Is AMOC Running Amuck?

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Urgency in the Atlantic Meridional Overturning Circulation (AMOC)?

How is AMOC pronounced? The AMOC (pronounced A-mock) is a gigantic ocean current system.

A few days ago, on February 9, 2024, a new study entitled

"Physics-based early warning signal shows that AMOC is on tipping course"

was published by Science.org. We'll go directly to the actual paper shortly, but first a shout-out for **Sherri Michelstein** in our group for picking up the news the day of publication!

She passed on to us the apnews.com article below; our attention was quickly caught by other articles in the press. I highly recommend reading these popular press articles, they provide a brief, but useful presentation of the most critical findings:

Approximate "Cheat Sheet":

1 meter → 3 feet **1 degree Celsius (^{0}C)** → 2 degree Fahrenheit (^{0}F)
ppm = parts per million **CO_2** = Carbon Dioxide
1 tonne = 1000 kilograms = 2205 pounds **1 gigatonne (1 Gt)** = 1 billion tonnes
1 trillion tonnes (1Tt) = 1000 gigatons

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Ocean system that moves heat gets closer to collapse, which could cause weather chaos, s...

apnews.com

https://apnews.com/article/atlantic-collapse-climate-change-abrupt-tipping-point-954f5b030b8510551ab7cd34b99e23d5

Atlantic Ocean circulation nearing 'devastating' tipping point, study finds

The Guardian

News

https://apple.news/AqJjvH7WKSnCIKFsmIqglkQ

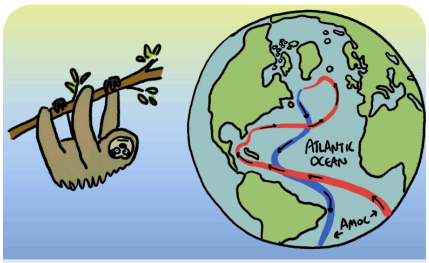
Oops, Scientists May Have Miscalculated Our Global Warming Timeline

Popular Mechanics

News

https://apple.news/Ax7C5J0hCRRu26HxKC4ySvg

The news even earned a cartoon treatment in The Guardian →



Are you ready for the collapse of the Atlantic meridional overturning circulation? No, you are...

The Guardian

News

https://apple.news/AhfH-bYixThe4n9_3lb06cg

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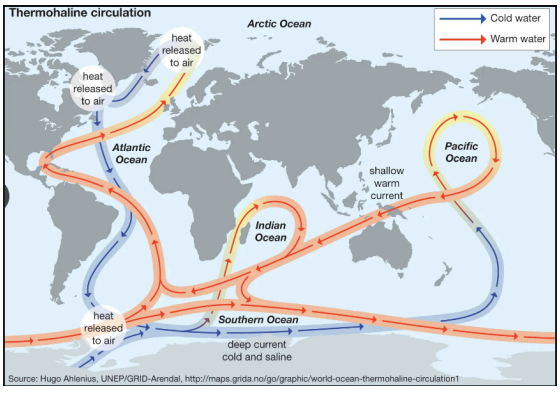
Given all of this press, we need to begin to grapple with the **potential for,** and the **impacts of**, such a collapse of the AMOC.

1. **What is** a "Collapse of the Atlantic Meridional Overturning Circulation"?
2. Is such a collapse even **POSSIBLE**?
3. How can the AMOC even be **measured** so we might detect changes (and how is **West Palm Beach** directly involved in this measurement)?
4. Why would we care (i.e., what are the likely **IMPACTS**, should a collapse occur)?
5. What **TIMELINE** had been projected by science before this latest study?
6. How is this study different, and what are its **new projections**?
7. Now what?!?

So, let's get started:

1. **What is** a "Collapse of the Atlantic Meridional Overturning Circulation"?

We saw in CSSG-2.6 and CSSG-2.7, where we studied the Great Conveyor Belt, that this is one of the Earth's Big Deals. In CSSG-2.12, we introduced the possibility of AMOC's Tipping Point. Take a look back at that material when you get a chance.



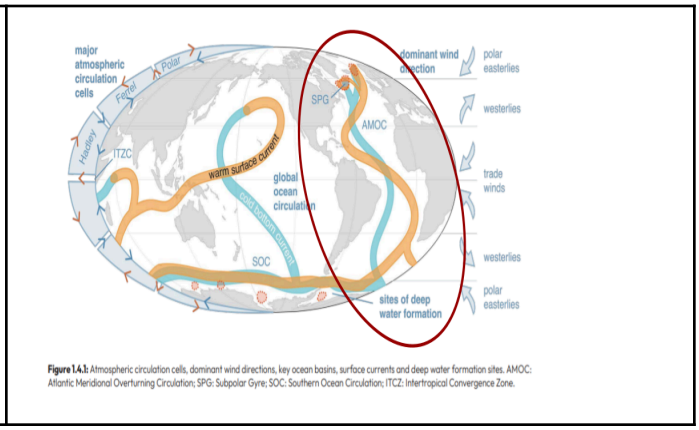


Figure 1.4.1: Atmospheric circulation cells, dominant wind directions, key ocean basins, surface currents and deep water formation sites. AMOC: Atlantic Meridional Overturning Circulation; SPG: Subpolar Gyre; SOC: Southern Ocean Circulation; ITCZ: Intertropical Convergence Zone.

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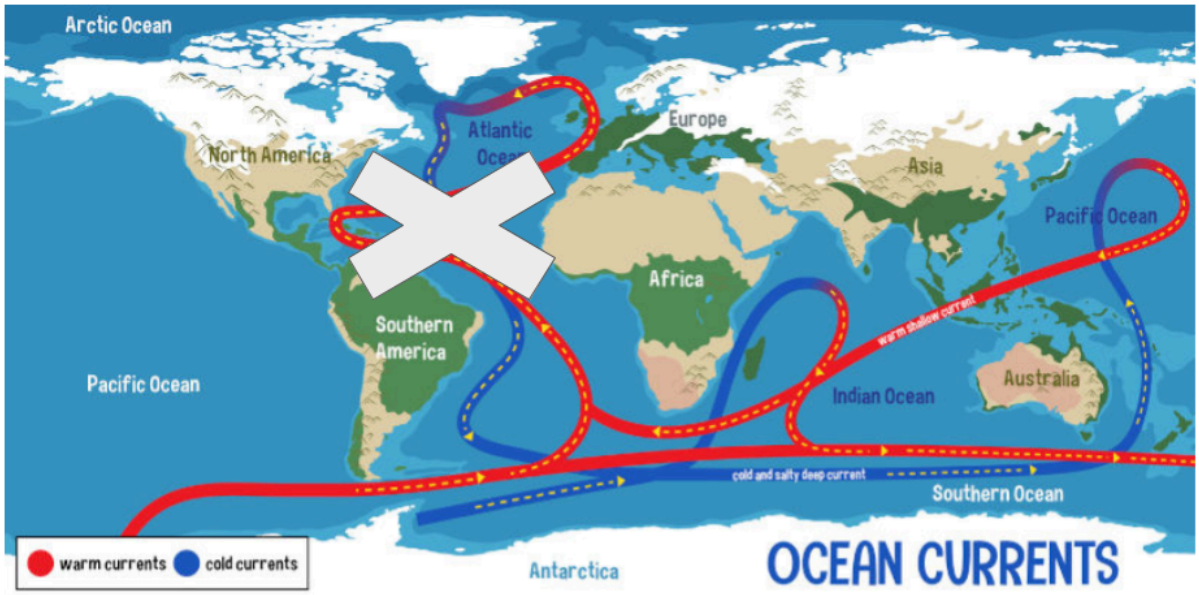
"Collapse" of the AMOC is literally what it sounds like: the warm waters flowing North basically STOP. This also means that the cold, salty deep waters cease to flow South. The transfer of heat stops.



https://johnmenadue.com/new-research-on-when-amoc-may-go-amok/

2. Is such a collapse even **POSSIBLE**?

From the National Oceanic and Atmospheric Administration (NOAA), we see a record of 25 such radical temperature reversals in the last 80,000 years (none in historic times). The best guess is that they were the result of AMOC collapses.

https://www.ncei.noaa.gov/sites/default/files/2021-11/2%20Heinrich%20and%20Dansgaard%E2%80%93Oeschger%20Events%20-%20Final-OCT%202021.pdf

"Climate during the last glacial period was far from stable. Heinrich and Dansgaard-Oeschger events occurred repeatedly throughout most of this time. Scientists Willi Dansgaard and Hans Oeschger first reported the Dansgaard-Oeschger (D-O) events in Greenland ice cores. Each of the 25

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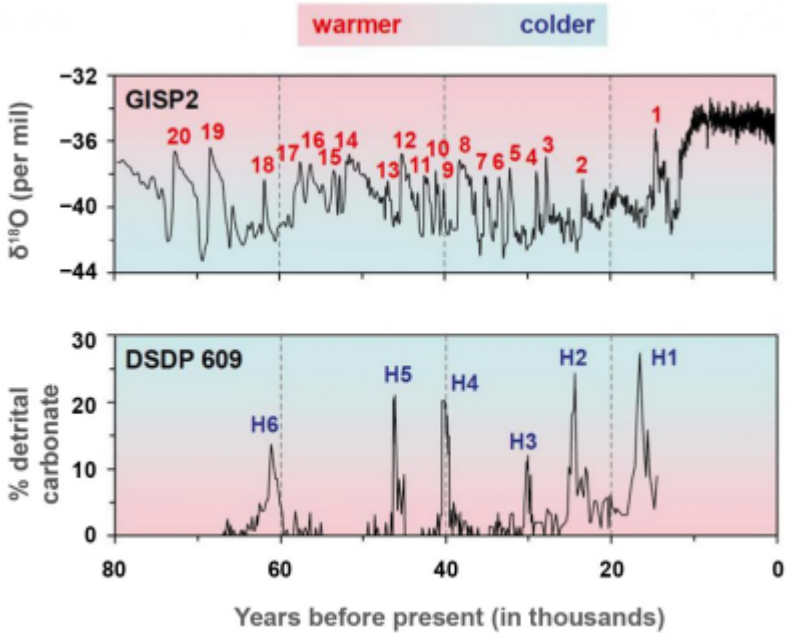
observed D-O events consisted of an abrupt warming to near interglacial conditions that occurred in a matter of decades and was followed by a gradual cooling."



These records imply we could certainly encounter such events. (I will note that, looking at the above chart, peaks 1-7 at least seem to look like both abrupt startup of the AMOC (warming in Greenland) and then abrupt collapse (cooling) followed by additional cooling a bit later. Quite complex behavior and would have resulted in very quick changes in climates.)

3. How can the AMOC even be **measured** so we might detect changes (and how is **West Palm Beach** directly involved in this)?

While the currents in the Atlantic are really complex, there are two places where they are being measured:

- **West Palm Beach** over to the Bahamas, and then all the way across the Atlantic at 26.5^0 N.
- Down at the bottom **tip of Africa**, at 34.5^0 S, the Conveyor current from the Indian Ocean and the Antarctic are turning North into the Atlantic.

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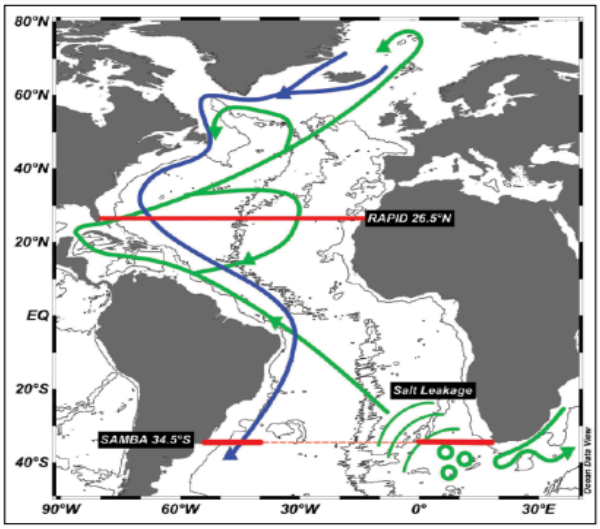
Let's take a closer look:



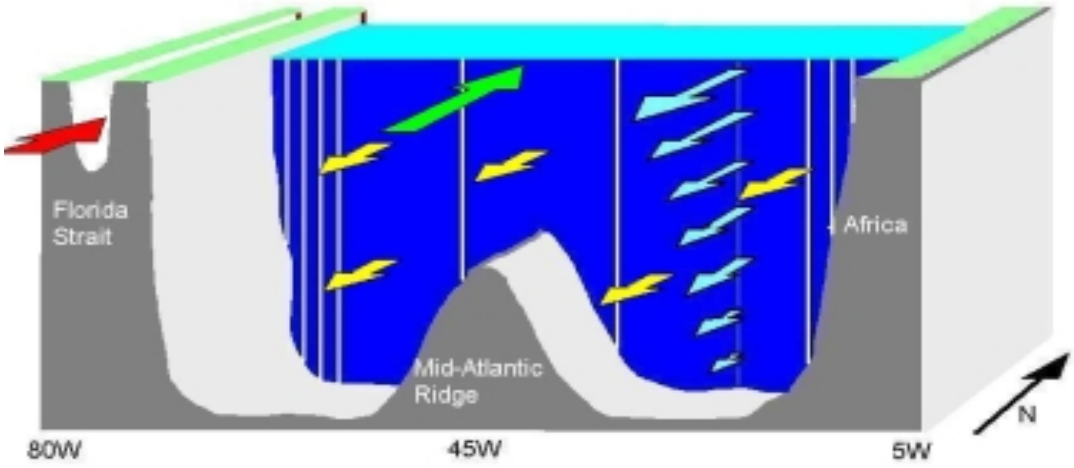
West Palm at 26.5^0 N

Bottom of Africa at 34.5^0 S

Fig. 1. A simplified schematic highlighting the meridional overturning circulation (MOC)—how currents flow between the southern and northern Atlantic Ocean. Blue lines refer to the pathway of the cold, deep water masses formed in the northern Atlantic; green lines correspond to the northward surface flow (including the Agulhas Current system south of Africa). Agulhas rings (green circles) and their saline influence into the eastern South Atlantic (green arcs) are shown. The existing South Atlantic MOC Basin-wide Array (SAMBA) array along 34.5°S is shown as a solid red line, and the proposed full transect, to be completed in 2014 and 2015, is shown as a dashed line. The Rapid Climate Change (RAPID) MOC/Meridional Overturning Circulation and Heat Flux Array (MOCHA) in the North Atlantic (referred to here as RAPID) is shown also as a solid red line along 26.5°N. Schematic adapted from Zahn [2009].

https://agupubs.onlinelibrary.wiley.com/doi/pdf/10.1002/2014EO060001

It's wild, but most of the conveyor flow carrying warmth to the North goes through our Florida Strait. (The green arrow depicted is wind-driven). The vertical lines are monitors tied to the bottom which transmit info to satellites.



https://rapid.ac.uk/rapidmoc/overview.php

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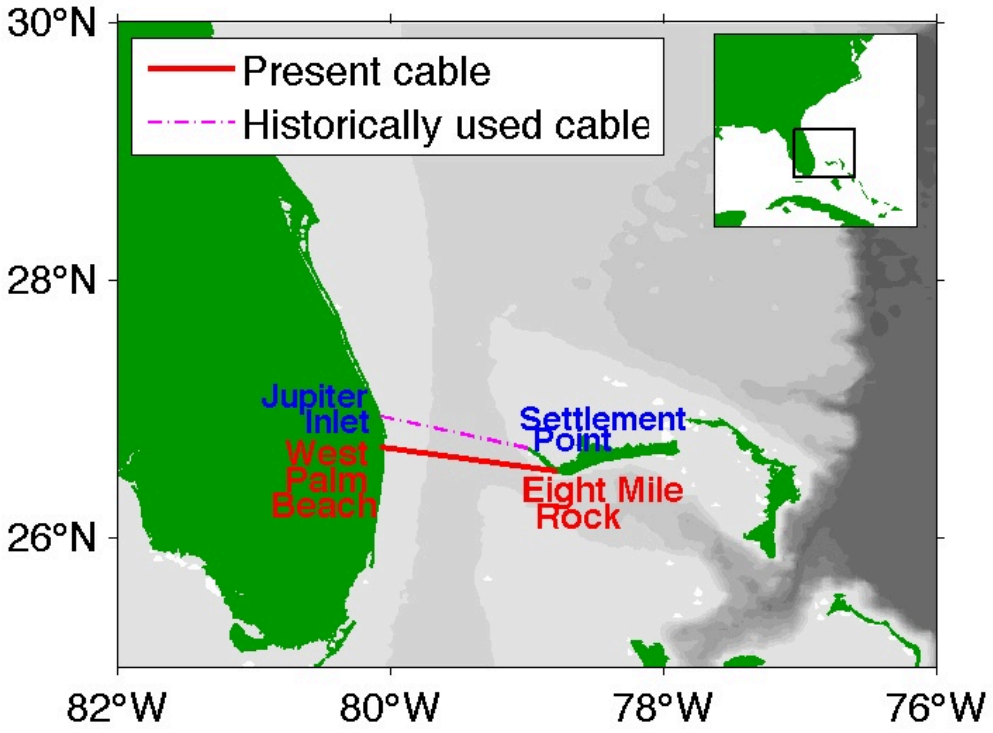

https://www.aoml.noaa.gov/phod/floridacurrent/index.php

And we're able to measure the flow because it goes over our telephone cable to the Bahamas and interacts with the Earth's magnetic field. Cool!

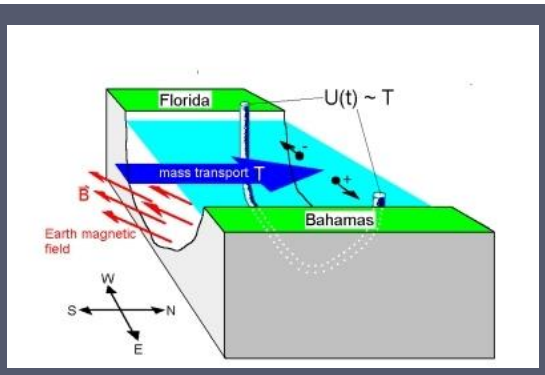

Figure 2: Monitoring currents in the Florida Straits using submerged telephone cables between the US and Bahamas.

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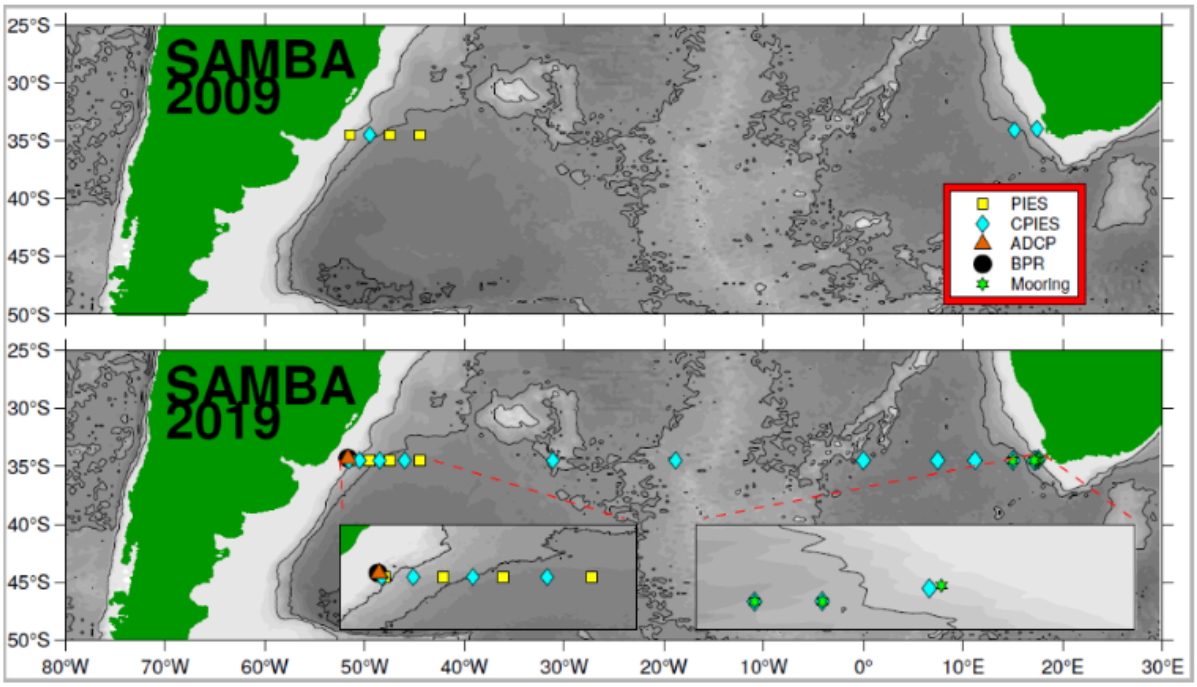
And the South Atlantic MOC Basin-wide Array (SAMBA) extending from the tip of Africa:



http://www.oceansites.org/tma/samba.html

And that's how the AMOC is measured directly. When surface temperatures, monitored by satellites are figured in, we can figure out a lot.

https://www.iatlantic.eu/news/new-moorings-deployed-to-strengthen-the-south-atlantic-observing-system/

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4. Why would we care (i.e., what are the likely **IMPACTS**, should a collapse occur)?

Turns out the potential impacts are severe (from the recent paper):

- The AMOC collapse dramatically changes the redistribution of heat (and salt) and results in a **cooling of the Northern Hemisphere**, while the Southern Hemisphere slightly warms.
- Atmospheric and sea-ice feedbacks further amplify the AMOC-induced changes, resulting in a very strong and **rapid cooling of the European climate with temperature trends of more than 3°C per decade**. [This gives sea-ice down to 50^0 N - which is South of Gothenburg!]
- In comparison with the present-day global mean surface temperature trend (due to climate change) of about 0.2°C per decade, **no realistic adaptation measures can deal with such rapid temperature changes under an AMOC collapse**.
- Other, major impacts would occur around the globe.

5. What **TIMELINE** had been projected by science before this latest study?

The IPCC in 2021, based on numerical models, considered collapse as likely not to occur this century, though we are heading in that direction.

Statistical analysis in 2023 https://www.nature.com/articles/s41467-023-39810-w pointed strongly to a this-century collapse, with mid-century as likely (!).

Two indicators of impending radical change were seen in 1) the slowing of the AMOC flows and 2) the increasing variability of the flow.

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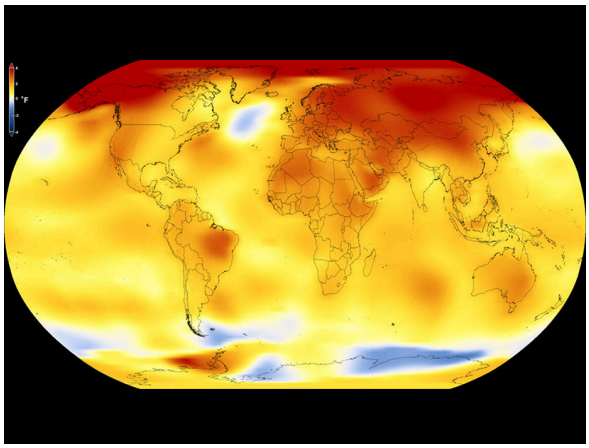
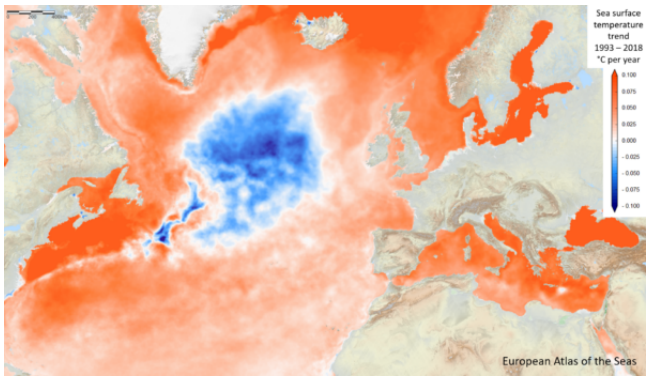
Interestingly, the Blue Dot up near Greenland is assessed by another recent analysis to have two components:

1. It's cooling because of increasing freshwater from melting ice, arctic flow, and precipitation, and
2. It's cooling because of slowing down of the AMOC, which reduces heat being carried North.

The study concluded that the AMOC slowdown (which may be as much as 10-15%, but may also be at least in part natural variability) was far more significant in this cooling than increasing freshwater. See below:



https://eos.org/articles/global-average-temperatures-in-2017-continued-upward-trend



Sea surface temperature trend 1993 – 2018, from European Atlas of the Seas

https://www.realclimate.org/index.php/archives/2022/12/the-water-south-of-greenland-has-been-cooling-so-what-causes-that/

Another study from 2023 https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9985640/ made a strong case for using the **salinity decrease** in the South Atlantic as a better indicator that the AMOC is slowing down than the temperature changes up in the "blue dot".

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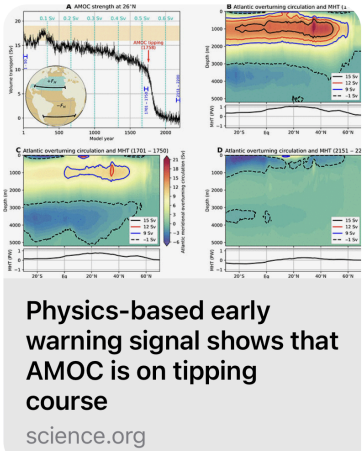
6. How is this study different, and what are its **new projections**?



https://www.science.org/doi/10.1126/sciadv.adk1189

For the first time, a physics-grounded analysis has been achieved which did not rely on a (virtual) radical dumping of freshwater (ice melt, precipitation, etc.) to disrupt the current. This model inserted additional freshwater very slowly (over 2000 model years) to see if a tipping point was a natural result. It was.

Advance warning of around 25 years appears to be related to the amount of freshwater (reduction in salinity), noted in the South Atlantic. That indicator is clearly reducing and, if its rate of reduction slows down, the onset of collapse may follow quickly. More study and data are urgently required.

Note that this is a similar result to the 2023 study mentioned above with respect to salinity already indicating an AMOC slowdown. What is new is that this result comes from a more solid physics basis.

7. Now what?!?

This really worries me. Seems like all sources think the AMOC will collapse. Now, with a more physics-based analysis, hopefully the threat can be better quantified temporally. The potential IMPACTS are apparently agreed upon.

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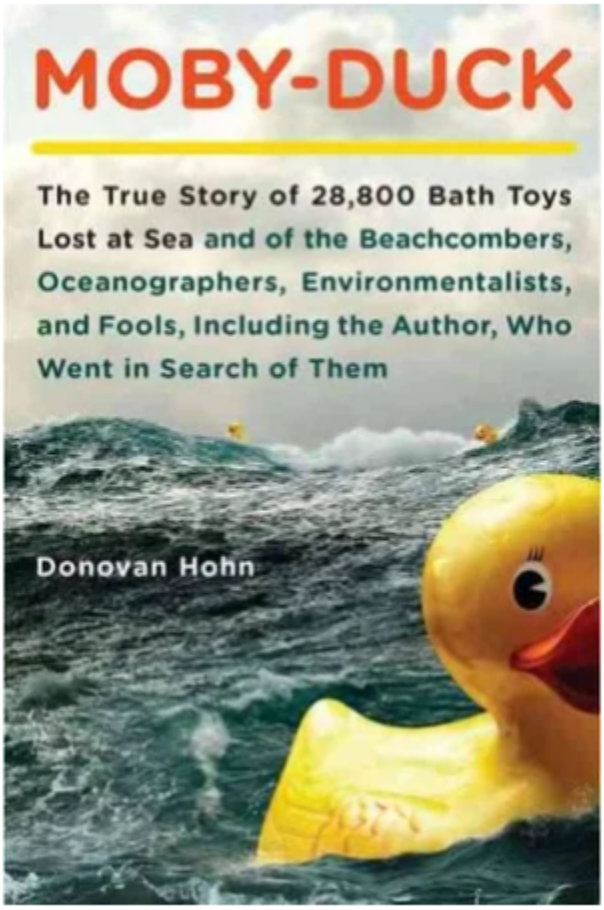
BONUS !!



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In 1992, around 29,000 rubber ducks fell off a cargo ship in the Pacific Ocean. This is where they made landfall.

The weird thing is that the long straight red line at the top of the map is probably actually only a few dozen km over the North Pole , but this projection is stretching it out.