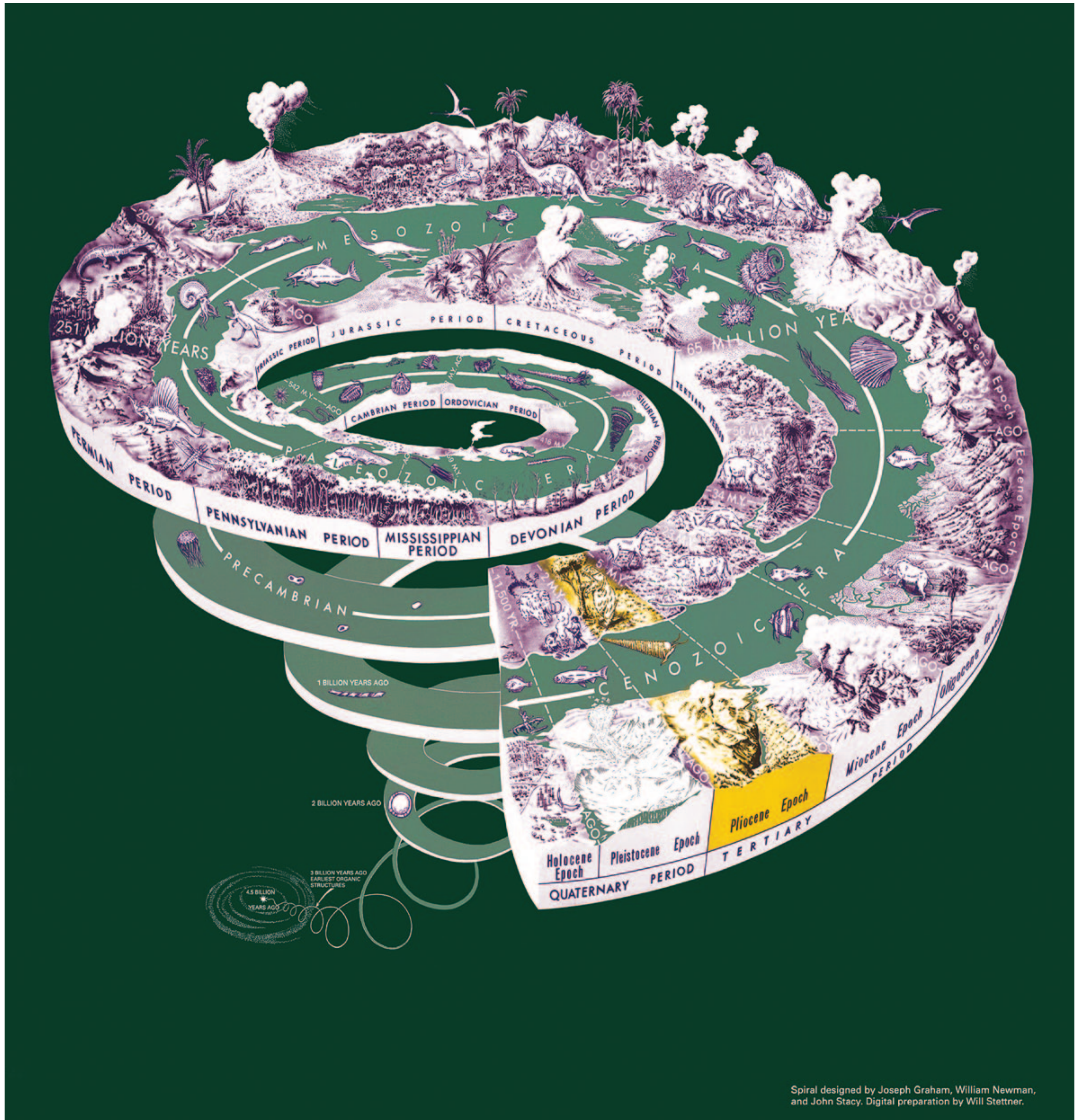
Can the Balmy Pliocene Predict Our Climate's Future?

by David Julian



Geologic timeline spiral courtesy of the U.S. Geological Survey

The past has just become the best way to test the future. About 4 million years ago, during the Pliocene, the oceans were actually warmer than they are today. Although that geologic era was among Earth's least eventful, the warm seas of the Pliocene are becoming a new proving ground for models of present and future climate.

Studying the past appears to be the only way we can see how climate responded over a long enough time span to understand it accurately.

Dr. Petra Dekens, an assistant professor in the Geosciences Department at San Francisco State University, is one of several researchers studying the Pliocene for exactly this reason: to test current global warming models against the only other period in Earth's history when it was exceptionally warm. "Today," Dekens explains enthusiastically, "we have all these fancy models, but how do you test them? We don't have a test-case Earth."

Enter the Pliocene, 5.8 to 1.8 million years ago. Ocean temperatures were several degrees warmer than they are now, as were atmospheric temperatures. The concentrations of CO_2, a major greenhouse gas, were much like ours are today. And there was a permanent El Niño in effect—the atmospheric phenomenon that causes warmer temperatures in the eastern Pacific and resultant floods and droughts on land. The Pliocene, according to Dekens, is the best example we have of how Earth will behave if it continues to warm.

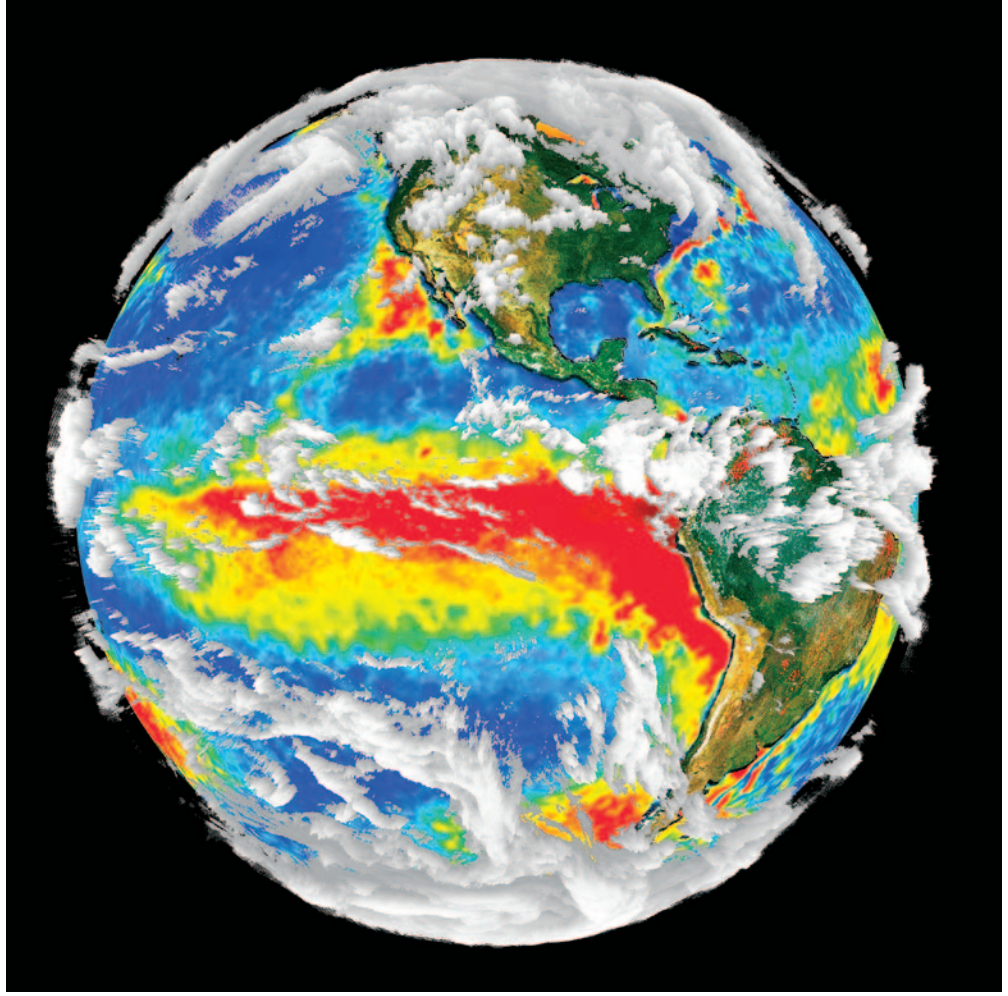
The Pliocene was also warm and stable for a long, long time, Dekens explains. The predictive power of current climate models breaks down because we are in transition from a cooler period to a warmer one. It's difficult to compare any model against such a limited set of data. The Pliocene, on the other hand, never varied more than a few degrees in almost a million years. For that reason, says Dekens, the era can act as a massive

G. sacculifer **is a foraminifera that lives in the top 50m of the ocean where it precipitates it's calcium carbonate shell, which is preserved in deep sea sediments, as seen here. The chemistry of the shell, in particular the Mg/Ca ratio, records conditions during the organisms growth, and can be used to reconstruct sea surface temperatures in the past.**

G. sacculfer image courtesy of Dr. Athanasios Koutavas, CUNY College of Staten Island

3D earth image

This synthetic image by R. B Husar, Washington University is a compilation from several satellite data sources. The ocean colors represent sea surface temperature anomalies (difference from normal) during a modern El Niño event, where temperatures are 4-5C warmer in the eastern equatorial Pacific compared to a normal year. This variation in sea surface temperature pattern causes changes in patterns of cloud cover and precipitation and affects climate globally. The sea surface temperature pattern in the early Pliocene warm period resembles the El Niño pattern, with significant warming in the eastern equatorial Pacific while the western equatorial Pacific remains relatively stable, and is thought to contribute to warn conditions during that time.



Synthetic image by R.B. Husar, Washington University: land layer by the Seaviewing Wide Field-of-view Sensor (SeaWiFS) Courtesy of the Geological Society of America

testing ground.

Gathering evidence, however, is something of a challenge. Most proof of Pliocene temperatures lies not only underground, but also under several thousand meters of water. This is where a paleoceanographer like Dekens comes in–someone who studies evidence of ocean activity from the geologic past. Dekens bases much of her work on the fossilized remains of shell-forming plankton known as Foraminifera–in particular, a surface-dwelling species called *G. sacculfer*. This microscopic single-celled organism can be a major food source for almost anything living in the ocean. The cells have also remained unchanged for the last 5 million years: *G. sacculfer* has lived within the same narrow zone of light penetration and warm water temperatures throughout the ocean's history. Because they do one very basic thing–build calcium shells for themselves–they can be used as accurate indicators of ocean conditions at the time they lived.

Foraminifera shells have a very specific ratio of calcium to magnesium. In warmer ocean water, magnesium can substitute for calcium. This is a "thermodynamic effect that's biologically mediated," Dekens explains. "Basically, the warmer the temperature, the more magnesium." Measuring the ratio of magnesium to calcium in these plankton shells from different eras turns out to be a very accurate indicator of ocean temperature throughout geologic history. "We can't measure temperature directly," says Dekens, "but we can measure this other process that we know is directly related to temperature."

"Unearthing" foraminifera from beneath deep ocean water is the most difficult part, but old oil drilling technology makes it possible. A specialized drilling ship, the JOIDES Resolution, is the primary gathering source for paleoceanographers. Originally designed to core the ocean bottom in search of oil, this ocean drilling technology now helps scientists study the effects of global warming caused, in part, by fossil fuels. Dekens has worked at SF State, at Texas A & M, and at other universities in conjunction with the Integrated Ocean Drilling Program (IODP) that operated the JOIDES Resolution. She and her colleagues take ocean bottom rock cores from selected sites and then analyze the marine fossil organisms, using the same technologies a terrestrial paleontologist would employ.

The rock cores come in 10-meter sections. Dekens and her coworkers shorten these into 1.5-meter sections. Finally, they split these shortened samples in half down the middle. They archive one of the halves in a massive cold-storage facility in Texas. Dekens then works on the other half. She uses the phrase "ground-truthing it" frequently and figuratively when speaking of the practical testing of her work against the real world.

The cores basically look like long sections of dark sea mud, and acquiring and setting up the mud cores is literally dirty work. Analyzing them, however, is surprisingly clean and carefully controlled. First, the scientists take out little sections of the core, dry them, and separate out the foraminifera with the aid of a microscope. "They look like popcorn," she notes. From there they are crushed and dissolved in a solution that reveals their relative ratios of magnesium to calcium. From this, Dekens can extrapolate the ocean temperature at the time they lived. This analytic work has "given me a re-appreciation for chemistry," Dekens laughs. "Chemistry is actually useful besides being chemistry!"

At the end of the day, the point of all this "groundwork" is to gain an increasingly detailed picture of the Pliocene climate and then, says Dekens, to use it "to better understand the (current) climate system." Because geoscientists have only been taking daily temperature measurements for the past 200 years, there isn't enough data to make good predictions about warming. In addition, she explains, ocean and air temperatures have only been climbing for a few decades. Studying the past appears to be the only way we can see how climate responded over a long enough time span to understand it accurately.

There are some problems, Dekens notes, with using the Pliocene as an analog and testing model. The most important is the similarity of CO_2 concentrations to current levels. In the Pliocene, CO_2 levels were exactly as they are today, yet average temperatures were 3 degrees warmer. Why, then, isn't our average global temperature 3 degrees higher, as well?

One explanation may lie in an increasingly positive feed-back loop at higher temperatures, but Dekens acknowledges that this is relatively new and poorly understood territory. Atmospheric concentrations of the greenhouse gas CO_2 are around 375 to 380 ppm (parts per million) today, she notes. Yet air trapped in ancient glacial ice reveals that CO_2 concentrations have been no higher than about 300 ppm throughout the last 1 million years, including during the warm period. In [colder] glacial times, CO_2 concentrations were about 220-200 ppm. If the Pliocene is an accurate model, with human-generated CO_2 nudging current levels up to 375 to 380 ppm, then air and ocean temperatures should be much warmer.

DR. PETRA DEKENS

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The similarity of greenhouse gas levels between the Pliocene and today "is kind of a weird thing," Dekens muses. If CO_2 levels are indeed similar, but the temperatures then were 3 degrees warmer–"… and 3 degrees is a lot!" she says–the questions become "Why was it warmer? Are the models wrong? Are they underestimating the amount of warming we're going to get? Or, was something else going on in the Pliocene that we still don't understand?"

As Dekens explains it, El Niño might be a contributor to the confusion. On average, El Niño years are warmer globally, she says, and current climate change models need to factor that in. "The sea surface temperature is going to make a huge difference to the climate. Part of the reason we get fog in San Francisco is because there's cold water coming up near the coast. But clouds reflect a lot of light away from the water surface. It's a positive feedback loop. A lot of the current models don't account for things like this."

In response to the modeling problem, Dekens has proposed a novel reorganization of the El Niño/La Niña concept which she calls "El Padre." El Niño is really the El Niño Southern Oscillation, she says. By definition it's an oscillation; it switches between El Niño and La Niña. El Niño is accompanied by warm ocean surface temperatures in the Eastern Pacific and La Niña, by cooler surface temperatures. "In some sense," Dekens continues, "you can't have a permanent El Niño. What we really mean by 'El Padre' is the background state of both." In other words, it refers to the overall pattern of warming everywhere regardless of periodic oscillations. "It's bigger than an El Niño," she says. "It's kind of a change in the mean state."

Dekens maintains that she and others must understand El Padre more fully before they can model its role in the Pliocene. With it, she says, scientists should be able to better compare current climate models and more accurately predict our own rapidly warming future.❖