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Why the Planet’s Past 485 Million Years Are a Climate Warning

A new study uncovers Earth’s deep temperature history and shows just how tightly carbon dioxide has always controlled the climate

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4 min read

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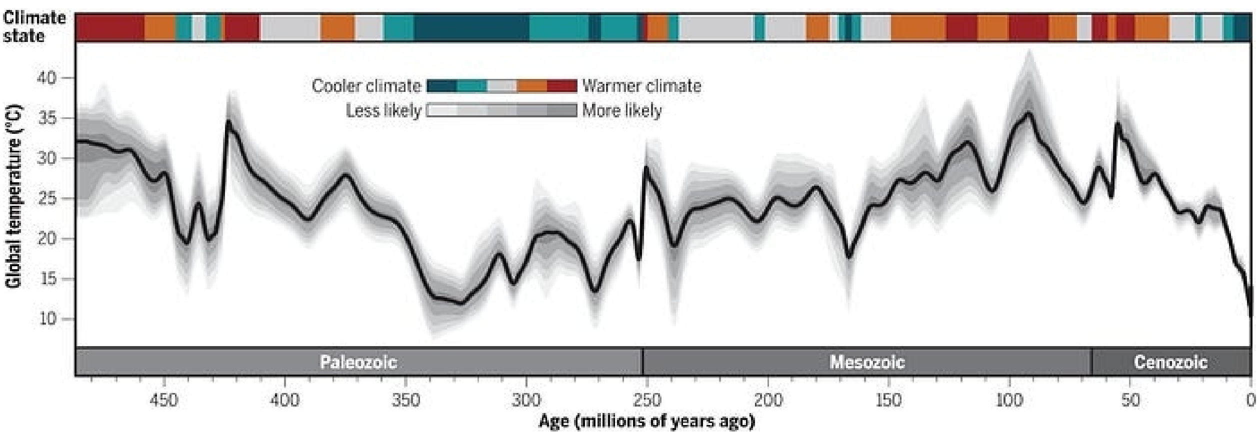
When I first joined the Smithsonian as a postdoc, the Deep Time exhibit was just beginning to take shape. You could feel the weight of it: this massive effort to bring Earth’s deep history to life. The models of ancient ecosystems arrived in crates, the fossil mounts slowly grew in the hall, and the curators debated where to place the dinosaurs.

Every time I visit now, I still love watching the visitors file in, wide-eyed and full of questions. But what surprises me most isn’t the fascination with dinosaurs. It is the genuine curiosity about Earth’s changing climate.

That curiosity is exactly what this study delivers on.

Published in *Science* in September 2024, the study offers a sweeping reconstruction of Earth’s surface temperature over the past 485 million years; essentially the entire history of complex life. For the first time, we now have a statistically robust temperature curve for the whole Eon.

That means we can trace the global mean surface temperature (GMST) from before the first forests to the rise of mammals. And perhaps more importantly, we can see how dramatically Earth’s climate has changed and what drove those changes.



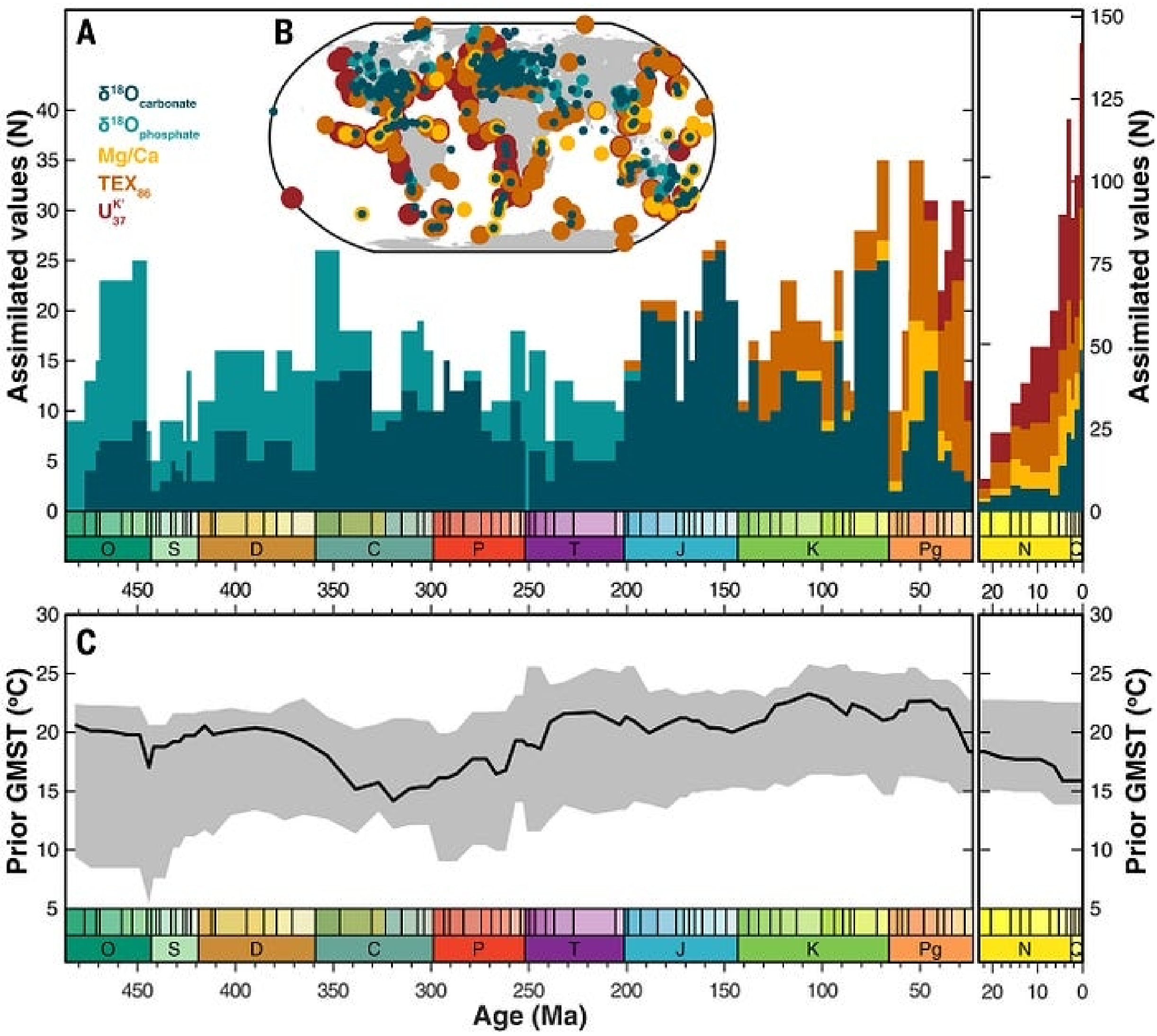
PhanDA global mean surface temperature across the last 485 million years. The gray shading corresponds to different confidence levels, and the black line shows the average solution. The colored bands along the top reflect the climate state, with cooler colors indicating icehouse (coolhouse and coldhouse) climates, warmer colors indicating greenhouse (warmhouse and hothouse) climates, and the gray representing a transitional state — Judd et al., 2024

The team behind the study, including colleagues from the Smithsonian, the University of Arizona, UC Davis, and the University of Bristol, used a technique called data assimilation. Think of it like blending thousands of puzzle pieces from two very different boxes: climate models and fossil-based temperature data.

While models give us theoretical projections, the fossil record gives us chemical fingerprints from ancient oceans. By integrating more than 150,000 data points with 850 climate simulations, they produced what they call the PhanDA curve (see above), a reconstruction of GMST spanning nearly half a billion years.

So what did they find?

First, Earth's temperature has swung far more wildly than previously thought. Over the Phanerozoic, GMST ranged between 11°C and 36°C. That's like flipping between an ice age and a sauna, many times over. Most strikingly, the planet has spent more time in greenhouse states (hot and ice-free) than in our current coldhouse state. Today's average of about 15°C is relatively chilly in a deep-time context.



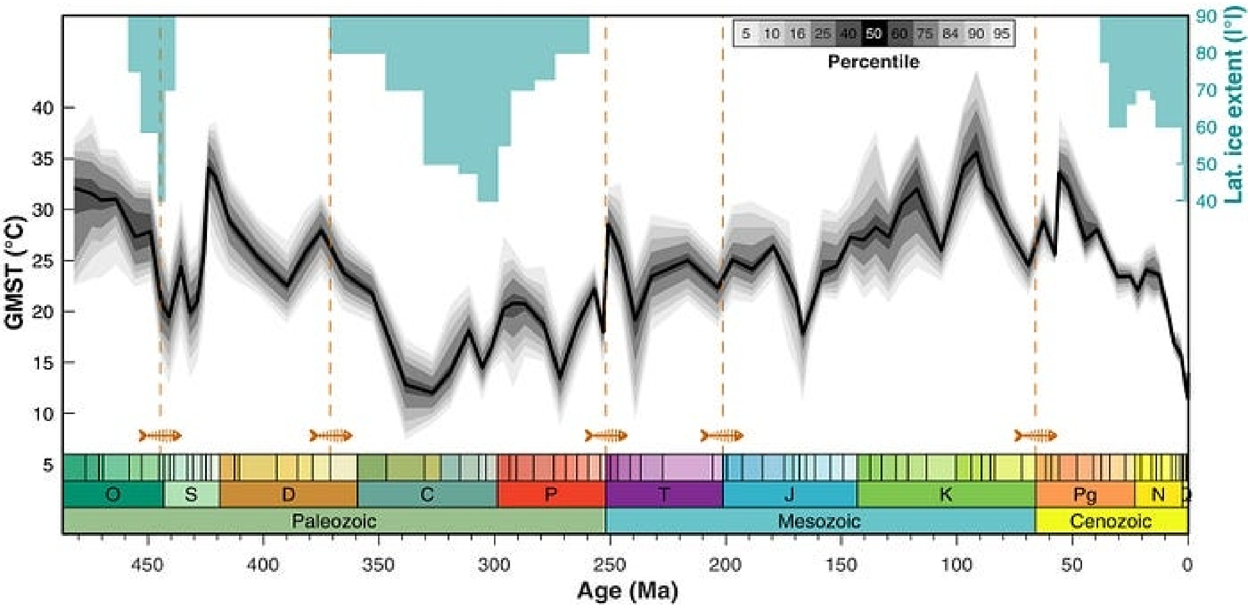
Proxy and model data used for the PhanDA reconstruction. Temporal (**A**) and spatial (**B**) distribution of stage-averaged proxy data used in the assimilation. © Range (gray band) and median (black line) of GMSTs within the prior model ensemble for each assimilated stage — Judd et al., 2024

Second, CO_2 is the star of the show. The new curve shows a strong correlation between atmospheric carbon dioxide levels and GMST. As one of the authors, paleoclimatologist Dr. Jessica Tierney, put it: That may sound obvious, but confirming it across 485 million years is no small feat.

Third, the study reveals something even more unexpected: the relationship between CO_2 and temperature appears remarkably stable. The researchers estimate that doubling CO_2 levels has historically raised GMST by about 8°C. That's higher than many modern climate sensitivity estimates, and it suggests that Earth's climate system has consistently responded to carbon dioxide in powerful ways, regardless of whether the world was covered in glaciers or rainforests.

They also uncovered something curious about the tropics. There has long been debate over whether tropical temperatures have a natural ceiling, a kind of planetary thermostat. But during hothouse periods, tropical oceans reached up to 42°C. That's hotter than most living species can tolerate today.

The implication? Life didn't avoid these regions; it likely adapted. The fossil record hints at this, but we still don't fully understand how ecosystems handled such heat. Or even more important, what species took a hit and went extinct.



Phanerozoic temperature history. PhanDA reconstructed GMST for the past 485 million years. Black line shows the median, shading corresponds to the ensemble percentile. Blue rectangles show the maximum latitudinal ice extent, and orange dashed lines show the timing of the five major mass extinctions of the Phanerozoic — Judd et al., 2024

From a conservation perspective, the most striking part is how fast we're changing things now. Earth has been hotter before, yes. But those shifts played out over hundreds of thousands or even millions of years.

We're compressing changes that took eons into just a few centuries

The press release accompanying the study puts it well: “Humans, and the species we share the planet with, are adapted to a cold climate. *Rapidly* putting us all into a warmer climate is a dangerous thing to do.”

Standing in the Deep Time exhibit years ago, surrounded by the story of our planet etched in fossils and dioramas, I felt a strange mix of wonder and urgency. This study brings both into sharper focus.

It doesn’t just give us a clearer picture of the past; it sharpens our view of what lies ahead, and reminds us that climate, like evolution, doesn’t wait for us to catch up.