Oceanic overturning slowdown may amplify CO_2 caused warming

Strengthened tropic-bound cold water currents increase insolation uptake

By **Malcolm Cumming**

Observation and modeling of the Atlantic Meridional Overturning Circulation (AMOC) system indicates it has been slowing down over the last few decades (1) by anywhere from 15% (2) to perhaps ~20% (3). The Gulf Stream is the northward flowing component of the AMOC. Evidence of a slowdown in Gulf Stream flow is corroborated by two recently recognized phenomena. The salinity of the Nordic Seas has been lowered by a decreased inflow of warm/saline waters from the North Atlantic (4).

There is another clue pointing to a slowing of Atlantic circulation. A portion of the considerable rise in sea levels along much of the US East Coast is probably attributable to a weakening of the North Atlantic Gyre (5). The Coriolis-forced circular flow of a gyre causes water levels to rise in the center – correspondingly sea levels along coastlines (outside the gyre) are lowered. When an oceanic gyre weakens, internal sea levels fall and coastal sea levels rise.

At first glance, it might seem counterintuitive that despite a weakening of the Gulf Stream and its North Atlantic Drift extension and the slowdown of the AMOC in general, the Labrador Current is getting stronger (6). The increased flow has not been overlooked by the tourism industry of Labrador and Newfoundland (7). Viewing icebergs now rivals whale-watch excursions in popularity. The explanation for the increased outflow of Arctic cold water *at the surface*, despite a reduced inflow, is that deep water production and outflow have been reduced.

The process that creates deep water is called *overturning*. Surface water is transformed to make it dense enough to displace all waters below and sink to the bottom. Water density is maximized when it is both extremely cold and relatively saline. The Nordic Seas and locations off the Ross and Weddell Seas provide the extreme cold necessary for rapidly chilling surface waters. Those three locations are also well-placed to receive inflows from meridional surface currents that deliver salty (by way of also being warm) waters from low latitudes. Should either high latitude warming or a reduction of salinity occur, overturning is weakened. That seems to be happening today. Not only is there a slowdown of the AMOC, recent findings of increased upwelling along the Benguela and Humboldt currents (8) likely indicate a similar increase in cold water surface outflows due to reduced overturning in the Southern Hemisphere.

Rising CO_2 and reduced overturning

The reduction of high latitude overturning, especially in the Arctic, is a result of the rise in atmospheric CO_2 levels, now over 400 ppm. Carbon dioxide has a far greater impact on temperatures in the Polar Regions than in the tropics. The reason is due to the relative differences made by water vapor and CO_2 in contributing to greenhouse effects in high and low latitude atmospheres. Water vapor is a very effective greenhouse gas (GHG). At the Equator, high vapor creates a greenhouse effect about four (4) times stronger than in the Arctic – around ten (10) times stronger than in the Antarctic (9). In contrast, insulating capacities of polar atmospheres are influenced to a greater extent by other (non-vapor) GHGs such as CO_2. Atmospheric carbon dioxide levels are disbursed evenly around the globe. Therefore, as CO_2 levels rise, they have a proportionally greater influence in increasing polar greenhouse effects. This accounts for much of today's disproportionate rise in Arctic temperatures.

Strong Arctic warming eliminates the first requirement of overturning – rapid chilling of surface water at a rate fast enough to remove enough heat to allow it to reach maximum density before it sinks away from the surface. But it does more. The rapid increase in atmospheric temperatures has triggered a massive increase in ice melt from Greenland glaciers. The fresh water that pours into the Arctic Ocean and Norwegian Seas dilutes the salinity of surface waters, further slowing the overturning process. In turn, the slowdown of deep water production reduces the draw of inflowing warm, saline waters, further reducing the salinity of surface waters.

Of the water that flows into the Norwegian Seas and Arctic Ocean, the slowdown in overturning increases the proportion that flows out at the surface and decreases that which flows out at depth. Studies in the past few decades estimate that deep outflow through the Labrador Sea may range between 14 and 17 Sverdrups (10). (1 Sverdrup = 1-million cubic meters/second.) Deep/bottom waters formed by overturning (e.g. North Atlantic Deep Water (NADW), Antarctic Bottom Water (AABW)) remain below the thermocline for a thousand years or more. Decreased deep water production means that greater amounts of cold water will be returned more quickly to lower latitudes at the surface. Rather than being sequestered for great lengths of time, surface waters are readily able to exchange thermal content with the atmosphere and space.

The Stephan-Boltzmann Law

An increase in the presence of cool surface waters at various locations in the lower latitudes affects the rate of heat absorption from solar radiation. We may be more familiar with the stated finding of the Stephan-Boltzmann Law which says that heat emitted from a surface is proportional to the fourth power of its {absolute} temperature. The math behind the formula also involves a difficult to fathom constant with a value of 5.6704 times 10 to the -8th power. The practical meaning of the law is that water radiates heat proportionally to its temperature – the warmer the temperature, the more heat is radiated. The law of proportionality also means that cooler water radiates less heat.

Conversely, the Stephan-Boltzmann Law tells us that cool water can absorb insolation at a higher rate than warm water. In other words, whereas heat *emission is proportional* to surface temperature, heat *absorption is inversely proportional* to surface temperature. Cold water absorbs heat more readily than warm water. Put another way, cold water has a higher heat-absorbing capacity than warm water.

The amount of energy required to raise one gram (1 cubic cm) of water by 1° Celsius is loosely defined as one (1) calorie. However, the Stephan-Boltzmann Law of proportionality demands the definition of a calorie must also refer to the initial temperature of the water being warmed. For example, it takes less energy to increase a gram of cool water starting at 14.5°C by 1°C than a gram starting at 24.5°C. These differently "sized" calories are more aptly called 15° and 25° calories respectively. The relative differences between these calories can be easily determined by comparing the (greater) rise in temperature accumulated by cold versus warm water (given similar volumes and the same time and amount of applied heat).

Increased low latitude ocean surface warming

The reduction of high latitude overturning means there is an ongoing switch between cold water return flows at depth and greater present-day return flows at the surface. The strengthening of the Labrador Current, together with the increased upwelling associated with the Benguela, Humboldt, Canary and California eastern boundary currents (8) and their presumed strengthening, is bringing increased volumes of cool surface waters to Equatorial latitudes. The result will be an increase in the amount of insolation absorbed at the surface and ultimately added to the heat content of the oceans.

The increased capacity for low latitude ocean surfaces to absorb heat is merely the inverse of the more intuitive, and perhaps more widely accepted, concept that western boundary currents such as the Gulf Stream and Agulhas Current deliver warm water to high latitudes where an increased rate of heat loss acts to cool temperatures. In effect, the slowdown of the AMOC is telling us that a countervailing warming in the low latitudes is being reestablished that is partly offsetting the cooling that takes place near the Poles.

Direct measurements of surface flows and temperatures in the subtropical and tropical regions of the North Atlantic, together with modeling of oceanic circulation under various levels of high latitude overturning should help confirm the validity of the concepts presented in this article. It is important to determine if there is an unrecognized feedback that is amplifying the direct warming resulting from rising atmospheric CO_2 levels. Upon further investigation, we may well find that the directly CO_2-caused reduction in oceanic overturning is expanding the flow of cold surface waters (with their heightened heat absorbing potential) to the tropics which, in turn, causes the low latitude oceans to absorb heat at a higher rate and further warm the world's oceans.

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