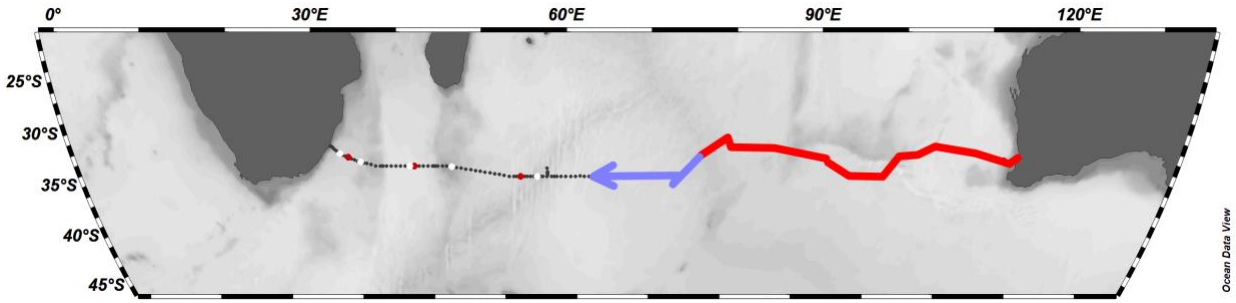
I05_2023 Weekly update 8/22/2023

Update 4 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 (as of 8/22)

- 115 stations (26 new) completed with 31 stations (8 new) with biological measurements, with the new bio measurements from separate casts.
- 8 floats (2 new) and 12 drifters (5 new) deployed: 1 SQUID float, 1 biogeochemical Argo float (*Nautifish*, as in nautical and as in "not a fish"), 3 "Directional Wave Spectra Barometric Drifters" (DWSBDs) and 2 NOAA drifters.
- ~5 combined hours of assorted weather and mechanical delays.
- I05 blog

Jaeden Hansen's rendition of the Nautifish. Clipped from a photo by Aurélie Moulin.

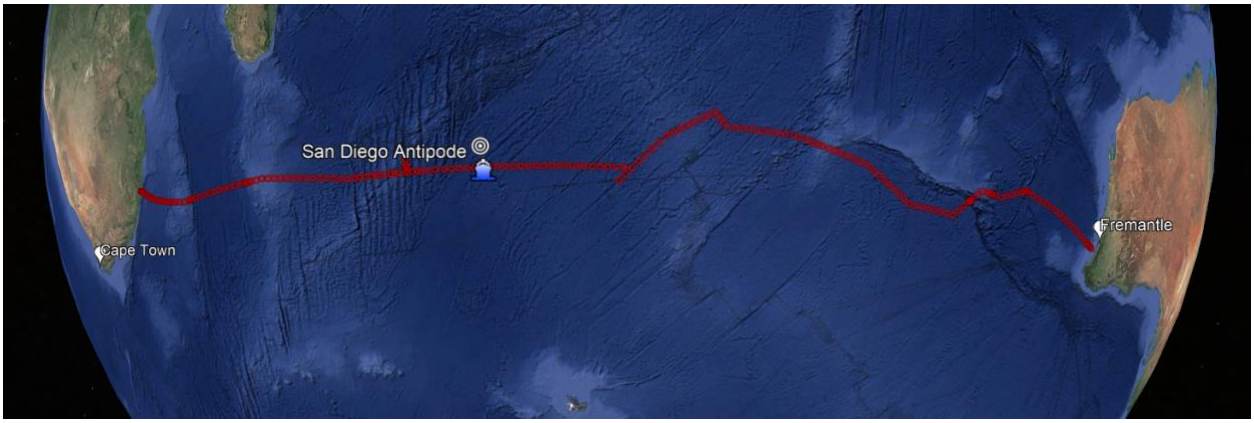
Another productive week is behind us, and we've weathered 1.5 bouts of stronger winds (we are still coming out of one) and a long series of >4000 m deep casts. The winds never prevented us from working outright but they did churn up the ocean enough to make us move more cautiously during transits and downcasts. For one station we sampled in place (without transiting to the next station) because the waves were threatening to inundate the staging bay once we started our transit. We also took a brief pause to replace an electrical termination that had been with us since a station in the early teens. Mostly, however, we've had few issues this week and we've been making good time. The wide, deep, and flat-bottomed Crozet Basin is giving us many similar stations in a row to get into our grooves. Progress has been efficient enough that we've continued doing separate bio-casts throughout the week.


(Left photo) A non-tournament practice ping-pong game between Kirsten Petzer (near left), Jaeden Hansen (far and left), Lydia Pinard (near right), and Nirmala Nair (far right). Clipped from a photo by Jom Lamoonkit. (Right photo) Andrew Collins (left) and Daniela Nestory (middle) enjoying the midday sun. Photo by Nataly Pineda.

Life at sea and staying sane

A cruise this long has parallels with running a marathon… though arguably without training for it first. Life on a research vessel can be exciting and adventurous, but recall that our team of scientists has been working 12+ hour days (84 hour weeks) nonstop for, as of today, over one month. Working on a research cruise is a feat of endurance, if of a different kind than a marathon. This blog by Sara Kurth (a running coach on the internet) breaks down the stages of running a marathon, and, if the analogy holds, then we're moving from "the Middle Miles" and into "the Dark Times." Sara cautions us about the "excitement wearing off" as well as "hitting the wall." She suggests we stay in the moment, and I think our team out here is doing that well. A ping-pong tournament is underway, an informal book club seems to have sprung up, there's a "high-stakes" betting ring focused around predicting future-station mixed layer depths, there are gatherings at the sides of the boat whenever sea life is spotted, and there are several personal science projects ongoing with some already using the data from this cruise. In addition, there are crafts projects, there are people learning languages and how to tie knots, there are board game nights and card game nights, and there's even an off-shift Dungeons and Dragons campaign. People are working on plans for the future as well: making travel plans, drafting conference abstracts, sending in job and internship applications, and writing funding proposals. Personally, I'm winding down before bed learning to read Tarot cards.

Generally, these are weeks where it is important to find our joys where we can, and to focus on how far we've come rather than how far we have yet to go. When I find myself thinking of who and what I am missing from home, I try to do so while sitting out on the bow and listening to the forceful and persistent growling of the winds whipping past the *Revelle*. It's a rich sound that reminds me of the joys of this calling, and the privileges of getting to witness remote parts of the world.



Speaking of remote, the RV Revelle is almost as far from home as possible right now. As I write this from station 116, the antipode for her berth at the Nimitz Marine Facility in San Diego—or the place on the exact opposite side of the globe from her home—is less than 2 degrees north of us.

Last week I said we'd focus this week on temperature changes and the week after on carbon, but I since remembered that the carbon accumulation signal should be relatively constant across the whole I05 section (not uncommon for the East-West sections) whereas there might be interesting and different temperature changes going in each basin. So, we're pushing temperature back another week to finish up more of the section and this week we'll talk about:

Anthropogenic carbon

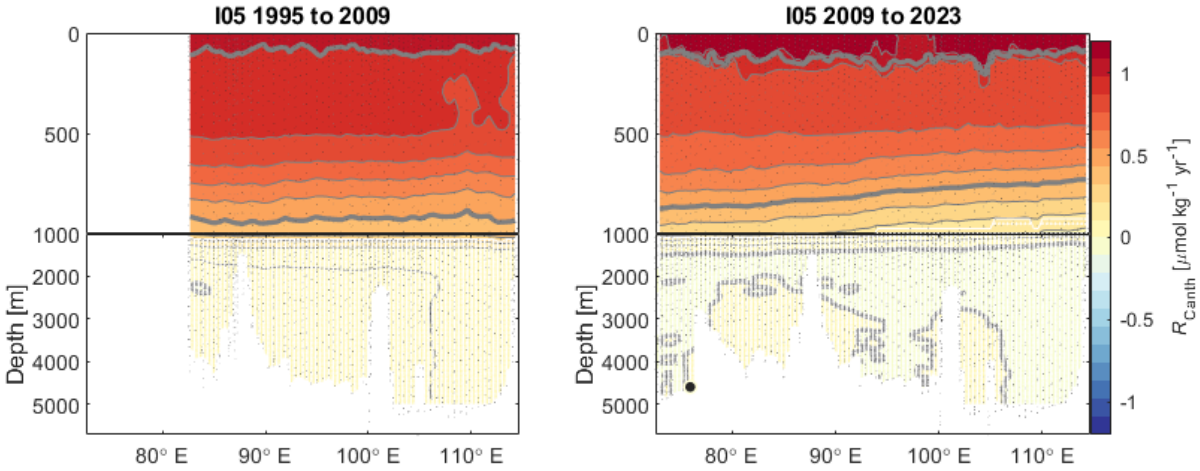
One of the goals for GO-SHIP is measuring decadal changes in the ocean "anthropogenic" carbon distribution, which is the carbon in the ocean because of human CO_2 emissions. Humans are emitting enough CO_2 gas each year to fill the Grand Canyon from floor to rim ~4.5 times over. The ocean is responding by dissolving some of what we are releasing, currently about a quarter of our emissions. This is slowing global warming by removing this heat-trapping gas from the atmosphere. On long timescales, ocean circulation will allow the ocean to take up an even larger fraction, and the ocean carbon cycle even has the potential to eventually mitigate most of our emissions… provided we can wait many thousands of years for the ocean carbon cycle to fully respond. There are many teams of people working on ways to speed up these responses (shameless plug for some news and a video from collaborators on one of our projects), but the distant potential success of these efforts still requires that we first find and implement ways to power our civilization and generate energy without emitting more CO_2.

Returning to GO-SHIP: With the ocean soaking up a quarter of human CO_2 emissions, ocean anthropogenic carbon uptake should be among the strongest signals of global change that we can measure on GO-SHIP cruises. However, there is also natural variability in the dissolved inorganic carbon concentration of seawater near the ocean's surface, so it can still be difficult to isolate the anthropogenic carbon uptake when simply differencing measurements from one decade to the next. Fortunately, the things that make dissolved carbon change (such as shifts in ocean circulation patterns and the growth and decay of plankton and other sea life) also change many of the other measurements that we make along GO-SHIP cruises. This allows us to leverage another GO-SHIP strength, having many different high-quality measurements on the same seawater, to separate out the changes that are the result of human

emissions from the changes that have occurred naturally. This is a topic that is near to my heart and some of my previous work focused on developing methods for teasing apart these signals.

The I05 section is one of the largest gaps in our record of the changing ocean anthropogenic carbon inventory due to the long time that has elapsed since the last occupation of this line in 2009. A few years back I decided to pause an analysis of anthropogenic carbon in the Indian Ocean because the statistics would be much stronger with the next (i.e., current) I05 record completed, and this is among the reasons that I enthusiastically volunteered to participate on this cruise when the ship time was made available. This is extra exciting for me, as this is the first time I've been able to confidently detect changes using only GO-SHIP cruises that I was on (I sailed on the 2009 cruise as a pH analyst).

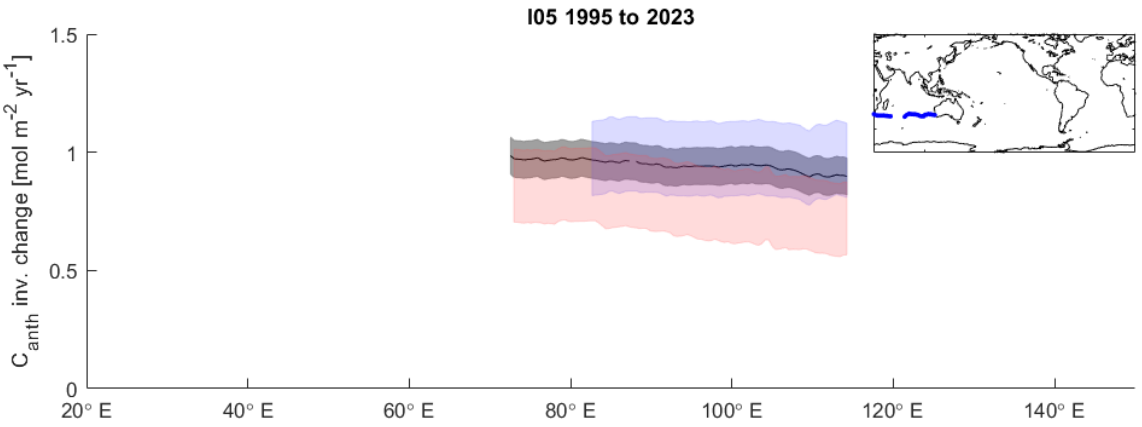
So, what are we seeing?:



Preliminary! Anthropogenic carbon accumulation along the I05 line between the earliest occupations and the previous occupation in 2009 (left) and a preliminary version of the same estimate made for the period between the 2009 cruise and our current occupation (right). The red bands near the surface reveal that, as is seen most places, the accumulation rate is greatest near the ocean surface. The areas covered in white dots (mostly in the lower parts of the panels below 1000 m) indicate places where the signal cannot be confidently separated from the noise inherent to the many measurements and calculations that are used to produce these estimates. The section on the left is shorter because the viable cruises for this analysis had a gap in the earliest occupation. It is pretty rare to be able to confidently detect accumulation all of the way down to 1000 m, but I05 is just north of the Antarctic Intermediate Water and Subantarctic Mode Water ventilation latitudes in the Southern Ocean, and these water masses are among the only ones that fill up these "intermediate" depths in the Southern Hemisphere. Thus, the waters at these depths along I05 have seen the atmosphere comparatively recently. Estimates are produced using the CAREER approach (Carter et al. 2019).

If you stare hard enough at these rates of change, there is an indication that the accumulation rate is slowing down. This is consistent with recent global findings as well as what we might expect when we consider that the ocean becomes less efficient at absorbing CO_2 the more it absorbs. However, one of the most difficult challenges for analyses like these is knowing how much confidence we can put in the

changes that we observe. When we plow through the statistics implied by the uncertainties in the measurements we get inventory change estimates like the following "column inventory" changes.



Preliminary! Column inventory changes—or changes added up across all depths in the ocean—for the period from 1995 to 2023 (black line with uncertainty ranges) and the uncertainty ranges for the period from 1995 to 2009 (blue band) and from 2009 to 2023 (red band). Forgive all of the wasted space in this figure… I wrote the code anticipating having the full section finished.

We can see that indeed the new red band is lower than the older blue band which would imply a slowdown, but the fact that they overlap implies that we cannot distinguish the rates of accumulation to high statistical confidence. Thus, this one section comparison is not enough to conclude that the accumulation rate is slowing down significantly. Fortunately, the statistics are improved when we consider changes along many different sections at once, and this is what I hope to do in my planned Indian Ocean analysis (and this possibility is another strength of having the full network of GO-SHIP cruises). However, it will have to wait a bit longer… A proper analysis requires fully quality-controlled measurements, and it will be about 6 months after we get back on shore before that process is completed and the final measurements are made (freely and publicly) available. I'm nevertheless updating my analysis frequently at sea with the preliminary numbers (and looking at some of the other recent Indian Ocean cruise measurements) just out of curiosity.