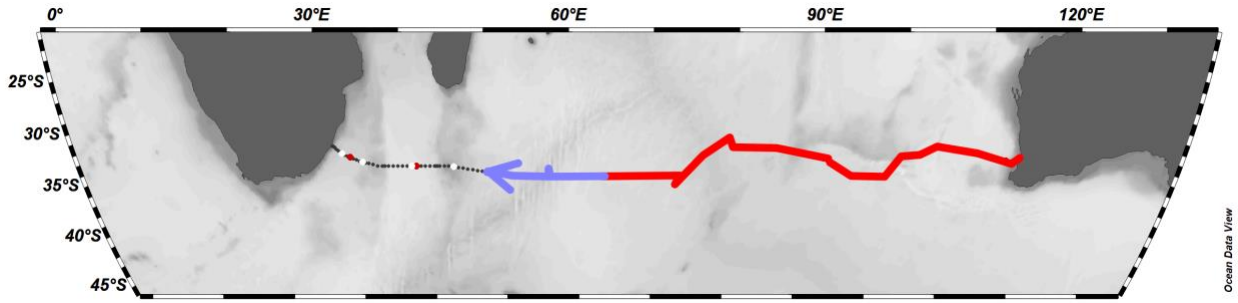
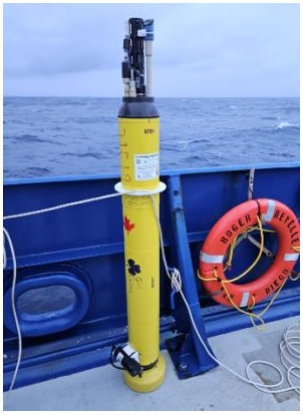
I05_2023 Update 8/30/2023

Update 5 of 7



A map of our planned cruise track with the completed stations covered in previous weeks with a red line and completed since the last update with a blue line. Upcoming planned and potential float deployment locations have larger dots.

Highlights



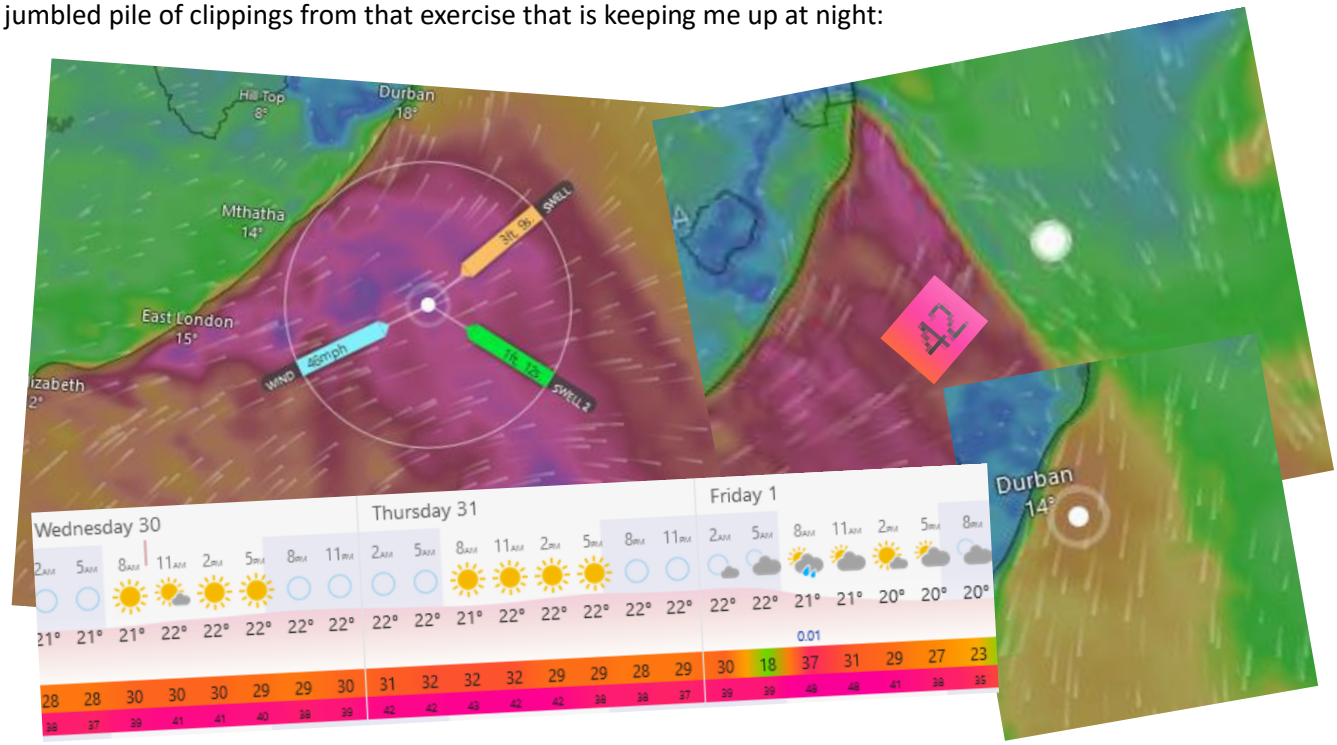
- 147 stations (32 new) completed with 38 stations (8 new) with biological measurements, with the new bio measurements from separate casts.
- 10 floats (2 new) and 18 drifters (6 new) deployed: 1 SQUID float, 1 biogeochemical Argo float (*Saturna Island*), 3 “Directional Wave Spectra Barometric Drifters” (DWSBDs) and 3 NOAA drifters.
- I05 blog

Saturna Island float, photo by Aurélie Moulin.

We are wrapping up another productive week in fair weather with no unplanned delays. We now have more than 3/4ths of our planned stations completed. We did pause a few times on short transits (particularly on our short jog to the north through a fracture zone in the South Indian Ridge) to allow our samplers to collect and run more samples. We also took advantage of a longer transit to get through most of a mechanical retermination, which means replacing the connection between the wire and the CTD/rosette. This junction is at the heart of our work… it simultaneously supplies power to the sensors and bottles, passes data back and forth, and holds up the several ton package of scientific equipment, all while being subjected to saltwater under up to ~600 times atmospheric pressure, so we try to keep it in pristine shape.

We’ve been fortunate with weather this week. One furious blotch of high winds that had been menacing our weather forecasts seemed to politely slide out of our way like one sailor making way through a passage for another. Now the forecasts suggest we should remain in calm weather for a few more days at least. Thanks to our good luck, the hard work and efficiency of our team, the amazing

performance of the *RV Roger Revelle*, and the skill and professionalism of her crew, we are back on a pace to finish out our science goals for this cruise before we run out of time. However, the cruise is still a few weeks from finished and there is at least one more known wild card: the Agulhas Current. The Agulhas rounds South Africa from the Indian Ocean into the Atlantic and supplies much of the seawater that that Atlantic Ocean later converts into bottom waters and exports at depth. It is a critical linkage in the great churning circulation of our oceans and the heat engine of our planet, and it has been implicated in past shifts in global climate. It is also—to hear the sea tales told by the various veterans of research cruises in the area—a place known for fickle and foul weather. I've been watching the weather forecasts for the area of the Agulhas where we will be working nearly as closely as our own. Here is an jumbled pile of clippings from that exercise that is keeping me up at night:



These are three separate high wind events in the Agulhas with the upper left being the first (which finished up recently) and the upper right being the forecast for 5 days from now (with 42 mph wind averages*). The lower right image (of current conditions) looks tame in comparison, but it is still on the edge of safe operations, and, from the bottom left plot, you'll see it can keep up those strong winds for several days at a stretch.*

To be fair, the Agulhas has its pleasant moments as well, but we'll be rolling the dice as to which face it will decide to show us when we arrive. For this reason, we're trying to keep a bit of time in our back pocket. If we get slammed by fierce weather then we can hope to wait out the worst of it and still finish most or all our work. If we luck out and are warmly welcomed to the area by calm seas and still skies then we can use the extra time to move at a slower pace and ensure that our chemistry analysts are able to sample this important current at high resolution.

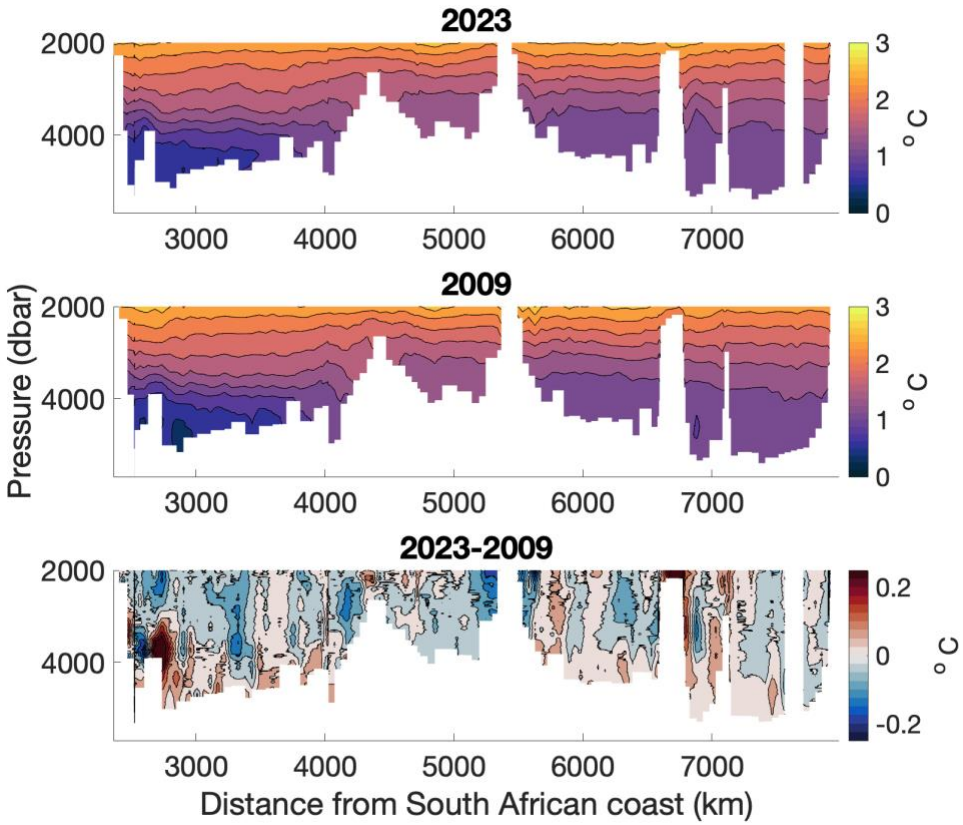
If all goes to plan, the next update will be written after the Agulhas work is completed and as we start our transit to Cape Town. The one after that will be a much shorter note sent as we are finishing demobilization. These will be spaced by both more and less than a week, so "no news" over this next

period is not necessarily bad news. During the last week we'll also be hard at work on the cruise report and getting ourselves and all our gear back home.

As promised, this week is focused on deep ocean temperature variability, and our writeup was kindly drafted by Co-Chief Kay.

Deep ocean warming – by Kay McMonigal

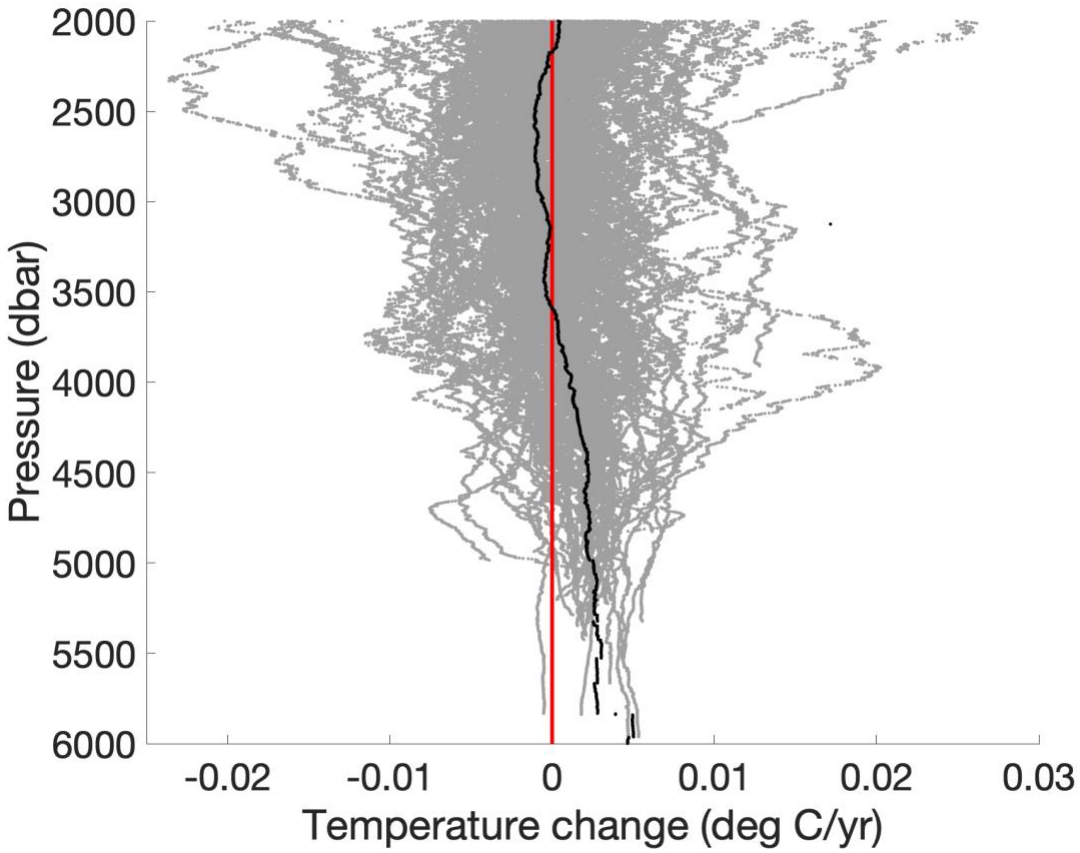
As a physical oceanographer, I am sometimes asked why we still need ships to obtain hydrographic data, when Argo floats and numerous satellites have near global coverage. One of the big holes in our temperature and salinity data is the deep (> 2000 m) ocean, which Argo floats (and satellites) do not yet routinely measure (side note: there are now pilot arrays of new variants on the Argo float that can handle the immense pressures of the greatest ocean depths, but these do not yet provide global coverage and the reference quality GO-SHIP measurements will remain an important component of global temperature monitoring even once they do). Constraining the warming rates of deep water masses such as Antarctic Bottom Water is an essential component of understanding heat uptake by the ocean. However, in the Indian Ocean, the lack of deep data have led to an inability to assess these deep warming rates. Our cruise track includes some deviations north and south to adequately cover the deepest parts of the basins, and will provide much needed insight. Deep salinity changes are also interesting, but I will hold off on talking about those until the salinity data have undergone more quality control.



Temperature across the I05 in 2023 (top), 2009 (middle), and 2023-2009 (bottom). Using simple linear interpolation (preliminary)

First, we can look at the temperature difference between 2023 and 2009, focusing on the area below 2000 dbar. Areas of both warming and cooling are evident, including several areas that have warming/cooling dipoles, possibly indicating a shift in the location of deep ocean currents. If you squint a little, there appears to be more red than blue in the deepest regions (below 4000 m depth), indicating a general warming of bottom waters.

However, my very preliminary linear interpolation doesn't do a good job at showing us the deepest profiles. For a better view of those, we can look directly at the profiles. Each gray dot is the difference between the 2023 and 2009 temperature divided by 14 years, to give an approximate warming rate at each station. The black line shows the mean warming rate at each pressure level. On average, there is warming below 3600 dbar. The mean warming rates are about 0.001-0.005 °C/year. This is in general agreement with studies of deep warming rates in the South Pacific Ocean. The densest waters (> 5800 dbar) have warmed the most (with the caveat that we have very few stations that extend to those depths). Clearly the deep Indian Ocean is warming, albeit with variations across the different deep basins.



Temperature of 2023 station temperature minus nearest 2009 station temperature (gray dots). Black dots show the mean at each pressure level. Preliminary data