

## Appendix: NCA Climate Science — Addressing Commonly Asked Questions from A to Z

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### Introduction

This section answers some commonly asked questions about climate change. These 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 global temperature still increasing? Isn't there recent evidence that it is actually cooling?

E. Is it getting warmer at the same rate everywhere? Are these trends likely to 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 recent climate changes?

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?

- 1 L. Is Antarctica gaining or losing ice? What about Greenland?
- 2 M. What about global cooling predictions in the 1970s?
- 3 N. How is climate projected to change in the future?
- 4 O. Does climate change affect severe weather?
- 5 P. Are the oceans affected by climate change?
- 6 Q. What is ocean acidification?
- 7 R. Should we trust the computer models of the Earth's climate?
- 8 S. What are the key uncertainties about climate change?
- 9 T. Are there tipping points in the climate system we should be concerned about?
- 10 U. Why should I care? How is climate change going to affect us?
- 11 V. Won't more warming be good for us?
- 12 W. Who will be most affected by climate change?
- 13 X. What can be done? Are there solutions?
- 14 Y. Is it better to act now or later?
- 15 Z. Can we reverse global warming?

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## 1 Questions and Answers

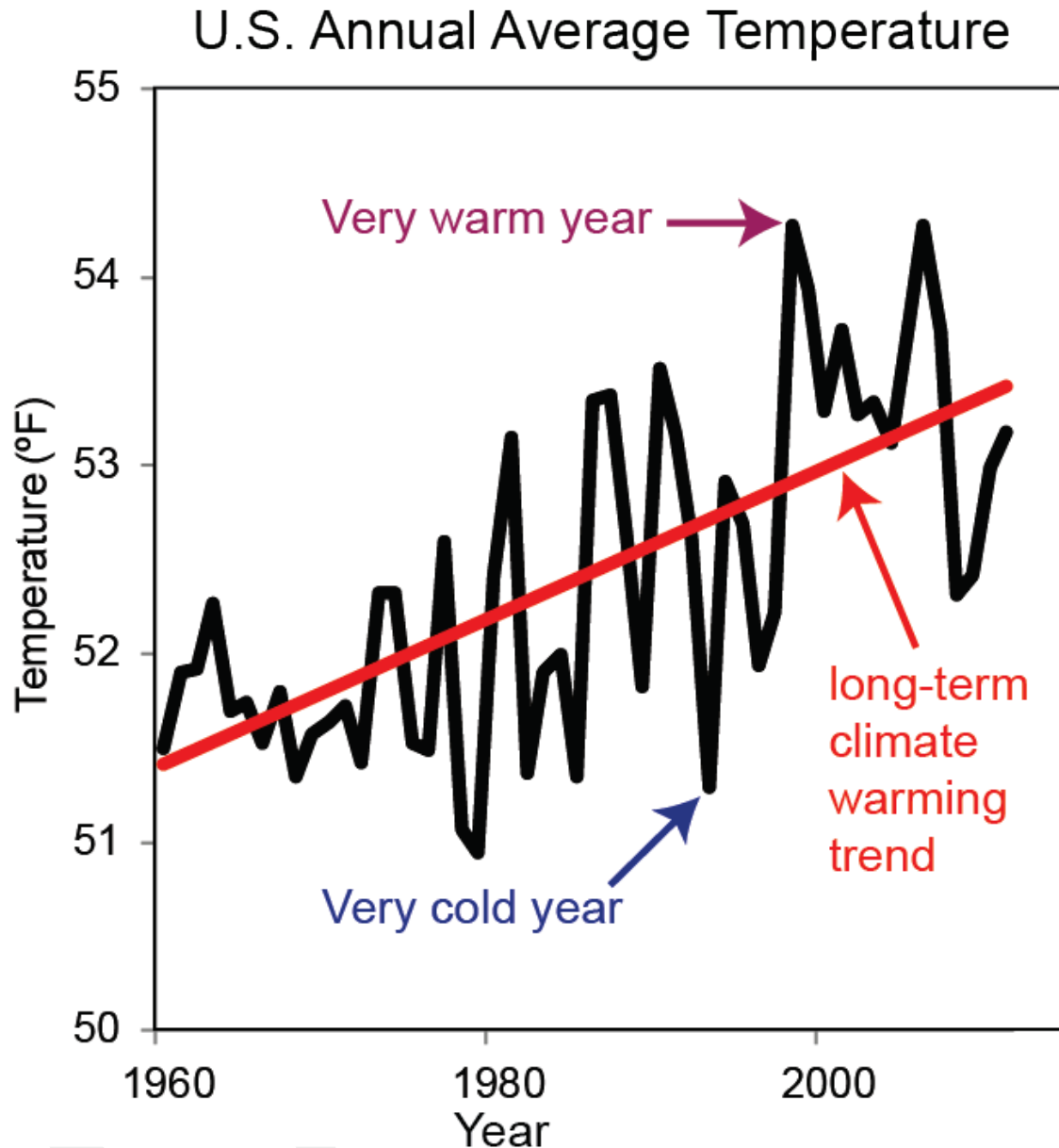
### 3 A. How can we predict what climate will be like in 100 years if we can't even predict the 4 weather next week?

5 We are all familiar with weather. Weather is the day-to-day and even year-to-year variations in  
6 temperature, precipitation, and other aspects of the atmosphere around us. From a scientific  
7 perspective, it is impossible to predict weather past about two weeks. From a practical  
8 perspective, state-of-the-art numerical weather prediction is very accurate for a few days to a  
9 week in advance.

10 If weather cannot be predicted even a few weeks into the future, how can scientists project the  
11 future climate decades in the future? Weather is made up of individual events; climate is the  
12 long-term statistics of those events. Just like individual people, individual events are difficult and  
13 often even impossible to predict. However, it is possible to predict the behavior or statistics of  
14 large groups of people: assessing the occurrence of diabetes or the risk of automobile accidents  
15 for a given population, for example, even though we cannot say which particular individuals will  
16 be affected. In the same way, it is also possible to estimate changes in the statistics of a large  
17 number of weather events, especially when we know what is causing them to change.

18 Climate is how the atmosphere behaves over relatively long periods of time, usually taken as the  
19 statistics of weather over time scales of 30 years or more. Climate is primarily the result of the  
20 local effects of geographic location (for example, whether you live in the mountains or near the  
21 ocean) combined with large-scale climate factors, including the energy received from the sun and  
22 levels of heat-trapping gases in the atmosphere. “Climate change” refers to changes in the long-  
23 term averages and variations in weather.

24 We know how these have changed in the past and can successfully explain the climate change  
25 that has already occurred. Because we understand the physics of how the atmosphere works  
26 relatively well, we use the same approach to estimate how the climate will change in the future in  
27 response to a given increase in human emissions of heat-trapping gases, or natural changes such  
28 as variations in energy from the Sun.



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2 **Figure 1: U.S. Annual Average Temperature**

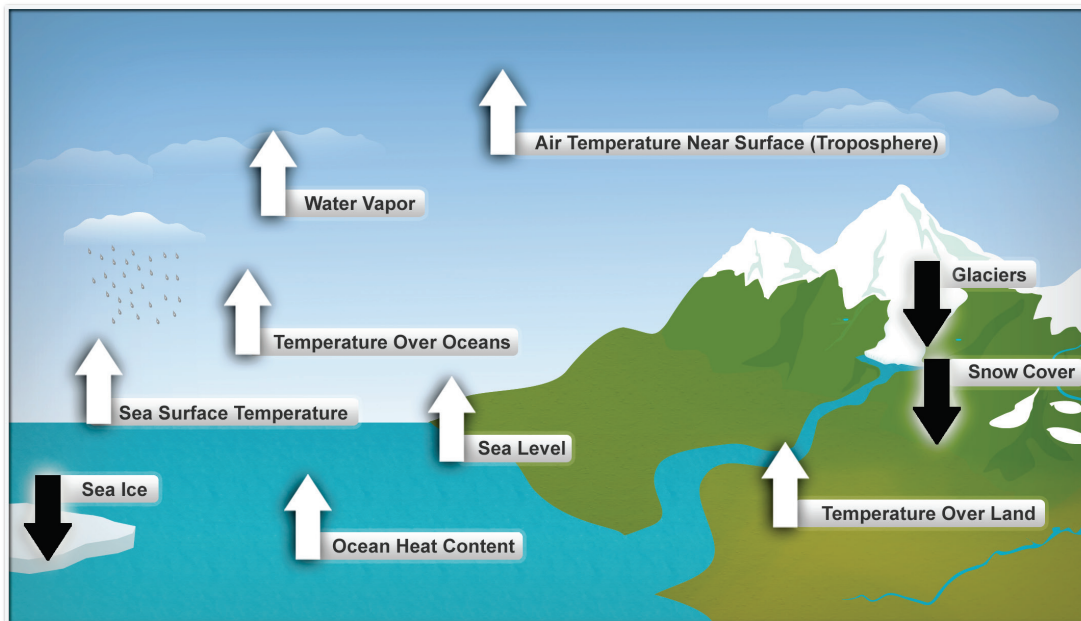
3 **Caption:** Day-to-day weather does not tell us much about climate. One cold day, or even  
4 a cold year, does not contradict a long-term warming trend, and one hot year does not  
5 prove it. Climate change refers to the changes in average weather conditions that persist  
6 for an extended period of time, over multiple decades or even longer. (Figure source  
7 adapted from Kunkel et al. 2012)

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

2 There is no question that the world has warmed since the 1800s. Evidence abounds, from the top  
3 of the atmosphere to the depths of the oceans. Changes in surface, atmospheric, and oceanic  
4 temperatures; glaciers, snow cover, and sea ice; sea level; and atmospheric water vapor have  
5 been documented by hundreds of studies conducted by many scientists in countries around the  
6 world.

7 Documenting climate change often begins with global average Earth surface temperatures, which  
8 formed the basis for the IPCC’s conclusion in 2007 that the “warming of the climate system is  
9 unequivocal.” Temperatures recorded by weather stations, however, are only one indicator of  
10 climate change. Broader evidence for a warming world comes from a wide range of physically  
11 consistent measurements of the Earth’s climate system.

### Ten Indicators of a Warming World



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### 13 **Figure 2: Ten Indicators of a Warming World**

14 **Caption:** Long-term observations of many aspects of the Earth’s climate show changes  
15 consistent with a warming world. Upward and downward arrows in the diagram indicate  
16 recently documented increases and decreases, respectively. (Figure source: NOAA  
17 NCDC)

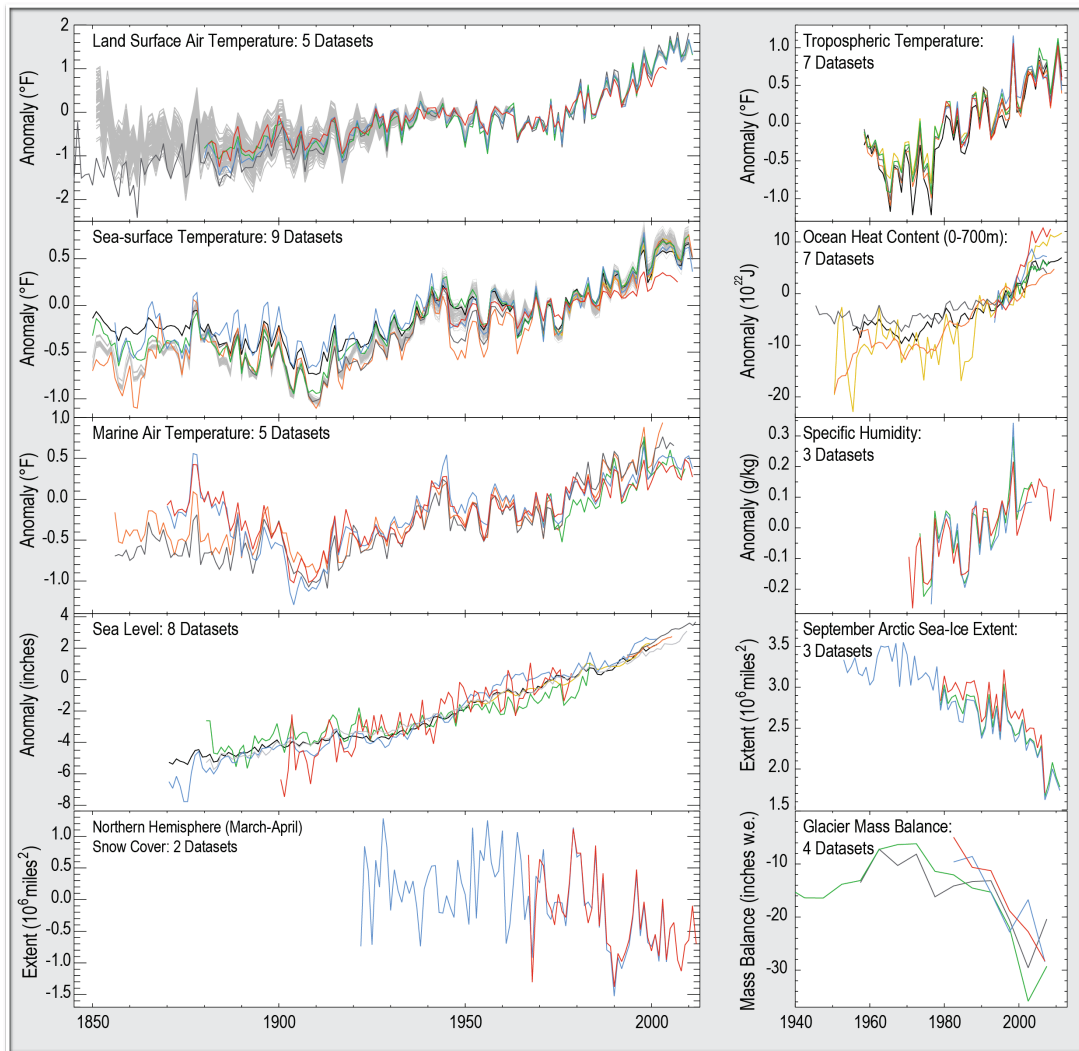
18 Observed warming is not confined to the Earth’s surface. Measurements by weather balloons and  
19 satellites consistently show that the temperature of the troposphere, the lowest layer of the  
20 atmosphere, has increased. The upper ocean has warmed, and more than 90% of the energy  
21 absorbed by the climate system since the 1960s has been stored in the oceans. As the oceans  
22 warm, seawater expands, causing sea level to rise.

23 Warmer air will, on average, contain a greater quantity of water vapor. Globally, analyses show  
24 that the amount of water vapor in the atmosphere has also increased over the land and the oceans.

- 1 About 90% of the glaciers and land-based ice sheets worldwide are melting as the Earth warms,  
2 adding further to the sea level rise. Spring snow cover has decreased across the Northern  
3 Hemisphere since the 1950s. There have been substantial losses in sea ice in the Arctic Ocean,  
4 particularly during the summer minimum in extent (see CAQ L for discussion of Antarctic sea  
5 ice).
- 6 All of these indicators and all of the independent data sets that have been assembled  
7 unequivocally point to the same conclusion: from the ocean depths to the top of the troposphere,  
8 the world has warmed. The upper atmosphere, specifically the stratosphere, has cooled, just as  
9 expected from the radiative effects of the increasing levels of carbon dioxide due to human  
10 activities, predominantly the burning of coal, oil, and natural gas.

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### Indicators of Warming from Multiple Data Sets



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**Figure 3: Indicators of Warming from Multiple Data Sets**

**Caption:** There are multiple datasets documenting changes in climate indicators, all consistent in supporting the conclusion of a warming planet. (Figure source: Kennedy et al. 2010)

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

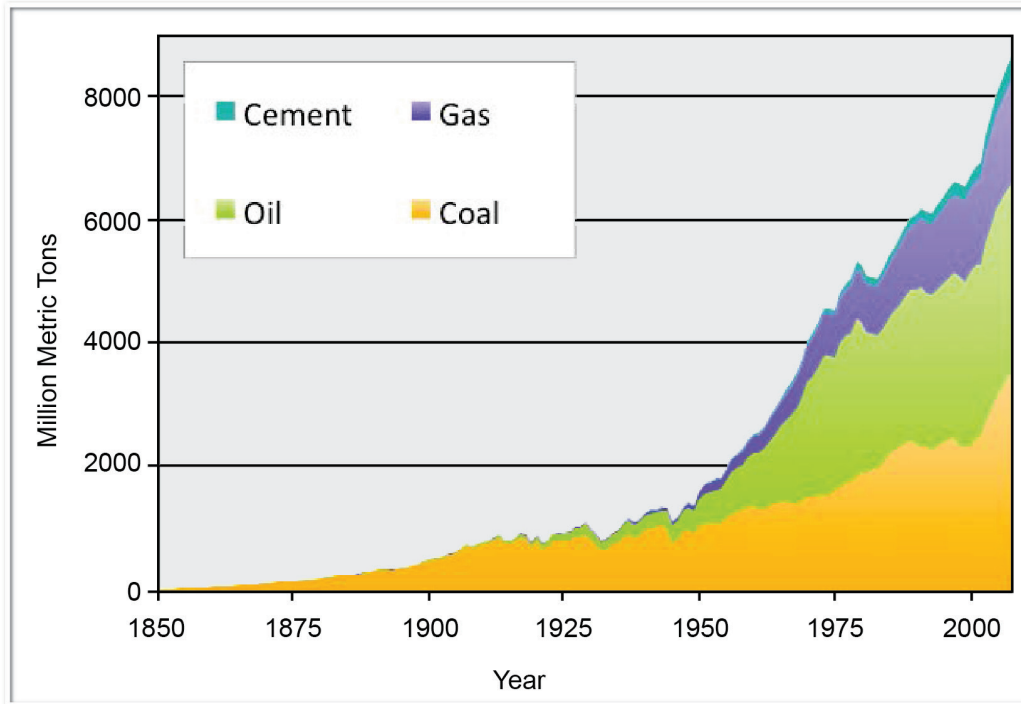
2 The Earth has experienced many large climate changes in the past. However, current changes in  
3 climate are unusual for two reasons: first, these changes are occurring faster than most past  
4 changes in the Earth’s climate; second, these changes are primarily the result of human activities.

5 In the past, climate change was driven exclusively by natural forcings: explosive volcanic  
6 eruptions that inject reflective particles into the upper atmosphere, changes in energy from the  
7 Sun, and periodic variations in the Earth’s orbit. Natural cycles that transfer heat between the  
8 ocean and the atmosphere, as well as slowly changing natural variations in heat-trapping gases in  
9 the atmosphere have also all altered global average temperature over periods ranging from  
10 months to millennia. Specifically, natural changes in atmospheric levels of heat-trapping gases  
11 have amplified the effects of natural influences on global temperature. For example, past glacial  
12 periods were initiated by shifts in the Earth’s orbit, but amplified by decreases in atmospheric  
13 levels of carbon dioxide and by greater reflection of solar radiation by ice and snow as the  
14 Earth’s climate system responded to a cooler climate. Some periods in the distant past were even  
15 much warmer than what scientists predict will occur from human-induced global warming over  
16 this century. But these changes in the distant past generally occurred much more slowly than  
17 current changes.

18 Natural factors are still affecting the planet’s climate today. The difference is that, since the  
19 beginning of the Industrial Revolution, humans have been adding increasing amounts of heat-  
20 trapping gases to the atmosphere at a much faster rate than can occur naturally. Records from ice  
21 cores, tree rings, soil boreholes, and other forms of “natural thermometers,” or “proxy” climate  
22 data, reveal three important findings. First, recent climate change is unusually rapid. After a  
23 glacial maximum, the Earth typically warms by about 7°F to 13°F over thousands of years. The  
24 current rate of warming is about 8 times faster.



## Carbon Emissions in the Industrial Age



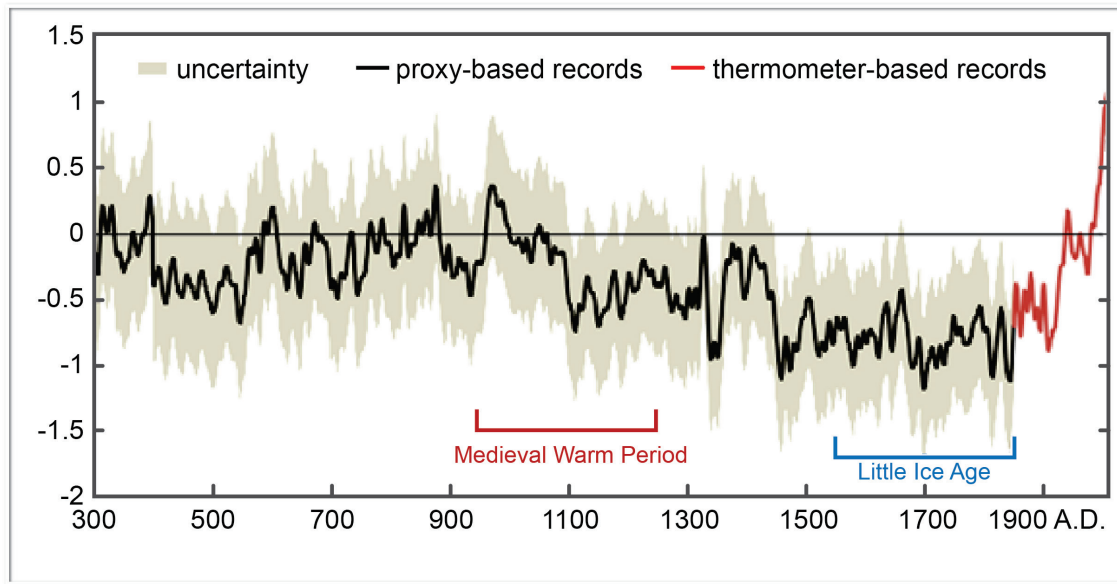
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2 **Figure 4: Carbon Emissions in the Industrial Age**

3 **Caption:** Carbon emissions from burning coal, oil, and gas and from producing cement,  
4 in units of million metric tons of carbon. (Source: Boden et al. 2010)

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

11 The fact is that human civilization didn't exist during previous warm periods. Our societies have  
12 not been built to withstand the changes that are anticipated in the relatively near future, and  
13 many are already experiencing the effects of higher temperatures, sea level rise, and other  
14 climate change-related impacts.

## 1700 Years of Global Temperature from Proxy Data



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**Figure 5: 1700 years of Global Temperature from Proxy Data**

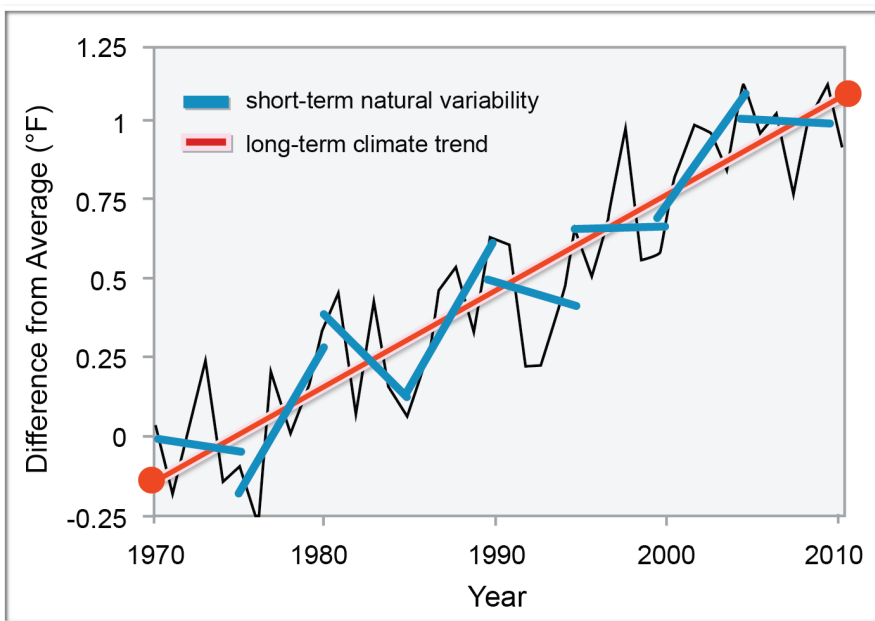
**Caption:** Temperature data for the Northern Hemisphere from surface observations (in red) and from proxies (in black; uncertainty range represented in gray). These analyses suggest that current temperatures are higher than seen globally in at least the last 1700 years, and that the last decade was the warmest decade. (Adapted from Mann et al. 2008)

1 **D. Is the global temperature still increasing? Isn't there recent evidence that it is actually**  
2 **cooling?**

3 Climate change is defined as a change in the average conditions over periods of 30 years or more  
4 (see CAQ A.). On these time scales, global temperature continues to increase. Over shorter time  
5 scales, however, natural variability (due to the effects of El Niño and La Niña events in the  
6 Pacific Ocean, for example, or volcanic eruptions or changes in energy from the Sun) can reduce  
7 the rate of warming or even create a temporary cooling.

8 From 1970 to 2010, for example, global temperature trends taken at five-year intervals range  
9 from decreases to sharp increases. The most recent five-year period, from 2005 to 2010, included  
10 the largest solar minimum experienced since the Little Ice Age of the late 1700s and also  
11 occurred during a period when natural cycles were causing greater than average amounts of heat  
12 to be taken up by the oceans. These natural factors contributed to a temporary downward trend in  
13 temperature.

### Short-term Variations Versus Long-term Trend

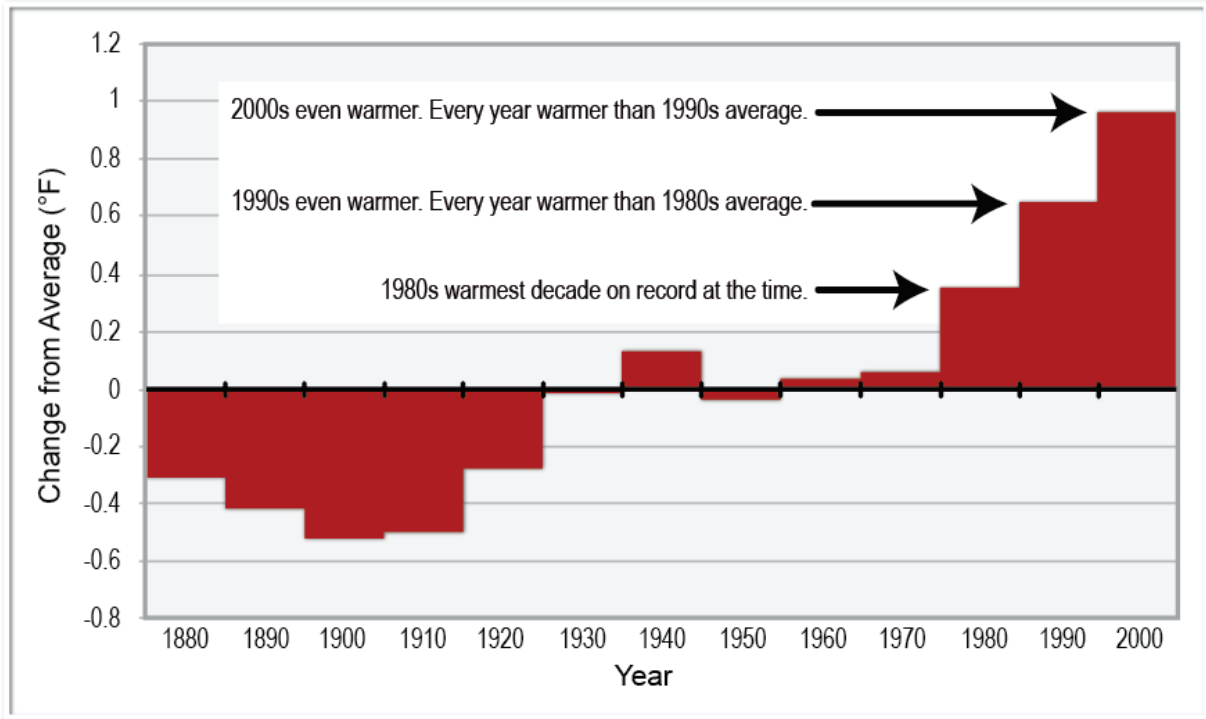


14  
15 **Figure 6: Short-term Variations Versus Long-term Trend**

16 **Caption:** Short-term trends in global temperature (here, the blue lines that show  
17 temperature trends at five-year intervals from 1970 to 2010) can range from decreases to  
18 sharp increases. The evidence of climate change is based on long-term trends over 20-30  
19 years or more (red line). Measurement data from NASA-GISS.

20 There is considerable decade-to-decade variability superimposed on the long-term trend. In most  
21 seasons and regions, the 1930s were relatively warm and the 1960s/1970s relatively cool. The  
22 most recent decade of the 2000s was unusually warm. In fact, this decade was characterized by  
23 the warmest winter everywhere except the Southeast, the warmest spring everywhere, the  
24 warmest summer in the Northwest and Southwest, and the warmest summer everywhere except  
25 the Southwest. On an annual basis, the 2000s were the warmest everywhere.

### Global Temperature Change: Decade Averages



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**Figure 7: Global Temperature Change: Decade Averages**

**Caption:** The last five decades have seen a progressive warming of the Earth. (From The State of the Climate 2009).

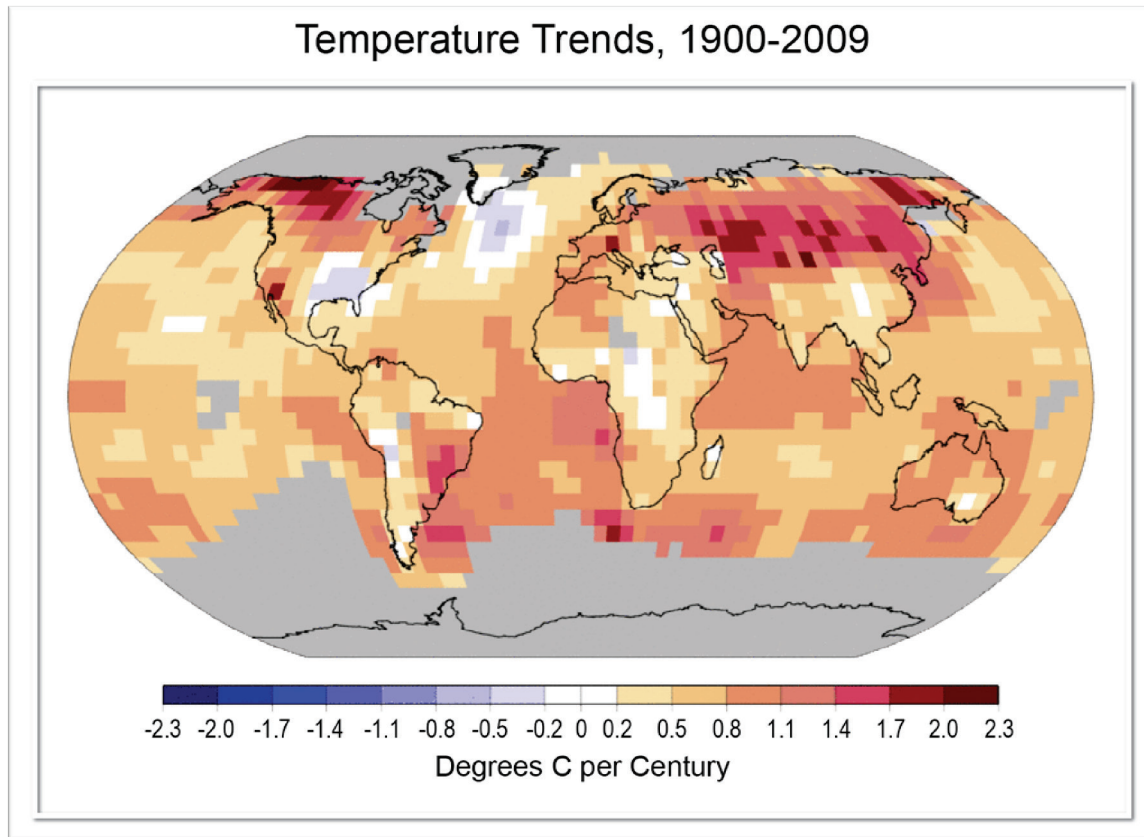
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1 **E. Is it getting warmer at the same rate everywhere? Are these trends likely to continue?**

2 Many scientists do not like the term “global warming” that has been popularly used to describe  
3 climate change, because it might imply that it is warming everywhere, which is not the case.  
4 Temperature changes in a given location are a function of multiple factors, from global to local  
5 and including both human and natural influences. In some parts of the world, including the  
6 southeastern U.S. and the North Atlantic region, temperatures actually fell over the last century.  
7 At smaller spatial scales, the relative influence of natural variations in climate compared to the  
8 human contribution is larger than at the global scale.

9 Many scientists prefer the term “climate change,” which connotes a much larger picture: broad  
10 changes in what are considered “normal” conditions. This definition encompasses both increases  
11 and decreases in temperature, as well as shifts in precipitation, changing risk of severe weather  
12 events, and other features of the climate system.

13 At the global scale, it is virtually certain that some future years will be cooler than the preceding  
14 year and likely that some decadal periods will be cooler than the preceding decade. Brief periods  
15 of faster temperature increases and also temporary decreases in global temperature can be  
16 expected to continue into the future. Nonetheless, each successive decade in the last 50 years has  
17 been the warmest on record, and the period from 2000 to 2010 was the warmest decade in at  
18 least the last 2,000 years. It is virtually certain that future global temperatures averaged over  
19 climate timescales of 30 years or more will be higher than preceding periods, and that global  
20 temperature will continue to increase throughout the remainder of this century as a result of heat-  
21 trapping gas emissions that have already been emitted from human activities, as well as future  
22 emissions. Regional and local temperatures exhibit greater variability than global temperatures,  
23 but even at a particular location, warming becomes increasingly likely as the timeframe  
24 lengthens.



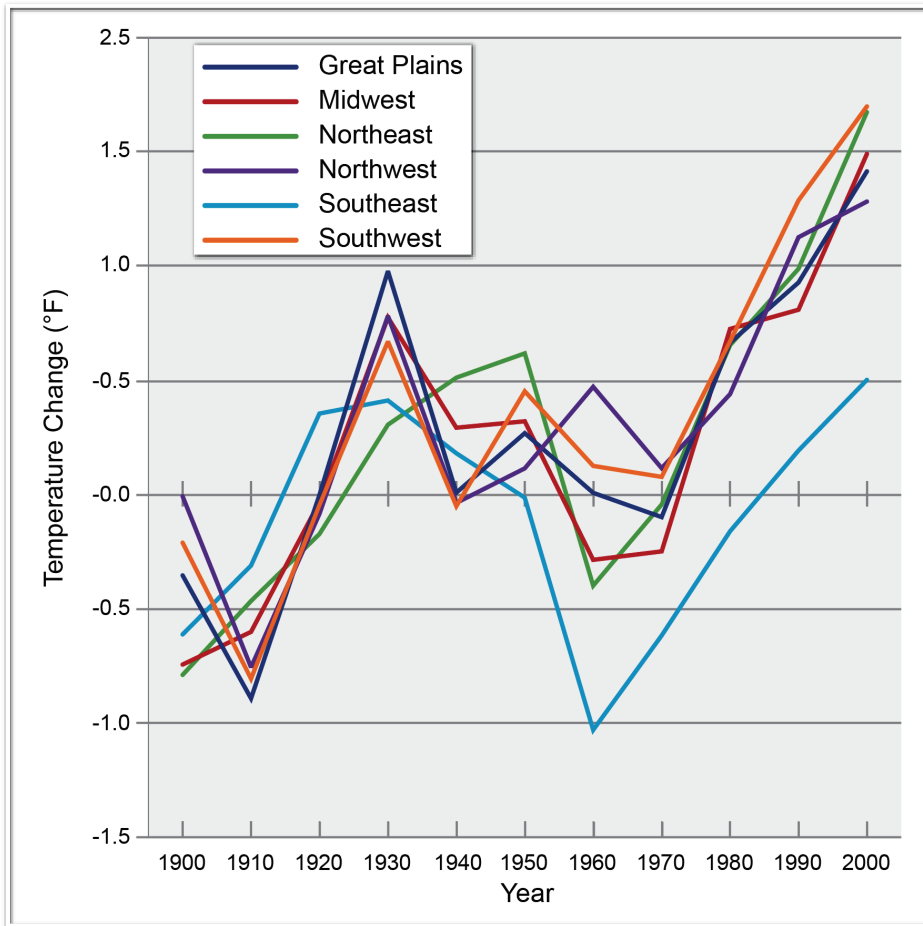
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**Figure 8: Temperature Trends, 1900-2009**

3 **Caption:** Observed trend in temperature from 1900 to 2009; yellow to red indicates  
4 warming, while blue indicates cooling. There are substantial regional variations in trends  
5 across the planet. For example, for the U.S., annual, winter, and spring temperatures are  
6 rising. In the summer, temperatures are rising in the Northwest, Southwest, and  
7 Northeast, but not in the Southeast, Midwest, and southern Great Plains. The lack of  
8 warming in the Southeast and in the Midwest and Great Plains summers is unusual in a  
9 global context, and has been dubbed the “warming hole.” These patterns exist because  
10 global circulation patterns transmit water and energy from the oceans across the land  
11 through a number of complicated mechanisms, such as the “jet stream” that moves from  
12 west to east in patterns that have been relatively consistent and predictable over time.  
13 Some of these mechanisms are now shifting in response to increased warming of the  
14 oceans and the atmosphere. Source: NOAA NCDC.

Regional Time Series of Decadal Average Temperature Change



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**Figure 9: Regional Time Series of Decadal Average Temperature Change**

**Caption:** Time series of decadal-averaged annual temperature (°F) for the six regions of the contiguous U.S. (Figure source: NOAA NCDC / CICS-NC)

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

2 The scientific basis for understanding how heat-trapping gases can affect the Earth's climate  
3 dates back to the French scientist and philosopher Joseph Fourier, who established the existence  
4 of the natural greenhouse effect in 1824. The heat-trapping abilities of greenhouse gases were  
5 corroborated by Irish scientist John Tyndall with experiments beginning in 1859.

6 The greenhouse effect is the result of heat-trapping gases, such as water vapor, carbon dioxide,  
7 and methane, in the Earth's atmosphere. These gases are virtually transparent to the Sun's  
8 energy, allowing nearly all of it to reach the Earth's surface. However, they are relatively opaque  
9 to the heat energy the Earth radiates back outward, trapping some of it inside the atmosphere and  
10 preventing it from escaping to space. Some of the trapped energy is re-radiated back down to the  
11 Earth's surface. This natural trapping effect makes the average temperature of the Earth nearly  
12 60°F warmer than what it would be otherwise.

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

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

23 In 1938, a British engineer, Guy Callendar, connected rising carbon dioxide levels to the  
24 observed increase in the Earth's temperature that had occurred to date. In 1958, Charles David  
25 Keeling began to measure atmospheric levels of carbon dioxide in the relatively unpolluted  
26 location of Mauna Loa on Hawai'i. Today, those data provide a clear record of the effect of  
27 human activities on the chemical composition of the global atmosphere.

28 Keeling's measurements maintain an accuracy and precision that allow scientists to separate  
29 fossil fuel emissions from natural sources, validating the work of scientists stretching back nearly  
30 two hundred years. Today, many more sources of data corroborate the work of these early  
31 pioneers in the field of climate science.



## A Brief History of Scientists Studying the Human Influence on Climate



**Figure 10: A Brief History of Scientists Studying the Human Influence on Climate**

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

3 Before the Industrial Revolution, natural levels of carbon dioxide in the atmosphere averaged  
4 around 280 parts per million (ppm). In other words, carbon dioxide made up about 0.028% of the  
5 volume of the atmosphere. Methane and nitrous oxide, other heat-trapping gases, made up even  
6 less, about 700 parts per billion (ppb) and 270 ppb, respectively. Over the last few centuries,  
7 emissions from human activities have increased carbon dioxide levels to more than 390 ppm.  
8 Over the same time period, methane and nitrous oxide levels in the atmosphere rose to around  
9 1800 ppb (parts per billion) and 320 ppb, respectively.

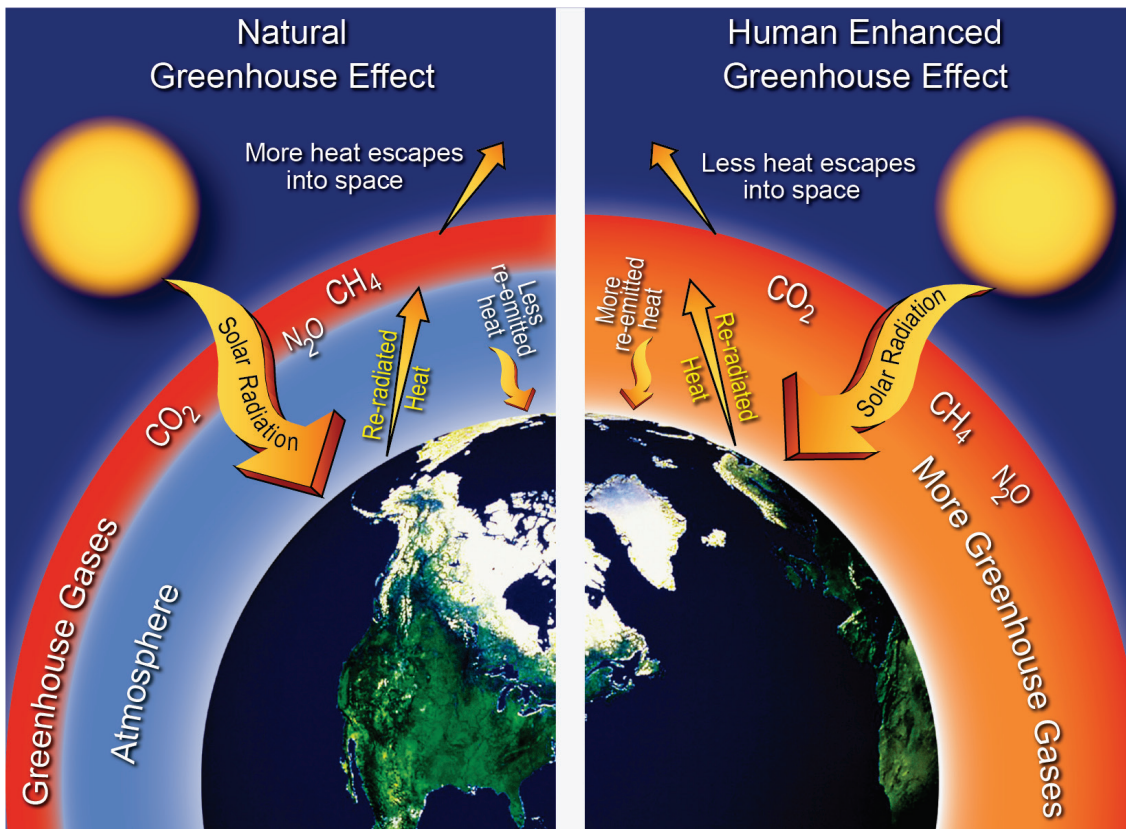
10 How could gases that make up such a small proportion of the atmosphere affect global climate?  
11 First, the amount of carbon dioxide contained in the atmosphere is more than 3,000 billion tons.  
12 That is the equivalent of over 16 billion blue whales, the largest known animal on Earth; not such  
13 a small amount after all. Second, we all know it's not the amount of a substance that matters, but  
14 the potency. A small amount of medicine can cure a disease; an amount of bacteria so small that  
15 they are invisible to the human eye can make us very sick.

16 The reason why heat-trapping gases like carbon dioxide, methane, and nitrous oxide have such  
17 an influence on Earth's climate is that they are transparent to visible and ultraviolet solar energy  
18 but are very strong absorbers of infrared heat energy. Water vapor is the most important naturally  
19 occurring heat-trapping greenhouse gas, but the amount of water vapor in the atmosphere tends  
20 to increase as the atmosphere warms – as a result, water vapor is considered a “feedback” rather  
21 than a direct forcing on climate.

22 Increases in atmospheric levels of heat-trapping gases like carbon dioxide, methane, and nitrous  
23 oxide, all of which are increasing because of human activities, enable these gases to absorb ever-  
24 increasing amounts of infrared heat energy. The gases absorb the infrared energy emitted from  
25 the Earth's surface and then radiate some of this heat back to the surface, effectively trapping the  
26 heat inside the Earth's climate system and warming the Earth's surface.

27 These heat-trapping gases do not absorb energy equally across the infrared spectrum. Carbon  
28 dioxide absorption is very strong at certain wavelengths of infrared radiation, whereas water  
29 vapor absorbs more broadly across most of the spectrum. Small increases in heat energy  
30 absorption by carbon dioxide and other heat-trapping gases can trigger increases in water vapor  
31 that amplify the infrared trapping, leading to further warming.

## Human Influence on the Greenhouse Effect



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### Figure 11: Human Influence on the Greenhouse Effect

**Caption:** **Left:** Naturally occurring heat-trapping gases, including water vapor, carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), and nitrous oxide (N<sub>2</sub>O), normally trap some of the Sun's heat, keeping the planet inhabitable as we know it. **Right:** Human activities, such as the burning of fossil fuels, are increasing levels of CO<sub>2</sub> and other heat-trapping gases, leading to an enhanced greenhouse effect. The result is global warming and unprecedented rates of climate change. (Figure source: National Park Service)

**1 H. Could the Sun or other natural factors explain recent climate changes?**

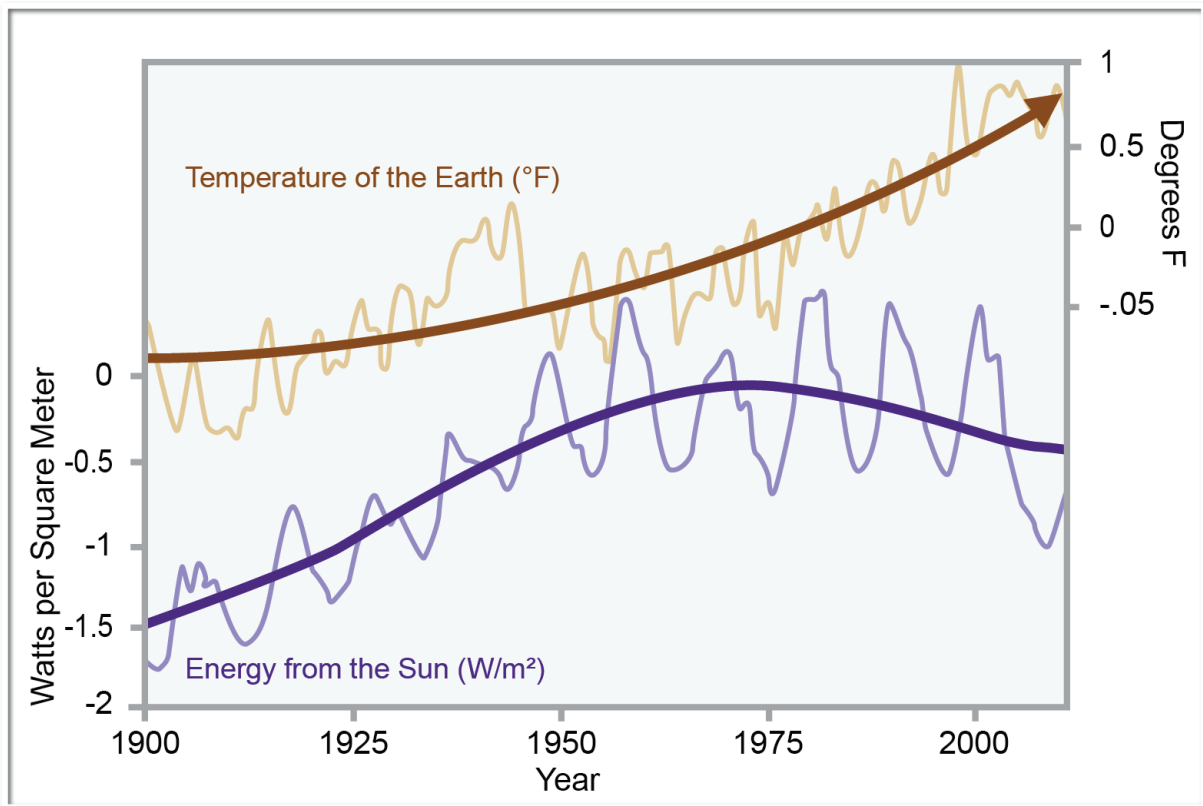
2 Changes in energy from the Sun are an important driver of the Earth's climate. Past proxy data  
3 (from ice cores, tree rings, and other evidence) reveal a generally good correlation between  
4 global temperature and changes in solar output. Over the last 50 years, however, temperature  
5 change cannot be explained by changes in the energy from the Sun. Since accurate satellite-  
6 based measurements of solar radiation began in 1978, the Sun's output has slightly decreased,  
7 which should result in slightly lower temperatures; but the Earth's temperature has continued to  
8 warm. All told, the Sun can explain less than 10% of the increase in temperature since 1750, and  
9 none of the increase in temperature since 1960.

10 Patterns of vertical temperature change (from the Earth's surface to the upper atmosphere)  
11 provide definitive evidence that the Sun cannot be responsible for the observed changes in  
12 climate. An increase in solar output would warm the atmosphere consistently from top to bottom.  
13 Warming from increasing heat-trapping gases, on the other hand, should be concentrated in the  
14 lower atmosphere. At the same time, heat-trapping gas-related warming would cool the upper  
15 atmosphere by reducing the amount of the Earth's infrared heat energy that reached it. This is  
16 exactly the pattern that has been observed. Satellite measurements and weather balloon records  
17 reveal that the troposphere has warmed and the stratosphere has cooled.

18 Large explosive volcanic eruptions can also cool climate for a few years after the eruption. In the  
19 atmosphere, sulfur dioxide from volcanoes is converted into sulfuric acid particles that can  
20 scatter sunlight, cooling the Earth's surface. Particles from exceptionally large eruptions like  
21 Pinatubo in 1991 or Krakatoa in 1883 can penetrate well into the stratosphere, where they can  
22 stay for several years. Eventually, they fall back into the troposphere where they are rapidly  
23 removed by precipitation. Volcanoes also emit carbon dioxide, but this amount is less than 1%  
24 annually of the emissions occurring from human activities.

25 Natural factors cannot explain recent warming. In fact, if global temperature over the last 50  
26 years were controlled by natural factors such as the Sun, it should have gotten cooler. Instead, it  
27 has warmed significantly.

## Global Temperature and Energy from the Sun



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### Figure 12: Global Temperature and Energy from the Sun

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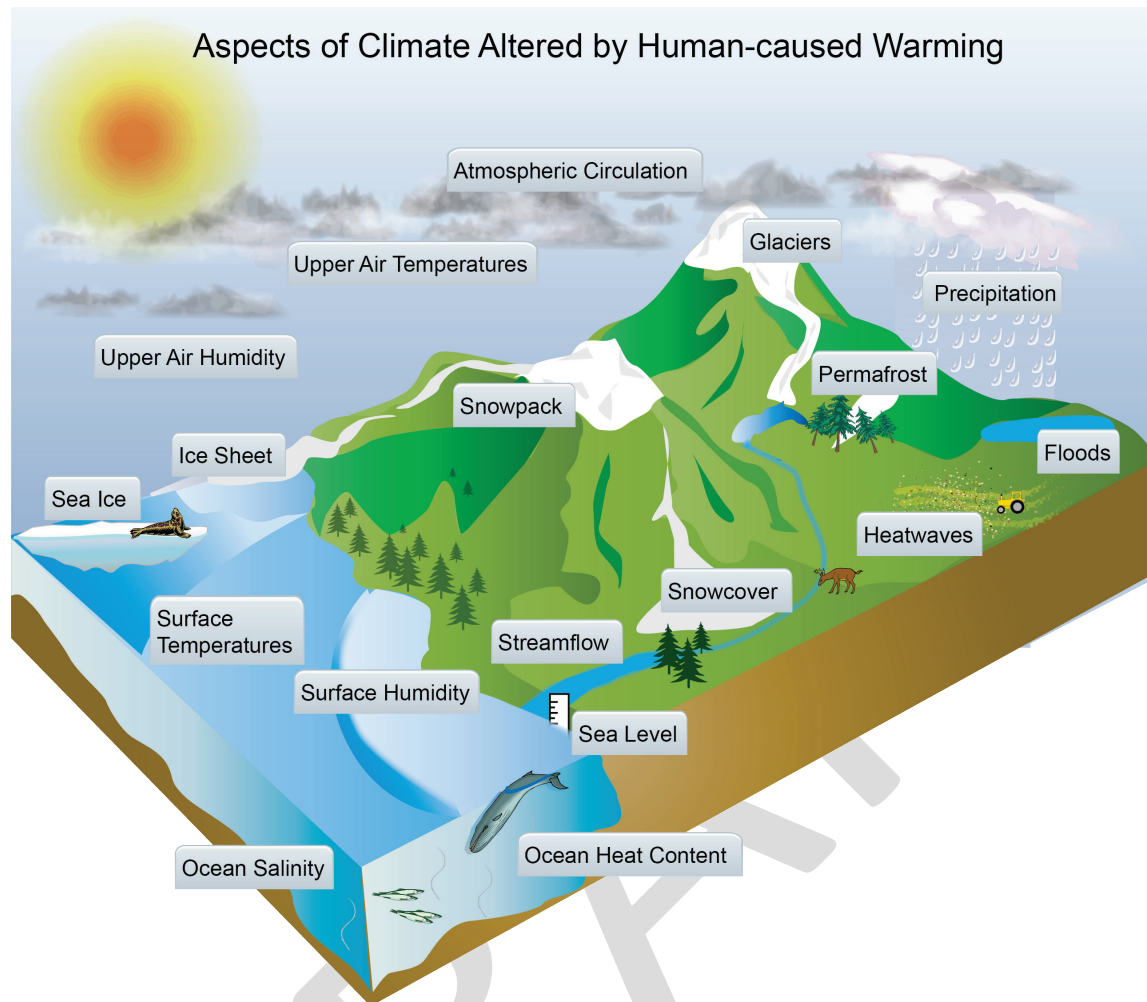
**Caption:** Changes in the global surface temperature and the solar flux since 1900 (relative to 1961-1990). The temperatures are based on observations, while the solar flux is based on satellite observations starting in 1978 and on proxy observations before then. The temperature data are from NASA GISS, and the TSI data (from 1880-1978) are from Krivova et al, (2007) and (from 1979-2010) PMOD.

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

2 Scientists are continually designing experiments to test whether observed climate changes are  
3 unusual and what the causes of these changes may be. This field of study is known as “detection  
4 and attribution.” Detection is simply looking for evidence of unusual changes or trends.  
5 Attribution attempts to identify the causes of these changes from a line-up of “prime suspects”  
6 that include changes in energy from the Sun, powerful volcanic eruptions, or human emissions of  
7 heat-trapping gases.

8 Such studies have clearly shown that human activities are primarily responsible for recent  
9 climate changes. Detection and attribution analyses have confirmed that a wide variety of recent  
10 changes (see CAQs C and H) cannot have been caused either by internal climate system  
11 variations or by solar and volcanic influences alone. Human influences on the climate system –  
12 including heat-trapping gas emissions, atmospheric particulates, land-use and land-cover change  
13 – are required to explain recent changes.

14 Detection and attribution has been used to quantify the contribution of human influences to  
15 changes in global average conditions, in extreme events, and even in the risk of specific types of  
16 events, such as the 2003 European heat wave. Such analyses have found it impossible to explain  
17 observed changes in many aspects of the climate system without including the influences of  
18 human activities on climate. Scientific analyses also provide extensive evidence that the  
19 likelihood of some types of extreme events (such as heavy rains, heat waves, and strong  
20 hurricanes) is now significantly higher due to human-induced climate change.

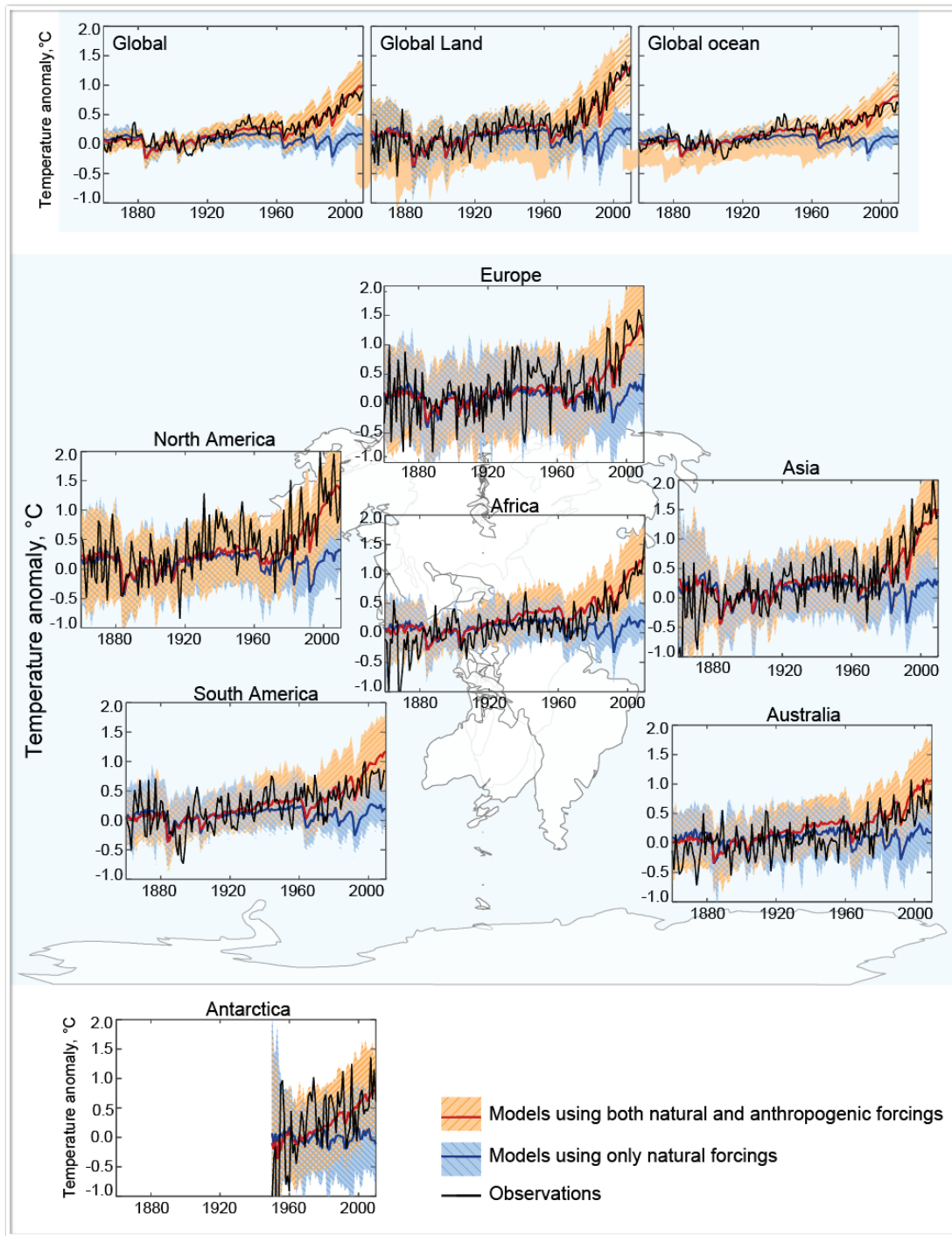


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**Figure 13: Aspects of Climate Altered by Human-caused Warming**

**Caption:** Figure shows some parts of the climate system in which changes have been attributed to human activities. 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 accounted for 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 single most significant contributor to recently observed climate changes. (Figure source: NOAA NCDC)

### Only Human Influences Can Explain Recent Warming



1

2 **Figure 14: Only Human Influences Can Explain Recent Warming**

3 **Caption:** Detection and attribution of surface air temperature changes at continental and  
 4 global scales. The black line depicts the observed changes in ten-year averages. The blue  
 5 shading represents estimates from a broad range of climate simulations including solely



1 natural (solar and volcanic) changes in forcing. The pink shading adds in the effects of  
2 including human contributions. It is impossible to explain the observed changes both  
3 globally and on a continent-by-continent basis without including the influence of human  
4 activities on climate. (Source: Jones et al. submitted)

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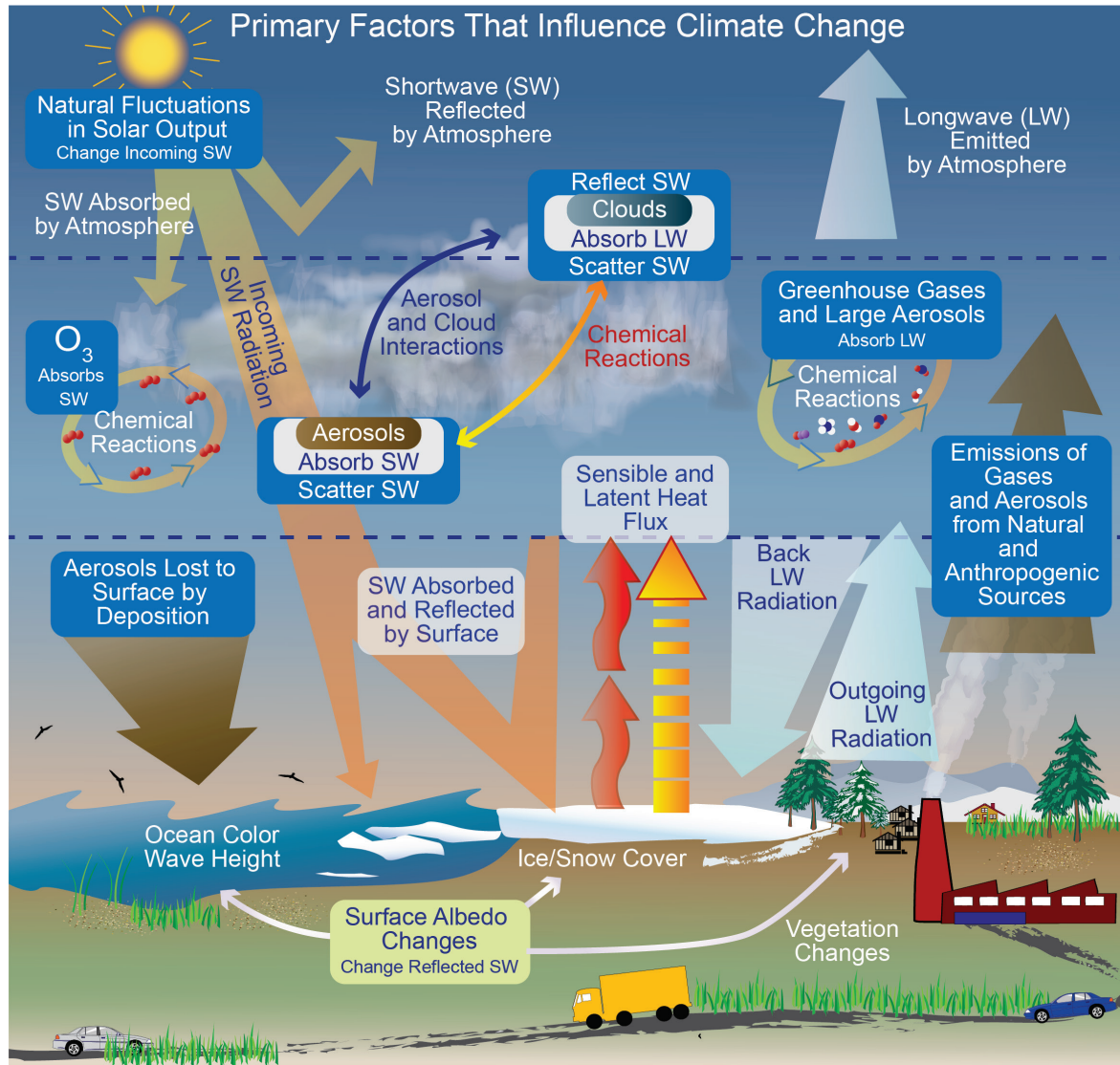
**1 J. What is and is not debated among climate scientists about climate change?**

2 The scientific method is built on scrutiny and debate among scientists. Scientists are rigorously  
3 trained to conduct experiments to test a question, or hypothesis, and submit their findings to the  
4 scrutiny of other experts in their field. Part of that scrutiny, known as “peer review,” includes  
5 independent scientists examining the data, analysis methods, and findings of a study that has  
6 been submitted for publication. This peer review process provides quality assurance for scientific  
7 results, ensuring that anything published in a scientific journal has been reviewed and approved  
8 by other independent experts in the field, and that the authors of the original study have  
9 adequately responded to any criticisms or questions they received. However, peer review is only  
10 the first step in the long process of acceptance of new ideas. After publication, other scientists  
11 will often undertake other studies that may support or reject the findings of the original study.  
12 Only after an exhaustive series of studies over many years, by many different research groups,  
13 are new ideas widely accepted.

14 Given the fact that science is built on the premise of criticism rather than consensus, the  
15 widespread agreement in the scientific community regarding the reality of climate change and  
16 the leading role of human activities in driving this change is nothing short of remarkable. More  
17 than 97% of scientists in this field agree that the world is unequivocally warming and that human  
18 activity is the primary cause of the warming experienced over the past 50 years.

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

26 This does not mean we have perfect understanding of climate change. Spirited debates on some  
27 details of climate science continue. These debates focus on questions such as: Exactly how  
28 sensitive is the Earth’s climate to human emissions of heat-trapping gases? How will climate  
29 change affect clouds? How do particle and soot emissions affect clouds? How will climate  
30 change be affected by changes in clouds and the oceans? All these questions and more serve as  
31 healthy indicators that the scientific method is alive and well in the field of climate science. But  
32 the primary role of human activities in driving recent change is not in dispute (see CAQ I).



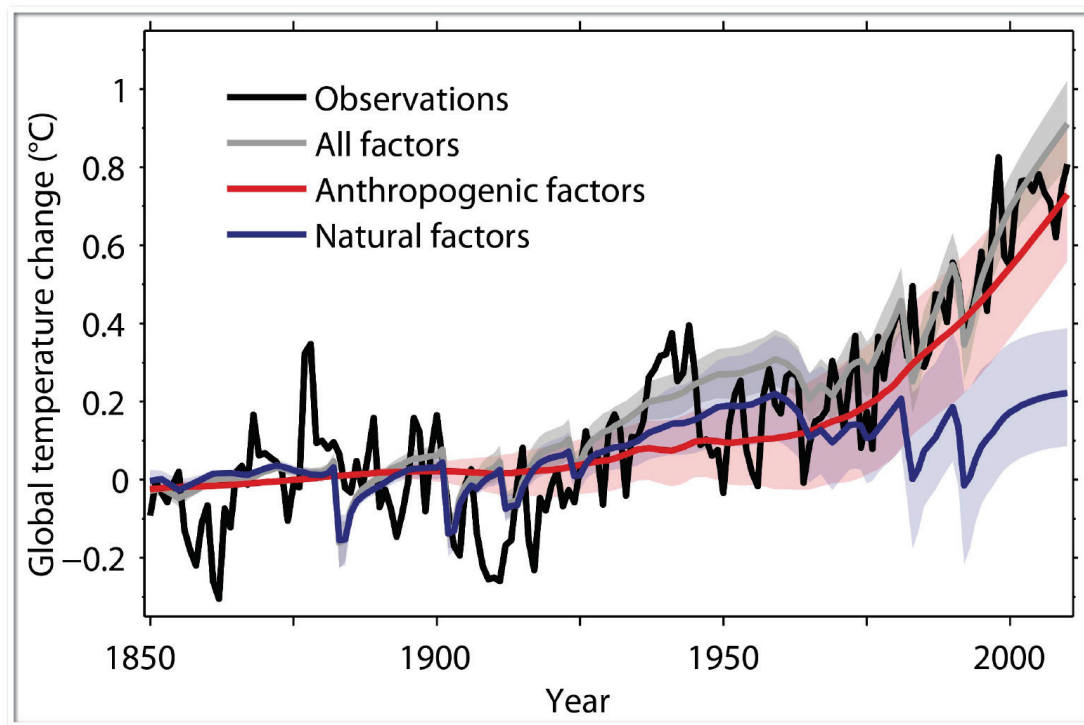
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**Figure 15: Primary Factors That Influence Climate Change**

**Caption:** Main drivers of climate change. The energy balance between incoming solar short wave (SW) radiation and outgoing long wave (LW) radiation is influenced by global climate “drivers.” Natural fluctuations in solar output (solar cycles) can cause changes in the amount of incoming SW radiation. Human activity changes the emissions of gases and particles, which are involved in atmospheric chemical reactions, resulting in modified ozone and aerosol amounts. Ozone and aerosols scatter and reflect SWR, changing the energy balance. Some aerosol particles act as cloud condensation nuclei, modifying the properties of cloud droplets. Because clouds interact strongly with both SW and LW radiation, small changes in the properties of clouds have important implications for the radiative budget. Human-caused changes in the concentrations of heat-trapping gases and large particles in the atmosphere modify the LWR portion of the energy balance by absorbing more outgoing LWR and reemitting less energy from altitudes having a lower temperature. The albedo (reflectivity) of the surface varies over

1 time and by location with changes in vegetation or land surface cover, snow or ice cover,  
 2 and ocean color. These changes are driven both by naturally occurring seasonal and  
 3 diurnal changes (for example, changes in snow cover from winter to summer), as well as  
 4 human influences (for example, changes in vegetation height). (Need Source)

### Natural and Human Contributions to Temperature Change



5  
 6 **Figure 16: Natural and Human Contributions to Temperature Change**

7 **Caption:** Relative contributions to global temperature changes since 1850. Black line  
 8 represents observed temperatures. Blue line indicates the modeled contribution of natural  
 9 factors to global temperatures. The red line indicates the contribution of human-caused  
 10 factors. The gray line represents the combined total of natural and human-caused factors.  
 11 The human-caused contribution dominates the temperature increase in recent decades.  
 12 (Source: adapted from Huber and Knutti, 2011)

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

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

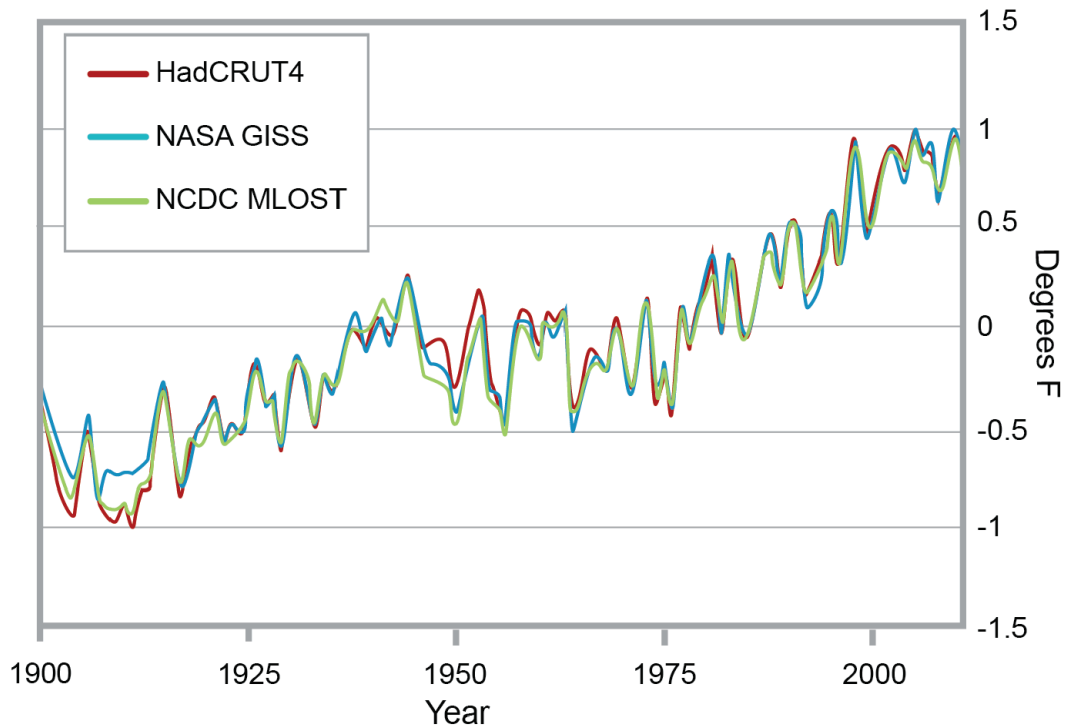
6 Scientists have undertaken painstaking efforts to obtain, digitize, and collate these records.  
7 Because of the way these measurements have been taken, many of the records contain  
8 extraneous effects caused by, for example, a change of instrument or a station move. It's  
9 essential to carefully examine the data to identify and adjust for such effects before the data can  
10 be used to estimate any change in climate.

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

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

23 There have been a number of studies that have examined the U.S. and global temperature records  
24 in great detail. These have used different ways to study the effects of instrument changes,  
25 observations changes, site moves, and other sources of error. All studies reinforce high  
26 confidence in the reality of the observed upward trends in temperature.

## Changes in Observed Global Average Temperature



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### **Figure 17: Changes in Observed Global Average Temperature**

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**Caption:** Temperature time series from three global surface records on land and oceans.

4

Thin lines show annual differences in temperature relative to the 1961-1990 average.

5

Differences between datasets arise from different choices in data selection, analysis, and

6

averaging to form a global mean. These differences are small and do not affect the

7

conclusion that the global surface temperatures are increasing. (Need Source)

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

2 The Antarctic region is characterized by two distinct types of ice: the ice sheet overlying the  
3 Antarctic continent itself, and the sea ice that lies on top of the Southern Ocean surrounding the  
4 Antarctic continent. Antarctic sea ice cover expands seasonally, covering about 5.8 million  
5 square miles at the end of winter and shrinking to about 0.8 million square miles at the end of  
6 summer. Because sea ice is simply frozen seawater at the top of the ocean, it does not affect  
7 global sea level. Since continuous satellite coverage began in the 1970s, Arctic summer sea ice  
8 has decreased substantially, but there has been little trend in Antarctic summer sea ice, in part  
9 because it already disappears around much of the continent.

10 The Antarctic ice sheet, consisting of a thick glacial ice (up to 3 miles deep) that was originally  
11 deposited as snow, is a different story. The amount of water locked up in the present-day  
12 Antarctic ice sheet is enough to raise sea level about 200 feet. Because Antarctica is so cold,  
13 there is little melt of the ice sheet in the summer. However, the ice on the continent slowly flows  
14 down the mountains and through the valleys toward the ocean. Some parts of the ice sheet extend  
15 out into the ocean as “ice shelves.” Here, above-freezing ocean water speeds up the process  
16 called “calving” that breaks the ice into free floating icebergs.

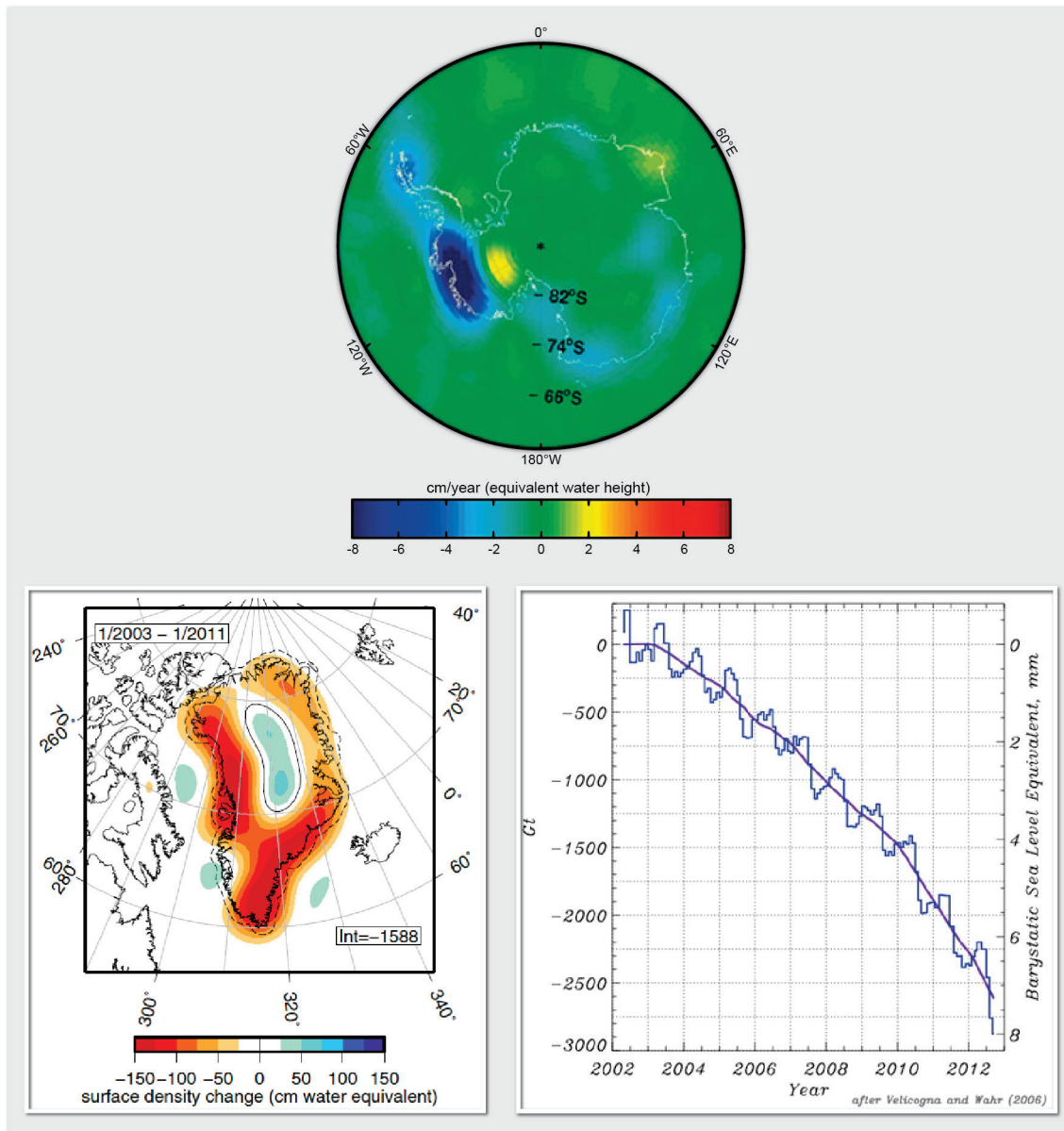
17 There is evidence that melting and calving and the flow of ice into the oceans around Antarctica  
18 has accelerated in recent decades and is now contributing about 0.005 to 0.010 inches per year to  
19 sea level rise. There is concern that the West Antarctic Ice Sheet, which sits partly below sea  
20 level and contains enough ice to raise global sea levels by 10 feet, could begin to lose ice much  
21 more quickly if ice shelves in the region begin to disintegrate at the edges.

22 Greenland contains only about one tenth as much ice as the Antarctic ice sheet, but if  
23 Greenland’s ice were to entirely melt, global sea level would rise 23 feet. (In Antarctica, only the  
24 melting of the West Antarctic ice sheet is considered plausible in the next few centuries.)  
25 Greenland is warmer than Antarctica and in a region where air and ocean temperatures are rising.  
26 Unlike Antarctica, melting occurs over large parts of the surface of Greenland’s ice sheet each  
27 summer. Greenland’s melt area has increased over the past several decades. Satellite  
28 measurements indicate that the Greenland ice sheet is presently thinning at the edges (especially  
29 in the south) and slowly thickening in the interior, increasing the steepness of the ice sheet,  
30 which causes the ice to flow toward the ocean. Several of the major outlet glaciers that drain the  
31 Greenland ice sheet have sped up in the past decade. Recent scientific studies suggest that  
32 warming of the ocean at the edges of the outlet glaciers may contribute to this speed-up.  
33 Regardless of the mechanism, it appears that Greenland’s ice loss has increased substantially in  
34 the past decade or two, and is now 0.01 to 0.02 inches per year (about twice the rate of  
35 Antarctica’s mass loss). This increased rate of ice loss means that Greenland’s contribution to  
36 global sea level rise is now similar to the effect from smaller glaciers worldwide and from  
37 Antarctica.

38 Together, ice sheet melt from Greenland and Antarctica represents the largest uncertainty in  
39 projections of future sea level rise.

40

## Evaluating Ice Loss



**Figure 18: Evaluating Ice Loss**

**Caption:** Scientists can evaluate ice loss 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 that show where the ice sheets are losing mass to the oceans. The blue regions in the figures show where the ice is getting thinner. The GRACE satellites have proven that on the whole, both Greenland and Antarctica are losing ice as the atmosphere and oceans warm. Source: top: NASA; bottom left, Harig and Simons (2012); bottom right, NOAA 2012 adapted from Velicogna and Wahr (2006). (Need Source)



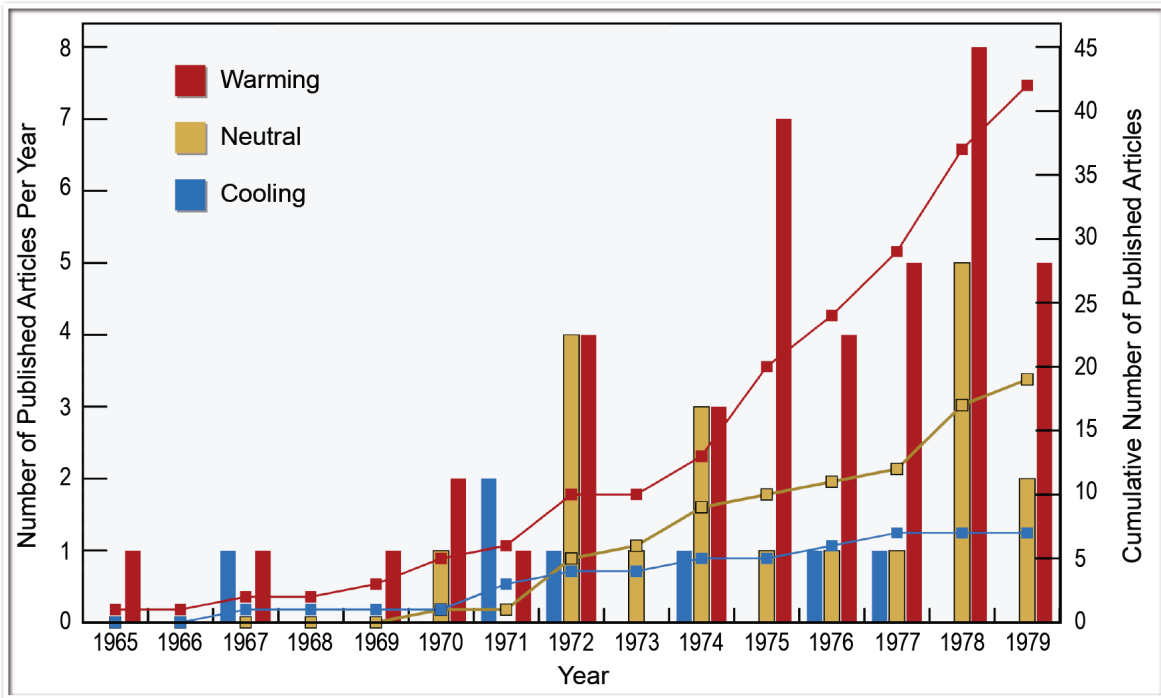
1 **M. What about global cooling predictions in the 1970s?**

2 An enduring myth about climate science is that in the 1970s the climate science community was  
3 predicting “global cooling” and an “imminent” ice age. A review of the scientific literature  
4 suggests that this was not the case. On the contrary, even then, discussions of human-related  
5 warming dominated scientific publications on climate and human influences.

6 Where did all the discussion about global cooling come from? First, temperature records from  
7 about 1940 to 1970 show a slight global cooling trend, intensified by temporary increases in  
8 snow and ice cover across the Northern Hemisphere. Unusually severe winters in Asia and parts  
9 of North America in 1972 and 1973 raised people’s concerns about cold weather. The popular  
10 press, including *Time*, *Newsweek*, and *The New York Times*, carried a number of articles about  
11 the cooling climate at that time.

12 Second, climate scientists study both natural and human-induced changes in climate. Over the  
13 last century, scientists have continued to try to understand when and why the Earth slipped into  
14 and out of ice ages. Confirmation of what are called the Milankovitch cycles (cyclical changes in  
15 the Earth’s orbit that explain the onset and ending of ice ages) led a few scientists in the 1970s to  
16 suggest that the current warm interglacial period might be ending soon, plunging the Earth into a  
17 new ice age over the next few centuries. Scientists continue to study this issue today; the latest  
18 information suggests that, if the Earth’s climate were being controlled primarily by natural  
19 factors, the next glaciation would begin sometime in the next 1,500 years. However, humans  
20 have so altered the composition of the atmosphere that the next glaciation has now been delayed  
21 indefinitely.

### Climate Change Literature Survey



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**Figure 19: Climate Change Literature Survey**

**Caption:** The number of papers classified as predicting, implying, or providing supporting evidence for future global cooling, warming, and neutral categories. For the period 1965 through 1979, the literature survey found seven papers suggesting further cooling, 20 neutral, and 44 warming. Based on Peterson et al. (2008).

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

2 Future climate cannot be “predicted” because we cannot predict what society will choose to do  
3 with regard to emissions. Rather, climate can be projected given various assumptions regarding  
4 future human activities and the response of the climate system to those influences.

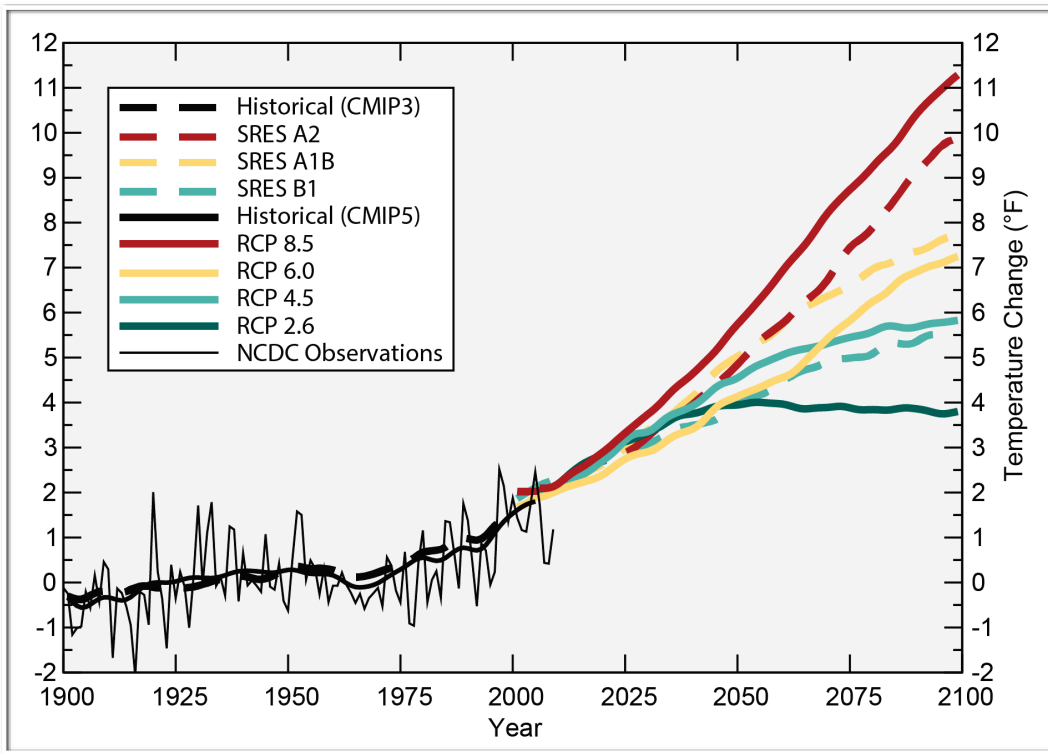
5 The relative importance of various sources of uncertainty changes over time. The uncertainties  
6 also depend on what type of change is being projected: whether in average conditions or  
7 extremes, or in temperature or precipitation, and so on. (see CAQ S).

8 Over the next few decades, global average temperature over 30-year climate timescales is  
9 expected to continue to increase (see CAQ D). The amount of climate change expected over this  
10 time period cannot be altered by reducing heat-trapping gas emissions or even by stabilizing  
11 atmospheric levels of carbon dioxide and other gases. This is because near-term warming will be  
12 caused primarily by emissions that have already occurred. There is a lag in the climate system’s  
13 response to changes in atmospheric composition. This lag is primarily the result of the very large  
14 heat storage capacity of the world’s oceans and the mixing time to the deep ocean. At smaller  
15 geographical scales, temperatures are projected to increase in most regions in the next few  
16 decades, but a few regions could experience temperature decreases – any climate change always  
17 represents the net effect of multiple global and local factors, both human-related and natural (see  
18 CAQ E).

19 Beyond the middle of this century, global and regional temperature will be determined primarily  
20 by the course of human emissions, as well as by the response of the Earth’s climate system to  
21 those emissions. Efforts to rapidly and significantly reduce emissions of heat-trapping gases can  
22 still limit the global temperature increase to 3.6°F (2°C). However, significantly greater  
23 temperature increases are expected if emissions follow higher scenarios associated with  
24 continuing growth in the use of fossil fuels; in that case, the increase in global air temperatures  
25 could exceed 12°F by the end of this century.

26 Precipitation patterns are also expected to continue change by the end of this century. In general,  
27 wet areas are projected to get wetter and dry areas, drier. In some areas, located in between  
28 wetter and drier areas, the total amount of precipitation falling over the course of a year is not  
29 expected to significantly change. Following the observed trends over recent decades, more  
30 precipitation is expected to fall as heavier precipitation events. In many mid-latitude regions,  
31 including the U.S., there will be fewer days with precipitation but the wettest days will be wetter.

### Average U.S. Temperature Projections



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**Figure 20: Average U.S. Temperature Projections**

**Caption:** Projected average annual temperature changes (°F) over the contiguous U.S. for multiple future emissions scenarios relative to the 1901-1960 average temperature. The dashed lines are results from the previous generation of climate models. The solid lines are results from the most recent generation of climate models. Differences in these projections are principally a result of differences in the emissions scenarios. Source: CMIP3, CMIP5, NOAA, 2012.

1 **O. Does climate change affect severe weather?**

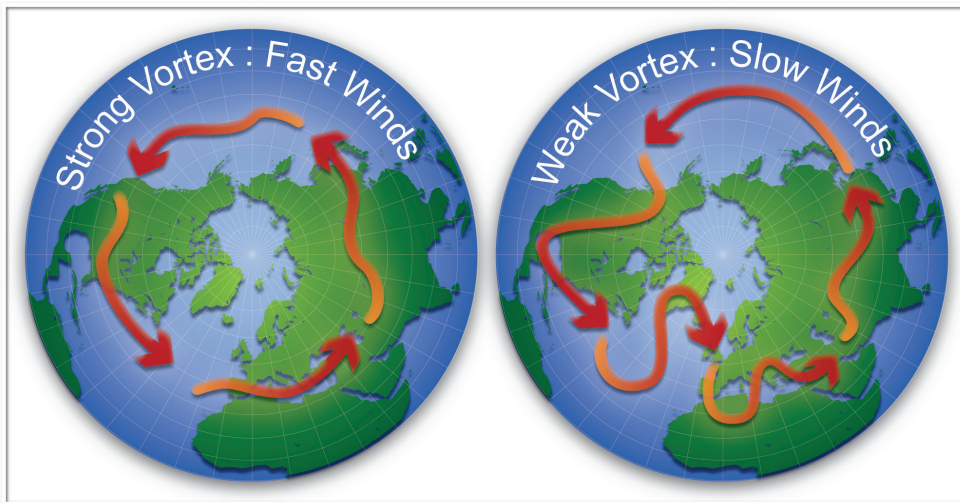
2 The harmful effects of severe weather raise concerns about how the risk of such events might be  
3 altered by climate change. An unusually warm month, a major flood or a drought, a series of  
4 intense rainstorms, an active tornado season, landfall of a major hurricane, a big snowstorm, or  
5 an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

7 Climate change can and has altered the risk of some extreme events. For example, more extreme  
8 high temperatures and fewer extreme cold temperatures occur in a warmer climate (but extreme  
9 cold events can and do still occur). In the U.S., twice as many hot temperature records than cold  
10 records were broken in the decade of 2000-2010. Also, in many areas, floods and droughts are  
11 more likely as the climate changes. Climate change can alter atmospheric circulation and weather  
12 patterns, affecting the location and frequency of these and other extremes. However, for many  
13 extreme weather events important to the U.S., such as tornadoes, more research is needed to  
14 understand how climate change will affect them.

15 While there is always a chance that particular extreme events may have occurred naturally, from  
16 a statistical perspective, the likelihood of some of these events has clearly increased due to  
17 climate change.

18 The analogy of a baseball player who takes steroids may be useful in understanding how human  
19 and natural factors affect extreme weather. Without steroids, a very good baseball player will hit  
20 some home runs. Steroids will increase the likelihood of his doing so. While the effect will not  
21 be apparent each time the player bats, his long-term average performance will show a change.  
22 Similarly, with the “steroids” of heat-trapping gases added to the atmosphere, some types of  
23 extreme climate and weather events have become more frequent and/or intense due to climate  
24 change.

## Blocking of Jet Stream



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**Figure 21: Blocking of Jet Streams**

**Caption:** Examples of jet streams showing typical eastward flow (left) and a blocking pattern (right). The blocking pattern leads to persistent extremes of temperature and precipitation in different regions. Recent studies suggest that blocking may become more common if the present pattern of warming (greater in higher latitudes than in lower latitudes) continues. (Redrawn by NOAA NCDC)

## 1 P. How are the oceans affected by climate change?

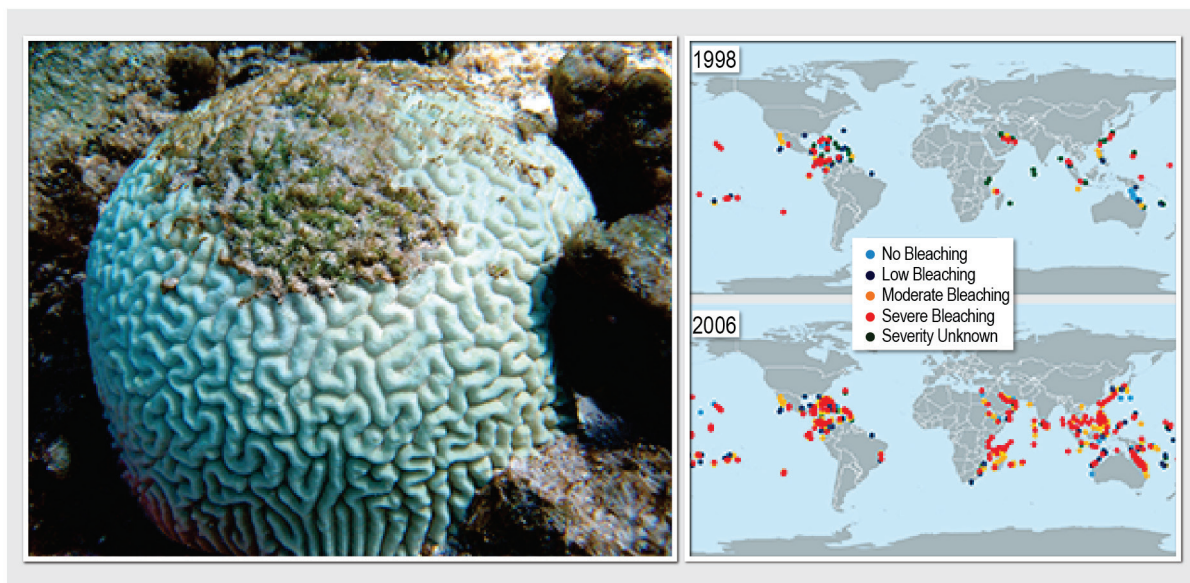
2 The oceans cover more than two-thirds of the Earth’s surface and play a very important role in  
 3 regulating the Earth’s climate and in climate change. Today, the world’s oceans absorb more  
 4 than 90% of the energy captured by human-emitted carbon dioxide and other heat-trapping  
 5 gases. This extra energy warms the ocean, causing it to expand. This in turn causes sea level to  
 6 rise. Of the 2.5 inches of global sea level rise observed over the last 35 years, about 1 inch is due  
 7 to this warming of the water. Most of the rest is due to the melting of glaciers and ice sheets.  
 8 Ocean levels are projected to rise another 1 to 4 feet over this century, with the difference largely  
 9 depending on the amount of global temperature rise and polar ice sheet melt.

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

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

21 In addition to the warming, the acidity of seawater is increasing. The oceans absorb about 25%  
 22 of the carbon dioxide released by fossil fuel burning every year. The dissolved carbon dioxide  
 23 reacts with seawater to form carbonic acid, which increases its acidity and reduces the  
 24 availability of calcium carbonate corals need to maintain their structure. Both the increased  
 25 acidity and higher temperature of the oceans are expected to negatively affect corals over the  
 26 coming decades and beyond.

### Coral Bleaching



27

1 **Figure 22: Coral Bleaching**

2 **Caption:** (left) Bleached brain coral (Credit: NOAA); (right) The global extent and  
3 severity of mass coral bleaching have increased worldwide over the last decade. (Source)

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**1 Q. What is ocean acidification?**

2 As human-related emissions of carbon dioxide build up in the atmosphere, excess carbon dioxide  
3 is also dissolving into the oceans, where it reacts with seawater to form carbonic acid. Calcium  
4 carbonate minerals are the building blocks for the skeletons and shells of many marine  
5 organisms. In areas with many marine organisms, the seawater is supersaturated with calcium  
6 carbonate minerals. This means there are abundant building blocks for calcifying organisms to  
7 build their skeletons and shells. However, continued ocean acidification is lowering the  
8 concentrations of these minerals in many parts of the ocean, affecting the ability of some  
9 organisms to produce and maintain their shells.

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

16 Ocean acidification is expected to affect ocean species to varying degrees. Photosynthetic algae  
17 and seagrasses may benefit from higher CO<sub>2</sub> conditions in the ocean, as they require CO<sub>2</sub> to live  
18 just like plants on land. On the other hand, studies have shown that a more acidic environment  
19 has dramatic negative effects on some calcifying species, including oysters, clams, sea urchins,  
20 shallow water corals, deep sea corals, and calcareous plankton. When shelled organisms are at  
21 risk, the entire food web may also be at risk.

## Ocean Acidification and the Food Web



22  
23 **Figure 23: Ocean Acidification and the Food Web**

24 **Caption:** The Pteropod, or “sea butterfly,” is a tiny sea creature about the size of a small  
25 pea. Pteropods are eaten by organisms ranging in size from tiny krill to whales and are a  
26 major source of food for North Pacific juvenile salmon. The photos above show what  
27 happens to a pteropod's shell when placed in seawater with a pH and carbonate levels  
28 projected for the year 2100. The shell slowly dissolves after 45 days. Photo credit:  
29 National Geographic Images.

**1 R. Should we trust the computer models of the Earth's climate?**

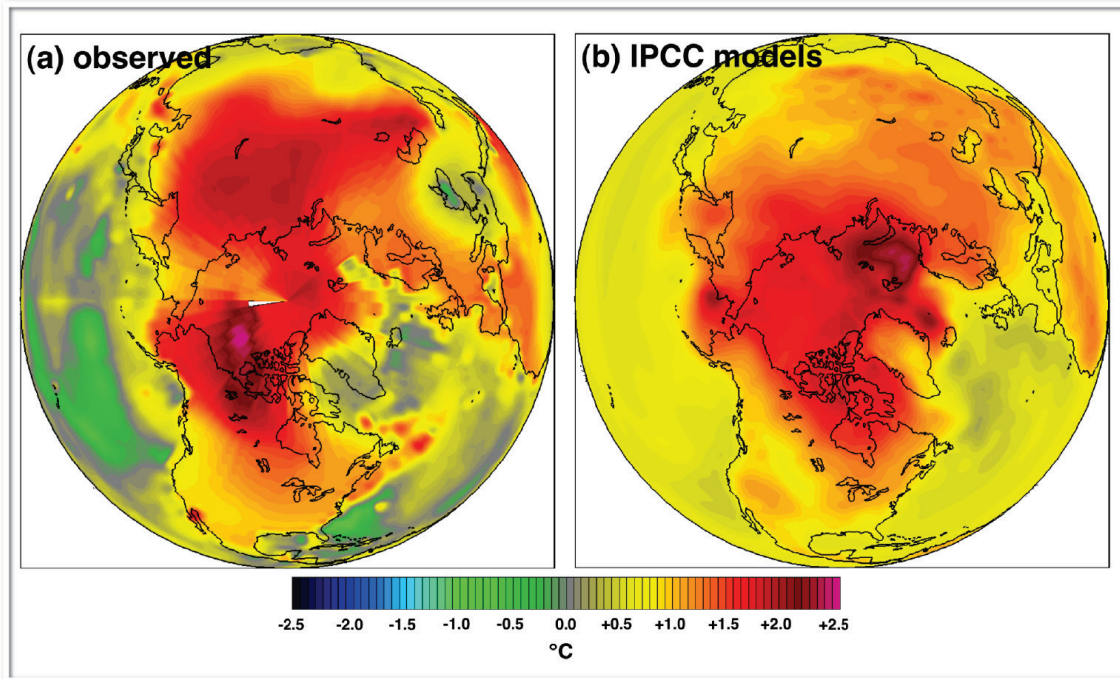
2 People depend on results generated by computer models every day. They are used to design  
3 airplanes, automobiles, houses, and control all of the electronics we use in our daily lives. In  
4 studying climate change, models serve as an important way to integrate different kinds of  
5 knowledge of how the climate system works.

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

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

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

## Climate Models and Temperature Change



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### Figure 24: Climate Models and Temperature Change

**Caption:** The geographical pattern and approximate magnitude of temperature changes over 50 years (1957-2006) 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 15 different global climate models used in the IPCC's Fourth Assessment Report.

**1 S. What are the key uncertainties about climate change?**

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

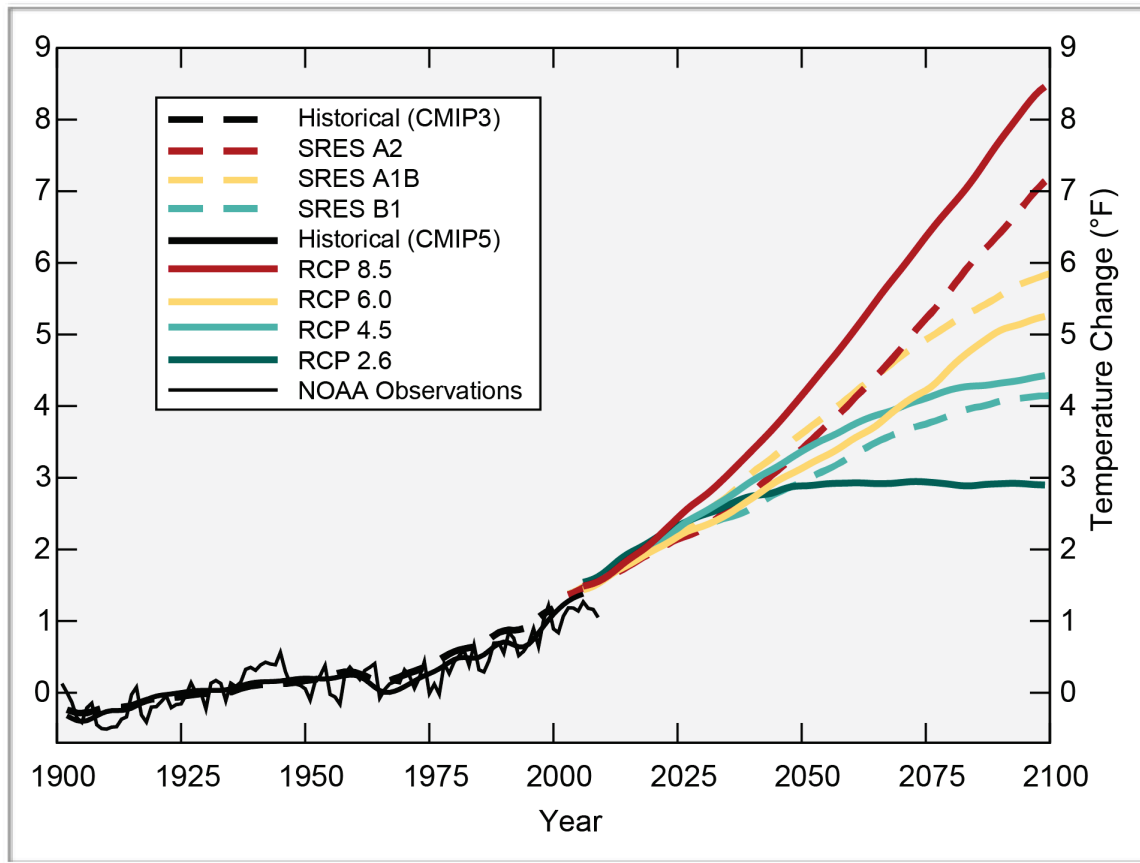
8 First, estimates of future climate changes are usually based on scenarios (or sets of assumptions)  
9 regarding how future emissions may change as a result of population, energy, technology, and  
10 economics. Society may choose to reduce emissions, or to continue to increase them. The  
11 differences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

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

22 A third source of uncertainty is scientific limitations. The Earth's climate system is complex, and  
23 continues to challenge scientists' understanding of exactly how it may respond to human  
24 influences. Observations of the climate system have grown substantially since the beginning of  
25 the satellite era, but are still limited. Climate models differ in the way they represent various  
26 processes (for example, cloud properties, ocean circulation, and turbulent mixing of air),  
27 although all of these representations are within the range of observations. As a result, different  
28 models produce slightly different projections of change, even when the models use the same  
29 scenarios.

30 Finally, there is always the possibility that there are processes and feedbacks not yet being  
31 included in future projections. In some cases, these feedbacks are already documented as  
32 occurring: for example, as the Arctic warms, methane and carbon dioxide trapped in permafrost  
33 is being released into the atmosphere, increasing the initial warming due to human emissions of  
34 heat-trapping gases (see CAQ T). However, for a given future scenario, the amount of future  
35 climate change can be specified within plausible bounds, determined not only from the  
36 differences in the "climate sensitivity" among models but also from information about climate  
37 changes in the past.

### Average Global Temperature Projections



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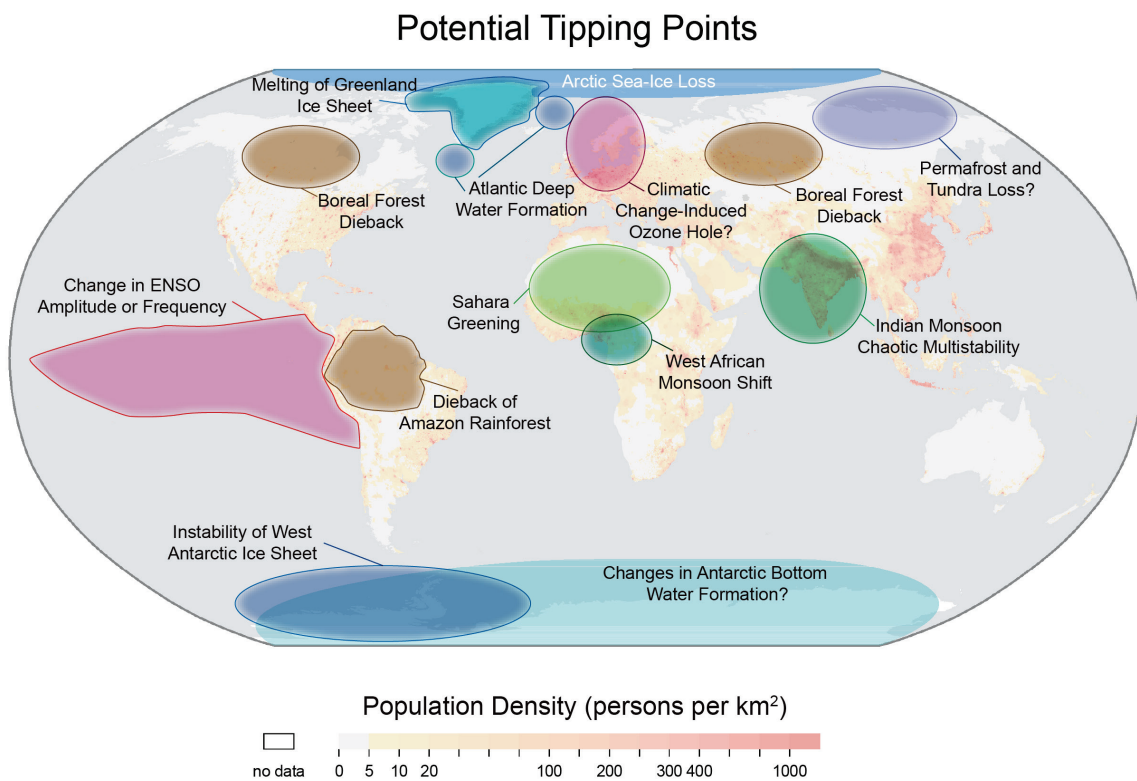
**Figure 25: Average Global Temperature Projections**

**Caption:** Projected global average annual temperature changes (degrees Fahrenheit) for multiple future emissions scenarios relative to the 1901-1960 average temperature. The dashed lines are results from the previous generation of climate models. The solid lines are results from the most recent generation of climate models. Differences in these projections are principally a result of differences in the emissions scenarios. (Figure source: Michael Wehner, LBNL. Data from CMIP3, CMIP5, and NOAA.)

1 **T. Are there tipping points in the climate system we should be concerned about?**

2 Most climate studies have considered only relatively gradual, continuous changes in the Earth’s  
3 climate system. However, there are a number of potential tipping points in the climate system, at  
4 which a small change in, for example, heat-trapping gas emissions, can cause a substantial  
5 change in the future state of a part of the climate system.  
6

7 Scientists have identified several elements in the climate system that could pass a tipping point  
8 this century and/or change substantially over this millennium under projected climate change.  
9 The tipping points have been identified based on observations of past abrupt climate changes,  
10 recent observations showing abrupt changes underway (for example, in the Arctic), process-  
11 based understanding of the dynamics of the climate system, and climate simulations showing  
12 tipping points in future projections.



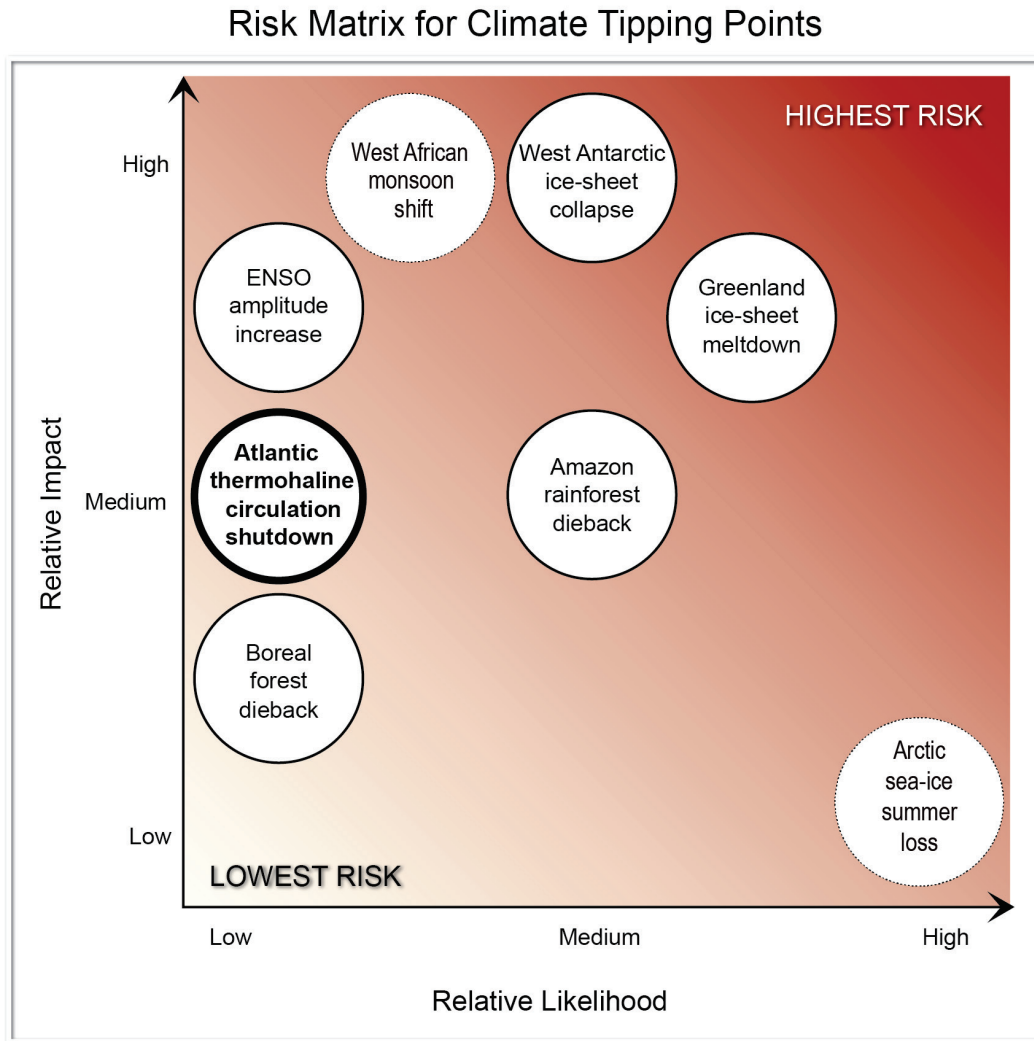
13  
14 **Figure 26: Potential Tipping Points**

15 **Caption:** Map of potential policy-relevant tipping elements in the Earth’s climate system  
16 overlain on population density. Question marks indicate systems whose status as tipping  
17 elements is particularly uncertain. (From Lenton et al. 2008).

18 We should be most concerned about those tipping points that are the most imminent (and thus  
19 the least avoidable), and those that would have the largest negative impacts. Generally, the more  
20 rapid and less reversible a transition is, the greater its impacts. Additionally, any amplifying  
21 effect on global climate change increases concern. For example, thawing permafrost releases  
22 heat-trapping gases, which leads to further warming and an acceleration of permafrost thaw. In

- 1 general, a tipping point may exist if a change of one element triggers additional processes that  
2 amplify the original change.
- 3 The proximity, rate, and reversibility of tipping points has been assessed through a mixture of  
4 climate modeling, literature review, and expert elicitation, but there is a need for more research  
5 into their impacts.
- 6 Climate scientists cannot predict when tipping points will be crossed, because of uncertainties in  
7 the climate system and because we do not know what pathway future emissions will take. But  
8 that does not mean that the risk should not be taken seriously. To use a medical analogy, just  
9 because your doctor cannot tell you the precise date and time that you will have a heart attack  
10 does not mean you should ignore medical advice to reduce your risk. Medical science is  
11 imperfect, just like climate science, but it can provide very useful advice regarding the risk of our  
12 actions and choices.

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**Figure 27: Risk Matrix for Climate Tipping Points**

**Caption:** An example risk matrix for climate tipping points. Relative likelihoods and impacts are assessed on a five-point scale: low, low-medium, medium, medium-high and high. Likelihood information comes from review of scientific literature and expert elicitation (lighter rings indicate systems not considered in expert elicitation). Impacts are based on limited research and subjective judgment, and are relative to the one system (bold ring) with multiple impacts studies. Impacts are considered on a time horizon of 1,000 years, assuming minimal discounting of impacts on future generations. Note that most tipping point impacts would be high if placed on an absolute scale, compared with other climate eventualities. Figure source: redrawn from Lenton (2011)



**1 U. Why should I care? How is climate change going to affect us?**

2 Multiple lines of evidence show that climate change is happening as a result of human activities.  
3 Climate change is altering the world around us, and these changes will become more and more  
4 evident with each passing decade.

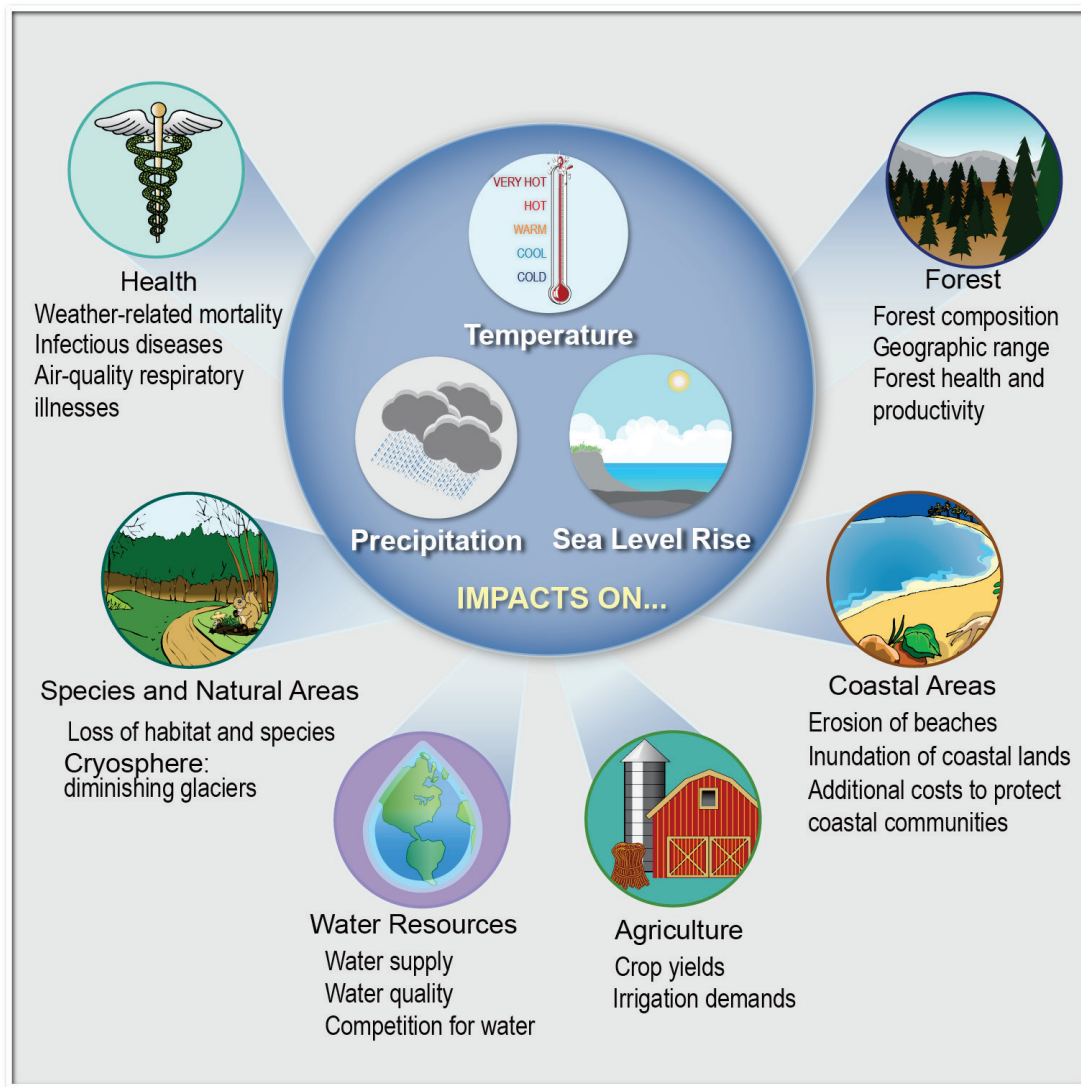
5 Climate change is already leading to more intense rainfall events and more extreme weather  
6 patterns. The changes in worldwide weather patterns will lead to more droughts in some area and  
7 more floods in others, as well as more frequent heat waves over many land areas. The risk  
8 associated with wildfires in the western U.S. is increasing, and coastal inundation is becoming a  
9 common occurrence in low-lying areas. Water supply availability is changing in many parts of  
10 the U.S.

11 Everyone on Earth will be affected by the changes that are occurring. To limit risks and  
12 maximize opportunities associated with the changes, people everywhere need to understand how  
13 climate change is going to affect them and what they can do to cope. There is significant  
14 likelihood that climate change will affect ecosystems and human systems – such as agricultural,  
15 transportation, water resources, and health infrastructure – in ways we are only beginning to  
16 understand. Moreover, climate change can interact with other stressors, such as population  
17 increase, land use change, and economic and political changes, in ways that we may not be able  
18 to anticipate, compounding the risks.

19 Although some impacts will likely be beneficial within limited sectors and regions, overall these  
20 changes will be costly. We do not have a choice about whether we will adapt, the choice is  
21 between proactive adaptation (where we plan ahead to limit the impacts) or reactive adaptation  
22 (where responses occur after the damage is already unavoidable).

23 In general, the larger and faster the changes in climate are, the more difficult it will be for human  
24 and natural systems to adapt. The climate system has been relatively stable during the time that  
25 human civilizations have been built, but the current pace of change is accelerating. Essentially,  
26 today's built infrastructure has been developed based on an assumption of "stationarity" in the  
27 climate. This assumption is likely no longer valid. This presents both challenges and  
28 opportunities for society as a whole as well as individual sectors and regions.

## Potential Effects of Climate Change



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**Figure 28: Potential Effects of Climate Change**

**Caption:** Climate change is likely to affect us in many ways. (Figure source: adapted from Phillippe Rekacewicz UNEP/GRID-Arendal 2012; Figure is from “Vital Climate Graphics” collection)

**1 V. Won't more warming be good for us?**

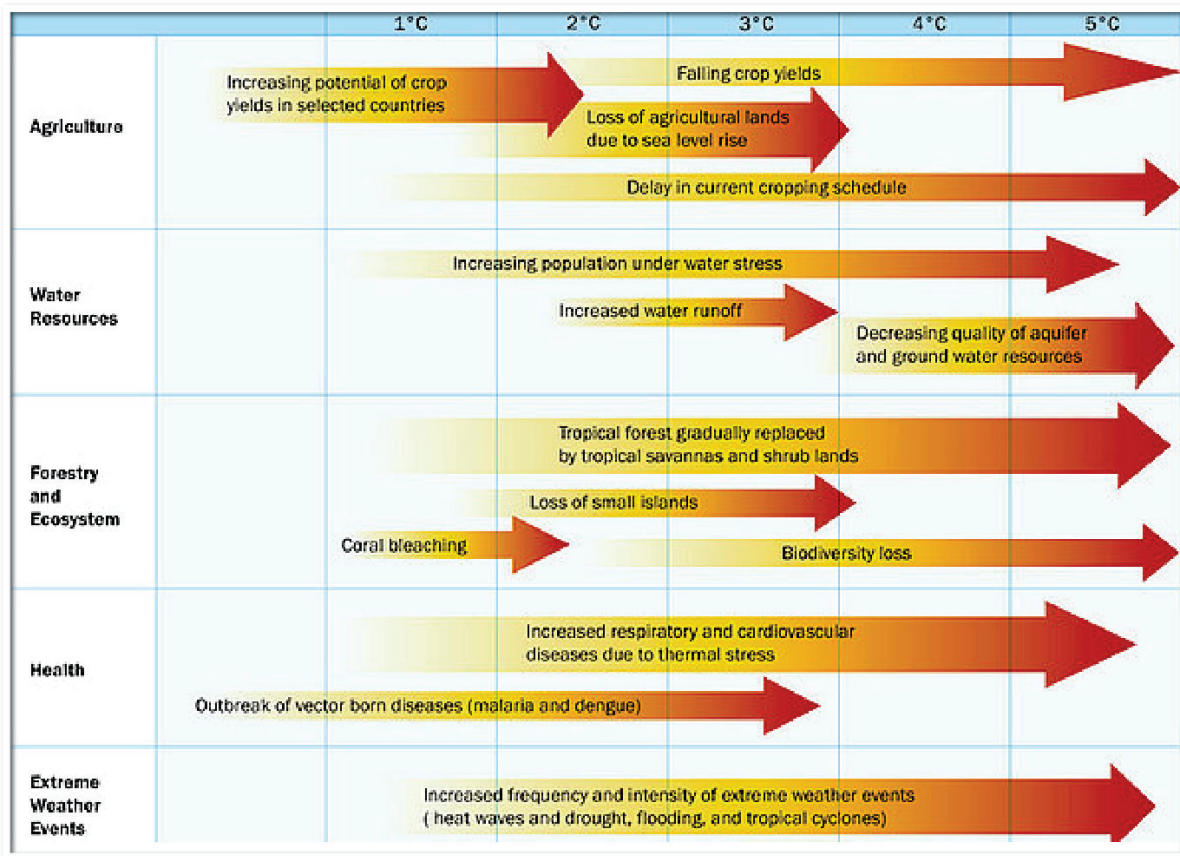
2 There are currently many parts of the globe (in the higher latitudes) that are colder than most  
3 people find comfortable, and it is easy to imagine how increasing temperatures in these regions  
4 could have positive effects. A longer period of frost-free days resulting in a longer growing  
5 season by itself can have positive effects on agricultural productivity. But it's not that simple –  
6 concerns about weeds, insects, and diseases in crops also increase with higher temperatures.  
7 Reduction in sea ice in the Arctic will open more shipping possibilities, but the higher  
8 temperatures in this region also open the potential for many negative consequences, including:  
9 major disruptions of ecosystems that are important sources of food and other valued products;  
10 habitat loss for endangered species; loss of culturally valued practices and subsistence lifestyles;  
11 loss of permafrost that may currently support roads, houses, and other infrastructure; and  
12 increases in wildfire.

13 Changes in average temperatures may have beneficial effects depending on where you live and  
14 on the nature of local economic activity. However, it is unlikely that rapid changes in extreme  
15 temperatures (which become more likely as heat-trapping gas concentrations rise) will result in  
16 positive outcomes for people or ecosystems because, on the whole, it is more difficult to be well-  
17 prepared for sudden changes.

18 Also, climate change is much more than changes in temperature. Changes are also occurring in  
19 the amount, intensity, frequency, and type of precipitation. For example, there has been an  
20 increase in the number of very heavy precipitation events across the U.S. over the last half  
21 century. Analyses of the frequencies of large-precipitation storms show that such events are  
22 occurring more often than in the past.

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

## Risks Increase with More Climate Change



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2 **Figure 29: Risks Increase with More Climate Change**

3 **Caption:** The risks from impacts increase with the amount of climate change. (Adapted  
4 from Stern 2006)

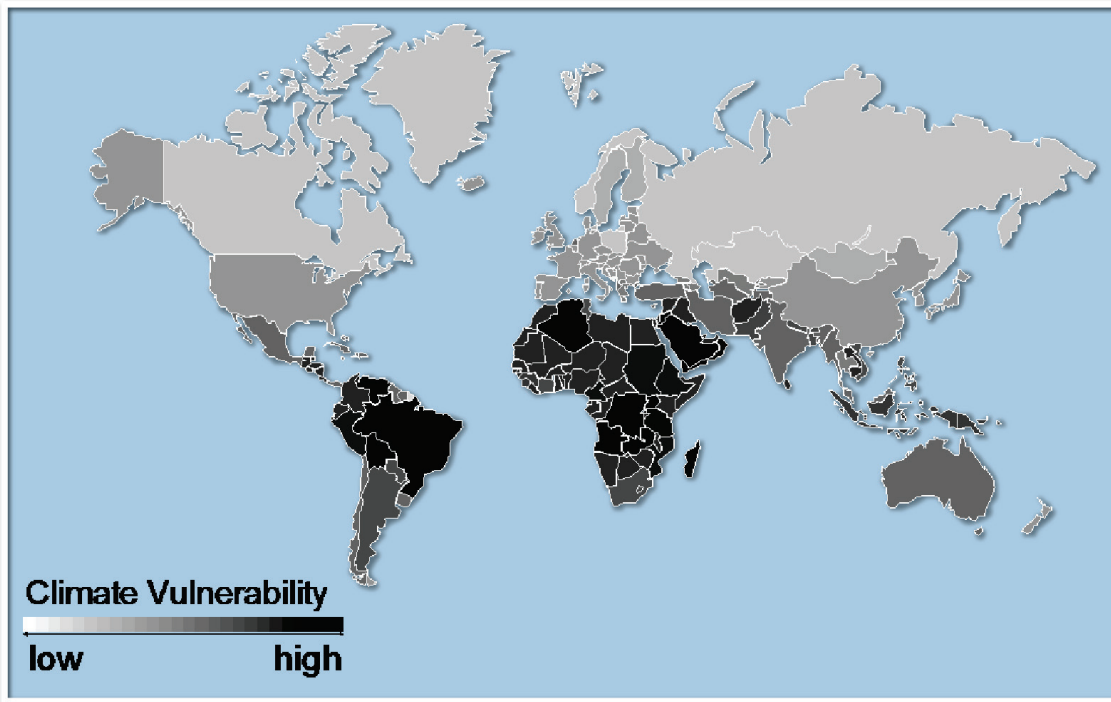
**1 W. Who will be most affected by climate change?**

2 All of us will be affected by climate change. This is not surprising when we consider that people  
3 and other life on Earth have adapted over time to the climate we have had in localities for many  
4 hundreds of years. Today, changes in climate are occurring so rapidly that it may be difficult to  
5 adapt to the changes. This is especially true for vulnerable groups within society such as the  
6 poor, the very young, and some older people who have few resources to adapt to changes in  
7 climate, which may bring higher food prices, increased water scarcity, environmental  
8 degradation, and coastal flooding. Also, two-thirds of the world's largest cities lie within a few  
9 feet of sea level, raising major concerns about the potential for climate change to create millions  
10 of new environmental refugees.

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

18 Ecosystems are also affected by climate change, in particular, fragile ecosystems have difficulty  
19 adapting to even small changes. As the climate continues to warm, major changes are expected  
20 in ecosystem structure and function, interactions among species, and species' geographic ranges,  
21 with predominantly negative consequences for biodiversity. Higher temperatures and  
22 precipitation changes will affect the habitats and migratory patterns of many types of wildlife.  
23 The ranges and distributions of many species will change; some species that cannot move or  
24 adapt may face extinction. In addition, climate changes such as increased floods and droughts are  
25 predicted to increase the risk of extinction for some plant and animal species, many of which are  
26 already at-risk due to other non-climate related factors.

### Climate Variability by Nation



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**Figure 30: Climate Variability by Nation**

**Caption:** Projected climate vulnerability interpolated to individual nations. (Source: Samson et al. 2011)

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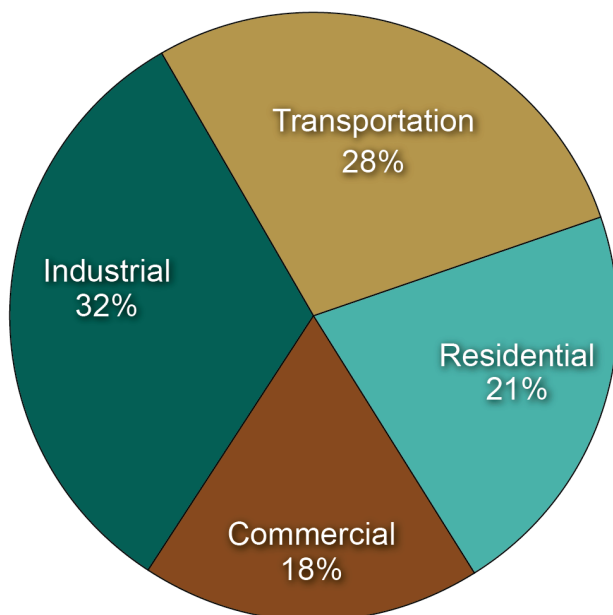
## 1 X. What can be done? Are there solutions?

2 There are multiple paths forward in response to climate change. One choice is do nothing and try  
3 to deal with the consequences. However, a number of economic analyses have concluded that the  
4 costs from inaction would be much larger than the costs of action. Technological “fixes,” such as  
5 “geoengineering,” may be possible but look to be extremely risky (see CAQ Z). Another choice  
6 is to significantly reduce the emissions of heat-trapping gases by changing the way that we use  
7 energy.

8 Increased efficiency in energy use is important, as is the increased use of energy technologies  
9 that do not produce carbon dioxide. For example, because about 28% of the energy used in the  
10 U.S. is used for transportation, changing the types of fuel that we use to those that do not  
11 contribute significantly to heat-trapping gas emissions (such as biofuels) and driving more  
12 efficient vehicles is one obvious path forward. A large amount of energy in the U.S. is also used  
13 to heat and cool buildings, so changes in building design could dramatically reduce energy use.  
14 There are many pathways that can help prevent the largest of the potential impacts on humanity  
15 and ecosystems from climate change.

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

### Energy Consumption by Sector

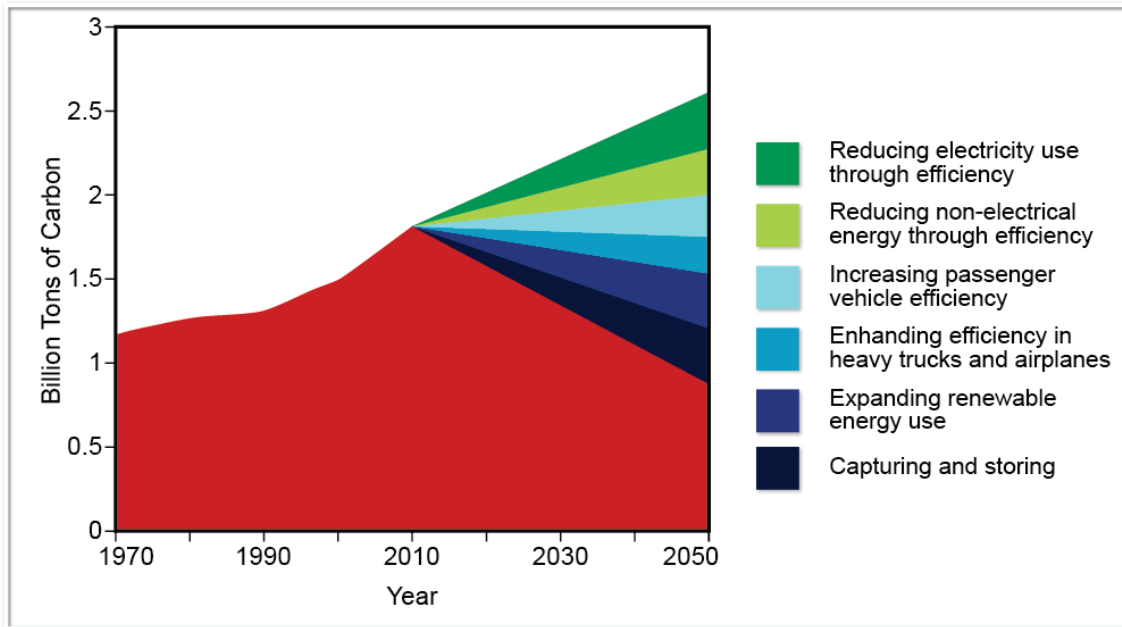


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23 **Figure 31: Energy Consumption by Sector**

1 **Caption:** Percentage of energy consumed by various economic sectors in the United  
 2 States in 2006. Percentages do not sum to 100% because of individual rounding. (Source:  
 3 NRC 2008).

How to Cut U.S. Global Warming Emissions in Half



4  
 5 **Figure 32: How to Cut U.S. Global Warming Emissions in Half**  
 6 **Caption:** Many pathways to reduce energy use, improve efficiency, and adopt new  
 7 technologies could contribute to a reduction in U.S. emissions. (Source: Pacala and  
 8 Socolow, 2004 and Kuuskraa et al., 2004)



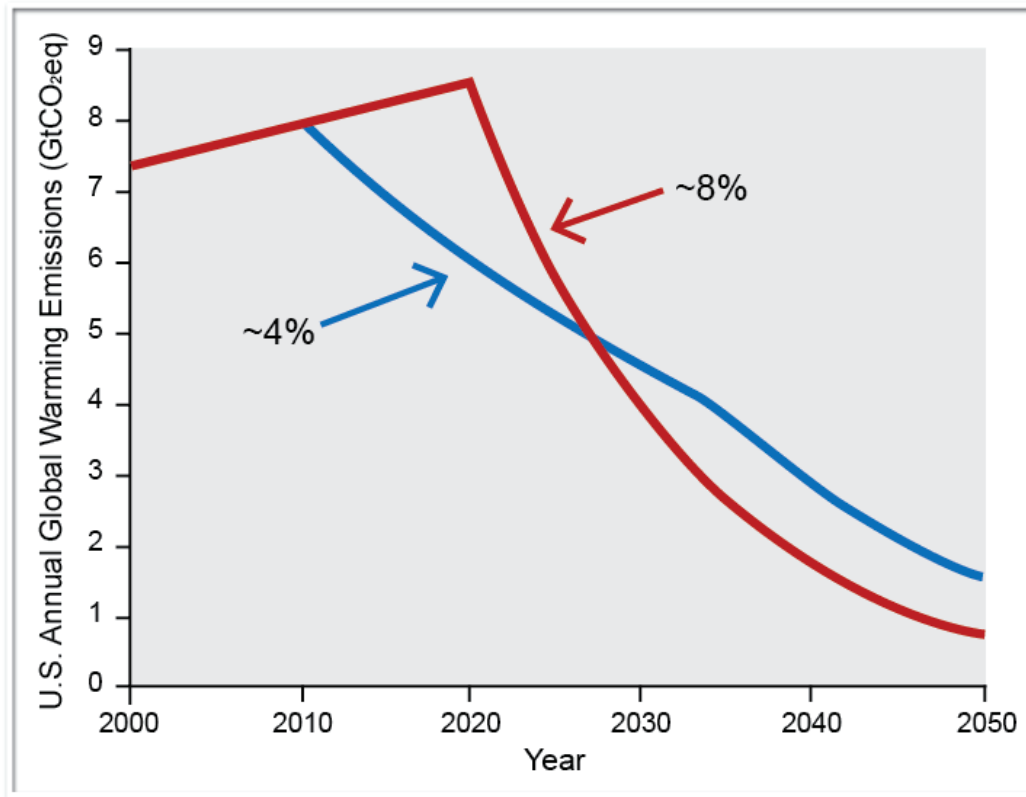
**1 Y. Is it better to act now or later?**

2 The effects on climate from current emissions of carbon dioxide and other heat-trapping gases  
3 can take decades to fully manifest. The resulting change in climate and the impacts of those  
4 changes can then persist for a long time. Waiting longer to manage emissions will result in more  
5 impacts, potentially exceeding the ability of human or natural systems to adapt. Thus it is not  
6 surprising that recent reports from the U.S. National Academy of Sciences, including America’s  
7 Climate Choices (NRC 2011) and America’s Energy Futures (NAS 2010), have concluded that  
8 the environmental, economic, and humanitarian risks posed by climate change indicate a  
9 pressing need for substantial action to limit the magnitude of climate change and to prepare to  
10 adapt to its impacts. They also concluded that substantial reductions of heat-trapping gas  
11 emissions should be among the nation’s highest priorities.

12 The National Academy of Sciences and others have concluded that acting now will reduce the  
13 risks posed by climate change and the pressure to make larger, more rapid, and potentially more  
14 expensive reductions later. Most actions taken to reduce vulnerability to climate change impacts  
15 are investments that make sense economically because they also offer protection against natural  
16 climate variations and extreme events as well. In addition, crucial investment decisions made  
17 now about equipment and infrastructure can “lock in” heat-trapping gas emissions for decades to  
18 come. Finally, while it may be possible to scale back or reverse many responses to climate  
19 change, it is difficult or impossible to “undo” climate change, once manifested.

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

## Two Emissions-Reduction Pathways



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**Figure 33: Two Emissions-Reduction Pathways**

**Caption:** This graph shows why earlier action to reduce emissions would be less difficult and expensive than delayed action. The lines show two pathways to achieve reductions of 80% below 2000 emissions by 2050, a level agreed by international negotiations to be a limit above which impacts become more severe. Starting in 2010 (blue line) requires a 4% per year reduction, while waiting until 2020 (red line) doubles the rate at which emissions must be reduced to 8%. (Source: UCS 2007)

**1 Z. Can we reverse global warming?**

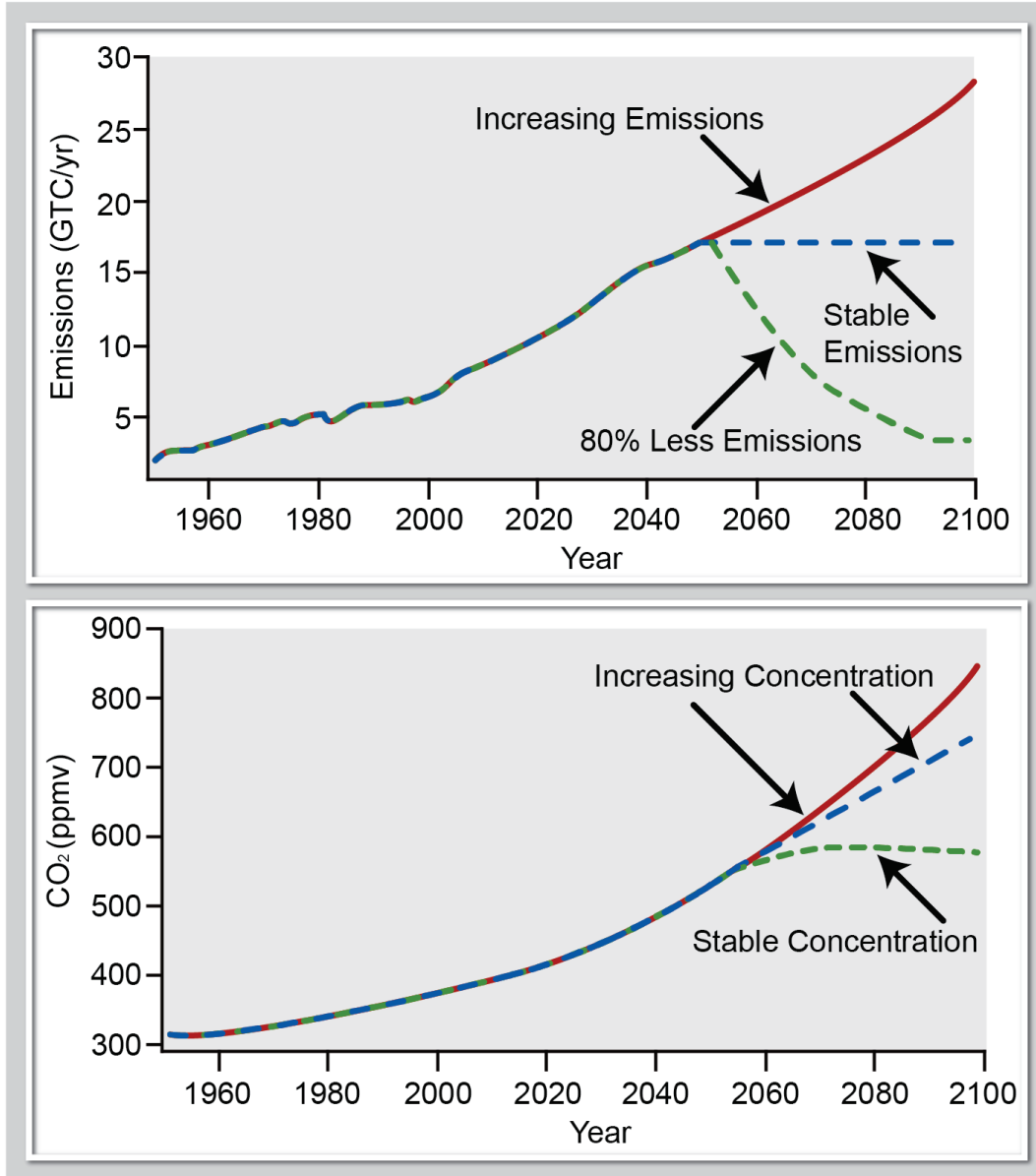
2 Even if all human-related emissions of carbon dioxide and the other heat-trapping gases were to  
3 stop today, the Earth’s temperature would continue to rise for a number of decades and then  
4 slowly begin to decline. However, because of the complex processes controlling carbon dioxide  
5 concentrations in the atmosphere, even after more than a thousand years, the global temperature  
6 would still be higher than it was in the preindustrial period. As a result, without technological  
7 intervention, it will not be possible to totally reverse climate change. We do face a choice  
8 between a little more warming and lot more, however. The amount of future warming will  
9 depend on our emissions pathway.

10 In theory, it may be possible to reverse global warming through technological interventions  
11 called geoengineering. There are two types of geoengineering approaches that have been  
12 proposed to alter the climate system: 1) removal of atmospheric carbon dioxide, and 2) altering  
13 the amount of the Sun’s energy that reaches the Earth (referred to as “solar radiation  
14 management”).

15 Various techniques for removal of atmospheric carbon dioxide, the longest-lived of the heat-  
16 trapping gases, have been proposed. At this time, however, there is no indication that any of  
17 them could be implemented on a large enough scale to have a significant effect. Investments in  
18 limiting emissions, combined with capturing and storing carbon, could possibly reverse the  
19 warming trend, but it remains to be seen if this is feasible.

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

## Emissions Reductions and Carbon Dioxide Concentrations



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**Figure 34: Emissions Reductions and Carbon Dioxide Concentrations**

**Caption:** Because emissions of carbon dioxide are greater than the sinks that remove it, emissions reductions larger than about 80% (green line-top graph) are required if concentrations are to be stabilized (green line-bottom graph). 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. From (NRC 2011)

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38 [treasury.gov.uk/stern\\_review\\_report.htm](http://www.hm-treasury.gov.uk/stern_review_report.htm)]
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