Cruise Report of the 2021 A20 US GO-SHIP Reoccupation

Release 1.0

Ryan Woosley

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GO-SHIP A20 2021 HYDROGRAPHIC PROGRAM

1.1 Cruise Scientific Objectives

Ryan Woosley

Complex oceanic responses to climate change can only be characterized with regular repeat high-quality shipboard measurements of climate-relevant ocean properties. GO-SHIP repeat transoceanic surveys (www.goship.org) provide full water column hydrographic observations with temporal and spatial resolutions adequate to resolve decadal variability in oceanic storage of heat, freshwater, carbon, oxygen, nutrients and transient tracers. Repeat hydrographic physical-biogeochemical measurements nominally along 52° 20'N in the North Atlantic Ocean enables scientists to better tackle important unresolved aspects of the Atlantic Ocean's response to decadal scale variability and increases in both heat and carbon dioxide as a result of anthropogenic activies. The U.S. GO-SHIP A20 2021 hydrographic section revisited this line for the fourth time, with prior transects occurring in 1997, 2003, and 2012. Temperature, salinity, and velocity measurements from A20 2021 reveal how the heat content of deep and bottom waters in the North Atlantic have changes over the last 24 years. A20 2021 measurements of oxygen, nutrients, transient tracers, and dissolved inorganic carbon allow quantifying the anthropogenic component in the total inventory changes of surface and deep waters. Combined carbon and current measurements from the repeat A20 line are used to determine rates of regional carbon accumulation and exchange with adjacent circulations. The overarching achievement of GO-SHIP A20 2021 measurements was the reoccupation of 90 full-depth CTD stations and the collection of water samples at different levels with 36 Niskin bottles. Measured temperature, salinity, pressure, oxygen, fluorometry, shear and micro-scale temperature, and the major nutrients, oxygen, salinity, CFC and carbon components (total dissolved inorganic carbon, total alkalinity, pH, and fugacity of CO2) were discretely analyzed on board. Measurements of dissolved organic carbon, nitrate isotopes, radiocarbon, and Sargassum seaweed samples were collected and will be measured in laboratories on shore. Core Argo and BGC-Argo floats along with SOFAR drifters were also deployed, generally after a CTD cast while leaving station.
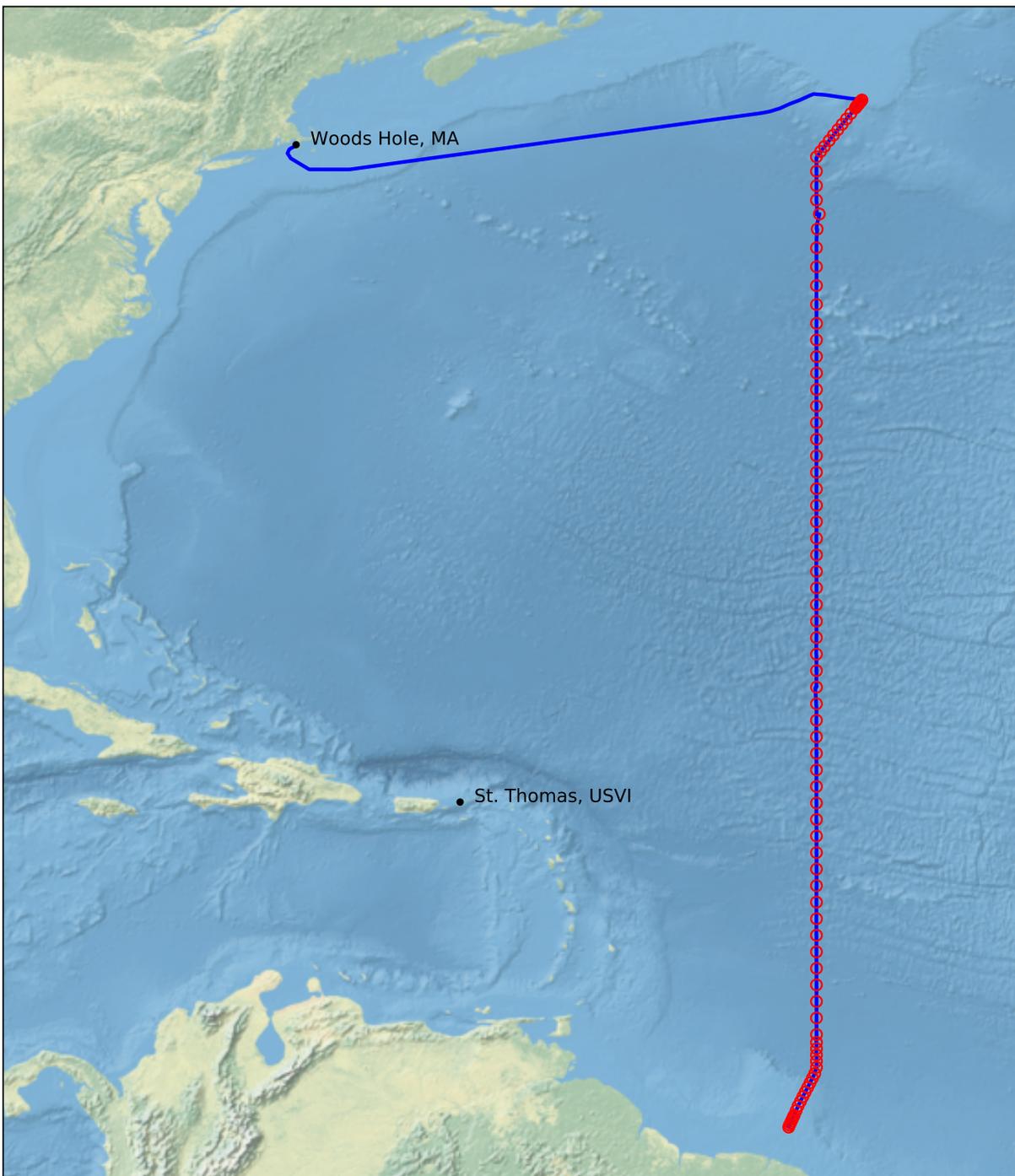
Fig. 1: Cruise track and station locations. The lack of cruise track between the last station and the end port of St. Thomas, USVI is due to the ship science data logger being turned off after the last station since the ship would enter Surinamese waters shortly after departing.

1.2 Programs and Principal Investigators

Program	Affiliation	Principal Investigator	Email
CTDO Data, Salinity, Nutrients, Dissolved O_2	*UCSD*, *SIO*	Susan Becker, Jim Swift	sbecker@ucsd.edu, jswift@ucsd.edu
Total CO_2 (DIC)	*AOML*, *PMEL*, *NOAA*	Richard Feely, Rik Wanninkhof	richard.a.feely@noaa.gov, Rik.Wanninkhof@noaa.gov
Underway Temperature, Salinity, and pCO_2	*PMEL*, *NOAA*	Simone Alin	simone.r.alin@noaa.gov
Total Alkalinity, pH	*SIO*, *RSMAS*	Andrew Dickson, Frank Millero	adickson@ucsd.edu, fmillero@rsmas.miami.edu
Discrete pCO_2	*PMEL*, *NOAA*	Rik Wanninkhof	Rik.Wanninkhof@noaa.gov
SADCP	*UH*	Eric Firing	efiring@soest.hawaii.edu
LADCP	*LDEO*	Andreas Thurnherr	ant@ldeo.columbia.edu
CFCs, *SF6*, *N2O*	*UW*	Mark Warner	warner@u.washington.edu
DOC, *TDN*	*RSMAS*	Dennis Hansell	dhansell@rsmas.miami.edu
Microgels	*RSMAS*	Dennis Hansell	dhansell@rsmas.miami.edu
C13 & C14	*UW*, *WHOI*	Rolf Sonnerup, Roberta Hansman	rolf@uw.edu, rhansman@whoi.edu
Transmissometry	*TAMU*	Wilf Gardner	wgardner@ocean.tamu.edu
Chipod	*OSU*	Jonathan Nash	nash@coas.oregonstate.edu
Argo Floats	*WHOI*	Susan Wijffels, Steven Jayne, Pelle Robbins	swijffels@whoi.edu, sjayne@whoi.edu, probbins@whoi.edu.
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Sargassum	*WHOI*	Dennis McGillicuddy	dmcgillicuddy@whoi.edu

1.3 Science Team and Responsibilities

Duty	Name	Affiliation	Email Address
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CTD Watchstander	Paige Hoel	*UCLA*	paigehoel@atmos.ucla.edu
CTD Watchstander	Francesca Alatorre	*UCSC*	falatorr@ucsc.edu
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Salts, CTD/Rosette Maintenance	Patrick A'Hearn	*TAMU*	pnahearn@gmail.com
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Dissolved O_2	Robert Freiberger	*UCSD*	rfreiberger@ucsd.edu
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DIC	Charles Featherstone	*NOAA*	charles.featherstone@noaa.gov
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CFCs, SF6	Mark Warner	*UW*	warner@u.washington.edu
CFCs, SF6	Rolf Sonnerup	*UW*	rolf@uw.edu
CFCs, SF6 student	Carla Mejías-Rivera	*U Puerto Rico*	clmejiasrivera@gmail.com
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pH, Total Alkalinity	Albert Ortiz	*U Miami*	albert.ortiz@rsmas.miami.edu
DOC, *TDN*	Abigail Tinari	*U Miami*	abigail.tinari@rsmas.miami.edu
Indep/Nurse	Lauren Elium	Other	n/a
Marine Technician	Stephen Jalickee	*UW*	jalickee@uw.edu
Marine Technician	Elizabeth Ricci	*UW*	ericci@uw.edu

TWO

CRUISE NARRATIVE

The 2021 A20 cruise is the fourth occupation of the line, nominally 52º 20' N, formally occupied as part of WOCE in 1997 and reoccupied in 2003 and 2012. A CTD transect of the line was also conducted in 1983. This occupation closely followed the 2012 GO-SHIP occupation except for an eastward shift of ~0.5 – 4 nm of the South American continental shelf stations (75 – 90) due to a slight change in the French Guiana EEZ in 2018. The original WOCE occupation had continental shelf and slope stations in the Suriname rather than French Guiana EEZ. A total of 98 stations were planned and a total of 90 were actually occupied. Unlike in 2012, the transect was conducted from north to south, as was done in 1997 and 2003. The March – April timing was slightly different than the April – May timing of the 2012 occupation, compared to July – August in 1997 and October – September in 2003. The full suite of core GO-SHIP chemical and physical parameters were measured (as described in the following sections) and will be compared to prior occupations for analysis of decadal scale changes covering 24 years.

The cruise departed Woods Hole, Massachusetts at 13:00 on March 16, 2021, after a four-day mobilization beginning on March 12. Due to the ongoing COVID-19 pandemic all participants were required to self-isolate for 14 days before boarding and receive two negative COVID tests prior to boarding. Those based in Florida were able to do their self-isolation there and board in Port Everglades, FL to avoid the risks of air travel. Once on-board, participants were not allowed to leave until arrival in St. Thomas, or back in Woods Hole for those also participating in A22. Mask wearing and social distancing was practiced as required by Coast Guard rules. Also, to reduce the risks of ocean research during a pandemic the number of science crew was kept to a minimum. Therefore, ancillary measurements which required an additional berth were not allowed. The smaller than normal science crew did present some challenges, as there were fewer extra helping hands than usual.

The station plan followed the 2012 stations closely, especially near the Grand Banks across the continental slope and shelf, as well as on the South American continental rise where tight station spacing (10 –13 nm) was maintained in water depths of up to 4900 m. Such tight spacing off of South America allowed for resolution of the Deep Western Boundary Current (DWBC) and the Guiana recirculation. Station resolution in the interior, deep, portion of the section was higher than that achieved in 2012. South of the continental shelf and slope of the Grand Banks (southeast of Newfoundland) 30 nm spacing was maintained between ~39 – 41º N (stations 16 – 21) which included crossing of the Gulf Stream, located near 40º N during our occupation. The location of the Gulf Stream was further north than it was in 2012 (between 38 and 39º N). Altimetry and sea surface temperature data indicate that the Gulf Stream had migrated slightly northward in the month proceeding this occupation. A storm awaited us at the first station causing a 24-hour delay to the beginning of science operations. Between 38º 33.36' N and 35º 13.32' N (stations 22 – 26) spacing was widened to 40 nm both to allow us to make up some of the time lost to weather, and also to avoid a large storm moving across the North Atlantic. The storm avoidance was successful and station spacing was narrowed to 35 nm from 35º 13.32' N to 10º 8.34'N (stations 27 – 69), at which point the South American rise was reached and station spacing tightened to follow the same spacing as in 2012. After the storm encountered at the first station, winds calmed down over the first few days of scientific operations and warm calm weather graced the remainder of the cruise.

2.1 Physical Oceanography

After a 1500-m-deep shakedown profile (station number 900) was collected at 41º 00.4' N 66º 14.4' W, the vessel proceeded to the first station of the section at 43º 06.3' N 50º 43.9' W. Sampling commenced on March 21, proceeding SSW-ward down the continental slope before turning southward at station 16. On stations 1-7 the upper 200m of the water column was comprised of cold Labrador Sea coastal water with temperatures below 3 degrees flowing predominantly eastward over the shelf break (stations 2-6) and northward on station 7 (Figures 1 and 2). The velocity field over the slope was complex and both horizontally and vertically sheared with evidence for eddy motion over the upper slope. Between 2000 m and 4500 m the density measurements show an approximately 200-m-thick boundary current carrying North Atlantic Deep Water (NADW) westward along the slope beneath a spatially variable current field. Between stations 9 and 19, the velocities above 3000 m are consistent with the "strong Northern Recirculation Gyre (NRG)" described in the cruise report of the previous occupation of this section [McCartney2012]. Below 3000 m, there were alternating currents with both east and westward flow likely affected by the topography. Westward zonal flow in the southern limb of the NRG (stations 18-19) extended across the full water column, consistent with the inferred forcing by the Gulf Stream, which dominated the currents on stations 20-22.
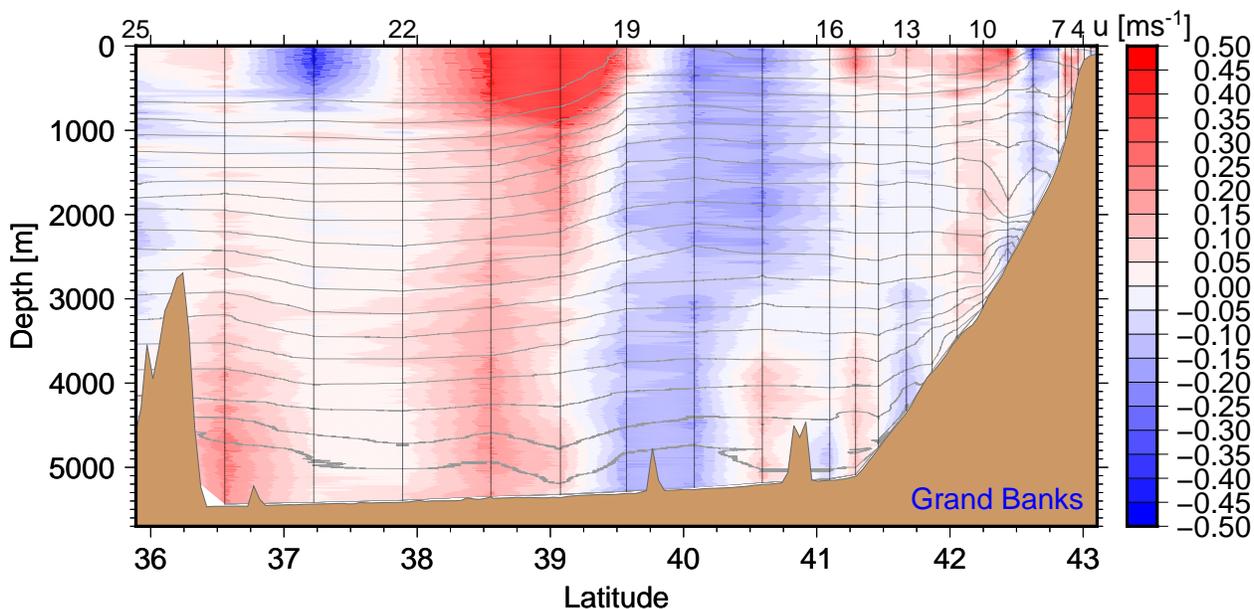
Fig. 1: Zonal velocity in the northern part of the section from the LADCP measurements; contours show arbitrarily spaced sigma-2 surfaces from the CTD data.

South of the Gulf Stream the cross-sectional (i.e. zonal) currents in the upper 1000 m show alternating bands with west- and eastward flow components extending all across the basin interior well into the tropics (figure 3). At greater depths the currents along the base of the flank of the Mid-Atlantic Ridge (MAR) that is corrugated by Fracture Zone valleys are both weaker and without clear spatial patterns, except for an apparent anticyclonic circulation around and above the Corner Seamounts near 36º N. South of about 32º N there is evidence (figure 4) for the topographic roughness of the MAR to elevate the energy in the high-frequency internal-wave field, which is closely related to turbulence and mixing.

South of ~15º N the Mid-Atlantic Ridge trends southeastward and the remainder of the section crosses a smooth abyssal plain before encountering the base of the South American continental slope of the Demerara Plateau on station 76 (figure 5). The zonal currents over the abyssal plain were meridionally banded and mostly spanned the full ocean depth. Over the continental slope the currents were complex and vertically sheared. The strong eastward flow below 2000 m over the lower slope (stations 76-79) is part of the DWBC carrying NADW along the American continent into the South Atlantic [Johns1993]. In the 2012 occupation of A20, eastward flow along this slope extended all the way up to about 1000m [McCartney2012] but during our occupation an anticyclonic eddy occupied the water column between 1000
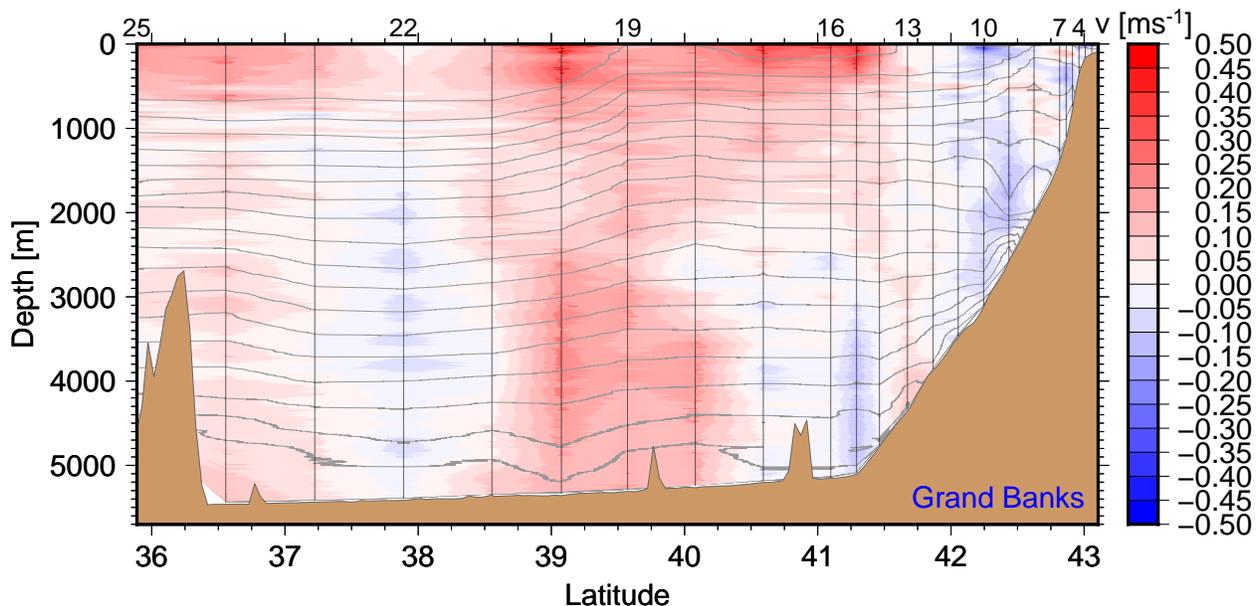
Fig. 2: Meridional velocity in the northern part of the section from the LADCP measurements; contours show arbitrarily spaced sigma-2 surfaces from the CTD data.
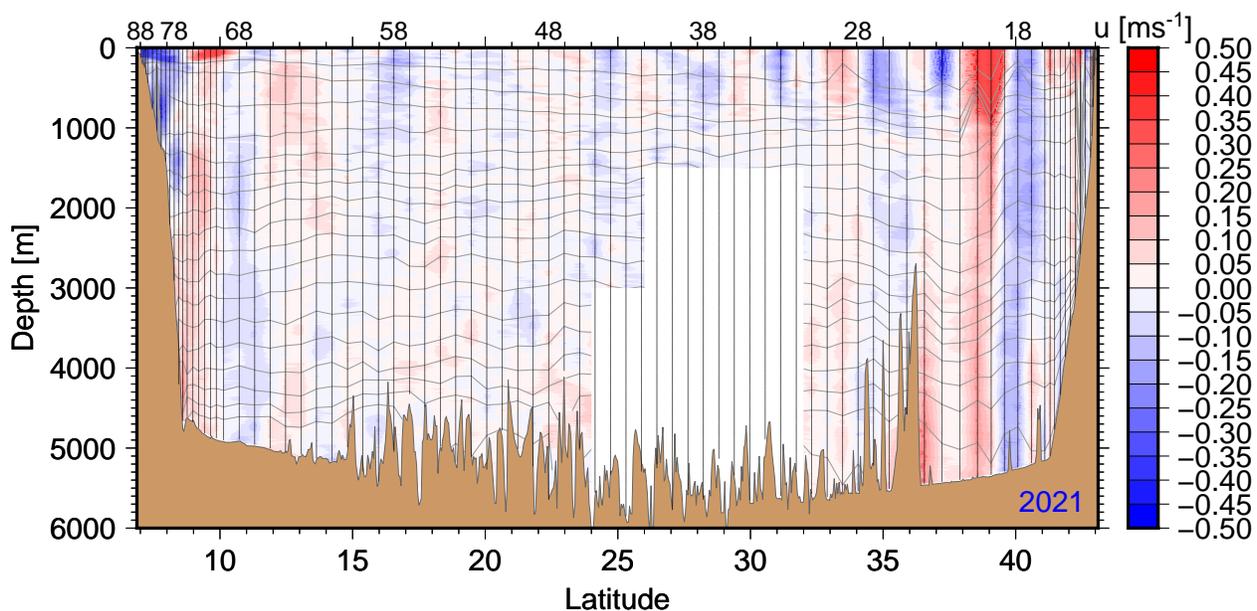
Fig. 3: Zonal velocity along the entire section from the LADCP measurements; contours show arbitrarily spaced sigma-2 surfaces from the CTD data. The data gap at depth between 24 and 32N is caused by insufficient acoustic backscatter contaminating the LADCP velocities.
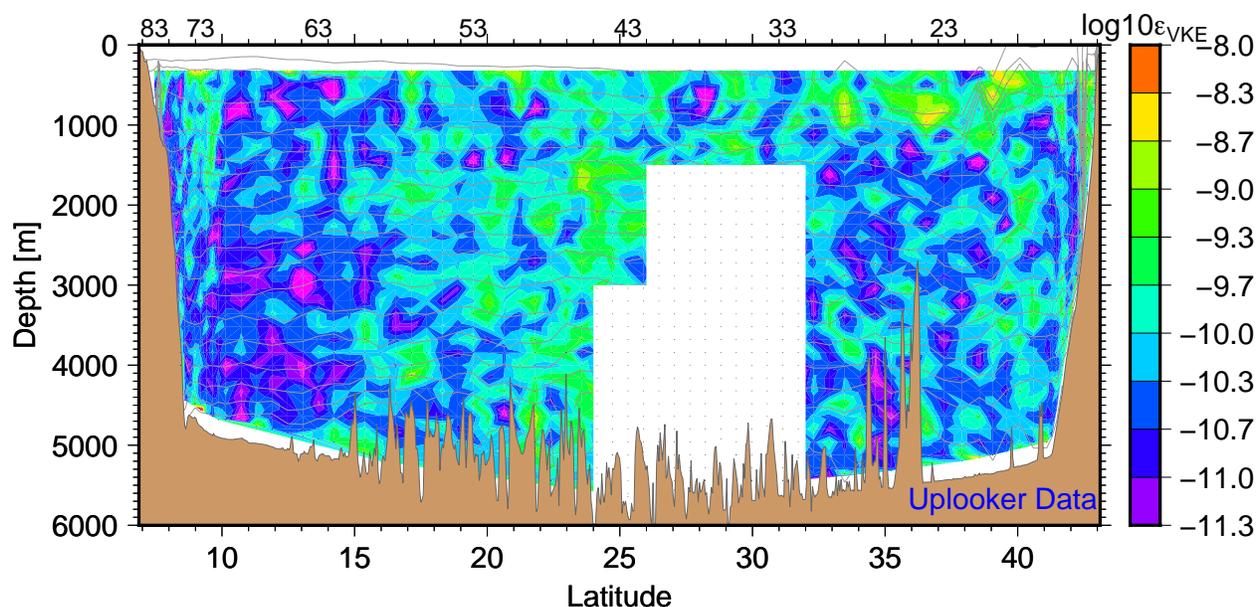
Fig. 4: Vertical kinetic energy from the LADCP-derived vertical velocity measurements scaled into units of dissipation of turbulent kinetic energy [Thurnherr2015]; contours and data gap as in Figure 3.

and 2000 m extending out to about 10º N. Between 200 and 1000 m all LADCP data collected in 2003, 2012 as well as in our occupation show a meridional dipole structure with westward flow banked against the slope and eastward flow further offshore, also extending to 10º N. In the upper 200 m of the water column, the North Brazil Current is flowing westward along the shelf break. In our data as well as in the 2003 occupation the North Brazil Current is bounded offshore by a strong eastward current, which could be its retroflection or, alternatively, a Brazil Current Ring. (In 2012 the North Brazil Current was similar to our observations but there was no eastward flow further offshore.)

Similar to the observations in 2012 (McCartney et al., 2012) we encountered the Amazon River Plume extending a considerable distance off the shelf break. In our observations (figure 6) this freshwater plume is limited to depths shallower than 10m, with the fresh water at the offshore edge of the plume (~100 km from the shelf break; station 80) extending no further than 80 cm below the sea surface. (The 10-30 cm thick almost completely fresh layers very close to the surface in profiles 82, 88 and 89 are likely caused by rainfall.)

2.2 Chemical Oceanography

The distribution of basic chemical and physical parameters were very similar to those of prior occupations in the deep water. The early March timing of this occupation explains the generally colder surface waters compared to 2012. The difference was most noticeable in the northern portion of the section over the Grand Banks, which were generally ~5ºC colder in 2021 compared to 2012. The deeper winter mixing was also obvious by the deeper penetration of high oxygen, and fresher, lower total alkalinity waters over the continental shelf and rise.

The slightly more northern location of the Gulf Steam in 2021 leads to significantly different structure to the chemical and physical properties between ~38 – 40ºN and must be accounted for when comparing the different occupations. The oxygen minimum between ~30 – 40ºN appears to be slightly deeper in 2021 as evidenced by a slight shift in the density structure in the upper water column. The shift is also clearly visible in the inorganic carbon parameters.

The upper 1000 m shows a general increase in dissolved inorganic carbon (DIC) of ~20 µmol/kg since 2012 with a corresponding decrease in pH. The increase in DIC is consistent with the increasing CO_2 content of the atmosphere due to anthropogenic activities. The near constant salinity normalized total alkalinity (TA) further supports the anthropogenic cause of increased DIC and decreased pH. There is also an area of increased DIC (~10 µmol/kg) compared to
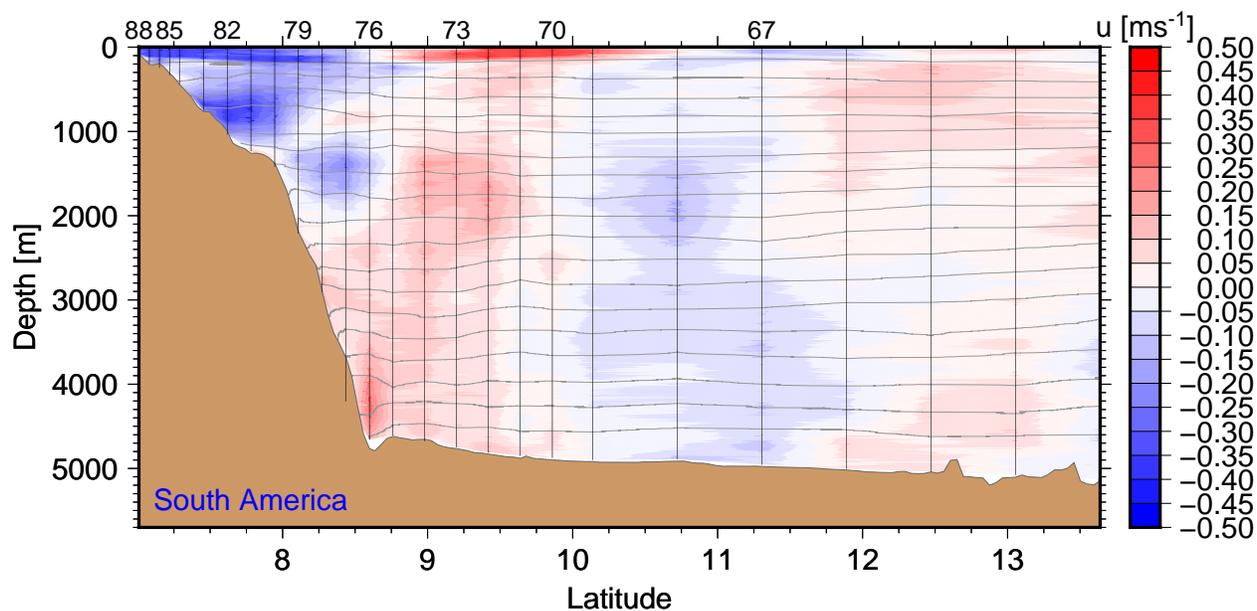
Fig. 5: Zonal velocity in the southern part of the section from the LADCP measurements; contours show arbitrarily spaced sigma-2 surfaces from the CTD data.

2003 at around 1500 m consistent with Labrador Sea Water as identified in the 2012 occupation [Woosley2016].

The outflow from the Amazon River can clearly be seen as a thin plume of freshwater in the upper ~10 m at the southernmost portion of the section. In 2012 the plume extended unusually far north (to about 11º N). In this occupation the plume was clearly marked by a drop in surface salinity to < 30 at ~ 7.8º N. Although the plume did not extend as far north, it was slightly fresher this occupation compared to 2012.
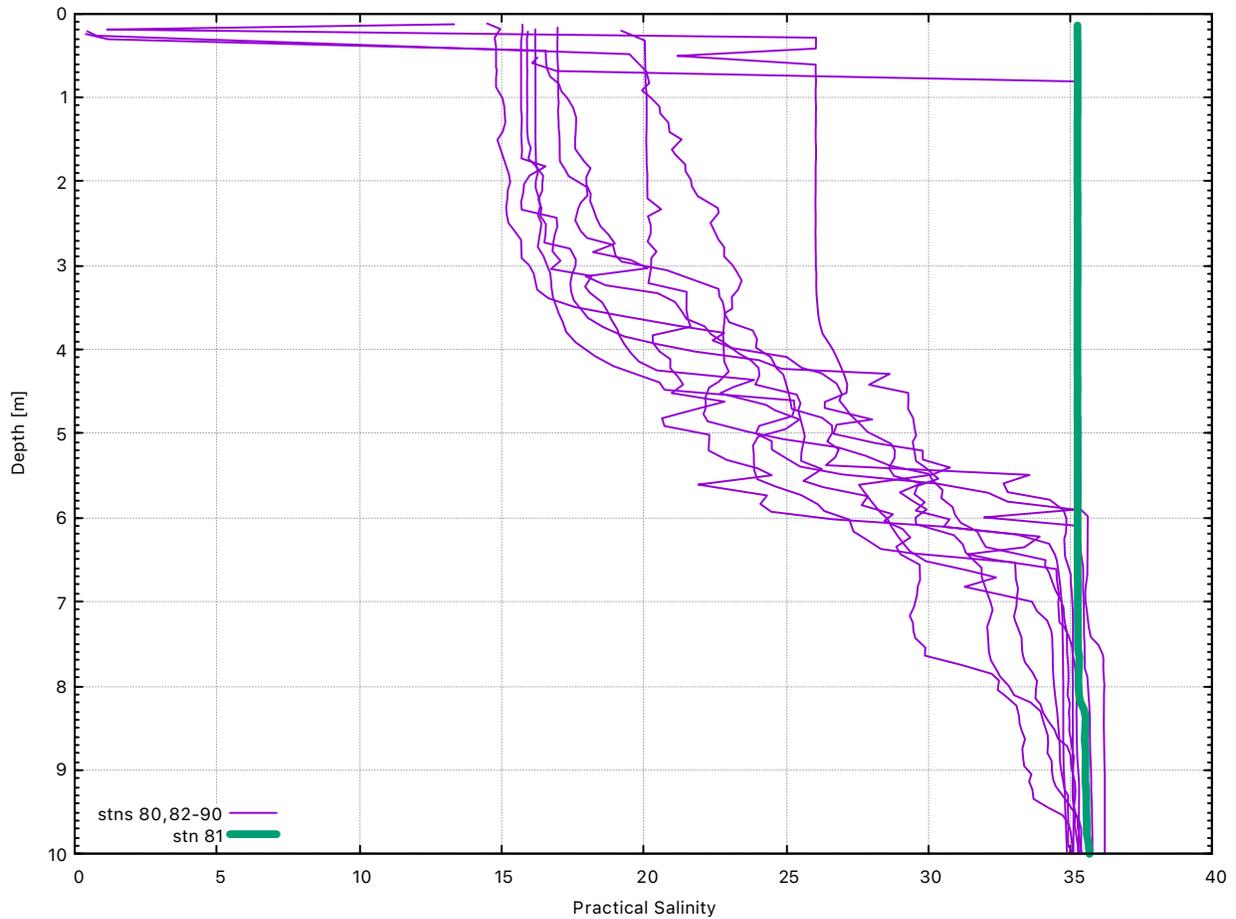
Fig. 6: CTD-derived salinity profiles close to the sea surface at the end of the upcasts, derived from specially processed 24-Hz data.

THREE

CTD AND ROSETTE SETUP

For A20-2021 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 fifth 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 A20-2021 weighs roughly 1500 lbs in air without water, and 2350 lbs in air with water. The package used on A20-2021 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/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 and LADCP 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. The 150 KHz bi-directional Broadband LADCP (RDI) unit was mounted vertically on the bottom side of the frame. The 150 Khz LADCP was later replaced with a 300 Khz LADCP during the cruise in the same position. The 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, and the CTD mounted south.

Equipment	Model	S/N	Cal Date	Stations	Group
Rosette	36-place	Yellow	–	901-90	*STS/ODF*
CTD	SBE9+	0914	–	901-90	*STS/ODF*
Pressure Sensor	Digiquartz	110547	Feb 5, 2021	901-90	*STS/ODF*
Primary Temperature	SBE3+	32309	Feb 2, 2021	901-90	*STS/ODF*
Primary Conductivity	SBE4C	43399	Nov 25, 2020	901-90	*STS/ODF*
Primary Pump	SBE5	51871	–	901-90	*UCSD*
Secondary Temperature	SBE3+	32380	Feb 2, 2021	901-90	*STS/ODF*
Secondary Conductivity	SBE4C	41880	Dec 4, 2020	901-90	*STS/ODF*
Secondary Pump	SBE5	58690	–	901-90	*UCSD*
Transmissometer	Cstar	1803DR	Aug 9, 2019	901-90	*TAMU*
Fluorometer Chlorophyll	WetLabs ECO-FL-RTD	1156	–	901-90	*STS/ODF*
Primary Dissolved Oxygen	SBE43	431138	Dec 5, 2020	901	*ODF*
Primary Dissolved Oxygen	SBE43	430275	Nov 14, 2020	1-14	*ODF*
Primary Dissolved Oxygen	SBE43	430255	Nov 13, 2020	15-90	*ODF*
Oxygen Optode	JFE Advantech RINKO-III	0297	April 7, 2017	901-35, 41-46	*ODF*
Oxygen Optode	JFE Advantech RINKO-III	0296	April 7, 2017	36-90	*ODF*
Reference Temperature	SBE35	0105	Feb 9, 2021	901-90	*STS/ODF*
Carousel	SBE32	1178	–	901-14	*STS/ODF*
Carousel	SBE32	0187	–	15-90	*STS/ODF*
Altimeter	Valeport 500	59116	–	901-15	*UCSD*
Altimeter	Valeport 500	53821	–	16-36, 39-90	*UCSD*
Altimeter	Valeport 500	67356	–	37	*UW*
Altimeter	Valeport 500	67355	–	38	*UW*
DL *LADCP*	Teledyne RDI WH150	19394	–	1-17, 35-40	*LDEO*
DL *LADCP*	Teledyne RDI WH300	24497	–	18-31, 40-90	*LDEO*
DL *LADCP*	Nortek Signature100	–	–	901, 32-34	*LDEO*
UL *LADCP*	Teledyne RDI WH300	12734	–	901-90	*LDEO*
D2 CTD	D2 CTD	02-1564	–	901-36	*WHOI*
D2 CTD	D2 CTD	02-1563	–	37-90	*WHOI*
Chipods	Chipod	2018 Ti44-2	–	901-90	*OSU*
Chipods	Chipod	2024 Ti44-7	–	901-90	*OSU*
Chipods	Chipod	2032 Ti44-15	–	901-90	*OSU*

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 terminated at the beginning of A20-2021, electrical retermination after station 9, and full retermination after station 23.

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 acquistion, and the cast would begin. Recovering the package at the end of the deployment was the reverse of launching. Once rolled back into the sampling bay, 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 looking into the rosette from the 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.
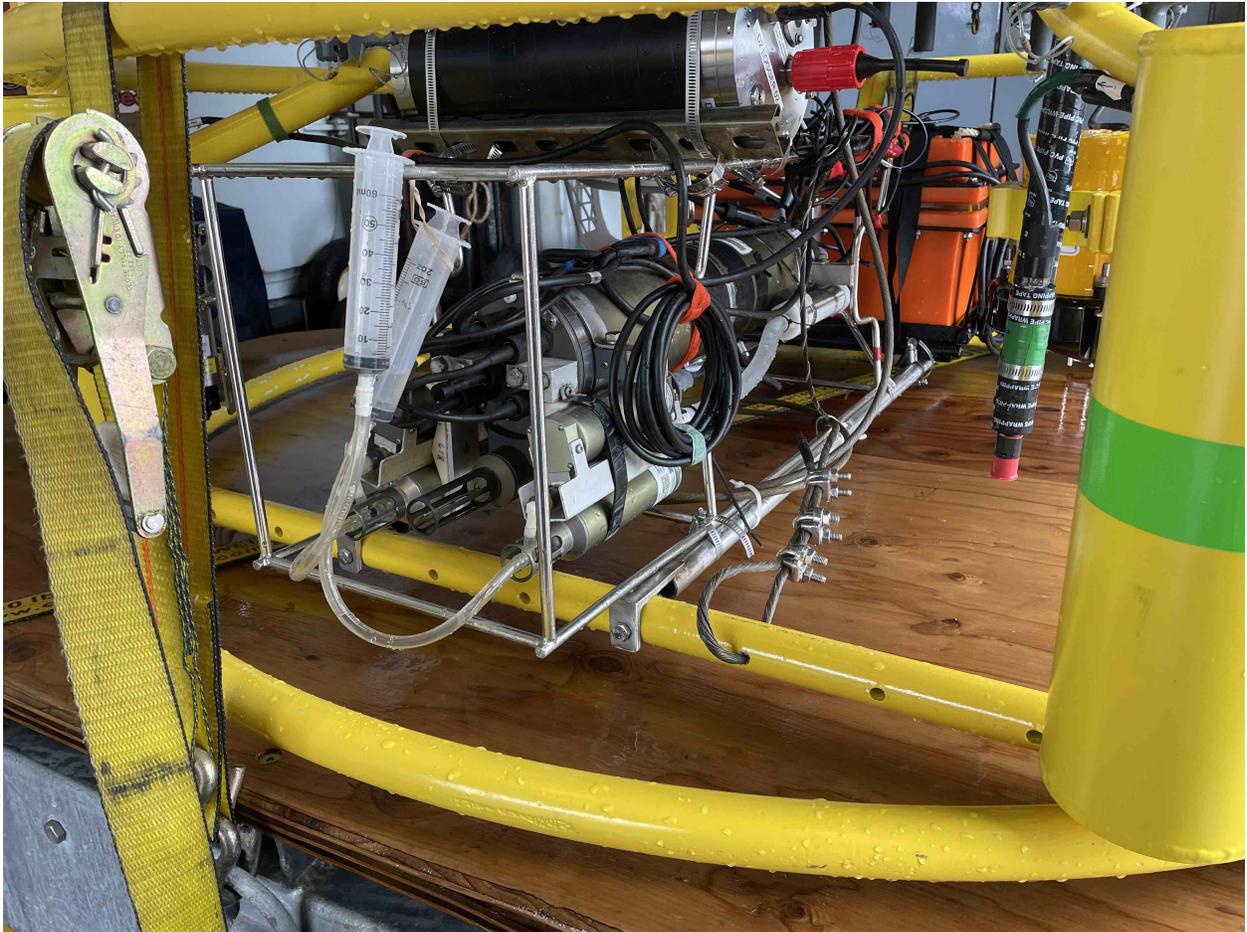
Fig. 5: Package setup from southwest, with CTD in foreground and downlooking chipod to the right.
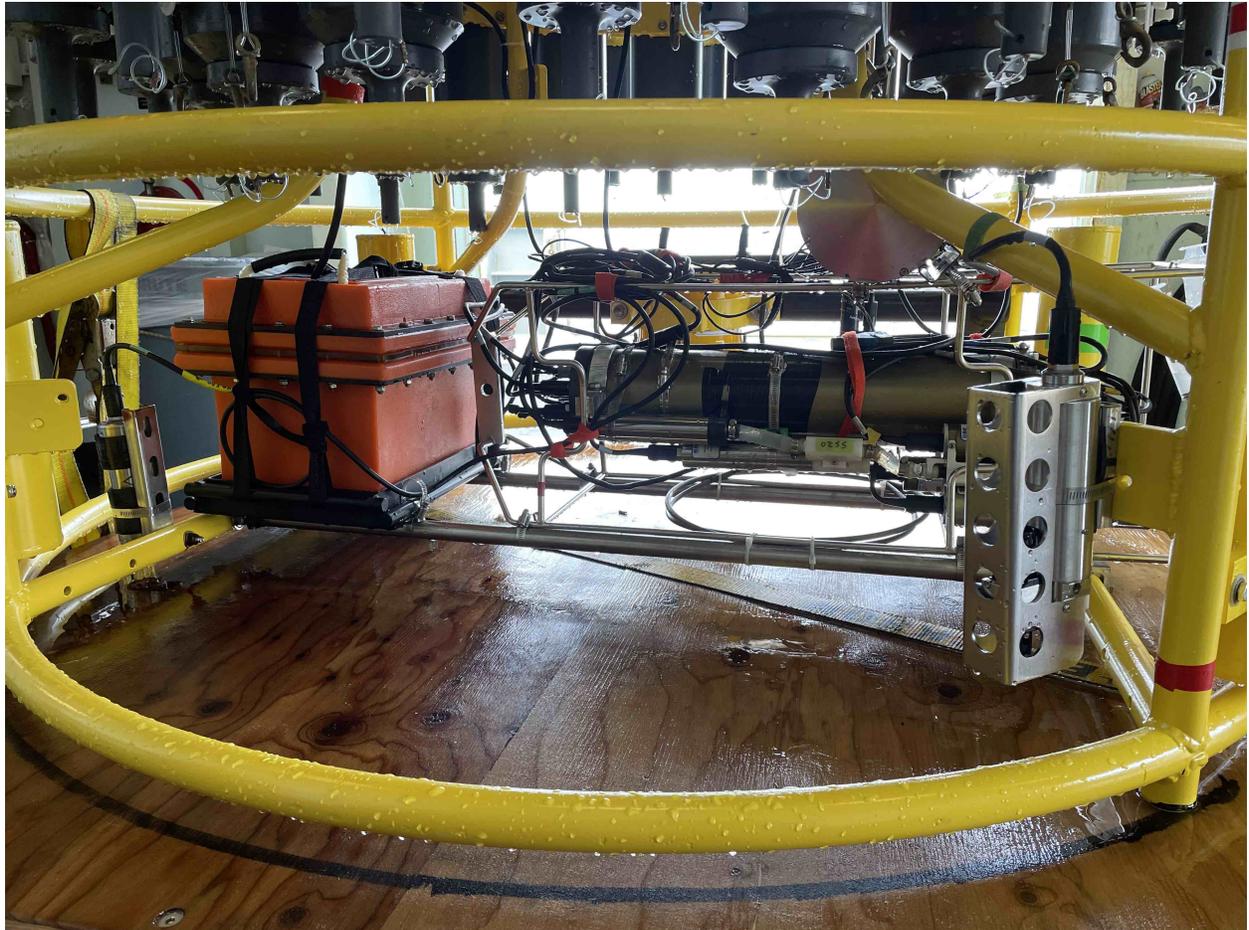
Fig. 6: Packaget setup from west
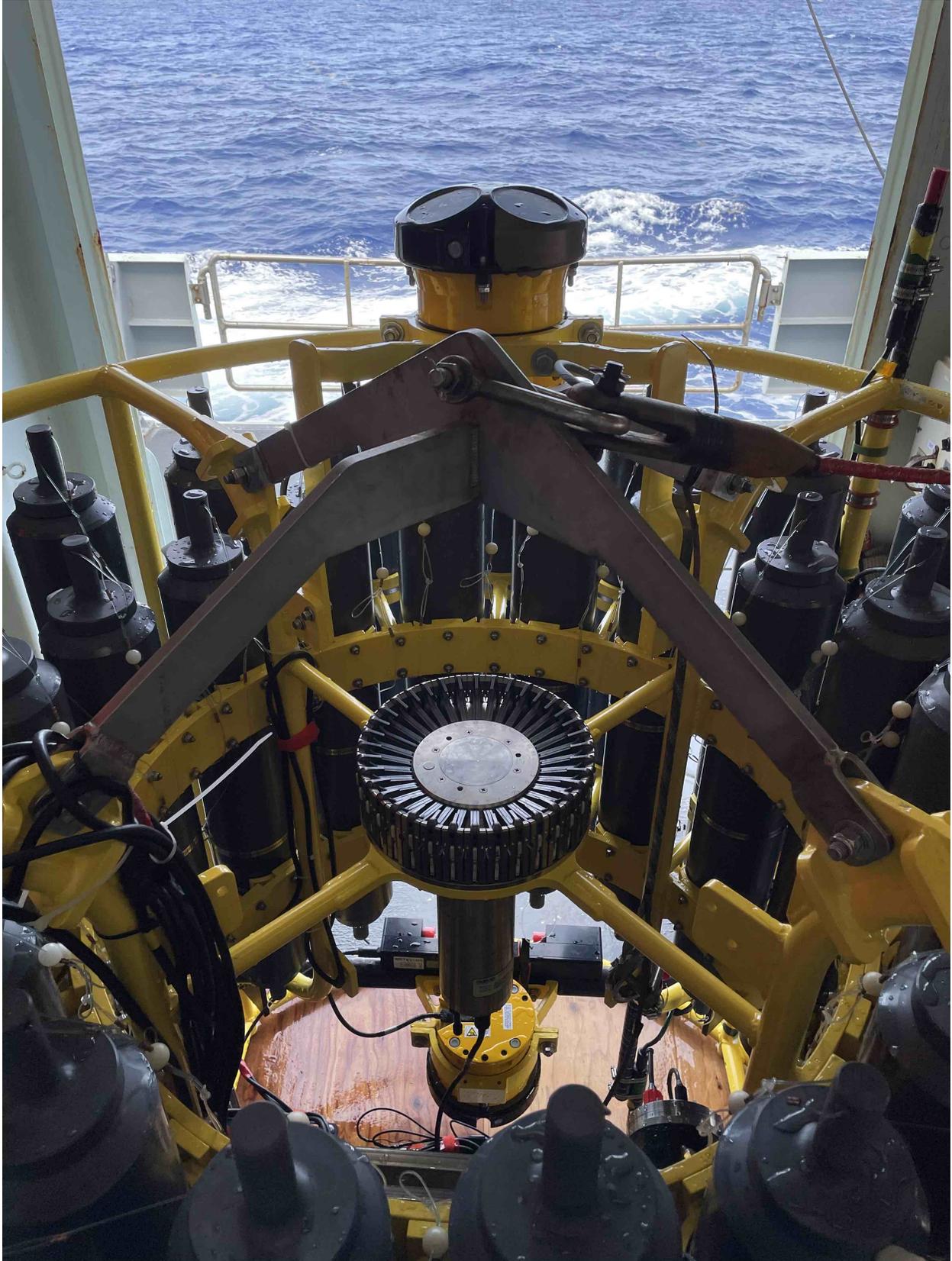
Fig. 7: Package setup from west, top view.

3.3 Maintenance and Calibrations

During A20-2021 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 took all but the first day allocated in port, which was used for unloading the container and setting up the labs. 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.

March 17, 2021

90101 – Test cast down to 1500 m in 2020 m water depth. SBE43 oxygen had noticeable near-surface spiking during both up and downcast. The sensor is suspected to have frozen and was replaced. Variable transmissometer data were observed at depth but were simply due to loose electrical tape flapping in front of the beam path.

March 21, 2021

No problems noted for stations 00101-00801.

March 22, 2021

00801 – No problems noted.

00901 – During upcast, bottle 31 did not receive firing confirmation. Attempted to manually fire from deck box but still did not receive any confirmation. Upcast continued as normal, stopping and "firing" bottles at target depths, but rosette was recovered with bottles 31-36 still open. Modulo errors started occuring after firing bottle 30, with 17 total errors at depth and 2 additional during recovery. The issue was found to be the electrical termination, which was done using butt connectors with low-temperature solder. The ground wire had a solid connection but the communcation wire connection separated after applying tension. Communcation wire was re-connected using regular solder.

01001 – Oxygen spike at ~2400 m.

March 23, 2021

01101 – SBE43 had normal behavior during downcast but erratic readings started in the upper 25 m during upcast.

01201 – SBE43 data were spiky during soak, even after pumps were activated. Spikiness continued while brought up to the surface before normalizing during the downcast. No more spikes occurred until 15 m from surface during upcast.

01301 – Similar to previous cast, spikiness was noted during soak and down to 70 m. Downcast data were fine but two large spikes occurred at ~1950 and ~160 m during upcast, with spikiness again occurring near-surface. All connections between 9+ and 43 were inspected and looked okay (no spikes occurred in altimeter, which shared a Y-cable with the SBE43). Straight cable from Y to SBE43 was replaced after cast. Bottle 12 did not close, bottle 36 fired on the fly.

01401 – SBE43 still spiky at surface and down to 80 m but "fuzziness" of signal at depth seems improved with new cable. Sensor 43-0275 was replaced with 43-0255, with the suspected issue being frozen sensor membrane. Bottle 12 did not close again. Carousel changed out, solenoid 12 was swollen.

01501 – New SBE43 data were significantly improved. Altimeter reading during bottom approach was "stuck" at 20 m for longer than reasonable, replaced S/N 59116 with 53821 after cast.

March 24, 2021

01601 – SBE43 oxygen "fuzziness" at depth has returned. New altimeter appears to be functioning properly.

01701 – Botle 36 fired on the fly.

01801 – Multibeam depth estimate and altimeter not in agreement, CTD got within 3 m of bottom. Multibeam software was updated with new soundspeed profile, continue to regulary update after subsequent casts. Heave compensation used after 400 m.

01901 – Bottle 28 closed itself on deck before deployment.

March 25, 2021

02001 – Strong Gulf Stream currents (2 m/s at surface), large wire angle and far drift expected.

02101 – No problems noted.

March 26, 2021

02201 – No problems noted.

02301 – During recovery, new AB was training on winch and mistakenly pulled wire in too fast and the Evergrip mechanical termination was pulled into the block and became stuck (two-blocked). Ship crew used a chain-fall and were able to safely pull the stuck termination from block. Log of tension data recorded a maximum of 11,000 lbs, above the nominal 10,000 lb breaking strength of the sea cable. 50 m of cable was removed and re-termination was done during transit to next station.

02401 – No problems noted.

March 27, 2021

02501 – No problems noted.

02601 – SeaSave failed to connect to water sampler, likely started software too soon after turning on deck box.

02701 – No problems noted.

02801 – No problems noted.

March 28, 2021

02901 – During deployment, tagline became tangled on rosette and CTD. Line was cut as rosette was mostly in the water. Recovered with tagline still badly tangled. Chipod S/N 2024 sensor tip poking out of its pressure case, both o-rings were exposed, and the interior was full of water. Entire sensor and housing were replaced prior to next cast.

03001 – No problems noted.

03101 – No problems noted.

March 29, 2021

03201 – No problems noted.

03301 – Erratic altimeter readings near bottom.

03401 – Erratic altimeter readings near bottom.

March 30, 2021

03501 – Erratic altimeter readings near bottom.

03601 – Rinko S/N 0297 was replaced with 0296 due to intermittent spiking during casts. Upon recovery, D2 S/N 1564 spit out oil, replaced with 1563 using same logger. Altimeter still erratic, replaced Valeport 500 S/N 53821 with TGT's 67356.

03701 – Altimeter S/N 67356 failed (was already bad?), replaced with TGT's 67355 which deck tested okay.

03801 – Altimeter was very noisy during bottom approach and then became completely unreliable, reading 99.9 m despite being near bottom. Cast was ended higher than normal to be safe, ~20 m. Swapped back to ODF altimeter S/N 53821. Bottle 2 closed at wrong depth, unclear if early or late.

April 1, 2021

04101 – Attached second Rinko (S/N 0297) in spare voltage channel, mounted behind the replacement (S/N 0296) to compare data signals. 0297 data are much more spiky than 0296, with voltages completely deviating on the upcast. End cap on 0297 may not have been removed prior to cast. Altimeter was spiky at bottom but reliable enough to get to 10 m from bottom.

04201 – Downlooking LADCP switched from 150 kHz to 300 kHz. Multibeam continuing to be unreliable, CTD was 40 m from bottom before watchstanders noticed. Proceeded to ~10 m from bottom, altimeter working much better. Suspected there was interference with 150 kHz possibly (though this has not been observed before by LADCP PI). Plumbing on secondary T/C line was loose after cast, replaced with spare/backup tubing.

04301 – Console "glitched" while attempting to fire bottle 30. Firing confirmation was not received and interface reset next bottle to be fired back to bottle 1. Students fired 1-6, assuming it was 31-36, at the appropriate depths, but upon recovery bottles 31-36 were open/unfired. Both the .bl file and reference thermometer have data recorded for 31-36. No recording for 30 despite bottle being closed upon recovery. SeaSave bottle firing settings updated to allow changing next bottle, instead of purely sequential.

April 2, 2021

04401 – No problems noted.

04501 – Bottle 2 likely closed at wrong depth, unclear if early or late. O_2 analyst recorded temperatures for bottles 1-3 as 8.0, 15.5, and 8.3 ºC.

04601 – No problems noted.

April 3, 2021

04701 – No problems noted.

04801 – Bottle 2 likely closed at wrong depth, unclear if early or late. O_2 analyst recorded temperatures for bottles 1-3 as 8.3, 14.6, and 9.0 ºC.

04901 – No problems noted.

05001 – No problems noted.

April 4, 2021

No problems noted for stations 05101–05301.

April 5, 2021

05401 – No problems noted.

05501 – Bottle 2 possibly closed at wrong depth, unclear if early or late. O_2 analyst recorded temperatures for bottles 1-3 as 7.6, 8.0, and 7.8 ºC. Replaced the entire latch mechanism on the water sampler.

05601 – Bottle 10 did not close. During upcast NMEA time froze for several seconds, ended up being ship problem of interference with Iridium antenna (not a CTD problem).

05701 – No problems noted.

April 6, 2021

No problems noted for stations 05801–06101.

April 7, 2021

No problems noted for stations 06201–06501.

April 8, 2021

06601 – No problems noted.

06701 – Fired bottles 1, 4, 3, 2, then normal (to avoid continually losing near-bottom depth, i.e., bottle 2).

06801 – Fired bottles 1, 4, 3, 2, then normal (to avoid continually losing near-bottom depth, i.e., bottle 2).

April 9, 2021

06901 – Bottle 10 didn't close, one chipod missing cap upon recovery.

07001 – No problems noted.

07101 – No problems noted.

April 10, 2021

07201 – Bottle 25 mistrip, temperatures for 24-26 were 14.5, 20.0, 15.8 ℃.

07301 – Bottle 2 mistrip again, temperatures 7.3, 23.2, and 8.0 ℃.

07401 – Fired bottles 1, 4, 3, 2, then normal (to avoid continually losing near-bottom depth, i.e., bottle 2).

07501 – Fired bottles 1, 4, 3, 2, then normal (to avoid continually losing near-bottom depth, i.e., bottle 2).

07601 – Getting bad SBE35RT readings in high gradient regions (16 ℃ change over ~200 m). Waiting for 1 minute prior to firing when possible.

April 11, 2021

07701 – Fired bottles 1, 4, 3, 2, then normal (to avoid continually losing near-bottom depth, i.e., bottle 2).

07801 – Fired bottles 1, 4, 3, 2, then normal (to avoid continually losing near-bottom depth, i.e., bottle 2).

07901 – Fired bottles 1, 4, 3, 2, then normal (to avoid continually losing near-bottom depth, i.e., bottle 2).

08001 – Fired bottles 2 and 3 at same depth for the remaining casts to test for misfires (casts no longer deep enough to have 36 unique bottles).

08101 – No problems noted.

April 12, 2021

08201 – Primary T/C line had large spike on downcast, likely biofouling in plumbing which eventually flushed out. Using secondary line for this cast.

08301 – No problems noted.

08401 – No problems noted.

08501 – No problems noted.

08601 – Strong surface currents, drifting slightly.

08701 – Strong surface currents, drifting slightly.

08801 – Strong surface currents, drifting slightly.

08901 – Bottle 8 misfired/dry fired in air after recovery.

09001 – No problems noted.

3.5 Sensor Problems

Oxygen sensor spikiness: The SBE 43 oxygen sensor showed erratic spikiness that disappeared after the cast was below ~50-100 m, but returned in the same depth range on the upcast. The suspicion is that some/all of the sensors froze, either during transit or while sitting in port, partially damaging but not completely ruining the internal membrane. Under sufficient pressure, the issue "fixed" itself for the duration of the cast. After swapping to the second spare, the issue was resolved. Rinko optode data were also used as primary for station 36 onward.

Altimeter spikiness: Four separate altimeters were used over the course of the cruise, two belonging to ODF and two belonging to TGT. The first ODF one flooded, the second was noisy. After trying the two owned by TGT, which were more noisy than the ODF spare, we swapped back. All altimeters were reporting spiky data, occasionally to the point of being unusable during the bottom approach (e.g. Fig 8, station 38). Additionally, multibeam depth estimates were inaccurate which caused further difficulty.

The multibeam issue was resolved by updating the sound speed profiles periodically to have a more reliable depth estimate. The altimeter issue was resolved after multiple changes to the rosette, including swapping downlooking ADCPs (from 150 KHz to 300 KHz) and adding additional rubber to increase the distance between the sensor and the unistrut mount. One suspicion was that the 150 KHz ADCP was interfering with the signal. It is also possible that the altimeter was not acoustically decoupled from the frame and was ringing with the ADCP frequency output. The downlooking ADCP was swapped multiple times (see ADCP section) during this time period so it is difficult to isolate exactly which solution was most important.
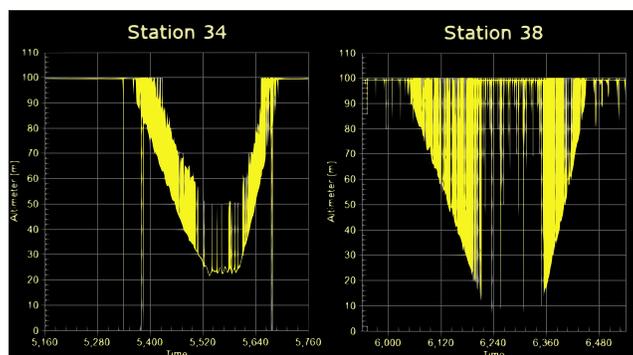
Fig. 8: Altimeter readings during bottom approach on stations 34 and 38.

Bottle mistrips: Throughout the cruise, guide rings had to regularly be raised up to ensure the bottle ends caps were could not close themselves before being fired. Water sampler latches failed to release multiple times, with bottles coming to the surface still latched open despite being "fired." Entire water sampler/carousel was replaced after station 14 due to a swollen solenoid inhibiting bottle firing.

FOUR

CTDO AND HYDROGRAPHIC ANALYSIS

PIs

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4.1 CTDO and Bottle Data Acquisition

The CTD data acquisition system consisted of an SBE-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 6 0m/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/chipod casts were completed.

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

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

A number of issues were encountered during A20-2021 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 Sensor Problems

Throughout the cruise, there were problems with multiple SBE43 oxygen sensors. The suspicion is that the sensor membranes were frozen either during transit or while in port. Erratic readings were observed in the upper ~100 m which then disappeared as the cast went deeper. Station 14 is shown as an example.

4.4 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:
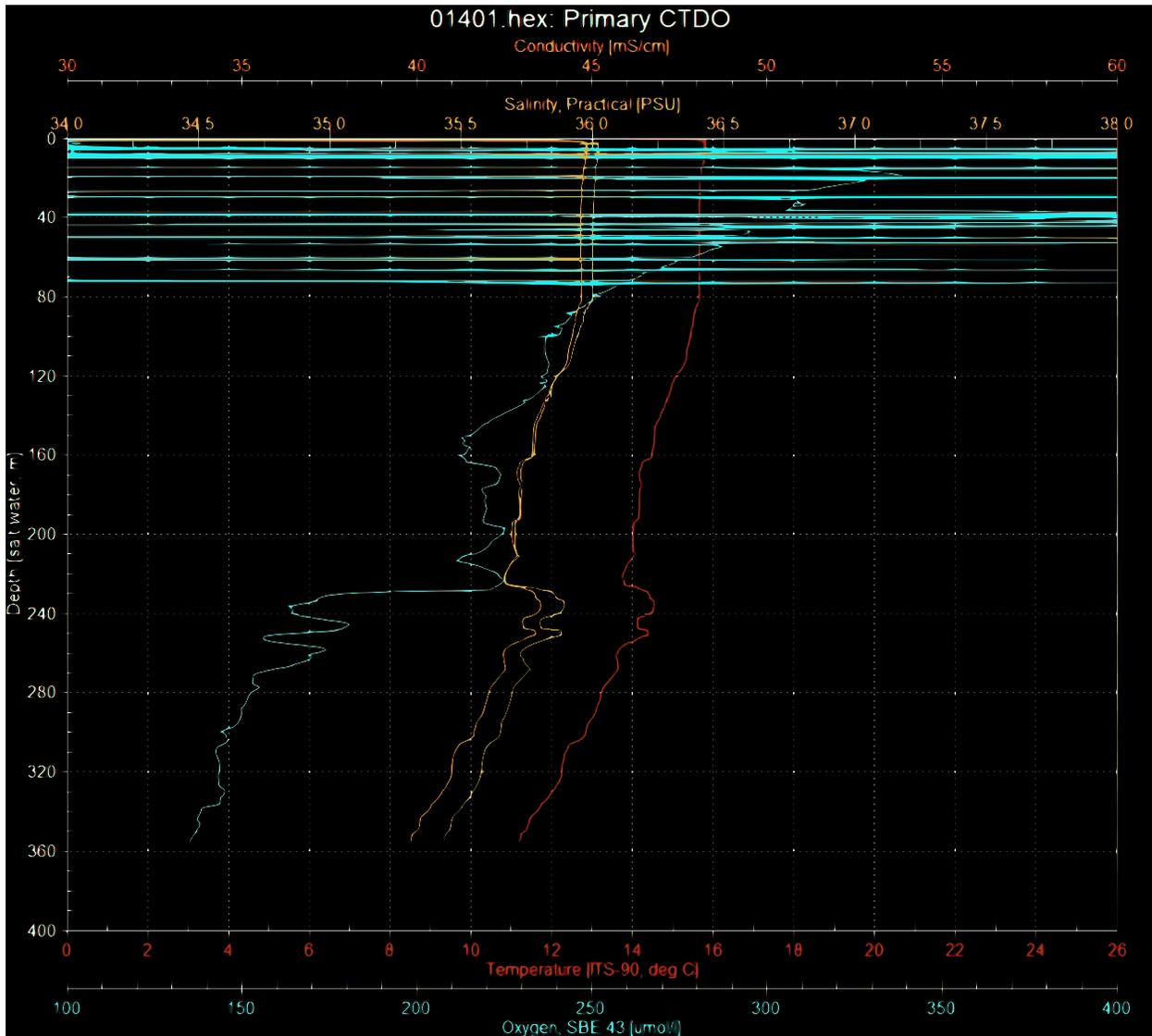
Fig. 1: Spiky oxygen in upper 80 m during downcast of station 14.

	Start P (dbar)	End P (dbar)
Min	-0.09	-0.24
Max	0.53	0.35
Average	0.15	0.02

On-deck pressure reading varied from -0.09 to 0.53 dbar before the casts, and -0.24 to 0.35 dbar after the casts. The pressure offset varied from -0.25 to 0.02, with a mean value of -0.13 dbar.

4.5 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:

$$T_{cor} = T + cp_2 P^2 + cp_1 P + ct_2 T^2 + ct_1 T + c_0$$

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
901-8	0.0	-1.5802e-7	0.0	0.0	-1.4125e-3
9-19	0.0	-2.0278e-7	0.0	0.0	-1.0778e-3
20-90	0.0	-3.5676e-7	0.0	0.0	8.3290e-5

Table 2: Secondary temperature (T2) coefficients.

Station	cp_2	cp_1	ct_2	ct_1	c_0
901-8	0.0	-3.4637e-7	0.0	0.0	-7.6459e-4
9-19	0.0	-1.4643e-7	0.0	0.0	-7.5597e-4
20-90	-5.0915e-11	1.4995e-7	0.0	0.0	-8.5699e-4

Corrected temperature differences are shown in the following figures.

The 95% confidence limits for the mean low-gradient (values -0.002°C $\leq$ T1-T2 $\leq$ 0.002°C) differences are $\pm$0.00456°C for SBE35RT-T1, $\pm$0.00452°C for SBE35RT-T2 and $\pm$0.00153°C for T1-T2. The 95% confidence limits for the deep temperature residuals (where pressure $\geq$ 2000dbar) are $\pm$0.00107°C for SBE35RT-T1, $\pm$0.00119°C for SBE35RT-T2 and $\pm$0.00098°C for T1-T2.

Minor complications impacted the temperature sensor data used for the A20-2021 cruise.
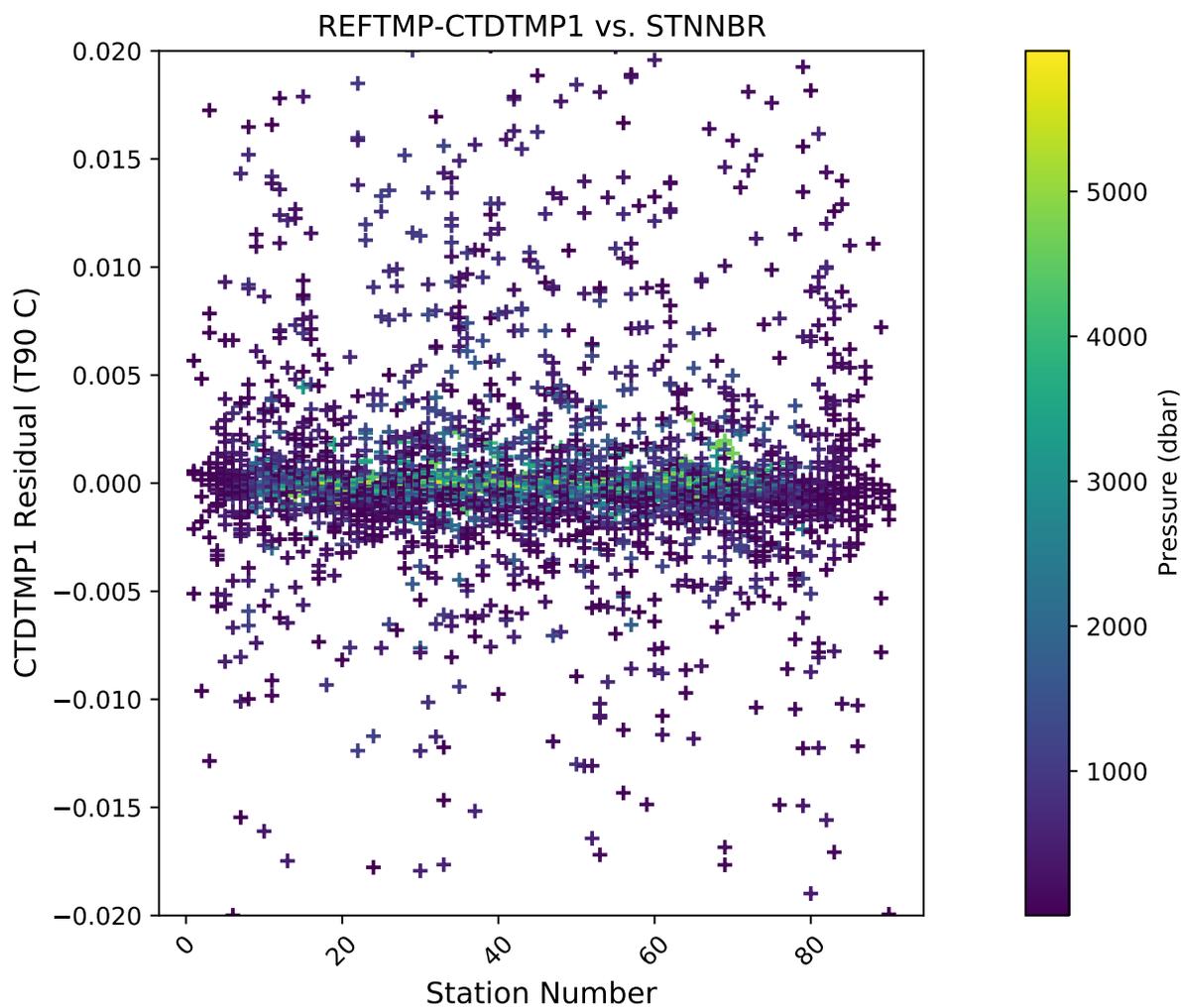
Fig. 2: SBE35RT-T1 versus station.
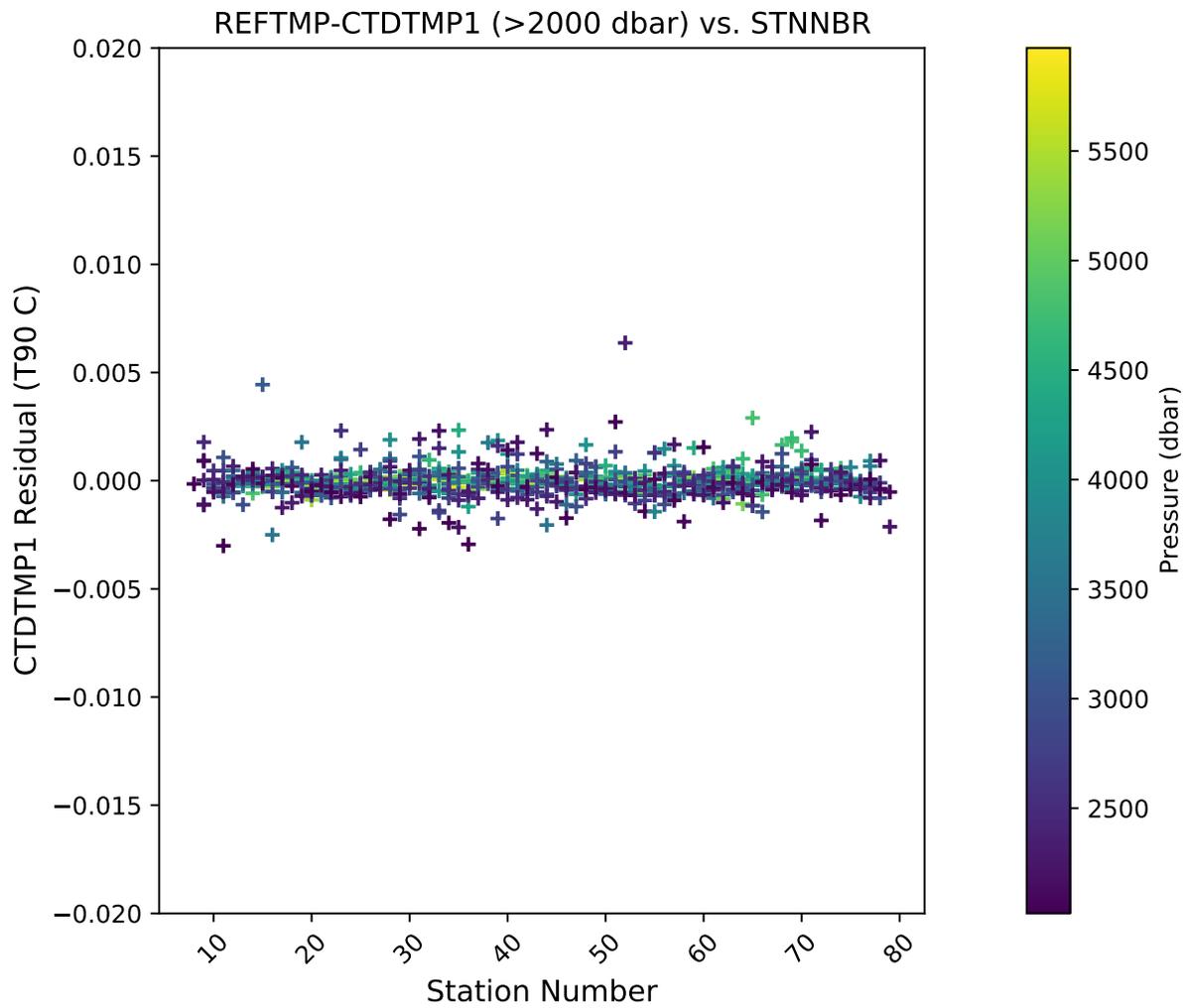
Fig. 3: Deep SBE35RT-T1 by station (Pressure $\geq$ 2000dbar).
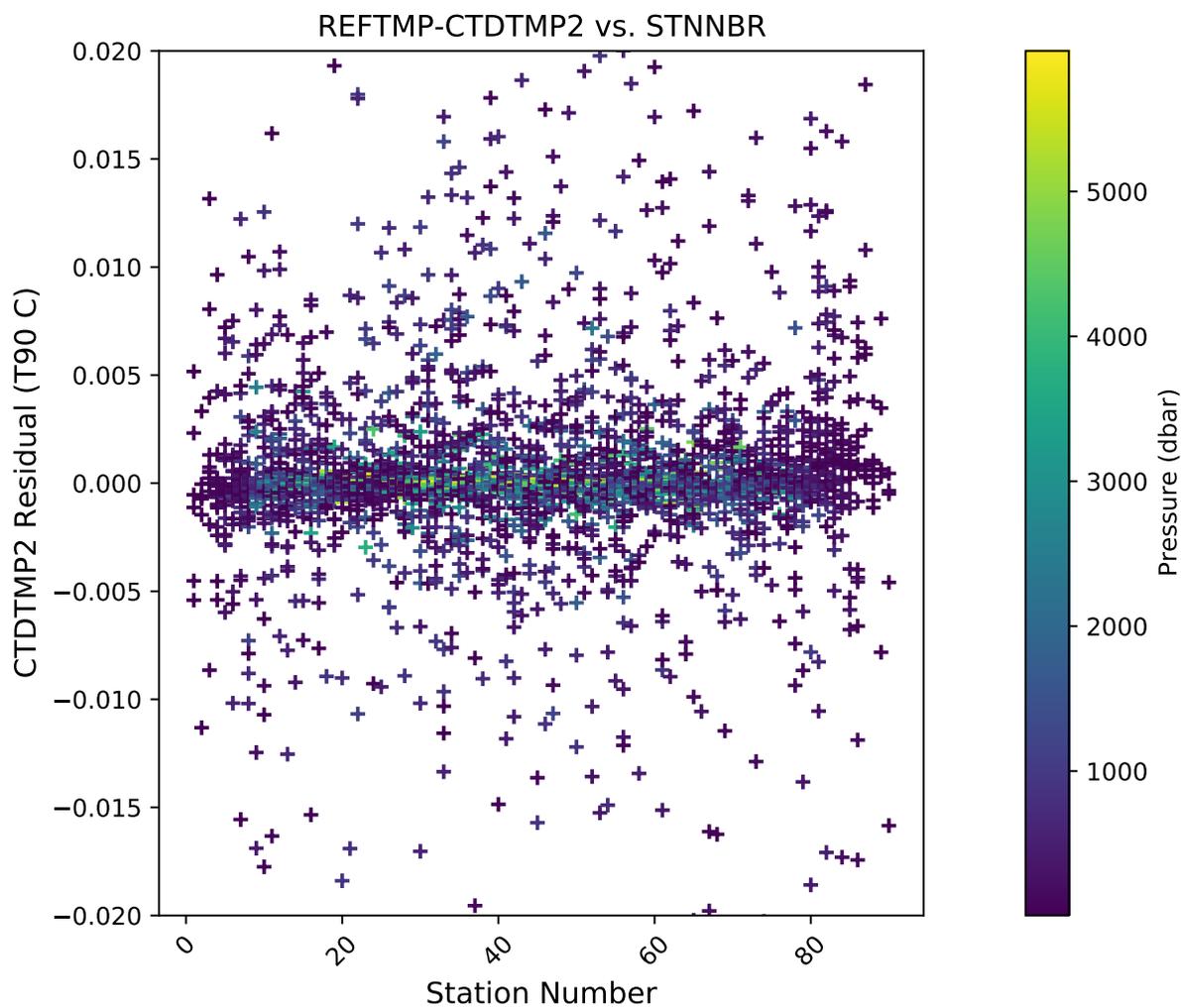
Fig. 4: SBE35RT-T2 versus station.
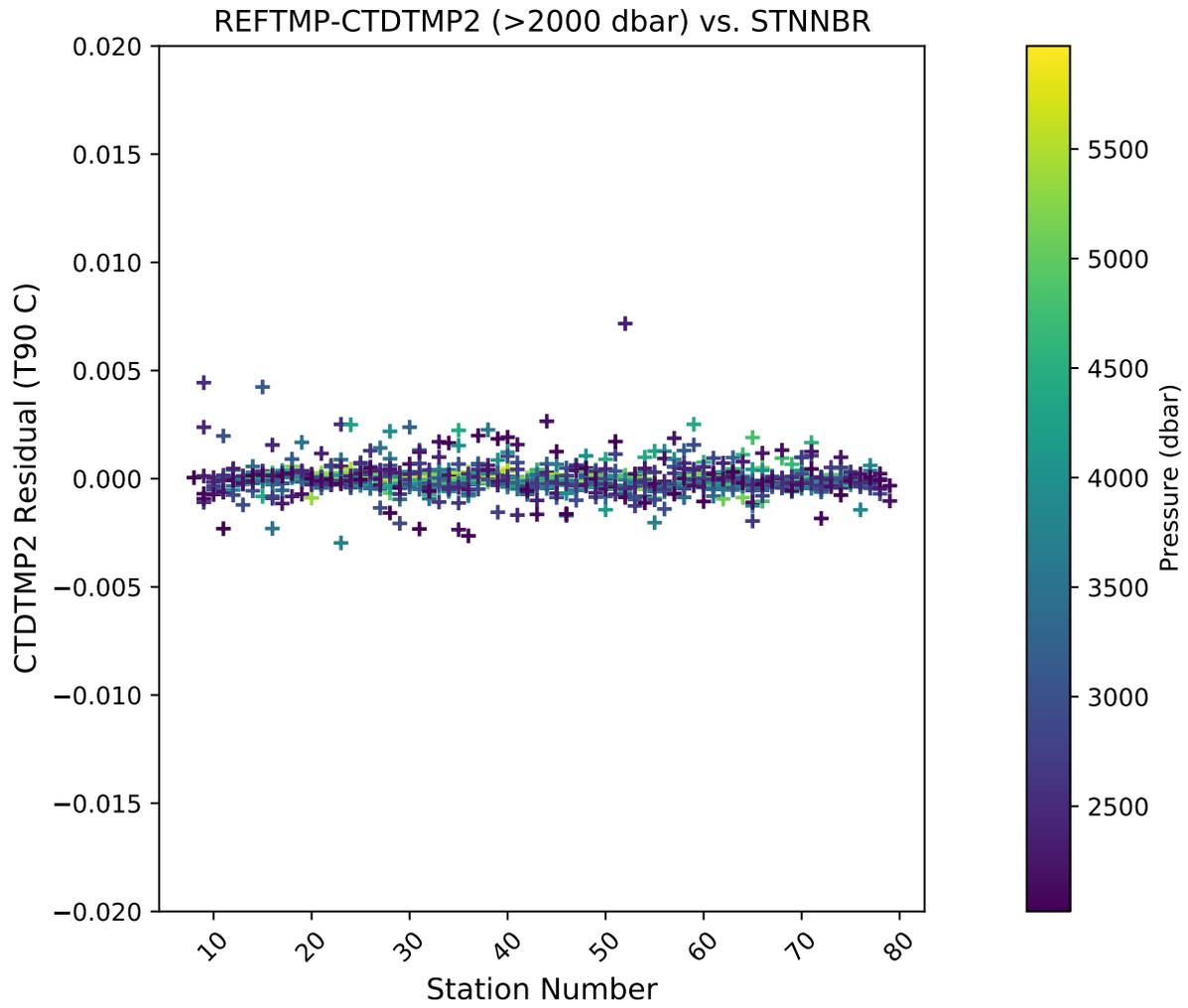
Fig. 5: Deep SBE35RT-T2 by station (Pressure $\geq$ 2000dbar).
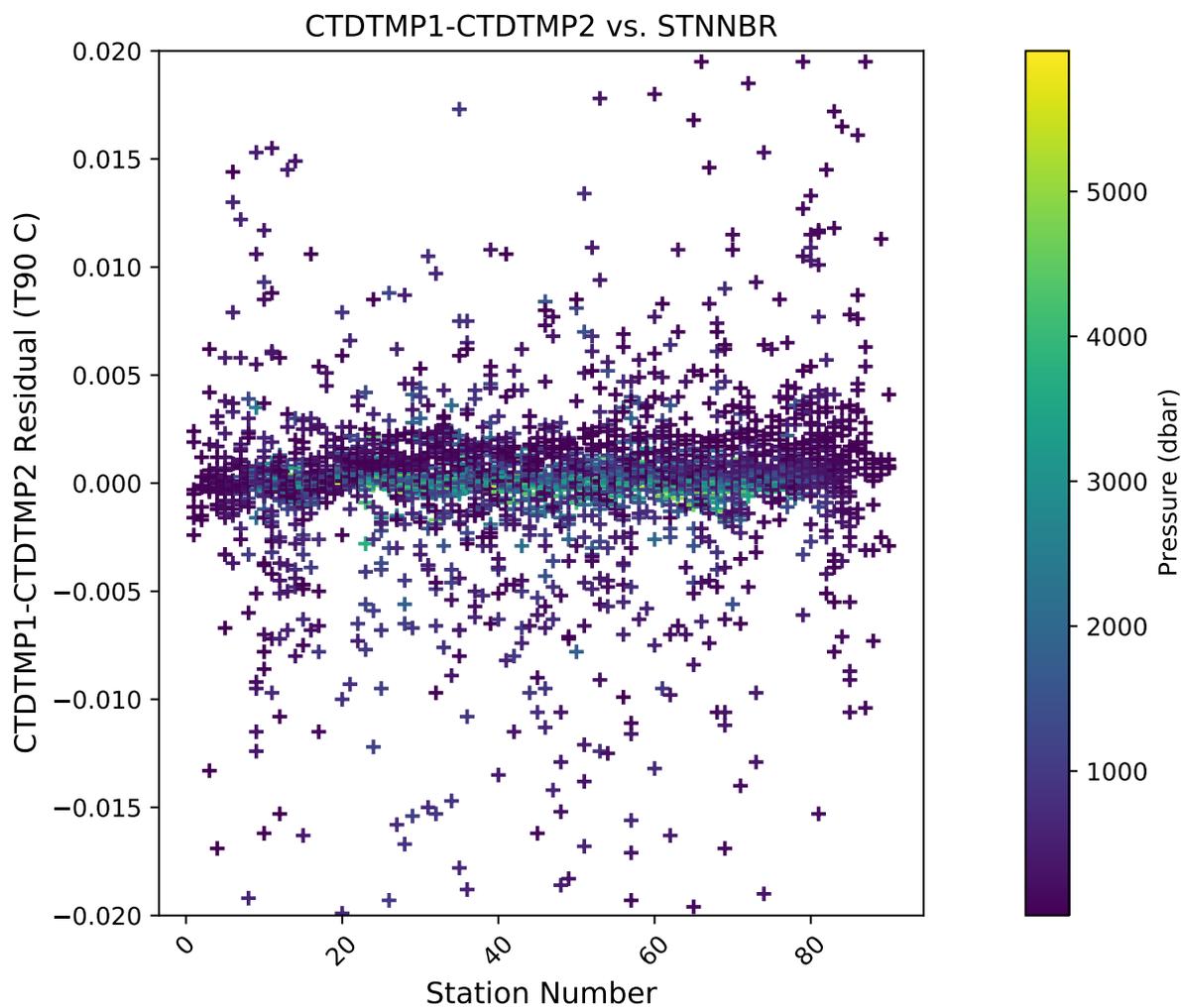
Fig. 6: T1-T2 versus station.
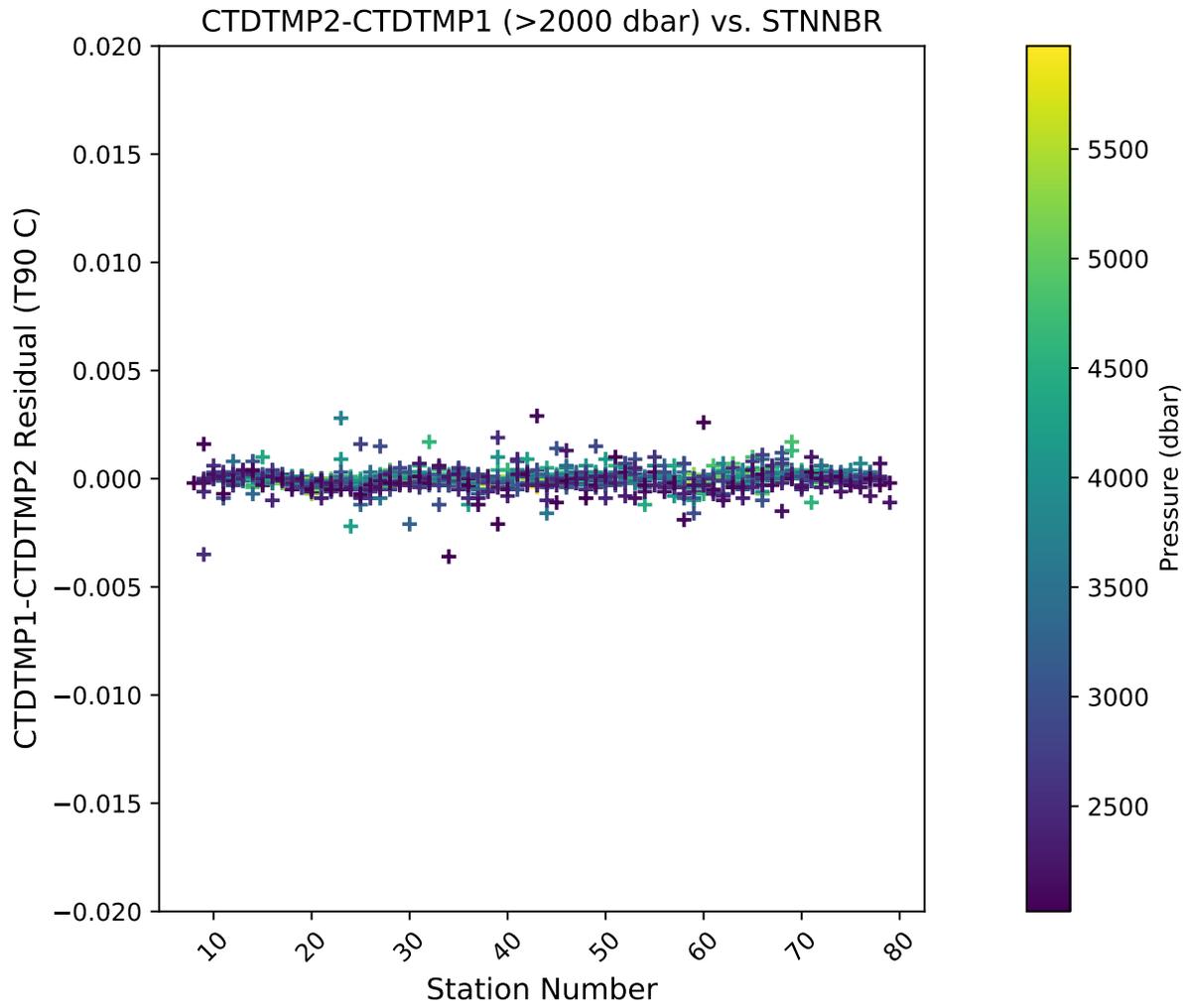
Fig. 7: Deep T1-T2 versus station (Pressure $\geq$ 2000dbar).
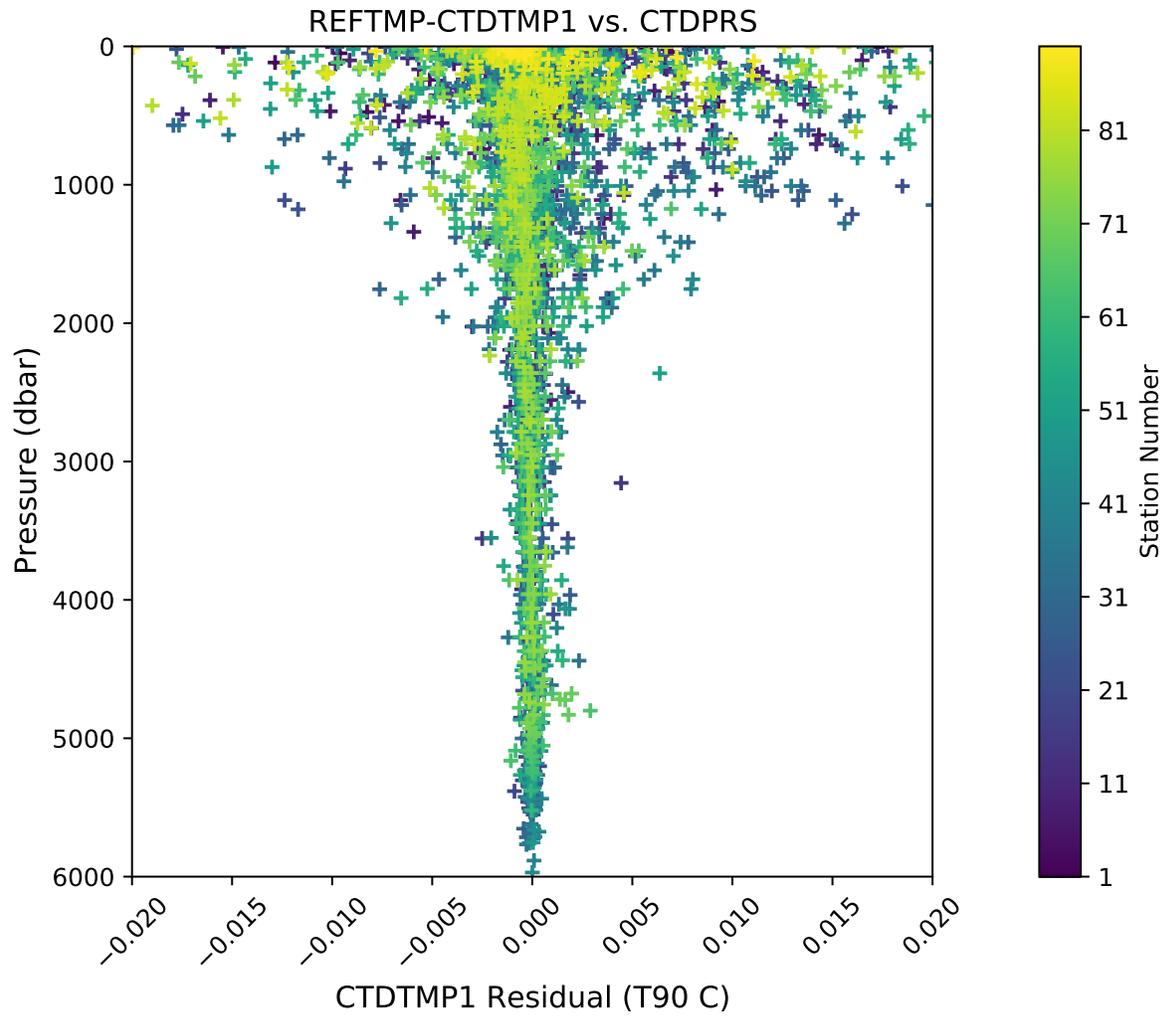
Fig. 8: SBE35RT-T1 versus pressure.
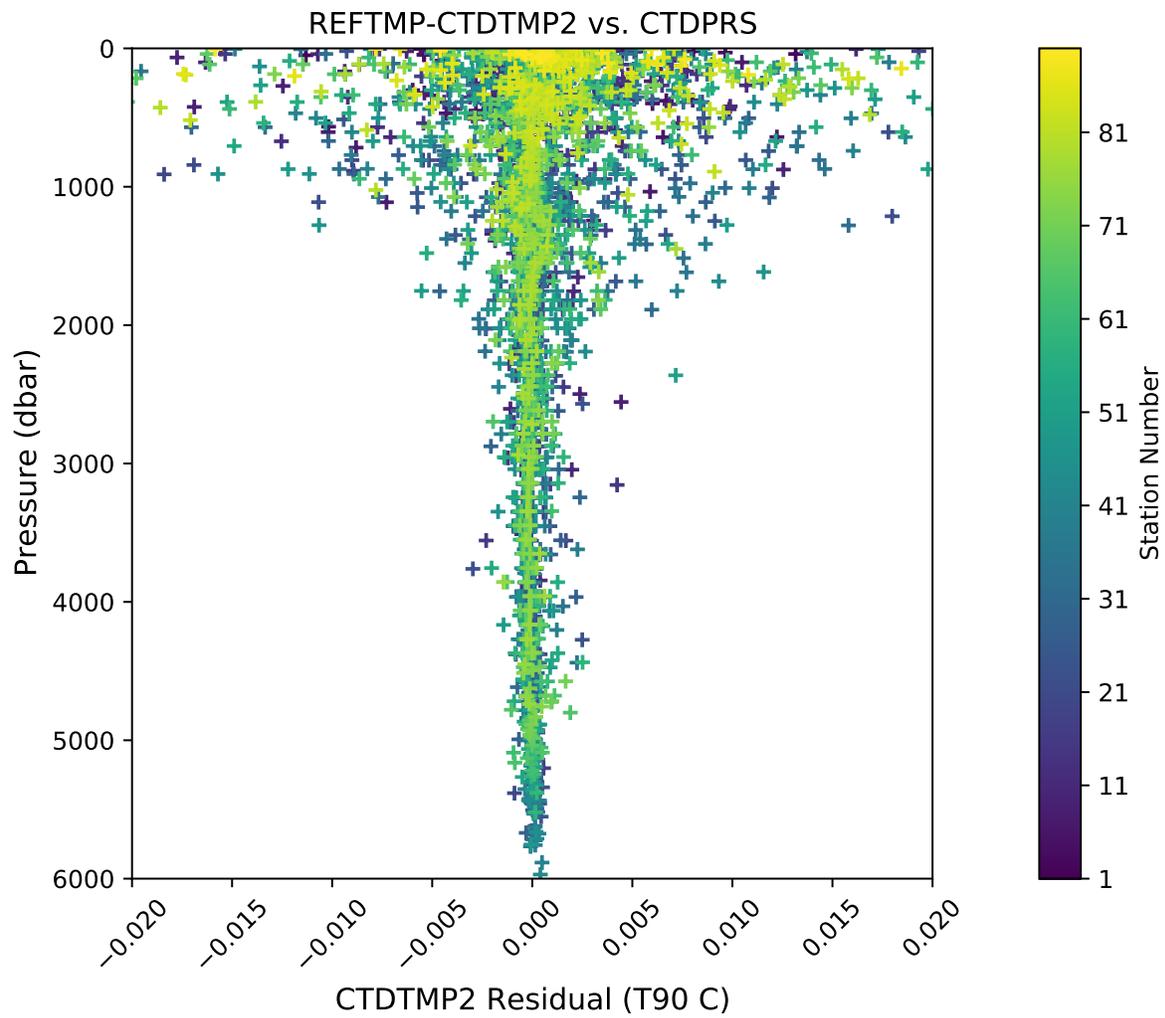
Fig. 9: SBE35RT-T2 versus pressure.
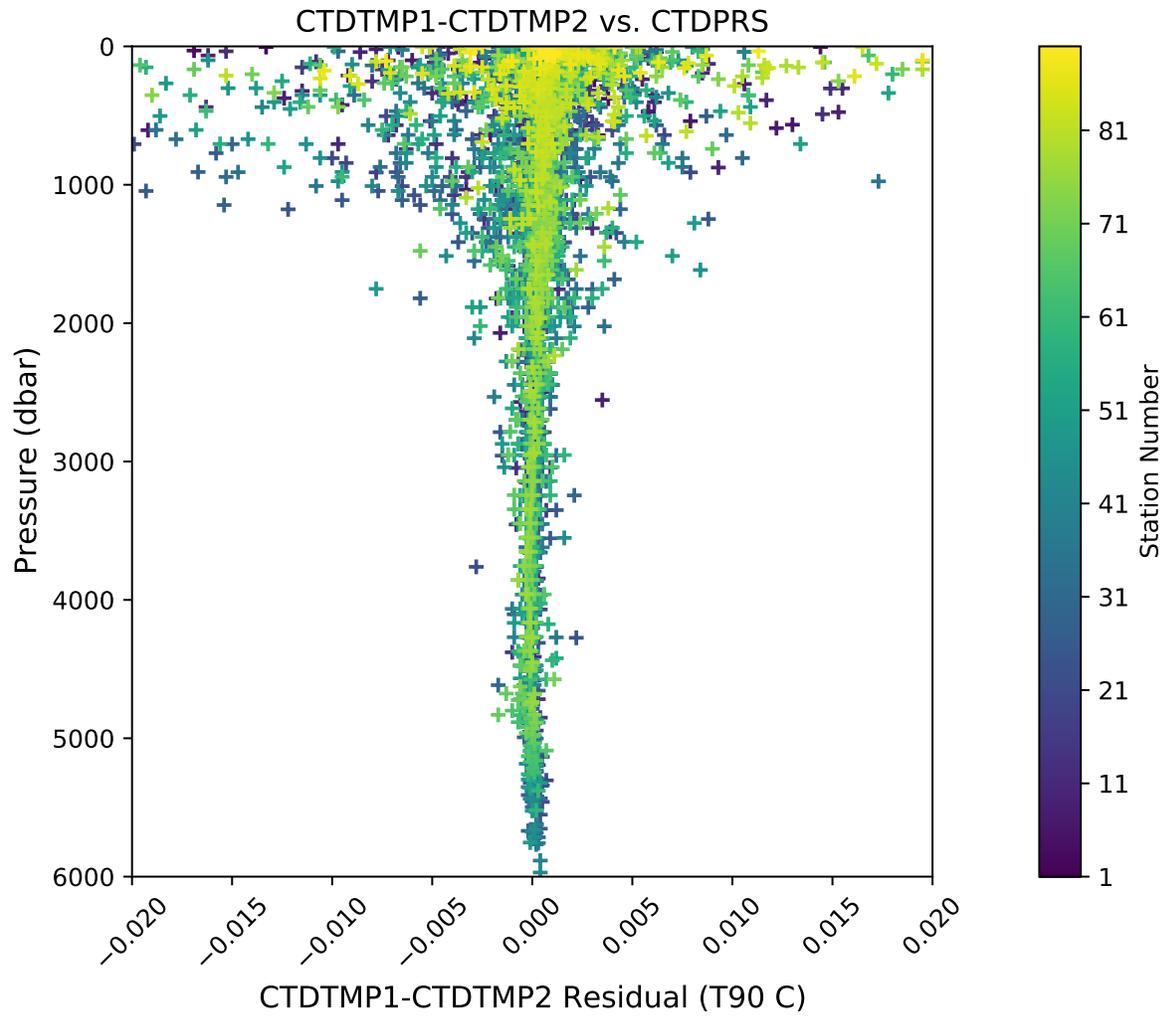
Fig. 10: T1-T2 versus pressure.

- Early stations had bottles fired on the fly, leading to some SBE35RT averaging periods outside of the intended depth.

- 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.

## 4.6 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.

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

$$C_{cor} = C + cp_2 P^2 + cp_1 P + ct_2 T^2 + ct_1 T + cc_2 C^2 + cc_1 C + \text{Offset}$$

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
901-90	0.0	-1.5095e-6	0.0	0.0	0.0	0.0	2.3449e-3
9-19	1.6923e-10	-1.3208e-6	0.0	0.0	0.0	-8.4712e-4	2.8040e-2
20-90	1.0156e-10	-1.0508e-6	0.0	0.0	0.0	-4.0501e-4	1.4077e-2

Table 4: Secondary conductivity (C2) coefficients.

Station	cp_2	cp_1	ct_2	ct_1	cc_2	cc_1	c_0
901-90	0.0	-9.2611e-7	0.0	0.0	0.0	0.0	4.8941e-3
9-19	0.0	-6.3966e-7	0.0	-7.0707e-4	0.0	0.0	5.249e-3
20-90	1.7710e-10	-1.6402e-6	0.0	0.0	0.0	-6.1245e-4	2.4370e-2

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 mPSU $\leq$ T1-T2 $\leq$ 0.002 mPSU) differences are $\pm$0.00559 mPSU for salinity-C1SAL. The 95% confidence limits for the deep salinity residuals (where pressure $\geq$ 2000dbar) are $\pm$0.00163 mPSU for salinity-C1SAL.
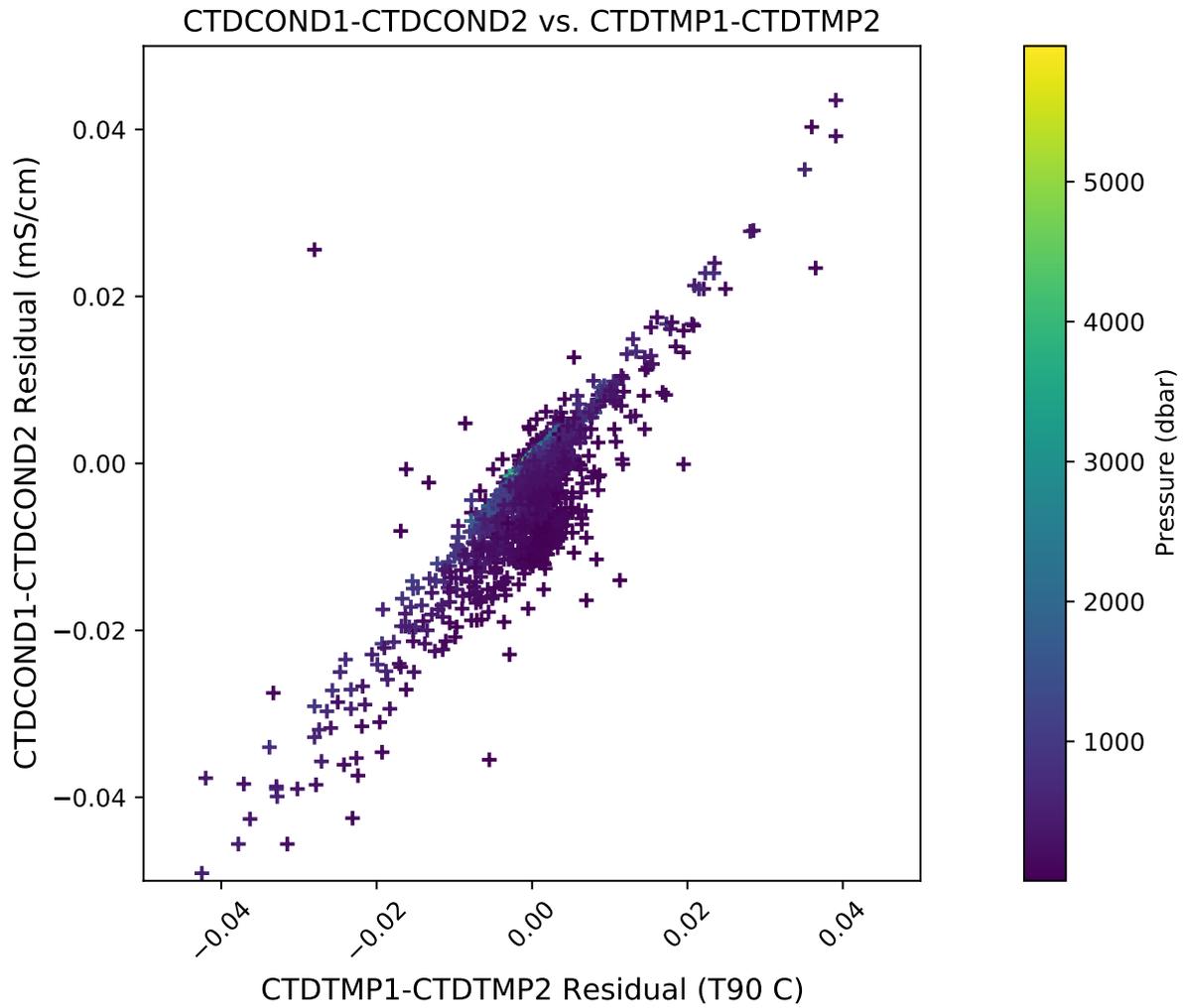
Fig. 11: Coherence of conductivity differences as a function of temperature differences.
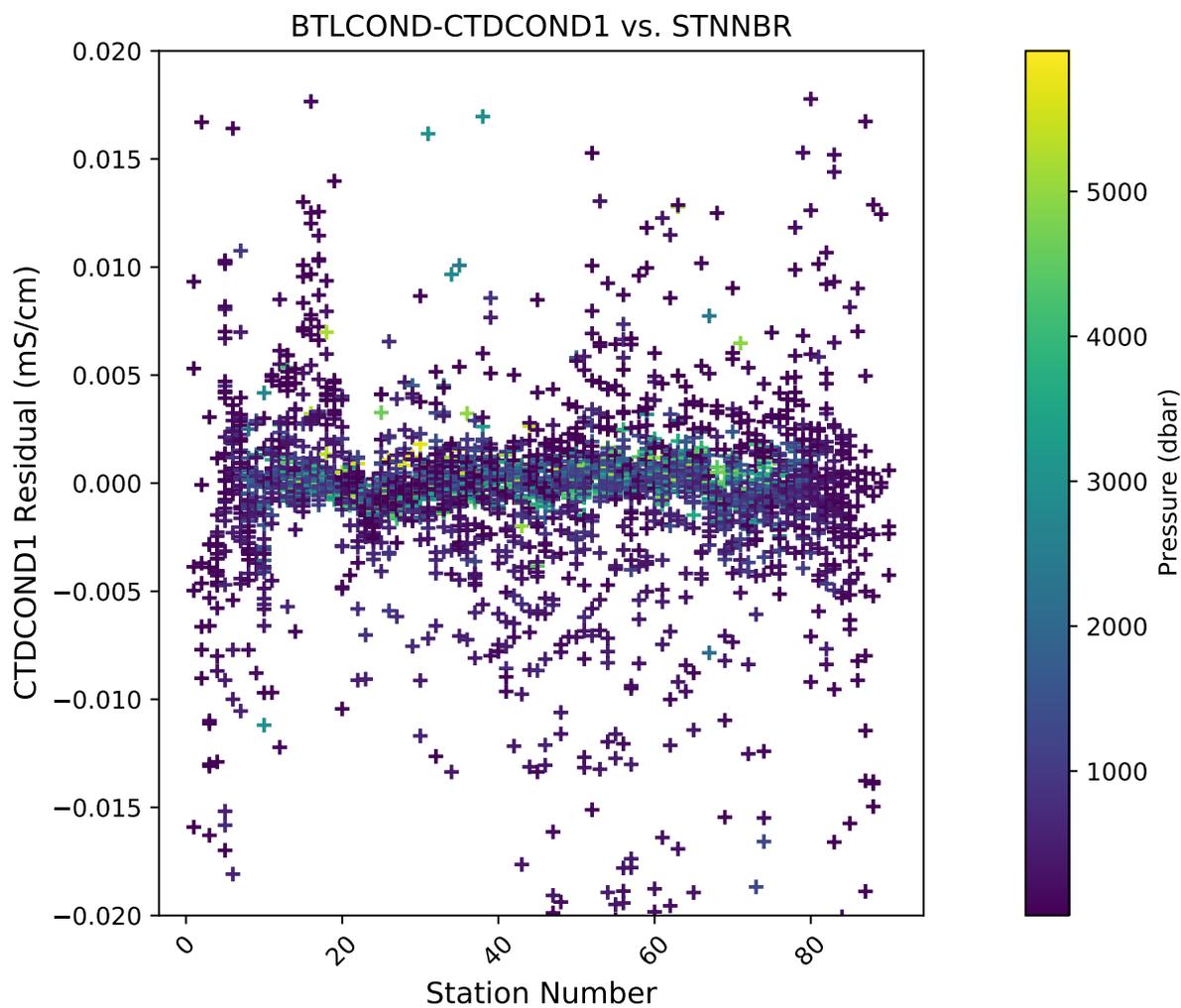
Fig. 12: Corrected C_{Bottle} - C1 versus station.
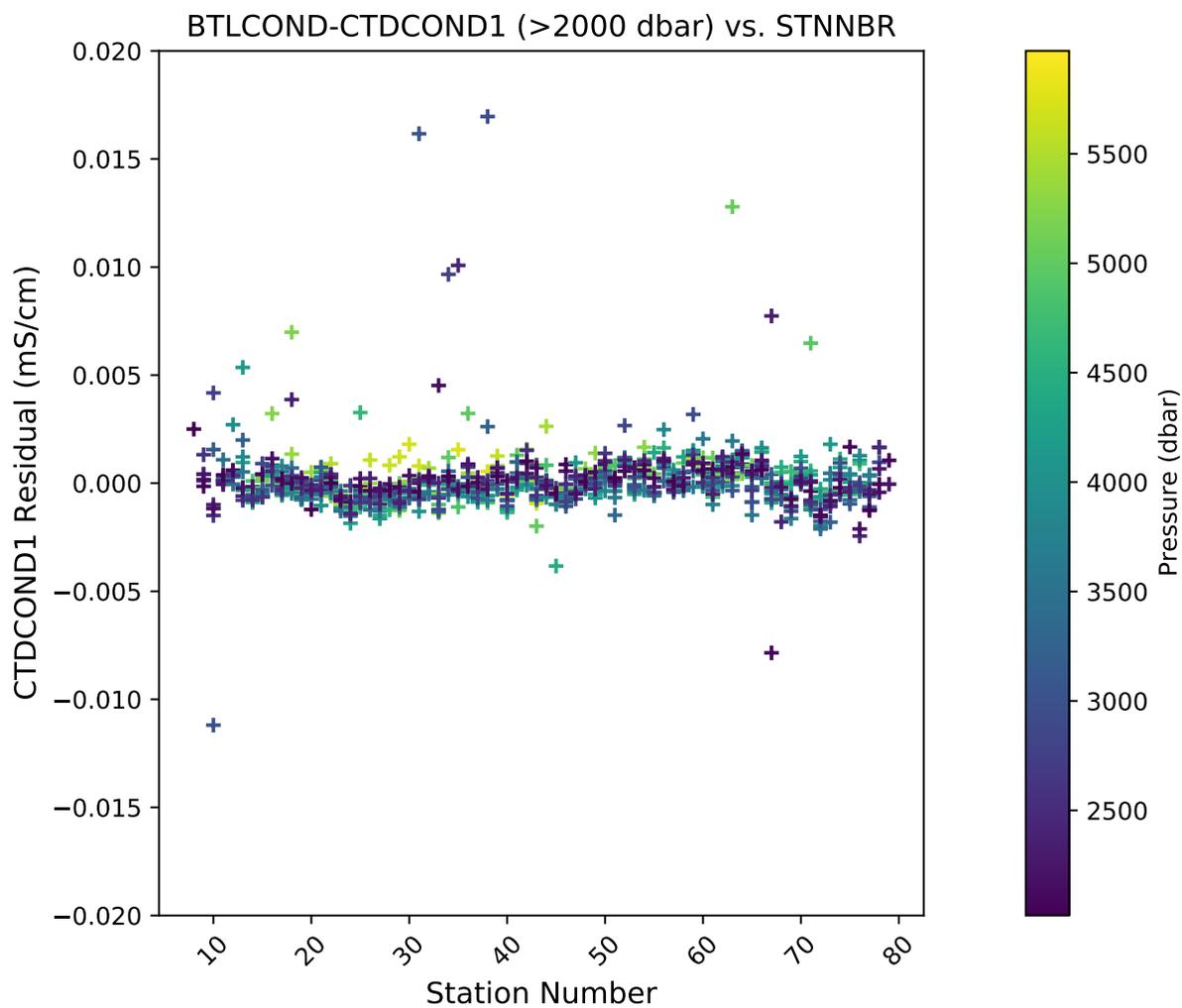
Fig. 13: Deep Corrected C_{Bottle} - C1 versus station (Pressure >= 2000dbar).
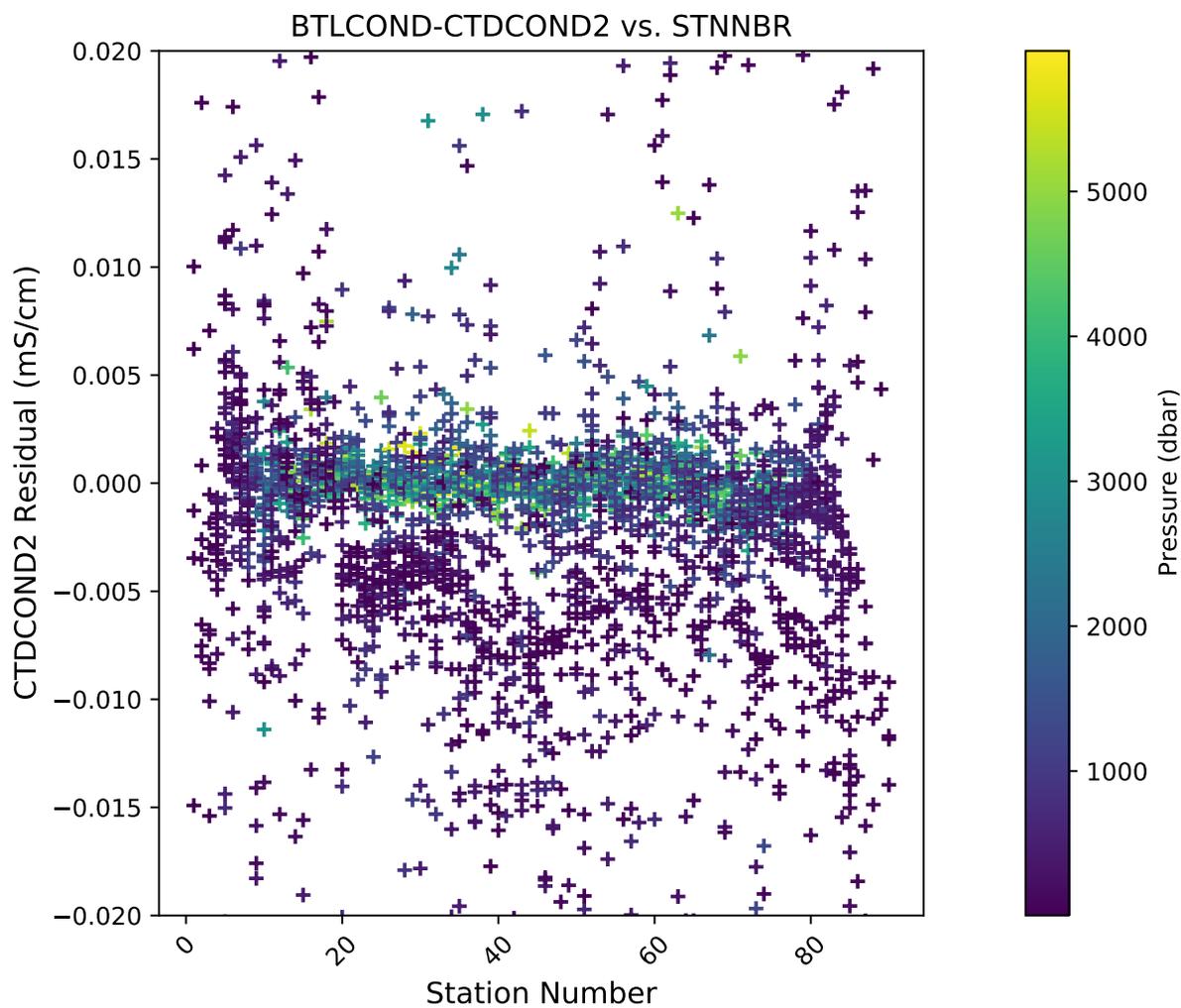
Fig. 14: Corrected C_{Bottle} - C2 versus station.
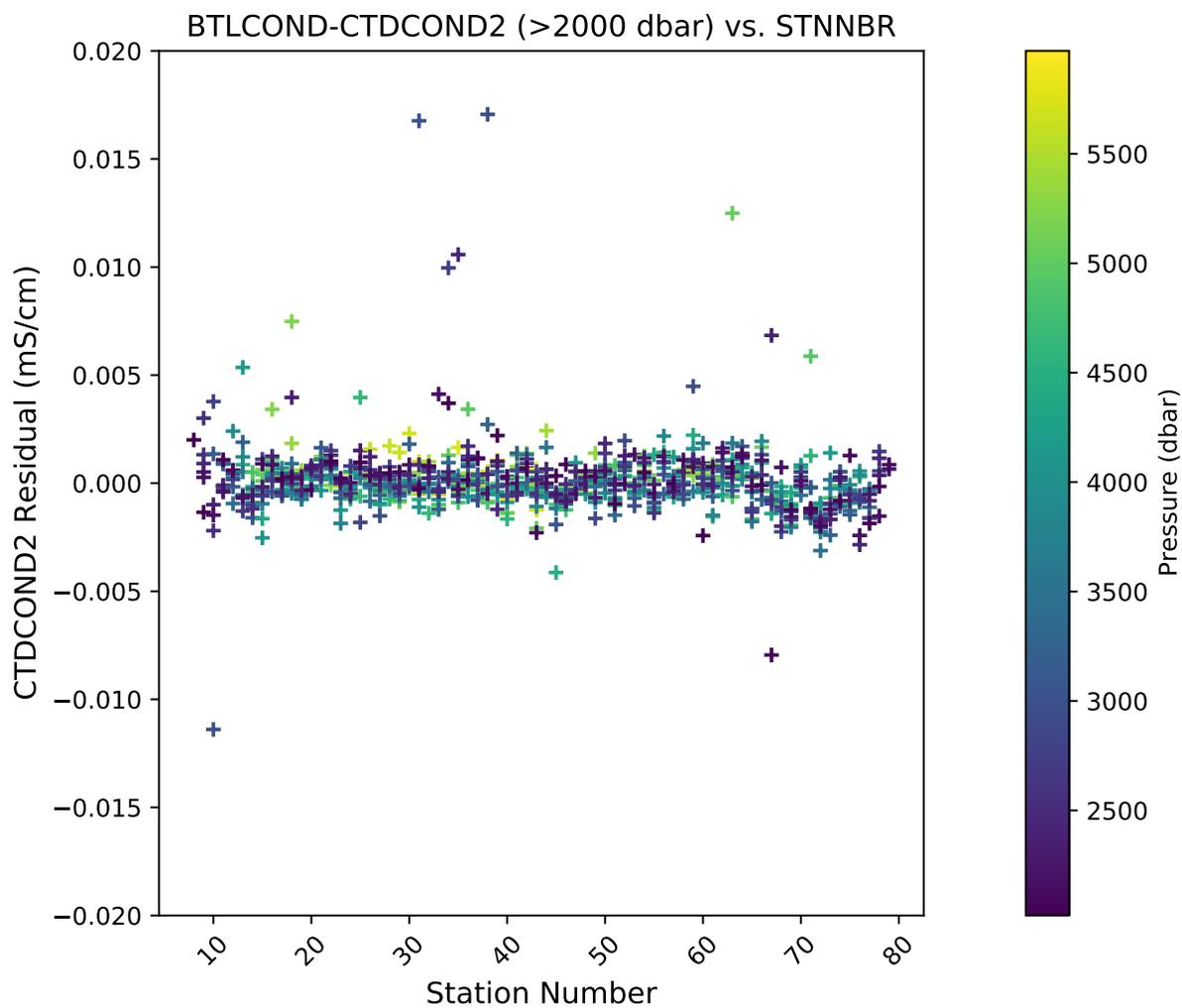
Fig. 15: Deep Corrected C_{Bottle} - C2 versus station (Pressure >= 2000dbar).
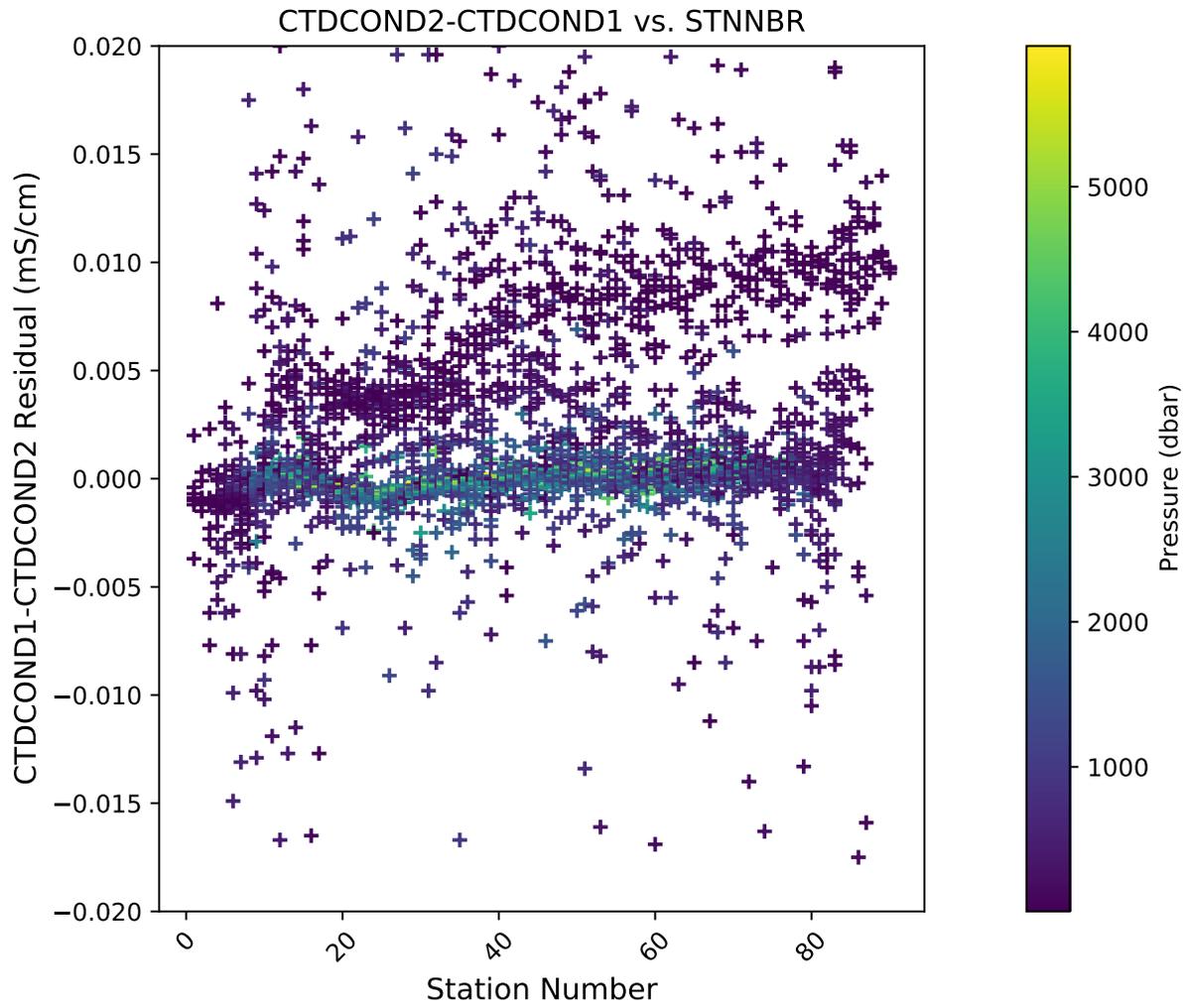
Fig. 16: Corrected C1-C2 versus station.
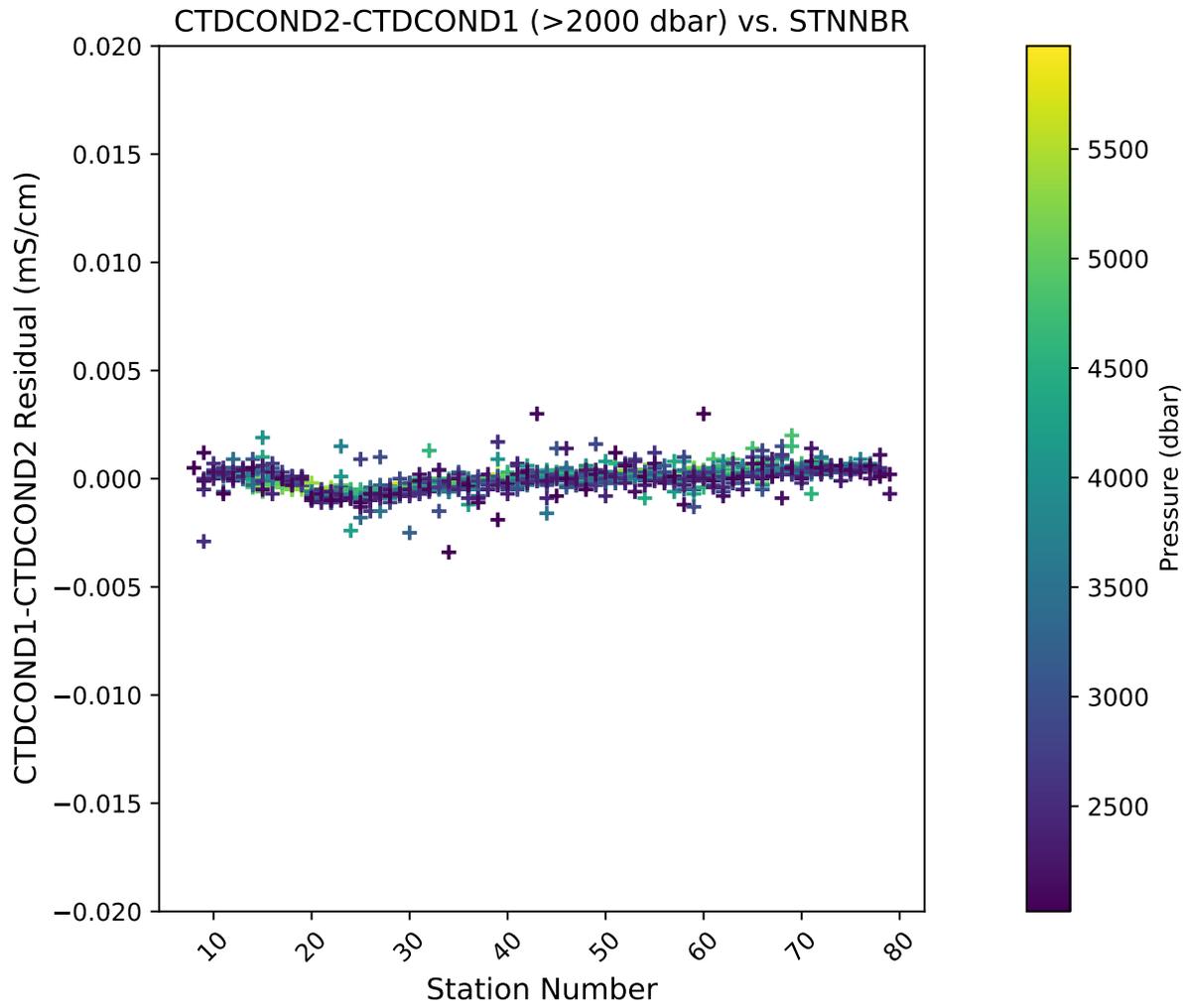
Fig. 17: Deep Corrected C1-C2 versus station (Pressure >= 2000dbar).
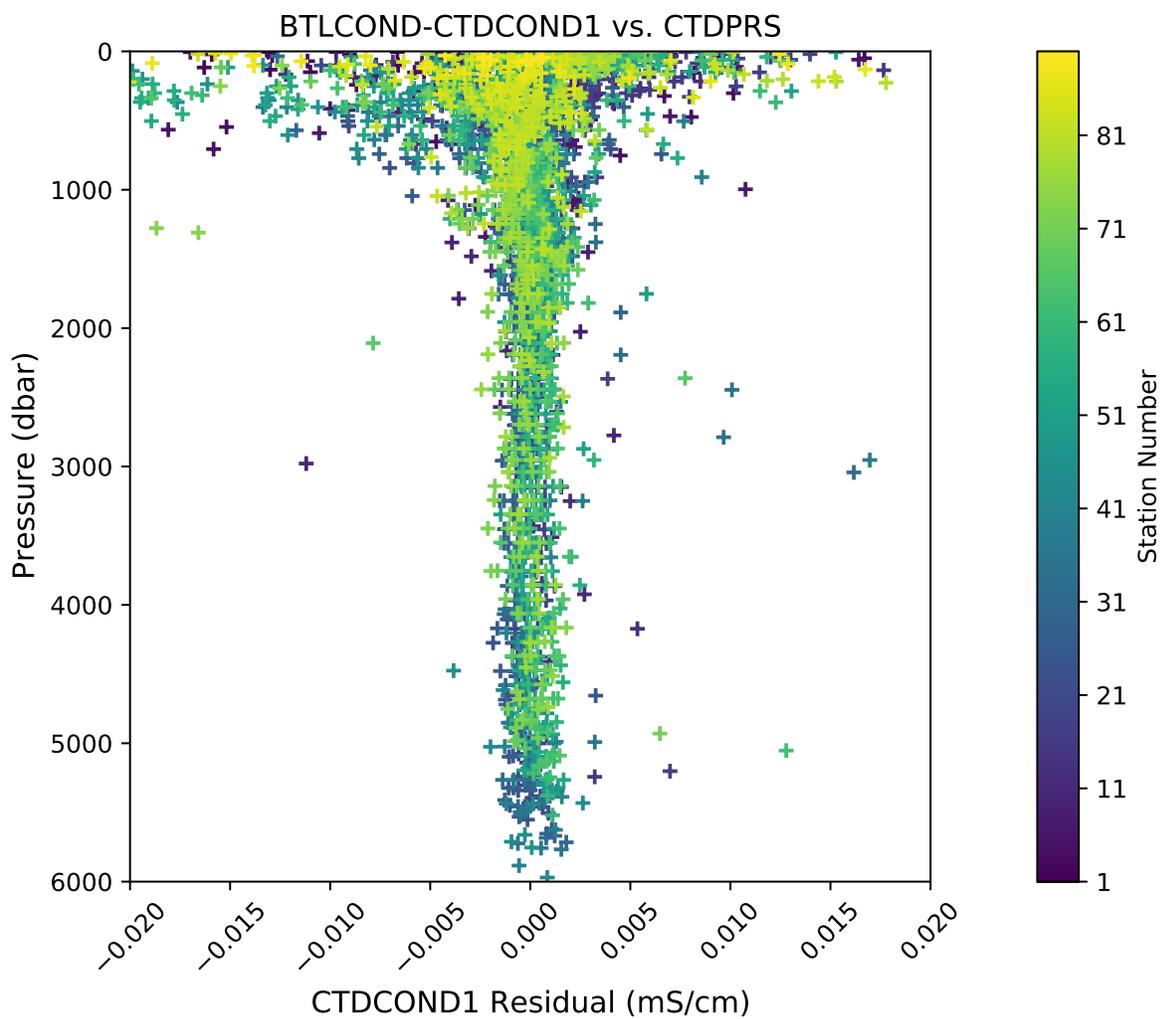
Fig. 18: Corrected C_{Bottle} - C1 versus pressure.
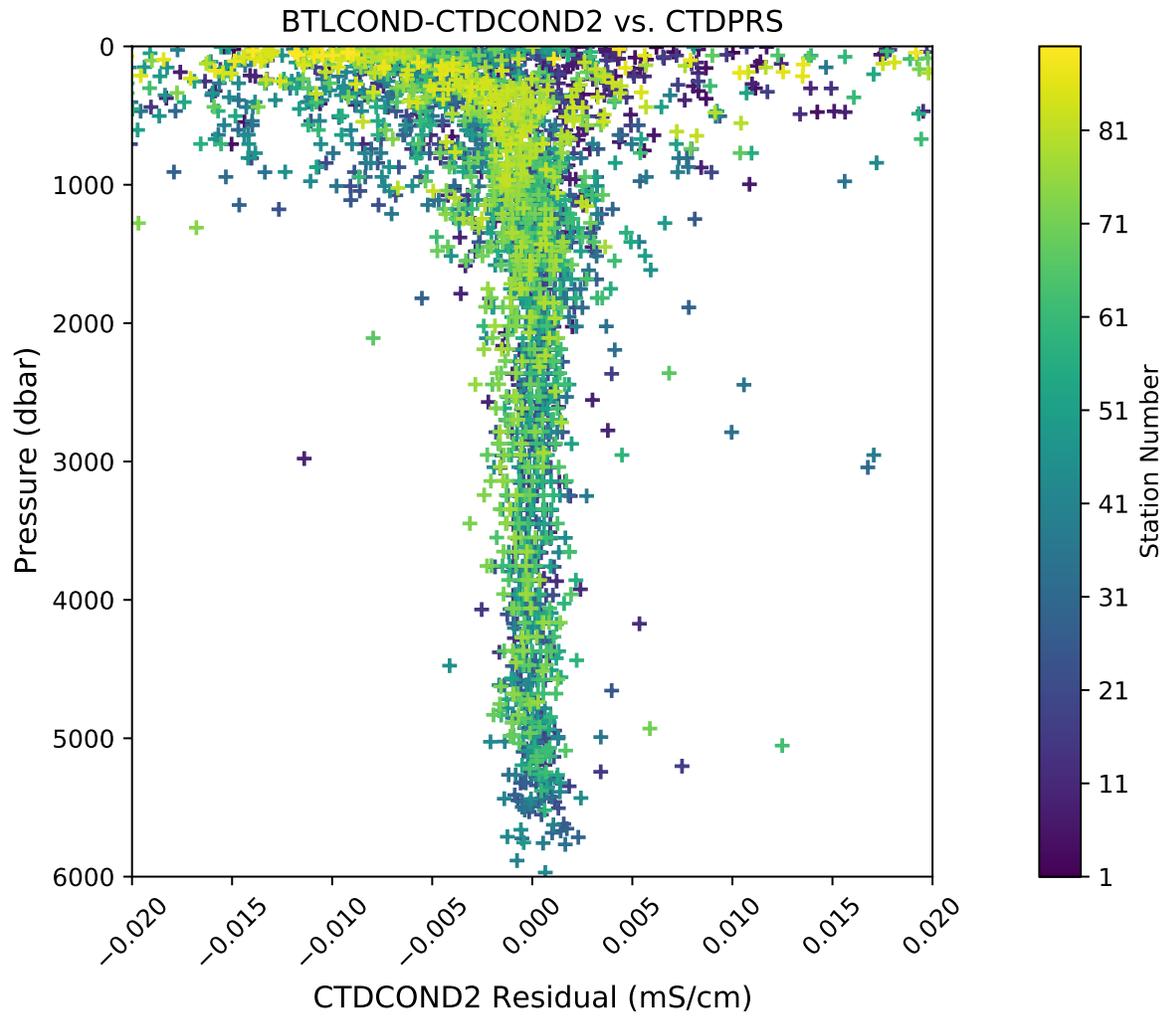
Fig. 19: Corrected C_{Bottle} - C2 versus pressure.
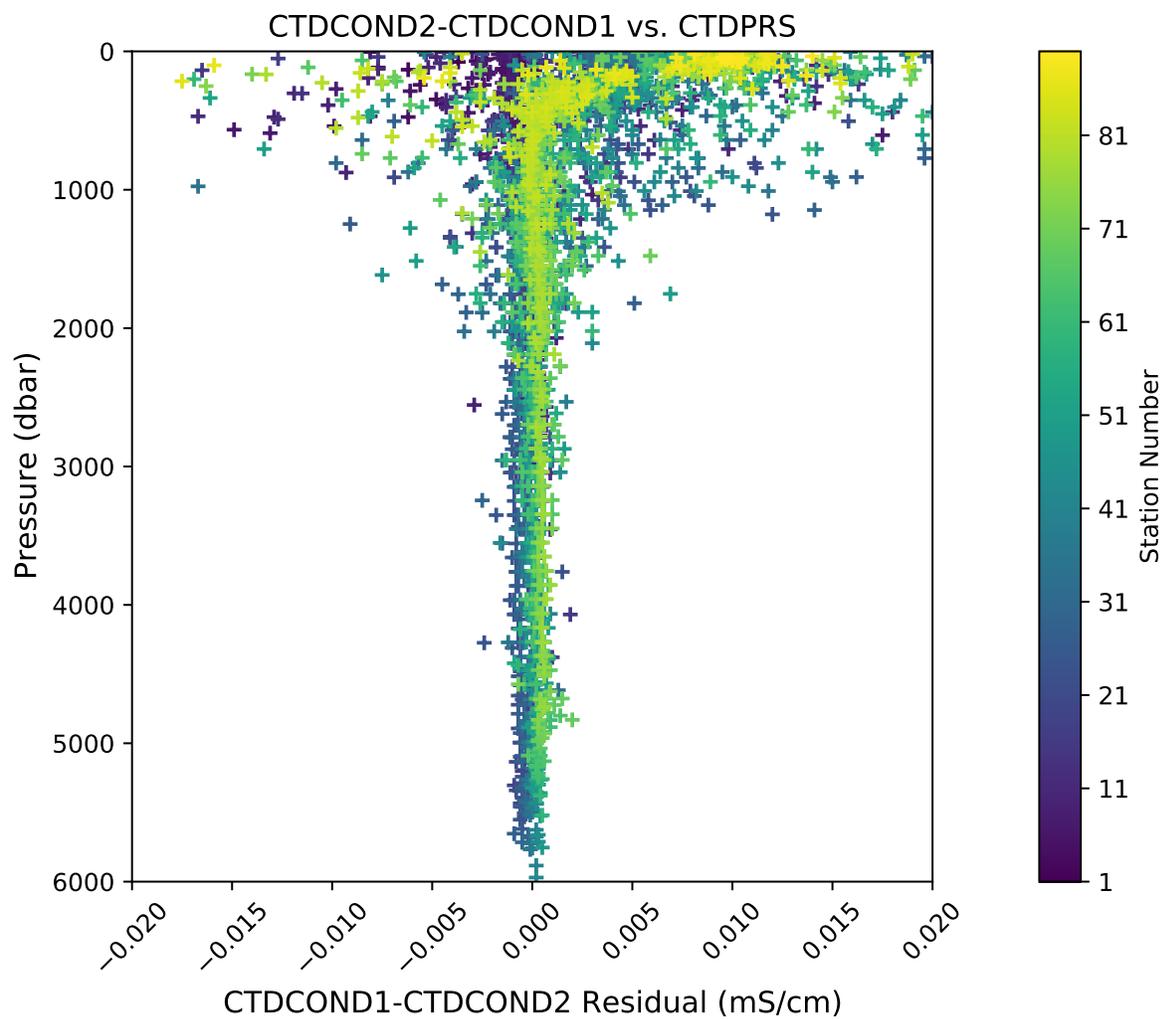
Fig. 20: Corrected C1-C2 versus pressure.
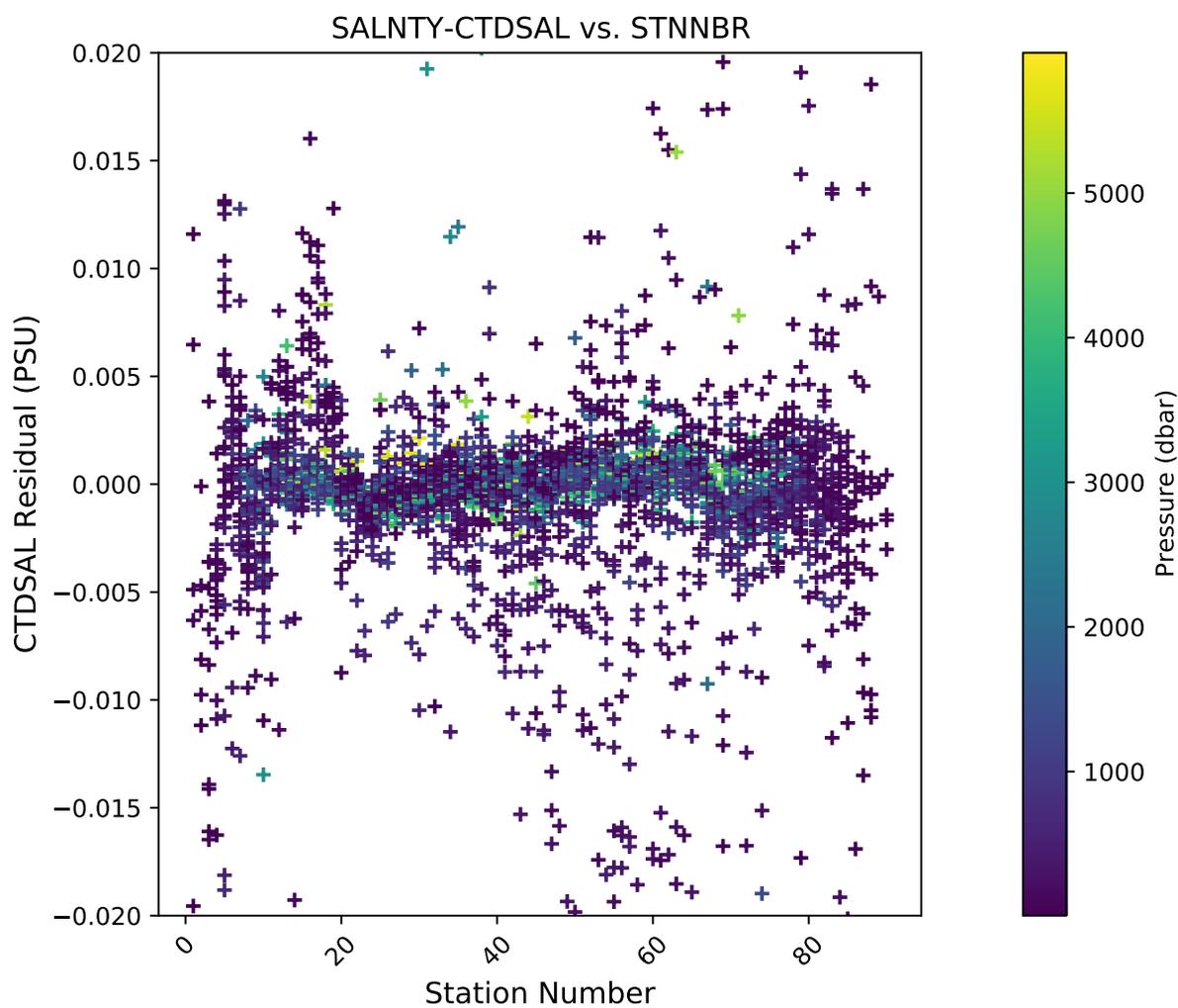
Fig. 21: Salinity residuals versus station.
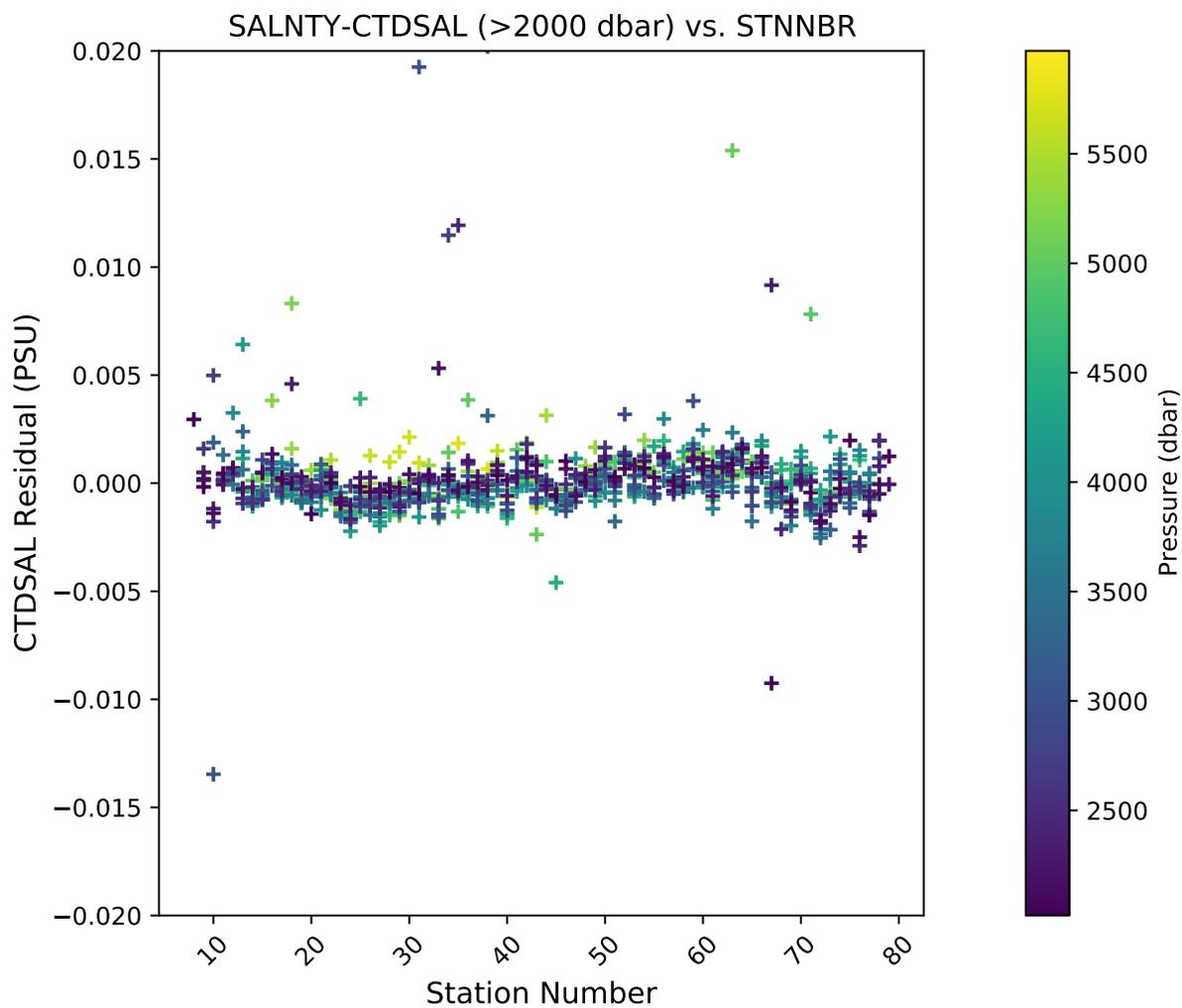
Fig. 22: Deep Salinity residuals versus station (Pressure >= 2000dbar).
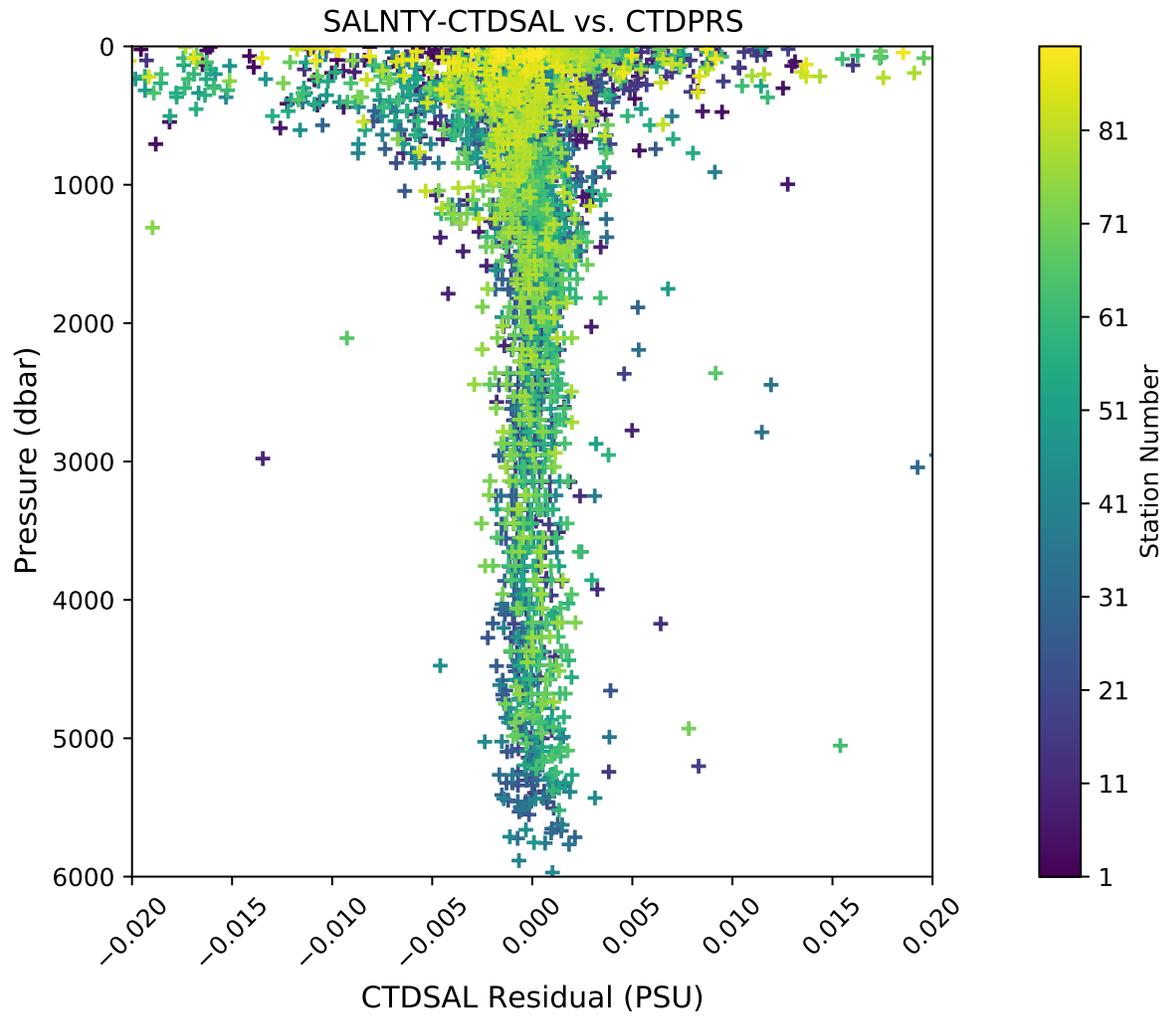
Fig. 23: Salinity residuals versus pressure.

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

- Early stations had bottles fired on the fly.

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

4.7 CTD Dissolved Oxygen (SBE43)

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

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

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

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

Where:

- V is oxygen voltage (V)

- D_1 and D_2 are (fixed) SBE calibration coefficients

- T is corrected CTD temperature (°C)

- p is corrected CTD pressure (dbar)

- dV/dt is the time-derivative of voltage (V/s)

- O_{sat} is oxygen saturation

- S_{OC}, V_{off}, τ_{20}, T_{cor}, and E are fit coefficients

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

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

Station	S_{oc}	V_{off}	τ_{20}	T_{cor}	E
901-90	4.6882e-1	-4.9580e-1	1.20	-1.6209e-4	3.7331e-2

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

The 95% confidence limits of 1.69 (µmol/kg) for all acceptable (flag 2) dissolved oxygen bottle data values and 1.61 (µmol/kg) for deep dissolved oxygen values are only presented as general indicators of the goodness of fit. CLIVAR GO-SHIP standards for CTD dissolved oxygen data are < 1% accuracy against on board Winkler titrated dissolved O_2 lab measurements.
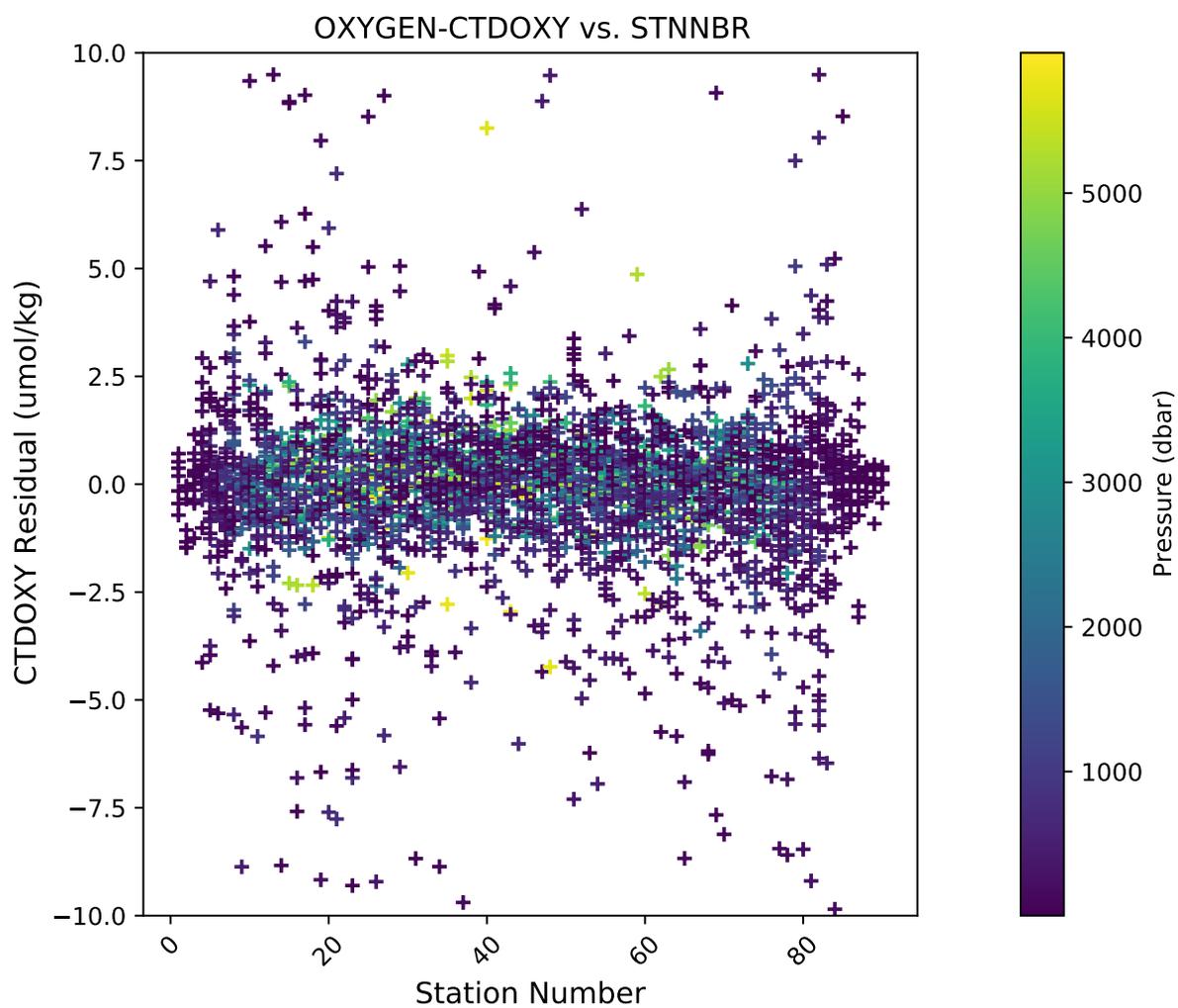
Fig. 24: O$_2$ residuals versus station.
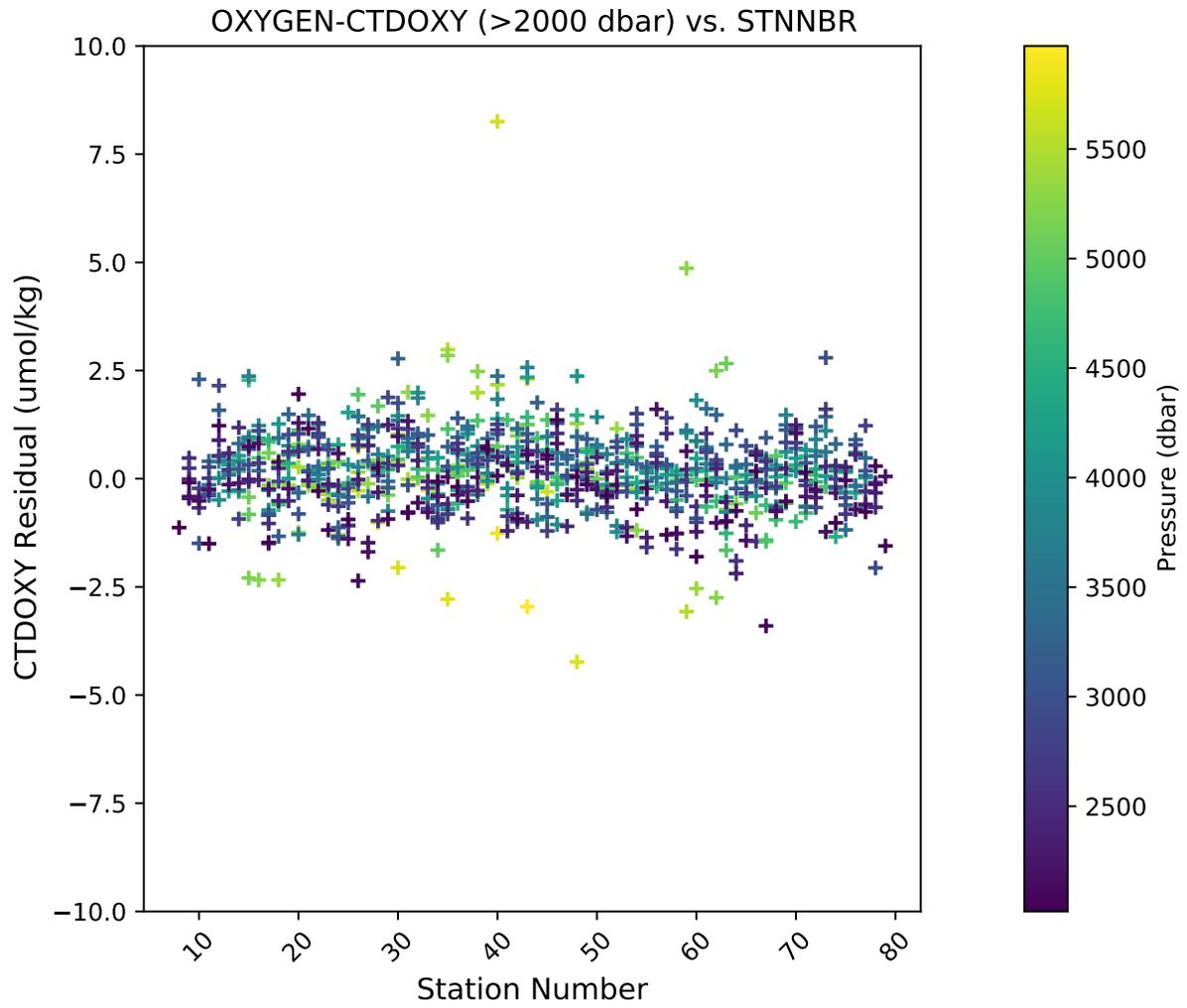
Fig. 25: Deep O_2 residuals versus station (Pressure >= 2000dbar).
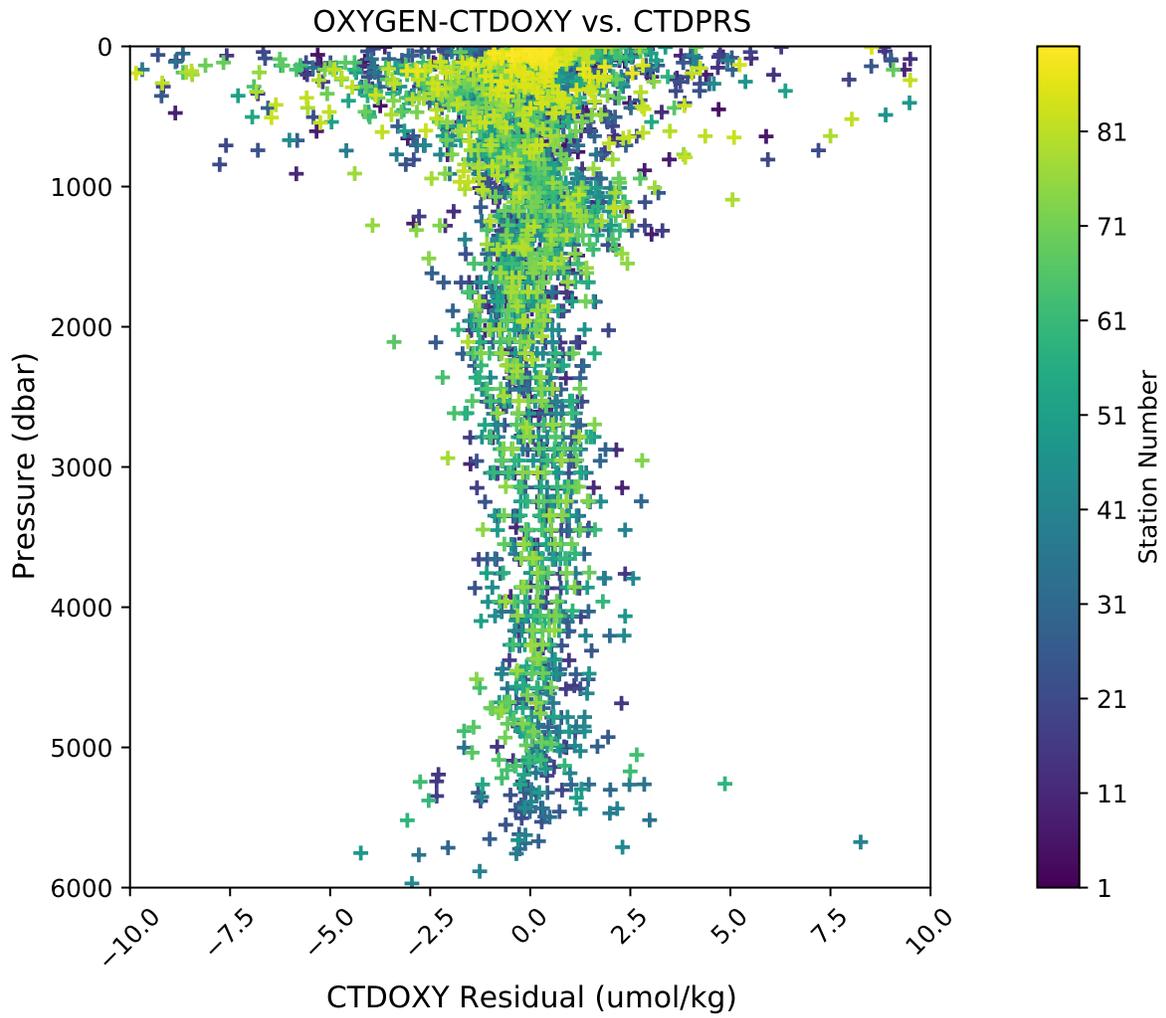
Fig. 26: O₂ residuals versus pressure.

A number of complications arose with the acquisition and processing of CTD dissolved oxygen data.

- Multiple SBE43 sensors were suspected to have frozen during transit or while sitting in port, causing erratic issues in the upper 100 m.

All compromised data signals were recorded and coded in the data files. The bottle trip levels affected by the signals were coded and are included in the bottle data comments section of the APPENDIX.

4.8 CTD Dissolved Oxygen (RINKO)

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

Rinko temperature (factory coefficients) was used for pre-cruise calibration. Generally, the Rinko III sensor appears to have performed as expected with no major problems or sharp drift throughout the deployment. An SBE 43 dissolved oxygen sensor was deployed simultaneously. Both oxygen sensor data sets were analyzed and quality controlled with Winkler bottle oxygen data. SBE 43 data are reported as primary oxygen (CTDOXY) for Stations 1-35, with Rinko III data used for the remaining stations (36-90).

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

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

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

where:

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

Oxygen is further corrected for pressure effects:

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

where:

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

Lastly, salinity corrections are applied [GarciaGordon1992]:

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

where:

- T_S is scaled temperature ($T_S = \ln[(298.15 - T)/(273.15 + T)]$)

- B_0, B_1, B_2, B_3, C_0 are solubility coefficients

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

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

Station	c_0	c_1	c_2	d_0	d_1	d_2	c_p
901-18	1.8737	4.7519e-2	1.1875e-3	7.2293e-3	-2.2105e-1	3.1239e-1	7.7734e-2
19-37	1.8699	6.6118e-2	1.406e-3	1.4025e-2	-2.2853e-1	3.1893e-1	8.586e-2
38-70	1.8734	-8.3703e-3	9.3629e-4	-6.6252e-3	-1.9367e-1	3.0974e-1	1.1084e-1
71-90	7.8045e-1	3.7031e-2	-2.5300e-4	5.8055e-3	-3.9786e-2	3.2919e-1	5.0959e-2

CTD dissolved O_2 residuals are shown in the following figures.
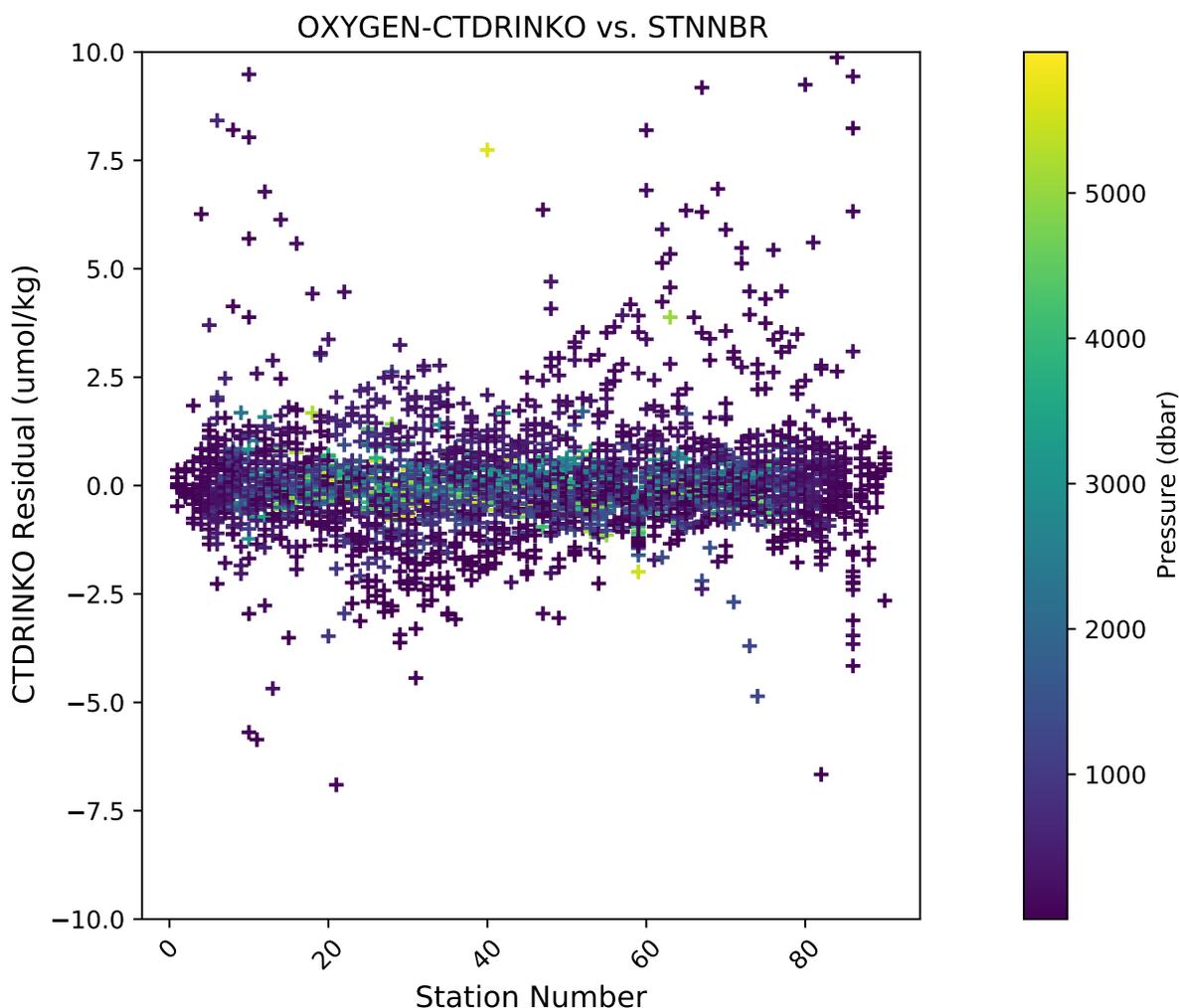
Fig. 27: O_2 residuals versus station.

The 95% confidence limits of 1.35 (µmol/kg) for all acceptable (flag 2) dissolved oxygen bottle data values and 0.91
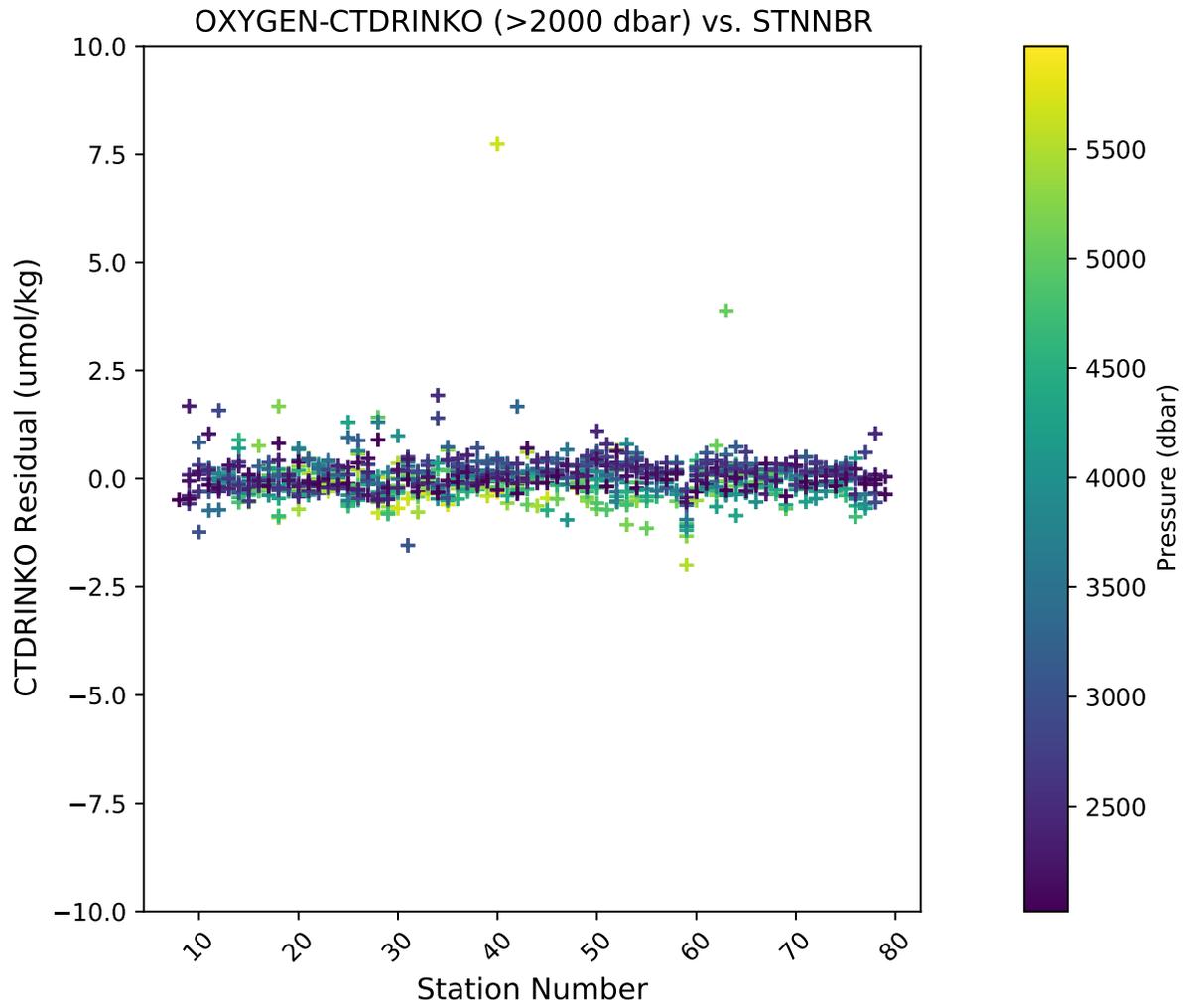
Fig. 28: Deep O_2 residuals versus station (Pressure >= 2000dbar).
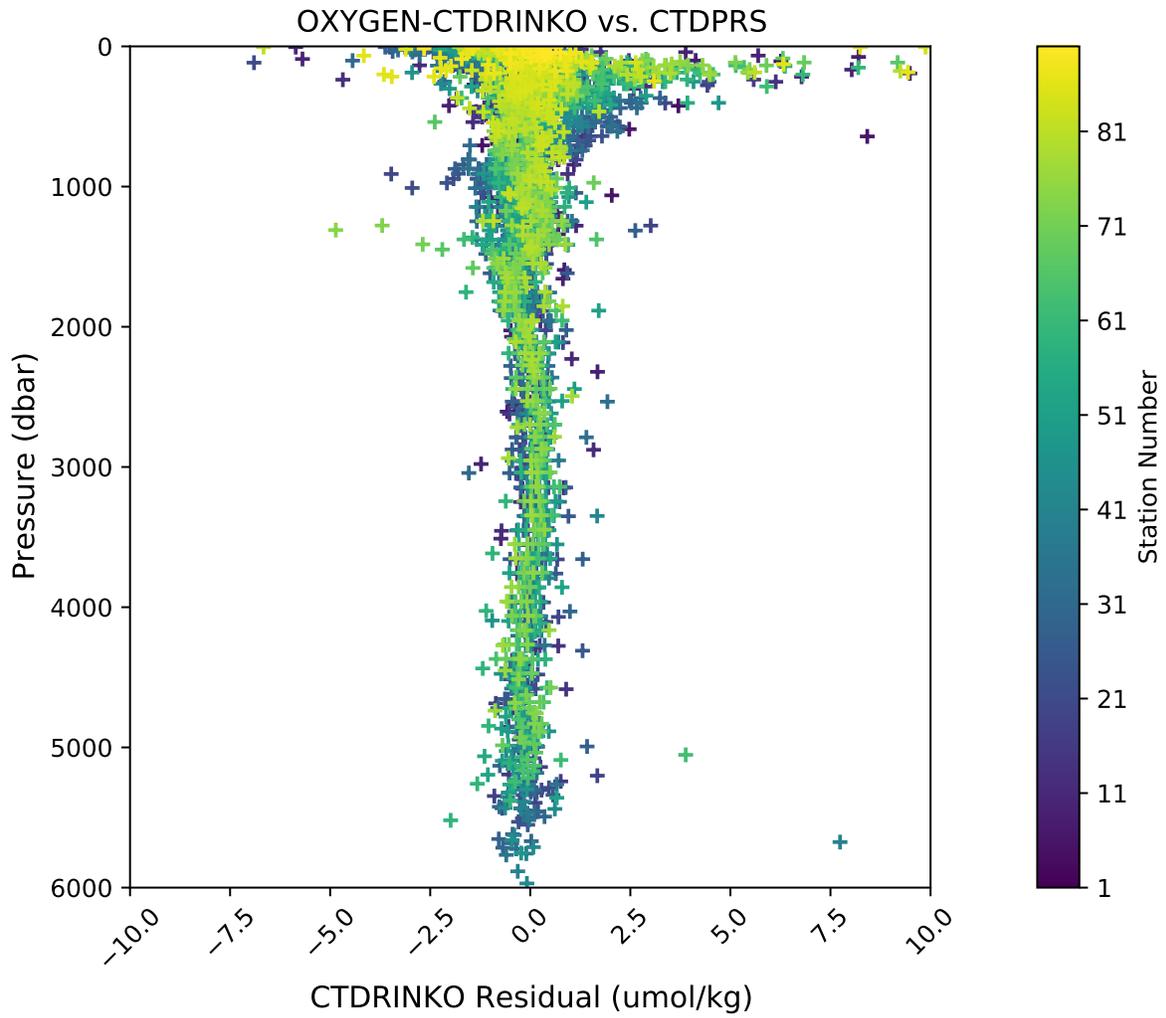
Fig. 29: O$_2$ residuals versus pressure.

(μmol/kg) for deep dissolved oxygen values are only presented as general indicators of the goodness of fit. CLIVAR GO-SHIP standards for CTD dissolved oxygen data are < 1% accuracy against on board Winkler titrated dissolved O_2 lab measurements.

A number of complications arose with the acquisition and processing of CTD dissolved oxygen data.

- Rinko S/N 297 was very noisy for the first ~35 casts and subsequently replaced with S/N 296 which had a much cleaner signal.

SALINITY

PIs

- Susan Becker

- James Swift

Technicians

- John Calderwood

- Patrick A'Hearn

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. 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 linear 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. Minor problems:

> There was a temperature excursion of the climate control chamber on the last day of analysis which had to be corrected before the last samples could be run.

> Three bottles were broken during sampling; four had their rims chipped. In all, seven sample bottles were damaged and replaced.

2963 total salinity samples were taken from a test cast, 90 CTD casts, and some underway seawater samples. 11 boxes (110 vials) of std seawater were consumed.

NUTRIENTS

Technicians

- Susan Becker (SIO)

- Alexandra Fine (AOML/CIMAS)

6.1 Summary of Analysis

- 2952 samples from 90 CTD stations

- The cruise started with new pump tubes and they were changed twice, before station 033 and station 064.

- 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 90%-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 sulfamilamide in 1.2N HCl and bring to 1 liter volume. Add 2 drops of 40% surfynol 465/485 surfactant. Store at room temperature in a dark poly bottle.

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

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

Imidazole Buffer Dissolve 13.6g imidazole in ~3.8 liters DIW. Stir for at least 30 minutes to completely dissolve. Add 60 ml of CuSO4 + NH4Cl mix (see below). Add 4 drops 40% Surfynol 465/485 surfactant. Let sit overnight before proceeding. Using a calibrated pH meter, adjust to pH of 7.83-7.85 with 10% (1.2N) HCl (about 10 ml of acid, depending on exact strength). Bring final solution to 4L with DIW. Store at room temperature.

NH4Cl + CuSO4 mix Dissolve 2g cupric sulfate in DIW, bring to 100 m1 volume (2%). Dissolve 250g ammonium chloride in DIW, bring to 1l liter volume. Add 5ml of 2% CuSO4 solution to this NH4Cl 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 H2SO4 sol'n Pour 420 ml of DIW into a 2 liter Ehrlenmeyer flask or beaker, place this flask or beaker into an ice bath. SLOWLY add 330 ml of conc H2SO4. This solution gets VERY HOT!! Cool in the ice bath. Make up as much as necessary in the above proportions.

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

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

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 H2SO4. (Dilute H2SO4 = 2.8ml conc H2SO4 or 6.4ml of H2SO4 diluted for PO4 moly per liter DW) (dissolve powder, then add H2SO4) 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 (Na2SiF6), nitrate (KNO3), nitrite (NaNO2), and phosphate (KH2PO4) 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$_4$ (uM)	SIL (uM)	NO$_2$ (uM)
0	0.0	0.0	0.0	0.0
3	15.50	1.2	60	0.50
5	31.00	2.4	120	1.00
7	46.50	3.6	180	1.50

6.9 Quality Control

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

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

As is standard ODF practice, a deep calibration "check" sample was run with stations 01-055 to estimate precision within the cruise. The water for the check samples was collected on the test cast from 1500m and was fixed with 1ml of saturated mercuric chloride to precent biological growth and stabilize the nutrient concentration. The deep check samples were discontinued when trouble shooting the issues with cadmium column efficiency since the mercuric chloride may have been contributing to the loss of column efficiency. The data are tabulated below for the first 55 stations.

Parameter	Concentration (µM)	stddev
NO_3	17.75	0.29
PO_4	1.16	0.03
SIL	12.8	0.3

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
-	(µmol/kg)	-	(µmol/kg)
NO_3	15.79	0.16	15.86
PO_4	1.18	0.01	1.177
Sil	34.8	0.16	34.7
NO_2	0.04	0.01	0.04

6.10 Analytical Problems

There were issues with the cadmium column efficiency for a series of stations/days. 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 deep check samples were used to calculate adjustment factors for the affected stations. The adjusted data for the affected stations was compared to adjacent stations and historical data during the QC checks.

OXYGEN ANALYSIS

PIs

- Susan Becker

- James Swift

Technicians

- Andrew Barna

- Robert "Ben" Freiberger

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 2947 oxygen measurements were made, of which 2937 were niskin samples and 10 were 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 $MnCl_2$ and NaI/NaOH (1 mL of each) were added via bottle-top dispensers to fix samples before stoppering. Flasks were shaken twice (10-12 inversions) to assure thorough dispersion of the precipitate - once immediately after drawing and then again after 30-60 minutes.

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

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

Cruise setup began on March 12th 2021 in Woods Hole, MA, USA.

A 5x batch (4.3L) of MnCl and a 4x (3.5L) batch of NaI/NaOH was made in port so more reagents would not need to be made while underway. Only a 2L of thiosulfate was made and would need to be made at least once more with the anticipated number of samples.

Due to low temperatures in Woods Hole, there was concern that the ODF oxygen standards may have frozen in the shipping container before load started. Good agreement with both the expected normality of a carefully prepared thiosulfate batch and an OSIL oxygen standard alleviated these concerns. The OSIL oxygen standard was run against the usual ODF oxygen standard during the a standardization around station 48. The OSIL standardization followed the same procedure as normal with the exception of using an Eppendorf pipette to dispense the standard.

The need for smoothing thiosulfate normality was considered separately for each thiosulfate batch (2 in total). Smoothing was performed on both batches, the first batch having no trend (averaged), the second batch showing a trend related to temperature control difficulty the ship had as the sea and air temperature warmed. The smoothed final values had differences no more than ±0.3 µmol/kg from the non smoothed values.

No further data updates are expected.
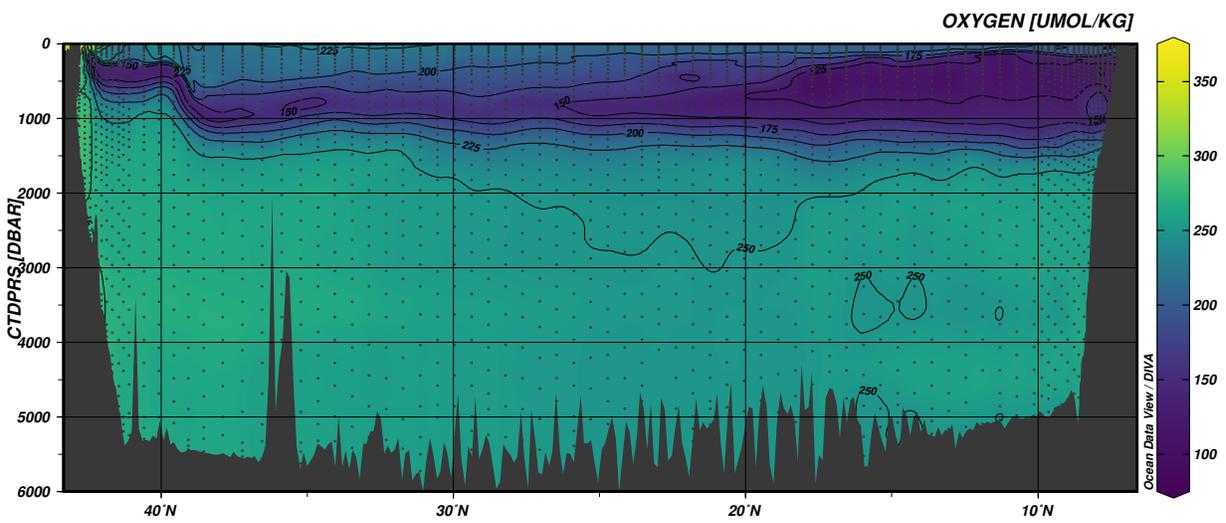
Fig. 1: Bottle oxygen data gridded on isopycnals.

EIGHT

TOTAL ALKALINITY

PI

- Andrew G. Dickson – SIO

- Frank Millero - RSMAS

Technicians

- Manuel Belmonte

- Carmen Rodriguez

8.1 Total Alkalinity

The total alkalinity of a sea water sample 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

Samples are dispensed using a Sample Delivery System (SDS) consisting of a volumetric pipette, various relay valves, and two air pumps controlled by LabVIEW 2012. Before filling the jacketed cell with a new sample for analysis, the volumetric pipette is cleared of any residual from the previous sample with the aforementioned air pumps. The pipette is then rinsed with new sample and filled, allowing for overflow and time 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 are used to convert the sample volume to mass for analysis.

Samples are analyzed using an open cell titration procedure using two 250 mL jacketed cells. One sample is undergoing titration while the second is being prepared and equilibrating to 20°C for analysis. After an initial aliquot of approximately 2.3-2.4 mL of standardized hydrochloric acid (~0.1M HCl in ~0.6M NaCl solution), the sample is stirred for 5 minutes while air is bubbled into it at a rate of 200 scc/m to remove any liberated carbon dioxide gas. A Metrohm 876 Dosimat Plus is used for all standardized hydrochloric acid additions. After equilibration, ~19 aliquots of 0.035 ml are added. Between the pH range of 3.5 to 3.0, the progress of the titration is monitored using a pH glass electrode/reference electrode cell, and the total alkalinity is computed from the titrant volume and e.m.f. measurements using a non-linear least-squares approach ([Dickson2007]). 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

Samples for total alkalinity measurements were taken at all A20 Stations (1-90). Three Niskin bottles at each station were sampled twice for duplicate measurements except for stations where 24 or less Niskin bottles were sampled. Stations at which 24 or less Niskin bottles were sample one or two Niskin bottles were sampled twice for duplicate measurements. Using silicone tubing, the total alkalinity samples were drawn from Niskin bottles into 250 mL Pyrex bottles, making sure to rinse the bottles and Teflon sleeved glass stoppers 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. After sampling was completed, each sample's temperature was equilibrated to approximately 20°C using a Thermo Scientific Isotemp water bath.

8.4 Problems and Troubleshooting

On one occassion, during analysis of station 25, the Agilent 34901A Data Acquisition/Switch Unit shut off and did not power back on. The unit had to be replaced with a spare and sample analysis was not interrupted. Throughout the cruise, glitches from the Sample Delivery System were experienced at random. At one point, the laptop controlling the SDS powered off and would not return back on. This too was replaced with a spare. Additionally, the Sample Delivery System program would freeze drawing sample in Deliver Sample or Prepare Pipette mode and caused a few sample bottles to be emptied. This resulted in a few lost samples. Furthermore, due to a novice operator, during analysis of station 34 the Metrohm 876 Dosimat Plus calibration was changed and samples were run with the incorrect calibration. However, the lead technician was able to find this error and corrected the mistake. Only 6 samples were analyzed using the icorrect dosimat calibration function but were recalculated to correct for this error.

8.5 Quality Control

Dickson laboratory Certified Reference Material (CRM) Batch 178 and 180 were used to determine the accuracy of the total alkalinity analyses. The total alkalinity certified value for these batches are:

- Batch 187 2204.98 ± 0.37 µmol/kg (32;16)
- Batch 192 2213.70 ± 0.53 µmol/kg (32;16)

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).

At least one reference material was analyzed at every A20 stations resulting in 142 reference material analyses. On A20, the measured total alkalinity value for each batch is:

- Batch 187 2205.54 ± 1.79 µmol kg-1 (107) [mean ± std. dev. (n)]
- Batch 192 2214.45 ± 1.58 µmol kg-1 (33) [mean ± std. dev. (n)]

If greater than 24 Niskin bottles were sampled at a station, three Niskin bottles on that station were sampled twice to conduct duplicate analyses. If 24 or less Niskin bottles were sampled at a station, one or two Niskins on that station were sampled twice for duplicate analyses. The standard deviation for the duplicates measured on A20 is:

Duplicate Standard Deviation ± 2.10 µmol kg–1 (111) [± std. dev. (n)]

The total alkalinity measurements for each A20 stations have been compared to measurements taken from the neighboring A20 2021 stations.

1689 total alkalinity values were submitted for A20. Further dilution corrections need to be applied to this data and will not be applied until onshore, therefore this data is to be considered premilinary.

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 CO2 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 $HgCl_2$ 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_2 (gas) by addition of excess hydrogen ion (acid) to the seawater sample, and the evolved CO_2 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^- ions at the anode. The OH^- ions react with the H^+ and the solution turns blue again. A beam of light is shone through the solution, and a photometric detector at the opposite side of the cell senses the change in transmission. Once the percent transmission reaches its original value, the coulometric titration is stopped, and the amount of CO_2 that enters the cell is determined by integrating the total change during the titration.

9.4 DIC Calculation

Calculation of the amount of CO2 injected was according to the CO2 handbook [DOE1994]. The concentration of CO2 ([CO2]) in the samples was determined according to:

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

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 $HgCl_2$ 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 1.26 µmol/kg for AOML 3 and 1.58 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 12-35.

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_2 (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 187 CRM value. The CRM certified value for this batch is 2002.85 µmol/kg.

The precision of the two DICE systems can be demonstrated via the replicate samples. Approximately 11% 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 difference for these

duplicates on AOML 3 and 4 respectively are 1.74 µmol/kg and 1.38 µmol/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	1.00448	27.990 ml	2003.23, N= 42	0.67	1.74
AOML4	1.00422	29.387 ml	2004.32, N= 43	1.27	1.38

9.6 Instrument Repairs

AOML 3 had a relay switch failure before Station 17. The relay switch and micro acid pump were replaced and the instrument functioned well for the rest of the cruise. AOML 4 had the 5V power supply fail during Station 65. The power supply was replaced with a new one and the instrument functioned well for the remainder of the cruise.

9.7 Underway DIC Samples

Underway samples were collected from the flow thru system in the hydro-lab during transit. Discrete DIC samples were collected approximately every 4 hours before the line of 90 CTD stations commenced with duplicates every fifth sample. A total of 38 discrete DIC samples including duplicates were collected while underway. The average difference for replicates of underway DIC samples was 0.68 µmol/kg and the average STDEV was 0.30.

9.8 Summary

The overall performance of the analytical equipment was good during the cruise. Including the duplicates, a total of 2245 samples were analyzed from 90 CTD casts for dissolved inorganic carbon (DIC), which equates to a DIC value for 68% of the niskins tripped. A total of 38 discrete DIC samples including duplicates were collected from the underway system and analyzed while in transit. 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.

TEN

DISCRETE PH ANALYSES (TOTAL SCALE)

PI

- Dr. Andrew Dickson
- Dr. Frank Millero

Technicians

- Daniela Nestory
- Albert Ortiz

10.1 Sampling

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

10.2 Analysis

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

10.3 Reagents

The mCP indicator dye was made up to a concentration of approximately 2.0mM and a total ionic strength of 0.7 M. A total of two batches were used during A20. The pHs of these batches were adjusted with 0.1 mol kg^{-1} solutions of HCl and NaOH (in 0.6 mol kg^{-1} NaCl background) to approximately 7.81, 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

At the beginning of the cruise two of the Kloehn V6 pumps were found to have leaky ports as indicator dye was found seeping into the cell port from the dye port. The Kloehn V6 pump was replaced and posed no issues for the remainder of the cruise. During station 27, Agilent 8453 spectrophotometer's self-test failed the RMS noise test. This resulted in a change of the dueterium bulb and immediately resolved the issue. Samples were run the day the bulb may have malfunctioned. However the reference seawater that was analyzed at the end of that day was remianed accurate. Thus no inaccurate measurements were taken while the dueterium bulb was performing suboptimally. Furthermore, the sample cell was broken due to stress on the sample inlet glass tubes, but the operator and lead tech were 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 A20 are:

Duplicate precision	$\pm$ 0.0009 (n=173)
Replicate precision	$\pm$ 0.0017 (n=104)
B192	7.7491 $\pm$ 0.00185 (n=52)
B192 within-bottle SD	$\pm$ 0.0005 (n=52)

2026 pH values were submitted for A20. 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.

ELEVEN

CFC-11, CFC-12, N$_2$O, AND SF$_6$

PIs

- Mark J. Warner (UW)

Analysts

- Mark J. Warner (UW)

- Rolf E. Sonnerup (UW)

- Carla L. Mejías-Rivera (UPR)

> **Warning:** Note that N$_2$O measurements are a Level 3 measurement. The concentrations were measured on the same water samples collected for the Level 1 CFC/SF$_6$ measurements. The N$_2$O analysis is still under development. Please contact the PI for any use of these data.

Samples for the analysis of dissolved CFC-11, CFC-12, SF$_6$, and N$_2$O were collected from approximately 1427 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, 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$_6$, and N$_2$O in air samples, seawater and gas standards were measured by shipboard 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 GC-EC 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 -60oC. During the purging of the sample (6 minutes at 170 ml min-1 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 175oC. The desorbed contents of the trap were back-flushed and transferred onto the analytical precolumns. 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$_2$O from CFC-12 and SF$_6$. Three analytical columns in three gas chromatographs with electron capture detectors were used in the analysis. CFC-11 was separated from other compounds by a long column consisting of 36 cm of Porasil B and 150 cm of Carbograph 1AC maintained at 80°C. CFC-12 and SF$_6$ 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$_2$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% CH4) that was directed onto the

second precolumn and into the third column for the N_2O analyses. The detectors for the CFC-11, and for CFC-12 and SF_6 were operated at 300ºC. The detector for N_2O was maintained at 320 ºC.

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 was recorded so that the amount of gas injected could be calculated. 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. Three sizes of gas sample loops were used. Multiple injections of these loop volumes could be made to allow the system to be calibrated over a relatively wide range of concentrations. Air samples and system blanks (injections of loops of CFC-free gas) were injected and analyzed in a similar manner. The typical analysis time for 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-1) of the compressed air to be directed to the gas sample valves of the CFC/SF_6/N_2O analytical system, while the bulk flow of the air (>7 l min-1) 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 a sets of 4 or 5 measurements analyzed when possible) were 222.8 $\pm$ 5.6 parts per trillion (ppt) for CFC-11 (n=27), 497.5 $\pm$ 3.4 ppt for CFC-12 (N=37), 10.6 $\pm$ 0.2 ppt for SF6 (N=19), and 307.1 $\pm$ 12.1 parts per billion for N2O (N=18) Note that a larger aliquot was required for higher precision N_2O analysis, and this higher aliquot resulted in SF_6 peak areas outside the range of the calibration curve used for seawater samples.

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_6 and parts per billion (ppb) for N_2O. Dissolved CFC concentrations are given in units of picomoles per kilogram seawater (pmol kg-1), SF_6 in femtomoles per kilogram seawater (fmol kg-1), and N_2O in nanomoles per kilogram seawater (nmol kg-1). CFC concentrations in air and seawater samples were determined by fitting their chromatographic peak areas to multi-point calibration curves, generated by injecting multiple sample loops of gas from a working standard (UW WRS 32399) into the analytical instrument. Full-range calibration curves were run at the beginning and end of the cruise, as well as during long transits/weather delays when possible. 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. Estimated limit of detection is 2 fmol kg-1 for CFC-11, 1 fmol kg-1 for CFC-12 and 0.01 fmol kg-1 for SF_6.

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_6. Based on the re-strips of numerous samples where the stripper blank was low and relatively constant, the mean values for N_2O were approximately 5-10% during the cruise.

On this expedition, based on the analysis of 35 duplicate samples (i.e two syringe samples collected from the same Niskin), we estimate precisions (1 standard deviation) of 2.2% or 0.0031 pmol kg-1 (whichever is greater) for dissolved CFC-11, 0.58% or 0.0011 pmol kg-1 for CFC-12 measurements, 0.016 fmol kg-1 or 1.9% for SF_6 (Stations 24-90), and 1.67% or 0.27 nmol kg-1 for N_2O.

11.1 Analytical Difficulties

The major issue affecting the data quality was that SF_6 was not being fully retained on the trap at the beginning of the cruise at the initial flow rates used for stripping (200 cc min-1). It took some time to diagnose this problem as none of the other compounds were affected. While a new trap was packed, the stripping flow was reduced to 170 cc min-1 resulting in partial retention of SF_6 on the analytical trap. Peak areas for an injection of a single large gas sample loop were about 60-80 K counts during this time period. The resulting precision for SF_6 was on the order of 10% based upon duplicate samples. The SF_6 data are flagged as 3 during this time period, meaning they are of questionable quality. The trap was replaced after Station 23, and the SF_6 peak areas for the injection of the large loop increased to 380-400K counts with the precisions reported above. SF_6 data from Stations 1-23 should only be interpreted for qualitative trends.

The trap appeared to be cooling/heating unevenly for Stations 23 and 24 which affected the N_2O measurements. The temperature of the trap needs to be below -45ºC or N_2O can pass through the MS 5A.

Data quality for CFC-11 is affected by a compound which elutes slightly later from the trap into the detector. The chromatographic peaks for the two compounds are often fused. Post-cruise processing should result in higher reported precisions.

DISSOLVED ORGANIC CARBON AND TOTAL DISSOLVED NITROGEN

PI

  • Dennis Hansell (UM)

Technician

  • Abby Tinari

Analysts

  • Lillian Custals

Support NSF

12.1 Project Goals

The goal of the DOM project is to evaluate dissolved organic carbon (DOC) and total dissolved nitrogen (TDN) concentrations along the A20 zonal transect.

12.2 Sampling

DOC profiles were taken from approximately every two out of three stations from 26 of 36 Niskin bottles ranging the full depth of the water column (55 of 90 stations; ~1294 DOC/TDN samples). All samples collected above 250 meters were filtered through an inline filter holding a combusted GF/F filter attached directly to the niskin. This was done to eliminate particles larger than 0.7 μm from the sample. To reduce contamination by the filter or filter holder, a new filter and holder was used for every station. All samples were rinsed 3 times with about 5 mL of seawater and collected into combusted 40 mL glass EPA vials. Samples were fixed with 100 μL of 4M Hydrochloric acid and stored at room temperature on board. Samples were shipped back to University of Miami for analysis via high temperature combustion on Shimadzu TOC-V or TOC L analyzers.

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

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

12.3 Standard Operating Procedure for DOC analyses – Hansell Lab UM

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

Extensive conditioning of the combustion tube with repeated injection of low carbon water (LCW) and deep seawater is essential to minimize the machine blanks. After conditioning, the system blank is assessed with UV oxidized low carbon water. The system response is standardized daily with a four-point calibration curve of potassium hydrogen phthalate solution in LCW. All samples are systematically referenced against low carbon water and deep Sargasso Sea (2600 m) reference waters and surface Sargasso Sea water every 6 – 8 analyses (Hansell 1998). The standard deviation of the deep and surface references analyzed throughout a run generally have a coefficient of variation ranging between 1-3% over the 3-7 independent analyses (number of references depends on the size of the run). Daily references waters were calibrated with DOC CRM provided by D. Hansell (University of Miami; [Hansell2005]).

12.3.1 DOC Calculation

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

12.4 Standard Operating Procedure for TDN analyses – Hansell Lab UM

TDN samples will be analyzed via high temperature combustion using a Shimadzu TOC-V or Shimadzu TOC-L at an inshore based laboratory at the University of Miami. The operating conditions of the Shimadzu TOC-V were slightly modified from the manufacturer's model system. The condensation coil was removed and the headspace of an internal water trap was reduced to minimize the system's dead space. The combustion tube contained 0.5 cm Pt pillows placed on top of Pt alumina beads to improve peak shape and to resuce alteration of combustion matrix throughout the run. Carrier gas was produced with a Whatman® gas generator [Carlson2010] and ozone was generated by the TNMI unite at 0.5L/min flow rate. Three to five replicate 100 μL of sample were injected at 130 mL/min flow rate into the combustion tube headed to 680°C, where the TN in the sample was converted to nitric oxide (NO). The resulting gas stream was passed through an electronic dehumidifier. The dried NO gas then reacted with ozone producing an excited chemiluminescence NO_2 species [Walsh1989] and the fluorescence signal was detected with a Shimadzu TNMI chemiluminescence detector. The resulting peak area was integrated with Shimadzu chromatographic software. Injections continue until 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 was assessed with UV oxidized low nitrogen water. The system response was standardized daily with a four-point calibration curve of potassium nitrate solution in blank water. All samples were systematically referenced against low nitrogen water and deep Sargasso Sea

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

12.4.1 TDN calculation

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

THIRTEEN

CARBON ISOTOPES IN SEAWATER (14/13C)

PI

- Roberta Hansman (WHOI)

- Rolf Sonnerup (UW)

Technician

- Abby Tinari

A total of 288 samples were collected from stations collected along the A20 transect. 32 samples (full) each were taken from 6 of the 90 stations and 16 (partial) samples each were taken from a separate 6 of the 90 stations. Full and partial sampling alternated approximately every 6 stations. Samples were collected in 500 mL airtight glass bottles. Using silicone tubing, the flasks were rinsed 3 times with seawater. While keeping the tubing at the bottom of the flask, the flask was filled and flushed by allowing it to overflow 1.5 times its volume. Once the sample was taken, about 10 mL of water was removed to create a headspace and 100 μL of 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 shipped to WHOI for analysis.

The radiocarbon/DIC content of the seawater (DI14C) is measured by extracting the inorganic carbon as CO_2 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_2 extracted from seawater is measured relative to the 13C/12C of a CO_2 gas standard calibrated to the PDB standard using and isotope radio mass spectrometer (IRMS) at NOSAMS.

LADCP

PI

- Dr. Andreas Thurnherr

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 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 Afterand 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.

During the night watch the LADCP data were processed for horizontal velocity using the LDEO_IX processing software and for vertical velocity using the LADCP_w processing software, both installed on the acquisition computer. Important diagnostic plots were printed out, inspected, 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. Over most of the section the LADCP data quality appears to be excellent, although there is a coverage gap in the deep waters of stations 32-45 caused by insufficient acoustic backscatter due to lack of particles in the water column in the center of the subtropical gyre. Inspection of the LADCP data from the 2012 occupation of A20 indicates similar problems in the same region, which are not flagged in the archived data, however. A more comprehensive post-cruise LADCP QC will be carried out by Thurnherr in his lab before submission of the new data to the archives.
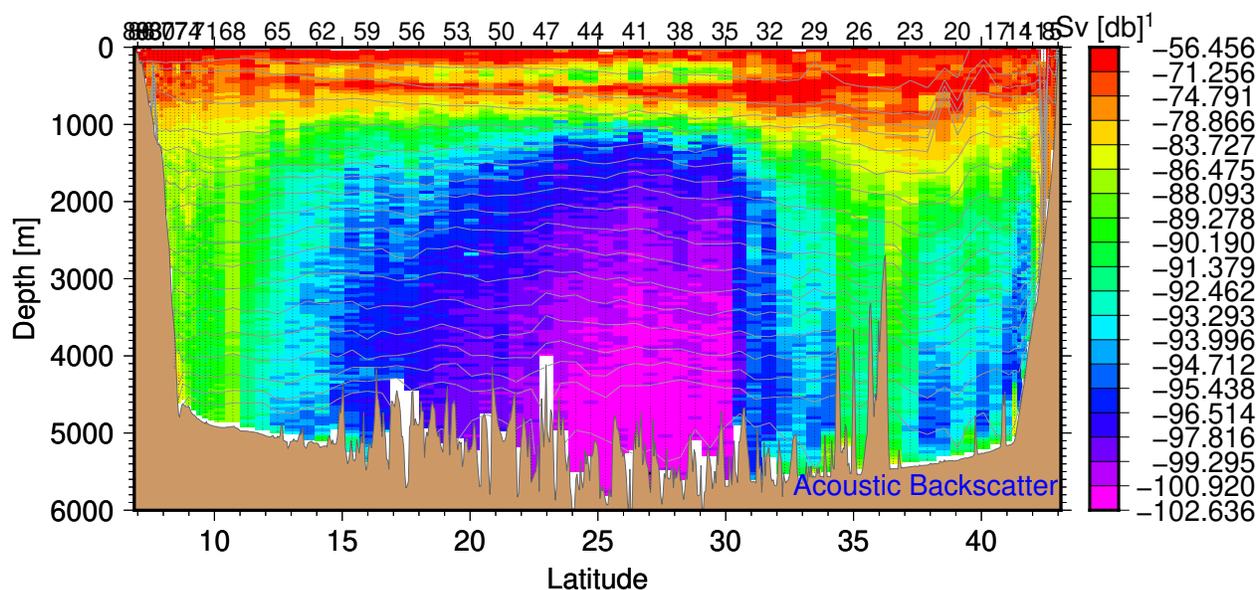
Fig. 1: Data gap caused by insufficient acoustic backscatter for stations 32-45.

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. 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.

Several different instruments were installed as downlookers during different casts. For the shakedown cast (900) a prototype Nortek Signature 100 ADCP (Sig100) was used. This instrument was provided as a loaner for testing. It was integrated into the LDEO LADCP system during pre-cruise quarantine, requiring a re-write of the data acquisition software and fabrication of an underwater adapter cable. While the instrument had performed well on the bench in Falmouth, ping synchronization stopped working reliably on the vessel. Since high-quality LADCP data can be collected without ping synchronization (requiring the detection and removal of the measurements affected by interference) the shakedown cast was carried out with the two ADCPs pinging independently. While the WH300 performed well, the Sig100 did not yield good data as indicated by bad values for zmax and zend. The instrument was therefore replaced with a 150kHz TRDI Workhorse (WH150, s/n 19394) with a recently manufacturer-refurbished transducer.

While the WH150 performed reasonably well, some of the processing diagnostic from the uplooker WH300 were noticably cleaner. Therefore, before station 18 the WH150 was replaced with a second WH300 (s/n 24497). This instrument performed very similar to the WH150, in particular showing the same (weak) anomalies in the processing diagnostics, which are therefore likely related to the installation location (about 5 feet below the pivot point of the rosette) of the downlooker instrument. As there was no apparent difference in the quality of the processed profiles before and after station 18 the WH300 (s/n 24497) was left installed until profile 31.

In the mean time the Sig100 data from the shakedown profile together with additional diagnostics were sent to the manufacturer for analysis. Nortek engineers indicated that the poor data quality was caused by electrical noise and, in particular, by a missing ground path between the electronics and the pressure case. The instrument was modified to provide such a ground path and installed again on the rosette for station 32. Since the data from this station were noticeably improved, compared to the shakedown profile, it was decided to leave the instrument on for another two profiles using different configurations (with and without ping synchronization) as well as with a different, simpler, newly fabricated underwater adapter cable lacking the synchronization connections. At the same time, a more careful analysis of the Sig100 data files was carried out, revealing that the quality of the recorded velocities was still considerably worse than those from the TRDI instruments. Therefore, the Sig100 was removed from the rosette and replaced by the WH150 used before on stations 1-17.

While this instrument performed well for a few casts its range deteriorated gradually but quite quickly to the point of not returning any bins with valid velocities at depth on station 41. The instrument was therefore replaced (again) for station 42 with the WH300 s/n 24497 which had been used before on station 18-31. While this instrument yielded very good data, several profiles showed strange echo-amplitude anomalies affecting a small number of the recorded ensembles. When, on station 52, the data from this instrument additionally contained an unexplained gap of 1.5s, it was decided to swap the downlooker with another spare (WH300 s/n 24477). This final instrument performed well and was left in place for the remainder of the cruise (profiles 53-90). While WH300 s/n 24497 is suitable as a spare it was nevertheless decided decided to ship another instrument to port in the USVI for the following cruise (A22).

While the Sig100 ADCP was not used any more, toward the end of the cruise a detailed engineering assessment of the data From the prototype Sig100 was provided by Nortek engineers, with the following summary:

Unfortunately, the instrument proved to be missing key noise-reduction hardware, including shielding plates, filter boards and ground connection, that caused noticeable range loss below 2000 m water depth. And additional issue also artificially increased the noise in the first 100-150 m. An on-site modification after the initial shakedown cruise (sic) significantly reduced the noise (correction of ground connection), but proved to be insufficient to correct all issues and reach the design specifications. However, data analysis does suggest near-instrument cells are still valid and that a properly built instrument should have a range of approximately 100 m in deep, low scattering conditions, with no velocity bias.

While this overall optimistic assessment is encouraging, additional work during post-cruise QC will be required to test the assertion that the velocity data from the near instrument cells (bins) are indeed valid.

CHIPODS

PI

- Jonathan Nash

15.1 Overview

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

15.2 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.

Logger Board SN	Pressure Case SN	Up/Down Looker	Cast Used
2018	Ti 44-2	Up	901-90
2024	Ti 44-7	Up	901-90
2032	Ti 44-15	Down	901-90

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

Fig. 2: Downward-looking chipod sensor attached to the rosette.

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

15.3 Issues

After recovering rosette on cast 02901, chipod S/N 2024 sensor end was poking out of its pressure case, with both o-rings were exposed and the interior full of seawater. Before cast 03001, the entire sensor and housing were replaced, using the same logger.

After cast 06901, the end cap for one of the chipods was lost. A replacement was printed using TGT's 3D printer.

Fig. 4: Flooded chipod with sensor separated from pressure case.

DISCRETE PCO2

PIs

- Rik Wanninkhof (NOAA/AOML)

Analysts

- N. Patrick Mears (CIMAS/RSMAS)

16.1 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 pCO2 were done with the discrete samples at 20ºC. A primary water bath was kept within 0.03ºC of the analytical temperature; a secondary bath was kept within 0.3ºC 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.

1260 samples were drawn from 63 CTD casts. 62 sets of duplicate bottles were drawn at numerous depths. The average relative standard error was 0.15%, while the median relative error was 0.09%.

An error in a USB hub connection resulted in the analysis program becoming frozen and draining one of the samples on station 9. A loose connection with the potentiometer controlling the sample water and gas flow resulted in a few delays but did not cause the loss of any samples. At the Southern most stations the surface water had measured values less than the lowest standard.
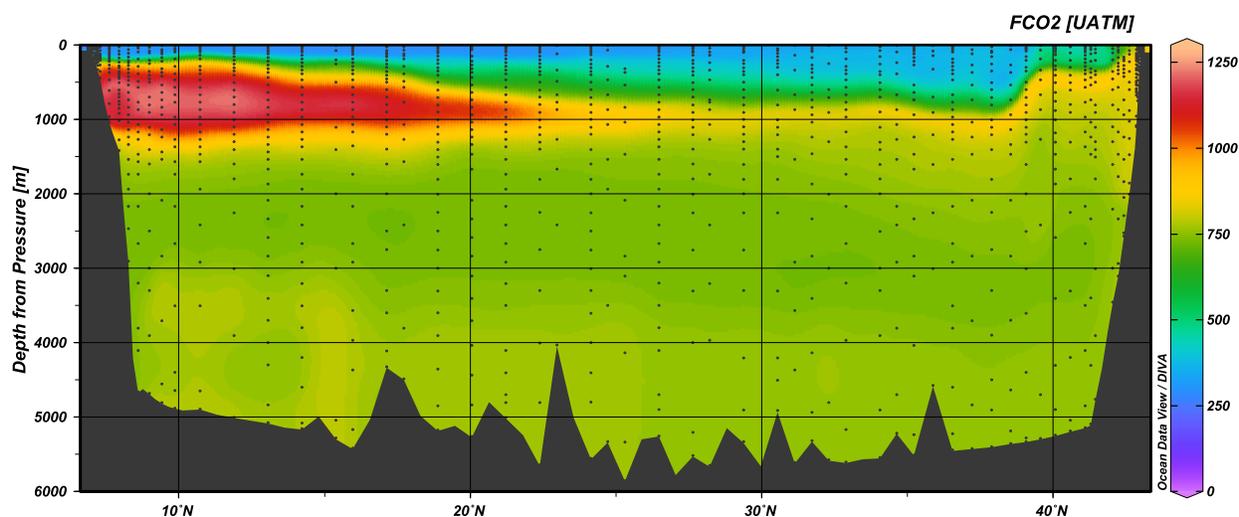
Fig. 1: fCO2 (uatm) section plot of the GO-Ship A20 section.

16.2 Underway Sampling

Underway samples were collected from the underway seawater line located in the aft wetlab that is connected to the same seawater line as the underway pCO2 system located in the hydrolab. The seawater is pumped from a bow seawater inlet located approximately 5.3 meters below the waterline through a sea chest where instruments measure and record temperature and salinity.

From the UW seawater line, 37 samples including duplicates were drawn during the transit from Port Everglades, Florida to Woods Hole and from Woods Hole to the first station.

16.3 Analyzer Description

The principles of the discrete pCO2 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 0.02ºC 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_2 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_2 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_2 program are reformatted so that a Matlab program designed for processing data from the continuous pCO_2 systems can be used to calculate the fugacity of the discrete samples at 20ºC. The details of the data reduction are described in [Pierrot2009].
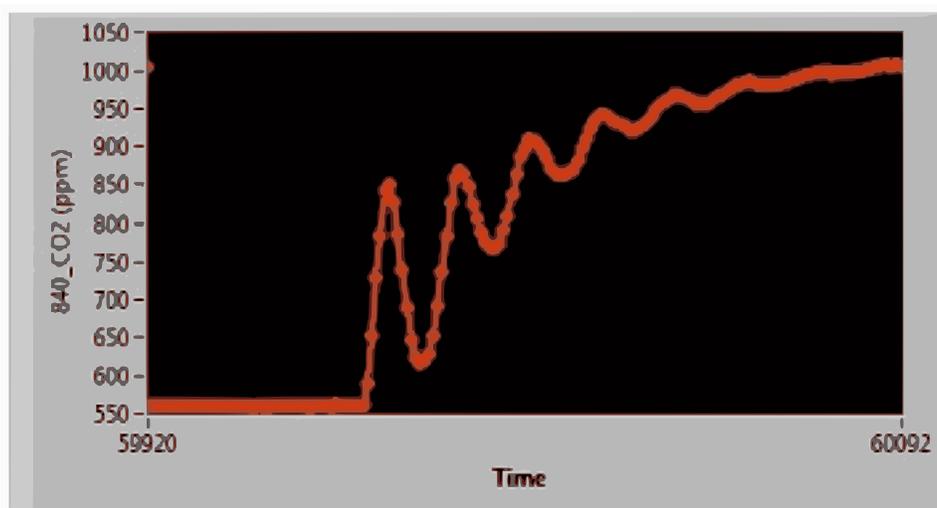
Fig. 2: CO2 oscillations during start of first sample in set of twelve

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. Francesca Alatrorre provided greatly needed assistance in collecting samples.

Table 1: Standard Gas Cylinders

Cylinder #	ppm CO_2
JB03282	288.46
JB03268	384.14
CB11243	591.61
CA05980	792.51
CA05984	1036.95
CA05940	1533.7

UNDERWAY PCO2

PIs

- Simone Alin (NOAA/PMEL)

Analysts

- Andrew Collins (NOAA/PMEL)

The partial pressure of CO2 (pCO2) in the surface ocean was measured throughout the duration of this expedition with a General Oceanics 8050 underway system.Uncontaminated seawater was continuously passed (~2.8 l/min) through a chamber where the seawater concentration of dissolved CO2 was equilibrated with an overlying headspace gas. The CO2 mole fraction of this headspace gas (xCO2) 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 CO2 concentrations certified by the NOAA Earth Science Research Laboratory in Boulder, CO ranging from ~300 – 900 ppm CO2. Additionally, a tank of 99.9995% ultra-high purity nitrogen gas was measured as a baseline 0% CO2 standard. Following measurements of standard gases, six measurements of atmospheric xCO2 were made of air supplied through tubing fastened to the ships 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) CO2 standard. In addition to measurements of seawater xCO2, atmospheric xCO2, 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 pCO2 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 pCO2 system. An Aanderaa 4330 optode plumbed in line with the pCO2 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.

During the transit from Woods Hole to the first hydrographic station, discrete samples (n=37) for measurements of dissolved inorganic carbon, total alkalinity, pH, DO, nutrients (nitrate, nitrate, silica, phosphate), and salinity were drawn from the ships uncontaminated seawater supply every four hours. These were analyzed onboard and will be used for comparison to measurements collected by the underway system.

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 two brief instances, the underway system was shut down for minor maintenance to be performed. During our initial transit to the first CTD station, the system was shut down while passing through the Canadian Exclusive Economic Zone. A ~12-hour data gap occurred (20-March) when the cable sending the ship's SCS data (position, intake temperature, etc) was loose; this data will be recovered and merged with the dataset during the next round of processing. Of 13,056 measurements, four were assigned a WOCE quality flag of 4 (bad measurement), while none were assigned a quality flag of 3 (questionable measurement) during this initial round of processing. Measurements of gas standards were within 1% of their certified value throughout the duration of the expedition, save for one brief 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 pCO2, pH and DO were measured during the brief

time spent on the continental shelf near the coast of South America, where extremely low values of pCO2 were measured. Concomitant changes were observed in pH, DO, DIC, and other variables. The likely causes of these low values are likely due to dilution of seawater by riverine input (e.g. Amazon; surface salinities dropped below 20 PSU), and potentially by fixation of dissolved carbon via primary production. However, further evaluation of these data and the supplementary suite of discrete measurements that were collected is needed before the controls on pCO2, 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.
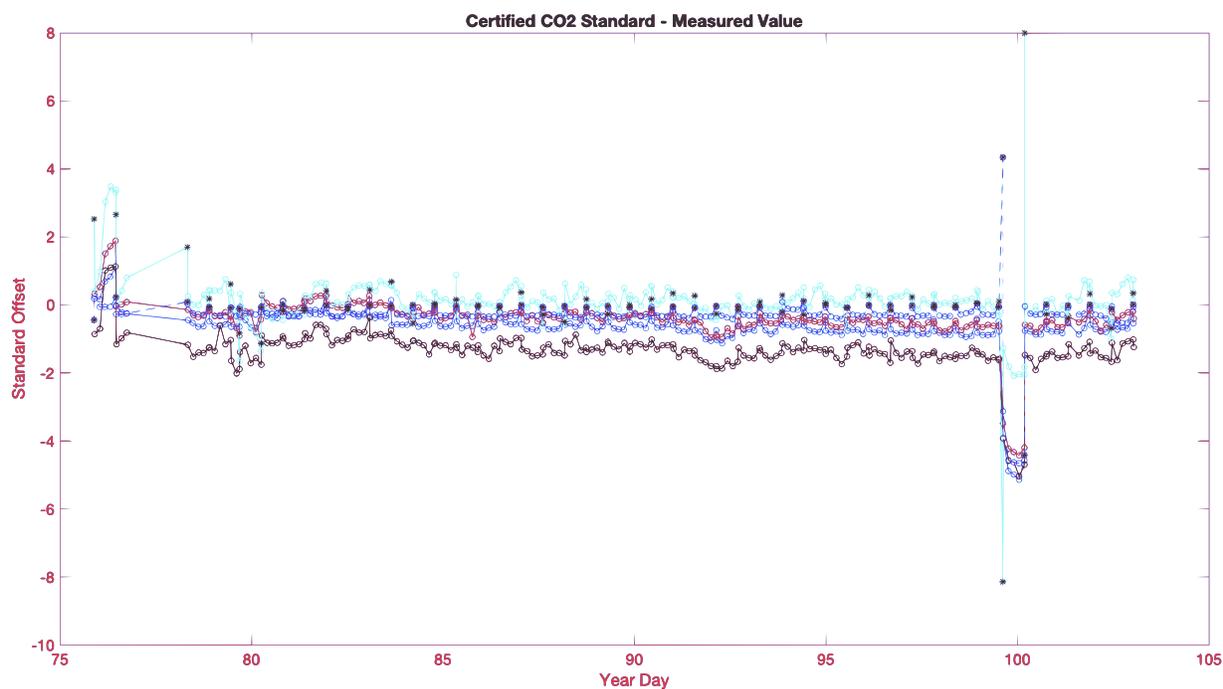
Fig. 1: Difference between measurements made by the non-dispersive infrared analyzer (Licor 7000) of gas standards and the known certified value of those standards (in ppm CO2).
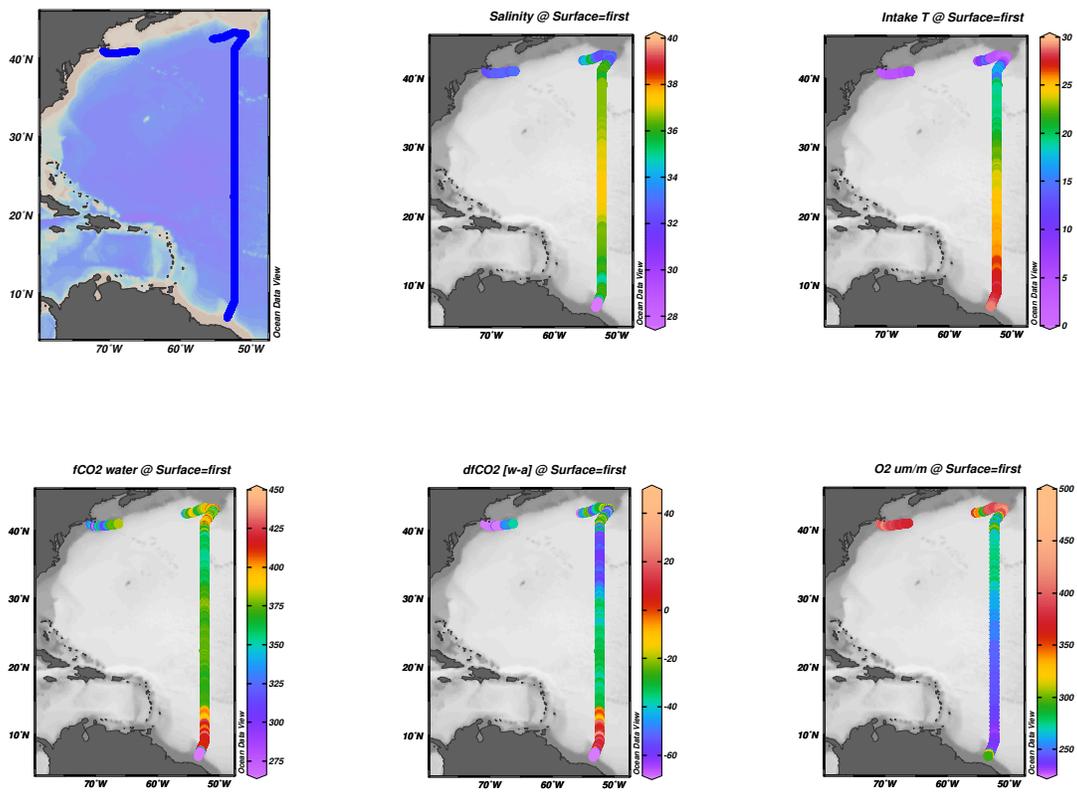
Fig. 2: Spatial distribution of the relevant parameters (sea surface temperature [SST, oC], sea surface salinity [PSU], fCO2 [ppm], pH, and DO [M]) measured by the underway pCO2 system during the 2021 GO-SHIP A20 research expedition.

FLOAT DEPLOYMENTS

18.1 GO-BGC Argo Floats

PIs:

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

Shipboard personnel:

- Andreas Thurnherr (LDEO)
- Elizabeth Ricci (UW SSSG)
- Stephen Jalickee (UW SSSG)
- Stephanie O'Daly (UAF)

8 biogeochemical (BGC) Argo floats were deployed on A20 as part of the Global Ocean Biogeochemistry (GO-BGC) program (https://go-bgc.org), which is funded by NSF Award 1946578. These BGC Argo floats on A20 were the first in this 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. Data are freely available through the Argo data portals and from the GO-BGC website. BGC-Argo floats are helping to resolve seasonal cycles of many key properties that are relevant to global biogeochemical processes.

The Atlantic sector for GO-BGC is led by the WHOI Argo group (Susan Wijffels, Roo Nicholson; planning Pelle Robbins), who planned the float deployment locations to span the length of both A20 and A22.

The floats have a 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 the 10-day drift, the floats dive to 2000 m and then ascend to the surface, during which data are measured and saved. The 2000 m-surface data profiles are then sent to shore via Iridium Satellite communication, using an antenna located at the top of the float. The floats deployed were UW-modified Teledyne Webb Apex floats. The floats are equipped with CTD, oxygen, nitrate, FLBB bio-optical, and pH sensors.

These 8 floats and 4 additional floats for the subsequent A22 voyage were readied at U. Washington (S. Riser Argo lab), and shipped to Woods Hole Oceanographic Institution (WHOI). In Woods Hole, UW Argo engineer Greg Brusseau tested each float prior to loading on R/V Thompson. WHOI provided excellent high-bay lab space with an adjacent outdoor parking lot where it was possible to test the floats, to satisfy the Covid19 pandemic isolation requirements.

Before the deployment of each float, the FLBB and the nitrate sensors were carefully cleaned using lens wipes, DI water and lens paper. The floats are self-activating, so no initial operations were required before their deployment to activate them. Co-chief scientist Andreas Thurnherr and Thompson marine technicians Elizabeth Ricci and Stephen

Jalickee were in charge of the GO-BGC float deployments. Additional assistance was provided by Stephanie O'Daly and the ABs on watch. The procedure required the use of a line strung through the deployment collar of the float. Each deployment occurred off the fantail while the ship was steaming at about 2 knots. Deployments were smooth with the exception of float 5906440 (UW ID 19107), during which the line tangled and the float was freed with a hook; a slight line hangup also occurred for float 5906434 (UW ID 19970).

Float deployments occurred after the completion of a CTD station. For all deployments, samples of nutrients, salinity, POC/HPLC, DIC, pH and alkalinity were taken at each depth, at least down to 2000 m. The HPLC and POC samples were taken from Niskin bottles tripped as duplicates, at the surface and at the chlorophyll maximum depths (DCM), or the base of the mixed layer if the DCM was not present. The samples were filtered by SIO/ODF team (Susan Becker and Alexandra Fine), and will be sent frozen to the U.S. for analysis (NASA for HPLC and SIO/UCSD for POC).

The floats were adopted by different schools and organizations in the U.S. as part of the outreach program "Adopt-a-float" (https://www.go-bgc.org/outreach/adopt-a-float). Each class named the float and received the details (and pictures) of their deployment from Andreas Thurnherr, via GO-BGC personnel onshore George Matsumoto (MBARI). Together with their teachers, the students will follow the float data, which can be easily downloaded and plotted from the website.

Seven of the floats began reporting data immediately, beginning with the engineering profile followed within a day by the first profile. The second float deployed (5906341, UW ID 19061) reported its engineering profile, but has not produced full profiles as of the end of the cruise. It appears that all sensors are working well, with the exception of pH on float 5906343 (UW ID 19881), which provided only a partial first profile. This was not related to issues with the float deployment.

The location and date of the float deployments are indicated in the table below, with WMO and UW ID numbers and the CTD cast at the deployment location.

Table 1: Summary of deployment details for the GO-BGC profiling floats.

WMO ID	UW ID	Longi-tude	Lati-tude	Date and Time (UTC)	CTD Station #	Comments	Deployer
5906342	19142	-52.33	40.0657	03/24/2021 2347	18	Clean	Stephen Jalickee
5906341	19061	-52.33	35.8859	03/27/2021 0800	25	Clean; No first profile	Elizabeth Ricci
5906440	19107	-52.33	31.66	03/29/2021 1240	32	Line tangled	Elizabeth Ricci
5906435	19512	-52.33	27.64	03/31/2021 1515	39	Clean	Elizabeth Ricci
5906340	19364	-52.33	24.14	04/02/2021 1215	45	Clean	Elizabeth Ricci
5906339	19588	-52.33	20.06	04/04/2021 1340	52	Clean	Elizabeth Ricci
5906343	19881	-52.33	15.97	04/06/2021 1400	59	Clean; pH partial	Elizabeth Ricci
5906434	19970	-52.33	11.89	04/08/2021 1425	66	Clean	Elizabeth Ricci

18.2 Core Argo Floats

PIs

- Susan Wijffels (WHOI)

- Steven Jayne (WHOI)

- Pelle Robbins (WHOI)

A total of 7 core Argo floats were deployed on this cruise. Co-chief scientist Andreas Thurnherr and Thompson marine technicians Elizabeth Ricci and Stephen Jalickee were in charge of the deployments. Additional assistance was provided by Stephanie O'Daly and the ABs on watch. All floats were deployed without problems using instructions provided by Jessica Kiosk and at the locations provided before the cruise by Pelle Robbins(WHOI Argo group).

Table 2: summary of the deployment details of the Core Argo floats

ID	S/N	Date	Time	CTD Station	Latitude	Longitude	Water Depth
A1	7617	04/01	0625	41	26.47N	52.33W	5200m
A2	7667	04/05	0330	54	18.89N	52.33W	5153m
A3	7625	04/05	2351	57	17.14N	52.33W	4300m
A4	7601	04/06	2106	60	15.39N	52.33W	5270m
A5	7602	04/06	1100	62	14.22N	52.33W	5170m
A6	7626	04/08	0043	64	13.06N	52.33W	5100m
A7	7605	04/09	0420	68	10.71N	52.33W	4910m

SOFAR DRIFTER DEPLOYMENTS

A total of 11 Sofar Ocean Technologies "Spotter" drifters were deployed on this cruise (Table 1). Co-chief scientist Andreas Thurnherr and Thompson marine technicians Elizabeth Ricci and Stephen Jalickee were in charge of the deployments. Additional assistance was provided by Stephanie O'Daly and the ABs on watch. The drifters were deployed by dropping them over the side with the vessel in motion.

The following description of the drifter program has been provided by Sofar Ocean Technologies: 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 globnal network publically 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

ID	S/N	Date	Time	Station	Latitude	Longitude	Depth
D1	1197	03/24	0730	16	41.10N	52.33W	5120m
D2	1191	03/24	2337	18	40.07N	52.33W	5220m
D3	1181	03/25	1509	20	39.08N	52.23W	5280m
D4	1192	03/26	0645	22	37.89N	52.33W	5350m
D5	0442	03/26	0350	23	37.22N	52.34W	5370m
D6	1195	03/27	0759	25	35.88N	52.33W	4450m
D7	1190	03/27	1555	26	35.22N	52.33W	5460m
D8	1188	03/28	0624	28	34.05N	52.33W	5050m
D9	1184	03/28	2136	30	32.89N	52.33W	5560m
D10	1170	03/29	1949	33	31.14N	52.34W	5560m
D11	1193	03/31	0040	37	28.81N	52.33W	5110m

SARGASSUM

PI

- Dennis McGillicuddy

20.1 Overview

Occupation of GO-SHIP lines A20 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. A20 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.

20.2 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.

TWENTYONE

MARINE MICROGELS

PI

- Dennis Hansell

Marine microgels are poorly understood, small particulate entities in the ocean. In terms of abundance, they are commonly micron size and smaller. Their formation is by self-assembly and ionic bridging between organic macromolecules. Their role and dynamics in the ocean are only poorly known, but they are prospectively a sink for high molecular weight dissolved organic matter, making that material available as small particles as a substrate for heterotrophic microbes. Few oceanic distributions have been established for microgels, yet it is from distributions that controls can be inferred. Samples are being taken at 3 locations (two stations each) during the current (2021) occupation of A20 in the North Atlantic. These data, in the context of hyrographic and DOC data, will provide more insights on the pool.

NITRATE δ^{15}N AND δ^{18}O

PI:

- Daniel Sigman (Princeton University)

Samplers:

- Francesca Alatorre

- Cassondra DeFoor

- Paige Hoel

- Elana Perez

Nitrate (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 NO_3^- (δ^{15}N and δ^{18}O) record biogeochemical and physical processes on different time scales. In general, nitrate consuming processes tend to raise the δ^{15}N and δ^{18}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°C in order to preserve them for land based analysis.

22.1 Analysis

The denitrifier method [Casciotti2002] [Sigman2001] will be used to analyze NO_3^-, δ^{15}N, and δ^{18}O. Briefly, this method converts all NO_3 to nitrous oxide (N_2O) via denitrifying bacteria before the sample is analyzed by an IRMS. Samples were collected at stations 9, 16, 19, 22, 24, 28, 33, 38, 44, 46,49, 51, 54, 56, 59,62, 64, 67, 69, 77, 88. At station 9 a problem with the CTD cable prevented bottles from tripping in the upper 100 m, therefore samples for the upper 100 m were collected on station 10.

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.

23.1 Francesca Alatorre

My experience aboard the R/V Thomas G Thompson for the US-GO SHIP, leg A20 has been one of the most exciting adventures of my academic career. Over the course of a little over a month, I have learned about the nuances of hydrographic and oceanographic research and how my interest in this field of research continues to grow steadily. I worked on board the R/V TGT as a CTD watchstander. My daily duties included: preparing the CTD rosette for launch while on predetermined station coordinates, monitoring the CTD package's decent and using its software to sample water at various depths, sampling salinity and pCO2 from up to 36 bottles and depths, and maintaining console and sample logs that detail important information from each cast. In the beginning, I was extremely intimated by the intricacies of the general CTD operations; it was quite a lot to take in. But I was incredibly lucky to be on the night shift with the CTD analyst who previously was a watchstander himself, and he walked me through all procedures until I was comfortable myself with fulfilling my duties.

Although over the course of this GO SHIP cruise, my belonging was questioned several times in regards to being the only undergraduate (from a university not known for their oceanography research) and among the few people of color aboard. The frequency of the microaggresions were unfortunately occurring on a daily basis by the other researchers on board. Regardless of the combined and deliberate effort to put me down and intimate me as a scientist and future researcher, I feel even more affirmed on my path to become an oceanographer. This experience has also afforded me the opportunity to meet some incredible, caring, and wonderful people that added to this journey rather than detract. Overall, this journey was an incredible learning experience about the Atlantic Ocean and about the details of how hydrography data is analyzed, collected, and processed; especially with the use of CTD rosette/package for collection. I sincerely hope to soon be able to work again on a research vessel like the R/V Thomas G. Thompson in the near future.

23.2 Cassondra DeFoor

I sailed on the Thomas G. Thompson from Woods Hole, Massachusetts to St. Thomas, US Virgin Islands on the A20 leg for US GO-SHIP. All of the crew members had to quarantine two weeks prior to boarding due to the COVID-19 pandemic. We boarded this ship eager to break our social isolation and collect samples from the Northern Atlantic on March 15th, 2021. I held the position of a CTD watch/stander for my first journey at sea. My duties included preparing the Niskin bottles and rinsing the sensors to the various instruments on the rosette prior to each cast, communicating with the winch operators to lower the rosette to ten meters above the ocean floor and then to each consecutive depth where we would close a Niskin bottle, ensuring that oxygen sensitive samples such as chlorofluorocarbon, oxygen, partial pressure of carbon dioxide, dissolved inorganic carbon, and pH, were sampled within 15 minutes of depressurizing each bottle, and taking samples for salinity analysis. This was the ideal position to introduce me to the world of oceanographic cruises. I learned valuable information about how samples are taken, what data is regularly monitored, and how to care for a Rosette, CTD, and Niskin bottles. I quickly realized it takes a village to make an oceanographic cruise successful and each person on ship has a vital job. It was also a great opportunity for me to learn about the field through masters and doctoral students, professional oceanographers, and the ship crew who spend a large portion of their time at sea.

Aside from the science, I enjoyed the serenity and easy-going nature of life at sea. We were very lucky to not have experienced much rough weather which made for an enjoyable journey. I spent much of my time disconnected from the internet and instead reading, playing solitaire and cribbage, and learning how to tie knots. Some of my favorite memories include visiting the bridge to watch the bow nod along with the waves, doing yoga outside on the stern on a sunny day, and playing the various records on the record player in the computer lab. Going to sea is an essential part of this career so I am grateful to have had the opportunity to sail on a US GO-SHIP leg this early in my journey. It solidified my desire to continue my pursuit as a chemical oceanographer. I hope that this is the first of many cruises that I take part in during my career.

23.3 Paige Hoel

I don't know when exactly the GO SHIP A20 cruise began to feel like home. I retrace my steps to the first day on the ship, when I got lost finding my stateroom and did seemingly endless circles through the doors and staircases and hallways all over the ship. It didn't feel like home then. But hours later, I knew I was in the right place at the right time.

Being around the scientists, the crew, the blue and endless ocean, just felt right. Like so many others on this cruise, I was coming out of my entirely remote and virtual new world of science, excited to interact with others for the first time, not just scientifically, but socially, for the first time in a while. As I spoke to everyone about their research, bit by bit I began to understand how unique and wonderful oceanographic cruises are. I was not only in an environment where I could nerd out about the ocean, but where everyone else around me was actively doing so. Socially, intellectually, scientifically, this cruise seems to have really been a goldilocks just right scenario. I am typing this in the main lab, listening to a sink gurgling and the alkalinity system breathing. I am home.

I can not yet say with certainty what this cruise has meant to me. I first dreamed of going on an oceanographic cruise around four years old. It was a national geographic documentary about oceanographer Robert Ballard that sparked my imagination in oceanography, and desire to do the science at sea. My love for oceanography grew with me. I applied to many cruises as an undergraduate and graduate student. No luck. I pressed on.

My fascination found a happy home in the world of biogeochemical modeling. My graduate studies found a happy home at UCLA in the Atmospheric and Oceanic Science department. Although I was fulfilled and fascinated by my research on waste water modeling and phytoplankton models, I felt a slight twang of melancholy when other oceanographers would speak about their times at sea, cruises both upcoming and past. My desire to go never faded, but my understanding of what types of oceanographers actually need to go on these cruises broadened. Modelers don't need to go on cruises. In fact, one of the primary purposes of modeling is to create data in the absence of direct observations. Why on earth would I NEED to go on a cruise?

The opportunity to be a CTD watch stander popped up on our lab groups slack channel. I spoke to my advisor, who

said any oceanographer, no matter their specific discipline, can glean so much from a cruise. I applied, I was accepted, and now I am at the end of this journey I have dreamed about for the last 21 years.

The tasks have felt a little mindless at times. The CTD watch stander does not need to think critically. But the role is mission critical, and I am endlessly thankful for the opportunity to have been at the intersection of scientists, crew, and our shared love, the ocean. As a watch stander I coordinated depths, samples, and paid attention to every small detail needed to ensure great samples. Without great samples, the scientific mission of the cruise cannot be met. Even if I had a tiny influence in making those amazing measurements, I am immensely proud.

GO SHIP provided me the opportunity to see the full lens of oceanography, the beautiful challenge of creating a snapshot of one piece of water, and given me a deep and profound appreciation for each carbon measurement I have ever used. GO SHIP gave me a home, an oceanographic home, in the middle of the Atlantic, moving at a speed of 12 knots, down 52.33 degrees west.

23.4 Carla Mejías-Rivera

Towards the end of my doctoral studies, I applied to the GO-SHIP A20 cruise eager to acquire additional knowledge in the field of chemical oceanography and to experience what is like to participate in a research expedition in open ocean. As a Chemist, I was especially interested to work with the CFC/SF6 tracers group. I was sure that having this opportunity was going to help me expand my knowledge in the field by learning a new research topic and providing me with numerous experiences that will surely clarify and open new options for my future in the field of oceanography.

My duties during the expedition consisted of collecting and analyzing water samples for CFC-12, CFC-11, SF_6 and N_2O. Sample collection for tracers was a completely new experience for me. Instead of collecting seawater into bottles, these samples are collected into a 250ml glass syringe, employing special care to avoid even the smallest bubble, since bubbles can alter the tracers' analysis. This was a challenging skill to acquire at the beginning but once learned, sampling was very fun. Samples in the syringes were then taken to the lab for analysis. They were injected, one at a time, into an instrument that extracts the tracers from the sample, separates, concentrates, and sends them into three different gas chromatographers. After processing, I had the opportunity to view the profiles and learn how to interpret the fundamental features. While looking at the data profiles and visually comparing them to the previous GO-SHIP expedition in the same transect (2012), we could not avoid seeing ourselves as "translators" of the ocean's message through chemical analysis... isn't it wonderful!?! So many stories can be told by looking at this data, some could serve as lessons learned, others could bring hope, but all equally fascinating.

While at sea, having the opportunity to meet other scientists and crew and get to know their work was overall very enriching and exciting. This opportunity was not only great for my professional development but also personally fulfilling. I am very grateful for all the people that made this possible, for those who shared their knowledge, for the amazing human beings I met, for all the lessons learned, and for the time I spent onboard the R/V Thomas G. Thompson.

23.5 Elena Perez

The past 4 weeks at sea sailed by oooweee! From March 16 to April 16, 2021 I've learned many a valuable lesson while onboard the R/V Thompson for the A20 line of US GO-SHIP cruises. Most importantly, I learned that being a CTD watchstander does not mean we have to stand for 12 hours a day. In fact, most of our work was done sitting in the computer lab: monitoring CTD casts and talking with the winch operators. When we weren't in the computer lab, we were usually in the staging bay. One of us would be helping sample salts/nitrates/pCO2. And the other person had to take on the tough duty of sample cop. Responsibilities of sample cop include: wrangling scientists into line, making sure there was enough water in the Niskin bottles for all of us, and prepping that there CTD for the next cast.

Overall, this experience has given me valuable insights into field work of oceanography. As an incoming graduate student, it's been great to observe with my own eyes the physics, biology, and chemistry of the oceans that I'll likely be learning about this fall 2021 in classrooms.

Beyond the science, I immensely enjoyed boat life (except when I was missing the creature comforts of life on land, e.g. dogs, good WiFi connection, etc.). I've listed below some of the best parts of boat life, in my opinion, in no particular order.

1) The best stargazing I've ever beared witness to. When you're 1,000+ miles from land with very very dark skies you're bound to see the Milky Way, a few satellites, and a handful of shooting stars if you stay out long enough

2) The sunrises everyday convinced me that night shift is way better than day shift. I've never seen so many sunrises in a row, and never seen a sunrise with 360º views all around.

3) Playing cribbage during downtime/when our shift was over. Cribbage is now the unofficial game of the R/V Thomas G. Thompson.

4) Decorating and watching the deployment of 8 of the first-ever biogeochemical Argo floats.

5) The bluest water I've ever seen. I loved sitting on the stern (or the bow, I'm not picky) and just watching the water and sargassum go by

6) Emptying all the Niskin bottles after everyone is done sampling.

7) All the birds. Although I haven't seen an albatross yet :/ I might just have to go on another cruise so I can catch a glimpse of one of these legendary birds

ABBREVIATIONS

ADCP Acoustic Doppler Current Profiler

AOML Atlantic Oceanographic and Meteorological Laboratory

AP Particulate Absorption Spectra

APL Applied Physics Laboratory

ASC Antarctic Support Contract

BAS British Antartic Survey

BGC Biogeochemical

Bigelow Bigelow Laboratory for Ocean Sciences

CDOM Chromophoric Dissolved Organic Matter

CFCs Chlorofluorocarbons

CIMAS Cooperative Institute of Marine and Atmospheric Science

CTDO Conductivity Temperature Depth Oxygen

DIC Dissolved Inorganic Carbon

DOC Dissolved Organic Carbon

ECO Edison Chouest Offshore

ENSTA ENSTA ParisTech

ETHZ Eidgenössische Technische Hochschule Zürich

FSU Florida State University

GO-BGC Global Ocean Biogeochemistry Array

HPLC High-Performance Liquid Chromatography

LDEO Lamont-Doherty Earth Observatory - Columbia University

LADCP Lowered Accoustic Doppler Current Profiler

MBARI Monterey Bay Aquarium Research Institute

MIT Massachussetts Institute of Technology

N2O 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$_6$ Sulfur Hexafluoride

SIO Scripps Institution of Oceanography

SOCCOM The Southern Ocean Carbon and Climate Observations and Modeling project. http://soccom.princeton.edu/

STS Shipboard Technical Support - *SIO*

TAMU Texas A&M University

TDN Total Dissolved Nitrogen

UArizona University of Arizona

U ALASKA University of Alaska

UCI University of California Irvine

U Colorado University of Colorado

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 Brüssel

WHOI Woods Hole Oceanographic Institution

Appendix A. Abbreviations

BOTTLE QUALITY COMMENTS

Sta-tion	Cast	Bottle	Param	Code	Comment
1	1	6	SALNTY	3	fresh, may be early closure
1	1	6	REFTMP	3	warm, rosette winched upward before acquisition finished
2	1	4	SALNTY	3	salty, may be early closure. bottle was leaking
4	1	12	SALNTY	3	much fresher than 13 (fired ~same depth), may be mis-sampled from bottle 14
5	1	2	SALNTY	3	fresh, may be late closure
5	1	5	SALNTY	3	a bit fresher than neighbors, may be late closure
5	1	32	REFTMP	3	warm, measurement may include air temp
6	1	11	SALNTY	3	fresh, may be late closure
6	1	12	SALNTY	3	fresh, may be late closure
6	1	31	SALNTY	3	salty, may be early closure
6	1	33	REFTMP	3	cold, insufficient stop time in gradient, may include air temp
7	1	4	SALNTY	3	salty, may be early closure or sampling error
7	1	11	SALNTY	3	fresh, may be late closure
8	1	1	SALNTY	3	salty, may be sampling error
8	1	32	REFTMP	3	warm, insufficient stop time in sharp gradient
9	1	22	REFTMP	3	warm, insufficient stop time in sharp gradient
9	1	30	SALNTY	3	salty, may be late closure. started having comms errors shortly after
10	1	2	SALNTY	3	fresh, may be sampling error
10	1	29	SALNTY	3	fresh, may be early/late closure or insufficient stop time
10	1	33	SALNTY	3	fresh, may be late closure or insufficient stop time
10	1	33	REFTMP	3	high variability, insufficient stop time in sharp gradient
10	1	34	SALNTY	3	fresh, may be late closure or insufficient stop time
10	1	35	SALNTY	3	fresh, may be late closure or insufficient stop time
11	1	35	SALNTY	3	very salty, may be early closure or insufficient stop time
11	1	35	REFTMP	3	cold, high variability, insufficient stop time in sharp gradient
12	1	1	SALNTY	3	salty, may be early/late closure or sampling error
12	1	8	SALNTY	3	salty, likely sampling error. autosal had difficulty finding good reading

Table 1 – continued from previous page

Station	Cast	Bottle	Param	Code	Comment
12	1	32	SALNTY	3	fresh, may be late closure or insufficient stop time
12	1	32	REFTMP	3	cold, rosette winched upward before acquisition finished
12	1	35	SALNTY	3	salty, may be early closure or insufficient stop time
13	1	3	SALNTY	3	salty, may be early/late closure or sampling error
13	1	6	SALNTY	3	salty, may be late closure
15	1	4	Bottle	4	Nutrients and O2 do not appear to fit the profilei; mistrip
16	1	1	SALNTY	3	salty, may be early/late closure
18	1	2	SALNTY	3	salty, may be early or late closure
18	1	12	SALNTY	3	salty, may be late closure
18	1	22	SALNTY	3	too fresh, may be early closure
18	1	28	Bottle	4	Nutrients and O2 do not appear to fit the profilei; mistrip
18	1	28	SALNTY	3	too salty, may be late closure
21	1	13	SALNTY	4	considerably lower than all other samples, likely sampling error
21	1	32	Bottle	4	Nutrients and O2 do not appear to fit the profilei; mistrip
21	1	32	SALNTY	4	possibly early closure or sampling error
24	1	5	SALNTY	3	fresh, may be early closure
25	1	1	SALNTY	3	salty, may be early closure or sampling error
25	1	34	SALNTY	4	extremely fresh for surface, may be an early closure
26	1	20	SALNTY	3	fresh, autosal had trouble finding value
27	1	25	Bottle	4	Nutrients and O2 do not appear to fit the profilei; mistrip
30	1	1	SALNTY	3	salty, may be early/late closure or sampling error
30	1	24	SALNTY	3	fresh, may be early closure or insufficient stop time
31	1	9	SALNTY	3	salty, may be late closure
31	1	32	Bottle	4	O2 draw temp low; nutrients do not fit profile; mistrip
31	1	32	SALNTY	3	way too fresh, suspect early closure
33	1	12	SALNTY	3	salty, may be late closure
34	1	9	Bottle	4	Salt and nutrients appear to match bottle 10; likely mistrip
34	1	9	SALNTY	3	salty, may be late closure
35	1	1	SALNTY	3	salty, may be early or late closure
35	1	11	SALNTY	3	salty, may be late closure
36	1	3	SALNTY	3	salty, may be late closure
36	1	31	SALNTY	3	fresh, may be early closure or insufficient stop time at high gradient
36	1	31	REFTMP	3	cold, insufficient stop time in sharp gradient
38	1	9	SALNTY	3	salty, may be late closure or sampling error
38	1	23	REFTMP	3	warm, rosette winched upward before acquisition finished
39	1	31	SALNTY	3	salty, may be late closure
40	1	2	Bottle	4	nutrients do not fit profile; mistrip
40	1	2	SALNTY	3	too salty, likely early or late closure

Table 1 – continued from previous page

Sta-tion	Cast	Bottle	Param	Code	Comment
41	1	36	SALNTY	3	very fresh, may be early closure
43	1	4	SALNTY	3	fresh, may be early closure
43	1	30	Bottle	4	CTD coms issue; bottle closed at unknown depth
43	1	31	Bottle	4	CTD coms issue; bottle closed at unknown depth
43	1	32	Bottle	4	CTD coms issue; bottle closed at unknown depth
43	1	33	Bottle	4	CTD coms issue; bottle closed at unknown depth
43	1	34	Bottle	4	CTD coms issue; bottle closed at unknown depth
43	1	35	Bottle	4	CTD coms issue; bottle closed at unknown depth
44	1	1	SALNTY	3	salty, may be early closure or sampling error
45	1	2	Bottle	4	O2 draw temp high; nutrients do not fit profile; mistrip
45	1	2	SALNTY	4	very salty, unclear if early or late closure. bottle was much warmer than 1 or 3
45	1	4	SALNTY	3	fresh, may be early closure
46	1	24	SALNTY	3	fresh, may be early closure or insufficient stop time
48	1	2	Bottle	4	O2 draw temp high; oxygen does not fit profile; mistrip
48	1	2	SALNTY	4	far too salty, likely closed early
49	1	31	SALNTY	3	fresh, may be early closure
50	1	14	SALNTY	3	salty, may be late closure. autosal had trouble finding value
52	1	8	SALNTY	3	salty, may be late closure or sampling error
53	1	30	SALNTY	3	fresh, may be early closure
53	1	33	SALNTY	3	salty, may be early closure
54	1	25	SALNTY	3	fresh, may be early closure
54	1	30	SALNTY	3	salty, may be late closure
55	1	29	SALNTY	3	fresh, may be early closure or insufficient stop time
56	1	3	SALNTY	3	salty, may be late closure
56	1	10	Bottle	4	Bottle did not close
56	1	20	REFTMP	3	warm, rosette winched upward before acquisition finished
56	1	22	REFTMP	3	warm, rosette winched upward before acquisition finished
56	1	32	SALNTY	3	salty, may be early closure or insufficient stop time
57	1	23	SALNTY	3	fresh, may be early closure or insufficient stop time
59	1	8	SALNTY	3	salty, may be late closure
59	1	21	SALNTY	3	fresh, possible early closure or mis-sampled
59	1	28	SALNTY	3	fresh, early closure or insufficient stop time
60	1	7	SALNTY	3	salty, may late closure. autosal had trouble finding value
60	1	31	SALNTY	3	fresh, early closure or insufficient stop time
60	1	32	SALNTY	3	salty, early closure or insufficient stop time
61	1	31	SALNTY	3	fresh, early closure or insufficient stop time
61	1	35	SALNTY	3	salty, may be early closure
62	1	30	SALNTY	3	fresh, early closure or insufficient stop time
63	1	2	SALNTY	3	salty, early/late closure or mis-sampled
63	1	27	SALNTY	3	fresh, may be early closure or insufficient stop time
63	1	29	SALNTY	3	fresh, may be early closure or insufficient stop time
63	1	31	SALNTY	3	fresh, may be early closure or insufficient stop time

Table 1 – continued from previous page

Sta-tion	Cast	Bottle	Param	Code	Comment
63	1	32	SALNTY	2	salty, may be early closure or insufficient stop time
64	1	26	SALNTY	3	too salty, likely late closure or mis-sampled
64	1	31	SALNTY	3	fresh, may be early closure or insufficient stop time
64	1	33	SALNTY	3	fresh, may be late closure
65	1	29	SALNTY	3	fresh, may be early closure or insufficient stop time
65	1	30	SALNTY	3	fresh, may be early closure or insufficient stop time
65	1	31	SALNTY	3	fresh, may be early closure or insufficient stop time
66	1	2	Bottle	4	O2 draw temp high; oxygen does not fit profile; mistrip
66	1	2	SALNTY	3	far too salty, late or early closure or mis-sampled
66	1	29	REFTMP	3	warm, rosette winched upward before acquisition finished
66	1	30	SALNTY	3	fresh, may be late closure or insufficient stop time
67	1	2	SALNTY	3	sampler error, unclear what order these were actually sampled in
67	1	3	SALNTY	3	sampler error, unclear what order these were actually sampled in
67	1	4	SALNTY	3	sampler error, unclear what order these were actually sampled in
67	1	11	SALNTY	3	salty, may be late closure or mis-sampled
67	1	12	SALNTY	2	fresh, may be early closure or mis-sampled
67	1	30	SALNTY	3	fresh, may be early closure or insufficient stop time
67	1	32	SALNTY	3	salty, may be late closure
67	1	35	SALNTY	2	salty, may be early closure
68	1	10	SALNTY	3	fresh, may be early closure
68	1	17	SALNTY	3	fresh, may be late closure or mis-sampled
68	1	26	REFTMP	3	warm, rosette winched upward before acquisition finished
68	1	31	SALNTY	3	fresh, may be early closure or insufficient stop time
68	1	32	SALNTY	3	fresh, may be early or late closure or insufficient stop time
68	1	34	SALNTY	3	salty, may be early closure or insufficient stop time
69	1	10	Bottle	4	Bottle did not close
69	1	28	SALNTY	3	fresh, may be early closure
70	1	31	SALNTY	3	fresh, may be early closure or insufficient stop time
70	1	31	REFTMP	3	cold, insufficient stop time in sharp gradient
70	1	34	SALNTY	3	salty, may be late closure
71	1	1	SALNTY	3	fresh, may be early or late closure. autosal had trouble finding value
71	1	30	SALNTY	3	fresh, may be early closure or insufficient stop time
71	1	31	SALNTY	3	fresh, may be early closure or insufficient stop time
71	1	31	REFTMP	3	warm, rosette winched upward before acquisition finished
71	1	35	SALNTY	3	fresh, may be late closure
72	1	5	SALNTY	3	fresh, may be early closure
72	1	6	SALNTY	3	fresh, may be early closure
72	1	7	SALNTY	3	fresh, may be early closure
72	1	30	SALNTY	3	fresh, may be early closure or insufficient stop time
72	1	32	REFTMP	3	cold, insufficient stop time in sharp gradient

Table 1 – continued from previous page

Sta-tion	Cast	Bottle	Param	Code	Comment
73	1	2	Bottle	4	O2 draw temp high; oxygen does not fit profile; mistrip
73	1	2	SALNTY	4	saltier than almost entire cast, very warm compared to bottles 1 and 3
73	1	3	SALNTY	3	salty, may be late closure
73	1	6	SALNTY	3	fresh, may be early closure
73	1	16	SALNTY	3	fresh, may be late closure
73	1	31	REFTMP	3	cold, insufficient stop time in sharp gradient
74	1	16	SALNTY	3	fresh, may be late closure
74	1	27	SALNTY	3	fresh, may be early closure or insufficient stop time
74	1	30	REFTMP	3	cold, insufficient stop time in sharp gradient
76	1	9	SALNTY	3	fresh, may be early closure
76	1	10	SALNTY	3	fresh, may be early closure
76	1	30	SALNTY	3	fresh, may be early or late closure
77	1	29	SALNTY	3	fresh, may be early closure or insufficient stop time
78	1	28	REFTMP	3	warm, rosette winched upward before acquisition finished
78	1	33	SALNTY	3	fresh, may be late closure
79	1	27	REFTMP	3	warm, rosette winched upward before acquisition finished
80	1	26	REFTMP	3	cold, insufficient stop time in sharp gradient
80	1	34	SALNTY	3	fresh, may be late closure
81	1	2	Bottle	4	oxygen does not fit profile; mistrip
81	1	2	SALNTY	3	fresh, may be late closure or mis-sampled
82	1	1	SALNTY	3	fresh, may be early closure
82	1	33	SALNTY	3	salty, may be early closure
82	1	34	SALNTY	3	extremely fresh
83	1	20	SALNTY	3	fresh, may be early closure
83	1	23	SALNTY	3	fresh, may be early closure or insufficient stop time
83	1	24	SALNTY	3	fresh, may be early closure
83	1	33	SALNTY	3	salty, may be insufficient stop time. sharp surface gradient
84	1	17	SALNTY	3	salty, may be late closure
84	1	24	SALNTY	3	fresh, may be late closure
84	1	25	SALNTY	3	very fresh, sharp surface gradient
85	1	6	SALNTY	3	fresh, may be early closure
85	1	6	REFTMP	3	warm, insufficient stop time in gradient
85	1	22	SALNTY	3	fresh, sharp surface gradient
86	1	1	SALNTY	3	salty, may be early or lateclosure
86	1	1	REFTMP	3	warm, insufficient stop time in gradient
86	1	3	SALNTY	3	salty, may be late closure
86	1	5	SALNTY	3	fresh, may be late closure
86	1	9	SALNTY	3	fresh, near sharp gradient
86	1	14	SALNTY	3	fresh, may be late closure
86	1	17	SALNTY	3	fresh, sharp surface gradient
87	1	14	SALNTY	3	fresh, near sharp gradient
88	1	10	SALNTY	3	fresh, near sharp gradient
89	1	1	SALNTY	3	fresh, may be sampling error

Table 1 – continued from previous page

Sta-tion	Cast	Bottle	Param	Code	Comment
89	1	4	SALNTY	3	fresh, may be late closure or sampling error
89	1	5	SALNTY	3	fresh, may be late closure or sampling error
89	1	7	SALNTY	3	fresh, near sharp gradient
90	1	5	SALNTY	3	salty, may be early closure
90	1	6	SALNTY	3	fresh, near sharp gradient

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
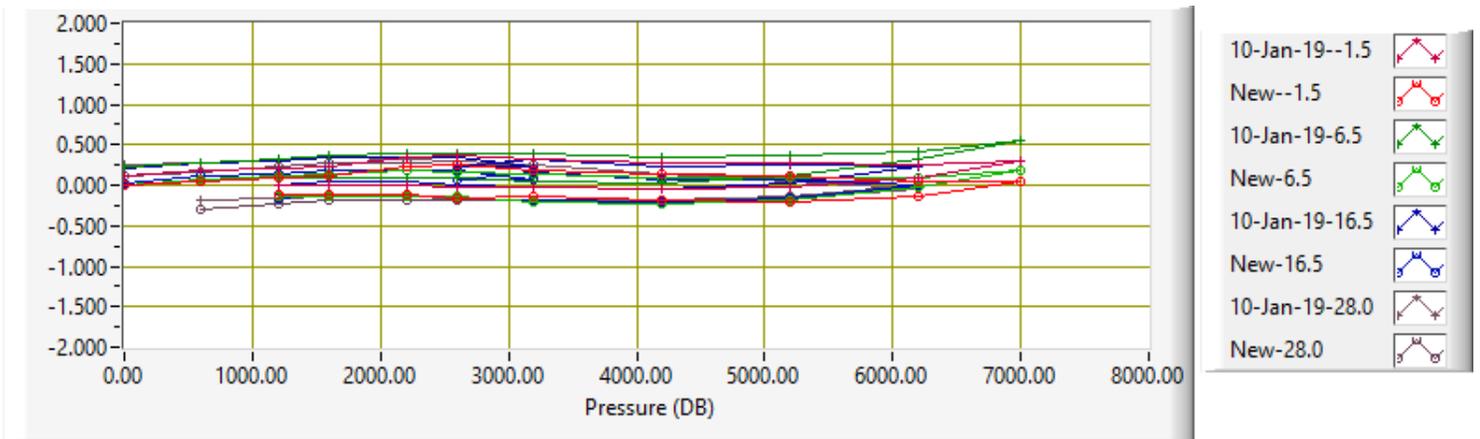
Temperature Calibration Report
STS Calibration Facility

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 = $1/\{g+h[\ln(f0/f)]+i[\ln^2(f0/f)]+j[\ln^3(f0/f)]\} - 273.15$ (°C)

Temperature IPTS-68 = $1/\{a+b[\ln(f0/f)]+c[\ln^2(f0/f)]+d[\ln^3(f0/f)]\} - 273.15$ (°C)

T68 = 1.00024 * T90 (-2 to -35 Deg C)

SBE3 Freq	SPRT ITS-T90	SBE3 ITS-T90	SPRT-SBE3 OLD_Coefs	SPRT-SBE3 NEW_Coefs
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
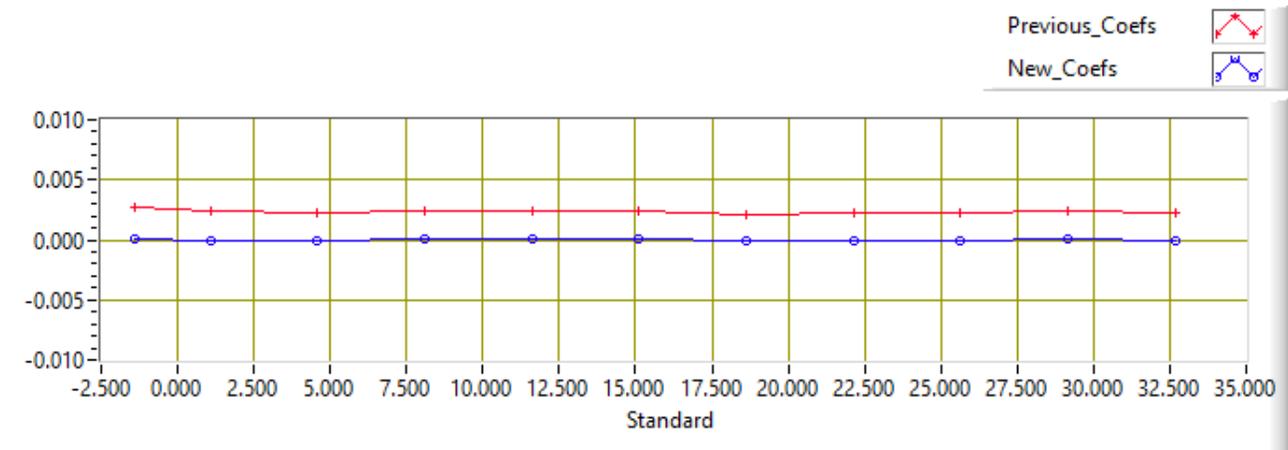
Temperature Calibration Report
STS Calibration Facility

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 = $1/\{g+h[\ln(f0/f)]+i[\ln^2(f0/f)]+j[\ln^3(f0/f)]\} - 273.15$ (°C)

Temperature IPTS-68 = $1/\{a+b[\ln(f0/f)]+c[\ln^2(f0/f)]+d[\ln^3(f0/f)]\} - 273.15$ (°C)

T68 = 1.00024 * T90 (-2 to -35 Deg C)

SBE3 Freq	SPRT ITS-T90	SBE3 ITS-T90	SPRT-SBE3 OLD_Coefs	SPRT-SBE3 NEW_Coefs
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
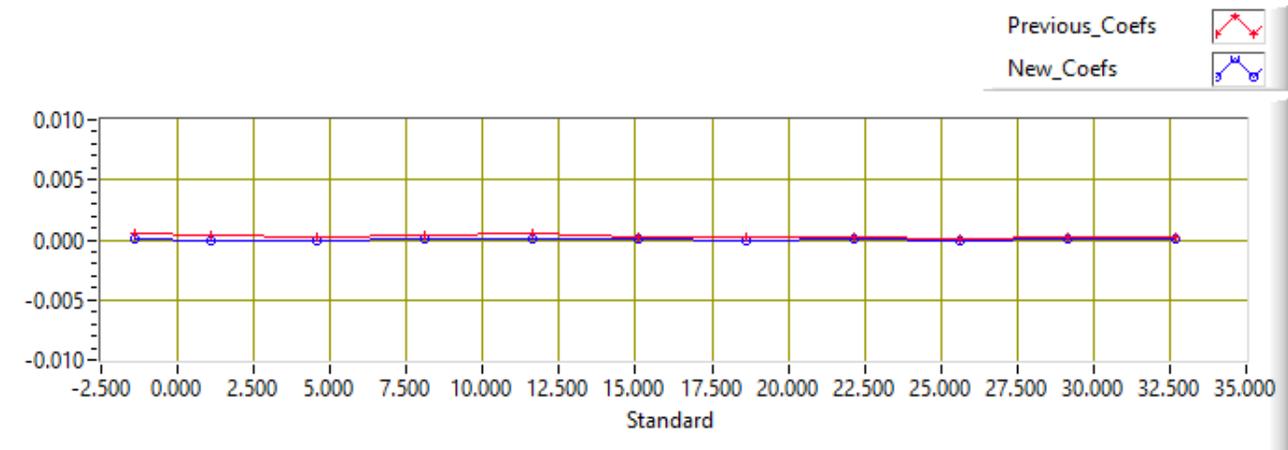
Sea-Bird Scientific
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Bellevue, WA 98005
USA

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

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); δ = CTcor; ε = CPcor;

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

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

Date, Slope Correction

● 28-Jan-20 0.9999566
▲ 25-Nov-20 1.0000000

POST CRUISE
CALIBRATION

1
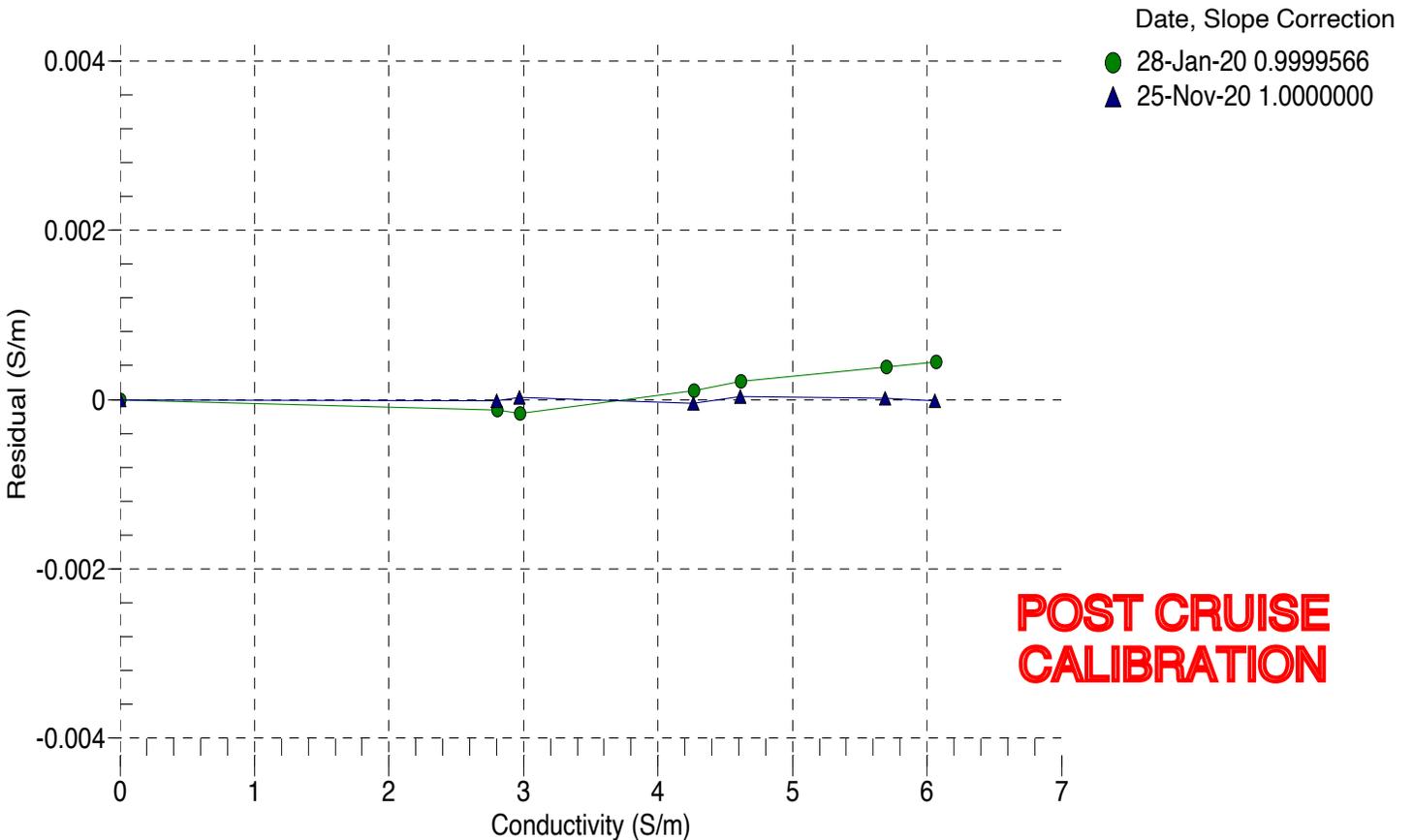
SENSOR SERIAL NUMBER: 1880
CALIBRATION DATE: 04-Dec-20

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); δ = CTcor; ε = CPcor;

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

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

Date, Slope Correction
● 24-Mar-20 1.0000940
▲ 04-Dec-20 1.0000000

POST CRUISE
CALIBRATION

1
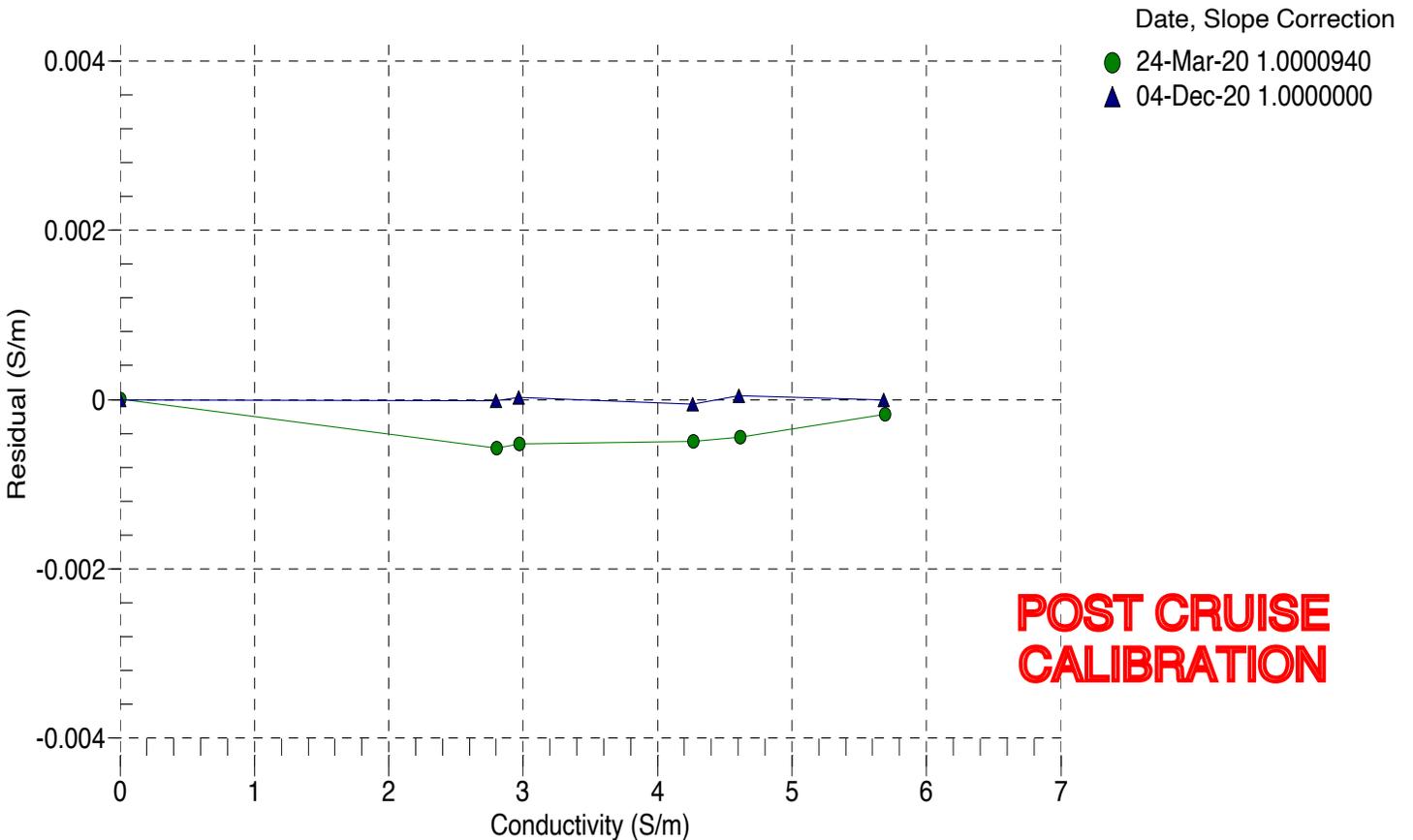
SBE SEA-BIRD ELECTRONICS, INC.

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 20th 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

Pressure

Time

Typical Test Profile
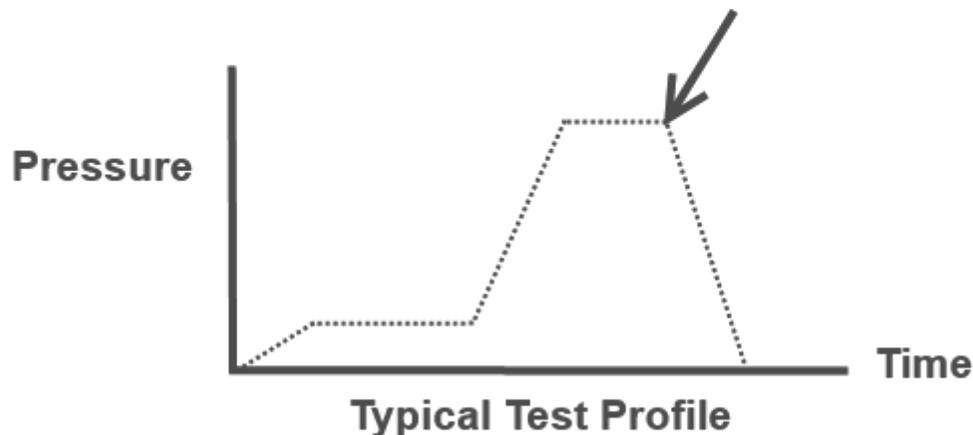
Temperature Calibration Report
STS Calibration Facility

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 = $1/\{a0+a1[\ln(f)]+a2[\ln2(f)]+a3[\ln3(f)]+a4[\ln4(f)]\} - 273.15$ (°C)

SBE35 Count	SPRT ITS-T90	SBE35 ITS-T90	SPRT-SBE35 OLD_Coefs	SPRT-SBE35 NEW_Coefs
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
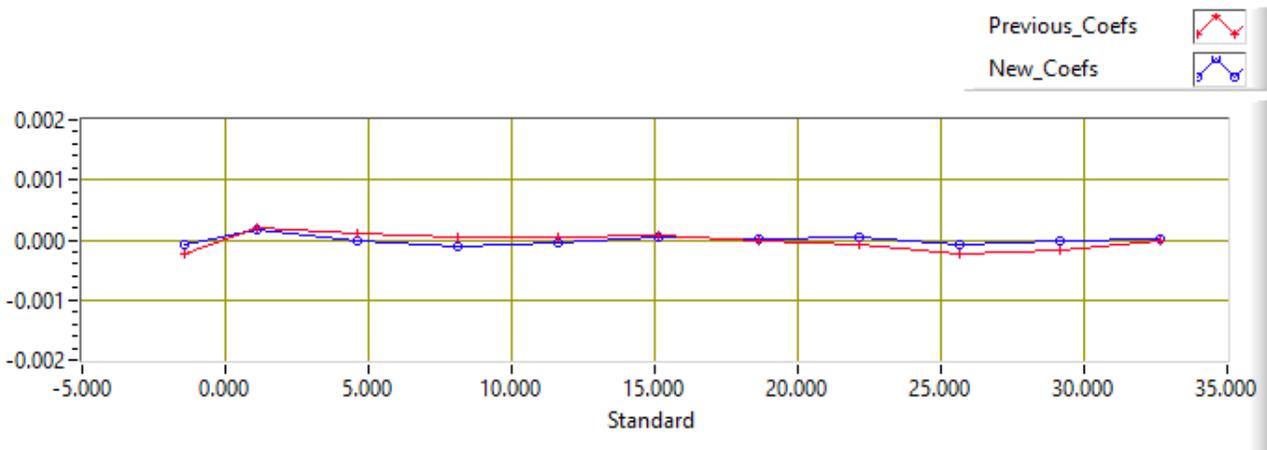
Sea-Bird Scientific
13431 NE 20th Street
Bellevue, WA 98005
USA

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

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

SBE 43 OXYGEN CALIBRATION DATA

COEFFICIENTS:		NOMINAL DYNAMIC COEFFICIENTS	
Soc = 0.4735	A = -4.1544e-003	D1 = 1.92634e-4	H1 = -3.300000e-2
Voffset = -0.5091	B = 1.9043e-004	D2 = -4.64803e-2	H2 = 5.00000e+3
Tau20 = 1.56	C = -2.8141e-006		H3 = 1.45000e+3
	E nominal = 0.036		

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) * $(1.0 + A * T + B * T^2 + C * T^3)$ * Oxsol(T,S) * exp(E * P / K)

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

Date, Slope (ml/l)
● 11-Jun-20 1.0085
▲ 13-Nov-20 1.0000

POST CRUISE CALIBRATION
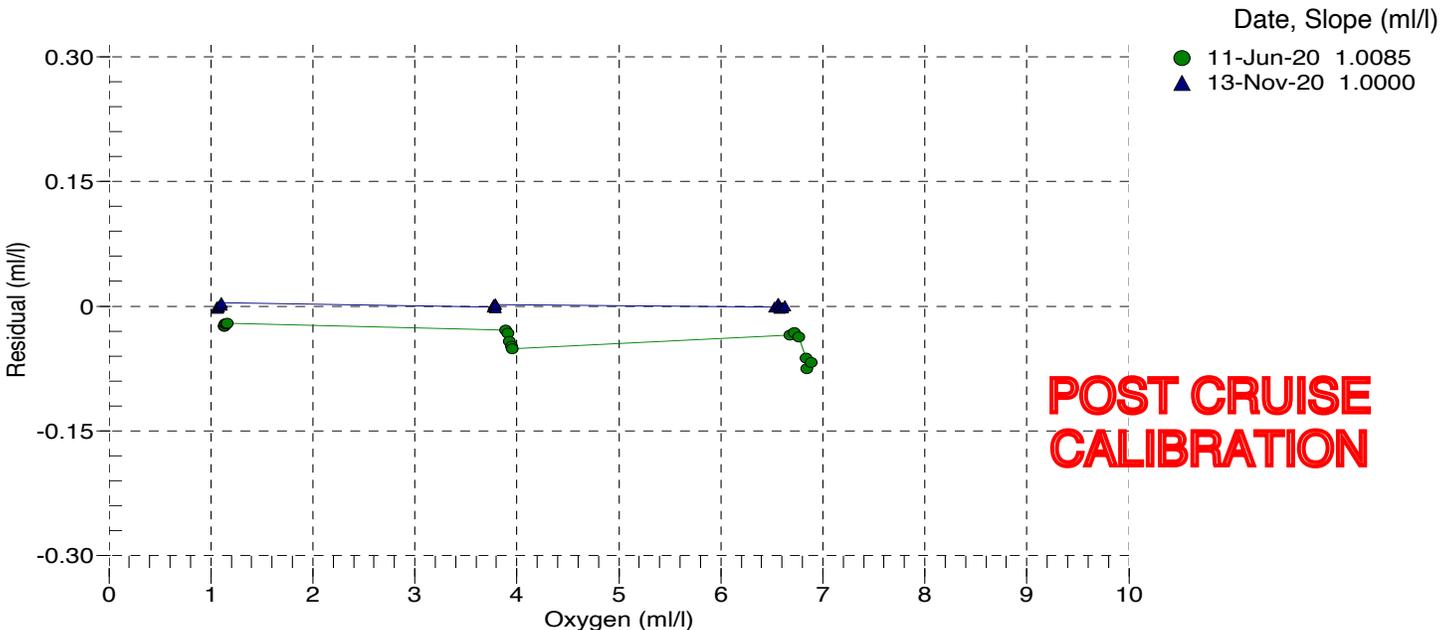
SENSOR SERIAL NUMBER: 0275
CALIBRATION DATE: 14-Nov-20

SBE 43 OXYGEN CALIBRATION DATA

COEFFICIENTS:

Soc = 0.5260	A = -4.3327e-003	
Voffset = -0.5023	B = 1.7664e-004	
Tau20 = 1.20	C = -3.0177e-006	
	E nominal = 0.036	

NOMINAL DYNAMIC COEFFICIENTS

|	
D1 = 1.92634e-4	H1 = -3.300000e-2
D2 = -4.64803e-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	0.713	1.06	−0.00
1.07	6.00	0.00	0.741	1.07	−0.00
1.08	12.00	0.00	0.783	1.08	−0.00
1.09	20.00	0.00	0.842	1.09	−0.00
1.09	26.00	0.00	0.886	1.09	−0.00
1.10	30.00	0.00	0.921	1.10	0.00
3.78	2.00	0.00	1.250	3.78	0.00
3.78	30.00	0.00	1.937	3.78	0.00
3.78	6.00	0.00	1.345	3.78	−0.00
3.79	20.00	0.00	1.683	3.79	0.00
3.79	12.00	0.00	1.490	3.79	0.00
3.79	26.00	0.00	1.834	3.79	−0.00
6.54	2.00	0.00	1.798	6.54	0.00
6.55	30.00	0.00	2.985	6.55	−0.00
6.55	6.00	0.00	1.962	6.55	−0.00
6.61	20.00	0.00	2.558	6.60	−0.00
6.61	26.00	0.00	2.823	6.61	0.00
6.61	12.00	0.00	2.224	6.61	−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^2 + C * T^3) * Oxsol(T,S) * exp(E * P / K)

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

Date, Slope (ml/l)
● 10-Aug-19 1.0003
▲ 14-Nov-20 1.0000

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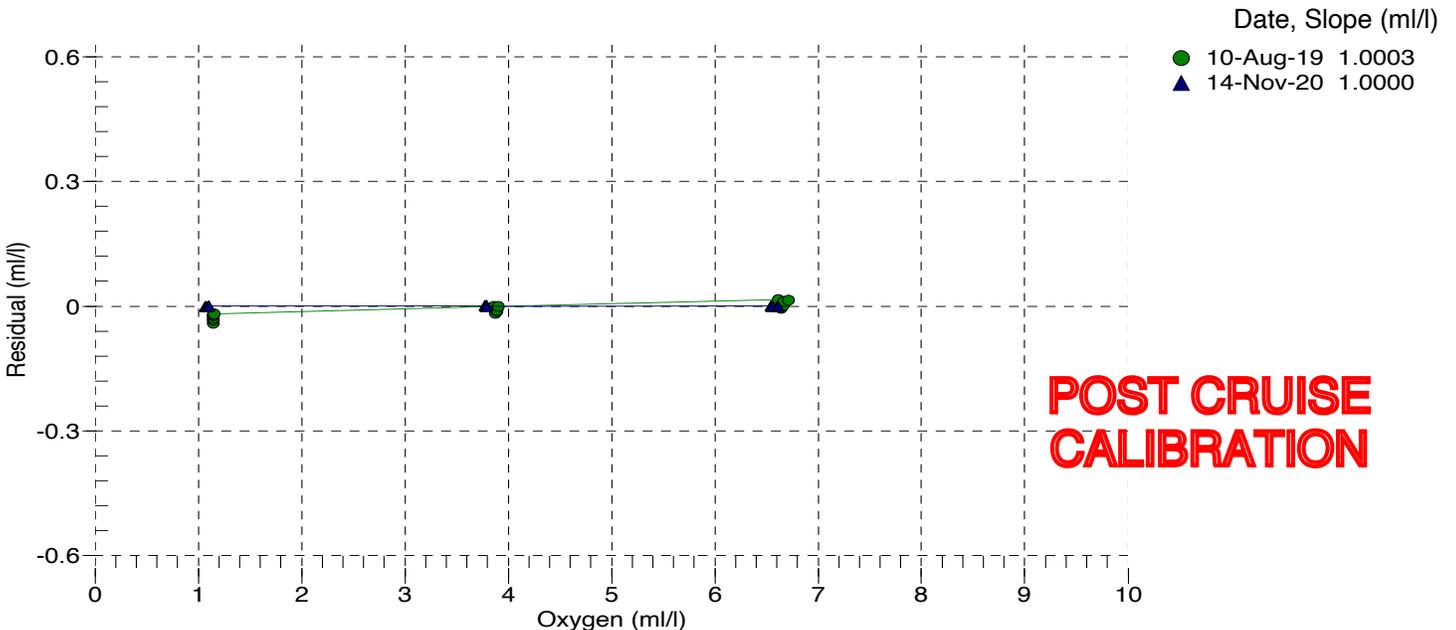
Sea-Bird Scientific
13431 NE 20th Street
Bellevue, WA 98005
USA

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

SENSOR SERIAL NUMBER: 1138
CALIBRATION DATE: 05-Dec-20

SBE 43 OXYGEN CALIBRATION DATA

| COEFFICIENTS:		NOMINAL DYNAMIC COEFFICIENTS	
	A = -3.1381e-003		
Soc = 0.5153	B = 1.5790e-004	D1 = 1.92634e-4	H1 = -3.300000e-2
Voffset = -0.5185	C = -2.8193e-006	D2 = -4.64803e-2	H2 = 5.00000e+3
Tau20 = 1.49	E nominal = 0.036		H3 = 1.45000e+3

BATH OXYGEN (ml/l)	BATH TEMPERATURE (°C)	BATH SALINITY (PSU)	INSTRUMENT OUTPUT (volts)	INSTRUMENT OXYGEN (ml/l)	RESIDUAL (ml/l)
1.07	2.00	0.00	0.735	1.07	-0.00
1.08	6.00	0.00	0.762	1.08	0.00
1.09	12.00	0.00	0.805	1.09	-0.00
1.11	20.00	0.00	0.864	1.11	-0.00
1.11	30.00	0.00	0.938	1.11	0.00
1.12	26.00	0.00	0.911	1.12	0.00
3.80	2.00	0.00	1.284	3.79	-0.00
3.80	6.00	0.00	1.377	3.80	-0.00
3.81	30.00	0.00	1.956	3.81	0.00
3.82	12.00	0.00	1.523	3.82	0.00
3.84	20.00	0.00	1.715	3.84	0.00
3.84	26.00	0.00	1.867	3.85	0.01
6.56	6.00	0.00	2.000	6.56	0.00
6.59	2.00	0.00	1.849	6.60	0.00
6.66	12.00	0.00	2.267	6.66	0.00
6.68	30.00	0.00	3.038	6.68	-0.00
6.70	20.00	0.00	2.607	6.70	-0.00
6.70	26.00	0.00	2.865	6.70	-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^2 + C * T^3) * Oxsol(T,S) * exp(E * P / K)

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

Date, Slope (ml/l)
● 05-Dec-20 1.0000

CALIBRATION
AFTER
MODIFICATIONS

1
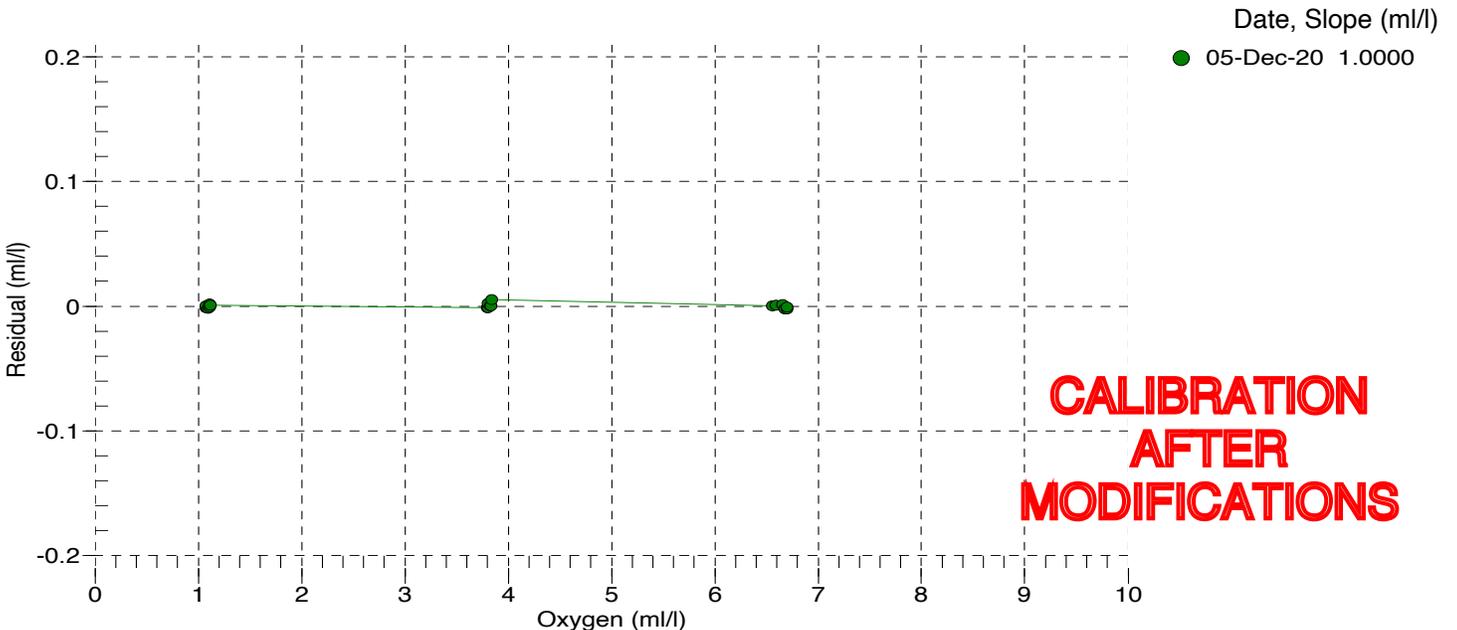
CALIBRATION CERTIFICATE

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

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

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: ±0.5% of full scale

Test for DO 0 %

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

Test for DO 100 %

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

Examined   M. TAKEISHI

Approved   a. Fukuoka

CALIBRATION CERTIFICATE

NAME : RINKO III

MODEL : ARO-CAV

SERIAL No. : 0297

Parameter : Temperature
Dissolved Oxygen

JFE Advantech Co., Ltd.

Temperature Calibration Certificate

Model	:	ARO-CAV
Serial No.	:	0297
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

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

2. Coefficients

$A = -5.274290e+00$

$B = +1.668004e+01$

$C = -2.153804e+00$

$D = +4.604609e-01$

3. Calibration results

Reference temperature [°C]	Instrument voltage [V]	Instrument temperature [°C]	Residual error [°C]	Acceptance [°C]	OK/NG
2.437	0.49011	2.438	0.001	±0.020	OK
10.737	1.07458	10.734	−0.003	±0.020	OK
17.463	1.57611	17.468	0.005	±0.020	OK
24.123	2.07080	24.120	−0.003	±0.020	OK
31.105	2.56470	31.106	0.001	±0.020	OK

4. Verification

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

Reference temperature [°C]	Instrument temperature [°C]	Residual error [°C]	Acceptance [°C]	Judgement
20.031	20.050	0.019	±0.020	Passed

Examined   R. Koshida

Approved   a. Fukuoka

Dissolved Oxygen Calibration Certificate

Model   :   ARO-CAV

Serial No. :   0297

Date   :   April 10, 2017

Location   :   Production Section

Method   :   Calibration is performed with the nitrogen gas (zero) and the oxygen saturated
                water (span) kept by air bubbling.

Film No.   :   164312BA

1. Equation

DO[%] =G+H × P'

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

2. Coefficients

A =   −4.454320e+01   E =   +4.000000e−03

B =   +1.411153e+02   F =   +6.250000e−05

C =   −3.006942e−01   G =   +0.000000e+00

D =   +1.065300e−02   H =   +1.000000e+00

3. Verification

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

Acceptance： ±0.5% of full scale

Test for DO 0 %

	Test condition		Instrument DO [%]	Residual error [%]	Acceptance [%]	Judgement
	Atm. pressure [hPa]	Reference DO [%]				
1st	1015.6	0.00	0.01	0.01	±1.00	Passed
2nd	1015.5	0.00	0.00	0.00	±1.00	Passed
3rd	1015.4	0.00	0.00	0.00	±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	99.93	−0.25	±1.00	Passed
2nd	25.1	1015.0	100.18	99.85	−0.33	±1.00	Passed
3rd	25.1	1014.9	100.17	99.90	−0.27	±1.00	Passed

Examined   *M. TAKEISHI*

Approved   *a. Fukuoka*

SEA·BIRD
SCIENTIFIC

C-Star Calibration

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

	Analog output	Digital output
V_{dark}	0.014 V	0 counts
V_{air}	4.795 V	15714 counts
V_{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: $Tr = (V_{sig} - V_{dark}) / (V_{ref} - V_{dark})$

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

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

Appendix C. Calibration Documents

BIBLIOGRAPHY

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[Thurnherr2015] Thurnherr, A. M., E. Kunze, J. M. Toole, L. St. Laurent, K. J. Richards, and A. Ruiz-Angulo (2015). Vertical kinetic energy and turbulent dissipation in the ocean. Geophys. Res. Lett. 42, 7639–7647.

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