### CLIMATE CHANGE

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section one

CLIMATE CHANGE

Photo by Kees van der Veen, Greenland, 2004
**IS CLIMATE CHANGING?**

**YES.** There is a consensus among scientists that climate change is occurring, with the list of skeptics slowly shrinking. This consensus has been strengthening over time as evidence of increasing global temperatures continues to build and prestigious scientific organizations endorse these conclusions. Temperature records, including those far from cities and over the oceans, are not the only evidence used by scientists. Warming is also indicated by worldwide retreat of mountain glaciers and snow cover, decreased sea-ice cover in the Arctic during the summer, melting permafrost, and shifts in biological activity with animals and plants moving polewards.

**HASN’T CLIMATE ALWAYS CHANGED?**

**YES.** Natural changes have occurred in the past, with variations in temperature and CO\textsubscript{2} concentrations documented from ice cores, tree rings, and many other climate archives. These changes, however, mostly took place over tens of thousands of years and were caused by natural factors such as variations in the earth’s orbit and volcanic activity. Rapid climate shifts have occurred occasionally in the past, although scientists continue to debate whether these were regional or global. However, the rise of human civilization over the last 10,000 years happened during a time of relatively stable climate. Changes expected from continuing human activity will be global, much more rapid than similar large changes that occurred in the past, and will have greater impact because of the much larger world population.

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**Global and hemispheric annual combined land-ocean-air temperature and SST anomalies (°C) (red) for 1850 to 2006 relative to the 1961 to 1990 mean, along with 5 to 95% error bar ranges, from HadCRUT3 (adapted from Brohan et al., 2006). The smooth blue curves show decadal variation. Source: IPCC AR4 WGI**

**Photo by Joel Plummer, Antarctica, 2006**
IS THE RECENT WARMING A RECOVERY FROM THE “LITTLE ICE AGE?”

**NO.** The “Little Ice Age” was not a continuous, well-defined, planetary-wide cold period but instead consisted of several intervals of below average temperatures in the Northern Hemisphere due to decreased solar radiation, increased volcanic activity, and changes in atmospheric circulation. The natural warming that followed the “Little Ice Age” was in response to a decrease in the sun-blocking effect of large volcanic eruptions and the coincidental slight increase in solar activity. Those natural causes cannot explain the magnitude and pattern of recent warming, especially the acceleration observed over the last few decades.

Evidence for the recent warming is based on direct measurements using modern instruments. To estimate temperatures over the last 1000 years, Michael Mann and colleagues analyzed many climate records, including tree rings, thermometers, and other climate archives. Their graph of average temperature in the Northern Hemisphere is commonly known as the “hockey stick” graph with the 20th century warming representing the upward pointing “blade”. Because available climate records are not evenly distributed over the planet, Mann and his colleagues developed techniques to estimate temperatures across large areas as well as estimate the uncertainties caused by not having climate records from everywhere. Although these techniques continue to be improved, resulting in minor changes in the “hockey stick” graph, the National Academy of Sciences provided an extensive report confirming the general findings of Mann’s study.

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**Q3**

**Q4**
I heard that some of Antarctica was cooling. Does this mean that global warming is wrong?

**NO.** To determine the validity and magnitude of climate change, we must look at the temperature of the entire planet, not temperatures in any single location. In fact, the expected warming will likely not be evenly distributed across the planet—local weather patterns such as winds and ocean currents will influence the amount of temperature rise observed at a particular location. Also, keep in mind that Antarctica is the size of the North American continent and has fewer than twenty stations where temperatures have been measured for several decades.

Only two of these stations are in the interior of Antarctica, with all others located on the coast. Extrapolating these measurements over the entire continent to detect temperature trends is difficult and large uncertainties remain.

**YES.** The amount of solar energy we receive depends on sunspot activity and changes in the Earth’s orbit around the sun. Although there was a strong correlation between solar energy and temperatures in the past, observations over the past few decades show that this correlation is no longer dominant. For example, changes in the Earth’s orbit have been linked to glacial cycles. Research has shown, however, that the changes in climate which occurred during these periods were not entirely due to these solar deviations. Other factors such as growth and recession of ice sheets and the amount of CO₂ transferred between the oceans, biosphere, and atmosphere likely played a much larger part in amplifying temperature changes. Recent measurements show small decreases in solar output over the last thirty years while at the same time global temperatures continued to rise, thus emphasizing the importance that CO₂ and other greenhouse gases have in the current warming trend.

Are variations in solar energy causing climate change?
section two

CAUSES OF CLIMATE CHANGE

Photo by Kees van der Veen, Greenland, 2003
WHAT IS THE GREENHOUSE EFFECT?

Created through the presence of certain atmospheric greenhouse gases, the greenhouse effect is actually extremely vital to life on our planet. This important effect occurs because atmospheric gases such as CO₂ and methane trap terrestrial radiation emitted from the Earth’s surface, thus preventing it from escaping to space. This extra heat in the atmosphere is then partially reradiated back to the Earth’s surface, allowing the planet’s average surface temperature to be about 31°C (87°F) warmer than it would be otherwise. Recent concerns revolve around the enhancement of the natural greenhouse effect through increased greenhouse gas emissions from burning fossil fuels and other human activities. These higher emission rates are amplifying the impact of the greenhouse effect, which, in simple terms, means we are warming the planet by trapping more of Earth’s radiation, thus increasing the supply of energy from the atmosphere to the surface.

SINCE CO₂ INCREASES LAG BEHIND TEMPERATURE RISES, AS SHOWN IN ICE CORES, HOW DOES CO₂ RELATE TO CLIMATE CHANGE?

Through the study of air trapped in Antarctic ice cores, scientists have determined that increases in CO₂ happen after increases in temperature. Some climate skeptics have pointed to this fact as proof that rising CO₂ levels are not causing the current warming. What these skeptics ignore is that many factors can lead to changes in climate, especially on the long time scale of glacial cycles. One factor may be dominant at one time, while another may be more important at some other time. The lag between CO₂ and temperature was predicted well before the Antarctic data showed this lag. Glacial cycles are caused by changes in incoming solar radiation, but this change is not big enough to explain the large temperature swings that occur over glacial cycles. Other mechanisms magnify the effect of solar variations. More ice reflects more sunlight, making temperatures colder, which leads to more ice, etc. Similarly, as temperatures start to warm following a glacial maximum, more CO₂ and other greenhouse gases are released into the atmosphere, which leads to further warming, causing further melting of the ice sheets and so forth. Scientists have not unraveled all of the details of what precisely caused changes in atmospheric CO₂ over glacial cycles, but for the discussion on modern climate change this is not important. These are many factors that influence climate, and CO₂ is one of these. By burning fossil fuels, cutting down forests, and through other activities, humans have been releasing large amounts of CO₂, and this has become the most important forcing mechanism for global climate.
HOW DO WE KNOW RECENT CO₂ INCREASES ARE DUE TO HUMAN ACTIVITIES?

This popular question can be answered by looking back through past records of human activities and comparing these activities to changes in CO₂ levels and global temperature. In doing so, it has been found that humans have been producing CO₂ at an unprecedented rate since the beginning of the Industrial Revolution, mainly through the burning of fossil fuels and clearing of forested land. Although there was an initial lag in temperatures, significant warming, especially over the last few decades, has occurred in response to these emissions. Through the study of carbon atom ratios and other techniques, scientists have been able to determine that human activities have increased atmospheric CO₂ concentrations by producing more CO₂ than can be absorbed by terrestrial plants and the ocean combined.

HOW DO WE KNOW THAT RECENT CLIMATE CHANGE IS CAUSED BY HUMANS?

Through a lot of work! An important part of climate science has been devoted to learning whether human activities or natural forcings best explain the recent warming. Satellites are used to determine that the sun is not getting brighter; cosmic-ray monitors are used to show that cosmic rays are not changing; thermometers are used to show that the extra heat in the atmosphere did not come from the oceans or from the ground. El Niño events, etc. These natural forcings are then combined with human-caused changes such as release of CO₂, changes in land cover and emission of soot and dust into the atmosphere, to explain these observations. If human effects are left out, the pattern of climate change over the past century, and especially over the past few decades, cannot be explained. Only by including human causes can these observations be explained, which is why scientists are confident in stating that human activities are having an effect on global climate.
section three

ICE SHEETS, SEA LEVEL & IMPACTS OF CLIMATE CHANGE

Photo by Kees van der Veen, Greenland, 2003
AREN'T CLIMATE PREDICTIONS BASED ON UNTESTED COMPUTER MODELS?

**NO.** Despite its chaotic nature, the climate system can be predicted quite well using computer programs (models) that account for the numerous processes which occur in the earth-atmosphere-ocean system. Testing each model requires comparing its past predictions against the conditions which were actually observed. When these computer simulations include the effects of increased greenhouse gas emissions and other natural factors, they accurately reproduce the large scale warming which occurred during the 20th century, including the dramatic increases in global temperature that have taken place over the past fifty years. Although these models are not all perfect, agreement between computer programs and observed results has improved our confidence in estimating future climate changes.

**WHAT IS SO BAD ABOUT A LITTLE WARMING?**

At first thought, the warming which will result from climate change may not seem like an unbearable consequence because, although most summers will be hotter, winters likely will become milder and more hospitable. Due to the complex nature of the Earth-climate system, however, other more undesirable deviations from current conditions will occur. Annual rainfall will likely decrease in the mid-latitudes and increase at higher latitudes, shifting optimal agricultural conditions poleward and causing crop yields to fall in many parts of the world. In response to warming, many environments will become drier and要求 more water to sustain life. In addition, the habitats of many plant and animal species will shift poleward, possibly leading to the extinction of some species. Weather patterns may also become more extreme, causing heatwaves, droughts, floods, and wildfires to become more frequent and prolonged. In addition, melting of polar ice sheets and mountain glaciers will lead to the displacement of coastline populations through rising sea level. Even parts of the world that do not feel the direct effects of climate change will be impacted economically by events which occur elsewhere. Overall, it is clear that a little warming will go a long way.

**CAN ANYTHING BE DONE ABOUT CLIMATE CHANGE?**

**YES.** Human induced climate change is a continuing process which can be slowed and/or reduced by immediate actions to reduce the amount of greenhouse gases emitted into the atmosphere. Taking action now will not entirely prevent changes from occurring due to the lag between increased concentrations of greenhouse gases and climate change. However, such action will slow the rate at which this change occurs, giving the planet and its inhabitants more time to adjust to the warming which will take place in the future.
HOW WILL CLIMATE CHANGE AFFECT ME?

The answer to this question really depends on where you live and how old you are. A changing climate will impact regional weather patterns around the world differently, allowing some areas to become wetter and some drier. Agriculture will thrive in some areas, but diminish in others, leaving lasting economic impacts on both producers and consumers. Plant and wildlife diversity could suffer as well, with warming temperatures allowing some species to flourish at the expense of others and possibly increasing extinction rates of those who cannot adapt. Coastal areas may become inundated as sea level rises from the melting of glaciers and ice sheets, displacing communities and altering land use along the coast.

In the end, although we may refuse to acknowledge it, the fact is that climate change will have an impact on every individual as well as the future of human civilization.

WHY SHOULD I BE WORRIED ABOUT SEA-LEVEL RISE?

At first thought, future rises in sea level seem like a localized issue restricted to coastal regions. However, the impacts of a rising ocean will affect everyone either directly or indirectly. Coastline populations will experience loss of home and property, causing thousands, if not millions, of people to be displaced. Relocation and adaption to further sea level rises will become an extremely costly process that could have a negative effect on the economies of many countries. In addition, coastal ecosystems that are the basis of life for numerous plant and animal species will also be destroyed.

Overall, the problems generated by sea level rise will extend far beyond the immediate coastal areas, and will consist of more than just loss of land.

![Image of Hurricane Ike on September 15, 2008.](Image)
HAVEN'T THE ICE SHEETS SURVIVED WARMING IN THE PAST?

**YES.** Research shows that ice sheets have both grown and shrunk in the past when the climate cooled and warmed, respectively. Although the shrinkage was small when only a little warming occurred, much of the Greenland and Antarctic ice sheets are believed to have largely or completely disappeared when significant warming took place. Scientists are still not sure how much of a temperature increase is necessary to cause significant reductions in the size of these massive bodies of ice but accelerated loss of ice from Greenland and Antarctica has been observed in recent decades. Moreover, observations strongly suggest that these ice sheets may reach a threshold that could make them unstable. We may, in fact, reach a temperature this century that, if maintained, would melt the Greenland ice sheet and large parts of the Antarctic ice sheet as well.

WON'T MELTING OF THE ICE SHEETS TAKE A LONG TIME?

**NOT NECESSARILY.** The last time ice sheets disappeared from America and Eurasia, collapsing ice sheets contributed to sea level rise at a rate of twenty meters per century over a 400 year period. Recent warming has led to the development of flow instabilities in the Greenland and Antarctic outlet glaciers which, in some cases, have increased their ocean-bound speeds by eight-fold. The delivery of additional icebergs to the ocean through this accelerated flow has led to an ongoing sea level rise of about an inch per decade—a rate that may increase as Greenland outlet glaciers continue to accelerate due to lubrication by meltwater. Even though the disintegration of an entire ice sheet is a process that could take centuries to complete, the consequences of such an event, especially on coastal and low-lying areas, would be severe.

ARE THERE TIPPING POINTS FOR ICE SHEETS?

**YES, although the amount of warming needed to reach the tipping point remains uncertain.** The existence of an ice sheet depends upon the rate of snow and ice accumulation compared to the rate of ice loss. If the accumulation rate exceeds that of loss, the sheet will grow. If the rate of ice loss is greater than ice accumulation, the sheet will shrink. During past climate changes, most ice sheets changed slowly in response to warming temperatures. However, there have been instances in which the tipping points were reached and rapid depletion of ice sheets occurred, causing huge bodies of ice to completely disappear. If steps are not taken to curb the current rate of warming, similar tipping points could be reached and massive ice sheet depletion could once again take place.

WHY ALL THE EXCITEMENT ABOUT THE ANTARCTIC AND GREENLAND ICE SHEETS WHEN THEY ARE CHANGING ONLY A LITTLE BIT?

Recent measurements indicate the large ice sheets of Antarctica and Greenland are losing ice at a relatively slow rate. In fact, recent changes in sea level are mainly due to the expansion of warm ocean water and the melting of mountain glaciers around the world. However, it is important to keep in mind what can happen rather than what is happening. Continued warming will eventually accelerate the melting rate of the ice sheets, allowing these massive bodies of ice to contribute significantly to rapid sea-level rise.