'Summer' and 'winter' in a deep-ocean current thousands of metres below the sea-surface

Mitchell Chandler[1]

[1]Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA, USA

If you've been to the coast, you will likely know the surface of the ocean is warmer in summer and colder in winter. But do seasonal changes in temperature also occur in the deep-ocean far below the sea-surface? Well, with the recent creation of robots that live in the ocean and can reach all the way to the seafloor, this question can now be answered. In our study, we used measurements collected by these robots to explore seasonal temperature changes in a deep-ocean current at the western boundary of the South Pacific Ocean. Temperatures within the deep-ocean current were found to be colder in the first half of the year and warmer in the second half of the year. Amazingly, these seasonal changes in ocean temperature 2000 to 4000-metres below the sea-surface appear to be caused by seasonal changes in winds at the sea-surface.

Source Article: Chandler M, Zilberman NV, Sprintall J. 2024. The deep western boundary current of the Southwest Pacific Basin: insights from Deep Argo. *Journal of Geophysical Research: Oceans*. 129:e2024JC021098. https://doi.org/10.1029/2024JC021098

What are Deep Western Boundary Currents?

Ocean currents transport large amounts of seawater and are found all over the ocean. We can think of these currents as the arteries and veins of the climate system because, much like how our arteries and veins transport blood around our body and help regulate our body temperature, these ocean currents transport water and heat around the ocean and help regulate the global temperature. You may have even heard of some of these ocean currents such as the East Australian Current (a real current that was referenced in the movie 'Finding Nemo') or the Gulf Stream. These are both known as Western Boundary Currents because they are found along the western boundary of an ocean. The East Australian Current is on the western side of the South Pacific Ocean and the Gulf Stream is on the western side of the North Atlantic Ocean.

But ocean currents are not just found near the surface. They are also found in the deep-ocean (below 2000-metres deep). Deep-ocean currents on the western side of an ocean (such as the Pacific Ocean, Indian Ocean, or Atlantic Ocean) are called Deep Western Boundary Currents. In the Southern Hemisphere, northward-flowing Deep Western Boundary Currents transport extremely cold and heavy seawater formed around Antarctica. These waters are known as deep waters and bottom waters. The Deep Western Boundary Currents in the Southern Hemisphere transport these deep and bottom waters away from Antarctica, filling the deep-ocean. Changes in deep and bottom waters are also transported by Deep Western Boundary Currents, with recent measurements at the western boundary of the South Pacific Ocean showing an increase in temperature, increase in carbon content, and decrease in oxygen content [1].

The Deep Western Boundary Current of the Southwest Pacific Ocean

Our recent work focussed on the Deep Western Boundary Current that flows north through the Southwest Pacific Ocean (Figure 1). This Deep Western Boundary Current carries huge amounts of deep and bottom waters, equivalent to about 6500 Olympic swimming pools per second [2]! Eventually, the water in this current exits the Southwest Pacific Ocean, crosses the equator, and enters the North Pacific Ocean. Because there are no deep-water formation sites in the North Pacific Ocean, this Deep Western Boundary Current carries the deep and bottom waters that fill most of the western South Pacific Ocean and North Pacific Ocean [3]! The temperature of the water in this current essentially sets the temperature of the deep Pacific Ocean.

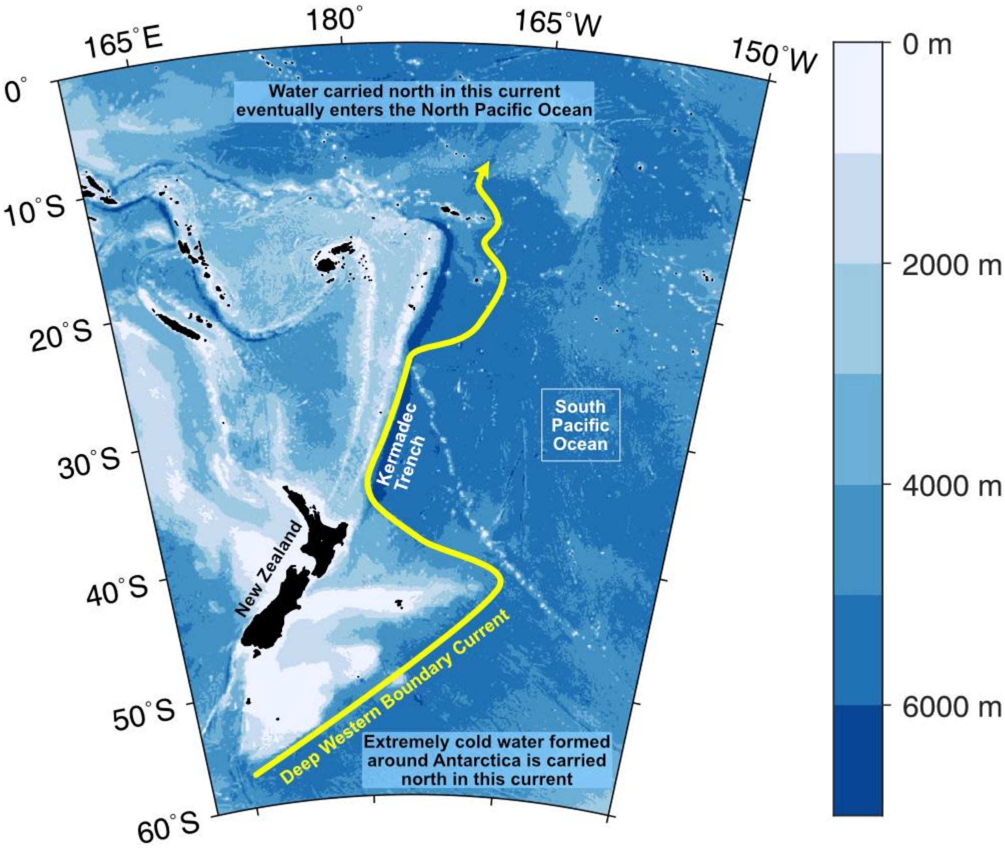

Figure 1: Map of the western boundary of the South Pacific Ocean. The path of the Deep Western Boundary Current is in yellow. Blue shading show the depth of the ocean in metres. Land is coloured black. The location of the Kermadec Trench (an ocean trench located to the north-east of New Zealand) is also labelled.

Using robots to measure the deep-ocean

In the past, the deep-ocean has typically been measured using equipment lowered from research ships (Figure 2a). However, research ships are expensive to operate and measuring from the sea-surface all the way down to the seafloor takes many hours. Furthermore, the ocean is so big that it often takes days to even reach a study location! We therefore have relatively few measurements of the deep-ocean, and even less measurements of Deep Western Boundary Currents.

Excitingly, the creation of ocean-going robots, called Deep Argo floats (Figure 2b), has provided us with a new way of measuring the deep-ocean. These robots live in the ocean for many years, drifting with ocean currents and measuring the temperature of the water and how salty the water is as they repeatedly travel between the sea-surface and seafloor every 10–15-days [4]. The maximum depth these robots can safely reach is 6000-metres below the surface, which is as deep as Denali (the highest mountain in North America) is tall! Deep Argo floats presently live in a few important ocean regions around the world, but the goal is to have them spread all over the global ocean. You can read more about the Argo program here. Although

Deep Argo floats are likely to transform how we measure the deep-ocean, we will still need research ships to provide the extremely accurate measurements required to confirm Deep Argo float measurements, and to measure other water properties (such as oxygen, nutrients, and carbon) that cannot yet be measured by Deep Argo floats.

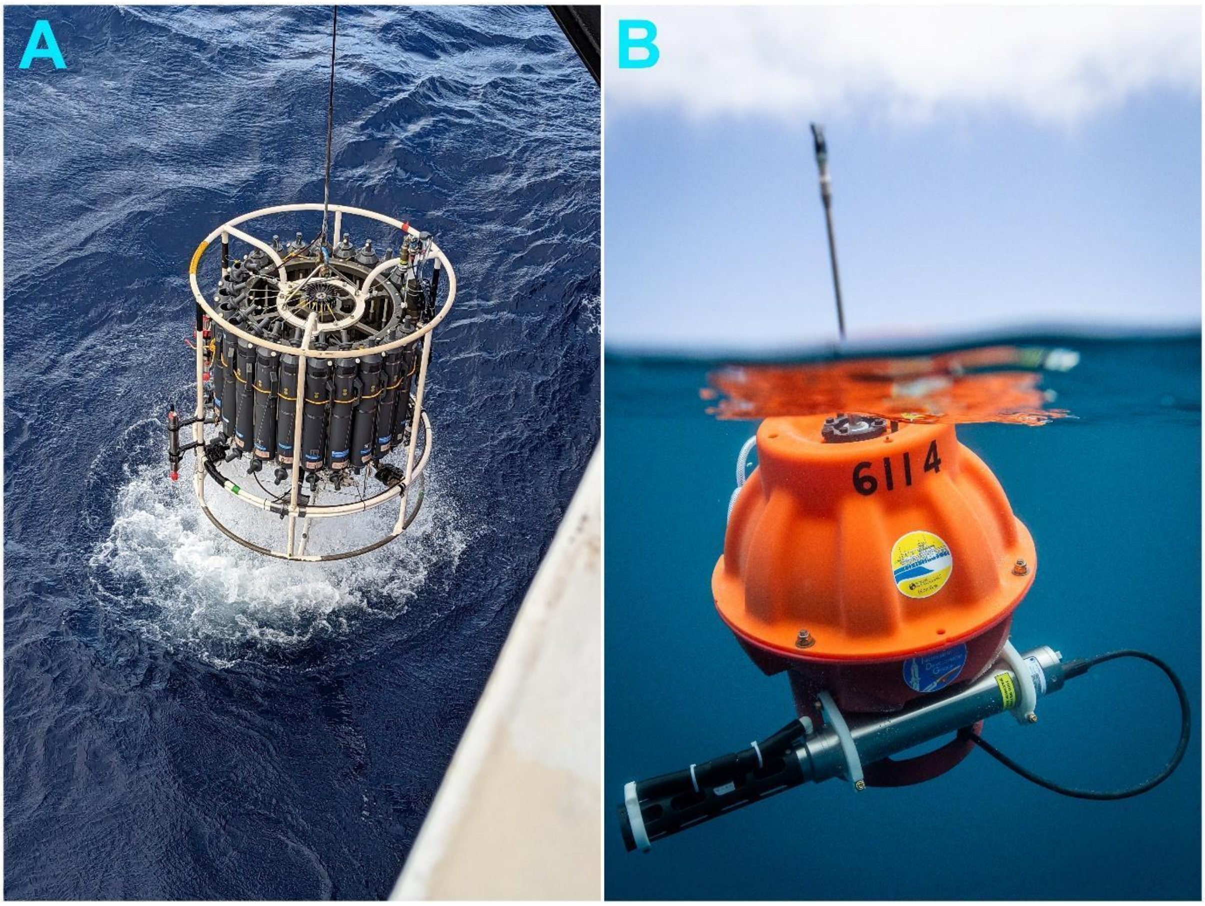

Figure 2: ***(A)*** *An example of the equipment used to make ship-based measurements of the deep-ocean (Photo credit: Mitchell Chandler).* ***(B)*** *A Deep Argo float (Photo credit: Scripps Institution of Oceanography at UC San Diego).*

Seasonal changes in the Southwest Pacific Ocean Deep Western Boundary Current

We know that, at the surface, air and ocean temperatures change during the year – you can feel it is warmer in summer and colder in winter – but are there changes in ocean temperature far below the sea-surface? To answer this question, we used measurements from 6 Deep Argo floats located within the Southwest Pacific Ocean Deep Western Boundary Current as it flows through the Kermadec Trench (an ocean trench located to the north-east of New Zealand; Figure 1). From these measurements, we found that – yes! – there were seasonal changes in ocean temperature within this Deep Western Boundary Current. Specifically, between 2000 to 4000-metres deep, we found colder temperatures in the first half of the year (which you can think of as the deep-ocean 'winter') and warmer temperatures in the second half of the year (which you can think of as the deep-ocean 'summer').

These seasonal changes in Deep Western Boundary Current temperature were caused by the vertical movement of isotherms (lines of constant temperature; Figure 3). Movement of isotherms towards the sea-surface brought colder water shallower and therefore caused cooling. Movement of isotherms away from the sea-surface brought warmer water deeper and therefore caused warming.

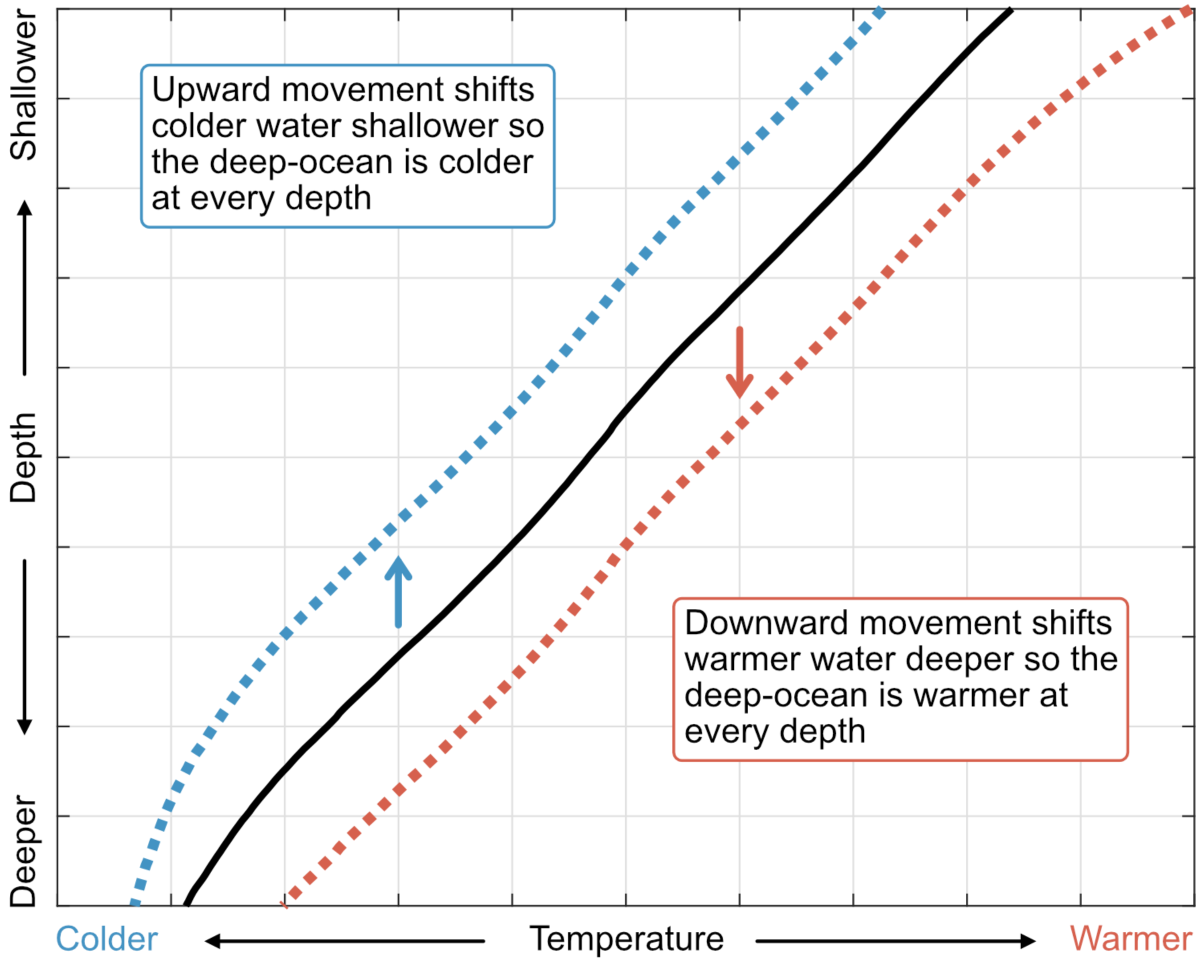

Figure 3: A diagram of ocean temperature (black line) against ocean depth that demonstrates how upward (blue) and downward (red) movement of water within the Deep Western Boundary Current causes seasonal changes in deep-ocean temperature.

Seasonal changes in surface temperature could not be causing these seasonal changes in deep-ocean temperature. Instead, at the northern end of the Kermadec Trench, the seasonal movement of isotherms appeared to be due to seasonal changes in surface winds. Local wind conditions that caused upward movement in the ocean occurred at the same time as deep-ocean cooling and local wind conditions that caused downward movement in the ocean occurred at the same time as deep-ocean warming. It is rather amazing that changes at the sea-surface seem to be causing changes in the ocean thousands of metres deep! This link between surface winds and deep-ocean temperature suggests that changes in seasonal wind patterns under climate change could affect seasonal temperature changes in this Deep Western Boundary Current.

A similar seasonal cycle in deep-ocean temperature was found when using a computer model that incorporated different ocean measurements [5]. This computer model also suggested that we may find different seasonal cycles if we were to move further north or south along the current. Unfortunately, we did not have enough measurements to explore seasonal changes elsewhere along this Deep Western Boundary Current. However, because Deep Argo floats are still out in the ocean making measurements, we will soon be able to determine if and how the seasonal cycle changes along the path of the Southwest Pacific Ocean Deep Western Boundary Current.

Are these seasonal changes seen in other Deep Western Boundary Currents?

In this study, we used measurements of ocean temperature collected by robots to explore seasonal changes in the Southwest Pacific Ocean Deep Western Boundary Current. At depths of 2000 to 4000-metres, ocean temperatures within the Kermadec Trench were colder in the first half of the year and warmer in the second half of the year. However, our study only looked at one region in one deep-ocean current. We do not yet know whether these seasonal deep-ocean temperature changes occur in Deep Western Boundary Currents in the Atlantic Ocean or Indian Ocean. Because seasonal changes in surface winds occur elsewhere, our guess is that other Deep Western Boundary Currents will also demonstrate seasonal temperature changes. Releasing more Deep Argo floats into the ocean at many different locations could provide the additional measurements needed to truly answer this question on a global scale.

References

[1] Sloyan BM, Wijffels SE, Tilbrook B, Katsumata K, Murata A, Macdonald AM. 2013. Deep ocean changes near the western boundary of the South Pacific Ocean. *Journal of Physical Oceanography*. 43:2132—2141. https://doi.org/10.1175/JPO-D-12-0182.1

[2] Whitworth T, Warren BA, Nowlin WD, Rutz SB, Pillsbury RD, Moore MI. 1999. On the deep western-boundary current in the Southwest Pacific Basin. *Progress in Oceanography*. 43:1—54. https://doi.org/10.1016/S0079-6611(99)00005-1

[3] Johnson GC. 2008. Quantifying Antarctic Bottom Water and North Atlantic Deep Water volumes. *Journal of Geophysical Research: Oceans*. 113:C05027. https://doi.org/10.1029/2007JC004477

[4] Roemmich D, Sherman JT, Davis RE, Grindley K, McClune M, Parker CJ, et al. 2019. Deep SOLO: a full-depth profiling float for the Argo program. *Journal of Atmospheric and Oceanic Technology*. 36:1967—1981. https://doi.org/10.1175/JTECH-D-19-0066.1

[5] Lellouche J-M, Greiner E, Bourdalle-Badie R, Garric G, Melet A, Drevillon M, et al. 2021. The Copernicus global 1/12° oceanic and sea ice GLORYS12 reanalysis. *Frontiers in Earth Science*. 9:698876. https://doi.org/10.3389/feart.2021.698876