HOW POTENTIAL CHANGES OF A SLOW, DEEP CURRENT IN THE ATLANTIC WILL INTENSIFY EXTREME WEATHER IN EASTERN AUSTRALIA

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Our planet is known to mostly gain heat from the sun along tropical latitudes. This contrasts with a net heat loss (i.e., cooling) at more temperate and polar latitudes.

This polarity is maintained via a necessary poleward transport of heat from equatorial regions. The Atlantic Meridional Overturning Circulation (AMOC; Figure 1), part of the global thermohaline circulation, describes the major mechanism responsible for this redistribution of heat in the Atlantic Ocean.

At the surface, powerful currents, such as the Gulf Stream, transport warm tropical water from the South and tropical Atlantic to the North Atlantic, which helps keep the European climate mild.

As the warm tropical water evaporates in the North Atlantic (transferring heat from the ocean to the atmosphere), it cools and becomes saltier which significantly increases its density and eventually starts sinking to form North Atlantic Deep Water (NADW). Driven by density gradients, these newly formed waters enter the bottom circulation of the AMOC, flowing all the way back to the coast of Antarctica where they either re-surface or are redirected to another ocean within a different branch of the thermohaline circulation.

The velocity of bottom water movement is drastically reduced compared to the surface velocity. The average age (e.g., time since last surfacing) of bottom water re-surfacing along the Antarctic coast is of the order of a thousand years, which gives oceans the ability to store nutrients and heat on extremely long timescales.

Climate records extending back 120,000 years show that AMOC has switched off, or dramatically slowed, during successive ice ages (Rahmstorf, 2002).

Towards the end of an ice age, AMOC recovers and modulates the European climate during interglacial periods, when the Earth's climate is warmer. Since human civilisation began around 5,000 years ago, the AMOC has been relatively stable. However, a slowdown has been detected over the past few decades (Smeed et al., 2019). This could have significant ramifications for Atlantic Ocean heat transport modulating the European climate, Arctic sea-ice extent, and other global climate phenomena.

CAUSE AND IMPACTS OF THE SLOWDOWN

One clear consequence of global warming is the melting of polar ice caps in Greenland and Antarctica. When these icecaps melt, they discharge massive amounts of freshwater into the oceans, making water more buoyant and reducing the sinking of dense water at high latitudes. Because there is less water able to sink as NADW and flow back to Antarctica in the deep ocean, the whole AMOC slows down. Around Greenland alone, 5 trillion tonnes of ice have melted in the past 20 years, equivalent to 10,000 Sydney Harbours worth of freshwater. This melt rate will increase over the coming decades if global warming continues unabated.

A collapse of AMOC would profoundly alter the world's oceans. In addition to slowing down the re-circulation of heat, it would deplete them of oxygen accumulated in cold surface water and starve the upper ocean of the upwelling of nutrients provided when deep waters resurface from the ocean abyss. The implications for marine ecosystems would be profound. With Greenland ice melt already well underway, Caesar et al. (2021) estimate the Atlantic overturning is at its weakest for at least the last millennium, with predictions of a collapse in coming centuries if greenhouse gas emissions go unchecked.

MODELING OF IMPACTS IN THE SOUTHERN HEMISPHERE

They artificially switched AMOC off by applying a massive meltwater anomaly in the North Atlantic and compared the results to an equivalent calculation with no meltwater applied. Their goal was to look beyond the regional impacts around Europe and North America to assess how Earth's climate would change in remote locations, as far south as Antarctica.

These model simulations revealed that without any AMOC, a massive accumulation of heat appears in the tropical South Atlantic. This excess of tropical Atlantic heat increases the tropical convection (i.e., precipitation) of moist warm air into the upper troposphere (about 10 kilometres into the atmosphere), which is then re-distributed into the Walker circulation (Figure 2), accelerating it.

Much like AMOC, the Walker circulation acts to balance regions of tropical convergence with regions of descending dry air and is composed of several "overturning" cells in the lower atmosphere along the equator. The acceleration of the Walker circulation causes more sinking of dry air to descend over the east Pacific. But in contrast to AMOC, an increase of sinking air strengthens the whole circulation, including surface easterly trade winds blowing over the Pacific. As most Australians well know, trade winds modulate the temperature of the tropical Pacific Ocean surface and are a major driver of the El Nino Southern Oscillation (ENSO) which expresses itself in successions of El-Nino and La-Nina events. Accelerated trade winds push more warm water towards the Indonesian seas and help put the tropical Pacific into a La Niña-like state, causing increased wet/dry conditions over the western/eastern Pacific.

In Australia, the current unrelenting La Niña has loaded the atmosphere with moister air over much of the eastern states and brought extremely warm ocean temperatures to northern Australia. Both contributed to some of the wettest conditions ever experienced, with record-breaking floods in New South Wales and Queensland. Meanwhile, over southwestern North America, a record drought and severe bushfires have put an enormous strain on emergency services and agriculture, with the 2021 fires alone estimated to have cost at least US$70 billion.

In addition to direct consequences for the Australian climate, Orihuela-Pinto et al. (2022) also found that an AMOC shutdown would be felt as far south as Antarctica. Rising warm air over the West Pacific resulting from the sustained La-Nina state would trigger atmospheric perturbations propagating to Antarctica, deepening the atmospheric low-pressure system over the Amundsen Sea, which sits off west Antarctica. This low-pressure system is known to influence ice sheet and ice shelf melt, as well as ocean circulation and sea-ice extent as far west as the Ross Sea.

SUMMARY

There is now increasing evidence that, aided by a warming climate, the AMOC has started to slow down over the past few decades. A slowdown of this key northern hemisphere climate regulator would have dramatic consequences in both the oceans and the atmosphere, modulating the European climate, Arctic sea-ice extent, and other global climate phenomena. In Australia, this would manifest as a persistent La Nina state with increased wet conditions, multiplying the likelihood of record-breaking floods such as the ones observed this year.

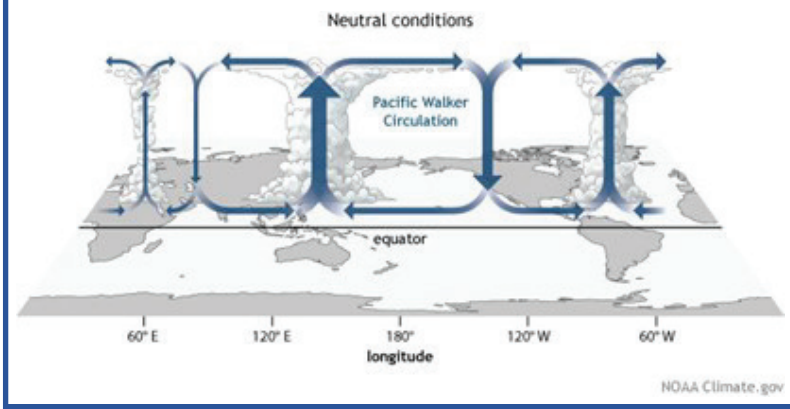

Figure 2: Details of the Walker circulation. Regions of tropical surface convection force rising air to reach the high troposphere and drift to regions of sinking dry air. The surface flow of the Walker circulation stimulates ocean evaporation, increase air moisture which is eventually fed back to tropical convergence regions.

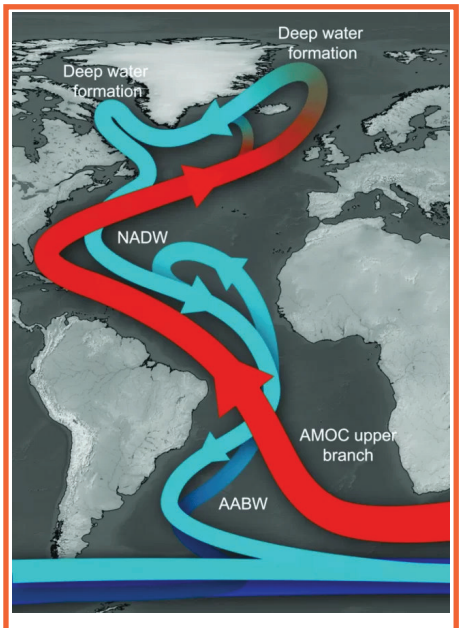

Figure 1. The main components of the Atlantic meridional overturning circulation. The northward flowing upper branch (red arrow) transports warm salty waters to the North Atlantic, and forms the North Atlantic Deep Waters (NADW) at high latitudes. The southward flowing NADW lies above the Antarctic Bottom Water (AABW). Source: Stefano Crivellari, University of Sao Paulo/Research Gate.

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Maxime's interests focus on physical oceanography and climate sciences. He holds a PhD in Quantitative Marine Science from the University of Tasmania. During his PhD, Maxime investigated global characteristics, changes and drivers of marine heatwaves, to improve our knowledge of these ocean extreme weather events.