Global Climate Change: Update 2015

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Introduction

The topic of global climate change has emerged over the past decade as the most widely discussed environmental subject in the world. It also shows no sign of taking a lower profile in coming years. The purpose of this fact sheet is to acquaint the reader with the basics of this topic by describing how global climate has changed in the past as well as why—along with a discussion of current temperature trends and what the future is likely to hold.

For a very basic introduction to the topic of global climate change, the reader should examine Ohio State University Extension fact sheet, CDFS-186-96, published in 1996: ohioline.osu.edu/cd-fact/pdf/0186.pdf.

One of the points that is important to note in reading this fact sheet is that the impacts of climate change on Earth’s history have been profound: global climate change is an important topic. Climate matters!

A History of Earth’s Climate

To understand the context in which global temperatures vary, it is instructive to consider the ranges over which temperatures have changed in the past, and to understand what has caused these changes and what the consequences have been.

A Note About Temperature Data

The best way to measure temperature is with a device such as a thermometer (i.e., something that measures temperature directly). Modern methods of measuring and recording temperatures have only been used consistently since the middle of the 19th century. When scientists try to reconstruct temperature trends before that time, they use natural processes on Earth that provide a great deal of information about its climate history. Examples include information about the environmental conditions that can be gained from analyzing coral reefs, tree rings, ice cores and sediments. These natural recorders of past climate conditions are known as “proxy” records since they provide an approximate value for temperatures during a time when humans were not present, or were not able to record observations.

Some of this information is stored in ice cores in places such as Greenland and Antarctica, and in the mountain glaciers of North and South America and Europe. The oldest ice core data goes back about 850,000 years. To obtain proxies even before that, scientists who study ancient climates (paleo-climatologists) primarily rely on sediments. By analyzing the composition and distribution of all kinds of sediments, they have constructed proxy data sets of global temperatures that go back nearly 1 billion years—almost a quarter of Earth’s existence.

The Past 600 Million Years

The graph in Figure 1 shows how temperatures have changed over the past 600 million years. This is an important period of time to consider because it was about 600 million years ago when large animals first made the scene on Earth. Note that over the course of this 600 million year period, Earth’s temperatures have tended to run about 10 degrees Celsius (18 degrees Fahrenheit) warmer than at the present—with the exception of two previous major cooling episodes, a minor one and another major cooling episode that is currently ongoing. The duration of these cold periods tends to be between 20 and 40 million years.

The driver behind these long-term tendencies is the position of the continents around the globe (Donn and Shaw, 1977). The position of continents slowly changes over time in a process called “continental drift.” When the continents are positioned in a way that the north pole and the south pole are able to receive the flow of warm ocean currents from the tropics, Earth is relatively warm—about 18 F warmer than at present—with the exception of two previous major cooling episodes, a minor one and another major cooling episode that is currently ongoing. The duration of these cold periods tends to be between 20 and 40 million years.

However, occasionally continents drift in such a way that puts them in a position where they block the polar regions from receiving the warm waters flowing from the tropics. When this occurs, the moderating affects of tropical currents on the polar regions are lost. As a result, cold air masses build in areas near the poles and...
the temperature on planet Earth declines substantially. This kind of arrangement leads to “ice house Earth,” where glaciers and snow are common.

As you can see by Figure 1, Earth went into an ice house state several million years ago. This is because (a) the northern polar region is now blocked from warm tropical waters by the continents of Eurasia and North America, as well as by Greenland, and (b) the southern polar region is blocked by the continent of Antarctica. The very large cold air masses that form over these polar regions interact with the air masses and ocean currents from the temperate and tropical regions and, as a result, they cool the entire planet. This has made for the present ice house Earth with which we humans are familiar. In fact, the entire human family (hominids) evolved within the period of the current ice house.

Ice House Earth

Now let’s take a look inside ice house Earth and see how temperatures tend to change within it. The graph in Figure 2 shows that once inside the ice house, Earth tends to go through warming and cooling cycles that last about 100,000 years. These cycles are caused by changes in Earth’s orbit around the sun. They are called Milankovitch cycles, named for the Serbian scientist who first made note of these orbital changes (Hewitt, 2000).

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Following the graph in Figure 3, note that global temperature peaked around 5,000—7,000 years ago, during a period called the Holocene Maximum. This period coincides with a number of very important developments in human history. It was during this time that humans first invented agriculture—substituting cultivation of crops and domestication of animals for the more precarious existence humans had as hunter-gatherers prior to this. Another important development associated with the Holocene Maximum is the creation of written language. The extent to which the mild climate of the Holocene Maximum contributed to developments such as agriculture and written language is an interesting topic to consider. One thing is clear, it was the mild conditions of the Holocene Maximum that made these developments possible.

Returning to Figure 3, note that temperatures have generally trended downward since the time of the Holocene Maximum, with some exceptions—referred to as “anomalies.”

The first warming anomaly occurred around 2,000 years ago—a period that roughly corresponds with the expansion of the Roman Empire. Temperatures during that period were mild, allowing for increased agricultural production and easier transit through mountainous areas where travel would otherwise be hindered by ice and snow. Large numbers of people were freed from employment in agricultural production due to higher productivity. These conditions made the Roman conquest of much of western Europe possible.

A cool era then developed in the fourth and fifth centuries, which corresponds with the historical period in Europe known as the “Dark Ages.” During this era, the Western Roman Empire fell apart. Historical records indicate that during this time, agricultural yields in Europe fell substantially. Over 98 percent of the European population had to work in agriculture in order to provide the food and fiber necessary to maintain life there.

Then, another warm period developed around the 10th—14th centuries that has come to be called the “Medieval Warm Period.” Again, agricultural yields increased and winters in Europe became milder. The changes that resulted from this warm period were significant. So much labor was freed from agriculture that large numbers of people were able to go into trades. This is the era when large cathedrals and castles were built all over Europe. An era of travel and exploration began. It was during this era that the Vikings established settlements in Greenland and in North America.

The Medieval Warm Period ended rather abruptly in the 14th century, ushering in a period observed in the northern hemisphere called the “Little Ice Age.” Historical records indicate that between the 15th and 17th centuries, it was not uncommon for large rivers such as the Thames in England to freeze and to remain frozen for much of the winter. Although the Little Ice Age transformed Europe in many ways, humans there were able to adapt in important ways. They sought more southerly routes in travel, for example, and adopted agricultural techniques that would allow for increased productivity even in a colder climate (Goosse, et al., 2006).

The Little Ice Age ended after temperatures bottomed out around the year 1600, when another warming anomaly began. We will examine this modern trend below.

![Figure 3: Global Average Temperature Changes During the Current Interglacial](image)


### The Past Two Millennia

In order to see some of the recent temperature trends discussed here with a greater level of resolution, let’s look at Figure 4. This figure is a composite of a number of studies that have attempted to measure global temperatures over the past 2,000 years.

Note that these studies show that the Medieval Warm Period had its origin after temperatures bottomed out around the early 8th century. Recall that this warm era ended after a cooling period began in the 14th century, which ultimately ushered in the Little Ice Age. A warming trend then returned as recently as the late part of the 16th century. Temperatures apparently reached the average level for the 2,000-year period by the middle of the 19th century, which just so happens to be the time when we can shift from the use of proxy data to actual observed temperature data.

If we graph the observed data onto the end of the proxy data to continue the graph in Figure 4, we see that temperatures in the early 21st century appear to be warmer than at any time in the past 2,000 years. The magnitude of this difference is about one-third of a degree Celsius (C), or roughly one-half of a degree Fahrenheit (F). This may not seem like much, but remember, temperature changes of about a degree C (1.8 F) produced the important implications we discussed in the Medieval Warm Period and the Little Ice Age.
The Modern Temperature Record

Weather Station Data

Figure 5 shows the temperature data from the mid-1800s to the early 21st century. This is the first graph we have reviewed here so far that is made completely of actual measured temperatures. The data for this graph comes from weather stations located at more than a thousand places all across the globe. The black dots show annual average temperatures, while the red line shows five-year running averages.

Note that after a slight cooling trend from 1880 to about 1915, a warming trend developed, which lasted until the mid-1940s. Following this, a slight cooling resumed until the 1970s, when a new warming trend emerged that has persisted into our new century. Overall, this graph reveals a global warming of about .8 C for the period, or about 1.4 F.

One of the criticisms that is often placed against this data set is that certain weather stations may be unduly influenced by an “urban heat island effect.” Imagine that a weather station was originally built in the countryside far from a city, but as time went by, more and more development brought pavement, buildings and automobiles nearer to the station. These changes can create a microclimate, where temperatures are warmer than they would ordinarily be—not because of global warming, but because of the propensity of pavement and concrete, as well as cars, to hold or create more heat over a local area. Scientists have adjusted weather station data to take the urban heat island into account.

Satellite Data

The most modern method of measuring global temperatures is from space, with satellites. NASA (the National Aeronautics and Space Administration) and NOAA (the National Oceanic and Atmospheric Administration) have been using satellites since December 1978 to measure the temperatures of the atmosphere.

Figure 6 shows monthly satellite temperature data for the lower troposphere (from the Earth’s surface up to 30,000 feet) for the period of January 1979 to the present. This graph presents monthly deviations from the average temperature over the period. Note that cooler than average months tend to dominate the early portion of the data set while warmer than average months dominate the more recent years.

A few important anomalies are apparent in the graph. Two of the cool periods (1982–1986 and 1992–1993) are associated with large volcanic eruptions (El Chichon and Mount Pinatubo, respectively). Each of these eruptions threw up enough ash and smoke to block solar radiation to the extent that they cooled the atmosphere over a period lasting for months. The record warm year of 1998 is associated with a very strong El Nino, which brings warm equatorial waters from the western Pacific Ocean to the areas adjacent to the west coast of Central and South America. The relative cooling observed in 2008 was associated with the effects of a very strong La Nina—a reverse of the El Nino phenomenon.

The overall trend for the satellite data set shows a warming of about .12 C per decade (about .2 F). Since the satellite data is completely free of any kind of urban heat island effect but still shows the same warming trend over the past three decades that the weather station data
shows, the evidence is very strong that global warming is indeed occurring within the parameters described by both data sets.

![Graph showing temperature deviations](image)

**Figure 6: Monthly Temperature Deviations in the Lower Troposphere, 1979 to the Present**

**Carbon Dioxide and Global Warming**

We have now had a chance to examine the changes in Earth’s temperature over a host of different time periods—ranging from millions of years down to just decades. Several things should be clear by now. First, temperature changes occur over different time periods. The Earth has been significantly warmer and significantly cooler than at present. Second, the causes of these changes vary based on the time frame we are considering. Over extremely long periods of time (millions of years), the position of continents relative to the polar regions is the dominant driver of climate. Over periods of tens of thousands of years, changes in Earth’s orbit around the sun are the dominant driver.

Understanding shorter term changes in temperature trends (over centuries or decades) has been somewhat more elusive to climate scientists. If we conclude that the Holocene Maximum (Figure 3) represented the turning point in our present interglacial, current temperature trends should be going down as we proceed toward the next Ice Age. We have seen however, that three counter trends have emerged since the time of the Holocene Maximum. The first, the one at the beginning of the first millennium A.D., and the second, the Medieval Warm period, must have had natural causes. This can also be said of the origin of the third (the one that ended the Little Ice Age). Human activities simply could not have caused any of these warming trends. Possible explanations include changes in solar activity and ocean currents.

But the warming that we have seen in recent decades has brought the global average temperature to a point that is likely to be at least as warm as it was during the Medieval Warm Period, and if this trend continues for even a few more decades, we will be back to the level that the Earth saw at the Holocene Maximum. Given what we know about climate history, the chances that these changes are “natural” seem small—especially when we consider the role of carbon dioxide.

Carbon dioxide (CO2) is a greenhouse gas, in the sense that it plays an important role in trapping heat in the Earth’s atmosphere. Data sets obtained from ice cores show that during previous interglacials, the atmospheric concentration of CO2 has tended to peak at between 280 and 300 parts per million (PPM). The data also show that during our present interglacial, the atmospheric concentration of CO2 had held rather constant at around 280 PPM until shortly after the industrial revolution began at the end of the 18th century. Since that time, CO2 concentrations have steadily increased.

Figure 7 shows the trend since 1970. The semi-annual fluctuations of about 5–7 PPM are caused by increased uptake of CO2 by plants in the summer in the Northern Hemisphere. Currently, the average annual CO2 concentration is about 400 PPM and is increasing at about 2.5 PPM per year.

When examining all the evidence, it seems very likely that increasing CO2 in the atmosphere is contributing to the current global warming we are witnessing. Moreover, as humans continue to burn more fossil fuels (coal, oil and natural gas), atmospheric CO2 will increase—and with it—so will global temperatures.

![Graph showing CO2 concentrations](image)

**Figure 7: Atmospheric CO2 Concentrations Since 1970**
Source: NOAA

**Implications of Warming**

So far, it appears that the warming we have witnessed in recent decades has, for the most part, been benign. When you stop and think about what aspects of human activities are most influenced by climate change, the three that emerge first are agriculture, tourism and maritime.
Agriculture

Most activities involved in agriculture take place outdoors, where they are highly subject to changes in climate. It is true that greenhouses, barns and poultry houses make up significant components of agriculture, but they are small in comparison to the outdoor growing of row crops, orchards, pastures, etc. Attempting to measure the impact of a warmer Earth on agricultural production is an enormous and multidisciplinary task. As temperatures rise, patterns of precipitation will change also; hence the emphasis on “global climate change” as opposed to simply considering “global warming.”

Agricultural researchers have used fairly sophisticated models to attempt to measure changes in agricultural output in response to climate change. Over the past few decades, global agricultural production has increased dramatically. Corn yields per acre have more than tripled over the past century as has milk production per cow for example. Several factors have contributed to these productivity increases, including better management practices, improved crop varieties and the health of food animals, animals used for food (U.S. Department of Agriculture, 2014).

Any forecast of future changes in agriculture must consider the fact that farmers are resilient. They will respond to opportunities and to education. If climate researchers and agricultural scientists keep farmers up to date on how climate will likely affect their operations, farmers will continue to adapt in ways that improve output and efficiency. This will and should be an important focus of research and extension regarding global climate change—since global food security depends upon it.

Tourism

While it is also true that some tourist activities take place indoors, again, much of this industry is motivated by the outdoors, where the quantity and quality of amenities are subject to changes in temperature and climate. This has very large implications for a host of recreation and tourism related activities including skiing, trips to the beach, etc.

Entrepreneurs in the tourist industry should be assumed to be resilient, just as farmers are. In that sense, providing them with information about coming challenges and opportunities should again be an important component of research and outreach regarding global climate change.

Maritime: The Oceans

Global climate change has a number of important impacts on the oceans. One impact is a change in sea level. When Earth’s temperature increases, sea levels rise. This is caused partly by thermal expansion of the oceans, and partly by the melting of ice on land—such as the snow and ice from mountains and the great ice sheets of Greenland and Antarctica. The warming over the past century has caused only a very minimal rise in sea level. If the current temperature trends continue over the next few decades, sea level rise will probably be in the range of 2–4 inches by mid-century, but warming beyond that would accelerate the rate of sea level rise in the second half of the 21st century by 1–3 feet.

A warmer climate will also open up much of the Arctic Ocean to navigation. The Arctic is likely to be virtually ice-free between the months of July and September by 2050. The elusive “Northwest Passage” sought by Arctic explorers in the 18th century will be a regular fact of life by that time and will have important implications for world trade as well as for the animals that inhabit the region.

Another impact that the oceans are witnessing is a change in pH caused by increasing CO2 concentrations in the atmosphere. The oceans have played a very important role in absorbing much of the CO2 emissions that human activities have caused. In this way, they act as a giant “sink,” preventing the increasing emissions from causing an even greater atmospheric level of CO2 than otherwise would have been the case. Research has shown that the oceans will continue to be able to act as a sink well beyond the year 2100 (Sabine, et al., 2004).

But as the oceans continue to absorb CO2, they are becoming more acidic. Marine biologists and oceanographers are studying the impacts these changes have made on coral reefs and ocean fisheries. This will continue to be a very important area of inquiry, especially since the oceans form a primary component of the Earth’s climate system and the marine biome is vital to human survival in many cultures. Protecting ocean ecosystems from changes in water temperatures and increasing acidity may arise as a substantial challenge in the future.

Sensitive Ecosystems

The oceans represent a subset of a larger group that we must consider: sensitive ecosystems in general. These ecosystems have developed over very long periods of time—where flora and fauna have adapted to current climate conditions. Complex relationships exist in the ecosystems (predator-prey, the food chain, pollination, etc). In the past, climate change has caused ecosystems to “migrate.” Barriers to migration, however, are ubiquitous. They include such things as natural and man-made barriers, ranging from mountains to desert to urban development. Climate changes in the past have also led to extinction of species. Understanding which specific ecosystems and species are most at risk and what, if anything, can be done to save them in the presence of climate change will also be an important component of future research and outreach.
Outlook

Many policy makers throughout the world—including heads of state and prominent members of legislatures—have vowed to do something to reduce CO2 emissions and concentrations. A number of important international agreements designed to cut CO2 emissions have been signed by the international community over the past two decades. But none of this has led to a reduction in CO2 emissions and concentrations.

In attempting to forecast the most likely scenario for CO2, we need to consider a number of factors. World population in January 2015 was estimated to be 7.2 billion, up from 4.0 billion in 1970. It is expected to grow to 9.0 billion by 2050. Much of this growth is in countries where living standards are relatively low in comparison to the United States, but these standards are expected to improve as economic development proceeds.

This means that the demand for energy will grow considerably in coming years and decades. What will be the source of this energy?

A number of new initiatives are underway to allow us to tap into solar and wind power in ways that seemed unimaginable even 15 years ago. The development of more fuel-efficient automobiles and airplanes has already been very impressive, and future gains in these areas are likely.

Despite all of these developments, however, it is very difficult to imagine that the use of fossil fuels such as coal, oil and natural gas will diminish anytime soon. Even if they peak as early as 2030—which seems to be an earliest case scenario—it is quite likely that global CO2 concentrations will rise to 450 PPM by 2050, when global average temperature is likely to be another 1 to 1.25 degrees C (1.8 to 2.25 degrees F) warmer than in the first decade of the century—and warmer than in any previous time during which humans have inhabited the Earth.

In the meantime, it seems prudent—even essential—that we maintain and even increase research and development into ways to gain energy efficiency as well as to continue to try to improve efforts to obtain energy from sources other than fossil fuels. Above all, we need to be prepared to face the challenges and opportunities that arise from the inevitable consequences of global climate change.

Recommended Reading


