Making Sense of
"Tipping Points"

Tipping Points: Part 3 - Potential AMOC Collapse

What is the Atlantic Meridional Overturning Circulation (AMOC)?

The AMOC is a system of ocean currents that circulates water **within the Atlantic Ocean**, bringing warm water north and cold water south. https://sos.noaa.gov/catalog/datasets/ocean-circulation-conveyor-belts/

You will remember the Great Global Conveyor Belt discussions from **CSSG-2.5, -2.6, and -2.7.** There are a lot of useful depictions of that global current, and here is one that shows how energy is moved around the globe via the atmosphere and the global current. Around ¼ of the energy is moved by the current, making it very important to appreciate.

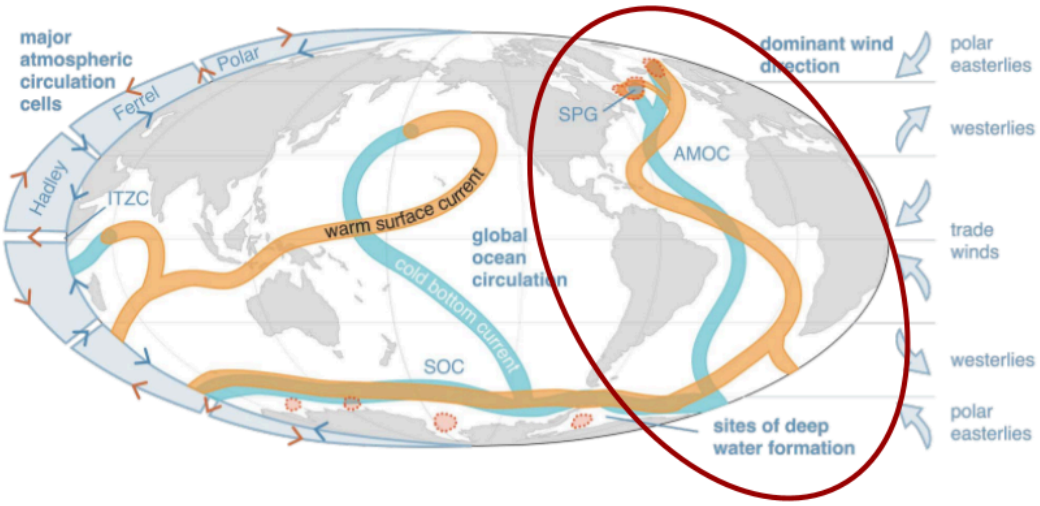

Figure 1.4.1: Atmospheric circulation cells, dominant wind directions, key ocean basins, surface currents and deep water formation sites. AMOC: Atlantic Meridional Overturning Circulation; SPG: Subpolar Gyre; SOC: Southern Ocean Circulation; ITCZ: Intertropical Convergence Zone.

GTP-Full-Document.pdf

The AMOC is circled; we will learn of its **PUMPS - the Overturning Circulation** at the top and bottom.

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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Here's another view - I recommend this very short video from NOAA:
https://sos.noaa.gov/catalog/datasets/ocean-circulation-conveyor-belts/

At the Northern end, around Greenland, the North Atlantic Current, which includes the Gulf Stream, brings warmth to Northern and Western Europe. Losing heat and gaining salt, the water plunges to the bottom and starts to head for the South. The sinking water has to be replaced and basically is sucking the surface warm current to the North. It is a Pump!

Atlantic Meridional Overturning Circulation (AMOC)

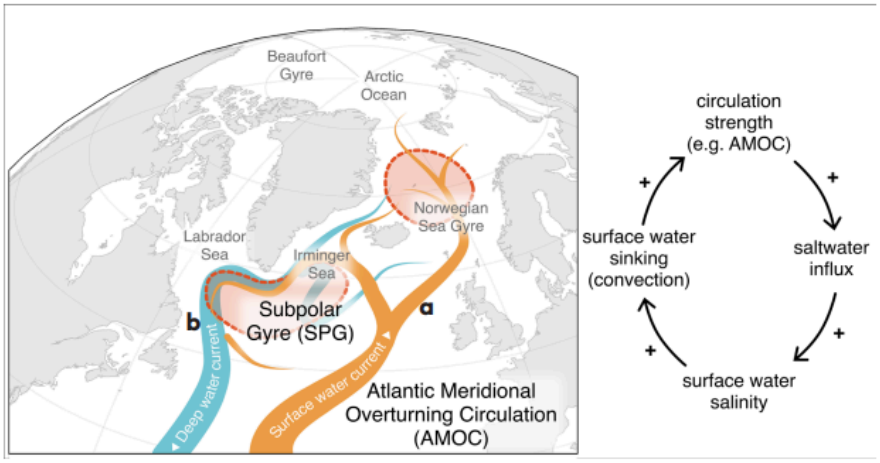

Figure 1.4.3: Overview over the major oceanic circulation systems in the North Atlantic. **a** The surface currents (orange pathways) are connected to deep ocean currents (blue) through sites where dense (cold, salty) water sinks, driving the overturning circulation (pink shading). **b** One critical feedback is the salt-advection feedback, in which the circulation strength determines how well the convection works, which in turn benefits the circulation.

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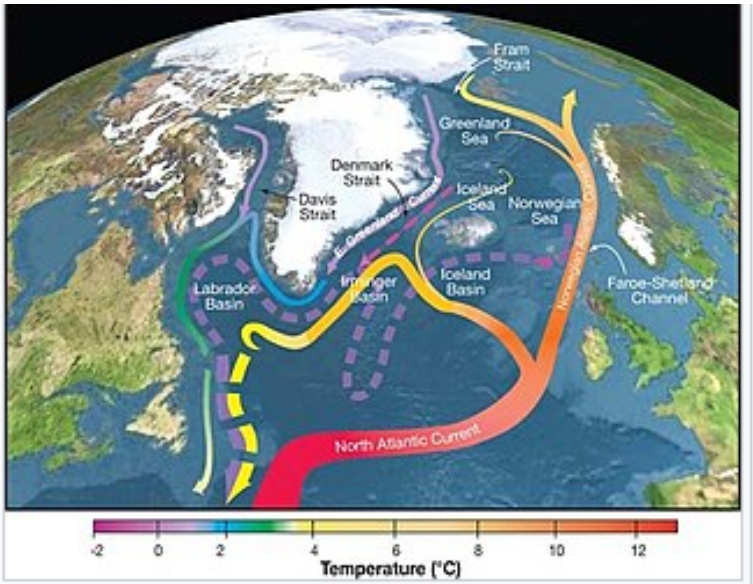
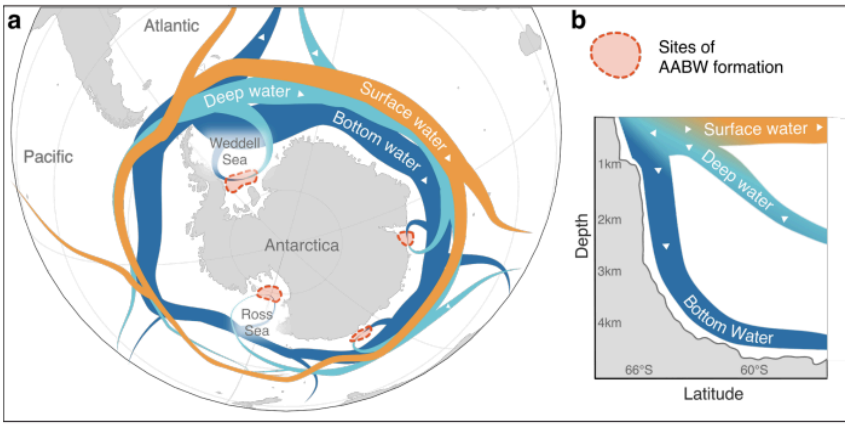
Here's another view:



Topographic map of the Nordic Seas and subpolar basins with surface currents (solid curves) and deep currents (dashed curves) that form a portion of the Atlantic meridional overturning circulation. Colors of curves indicate approximate temperatures.

At the Southern end, around Antarctica, the action is more complicated - but similar in its physics. The Pump sucks up Deep Water from the North, makes it super cold and drives up the salinity - making it far denser, and plunges it even further down to make Antarctic Bottom Water (AABW). This water will eventually mix with Deep Waters, returning to the Antarctic for pumping. [If you want to meditate on this beautiful complexity over all the Oceans, take another look at CSSG-2.7.



re 1.4.8: Circulations and potential tipping systems in the Southern Ocean. Adapted from Li, et al (2023) and IPCC SROCC Fig CB7.1

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What can slow or stop the **Overturning Circulation - the PUMP of the Global Conveyor Belt**:

- As polar regions warm, the warmer surface currents heading for the poles, like the Gulf Stream, would still cool, but not as much. **This reduces cooling, making the surface water harder to overturn.**
- As global ocean temperatures rise, the surface water heading for the poles will be harder to strongly cool. **This reduces cooling, making the surface water harder to overturn.**
- As the warmer surface waters approach the North, and cooling winds weaken over Antarctica, less ice is formed so less fresh water is taken out which would have made the water saltier. **This reduces salinity, making the surface water harder to overturn.**
- As the Greenland and Antarctic Ice sheets melt, more fresh water is dumped into the ocean. **This reduces salinity, making the surface water harder to overturn.**
- As global warming increases precipitation because warm air picks up more water, more fresh water is dumped into the ocean. **This reduces salinity, making the surface water harder to overturn.**

What are the **impacts** of slowing or stopping the AMOC?

- Sea Levels along the US East Coast will rise faster than elsewhere. AMOC exerts a major control on North Atlantic sea level, particularly along the Northeast Coast of North America. Exceptional AMOC weakening during the winter of 2009–10 has been implicated in a damaging 13 cm sea level rise along the New York coastline.[23] (from Wikipedia).
- The net northward heat transport in the Atlantic is unique among global oceans, and is responsible for the relative warmth of the Northern Hemisphere.[1] AMOC carries up to 25% of the northward global atmosphere-ocean heat transport in the northern hemisphere.[24] This is generally thought to ameliorate the climate of Northwest Europe, although this effect is the subject of debate.[25][26][27]
- AMOC is the largest carbon sink in the Northern Hemisphere, sequestering approximately 0.7 Pg (0.7 Gt) C/year.[30] Same for Antarctic overturning circulation.

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Severe weakening of the AMOC has the potential to cause an outright collapse of the circulation, which would not be easily reversible and thus constitute one of the tipping points in the climate system.[10] A shutdown would have far greater impacts than a slowdown on both the marine and some terrestrial ecosystems: it would lower the average temperature and precipitation in Europe, slashing the region's agricultural output,[11] and may have a substantial effect on extreme weather events.[12] https://en.wikipedia.org/wiki/Atlantic_meridional_overturning_circulation

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So, here are some **Punchlines.** It is critical to realize that direct data on the flow of the conveyor current was not available until 2004. There is some evidence of slowing from various records. Almost all of the factors which can impact flow are going the wrong direction, but direct evidence will take more time to ensure natural variability is understood. **[STILL NEEDS WORK!]**

Projected "Tipping Point"- Collapse of the:	Best Estimate of how soon might Irreversibility be reached?	Dominated by	What's the Ultimate Impact?	How Long till the Ultimate Impact is Reached (IF OCCURS)?	How much Impact this Century (IF OCCURS)?
Atlantic Meridional Overturning Circulation (AMOC) **Shutdown/ Collapse**		- Ocean warming - Precipitation increase - Greenland ice sheet meltwater increase - Arctic river discharge increase	- Cooling of up to 10 ^{0}C in Northern and Western Europe	Feedback-dependent: Century (basin-wide salt distribution feedback)	Few decades (North Atlantic salt distribution feedback), < few decades (sudden increase in sea ice cover in all convective overturning regions)
North Atlantic Subpolar Gyre (SPG) **Collapse**	Perhaps with Global warming 1.1 - 3.8°C			Perhaps somewhere with Global warming 1.1-3.8°C	Years to few decades
Southern Ocean circulation Antarctic Overturning Collapse / Rapid continental shelf warming		Ocean warming Antarctic ice sheet meltwater increase	AABW formation & abyssal overturning shutdown, unfolding within decades		

There is medium confidence (about 5 on a scale of 1 to 10) that an AMOC collapse would not happen before 2100, though a collapse is judged to be as likely as not by 2300. Hence the possibility of an AMOC collapse within the next century is very much left open by the latest IPCC report.