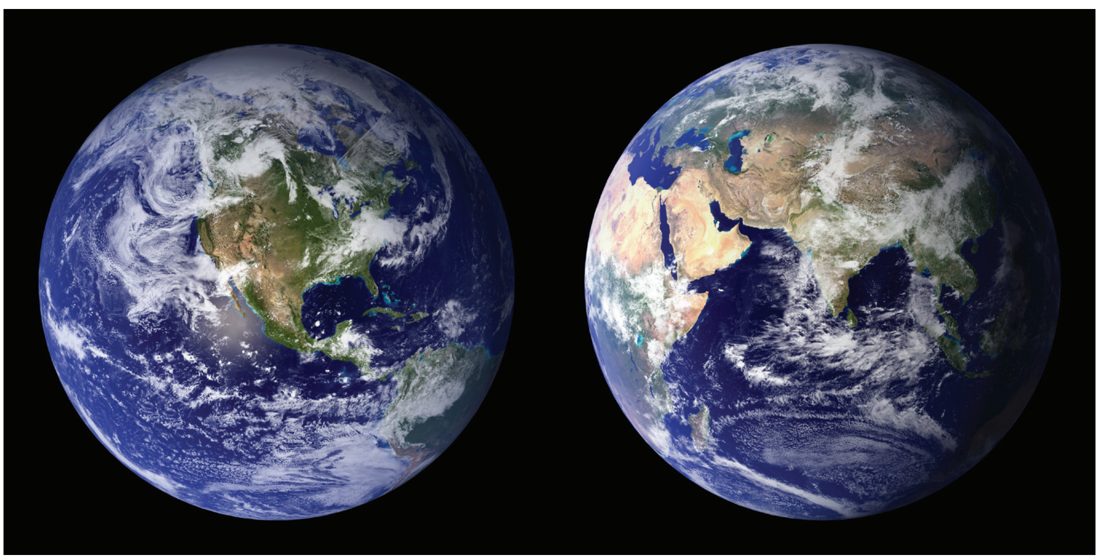
# The **Teacher-Friendly** Guide™

# to Climate Change



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On the front cover: the "Blue Marble." Composite images produced by NASA in 2001-2002.

On the back cover: Atmospheric $CO_2$ concentration at Mauna Loa Observatory from 1958 to 2014 (NOAA).

# Chapter 12: Frequently Asked Questions About Climate Change

## 1. Is there consensus among climate scientists that global warming is occurring and that humans are the cause?

Yes. Multiple studies published in peer-reviewed scientific journals[1] show that 97 percent or more of actively publishing climate scientists agree: climate-warming trends over the past century are extremely likely due to human activities. In addition, most of the leading scientific organizations worldwide have issued public statements endorsing this position; two hundred scientific societies from 76 countries concur.[2] Consider the statement of a leading US scientific society, the American Geophysical Union:

> *"The Earth's climate is now clearly out of balance and is warming. Many components of the climate system—including the temperatures of the* **atmosphere***, land and ocean, the extent of* **sea ice** *and* **mountain glaciers***, the* **sea level***, the distribution of precipitation, and the length of seasons—are now changing at rates and in patterns that are not natural and are best explained by the increased atmospheric abundances of* **greenhouse gases** *and* **aerosols** *generated by human activity during the 20th century." (Adopted December 2003, Revised and Reaffirmed December 2007.)*[3]

***atmosphere*** • *the layer of gases that surrounds a planet.*

***sea ice*** • *frozen seawater at the surface of the ocean.*

***mountain glacier*** • *a glacier found in high mountains, often spanning across multiple peaks.*

***sea level*** • *global sea level is the average height of Earth's oceans. Local sea level is the height of the ocean as measured along the coast relative to a specific point on land.*

***greenhouse gas*** • *a gas that absorbs and re-radiates energy in the form of heat; carbon dioxide, water vapor, and methane are examples.*

CHAPTER AUTHORS

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***A Very Short Guide to Climate Change***

[1] A recent synthesis of consensus estimates was published by J. Cook et al: "Consensus on consensus: a synthesis of consensus estimates on human-caused global warming," in Environmental Research Letters, Volume 11, Number 4, 048002 (http://iopscience.iop.org/1748-9326/11/4/048002), doi:10.1088/1748-9326/11/4/048002.

[2] For a list of these organizations see https://www.opr.ca.gov/s_listoforganizations.php.

[3] Statements from many professional organizations can be found here: http://www.ucsusa.org/global_warming/science_and_impacts/science/scientific-consensus-on.html#.WPEdBFPyu-4.

# Frequently Asked Questions

***aerosol*** • *the suspension of very fine solid or liquid particles in a gas.*

***Younger Dryas*** • *an abrupt shift in the Northern Hemisphere from a warm to a cold climate and then an abrupt shift back again, occurring over about 1,200 years starting around 13,000 years ago. The shift back to a warmer climate occurred with a 10°C (18°F) rise in temperature over only a decade.*

## 2. If geology tells us that the Earth's climate has changed in the past, why should we be concerned that it is changing now?

We are concerned about the *rate* of change. Consider the change in global climate that marked the end of the last ice age. During the 6000 year interval of rapid post-glacial global warming (about 17,000 to 11,000 years ago), Earth's average temperature increased 8°C. During that same interval, sea level rose by 80 meters (262 feet), and the atmospheric $CO_2$ concentration increased by 70 ppm (from 190 to 260 ppm).[4] Contrast these rates—which are an extreme example of natural change—with that of recent decades. At the current rate of global temperature increase (+0.02 °C/year[5]), a change of 8°C will take only 400 years, over 10 times faster than average post-glacial warming. Or consider that while a post-glacial increase of 70 ppm took 6000 years, the current atmospheric $CO_2$ concentration jumped 70 ppm in just 38 years, from 1979 to its current level of 407 ppm (April, 2017).[6]

The concern of such high rates of change is that in many respects both natural ecosystems and human populations would not be able to keep pace with the change. More specifically, most species of organisms are adapted to a particular set of temperatures, food resources, chemical environments, and ecological interactions that develop over hundreds of thousands of years; if these species cannot quickly extend their geographic ranges into similar environments, they may go extinct. There *have* been rare intervals of natural climate change as fast or faster than the 6000 year interval of post-glacial global warming, such as a localized cooling and rewarming event at the very end of that interval (the **Younger Dryas**) and at the Paleocene-Eocene Thermal Maximum, but high rates of extinction have been attributed to such events. And humans, while remarkably adaptable culturally, live within many constraints of infrastructure, available food and shelter, financial resources, and national boundaries. Thus even taking human ingenuity into account, large populations of people will not likely be able to easily relocate to find alternative resources.

Over the past billion years, of course, the Earth has experienced climates that were much warmer than those of today, as well as much colder periods. While many organisms and, theoretically, humans could survive in these more extreme global climates, the climate would not be generally hospitable. In the mid-Cretaceous period, for example, average global temperatures were as much as 9°C (16°F) warmer than today, and sea level was about 100 meters (328 feet) higher than today, covering large tracts of the continent. More importantly, humans have built a global civilization around the relatively stable climate conditions of the past 10,000 years. Even if species extinctions were not greatly increased, and even if humans in developed countries were insulated from changes going on elsewhere, there are vast parts of the world where millions of

[4] Data from Vostok ice core and Barbados corals.

[5] These and many other data, visualizations, plots, etc. can be found at climate.nasa.gov/vital-signs.

[6] Data from the Scripps Institute $CO_2$ program.

people are much more sensitively connected to their environment and cannot readily move or otherwise adapt in a short span of time.

**See Chapter 4: Climate Change Through Earth History for more information on past climates.**

*anthropogenic* • *made by humans, or resulting from human activity.*

## 3. How can we be sure that changes going on now are not just part of natural climate variation?

There are three major reasons why most climate scientists are convinced that the current warming is not due to natural processes:

a) We know that greenhouse gases are accumulating in the atmosphere at levels that have not been experienced in over 20 million years.

b) The pattern of the observed warming fits the pattern that we would expect from warming caused by the buildup of greenhouse gases. That is, almost all areas of the planet are warming; the Earth's surface and lower atmosphere are warming; the upper atmosphere is cooling; and the temperature changes are greatest in the Arctic during winter.

c) The warming is much more rapid than most of the natural variations we have seen in the past. The past century of warming cannot be explained without factoring in **anthropogenic** influences. Only by including the net effect of human-made greenhouse gases and aerosols can the observed changes be reproduced to match the actual record.

**See Chapter 5: Evidence and Causes of Recent Climate Change for more detail on the causes of current climate change.**

There are no known sources of natural variation that would give rise to changes as rapid as those observed in global temperature over the past 150 years. There is, however, a human-induced cause (increased $CO_2$) that not only fits the variation extremely well, but has long been expected to give rise to such change based on basic physical principles. We know the amount of $CO_2$ that humans release to the atmosphere, and analysis of the chemistry of the $CO_2$ identifies it unequivocally as anthropogenic. Over the last million years, the current atmospheric changes are unprecedented.

Could current change just be unusually extreme variation that we do not yet understand? While all phenomena are open to new explanations, and scientists must always be ready to consider other options, scientists do not favor or give equal weight to random or unknown variation if another known explanation fits

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***carbon-14*** • *an isotope of carbon often used in dating materials.*

***fossil fuel*** • *a non-renewable, carbon-based fuel source like OIL, NATURAL GAS, or COAL, developed from the preserved organic remains of fossil organisms.*

***coal*** • *a rock formed from ancient plant matter that can be burned as fuel. Since coal is formed from fossilized plant remains it is considered a FOSSIL FUEL.*

***oil*** • *a naturally occurring, flammable liquid found in geologic formations beneath the Earth's surface and consisting primarily of hydrocarbons. Oil, also called PETROLEUM, is a fossil fuel, formed when large masses of dead organisms (usually algae or plankton) are buried underneath sediments and subjected to intense heat and pressure.*

***natural gas*** • *a hydrocarbon gas mixture composed primarily of methane ($CH_4$), but also small quantites of hydrocarbons such as ethane and propane. See also FOSSIL FUEL.*

the available data. Some explanations fit available evidence much better than others, and it would be inappropriate to act as if every explanation, no matter how unlikely, should receive equal treatment.

## 4. How do we know the increase in $CO_2$ since the 1800s is from human activities?

There are several lines of evidence that indicate an anthropogenic source for the increase in $CO_2$. One of the most compelling is the decrease in the radiocarbon (**carbon-14**) content of the atmosphere from1850 to 1950 that correlates well with the increase in $CO_2$. Carbon-14 is not found in **fossil fuels**, so burning fossil fuels increases $CO_2$ but dilutes the carbon-14 in the atmosphere. Since **coal**, **oil** and **natural gas** are valuable commodities there are quite good records of their use over the last 200 years. The dilution of carbon-14 is exactly what one would predict given the known history of fossil fuel consumption. And there is no other plausible source of the increased $CO_2$ that can explain the dilution of the carbon-14. After 1950 the carbon-14 budget of the atmosphere was perturbed by nuclear weapons testing, which generated large quantities of carbon-14, masking the subsequent dilution. However, a similar calculation can be carried out for carbon-13 to the present day, and this too is consistent with a fossil fuel source for the increased $CO_2$.

**See Chapter 5: Evidence and Causes of Recent Climate Change for more detail on the causes of current climate change.**

## 5. Correlation is not proof of causation. Although temperature and $CO_2$ are correlated, how do we know that $CO_2$ is the cause of the current warming?

For any given scientific problem, scientists look at the sum of observable evidence and formulate hypotheses that can explain this evidence. We make predictions and design experiments to confirm, modify, or contradict these hypotheses, and then modify hypotheses as new information becomes available. In the case of anthropogenic $CO_2$-driven global warming, we have a hypothesis (first articulated over 100 years ago) that is based on well-established laws of physics, is consistent with extremely large quantities of observations and data, both contemporary and historical, and is supported by both conceptually simple and very sophisticated and refined global climate models that can successfully reproduce the climate's behavior over the last century. The confluence these many forms of independent evidence provide very strong confidence that $CO_2$ is the cause of current warming.

## 6. There was discussion of a warming hiatus at the beginning of the 21st century. Is this pause real, and what is the current status?

There has not been a warming "pause" in the early 21st century. Annual temperatures have a lot of natural variation from year to year—climate is defined as a long-term average (thirty years or more) for this reason. If an observer examines only the data across a very short time frame, for example, a few years or a single decade, then the long-term trend may be difficult to discern. An analogy might be trying to discern the change from winter to summer by observing just a week of weather in late March; given the natural day-to-day variation, the trend may not be obvious without at least a few weeks of data, and preferably all the data from January to July. In *Figure 12.1* the years from 2000-2010 show variability of around 0.5°C (the anomaly above the long term average temperature). Yet when that decade is viewed in the context of decades before and after, it is clear that the data from the 2000s are part of a long-term upward trend.

The argument for a "hiatus" was in no small part based on picking a very unusually warm year (1998) as a starting point. Relative to that year alone, following years looked less unusual. Further, there was no hiatus in other observations related to global warming. For example, sea level continued to rise through the 2000-2010 interval. Conclusions should always be drawn on all available data—not a subset. The first decade of the 21st century was much warmer than the long-term baseline, and the subsequent years show a continued warming trend.

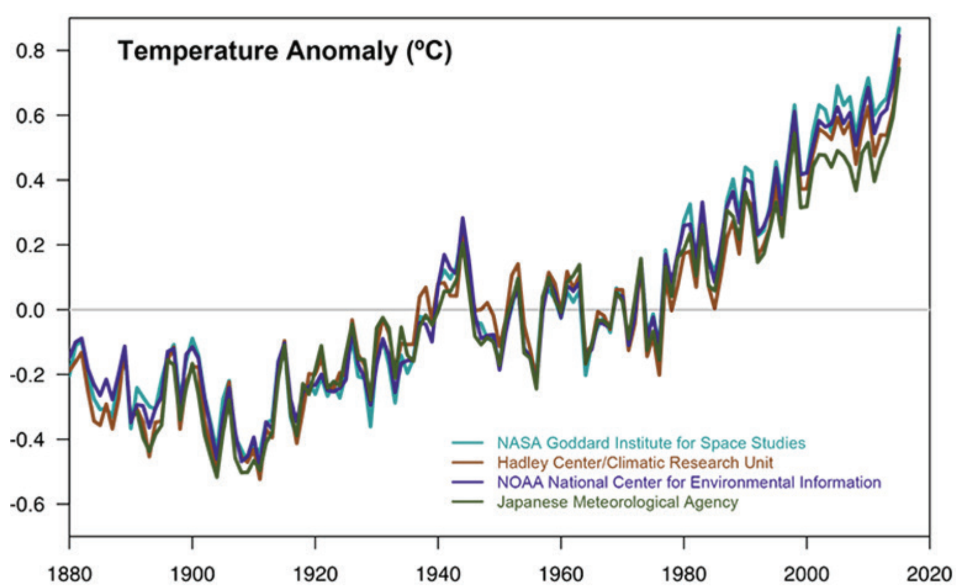


*Figure 12.1: Temperature data from four international science institutions. All show rapid warming in the past few decades and that the last decade has been the warmest on record. Data sources: NASA's Goddard Institute for Space Studies, NOAA National Climatic Data Center, Met Office Hadley Centre/Climatic Research Unit and the Japanese Meteorological Agency. (See Teacher-Friendly Guide website for a full color version.)*

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**permafrost** • *a layer of soil below the surface that remains frozen all year round. Its thickness can range from tens of centimeters (inches) to a few meters (yards). Permafrost is typically defined as any soil that has remained at a temperature below the freezing point of water for at least two years.*

**ocean acidification** • *the increasing acidity, or lowered pH, of ocean waters, caused by absorption of atmospheric carbon dioxide.*

## 7. Why would global warming necessarily be bad for humans? Are people who are arguing that global warming is happening being alarmists?

It is true that some places with cold climates could see benefits from global warming. These positive effects include longer growing seasons and greater agricultural productivity in high-latitude countries like Canada and Russia, smaller winter heating bills, and fewer hassles with icy roads. However, there will also almost certainly be a larger number of more significant negative consequences. For example, high latitude ecosystems—such as the Arctic and Antarctic—will change dramatically, leading to reduction or extinction of many species. As **permafrost** melts, buildings and roads built on it will sink, tilt, or collapse entirely. This phenomenon is already observed. Droughts and severe weather events such as floods and tropical storms are predicted to become stronger and more frequent. Rising sea level will be difficult to deal with along densely-populated low-lying coastlines like those in Louisiana and Bangladesh and on coral atolls, and poorer countries will be disproportionately affected. Insect-vectored human diseases will spread into areas in which they were formerly not a problem. Domestic and agricultural water supplies are projected to decrease. **Ocean acidification** will further endanger already-threatened coral reefs that form the ecological base for other marine life.

Increasing temperatures also mean that climates (and the ecosystems associated with them) will shift poleward. Poisonous or ecologically aggressive insects and plants that thrive in warmer climates will be able to migrate as temperatures increase. Pest species will have more reproductive cycles as temperatures increase. We already see agricultural and forest pest species undergoing a population expansion that has creates increased agricultural damage.

We should be alarmed. Climate change will have serious impacts on humans, including health, agriculture, land use, and water availability. These are not science fiction. Our current lifestyle, including the ability to feed a large number of people, move vast quantities of goods large distances quickly, and live in the wide range of environments that we do, revolves around a stable climate system. Realistic worst-case scenarios of climate change could very plausibly lead to massive disruption of modern lifestyles, the global economy, and even national security.

**See Chapter 9: Climate Change Adaptation for more on the impacts of climate change and strategies for adapting.**

## 8. Won't new technologies and "green energy" get us out of this?

We are already in the process of designing and deploying technologies that produce or use energy that do not contribute to global warming. Many countries and US states have adopted climate and fossil-fuel reduction targets and timelines. We are working to engineer effective ways to sequester the carbon that we are currently emitting and store it below ground. We continue to employ available energy-efficient technologies. It is important to recognize, however, that even the most fast-paced of these technological solutions will take decades, at best, to make a significant difference. Meanwhile, it is important for all stakeholders to work to make the problem as small as possible. Smaller problems are less expensive and much easier to solve.

**See Chapter 7: Climate Change Mitigation and Chapter 8: Geoengineering for more on technological solutions.**

## 9. We have trouble forecasting the local weather for next week with reasonable accuracy; how can we predict the climate over the next 100 years?

Although weather and climate are complex systems, that does not mean that they are entirely unpredictable. The unpredictable character of complex systems arises from their sensitivity to changes in the conditions that control their development. Weather is a highly complex mix of events that happen in a particular locality on any particular day, including small changes in rainfall, temperature, humidity, and other factors that can cause weather to vary. These changes are under continual observation, and, since current conditions are the starting point for forecasting future conditions, these observations are used to update weather predictions in real time. This is why tomorrow's weather forecast is more accurate than next week's.

Climate is the longer-term generalization about a region's weather—the average of decades of weather patterns in a region. Although weather changes rapidly on human timescales, climate changes more slowly. And just like weather forecasting, current observations are input to climate models to make them more robust. Accurate prediction is a matter of choosing the right timescale—days in the case of weather, and decades to centuries in the case of climate, using every available observation to update the predictions. As an example, we can predict with a high degree of confidence that in Chicago January 2020 will be colder on average than July 2020, and that the *average* Chicago temperature that year will be higher than that of Dallas—that's climate. But we can't predict for these places what the temperature will be, or whether it will rain or snow, on any given day during those months. That's weather, and cannot be predicted that far in advance.

## 10. A lot of climate predictions depend on computer models. How much can we trust such models?

Numerical models (General Circulation Models or GCMs), representing physical processes in the atmosphere, ocean, cryosphere and land surface, are the most advanced tools currently available for simulating the response of the global climate system to increasing greenhouse gas concentrations. GCMs are based on equations of fluid motion, and are the subjects of intense research and continued improvement. Global GCMs often contain smaller-scale regional models nested within them for better resolution and accuracy. Hundreds of individual parameters provide the input to a GCM; these include, for example, air temperature and pressure at various elevations, ocean temperature and pressure at multiple depths, horizontal and vertical velocities (e.g., winds and currents), radiation at short, medium and long wavelengths, land surface processes such as evaporation and transpiration, land and sea surface albedo (reflectivity), cloud cover, and elevation. Thus GCMs are used to model a variety of different processes at different scales. In order to validate a model and its predictions for the future, the model is run for past climates to test its ability to reconstruct the events that we already know. If a GCM predicts the past (which the best models do well), they provide similarly robust predictions for the future. Models designed two decades ago have proved to be good predictors of the climate that we are currently experiencing.

However, it's important to realize that the basic features of climate change were successfully calculated in the 1890s by the famous Swedish chemist Svante Arrhenius, and in the 1930s by the British scientist Guy Callendar, well before the computer age. Simple models such as those that can be done without even an electronic calculator, somewhat more sophisticated ones that can be run on a laptop, and much more complex GCM models that must be run on large computer clusters all give similar overall results. The reason that many climate scientists use GCMs is not because they are the only way to model climate change, but because they give more detail and insight into the ways that climate processes change in response to increases in greenhouse gas emissions.

**See *Box 6.2* in Chapter 6: US Regional Climates Current and Future for an analogy that describes a climate model.**

## 11. Those who assert that climate change is real and those who deny it both show data and graphs that support these opposing positions. How is this possible?

In order for a scientific hypothesis to become accepted idea it must pass a very important hurdle: the idea must be the best explanation for *all* of the available data and observations. Human-caused global warming currently meets that criterion. In the last decade there have been several high-profile instances in which climate change deniers have presented only partial data sets in order to support their opposing beliefs. This practice is called “cherry-picking,” and is not part of an honest scientific endeavor. For example, GCMs model hundreds of climate parameters and some of these parameters are known better than others. Thus some parameters have larger uncertainties while others are much more certain. Some climate change skeptics have selected the least certain parameters, and have withheld (or deleted) the uncertainty margins, to show how “poorly” they match observations. This is not good science.

Consider a sports analogy. Think of a football team—not all players are equally skilled. Would you assess that team’s chances for a championship based on the performance of only one relatively mediocre player? Not likely, because it’s the overall performance of all the individuals working as a team that results in the team’s performance. Analysis of all the players and their interactions, or, for a climate model, all the climate parameters, will produce the most accurate predictions.

A second method that uses real data in order to create a false impression is manipulation of the scale on a graph. As discussed in the “warming hiatus” question above (Question 6), showing data over a very short time frame can be misleading. Similarly, using a vertical scale to either magnify or suppress a trend can also be misleading. For example, the temperature data plotted on the two graphs in *Figure 12.2* is exactly the same (the same data from Question 5), but the scale has been expanded in the right-hand graph to compress the data and make the temperature increase appear non-existent. This procedure has been used by some who deny the existence or significance of climate change to give an impression of “no problem.”

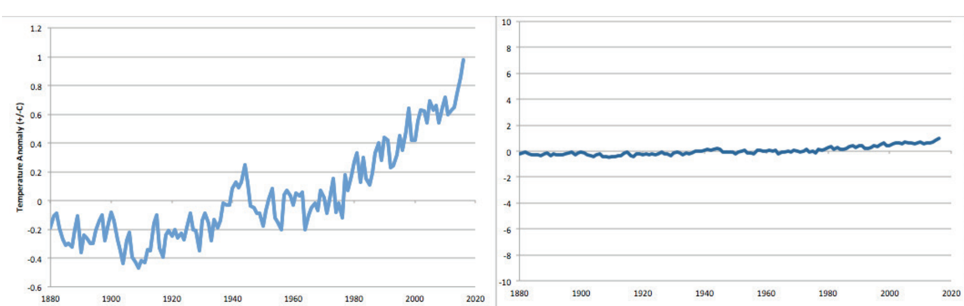


*Figure 12.2. Historical temperature observations plotted on different scales.*

***sunspot cycles** • an 11-year cycle over which the number of SUNSPOTS varies, associated with a cyclical variation in the Sun's magnetic field.*

## 12. Couldn't the sun be responsible for the observed recent climate changes?

The sun plays a central role in determining how warm our planet is. The issue today is how much solar changes have contributed to the recent warming, and what that tells us about future climate. The current scientific consensus is that changes in the energy output from the sun do not successfully account for the current warming trend. Eleven-year **sunspot cycles** have been consistently recorded, but these have risen and fallen as expected, never increasing their net output of energy. Nor do other solar outputs correlate with the warming trend. So for the period for which we have direct, observable records, the Earth has warmed dramatically even though there has been no corresponding rise in any kind of solar activity.

## 13. Aren't human $CO_2$ emissions too tiny to matter?

The important issue here is one of balance. $CO_2$ is part of the Earth's **carbon cycle**. When we take humans out of the equation and consider only natural processes, the carbon cycle runs in approximate balance on human time scales. In a balanced carbon cycle, $CO_2$ inputs to the atmosphere equal $CO_2$ outputs. Humans disrupt that balance. Human carbon emissions are currently 9 billion tons per year (1 billion tons = 1 Gigaton = 1 Gt).[7] This is a small number compared to the annual 120 Gt of carbon released to the atmosphere via decomposition and plant respiration. However, plants also remove 120 Gt/year via photosynthesis. The natural cycle of $CO_2$ is balanced, with uptake by plants and the oceans equal to release. Human emissions have no compensating removal process. Thus, the largest fraction of the 9 Gt that we add to the atmosphere stays in the atmosphere, with a substantial fraction of the rest absorbed into the surface ocean, increasing ocean acidity. Without a human effort to sequester (remove) atmospheric carbon to balance our input, we will continue to see increasing levels of atmospheric $CO_2$ and ocean acidity.

Some people have compared human carbon inputs to volcanic carbon emissions, saying that human emissions are less than volcanic emissions. This is untrue. All volcanoes, worldwide, emit an average of about 50 Mt of carbon per year. This is less than 1% of anthropogenic emissions.

The 9 Gt of annual anthropogenic input is enough to push atmospheric $CO_2$ concentrations to extremely high levels. Ice cores show that carbon dioxide levels in the atmosphere stayed between 260 and 280 parts per million for the past 10,000 years. This stability tells us that $CO_2$ sources and sinks have been very close to balanced over that long time span. $CO_2$ began to exceed that range during the Industrial Revolution, about 1850. Since them $CO_2$ has

[7] You may see references elsewhere (including Chapter 8 of this Guide) to global annual emissions of around 32 Gt. This figure is for $CO_2$, not carbon. One Gt of carbon corresponds to 3.667 Gt of $CO_2$, so 9 Gt of carbon emitted annually corresponds to 33 Gt of $CO_2$ emitted annually.

risen dramatically. In the past decade $CO_2$ levels have risen to 407ppm. The last time atmospheric $CO_2$ reached 400 ppm was 3.6 million years ago during the Pliocene epoch.[8] At that time Arctic summer temperatures averaged 60°F (15.5°C), 14 degrees warmer than present, and there was little to no year-round Arctic sea ice or Northern Hemisphere glaciers. Anthropogenic additions of $CO_2$ are creating conditions that Earth has not experienced for millions of years.

**greenhouse effect** • *the influence of GREENHOUSE GAS molecules in the Earth's atmosphere to retain heat (infrared radiation) radiating from the Earth's surface that would otherwise escape into space.*

**methane** • *$CH_4$, a greenhouse gas formed from organic matter under heat and pressure from burial and from fermentation of organic matter by bacteria in low oxygen settings, including the digestion of animals.*

## 14. Why does $CO_2$ matter so much if it isn't the most important greenhouse gas?

The **greenhouse effect**—created by gases that absorb long wavelength radiation—currently keeps our planet 20° to 30°C warmer than it would be otherwise. This is essential for life on our planet to thrive. Global warming is the rise in temperature caused by an increase in the levels of greenhouse gases. Water vapor is the most important contributor to the greenhouse effect. Approximately 50% of the greenhouse effect is due to water vapor, with another 25% due to clouds and 20% due to $CO_2$, with other gases accounting for the remainder.

**See Chapter 3: What is Climate? for more detail on the greenhouse effect.**

So why are climate scientists not more worried about water vapor than about $CO_2$? The answer has to do with how long greenhouse gases persist in the atmosphere. Excess $CO_2$ accumulates, warming the atmosphere, which raises water vapor levels and causes further warming. The rapid turnover of water vapor, through evaporation and precipitation, means that even if human activity was directly adding or removing significant amounts of water vapor (which it is not), there would be no slow build-up of water vapor as is happening with $CO_2$. The level of water vapor in the atmosphere is determined mainly by temperature, and any excess is rapidly lost. The level of $CO_2$ is determined by the balance between sources and sinks, and it would take hundreds of years for it to return to pre-industrial levels even if all emissions ceased tomorrow. To put this another way, there is no limit to how much rain can fall, but there is a limit to how much extra $CO_2$ that the oceans and other sinks can soak up.

Carbon dioxide is not the only greenhouse gas emitted by humans. Many greenhouse gases, such as **methane** ($CH_4$), are far more powerful than $CO_2$ in terms of infrared absorption per molecule. However, the overall quantities and impacts of these other gases are smaller than those of $CO_2$; methane has a shorter residence time in the atmosphere, eventually oxidizing to $CO_2$. Even allowing for the relative strength of the effects, $CO_2$ is still responsible for 60% of the additional warming caused by all the greenhouse gases emitted as a result of human activity.

[8] To learn more about the last time $CO_2$ levels were this high on Earth, see the article "Ice-Free Arctic in Pliocene, Last Time $CO_2$ Levels above 400 PPM" in Scientific American: https://www.scientificamerican.com/article/ice-free-arctic-in-pliocene-last-time-co2-levels-above-400ppm/.

# Frequently Asked Questions

**ice core** • *a large cylinder of ice extracted from an ice sheet or glacier, such as is found in Antarctica, Greenland, or on very high mountains worldwide. Chemical analysis of the ice and air bubbles can reveal information about the climate at the time the ice formed, as can materials such as dust or pollen found in the ice.*

**glacial-interglacial cycle** • *an alternation between times in Earth's history when continental ICE SHEETS grow and advance toward lower latitudes (GLACIALS), and times when the climate is warmer and ice sheets melt back (INTERGLACIALS).*

**Milankovich cycles** • *cyclical changes in the amount of heat received from the Sun, associated with how the Earth's orbit, tilt, and wobble alter its position with respect to the Sun. These changes affect the global climate, most notably alterations of glacial and interglacial intervals.*

## 15. Some ice cores show that $CO_2$ increases lag behind temperature rises. Doesn't this disprove the link to global warming?

The Antarctic **ice core** record of the past 800,000 years has provided a record of $CO_2$ and temperature data showing a close correlation in a series of 100,000 year **glacial-interglacial cycles**. During spans of several thousand years during transitions from glacials to interglacials there have been periods during which temperatures warmed and $CO_2$ rose relatively quickly; previous research indicated that warming events preceded $CO_2$ increases by roughly 800 years. This led some people to argue that $CO_2$ could not have been important for climate, as climate appeared to warm before the influence of increased $CO_2$. There are two important phenomena here. First, changes in the Earth's orbit (**Milankovich cyles**) provide modest changes in total global insolation that drive glacial-interglacial cycles, including the initial trigger that starts warming at the peak of each glacial advance. Second, temperature and $CO_2$ are an example of a positive feedback loop that occurs at many times scales and throughout glacial-interglacial cycles, amplifying the warming trend: as climate warms, $CO_2$ is released from the oceans and carbon-rich soils; in turn, as $CO_2$ increases, climate warms.

**See Chapter 3: What is Climate? for more detail on the carbon cycle and on Milankovich cycles. See Chapter 4: Climate Change Through Earth History for more about glacial-interglacial cycles.**

It is also important to note that in the last few years the dating of ice cores that contain the $CO_2$ record has improved. It is relatively straightforward to measure the amount of $CO_2$ trapped in ice cores, and to estimate changes in the temperature recorded in the ice core, but dating the *age* when the $CO_2$ was trapped is not. The uncertainties in the early estimates were more than 600 years. New dating techniques have shown that there is no statistically significant difference between the timing of temperature increases and $CO_2$ increases. At some points during deglaciations, temperature appears to lead $CO_2$, but at others $CO_2$ increases appear to precede warming. This is an outcome of the feedback connections between the carbon cycle and climate system.[9]

[9] A technical discussion of this point is found here: F. Parrenin et al. (2013). Synchronous Change of Atmospheric CO2 and Antarctic Temperature During the Last Deglacial Warming. Science 01 Mar 2013: Vol. 339, Issue 6123, pp. 1060-1063. DOI: 10.1126/science.1226368.

## 16. Climate websites refer to both the IPCC and, more recently, the NIPCC. What is the difference between these two organizations?

The Intergovernmental Panel on Climate Change (IPCC) was created by the United Nations in 1988 to review scientific conclusions on climate change that have already passed peer review and been published in the scientific literature. The IPCC includes thousands of climate scientists and is open to all member countries of the United Nations and the World Meteorological Organization. The IPCC publishes periodic reports on the state of global climate (1990, 1995, 2001, 2007 and 2014). These assessment reports involve more than 500 lead authors and 2000 reviewers from more than 100 participating nations, and cite >9000 published scientific literature sources. The 2014 Report makes the following conclusions:

> *"Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen….*
>
> *Human influence on the climate system is clear, and recent anthropogenic emissions of greenhouse gases are the highest in history. Recent climate changes have had widespread impacts on human and natural systems."*[10]

The IPCC reports been criticized by the NIPCC. The "Nongovernmental International Panel on Climate Change" is sponsored by the Heartland Institute, a US-based conservative think tank best known for fighting government regulation of the tobacco and fossil fuel industries. Heartland has campaigned to downplay threats posed by second-hand smoke, acid rain, and ozone depletion, as well as against the Endangered Species Act. The Heartland NIPCC also issues periodic reports, timed to coincide with the release of IPCC assessment reports and formatted to look like them. NIPCC reports are authored by fewer than 50 individuals and the most recent report cites only 72 papers, mostly written by the NIPCC authors.[11]

[10] See the IPCC Summary for Policymakers here: https://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_SPM.pdf.

[11] Learn more about debunking the report at: https://ncse.com/files/nipcc.pdf.

## 17. Is climate change too big or too far along to be stopped?

It's possible to greatly slow down and diminish potential future climate change.

Human societies have developed under the rubric of certain climate patterns and have always depended on climate-dependent natural resources. For example, in the western US most residents rely on winter snow pack to store water that arrives in the winter for delivery in the summer when their demands are highest. Because significant climate change would alter accustomed climate patterns and regional natural resources (some natural systems will be irreversibly damaged by global warming), it could pose disruptions to socioeconomic systems around the world. These disruptions would be worse where global warming worsens existing conflicts over scarce resources and where the funding or capacity for preparing for or adapting to these changes is lacking. Many people agree that global warming is likely to have worse consequences for those with the least resources and therefore least able to adapt—the economically or politically vulnerable, for example.

"Stopping" anthropogenic global warming completely is now widely viewed as impossible in the short-term. There is, however, still time to minimize it, and there are things that we can do. Global warming *is* reversible in the long-term, at least in the sense that we could, eventually, bring global greenhouse gas emissions, the "human" part of climate change, back down. The issue here is a matter of how long we can wait. The sooner we reduce emissions, the better.

Even if we were to stop fossil fuel burning altogether and immediately, temperatures would almost certainly continue to rise because of the additional $CO_2$ already in the atmosphere. Carbon dioxide concentrations would eventually start to decline, but it would take much longer for them to return to preindustrial levels than they did to build up. This means that even in this extreme "best case" scenario, we still need to expect some level of climate change and to prepare accordingly.

**See Chapter 7: Climate Change Mitigation and Chapter 9: Climate Change Adaptation for more information on strategies to respond to climate change.**

## 18. What can be done by the average citizen?

The actions of individuals are where everything begins. We can, as individuals, reduce our reliance on fossil fuels in transportation, home heating and lighting, and consumption of goods. We can look for a lower emission vehicle when it's time for a new car. We can utilize public transportation. We can install energy-efficient appliances in our homes and businesses. We may be able to switch to alternative energy systems for home heating and electricity (*Figure 12.3*), or join a renewable energy co-op. We can make choices as consumers that

*Figure 12.3: Aerial view of a solar farm near Austin, Texas.*

minimize climate impact. For example, buying food in season and grown locally reduces the emissions that result from transporting food long distances. Beyond reducing our own emissions we can offset the emissions we cannot eliminate by supporting alternative energy technologies and reforestation efforts. Some corporations are beginning to act to offset their contributions to global warming. This is voluntary in the US, but mandatory in Europe. An individual might also think about the way a corporation is addressing global warming before making investment choices.

Individuals can work collaboratively to support communities and collective actions. Transportation, energy use, and other policies at the local, state, and federal levels will all influence greenhouse gas emissions. We can work for broad societal change, voting with our wallets when we make climate-friendly purchases, and at the ballot box when we choose representatives who will champion climate-neutral policies. Every step that we take—as an individual, as a community, or as a nation—to reduce our climate impact is a step that makes the problem a little smaller, a little less difficult. This is *enormously* important.

Shifting the world's economy away from its dependence on fossil fuels is the single step that would do the most to reduce anthropogenic climate change. This is also a huge challenge that will not be accomplished by any one change. It will require actions big and small by individuals, corporations, and governments around the world. Although people sometimes feel that nothing that they do matters, the only thing that *does* matter is what people do.