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The proof of the pudding: Past sea-level change

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ABSTRACT
A new record of past sea-level change for 3 million years ago when the global climate was 2 degrees warmer and the implications for ice sheet response in the current warming climate.

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Polar ice sheets are sensitive indicators of Earth's changing climate. They have evolved and changed over the last 50 million years in response to a long-term cooling trend that resulted from decreasing carbon dioxide in the atmosphere, ultimately producing the ice sheets we see today. This trend is superimposed with regular shorter-term cycles. The most recent of these caused the last ice age (glacial period) 20,000 years ago. Such a cycle evolved into the present warm stable climate (interglacial period) that has allowed the development of human civilisation.

These glacial cycles are controlled by variations in Earth's orbit that cause relatively small changes to incoming solar radiation (heat from the Sun) to Earth's atmosphere. Such changes are amplified through feedbacks making major impacts on Earth's climate system. The background climate state determines the degree to which these glacial cycles cause the polar ice sheets to grow and retreat and drive global sea-level change. Greenhouse gases - primarily carbon dioxide - control the background climate state.

While the physics of increasing carbon dioxide and the contribution to warming temperatures is mostly understood, looking at past periods when the climate conditions were different than today, show us the proof of this relationship. The proof in the pudding, so-to-speak. We study the past to fully understand the sensitivity and long-term response of the ice sheets, and consequently sea-level that may occur under projected climate change.

Traditionally, long-term changes of ice on land have been studied by changes in the chemical composition of deep ocean water. However, sea-level fluctuations are a more accurate measure of ice volume change. This study has put forward a new method to overcome some of the underlying issues when reconstructing sea level from indirect geological evidence and has used that method to study the sea-level change in the past.

Of interest, is a time period 3 million years ago (the mid-Pliocene Warm Period), the last time atmospheric carbon dioxide levels were similar to modern (~400 parts per million), and the global temperature was 2-3°C warmer than today. At this time the geography of Earth looked very much the same as today, and there were ice sheets on Antarctica and Greenland. These characteristics are important for understanding climate change in the context of heat transfer and distribution pathways that exist around the planet today – critical components of the "climate engine".

Through geological drilling, we have recovered a continuous and high-resolution rock record that contains repeating layers of shallow-marine sediments (deposited in <150 m water depth). This record represents water depth shallowing and deepening in response to ice-sheet accumulation and melting during glacial and interglacial periods. We measured the size of the sand grains in the layers using a theoretical calculation to determine past changes in water depth. This is based on the physical relationship of water depth and sand transport as a function of wave energy. Simply put, when you stand on a beach, the sand is coarse because the waves are energetic and can move the relatively large grains around, and as you move into deeper water, the sand gets progressively finer because there is less energy provided by the waves. When the sediment layers are sandier, it represents deposition in shallow water. When the layers are less sandy (muddier), it represents deeper water.

The results from our study display cycles of changing sea level between 5 and 25 m over glacial-interglacial alternations. Changes in the Antarctic ice sheets drove this sea-level change; we know that the Greenland ice sheet on its own was too small to provide this scale of change. Portions of the Antarctic ice sheet that are sitting on a rock below sea level are called marine-based ice sheets. They are thought to be highly sensitive to melting in response to warmer ocean temperatures – which may occur in a runaway manner. These marine-based ice sheets currently contain the equivalent of 23 m of global sea-level rise if they melted entirely. We suggest that the loss of these sensitive ice sheets contributed to the changes in sea level we saw 3 million years ago – the last time Earth's climate was 2°C.

This is particularly important for the 2°C Paris Target, which is thought to be the threshold for runaway melting of the marine-based ice sheets. Our record of sea level is looking at ice sheet response over thousands of years and suggests we are committing our planet to tens of meters of sea-level rise if we continue to raise atmospheric carbon dioxide and global temperatures.