Cruise Report of the 2022 P02W US GO-SHIP Reoccupation

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CHAPTER

ONE

GO-SHIP P02 2022 HYDROGRAPHIC PROGRAM

1.1 Summary

The Leg 1 2022 reoccupation of the GO-SHIP P02 hydrographic line, RR2204 (*Fig. 1*) included 117 stations using a 36-bottle rosette: One station (Sta 1, 21.000°N, 140.050°E) along the transit from Guam at which core/bio[1] measurements were acquired between 1500/1000 m and the surface in support of a GO-BGC Argo float deployment; A single underway HPLC sample in support of a second float deployment (Sta 2, 26.670°N, 137.080°E); full water column core sampling at 12 stations from 32.507°N, 133.030°E to 30.000°N, 134.860°E, and 103 stations eastward along 30°N to 198.786°E. Biology samples were obtained approximately every third station. In all, 10 GO-BGC floats were deployed - all (except the underway Sta 2 float) were supported by both core and bio sampling.

The planned station spacing included very close spacing down the Japan coast and across the region of the Kuroshio its large loop and generally 30 nm spacing across the rest of the section. The delay at the start and a limited allowed time in the Japan EEZ led to a reduced number of stations in the west (9 vs. 15 coming south to 30°N, 23 vs. 33 in the Japan EEZ, and 46 vs. 59 west of 159°E where in 2022 30 nm spacing was resumed). The planned 131 stations were reduced to 117, but with fantastic weather and seas, Leg 1 finished only 1° west of the original longitudinal goal.

The rosette instruments included dual CTDs, one with oxygen (SBE43), a secondary separate RINKO oxygen sensor, fluorometer, transmissometer, upward and downward-looking LADCPs an underwater vision profiler (UVP), two upward-looking and one downward-looking Chi-POD. All 10 GO_BGC floats deployed had biochemical sensors. Along all transits, including those in Japanese waters, continuous underway shipboard multibeam bathymetry, TSG, met and pCO2 data were collected and a flow-through cytometer was run. The SADCP ran continuously. The EK-80 ran during each cast. There was also discrete underway sampling three times a day that included HPLC, POM, POC/N and DNA/RNA. Please see individual sections for further detail.

[1] Throughout "core" refers to the regular (GO-SHIP levels 1-2) sampling and "bio" refers to the biology sampling performed by the Bio GO-SHIP team. See Bio section of this report for the details on the bio sampling.

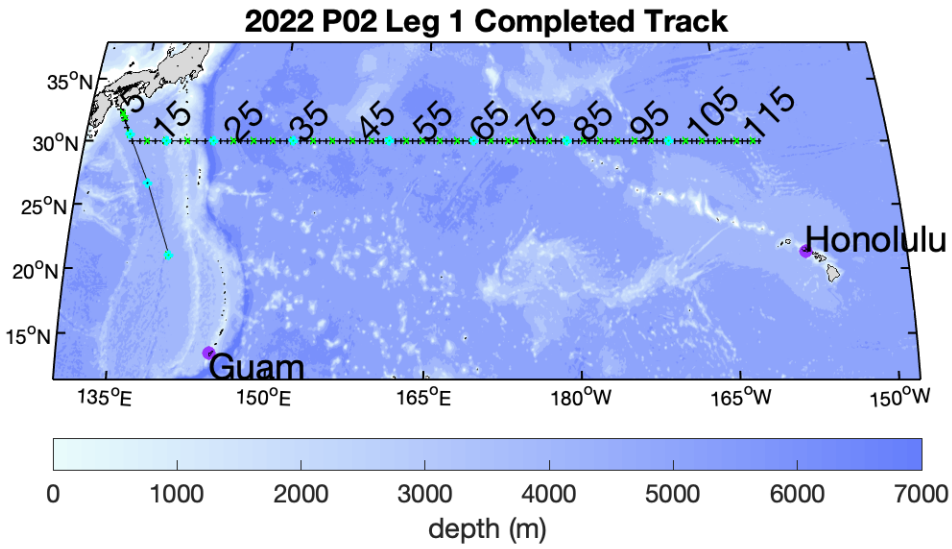

Fig. 1: Black crosses - for P02W 2022 station locations; green crosses - stations that included bio-only bottles and/or casts, cyan asterisks - GO-BGC float deployments; purple dots - departure (Guam, Navy Base) and arrival (University of Hawaii Pier, Honolulu) ports; and blue shading - 1 minute Smith and Sandwell bathymetry.

1.2 Programs and Principal Investigators

Program	Affiliation	Principal Investigator	Email
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1.3 Science Team and Responsibilities

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CHAPTER

TWO

CRUISE NARRATIVE

The 2022 re-occupation of P02W along 30°N in the Pacific was defined by a week-long delay, a quick start, a well-defined crossing of the Kuroshio and then its large loop, deep western casts including the Izu-Ogasawara Trench, and except for one post-Kuroshio wire re-termination, supported by a nearly continuous spell of calm weather and seas, no interruption to routine deployments and recoveries. Technical difficulties were generally minimal and short lived.

2.1 Quarantine, Delay and Transit

Most of the science party arrived in Guam by evening of April 9, glad to have the 20+ hours of masked flying time over. One person was unable to come due to a last-minute family emergency. A series of fortunate events led us to an eager young marine biologist from the University of Guam, who was willing to drop everything to join our Bio GO-SHIP team in the P02 pilot project that would include both bio-only casts and multiple underway measurements. We settled into quarantine by noon on the 11th. Amazingly, we managed to get 90% of our assorted multi-disciplinary/institutional/generational group to book rooms in the same hotel. This has allowed us (our co-chief Shuwen Tan did all the leg work) to set up group PCR testing prior to boarding without the necessity of leaving the hotel.

Most of the pre-cruise logistical issues revolved around a lack of cargo flights from Honolulu the week prior to our load. While most were sorted out prior to the original departure date (April 22), part of the CFC shipment was delayed until the day before our final departure of April 30).

One item of note is that on one of the cruises out Guam earlier this year a rosette was lost. However, after a thorough investigation and the setting up of new protocols and safety features, we were confident that our GO-SHIP 36-bottle rosette would not suffer the same fate.

While in quarantine we continued to follow the behavior of the Kuroshio as this would affect our final station plan (*Fig. 1*). We held daily virtual meetings with the students and held non-required all-hands meetings (check in was required). Our student led GO-SHIP/GO-BGC blog (can be accessed through either https://usgoship.ucsd.edu/blogs/ or https://www.go-bgc.org/expedition/north-pacific-2022/) and weekly reports (https://usgoship.ucsd.edu/2022/04/16/weekly-reports-from-2022-p02-leg-1/) were started.

After 7 days in COVID quarantine (April 11-17), the science party boarded the R/V Revelle for MOB (April 18-22) with the intention of departing on April 22 at 16:00 (local, 10 hours ahead of UTC). However, due to the ship's inability to hire a key member of the engineering department, the ship did not depart until 10:00 (local) on April 30th. As we could not leave the ship, our time was well spent setting up and for the students, learning about the equipment, waiting and dealing with the shipment delays, creating a new bracket for the ODF rosette so that the upward-looking LADCP could sit above the bottles and not be crushed by the CAST-6 (*Fig. 2*), and decorating the floats for schools which had adopted them. The R/V Revelle left the dock at 10:00 (local) on April 30. Once out of the Navy Harbor, we picked up two of our science party (who had not been able to gain access to the Navy Base) via launch before heading out into open waters.

The Revelle then steamed for ~2 days before reaching the first "test" station. It included 3 casts. The first, a dip to 20 m to fire all bottles. ODF, DIC, and bio took water from this cast to keep their equipment up and running over the 5-day transit. A second cast included both core and bio sampling, and the third cast was a float deployment. Because this

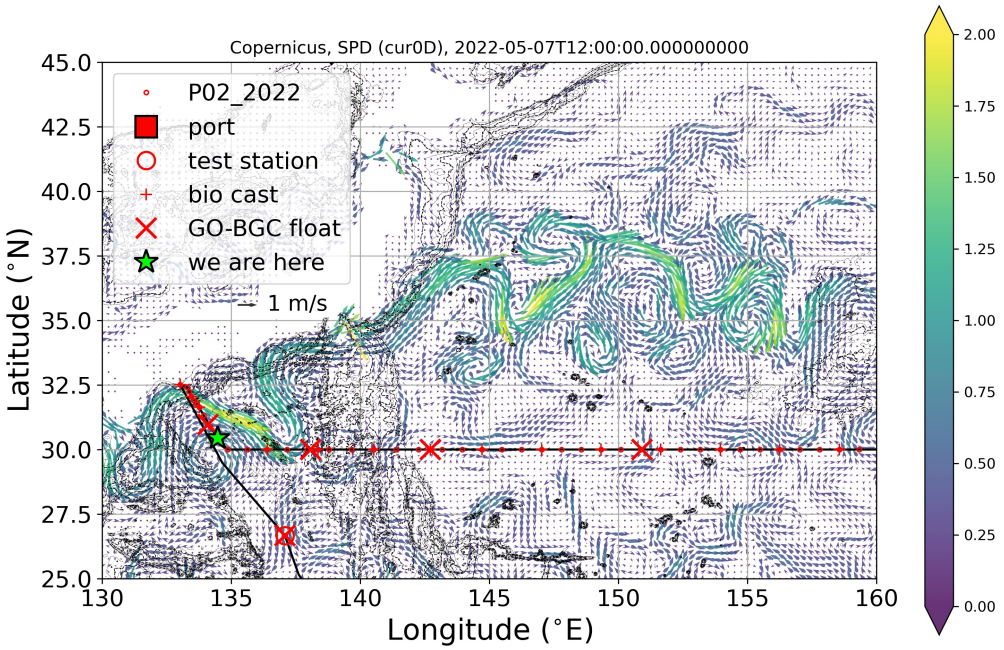


Fig. 1: The western end of the planned 2022 P02W track. Symbols represent station locations: Full-depth casts (red circles), with Bio 1000 m casts (red crosses), with GO-BGC float deployments (red "x"s). The green star represents the location of Station 11. Arrows represent the estimate of surface velocity from the Copernicus physical model for 5/07/22 12:00 UTC, the color shading indicates the amplitude of the surface velocity.

Fig. 2: Before (upper right) and after (upper left) views of the rosette illustrating the newly designed bracket (lower left panel) and it position protecting the rosette instrumentation as it docks with CAST-6 (lower right panel).

station included samples analyzed and saved in support of the GO-BGC float deployment it became Sta 1. It should be noted however that this is not a full-depth station. After slowing to deploy a second float while in international waters, sampling on the regular line began on May 5 at 32.507°N, 133.03°E (Sta 3).

2.2 Station Spacing and Sampling Details

The actual station spacing deviated from the planned spacing mainly due to the 8-day delay in port (a protracted wait to hire a key crew member), which then prematurely closed the requested window for sampling within Japanese waters. The close spacing coming southeast down the Japan slope was kept, but when not in steeply sloping bathymetry or frontal regions - spacing was first increased to 40 nm and then to 45 nm with one instance of 48 nm spacing. The slightly closer spacing was based on the hope that an EEZ clearance extension would be granted. The longer spacing occurred as the window of opportunity closed. Having occupied a station (Sta 22, 30.000°N, 142.256°E) on the western side of the Izu-Ogasawara Trench and with no extension in sight, the planned 6000 m station in the center of the trench was cancelled in favor of a location on the eastern side (Sta 23, 30.000°N, 143.177 °E). News of an extension came after the Sta 23 cast, only a few hours prior to the end of the original clearance, at which point spacing was reduced back to 35 nm. Still dealing with the reduced days at sea due to the original delay, 35 nm spacing was maintained until Sta 46 (30.000°N, 158.658°E), where upon it was reduced to the standard 30 nm. The only change to this spacing occurred at the Mercury Seamount (Sta 71-73, ~173.2°E) where the 2013 stations on either side were re-occupied and we included a shallow station at the peak in between (Sta 72).

The Bio team took rosette samples at approximately every third station on the line. At six stations (Sta: 1, 6, 11, 14, 17, and 20) in western waters where casts were less than 5000 m deep, these samples came from 12 rosette bottles (core sampling using the other 24). Beginning at the first 6000 m station (Sta 23) and every third station thereafter there was a separate 1000 m bio" cast, where 19 bottles were tripped (at 1000 m, 500 m, 200 m, 150 m, 2x100 m, 75 m, 40 m, and 11 x5 m or the "surface") for what became known as "standard bio". On the bio stations where floats were deployed (aka "float bio"), 20 bottles were tripped (at 1000 m, 500 m, 2x200 m, below the chlorophyll max (according to the fluorometer), 2 x the chlorophyll max, above the chlorophyll max, below the mixed layer, and 11 x 5 m or the "surface"). The bio casts took a little less than an hour to go down and up, and for the standard bio 20-30 minutes to sample and get back in the water. They became quicker as we became more proficient at sampling. Having the CTD watch assist was paramount to this efficiency and a sample cop was absolutely necessary to avoid mistakes. Float bio casts took 5-10 minutes longer because they were more complicated.

There were a total of 115 full water column casts that included CTD, Bullister bottle, fluorometer, transmissometer, and upward & downward-looking LADCP and Chi-PODS. The UVP ran for 114 of these. There were 33 separate bio-casts and another 6 casts (in waters less than 5000 m deep) that included 12 bio-only bottles and 24 core bottles. These combined casts required stricter use of water by both groups, but worked well without adding the extra time to the stations for bio-sampling and re-cocking & re-deployment of the rosette for a second cast (a savings of about 1.5 hours). It should be noted however, that including the bio-casts gave the other teams (particularly CFCS, DIC, and pH/TAlk) more time to analyze their data which meant that for the most part they were able to keep up if not full sampling on all 36 bottles, then at-least two-thirds sampling on every station.

Water samples (up to 36) were collected in 10 L Bullister bottles at all stations providing water samples for CFCs/SF_6, Total DIC, Total Alkalinity, pH, dissolved oxygen, nutrients, salinity, DOC, $DI^{13/14}C$. There was also discrete underway sampling three times a day that included HPLC, FCM, POM (POC, PON, POP, PCOD) and genetics (DNA/RNA). Underway surface pCO_2, temperature, salinity, dissolved oxygen, multi-beam bathymetry and meteorological measurements were collected. XBTs provided upper water column temperature profiles for calibration of the multi-beam on all days that CTD casts were not performed. With few exceptions, casts were made to within 10-12 m of the bottom. Note the exceptions are casts that were purposely made to 3-6 m in calm waters.

The standard three-station schema was used to choose sampling depths. These schema are designed to sample the full water column over a span of the three stations (e.g. if the first station trips bottles at 600 m and 700 m, the next will sample 635 m and 735m, the third 665 m and 765, and the rotation begins again with the fourth sampling 600 m and 700 m). Near the bottom the schema were manually manipulated to avoid gaps due to extremely flat or steeply sloped bathymetry. Particularly near the bottom, it is not necessary to be overly concerned about hitting these depths

exactly so unless the wire out is significantly different from the CTD depth, it can be used as the target. Closer to the surface where bottle trips are more narrowly spaced, correcting the target wire out to get the desired target depth can be beneficial to the overall consistency, but being off by a meter or two at 100 m is irrelevant. Surface bottle depth was defined by the res-tech on duty who would bring the rosette up to the "surface" for the last bottle trip. The goal is to cover the water column, not measure a specific set of depths (*Fig. 3*).

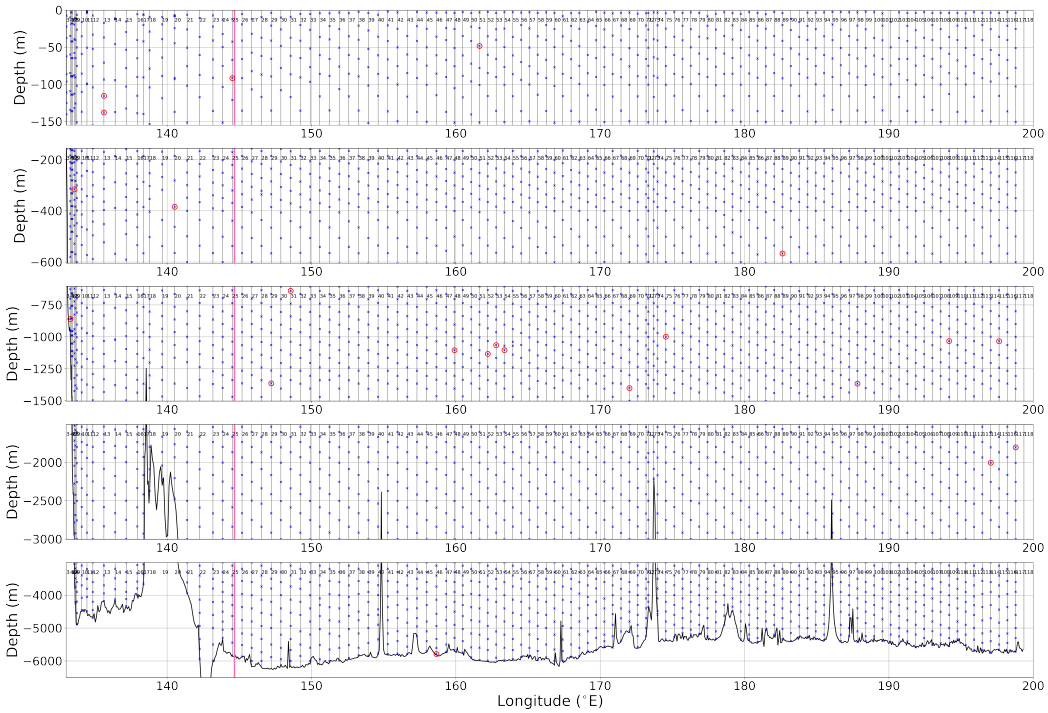


Fig. 3: Along-track bathymetry with P02 Leg 1 occupied stations 1-117 (numbered vertical lines). Five panel section plot indicating depth in meters of each of the bottles tripped (blue crosses). Red circles indicate bottles with problems (misfires, leaking, etc). The pink vertical line indicates the longitude of the eastern edge of the Japanese EEZ. From top to bottom panels represent depth ranges 0 to <150 m, 150 to < 600 m, 600 to < 1500 m, 1500 to 3000 m, and 3000 to 6000 m. (Image credit: Shuwen Tan).

For every deployment and recovery an entry from made in the UNOLS E-logger (https://www.unols.org/sites/default/files/R2R_EventLogger.pdf) that included the transect (P02W), the station # (SSS), the cast number (CC), the estimated depth from the Multibeam, the author id-name, and a possible comment. The E-logger software provided the date/time & position stamps. The event number that is made up of the UTC date (YYYMMDD) and time (HHMM), and a 3-digit extension was assigned by the software. For example: 20220608.1120.001 was the recovery of the Sta 117 cast on June 8th at 11:20 UTC. Had another operator on a different cruise entered an event at the exact same time it would have been given a different 3-digit extension. E-logger was used consistently for the casts and for turning the EK-80 on and off during casts. There are a few entries for the bio-underway samples, but these were not maintained consistently. On the console log sheet, the event number was written as MMDD.HHMM without the year or 3-digit extension (neither of which changed over the course of the cruise).

2.3 Sampling and Analysis Challenges

While the details of the lab and rosette issues are described and/or listed in the individual sections of this report, a few of the most notable are listed here.

Bullister 19 was a problem bottle. We found that it would trip but then find a balance point so it would not close. Then after various adjustments to the lanyard and raising it up, bottle 20 began periodically catching 19's lanyard, so that 20 would not close properly. We made an effort to adjust so as to avoid large gaps over the three-station schema rotation. Still, it was frustrating as these two bottles tended to close at the oxygen minimum.

The only truly notable data gap was when CFCs got behind for one two-day stint because of equipment failure (Sta 17-20 are missing CFC-11, CFC-12, SF_6 and N_2O). There are two short gaps in the pCO_2 data set that were caused by first equipment issues and secondly electrical issues in the lab. Please see the *pCO2 section* for discussion of the various water intakes on the *Revelle* and their associated temperatures (that go into the pCO_2 numbers). There is one full cast and 4 bio-casts where the transmissometer was purposely blacked out for calibration purposes. We lost one cast of UVP data due to corrosion and then a couple of others due to the battery's inability to handle both a bio cast and full cast in quick succession. Later (after May 25) due to a software issue, the UVP data while still being collected, could no longer be downloaded.

One particular misstep is noteworthy. In 2016, President Obama increased by presidential proclamation the footprint of the Papahanaumokuakea Marine National Monument to the seaward limit of the EEZ. However, this change appears to have never been updated in the current NOAA and Coast Pilot navigation charts used by the bridge or our UCSD personnel assisting us with clearance requests and permit. The net result was that while we thought we had closest point of approach of 90 nm, we instead occupied 16 stations, took numerous underway samples and other measurements and deployed float WMO# 5906516 within its boundaries. We were contacted by U.S. Fish & Wildlife Service National Wildlife Refuge System Division of Refuge Law Enforcement and after multiple conversations between them, Captain Galiher and the acting UCSD Marine Superintendent Eric Buck, and contact with the UCSD Port Captain Wes Hill, it was left as an "educational opportunity". The captain will follow-up to make sure that this change and any others are updated into the charts they use. The next occupation of P02W will have to acquire a permit for sampling in this region. Such a permit should be possible as scientific research is allowed, though whether there will be any restrictions we cannot tell at this juncture.

The cruise ended in Honolulu, Hawaii on June 10th, 2011, where the small amount deMOB activity occurred. All Leg 2 shipments also came aboard, ready for stowing. While crew turnover occurred on the 10th, most science party members stayed on the Revelle until June 11th for cross-over discussions with the members of the Leg-2 science party who were in quarantine in Honolulu and boarded on the 11th.

2.4 Acknowledgements

We would like to thank the officers and crew of the R/V *Revelle* who have gone above and beyond to welcome us and support the science on this expedition. They have worked with us every step of the way from handling the repercussions of the 8-day delay in port to seeing us through to the middle of the North Pacific with speed, alacrity and accuracy. Their efforts have included:

- Not just driving the ship (big thank you to the Bridge – to Captain Heather, for her care in bringing us onto station, to our 2nd Mate and Navigator Trey for his smooth sailing into station (and apparent joy at receiving new positions), and to Henry – whoa! and just how close are you to our specified position? Was that 3.1 cm?)
- Great conversations on the bridge assisting us with our station plan and EEZ gymnastics, creating a "plankton" flag, your noontime reports to JCG, handling that misstep with a marine preserve and finding the quickest route home (thank you for our early morning chats, Trey and Captain Heather)
- Running our winch through all hours of the day and night, providing some enjoyable radio chatter (thank you Bob, Joey, Jake, Feivel and Gomez; Gomez thank you too for the fantastic blog post and inspired artwork)

- Feeding us outstanding cuisine – an amazing variety of soups, taco Tuesdays, Sunday dinners, always a vegetarian option or two or three, an array of birthday cakes, muffins and cookies, and crème brulée after our last full day of sampling – we can't thank you enough Jay and Mark, and a great murmuring of thanks from the night-shift to Trey for bringing out 4 am delicacies.
- Burning those pesky insect-ridden float boxes (thank you Joe and Fievel), your care use of chemical products Joe and for everything else required after the winch work took over your labor force.
- Sorting out winch and wire challenges and fixing everything from the smallest detail to the greatest problems (the list is long here, big thank you to our res-techs Josh and Royhon, our Bosun Joe, our chief engineer Chance (love that bracket) and Harry as well as all the engineers for ship and equipment up and running).
- Thank you to our Chief Mate Michael for wonderful stories and sound advice and to all the other friendly faces in the passageways and mess: Daryl, Delvin, Jeffrey, Brian, Pete, and Bobby.
- Thanks to all of you from all of us for speeding us along so that we could sample the full line with minimal loss of data and have some fun while we were doing it.

We would also like to recognize the tremendous assistance we received from Hannah Delapp at UCSD and Sasaki Eriko at MOFA with sorting out the initial Japan clearance request (MSR), and then Hannah along with Junko Nagahama at the State Dept for making the extension possible. Lastly co-chief sci, Shuwen and chief sci, Alison would like to thank Natalie Freeman (who, although chosen, was unable to sail as co-chief for Leg 2) for her assistance with model output software and sending us weather and current updates, as well as Andreas Thurnherr, chief sci for Leg 2 for the fantastic pre-cruise discussion and collaboration. Best of good fortune, calm winds and following seas to Leg 2.

CHAPTER

THREE

PRELIMINARY SCIENCE REMARKS

3.1 Kuroshio Large Meander

Unlike 1994, 2004, and 2013 P02 occupations, the Kuroshio during the occupation of leg 1 was in its Large Meander (LM) status rather than in the mode where it takes a "straight" path following the coastline of Japan. This LM event started at the beginning of 2018 and still exists today (10th June 2022). This makes it the longest-lasting event in the eight LM events that have taken place since 1950, i.e., at least 4 years compared to a typical 1 to 2-year lifespan ([Qiu2021]). We were able to visualize the Kuroshio LM live thanks to the Ship-board ADCP (SADCP) UHDAS vector plots and sections that were updated every 5 mins. Qiu and Chen (2021) suggest that the persistence of Kuroshio LM is due to a constant feed of intense anticyclonic eddies shed from the Subtropical Countercurrent. During the period of Kuroshio-related occupation (May 4 to 7 UTC), an anti-cyclonic eddy located west of the Kuroshio LM was recognized in the Copernicus model data being sent to those on board (see Fig. 2 in the Narrative Section). Stations 9-12 (May 6) sampled the northeastern edge of that eddy (see Fig.1 and near the turn onto 30°N in Fig. 2). BGC-float was deployed at Station 11 on May 6.

3.2 Rough Topography: Izu-Ogasawara Ridge and the Mercury Seamount

In addition to repeating the previously occupied WOCE/CLIVAR stations, some stations in Leg-1 are intentionally adjusted to measure water properties near rough topography (Fig. 3: 018, 019, 073 on top of ridges/seamounts; 071, 072, 074 on the slopes). From LADCP data alone (preliminary results from Kurtis Anstey and interpretation by Andreas Thurnherr), we are excited to report prominent internal wave signals and features in turbulent dissipation rates (ϵ) that appear to be associated with rough topography. The former can be visualized from the periodic horizontal velocities throughout the water column (Fig. 4, 5). Large ϵ are found above 1500 m at stations on top of ridges/seamounts and bottom-intensified ϵ are found on the slope of the seamount (station 072).

3.3 EK-80 Remarks

The Simrad EK-80 fisheries sonar (https://www.simrad.online/ek80/ref_en/default.htm) has been turned on during the deployment of both bio casts and core casts throughout the cruise. Thanks to the real-time display, identifying and interpreting interesting features has become a source of great interest for many in the computer lab. Fascinating features including Kelvin-Helmholtz billows (Fig. 6), internal waves at the thermocline, and internal waves in the wake of the ship were identified, and other unidentified phenomena were archived as screenshots. The EK-data from the cruise will also be archived.

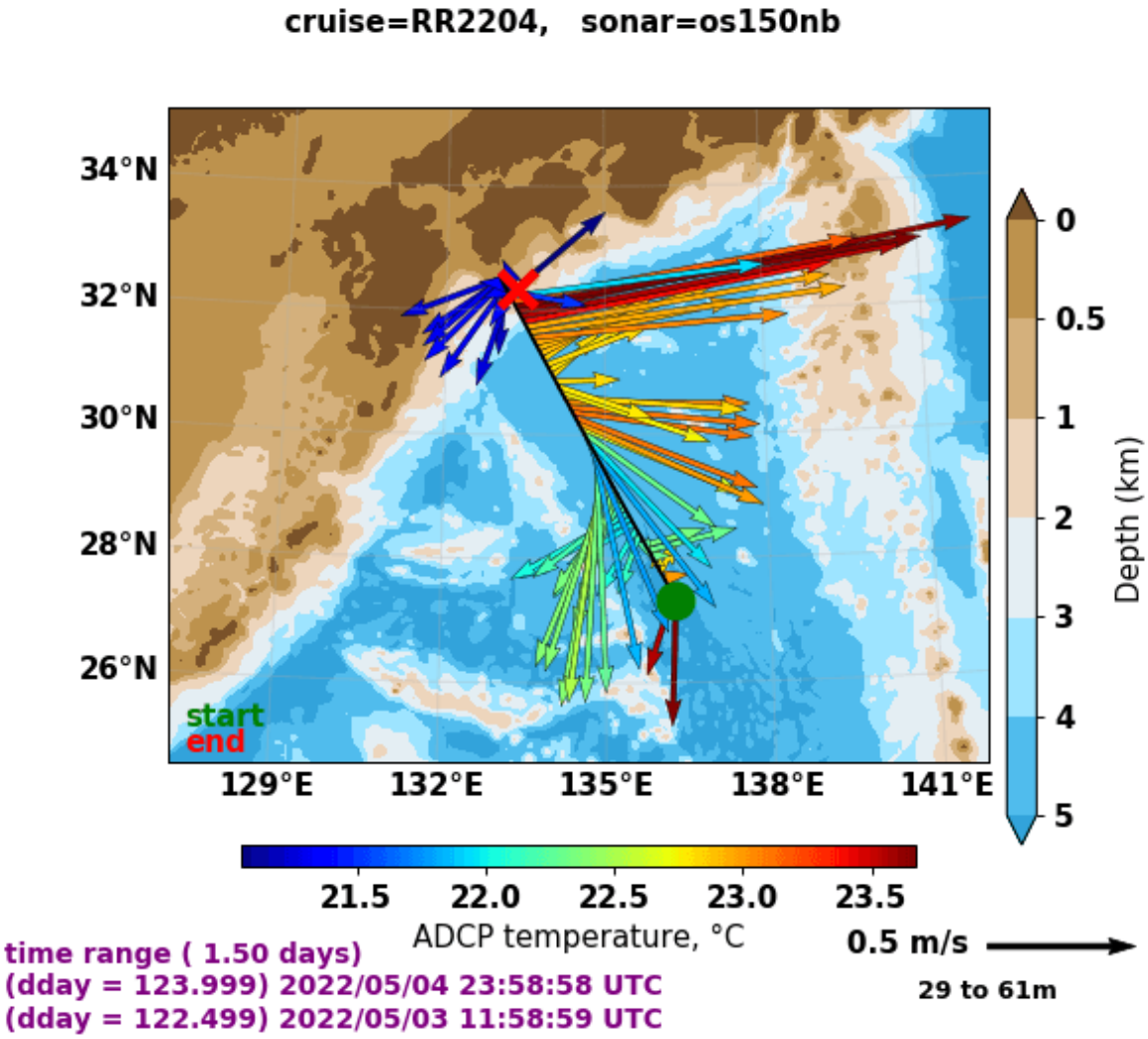


Fig. 1: SADCP-based surface (29 m to 61 m average) current velocities (arrows) and temperature (colormap) during the period of May 3th-4th (during transit to Sta 3). Dark red arrows north of 31.2°N and near 137°E indicate the warm and rapid Kuroshio and its deviation from the coastline. (Source: UHDAS 5-mins surface vector plot, University of Hawaii UHDAS system, https://currents.soest.hawaii.edu/uhdas_fromships.html)

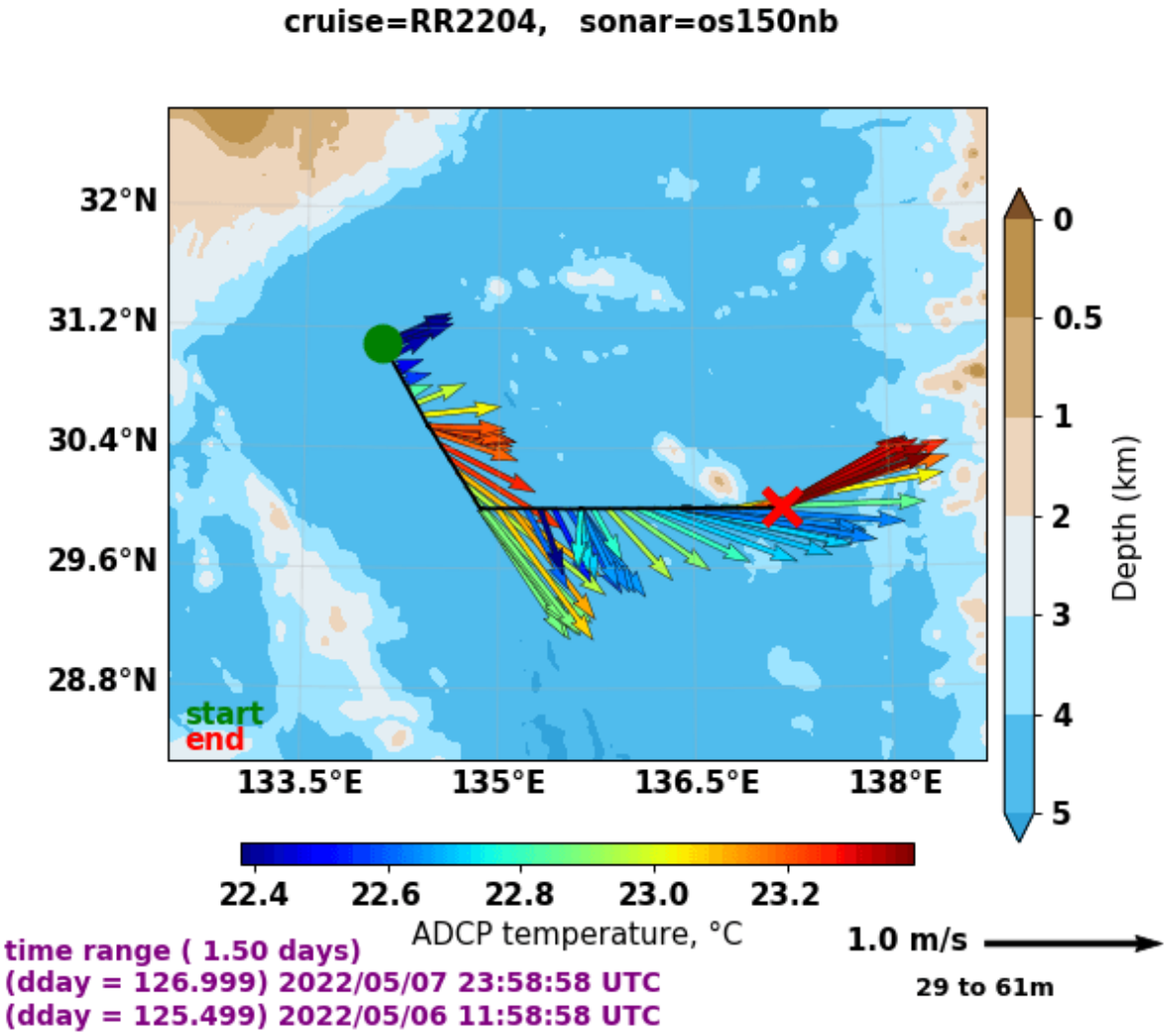


Fig. 2: SADCP-based surface (29 m to 61 m average) current velocities (arrows) and temperature (colormap) during the period of May 6th-7th (coming down the slope and turning eastward).

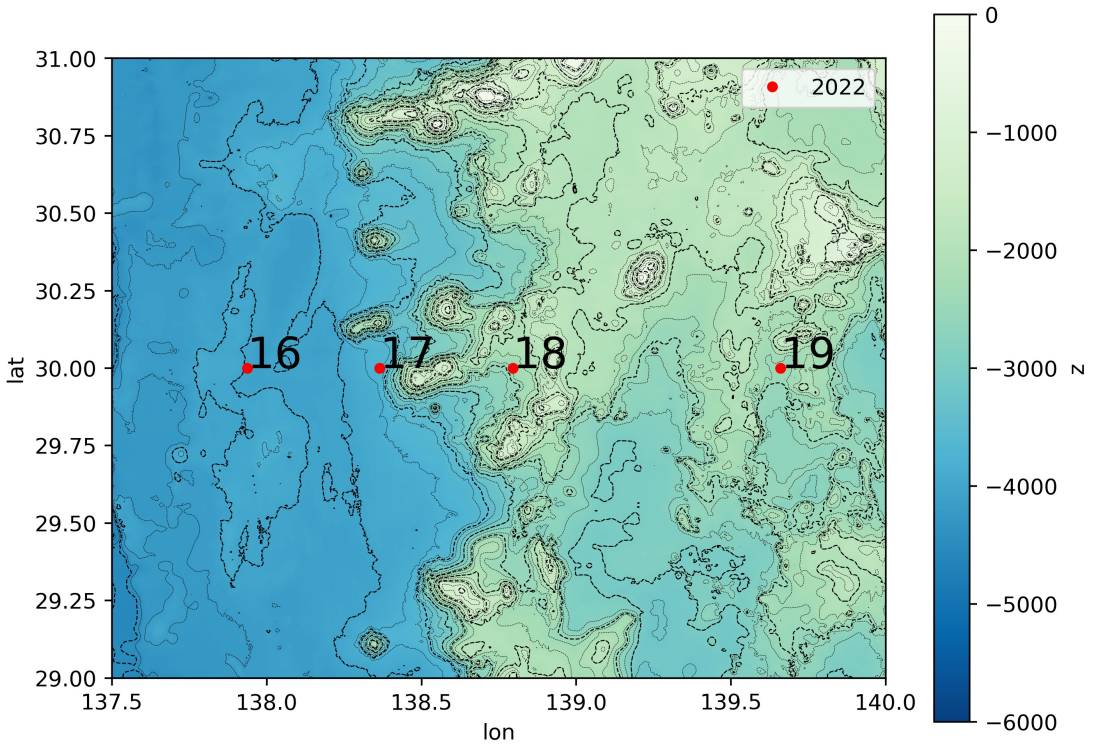


Fig. 3: Map of station locations over the western part of the Izu-Ogasawara Ridge overlaid on the SRTM 15 arcsecond bathymetry profiles of the turbulent kinetic energy dissipation rate ([Tozer2019]).

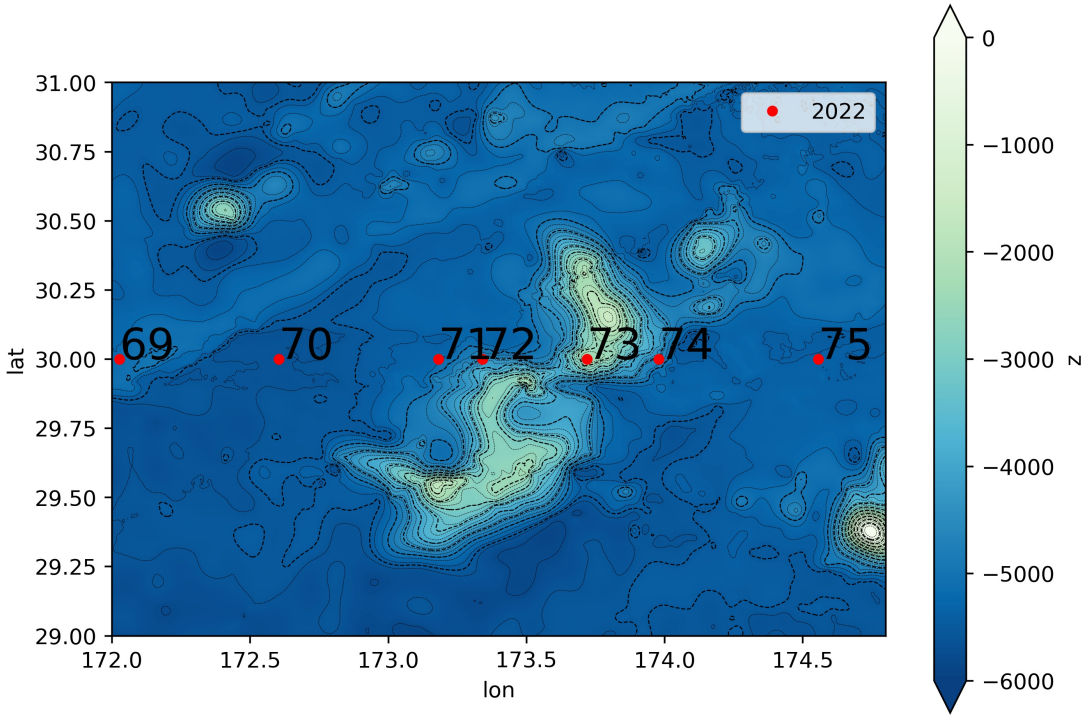
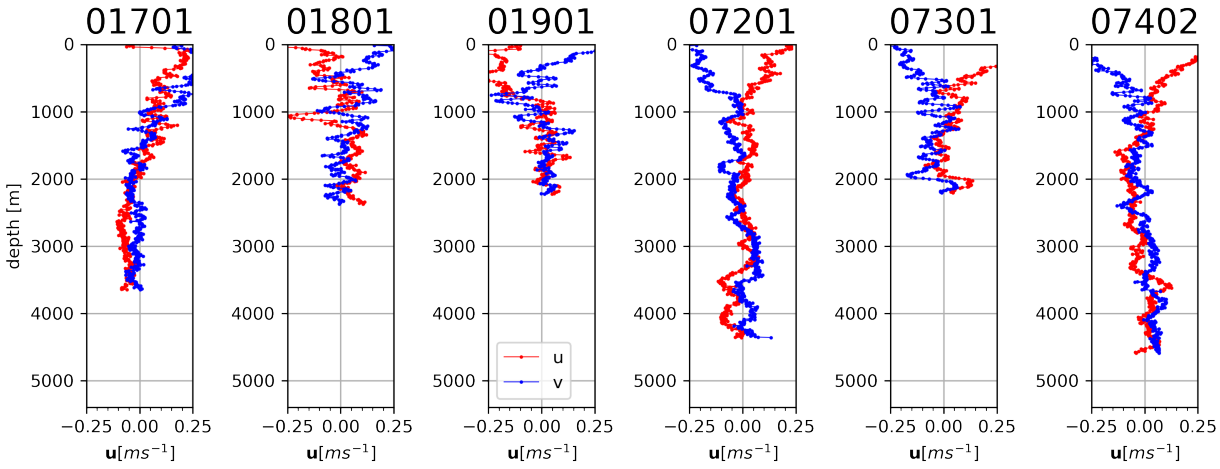


Fig. 4: Map of station locations near the Mercury Seamount located northwest of the Hawaiian Ridge overlaid on the SRTM 15 arcsecond bathymetry profiles of the turbulent kinetic energy dissipation rate ([Tozer2019]).



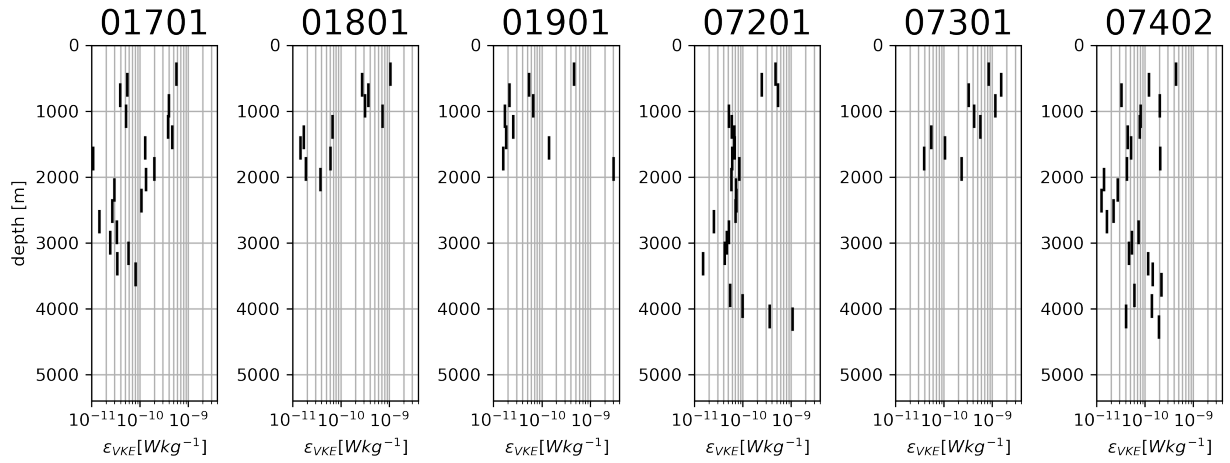


Fig. 5: Horizontal velocities from LADCP measurements at the four stations (the 01 and 02 values after the station numbers enumerate the cast). (Image credit Shuwen Tan).

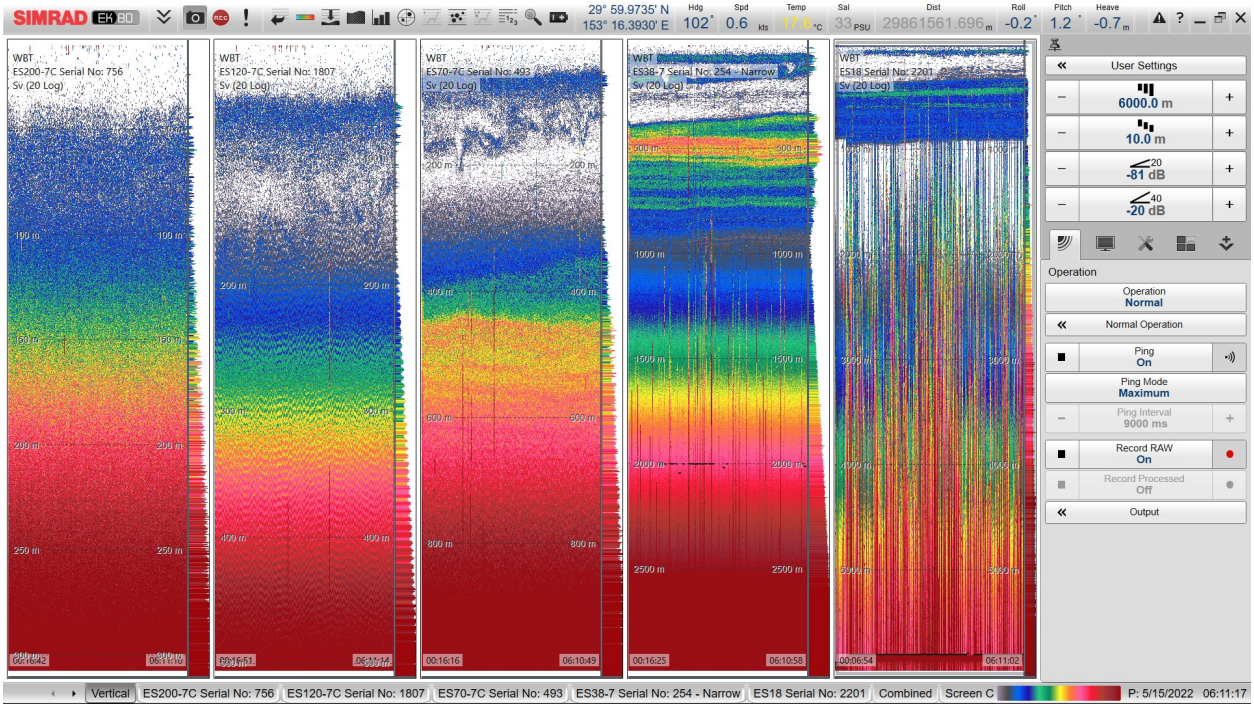


Fig. 6: Simrad EK-80 monitor output (x-axis is time, y-axis is depth) during Station 38 which had two casts on 1430-2030 May 15 (local time = UTC+11). The subpanels show results from different frequencies which translate into resolution of different depth ranges from left to right a) ES200 0-300, b) ES120 0-500, c) ES70 0 -1000, d) ES38 0-3000 and e) ES18 0-bottom. (Image Credit: UCSD Shipboard Technical Services).

3.4 North Pacific Mode Water

North Pacific Subtropical Mode Water (NPSTMW) is formed to the east/south of Kuroshio/Kuroshio Extension in the late winter and early spring. Subducted, it tends eastward, and like all mode waters is well mixed and is therefore recognizable by its low potential vorticity (see band of purple to blue colors centered at about 200 m in the upper panels of Fig. 6). In the North Pacific, there is an Eastern Subtropical Mode Water as well. With overlapping characteristics, the two are distinguished as existing to the east and west of the date line (180° longitude lies almost directly under the "o" in the title word "Vorticity"). NPSTMW is only one of several mode waters formed in the northwestern Pacific which is an area rich frontal zones and meteorology conducive to mode water formation. Here one can see the high PV in the region of the Kuroshio and its meander reaching down to 600-700 m. The latter is particularly strong in 2022 (upper panel, see Section 1 above discussion the meander dynamics). In both years, NPSTMW reaches to about 400 m, the expected depth of winter mixing according to the literature, and as expected. These waters rise as they cross the basin eastward. That said, the character of the NPSTMW layer as well as the water above seem different in the two occupations. While this may be an actual difference, it seems likely that the low 2013 station spacing (even lower than in 2012) may be playing a role in creating this apparent difference. Time of year may also be a factor as the 2022 occupation began nearly a full month later at a sensitive time of year for this water mass. We note that radiocesium isotopes originating from the Fukushima Dai-ichi Power Plants and measured on the 2013 occupation suggest that the NPSTMW at 161°E (~ 2700 km) is no more that 2 years old ([Yoshida2015]).

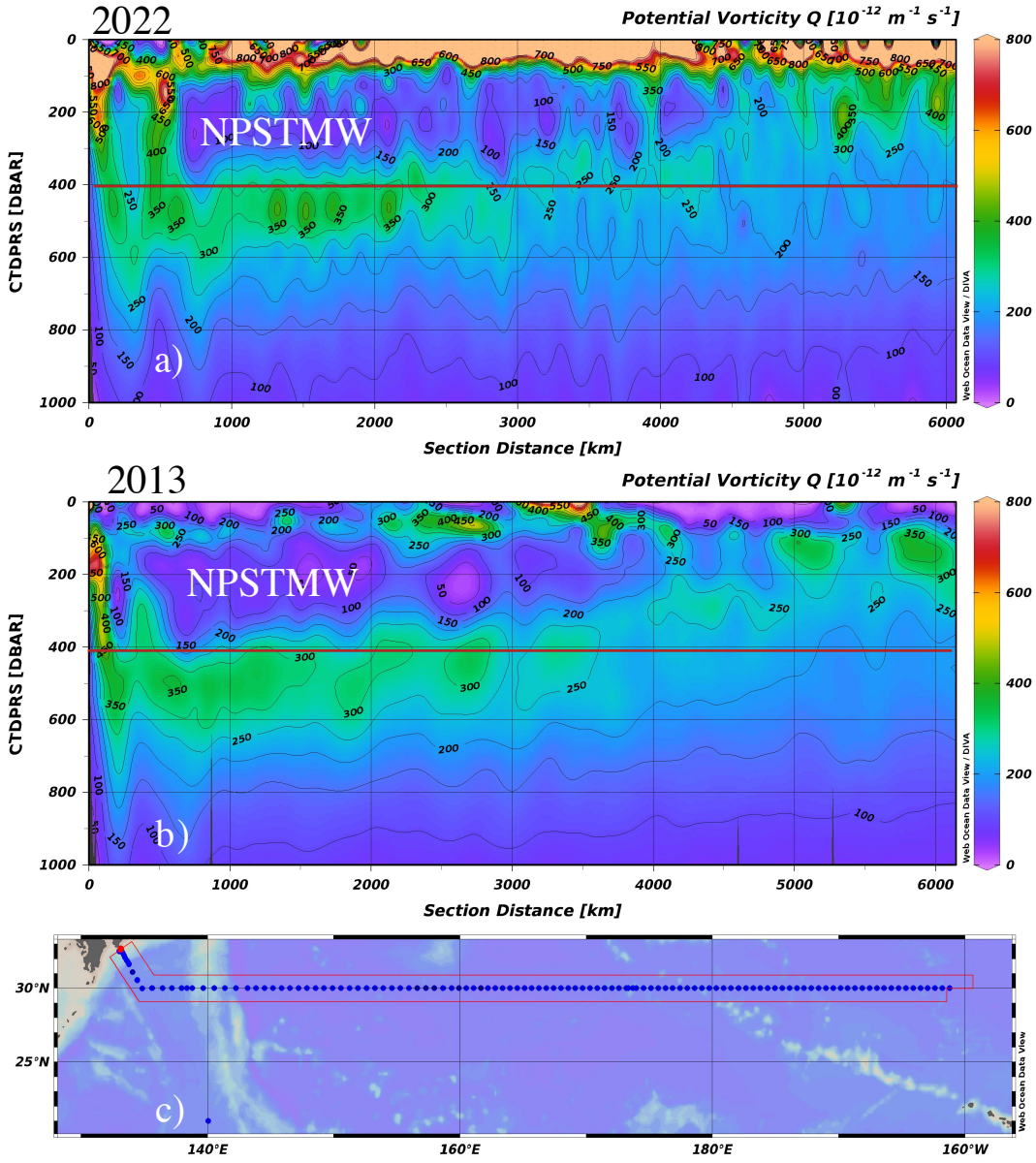


Fig. 7: Potential Vorticity (units 10^{-12} m^{-1} s^{-1}) sections for the upper thousand meters for 2022 stations 3-117 (upper panel) and the station covering the same distance (6067 km) from the first station for the 2013 occupation (middle panel). The lower panel illustrates the 2022 stations included. (Image created using Web Ocean Data View 5.4.5, web server 28)

CHAPTER

FOUR

CTD AND ROSETTE SETUP

For P02W-2022 a *SIO STS* 36-place yellow rosette and bottles were used. The rosette was sent to Guam in early January, 2022. The rosette and bottles were built before P06 2017, making this the thirteenth time this package has been deployed. A steel bridle was added to the top of the rosette to adapt to the winch head. The bottles were made with new PVC, with new non-baked o-rings and electro-polished steel springs. Springs within the Bullister-style Niskin bottles were electropolished stainless steel. Bottle lanyards were made from 300-pound monofilament. No sample contamination has been noticed by the change in o-rings and springs. The package used on P02W-2022 weighs roughly 1500 lbs in air without water and 2350 lbs in air with water. The package used on P02W-2022 weighs roughly 950 lbs in water. In addition to the standard *CTDO* package on GO-SHIP cruises three chipods, two *LADCP*, and one *UVP* were mounted on the rosette.

During the cruise we encountered a handful of problems, most notably noise between the primary and secondary CTD lines. We describe all of the above in more detail in the sections below.

4.1 Underwater Sampling Package

CTDO/rosette/LADCP/UVP/chipod casts were performed with a package consisting of a 36 bottle rosette frame, a 36-place carousel and 36 Bullister style Niskin bottles with an absolute volume of 10.6 L. Underwater electronic components primarily consisted of a SeaBird Electronics housing unit with Paroscientific pressure sensor with dual plumbed lines where each line has a pump, temperature sensor, conductivity sensor, and exhaust line. A SeaBird Electronics membrane oxygen sensor was mounted on the "primary" line. A reference thermometer, RINKO oxygen optode, transmissometer, chlorophyll-a fluorometer, and altimeter were also mounted on the rosette. Chipod, LADCP, and UVP instruments were deployed with the CTD/rosette package and their use is outlined in sections of this document specific to their titled analysis.

CTD and cage were horizontally mounted at the bottom of the rosette frame, located below the carousel for all stations. The temperature, conductivity, dissolved oxygen, respective pumps and exhaust tubing was mounted to the CTD and cage housing as recommended by SBE. The reference temperature sensor was mounted between the primary and secondary temperature sensors at the same level as the intakes for the pumped temperature sensors. The transmissometer was mounted horizontally on the lower LADCP brace with hose clamps, avoiding shiny metal inside that would introduce noise in the signal. The hose clamps for the transmissometer were covered in black electrical tape. The oxygen optode, fluorometer, and altimeter were mounted vertically inside the bottom ring of the rosette frames, with nothing obstructing their line of sight. One 300 KHz bi-directional Broadband LADCP (RDI) unit was mounted vertically on the bottom side of the frame. Another 300 KHz bi-directional Broadband LADCP (RDI) unit was mounted vertically on the top side of the frame. The LADCP battery pack was also mounted on the bottom of the frame. The LADCP and LADCP battery pack were mounted near (90°) each other at the beginning of the cruise. Imagining the now of the ship to be north, the LADCP battery was mounted on the south side of the rosette, the up/down LADCPs were on the west side, the UVP on the east, and CTD mounted to the north.

Equipment	Model	S/N	Cal Date	Stations	Group
Rosette	36-place	Yellow	–	1-117	*STS*/*ODF*
CTD	SBE9+	1281	–	1-117	*STS*/*ODF*
Pressure Sensor	Digiquartz	136428	Dec 7, 2021	1-117	*STS*/*ODF*
Primary Temperature	SBE3+	35046	Mar 2, 2022	1-8	*STS*/*ODF*
Primary Temperature	SBE3+	34941	Mar 9, 2022	9-40	*STS*/*ODF*
Primary Temperature	SBE3+	36049	Mar 17, 2022	41-117	*STS*/*ODF*
Primary Conductivity	SBE4C	43578	Mar 22, 2022	1-117	*STS*/*ODF*
Primary Pump	SBE5	51892	–	1-41,51-117	*UCSD*
Primary Pump	SBE5	53626	–	41-50	*UCSD*
Secondary Temperature	SBE3+	34941	Mar 9, 2022	1-8	*STS*/*ODF*
Secondary Temperature	SBE3+	36018	Mar 3, 2022	9-40	*STS*/*ODF*
Secondary Temperature	SBE3+	34138	Mar 17, 2022	41-117	*STS*/*ODF*
Secondary Conductivity	SBE4C	42569	Mar 17, 2022	1-117	*STS*/*ODF*
Secondary Pump	SBE5	51871	–	1-42	*UCSD*
Secondary Pump	SBE5	58692	–	42-50	*UCSD*
Secondary Pump	SBE5	53626	–	51-117	*UCSD*
Transmissometer	Cstar	1873DR	Jan 5, 2022	1-117	*TAMU*
Fluorometer Chlorophyll	WetLabs ECO-FL-RTD	4334	–	1-117	*STS*/*ODF*
Dissolved Oxygen	SBE43	430060	Mar 15, 2022	1-32	*ODF*
Dissolved Oxygen	SBE43	430185	Mar 15, 2022	32-93	*ODF*
Dissolved Oxygen	SBE43	431508	Oct 8, 2021	94-117	*ODF*
Oxygen Optode	JFE Advantech Rinko-III	0296	Apr 7, 2017	1-10	*ODF*
Oxygen Optode	JFE Advantech Rinko-III	0251	Apr 7, 2017	11-117	*ODF*
Reference Temperature	SBE35	0105	Mar 15, 2022	1-117	*STS*/*ODF*
Carousel	SBE32	1178	–	1-117	*STS*/*ODF*
Altimeter	Valeport 500	53821	–	1-117	*UCSD*
UVP	–	201	–	1-117	*UAF*
Chipods	Chipod	2014 Ti44-8	–	1-117	*OSU*
Chipods	Chipod	2013 TI44-12	–	1-117	*OSU*
Chipods	Chipod	2032 Ti44-15	–	1-117	*OSU*

4.2 Winch and Deployment

The CAST6 winch and deployment system was used for all stations. The rosette system was suspended from a UNOLS-standard three-conductor 0.322" electro-mechanical sea cable. The sea cable was terminated with an Evergrip (primary), Guy Grip (secondary), and set of Crosby Clips (tertiary). No electrical issues occurred on P02W. There were continuous issues with wire twist and had to "move up" the termination 3 times during the cruise.

The deck watch prepared the rosette 10-30 minutes prior to each cast. The bottles were cocked and all valves, vents, and lanyards were checked for proper orientation. Any biofouling noted was cleaned off the outside of the rosette before the next cast, and the inside of the bottles were checked for biofouling and sprayed down. LADCP technician would check for LADCP battery charge, prepare instrument for data acquisition, and disconnect cables. Once stopped on station, the Marine Technician would check the sea state prior to cast and decide if conditions were acceptable for deployment. The rosette was moved from the sampling bay out to the deck using the *Revelle's* tugger-driven cart. Once on deck, sea cable slack was pulled up by the winch operator. CTD watch standers would then turn on the deckbox and begin data acquistion, and the cast would begin. Recovering the package at the end of the deployment was the reverse of launching. Once rolled back into the sampling bay, a technician secured the cart to the deck using additional ratchet straps. The carousel was rinsed and sensors were cleaned (as described below) after every cast, and then samplers were allowed to begin collecting water.

Fig. 1: Package sensor setup from south.

Fig. 2: Package sensor setup from east.

Fig. 3: Package sensor setup from north.

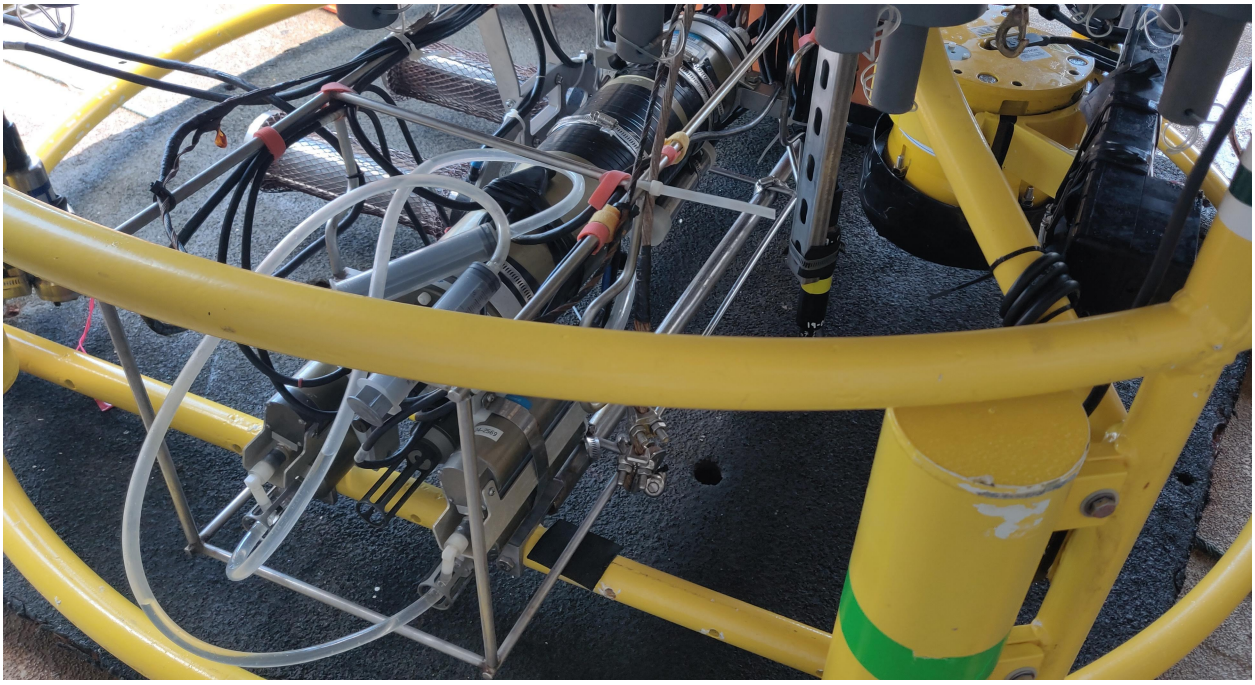


Fig. 4: Package setup from southwest, from left to right: CTD cage, downward facing chipod, downward facing LADCP, transmissometer bar.

Fig. 5: Package setup from southwest, from left to right: (Foreground) ECO fluorometer, UVP, RINKO, altimeter.

Fig. 6: Package setup from west.

Fig. 7: Package setup from west, top view.

4.3 Maintenance and Calibrations

During P02W-2022 routine maintenance was done to the rosette to ensure quality of the science done. Actions taken included rinsing all electrical instruments on the rosette down with fresh water after each cast and adjusting hose clamps and guide rings as needed such that lanyards had appropriate tension. Care was taken not to rinse the spigots and other parts of the bottle that might be touched by samplers in order to not contaminate the samples. After each cast, syringes of fresh water were connected to the plumbed lines to rinse the sensors and allow them to soak between casts. While in freezing conditions, water was drained after rinse to avoid freezing in the plumbing. Overhead heaters recently installed on the Thompson were run while in freezing or near-freezing conditions. The rosette was routinely examined for valve and o-ring leaks, which were maintained as needed. SBE35RT temperature data was routinely downloaded each day.

Every 20 stations, the transmissometer windows were cleaned and on deck blocked and un-blocked voltage readings were recorded prior to the cast. The transmissometer was also calibrated before the start and after the end of science operations.

4.4 Logs

In port: Preparation of the CTD and rosette was minimal as it had nearly the same setup as A20 2021, which had just been completed. UVP arrived in St. Thomas and was mounted opposite the ADCP. Downlooking chipod mounting pole was swapped out to allow the sensor to be closer to the leading edge of the rosette. Additional integrity checks on the rosette, such as checking lanyard angles, o-ring and lanyard replacement, and spigot movement waited until being underway to be checked as lower priority tasks. We are using a new mounting system for the downward looking LADCP which has the LADCP clamped facing inward instead of outward, which will cause problems if we need to change that LADCP in rough weather.

May 1, 2022

00101 - Test station to 20 m. Fired 36 bottles.

00102 - Test station to 1504 m. UVP turned on and voltage spikes were confirmed as real. Bottle 6 misfired at console.

00201 - Float deployed. CTD cast abandoned to save time.

May 4, 2022

00301 - Shallow 160 m cast with only 10 bottles to fire. Up-facing chipods were loose. Tightened hose clamps.

00401 - Bottle #2 o-ring broke on top vent upon recovery. Replaced.

May 5, 2022

00501 - No issues noted.

00601 - No issues noted.

00701 - No issues noted.

00801 - Primary temperature static to unrealistic value around 3150 m during upcast. Swapped T1 with T2 and replaced bad sensor. Spigot pins on bottles 6, 8 were bent and were straightened on recovery.

00901 - Alarms went off in computer lab approximately 5 minutes into 20 m soak. Deck box reading 1110, rather than normal 0110/0111. Recovered CTD and checked external wiring.

00902 - Alarms went off prior to contact with the surface. Reterminated end of cable upon recovery.

May 6, 2022

00903 - Alarms went off before reaching 20 m soak depth. Replaced sea cable upon recovery. Covered new T2 sensor with dummy plug.

00904 - Restech checked deckbox connections in computer lab and confirmed they were loose. Deployed with dummy on T2 to soak depth with no alarms and continued to approx. 4200 m. Connected T2 upon recovery and tested on deck.

01001 - Abnormal behavior on RINKO serial 0296, upcast and downcast do not match each other or the SBE43. SBE35 hit cap on internal storage and reference temperatures were not recorded. Replaced RINKO 0296 with S/N 0251 following recovery.

May 7, 2022

01101 - UVP battery exploded. Cable changed out and other damaged materials replaced. SBE35 hit cap on in ternal storage and references temperatures were not recorded.

01201 - RINKO 0251 spiking to 0 V during both down and upcasts. Replaced RINKO cable upon recovery. Data logging accidently ended pematurely during recovery. Turned back on for on-deck pressure.

May 7, 2022

01301 - No issues noted, new RINKO cable solved spiking behavior.

01401 - No issues noted.

01501 - No issues noted.

May 8, 2022

01601 - No issues noted.

01701 - “Fire bottle” button pressed 37 times in SeaSave, final button press at the surface.

01801 - No issues noted.

01901 - Paused approximately 100 m from seafloor waiting for restech assistance.

May 9, 2022

02001 - No issues noted.

02101 - No issues noted.

02201 - No issues noted.

May 10, 2022

02301 - Bio cast. No issues noted.

02302 - No issues noted.

02401 - No issues noted.

02501 - No issues noted.

May 11, 2022

02601 - Bio cast. No issues noted.

02602 - UVP voltage was static or unresponsive beyond ~1500 m.

02701 - Restechs observed significant spinning during recoveries and wrapped ~10 m of cable within the inside of the rosette to reduce spinning.

02801 - Replaced o-ring on bottle 10 valve and used hose clamps to secure slack cable to inside of rosette and away from lanyards.

May 12, 2022

02901 - Bio cast. Dark cast. Observed top caps of bottles 16 and 34 catching on lanyards of bottles 17 and 35, respectively. Lowered 16, 34, and raised 35. Replaced cracked spigot washer on bottle 9.

02902 - Tape left on transmissometer from dark cast. UVP voltage static or unresponsive below ~1700 m. Confirmed to be a battery problem associated with insufficient charge following bio casts. Bottle 16 was too low and caught on rosette frame. Raised bottle 16.

03001 - No problems noted. UVP operational as normal.

03101 - Raised bottle 17 to reduce chance of catching on bottle 16.

May 13, 2022

03201 - Bio cast. Bio fouling event and recovered to clean off sensors.

03202 - Bio cast. Primary and secondary CTD lines had noisy offsets during soak period.

03203 - Primary and secondary CTD lines had noisy offsets during soak period. Noticed significant noise and changes in SBE43 baseline during upcast. Changed SBE43 sensor out when recovered. Reterminated winch cable due to kink during recovery.

03301 - Primary and secondary CTD offsets improving. New SBE43 still noisy, but no changes in baseline.

03401 - No issues noted.

May 14, 2022

03501 - Bio cast. No issues noted.

03502 - SBE43 a little noisy after 1200 m.

03601 - No issues noted.

03701 - Adjusted guide rings on bottles 2, 31.

May 15, 2022

03801 - Bio cast.

03802 - No issues noted.

03901 - No issues noted.

04001 - Primary and secondary offsets significantly noisy and spiky. Recovered CTD and tested pumps. Replaced secondary temperature sensor.

04002 - Primary and secondary offsets still noisy. Recovered CTD, tested pumps, and replaced primary temperature sensor.

04003 - Offsets still noisy at soak depth. Deployed regardless and noise dissapated by 150 m depth. Noise may have been related to ship heave and pycnocline depth.

May 16, 2022

04101 - Bio cast. Noisy soak.

04102 - Noisy soak. Replaced primary pump to attempt to remedy soak noise.

04201 - Chipod 14-32 (top) had popped loose and flooded. Replaced with 14-36. Replaced secondary pump to attempt to remedy soak noise. Bottom spring to cap connection broke on bottle 6. Crimped new line and reattached cap prior to 04301.

04301 - No issues noted.

May 17, 2022

04401 - Bio cast. Crimp on bottom of bottle 6 failed. Reattached spring with knot.

04402 - No issues noted.

04501 - Bottle 19 suspected of mistrip.

04601 - No issues noted.

May 18, 2022

04701 - Bio cast.

04702 - Valve o-ring broken on bottle 1.

04801 - Bottle 19 confirmed to be mistripping on 04501 and 04801. Raised bottle 19 for better lanyard angle with carousel.

04901 - Bottle 19 fired. SBE43 noisy around 4000 m.

May 19, 2022

05001 - Bio cast. Soak is still noisy. Replaced primary pump.

05002 - Soak is still noisy. Replaced secondary pump.

05101 - Replaced o-rings on bottles 4, 6, 11, 12, 16, 20, 23, 26, 27. RINKO was loose.

05201 - Primary and secondary offsets noisy and spiky up to 30 m. Bottle 19 suspected of mistrip.

May 20, 2022

05301 - Bio cast. Bottles not fired sequentially.

05302 - No issues noted.

05401 - Bottle 19 came up empty. Changed out carousel latch. Raised bottle 19 to highest position possible.

05501 - No issues noted.

May 21, 2022

05601 - Bio cast. Changed pump Y cable to attempt to improve temperature and conductivity offsets.

05602 - No change in soak noise.

05701 - UVP suspected of slipping.

05801 - No issues noted.

05901 - Bio cast. No issues noted.

May 22, 2022

05902 - No issues noted.

06001 - No issues noted.

06101 - No issues noted.

06201 - Bio cast. Dark cast. Grease on vent of bottle 24 when recovered.

May 23, 2022

06202 - No issues noted.

06301 - No issues noted.

06401 - Bottle 16 accidently fired at 1615 m while CTD was moving.

06501 - Bio cast. No issues noted.

06502 - No issues noted.

May 24, 2022

06601 - No issues noted.

06701 - No issues noted.

06801 - Bio cast. No issues noted.

06802 - No issues noted.

May 25, 2022

06901 - Bottle 16 came up empty. Lower cap caught on rosette frame. Raised bottle 16 to ensure better closure.

07001 - Rinsed lower 600 m of winch wire upon rosette recovery.

07101 - Bio cast. No issues noted.

07102 - Biofouling event but sampling and CTD data look normal.

May 26, 2022

07201 - Spigot on niskin 33 replaced after sampling as it was suspected of leaking when subsampled.

07301 - No issues noted.

07401 - Bio cast.

07402 - Spiky offsets in primary and secondary CTD lines during downcast.

07501 - Lanyard of bottle 19 caught in top of bottle 20. Remade lanyard.

May 27, 2022

07601 - No issues noted.

07701 - Bio cast. No issues noted.

07702 - No issues noted.

07801 - No issues noted.

07901 - No issues noted.

May 28, 2022

08001 - Bio cast. No issues noted.

08002 - Cast delayed 10 minutes due to personnel miscommunication.

08101 - Considerable difference between upcast and downcast in oxygen sensors.

08201 - No issues noted.

May 29, 2022

08301 - Bio cast. No issues noted.

08302 - No issues noted.

08401 - Complaints of tightness on bottle 10 spigot. Replaced spigot with no signs of problems in old o-rings.

08501 - Spiked in offsets between primary and secondary CTD sensors at depths of 700 - 1240 m.

May 30, 2022

08601 - Bio cast. Spigot on bottle 13 was hard to depress and was replaced after sampling.

08602 - No issues noted.

08701 - No issues noted.

08801 - No issues noted.

08901 - Bio cast. Replaced spigot on bottle 6. Offsets in primary and secondary CTD sensors were noisy and spiky.

08902 - Bottle 24 not sealed upon recovery due to collision with top bar. Lowered bottle 24 1/4" after sampling.

May 31, 2022

09001 - No issues noted.

09101 - No issues noted.

09201 - Bio cast. Dark cast. No issues noted.

09202 - No issues noted.

June 1, 2022

09301 - SBE43 noisy at depths exceeding 800 m. Changed SBE43 out when recovered.

09401 - Bottle 19 lanyard caught in top of bottle 20. Remade lanyard. Biofouling on bottles 10 - 13. New SBE43 still noisy at depth.

09501 - Bio cast. No issues noted.

09502 - SBE43 noisy at depths exceeding 800 m. Changed SBE43 cable out when recovered.

09601 - No issues noted.

June 2, 2022

09701 - No issues noted.

09801 - Bio cast. Significant noise in CTD primary and secondary sensors at soak depth.

09802 - Bottle 16 came up warm (8 degrees warmer than it should have), suggesting mistrip. Raised bottle 16 and 17 to ensure bottle 16 closed and did not get caught in lanyard of 17.

09901 - No issues noted.

June 3, 2022

10001 - No issues noted.

10101 - Bio cast. No issues noted.

10102 - SBE43 noisy after 800 m during downcast.

10201 - Bottle 30 accidently skipped, with bottle 31 fired at 30's intended depth.

June 4, 2022

10301 - No issues noted.

10401 - Bio cast. Offsets in primary and secondary CTD sensors became very spiky at 500 m during upcast. Adjusted secondary pump height upon recovery.

10402 - Adjusted heights and orientations on bottles 1, 4, 20. Adjusted guide rings on 1, 31, and 33.

10501 - SBE43 is less noisy than rest of cruise.

10601 - No issues noted.

June 5, 2022

10701 - Bio cast. Added additional hoseclamp to primary pump tubing.

10702 - No issues noted.

10801 - No issues noted.

10901 - Bottle 19 lanyard caught in top of bottle 20. Remade lanyard and adjusted rest of lanyard to ensure lanyard angled toward 18 when fired, rather than 20. Many spikes in T and S sensor offsets in upper 120 m due to considerable ship heave.

No issues noted.

11001 - Bio cast. No issues noted.

11002 - No issues noted.

11101 - No issues noted.

11201 - No issues noted.

June 7, 2022

11301 - Bio cast. Dark cast. No issues noted.

11302 - No issues noted.

11401 - Bottle 13 leaking from bottom during sampling on deck. Changed o-ring.

11501 - Bottle 19 lanyard caught in top of bottle 20. Remade lanyard and further adjusted bottle 19 by lowering to original height.

11601 - Bio cast. No issues noted.

June 8, 2022

11602 - No issues noted.

11701 - No issues noted.

4.5 Sensor Problems

T,C offsets: During 20 m soak, sensor offsets in primary and secondary lines (T2 - T1, C2 - C1) were noisy or spiky following station 32. This was occasionally exacerbated by ship heave within a steep density gradient.

SBE43: SBE43 O_2 was consistently noisy at depths of 800 m or greater on downcasts and upcasts following station 32. This improved around station 104, where the height of the secondary pump was lowered.

CHAPTER

FIVE

CTDO AND HYDROGRAPHIC ANALYSIS

PIs

- Todd Martz (SIO)
- Susan Becker (SIO)

Technicians

- Aaron Mau (SIO)

5.1 CTDO and Bottle Data Acquisition

The CTD data acquisition system consisted of an SBE-11+ (V2) deck unit and a networked generic PC workstation running Windows 10. SBE SeaSave7 v.7.26.7.121 software was used for data acquisition and to close bottles on the rosette.

CTD deployments were initiated by the console watch operators (CWO) after the ship had stopped on station. The watch maintained a CTD cast log for each attempted cast containing a description of each deployment event and any problems encountered.

Once the deck watch had deployed the rosette, the winch operator would lower it to 20 meters. The CTD sensor pumps were configured to start 10 seconds after the primary conductivity cell reports salt water in the cell. The CWO checked the CTD data for proper sensor operation, waited for sensors to stabilize, and instructed the winch operator to bring the package to the surface in good weather or no more than 5 meters in high seas. The winch was then instructed to lower the package to the initial target wire-out at no more than 60 m/min after 100 m depending on depth, sea-cable tension, and the sea state.

The CWO monitored the progress of the deployment and quality of the CTD data through interactive graphics and operational displays. The altimeter channel, CTD pressure, wire-out and center multi-beam depth were all monitored to determine the distance of the package from the bottom. The winch was directed to slow decent rate to 30 m/min 100 m from the bottom, and 20 m/min 50 m from the bottom. The bottom of the CTD cast was usually to within 10-20 meters of the bottom determined by altimeter data. For each full upcast, the winch operator was directed to stop the winch at up to 36 predetermined sampling pressures. During upcasts specific to bio sampling, the winch operator was directed to stop at up to 21 predetermined sampling pressures. These standard depths were staggered every station using 3 sampling schemes. The CTD CWO waited 30 seconds prior to tripping sample bottles, to ensure package had shed its wake. An additional 15 seconds elapsed before moving to the next consecutive trip depth, which allowed for the SBE35RT to record bottle trip temperature averaged from 13 samples.

After the last bottle was closed, the CWO directed winch to recover the rosette. Once the rosette was out of the water and on deck, the CWO terminated the data acquisition, turned off the deck unit and assisted with rosette sampling.

Additionally, the watch created a sample log for the deployment which recorded the depths bottles were tripped and correspondence between rosette bottles and analytical samples drawn.

The CTD sensors were rinsed after every cast using syringes of fresh water connected to Tygon tubing. The tubing was left on the CTD between casts, with the temperature and conductivity sensors immersed in fresh water.

Each bottle on the rosette had a unique serial number, independent of the bottle position on the rosette. Sampling for specific programs were outlined on sample log sheets prior to cast recovery or at the time of collection. The bottles and rosette were examined before samples were drawn. Any abnormalities were noted on the sample log, stored in the cruise database and reported in the APPENDIX.

5.2 CTDO Data Processing

Shipboard CTD data processing was performed after deployment using SIO/ODF CTD processing software "ctdcal" v. 0.1.3b. CTD acquisition data were copied onto a OS X system, and then processed. CTD data at bottle trips were extracted, and a 2-decibar downcast pressure series created. The pressure series data set was submitted for CTD data distribution after corrections outlined in the following sections were applied.

A total of 117 CTD stations were occupied including one test station. A total of 148 CTDO/rosette/LADCP/UVP/chipod casts were completed.

CTD data were examined at the completion of each deployment for clean corrected sensor response and any calibration shifts. As bottle salinity and oxygen results became available, they were used to refine conductivity and oxygen sensor calibrations.

Temperature, salinity and, dissolved O_2 comparisons were made between down and upcasts as well as between groups of adjacent deployments. Vertical sections of measured and derived properties from sensor data were checked for consistency.

A number of issues were encountered during P02W-2022 that directly impacted CTD analysis. Issues that directly impacted bottle closures, such as slipping guide rings, were detailed in the Underwater Sampling Package section of this report. Temperature, conductivity, and oxygen analytical sensor issues are detailed in the following respective sections.

5.3 Pressure Analysis

Laboratory calibrations of CTD pressure sensors were performed prior to the cruise. Dates of laboratory calibration are recorded on the underway sampling package table and calibration documents are provided in the APPENDIX.

The lab calibration coefficients provided on the calibration report were used to convert frequencies to pressure. Initial SIO pressure lab calibration slope and offsets coefficients were applied to cast data. A shipboard calibration offset was applied to the converted pressures during each cast. These offsets were determined by the pre and post-cast on-deck pressure offsets. The pressure offsets were applied per cast.

CTD #1281:

	Start P (dbar)	End P (dbar)
Min	-0.16	-0.46
Max	0.23	0.13
Average	-0.04	-0.28

On-deck pressure reading varied from -0.16 to 0.23 dbar before the casts, and -0.46 to 0.13 dbar after the casts. The pressure offset varied from -0.30 to 0.10, with a mean value of -0.24 dbar.

5.4 Temperature Analysis

Laboratory calibrations of temperature sensors were performed prior to the cruise at the SIO Calibration Facility. Dates of laboratory calibration are recorded on the underway sampling package table and calibration documents are provided in the APPENDIX.

The pre-cruise laboratory calibration coefficients were used to convert SBE3plus frequencies to ITS-90 temperature. Additional shipboard calibrations were performed to correct systematic sensor bias. Two independent metrics of calibration accuracy were used to determine sensor bias. At each bottle closure, the primary and secondary temperature were compared with each other and with a SBE35RT reference temperature sensor.

The SBE35RT Digital Reversing Thermometer is an internally-recording temperature sensor that operates independently of the CTD. The SBE35RT was located equidistant between the two SBE3plus temperature sensors. The SBE35RT is triggered by the SBE32 carousel in response to a bottle closure. According to the manufacturer's specifications, the typical stability is 0.001 °C/year. The SBE35RT was set to internally average over 13 samples, approximately a 15 second period.

A functioning SBE3plus sensor typically exhibit a consistent predictable well-modeled response. The response model is second-order with respect to pressure and second-order with respect to temperature:

$$T_{cor} = T + cp_2P^2 + cp_1P + ct_2T^2 + ct_1T + c_0$$

Fit coefficients are shown in the following tables.

Table 1: Primary temperature (T1) coefficients.

Station	cp_2	cp_1	ct_2	ct_1	c_0
1-8	0.0	-2.5655e-7	0.0	0.0	1.4204e-4
9-40	0.0	-1.7576e-7	0.0	0.0	2.8372e-5
41-117	-0.0	-9.2544e-9	0.0	0.0	4.9377e-4

Table 2: Secondary temperature (T2) coefficients.

Station	cp_2	cp_1	ct_2	ct_1	c_0
1-8	0.0	-2.2795e-8	0.0	0.0	-2.9018e-4
9-41	0.0	-4.2754e-7	0.0	0.0	2.217e-4
42-117	-1.4293e-11	2.0618e-7	0.0	0.0	-7.9777e-6

Corrected temperature differences are shown in the following figures.

The 95% confidence limits for the mean low-gradient (values -0.002 °C $\leq$ T1-T2 $\leq$ 0.002 °C) differences are $\pm$0.00521 °C for SBE35RT-T1, $\pm$0.00530 °C for SBE35RT-T2 and $\pm$0.00129 °C for T1-T2. The 95% confidence limits for the deep temperature residuals (where pressure $\geq$ 2000 dbar) are $\pm$0.00062 °C for SBE35RT-T1, $\pm$0.00072 °C for SBE35RT-T2 and $\pm$0.00067 °C for T1-T2.

Problems arose during the P02W-2022 cruise, prompting CTD temperature sensors (SBE3) to be exchanged.

- While deploying during station 9, cables to the deck box were loose. This was misdiagnosed as a sensor problem and was deployed without a secondary sensor on cast 4.
- Differences in primary and secondary SBE3 were abnormally large during the pre-cast soak following station 32 and the sensors were exchanged during stations 40 and 41 to troubleshoot.

Minor complications impacted the reference temperature sensor (SBE35) data.

- Internal memory overflowed following station 9 and data was not captured during stations 10 and 11.
- During casts designated for bio, many bottles were fired at the surface and sometimes were too fast (< 15 seconds) for a reading.

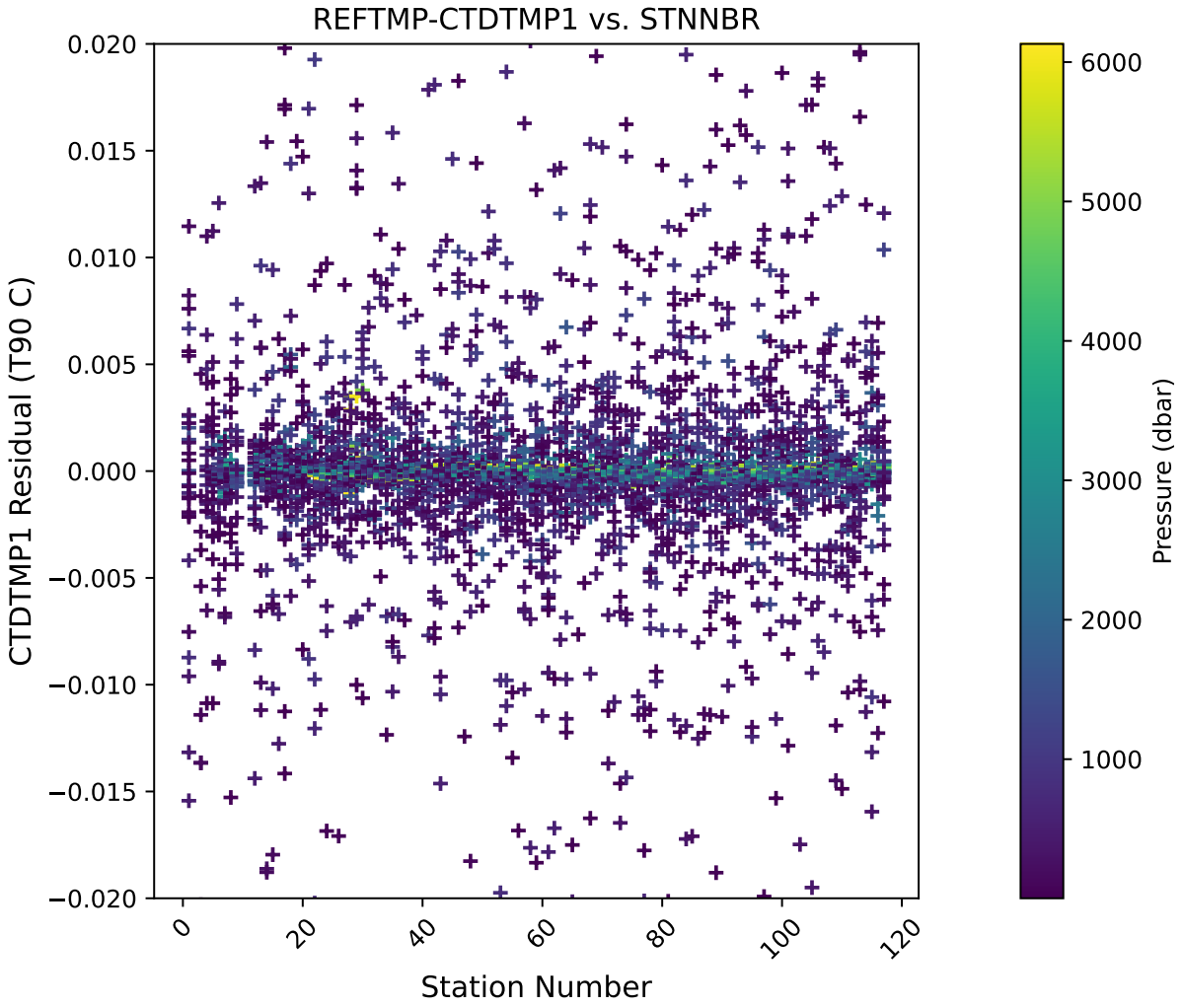


Fig. 1: SBE35RT-T1 versus station.

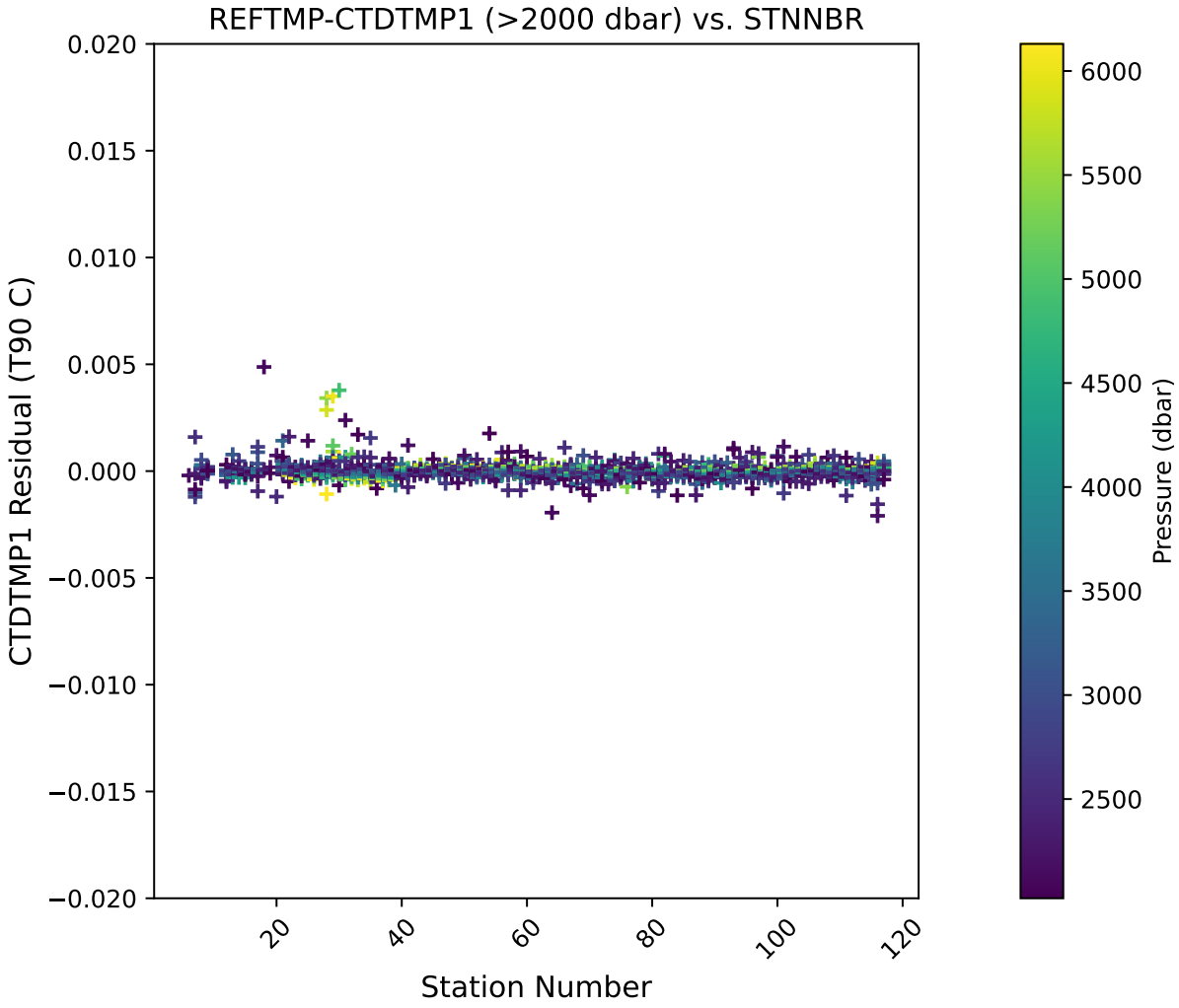


Fig. 2: Deep SBE35RT-T1 by station (Pressure $\geq$ 2000dbar).

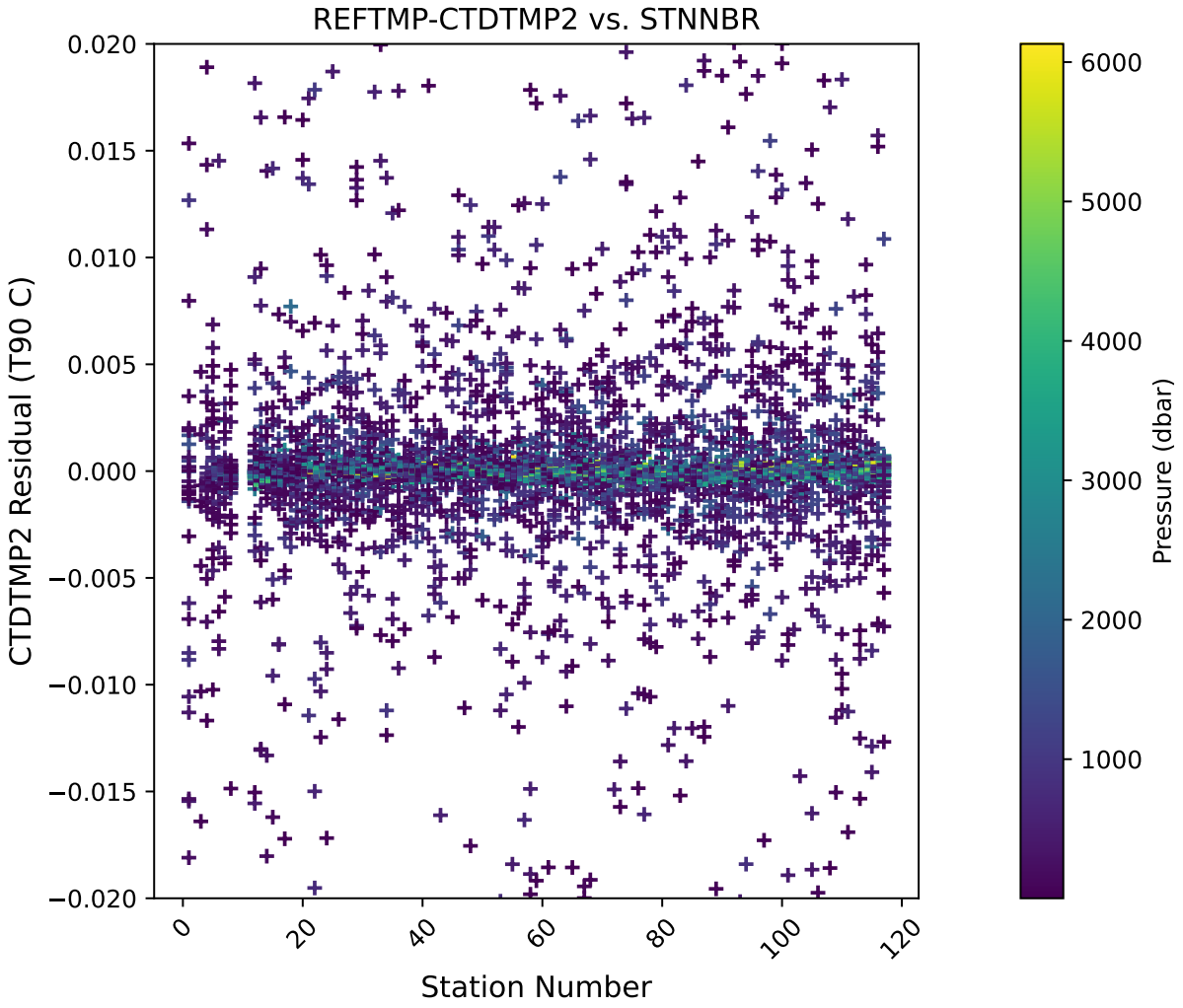


Fig. 3: SBE35RT-T2 versus station.

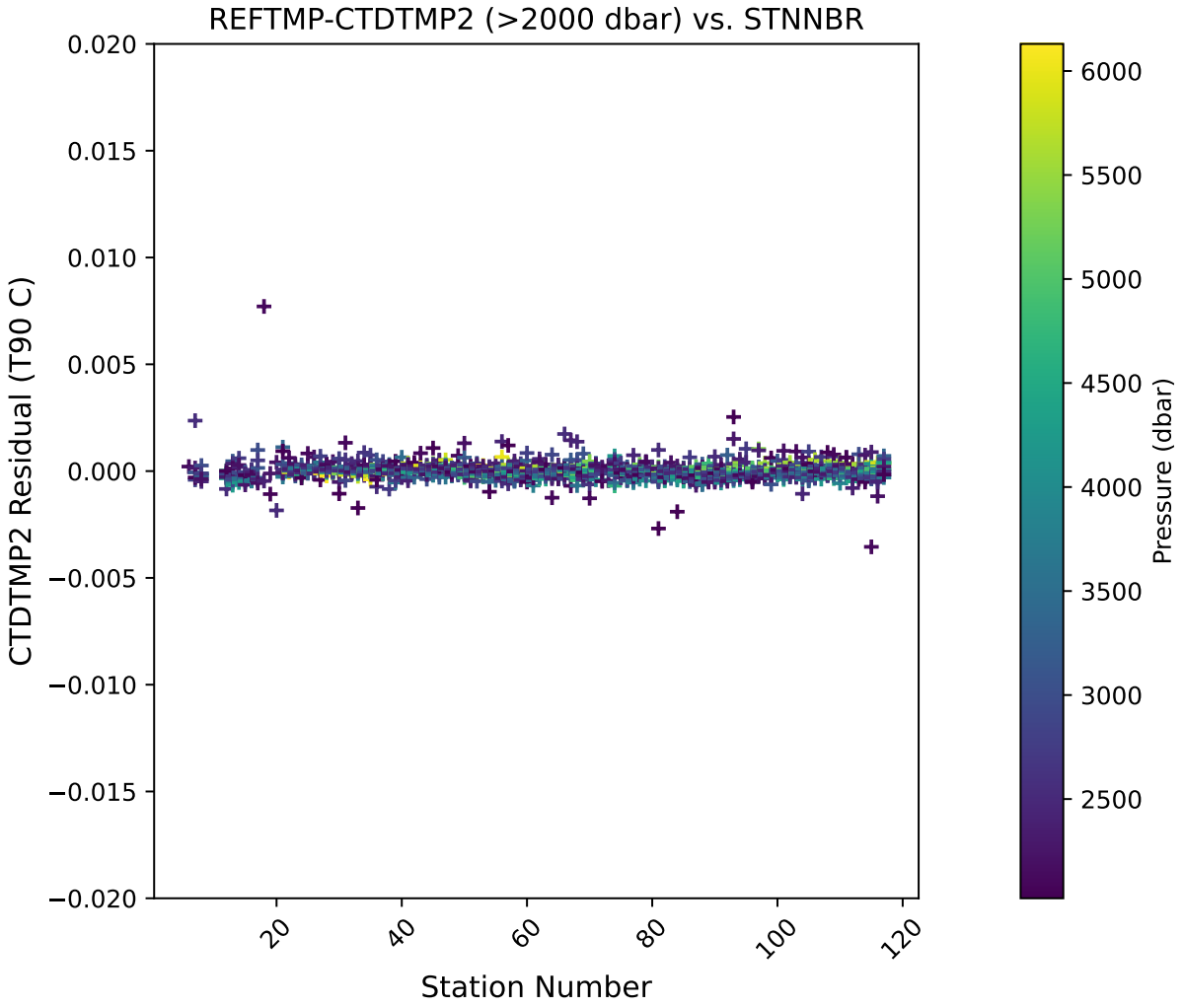


Fig. 4: Deep SBE35RT-T2 by station (Pressure $\geq$ 2000dbar).

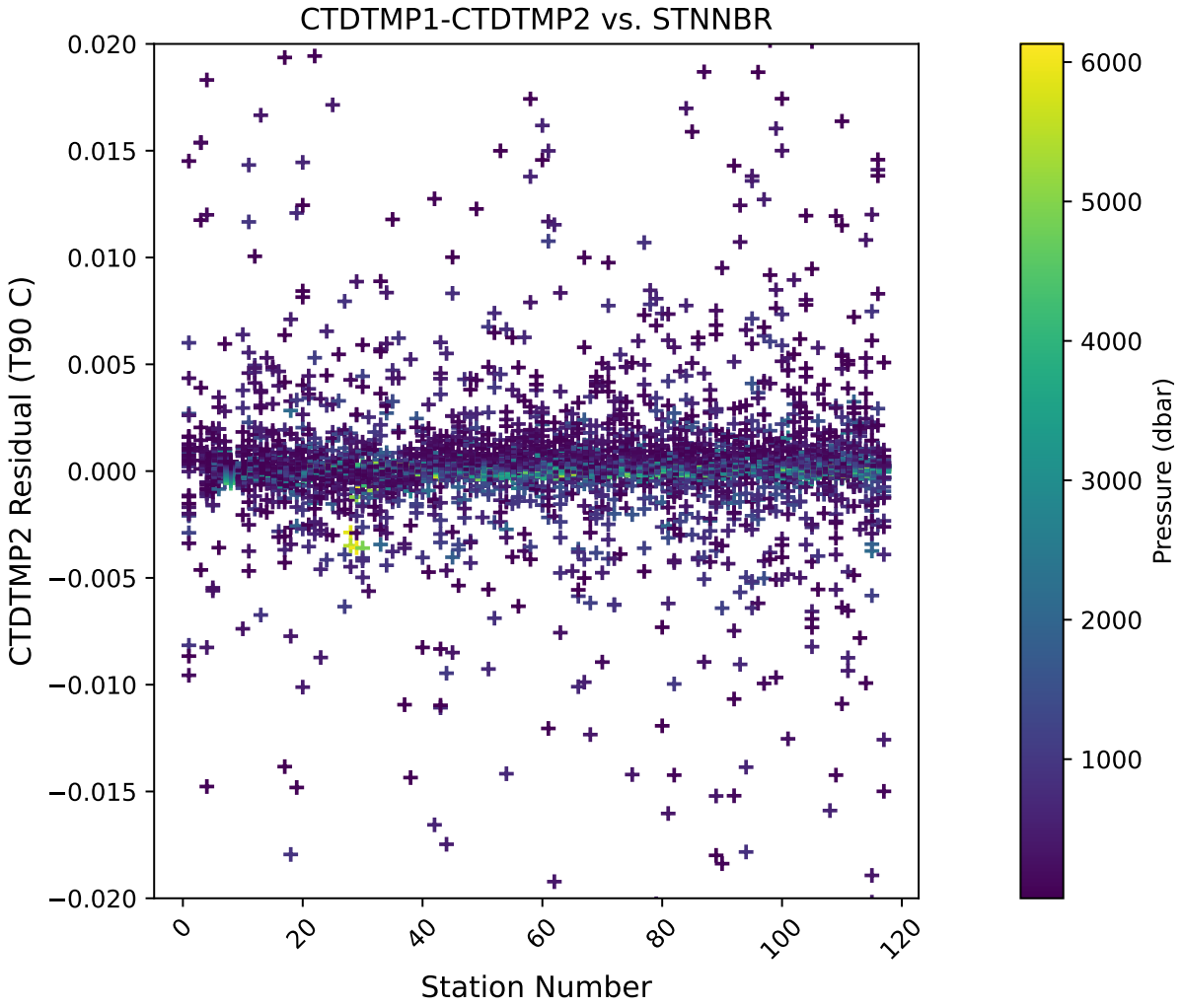


Fig. 5: T1-T2 versus station.

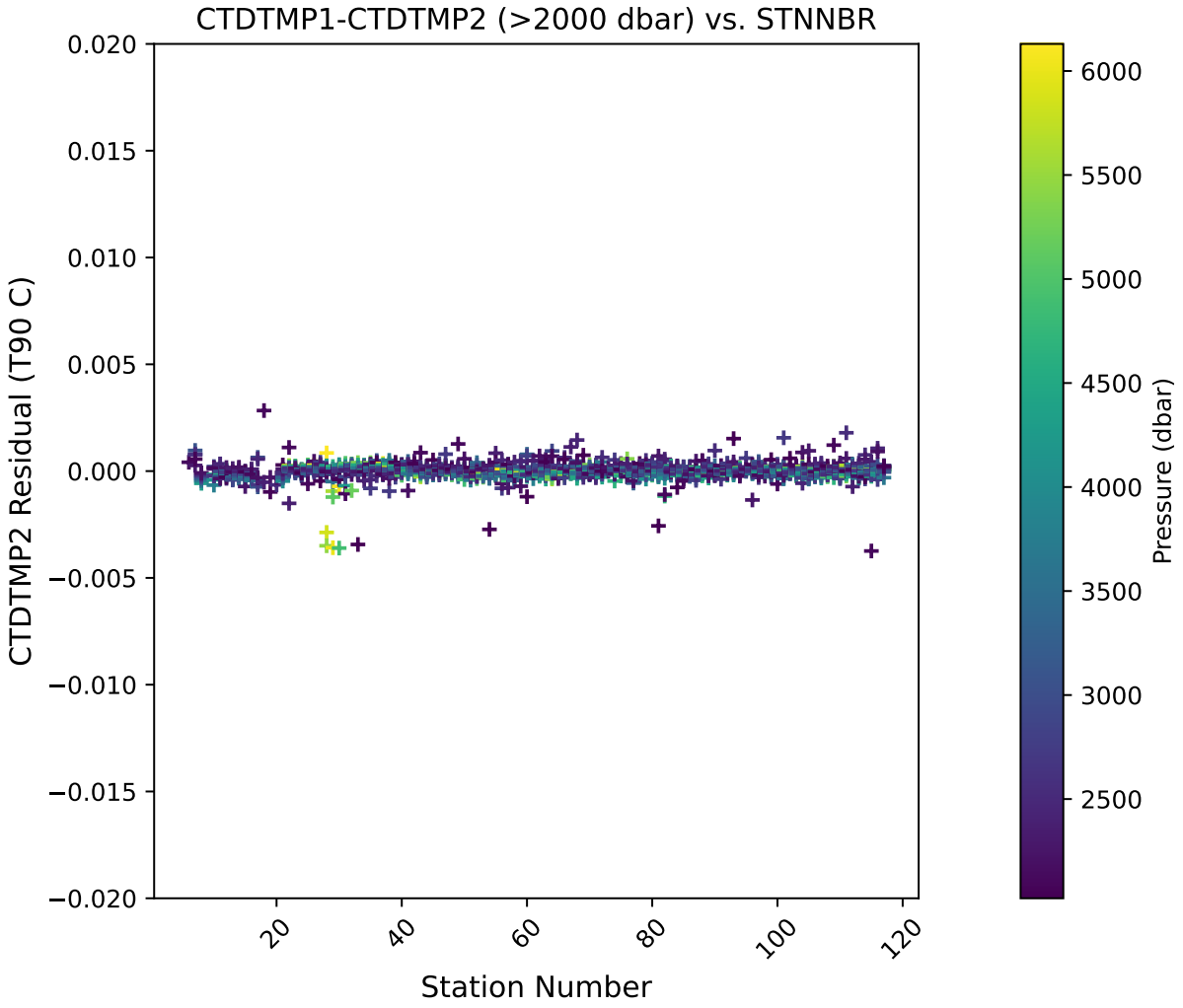


Fig. 6: Deep T1-T2 versus station (Pressure $\geq$ 2000dbar).

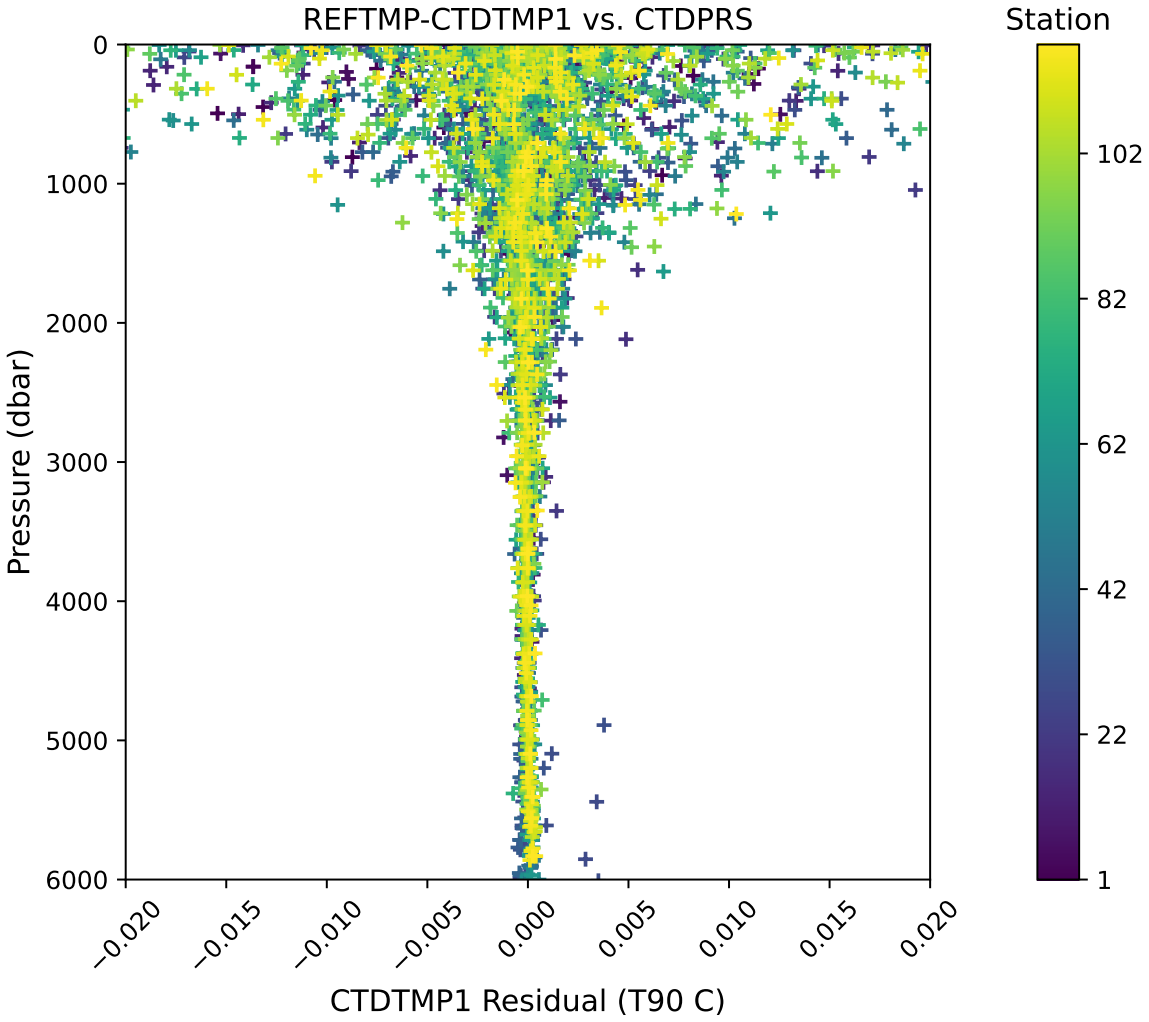


Fig. 7: SBE35RT-T1 versus pressure.

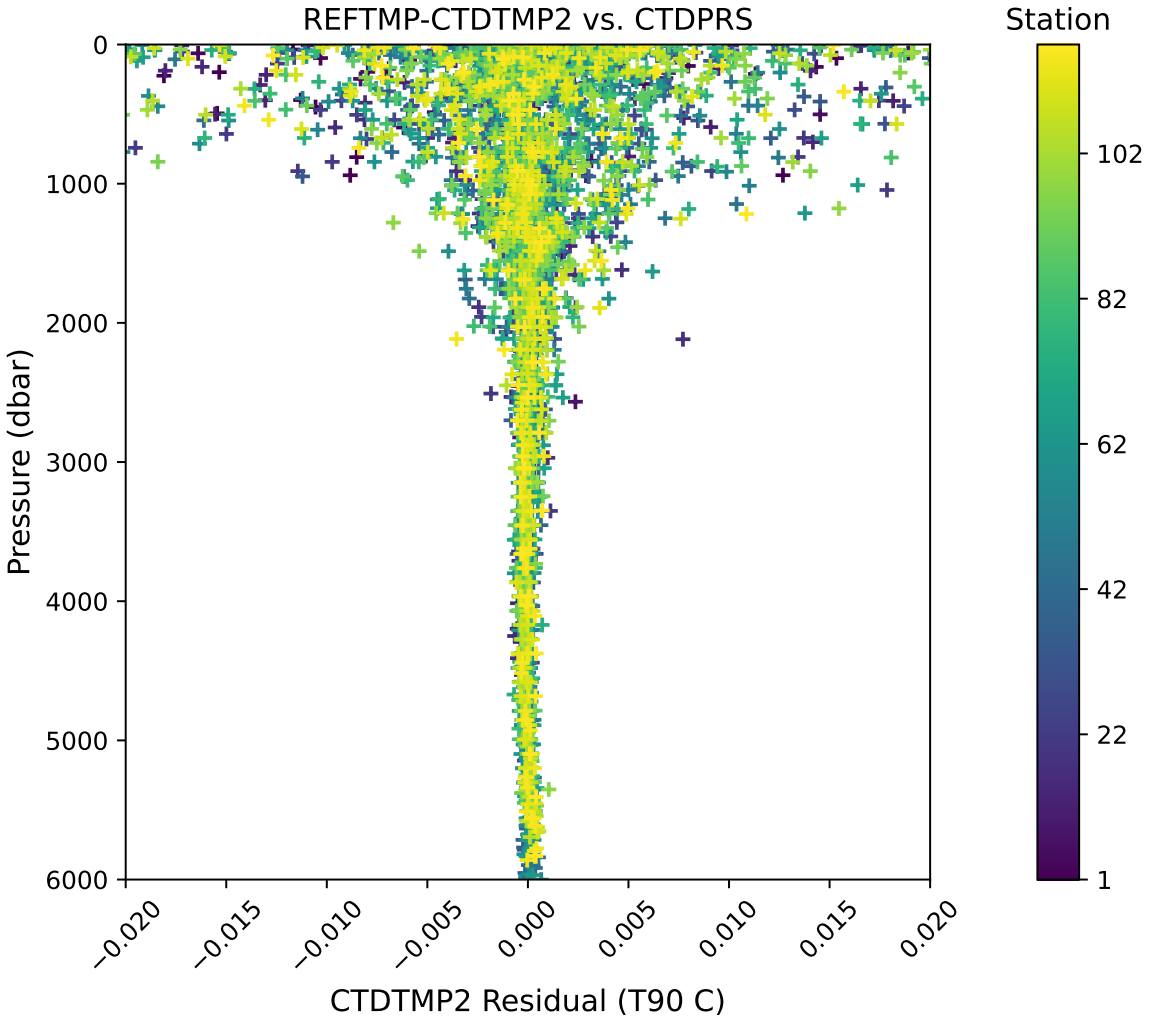


Fig. 8: SBE35RT-T2 versus pressure.

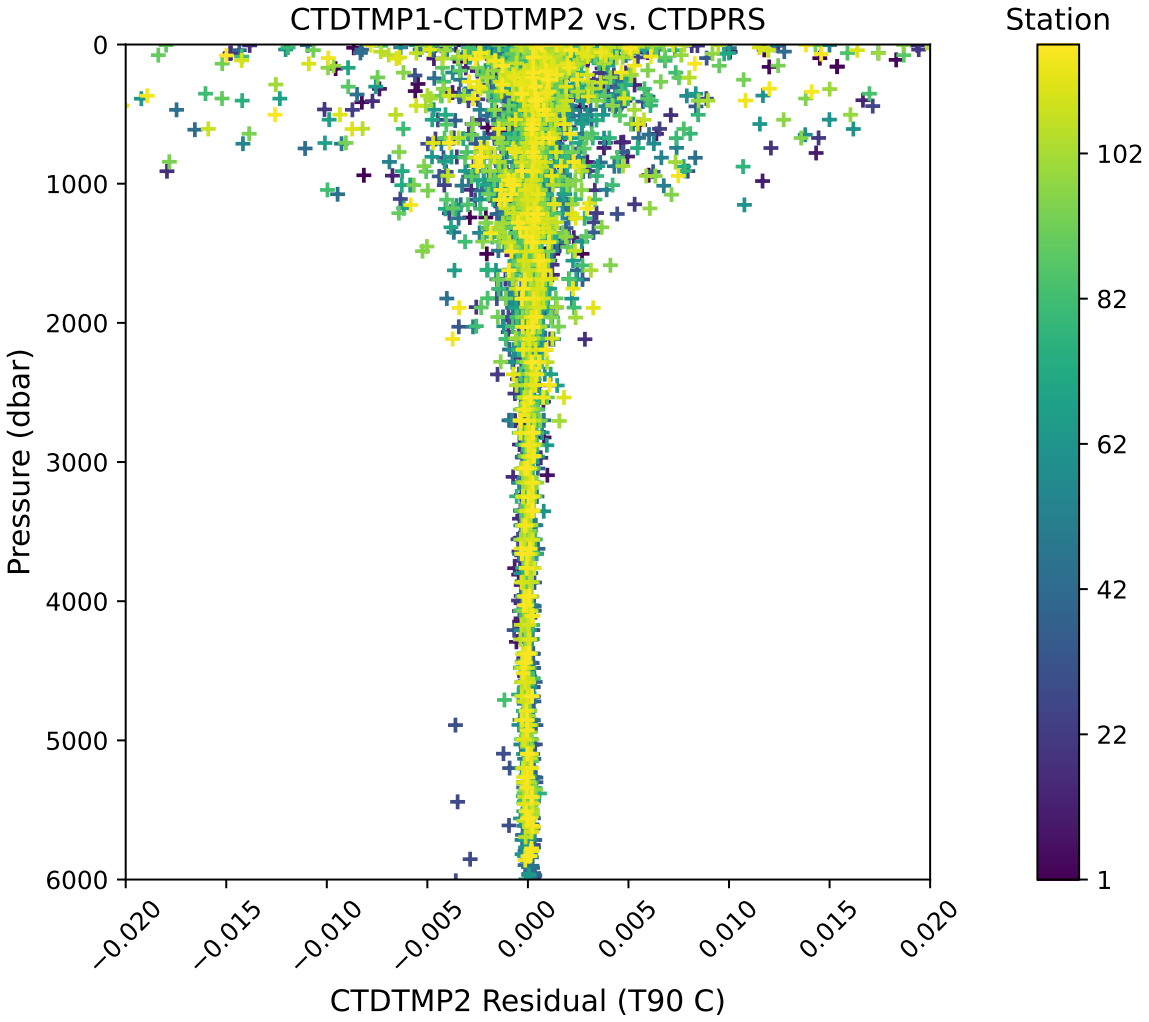


Fig. 9: T1-T2 versus pressure.

The resulting affected sections of data have been coded and documented in the quality code APPENDIX.

5.5 Conductivity Analysis

Laboratory calibrations of conductivity sensors were performed prior to the cruise at the Sea-Bird Calibration Facility. Dates of laboratory calibration are recorded on the underway sampling package table and calibration documents are provided in the APPENDIX.

The pre-cruise laboratory calibration coefficients were used to convert SBE4C frequencies to mS/cm conductivity values. Additional shipboard calibrations were performed to correct sensor bias. Corrections for both pressure and temperature sensors were finalized before analyzing conductivity differences. Two independent metrics of calibration accuracy were examined. At each bottle closure, the primary and secondary conductivity were compared with each other. Each sensor was also compared to conductivity calculated from check sample salinities using CTD pressure and temperature.

The differences between primary and secondary temperature sensors were used as filtering criteria to reduce the contamination of conductivity comparisons by package wake. The coherence of this relationship is shown in the following figures.

A functioning SBE4C sensor typically exhibit a predictable modeled response. Offsets for each C sensor were determined using C_{Bottle} - C_{CTD} differences in a deeper pressure range (500 or more dbars). After conductivity offsets were applied to all casts, response to pressure, temperature and conductivity were examined for each conductivity sensor. The response model is second-order with respect to pressure, second-order with respect to temperature, and second-order with respect to conductivity:

$$C_{cor} = C + cp_2P^2 + cp_1P + ct_2T^2 + ct_1T + cc_2C^2 + cc_1C + \text{Offset}$$

Fit coefficients are shown in the following tables.

Table 3: Primary conductivity (C1) coefficients.

Station	cp_2	cp_1	ct_2	ct_1	cc_2	cc_1	c_0
1-117	0.0	4.3091e-8	0.0	0.0	0.0	0.0	-1.6721e-3

Table 4: Secondary conductivity (C2) coefficients.

Station	cp_2	cp_1	ct_2	ct_1	cc_2	cc_1	c_0
1-117	0.0	-2.3585e-7	0.0	0.0	0.0	0.0	4.6397e-3

Salinity residuals after applying shipboard P/T/C corrections are summarized in the following figures. Only CTD and bottle salinity data with "acceptable" quality codes are included in the differences. Quality codes and comments are published in the APPENDIX of this report.

The 95% confidence limits for the mean low-gradient (values -0.002 °C $\leq$ T1-T2 $\leq$ 0.002 °C) differences are $\pm$0.00521 °C for SBE35RT-T1, $\pm$0.00530 °C for SBE35RT-T2 and $\pm$0.00129 °C for T1-T2.

The 95% confidence limits for the mean low-gradient (values -0.002 ºC $\leq$ T1-T2 $\leq$ 0.002 ºC) differences are $\pm$0.00834 mPSU for salinity-C1SAL, $\pm$0.00659 mPSU for salinity-C2SAL and $\pm$0.00358 mPSU for C1SAL-C2SAL. The 95% confidence limits for the deep salinity residuals (where pressure $\geq$ 2000 dbar) are $\pm$0.00225 mPSU for salinity-C1SAL, $\pm$0.00179 mPSU for salinity-C2SAL and $\pm$0.00178 mPSU for C1SAL-C2SAL.

Minimal issues affected conductivity and calculated CTD salinities during this cruise.

- Bottle stops in halocline may have had insufficient stop time during some casts, leading to low-biased measurements.

The resulting affected sections of data have been coded and documented in the quality code APPENDIX.

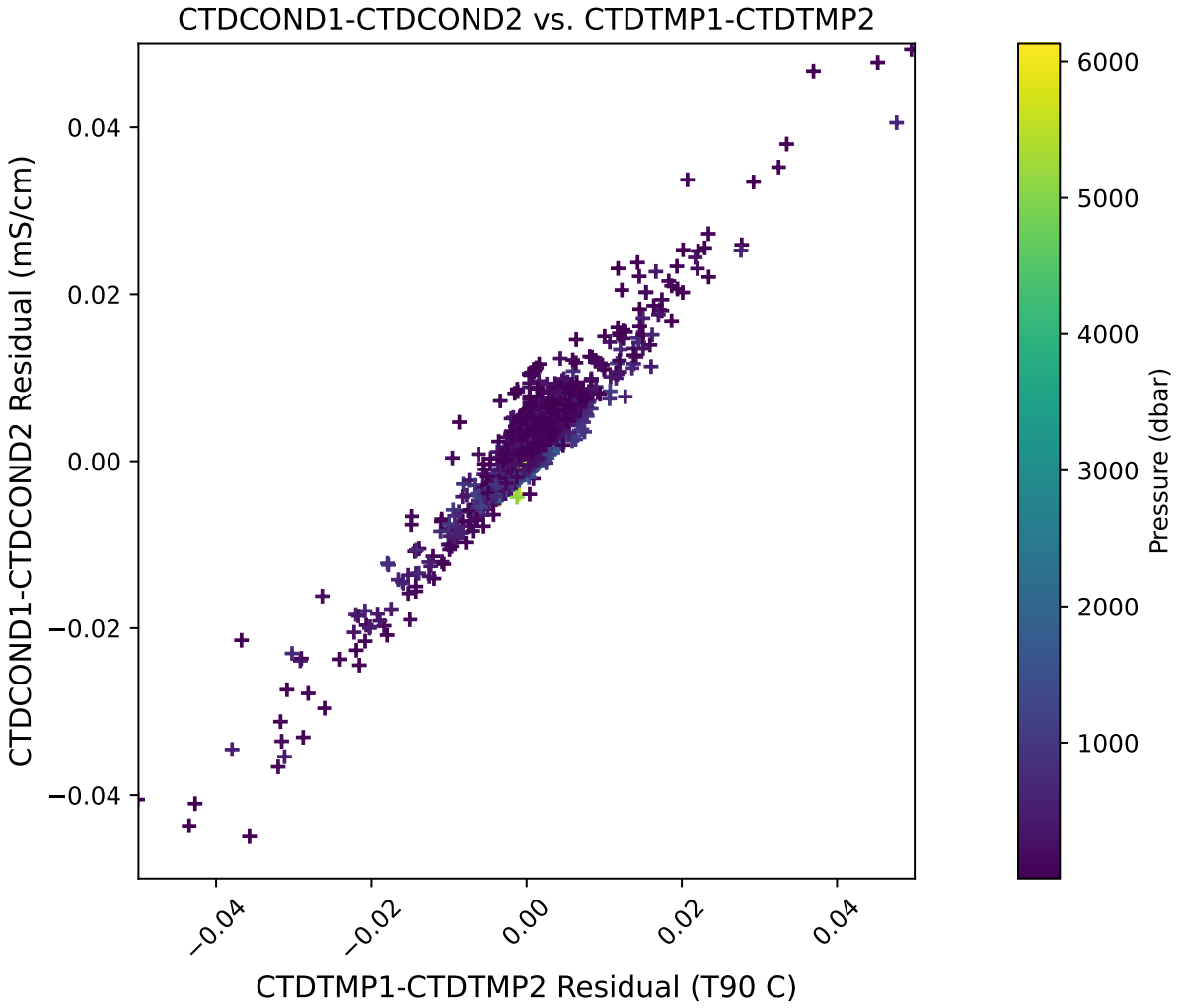


Fig. 10: Coherence of conductivity differences as a function of temperature differences.

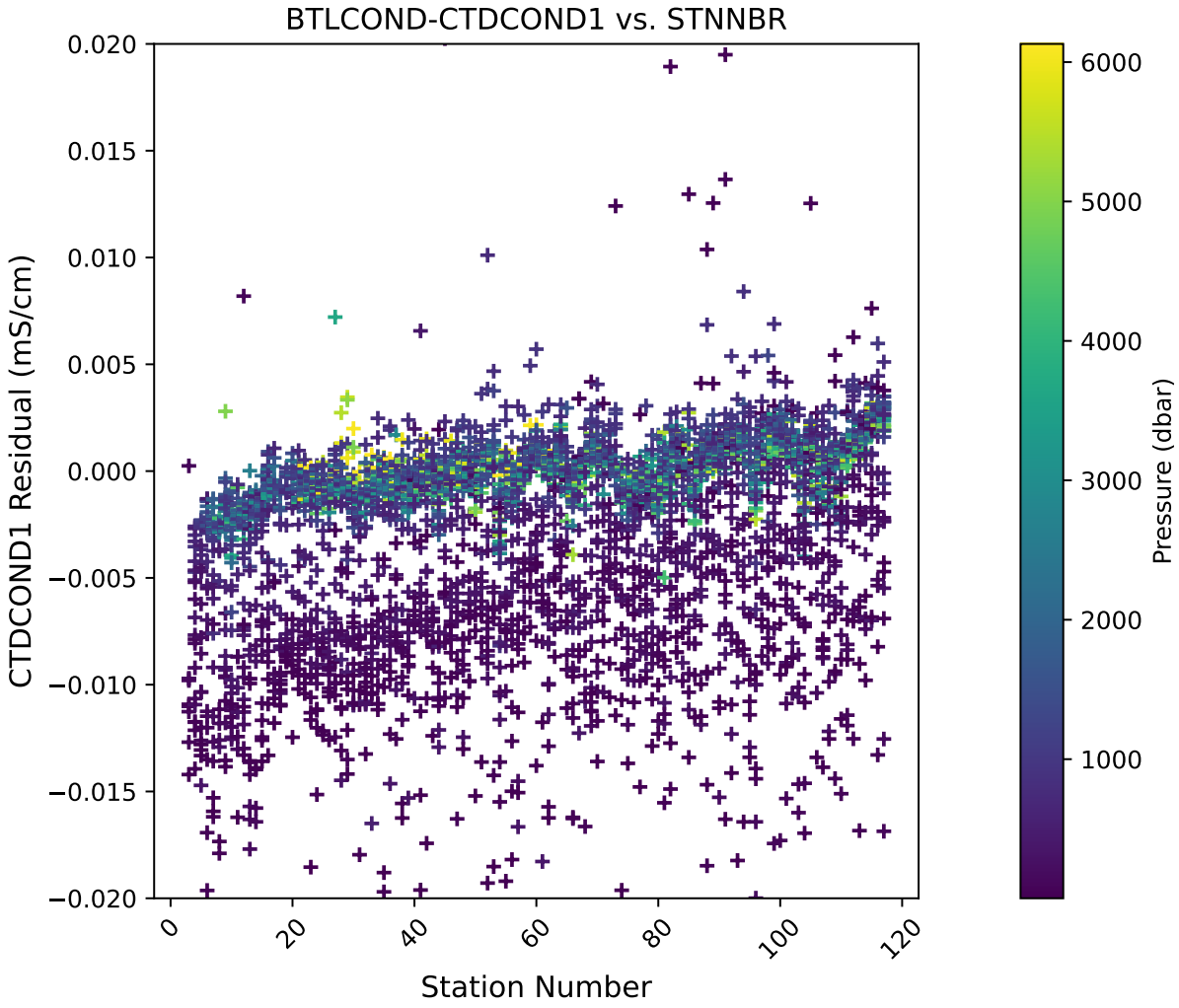


Fig. 11: Corrected C_{Bottle} - C1 versus station.

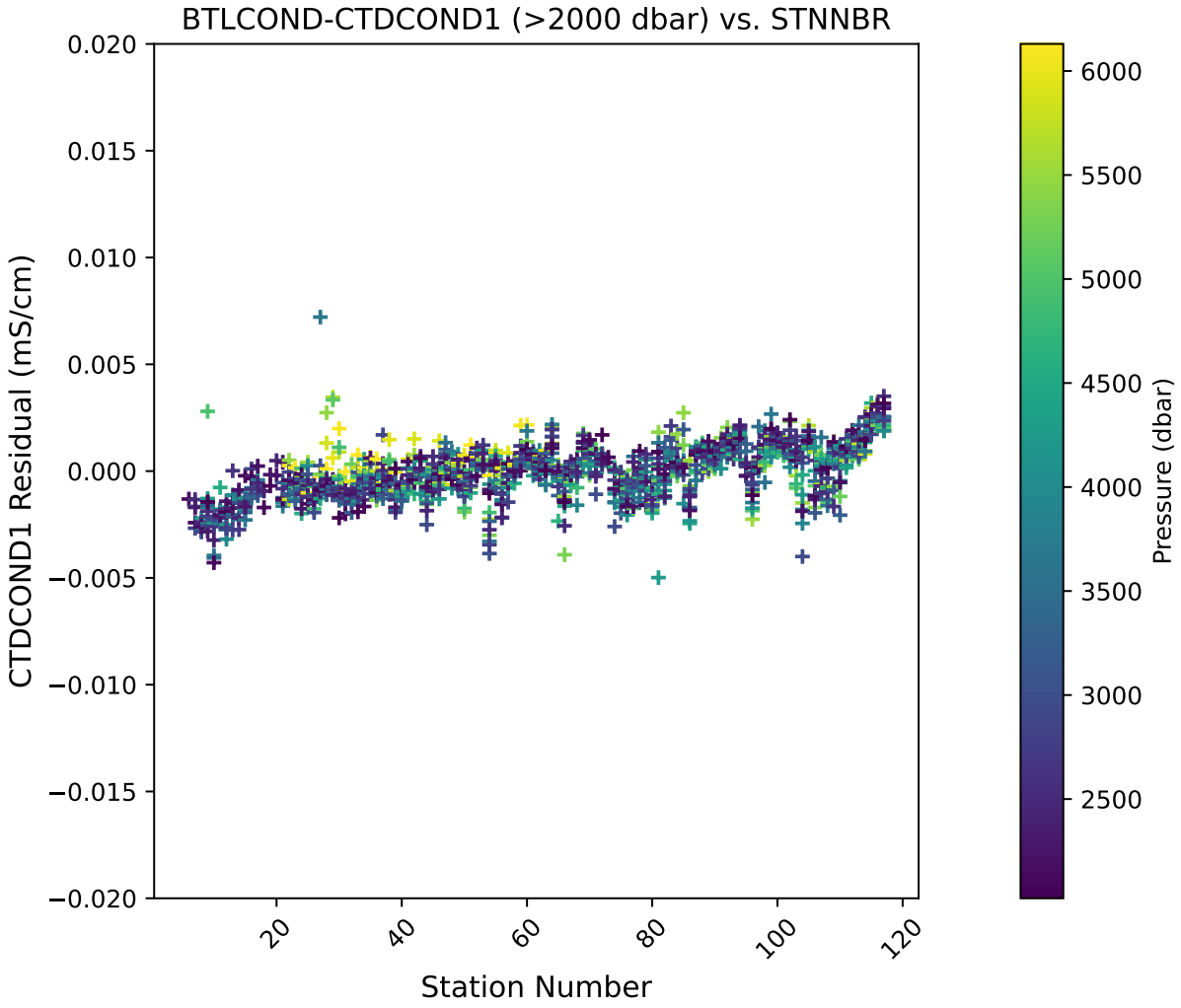


Fig. 12: Deep Corrected C_{Bottle} - C1 versus station (Pressure >= 2000dbar).

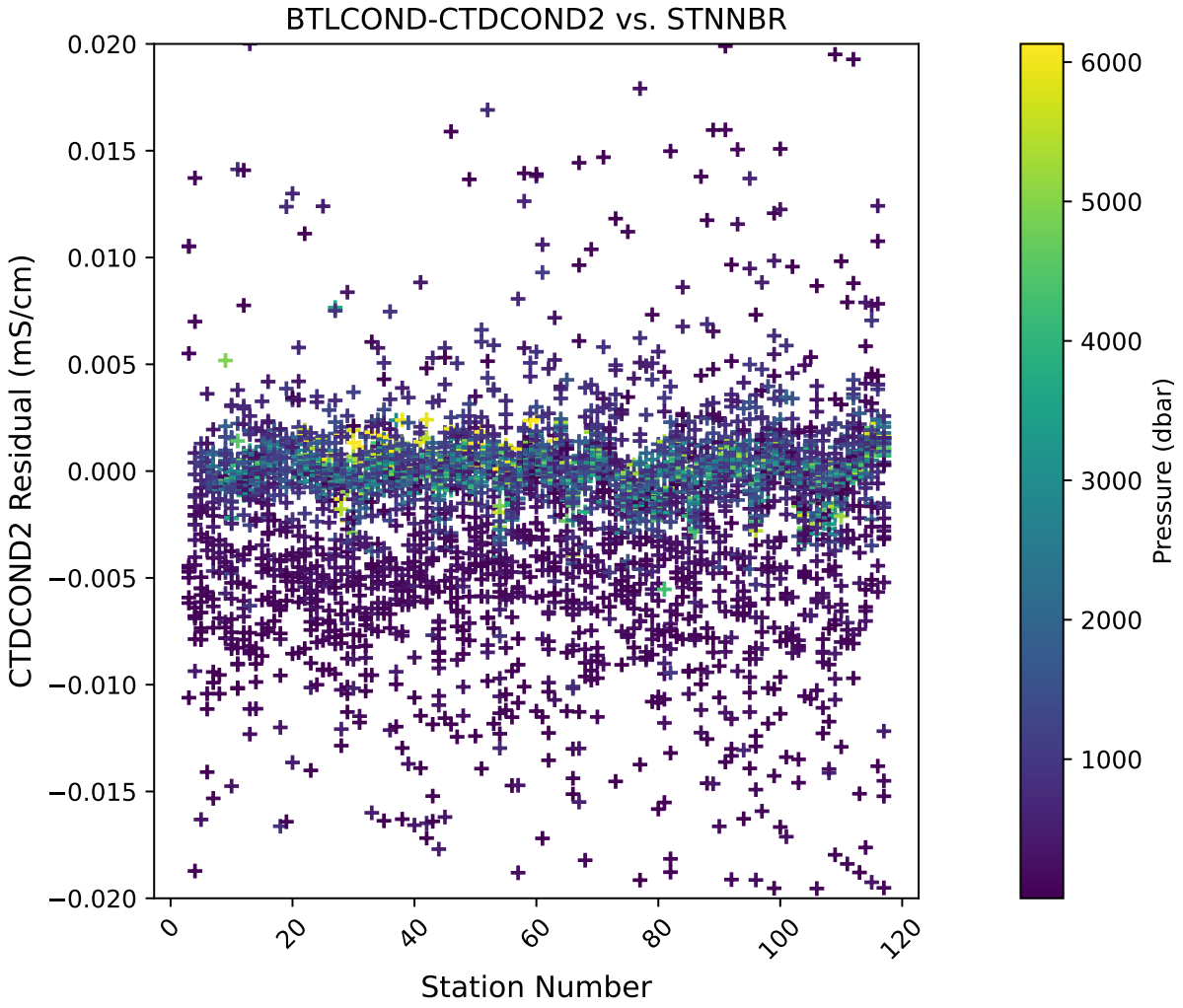


Fig. 13: Corrected C_{Bottle} - C2 versus station.

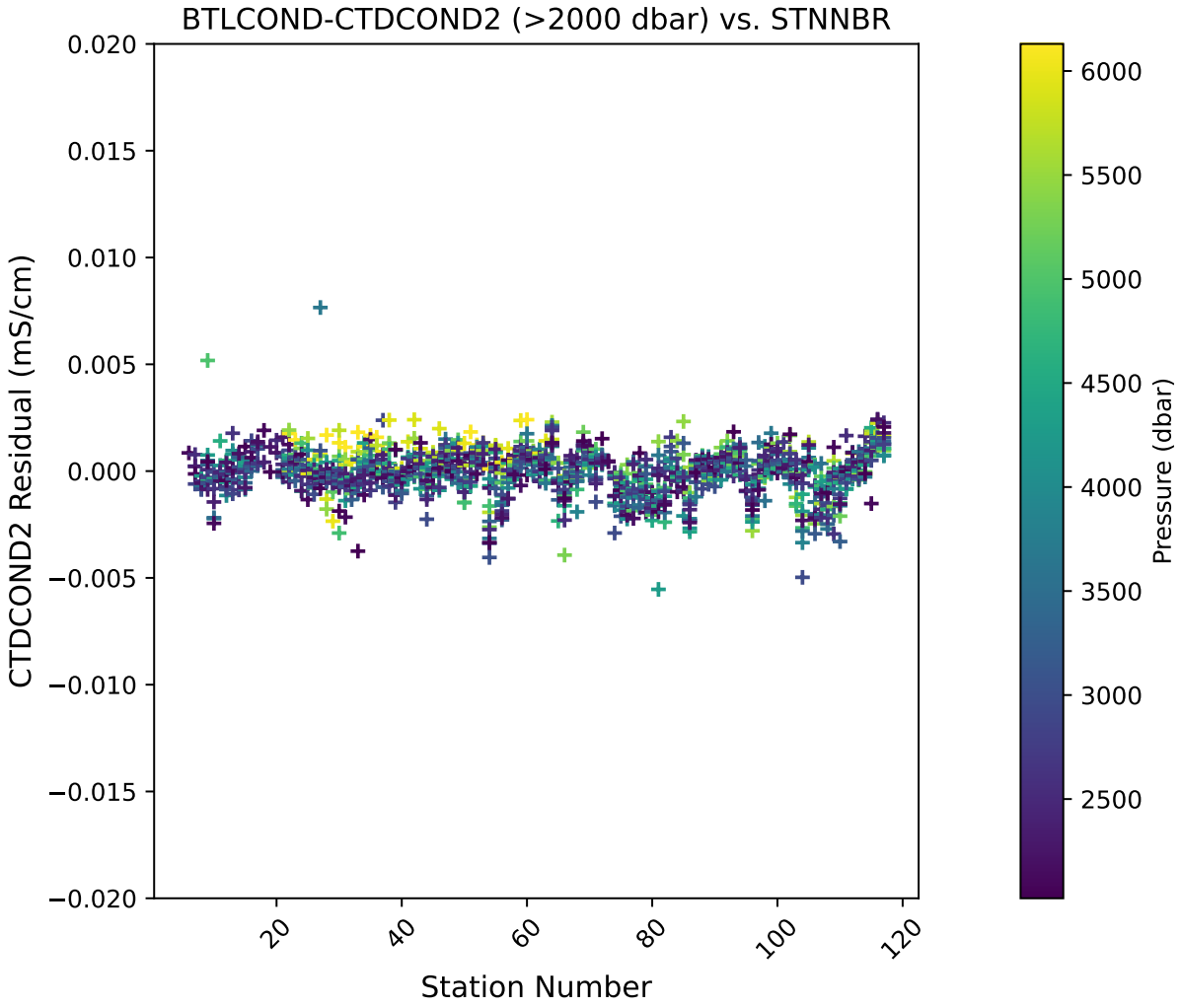


Fig. 14: Deep Corrected C_{Bottle} - C2 versus station (Pressure >= 2000dbar).

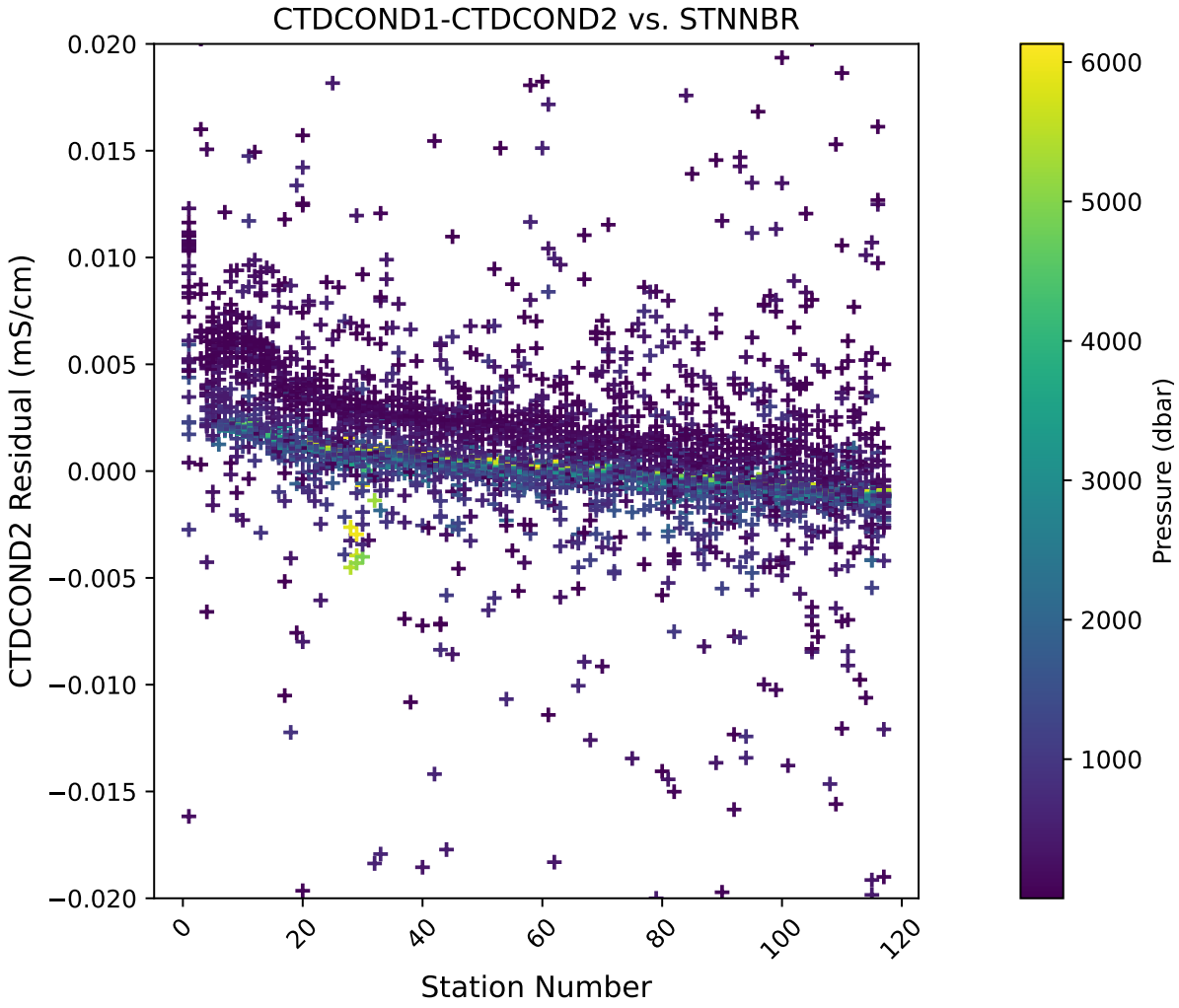


Fig. 15: Corrected C1-C2 versus station.

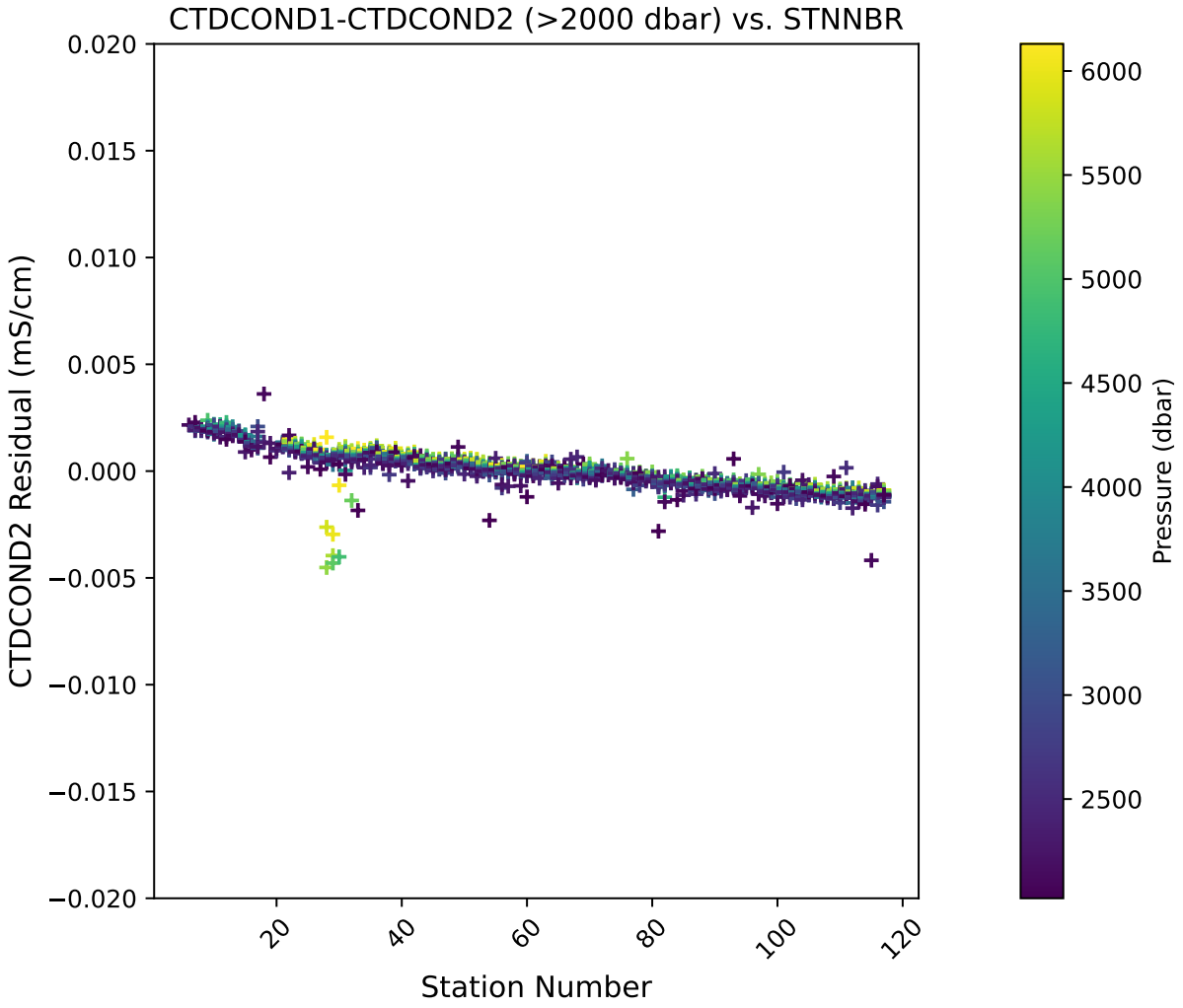


Fig. 16: Deep Corrected C1-C2 versus station (Pressure >= 2000dbar).

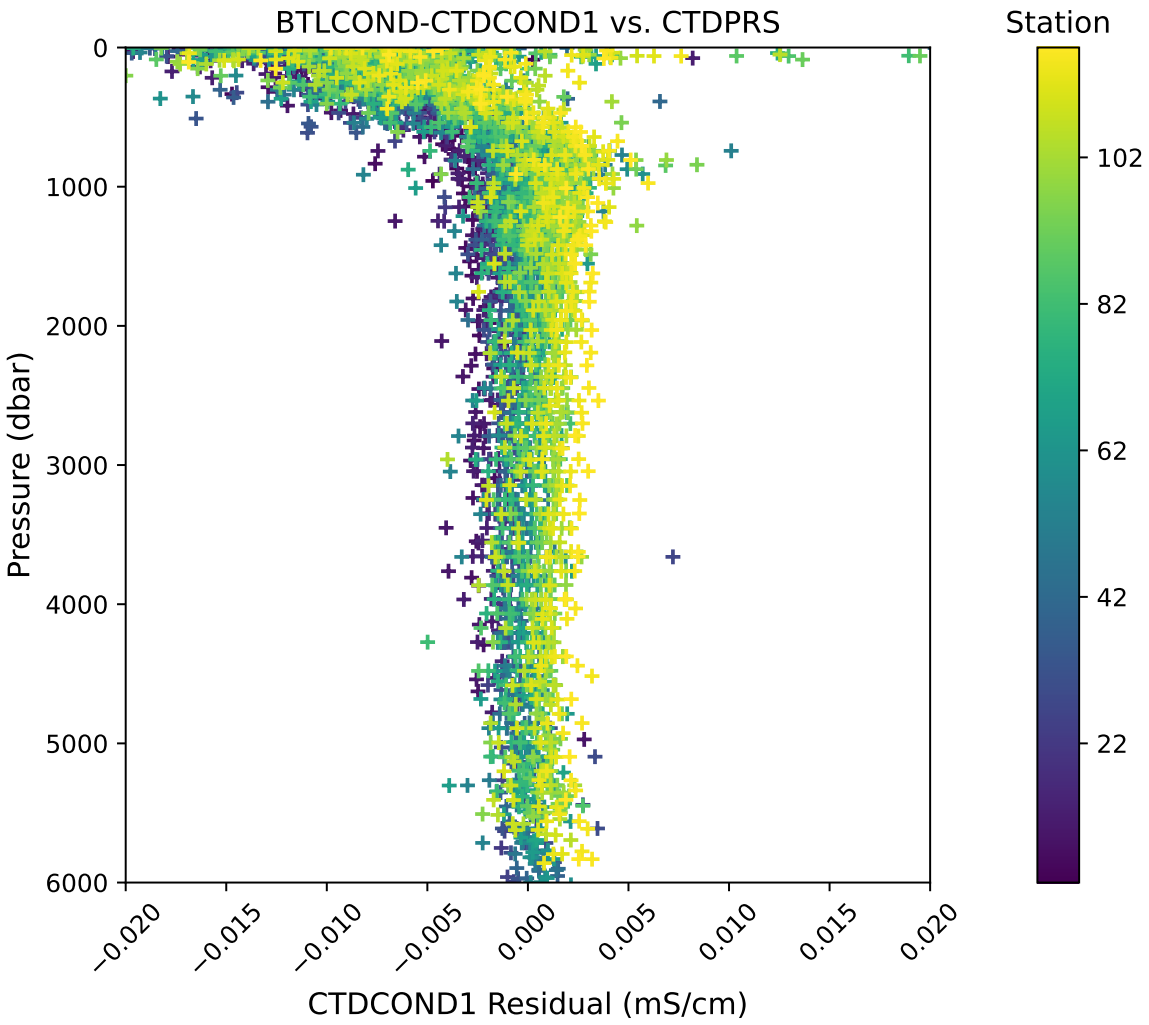


Fig. 17: Corrected C_{Bottle} - C1 versus pressure.

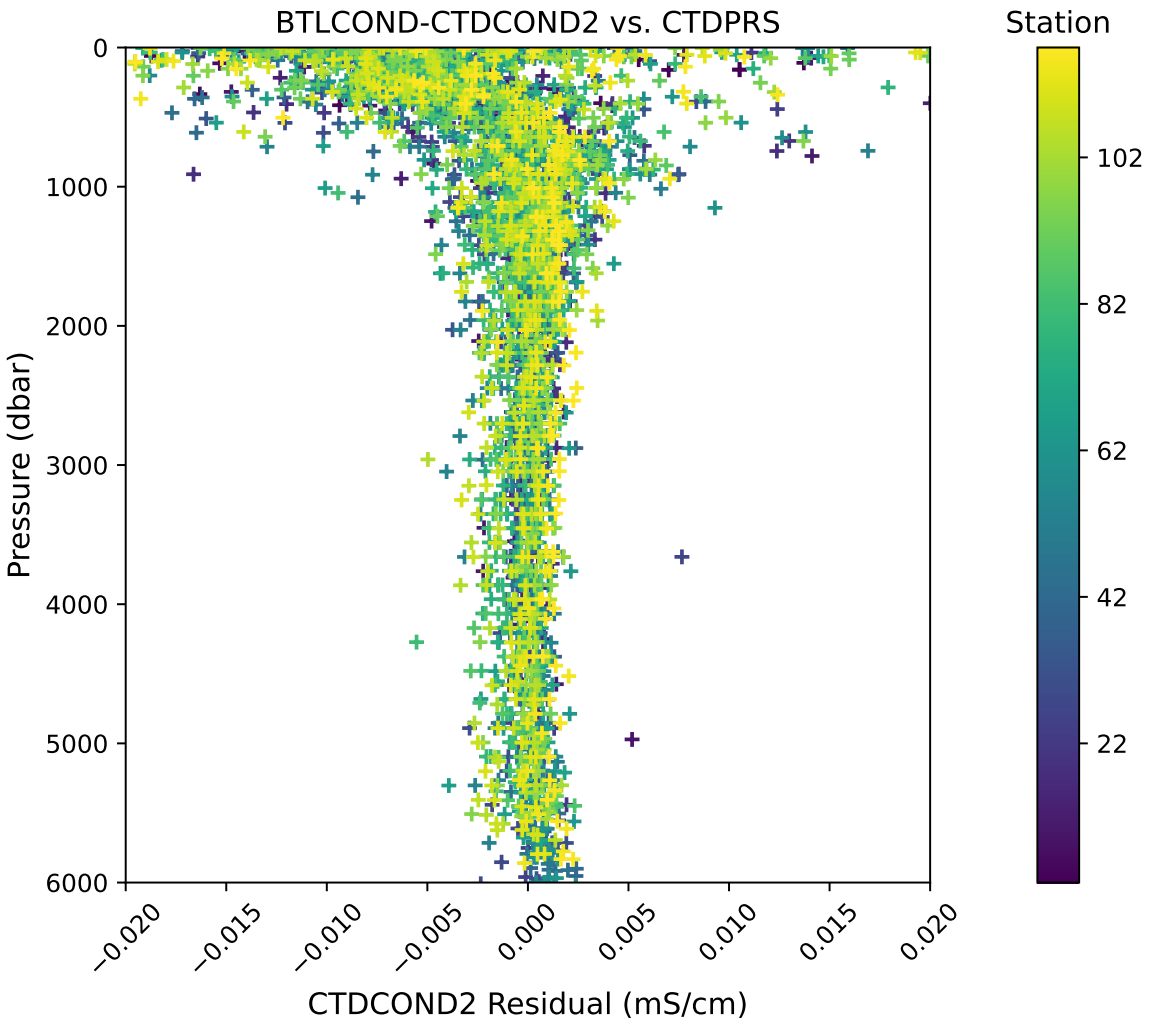


Fig. 18: Corrected C_{Bottle} - C2 versus pressure.

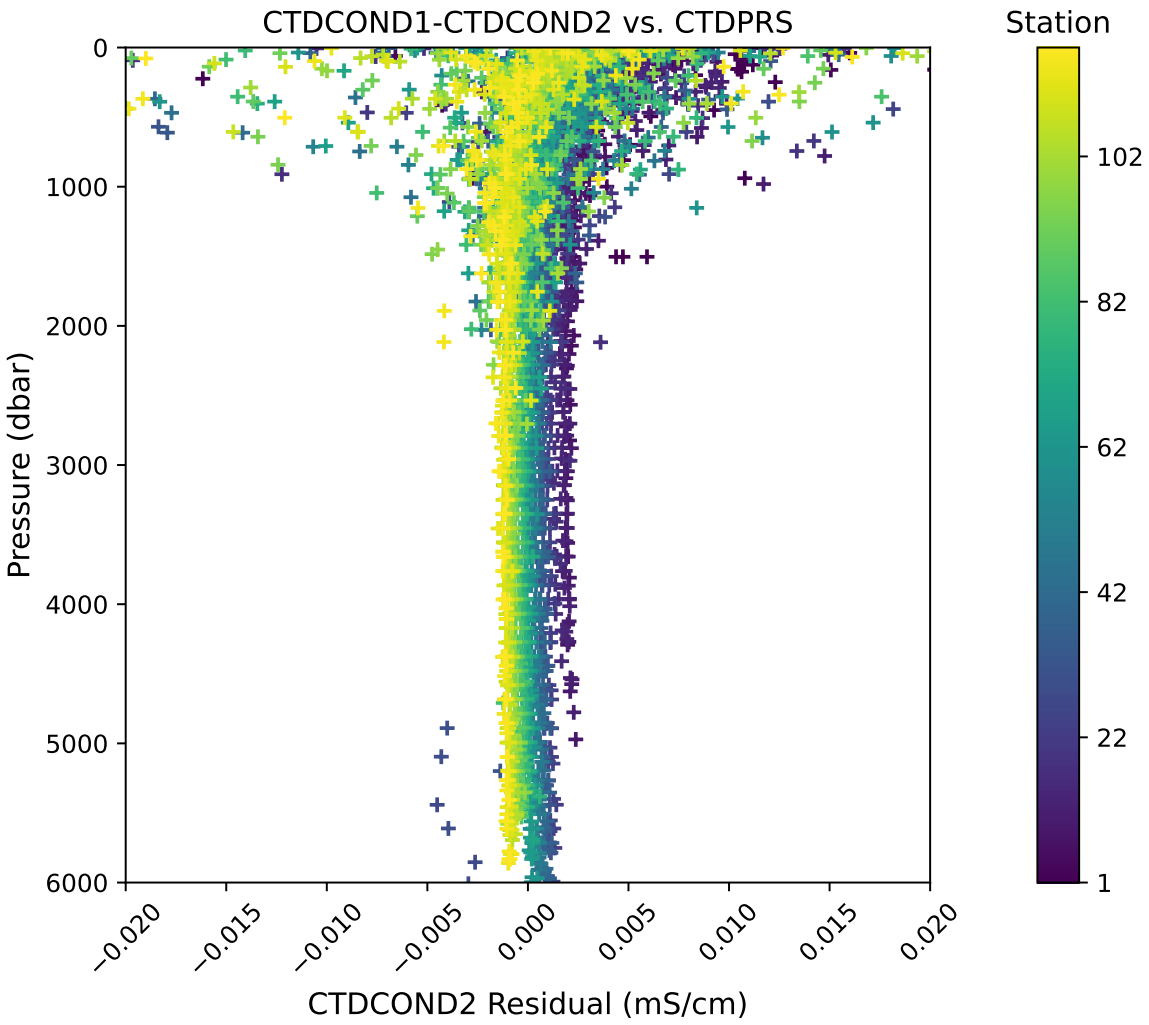


Fig. 19: Corrected C1-C2 versus pressure.

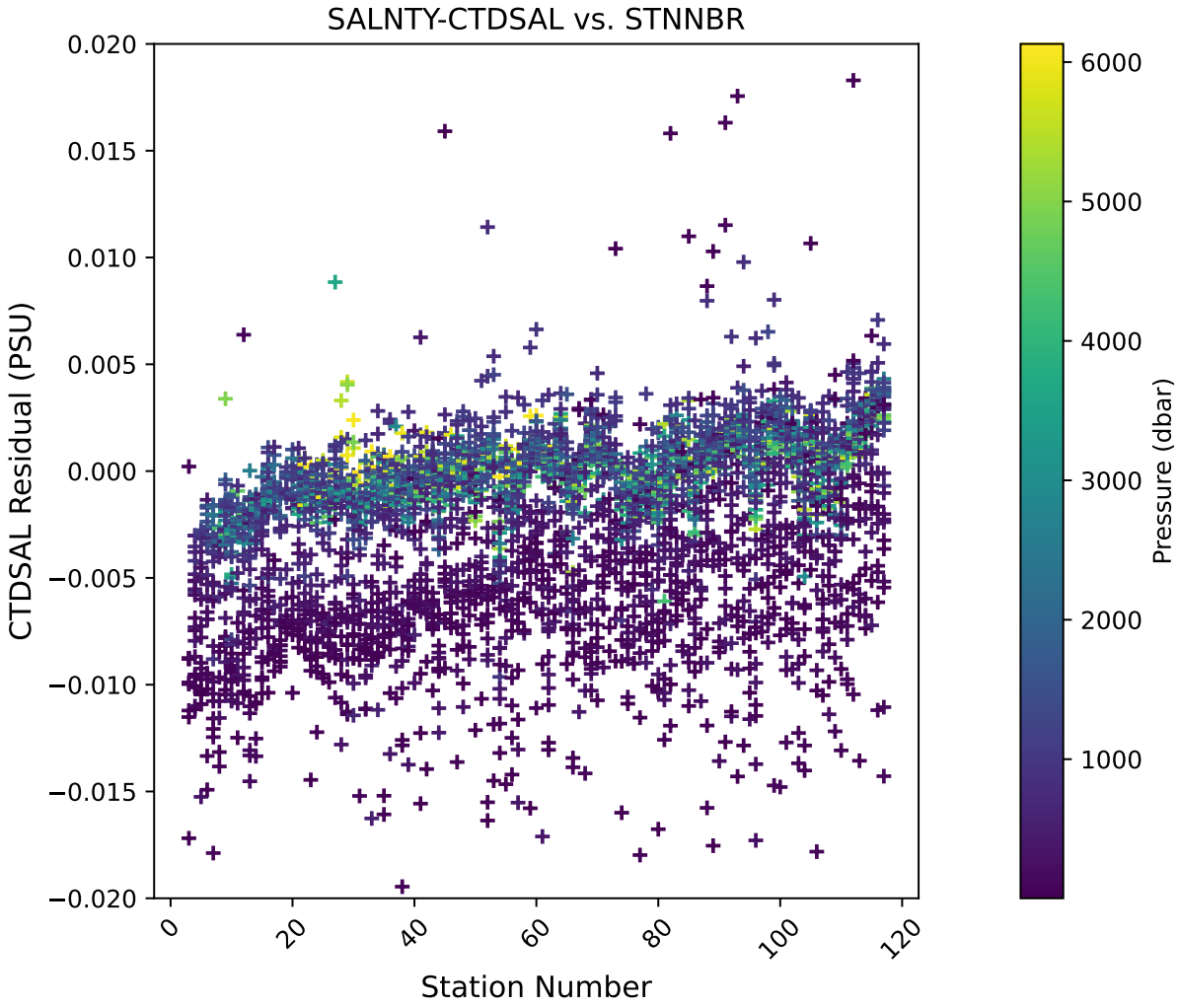


Fig. 20: Salinity residuals versus station.

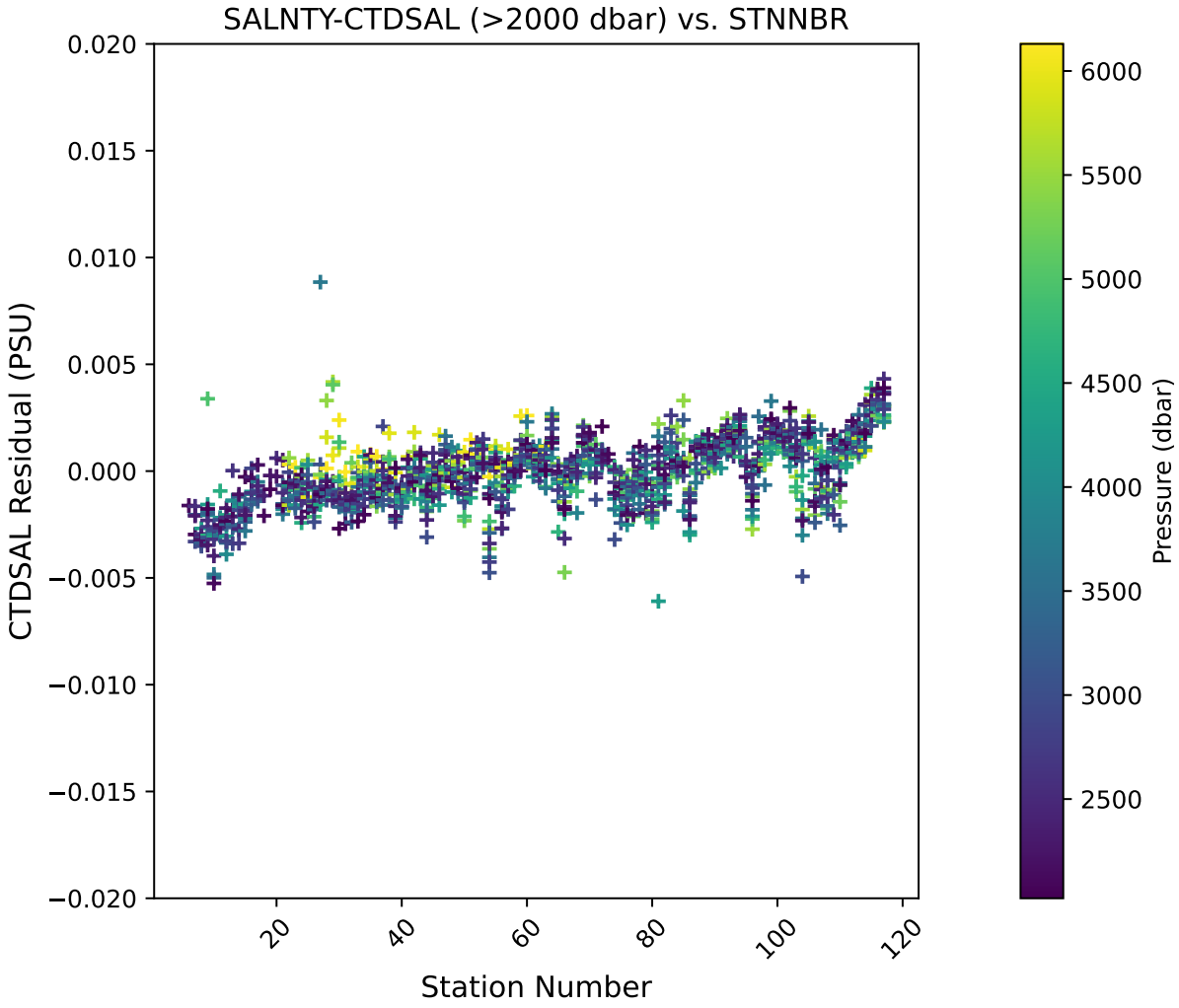


Fig. 21: Deep Salinity residuals versus station (Pressure >= 2000dbar).

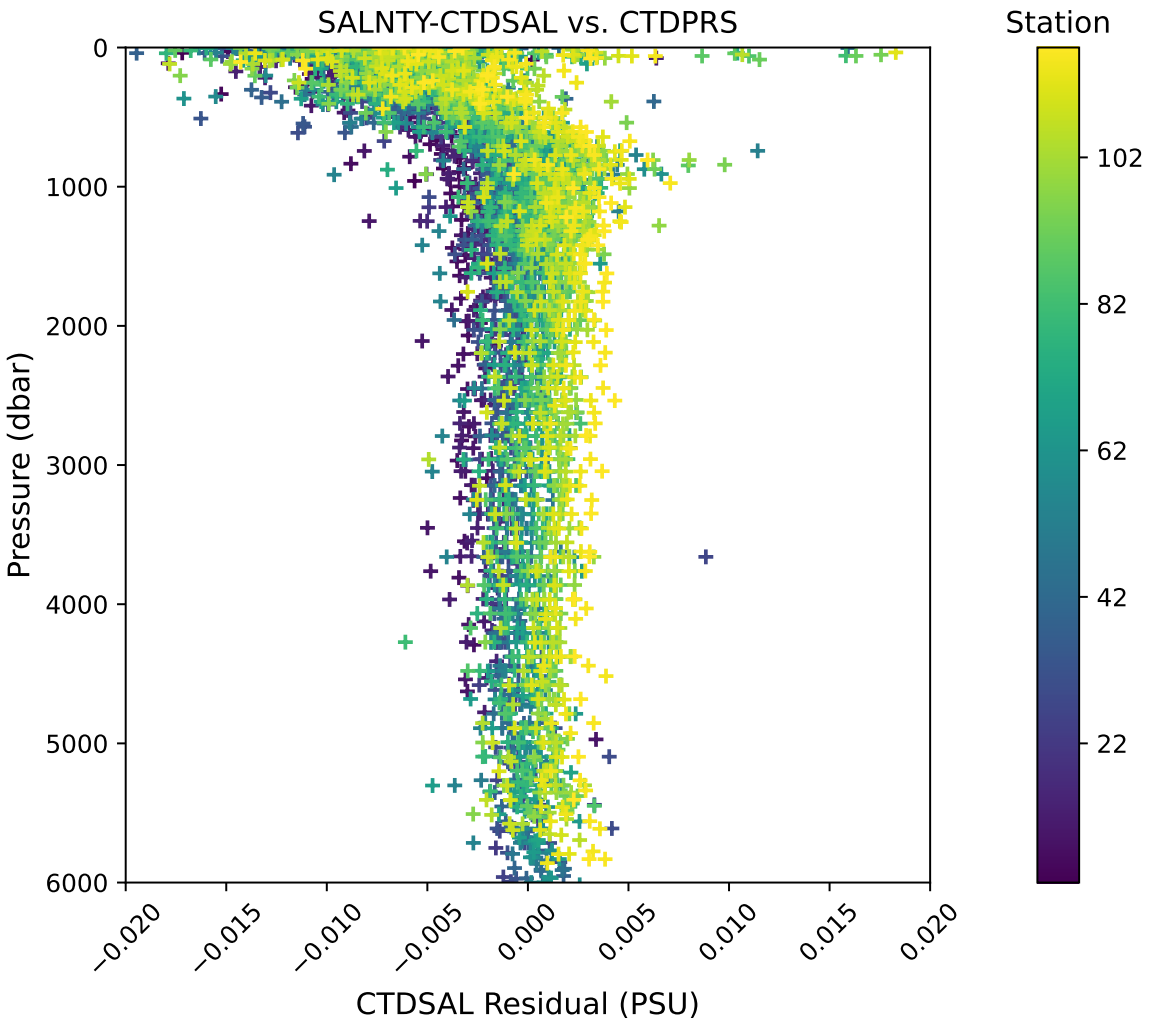


Fig. 22: Salinity residuals versus pressure.

5.6 CTD Dissolved Oxygen (SBE43)

Laboratory calibrations of the dissolved oxygen sensors were performed prior to the cruise at the SBE calibration facility. Dates of laboratory calibration are recorded on the underway sampling package table and calibration documents are provided in the APPENDIX.

The pre-cruise laboratory calibration coefficients were used to convert SBE43 frequencies to µmol/kg oxygen values for acquisition only. Additional shipboard fitting were performed to correct for the sensors non-linear response. Corrections for pressure, temperature, and conductivity sensors were finalized before analyzing dissolved oxygen data. Corrections for hysteresis are applied following Sea-Bird Application Note 64-3. The SBE43 sensor data were compared to dissolved O_2 check samples taken at bottle stops by matching the downcast CTD data to the upcast trip locations along isopycnal surfaces. CTD dissolved O_2 was then calculated using Clark Cell MPOD O_2 sensor response model for Beckman/SensorMedics and SBE43 dissolved O_2 sensors. The residual differences of bottle check value versus CTD dissolved O_2 values are minimized by optimizing the PMEL DO sensor response model coefficients using the BFGS non-linear least-squares fitting procedure.

The general form of the PMEL DO sensor response model equation for Clark cells follows Brown and Morrison [Mill82] and Owens [Owen85]. Dissolved O_2 concentration is then calculated:

$$O_2 = S_{oc} \cdot (V + V_{\text{off}} + \tau_{20} \cdot e^{(D_1 \cdot p + D_2 \cdot (T-20))} \cdot dV/dt) \cdot O_{sat} \cdot e^{T_{cor} \cdot T} \cdot e^{[(E \cdot p)/(273.15+T)]}$$

Where:

- V is oxygen voltage (V)
- D_1 and D_2 are (fixed) SBE calibration coefficients
- T is corrected CTD temperature (°C)
- p is corrected CTD pressure (dbar)
- dV/dt is the time-derivative of voltage (V/s)
- O_{sat} is oxygen saturation
- S_{oc}, V_{off}, τ_{20}, T_{cor}, and E are fit coefficients

All stations were fit together to get an initial coefficient estimate. Stations were then fit individually to refine the coefficients as the membrane does not deform the same way with each cast. If the fit of the individual cast had worse resdiuals than the group, they were reverted to the original group fit coefficients.

Table 5: SBE43 group fit coefficients. Coefficients were further refined station-by-station.

Station	S_{oc}	V_{off}	tau_{20}	T_{cor}	E
1-117	4.5239e-1	-4.4878e-1	1.2000e+0	2.9469e-3	3.9203e-2

CTD dissolved O_2 residuals are shown in the following figures *O2 residuals versus station.* through *Deep O2 residuals versus station (Pressure >= 2000dbar).*.

The 95% confidence limits of 1.67 (µmol/kg) for all acceptable (flag 2) dissolved oxygen bottle data values and 1.34 (µmol/kg) for deep dissolved oxygen values are only presented as general indicators of the goodness of fit. CLIVAR GO-SHIP standards for CTD dissolved oxygen data are < 1% accuracy against on board Winkler titrated dissolved O_2 lab measurements.

Issues arose with the acquisition and processing of CTD dissolved oxygen data.

- SBE43 data appeared noisy at depths exceeding 800 m following a biofouling event during station 32. Sensors were replaced at stations 32 and 94 in an attempt to alleviate the noise, which gradually dissapated by station 101.

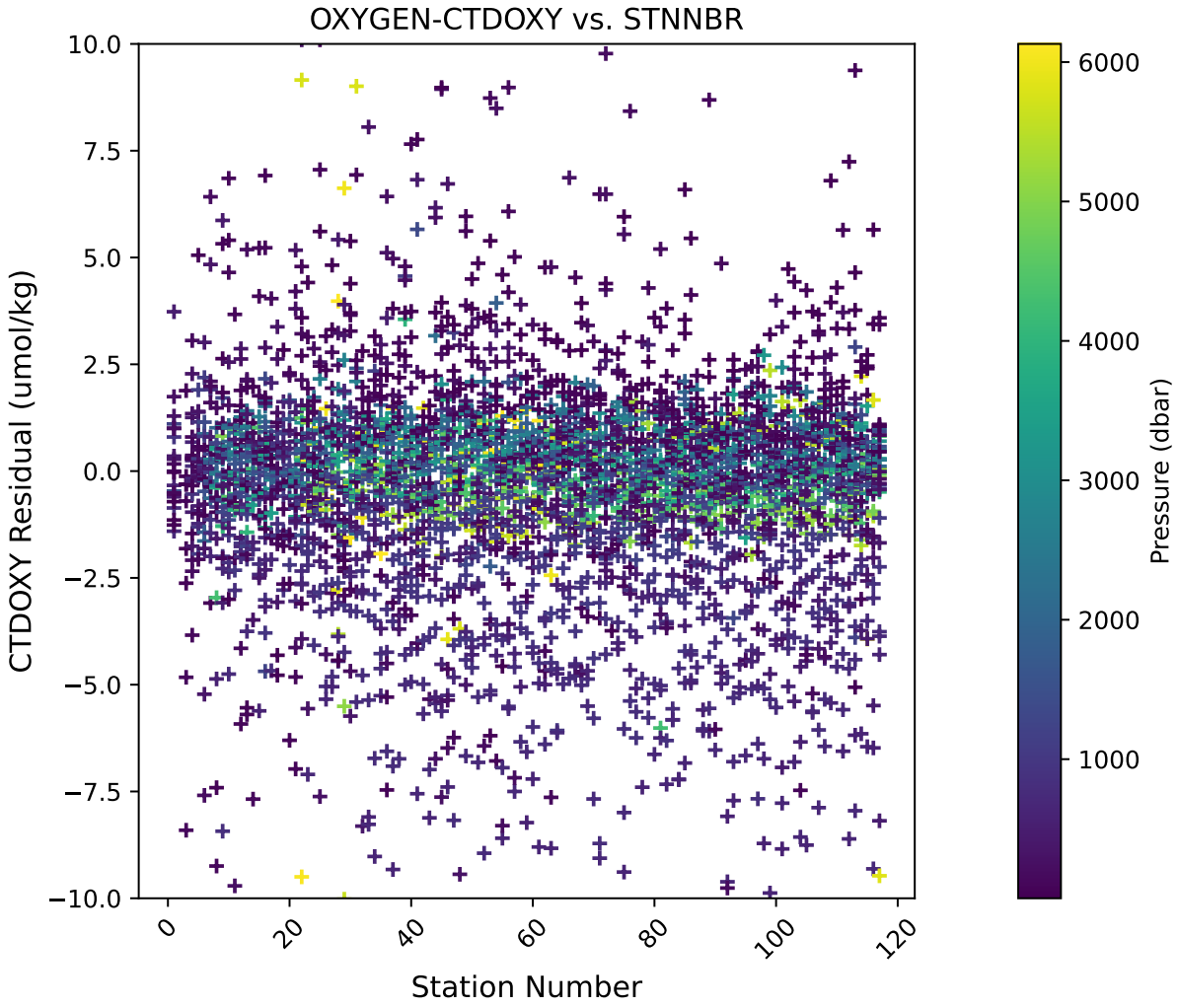


Fig. 23: O_2 residuals versus station.

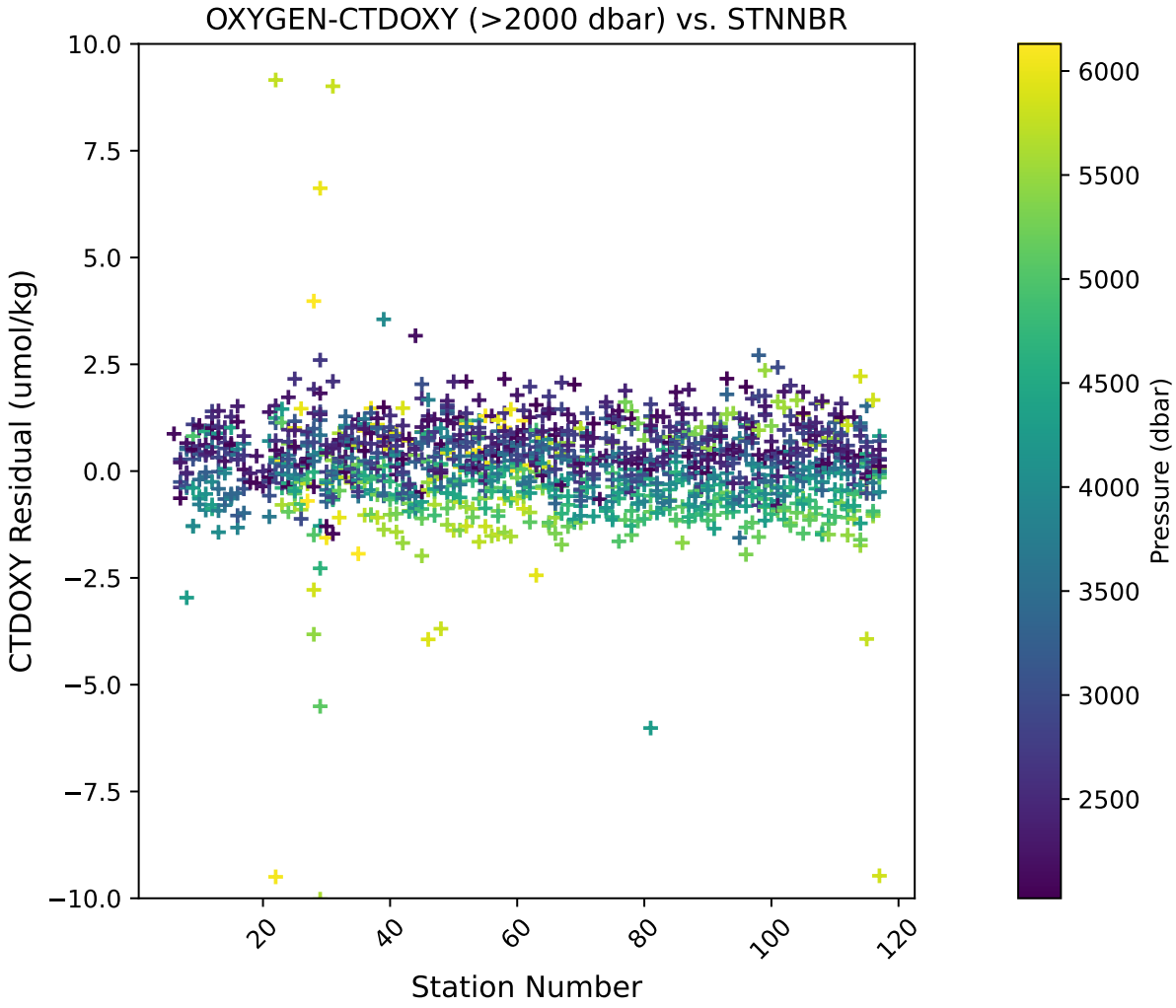


Fig. 24: Deep O_2 residuals versus station (Pressure >= 2000dbar).

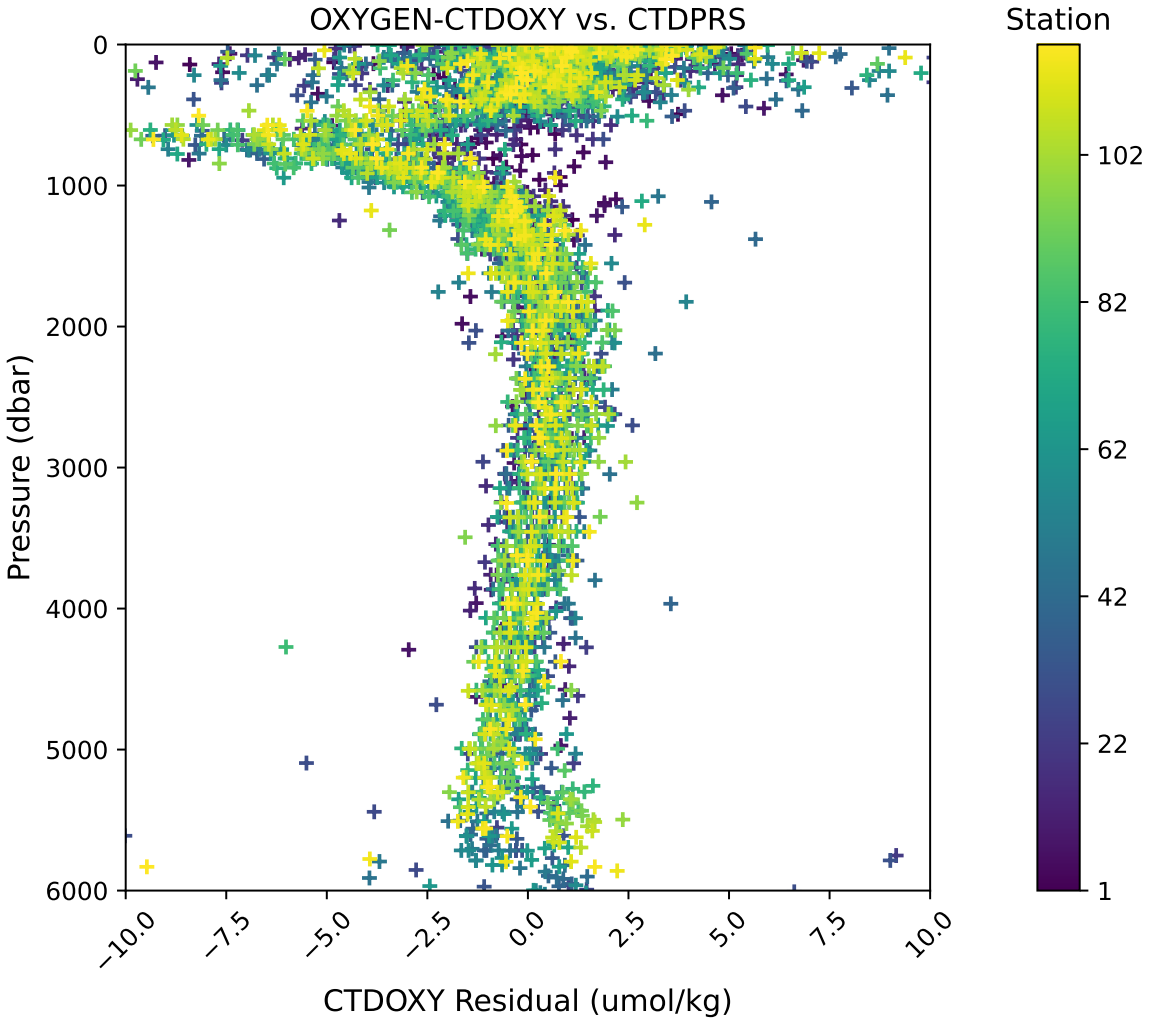


Fig. 25: O_2 residuals versus pressure.

5.7 CTD Dissolved Oxygen (RINKO)

A two-point calibration was performed prior and after deployment on the rosette. These calibrations produced sets of calibration coefficients (G and H) to adjust factory calibration of dissolved oxygen raw voltage. The calibrations also provided an assessment of foil degradation over the course of the 90 stations. As per manufacturer (JFE Advantech Co., Ltd.) recommendation, 100% saturation points were obtained via bubbling ambient air in a stirred beaker of tap water about 30 minutes, removing air stone, then submersing the powered Rinko. Zero point calibrations also followed general manufacturer recommendations, using a sodium sulfite solution (25g in 500mL deionized water). Dissolved oxygen raw voltage (DOout), atmospheric pressure, and solution temperature were recorded for calculation of new oxygen sensor coefficients (G and H).

Rinko temperature (factory coefficients) was used for pre-cruise calibration. Generally, the Rinko III sensor appears to have performed as expected with no major problems or sharp drift throughout the deployment. An SBE 43 dissolved oxygen sensor was deployed simultaneously. Both oxygen sensor data sets were analyzed and quality controlled with Winkler bottle oxygen data. RinkoIII data used as primary oxygen for all stations (1-117), excluding stations 10-12 when the RINKO cable needed to be changed.

RINKO data was acquired, converted from volts to oxygen saturation, and then multipled by the oxygen solubility to find values in µmol/kg. The resulting data were then fitted using the equations developed by [Uchida08]:

$$[O_2] = (V_0/V_c - 1)/K_{sv}$$

$$K_{sv} = c_0 + c_1 T + c_2 T^2, \quad V_0 = 1 + d_0 T, \quad V_c = d_1 + d_2 V_r$$

where:

- T is temperature (ºC)
- V_r is raw voltage (V)
- V_0 is voltage at zero O_2 (V)
- c_0, c_1, c_2, d_0, d_1, d_2 are calibration coefficients

Oxygen is further corrected for pressure effects:

$$[O_2]_c = [O_2](1 + c_p P/1000)^{1/3}$$

where:

- P is pressure (dbar)
- c_p is pressure compensation coefficient

Lastly, salinity corrections are applied [GarciaGordon1992]:

$$[O_2]_{sc} = [O_2]_c \exp[S(B_0 + B_1 T_S + B_2 T_S^2 + B_3 T_S^3) + C_0 S^2]$$

where:

- T_S is scaled temperature (T_S = ln[(298.15 – T)/(273.15 + T)])
- B_0, B_1, B_2, B_3, C_0 are solubility coefficients

All stations excluding 10-12 were fit together to get an initial coefficient estimate. Stations were then fit in groups of similar profiles to get a further refined estimate. Individual casts were then fit to remove the noticeable time drift in coefficients If the fit of the individual cast had worse resdiuals than the group, they were reverted to the original group fit coefficients.

Table 6: Rinko group fit coefficients. Coefficients were further refined station-by-station.

Station	c_0	c_1	c_2	d_0	d_1	d_2	c_p
1-9	1.215e+0	1.5739e-2	8.2708e-5	-1.5391e-3	-9.9882e-2	3.1492e-1	8.507e-2
10-12	-6.3699e+2	1.6180e+3	3.2984e+2	-3.0743e+0	-3.0791e-3	-6.5677e-5	2.e-1
13-117	1.214e+0	1.8755e-2	4.1815e-5	-6.8659e-5	-9.1177e-2	3.2950e-1	8.6109e-2

CTD dissolved O_2 residuals are shown in the following figures.

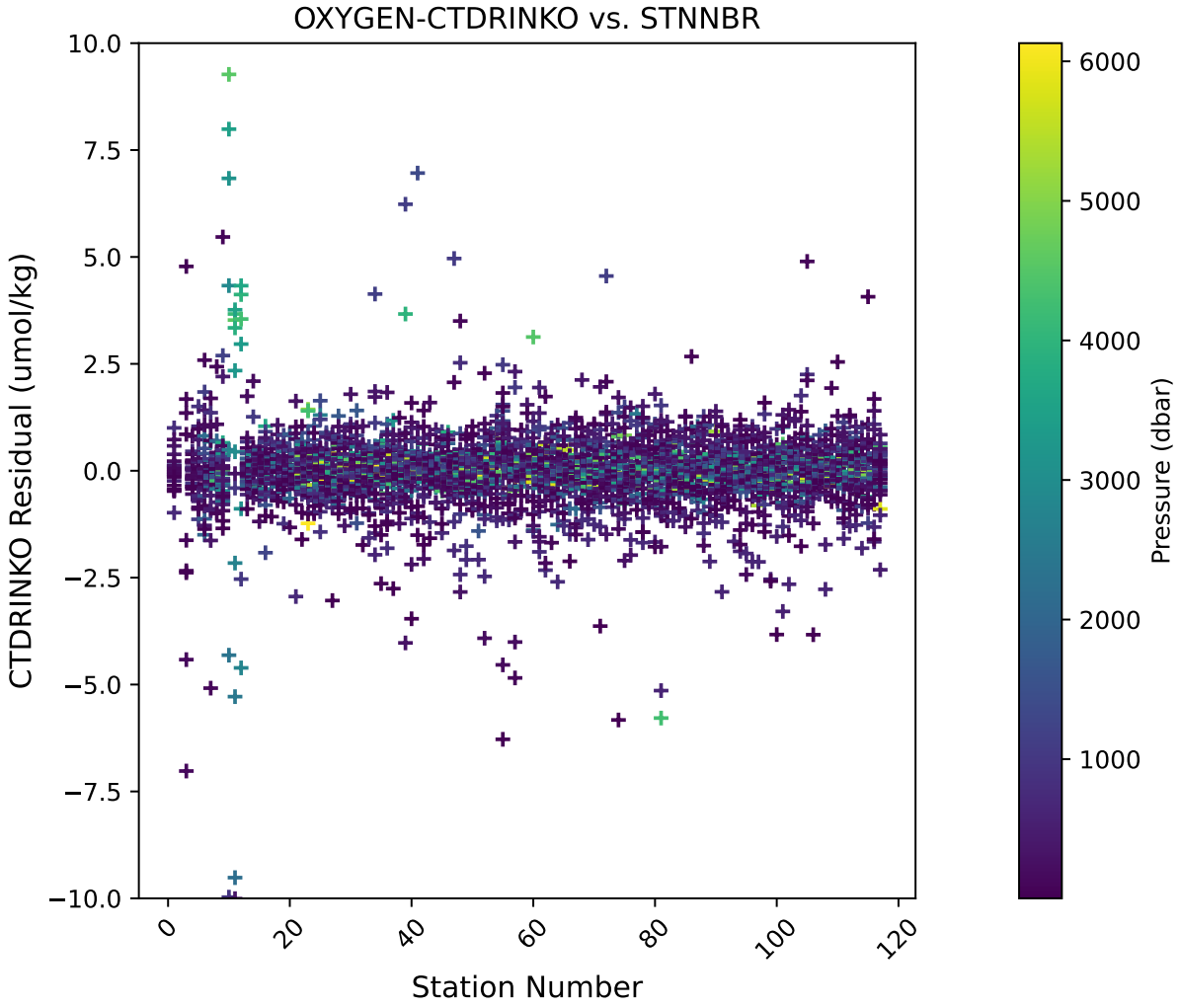


Fig. 26: O_2 residuals versus station.

The 95% confidence limits of 0.95 (µmol/kg) for all acceptable (flag 2) dissolved oxygen bottle data values and 0.58 (µmol/kg) for deep dissolved oxygen values are only presented as general indicators of the goodness of fit. CLIVAR GO-SHIP standards for CTD dissolved oxygen data are < 1% accuracy against on board Winkler titrated dissolved O_2 lab measurements.

Issues arose with the RINKO between stations 10-12. * During 10, the RINKO upcast and downcast displayed abnormal voltages, prompting us to exchange sensor serial 0296 for 0251. * During 11-12, the RINKO voltage routinely spiked to 0. This was resolved by exchanging the RINKO cable connecting it to the CTD. For these reasons, RINKO fit

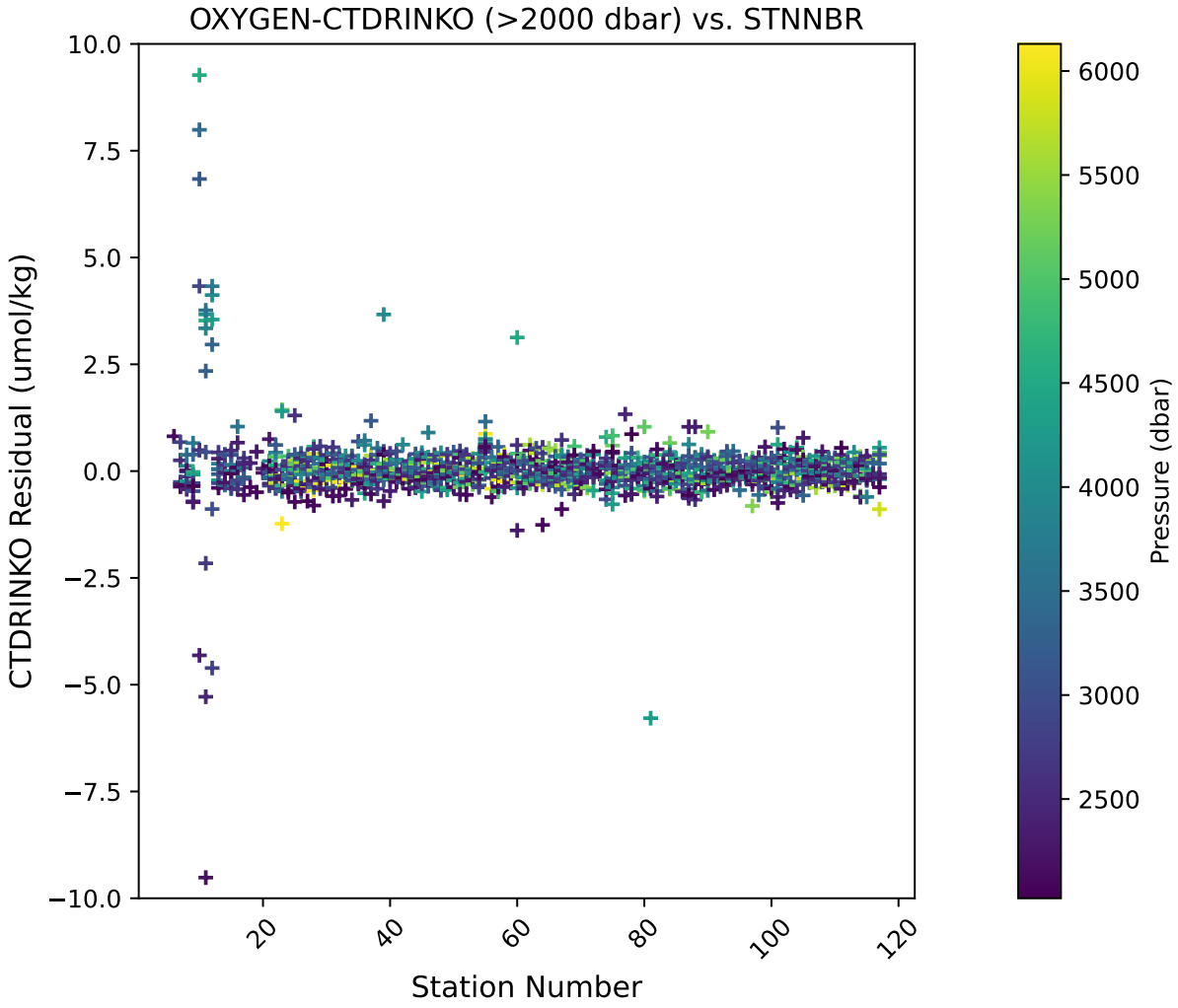


Fig. 27: Deep O_2 residuals versus station (Pressure >= 2000dbar).

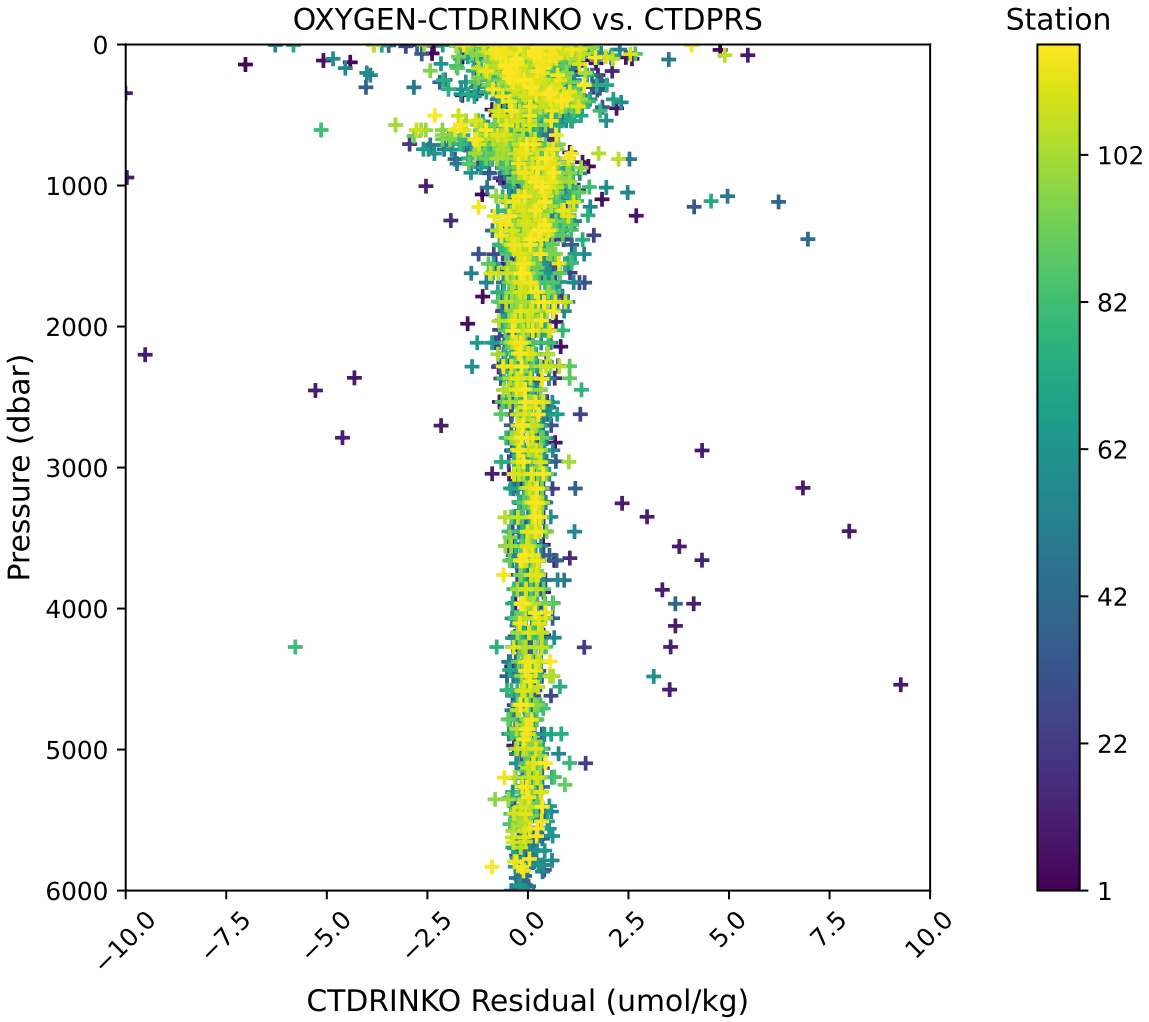


Fig. 28: O_2 residuals versus pressure.

coefficients during stations 10-12 are anomalous and SBE43 oxygen is reported instead.

5.8 BIO Casts

Throughout P02W-2022, 32 bio casts were taken prior to the full cast for separate, large volumes of water for biological analyses. The first bio cast was cast 1 at station 23. The last bio cast was cast 1 at station 116. Salinity and oxygen analyses were not performed during these casts and therefore the CTD was not fit for those parameters.

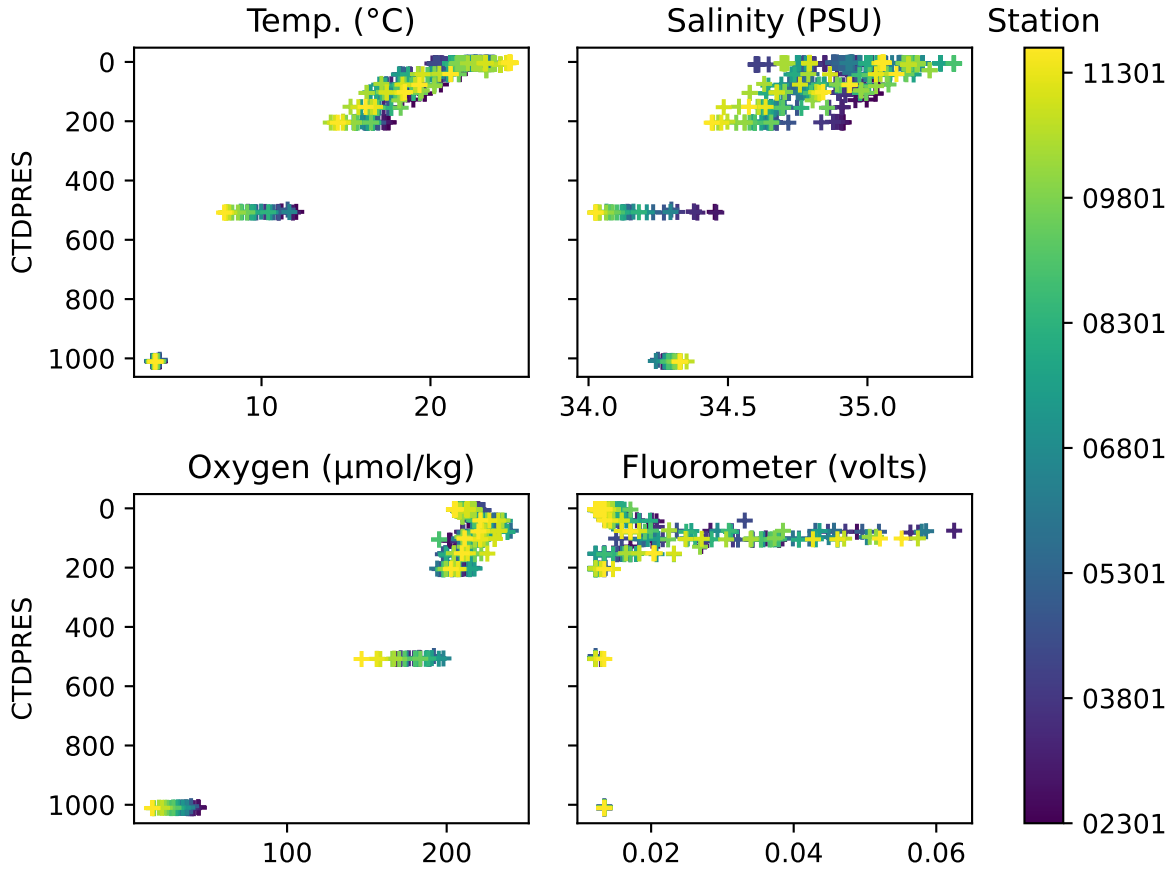


Fig. 29: CTD bottle values for temperature, salinity, oxygen, and fluorometer voltage plotted against CTD pressure across all bottle casts.

CHAPTER

SIX

SALINITY

PIs

- Todd Martz (SIO)
- Susan Becker (SIO)

Technicians

- John Calderwood (SIO)
- Royhon Agostine (SIO)

6.1 Equipment and Techniques

Two Guildline Autosals were on board and operational, SIO-owned 8400A S/N 57-526 and 8400B S/N 69-180. S/N 57-526 was used for all salinity measurements during this cruise. The salinity analysis was run in the ship's Climate Controlled Chamber, a refrigerator port and amidships between the Computer Lab and Bioanalytical Lab. The chamber temperature varied between about 21 and 25 degrees Celcius around 3 times each hour, with an average (based on measuring temperatures of items in the chamber) of about 23°C.

IAPSO Standard Seawater Batch P-165 was used for all calibrations: K15 = 0.99986, salinity 34.994, expiration 2024-04-15. A LabView program developed by Carl Mattson was used for monitoring temperatures, logging data and prompting the operator. Salinity analyses were performed after samples had equilibrated to laboratory temperature of 23°C, usually 8 hours or more after collection. Samples were placed under fans to speed their acclimatization to the set room temperature.

The salinometer was standardized for each group of samples analyzed (normally 1 or 2 casts, up to 72 samples) using two bottles of standard seawater: one at the beginning and one at the end of each set of measurements. For each calibration standard and sample reading, the salinometer cell was initially flushed at least 2 times before a set of conductivity ratio readings was recorded. Standardization conductivity offsets did not exceed 0.00005 mS/cm for all casts. Between runs the water from the last standard was left in the cell.

6.2 Sampling and Data Processing

The salinity samples were collected in 200 ml Kimax high-alumina borosilicate bottles that had been rinsed at least three times with sample water prior to filling. The bottles were sealed with plastic insert thimbles and Nalgene screw caps. This assembly provides very low container dissolution and sample evaporation. Prior to sample collection, inserts were inspected for proper fit and loose inserts replaced to insure an airtight seal. Laboratory temperature was also monitored electronically throughout the cruise. PSS-78 salinity [UNESCO1981] was calculated for each sample from the measured conductivity ratios. The offset between the initial standard seawater value and its reference value was applied to each sample. Then the difference (if any) between the initial and final vials of standard seawater was

applied to each sample as a function of elapsed run time. The corrected salinity data was then incorporated into the cruise database.

6.3 Narrative

3955 salinity samples were taken during P02W-2022, including 22 samples from test cast 00102. Due to ambient electrical noise, the 8400A Autosal was used over the 8400B Autosal for all samples and practice. 8 samples were used for practice prior to arrival at the test station and are not reported. One sample bottle (#2) was broken and replaced during sampling, but the cast number was not recorded. One sample bottle (#34) was broken and replaced during sampling of cast 05701.

CHAPTER

SEVEN

NUTRIENTS

Technicians

- Susan Becker: Scripps Institution of Oceanography
- Megan Roadman: Scripps Institution of Oceanography

7.1 Summary of Analysis

- 3976 samples from 117 CTD stations
- The cruise started with new pump tubes and they were changed twice, before stations 039 and 082
- 6 sets of Primary/Secondary mixed standards and 3 sets of primary Nitrite standards were made up over the course of the cruise.
- The cadmium column efficiency was checked periodically and ranged between 85%-100%.

7.2 Equipment and Techniques

Nutrient analyses (phosphate, silicate, nitrate+nitrite, and nitrite) were performed on a Seal Analytical continuous-flow AutoAnalyzer 3 (AA3). The methods used are described by Gordon et al [Gordon1992] Hager et al. [Hager1972], and Atlas et al. [Atlas1971]. Details of modification of analytical methods used in this cruise are also compatible with the methods described in the nutrient section of the updated GO-SHIP repeat hydrography manual (Becker et al., 2019, [Becker2019]).

7.3 Nitrate/Nitrite Analysis

A modification of the Armstrong et al. (1967) [Armstrong1967] procedure was used for the analysis of nitrate and nitrite. For nitrate analysis, a seawater sample was passed through a cadmium column where the nitrate was reduced to nitrite. This nitrite was then diazotized with sulfanilamide and coupled with N-(1-naphthyl)-ethylenediamine to form a red dye. The sample was then passed through a 10mm flowcell and absorbance measured at 520nm. The procedure was the same for the nitrite analysis but without the cadmium column.

REAGENTS

Sulfanilamide Dissolve 10g sulfamilamide in 1.2N HCl and bring to 1 liter volume. Add 2 drops of 40% surfynol 465/485 surfactant. Store at room temperature in a dark poly bottle.

Note: 40% Surfynol 465/485 is 20% 465 plus 20% 485 in DIW.

N-(1-Naphthyl)-ethylenediamine dihydrochloride (N-1-N) Dissolve 1g N-1-N in DIW, bring to 1 liter volume. Add 2 drops 40% surfynol 465/485 surfactant. Store at room temperature in a dark poly bottle. Discard if the solution turns dark reddish brown.

Imidazole Buffer Dissolve 13.6g imidazole in ~3.8 liters DIW. Stir for at least 30 minutes to completely dissolve. Add 60 ml of $CuSO_4$ + NH_4Cl mix (see below). Add 4 drops 40% Surfynol 465/485 surfactant. Let sit overnight before proceeding. Using a calibrated pH meter, adjust to pH of 7.83-7.85 with 10% (1.2N) HCl (about 10 ml of acid, depending on exact strength). Bring final solution to 4L with DIW. Store at room temperature.

NH_4Cl + $CuSO_4$ mix Dissolve 2g cupric sulfate in DIW, bring to 100 m1 volume (2%). Dissolve 250g ammonium chloride in DIW, bring to 1l liter volume. Add 5ml of 2% $CuSO_4$ solution to this NH_4Cl stock. This should last many months.

7.4 Phosphate Analysis

Ortho-Phosphate was analyzed using a modification of the Bernhardt and Wilhelms (1967) [Bernhardt1967] method. Acidified ammonium molybdate was added to a seawater sample to produce phosphomolybdic acid, which was then reduced to phosphomolybdous acid (a blue compound) following the addition of dihydrazine sulfate. The sample was passed through a 10mm flowcell and absorbance measured at 820nm.

REAGENTS

Ammonium Molybdate H_2SO_4 sol'n Pour 420 ml of DIW into a 2 liter Ehrlenmeyer flask or beaker, place this flask or beaker into an ice bath. SLOWLY add 330 ml of conc H_2SO_4. This solution gets VERY HOT!! Cool in the ice bath. Make up as much as necessary in the above proportions.

Dissolve 27g ammonium molybdate in 250ml of DIW. Bring to 1 liter volume with the cooled sulfuric acid sol'n. Add 3 drops of 15% DDS surfactant. Store in a dark poly bottle.

Dihydrazine Sulfate Dissolve 6.4g dihydazine sulfate in DIW, bring to 1 liter volume and refrigerate.

7.5 Silicate Analysis

Silicate was analyzed using the basic method of Armstrong et al. (1967). Acidified ammonium molybdate was added to a seawater sample to produce silicomolybdic acid which was then reduced to silicomolybdous acid (a blue compound) following the addition of stannous chloride. The sample was passed through a 10mm flowcell and measured at 660nm.

REAGENTS

Tartaric Acid Dissolve 200g tartaric acid in DW and bring to 1 liter volume. Store at room temperature in a poly bottle.

Ammonium Molybdate Dissolve 10.8g Ammonium Molybdate Tetrahydrate in 1000ml dilute H_2SO_4. (Dilute H_2SO_4 = 2.8ml conc H_2SO_4 or 6.4ml of H_2SO_4 diluted for PO_4 moly per liter DW) (dissolve powder, then add H_2SO_4) Add 3-5 drops 15% SDS surfactant per liter of solution.

Stannous Chloride stock: (as needed)

Dissolve 40g of stannous chloride in 100 ml 5N HCl. Refrigerate in a poly bottle.

NOTE: Minimize oxygen introduction by swirling rather than shaking the solution. Discard if a white solution (oxychloride) forms.

working: (every 24 hours) Bring 5 ml of stannous chloride stock to 200 ml final volume with 1.2N HCl. Make up daily - refrigerate when not in use in a dark poly bottle.

7.6 Sampling

Nutrient samples were drawn into 30 ml polypropylene screw-capped centrifuge tubes. The tubes and caps were cleaned with 10% HCl and rinsed 2-3 times with sample before filling. Samples were analyzed within 4 hours after sample collection, allowing sufficient time for all samples to reach room temperature. The centrifuge tubes fit directly onto the sampler.

7.7 Data Collection and Processing

Data collection and processing was done with the software provided with the instrument from Seal Analytical (AACE). After each run, the charts were reviewed for any problems during the run, any blank was subtracted, and final concentrations (micro moles/liter) were calculated, based on a linear curve fit. Once the run was reviewed and concentrations calculated a text file was created. That text file was reviewed for possible problems and then converted to another text file with only sample identifiers and nutrient concentrations that was merged with other bottle data.

7.8 Standards and Glassware Calibration

Primary standards for silicate (Na_2SiF_6), nitrate (KNO_3), nitrite ($NaNO_2$), and phosphate (KH_2PO_4) were obtained from Johnson Matthey Chemical Co. and/or Fisher Scientific. The supplier reports purities of >98%, 99.999%, 97%, and 99.999 respectively.

All glass volumetric flasks and pipettes were gravimetrically calibrated prior to the cruise. The primary standards were dried and weighed out to 0.1mg prior to the cruise. The exact weight was noted for future reference. When primary standards were made, the flask volume at 20C, the weight of the powder, and the temperature of the solution were used to buoyancy-correct the weight, calculate the exact concentration of the solution, and determine how much of the primary was needed for the desired concentrations of secondary standard. The new standards were compared to the old before use.

All the reagent solutions, primary and secondary standards were made with fresh distilled deionized water (DIW).

Standardizations were performed at the beginning of each group of analyses with working standards prepared every 12-16 hours from a secondary. Working standards were made up in low nutrient seawater (LNSW). Multiple batches of LNSW were used on the cruise. The first batch of LNSW was treated in the lab. The water was re-circulated for ~8 hours through a 0.2 micron filter, passed a UV lamp and through a second 0.2 micron filter. The actual concentration of nutrients in this water was empirically determined during the standardization calculations.

The concentrations in micro-moles per liter of the working standards used were:

-	N+N (uM)	PO_4 (uM)	SIL (uM)	NO_2 (uM)
0	0.0	0.0	0.0	0.0
3	15.50	1.2	60	0.50
5	31.00	2.4	120	1.00
7	46.50	3.6	180	1.50

7.9 Quality Control

All final data was reported in micro-moles/kg. NO_3, PO_4, and NO_2 were reported to two decimals places and SIL to one. Accuracy is based on the quality of the standards the levels are:

NO_3	0.05 µM (micro moles/Liter)
PO_4	0.004 µM
SIL	2-4 µM
NO_2	0.05 µM

Reference materials for nutrients in seawater (RMNS) were used as a check sample run with every station. The RMNS preparation, verification, and suggested protocol for use of the material are described by [Aoyama2006] [Aoyama2007], [Aoyama2008], Sato [Sato2010] and Becker et al. [Becker2019]. RMNS batch CM was used on this cruise, with each bottle being used for all runs in one day before being discarded and a new one opened. Data are tabulated below.

Parameter	Concentration	stddev	assigned conc
-	(µmol/kg)	-	(µmol/kg)
NO_3	33.16	0.13	33.2
PO_4	2.38	0.01	2.38
Sil	100.4	0.61	100.5
NO_2	0.019	0.008	0.02

7.10 Analytical Problems

There were issues with carryover and sensitivity on the phosphate channel early in the cruise that were resolved over time. Similar problems with Silicate were encountered for the last few stations. The values of the reference material and the were used to monitor data quality. Adjustments based on the values obtained for the references material were made as necessary. The adjusted data for affected stations was compared to adjacent stations and historical data during the final QC checks.

CHAPTER

EIGHT

OXYGEN ANALYSIS

PIs

- Susan Becker (SIO)
- James Swift (SIO)

Technicians

- Andrew Barna (SIO)
- Elisa Aitoro (SIO)

8.1 Equipment and Techniques

Dissolved oxygen analyses were performed with an SIO/ODF-designed automated oxygen titrator using photometric end-point detection based on the absorption of 365nm wavelength ultra-violet light. The titration of the samples and the data logging were controlled by PC LabView software. Thiosulfate was dispensed by a Dosimat 665 buret driver fitted with a 1.0 ml burette.

ODF used a whole-bottle modified-Winkler titration following the technique of Carpenter [Carpenter1965] with modifications by [Culberson1991] but with higher concentrations of potassium iodate standard (~0.012 N), and thiosulfate solution (~55 g/L).

Pre-made liquid potassium iodate standards and reagent/distilled water blanks were run every day (approximately every 3-4 stations), with samples analysed within 24 hours of the last standard.

8.2 Sampling and Data Processing

A total of 3975 oxygen measurements were made, all but one of which were niskin samples. Niskin samples were collected soon after the rosette was secured on deck, either from fresh niskins or immediately following CFC sampling.

Nominal 125 mL volume-calibrated biological oxygen demand (BOD) flasks were rinsed 3 times with minimal agitation using a silicone draw tube, then filled and allowed to overflow for at least 3 flask volumes, ensuring no bubbles remained. Pickling reagents MnCl2 and NaI/NaOH (1 mL of each) were added via bottle-top dispensers to fix samples before stoppering. Flasks were shaken twice (10-12 inversions) to assure thorough dispersion of the precipitate - once immediately after drawing and then again after 30-60 minutes.

Sample draw temperatures, measured with an electronic resistance temperature detector (RTD) embedded in the draw tube, were used to calculate umol/kg concentrations, and as a diagnostic check of bottle integrity.

Niskin samples were analysed within 2-12 hours of collection, and the data incorporated into the cruise database. Underway samples were analysed within 96 hours of collection.

Thiosulfate normalities were calculated for each standardisation and corrected to 20°C. The 20°C thiosulfate normalities and blanks were plotted versus time and were reviewed for possible problems, and were subsequently determined to be stable enough that no smoothing was required.

8.3 Volumetric Calibration

Oxygen flask volumes were determined gravimetrically with degassed deionised water to determine flask volumes at ODF's chemistry laboratory. This is done once before using flasks for the first time and periodically thereafter when a suspect volume is detected. The 10 mL Dosimat buret used to dispense standard iodate solution was calibrated using the same method.

8.4 Standards

Liquid potassium iodate standards were prepared in 6 L batches and bottled in sterile glass bottles at ODF's chemistry laboratory prior to the expedition. The normality of the liquid standard was determined by calculation from weight. The standard was supplied by Alfa Aesar and has a reported purity of 99.4-100.4%. All other reagents were "reagent grade" and were tested for levels of oxidising and reducing impurities prior to use.

8.5 Narrative

The oxygen analytical rig was setup in the main lab of the Revelle. As a result of wanting to conserve DI water while in port, only 1L batches of all reagents were made until the ship was underway.

No major analytical issues were encountered. A few high end points occurred and were corrected for. The analytical computer would freeze occasionally, but never while doing analysis.

The thiosulfate stability was considered in 3 batches and showed remarkable stability throughout the entire cruise. No trends were observed or corrected for.

An OSIL standard was run against the usual ODF working standard using a hand pipetter. The agreement between the OSIL and the ODF standard was just within the daily tolerance.

No data updates are expected.

CHAPTER

NINE

TOTAL ALKALINITY

PIs

- Andrew G. Dickson (SIO)

Technicians

- Daniela Nestory (SIO)
- Sara Gray (SIO)

9.1 Total Alkalinity

The total alkalinity of sea water is defined as the number of moles of hydrogen ion equivalent to the excess of proton acceptors (bases formed from weak acids with a dissociation constant K < 10E-4.5 at 25°C and zero ionic strength) over proton donors (acids with K > 10E-4.5) in 1 kilogram of sample.

9.2 Total Alkalinity Measurement System

Sample Delivery System:

Samples are dispensed using a Sample Delivery System (SDS) which has been calibrated for volume in the lab prior to the cruise. Its volume is confirmed immediately before use at sea to ensure a consistent volume will be delivered for each sample. The SDS consists of a volumetric pipette, various relay valves, an air pump, and is controlled by a program in LabVIEW 2012.

Before attaching a sample bottle to the SDS, the volumetric pipette is cleared of any residual solution. The pipette is then rinsed and filled with the sample. The sample overflows and time is allowed for the sample temperature to equilibrate.

The sample bottle temperature is measured using a DirecTemp thermistor probe inserted into the sample bottle and the volumetric pipette temperature is measured using a DirecTemp surface probe placed directly on the pipette. These temperature measurements, along with the bottle salinity, are used to convert the sample volume to mass for analysis.

Samples are delivered into a 250-mL water-jacketed open cell for titration analysis. While one sample is undergoing titration, a second sample is prepared with the SDS and equilibrated to 20°C for analysis.

Open-Cell Titration:

The total alkalinity is measured through an open-cell titration with a dilute hydrochloric acid titrant of known concentration. A Metrohm 876 Dosimat Plus is used for all standardized hydrochloric acid additions.

An initial aliquot of approximately 2.3-2.4 mL of standardized hydrochloric acid (~0.1M HCl in ~0.6M NaCl solution) is first delivered and the sample is stirred for 5 minutes while air is bubbled into at a rate of 200 scc/m to remove any liberated carbon dioxide gas.

After equilibration, ~19 aliquots of 0.035 ml are added. Between the pH range of 3.5 to 3.0, the progress of the titration is monitored using a pH glass electrode/reference electrode cell, and the total alkalinity is computed from the titrant volume and e.m.f. measurements using a non-linear least-squares approach ([Dickson2007]).

A Thermo Scientific Isotemp water bath is connected to the water-jacketed open cell to maintain a cell temperature of approximately 20oC. An Agilent 34970A Data Acquisition/Switch Unit with a 34901A multiplexer is used to read the voltage measurements from the electrode and monitor the temperatures from the sample, acid, and room.

The calculations for this procedure are performed automatically using LabVIEW 2012.

9.3 Sample Collection

Alkalinity samples are drawn using silicone tubing connected to the Niskin bottles and collected into 250 mL Pyrex bottles. The sample bottles and Teflon-sleeved glass stoppers were rinsed at least twice before the final filling. A headspace of approximately 3 mL was removed and 0.05 mL of saturated mercuric chloride solution was added to each sample for preservation. The samples were equilibrated prior to analysis at approximately 20°C using a Thermo Scientific Isotemp water bath.

Samples for total alkalinity were taken at all stations during A22 (1-90). Except for a few instances, alkalinity samples were collected from each niskin where DIC and pH were collected, to over-characterize the CO2 system. The typical sample scheme of full collection on even-numbered stations (36 niskin bottles) and partial collection (~8-20 bottles) on odd-numbered stations was followed.

In order to evaluate the reproducibility of the alkalinity system, duplicate samples (two separate alkalinity bottles) were collected at a minimum of 10% of total samples. For instance, when all 36 niskins were sampled, 3 duplicate samples were collected for alkalinity. When alkalinity sampled a partial cast, one or two duplicate samples were collected.

9.4 Problems and Troubleshooting

There were no major analytical issues encountered.

At a few points during the cruise, the electrode was changed due to signs of aging. Any affected samples were re-analyzed for accurate values.

9.5 Quality Control

Certified Reference Material (CRMs) and duplicate samples (two bottles collected from one niskin) were used to quality check the functioning of the total alkalinity system throughout the cruise.

Dickson laboratory Certified Reference Material (CRM) Batches 188, 199 and 200 were used to determine the accuracy of the total alkalinity analyses. The total alkalinity certified value for these batches are:

- Batch 188: 2264.96 $\pm$ 0.73 µmol/kg
- Batch 199 2202.75 $\pm$ 0.70 µmol/kg
- Batch 200 2186.43 $\pm$ 0.42 µmol/kg

The cited uncertainties represent the standard deviation.

A CRM sample was analyzed at a minimum frequency of once per every 20 runs, but more often once per every 15 runs. Because total alkalinity is not affected by gas-exchange, brand new CRM bottles were reserved for pH and DIC analysis. These pre-opened bottles were subsequently used for alkalinity analysis.

242 reference material samples were analyzed on P02W.

The average measured total alkalinity value for each batch is:

- Batch 188: 2265.58 $\pm$ 1.54 µmol kg-1 (n = 35; 19)
- Batch 199 2202.88 $\pm$ 1.33 µmol/kg (n = 135, 80)
- Batch 200 2186.20 $\pm$ 1.10 µmol/kg (n = 93, 48)

Figures in parentheses are the number of analyses made (total number of analyses; number of separate bottles analyzed).

Duplicate samples were also used to check the reproducibility of the system. The absolute value of the mean offset between duplicate samples and the standard deviation are given below.

Mean duplicate sample offset: 0.96 $\pm$ 0.90 µmol kg-1 (n = 230)

3036 total alkalinity values were submitted for P02W.

Further dilution corrections need to be applied to this data back onshore, therefore, this data is to be considered preliminary.

CHAPTER

TEN

DISCRETE PH ANALYSES (TOTAL SCALE)

PI

- Dr. Andrew Dickson (SIO)

Technicians

- Albert Ortiz (RSMAS)
- Brison Grey (RSMAS)

10.1 Sampling

Samples were collected in 250 mL Pyrex glass bottles and sealed using grey butyl rubber stoppers held in place by aluminum-crimped caps. Each bottle was rinsed two times and allowed to overflow by one half additional bottle volume. Prior to sealing, each sample was given a 1% headspace and poisoned with 0.02% of the sample volume of saturated mercuric chloride ($HgCl_2$). Samples were collected only from Niskin bottles that were also being sampled for both total alkalinity and dissolved inorganic carbon in order to completely characterize the carbon system. Additionally, duplicate samples were collected from all stations for quality control purposes.

10.2 Analysis

pH was measured spectrophotometrically on the total hydrogen scale using an Agilent 8453 spectrophotometer and in accordance with the methods outlined by Carter et al, 2013. [Carter2013]. A Kloehn V6 syringe pump was used to autonomously fill, mix, and dispense sample through the custom 10cm flow-through jacketed cell. A Thermo Fisher Isotemp recirculating water bath was used to maintain the cell temperature at 25.0°C during analyses, and a YSI 4600 precision thermometer and probe were used to monitor and record the temperature of each sample during the spectrophotometric measurements. Purified meta-cresol purple (mCP) was the indicator used to measure the absorbance of light measured at two different wavelengths (434 nm, 578 nm) corresponding to the maximum absorbance peaks for the acidic and basic forms of the indicator dye. A baseline absorbance was also measured and subtracted from these wavelengths. The baseline absorbance was determined by averaging the absorbances from 725-735nm. The ratio of the absorbances was then used to calculate pH on the total scale using the equations outlined in Liu et al., 2011 [Liu2011]. The salinity data used was obtained from the salinity analysis conducted on board.

10.3 Reagents

The mCP indicator dye was made up to a concentration of approximately 2.0mM and a total ionic strength of 0.7 M. A total of two batches were used during A22. The pHs of these batches were adjusted with 0.1 mol kg^{-1} solutions of HCl and NaOH (in 0.6 mol kg^{-1} NaCl background) to approximately 7.80, measured with a pH meter calibrated with NBS buffers. The indicator was obtained from Dr. Robert Byrne at the University of Southern Florida and was purified using the flash chromatography technique described by Patsavas et al., 2013. [Patsavas2013].

10.4 Data Processing

An indicator dye is itself an acid-base system that can change the pH of the seawater to which it is added. Therefore it is important to estimate and correct for this perturbation to the seawater's pH for each batch of dye used during the cruise. To determine this correction, multiple bottles from each station were measured twice, once with a single addition of indicator dye and once with a double addition of indicator dye. The measured absorbance ratio (R) and an isosbestic absorbance (A_{iso}) were determined for each measurement, where:

$$R = \frac{A_{578} - A_{\text{base}}}{A_{434} - A_{\text{base}}}$$

and

$$A_{\text{iso}} = A_{488} - A_{\text{base}}$$

The change in R for a given change in A_{iso}, $\Delta R/\Delta A_{\text{iso}}$, was then plotted against the measured R-value for the normal amount of dye and fitted with a linear regression. From this fit the slope and y-intercept (b and a respectively) are determined by:

$$\Delta R/\Delta A_{\text{iso}} = bR + a$$

From this the corrected ratio (R') corresponding to the measured absorbance ratio if no indicator dye were present can be determined by:

$$R' = R - A_{\text{iso}}(bR + a)$$

10.5 Problems and Troubleshooting

During the beginning of the cruise, the tungsten lamp in the spectrophotometer was replaced due to aging.

Around station 50, the sample cell was broken due to stress on the cell body. The

10.6 Standardization/Results

The precision of the data was assessed from measurements of duplicate analyses, replicate analyses (two successive measurements on one bottle), and certified reference material (CRM) Batch 200 (provided by Dr. Andrew Dickson, UCSD). two or three duplicates and one or two replicate measurements were performed on every station when at least twenty-four Niskins were sampled. If less than twenty-four Niskins were sampled, only one or two duplicates and one replicate measurement were performed. CRMs were measured at the beginning and ending of each day.

The precision statistics for P02W are:

Duplicate precision	$\pm$ 0.0008 (n= 258)
B200	7.7991 $\pm$ 0.0014 (n= 58)

3035 pH values were submitted for P02W. Additional corrections will need to be performed and these data should be considered preliminary until a more thorough analysis of the data can take place on shore.

CHAPTER

ELEVEN

DISSOLVED INORGANIC CARBON (DIC)

PI's

- Richard A. Feely (NOAA/PMEL)
- Rik Wanninkhof (NOAA/AOML)

Technicians

- Dana Greeley (NOAA/PMEL)
- Julian Herndon (NOAA/PMEL)

11.1 Sample Collection

Samples for *DIC* measurements were drawn (according to procedures outlined in the PICES Special Publication, Guide to Best Practices for Ocean CO_2 Measurements [Dickson2007]) from Bullister style niskin bottles into ~310ml borosilicate glass flasks using platinum-cured silicone tubing. The flasks were rinsed once and filled from the bottom with care not to entrain any bubbles, overflowing by at least one-half volume. The sample tube was pinched off and withdrawn, creating a 6ml headspace and 0.12 ml of saturated $HgCl_2$ solution was added as a preservative. The sample bottles were then sealed with glass stoppers lightly covered with Apiezon-L grease. DIC samples were collected from a variety of depths with approximately 10% of these samples taken as duplicates.

11.2 Equipment

The analysis was done by coulometry with two analytical systems (PMEL1 and PMEL2) used simultaneously on the cruise. Each system consisted of a coulometer (5015O UIC Inc) coupled with a Dissolved Inorganic Carbon Extractor (DICE). The DICE system was developed by Esa Peltola and Denis Pierrot of NOAA/AOML and Dana Greeley of NOAA/PMEL to modernize a carbon extractor called SOMMA ([Johnson1985], [Johnson1987], [Johnson1993], [Johnson1992], [Johnson1999]). The two DICE systems were set up in a seagoing container modified for use as a shipboard laboratory on the aft main working deck of the *RV Roger Revelle*.

11.3 DIC Analysis

In coulometric analysis of DIC, all carbonate species are converted to CO_2 by addition of excess hydrogen ion (acid) to the seawater sample, and the evolved CO_2 is swept into the titration cell of the coulometer with CO_2 free dry air or compressed nitrogen where it reacts quantitatively with a proprietary reagent based on ethanolamine to generate hydrogen ions. In this process, the solution changes from blue to colorless, triggering a current through the cell and causing coulometric generation of OH^- ions at the anode. The OH^- ions react with the H^+ and the solution turns blue again. A beam of light is shone through the solution, and a photometric detector at the opposite side of the cell senses the change in transmission. Once the percent transmission reaches its original value, the coulometric titration is stopped, and the amount of CO_2 that enters the cell is determined by integrating the total change during the titration.

11.4 DIC Calculation

The amount of CO_2 injected was calculated according to the 2007 PICES Special Publication. Each DICE instrument has a modified SBE45 salinity sensor, but all DIC values were recalculated to a molar weight (µmol kg^{-1}) using density obtained from the CTD's salinity.

The DIC values were corrected for dilution resulting from the addition of 0.12 ml of saturated $HgCl_2$ used for sample preservation. The correction factor used for this dilution is 1.000397. A correction was also applied for the offset from the Certified Reference Material (CRM). This additive correction was applied for each cell using the value of the CRM obtained at the beginning of the cell. The coulometer cell solution was replaced after 24-28 mg of carbon was titrated, typically after 10-12 hours of continuous use. The blanks (background noise per cell) ranged from 12-50.

11.5 Calibration, Accuracy, and Precision

The stability of each coulometer cell solution was confirmed three different ways.

1) Gas loops were always run at the beginning and usually at the end of each cell;

2) CRM's supplied by Dr. A. Dickson of SIO, were measured near the beginning; and

3) Duplicate samples were run throughout the life of the cell solution.

Each coulometer was calibrated by injecting aliquots of pure CO_2 (99.999%), as a standard, by means of an 8-port valve ([Wilke1993]) outfitted with two calibrated sample loops of different sizes (~1ml and ~2ml). The instruments were each separately calibrated at the beginning of each cell with a minimum of two sets of these gas loop injections; and when time allowed at the end of each cell to ensure no drift during the life of the cell.

The accuracy of the DICE measurement is determined with the use of standards, Certified Reference Materials (CRMs) consisting of filtered and UV irradiated seawater, supplied by Dr. A. Dickson of Scripps Institution of Oceanography (SIO). The CRM accuracy is determined manometrically on land in San Diego and the DIC data reported have been corrected to batches 188 and 199 CRM values. Batch 188 was used for the first 23 stations and batch 199 for the next 84, followed by batch 200 for the final 9 stations. The CRM certified value for batch 188 is 2099.26 µmol kg^{-1} and for 199 is 2021.66 µmol kg^{-1} and for 200 is 2022.46 µmol kg^{-1}. The summary table below (table 1) lists information for the CRMs.

The precision of the two DICE systems can be demonstrated via the replicate samples. Approximately 10% of the niskins sampled were duplicates taken as a check of our precision. These replicate samples were interspersed throughout the station analysis for quality assurance and integrity of the coulometer cell solutions. The average absolute difference from the mean of these replicates is 0.82 µmol kg^{-1}; No systematic differences between the replicates were observed (table 2).

11.6 Instrument Repairs

We almost made it through the entire leg without any major equipment problems. Early on, we had some sticky tubing in some drain valves, but nothing that impacted the end data… Until station 95. What looked like a simple leaky fitting turned out to be a bit more problematic. It seems the rinsing of the pipette on DICE 2 was not completely draining during the first two initial rinses. Thus, the extra rinse from the pipette was ending up in the gas stripper and the pipette calibration was way off. This was intermittent on stations 95 and 97 on system 2 and thus not noticed during the CRM run. And of course, the gas loop calibration was unaffected by this as well. However, once the data were plotted up it became readily apparent a fix was needed. By simply adjusting the drain time of the pipette rinse cycle, we patched it up until we had a bit of time between stations and sample analysis. Before station 100, it was determined that the tubing in pinch valve 1 had formed a small crack at the valve and Pneumatic Gas was escaping enough to change the pipette drain time. By replacing the tubing that fixed the issue and we were back in normal operation. It appears we may have lost 2 stations worth of data. Some of it may be salvageable, but until a more thorough shore side examination can be done the data from those two stations will be flagged questionable (3) or bad (4).

11.7 Summary

The overall performance of the analytical equipment was good during the cruise. As is standard operating procedure, the pipette calibrations will need to be repeated upon return to shore. Both systems ran with slightly higher than normal background noise (blanks) than we are used to seeing. It is believed this extra noise is due to the new bow thruster the Revelle had installed during the mid-life refit and the need for all thrusters (Z-drive included) to be calibrated so they work as a team. This extra instrument noise is apparent while on station but not while the ship is underway. Further supporting this belief, we had no extra background noise in Seattle or while tied up at the pier while in Guam. Even with this additional background noise, the overall precision and accuracy and comparison to the 2013 P02 data set leads us to believe the systems were not compromised by this higher blank. Including the duplicates, over 3,300 samples were analyzed for dissolved inorganic carbon. Therefore, DIC analyzed over 75% of the niskins made available to us. The DIC data reported to the database directly from the ship are to be considered preliminary until a more thorough quality assurance can be completed shore side.

Calibration data during this cruise:

CRM Info	PMEL1			PMEL2		
Batch - Cert.	Ave	N	Std Dev	Ave	N	Std Dev
188 - 2099.26	2098.97	19	1.52	2097.68	21	2.01
199 - 2021.66	2021.01	47	1.32	2020.31	45	1.35
200 - 2022.46	2022.10	5	0.66	2022.50	5	0.87

SYSTEM	Average Gas Loop Cal Factor	Pipette Volume	Observed
PMEL1	1.00547	27.571 ml	0.77
PMEL2	1.00340	26.363 ml	0.87

CHAPTER

TWELVE

DISSOLVED ORGANIC CARBON AND TOTAL DISSOLVED NITROGEN

PI

- Dennis Hansell (U Miami)

Technician

- Abby Tinari (U Miami)

Analysts

- Lillian Custals

Support NSF

12.1 Project Goals

The goal of the DOM project is to evaluate dissolved organic carbon (DOC) and total dissolved nitrogen (TDN) concentrations along the P02W zonal transect.

12.2 Sampling

DOC profiles were taken from approximately every two out of three stations from 26 of 36 niskin bottles ranging the full depth of the water column (80 of 117 stations; 2012 DOC/TDN samples). All samples collected above 250 meters were filtered through an inline filter holding a combusted GF/F filter attached directly to the niskin. This was done to eliminate particles larger than 0.7 µm from the sample. To reduce contamination by the filter or filter holder, a new filter and holder was used for every station. All samples were rinsed 3 times with about 5 mL of seawater and collected into combusted 40 mL glass EPA vials. Samples were fixed with 100 µL of 4M Hydrochloric acid and stored at room temperature on board. Samples were shipped back to University of Miami for analysis via high temperature combustion on Shimadzu TOC-V or TOC L analyzers.

Sample vials were prepared before the cruise by combustion at 450°C for 12 hours to remove any organic matter. Vial caps were cleaned by soaking in DI water overnight, followed by a 3 times rinse with DI water and left out to dry.

Sampling goals for this cruise were to continue high-resolution, long-term monitoring of DOC distribution throughout the water column, in order to help better understand biogeochemical cycling in global oceans.

12.3 Standard Operating Procedure for DOC analyses – Hansell Lab U Miami

DOC samples will be analyzed via high temperature combustion using a Shimadzu TOC-V or Shimadzu TOC-L at an inshore based laboratory at the University of Miami. The operating conditions of the Shimadzu TOC-V have been slightly modified from the manufacturer's model system. The condensation coil has been removed and the headspace of an internal water trap was reduced to minimize the system's dead space. The combustion tube contains 0.5 cm Pt pillow on top of Pt alumina beads to improve peak shape and to reduce alteration of combustion matrix throughout the run. CO_2 free carrier gas is produced with a Whatman® gas generator ([Carlson2010]). Samples are drawn into a 5 mL injection syringe and acidified with 2M HCL (1.5%) and sparged for 1.5 minutes with CO_2 free gas. Three to five replicate 100 µL of sample are injected into a combustion tube headed to 680°C. The resulting gas stream is passed through several water and halide traps, including an added magnesium perchlorate trap. The CO_2 in the carrier gas is analyzed with a non-dispersive infrared detector and the resulting peak area is integrated with Shimadzu chromatographic software. Injections continue until at least three injections meet the specified range of a SD of 0.1 area counts, CV $\leq$ 2% or best 3 of 5 injections.

Extensive conditioning of the combustion tube with repeated injection of low carbon water (LCW) and deep seawater is essential to minimize the machine blanks. After conditioning, the system blank is assessed with UV oxidized low carbon water. The system response is standardized daily with a four-point calibration curve of potassium hydrogen phthalate solution in LCW. All samples are systematically referenced against low carbon water and deep Sargasso Sea (2600 m) reference waters and surface Sargasso Sea water every 6 – 8 analyses ([Hansell 1998]_). The standard deviation of the deep and surface references analyzed throughout a run generally have a coefficient of variation ranging between 1-3% over the 3-7 independent analyses (number of references depends on the size of the run). Daily references waters were calibrated with DOC CRM provided by D. Hansell (University of Miami; ([Hansell 2005]_)).

12.3.1 DOC Calculation

$$\mu\text{MC} = \frac{\text{average sample area} - \text{average machine blank area}}{\text{slope of std curve}}$$

12.4 Standard Operating Procedure for TDN analyses – Hansell Lab U Miami

TDN samples were analyzed via high temperature combustion using Shimadzu TOC-V with attached Shimadzu TNMI unit at an inshore based laboratory at the University of Miami. The operating conditions of the Shimadzu TOC-V were slightly modified from the manufacturer's model system. The condensation coil was removed and the headspace of an internal water trap was reduced to minimize the system's dead space. The combustion tube contained 0.5 cm Pt pillows placed on top of Pt alumina beads to improve peak shape and to resuce alteration of combustion matrix throughout the run. Carrier gas was produced with a Whatman® gas generator ([Carlson2010]) and ozone was generated by the TNMI unite at 0.5L/min flow rate. Three to five replicate 100 µL of sample were injected at 130 mL/min flow rate into the combustion tube headed to 680°C, where the TN in the sample was converted to nitric oxide (NO). The resulting gas stream was passed through an electronic dehumidifier. The dried NO gas then reacted with ozone producing an excited chemiluminescence NO_2 species ([Walsh1989]) and the fluorescence signal was detected with a Shimadzu TNMI chemiluminescence detector. The resulting peak area was integrated with Shimadzu chromatographic software. Injections continue until at least three injections meet the specified range of a SD of 0.1 area counts, CV $\leq$ 2% or best 3 of 5 injections.

Extensive conditioning of the combustion tube with repeated injections of low nitrogen water and deep seawater was essential to minimize the machine blanks. After conditioning, the system blank was assessed with UV oxidized low nitrogen water. The system response was standardized daily with a four-point calibration curve of potassium nitrate solution in blank water. All samples were systematically referenced against low nitrogen water and deep Sargasso Sea

reference waters (2600 m) and surface Sargasso Sea water ever 6-8 analyses ([Hansell1998]). Daily references waters were calibrated with deep CRM provided by D. Hansell (University of Miami; [Hansell2005])).

12.4.1 TDN calculation

$$\mu\text{MN} = \frac{\text{average sample area} - \text{average machine blank area}}{\text{slope of std curve}}$$

CHAPTER

THIRTEEN

CARBON ISOTOPES IN SEAWATER (14/13C)

PI

- Roberta Hansman (WHOI)
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Technician

- Abby Tinari (U Miami)

A total of 544 samples were collected from stations collected along the P02W transect. 32 samples (full casts) were taken from 15 of the 117 stations, 24 samples (bio casts) were taken from a separate 2 of the 117 stations and 16 stations (partial casts) were taken from a separate 1 of the 117 stations. Station spacing was closer (every 3 stations) towards the beginning of the transect then spread out to every 8 stations in the middle of the transect. Station locations followed previous P02 occupations. Samples were collected in 500 mL airtight glass bottles. Using silicone tubing, the flasks were rinsed 3 times with seawater. While keeping the tubing at the bottom of the flask, the flask was filled and flushed by allowing it to overflow 1.5 times its volume. Once the sample was taken, about 10 mL of water was removed to create a headspace and 100 µL of saturate mercuric chloride solution was added to the sample. To avoid contamination, gloves were used when handling all sampling equipment and plastic bags were used to cover any surface where sampling or processing occurred.

After each sample was taken, the glass stoppers and ground glass joint were dried and Apiezon-M grease was applied to ensure an airtight seal. Stoppers were secured with a large rubber band wrapped around the entire bottle. Samples were stored in AMS crates in the ship's dry laboratory. Samples were shipped to WHOI for analysis.

The radiocarbon/DIC content of the seawater ($\delta^{14}C$) is measured by extracting the inorganic carbon as CO_2 gas, converting the gas to graphite and then counting the number of ^{14}C atoms in the sample directly using an accelerated mass spectrometer (AMS).

Radiocarbon values will be reported as ^{14}C using established procedures modified for AMS applications. The $^{13}C/^{12}C$ of the CO_2 extracted from seawater is measured relative to the $^{13}C/^{12}C$ of a CO_2 gas standard calibrated to the PDB standard using and isotope radio mass spectrometer (IRMS) at NOSAMS.

CHAPTER

FOURTEEN

CFC, SF_6, AND N_2O

PIs

- Dong-Ha Min (UT)

Analysts

- David Cooper (UT)
- Carol Gonzalez (UT)
- Sidney Wayne (UCSD)

Samples for the analyses of the dissolved chlorofluorocarbons (CFCs, freons) F11 and F12, sulfur hexafluoride (SF_6) and nitrous oxide (N_2O) were collected and analyzed during RR2204. Seawater samples were taken from all casts, with full profiles generally taken from alternating casts and strategically determined bottles sampled from the remaining casts. These measurements are complemented by periodic measurements of air samples.

Seawater samples were drawn from 10 liter Niskin bottles. Samples for CFC and SF_6 were the first samples drawn, taking care to check the integrity of the sample and coordinate the sampling analysts to minimize any time between the initial opening of each bottle and the completion of sample drawing. To minimize contact with air, the CFC samples were drawn directly through the stopcocks of the Niskin bottles into 250 ml precision glass syringes. Syringes were rinsed and filled via three-way plastic stopcocks. The syringes were subsequently held at 0-5 degrees C until 30 minutes before being analyzed. At that time, the syringe was placed in a bath of surface seawater heated at approximately 28 °C.

For atmospheric sampling, a ~90 m length of 3/8" OD Dekaron tubing was run from the main lab to the bow of the ship. A flow of air was drawn through this line into the main laboratory using an air-cadet pump. The air was compressed in the pump, with the downstream pressure held at ~1.5 atm. using a backpressure regulator. A tee allowed a flow (100 ml min-1) of the compressed air to be directed to the gas sample valve of the CFC analytical system, while the bulk flow of the air (>7 l min-1) was vented through the backpressure regulator. Analysis of bow air was performed at several locations along the cruise track. Approximately five measurements were made at each location to increase the precision. Atmospheric data were not submitted to the database, but were found to be in excellent agreement with current global databases.

Concentrations of CFC-1l, CFC-12, SF_6 and N_2O in air samples, seawater samples and gas standards were measured by shipboard electron capture gas chromatography (ECD-GC) using techniques described by [Bullister2008]. This method has been modified with the addition of an extra ECD to accommodate N_2O analysis. For seawater analyses, water was transferred from a glass syringe to a glass sparging chamber (~200 ml). The dissolved gases in the seawater sample were extracted by passing a supply of CFC-free purge gas through the sparging chamber for a period of 6 minutes at 120 - 140 ml/min. Water vapor was removed from the purge gas by passage through a Nafion drier, backed up by a 18 cm long, 3/8" diameter glass tube packed with the desiccant magnesium perchlorate. This tube also contained a short length of Ascarite to remove carbon dioxide, a potential interferent in N_2O analysis. The sample gases were concentrated on a cold-trap consisting of a 1/16" OD stainless steel tube with a ~5 cm section packed tightly with Porapak Q (60-80 mesh), a 22 cm section packed with Carboxen 1004 and a 2.5 cm section packed with molecular sieve MS5A. A neslab cryocool was used to cool the trap, to below -50°C. After 6 minutes of purging, the trap was

isolated, and it was heated electrically to ~150°C. The sample gases held in the trap were then injected onto a precolumn (~60 cm of 1/8" O.D. stainless steel tubing packed with 80-100 mesh Porasil B, held at 80°C) for the initial separation of CFC-12 and CFC-11 from later eluting peaks. After the F12 had passed from the pre-column through the second pre-column (22 cm of 1/8" O.D. Stainless steel tubing packed with Molecular Sieve 5A, 100/120 mesh) and into the analytical column #1 (~170 cm of 1/8" OD stainless steel tubing packed with MS5A and held at 80°C) the outflow from the first precolumn was diverted to the second analytical column (~150 cm 1/8" OD stainless steel tubing packed with Carbograph 1AC, 80-100 mesh, held at 80°C). After F11 had passed through the first precolumn, the flow was diverted to a third analytical column (1/8" stainless steel tube with 30cm Molecular Sieve 5A, 60/80 mesh) for N_2O analysis. The first pre-column was then backflushed and vented. The first two analytical columns and precolumn 1 were held isothermal at 80 degrees C in an Agilent (HP) 6890N gas chromatograph with two electron capture detectors (250°C). The third analytical column and second pre-column were held at 160C in a Shimadzu GC-8A gas chromatogram. The ECD in the Shimadzu was held at 250°C.

The analytical system was calibrated using a blended standard gas (seawater ratio, PMEL 464568), with available further reference to a second atmospheric ratio standard. Gas sample loops of known volume were thoroughly flushed with standard gas and injected into the system. The temperature and pressure was recorded so that the amount of gas injected could be calculated. The procedures used to transfer the standard gas to the trap, precolumn, main chromatographic column, and EC detector were similar to those used for analyzing water samples. Four sizes of gas sample loops were used. Multiple injections of these loop volumes could be made to allow the system to be calibrated over a relatively wide range of concentrations. Air samples and system blanks (injections of loops of CFC-free gas) were injected and analyzed in a similar manner. The typical analysis time for seawater, air, standard or blank samples was ~12 minutes. Concentrations of the CFCs in air, seawater samples, and gas standards are reported relative to the SIO98 calibration scale (e.g. [Bullister2010]). Concentrations in air and standard gas are reported in units of mole fraction CFC in dry gas, and are typically in the parts per trillion (ppt) range. Dissolved CFC concentrations are given in units of picomoles per kilogram seawater (pmol kg-1). CFC concentrations in air and seawater samples were determined by fitting their chromatographic peak areas to multi-point calibration curves, generated by injecting multiple sample loops of gas from a working standard (PMEL cylinder 464568) into the analytical instrument. The response of the detector to the range of moles of CFC passing through the detector remained relatively constant during the cruise. Full-and partial-range calibration curves were run several times during the cruise. Single injections of a fixed volume of standard gas at one atmosphere were run much more frequently (at intervals of ~90 minutes) to monitor short-term changes in detector sensitivity.

The purging efficiency of the stripper was estimated by re-purging a water sample in the upper concentration range and measuring the residual signal. At a flow rate of 120 cc/min for 6 minutes, the purging efficiency for SF_6 and F12 was greater than 99% and the efficiency for F11 was about 99%. The purging efficiency for N_2O was about 95%, but subject to some degree of variability due to changes in flow rate and purging temperature. Although correction is made for this variability, N_2O data from stations 1-22 were rather more compromised than subsequent data.

Results of 3234 seawater samples are reported from 113 of the 117 stations, with stations 17-20 omitted due to system problems. Duplicates were taken from 90 stations to estimate precision and variability. Low-level samples were selected from deep samples and higher level (surface) samples were mostly taken from the upper water column. From the higher level samples, we calculate the average deviation to be less than 1.0% from the mean of the pairs for F12, F11 and N_2O measurements, and 2.0% from the mean for SF_6 measurements. Deviation from the mean of pairs from deeper samples averaged less than 5% (or 0.01 pM) from the mean for F12 and F11 and approximately 10% for SF_6. Due to the exceedingly low levels of SF_6 present in deeper water, accurate estimates of precision are not possible. A small number of additional water samples had anomalous SF_6 or CFC concentrations relative to adjacent samples. These samples occurred sporadically during the cruise, were not clearly associated with other features in the water column (e.g., anomalous dissolved oxygen, salinity, or temperature features) and are omitted from the reported data.

CHAPTER

FIFTEEN

LADCP

PI

- Dr. Andreas Thurnherr (LDEO)

Cruise Participant

- Kurtis Anstey (University of Victoria)

15.1 Data Acquisition and QC

To collect full-depth profiles of horizontal and vertical ocean velocities, two acoustic Doppler current profilers (ADCPs), one facing upward (uplooker, UL) and the other downward (downlooker, DL), as well as a DeepSea Power & Light rechargeable 48V battery and cables, were installed on the conductivity, temperature, depth (CTD) system rosette. The lowered ADCP (LADCP) system was provided by the Lamont-Doherty Earth Observatory (LDEO). The LADCP system is self-contained, requiring on-deck cable connections via a five-wire star-cable to charge the battery and communicate. Each end of the star-cable had a short extension cable attached to mitigate wear. The battery charger was affixed to an elevated power box in the hanger, with an extension power cable run into the wet lab to be plugged in near to the hanger door. Installed on the bench were the LADCP data acquisition computer, a Mac Mini, and a bench-top power supply for the ADCPs.

While cruising the LADCP system in the hanger was left connected to the (unpowered) battery charger, as well as to two deck cables leading to the data acquisition computer and the bench-top power supply. The male plug of the (disconnected) adapter cable between the battery and the LADCP star-cable was dummied. While the deck cables in the wet lab were permanently connected to the acquisition computer with RS232-to-USB adapters, the corresponding power supply was turned on and off with a toggle adapter. With this setup there is no voltage to any of the LADCP cables on the rosette.

A few minutes before rosette deployment, the battery was disconnected from the charger and connected to the LADCP system via the extension power / star-cable. The male plug of the battery charger cable was dummied. To begin data acquisition, the instruments were woken up by the acquisition computer by checking storage contents, data from the previous cast deleted from the built-in memory cards, and the instruments programmed to start pinging. The two deck cables were disconnected from the two star-cable extensions. The deck cables and star-cable extension connectors were dummied, and the latter secured to the rosette frame with velcro straps to avoid excessive motion during the cast. The CTD operator and/or res-tech were notified that the LADCP system was ready for deployment. Deployment information was recorded on LADCP log sheets, either when the data acquisition was started or once the CTD system had entered the water.

Upon recovery, the velcro straps securing the dummied star-cable extensions were removed, as well as the dummies, the cable ends rinsed with fresh water, and the star-cable extensions connected to the deck cables (also un-dummied). Using the acquisition computer, LADCP data acquisition was stopped by initiating the data download. The bench top power supply was activated, the LADCP battery disconnected from the adapter cable on the rosette, the male end of the battery adapter cable on the rosette with two exposed pins now carrying 48V (from the bench-top power supplies)

dummied, and the battery cable attached to the (still unpowered) battery charger cable. Power was applied to the battery charger via an accessible power toggle switch below the charger, and the time noted on the LADCP log sheet.

After data from the cast had finished downloading (about 20 minutes for deep casts), the bench top power supply was deactivated with the bench power toggle switch. The new data files (one for each the UL and DL) were roughly quality-checked by integrating the measured vertical velocities in time, yielding estimates for the maximum depth (zmax) and the end depth (zend) of the profile, and these values recorded on the log sheet. Once the battery was fully charged (usually about an hour after charging was initiated, as indicated by the charger LED status) the charger was disconnected from power, and the time noted on the log sheet. At this stage, the LADCP system was ready for the next cast.

Communication between the acquisition computer and the LADCP system was handled by Thurnherr's custom acquisition software (acquire2), implemented as a set of UNIX shell commands designed to minimize the possibility of operator error. Primary commands are:

Ldir: Lists the status of the LADCP memory, including number of files, file size, etc.

Lstart: Wakes the instruments, lists their memory contents, clears the memory (after operator confirmation), and instructs the instruments to begin pinging by uploading command files. CTD station and cast number must be provided by the operator, as the LADCP files use an independent numbering scheme.

Ldownload: Interrupts the running data acquisition, downloads data, and backs up data files.

Lcheck: Integrates the measured vertical velocities from both the UL and DL to estimate zmax and zend, which are displayed with other useful profile statistics before data files are backed up, again.

Lreset: Resets the LADCP system after swapping instruments or in case of communications issues.

After each cast, data were quality-checked with an initial processing run of both horizontal and vertical velocities. CTD .cnv data were obtained from the ship's shared drive and processed into 1 and 6 Hz formats. These were used with LADCP_w (vertical velocity) and LDEO_IX (horizontal velocity) processing software to produce diagnostic logs, figures, and post-processed data files. Additionally, LADCP data quality was continuously monitored via horizontal velocity section plots (Figure 1), useful for identifying large-scale data inconsistencies. A written assessment, diagnostics, and figures were sent to Thurnherr's lab in Lamont via rsync. A more comprehensive post-cruise data quality-check will be carried out by Thurnherr in his lab before submission of the combined leg 1 and 2 data to the archives.

15.2 Instrumentation

Two 300kHz Teledyne RDI Workhorse Monitor ADCPs (WHM300HZ) were used at the beginning of the cruise, a primary/DL (S/N 3441) and secondary/UL (S/N 150), working well. The secondary is synced to the primary to follow a staggered ping rate of 1.3 and 1.6 seconds, designed to mitigate acoustic reflection depth issues. The UL made use of the Teledyne RDI WM15 surface-/bottom-tracking command, while the DL did not, though the use of this command is arbitrary for the purposes of bottom-tracking during this cruise. Data quality for the duration of the cruise is generally good, with typically negligible issues associated with the following events:

Upon recovery at station 029 the UL would not respond to the *Ldownload* prompt. A full reset procedure – including software checks (Lreset), complete cable reconfiguration, and a power assessment – was conducted and it was determined that the issue was the UL, itself. The instrument was replaced with a spare LADCP of the same model (S/N 754), after which system operations returned to normal. The entire system configuration was refastened to the rosette, the battery reset in its tray, and again tested positive for operation. UL data were lost for this cast, and DL data appear to end deep during the upcast (5530.2 m) but is otherwise fine according to initial quality checks. The new UL and original DL were used for the duration of the cruise.

During the first half of the cruise, the battery was twice temporarily removed during CTD troubleshooting, without issue (stations 009 and 028).

For some of the deepest casts (> 6000 m, stations 027, 031), the seabed would be at the edge of the DL bottom-tracking range, causing erroneous values for seabed depth when using Lcheck. Despite this, the processing software could correctly determine seabed depth from the data.

At station 046, the *Lstart* command was given with the deck and star-cable extensions connected in a 'crossed' configuration, so that the DL was detected as the UL, and vice versa, and the WM15 commands were leading to a failed start. Before the cause was identified, the LADCP WM15 commands were disabled for both instruments, and so the true UL (which usually runs with WM15 enabled) was cast with WM15 disabled. Upon recovery, inspection of the data revealed the cause, and the data files were revised to reflect the correct DL and UL configuration. The initial data quality-checks suggest that the data are fine.

In the second half of the cruise, the installed battery began to show extended charging times and low voltage, particularly after combined bio- and deep-casts. When it began to no longer reach 'trickle-charge' (~80%) between casts, it was deemed unusable and swapped for a spare battery. Another spare was strapped to the deck near the rosette staging area for emergency access. The replacement battery continued to work optimally for the duration of the cruise. However, despite reaching full charge consistently and quickly between casts, the voltage of the replacement did appear to be slowly falling during the last few stations.

A cabling adjustment before station 071 placed a bulk of coiled CTD wire adjacent to the UL, potentially problematic for the ADCP's magnetic components, but does not appear to have affected data quality.

Attempting to account for a lack of scatterers in the deep regions of the latter half of the cruise, the command files for both the DL and UL were adjusted (station 080) for larger depth bins (8 m changed to 10 m), less blanking distance (first bin changed to 4m), and lower ambiguity velocity (4 m/s changed to 2.5 m/s). The introduction of these adjustments may have led to the detection of cast intermittent wake effects, manifesting as a region of poor vertical velocity data around 3400 m, from the DL. After a further adjustment of the DL by 45° CCW (station 093), the issue was no longer detected, and profile quality is good for the remainder of the cruise.

15.3 Preliminary results

Though not yet fully QC'd or processed, the horizontal and vertical velocity data show signs of expected mean currents (e.g. Kuroshio), regional eddies, and low-frequency (likely near-inertial, based on qualitative vertical wavelength), highly energetic internal waves near slope, and over seamount, topography.

From vertical velocities, an estimate of vertical kinetic energy (VKE), and therefore turbulent dissipation (ϵ_{VKE}) can be made for each station profile. However, as there are both DL and UL data contributing to the vertical velocity profile, averaging to determine ϵ_{VKE} can be performed at different points in the process. Determining VKE from the final combined DL and UL vertical velocity profile results in 'combination ϵ_{VKE}', while first determining VKE from the individual DL and UL profiles and then combining the VKE profiles results in 'DL & UL ϵ_{VKE}'. From the combined method, dissipation appears to increase near the surface and topography (Figure 2, upper), notably so near slopes and seamounts, exceeding 10^{-9} W kg^{-1} in some cases. Away from topography, dissipation can recede to background values less than 10^{-11} W kg^{-1}. By comparison, the latter method results in generally higher values of ϵ_{VKE} (Figure 2, lower), with less obvious features near topography and additional data gaps. Statistically, these assumptions are confirmed (Figure 3) – the combined method has a greater range of intensity, while the latter method trends toward its mean, higher than that of the combined method. The correlation between the two methods results is good, but there is an obvious difference at an r-value of 0.82. Further analysis will be required to decide which method is most appropriate.

15.4 Figures

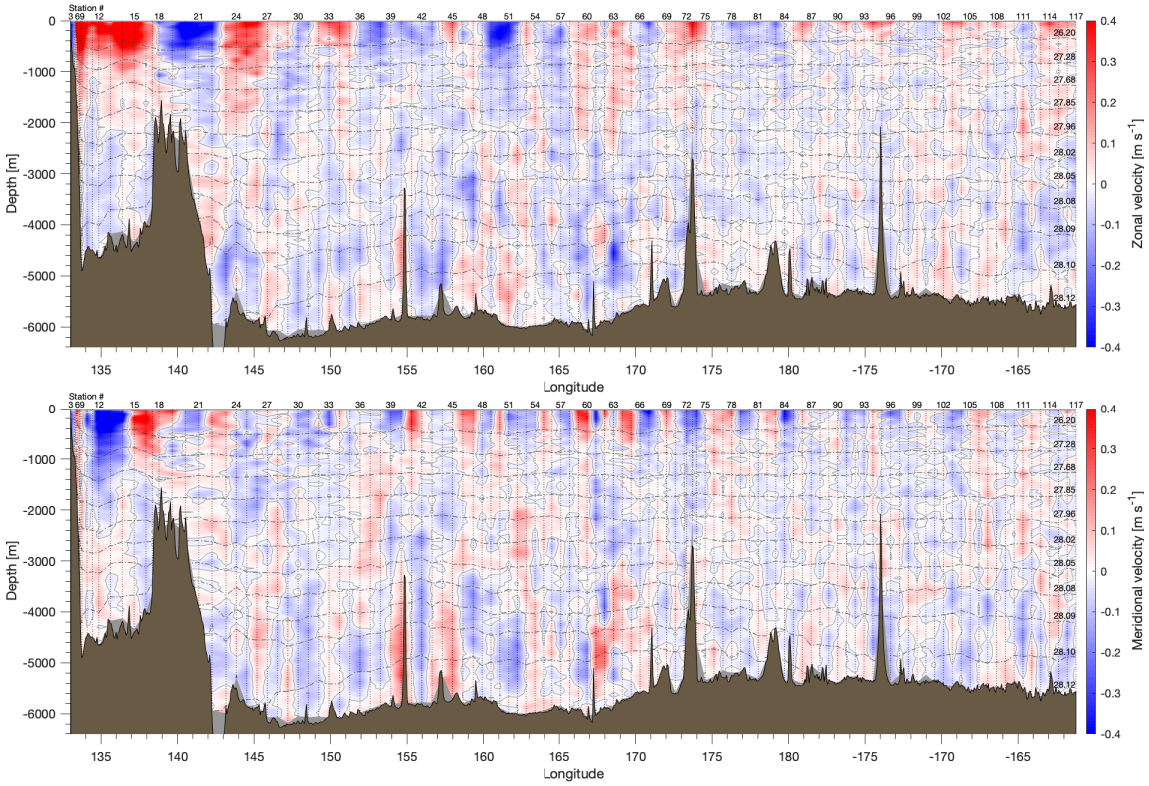


Fig. 1: Figure 1. Zonal (upper) and meridional (lower) velocity sections for GO-SHIP P2 leg 1. Horizontal velocity data were smoothed for vertical scales < 50 m, to filter instrument noise, and are constrained by time- and GPS-synchronised CTD, SADCP, and bottom-tracking data by LDEO_IX software. Station profiles are shown as vertical dotted gray lines, zero-velocity contours as thin grey lines, and dot-dashed black lines are neutral density contours ([Jackett1997]), labelled right (units of kg m^{-3}). Interpolated data were blanked linearly between stations, near the seabed, with bathymetry determined from ETOPO1 global relief data ([NOAA2009]). There is evidence of regional mean currents, eddies, and internal wave activity near topography.

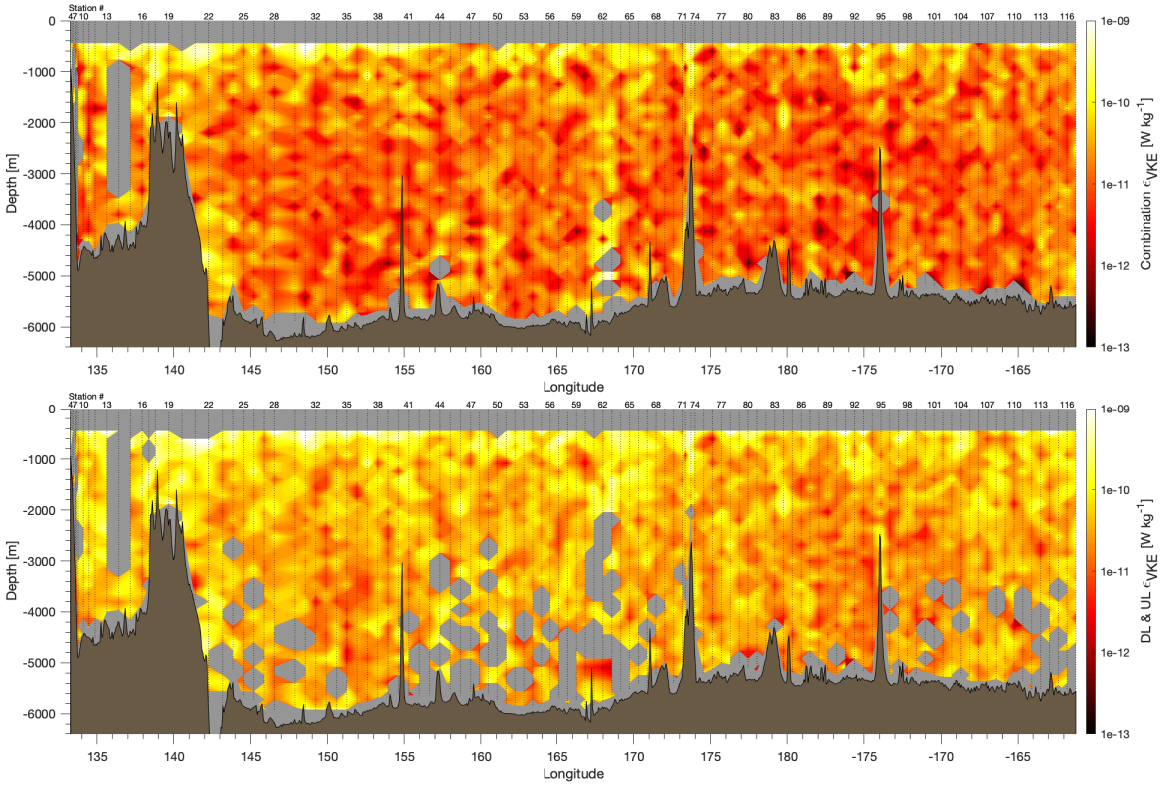


Fig. 2: Figure 2. Section plots of combination ϵ_{VKE} (upper) and DL & UL ϵ_{VKE} (lower). Interpolated data were blanked linearly between stations, near the seabed, with bathymetry determined from ETOPO1 global relief data ([NOAA2009]). There is evidence of enhanced dissipation near the surface and topography. The averaging method in the upper panel better resolves these features.

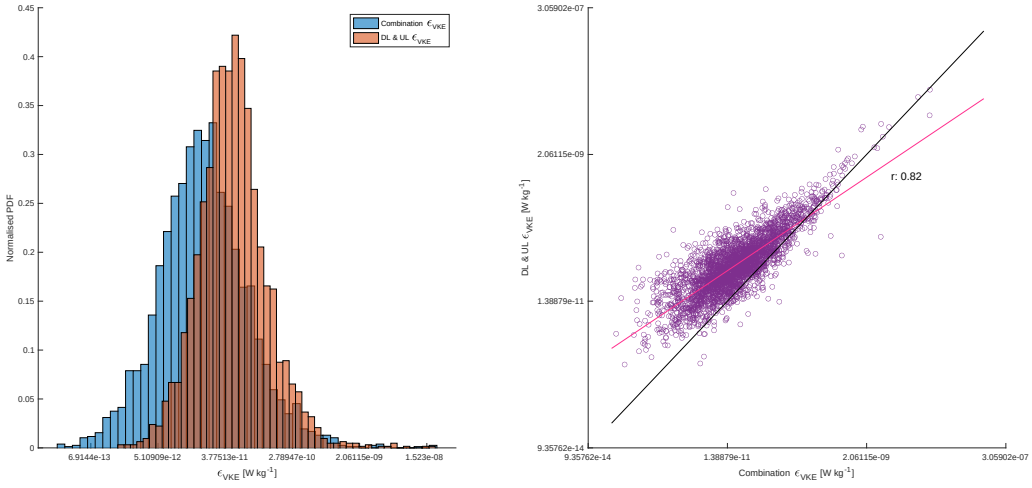


Fig. 3: Figure 3. Statistics for combination ϵ_{VKE} and DL & UL ϵ_{VKE} averaging methods. The former method has a greater range of intensities, while the later trends towards its greater mean. The two methods are correlated at r = 0.82.

CHAPTER

SIXTEEN

BIO GO-SHIP

PIs

- Adam Martiny (UCI)

Samplers

- Adam Fagan (UCI)
- Star Dressler (UOG)
- Stephanie O'Daly (UAF)

16.1 Genetics

Genetics samples were collected approximately at 0600, 1200, and 2000 local time from the uncontaminated underway seawater system and pre-filtered (30 µm mesh) (88 stations). Samples were also collected using the CTD at 5m, 100m, 200m, and 1000m (39 stations). If the CTD collection coincided with one of the standard collection times, it would take that slot, otherwise the CTD cast would be a fourth collection period. In total, 285 samples were collected (129 with the underway and 156 with the CTD). Up to 8L of seawater was collected into a plastic cubitainer and filtered immediately after collection. Water was filtered through a Sterivex 0.22 µm filter using a peristaltic pump at a low speed. Once all water is pumped through the Sterivex cartridge, one end is sealed with Crito-seal putty. 1620 µL of sterile lysis buffer is pipetted into the filter cartridge and the other end is sealed with a luer-lok cap. The filter is placed in a separate Ziplok bag and preserved frozen at -80°C until shipment to the Adam Martiny lab at UC Irvine for further analysis. Final filtration volume was recorded for all samples. Gloves were worn during all steps, and were also used by all samplers at the rosette.

Prior to the cruise, all silicone tubing, Omnifit caps and cubitainers were cleaned in soapy water, 10% HCL, and Milli-Q water. Weekly, the tubing and Omnifit caps were soaked in a 10% bleach solution over four hours and rinsed with Milli-Q water. Between sample collections, the tubing and sample container were rinsed 3x with Milli-Q water.

16.2 Particulate Organic Matter

Particulate organic matter (POM) samples were collected for particulate organic carbon (POC), nitrogen (PON), phosphorous (POP) and particulate chemical oxygen demand (PCOD). POM samples were collected approximately at 0600, 1200, and 2000 local time from the uncontaminated underway seawater system and pre-filtered (30 µm mesh) (88 stations). Samples were also collected using the CTD at 5m (39 stations). In total, 1068 samples were collected (717 with the underway and 351 with the CTD). If the CTD collection coincided with one of the standard collection times, it would take that slot, otherwise the CTD cast would be a fourth collection period. In total, 127 stations were sampled (underway and CTD). Each sample passed through a GF/F filter (nominal pore size 0.7 µm). An aspirator pump was used to pull water through the filters at a vacuum setting of -0.06 to -0.08 MPa. Nine carboys were filled with 3-8L of water (volume biomass-dependent) and designated as follows: 3x POP, 3x POC/PON, 3x PCOD. POP filters were

rinsed with 5mL of 0.017M Na_2SO_4 to remove traces of dissolved organic phosphorous at the end of filtration. PCOD filters were rinsed with 5ml of Milli-Q water to remove excess salt at the end of filtration. Filters were folded and stored frozen at -80°C in pre-combusted foil squares.

All carboys were rinsed 3x with sample water before collection. GF/F filters and foil squares were precombusted at 500°C for 4.5 hours. Prior to the cruise, all silicone tubing, filter holders, and carboys were cleaned in soapy water, 10% HCL, and Milli-Q water. All filters will be shipped frozen and analyzed by the Martiny lab at UC Irvine. Gloves were used for all steps mentioned above.

16.3 Small Volume Particulate Organic Carbon/Nitrogen

Small volume particulate organic carbon/ nitrogen (POC/N) samples were collected approximately at 0600, 1200, and 2000 local time from the uncontaminated underway seawater system and pre-filtered (30 µm mesh) (16 stations). Samples were also collected using the CTD ranging from 200m to 5m (8 stations). In total, 104 samples were collected (48 with the underway and 56 with the CTD). If the CTD collection coincided with one of the standard collection times, it would take that slot, otherwise the CTD cast would be a fourth collection period. In total, 24 stations were sampled (underway and CTD).

Three samples of 0.5 - 2L of water were collected when using the underway and six samples of approximately 2L with one replicate at a random depth were collected using the CTD during a float deployment. Samples were stored in a HPDE bottle rinsed 3x with DI and sample water before being filtered onto 25mm GF/F filters using a vacuum pump set at 100mmHg. 1L of sampled water is re-filtered onto a new GF/F to create a blank for the underway. For CTD collection a wet blank is created by stacking two filters, filtering 1L of filtered sample water and using the bottom filter as a blank. Filters were folded and stored frozen at -80°C in pre-combusted foil squares. Small volume POC/N were collected to compare to POC/N samples described above in order to compare across methods. Sample bottles and funnels were rinsed with DI 3x after each sample period.

16.4 HPLC Pigments

HPLC samples were collected approximately at 0600, 1200, and 2000 local time from the uncontaminated underway seawater system and pre-filtered (30 µm mesh) (83 stations). Samples were also collected using the CTD ranging from 200m to 5m (42 stations). In total, 259 samples were collected (101 with the underway and 158 with the CTD). If the CTD collection coincided with one of the standard collection times, it would take that slot, otherwise the CTD cast would be a fourth collection period. In total, 125 stations were sampled (underway and CTD).

One to two samples were collected when using the underway and three to six samples with one replicate at a random depth using the CTD depending if there was a float deployment (three samples with no float deployment). Samples were stored in a HPDE bottle rinsed 3x with DI and sample water before being filtered onto 25mm GF/F filters using a vacuum pump set at 100mmHg. Filters were folded twice and stored frozen at -80°C in 1ml cryovials. Sample bottles and funnels were rinsed with DI 3x after each sample period.

NASA requires 10% of samples to be duplicates, resulting in two sample being taken, rather than one during underway sampling.

16.5 FCM

HPLC samples were collected approximately at 0600, 1200, and 2000 local time from the uncontaminated underway seawater system and pre-filtered (30 µm mesh) (83 stations). Samples were also collected using the CTD ranging from 1000m to 5m (42 stations). In total, 419 samples were collected (83 with the underway and 336 with the CTD). If the CTD collection coincided with one of the standard collection times, it would take that slot, otherwise the CTD cast would be a fourth collection period. In total, 125 stations were sampled (underway and CTD).

Single samples were collected when using the underway and eight samples at unique depths were collected using the CTD. Samples were collected in a 50ml tinted falcon tube, with 1.8ml being extracted and put into a 2ml cryovial. In a fumehood, 18 µL of a preservation mixture (50/50 of 25% Glutaraldehyde and 2% Kolliphor) are added to the sample. The sample is inverted several times and allowed to sit for 10 minutes. After the 10 minutes the samples are flash frozen in liquid nitrogen and finally stored in a -80°C freezer.

CHAPTER

SEVENTEEN

UNDERWATER VISION PROFILER 5 HD (UVP)

PI

- Andrew McDonnell (University of Alaska, Fairbanks)

Cruise Participant

- Stephanie O'Daly (Lead, Ph.D. Student, University of Alaska, Fairbanks)
- Kurtis Anstey (Secondary, M.S. Student University of Victoria)

17.1 System Configuration and Sampling

The Underwater Vision Profiler 5 (UVP5) HD (High Definition) serial number 201 was programmed, mounted on the rosette, and charged. This instrument is owned by Emmanuel Boss at University of Maine. The UVP5 is outfitted with a High Definition 4 Mp camera with an acquisition frequency of up to 20 Hz. This optical imaging device obtains in situ concentrations and images of marine particles and plankton throughout the water column, capturing objects sized ~100 µm to several cm in diameter. The camera of the UVP5 HD is different from the previous non-HD version, but the operations are identical for both. The instrument and data processing are described in [Picheral2010]. Depth trigger mode was used throughout the entirety of the cruise, programmed to turn on at 15 m with a maximum depth of 6000 m. A 20 m soak for one minute was used throughout the cruise.

17.2 Problems

On station 011 cast 01, the UVP voltage read 0 on deck after the CTD was powered on. The voltage came up to a non-zero number when the rosette hit the water, but it didn't appear that the UVP turned on during the one-minute soak at 20 meters. After the cast, corrosion was found between the power shunt and the 1m power cable extension indicating seawater intrusion. No data was collected on this cast. Those parts were swapped out for spares and this problem did not occur again. A reading of 0 volts on the deck indicates that a good seal has not been made between the power shunt and the 1 m power cable extension. If this is found again in the future the power shunt should be inspected and replaced on the 1 m power cable extension. Additionally, we started drying and greasing the power shunt before application before every cast as instructed by the instrument manufacturers. Cans of compressed air can be used to dry the shunt or the ship's air compressors.

Once we left the Japanese EEZ and Bio Casts started happening separately from core casts we started having other issues with the UVP. On station 026 cast 02 the UVP did not save all of the associated metadata files that allow us to process the particle size distributions. On station 027 cast 01 the UVP shut off at 1100m on the downcast. Then on station 029 cast 02 the UVP did not save all of the associated metadata files again. I believe these issues are due to the limited charging time after the Bio Casts before the full casts. We started dummying up the UVP for bio casts and only running it for the full casts and these issues did not occur for the rest of the cruise.

The last and most consequential issue we ran into with the UVP on this cruise occurred after station 057 cast 01. We were able to download and delete the data from the UVP for this station, but when I tried to perform a light test the UVP did not respond to any commands. I swapped out all associated cabling for spares and the deck box for a spare deck box and this did not establish good deck communication with the UVP. After discussing with the manufacturers, we decided the issue is likely a bad Sea Data bulkhead connector. I continued running the UVP for every core cast and it appeared to turn on based on the CTD voltage and by visual inspection of the lights at the surface for the rest of the cruise. I was never able to establish communication with the instrument again and therefore was not able to download data. Based on my calculations there should be enough space on the internal memory card for the rest of Leg 1 and Leg 2 of P02 if the particle concentrations are similar to the first 57 stations. When the internal memory card is full the instrument will not turn on anymore. The instrument will be run until this occurs, if at all, on Leg 2. Then the instrument will be sent to the manufacturers for maintenance who will open the bulkhead and hopefully download the data from the remaining stations.

17.3 General Particle Patterns

Near Japan, we see medium particle abundance overall with a surface and subsurface particle abundance maximum. A deep nephloid layer is not present and with there is a medium mean particle size increases with depth (Fig. 1). In the Kuroshio current, we see low particle abundance at the surface and subsurface with a very strong deep nephloid layer (high particle abundance) reaching 500 m above the seafloor (Fig. 2). Off the Japanese continental shelf, we see a strong surface particle abundance maximum at around 100m with a large average particle size and a subsurface particle maximum at around 400 m with low average particle size, and low particle abundances down the seafloor (Fig. 3). At the off-shelf stations, we see lower particle abundances with moderate surface and subsurface particle abundance maximum and no deep nephloid layer (Fig. 4).

17.4 Future Data Analysis

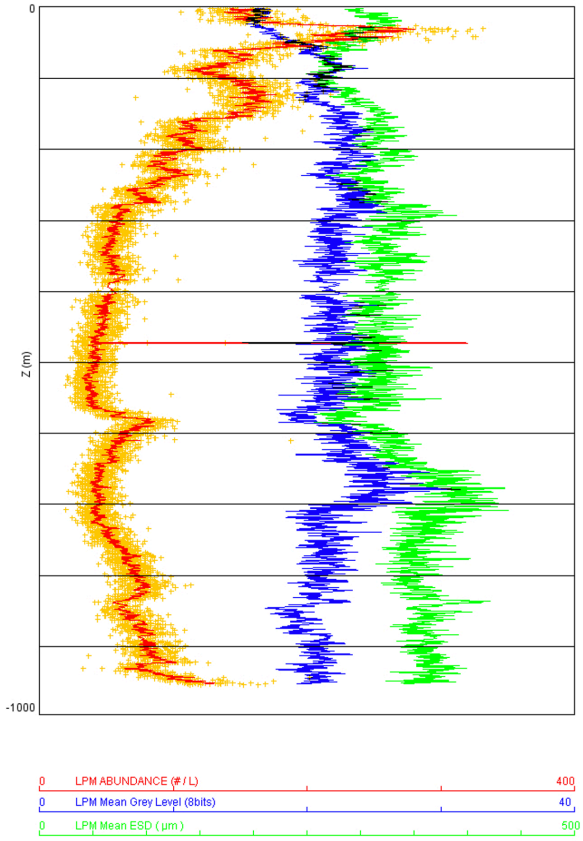
Total image count gathered during the cruise from the first 57 stations was 585,700 images. A combination of machine learning and manual validation will be used to sort images using the Ecotaxa database. Images will be sorted into various zooplankton taxa and detrital categories. Zooplankton categories will include crustacea (including copepods and krill), gelatinous (larvacean, jellyfish, salps), and rhizaria. Examples of these images are shown in Fig. 5.

17.5 Figures

Fig. 1: Examples of preliminary profiles at station 4. Plots show total large particulate matter (LPM) abundance, mean grey level (brightness) of LPM, and equivalent spherical diameter (ESD) (right) and particle concentration in size bins (left) both plotted against depth (meters). Near Japan, we see medium particle abundance overall with a surface and subsurface particle abundance maximum. A deep nephloid layer is not present and with there is a medium mean particle size increases with depth.

Fig. 2: Examples of preliminary profiles at station 10. Plots show total large particulate matter (LPM) abundance, mean grey level (brightness) of LPM, and equivalent spherical diameter (ESD) (right) and particle concentration in size bins (left) both plotted against depth (meters). In the Kuroshio current, we see low particle abundance at the surface and subsurface with a very strong deep nephloid layer (high particle abundance) reaching 500 m above the seafloor.

Fig. 3: Examples of preliminary profiles at station 20. Plots show total large particulate matter (LPM) abundance, mean grey level (brightness) of LPM, and equivalent spherical diameter (ESD) (right) and particle concentration in size bins (left) both plotted against depth (meters). Off the Japanese continental shelf, we see a strong surface particle abundance maximum at around 100m with large average particle size and a subsurface particle maximum at around 400 m with low average particle size, and low particle abundances down the seafloor.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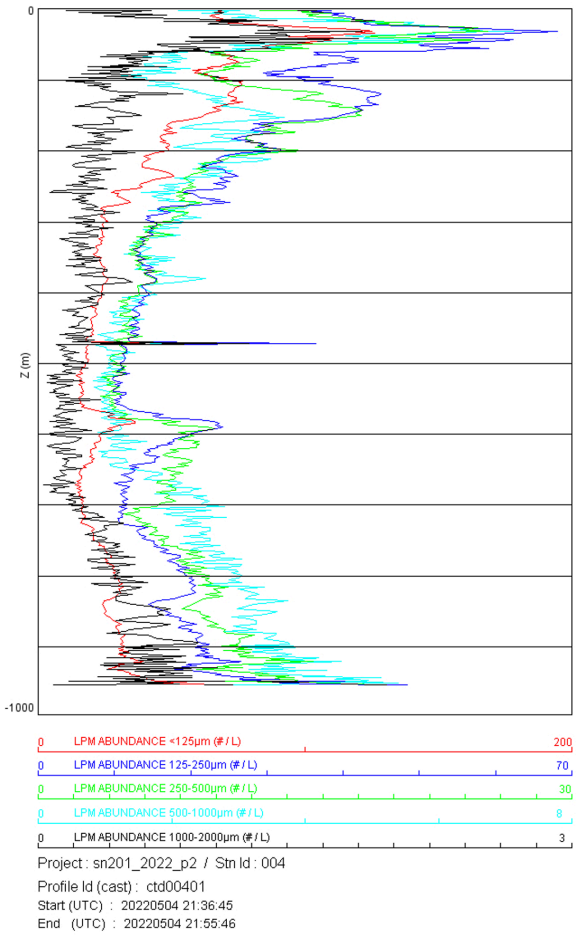
End (UTC) : 20220504 21:55:46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0 LPM ABUNDANCE 1000-2000µm (#/L) 3
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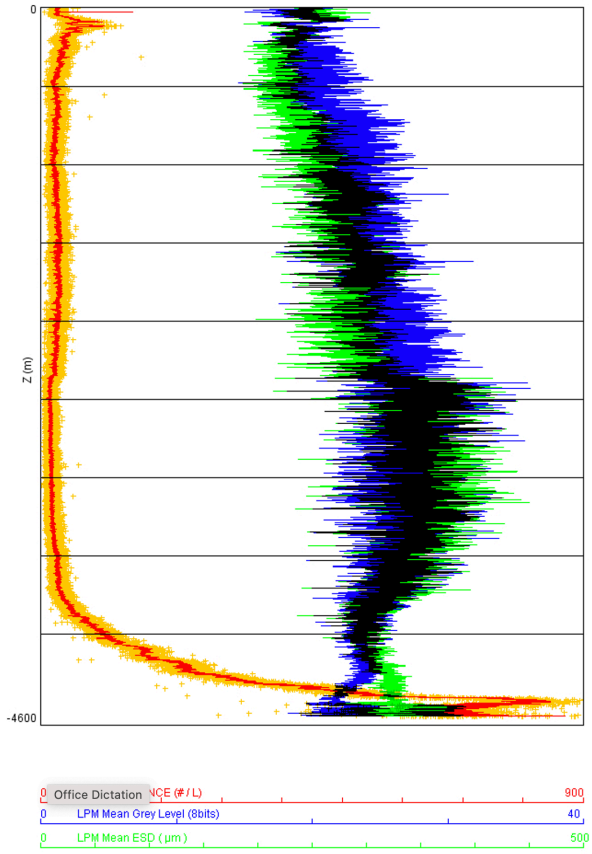

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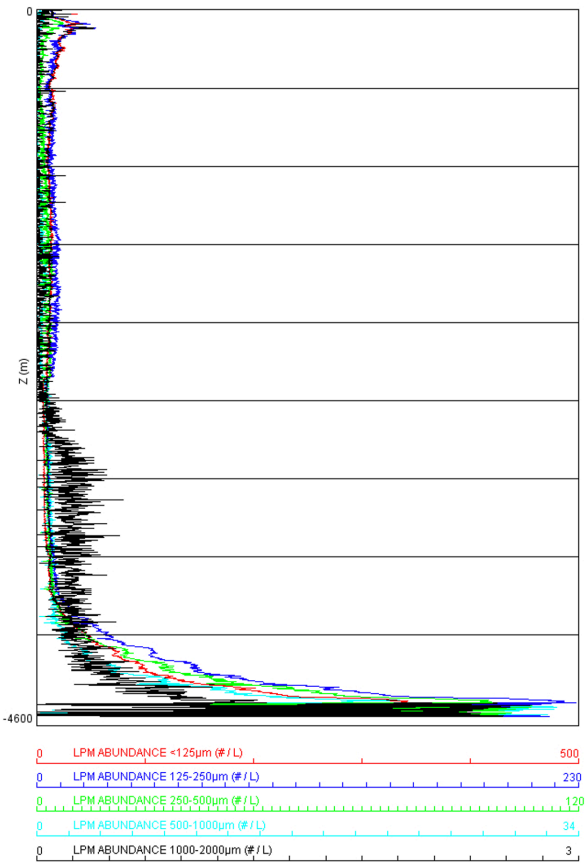

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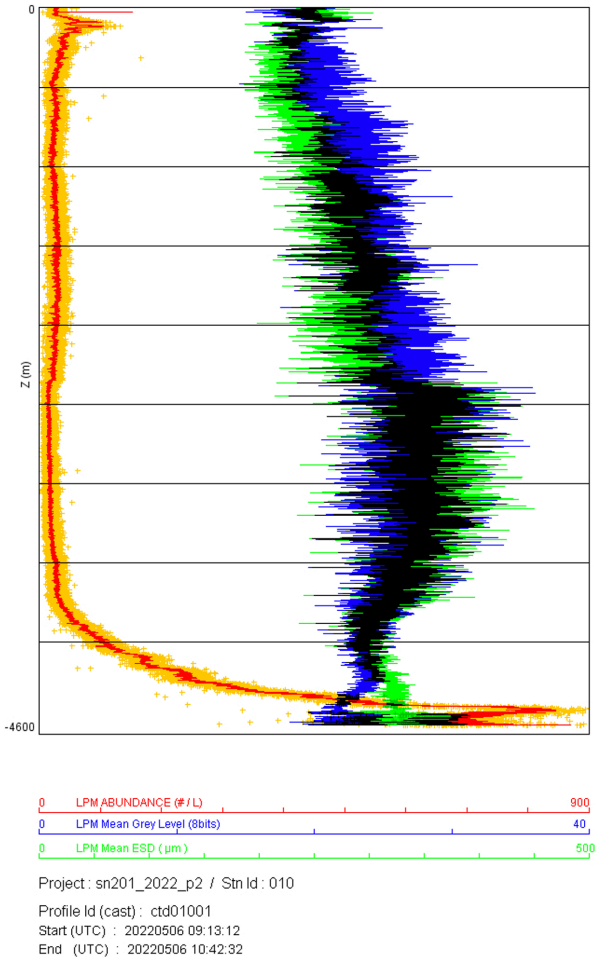
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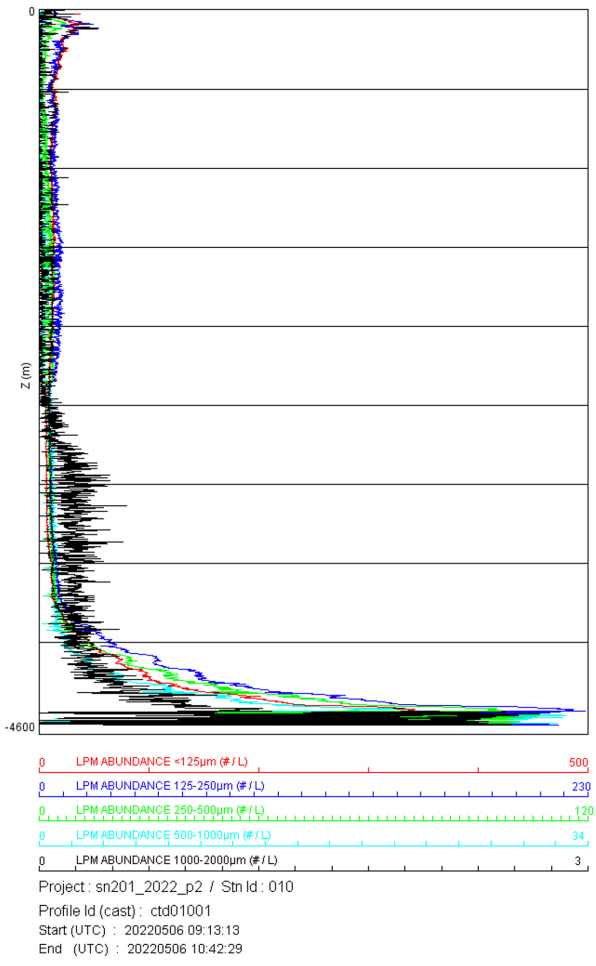
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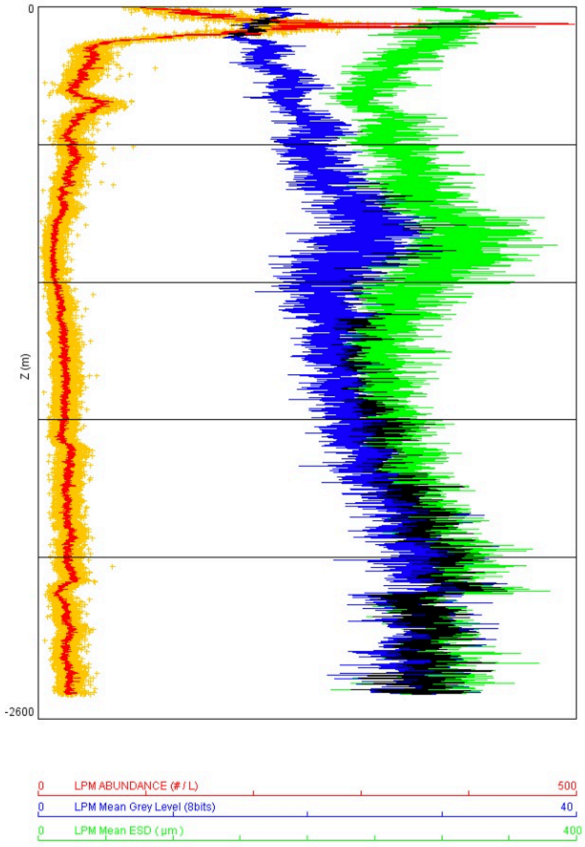
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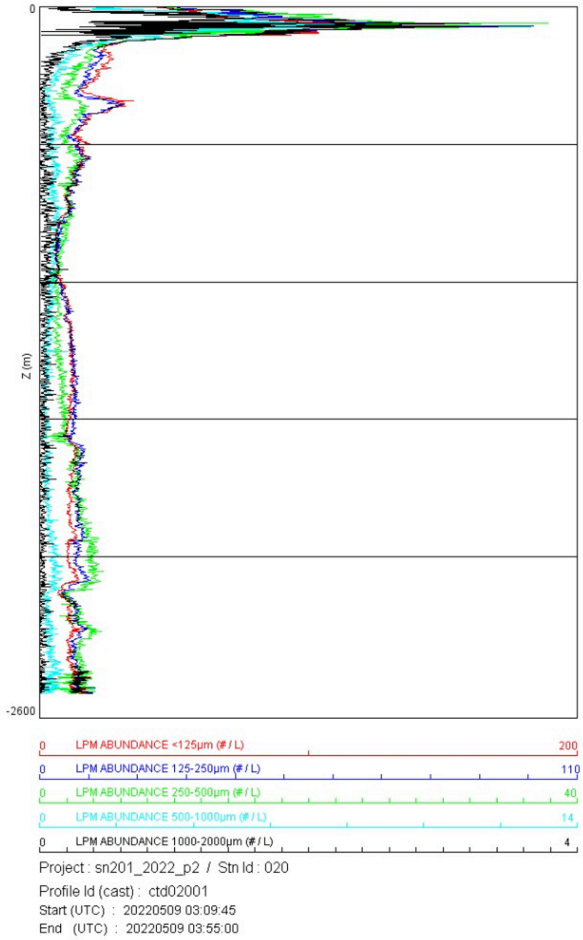
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Fig. 4: Examples of preliminary profiles at station 51. Plots show total large particulate matter (LPM) abundance, mean grey level (brightness) of LPM, and equivalent spherical diameter (ESD) (right) and particle concentration in size bins (left) both plotted against depth (meters). At the off-shelf stations, we see lower particle abundances with moderate surface and subsurface particle abundance maximum and no deep nephloid layer.

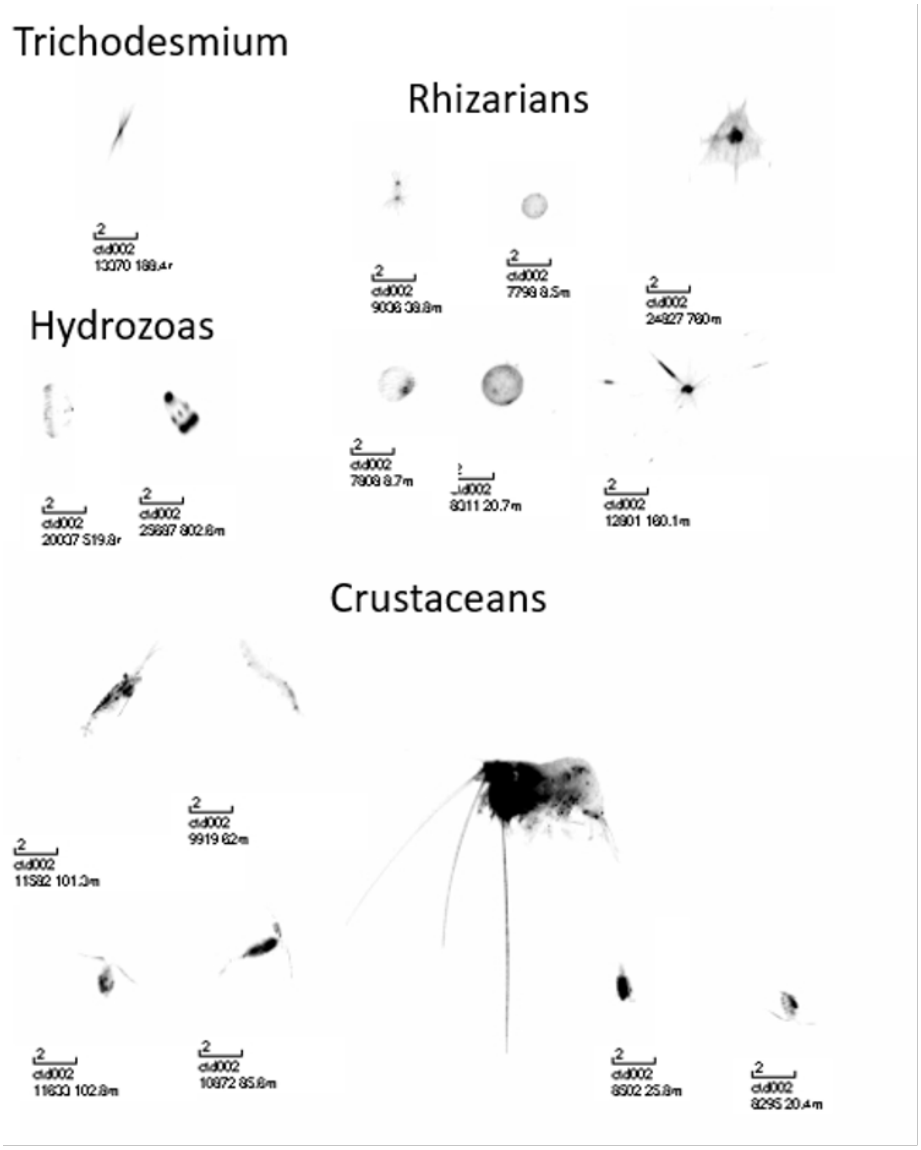


Fig. 1: Fig. 5: Examples of particle and plankton images captured by the UVP5HD and processed by custom software. The scale bar indicates 2 millimeters. Station number, image number for that cast, and depth at which the image was captured are also given in the image.

CHAPTER

EIGHTEEN

UNDERWAY PCO_2

PIs

- Simone Alin (NOAA/PMEL)

Technicians

- Julian Herndon (UW/NOAA/PMEL)
- Andrew Collins (UW/NOAA/PMEL)

With assistance from Mr. Nick Benz (SIO-STS) to identify and clarify the source of MET data supplied by the ship; Mr. Royhon Agostine (SIO-STS) and Mr. Jake Pate (SIO-Revelle) to locate and identify the various scientific seawater supply systems aboard.

The partial pressure of carbon dioxide (pCO_2) in the surface ocean was measured throughout the cruise track of this cruise with a General Oceanics 8050 pCO_2 Measuring System. Uncontaminated seawater was continuously passed (~1.7-2.1 L/min) through a chamber where the seawater concentration of dissolved CO_2 was equilibrated with an overlaying headspace gas. The CO_2 mole fraction of this headspace gas (xCO_2) was measured every two minutes via a non-dispersive infrared analyzer (LiCor 7000) for 60 consecutive measurements. At the end of these 60 discrete measurements, a set of five standard gases was analyzed; four of these standards have known CO_2 concentrations certified by the NOAA Earth Science Research Laboratory (ESRL) ranging from ~300 to ~900 ppm CO_2 (see Table 1). The fifth standard is a tank of 99.9995% ultra-high purity nitrogen gas, used as a baseline 0% CO_2. Following the measurements of standard gases, six consecutive measurements of atmospheric xCO_2 were made of air supplied through tubing fastened to the ships forward jack staff. Twice a day, the infrared analyzer was zeroed and spanned using the nitrogen gas and the highest concentration CO_2 standard (911.41 ppm). In addition to measurements of seawater xCO_2, atmospheric xCO_2, and standard gases, other variables were monitored to evaluate system performance (e.g. gas and water flow rates, pump speeds, equilibrator pressures, etc.). For more detail on the general design and operation of this underway pCO_2 system, see [Pierrot2009].

In coordination with Mr. John Ballard (ODF-SIO) and before departing from Guam, the pCO_2 system received maintenance by Andrew Collins and Julian Herndon. We replaced the Nafion tubes, replumbed the ATM and EQU return lines (which were found to have been plumbed backwards), replaced the vent flow meter and added a filter upstream of it to help prolong its useful life, disassembled and cleaned the water flow meter which was stuck due to corrosion and salt build up inside the impeller housing. The run routine was adjusted as described above and all the gas and water flows were adjusted. The standard gases onboard were replaced with certified standards from ESRL; the existing standards had been sourced from Praxair. The Resident Technicians onboard used bleach to clean/sanitize the scientific seawater system after we departed Guam and prior to the pCO_2 system being turned on. Model and serial numbers for the pCO_2 instrument components and ancillary instruments have been recorded in a separate Excel file and will reported as part of the metadata that will accompany the final/processed pCO_2 data submission. This pCO_2 system does not have a Druck or other external barometer installed in the dry box to measure the pressure in the LiCor cell. The primary equilibrator in this pCO_2 system is an older, non-jacketed equilibrator built using a clear plastic filter housing.

18.1 Notes on seawater source and data:

The pCO_2 system on this cruise was installed in the Hydrolab. The R/V *Revelle* has three separate but related sources of uncontaminated underway seawater. The first (#1) is fairly typical of her AGOR-24 sister ships like the R/V *Brown* and the R/V *Thompson* with an intake at the bow that feeds all the labs. The second (#2) is sourced from the engine room sea-chest and is plumbed into the rest of the ship via a "T" in the system in the Hydrolab. This system has a baffle/diaphragm pump to supply intake water for biologists concerned about damage to the organisms by the centrifugal pump used for system #1. This (system #1) is the system that was used on this cruise. The residence time of water in the engine room sea-chest is believed, by the Chief Engineer, to be less than a minute given the large volume of water taken from it to cool the engines. There is no antifouling system installed in this engine room sea-chest. The third (#3) system is an isolated/standalone flow-through at the bow, but separate from #1 at the bow. System #3 has a TSG45 and SBE38, downstream and upstream respectively, of the centrifugal pump. System #3 takes water in at the bow thruster and dumps it out over the side a few feet away. This was an installation done in drydock to get around the modifications associated with installing the new bow thruster during the mid-life refurbishment. The result is that the intake seawater temperature for system #1 and #2 comes from the independent system #3. Salinity can be sourced either from system #3 or a separate TSG45 installed in the Hydrolab that is fed by either system #1 or #2. System #1 (bow intake) does NOT have its own intake temperature probe. System #2 (engine room sea-chest) does NOT have an intake temperature probe. The pCO_2 system in the Hydrolab received water from system #2, intake temperature from system #3 and salinity data from the TSG45 in the Hydrolab, which measured salinity (along with temperature) of the source water from the sea-chest once it reached the Hydrolab. The pCO_2 received water from a "T" before the sea-chest water was de-bubbled and subsequently fed to the TSG45. To facilitate data processing and future troubleshooting of the *Revelle* pCO_2 system, the column headings for data in the pCO_2 files sourced from the ship are identified in Table 2. Serial numbers and additional details for the instruments in table #2 are in a separate Excel file and will be reported as part of the metadata for pCO_2 data submitted for this cruise.

Table 1: Table 1: Standard gases for P02W 2022 cruise UW pCO_2 system.

Standard	Concentration (ppm)	Tank Serial Numbers
1	0.0	Praxair 5.0 Ultra High Purity N2
2	283.42	LL55868
3	399.51	LL127199
4	539.97	LL127204
5	911.41	LL127176

Table 2: Table 2: pCO_2 system ship supplied data column headers for P02W 2022 cruise, Leg 1. MWL = mean water level.

Column Header	Instrument	System	Location
TSGF1	SW flow meter	3	Bow
TSGT2	TSG45 temperature	2 and 3	Hydrolab
TSGS2	TSG45 salinity	2 and 3	Hydrolab
TSGF2	SW flow meter to TSG45	2 and 3	Hydrolab
PCO2F	SW flow meter to pCO_2	2 and 3	Hydrolab
SST	SBE 38 temperature	3	Bow
AT	RM Young temperature	MET	56' above MWL*
BP	RM Young barometer	MET	56' above MWL*
HDG	Konsberg GPS		
SOG	Speed over ground		

While the raw data is not reported here, it has been collected and will be analyzed using MATLAB® routines developed by Dr. Denis Pierrot of the Atlantic Oceanographic and Meteorological Lab in Miami, FL. Measurements of gas standards were generally within 1% of their certified value throughout the duration of the cruise. During Leg 1 there were two separate, short periods where the instrument was not recording data. The first time was as a result of a

Windows 10 initiated update that restarted the computer and the second was the result of a loss of power due to a heavy load on the circuit used at the time. In response, additional Windows updates were delayed until after the date of arrival in Hawaii, where an update will be run manually prior to Leg 2 to avoid a repeat situation. The power loss has been addressed by changing the pCO_2 instrument power source to the ship's clean power supplied by the UPS in the Main Lab.

The data from the pCO_2 system that is included as part of the ships data supplied by the onboard Resident Technicians to the Chief Scientist is xCO_2 (not pCO_2) that has not been processed or evaluated for QA/QC and as such should be considered preliminary.

CHAPTER

NINETEEN

CHIPODS

PI

- Jonathan Nash (OSU)

19.1 Overview

Chipods are instrument packages that measure turbulence and mixing in the ocean. Specifically, they are used to compute turbulent diffusivity of heat (K) which is inferred from measuring dissipation rate of temperature variance (χ) from a shipboard CTD. Chipods are self-contained, robust and record temperature and derivative signals from FP07 thermistors at 100 Hz; they also record sensor motion at the same sampling rate. Details of the measurement and our methods for processing χ can be found in [Moum_and_Nash2009]. In an effort to expand our global coverage of deep ocean turbulence measurements, the ocean mixing group at Oregon State University has supported chipod measurements on all of the major global repeat hydrography cruises since December 2013.

19.2 System Configuration and Sampling

Three chipods were mounted on the rosette to measure temperature (T), its time derivative (dT/dt), and x and z (horizontal and vertical) accelerations at a sampling rate of 100 Hz. Two chipods were oriented such that their sensors pointed upward. The third one was pointed downward.

The up-looking sensors were positioned higher than the Niskin bottles on the rosette in order to avoid measuring turbulence generated by flow around the rosette and/or its wake while its profiling speed oscillates as a result of swell-induced ship-heave. The down-looking sensors were positioned as far from the frame as possible and as close to the leading edge of the rosette during descent as possible to avoid measuring turbulence generated by the rosette frame and lowered ADCP.

The chipods were turned on by connecting the sensors to the pressure case at the beginning of the cruise. They continuously recorded data until the end of the leg. Only one issue occurred with the chipods following the recovery of cast 04201. The sensor tip (14-32) had popped out of the holder and water had gotten inside. The tip and holder were replaced (14-36) on recovery.

Upward-looking chipod sensors attached to the rosette.

Downward-looking chipod sensor attached to the rosette.

Logger Board SN	Pressure Case SN	Up/Down Looker	Cast Used
2013	Ti 44-12	Up	1-117
2032	Ti 44-15	Up	1-117
2014	Ti 44-08	Down	1-117

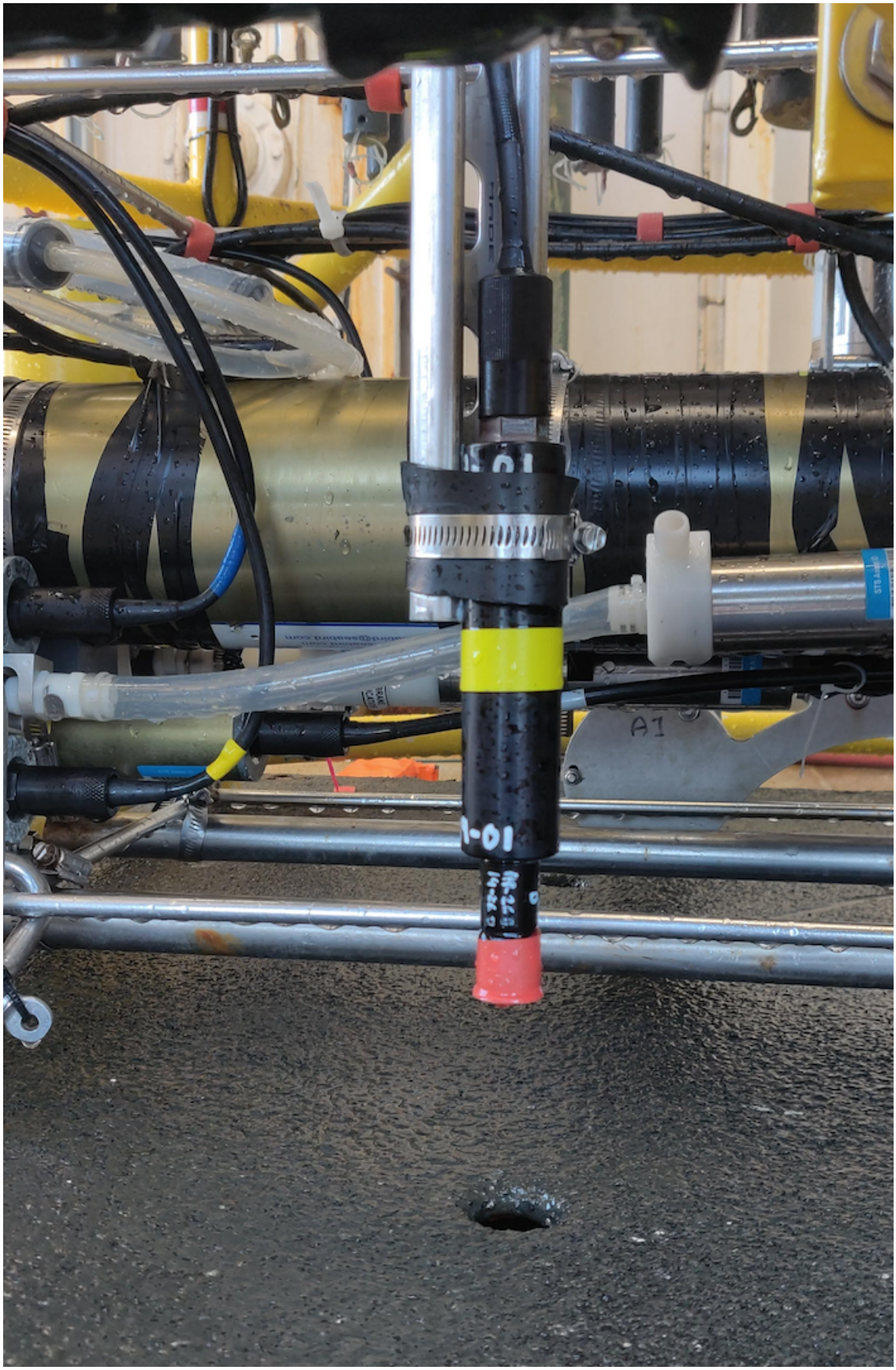

A1

Fig. 1: Highly sensitive temperature probe, which is sampled at 100Hz.

CHAPTER

TWENTY

FLOAT DEPLOYMENTS

A total of 10 *GO-BGC* Argo floats were deployed during the 2022 P02W research cruise The GO-BGC floats measure temperature, salinity, pressure, O_2, NO_3, pH, and bio-optics.

20.1 GO-BGC Argo Floats

PIs

- Kenneth Johnson (MBARI)
- Lynne Talley (UCSD/SIO)
- Susan Wijffels (WHOI)
- Curtis Deutsch (Princeton)
- Steven Riser (UW)
- Jorge Sarmiento (Princeton)

Shipboard personnel

- Lauren Moseley (Columbia/LDEO)
- Shuwen Tan (Columbia/LDEO)

10 biogeochemical (BGC) Argo floats were deployed on P02W as part of the Global Ocean Biogeochemistry (GO-BGC) program (https://go-bgc.org), which is funded by NSF Award OCE-1946578. GO-BGC contributes to international and US BGC-Argo, and all floats conform to Argo mission requirements. BGC-Argo floats will help to resolve seasonal cycles of many key properties relevant to global biogeochemical processes.

All floats deployed were UW-modified Teledyne Webb Apex floats equipped with SBE41-CP CTDs, O_2, NO_3, pH, and FLBB bio-optical sensors. The floats for the P02 cruise were provided by the UW float lab (S. Riser Argo lab).

At sea, CTD watchstander Lauren Moseley and co-chief scientist Shuwen Tan were in charge of deployments. Before each deployment, they carefully cleaned the NO_3 and FLBB bio-optical sensors. Each sensor was rinsed with DI water, wiped/dabbed with lens wipes, rinsed with DI water again, then wiped/dabbed with lens paper. The floats were set to self-activate, so sensor cleaning was the only pre-deployment preparation required. Floats were deployed from the aft stern as the ship steamed slowly away from the CTD station. Floats were lifted over the stern, then carefully lowered into the water with a slip-line strung through the deployment collar of the float. Deployments were completed by Lauren Moseley (deployments #1 and #10), Shuwen Tan (deployments #2 and #7), Sophie Shapiro (deployment #3), Mariana Aguirre Nunes (deployments #4, #6, and #8), and Vic Dina (deployments #5 and #9), with assistance from the ResTechs on watch (Royhon Agostine and Josh Manger, SIO). All deployments were clean with no tangling or hangups of the slip-line.

All floats operate on a standard Argo profiling 10-day cycle. After an initial test dive, the floats descend to a parking depth of 1000 m, and then drift for 10 days with the ocean currents. After 10 days, the floats dive to 2000 m and then

ascend to the surface, during which data are measured and saved. The data are then sent to shore via Iridium Satellite communication. All of the floats began reporting data immediately and the sensors are operating well. All data is publicly available via the GO-BGC data portals and the Argo GDAC.

All deployments occurred at "full" carbon stations so that all GO-SHIP carbon parameters were analyzed for each depth sampled (34 depths from surface to 10 m off bottom). Additionally, duplicate bottles were tripped at the surface (~5 m) and at the depth of the chlorophyll maximum to allow for the addition of *POC* and *HPLC* sampling at these stations. POC and HPLC samples were collected and filtered by the Bio team (Star Dressler and Adam Fagan) and will be sent frozen for analysis at NASA for HPLC and SIO/UCSD for POC.

All floats were adopted by different schools and organizations in the US as part of the Adopt-a-float program (https://www.go-bgc.org/outreach/adopt-a-float). Names and images provided by the adoptees were skillfully drawn onto the floats by P02W science and crew party members. Each class received the details their deployment via posts to the GO-BGC expeditions webpage by onshore personnel George Matsumoto (MBARI). Together with their teachers, the students will follow the float data, which can be easily downloaded and plotted from the website.

Table 1: Float deployments.

Deployment	WMO	Lat	Lon	Date and Time (UTC)	CTD Station
1	5906519	21.00	140.05	05/01/2022 23:25	1
2	5906513	26.67	136.68	05/03/2022 07:39	2
3	5906510	30.54	134.46	05/06/2022 20:12	11
4	5906511	30.00	138.37	05/08/2022 11:57	15
5	5906522	30.00	143.18	05/10/2022 07:06	23
6	5906518	30.00	151.25	05/14/2022 09:33	35
7	5906515	30.00	161.07	05/19/2022 08:43	50
8	5906512	30.00	169.72	05/24/2022 03:00	65
9	5906516	30.00	179.17	05/29/2022 08:53	83
10	5906521	30.00	-170.45	06/03/2022 16:08	101

CHAPTER

TWENTYONE

STUDENT STATEMENTS

U.S. GO-SHIP thanks all of the students who participated on the cruise for their important contribution to collection of this essential global ocean data set, used as the benchmark for accuracy of all other deep ocean observing systems. The training opportunity for students and leadership is an important part of US GO-SHIP's mission. We are committed to do so in a fair, cooperative and professional environment, ensuring an inclusive, safe and productive climate at sea. We thank the students for their honest reflections on their experiences that are included in this section. We have reached out to those who expressed concerns and are taking issues raised seriously, by working to address and prevent these issues from occurring in the future. We also thank them for their feedback in the anonymous post-cruise survey, which we are using to continue to improve our program. This will include ongoing education for all members of our community to create a more inclusive environment.

21.1 Kurtis Anstey

As a soon-to-defend MSc student in ocean physics, I should have had ample experience at sea, by this point. However, due to the restrictions of pursuing a graduate degree during COVID, the research cruises I was scheduled for were either cancelled or the roster reduced to 'essential' – graduate students not included! This is fair, but also very inconvenient when working towards a career in observational physical oceanography. Leg 1 of line P-2, for GO-SHIP in 2022, offered me the experience I needed, and more. Much of my research deals with velocity data obtained from acoustic Doppler current profilers (ADCP), and up to this point I had only dealt with the software and data. As the focus of my position onboard, I operated and performed QC for the lowered ADCP instruments, of which there were two attached to the rosette. Working directly with the instruments provides an understanding that you just don't get at your desk. Additionally, I gained experience as the off-shift operator for the Underwater Vision Profiler (UVP), and assisting with CTD watch procedures, sampling, and deployment/recovery of the rosette. Not to mention the immersion of eight weeks of ship-life, in general. The scientists and crew were kind and incredibly helpful, and there was no shortage of fun to be found between processing and casts. And the food was 'chef's kiss'! The hands-on experience gained from this research cruise more than makes up for the gap in my education, and I feel I now have the practical knowledge to move confidently into a career in physical oceanography.

APPENDIX

A

ABBREVIATIONS

ADCP Acoustic Doppler Current Profiler

AOML Atlantic Oceanographic and Meteorological Laboratory

AP Particulate Absorption Spectra

APL Applied Physics Laboratory

BGC Biogeochemical

CDOM Chromophoric Dissolved Organic Matter

CFCs Chlorofluorocarbons

CTDO Conductivity Temperature Depth Oxygen

DIC Dissolved Inorganic Carbon

DOC Dissolved Organic Carbon

ECO Edison Chouest Offshore

FSU Florida State University

GO-BGC Global Ocean Biogeochemistry Array

HPLC High-Performance Liquid Chromatography

LDEO Lamont-Doherty Earth Observatory - Columbia University

LADCP Lowered Accoustic Doppler Current Profiler

MBARI Monterey Bay Aquarium Research Institute

MIT Massachussetts Institute of Technology

N_2O Nitrous oxide

NOAA National Oceanographic Atmospheric Administration

NSF National Science Foundation

ODF Oceanographic Data Facility - *SIO*

OSU Oregon State University

PMEL Pacific Marine Environmental Laboratory

POC Particulate Organic Carbon

PON Particulate Organic Nitrogen

POM Particulate Organic Matter

RSMAS Rosenstiel School of Marine and Atmospheric Science - *U Miami*

SADCP Shipboard Acoustic Doppler Current Profiler

SEG Shipboard Electronics Group

SF_6 Sulfur Hexafluoride

SIO Scripps Institution of Oceanography

STS Shipboard Technical Support - *SIO*

TAMU Texas A&M University

TDN Total Dissolved Nitrogen

UAF University of Alaska Fairbanks

UCI University of California Irvine

UCSD University of California San Diego

UH University of Hawaii

U Miami University of Miami

UOG University of Guam

UT University of Texas

UVic University of Victoria

UVP Underwater Vision Profiler

UW University of Washington

WHOI Woods Hole Oceanographic Institution

APPENDIX

B

BOTTLE QUALITY COMMENTS

Station	Cast	Bottle	Param	Code	Comment

APPENDIX

C

CALIBRATION DOCUMENTS

Pressure Calibration Report
STS Calibration Facility

SENSOR SERIAL NUMBER: 1281
CALIBRATION DATE: 07-DEC-2021
Mfg: SEABIRD Model: 09P CTD Prs s/n: 136428

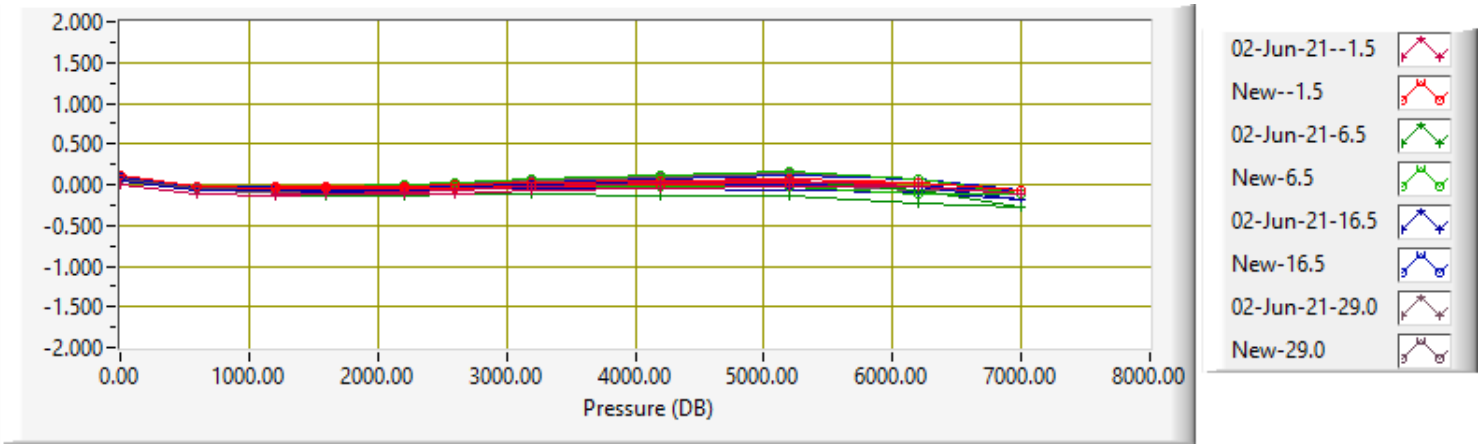
C1= -4.160481E+4
C2= -3.219786E-1
C3= 1.105909E-2
D1= 3.538794E-2
D2= 0.000000E+0
T1= 3.013965E+1
T2= -3.914456E-4
T3= 4.524706E-6
T4= -6.654717E-9
T5= 0.000000E+0
AD590M= 1.27846E-2
AD590B= -9.25586E+0
Slope = 1.00000000E+0
Offset = 0.00000000E+0

Calibration Standard: Mfg: FLUKE Model: P3125 s/n: 70856
t0=t1+t2*td+t3*td*td+t4*td*td*td
w = 1-t0*t0*f*f
Pressure = (0.6894759*((c1+c2*td+c3*td*td)*w*(1-(d1+d2*td)*w)-14.7)

Sensor Output	DWT	Sensor New_Coefs	DWT-Sensor Prev_Coefs	DWT-Sensor NEW_Coefs	PT-DegC	Bath_Temp
33184.484	0.27	0.15	-0.01	0.12	-0.79	-1.522
33529.461	600.32	600.33	-0.12	-0.01	-0.79	-1.523
33870.352	1200.35	1200.38	-0.13	-0.04	-0.79	-1.523
34095.434	1600.37	1600.41	-0.12	-0.04	-0.79	-1.523
34429.896	2200.40	2200.44	-0.11	-0.04	-0.78	-1.523
34650.800	2600.41	2600.46	-0.10	-0.04	-0.78	-1.523
34979.159	3200.48	3200.50	-0.08	-0.03	-0.78	-1.523
35518.611	4200.53	4200.53	-0.05	-0.01	-0.78	-1.523
36048.722	5200.59	5200.57	-0.02	0.02	-0.78	-1.523
36569.891	6200.60	6200.59	-0.02	0.02	-0.78	-1.523
36980.687	7000.60	7000.66	-0.11	-0.06	-0.78	-1.522
36569.868	6200.57	6200.54	-0.01	0.03	-0.78	-1.522
36048.668	5200.56	5200.48	0.04	0.08	-0.79	-1.522
35518.570	4200.53	4200.47	0.02	0.06	-0.79	-1.522
34979.128	3200.49	3200.46	-0.02	0.03	-0.79	-1.522
34650.795	2600.45	2600.45	-0.07	-0.01	-0.79	-1.522
34429.893	2200.42	2200.45	-0.09	-0.03	-0.79	-1.522
34095.434	1600.38	1600.41	-0.11	-0.03	-0.79	-1.522

Sensor Output	DWT	Sensor New_Coefs	DWT-Sensor Prev_Coefs	DWT-Sensor NEW_Coefs	PT-DegC	Bath_Temp
33870.344	1200.35	1200.38	-0.11	-0.02	-0.79	-1.523
33529.450	600.32	600.31	-0.10	0.01	-0.79	-1.523
33187.695	0.27	0.15	0.01	0.12	7.25	6.485
33532.691	600.32	600.34	-0.12	-0.02	7.25	6.485
33873.596	1200.35	1200.39	-0.13	-0.04	7.25	6.485
34098.690	1600.37	1600.41	-0.13	-0.04	7.25	6.485
34433.169	2200.41	2200.46	-0.14	-0.05	7.25	6.484
34654.079	2600.42	2600.46	-0.13	-0.04	7.25	6.484
34982.435	3200.45	3200.47	-0.11	-0.02	7.25	6.484
35521.908	4200.46	4200.49	-0.13	-0.03	7.25	6.484
36052.022	5200.46	5200.48	-0.13	-0.02	7.25	6.484
36573.272	6200.48	6200.59	-0.24	-0.11	7.25	6.484
36984.076	7000.51	7000.64	-0.28	-0.13	7.25	6.484
36573.222	6200.57	6200.50	-0.06	0.07	7.25	6.485
36051.999	5200.59	5200.43	0.05	0.16	7.25	6.485
35521.885	4200.57	4200.45	0.02	0.12	7.25	6.485
34982.416	3200.51	3200.44	-0.01	0.08	7.25	6.485
34654.069	2600.46	2600.45	-0.07	0.02	7.24	6.485
34433.161	2200.44	2200.44	-0.10	-0.01	7.24	6.485
34098.685	1600.39	1600.41	-0.11	-0.02	7.24	6.485
33873.587	1200.36	1200.38	-0.11	-0.02	7.24	6.485
33532.679	600.32	600.32	-0.10	-0.00	7.24	6.485
33190.832	0.27	0.18	0.04	0.09	17.23	16.491
33535.848	600.33	600.35	-0.07	-0.02	17.24	16.493
33876.777	1200.36	1200.39	-0.07	-0.03	17.25	16.492
34101.892	1600.39	1600.41	-0.06	-0.03	17.25	16.492
34436.397	2200.43	2200.45	-0.07	-0.03	17.26	16.492
34657.327	2600.44	2600.46	-0.06	-0.02	17.25	16.492
34985.713	3200.47	3200.48	-0.05	-0.00	17.26	16.491
35525.226	4200.48	4200.48	-0.05	-0.00	17.26	16.491
36055.397	5200.49	5200.50	-0.07	-0.01	17.26	16.491
36576.653	6200.53	6200.54	-0.10	-0.01	17.26	16.491
36987.507	7000.54	7000.62	-0.19	-0.08	17.26	16.491
36576.636	6200.57	6200.51	-0.03	0.06	17.26	16.491
36055.374	5200.57	5200.46	0.04	0.11	17.25	16.492
35525.205	4200.52	4200.46	0.01	0.07	17.23	16.492
34985.697	3200.49	3200.46	-0.01	0.03	17.23	16.492
34657.320	2600.45	2600.46	-0.05	-0.01	17.23	16.492
34436.391	2200.42	2200.45	-0.07	-0.03	17.23	16.492
34101.893	1600.38	1600.43	-0.08	-0.05	17.23	16.491
33876.773	1200.35	1200.39	-0.08	-0.04	17.23	16.491
33535.836	600.32	600.33	-0.05	-0.01	17.23	16.491
33193.464	0.27	0.19	-0.01	0.08	29.78	29.003
33538.531	600.33	600.37	-0.10	-0.04	29.78	29.002
33879.505	1200.36	1200.41	-0.10	-0.05	29.78	29.002
34104.652	1600.39	1600.44	-0.09	-0.05	29.78	29.002

Sensor Output	DWT	Sensor New_Coefs	DWT-Sensor Prev_Coefs	DWT-Sensor NEW_Coefs	PT-DegC	Bath_Temp
34439.199	2200.43	2200.47	-0.07	-0.04	29.78	29.002
34660.159	2600.44	2600.48	-0.05	-0.04	29.78	29.002
34988.587	3200.48	3200.49	-0.02	-0.02	29.78	29.002
35528.174	4200.49	4200.50	-0.01	-0.01	29.78	29.002
36058.400	5200.48	5200.49	0.01	-0.00	29.79	29.001
36579.741	6200.49	6200.56	-0.06	-0.07	29.79	29.000
36990.617	7000.49	7000.57	-0.07	-0.08	29.79	29.001
36579.691	6200.52	6200.46	0.07	0.06	29.79	29.001
36058.364	5200.55	5200.42	0.14	0.13	29.78	29.002
35528.137	4200.53	4200.44	0.10	0.09	29.78	29.003
34988.564	3200.49	3200.45	0.04	0.04	29.78	29.002
34660.145	2600.45	2600.45	-0.02	-0.00	29.78	29.002
34439.185	2200.42	2200.45	-0.05	-0.03	29.78	29.001
34104.645	1600.38	1600.43	-0.08	-0.05	29.78	29.001
33879.496	1200.35	1200.40	-0.09	-0.04	29.78	29.002
33538.512	600.32	600.33	-0.08	-0.01	29.78	29.001
33193.437	0.27	0.14	0.04	0.12	29.78	29.000



Sea-Bird Scientific
13431 NE 20th Street
Bellevue, WA 98005
USA

+1 425-643-9866
seabird@seabird.com
www.seabird.com

SENSOR SERIAL NUMBER: 2569
CALIBRATION DATE: 17-Mar-22

SBE 4 CONDUCTIVITY CALIBRATION DATA
PSS 1978: C(35,15,0) = 4.2914 Siemens/meter

COEFFICIENTS:

```
g =  -1.04574666e+001
h =   1.58020915e+000
i =   1.92446352e-003
j =  -2.24202625e-005

CPcor = -9.5700e-008 (nominal)
CTcor =  3.2500e-006 (nominal)
```

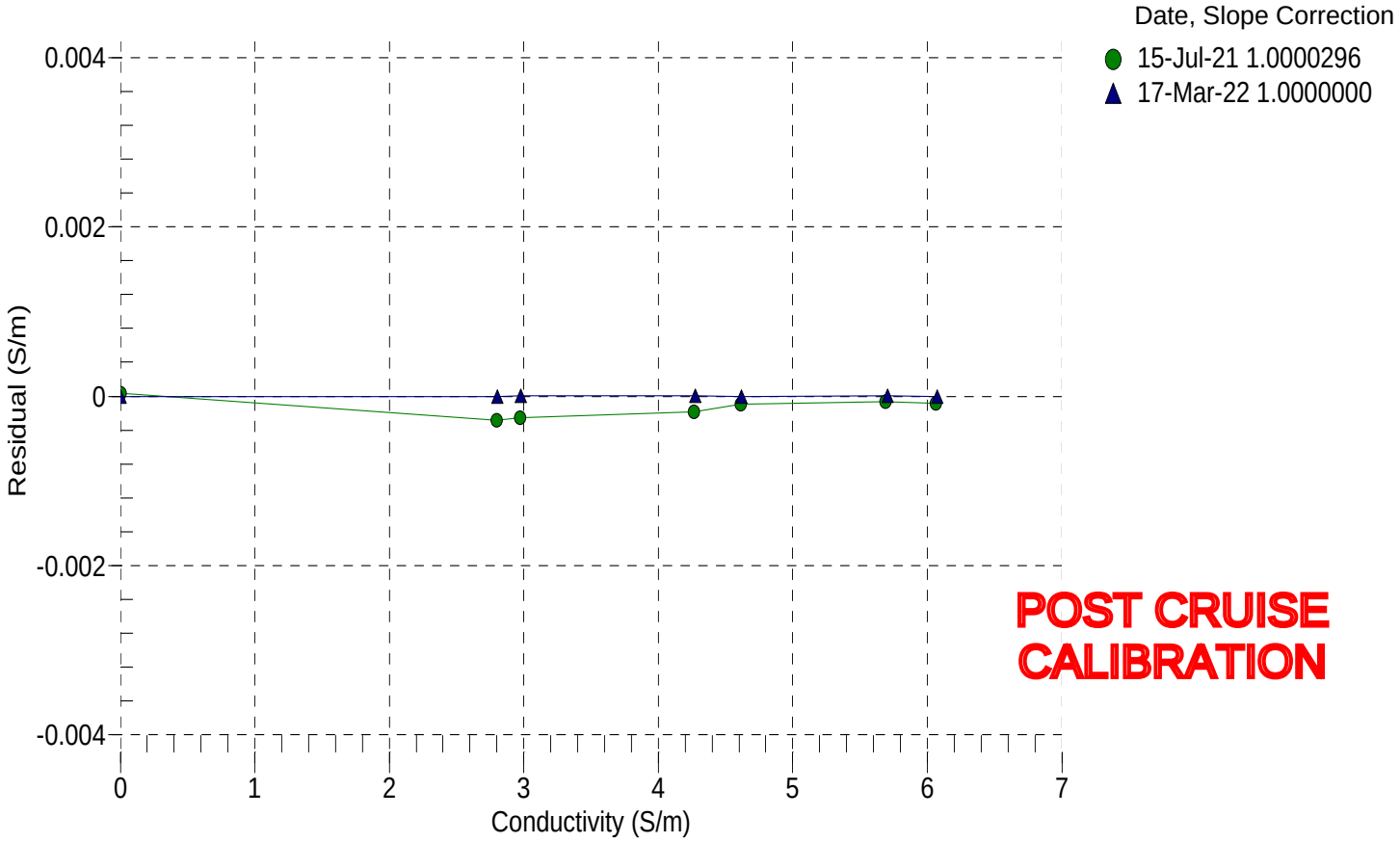
BATH TEMP (° C)	BATH SAL (PSU)	BATH COND (S/m)	INSTRUMENT OUTPUT (kHz)	INSTRUMENT COND (S/m)	RESIDUAL (S/m)
0.0000	0.0000	0.00000	2.56861	0.00000	0.00000
-1.0001	34.8352	2.80595	4.92316	2.80595	-0.00000
0.9999	34.8357	2.97746	5.03130	2.97746	0.00000
14.9999	34.8360	4.27376	5.78316	4.27377	0.00000
18.4999	34.8361	4.62070	5.96822	4.62070	-0.00000
29.0000	34.8319	5.70459	6.51234	5.70459	0.00001
32.5000	34.8212	6.07675	6.68888	6.07674	-0.00000

f = Instrument Output (kHz)

t = temperature (°C); p = pressure (decibars); δ = CTcor; ε = CPcor;

Conductivity (S/m) = $(g + h * f^2 + i * f^3 + j * f^4) / 10 (1 + \delta * t + \varepsilon * p)$

Residual (Siemens/meter) = instrument conductivity - bath conductivity



Sea-Bird Scientific
13431 NE 20th Street
Bellevue, WA 98005
USA

+1 425-643-9866
seabird@seabird.com
www.seabird.com

SENSOR SERIAL NUMBER: 3578
CALIBRATION DATE: 22-Mar-22

SBE 4 CONDUCTIVITY CALIBRATION DATA
PSS 1978: C(35,15,0) = 4.2914 Siemens/meter

COEFFICIENTS:

```
g =  -9.47463002e+000
h =   1.14725777e+000
i =  -5.49238016e-004
j =   1.02257222e-004

CPcor = -9.5700e-008 (nominal)
CTcor =  3.2500e-006 (nominal)
```

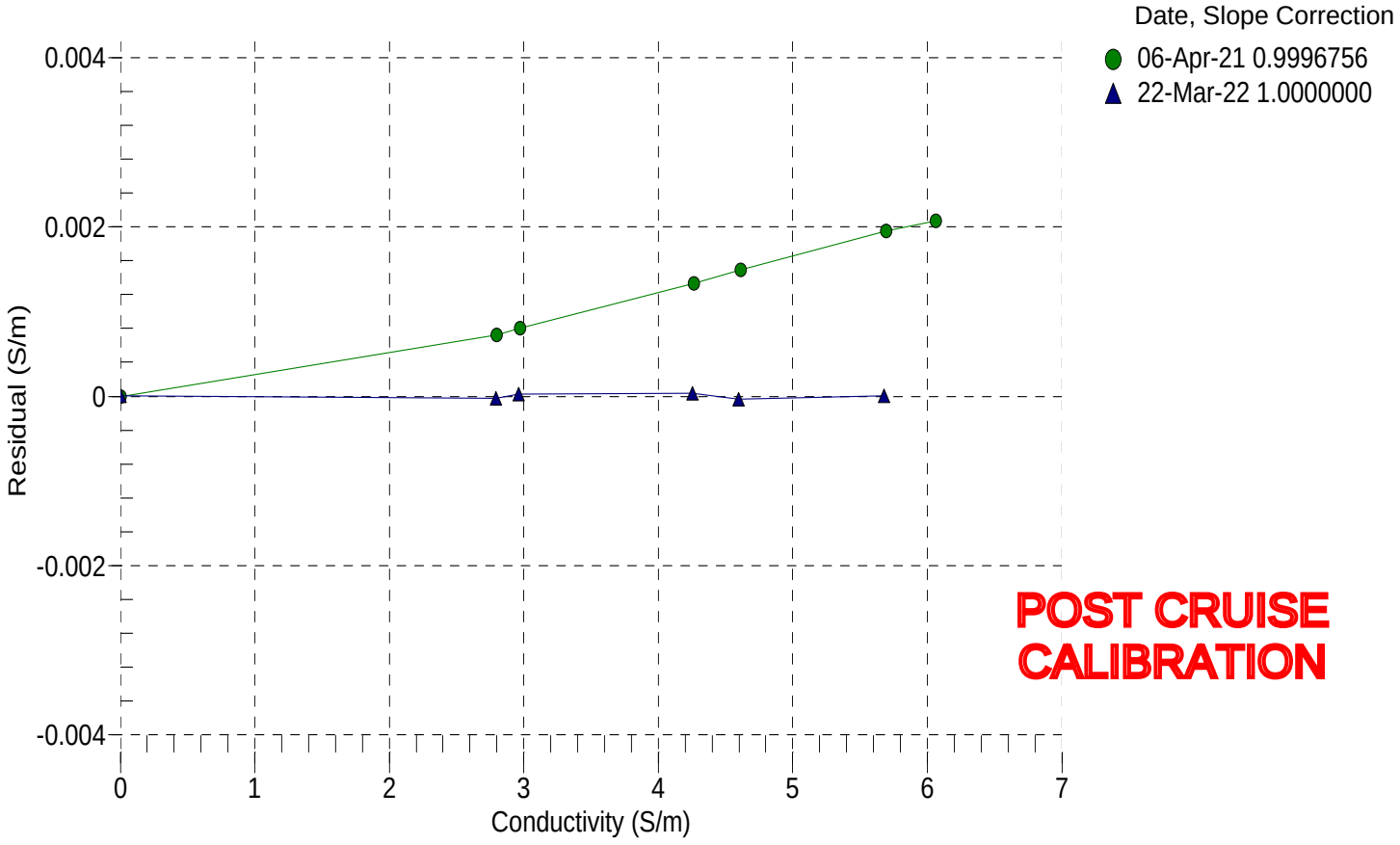
BATH TEMP (° C)	BATH SAL (PSU)	BATH COND (S/m)	INSTRUMENT OUTPUT (kHz)	INSTRUMENT COND (S/m)	RESIDUAL (S/m)
0.0000	0.0000	0.00000	2.87468	0.00000	0.00000
-1.0000	34.6472	2.79222	5.70884	2.79219	-0.00003
1.0000	34.6471	2.96288	5.83749	2.96290	0.00003
15.0000	34.6463	4.25296	6.73011	4.25299	0.00003
18.5001	34.6449	4.59809	6.94927	4.59805	-0.00004
29.0000	34.6383	5.67644	7.59308	5.67644	0.00001
32.5000	34.6230	6.04608	7.80118	6.04573	-0.00035

f = Instrument Output (kHz)

t = temperature (°C); p = pressure (decibars); δ = CTcor; ε = CPcor;

Conductivity (S/m) = $(g + h * f^2 + i * f^3 + j * f^4) / 10 (1 + \delta * t + \varepsilon * p)$

Residual (Siemens/meter) = instrument conductivity - bath conductivity



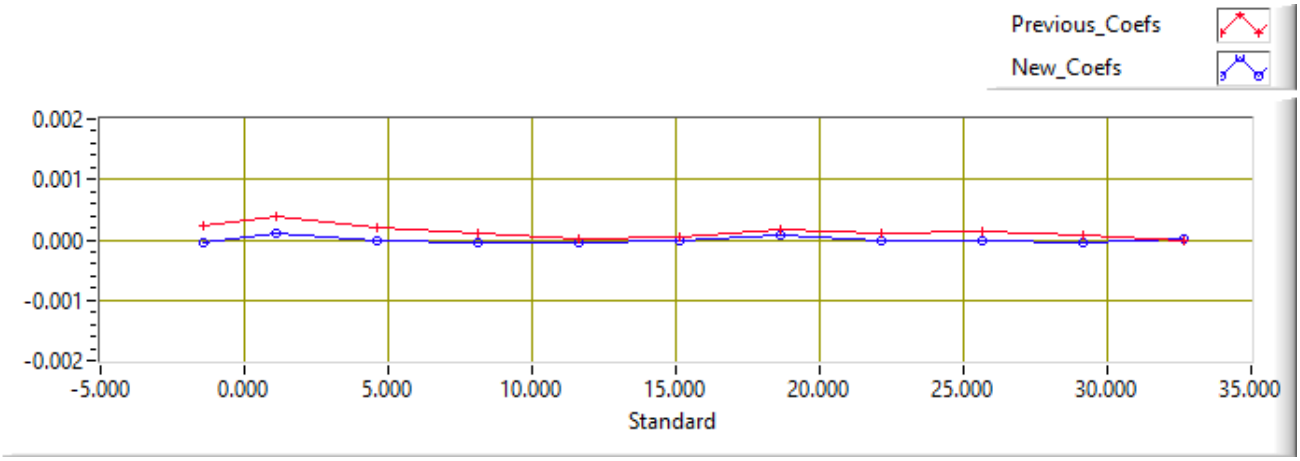
Temperature Calibration Report
STS Calibration Facility

SENSOR SERIAL NUMBER: 0105
CALIBRATION DATE: 15-Mar-2022
Mfg: SEABIRD Model: 35
Previous cal: 09-Feb-21
Calibration Tech: MVK

ITS-90_COEFFICIENTS
a0 = 6.524193824E-3
a1 = -1.849038085E-3
a2 = 2.569536069E-4
a3 = -1.400059014E-5
a4 = 2.909840456E-7
Slope = 1.000000 Offset = 0.000000
Calibration Standard: Mfg: Isotech Model: MicroK100 s/n: 291088-2

Calibration Standard: Mfg: Isotech Model: MicroK100 s/n: 291088-2
Temperature ITS-90 = 1/{a0+a1[ln(f)]+a2[ln2(f)]+a3[ln3(f)]+a4[ln4(f)} - 273.15 (°C)

SBE35 Count	SPRT ITS-T90	SBE35 ITS-T90	SPRT-SBE35 OLD_Coefs	SPRT-SBE35 NEW_Coefs
921181.3716	-1.4298	-1.4298	0.00024	-0.00006
823747.7314	1.0749	1.0748	0.00040	0.00011
705943.7767	4.5815	4.5815	0.00021	-0.00001
606521.2201	8.0900	8.0900	0.00010	-0.00004
522477.9212	11.5985	11.5986	0.00003	-0.00005
451384.5810	15.1014	15.1014	0.00004	-0.00002
390849.1226	18.6137	18.6136	0.00017	0.00009
339363.4042	22.1233	22.1233	0.00012	0.00000
295402.2109	25.6355	25.6355	0.00014	-0.00001
257832.7582	29.1445	29.1446	0.00008	-0.00004
225602.7730	32.6547	32.6547	-0.00000	0.00002



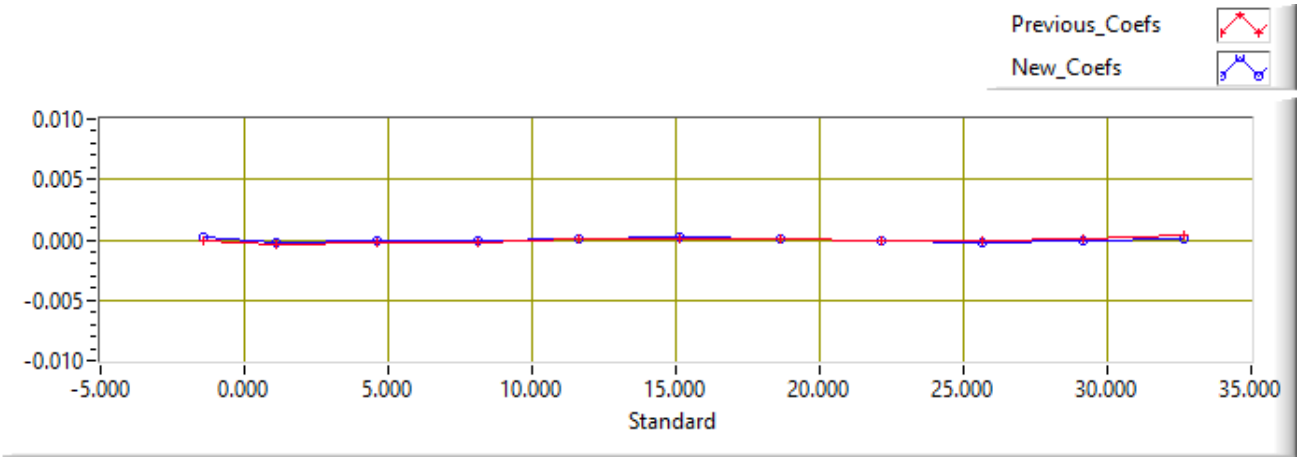
Temperature Calibration Report
STS Calibration Facility

SENSOR SERIAL NUMBER: 4138
CALIBRATION DATE: 17-Mar-2022
Mfg: SEABIRD Model: 03
Previous cal: 31-Aug-21
Calibration Tech: AJM

ITS-90_COEFFICIENTS	IPTS-68_COEFFICIENTS ITS-T90	
g = 4.32516790E-3	a = 4.32535573E-3	
h = 6.27336486E-4	b = 6.27540205E-4	
i = 2.00203041E-5	c = 2.00510291E-5	
j = 1.55382422E-6	d = 1.55518090E-6	
f0 = 1000.0	Slope = 1.0	Offset = 0.0

Calibration Standard: Mfg: Isotech Model: MicroK100 s/n: 291088-2
Temperature ITS-90 = 1/{g+h[ln(f0/f)]+i[ln2(f0/f)]+j[ln3(f0/f)]} - 273.15 (°C)
Temperature IPTS-68 = 1/{a+b[ln(f0/f)]+c[ln2(f0/f)]+d[ln3(f0/f)]} - 273.15 (°C)
T68 = 1.00024 * T90 (-2 to -35 Deg C)

SBE3 Freq	SPRT ITS-T90	SBE3 ITS-T90	SPRT-SBE3 OLD_Coefs	SPRT-SBE3 NEW_Coefs
2889.1750	-1.4300	-1.4302	-0.00002	0.00020
3058.7838	1.0742	1.0744	-0.00039	-0.00022
3308.2564	4.5810	4.5811	-0.00019	-0.00007
3572.2452	8.0890	8.0891	-0.00022	-0.00014
3851.2432	11.5994	11.5993	0.00007	0.00013
4144.7378	15.1008	15.1006	0.00014	0.00019
4454.8273	18.6132	18.6131	0.00005	0.00008
4780.7934	22.1234	22.1234	-0.00001	-0.00002
5123.3570	25.6352	25.6354	-0.00011	-0.00017
5482.4267	29.1442	29.1443	0.00002	-0.00013
5858.9713	32.6564	32.6562	0.00042	0.00015



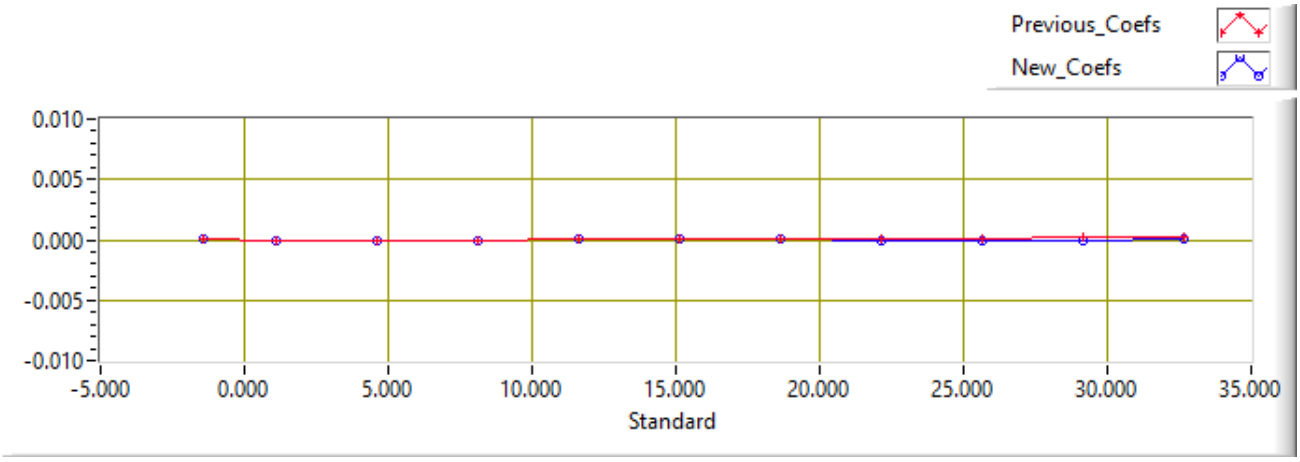
Temperature Calibration Report
STS Calibration Facility

SENSOR SERIAL NUMBER: 4941
CALIBRATION DATE: 09-Mar-2022
Mfg: SEABIRD Model: 03
Previous cal: 31-Aug-21
Calibration Tech: AJM

ITS-90_COEFFICIENTS	IPTS-68_COEFFICIENTS ITS-T90	
g = 4.36052717E-3	a = 4.36072637E-3	
h = 6.41687693E-4	b = 6.41898355E-4	
i = 2.28813698E-5	c = 2.29135945E-5	
j = 2.15275286E-6	d = 2.15425958E-6	
f0 = 1000.0	Slope = 1.0	Offset = 0.0

Calibration Standard: Mfg: Isotech Model: MicroK100 s/n: 291088-2
Temperature ITS-90 = 1/{g+h[ln(f0/f)]+i[ln2(f0/f)]+j[ln3(f0/f)]} - 273.15 (°C)
Temperature IPTS-68 = 1/{a+b[ln(f0/f)]+c[ln2(f0/f)]+d[ln3(f0/f)]} - 273.15 (°C)
T68 = 1.00024 * T90 (-2 to -35 Deg C)

SBE3 Freq	SPRT ITS-T90	SBE3 ITS-T90	SPRT-SBE3 OLD_Coefs	SPRT-SBE3 NEW_Coefs
3000.3682	-1.4293	-1.4293	0.00010	0.00005
3173.7371	1.0751	1.0751	-0.00000	-0.00003
3428.5184	4.5817	4.5818	-0.00009	-0.00010
3697.8770	8.0908	8.0908	-0.00001	-0.00001
3982.1314	11.6009	11.6008	0.00011	0.00010
4280.7697	15.1016	15.1016	0.00006	0.00003
4595.9846	18.6143	18.6143	0.00007	0.00001
4926.8615	22.1239	22.1240	0.00005	-0.00005
5274.2376	25.6360	25.6360	0.00014	-0.00001
5637.7164	29.1432	29.1433	0.00016	-0.00004
6018.7425	32.6565	32.6565	0.00029	0.00004



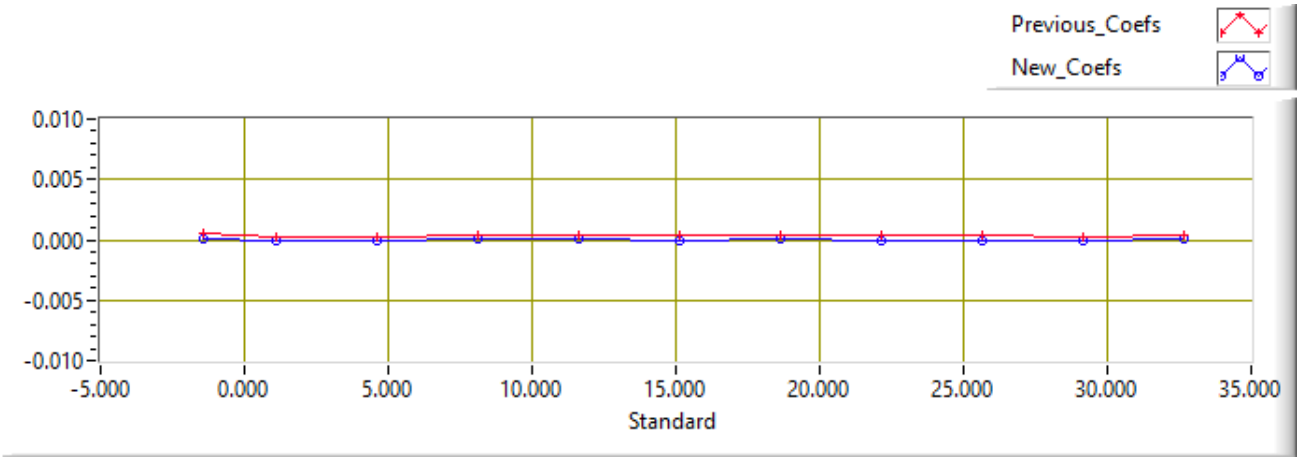
Temperature Calibration Report
STS Calibration Facility

SENSOR SERIAL NUMBER: 5046
CALIBRATION DATE: 02-Mar-2022
Mfg: SEABIRD Model: 03
Previous cal: 24-Feb-21
Calibration Tech: MVK

ITS-90_COEFFICIENTS	IPTS-68_COEFFICIENTS ITS-T90	
g = 4.41636859E-3	a = 4.41658635E-3	
h = 6.44196855E-4	b = 6.44412734E-4	
i = 2.26266614E-5	c = 2.26589816E-5	
j = 2.07106898E-6	d = 2.07252479E-6	
f0 = 1000.0	Slope = 1.0	Offset = 0.0

Calibration Standard: Mfg: Isotech Model: MicroK100 s/n: 291088-2
Temperature ITS-90 = 1/{g+h[ln(f0/f)]+i[ln2(f0/f)]+j[ln3(f0/f)]} - 273.15 (°C)
Temperature IPTS-68 = 1/{a+b[ln(f0/f)]+c[ln2(f0/f)]+d[ln3(f0/f)]} - 273.15 (°C)
T68 = 1.00024 * T90 (-2 to -35 Deg C)

SBE3 Freq	SPRT ITS-T90	SBE3 ITS-T90	SPRT-SBE3 OLD_Coefs	SPRT-SBE3 NEW_Coefs
3276.5574	-1.4290	-1.4291	0.00053	0.00008
3465.8594	1.0752	1.0752	0.00030	-0.00009
3744.0916	4.5827	4.5828	0.00026	-0.00007
4038.0594	8.0910	8.0909	0.00037	0.00004
4348.2547	11.6005	11.6004	0.00043	0.00008
4674.1811	15.1015	15.1015	0.00032	-0.00006
5018.1189	18.6143	18.6143	0.00044	0.00004
5379.1382	22.1246	22.1246	0.00043	0.00000
5757.8618	25.6350	25.6350	0.00042	0.00000
6154.5491	29.1447	29.1448	0.00027	-0.00009
6569.8498	32.6566	32.6565	0.00032	0.00006



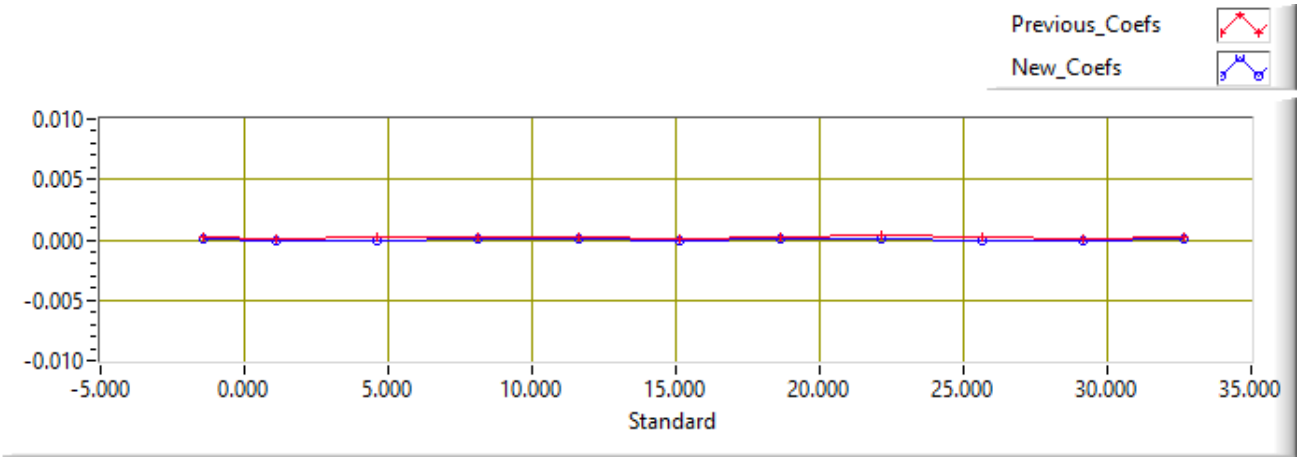
Temperature Calibration Report
STS Calibration Facility

SENSOR SERIAL NUMBER: 6018
CALIBRATION DATE: 02-Mar-2022
Mfg: SEABIRD Model: 03
Previous cal: 24-Feb-21
Calibration Tech: MVK

ITS-90_COEFFICIENTS	IPTS-68_COEFFICIENTS ITS-T90	
g = 4.36187980E-3	a = 4.36207948E-3	
h = 6.37713526E-4	b = 6.37923075E-4	
i = 2.21508074E-5	c = 2.21825746E-5	
j = 2.03138571E-6	d = 2.03284160E-6	
f0 = 1000.0	Slope = 1.0	Offset = 0.0

Calibration Standard: Mfg: Isotech Model: MicroK100 s/n: 291088-2
Temperature ITS-90 = 1/{g+h[ln(f0/f)]+i[ln2(f0/f)]+j[ln3(f0/f)]} - 273.15 (°C)
Temperature IPTS-68 = 1/{a+b[ln(f0/f)]+c[ln2(f0/f)]+d[ln3(f0/f)]} - 273.15 (°C)
T68 = 1.00024 * T90 (-2 to -35 Deg C)

SBE3 Freq	SPRT ITS-T90	SBE3 ITS-T90	SPRT-SBE3 OLD_Coefs	SPRT-SBE3 NEW_Coefs
3025.6386	-1.4290	-1.4291	0.00027	0.00006
3201.3846	1.0752	1.0752	0.00012	-0.00009
3459.8000	4.5827	4.5827	0.00018	-0.00003
3732.9699	8.0910	8.0909	0.00028	0.00006
4021.3636	11.6005	11.6004	0.00027	0.00004
4324.5238	15.1015	15.1016	0.00014	-0.00010
4644.5878	18.6143	18.6143	0.00028	0.00003
4980.7012	22.1246	22.1245	0.00036	0.00010
5333.4873	25.6350	25.6350	0.00023	-0.00002
5703.1694	29.1447	29.1448	0.00010	-0.00012
6090.3748	32.6566	32.6565	0.00023	0.00006



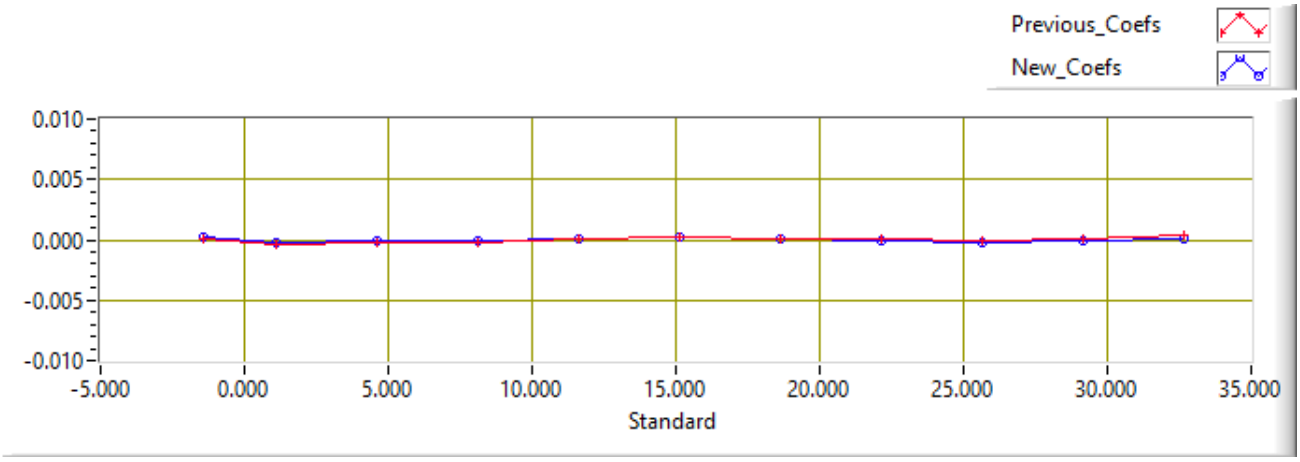
Temperature Calibration Report
STS Calibration Facility

SENSOR SERIAL NUMBER: 6049
CALIBRATION DATE: 17-Mar-2022
Mfg: SEABIRD Model: 03
Previous cal: 31-Aug-21
Calibration Tech: AJM

ITS-90_COEFFICIENTS	IPTS-68_COEFFICIENTS ITS-T90	
g = 4.31264709E-3	a = 4.31283085E-3	
h = 6.27365760E-4	b = 6.27568511E-4	
i = 1.99855976E-5	c = 2.00163145E-5	
j = 1.56729241E-6	d = 1.56865339E-6	
f0 = 1000.0	Slope = 1.0	Offset = 0.0

Calibration Standard: Mfg: Isotech Model: MicroK100 s/n: 291088-2
Temperature ITS-90 = 1/{g+h[ln(f0/f)]+i[ln2(f0/f)]+j[ln3(f0/f)]} - 273.15 (°C)
Temperature IPTS-68 = 1/{a+b[ln(f0/f)]+c[ln2(f0/f)]+d[ln3(f0/f)]} - 273.15 (°C)
T68 = 1.00024 * T90 (-2 to -35 Deg C)

SBE3 Freq	SPRT ITS-T90	SBE3 ITS-T90	SPRT-SBE3 OLD_Coefs	SPRT-SBE3 NEW_Coefs
2828.1534	-1.4300	-1.4302	0.00001	0.00020
2993.9491	1.0742	1.0744	-0.00033	-0.00020
3237.7958	4.5810	4.5811	-0.00018	-0.00010
3495.7969	8.0890	8.0891	-0.00018	-0.00012
3768.4416	11.5994	11.5993	0.00009	0.00012
4055.2179	15.1008	15.1006	0.00020	0.00021
4358.1828	18.6132	18.6131	0.00007	0.00006
4676.6220	22.1234	22.1234	0.00002	-0.00002
5011.2402	25.6352	25.6354	-0.00006	-0.00016
5361.9492	29.1442	29.1443	0.00004	-0.00014
5729.6864	32.6564	32.6562	0.00045	0.00015



Temperature Calibration Certificate

Model	:	ARO-CAV
Serial No.	:	0251
Date	:	December 21, 2015
Location	:	Production Section
Method	:	Calibration equation is determined from third order regression of samples of the reference temperature against instrument voltages. Samples are taken at approximately 3, 10, 17, 24, and 31 °C.

1. Equation

Instrument temperature[°C] = $A+B \times V+C \times V^2+D \times V^3$ V: Instrument voltage[V]

2. Coefficients

A = −5.275295e+00
B = +1.670109e+01
C = −2.172049e+00
D = +4.643500e−01

3. Calibration results

Reference temperature [°C]	Instrument voltage [V]	Instrument temperature [°C]	Residual error [°C]	Acceptance [°C]	OK/NG
3.176	0.53955	3.176	0.000	±0.020	OK
9.842	1.00891	9.841	−0.001	±0.020	OK
16.630	1.51318	16.632	0.002	±0.020	OK
24.180	2.07520	24.179	−0.001	±0.020	OK
31.348	2.58124	31.348	0.000	±0.020	OK

4. Verification

Criteria of judgement : Residual error of the instrument temperature at arbitrary point is within the acceptance value.

Reference temperature [°C]	Instrument temperature [°C]	Residual error [°C]	Acceptance [°C]	Judgement
19.921	19.923	0.002	±0.020	Passed

Examined K. Shimotsu

Approved A. Fukuoka

Dissolved Oxygen Calibration Certificate

Model	:	ARO-CAV
Serial No.	:	0251
Date	:	December 21, 2015
Location	:	Production Section
Method	:	Calibration is performed with the nitrogen gas (zero) and the oxygen saturated water (span) kept by air bubbling.
Film No.	:	151502B

1. Equation

DO[%] =G+H × P'

Here, P'[%] consists of the coefficients A-F determined by the initial calibration.

2. Coefficients

A =	-3.893493e+01	E =	+4.000000e-03
B =	+1.192391e+02	F =	+4.760000e-05
C =	-3.509264e-01	G =	+0.000000e+00
D =	+1.006600e-02	H =	+1.000000e+00

3. Verification

Criteria of judgement : Residual error of the instrument DO at arbitrary point is within the acceptance value. The test is performed 3 times.

Acceptance: ±0.5% of full scale

Test for DO 0 %

	Test condition		Instrument DO [%]	Residual error [%]	Acceptance [%]	Judgement
	Atm. pressure [hPa]	Reference DO [%]				
1st	1023.7	0.00	-0.04	-0.04	±1.00	Passed
2nd	1023.7	0.00	0.04	0.04	±1.00	Passed
3rd	1023.8	0.00	0.04	0.04	±1.00	Passed

Test for DO 100 %

	Test condition			Instrument DO [%]	Residual error [%]	Acceptance [%]	Judgement
	Water T. [℃]	Atm. pressure [hPa]	Reference DO [%]				
1st	25.1	1023.9	101.09	100.75	-0.34	±1.00	Passed
2nd	25.1	1023.9	101.09	100.54	-0.55	±1.00	Passed
3rd	25.1	1024.0	101.10	100.59	-0.51	±1.00	Passed

Examined R. Kashida

Approved A. Fukuoka

CALIBRATION CERTIFICATE

NAME	:	RINKO Ⅲ
MODEL	:	ARO-CAV
SERIAL No.	:	0296
Parameter	:	Temperature Dissolved Oxygen

JFE

JFE Advantech Co., Ltd.

Temperature Calibration Certificate

Model	:	ARO-CAV
Serial No.	:	0296
Date	:	April 07, 2017
Location	:	Production Section
Method	:	Calibration equation is determined from third order regression of samples of the reference temperature against instrument voltages. Samples are taken at approximately 3, 10, 17, 24, and 31 °C.

1. Equation

Instrument temperature[°C] = $A+B \times V+C \times V^2+D \times V^3$ V: Instrument voltage[V]

2. Coefficients

A = −5.305905e+00
B = +1.666857e+01
C = −2.142681e+00
D = +4.582805e−01

3. Calibration results

Reference temperature [°C]	Instrument voltage [V]	Instrument temperature [°C]	Residual error [°C]	Acceptance [°C]	OK/NG
2.437	0.49243	2.437	0.000	±0.020	OK
10.737	1.07715	10.735	−0.002	±0.020	OK
17.463	1.57825	17.466	0.003	±0.020	OK
24.123	2.07288	24.121	−0.002	±0.020	OK
31.105	2.56635	31.105	0.000	±0.020	OK

4. Verification

Criteria of judgement : Residual error of the instrument temperature at arbitrary point is within the acceptance value.

Reference temperature [°C]	Instrument temperature [°C]	Residual error [°C]	Acceptance [°C]	Judgement
20.068	20.086	0.018	±0.020	Passed

Examined R. Kashida

Approved A. Fukuoka

Dissolved Oxygen Calibration Certificate

Model	:	ARO-CAV
Serial No.	:	0296
Date	:	April 10, 2017
Location	:	Production Section
Method	:	Calibration is performed with the nitrogen gas (zero) and the oxygen saturated water (span) kept by air bubbling.
Film No.	:	164312BA

1. Equation

DO[%] =G+H × P'

Here, P'[%] consists of the coefficients A-F determined by the initial calibration.

2. Coefficients

A =	−4.524084e+01	E =	+4.000000e−03
B =	+1.449377e+02	F =	+6.250000e−05
C =	−3.051590e−01	G =	+0.000000e+00
D =	+1.065300e−02	H =	+1.000000e+00

3. Verification

Criteria of judgement : Residual error of the instrument DO at arbitrary point is within the acceptance value. The test is performed 3 times.

Acceptance: ±0.5% of full scale

Test for DO 0 %

	Test condition		Instrument DO [%]	Residual error [%]	Acceptance [%]	Judgement
	Atm. pressure [hPa]	Reference DO [%]				
1st	1015.7	0.00	0.02	0.02	±1.00	Passed
2nd	1015.7	0.00	0.02	0.02	±1.00	Passed
3rd	1015.7	0.00	0.02	0.02	±1.00	Passed

Test for DO 100 %

	Test condition			Instrument DO [%]	Residual error [%]	Acceptance [%]	Judgement
	Water T. [°C]	Atm. pressure [hPa]	Reference DO [%]				
1st	25.1	1015.0	100.18	99.89	−0.29	±1.00	Passed
2nd	25.1	1015.0	100.18	99.94	−0.24	±1.00	Passed
3rd	25.1	1014.9	100.17	99.95	−0.22	±1.00	Passed

Examined M. TAKEISHI

Approved A. Fukuoka

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SENSOR SERIAL NUMBER: 0060
CALIBRATION DATE: 15-Mar-22

SBE 43 OXYGEN CALIBRATION DATA

COEFFICIENTS:
Soc = 0.5069
Voffset = -0.4968
Tau20 = 1.20

A = -4.5924e-003
B = 1.9638e-004
C = -2.9709e-006
E nominal = 0.036

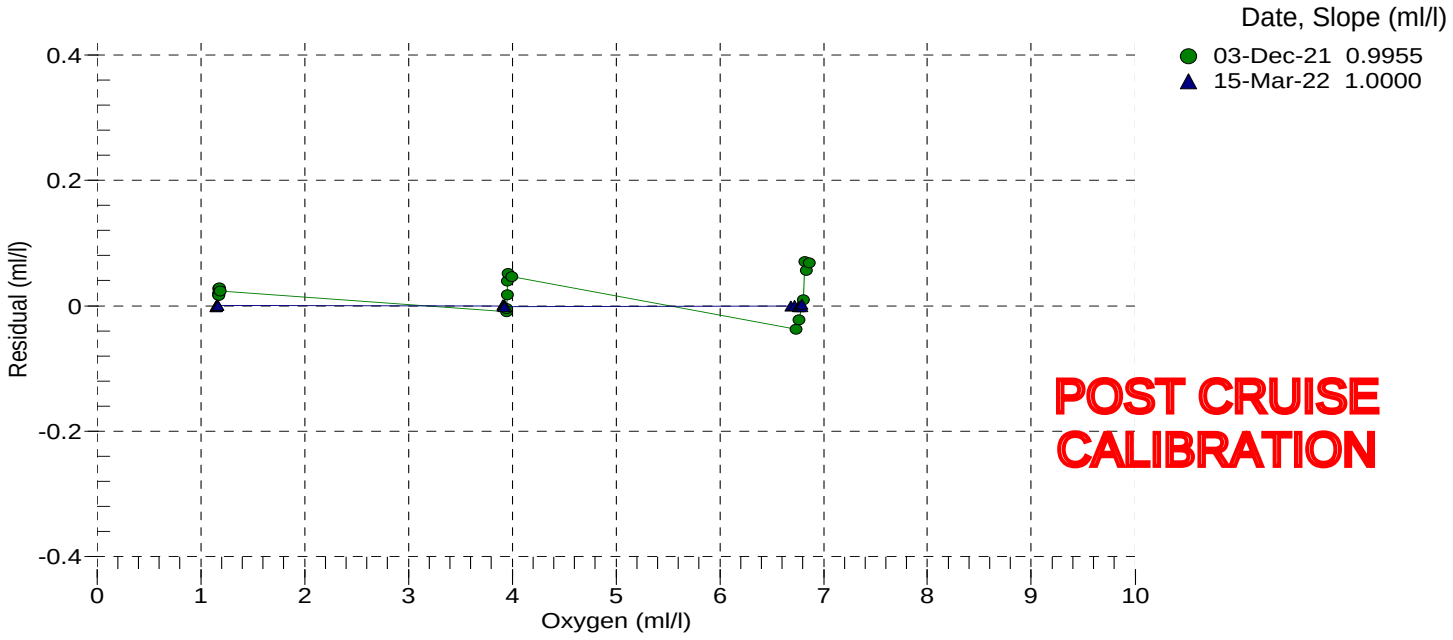
NOMINAL DYNAMIC COEFFICIENTS
D1 = 1.92634e-4
D2 = -4.64803e-2
H1 = -3.300000e-2
H2 = 5.00000e+3
H3 = 1.45000e+3

BATH OXYGEN (ml/l)	BATH TEMPERATURE (° C)	BATH SALINITY (PSU)	INSTRUMENT OUTPUT (volts)	INSTRUMENT OXYGEN (ml/l)	RESIDUAL (ml/l)
1.15	2.00	0.00	0.733	1.15	-0.00
1.15	6.00	0.00	0.763	1.15	0.00
1.15	12.00	0.00	0.808	1.15	-0.00
1.16	20.00	0.00	0.870	1.16	0.00
1.16	26.00	0.00	0.916	1.16	0.00
1.17	30.00	0.00	0.951	1.17	0.00
3.91	2.00	0.00	1.301	3.91	-0.00
3.91	6.00	0.00	1.403	3.92	0.00
3.92	20.00	0.00	1.759	3.92	0.00
3.92	30.00	0.00	2.023	3.92	0.00
3.92	12.00	0.00	1.557	3.92	0.00
3.92	26.00	0.00	1.915	3.92	-0.00
6.69	2.00	0.00	1.872	6.69	-0.00
6.72	6.00	0.00	2.052	6.72	0.00
6.76	12.00	0.00	2.323	6.76	-0.00
6.77	20.00	0.00	2.676	6.77	-0.00
6.79	30.00	0.00	3.137	6.79	-0.00
6.79	26.00	0.00	2.952	6.79	0.00

V = instrument output (volts); T = temperature (°C); S = salinity (PSU); K = temperature (°K)
Oxsol(T,S) = oxygen saturation (ml/l); P = pressure (dbar)

$$\text{Oxygen (ml/l)} = \text{Soc} * (V + \text{Voffset}) * (1.0 + A * T + B * T^2 + C * T^3) * \text{Oxsol}(T,S) * \exp(E * P / K)$$

Residual (ml/l) = instrument oxygen - bath oxygen



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SENSOR SERIAL NUMBER: 0185
CALIBRATION DATE: 15-Mar-22

SBE 43 OXYGEN CALIBRATION DATA

COEFFICIENTS:
Soc = 0.4772
Voffset = -0.5018
Tau20 = 1.54

A = -3.8659e-003
B = 1.6601e-004
C = -2.5194e-006
E nominal = 0.036

NOMINAL DYNAMIC COEFFICIENTS
D1 = 1.92634e-4
D2 = -4.64803e-2
H1 = -3.300000e-2
H2 = 5.00000e+3
H3 = 1.45000e+3

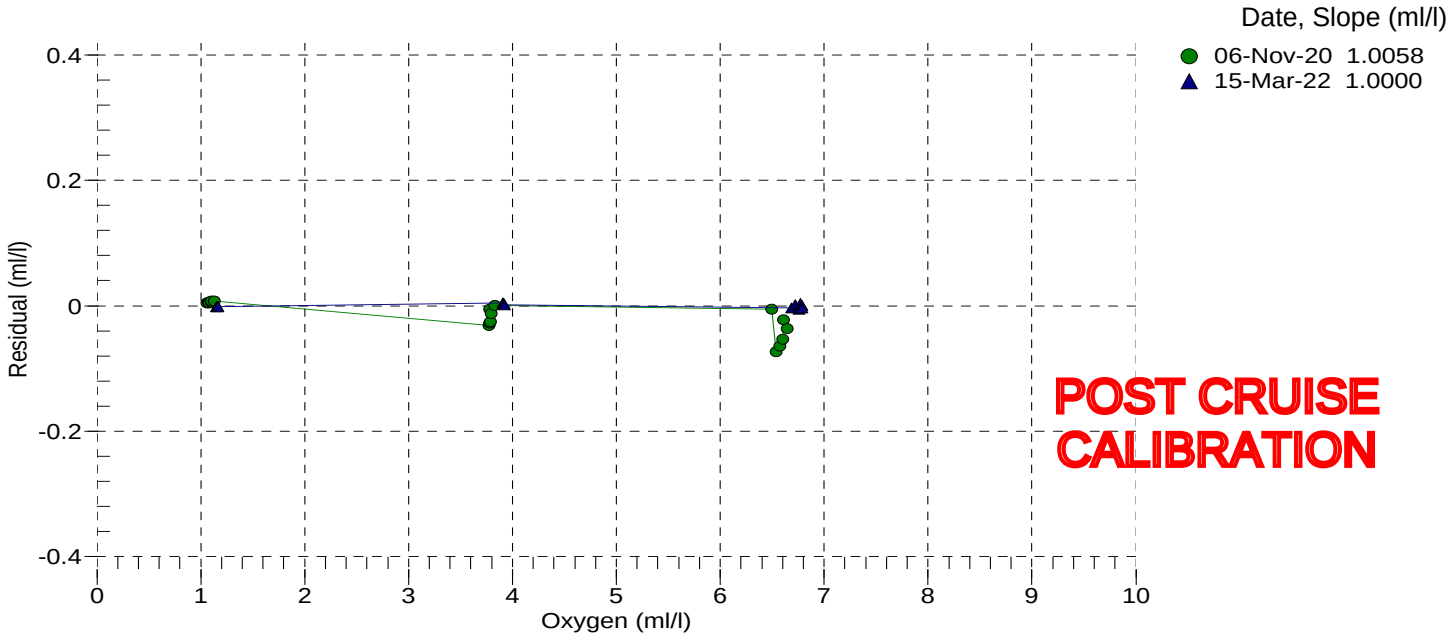
BATH OXYGEN (ml/l)	BATH TEMPERATURE (° C)	BATH SALINITY (PSU)	INSTRUMENT OUTPUT (volts)	INSTRUMENT OXYGEN (ml/l)	RESIDUAL (ml/l)
1.15	2.00	0.00	0.752	1.15	-0.00
1.15	6.00	0.00	0.784	1.15	-0.00
1.15	12.00	0.00	0.831	1.15	-0.00
1.16	20.00	0.00	0.894	1.15	-0.00
1.16	26.00	0.00	0.944	1.16	-0.00
1.17	30.00	0.00	0.980	1.17	-0.00
3.91	2.00	0.00	1.355	3.91	0.00
3.91	6.00	0.00	1.461	3.92	0.00
3.92	20.00	0.00	1.835	3.92	0.00
3.92	30.00	0.00	2.112	3.92	0.00
3.92	12.00	0.00	1.623	3.93	0.00
3.92	26.00	0.00	2.000	3.93	0.00
6.69	2.00	0.00	1.960	6.68	-0.00
6.72	6.00	0.00	2.148	6.72	0.00
6.76	12.00	0.00	2.430	6.75	-0.01
6.77	20.00	0.00	2.804	6.77	0.00
6.79	30.00	0.00	3.288	6.79	0.00
6.79	26.00	0.00	3.091	6.79	-0.00

V = instrument output (volts); T = temperature (°C); S = salinity (PSU); K = temperature (°K)

Oxsol(T,S) = oxygen saturation (ml/l); P = pressure (dbar)

$$\text{Oxygen (ml/l)} = \text{Soc} * (V + \text{Voffset}) * (1.0 + A * T + B * T^2 + C * T^3) * \text{Oxsol}(T,S) * \exp(E * P / K)$$

Residual (ml/l) = instrument oxygen - bath oxygen



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SENSOR SERIAL NUMBER: 1508
CALIBRATION DATE: 08-Oct-21

SBE 43 OXYGEN CALIBRATION DATA

COEFFICIENTS:
Soc = 0.5690
Voffset = -0.5028
Tau20 = 1.45
A = -3.7769e-003
B = 1.3435e-004
C = -1.6085e-006
E nominal = 0.036

NOMINAL DYNAMIC COEFFICIENTS
D1 = 1.92634e-4
D2 = -4.64803e-2
H1 = -3.300000e-2
H2 = 5.00000e+3
H3 = 1.45000e+3

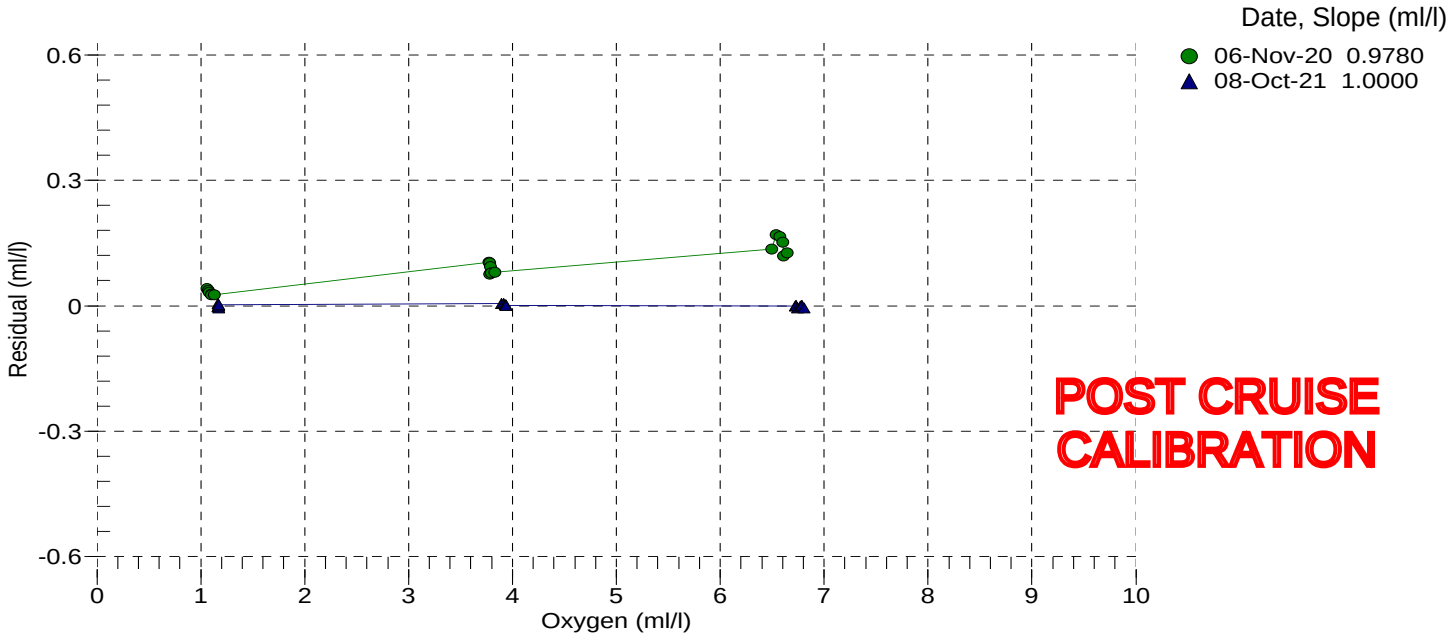
BATH OXYGEN (ml/l)	BATH TEMPERATURE (° C)	BATH SALINITY (PSU)	INSTRUMENT OUTPUT (volts)	INSTRUMENT OXYGEN (ml/l)	RESIDUAL (ml/l)
1.16	12.00	0.00	0.781	1.16	-0.00
1.17	30.00	0.00	0.907	1.17	0.01
1.17	6.00	0.00	0.742	1.17	-0.00
1.17	2.00	0.00	0.716	1.16	-0.01
1.17	20.00	0.00	0.838	1.17	-0.00
1.18	26.00	0.00	0.881	1.18	0.00
3.90	30.00	0.00	1.848	3.90	0.01
3.91	26.00	0.00	1.761	3.92	0.01
3.93	20.00	0.00	1.628	3.93	0.00
3.93	6.00	0.00	1.311	3.94	0.00
3.94	12.00	0.00	1.447	3.94	0.00
3.94	2.00	0.00	1.223	3.94	0.00
6.72	6.00	0.00	1.884	6.72	-0.00
6.73	2.00	0.00	1.733	6.73	0.00
6.74	30.00	0.00	2.824	6.74	-0.01
6.77	26.00	0.00	2.677	6.77	-0.00
6.78	12.00	0.00	2.131	6.78	0.00
6.81	20.00	0.00	2.449	6.80	-0.01

V = instrument output (volts); T = temperature (°C); S = salinity (PSU); K = temperature (°K)

Oxsol(T,S) = oxygen saturation (ml/l); P = pressure (dbar)

$$\text{Oxygen (ml/l)} = \text{Soc} * (V + \text{Voffset}) * (1.0 + A * T + B * T^2 + C * T^3) * \text{Oxsol}(T,S) * \exp(E * P / K)$$

Residual (ml/l) = instrument oxygen - bath oxygen



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ECO Chlorophyll Fluorometer Characterization Sheet

Date: 1/7/2022 S/N: FLRTD-4334

Chlorophyll concentration expressed in µg/l can be derived using the equation:

CHL (µg/l) = Scale Factor * (Output - Dark Counts)

	Analog Range 1	Analog Range 2	Analog Range 4 (default)		Digital	
Dark Counts	0.060	0.031	0.017	V	45	counts
Scale Factor (SF)	7	13	26	µg/l/V	0.0079	µg/l/count
Maximum Output	4.97	4.97	4.97	V	16380	counts
Resolution	0.9	0.9	0.9	mV	1.0	counts

Ambient temperature during characterization 21.0 °C

Analog Range: 1 (most sensitive, 0–4,000 counts), 2 (midrange, 0–8,000 counts), 4 (entire range, 0–16,000 counts).

Dark Counts: Signal output of the meter in clean water with black tape over detector.

SF: Determined using the following equation: SF = x ÷ (output - dark counts), where x is the concentration of the solution used during instrument characterization. SF is used to derive instrument output concentration from the raw signal output of the fluorometer.

Maximum Output: Maximum signal output the fluorometer is capable of.

Resolution: Standard deviation of 1 minute of collected data.

The relationship between fluorescence and chlorophyll-a concentrations *in-situ* is highly variable. The scale factor listed on this document was determined using a mono-culture of phytoplankton (*Thalassiosira weissflogii*). The population was assumed to be reasonably healthy and the concentration was determined by using the absorption method. To accurately determine chlorophyll concentration using a fluorometer, you must perform secondary measurements on the populations of interest. This is typically done using extraction-based measurement techniques on discrete samples. For additional information on determining chlorophyll concentration see "Standard Methods for the Examination of Water and Wastewater" part 10200 H, published jointly by the American Public Health Association, American Water Works Association, and the Water Environment Federation.

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C-Star Calibration

Date January 5, 2022 S/N# CST-1873DR Pathlength 25cm

	Analog output	Digital output
V_d	0.008 V	0 counts
V_{air}	4.800 V	15729 counts
V_{ref}	4.700 V	15398 counts

Temperature of calibration water	21.9	°C
Ambient temperature during calibration	22.0	°C

Relationship of transmittance (Tr) to beam attenuation coefficient (c), and pathlength (x, in meters): $\mathbf{Tr = e^{-cx}}$

To determine beam transmittance: $\mathbf{Tr = (V_{sig} - V_{dark}) / (V_{ref} - V_{dark})}$

To determine beam attenuation coefficient: $\mathbf{c = -1/x * \ln (Tr)}$

$\mathbf{V_d}$ Meter output with the beam blocked. This is the offset.
$\mathbf{V_{air}}$ Meter output in air with a clear beam path.
$\mathbf{V_{ref}}$ Meter output with clean water in the path.
Temperature of calibration water: temperature of clean water used to obtain V_{ref}.
Ambient temperature: meter temperature in air during the calibration.
$\mathbf{V_{sig}}$ Measured signal output of meter.

VALEPORT

This document certifies that the instrument detailed below has been calibrated according to Valeport Limited's Standard Procedures, using equipment with calibrations traceable to UKAS or National Standards.

Calibration Certificate Number:	43900
Instrument Type:	Altimeter
Instrument Serial Number:	53821
Calibrated By:	J.Harper
Date:	28/01/2016
Signed:	

Full details of the results from the calibration procedure applied to each fitted sensor are available, on request, via email. This summary certificate should be kept with the instrument.

Valeport Ltd | St Peter's Quay | Totnes | Devon | TQ9 5EW | UK
T: +44 (0) 1803 869292 | F: +44 (0) 1803 869293

Instrument Serial Number	53821
Sensor Type	500kHz Neptune
Altimeter Range (m)	100m
Certificate Number	43900

Stage 1

Test the assembled altimeter in a body of water to ensure a signal is recieved at the minimum range. Taking direct readings from the unit immerse the head till it is roughly 0.1m from the bottom, readings should come through - if not then the signal is being saturated and there is a problem

To inhibit spurious readings set using: #226;40

	Pass/Fail
Bench Test Min Range <0.1m	Pass

Stage 2

Using a mini SVS or similar, measure the average sound velocity for the water in the tow tank and input the value in the cell below.

Enter the SOS	1481.712

Input SOS value to the altimeter using: #830;1481.7120

Stage 3

Fit the altimeter into the calibration fixture and lower the assembly into the tank till it is about 0.5m down facing the far end of the tow tank and clamp in place. Using the distance markers on the wall align the front edge of the trolley with the datum line to set the front of the altimeter at stated distance from the wall.

To determine the Range Offset		
Distance m	Measured Range m	Measured Offset m
1	1.018	-0.018

Stage 4: Enter the Offset Correction
#828;-0.0180

Stage 5 - Range Check after Offset Correction			
Distance m	Measured Range m	Measured Offset m	Pass/Fail
1	0.998	0.002	Pass
5	5.003	-0.003	Pass

Stage 6: Reset the SOS
#830;1500

Stage 7: Reset maximum range to 105m		Stage 8: Reset spurious range
#823;105	(500kHz units)	#226;0

Calibrated by:	J.Harper	Date:	28/01/2016

ltimeter Build and Calibration Record

ument type	Altimeter
al number	53821
d rate set ex factory	115200

Calibration History:	Certificate	Date
	43900	28/01/2016

System Components	Original Manufacture				Modification				Modification				Modification			
	Part (Blank=Not Fitted)	Iss	Serial Number	Range / Firmware	Part (Blank=Not Fitted)	Iss	Serial Number	Range / Firmware	Part (Blank=Not Fitted)	Iss	Serial Number	Range / Firmware	Part (Blank=Not Fitted)	Iss	Serial Number	Range / Firmware
board	0430502	C	110929													
board	0430501	C	78627	ACTEL 0430707												
				ATMEL 0430704A13												
ducer Assembly	500kHz Neptune		31059	100m												
ure sensor	PAA - 10LX		N/A	N/A												
	Name			P Tremlett	Name				Name				Name			
	Date			28/01/2016	Date				Date				Date			
	Signed				Signed				Signed				Signed			

Calibrated to Valeport's procedures using test equipment with calibrations traceable to UKAS or national standards

BIBLIOGRAPHY

[Qiu2021] Qiu, B., and Chen, S. (2021). Revisit of the Occurrence of the Kuroshio Large Meander South of Japan. Journal of Physical Oceanography 51, 12, 3679-3694

[Tozer2019] Tozer, B, Sandwell, D. T., Smith, W. H. F., Olson, C., Beale, J. R., & Wessel, P. (2019). Global bathymetry and topography at 15 arc sec: SRTM15+. Earth and Space Science, 6, 1847. https://doi.org/10.1029/2019EA000658

[Yoshida2015] Yoshida, S., A. M. Macdonald, S. R. Jayne, I. I. Rypina and K. O. Buesseler (2015) Observed eastward progression of the Fukushima 134Cs signal across the North Pacific, GRL, doi: 10.1002/2015GL065259.

[Mill82] Millard, R. C., Jr., "CTD calibration and data processing techniques at WHOI using the practical salinity scale," Proc. Int. STD Conference and Workshop, p. 19, Mar. Tech. Soc., La Jolla, Ca. (1982).

[Owen85] Owens, W. B. and Millard, R. C., Jr., "A new algorithm for CTD oxygen calibration," Journ. of Am. Meteorological Soc., 15, p. 621 (1985).

[Uchida08] Uchida, H., Kawano, T., Kaneko, I., Fukasawa, M. "In Situ Calibration of Optode-Based Oxygen Sensors," J. Atmos. Oceanic Technol., 2271-2281, (2008)

[GarciaGordon1992] García, H. E., and L. I. Gordon, 1992: Oxygen solubility in sea- water: Better fitting equations. Limnol. Oceanogr., 37, 1307– 1312.

[UNESCO1981] UNESCO 1981. Background papers and supporting data on the Practical Salinity Scale, 1978. UNESCO Technical Papers in Marine Science, No. 37 144.

[Armstrong1967] Armstrong, F.A.J., Stearns, C.A., and Strickland, J.D.H., "The measurement of upwelling and subsequent biological processes by means of the Technicon Autoanalyzer and associated equipment," Deep-Sea Research, 14, pp.381-389 (1967).

[Atlas1971] Atlas, E.L., Hager, S.W., Gordon, L.I., and Park, P.K., "A Practical Manual for Use of the Technicon AutoAnalyzer in Seawater Nutrient Analyses Revised," Technical Report 215, Reference 71-22, p.49, Oregon State University, Department of Oceanography (1971).

[Aoyama2006] Aoyama, M., 2006: 2003 Intercomparison Exercise for Reference Material for Nutrients in Seawater in a Seawater Matrix, Technical Reports of the Meteorological Research Institute No.50, 91pp, Tsukuba, Japan.

[Aoyama2007] Aoyama, M., Susan B., Minhan, D., Hideshi, D., Louis, I. G., Kasai, H., Roger, K., Nurit, K., Doug, M., Murata, A., Nagai, N., Ogawa, H., Ota, H., Saito, H., Saito, K., Shimizu, T., Takano, H., Tsuda, A., Yokouchi, K., and Agnes, Y. 2007. Recent Comparability of Oceanographic Nutrients Data: Results of a 2003 Intercomparison Exercise Using Reference Materials. Analytical Sciences, 23: 1151-1154.

[Aoyama2008] Aoyama M., J. Barwell-Clarke, S. Becker, M. Blum, Braga E. S., S. C. Coverly,E. Czobik, I. Dahllof, M. H. Dai, G. O. Donnell, C. Engelke, G. C. Gong, Gi-Hoon Hong, D. J. Hydes, M. M. Jin, H. Kasai, R. Kerouel, Y. Kiyomono, M. Knockaert, N. Kress, K. A. Krogslund, M. Kumagai, S. Leterme,

Yarong Li, S. Masuda, T. Miyao, T. Moutin, A. Murata, N. Nagai, G.Nausch, M. K. Ngirchechol, A. Nybakk, H. Ogawa, J. van Ooijen, H. Ota, J. M. Pan, C. Payne, O. Pierre-Duplessix, M. Pujo-Pay, T. Raabe, K. Saito, K. Sato, C. Schmidt, M. Schuett, T. M. Shammon, J. Sun, T. Tanhua, L. White, E.M.S. Woodward, P. Worsfold, P. Yeats, T. Yoshimura, A.Youenou, J. Z. Zhang, 2008: 2006 Intercomparison Exercise for Reference Material for Nutrients in Seawater in a Seawater Matrix, Technical Reports of the Meteorological Research Institute No. 58, 104pp.

[Becker2019] Becker, S., Aoyama M., Woodward M., Baaker, K., Covery, S., Mahaffey, C., Tanhua, T., "GO-SHIP Repeat Hydrography Nutrient Manual, 2019: The Precise and accurate determination of dissololved inorganic nutrients in seawater;Continuos Flow Analysis methods. Ocean Best Practices, August 2019.

[Bernhardt1967] Bernhardt, H., and Wilhelms, A., "The continuous determination of low level iron, soluble phosphate and total phosphate with the AutoAnalyzer," Technicon Symposia, I,pp.385-389 (1967).

[Gordon1992] Gordon, L.I., Jennings, J.C., Ross, A.A., Krest, J.M., "A suggested Protocol for Continuous Flow Automated Analysis of Seawater Nutrients in the WOCE Hydrographic Program and the Joint Global Ocean Fluxes Study," Grp. Tech Rpt 92-1, OSU College of Oceanography Descr. Chem Oc. (1992).

[Hager1972] Hager, S.W., Atlas, E.L., Gordon L.I., Mantyla, A.W., and Park, P.K., " A comparison at sea of manual and autoanalyzer analyses of phosphate, nitrate, and silicate ," Limnology and Oceanography, 17,pp.931-937 (1972).

[Sato2010] Sato, K., Aoyama, M., Becker, S., 2010. RMNS as Calibration Standard Solution to Keep Comparability for Several Cruises in the World Ocean in 2000s. In: Aoyama, M., Dickson, A.G., Hydes, D.J., Murata, A., Oh, J.R., Roose, P., Woodward, E.M.S., (Eds.), Comparability of nutrients in the world's ocean. Tsukuba, JAPAN: MOTHER TANK, pp 43-56.

[Carpenter1965] Carpenter, J. H., "The Chesapeake Bay Institute technique for the Winkler dissolved oxygen method," Limnology and Oceanography, 10, pp. 141-143 (1965).

[Culberson1991] Culberson, C. H., Knapp, G., Stalcup, M., Williams, R. T., and Zemlyak, F., "A comparison of methods for the deter mination of dissolved oxygen in seawater," Repor t WHPO 91-2, WOCE Hydrographic Programme Office (Aug 1991).

[Carter2013] Carter, B.R., Radich, J.A., Doyle, H.L., and Dickson, A.G., "An Automated Spectrometric System for Discrete and Underway Seawater pH Measurements," Limnology and Oceanography: Methods, 2013.

[Liu2011] Liu, X., Patsavas, M.C., Byrne R.H., "Purification and Characterization of meta Cresol Purple for Spectrophotometric Seawater pH Measurements," Environmental Science and Technology, 2011.

[Patsavas2013] Patsavas, M.C., Byrne, R.H., and Liu X. "Purification of meta-cresol purple and cresol red by flash chromatography: Procedures for ensuring accurate spectrophotometric seawater pH measurements," Marine Chemistry, 2013.

[Dickson2007] Dickson, A.G., Sabine, C.L. and Christian, J.R. (Eds.), (2007): *Guide to Best Practices for Ocean CO2 Measurements*. PICES Special Publication 3, 191 pp.

[Johnson1985] Johnson, K.M., A.E. King, and J. McN. Sieburth (1985): *"Coulometric DIC analyses for marine studies: An introduction."* Mar. Chem., 16, 61-82.

[Johnson1987] Johnson, K.M., P.J. Williams, L. Brandstrom, and J. McN. Sieburth (1987): *"Coulometric total carbon analysis for marine studies: Automation and calibration."* Mar. Chem., 21, 117-133.

[Johnson1992] Johnson, K.M. (1992): Operator's manual: *"Single operator multiparameter metabolic analyzer (SOMMA) for total carbon dioxide (CT) with coulometric detection."* Brookhaven National Laboratory, Brookhaven, N.Y., 70 pp.

[Johnson1993] Johnson, K.M., K.D. Wills, D.B. Butler, W.K. Johnson, and C.S. Wong (1993): *"Coulometric total carbon dioxide analysis for marine studies: Maximizing the performance of an automated continuous gas extraction system and coulometric detector."* Mar. Chem., 44, 167-189.

[Johnson1999] Johnson, K.M., Körtzinger, A.; Mintrop, L.; Duinker, J.C.; and Wallace, D.W.R. (1999). *Coulometric total carbon dioxide analysis for marine studies: Measurement and interna consistency of underway surface TCO2 concentrations.* Marine Chemistry 67:123–44.

[Wilke1993] Wilke, R.J., D.W.R. Wallace, and K.M. Johnson (1993): "Water-based gravimetric method for the determination of gas loop volume." Anal. Chem. 65, 2403-2406

[Carlson2010] Carlson, C. A., D. A. Hansell, N. B. Nelson, D. A. Siegel, W. M. Smethie, S. Khatiwala, M. M. Meyers and E. Halewood 2010. Dissolved organic carbon export and subsequent remineralization in the mesopelagic and bathypelagic realms of the North Atlantic basin. Deep Sea Research II, 57: 1433-1445.

[Hansell1998] Hansell, D.A. and C.A. Carlson 1998. Deep ocean gradients in the concentration of dissolved organic carbon. Nature, 395: 263-266.

[Hansell2005] Hansell, D.A. 2005 Dissolved Organic Carbon Reference Material Program. EOS, 35:318-319.

[Walsh1989] Walsh, T.W., 1989. Total dissolved nitrogen in seawater: a new high-temperature combustion method and a comparison with photo-oxidation. Mar. Chem., 26:295-311.

[Bullister2010] Bullister, J.L. and T. Tanhua. 2010. Sampling and Measurement of Chlorofluorocarbons and Sulfur Hexafluoride in Seawater. In: The GO-SHIP Repeat Hydrography Manual: A Collection of Expert Reports and Guidelines. IOCCP Report No. 14, ICPO Publication series No. 134, Version 1.

[Bullister2008] Bullister, J.L. and D.P. Wisegarver. 2008. The shipboard analysis of trace levels of sulfur hexafluoride, chlorofluorocarbon-11 and chlorofluorocarbon-12 in seawater. Deep-Sea Res. I, v. 55, pp. 1063-1074.

[Jackett1997] Jackett, David R., Trevor J. McDougall, 1997: A Neutral Density Variable for the World's Oceans. J. Phys. Oceanogr., 27, 237–263. doi: 10.1175/1520-0485(1997)0272.0.CO;2

[NOAA2009] NOAA National Geophysical Data Center. 2009: ETOPO1 1 Arc-Minute Global Relief Model. NOAA National Centers for Environmental Information. Accessed May 25, 2022.

[Picheral2010] Picheral, M., Guidi, L., Stemmann, L., Karl, D.M., Iddaoud, G., Gorsky, G., 2010. The Underwater Vision Profiler 5: An advanced instrument for high spatial resolution studies of particle size spectra and zooplankton. Limnol. Ocean. Methods 8, 462–473.

[Pierrot2009] Pierrot, D., Neill, C., Sullivan, K., Castle, R., Wanninkof, R.W., Lüger, H., Johannessen, T., Olsen, A., Feely, R.A., Cosca, C.E.; 2009. Recommendations for autonomous underway pCO2 measuring systems and data-reduction routines. Deep-Sea Research II 56 (2009) 512–522

[Moum_and_Nash2009] Moum, J., and J. Nash, Mixing Measurements on an Equatorial Ocean Mooring, Journal of Atmospheric and Oceanic Technology, 26(2), 317–336, 2009

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