

Was Earth already heating up, or did global warming reverse a long-term cooling trend?

February 19 2023, by Ellie Broadman and Darrell Kaufman



Trees are the best-known natural archives. Here are several others that hold evidence of past temperature. Cores or other samples from these archives can be used to reconstruct changes over time. Credit: Viktor O. Leshyk, Author provided

Over the past century, the Earth's average temperature has swiftly [increased by about 1 degree Celsius](#) (1.8 degrees Fahrenheit). The evidence is hard to dispute. It comes from thermometers and other sensors around the world.

But what about the thousands of years before the Industrial Revolution, before thermometers, and before humans warmed the [climate](#) by [releasing heat-trapping carbon dioxide from fossil fuels](#)?

Back then, was Earth's [temperature](#) warming or cooling?

Even though scientists know more about the most recent 6,000 years than any other multimillennial interval, studies on this long-term global temperature trend have come to [contrasting conclusions](#).

To try to resolve the difference, we conducted a comprehensive, global-scale assessment of the existing evidence, including both natural archives, like [tree rings](#) and seafloor sediments, and [climate models](#). Our results, [published Feb. 15, 2023](#), suggest ways to improve climate forecasting to avoid missing some important slow-moving, naturally occurring climate feedbacks.

Global warming in context

Scientists like us who study past climate, or [paleoclimate](#), look for [temperature data](#) from far back in time, long before thermometers and satellites.

We have two options: We can find information about past climate stored [in natural archives](#), or we can simulate the past using [climate models](#).



Ellie Broadman, right, an author of this article, holds a sediment core from a lake on Alaska's Kenai Peninsula. Credit: Emily Stone

There are several natural archives that record changes in the climate over time. The growth rings that form each year in [trees](#), [stalagmites](#) and [corals](#) can be used to reconstruct past temperature. Similar data can be found in [glacier ice](#) and in tiny shells found in the [sediment that builds up over time at the bottom of the ocean](#) or [lakes](#). These serve as substitutes, or proxies, for thermometer-based measurements.

For example, changes in the width of tree rings can [record temperature fluctuations](#). If temperature during the growing season is too cold, the

tree ring forming that year is thinner than one from a year with [warmer temperatures](#).

Another temperature proxy is found in seafloor sediment, in the remains of tiny ocean-dwelling creatures called [foraminifera](#). When a foraminifer is alive, the chemical composition of its [shell changes depending on the temperature of the ocean](#). When it dies, the shell sinks and gets buried by other debris over time, forming layers of sediment at the ocean floor. Paleoclimatologists can then extract sediment cores and chemically analyze the shells in those layers to determine their composition and age, sometimes going back millennia.

Climate models, our other tool for exploring past environments, are mathematical representations of the Earth's climate system. They model relationships among the atmosphere, biosphere and hydrosphere to create our best replica of reality.

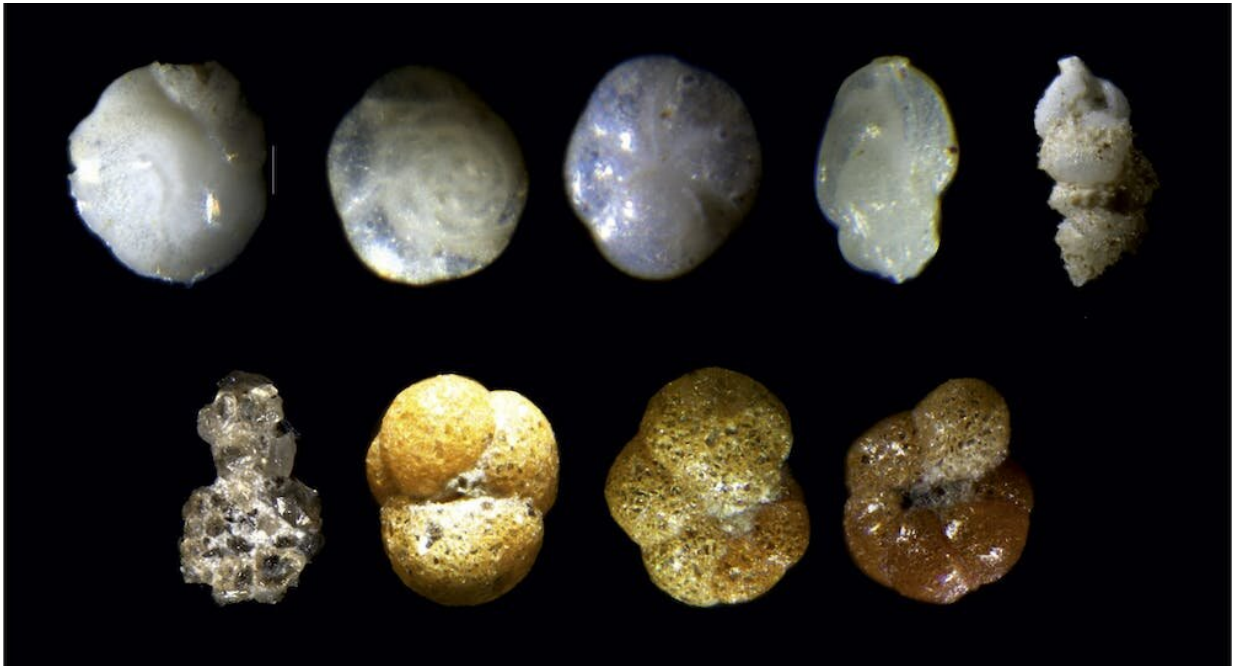
Climate models are used to [study current conditions](#), [forecast changes in the future](#) and [reconstruct the past](#). For example, scientists can input the past concentrations of greenhouse gases, which we know from [information stored in tiny bubbles in ancient ice](#), and the model can use that information to simulate past temperature. Modern climate data and details from natural archives are used to test their accuracy.

Proxy data and climate models have different strengths.

Proxies are tangible and measurable, and they often have a well-understood response to temperature. However, they are not evenly distributed around the world or through time. This makes it difficult to reconstruct global, continuous temperatures.

In contrast, climate models are continuous in space and time, but while they are often very skillful, they will never capture every detail of the

climate system.



Some example of foraminifera shells. Credit: [From Anna Tikhonova, Sofia Merenkova, Sergei Korsun and Alexander Matul via Wikimedia, CC BY](#)

A paleo-temperature conundrum

In our [new review paper](#), we assessed climate theory, proxy data and model simulations, focusing on indicators of global temperature. We carefully considered naturally occurring processes that affect the climate, including long-term variations in [Earth's orbit around the Sun](#), greenhouse gas concentrations, [volcanic eruptions](#) and [the strength of the Sun's heat energy](#).

We also examined important climate feedbacks, such as vegetation and

sea ice changes, that can [influence global temperature](#). For example, there is strong evidence that [less Arctic sea ice](#) and [more vegetation cover](#) existed during a period around 6,000 years ago than in the 19th century. That would have darkened the Earth's surface, causing it to absorb more heat.

Our two types of evidence offer different answers regarding the Earth's temperature trend over the 6,000 years before modern global warming. Natural archives generally show that Earth's average temperature roughly 6,000 years ago was warmer by [about 0.7 C \(1.3 F\) compared with the 19th century median](#), and then cooled gradually until the Industrial Revolution. We found that most evidence points to this result.

Meanwhile, climate models generally show a slight warming trend, corresponding to a gradual increase in carbon dioxide as [agriculture-based societies developed](#) during the millennia after [ice sheets retreated](#) in the Northern Hemisphere.

How to improve climate forecasts

Our assessment highlights some ways to improve climate forecasts.

For example, we found that models would be more powerful if they more fully represented certain climate feedbacks. One [climate model experiment](#) that included increased vegetation cover in some regions 6,000 years ago was able to simulate the global temperature peak we see in proxy records, unlike most other model simulations, which don't include this expanded vegetation.

Understanding and better incorporating these and other feedbacks [will be important](#) as scientists continue to improve our ability to predict future changes.

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