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Scientists explore complex pattern of tipping points in the Atlantic's current system

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An international team of scientists has warned against relying on nature providing straightforward 'early warning' indicators of a climate disaster, as new mathematical modeling shows new fascinating aspects of the complexity of the dynamics of climate.

It suggests that the climate system could be more unpredictable than previously thought.

By modeling the Atlantic meridional overturning circulation, one of the main ocean current systems, the team which included mathematicians from the University of Leicester have found that the stability of the system is much more complex than simple 'on-off' states as previously assumed. Switches between these states might lead to major changes in the regional climate of the North Atlantic region, yet a far cry from the massive impacts of a transition between the qualitatively different states.

But some of these minor transitions might eventually upscale to cause a major changeover between the qualitatively different states, with massive global climatic impacts. Early warning signals might be unable to distinguish the degree of severity of the ensuing tipping points. Like a tower of Jenga blocks, removing some blocks may affect the stability of the system, but we cannot be certain which block will bring the whole system tumbling down.

Their findings are published in *Science Advances* in a paper led by the Niels Bohr Institute at the University of Copenhagen.

The Atlantic meridional overturning circulation is one of the most important fundamental features of the climate system. It transports heat from low to high latitudes in the northern Atlantic, so it helps create positive thermal anomalies in northern and western Europe and in the North Atlantic region downwind. A slowdown of the circulation would result in a relative cooling in this region.

Predicting the behavior of our climate, as in the Atlantic meridional overturning circulation, is challenging due to its incredible complexity. Scientists either need a model of the highest possible resolution, or try to understand its behavior using a less resource-intensive model that allows for rigorous statistical analysis.

Professor Valerio Lucarini from the University of Leicester School of Mathematical and Computer Science said, "Within each state, there is a multiplicity of nearby states. Depending on where or what you are observing, you might find some indicators of nearing collapse. But it is not obvious whether this collapse will be contained to nearby states or lead to a major upheaval, because the indicators only reflect the local properties of the system.

"These states are the different ways that the Atlantic meridional overturning circulation organizes itself at large scales, with key implications for the global climate and especially regionally in the North Atlantic. Under some scenarios, the circulation could reach a 'tipping point' where the system is no longer stable and will collapse. Early warning indicators tell us that the system might be jumping to another state, but we do not know how different it will be.

"In a separate investigation we have seen something similar occurring in paleoclimatic records: when you change your timescale of interest—just like a magnification lens—you can discover smaller and smaller scale distinct features that are indicative of competing modes of operation of the global climate.

"Paleoclimatic records of the last 65 million years allowed us to provide a new interpretation of the climate evolution over that time period, and reveal these multiple competing states.

"This study paves the way to looking at the climate through the lens of statistical mechanics and complexity theory. It really stimulates a new outlook of climate, in which you have to put together complex numerical simulations, observational evidence and theory in an unavoidable mixture. You have to appreciate and endorse this complexity. There is no shortcut, no free lunch in our understanding of climate, but we are learning a lot from it."

More information: Johannes Lohmann, Multistability and Intermediate Tipping of the Atlantic Ocean Circulation, *Science Advances* (2024). DOI: 10.1126/sciadv.adi4253. www.science.org/doi/10.1126/sciadv.adi4253

Provided by University of Leicester

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