



# **Cruise Report of the 2021 A22 US GO-SHIP Reoccupation**

*Release Draft 1*

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## GO-SHIP A22 2021 HYDROGRAPHIC PROGRAM

### 1.1 Cruise Scientific Objectives

Viviane Menezes

The A22 2021 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's overall objective is to collect quasi-decadal, highly accurate, surface-to-bottom, coast-to-coast, physical, and chemical oceanic observations. These measurements are essential to monitoring long-term changes in heat, freshwater, carbon, oxygen, and other tracers in the global ocean—the main reservoir in the Earth System.

The A22 meridional transect spans the western North Atlantic from the tropics to the subtropics and is the only GO-SHIP transect in the Caribbean Sea. This year, the A22 worked from South America's continental shelf break, near Aruba, to Puerto Rico and thence northwards to Bermuda along the 66° W meridian. From Bermuda, the transect stretched to the continental shelf south of Woods Hole, following the Line W path ([scienceweb.whoi.edu/linew/index.php](http://scienceweb.whoi.edu/linew/index.php)). This is the first reoccupation of Line W after the end of that program in 2014, whose objective was monitoring the deep limb of the Atlantic Meridional Overturning Circulation (AMOC).

Along the way, the A22 transect crossed major western boundary currents systems: the Caribbean Current, the Gulf Stream, and the North Atlantic Deep Western Boundary Current (DWBC) at different latitudes. The latter two are primary conduits of the AMOC.

Although the A22 transect has been slightly modified over the years, this was the fourth reoccupation of this line in the last three decades. The A22 was first occupied in 1997 (79 stations; R/V Knorr) during WOCE (World Ocean Circulation Experiment), then in 2003 (82 stations; R/V Knorr) and 2012 (81 stations; R/V Atlantis) as part of the CLIVAR (Climate Variability and Predictability).

In 2021, 90 CTD/LADCP/rosette stations were performed over the course of 27-days during boreal spring (20 April - 16 May 2021). Stations were nominally spaced by about 30 nm (50 km) in the open-ocean but closer ( $\leq 15$  nm) at boundary currents and major topographic features. At each station, a suite of surface to bottom vertical profiles was collected using electronic sensors (CTDO, LADCPS, chi-pods, transmissometer, UVP (Underwater Vision Profile)), and 36 Niskin bottles for sampling water at discrete vertical levels.

Data collected during the A22 2021 were (some samplings will be processed in labs onshore):

- Pressure, temperature, salinity, dissolved oxygen
- Fluorescence, shear and micro-scale temperature
- Current velocities from lowered and shipboard ADCPs
- Major nutrients (silicate, phosphate, nitrate, nitrite)
- Transient tracers (Chlorofluorocarbons (CFC-11 and 12), Sulphur Hexafluoride (SF<sub>6</sub>) and Nitrous Oxide (N<sub>2</sub>O))
- Carbon components: total dissolved inorganic carbon (DIC), total alkalinity, pH, and partial pressure of CO<sub>2</sub>, dissolved organic carbon (DOC), total dissolved nitrogen (TDN)

- Nitrate isotopes and radiocarbons
- HPLC pigments and particulate organic carbon (POC)
- Sargassum seaweed
- Bathymetry and shipboard meteorological observations
- UVP high-resolution digital images to study large (>100  $\mu\text{m}$ ) particles and zooplankton
- Size-fractionated microbial respiration
- $\delta^{18}\text{O}$  (ratio of stable isotopes oxygen-18 and oxygen-16) and  $\delta\text{D}$  (Deuterium) for studying the hydrological cycle

In addition to the above measurements, during the A22 8 Argo (Core), 4 Go-BGC and 2 RAFOS floats, and 19 solar-powered spotter buoys (measuring wave, wind, and sea surface temperature) were deployed.

## 1.2 Programs and Principal Investigators

Program	Affiliation	Principal Investigator	Email
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## CRUISE NARRATIVE

The A22 2021 occupation (Figure 1) followed the 2012 transect, except that nine stations were added in the region between the south of Puerto Rico and Bermuda. These additional stations made the nominal spacing for the 2021 occupation about 30 nm (50 km) in the open ocean. Like 2012, stations were more spaced (more than 40- nm) in two areas: around Puerto Rico and Bermuda because the sea is very shallow there ( $< 50$  m). The initial cruise length (28-days) was planned so that there were two weather days if a weather system put CTD operations on hold. Previous occupations of this transect were impacted by weather systems. In 2012, a similar period (April-May) as 2021, a weather system delayed operation at the beginning of the cruise. As explained below, the weather was not a problem in 2021; all 90 planned stations were successfully occupied, with the full suite of core GO-SHIP chemical and physical parameters measured from the sea surface to 10 m above the seafloor (as described in the following sections). The A22 2021 cruise had a total duration of 27 days.

In contrast to 2012, the A22 started at its most equatorial position (12.6N-70W) and ran northward. We departed from St. Thomas (18.3N-64.9W), US Virgin Island, on April 20 and arrived in Woods Hole (41.5N-70.7W), Massachusetts, on May 16, a day earlier than initially predicted due to excellent weather and a faster transit speed than anticipated (sustained 13 knots). The A22 was occupied immediately after the A20 (~52W), which started in Woods Hole, Massachusetts, and worked towards St. Thomas.

Because of the COVID-19 pandemics, we had fewer participants during the A20/A22 journey, each leg with a science party of twenty-five members. The smaller science party decreased our ability to take level-3 measurements in these legs compared with previous (pre-COVID) GO-SHIP cruises. More than half (14 members) participated on both cruises totalizing more than 2-months at sea.

As part of the COVID-19 protocol, all members had to self-isolate in a facility for two weeks, take several COVID tests, measure body temperature twice a day (recording them online), and wear face masks. Twelve people observed isolation in St. Thomas, including the chief and co-chief scientists for the A22. One of the members broke the COVID protocol by walking outside the isolation property without a mask and could not come on board. In total, each member isolating at St. Thomas took 4 to 5 tests: before traveling to St. Thomas (1-2), at St. Thomas (2), and before board the ship (1). All 11 members were negative for COVID-19 and allowed to board R/V Thompson. During the first two weeks of the cruise, all participants wore masks outside their staterooms, kept social distance (only two people per table were allowed during meal times), and continued to monitor their body temperature through the cruise. With this strict protocol being followed by all, no COVID case was registered in both A20 and A22.

The R/V Thompson departed from St. Thomas, US Virgin Island on April 20, 08:00 AST. The transit to the first station near South America was short (about 1.75 days). While in transit, early on April 21, the first Core Argo float (~15.27N-69.06W) was deployed. A test station was done in international waters (4700 m deep) to train the CTD watch-standers and incoming lab technicians. For the test station, noon time was chosen so both watches could participate it. The first cast had to be aborted as a cap was not removed. This was the only time during the A22 that a cast was aborted. The package was redeployed after bringing it back to the deck to remove the cap. Later, it was determined that the UVP did not restart on the redeployment, but the decision was made to continue with the cast. No further incident with UVP happened for the entire cruise. During the test station, the CTD watch-standers learned from the ODF technicians how to prepare the rosette, fill in the logs, make a bottom approach, and fire the bottles. It was a slow cast as everybody was learning, and mistakes were being corrected. All 36 bottles were fired, giving the CTD watch-standers as much

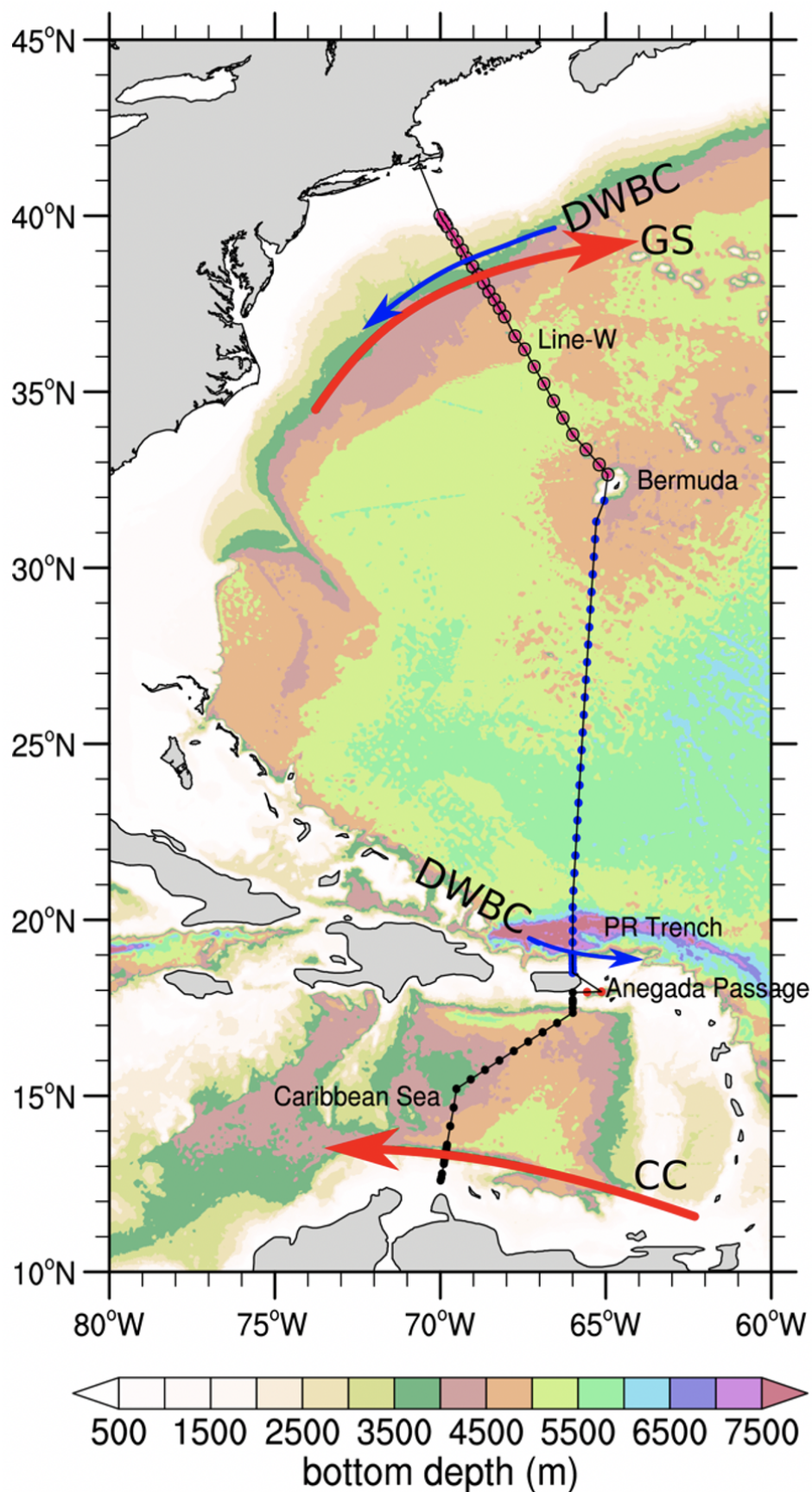


Fig. 1: GO-SHIP A22 2021 occupation. Black dots are used for CTD/LADCP/rosette stations in the Caribbean Sea, pink in the Aneгада Passage, blue along 66°W and pink following the Line-W. PR stands for Puerto Rico.

experience as possible before beginning the first part of the A22 line where stations were close together ( $< 10$  nm in the Caribbean Current).

We arrived at the first station in the early hours of April 22. Throughout the next 24-hours, 7 stations were occupied in the Caribbean Current. The next day, we slowed the pace between stations (even waiting on), from 2h to 2.5h, to give more time for equipment charging (LADCP and UVP) and lab analysis. This procedure was adopted throughout the cruise. In every segment with stations closer than 20 nm, the time between casts was set to 2.5 or 3h depending on whether it was a half/full carbon station. This allowed the labs to take and analyze samples as much as possible, resulting in more complete datasets. Full carbon stations mean that carbon parameters samples are taken from all Niskin bottles. On partial stations (depending on how backed-up analysis is), samples are collected from about half bottles. Bottles on partial stations were selected to capture good vertical resolution. Most skipped bottles were in deep waters where DIC change is much smaller than in upper layers. At the 2021 A22 occupation, even stations were full carbon, and odds partial.

Time for lab analysis is an important parameter that should be considered in future GO-SHIP cruise planning. One thing that worked well was always keeping the labs informed about the time of arrival at stations for the next two/three days ahead. This helped the techs to plan the sampling better, as many of them have expressed. For estimating the time of arrival at stations, we used the Matlab routines from Alison Macdonald (WHOI), who kindly shared with us. We adapted the routines to the A22 specificities— everything worked well and avoid sample analysis falling behind schedule.

The weather was good, and the sea was flat most of the time during the 2021 occupation, except by a single day (May 10, 2021). Typically, winds were around 10 to 15 m/s along the A22 (Figure 2). The only time the winds peaked above 35 m/s was on May 10, when CTD operation was put on hold for almost a day during station #73. This was the single weather day for all cruise. Thanks to the weather forecast, we knew well in advance that the ship would face strong winds and high waves.

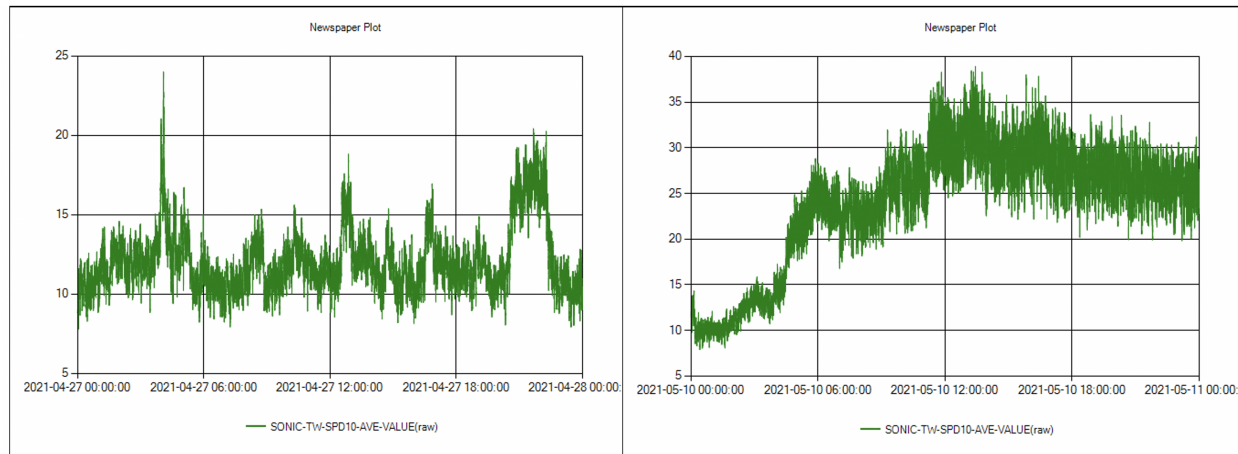


Fig. 2: Real-time winds during the GO-SHIP A22 2021 occupation. Left is a typical day with wind strength varying from 10-20 m/s. Right is the winds for May 10 when the CTD operations were put on hold.

The good weather and flat sea made CTD deployments straightforward during the 2021 occupation (Figure 3). Only minor issues happened as documented later in this report: few unfired bottles, a broken O-ring, a missed target depth, wrong numbers in the sample log, and LADCP cable connections. These issues were sporadic and immediately fixed. Besides these minor issues, two mild injuries happened during rosette preparation, which led us to double our attention as a precaution. The injuries were a slight concern through the cruise, although everybody was well.

All 16 floats and 19 spotter buoys were deployed after stations with a ship speed of a few knots. All of them were successfully deployed by the CTD watchstanders and R/V Thompson marine technicians, as later described. For the Go-BGC floats, the deployments were chosen to match full carbon stations. This decision was taken to avoid disrupting the vertical sampling scheme of carbon parameters and at the same time to have enough depths between the surface and 2000 m to compare with these floats.



Fig. 3: Flat sea and fair winds during GO-SHIP A22 2021 occupation. Left on May 3 and Right on May 15.

Sargassum samples, a piggy-back project during the A22 2021, were also collected when stations were in the US EEZ (exclusive economic zone) or international waters. This work was conducted by the ABs coordinated by the chief-mate.

## 2.1 Principal Finding and Features

The A22 transect occupied the western North Atlantic, extending from South America to the continental shelf of the Cape Cod. Along the way, it crossed main water masses of the North Atlantic (Figure 4): a strong signal of Antarctic Intermediate Water (AAIW) at the Caribbean Sea, a vestige of Antarctic Bottom Water (AABW) north of Puerto Rico ( $\gamma = 28.162 \text{ kg/m}^3$ ), the salty Subtropical Underwater (STUW) from the Caribbean Sea to  $23\text{--}25^\circ\text{N}$ , several types of North Atlantic Deep Water (NADW) north of  $30^\circ\text{N}$  and mixed waters of the Slope Sea, north of the Gulf Stream.

In the Caribbean Sea, the water mass distribution was similar to the previous occupations. No significant change in properties in the deep ocean was observed compared to 2012 (Figure 5). But, there was slight warming and salinification over the entire basin at those depths. Between 100-300 m, the saline STUW (with salinity  $> 37$ ) was easily spotted in all stations in the Caribbean (Figure 6). The STUW continued to be spotted north of Puerto Rico until  $25^\circ\text{N}$  (Figure 6, upper panel).

The fingerprint of AAIW (low salinity and low oxygen in the North Atlantic) was also present between 600-1000 m in the Caribbean (Figure 6). The AAIW enters the Caribbean basin through the Anegada Passage. Two stations were realized there during 2021, instead of one as in 2012. In both stations, there was a clear AAIW signal. As in 2012, the AAIW signature was intensified near South America, and its signature faded outside the Caribbean.

Like 2012, the water column was well mixed and weakly stratified in the Caribbean Sea below 2000 m (Figure 6). No strong density front or mesoscale eddies could be identified in the density field at the upper layer. Between 1500-2500, slightly slanted isopycnals were noticeable near Puerto Rico (Figure 6, lower left panel), probably associated with the Caribbean deep cyclonic gyre described by [Joyce2001] based on the 1997 A22 occupation.

The thermohaline front associated with the Gulf Stream was apparent at the end of the section (Figure 6). The Gulf Stream was particularly strong, with speeds measured by the shipboard ADCP of about 2.2 m/s in its core. Concurrent altimetry measurements (Figure 7) slightly underestimated it, with a maximum speed of 1.7 m/s.

Compared with 2012, cooling in the deep ocean was observed north of Puerto Rico, where the DWBC passes (Figure 5). This was accompanied by a slight freshening. Below 4500, where a vestige of AABW was detected, the cooling seems to be intensified. As a result, there was an uplift of  $\gamma = 28.15$  by about 200 m in the water column. CFCs



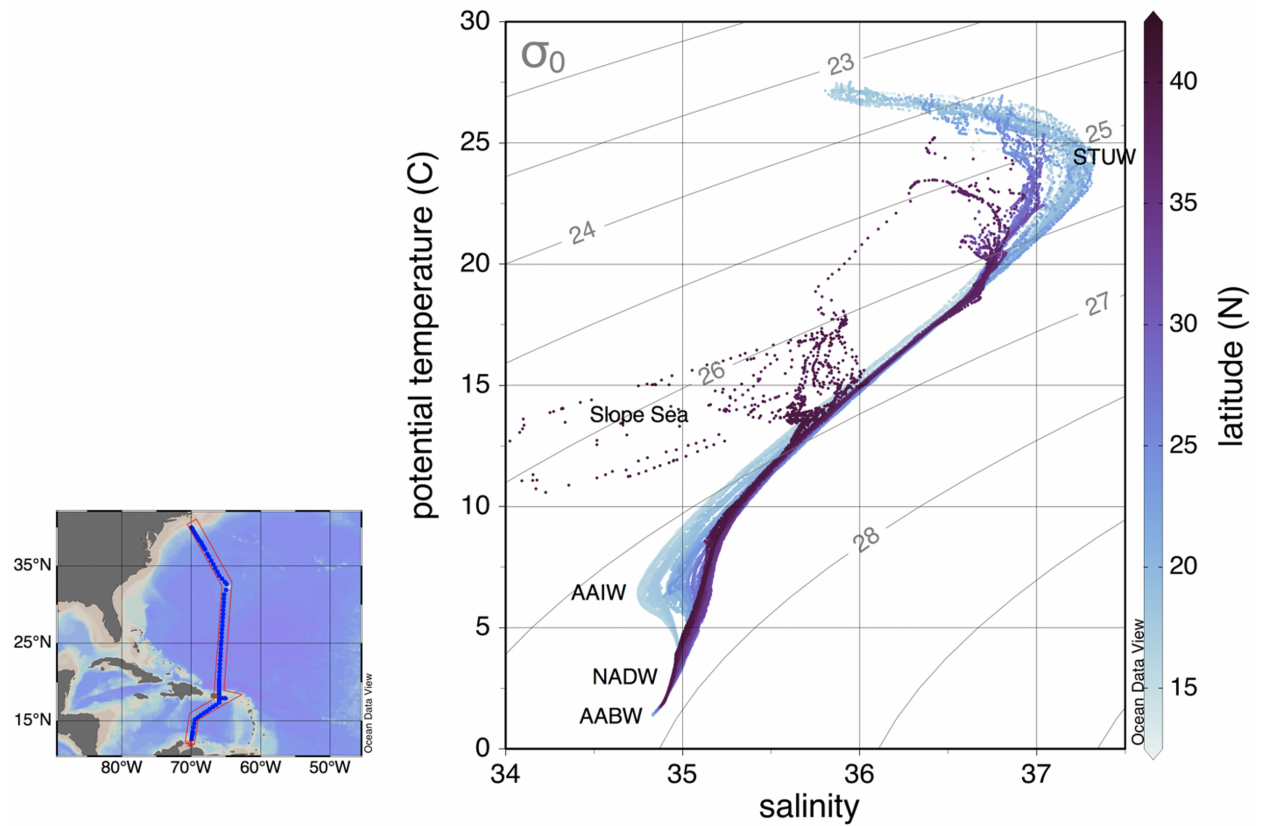


Fig. 4: Temperature-Salinity diagram for the A22 2021 occupation. Color shows the latitude and contours potential density anomaly ( $\text{kg/m}^3$ ). Map displays the A22 transect in the western North Atlantic. Water mass classification based on neutral density ( $\gamma$ ) as defined by Joyce et al. (2001)

measurements (not shown) also suggest changes north of Puerto Rico. In 2012, it was found an eddy with unusual water properties, near 21.5°N, just north of the Puerto Rico Trench. The property anomalies - high oxygen and CFCs, low salinity, and nutrients – were particularly strong between 1000-1500 meters depth. It was suggested that this eddy originated to the east of Newfoundland. In 2021, the eddy was not present.

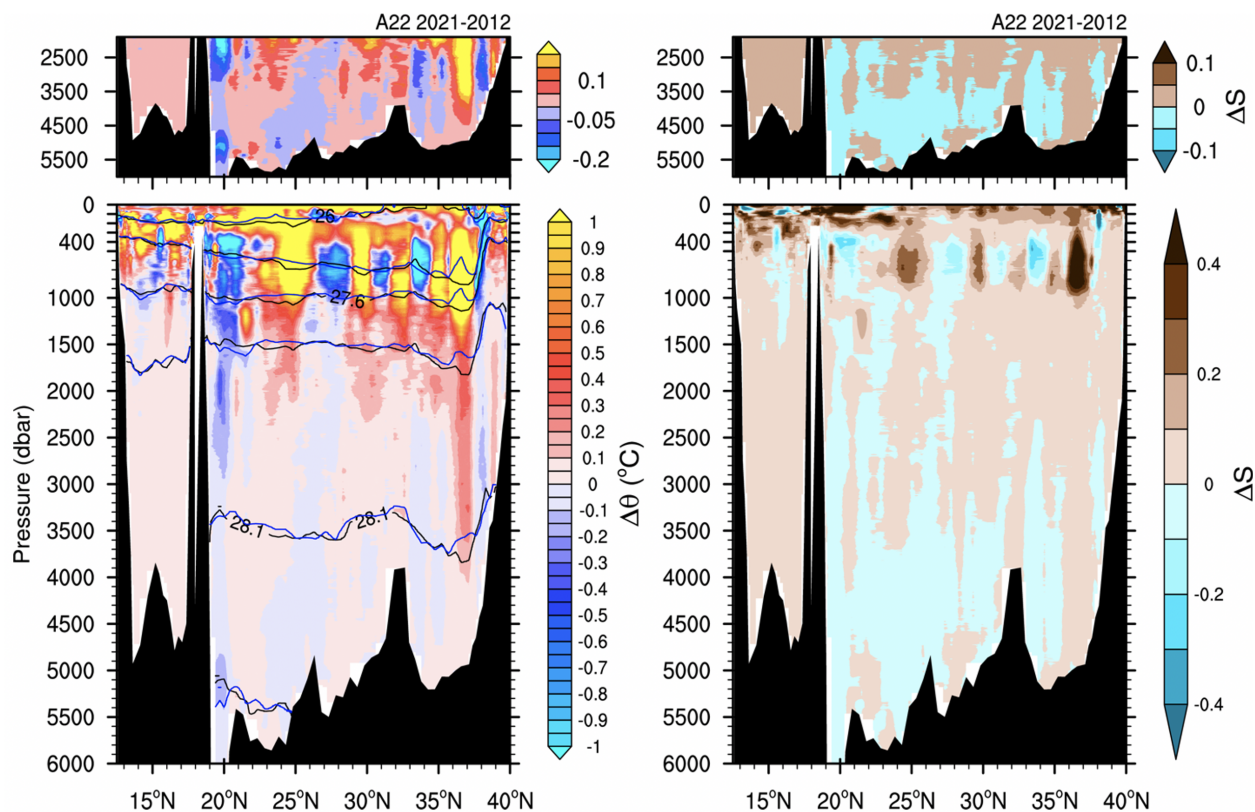


Fig. 5: Difference in potential temperature (left) and salinity (right) between 2021 and 2012 A22 occupations. Contours are neutral density in 2021 (black) and 2012 (blue).

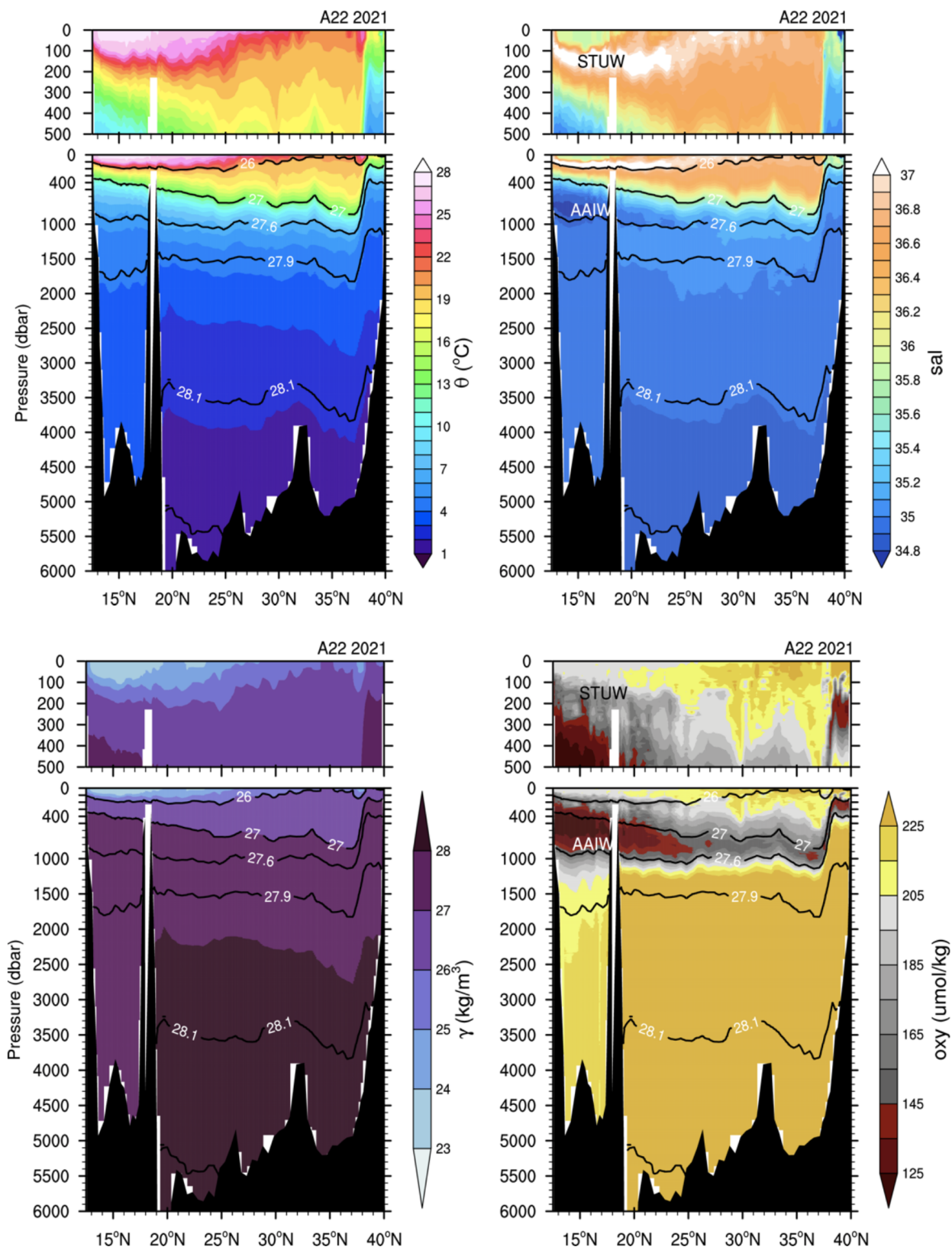


Fig. 6: Potential temperature (upper left) and salinity (upper right) distributions at A22 2021 (stations 1-90) from CTD data. Same for neutral density (lower left) and dissolved oxygen (lower right). Contours are  $\gamma = 26, 27, 27.6, 27.9, 28.1$ , and  $28.15 \text{ kg/m}^3$ .

## 2.1. Principal Finding and Features

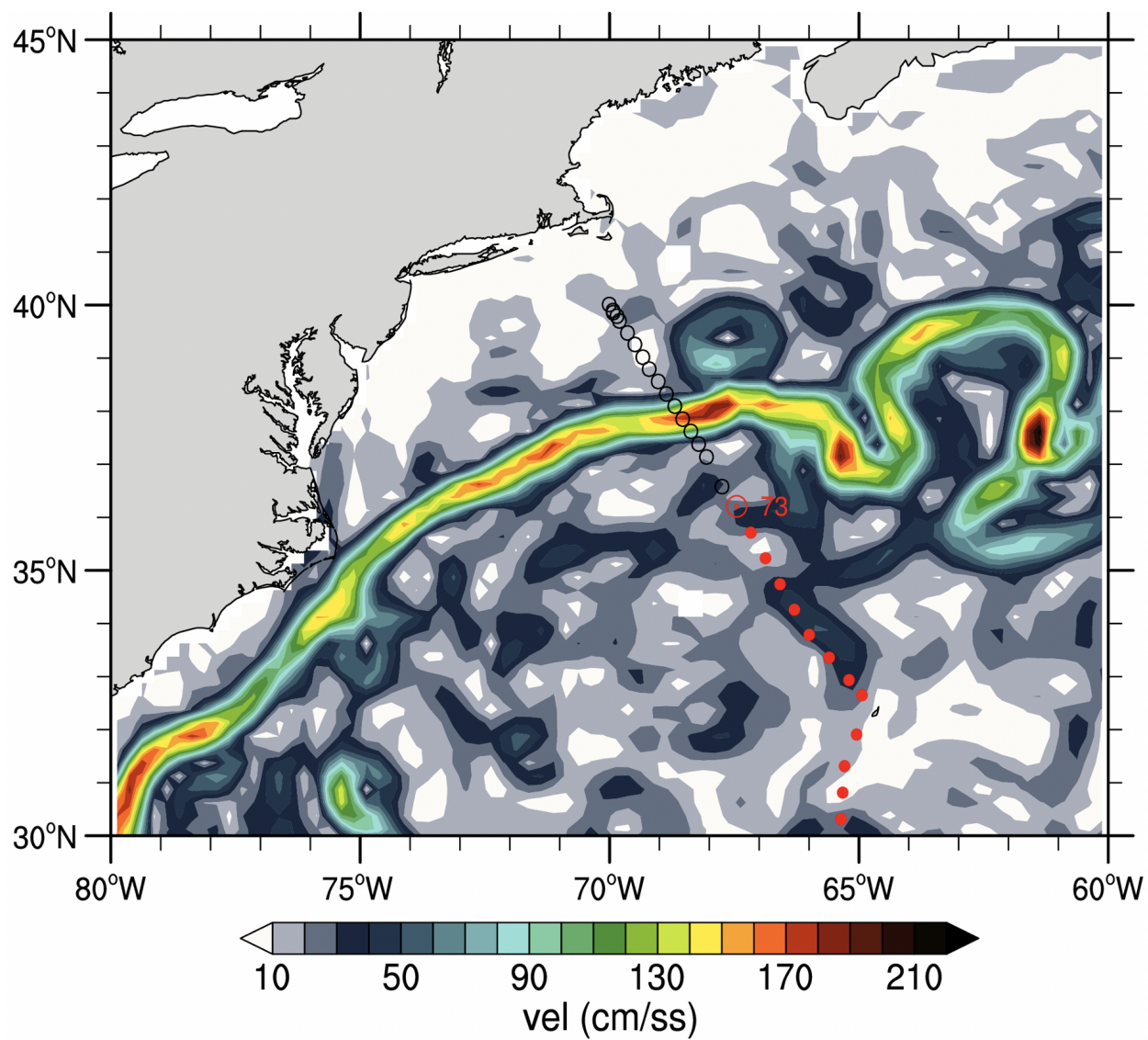


Fig. 7: Geostrophic velocities for May 11 from satellite altimeters and A22 stations (dots).



## CTD AND ROSETTE SETUP

For A22-2021 the new STS 36 place yellow rosette and bottles, built in 2017, were used. The rosette and bottles were built before P06 2017, making this the seventh time this package has been deployed. The bottles were made with new PVC, with new non-baked o-rings and electro-polished steel springs. This represents a change from the past, where on GO-SHIP cruises using ODF equipment before P06 2017 o-rings were baked for 3 days at 100°C at 1-3 Torr in a sweeper gas of hydrogen. Springs used to be painted and Tygon tubing added to the ends to prevent paint wearing away from bottle firing. As on P06 2017 no sample contamination has been noticed by the change in o-rings and springs. The package used on A22-2021 weighs roughly 1500 lbs in air without water, and 2350 lbs in air with water. The package used on A22-2021 weighs roughly 950 lbs in water. In addition to the standard CTDO package on GO-SHIP cruises three chipods, two LADCPs, and one experimental CTD were mounted on the rosette. During the cruise we encountered a handful of problems, most notably noisy altimeter data and bottle firing issues. We describe all of the above in more detail in the sections below.

### 3.1 Underwater Sampling Package

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

CTD and cage were horizontally mounted at the bottom of the rosette frame, located below the carousel for all stations. The temperature, conductivity, dissolved oxygen, respective pumps and exhaust tubing was mounted to the CTD and cage housing as recommended by SBE. The reference temperature sensor was mounted between the primary and secondary temperature sensors at the same level as the intake tubes for the exhaust lines. The transmissometer was mounted horizontally on the lower LADCP brace with hose clamps around both of its ends, avoiding shiny metal or black tape inside that would introduce noise in the signal. The oxygen optode, fluorometer, and altimeter were mounted vertically inside the bottom ring of the rosette frames, with nothing obstructing their line of sight. One 300 KHz bi-directional Broadband LADCP (RDI) unit was mounted vertically on the bottom side of the frame. Another 300 KHz bi-directional Broadband LADCP (RDI) unit was mounted vertically on the top side of the frame. The LADCP battery pack was also mounted on the bottom of the frame. The LADCP and LADCP battery pack were mounted next to each other at the beginning of the cruise. If we imagine the LADCP battery being north on the rosette, the LADCP was mounted east, the CTD mounted south, and the UVP mounted west.

Equipment	Model	S/N	Cal Date	Stations	Group
Rosette	36-place	Yellow	–	901-90	<i>STSI/ODF</i>
CTD	SBE9+	0914	–	901-90	<i>STSI/ODF</i>
Pressure Sensor	Digiquartz	110547	Feb 5, 2021	901-90	<i>STSI/ODF</i>
Primary Temperature	SBE3+	32309	Feb 2, 2021	901-90	<i>STSI/ODF</i>
Primary Conductivity	SBE4C	43399	Nov 25, 2020	901-90	<i>STSI/ODF</i>
Primary Pump	SBE5	51871	–	901-90	<i>UCSD</i>
Secondary Temperature	SBE3+	32380	Feb 2, 2021	901-90	<i>STSI/ODF</i>
Secondary Conductivity	SBE4C	41880	Dec 4, 2020	901-90	<i>STSI/ODF</i>
Secondary Pump	SBE5	58690	–	901-90	<i>UCSD</i>
Transmissometer	Cstar	1803DR	Aug 9, 2019	901-90	<i>TAMU</i>
Fluorometer Chlorophyll	WetLabs ECO-FL-RTD	1156	–	901-90	<i>STSI/ODF</i>
Dissolved Oxygen	SBE43	430255	Nov 13, 2020	901-90	<i>ODF</i>
Oxygen Optode	JFE Advantech Rinko-III	0296	Apr 7, 2017	901-90	<i>ODF</i>
Reference Temperature	SBE35	0105	Feb 9, 2021	901-90	<i>STSI/ODF</i>
Carousel	SBE32	0187	–	901-43	<i>STSI/ODF</i>
Carousel	SBE32	1178	–	44-90	<i>STSI/ODF</i>
Altimeter	Valeport 500	53821	–	901-59, 61-90	<i>UCSD</i>
Altimeter	Valeport 500	48049	–	60	<i>UCSD</i>
DL <i>LADCP</i>	Teledyne RDI WH300	24497	–	901-90	<i>LDEO</i>
UL <i>LADCP</i>	Teledyne RDI WH300	12734	–	901-90	<i>LDEO</i>
UVP	–	207	–	901-90	<i>UAF</i>
D2 CTD	D2 CTD	01-1563	–	901-45	<i>WHOI</i>
D2 CTD	D2 CTD	01-1565	–	46-90	<i>WHOI</i>
Chipods	Chipod	2008 Ti44-5	–	901-90	<i>OSU</i>
Chipods	Chipod	2027 Ti44-3	–	901-90	<i>OSU</i>
Chipods	Chipod	2030 Ti44-11	–	901-90	<i>OSU</i>

## 3.2 Winch and Deployment

The aft DESH-5 winch deployment system was used for all stations. The rosette system was suspended from a UNOLS-standard three-conductor 0.322” electro-mechanical sea cable. The sea cable was already terminated from the previous leg (A20) and no electrical or mechanical issues occurred on A22.

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



Fig. 1: Package sensor setup from south.





Fig. 2: Package sensor setup from east.



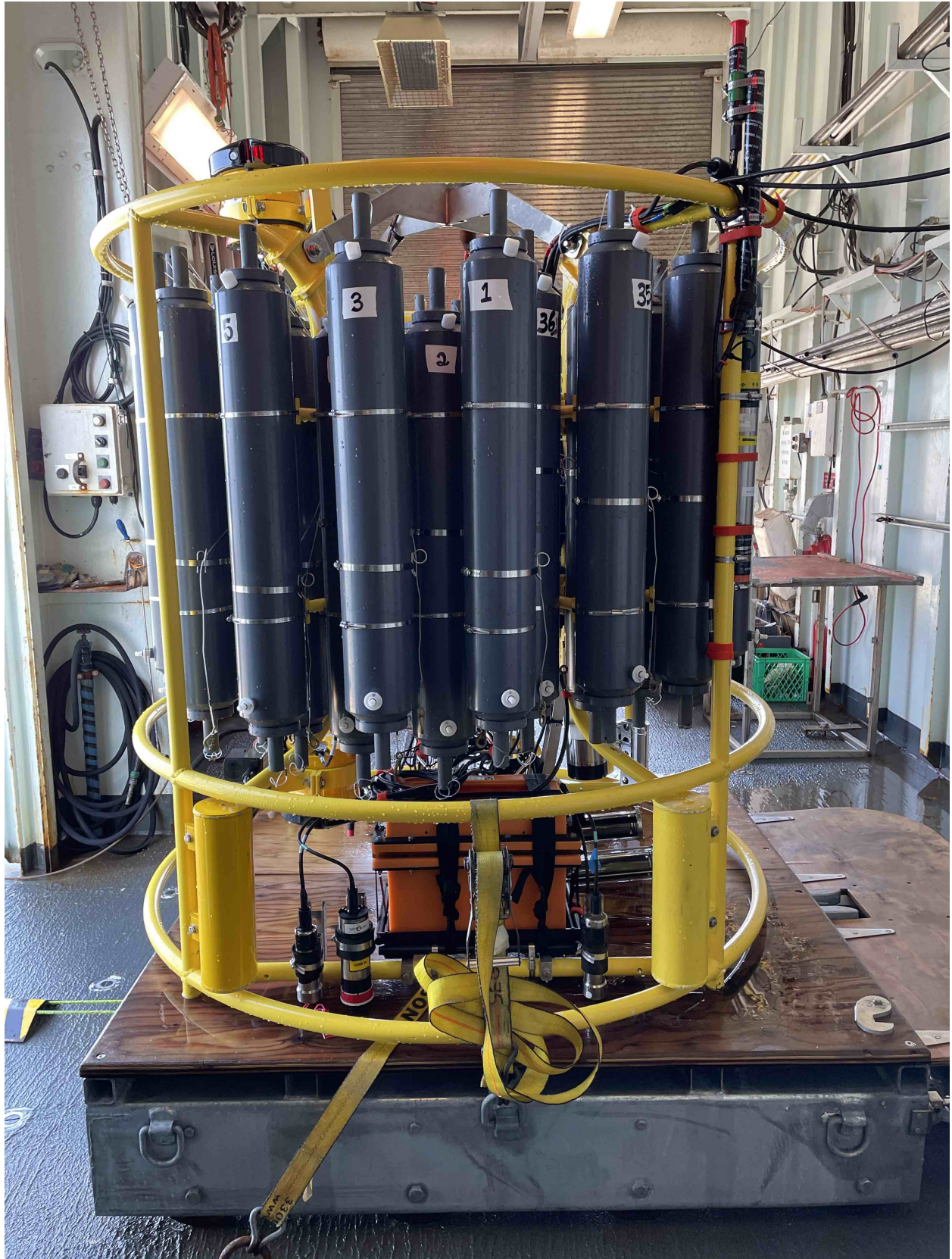


Fig. 3: Package sensor setup from north.



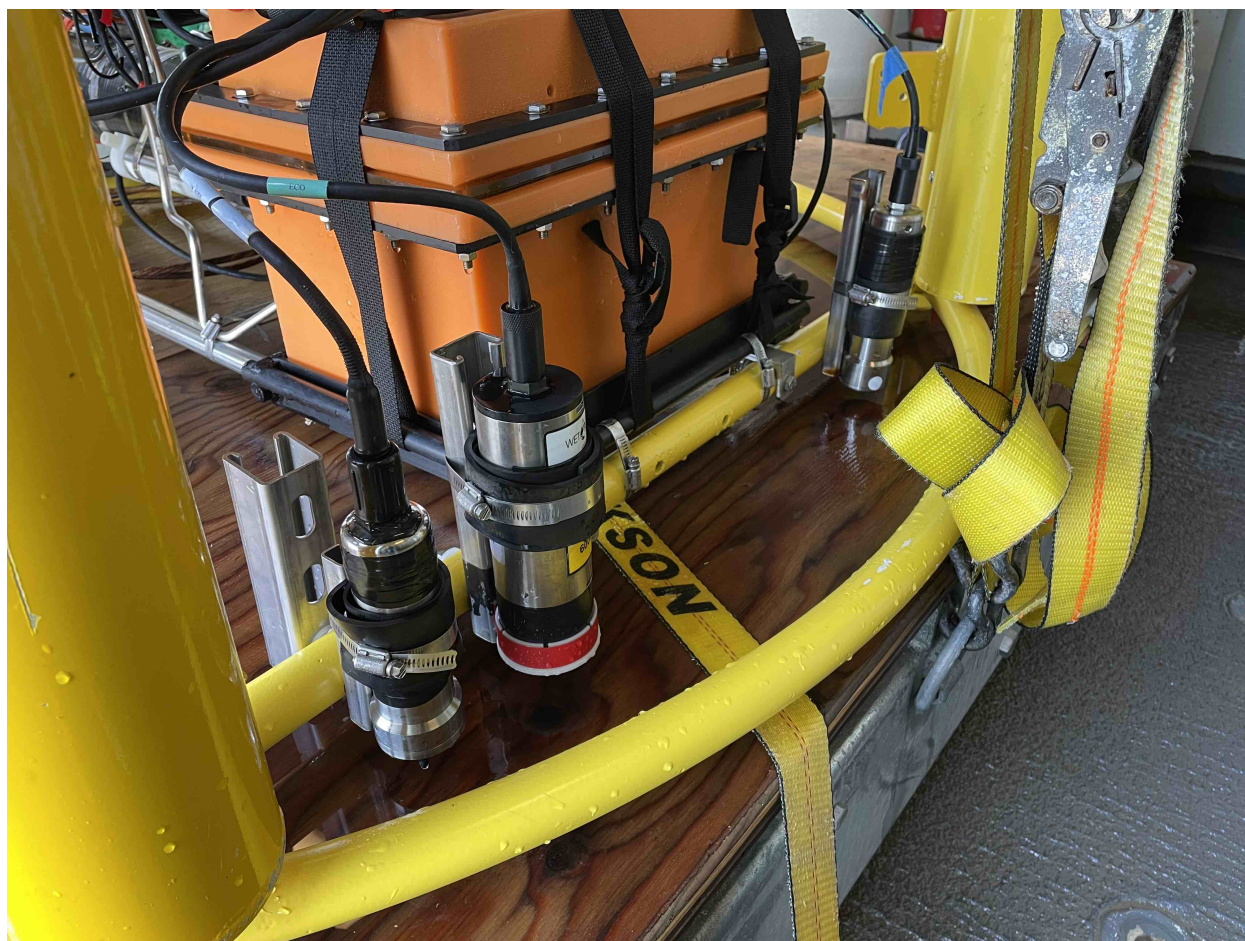


Fig. 4: From left to right: oxygen optode, fluorometer, LADCP battery pack, altimeter.



Fig. 5: Package setup from southwest, with CTD in foreground and downlooking chipod to the right.





Fig. 6: Paket setup from west.



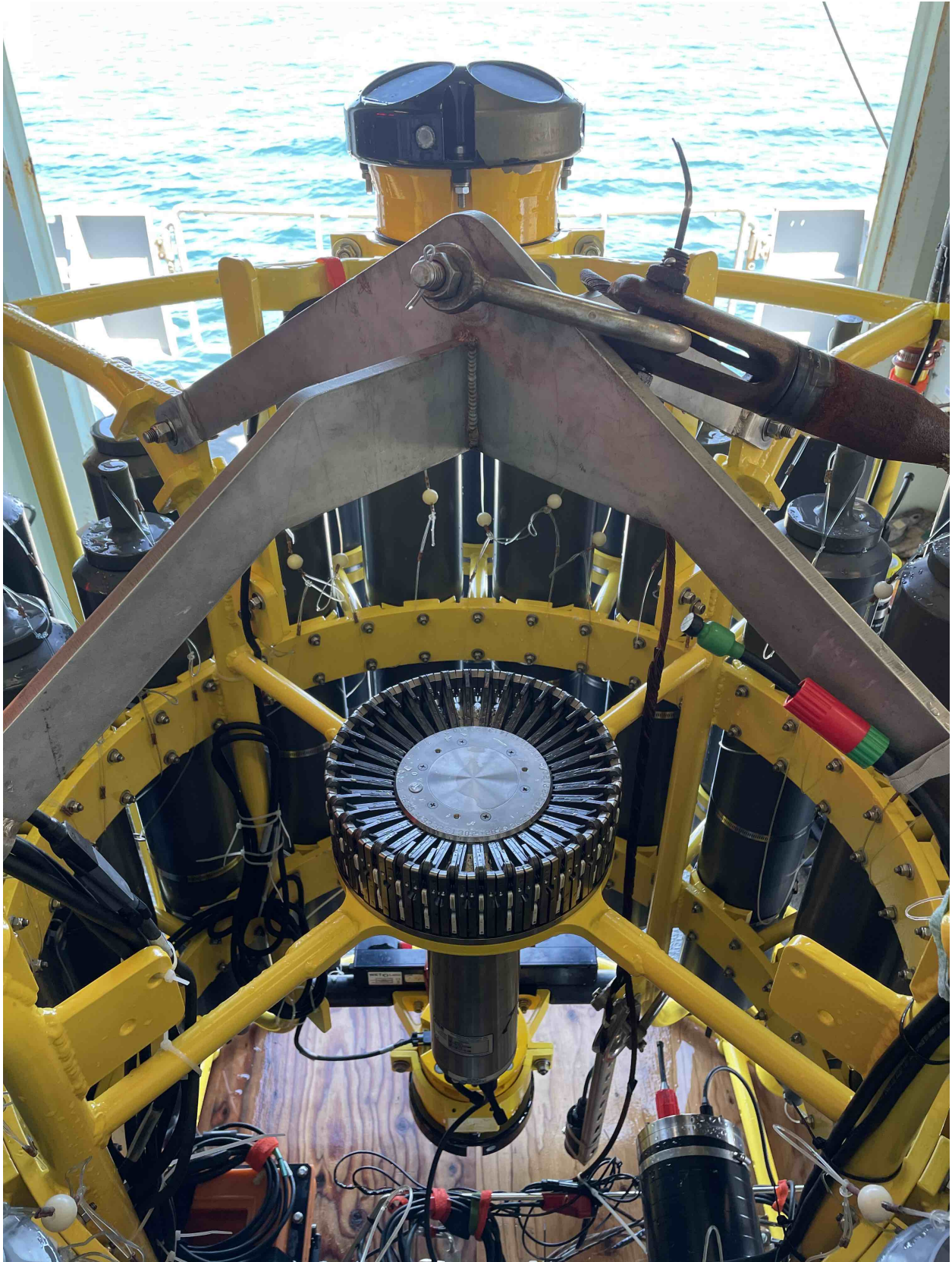


Fig. 7: Package setup from west, top view.

### 3.3 Maintenance and Calibrations

During A22-2021 routine maintenance was done to the rosette to ensure quality of the science done. Actions taken included rinsing all electrical instruments on the rosette down with fresh water after each cast and adjusting hose clamps and guide rings as needed such that lanyards had appropriate tension. Care was taken not to rinse the spigots and other parts of the bottle that might be touched by samplers in order to not contaminate the samples. After each cast, syringes of fresh water were connected to the plumbed lines to rinse the sensors and allow them to soak between casts. While in freezing conditions, water was drained after rinse to avoid freezing in the plumbing. Overhead heaters recently installed on the Thompson were run while in freezing or near-freezing conditions. The rosette was routinely examined for valve and o-ring leaks, which were maintained as needed. SBE35RT temperature data was routinely downloaded each day.

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

### 3.4 Logs

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

April 21, 2021

90001 – First test cast aborted around 350 m. Tube connecting the primary and secondary pumps (attached in port to prevent fouling of the plumbing lines) was not removed prior to start of cast, identified initially in data by large differences in primary/secondary T/C lines.

90002 – Test cast to 4500 m. UVP did not turn on during ascent from initial 20 m soak. Tried soaking again (at 20 m), still did not activate. Upon recovery, data from cast 90001 was present but nothing was recorded from 90002. The assumption is that the rosette was not on deck long enough to fully power cycle the UVP.

April 22, 2021

00101 – UVP turned on as expected; no issues noted. Adjusted guide ring on bottle 30.

00201 – Bottles 4, 5, 6, and 9 were leaking, 11 and 12 had loose vents.

00301 – Fired surface bottle (#23) on the fly due to large swell. Rosette sat at 35 m for longer than standard while deck crew prepared for recovery.

00401 – Adjusted guide ring on bottles 29, 30, 32 before cast.

00501 – No issues noted.

00601 – No issues noted.

April 23, 2021

00701 – Bottle 25 did not close, top cap was stuck against rosette frame crossbar. Entire bottle was moved downward to prevent that from happening again.

00801 – No issues noted.

00901 – No issues noted.

01001 – ADCP data reported in multiple files, suspected power issues. Swapped out cable and battery.

April 24, 2021

01101 – No issues noted.

01201 – Bottle 3 did not fire.

01301 – No issues noted.

01401 – Surface bottle (#36) was too cold, closer to temperature of 400-500 m bottles. Inspecting after cast, the bottom end cap was loose enough to close itself, likely early closure. Adjusted guide ring to prevent early closures.

April 25, 2021

01501 – No issues noted.

01601 – Adjusted guide ring for bottle 32 before cast. Miscommunication with winch during bottom approach: stopped early (~20 m from bottom), fired bottle as normal, after which winch continued downward briefly. On way up, bottle 2 was misfired shortly after leaving the bottom.

01701 – No issues noted.

01801 – No issues noted.

April 26, 2021

No issues noted for stations 01901-02101.

April 27, 2021

02201 – No issues noted.

02301 – No issues noted.

02401 – ~160 m salinity spike (just primary line?)

02501 – No issues noted.

02601 – No issues noted.

02701 – Taking less than half a rosette worth of bottles, fired odd bottles to make recovery easier (uniformly distributed weight instead of all to one side). Was confusing for analysts in other groups, will not do again.

02801 – 115 m depth bottle mistakenly skipped, shifted remaining bottles appropriately.

April 28, 2021

02901 – No issues noted.

03001 – Adjusted guide rings on 2, 10, 12, 14, 19, 32-36 before cast.

03201 – Raised bottle 26 up before cast, may have been firing late because of poor placement.

03301 – Bottle 3 did not close.

April 29, 2021

03401 – Bottle 22 did not close. Adjusted bottle 23 height since it was getting stuck on crossbar.

03501 – Bottle 3 did not close. Replaced carouse latch for bottle 33 and raised bottle 22 to improve lanyard angle.

03601 – Adjusted guide ring son bottle 2, 8, 9, 17, 19, 21, 24.

03701 – Air vent on bottle 35 was not fully shut.

April 30, 2021

03801 – Salinity signal was a little spiky during soak but quickly remedied itself (may just be bottom of mixed layer or something pulled through lines?).

03901 – Bottle 26 guide ring adjusted upward.

04001 – No issues noted.

May 1, 2021

04101 – Bottle 3 did not fire, bottle 16 was leaking due to loose air vent. Bottle 26 accidentally misfired on fly.

04201 – Bottle 3 did not fire.

04301 – Adjusted guide rings on bottles 17-21, 23, 32. Skipped firing bottle 3, will repair “spare” (i.e. primary) carousel during cast and replace during transit to next.

May 2, 2021

04401 – Adjusted guide ring on bottle 15. Replaced carousel with primary, after swapping solenoid #12.

04501 – No issues noted.

04601 – D2 1563 replaced with 1565 at PI’s request. Adjusted guide rings on bottles 11, 15, 19, 21, 23, 29, 30, 33, and 35. UVP did not show much change in surface during soak but was fine during cast; suspected the upper water column did not have much to photograph.

04701 – Downlooking chipod was remounted with thicker rubber between unistruct and frame, hoping to stop the shifting which is occurring during deployment, cast, or recovery.

May 3, 2021

04801 – Spigot on bottle 35 was not fully closed.

04901 – Altimeter spiking during bottom approach.

05001 – Replaced spigot o-rings for bottle 16 before cast, was sticky and hard to fully close. Altimeter continuing to be spiky during bottom approach.

May 4, 2021

05101 – Bottle 35 was leaking, broken air vent o-ring – replaced before next cast. Also replaced for bottles 5, 7, and 9.

05201 – Altimeter continuing to be spiky during bottom approach.

05301 – Adjusted guide rings on 18, 29-34 before cast. Altimeter did not kick in until ~50 m from bottom, then was noisy during the entire bottom approach; stopped ~20 m from bottom to be conservative. Bucket testing afterward did not reveal any obvious problems and comparison with a new (presumably function) altimeter had the same results.

05401 – Adjusted guide rings on 8, 10, 36. Same altimeter behavior.

May 5, 2021

05501 – Same altimeter behavior. Will leave as is since the behavior is now predictable, rather than introduce new unknowns. Bottle 25 fired quickly after stop, rather than waiting 30 seconds. Spigot pull tab on bottle 6 broken on recovery.

05601 – Same altimeter behavior.

05701 – Replaced o-rings and broken pull tab on bottle 6 before cast.

May 6, 2021

05801 – Spiky transmissometer data, tape on hose clamp came loose. After cast, wrapped electrical tape in a spiral around hose clamp to prevent it from peeling up.

05901 – Altimeter seems to be getting worse, swapping in TGT’s 48049 before cast 60.

06001 – Adjusted guide rings on 10, 18, 20, 24, 29-33, 35, 36. Altimeter not much different. Swapping back to original (S/N 53821) and also swapping to TGT’s cable to see if that is the issue.

06101 – Altimeter behavior largely the same. Ultimately decided noise is due to rosette angle and bathymetry scattering the pings, the effect of which is reduced closer to the bottom.

May 7, 2021

06201 – Transmissometer spike ~1130 m.

06301 – Adjusted guide rings on the usual bottles. After cinching down with drill, tightened every hose clamp further with a screwdriver. Was able to get at least 1/4 turn out of each, drill not as powerful as it used to be?

06401 – No issues noted.

May 8, 2021

06501 – Raining heavily during deployment.

06601 – No issues noted.

06701 – No issues noted.

May 9, 2021

06801 – No issues noted.

06901 – Rubber between top bottle standoff sliding out, removed after cast. Hose clamp was not tightened down so bottle was a little loose.

07001 – At 5 m bottle stop, there was a miscommunication and the ship rotated to face into the swell. Rotated before bottle fired so sample is highly contaminated.

07101 – Tightened all guide ring hose clamps with screwdriver once again.

May 10, 2021

07201 – No issues noted.

Weather delay for the rest of the day.

May 11, 2021

07301 – Changed top end cap, lanyards connected to it, and o-ring. Miscommunication between shifts led to the interior lanyard (cap to spring) to be changed again.

07401 – No issues noted.

07501 – Bottle 29 vent was not fully closed.

May 12, 2021

07601 – Bottle 2 did not seal all the way, o-ring not well seated – o-ring replaced by night shift (miscommunication again, o-ring was just recently changed). Inter-lanyards (cap to cap) replaced on bottles 28 and 29.

07701 – Bottle 2 o-ring not well seated again, may have questionable data. Tried to remove any twist in o-ring and re-seat. Gulf Stream currents very strong, large wire angle.

07801 – Inter-lanyard (cap to cap) for bottle 29 was very tight upon recovery, removed shortly after getting on deck. Old one was ~1.5” too short – replaced with a new one of appropriate length before cast 79. Bottle 2 o-ring unseated again, replaced end cap with original one that was working properly.

May 13, 2021

07901 – ADCP having trouble turning on, cast slightly delayed. Rosette drifted upward during bottom bottle stop.

08001 – No issues noted.

08101 – Adjusted guide ring 23, tightened all others with screwdriver. Spigot on bottle #16 is very sticky, replaced before cast 82.

08201 – No issues noted.

May 14, 2021

08301 – No issues noted.

08401 – No issues noted.

08501 – Mixed layer shallow, no good spot to switch to auto-cast.

08601 – Trying bottle stop experiment, fired triplicates at 30, 60, and 90 seconds after stop, at two depths.

08701 – No issues noted. Trying bottle stop experiment, fired triplicates at 30, 60, and 90 seconds after stop, at two depths.

May 15, 2021

08801 – Trying bottle stop experiment, fired triplicates at 30, 60, and 90 seconds after stop, at two depths.

08901 – No issues noted.

09001 – No issues noted.

### **3.5 Sensor Problems**

*SBE 32 Carousel:* Another solenoid failure, this time in secondary carousel. Primary was fixed and swapped in on before cast 44. Pictures of swollen solenoid shown below.

*Altimeter spiking:* Ended up just being bathymetry/bad returns. Swapping altimeter and cables made no difference.

*Bottle guide rings:* Guide rings continually slipped during the whole cruise. In the end, the issue was they were not being sufficiently tightened by the normal drill we used – fixed by hand tightening further with screwdriver.





Fig. 8: Bad solenoid (center), cloudy and raised edge from corrosion.



Fig. 9: Bad solenoid (left), cloudy and raised edge from corrosion.



## CTDO AND HYDROGRAPHIC ANALYSIS

### PIs

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### Technicians

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## 4.1 CTDO and Bottle Data Acquisition

The CTD data acquisition system consisted of an SBE-11+ (V2) deck unit and a networked generic PC workstation running Windows 10. SBE SeaSave7 v.7.26.7.107 software was used for data acquisition and to close bottles on the rosette.

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

Once the deck watch had deployed the rosette, the winch operator would lower it to 10 meters. The CTD sensor pumps were configured to start 10 seconds after the primary conductivity cell reports salt water in the cell. The CWO checked the CTD data for proper sensor operation, waited for sensors to stabilize, and instructed the winch operator to bring the package to the surface in good weather or no more than 5 meters in high seas. The winch was then instructed to lower the package to the initial target wire-out at no more than 30 m/min for the first 100 m and no more than 60 m/min after 100 m depending on sea-cable tension and the sea state.

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

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

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

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

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

## 4.2 CTDO Data Processing

Shipboard CTD data processing was performed after deployment using SIO/ODF CTD processing software “ctdcal” v. 0.1. CTD acquisition data were copied onto a OS X system, and then processed. CTD data at bottle trips were extracted, and a 2-decibar downcast pressure series created. The pressure series data set was submitted for CTD data distribution after corrections outlined in the following sections were applied.

A total of 90 CTD stations were occupied including one test station. A total of 91 CTDO/rosette/LADCP/UVP/chipod casts were completed.

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

Temperature, salinity and, dissolved O<sub>2</sub> comparisons were made between down and upcasts as well as between groups of adjacent deployments. Vertical sections of measured and derived properties from sensor data were checked for consistency.

A number of issues were encountered during A22-2021 that directly impacted CTD analysis. Issues that directly impacted bottle closures, such as slipping guide rings, were detailed in the Underwater Sampling Package section of this report. Temperature, conductivity, and oxygen analytical sensor issues are detailed in the following respective sections.

## 4.3 Pressure Analysis

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

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

CTD #0914:

	Start P (dbar)	End P (dbar)
Min	-0.20	-0.28
Max	0.05	-0.08
Average	0.09	-0.19

On-deck pressure reading varied from -0.20 to 0.05 dbar before the casts, and -0.28 to -0.08 dbar after the casts. The pressure offset varied from -0.24 to 0.09, with a mean value of -0.1 dbar.

## 4.4 Temperature Analysis

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

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

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

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

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

Fit coefficients are shown in the following tables.

Table 1: Primary temperature (T1) coefficients.

Station	$cp_2$	$cp_1$	$ct_2$	$ct_1$	$c_0$
901-29	9.127e-11	-7.1661e-7	0.0	0.0	4.7065e-4
30-72	8.4036e-11	-8.6330e-7	0.0	0.0	1.1989e-3
73-90	-4.6532e-11	1.2251e-7	0.0	0.0	-8.1808e-4

Table 2: Secondary temperature (T2) coefficients.

Station	$cp_2$	$cp_1$	$ct_2$	$ct_1$	$c_0$
901-29	0.0	-2.1424e-7	0.0	0.0	-1.4331e-4
30-72	0.0	-8.1227e-8	0.0	0.0	-6.3841e-4
73-90	0.0	-1.3354e-7	0.0	0.0	-7.2422e-4

Corrected temperature differences are shown in the following figures.

The 95% confidence limits for the mean low-gradient (values  $-0.002^\circ\text{C} \leq T1-T2 \leq 0.002^\circ\text{C}$ ) differences are  $\pm 0.00391^\circ\text{C}$  for SBE35RT-T1,  $\pm 0.00387^\circ\text{C}$  for SBE35RT-T2 and  $\pm 0.00157^\circ\text{C}$  for T1-T2. The 95% confidence limits for the deep temperature residuals (where pressure  $\geq 2000\text{dbar}$ ) are  $\pm 0.00087^\circ\text{C}$  for SBE35RT-T1,  $\pm 0.00099^\circ\text{C}$  for SBE35RT-T2 and  $\pm 0.00087^\circ\text{C}$  for T1-T2.

**Minor complications impacted the temperature sensor data used for the A22-2021 cruise.**

- Near-surface temperature gradients in the southern end of the survey were extremely sharp, occasionally causing SBE35RT readings to be questionable.

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

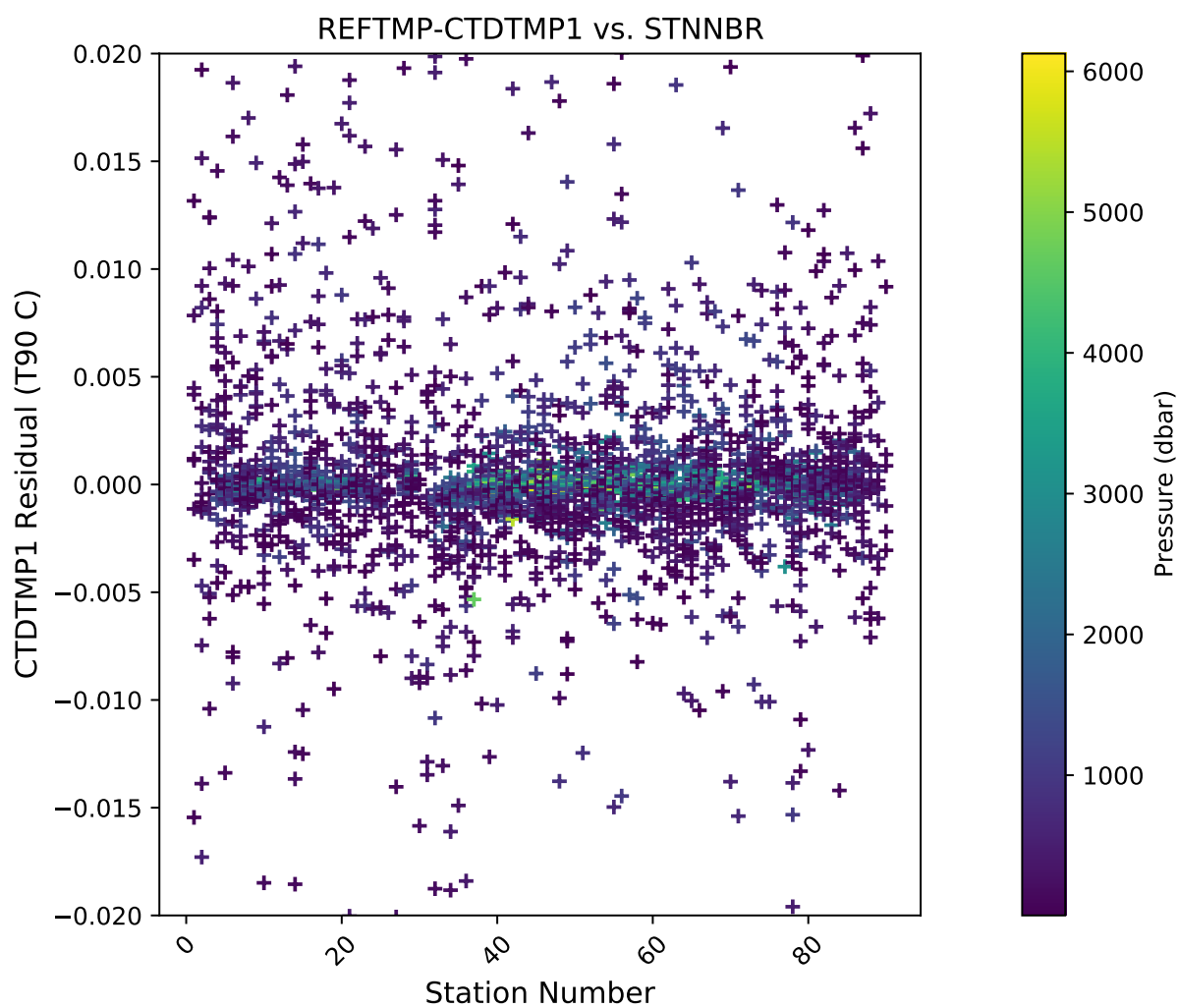


Fig. 1: SBE35RT-T1 versus station.



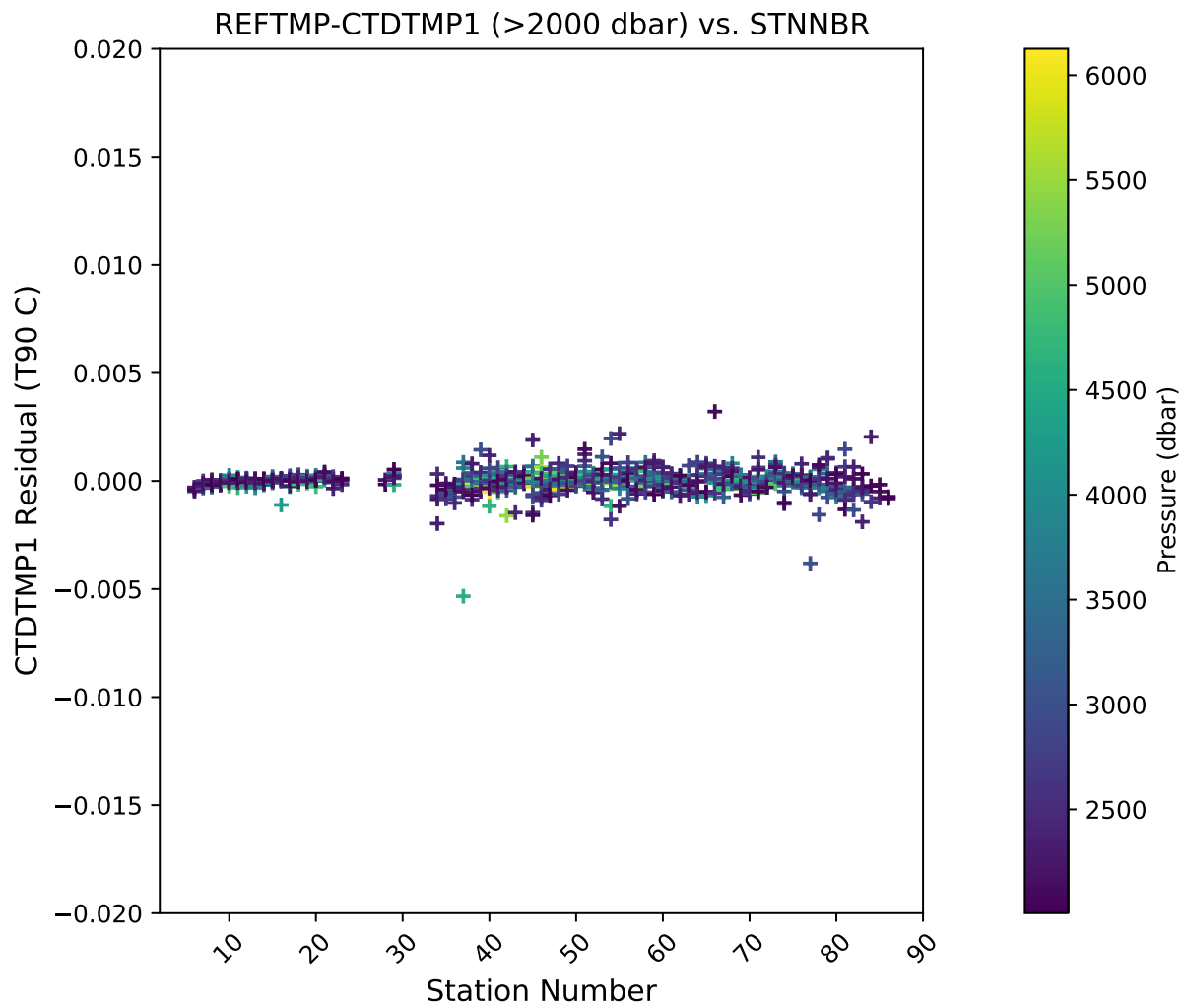


Fig. 2: Deep SBE35RT-T1 by station (Pressure  $\geq 2000$ dbar).

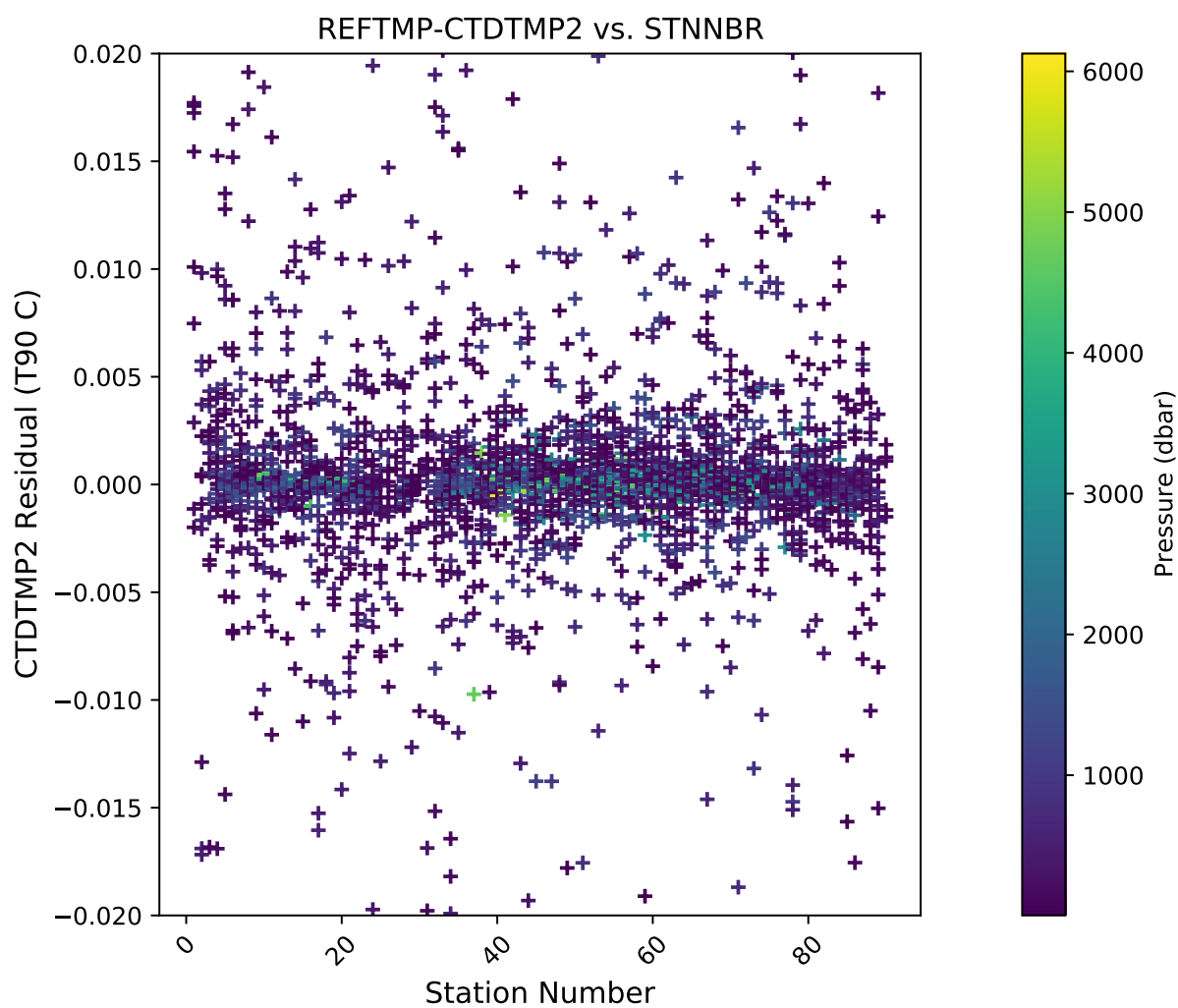


Fig. 3: SBE35RT-T2 versus station.

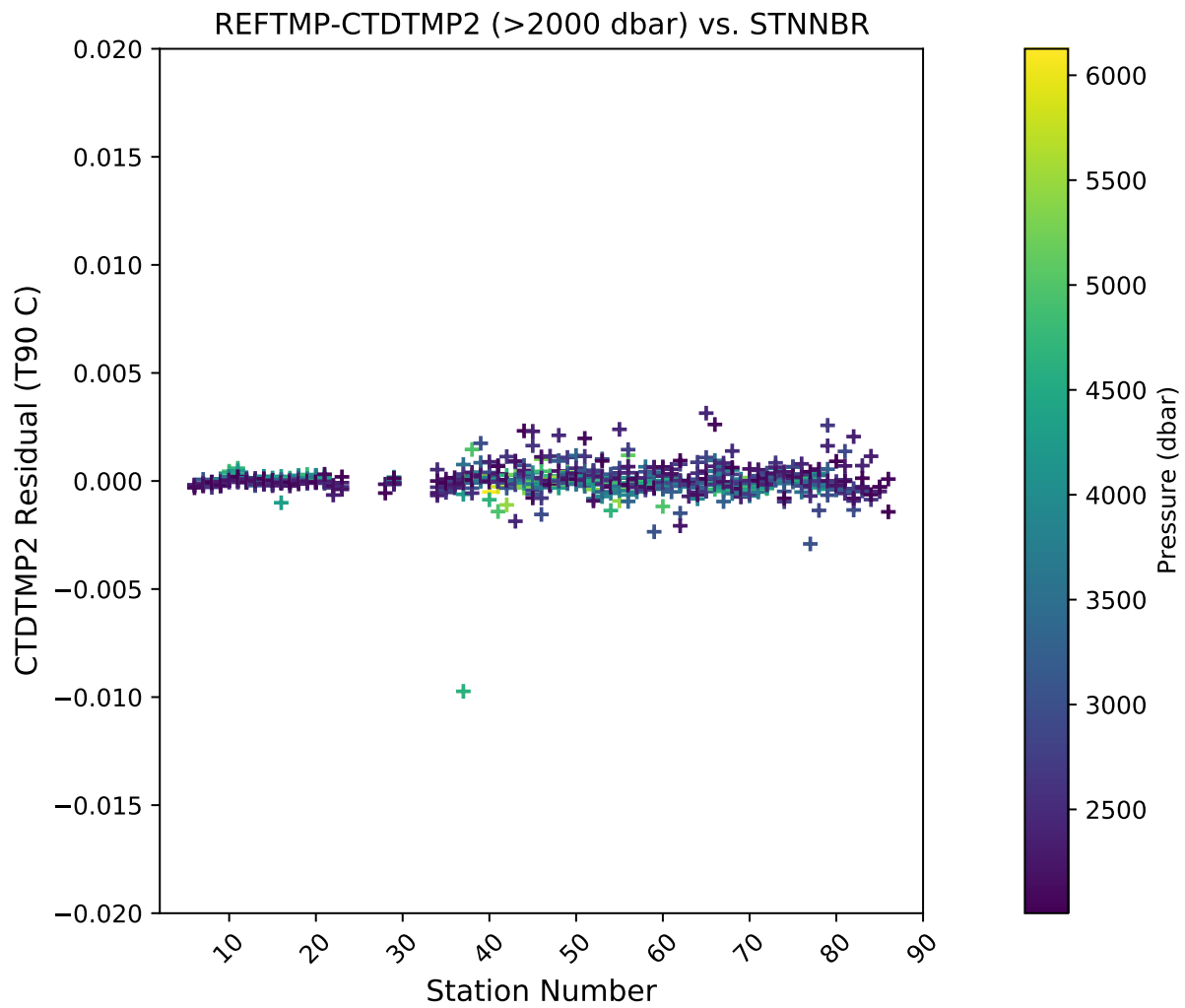


Fig. 4: Deep SBE35RT-T2 by station (Pressure  $\geq 2000$ dbar).

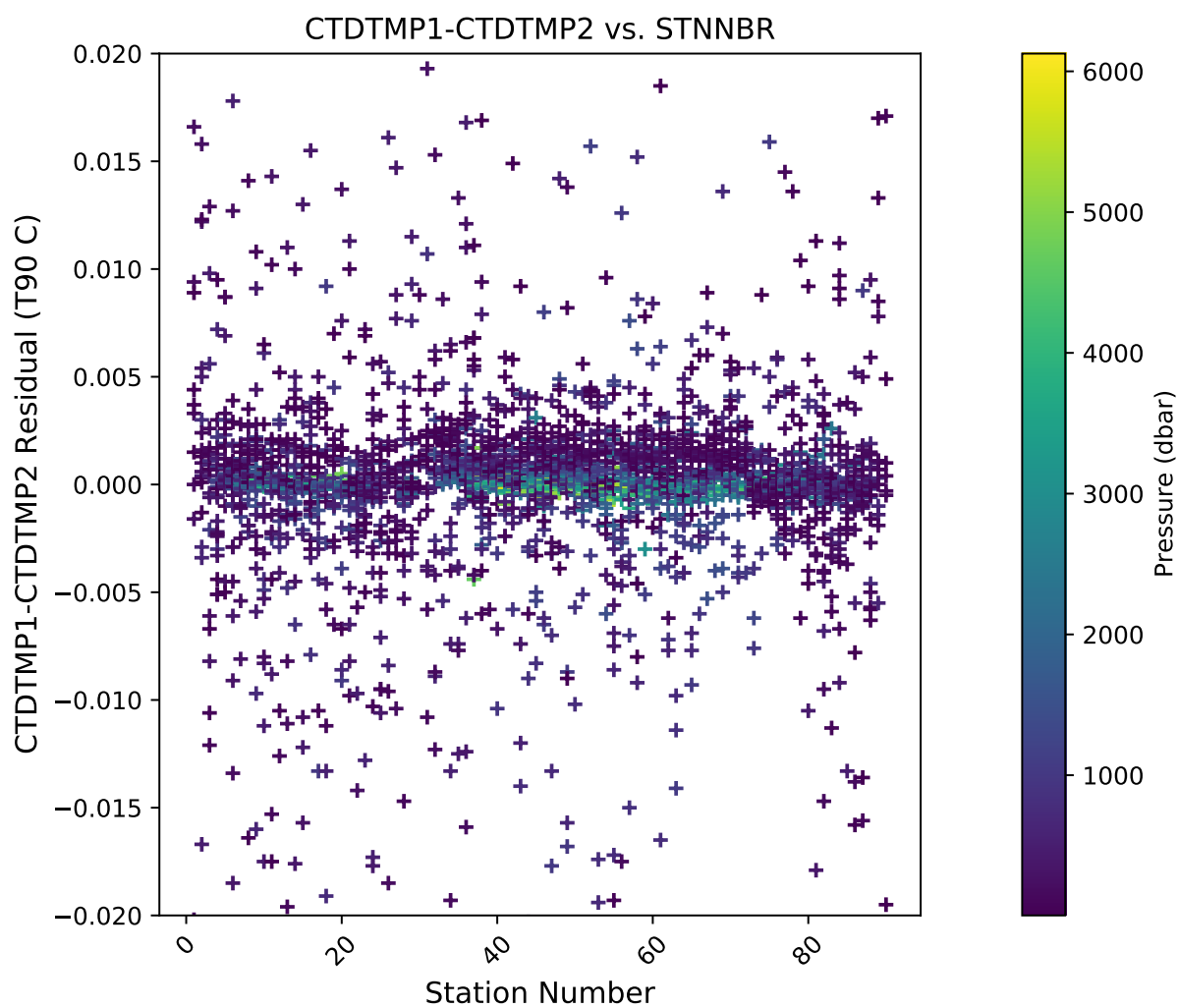


Fig. 5: T1-T2 versus station.



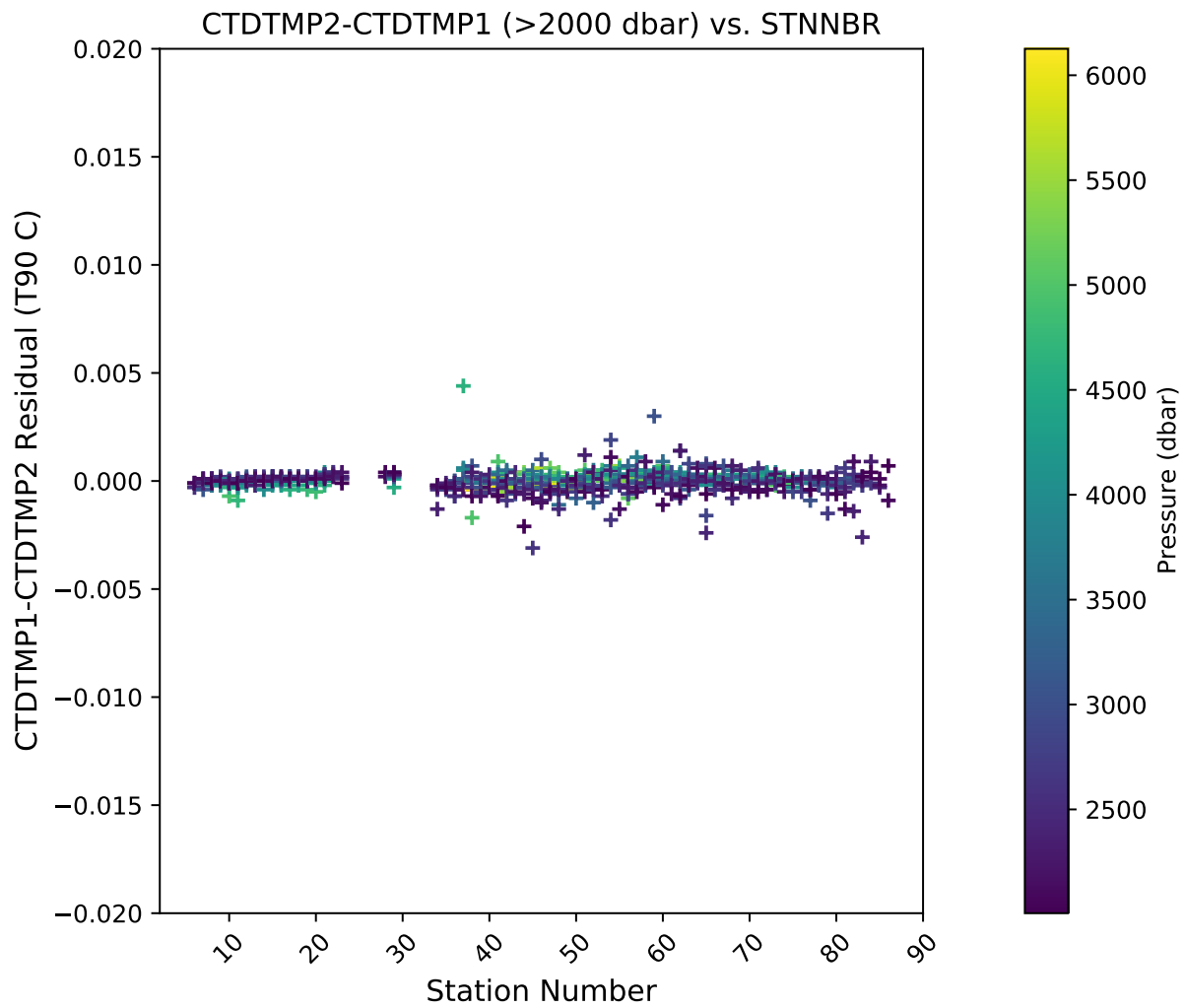


Fig. 6: Deep T1-T2 versus station (Pressure  $\geq 2000$ dbar).

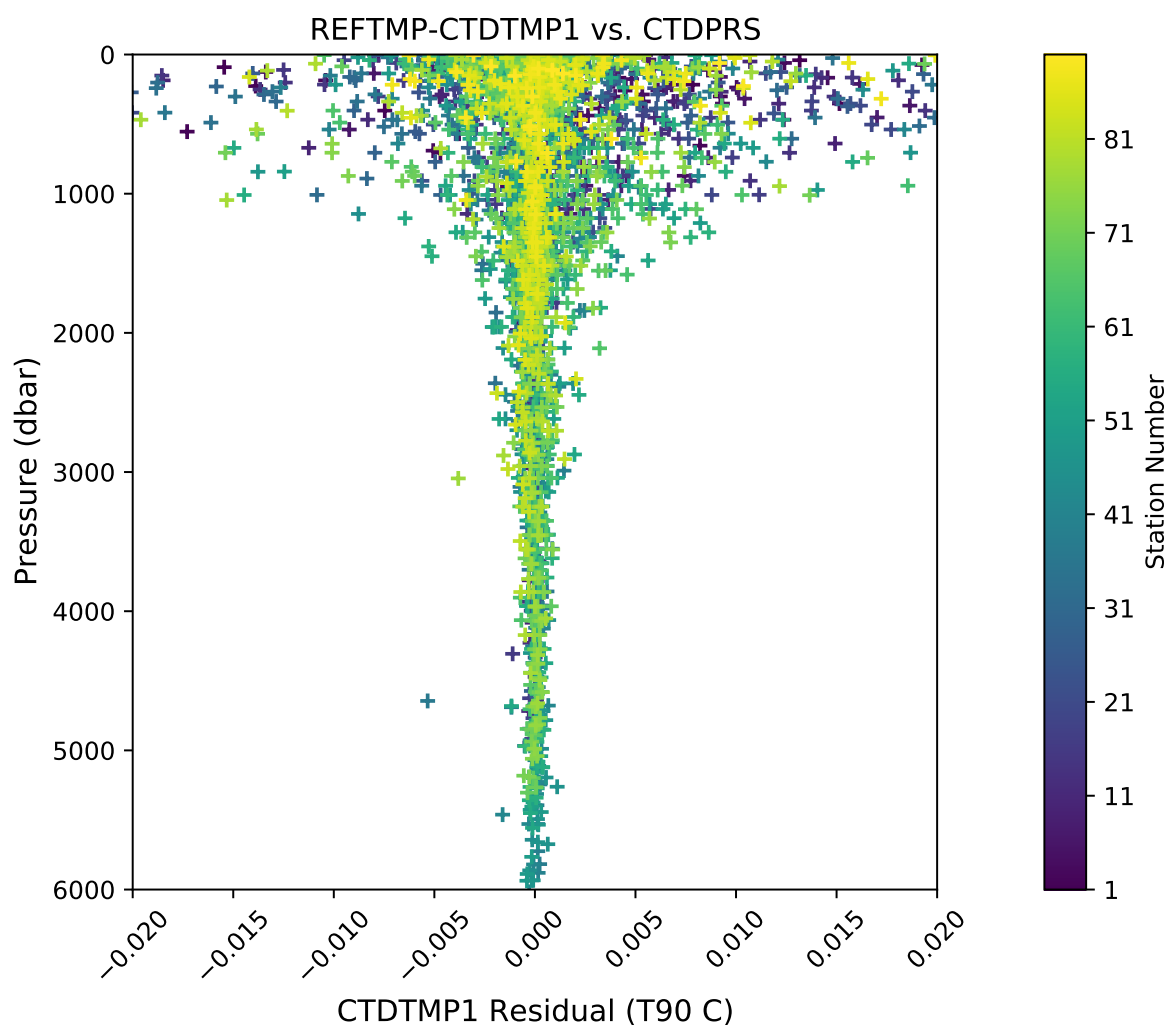


Fig. 7: SBE35RT-T1 versus pressure.

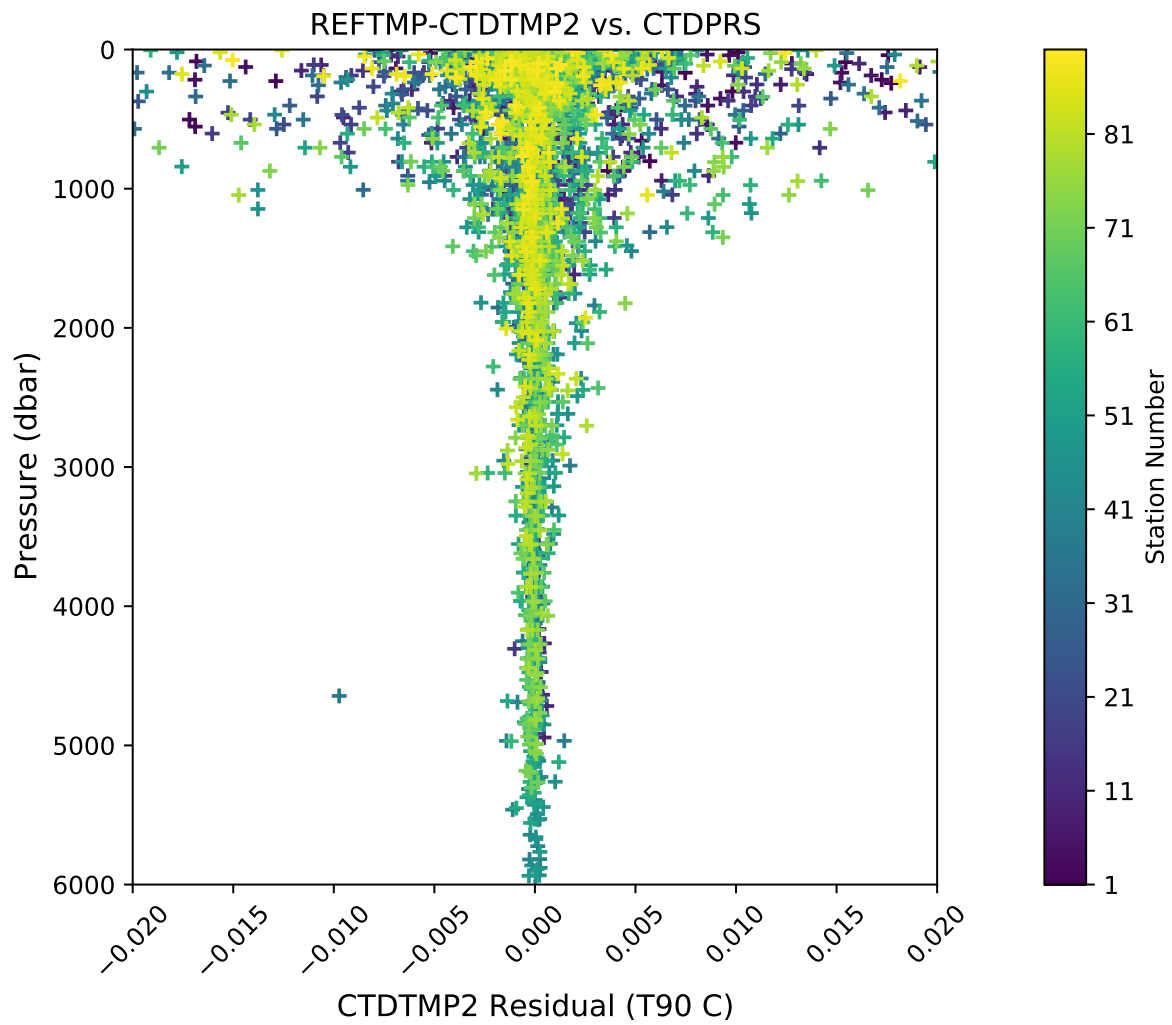


Fig. 8: SBE35RT-T2 versus pressure.

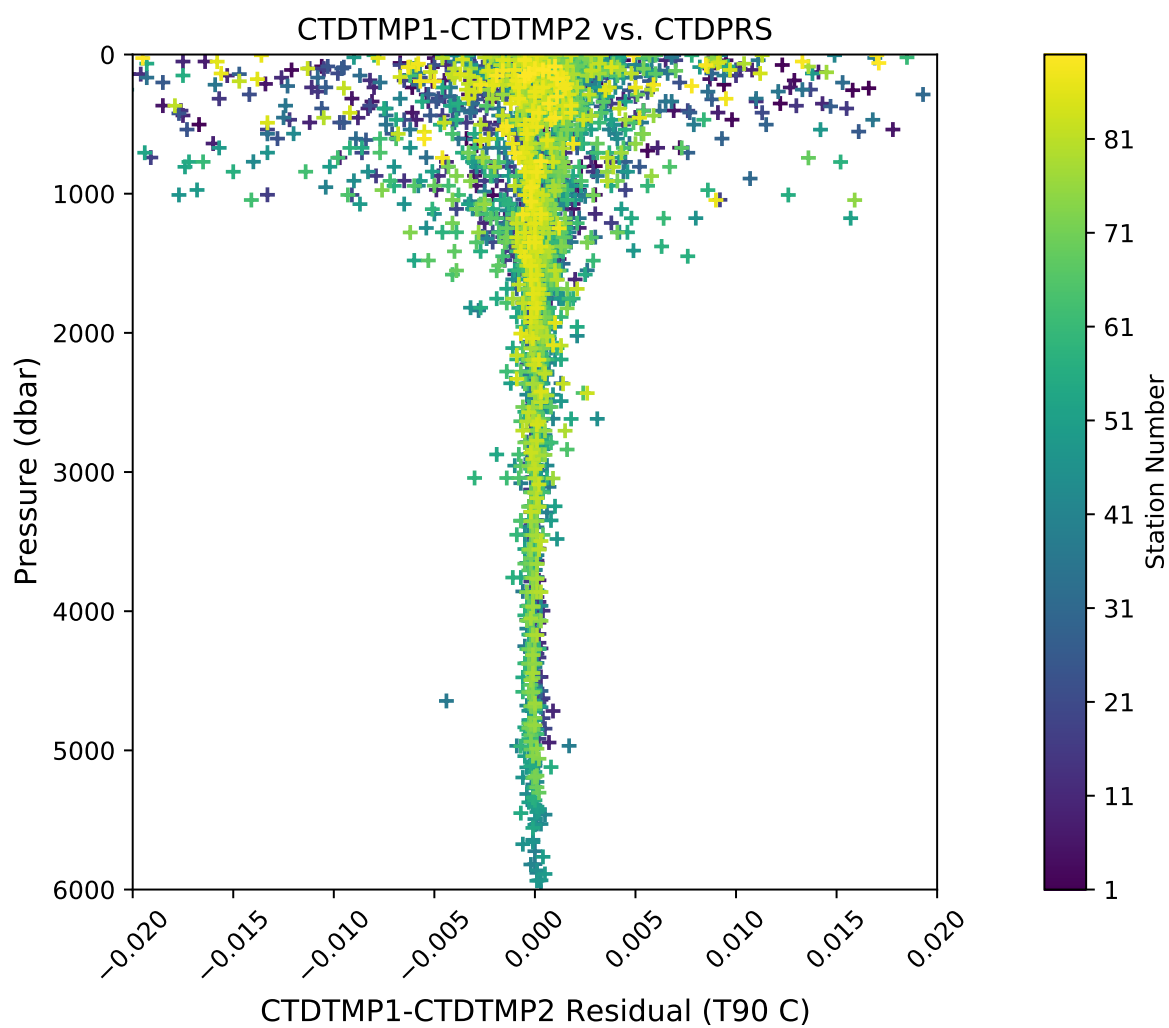


Fig. 9: T1-T2 versus pressure.



## 4.5 Conductivity Analysis

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

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

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

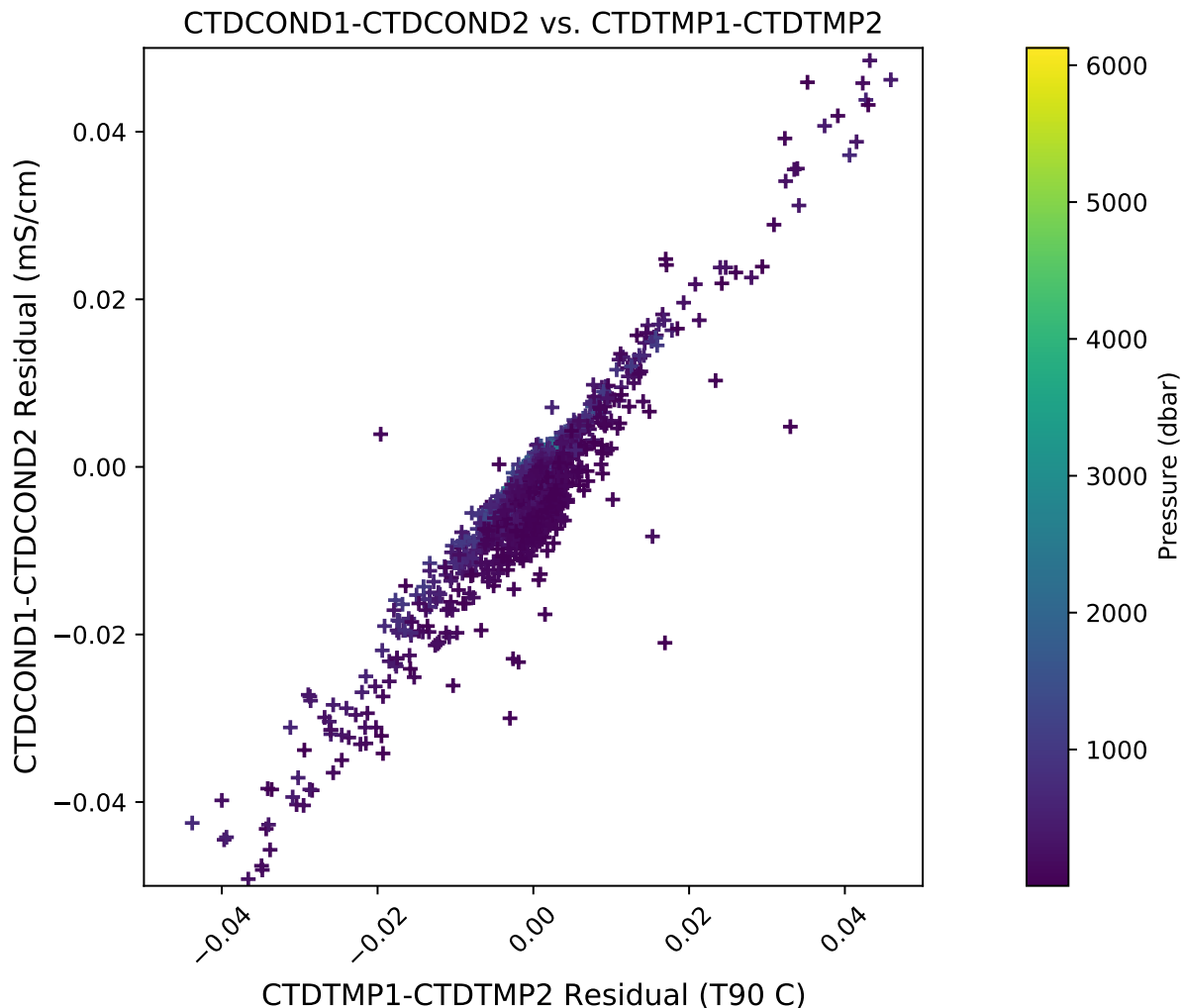


Fig. 10: Coherence of conductivity differences as a function of temperature differences.

A functioning SBE4C sensor typically exhibit a predictable modeled response. Offsets for each C sensor were deter-

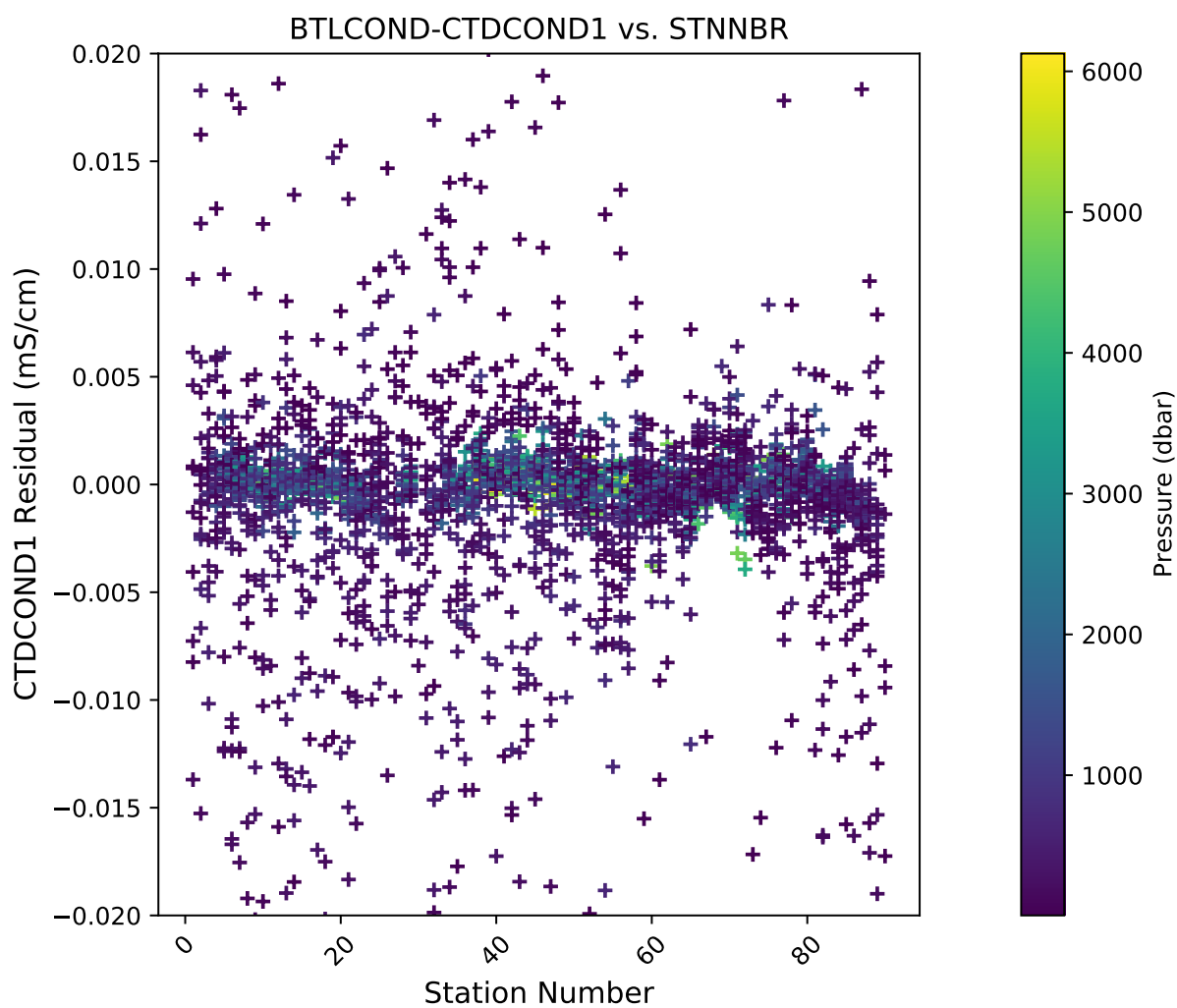


Fig. 11: Corrected  $C_{\text{Bottle}} - C_1$  versus station.

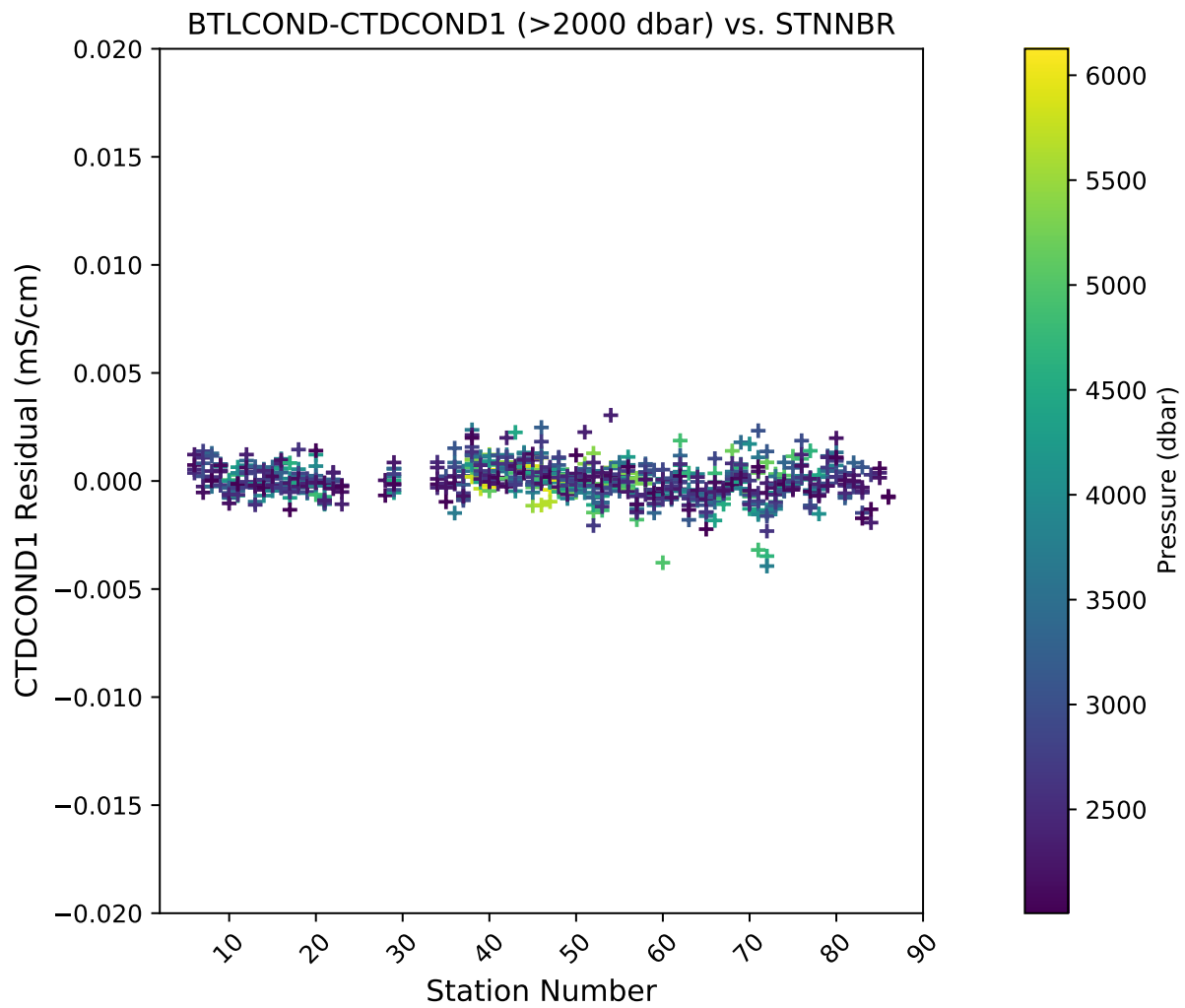


Fig. 12: Deep Corrected  $C_{\text{Bottle}} - C_1$  versus station (Pressure  $\geq 2000$ dbar).

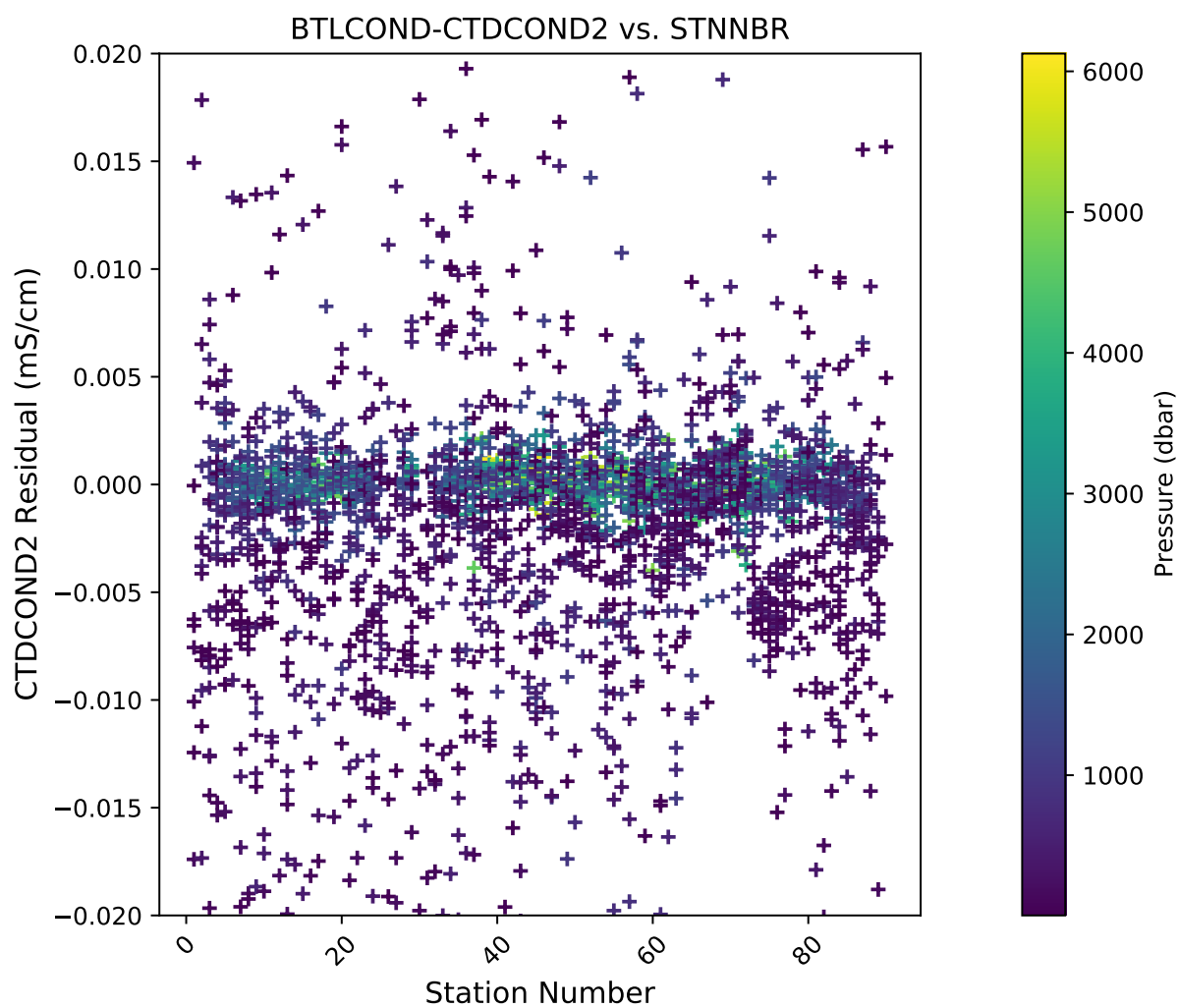


Fig. 13: Corrected  $C_{\text{Bottle}} - C_2$  versus station.



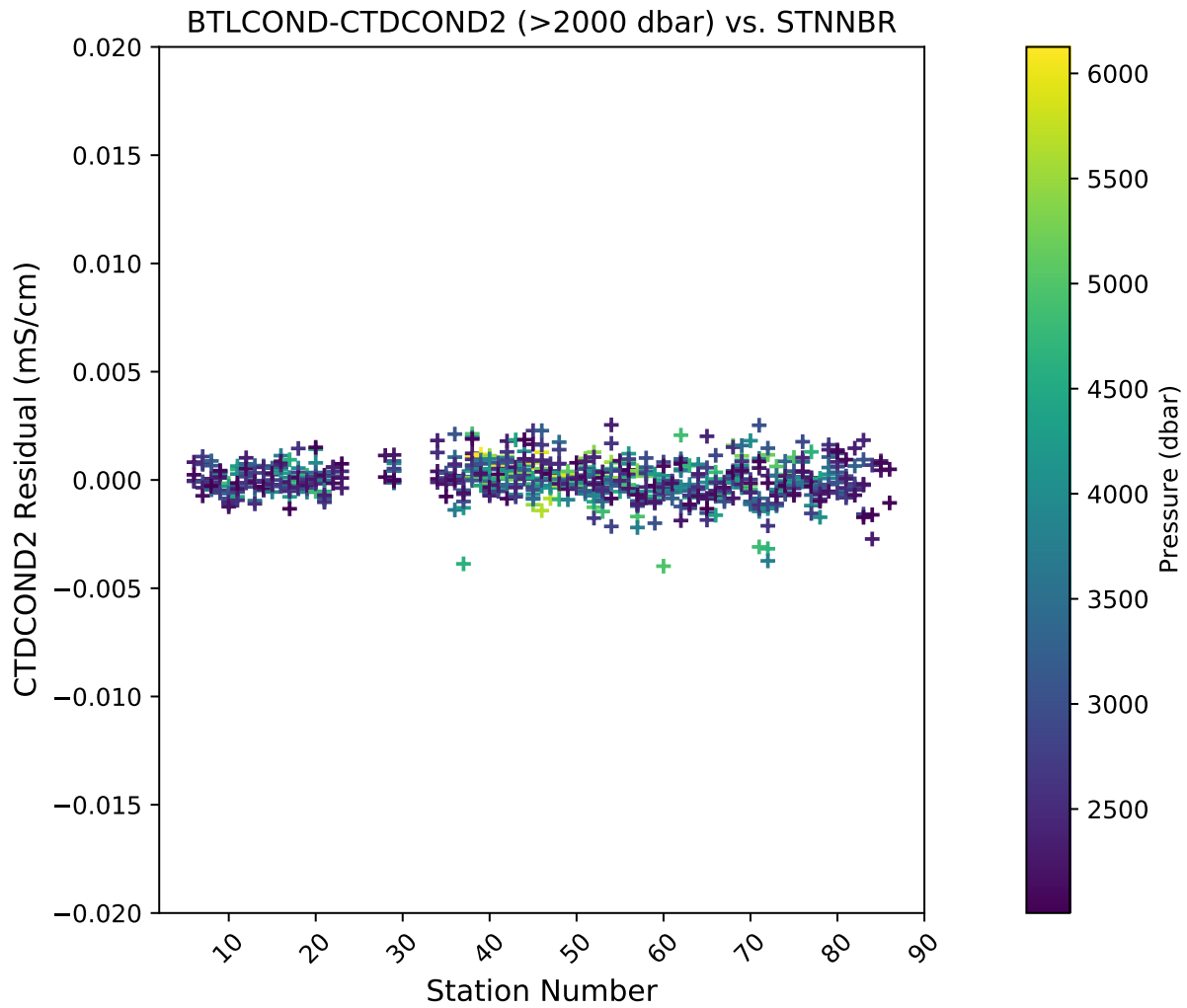


Fig. 14: Deep Corrected  $C_{\text{Bottle}} - C_2$  versus station (Pressure  $\geq 2000$ dbar).

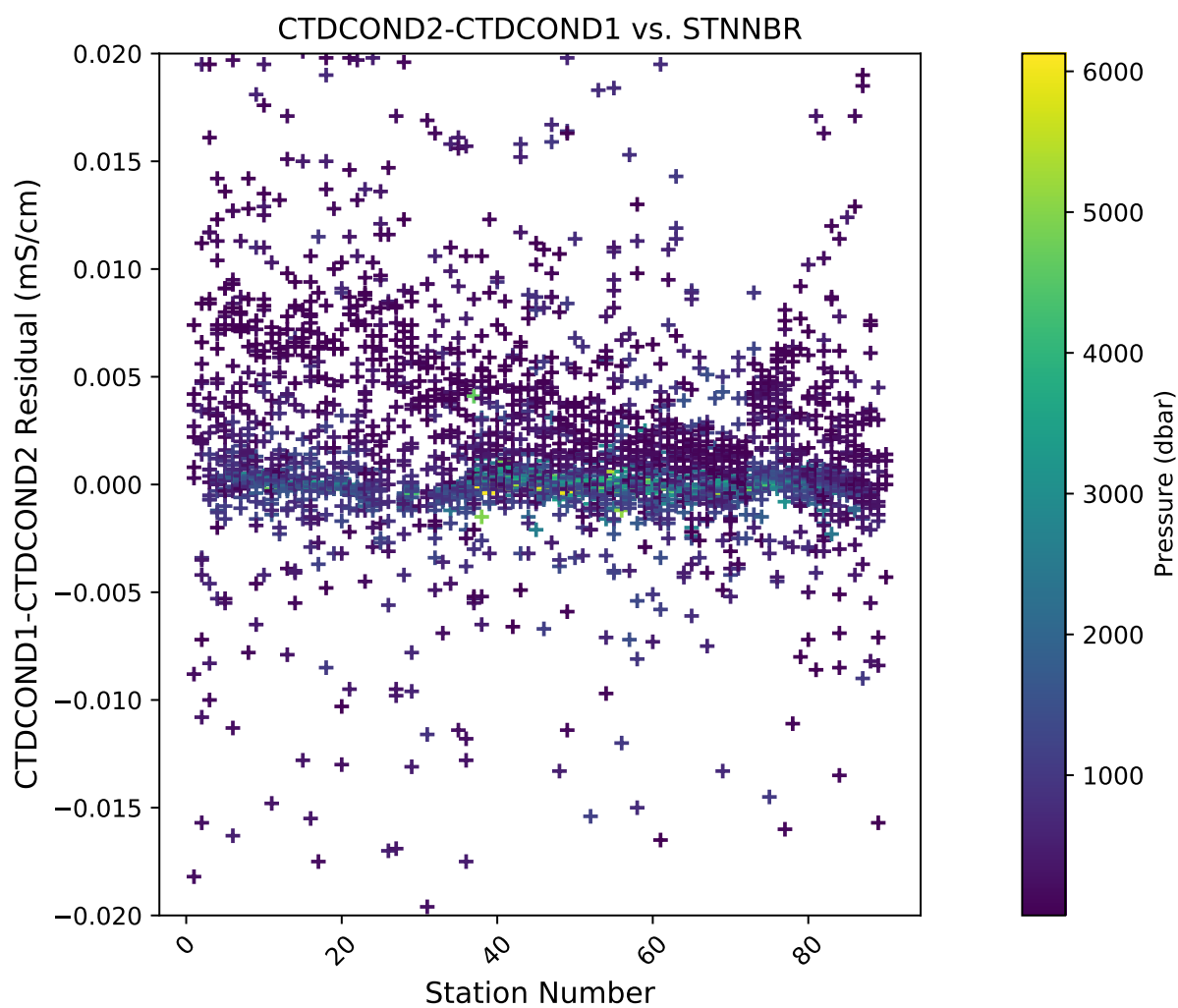


Fig. 15: Corrected C1-C2 versus station.

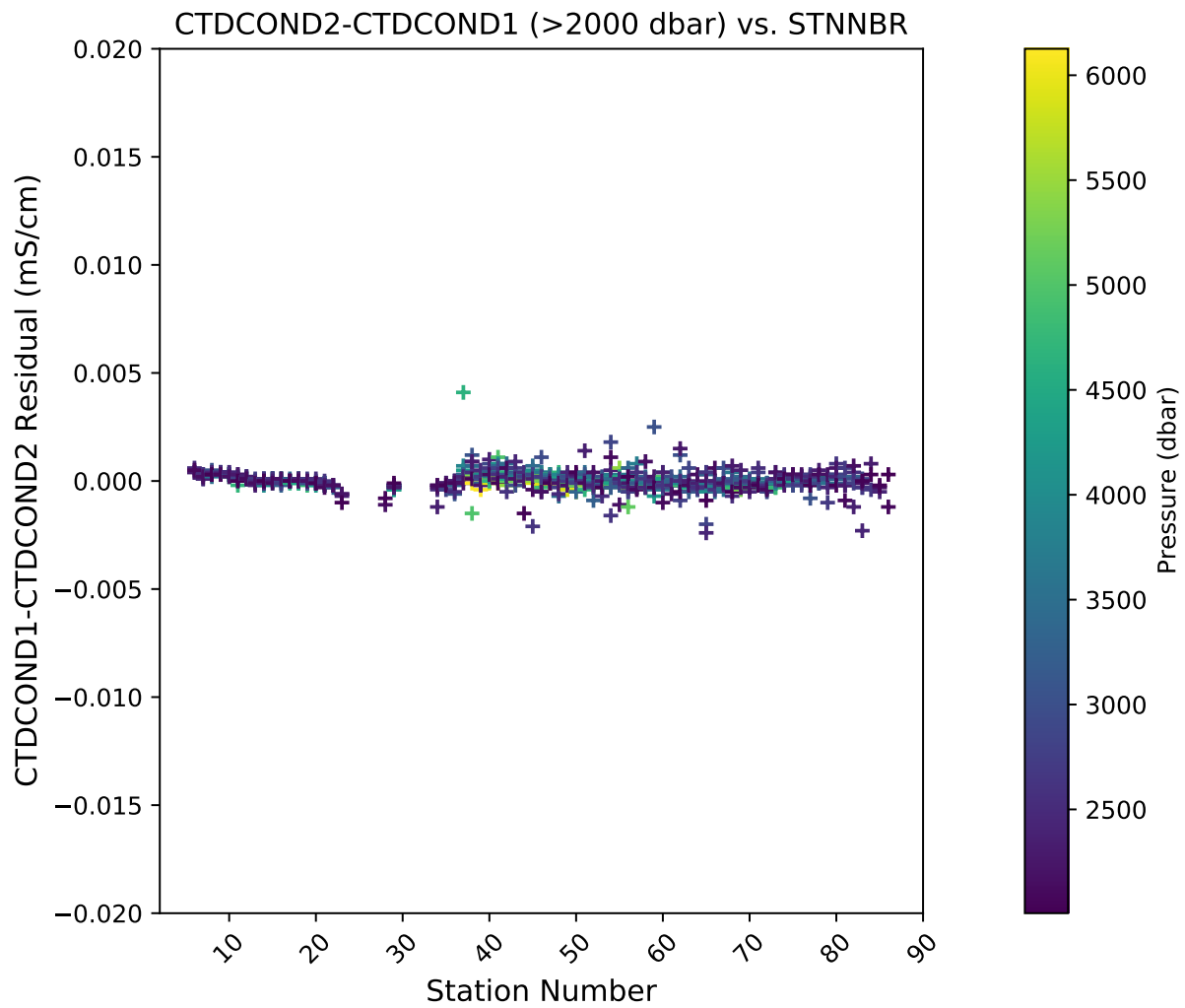


Fig. 16: Deep Corrected C1-C2 versus station (Pressure  $\geq 2000$ dbar).

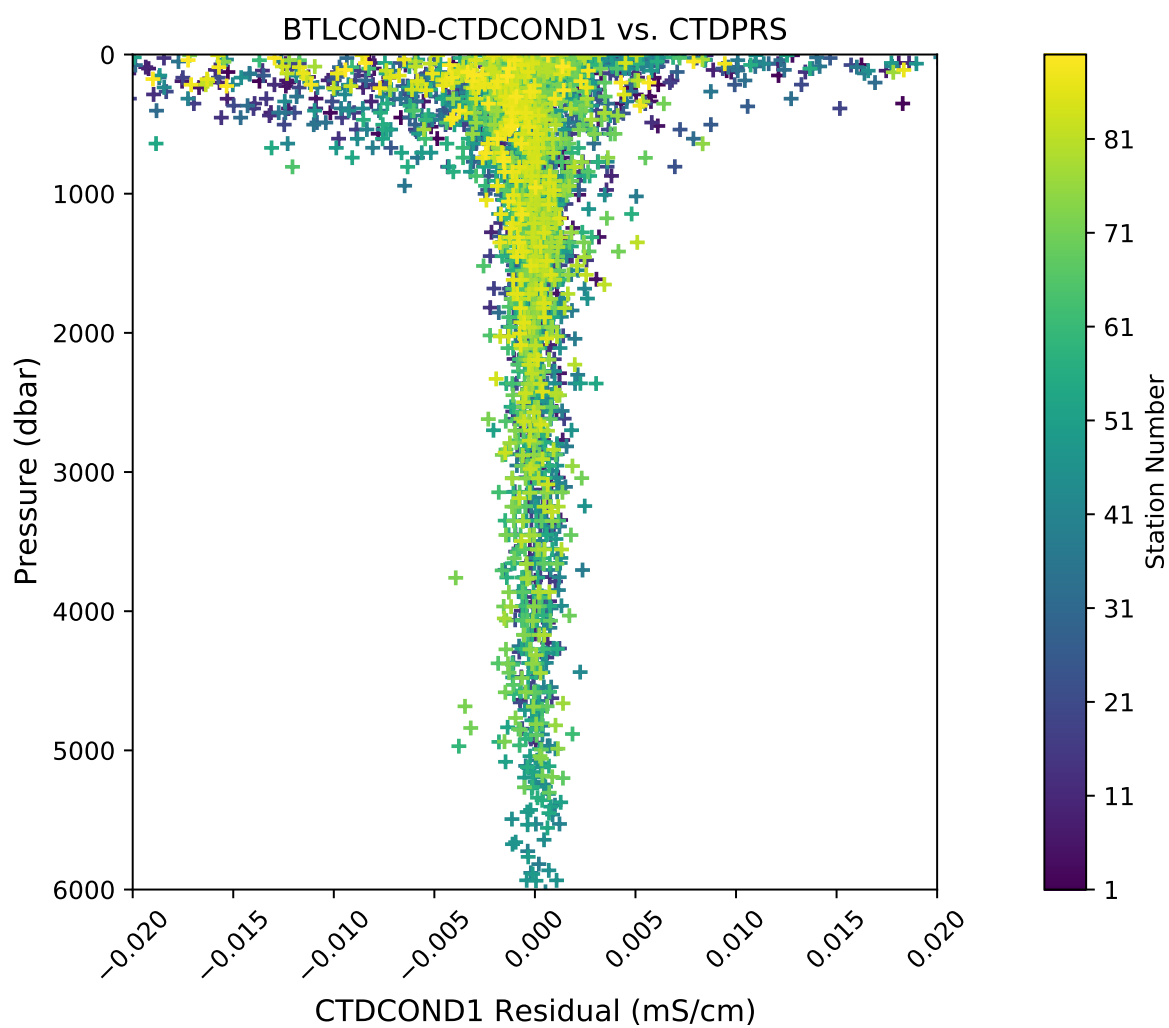


Fig. 17: Corrected  $C_{\text{Bottle}} - C_1$  versus pressure.

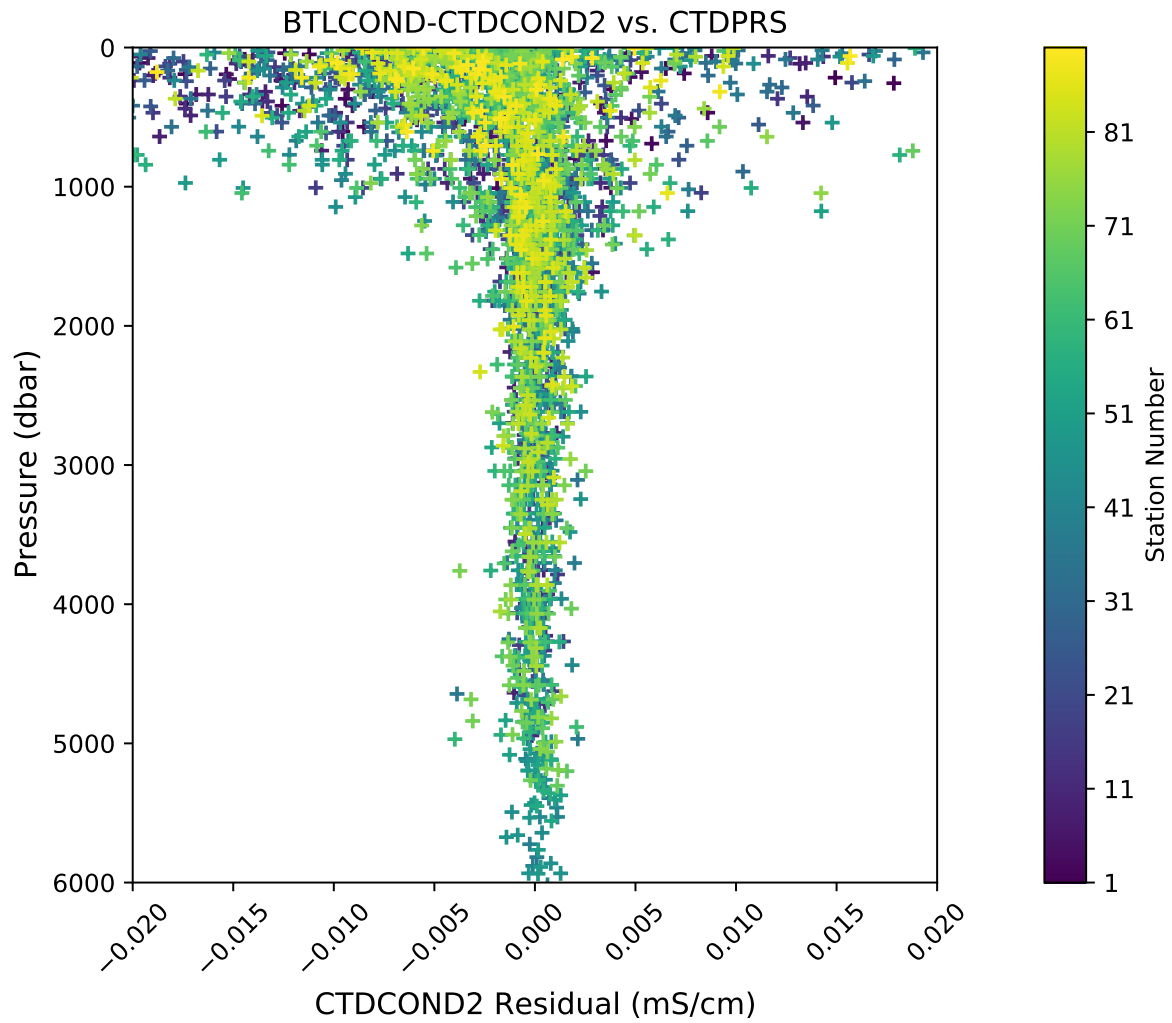


Fig. 18: Corrected  $C_{\text{Bottle}} - C_2$  versus pressure.



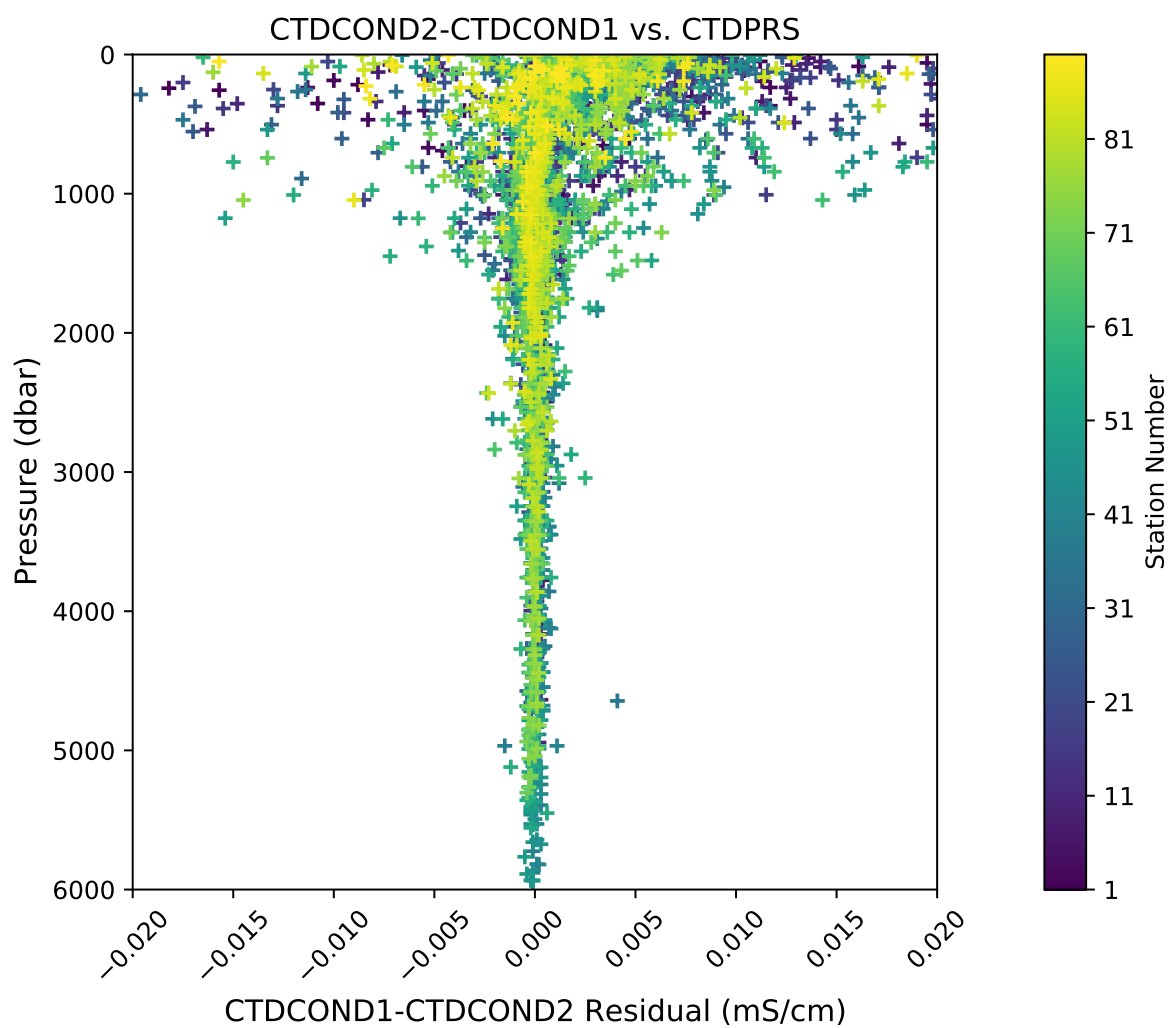


Fig. 19: Corrected C1-C2 versus pressure.

mined using  $C_{\text{Bottle}} - C_{\text{CTD}}$  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:

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

Fit coefficients are shown in the following tables.

Table 3: Primary conductivity (C1) coefficients.

Station	$cp_2$	$cp_1$	$ct_2$	$ct_1$	$cc_2$	$cc_1$	$c_0$
901-29	2.2312e-10	-1.7838e-6	0.0	-3.7387e-4	0.0	0.0	1.4153e-3
30-73	2.9375e-10	-2.7234e-6	0.0	-5.1639e-4	0.0	0.0	3.1780e-3
74-90	3.0952e-11	-7.2679e-7	0.0	-2.3689e-4	0.0	0.0	-1.1248e-3

Table 4: Secondary conductivity (C2) coefficients.

Station	$cp_2$	$cp_1$	$ct_2$	$ct_1$	$cc_2$	$cc_1$	$c_0$
901-29	1.6912e-10	-1.3829e-6	0.0	0.0	0.0	-3.2935e-4	1.3273e-2
30-73	1.7407e-10	-1.6959e-6	0.0	0.0	0.0	-5.1483e-4	2.0042e-2
74-90	5.4163e-11	-9.0604e-7	0.0	0.0	0.0	-2.0301e-4	8.8063e-3

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

The 95% confidence limits for the mean low-gradient (values  $-0.002\text{ }^{\circ}\text{C} \leq T_1 - T_2 \leq 0.002\text{ }^{\circ}\text{C}$ ) differences are  $\pm 0.00512$  mPSU for salinity-C1SAL. The 95% confidence limits for the deep salinity residuals (where pressure  $\geq 2000$ dbar) are  $\pm 0.00158$  mPSU for salinity-C1SAL.

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

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

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

## 4.6 CTD Dissolved Oxygen (SBE43)

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

The pre-cruise laboratory calibration coefficients were used to convert SBE43 frequencies to  $\mu\text{mol/kg}$  oxygen values for acquisition only. Additional shipboard fitting were performed to correct for the sensors non-linear response. Corrections for pressure, temperature, and conductivity sensors were finalized before analyzing dissolved oxygen data. Corrections for hysteresis are applied following Sea-Bird Application Note 64-3. The SBE43 sensor data were compared to dissolved  $\text{O}_2$  check samples taken at bottle stops by matching the downcast CTD data to the upcast trip locations along isopycnal surfaces. CTD dissolved  $\text{O}_2$  was then calculated using Clark Cell MPOD  $\text{O}_2$  sensor response model for Beckman/SensorMedics and SBE43 dissolved  $\text{O}_2$  sensors. The residual differences of bottle check value versus CTD dissolved  $\text{O}_2$  values are minimized by optimizing the PMEL DO sensor response model coefficients using the BFGS non-linear least-squares fitting procedure.

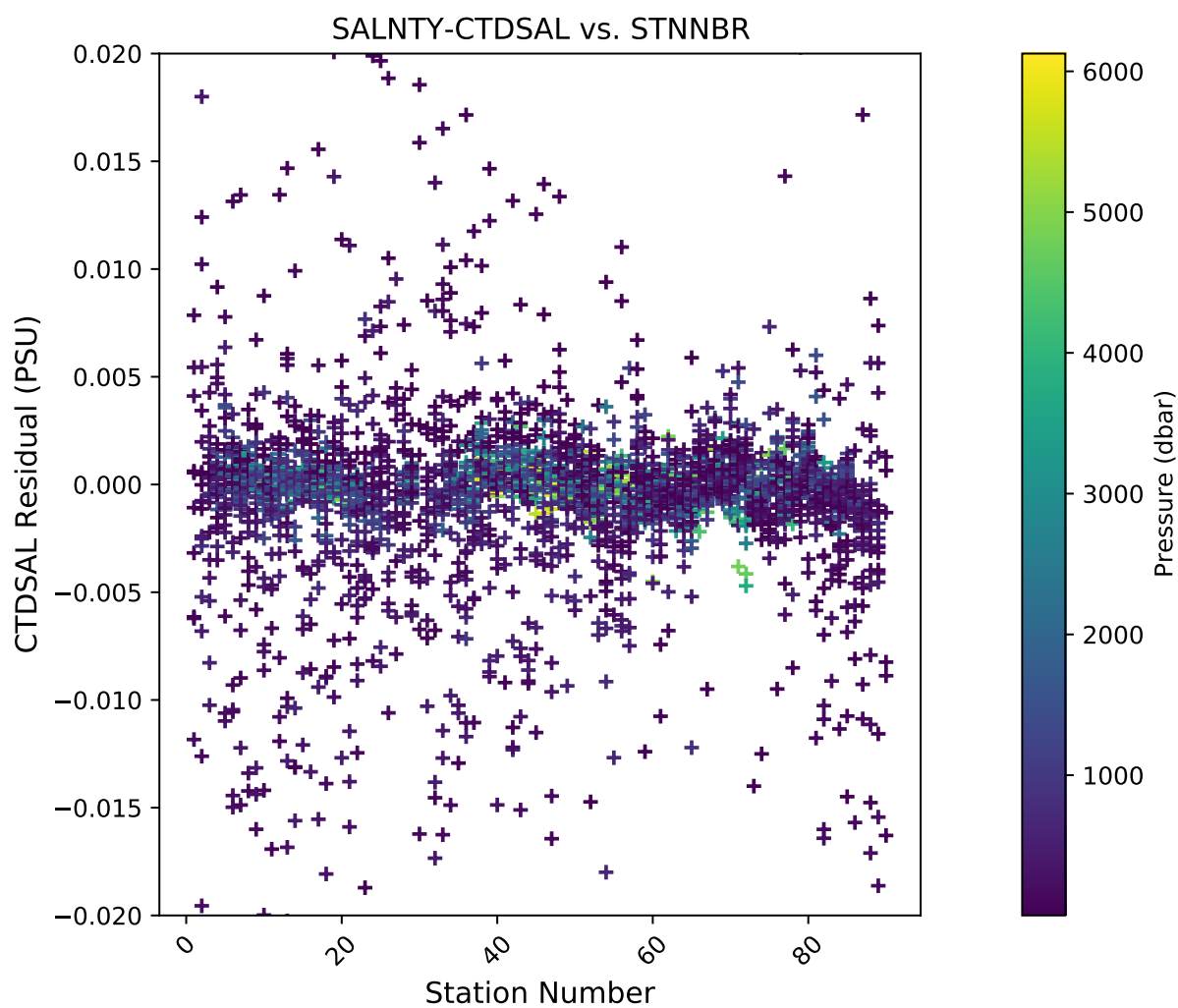


Fig. 20: Salinity residuals versus station.

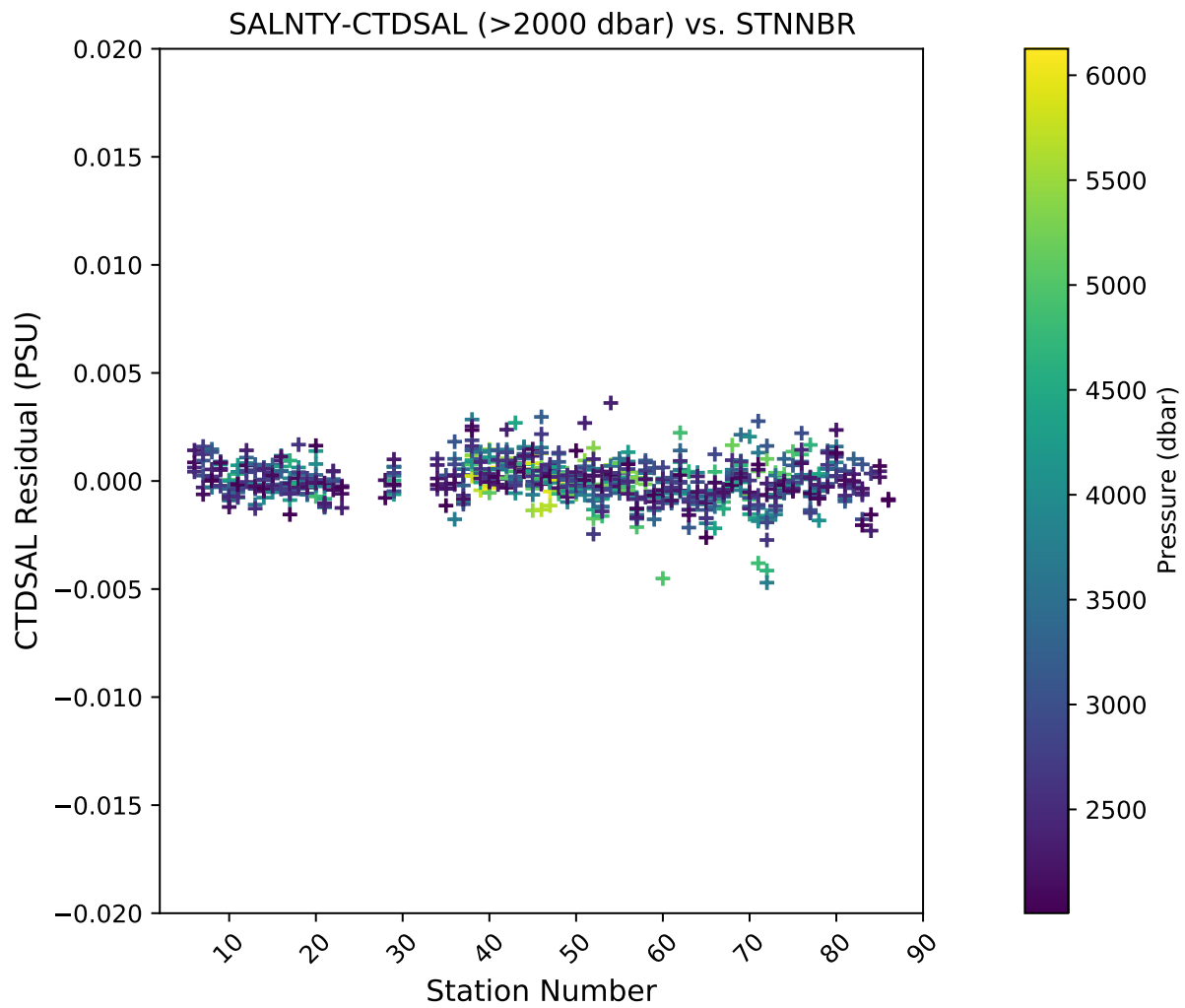


Fig. 21: Deep Salinity residuals versus station (Pressure  $\geq 2000$ dbar).

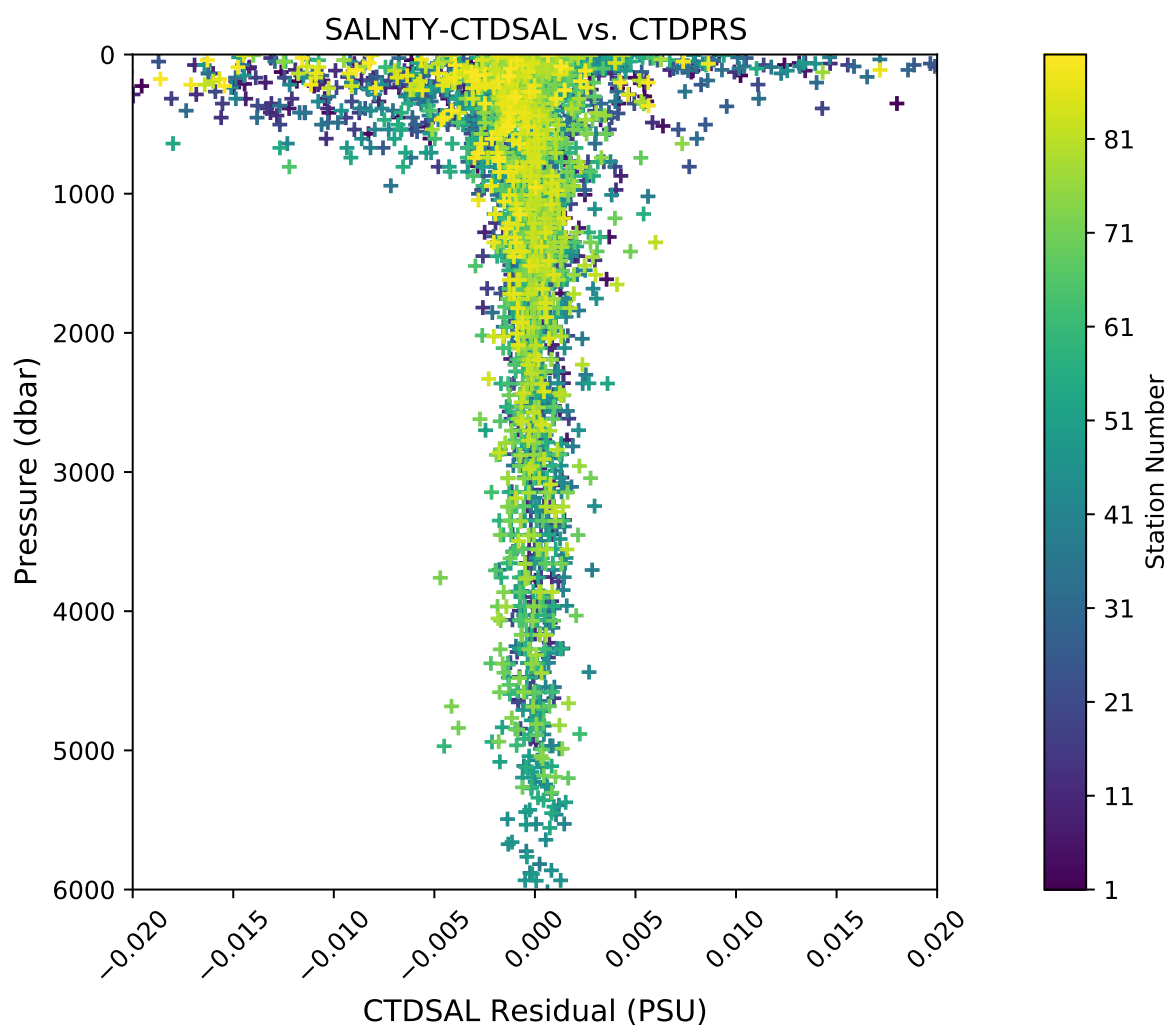


Fig. 22: Salinity residuals versus pressure.



The general form of the PMEL DO sensor response model equation for Clark cells follows Brown and Morrison [Mill82] and Owens [Owen85]. Dissolved O<sub>2</sub> concentration is then calculated:

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

Where:

- V is oxygen voltage (V)
- D<sub>1</sub> and D<sub>2</sub> 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<sub>sat</sub> is oxygen saturation
- S<sub>oc</sub>, V<sub>off</sub>, τ<sub>20</sub>, T<sub>cor</sub>, and E are fit coefficients

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

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

Station	S <sub>oc</sub>	V <sub>off</sub>	τ <sub>20</sub>	T <sub>cor</sub>	E
901-90	4.7574e-1	-5.0079e-1	1.56	-3.1680e-4	3.754e-2

CTD dissolved O<sub>2</sub> residuals are shown in the following figures *O2 residuals versus station*, through *Deep O2 residuals versus station (Pressure >= 2000dbar)*.

The 95% confidence limits of 1.71 (μmol/kg) for all acceptable (flag 2) dissolved oxygen bottle data values and 1.52 (μmol/kg) for deep dissolved oxygen values are only presented as general indicators of the goodness of fit. CLIVAR GO-SHIP standards for CTD dissolved oxygen data are < 1% accuracy against on board Winkler titrated dissolved O<sub>2</sub> lab measurements.

#### Minimal issues arose with the acquisition and processing of CTD dissolved oxygen data.

- Fitting routines were not behaving well for certain stations. SBE43 data are not reported but will be further investigated on land.

## 4.7 CTD Dissolved Oxygen (RINKO)

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

Rinko temperature (factory coefficients) was used for pre-cruise calibration. Generally, the Rinko III sensor appears to have performed as expected with no major problems or sharp drift throughout the deployment. An SBE 43 dissolved oxygen sensor was deployed simultaneously. Both oxygen sensor data sets were analyzed and quality controlled with Winkler bottle oxygen data. RinkoIII data used as primary oxygen for all stations (1-90).

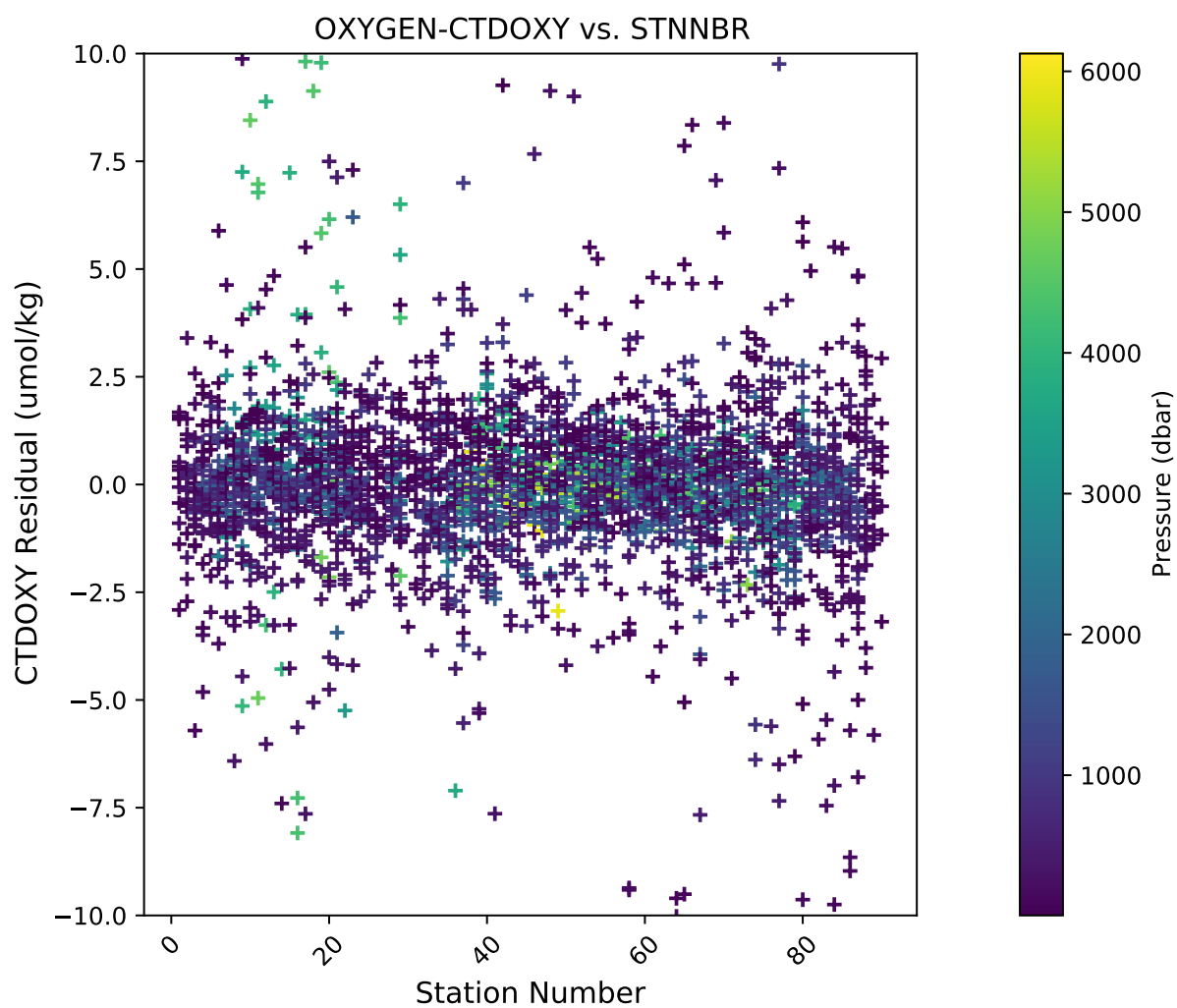


Fig. 23: O<sub>2</sub> residuals versus station.

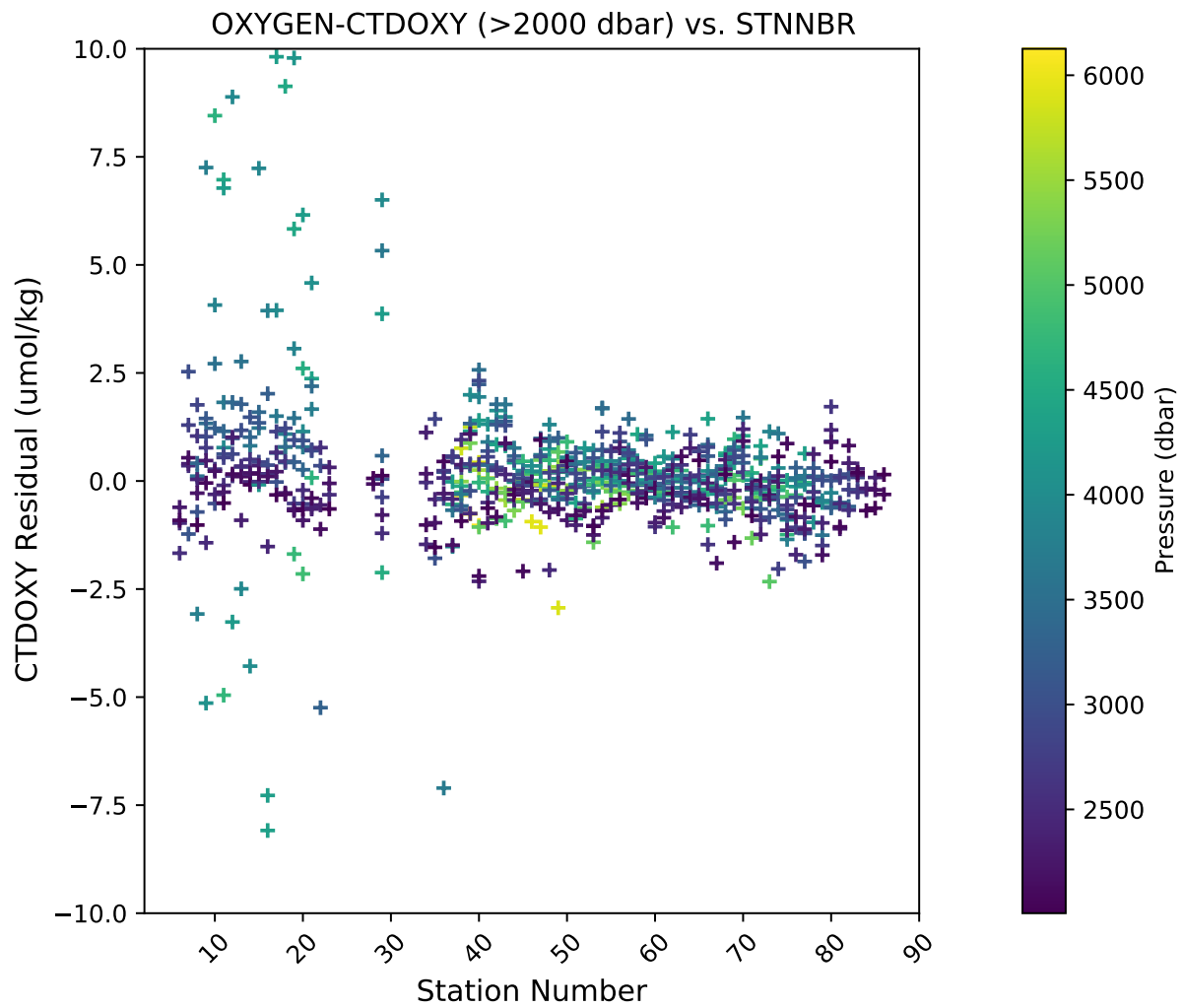


Fig. 24: Deep O<sub>2</sub> residuals versus station (Pressure  $\geq$  2000dbar).

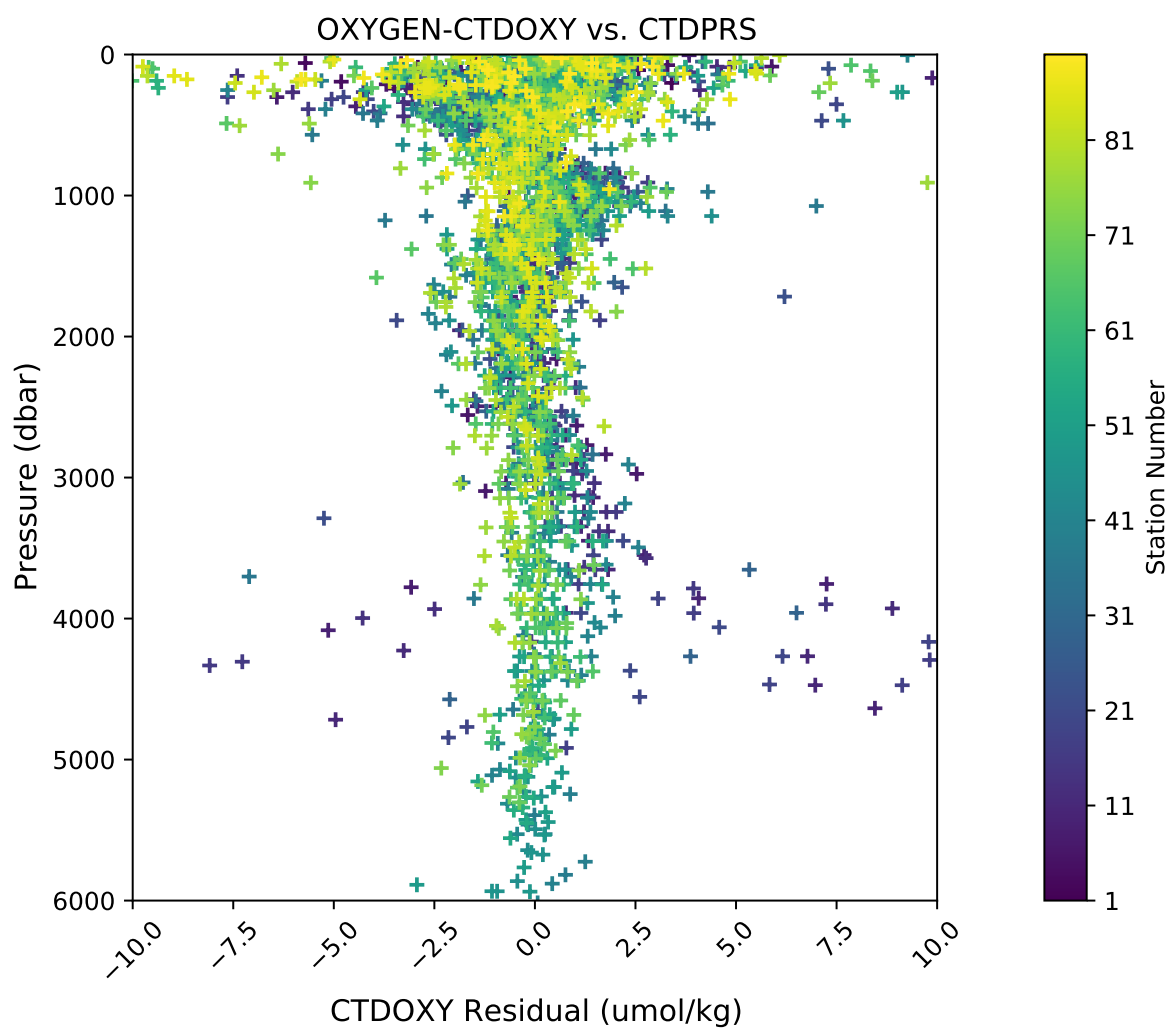


Fig. 25: O<sub>2</sub> residuals versus pressure.

RINKO data was acquired, converted from volts to oxygen saturation, and then multiplied by the oxygen solubility to find values in  $\mu\text{mol/kg}$ . The resulting data were then fitted using the equations developed by [Uchida08]:

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

$$K_{sv} = c_0 + c_1T + c_2T^2, \quad V_0 = 1 + d_0T, \quad V_c = d_1 + d_2V_r$$

where:

- T is temperature ( $^{\circ}\text{C}$ )
- $V_r$  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]:

$$[O_2]_{sc} = [O_2]_c \exp[S(B_0 + B_1T_S + B_2T_S^2 + B_3T_S^3) + C_0S^2]$$

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. Stations were then fit in groups of similar profiles to get a further refined estimate. Individual casts were then fit to remove the noticeable time drift in coefficients. If the fit of the individual cast had worse residuals than the group, they were reverted to the original group fit coefficients.

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

Station	$c_0$	$c_1$	$c_2$	$d_0$	$d_1$	$d_2$	$c_p$
901-29	1.8834	2.7106e-2	7.5022e-4	5.1571e-4	-1.9373e-1	3.0792e-1	8.7822e-2
30-72	1.8612	2.9074e-2	9.2059e-4	2.4233e-3	-1.9987e-1	3.1466e-1	9.7739e-2
73-90	1.8783	4.8992e-2	2.2758e-4	2.9361e-3	-1.8483e-1	2.9822e-1	6.7778e-2

CTD dissolved  $O_2$  residuals are shown in the following figures.

The 95% confidence limits of 1.27 ( $\mu\text{mol/kg}$ ) for all acceptable (flag 2) dissolved oxygen bottle data values and 0.58 ( $\mu\text{mol/kg}$ ) for deep dissolved oxygen values are only presented as general indicators of the goodness of fit. CLIVAR GO-SHIP standards for CTD dissolved oxygen data are < 1% accuracy against on board Winkler titrated dissolved  $O_2$  lab measurements.

No issues arose with the acquisition and processing of CTD dissolved oxygen data.



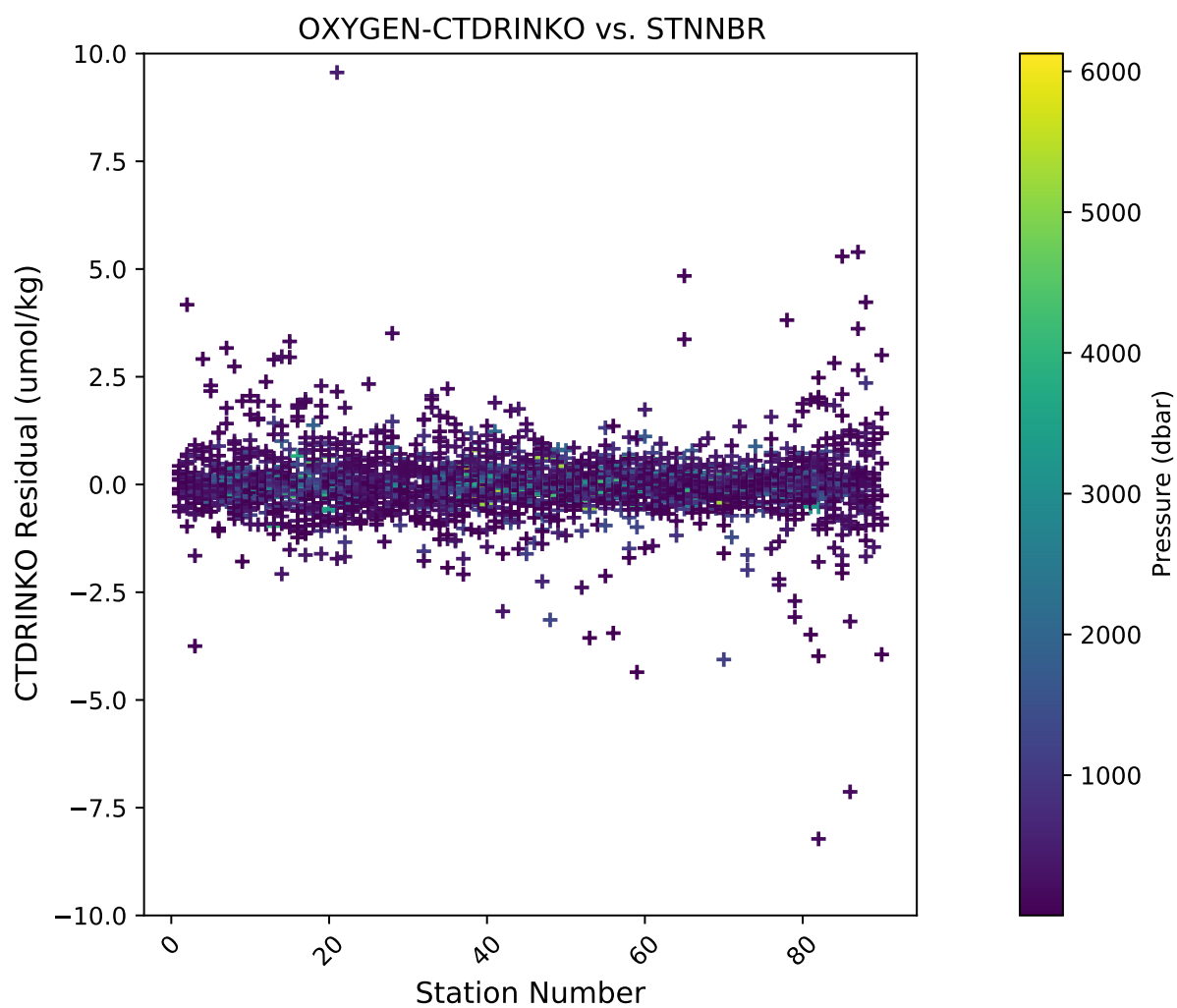


Fig. 26: O<sub>2</sub> residuals versus station.

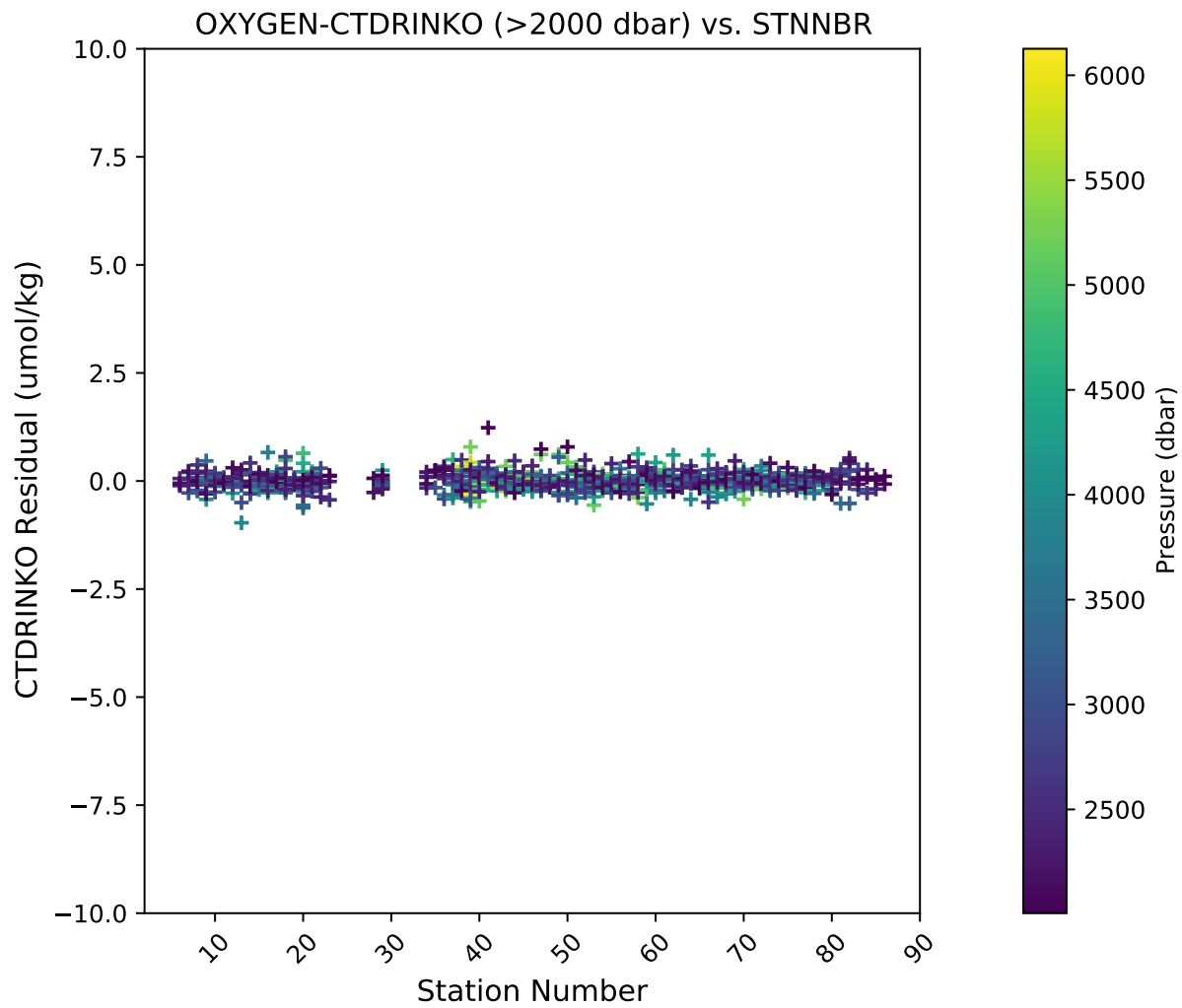


Fig. 27: Deep O<sub>2</sub> residuals versus station (Pressure  $\geq$  2000dbar).

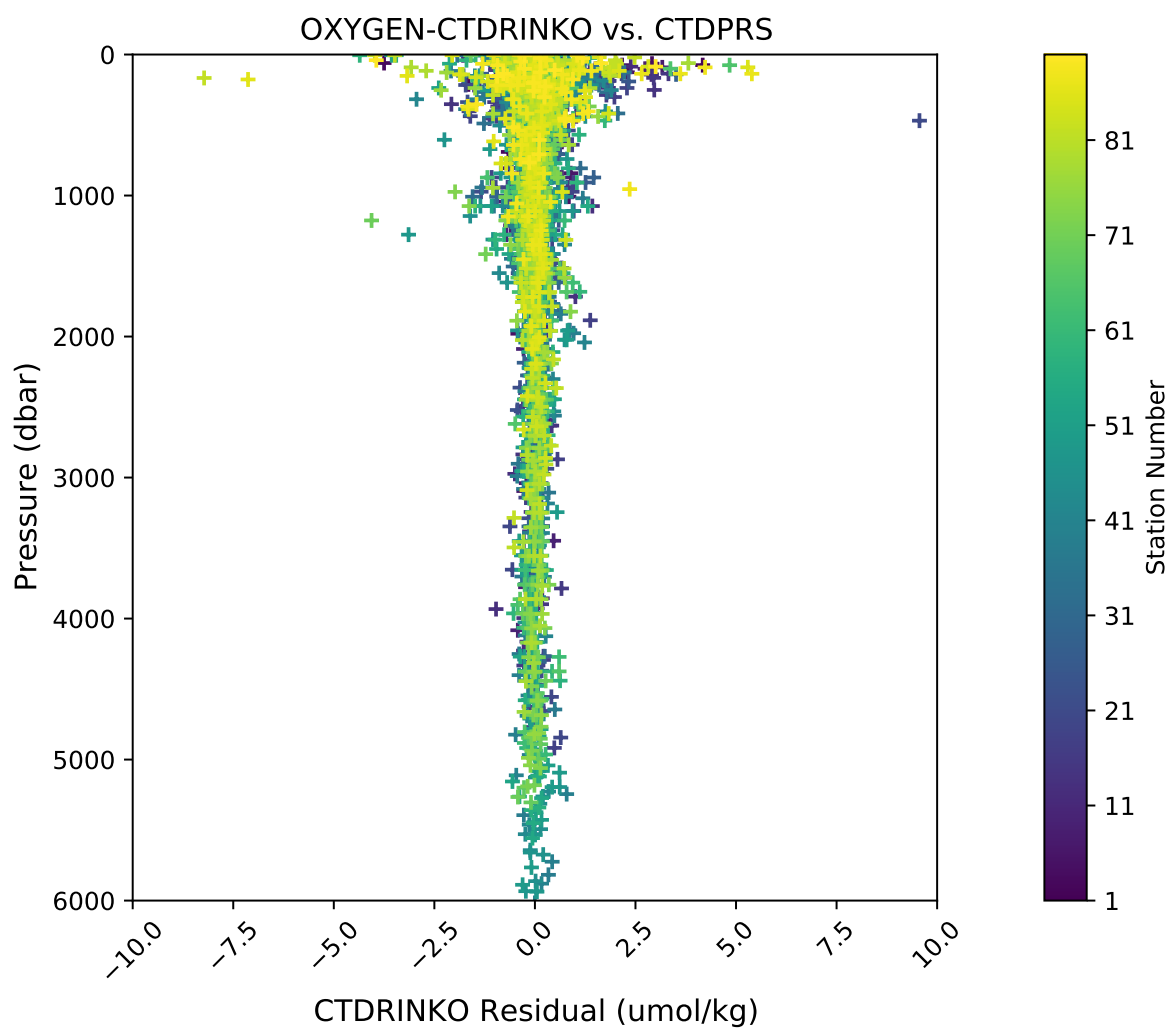


Fig. 28: O<sub>2</sub> residuals versus pressure.

## SALINITY

**PIs**

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

**Technicians**

- John Calderwood (SIO)
- Caitlyn Webster (SIO)

## 5.1 Equipment and Techniques

Two Guildline Autosals were on board and operational, SIO-owned 8400B S/N 69-180, and UW-owned 8400B S/N 94-894. S/N 69-180 was used for all salinity measurements during this cruise. The salinity analysis was run in the ship's Climate Controlled Chamber, a refrigerator port and amidships between the Computer Lab and Bioanalytical Lab. The chamber temperature varied between about 21 and 25 degrees Celcius around 3 times each hour, with an average (based on measuring temperatures of items in the chamber) of about 23C.

Both instruments were serviced prior to the cruise by their respective institutions and shipped to WHOI with other equipment in March. IAPSO Standard Seawater Batch P-164 was used for all calibrations: K15 =0.99985, salinity 34.994, expiration 2023-03-23. A LabView program developed by Carl Mattson was used for monitoring temperatures, logging data and prompting the operator. Salinity analyses were performed after samples had equilibrated to laboratory temperature of 23°C, usually 8 hours or more after collection. The salinometer was standardized for each group of samples analyzed (normally 1 or 2 casts, up to 72 samples) using two bottles of standard seawater: one at the beginning and one at the end of each set of measurements.

Between runs the water from the last standard was left in the cell. 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.

## 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 replaced to insure an airtight seal. Laboratory temperature was also monitored electronically throughout the cruise. PSS-78 salinity [UNESCO1981] was calculated for each sample from the measured conductivity ratios. The offset between the initial standard seawater value and its reference value was applied to each sample. Then the difference (if any) between the initial and final vials of standard seawater was

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

## **5.3 Narrative**

No major problems were encountered during this cruise.

2975 total salinity samples were taken from a test cast (5 samples) and 90 CTD casts (2970). Three sample bottles were broken during sampling.



## NUTRIENTS

## Technicians

- Susan Becker (SIO)
- Alexandra Fine (AOML/CIMAS)

## 6.1 Summary of Analysis

- 2977 samples from 90 CTD stations
- The cruise started with new pump tubes and they were changed once, before station 033.
- 2 sets of Primary/Secondary standards were made up over the course of the cruise.
- The cadmium column efficiency was checked periodically and ranged between 85%-100%.

## 6.2 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, [Becker 2019]).

## 6.3 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 sulfanilamide in 1.2N HCl and bring to 1 liter volume. Add 2 drops of 40% surfynol 465/485 surfactant. Store at room temperature in a dark poly bottle.

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

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

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

**NH<sub>4</sub>Cl + CuSO<sub>4</sub> mix** Dissolve 2g cupric sulfate in DIW, bring to 100 ml volume (2%). Dissolve 250g ammonium chloride in DIW, bring to 11 liter volume. Add 5ml of 2% CuSO<sub>4</sub> solution to this NH<sub>4</sub>Cl stock. This should last many months.

## 6.4 Phosphate Analysis

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

### REAGENTS

**Ammonium Molybdate H<sub>2</sub>SO<sub>4</sub> sol'n** Pour 420 ml of DIW into a 2 liter Erlenmeyer flask or beaker, place this flask or beaker into an ice bath. SLOWLY add 330 ml of conc H<sub>2</sub>SO<sub>4</sub>. This solution gets VERY HOT!! Cool in the ice bath. Make up as much as necessary in the above proportions.

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

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

## 6.5 Silicate Analysis

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

### REAGENTS

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

**Ammonium Molybdate** Dissolve 10.8g Ammonium Molybdate Tetrahydrate in 1000ml dilute H<sub>2</sub>SO<sub>4</sub>. (Dilute H<sub>2</sub>SO<sub>4</sub> = 2.8ml conc H<sub>2</sub>SO<sub>4</sub> or 6.4ml of H<sub>2</sub>SO<sub>4</sub> diluted for PO<sub>4</sub> moly per liter DW) (dissolve powder, then add H<sub>2</sub>SO<sub>4</sub>) Add 3-5 drops 15% SDS surfactant per liter of solution.

**Stannous Chloride** stock: (as needed)

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

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

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

## 6.6 Sampling

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

## 6.7 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.

## 6.8 Standards and Glassware Calibration

Primary standards for silicate ( $\text{Na}_2\text{SiF}_6$ ), nitrate ( $\text{KNO}_3$ ), nitrite ( $\text{NaNO}_2$ ), and phosphate ( $\text{KH}_2\text{PO}_4$ ) were obtained from Johnson Matthey Chemical Co. and/or Fisher Scientific. The supplier reports purities of >98%, 99.999%, 97%, and 99.999 respectively.

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

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

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

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

-	N+N (uM)	PO <sub>4</sub> (uM)	SIL (uM)	NO <sub>2</sub> (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

## 6.9 Quality Control

All final data was reported in micro-moles/kg.  $\text{NO}_3$ ,  $\text{PO}_4$ , and  $\text{NO}_2$  were reported to two decimals places and SIL to one. Accuracy is based on the quality of the standards the levels are:

$\text{NO}_3$	0.05 $\mu\text{M}$ (micro moles/Liter)
$\text{PO}_4$	0.004 $\mu\text{M}$
SIL	2-4 $\mu\text{M}$
$\text{NO}_2$	0.05 $\mu\text{M}$

The deep check sample that is normally run was discontinued due to issues with cadmium column efficiency on A20. It is thought the mercuric chloride may have been contributing to the loss of column efficiency.

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. [Becker 2019]. RMNS batch C0 was used on this cruise, with each bottle being used for all runs in one day before being discarded and a new one opened. Data are tabulated below.

Parameter	Concentration	stddev	assigned conc
-	( $\mu\text{mol/kg}$ )	-	( $\mu\text{mol/kg}$ )
$\text{NO}_3$	15.86	0.02	15.86
$\text{PO}_4$	1.17	0.005	1.177
Sil	34.7	0.12	34.72
$\text{NO}_2$	0.04	0.005	0.04

## 6.10 Analytical Problems

There were issues with the cadmium column efficiency on A20. The exact issue was never clearly identified but it appears to have been a combination of buffer that was not stable which affected the efficiency and life span of the cadmium reduction columns. The values of the reference material and the were used to in addition to the periodic column efficiency checks to monitor data quality. Adjustments based on the values obtained for the references material were made as necessary. The adjusted data for affected stations was compared to adjacent stations and historical data during the final QC checks.

## OXYGEN ANALYSIS

### PIs

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

### Technicians

- Andrew Barna (SIO)
- Robert “Ben” Freiburger (SIO)

## 7.1 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.

## 7.2 Sampling and Data Processing

A total of 2969 oxygen measurements were made, all of which were niskin samples. There are no underway 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<sub>2</sub> and NaI/NaOH (1 mL of each) were added via bottle-top dispensers to fix samples before stoppering. Flasks were shaken twice (10-12 inversions) to assure thorough dispersion of the precipitate - once immediately after drawing and then again after 30-60 minutes.

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

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

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

## 7.3 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.

## 7.4 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.

## 7.5 Narrative

The analytical rig remained set up from the just completed 2021 occupation of A20. This included all the reagents, though more NaI/OH and MnCl<sub>2</sub> were made while in port.

The thiosulfate stability was considered in 4 batches and showed remarkable stability throughout the entire cruise. No trends were observed or corrected for.

There was a freezing concern regarding the liquid reagents shipped to WHOI prior to the start of A20. To verify that our standards were good, some OSIL KIO<sub>3</sub> standard was shipped to the US Virgin Islands to load during the port call. These standards were all run during the transit around Puerto Rico (between stations 29 and 30). All the ODF standards agreed with each other, the OSIL standards were inconclusive. Though perhaps the lesson learned was that the lead analyst lacked sufficient skill with hand pipettes to use them.

No data updates are expected.



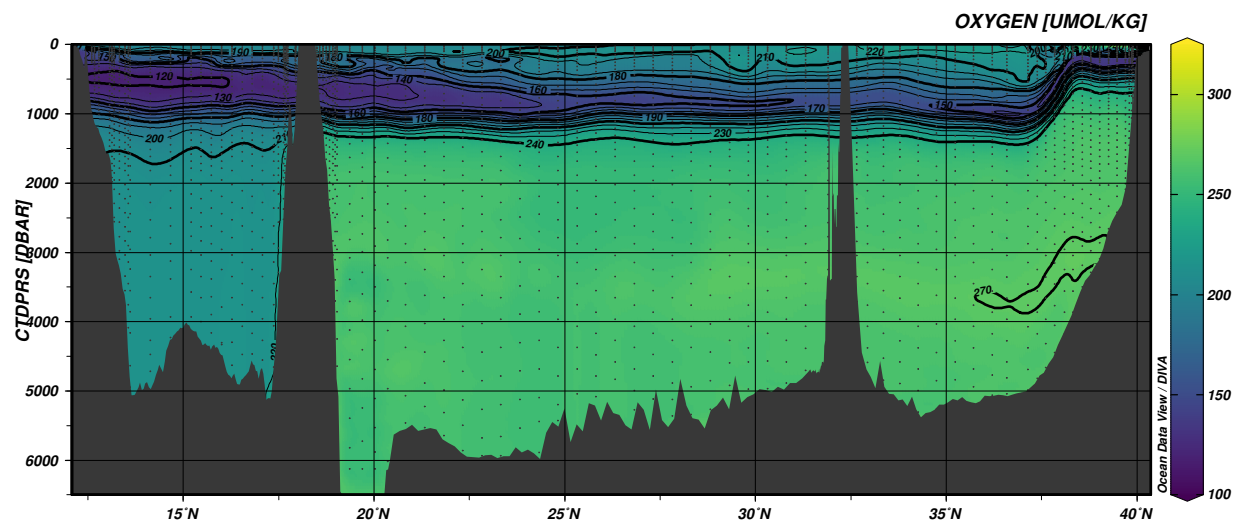


Fig. 1: Bottle oxygen data gridded on isopycnals.



## TOTAL ALKALINITY

### PIs

- Andrew G. Dickson (SIO)
- Frank J. Millero (RSMAS)

### Technicians

- Carmen Rodriguez (RSMAS)
- Daniela Nestory (SIO)

## 8.1 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  $K < 10^{-4.5}$  at 25°C and zero ionic strength) over proton donors (acids with  $K > 10^{-4.5}$ ) in 1 kilogram of sample.

## 8.2 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.

### **8.3 Sample Collection**

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

Samples for total alkalinity were taken at all stations during A22 (1-90). Except for a few instances, alkalinity samples were collected from each niskin where DIC and pH were collected, to over-characterize the CO<sub>2</sub> system. The typical sample scheme of full collection on even-numbered stations (36 niskin bottles) and partial collection (~8-20 bottles) on odd-numbered stations was followed.

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

### **8.4 Problems and Troubleshooting**

There were a few issues encountered at the start of the cruise which delayed sample processing but did not impede sample intake. It was determined that the SDS\_A system, which had been used on Leg 1 (A20), was leaking and further use would be problematic for this leg. The spare system (SDS\_B) was swapped in and extra time was needed to confirm the accuracy and stability of the replacement SDS. Surplus alkalinity bottles were available to stockpile samples so productivity was not impeded. Also at the start of the cruise, an error in the Labview program's file creation resulted in configuration equations being omitted which had to be reinput by hand initially. A typo in the input equations was soon discovered and corrected.

The SDS system occasionally freezes at different points in the procedure. However the technicians were alert to this issue and were able to save most samples when this occurred.

Although the temperature in the lab was very stable for the majority of the cruise, just before entering the Gulf Stream (starting at station 71), the room temperature dropped by approximately 2°C. The acid temperature dropped as well, causing errors in the calculations. The engineers of the R/V TG Thompson worked to increase and stabilize the room temperature. The cool climate continued for a couple of days, so time was spent to combat temperature instability. Samples were not run when the appropriate range in temperature could not be achieved.

## 8.5 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 178 and 192 were used to determine the accuracy of the total alkalinity analyses. The total alkalinity certified value for these batches are:

- Batch 178:  $2216.53 \pm 0.61$   $\mu\text{mol/kg}$  (132; 75)
- Batch 192:  $2213.70 \pm 0.53$   $\mu\text{mol/kg}$  (132; 67)

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. 264 reference material samples were analyzed on A22.

The average measured total alkalinity value for each batch is:

- Batch 178:  $2217.97 \pm 1.99$   $\mu\text{mol kg}^{-1}$  (n = 132)
- Batch 192:  $2214.40 \pm 1.80$   $\mu\text{mol kg}^{-1}$  (n = 132)

Duplicate samples were also used to check the reproducibility of the system. The absolute value of the mean offset between duplicate samples and the standard deviation are given below. Mean duplicate sample offset:  $1.35 \pm 1.03$   $\mu\text{mol kg}^{-1}$  (n = 161)

1884 total alkalinity values were submitted for A22.

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





## DISSOLVED INORGANIC CARBON (DIC)

### PI's

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

### Technicians

- Charles Featherstone (NOAA/AOML)
- Andrew Collins (NOAA/PMEL)

## 9.1 Sample Collection

Samples for DIC measurements were drawn (according to procedures outlined in the PICES Publication, *Guide to Best Practices for Ocean CO<sub>2</sub> Measurements* [Dickson2007]) from Niskin bottles into 294 ml borosilicate glass bottles using silicone tubing. The flasks were rinsed once and filled from the bottom with care not to entrain any bubbles, overflowing by at least one-half volume. The sample tube was pinched off and withdrawn, creating a 6 ml headspace, followed by 0.12 ml of saturated HgCl<sub>2</sub> solution which was added as a preservative. The sample bottles were then sealed with glass stoppers lightly covered with Apiezon-L grease and were stored at room temperature for a maximum of 12 hours.

## 9.2 Equipment

The analysis was done by coulometry with two analytical systems (AOML 3 and AOML 4) used simultaneously on the cruise. Each system consisted of a coulometer (CM5017 UIC Inc) coupled with a Dissolved Inorganic Carbon Extractor (DICE). The DICE system was developed by Esa Peltola and Denis Pierrot of NOAA/AOML and Dana Greeley of NOAA/PMEL to modernize a carbon extractor called SOMMA ([Johnson1985], [Johnson1987], [Johnson1993], [Johnson1992], [Johnson1999]).

The two DICE systems (AOML 3 and AOML 4) were set up in a seagoing container modified for use as a shipboard laboratory on the aft main working deck of the R/V Thomas G Thompson.

### 9.3 DIC Analysis

In coulometric analysis of DIC, all carbonate species are converted to CO<sub>2</sub> (gas) by addition of excess hydrogen ion (acid) to the seawater sample, and the evolved CO<sub>2</sub> gas is swept into the titration cell of the coulometer with 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<sup>-</sup> ions at the anode. The OH<sup>-</sup> ions react with the H<sup>+</sup> and the solution turns blue again. A beam of light is shone through the solution, and a photometric detector at the opposite side of the cell senses the change in transmission. Once the percent transmission reaches its original value, the coulometric titration is stopped, and the amount of CO<sub>2</sub> that enters the cell is determined by integrating the total change during the titration.

### 9.4 DIC Calculation

Calculation of the amount of CO<sub>2</sub> injected was according to the CO<sub>2</sub> handbook [DOE1994]. The concentration of CO<sub>2</sub> ([CO<sub>2</sub>]) in the samples was determined according to:

$$[\text{CO}_2] = \text{Cal. Factor} * \frac{(\text{Counts} - \text{Blank} * \text{Run Time}) * K \mu\text{mol/count}}{\text{pipette volume} * \text{density of sample}}$$

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.

The instrument has a salinity sensor, but all DIC values were recalculated to a molar weight (μmol/kg) using density obtained from the CTD's salinity. The DIC values were corrected for dilution due to the addition of 0.12 ml of saturated HgCl<sub>2</sub> used for sample preservation. The total water volume of the sample bottles was 294 ml (calibrated by Esa Peltola, AOML). The correction factor used for dilution was 1.00041. 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 average correction was 1.51 μmol/kg for AOML 3 and 1.06 μmol/kg for AOML 4.

The coulometer cell solution was replaced after 24-28 mg of carbon was titrated, typically after 9-12 hours of continuous use. The blanks ranged from 12-55.

### 9.5 Calibration, Accuracy, and Precision

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

1. Gas loops were run at the beginning of each cell
2. CRM's supplied by Dr. A. Dickson of SIO, were analyzed at the beginning of the cell before sample analysis.
3. 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<sub>2</sub> (99.999%) by means of an 8-port valve [Wilke1993] outfitted with two calibrated sample loops of different sizes (~1ml and ~2ml). The instruments were each separately calibrated at the beginning of each cell with a minimum of two sets of these gas loop injections.

The accuracy of the DICE measurement is determined with the use of standards (Certified Reference Materials (CRMs), consisting of filtered and UV irradiated seawater) supplied by Dr. A. Dickson of Scripps Institution of Oceanography (SIO). The CRM accuracy is determined manometrically on land in San Diego and the DIC data reported to the data base have been corrected to this batch 178 CRM value. The CRM certified value for this batch is 1952.65 μmol/kg.

The precision of the two DICE systems can be demonstrated via the replicate samples. Approximately 10% of the niskins sampled were duplicates taken as a check of our precision. These replicate samples were interspersed throughout the station analysis for quality assurance and integrity of the coulometer cell solutions. The average absolute difference

of these replicates was 1.34 (AOML 3) and 1.49 (AOML 4)  $\mu\text{mol/kg}$  - No major systematic differences between the replicates were observed.

The pipette volume was determined by taking aliquots of distilled water from volumes at known temperatures. The weights with the appropriate densities were used to determine the volume of the pipettes.

Calibration data during this cruise:

UNIT	Ave Gas Cal Factor	Pipette	Ave CRM	Std Dev	Ave Difference Dupes
AOML3	1.00390	27.990 ml	1953.24, N = 43	1.14	1.34
AOML4	1.00313	29.387 ml	1952.20, N = 41	1.25	1.49

## 9.6 Instrument Repairs

AOML 3 had a relay switch failure before Station 41. The relay switch and micro acid pump were replaced and the instrument functioned well for the rest of the cruise. The pipette was not filling properly before Station 54. Valve 13 was found to be defective and replaced which corrected the filling of the pipette. AOML 3 functioned well for the remainder of the cruise.

## 9.7 Summary

The overall performance of the analytical equipment was good during the cruise. Including the duplicates, a total of 2208 samples were analyzed from 90 CTD casts for dissolved inorganic carbon (DIC), which equates to a DIC value for 68% of the niskins tripped. The DIC data reported to the database directly from the ship are to be considered preliminary until a more thorough quality assurance can be completed shore side.



## DISCRETE PH ANALYSES (TOTAL SCALE)

### PI

- Dr. Andrew Dickson (SIO)
- Dr. Frank Millero (RSMAS)

### Technicians

- Sidney Wayne (HPU)
- Albert Ortiz (RSMAS)

## 10.1 Sampling

Samples were collected in 250 mL Pyrex glass bottles and sealed using grey butyl rubber stoppers held in place by aluminum-crimped caps. Each bottle was rinsed two times and allowed to overflow by one half additional bottle volume. Prior to sealing, each sample was given a 1% headspace and poisoned with 0.02% of the sample volume of saturated mercuric chloride ( $\text{HgCl}_2$ ). Samples were collected only from Niskin bottles that were also being sampled for both total alkalinity and dissolved inorganic carbon in order to completely characterize the carbon system. Additionally, duplicate samples were collected from all stations for quality control purposes.

## 10.2 Analysis

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

## 10.3 Reagents

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

## 10.4 Data Processing

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

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

and

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

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:

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

## 10.5 Problems and Troubleshooting

During the beginning of the cruise, the sample cell was broken due to stress on the sample inlet glass tubes, but the lead tech was able to rig the cell to remain operable.

## 10.6 Standardization/Results

The precision of the data was assessed from measurements of duplicate analyses, replicate analyses (two successive measurements on one bottle), and certified reference material (CRM) Batch 192 (provided by Dr. Andrew Dickson, UCSD). two or three duplicates and one or two replicate measurements were performed on every station when at least twenty-four Niskins were sampled. If less than twenty-four Niskins were sampled, only one or two duplicates and one replicate measurement were performed. CRMs were measured at the beginning and ending of each day.

The precision statistics for A22 are:

Duplicate precision	$\pm 0.0009$ (n=190)
Replicate precision	$\pm 0.0010$ (n=104)
B192	$7.7493 \pm 0.0016$ (n=47)
B192 within-bottle SD	$\pm 0.0010$ (n=47)

2001 pH values were submitted for A22. 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.





## CFC, SF<sub>6</sub>, AND N<sub>2</sub>O

### PIs

- Mark J. Warner (UW)

### Analysts

- Mark J. Warner (UW)
- Bonnie X. Chang (UW)
- Lillian Henderson (RSMAS)

<p><b>Warning:</b> Note that N<sub>2</sub>O measurements are a Level 3 measurement. The concentrations were measured on the same water samples collected for the Level 1 CFC/SF<sub>6</sub> measurements. The N<sub>2</sub>O analysis is still under development. Please contact the PI for any use of these data.</p>
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Samples for the analysis of dissolved CFC-11, CFC-12, SF<sub>6</sub>, and N<sub>2</sub>O were collected from approximately 1417 of the Niskin water samples during the expedition. When taken, water samples for tracer analysis were the first samples drawn from the 10-liter bottles. Care was taken to co-ordinate the sampling of the tracers with other samples to minimize the time between the initial opening of each bottle and the completion of sample drawing. In most cases, dissolved oxygen, partial pressure of CO<sub>2</sub>, dissolved inorganic carbon, and pH samples were collected within several minutes of the initial opening of each bottle. To minimize contact with air, the tracer samples were collected from the Niskin bottle petcock into 250-cc ground glass syringes through plastic 3-way stopcocks. The syringes were stored in the dark in a large ice chest in the laboratory at 3.5° - 6° C until 30-45 minutes before analysis to reduce the degassing and bubble formation in the sample. At that time, they were transferred to a water bath at approximately 35° C to warm the samples prior to analysis in order to increase the stripping efficiency.

Concentrations of CFC-11, CFC-12, SF<sub>6</sub>, and N<sub>2</sub>O in air samples, seawater and gas standards were measured by ship-board electron capture gas chromatography (EC-GC). This system from the University of Washington was located in a portable laboratory on the fantail. Samples were introduced into the EC-GC via a purge and trap system. Approximately 200-ml water samples were purged with nitrogen and the compounds of interest were trapped on a Porapak Q/Carboxen 1000/Molecular Sieve 5A trap cooled by an immersion bath to >-55°C. During the purging of the sample (6 minutes at 170 ml min<sup>-1</sup> flow), the gas stream was stripped of any water vapor via a Nafion trap in line with an ascarite/magnesium perchlorate dessicant tube prior to transfer to the trap. The trap was then isolated and heated by direct resistance to 175°C. The desorbed contents of the trap were back-flushed and transferred onto the analytical pre-columns. The first precolumn was a 40-cm length of 1/8-in tubing packed with 80/100 mesh Porasil B. This precolumn was used to separate the CFC-11 from the other gases. The second pre-column was 13 cm of 1/8-in tubing packed with 80/100 mesh molecular sieve 5A. This pre-column separated the N<sub>2</sub>O from CFC-12 and SF<sub>6</sub>. Three analytical columns in three gas chromatographs with electron capture detectors were used in the analysis. CFC-11 was separated from other compounds (e.g. CFC-113 and CCl<sub>4</sub>) by a column consisting of 36 cm of Porasil B and 150 cm of Carbograph 1AC maintained at 80°C. CFC-12 and SF<sub>6</sub> were analyzed using a column consisting of 2.33 m of molecular sieve 5A and 1.5 m of Carbograph 1AC maintained at 80°C. The analytical column for N<sub>2</sub>O was 30 cm of molecular sieve 5A in a 120°C oven. The carrier gas for this column was instrumental grade P-5 gas (95% Ar / 5% CH<sub>4</sub>) that was

directed onto the second precolumn and into the third column for the N<sub>2</sub>O analyses. The detectors for the CFC-11, and for CFC-12 and SF<sub>6</sub> analyses were operated at 300°C. The detector for N<sub>2</sub>O was maintained at 320 °C.

The analytical system was calibrated frequently using a standard gas of known gas composition. Gas sample loops of known volume were thoroughly flushed with standard gas and injected into the system. The temperature and pressure were recorded so that the amount of gas injected could be calculated. CFC concentrations in air and seawater samples were determined by fitting their chromatographic peak areas to multi-point calibration curves, generated by injecting multiple sample loops of gas from a working standard (UW WRS 32399) into the analytical instrument. A full range of calibration points were run at the beginning and end of the cruise, as well as during long transits/weather delays when possible. The procedures used to transfer the standard gas to the trap, precolumns, main chromatographic columns and EC detectors were similar to those used for analyzing water samples. Single injections of a fixed volume of standard gas at one atmosphere were run much more frequently (at intervals of 2 hours) to monitor short-term changes in detector sensitivity. Air samples and system blanks (injections of loops of CFC-free gas) were injected and analyzed in a similar manner. The typical analysis time for samples was 740 sec.

For atmospheric sampling, an ~100 meter length of 3/8-in OD Dekaron tubing was run from the portable laboratory to the bow of the ship. A flow of air was drawn through this line to the main laboratory using an Air Cadet pump. The air was compressed in the pump, with the downstream pressure held at ~1.5 atm. using a back-pressure regulator. A tee allowed a flow (100 ml min<sup>-1</sup>) of the compressed air to be directed to the gas sample valves of the CFC/SF<sub>6</sub>/N<sub>2</sub>O analytical system, while the bulk flow of the air (>7 l min<sup>-1</sup>) was vented through the back-pressure regulator. Air samples were generally analyzed when the relative wind direction was within 50 degrees of the bow of the ship to reduce the possibility of shipboard contamination. The pump was run for approximately 30 minutes prior to analysis to insure that the air inlet lines and pump were thoroughly flushed. The average atmospheric concentrations determined during the cruise (from sets of 3 or 4 measurements analyzed when possible) were 221.9 +/- 1.8 parts per trillion (ppt) for CFC-11 (n=27), 496.6 +/- 1.8 ppt for CFC-12 (N=40), 10.8 +/- 0.2 ppt for SF<sub>6</sub> (N=15), and 332.9 +/- 2.0 parts per billion for N<sub>2</sub>O (N=19).

Concentrations of the CFCs in air, seawater samples and gas standards are reported relative to the SIO98 calibration scale [Prinn00]. Concentrations in air and standard gas are reported in units of mole fraction in dry gas, and are typically in the parts per trillion (ppt) range for CFCs and SF<sub>6</sub> and parts per billion (ppb) for N<sub>2</sub>O. Dissolved CFC concentrations are given in units of picomoles per kilogram seawater (pmol/kg), SF<sub>6</sub> in femtomoles per kilogram seawater (fmol/kg), and N<sub>2</sub>O in nanomoles per kilogram seawater (nmol/kg). Estimated limit of detection is 1 fmol/kg for CFC-11, 1 fmol/kg for CFC-12 and 0.01 fmol/kg for SF<sub>6</sub>.

The efficiency of the purging process was evaluated by re-stripping water samples and comparing the residual concentrations to initial values. These re-strip values were less than 1% for CFC-11 and essentially zero for CFC-12 and SF<sub>6</sub>. Based on the re-strips of numerous samples where the stripper blank was low and relatively constant, the mean values for N<sub>2</sub>O were approximately 5-10% during the cruise.

On this expedition, based on the analysis of 40 duplicate samples (i.e. two syringe samples collected from the same Niskin), we estimate precisions (1 standard deviation) of 0.65% or 0.0012 pmol/kg (whichever is greater) for dissolved CFC-11, 0.36% or 0.00058 pmol/kg for CFC-12 measurements, 0.017 fmol/kg or 1.98% for SF<sub>6</sub>, and 0.67% or 0.096 nmol/kg for N<sub>2</sub>O.

## 11.1 Analytical Difficulties/Acknowledgements

During A20, two immersion coolers failed – the first lost coolant through a leak during transport to the start of A20; the second had its low-stage compressor fail during the transit after the completion of the measurement program of A20. Without an immersion cooler for the trapping process, we would have only been able to measure CFC-12 for A22. Thanks to the efforts of Dana Greeley, Eric Wisegarver, the shipping department at NOAA-PMEL and the tracer measurement lab at NOAA-PMEL, a spare working immersion cooler was located, tested, and shipped to St. Thomas in advance of the departure for A22. We were only able to make high-precision measurements during this cruise due to the efforts, above and beyond, of the people listed above. These individuals deserve the credit for the quality of the reported data.

## DISSOLVED ORGANIC CARBON AND TOTAL DISSOLVED NITROGEN

### PI

- C. Carlson (UCSB)

### Technician

- Chance English (UCSB)

### Analysts

- Keri Opalk
- Elisa Halewood

**Support** NSF

## 12.1 Project Goals

The goal of the DOM project is to evaluate dissolved organic carbon (DOC) and total dissolved nitrogen (TDN) concentrations along the A22 meridional transect occupied between April and May 2021.

## 12.2 Sampling

DOC profiles were taken at every other station from every depth sampled by the CTD (45 stations) DOC samples were passed through an inline filter holding a combusted GF/F filter attached directly to the Niskin for samples in the top 500 m of each cast. This was done to eliminate particles larger than 0.6  $\mu\text{m}$  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  $\mu\text{mol kg}^{-1}$  resolution. All samples were rinsed 3 times with about 5 mL of seawater and collected into combusted 40 mL glass EPA vials. Samples were fixed with 75  $\mu\text{L}$  of 4N Hydrochloric acid and stored at room temperature on board. Samples were shipped back to UCSB for analysis via high temperature combustion on Shimadzu TOC-V or TOC L analyzers.

Sample Vials were prepared for this cruise by soaking in 10% Hydrochloric acid, followed by a 3 times rinse with DI water. The vials were then combusted at 450°C for 4 hours to remove any organic matter. Vial caps were cleaned by soaking in DI water overnight, followed by a 3 times rinse with DI water and left out to dry.

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

## 12.3 Standard Operating Procedure for DOC analyses – Carlson Lab UCSB

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

Extensive conditioning of the combustion tube with repeated injections of low carbon water (LCW) and deep seawater is essential to minimize the machine blanks. After conditioning, the system blank is assessed with UV oxidized low carbon water. The system response is standardized daily with a four-point calibration curve of potassium hydrogen phthalate solution in LCW. All samples are systematically referenced against low carbon water and deep Sargasso Sea (2600 m) or Santa Barbara Channel (400 m) reference waters and surface Sargasso Sea or Santa Barbara Channel sea water every 6 – 8 analyses [Hansell1998]. The standard deviation of the deep and surface references analyzed throughout a run generally have a coefficient of variation ranging between 1-3% over the 3-7 independent analyses (number of references depends on size of the run). Daily reference waters were calibrated with DOC CRM provided by D. Hansell (University of Miami; [Hansell2005]).

### 12.3.1 DOC Calculation

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

## 12.4 Standard Operating Procedure for TDN analyses – Carlson Lab UCSB

TDN samples were analyzed via high temperature combustion using a Shimadzu TOC-V with attached Shimadzu TNM1 unit at an in-shore based laboratory at the University of California, Santa Barbara. The operating conditions of the Shimadzu TOC-V were slightly modified from the manufacturer's model system. The condensation coil was removed and the headspace of an internal water trap was reduced to minimize the system's dead space. The combustion tube contained 0.5 cm Pt pillows placed on top of Pt alumina beads to improve peak shape and to reduce alteration of combustion matrix throughout the run. Carrier gas was produced with a Whatman® gas generator [Carlson2010] and ozone was generated by the TNM1 unit at 0.5L/min flow rate. Three to five replicate 100 µl of sample were injected at 130mL/min flow rate into the combustion tube heated to 680°C, where the TN in the sample was converted to nitric oxide (NO). The resulting gas stream was passed through an electronic dehumidifier. The dried NO gas then reacted with ozone producing an excited chemiluminescence NO<sub>2</sub> species [Walsh1989] and the fluorescence signal was detected with a Shimadzu TNMI chemiluminescence detector. The resulting peak area was integrated with Shimadzu chromatographic software. Injections continue until at least three injections meet the specified range of a SD of 0.1 area counts, CV  $\leq 2\%$  or best 3 of 5 injections.

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

solution in blank water. All samples were systematically referenced against low nitrogen water and deep Sargasso Sea reference waters (2600 m) and surface Sargasso Sea water every 6 – 8 analyses [Hansell1998]. Daily reference waters were calibrated with deep CRM provided by D. Hansell (University of Miami; [Hansell2005]).

Dissolved organic nitrogen (DON) concentrations are calculated as the difference between TDN and DIN. Samples with less than 10  $\mu\text{mol/kg}$  DIN are most reliable estimates of DON.

#### 12.4.1 TDN calculation

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





## CARBON ISOTOPES IN SEAWATER (14/13C)

### PI

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

### Technician

- Chance English (UCSB)

A total of 16-32 samples were collected from 13 stations along the A22 meridional transect. Samples were taken from 16 or 32 bottles from stations deemed “shallow” or “deep”, respectively. Shallow stations were sampled to approximately 1500m and deep stations were sampled through the full depth of the station. Duplicates were made at 8 separate stations from one of the 16 or 32 niskin bottles sampled during a cast. Samples were collected in 500 mL airtight glass bottles. Using silicone tubing, the flasks were rinsed 2 times with seawater from the surface niskin. While keeping the tubing at the bottom of the flask, the flask was filled and flushed by allowing it to overflow 1.5 times its volume. Once the sample was taken, about 10 mL of water was removed to create a headspace and 120 L of 50% saturated mercuric chloride solution was added to the sample. To avoid contamination, gloves were used when handling all sampling equipment and plastic bags were used to cover any surface where sampling or processing occurred.

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

The radiocarbon/DIC content of the seawater (DI14C) is measured by extracting the inorganic carbon as CO<sub>2</sub> gas, converting the gas to graphite and then counting the number of 14C atoms in the sample directly using an accelerated mass spectrometer (AMS).

Radiocarbon values will be reported as 14C using established procedures modified for AMS applications. The 13C/12C of the CO<sub>2</sub> extracted from seawater is measured relative to the 13C/12C of a CO<sub>2</sub> gas standard calibrated to the PDB standard using an isotope ratio mass spectrometer (IRMS) at NOSAMS.

Table 1: Stations sampled

6 (shallow)	12 (shallow)	16 (duplicate only)
18 (deep)	36 (deep)	40 (deep)
46 (shallow)	50 (deep)	54 (shallow)
60 (deep)	66 (shallow)	72 (deep)
76 (shallow)	82 (deep)	



## LADCP

### PI

- Dr. Andreas Thurnherr (LDEO)

### Cruise Participant

- Ali Siddiqui (JHU)

## 14.1 Data Acquisition and QC

In order to collect full-depth profiles of horizontal and vertical ocean velocity, two Acoustic Doppler Current Profilers (ADCPs), one facing upward (uplooker) and the other downward (downlooker), as well as a Deep Sea Power And Light rechargeable 48V battery and cables were installed on the CTD rosette. This lowered ADCP (LADCP) system was provided by the Lamont-Doherty Earth Observatory. The LADCP system is self contained, requiring on-deck cable connections to charge the battery and for communicating with the ADCPs. The battery charger was affixed to an elevated cable run in the CTD bay and connected to a long power cord extension terminating on a bench in the wet lab next to the bulkhead door leading to the CTD bay. On the bench, the LADCP data acquisition computer, a Mac Mini, as well as two bench-top power supplies for the ADCPs were installed.

Between casts the LADCP system in the CTD bay was left connected to the (unpowered) battery charger, as well as to the two deck cables leading to the data acquisition computer and to the bench-top power supplies. The male plug of the (disconnected) adapter cable between the battery and the LADCP star cable was dummied up. While the deck cables in the wet lab were permanently connected to the acquisition computer with RS232-to-USB adapters, the corresponding power connectors were left disconnected from the bench-top power supplies. With this setup there is no voltage on any of the LADCP cables on the rosette.

A few minutes before the CTD was moved out of the bay for deployment the battery was disconnected from the charger and connected to the ADCPs via an adapter cable and the star cable, both permanently installed on the rosette. The male connector of the battery charger cable was dummied up. In order to start data acquisition, the instruments were woken up by the acquisition computer, the data from the previous cast deleted from their built-in memory cards, and the instruments were programmed to start pinging. Finally the two deck cables were disconnected from the pig-tails that were also permanently installed on the rosette in order to protect the expensive star cable from unnecessary wear. The deck cables and pig tail connectors were dummied up and the latter were secured to the rosette with a velcro strap to avoid whipping during the casts. Once everything was set up, the CTD operator and/or the marine tech were notified that the LADCP system was ready for deployment. Deployment information was logged on LADCP log sheets either when the data acquisition was started or once the CTD system had entered the water.

After the CTD had been secured in the bay after each cast the velcro securing the dummied up pig-tail ends to the rosette was removed, the dummied up pig-tail ends were rinsed with fresh water, the dummy plugs were removed, and the pig tails were connected to the deck cables. Using the acquisition computer, LADCP data acquisition was stopped after which the data download was initiated. Afterwards the two bench top power supplies were connected to the deck cables in the lab, the battery was disconnected from the adapter cable on the rosette, the male end of the battery adapter

cable on the rosette with two exposed pins now carrying 48V (from the bench-top power supplies) was dummied up, and the battery cable was attached to the (still unpowered) charger cable. Afterwards power was applied to the battery charger in the wet lab and the time noted on the LADCP log sheet.

After the data from the cast had finished downloading (after about 20 minutes on deep casts), the bench top power supplies were disconnected from the deck cables in the lab. Then the data files were checked by integrating the measured vertical velocities in time, which yields estimates for the maximum depth (zmax) and the end depth (zend) of the profile, both of which were recorded on the log sheet. After the battery was fully charged (usually about an hour after charging was initiated, as indicated by LEDs on the charger) the charger was disconnected from power in the wet lab and the time was noted on the log sheet. At this stage, the LADCP system was ready for the next cast.

Communication between the acquisition computer and the ADCPs was handled by a new acquisition software (acquire2), implemented as a set of UNIX shell commands designed to minimize the possibility of operator errors. Three different commands are used:

*Lstart:* This command wakes the instruments, lists their memory contents, clears the memory (after operator confirmation) and programs the instruments to start pinging by uploading command files. CTD station and cast numbers must be provided by the operator since the LADCP files use an independent numbering scheme. (CTD station and cast information, as well as the LADCP profile number were noted on the LADCP log sheet.)

*Ldownload:* This command interrupts the running data acquisition, downloads the data and backs up the data files to a network drive.

*Lcheck:* This command integrates the measured vertical velocities from both ADCPs to estimate zmax and zend, which are displayed together with other useful profile statistics before the data files are backed up (again) on the network drive.

While these three commands are all that is needed for LADCP data acquisition, a fourth command (Lreset) is available for resetting the ADCPs after swapping instruments and in case of communications problems, of which there were none during this cruise.

Once or twice a day the LADCP and CTD time-series data were transmitted with rsync to Thurnherr's lab, where the data were processed for horizontal velocity using the LDEO\_IX processing software and for vertical velocity using the LADCP\_w processing software. Important diagnostic plots were inspected in the lab, and summary plots for every profile together with a short written assessment was emailed back to the vessel and filed in a ring binder. In addition to these processing diagnostics, LADCP data quality was continuously monitored by creating section plots, some of which can be found in the narrative section of this cruise report. A comprehensive post-cruise LADCP QC will be carried out by Thurnherr in his lab before submission of the new data to the archives.

## 14.2 Instrumentation

A single 300kHz TRDI Workhose Monitor ADCP (WH300, s/n 12734), fitted with a custom self-recording accelerometer/magnetometer package, was installed as the uplooker during all casts. This was the same as used in the first leg (A20). The data from the accelerometer/magnetometer package will be downloaded after the instruments return to the lab and used for QC and final processing if needed.

A second 300kHz TRDI Workhose Monitor ADCP (WH300 s/n 24477) was used as the downlooker during the entire A22 cruise. The same instrument was used for profiles 53-90 in the first leg as well.

While both the ADCPs performed well, there was an error in data acquisition at station 9 and 10. The downlooker ADCP was recording data in two separate files, which indicated a power supply issue during downcast. The issue first appeared at station 9 and persisted in station 10, at which point the non-spillable lead acid battery mounted on the rosette (SN01283) was replaced with a separate fully charged battery. A voltage of 51.3 V was measured using a multimeter before installation. Along with the battery, the star cable along with the deck cable pig tails were also replaced with new ones. It was found that the error was resolved after this operation and both the ADCPs were collecting data in a single file. However, while reconnecting the star cable to the ADCPs, the uplooker and downlooker connections were interchanged which led to the ADCP files of profiles 11-16 being mislabeled (DL instead of UL and vice versa). This issue was subsequently resolved by simply switching the connections of the two serial adapter connectors for the two

ADCPs. There were no issues up till station 51, when the uplooker ADCP started storing data in 2 files again. Since there was no data deterioration, it was decided to not change the cables once again, instead a new deck cable along with a battery star cable adapter were kept on stand by in case of any potential issues. The data files for the rest of the cruise were collected for the uplooker ADCP in 2 files. The processing software however, had no issues dealing with it.

## 14.3 Figures

The section plots shown in Figs. 1 & 2 show the zonal and meridional LADCP velocities obtained from the 90 stations occupied.

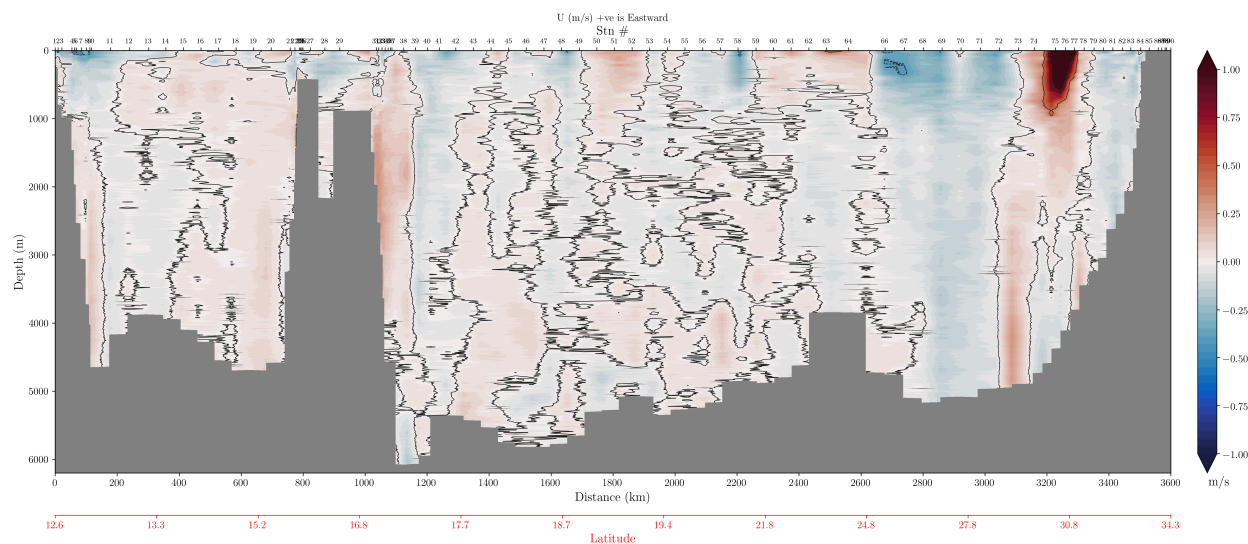


Fig. 1: Zonal velocity section for A22 using the LADCP data.

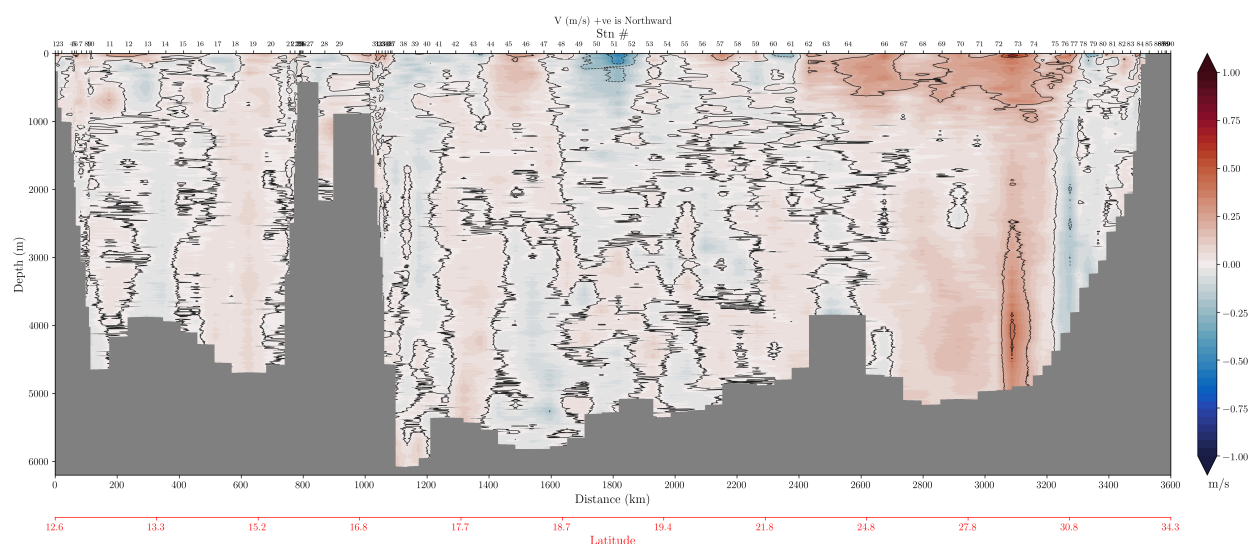


Fig. 2: Meridional velocity section for A22 using the LADCP data.



## DISCRETE PCO<sub>2</sub>

### PIs

- Rik Wanninkhof (NOAA/AOML)

### Analysts

- N. Patrick Mears (CIMAS/RSMAS)

## 15.1 Sampling

Samples were drawn from 11-L Niskin bottles into 500 ml glass bottles using nylon tubing with a Silicone adapter that fit over the drain cock. Bottles were first rinsed three times with ~25 ml of water. They were then filled from the bottom, overflowing a bottle volume while taking care not to entrain any bubbles. About 5 ml of water was withdrawn to allow for expansion of the water as it warms and to provide space for the stopper and tubing of the analytical system. Saturated mercuric chloride solution (0.24 ml) was added as a preservative. The sample bottles were sealed with glass stoppers lightly covered with grease and were stored at room temperature for a maximum of fourteen hours prior to being run.

The analyses for pCO<sub>2</sub> were done with the discrete samples at 20°C. A primary water bath was kept within 0.03°C of the analytical temperature; a secondary bath was kept within 0.3°C the analytical temperature. The majority of the samples were analyzed in batches of twelve bottles, which took approximately 3.5 hours including the six standard gases. When twelve bottles were moved into the primary water bath for analyses, the next twelve bottles were moved into the secondary water bath. No sample bottle spent less than two hours in the secondary water bath prior to being moved to the analytical water bath. Duplicate samples from the same Niskin were drawn to check the precision of the sampling and analysis.

1302 samples were drawn from 50 CTD casts. Fifty sets of duplicate bottles were drawn at numerous depths. The average relative standard error was 0.11%, while the median relative error was 0.09%.

No serious errors occurred.

## 15.2 Analyzer Description

The principles of the discrete pCO<sub>2</sub> system are described in [Wanninkhof1993] and [Chipman1993]. The major difference in the current system is the method of equilibrating the sample water with the constantly circulating gas phase. This system uses miniature membrane contactors (Micromodules from Memrana, Inc.), which contain bundles of hydrophobic micro-porous tubes in polycarbonate shells (2.5 x 2.5 x 0.5 cm). The sample water is pumped over the outside of the tubing bundles in two contactors in series at approximately 25 ml/min and to a drain. The gas is recirculated in a vented loop, which includes the tubing bundles and a non-dispersive infrared analyzer (LI-COR™ model 840) at approximately 32 ml/min.



The flow rates of the water and gas are chosen with consideration of competing concerns. Faster water and gas flows yield faster equilibration. A slower water flow would allow collection of smaller sample volume; plus a slower gas flow would minimize the pressure increase in the contactor. Additionally, the flow rates are chosen so that the two fluids generate equal pressures at the micro-pores in the tubes to avoid leakage into or out of the tubes. A significant advantage of this instrumental design is the complete immersion of the miniature contactors in the constant temperature bath. Also in the water bath are coils of stainless steel tubing before the contactors that ensure the water and gas enter the contactors at the known equilibration temperature.

The instrumental system employs a large insulated cooler (Igloo Inc.) that accommodates twelve sample bottles, the miniature contactors, a water circulation pump, a copper coil connected to a refrigerated circulating water bath, an immersion heater, a 12-position sample distribution valve, two thermistors, and two miniature pumps. The immersion heater works in opposition to the cooler water passing through the copper coil. One thermistor is immersed in the water bath, while the second thermistor is in a sample flow cell after the second contactor. The difference between the two thermistor readings was consistently less than 0.02°C during sample analyses. In a separate enclosure are the 8-port gas distribution valve, the infrared analyzer, a barometer, and other electronic components. The gas distribution valve is connected to the gas pump and to six standard gas cylinders.

To ensure analytical accuracy, a set of six gas standards (ranging from 288 to 1534 ppm) was run through the analyzer before and after every sample batch. The standards were obtained from Scott-Marin and referenced against primary standards purchased from C.D. Keeling in 1991, which are on the WMO-78 scale.

A custom program developed using LabView™ controls the system and graphically displays the CO<sub>2</sub> concentration as well as the temperatures, pressures and gas flow during the 15-minute equilibration. The analytical system was running well enough that the equilibration period was shortened to 12 minutes for the second half of the cruise. The CO<sub>2</sub> in the gas phase changes greatly within the first minute of a new sample and then goes through nearly two more oscillations. The oscillations dampen quickly as the concentration asymptotically approaches equilibrium. The flows are stopped, and the program records an average of ten readings from the infrared analyzer along with other sensor readings. The data files from the discrete pCO<sub>2</sub> program are reformatted so that a Matlab program designed for processing data from the continuous pCO<sub>2</sub> systems can be used to calculate the fugacity of the discrete samples at 20°C. The details of the data reduction are described in [Pierrot2009].

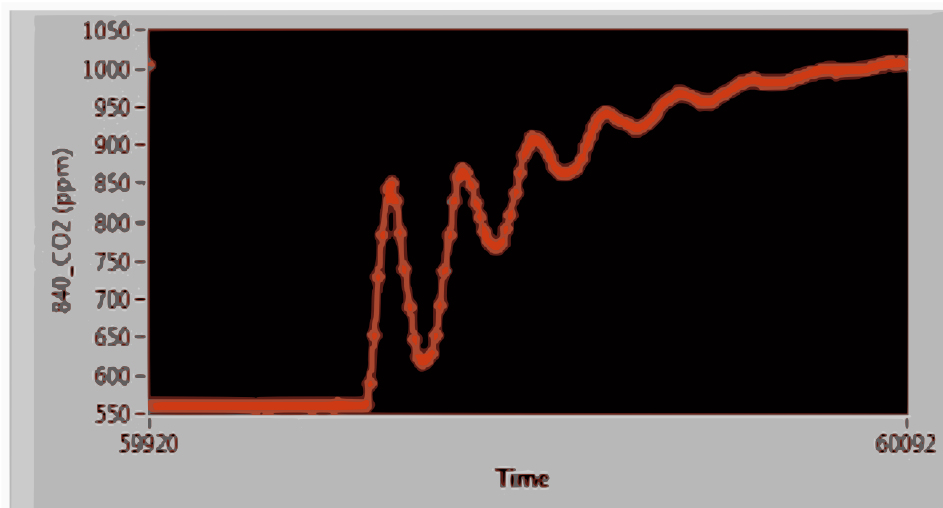


Fig. 1: CO<sub>2</sub> oscillations during start of first sample in set of twelve

The instrumental system was originally designed and built by Tim Newberger and was supported by C. Sweeney and T. Takahashi. Their skill and generosity has been essential to the successful use and modification of this instrumental system. Victoria Schoenwald assisted in collecting samples.

Table 1: Standard Gas Cylinders

Cylinder #	ppm CO <sub>2</sub>
JB03282	288.46
JB03268	384.14
CB11243	591.61
CA05980	792.51
CA05984	1036.95
CA05940	1533.7



## UNDERWAY $p\text{CO}_2$

### PIs

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### Analysts

- Andrew Collins (NOAA/PMEL)

The partial pressure of  $\text{CO}_2$  ( $p\text{CO}_2$ ) in the surface ocean was measured throughout the duration of this expedition with a General Oceanics 8050 underway system. Uncontaminated seawater was continuously passed ( $\sim 2.8$  l/min) through a chamber where the seawater concentration of dissolved  $\text{CO}_2$  was equilibrated with an overlying headspace gas. The  $\text{CO}_2$  mole fraction of this headspace gas ( $x\text{CO}_2$ ) was measured approximately every three minutes via a non-dispersive infrared analyzer (Licor 7000). Roughly every three hours, the system measured four gas standards with known  $\text{CO}_2$  concentrations certified by the NOAA Earth Science Research Laboratory in Boulder, CO ranging from  $\sim 300 - 900$  ppm  $\text{CO}_2$ . Additionally, a tank of 99.9995% ultra-high purity nitrogen gas was measured as a baseline 0%  $\text{CO}_2$  standard. Following measurements of standard gases, six measurements of atmospheric  $x\text{CO}_2$  were made of air supplied through tubing fastened to the ship's starboard jackstaff. Twice a day, the infrared analyzer was calibrated via a zero and span routine using the nitrogen gas and the highest concentration (872.6 ppm)  $\text{CO}_2$  standard. In addition to measurements of seawater  $x\text{CO}_2$ , atmospheric  $x\text{CO}_2$ , and standard gases, several variables were monitored to evaluate system performance (e.g. gas and water flow rates, pump speeds, equilibrator pressures, etc). For more detail on the general design of this underway  $p\text{CO}_2$  system, see [Pierrot2009].

A Seabird (SBE) 38 temperature sensor located at the ship's seawater intake provided measurements of in situ seawater temperature, while a SBE 45 thermosalinograph monitored temperature and salinity in the bow of the ship before the seawater reached the  $p\text{CO}_2$  system. An Aanderaa 4330 optode plumbed in line with the  $p\text{CO}_2$  system water supply measured dissolved oxygen (DO) continuously. Additionally, a modified SeaFET system was also plumbed in line which measured pH throughout the duration of the cruise.

A preliminary round of processing was performed on this dataset using Matlab routines developed by Denis Pierrot of the Atlantic Oceanic and Meteorological Lab in Miami, FL. In one brief (10 minute) instance, the underway system was shut down for minor maintenance to be performed. Two brief instances of data loss occurred when the ship's data transmission dropped, resulting in the loss of position, temperature, salinity, etc data for 217  $p\text{CO}_2$  measurements. These measurements will be merged with the  $p\text{CO}_2$  dataset during the next round of processing. Of 12,897 measurements, only 13 were assigned a WOCE quality flag of 4 (bad measurement), all of which were due to contamination of atmospheric measurements by exhaust from the ship. At this time, no measurements were assigned a quality flag of 3 (questionable measurement). Measurements of gas standards were within 1% of their certified value throughout the duration of the expedition, save for one brief initial period where the Licor demonstrated some drift (Figure 1).

Preliminary review of collected data suggest that the main control on the surface seawater carbonate system was temperature (Figure 2). Excursions from thermodynamic controls on  $p\text{CO}_2$ , pH and DO were measured in the northern section of the cruise on line W, where mild undersaturation ( $\sim 320$  ppm) relative to atmospheric values of  $p\text{CO}_2$  were measured. Concomitant changes were observed in discrete measurements of pH, DO, DIC, and other variables. Fluorescence and chlorophyll data suggest the presence of a prolonged phytoplankton bloom, which likely explains these observations.

However, further evaluation of these data and the supplementary suite of discrete surface CTD measurements that were collected is needed before the controls on  $p\text{CO}_2$ , pH and DO can be fully elucidated.

This dataset should be considered preliminary; additional quality control and quality assurance is needed before these data can be considered final.

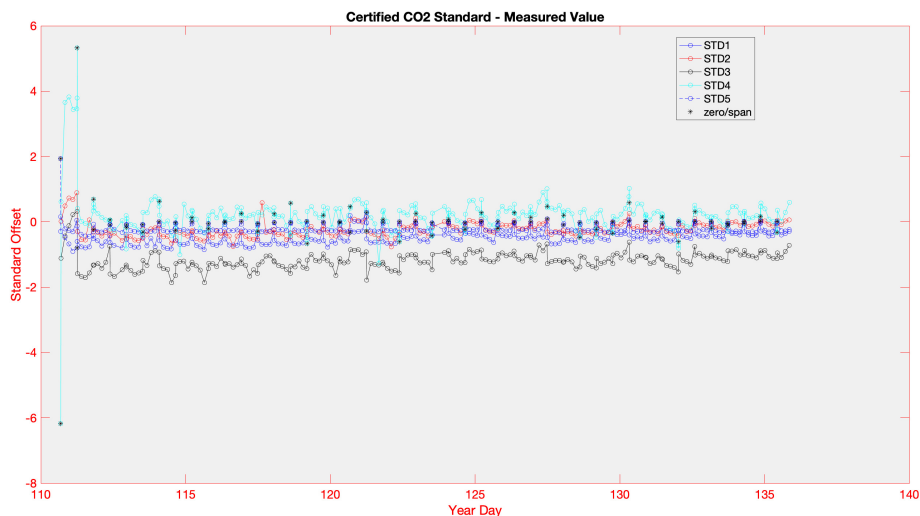


Fig. 1: Difference between measurements made by the non-dispersive infrared analyzer (Licor 7000) of gas standards and the known certified value of those standards (in ppm  $\text{CO}_2$ ).

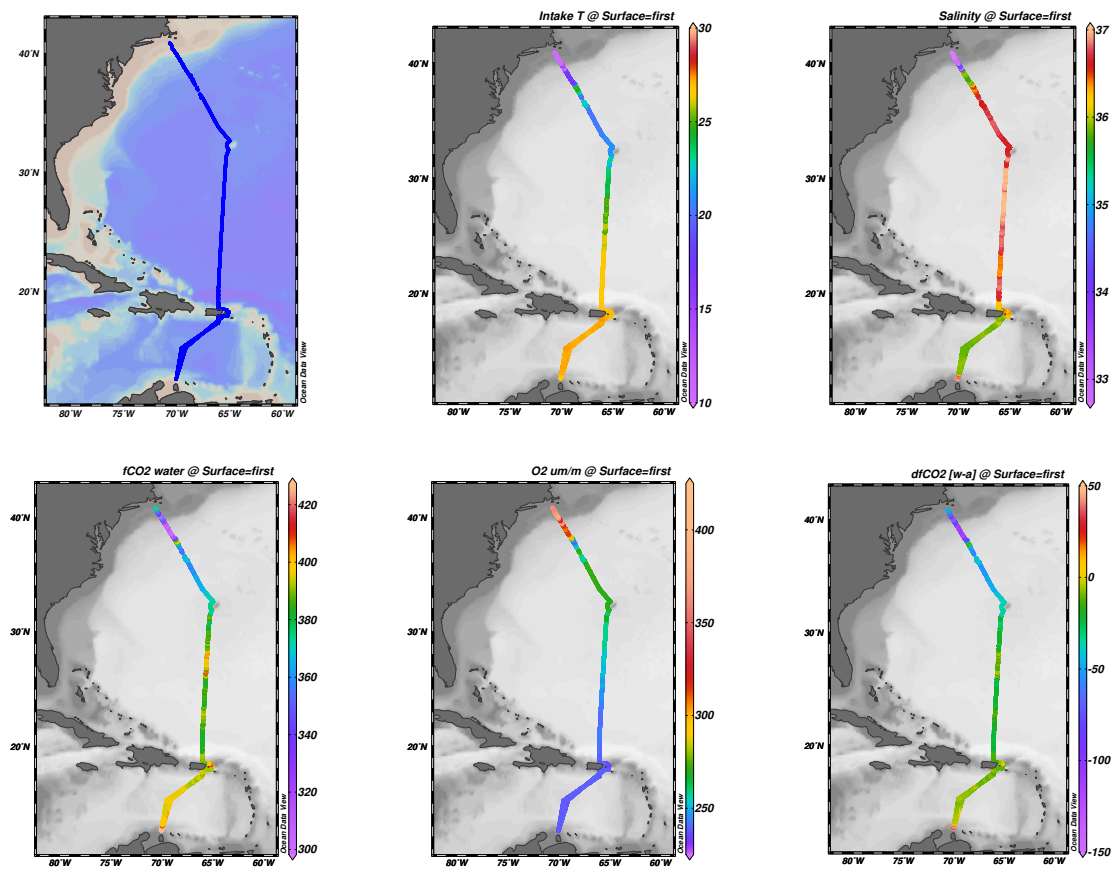


Fig. 2: Spatial distribution of relevant parameters (sea surface temperature [SST, °C], sea surface salinity [PSU], fCO<sub>2</sub> [ppm], air-sea fCO<sub>2</sub> disequilibrium [ppm] and dissolved oxygen [μM]) measured by the underway pCO<sub>2</sub> system during the 2021 GO-SHIP A22 research expedition.



## FLOAT DEPLOYMENTS

A total of 14 profiling floats from 3 different programs were deployed during the 2021 A22 research cruise. 10 are part of the Core Argo program (<https://argo.ucsd.edu/>) (8 WHOI, 2 Argo Canada - RBR pilot program). The remaining 4 are part of the new Global Ocean Biogeochemical Argo array (<https://www.go-bgc.org/>). Additionally, two RAFOS floats were deployed as tests for Viviane Menezes upcoming Deep Madagascar Basin (DMB) Experiment. Both Core and Go-GBC floats measure temperature, salinity, and pressure. Go-BGC floats additionally measure O<sub>2</sub>, NO<sub>3</sub>, pH, and bio-optics. Details for each float type follow.

### 17.1 WHOI Core Argo Floats

#### PIs

- Susan Wijffels (WHOI)
- Steven Jayne (WHOI)
- Pelle Robbins (WHOI)

#### Shipboard personnel:

- Jesse Anderson (WHOI)
- Elizabeth Ricci (UW SSSG)
- Stephen Jalickee (UW SSSG)

A total of 8 WHOI Core Argo floats were deployed during the A22 cruise. All floats were MRV Systems Solo II (S2-A) floats equipped with Seabird SBE41-CP CTDs and Iridium antennas. Parameters measured are temperature, salinity, and pressure. These floats were readied for deployment by the skilled members of the WHOI float lab. Jessica Kozik (WHOI) handled dockside logistics for getting the floats to the R/V Thompson prior to the first leg of the A20/A22 cruise. Shock watches indicated that the floats were handled properly during transport from the WHOI float lab to the R/V Thompson main lab. Deployment training was provided via videoconference prior to ship departure. All floats were armed and ready for deployment prior to joining the ship. Pelle Robbins (WHOI) determined float deployment locations, prioritizing regions with coverage gaps for the target Argo spatial coverage. At sea, R/V Thompson SSGs Elizabeth Ricci and Stephen Jalickee, and co-chief scientist Jesse Anderson were in charge of deployments. Additional assistance was provided by ABs and student CTD watch standers. Float deployment boxes were packaged in plastic bags and wrap to protect the cardboard boxes and cornstarch release harness. Just before deployment, the plastic layers were removed. Then, a slip-line and the 4 deployment bridle loops were passed through a carabiner. After lifting the box over the stern, the boxes were lowered to water level using the slip-line. All cornstarch water releases worked as designed and the float boxes were released without issues. Deployments occurred from the port stern while the ship slowly steamed away from station.

All floats will complete standard Argo missions. The floats will drift at 1,000 m then dive to 2,000 m before collecting data on the way back up to the surface every 10 days. All floats are working well. Data is publicly available via the Argo program GDACs.



Table 1: Summary of the deployment details of the Core Argo floats

#	S/N	WMO ID	Lat	Lon	Date/Time (UTC)	CTD Station
1	7627	4903344	15.2679	-69.0612	04/21/2021 11:47	In transit
2	7670	4903349	14.1457	-69.6996	04/24/2021 07:59	11
3	7673	4903351	15.19	-69.51	04/24/2021 20:10	13
4	7671	4903350	17.0716	-66.4696	04/26/2021 16:06	20
5	7668	4903347	19.691	-65.998	04/30/2021 19:01	39
6	7653	4903345	21.8282	-65.9188	05/02/2021 08:06	44
7	7669	4903348	25.3497	-65.6969	05/04/2021 10:01	51
8	7657	4903346	26.8181	-65.5993	05/05/2021 06:54	54

## 17.2 Argo Canada

### PIs

- Clark Richards (BIO)
- Blair Greenan (Argo Canada)

### Shipboard personnel

- Jesse Anderson (WHOI)
- Elizabeth Ricci (UW SSSG)
- Stephen Jalickee (UW SSSG)

2 profiling floats were deployed for Argo Canada. Both floats were NKE Instrumentation ARVOR-I floats equipped with RBR CTDs and Iridium antennas. These floats are part of the RBR Argo pilot program being tested for the Core Argo float array. Data collected from these two floats will be used to characterize RBR sensor dynamic response and pressure corrections. Parameters measured are temperature, salinity, and pressure. To aid in evaluating sensor performance, both floats were deployed at roughly the same location following A22 CTD cast 18. A companion float which is equipped with the CTD (SBE41-CP) used by most Core Argo floats was also deployed at this location. The deployment location in the Caribbean was chosen by Clark Richards to take advantage of deep water stability and thermohaline staircases when evaluating sensor responses.

After shipment from BIO to WHOI, Jessica Kozik (WHOI) readied the floats for deployment. Jessica also handled dockside logistics in Woods Hole prior to the preceding A20 cruise departure. Float initialization and deployment training were provided by Clark Richards via videoconference. At sea, Jesse Anderson started the float mission by removing the magnets attached with Velcro approximately 45 minutes before deployment. The expected slow 5 Ev and 5 pump activations were heard. Following a full auto-test, the buzzers started indicating that the floats were ready for deployment. The floats were deployed just after a GO-BGC float (UW float #19443, WMO # 5906437) while the ship was slowly steaming away from station. Floats were lowered into the water by a slip-line strung through the deployment collar hole. R/V Thompson SSG Stephen Jalickee was the deployer with help from ABs on watch.

The floats will complete Argo-type profile missions. Currently, the floats are set to profile from 2,000 m to the surface every 2 days, with a drift at 1,000 m between profiles. Data is collected during the upward profile and data is transmitted via Iridium at the surface. Both floats are performing well. Data is being processed by the MEDS DAC and are available to the public via the Argo program GDAC.

Table 2: Summary of the deployment details of the Argo Canada floats.

#	ID	WMO ID	Lat	Lon	Date/Time (UTC)	CTD Station
1	A13500-20CA001	4902533	16.5421	-67.3423	04/26/2021 03:19	18
2	A13500-20CA002	4902534	16.5429	-67.3409	04/26/2021 03:21	18

## 17.3 GO-BGC Argo Floats

### PIs:

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

### Shipboard personnel:

- Jesse Anderson (WHOI)
- Elizabeth Ricci (UW SSSG)
- Stephen Jalickee (UW SSSG)

4 biogeochemical (BGC) Argo floats were deployed on A22 as part of the Global Ocean Biogeochemistry (GO-BGC) program (<https://go-bgc.org>), which is funded by NSF Award 1946578. BGC Argo floats deployed during A22 are among the first dozen floats deployed for this new program, which is slated to grow to 500 floats globally over the next 5 years. GO-BGC contributes to international and US BGC-Argo, and all floats conform to Argo mission requirements. BGC-Argo floats will help to resolve seasonal cycles of many key properties relevant to global biogeochemical processes. The GO-BGC Atlantic sector is led by the WHOI Argo group (Susan Wijffels, Roo Nicholson; planning Pelle Robbins), who determined float deployment locations for A22 as well as the preceding A20 cruise.

All floats deployed were UW-modified Teledyne Webb Apex floats equipped with SBE41-CP CTDs, O<sub>2</sub>, NO<sub>3</sub>, pH, and FLBB bio-optical sensors. The floats for the A20/A22 cruises were readied at the UW float lab (S. Riser Argo lab) and shipped to WHOI. At WHOI, Argo engineer Greg Brusseau (UW) tested each float and armed them for deployment prior to being loaded on the R/V Thompson. WHOI provided excellent high-bay lab space with an adjacent outdoor parking which satisfied COVID-19 requirements for Greg to complete this work. Workspace and dockside logistics were coordinated by Jessica Kozik (WHOI). Deployment training was provided via videoconference.

At sea, R/V Thompson SSGs Elizabeth Ricci and Stephen Jalickee, and co-chief scientist Jesse Anderson were in charge of deployments. Before each deployment, Jesse Anderson carefully cleaned the NO<sub>3</sub> and FLBB bio-optical sensors. Each sensor was rinsed with DI water, wiped/dabbed with lens wipes, rinsed with DI water again, then wiped/dabbed with lens paper. The floats were set to self-activate, so sensor cleaning was the only pre-deployment preparation required. Floats were deployed from the port stern as the ship steamed slowly away from the CTD station. Floats were lifted over the stern, then carefully lowered into the water with a slip-line strung through the deployment collar of the float. Deployments were completed by SSGs Elizabeth Ricci (deployment #2 and 3) and Stephen Jalickee (deployment #1 and 4) with assistance from ABs on watch. Ben Freiburger (SIO) helped with the last deployment. All deployments were clean with no tangling or hangups of the slip-line.

All floats operate on a standard Argo profiling 10-day cycle. After an initial test dive, the floats descend to a parking depth of 1000 m, and then drift for 10 days with the ocean currents. After 10-days, the floats dive to 2000 m and then ascend to the surface, during which data are measured and saved. The data are then sent to shore via Iridium Satellite communication. All of the floats began reporting data immediately and the sensors are operating well. The only exception is UW float #19443 (WMO #5906437) which has not reported data from the FLBB, potentially due to an issue with the cable. All data is publicly available via the GO-BGC data portals and the Argo GDAC.

All deployments occurred at “full” carbon stations so that all GO-SHIP carbon parameters were analyzed for each depth sampled (34 depths from surface to 10 m off bottom). Additionally, duplicate bottles were tripped at the surface (~5 m) and at the depth of the chlorophyll maximum to allow for the addition of POC and HPLC sampling at these stations. POC and HPLC samples were collected and filtered by the SIO/ODF team (Susan Becker and Alexandra Fine) and will be sent frozen for analysis at NASA for HPLC and SIO/UCSD for POC. Unfortunately, the transmissometer had spiky data on CTD cast 58 (UW float #19531, WMO #5906439) due to the tape covering the clamps coming loose.

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

Table 3: Summary of the deployment details of the GO-BGC Argo floats

#	UW ID	WMO ID	Lat	Lon	Date/Time (UTC)	CTD Station	Adopt-a-Float Name
1	19443	5906437	16.5421	-67.3423	04/26/2021 03:16	18	Comets
2	19605	5906436	23.8226	-65.792	05/03/2021 13:08	48	The Dogie Diver
3	19531	5906439	28.8169	-65.4643	05/06/2021 10:17	58	AHEA
4	19129	5906438	34.7433	-66.5846	05/09/2021 21:34	70	Integrity

## 17.4 RAFOS Float

PIs

- Viviane Menezes (WHOI)
- Heather Furey (WHOI)

Two acoustically-tracked RAFOS floats ballasted for 4000 m depth were deployed in this cruise on station #56 (27.82N; 65.53W). These floats are part of the Deep Madagascar Basin (DMB) Experiment funded by NSF and lead by Viviane Menezes. The floats were released as an at-sea test before the deployment of 73 floats scheduled for 2022 in the South Indian Ocean. The float configuration at USVI port was conducted by the chief-scientist Viviane Menezes and co-chief scientist Jesse Anderson, and deployment by the marine technician Stephen Jalickee, CTD watchstander Ali Siddiqui and chief-scientist Viviane Menezes. Drop-weight serial number confirmation was done by Viviane Menezes and checked by Ali Siddiqui. Configuration followed the instructions prepared by Heather Furey, a research specialist at WHOI and co-PI in the DMB.

## SOFAR SPOTTER DRIFTER DEPLOYMENTS

A total of 19 Sofar Ocean Technologies Spotter drifters were deployed on the A22 cruise (<https://www.sofaroccean.com/products/spotter>). Co-chief scientist Jesse Anderson and R/V Thompson SSGs Elizabeth Ricci and Stephen Jalickee were in charge of the deployments. Additional assistance was provided by multiple science party members. The drifters were deployed by dropping them over the port stern while the vessel steamed away from station or during transits between stations. Parameters measured are complete wave spectrum and winds (speed and direction, derived from wave spectra). All spotters deployed are working well. Data will be publicly available as per Level 3 data requirements of the GO-SHIP program.

SOFAR technologies provided the following description: Sofar Ocean Technologies is deploying a global free-floating metocean sensor array which develops new assimilation strategies to improve global ocean weather forecast models. The network of Sofar buoys make observations of real-time ocean conditions including surface winds, waves and currents, and transmit the data back to shore through an integrated satellite connection. Sofar is working to expand its coverage in the Atlantic, Indian, and Southern Oceans by utilizing Ship of Opportunity partner groups, with all data from the global network publicly available in real time through the Sofar Weather Dashboard. Data exports are also available to partner groups as part of our research grants program, either directly to deployment partners, or through our Climate Initiative. Sofar's work is funded in part by the US Office of Naval Research, which has sponsored several research projects including an upcoming effort to directly observe hurricane activity in the Atlantic in order to improve hurricane forecasting and operational tracking systems.

Table 1: Summary of the deployment details of the Sofar. Stations marked with \* had deployment information reconstructed from ship records and CTD console logs.

Deployment	ID	Lat	Lon	Date and Time (UTC)	CTD Station
1	1171	23.82	-65.79	05/03/2021 13:08	48
2	1177	24.33	-65.76	05/03/2021 20:06	49
3	1186	24.82	-65.73	05/04/2021 03:10	50
4	1035	25.35	-65.70	05/04/2021 10:02	51
5	1169	25.81	-65.66	05/04/2021 16:40	52
6	1180	26.82	-65.60	05/05/2021 06:54	54
7	1185	27.82	-65.53	05/05/2021 20:48	56
8	1175	34.74	-66.58	05/09/2021 21:34	70
9	1187	35.72	-67.17	05/10/2021 11:18	72
10	1189	37.14	-68.06	05/12/2021 04:44	75
11	1062	37.39	-68.22	05/12/2021 11:42	76
12*	1168	37.52	-68.30	05/12/2021 12:40	between 76/77
13*	1182	37.63	-68.33	05/12/2021 18:10	77
14*	1094	37.74	-68.44	05/12/2021 19:20	between 77/78
15*	1183	37.85	-68.43	05/13/2021 00:40	78
16*	0986	37.99	-68.58	05/13/2021 02:15	between 78/79
17*	1178	38.11	-68.56	05/13/2021 07:51	79
18*	1176	38.33	-68.86	05/13/2021 13:10	80
19*	1194	38.56	-68.03	05/13/2021 18:40	81

## CHIPODS

### PI

- Jonathan Nash (OSU)

## 19.1 Overview

Chipods are instrument packages that measure turbulence and mixing in the ocean. Specifically, they are used to compute turbulent diffusivity of heat ( $K$ ) which is inferred from measuring dissipation rate of temperature variance ( $\chi$ ) from a shipboard CTD. Chipods are self-contained, robust and record temperature and derivative signals from FP07 thermistors at 100 Hz; they also record sensor motion at the same sampling rate. Details of the measurement and our methods for processing  $\chi$  can be found in [Moum\_and\_Nash2009]. In an effort to expand our global coverage of deep ocean turbulence measurements, the ocean mixing group at Oregon State University has supported chipod measurements on all of the major global repeat hydrography cruises since December 2013.

## 19.2 System Configuration and Sampling

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

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

The chipods were turned on by connecting the sensors to the pressure case at the beginning of the cruise. They continuously recorded data until the end of the leg. The sensors had no issues of note this cruise. Two end caps were lost and replacements were printed using TGT's 3D printer. The printed caps broke on multiple occasions, with additional ones being printed as needed.

Logger Board SN	Pressure Case SN	Up/Down Looker	Cast Used
2027	Ti 44-3	Up	901-90
2030	Ti 44-11	Up	901-90
2008	Ti 44-5	Down	901-90



Fig. 1: Upward-looking chipod sensors attached to the rosette.



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Fig. 3: Highly sensitive temperature probe, which is sampled at 100Hz.

## UNDERWATER VISION PROFILER 5 HD (UVP)

### PI

- Andrew McDonnell (University of Alaska, Fairbanks)

### Cruise Participant

- Stephanie O'Daly (Lead; University of Alaska, Fairbanks)
- Ali Siddiqui (Secondary; Johns Hopkins University)

## 20.1 System Configuration and Sampling

The Underwater Vision Profiler 5 (UVP5) HD serial number 207 was programmed, mounted on the rosette, and charged. The UVP5 is outfitted with a High Definition 4 Mp camera with an acquisition frequency of up to 20 Hz. This optical imaging device obtains in situ concentrations and images of marine particles and plankton throughout the water column, capturing objects sized  $\sim 100\ \mu\text{m}$  to several cm in diameter. The camera of the UVP5 HD is different from the previous non-HD version, but the operations are identical for both. The instrument and data processing are described in [Picheral2010]. Depth trigger mode was used throughout the entirety of the cruise, programmed to turn on at 15 m with a maximum depth of 6000 m. A 20 m soak for one minute was used throughout the cruise. The UVP turned on and off as expected for all cruise stations using this configuration.

## 20.2 General Particle Patterns

Near South America, we see low particle abundance overall with a strong surface and often present subsurface particle abundance maximum (Fig. 1). A deep nephroid layer generally was not present. Additionally, we observed a moderate mean particle size at all depths. Moving further north, but still south of the Gulf Stream, we see even lower particle abundance with a smaller mean particle size (Fig. 2). In the Gulf Stream, we see elevated particle abundance at the surface with a very strong deep nephroid layer signal at depth with a smaller mean particle size at all depths (Fig. 3). Stations north of the Gulf Stream were consistent with very high particle abundance at the surface with a slightly elevated particle abundance at depth indicating a slight deep nephroid layer signal at depth (Fig. 4). We saw a higher mean particle size at all depths in this region.

## 20.3 Future Data Analysis

Total image count gathered during the cruise was 628,260 images. A combination of machine learning and manual validation will be used to sort images using the Ecotaxa database. Images will be sorted into various zooplankton taxa and detrital categories. Zooplankton categories will include crustacea (including copepods and krill), gelatinous (larvacean, jellyfish, salps), and rhizaria. Examples of these images are shown in Fig. 5.

## 20.4 Problems

At the test station, the UVP turned on during the initial 20 m soak and sampled during the downcast. When the rosette was at 300m the cast was aborted to remove tubing from the pump. The UVP turned off during the up cast, as expected. The CTD was redeployed, but the UVP did not turn on during the 20 m soak and did not sample during the downcast. I believe the UVP needed to be on deck longer to allow the camera to fully turn off after the initial cast. We didn't have to abort any other casts on this cruise, so I was not able to test this hypothesis. To be safe, in the future it would probably be best to unplug and re-plug the power shunt between casts after aborted casts.

## 20.5 Figures

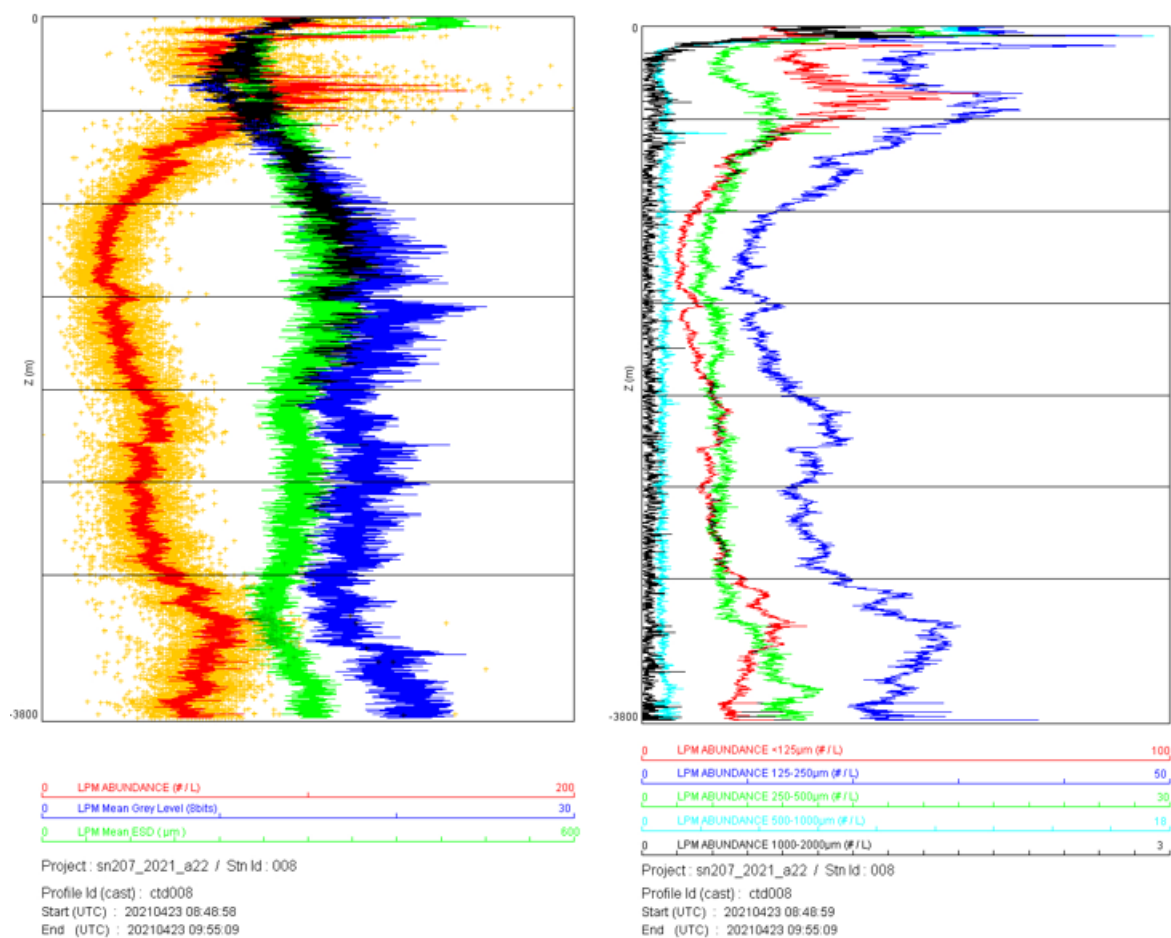


Fig. 1: Examples of preliminary profiles at station 8. Plots show total large particulate matter (LPM) abundance, mean grey level (brightness) of LPM, and equivalent spherical diameter (ESD) (right) and particle concentration in size bins (left) both plotted against depth (meters). Near South America, we see low particle abundance overall with a surface and subsurface particle abundance maximum. A deep nephroid layer is not present and with there is a medium mean particle size at all depths.

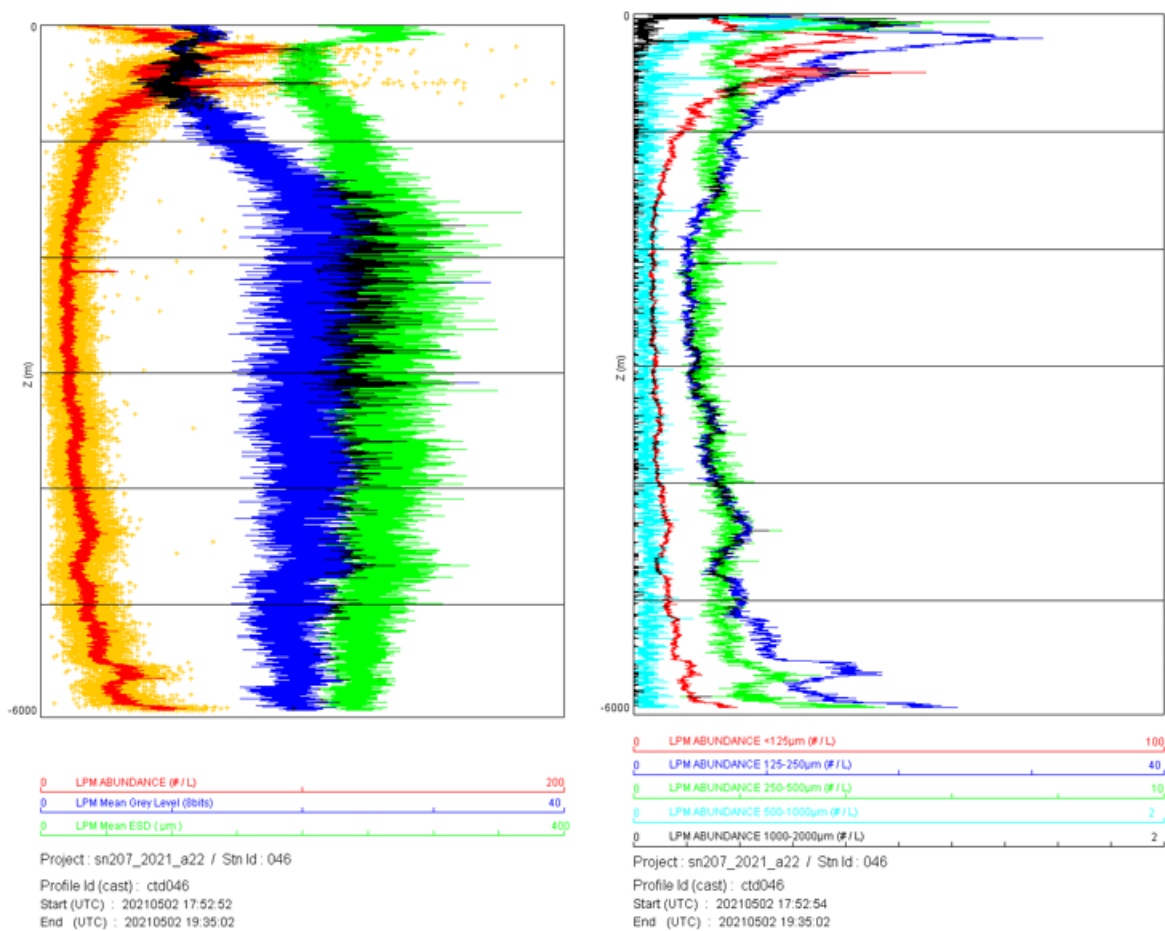


Fig. 2: Examples of preliminary profiles at station 46. Plots show total large particulate matter (LPM) abundance, mean grey level (brightness) of LPM, and equivalent spherical diameter (ESD) (right) and particle concentration in size bins (left) both plotted against depth (meters). South of the Gulf Stream, we see low particle abundance with a smaller mean particle size.

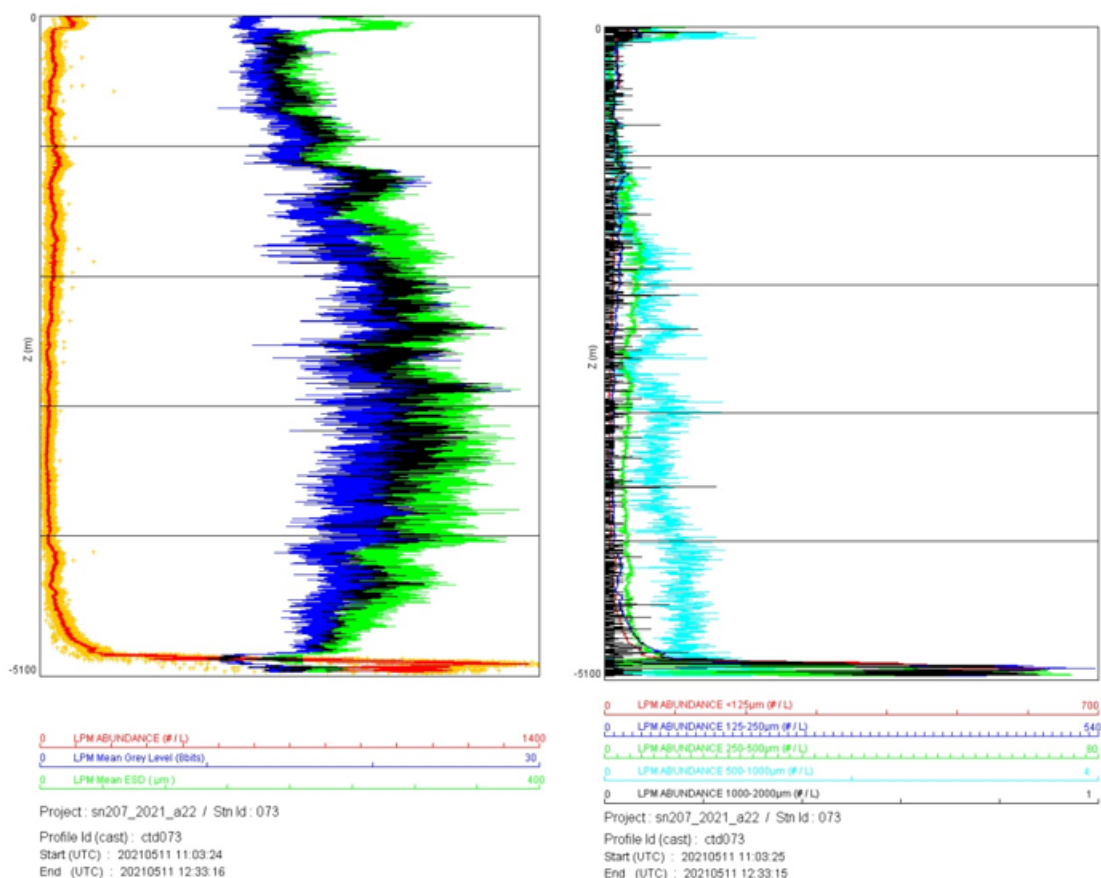


Fig. 3: Examples of preliminary profiles at station 73. Plots show total large particulate matter (LPM) abundance, mean grey level (brightness) of LPM, and equivalent spherical diameter (ESD) (right) and particle concentration in size bins (left) both plotted against depth (meters). In the Gulf Stream, we see elevated particle abundance at the surface with a very strong deep nephroid layer signal at depth and a smaller mean particle size.

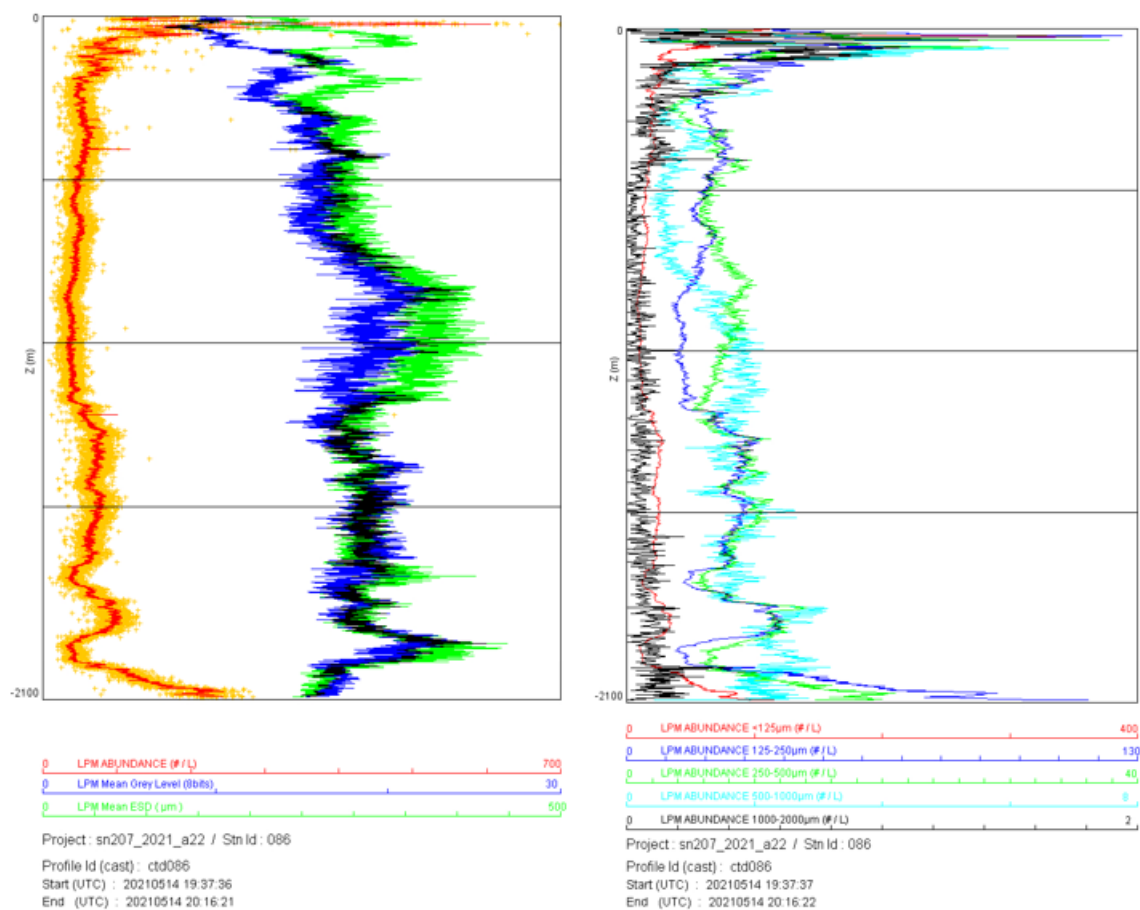


Fig. 4: : Examples of preliminary profiles at station 86. Plots show total large particulate matter (LPM) abundance, mean grey level (brightness) of LPM, and equivalent spherical diameter (ESD) (right) and particle concentration in size bins (left) both plotted against depth (meters). North of the Gulf Stream, we see very high particle abundance at the surface with a slight deep nephroid layer signal at depth and a higher mean particle size.

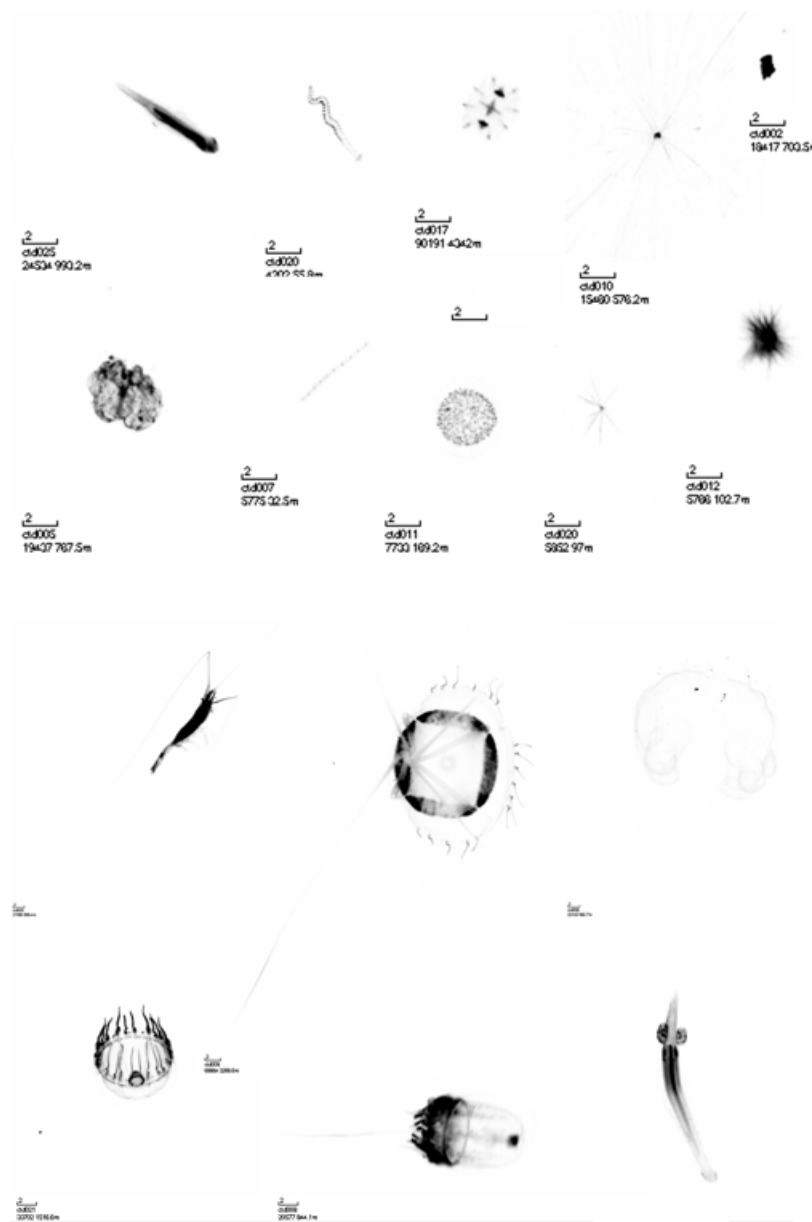


Fig. 5: Examples of particle and plankton images captured by the UVP5HD and processed by custom software. The scale bar indicates 2 millimeters. Station number, image number for that cast, and depth at which the image was captured are also given in the image.





## SARGASSUM

### PI

- Dennis McGillicuddy

## 21.1 Overview

Occupation of GO-SHIP lines A22 by R/V Thomas G. Thompson offered an exceptional opportunity to sample the Great Atlantic Sargassum Belt [Wang2019]. Satellite imagery indicates another significant bloom began just before the cruise, with the abundance of Sargassum in February of 2021 near the top of that observed in Februaries of the last five years, second only to February 2018. Given the seasonality of the phenomenon, Sargassum abundance was expected to increase during the course of the cruise.

Recent evidence suggests a long-term shift in the elemental stoichiometry of the seaweed (particularly N:P), which may reflect changes in nutrient supply fueling these blooms [Lapointe\_submitted]. Sargassum tissue samples in the high-abundance region of the tropical and southern subtropical Atlantic are very few in number, with opportunistic sampling by the R/V Thomas G. Thompson in August 2019 providing most of the measurements of which we are aware.

Clearly more observations are needed to test the hypothesis of a long-term shift in N:P and its implications for nutrient supply and Sargassum bloom dynamics. A22 extended into the high-abundance region, and the core hydrographic and inorganic nutrient measurements will be extremely valuable for interpreting satellite-based Sargassum abundance. The critical need for opportunistic sampling is Sargassum tissue.

## 21.2 Procedure

Seaweed sampling was conducted by dipnet affixed to a standard recovery pole. A standard sample is 30-40g, an amount that fits easily into a quart-sized Ziploc bag. When sufficient biomass was available, 12 samples per station were collected, 6 dried and 6 frozen, each comprised of triplicates for the two species *S. fluitans* and *S. natans* which are easily distinguishable by their pods and leaves. In the event that sufficient biomass was not available, dried samples were prioritized.

Samples to be dried were rinsed with DI water, shaken dry, and placed in drying oven on parchment paper with name of designated species and station. Drying oven temperature were set between 55 and 65 C and checked periodically with a thermometer inserted into top dryer vent. Once sample was “bone dry” or crispy (typically 24-48 hours), sample were placed in Ziploc bag and labeled with species, station location collected, and date of collection.

Samples to be frozen were separated by species and placed in Ziploc bags, labeled with a code referencing date, location, type. Excess water was removed (with paper towel) prior to sealing bags and bags were stored in a freezer and covered with a black blanket to keep samples dark. Additional sample details were recorded on log sheets, including date, time, location, GPS, etc.



## NITRATE ISOTOPES $\delta^{15}\text{N}$ AND $\delta^{18}\text{O}$

**PI:**

- Daniel Sigman (Princeton University)

**Samplers:**

- Holly Olivarez
- Maya Prabhakar
- Victoria Schoenwald
- Ali Siddiqui

Nitrate ( $\text{NO}_3^-$ ) is the primary form of fixed nitrogen (N) in the sea and an essential macronutrient, the supply of which can limit primary production and carbon export from the surface ocean. The dual isotopes of  $\text{NO}_3^-$  ( $\delta^{15}\text{N}$  and  $\delta^{18}\text{O}$ ) record biogeochemical and physical processes on different time scales. In general, nitrate consuming processes tend to raise the  $\delta^{15}\text{N}$  and  $\delta^{18}\text{O}$  of nitrate equally while nitrate producing processes tend to decouple the dual isotopes. Since different processes leave different imprints on the isotopic composition of nitrate, the dual isotopes can be used to separate and quantify the impact of multiple N fluxes acting on the nitrate pool.

Seawater samples for nitrate isotope analyses were collected from all depths at about every two degrees of latitude. Two 30mL samples were collected from each niskin bottle fired at depths shallower than 300 m. One 30mL sample was taken from all other depths. All bottles were rinsed once with half their full volume before being filled with seawater. The samples were stored onboard at  $-20^\circ\text{C}$  in order to preserve them for land based analysis.

### 22.1 Analysis

The denitrifier method [Casciotti2002] [Sigman2001] will be used to analyze  $\text{NO}_3^-$ ,  $\delta^{15}\text{N}$ , and  $\delta^{18}\text{O}$ . Briefly, this method converts all  $\text{NO}_3^-$  to nitrous oxide ( $\text{N}_2\text{O}$ ) via denitrifying bacteria before the sample is analyzed by an IRMS. Samples were collected at stations 1, 11, 15, 22, 31, 41, 43, 46, 50, 55, 61, 67, 73, 77, 83, and 90.



## INT (MICROBIAL RESPIRATION)

### PI

- Craig Carlson (UCSB)

### Technician

- Chance English

### Analysts

- Chance English

**Support** NSF

## 23.1 Motivation

Heterotrophic Respiration is the fundamental process by which organisms obtain energy from organic matter and at the ecosystem level represents the largest sink for organic matter in the ocean [DelGiorgio2005]. Understanding the magnitude and variability of microbial respiration is critical for the understanding the metabolic balance of the ocean and the efficiency at which carbon is stored in the ocean. Measurements for respiration are rarely performed due to constraints in methodology and feasibility and thus respiration remains one of the least constrained parameters in contemporary oceanography [Robinson2019]. However, recent advances in methodology via the Iodo-nitro-tetrazolium (INT) reduction assay have improved the ability to measure microbial respiration in aquatic environments [García-Martín2019]. During this cruise, community and size-fractionated respiration rates were determined using the INT reduction method described below.

## 23.2 Sampling

### *In-Vivo Iodo-Nitro-Tetrazolium (INT) Reduction Assay*

This method is based on the reduction of INT, a water soluble, membrane permeable salt which passively penetrates into the cell, by dehydrogenase enzymes in the electron transport system forming insoluble formazan crystals (INT-f) [Martínez-García2009]. The in-vivo method is based on a variation of the in-vitro method described by [Packard1996]. Whole seawater was collected from 5m using the ship's underway seawater system at 30 stations across the transect. Five 250 ml polycarbonate bottles were rinsed with sample water and filled, two of which were immediately killed with 0.2 filtered formalin (2% v/v final concentration) and used as a control. The remaining 3 bottles were inoculated with 8mM INT solution to a final concentration of 0.2 mM. Samples were incubated within 1 degree of in situ temperature for 2-2.5 hours and subsequently fixed with formalin. Because the INT-f is formed internally, cells can be size-fractionated post-incubation and the INT-reduction rate determined for different size classes, specifically bacterial (0.2-0.8µm) and non-bacterial (>0.8µm). During A22 samples were filtered sequentially through a 0.8 and 0.2 µm polycarbonate filter which were then stored in 2ml sterile cryovials at -20°C until further analysis. Samples from A22 were stored on board

until being shipped back to an in-shore laboratory at the University of California, Santa Barbara. The method uses the spectrophotometric absorption of the INT-f at 485 nm to determine the rate at which the insoluble crystals are formed inside the cell membranes. Absorbance of each sample will be determined by incubating the filters in 1 mL of 1-propanol, followed by sonication and centrifugation. The concentration of the INT-f in solution is calculated from its absorbance by applying a standard curve previously determined using twelve different concentrations of stock INT-f dissolved in pure 1-propanol.

Table 1: Stations sampled

2	10	14	18	20	22
32	34	38	41	42	44
48	50	52	54	58	62
64	68	70	72	73	74
76	78	80	84	86	88

## OXYGEN STABLE ISOTOPE RECORD ( $\delta^{18}\text{O}$ )

### PI

- Kaustubh Thirumalai

### Cruise Participant

- Maya Prabhakar

## 24.1 Intent

The creation of a seawater  $\delta^{18}\text{O}$  record for studying recent and modern planktic foraminiferal  $\delta^{18}\text{O}$  in the N. Atlantic to reconstruct past climate and create modern calibrations.

## 24.2 Sampling

At least two 5mL samples of water were collected at every station. Every station was sampled at 5m (surface, mixed layer) and at the chlorophyll maximum, which varies at each station. Opportunistic third and fourth samples were taken when Stephanie O'Daly's underwater vision profiler photographs showed foraminifera at those depths at nearby stations. Samples were taken at the end of sampling by running vials under a weak stream from the bottle spigot until air bubbles were absent. The sample was then capped and inverted to check for air bubbles. Some samples were lost early in the cruise due to inexperience sampling from the bottles, resulting in air bubbles, causing the additional step of an inversion to be added. Samples were then parafilmed to prevent atmosphere and sample interaction. If, upon inspection, samples were deemed improperly parafilmed, additional parafilm was used to ensure a seal. Samples were labeled and stored in a temperature-controlled room. Depth, longitude, latitude, bottle number, date, sampler, and notes were recorded during sampling.

## 24.3 Processing

Samples will be processed on a Picarro isotopic water analyzer at the St. Petersburg Coastal and Marine Science Center. Methods and data will be published within the next three years.



## 24.4 Acknowledgements

I would like to acknowledge the help of another student, Holly Olivarez, in sampling when I was unable.

## 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.

### 25.1 Lillian Henderson

As primarily a marine organic geochemist, the research I do on a daily basis involves intensive lab work and wet chemistry in order to isolate individual compounds for stable carbon and nitrogen isotope analysis. Because of the time required to prepare each sample, I typically work with relatively small datasets/sample sizes. In contrast, the CFC work I was able to do on the GO-SHIP A22 hydrographic cruise involves very little sample preparation, allowing for much larger collections of data. These larger datasets provide better understanding of the global ocean circulation patterns. Being a part of this cruise provided me an opportunity to learn a new sampling method and analytical technique that I would not have been exposed to otherwise. I learned about the analytical system used to measure CFC/SF6/N2O concentrations and how these data are used. I had a great time getting to know everyone, and I hope to work on another GO-SHIP cruise in the future!

### 25.2 Holly Olivarez

*Environmental Studies Program and the Institute of Arctic and Alpine Research (INSTAAR)*

As a graduate student who statistically models the variability of air-sea CO<sub>2</sub> flux using in situ surface ocean p[CO<sub>2</sub>] observations, I am very grateful for the experience and perspective I gained from being part of the A22 hydrographic research cruise. From the science to the people on the ship, being here has helped me grow as a human and as a scientist. Even though I have worked in an observational environment before, it was not related to oceanography. The ocean knows no borders and sharing passion and curiosity for this critical system on Earth with fellow scientists and ship crewmates was priceless. I learned of the many ways one small, overlooked detail (either due to inexperience or fatigue) can disrupt or invalidate a rosette full of freshly collected seawater, or how moving a cast time to accommodate dinner for samplers impacts the ship crew, too. I learned about folks who care so deeply about “good” data that they devote their career to the science of taking accurate and precise measurements.

I also learned that those who have been at sea for much of their career, either as a scientist or as a ship crewmate, can teach me more than I've learned in any classroom or textbook. I suppose the real challenge then becomes finding the

intersection between those who teach in a classroom, who lay the groundwork for future real-world application, and those who teach us in the moment as we are doing the actual science.

My PhD research is based on the simulated Earth system but grounded in real world observations. Without observations, scientists' simulations of the Earth system would be purely theoretical. This experience has given me the perspective and recognition of real-world observations as the foundation of what I do. This is something I will not forget as I forge ahead in my career. Thank you to all involved in the GO-SHIP project and thank you for the opportunity to be a part of it.

## **25.3 Maya Prabhakar**

As a paleoclimate student with a background in geology, moving my fieldwork from land to sea has been a sizable shift. The Thompson, and GO-SHIP, is a great introduction to ocean research. I attended as a CTD watch-stander to better understand how CTD data is collected since I use it often in my research. I have thoroughly met my goal. We, the attending students, have prepped casts for deployment and for sampling, giving us a good understanding of the mechanical workings of the rosette. Monitoring casts has allowed us to see the change in station oceanography in real time and provided good conversations. The limitations of the subsequent data and uncertainties are better categorized in my head when thinking about the datasets I use from GO-SHIP and similar projects. Our graduate curriculum is light in physical oceanography, so being able to ask questions consistently for a month provided a useful learning experience. I am primarily interested in noting the data from the Gulf Stream because I focus on the Arctic and the Fram Strait, which are heavily influenced by the Gulf Stream. This cruise has brought about several questions related to my field of study which I plan to explore when I am.

I have been consistently fortunate to work for, and with, numerous women and racial minorities during school. This is a strong contrast to the ship. I am still fortunate to be working under two amazing women acting as chief scientists during this leg and I have loved being able to ask questions and discuss science with them and the other women on board, but I have run into multiple occasions during this leg where I have been patronized consistently by a handful of people, often on topics I have training and experience in. It has reminded me to be grateful as a racial minority and a woman to work in the labs I do and collaborate with the people I currently work with. It is an unfortunate epidemic in the whole of science, but I note it as a distinct failure of the GO-SHIP cruise.

Being able to actively learn and bring a background of geology to the cruise has been a lot of fun and a welcome change from the zoom learning of a covid-19 world. I have gained numerous skills and insights that will help me navigate future fieldwork and create new discussions in my lab. I look forward to publishing the geochemical data from this cruise.

## **25.4 Victoria Schoenwald**

The A22 leg of this year's GO-SHIP cruise was my first glance into what observational oceanography is all about. I participated as a CTD Watch Stander on the night shift for 30 days which involved long hours of watching the CTD rise and fall into the water while monitoring screens taking real time data from temperature to voltage spikes from the UVP. Being a part of a modelling lab as a graduate student at the UM RSMAS, I would not have had the opportunity to go to sea if not for programs like GO-SHIP. I am grateful that all of the scientists on board were happy to allow new students to become part of their research. When I first decided to pursue a career in oceanography, I was excited about discovering the way the ocean, atmosphere, and land interact with one another. I later realized that my interests aligned well with global climate modelling and field work would not be part of my Ph.D. experience. From the start I knew that I would want to get back into field work some way or another so when I discovered there were openings to come on the A22 leg I was very excited.

Back in Miami I was researching sea level rise and coastal flooding using global data sets and climate models. Being on the CTD team therefore allowed me to see where some of my data is coming from and how the ocean off of the East Coast of the U.S. has been changing over the years. Besides the knowledge I learned from the science team one of the most rewarding parts of the cruise was getting to know the crew. I enjoyed hearing their stories about travelling, life at sea and gained perspective on careers that I previously knew nothing about. Getting to know more people who love

the ocean as much as I do has made this month an unforgettable one. This experience has reminded me why I chose to research the ocean in the first place, and I hope to have the chance to participate in more research cruises in the future.

## 25.5 Ali Siddiqui

To whoever reads this in 10 years

Hi there!

I was a CTD watchstander and the LADCP operator for the A22 2021 GO-SHIP cruise.

If you're a student reading this, wondering what a watchstander or an LADCP operator experiences in a GO-SHIP cruise, I might not be able to do justice in this short statement. If you're a PI reading this, and wondering if your students should take part in a GO-SHIP cruise, this statement would only offer a fleeting peak into the experiences of potential students. If you're just someone browsing through student statements, I hope this one offers you something of value about the lives of GO-SHIP participants. I guess the only person who really needs to read this is Mike Kovatch who's wonderful job gives him the pleasure to make cruise reports which contain the tired musings of departing students. So, let me be terse.

As someone whose research involves modeling the ocean using computers, it's very easy for me to forget what the real ocean looks like. The ocean exists in the virtual world with smooth data and exact floating points accurate to the precision of the computer. What the CTD watchstanding taught me was how the ocean really looks like. In person. Or in water? It taught me the importance of taking accurate, reliable and long-term measurements of the ocean using the CTD. It is very easy to sit in a lab and complain about missing data in the ocean. What this cruise has taught me is the value of recording data during each CTD cast and the amount of hard work and labor that goes into procuring a single vertical profile in the deep ocean. Undoubtedly, I'm going to be a better oceanographer after this cruise, or at least a more informed one.

As for the LADCP, even though I had read up about the theory of the Acoustic Doppler and its functionality, it was an extremely enlightening experience to operate the instrument on my own. Admittedly, I was very nervous in the beginning but things got better as we performed regular deployments. Processing and understanding the ADCP data was another trick of the trade that I got to learn as we made our way from the Caribbean to the familiar shores of Woods Hole. Hopefully, I will have more opportunities in the future to operate the LADCP.

There are a few of lessons that I will take away from my experience. I hope when someone reads this, they would find them helpful too. The first is about the importance of the ship crew. Without them, no science would ever be done. On the R/V Thompson, the crew was the star of the show in my eyes. They would help us with deployments, carry out maintenance on the ship, feed us, navigate us, and most importantly give us a glimpse into the lives of people who spend half their lives on the sea. If any person in a position of leadership is reading this, I want to acknowledge how important the crew of the R/V TGT was to us and commend them on a brilliant job they did to help us do our science. Another lesson was about the importance of staying patient on the ship. Taking measurements in the sea can get monotonous after a while, and people tend to slack off and become impatient with the process. I realized how important it was to carefully go through each and every step in our deployments, right from preparing and keeping track of log sheets to preparing the rosette for each cast, all the way up to firing bottles at the right depth and eventual recovery and sampling. Even though we get trained in all these exercises, it is interesting to see how much one can learn about an activity each time you repeat it. This brings me to the final lesson worth typing in this statement, which is that of mental well being at sea. The ship is a small space to be in for a month with a bunch of people who you've never met. It is very easy to get cranky around mid-way through the cruise. However, it really helps if you have something to occupy yourself with on your time off. Reading books, playing chess or catan and even darts, personal writing, admiring the ocean and the stars on the hammock at the bow, were some of the things that helped me keep myself cheerful. Obviously, this was on top of making friends with some really amazing people on the ship.

If that doesn't give much glimpse into the mind of a watchstander, then maybe the knowledge that most of us were even dreaming of the CTD and muttering, "Roger that, we are ready to deploy", should tell you all about the experience.

With hope,

Ali Siddiqui

## ABBREVIATIONS

<b>ADCP</b>	Acoustic Doppler Current Profiler
<b>AOML</b>	Atlantic Oceanographic and Meteorological Laboratory
<b>AP</b>	Particulate Absorption Spectra
<b>APL</b>	Applied Physics Laboratory
<b>ASC</b>	Antarctic Support Contract
<b>BAS</b>	British Antarctic Survey
<b>BGC</b>	Biogeochemical
<b>BIO</b>	Bedford Institute of Oceanography
<b>Bigelow</b>	Bigelow Laboratory for Ocean Sciences
<b>CDOM</b>	Chromophoric Dissolved Organic Matter
<b>CFCs</b>	Chlorofluorocarbons
<b>CIMAS</b>	Cooperative Institute of Marine and Atmospheric Science
<b>CTDO</b>	Conductivity Temperature Depth Oxygen
<b>CU Boulder</b>	University of Colorado Boulder
<b>DFO-MPO</b>	Fisheries and Oceans Canada, Pêches et Océans Canada
<b>DIC</b>	Dissolved Inorganic Carbon
<b>DOC</b>	Dissolved Organic Carbon
<b>ECO</b>	Edison Chouest Offshore
<b>ENSTA</b>	ENSTA ParisTech
<b>ETHZ</b>	Eidgenössische Technische Hochschule Zürich
<b>FSU</b>	Florida State University
<b>GO-BGC</b>	Global Ocean Biogeochemistry Array
<b>HPLC</b>	High-Performance Liquid Chromatography
<b>HPU</b>	Hawaii Pacific University
<b>JHU</b>	Johns Hopkins University
<b>LDEO</b>	Lamont-Doherty Earth Observatory - Columbia University
<b>LADCP</b>	Lowered Acoustic Doppler Current Profiler

**MBARI** Monterey Bay Aquarium Research Institute

**MIT** Massachusetts Institute of Technology

**N<sub>2</sub>O** Nitrous oxide

**NOAA** National Oceanographic Atmospheric Administration

**NBP** RVIB Nathaniel B Palmer

**NSF** National Science Foundation

**ODF** Oceanographic Data Facility - *SIO*

**OSU** Oregon State University

**PMEL** Pacific Marine Environmental Laboratory

**POC** Particulate Organic Carbon

**POM** Particulate Organic Matter

**Princeton** Princeton University

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

**SADCP** Shipboard Acoustic Doppler Current Profiler

**SEG** Shipboard Electronics Group

**SF<sub>6</sub>** Sulfur Hexafluoride

**SIO** Scripps Institution of Oceanography

**SOCOM** The Southern Ocean Carbon and Climate Observations and Modeling project. <http://socom.princeton.edu/>

**STS** Shipboard Technical Support - *SIO*

**TAMU** Texas A&M University

**TDN** Total Dissolved Nitrogen

**UAF** University of Alaska Fairbanks

**UArizona** The University of Arizona.

**UCI** University of California Irvine

**UCLA** University of California Los Angeles

**UCSB** University of California Santa Barbara

**UCSC** University of California Santa Cruz

**UCSD** University of California San Diego

**UH** University of Hawaii

**U Maine** University of Maine

**U Miami** University of Miami

**UNR** University of Nevada Reno

**UNSW** University of New South Wales

**U Puerto Rico** University of Puerto Rico

**USAP** United States Antarctic Program

**USCG** United States Coast Guard

**UT** University of Texas

**UVP** Underwater Vision Profiler

**UW** University of Washington

**UWA** University of Western Australia

**U. Wisconsin** University of Wisconsin

**VUB** Vrije Universiteit Brussel

**WHOI** Woods Hole Oceanographic Institution





## BOTTLE QUALITY COMMENTS

Sta- tion	Cast	Bottle	Param	Code	Comment
1	1	1	SALNTY	3	salty, may be early or late closure
2	1	8	SALNTY	3	fresh, may be early closure
3	1	21	SALNTY	3	a bit fresh, could be early or late closure
4	1	21	SALNTY	3	fresh, may be early closure
4	1	23	SALNTY	3	salty, may be early closure
5	1	15	SALNTY	3	suppression dial was set incorrectly, manually corrected afterward but with uncertain accuracy/precision
5	1	16	SALNTY	3	suppression dial was set incorrectly, manually corrected afterward but with uncertain accuracy/precision
5	1	17	SALNTY	3	suppression dial was set incorrectly, manually corrected afterward but with uncertain accuracy/precision
5	1	18	SALNTY	3	suppression dial was set incorrectly, manually corrected afterward but with uncertain accuracy/precision
5	1	19	SALNTY	3	suppression dial was set incorrectly, manually corrected afterward but with uncertain accuracy/precision
5	1	20	SALNTY	3	suppression dial was set incorrectly, manually corrected afterward but with uncertain accuracy/precision
5	1	21	SALNTY	3	suppression dial was set incorrectly, manually corrected afterward but with uncertain accuracy/precision
5	1	22	SALNTY	3	suppression dial was set incorrectly, manually corrected afterward but with uncertain accuracy/precision
5	1	23	SALNTY	3	suppression dial was set incorrectly, manually corrected afterward but with uncertain accuracy/precision
5	1	24	SALNTY	3	suppression dial was set incorrectly, manually corrected afterward but with uncertain accuracy/precision

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Table 1 – continued from previous page

Station	Cast	Bottle	Param	Code	Comment
5	1	25	SALNTY	3	suppression dial was set incorrectly, manually corrected afterward but with uncertain accuracy/precision
5	1	28	SALNTY	3	salty, may be early closure
6	1	24	SALNTY	3	fresh, may be early closure or insufficient stop time
6	1	29	SALNTY	3	very fresh, earlier closure or mis-sample
6	1	31	SALNTY	3	salty, could be early closure
7	1	25	Bottle	4	Top endcap did not close
7	1	31	SALNTY	3	fresh, could be late closure
9	1	26	SALNTY	3	fresh, could be early closure
10	1	26	SALNTY	3	fresh, could be early closure or insufficient stop time
11	1	34	SALNTY	3	salty, could be early closure
12	1	3	Bottle	4	Top endcap did not close
12	1	26	SALNTY	3	fresh, could be early closure
12	1	33	SALNTY	3	salty, could be early closure
13	1	26	SALNTY	3	fresh, could be early closure
13	1	30	SALNTY	3	fresh, may be early or late closure
14	1	22	SALNTY	3	fresh, may be early closure
14	1	25	SALNTY	3	fresh, may be early closure or insufficient stop time
14	1	28	SALNTY	3	fresh, may be early closure or insufficient stop time
14	1	30	SALNTY	3	fresh, likely sampling error
14	1	32	SALNTY	3	salty, may be early closure
14	1	36	Bottle	4	Low O2 Draw temp; spigot pushed in
15	1	28	SALNTY	3	fresh, may be early closure or insufficient stop time
15	1	31	SALNTY	2	salty, may be early closure
15	1	32	SALNTY	2	salty, may be early closure
15	1	33	SALNTY	3	salty, may be early closure
16	1	28	SALNTY	3	likely mis-sampled, nearly identical to bottle 29
17	1	31	SALNTY	3	too fresh, could be late or early closure
17	1	32	SALNTY	3	salty, may be early closure
18	1	28	SALNTY	3	likely mis-sampled, nearly identical to bottle 29
18	1	32	SALNTY	3	salty, may be early closure
18	1	33	SALNTY	3	fresh, may be late closure
19	1	25	SALNTY	3	fresh, may be early closure or insufficient stop time
19	1	27	SALNTY	3	fresh, may be early closure
19	1	32	SALNTY	3	salty, may be early closure
20	1	24	SALNTY	3	fresh, may be early closure or insufficient stop time
20	1	26	REFTMP	3	high variability, insufficient stop time
20	1	28	SALNTY	3	salty, may be late closure
20	1	28	REFTMP	3	warm, rosette winched upward before acquisition finished
20	1	32	SALNTY	3	salty, may be early closure
21	1	29	REFTMP	3	warm, rosette winched upward before acquisition finished
21	1	33	SALNTY	3	salty, may be early closure
22	1	23	SALNTY	3	fresh, may be early closure or insufficient stop time
22	1	32	SALNTY	3	salty, may be early closure

continues on next page

Table 1 – continued from previous page

Sta- tion	Cast	Bottle	Param	Code	Comment
22	1	33	SALNTY	3	salty, may be early closure
23	1	31	SALNTY	3	salty, may be early closure
26	1	15	SALNTY	3	fresh, may be early closure or insufficient stop time
26	1	20	SALNTY	3	salty, may be early closure
28	1	26	SALNTY	3	fresh, may be late closure
29	1	17	SALNTY	3	fresh, mis-sampled or late closure
31	1	14	SALNTY	3	salty, may be early closure or insufficient stop time
32	1	22	SALNTY	3	salty, may be early closure
33	1	3	Bottle	4	bottle did not close
34	1	22	Bottle	4	bottle did not close
35	1	3	Bottle	4	bottle did not close
35	1	20	SALNTY	3	fresh, could be early closure
35	1	29	SALNTY	3	fresh, could be late closure
37	1	25	SALNTY	3	fresh, could be early closure
38	1	7	SALNTY	3	salty, could be late closure
38	1	12	SALNTY	3	salty, could be late closure
38	1	13	SALNTY	3	salty, could be late closure
38	1	20	SALNTY	3	salty, could be early closure
38	1	35	SALNTY	3	salty, could be early closure or insufficient stop time
40	1	26	SALNTY	3	fresh, may be early closure or insufficient stop time
41	1	2	Bottle	4	High O2 draw temp; nutrient and o2 values off
41	1	2	SALNTY	4	extremely salty, very late or early closure
41	1	3	Bottle	4	bottle did not close
41	1	26	REFTMP	3	warm, rosette winched upward before acquisition finished
42	1	3	Bottle	4	bottle did not close
42	1	11	SALNTY	3	salty, may be late closure
42	1	24	SALNTY	3	fresh, may be early closure or insufficient stop time
42	1	26	SALNTY	3	fresh, could be early closure
42	1	27	SALNTY	3	fresh, could be early closure
42	1	28	SALNTY	3	fresh, could be early closure
43	1	5	SALNTY	3	salty, may be late closure
44	1	34	SALNTY	3	salty, may be early closure or insufficient stop time
45	1	33	SALNTY	3	salty, could be early closure
46	1	8	SALNTY	3	salty, could be late closure
46	1	10	SALNTY	3	salty, could be late closure
47	1	34	SALNTY	3	salty, may be early closure
47	1	35	SALNTY	3	salty, looks like mistakenly sampled from bottle 34
51	1	11	SALNTY	3	salty, may be late closure
52	1	10	SALNTY	3	fresh, could be early closure
54	1	12	SALNTY	3	salty, sample bottle was not well sealed
55	1	23	SALNTY	3	fresh, may be early closure or insufficient stop time
56	1	15	SALNTY	3	fresh, likely mis-sampled from bottle 14
56	1	16	SALNTY	3	fresh, likely mis-sampled from bottle 15
57	1	2	SALNTY	3	fresh, may be early closure
57	1	18	SALNTY	3	salty, could be early or late closure
58	1	36	REFTMP	3	cold, may include air temp

continues on next page

Table 1 – continued from previous page

Station	Cast	Bottle	Param	Code	Comment
60	1	1	SALNTY	3	fresh, large deviation in values from salt analyst
61	1	35	SALNTY	3	salty, may be late closure
61	1	35	REFTMP	3	warm, rosette winched upward before acquisition finished
62	1	1	SALNTY	3	salty, may be early/late closure or sampling error
63	1	6	SALNTY	3	fresh, could be early closure
65	1	9	SALNTY	3	fresh, could be early closure
65	1	20	SALNTY	3	fresh, could be early closure or insufficient stop time
66	1	3	SALNTY	3	fresh, could be early closure
69	1	7	SALNTY	3	salty, could be late closure
71	1	2	SALNTY	3	fresh, could be early closure
71	1	8	SALNTY	3	salty, could be late closure
72	1	3	SALNTY	3	fresh, could be early closure or sampling error
72	1	6	SALNTY	3	fresh, could be early closure or sampling error
72	1	9	SALNTY	3	fresh, could be early closure
72	1	10	SALNTY	3	fresh, could be early closure
76	1	2	Bottle	3	Top o-ring unseated
76	1	2	SALNTY	3	salty, may be late closure or leaker
76	1	7	SALNTY	3	salty, could be late closure
79	1	31	SALNTY	3	fresh, strong currents and large down/upcast variability
79	1	32	SALNTY	3	salty, could be late closure or ship heave
79	1	32	REFTMP	3	high variability, may be ship heave
80	1	8	SALNTY	3	salty, could be late closure
81	1	13	SALNTY	3	salty, could be late closure or sampling error
81	1	35	SALNTY	3	salty, could be late closure or some intrusion
83	1	6	SALNTY	3	fresh, could be early closure
83	1	33	SALNTY	3	fresh, could be early or late closure
84	1	2	SALNTY	3	fresh, could be early or late closure
85	1	32	REFTMP	3	cold, insufficient stop time in sharp gradient
85	1	33	REFTMP	3	cold, insufficient stop time in sharp gradient
86	1	27	SALNTY	3	fresh, could be in sufficient stop time
86	1	28	SALNTY	3	fresh, could be in sufficient stop time
86	1	34	SALNTY	3	fresh, could be late closure
86	1	35	SALNTY	3	fresh, could be late closure or a strange feature
87	1	28	SALNTY	3	salty, could be early closure
87	1	29	SALNTY	3	fresh, could be early or late closure
87	1	32	SALNTY	3	fresh, could be late closure or insufficient stop time
88	1	14	SALNTY	3	fresh, may be insufficient stop time
88	1	26	SALNTY	3	salty, could be late closure or may be insufficient stop time
89	1	19	SALNTY	3	fresh, could be late closure or may be insufficient stop time
89	1	19	REFTMP	3	cold, may include air temp
90	1	6	REFTMP	3	warm, rosette winched upward before acquisition finished
90	1	7	SALNTY	3	fresh, could be late closure or may be insufficient stop time

## CALIBRATION DOCUMENTS

# Pressure Calibration Report

## STS Calibration Facility

SENSOR SERIAL NUMBER: 0914

CALIBRATION DATE: 05-FEB-2021

Mfg: SEABIRD Model: 09P CTD Prs s/n: 110547

C1= -4.347419E+4

C2= 9.519583E-2

C3= 1.217347E-2

D1= 3.695368E-2

D2= 0.000000E+0

T1= 3.006841E+1

T2= -2.734151E-4

T3= 3.937442E-6

T4= 5.448912E-9

T5= 0.000000E+0

AD590M= 1.28789E-2

AD590B= -8.81353E+0

Slope = 1.00000000E+0

Offset = 0.00000000E+0

Calibration Standard: Mfg: FLUKE Model: P3125 s/n: 70856

$t0 = t1 + t2 * td + t3 * td * td + t4 * td * td * td$

$w = 1 - t0 * t0 * f * f$

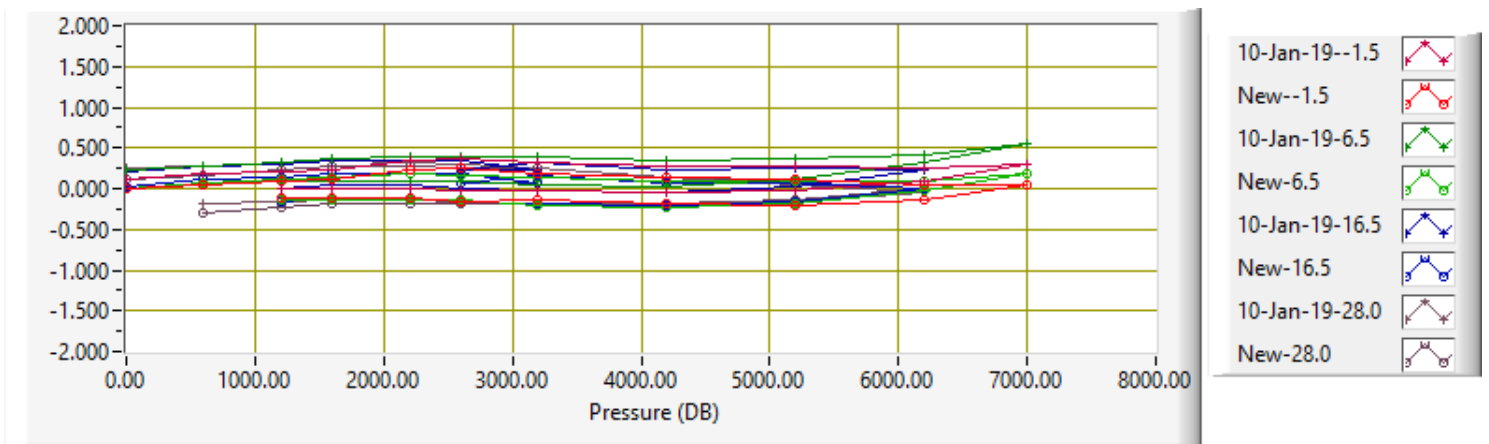
Pressure =  $(0.6894759 * ((c1 + c2 * td + c3 * td * td) * w * (1 - (d1 + d2 * td) * w) - 14.7)$

Sensor Output	DWT	Sensor New Coefs	DWT-Sensor Prev Coefs	DWT-Sensor NEW Coefs	PT-DegC	Bath_Temp
33262.977	0.27	0.27	0.12	-0.00	-0.94	-1.524
33593.871	600.32	600.26	0.17	0.06	-0.93	-1.523
33921.049	1200.33	1200.24	0.21	0.09	-0.93	-1.523
34137.163	1600.35	1600.23	0.24	0.12	-0.93	-1.523
34458.372	2200.39	2200.15	0.35	0.23	-0.93	-1.524
34670.629	2600.41	2600.16	0.37	0.25	-0.93	-1.523
34986.255	3200.43	3200.24	0.31	0.18	-0.93	-1.523
35505.006	4200.40	4200.27	0.28	0.13	-0.93	-1.523
36015.059	5200.40	5200.29	0.29	0.11	-0.93	-1.523
36516.815	6200.41	6200.36	0.26	0.05	-0.93	-1.523
36912.408	7000.37	7000.31	0.30	0.06	-0.93	-1.523
36516.889	6200.38	6200.51	0.08	-0.13	-0.93	-1.523
36015.219	5200.41	5200.61	-0.02	-0.20	-0.93	-1.523
35505.191	4200.44	4200.63	-0.04	-0.19	-0.93	-1.523
34986.433	3200.44	3200.58	-0.01	-0.14	-0.93	-1.523
34670.827	2600.39	2600.54	-0.03	-0.15	-0.94	-1.523
34458.548	2200.37	2200.48	0.00	-0.11	-0.93	-1.523
34137.296	1600.36	1600.48	-0.00	-0.12	-0.94	-1.523

Sensor Output	DWT	Sensor New Coefs	DWT-Sensor Prev Coefs	DWT-Sensor NEW Coefs	PT-DegC	Bath_Temp
33921.159	1200.34	1200.45	0.01	-0.10	-0.94	-1.523
33593.964	600.31	600.43	-0.00	-0.12	-0.94	-1.523
33265.090	0.27	0.26	0.23	0.01	6.71	6.484
33596.020	600.32	600.25	0.28	0.07	6.73	6.484
33923.231	1200.34	1200.22	0.33	0.11	6.75	6.484
34139.364	1600.36	1600.21	0.36	0.15	6.76	6.484
34460.652	2200.40	2200.22	0.40	0.18	6.78	6.484
34672.944	2600.42	2600.25	0.39	0.16	6.78	6.484
34988.582	3200.43	3200.29	0.38	0.14	6.81	6.484
35507.396	4200.43	4200.35	0.34	0.08	6.81	6.484
36017.495	5200.44	5200.35	0.38	0.09	6.83	6.484
36519.254	6200.42	6200.34	0.41	0.08	6.83	6.484
36914.833	7000.36	7000.17	0.55	0.18	6.86	6.484
36519.312	6200.42	6200.43	0.32	-0.01	6.88	6.484
36017.652	5200.46	5200.64	0.11	-0.18	6.89	6.484
35507.591	4200.45	4200.69	0.02	-0.24	6.89	6.484
34988.776	3200.42	3200.62	0.04	-0.20	6.89	6.484
34673.126	2600.40	2600.54	0.08	-0.14	6.90	6.484
34460.851	2200.40	2200.53	0.09	-0.13	6.91	6.484
34139.559	1600.36	1600.50	0.08	-0.13	6.91	6.484
33923.409	1200.34	1200.47	0.08	-0.13	6.93	6.484
33596.164	600.31	600.42	0.11	-0.11	6.94	6.484
33267.148	0.27	0.25	0.20	0.02	17.27	16.489
33598.103	600.31	600.20	0.28	0.11	17.27	16.489
33925.365	1200.32	1200.19	0.31	0.14	17.27	16.489
34141.531	1600.35	1600.17	0.34	0.17	17.27	16.489
34462.869	2200.39	2200.20	0.35	0.19	17.27	16.489
34675.177	2600.40	2600.20	0.35	0.20	17.27	16.489
34990.902	3200.40	3200.33	0.23	0.07	17.27	16.490
34675.234	2600.38	2600.31	0.23	0.07	17.27	16.489
34990.870	3200.43	3200.27	0.32	0.16	17.27	16.489
35509.760	4200.39	4200.32	0.24	0.07	17.27	16.489
36019.924	5200.38	5200.32	0.25	0.07	17.28	16.489
36521.797	6200.40	6200.38	0.22	0.01	17.28	16.489
36020.065	5200.43	5200.59	0.02	-0.16	17.28	16.490
35509.913	4200.40	4200.62	-0.04	-0.21	17.27	16.489
34991.029	3200.39	3200.57	-0.02	-0.18	17.27	16.489
34675.353	2600.38	2600.54	0.00	-0.16	17.27	16.489
34463.035	2200.39	2200.51	0.04	-0.12	17.27	16.489
34141.696	1600.36	1600.48	0.04	-0.13	17.27	16.489
33925.527	1200.33	1200.49	0.01	-0.16	17.27	16.489
33598.228	600.31	600.43	0.05	-0.12	17.27	16.489
33268.160	0.27	0.15	0.26	0.11	28.87	28.000
33599.211	600.31	600.16	0.26	0.15	28.87	28.000
33926.523	1200.34	1200.11	0.31	0.23	28.87	28.000
34142.724	1600.36	1600.08	0.35	0.28	28.87	28.000



Sensor Output	DWT	Sensor New Coefs	DWT-Sensor Prev Coefs	DWT-Sensor NEW Coefs	PT-DegC	Bath_Temp
34464.126	2200.37	2200.10	0.32	0.27	28.87	28.000
34676.481	2600.38	2600.11	0.29	0.26	28.87	28.000
34992.232	3200.42	3200.17	0.26	0.25	28.87	28.000
35511.255	4200.43	4200.28	0.13	0.14	28.87	28.000
36021.545	5200.40	5200.33	0.04	0.07	28.88	28.000
36523.496	6200.35	6200.36	-0.05	-0.01	28.88	28.000
36021.659	5200.43	5200.56	-0.17	-0.13	28.87	27.999
35511.424	4200.44	4200.61	-0.19	-0.17	28.87	28.000
34992.457	3200.41	3200.60	-0.18	-0.19	28.87	28.000
34676.719	2600.38	2600.57	-0.16	-0.18	28.87	28.000
34464.373	2200.37	2200.56	-0.15	-0.19	28.87	27.999
34142.980	1600.36	1600.55	-0.13	-0.19	28.87	27.999
33926.777	1200.34	1200.58	-0.16	-0.24	28.87	28.000
33599.463	600.31	600.62	-0.19	-0.30	28.87	28.000
33268.316	0.27	0.43	-0.03	-0.17	28.87	27.999



# Temperature Calibration Report

## STS Calibration Facility

SENSOR SERIAL NUMBER: 2309

CALIBRATION DATE: 02-Feb-2021

Mfg: SEABIRD Model: 03

Previous cal: 22-Aug-18

Calibration Tech: JRB

ITS-90_COEFFICIENTS	IPTS-68_COEFFICIENTS ITS-T90	
g = 4.35766978E-3	a = 4.35786799E-3	
h = 6.44842157E-4	b = 6.45053483E-4	
i = 2.41461092E-5	c = 2.41788429E-5	
j = 2.32316822E-6	d = 2.32475796E-6	
f0 = 1000.0	Slope = 1.0	Offset = 0.0

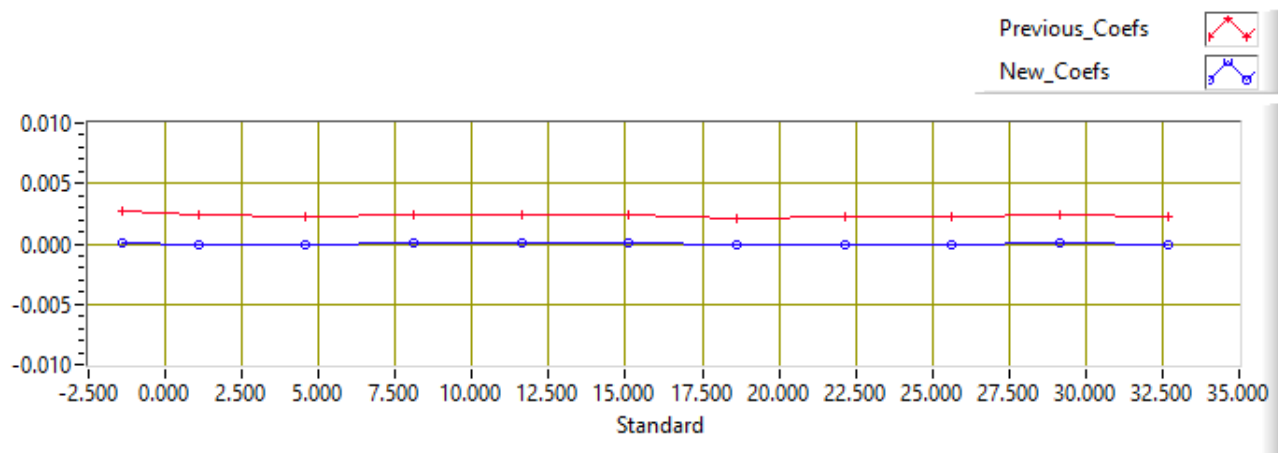
Calibration Standard: Mfg: Isotech Model: MicroK100 s/n: 291088-2

Temperature ITS-90 =  $1/(g+h[\ln(f_0/f)]+i[\ln^2(f_0/f)]+j[\ln^3(f_0/f)]) - 273.15$  (°C)

Temperature IPTS-68 =  $1/(a+b[\ln(f_0/f)]+c[\ln^2(f_0/f)]+d[\ln^3(f_0/f)]) - 273.15$  (°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
2975.5870	-1.4260	-1.4261	0.00265	0.00009
3147.1972	1.0788	1.0789	0.00238	-0.00009
3399.3413	4.5854	4.5856	0.00226	-0.00011
3665.8671	8.0939	8.0939	0.00234	0.00004
3947.2597	11.6048	11.6047	0.00238	0.00012
4242.8745	15.1060	15.1060	0.00233	0.00008
4554.7523	18.6173	18.6174	0.00216	-0.00009
4882.4355	22.1289	22.1290	0.00220	-0.00007
5225.9295	25.6375	25.6375	0.00223	-0.00005
5586.0060	29.1476	29.1475	0.00243	0.00012
5963.0718	32.6596	32.6596	0.00228	-0.00004



# Temperature Calibration Report

## STS Calibration Facility

SENSOR SERIAL NUMBER: 2380

CALIBRATION DATE: 02-Feb-2021

Mfg: SEABIRD Model: 03

Previous cal: 01-Oct-19

Calibration Tech: JRB

ITS-90_COEFFICIENTS	IPTS-68_COEFFICIENTS ITS-T90	
g = 4.34100532E-3	a = 4.34119811E-3	
h = 6.41789424E-4	b = 6.41998534E-4	
i = 2.37299874E-5	c = 2.37624492E-5	
j = 2.23207901E-6	d = 2.23365599E-6	
f0 = 1000.0	Slope = 1.0	Offset = 0.0

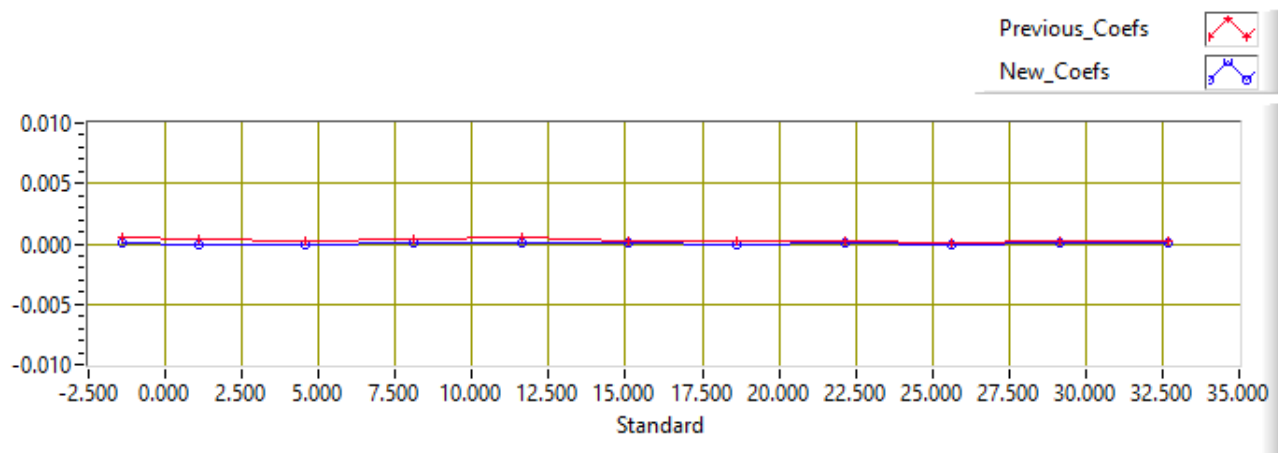
Calibration Standard: Mfg: Isotech Model: MicroK100 s/n: 291088-2

Temperature ITS-90 =  $1/(g+h[\ln(f_0/f)]+i[\ln^2(f_0/f)]+j[\ln^3(f_0/f)]) - 273.15$  (°C)

Temperature IPTS-68 =  $1/(a+b[\ln(f_0/f)]+c[\ln^2(f_0/f)]+d[\ln^3(f_0/f)]) - 273.15$  (°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
2908.1745	-1.4260	-1.4261	0.00050	0.00008
3076.3906	1.0788	1.0789	0.00033	-0.00006
3323.6099	4.5854	4.5856	0.00024	-0.00013
3584.9964	8.0939	8.0939	0.00035	0.00001
3861.0310	11.6048	11.6047	0.00047	0.00015
4151.1088	15.1060	15.1060	0.00030	0.00001
4457.2075	18.6173	18.6173	0.00024	-0.00004
4778.9118	22.1289	22.1289	0.00031	0.00006
5116.2600	25.6375	25.6376	0.00009	-0.00015
5469.9675	29.1476	29.1476	0.00027	0.00005
5840.4566	32.6596	32.6596	0.00021	0.00002





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SENSOR SERIAL NUMBER: 3399  
CALIBRATION DATE: 25-Nov-20

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

COEFFICIENTS:

g = -9.90599021e+000  
h = 1.49772528e+000  
i = -2.27347443e-003  
j = 2.57836284e-004

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

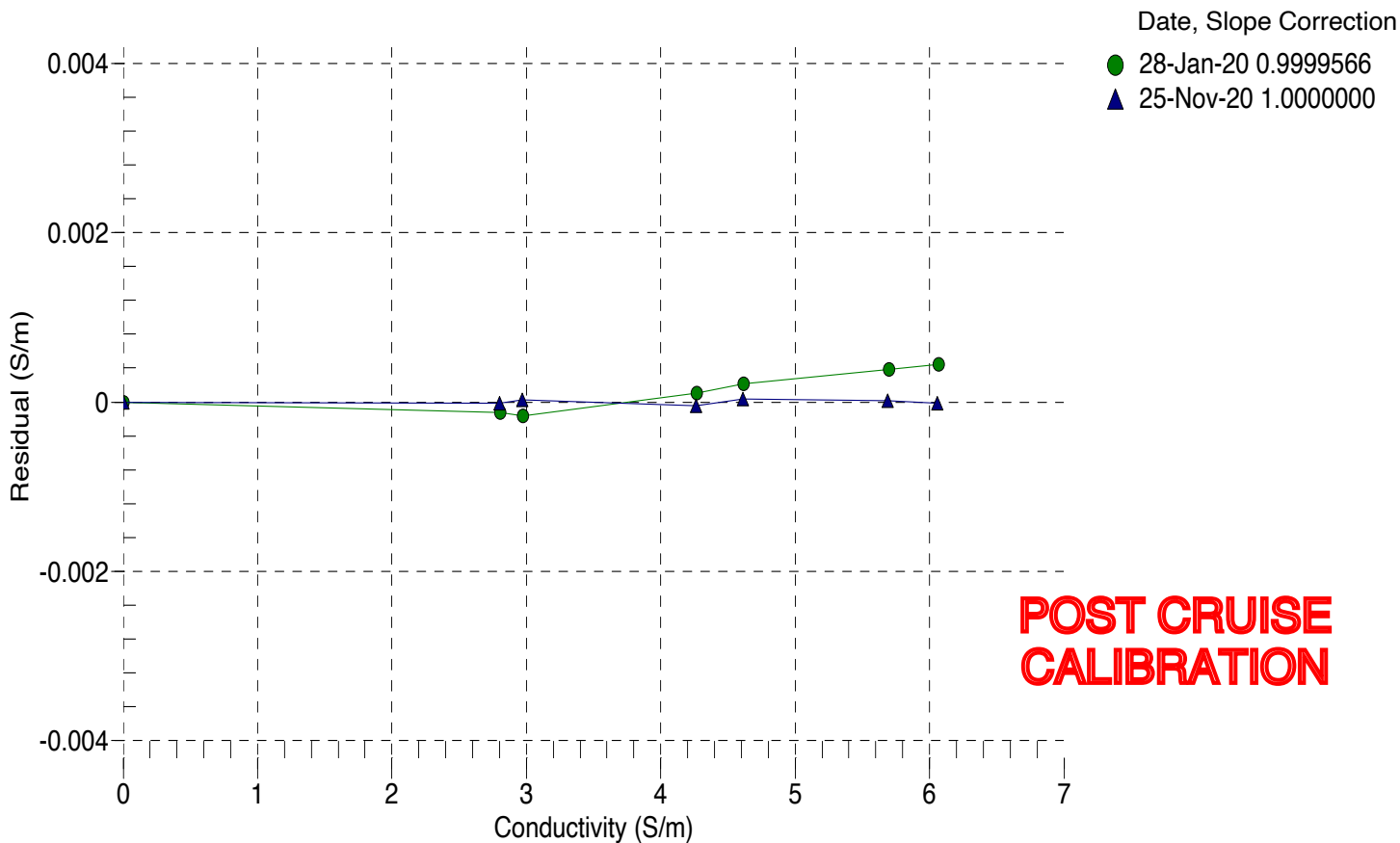
BATH TEMP (° C)	BATH SAL (PSU)	BATH COND (S/m)	INSTRUMENT OUTPUT (kHz)	INSTRUMENT COND (S/m)	RESIDUAL (S/m)
0.0000	0.0000	0.00000	2.57534	0.00000	0.00000
-1.0000	34.7650	2.80083	5.03961	2.80082	-0.00001
1.0000	34.7630	2.97184	5.15198	2.97186	0.00002
15.0000	34.7550	4.26489	5.93250	4.26484	-0.00005
18.5000	34.7466	4.61012	6.12400	4.61015	0.00003
29.0000	34.7247	5.68900	6.68668	5.68902	0.00002
32.5000	34.6927	6.05687	6.86785	6.05685	-0.00002

f = Instrument Output (kHz)

t = temperature (°C); p = pressure (decibars);  $\delta$  = CTcor;  $\epsilon$  = CPcor;

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

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





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SENSOR SERIAL NUMBER: 1880  
CALIBRATION DATE: 04-Dec-20

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

COEFFICIENTS:

g = -3.96399499e+000  
h = 4.84055685e-001  
i = -5.86292632e-004  
j = 5.45468975e-005

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

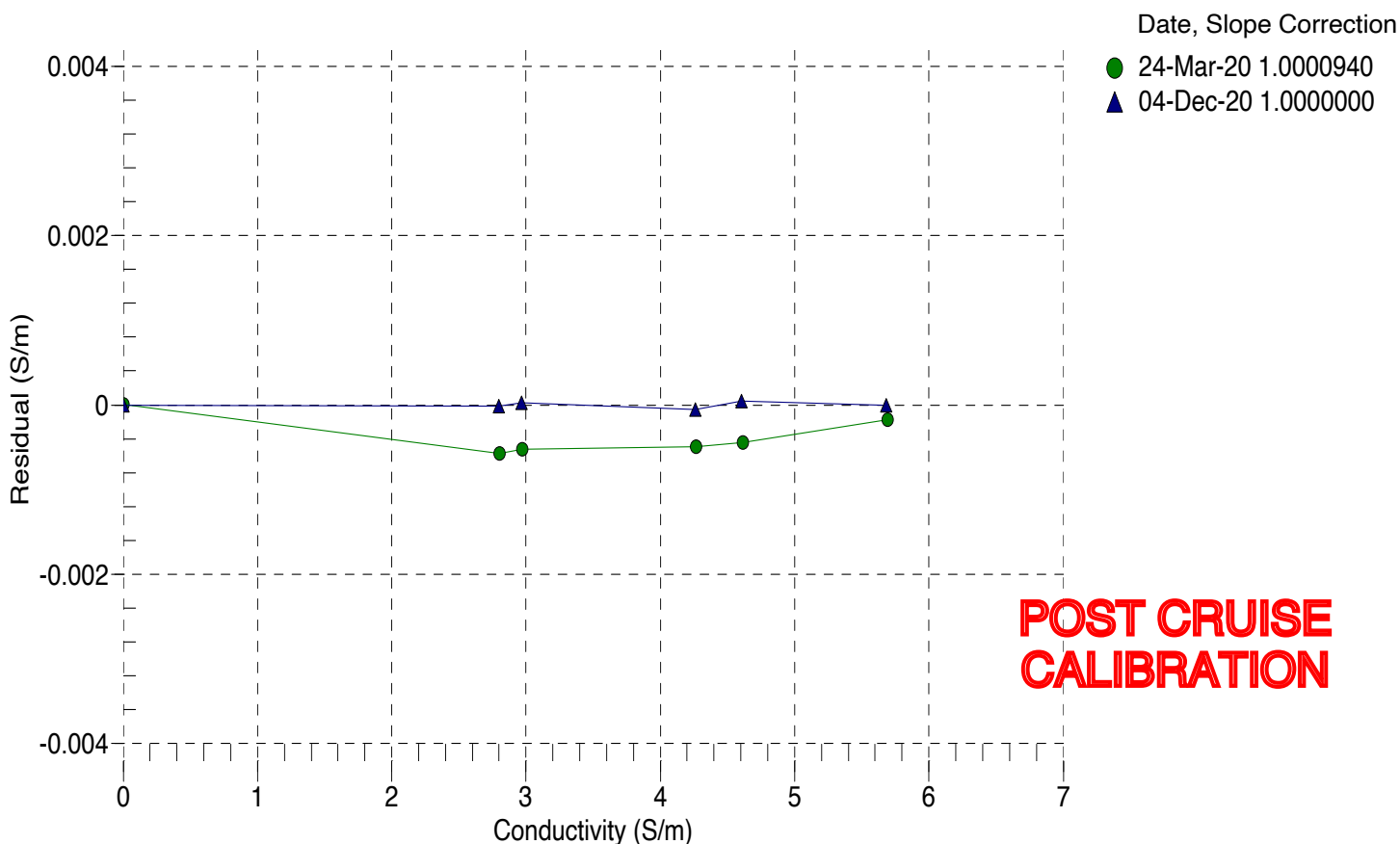
BATH TEMP (° C)	BATH SAL (PSU)	BATH COND (S/m)	INSTRUMENT OUTPUT (kHz)	INSTRUMENT COND (S/m)	RESIDUAL (S/m)
0.0000	0.0000	0.00000	2.86531	0.00000	0.00000
-1.0000	34.7034	2.79633	8.13117	2.79632	-0.00001
1.0000	34.7028	2.96719	8.34539	2.96721	0.00002
15.0000	34.7013	4.25900	9.81212	4.25894	-0.00005
18.5000	34.6979	4.60435	10.16784	4.60440	0.00005
29.0000	34.6895	5.68388	11.20490	5.68388	-0.00001
32.5000	34.6740	6.05398	11.53820	6.05381	-0.00017

f = Instrument Output (kHz)

t = temperature (°C); p = pressure (decibars);  $\delta$  = CTcor;  $\epsilon$  = CPcor;

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

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





# SEA-BIRD ELECTRONICS, INC.

13431 NE 20th St. Bellevue, Washington 98005 USA

Phone: (425) 643-9866 Fax: (425) 643-9954 www.seabird.com

**Service**

**Report**

**RMA Number**

87926

## Customer Information:

**Company** Scripps Institute of Oceanography

**Date** 3/16/2016

**Contact** Carl Mattson

**PO Number** TBD

**Serial Number** 051871

**Model Number** SBE 05T

## Services Requested:

1. Evaluate/Repair Instrumentation.

## Problems Found:

1. Pump needs 10-18 VDC -Test pump cable.

## Services Performed:

1. Performed initial diagnostic evaluation.
2. Performed internal inspection and O-ring and thrust washer replacements.
3. Performed hydrostatic pressure test.

## Special Notes:



**Sea-Bird Electronics, Inc.**

13431 NE 20<sup>th</sup> St. Bellevue, Washington 98005 USA  
www.seabird.com

Phone: (425) 643-9866

Fax: (425) 643-9954

Email: seabird@seabird.com

## Pressure Test Certificate

Test Date: **04/14/16**

Description: **SBE-5T Submersible Pump**

### Sensor Information:

Model Number: **5T**

Serial Number: **8690**

### Pressure Test Protocol:

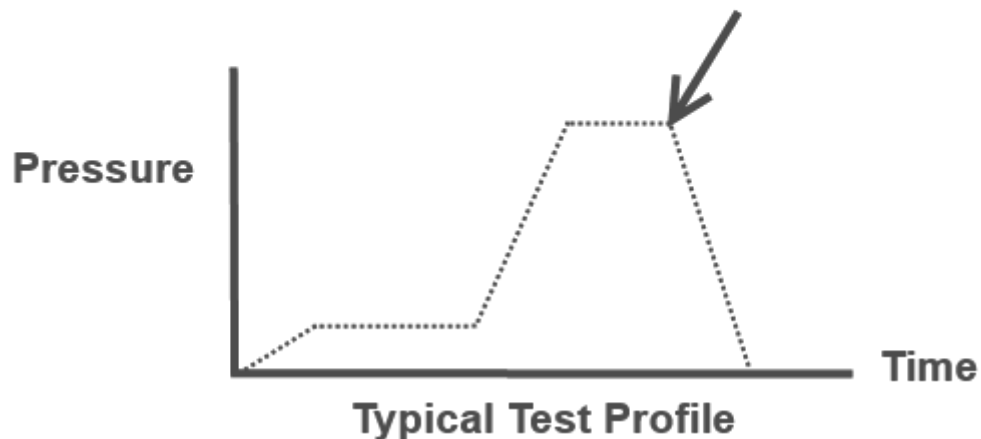
Low Pressure Test: **40** PSI Held For: **15** Minutes

High Pressure Test: **10000** PSI Held For: **15** Minutes

Passed Test: **Yes**

Tested By: **nd**

**High pressure is generally equal to the maximum depth rating of the instrument**





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SENSOR SERIAL NUMBER: 0255  
CALIBRATION DATE: 13-Nov-20

# SBE 43 OXYGEN CALIBRATION DATA

COEFFICIENTS:  
Soc = 0.4735  
Voffset = -0.5091  
Tau20 = 1.56  
A = -4.1544e-003  
B = 1.9043e-004  
C = -2.8141e-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

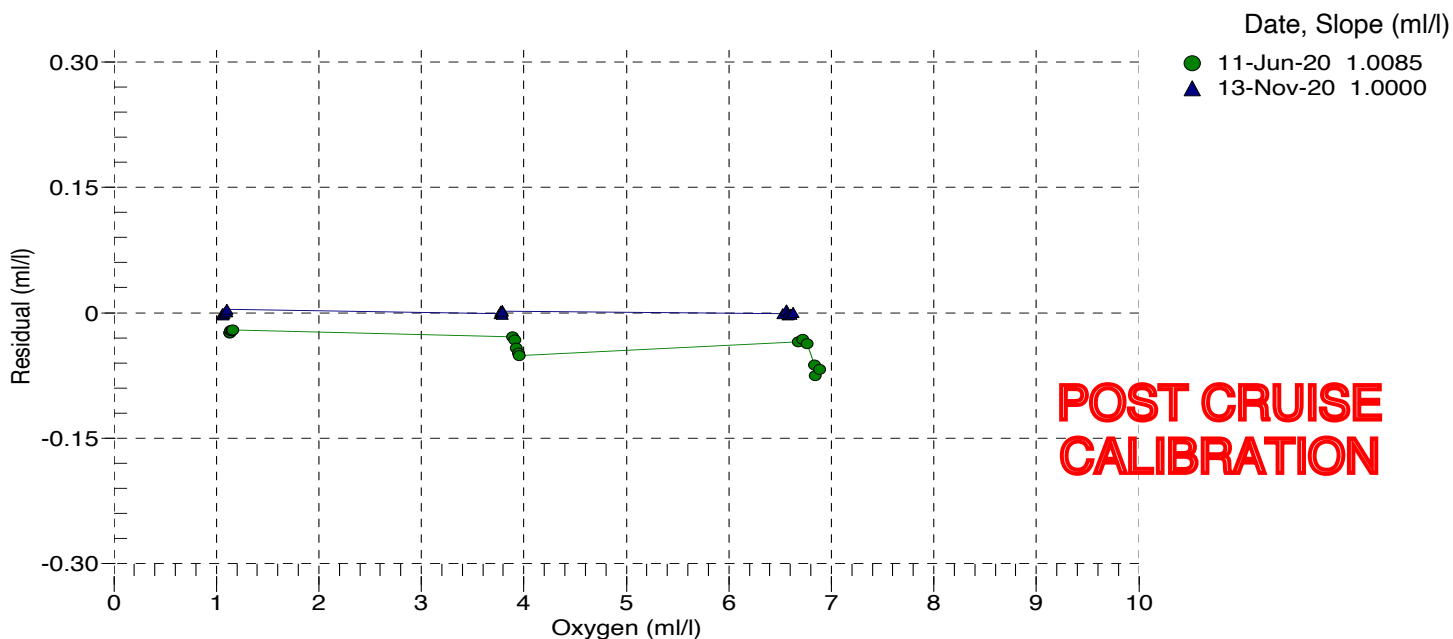
BATH OXYGEN (ml/l)	BATH TEMPERATURE (° C)	BATH SALINITY (PSU)	INSTRUMENT OUTPUT (volts)	INSTRUMENT OXYGEN (ml/l)	RESIDUAL (ml/l)
1.06	2.00	0.00	0.742	1.06	-0.00
1.07	6.00	0.00	0.772	1.06	-0.00
1.08	12.00	0.00	0.819	1.08	-0.00
1.09	20.00	0.00	0.882	1.09	0.00
1.10	26.00	0.00	0.931	1.10	0.00
1.10	30.00	0.00	0.964	1.10	0.00
3.77	2.00	0.00	1.338	3.77	-0.00
3.77	30.00	0.00	2.062	3.78	0.00
3.78	6.00	0.00	1.443	3.78	0.00
3.79	12.00	0.00	1.599	3.79	-0.00
3.79	26.00	0.00	1.962	3.79	0.00
3.79	20.00	0.00	1.807	3.79	0.00
6.53	2.00	0.00	1.945	6.53	-0.00
6.56	6.00	0.00	2.132	6.57	0.00
6.58	30.00	0.00	3.214	6.58	-0.00
6.58	12.00	0.00	2.403	6.58	-0.00
6.60	20.00	0.00	2.767	6.60	-0.00
6.63	26.00	0.00	3.049	6.63	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)

Oxygen (ml/l) = Soc \* (V + Voffset) \* (1.0 + A \* T + B \* T<sup>2</sup> + C \* T<sup>3</sup>) \* Oxsol(T,S) \* exp(E \* P / K)

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





# CALIBRATION CERTIFICATE

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



JFE Advantech Co., Ltd.

# Temperature Calibration Certificate

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

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

2. Coefficients  
A = -5.305905e+00  
B = +1.666857e+01  
C = -2.142681e+00  
D = +4.582805e-01

3. Calibration results

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

4. Verification

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

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

Examined

*R. Kashida*

Approved

*A. Fukuoka*

# Dissolved Oxygen Calibration Certificate

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

## 1. Equation

$$DO[\%] = G + H \times P'$$

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

## 2. Coefficients

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

## 3. Verification

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

Acceptance:  $\pm 0.5\%$  of full scale

Test for DO 0 %

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

Test for DO 100 %

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

Examined M. TAKEISHI  
 Approved a. Fukuoka

# Temperature Calibration Report

## STS Calibration Facility

SENSOR SERIAL NUMBER: 0105

CALIBRATION DATE: 09-Feb-2021

Mfg: SEABIRD Model: 35

Previous cal: 04-Mar-19

Calibration Tech: CAL

### ITS-90 COEFFICIENTS

a0 = 5.975308880E-3

a1 = -1.681244320E-3

a2 = 2.377301998E-4

a3 = -1.302239067E-5

a4 = 2.723298781E-7

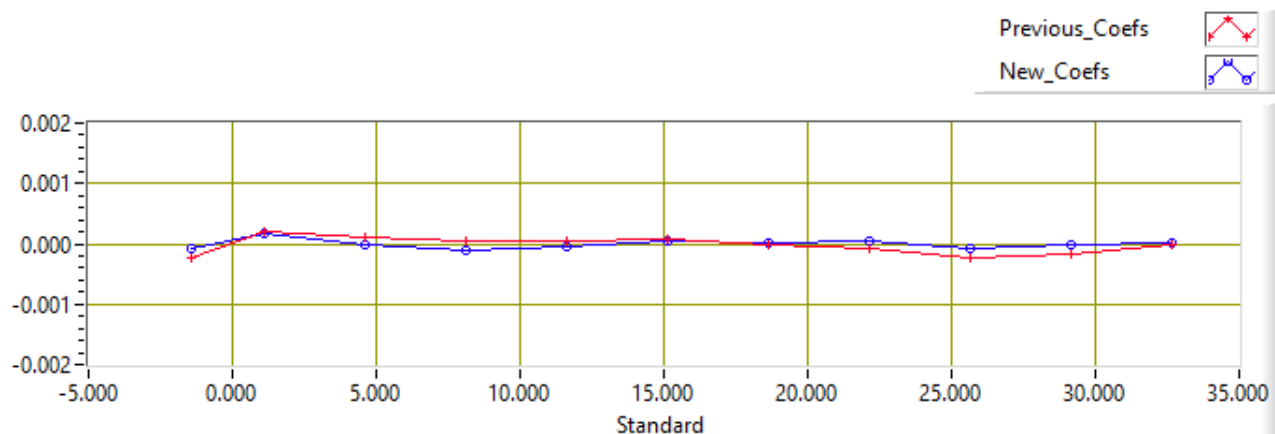
Slope = 1.000000 Offset = 0.000000

Calibration Standard: Mfg: Isotech Model: MicroK100 s/n: 291088-2

Calibration Standard: Mfg: Isotech Model: MicroK100 s/n: 291088-2

Temperature ITS-90 =  $1/[a_0 + a_1[\ln(f)] + a_2[\ln^2(f)] + a_3[\ln^3(f)] + a_4[\ln^4(f)]] - 273.15$  (°C)

SBE35 Count	SPRT ITS-T90	SBE35 ITS-T90	SPRT-SBE35 OLD Coefs	SPRT-SBE35 NEW Coefs
921017.6404	-1.4262	-1.4261	-0.00023	-0.00009
823597.3265	1.0788	1.0786	0.00020	0.00018
705820.0404	4.5853	4.5853	0.00012	-0.00001
606424.7522	8.0935	8.0936	0.00005	-0.00010
522375.2763	11.6031	11.6032	0.00006	-0.00005
451318.4282	15.1050	15.1049	0.00009	0.00006
390785.6089	18.6176	18.6176	-0.00003	0.00003
339309.7652	22.1272	22.1272	-0.00007	0.00006
295375.1636	25.6377	25.6377	-0.00023	-0.00007
257804.2798	29.1473	29.1473	-0.00016	-0.00003
225560.7487	32.6597	32.6596	0.00000	0.00003



## C-Star Calibration

Date	August 9, 2019	S/N#	CST-1803DR	Pathlength	25 cm
------	----------------	------	------------	------------	-------

	Analog output	Digital output
$V_{\text{dark}}$	0.014 V	0 counts
$V_{\text{air}}$	4.795 V	15714 counts
$V_{\text{ref}}$	4.699 V	15400 counts

Temperature of calibration water	24.7 °C
Ambient temperature during calibration	21.8 °C

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

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

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

$V_{\text{dark}}$  Meter output with the beam blocked. This is the offset.

$V_{\text{air}}$  Meter output in air with a clear beam path.

$V_{\text{ref}}$  Meter output with clean water in the path.

Temperature of calibration water: temperature of clean water used to obtain  $V_{\text{ref}}$ .

Ambient temperature: meter temperature in air during the calibration.

$V_{\text{sig}}$  Measured signal output of meter.

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