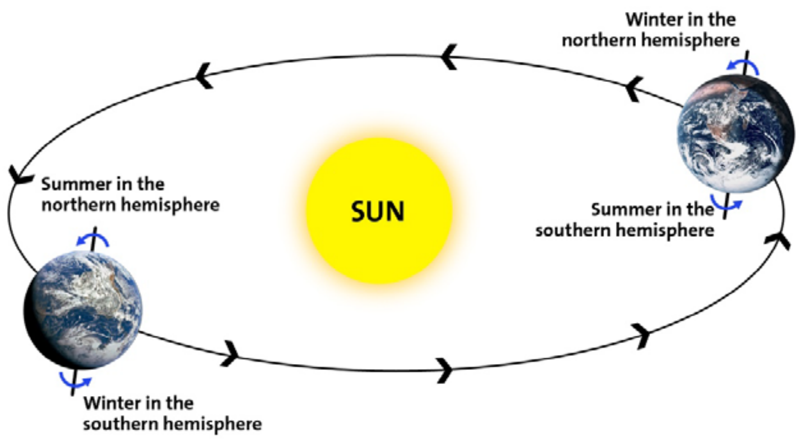
Climate is always changing—now it's us.

Suppose you are having a conversation about the influence of human activities on the climate. Someone might say that the climate is always changing and has been ever since the Earth was formed four-and-a-half billion years ago with no humans around. This is true. There are many natural factors that affect the climate, but, except for catastrophic events, like a meteor strike, the changes occur slowly over thousands to millions of years. Living things had time to adapt and evolve with the changes. An ancient climate that produced abundant plant growth is important today, because the remains of those plants are our fossil fuels, coal, oil, and gas. But the climate we are most interested in is the one we evolved in and are living in, so we need to look at the more recent past, say several hundred thousand years, for clues about what natural climate change is occurring, how human activities are rapidly disturbing it, and what we can do about it.

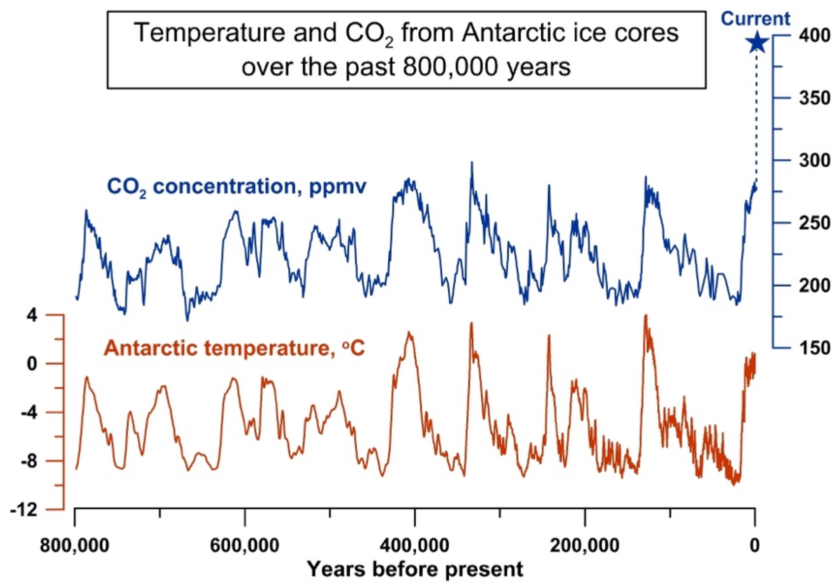
During the nineteenth century, scientists found evidence, mainly from geology, that sea levels had changed by many meters several times during the past several hundred thousand years. The most obvious explanation was that the planet had cycled between cold states, ice ages, with a lot of water tied up in ice on land (so low sea level) and warm states with much less land ice (and high sea level). In the 1860s, a Scottish scientist, James Croll, hypothesized that changes in the Earth's orbit around the sun caused these climate changes. This idea was expanded and made more quantitative by a Serbian engineer, mathematician, and astronomer, Milutin Milankovitch, in the early twentieth century.



Elaine Seward, ACS Climate Science Toolkit

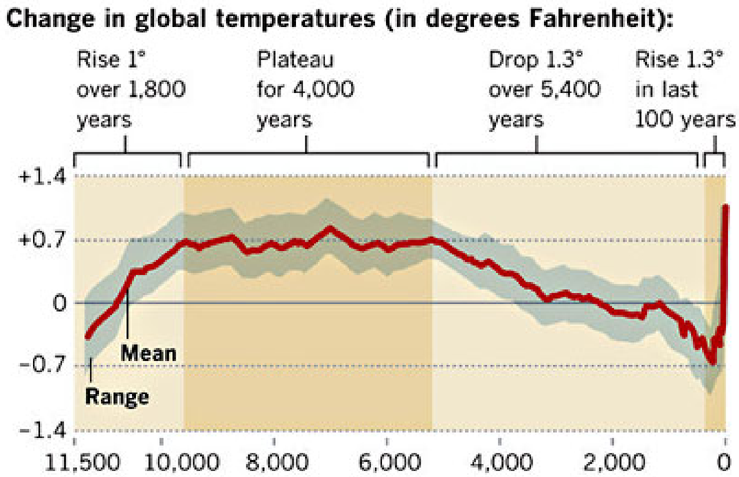
The Earth's movements wobble and wander a bit over time. The figure shows how the rotational axis is tilted, which is why we have seasons. The direction of the tilt (as you look down from the top of the planet) changes, like a wobbly spinning top, making a complete cycle about every 27,000 years. (This means that, in about 13,500 years, June will be the beginning of winter in the northern hemisphere and summer in the southern.) The degree of the tilt also changes by a few degrees in a 41,000-year cycle. The Earth's orbit around the sun changes shape from slightly more circular to more elliptical on about a 100,000-year cycle. What Milankovitch did was use these astronomical data (now called Milankovitch cycles) to calculate (without a calculator or computer) the geometry of the Earth relative to the sun for the past several hundred thousand years. He found a particular geometry recurring about every 100,000 years that coincided with the ending of the ice ages and onset of the warm periods, one of which we are living in now.

So what happens on Earth to initiate a warm period? And why does it end and return to an ice age? The beginning seems to be triggered by some ice melt and ocean warming when the planet geometry maximizes the amount of summer sunlight striking the northern hemisphere where most of the ice is. By itself, this disturbance isn't enough to end the ice age, but feedback from rising atmospheric carbon dioxide released from warming oceans does the trick. Evidence for this feedback comes from more recent, end-of-twentieth-century data from ice cores drilled from the massive Antarctic and Greenland ice sheets. Air mixed with snow that falls on these ice sheets gets trapped by the next season's snow and ends up as bubbles in the ice that forms as layer after layer of snow piles on top. The ice layers that build up stretch back at least a million years and can be extracted by drilling into the sheet with a hollow borer. This figure shows the carbon dioxide concentration in layers going back 800,000 years, together with the temperature at the corresponding time. (Temperature is calculated from an isotopic analysis of the water molecules in the ice surrounding the air bubbles.)



The data show that the carbon dioxide concentration is about 180 parts per million by volume, ppmv, (that is, if a million volumes of air were separated into its component gases, 180 would be carbon dioxide) during the coldest periods and about 280 ppmv during the warmest periods. The change in Antarctic temperature is about double the average change for the Earth as a whole. These changes in the greenhouse gas concentration change the Earth's average temperature by about 4 °C (about 7 °F). For the warm period we are living in, this temperature change from the preceding ice age took about 10,000 years. We have been at a warm temperature for about 10,000 more years, during which time civilization, agriculture, and industry have developed. In the 250 years following the Industrial Revolution, the carbon dioxide concentration has risen rapidly to 410 ppmv and continues to rise.

The figure shows that there are more and longer cold periods than warm ones. The natural state of the Earth for at least the past million years has been cold. The Milankovitch cycles increase the solar energy reaching an appropriate part of the planet, upset the steady-state level of carbon dioxide, and give "bursts" of warming. But then, the slow processes that remove the extra carbon dioxide, mainly by forming and precipitating calcium carbonate in the oceans, begin to predominate and the Earth cools once again. None of the peaks of the warm periods last more than a few thousand years, so it's likely that ours should be cooling and, indeed, as this figure shows the planet was slowly cooling for about the past 5000 years.



But now, the temperature has spiked upward to exceed its highest value in 10,000 years and continues to climb. This is not a natural, nor expected, climate change. The present temperature rise (right side of the figure) is about 25 times faster than the natural temperature rise coming out of the ice age (left side of the figure). The rapidly rising temperature is caused by the rapidly increasing concentration of atmospheric carbon dioxide and increasing greenhouse effect. The consequences of the warming globe are melting ice on land and sea, rising sea levels, shifting and more extreme weather patterns, more drought in some places and more flooding in others, and changes in habitat and extinction of some living species. If the temperature continues to rise, these changes will become even more severe and others can be anticipated. To avoid as much catastrophic disruption as possible, we must stop adding carbon dioxide to the atmosphere.

The major contributor to the increasing amount of carbon dioxide (and rising temperature) is the burning of fossil fuels. We use the energy released mainly for transportation and generation of electricity and these are clearly the targets to become "decarbonized" as quickly as possible. Each of us can immediately begin this process in many different ways. You can walk, bike, and take public transportation. If you must drive, opt for a hybrid vehicle or even better an electric. Fly less (or purchase carbon offsets to at least somewhat compensate for the plane's emissions). Coal and natural gas power stations cannot be replaced overnight by carbon-free electricity generation, but, if we use less electrical energy, they will not have to run as much during the time when they are being replaced. You can help reduce the amount of energy needed by using more efficient appliances and light bulbs, turning off electrical devices (that includes computers) when not in use, and simply buying less stuff (so less stuff has to be made). Our diets also involve energy in many ways to produce the food we eat. Meat and meat products require much more energy to bring to the table than fruits, vegetables, and nuts. Moving to a less meat, more vegetable rich diet is good for the planet's temperature. And as you choose your ways to reduce carbon dioxide emissions, make your voice heard. Do this literally in discussions in your social communities and by proxy in your votes for local, state, and national governmental candidates who will advocate for and create policies that mitigate human-caused climate change.