How climate change impacts the Indian Ocean dipole, leading to severe droughts and floods

A study led by Brown researchers showed how melting ice water from massive glaciers can ultimately lead to droughts and flooding in East Africa and Indonesia.

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PROVIDENCE, R.I. [Brown University] — With a new analysis of long-term climate data, researchers say they now have a much better understanding of how climate change can impact and cause sea water temperatures on one side of the Indian Ocean to be so much warmer or cooler than the temperatures on the other — a phenomenon that can lead to sometimes deadly weather-related events like megadroughts in East Africa and severe flooding in Indonesia.

The analysis, described in a new study in Science Advances by an international team of scientists led by researchers from Brown University, compares 10,000 years of past climate conditions reconstructed from different sets of geological records to simulations from an advanced climate model.

The findings show that about 18,000 to 15,000 years ago, as a result of melted freshwater from the massive glacier that once covered much of North America pouring into the North Atlantic, ocean currents that kept the Atlantic Ocean warm weakened, setting off a chain of events in response. The weakening of the system ultimately led to the strengthening of an atmospheric loop in the Indian Ocean that keeps warmer water on one side and cooler water on the other.

This extreme weather pattern, known as a dipole, prompts one side (either east or west) to have higher-than-average rainfall and the other to have widespread drought. The researchers saw examples of this pattern in both the historical data they studied and the model's simulation. They say the findings can help scientists not only better understand the mechanisms behind the east-west dipole in the Indian Ocean, but can one day help to produce more effective forecasts of drought and flood in the region.

"We know that in the present-day gradients in the temperature of the Indian Ocean are important to rainfall and drought patterns, especially in East Africa, but it's been challenging to show that those gradients change on long time-scales and to link them to long-term rainfall and drought patterns on both sides of the Indian Ocean," said James Russell, a study author and professor of Earth, environmental, and planetary sciences at Brown. "We now have a mechanistic basis to understand why some of the longer-term changes in rainfall patterns in the two regions have changed through time."

In the paper, the researchers explain the mechanisms behind how the Indian Ocean dipole they studied formed and the weather-related events it led to during the period they looked at, which covered the end of the last Ice Age and the start of the current geological epoch.

The researchers characterize the dipole as an east-west dipole where the water on the western side — which borders modern day East African countries like Kenya, Ethiopia and Somalia — is cooler than the water on eastern side toward Indonesia. They saw that the warmer water conditions of the dipole brought greater rainfall to Indonesia, while the cooler water brought much drier weather to East Africa.

That fits into what is often seen in recent Indian Ocean dipole events. In October, for example, heavy rain led to floods and landslides in Indonesian islands of Java and Sulawesi, leaving four people dead and impacting over 30,000 people. On the opposite end, Ethiopia, Kenya and Somalia experienced intense droughts starting in 2020 that threatened to cause famine.

The changes the authors observed 17,000 years ago were even more extreme, including the complete drying of Lake Victoria — one of the largest lakes on Earth.

"Essentially, the dipole intensifies dry conditions and wet conditions that could result in extreme events like multi-year or decades-long dry events in East Africa and flooding events in South Indonesia," said Xiaojing Du, a Voss postdoctoral researcher in the Institute at Brown for Environment and Society and Brown's Department of Earth, Environmental and Planetary Sciences, and the study's lead author. "These are events that impact people's lives and also agriculture in those regions. Understanding the dipole can help us better predict and better prepare for future climate change."

The dipole the researchers studied formed from the interactions between the heat transport system of the Atlantic Ocean and an atmospheric loop, called a Walker Circulation, in the tropical Indian Ocean. The lower part of the atmospheric loop flows east to west across much of the region at low altitudes near the ocean surface, and the upper part flows west to east at higher altitudes. The higher air and lower air connect in one big loop.

Interruption and weakening of the Atlantic Ocean heat transport, which works like a conveyor belt made of ocean and wind currents, was brought on by massive melting of the Laurentide ice sheet that once covered most of Canada and the northern U.S. The melting cooled the Atlantic and consequent wind anomalies triggered the atmospheric loop over the tropical Indian Ocean to become more active and extreme. That then led to increased precipitation in the east side of the Indian Ocean (where Indonesia sits) and reduced precipitation in the west side, where East Africa sits.

The researchers also show that during the period they studied, this effect was amplified by a lower sea level and the exposure of nearby continental shelves.

The scientists say more research is needed to figure out exactly what effect the exposed continental shelf and lower sea level has on the Indian Ocean's east-west dipole, but they're already planning to expand the work to investigate the question. While this line of the work on lower sea levels won't play into modeling future conditions, the work they've done investigating how the melting of ancient glaciers impacts the Indian Ocean dipole and the heat transport system of the Atlantic Ocean may provide key insights into future changes as climate change brings about more melting.

"Greenland is currently melting so fast that it's discharging a lot of freshwater into the North Atlantic Ocean in ways that are impacting the ocean circulation," Russell said. "The work done here has provided a new understanding of how changes in the Atlantic Ocean circulation can impact Indian Ocean climate and through that rainfall in Africa and Indonesia."

The study was supported with funding from the Institute at Brown for Environment and Society and the National Science Foundation.

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