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Climate models may underestimate future warming on tropical mountains

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The Lewis glacier on Mt. Kenya has lost 90 percent over the last 75 years. New research suggests future warming on Mt. Kenya and other tropical peaks may happen much faster than climate models currently predict. Credit: Hilde Eggermont

In few places are the effects of climate change more pronounced than on tropical peaks like Mount Kilimanjaro and Mount Kenya, where centuries-old glaciers have all but melted completely away. Now, new research suggests that future warming on these peaks could be even greater than climate models currently predict.

Researchers led by a Brown University geologist reconstructed temperatures over the past 25,000 years on Mount Kenya, Africa's second-highest peak after Kilimanjaro. The work shows that as the world began rapidly warming from the last ice age around 18,000 years ago, mean annual temperatures high on the mountain increased much more quickly than in surrounding areas closer to sea level. At an elevation of 10,000 feet, mean annual temperature rose 5.5 degrees Celsius from the ice age to the pre-industrial period, the study found, compared to warming of only about 2 degrees at sea level during the same period.

"When we run state-of-the-art climate models backward in time to this period, they underestimate the temperature changes at high elevations," said James Russell, an associate professor in the Department of Earth, Environmental and Planetary Sciences and a fellow at the Institute at Brown for Environment and Society. "That implies that the models may similarly underestimate high-elevation warming in the future."

The study, which Russell led with Shannon Loomis, his former graduate student, is published in the journal *Science Advances*.

Temperature differences

Questions among scientists about how global warming affects tropical high elevations date back about 30 years. In 1985, influential research by Brown geologist Warren Prell showed that from the last ice age to the pre-industrial period, sea surface temperatures in the tropics rose only a degree or two. Meanwhile, temperature records estimated from high-altitude tropical glaciers suggested much more dramatic warming at high elevation.

"The climate modeling community thought there must be something wrong with one of these temperature records," Russell said, "because the models simply can't reproduce such a big difference in warming between high and low elevations."

Subsequent work has largely confirmed the sea surface temperature estimates, but questions about the high-elevation data remained. This new study aimed to generate new, more robust high-elevation records.

Over the past decade, Russell's co-author Jaap Damsté of the University of Utrecht and colleagues have developed a new method of tracking temperature through time by studying the remains of ancient microbes. Specifically, they look at organic compounds called GDGTs that are produced in microbial cell walls. The chemical makeup of GDGTs is sensitive to temperature. In order to keep GDGTs and cell walls in a stable and permeable state, microbes alter the chemical makeup of GDGTs in response to temperature changes. Russell and his team have been able to precisely calibrate GDGT composition found in lake sediments with air temperatures through time.

Sediments from Lake Rutundu, located on the slopes of Mt. Kenya, helped researchers develop a temperature record at high elevation over the past 25,000 years. Credit: Hilde Eggermont

"We thought we could use this new temperature proxy to create a record of high-elevation temperature since the last ice age that either confirms or refutes the glacier-derived record," Russell said.

For the study, Russell and his colleagues looked at sediment cores taken from the bottom of Lake Rutundu, a volcanic lake on Mount Kenya at an elevation of around 10,000 feet. The cores preserve the signature of GDGT chemistry dating back more than 25,000 to the ice age. The data suggested that mean annual temperatures at Lake Rutundu increased about 5.5 degrees Celsius since the last ice age—a figure consistent with the previous high elevation temperature proxies. Meanwhile, temperature data from two lakes closer to sea level—Lake Tanganyika and Lake Malawi—suggest much more modest temperature changes of about 3.3 degrees and 2 degrees respectively.

Climate models are able to reproduce the temperature changes at low elevations, but they underestimate the high-elevation change by 40 percent, Russell says. That suggests there's something amiss in the way the models simulate changes in the atmospheric lapse rate—the rate at which air temperature varies with altitude.

"All climate models calculate a lapse rate—it's integral to the output of the model," Russell said. "What this work shows is that there's a problem in the way the models make that calculation."

Implications for future climate change

It's difficult to diagnose exactly what that problem is, Russell says, but it likely has something to do with the way models treat atmospheric water vapor content. Water vapor content is the strongest controlling factor in governing the lapse rate (moist air cools more slowly with altitude).

"We would argue that there's probably a problem in the water vapor concentrations and therefore the feedback," Russell said.

Whatever the source of the problem, the ramifications for tropical mountains may be significant. The models miss almost half the temperature change at high elevations in the past, and they may be underestimating future change as well.

"These are very fragile ecosystems that house extraordinary biodiversity and unique environments such as tropical glaciers," Russell said. "Our results suggest future warming in these environments could be more extreme than we predict."

More information: "The tropical lapse rate steepened during the Last Glacial Maximum" *Science Advances*, advances.sciencemag.org/content/3/1/e1600815

Provided by Brown University

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