Past and present climate

What prehistoric and modern records say about future climes

By Zack Guido

How would you know your heating bills were high this winter if you did not have records of past bills? The same logic applies to climatology. To understand if the observed warming of the last 100 years and the rise in greenhouse gases is unusual, scientists have mined data from ice and sediment cores, tree rings, and other sources to piece together detailed paleoclimate records for much of the past two million years and as far back as 65 million years.

From these records, scientists now know that atmospheric concentrations of greenhouse gases such as carbon dioxide (CO_2) are more elevated today than at any period in the past 650,000 years; temperature often has changed by more than 10 degrees Fahrenheit in a matter of decades; the current global temperature is warmer than it has been during at least the last 500 years; and the climate during this modern instrumental age of the last 100 years or so has been less variable than in the more distant past.

The paleodata has revealed something else: if warming continues unabated, as climate models suggest, the resulting climate change within this century would be extremely unusual in geological terms, according to the International Panel on Climate Change (IPCC).

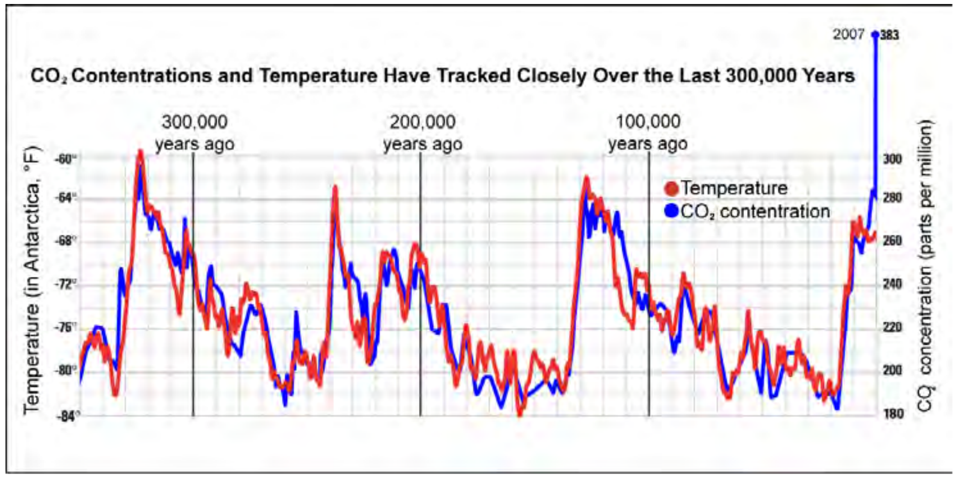

Figure 1: Ice core records from Vostok, Antarctica, show temperature near the South Pole has varied during the past 350,000 years in a regular pattern that constitutes the ice age/interglacial cycles. Changes in carbon dioxide concentrations track closely with changes in temperature during these cycles. *Credit: Image is modified and courtesy of the Marian Koshland Science Museum of the National Academy of Sciences.*

Unearthing Pre-historic Climate

We need examples in the past to understand present climate and anticipate future changes, said Connie Woodhouse, associate professor of geography and regional development at The University of Arizona and a CLIMAS affiliate. The examples are often found in proxies, natural phenomena that leave clues about past climate and are used when direct measurements are not available. Gases trapped in ice and the shells of tiny ocean organisms buried in ocean floor sediments, for instance, provide reliable and valuable climate information.

Many oceanographers have drilled the sea floor and analyzed diatom and foraminifera shells because their chemical make-up can be altered by changes in ocean water, revealing a historical record of shifts in ocean temperatures. Climate records derived from shells dive deepest into the past, providing insight into climate as far back as 65 million years, roughly when dinosaurs inhabited the Earth. The most detailed records from shells, however, span about the past two million years.

While sea-faring scientists have found climate clues at ocean depths, polar and high altitude expeditions have recovered miles of ice cores that contain preserved atmospheric gases in the frozen water. Captured in these cores, oxygen, CO_2, and other gases such as methane have illuminated in detail atmospheric and climate conditions of the past 650,000 years.

The climate records from these ancient sources have contributed immeasurably to climatology, revealing numerous glacial-interglacial cycles during the past three million years in which average global temperatures have oscillated by about 10 degrees F and regional temperatures have shifted even more. The records also have shown the intervals between the glacial maximums were similar at times during this period. For the past 400,000 years, for example, the area covered by the continental ice sheets was greatest about every 100,000 years. Prior to this period, the intervals between glacial maximums were longer, but they still occurred regularly.

This rhythm begged for an explanation—what caused glaciations and the warmer intervals to be periodic? The widely accepted theory is that glacial periods are instigated by changes in solar energy striking the Earth's surface. These cycles are known as Milankovitch cycles, named after the man who first proposed the idea that ice ages were triggered by variations in the Earth's astronomical position. Scientists believe changes in the Earth's tilt, axis of rotation, and the ellipticity of its orbit around the Sun slightly altered

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the amount of solar energy striking the Northern Hemisphere.

The solar energy changes, however, are relatively small and do not explain the degree of temperature change. Many scientists believe that while solar energy variations likely kicked off the transitions between warmer and cooler times, changes in the concentration of greenhouse gases in the atmosphere instigated by the warming or cooling are most likely responsible for amplifying the change.

These ideas are again rooted in ice. Cores drilled in Antarctica show that temperature and CO_2, a powerful greenhouse gas that has an intensifying effect on temperature, have been nearly in lockstep (Figure 1). The cores also show that changes in temperatures generally precede changes in CO_2 by several centuries. In its latest assessment report published in 2007, the IPCC stated the probability is greater than 90 percent that CO_2 variations strongly amplified climate but did not trigger the end of glacial periods. In other words, solar energy changes set in motion warming that in turn sparked other changes, such as increases in greenhouse gases that caused temperatures to rise by about 10 degrees F.

The ice cores also contained atmospheric gases that showed CO_2 varied between 180 and 300 parts per million (ppm) during the past 650,000 years, and concentrations of methane, another greenhouse gas, ranged from 320 to 790 parts per billion (ppb). To put this in perspective, the IPCC reported that CO_2 concentrations in 2007 topped 383 ppm, while methane reached 1,775 ppb in 2005. Since the beginning of the Industrial Revolution, the burning of fossil fuels, deforestation, and other human activities have contributed to these increased atmospheric concentrations. In the mid-eighteenth century, before the height of the modern industrial era, the estimated atmospheric concentration of CO_2 was 280 ppm.

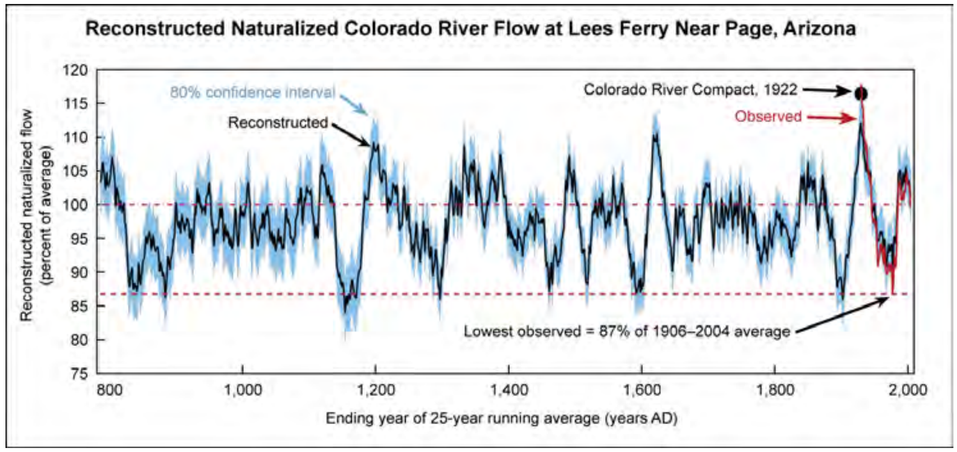

Figure 2: Colorado River flows reconstructed from tree-rings that spans the period 792–2005. The black line is the 25-year running average. Flows are plotted as a percentage of the 1906–2004 average, which incorporates most of the years in which instruments measured the flows (average is equal to 15.0 million acre-feet). *Credit: Figure modified from Meko et al., 2007.*

The use of past climate to better understand current conditions is vital, said Jonathan Overpeck, director of the Institute for Environment and Society and a geosciences professor at the UA, because knowledge of past climate provides a long context for better understanding recent climate change and the full range of natural variability.

Abrupt Climate Changes

While recurring cold and warm periods characterize past climates, so, too, do punctuated, large climate changes. Transitions into and out of the warmer and colder periods, for example, were not always gradual.

Researchers are trying to understand the "pop" in the system—the reasons why past temperatures have increased and decreased rapidly, said Joellen Russell, assistant professor of geosciences at the UA whose research includes using state-of-the-art climate models to simulate past climates.

Abrupt climate change occurs when the climate system crosses a threshold, triggering a rapid transition to a new climate state. A climate system with thresholds behaves similarly to a tipping bucket balanced over a pivot—the bucket remains upright until one too many water droplets topples it. The paleorecord is full of rapid climate changes and suggests that gradual changes, such as an increase in solar radiation striking the Earth or the melting of polar ice, may cause a large and rapid jump in temperature.

In the paleoclimate record, an intensely studied rapid climate change occurred approximately 12,800 years ago, marking the beginning of the Younger Dryas, a 1,200-year cool period observed most notably in the North Atlantic region. Ice core analyses indicate the period began with a few, decade-long cooling intervals and ended with a jump in regional temperature of about 15 degrees F in 10 years.

Another rapid climate change occurred about 8,200 years ago when temperatures around the north Atlantic Ocean fell by as much as 18 degrees F and Europe cooled by around 4 degrees F. Many scientists believe that this cooling was instigated by the catastrophic draining of mammoth lakes that formed from glacial melt-water at the toe of the

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continental ice sheet. Scientists hypothesize that as the ice sheet retreated in response to warming temperatures, seven times the amount of water contained in all five of the Great Lakes flushed into the north Atlantic Ocean. The influx of fresh water seemingly disrupted oceanic circulation; the current that delivered tropical heat to Europe weakened, and air temperatures plummeted.

Scientists believe that rapid climate change is a relatively common occurrence. By some estimates, more than 24 events of similar duration, degree of temperature change, and global extent as the Younger Dryas occurred in the last 110,000 years.

While some of the rapid climate changes have solid explanations, others, like the sudden warming at the end of the last glacial period, about 20,000 years ago, are still a mystery.

Researchers know, for instance, that for a small increase in solar radiation, a disproportionally large temperature change occurs, Russell said, referring to the jump in global temperature at the end of the last glaciation. "But there are 28 different theories about how feedbacks amplify the sun cycles," she said.

The past is the key to the future

Closer to home, reconstructions of tree growth in the western United States. have been particularly helpful in revealing climate for the past 8,000 years. By analyzing the width of tree-rings, which are altered by precipitation in some species and temperature in others, scientists have discovered that the past has been riddled with droughts. A detailed record of Colorado River flows spanning the last 1,200 years, for example, shows numerous periods when flows were lower than the current 100-year average (Figure 2).

"During the medieval period between 800 and 1300 AD, the West experienced persistent and frequent droughts," Woodhouse said. However, dry periods were common even after the medieval period. The longest and most severe occurred in the late 1500s. During this megadrought, the Colorado River had low flows for about six consecutive decades.

In fact, the paleorecord reveals that the average flow over the past 1,200 years is less than the amount allocated for use in 1922 by the Colorado River Compact, an agreement signed by seven western states—including Arizona and New Mexico—and Mexico that governs the water rights of the Colorado River. This information is vital for future water supply management. The U.S. Bureau of Reclamation recently incorporated tree-ring reconstructions into new river operating guidelines designed to prevent the depletion of water from Lakes Mead and Powell.

Records from tree-rings, ice and sediment cores, and other paleoclimate proxies have articulated valuable lessons for planning for the future: climate variability is greater and climate change is faster than they have been in modern times.

While the present has opened the door to the past, the past now provides insight to apply to the future.

"Since the paleorecord shows that there have been megadroughts in the past, it is important that the Southwest become resilient to this degree of change," Overpeck said.

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Related Links

Records of past climate span the globe and describe climatic conditions as far back as 65 millions years. They provide a rich context to understand current climate and to anticipate future changes. More information on paleoclimate and past climate reconstructions can be found at the following Web sites.

Data for the Western United States spanning about the last 100 years based on instrumental measurements:
http://www.cefa.dri.edu/Westmap/

Global and regional temperature data from various sources that span numerous periods:
http://www.ncdc.noaa.gov/paleo/recons.html

Paleoclimate information derived from tree-rings:
http://www.ncdc.noaa.gov/paleo/treering.html

Paleoclimate information derived from ice-cores:
http://www.ncdc.noaa.gov/paleo/icecore.html

IPCC 4th assessment report (chapter 6 focuses on paleoclimate:
http://www.ipcc.ch/ipccreports/assessments-reports.htm

On-line book about abrupt climate change issued by the National Academy of the Sciences:
http://www.nap.edu/openbook.php?isbn=0309074347