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Research shows how the Little Ice Age affected South American climate

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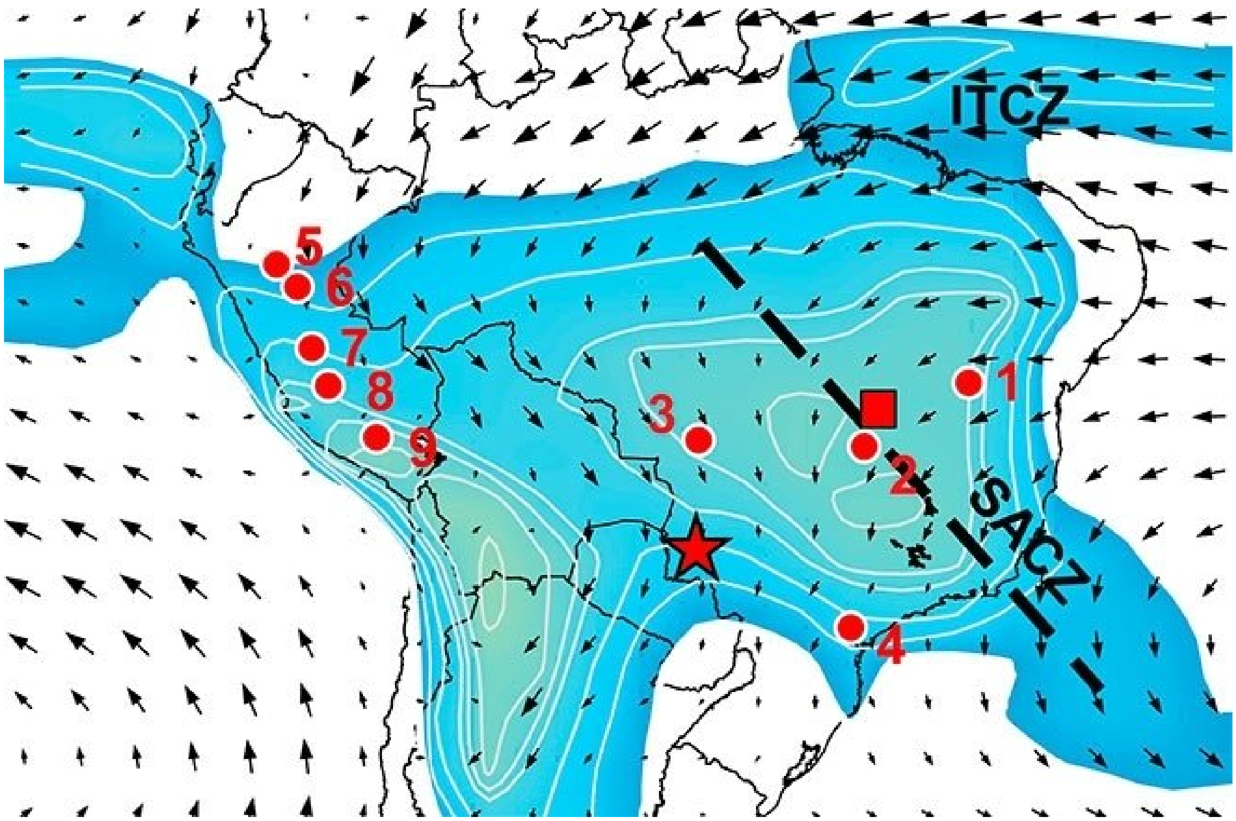

Isotopic records obtained from caves show how rainfall distribution in Brazil varied during global climate changes that affected Europe in the Middle Ages . Credit: Novello et al. / Geophysical Research Journal

A new study published in *Geophysical Research Letters* shows that the so-called Little Ice Age—a period stretching from 1500 to 1850, during which mean temperatures in the northern hemisphere were considerably lower than present—exerted effects on the climate of South America.

Based on an analysis of speleothems (cave formations) in the Brazilian states of Mato Grosso do Sul and Goiás, the study revealed that in the 17th and 18th centuries, the climate of southwestern Brazil was wetter than it is now, for example, while that of the country's Northeast region was drier.

The same Brazilian cave records showed that the climate was drier in Brazil between 900 and 1100 during a period known as the Medieval Climate Anomaly (MCA), when the northern hemisphere's climate was warmer than it is now.

The study's authors are physicist Valdir Felipe Novello and geologist Francisco William Cruz, researchers at the University of São Paulo's Geoscience Institute (IGC-USP), in collaboration with colleagues in Brazil, the United States and China. The study detected dry and wet periods in the Brazilian paleoclimate by analyzing the oxygen isotopes in calcium carbonate molecules found in speleothems. "In Professor Cruz's group, we traveled throughout Brazil collecting samples of cave rocks. The composition of oxygen isotopes in the calcium carbonate deposited over centuries and millennia to form speleothems [stalagmites and stalactites] shows whether the climate was drier or wetter in the past," said Novelo.

Dry and wet season isotopes

Isotopes are variants of a chemical element. While all isotopes of any element have the same number of protons in each atom, different isotopes have different numbers of neutrons. For example, oxygen 16 (^{16}O) has eight protons and eight neutrons, while oxygen 18 (^{18}O) has eight protons and ten neutrons.

"In nature, there is approximately one atom of oxygen 18 for every 1,000 atoms of oxygen 16," Novello explained. ^{18}O is heavier than ^{16}O, so when it starts to rain, water molecules with ^{18}O precipitate first.

As a result, the amount of ^{16}O in the rain cloud rises relative to the amount of ^{18}O, which necessarily decreases since most of the original ^{18}O precipitates as rain. "When it rains heavily, the rain's isotope profile changes," Novello said.

To determine how changes in past rainfall regimes can be measured, Novello and Cruz analyzed records of the $^{16}O/^{18}O$ ratio preserved in speleothem calcium carbonate.

Caves form during long rainy periods in regions of karst, a type of landscape comprising carbonatic rocks such as limestone. Rainwater comes into contact with carbon gas (CO2) dissolved in the air and soil. The result of this chemical reaction is slightly acidic water, which penetrates the soil until it reaches underground calcareous rock.

Calcareous rock is insoluble in water with neutral pH but dissolves in the presence of acidic water (which has a moderately low pH), leading to the formation of the natural underground voids we call caves.

The researchers explained that speleothems form when calcium carbonate-loaded rainwater that has penetrated the soil reaches the cave's roof. Slow continuous dripping over thousands of years precipitates the calcium carbonate dissolved in each drop in the form of speleothems, as stalactites suspended from the roof of the cave and as stalagmites rising from the floor.

Any calcium carbonate precipitating from the roof is deposited on the floor in layers that build up to form stalagmites. Speleothems preserve the isotope signature of the oxygen in the rain that fell at the time when each layer of calcium carbonate was deposited.

"So, in a region with heavy rainfall, for example, you tend to find speleothems with sequences of layers containing less ^{18}O. Conversely, in regions with a dry climate, the small amount of rainfall contains more ^{18}O. When this water penetrates the soil and dissolves calcium carbonate, it ends up creating speleothems with a relatively high level of ^{18}O."

Rock dating and isotope analysis

Novello collected rock samples from two stalagmites in Jaraguá Cave, near Bonito, Mato Grosso do Sul, and from stalagmites in São Bernardo Cave and São Mateus Cave, located in Terra Ronca State Park, Goiás.

Two samples from two different stalagmites were collected in Jaraguá Cave. One of them grew continuously for 800 years according to uranium-thorium dating, between 1190 and 2000, a period that included the LIA. The other sample grew continuously in 442-1451, a period that included the MCA.

In Goiás, Novello collected a rock sample from São Bernardo Cave which covered the period 1123-2010, which included the LIA. São Mateus Cave yielded sample dated to the period 264-1201, which included the MCA.

The study showed that the ^{18}O profile of the samples from Jaraguá Cave displayed declining levels of oxygen in the period 400-1400, suggesting a moderately wet climate in central Brazil during the period (which included the MCA in the northern hemisphere).

Levels of ^{18}O in the samples from Jaraguá Cave fell between 1400 and 1770, reflecting a rise in moisture during the period (which included the LIA in the northern hemisphere), but rose between 1770 and 1950, in line with falling moisture.

A similar analysis of the samples from São Bernardo Cave and São Mateus Cave in Goiás did not show any clear trend, but there were a number of long wet periods, mainly 680-780 and 1290-1350, with spikes in 1050, 1175 and 1490.

On the other hand, the wet period documented by the record from the Jaraguá Cave during the LIA in 1500-1850 is consistent with the wet conditions favored by passage of the South Atlantic Convergence Zone (SACZ), a large cloud system with a northwest-southeast orientation that extends from southern Amazonia to the central South Atlantic in the summer.

"The SACZ is the cloud mass responsible for the long periods of rain that occur in Brazil's Southeast region. The isotopes tell the full story of this wet mass and its movement across the continent," Novello said.

In a previous study using isotope records from caves in Brazil's Northeast region (at Iraquara, Bahia), Novello had inferred that a drier climate prevailed during the LIA in that region, which is outside the SACZ.

"The data from speleothems in Bonito, associated with known paleoclimate data from Peru, show that during the LIA, the SACZ more frequently stalled further to the southwest over an area that extends from Peru to São Paulo via Mato Grosso do Sul," he said. "On the other hand, the data from the caves in Goiás and Iraquara suggest the SACZ didn't reach Goiás, Bahia and the Northeast during the LIA, but stayed put over the Southeast. As a result, the Northeast became drier."

Although the records from the two caves in Goiás (and three other caves) showed no significant change in the average proportion of ^{18}O

during the periods that included the MCA and LIA, they did point to strong variability on a multidecadal to centennial timescale during the period of transition from the MCA to the LIA (1100-1500).

Convergence zones

"There's coherence between climate changes in South America and the climate data for the northern hemisphere," said Cruz, principal investigator for the FAPESP-funded project. "Earth's climate is entirely interconnected. If there are anomalies in high-latitude regions, this will be reflected in the tropics."

"When we look at the paleoclimate data for the period corresponding to the LIA, we see more cold in South America, but the rainfall patterns changed," Novello said. From this information, it can be concluded that if the climate grows colder in the northern hemisphere, it rains more in the southern hemisphere. The moisture convergence ends up moving south. Conversely, when the climate warms up in the northern hemisphere, it rains less in the southern hemisphere.

"In the equatorial regions, there's a belt of cloud called the Inter Tropical Convergence Zone. Its location corresponds to the area where the ocean surface is warmer. This warmer region creates a low-pressure zone to which all the moisture converges, and so more rain falls."

During the LIA, when the difference between the cooler climate in the northern hemisphere and the warmer climate in the southern hemisphere was greater, the winds that converged from the northern hemisphere to the Inter Tropical Convergence Zone (ITCZ) carried more moisture than they do now. This greater moisture contributed to an increase in the volume of cloud in the ITCZ, which advanced east-west over the equator from the Atlantic to the Amazon, where it began raining torrentially. This was when all the ^{18}O contained in the clouds precipitated.

"The cooling of the North Atlantic during the LIA intensified the northeast trade winds, which favored the transport of moisture to the Amazon. This is the opposite of what happens in years when the northeast trade winds are less intense: they tend to be drier years," Cruz said.

Once the cloud masses in the ITCZ reach the Amazon, they contribute moisture that is richer in ^{16}O to the SACZ. The extra amount of this isotope is recorded by speleothems.

During the MCA, the northern hemisphere's warmer climate formed a low-pressure zone to which wet winds converged from the South Atlantic. "The ITCZ moved further north. All of South America became drier," Cruz said.

More information: V. F. Novello et al, Two Millennia of South Atlantic Convergence Zone Variability Reconstructed From Isotopic Proxies, *Geophysical Research Letters* (2018). DOI: 10.1029/2017GL076838

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