Cruise Report of the US-GOSHIP 2025 Reoccupation of I09N

Release Working Draft

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CHAPTER

ONE

GO-SHIP I09N 2025 HYDROGRAPHIC PROGRAM

1.1 Scientific Objectives & Background

The I09N 2025 cruise aboard the UNOLS vessel R/V *Thomas G. Thompson* was undertaken as part of the US GO-SHIP (Global Ocean Ship-based Hydrographic Investigations Program), a major contributor to international GO-SHIP. The program aims to collect highly accurate, surface-to-bottom, coast-to-coast, physical, and biogeochemical observations at quasi-decadal timescales. These measurements are essential to understanding long-term changes in heat, freshwater, carbon, oxygen, and other tracers in the global ocean—the main reservoir in the Earth System.

The I09N is a meridional transect in the Eastern Indian Ocean that spans from the Broken Ridge at about 28°S to the Bay of Bengal in the North Fig. 1.1. When I09N and I08S transects are combined, the line extends from the Antarctic continental shelf to the Bay of Bengal, resulting in a coast-to-coast section.

The 2025 cruise is the fourth occupation of the I09N. The I09N was first occupied in 1995 (130 stations; R/V *Knorr*) during WOCE (World Ocean Circulation Experiment), then in 2007 (111 stations; R/V *Roger Revelle*) as part of the CLIVAR (Climate Variability and Predictability) and in 2016 (113 stations; R/V *Roger Revelle*) as part of GO-SHIP. Except for 1995, when the cruise was during boreal winter (January-March), all other occupations (including the present ones) took place in boreal spring (March-May).

Compared with the last two occupations, the I09N 2025 ended further north (20°N) thanks to the clearance granted by the Bangladesh government to collect observations within Bangladesh's exclusive economic zone (EEZ) Fig. 1.2.

While the southern portion of the I09N has remained unchanged over the years, extending nominally along the 95° E meridian, parallel to the Ninety East Ridge, the North Indian Ocean portion has been significantly modified. In 1995, the transect comprised two parts north of the Equator: a quasi-meridional section confined to the east of 90° E from the Equator to Myanmar and a slanted section with lower spatial resolution across the Bay of Bengal Fig. 1.2. The quasi-meridional section crossed Indonesia, India, and Myanmar EEZs, while the slanted section was mostly over international waters. For 2007, the two sections were merged into one, with all stations located over international waters. Due to a dispute over EEZ delimitations, the transect in 2007 ended at 17.5° N, far from the continental shelf. Instead of occupying the northern end of the transect, a bow-tie section was performed in the central Bay of Bengal between 6-10° N Fig. 1.2. A similar trajectory was taken ten years later, but with the bow tie extending even further. As in 2007, the 2016 occupation ended far from the shelf due to clearance issues.

For the 2025 occupation, the I09N northern ending was extended from 17.5° N to 20° N along the 89.86° E meridian, with the last station located at the continental slope at depths of about 1100 m Fig. 1.2. The location of the northernmost station was chosen based on the total number of at-sea days designed for the 2025 cruise. Compared to the 2007 and 2016 occupations, nine new stations were added at the northern end, although, during the cruise, we had to skip the last two stations of 2007 and 2016 as described later. For 2025, the bow-tie feature in the central Bay of Bengal was also removed Fig. 1.2, making the I09N more like other GO-SHIP meridional sections.

Furthermore, the I09N 2025 included the Bio GO-SHIP, which aims to gather global oceanic observations to understand the planktonic ecosystem. In 2025, the Bio component consisted of two parts: analyzing surface waters from the underway system and obtaining vertical profiles of bio-parameters from the surface to 1000 m at specific hydrographic stations (from independent casts when time allowed).

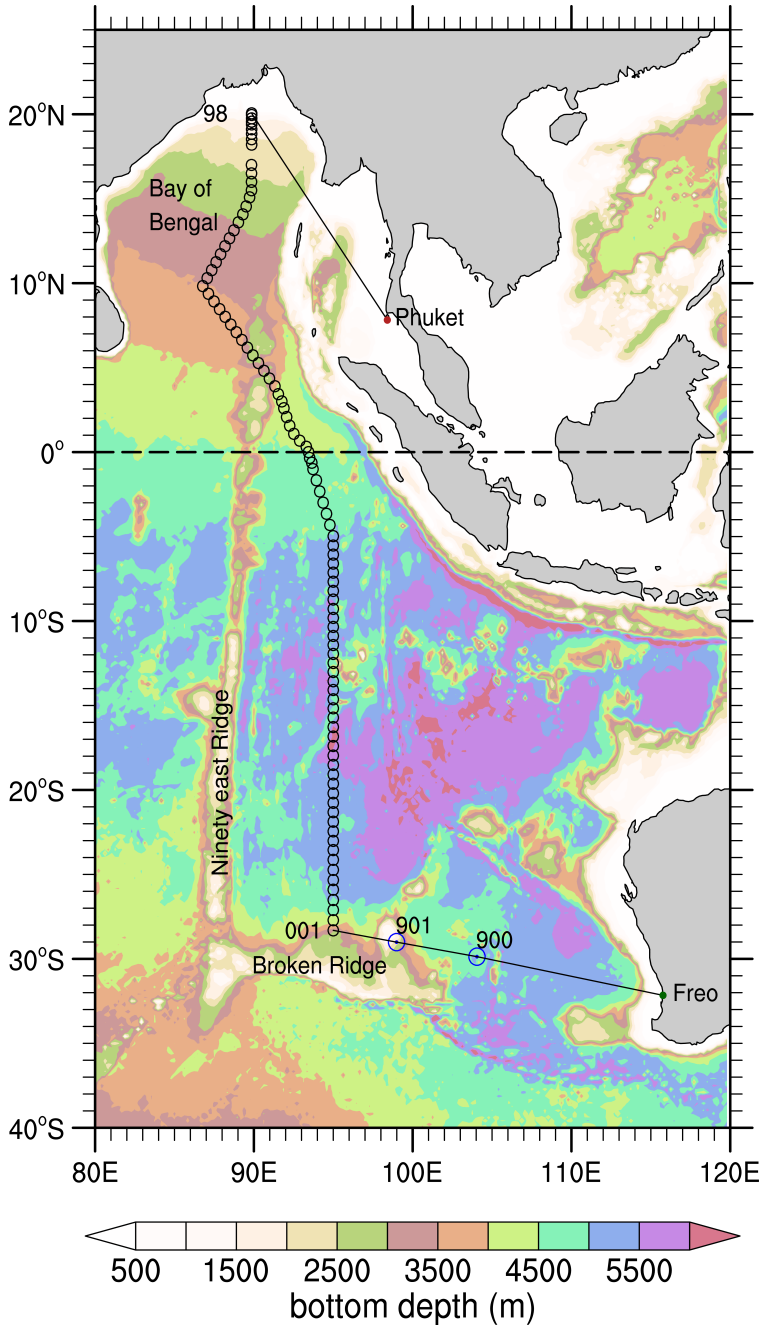

Fig. 1.1: GO-SHIP I09N 2025 occupation. Black circles are used for CTD/LADCP/rosette stations (0 to 98), and blue circle-dot symbols for test station locations (900 and 901). Shaded colors are bottom depths from GEBCO 2024. The dark green dot shows the departure port, and the red dot the arrival port. The dashed line marks the Equator.

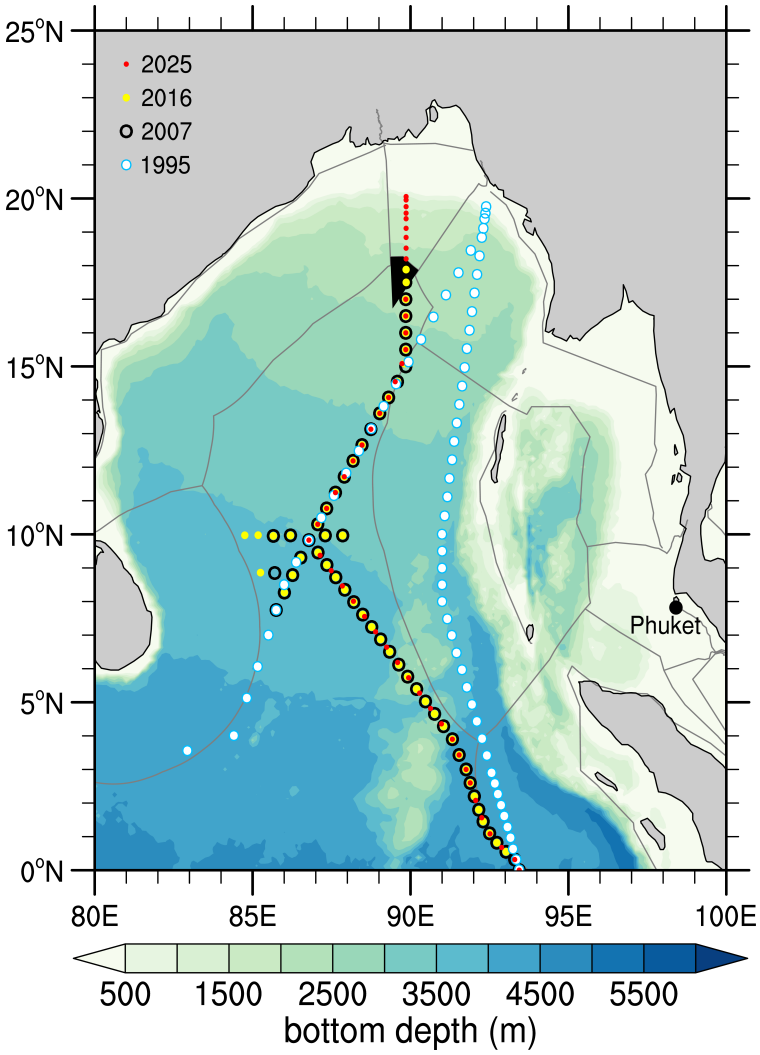

Fig. 1.2: I09N occupations in the North Indian Ocean over the years. Red dots show stations for the present occupation, and yellow dots show stations for the 2016 occupation. Black circles are stations occupied in 2007, and blue circles are those occupied in 1995. The black polygon shows the area where we did not occupy in 2025 due to border interpretation (see text).

Ultimately, the I09N 2025 cruise, which took place between March 21 and April 27, 2025, occupied 98 CTD/LADCP/rosette stations. These stations were nominally spaced about 30 nm (50 km) apart in the open ocean, although some were spaced up to 42 nm, and they were closer at boundary currents and prominent topographic features.

At each station, a suite of surface-to-bottom vertical profiles was collected using electronic sensors (CTD-O, LADCP, fluorometer, and transmissometer) and 36 10-L Niskin bottles for sampling water at discrete vertical levels.

Data collected during the 2025 I09N were (some samplings will be processed in labs onshore):

- Pressure, temperature, salinity, and dissolved oxygen from electronic sensors and bottles
- Fluorescence and light transmissivity
- Current velocities from lowered and shipboard ADCPs (Acoustic Doppler Current Profilers)
- Major inorganic nutrients (silicate, phosphate, nitrate, nitrite)
- Transient tracers: Chlorofluorocarbons (CFC-11 and -12), Sulphur Hexafluoride (SF_6), and Nitrous Oxide (N_2O)
- Carbon components: total dissolved inorganic carbon (DIC), total alkalinity, pH, and partial pressure of CO_2, dissolved organic carbon (DOC), total dissolved nitrogen (TDN), $\delta^{14}C$, and $\delta^{13}C$
- Oxidized iodine (iodate) and reduced iodine (iodide)
- Bathymetry (multibeam), shipboard meteorological and surface temperature and salinity observations
- $\delta^{18}O$ (ratio of stable isotopes oxygen-18 and oxygen-16) and $\delta^{15}N$ isotopes
- Bio GO-SHIP (bottles and underway): HPLC pigments, Flow cytometer (FCM), DNA, RNA, chemical oxygen demand (PCOD), particulate organic matter (nitrogen-PON, phosphorus-POP, carbon-POC), particulate inorganic carbon (PIC)

In addition to the above measurements, during the 2025 I09N, we deployed 12 Argo (Core) floats, 7 GO-BGC floats, 6 EM-APEX SQUID (Sampling QUantitative Internal-wave Distribution) floats, and 20 surface drifters (SVP) from the Global Drifter Program.

Along the way, the I09N crossed four distinct regimes Fig. 1.3:

1) Subtropical gyre regime characterized by the presence of the eastward South Indian Countercurrent and the Eastern Gyral Current in the upper layer. In this area, the salty Subtropical Underwater (STW; 0-400 m), the Subantarctic Mode Water (SAMW; 500-800 m), the cold and highly oxygenated Antarctic Intermediate Water (AAIW; centered around 1000 m), and at the abyss, the Antarctic Bottom Water/Lower Circumpolar Deep Water stand out.

2) Fresh Indonesian Throughflow (ITF) plume regime, which is carried westward by the South Equatorial Current (SEC). The fresh plume is expressed at the surface and subsurface through the Indonesian Throughflow Water (ITW; 0-500 m) and Intermediate Indonesian Throughflow Water (IIW; ~1000-1200 m)

3) The Equatorial regime with its vertically stacked jets. In 2025, the spring Wyrtki Jet at the surface (core around 120 m) was well developed

4) The low-oxygenated and fresh waters of the Bay of Bengal and its monsoon-dominated circulation.

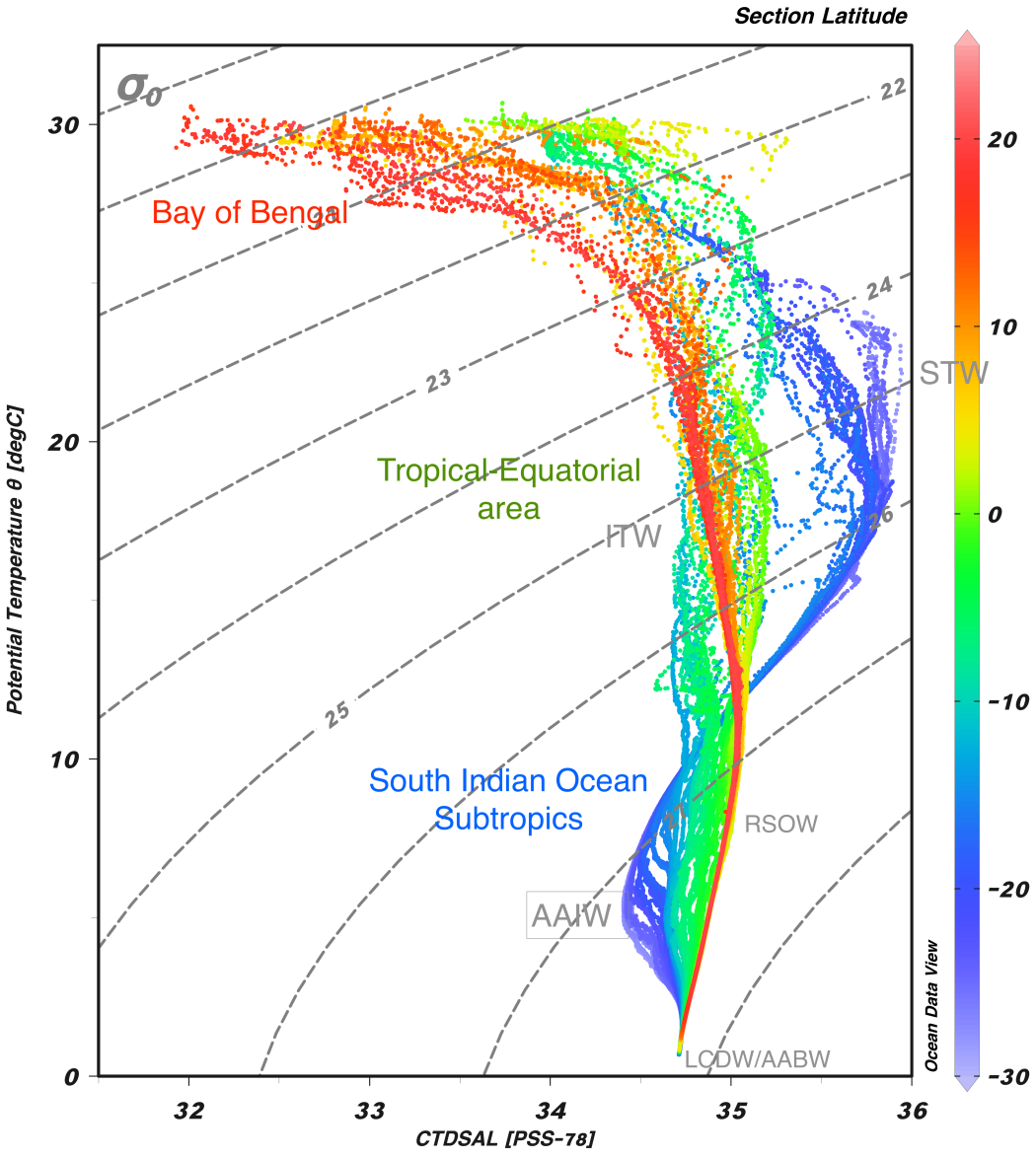

Fig. 1.3: Temperature-Salinity diagram from calibrated CTD observations collected during the I09N 2025 cruise. Colors show the latitude at which the data have been collected. Blue is used for the Subtropical South Indian Ocean, green for the tropical and equatorial area, and red for the Bay of Bengal. Primary water masses are highlighted.

1.2 Programs and Principal Investigators

Program	Affiliation	Principal Investigator	Email
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SQUID/EM-APEX	*UW*	James Girton	girton@uw.edu
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1.3 Science Team and Responsibilities

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Table 1.1 – continued from previous page

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CHAPTER

TWO

CRUISE NARRATIVE

The 2025 cruise sailed from Henderson, Australia, to Phuket, Thailand, from March 21, 0800 (UTC+8) to April 27, 0800 (UTC+7), 2025, covering 38 days at sea and 5078.8 nautical miles. Instead of Fremantle port, which had been used in all previous I09N occupation, this time the AMC Australian Marine Complex served as our departure point. AMC is located in Henderson, Western Australia, a suburb of Perth in the City of Cockburn, approximately 30 minutes from Fremantle.

Like the last two occupations, the arrival port was Phuket Deep Sea Port in the Andaman Sea, about 23 miles (37 km) from Phuket town.

2.1 Mobilization & Delayed Departure

The AMC is a marine industrial complex that is also used by the Royal Australian Navy. Due to its higher security protocols, the mobilization required more coordination effort than typical GO-SHIP cruises. Given that the AMC is in a relatively remote area with tightly controlled access (even walking on the dock outside the vessel is prohibited), the science party stayed in Fremantle during mobilization. We used a shuttle kindly provided by Scripps to go to the AMC daily (arriving at 0800 and returning at 1700). With all science party members adhering to the required protocols and the efficiency of the R/V *Thompson* crew, our mobilization was flawless, except for the delay in the arrival of the DIC container.

The late arrival of the DIC container was due to a hold requested by the Australian government. This hold was placed in Singapore because of a small volume of acetone inside. With this minor incident, we (including the Agent) learned that acetone is a controlled substance in Australia. The acetone was removed from the container, allowing it to be released and continue its journey to Australia. After discussions at the GO-SHIP Executive Committee, we decided to wait a few days for the container, as DIC is a critical Level 1 GO-SHIP measurement. Consequently, the I09N departure from AMC was postponed by five days, from March 17, 2025, to March 21, 2025.

Due to the DIC van's late arrival, we experienced an extended mobilization period in Henderson from March 13 to 20 (instead of March 13-16), which was more than sufficient to set up all labs well before departure. The R/V *Thompson* port captain coordinated with the Gulf Agency Company (GAC) to provide us with a shore crane on the first and last days of mobilization to load the ODF and float containers (on the first day) and the DIC (on the last day). A dedicated container for the floats was the solution found by R/V *Thompson* due to the large number of lithium batteries on this trip (25 floats).

As a backup plan, the DIC PIs also worked diligently to assemble and air freight thousands of bottles to Australia. These backup bottles were stored at the Bio Lab and traveled with us until Phuket. Fortunately, we did not need to use them, as the DIC team put in a lot of effort on the last day of mobilization to set up the lab, which functioned well during the cruise.

Due to logistical issues with a few groups (including the DIC), the berthing arrangement was only finalized at the last minute, and we thank the R/V *Thompson* for understanding the situation. Additionally, one of the CTD watchstanders was not cleared to sail due to a medical incident. To help the CTD team, the LADCP student kindly agreed to serve as a watchstander when not involved in LADCP tasks.

Notice that on March 12 (the day before our mobilization), Jim Happell tested the R/V *Thompson*'s main lab for background $\delta^{14}C$ and tritium as part of the UNOLS (University-National Oceanographic Laboratory System) SWAB program.

2.2 Changes Due to Late Departure

Although the I09N 2025 was initially set to have a similar duration (41 days) as previous occupations (39 days in 2016; 41 days in 2007 and 1995), our original program was slightly different from past ones: 37 days for occupying the full extent of I09N, 2 days to re-occupy the northern end of I08S (34°S-28°S), and 1.54 days for activities related to Bio GO-SHIP ("bio casts").

A bio-cast is an independent daily cast down to a depth of 1000 m, in which 22-26 of the 36 10-L Niskin bottles are fired to sample exclusively biological parameters. For the I09N 2025, the bio team predetermined the bottles as follows: two bottles at 1000 m, one at 500 m, two at 200 m, one at 150 m, two at 100 m, one at 75 m, one at 40 m, and the remainder at 5 m. In the event of a concurrent BGC float deployment, two additional depths were incorporated into the bio cast at the chlorophyll maximum and 50 m below it.

We planned to conduct a bio-cast once a day at the stations closer to noon. Unfortunately, the late departure and issues at sea (described later) prevented us from adhering to the original plan. This led to several modifications related to Bio GO-SHIP operations that were implemented during the cruise to save time. In the end, from the 18 independent bio-casts that we initially scheduled, we performed 14 of them, mainly within the Bay of Bengal. The combined bio/core casts totalized 11.

From 'at-sea' days allocated for the I09N 2025 cruise, approximately 8 days were spent transiting to and from ports (4.32 days from AMC to the 1st station, including a stop for a test cast, and 3.14 days from the last station to Phuket, assuming a vessel speed of 12 knots). Due to the late departure, the total length of the cruise was reduced by 5 days (12.2%), but transit times did not change significantly (7.35 days). Fortunately, the R/V *Thompson* had kindly extended our period at sea by one day. Instead of arriving on April 26 as initially scheduled, our arrival was moved to April 27. Consequently, the I09N 2025 lasted for 38 days in the end.

With the reduction of the cruise length from 41 to 38 days, the reoccupation of the I08S stations (south of Broken Ridge) was excluded from the plan. Prior to the DIC issue, we intended to conduct eleven stations belonging to the I08S to fill a gap in the data left by the 2024 occupation of that line. This gap resulted from a storm that prevented the I08S team from collecting data in that area. The decision not to proceed with the I08S stations also considered the weather forecast for the period of March 21-28, 2025, which indicated stormy seas around 34° S, potentially causing further delays for our cruise. Consequently, the I09N 2025 commenced at Broken Ridge at 28.313° S and 95° E, just as in the last two occupations.

Additionally, we increased the distance between stations in the equatorial region (3° S-3° N) from 20 nm (1995, 2007, and 2016 occupations) to 30 nm. Given these changes, upon departing from Fremantle, we planned to occupy 106 stations between the Broken Ridge and the Bay of Bengal continental slope, instead of 122 stations. However, issues at sea, as described next, reduced the number of stations to 98, which is 20% less than our original plan (122 stations) and 13.3% less than in 2016 (113 stations). The reduction was achieved at sea by increasing the spacing between stations to about 40 nm between 4.3° S and 1° S.

2.3 At Sea Time

We departed Henderson on March 21 at 11:00 AWST (UTC+8) heading towards the Broken Ridge to occupy the first I09N 2025 station. While in transit to the first station, which took about four days, we stopped halfway (on March 23) for a test station in international waters (29.87° S-104.05° E and 3527 m deep). Time was carefully picked so both watches could participate and be trained. We had several objectives for the test station: first, to train our CTD watch-standers and incoming lab technicians; second, to verify if the instruments and the winch were functioning properly; and third, to coordinate the workflow between bio and core GO-SHIP casts.

The plan for the test station was as follows: perform a shallow bio-cast down to 1000 m while firing 22 bottles at pre-determined depths set by the Bio GO-SHIP team on board, sample these bottles, re-cock the rosette, deploy the rosette

again for a deep cast (down to 10 m above the bottom), fire the 36 bottles, sample all bottles and analyze afterward.

At the test station, we began the procedure as usual, and nothing indicated the sequence of problems we would encounter: the winch software froze, the bottles could not be fired and the cable became tangled. Ultimately, we lost communication with the CTD package. The cast was aborted, and the package was retrieved to the surface. No water was collected, and the deep cast was not attempted.

Resolving the multiple issues we encountered at the test station, including the DASH-5 winch problem, required time. Given our late departure, we continued sailing toward the first station. At the same time, R/V *Thompson* Marine Techs debugged the winch, and the ODF team addressed the CTD package issues. The problems were fixed by replacing the carousel (SBE32) and cables.

A second test station (29° S-98.98° E; 2197 m) was conducted on March 24 at 11:00. We only performed the bio-cast (from the surface to a depth of 1000 m) to save time. The main objective was to verify the readiness of the winch and the CTD package, train the CTD watch standers, and provide water for the Bio team to begin their work. All 36 bottles were fired, and the transmissometer was covered with black tape for calibration (a procedure that the Bio team conducted weekly throughout the cruise). Everything worked well this time. During the second test station, the CTD watch standers learned from Scripps ODF (Ocean Data Facility) technicians how to prepare the rosette, fill in the logs, and fire the bottles. As it was a shallow cast, they did not have the opportunity to conduct a bottom approach, which they needed to learn in effective stations.

We arrived at the first station late on March 25 (23:40, AWST). The station was located on the northern flank of the Broken Plateau (28.31°S-95°E), at a depth of 3093 m. Everything functioned well despite the spiky altimeter readings during our bottom approach. Problems with the altimeter were common throughout the I09N 2025 cruise, leading us to change units and cables several times, as described later. This was the first experience for our CTD watch standers with bottom approximation. The first bottle was fired 10 m above the bottom, as is standard in GO-SHIP. It was a slow cast as everyone was learning, and mistakes were being corrected.

On Station 2, the aft winch display stopped working. We had no information about the speed or wire payout. The altimeter also had issues, so we fired the first bottle 20 m above the bottom. Later in the cruise, we found that the multibeam readings tended to be deeper than the LADCP bottom estimates Fig. 2.1. After we identified the bias, Marine Tech Brandon Russell and LADCP student Ilmar Leimann worked diligently to regularly feed the multibeam with sound speed profiles derived from our collected CTD data, resulting in multibeam readings that became much closer to LADCP estimates.

Due to the winch failure, we postponed operations at Station 3 to replace the winch and conduct a mechanical re-termination. From Station 3 until the end of the cruise, we utilized the forward winch instead of the aft winch. Both winches were DASH-5. We also changed the ship's local time from UTC+8 to UTC+7, which persisted until the end of the cruise.

Stations 4 and 5 progressed without major incidents, aside from the noisy altimeter that troubled us throughout the cruise. We replaced the altimeter and cables for station 4, but this did not resolve the problem as we had hoped. The only other issue was a leak in the underway system used by the Bio team, which the R/V *Thompson* crew worked swiftly to address.

We began Station 6 with a bio-cast and encountered no issues, except for the slow sampling of 22 bottles for bio measurements for the first time. However, during the deep cast that followed the bio-cast, the altimeter completely failed during the bottom approximation, which became a recurring issue.

The problems, however, drastically worsened at Stations 7 and 8, causing further cruise delays and significant adjustments in the station plan and bio-casts. On Station 7 (March 27), we again were unable to fire bottles from the CTD console. The deck box was rebooted several times, but this did not solve the problem. Some bottles were closed and collected water, while others remained open. Due to these issues, it is unknown at what depths many of the bottles were closed. After that, the fish (CTD unit, SBE 9+) was replaced.

At Station 8 (24.14° S-95° E), everything went wrong. Nothing worked; there were multiple modulo errors and a conductivity sensor had failed. After aborting the cast, we held position at Station 8 from March 26 at 10:00 to March 29 at 05:30.

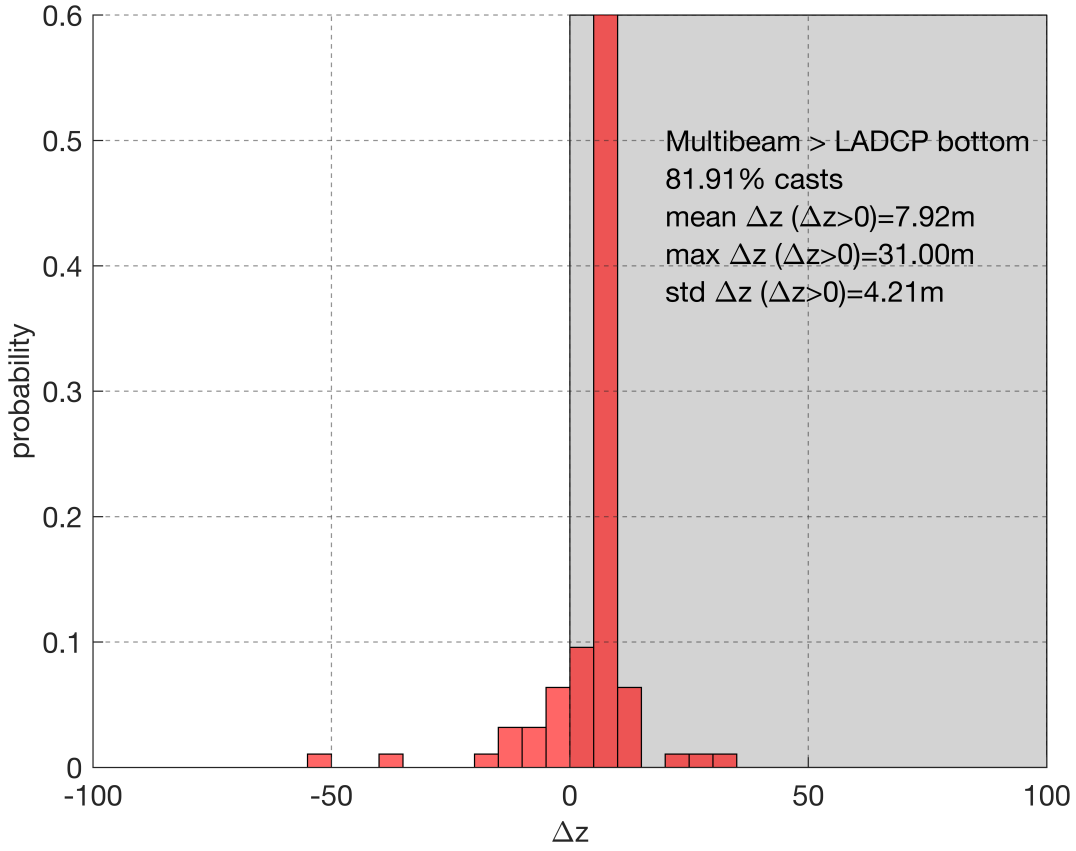

Fig. 2.1: Probability distribution of the differences between the multibeam readings and LADCP bottom estimations for the whole cruise.

A confluence of problems occurred at Station 8, leading to a 3-day hold. First, the ODF team discovered an issue with the wire. To solve the problem, they cut 20 m of wire and performed full mechanical and electrical terminations. Second, the ship's z-drive failed and required repairs. Finally, the winch heave compensation system did not function satisfactorily and needed repairs.

Last but not least, at Station 8, the sea became slightly rough due to Tropical Cyclone (TC) Courtney approaching us Fig. 2.2. TC Courtney was a severe tropical hurricane that formed in the Indian Ocean on March 26, around 16.6° S and 111° E, and moved westward, passing over the 95° E meridian. According to weather forecasts, TC Courtney may have reached Category 4 and was the world's strongest storm of the month, which resulted in a weather hold. Only after TC Courtney moved west of our line at 95° S did the sea state begin to improve. This allowed the R/V *Thompson* crew to repair the z-drive, although we continued to encounter minor issues with it (and the bow thruster) throughout the Equatorial zone, both components critical to the ship's dynamic positioning system to keep the ship in position on station.

Fig. 2.2: TC Courtney. Forecast for March 28, 2025, from Windy.com based on the ECMWF model. Highlighted is our position on Station 8 on that day.TC Courtney even reached Cat 4 in the following days during our 3-day hold.

After all repairs and with an improved sea state, we performed a shallow cast (1000 m) on March 29 at 04:00 for testing. We fired 22 bottles on the fly (to save time) and 14 bottles at the surface for the Bio team. Except for Bio, no water samples were drawn from the rosette. We labeled this cast 008/03 (the previous two had been aborted). With the success of the shallow cast, we proceeded to execute a deep cast. Unfortunately, the altimeter stopped functioning at about 40 m above the bottom, and as a precaution, we fired the first bottle at that depth. Aside from the altimeter malfunction, it was a successful cast (008/04).

Due to the three days lost at Station 8 and the decrease in vessel speed caused by TC Courtney's influence, we had to modify our station plan, reducing the total number of stations from 106 to 89. In the updated plan, stations north of 4.3° S were set to be 41.8 nm (4.3° S-0.3° N), 25-33 nm (0.3° N-3.9° N), 37.3 nm (3.9° N-9.8° N), 42-45 nm (9.8° N-17° N), 30-42 nm (17° N-19.3° N), and less than 22 nm north of that. The stations south of 4.3° S were maintained as previous occupations (nominally at 30 nm) due to the richness of water mass distribution in the Southern Hemisphere and their

frontal zones. This choice was also influenced by the fact that the I09N trajectory south of the Equator has not changed since the first occupation in 1995, allowing for direct evaluation of property changes over the last 30 years. While there was a significant reduction in the number of stations, we still aimed to accomplish all critical mission objectives.

After all the problems leading up to Station 8, there were no major technical problems afterward. Issues that persisted while sailing in the Southern Hemisphere were related to the z-drive and bow thruster, causing further delays at some stations. Another persistent problem was the intermittency of the altimeter, which sometimes functioned and sometimes failed completely Fig. 2.3. Following our discovery that we may have had a few near-miss bottom touches (Fig. 2.3, black circles), we changed the protocol for the bottom approach. This finding was based on the LADCP data processed in real-time by Ilmar Leimann. For stations after Station 41, when the altimeter was not functioning, our maximum depth was 30 m above the multibeam reading, particularly if the local bottom was rough.

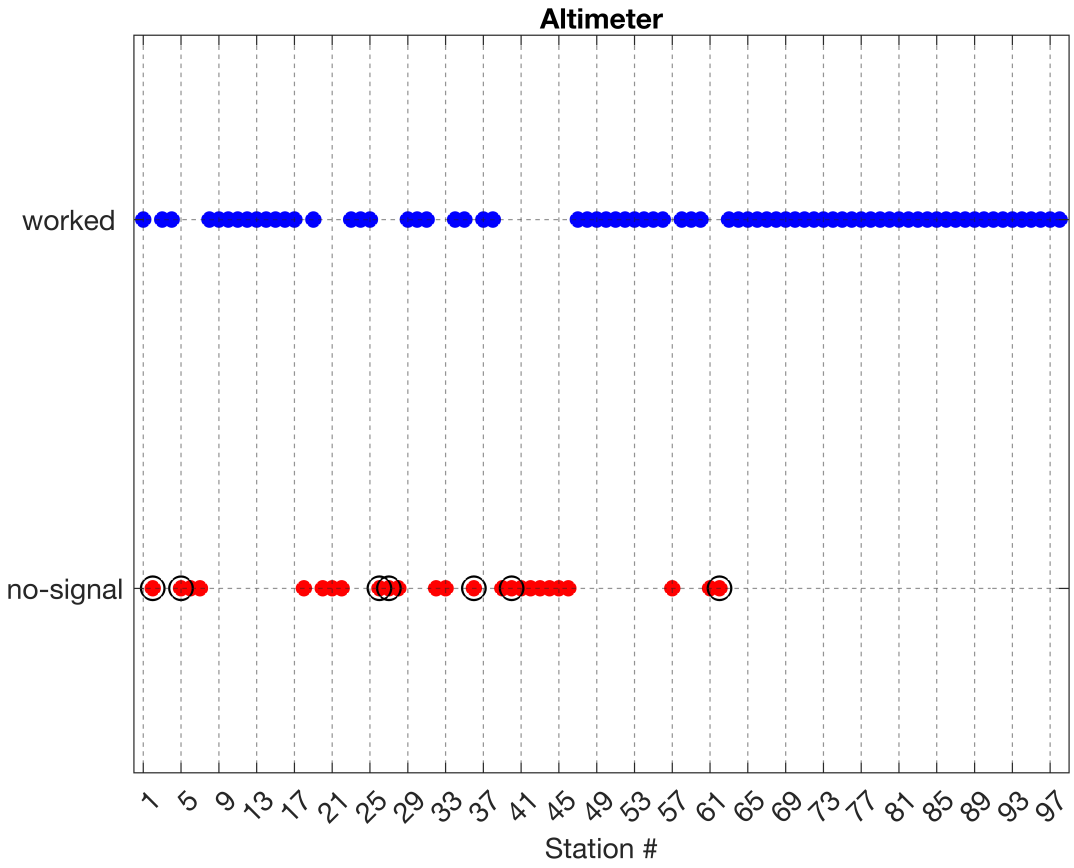

Fig. 2.3: Altimeter status during the I09N 2025 cruise. Blue is used for stations when the altimeter worked, and red when there was no altimeter signal. Black circles highlight the near-miss stations, i.e., when the CTD package was 5 m or less from the ocean bottom, according to the LADCP data.

Station 12 marked the last station with independent bio-casts, although we resumed them by the cruise's end (Station 64) when the ship's overall performance improved. At that point in the cruise, the bio-casts took about two hours, accounting for the rosette preparation, deployment, firing of 22-26 bottles, sampling, and the issues the ship faced with positioning due to problems in the z-drive and bow thruster. Our time forecast calculations indicated that we would not arrive in Phuket on time if we performed all the remaining bio-casts.

Between Stations 12 and 64, instead of conducting independent bio-casts, we created an integrated bio/core cast (described in the next section) that occurred at the closest station to noon. During this period, we only conducted independent bio-casts at stations where BGC floats were deployed due to water demand. We could not meet the water demand of all groups with just 36 bottles.

Starting in the equatorial zone (around 2°-3° S), far from the influence of TC Courtney, the ship's performance improved

drastically. The z-drive and bow thruster issues subsided (thanks to the tireless efforts of R/V *Thompson* engineers), and the ship began to sustain speeds of 12-13 knots between stations, giving us some time back. We initially added two stations to our plan near the Equator: one at 0.63° S and another at 0°. These stations had been previously occupied in 1995, 2007, and 2016. Adding these new stations reduced the spacing between them near the Equator from 41.8 nm to 18-23 nm. We chose to add these stations because forecasts from CMEMS Operational Mercator indicated that the near-surface eastward Wyrtki Jet along the Equator was well developed, and the I09N track would cross its core in the eastern basin Fig. 2.4. According to the GLORYS-12 reanalysis, the Wyrtki Jet was absent in 2016 but present in 2007. Wyrtki Jets occur during boreal spring (April-May) and fall (October-November) within +/- 2° of the Equator and are essential features in heat and mass transport between the western and eastern Indian Ocean. The observations we collected will allow us to evaluate the multi-decadal differences.

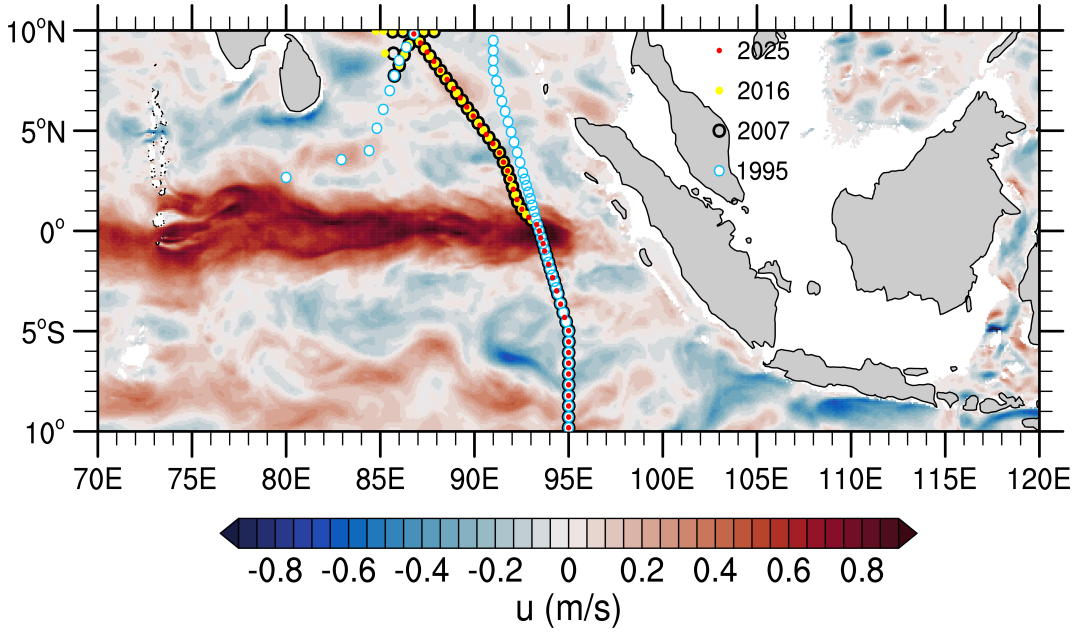

Fig. 2.4: Zonal velocities at 110 m from the CMEMS Operational Mercator forecast for April 11, 2025, when the I09N 2025 cruise crossed the equatorial zone. Circles show all I09N trajectories (1995, 2007, 2016, 2025).

With the ship's performance sustained over time, we reduced the spacing between stations north of 3.9° N to 26-34 nm until 17° N and 6-19 nm north of it. These changes resulted in the potential for 100 stations to be occupied by the I09N, which, in the end, could not be as later explained.

Although the altimeter readings remained spiky until the end of the cruise, their functioning became less erratic north of the Equator Fig. 2.3. The improvement occurred after the ODF implemented a series of changes, but the culprit for the previous faults could not be pinpointed. The better performance and more accurate multibeam readings enabled the CTD watchstanders to safely maneuver the package to 10 m above the bottom.

The pleasant weather and calm sea after we crossed TC Courtney's zone of influence made CTD deployments straightforward, and no other significant technical problems occurred. Only minor issues were noted, as documented later in this report: a few unfired bottles and missed target depths, a few mistakes in filling out sample logs and sampling from Niskin bottles, LADCP cable and instrument reconfigurations, among others. These issues, typical of any cruise, were sporadic and resolved promptly.

An unusual occurrence happened at Station 75 (10.3° N-87° E) when a fishing boat came very close to the CTD package in the water. As a precaution, the bridge required the package to resurface without all bottles being fired. The crew acted swiftly to prevent any problems.

Unfortunately, we had to skip the last two northern stations occupied in 2007 and 2016 due to the nuanced difference between the Exclusive Economic Zone and the Extended Continental Shelf boundaries, the latter of which is in dispute. We learned about this issue just when arriving at the first of these stations, and after discussing it with the captain, we

concluded that not occupying them was the best course of action. Consequently, there was a gap of about 72 nm between 17° N and 18.2° N, with only 98 stations occupied in total during the I09N 2025 cruise.

Near the end of the line, stations became progressively closer together, with spacing varying from 6 to 19 nm. In GO-SHIP cruises, the time required for lab analysis and equipment charging (e.g., LADCP) is critical. Thus, we increased the time between stations. To accomplish this, we slowed the pace between stations, even waiting at stations when necessary. This arrangement allowed the labs to take and analyze as many samples as possible, resulting in a more complete dataset of carbon parameters, particularly by performing all planned full carbon stations. Full carbon stations mean that carbon parameter samples are taken from all 36 Niskin bottles. At partial stations, samples are collected from 24 Niskin bottles, with depths chosen to capture good vertical resolution. Due to the combined bio-core casts between Stations 12 and 64, the sequence of full and partial stations during the I09N 2025 occupation did not follow the usual GO-SHIP pattern (full-partial-full-partial-…); in combined bio-core casts, all stations were 'full carbon' as we were using only 24 bottles for the core GO-SHIP measurements.

Additionally, we did not collect any data from the underway system for most Bio GO-SHIP measurements north of 17.5° N, as those measurements were not requested as part of the Bangladesh EEZ clearance process. Instead, these data were collected only from the Niskin bottle, as granted by the Bangladesh government. In this case, the only measurement not collected was PIC, as it was not part of the set of variables included in the MSR (Marine Science Research) request.

During the cruise, floats and surface drifters were deployed by the end of stations at a ship speed of a few knots. BGC floats were deployed only during daylight, preferably at stations closer to noon. For each of the seven BGC floats deployed, an independent bio cast was conducted, sometimes before the deep cast and sometimes after, depending on the time we arrived at the stations. All floats and surface drifters were deployed south of the Bangladesh EEZ following the plan determined by the respective PIs.

2.4 Choice of Discrete Depths and Staggering Scheme

For the 2025 occupation of the I09N, the standard WOCE/CLIVAR/GO-SHIP staggering scheme for 36 bottles was adopted for all regular stations. In this scheme, the vertical distribution of discrete depths rotates every three stations (I-II-III) and depends on the local bottom depth (shallow, mid, and deep). The first Niskin bottle is fired 10 m above the bottom, and the last at the surface, nominally at 5 m Fig. 2.5. Most of our stations had bottom depths above 6000 m, except for stations 20 to 22, which have bottom depths that exceed that. The first bottle was fired at 6000 m for those stations because the instruments are rated to this depth. In this latter case, we used the staggering scheme I for deep stations. For all other stations, we used the staggering scheme for medium depths.

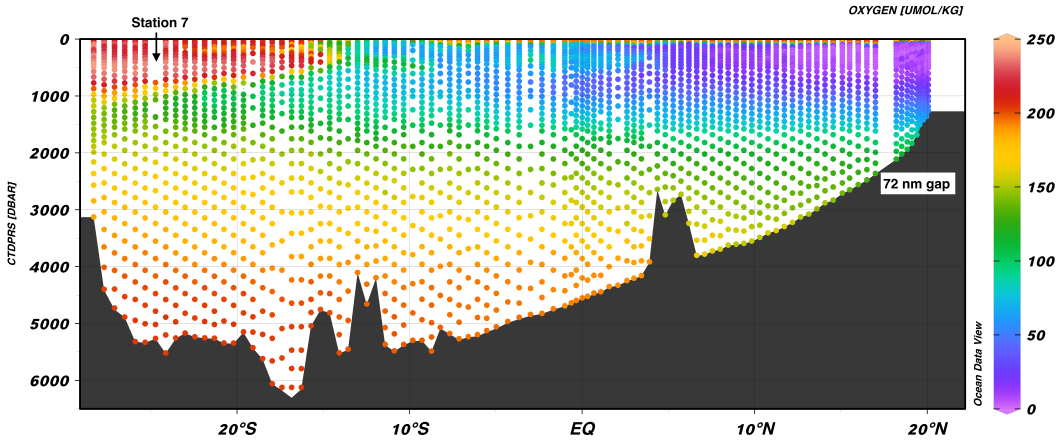

Fig. 2.5: Dissolved oxygen at discrete Niskin bottles collected during the 2025 of the I09N line. Highlighted is Station 7, where the depths of several bottles closed are unknown, and the two stations we did not occupy (72 nm gap).

For stations with integrated bio/core casts, we used the GO-SHIP 24-bottle staggering scheme instead (surface to 10

m above the bottom). We combined the selected 24 depths of the latter scheme with 12 depths determined by the Bio GO-SHIP team (1000 m, 200 m, 100 m, and nine bottles deployed at the surface). Given the large volume of water needed by the Bio team, we adjusted our closest depths to match 5, 100, 200, and 1000 m of bio, ensuring they had an adequate water supply when required. This merged scheme was the compromise we reached that allowed us to maintain our pace to the north while still partially achieving the objectives of GO-SHIP and Bio GO-SHIP.

Additionally, we reduced the number of fired bottles at stations with bottom depths shallower than 3900 m while keeping a vertical resolution like previous stations. This new pattern started at station 62 (4.36° N-90.98° E) and lasted until the end of the cruise. For that, we used the 36-bottle staggering medium depth scheme as a basis. The number of fired bottles varied from 22 to 34.

CHAPTER

THREE

CTD AND ROSETTE SETUP

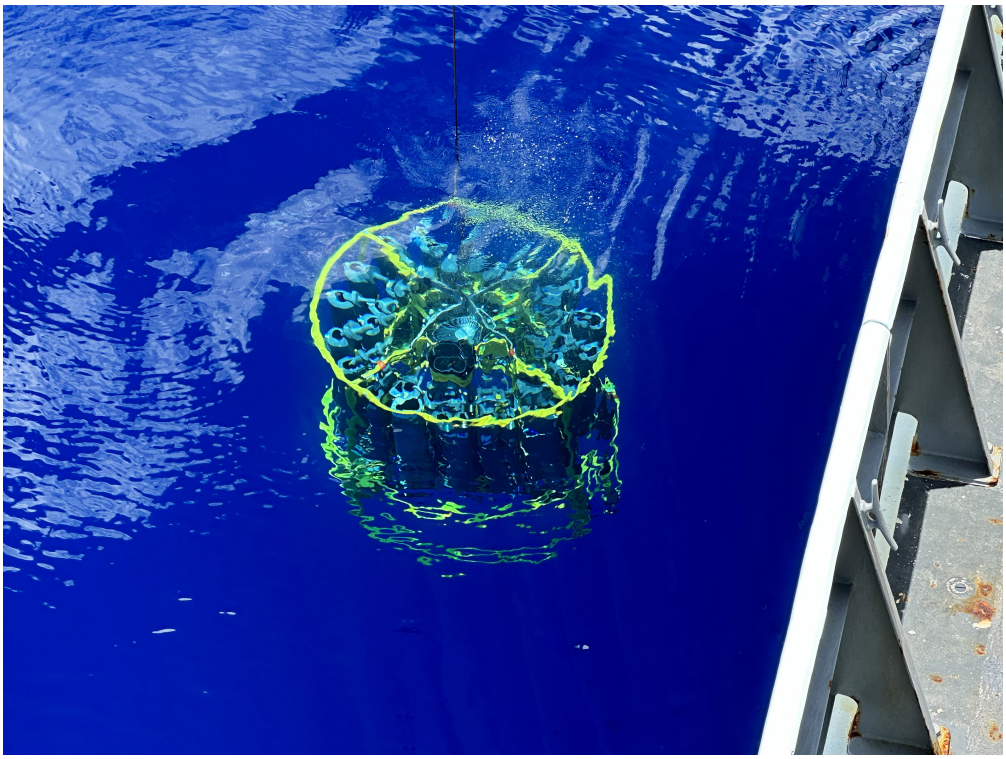

Fig. 3.1: *Image credit Allen Smith*

For I09N a SIO/STS 36-place yellow rosette and bottles were used. 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. Springs within the Bullister-style Niskin bottles were electropolished stainless steel. Bottle lanyards were made from 300-pound monofilament. No sample contamination from the o-rings and springs was detected. The package used on I09N weighs roughly 1500 lbs in air without water, 2350 lbs in air with water and approximately 950 lbs in water. In addition to the standard CTDO package, two LADCP were mounted on the rosette.

3.1 Underwater Sampling Package

Rosette/CTD/LADCP casts were performed with a package consisting of a 36-bottle rosette frame (SIO/STS), a 36-place carousel (SBE32), and 36 10-L Bullister bottles (SIO/STS) with an absolute volume of 10.4 L. Underwater electronic components consisted of a Sea-Bird Electronics SBE9plus CTD with dual pumps (SBE5T), dual temperature (SBE3plus), dual conductivity (SBE4C), dissolved oxygen (SBE43), transmissometer (Wetlabs), fluorometer (Wetlabs FLRTD), altimeter (Valeport VA500) and an optical oxygen sensor (RINKO). An SBE35RT reference temperature

Fig. 3.2: 36-place rosette with bottles and instrument package.

sensor was connected to the SBE32 carousel and recorded a temperature for each bottle closure. The sea cable armor was used for ground (return). Power to the SBE9plus CTD (and CTD sensors), SBE32 carousel, and auxiliary sensors was provided through the sea cable from the SBE11plus deck unit in the computer lab. The sensor serial numbers, calibration dates, and A/D channel are listed in Table 3.1 below.

Table 3.1: Rosette Sensors

Sensor & Serial Number	Cal. Date	A/D Channel
9plus SN 0381 (removed)	9/29/2023	
9plus SN 0569	4/23/2024	
3plus SN 2039 (primary)	12/10/2024	
3plus SN 4588 (secondary)	12/10/2024	
4C SN 1744 (primary - removed)	10/24/2024	
4C SN 2319 (primary)	1/22/2025	
4C SN 1879 (secondary)	12/11/2024	
5T SN 1799 (secondary - removed)	10/9/2023	
5T SN 3342 (secondary)	11/1/2022	
5T SN 8689 (primary)	10/9/2023	
35RT SN 0035	12/19/2024	
43 SN 4355 (initial sensor - removed)	11/6/2024	Aux4 V6
43 SN 1136 (suspected cracked cell - removed)	11/6/2024	Aux4 V6
43 SN 1071 (on rosette for the remainder)	12/17/2024	Aux4 V6
Transmissometer SN 1873	8/2/2023	Aux1 (low order) V0
Alt. VA500 SN 88639	3/11/2023	Aux3 V4
Alt. VA500 SN 78548	8/20/2021	Aux3 V4
RINKO SN 0479	9/27/2023	Aux2 V2 & V3
FLRTD SN 9157	10/22/2024	Aux1 (high order) V1

All electronics were mounted below the carousel. The SBE9plus was mounted into its cage mount and attached to the bottom of the rosette frame across grid bars in the center of the rosette. The SBE4C conductivity, SBE3plus temperature, and SBE43 dissolved oxygen sensors and their respective pumps and tubing were assembled as recommended by SBE on the CTD cage. The SBE35 sensor was mounted to the SBE9 between the primary and secondary SBE3 sensors.

Fig. 3.3: CTD instrument package showing sensor locations. Altimeter is seen mounted to the rosette frame.

The transmissometer was mounted horizontally, and the fluorometer, altimeter, and RINKO were mounted vertically

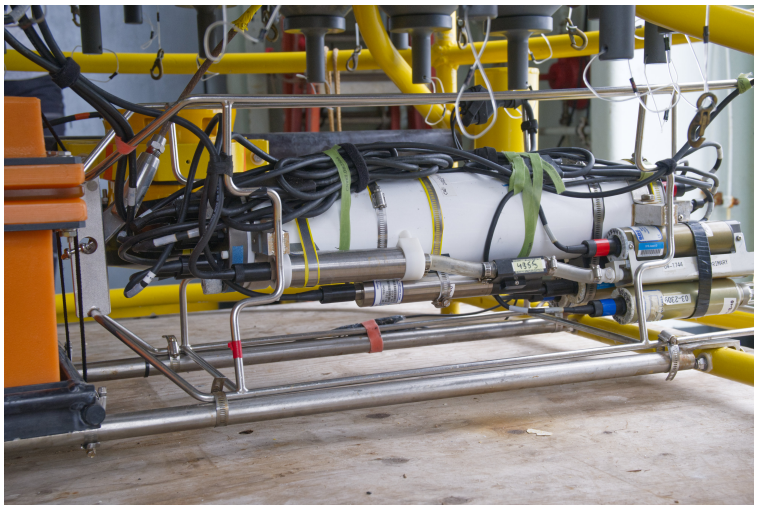

Fig. 3.4: CTD instrument package showing sensor locations. LADCP battery is visible behind.

along the bottom of the rosette frame. Both the upward-looking and the downward-looking ADCP's were mounted vertically on one side of the frame between the bottles and the CTD. The ADCP battery pack was located on the opposite side of the center grid bars, mounted on the bottom of the frame. In front of the battery pack, the transmissometer was mounted along a Unistrut on the bottom frame.

Fig. 3.5: Downward-looking LADCP and battery pack.

Additionally, an RBRduet3 TD/deep temperature and pressure logger (S/N 234746) was mounted beside the SBE35. Data were collected from this instrument for testing purposes only, and are not presented here.

The top, inside, and bottom end cap lanyards were replaced before the rosette was shipped to Australia. Lanyard measurements on the niskin's accounted for the addition of the lifting ring mounted to the frame above the water sampler. This ring ensures that all the bottles are cocked at the appropriate angle and will close when fired. All bottle o-rings were replaced during the transit to the first station.

The rosette system was suspended from a UNOLS-standard three-conductor 0.322" electro-mechanical (EM) sea cable. The sea cable underwent 4 full mechanical terminations and 1 electrical termination, all within the first 15 stations. These reterminations occurred due to communication errors with the SBE9plus and SBE32, and errors in the ship's winch readouts. During the ship's troubleshooting of the aft winch, the termination with the .322 wire was moved to

Fig. 3.6: Transmissometer, Rinko oxygen optode and fluorometer mounted to the rosette frame with LADCP battery pack.

the forward winch. The following stations gave sufficient wire data until the winch speed readings cut out. The winch errors could not be resolved and required another retermination on the forward spool.

During cast 00802, there were several modulo errors, resulting in an electrical retermination, as it had been found that the armor and ground pigtail connection was not fully connected. However, the subsequent test cast gave the same pylon communication issues as before, as well as over 30 modulo errors. This led to another retermination with the Figi fittings, which passed the ships' pull test, but upon testing the conductors, all 3 were found to be shorted, as the inner barrel of the fitting cut through the conductors and the inner armor cut through the PVC jacket. Between all the lost time as well as the finite amount of Figi fitting supplies, the final retermination used 3 Crosby clips for the tertiary termination point and guy grips on the other two points. Any delays after the last retermination were due to weather or ship issues with the z-drive (bow thruster).

Kinks in the EM cable result from the shock loading on sheaves at shallow depths during launch and recovery. Shock loading did not occur on this cruise, as the winch would use the heave compensation setting during less-than-ideal sea states, and the wire remained free of kinks and in good working condition.

The CTD watchstanders prepared the rosette 15-30 minutes before each cast. The bottles were cocked, and all spigots, vents, and lanyards were checked for proper orientation. LADCP technician would check for LADCP battery charge, prepare instruments for data acquisition, and disconnect cables. The Marine Technician would check the sea state ~15 minutes before station arrival and decide if conditions were acceptable for bringing out the rosette. The rosette was moved from the sampling bay to the starboard side of the deck using the Thompson's (accordion) deployment platform. Once on deck, sea cable slack was pulled up by the winch operator and taglines were manned by the AB's.

The CTD was powered up, and the data acquisition system started from the computer lab when directed by the marine technician from the deck. The winch operator was directed by the deck to raise the package. The hydro boom and rosette were extended outboard, and the package was kept level quickly lowered into the water. At the surface, the technician told the winch operator to "zero" the wire out and lower the rosette to 10 meters, where it was held until the console operators determined that all sensors had turned on and data looked good. The winch operator was then directed to bring the package back to the surface and to begin the descent. Each rosette cast was lowered to within 10 meters of the bottom, using the altimeter, winch wireout, and multibeam depth to determine the distance.

For each upcast, the winch operator was directed to stop the winch at some number (between 10 and 36) of standard sampling depths. These standard depths were staggered at every station based on different schemes derived by the Chief Scientists. To ensure the package shed wake had dissipated, the CTD console operator waited 30 seconds prior to tripping sample bottles. Before moving to the next consecutive trip depth, an additional 15-second pause was observed. The marine technician directed the package to the surface for the last bottle trip. Recovering the package at the end of

the deployment was essentially the reverse of launching. Once the rosette was on deck, the console operator terminated the data acquisition, turned off the deck unit, and assisted with rosette sampling. The rosette was secured on the cart and moved into the aft hanger for sampling. The bottles and rosette were examined before samples were taken, and anything unusual was noted on the sample log. Routine CTD maintenance included flushing the conductivity and oxygen sensors with freshwater between casts to maintain sensor stability and rinsing the rest of the sensors (including the carousel) with freshwater.

Rosette maintenance was performed regularly. Caps, spigots, and o-rings were inspected for leaks. Occasional reorientation of the bottles was required to ensure proper firing and sampling. Lanyards were replaced as needed. A few vents needed to be replaced after damage from tagline hooks during recovery.

Several stations revealed erroneous sensor data requiring multiple spare sensor swaps. A test cast during transit to the first station had no communication with the SBE32 carousel, so bottles were fired on the fly during the upcast. Once on deck, only 3 bottles had successfully fired, none of which were manually fired at the console. After an attempted cable swap failed to resolve the issue, and a deck test of the Thompsons' spare 24-place SBE32 proved successful, the pylon was switched with the spare 36-place SN-0187.

Station 00701 experienced multiple bottle-fire failures, and during troubleshooting, the SBE9+ was swapped from SN 0381 to SN 0569.

Attempted cast 00801 revealed that the primary conductivity sensor SN 1744 had failed. This sensor was swapped to SBE4C SN 2319 after the cast was aborted.

Throughout the cruise, the VA500 altimeter(s) data did not consistently pick up the seafloor. Data looked good during 00101, but all subsequent casts only saw intermittent readings at best between 90-20 m from the bottom until cast 00602, which saw no altimeter readings at all despite reaching appx 10 m from the bottom (confirmed by LADCP data post cast). Both cable and sensor were swapped (from SN 78548 to SN 88639) with no better results. After 01501, the ship's altimeter was installed onto the rosette (SN 67356) and performed about the same as ODF's sensors. The ships' spare VA500, ODF's spare VA500, and the installed VA500 all had settings verified and performed well in the Valeport terminal during bucket tests. All sensors had no signs of any corrosion or hot pins so bad readings were assumed to be caused by the aux port on the SBE9+. To prove this, a generic wye cable was used on the SBE43 aux port to see if the altimeter would perform a cleaner bottom approach.

Station 05401 was the first cast after removing the generic wye cable from the altimeter/SBE43. During this cast, the SBE43 data looked noisy, resulting in both a cable swap and an aux port swap. Failure to make a cleaner profile caused the sensor to be swapped to SN 1136. The resulting profile looked suspiciously like a cracked cell. SBE43 SN 1071 was installed and looked good from station 05801 until the end of operations.

The altimeter and fluorometer were swapped in position on the rosette to attempt to eliminate the excess of noise (on the altimeter). This was futile, but almost all the noise was eliminated during a cast where the LADCP was never powered on. Altimeter depths vs the multibeam depths look realistic when doing the bottom approach but during some casts, if the payout speed dropped too significantly, the reading from the altimeter would also drop out.

CHAPTER

FOUR

CTDO AND HYDROGRAPHIC ANALYSIS

PIs

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4.1 CTDO and Bottle Data Acquisition

The CTD data acquisition system consisted of an SBE 11plus V2 deck unit and a networked Windows 10 PC workstation. Sea-Bird SeaSave V7 version 7.26.7 software was used for data acquisition and to close bottles on the rosette.

CTD deployments were initiated by the console watch operators (CWO) once the ship was positioned on each station. The CWO maintained a detailed console log for each attempted cast to record cast metadata, each bottle fired and any notable issues encountered.

CTD data acquisition was begun with the rosette on deck. Deck crew deployed the rosette and immediately lowered it to 10 meters. The CTD sensor pumps were configured to start immediately after the primary conductivity cell detects salt water. The CWO checked the CTD data for proper sensor operation, waited for sensors to stabilize, and instructed the winch operator to bring the package back to the surface. Deck crew determined the surface depth based on their judgement of weather and sea state. The winch operator was then instructed to lower the rosette 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. During periods of higher sea states, automatic heave compensation was enabled on the winch, resulting in variable payout rates at a maximum of 50 m/min.

The CWO monitored the progress of the deployment and quality of the CTD data through real-time displays. The altimeter, CTD pressure, wire-out and multi-beam depth sounder 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 at 100 m from the bottom, and 20 m/min when 30 m from the bottom. The bottom depth of the cast was usually within 10 meters of the bottom as determined from the altimeter data. For each full upcast, the winch operator was directed to stop the winch at up to 36 predetermined depths. The CWO allowed 30 seconds at each stop before closing the sample bottle. An additional 15 seconds were allowed after bottle closure for the SBE35RT reference temperature sensor to record 13 samples and compute an average. The rosette was then raised to the next target depth. For the last bottle, the winch operator was instructed to return the rosette to the surface, and then used their judgement to bring the rosette as close to the surface as was possible in the prevailing wind and sea conditions. After the last surface bottle was closed, the CWO directed the deck crew to recover the rosette.

Once the rosette was out of the water and on deck, the CWO terminated the data acquisition. Each bottle and the rosette were examined before sampling began. A sample log was kept during sampling, recording all analytical samples drawn from each bottle. The CTD sensors were rinsed after every cast using syringes of fresh water connected to Tygon tubing. Between casts, the tubing was left in place to keep 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. If a Niskin bottle was replaced, the new bottle was tracked in the cruise database.

Several software issues arose affecting data acquisition. At station 7, communication with the water sampler became unreliable and acquisition was stopped and restarted twice during the upcast in effort to restore communication, resulting in multiple data files for the cast. At station 20, acquisition was unintentionally stopped during the upcast. Operators restarted acquisition and completed the cast, which also resulted in multiple data files. For both casts, raw data files were manually cut-and-pasted together in a single file for processing with CTDCAL, described below.

At two stations, 9 and 12, Sea Save failed to record the 36th bottle, even though in both cases the bottle did indeed close. For the purpose of data processing, we assume these bottles closed at the surface as intended, but since there is no record of the closure in the raw CTD data to confirm, we treat these bottle data as suspect.

4.2 CTDO Data Processing

Shipboard CTD data processing was performed after deployment. Sea-Bird SeaSoft V2 Data Processing software was used to generate bottle summary files and bin-averaged converted files in 1 Hz, 1 dbar and 2 dbar bins for immediate use aboard the ship following the cast. An additional converted raw file was generated with parameters specified by the LADCP group for their use.

Raw CTD data were manually fit and quality controlled using SIO/ODF CTD processing software ctdcal v. 0.1.4 running on an Apple MacOS system. CTD data at bottle stops were extracted to create a 2 db downcast pressure series. The pressure series data were submitted for CTD data distribution after corrections outlined in the following sections were applied.

A total of 100 CTD stations were occupied including two test-cast stations. A total of 115 casts were processed.

CTD data were examined at the completion of each cast 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 oxygen comparisons were made between upcasts and downcasts as well as between groups of adjacent deployments. Vertical sections of measured and derived properties from sensor data were checked for consistency.

For Bio-GO-SHIP casts where bottle sampling for salts and oxygen was not performed, fit coefficients were obtained from the nearest proximal cast, which in most cases was the same station.

Issues that directly impacted CTD analysis are described in this section. Issues that affected bottle closures are detailed in the *CTD and Rosette Setup* section of this report. Temperature, conductivity and oxygen sensor issues are detailed in the subsections below.

4.3 Pressure Analysis

CTD pressure was provided by an SBE 9plus profiling CTD unit. Serial number 09-0381 was used through station 7. Serial number 09-0569 was used for the remainder of the cruise. No performance issues were noted with either instrument.

Laboratory calibrations of CTD pressure sensors were performed prior to the cruise. Dates of laboratory calibration are recorded in Table 3.1. Calibration documents are provided in the APPENDIX.

The lab calibration coefficients provided on the calibration report were used to convert raw sensor frequency to pressure. Initial SIO pressure lab calibration coefficients were entered into SeaSave configurations and applied to cast data during acquisition.

Additionally, on-deck pressures were recorded at the start and end of each cast to characterize offsets for each sensor. Starting offsets remained consistent, and the mean starting offset was subtracted from all casts for each sensor. Offsets at the end of casts were more variable.

On-deck pressure offsets observed throughout the cruise are shown in Fig. 4.1. Maximum, minimum and average offsets observed for each sensor are presented in Table 4.1.

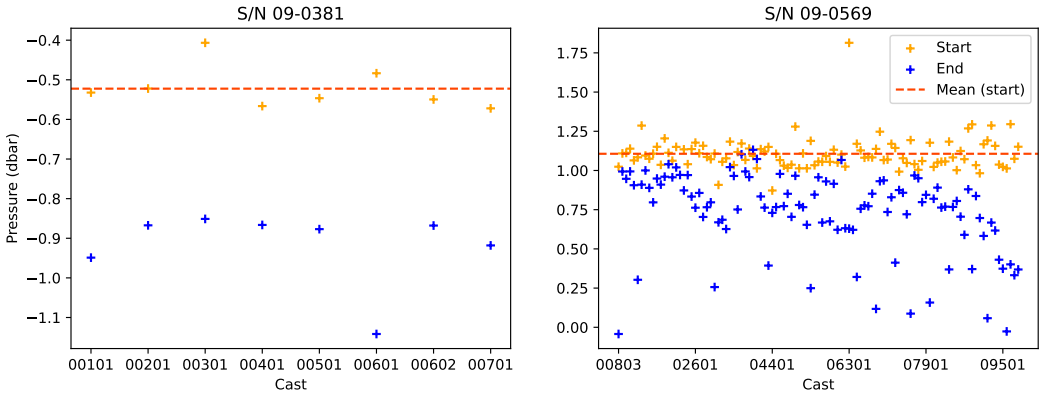


Fig. 4.1: SBE9+ on-deck pressure offsets by cast.

Table 4.1: SBE9plus Pressure Offsets

Pressure Offsets		Start (dbar)	End (dbar)
CTD SN: 09-0381	Min	-0.5721	-1.1416
	Max	1.0240	-0.0427
	Mean	-0.3505	-0.8201
CTD SN: 09-0381	Min	0.8724	-0.0263
	Max	1.8142	1.1318
	Mean	1.1073	0.7393

4.4 Temperature Analysis

CTD temperature was provided by primary and secondary SBE 3plus temperature sensor units. Serial number 03-2039 was used on the primary CTD channel, and serial number 03-4588 was used on the secondary channel. Both were used for the duration of the cruise with no performance issues noted. Reference temperatures were provided by an SBE35RT Digital Reversing Thermometer. Serial number 35-0035 was used for the duration of the cruise with no performance issues noted.

Laboratory calibrations of temperature sensors were performed prior to the cruise at the SIO Calibration Facility. Dates of laboratory calibration are recorded in Table 3.1. Calibration documents are provided in the APPENDIX.

The pre-cruise laboratory calibration coefficients were used to convert SBE3plus frequency 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 13 samples, which is approximately a 15 second period.

The SBE3plus sensor typically exhibits a consistent well-modeled response, which 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 4.2: Primary temperature (T1) coefficients.

Station	cp_2	cp_1	ct_2	ct_1	c_0
All	0.0	-4.4934e-7	0.0	0.0	2.0278e-3

Table 4.3: Secondary temperature (T2) coefficients.

Station	cp_2	cp_1	ct_2	ct_1	c_0
All	0.0	-4.3224e-7	0.0	0.0	1.6706e-3

Corrected temperature differences are shown in the following figures.

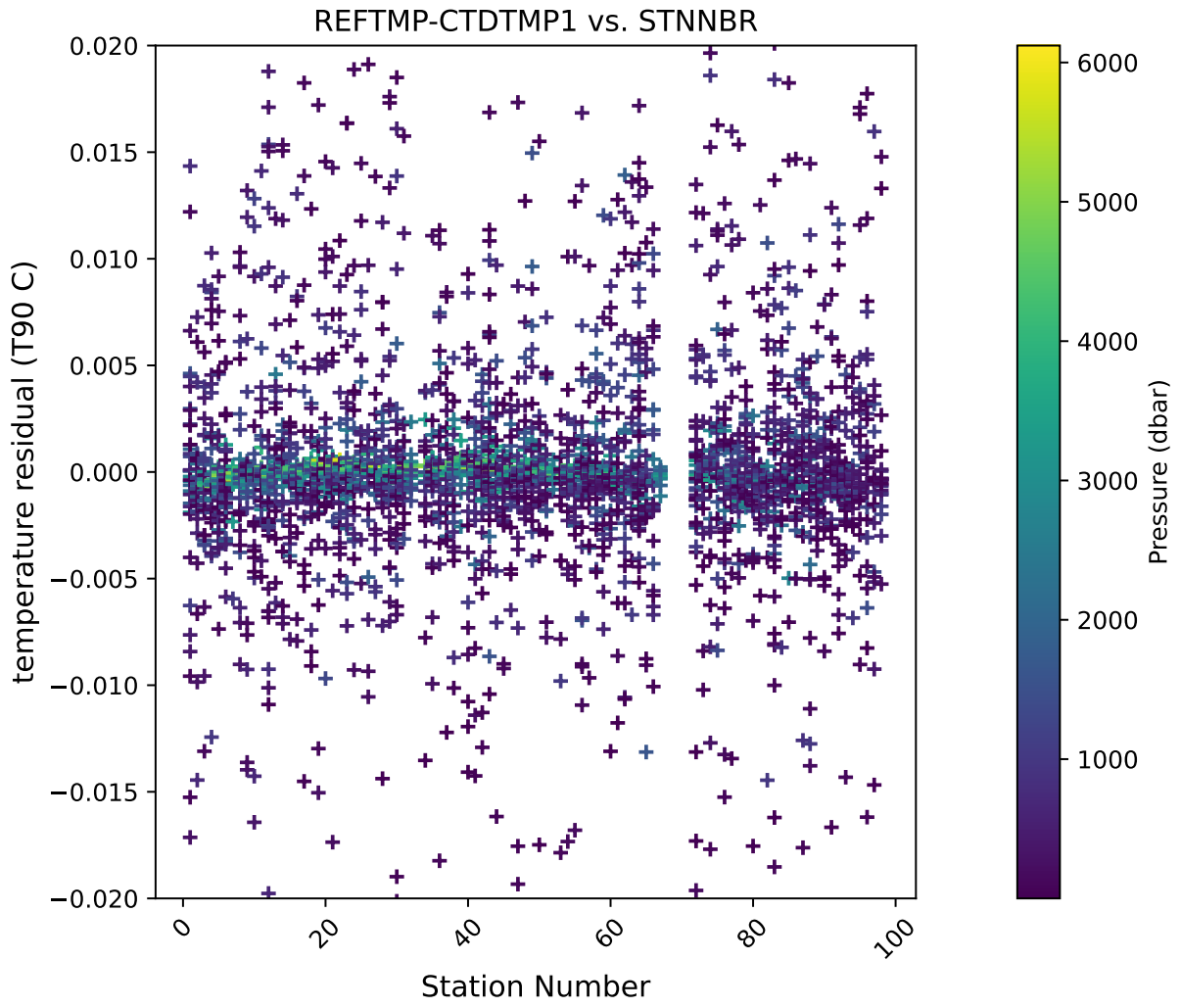


Fig. 4.2: SBE35RT-T1 versus station.

The 95% confidence limits for the mean low-gradient (values -0.002 °C $\leq$ T1-T2 $\leq$ 0.002 °C) differences are $\pm$0.00561 °C for SBE35RT-T1, $\pm$0.00559 °C for SBE35RT-T2 and $\pm$0.00163 °C for T1-T2. The 95% confidence limits for

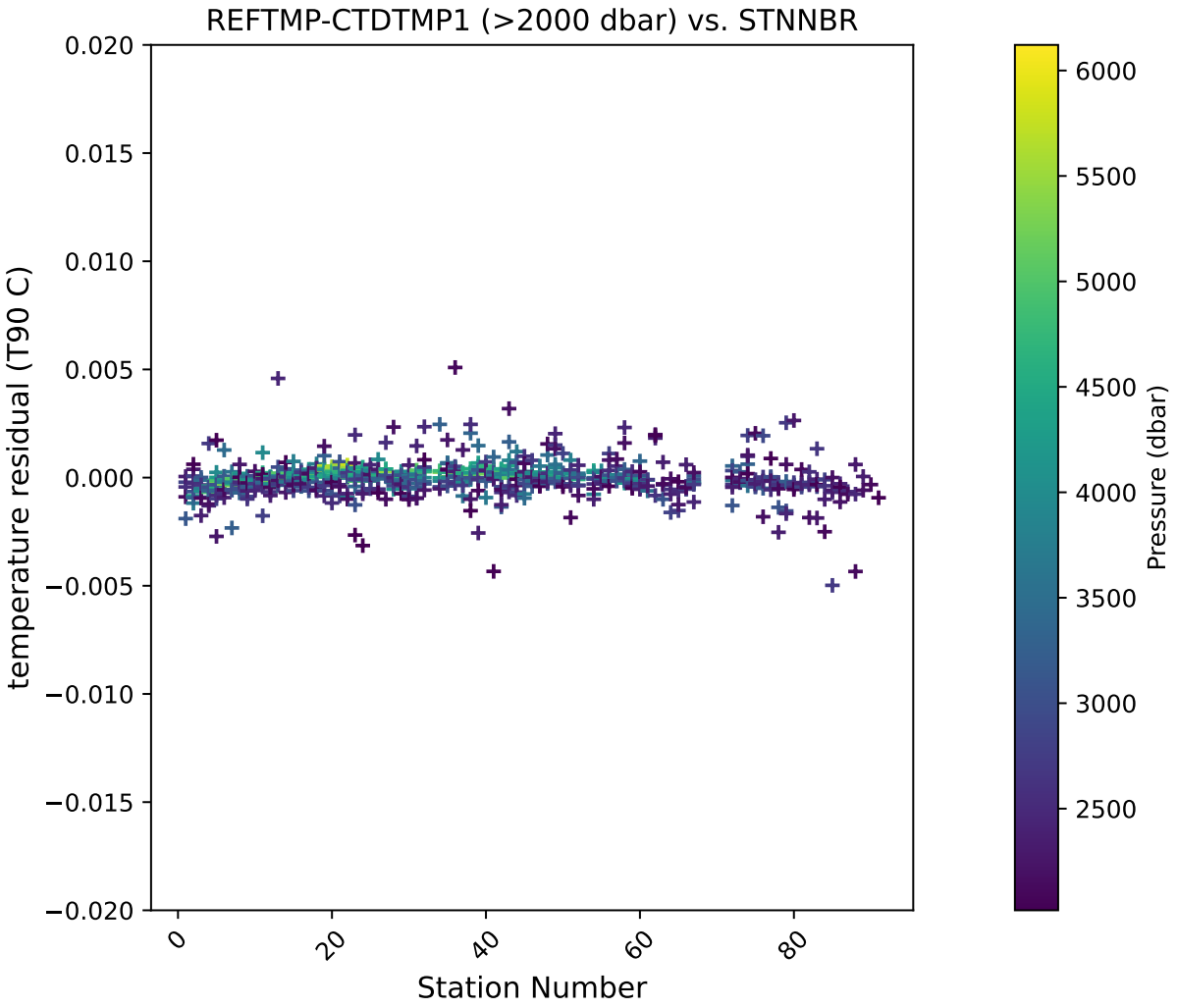


Fig. 4.3: Deep SBE35RT-T1 by station (Pressure $\geq$ 2000dbar).

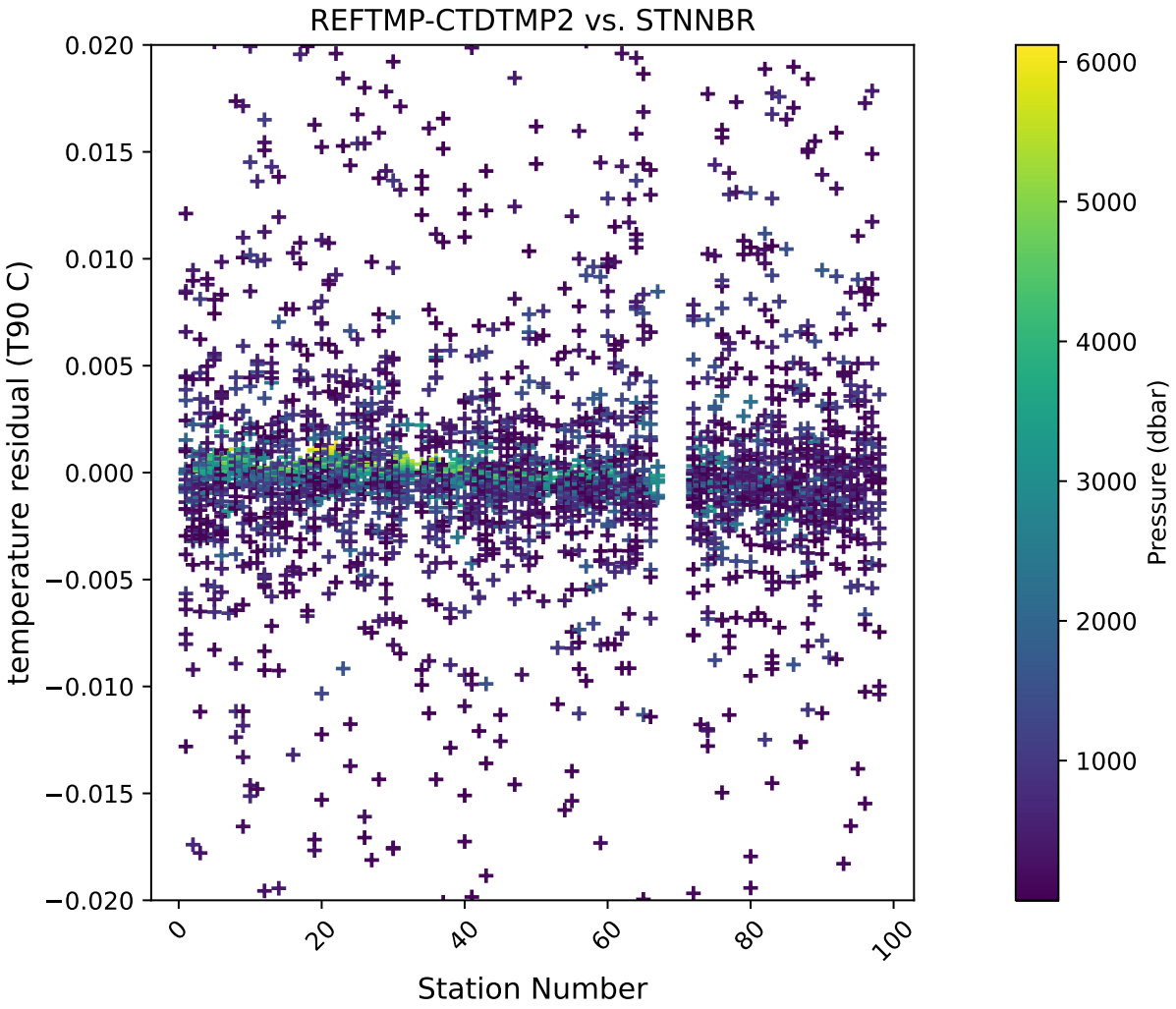


Fig. 4.4: SBE35RT-T2 versus station.

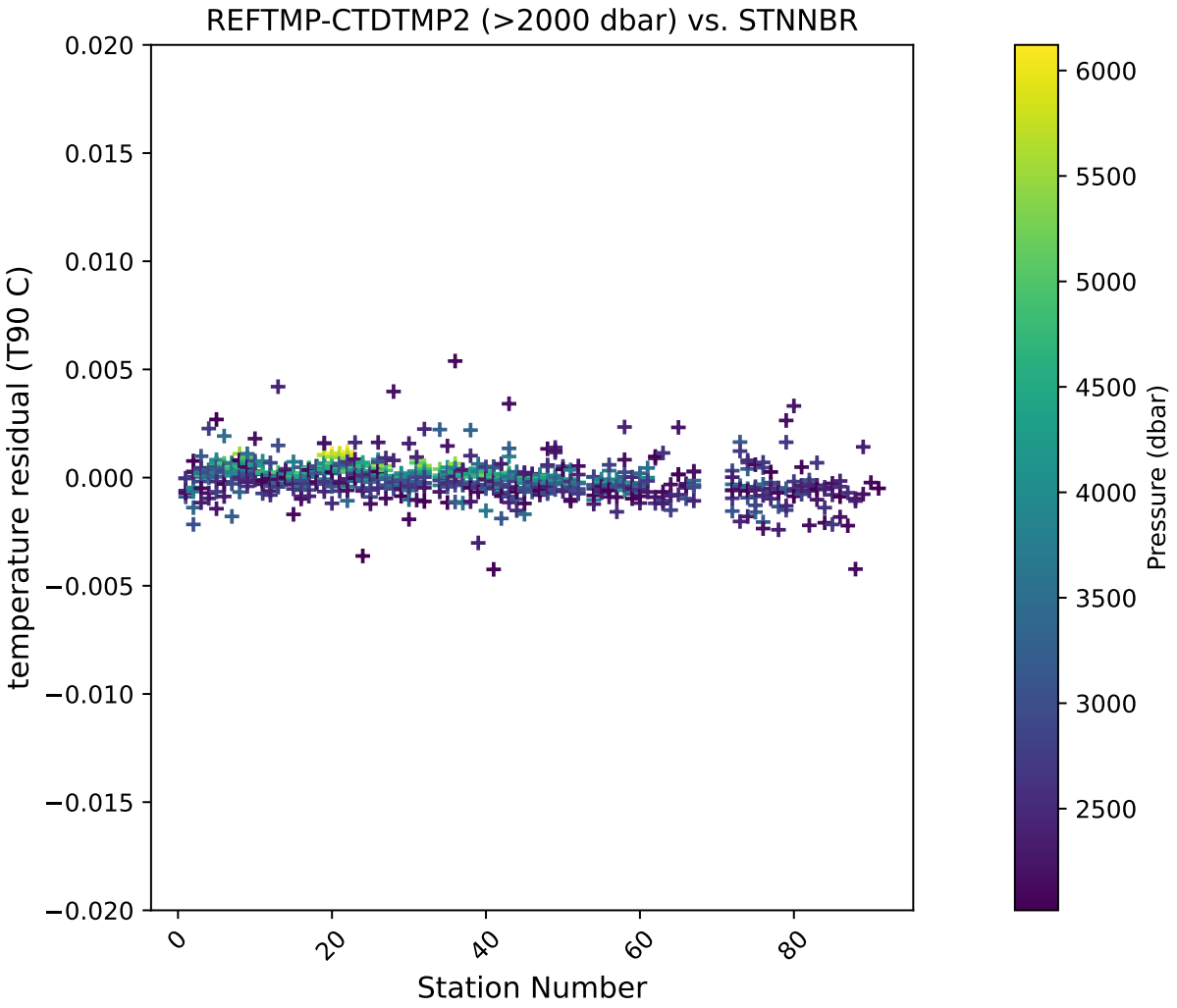


Fig. 4.5: Deep SBE35RT-T2 by station (Pressure $\geq$ 2000dbar).

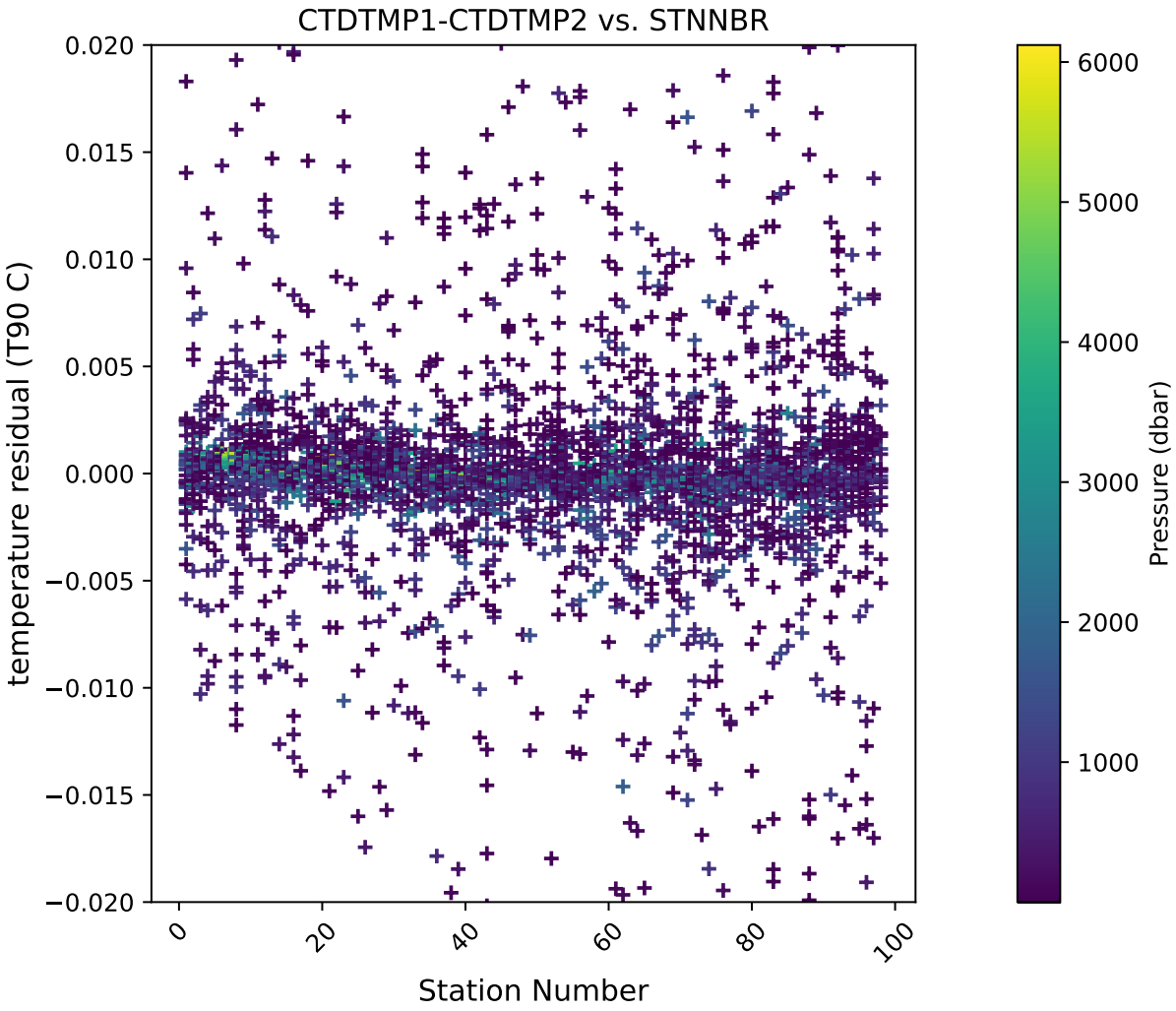


Fig. 4.6: T1-T2 versus station.

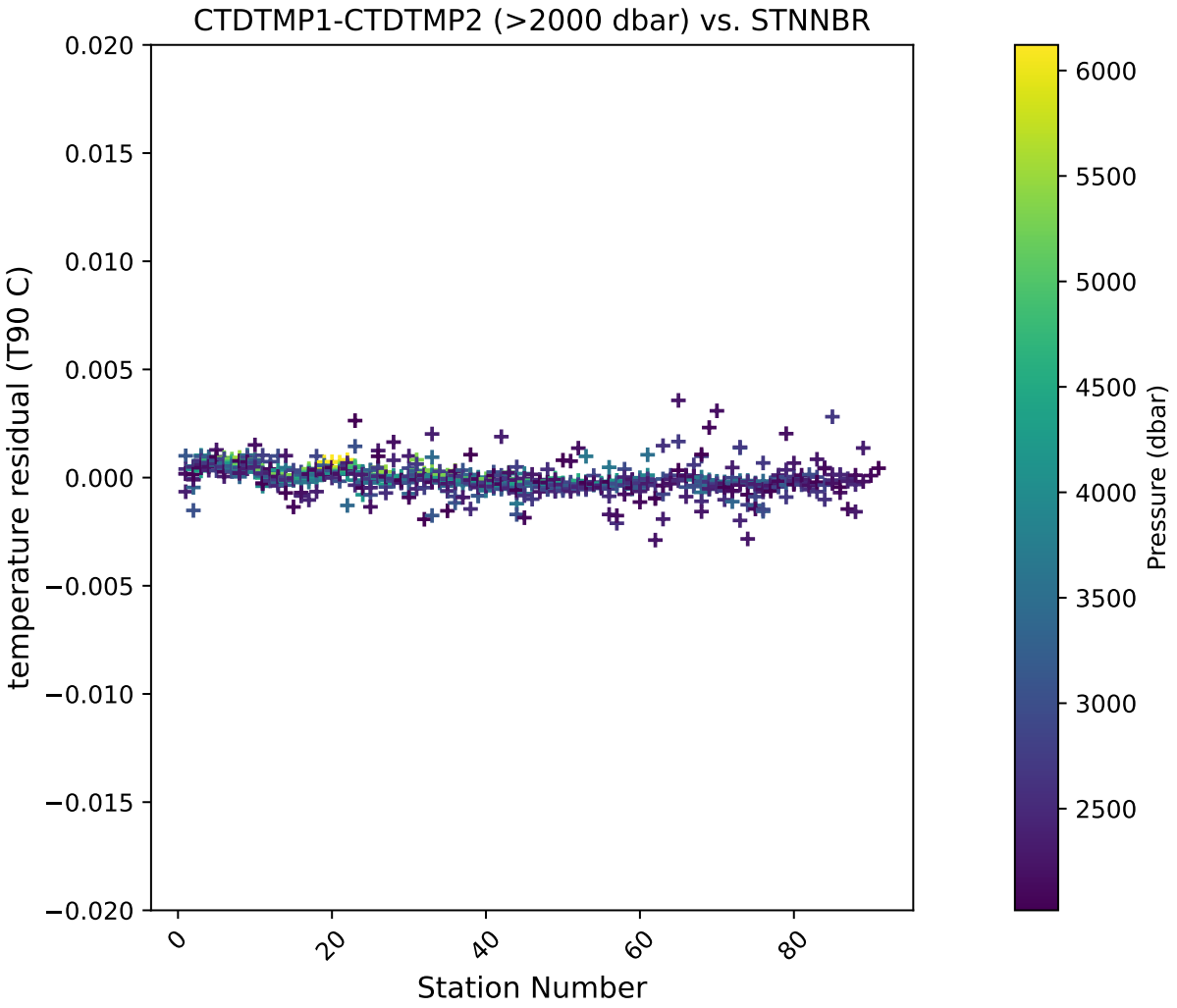


Fig. 4.7: Deep T1-T2 versus station (Pressure $\geq$ 2000dbar).

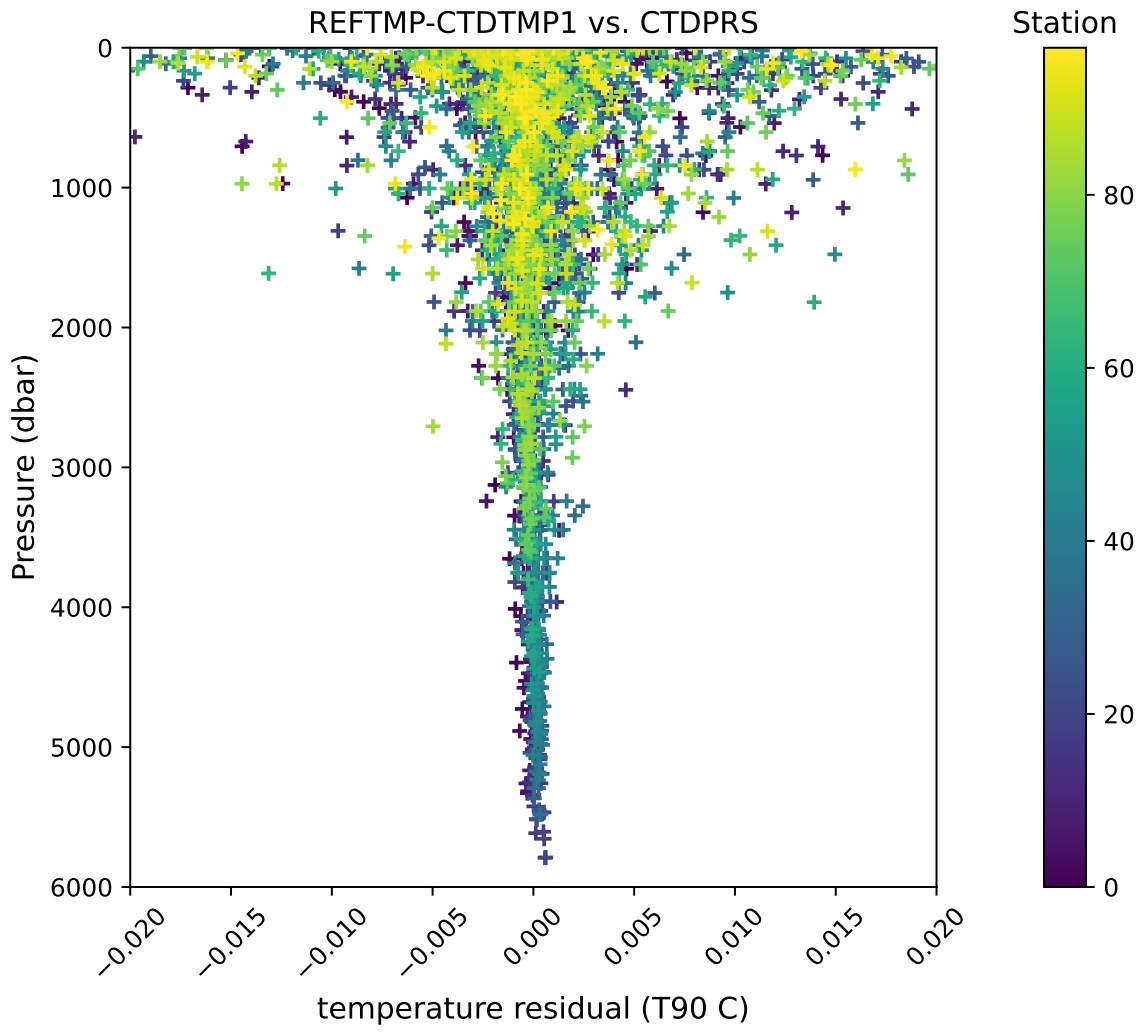


Fig. 4.8: SBE35RT-T1 versus pressure.

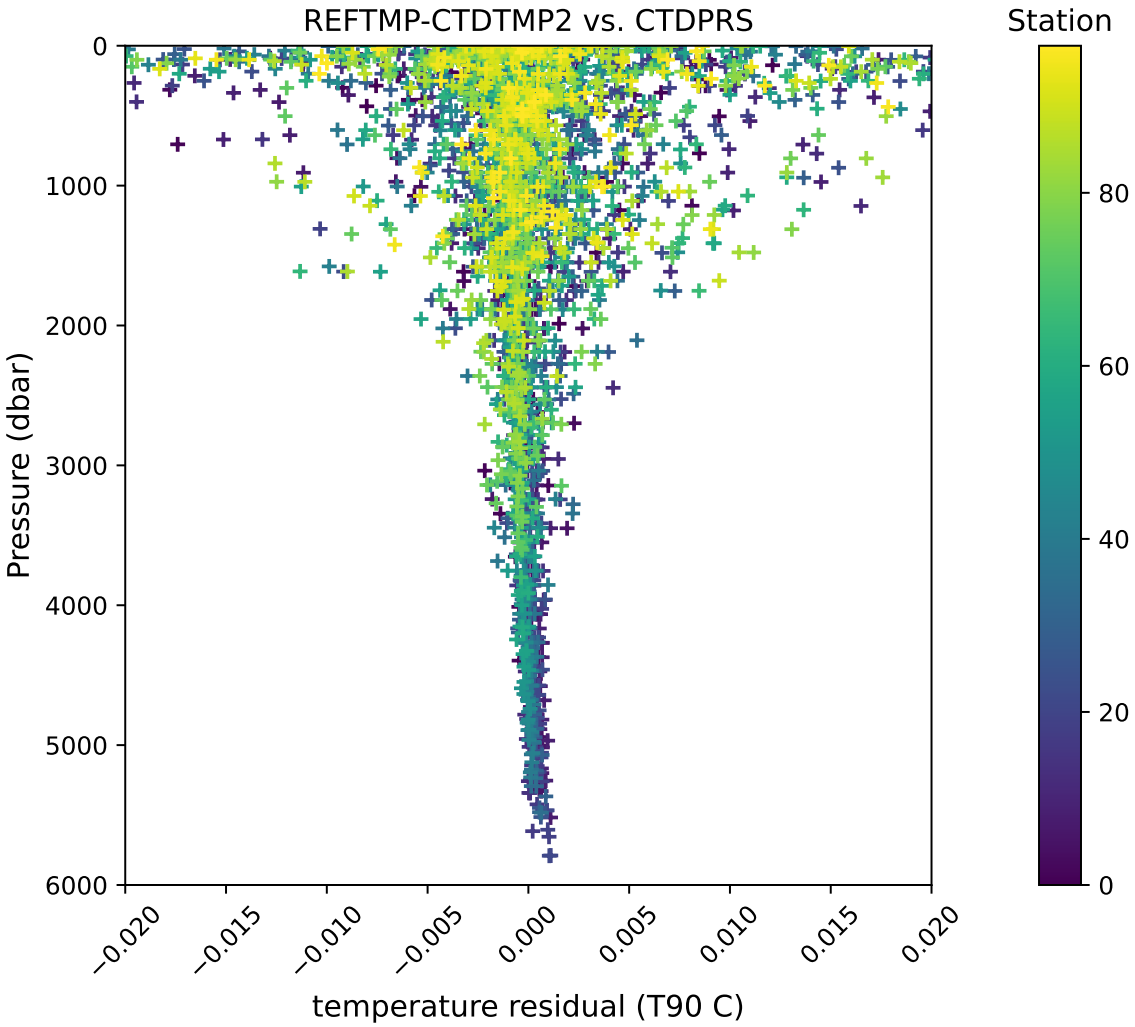


Fig. 4.9: SBE35RT-T2 versus pressure.

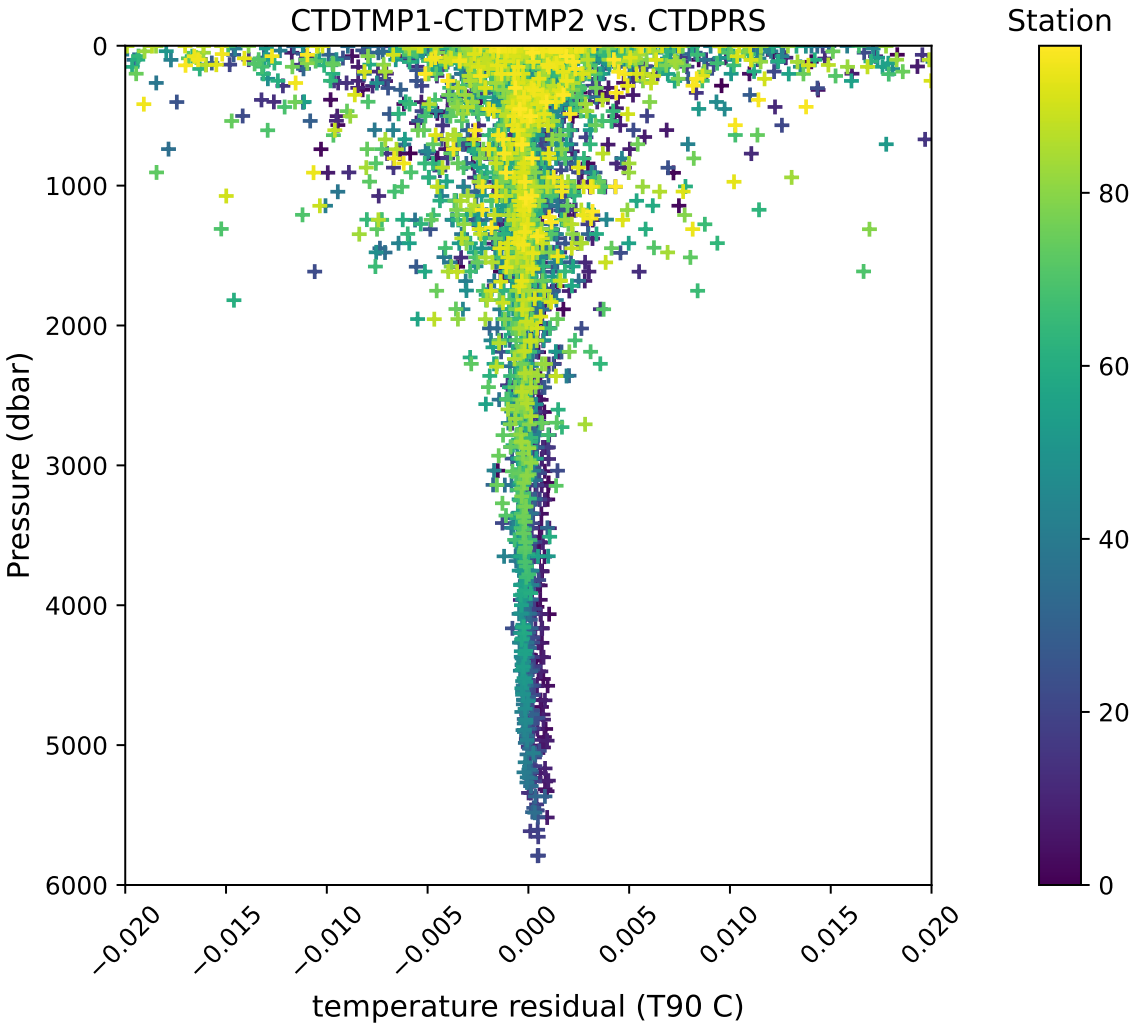


Fig. 4.10: T1-T2 versus pressure.

the deep temperature residuals (where pressure $\geq$ 2000 dbar) are $\pm$0.00113 °C for SBE35RT-T1, $\pm$0.00132 °C for SBE35RT-T2 and $\pm$0.00118 °C for T1-T2.

Issues affecting SBE35RT reference temperature data were:

- On several occasions, internal recorder memory was exceeded, resulting in incomplete or no samples recorded for some casts. Casts with incomplete reference samples were 03201, 03901, 05201 and 06701. Casts with no reference samples were 03301, 05301, 06801, 06901, 06902, 07001 and 07101.

4.5 Conductivity Analysis

CTD conductivity was provided by primary and secondary SBE 4C conductivity sensor units. Serial numbers 04-1744 and 04-2319 were used on the primary CTD channel, and serial number 04-1879 was used on the secondary channel. Issues with the primary conductivity sensors are detailed later in this section.

Laboratory calibrations of conductivity sensors were performed prior to the cruise at the Sea-Bird calibration facility. Dates of laboratory calibration are recorded in Table 3.1. Calibration documents are provided in the APPENDIX.

The pre-cruise laboratory calibration coefficients were used to convert SBE 4C frequency to mS/cm. 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 bottle sample salinity 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.

The SBE 4C sensor typically exhibits a predictable modeled response. Offsets for each 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 4.4: Primary conductivity (C1) coefficients.

Station	cp_2	cp_1	ct_2	ct_1	cc_2	cc_1	c_0
1-7	0.e+0	-6.2152e-7	0.e+0	0.e+0	0.e+0	1.3869e-4	-1.9726e-3
8-98	0.e+0	-7.5055e-7	0.e+0	0.e+0	0.e+0	-1.4376e-5	3.7609e-3

Table 4.5: Secondary conductivity (C2) coefficients.

Station	cp_2	cp_1	ct_2	ct_1	cc_2	cc_1	c_0
1-7	0.e+0	-6.8127e-7	0.e+0	0.e+0	0.e+0	2.7767e-4	-5.4275e-3
8-98	0.e+0	-9.1548e-7	0.e+0	0.e+0	0.e+0	-1.6001e-4	9.0660e-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.

The 95% confidence limits for the mean low-gradient (values -0.002 °C $\leq$ T1-T2 $\leq$ 0.002 °C) differences are $\pm$0.06026 mPSU for salinity-C1SAL. The 95% confidence limits for the deep salinity residuals (where pressure $\geq$ 2000 dbar) are $\pm$0.00289 mPSU for salinity-C1SAL.

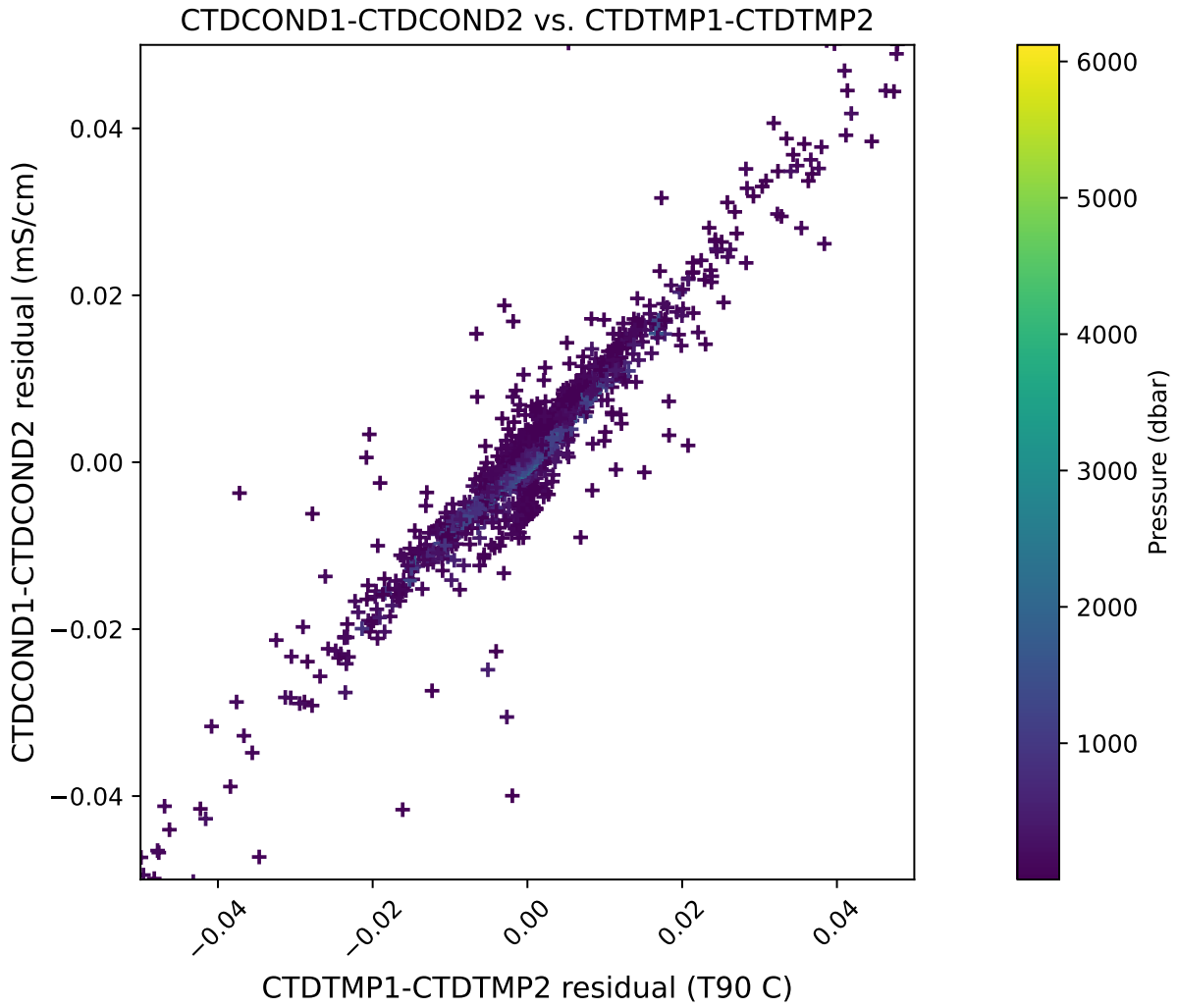


Fig. 4.11: Coherence of conductivity differences as a function of temperature differences.

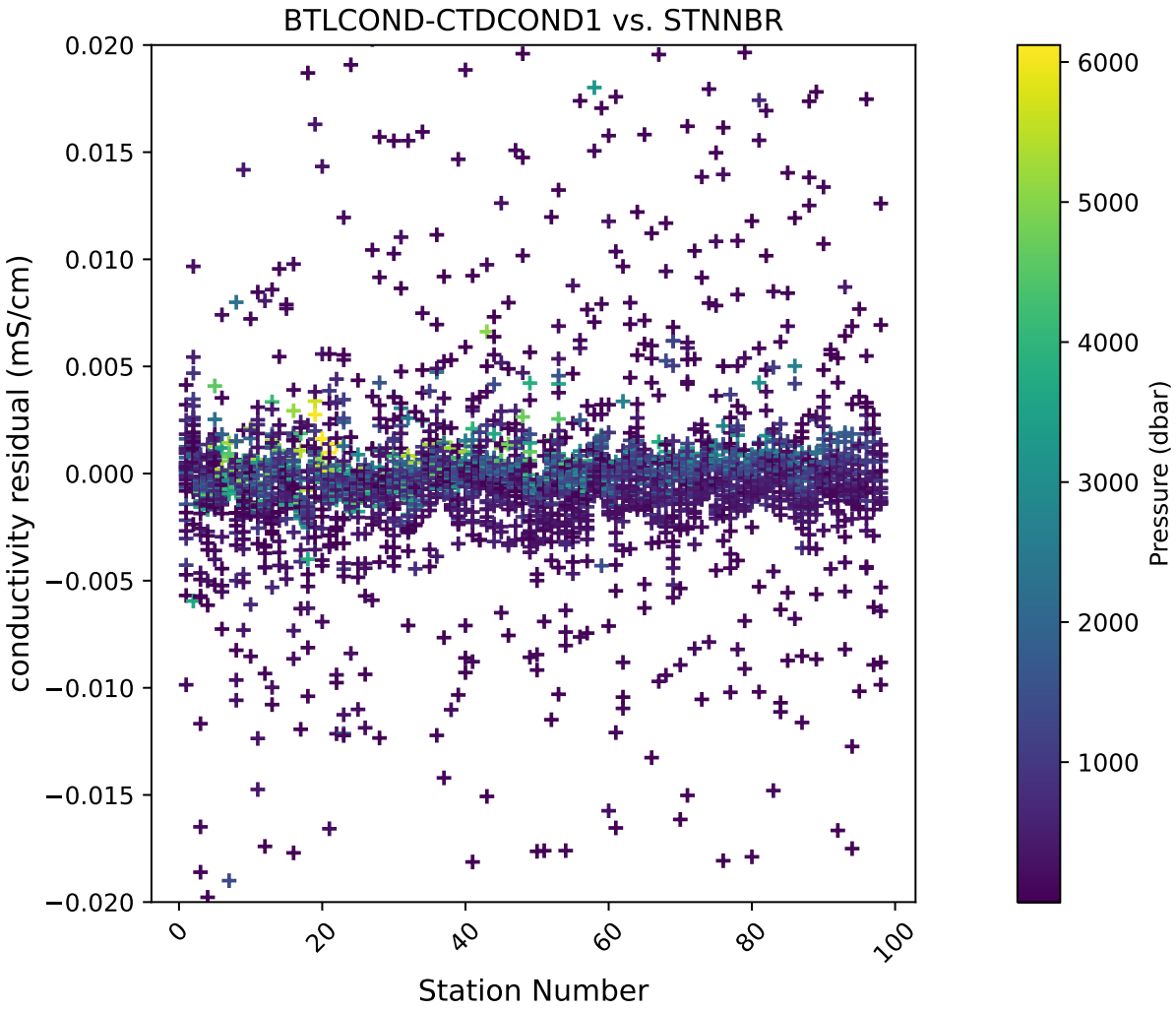


Fig. 4.12: Corrected C_{Bottle} - C1 versus station.

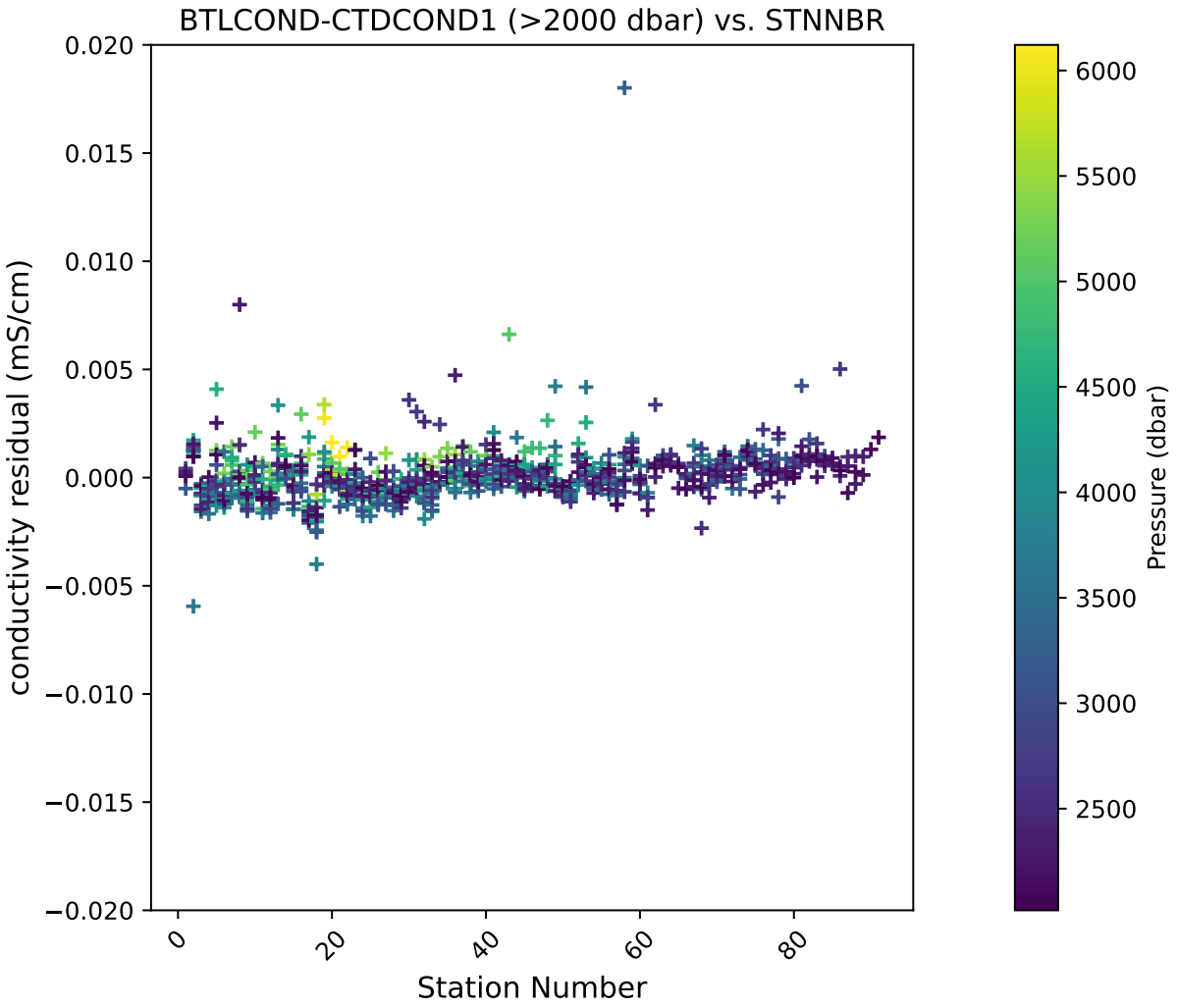


Fig. 4.13: Deep Corrected C_{Bottle} - C1 versus station (Pressure >= 2000dbar).

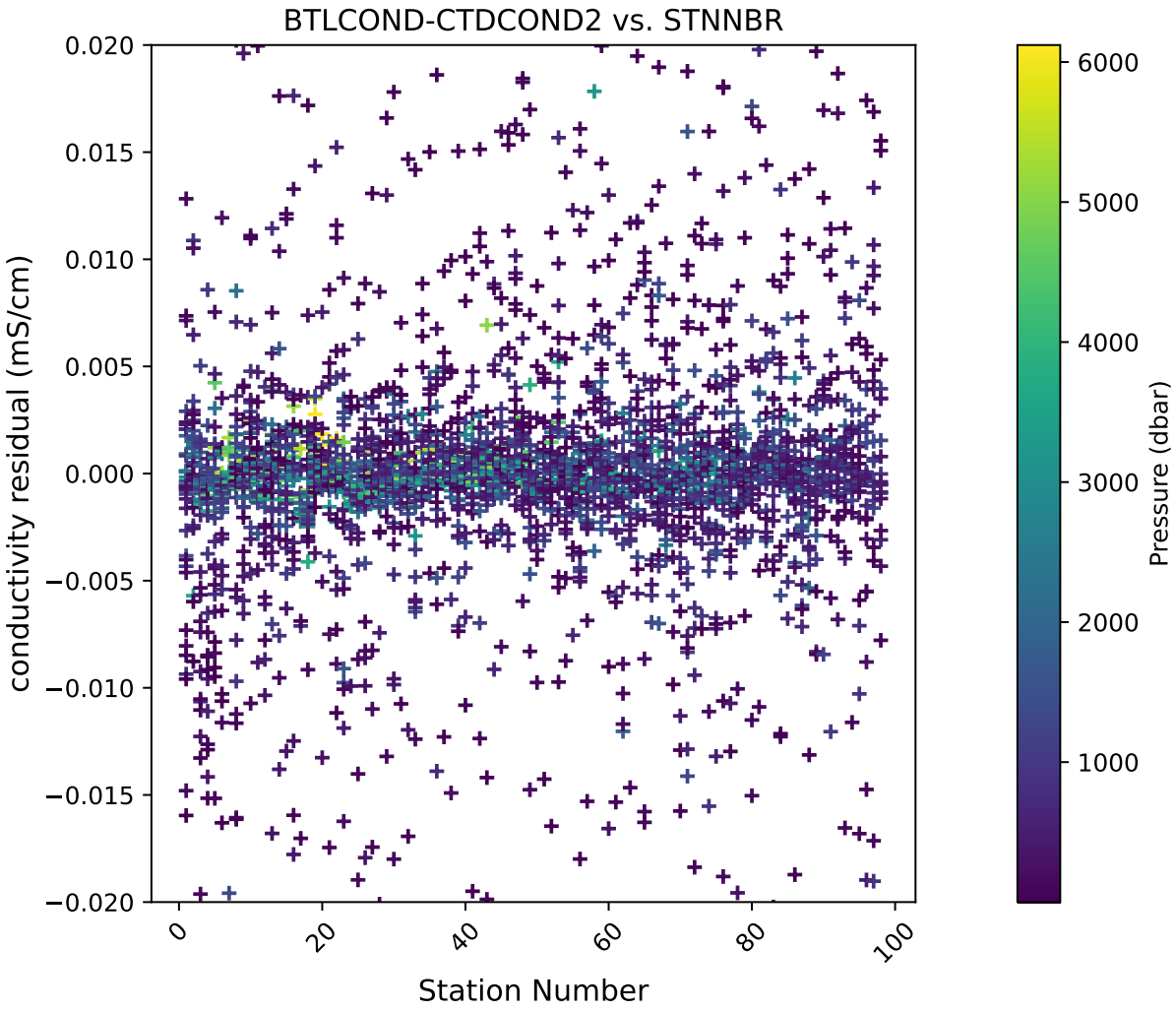


Fig. 4.14: Corrected C_{Bottle} - C2 versus station.

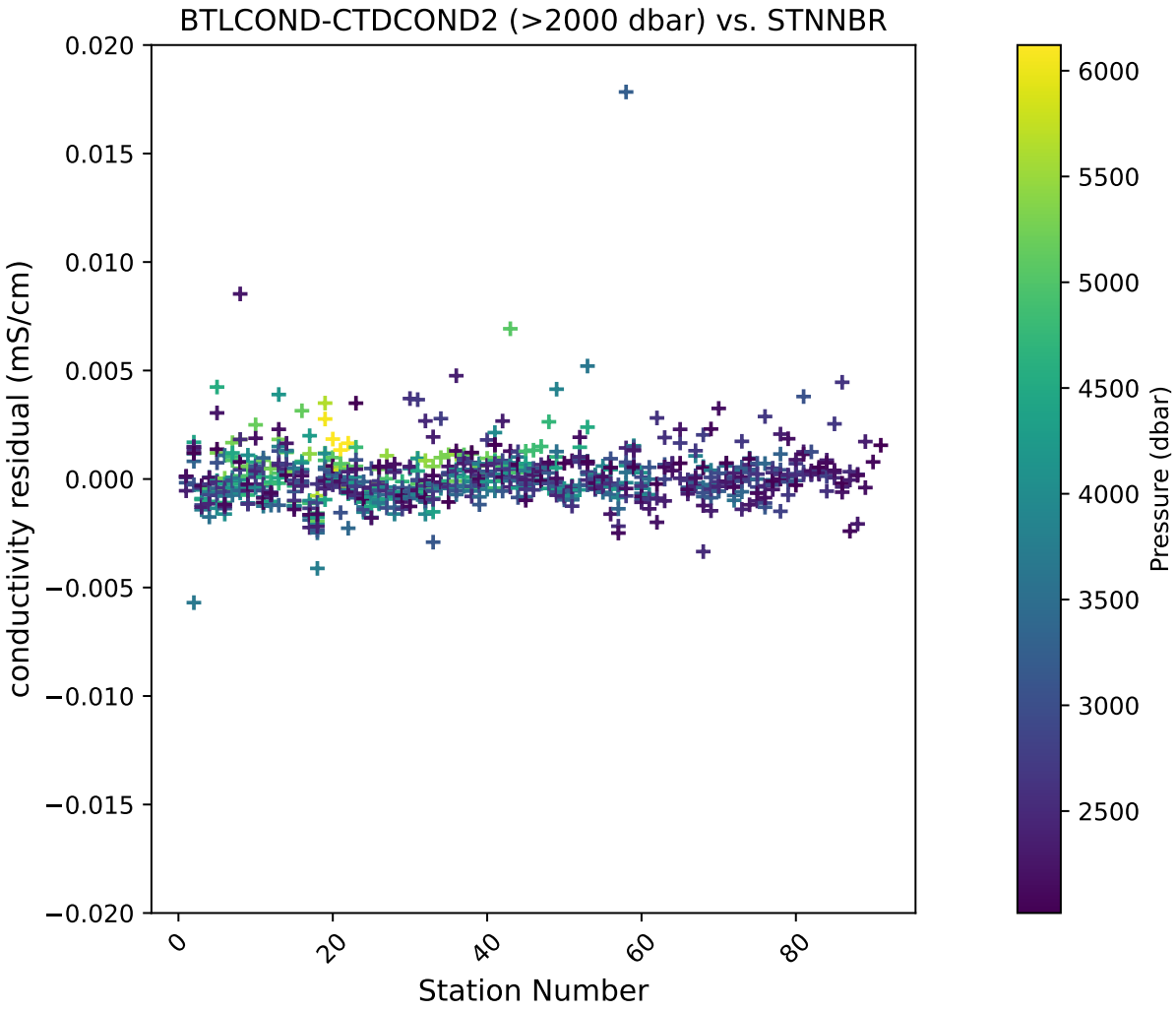


Fig. 4.15: Deep Corrected C_{Bottle} - C2 versus station (Pressure >= 2000dbar).

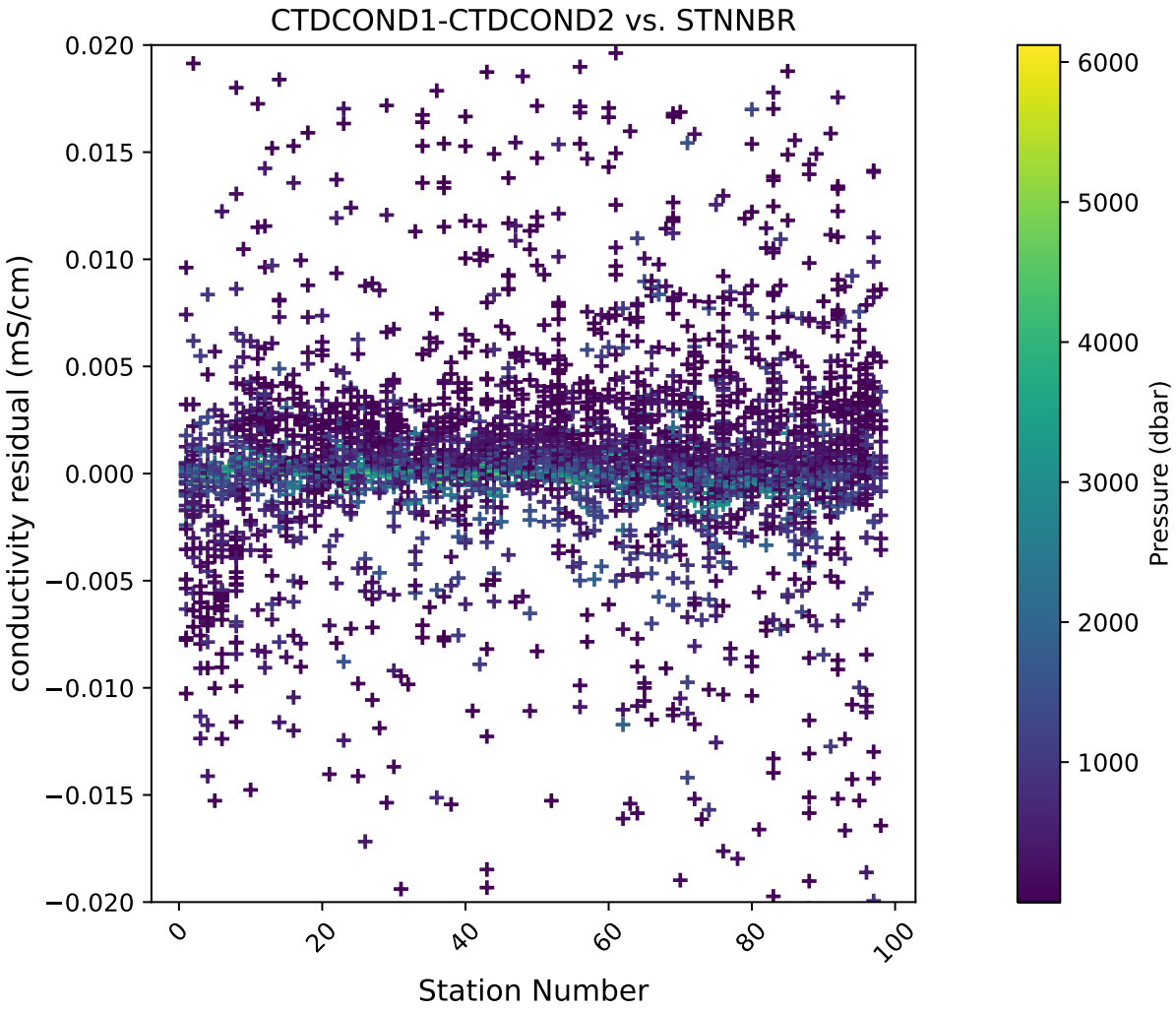


Fig. 4.16: Corrected C1-C2 versus station.

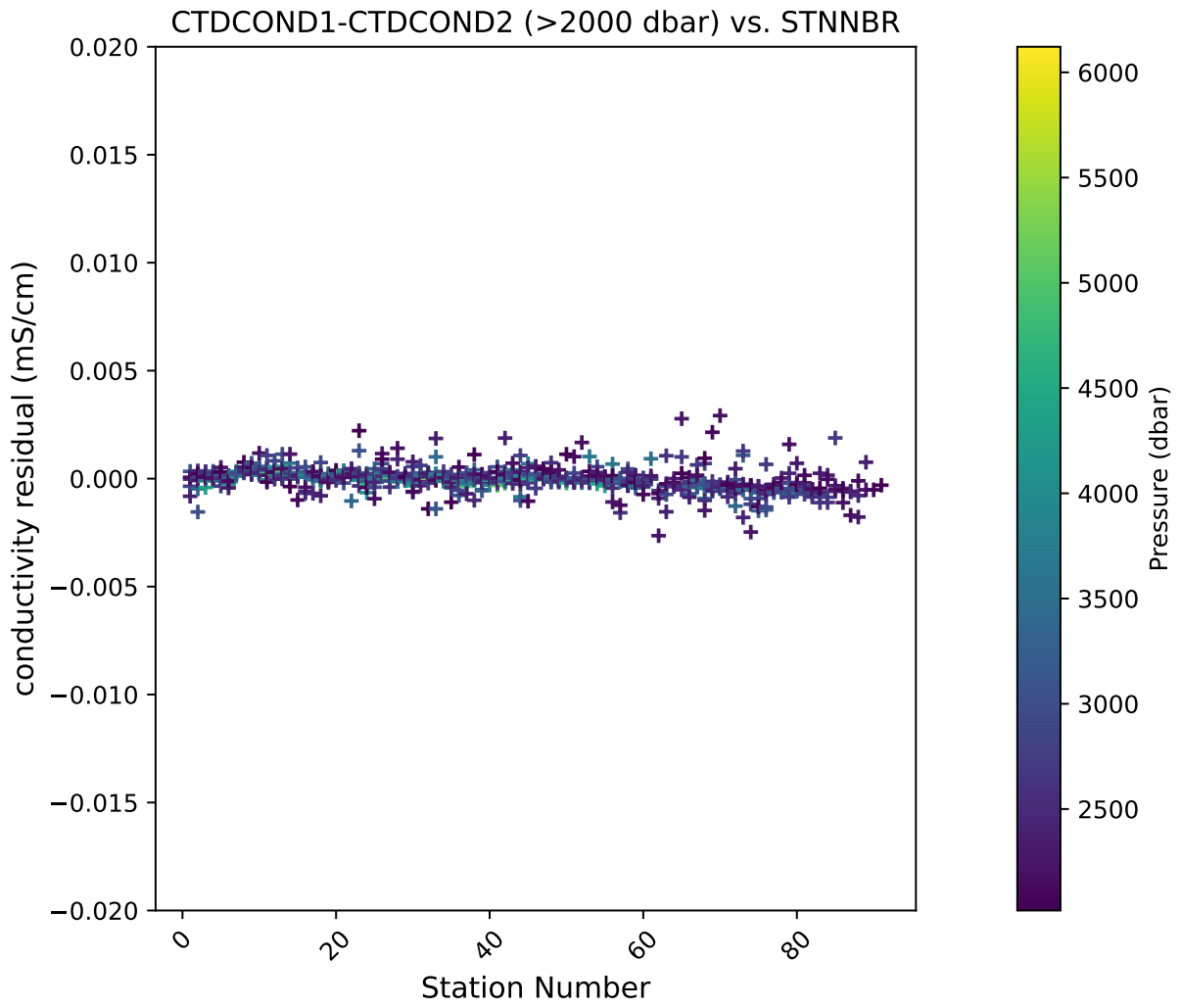


Fig. 4.17: Deep Corrected C1-C2 versus station (Pressure >= 2000dbar).

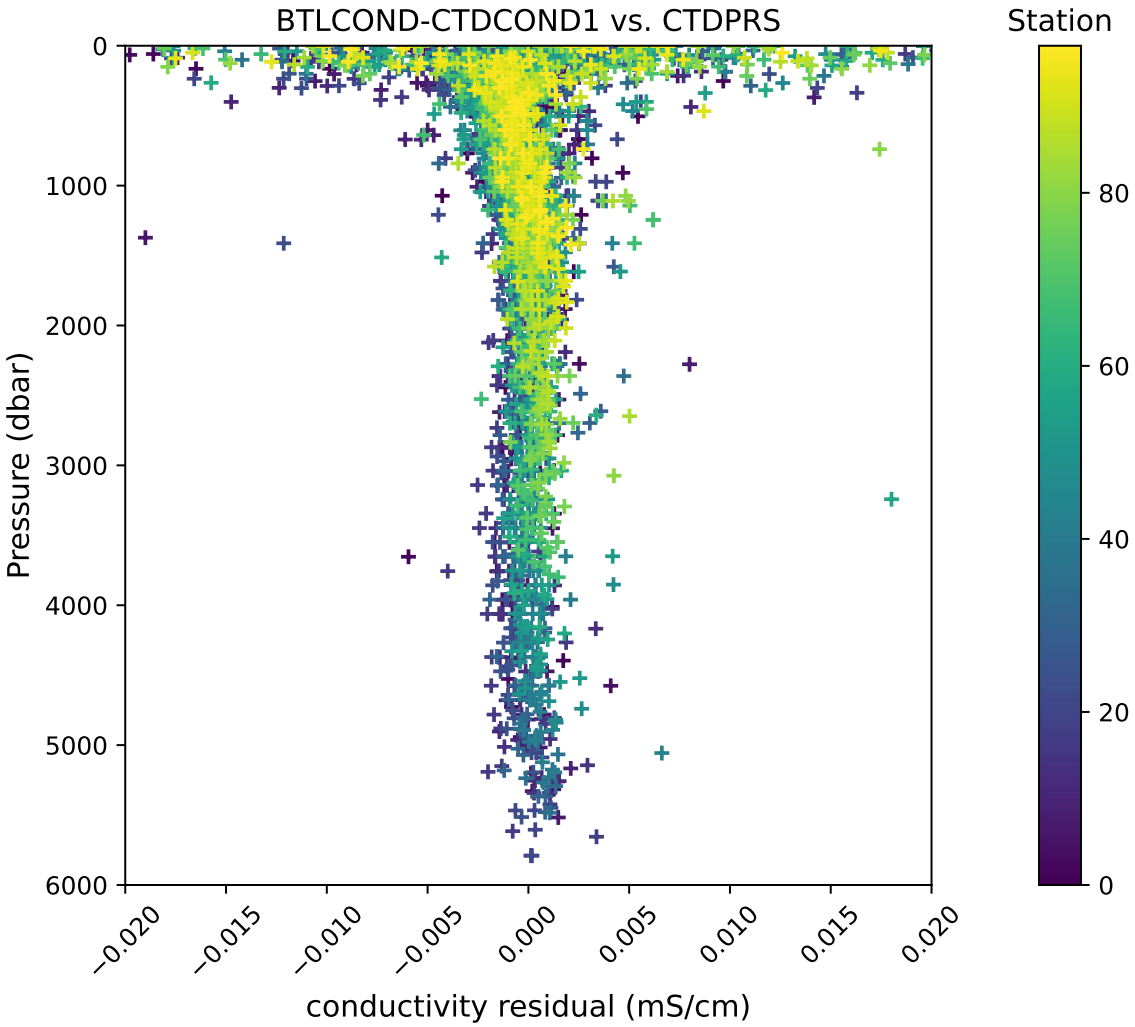


Fig. 4.18: Corrected C_{Bottle} - C1 versus pressure.

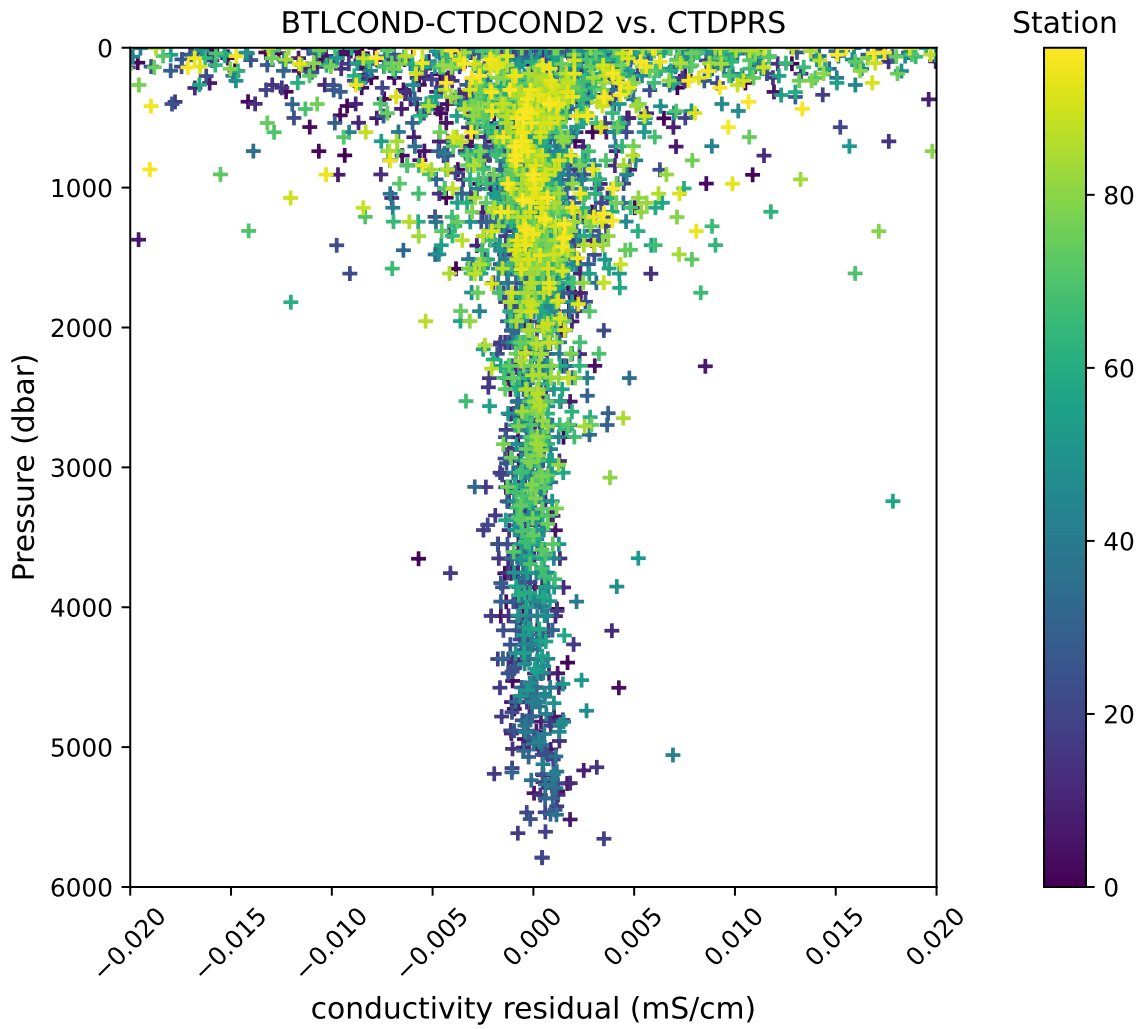


Fig. 4.19: Corrected C_{Bottle} - C2 versus pressure.

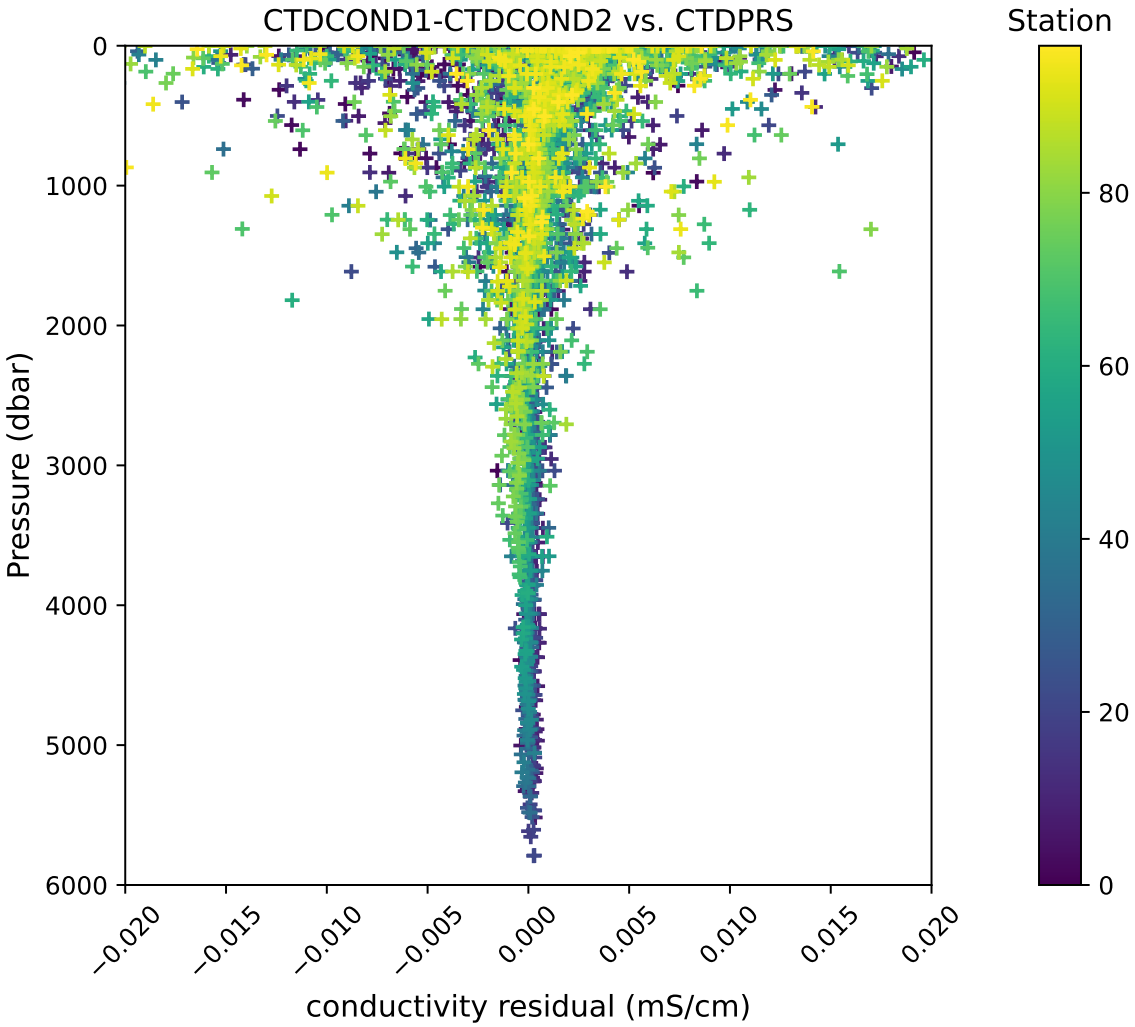


Fig. 4.20: Corrected C1-C2 versus pressure.

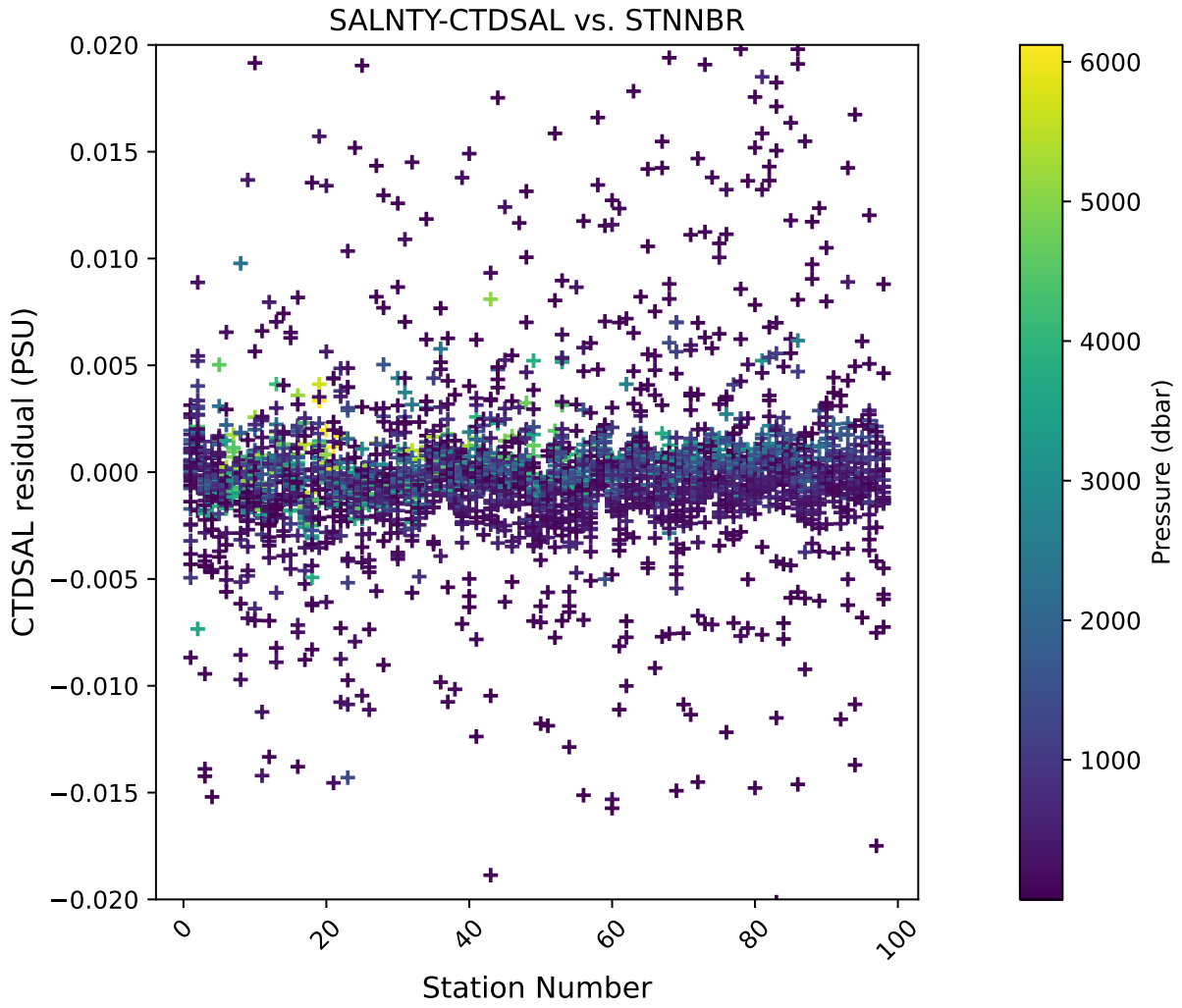


Fig. 4.21: Salinity residuals versus station.

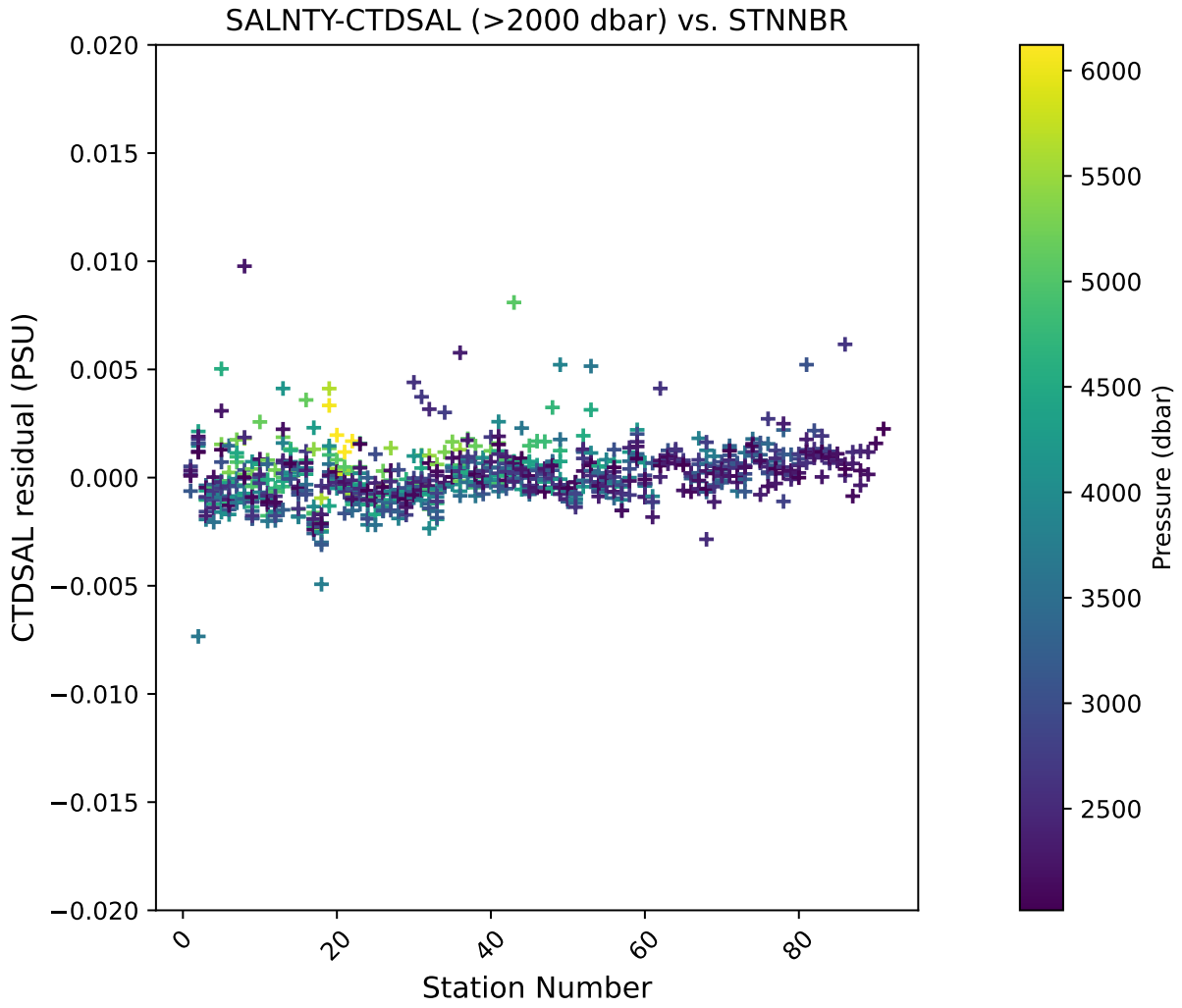


Fig. 4.22: Deep Salinity residuals versus station (Pressure >= 2000dbar).

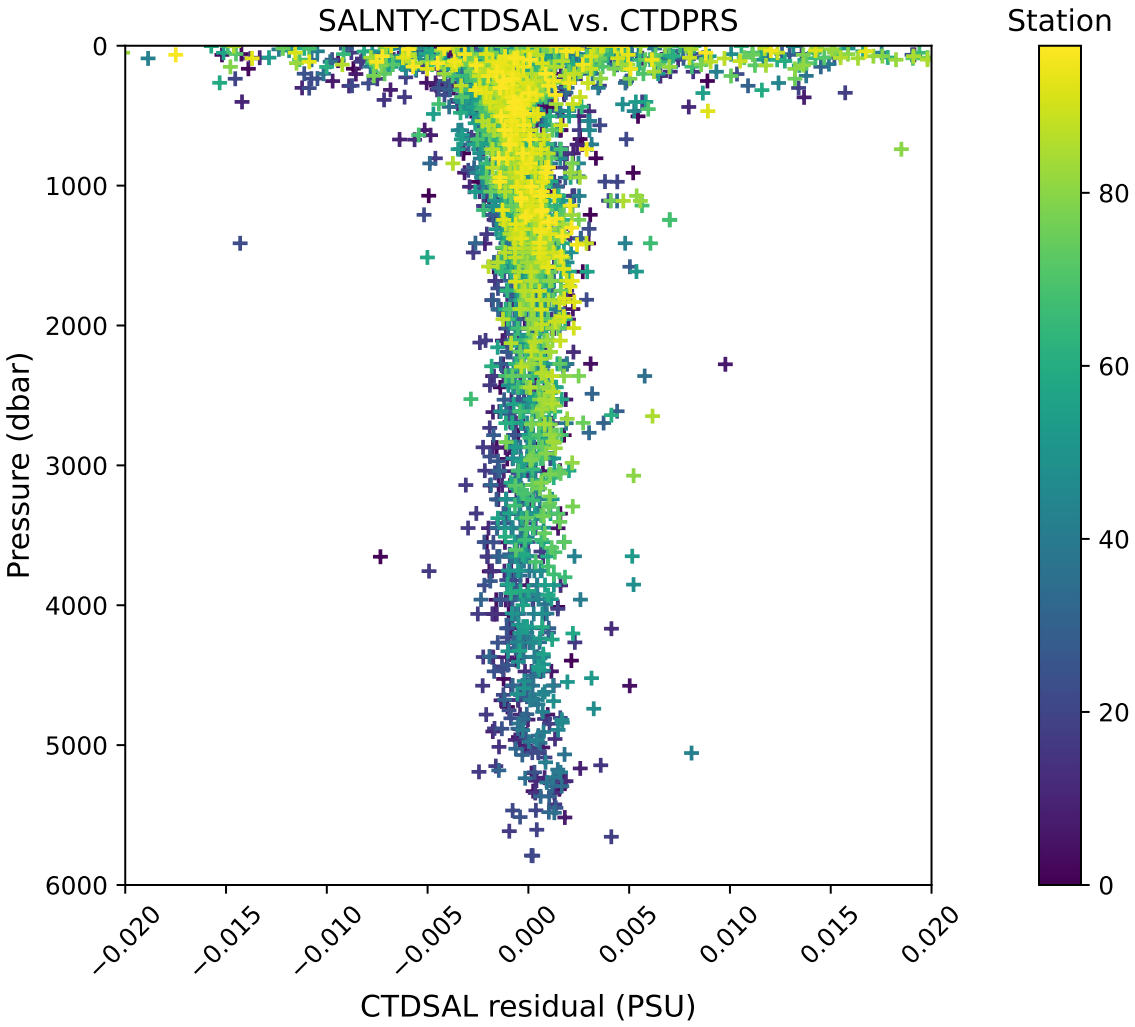


Fig. 4.23: Salinity residuals versus pressure.

Issues affecting SBE 4C salinity data were:

- The primary conductivity sensor 04-1744 failed during the pre-cast soak for 00801. The cast was immediately aborted and the sensor was replaced by sensor 04-2319. No other data were affected.

4.6 CTD Dissolved Oxygen (SBE43)

A Sea-Bird SBE 43 oxygen sensor installed on the CTD primary T-C channel provided one of two sources of dissolved oxygen data. Serial numbers 43-4355, 43-1136 and 43-1071 were used during the cruise. Performance issues are noted below.

Laboratory calibrations of the dissolved oxygen sensors were performed prior to the cruise at the SBE calibration facility. Dates of laboratory calibration are recorded in Table 3.1. Calibration documents are provided in the APPENDIX.

The pre-cruise laboratory calibration coefficients were used to convert SBE 43 frequency to µmol/kg oxygen values for acquisition only. Additional shipboard fitting was performed to correct for the sensor's non-linear response and for calibration drift over the course of the cruise. 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 SBE 43 sensor data were compared to dissolved oxygen bottle samples by matching the downcast CTD data to the upcast bottle stop locations along isopycnal surfaces. CTD dissolved oxygen was then calculated using Clark Cell MPOD oxygen sensor response model for Beckman/SensorMedics and SBE 43 dissolved oxygen sensors. The residual differences of bottle values versus CTD dissolved oxygen 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 Millard [Mill82] and Owens [Owen85]. Dissolved oxygen 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 individual cast's coefficients yielded worse residuals, they were reverted to the original group fit coefficients.

Table 4.6: SBE43 group fit coefficients. Coefficients were further refined station-by-station.

Station	S_{oc}	V_{off}	τ_{20}	T_{cor}	E
All	4.8434e-1	-5.1537e-1	1.9201e+0	-7.2898e-4	3.7639e-2

CTD dissolved O_2 residuals are shown in figures Fig. 4.24 through Fig. 4.26.

The 95% confidence limits of 1.16 (µmol/kg) for all acceptable (flag 2) dissolved oxygen bottle data values and 1.09 (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 titration measurements.

Issues affecting SBE 43 oxygen data were:

- Sensor 43-4355 became increasingly noisy with depth around cast 05401. It was replaced with sensor 43-1136 prior to cast 05601, which exhibited similar symptoms. Sensor 43-1071 was installed prior to cast 05801 and was used for the remainder of the cruise.

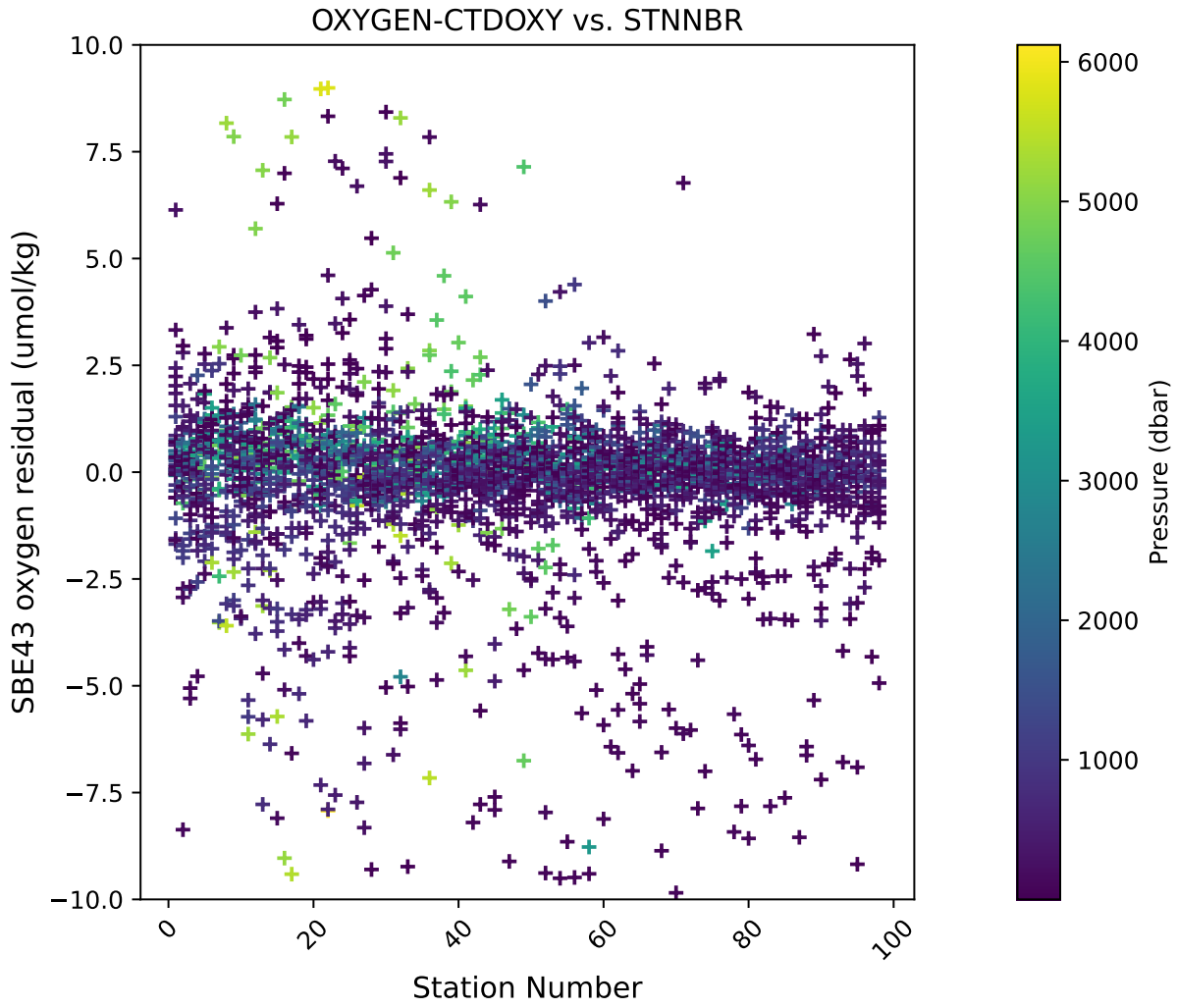


Fig. 4.24: CTD (SBE43) O_2 residuals versus station

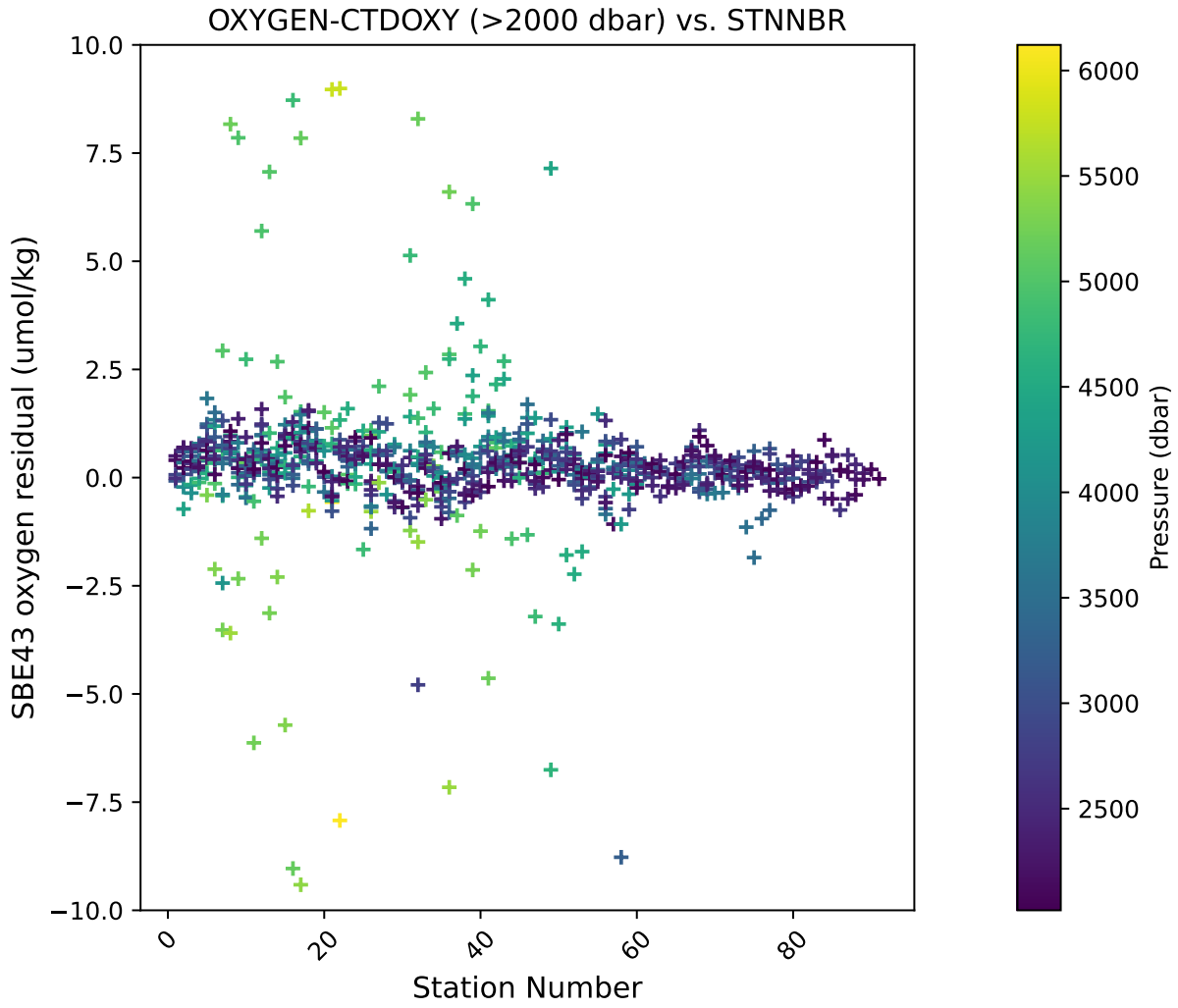


Fig. 4.25: CTD (SBE43) deep O_2 residuals versus station (Pressure >= 2000dbar)

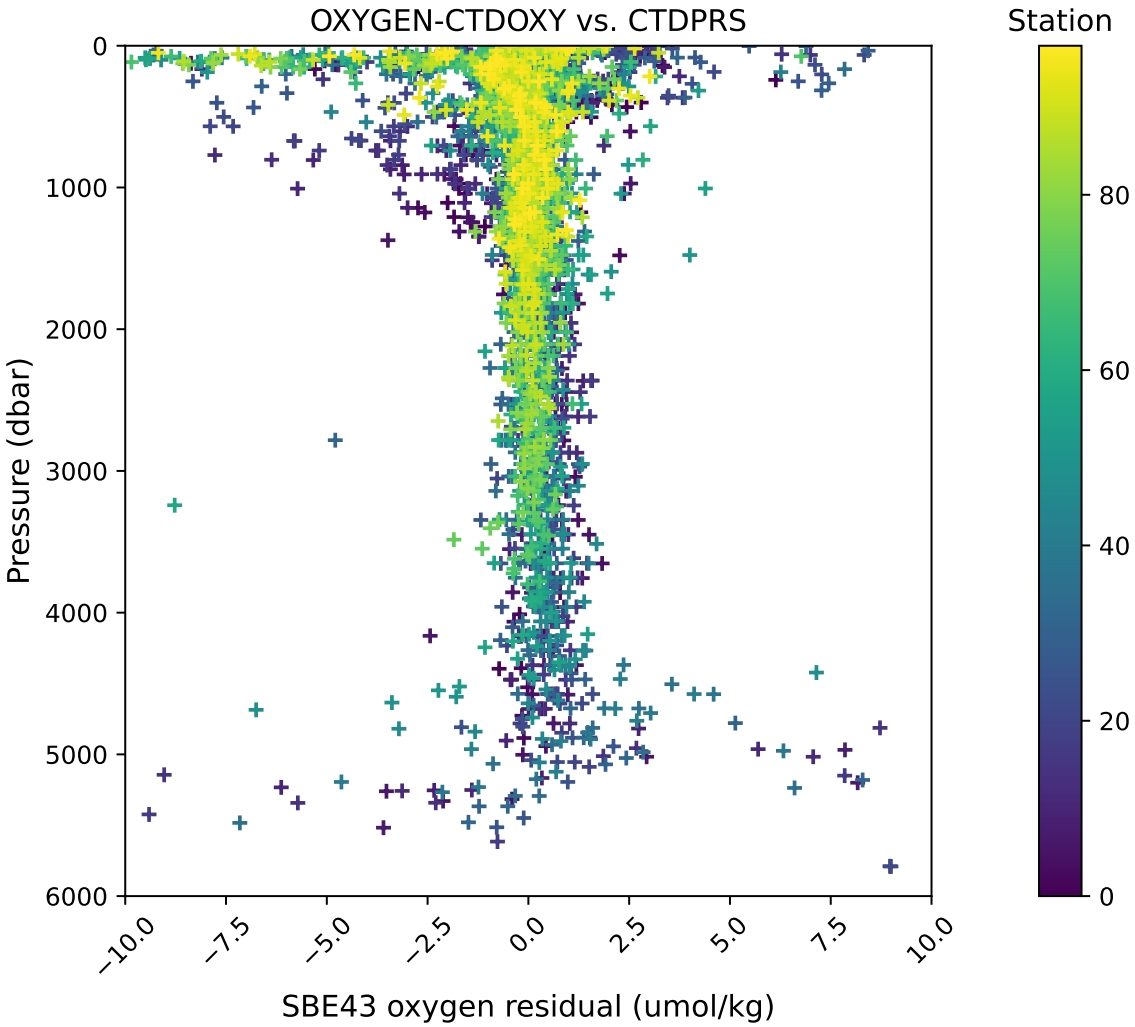


Fig. 4.26: CTD (SBE43) O_2 residuals versus pressure.

4.7 CTD Dissolved Oxygen (RINKO)

A JFE Advantech Co., LTD RINKO III (ARO-CAV) provided the second of two sources of dissolved oxygen data. Serial number 0479 was used for the duration of the cruise with no performance issues noted.

RINKO data are reported as primary CTD oxygen for all stations.

RINKO raw voltage data were acquired, converted to oxygen saturation, and then multiplied by the oxygen solubility to give 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 (°C)
- 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 were fit together to get an initial coefficient estimate. Station 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 residuals than the group, they were reverted to the original group fit coefficients.

Table 4.7: 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
1-7	1.1163e+0	4.9784e-3	-7.8398e-6	-6.6075e-3	-9.3903e-2	3.1071e-1	6.7441e-2
8-59	1.1043e+0	5.2558e-3	3.0062e-4	-2.3692e-3	-8.4537e-2	3.1824e-1	9.6997e-2
60-98	1.1815e+0	1.4274e-2	5.8961e-4	3.1956e-3	-1.2031e-1	3.3551e-1	1.1923e-1

CTD (Rinko) dissolved O_2 residuals are shown in figures Fig. 4.27 through Fig. 4.29.

The 95% confidence limits of 0.72 (µmol/kg) for all acceptable (flag 2) dissolved oxygen bottle data values and 0.40 (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 titration measurements.

No performance issues were noted with the RINKO III sensor.

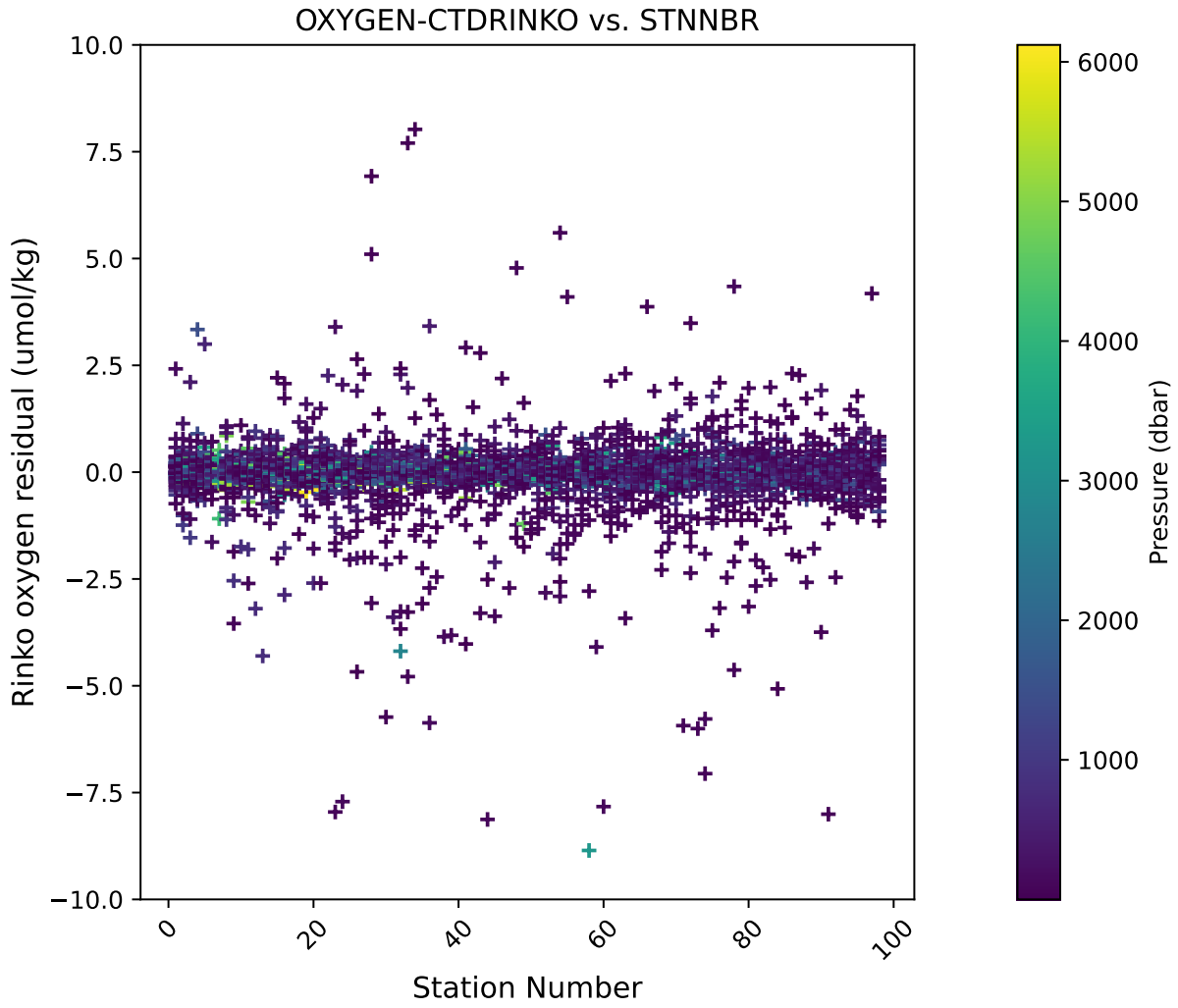


Fig. 4.27: CTD (Rinko) O_2 residuals versus station.

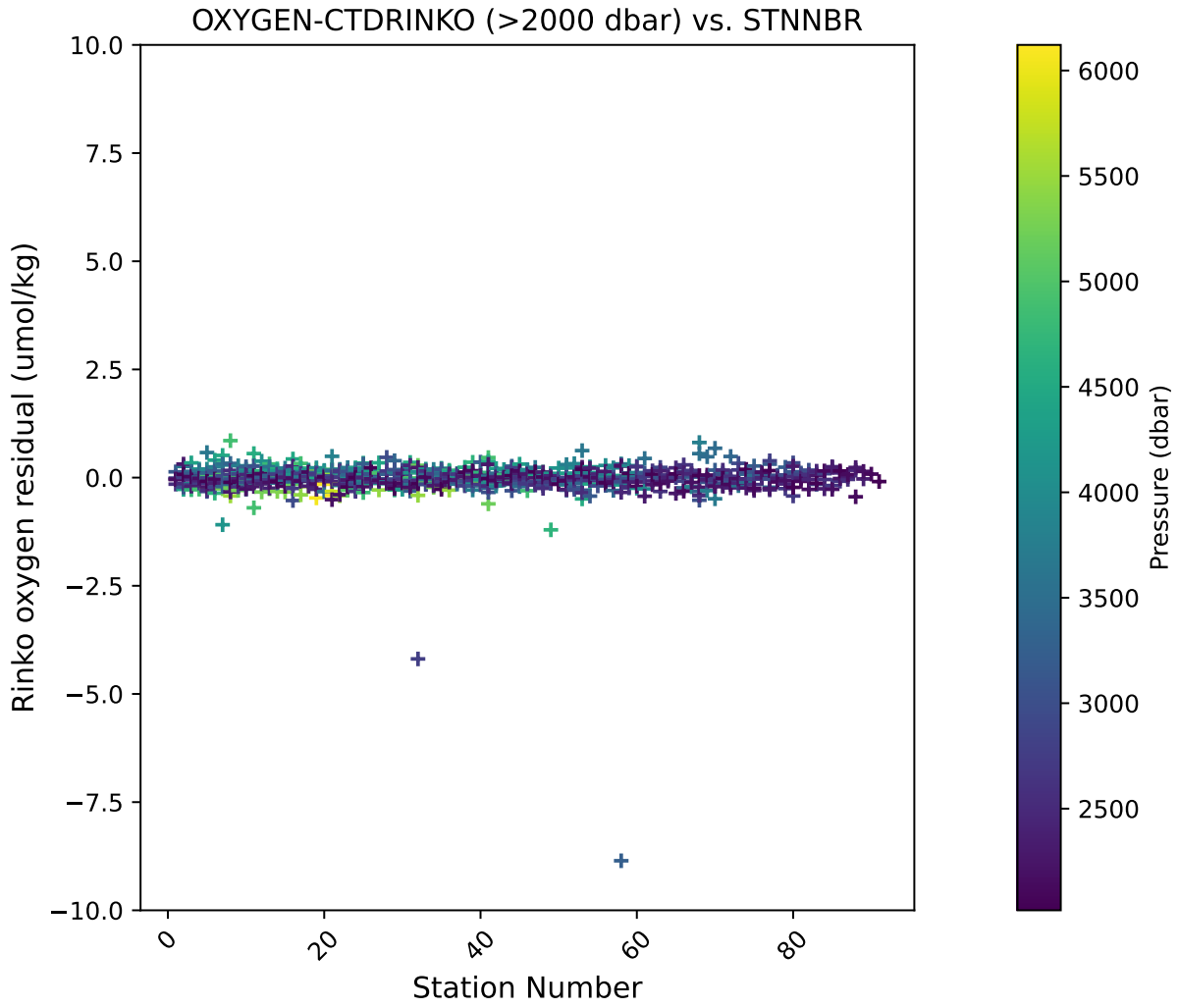


Fig. 4.28: CTD (Rinko) deep O_2 residuals versus station (Pressure >= 2000dbar).

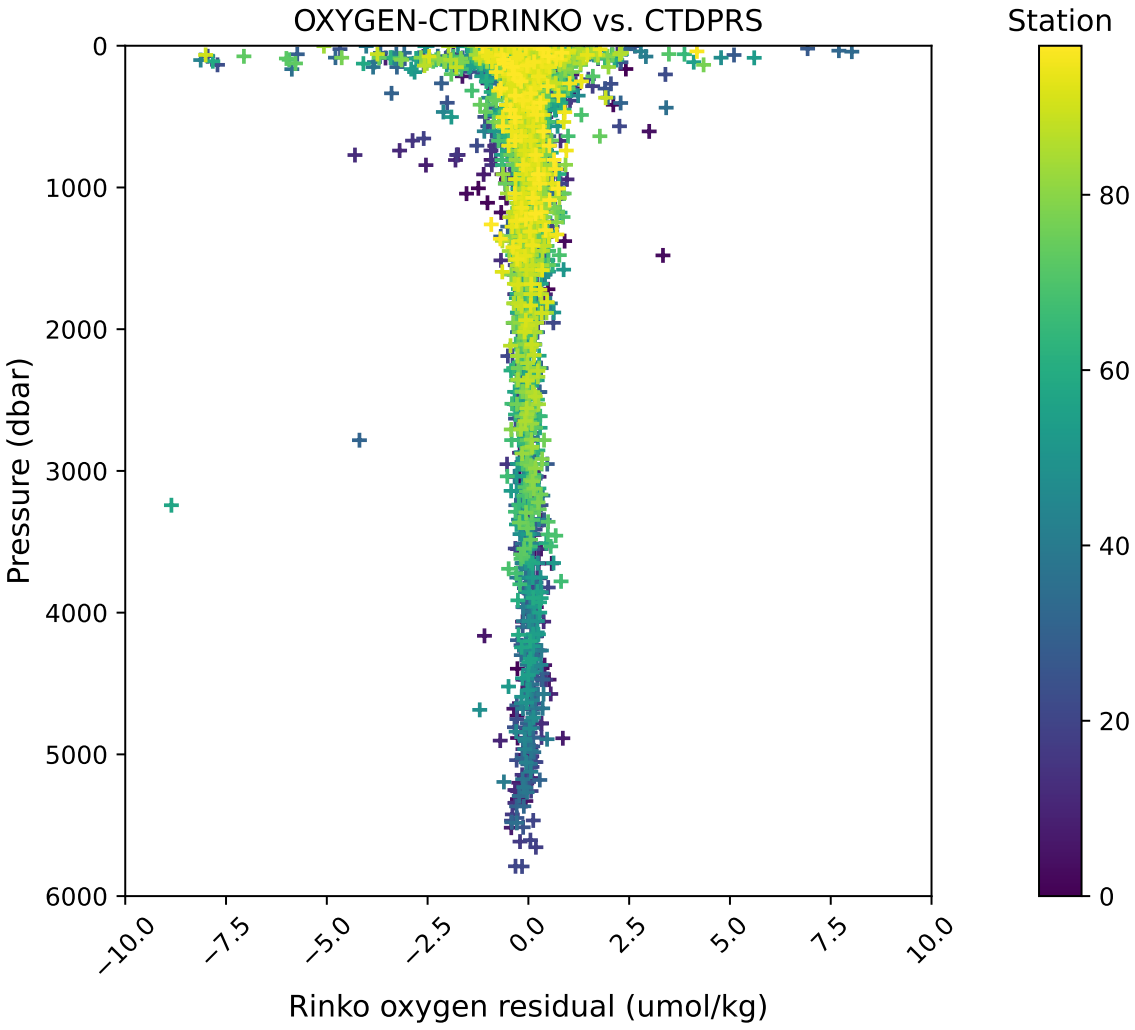


Fig. 4.29: CTD (Rinko) O_2 residuals versus pressure.

CHAPTER

FIVE

SALINITY

PIs

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

Technicians

- John Calderwood (SIO)
- Jessica McLaughlin (SIO)

5.1 Equipment and Techniques

Two Guildline Autosals were on board and operational, SIO-owned 8400B S/N 74309 and 8400B S/N 74307. S/N 74309 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 21.5 and 24.5 degrees Celsius around 3 times each hour, with an average (based on measuring temperatures of items in the chamber) of about 23.5°C. IAPSO Standard Seawater Batch P167 was used for all calibrations: K15 = 0.99988, Practical salinity = 34.995, expiration 2026-02-21.

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 a laboratory temperature of 24 °C, 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 (up to 2 casts, or 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.

5.2 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 were replaced to ensure 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 were then incorporated into the cruise database. During I09N, approximately 108 bottles of standard seawater were used for analysis.

5.3 Narrative

3,159 samples were analyzed, and seven sample bottles were broken over the course of the cruise. No major problems were encountered.

CHAPTER

SIX

OXYGEN ANALYSIS

PIs

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

Technicians

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

6.1 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.

6.2 Sampling and Data Processing

A total of 3,173 oxygen measurements were made, all 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 $MnCl_2$ 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.

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.

6.3 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.

6.4 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.

6.5 Narrative

The oxygen analytical rig was setup in the main lab of the R/V Thompson abeam of the aft air handler. Except for the single batch of thiosulfate, four batches of each reagent were made during mobilization in Fremantle. Additional batches were made as needed throughout the cruise.

When the ODF Oxygen standard was swapped the second time (third standard to be used), and unacceptable jump in thiosulfate normality was observed. A fourth standard was opened and used instead. This fourth standard resulted in a normality that was within our tolerances for day to day normality variation.

A few high end points occurred and were corrected for.

The thiosulfate stability was considered in 3 batches and showed stability throughout the entire cruise.

No trends were observed or corrected for.

No data updates are expected.

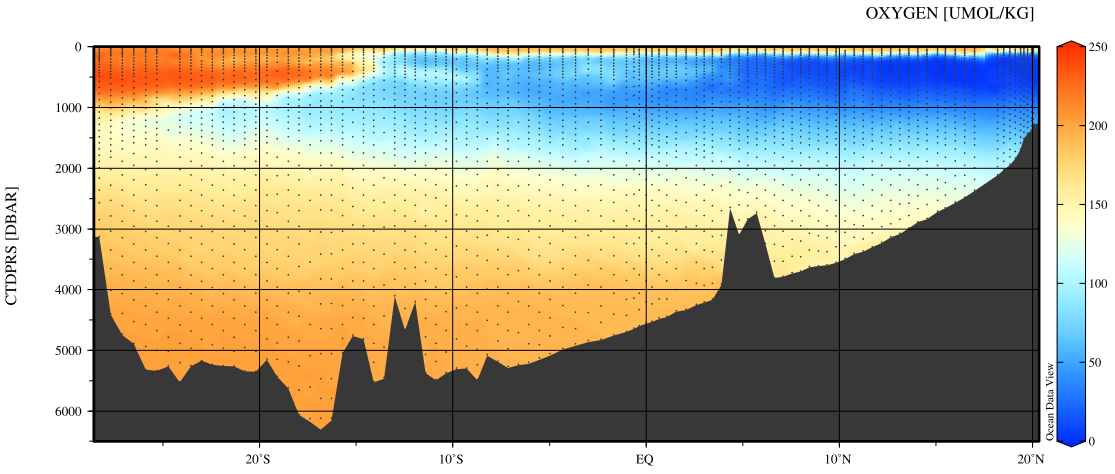


Fig. 6.1: Section plot of dissolved oxygen concentrations along I09N.

CHAPTER

SEVEN

NUTRIENTS

PIs

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

Technicians

- Megan Roadman (SIO)
- Vincent Johnson (SIO)

7.1 Summary of Analysis

- 3173 samples from 98 CTD stations
- The cruise started with new pump tubes and they were changed three times, before stations 34, 53 and 76.
- 4 sets of Primary/Secondary mixed standards and 2 sets of primary Nitrite standards were made up over the course of the cruise.
- The cadmium column efficiency was checked periodically and ranged between 95%-100%. Columns were changed when the efficiency fell below 95%. Seven columns were used for this cruise.

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 Brij, a surfactant. Store at room temperature in a dark poly bottle.

Note: 35% Brij - 35g 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). 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 10 mm flowcell and absorbance measured at 820 nm.

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 5% SDS 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 10 mm 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 5% 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 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 0.1 mg prior to the cruise. The exact weight was noted for future reference. When primary standards were made, the flask volume at 20 °C, 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). Two batches of LNSW was used on the cruise. One was collected on I08S and 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 LNSW was brought in multiple 5L bottles. The second batch was collected during the cruise, on station 45.

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

As is standard ODF practice, a deep calibration "check" sample was run with each set of samples to estimate precision within the cruise. The data are tabulated below.

Parameter	Concentration (µM)	stddev
NO_3	33.76	0.17
PO_4	2.33	0.01
SIL	114.3	0.56

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 2 runs before being discarded and a new one opened. The RMNS was analyze both before and after the samples. Data are tabulated below.

Parameter	Concentration	stddev	assigned conc
-	(µmol/kg)	-	(µmol/kg)
NO_3	33.16	0.15	33.2
PO_4	2.38	0.03	2.38
SIL	100.9	0.4	100.5
NO_2	0.029	0.009	0.02

7.10 Analytical Problems

Occasional baseline drift and jumps for the nitrite and phosphate channels and were closely monitored throughout cruise. The values of the reference material and were used to monitor data quality. Adjustments based on the values obtained for the reference material were made as necessary, using the RMNS values from the end of each run.

CHAPTER

EIGHT

DISSOLVED INORGANIC CARBON (DIC)

PIs

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

Technicians

- Abigail Tinari (UW-CICOES)
- Chuck Featherstone (NOAA-AOML)

8.1 Introduction

The discrete dissolved inorganic carbon and underway fCO_2 measurements on the I09N cruise (March 21st – April 27th, 2025) were conducted by Abigail Tinari of the Pacific Marine Environmental Laboratory (UW/CICOES) and Chuck Featherstone of the Atlantic Oceanographic and Meteorological Laboratory (NOAA/AOML). The PMEL Carbon Group's Dissolved Inorganic Carbon (DIC) mobile container-based laboratory slated for deployment on this cruise was delayed in Singapore during transit between Seattle, WA, USA and Perth, WA, AU. To ensure DIC samples could be collected, carbon chemistry laboratories at PMEL and SIO air shipped 2,100 backup sample bottles directly to the vessel in port in Fremantle, WA, AU. The back up plan, if the container-based laboratory did not arrive, was to collect samples and bring them back to PMEL to analyze after the cruise. The van was expected to arrive in Fremantle, WA, AU three days after the initial cruise departure. A decision was made by GO-SHIP leadership to delay the cruise and wait for the DIC van to arrive in Fremantle. The van arrived on March 20th and the ship departed the following day.

8.2 Sample collection

Samples for DIC measurements were drawn according to procedures outlined in the PICES Publication, Guide to Best Practices for Ocean CO_2 Measurements [Dickson07], from Niskin bottles into 310 ml borosilicate glass bottles using silicone tubing. The flasks were rinsed three times and filled from the bottom with care not to entrain any bubbles, overflowing by one half- to one full-volume. The sample tube was pinched off and withdrawn, creating a ~6 ml headspace, followed by the addition of 0.12 ml of saturated $HgCl_2$ solution as a preservative. The sample bottles were then sealed with glass stoppers lightly coated with Apiezon-L grease and were stored at room temperature for a maximum of 12-24 hours until analysis. DIC samples were collected from a variety of depths with approximately 10% of these samples collected as duplicates.

8.3 Equipment

The dissolved inorganic carbon analyses was conducted 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 (Johnson et al. [Johnson85], [Johnson87], [Johnson93], and [Johnson99]; Johnson [Johnson92]). The two DICE systems were set up within the seagoing container modified for the use as a shipboard laboratory on the aft main working deck of the R/V Thomas G. Thompson.

8.4 DIC Analysis

In coulometric analysis of DIC, all carbonate species are converted to CO_2 (gas) by addition of excess hydrogen ion (acid) to the seawater sample, and the evolved CO_2 gas is carried into the titration cell of the coulometer with CO_2 free pure 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 coulometrical 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 transmitted through the solution, and a photometric detector at the opposite side of the cell measures the change in light transmission. Once the percent transmission reaches its original value, the coulometric titration is stopped, and the amount of CO_2 that entered the cell is determined by integrating the total change during the titration.

8.5 DIC Calculation

The amount of CO_2 injected was calculated according to the CO_2 handbook [DOE94]. The concentration of CO_2 ($[CO_2]$) in the samples was determined according to:

$$[CO_2] = \text{Cal. Factor} * (\text{Counts} - \text{Blank} * \text{Run Time}) * \frac{\text{K µmol/count}}{\text{pipette volume} * \text{density of sample}}$$

where Cal. Factor is the calibration factor, Counts is the instrument reading at the end of the analysis, Blank is the counts/minute determined from blank runs performed at least once for each cell solution, Run Time is the length of coulometric titration (in minutes), and K is the conversion factor from counts to micromoles.

All DIC values were recalculated to a molar weight (µmol/kg) using density derived from the CTD's salinity sensor. The DIC values were corrected for dilution due to 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 CRM. This additive correction was applied for each cell using the CRM value obtained at the beginning of the cell. The coulometer cell solution was replaced after 25 – 28 mg of carbon was titrated, typically after 9 – 12 hours of continuous use.

8.6 Calibration, Accuracy and Precision

The stability of each coulometer cell solution was confirmed three different ways: Gas loops were run at the beginning of each cell, CRMs supplied by Dr. A. Dickson of SIO, were analyzed at the beginning of the cell before sample analysis, and duplicate samples from the same Niskin, were measured near the beginning, middle and end of each cell.

Each coulometer was calibrated by injecting aliquots of pure CO_2 (99.999%), as a standard, by means of an 8-port valve (Wilke et al., [Wilke93]) 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.

The accuracy of the DICE measurement is evaluated with the use of 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 the certified value (DIC = 2029.30 µmol/kg) for the batch used (219). The summary table below 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 had analytical replicates 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 was 1.2 µmol/kg; no systematic differences between the replicates were observed.

8.7 Summary

The overall performance of the analytical equipment during I09N 2025 was good. A few minor equipment issues were encountered, but nothing that compromised the quality of the data. While in transit to the port, the door to the van had shifted and would not close. The *Thompson*'s engineers repaired the problem at the beginning of the cruise. Throughout the cruise there was higher than usual background noise (i.e. blanks) when the cells initially started. After running a few samples the increments (counts between minutes of the titration) would lower and the noise seemed to settle out. This occurred more often on the day shift (noon to midnight local time) than on the night shift (midnight to noon). When removing the ship's air line there was water that came out. This may have caused the air to become compromised and may be why the background noise was so high.

Including the duplicates, 3102 samples were analyzed for dissolved inorganic carbon during this I09N cruise. Assuming that ~15% of total niskins tripped during this cruise were used for biological analysis, DIC was analyzed for approximately 84.4% of niskins made available to us. The DIC data reported to the database directly from the ship are considered preliminary until a more thorough quality assurance can be completed shore side.

SYSTEM	Average Gas Loop Cal Factor	Pipette Volume	Duplicate
PMEL1	1.00741	27.603	1.05
PMEL2	1.00448	26.403	1.34

CRM Info	PMEL1	•	•	PMEL2	•	•
Batch-Cert	Average	N	Std. Dev	Average	N	Std. Dev
219–2029.30	2029.71	60	2.82	2026.97	70	2.5

CHAPTER

NINE

TOTAL ALKALINITY

PIs

- Andrew G. Dickson (SIO)

Technicians

- Daniela Nestory (SIO)
- Marshal Thrasher (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 (Dickson, 2007).

A Thermo Scientific Isotemp water bath is connected to the water-jacketed open cell to maintain a cell temperature of approximately 20 °C. 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 bottle 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 0.12 mL of 50% 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 where a core cast was completed.

Alkalinity samples were collected from each niskin where DIC and pH were collected, to completely characterize the CO_2 system. The typical sample scheme was as follows: Alternated between a full collection (36 niskins) and a half collection (24 bottles).

To evaluate the reproducibility of the alkalinity system, 2 duplicate samples (two separate alkalinity bottles) were collected on each cast.

9.4 Problems and Troubleshooting

We experienced electrical issues between stations 7 and 8 where either dirty power from the ship lines or an external EMF force was preventing the electrode from accurately recording voltages. Stations 10 and 11 were collected and stored in 500 mL borosilicate bottles and sealed with grease and rubber bands while we attempted to troubleshoot the issue. After ~24 hours, the problem seemed to have resolved itself, as voltage readings and CRMs returned to normal.

Further, the certified hydrochloric acid concentration of Batch A29 (obtained from Dickson CO2 Standards Lab) was not analyzed before use so we used average CRM values to estimate the value. Between stations 1 and 6 we used an HCl concentration of 1.00020 µmol kg^{-1}; however, this proved to be too high and was subsequently changed to 0.0999333 µmol kg^{-1} for the remaining stations.

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 219 and 220 were used to determine the accuracy of the total alkalinity analyses.

The total alkalinity certified values for these batches are:

- Batch 219: 2183.64 $\pm$ 0.80 µmol/kg (36; 18)
- Batch 220: 2148.32 $\pm$ 0.78 µmol/kg (12; 6)

*Preliminary value

The cited uncertainties represent the standard deviation. Figures in parentheses are the number of analyses made (total number of analyses; number of separate bottles analyzed).

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. The reported values include materials ran alongside stations 6–98 due to changes in the hydrochloric acid concentration (detailed above).

242 reference material samples were analyzed during I09N.

The average measured total alkalinity value for each batch is:

- Batch 219: 2182.40 $\pm$ 1.30 µmol/kg (134; 74)
- Batch 220: 2147.00 $\pm$ 1.50 µmol/kg (72; 46)

Duplicate samples were also used to check the reproducibility of the system. The pooled standard deviation of duplicate samples is given below.

Duplicate precision: $\pm$ 1.07 µmol kg-1 (n = 187 pairs)

2785 total alkalinity values were submitted for I09N.

These data are to be considered preliminary.

CHAPTER

TEN

DISCRETE PH ANALYSES (TOTAL SCALE)

PI

- Dr. Andrew Dickson (SIO)

Technicians

- Daniela Nestory (SIO)
- Cora McKean (SIO)
- Anna Terrenzi (SIO)

10.1 Analysis

pHT 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 725-735 nm. 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.

10.2 Reagents

The mCP indicator dye was made up to a concentration of approximately 2.0 mM and a total ionic strength of 0.7 M. A total of two dye batches were used during I09N. The pHT of these batches was 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].

10.3 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:

$R = (A_{578} - A_{base})/(A_{434} - A_{base})$

and

$R = A_{488} - A_{base}$

The change in R for a given change in A_{iso}, $\Delta R/(\Delta A)_{iso}$, 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:

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

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

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

10.4 Sample Collection

Samples were collected in 250 mL Pyrex glass bottles and sealed using 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 0.11 mL of 50% saturated mercuric chloride solution was added to each sample for preservation. Samples were collected only from niskin bottles that were also being sampled for both total alkalinity and dissolved inorganic carbon to completely characterize the carbon system. Additionally, duplicate samples were collected from all stations for quality control purposes.

The typical sample scheme was as follows: Alternation between a full collection (36 niskins) and a half collection (24 bottles).

10.5 Problems and Troubleshooting

We did not experience any major issues with the pH system during this cruise.

10.6 Standardization/Results

The precision of the data was assessed from measurements of duplicate analyses and certified reference material (CRM) Batch 207 (provided by Dr. Andrew Dickson, UCSD).

To evaluate the reproducibility of the pH system, two duplicate samples (two samples from one niskin bottle) were collected on each cast.

CRMs were measured at the beginning and ending of each day.

The precision statistics for I09N are:

Duplicate precision $\pm$ 0.0008 (n = 193 pairs) CRM Batch 220 7.7921 $\pm$ 0.0011 (n = 63)

2790 pH values were submitted for I09N.

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

CFC-11, CFC-12, SF_6, AND N_2O

PIs

- Jim Happell (University of Miami)
- Rana Fine (University of Miami)

Technicians

- Jim Happell (lead analyst, University of Miami)
- Alexis Wysocki (2nd analyst, University of Miami)
- Mary Kate Dinneen (Tracer Student, USC)

11.1 Sample Collection

All water samples were collected from the 10.4 liter Niskin bottles on the ODF rosette. A water sample was collected from the Niskin bottle petcock using silcone tubing to fill a 300 ml BOD bottle. The tubing was flushed of air bubbles. The BOD bottle was placed into a plastic overflow container. Water was allowed to fill BOD bottle from the bottom into the overflow container. The stopper was held in the overflow container to be rinsed. Once water started to flow out of the overflow container the overflow container/BOD bottle was moved down so the tubing came out and the bottle was stoppered under water while still in the overflow container. Air samples, pumped into the system using an Air Cadet pump from a polyethylene air intake hose mounted high on the foremast were also run. Air measurements are used as a check on accuracy.

11.2 Equipment and Technique

CFC-11, CFC-12, SF_6, and N_2O were measured on 97 out of 98 stations for a total of 2619 discrete sample depths. Analyses were performed on a custom-built purge and trap gas chromatograph (GC) equipped with an electron capture detector (ECD). This system had recently been rebuilt, with a new gas chromatograph, new values actuators, and new instrument control and data acquisition software. Modifications were also made to measure N_2O, along with the other three parameters. The samples were stored at room temperature and analyzed within 12 hours of collection. Every 18 to 24 samples were followed by a blank and a standard. A subset of samples were held after measurement and was sent through the process again in order to "restrip" it to determine the efficiency of the purging process.

11.3 Calibration

A gas phase standards, 426505, was used for calibration. The concentrations of the compounds in this standard are reported on the SIO 2005 absolute calibration scale. Calibration curves were run over the course of the cruise. Estimated accuracy is +/- 2%. Precision for CFC-12, CFC-11, SF_6 and N_2O was less than 2% based on 47 replicate measurements. Estimated limit of detection is 1 fmol/kg for CFC-11, 3 fmol/kg for CFC-12 and 0.05 fmol/kg for SF_6.

CHAPTER

TWELVE

LOWERED ACOUSTIC DOPPLER CURRENT PROFILER (LADCP)

PI:

- Andreas Thurnherr (LDEO)

Cruise Participant:

- Ilmar Leimann (University of Bremen)

Lowered Acoustic Doppler Current Profiler (LADCP) data were collected on all stations (001/01–098/01). For all profiles a dual head system was used consisting of a downlooker and an uplooker. All profiles were sent daily to A. Thurnherr for shore-based processing and QC. Preliminary processing for horizontal velocity was also performed onboard using the LDEO_XI_0 (Beta) software (https://www.ldeo.columbia.edu/~ant/LADCP/).

Four different 300 kHz TRDI Workhorse Monitor ADCPs were used during this cruise: WH units #22656 and #24497, and WH2 units #27076 and #27077. The corresponding configurations used during the cruise are shown in Table 12.1. In all configurations, the downlooker (DL) was used as the primary (master) instrument.

Table 12.1: Configurations of ADCPs during I09N

Station/Cast	WH/WH2 S/N
00101 - 02101	#27076 - DL, #24497 - UL
02201 - 04301	#27076 - DL, #22656 - UL
04302 - 04401	#27076 - DL, #27077 - UL
04501 - 06901	#22656 - DL, #27077 - UL
06902 - 07001	#22656 - DL, #27076 - UL
07101 - 09801	#22656 - DL, #27077 - UL

The 2025 occupation of I09N is the first US GO-SHIP cruise where TRDI Workhorse 2 (WH2) ADCPs were used. Lab-testing prior to the cruise revealed communications problems when two WH2 instruments are connected using a star cable—on wakeup, the break sent to the second instrument would freeze the first. Additionally, both WH2 units exhibited long and inconsistent delays, sometimes exceeding one minute, after erasing data from the internal memory cards. As a result, most LADCP profiles on this cruise were collected using a WH/WH2 combination. While diagnosing instrument issues, two profiles (04302 and 04401) were taken using a dual WH2 setup. A new script (LADCPstart_sequential) was introduced into the acquire software to enable sequential programming of the two WH2s without needing to connect both at the same time. Another issue identified with the WH2s is that their data files differ somewhat in format from older TRDI ADCPs. Onboard processing software for both horizontal and vertical velocity was updated during the cruise to handle these differences.

The data from station 07201 is missing due to human error. After station 02101, the UL was changed because the data quality of the previous UL was poor. One of the old WH ADCPs was found to return valid but low-quality data, which was the reason for the change after station 02101 (#24497). At station 04301, the UL generated multiple raw files, so it was replaced. However, the same issue reoccurred at station 04401, leading to a change in the DL instead. For testing purposes, the UL was changed again for stations 06902 to 07001. When the problem with the UL reoccurred,

the previous configuration of DL and UL was reinstated. Additionally, one of the new WH2 ADCPs was discovered to have a problem that causes data anomalies about half an hour into a profile (#27076).

The standard US GO-SHIP ADCP setup was used for all profiles; this setup uses 8 m pulse and bin lengths, as well as a zero blanking distance, which requires the data from the first bin to be discarded.

After station 06101, the battery (SeaBattery Power Module) was changed. Although the previous battery (S/N 01223) was performing well, oil was observed on the deck and in the water after recovering the CTD on several stations, suggesting a possible slow leak. It was therefore replaced with another battery (S/N 01009).

Additionally, the Independent Measurement Package (IMP) was used until it became flooded during station 05101 (see Table 12.2). The IMP is a small, standalone device that enhances the accuracy of velocity measurements from Lowered Acoustic Doppler Current Profilers (LADCPs) by providing precise external readings of heading, pitch, and roll. Field tests have shown that incorporating IMP data can reduce discrepancies between LADCP and shipboard ADCP (SADCP) measurements by 10–20%, resulting in more reliable ocean current observations (Thurnherr et al., 2017 [Thurnherr2017]).

Table 12.2: IMP profile groups with the same relative instrument orientation and according recording mode

Station/Cast	Recording mode
00101 - 01401	sync pulses
01501 - 03401	sync pulses
03501 - 04001	sync pulses
04801 - 05001	independent/autonomously

Fig. 12.1 and Fig. 12.2, show the preliminary results of the zonal and meridional velocity components from the LADCP. These are presented for both the upper ocean (down to 1000 m) and the full water column along the I09N section.

The figures clearly show strong horizontal velocities in the zonal Equatorial Undercurrent region near the Equator. Additionally, in the upper 150 meters, a distinct pattern in zonal velocities is visible from 10° S to 4° S, corresponding to the locations of the Eastern Gyral Current, the South Equatorial Current, and the South Equatorial Countercurrent (Phillips et al., 2021 [Phillips2021]). Along the Equator, a narrow, jet-like current flows eastward at high speed at a depth of around 150 meters. This is known as the Wyrtki Jet (Wyrtki, 1973 [Wyrtki1973]), which develops during both transition periods between the monsoons.

Post-cruise processing and additional QC will be conducted at LDEO. At that point it will be determined which profiles are of sufficient quality for inclusion in the final CLIVAR ADCP archives.

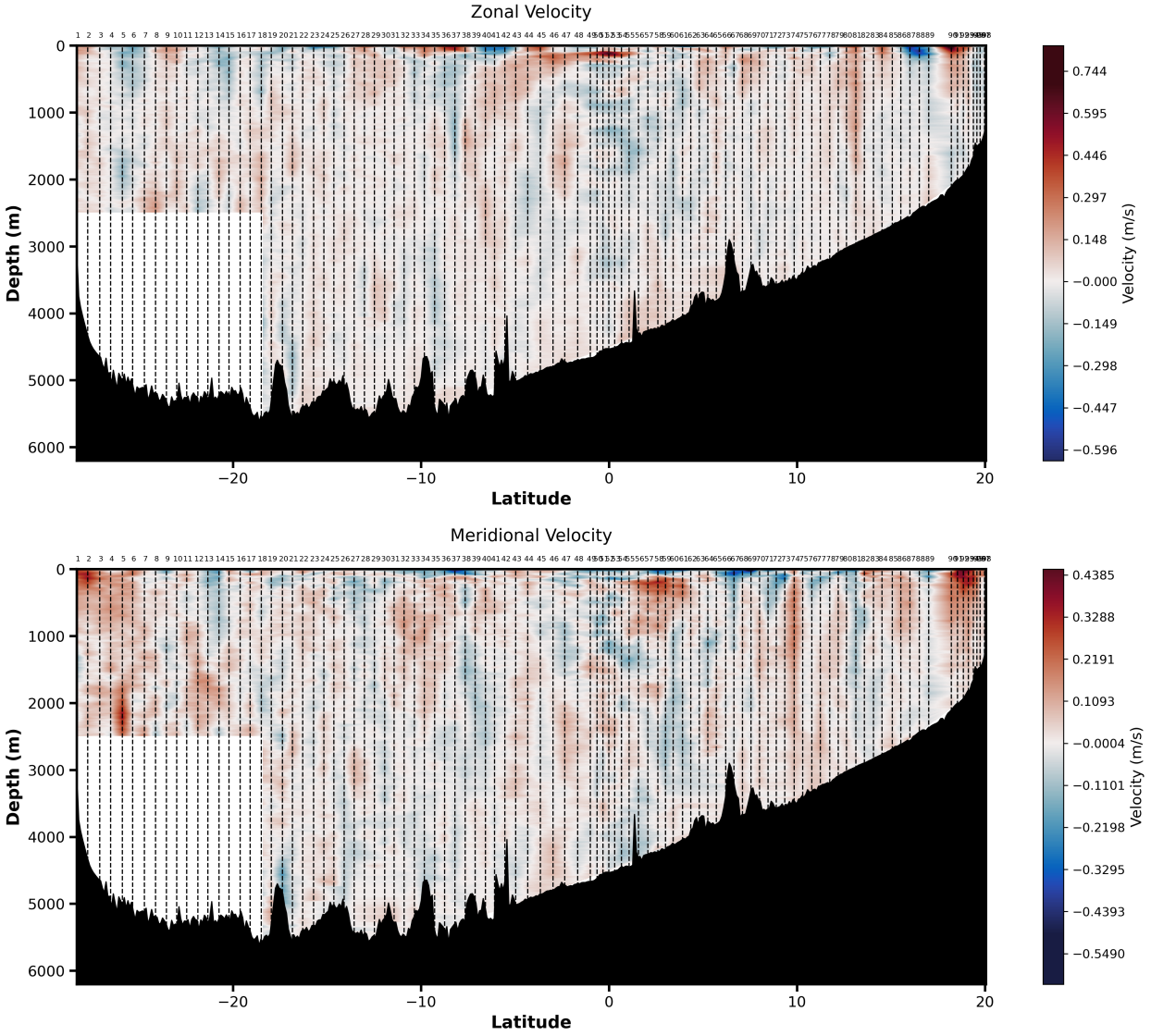


Fig. 12.1: Preliminary zonal (upper panel) and meridional (lower panel) velocities from the LADCP. The blanked-out regions indicate areas with insufficient acoustic backscatter. Vertical dashed lines mark station locations, and the filled black area represents topography.

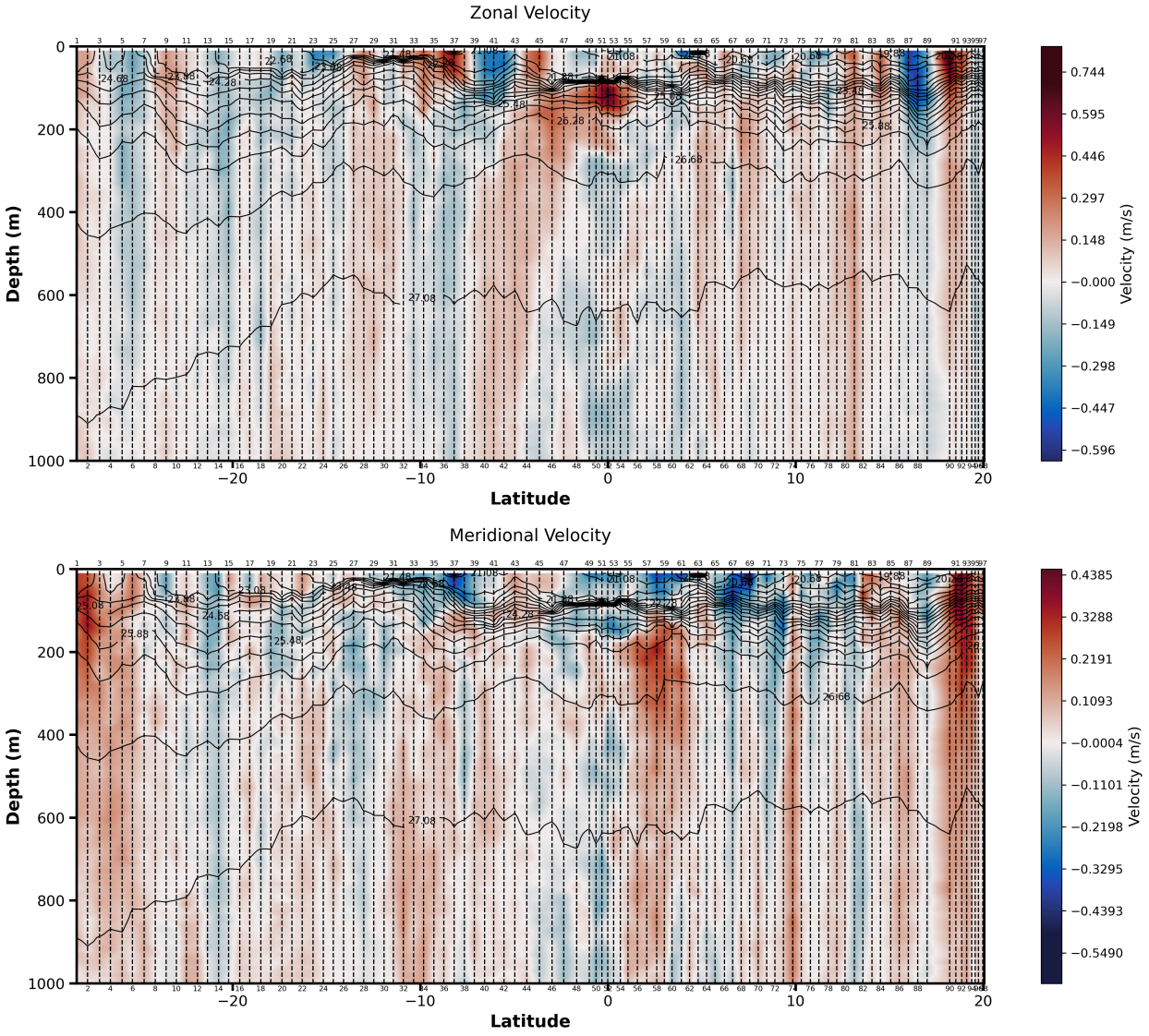


Fig. 12.2: Preliminary zonal (upper panel) and meridional (lower panel) velocities in the upper 1000 m from the LADCP. Black solid lines indicate potential density contours, and vertical dashed lines mark station locations.

CHAPTER

THIRTEEN

UNDERWAY DATA ACQUISITION

Additional underway measurements were collected as available from the systems aboard the R/V Thomas G. Thompson throughout the cruise, notably including:

Meteorological and Marine Surface Variables

- Meteorological sensor suite (air temperature, wind speed and direction, humidity, barometric pressure)
- Scientific Wave Radar: Rutter WAMOS II-300
- Underway surface seawater diaphragm pump
- Seabird Thermosalinograph (surface temperature, salinity)
- Underway surface pCO_2

Shipboard Acoustic Doppler Current Profiler (SADCP; PI: Jules Hummon, UH)

- RDI Ocean Surveyor 75kHz
- RDI Workhorse 300kHz
- UHDAS digital data acquisition system

Seafloor Mapping

- Shipboard Multibeam Sonar: Kongsberg EM-302

Gravimeter

- DCS Gravimeter

CHAPTER

FOURTEEN

CARBON ISOTOPES (δ^{14}C AND δ^{13}C)

PIs

- Roberta Hansman (WHOI)
- Alan Gagnon (WHOI)
- Rolf Sonnerup (UW)

Technician

- Kendra Hyles (UCSB)

14.1 Sampling Details

A total of 672 samples were collected from 28 stations. δ^{14}C/δ^{13}C samples were collected every 2 degrees change in latitude, from 28°S to 20°N. Samples were collected in 100 mL airtight glass bottles. Using silicone tubing, the flasks were rinsed 3 times with the water from the sample bottle. While keeping the tubing near the bottom of the flask, the flask is filled and flushed by allowing it to overflow one and a half times its full volume. 22 unique depths were selected from the 36 niskin rosette utilized, and two duplicate samples were collected at every station at the upper and lower halves of the eater column, respectively. Once the samples were taken, a small amount of water (~5 mL) was removed to create a headspace and 100 µL of 50% saturated mercuric chloride solution was added in the sampling bay. This is the same supply of mercuric chloride solution used for the other DIC samples collected. After all samples are collected from a cast the glass stoppers are dried and greased using Apiezon M high vacuum seal grease, and rubber banded shut to keep the glass stoppers in place during shipping. The filled bottles are stored in NOSAMS crates inside the ship's main laboratory prior to being loaded into a container and shipped back to the United States for analysis.

CHAPTER

FIFTEEN

DISSOLVED ORGANIC MATTER (DOM)

PI

- Craig Carlson (UCSB)

Technician

- Kendra Hyles (UCSB)

15.1 Project Goals

The goal of the DOM project is to provide high resolution, long term monitoring of Dissolved Organic Carbon (DOC) and Total Dissolved Nitrogen (TDN) distributions throughout the water column, in order to help better understand biogeochemical cycling in global oceans. For 2025 the Carlson Lab at UCSB will evaluate dissolved organic carbon (DOC) and total dissolved nitrogen (TDN) concentrations along the US GO-SHIP IO9N transect.

15.2 Sampling Plan

Over the course of the I09N cruise, DOC/TDN was sampled at every other station in conjunction with DIC, Alkalinity, and pH. For these, DOM was sampled from up to 36 unique Niskins ranging the full depth of the water column, with two duplicates randomly selected for a total of 38 samples collected per cast. At 4 stations, every depth was sampled in replicate. In addition, at intermediate stations where DOM was not collected for the full depth profile, a single surface sample was collected (in replicate) to increase surface resolution across this section. DOM was sampled at 49 stations for full depth profiles, and an additional 49 surface sample-only stations were also collected for a total of 1,860 individual samples.

15.3 Sampling Details

DOC samples were passed through an inline filter holding a combusted GF/F filter attached directly to the Niskin for samples shallower than 500 meters. This was done to eliminate particles larger than 0.7 µm from the sample. Samples from deeper depths were not filtered. Previous work has demonstrated that there is no resolvable difference between filtered and unfiltered samples in waters below the upper 500 m at the µmol kg^{-1} resolution.

To avoid contamination, nitrile gloves were used when handling all sampling equipment and clean lab surfaces were used for processing samples. After each station, all equipment used for sampling was rinsed with 10% hydrochloric acid and MilliQ water in preparation for the following station. All samples were rinsed 3 times with ~5 mL of seawater and collected into 40 mL glass EPA vials.

Sample vials were prepared in advance for this cruise by combusting at 450 °C for 4 hours to remove any organic matter. Vial caps were cleaned by soaking in 10% hydrochloric acid, followed by a soak in Nanopure water overnight, followed by a 3 times rinse with Nanopure water and left out to dry. Samples were fixed with 50 µL of 4M hydrochloric acid and stored upright in well sealed pelican coolers just below room temperature (~12-15 °C) on board. Samples were never

frozen. Samples will be shipped back to UCSB for analysis via high temperature combustion on Shimadzu TOC-V or TOC-L analyzers.

15.4 Standard Operating Procedure for DOM analyses (Carlson Lab, UCSB)

DOC samples will be analyzed via high temperature combustion using a Shimadzu TOC-V or Shimadzu TOC-L in a shore based laboratory at the University of California, Santa Barbara. The operating conditions of the Shimadzu TOC-V have been slightly modified from the manufacturer's model system. These methods have been added to the GO SHIP Practices collection and are fully detailed in Halewood et. al, 2022 [Halewood2022], and previously [Carlson2010] [Hansell2005] [Hansell1998] [Walsh1989]. Final results are reported in units of μmol kg^{-1}. Where possible direct measures of sample salinity and analytical temperature are used to calculate average seawater density. In practice we have found that applying an average seawater density of 1.027 kg m^{-3} to open ocean water column DOM samples, compared to direct measure of sample density results in a difference of less than 0.01 μmol kg^{-1} (i.e., less than analytical resolution). However, when salinity and an average analytical lab temperature are available or in regions where salinity varies strongly, a more accurate density correction is determined and applied for each sample. Each parameter includes a field for quality control flags.

CHAPTER

SIXTEEN

UNDERWAY SURFACE CO_2

Principal Investigator

- Simone Alin (NOAA/PMEL)

Technician

- Abigail Tinari (UW-CICOES)

The mole fraction of carbon dioxide (xCO_2) in the surface ocean was measured throughout the cruise track with a General Oceanics 8050 CO_2 Measuring System. Uncontaminated seawater was continuously passed (~2.5-3.5 L/min) through a chamber where the seawater concentration of dissolved CO_2 was equilibrated with an overlying 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 mole fractions certified by the NOAA Earth System Research Laboratories (ESRL) ranging from ~300 to ~900 ppm CO_2 (see Table 18.1). 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 CO_2 mole fractions were made of air supplied through tubing fastened to the ships forward jack staff. Approximately twice a day, the infrared analyzer was zeroed and spanned using the nitrogen gas and the highest concentration CO_2 standard (704.20 ppm). This occurred until April 17th, 2025 when it was deemed necessary to zero and span the infrared analyzer after every set of discrete measurements and standards. This was due to the infrared analyzer's significant drift over the course of 12 hours. 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 pressure and temperature, etc.). For more detail on the general design and operation of this underway CO_2 system, see Pierrot et al., 2009 [Pierrot09].

Before departing from Fremantle, the underway CO_2 system received routine maintenance. Some of the maintenance items were: replaced the water pump, installed a UPS. Model and serial numbers for the CO_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. The underway CO_2 system on this cruise was installed in the aft, port side Hydrolab. Uncontaminated seawater from the bow of the vessel is pumped to the system via the ship's uncontaminated seawater system. On this cruise, the pump used was a baffle/diaphragm pump at the request of the onboard biologists, who were concerned about damage to the organisms by the centrifugal pump normally used for this purpose. This pump was delivering sufficient water volume to the underway CO_2 system on this cruise. The vessel provides meteorological data, salinity (TSG45), intake temperature (SBE38), and GPS information from vessel owned and maintained instruments, which are recorded in the data file alongside every sample measurement.

There were a number of separate interruptions in data collection throughout the cruise during periods where adjustments were made to gas flows and when troubleshooting was necessary to ensure the best quality data. Whenever possible, these interruptions were done when the vessel was on station. As mentioned above, the infrared analyzer had significant drift throughout the cruise so a new sampling plan, of zeroing and spanning the instrument after every set of standards, was enacted to attempt to reduce the drift. A few hours' worth of transiting data was affected due to a burst hose within the ship's underway system. Measurements of gas standards were mostly within 1% of their certified value throughout the duration of the cruise.

Standard	Concentration (ppm)	Tank Serial Numbers
1	304.26	LL12289
2	493.30	LL122858
3	639.36	LL122359
4	704.20	LL132516
5	0	Praxair 5.0 Ultra High Purity N2

While the raw data are not reported here or included in the Scripps Ocean Data Facility (SIO-ODF) database for this cruise, they has been collected and will be returned to PMEL and analyzed using MATLAB® routines developed by Dr. Denis Pierrot of the Atlantic Oceanographic and Meteorological Lab (AOML) in Miami, FL. The data will be submitted along with other cruise data and also submitted to the Surface Ocean CO_2 Atlas (SOCAT).

CHAPTER

SEVENTEEN

NO_3^- AND DON ISOTOPES ($\delta^{15}N$ & $\delta^{18}O$)

PI

- François Fripat (Université Libre de Bruxelles, Brussels)

At-Sea Sampling

- Alessandra Quigley (Columbia)
- Genevieve Clow (University of Colorado-Boulder)
- Roxanne Mina (University of South Florida)
- Ilmar Leimann (University of Bremen & MARUM, Germany)

17.1 Sampling

Samples for nitrogen (N) and oxygen (O) isotope analysis in nitrate (NO_3^-), combined nitrate and nitrite ($NO_3^- + NO_2^-$), and dissolved organic nitrogen (DON) were collected at 33 stations evenly distributed along the transect. Between stations 1 and 37, samples were collected from all sampled niskins every 4 stations. Between stations 37 and 94, samples were collected from all sampled niskins every 3 stations. Between stations 94-98, samples were collected from all sampled niskins on each station. In total, 1026 samples were obtained. High-resolution measurements of NO_3^- $\delta^{15}N$ and $\delta^{18}O$ provide a powerful means to trace the sources and sinks of bioavailable (i.e., fixed) nitrogen at the scale of the Indian Ocean, and to investigate the coupling between biogeochemical cycling and ocean circulation. Meanwhile, $\delta^{15}N$ in DON may offer novel insights into this still poorly characterized pool of bioavailable nitrogen—particularly regarding potential in situ production and consumption processes.

17.2 Analysis

Unfiltered samples for N and O isotopic composition of NO_3^- and DON were collected in 60 mL plastic bottles and stored frozen (-20 °C) until analysis. $NO_3^- + NO_2^-$ $\delta^{15}N$ and $\delta^{18}O$ will be measured at the Université Libre de Bruxelles using the denitrifier method (Sigman et al., 2001 [Sigman2001]; Casciotti et al., 2002 [Casciotti2002]). Briefly, 3-20 nmol of $NO_3^- + NO_2^-$ is quantitatively converted to N_2O gas by denitrifying bacteria that lack an active N_2O reductase. The N_2O is then analysed by gas chromatography-isotope ratio mass spectrometer (MAT253, Thermo) with on-line cryo-trapping (Weigand et al., 2016 [Weigand2016]). Measurements are referenced to air N_2 for $\delta^{15}N$ and VSMOW for $\delta^{18}O$ using the nitrate reference materials IAEA-NO3 and USGS-34. For NO_3^- $\delta^{15}N$ and $\delta^{18}O$ analysis, NO_2^- is removed with the sulfamic acid method prior to the isotopic analysis (Granger and Sigman, 2009 [Granger2009]). The reproducibility is generally better than 0.1‰ for $\delta^{15}N$ and $\delta^{18}O$, respectively. DON $\delta^{15}N$ will be measured on the same samples as for NO_3^- using the combined persulfate-denitrifier method (Knapp et al., 2005 [Knapp2005]). Briefly, DON is oxidized to nitrate using a persulfate oxidizing reagent. The nitrate is then quantitively converted to N_2O using the 'denitrifier' method as described above, allowing to measure both the concentration and $\delta^{15}N$.

CHAPTER

EIGHTEEN

δ^{13}C - DISSOLVED INORGANIC CARBON (DIC)

PI

- Wei-jun Cai (University of Delaware)

Technician

- Songying Tang (University of Delaware)

18.1 Sampling

Samples for δ^{13}C-DIC measurements were drawn according to procedures outlined in the PICES Special Publication, Guide to Best Practices for Ocean CO_2 Measurements (Dickson et al., 2007 [Dickson2007]), from the rosette sample bottles into cleaned 250 mL and 125 mL borosilicate glass bottles. Bottles were rinsed three times and filled from the bottom, with one bottle volume of overflow. After collection, approximately 2 mL of headspace was removed, and saturated mercuric chloride solution was added to each sample for preservation (0.1 mL for 250 mL bottles and 0.05 mL for 125 mL bottles). Sample bottles were then sealed with glass stoppers lightly covered with Apiezon-L grease and stoppers were fixed with rubber bands and clips. δ^{13}C-DIC samples were collected at every station in conjunction with DIC, Alkalinity, and pH measurements, with some deep depths skipped at DIC partial casts to ensure enough bottles remained for future stations. Two to three replicate samples were typically taken from the surface, at the oxygen minimal depth, and from bottom rosette sample bottles. All samples are being securely stored on the ship and will be shipped back to the United States for analysis. A special thanks to Daniela Nestory for providing the saturated mercuric chloride solution. Another special thanks to Genevieve Clow who took the night shift samples.

18.2 Analysis

The analysis will be conducted in the laboratory of University of Delaware.

CHAPTER

NINETEEN

IODINE

PIs

- James Moffett (USC)
- Adam Martiny (UCI)

At Sea

- Mary Dinneen (USC)
- Star Dressler (UCI)
- Eli Mally (UCI)

19.1 Significance of Iodine in the Bay of Bengal OMZ

Iodine is a redox-reactive element that exhibits a disequilibrium between iodate and iodide in seawater, particularly within oxygen minimum zones (OMZs). Iodide has been observed to accumulate along the upper boundaries of OMZs (Farrenkopf and Luther, 2002 [Farrenkopf2002]), likely due to its redox sensitivity under low-oxygen conditions. This accumulation also shows a strong correlation with nitrate, at times more distinctly related than oxygen levels (Reyes-Umana et al., 2022 [ReyesUmana2022]). Furthermore, iodide plays a specialized role in the metabolic pathways of certain bacteria found in OMZs, particularly those associated with the *idrA* gene (Reyes-Umana et al., 2022 [ReyesUmana2022]). Recent studies in the Bay of Bengal reveal distinct iodide features associated with the region's low-oxygen environment (Shaikh et al., 2024 [Shaikh2024]), highlighting the potential for similar iodide-based microbial metabolism in this setting as well as geochemical reduction of iodate to iodide associated with high nitrate and low oxygen. Our analyses aim to investigate the biogeochemical relationships between low oxygen, elevated nutrients, and iodate reductase pathways in the Bay of Bengal's prominent OMZ.

19.2 Iodine Sampling Method

100 mL filtrate taken in two 50 mL falcon tubes were collected daily using a Sterivex filter and peristaltic pump filtering setup from Bio GO-SHIP casts, as well as from mid-day underway seawater, via the Bio GO-SHIP DNA filtering system. Samples were initially frozen at –20 °C and later transferred to –80 °C for long-term storage. After reaching 10° N, additional 125 mL samples were collected directly from the CTD rosette from depths of interest—selected based on features of the Bay of Bengal (BoB) oxygen minimum zone (OMZ) profile—and processed using the same filtering system, then similarly frozen.

A total of 134 iodide samples were collected and will be transported back to the University of Southern California, where they will be analyzed for iodide content by Mary Dinneen in the Moffett Lab.

CHAPTER

TWENTY

BIO-GO-SHIP

PIs

- Harriet Alexander (WHOI)
- Jason Graff (OSU)
- Adam Martiny (UC Irvine)
- Catherine Mitchell (Bigelow Laboratory for Ocean Sciences)
- Nicole Poulton (Bigelow Laboratory for Ocean Sciences)
- Luke Thompson (AOML)

Technicians

- Star Dressler (UC Irvine)
- Laura Lubelczyk (Bigelow Laboratory for Ocean Sciences)
- Eli Mally (UC Irvine)

Bio-GO-SHIP sampled I09N with underway and CTD water at distinct time points throughout each day. This included continuous inline, discrete transit inline, PACE OCI satellite overpass discrete transit inline, CTD "bio-cast", and CTD bio-cast with Global Ocean Biogeochemistry Array (BGC) float deployments. During I09N, Bio-GO-SHIP completed 100 transit inline stations (including 33 PACE overpass transit inline stations), 31 CTD bio-cast stations, and 7 BGC float deployment bio-cast stations. Once the ship entered the Bangladesh EEZ, transit inline stations were taken from the CTD, making 7 stations counted as both "transit" and "CTD" stations.

20.1 Continuous Inline

A diaphragm pump underway system provided continuous flow from surface waters for optical instrumentation (BB3, ACS), Imaging Flow CytoBot (IFCB), flow cytometer (FCM), and particulate inorganic carbon via acid labile backscattering (PIC using ECO-VSF) as well as temperature, salinity, and fluorescence. All underway water was run through a vortex debubbler before being sampled. Continuous instrumentation was run until the final station at 19° 57.36' N 89° 51.6' E.

20.1.1 Inline Optics

The BB3 backscatter casket and Wet Labs ACS-111 received continuous inline water throughout I09N, passing through a filter for 10 minutes of every hour. Inlinino software, connected to communication channels, monitored flow rate, filtration timing, latitude/longitude coordinates, UTC time, and data from the sensors. The BB3 and ACS were cleaned with DI water and isopropyl alcohol wipes about once per week.

20.1.2 Imaging FlowCytobot

The McLane IFCB received continuous inline water throughout I09N, with a single 5 mL sample processed every 20 minutes. Underway water passed through a 200 micron screen (cleaned 2 times per day) and a 150 micron screen (cleaned once per week) before reaching the instrument. Every 25 samples the instrument was cleaned and every 25 samples calibration beads were run. Files will be analyzed for particle size distribution and functional phytoplankton groups at a later point in time.

20.1.3 Cytek Northern Lights Spectral Flow Cytometer

The shipboard Cytek flow cytometer received continuous inline water and operated on a SpectroFlo software template where a three minute inline water sample (approximately 180 microliters) was processed followed by a wait time of four minutes, collecting approximately 190 samples in each 24 hour period. Underway water passed through a 200 micron screen before reaching the instrument. Maintenance included once-daily particle size calibration, twice-daily cleanings of the instrument and the prefilter, and cleaning of the inline tubing and sample port once per week. Files will be analyzed for pico- and nanoplankton populations at a later point.

20.1.4 Acid-Labile Backscattering for Particulate Inorganic Carbon

Continuous inline water passed through a series of instruments as follows and data was recorded in LabView software:

1) SeaBird T-sal to measure salinity and temperature
2) WetLabs WetSTAR chlorophyll fluorometer
3) WetLabs VSF in a dark housing (Backscattering at 100, 125, and 150 degrees at three wavelengths)
4) WetLabs Flow Meter to record flow rate through the system (avg 2L per minute)

On a cycle of roughly 20 minutes, 10% acetic acid was pumped through a mixing coil at a sufficient rate to bring the pH below the dissociation point for calcite (< 6.0). After 60 points were recorded at this low pH, the acid pump shuts off, raw seawater is restored, and 60 more points were recorded at normal pH. The difference between total and acidified backscattering represents "acid-labile backscattering" which is an optical proxy for the concentration of PIC, particulate organic carbon (Balch and Drapeau, 2004 [Balch2004]). Once daily (while on station if possible), water was passed through a 0.2 um filter for 20-30 minutes, providing a filtered seawater blank. Approximately once per week the pH probe was calibrated and the fluorometer and VSF were cleaned.

20.2 Discrete Transit Inline Sampling

Flow cytometry (FCM), particulate inorganic carbon (PIC), environmental DNA (eDNA), RNA, particulate organic matter (POM), high performance liquid chromatography (HPLC), and iodine samples were discretely collected from the underway system at approximately 0600, 1200, and 2000 local time. If the PACE overpass or bio-cast timing occurred within three hours in either direction of these time points, then the inline sampling effort was modified to be included with the PACE overpass or bio-cast sampling.

A single sample was taken for FCM, PIC, eDNA, HPLC, and iodine. POM comprises three sample types with each type sampled as a triplicate, including particulate organic phosphorus (POP), particulate organic carbon and nitrogen (POCN), and particulate chemical oxygen demand (PCOD). A single RNA sample was taken at the 1200 time point only. The total number of samples listed below includes all discrete transit inline samples for each sample type, including samples taken during PACE overpass transit inline samples.

Discrete inline sampling was discontinued once the ship entered the Bangladesh EEZ at 17° 19.424' N 89° 51.582' E, after which the transit station samples were gathered from the CTD until the final station.

20.2.1 Flow Cytometry

Discrete FCM samples were collected in 50-mL dark Falcon tubes and preserved for later analysis. Nitrile gloves were worn for sample collection and processing. Falcon tubes were rinsed quickly three times with sample water prior to sample collection, and sample processing took place as quickly as possible. However, for times when the bio-cast was combined with a main cast, FCM was the last sample taken from the rosette, typically around 1 hour after the CTD was brought onboard. From the Falcon tubes, 1.8 mL of seawater was pipetted into a 2 mL cryovial. In a fume hood, 18 µL of a preservation mixture (half 25% Glutaraldehyde and half 2% Kolliphor) was added to each cryovial. The cryovial was inverted several times and placed on a vial stand in a refrigerator for approximately 10 minutes. The vials were flash frozen in a cryo-cane in a liquid nitrogen dewar then later moved to storage in the -80 °C freezer. On I09N, 140 total FCM samples were processed from underway transit stations. These samples will be analyzed for pico- and nano-plankton populations as well as for total bacteria (stained with SYBR Green DNA stain) at the laboratory.

20.2.2 Particulate Inorganic Carbon

Discrete PIC samples were collected in a 1 L dark Nalgene bottle after the bottle was rinsed three times. Nitrile gloves were worn for sample collection and processing. A graduated cylinder was used to measure out 200 mL and filter it onto a 25 mm 0.4 micron Nuclepore filter using a filter manifold and vacuum pump. The filter cup and filter were rinsed with a potassium tetraborate solution (3.06 g in 500 mL of deionized water). Filters were folded in half with the sample facing inward and stored in a 15 mL centrifuge tube. Caps were left loose and samples were placed in a 60 °C drying oven for a minimum of 24 hours. When samples were completely dry, caps were tightened and the tubes stored at room temperature to be analyzed in the laboratory. On I09N, 157 total PIC samples were collected from underway transit stations.

20.2.3 eDNA and RNA

Discrete eDNA and RNA samples were gathered in ~9.00 L spigoted carboys. Filtering of sample water through 0.22 µm Sterivex filters took place as quickly as possible following sampling. Nitrile gloves were worn for sample collection and processing. Prior to gathering sample water, each carboy was quickly rinsed three times with sample water. For filtration, clean tubing ran from each carboy through a peristaltic pump head to the Sterivex filter and emptied directly into the sink. Five samples could be run simultaneously. Prior to attaching the Sterivex, a small amount of sample water was flushed through the line. Following filtration, each filter was cleared of remaining liquid and processed with 1000 µl of DNA/RNA Shield. All samples were labeled following protocol and stored at –80 °C for later analysis. Following filtration, sample lines were cleaned with 2% bleach solution and DI water. On I09N, 72 total samples were processed for eDNA from underway transit stations, and 17 total samples were processed for RNA from underway transit stations.

20.2.4 Particulate Organic Matter

Discrete POM (including POP, POCN, and PCOD) samples were gathered in triplicates of ~9.00 L spigoted carboys. Filtering of sample water through pre-combusted 25 mm glass fiber filters (GF/Fs) took place as quickly as possible following sampling. Nitrile gloves were worn for sample collection and processing. Prior to gathering sample water, each carboy was quickly rinsed three times with sample water. Tubing connected to each spigot flowed through the filter housing with GF/Fs and to an aspirator pump that emptied into a sink. Following filtration, POP sample filters were rinsed with approximately 5 mL of Na_2SO_4 solution to remove traces of dissolved phosphorus from the filter. Each filter was removed with tweezers, folded sample-side inwards into pre-combusted aluminum foil, labeled according to protocol, and stored at –80 °C for later analysis. Sample lines and filter housings were rinsed with DI water. On I09N, 237 POP samples, 201 POCN samples, and 203 PCOD samples were processed from underway transit stations.

20.2.5 High Performance Liquid Chromatography

Discrete HPLC samples were gathered in ~2.00 L sample bottles, with approximately 10% of samples gathered as duplicates. Filtering of sample water through pre-combusted 25 mm glass fiber filters (GF/Fs) took place as quickly as possible following sampling. Nitrile gloves were worn for sample collection and processing. Prior to gathering sample water, each bottle was quickly rinsed three times with sample water. GF/F filters were secured on a filtration manifold attached to a vacuum pump. After filtration, filters were folded in half sample-side inwards, placed in a cryovial,

labeled following protocol, and stored at –80° C for later analysis. On I09N, 141 total HPLC samples were processed for underway transit sampling.

20.2.6 Iodine

Iodine was discretely gathered by Bio-GO-SHIP technicians for James Moffett of the University of Southern California. A total sample volume of ~90 mL was gathered in two 50 mL falcon tubes after the sample water passed through the 0.22-µm Sterivex filter of the eDNA/RNA filtration rig. Falcon tubes were frozen upright in a tube rack in a -20° C freezer before being stored in a ziplock bag and transferred to the –80° C freezer. On I09N, 46 total iodine samples were processed during the cruise.

20.3 PACE Overpass Discrete Inline Sampling

At the approximate overpass time of the PACE OCI satellite at the ships given location throughout the cruise, a suite of discrete inline samples were taken, including small volume particulate organic carbon and nitrogen (small volume POCN), FCM, PIC, and HPLC. Small volume POCN was sampled in a three volume regression (~2L, 1L, 0.5L) with a 1L wet blank taken each day and a dry blank taken approximately every three days. FCM, PIC, and HPLC were sampled in triplicates. If the skies were completely overcast, only a single HPLC sample was taken. The same sampling protocols were followed as listed in section 2, and the protocol for small volume POCN is described below.

These samples will serve as ground truthing/validation data for NASA's PACE OCI satellite. This daily sampling effort often aligned with the 1200 discrete inline sampling effort outlined in section 2, in which case eDNA, RNA, POM, and iodine were also discretely sampled. During the 33 number of PACE overpass inline sampling stations on I09N, 87 total small volume POCN samples (not including wet and dry blanks), 85 total HPLC samples, 93 total PIC samples, and 79 total FCM samples were processed.

PACE overpass discrete sampling was gathered from the underway system until the ship entered the Bangladesh EEZ at 17° 19.424' N 89° 51.582' E, after which the overpass samples were gathered from the CTD until the final station.

20.3.1 Small Volume Particulate Organic Carbon and Nitrogen

Discrete small volume POCN samples were gathered in ~2.00 L sample bottles. Filtering of sample water through pre-combusted 25 mm glass fiber filters (GF/Fs) took place as quickly as possible following sampling. Nitrile gloves were worn for sample collection and processing. Prior to gathering sample water, each bottle was quickly rinsed three times with sample water. GF/F filters were secured on a filtration manifold attached to a vacuum pump. After filtration, filters were folded in half sample-side inwards, placed in pre-combusted tin foil, labeled following protocol, and stored at –80° C for later analysis.

20.4 CTD Sampling

CTD bio-cast sampling occurred about once a day, with preference to a station that was as close to local 1200 as possible. Original protocol had the bio-cast occuring separately of the full GO-SHIP cast, descending to a maximum depth of 1000 meters, and firing 26 Niskin bottles for Bio-GO-SHIP sampling. Following the delays and technical difficulties of I09N, separate 1000 meter bio-casts were discontinued as a time-saving measure. A sampling scheme that merged the bio-cast with the full cast was implemented, which provided Bio-GO-SHIP with 12 Niskin bottles. The remaining Bio-GO-SHIP samples were taken from the remaining sample water left in Niskin bottles after GO-SHIP finished sampling. With shallower depths, more Niskin bottles became available for Bio-GO-SHIP. The majority of the bio-casts performed on I09N were combined casts.

The original 1000 m separate bio-cast had the following sampling scheme: eDNA at depths 1000 m, 200 m, 100 m, and 5 m; RNA at 5 m; POM at 5 m; HPLC at 100 m, 40 m, and 5 m; FCM at 1000 m, 500 m, 200 m, 150 m, 100 m, 75 m, 40 m, and 5 m. Iodine was sampled at the same depths as eDNA at the majority of bio-cast stations. Each sampling protocol is the same listed in section 2, and water was sampled from the Niskin bottles using a small piece of silicone tubing. When the bio-cast was combined with the full cast, there were slight changes to this scheme. eDNA,

RNA, POM, and some FCM depths received their own Niskin bottles at the preferred listed depth. One replicate of POP and PCOD were not sampled on the shared casts. HPLC and some FCM depths were sampled from remaining sample water from GO-SHIP bottles. If GO-SHIP depths were not aligned with the preferred Bio-GO-SHIP scheme, the closest available depth was chosen. HPLC at around 40 m and 100 m on the shared casts did not always have a full 2 L of remaining sample water.

A beam transmissometer, attached to the Niskin rosette, was additionally managed by Bio-GO-SHIP. The lenses of the transmissometer were cleaned with isopropyl alcohol wipes and deionized water daily. "Dark casts" were performed about once per week, where electrical tape was placed over the lenses during deployment. These dark casts serve as calibration of temperature and pressure during data analysis.

During I09N bio-casts, 109 total samples were gathered for eDNA, 26 samples for RNA, 91 samples for POP, 87 samples for POCN, 76 samples for PCOD, 108 samples for HPLC, and 236 samples for FCM. Additionally, at the second GO-SHIP CTD test station (8.217° N 95.0° E), 28 eDNA samples from surface waters were processed as reference samples for DNA extraction protocol.

20.4.1 BGC Float Stations

At CTD stations aligned with BGC float deployments, a separate 1000 m bio-cast was implemented. The same sampling scheme for a separate bio-cast, as listed above, was followed. Additional HPLC and small volume POCN samples were taken for BGC float calibration/validation analysis. Small volume POCN was gathered at depths 100 m, 40 m, and 5 m. HPLC and small volume POCN was additionally gathered at depths of the chlorophyll maximum and the chlorophyll maximum + 50 m depth. HPLC was sampled in duplicates at the chlorophyll maximum + 50 m depth, and small volume POCN was sampled in duplicates at the chlorophyll maximum depth. The chlorophyll maximum was determined during the CTD down-cast by the fluorometer attached to the Niskin rosette. The same sampling protocols for all sample types are the same as listed in section 2 and 3, and water was sampled from the Niskin bottles using a small piece of silicone tubing. For small volume POCN at float stations, sample processing always included a dry blank and a wet blank from the chlorophyll maximum duplicate.

During the 7 BGC float deployments on I09N, 42 total samples were gathered for HPLC, and 42 total samples were gathered for small volume POCN (not including wet and dry blanks).

CHAPTER

TWENTYONE

IRON

PI

-

At Sea

- Mary Dinneen (USC)

21.1 Background

Iron is an essential micronutrient that functions as a metal cofactor in numerous critical metalloenzymes involved in microbial growth and metabolism. The Indian Ocean, influenced by substantial aeolian dust deposition and riverine inputs, presents a unique environment to investigate the distribution of iron and other trace metals, such as manganese and cadmium. Understanding the biogeochemical cycling of these metals in this region is key to forming a more integrated picture of their roles in oceanic nutrient dynamics and microbial ecology.

21.2 Sampling Method

Surface water samples were collected in 125 mL triplicates using a pole sampling system (Fig. 21.1) deployed from the starboard side of the ship at every 5 degrees of latitude along the I09 transect.

Nine stations total were sampled immediately upon arrival. All samples were stored at 4 °C in two sealed bags. The 125 mL polyethylene bottles were cleaned to trace metal clean standards by soaking in 10% HCl for 3 weeks and thoroughly rinsing with Milli-Q water before being double-bagged for storage at the Moffett Lab at the University of Southern California. All bottles were handled with appropriate personal protective equipment (PPE) and immediately bagged after sampling to minimize the risk of contamination.

Samples will be transported back to the University of Southern California, where they will be acidified and analyzed for iron and other trace metals (e.g., cadmium and manganese) using a SeaFAST system followed by ICP-MS. Analyses will be conducted by Mary Dinneen in the Moffett Lab.

Fig. 21.1: Mary Dinneen and Jake Howat retrieving a surface water pole sample. *Image by Laura Lubelczyk*

CHAPTER

TWENTYTWO

SURFACE DRIFTERS

PI

- Shaun Dolk (NOAA AOML)

Deployment

- Leah Chomiak (U Miami-CIMAS)

A total of 20 surface drifters from NOAA's Global Drifter Program (https://www.aoml.noaa.gov/global-drifter-program/) were deployed at targeted locations provided by the PI along the I09N transect. Targeted locations were determined based on drifter priority as of March 24, 2025 using Drifter Value Maps (https://www.aoml.noaa.gov/phod/gdp/value_maps.php). This priority scheme was set to maximize drifter lifetimes and account for active drifters within the region (including their age and number of operational sensors). Despite low value within the Bay of Bengal, the region was considered low priority due to the immense amount of local activity, which historically result in short drifter lifetimes.

All drifters were deployed off the port stern at a speed of 5 kts once the ship began to get underway following a CTD cast. Targeted deployments followed the nearest planned CTD station. All drifters were staged on the aft deck shortly before launch, where all plastic was removed according to instruction. Two people assisted with each deployment, and deployment times, locations, and drifter identification numbers were logged appropriately (see Table 22.1). Real-time data and visualization are available through the Observing System Monitoring Center (OSMC; https://viz.pmel.noaa.gov/osmc/?color_by=platform_type). More tools are available at https://www.aoml.noaa.gov/phod/gdp/real-time_data.php.

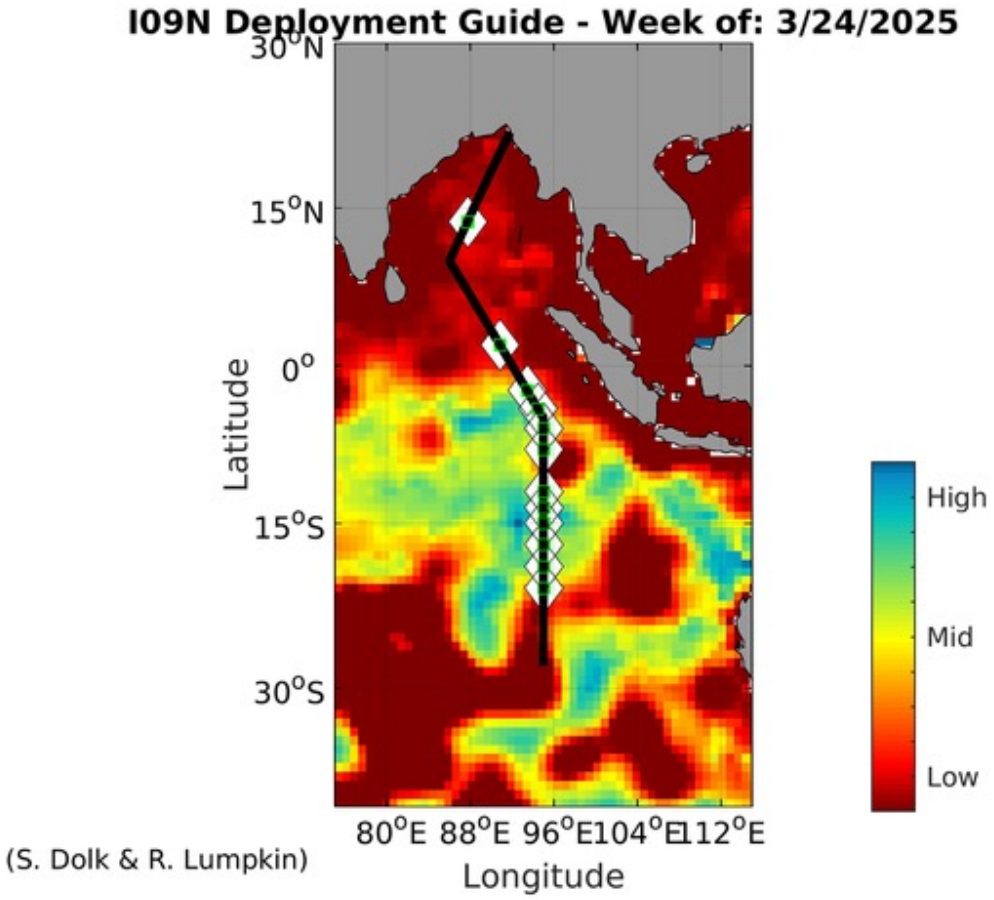


Fig. 22.1: Targeted deployment strategy along the I09N transect using the Drifter Deployment Value Map of the Indian Ocean. Figure by Shaun Dolk, NOAA AOML.

Table 22.1: Drifter Deployments

Drifter ID	Station	Latitude	Longitude	Date (UTC)	Time (UTC)
300534064294230	13	21°18.997 S	94°59.986 E	3/30/25	17:31
300534064293290	17	19°05.001 S	95°00.000 E	4/1/25	00:54
300534064293640	17	19°05.001 S	95°00.000 E	4/1/25	00:54
300534064292630	21	16°49.703 S	94°59.987 E	4/2/25	07:46
300534064293280	21	16°49.911 S	94°59.987 E	4/2/25	07:45
300534064293350	24	15°10.200 S	95°00.000 E	4/3/35	05:43
300534064293670	24	15°10.200 S	95°00.000 E	4/3/25	05:44
300534064294240	27	13°33.965 S	94°59.999 E	4/4/25	03:43
300534064294270	27	13°33.965 S	94°59.999 E	4/4/25	03:44
300534064293240	30	11°56.885 S	94°59.977 E	4/5/25	02:40
300534064294230	30	11°56.885 S	94°59.977 E	4/5/25	02:39
300534064293940	37	8°13.110 S	95°00.000 E	4/7/25	04:49
300534064293960	37	8°13.110 S	95°00.000 E	4/7/25	04:49
300534064293230	41	6°3.622 S	94°59.865 E	4/8/25	10:50
300534064293660	41	6°3.720 S	94°59.867 E	4/8/25	10:48
300534064293950	45	3°39.215 S	94°34.464 E	4/9/25	18:52
300534064293360	45	3°39.215 S	94°34.464 E	4/9/25	18:53
300534064293650	47	2°19.370 S	94°8.704 E	4/10/25	09:30
300534064292940	57	2°4.586 N	94°3.794 E	4/13/25	05:32
300534064293930	83	14°4.439 N	89°18.354 E	4/20/25	04:19

CHAPTER

TWENTYTHREE

FLOAT DEPLOYMENT

Deployment

- Guillaume Liniger (MBARI)

A total of 25 floats were deployed during the I09N cruise: 6 EM-APEX SQUID floats from the Applied Physics Laboratory at the University of Washington (APL-UW), 12 SOLO II core Argo floats from Scripps Institution of Oceanography, UCSD (SIO), and 7 S2-BGC Biogeochemical (BGC) Argo floats also from SIO as part of the GO-BGC program. Details are provided below for each float category.

23.1 SQUID Floats

PI:

- James Girton (APL-UW)

Six EM-APEX (ElectroMagnetic Autonomous Profiling EXplorers) were deployed during this I09N 2025 cruise. These floats measure temperature, salinity, horizontal velocity, and turbulence (temperature microstructure) and are part of the Sampling Quantitative Internal-wave Distribution project (SQUID), sponsored by NSF as a component of the National Oceanographic Partnership Program's Global Internal Waves initiative and led by James Girton (APL-UW, girton@uw.edu). The SQUID program aims to quantify the broad scale characterization of internal waves climates through the use of autonomous profiling floats. Prior to cruise departure, floats were tested by engineer Jacob Dossett (APL-UW) to make sure all were responding and ready to be deployed.

The EM-APEX float details and deployment locations are listed in Table 23.1 below.

Table 23.1: Summary of EM-APEX float deployment

Float ID	Station number	Lat (N)	Lon (E)	Date (UTC)	Time (UTC)
10330	8	-28.08	95.00	29/3/25	2:12
10339	20	-17.4	95.00	1/4/25	23:55
10340	39	-7.13	95.00	7/4/25	20:12
10691	48	-1.67	93.94	10/4/25	17:20
10692	60	3.34	91.54	13/4/25	23:53
10693	74	9.83	86.78	17/4/25	19:30

All floats were stored horizontally in individual crates outside or in a container on the aft deck with core and BGC-Argo floats. All SQUID floats followed the same protocol for deployment:

1. About 30 to 45 min before deployment, the 5 caps on the electrodes were removed and replaced by shade caps with small air hole on top.

2. At deployment time, after the CTD/rosette cast was completed and secured on deck, floats were secured using the A-frame with the help of the marine crew. Once attached, the 3 caps on top of the floats were removed as well as the Tμ probe's protective cover (by lifting and tilting the cover over and past the probes without contact).
3. Finally, floats were deployed from the monofilament loop on the side of the float using a quick release system at a speed of 1 to 2 kts once the ship began to get underway following a CTD cast.

Fig. 23.1: EM-APEX floats in their individual crates. *Image credit Guillaume Liniger*

Fig. 23.2: EM-APEX float getting ready for deployment. Caps and protection are carefully removed. Deployment was handled by Guillaume Liniger with the help of the marine crew. *Image credit Allen Smith*

23.2 Core Argo Floats

PIs:

- Sarah Purkey (SIO)

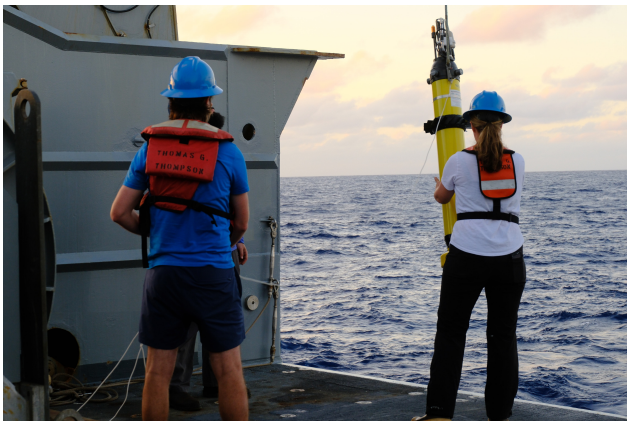


Fig. 23.3: EM-APEX float being deployed from the A-frame and put in water using the quick release white line. Deployment was handled by Guillaume Liniger with the help of the marine crew. *Image credit Allen Smith*

- John Gilson (SIO)

A total of 12 SOLO-II core Argo built by the Instrument Development Group (IDG) at SIO in Sand Diego, CA, were deployed during this I09N 2025 cruise. Each float is equipped with temperature, salinity and pressure sensors and can profile the water column down to 2000 m.

The floats follow the Argo profiling protocol of parking at 1000 and profiling from 2000 m to the surface every 10 days.

All floats were stored vertically in individual degradable cardboard box in a plastic bag and wrapped to protect the cardboard boxes. The cardboard box was held together with two bands of soluble PVA tape on the side and red plastic tape at the top and bottom end. Floats were stored in a container on the aft part of the ship with the SQUID and BGC-Argo floats.

Prior departure during mobilization, a performing self-test was carried on each individual float by Melissa Miller (SIO), and Guillaume Liniger. All 12 floats passed self-test and were ready for deployment.

All core floats were deployed in their individual cardboard box after the CTD/rosette cast was completed and back on deck, with the ship speed going from 1 to 2 knots. They were deployed from of the aft part of the boat with a lowering line. The box protects the delicate parts of the floats from impact during deployment. The plastic wrap and the red plastic packing tape at the top and bottom of the cardboard box was removed just prior deployment. Once in the water, the PVA tape dissolves, the box unfurls and the float is released. Floats were deployed by Guillaume Liniger with the help of the marine crew.

Each float was assigned a serial number and specific location for deployment that is summed up in Table 23.2 below.

Table 23.2: Summary of Core Argo float deployment

Float ID	Station number	Lat (N)	Lon (E)	Date (UTC)	Time (UTC)
3164	2	-27.72	94.96	25/3/25	6:38
3223	5	-25.91	94.99	26/3/25	6:21
3264	8	-24.08	95.00	29/3/25	2:05
3303	12	-21.88	95.00	30/3/25	10:05
3310	33	-10.35	95.00	6/4/25	00:17
3322	37	-8.22	95.01	7/4/26	4:47
3233	39	-7.13	95.00	7/4/25	20:17
3324	41	-6.07	95.00	8/4/25	10:49
3325	46	-2.99	94.36	10/4/25	2:00
3326	48	-1.67	93.94	10/4/25	17:15
3332	56	1.56	92.26	12/4/25	11:13
3344	60	3.34	91.54	13/4/25	23:57

23.3 BGC-Argo Floats

PIs:

- Sarah Purkey (SIO)
- John Gilson (SIO)
- Lynne Talley (SIO)
- Ken Johnson (MBARI)

Seven S2-BGC BGC-Argo floats were deployed on the cruise as part of the GO-BGC (Global Ocean Biogeochemistry Array) programs (NSF OPP-1936222 and OCE-1946578). All the BGC floats were manufactured by MRV Systems and prepared by IDG for deployment (inspected and ballasted). The GO-BGC program utilizes autonomous robotic floats to measure temperature, salinity, pH, nitrate, chlorophyll, suspended particles, light, and derived parameters such as dissolved organic carbon (DIC), pCO2 and total alkalinity in the ocean from the surface to 2000 m. These floats can operate continuously for years in all weather conditions, providing near real-time observations of ocean biogeochemistry and ecosystems throughout the world's oceans.

Each float deployed carries sensors for temperature, salinity, dissolved oxygen, pH, nitrate, oxygen, chlorophyll-a fluorescence (chl-a), particulate backscatter (bbp) and downwelling irradiance.

The floats follow the Argo profiling protocol of parking at 1000 m, and profiling from 2000 m to the surface every 10 days.

Eight floats were originally shipped to be deployed. As for the core Argo, each float underwent a performing self-test prior departure. Float 4033 did not respond and failed the test three times and was therefore shipped back to SIO prior to departure.

The deployment followed the same protocol as the core floats, except that the SUNA (nitrate), ECO (chl-a and b_(bp)) and OCR (irradiance) sensors were cleaned just before deployment.

1. The three sensors were first cleaned by rinsing lenses using deionized water and cleaned using pre-moistened pads by gently tap/dabbing the lens surface with the wipe.
2. Rinsing using deionized water
3. Tab/dab dry with lens paper

Note that for the SUNA sensor, it was cleaned using a Q-tip.

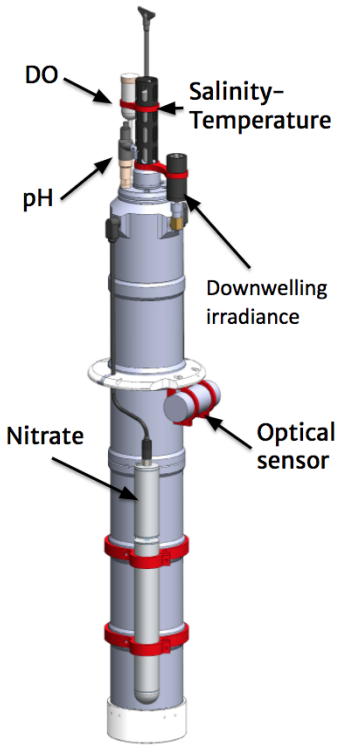


Fig. 23.4: Schematic of a SOLO BGC-Argo float deployed during the cruise. From https://www.go-bgc.org/floats

All S2-BGC floats were deployed according to the same protocol discussed above for the SOLO-IIs. Plastic wrap and non-water soluble tape were removed, and floats were lowered into the water in their cardboard deployment boxes by rope (see Fig. 23.6 and Fig. 23.7).

GO-BGC is partnering with teachers and classrooms across the country and around the world to inspire and educate students about global ocean biogeochemistry and climate change through our "Adopt-A-Float" initiative (https://www.go-bgc.org/outreach/adopt-a-float). Each float was sponsored by a school (see Table 23.3) and were already decorated by Melissa Miller before being shipped.

At each deployment, a BIO cast was performed to collect particulate organic carbon (POC) and high-performance liquid chromatography (HPLC) samples. The POC samples were collected at 5 m, 40 m, 100 m, Deep chl-a maximum (DCM) and DCM+50 m, and filtered onboard by Guillaume Liniger. In addition to these samples, the bio team (Star Dressler, Eli Mally and Laura Lubelczyk) collected and filtered sampled for HPLC at 5 m, 40 m, 100 m, DCM and DCM+50 m. All HPLC and POC samples were frozen to be sent to for analysis at NASA for HPLC and SIO/UCSD for POC, and will be used to calibrate the floats' sensors. See more details in the Bio-GO-SHIP section.

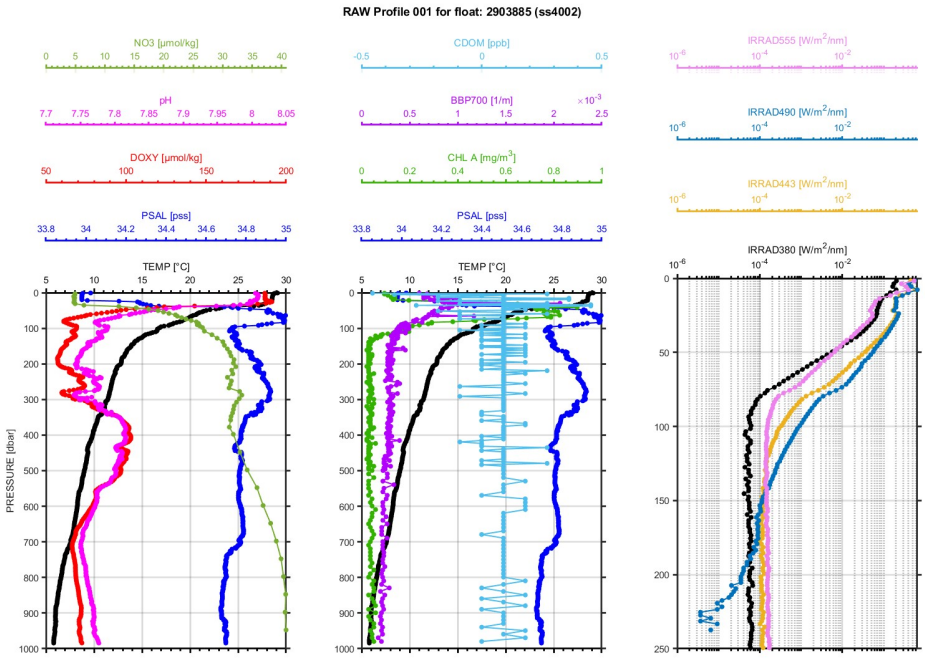


Fig. 23.5: First profiles taken by float 4002.

Fig. 23.6: BGC-Argo float getting ready for deployment. Float was brought outside the container on deck and all tapes and stickers were removed. Deployment was handled by Guillaume Liniger with the help of the marine crew. *Image credit Allen Smith.*

Fig. 23.7: BGC-Argo float getting ready for deployment. Float was deployed using two lines and rolled down slowly to the water in its cardboard box. Deployment was handled by Guillaume Liniger with the help of the marine crew. *Image credit Leah Chomiak.*

Table 23.3: Summary of BGC-Argo float deployment

Float ID	WMO	Station number	Lat (N)	Lon (E)	Date (UTC)	Time (UTC)	Adopt-a-float name
4002	2903885	30	-11.95	95.00	5/4/25	2:41	Floater the explorer
4032	1902372	43	-4.98	95.00	9/4/25	2:45	Iron Seahorse II
4014	1902373	53	0.317	93.3	12/4/25	2:40	Sakai Coho II
4009	2903829	64	5.27	90.29	15/4/25	1:38	Cougar 7300
4023	2903831	72	8.92	87.49	17/4/25	6:55	Humbertito the Squid
4015	1902367	83	14.07	89.31	20/4/25	4:36	Grace
4025	2903915	88	16.50	89.85	21/4/25	8:13	Coast Union High School
4033							Ethan Allen

Float 4025 was last deployed at station 88 latitude 16.50N instead of targeted latitude 17.88N due to time constraints (deployment during the day).

CHAPTER

TWENTYFOUR

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.

24.1 Alessandra Quigley

Columbia University

Setting sail on I09N has been an incredible adventure. As a biophysical modeller working on drivers and impacts of marine extremes, it was exciting to actually go to sea and experience the data collection process myself. On the *Thompson*, I was a CTD watchstander; responsible for preparing the rosette, monitoring and controlling its descent via the winch operator, and collecting water samples at various depths. There proved to be a learning curve, especially with (unexpectedly) no other watchstanders on my shift, and at times the 12 hour shift was a test of stamina. But I was rewarded richly with sightings of manta rays, spinner dolphins, flying fish, and some of the best stars I've ever seen. Thank you to the crew, who supplied me with ginger tea and a bucket I could carry around while I was seasick; and to my coworkers, who let me take breaks when nature called. I wanted to find out if I enjoy this type of work, and I found out I don't. But this has been an immense learning experience, and I am incredibly grateful for the opportunity.

24.2 Genevieve Clow

University of Colorado-Boulder

I'm grateful for the opportunity to have joined the I09N GO-SHIP cruise as a CTD watchstander. My responsibilities included preparing the rosette for deployment, monitoring the sensor data on the downcast, and firing bottles at specified depths on the upcast. In addition to these duties, I sampled ^{13}C isotopes and assisted with sampling salts and other isotopes.

This was both my first extended time at sea and my first fieldwork experience. I enjoyed spending time on the ocean, which I love but rarely get to visit. I'm currently a graduate student at the University of Colorado Boulder, where I study marine biogeochemistry using Earth system models and satellite observations. I wanted to gain hands-on field experience before graduating, and I'm grateful that I had the chance to do so. I've learned a ton and broadened my perspective as an oceanographer. I now have a greater appreciation for the effort that it takes for every single sample to be collected and analyzed. Additionally, I witnessed the immense coordination, teamwork, and perseverance required for a successful research cruise. I've been continually impressed by the work ethic and endurance of every member of the

team. Working 12-hour shifts for 40 days straight is challenging—especially while living in an unfamiliar environment, far from home.

I would like to thank the ship's crew for their tireless work in supporting the science and making the ship a comfortable home for our time at sea. I'm also incredibly grateful to the science team, especially my night shift colleagues. Special thanks to our co-chief scientist, Leah, who led the night shift and patiently showed me the ropes. Thanks to Leah, Allen, and John for sharing their CTD wisdom. I was also lucky to work alongside fellow CTD watchstander Roxanne Mina, who was an outstanding co-worker and friend. Thank you all so much!

24.3 Ilmar Leimann

University of Bremen & MARUM, Germany

Participating in the 2025 GO-SHIP I09N Indian Ocean cruise aboard the R/V Thomas G. Thompson was an incredible opportunity to engage firsthand with oceanographic research beyond the desk and into the open sea. My primary responsibility on the cruise was managing the LADCP (Lowered Acoustic Doppler Current Profiler), a vital instrument used to measure velocity profiles throughout the water column during CTD casts. Before each deployment, I ensured the instrument was correctly configured, powered, and securely mounted to the CTD rosette. After recovery, I downloaded and processed the data, working closely with the science team to assess data quality and troubleshoot the occasional surprises. As I quickly learned, LADCPs are a bit like cats—sometimes temperamental, and occasionally only cooperative after a snack and some patience.

Beyond the science, the Indian Ocean offered us unforgettable moments—fiery sunsets, mirror-calm mornings, and the kind of brilliant, star-filled skies you only see in the middle of nowhere.

I'm incredibly grateful to the GO-SHIP team, the crew of the R/V Thomas G. Thompson, and especially to Andreas Thurnherr for the LADCP training both on land and at port, as well as for his continued support throughout the cruise. I also want to thank my fellow shipmates for their camaraderie, humor, and dedication. This experience has reinforced my passion for oceanography—not just as a theoretical pursuit, but as something dynamic, hands-on, and full of discovery. It's hard to explain to someone back home just how exciting it is to watch real-time velocity data scroll across the screen while the ship gently rocks beneath your feet—it's something you simply have to experience for yourself to know whether you'll love it or not.

24.4 Mary Kate (MK) Dinneen

University of Southern California

When I learned about the opportunity to study CFCs, N_2O, and SF_6 through shipboard analyses in the Bay of Bengal, I was thrilled for a long stint at sea learning an entirely new analysis method. I typically study metals, specifically Fe(II), which involves a completely different method of analysis - although iron, like CFCs, is gas sensitive, making the rush of sampling that much more exciting (no sarcasm intended, it really is quite fun). I honed in skills that I didn't realize were weak, such as laboratory plumbing. Working with gas lines and mass flow controllers for experiments in a lab on land has often made me feel like a sort of plumber, but working with a gas chromatograph system on a moving ship is the next level of plumbing, and hopefully by the end of this cruise I will have earned my badge as professional gas line plumber.

In addition to the skillbuilding opportunity of measuring CFCs, SF_6, and N_2O at sea, I've also never been a part of such a routine and thorough research transect. GO-SHIP runs a tight ship of 12-hour shifts and around-the-clock 36-bottle (depth depending) casts. The discipline required to maintain 12-hour shifts of sampling and analyzing for over 30 days was an incredible opportunity for character strengthening. Although I have to admit, I genuinely love the communion and bustle of sampling, and the cold water from the deep ocean is always a welcomed relief from the hot days at sea in the Indian Ocean. Observing real data take shape is also such an immediately gratifying experience that gives a boost of encouragement and challenges the mind to ask questions of "how" and "why". Furthermore, the collaboration of various backgrounds on GO-SHIP allowed me to gain various perspectives that I'm not typically exposed to in my own trace metal discipline, allowing these "hows" and "whys" to be both answered and expanded upon.

Since beginning my journey in the field of chemical oceanography I have been enamored by unique chemical niches within our oceanic systems. One such niche that I have built my PhD thesis around is low oxygen regimes. The Bay of Bengal has been an exciting place to be able to see these low oxygen features develop. I am also increasingly fascinated by the interactions of physical and chemical signatures, which this cruise fostered with the unique opportunity to see the chemical signatures of water masses completely shift over distance. Visually observing the Antarctic intermediate water mass dissipate through dilution and age via firsthand experience of analyzing remarkably shallow CFC features highlighted the innate cohesiveness of chemical and physical oceanography. Although I have always had an interest in the physical and chemical oceanographic disciplines, they have often seemed distinct in objectives. This cruise has thus allowed me to conceptualize how effortlessly they can be intertwined and how we should resist ignoring one discipline for the sake of the other.

I've grown a tremendous appreciation for consensus data and research through being a part of the I09N GO-SHIP transect, and I hope there will be more opportunities to further explore and contribute to consensus transects in the future.

24.5 Roxanne Mina

University of South Florida

I told myself that I09N would be my last attempt to get on a GO-SHIP cruise before focusing on school as an incoming graduate student. I was initially accepted to join ARC01, then A16S, before postponements and ship mechanical issues prevented both cruises from going forward. I'm grateful to my past-self for going forward with my decision to apply for the third time because I had a great experience being a CTD Watchstander to support the I09N hydrographic cruise.

As a CTD Watchstander, my main role was to prepare the CTD-rosette bottle system on deck, monitor the CTD and fire bottles at various depths in the lab, and upon recovery, assist with water sampling. In addition, I assisted with LADCP during the night shift, deployed a few drifters, and helped sample a wide variety of parameters like salts, isotopes, total alkalinity, dissolved organic carbon, and more. After five weeks at sea, I've learned that observational oceanography is more than just getting ready to sample the next station. With every station, I was repeatedly reminded how much effort, coordination, and teamwork it takes to monitor the global ocean.

Science at sea is not without its challenges. The computer lab is the first to know when a problem occurs: unresponsive CTD, modulo errors, cyclone-induced weather hold, faulty altimeter, and replacing just about every part of the CTD-rosette bottle system. How do you react when things don't go according to plan? How do you choose to go forward and solve each issue? Watching the experienced members solve each issue gave me the optimism and belief that for every problem there's a solution. Outside of CTD issues, I also realized that when the excitement of the cruise wears out and some days feel harder than others, having a good science and ship makes a huge difference. The people who are communicators, collaborators, and team players are the ones who make the work more enjoyable and the difficult days a little easier.

Now that the cruise is over and the job is done, I can see myself going out onto another oceanographic cruise in the future. I'm thankful for the many people that I met, especially our chief and co-chief scientist Leah and Viviane for making me feel welcome and supported throughout the ~40 days on board. Science at sea requires people who are not only dedicated to every station we sample and every sample we collect. Despite our initial challenges, I'm proud of the work that was done and the future research that will be possible as a result of this cruise. I plan to take the lessons I learned forward into my future interests and career. I would love to go on another oceanographic cruise with GO-SHIP or with another program. This was a positive experience and I can see myself being in a career within observational oceanography.

APPENDIX

A

ABBREVIATIONS

ADCP
Accoustic Doppler Current Profiler

AOML
Atlantic Oceanographic and Meteorological Laboratory - *NOAA*

BFGS
Broyden-Fletcher-Goldfarb-Shanno algorithm

BGC
Biogeochemical

CFC
Chlorofluorocarbons

CICOES
Cooperative Institute for Climate, Ocean, & Ecosystem Studies

CIMAS
Cooperative Institute For Marine And Atmospheric Studies - *UM*

CLIVAR
Climate Variability and Predictability

CTDO
Conductivity Temperature Depth Oxygen, relating to CTD data and acquisition package

DCM
Deep Chlorophyll Max

DIC
Dissolved inorganic carbon

DO
Dissolved Oxygen

DOC
Dissolved Organic Carbon

DOM
Dissolved Organic Matter - including *DOC* and *TDN*

EM-APEX
ElectroMagnetic Autonomous Profiling EXplorers

ETs
Electronics Technicians

GO-SHIP
Global Ocean Ship-based Hydrographic Investigations Program

HPLC
High-Performance Liquid Chromatography

IAPSO
International Association for the Physical Sciences of the Oceans

ICP-MS
Inductively coupled plasma mass spectrometry

LDEO
Lamont-Doherty Earth Observatory - Columbia University

MBARI
Monterey Bay Aquarium Research Insitute

ML
Surface Mixed Layer

MTs
Marine Technicians

NOAA
National Oceanographic Atmospheric Administration

NSF
National Science Foundation

ODF
Oceanographic Data Facility - *SIO*

OSU
Oregon State University

PMEL
Pacific Marine Environmental Laboratory

RSMAS
Rosenstiel School of Marine, Atmospheric and Earth Science - *UM*

SBE
SeaBird Electronics

SF_6
Sulfur Hexafluoride, commonly used as an ocean tracer and measured with CFCs.

TA
Total Alkalinity

TDN
Total Dissolved Nitrogen

SIO
Scripps Institution of Oceanography

SQUID
Sampling Quantitative Internal-wave Distribution project

STS
Shipboard Technical Support - *SIO*

UCI
University of California, Irvine

UCSB
University of California, Santa Barbara

UCSD
University of California, San Diego

UDEL
University of Delaware

UH
University of Hawaii

ULB
Université libre de Bruxelles

USC
University of Southern California

UM
University of Miami

UNOLS
University-National Oceanographic Laboratory System

UW
University of Washington

WHOI
Woods Hole Oceanographic Institution

WOCE
World Ocean Circulation Experiment

APPENDIX

B

CALIBRATION DOCUMENTS

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

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

SENSOR SERIAL NUMBER: 0381
CALIBRATION DATE: 29-Sep-23

SBE 9plus PRESSURE CALIBRATION DATA
10000 psia S/N 58952

DIGIQUARTZ COEFFICIENTS:

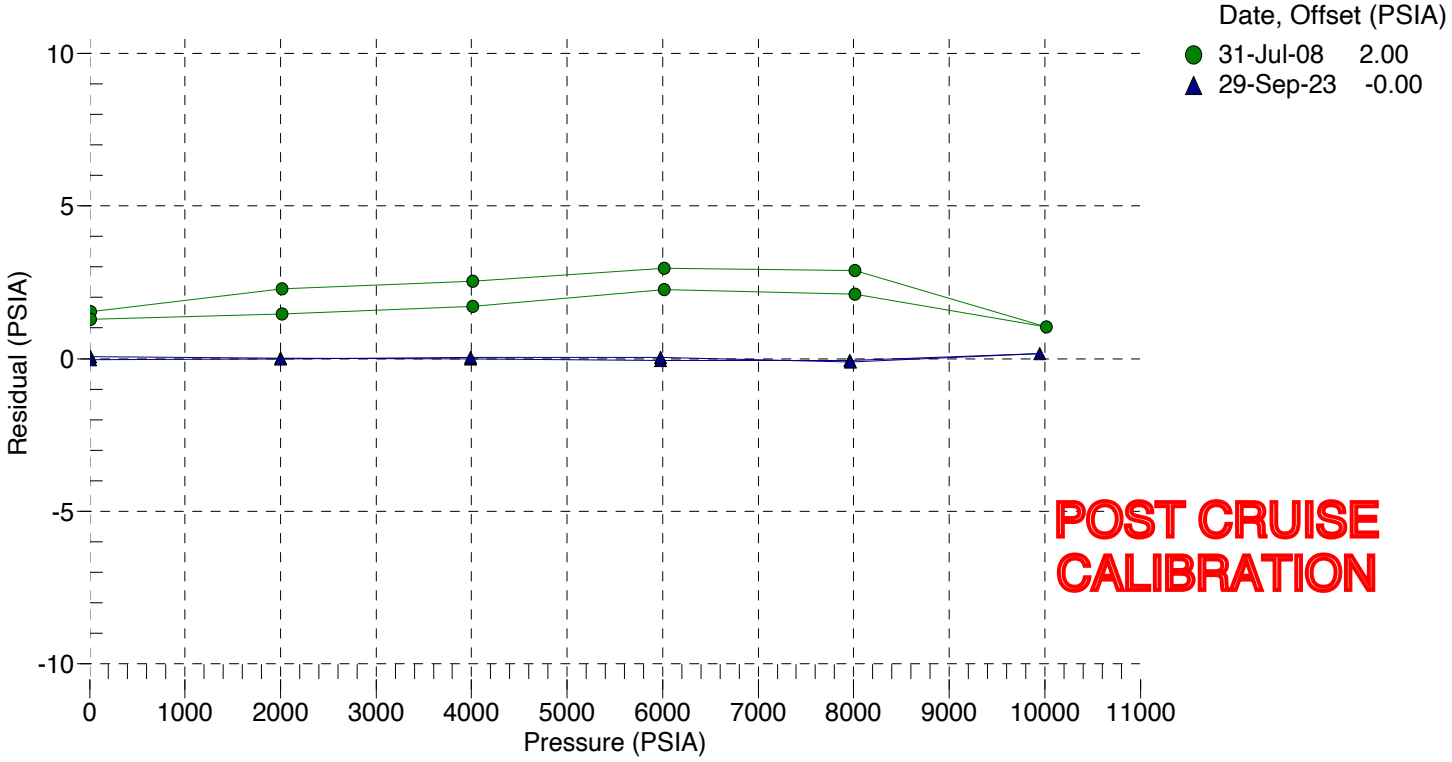
C1 = -5.136813e+004
C2 = 1.927312e-001
C3 = 1.549040e-002
D1 = 4.234600e-002
D2 = 0.000000e+000
T1 = 3.002156e+001
T2 = -2.996327e-004
T3 = 4.043490e-006
T4 = 2.578570e-009
T5 = 0.000000e+000

AD590M, AD590B, SLOPE AND OFFSET:

AD590M = 1.28081e-002
AD590B = -9.41513e+000
Slope = 1.00007
Offset = 1.0611 (dbars)

PRESSURE (PSIA)	INSTRUMENT OUTPUT (Hz)	INSTRUMENT TEMPERATURE (°C)	INSTRUMENT PRESSURE (PSIA)	CORRECTED PRESSURE (PSIA)	RESIDUAL (PSIA)
14.466	33319.10	25.3	12.997	14.536	0.070
2000.750	33956.10	25.3	1999.087	2000.762	0.012
3987.804	34579.60	25.4	3985.975	3987.786	-0.018
5974.889	35190.10	25.4	5972.878	5974.825	-0.064
7961.999	35788.30	25.4	7959.855	7961.939	-0.060
9949.903	36375.10	25.5	9947.844	9950.064	0.161
7963.048	35788.60	25.5	7960.842	7962.926	-0.122
5975.422	35190.30	25.5	5973.500	5975.448	0.026
3988.339	34579.80	25.5	3986.567	3988.378	0.039
2001.346	33956.30	25.5	1999.653	2001.328	-0.018
14.465	33319.10	25.6	12.899	14.438	-0.027

Residual (PSIA) = corrected instrument pressure - reference pressure



Pressure Calibration Report
STS Calibration Facility

SENSOR SERIAL NUMBER: 0569
CALIBRATION DATE: 23-APR-2024
Mfg: SEABIRD Model: 09P CTD Prs s/n: 75672

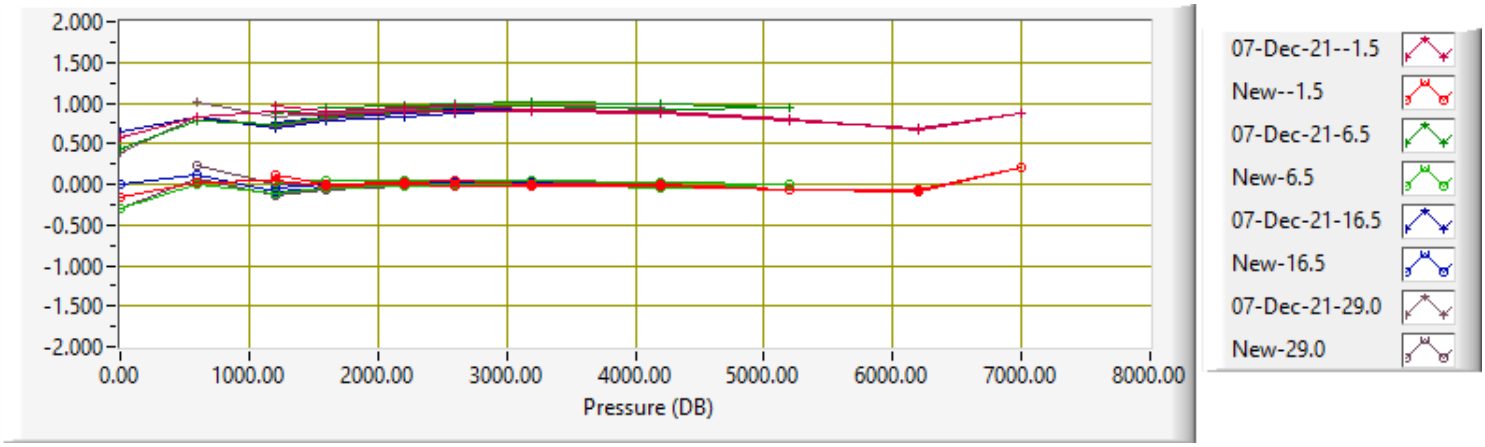
C1= -4.261861E+4
C2= -2.432170E-1
C3= 1.159827E-2
D1= 3.732219E-2
D2= 0.000000E+0
T1= 3.044556E+1
T2= -4.160749E-4
T3= 4.311750E-6
T4= -3.229397E-9
T5= 0.000000E+0
AD590M= 1.28617E-2
AD590B= -8.28826E+0
Slope = 1.00000000E+0
Offset = 0.00000000E+0

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
32850.879	0.27	0.43	0.58	-0.16	-1.19	-1.516
33184.191	600.39	600.38	0.82	0.01	-1.14	-1.516
33513.730	1200.44	1200.40	0.90	0.04	-1.08	-1.516
33731.413	1600.48	1600.51	0.86	-0.03	-1.05	-1.516
34054.849	2200.54	2200.55	0.90	-0.01	-1.01	-1.516
34268.518	2600.57	2600.60	0.90	-0.02	-0.99	-1.516
34586.132	3200.61	3200.62	0.91	-0.02	-0.96	-1.515
35108.062	4200.67	4200.70	0.87	-0.03	-0.94	-1.515
35621.083	5200.71	5200.78	0.78	-0.07	-0.92	-1.515
36125.559	6200.74	6200.82	0.68	-0.08	-0.89	-1.515
36523.102	7000.76	7000.55	0.87	0.21	-0.87	-1.515
36125.584	6200.75	6200.83	0.67	-0.09	-0.85	-1.515
35621.119	5200.72	5200.78	0.79	-0.06	-0.84	-1.515
35108.105	4200.68	4200.68	0.91	-0.00	-0.83	-1.516
34586.192	3200.61	3200.61	0.92	-0.00	-0.82	-1.516
34268.582	2600.57	2600.54	0.96	0.04	-0.79	-1.515
34054.948	2200.54	2200.52	0.93	0.02	-0.76	-1.515
33731.530	1600.48	1600.47	0.89	0.01	-0.76	-1.515

Sensor Output	DWT	Sensor New_Coefs	DWT-Sensor Prev_Coefs	DWT-Sensor NEW_Coefs	PT-DegC	Bath_Temp
33513.852	1200.44	1200.33	0.97	0.11	-0.74	-1.514
33184.292	600.39	600.22	0.98	0.17	-0.73	-1.514
32854.338	0.27	0.55	0.43	-0.29	6.82	6.494
33187.620	600.40	600.40	0.79	-0.00	6.90	6.493
33517.252	1200.45	1200.56	0.74	-0.12	6.94	6.494
33734.883	1600.49	1600.54	0.84	-0.05	6.99	6.494
34058.333	2200.56	2200.58	0.90	-0.02	7.02	6.494
34271.999	2600.59	2600.59	0.95	0.00	7.04	6.495
34589.632	3200.63	3200.62	0.97	0.01	7.07	6.495
35111.633	4200.71	4200.76	0.91	-0.05	7.09	6.495
35624.645	5200.76	5200.75	0.94	0.01	7.12	6.496
35111.608	4200.71	4200.68	1.00	0.03	7.14	6.495
34589.698	3200.64	3200.59	1.01	0.05	7.27	6.495
34272.080	2600.60	2600.56	0.99	0.04	7.29	6.495
34058.412	2200.56	2200.52	0.97	0.04	7.30	6.496
33734.957	1600.50	1600.45	0.94	0.05	7.31	6.496
33517.327	1200.45	1200.42	0.88	0.03	7.33	6.495
33187.684	600.40	600.20	0.99	0.20	7.35	6.495
32857.641	0.27	0.27	0.64	-0.01	17.01	16.501
33191.042	600.39	600.29	0.83	0.11	17.06	16.501
33520.753	1200.44	1200.54	0.69	-0.10	17.09	16.502
33738.402	1600.48	1600.53	0.78	-0.05	17.11	16.502
34061.893	2200.54	2200.57	0.84	-0.03	17.15	16.502
34275.584	2600.58	2600.59	0.88	-0.01	17.18	16.503
34593.246	3200.61	3200.62	0.91	-0.01	17.20	16.503
35115.290	4200.68	4200.72	0.88	-0.05	17.23	16.503
34593.248	3200.61	3200.60	0.93	0.02	17.24	16.503
34275.596	2600.58	2600.56	0.91	0.02	17.27	16.503
34061.911	2200.54	2200.53	0.88	0.01	17.28	16.503
33738.435	1600.48	1600.48	0.82	-0.00	17.30	16.503
33520.790	1200.44	1200.48	0.75	-0.04	17.32	16.502
33191.082	600.39	600.21	0.90	0.18	17.34	16.502
32860.791	0.27	0.56	0.40	-0.30	29.55	29.013
33194.118	600.40	600.34	0.83	0.06	29.63	29.014
33523.880	1200.45	1200.57	0.70	-0.13	29.68	29.014
33741.562	1600.49	1600.56	0.80	-0.07	29.70	29.014
34065.100	2200.56	2200.59	0.87	-0.03	29.75	29.015
34278.831	2600.60	2600.62	0.90	-0.02	29.78	29.015
34596.548	3200.64	3200.65	0.92	-0.01	29.80	29.015
35118.647	4200.71	4200.69	0.95	0.02	29.83	29.015
34596.537	3200.64	3200.61	0.96	0.02	29.83	29.015
34278.816	2600.60	2600.56	0.96	0.04	29.86	29.015
34065.100	2200.56	2200.54	0.92	0.02	29.87	29.014
33741.558	1600.50	1600.49	0.87	0.01	29.89	29.014
33523.858	1200.45	1200.45	0.83	-0.01	29.91	29.013
33194.074	600.40	600.16	1.01	0.24	29.92	29.014

Sensor Output	DWT	Sensor New_Coefs	DWT-Sensor Prev_Coefs	DWT-Sensor NEW_Coefs	PT-DegC	Bath_Temp
32860.625	0.27	0.14	0.84	0.13	29.95	29.015



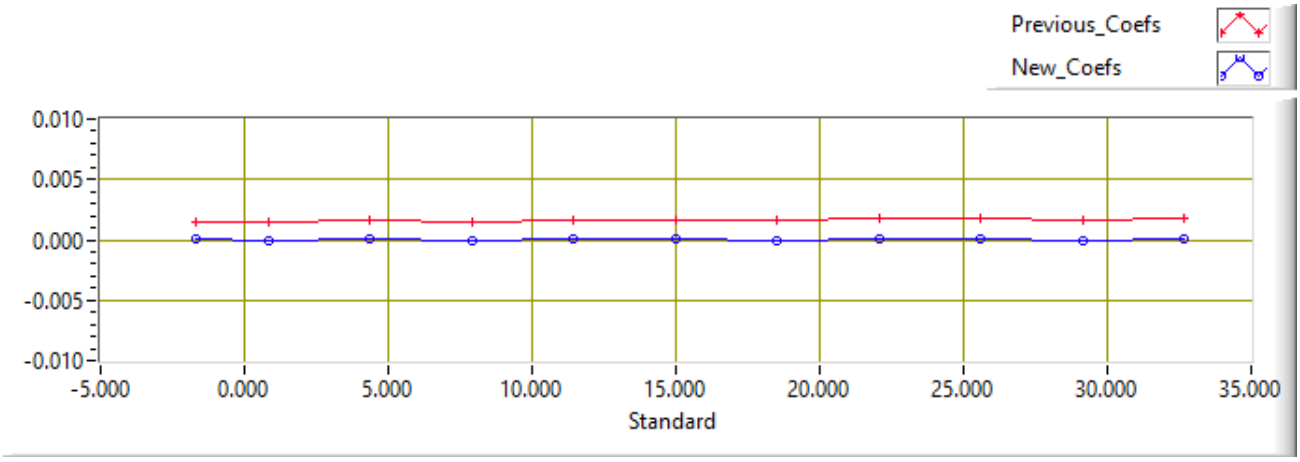
Temperature Calibration Report
STS Calibration Facility

SENSOR SERIAL NUMBER: 2309
CALIBRATION DATE: 10-Dec-2024
Mfg: SEABIRD Model: 03
Previous cal: 14-May-24
Calibration Tech: CAL

ITS-90_COEFFICIENTS	IPTS-68_COEFFICIENTS ITS-T90	
g = 4.35734870E-3	a = 4.35754685E-3	
h = 6.44248910E-4	b = 6.44460112E-4	
i = 2.37360400E-5	c = 2.37686894E-5	
j = 2.23267084E-6	d = 2.23424169E-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
2955.8314	-1.7179	-1.7179	0.00154	0.00001
3128.6182	0.8158	0.8158	0.00144	-0.00005
3382.6187	4.3624	4.3623	0.00159	0.00011
3650.7305	7.9030	7.9031	0.00142	-0.00010
3933.8287	11.4450	11.4449	0.00162	0.00004
4231.4245	14.9776	14.9775	0.00167	0.00003
4545.3084	18.5176	18.5177	0.00161	-0.00010
4874.9841	22.0555	22.0554	0.00182	0.00006
5221.2667	25.5957	25.5956	0.00186	0.00007
5583.6603	29.1299	29.1300	0.00169	-0.00008
5963.7578	32.6709	32.6709	0.00171	0.00002



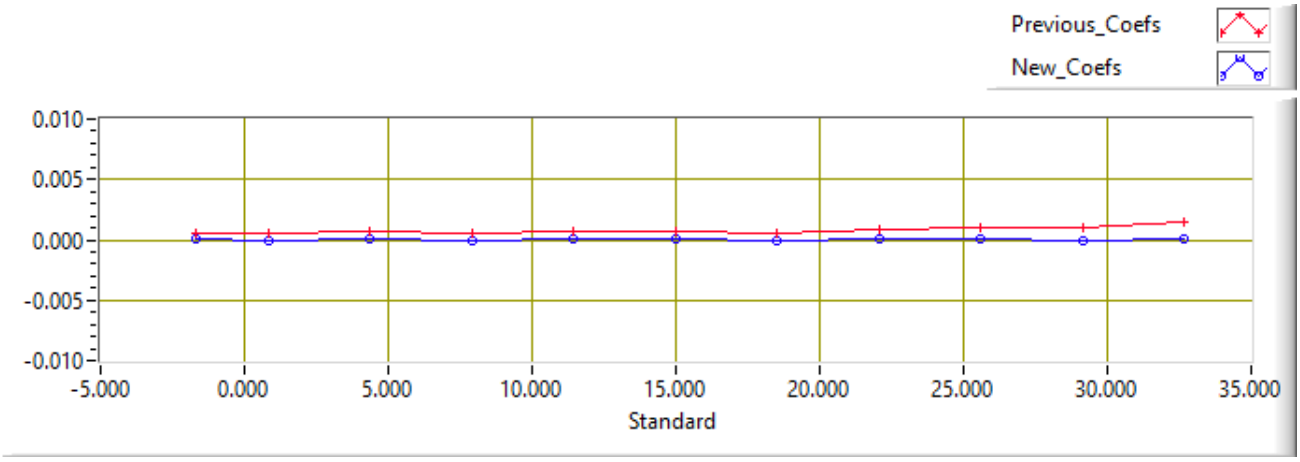
Temperature Calibration Report
STS Calibration Facility

SENSOR SERIAL NUMBER: 4588
CALIBRATION DATE: 10-Dec-2024
Mfg: SEABIRD Model: 03
Previous cal: 10-Oct-23
Calibration Tech: CAL

ITS-90_COEFFICIENTS	IPTS-68_COEFFICIENTS ITS-T90	
g = 4.35570591E-3	a = 4.35590362E-3	
h = 6.38658342E-4	b = 6.38867893E-4	
i = 2.14004958E-5	c = 2.14322722E-5	
j = 1.87986605E-6	d = 1.88129396E-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
2966.3241	-1.7179	-1.7179	0.00058	0.00001
3140.2652	0.8158	0.8158	0.00053	-0.00005
3395.9522	4.3624	4.3622	0.00070	0.00011
3665.8320	7.9030	7.9031	0.00049	-0.00010
3950.7825	11.4450	11.4450	0.00064	0.00002
4250.3050	14.9776	14.9775	0.00072	0.00005
4566.2141	18.5176	18.5177	0.00062	-0.00012
4897.9978	22.0555	22.0554	0.00089	0.00006
5246.4801	25.5957	25.5956	0.00107	0.00009
5611.1721	29.1299	29.1300	0.00104	-0.00011
5993.6604	32.6709	32.6709	0.00141	0.00003



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SENSOR SERIAL NUMBER: 1744
CALIBRATION DATE: 24-Oct-24

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

COEFFICIENTS:

```
g =  -9.91907241e+000
h =   1.38824413e+000
i =  -6.56974297e-003
j =   4.72172532e-004

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

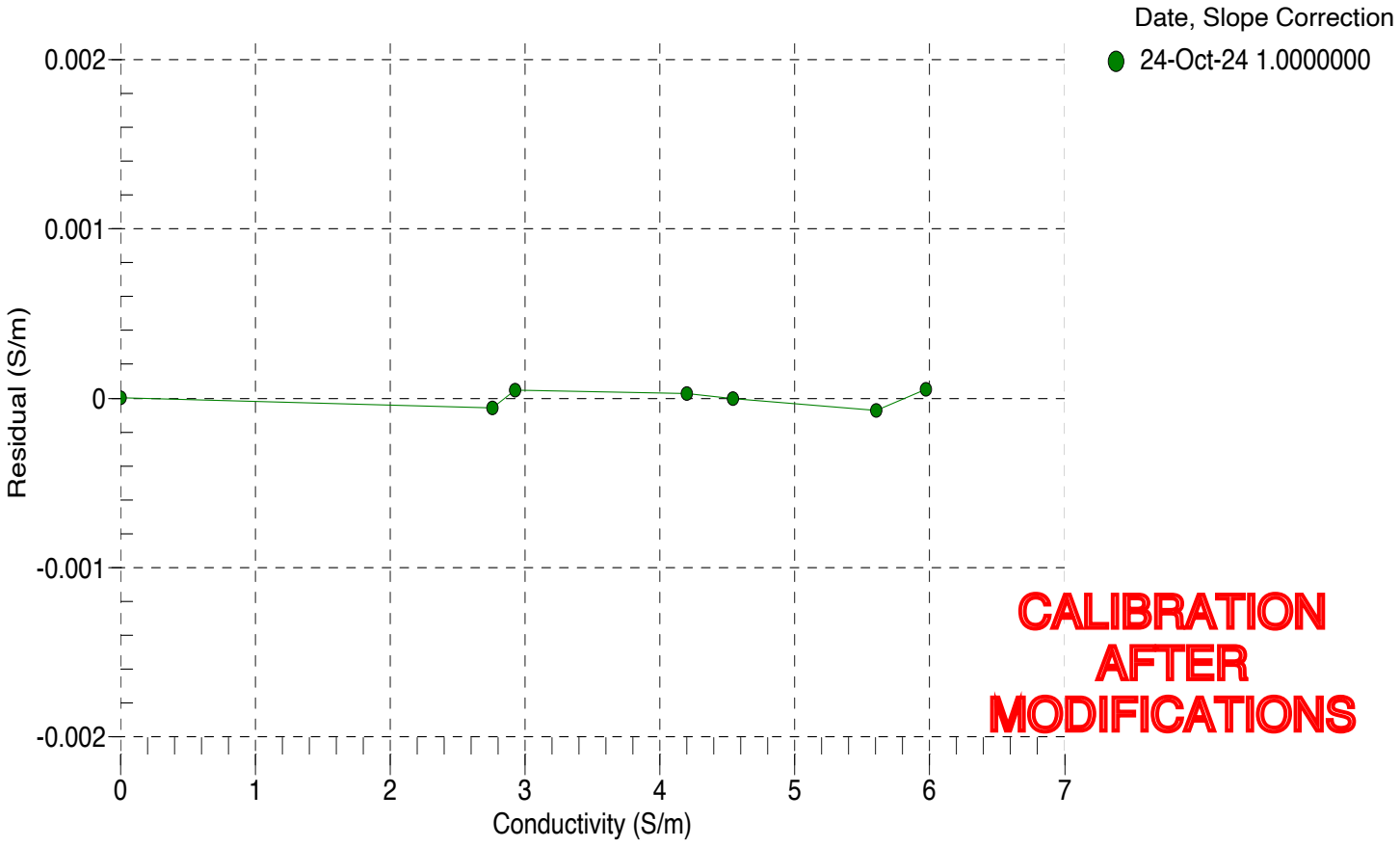
BATH TEMP (° C)	BATH SAL (PSU)	BATH COND (S/m)	INSTRUMENT OUTPUT (kHz)	INSTRUMENT COND (S/m)	RESIDUAL (S/m)
0.0000	0.0000	0.00000	2.68684	0.00000	0.00000
-1.0000	34.1649	2.75694	5.23714	2.75688	-0.00006
1.0000	34.1649	2.92553	5.35406	2.92558	0.00005
14.9999	34.1645	4.20001	6.16592	4.20004	0.00003
18.4999	34.1628	4.54092	6.36545	4.54091	-0.00000
29.0000	34.1559	5.60619	6.95177	5.60611	-0.00007
32.5000	34.1410	5.97139	7.14164	5.97144	0.00005

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



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SENSOR SERIAL NUMBER: 1879
CALIBRATION DATE: 11-Dec-24

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

COEFFICIENTS:

```
g =  -3.98102584e+000
h =   5.15820653e-001
i =  -4.92126225e-004
j =   5.35487932e-005

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

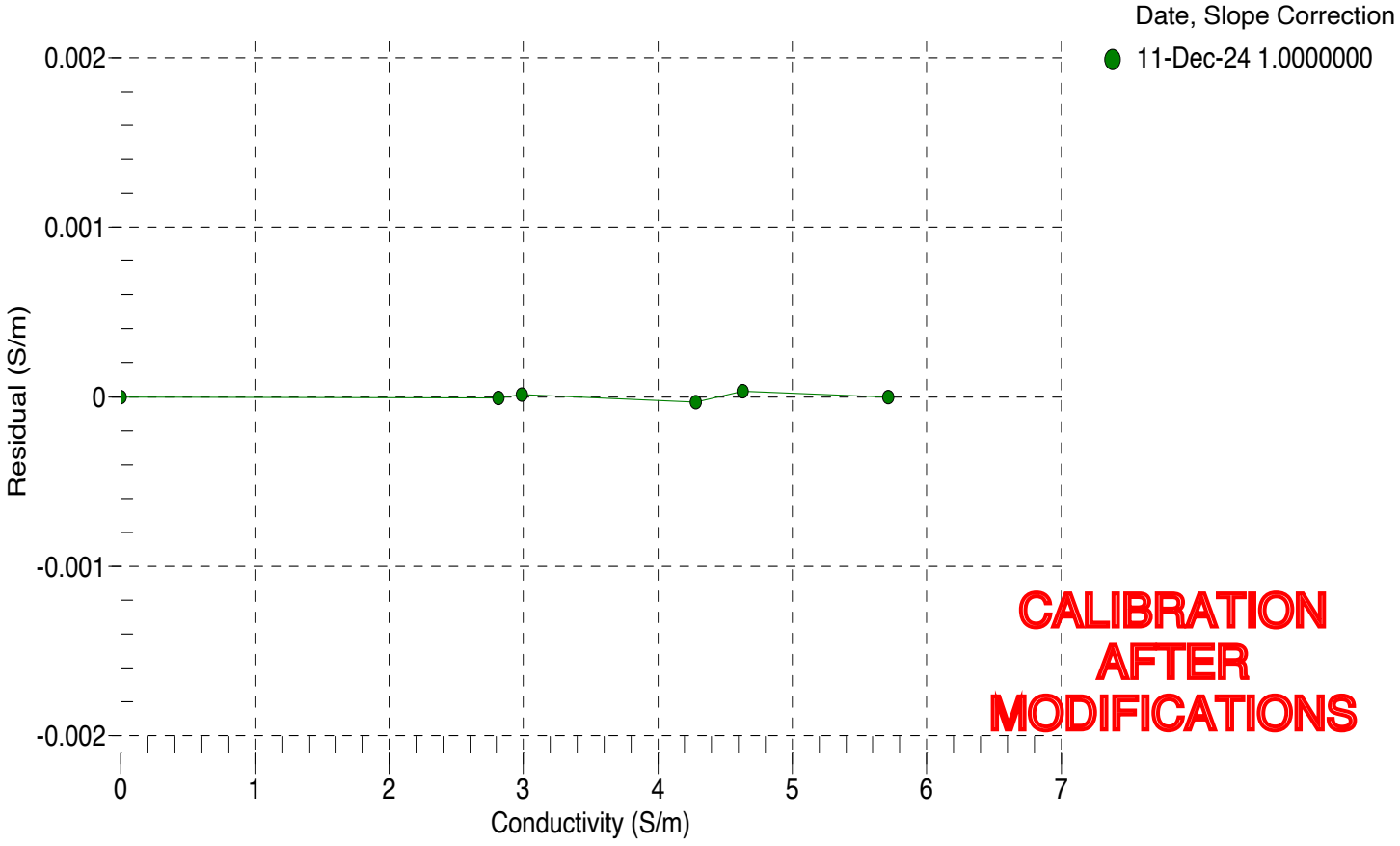
BATH TEMP (° C)	BATH SAL (PSU)	BATH COND (S/m)	INSTRUMENT OUTPUT (kHz)	INSTRUMENT COND (S/m)	RESIDUAL (S/m)
0.0000	0.0000	0.00000	2.78068	0.00000	0.00000
-1.0001	34.9364	2.81334	7.89460	2.81333	-0.00001
0.9999	34.9363	2.98523	8.10258	2.98525	0.00001
15.0000	34.9334	4.28445	9.52638	4.28442	-0.00003
18.5000	34.9267	4.63143	9.87134	4.63146	0.00003
29.0000	34.8976	5.71413	10.87569	5.71413	-0.00000
32.5000	34.8543	6.08187	11.19550	6.08158	-0.00029

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



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SENSOR SERIAL NUMBER: 2319
CALIBRATION DATE: 22-Jan-25

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

COEFFICIENTS:

```
g =  -1.04048103e+001
h =   1.51122518e+000
i =   2.01209394e-004
j =   7.54749865e-005

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

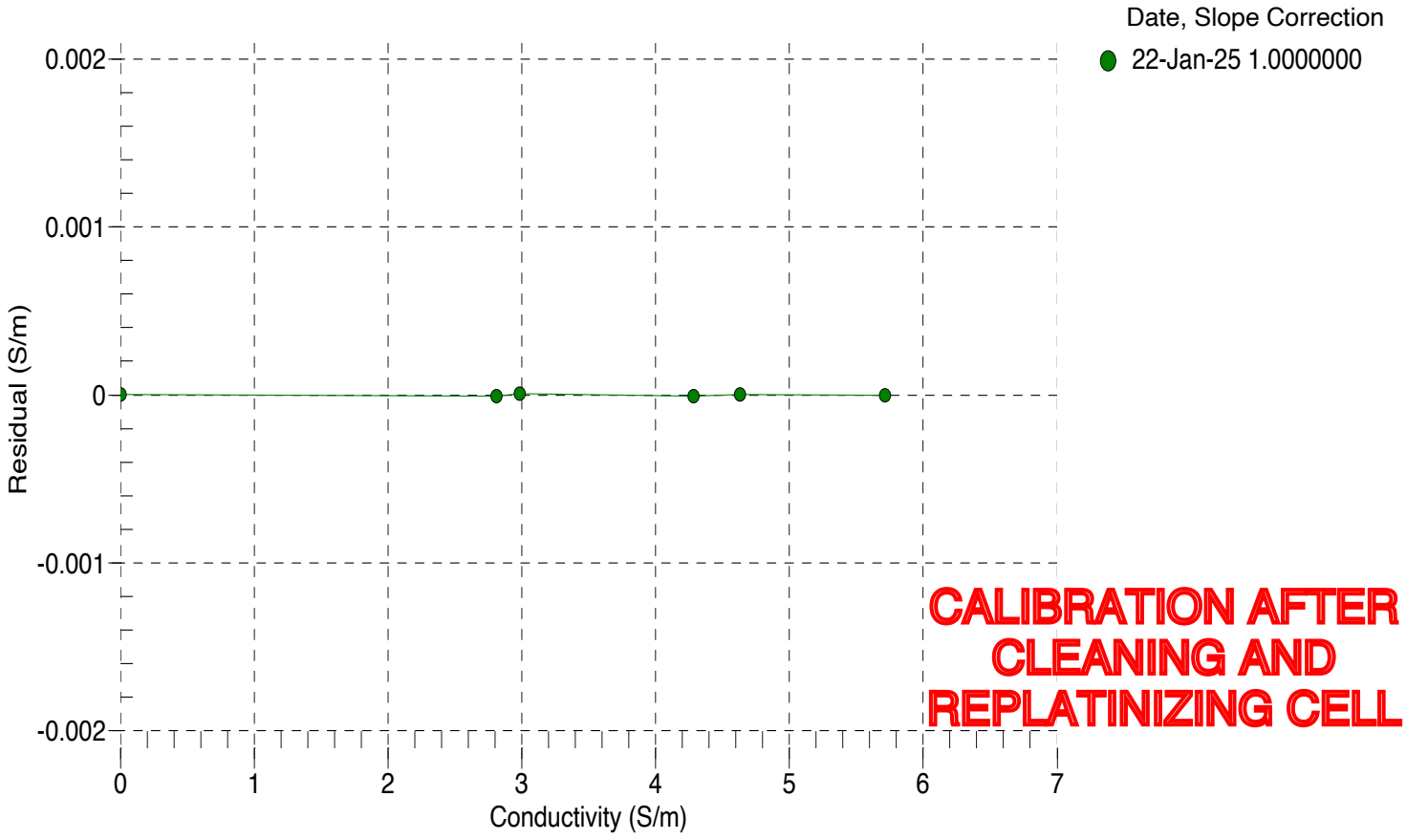
BATH TEMP (° C)	BATH SAL (PSU)	BATH COND (S/m)	INSTRUMENT OUTPUT (kHz)	INSTRUMENT COND (S/m)	RESIDUAL (S/m)
0.0000	0.0000	0.00000	2.62302	0.00000	0.00000
-1.0001	34.9185	2.81203	5.04412	2.81202	-0.00001
0.9999	34.9178	2.98380	5.15518	2.98381	0.00001
14.9999	34.9127	4.28217	5.92729	4.28217	-0.00001
18.4999	34.9057	4.62894	6.11693	4.62894	0.00000
29.0000	34.8834	5.71207	6.67439	5.71207	-0.00000
32.4999	34.8584	6.08249	6.85443	6.08224	-0.00025

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



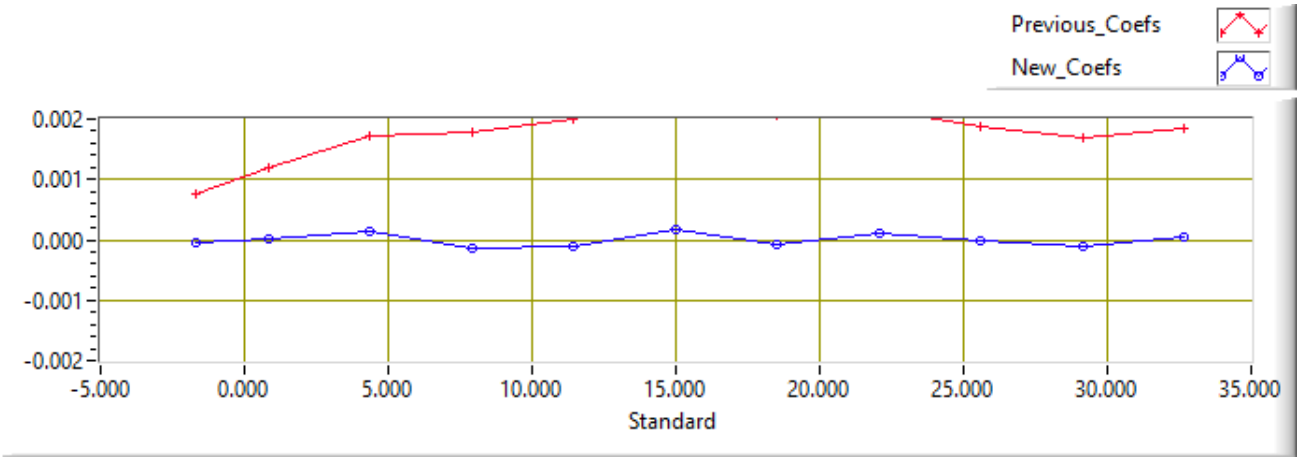
Temperature Calibration Report
STS Calibration Facility

SENSOR SERIAL NUMBER: 0035
CALIBRATION DATE: 19-Dec-2024
Mfg: SEABIRD Model: 35
Previous cal: 16-May-24
Calibration Tech: CAL

ITS-90_COEFFICIENTS
a0 = 4.436286448E-3
a1 = -1.200752409E-3
a2 = 1.831406325E-4
a3 = -1.023929640E-5
a4 = 2.198260221E-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
665266.0072	-1.7171	-1.7171	0.00077	-0.00004
595323.8774	0.8158	0.8158	0.00118	0.00003
510805.0753	4.3614	4.3613	0.00173	0.00014
439551.5707	7.9040	7.9042	0.00179	-0.00013
379305.2077	11.4457	11.4458	0.00201	-0.00011
328345.8969	14.9780	14.9778	0.00235	0.00016
284912.8350	18.5179	18.5180	0.00206	-0.00009
247913.5455	22.0560	22.0559	0.00215	0.00012
216282.6242	25.5947	25.5947	0.00187	-0.00002
189196.0640	29.1311	29.1312	0.00168	-0.00010
165896.4172	32.6720	32.6720	0.00184	0.00005



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SENSOR SERIAL NUMBER: 4355
CALIBRATION DATE: 06-Nov-24

SBE 43 OXYGEN CALIBRATION DATA

COEFFICIENTS:
Soc = 0.4747
Voffset = -0.5236
Tau20 = 1.92
A = -2.4840e-003
B = 1.3198e-004
C = -2.5940e-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

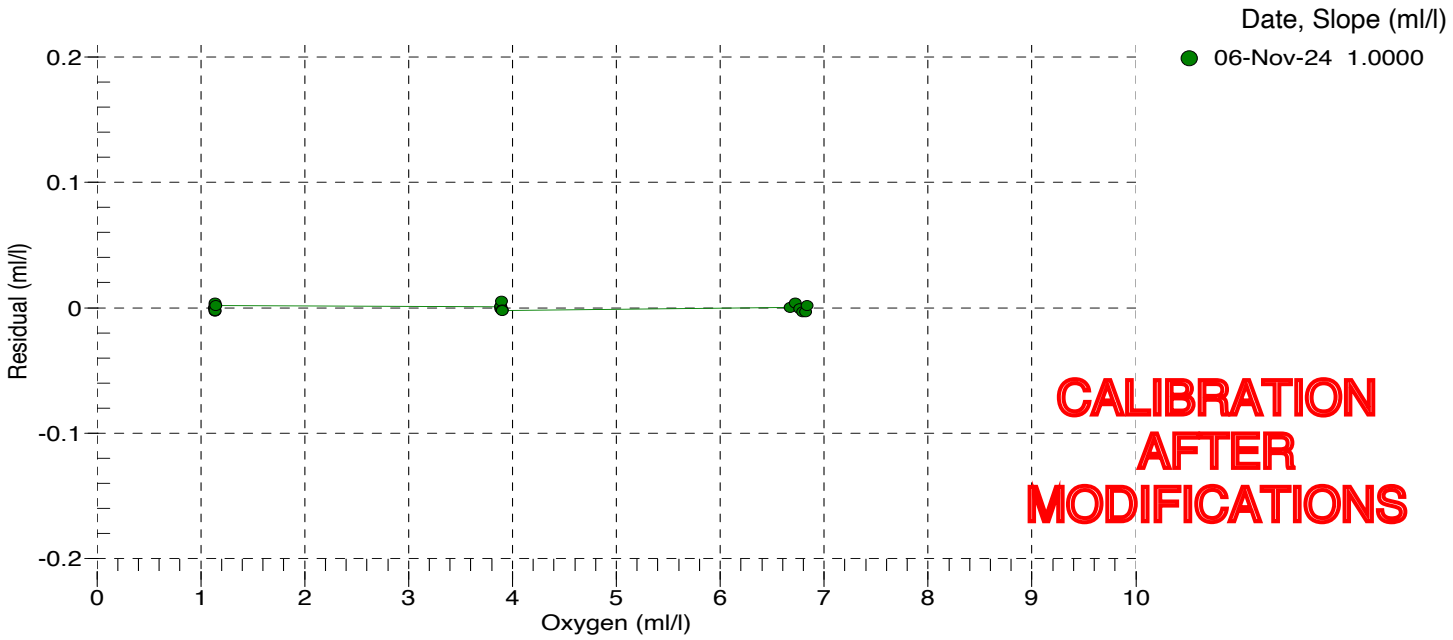
BATH OXYGEN (ml/l)	BATH TEMPERATURE (° C)	BATH SALINITY (PSU)	INSTRUMENT OUTPUT (volts)	INSTRUMENT OXYGEN (ml/l)	RESIDUAL (ml/l)
1.13	12.00	0.00	0.845	1.13	-0.00
1.14	6.00	0.00	0.801	1.14	-0.00
1.14	20.00	0.00	0.908	1.14	0.00
1.14	2.00	0.00	0.772	1.14	-0.00
1.14	30.00	0.00	0.991	1.14	0.00
1.14	26.00	0.00	0.957	1.14	0.00
3.88	30.00	0.00	2.112	3.89	0.00
3.89	6.00	0.00	1.474	3.89	-0.00
3.89	12.00	0.00	1.628	3.89	0.00
3.89	26.00	0.00	2.001	3.90	0.01
3.90	20.00	0.00	1.837	3.90	-0.00
3.90	2.00	0.00	1.376	3.90	-0.00
6.68	2.00	0.00	1.983	6.68	0.00
6.72	6.00	0.00	2.168	6.73	0.00
6.76	12.00	0.00	2.441	6.76	-0.00
6.80	30.00	0.00	3.300	6.79	-0.00
6.82	20.00	0.00	2.822	6.82	-0.00
6.83	26.00	0.00	3.114	6.83	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: 1136
CALIBRATION DATE: 06-Nov-24

SBE 43 OXYGEN CALIBRATION DATA

COEFFICIENTS:
Soc = 0.4915
Voffset = -0.5303
Tau20 = 1.18
A = -3.8592e-003
B = 1.7865e-004
C = -3.4284e-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

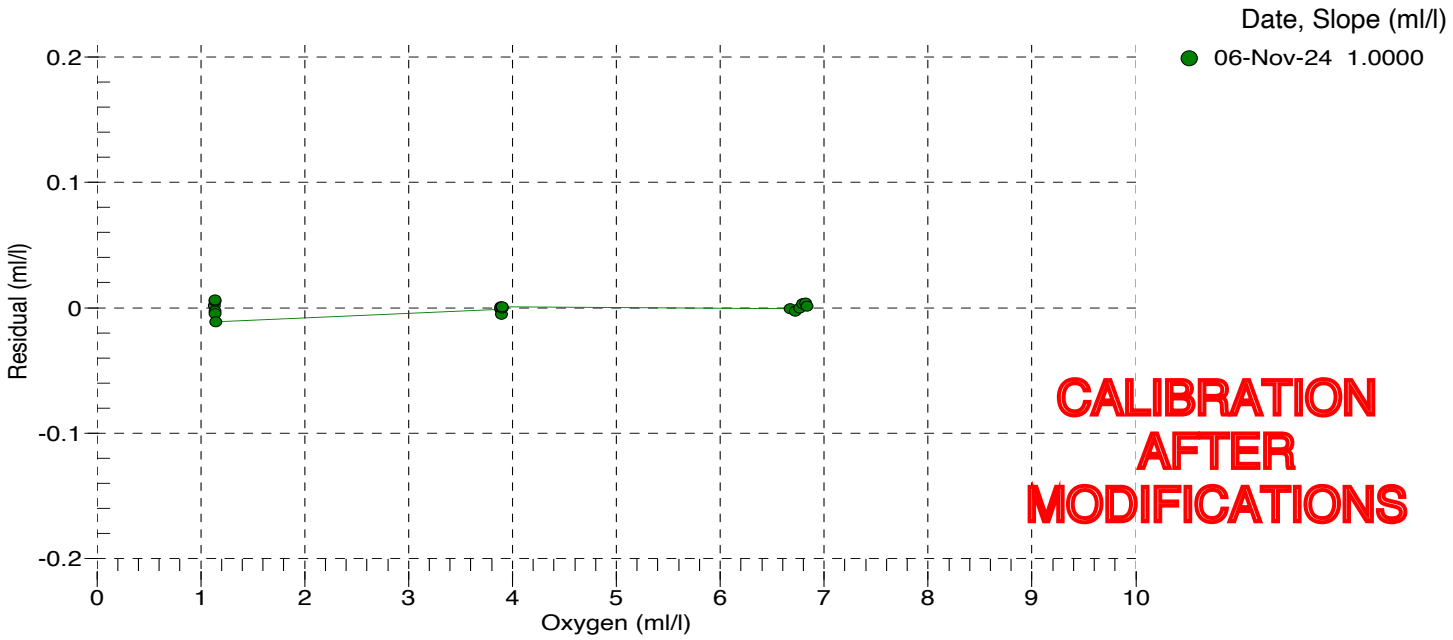
BATH OXYGEN (ml/l)	BATH TEMPERATURE (° C)	BATH SALINITY (PSU)	INSTRUMENT OUTPUT (volts)	INSTRUMENT OXYGEN (ml/l)	RESIDUAL (ml/l)
1.13	12.00	0.00	0.845	1.14	0.00
1.14	6.00	0.00	0.802	1.14	0.01
1.14	20.00	0.00	0.906	1.14	-0.00
1.14	2.00	0.00	0.773	1.15	0.01
1.14	30.00	0.00	0.989	1.14	-0.00
1.14	26.00	0.00	0.952	1.13	-0.01
3.88	30.00	0.00	2.099	3.88	-0.00
3.89	6.00	0.00	1.455	3.89	0.00
3.89	12.00	0.00	1.609	3.89	-0.00
3.89	26.00	0.00	1.981	3.89	-0.01
3.90	20.00	0.00	1.820	3.90	-0.00
3.90	2.00	0.00	1.357	3.90	0.00
6.68	2.00	0.00	1.944	6.68	-0.00
6.72	6.00	0.00	2.128	6.72	-0.00
6.76	12.00	0.00	2.404	6.76	-0.00
6.80	30.00	0.00	3.276	6.80	0.00
6.82	20.00	0.00	2.788	6.83	0.00
6.83	26.00	0.00	3.081	6.83	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: 1071
CALIBRATION DATE: 17-Dec-24

SBE 43 OXYGEN CALIBRATION DATA

COEFFICIENTS:
Soc = 0.3942
Voffset = -0.5154
Tau20 = 0.97
A = -2.7112e-03
B = 1.5314e-04
C = -2.5251e-06
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

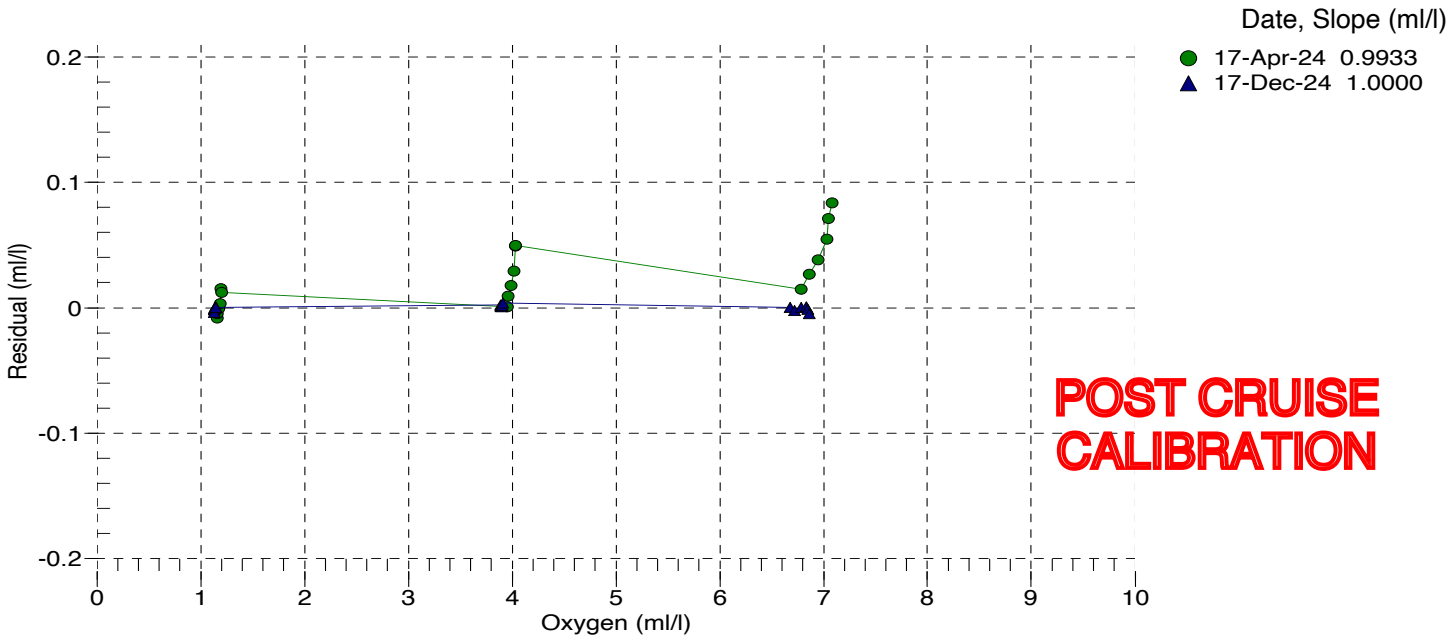
BATH OXYGEN (ml/l)	BATH TEMPERATURE (° C)	BATH SALINITY (PSU)	INSTRUMENT OUTPUT (volts)	INSTRUMENT OXYGEN (ml/l)	RESIDUAL (ml/l)
1.13	12.00	0.00	0.902	1.13	-0.00
1.13	6.00	0.00	0.849	1.13	-0.00
1.13	2.00	0.00	0.813	1.13	-0.00
1.14	20.00	0.00	0.977	1.14	0.00
1.15	26.00	0.00	1.034	1.15	0.00
1.15	30.00	0.00	1.072	1.15	0.00
3.89	2.00	0.00	1.540	3.89	0.00
3.89	6.00	0.00	1.662	3.89	0.00
3.90	12.00	0.00	1.847	3.90	0.00
3.90	20.00	0.00	2.092	3.90	0.00
3.91	26.00	0.00	2.284	3.91	0.00
3.91	30.00	0.00	2.416	3.92	0.00
6.68	2.00	0.00	2.274	6.68	0.00
6.72	6.00	0.00	2.493	6.71	-0.00
6.78	12.00	0.00	2.831	6.78	0.00
6.83	20.00	0.00	3.275	6.83	0.00
6.85	30.02	0.00	3.838	6.85	-0.00
6.86	26.00	0.00	3.615	6.86	-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



Temperature Calibration Certificate

Model	:	ARO-CAV-CM
Serial No.	:	0479
Date	:	September 26, 2023
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 = −1.186834e+01
B = +2.148828e+01
C = −3.622758e+00
D = +6.805231e−01

3. Calibration results

Reference temperature [°C]	Instrument voltage [V]	Instrument temperature [°C]	Residual error [°C]	Acceptance [°C]	OK/NG
2.628	0.75769	2.629	0.001	±0.020	OK
9.709	1.18903	9.704	−0.005	±0.020	OK
16.733	1.64728	16.740	0.007	±0.020	OK
23.468	2.09216	23.463	−0.005	±0.020	OK
31.150	2.58044	31.151	0.001	±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
20.056	20.059	0.003	±0.020	Passed

Examined R. SHOJI

Approved M. Ujinaki

JFE Advantech Co., Ltd.

Dissolved Oxygen Calibration Certificate

Model	:	ARO-CAV-CM
Serial No.	:	0479
Date	:	September 27, 2023
Location	:	Production Section
Method	:	Calibration is performed with the nitrogen gas (zero) and the oxygen saturated water (span) kept by air bubbling.
Film No.	:	230453BA

1. Equation

DO[%] =G+H × P'

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

2. Coefficients

A =	−4.469522e+01	E =	+3.800000e-03
B =	+1.382913e+02	F =	+4.520000e-05
C =	−3.695831e-01	G =	+0.000000e+00
D =	+9.741000e-03	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	1010.0	0.00	−0.07	−0.07	±1.00	Passed
2nd	1010.0	0.00	−0.08	−0.08	±1.00	Passed
3rd	1010.1	0.00	−0.09	−0.09	±1.00	Passed

Test for DO 100 %

	Test condition			Instrument DO [%]	Residual error [%]	Acceptance [%]	Judgement
	Water T. [°C]	Atm. pressure [hPa]	Reference DO [%]				
1st	25.0	1009.0	99.57	99.50	−0.07	±1.00	Passed
2nd	24.9	1009.0	99.57	99.54	−0.03	±1.00	Passed
3rd	24.8	1008.9	99.56	99.33	−0.23	±1.00	Passed

Examined M. FUJITA

Approved M. Ujinaki

JFE Advantech Co., Ltd.

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ECO Chlorophyll Fluorometer Characterization Sheet

Date: 10/22/2024 S/N: FLRTD-9157

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	0.065	0.035	0.019	V	50	counts
Scale Factor (SF)	6	13	25	µg/l/V	0.0076	µg/l/count
Maximum Output	4.97	4.97	4.97	V	16380	counts
Resolution	0.1	0.1	0.1	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.

CALIBRATION CERTIFICATE

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:	68267
Instrument Type:	VA500 SBE1 Altimeter
Instrument Serial Number:	78548
Calibrated By:	R. Musgrove
Date:	20/08/2021
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.

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Registered in England No: 1950444

Altimeter Build and Calibration Record

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Instrument type	Altimeter
Serial number	78548
Baud rate set ex factory	9600

Calibration History:

Certificate	Date
68267	20/08/2021

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
PSU board	0430502	D1	1021470													
Micro board	0430501	E0	1023222	ACTEL 0430707												
				ATMEL 0430704A16												
Transducer Assembly	500kHz		44340	100m												
Pressure sensor	PAA - 10LX															
	Name			E.Laight	Name				Name				Name			
	Date			20/08/2021	Date				Date				Date			
	Signed				Signed				Signed				Signed			

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

Instrument Serial Number	78548
Sensor Type	500kHz
Altimeter Range (m)	100m
Certificate Number	68267

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	1475.304

Input SOS value to the altimeter using: **#830;1475.3040**

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	1	0	Pass
5	5.001	-0.001	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:	R Musgrove	Date:	20/08/2021

Altimeter Build and Calibration Record

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Instrument type	Altimeter
Serial number	88639
Baud rate set ex factory	9600

Calibration History:	Certificate	Date
	79605	03/11/2023

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
PSU board	0430502	D1	1067192													
Micro board	0430501	E1	1066910	ACTEL 0430707												
				ATMEL 0430704A16												
Transducer Assembly	500kHz		48697	100m												
Pressure sensor	PAA - 10LX		N/A	N/A												

Original Manufacture		Modification		Modification		Modification	
Name	K. Bovey	Name		Name		Name	
Date	03/11/2023	Date		Date		Date	
Signed	K A Bovey	Signed		Signed		Signed	

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

Instrument Serial Number	88639
Sensor Type	500kHz
Altimeter Range (m)	100m
Certificate Number	79605

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	1469.415

Input SOS value to the altimeter using: **#830;1469.4150**

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	1.022	-0.022

Stage 4: Enter the Offset Correction
#828;-0.0220

Stage 5 - Range Check after Offset Correction			
Distance m	Measured Range m	Measured Offset m	Pass/Fail
1	1	0	Pass
5	5	0	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:	03/11/2023
			

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C-Star Calibration

Date August 2, 2023 S/N# CST-1873DR Pathlength 25cm

	Analog output	Digital output
V_d	0.014 V	0 counts
V_{air}	4.820 V	15783 counts
V_{ref}	4.702 V	15397 counts

Temperature of calibration water	23.5	°C
Ambient temperature during calibration	22.6	°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.

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