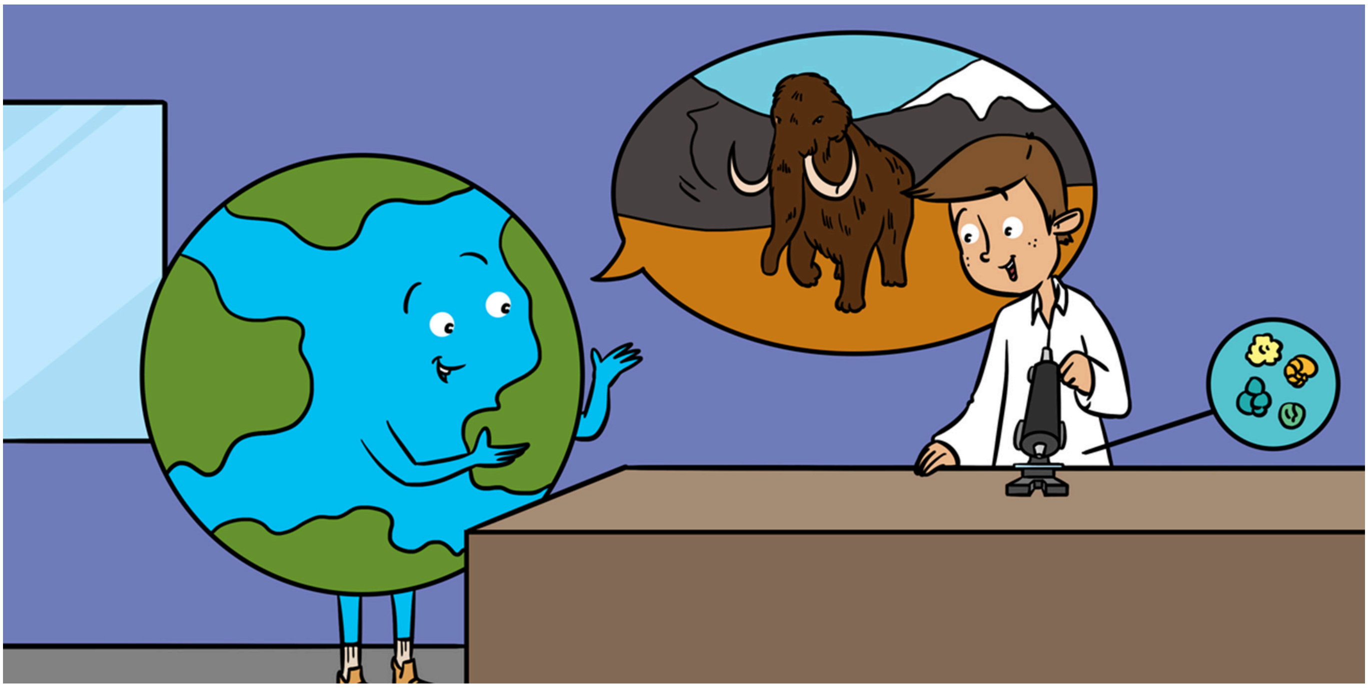
EARTH AND ITS RESOURCES
Published: 24 May 2022
doi: 10.3389/frym.2022.684983



UNDERSTANDING THE CLIMATE OF ANCIENT EARTH

Edward Armstrong[1,2*], *Alexander Farnsworth*[2,3], *Vittoria Lauretano*[4] and *Caitlyn Witkowski*[3,4,5]

[1] *Department of Geosciences and Geography, University of Helsinki, Helsinki, Finland*
[2] *School of Geographical Sciences, University of Bristol, Bristol, United Kingdom*
[3] *Cabot Institute, University of Bristol, Bristol, United Kingdom*
[4] *School of Chemistry, University of Bristol, Bristol, United Kingdom*
[5] *Schools of Earth Sciences, University of Bristol, Bristol, United Kingdom*

YOUNG REVIEWER:

ETHAN
AGE: 9

The Earth has been around for a long time. Earth's climate history is called its paleoclimate, where "paleo" means old or ancient. In this article, we explain how studying paleoclimate helps us understand how and why the Earth (and the life on it) evolved over time. Scientists can study the fossils, chemicals, and minerals preserved in ice or ancient rocks. Using this information, as well as computer models of Earth's past climate, scientists can figure out climate changes going back millions of years. Understanding past climate changes helps us understand how Earth's climate is changing now, and how it might further change in the future.

WHAT WAS EARTH'S CLIMATE LIKE IN THE PAST?

The Earth is 4.5 billion years old—that is 4,500,000,000 years! It would take you over 1,000 years just to count to that number! Modern humans have only been around for about 200,000 years, so a lot of time passed before humans had an impact on the Earth.

CLIMATE

The average long-term pattern of weather in a region or across the Earth.

PALEOCLIMATE

The climate of the Earth at a particular time in the past, when direct measurements (such as from a thermometer) could not be taken.

Throughout Earth's history, the planet's **climate** has changed dramatically. The climate of ancient Earth is called its **paleoclimate**, and scientists study it to understand how Earth's climate might change in the future. In Figure 1, you can see how, in the past, Earth's climate was either much warmer or much colder than it is today. Over the past million years, there have been several ice ages, occurring approximately every 100 thousand years (Figure 1B). During the more recent ice ages, early humans started to evolve to what we are now. Thick ice sheets covered much of Europe and North America; in the UK, ice extended up to 1,000 meters above your head! Temperatures were much colder, but there were still big animals that were specially adapted to those icy environments, including wooly mammoths and saber-toothed tigers.

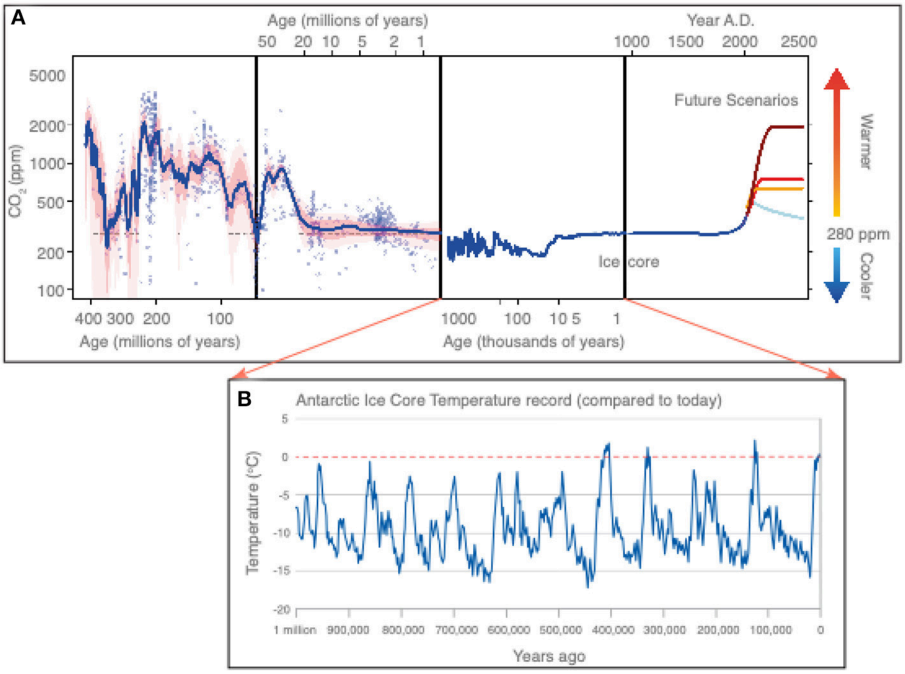


Figure 1

Figure 1

(A) Changes in Earth's carbon dioxide (CO_2) (left) and temperature (right) over the last 400 million years [1]. This is only a small section of Earth's 4.5-billion-year history. Notice how the x-axis changes. The red line shows the amount of CO_2 in the atmosphere before humans started burning fossil fuels. Future scenarios are dependent on how much CO_2 we release. **(B)** A more detailed view of temperature changes throughout the ice ages over the past 1 million years, constructed from Antarctic ice cores [2]. These show how much climate has changed naturally throughout Earth's history.

If we keep going further back in time, temperatures were much higher than they are today. During the Eocene (about 56–45 million years ago), there were no ice caps at all, and palm trees and crocodiles lived in the Arctic! Before then, between 150 and 80 million years ago in the Cretaceous period, dinosaurs lived on the Earth. Temperatures were even higher, more than 13°C warmer than today. A lot of the Earth was covered in tropical rainforests, including the UK. Antarctica was covered with forests, and those fossils tell us that cold-blooded reptiles lived there, similar to those that live in the tropics today.

If we continue to go back in time, around 600–700 million years ago, there was a period called the Cryogenian. During this period, the Earth was completely covered in ice, even at the equator. Scientists call this "snowball Earth." This may sound unpleasant, but these cold temperatures likely led to an explosion of life in the oceans, which was responsible for the start of most living things we see today. As you can see, humans are just a tiny part of Earth's history.

WHAT CONTROLLED PAST CLIMATES?

So what caused these big changes in climate? This is complicated because there are many different reasons, and they occurred over different timescales.

One major long-term controller of climate is the amount of **greenhouse gases** in the atmosphere. These gases include carbon dioxide (CO_2) and methane (CH_4), and they act like a greenhouse around the Earth by trapping heat energy from the Sun. More greenhouse gases trap more heat, so temperatures rise. The amount of greenhouse gases has changed slowly and naturally throughout Earth's history. There are lots of reasons for these changes, including the amount of volcanic activity, changes in ocean circulation, the types of vegetation, and complicated processes like weathering of rocks. More recently, greenhouse gases have been increasing dramatically due to human activity such as burning **fossil fuels**. A rapid increase in greenhouse gases is playing a major role in the climate change that is happening today [3].

GREENHOUSE GASES

These are gases that are in the atmosphere and trap heat from the sun. They include carbon dioxide and methane.

FOSSIL FUELS

Natural fuels that have formed underground over a long period of time from the remains of living organisms.

Another major controller of climate is the position of Earth's continents (Figure 2A). Continents move on very long timescales because blocks of land sit on a layer of molten lava called the mantle, which is moving them very slowly. Every 300–500 million years, Earth's continents join together into one massive continent. For example, around 175 million years ago, all of Earth's land was joined together in one supercontinent called Pangea. When Pangea broke apart, it changed wind and ocean currents, eroded land, and created big volcanoes. All these things had significant impacts on Earth's climate, partly by changing the amount of greenhouse gases in the atmosphere.

Earth's vegetation also influences climate. The first land plants evolved about 470 million years ago and began to suck CO_2 out of the atmosphere. These early plants may therefore have cooled the climate leading to "snowball Earth." Later, vegetation with dark green leaves (like ferns and trees) evolved. The dark colors absorbed the Sun's energy, which may have helped warm the planet.

The Sun's energy is the most important factor keeping the planet warm enough for life to exist—but the amount of energy we receive from the Sun is not constant. The way the Earth travels around the Sun changes

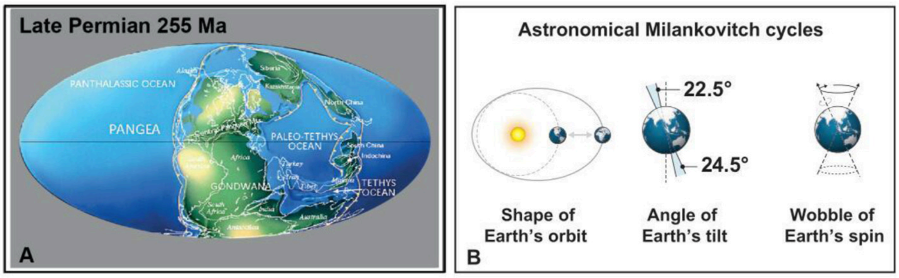


Figure 2

Figure 2

Natural processes that control climate. **(A)** The position of Earth's continents can change. In the past all of Earth's land was joined together in one super continent called Pangea [4]. **(B)** The Earth's orbit around the Sun changes through time [5]. These are called Milankovitch cycles, and they impact the amount of heat that reaches the earth, which can influence climate.

in cycles of hundreds of thousands of years. The amount of energy reaching Earth is controlled by how close the Earth is to the Sun, how much the Earth's axis tilts, and how much the Earth wobbles as it spins. These cyclic changes are called **Milankovitch cycles** (Figure 2B). These cycles impact Earth's climate and are responsible for the ice ages that occurred over the past 2 million years (Figure 1B) [5].

MILANKOVITCH CYCLES

Refer to natural changes in Earth's orbit around the sun that occur over long periods of time. These alter the amount of heat that reaches the Earth which impacts climate.

There are also short, explosive events that can impact climate, including meteorites, which are big rocks from outer space that hit the Earth. For example, the dinosaurs went extinct when a huge meteorite hit the Earth 65 million years ago. The impact released ash and soot high into the atmosphere, which reflected some of the Sun's energy back into space, away from the Earth. This cooled the planet; meaning plants and dinosaurs could no longer survive. However, seeds buried in the soil were preserved and grew again when the climate started to recover and warm.

HOW DO WE MEASURE PAST CLIMATES?

Because we do not have a time machine to go back and measure Earth's paleoclimate, scientists must use creative methods to understand what climate used to be like. One way to look into the past is to drill and extract ice from the north and south poles. These **ice cores** can be up to 3,000 meters long! Scientists directly measure small air bubbles in the ice that still contain CO_2 from when they were formed, some as long as 800,000 years ago.

ICE CORES

A long cylinder of ice that is drilled out of an ice sheet or glacier. They can give scientists information about past climates.

As we discussed, there were many times during Earth's history when there was no ice on the Earth. So, what do scientists do then? One method is to use **proxies**. Proxies are physical materials that record past conditions. Proxy materials can be fossils, molecules, or minerals found in ancient sediments (Figure 3). For example, fossils of animals and plants (including plant pollen) can tell us about the climate of the past. If sediments contain palm tree fossils, for example, the climate was probably hot and tropical in that location in the past.

PROXIES

Preserved physical materials, such as fossils, minerals or molecules, which record past conditions and can be used to reconstruct past climate.

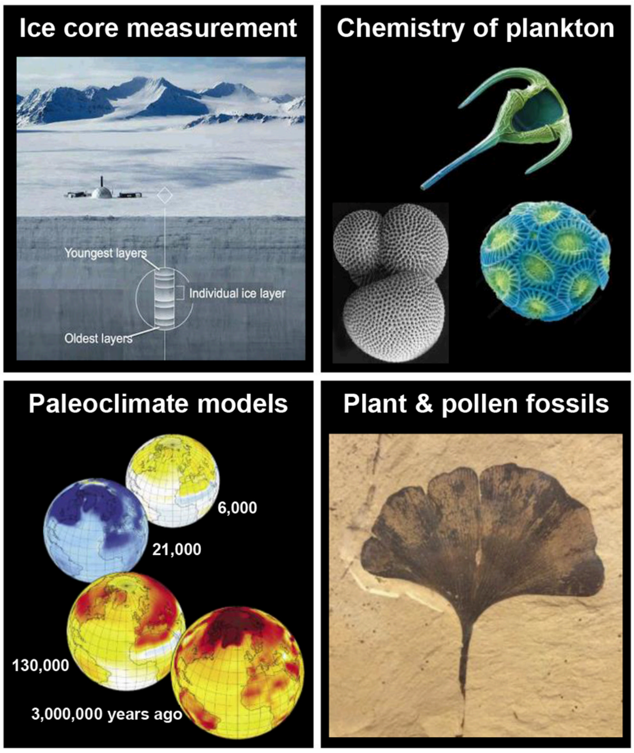


Figure 3

Figure 3

Scientists use ice cores, proxies like shelled organisms and fossils, and climate models to estimate past changes in paleoclimate.

One of the most useful proxies is found in the oceans—the remains of tiny, shelled organisms called plankton. During their lives, these tiny organisms built their shells from molecules in the surrounding water. When they died, their shells floated to the ocean floor and were buried. When scientists dig up these tiny shells, they can calculate the number of organisms and analyze the molecules in the shells. This helps them understand what the environment was like when those organisms were alive, including climate factors like CO_2 and temperature.

Another method to reconstruct the past is to use computers to build model worlds that simulate both past and future climate. These models use mathematical equations to represent the complex processes that make up the climate system. Scientists set up these models using information about the world today, which can then be changed to match the conditions found in the past. These models are very complex, so they need to be run on big supercomputers. Scientists can run simulations with the models to provide information about what the climate might have been like in the past.

Combining climate models with results from proxies gives scientists a powerful tool to more accurately understand paleoclimate.

WHY IS PALEOCLIMATE IMPORTANT AND HOW CAN IT HELP US UNDERSTAND THE FUTURE?

Studying paleoclimate is important for understanding Earth's past. It explains why the present-day Earth is the way it is, such as why certain animals and plants live where they do. Studying paleoclimate shows us how the Earth (and life on Earth) responds to change.

As you have seen, Earth's climate has changed a lot in the past, but these changes usually take many thousands of years. Right now, we are seeing climate change happening over just a few decades, making it difficult to know what will happen next. Therefore, it is also important to study paleoclimate to understand the future of our planet.

One of the most important things for scientists to understand is exactly how changes in greenhouses gases (like CO_2) affect temperature. This is known as **climate sensitivity**. Paleoclimate information can be used to help scientists better understand climate sensitivity. This information can be used to improve climate models, so scientists can more accurately predict how current changes in greenhouse gases might impact future climate. Climate affects all life on Earth, including plants, animals and us—so, understanding our past will help us prepare for our future.

CLIMATE SENSITIVITY

A measure of how sensitive the climate is to a change in greenhouse gases.

FUNDING

EA is funded by a Kone Foundation Grant (No. 202006876). AF is funded by a Leverhulme Research Project Grant (RPG-2019-365). AF, VL, and CW are funded on a joint UK-China Project administered by the UK Natural Environment Research Council (NE/P013805/1) and the Natural Science Foundation of China Project (Nos. 41661134049, 41772026).

REFERENCES

1. Foster, G. L., Royer, D. L., and Lunt, D. J. 2017. Future climate forcing potentially without precedent in the last 420 million years. *Nat. Commun*. 8:14845. doi: 10.1038/ncomms14845
2. Bintanja, R., and van de Wal, R. S. W. 2008. *Global 3ma Temperature, Sea Level and Ice Volume Reconstructions*. NOAA. Available online at: https://www.ncdc.noaa.gov/paleo/study/11933
3. Nogherotto, R., Burgard, C., and Jones, C. 2022. What is causing our climate to change so quickly now? *Front. Young Minds* 10:668763. doi: 10.3389/frym.2022.668763
4. Scotese, C. R. *Plate Tectonic Maps and Continental Drift Animations, PALEOMAP Project*. Available online at: www.scotese.com.
5. Hodell, D. A. 2016. The smoking gun of the ice ages. *Science* 354:1235–6. doi: 10.1126/science.aal4111

SUBMITTED: 24 March 2021; **ACCEPTED:** 28 April 2022;
PUBLISHED ONLINE: 24 May 2022.

EDITOR: Chris Jones, Met Office Hadley Centre (MOHC), United Kingdom

SCIENCE MENTOR: Maggie Chen

CITATION: Armstrong E, Farnsworth A, Lauretano V and Witkowski C (2022) Understanding the Climate of Ancient Earth. Front. Young Minds 10:684983. doi: 10.3389/frym.2022.684983

CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWER

ETHAN, AGE: 9

Ethan is a 9-years old boy that is currently in the fourth grade. He enjoys reading, writing, and studying math and history. During his free time, he plays basketball, tennis, and various other sports with his younger brother. He also loves exploring and learning about the nature and is currently a kid reporter. He lives in Virginia with his younger brother and parents.

AUTHORS

EDWARD ARMSTRONG

Edward Armstrong is a climate scientist who works at the University of Helsinki, Finland. He investigates climate over the Quaternary period (the past 2.5 million years), mainly focusing on the ice ages over the past 120 thousand years. He uses climate models to reconstruct climate over this period and uses the results to try and understand how ocean and atmospheric circulation have changed. He also investigates what may have caused rapid climate change events because a better understanding may help us more accurately predict future climate change. *edward.armstrong@ad.helsinki.fi

ALEXANDER FARNSWORTH

Since childhood, Alex has been fascinated with how the weather and climate behave—he wanted to be a storm chaser! Now he is fortunate enough to be a meteorologist and climate modeler at the University of Bristol, interested in

monsoons, past environment reconstructions, and global extinction events such as the one that killed the dinosaurs. Instead of predicting what the weather will be like tomorrow, he modifies climate models to look at what the weather was like anywhere between 1 million and 300 million years ago, to better understand how the weather and climate will change in the future.

VITTORIA LAURETANO

Vittoria Lauretano is a postdoctoral researcher at the University of Bristol in the United Kingdom. After studying geology at the University of Chieti (Italy), she completed a Ph.D. in geosciences at the University of Utrecht (The Netherlands) in 2016, focusing on global warming events from the past (∼50-million years ago) using the shells of marine organisms. In her doctoral research, she studied how orbital cycles influenced the carbon cycle and deep-sea temperatures in past oceans. Currently, she uses organic geochemistry to reconstruct how temperatures changed on land over the past 66 million years, using fossil remains from bacteria.

CAITLYN WITKOWSKI

Dr. Caitlyn Witkowski received her bachelor's degree from Bryant University in the United States, her master's degree from Bryant University and China University of Geoscience, and doctorate from the Royal Netherlands Institute for Sea Research. Cait is currently a postdoctoral research associate at the University of Bristol in the United Kingdom. Cait's specialty is organic geochemistry, and she analyzes chemicals from organisms that died long ago and were buried in rocks (sometimes as long as 500 million years ago!). She loves uncovering the past to help us predict the future planet—especially changes in carbon dioxide (CO_2) and temperature.