Climate changes, but not always for the same reason. Today's rapid climate change is due entirely to man. The Holocene—the last 12,000 years—has been seen as having a stable climate, with a lack of chaos that allowed humans to settle down, develop agriculture, build civilizations and thrive.

But a research team from Europe has now questioned that narrative, using climate modeling with updated data to find that the mid- to late-Holocene saw several large dips in temperature, contrary to the picture usually presented by the IPCC, the world scientific organization that assesses climate science. The findings are published in the journal *Communications Earth & Environment*.

They found that there were eleven long-lasting cold periods in the Northern Hemisphere over the last 8,000 years.

These periods of climate cooling were the result of vigorous volcanic activity. A group of volcanoes erupting over just a few decades would cool the surface due to all the dirt and dust particles, called aerosols, that they belched into the stratosphere. Those aerosols reflected sunlight, dimming the surface and causing prolonged cooling.

The planet cooled further due to the ice-albedo feedback—as more ice formed due to the initial cooling, more sunlight was reflected, cooling the planet even further.
The cold intervals weren't continuous or constantly cold, but eras when the long-term average was significantly below normal. Here, "significantly" means a couple of degrees Celsius. It doesn't take much change to produce drastic changes in the Earth's climate.

For example, the global temperature difference between today and the depth of the last icy period, the so-called Glacial Maximum about 23,000 years ago (which saw 3 km of ice over Chicago) was only about 7°C, with one degree of that being due to modern manmade warming. The ocean level was 125 meters lower than today as sea water turned to ice.

One example is the Little Ice Age that occurred from 1300 to about 1850, formed by a cluster of strong volcanic eruptions in the late 1200s. A long-term solar minima over that interval, such as the Maunder and Dalton Minimums, didn't help.

While the Little Ice Age wasn't global, the vast majority of humans at that time lived in the Northern Hemisphere and found life difficult as their crops failed and famines broke out.

But there were some significant uncertainties. Late Holocene models of the global average temperature shown by the IPCC, the international group that assesses climate science, are "misleading," said co-author Michael Sigl of the Physics Institute and Oeschger Center for Climate Change Research at the University of Bern in Switzerland.

"This is due to a range of issues such as changing variability back in time, dating uncertainties, seasonal bias since many of the records only represent summer temperatures, and hemispheric bias as the majority of records used are in the Northern Hemisphere."

To help close this gap, the group proceeded to reconstruct a
comprehensive Holocene climate timeline using the Max Planck Institute Earth System Model, a recently revised record of solar energy (irradiance) received at the top of Earth's atmosphere, and new reconstructions of volcanic forcing. (Reconstruction is the process of determining past climate or, in this case, volcanic activity, using all available sources of evidence, such as proxies, a metric that changes in a known way based on other, measurable, variables.)

They find that the Holocene has seen many extreme episodes of climate change, all cooling, with some having a magnitude three times larger than those over the last 2,000 years.

The work included several factors known to influence climate: solar irradiance, greenhouse gases, variations in Earth's orbital parameters (such as the tile of its axis, which affects the strength of the sun's rays striking the upper atmosphere; there are three, collectively called Milankovitch factors), and atmospheric aerosols, measured as aerosol optical depth, a value measuring how much light passes through a material. Together, these determine the climate forcing—how much the sum of the factors determines the surface temperature.

They found that over the Holocene, occasional drops in climate forcing caused Northern Hemisphere temperature dips of as much as 2°C. (Modern temperature change, which is positive, attributable to man and is mostly due to anthropogenic greenhouse gas emissions is about 1.2°C.)

There was a small but statistically-significant decrease in aerosol dimming over the course of the 8,000-year period, and relatively large variations between periods of relatively high eruptions and low ones. (Examples of the latter include the Roman and Medieval Warm Periods.) And as noted, some extreme events were up to three times larger than those of the last 2,000 years.
There were no natural warm intervals found. (Both the Roman and Medieval Warm Periods were regional, not extending over the Northern Hemisphere.) Although volcanoes emit carbon dioxide, a powerful greenhouse gas, the amount if relatively small and aerosol cooling easily dominates. (On average, humans emit 40- to 100-times as much carbon dioxide as do volcanoes.)

These kind of climate investigation tools, a fully coupled Earth system model that incorporates the atmospheric and ocean, land and ice surfaces, the carbon cycle and other components, given by the best available reconstruction of the major natural climate drivers such as volcanic eruptions, can help to close this gap, as these "can provide a very fine-grained picture of past climate evolution resolving the amplitudes of natural climate variability," said Sigl.

**More information:** Evelien J. C. van Dijk et al, High-frequency climate forcing causes prolonged cold periods in the Holocene, *Communications Earth & Environment* (2024). [DOI](https://doi.org/10.1038/s43247-024-01380-0)

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