.

Precipitation patterns are also expected to continue to change throughout this century and beyond. In general, wet areas are projected to get wetter and dry areas, drier. In some areas, located in between wetter and drier areas, the total amount of precipitation falling over the course of a year is not expected to significantly change. Following the observed trends over recent decades, more precipitation is expected to fall as heavier precipitation events. In many midlatitude regions, including the U.S., there will be fewer days with precipitation but the wettest days will be wetter. Large-scale shifts towards wetter or drier conditions and the projected increases in heavy precipitation are expected to be greater under higher emissions scenarios as compared to lower ones.

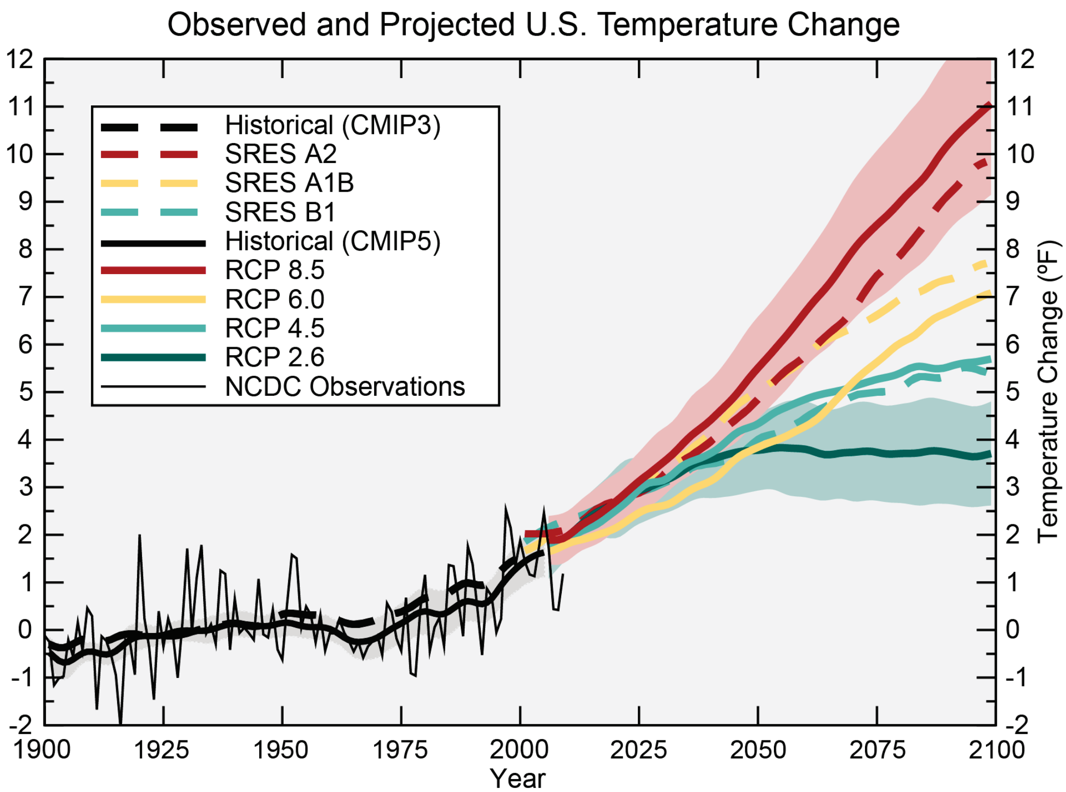

Figure 19: Observed and Projected U.S. Temperature Change

Caption: Projected average annual temperature changes over the contiguous U.S. for multiple future scenarios relative to the 1901-1960 average temperature. The dashed lines are results from the previous generation of climate models and scenarios, while solid lines show the most recent generation of climate model simulations and scenarios. Changes in temperature over the U.S. are expected to be higher than the change in global average temperatures (Figure 24). Differences in these projections are principally a result of differences in the scenarios. (Data from CMIP3, CMIP5, and NOAA NCDC).

O. Does climate change affect severe weather?

Yes, climate change can and has altered the risk of certain types of extreme weather events. The harmful effects of severe weather raise concerns about how the risk of such events might be altered by climate change. An unusually warm month, a major flood or a drought, a series of intense rainstorms, an active tornado season, landfall of a major hurricane, a big snowstorm, or an unusually severe winter inevitably lead to questions about possible connections to climate change.

For example, more extreme high temperatures and fewer extreme cold temperatures occur in a warmer climate (although extreme cold events can and do still occur – just less frequently). In the U.S., more than twice as many high temperature records as compared to low temperature records were broken in the period of 2001-2012.

Also, in many areas, heavy rainfall events have already, and will continue to become more frequent and severe as climate continues to change. The intensity and rainfall rates of Atlantic hurricanes are projected to increase, with the strongest storms getting stronger. Recent research has shown how climate change can alter atmospheric circulation and weather patterns such as the jet stream, affecting the location, frequency, and duration of these and other extremes. While there have always been extreme events due to natural causes, scientific evidence indicates that the probability and severity of some types of events has increased due to climate change.

For other types of extreme weather events important to the U.S., such as tornadoes and severe thunderstorms, more research is needed to understand how climate change will affect them. These events occur over much smaller scales, which makes observations and modeling more challenging. Projecting the future influence of climate change on these events can also be complicated by the fact that some of the risk factors for these events may increase with climate change, while others may decrease.

P. How are the oceans affected by climate change?

The oceans cover more than two-thirds of the Earth's surface and play a very important role in regulating the Earth's climate and in climate change. Today, the world's oceans absorb more than 90% of the heat trapped by increasing levels of carbon dioxide and other greenhouse gases in the atmosphere due to human activities. This extra energy warms the ocean, causing it to expand. This in turn causes sea level to rise. Of the global rise in sea level observed over the last 35 years, about 40% is due to this warming of the water. Most of the rest is due to the melting of glaciers and ice sheets. Ocean levels are projected to rise another 1 to 4 feet over this century, with the precise number largely depending on the amount of global temperature rise and polar ice sheet melt.

Observations from past climate combined with climate model projections of the future suggest that over the next 100 years the Atlantic Ocean's overturning circulation (known as the "Ocean Conveyor Belt") could slow down as a result of climate change. These ocean currents carry warm water northward across the equator in the Atlantic Ocean, warming the North Atlantic (and Europe) and cooling the South Atlantic. A slowdown of the Conveyor Belt would increase regional sea level rise along the east coast of the United States and change patterns of temperature in Europe and rainfall in Africa and the Americas, but would not lead to global cooling.

Warming ocean waters also affect marine ecosystems like coral reefs, which can be very sensitive to temperature changes. When water temperatures become too high, coral expel the algae (called zooxanthellae) which help nourish them and give them their vibrant color. This is known as coral bleaching. If the high temperatures persist, the coral die.

In addition to the warming, the acidity of seawater is increasing as a direct result of increasing atmospheric carbon dioxide (see FAQ Q). The oceans are now absorbing about 30% of the carbon dioxide produced by human activities every year. The dissolved carbon dioxide reacts with seawater to form carbonic acid, which makes the water more acidic, making it more difficult for shellfish, corals, and other living things to grow their shells or skeletons. Both the increased acidity and higher temperature of the oceans are expected to negatively affect corals and other living things over the coming decades and beyond.

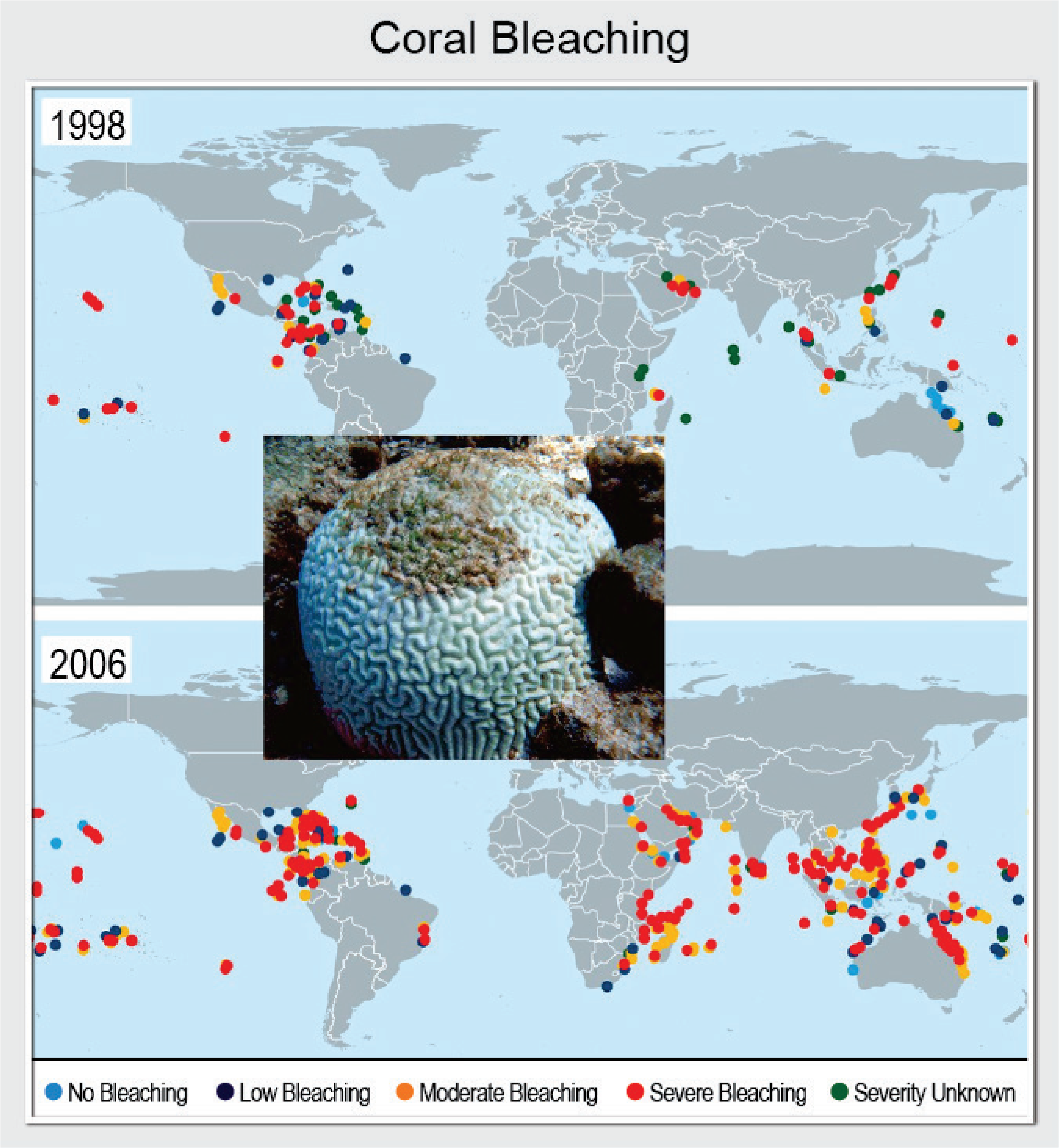

Figure 21: Coral Bleaching

Caption: (Insert) Bleached brain coral (Photo credit: NOAA); (Maps) The global extent and severity of mass coral bleaching have increased worldwide over the last decade. Red dots indicate severe bleaching. (Figure source: Marshall and Schuttenberg 2006[15]; Photo credit: NOAA).

Q. What is ocean acidification?

As human-induced emissions of carbon dioxide build up in the atmosphere, excess carbon dioxide dissolves into the oceans, where it reacts with seawater to form carbonic acid, which makes ocean waters more acidic and corrosive. These changes to ocean chemistry can affect many living things, and possibly the entire food web.

Dissolved calcium and carbonate ions are the building blocks for the skeletons and shells of many living things in the oceans. Ocean acidification lowers the availability of carbonate ions in many parts of the ocean, affecting the ability of some marine life to produce and maintain their shells.

Since the beginning of the Industrial Revolution, the pH of surface ocean waters has fallen by 0.1 pH units, representing approximately a 30% increase in acidity. The oceans will continue to absorb carbon dioxide produced by human activities and become even more acidic in the future. Projections of carbon dioxide levels indicate that by the end of this century the surface waters of the ocean could be as much as 150% more acidic, resulting in a pH that the oceans haven't experienced for more than 20 million years and effectively transforming marine life as we know it.

Ocean acidification is expected to affect ocean species to varying degrees. Some photosynthetic algae and seagrass species may benefit from higher CO_2 conditions in the ocean, as they require CO_2 to live, as do plants on land. On the other hand, studies have shown that a more acidic environment has dramatic negative effects on some calcifying species, including pteropods, oysters, clams, sea urchins, shallow water corals, deep sea corals, and calcareous plankton. When shelled species are at risk, the entire food web may also be at risk.

Ocean Acidification and the Food Web

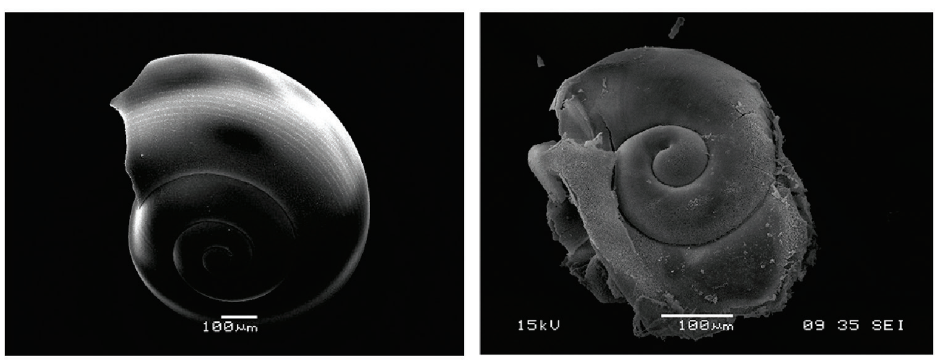

Figure 22: Ocean Acidification and the Food Web

Caption: Pteropods, or "sea butterflies," are sea creatures about the size of a small pea. Pteropods are eaten by organisms ranging in size from tiny krill to whales, and are an important source of food for North Pacific juvenile salmon. The photos above show what happens to a pteropod's shell when it encounters seawater that is too acidic. The left panel shows a shell collected from a live pteropod from a region in the Southern Ocean where acidity is not too high. The shell on the right is from a pteropod collected in a region with higher acidity (Photo credits: (left) Bednaršek et al. 2012;[16] (right) Nina Bednaršek).

R. How reliable are the computer models of the Earth's climate?

Climate models are used to analyze past changes in the long-term averages and variations in temperature, precipitation, and other climate indicators, and to make projections of how these trends may change in the future. Today's climate models do a good job at reproducing the broad features of the present climate and changes in climate, including the significant warming that has occurred over the last 50 years. Hence, climate models can be useful tools for testing the effects of changes in the factors that drive changes in climate, including heat-trapping gases, particulates from human and volcanic sources, and solar variability.

Scientists have amassed a vast body of knowledge regarding the physical world. Unlike many areas of science, however, scientists who study the Earth's climate cannot build a "control Earth" and conduct experiments on this Earth in a lab. To experiment with the Earth, scientists instead use this accumulated knowledge to build climate models, or "virtual Earths." In studying climate change, these virtual Earths serve as an important way to integrate different kinds of knowledge of how the climate system works. These models can be used to test scientific understanding of the response of the Earth's climate to past changes (such as the transition from the last glacial maximum to our current warm interglacial period) as well as to develop projections of future changes (such as the response of the Earth's climate to human activities).

Climate models are based on mathematical and physical equations representing the fundamental laws of nature and the many processes that affect the Earth's climate system. When the atmosphere, land, and ocean are divided up into small grid cells and these equations are applied to each grid cell, the models can capture the evolving patterns of atmospheric pressures, winds, temperatures, and precipitation. Over longer timeframes, these models simulate wind patterns, high and low pressure systems, and other weather characteristics that make up climate.

Some important physical processes are represented by approximate relationships because the processes are not fully understood, or they are at a scale that a model cannot directly represent. Examples include clouds, convection, and turbulent mixing of the atmosphere, for which important processes are much smaller than the resolution of current models. These approximations lead to uncertainties in model simulations in climate.

Climate models require enormous computing resources, especially to capture the geographical details of climate. Today's most powerful supercomputers are enabling climate scientists to more thoroughly examine effects of climate change in ways that were impossible just five years ago. Over the next decade, computer speeds are predicted to increase another 100 fold or more, permitting even more details of the climate system to be explored.

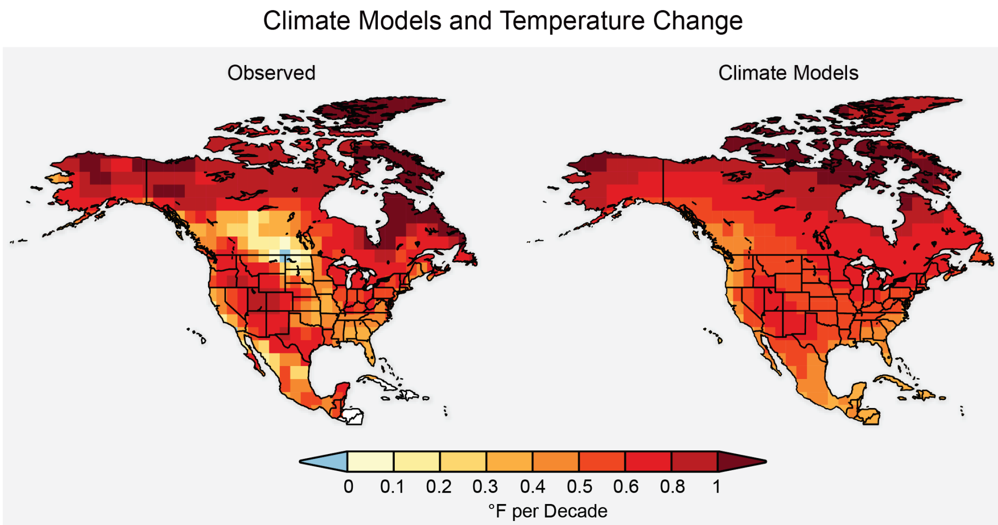

Figure 23: Climate Models and Temperature Change

Caption: The large-scale geographical patterns and approximate magnitude of the surface air temperature trend from 1980 to 2005 from observational data (left) is approximately captured by computer models of the climate system (right). The pattern from the computer models is an average based on 43 different global climate models (CMIP5) used in the IPCC's Fifth Assessment Report. The observations are a combination of both the human contribution to recent warming as well as the natural temperature variations. Averaging these model simulations suppresses the natural variations showing mainly the human contribution, which is the reason that the smaller scale details are different between the two maps. (Figure source: NOAA NCDC / CICS-NC).

S. What are the key uncertainties about climate change?

Available evidence gives scientists confidence that humans are having a significant effect on climate and will continue to do so over this century and beyond. In particular, continued use of fossil fuels and resulting emissions will significantly alter climate and lead to a much warmer world. Of course, it is impossible to predict the future with absolute certainty. The precise amount of future climate change that will occur over the rest of this century is uncertain due to several reasons.

First, projections of future climate changes are usually based on scenarios (or sets of assumptions) regarding how future emissions may change as a result of population, energy, technology, and economics. Society may choose to reduce emissions, or to continue to increase them. The differences in projected future climate under different scenarios are generally small for the next few decades. By the second half of the century, however, human choices, as reflected in these scenarios, become the key determinant of future climate change. And human choices are nearly impossible to predict.

A second source of uncertainty is natural variability, which affects climate over timescales from months to decades. These natural variations are largely unpredictable and are superimposed on the warming from increasing heat-trapping gases. Uncertainty in the sun's future output is another source of variability that is independent of human actions. Estimates of past changes in solar variability over the last several millennia suggest that the magnitude of solar effects over this century are likely to be small compared to the magnitude of the climate change effects projected from human activities.

A third source of uncertainty involves limitations to our current scientific knowledge. The Earth's climate system is complex, and continues to challenge scientists' understanding of exactly how it may respond to human influences. Observations of the climate system have expanded substantially since the beginning of the satellite era, but are still limited. Climate models differ in the way they represent various processes (for example, cloud properties, ocean circulation, and turbulent mixing of air). As a result, different models produce slightly different projections of change, even when the models use the same scenarios. Scientists often use multiple models in order to incorporate this range of results.

Finally, there is always the possibility that there are processes and feedbacks not yet being included in future projections. For example, as the Arctic warms, carbon trapped in permafrost may be released into the atmosphere, increasing the initial warming due to human emissions of heat-trapping gases (see FAQ T).

However, for a given future scenario, the amount of future climate change can be specified within plausible bounds, determined not only from the differences in the "climate sensitivity" among models but also from information about climate changes in the past.

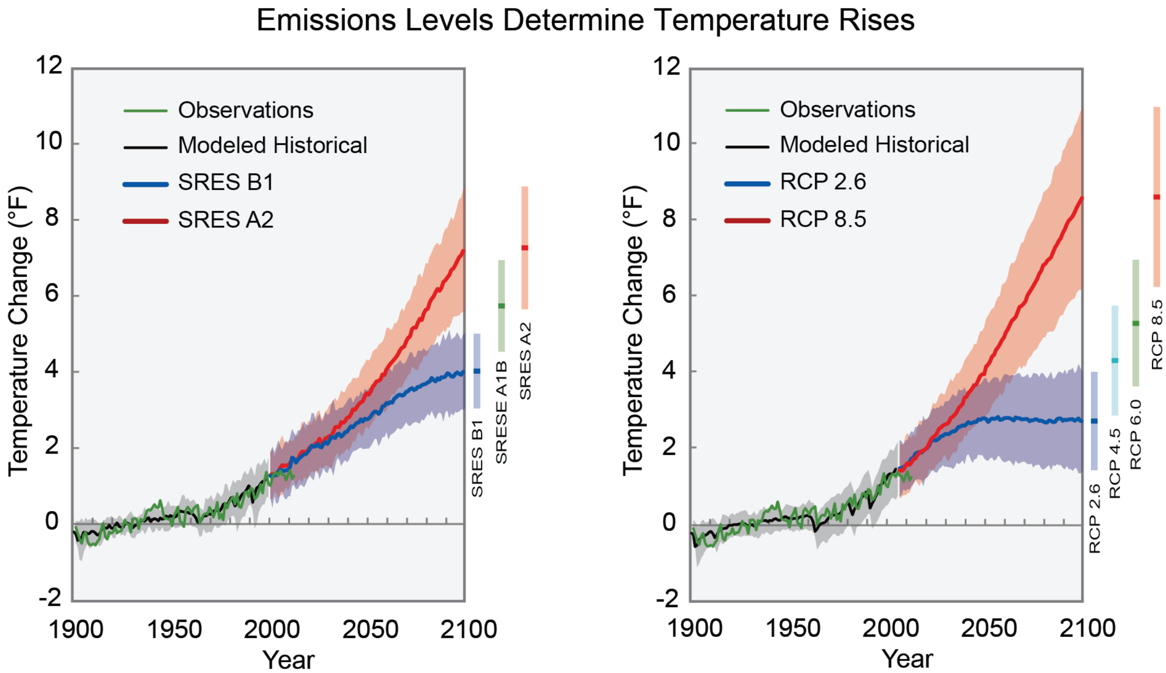

Figure 24: Emissions Levels Determine Temperature Rises

Caption: Projected global average annual temperature changes for multiple future scenarios relative to the 1901-1960 average temperature. Each line represents a central estimate of global average temperature rise for a specific emissions pathway. Shading indicates the range (5 to 95 percentile) of results from a suite of climate models. The left panel shows results from the previous generation of climate models (CMIP3), and the right panel shows results from the most recent generation of climate models (CMIP5). Projections in 2099 for additional emissions pathways are indicated by the bars to the right of each panel. In all cases, temperatures are expected to rise, although the difference between lower and higher emissions pathways is substantial. (Data from CMIP3, CMIP5, and NOAA NCDC).

T. Are there tipping points in the climate system?

Most climate studies have considered only relatively gradual, continuous changes in the Earth's climate system. However, there are a number of potential "tipping points" in the climate system – points where a threshold is crossed, resulting in a substantial change in the future state of the climate system, regionally and/or globally.

Scientists have identified several aspects of the climate system that could pass a tipping point and/or change substantially under projected climate change (see the figure below for key examples). These tipping points have been identified based on observations of past abrupt climate changes, recent observations showing abrupt changes underway (for example, in the Arctic), process-based understanding of the dynamics of the climate system, and climate simulations showing tipping points in future projections. There is no clear scientific consensus at this time as to whether major tipping points, other than loss of the Arctic sea ice in summer, will be reached during this century.

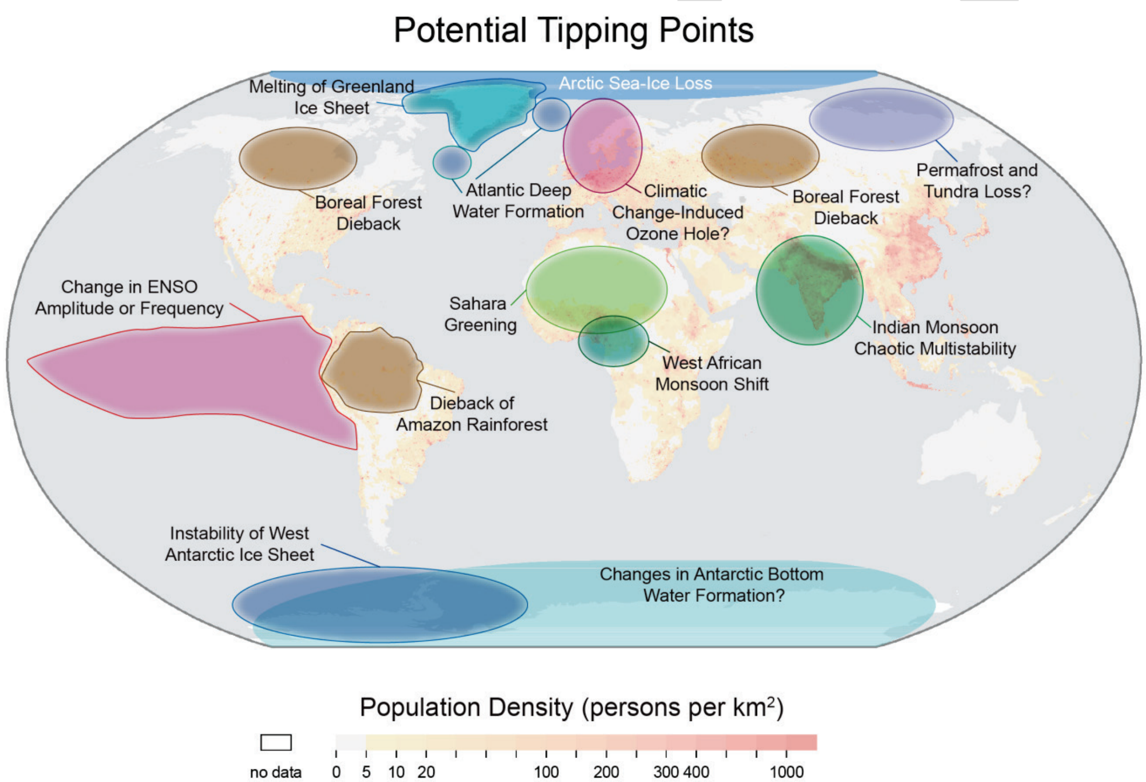

Figure 25: Potential Tipping Points

Caption: Stylized map of potential policy-relevant tipping elements in the Earth's climate system overlain on population density. Question marks indicate systems whose status as tipping elements is particularly uncertain. (Figure source: adapted from Lenton et al. 2008[17]).

Some tipping points are more imminent, and some would have larger impacts than others. For example, the rapid decline of Arctic sea ice exposes the darker ocean surface which absorbs increasing amounts of heats and reduces the amount of new seasonal ice formed. This drastic reduction in sea ice can tip the Arctic Ocean into a permanent, nearly ice-free state in summer. There is some evidence that reductions in ice cover are already leading to changes in weather patterns affecting the U.S. and Europe.

Currently, the proximity, rate, and reversibility of tipping points are usually assessed through a mixture of climate modeling, literature review, and expert elicitation. However, there is a need for more research in this area. Climate scientists cannot predict when tipping points will be crossed because of uncertainties in the climate system and because we do not know what pathway future emissions will take. But an absence of certainty does not indicate an absence of risk. To use a medical analogy, just because your doctor cannot tell you the precise date and time that you will have a heart attack does not mean you should ignore medical advice to reduce your risk by taking preventative measures like exercising more, losing weight, and changing your diet. Medical science is imperfect, just like climate science, but it can provide very useful advice regarding the risks of our actions and choices – and the benefits of preventative measures.

U. How is climate change affecting society?

Multiple lines of evidence show that climate change is happening as a result of human activities. Climate change is altering the world around us, and these changes will become increasingly evident with each passing decade. Climate change is already leading to more intense rainfall events and more extreme weather patterns. It will lead to more droughts in some areas and more floods in others, as well as more frequent heat waves over many land areas. Changing temperature and precipitation patterns, as well as increasing sea level, are important factors for different parts of the U.S. The risk associated with wildfires in the western U.S. is increasing, and coastal inundation is becoming a common occurrence in low-lying areas. Water supply availability is changing in many parts of the U.S.

Many people are already being affected by the changes that are occurring, and more will be affected as these changes continue to unfold. To limit risks and maximize opportunities associated with the changes, people need to understand how climate change is going to affect them and what they can do to adapt, as well as what we can to reduce future climate change by reducing global emissions. Climate change will affect ecosystems and human systems – such as agricultural, transportation, water resources, and health-related infrastructure – in ways we are only beginning to understand. Moreover, climate change can interact with other stressors, such as population increase, land use change, and economic and political changes, in ways that we may not be able to anticipate, compounding the risks.

Although some impacts will likely be beneficial within limited sectors and regions, economic analyses indicate that the costs of inaction will be many times greater than the costs of action to reduce emissions.

In general, the larger and faster the changes in climate occur, the more difficult it will be for human and natural systems to adapt. The climate system has been relatively stable during the time that human civilizations have existed, but the current pace of change is accelerating. Essentially, today's built infrastructure has been developed based on the assumption that future climate will be like that of the past. This assumption is likely no longer valid.

Since climate change is occurring, adaptation in some form will be inevitable. The choice is between proactive adaptation (where we plan ahead to limit the impacts) or reactive adaptation (where responses occur after the damage is already unavoidable).

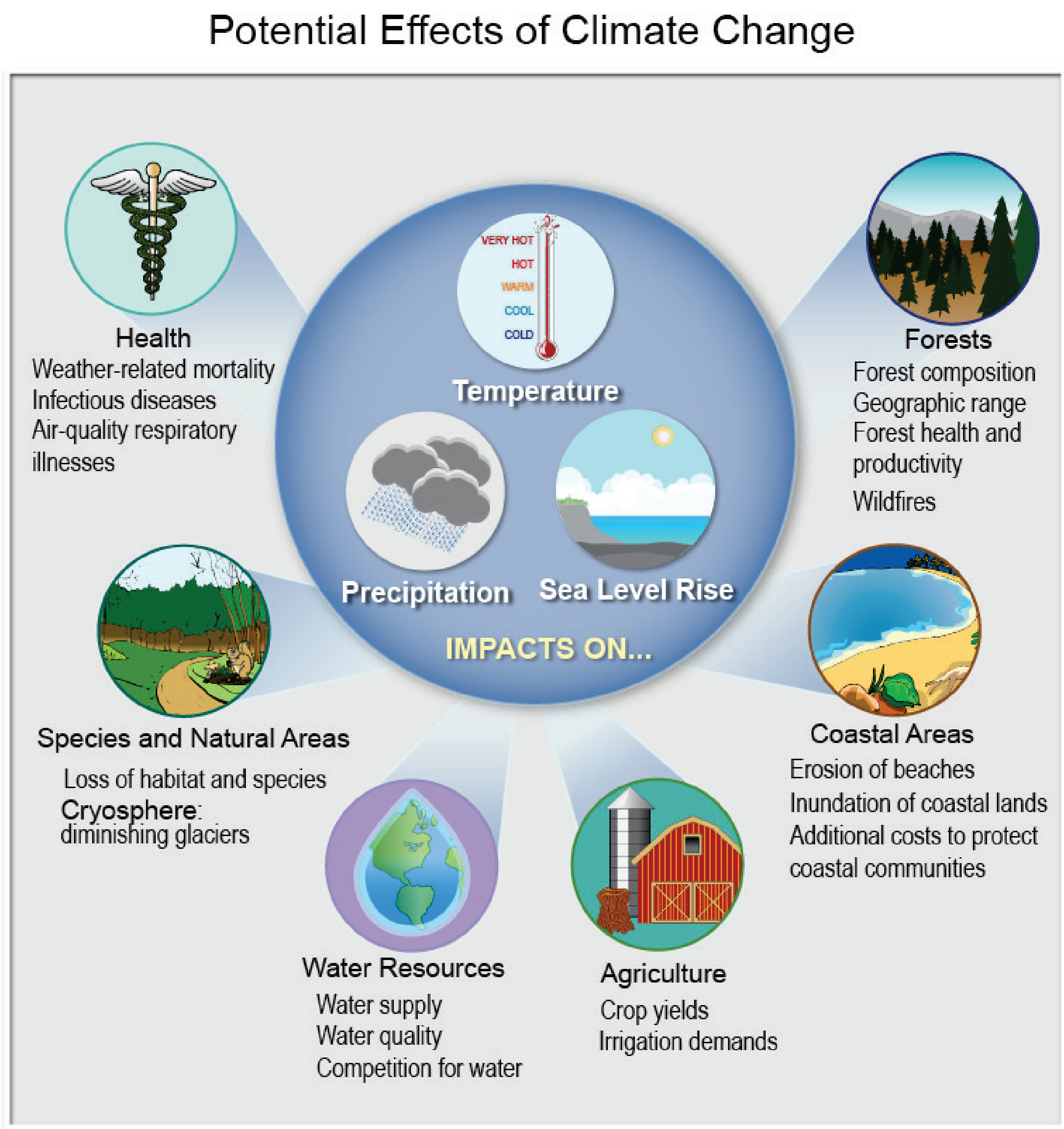

Figure 26: Potential Effects of Climate Change

Caption: Climate change is likely to affect human society and the natural environment in many ways. The National Climate Assessment's sectoral impacts chapters examine these impacts by category in detail. (Figure source: adapted from Phillipe Rekacewicz UNEP/GRID-Arendal 2012, "Vital Climate Graphics" collection [18]).

V. Are there benefits to warming?

While some benefits may be expected, all analyses of this question have concluded that there will be more negative effects than positive ones. This is because our society and infrastructure have been built for the climate of the past, and any rapid change from that climate imposes difficulties and costs. For example, many major cities are located on the coasts where they are vulnerable to sea level rise. And there has been rapid population growth in the U.S. Southwest, where increasing heat and drought threaten water supplies and cause increased wildfires. In addition, ecosystems that we rely on for our food and water are adapted to the cooler climate that our planet has experienced over recent centuries.

Increases in average temperatures may have some benefits, depending on where you live and on the nature of local economic activity. For example, the longer growing season can have some benefits, especially to agriculture and gardeners. However, it is unlikely that rapid changes in extreme temperatures (which become more likely as heat-trapping gas emissions continue to increase) will result in positive outcomes for people or ecosystems because, on the whole, it is more difficult to be well prepared for sudden changes.

For example, many higher latitude locations are colder than most people find comfortable, and it is easy to imagine how increasing temperatures in these regions could have some positive effects. Reduction in sea ice in the Arctic will open more shipping possibilities, but the higher temperatures in this region also have the potential for many negative consequences, including: major disruptions of ecosystems that are important sources of food and other valued products; habitat loss for endangered species; loss of culturally valued practices and subsistence lifestyles; loss of permafrost that may currently support roads and other infrastructure; and increases in the frequency and range of wildfires.

Also, climate change is much more than changes in temperature. In many places, the amount, intensity, frequency, and type of precipitation is changing. For example, there has been an increase in very heavy precipitation events across the U.S. over the last half century, many of which can increase risks of flooding. Analyses of the frequencies of high-intensity precipitation events show that such events are occurring more often than in the past.

Precipitation is generally increasing at higher northern latitudes and decreasing in the tropics and subtropics over land. In general, wet areas are getting wetter and dry areas are getting drier. Scientific analyses also indicate a strong link between changing trends in severe weather events and the changing climate. Analyses also suggest that these severe heat and extreme precipitation events will become more common in the future.

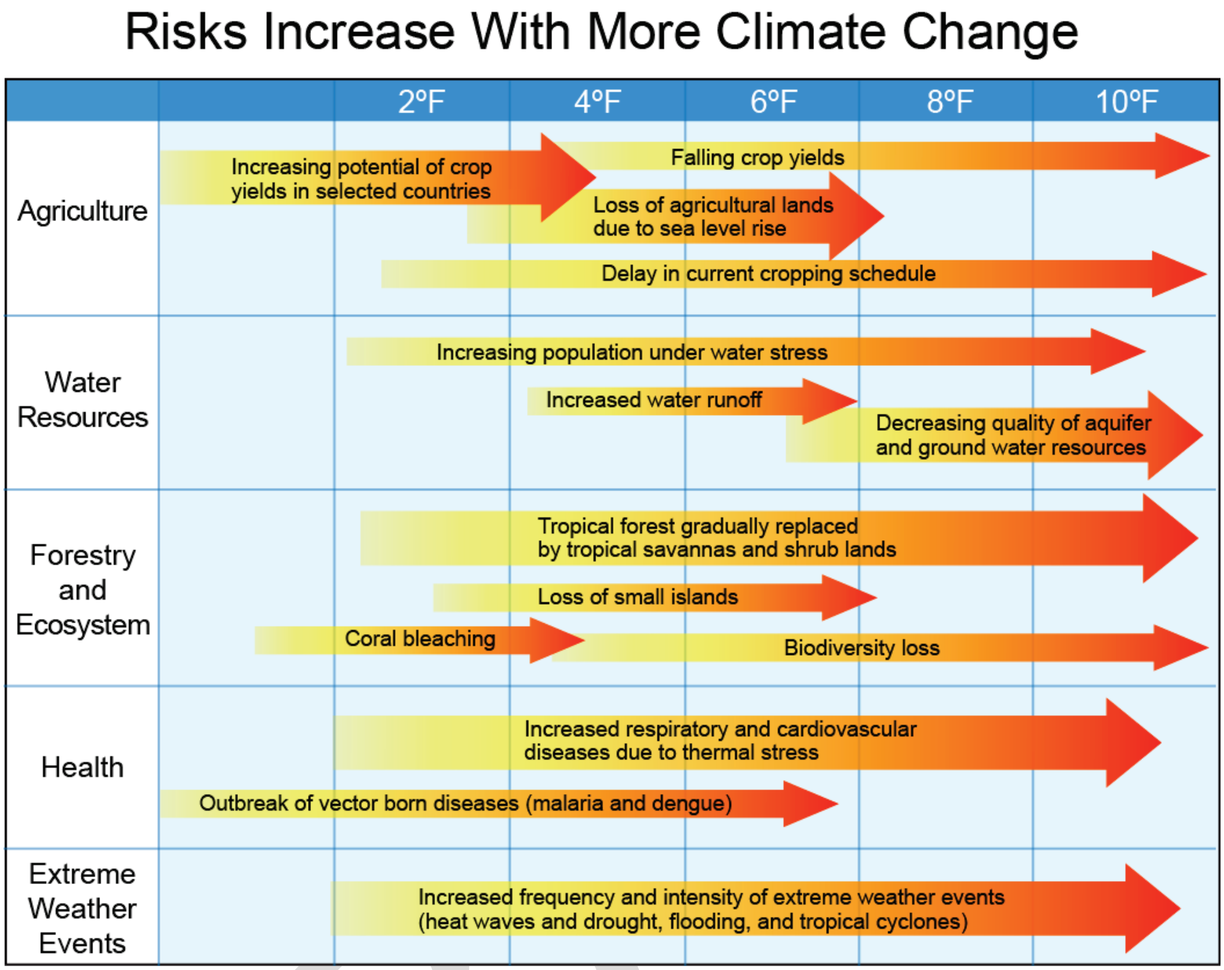

Figure 27: Risks Increase with More Climate Change

Caption: The risks from impacts increase with the amount of climate change (Adapted from Stern 2006). If current emission trends continue, temperatures are projected to exceed an increase of 10º F by the end of this century.

W. Are some people and ecosystems more vulnerable than others?

All of us will be affected by climate change. This is not surprising when we consider that people and other life on Earth have had hundreds, and even thousands, of years to adapt to our current climate. It is also not surprising because global commerce, economies and societies are more linked than at any time in human history. Today, changes in climate are occurring so rapidly that it may be difficult to adapt to the changes. This is especially true for vulnerable groups within society such as the poor, the very young, and some older people who have less mobility and fewer resources to cope with hotter temperatures, higher food prices, increased water scarcity, environmental degradation, and coastal flooding.

How and where we grow our food, the types of buildings and infrastructure we design, even where our cities are located are all based on the assumption of a relatively stable climate. Because of that assumption, two-thirds of the world's largest cities lie within a few feet of sea level. The rising sea level will require adaptation to avoid major disruptions. Without adaptation, there is a significant risk that climate change will create millions of new environmental refugees and impose infrastructure costs that could exceed a trillion dollars *per year* in coastal cities worldwide.

Longer, more intense, and more frequent heat waves increase concerns about heat-related death and illness. Without further major decreases in pollution emissions, it is virtually certain that air quality in cities will decline, since greater heat also worsens air pollution such as ozone or smog. Insect-borne illnesses are also likely to increase in some areas as many insect ranges expand. The health effects of climate change are especially serious for the very young, very old, or for those with heart and respiratory problems. However, higher winter temperatures may reduce the negative health impacts from cold weather as well.

Ecosystems are also affected by climate change; for example, fragile ecosystems in desert and mountainous regions that are already under stress have difficulty adapting to even small changes. As the climate continues to change, major impacts are expected on ecosystem structure and function, in the interactions among species, and in species' geographic ranges, with the result that species that cannot move or adapt may face extinction. In addition, climate changes such as increased floods and droughts are predicted to increase the risk of extinction for some plant and animal species, many of which are already at risk due to other non-climate related factors.

X. What can be done? Are there solutions?

The most direct way to significantly reduce the magnitude of future climate change is to reduce the emissions of heat-trapping gases by changing the way that energy is obtained and used. Emissions can be reduced by increasing the efficiency of energy use and hastening the transition to non-carbon energy sources. For example, because about 28% of the energy used in the U.S. is used for transportation, developing and driving more efficient vehicles and changing to fuels that do not contribute significantly to heat-trapping gas emissions is one obvious path forward. A large amount of energy in the U.S. is also used to heat and cool buildings, so changes in building design could dramatically reduce energy use. While there is no single silver bullet that will solve all the challenges posed by climate change, there are many options that can reduce our emissions and help prevent some of the potentially serious impacts of climate change. There will be some costs to these changes, but a number of economic analyses have concluded that the costs of inaction would be many times greater than the costs of action.

Because impacts are already occurring and anticipated to increase, adaptation to the impacts of climate change will be required. Adaptation decisions range from being better prepared for extreme events such as floods and droughts, to identifying economic opportunities that come from investments in adaptation and mitigation strategies and technologies, to integrating considerations of new climate-related risks into city planning, public health and emergency preparedness, and ecosystem management.

Also, technological fixes, such as "geoengineering," may be possible but could be extremely risky and would do nothing to slow ocean acidification (see FAQ Z).

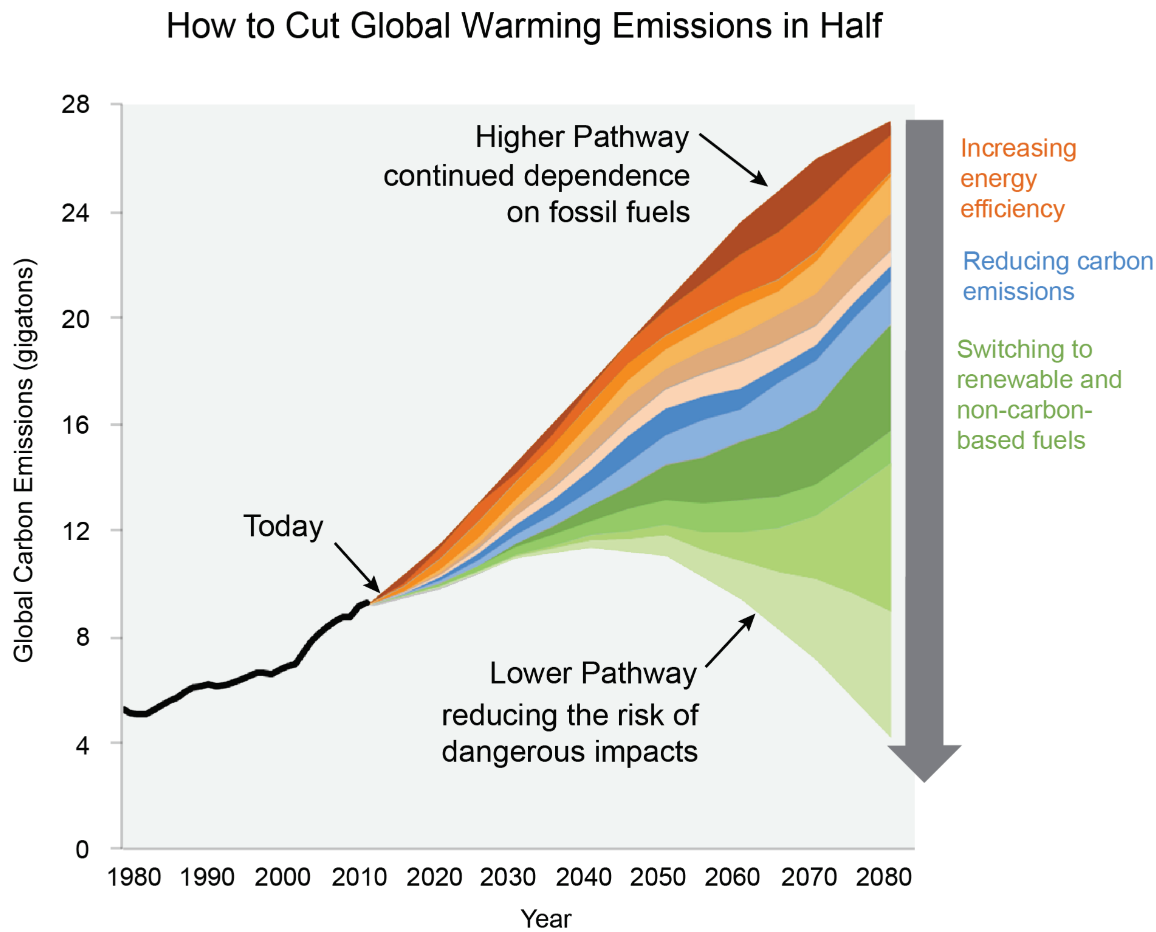

Figure 29: How to Cut Global Warming Emissions in Half

Caption: Many pathways to reduce energy use, improve efficiency, and adopt new technologies could contribute to a significant reduction in emissions. (Data from Boden et al. 2012[19]).

Y. Are there advantages to acting sooner rather than later?

The sooner we act, the less costly it will be, and the lower the risk of severe impacts. The effects of current emissions of carbon dioxide and other heat-trapping gases on climate can take decades to fully manifest themselves. The resulting change in climate and the impacts of those changes can then persist for a long time. The longer these changes in climate continue, the greater the resulting impacts. It will become increasingly costly to adapt, and some systems will not be able to adapt if the change is too much or too fast. Thus it is not surprising that recent reports from the U.S. National Academy of Sciences, including America's Climate Choices[20] and America's Energy Futures,[21] have concluded that the environmental, economic, and humanitarian risks posed by climate change indicate a pressing need for substantial action to limit the magnitude of climate change and to prepare to adapt to its impacts. They also concluded that substantial reductions of heat-trapping gas emissions should be among the nation's highest priorities.

The National Academy of Sciences and others have concluded that acting now will reduce the risks posed by climate change and the pressure to make larger, more rapid, and potentially more expensive reductions later. Actions taken to reduce vulnerability to climate change impacts can be considered as investments that can make sense economically, especially if they also offer protection against natural climate variations and extreme events. In addition, investment decisions made now about equipment and infrastructure can "lock in" emissions of heat-trapping gases for decades to come. Finally, while it may be possible to alter our responses to climate change, it is difficult or impossible to "undo" climate change once it has occurred.

Current efforts at local and state levels, and by the private sector, are important, but are insufficient to limit warming to the lower scenarios described throughout this report. Thus, numerous analyses have called for policies that establish coherent national and international goals and incentives, and that promote strong U.S. engagement in international-level response efforts. The National Academy of Sciences found that the inherent complexities and uncertainties of climate change will be best met by applying a risk management approach and by making efforts to significantly reduce heat-trapping gas emissions; prepare for adapting to impacts; invest in scientific research, technology development, and information systems; and facilitate engagement between scientific and technical experts and the many types of people making America's climate choices.

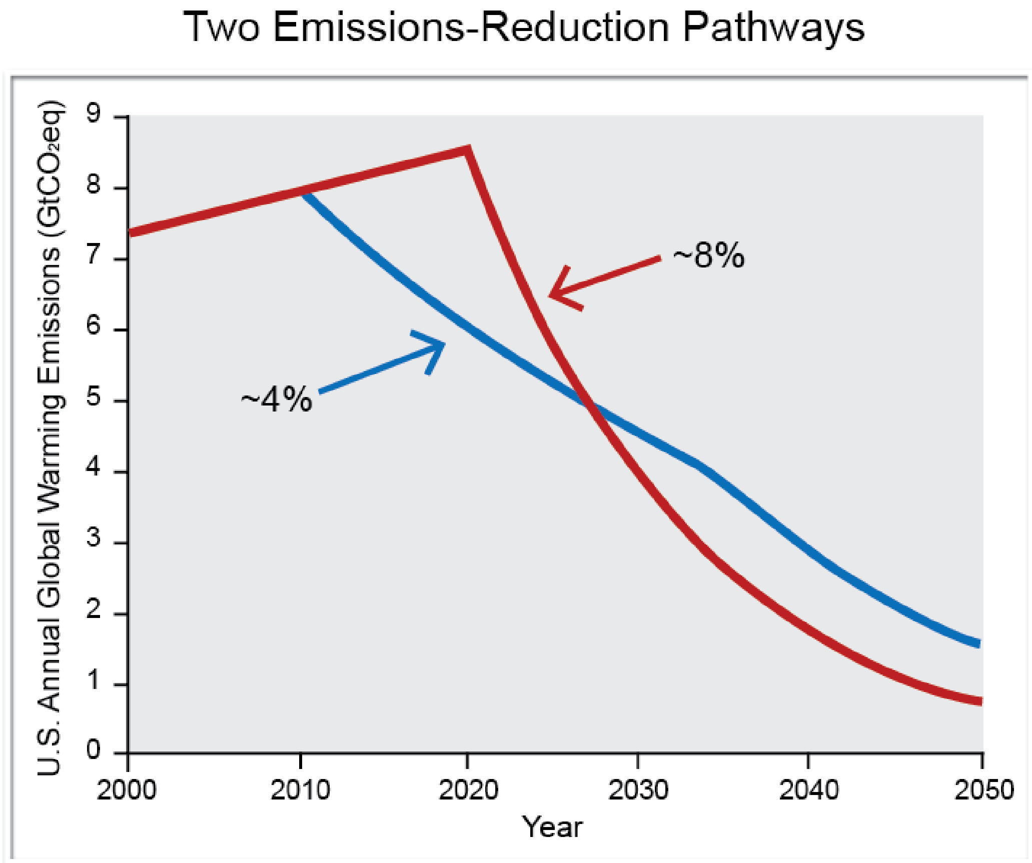

Figure 30: Two Emissions-Reduction Pathways

Caption: This graph shows why earlier action to reduce emissions would be less difficult and expensive than delayed action. Two pathways show how a cumulative carbon emissions budget of 265 Gigatons of CO_2 could be maintained by 2050 (consistent with stabilizing atmospheric CO_2 at 450 ppm, as targeted by many nations). By initiating reduced emissions efforts in 2010 (blue line), a 4% per year reduction would have been required; waiting until 2020 to reduce emissions (red line) doubles the rate at which emissions must be reduced. (Figure source: Luers et al. 2007[22]).

Z. Can we reverse global warming?

While we can't stop climate change in its tracks, we can limit it to less dangerous levels by reducing our emissions. Even if all human-related emissions of carbon dioxide and the other heat-trapping gases were to stop today, Earth's temperature would continue to rise for a number of decades and then slowly begin to decline. However, focusing on short-lived types of emissions, such as methane and black carbon (soot), can reduce the rate of change in the near term. Because of the complex processes controlling carbon dioxide concentrations in the atmosphere, even after more than a thousand years, the global temperature would still be higher than it was in the preindustrial period. As a result, without technological intervention, it will not be possible to totally reverse climate change. We do face a choice between a little more warming and lot more warming, however. The amount of future warming will depend on our future emissions.

In theory, it may be possible to reverse global warming through technological interventions called geoengineering. Two types of geoengineering approaches have been proposed to alter the climate system: 1) removal of carbon dioxide from the atmosphere, and 2) altering the amount of the sun's energy that reaches the Earth (referred to as "solar radiation management").

Various techniques for removal of carbon dioxide from the atmosphere have been proposed. At this time, however, there is no indication that any of them could be implemented on a large enough scale to have a significant effect. Investments in limiting emissions, combined with capturing and storing carbon, could possibly reverse the warming trend, but it remains to be seen if this is feasible.

Artificial injection of stratospheric particles and cloud brightening are two examples of "solar radiation management" techniques. The cooling effect that some types of particles have on the atmosphere has led to the proposal of an array of possible geoengineering projects, especially with the goal of offsetting the warming until more non-fossil fuel energy is put into place. However, the climate system is complex and experimenting without complete understanding could result in unintended and potentially dangerous side effects on our health, ecosystems, agricultural yields, and even the climate itself. Even if such engineering approaches were economically feasible, the potential impacts on the environment need to be better understood. One important consideration regarding solar radiation management is that ocean acidification would still continue even if warming could otherwise be reduced by reflecting light away from our atmosphere. Much more research is needed to see if such approaches could be environmentally feasible. In the meantime, there are significant concerns about ecological and other side effects of some of these technologies.

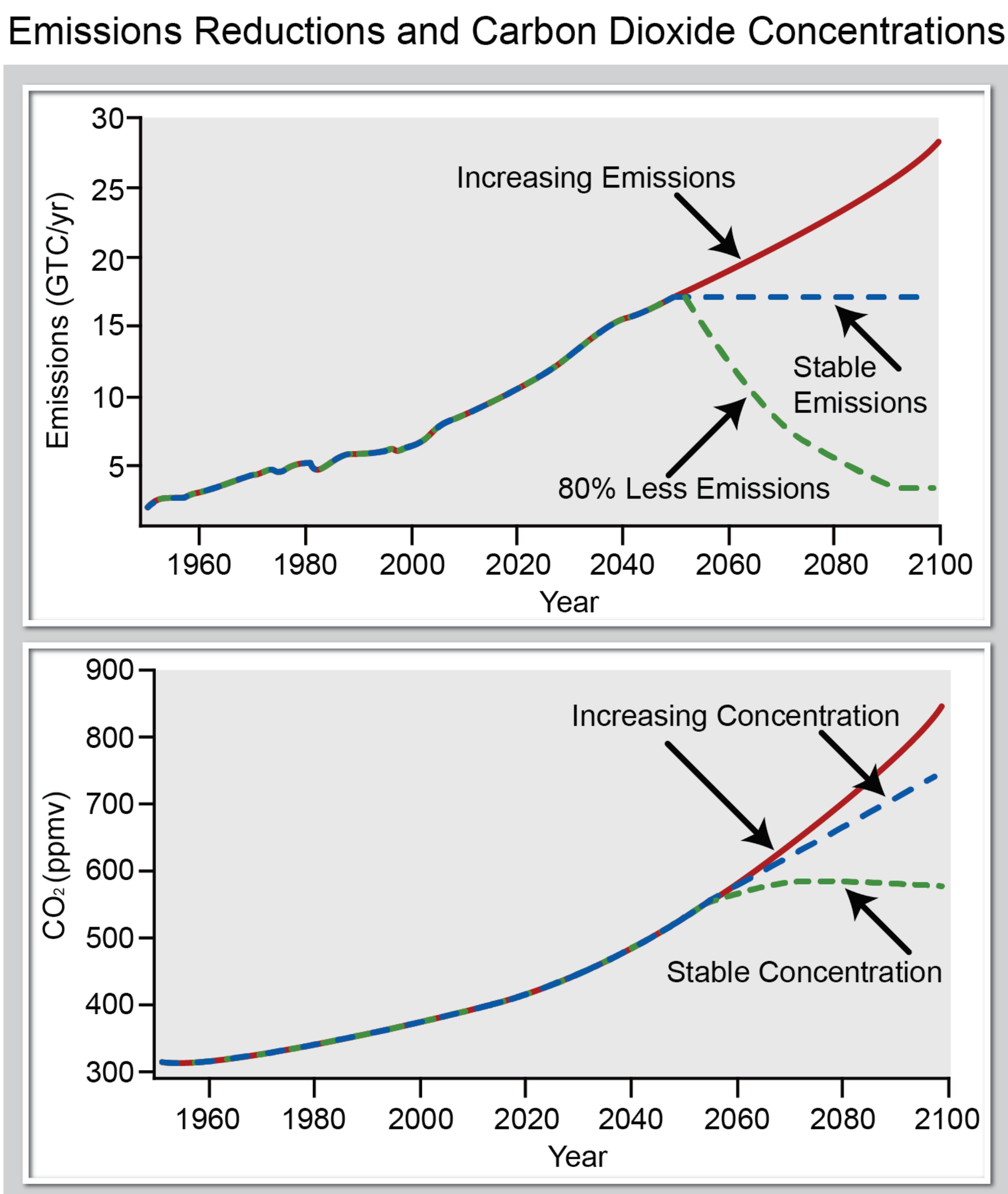

Figure 31: Emissions Reductions and Carbon Dioxide Concentrations

Caption: To reduce the changes occurring in climate, we would need to stabilize atmospheric levels of carbon dioxide, not simply stabilize current emission levels of carbon dioxide. Just stabilizing emissions still leads to increasing amounts of carbon dioxide in the atmosphere, because emissions are greater than the sinks that remove it (blue line). To stabilize levels of atmospheric carbon dioxide, emissions would need to be reduced significantly, on the order of 80% or more compared to the present day (green line). The lower graph shows how carbon dioxide concentrations would be expected to evolve depending upon emissions for one illustrative case, but this applies for any chosen target. (Figure source: NRC 2011[23]).

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