

Paleoclimatology: Examples of Ecological Impacts from Prehistoric Climate Change

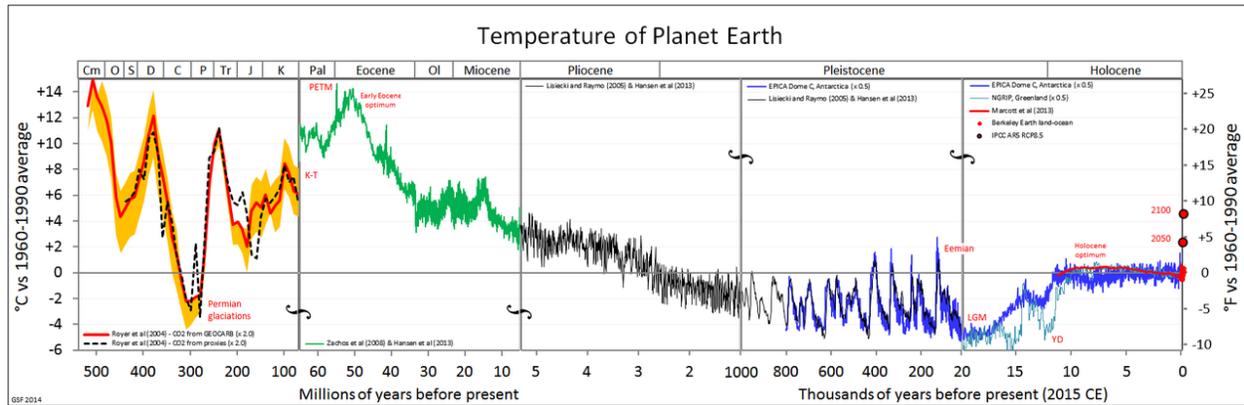
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Source: Glen Fergus 2014

Introduction

Climate change is a pressing issue that has received a lot of attention from the media, our political leaders, and research institutions. Much research is produced on the environmental, ecological, and societal impacts of global warming. Discussions about climate change often focus on mitigation and adaptation to future climate scenarios. The purpose of this article is to shed light on past climates, which are useful for predicting the future environmental impacts of climate change.

Paleoclimatology is the study of prehistoric climates, and is related to paleobiogeography, paleoecology, and paleogeography. All of these “paleo” research foci use similar techniques to recreate past species distributions, plant physiology, and Earth’s geology. Paleoclimatologists are able to recreate past climates and can produce informed theories of these past climates’ effects on prehistoric life forms. Reflecting on the past climates can provide insight into the possible future effects of anthropogenic global climate change.

Historical timeframes

Climate data can be broken up into three categories: instrumental, historical, and prehistoric. The instrumental category is limited to the timeframe during which society has had technical instruments to record climate data. Instrumental climate data is highly accurate, but only available during the past 150 years. To this day, some regions on the planet are still missing proper data due to a lack of funding and other technical challenges.

Climate data can also come from historical and prehistorical data sets. Historical data comes from written records predating the invention of precise climate-measuring methods and instruments. Historical data originates from official documents, journals, letters, ancient writings, and other human records. Recorded droughts in Midwestern North America dating to early fourteenth century pueblo societies are an example of the use of prehistoric date.^{3,4} Prehistoric data sets originate from climate proxies (discussed below), which reveal information on prehistoric climates.⁶ Scientists can

recreate past climates spanning millions of years with these proxies. These climatic datasets derived from proxies can help scientists hypothesize whether current or future droughts are extreme events, or simply climate variation.

Climatic proxies

Scientists use climate proxies to reconstruct past abiotic conditions on Earth. Climate proxies are preserved physical characteristics which assist scientists in making inferences about prehistoric meteorological conditions. Ice cores, fossils, tree rings, and pollen are several examples of proxies, which can be used to recreate past climates.

Different proxies vary in resolution and in timespan. Combining several proxies can maximize accuracy in recreating past climates. Many proxies have bands or rings which can express annual variations in climate. Tree rings are a common example and can be used to look at more recent history and have a yearly resolution. Tree rings form yearly and, depending on the ring size, chemical composition, and color, scientists can use tree rings to recreate past climatic variation. The tree ring size can show years of heavy precipitation compared to years with drought. Fossilized tree ring can assist in assessing further back in Earth's history. Seafloor sedimentation, another climatic proxy, can span far into the past though seafloor sediment as a proxy may reveal less yearly data. Drilling cores in ocean sediment may yield small fossils and chemical compounds, which scientists can use to interpret prehistoric climates.¹²

Fossils of preserved organisms can provide information about past environmental conditions and climates. Preserved fossils illustrate population adaptation and evolution in certain environmental conditions. Used as a proxy, mass extinction and localized extinction indicate dangerous environmental conditions, which species did not withstand.

Past climatic extremes: Paleocene-Eocene Thermal Maximum

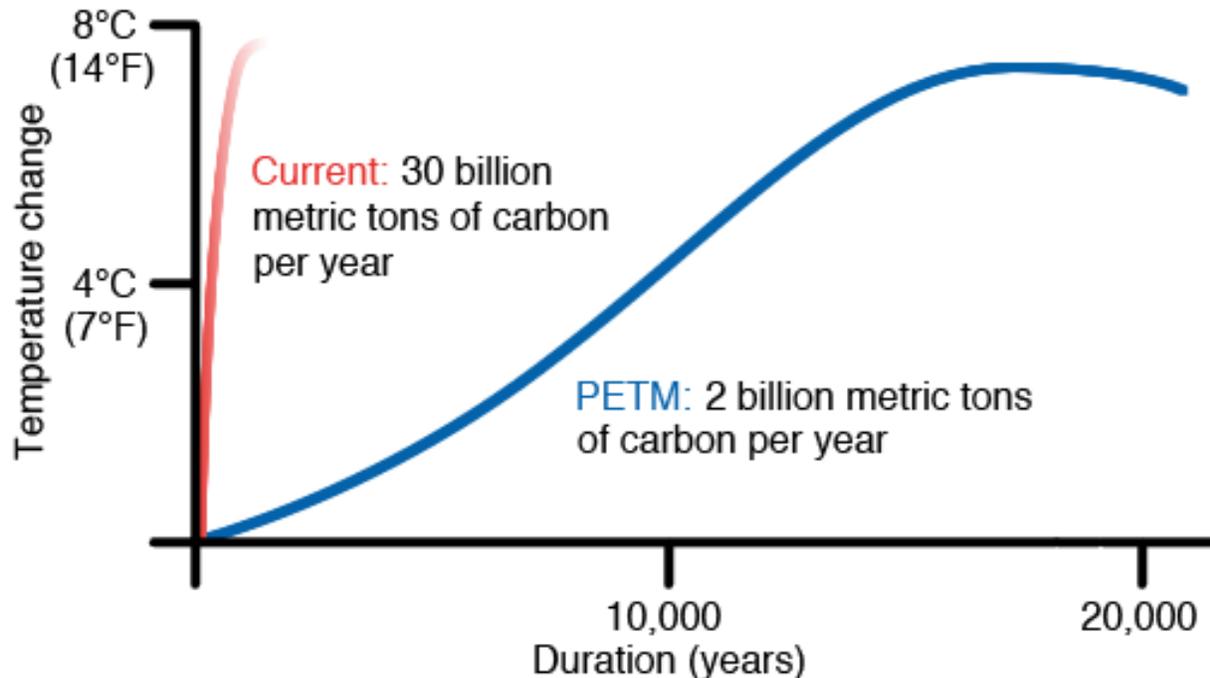
Looking back at past climatic conditions can confirm whether our current climate conditions are outliers. Extreme climatic events have occurred throughout Earth's history. The Paleocene Eocene Thermal Maximum is a good historic example, the climatic effects of which were similar to Intergovernmental Panel on Climate Change's (IPCC) ARC 5 scenario. The Paleocene-Eocene Thermal Maximum or PETM occurred more than 55 million years ago at the boundary between the Paleocene and Eocene epochs.⁵ Scientists agree that during this time period, global average temperatures drastically increased by five to eight degrees Celsius, which is similar to the IPCC's ARC 5 scenario.

Prehistoric increases of greenhouse gases

Scientists have confirmed that as a minimum of 3,000 Gigatons of carbon was released into the atmosphere during the PETM.⁹ Although the scientific community agrees that large amounts of carbon were released into the atmosphere during the PETM, the underlying mechanism remains

controversial. Scientists theorize numerous possible causes for the massive release of carbon, including high levels of volcanic activity, bolide impacts, burning peatland, or the release of gas from methane hydrates. Some researchers believe that, because of its unprecedented scale, the large quantity of carbon released into the atmosphere could have been the result of a combination of two or more of the above sources.

Studying prehistoric climate warming events can shed light on potential ecological impacts resulting from future climate change scenarios. However, it is important to note that future temperatures are expected to rise more quickly than they did during the PETM. During the PETM, temperatures rose at an estimated 0.025°C per hundred years compared to our current situation. In comparison, global temperatures are expected to rise by 1-4°C per one hundred years as a result of anthropogenic global warming—at least ten times the rate of warming during the PETM.² Although there are uncertainties involved in predicting future climates, it is important to note that the ecological effects of global climate change could be more severe due to the more rapid rate of warming. The remainder of this paper will focus on the effects of climatic warming on biota during the PETM.



Source: <https://www.wunderground.com/climate/PETM.asp>

Extinction and migration of species

One of the most dramatic consequences of global warming will be the extinction of species that can neither adapt to warmer temperatures nor migrate to cooler latitudes. During the PETM, several species of microorganisms from the class Foraminifera went extinct. Scientists have determined that environmental conditions during the PETM were unfavorable to these marine protozoans due rising

ocean temperatures and increasing ocean acidification, which have been correlated with increasing greenhouse gas emissions during the same period. Many foraminiferans possess shells composed of calcium carbonate (CaCO₃), which is vulnerable to acid. Chemical analysis of preserved foraminifera shells have revealed that the mass extinction of these calcareous foraminifera was linked to the increases in ocean temperatures and acidity during the PETM.

Species are always in competition for limited resources. When one species outcompetes the others, a regime shift will occur. During the PETM, high-latitude warming resulted in the expansion of warmer, lower-latitude ecosystems. Many species from the equator and mid-latitudes migrated north and south into high latitude regions that were now much warmer than they had been previously. The discovery of fossilized alligator remains in the Arctic Circle evidences the dramatic warming that occurred in the polar and sub-polar regions during the PETM.¹⁰

Dwarfing of species

One interesting result of the PETM was the apparent dwarfing of some mammalian species. Paleoclimatologists have observed that members of the genera *Sifrihippus* and *Ectocion* exhibited reduced body sizes during the PETM.¹ For example, prior to the PETM, members of the species *Sifrihippus sandrea*, an ancestor of the modern horse, weighed approximately 5.6kg. During the PETM, average body size in *S. sandrea* decreased to about 3.9kg. 400,000 years after the PETM, once global temperatures had returned to pre-PETM levels, *S. sandrea* weighed as much as 7.0kg. Scientists have been able to directly correlate this change in size to an extreme increase of carbon dioxide in the atmosphere during the PETM via the analysis of carbon isotopes collected from fossil *S. sandrea* jawbones. However, while interesting, it is unclear whether a similar phenomenon would occur as a result of future, anthropogenic warming.

Relevance

The IPCC has modeled several climate warming scenarios in the Climate Change 2014 Synthesis Report Summary for Policymakers. Depending on the scenario, the IPCC predicts that global temperatures could increase by 2-4°C by 2100. The Paleocene Eocene Thermal Maximum occurred over 55 million years ago and saw a similar increase in global temperatures of 3-7°C. By studying the PETM, a more accurate picture can be painted of the probable effects that a warming climate could have on earth's biodiversity. As outlined in this paper, prehistoric climatic warming resulted in a number of effects, including mass extinctions (especially of foraminifera) and the reduction in the size of some mammalian species. Finally, the migration of species from low to high latitudes during the PETM provides additional insight into the possible effects of a warming climate.

Johann Stiepani/ October 2, 2016

Notes

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