Q&A: How rate of CO_2 rise can affect a global ocean current

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As we burn fossil fuels, the amount of carbon dioxide in Earth's atmosphere is gradually rising, and with it, the planet's average temperature. How fast the level of atmospheric carbon dioxide—and with it, the temperature—goes up matters for the ability of humans and ecosystems to adjust. A slower increase gives humans time to move away from low-lying areas and animals time to move to new habitats.

It turns out the rate of that increase matters for non-living systems, too. A University of Washington study looked at how a major current in the Atlantic Ocean that includes the Gulf Stream will respond to a doubling of carbon dioxide from preindustrial levels.

The study, published in the *Proceedings of the National Academy of Sciences*, found that when carbon dioxide levels rise more gradually, they have less impact on the ocean circulation.

UW News sat down with author Camille Hankel, a UW postdoctoral researcher in the Cooperative Institute for Climate, Ocean and Ecosystem Studies, to learn more about her study.

Why did you choose to study how the rate of rising CO_2 affects the climate system?

Camille Hankel: In my Ph.D., some of my work was on "climate tipping points," which emerge from the hypothesis that there might be some sort of critical thresholds of warming or CO_2 change that can lead to very abrupt and irreversible change in some parts of the climate system.

Through that work, I got exposed to some literature on "rate-induced tipping points," which is the idea that instead of crossing a critical level, there could be some critical rates of CO_2 change that are important for the climate system.

Specifically, I read this study that was looking at this idea in the context of the AMOC, the Atlantic Meridional Overturning Circulation, which is this large-scale ocean circulation. That study was using what we call a box model—a simplified, mathematical representation of the ocean circulation. And I thought, hey, I can run these global models, which are much more realistic representations of the Earth's climate, including ocean, atmosphere, land and sea ice, and test whether the rate of CO_2 change really is that important.

What is the Atlantic Meridional Overturning Circulation, which includes the Gulf Stream ocean current, and why is it so important for Earth's climate?

CH: It's one of the large-scale, key features of the climate system. In particular, it transports a lot of heat from the low latitudes in the South Atlantic to the higher latitudes closer to the North Pole. So it delivers a lot of heat, primarily to Northern Europe.

It also distributes nutrients around through this sort of sinking motion that characterizes the circulation—it draws the surface waters down into the deep ocean, and recirculates deep water up to the surface. It's a big feature of the climate system, particularly in the North Atlantic, but also globally.

We've heard about a potential slowdown of the Gulf Stream current that could affect European weather. This was dramatized (perhaps not accurately) in the 2004 disaster movie 'The Day After Tomorrow.' Are we actually seeing a slowdown in Atlantic Ocean circulation?

CH: We have a pretty short observational record of the AMOC current, and it's sparse. You have to imagine, this is a 3D circulation in the entire Atlantic basin, and we have a couple little slices of data in particular parts of the Atlantic. We are seeing a modest slowdown so far, but it's a pretty noisy and uncertain observational record, so it's hard to tell.

I would say, however, that slowdown seen in current observations would match the model predictions of future slowdowns. And we also see a pattern in temperature changes where, while the rest of the globe is warming right now as we increase CO_2, there's what people call a "warming hole" over the North Atlantic.

We're not seeing as much warming in that North Atlantic region compared to the rest of the globe. And it's hard to conclusively attribute what's causing it in the Earth's climate, but the idea is that the modest slowdown of the AMOC that we've seen so far could be one contributing factor to that lack of warming we're seeing in the North Atlantic.

So the observations suggest some slowdown, though much less dramatic than what was depicted in that movie.

Why is the AMOC expected to slow down under climate change?

CH: One way of thinking about what drives this major ocean current is differences in ocean density. You have this really important zone in the North Atlantic where the waters sink because the surface waters are heavier than the waters below. When you change CO_2 levels, you do two things.

You start to warm the ocean's surface, and by melting glaciers as well as changing sea ice, you add freshwater to the surface of the otherwise salty ocean. Both warming and freshening reduce the density of that upper ocean water and potentially inhibit or disrupt that critical sinking motion.

There are other ways of looking at it, but the one I look at in the study is understanding how those density perturbations happen in a higher-CO_2 climate and how they modulate the sensitivity to the rate of CO_2 change that I find in the AMOC's response to CO_2.

Your study finds that if atmospheric carbon dioxide doubles from pre-industrial levels more slowly, there's less slowdown in the Atlantic Ocean compared to if CO_2 doubles more quickly. Is that because everything is happening more slowly?

CH: Yes, that's part of it. The different parts of the climate system—the ocean, atmosphere, and ice—all have different response timescales to CO_2 changes, meaning they respond to perturbations with different lag times. Then how these components of the climate interact with each other under slower or faster CO_2 changes can look very different, and in this case influence the ocean circulation.

Specifically, I found what's known as a positive feedback—a sort of self-amplifying cycle—that helps explain why the level of AMOC weakening depends on the rate of CO_2 change. In this feedback cycle, the initial modest amount of AMOC slowdown leads to a reduction of heat transport into the Arctic, which in turn cools the region and leads to a temporary period of Arctic sea ice expansion.

This sea ice expansion causes more ice to be exported to the North Atlantic, where it melts and adds freshwater to the ocean, causing the AMOC to slow down even more: hence the self-amplifying cycle. It turns out that this feedback cycle is more effective at amplifying AMOC weakening under more rapid CO_2 changes than under gradual CO_2 changes.

What is the importance of this work?

CH: We know about AMOC slowdowns—there's a ton of work on that, and the mechanisms that drive such an AMOC slowdown. But what's new is this sensitivity of circulation changes to the rate of CO_2 increase, independent of the total change in concentration of CO_2.

When we think about policy and basic science, we tend to focus a lot on how the level of global warming can impact the climate system. I'm trying to bring a new perspective by thinking about the rate of increase as a driver. That could have a lot of impacts.

You can imagine that if multiple different climates are possible for the same level of warming, then limiting us to 1.5 °C or 2 °C could have different meanings, right? I do think the most important thing for the climate system is always how much CO_2 you have put into the atmosphere, but how quickly you got to that point clearly matters as well.

More information: Camille Hankel, The effect of CO_2 ramping rate on the transient weakening of the Atlantic Meridional Overturning Circulation, *Proceedings of the National Academy of Sciences* (2024). DOI: 10.1073/pnas.2411357121

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