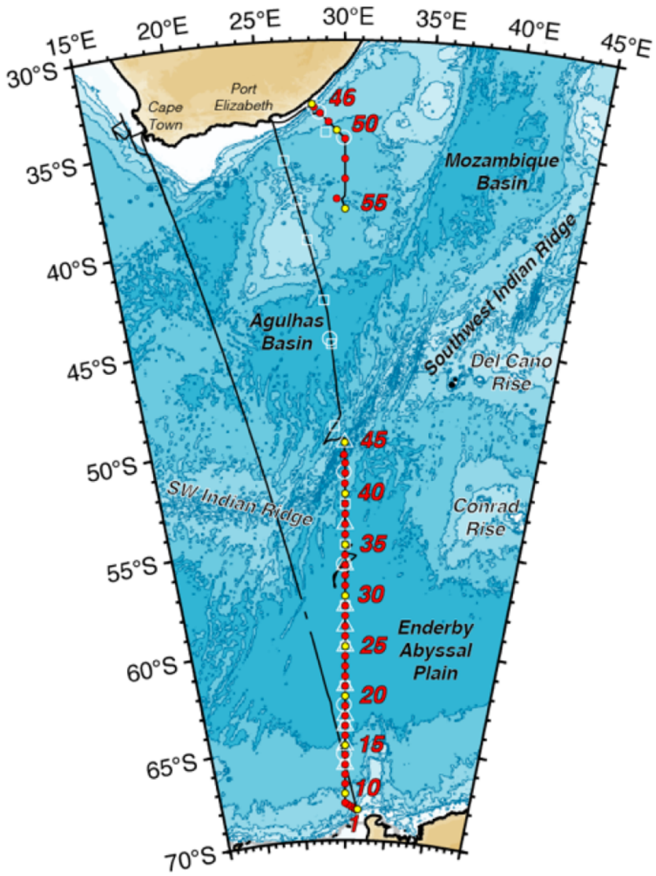
CRUISE REPORT: I06S
(Updated OCT 2019)



Highlights

Cruise Summary Information

Section Designation	**I06S**
Expedition designation (ExpoCodes)	**325020190403**
Chief Scientists	**Alejandro Orsi / TAMU**
Dates	2019 APR 03 - 2019 MAY 14
Ship	r/v *Thomas G. Thompson*
Ports of call	Cape Town
Geographic Boundaries	33° 14' 3" S 28° 5' 43" E 31° 32' 4" E 68° 21' 14" S
Stations	55
Floats and drifters deployed	18 Argo floats and 16 drifters deployed
Moorings deployed or recovered	0

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Final Report Assembly by Jerry Kappa, UCSD/SIO

Links to Select Topics

Shaded sections are not relevant to this cruise or were not available when this report was compiled.

Cruise Report of the 2019 I06 US GO-SHIP Reoccupation

Release Draft 1

Alejandro Orsi

Jun 04, 2019

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CHAPTER

ONE

GO-SHIP I06 2019 HYDROGRAPHIC PROGRAM

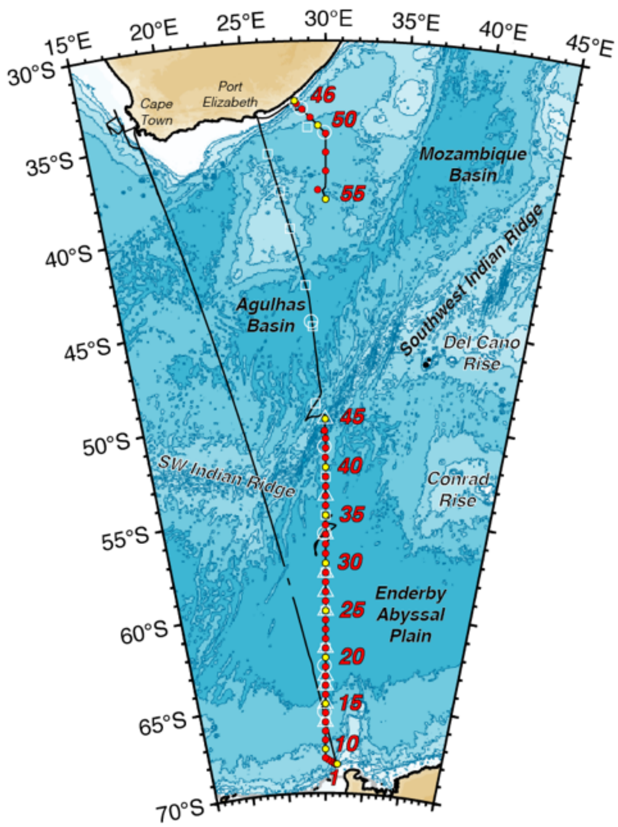

Fig. 1: Cruise track and CTD station locations (red dots) during GO-SHIP I6S 2019. White triangles, circles and squares indicate deployment locations of ARGO and SOCCOM floats and surface drifters.

1.1 Cruise Scientific Objectives

Alejandro Orsi

Complex oceanic responses to climate change are poorly characterized due to a general lack of repeat high-quality shipboard measurements of climate-relevant ocean properties. GO-SHIP repeat transoceanic surveys (www.go-ship.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 along 30°E in the southern Indian Ocean enables scientists to better tackle important unresolved aspects of Southern Ocean adjustment to atmospheric global warming. The U.S. GO-SHIP I6S 2019 hydrographic section revisited this intercontinental line after its first occupation in 2008, itself a repeat of the original 1996 WOCE transect by France. Temperature, salinity, and velocity measurements from I6S 2019 reveal how the heat content of deep and bottom waters in the Enderby Basin have changed while their parent waters over the Antarctic continental shelves have not, but freshened instead. I6S 2019 measurements of oxygen, nutrients, 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 I6S line are used to determine rates of regional carbon accumulation and exchange with adjacent circulations. The overarching achievement of GO-SHIP I6S 2019 measurements was the reoccupation of 55 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 were discretely analyzed on board. Argo and SOCCOM floats and surface drifter deployments were usually carried out after leaving CTD stations or during slow transits.

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*	Dana Greely, Rik Wanninkhof	dana.greeley@noaa.gov, Rik.Wanninkhof@noaa.gov
Underway Temperature, Salinity, and pCO_2	*PMEL*, *NOAA*	Dana Greely	dana.greeley@noaa.gov
Total Alkalinity, pH	*UCSD*, *SIO*	Andrew Dickson	adickson@ucsd.edu
SADCP	*UH*	Eric Firing	efiring@soest.hawaii.edu
LADCP	*LDEO*	Andreas Thurnherr	ant@ldeo.columbia.edu
CFCs, *SF6*, N20	*UT*	Dong-Ha Min	dongha@mail.utexas.edu
DOC, *TDN*, TOC, TN	*RSMAS*	Dennis Hansell	dhansell@rsmas.miami.edu
C13 & C14	*WHOI*, *Princeton*	Ann McNichol, Robert Key	amcnichol@whoi.edu, key@princeton.edu
Transmissometry	*TAMU*	Wilf Gardner	wgardner@ocean.tamu.edu
Fluorescence and Backscatter (*SOCCOM*)	*U Maine*	Emmanuel Boss	emmanuel.boss@maine.edu
Chipod	*OSU*	Jonathan Nash	nash@coas.oregonstate.edu
d18O	*BAS*	Mike Meredith	mmm@bas.ac.uk
CSIRO Argo Floats	CSIRO	Rebecca Cowley	rebecca.cowley@csiro.au
NOAA/PMEL Argo Floats	*PMEL*, *NOAA*	NOAA/PMEL	elizabeth.steffen@noaa.gov
SOCCOM Floats	*UW*, *UCSD*, *SIO*	Steve Riser, Ken Johnson, Lynne Talley	riser@ocean.washington.edu, ltalley@ucsd.edu
Surface Drifters	*NOAA*, *AOML*	Shaun Dolk	Shaun.dolk@noaa.gov
GPS data/bathymetry	*UCSD*	David Sandwell	dsandwell@ucsd.edu
UVP	*U Alaska* Fairbanks	Andrew McDonnell	amcdonnell@alaska.edu
Gliders	Caltech	Andrew Thompson	andrewt@caltech.edu

1.3 Science Team and Responsibilities

Duty	Name	Affiliation	Email Address
Chief Scientist	Alejandro Orsi	*TAMU*	aorsi@tamu.edu
Co-Chief Scientist, floats and drifters	Isabella Rosso	*UCSD*	irosso@ucsd.edu
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Nutrients, Database Support	Melissa Miller	*UCSD ODF*	mhite@ucsd.edu
CTDO Processing	Kenneth Jackson	*UCSD ODF*	kjackson@ucsd.edu
Salts, ET, CTD/Rosette Maintenance	John Calderwood	*UCSD SEG*	jcalderwood@ucsd.edu
Salts, CTD/Rosette Maintenance	Joseph Gum	*UCSD ODF*	jgum@ucsd.edu
Dissolved O_2, Database Management	Andrew Barna	*UCSD ODF*	abarna@ucsd.edu
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UVP	Jessica Pretty	*U ALASKA*	jlpretty@alaska.edu
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DIC	Patrick Mears	*U Miami*	andrew.collins@noaa.gov
CFCs, SF6	David Cooper	*UT*	davidcooper59@gmail.com
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CFCs, SF6 student	Garrett Walsh	*TAMU*	gxwalsh@tamu.edu
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Total Alkalinity	Wiley Wolfe	*UCSD*	wwolfe@ucsd.edu
pH	Kayleen Fulton	*UCSD*	kcfulton@ucsd.edu
DOC, *TDN*, Radio Carbon	Chelsi Lopez	*U Miami*	chelsi.lopez@rsmas.miami.edu
Indep/Nurse	Rachel Campbell	Other	n/a
Marine Technician, Lead	Jen Nomura	*UW*	jnomura@uw.edu
Marine Technician	Croy Carlin	*UW*	croyc@uw.edu

CHAPTER

TWO

CRUISE NARRATIVE

Alejandro Orsi

Before starting our journey South the entire team safely made it to Cape Town, where for a few balmy days we savored the majestic scenery of Table Mountain, the region's vibrant music and its culinary delights. Waiting for us docked at berth A was our ship, the research vessel Thomas G. Thompson. We were greeted by the Captain and an impressive crew eager to facilitate our smooth transition to living and working on the ship. A couple of days before departure the Thompson was refueled and fully loaded with palettes of fresh goods to keep everybody well- nourished during the next 40 days (or so). Since no science party had to move out of the ship, we were able to board and begin loading right away the numerous pieces of equipment from our different groups. The ODF container arrived early on, as did the DIC van later secured on the back deck, whereas ODF's was transferred to the forward 02 deck. Just watching everybody work together so efficiently during the set-up days gave the privileged assurance of having an excellent team to face the likely upcoming challenges on this cruise. Most impressive is the overall collegiate, respectful and friendly atmosphere surrounding the Thompson since we started our journey.

A blessing in disguise, perhaps, resulted in a delayed departure by a few hours. Before setting sail around 4 PM on April 3, 2019 a scorching smell emanated from loose light bulbs in a switchboard panel; it had to be repaired with the help of a local electrician. We then enjoyed the magnificent, albeit brief, sailing experience of leaving the city and the Cape of Good Hope behind us, in a sunny afternoon of calm seas. But the test to our seaworthiness came up earlier than expected. Rough seas and strong gusty winds took a heavy toll on our progress to the south. Rolls during the storm left one of the main engines inoperable. After almost 26 hours of transit the Captain and I decided to turn around and pursue the purchasing of replacement parts. We were back to an area off Cape Town late in the afternoon of April 6. The needed pump was not available in South Africa. One was purchased from Caterpillar and scheduled to be hand-carried from Seattle to Cape Town. Meanwhile Meegan Corcoran, our benefactress Port Captain on her way back to the U.S., managed to locate, purchase and FedEx another spare part during a layover in Amsterdam! An arrival date for either of these parts was unknown, considering ongoing strikes in South Africa. We could only wait. But we also took advantage of the temporary impasse to conduct our test cast, originally planned to take place at a location farther to the south. With some minor hiccups for which we had plenty of time to iron out, all instruments and data acquisition protocols were successfully tested. Then we could only wait, and wait more, for the engine's parts. Fortunately, both items cleared customs and were available to our agent at about the same time. They were delivered to the boat around 8 PM on April 8, 2019.

With the affected engine fixed while underway, and a spare part in stock, we were ready to face our second southward crossing of the Agulhas Current Retroflection. This time Mother Nature was more merciful, allowing us to steam at an average speed of 12.5 knots. Against all odds, favorable cruising conditions prevailed for another 8 days, and counting! We crossed the Antarctic Circle paying due respect to king Neptune and celebrating the new Red Noses aboard. Shortly after, in the morning of April 16, we woke up to a smooth sea covered with grease ice, that rapidly turned into a patchy field of small-sized pancake ice. The Thompson's Captain and Mates very skillfully navigated towards the target 536-m isobath off Riiser Land near 31°E. At one point, still at water depths of about 700 m, we hesitated about continuing straight further south because patches of older sea ice ahead of us were moving fast to the southwest. Again, we were fortunate to find a long lead oriented almost across the local isobaths and only a little off the intended track. We followed it slowly at 2 knots for about two hours and stopped over the 530-m isobath to occupy our first station.

All things considered, our petition of compensatory ship time loss (5 days) due to engine problems was followed by an empathetic 2-day extension of our cruise. This is entirely the result of the prompt intervention and collaboration between University of Washington, GO-SHIP Program and National Science Foundation managers. In addition, our swift steam to the Antarctic shelf resulted in about 1-day gain. Therefore, with Station 1 we started I06S measurements at 8:47 UCT on April 16, 2019 with a net ship time deficit of about two days.

A punishing sampling pace was kept, as expected, along the planned short (39 nm) northwestward segment of nine closely-spaced stations (1 nm to 10 nm) across the Antarctic slope. These extenuating circumstances resulted in the general backlog of different samples, to be processed at a later time during the longer transits between stations 30 nm apart. Less than 24 hours after starting Station 1, we completed station 9 at a water depth of 3776 m and changed course to continue due north along 30°E.

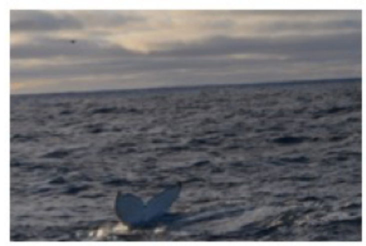
By April 20 we had already surveyed the southernmost 330 nm of the long (1,980 nm) meridional segment of I06S, occupying 10 more stations in about 41 hours. In addition, our trained students have also assisted in the overboard deployment of two surface drifters, four ARGO floats and two SOCCOM floats. We have been occasionally visited by humpback whales and Antarctic petrels, as well as cruised by large distant icebergs and enjoyed spectacular views of Aurora Borealis, sunsets, and bioluminescence. Eerie or not, weather and seas have been extremely sympathetic to us since we left Cape Town for the second time.

Two pump replacement parts are transferred to the RV Thomas G. Thompson at night.

A lead in the pack of thin pancake ice allowed us to reach the desired water depth (526 m) to occupy station 1.

CTD station 1 about to start near the shelf break at 68.4°S, 31.4°E.

A distant, yet impressive, tabular iceberg.



A curious humpback whale while at station.

On April 30 the successful ~4-hr deployment of one glider was carried out from a zodiac, with the joyful assistance and training of a graduate student and the Co-Chief Scientist. A second glider was more spectacularly launched with the Thompson's crane. Trained students assisted in the overboard deployment of more surface drifters, ARGO and SOCCOM floats. By May 1, in one way or another, we had worked progressively along the main I6S meridional line. However, we had also been halted extensively, and forced to prematurely terminate the first cast of Sta. 44, waiting for the recommended working conditions of swells smaller than 3-5 m – atypical in the Southern Ocean. Almost 3 full days (25-28 April) of work were lost to bad weather during the passage of a large cyclone.

During workable periods of time we managed to maintain a commendable pace. A total of 27 stations (Sta. 16-43) were occupied in the Enderby Abyssal Plain, all located at water depths greater than 5000 m, at an average time of 3.9 hours per station. All of the 30-nm transits between stations were done at ship speeds exceeding 11 knots.

A 51.6-hr delay in CTD work between April 30 and May 2 was caused by another large storm. We managed to occupy Stas. 44 and 45 before the next mega storm got in our way, this timewe valiantly battled it for 42.7 hours during May

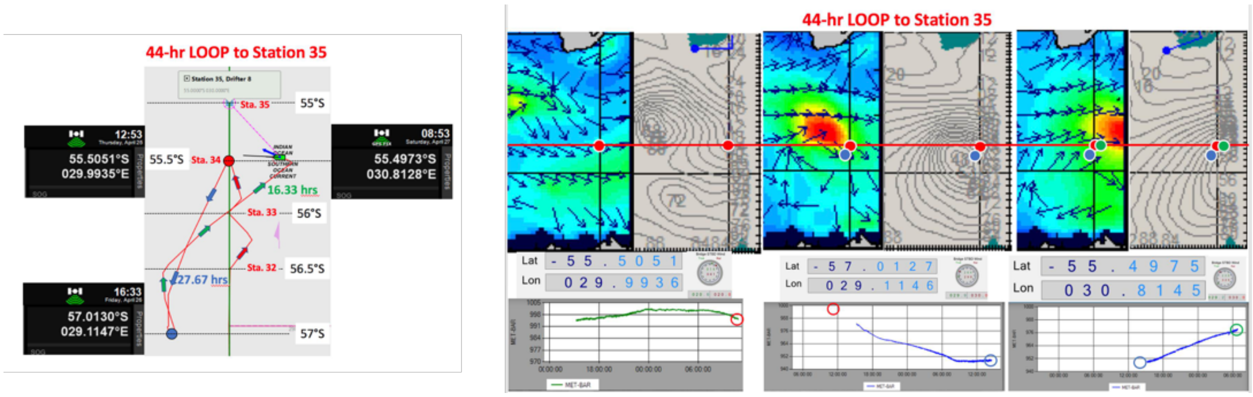


Fig. 1: Dodging attempt as a large low-pressure passed through our cruise track during 25-27 April. The final science delay was of about three full days.

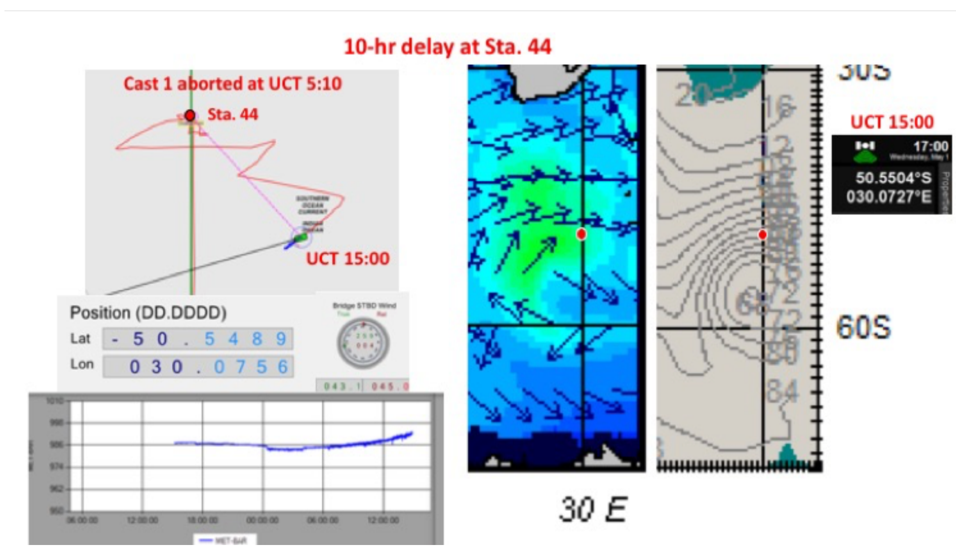


Fig. 2: A relatively weaker storm interrupts science work on May 1st, for 1.15 days.

2-4. Combining these last two bad weather- related delays to those suffered in April 24 (9.8 hours), April 25-28 (71.6 hours), plus 7 hours here and there, it adds up to 7.6 days or 18.7% of the cruise duration.

The most unfortunate event in our cruise was the medical evacuation of a graduate student, while we were coping a storm on May 4 near 30°E, 50°S. The rapid transit to Port Elizabeth (yet **10.7%** of the cruise duration) resulted in the successful evacuation and provision of appropriate health care to the student in land. Nonetheless, the **4.3-day** transit back to the planned location of Sta. 46 could not be accomplished in the amount of time left.

About 130 nm northeast of Port Elizabeth we occupied a relocated Sta. 46 at water depth of about 550 m. Stations 47 to 51 (30°E, 35°S) were located farther to the southeast with progressively larger spacing in between (10 to 35 nm). The last four stations were intended to be 1° latitude reoccupations along 30°E, but interference from a chines fishing vessel resulted in the slight relocation of Sta. 54. Strict implementation of the 23:00 May 11 deadline to our brief and final 69 hours of work time placed Sta. 55 at 30°E, 38.5°S. Near 23:00 local on May 11, 2019 we had finished Sta. 55 at 30°E, 38.5°S, ending the sixth calendar week since departing Cape Town at 16:00 local on April 3, 2019.

All in all, accounting for the time spent on transit between and at stations, the total of work time was **14.8 days**, only **36.3%** of the 40.7-day cruise. Our expert and relentless teams of hard- working scientists defied punishing weather, mechanical and medical failures to accomplish, on average four deep CTD stations per work day.

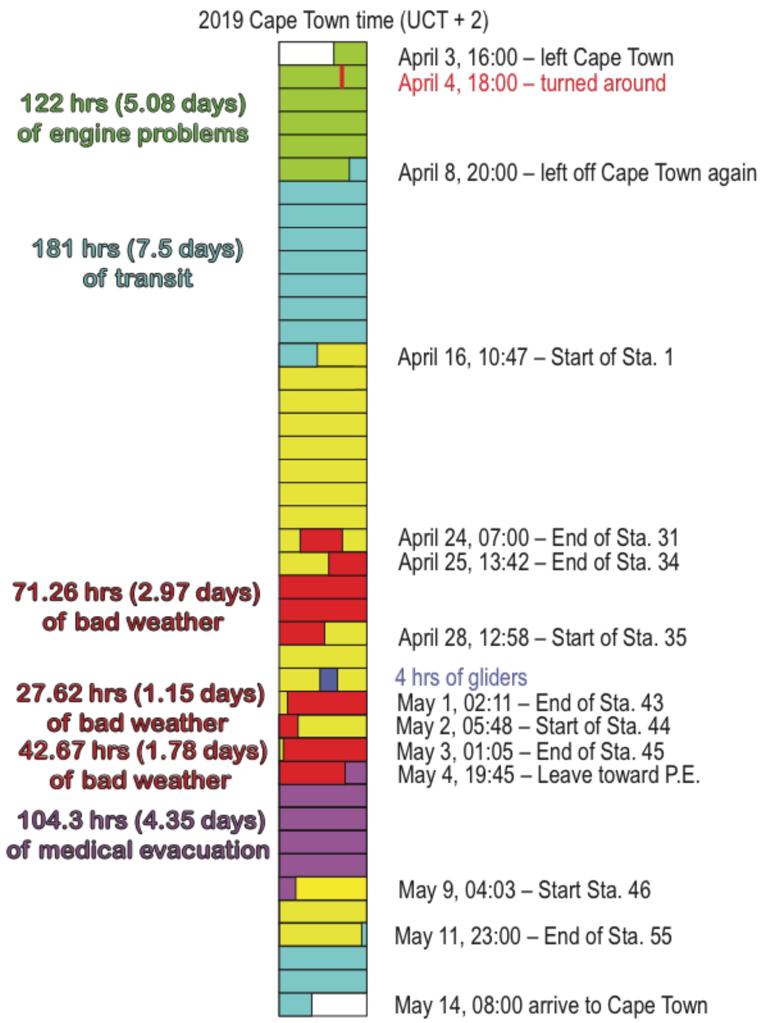


Fig. 3: GO-SHIP I6S 2019 cruise timeline.

2.1 Main Result

2019 occupation of the GO-SHIP I6S Hydrographic Section: overall accomplishment of the original hydrographic plan was around 60%, or 55 out of 91 CTD stations.

How did this happen? Unfavorable seas, sea-ice and weather are all well-known and unavoidable conditions that make working in the Southern Ocean so uniquely unpredictable. The sole remoteness of the I6S line required long steaming times: 7.5 days to the first station, and 2.4 days from the last station to Cape Town. That is, 24.3% of the cruise time was spent on steaming back and for to do CTD work.

Engine problems resulted in the loss of 5.1 days, but they happened at the very beginning of our cruise, and it was partially ameliorated with two additional days.

What ifs? It's understandable that sometimes we contemplate alternative scenarios to less than desirable story endings. Consider, for instance, how efficient our science teams performed throughout the working time on this cruise. At the established working pace and 30-nm spacing a happy ending would have needed:

a) 6.3 more work days to fill in the 11.5° gap now left unsampled along 30°E; or

b) only 1.3 days of bad weather out of 41 days in the Southern Ocean; or

c) a more reasonable 3.3 bad weather days and no engine failures; or,

d) even with all the experienced bad weather but sparing preventable mechanical and health failures.

It is hoped that, in addition to acquiring new hydrographic measurements with the highest quality standards, our I6S 2019 experience will also better prepare the next generations for the many challenges of working in the Southern Ocean.

2.2 Summary

The quality of the data collected is very high, particularly from the chemistry teams who have delivered an excellent and very high-resolution data set. We are confident that this occupation of I6S has uncovered clear and ongoing changes in the deep ocean heat and carbon content, and chemistry. The mixing information taken via the shear measured by the LADCP, sADCP and fine and microscale properties via the chi-pods and CTD will also be very insightful and unprecedented along this line.

CHAPTER

THREE

CTD AND ROSETTE SETUP

For I06S-2019 the new STS 36 place yellow rosette and bottles, built in 2017, were used. These rosette and bottles was built before P06 2017, making this the third 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 I06S-2019 weighs roughly 1500 lbs in air without water, and 2350 lbs in air with water. The package used on I06S-2019 weighs roughly 950 lbs in water. In addition to the standard CTDO package on GO-SHIP cruises three chipods, two LADCPs, and one UVP were mounted on the rosette. During the cruise we encountered numerous problems, most notably modulo errors through the cruise resulting in multiple re-terminations. 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, transmissometer, chlorophyll-a fluorometer and backscatter meter, and altimeter were also mounted on the rosette. Chipod, LADCP, and UVP instruments were deployed with the CTD/rosette package and their use is outlined in sections of this document specific to their titled analysis.

CTD and cage were horizontally mounted at the bottom of the rosette frame, located below the carousel for all stations. The temperature, conductivity, dissolved oxygen, respective pumps and exhaust tubing was mounted to the CTD and cage housing as recommended by SBE. The reference temperature sensor was mounted between the primary and secondary temperature sensors at the same level as the intake tubes for the exhaust lines. The transmissometer was mounted horizontally on the lower LADCP brace with hose clamps around both of its ends, avoiding shiny metal or black tape inside that would introduce noise in the signal. The fluorometer and backscatter meter and altimeters 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 being north on the rosette, the LADCP battery was mounted east, the CTD mounted west, and the UVP mounted south.

Equipment	Model	S/N	Cal Date
Rosette	36-place	Yellow	_
CTD	SBE9+	0830	_
CTD	SBE9+	0914	_
CTD	SBE9+	0057	_
Pressure Sensor	Digiquartz	99676	Jan 10, 2019
Pressure Sensor	Digiquartz	110547	Jan 10, 2019
Pressure Sensor	Digiquartz	34901	Oct 25, 2017
Primary Temperature	SBE3+	32380	Feb 12, 2019
Primary Conductivity	SBE4C	44545	Feb 27, 2019
Primary Conductivity	SBE4C	42659	Feb 27, 2019
Primary Conductivity	SBE4C	42319	Feb 27, 2019
Primary Pump	SBE5	51892	_
Primary Pump	SBE5	51549	_
Secondary Temperature	SBE3+	35844	Feb 11, 2019
Secondary Conductivity	SBE4C	42818	Feb 27, 2019
Secondary Pump	SBE5	54890	_
Transmissometer	Cstar	CST-1803DR	Sep 16, 2016
Transmissometer	Cstar	CST-1636DR	Sep 16, 2016
Fluorometer Chlorophyll and Backscatter	WetLabs	FLBBRTD-3698	Sep 23, 2014
Primary Dissolved Oxygen	SBE43	433521	Feb 22, 2019
Primary Dissolved Oxygen	SBE43	430197	Feb 2, 2019
Primary Dissolved Oxygen	SBE43	430255	Jun 28, 2018
Reference Temperature	SBE35	0105	Feb 01, 2018
Carousel	SBE32	1178	_
Altimeter	Valeport 500	62488	_
Altimeter	Valeport 500	59116	_
Underwater Vision Profiler 5 HD (UVP)	Underwater Vision Profiler 5 HD		_
DL LADCP	150 kHz Teledyne RDI WHM150		_
DL LADCP	300 kHz Teledyne RDI WHM300		_
UL LADCP	300 kHz Teledyne RDI WHM300		_
Chipods	Chipod	Logger 2008/Pressure Case Ti 44-5	**FIRST_STA**
Chipods	Chipod	Logger 2027/Pressure Case Ti 44-3	**FIRST_STA**
Chipods	Chipod	Logger 2030/Pressure Case Ti 44-11	**FIRST_STA**

3.2 Winch and Deployment

The forward DESH5 winch deployment system was used for all but the last three stations. After the wire on the forward DESH5 winch had a strand of outer armor wire peel off and form a birdcage with roughly 100 meters of wire, the rosette was reterminated with the aft DESH5 winch. 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 I06S-2019, and multiple times afterwards.

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 outsides of the rosette before the next cast, and the insides 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. The UVP battery was monitored for charge and connectors were checked for fouling and connectivity. Once stopped on station, the Marine Technician would check the sea state prior to cast and decide if conditions were acceptable for deployment. Recovering the package at the end of the deployment was the reverse of launching. The Marine Technician would perform a quick check of the rosette before allowing samplers to sample. The rosette would be rinsed off after every

Fig. 1: Package sensor looking into the rosette from the south, with UVP directly in front of the camera.

Fig. 2: Package sensor setup with top as southeast, to show in order from top clockwards CTD, downward LADCP, LADCP battery, and UVP.

Fig. 3: Package sensor setup from left to right, LADCP battery, LADCP, transmissometer, chipod, CTD in back right.


35
34
33
32
31

Fig. 5: Package setup from west, with CTD in foreground.

cast.

3.3 Maintenance and Calibrations

During I06S-2019 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. 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 salt water filled syringes were connected to the plumbed lines to rinse the sensors between casts while in freezing conditions. Salt water was used instead of fresh water due to the lower freezing point to prevent it from freezing when exposed to the outside air. Overhead heaters recently installed on the Thompson were run while in freezing or near freezing conditions. The rosette was routinely examined for valves 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 an on deck blocked and un-blocked voltage readings were recorded prior to the cast. The transmissometer was also calibrated before and after the start and end science operations. The same calibration was performed at the of the cruise during transit to Cape Town. Black tape was put on the outside of the FLBB sensors to do a calibration “dark cast”. Dark casts were done at the beginning and end of the cruise to measure pressure effects on the sensor. A dark cast was performed on a cast where depths reached at least 2000 meters, preferably average full ocean depth for the cruise, and where previous profiles showed little FLBB activity. The post cruise dark cast was performed in a bucket due to running out of time.

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. The large amount of time used for CTD and rosette can be attributed to the lack of support personnel flown out to assist with setup, and instead using ODF personnel and experience to help the following programs: LADCP, UVP, chipods, transmissometry, SOCCOM. On various previous cruises LADCP, UVP, and chipods have all sent out an additional person to help install and familiarize cruise participants with their instruments, for various reasons on this cruise no one from these groups were available to fly out to Cape Town to help setup. This led to a large time crunch as all groups want to get their equipment mounted for testing, yet the students designated as cruise participants have very little experience with setup requiring the use of ODF technicians to work long days and nights in port to prepare the rosette for transit. Additional integrity checks on the rosette, such as checking lanyard angles, o-ring and lanyard replacement, and spigot movement waited until being underway to be checked as lower priority tasks.

We are using a new mounting system for the downward looking LADCP which has the LADCP clamped facing inward instead of outward, which will cause problems if we need to change that LADCP in rough weather.

April 6, 2019 – Test cast #1

90001 – Test cast aborted due to deck box complaining upon entering the water, deck box LEDs displaying 0001. Upon recovery the CTD was inspected, and the Y cable from fish to water sampler to SBE 35 showed signs of water leakage into the cable in the form of a greenish, copper patina on the cable. Cable was replaced with a second Y cable.

April 7, 2019 – Test cast #2

90101 – Test cast occurred with minimal beeping in upper 100 meters of water column. As the beeping quickly went away, the cast continued to the bottom and back without any further problems.

90201 – Third test cast done to 100 meters to check for deck box beeping in the upper water column while still waiting for the pumps to arrive in Cape Town. No beeping or other signs of error showed up during the test cast.

April 16, 2019 – First stations, teething issues.

00101 – Bottles fired on fly from 7 to 18. 00201 – RS-232 communication timeout during the cast, 35-10 m above seafloor. On recovery fired bottles on the fly from 6 to 21. 00301 – Hydroboom issues during cast, held at surface for 15 minutes while troubleshooting. 00401 – Slight delay before rosette deployment due to troubleshooting Hydroboom. Issue resolved – wire came undone inside box above hydroboom, was reattached. 00501 – Staging bay was around or below -2C during sampling of 00401. Primary and secondary lines were frozen without notice, deployment of rosette into water with pumps not coming on immediately. Attempted to defrost lines by soaking at 300m in 1C water, eventually gave up and came to surface to defrost on deck with lukewarm water and heaters. Cast recording for roughly 40-60 minutes total. 00502 – Deployed after defrosting sensors with primary conductivity problems. Changed primary conductivity from 4545 to 2659 post cast.

April 17, 2019 Sensors (Unknown bulkhead connectors) day

00601 – Primary conductivity sensor should've been 2569 as noted on the CI, instead 2659 was brought. Conductivity was okay after entering proper calibration, then failed at depth, swapped to 2319 post cast. 00701 – Data acquisition started in water, no deck reading. Conductivity seems okay. 00801 – Pre cast switched oxygen sensor from 3521 to 0197 to attempt to fix spiky oxygen trace. 00901 – Oxygen profile still noisy, nothing changed. 01001 – Oxygen profile still noisy. Changed primary pump from 1892 to 1549.

April 18, 2019 – Deck pressures day

01101 – Oxygen profile still noisy, changed oxygen sensor from 0197 to TGT SN: 0542. 01201 – Fired bottles on the fly. Niskin 24 top cap apparently grazed UVP cable (not sure power or data) and trapped it in top of bottle, ripping the cable out of the bulkhead connector of UVP. Due to unknown depth at which the cable was ripped out, UVP was removed as precautionary measure until it could be triaged with remote assistance. 01301 – Fired bottles on the fly. Noticed that pre and post deck pressure is fluctuating largely, slightly under 2 decibar, watching pressures. 01401 – Niskin 14 spigot leaking, reasons unknown. Rosette slimed, possibly on this cast.

April 19, 2019 – UVP day

01501 – FLBB dark cast for SOCCOM. 01601 – Noisy altimeter at bottom, not fully dropped out 20 meters from bottom. 01701 – Attached UVP prior to cast, causing delay of ~20-30 minutes on station. This was done adhoc and is secured with one metal cylinder bracket on top and one large hose clamp with rubber for spacing and padding on bottom. Noisy altimeter, complete dropout 20 meters from bottom. 01801 – Tag line still attached on cast, brought back out. Altimeter very jumpy on bottom approach, dropped out at 20 m.

April 20, 2019 – Fishes day

01901 – Changed fish from 0830 to 0914 prior to cast. Noisy oxygen, altimeter still dropped out 20 meters from bottom. 02001 – Modulo error count: 10. Changed fish from ODF SN: 0914 to UW SN: 0057 prior to cast. Did transmissometer calibration post cast. 02101 – Modulo error count: 9. Changed altimeter from 62488 to 59116 prior to cast. New altimeter works fine for bottom approach.

April 21, 2019 – Modulo errors/Electrical retermination day

02201 – Modulo error count: 20. 02301 – Modulo error count: 55. Bottle 19 lanyard caught on spigot of bottle 18 when closing, bottom cap did not close. Inspected electrical termination post cast, no apparent water leakage. Replaced Y-cable from fish to sea cable with third and last cable brought. 02401 – Modulo error count: 110. Replaced electrical termination post cast with TGT pigtails and Y-cable. UW marine tech Croy Carlin did the electrical termination.

April 22, 2019

The request was received to swap the downward looking WH150 ADCP with the WH300 ADCP. Weather is being evaluated for best chance of doing so without damaging the ADCPs or the rosette.

02501 – Modulo error count: 30.

02601 – Modulo error count: 81. Removed CTD ASAP upon recovery of cast for cable inspection. After thorough inspection of cables on CTD, water was discovered leaking from third Y-cable between CTD, water sampler, and SBE 35. This cable was replaced with the second Y-cable with the splice. Oxygen sensor cable had suspicious bubbles near the connector, and so cable was replaced. Normal levels of abrasion and wear and tear were seen on the other cables, and so were reconnected. During inspection cable pins and bulkhead connectors were cleaned with contact cleaner, lubricated, and reconnected.

02701 – Modulo error count: 26.

April 23, 2019

02801 – Modulo error count: 63.

02901 – Modulo error count: 16. Bottle 7 did not trip, cleaned and worked latch prior to cast.

03001 – Modulo error count: 8. Swapped on straight cable from CTD to carousel, no SBE 35 for this cast. Cable removed was the second Y-cable tried with the old splice c. 2008. Bottle 7 did not trip again.

April 24, 2019

03101 – Modulo error count: 28. Straight cable from CTD to carousel still on, no SBE 35 for this cast. Swapped on straight ECO cable before cast to troubleshoot if spliced FLBB cable was cause of modulo errors. Modulo errors still occurred starting at ~2800 meters. FL signal dropped from background noise (0.05V) to 0V at multiple points on cast, cable is suspect. Put original spliced FLBB cable on after cast. Bottle 7 was moved upwards to adjust angle for lanyard pull, and so bottle 7 did trip on this cast.

03201 – Modulo error count: 32. Before cast marine techs megged connection loop from lab to CTD, reading 410 megaohms at 500 V. Inspection of winch and slip ring showed equipment in good state.

Sharp offset in transmissometer reading at ~1250 meters on downcast with no adjustment back on upcast at same pressure. Transmissometers switched from CST-1803DR to CST-1636DR post cast. While on recovery inspection of the sensor showed no fouling, and deck readings showed no errors, transmissometers were changed as a precautionary effort. Attempting to change cables lead to a search of ODF cables, of which all remaining cables looked to be in worse shape, attempting to use UW cables showed a different pinout that did not supply power to the instrument once a deck test was run.

03301 – Modulo error count: 19. Bottle 16 spigot was broken on recovery.

April 25, 2019

03401 – Modulo error count: 40. Did comprehensive bottle maintenance on rosette, checked guide rings and spigots – no major adjustments of note.

Weather delay. When the decision was made to steam south for calmer weather ODF SBE 9 SN: 0830 was swapped back onto the rosette to test if the UW SBE 9 was cause of modulo errors, with current configuration as is on rosette. Test cast was started at the end of April 25 and ended on April 26.

WH150 (big, downward looking ADCP) was swapped with WH300 during weather delay. Preliminary data from dual WH300 configuration looks good.

ODF SBE 9 SN:0914 pressure port was put in its cage with pressure port facing the flat end, an empty tape container put underneath it, and port removed to allow oil to drip out from below into the empty tape container. Very little oil or seawater dripped into the container, leading to likely large air bubbles forming in pressure port.

April 26, 2019

Weather delay.

90301 - Pulled test cast up after 2 modulo errors at roughly 3000 meters. Conclusion is that barring a full rebuild of CTD with intensive inspection of each sensor and cable as we swap back to UW SBE 9 SN: 0057, potential cause of modulo errors might not be found. A test cast would then be required to see if problem is fixed, which is not feasible in this weather. Modulo error issue is concluded for now barring major failure during cast.

ODF SBE 9 SN: 0914 pressure sensor port was filled with vegetable oil as a substitute for DC-200 silicone oil. One of the primary ingredients of vegetable oil is canola oil, also known as rapeseed oil, which used to be the preferred oil of choice for lubricating things entering water. Canola oil may still be used on ships for spraying on winch drums between casts. Or is it linseed oil? Unfortunately without a test cast, we will not see if said oil serves as a decent substitute in case oil disappearance.

April 27, 2019

Weather delay. UW SBE 9 SN: 0057 was swapped back onto the rosette. SBE 35 is cabled up and will remain so for the remainder of the cruise. Y-cable used for SBE 35 is the original cable on rosette, which was re-spliced at sea. Second Y-cable, which had the older splice presumably c. 2008, was left off.

Third Y-cable was cut apart at problem area and insulation showed green patina on inside of insulation, signs of water intrusion and corrosion. Thorough inspection remains to be done of the length of the cable and possibly the other two legs of the cable.

LADCP battery has not been charging while losing power. The battery was switched to the second battery, which has been tested and is working.

April 28, 2019

03501 – Modulo error count: 112. First cast in the water after 55 hours without station work. During swap of fish voltage channels were accidentally switched, V3 for altimeter and V4 for UVP. UVP did not soak long enough to come on due to this mixup.

03601 – Modulo error count: ???. Removed Y-cable on V2/V3 prior to cast. UVP is now pulled from CTD, transmissometer is on straight cable to V2, altimeter on straight cable to V4. No noticeable change made.

Inner lanyard on top cap of bottle 2 was noticed to only be on spring by one line instead of two. The lanyard was adjusted to have both lines attached, fraying should be monitored for the rest of the cruise.

April 29, 2019

03701 – Modulo error count: 28. Put Y-cable back on V2/V3 connector, UVP hooked up again. UVP signal was on the rails (0 or 5 volts) for most of the cast, not showing a typical profile for UVP. Post cast UVP power cable was noticed to have corrosion on pins, person in charge of UVP will now be rinsing and cleaning pins after unplugging each time.

During recovery it was snowing, leading to the pallet being wet and slippery. While bringing the rosette in rosette slipped off of the pallet by 2/3rds. Wooden blocks to stop sliding were installed on the pallet in addition to straps that were used in adverse conditions.

03801 – Modulo error count: 10. On recovery a tagging hook slipped off the horizontal rung and grabbed a vertical stanchion with chipod cable on it, causing damage to cable. Cable was replaced after sampling. Chipod connected to damaged cable was upward looking SN: 7.

Bottle 7 was noticed to have an anomalous oxygen draw temperature, suspected mistrip. Bottle will be adjusted post sampling.

03901 – Modulo error count: 6. Bottles 3, 7, 13, 18, 19 had guide rings adjusted to prevent bottle caps closing too early prior to cast. The sea cable was found stuck between a horizontal bar and a tab on its run down from the shackle down to the CTD. The sea cable was freed from being stuck there on the hypothesis that at pressure and in sudden tension loads or movement might be enough to cause a slight pinch in the cable or other deformation leading to modulo errors. There are some spikes in the data that look like they could be modulo errors, yet without a modulo error attached to them.

April 30, 2019

04001 – No modulo errors.

04101 – No modulo errors.

04201 – No modulo errors. Rosette kissed the side of the ship during deployment due to swell and ship motion.

04301 – No modulo errors.

At this point the modulo error problem is believed to be resolved. Any new problems related to modulo errors will be believed to be due to a new problem.

May 1, 2019

04401 – No modulo errors. Cast was canceled at 1800 meters downcast due to incoming weather.

May 2, 2019

04402 – Modulo error count: 18. Due to heavy weather ship was drifting a lot, altimeter did not kick in at expected depth due to wire angle. Multiple stops and slow descents to allow angle to settle out before eventually locking in bottom depth with altimeter.

04501 – No modulo errors. Descended in heavy weather, slowed down early in order to allow angle to settle out.

May 3, 2019

No stations or issues addressed.

May 4, 2019

No stations or issues addressed.

May 5, 2019

No stations or issues addressed.

May 6, 2019

No stations or issues addressed.

May 7, 2019

No stations or issues addressed.

May 8, 2019

No stations or issues addressed.

May 9, 2019

04601 – An air vent screw was noticed broken on bottle 33 prior to the cast, and replaced.

04701 – No problems noted.

04801 – Air vent screws on bottles 15 and 17 were noticed opened prior to sampling.

04901 – No problems noted.

May 10, 2019

05001 – No problems noted.

05101 – One strand of the outer armor on the wire started birdcaging on upcast around 3700 meters at point where level wind takes in wire from block. Operations were stopped as the birdcage was cleared from the wire, during which a Yale grip was put in place on the wire downstream of the birdcage in case anything happened. 52 to 54 wraps of wire on the winch appear to have been stripped of a single armor wire, roughly equivalent to 100 meters of wire. Once safe to bring aboard the rosette came up at normal speeds, 60 meters per minute below 100 meters of water depth and 30 meters per minute above 100 meters of water depth.

Post recovery the termination was cut and the aft DESH-5 winch was used for deployment, necessitating mechanical and electrical retermination. It was noted that on previous cruises the winch had electrical signal problems leading to 300+ modulo errors, and so ground was doubly connected to both the armor and the red wire, while signal was connected to the white wire. Deck tests showed no problems before deployment.

Bottles 8 through 34 were fired on the fly. Bottles 35 and 36 were fired while stopped at the surface while waiting for conditions to recover.

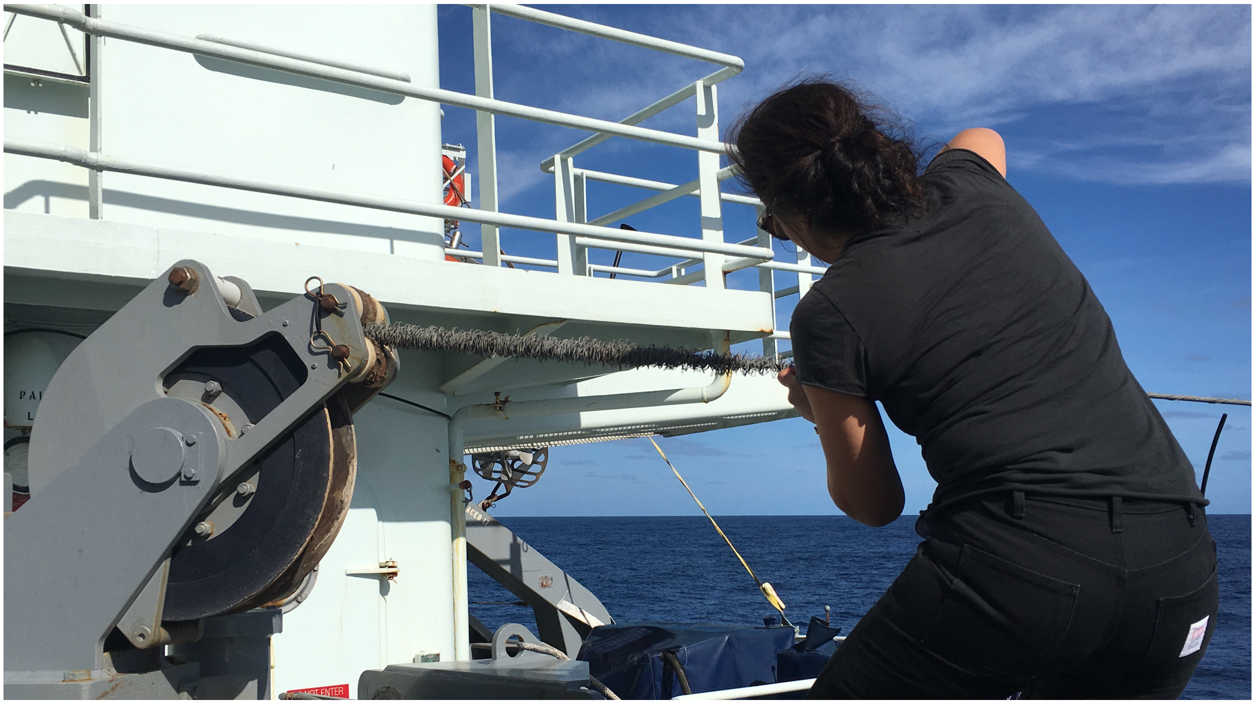


Fig. 6: Birdcage of approximately 100 meters of wire forming outside of the level wind intake being freed by RV Thompson marine technician Jen Nomura.

05201 – No problems noted during cast. Bottle 12 was open on recovery, status unknown. The bottle was adjusted upwards between 0.5 to 1 inch post sampling.

May 11, 2019

05301 – No problems noted during cast.

05401 – Modulo error count: 7. A Chinese fishing vessel was occupying station, causing a diversion to the west of several nautical miles.

05501 – Modulo error count: 14.

May 12, 2019

During disassembly of the rosette and CTD, nothing out of place was noticed. The SOCCOM FLBB dark cast was done on deck, with files named "FLBB_postcruise_deck_readings". The final transmissometer deck calibration was done with files named "tx_deckcal_1636_20190512".

3.5 Major Problems (Triage, Care, Analysis):

Deckbox beeping: One of the more common errors that points to bad cabling, most likely water intrusion. Upon recovery and inspection we found the damaged cable, replaced it, and everything worked well afterwards.

Drifting pre and post pressure points on deck: The first sign of a failing pressure sensor is instability of a deck pressure readings. This can be monitored by deck pressure readings pre and post cast, where the CTD is on before deployment into the water and after recovery. This can also be tested by leaving a CTD powered on for 15-30 minutes and plotting the pressure on deck. If the pressure on deck drifts by more than 0.1-0.2 decibar over this time consider looking for problems. Remember 0.1 decibar is equal to 10 milibar – unless a large storm system is passing over you very quickly, a drift of 1 decibar during a deck test is equivalent to a change of 100 milibar in the atmosphere.

Fig. 8: FLBB readings taken on deck post last station. FL average reading was 0.050 volts, BB average reading was 0.070 volts.

The current hypothesis for lack of oil in the sensor is thermal expansion of the oil causing the fluid to leak out of the nylon tubing. The CTDs were filled with oil in San Diego in January, roughly at 20 C/high 60s F. The CTDs were then shipped to South Africa by sea, where they sat in their shipping container in the African summer for weeks/months, which caused the oil to slowly leak out of CTDs onto the porous wooden crate, which would have absorbed the oil, leaving no trace of what had happened.

After seeing a 2 decibar change between pre and post cast readings the decision was made to swap CTDs. Unfortunately the second ODF CTD was shipped in the same manner and so had the same pressure problem to greater effect, where the pressure sensor thought it was at 5 decibar when it was out of the water. This can be explained by water being trapped in the pressure port and not leaving the port fast enough. The second ODF CTD was then quickly replaced with a UW CTD after attempting to find a substitute to fill the pressure ports with oil.

The problem was solved by switching to the ship's CTD. The CTD's most recent calibration is late 2017, which is within Seabird's schedule. In the future mineral oil used for refilling the LADCP battery housing could also be used to fill the pressure port, an option we had not thought of at the time.

Oxygen sensor spikiness: The SBE 43 oxygen sensor showed uncharacteristic spikiness sharper than usually seen with membrane issues. The spikes occurred after the plumbed lines for the CTD froze over on deck while in negative Celcius weather, leading to initial thoughts of it being a frozen or damaged membrane. However after swapping the sensors the signal was still spiky. A third swap was done to a UW SBE 43 in order to preserve the final ODF SBE 43 unused sensor as a spare. When the third SBE 43 also had the same spiky trace, electrical problems were suspected and a spare cable was swapped in, with no change. Finally the cabled connector position was swapped where the SBE 43 was moved from its own voltage channel (V6) to another voltage channel (UVP, V3), which showed a cleaned signal.

Altimeter spikiness: The altimeter signal was spiky on approach of the bottom after working well for the start of the cruise. The signal was very spiky within 100 meters, and then would drop out ~20 meters from the seafloor, requiring watchstanders to manually stop the winch operator without telemetry to guide. The altimeter was swapped out for the backup altimeter, which solved the issue.

Modulo errors: Modulo errors have dominated the cruise so far. While worrying more for their potential problem of continuous bad signal, the total modulo errors to date represent less than 1% of all scans per cast at worst, usually less than 0.1% of all scans. Attempts to solve the modulo error issue have been inconclusive at best, attempting fish swaps, cable swaps, and inspections of all parts of the entire CTD system from lab to deployment to rosette. While we have found cables that need to be repaired and replaced, no conclusive smoking gun has been found to date.

Modulo errors represent transmission problems, where a known function on the CTD produces a value for the deck box/computer to verify. If this value is not correct, you have a modulo error, where a scan may or may not be affected. Only the check value could be altered, or only the metadata and so no scientific data is affected, or the data could have erroneous values. In very small amounts the data will be binned and dealt with, leading to little to no impact on the data. Problems would occur as more and more modulo errors occur, leading to unreliable communication with the CTD. If the issue is inside the transmission loop between the CTD and the deck box communications to the CTD could be affected, leading to bottles not being fired when told to, or not being reported as fired. If the modulo error rate approaches 25-50% of data, the CTD signal may be unsalvageable for high quality data.

After switching to the aft DESH-5 winch modulo errors started again, this time known about from previous cruises. These modulo errors seem to be caused by something in the winch/wire setup, and so the cable was double grounded to the armor and the red wire. The spread of modulo errors was much greater, with errors starting higher in the water column and also sometimes occurring mostly on the upcast.

3.6 Cruise Lessons

Have repair kits for all conditions, no matter how unlikely: After the recent discussion on the RVTEC mailing list about a SBE 9 with drifting pressure and most likely loss of oil in the pressure port, it seems fitting that the first headscratcher once station work started is the same problem.

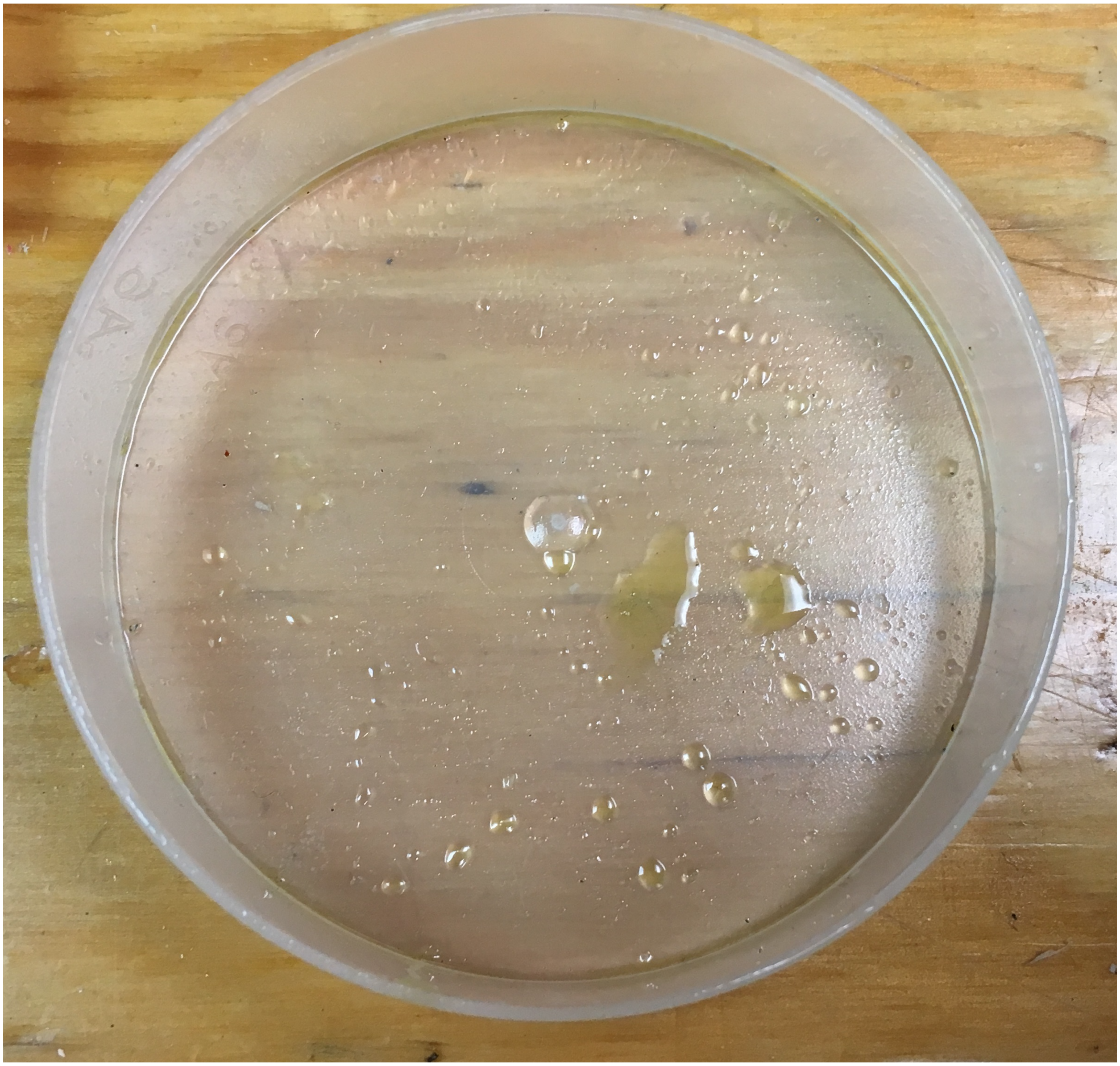


Fig. 9: Tiny amount of oil dripped out from the pressure port due to gravity. No free oil was visible to the eye in the sensor.

Ad hoc oil refill procedure: Stick thin wire down pressure port, to be used as displacer. We used 22 gauge solid wire, which fits in both the nylon tubing and the pressure port channel. Fill pressure port well with oil. Pull wire partially out, which causes oil to be sucked down into the channel. Repeat process, refilling well with more oil and continue to pull wire out section by section until wire is fully removed and oil well is filled.

Use known good equipment, including ancillaries: ODF did not bring its usual set of equipment out to sea for I06S. While sensors were checked and found in good order before shipping, the cables shipped out for use were found to have problems. Roughly a half dozen cables were swapped on and off of the CTD in the process of testing, and of those more than half of them were already spliced or had water damage after the cast. Two of the three Y-cables connecting the CTD, water sampler, and SBE 35 had extended water damage, with metal sheathing inside the insulation being corroded away for a foot or more. Additional cables that were evaluated to be put on the CTD were found to be damaged, with visible gaps in the insulation through which the inner wires could be seen. A thorough check of all equipment sent especially when they have an unknown service or use history would have cut down on problems and overtime over the cruise.

Trust your experience: Issues were encountered that could have been avoided had different choices been made. Inexperienced cruise participants with equipment on the rosette made decisions that ended up costing time and willpower in the long run, wearing down personnel on the cruise. Instead of listening to the instrument expert, who may have field tested the equipment a couple of cruises previously, allow the cruise experts with decades of experience to have final say on how equipment is mounted and prepared for deployment.

Have enough support on the ship: The amount of science achieved would not have been possible without the Thompson's marine technicians on the ship supporting the ODF technicians in troubleshooting the CTD and rosette issues. Both Croy Carlin and Jen Nomura were invaluable in helping keeping the CTD running and stations moving, and while ODF tries to bring enough experience and hands to deal with any encounter at sea, having another set of experienced hands to step in and do the work when issues have you doubting yourself allowed the cruise to accomplish more stations that would have without them available. This cruise may be an outlier in problems encountered along the way, but having four experienced technicians with CTD work made the workload manageable, which would have crushed two experienced technicians with 24-hour work.

CHAPTER

FOUR

CTDO AND HYDROGRAPHIC ANALYSIS

PIs

- Susan Becker
- James Swift

Technicians

- Kenneth Jackson

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 7. SBE SeaSave7 v.7.26.1.8 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 logs for each attempted cast containing a description of each deployment event.

Once the deck watch had deployed the rosette, the winch operator would lower it to 20 meters. The CTD sensor pumps were configured to start 10 seconds after the primary conductivity cell reports salt water in the cell. The CWO checked the CTD data for proper sensor operation, waited for sensors to stabilize, and instructed the winch operator to bring the package to the surface in good weather or no more than 5 meters in high seas. The winch was then instructed to lower the package to the initial target wire-out at no more than 30m/min to 100m and no more than 60m/min after 100m 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 40m/min 100m from the bottom and 20m/min 30m 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 up-cast, 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 shed wake had dissipated. 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 14 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 would be later used to record the depths bottles were tripped and correspondence between rosette bottles and analytical samples drawn.

Normally the CTD sensors were rinsed after each station using a fresh water tap connected to Tygon tubing. The tubing was left on the CTD between casts, with the temperature and conductivity sensors immersed in fresh or salt water depending on ambient air temperatures.

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 python CTD processing software 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 down-cast 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 55 CTD stations were occupied including one test station. A total of 150 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 shipboard conductivity and oxygen sensor calibrations.

Temperature, salinity and dissolved O_2 comparisons were made between down and up casts 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 I06S-2019 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 many problems with the CTDO sensors, leading to CTD downcast data to be flagged questionable. SBE43 oxygen sensors were slightly noisy for most of the cruise, however there were a few notable casts that contained extremely noisy data. Stations 7 and 34 are shown as examples.

Several stations also had a combination of the conductivity, temperature, and oxygen sensors producing spikes and questionable voltages. Station 24 is shown as an example below.

Stations 29 and 32 (not shown) are other examples of stations with large sections of the profile flagged as questionable.

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. Initially 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 configuration cast sets.

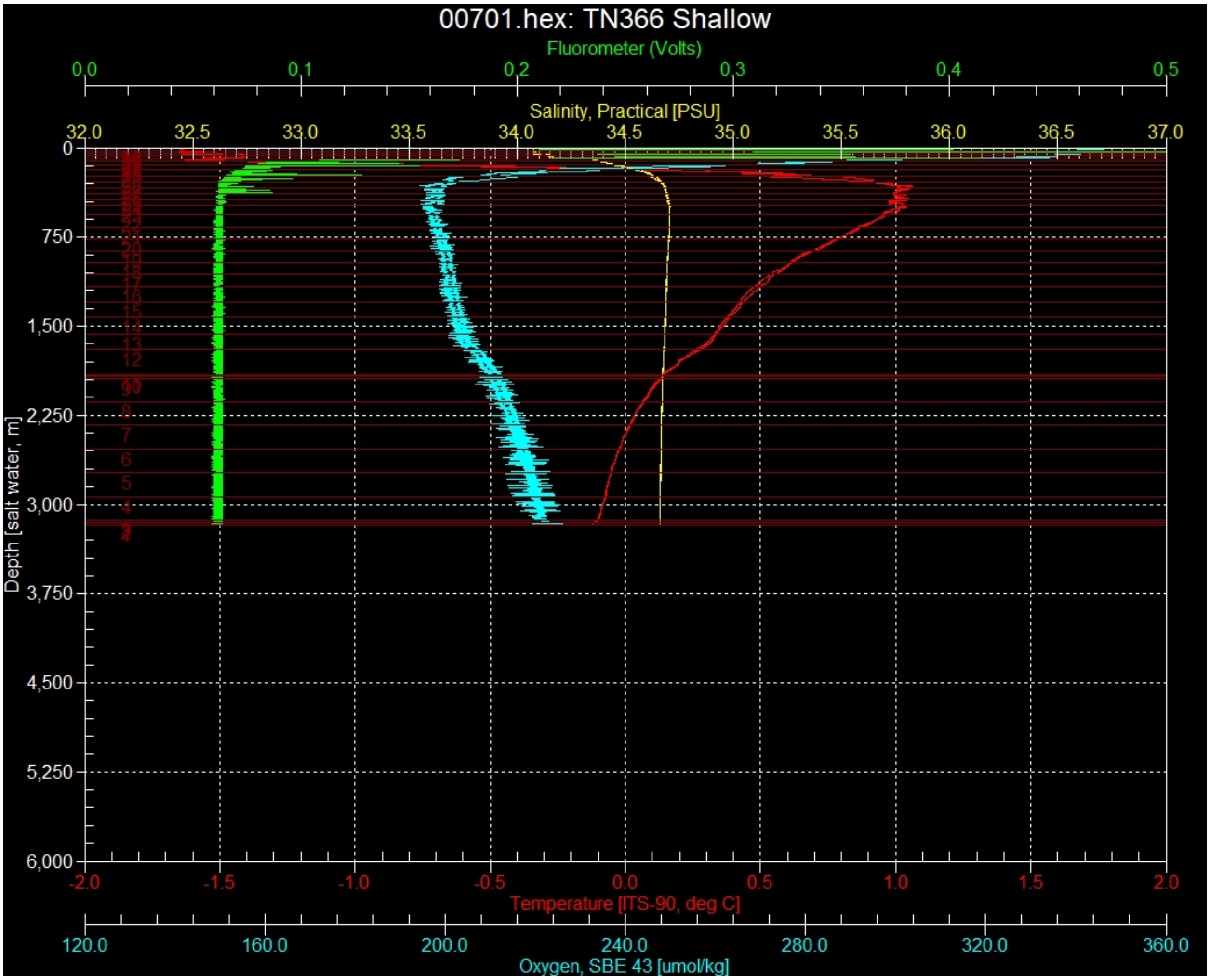


Fig. 1: Station 7

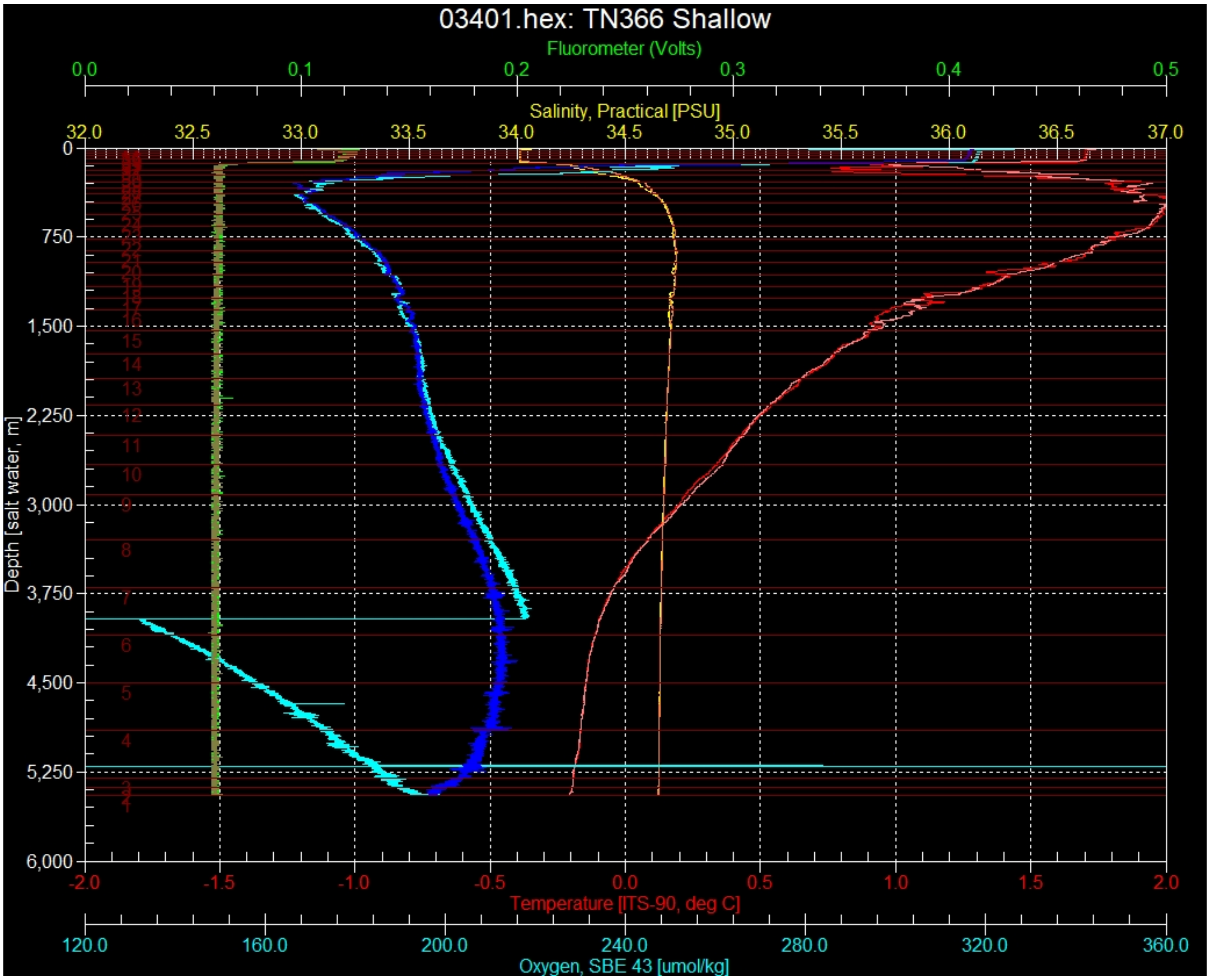


Fig. 2: Station 34

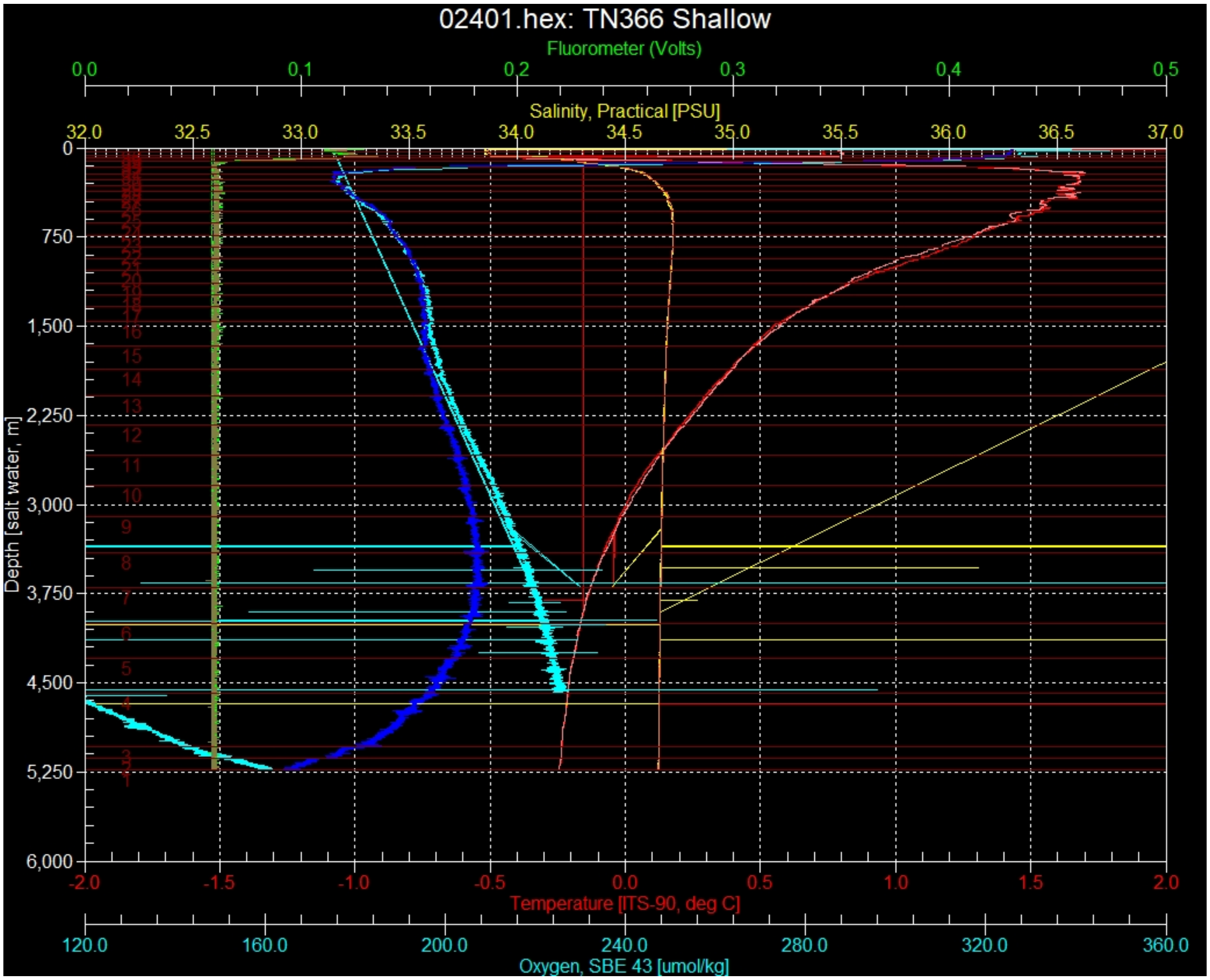


Fig. 3: Station 24

CTD #0830 (Stations: 1-18):

	Start P (dbar)	End P (dbar)
Min	-2.2	-1.3
Max	0.01	-0.3
Average	-0.86	-0.64
Applied Offset		-0.216

On-deck pressure reading for varied from -2.2 to 0.01 dbar before the casts, and -1.3 to 0.3 dbar after the casts. Before and after average difference was -0.86 and -0.64 dbar respectively. The overall average offset before and after cast was -0.216 dbar.

CTD #0914 (Stations: 19):

	Start P (dbar)	End P (dbar)
Min	-0.2	3.9
Max	-0.2	3.9
Average	-0.2	3.9
Applied Offset		4.102

On-deck pressure reading for varied from -0.2 to -0.2 dbar before the casts, and 3.9 to 3.9 dbar after the casts. Before and after average difference was -0.2 and 3.9 dbar respectively. The overall average offset before and after cast was 4.102 dbar.

CTD #0057 (Stations: 20-55):

	Start P (dbar)	End P (dbar)
Min	-0.44	-0.42
Max	0.21	0.31
Average	-0.09	-0.16
Applied Offset		-0.0709

On-deck pressure reading for varied from -0.44 to 0.21 dbar before the casts, and -0.42 to 0.31 dbar after the casts. Before and after average difference was -0.09 and -0.16 dbar respectively. The overall average offset before and after cast was -0.0709 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 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 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, a first order with respect to temperature and a first order with respect to time. The functions used to apply shipboard calibrations are as follows.

$$T_{cor} = T + D_1 P_2 + D_2 P + D_3 T_2 + D_4 T + \text{Offset}$$

$$T_{90} = T + tp_1 P + t_0$$

$$T_{90} = T + aP_2 + bP + cT_2 + dT + \text{Offset}$$

Corrected temperature differences are shown in the following figures.

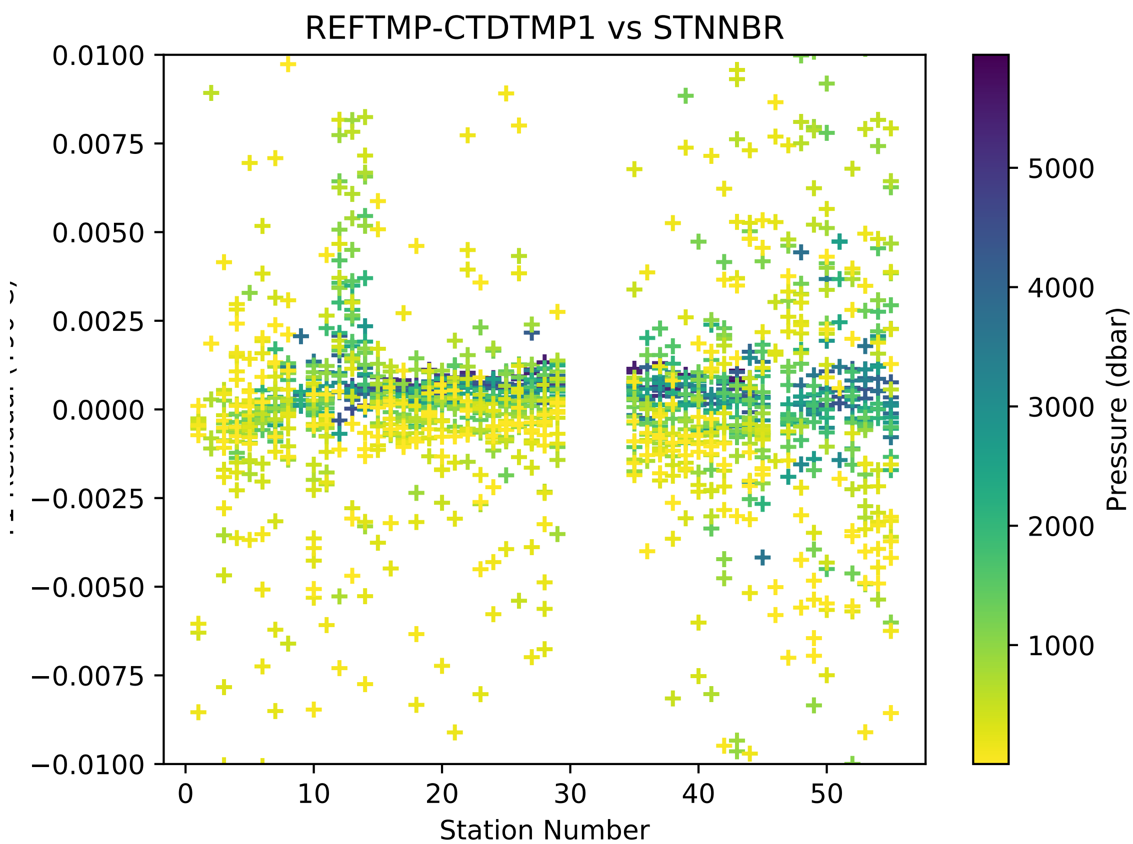


Fig. 4: SBE35RT-T1 by station.

The 95% confidence limits for the mean low-gradient (values -0.002°C $\leq$ T1-T2 $\leq$ 0.002°C) differences are $\pm$0.0068°C for SBE35RT-T1, $\pm$0.0067°C for SBE35RT-T2 and $\pm$0.0052°C for T1-T2. The 95% confidence limits for the deep temperature residuals (where pressure $\geq$ 2000dbar) are $\pm$0.00096°C for SBE35RT-T1, $\pm$0.0020°C for SBE35RT-T2 and $\pm$0.0018°C for T1-T2.

Minor complications impacted the temperature sensor data used for the I06S cruise.

- The SBE35RT sensor data was not available for stations 30 to 34 due to the SBE35RT not being installed.
- The SBE35RT sensor memory was partially full, and there are partial data reported for cast on station 9.
- Early stations and station with bad weather had bottles fired on the fly, leading to some SBE35RT averaging periods outside of the intended depth.

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

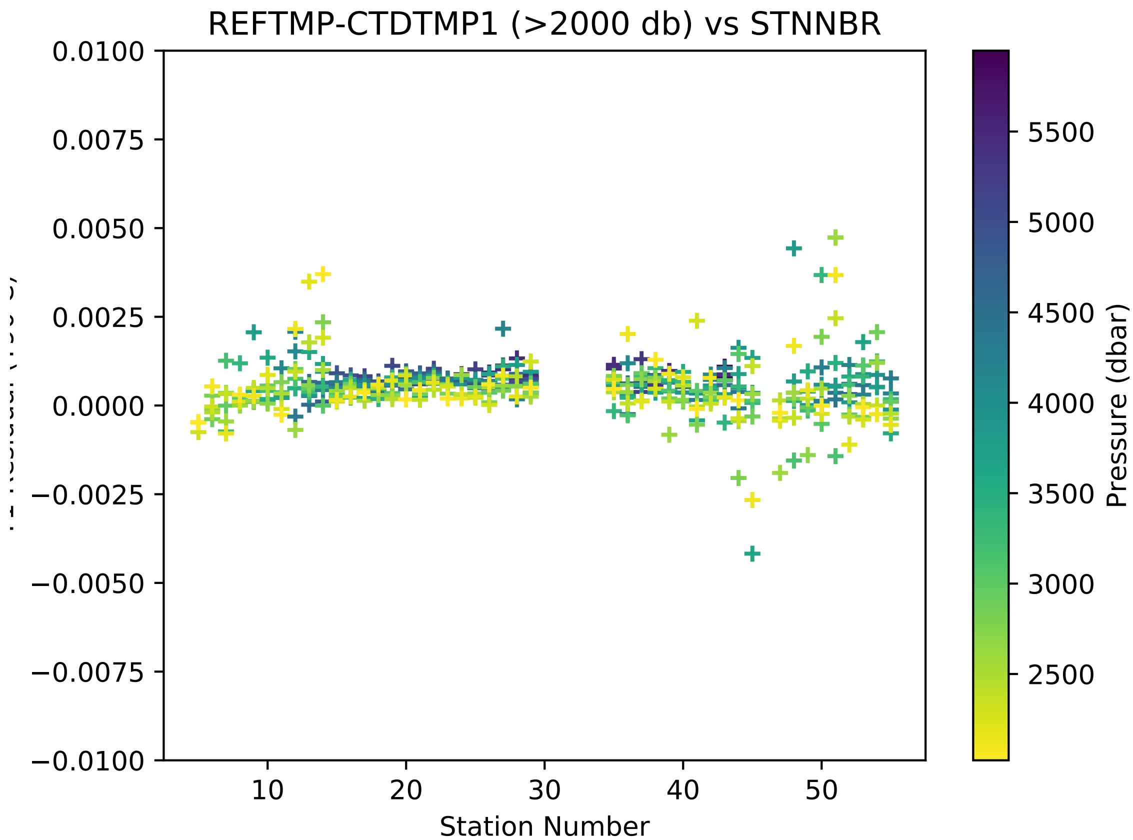


Fig. 5: Deep SBE35RT-T1 by station (Pressure ≥ 2000dbar).

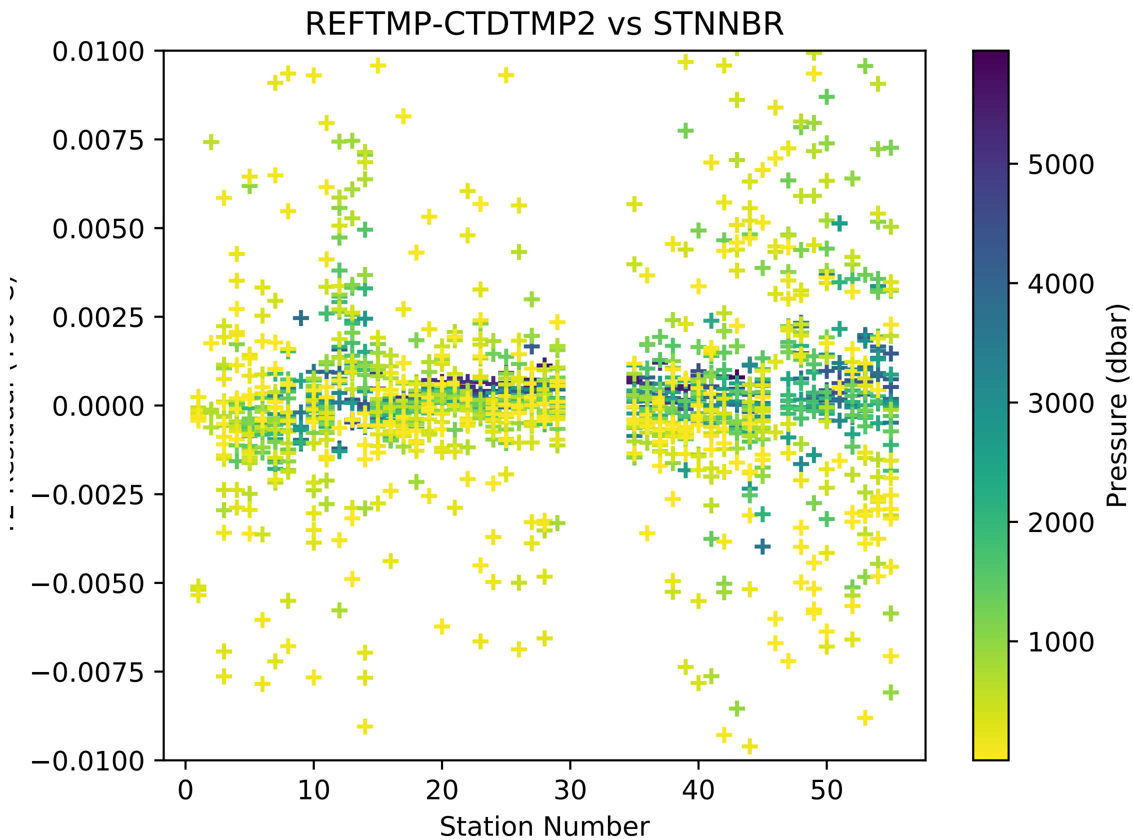


Fig. 6: SBE35RT-T2 by station.

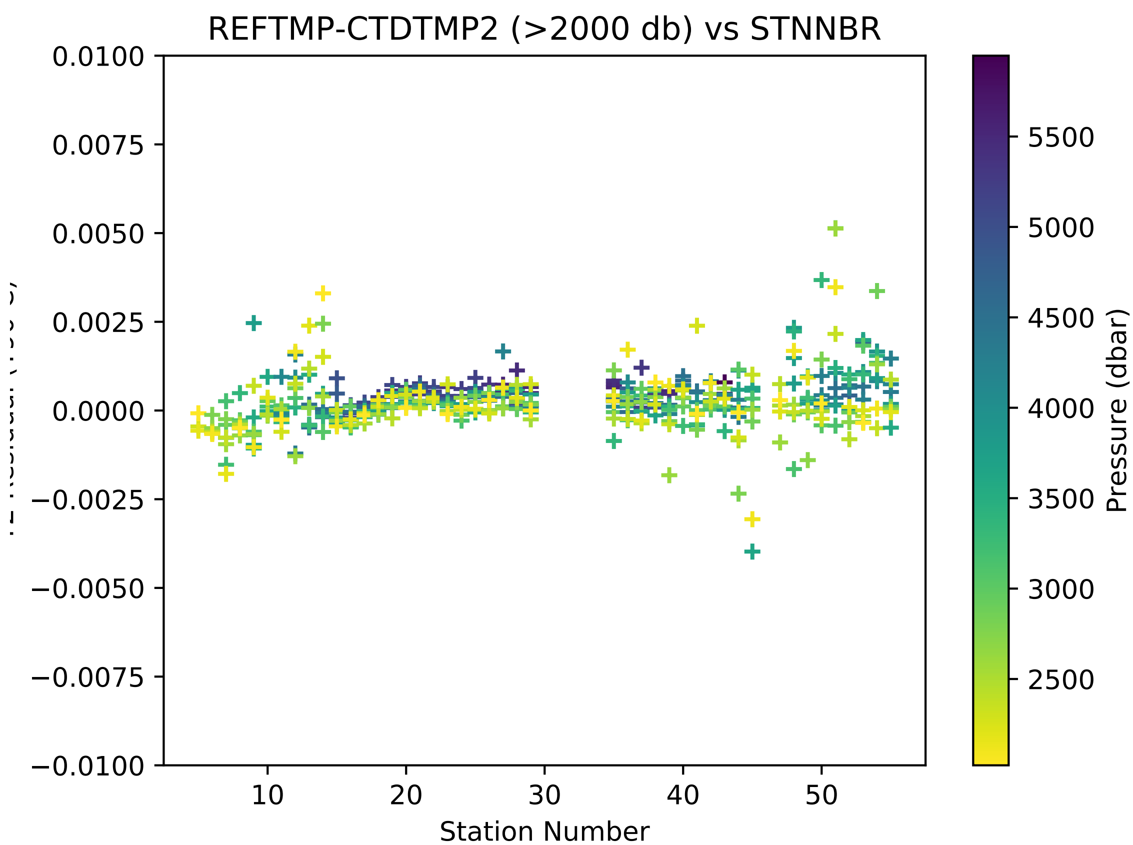


Fig. 7: Deep SBE35RT-T2 by station (Pressure ≥ 2000dbar).

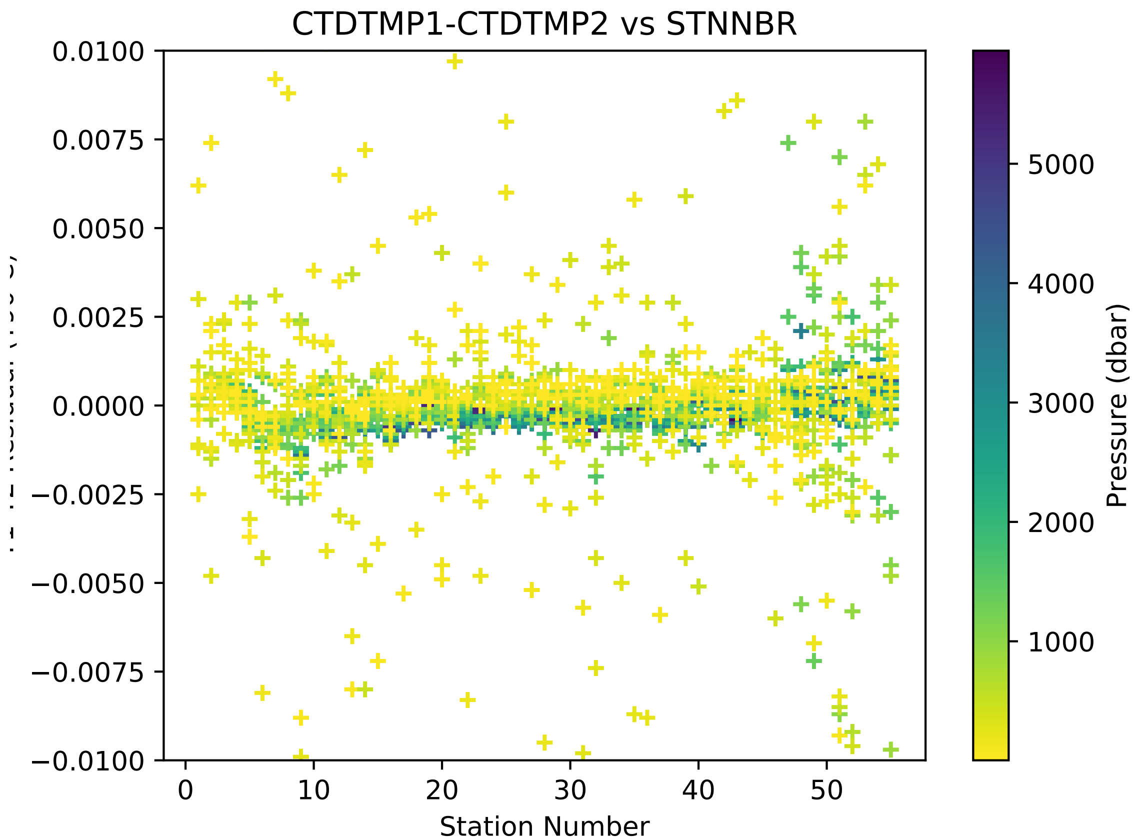


Fig. 8: T1-T2 by station.

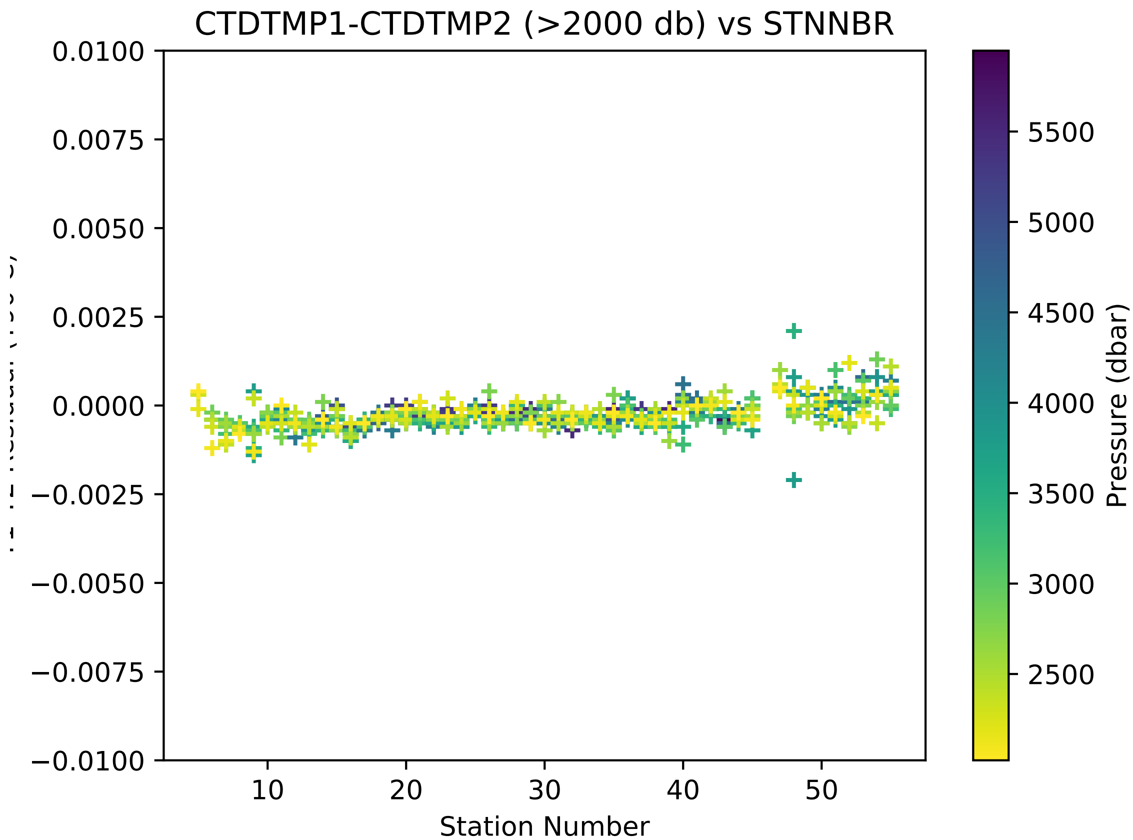


Fig. 9: Deep T1-T2 by station (Pressure ≥ 2000dbar).

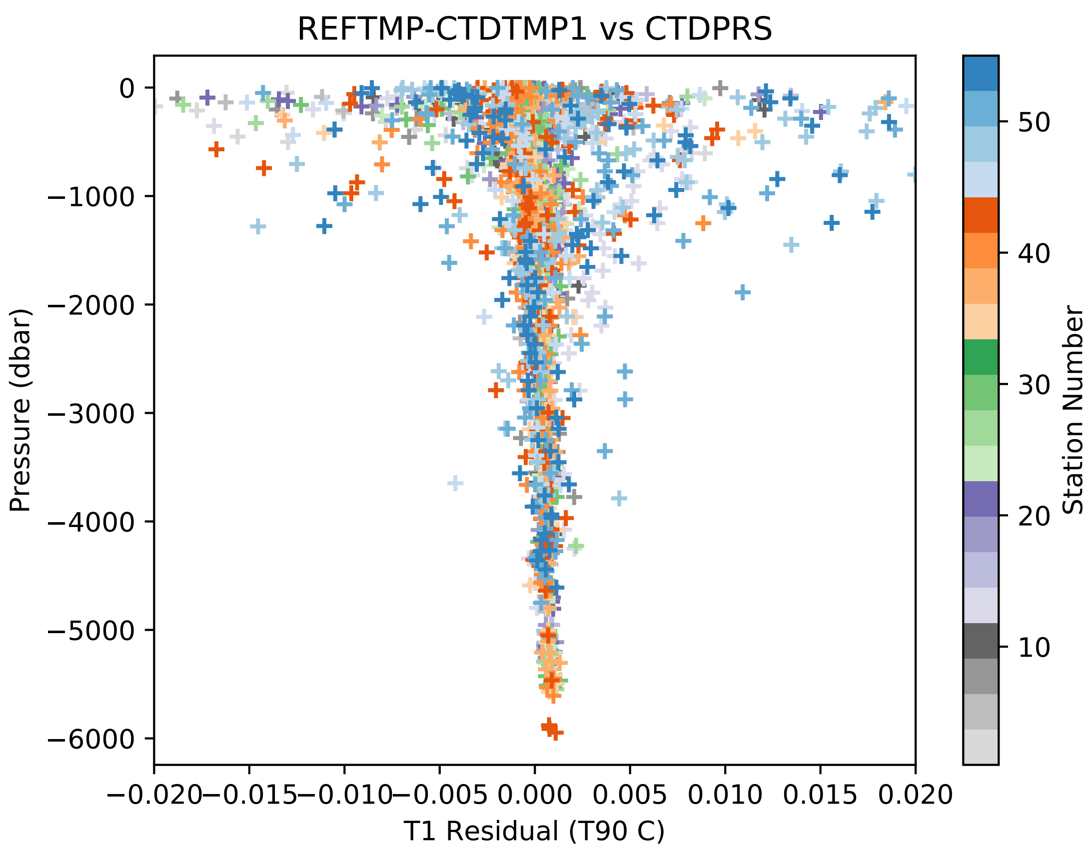


Fig. 10: SBE35RT-T1 by pressure.

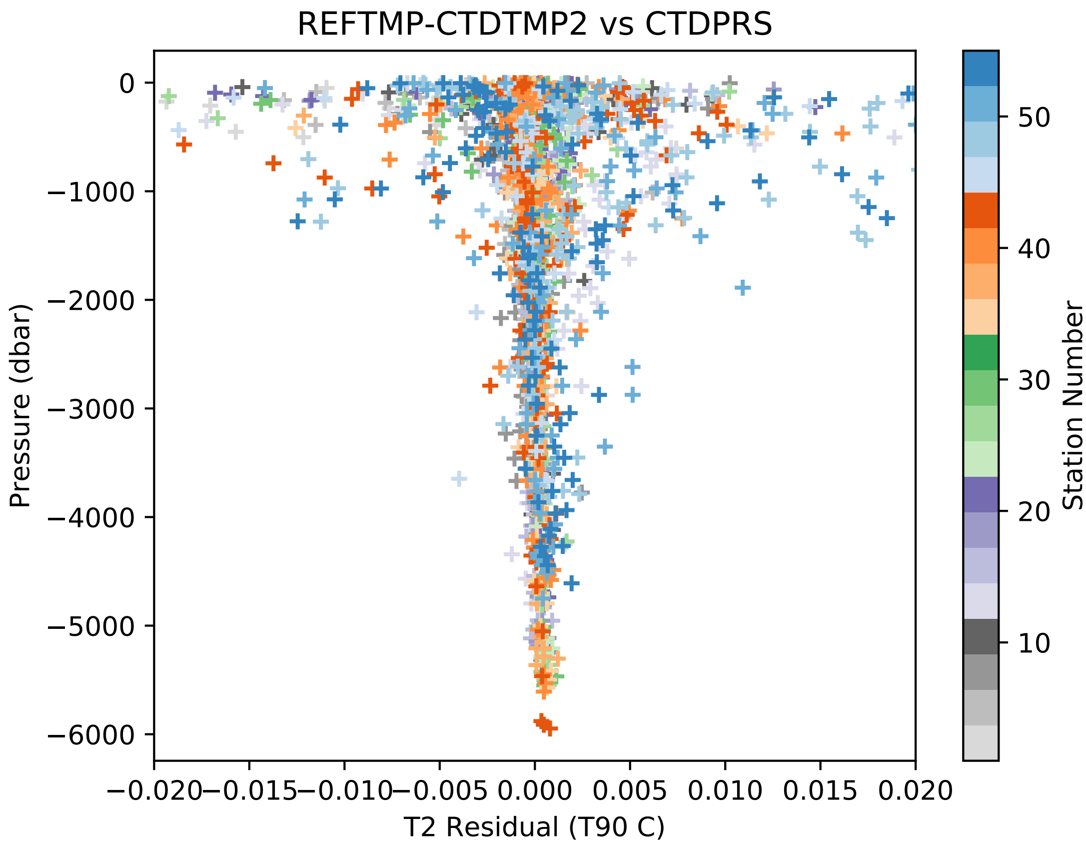


Fig. 11: SBE35RT-T2 by pressure.

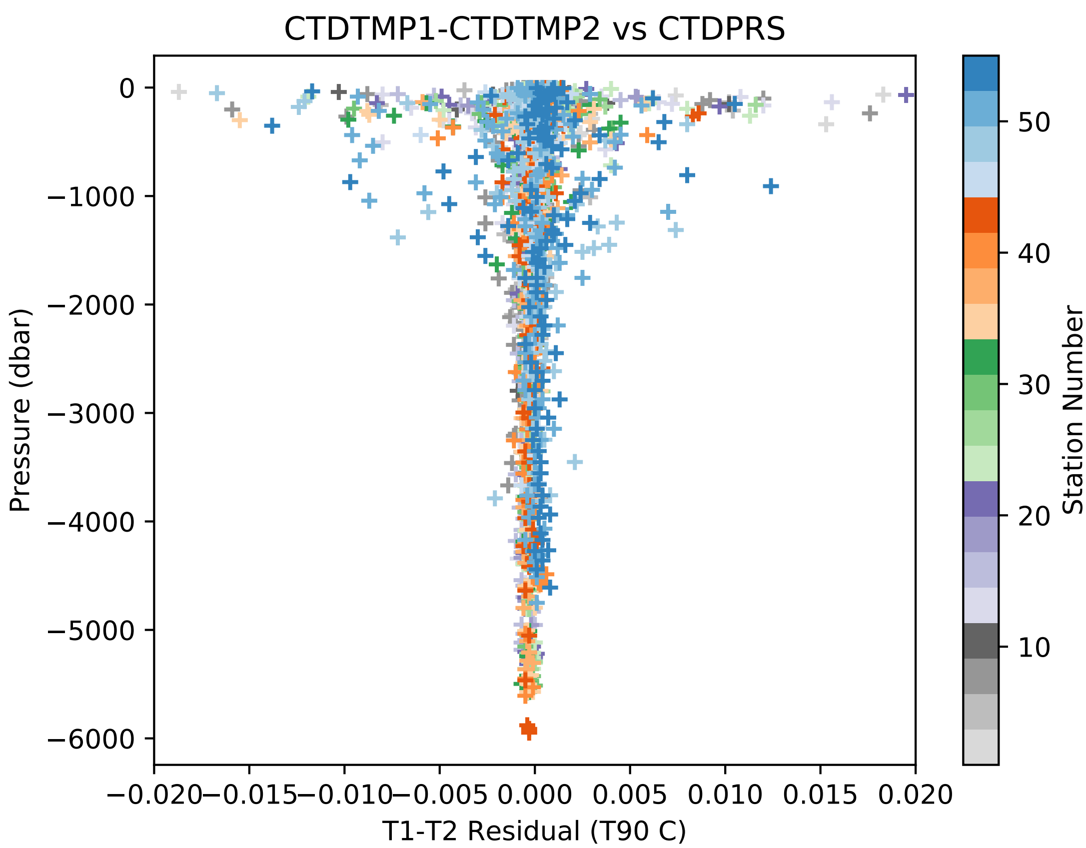


Fig. 12: T1-T2 by pressure.

4.6 Conductivity Analysis

Laboratory calibrations of conductivity sensors were performed prior to the cruise at the SeaBird 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 ship-board calibrations were performed to correct sensor bias. Corrections for both pressure and temperature sensors were finalized before analyzing conductivity differences. Two independent metrics of calibration accuracy were examined. At each bottle closure, the primary and secondary conductivity were compared with each other. Each sensor was also compared to conductivity calculated from check sample salinities using CTD pressure and temperature.

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

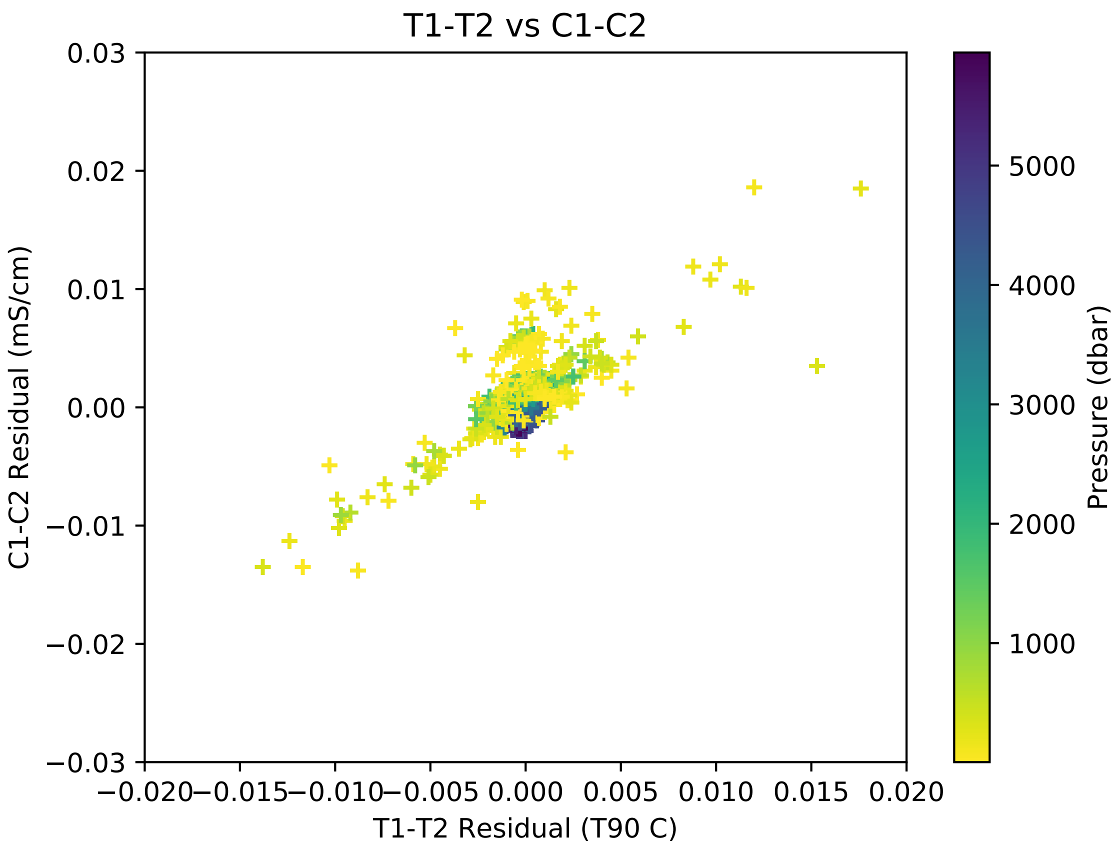


Fig. 13: Coherence of conductivity differences as a function of temperature differences.

Uncorrected conductivity comparisons are shown in figures *Uncorrected CBottle - C1 by station.* through *Uncorrected C1-C2 by station.*.

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.

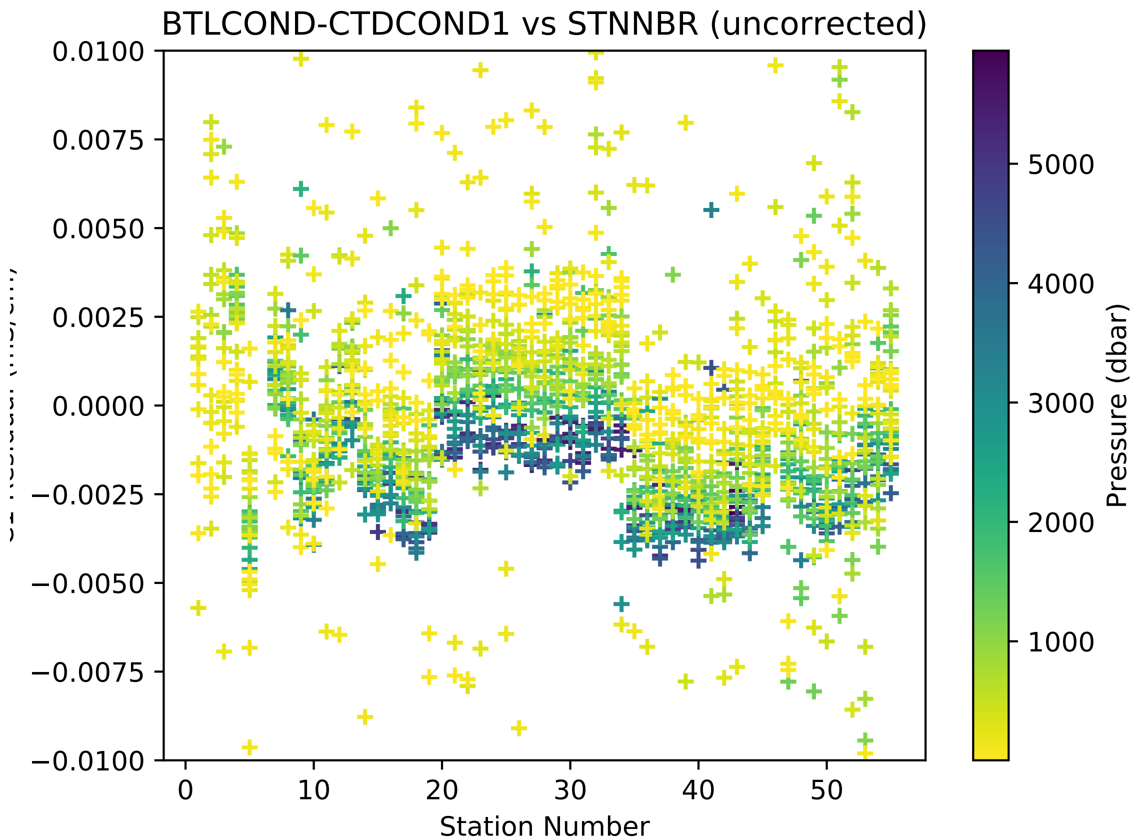


Fig. 14: Uncorrected C_{Bottle} - C1 by station.

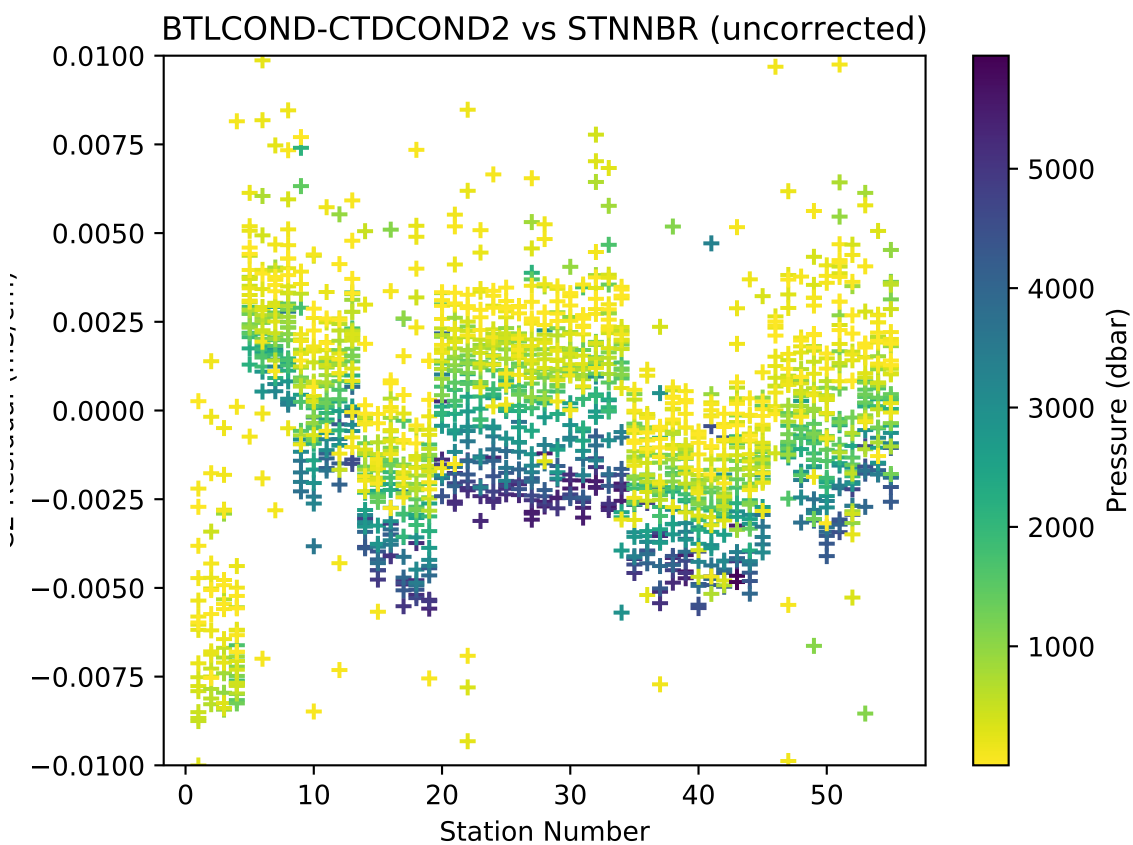


Fig. 15: Uncorrected C_{Bottle} - C2 by station.

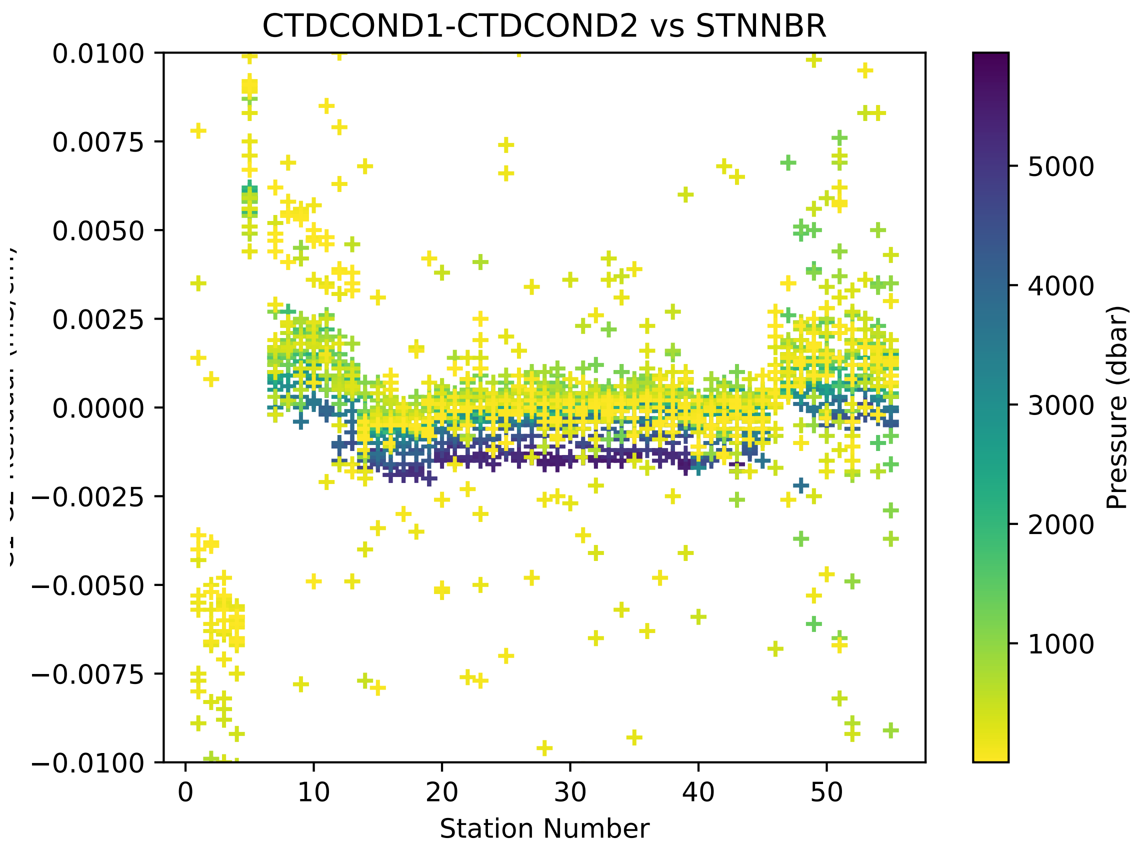


Fig. 16: Uncorrected C1-C2 by station.

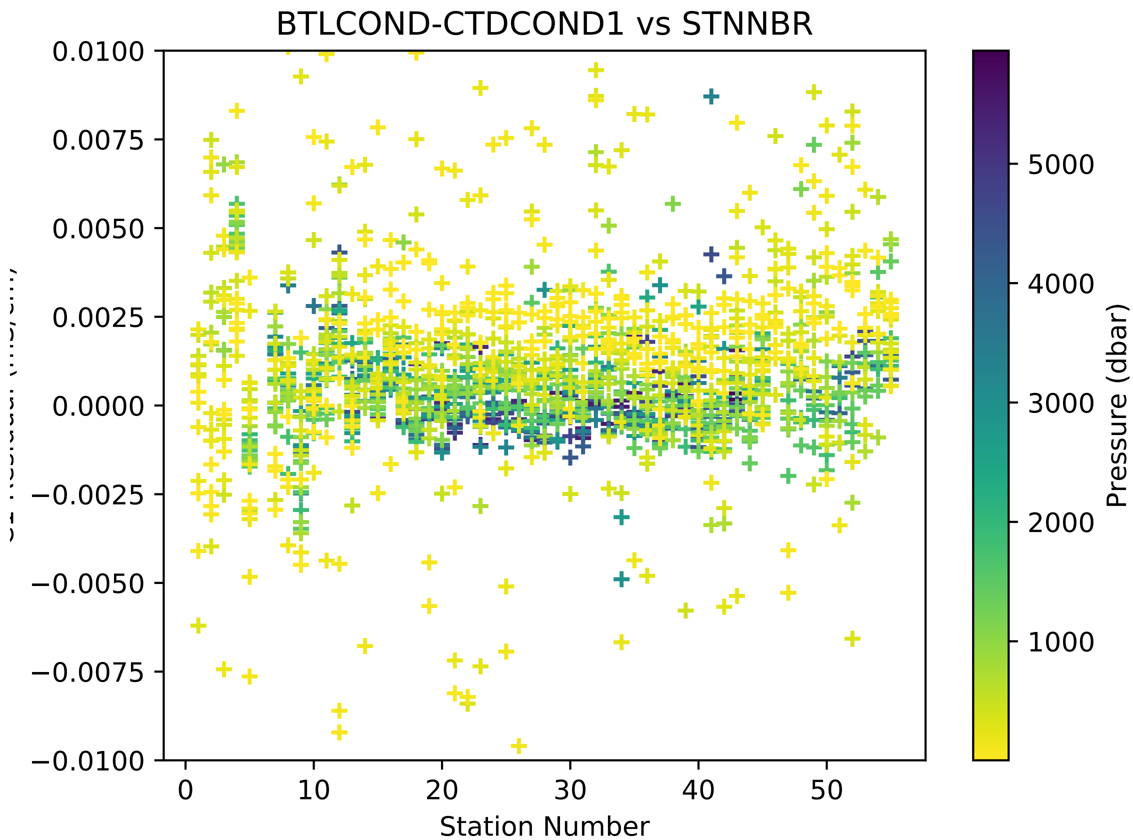


Fig. 17: Corrected C_{Bottle} - C1 by station.

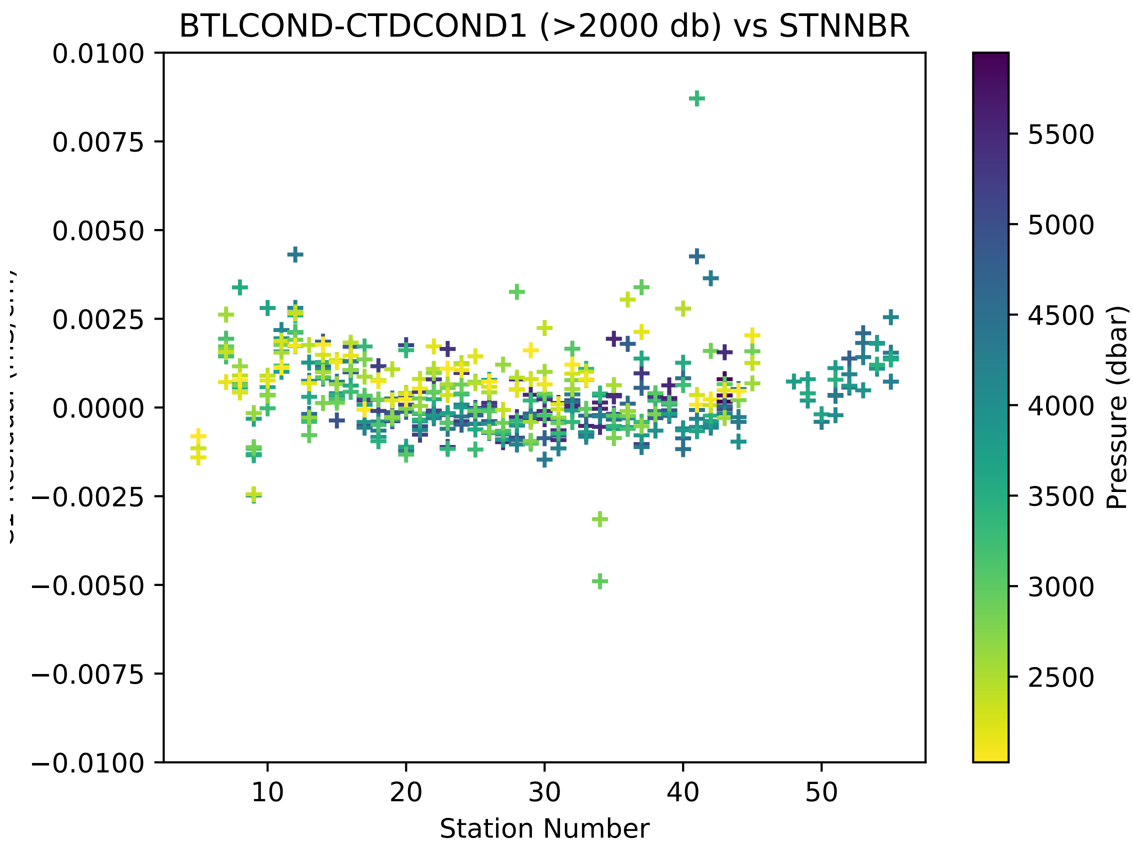


Fig. 18: Deep Corrected C_{Bottle} - C1 by station (Pressure >= 2000dbar).

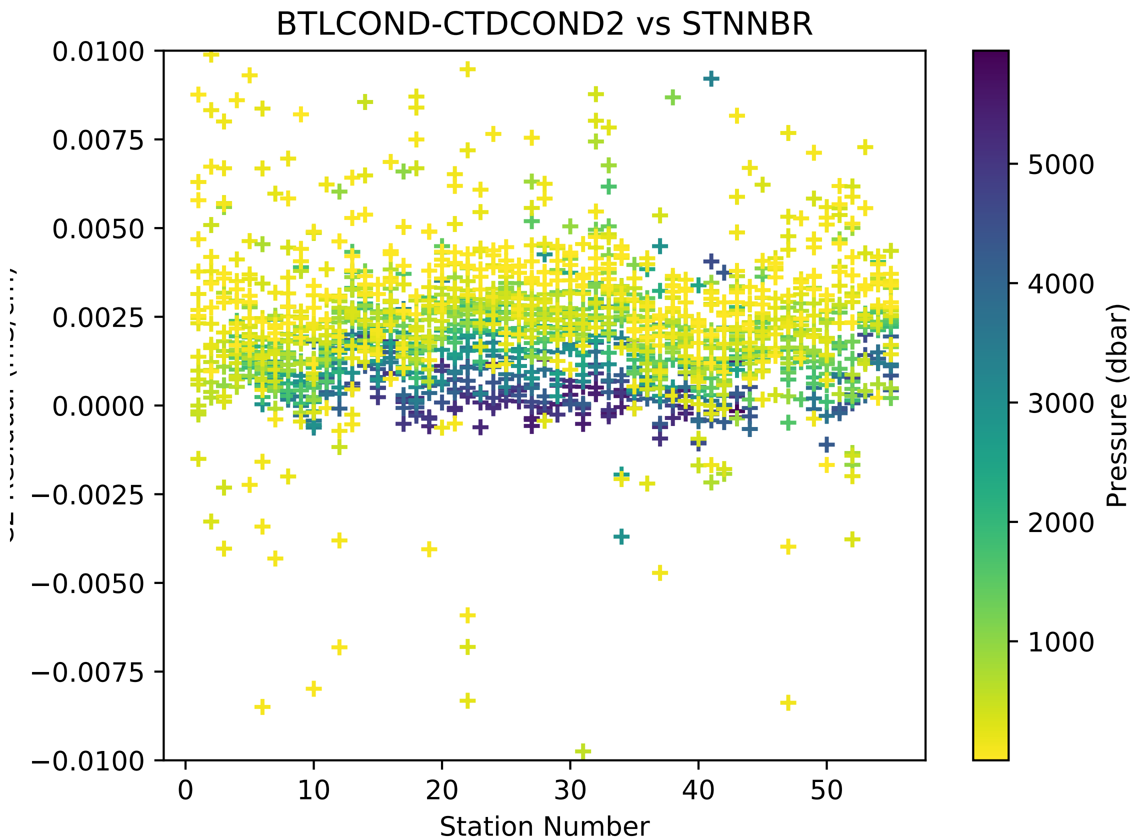


Fig. 19: Corrected C_{Bottle} - C2 by station.

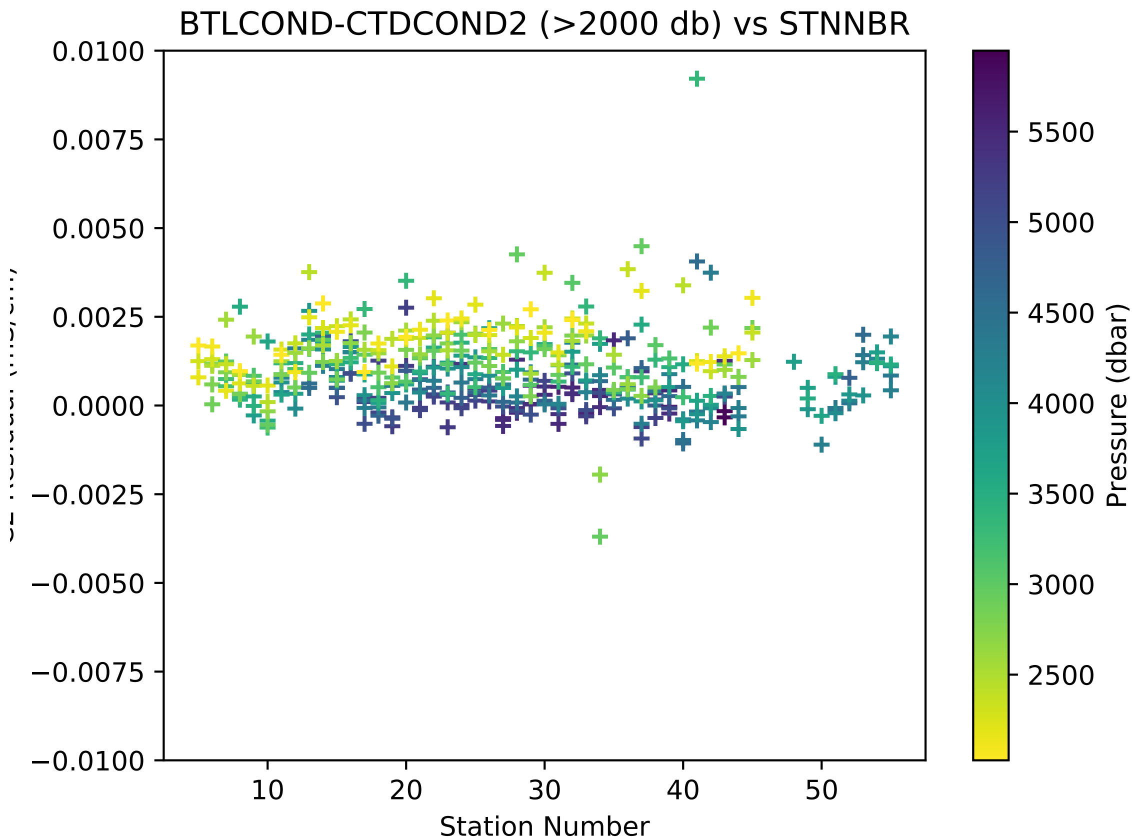


Fig. 20: Deep Corrected C_{Bottle} - C2 by station (Pressure >= 2000dbar).

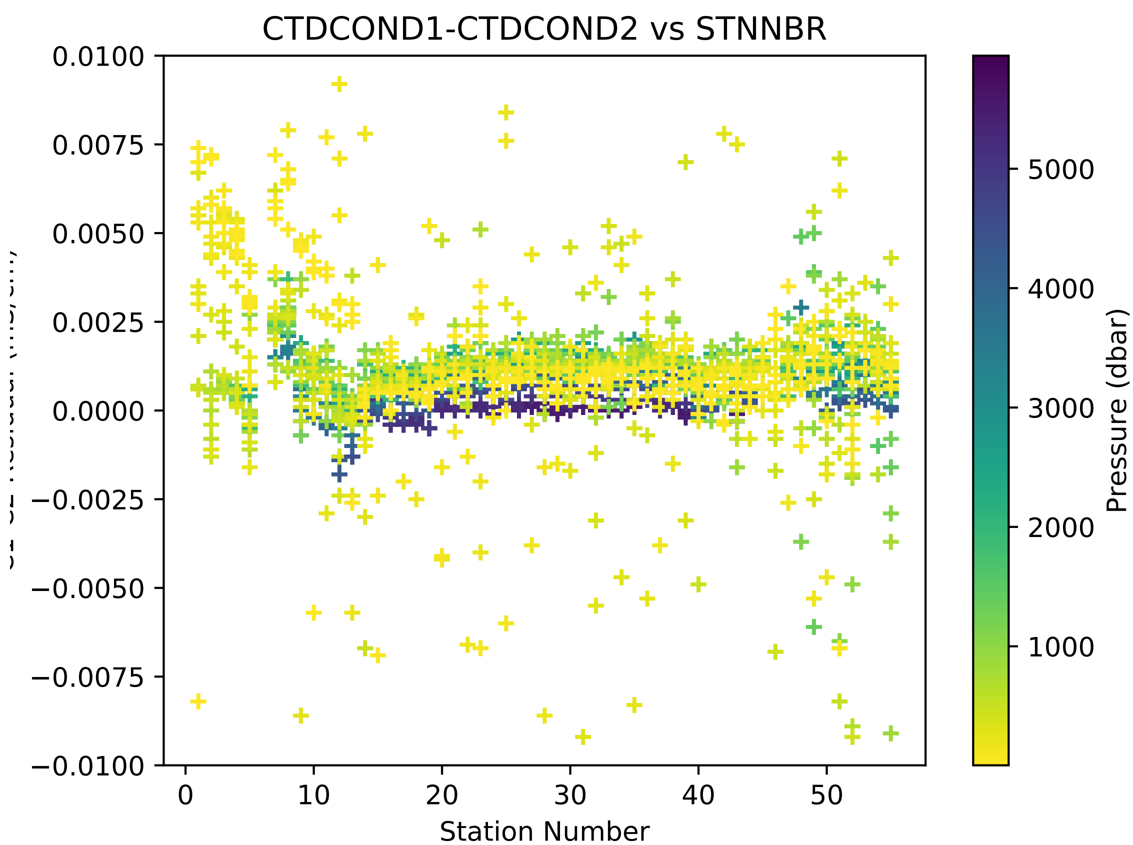


Fig. 21: Corrected C1-C2 by station.

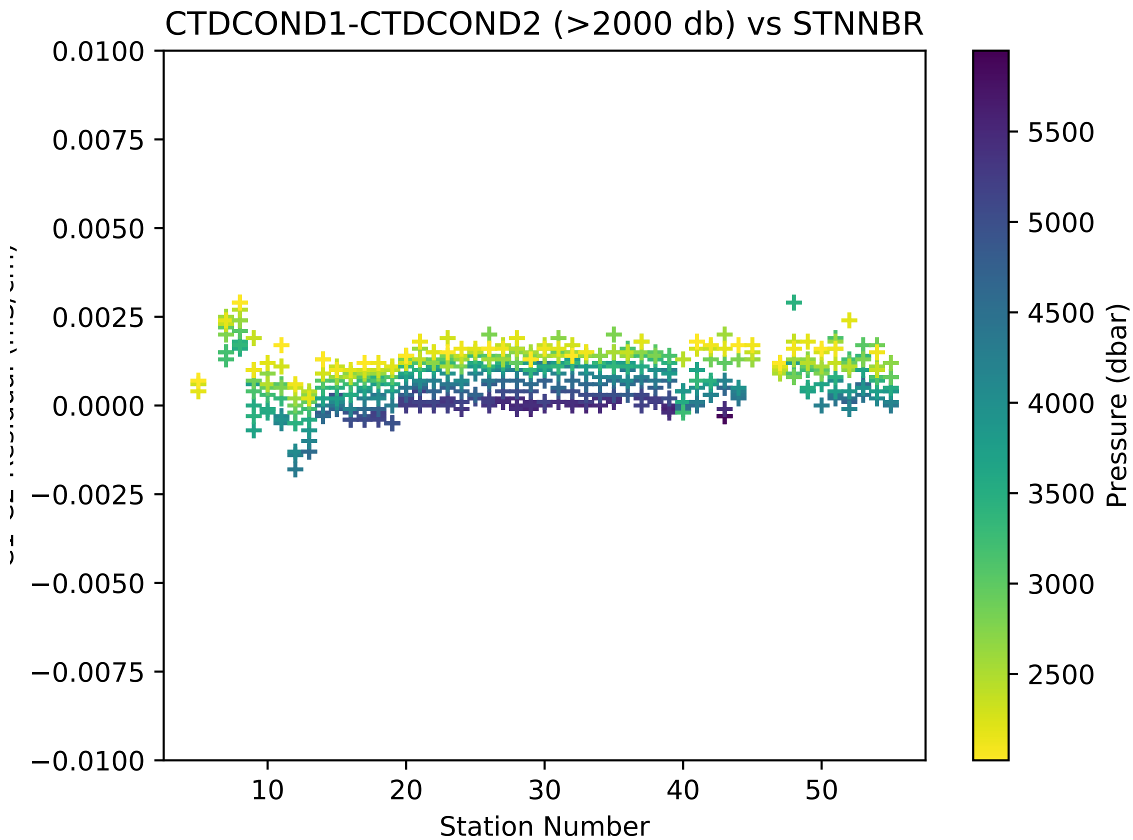


Fig. 22: Deep Corrected C1-C2 by station (Pressure >= 2000dbar).

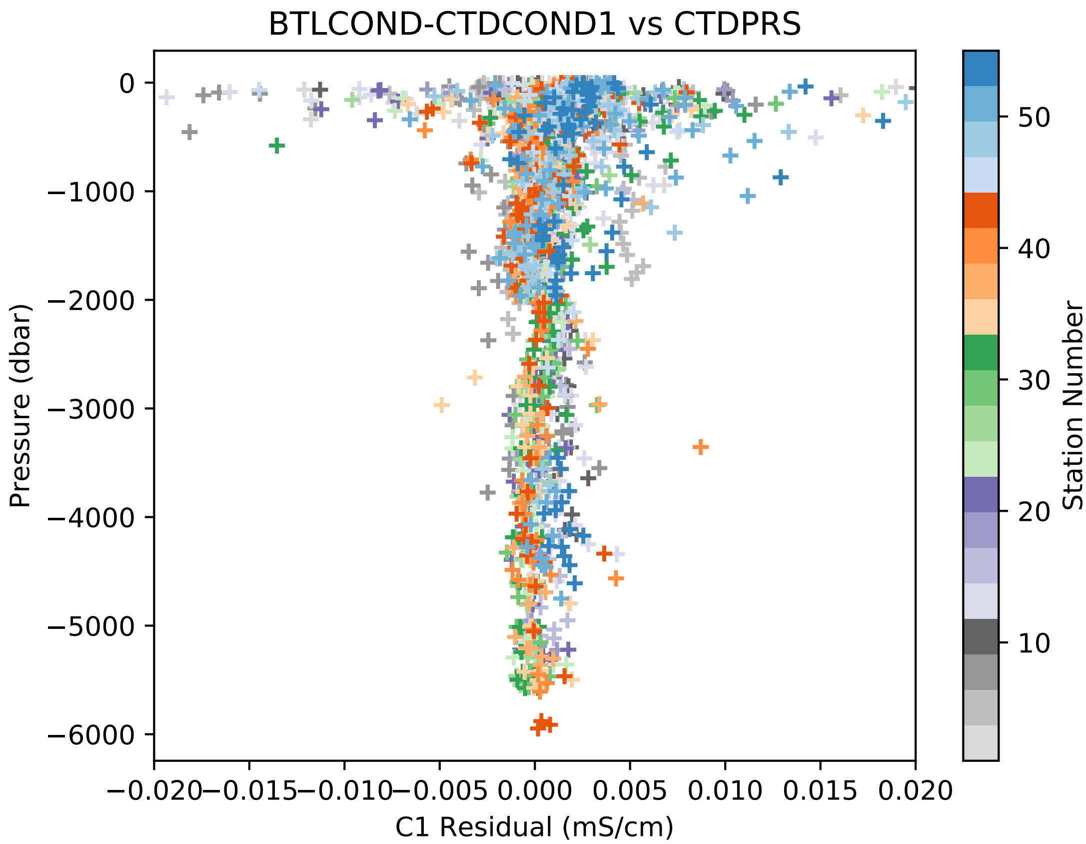


Fig. 23: Corrected C_{Bottle} - C1 by pressure.

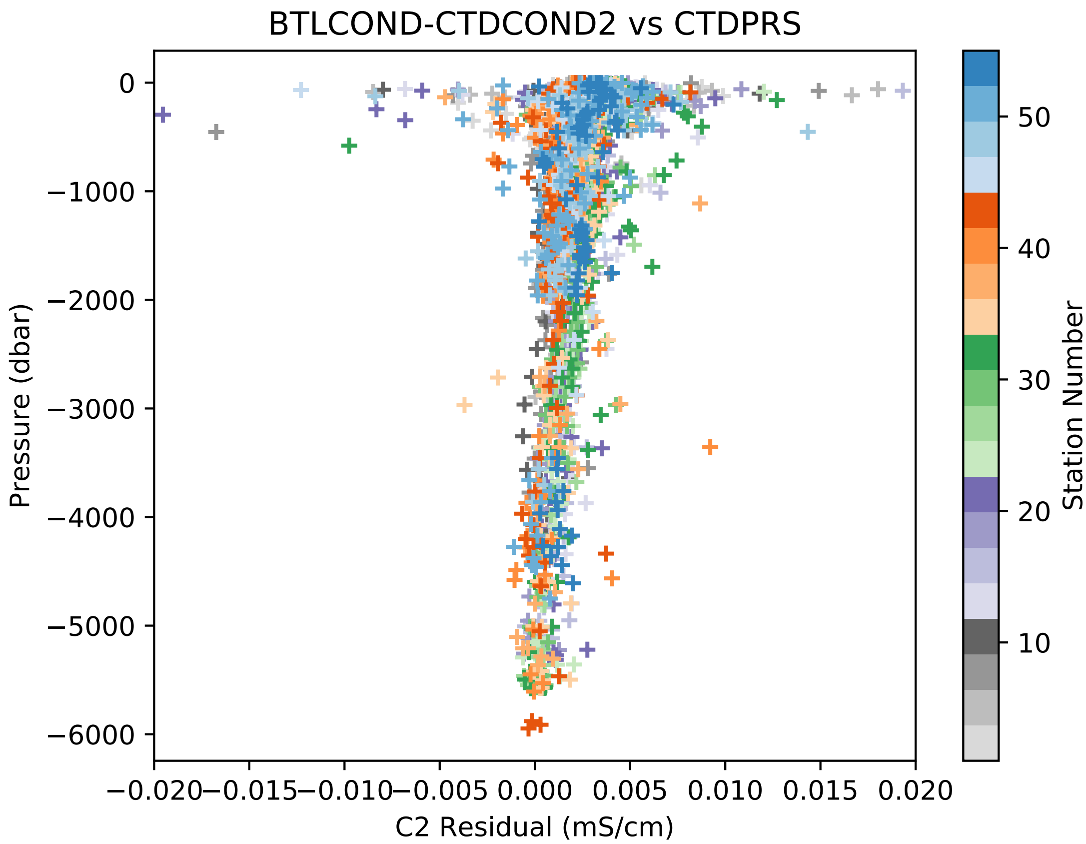


Fig. 24: Corrected C_{Bottle} - C2 by pressure.

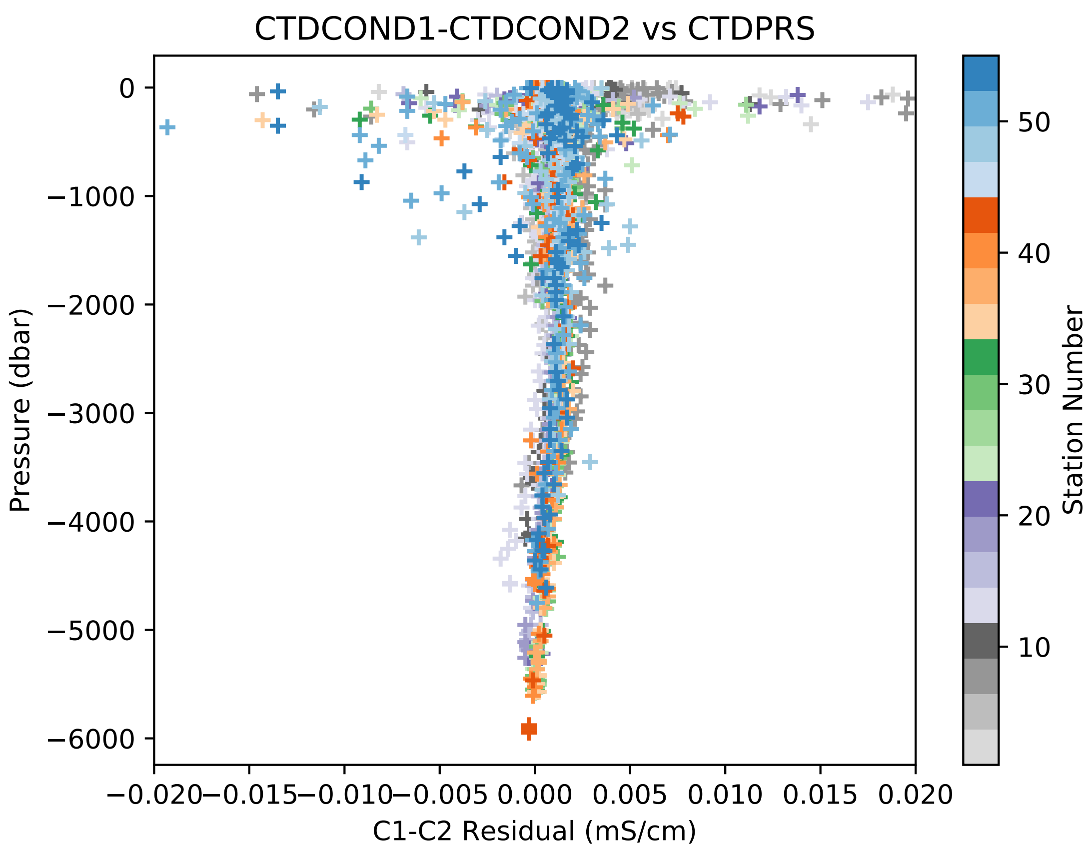


Fig. 25: Corrected C1-C2 by pressure.

The response model is second order with respect to pressure, second order with respect to temperature, second order with respect to conductivity and a first order with respect to time. The functions used to apply shipboard calibrations are as follows.

Corrections made to all conductivity sensors are of the form:

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

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.

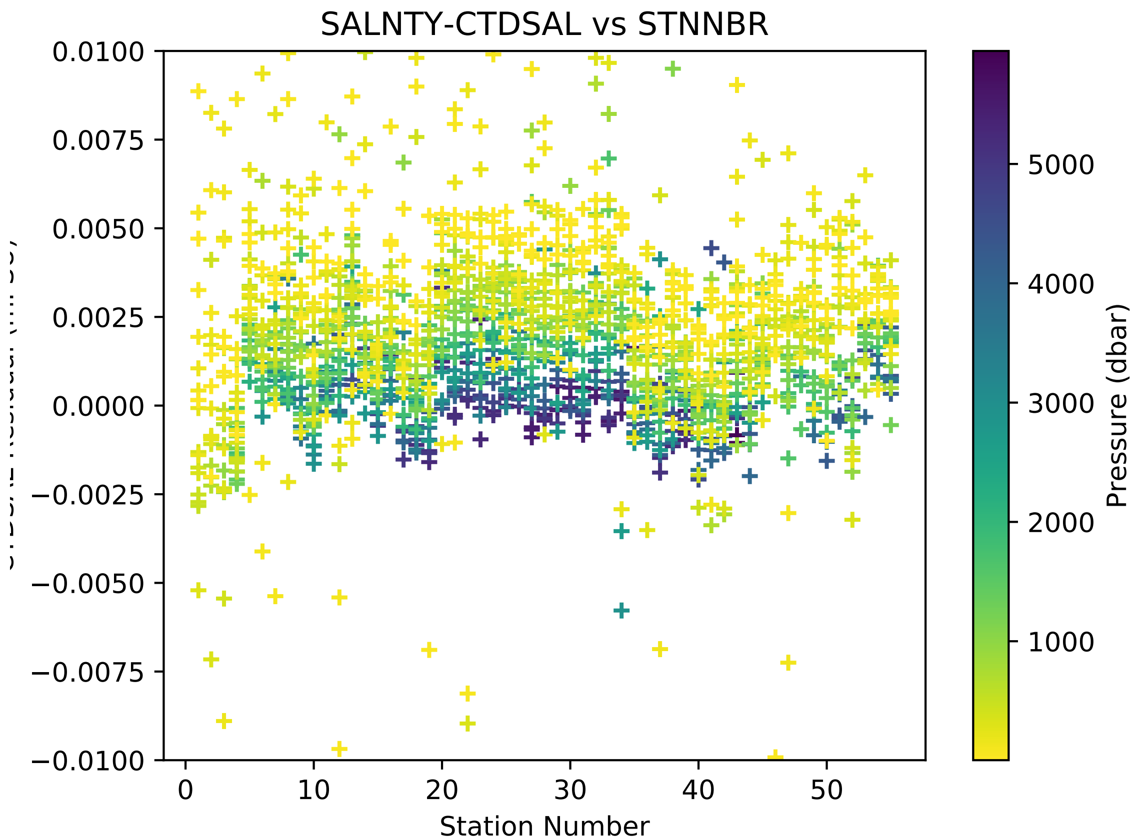


Fig. 26: Salinity residuals by station.

The 95% confidence limits for the mean low-gradient (values -0.002 mPSU $\leq$ T1-T2 $\leq$ 0.002 mPSU) differences are $\pm$0.0538 mPSU for salinity-C1SAL. The 95% confidence limits for the deep salinity residuals (where pressure $\geq$ 2000dbar) are $\pm$0.0317 mPSU for salinity-C1SAL.

A number of issues affected conductivity and calculated CTD salinities during this cruise.

- Primary conductivity sensor (S/N: 2569) failed shortly after the bottom of cast 116/01. Inspection after recovery showed goo inside the cell.
- Bottle salinity analysis was complicated due to problems with the two Autosals, leading to knock-on problems when attempting to calibrate conductivity against bottle salinity.
- Salinity lab temperatures were unstable during the time of analysis for stations 134-142. Further details on lab temperature complications are outlined in the Salinity section of this report.

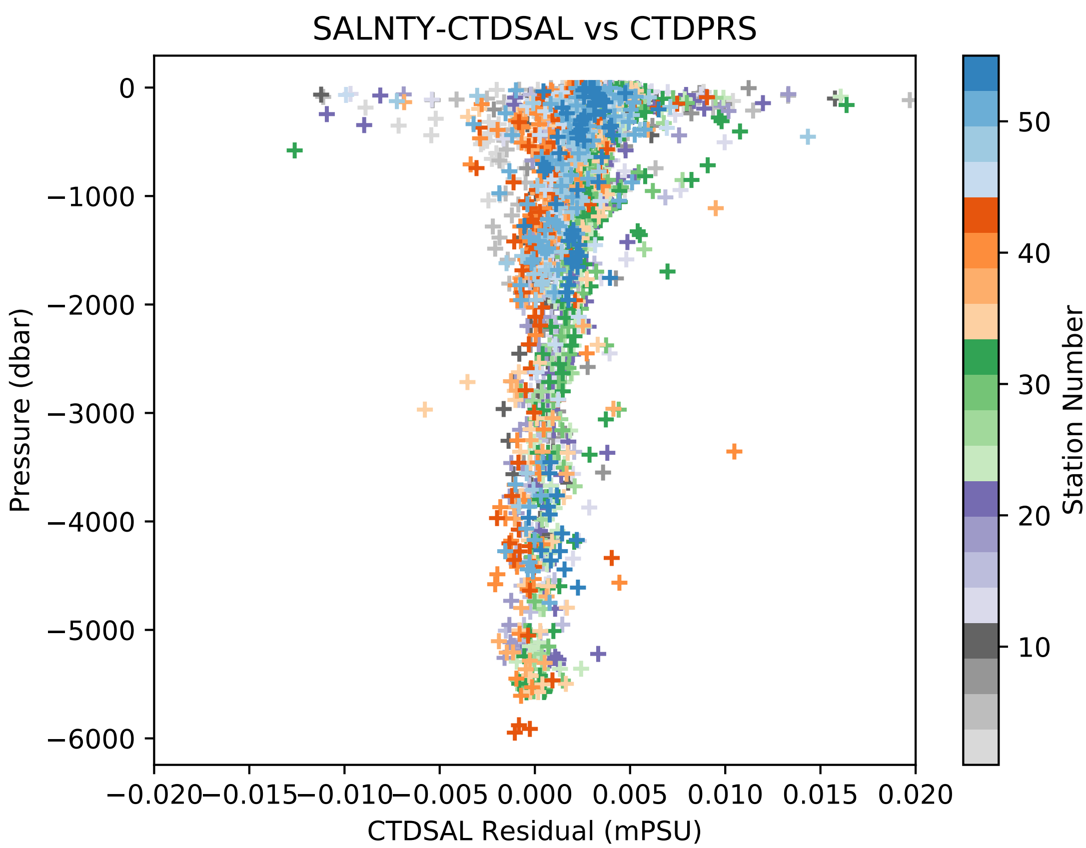


Fig. 27: Salinity residuals by pressure.

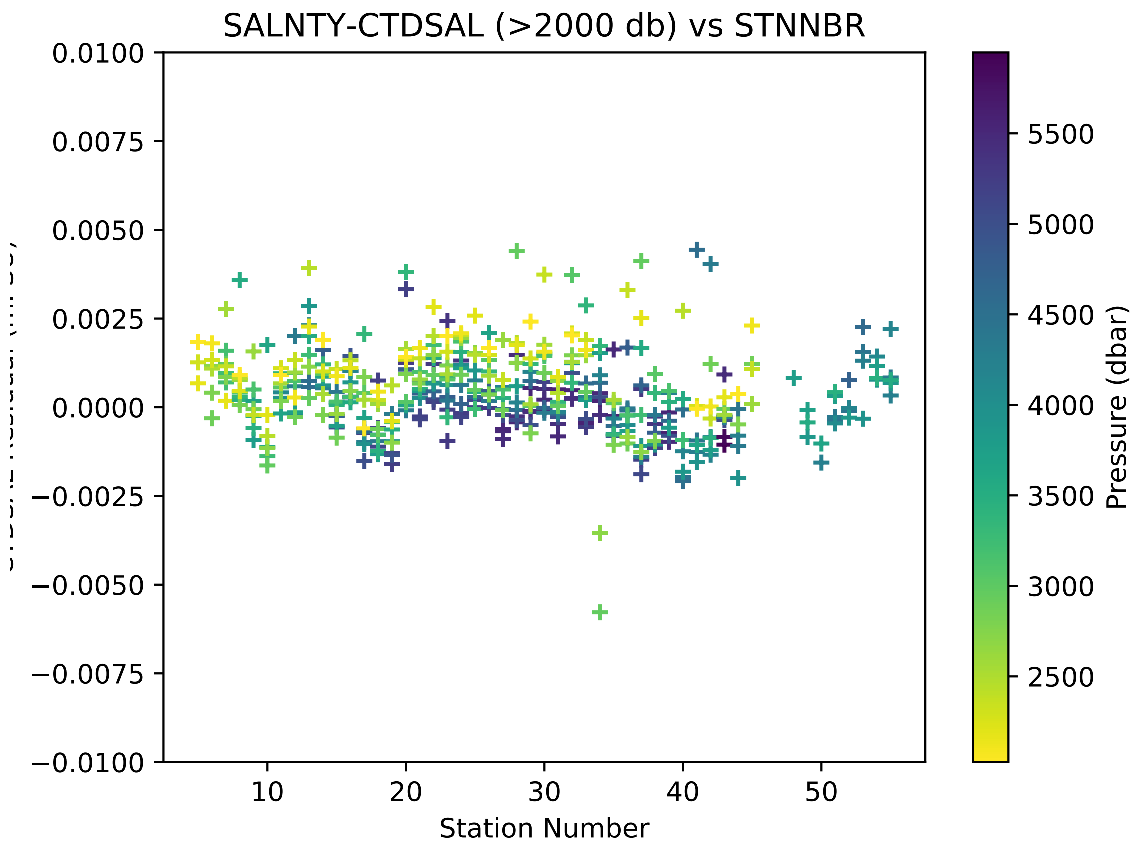


Fig. 28: Deep Salinity residuals by station (Pressure >= 2000dbar).

- Early stations and station with bad weather 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

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. The SBE43 sensor data were compared to dissolved O_2 check samples taken at bottle stops by matching the down cast CTD data to the up cast 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 SIO DO sensor response model coefficients with a Levenberg-Marquardt non-linear least-squares fitting procedure.

The general form of the SIO DO sensor response model equation for Clark cells follows Brown and Morrison [Mill82] and Owens [Owen85] SIO models DO sensor secondary responses with lagged CTD data. In-situ pressure and temperature are filtered to match the sensor responses. Time constants for the pressure response (τ_p), a slow τ_{Tf} and fast τ_{Ts} thermal response, package velocity τ_{dP}, thermal diffusion τ_{dT} and pressure hysteresis τ_h are fitting parameters. Once determined for a given sensor, these time constants typically remain constant for a cruise. The thermal diffusion term is derived by low-pass filtering the difference between the fast response T_s and slow response T_l temperatures. This term is intended to correct non-linearity in sensor response introduced by inappropriate analog thermal compensation. Package velocity is approximated by low-pass filtering 1st-order pressure differences, and is intended to correct flow-dependent response. Dissolved O_2 concentration is then calculated:

$$O_2\text{ml/l} = \left[C_1 \cdot V_{\text{DO}} \cdot e^{C_2 \frac{P_h}{5000}} + C_3\right] \cdot f_{\text{sat}}(T, P) \cdot e^{\left(C_4 t_l + C_5 t_s + C_7 P_l + C_6 \frac{dO_c}{dT} + C_8 \frac{dP}{dTt} + C_9 dT\right)}$$

Where:

- O_2 ml/l Dissolved O_2 concentration in ml/l
- V_{DO} Raw sensor output
- C_1 Sensor slope
- C_2 Hysteresis ronse coefficient
- C_3 Sensor offset
- f_{sat} (T , P)|O2| saturation at T,P (ml/l)
- T In-situ temperature (°C)
- P In-situ pressure (decibars)
- P_h Low-pass filtered hysteresis pressure (decibars)
- T_l Long-ronse low-pass filtered temperature (°C)
- T_s Short-ronse low-pass filtered temperature (°C)
- P_l Low-pass filtered pressure (decibars)
- dO_c / dt Sensor current gradient (µamps/sec)
- dP/dt Filtered package velocity (db/sec)

- dT Low-pass filtered thermal diffusion estimate (T_s - T_l)
- C_4 - C_9 Ronse coefficients

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

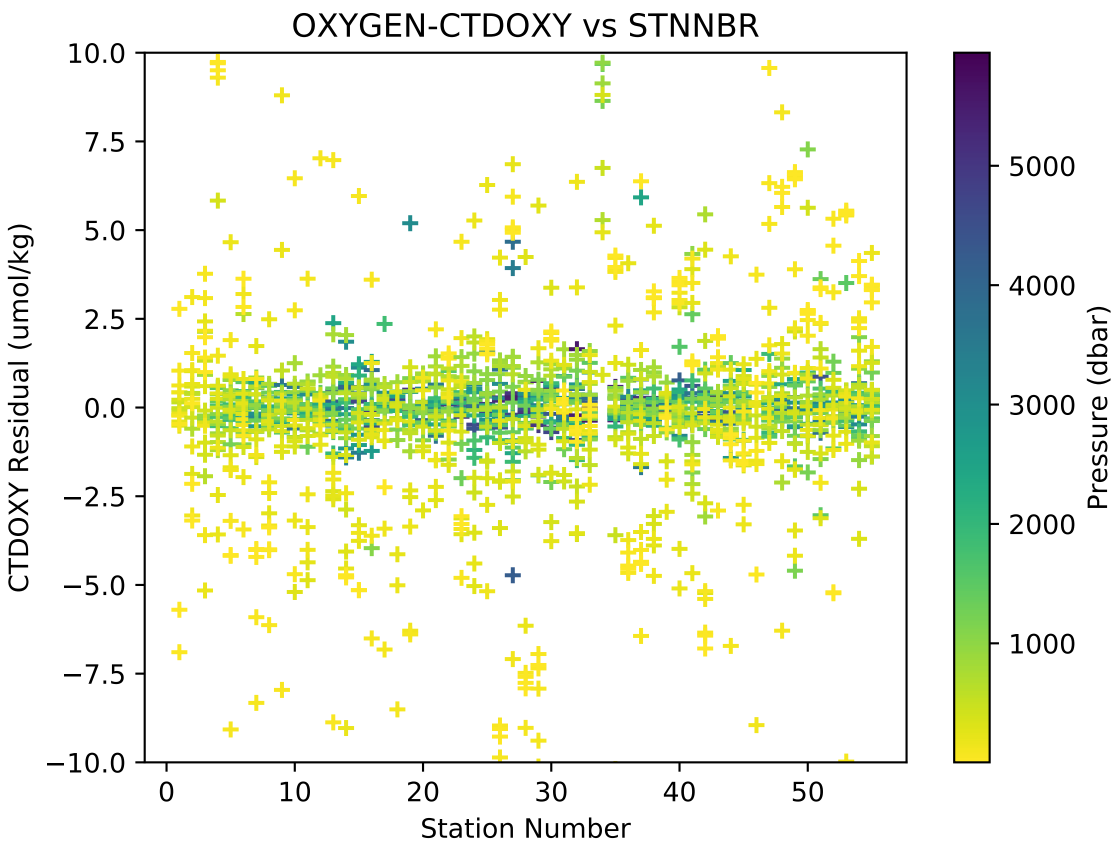


Fig. 29: O_2 residuals by station.

The standard deviations of 4.78 (µmol/kg) for all dissolved oxygen bottle data values and 2.12 (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.

- All SBE43 sensors used exhibited unusual amounts of noise and spikes throughout the cruise due to electrical problems

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.

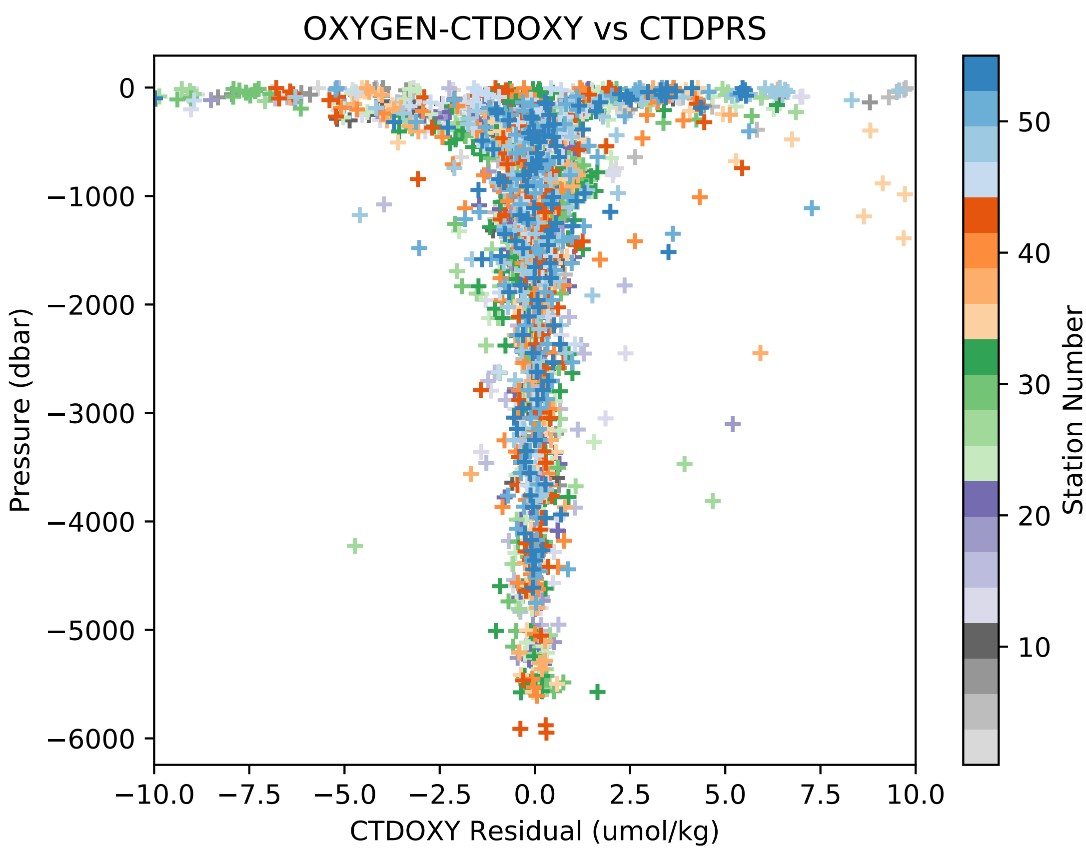


Fig. 30: O_2 residuals by pressure.

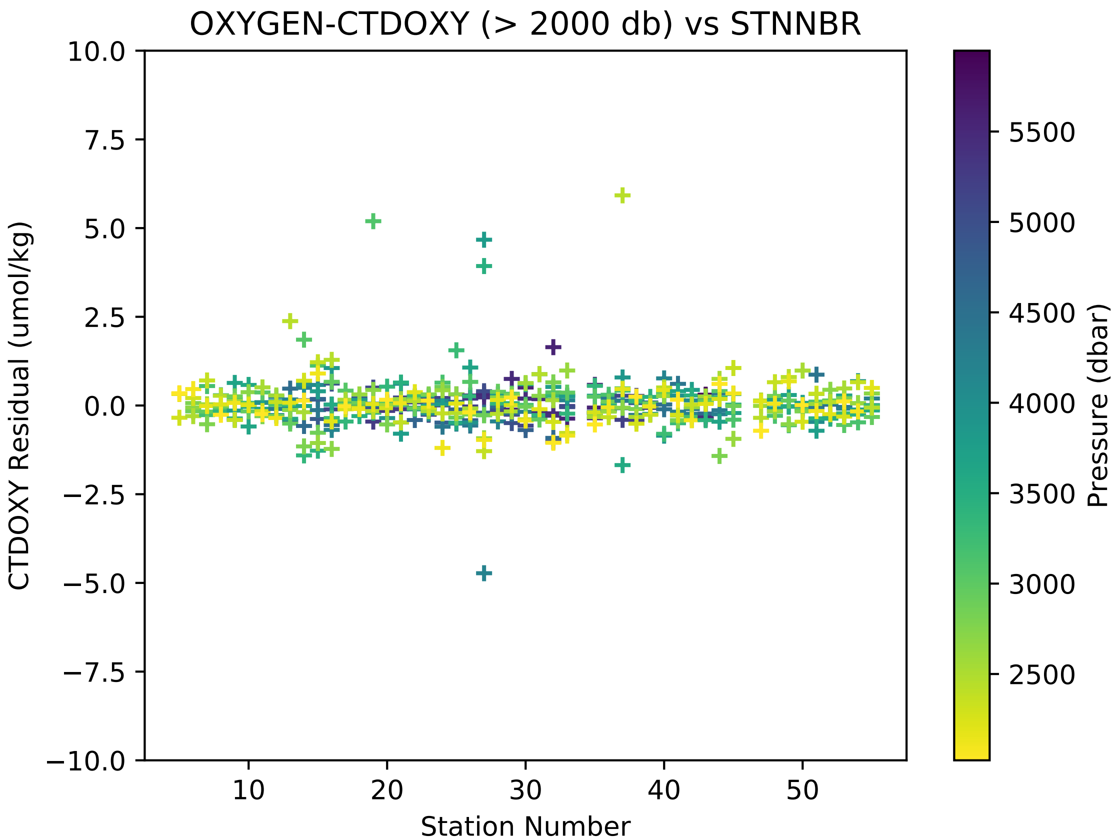


Fig. 31: Deep O_2 residuals by station (Pressure >= 2000dbar).

CHAPTER FIVE

SALINITY

PIs

- Susan Becker
- James Swift

Technicians

- John Calderwood
- Joseph Gum

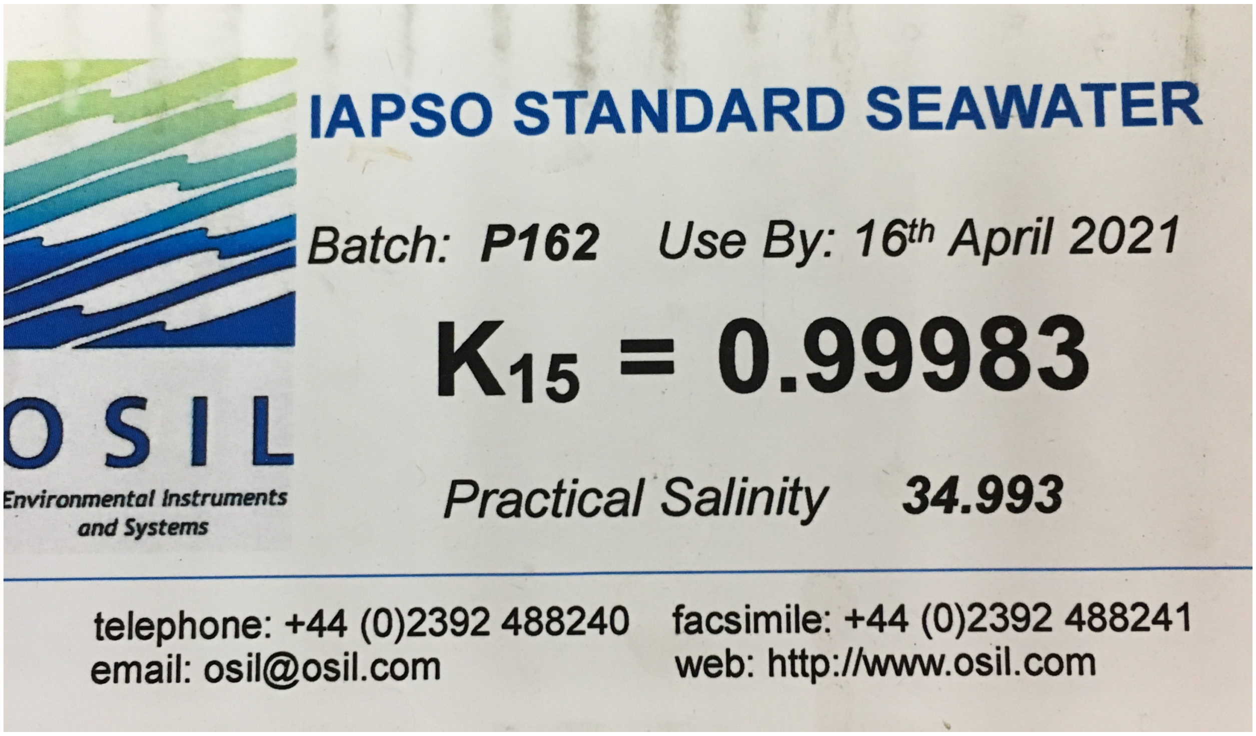
5.1 Equipment and Techniques

Two Guildline Autosals located in salinity analysis room, an 8400B (S/N 69-180) and an 8400A (S/N 57-526), were used for all salinity measurements. The salinity analysis room for I06S was located in the Climate Controlled Chamber, a refrigerator port and amidships between the Computer Lab and Bioanalytical Lab. Both were serviced prior to TGT366/I06S in San Diego and sent with other equipment in January. The salinometer readings were logged on a computer using a LabView program developed by Carl Mattson. The Autosal water bath temperature was set to 21°C. The laboratory's temperature was set and maintained to 20°C. This is to ensure stabilize reading values and improve accuracy. Salinity analyses were performed after samples had equilibrated to laboratory temperature range of 20-21°C, usually 8 hours after collection. The salinometer was standardized for each group of samples analyzed (1 or 2 casts, up to 72 samples) using two bottles of standard seawater: one at the beginning and end of each set of measurements. The salinometer output was logged to a computer file. The software prompted the analyst to flush the instrument's cell and change samples when appropriate. Between runs the water from the last standard was left in the cell. For each calibration standard, the salinometer cell was initially flushed 2 times before a set of conductivity ratio reading was taken. For each sample, the salinometer cell was initially flushed at least 2 times before a set of conductivity ratio readings were taken.

IAPSO Standard Seawater Batch P-162 was used to standardize all casts.

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 custom-made 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

Autosal 69-180 was used to process samples from the test cast, underway, and the first two stations. Communication errors between Labview and Autosal 69-180 occurred during processing of samples, causing the Labview software to lose connection with the Autosal. The issue was tracked down to the serial-to-USB converter, which had its buffer settings set lower than expected. Once the buffer value was fixed, the problem appeared to disappear. A red fleck was found in the cell before the running of samples from station 3. The fleck is suspected to be from red paint, or from the red rubber stopper used to fill the top of the bottle. Autosals were subsequently switched from 69-180 to 57-526. Autosal 57-526 was used from station 3 to 55, with its most notable problem being water being stuck in the manifold, causing problems of sections of the cell not filling with water. This water had to be cleared out multiple times during the cruise. At one point after clearing the manifold of water the standard number drifted by 40 units. After much head scratching and waiting it went back to the previous standard range a few hours later. Autosal 57-526, being a model 8400A, appeared to be more unstable with its standard numbers between runs.

1882 salinity samples were taken. 1 sample was lost during measurement due to sampler error. One bottle was broken during sampling.

CHAPTER SIX

NUTRIENTS

PIs

- Susan Becker
- James Swift

Technicians

- Susan Becker
- Melissa Miller

6.1 Summary of Analysis

- 1888 samples from 55 CTD stations, plus 73 from the underway system
- The cruise started with new pump tubes and they were changed 2 times, before stations 19 and 44.
- 3 sets of Primary/Secondary standards were made up over the course of the cruise.
- The cadmium column efficiency was checked periodically and ranged between 91%-100%. The column was replaced if/when the efficiency dropped below 96%.

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, in prep) [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 1-3 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 (ACCE ver 7.04) provided with the instrument from Seal Analytical. 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. Primary and secondary standards were made up every 7-10days. 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 10-12 hours from a secondary. Working standards were made up in low nutrient seawater (LNSW). One batch of LNSW was used on the cruise. LNSW was treated in the lab. The water was first filtered through a 0.45 micron filter then 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 each set of samples to estimate precision within the cruise. The data are tabulated below.

Parameter	Concentration (µM)	stddev
NO^3	24.60	0.30
PO_4	1.67	0.01
SIL	51.1	0.3

Reference materials for nutrients in seawater (RMNS) were also used as a check sample run once a day. 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 CG was used on this cruise, with each bottle being used once or twice before being discarded and a new one opened. Data are tabulated below.

Parameter	Concentration	stddev	assigned conc
-	(µmol/kg)	-	(µmol/kg)
NO^3	23.69	0.11	23.7
PO_4	1.70	0.007	1.70
Sil	56.3	0.2	56.4
NO_2	0.06	0.006	0.06

6.10 Analytical Problems

No major analytical problems.

CHAPTER

SEVEN

OXYGEN ANALYSIS

PIs

- Susan Becker
- James Swift

Technicians

- Andrew Barna
- Zac Anderson

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 1952 oxygen measurements were made, of which 1880 were niskin samples and 72 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 $MnCl2$ and $NaI/NaOH$ (1 mL of each) were added via bottle-top dispensers to fix samples before stoppering. Flasks were shaken twice (10-12 inversions) to assure thorough dispersion of the precipitate - once immediately after drawing and then again after 30-60 minutes.

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

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

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

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 28th 2019 in Cape Town, South Africa.

The initial thiosulfate batch was discarded due to flaky material in the solution that would not dissolve. The problem was pinpointed as an improperly cleaned 4 L reagent jug. Subsequent thiosulfate batches were made independently as needed throughout the cruise in a clean 1 L reagent bottle.

During setup, it was discovered that many ODF oxygen standard bottles were leaking slightly from around the sealed cap when opened, an egregious standard was not used, but others were used as normal throughout the cruise. No differences were noted in Thiosulfate normality when any ODF standard was changed. Otherwise, setup ran smoothly and the analysis rig was running, secured, and standardised before leaving port on April 3rd.

Following a 5-day delay caused by a failed engine water pump, underway samples were collected every 4 hours during the 8-day transit to the first station.

Some slight stepping was seen during titration endpoints, usually beginning after halfway through a sample run. This was caused by fluctuation in UV lamp voltage and solved by power cycling the UV lamp power supply. The power supply was temporarily swapped out with an older spare. However, this was found to have the same issue but more persistently, so the original power supply was reinstalled. This issue had no impact on sample analysis quality.

Science was temporarily halted after station 45 for a medical evacuation to Port Elizabeth, during which underway samples were collected every 4 hours, and then again following a successful drop-off until station 46 was reached and normal science activities resumed.

An OSIL oxygen standard was run against the usual ODF oxygen standard during the last standardisation of the cruise. The OSIL standard resulted in thiosulfate normality within specification of the ODF oxygen standard, which confirmed the leaking standard caps discovered at the beginning of the cruise did not adversely impact the integrity of the standards. The OSIL standardisation 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 (3 in total). There was no drift or trend observed in any of the batches, so no smoothing procedure was performed.

CHAPTER

EIGHT

TOTAL ALKALINITY

PI

- Andrew G. Dickson – Scripps Institution of Oceanography

Technicians

- Manuel Belmonte
- Wiley Wolfe

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 I06S Stations (1-55). Three or four 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 two or three 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 two ocassions, during bad weather days, we shut down our total alkalnity system and upon restarting the Alkalinity 2.9j program it could not locate the running file to load the appropriate system configurations or locate the running data file for I06S and log subsequent data. Somehow the cruise file identifier was corrupte upon shutown or restart so the program could not load the appropriate configurations. Luckily, the corrupted file identifier was notice by the lead operator an correted to solve this issue. The second time the soure of this issue was not the corruped file identifier and the atual culprit was not found. This issue reverte the program to its default configuration, but luckily the program was able to locate the data file. The operator was told to input all of the appropriate configurations and was able to continue work as usual.

Throughout the cruise, glitches from the Sample Delivery System were experienced at random. 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 3 lost samples. Also during station 39 a shift in the Sample Delivery System's delivery volume was noticed causing smaller samples sizes to be dispensed. No further samples were run until a calibration using a manual pipette was performed to correct this issue.

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 178 2216.53 $\pm$ 0.61 μmol/kg (32;16)
- Batch 180 2224.47 $\pm$ 0.56 μmol/kg (30;15)

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 I06S stations resulting in 240 reference material analyses. On I09N, the measured total alkalinity value for each batch is:

- Batch 178 2216.53$\pm$ 2.25 μmol kg-1 (83) [mean $\pm$ std. dev. (n)]
- Batch 180 2224.00$\pm$ 1.56 μmol kg-1 (157) [mean $\pm$ std. dev. (n)]

If greater than 24 Niskin bottles were sampled at a station, three or four Niskin bottles on that station were sampled twice to conduct duplicate analyses. If 24 or less Niskin bottles were sampled at a station, two or three Niskins on that station were sampled twice for duplicate analyses. The standard deviation for the duplicates measured on I06S is:

Duplicate Standard Deviation $\pm$ 1.55 µmol kg–1 (143) [$\pm$ std. dev. (n)]

The total alkalinity measurements for each I06S stations have been compared to measurements taken from the neighboring I06S 2019 stations.

1209 total alkalinity values were submitted for I06S. Further volume and dilution corrections need to be applied to this data and will not be applied until onshore, therefore this data is to be considered premilinary.

CHAPTER

NINE

DISSOLVED INORGANIC CARBON (DIC)

PI's

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Technicians

- N. Patrick Mears(NOAA/AOML)
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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 0.16 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 (CM5015 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:

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

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 (Âµmol/kg) using density obtained from the CTDâ€™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 305.55 ml (calibrated by Dana Greeley, AOML). The correction factor used for dilution was 1.0004. 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 (Â± SD) correction was 5.5 Â±1.21 Âµmol/kg for AOML 3 and 1.3 Â± 1.53 Âµmol/kg for AOML 4

The coulometer cell solution was replaced after 25 â€“ 28 mg of carbon was titrated, typically after 9 â€“ 12 hours of continuous use. The blanks ranged from 12-28.

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 measured near the beginning; middle and end of each cell
3. Duplicate samples from the same niskin were run throughout the life of the cell solution.

Each coulometer was calibrated by injecting aliquots of pure CO2 (99.999%) by means of an 8-port valve [Wilke1993] outfitted with two calibrated sample loops of different sizes (~1ml and ~2ml). The instruments were each separately calibrated at the beginning of each cell with a minimum of two sets of these gas loop injections.

The accuracy of the DICE measurement is determined with the use of standards (Certified Reference Materials (CRMs), consisting of filtered and UV irradiated seawater) supplied by Dr. A. Dickson of Scripps Institution of Oceanography (SIO). The CRM accuracy is determined manometrically on land in San Diego and the DIC data reported to the data base have been corrected to this batch 178 CRM value. The CRM certified value for this batch is 1952.62 Âµmol/kg.

The precision of the two DICE systems can be demonstrated via the replicate samples. Approximately 11.3% 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 1.45 Âµmol/kg and 1.45 Âµmol/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	L Loop	S Loop	Pipette	Ave CRM1	Std Dev	Dupes
AOML3	1.002012	1.002196	28.003 ml	1946.80, N= 41	1.21	1.45
AOML4	1.00442	1.00420	29.3888 ml	1952.36, N= 35	1.53	1.45

9.6 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 with duplicates every fourth sample. A total of 89 discrete DIC samples including duplicates were collected while underway. The average difference for replicates of underway DIC samples was 1.18 µmol/kg and the average standard deviation was 0.91.

9.7 Summary

The overall performance of the analytical equipment was good during the cruise. On two occasions the air supply was unexpectedly reduced to the van. Steps were taken to prevent any issues with samples being run. During the running of samples for station 8, an unknown issue prevented the pipette from fully filling during several bottle runs. It is unknown as to what caused this to occur however, it passed without discovering the cause.

Including the duplicates, 1,561 samples were analyzed from 55 CTD casts for dissolved inorganic carbon (DIC) which means that there is a DIC value for approximately 82% of the niskins tripped.The DIC data reported to the database directly from the ship are to be considered preliminary until a more thorough quality assurance can be completed shore side.

CHAPTER

TEN

DISCRETE PH ANALYSES (TOTAL SCALE)

PI

- Dr. Andrew Dickson

Technicians

- Manuel Belmonte
- Kayleen Fulton

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 I06S. 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 7.7, measured with a pH meter calibrated with NBS buffers. The indicator was obtained from Dr. Robert Byrne at the University of Southern Florida and was purified using the flash chromatography technique described by Patsavas et al., 2013. [Patsavas2013].

10.4 Data Processing

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

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

and

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

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

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

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

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

10.5 Problems and Troubleshooting

Throughout the course of the cruise the pH spectrophotometric system performed optimally. After a bad weather break and upon start up of the system the operator noticed the system's inability to yield repeatable values for the same sea water source. The lead technician was able to diagnose that the tungsten and deutrium bulbs in the Agilent 8453 spectophotometer had burned out and a quick replacement of these bulbs solved this issue without affecting any sample measurements.

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 180 (provided by Dr. Andrew Dickson, UCSD). Three or four 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 two or three duplicates and one replicate measurement were performed. CRMs were measured at the beginning and ending of each day.

The precision statistics for I06S are:

Duplicate precision	± 0.0099 (n=97)
Replicate precision	± 0.0005 (n=49)
B180	7.8828 ± 0.0017 (n=56)
B180 within-bottle SD	± 0.0007 (n=56)

1449 pH values were submitted for I06S. Additional corrections will need to be performed and these data should be considered preliminary until a more thorough analysis of the data can take place on shore.

CHAPTER

ELEVEN

CFC-11, CFC-12, CFC-113, AND SF_6

PIs

- Dong-Ha Min (University of Texas (Austin))

Analysts

- David Cooper
- Mark Lopez
- Garrett Walsh

Samples for the analyses of the dissolved chlorofluorocarbons (CFCs, freons) F11 and F12, sulfur hexafluoride (SF6) and nitrous oxide (N2O) were collected and analyzed during TN366. Seawater samples were taken from all casts, with full profiles generally taken from alternating casts and strategically determined bottles sampled from the remaining casts. These measurements are complemented by periodic measurements of air samples. Seawater samples were drawn from 10 liter Niskin bottles. Samples for CFC and SF6 were the first samples drawn, taking care to check the integrity of the sample and coordinate the sampling analysts to minimize any time between the initial opening of each bottle and the completion of sample drawing. To minimize contact with air, the CFC samples were drawn directly through the stopcocks of the Niskin bottles into 250 ml precision glass syringes. Syringes were rinsed and filled via three-way plastic stopcocks. The syringes were subsequently held at 0-5 degrees C until 30 minutes before being analyzed. At that time, the syringe was placed in a bath of surface seawater heated at approximately 30 degrees C. For atmospheric sampling, a ~90 m length of 3/8" OD Dekaron tubing was run from the main lab to the bow of the ship. A flow of air was drawn through this line into the main laboratory using an air-cadet pump. The air was compressed in the pump, with the downstream pressure held at ~1.5 atm. using a backpressure regulator. A tee allowed a flow (100 ml min-1) of the compressed air to be directed to the gas sample valves of the CFC analytical systems, while the bulk flow of the air (>7 l min-1) was vented through the backpressure regulator. Analysis of bow air was performed at several locations along the cruise track. Approximately five measurements were made at each location to increase the precision. Atmospheric data were not submitted to the database, but were found to be in excellent agreement with current global databases.

Concentrations of CFC-1l, CFC-12, SF6 and N2O in air samples, seawater samples and gas standards were measured by shipboard electron capture gas chromatography (ECD-GC) using techniques described by Bullister and Wisegarver (2008). This method has been modified with the addition of an extra ECD to accommodate N2O analysis. For seawater analyses, water was transferred from a glass syringe to a glass-sparging chamber (~200 ml). The dissolved gases in the seawater sample were extracted by passing a supply of CFC-free purge gas through the sparging chamber for a period of 6 minutes at 120 - 140 ml/min. Water vapor was removed from the purge gas by passage through a Nafion drier, backed up by a 18 cm long, 3/8" diameter glass tube packed with the desiccant magnesium perchlorate. The sample gases were concentrated on a cold-trap consisting of a 1/16" OD stainless steel tube with a ~5 cm section packed tightly with Porapak Q (60-80 mesh), a 22 cm section packed with Carboxen 1004 and a 2.5 cm section packed with molecular sieve MS5A. A neslab cryocool was used to cool the trap, to below -50°C. After 6 minutes of purging, the trap was isolated, and it was heated electrically to ~150°C. The sample gases held in the trap were then injected onto a precolumn (~60 cm of 1/8" O.D. stainless steel tubing packed with 80-100 mesh Porasil B, held at 80°C) for the initial separation of CFC-12 and CFC-11 from later eluting peaks. After the F12 had passed from the pre-column through the second pre-column (22 cm of 1/8” O.D. Stainless steel tubing packed with Molecular Sieve 5A, 100/120 mesh) and into the analytical column #1 (~170 cm of 1/8” OD stainless steel tubing packed with MS5A and held at 80°C) the outflow from the first precolumn was diverted to the second analytical column (~150 cm 1/8” OD stainless steel tubing packed with Carbograph 1AC, 80-100 mesh, held at 80°C). After F11 had passed through the first precolumn, the flow was diverted to a third analytical column (1/8” stainless steel tube with 30cm Molecular Sieve 5A, 60/80 mesh) for N2O analysis. The first pre-column was then backflushed and vented. The first two analytical columns and precolumn 1 were held isothermal at 80 degrees C in an Agilent (HP) 6890N gas chromatograph with two electron capture detectors (250°C). The third analytical column and second pre-column were held at 160C in a Shimadzu GC-8A gas chromatogram. The ECD in the Shimadzu was held at 250C.

The analytical system was calibrated using a blended standard gas (seawater ratio, PMEL 464568), with further reference to a second atmospheric ratio standard (PMEL 72615). Gas sample loops of known volume were thoroughly flushed with standard gas and injected into the system. The temperature and pressure was recorded so that the amount of gas injected could be calculated. The procedures used to transfer the standard gas to the trap, precolumn, main chromatographic column, and EC detector were similar to those used for analyzing water samples. Four sizes of gas sample loops were used. Multiple injections of these loop volumes could be made to allow the system to be calibrated over a relatively wide range of concentrations. Air samples and system blanks (injections of loops of CFC-free gas) were injected and analyzed in a similar manner. The typical analysis time for seawater, air, standard or blank samples was ~12 minutes. Concentrations of the CFCs in air, seawater samples, and gas standards are reported relative to the SIO98 calibration scale (e.g. Bullister and Tanhua, 2010). Concentrations in air and standard gas are reported in units of mole fraction CFC in dry gas, and are typically in the parts per trillion (ppt) range. Dissolved CFC concentrations are given in units of picomoles per kilogram seawater (pmol kg-1). CFC concentrations in air and seawater samples were determined by fitting their chromatographic peak areas to multi-point calibration curves, generated by injecting multiple sample loops of gas from a working standard (PMEL cylinder 464568) into the analytical instrument. The response of the detector to the range of moles of CFC passing through the detector remained relatively constant during the cruise. Full-and partial-range calibration curves were run several times during the cruise. Single injections of a fixed volume of standard gas at one atmosphere were run much more frequently (at intervals of ~90 minutes) to monitor short-term changes in detector sensitivity.

The purging efficiency of the stripper was estimated by re-purging a high-concentration water sample and measuring this residual signal. At a flow rate of 120 cc min -1 for 6 minutes, the purging efficiency for SF6 and F12 was greater than 99%, the efficiency for F11 was about 99%. The purging efficiency for N2O was about 95%, but subject to some degree of variability due to changes in flow rate and purging temperature. Although correction is made for this variability, N2O data from stations 1-22 were rather more compromised than subsequent data.

Results of 1461 seawater samples are reported from 55 stations, with data for SF6, F12 and F11. Additional data for N2O will likely be submitted after further post-cruise quality control. Duplicates were taken from 32 stations to estimate precision and run variability tests. Low-level samples were selected from deep casts and higher level (surface) samples were mostly taken from the ship’s underway sampling system. From the surface samples, we calculate the average deviation to be less than 0.5% from the mean of the pairs for F12, F11 and N2O measurements, and 1.6% from the mean for SF6 measurements. Deviation from the mean of pairs from deeper samples averaged less than 2% (or 0.01 pM) from the mean for F12 and F11 and approximately 0.04 fM for SF6. Due to the exceedingly low levels of SF6 present in deeper water, accurate estimates of precision are not possible. A very small number of additional water samples had anomalous SF6 or CFC concentrations relative to adjacent samples. These samples occurred sporadically during the cruise and were not clearly associated with other features in the water column (e.g., anomalous dissolved oxygen, salinity, or temperature features).

References Bullister, J.L. and T. Tanhua. 2010. Sampling and Measurement of Chlorofluorocarbons and Sulfur Hexafluoride in Seawater. In: The GO-SHIP Repeat Hydrography Manual: A Collection of Expert Reports and Guidelines. IOCCP Report No. 14, ICPO Publication series No. 134, Version 1. Bullister, J.L. and D.P. Wisegarver. 2008. The shipboard analysis of trace levels of sulfur hexafluoride, chlorofluorocarbon-11 and chlorofluorocarbon-12 in seawater. Deep-Sea Res. I, v. 55, pp. 1063-1074.

CHAPTER

TWELVE

DISSOLVED ORGANIC CARBON, TOTAL ORGANIC CARBON, DISSOLVED NITROGEN AND TOTAL NITROGEN

PI

- Dennis Hansell (UM)

Technician

- Chelsi Lopez

Analysts

- Lillian Custals
- Chelsi Lopez

Support NSF

12.1 Project Goals

The goal of the DOM project is to evaluate dissolved organic carbon (DOC), total organic carbon (TOC), total nitrogen (TN) and total dissolved nitrogen (TDN) concentrations along the I06S zonal transect.

12.2 Sampling

DOC profiles were taken from approximately every two out of three stations from 24 of 36 niskin bottles ranging the full depth of the water column (32 of 54 stations; ~768 DOC/TN samples). DOC samples were passed through an inline filter holding a combusted GF/F filter attached directly to the Niskin for all depths collected. This was done to eliminated 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 after 12 samples were collected through it. Total organic carbon (TOC) samples were collected from 19 of 36 depths per station, approximately at all depths deeper than 250 meters (32 of 54 stations; ~608 TOC/TDN samples). Though previous work has suggested that DOC at depth is equivalent to TOC (or whole water sampels taken from the niskin, without the need for inline filtration), we aimed to ensure that this assumption is valid by collecting both whole water (TOC) and filtered water (DOC) during this cruise. 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 4N 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 in shore based laboratory at the University of California, Santa Barbara. The operating conditions of the Shimadzu TOC-V have been slightly modified from the manufacturer's model system. The condensation coil has been removed and the headspace of an internal water trap was reduced to minimize the system's dead space. The combustion tube contains 0.5 cm Pt pillows placed on top of Pt alumina beads to improve peak shape and to reduce alteration of combustion matrix throughout the run. CO_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 CO2 free gas Three to five replicate 100 µl of sample are injected into a combustion tube heated to 680°C. The resulting gas stream is passed though several water and halide traps, including an added magnesium perchlorate trap. The CO2 in the carrier gas is analyzed with a non-dispersive infrared detector and the resulting peak area is integrated with Shimadzu chromatographic software. Injections continue until the at least three injections meet the specified range of a SD of 0.1 area counts, CV $\leq 2\%$ or best 3 of 5 injections.

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

12.4 DOC calculation

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

12.5 Standard Operating Procedure for TN/TDN analyses- Hansell Lab UM

TN/TDN samples were analyzed via high temperature combustion using a Shimadzu TOC-V with attached Shimadzu TNM1 unit at an in-shore based laboratory at the University of California, Santa Barbara. The operating conditions of the Shimadzu TOC-V were slightly modified from the manufacturer's model system. The condensation coil was removed and the headspace of an internal water trap was reduced to minimize the system's dead space. The combustion tube contained 0.5 cm Pt pillows placed on top of Pt alumina beads to improve peak shape and to reduce alteration of combustion matrix throughout the run. Carrier gas was produced with a Whatman® gas generator [Carlson2010] and ozone was generated by the TNM1 unit at 0.5L/min flow rate. Three to five replicate 100 µl of sample were injected at 130mL/min flow rate into the combustion tube heated to 680°C, where the TN in the sample was converted to nitric oxide (NO). The resulting gas stream was passed through an electronic dehumidifier. The dried NO gas then reacted with ozone producing an excited chemiluminescence NO_2 species [Walsh1989] and the fluorescence signal was detected with a Shimadzu TNMI chemiluminescence detector. The resulting peak area was integrated with

Shimadzu chromatographic software. Injections continue until at least three injections meet the specified range of a SD of 0.1 area counts, CV $\leq 2\%$ or best 3 of 5 injections.

Extensive conditioning of the combustion tube with repeated injections of low nitrogen water and deep seawater was essential to minimize the machine blanks. After conditioning, the system blank was assessed with UV oxidized low nitrogen water. The system response was standardized daily with a four-point calibration curve of potassium nitrate solution in blank water. All samples were systematically referenced against low nitrogen water and deep Sargasso Sea reference waters (2600 m) and surface Sargasso Sea water every 6 – 8 analyses [Hansell1998]. Daily reference waters were calibrated with deep CRM provided by D. Hansell (University of Miami; [Hansell2005]).

Dissolved organic nitrogen (DON) concentrations are calculated as the difference between TDN and DIN. Samples with less than 10 µmol/kg DIN are most reliable estimates of DON.

12.6 TDN calculation

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

CHAPTER THIRTEEN

CARBON ISOTOPES IN SEAWATER (14/13C)

PI

- Ann McNichol (WHOI)

Technician

- Chelsi Lopez

A total of 432 samples were collected from stations collected along the I06S transect. 32 samples each were taken from 17 of 54 stations, approximately every fourth station. Samples were collected in 500 mL airtight glass bottles. Using silicone tubing, the flasks were rinsed 3 times with seawater from the surface niskin. While keeping the tubing at the bottom of the flask, the flask was filled and flushed by allowing it to overflow 1.5 times its volume. Once the sample was taken, about 10 mL of water was removed to create a headspace and 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 CO2 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 CO2 extracted from seawater is measured relative to the 13C/12C of a CO2 gas standard calibrated to the PDB standard using and isotope radio mass spectrometer (IRMS) at NOSAMS.

CHAPTER FOURTEEN

LADCP

PI

- Dr. Andreas Thurnherr

Cruise Participant

- Benjamin Musci

LADCP was collected during full depth CTD casts at all stations by Benjamin Musci. Quality control, preliminary processing, and post-processing for horizontal and vertical velocity was made on board by Benjamin Musci. Approximately every 3 casts data was sent to Andreas Thurnherr for further QC.

14.1 LADCP system configuration

An upward-looking (UL) and a downward-looking (DL) ADCP, and a rechargeable battery, were affixed to the rosette using custom brackets (Figure 1 and 2). The UL instrument was positioned ~5 inches over the top rosette ring while the DL instrument was positioned between Niskin bottles 4 and 6 and affixed through the brackets to one of the rosette bottom cross bars. The transducers on the DL were about 5 inches above the bottom ring of the rosette.

An external magnetometer/accelerometer package (independent measurement package; IMP) was installed inside the Teledyne RDI WHM300 UL ADCP (SN: 12734) to collect additional pitch, roll and heading data. A star cable was used to connect both UL and DL ADCPs to the battery and deck/connection cables.

While on deck, two communications and one power cable ran from the aft wet lab to the staging bay where the CTD package rested on a pallet while in transit between stations. One of the power cables connected the battery to a battery charger while the second power cable connected the ADCPs through the star cable to a power supply. The communications cable connected the ADCPS to a MAC computer via a USB serial adapter which was used for communications to the instrument and data download. The LADCP acquisitions computer clock was synced to the master clock via the ship network system and set to UTC.

Three different ADCP instruments were used during the course of the cruise, two of which were always deployed on the Rosette. The initial set-up consisted of the Teledyne RDI WHM150 (S/N:24544) as DL and a Teledyne RDI WHM300 (S/N:12734) as the UL. An alternative UL, another Teledyne RDI WHM300 (S/N:24477), was also provided and would be used heavily. Two battery packages were used during the course of the cruise, a Deepsea Power and Light SB 48 V/16 A (S/N: 01283) and another Deepsea Power and Light SB 48 V/16 A (S/N: N/A). All instruments were set up to record velocity data with 8 m bins and zero blanking distance. Staggered pinging was used to avoid previous ping interference.

14.2 Problems/Setup changes

Several issues arose during the course of the cruise, with some compromising data quality, although data is available for all casts on the cruise. Independent issues concerning the CTD also occurred, which negatively affected LADCP data quality for numerous casts.

- Station 1: Due to DL vertical velocity data issues during the test cast, the primary UL (SN:12734) was swapped with the alternative UL (SN: 24477). The vertical velocity residuals in the DL were correlated with distance from the instrument, and DC-DC converter in the Ras-Pi in the UL was thought to be the culprit.

No IMP for stations 1-9.

- Station 2: The CTD lost power at some point during the bottom portion of the downcast. It was restarted during the cast, so 2 CTD (.cnv) files were created, which must be stitched together manually for processing.
- Station 5: "Long-ish gap" (on the order of 10's of seconds) warnings became more frequent on stations 1-4, so UL was switched to master role, with DL as slave. CTD froze during initial cast, so cast was aborted and restarted. CTD cast number is 00502.
- Station 5-7: Master and slave ADCP roles were switched, but not the file naming format. Thus for casts 005-00 master was still saved as DL, despite it being UL data. I.e. files such as 005DL000.000 are actually 005UL000.000, and vice versa.
- Station 8: Master and slave roles swapped back to original configuration.
- Station 10: Vertical velocity quality issues in DL continuing. Rules out that problem is caused by UL, so switched back to primary UL with IMP/ras-pi for this cast. UL is still slave. Note, fortunately it appears that because the scattering environment for 1-9 is good, satisfactory vertical velocity data can be produced from the UL only.
- Station 15: Data download/endladcp2 command failed. Each ADCP lost power momentarily during different parts of the cast, which caused data download issues. No data was lost, but data files with actual data are 015UL001.000 and 015DL000.000.
- Station 16: Master slave roles switched in attempt to remedy donwload issues in 015. Master is UL.
- Station 017: Swapped out faulty deck cable. No data lost.
- Station 018: CTD pressure readings became erroneous during cast, particularly near the surface. CTD transmission issues as well cause issues in vertical velocity processing.
- Station 019: Swapped CTDs prior to this cast (from fish 0830 to 0914). Pressure readings are still wrong near the surface, particularly at beginning and end of cast. May not be able to trust fidelity of pressure data for casts up until this point (1-19). Particularly stations 001, 002, 004, 005, 009, 010, 011, 014, 018, 019 show pressure problems at surface. Note that pressure surface anomalies should not greatly affect ADCP data quality because of LADCP surface detection problems near the surface anyway (due to sidelobe and vessel interference). The main effect of these pressure anomalies to this point seems to cause gaps in the vertical velocity profiles. Although the following stations may show anomalies for pressure at depth 006, 007, 008, 012, 013, 015, 016, 017.
- Station 20-27: Swapped to third CTD (from ODF 0914 to UW 0057) due to continued pressure and data transmission problems. Pressure data seems ok, but data transmission problems cause time lag issues in the vertical velocity processing. Particularly for the downcast.
- Station 20-39: CTD transmission problems continue. They do not seem to contaminate the horizontal velocity data, but they cause significant time lag editing issues in vertical velocity and make some data potentially unusable.
- Station 25: Changed CTD termination, transmission problems remain.

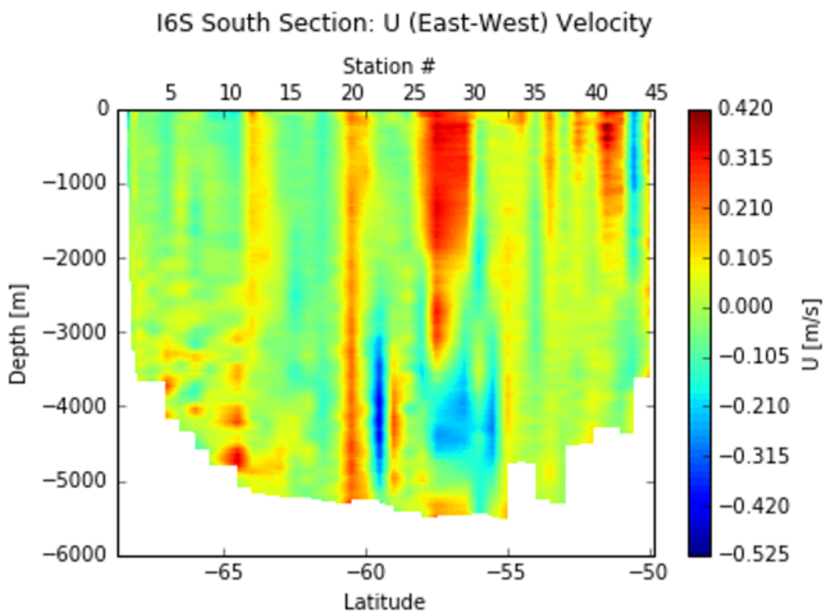
- Station 28: LADCPs momentarily lost power before cast, so data is in *001.000 files and not *000.000 files. No data lost. Large inversion residuals for the DL, but solution may be usable.
- Station 29: DL continues to produce poor data. DL seems to have to performed especially poorly in this station, as evidenced by the inversion residuals. DL data in this run may be unusable. LADCPs momentarily lost power before cast, so data is in *001.000 files and not *000.000 files. No data lost.
- Station 31: Excessive CTD transmission problems on this casts cause LEDO_IX processing to fail, as it cannot solve for time lag. No velocity profile could be generated. Not clear if this data will be usable. LADCPs momentarily power before cast, so data is in *001.000 files and not *000.000 files.
- Station 32-33: LADCPs lost power during cast, so data is in *001.000 files and not *000.000 files. Data was not collected until ~700m into donwcast for both 032 and 033. 033 seems to have only momentarily lost power. Additionally, CTD transmission problems here likely causing time lag offsets in horizontal velocity. Likely the cause of failed time lag in 031 as well.
- Station Test Cast2 - 903: Because of continued issues with the vertical velocity from the DL (high error and depth correlated residuals, stations 001-034) the WHM150 (S/N:24544) DL was swapped with the WHM300 (S/N:24477) and the new WHM300 was set as the master. This immediately solved the vertical velocity DL data issues. Would have been switched sooner but weather and CTD troubleshooting prevented it. Although, LADCPs momentarily lost power before cast, so data is in *001.000 files and not 000.000 files. No data lost. This test cast was completed after station 034 to test CTD troubleshooting. Prior to cast CTD was switched from 0057 to 0830. Transmission problems remain.
- Station 35: CTD swapped back to UW 0057 from 0830, and this configuration remained for rest of cruise. Swapped to back up battery Deepsea Power and Light SB 48 V/16 A (S/N: 01283), as had determined that battery on the rosette was causing the data partitioning problems in stations 033,032,031,028, and 027.
- Station 36-37: CTD transmission problems cause vertical vel time lag editing to remove large number of samples.
- Station 40: CTD transmission problems resolved before this cast. Sea cable was being pinched under impulsive loads, causing transmission problems.
- Station 42: Large towing velocities near the surface due to weather and strong currents cause disagreements in velocity data in the upper 800m or so.
- Station 44: Large towing velocities near the surface due to weather and strong currents cause some disagreement in velocity data. CTD transmission issues returned as well.
- Station 51: Winch wire began to fray during upcast. Took 2-2.5 hours to repair and so CTD was stationary at about 3000m during that process. Then for remainder of upcast, rosette was not stopped and bottles fired on the fly.

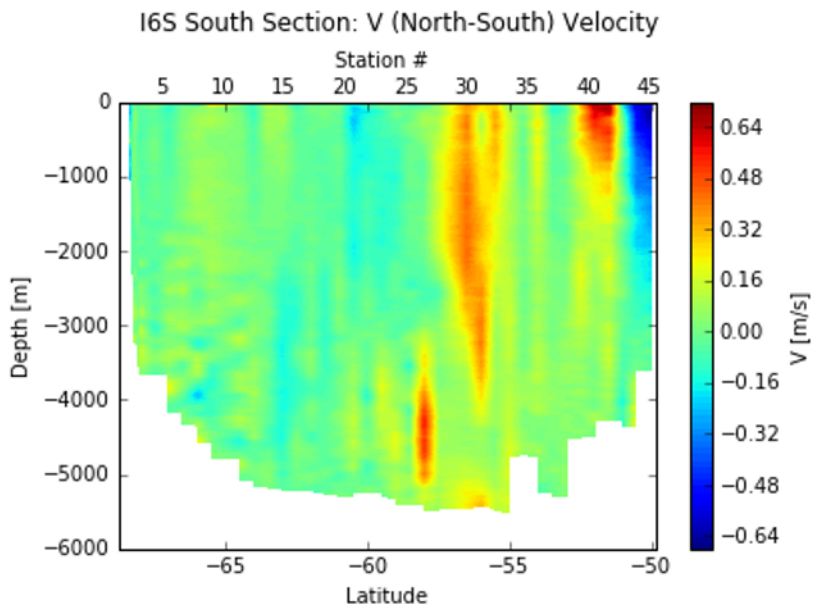
DCP programming and data acquisition were carried out by Benjamin Musci using the LDEO Acquire software running on a MAC computer. Prior to each cast, the corresponding command files were sent to both the UL and DL ADCPs, the ADCPS were switched to battery power, communications were then terminated, deck cables disconnected and all connections were secured and sealed with dummy plugs. After the rosette was brought back up on desk following a cast, the communication and power cables were connected to the MAC computer. Data acquisition were terminated and files were downloaded with the corresponding command using the Acquire software. The battery was disconnected from the star cable and connected to a charger via a deck cable running from the staging bay to the wet lab. The battery remained connected to the charger between stations. The battery pack was periodically vented manually to prevent pressure build up. The second battery (S/N: 01283) was vented more frequently as the gas build up during charging caused large bubbles. Log files were kept for each cast with LADCP and CTD information to ensure all steps were made properly.

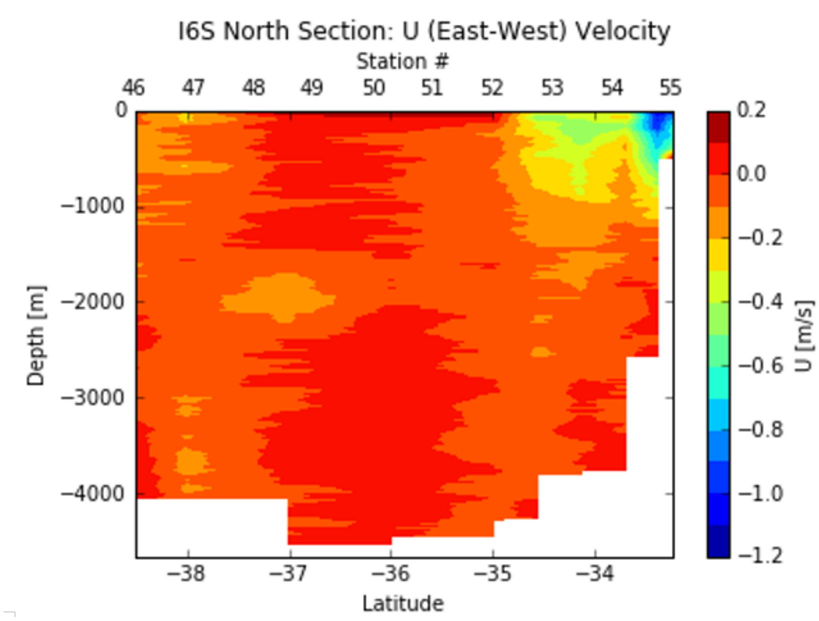
14.3 Data Processing and Quality Control

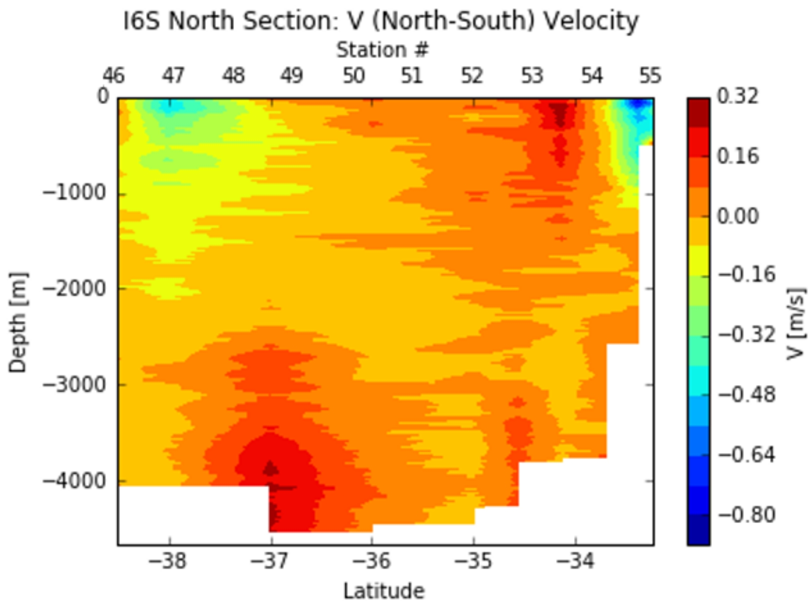
The ADCP data was processed daily by B. Musci using the Matlab-based LDEO LADCP processing software version IX (1). Processing warnings and figures created through the software were reviewed for signs of anomalies such as rosette rotation and tilt, biased shear, agreement between LADCP and SADCP velocities, beam strength and range and ADCP distance to the sea bottom. Data was sent to Andreas Thurnherr every 3 stations or when questionable profiles were observed.

Figures 1, 2, 3, and 4 show the preliminary results of zonal and meridional velocities for all the available stations. The stations of the cruise were split up into a North and South portion, due to the medical evacuation that caused the abandonment of the planned science program at 50S. After evacuation a portion of the planned Northern stations were completed. 45 stations were completed in the Southern portion of the cruise and the final 10 in the Northern portion. The resolution of the Northern portion was compromised because of this. Maximum values reach up ~65 cm/s in the upper ~1000m during the southern portion, and ~120 cm/s in the upper ~200m during the northern portion. There is a relatively strong upper ocean current at ~57 S, and an equally strong current at depth around ~59 S in the southern portion. In the northern portion there is an extremely strong current at ~33 S. Further QC and post-processing of horizontal and vertical velocities at all available stations will be done by Andreas Thurnherr at LDEO post-cruise.




I6S South Section: V (North-South) Velocity
Station #
5 10 15 20 25 30 35 40 45
Depth [m]
0
−1000
−2000
−3000
−4000
−5000
−6000
−65 −60 −55 −50
Latitude
0.64
0.48
0.32
0.16
0.00
−0.16
−0.32
−0.48
−0.64
V [m/s]


I6S North Section: U (East-West) Velocity
Station #
46 47 48 49 50 51 52 53 54 55
Depth [m]
0
−1000
−2000
−3000
−4000
−38 −37 −36 −35 −34
Latitude
0.2
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
−1.2
U [m/s]


I6S North Section: V (North-South) Velocity
Station #
46
47
48
49
50
51
52
53
54
55
0
−1000
−2000
−3000
−4000
Depth [m]
−38
−37
−36
−35
−34
Latitude
0.32
0.16
0.00
−0.16
−0.32
−0.48
−0.64
−0.80
V [m/s]

CHAPTER

FIFTEEN

UNDERWATER VISION PROFILER 5 HD (UVP)

PI

- Andrew McDonnell

Cruise Participant

- Jessica Pretty (Technician)

15.1 System Configuration and Sampling

The Underwater Vision Profiler 5 (UVP5) HD serial number 207 was programmed, mounted on the rosette, and charged. The UVP5 is outfitted with a High Definition 4 Mp camera with an acquisition frequency of up to 20 Hz. This optical imaging device obtains in situ concentrations and images of marine particles and plankton throughout the water column, capturing objects sized ~100 μm to several cm in diameter. The camera of the UVP5 HD is different from the previous non-HD version, but the operations are identical for both. The instrument and data processing are described in Picheral et al., 2010 [Picheral2010]. Across the Antarctic shelf, particle abundance (#/L) showed a subsurface maxima up to 150 particles per liter between 50-100m. A second maxima, usually smaller than the shallower, was seen a few hundred meters above the seafloor. Mean size, ranging between 0.1 and 0.6 mm across the Antarctic shelf tended to increase until a few hundred meters above the seafloor, usually in the same depth range as particle abundance minima. As particles became more abundant, mean size decreased. Through the open ocean transect, maximum particle abundances were lower overall, usually less than 50 particles per liter. Increases in particle abundance were also seen 100-200m above the seafloor. Open ocean mean sizes tended to range between 0.1 and 0.4mm.. Patterns in particle abundance were notably different across the East African shelf than the Antarctic shelf, with maximum particle abundances shown in shallower water.

Some image sorting was performed during the cruise using an offline version of the Ecotaxa database. Total image count gathered during the cruise was over 800,000 images; just over 146,000 were sorted and validated using a combination of machine learning and manual validation. Categories sorted into included various zooplankton taxa and detrital categories. Zooplankton categories included crustacea (including copepods and krill), gelatinous (larvacean, jellyfish, salps), and rhizaria. Detrital images were sorted into general detritus as well as 'dark and fluffy' as well as 'light and fluffy'. Examples of these images are shown in figures 2 to 11.

15.2 Figures

15.3 Problems

The CTD rosette was dragged from inside the staging by onto the deck resulting in damage to the UVP 25 meter data cable as well as a 1 meter pigtail. The data cable was respliced and repaired, but the area where the damage occurred

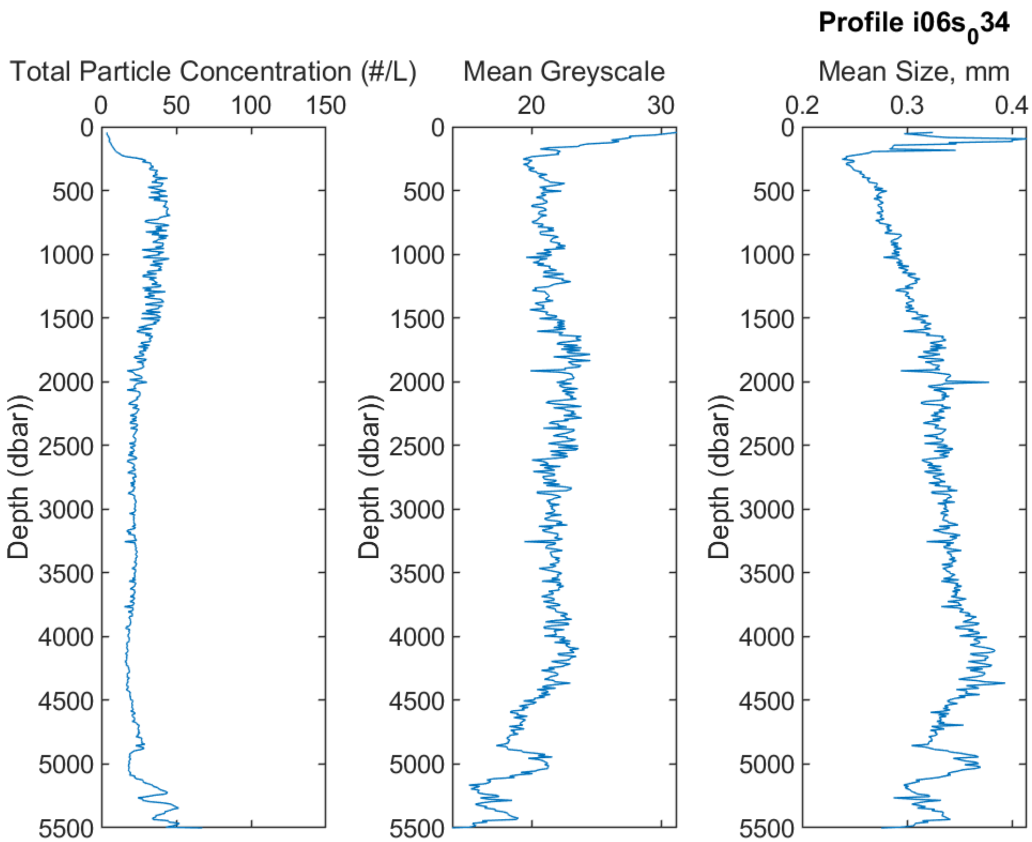
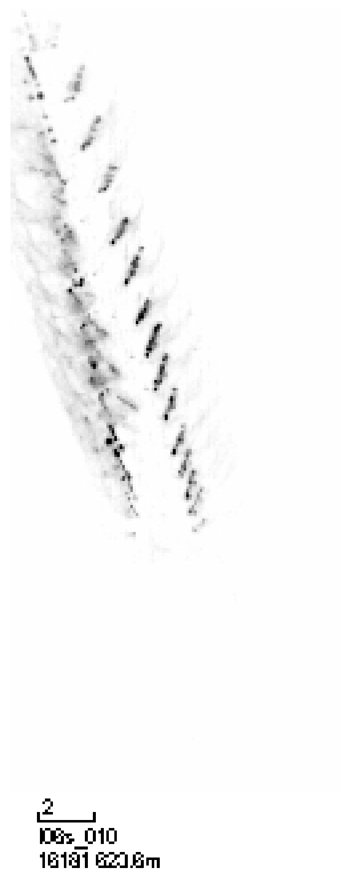
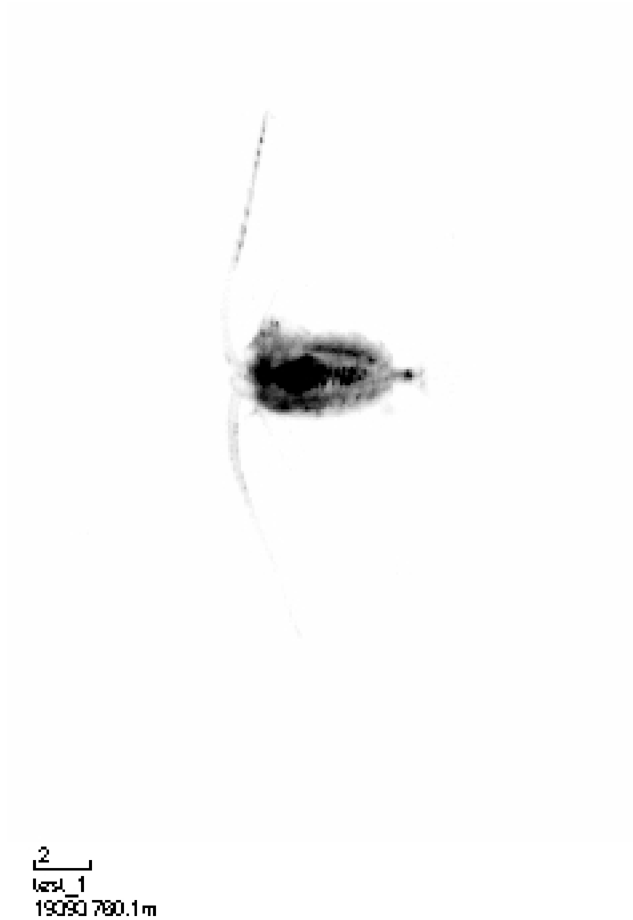
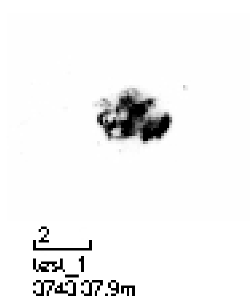
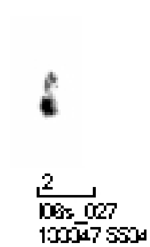


Fig. 1: Figure 1 - Typical Open Ocean Profile from Station 034 of Particle Abundance (#/L), Mean Size (mm), and Greyscale (a proxy for how opaque the images tended to be)

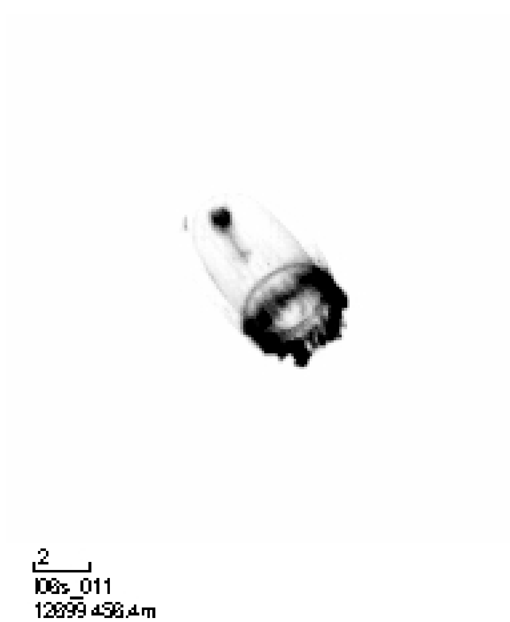

2
I06s_010

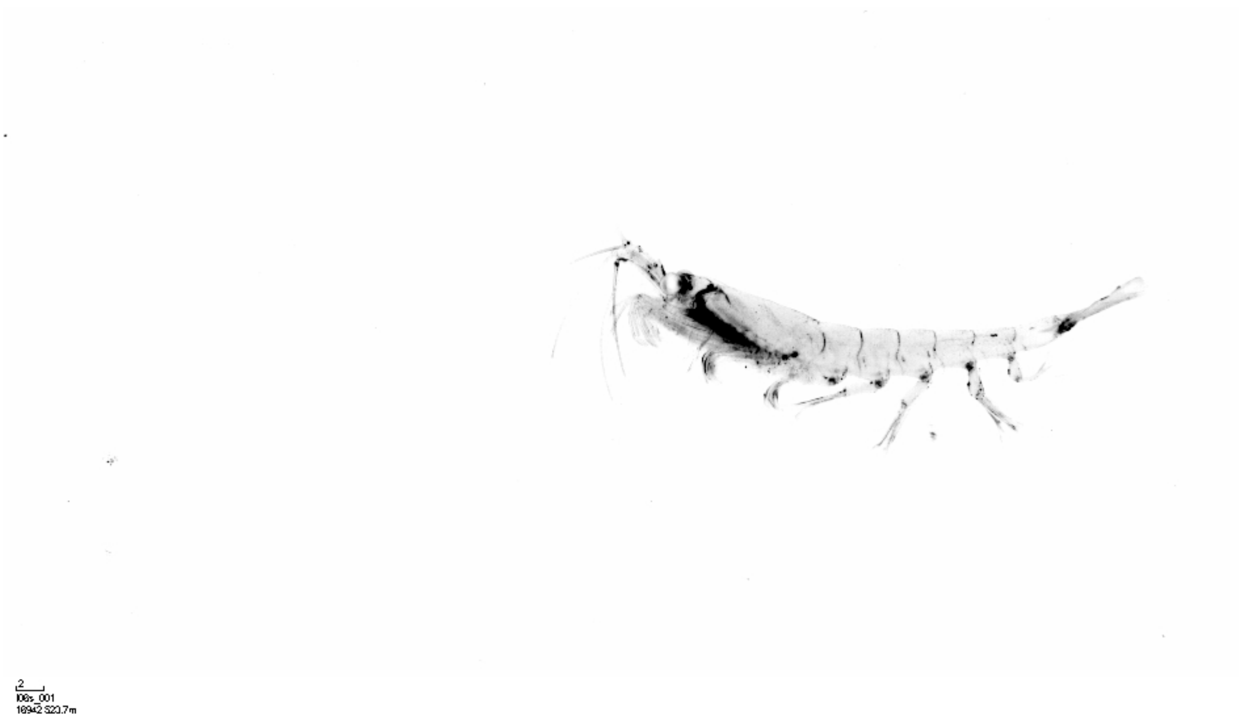

2
test_1
19090 780.1m

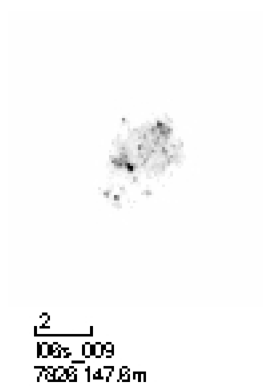

2
test_1


2
I06s_027


2
I06s_011


2
I06s_011





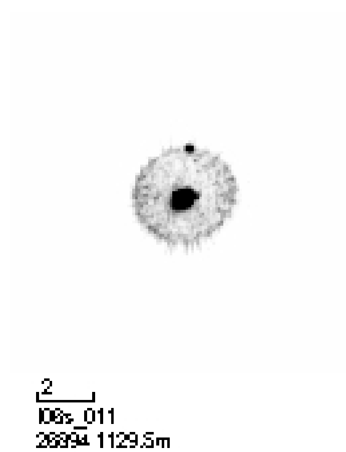


Fig. 2: Figures 2 to 11 - Examples of particle and plankton images captured by the UVP5HD and processed by custom software. The scale bar indicates 2 millimeters. Station number, image number for that cast, and depth at which the image was captured are also given in the image.

on the 1m power pigtail made it necessary to replace the cable. A cable was borrowed from the R/V Thompson for the duration of the cruise.

Stations 12 to 16 are missing as UVP cables were snagged by a closing niskin bottle, and pulled from the bulkhead at depth. The UVP was removed from the rosette and The manufacturer of the UVP5, Hydroptic, was consulted for assistance with troubleshooting. The UVP was inspected and tested for water intrusion damage; after it was determined safe to do so (no damage) the UVP was reassembled and UVP was re-mounted onto the rosette frame before station 17 with new hardware as the mounts previously used needed to be replaced.

Stations 22, 32, 35, & 36 are missing due to unknown sampling error - the UVP appeared to be functioning properly but no file was created. Power shunt pins were cleaned and tested for functionality - appeared to be in working order (no resistance between pins 1 & 3), but after cleaning casts are successful. Station 38 data is not usable as a cable within the rosette came loose and obstructed the view of the camera during part of the cast. Station 39 is missing due to user error: the UVP was deployed with the dummy plug instead of power shunt. Station 41 data contains an artifact throughout the cast, thought to be a small fiber that adhered to the inside of the camera lens. The artifact is easily identified and removed, but it is unknown whether this corrupts the data or can be accounted for.

15.4 Reference

CHAPTER

SIXTEEN

CHIPODS

PI

- Jonathan Nash

Cruise Participants

- Michael Kovatch
- Daniela Faggiani Dias

16.1 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 chi can be found in Moum and Nash [2009] (Moum, J., and J. Nash, Mixing Measurements on an Equatorial Ocean Mooring, Journal of Atmospheric and Oceanic Technology, 26(2), 317–336, 2009). 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 Dec 2013.

16.2 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.

Logger Board SN	Pressure Case SN	Up/Down Looker	Cast Used
2008	Ti 44-5	Up	1-55
2027	Ti 44-3	Up	1-55
2025	Ti 44-7	Down	0
2030	Ti 44-11	Down	1-55

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

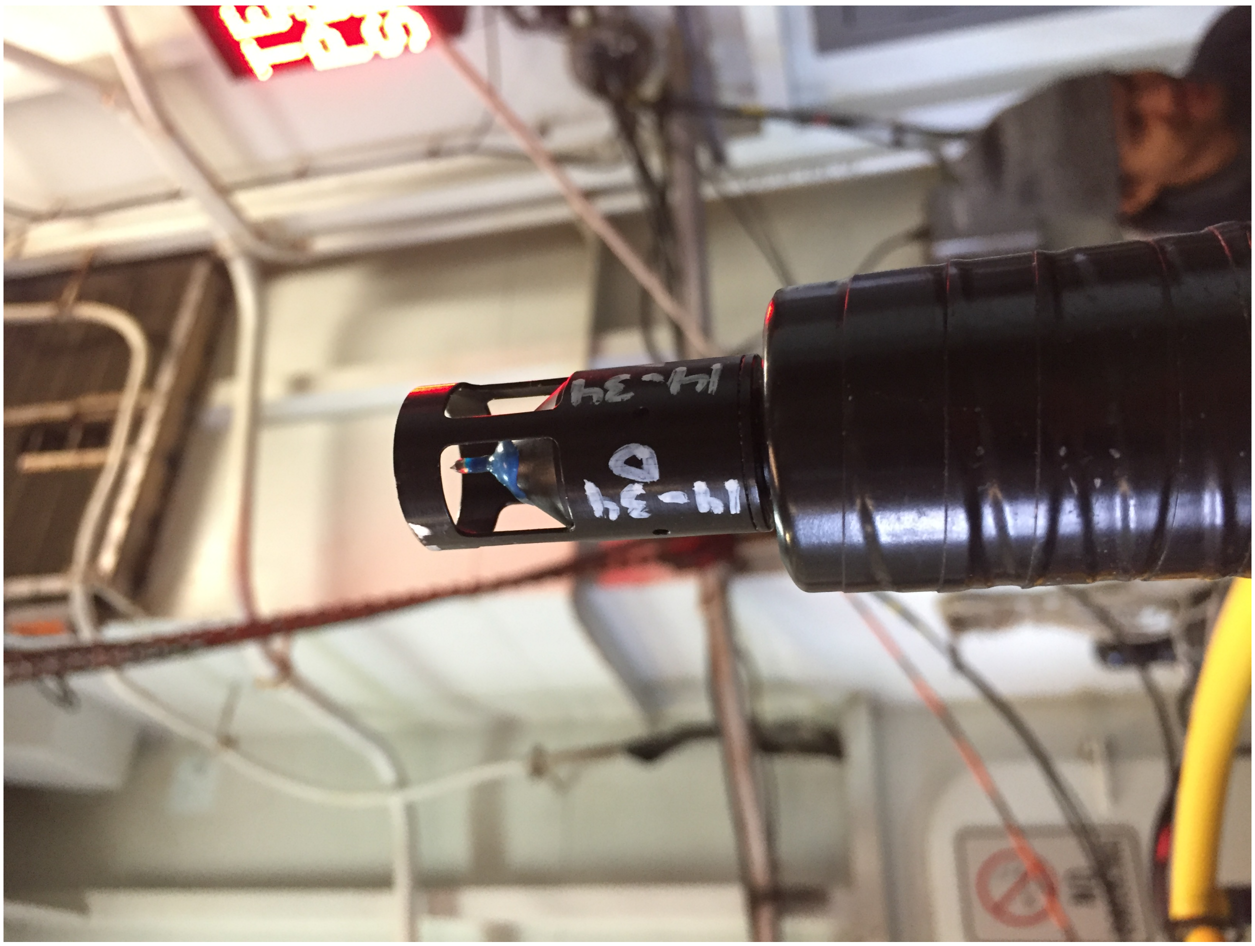


Fig. 2: Highly sensitive temperature probe, which is sampled at 100Hz

16.3 Data

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. Data was uploaded onto the computer a few times to ensure proper functioning and data collection.

SN2025 was replaced by SN2030 on 04/05 since we were unable to communicate with it. SN2008 had sensor cable pulled off during CTD recovery on 04/29 ~12:30.

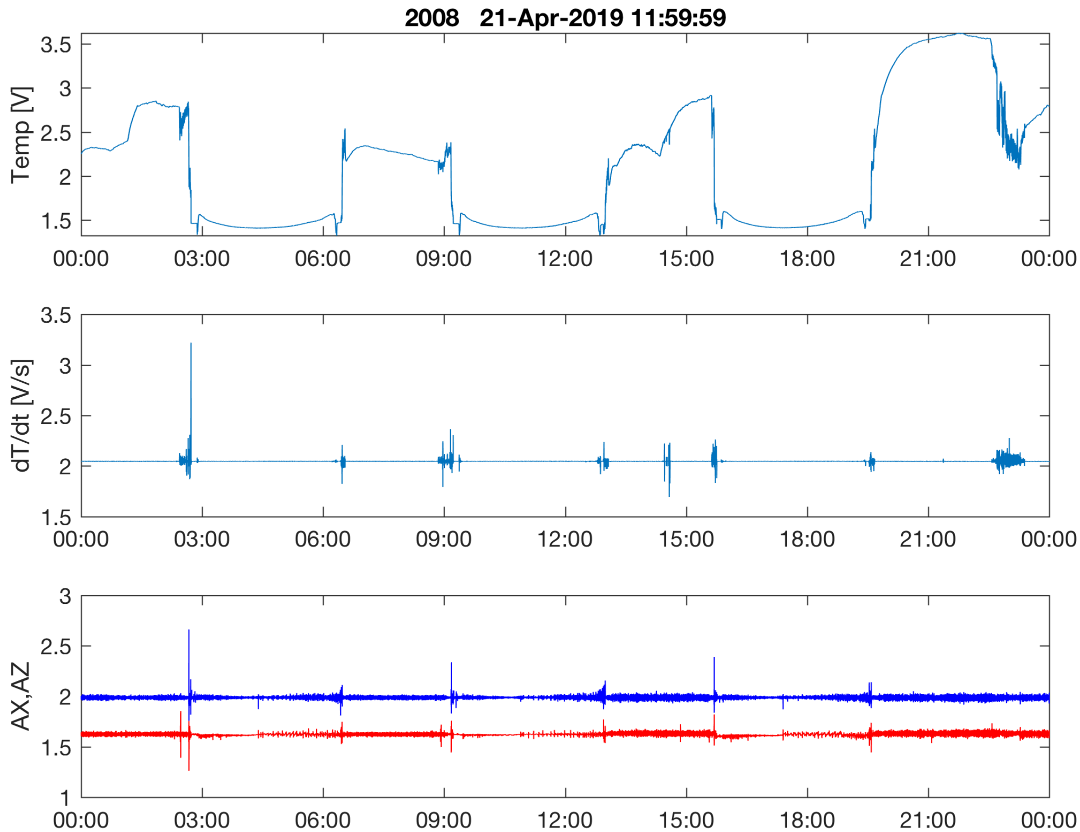


Fig. 3: A typical plot of chipod raw data

CHAPTER

SEVENTEEN

UNDERWAY PCO2

PIs

- Rik Wanninkhof (NOAA/AOML)

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 pCO2 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, etc). For more detail on the general design of this underway pCO2 system, see Pierrot et. al (2009). 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 Cape Town to the continental shelf of Antarctica and the excursion to Port Elizabeth, discrete samples (n=73) 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. pH was calculated from recorded voltages using the Matlab scripts provided as supplementary material in Bresnahan et. al (2014). Of 15,744 measurements, 627 were assigned a WOCE quality flag of 4 (bad measurement), while 72 were assigned a quality flag of 3 (questionable measurement). Measurements of gas standards were within 1% of their certified value throughout the duration of the expedition (Figure 1).

Preliminary review of collected data suggest that the main control on the surface seawater carbonate system was tem-perature (Figure 2). Excursions from thermodynamic controls on pCO2, pH and DO were measured during the brief times spent on the continental shelf near the coast of South Africa, where higher rates of organic matter remineral-ization may have been contributed to increases in pCO2 and decreases in pH and DO. 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. In two brief instances, the underway system was stopped due to problems with seawater supply that were encountered on account of extremely rough weather. This dataset should be considered preliminary; additional quality control and quality assurance is needed before these data can be considered final.

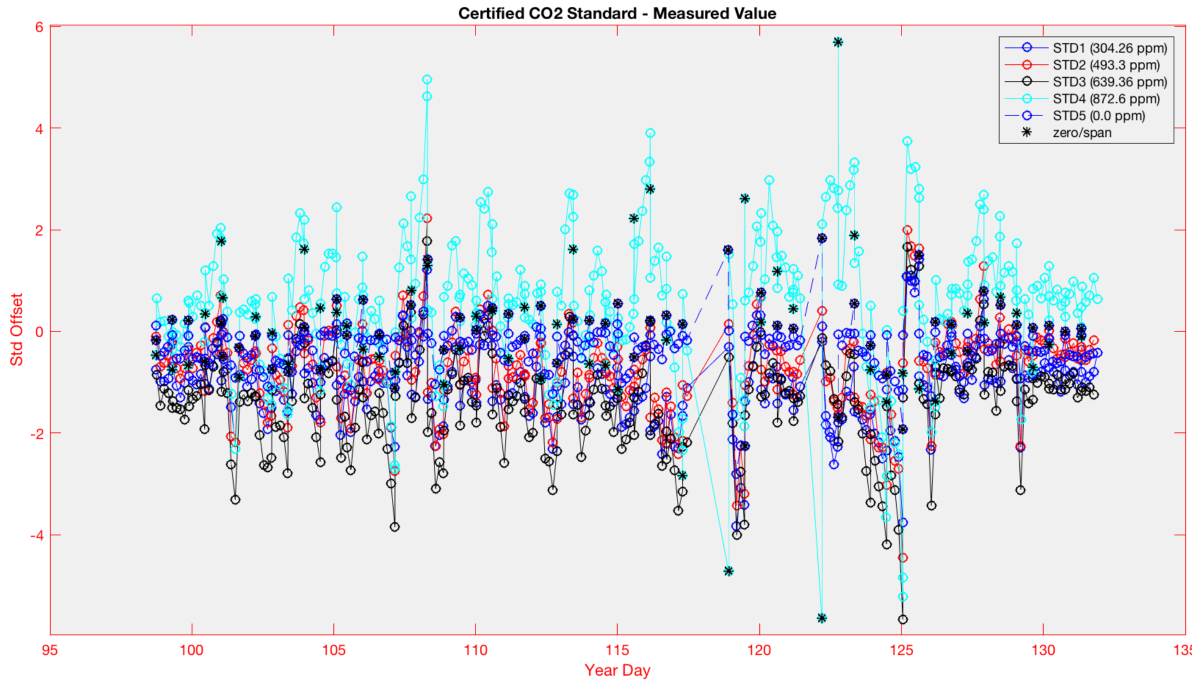


Fig. 1: Difference between measurements made by the non-dispersive infrared analyzer (Licor 7000) of gas standards and the known certified value of those standards (in ppm CO2).

Literature cited:

- Pierrot, D., Neill, C., Sullivan, K., Castle, R., Wanninkof, R.W., Lüger, H., Johannessen, T., Olsen, A., Feely, R.A., Cosca, C.E.; 2009. Recommendations for autonomous underway pCO2 measuring systems and data-reduction routines. Deep-Sea Research II 56 (2009) 512–522
- Bresnahan, P.J., Martz, T.R., Takeshita, Y., Johnson, K.S., LaShomb, M.; 2014 Best practices for autonomous measurement of seawater pH with the Honeywell Durafet. Methods in Oceanography 9 (2014) 44-60

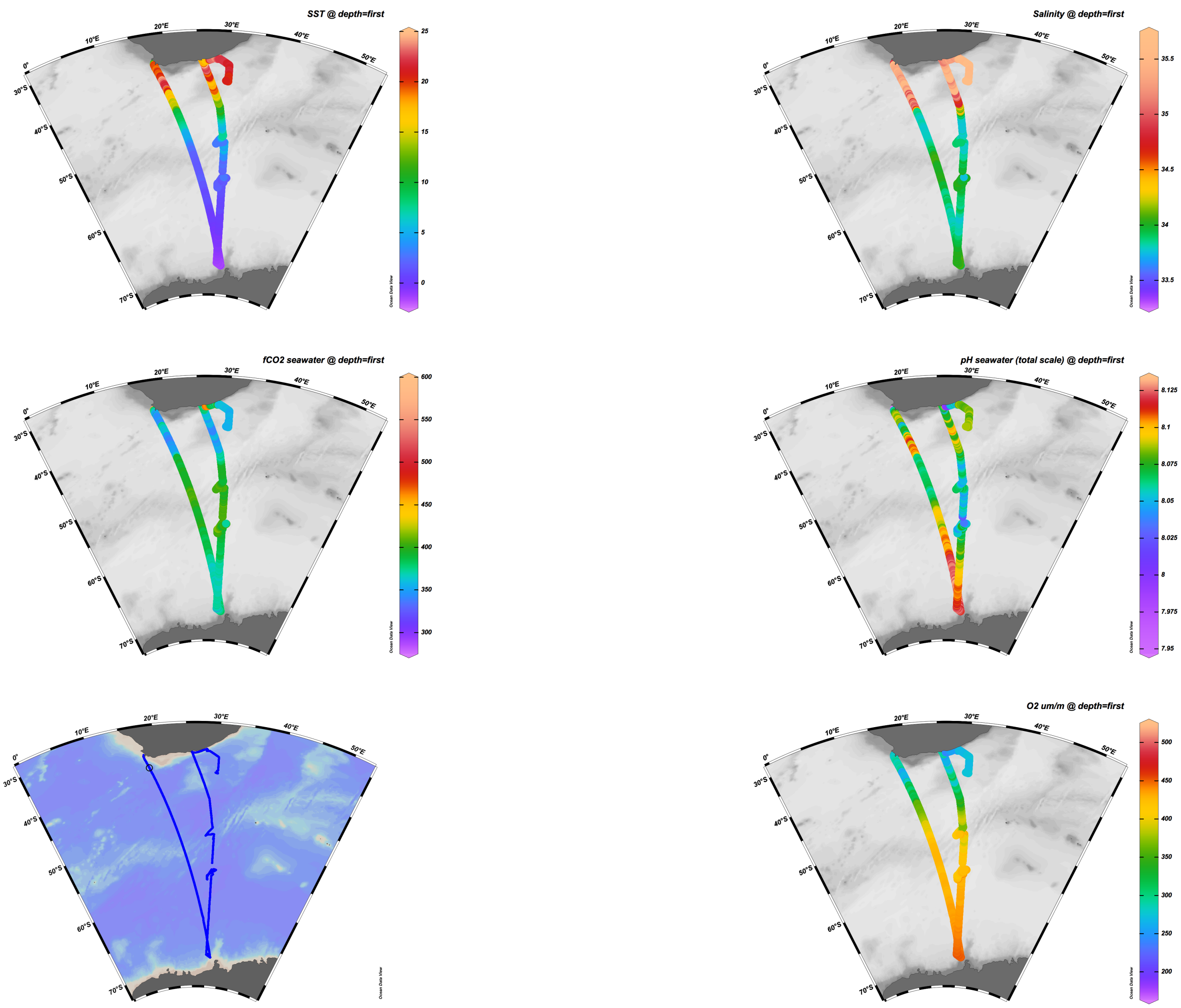


Fig. 2: Spatial distribution of the relevant parameters (sea surface temperature [SST, oC], sea surface salinity [PSU], fCO2 [ppm], pH, and DO [M]) measured by the underway pCO2 system during the 2019 GO-SHIP I06S research expedition.

CHAPTER

EIGHTEEN

FLOAT DEPLOYMENTS

A total of 18 profiling Argo floats were deployed during the GO-SHIP I06S 2019 cruise: 2 NOAA/PMEL and 9 CSIRO core Argo float, and 7 biogeochemical Argo of the SOCCOM program. Isa Rosso (postdoc at SIO and SOCCOM personnel) was responsible for all the deployments and kept the communication with the various PIs of the programs. The assistance from the UW marine technicians was necessary for all deployments. In addition, the watch stander students were trained to provide assistance with the deployment.

Each deployment occurred with the use of a line strung to the float, with one end of the line tied to a cleat and the other held by the marine technician. Deployments were always done on departure from a CTD station while the ship was steaming at 1-3 knots, except for SOCCOM BGC float UW ID #12882 that was deployed during the medical evacuation, on the way to Port Elizabeth (see Narrative).

The floats have a 10-day cycle, except for SOCCOM float #12888 which was set with a 5-day cycle for the first 2 months, as its measurements will be combined with the 2 Caltech sea gliders that were deployed during the cruise. 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. Measurements comprehend temperature, salinity, pressure and additional biogeochemical measurements for the SOCCOM type.

As the sea ice will grow in the colder months and potentially cap the floats underneath, ice avoidance software on the floats will allow them to survive beneath it, keeping the cycle and just storing the collected measurements until they can get free from the ice and send data to the satellite communication. Each of these floats was self-activating, so no initial operations where required before their deployment to activate them.

Argo data is used in various applications, from operational use (to monitor local environmental conditions and alert significant temperature and salinity changes, and forecasts) to research (ocean circulation, water mass properties/formation, air-sea fluxes, ocean dynamics, seasonal-interannual variability, state estimates). In addition, with the new BGC floats measuring oxygen, nutrients, chlorophyll, backscatter and pH, we can now quantify and understand the seasonal cycles of the biogeochemical and physical processes, as we are dramatically expanding the in situ winter biogeochemical observations.

Each float program is discussed in the following sections.

18.1 SOCCOM floats

PIs

- Steven Riser (UW)
- Kenneth Johnson (MBARI)
- Lynne Talley (SIO)

7 biogeochemical floats have been deployed, as part of the "Southern Ocean Carbon and Climate Observations and Modeling" project (SOCCOM). SOCCOM is a U.S. project sponsored by NSF that focuses on carbon and climate in the Southern Ocean. Its goal is to deepen our knowledge of the processes that regulate the carbon export in the Southern Ocean. At present, SOCCOM has 130 active floats, and the data are available to the public at http://soccom.princeton.edu/content/float-data.

5 of the floats deployed during I06S were UW-modified Teledyne Webb Apex floats and 2 (UW ID #0888 and #0889) were built by Seabird Navis. The floats are equipped with CTD, oxygen, nitrate, FLBB bio-optical and pH sensors. Data acquisition is made available through Iridium Satellite communication and GPS.

Andrew Meyer (UW) tested each float at the beginning of the voyage during the port call in Cape Town, South Africa. All were tested "good".

Before the deployment of each float, the fluorometer/backscatter and the nitrate sensors were carefully cleaned using lens wipes, DI water and lens paper. Isa Rosso, SOCCOM personnel responsible for the floats deployment during this voyage, together with the UW marine technicians Jennifer Nomura and Croy Carlin, were in charge of all the SOCCOM float deployments. Additional assistance was received by watch-stander Maximilian Kotz and ODF/SIO technician Melissa Miller. The procedure required the use of a line strung through the deployment collar of the float. Each deployment occurred on the port side, stern, while the ship was steaming at about 1-2.5 knots. No issues were encountered during the deployments, except for the Navis #0888: the deployment line got tangled, and it was decided to cut the line, rather than try to recover the float. Recovering the float, attached only on one end of the line, would have probably resulted in the float dropping (if the line suddenly got free) or in the float hitting the side of the ship and compromise the sensors. Cutting the line in situations like these is normal procedure, but of course is far from being ideal: the rope could tangle around the sensors and/or change the ballasting during the course of its life.

The deployments occurred after the completion of the CTD station that was chosen to be the closest to the planned deployment location and had a bottom depth greater than 2500 m, except for the float #12882, which was deployed during the medical evacuation steaming to Port Elizabeth. For this float, only surface samples (nutrients, salinity, POC/HPLC, DIC, pH, Alk) were collected from the uncontaminated seawater intake line. For the deployment, the ship slowed down to 2.5 knots, and the whole operation took approximately 10 minutes.

For all the other 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 the 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 Melissa Miller), and will be sent frozen to the U.S. for analysis (NASA for HPLC and UCSB for POC). Full-depth (with at least higher resolution in the top 2000 m) samples of salts, pH, alkalinity, dissolved inorganic carbon, nitrate and oxygen were collected and analysed on board, for future validate the floats' sensors. Data from a FLBB sensor mounted on the CTD rosette, provided by Emmanuel Boss, will also be used for the validation of the sensor on the float. To calibrate the FLBB, a dark cast was taken at station #15: a black electrical tape was placed on the sensor, in order to get the background value. The tape was carefully removed after the cast and the sensor cleaned using ethanol and DIW. pH samples were collected and analysed by personnel from SIO, part of A. Dickson's lab; dissolved inorganic carbon samples by personnel from AOML and PMEL; oxygen, nitrate and salinity samples by the ODF group at SIO.

The floats were adopted by different schools in the US and one school in Sydney (Australia), as part of the outreach program "Adopt-a-float". Each class named the float and received the details (and pictures) of their deployment from Isa Rosso, via SOCCOM personnel onshore George Matsumoto (MBARI). Together with their teachers, the students will follow the data of the float, which can be easily downloaded and plotted at the website www.mbari.org/science/upper-ocean-systems/chemical-sensor-group/soccomviz. As part of this outreach program, a blog post was written on the I06S blog http://usgoship-i06s2019.blogspot.com, either by Isa Rosso, Giuliana Viglione, Melissa Miller or Maximilian Kotz.

Each float has reported its first profiles and it looks like the sensors are all working well, except for pH on the float #12888: the SOCCOM team communicated that it looked like there is a "controller-related issue affecting the pH sensor", which results in a very few pH measurements returned throughout the profile (with higher resolution in the top 200 m). The float is under monitor, and it might start working properly at some point.

The location and date of the float deployments are indicated in the table below, with UW ID numbers, list of parameters measured by the floats and the CTD cast (if any) at the location of deployment.

Table 1: summary of the deployment details of the SOCCOM floats

UW ID	Longitude (°E)	Latitude (°S)	Date and Time (UTC)	Depth (m)	Parameters	CTD Station #	Deployers
Apex 12878	29.9958	65.4993	4/18/19 23:19	4710	CTD, oxygen, nitrate, pH, fluorescence and backscattering	14	Jennifer Nomura and Isa Rosso
Apex 12892	29.9997	62.998	4/20/19 8:50	5165	CTD, oxygen, nitrate, pH, fluorescence and backscattering	19	Jennifer Nomura and Isa Rosso
Apex 12885	29.9896	56.0031	4/25/19 4:15	5463	CTD, oxygen, nitrate, pH, fluorescence and backscattering	33	Jennifer Nomura and Maximilian Kotz
Apex 12888	29.9915	51.4879	4/30/19 19:20	4257	CTD, oxygen, nitrate, pH, fluorescence and backscattering	42	Croy Carlin and Melissa Miller
Apex 12882	29.0112	44.9717	5/6/19 0:28	5804	CTD, oxygen, nitrate, pH, fluorescence and backscattering	On the way to Port Elizabeth	Jennifer Nomura and Isa Rosso
Navis 0888	28.55	33.6965	5/9/19 17:48	5747	CTD, oxygen, nitrate, pH, fluorescence and backscattering	48	Croy Carlin and Melissa Miller
Navis 0889	30.0002	35.0034	5/10/19 11:55	4448	CTD, oxygen, nitrate, pH, fluorescence and backscattering	15	Croy Carlin, Isa Rosso and Melissa Miller

The figure below shows an example of profiles for the float #12878, the first SOCCOM float to be deployed on this cruise.

18.2 CSIRO floats

PIs

- Rebecca Cowley

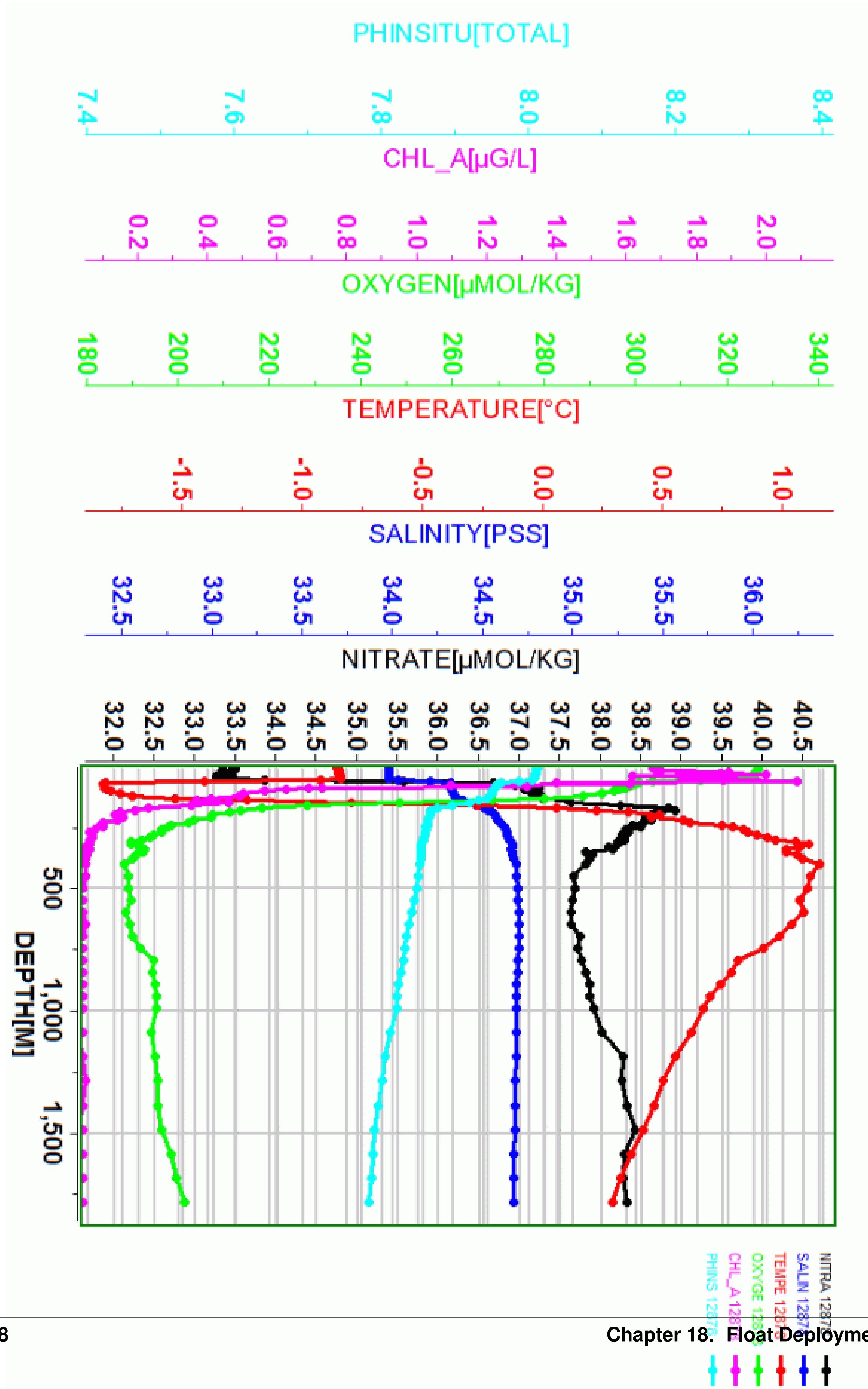
9 CSIRO core Argo floats were deployed during the cruise. We have received confirmation that all the floats have reported correctly. The floats were checked and prepared in port in Cape Town by Craig Hanstein (CSIRO).

The floats were deployed in their original bio-degradable cardboard boxes, as requested, in order to prevent any damage. Four straps were attached around the box, connected to a water release mechanism (a metal cylinder) at the bottom and with four trailing loops on the top. The deployment line was slipped through the trailing loops, and then secured on the other end to a cleat.

However, the water release mechanism on the first float never opened up: we waited about 5 minutes and by that time the box was disintegrating at the bottom, which made it impossible for us to recover the whole box. The MT shook the harnesses around, releasing the box. The surface temperature was about -0.5 C. We decided to open the boxes before deploying the floats, based on this, for waters below 0 C.

Other than this initial hiccup, the deployments went smooth, thanks to the very skilled MTs onboard.

The details were recorded by either Isa Rosso or the watch-stander students, and sent to the CSIRO team by I. Rosso. The location and date of the CSIRO float deployments are indicated in the table below, with serial numbers, CTD cast


PHINSITU[TOTAL]
7.4 7.6 7.8 8.0 8.2 8.4
CHL_A[µG/L]
0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0
OXYGEN[µMOL/KG]
180 200 220 240 260 280 300 320 340
TEMPERATURE[°C]
-1.5 -1.0 -0.5 0.0 0.5 1.0
SALINITY[PSS]
32.5 33.0 33.5 34.0 34.5 35.0 35.5 36.0
NITRATE[µMOL/KG]
32.0 32.5 33.0 33.5 34.0 34.5 35.0 35.5 36.0 36.5 37.0 37.5 38.0 38.5 39.0 39.5 40.0 40.5
DEPTH[M]
500 1,000 1,500

at the location of deployment and name of the personnel who deployed the floats.

Table 2: summary of the deployment details of the 9 CSIRO Argo floats

ID	Date and time (UTC)	Longitude (°E)	Latitude (°S)	Depth (m)	CTD Station #	Deployers
8446	4/18/19 17:50	29.9933	66.0014	4773	13	Croy Carlin, Isa Rosso
8447	4/19/19 6:00	29.9919	65.002	4869	15	Jennifer Nomura, Isa Rosso
8438	4/19/19 19:40	29.9973	64.005	5097	17	Croy Carlin, Kay McMonigal
8439	4/20/19 2:15	30.0093	63.4985	5128	18	Jennifer Nomura, Michael Kovatch
8440	4/20/19 23:40	29.9953°	61.9969	5186	21	Jennifer Nomura, Daniela Faggiani-Dias
8455	4/23/19 13:44	30.002	58.0091	5433	29	Croy Carlin, Kay McMonigal
8456	4/25/19 4:00	29.9896	56.0031	5463	33	Jennifer Nomura, Maximilian Kotz
8457	4/29/19 5:13	30.0015	53.997	5198	37	Jennifer Nomura, Michael Kovatch
8458	5/2/19 23:13	29.9698	49.9945	3475	45	Croy Carlin, Maximilian Kotz

18.3 NOAA/PMEL floats

PI

- Elizabeth Steffen

2 NOAA/PMEL Seabird Navis core Argo floats have been deployed during I06S, as part of the global Argo array. The floats were all successfully deployed, with no issues. After the deployment, the details were recorded by I. Rosso and sent to the PI. Date, time, location of the deployment, CTD cast associated with the deployments and the name of the deployers are reported in the Table below.

Table 3: summary of the deployment details of the 2 NOAA/PMEL floats

ID	Date and Time (UTC)	Longitude (°E)	Latitude (°S)	Depth (m)	CTD Station #	Deployers
946	4/22/19 6:53	30.0135	60.0155	5181	25	Jennifer Nomura, Daniela Faggiani-Dias
947	4/22/19 22:48	30.0027	59.0159	5427	27	Croy Carlin, Michael Kovatch

CHAPTER

NINETEEN

δ18O

PIs

- Michael Meredith (BAS)
- Melanie Leng (BAS)

Technicians

- Isa Rosso
- Mike Kovatch
- Daniela Faggiani-Dias
- Maximilian Kotz
- Loicka Baille
- Guiliana Viglione
- Kay McMonigal

19.1 Equipment and Techniques

A total of 1302 high density polyethylene (HDPE) wide-mouth 30-ml vials were used to collect δ18O samples at all I06S CTD station, following the protocol and sampling strategy provided by the PIs, as described below.

Watch standers and leaders from each shift drew δ18O samples last, after all other programs had finished with theirs. Collection was straightforward. It required filling the vial in half and shaking; filling to the top and leaving only minimal air; closing tight; drying with kimpwipes or paper towels; placing vinyl electrical tape around the neck of the vial and the bottom of the cap to seal the sample.

A maximum of 24 samples per station were distributed with higher resolution within the surface, intermediate and bottom layers, whereas with lower resolution within deep waters. Paper and electronic logs of all the δ18O samples include station (location), Niskin Bottle (depth), and sample numbers, which were also recorded on the vials.

Once back to port, the samples were shipped back to UK, for analysis.

CHAPTER

TWENTY

DRIFTER DEPLOYMENTS

PI

- Shaun Dolk (*AOML*)

16 drifters (8 SVP and 8 SVP-barometer) were deployed on the I06S line as part of the Global Drifter Program. Only the plastic wrap was removed before their deployment. In the case of the two deployments occurring at the same location (at 60° S), the drifters were released with 30 seconds of distance between each other, in order to avoid any entanglement amongst the drifters' drogues. After collecting the release details (see table below) by either the watch stander students or Isa Rosso, the data (see the table below) were communicated to S. Dolk by I. Rosso.

2 of the drifters were adopted as part of the outreach "Adopt-a-drifter" program, by schools in Colorado and in Ukraine: ID #300234066615940 and #300234066338770. Teacher and students will follow the drifters' journey and their data, which is public available at https://www.adp.noaa.gov. As outreach activity, 2 blog posts were written including the details of the adopted drifters.

Table 1: Table of deployments

ID	Date and Time (UTC)	Longitude (°E)	Latitude (°S)	Deployed from	Ship speed (kn)	Height above sea level (m)	Deployers
66615940	4/18/19 17:42	29.9962	66.0008	Port stern	1	3	Loicka Baille and Giuliana Viglione
66615920	4/19/19 19:40	29.9973	64.0003	Port stern	3	3	Daniela Faggiani-Dias and Isa Rosso
66615970	4/20/19 23:36	29.998	61.9996	Port stern	3	3	Kay McMonigal and Croy Carlin
66338770	4/22/19 6:54	30.0128	60.0159	Port stern	3	3	Daniela Faggiani-Dias and Maximilian Kotz
66615930	4/22/19 6:54	30.0126	60.016	Port stern	3	3	Daniela Faggiani-Dias and Maximilian Kotz
66339760	4/23/19 13:44	30	58	Port stern	1.5	3	Giuliana Viglione and Croy Carlin
66338830	4/28/19 15:40	30	54.99	Port stern	3	3	Kay McMonigal and Croy Carlin
66339780	0429/2019 19:25	30.0013	52.999	Port stern	1.2	3	Kay McMonigal and Croy Carlin
66337840	5/4/19 23:42	29.1918	49.187	Port stern	12	3	Isa Rosso and Croy Carlin
66616940	5/5/19 23:05	29.0417	45.1769	Port stern	10.5	3	Isa Rosso and Croy Carlin
66338790	5/6/19 11:05	28.5789	43.0193	Port stern	12	3	Isa Rosso and Croy Carlin
66338810	5/7/19 2:24	27.5775	40.032	Port stern	11.4	3	Daniela Faggiani-Dias and Michael Kovatch
66338990	5/7/19 13:38	26.9881	38.0151	Port stern	12.9	3	Croy Carlin
66616830	5/8/19 0:00	26.3272	36.0271	Port stern	12	3	Isa Rosso and Jennifer Nomura
66616920	5/9/19 3:00	28.0963	33.2332	Starboard stern	4	3	Daniela Faggiani-Dias and Jennifer Nomura
66616950	5/9/19 17:58	28.87	34.66	Port stern	11.4	3	Croy Carlin and Benjamin Mushi

CHAPTER

TWENTYONE

GLIDER DEPLOYMENTS

PIs

- Andrew Thompson
- Alison Gray

Technicians

- Giuliana Viglione
- Maximilian Kotz

Two ocean gliders were deployed along the GO-SHIP IO6S section at 51.5S. The deployment was part of a collaborative proposal between Andrew Thompson, Caltech, and Curtis Deutsch & Alison Gray, U. Washington, to quantify submesoscale dynamical contributions to carbon flux in the southern ocean, by tracking a bio-geochemical SOCCOM float with the two gliders. The gliders were equipped with a Seabird SBE3 temperature and SBE4 conductivity sensor, an Aanderaa 4831 Oxygen optode, and a WETLabs ECO Puck BB2FL fluorometer.

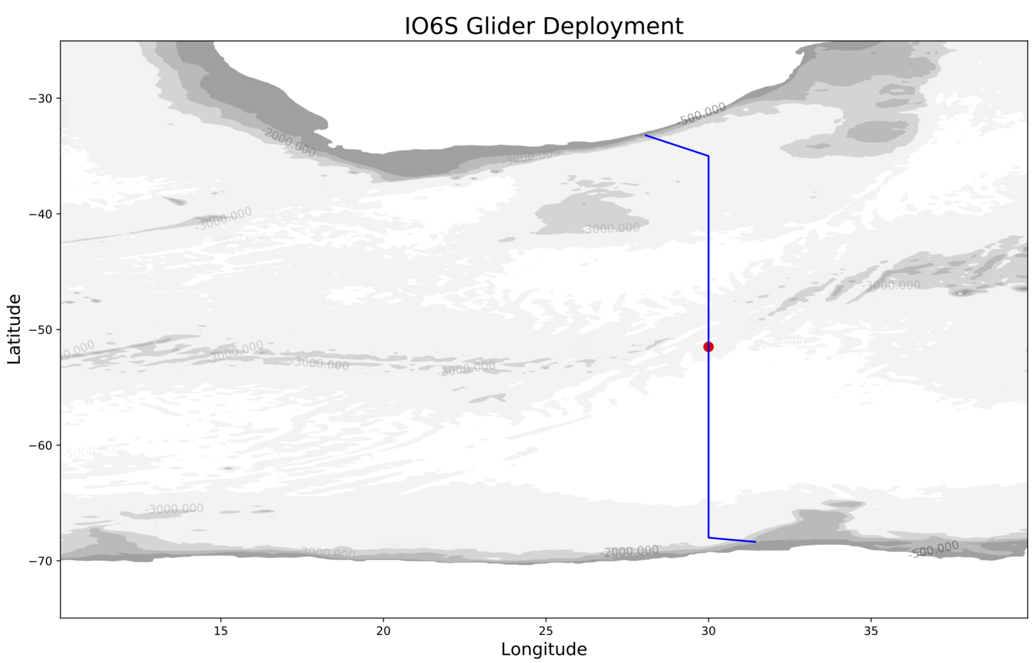


Fig. 1: Glider deployment location (red) on IO6S line (blue).

21.1 Preparation

On the 02/04/2019, while in port at Cape Town, Giuliana Viglione and Maximilian Kotz (Caltech Graduate Students) ran the two gliders through self-tests and simulation-dives to check their communications and mechanical capabilities.

These tests required the gliders to be carried to the back deck by 4 personnel and then ratchet strapped to the railing so that their antenna were angled at least 50 degrees from horizontal. During the course of the cruise, the personnel responsible for moving the gliders between the back-deck and main-lab were the two Caltech graduate students; two additional volunteers were regularly recruited from the science party or crew.

An issue was discovered with SG 660, the bladder of which was not pumping to its full capacity. While in transit, this glider was taken out again and given specific instructions to pump to full; it was found to be able to do so and the issue was considered resolved.

On the 23rd of April, the software on the glider basestation was updated by Kongsberg, the manufacturers. Self-tests and simulation-dives were required again to check that the gliders were compatible with the update. Unfortunately it was discovered that both gliders were unable to log in to the basestation via their Iridium satellite communication.

Over the following days, further tests were run to troubleshoot the issue. On the 29th of April the problem was resolved by coordinated tests by Giuliana, Max and the Kongsberg and Caltech personnel.

Fig. 2: Self-tests and simulation-dives were run with the gliders ratchet strapped to the back deck, in port in Cape Town (Giuliana Viglione)

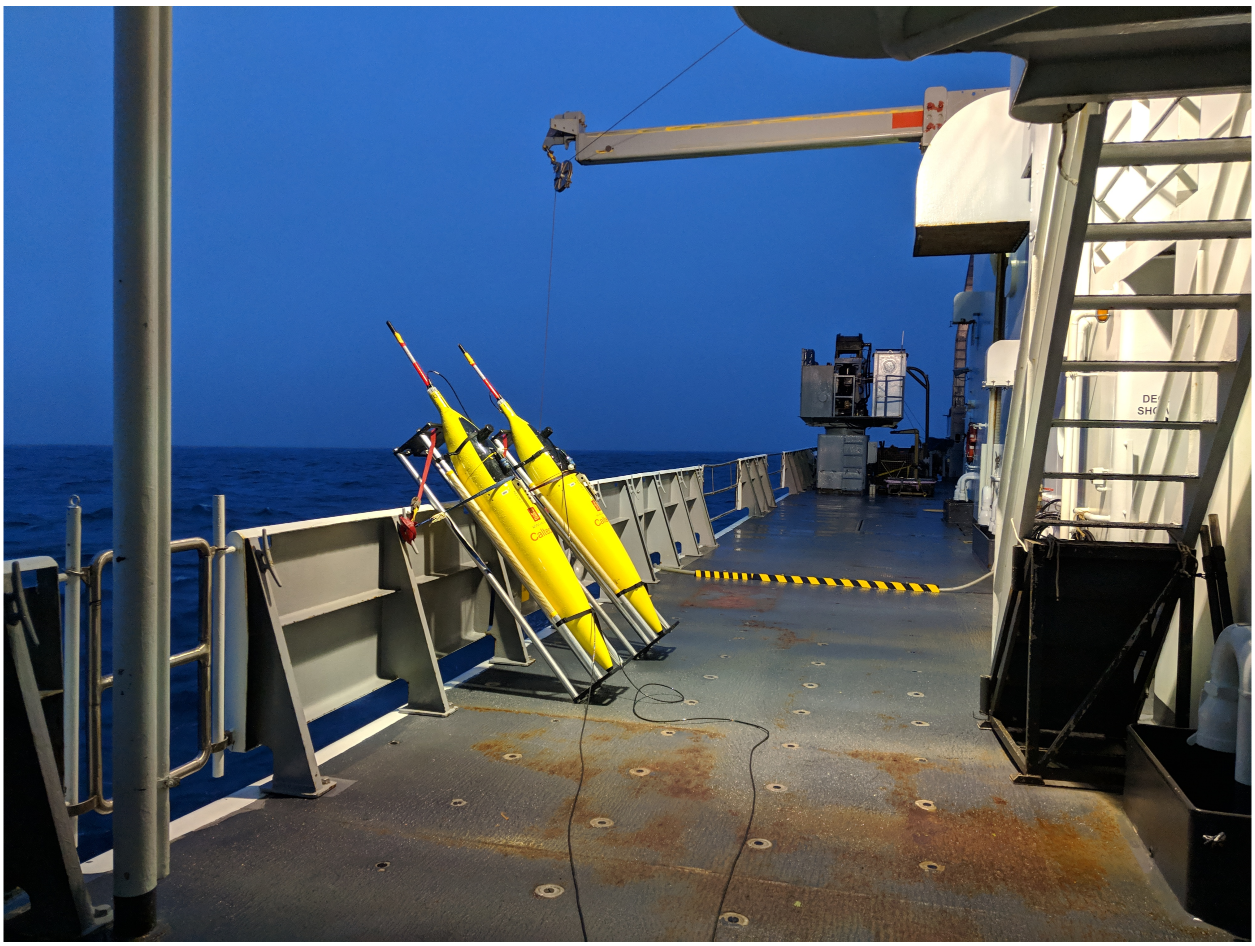


Fig. 3: Self-tests and simulation-dives were run with the gliders ratchet strapped to the back deck, tests run on the gliders during a CTD cast (Giuliana Viglione)

21.2 Deployments

On the 30th of April the two gliders were deployed at 51.5S before casting the CTD. The weather was good enough for the captain to agree to deploy via zodiac. At 10:30 (UTC) The two gliders were transported to the O2 deck via the outside stairs. Their wings and rudder were attached and they were strapped to the railing and set to launch mode.

The cap of the fluorometer became detached during this procedure and some grease was smeared across the sensor. This was fixed by Joseph Gum (ODF/SIO technician) who reattached the casing and cleaned the sensor.

SG 660

At approximately 11:30 (UTC) the first glider, SG 660, was carried into the zodiac in its cradle and was ratchet strapped at both top and bottom to the zodiac to prevent it from slipping. The zodiac was driven by Todd Schwartz (third mate); Bernadette Castner (A.B.) and Isa Rosso (co-chief scientist) also came aboard to assist Max with the deployment. The zodiac was lowered over the edge of the ship and driven 500m from the ship.

Bernadette attached a line to SG 660 by looping it around the notches at the base of the rudder; this provided security while Max and Isa Rosso lowered it over the edge and held it still in the water until it achieved neutral buoyancy. The glider was held for approximately 10 minutes until only its rudder and antenna were above the waterline - a criteria which was hard to judge amongst the waves. From the ship Giuliana then gave the instruction to dive and the line was released. The glider was watched for approximately 15 minutes until it dived out of sight. The zodiac returned to the ship and was raised out of the water.

SG 659

The second glider, SG 659, was strapped to the zodiac and the process repeated. Unfortunately, the zodiac engine overheated while driving away from the boat. The decision was made to return slowly to the ship and to deploy SG 659 via crane.

A line was attached to the glider via the notches at the base of its rudder, this was then connected to the crane with a second line and quick release pin. The winch was operated by Frank Leo Spetla (A.B.). The glider was raised from its cradle, and guided by hand as the crane raised it over the side of the ship. Without any suitable places to attach tag lines, the gliders motion became unstable and it swung close to the ship. Twice it narrowly avoided the hull before the crane was able to lower and release it, approximately 5 metres from the ship. The glider fully submerged and came up at a safe distance from the ship. The command to dive was given and the glider was watched until its antenna disappeared beneath the waves. **In future it would be strongly advised to avoid using the crane without tag lines for deployment.**

SOCCOM float 12888 was deployed shortly after the CTD cast at the same latitude and longitude. The two gliders will continue to track it over the coming four months; the data from their first dives has come back and shows they are working correctly.

Fig. 4: zodiac lowered over side of ship with SG 660 ratchet strapped to the centre in its cradle. (Andrew Collins)

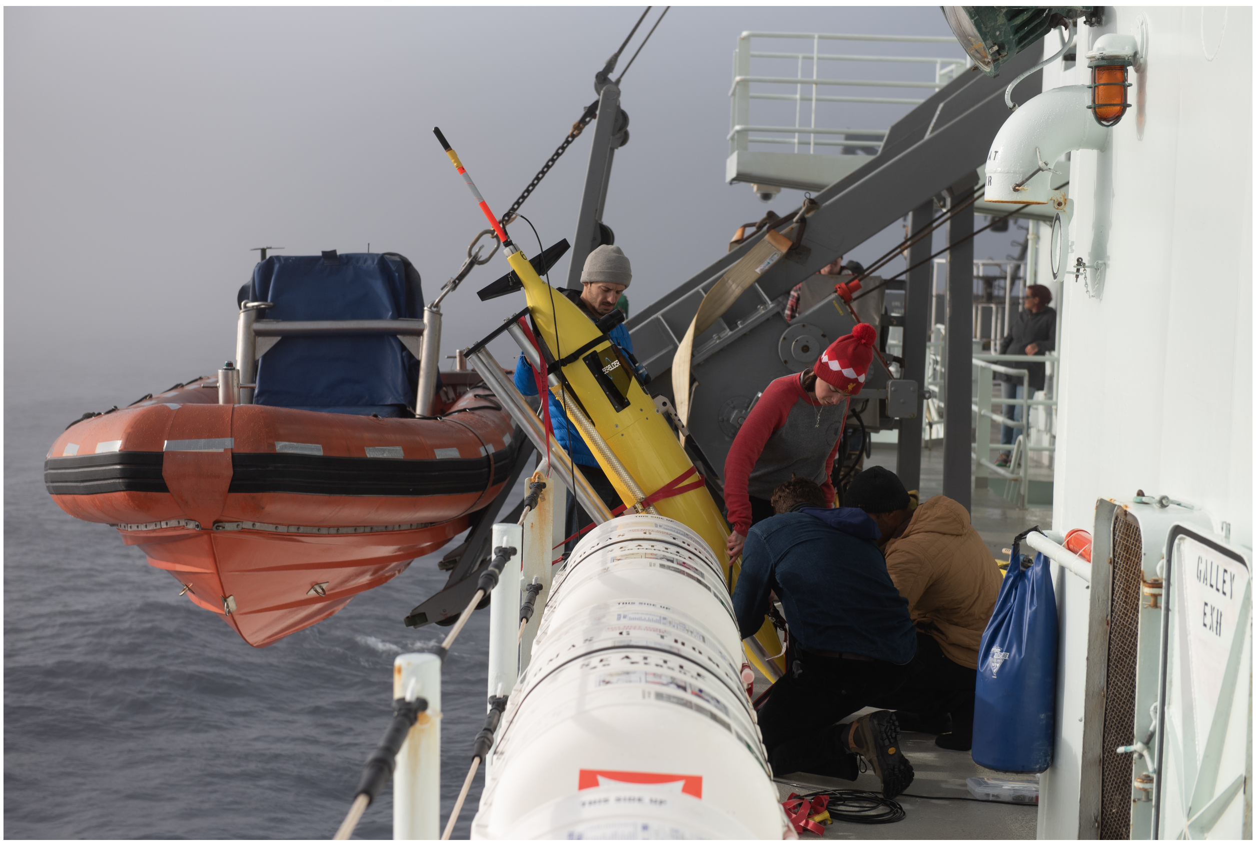


Fig. 5: SG 660 is set to launch mode on the 02 deck of the RV. Thomas G. Thompson. (Andrew Collins)

Fig. 6: SG 660 is held in the water until the rudder and antenna are above the water line. (Isa Rosso)

Glider	Date	Time (UCT)	Latitude	Longitude	Method
SG660	2019-04-30	12:12	-51.5	30	Zodiac
SG659	2019-04-30	13:30	-51.5	30	Crane

CHAPTER

TWENTYTWO

STUDENT STATEMENTS

22.1 Daniela Faggiani Dias

GO-SHIP has provided me with an invaluable experience by giving me the opportunity to sail with the RV Thompson for the I06S line. My work at SIO focuses on identifying predictable patterns in the ocean and the atmosphere on time scales longer than seasonal. I use a suite of long time series of observational data and modelling experiments to identify such patterns and to better understand the mechanisms that give rise to those predictable scales. The data that I use for this project usually comes in the format of a final product: data from many years, collected in many ways, compiled, processed, and interpolated. Numbers on the screen of my computer. However, being at sea and helping to collect data for many projects has helped me immensely to understand the complexity involved in generating such datasets. As my grandmother says, "It is good to know where your food comes from."

My main role during the cruise was as CTD watch stander. The job consists in preparing the Rosette before each cast, overseeing the CTD cast once the Rosette is in the water and triggering the bottles to collect water at different depths. In addition to this, I was helping to collect water samples for salinity and alkalinity and helping with the deployment of drifters and ARGO floats. I was also responsible of download the data and troubleshooting the Chi-pods (those are instruments that measure the acceleration and temperature derivatives to estimate the turbulent mixing). All those tasks helped me to appreciate the behind the scenes of all the effort that is put to perform every CTD cast, to collect and to run every water sample, to process the data and to make sure that all the equipment is working well with the minimal error possible. It also helped me to better understand all the limitations that we have when working with observational oceanography and the colossal effort that is required to make everything run smoothly. And, even with all the care that the scientists and the crew put when organizing the cruise, unfortunate and unexpected events may happen and sometimes not everything can be accounted for. In this cruise, we had many of those unfortunate events: engine problems, weather days, medical emergency evacuation, flooding inside the ship and many problems with the CTD "fish", that had to be replaced a few times. It is great to be able to see that, despite all those unfortunate events, we are building a great and reliable database to better understand different aspects of the ocean and how it has been changing.

Besides the professional aspects of the cruise, there is something else that cannot be forgotten: personal growth. During the six weeks of the cruise, you have to share small spaces with the same few people. There are not many distractions. Time has a different pace. There is plenty of time to talk to your colleagues without the distraction of our everyday life. Because of that, the rush that we are used to in our lives does not play a role here and we are more able to make real and deep human connections.

As the cruise comes to an end, I will miss being at sea. I will miss the feeling of the ship dancing with the waves in a perfect synchrony. I will miss walking upstairs to the bridge and, for hours, staring at the ocean. In the rough days, staring at the 50 feet waves, staring at the ship navigating throughout those seas. I will miss the turquoise color of the ocean when those waves break, a moment of such delicacy that contrasts with the roughness of the environment that surround us. I will also miss the few moments we had of quiet and glassy seas, the very few sunny days when we could sit outside in the back deck and the beautiful skies in the night, when we could see and try to guess the constellations in the Southern Hemisphere. I will miss being at sea.

I truly appreciate the opportunity that was given by the Go SHIP program.

22.2 Maximilian Kotz

As an incoming graduate student, I felt very lucky to take part in the 2019 GO-SHIP IO6S cruise before actually starting grad school. While primarily on the cruise to deploy two sea gliders for my PI, I had also volunteered to participate in the CTD watch with the other 5 graduate students on board. My offer to do so could not have been better rewarded. After 6 weeks of over-seeing CTD casts, taking water samples for a variety of properties and deploying numerous SOCCOM floats and drifters as well as the two sea gliders, I feel I have been thoroughly initiated into the world of oceanography.

Learning first hand about measurement and deployment techniques has given me a respect and understanding for the data that beforehand I had downloaded and analysed with little appreciation. Plotting underway data as we transit and discussing CTD data as we cast has helped me to learn about the structure of the southern ocean. Seeing the beauty of the oceans we study has deepened my desire to learn about them. But perhaps most importantly, working alongside such skilled, dedicated technicians and scientists has been an absolute pleasure. The atmosphere of the sampling bay was equal parts professionalism and hilarity; and the guidance of co-chief scientist Isa Rosso with all things scientific and personal was nothing short of exceptional.

I am grateful to GO-SHIP for the opportunity to be part of this cruise and I hope to have the opportunity to do so again in the future. I look forward to piloting the gliders over the coming months and to using their and SOCCOM's data over the coming years in my PhD.

22.3 Michael Kovatch

I applied to the GO-SHIP I06S cruise in order to experience being out in the field on a large research vessel, work with oceanographic data collection, and to sample in a new part of the ocean. Field work is one of my favorite aspects of oceanography, but all of my previous work has been shorter, closer to shore, and on smaller vessels and boats. Previously working only in the Gulf of Mexico and off of central California, the opportunity to travel to the Southern Hemisphere and spend time in the Indian and Southern Oceans was an exciting prospect.

My duties at sea were varied and interesting, so no point of the cruise ever felt boring. My primary role was being a CTD watchstander, which involved monitoring the live data outputs of temperature, salinity, density, oxygen, fluorescence, and more as the rosette was lowered to 10 meters above the ocean bottom. This also meant communicating with the winch operator to ensure the wire tension was kept in an acceptable range and firing Niskin bottles on the upcasts to collect water samples which would subsequently be analyzed at the surface. Once the rosette was recovered, I assisted in sampling alkalinity, salts, and dO18. The other watchstanders and I also took turns being 'sample cop', which meant keeping track of and policing the order in which people were allowed to sample from the Niskin bottles to ensure high-quality samples of CFCs, oxygen, carbon, and pH.

In addition to watchstander responsibilities, I was one of the students trained to work with the chipods, which are high-frequency temperature sensors that are used to infer small-scale mixing. This required beginning data acquisition and monitoring that the values of temperature, etc. made sense. Lastly, I assisted with deployments of Argo floats and surface drifters.

Overall, this cruise has been an excellent experience. I met so many interesting people who were able to provide further insight into the diversity of oceanographic research and careers. It was helpful in reaffirming my passion for being in the field and collecting data. The cruise was a great environment to work in, with endless camaraderie, stories, and deep discussions. I am very grateful for the time I got to spend on the R/V Thompson with the rest of the crew, both science and ship. I hope to be able to participate in future cruises!

22.4 Loicka Baille

As an undergraduate student, being able to join a cruise so early in my career has been a rare and incredibly opportunity. I'm very thankful for my advisor, Alejandro Orsi for this chance. I was part of the CTD watch-stander team which was in charge of preparing the rosette, firing bottles, and collecting salinity samples. I also volunteered to help collect alkalinity and oxygen 18 samples. This cruise allowed me to work with world class instruments and scientists, and see first-hand how science is being done, and how data is collected. Being around so many graduate students, I am much better informed on what graduate school consists of, what criteria to look for when applying and what different tracks might be out there.

Being an undergraduate student leaving to go on a cruise mid-semester, I had to take the remaining of my classes online. Taking 7 classes while working 12 hours shifts and having limited internet connection was definitely one of the most challenging part of this cruise. I'm grateful to my teammates, work technicians and professors for supporting and helping me getting my classes done. Aside from science and classes, there was some free time left. It was filled with card games, board games, ping-pong tournaments, and jaw-dropping pranks among the science team.

I'm extremely thankful for having the chance to work with wonderful people that made this experience incredibly enjoyable while instructive. I'm grateful to the GO-SHIP program for providing me with this wonderful opportunity and hope to continue to participate and contribute to future cruises as well.

APPENDIX

A

ABBREVIATIONS

ADCP Acoustic Doppler Current Profiler

AOML Atlantic Oceanographic and Meteorological Laboratory

AP Particulate Absorbtion Spectra

APL Applied Physics Laboratory

ASC Antarctic Support Contract

BAS British Antartic Survey

Bigelow Bigelow Laboratory for Ocean Sciences

CDOM Chromophoric Dissolved Organic Matter

CFCs Chlorofluorocarbons

CTDO Conductivity Temperature Depth Oxygen

DIC Dissolved Inorganic Carbon

DOC Dissolved Organic Carbon

ECO Edison Chouest Offshore

ENSTA ENSTA ParisTech

ETHZ Edgenössische Technische Hochschule Zürich

FSU Florida State University

HPLC High-Performance Liquid Chromatography

LDEO Lamont-Doherty Earth Observatory - Columbia University

LADCP Lowered Accoustic Doppler Profiler

MBARI Monterey Bay Aquarium Research Institute

NOAA National Oceanographic Atmospheric Administration

NBP RVIB Nathaniel B Palmer

NSF National Science Foundation

ODF Ocean 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*

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

UA University of Arizona

U ALASKA University of Alaska

UCI University of California Irvine

U Colorado University of Colorado

UCSB University of California Santa Barbara

UCSD University of California San Diego

UH University of Hawaii

U Maine University of Maine

U Miami University of Miami

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

BOTTLE QUALITY COMMENTS

Station	Cast	Bottle	Param	Code	Comment
4	1	2	OXYGEN	3	Flask 692 suspected bad; code 3 to be conservative
4	1	32	PH_TMP	5	MISTRIP
4	1	32	PH_TOT	5	MISTRIP
6	1	24	OXYGEN	4	Bad O2 Flask
7	1	6	NITRAT	4	mis trip? Oxy high nuts low
7	1	6	PHSPHT	4	mis trip? Oxy high nuts low
7	1	6	SILCAT	4	mis trip? Oxy high nuts low
7	1	6	NITRIT	4	mis trip? Oxy high nuts low
8	1	34	PH_TOT	4	mis trip
8	1	34	PH_TMP	4	mis trip
10	1	11	NITRAT	4	all nut values low
10	1	11	SILCAT	4	all nut values low
10	1	11	PHSPHT	4	all nut values low
10	1	11	NITRIT	4	all nut values low
10	1	26	OXYGEN	3	Flask 692 suspected bad; code 3 to be conservative
11	2	8	PH_TOT	5	LEAKY NISK
11	2	8	PH_TMP	5	LEAKY NISK
12	1	24	OXYGEN	4	Bad O2 Flask
14	1	26	OXYGEN	3	Flask 692 suspected bad; code 3 to be conservative
15	1	26	OXYGEN	3	Flask 692 suspected bad; code 3 to be conservative
16	1	17	NITRAT	4	high nuts low oxy

Continued on next page

Table 1 – continued from previous page

Station	Cast	Bottle	Param	Code	Comment
16	1	17	NITRIT	4	high nuts low oxy
16	1	17	SILCAT	4	high nuts low oxy
16	1	17	PHSPHT	4	high nuts low oxy
16	1	22	NITRAT	4	all nuts high, oxy low, mistrip? Check bottle salts
16	1	22	SILCAT	4	all nuts high, oxy low, mistrip? Check bottle salts
16	1	22	PHSPHT	4	all nuts high, oxy low, mistrip? Check bottle salts
16	1	22	NITRIT	4	all nuts high, oxy low, mistrip? Check bottle salts
16	1	24	PHSPHT	4	all nuts high, oxy low, mistrip? Check bottle salts
16	1	24	OXYGEN	4	Bad O2 Flask
16	1	24	SILCAT	4	all nuts high, oxy low, mistrip? Check bottle salts
16	1	24	NITRAT	4	all nuts high, oxy low, mistrip? Check bottle salts
16	1	24	NITRIT	4	all nuts high, oxy low, mistrip? Check bottle salts
18	1	2	OXYGEN	3	Flask 692 suspected bad; code 3 to be conservative
18	1	28	NITRIT	4	all nuts high, oxy low, mistrip? Check bottle salts
18	1	28	SILCAT	4	all nuts high, oxy low, mistrip? Check bottle salts
18	1	28	PHSPHT	4	all nuts high, oxy low, mistrip? Check bottle salts
18	1	28	NITRAT	4	all nuts high, oxy low, mistrip? Check bottle salts
19	1	15	SILCAT	3	high sil?
22	1	26	OXYGEN	3	Flask 692 suspected bad; code 3 to be conservative
23	1	10	NITRIT	4	all nuts high
23	1	10	NITRAT	4	all nuts high
23	1	10	PHSPHT	4	all nuts high
23	1	10	SILCAT	4	all nuts high
25	1	26	OXYGEN	3	Flask 692 suspected bad; code 3 to be conservative
27	1	2	OXYGEN	3	Flask 692 suspected bad; code 3 to be conservative
28	1	27	OXYGEN	4	Bad O2 Flask
29	1	3	PHSPHT	4	all nuts low, mis-sampled
29	1	3	SILCAT	4	all nuts low, mis-sampled
29	1	3	NITRAT	4	all nuts low, mis-sampled
29	1	3	NITRIT	4	all nuts low, mis-sampled
29	1	14	PHSPHT	4	po4 value high

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Table 1 – continued from previous page

Station	Cast	Bottle	Param	Code	Comment
30	1	2	OXYGEN	3	Flask 692 suspected bad; code 3 to be conservative
31	1	2	OXYGEN	3	Flask 692 suspected bad; code 3 to be conservative
33	1	11	NITRIT	4	all nuts high mis-sampled
33	1	11	SILCAT	4	all nuts high mis-sampled
33	1	11	PHSPHT	4	all nuts high mis-sampled
33	1	11	NITRAT	4	all nuts high mis-sampled
36	1	2	OXYGEN	3	Flask 692 suspected bad; code 3 to be conservative
37	1	27	OXYGEN	4	Bad O2 Flask
39	1	2	OXYGEN	3	Flask 692 suspected bad; code 3 to be conservative
40	1	2	OXYGEN	3	Flask 692 suspected bad; code 3 to be conservative
42	1	27	OXYGEN	4	Bad O2 Flask
43	1	2	OXYGEN	3	Flask 692 suspected bad; code 3 to be conservative
46	1	27	OXYGEN	4	Bad O2 Flask
49	1	15	OXYGEN	4	Bad O2 Flask
52	1	30	OXYGEN	3	Bottle Oxygen is a little high on this one
53	1	27	OXYGEN	4	Bad O2 Flask

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Table 1 – continued from previous page

Station	Cast	Bottle	Param	Code	Comment
55	1	26	OXYGEN	3	Flask 692 suspected bad; code 3 to be conservative
57	1	26	OXYGEN	3	Flask 692 suspected bad; code 3 to be conservative
58	1	27	OXYGEN	4	Bad O2 Flask
59	1	26	OXYGEN	3	Flask 692 suspected bad; code 3 to be conservative
59	1	28	NITRAT	4	mis trip code bottle and all other parameters
59	1	28	PHSPHT	4	mis trip code bottle and all other parameters
59	1	28	NITRIT	4	mis trip code bottle and all other parameters
59	1	28	SILCAT	4	mis trip code bottle and all other parameters
60	1	27	OXYGEN	4	Bad O2 Flask
63	1	26	OXYGEN	3	Flask 692 suspected bad; code 3 to be conservative
64	1	3	OXYGEN	4	O2 value very high; does not fit profile
64	1	26	OXYGEN	3	Flask 692 suspected bad; code 3 to be conservative
65	1	2	OXYGEN	3	Flask 692 suspected bad; code 3 to be conservative
68	1	2	NITRIT	3	all nut values low
68	1	2	SILCAT	3	all nut values low
68	1	2	PHSPHT	3	all nut values low
68	1	2	NITRAT	3	all nut values low
69	1	26	OXYGEN	3	Flask 692 suspected bad; code 3 to be conservative
71	1	2	OXYGEN	3	Flask 692 suspected bad; code 3 to be conservative

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Table 1 – continued from previous page

Station	Cast	Bottle	Param	Code	Comment
75	1	26	OXYGEN	3	Flask 692 suspected bad; code 3 to be conservative
76	1	2	OXYGEN	3	Flask 692 suspected bad; code 3 to be conservative
78	1	2	OXYGEN	3	Flask 692 suspected bad; code 3 to be conservative
79	1	2	OXYGEN	3	Flask 692 suspected bad; code 3 to be conservative
85	1	2	OXYGEN	3	Flask 692 suspected bad; code 3 to be conservative
89	1	2	OXYGEN	3	Flask 692 suspected bad; code 3 to be conservative
90	1	31	OXYGEN	3	Bottle Oxygen is a little high on this one
90	1	36	OXYGEN	3	Bottle Oxygen is a little low on this one
91	1	2	OXYGEN	3	Flask 692 suspected bad; code 3 to be conservative
94	1	2	OXYGEN	3	Flask 692 suspected bad; code 3 to be conservative
95	1	2	OXYGEN	3	Flask 692 suspected bad; code 3 to be conservative
95	1	35	PH_TOT	4	mis trip
95	1	35	PH_TMP	4	mis trip
98	1	36	OXYGEN	3	Bottle Oxygen is a little low on this one

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Table 1 – continued from previous page

Station	Cast	Bottle	Param	Code	Comment
100	1	26	OXYGEN	3	Flask 692 suspected bad; code 3 to be conservative
101	1	8	PH_TMP	3	3 bottle cracked
101	1	8	PH_TOT	3	3 bottle cracked
101	1	24	OXYGEN	5	sample lost
104	1	26	OXYGEN	3	Flask 692 suspected bad; code 3 to be conservative
105	1	2	OXYGEN	3	Flask 692 suspected bad; code 3 to be conservative
108	1	2	OXYGEN	3	Flask 692 suspected bad; code 3 to be conservative
111	1	2	OXYGEN	3	Flask 692 suspected bad; code 3 to be conservative
114	1	2	OXYGEN	3	Flask 692 suspected bad; code 3 to be conservative
117	1	2	OXYGEN	3	Flask 692 suspected bad; code 3 to be conservative
118	1	11	PH_TOT	5	BOTTLE BROKE
118	1	11	PH_TMP	5	BOTTLE BROKE
120	1	26	OXYGEN	3	Flask 692 suspected bad; code 3 to be conservative
121	2	24	PH_TMP	4	mistrip
121	2	24	PH_TOT	4	mistrip
122	1	26	OXYGEN	3	Flask 692 suspected bad; code 3 to be conservative
123	1	2	OXYGEN	3	Flask 692 suspected bad; code 3 to be conservative
123	1	24	PH_TMP	4	MISTRIP?
123	1	24	PH_TOT	4	MISTRIP?
123	1	31	PH_TMP	4	mistrip

Continued on next page

Table 1 – continued from previous page

Station	Cast	Bottle	Param	Code	Comment
123	1	31	PH_TOT	4	mistrip
128	1	24	OXYGEN	5	sample lost
128	1	26	OXYGEN	3	O2 Value very high; does not fit profile

APPENDIX

C

CALIBRATION DOCUMENTS

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

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

SENSOR SERIAL NUMBER: 0057
CALIBRATION DATE: 25-Oct-17

SBE 9plus PRESSURE CALIBRATION DATA
10000 psia S/N 34901

DIGIQUARTZ COEFFICIENTS:

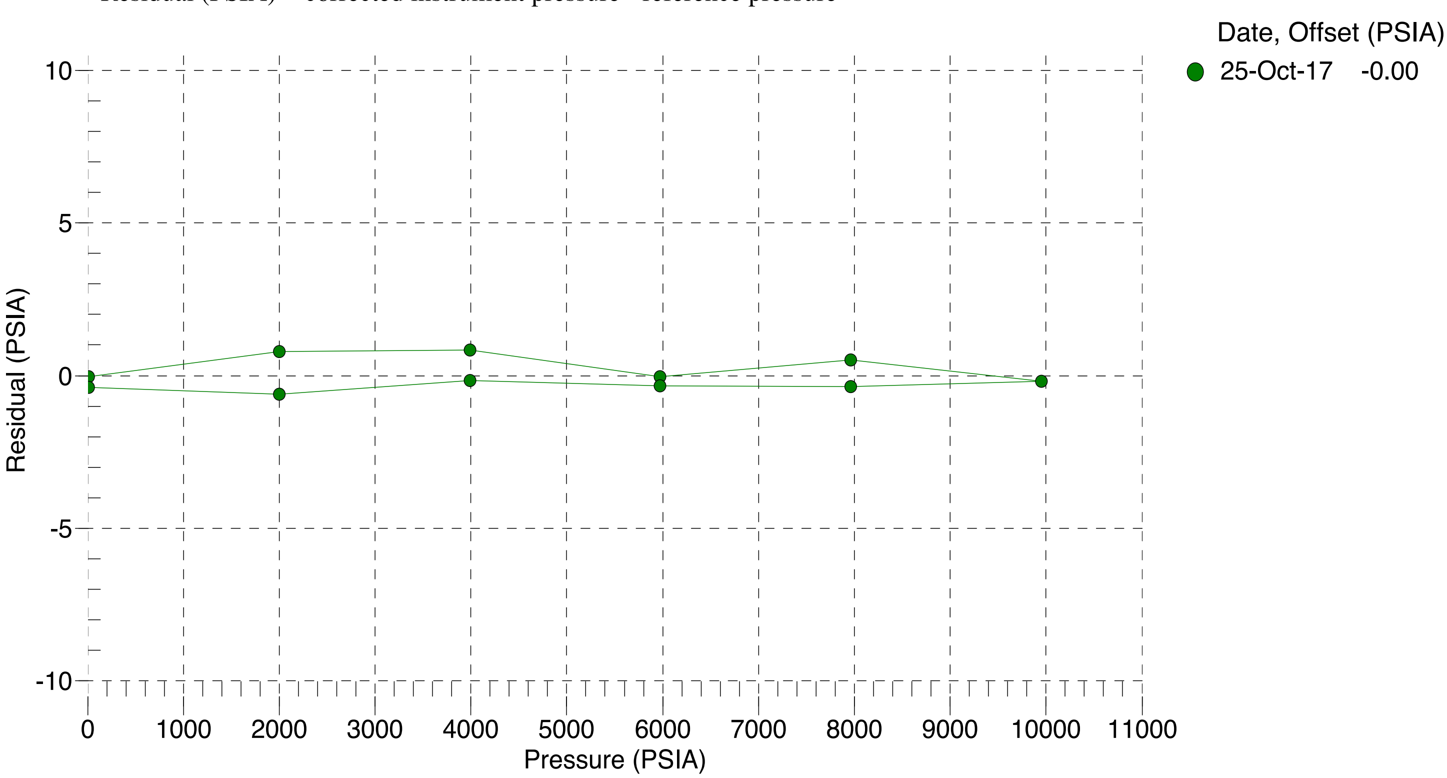
```
C1 =  -2.869955e+004
C2 =  -1.565582e+000
C3 =   9.161829e-003
D1 =   3.074801e-002
D2 =   0.000000e+000
T1 =   3.023683e+001
T2 =  -1.016075e-003
T3 =   4.744095e-006
T4 =   0.000000e+000
T5 =   0.000000e+000
```

AD590M, AD590B, SLOPE AND OFFSET:

```
AD590M =    1.13300e-002
AD590B =  -8.49858e+000
Slope  =    0.99981
Offset =  -7.6055 (dbars)
```

PRESSURE (PSIA)	INSTRUMENT OUTPUT (Hz)	INSTRUMENT TEMPERATURE (°C)	INSTRUMENT PRESSURE (PSIA)	CORRECTED PRESSURE (PSIA)	RESIDUAL (PSIA)
14.673	33107.90	20.8	25.677	14.644	-0.029
2001.203	34230.80	20.9	2013.397	2001.986	0.783
3987.814	35313.10	20.9	4000.437	3988.648	0.834
5975.185	36358.80	20.9	5987.318	5975.151	-0.034
7962.338	37371.70	20.9	7975.386	7962.841	0.503
9949.973	38353.50	20.9	9962.702	9949.780	-0.193
7962.354	37371.30	21.0	7974.531	7961.986	-0.368
5975.189	36358.70	21.0	5987.012	5974.846	-0.343
3988.072	35312.80	21.0	3999.694	3987.905	-0.167
2001.283	34230.20	21.0	2012.080	2000.669	-0.614
14.669	33107.90	21.0	25.307	14.274	-0.395

Residual (PSIA) = corrected instrument pressure - reference pressure



Pressure Calibration Report
STS Calibration Facility

SENSOR SERIAL NUMBER: 0914
CALIBRATION DATE: 10-JAN-2019
Mfg: SEABIRD Model: 09P CTD Prs s/n: 110547

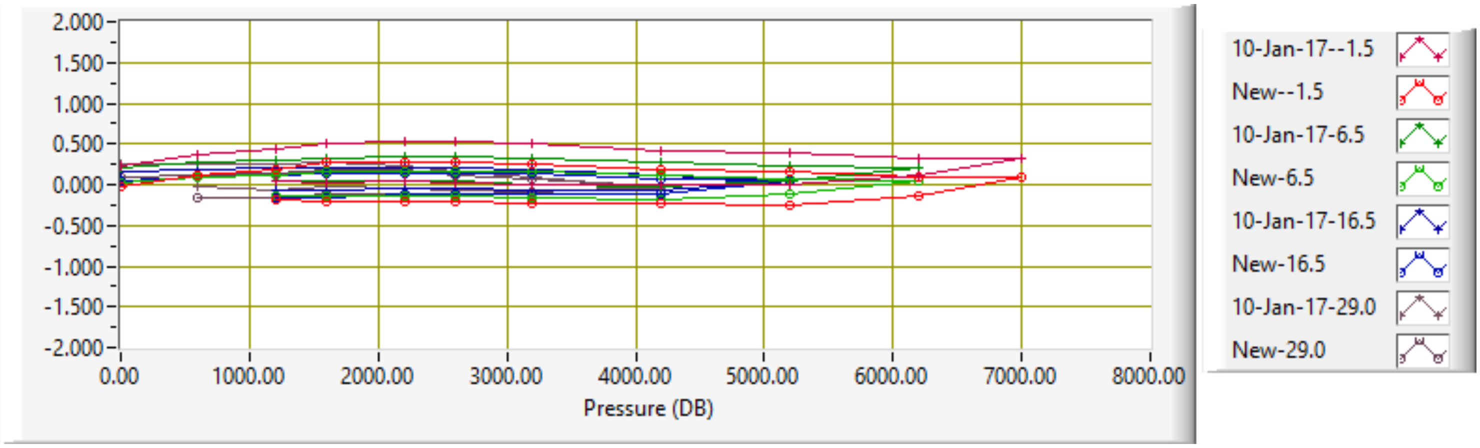
C1= -4.347481E+4
C2= 1.128938E-1
C3= 9.183598E-3
D1= 3.683315E-2
D2= 0.000000E+0
T1= 3.006834E+1
T2= -2.833701E-4
T3= 4.669014E-6
T4= -7.987024E-9
T5= 0.000000E+0
AD590M= 1.28789E-2
AD590B= -8.81353E+0
Slope = 1.00000000E+0
Offset = 0.00000000E+0

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	Standard	Sensor New_Coefs	Standard-Sensor Prev_Coefs	Standard-Sensor NEW_Coefs	Sensor_Temp	Bath_Temp
33263.043	0.27	0.28	0.24	-0.01	-0.95	-1.534
33593.895	600.32	600.20	0.36	0.12	-0.95	-1.534
33921.065	1200.35	1200.17	0.43	0.18	-0.95	-1.534
34137.152	1600.37	1600.10	0.51	0.27	-0.94	-1.534
34458.414	2200.41	2200.13	0.52	0.28	-0.94	-1.533
34670.676	2600.42	2600.14	0.52	0.28	-0.94	-1.534
34986.292	3200.45	3200.20	0.49	0.25	-0.94	-1.534
35505.085	4200.46	4200.29	0.41	0.17	-0.94	-1.534
36015.154	5200.48	5200.32	0.40	0.16	-0.94	-1.534
36516.921	6200.47	6200.38	0.32	0.09	-0.94	-1.534
36912.545	7000.44	7000.36	0.32	0.08	-0.94	-1.534
36517.025	6200.46	6200.59	0.11	-0.13	-0.94	-1.534
36015.357	5200.47	5200.72	-0.01	-0.25	-0.95	-1.534
35505.299	4200.47	4200.71	0.01	-0.23	-0.95	-1.534
34986.548	3200.46	3200.69	0.01	-0.23	-0.95	-1.534
34670.933	2600.43	2600.64	0.03	-0.21	-0.95	-1.534
34458.668	2200.41	2200.61	0.04	-0.21	-0.96	-1.534

Sensor Output	Standard	Sensor New_Coefs	Standard-Sensor Prev_Coefs	Standard-Sensor NEW_Coefs	Sensor_Temp	Bath_Temp
34137.408	1600.37	1600.59	0.03	-0.22	-0.96	-1.534
33921.264	1200.35	1200.54	0.05	-0.19	-0.96	-1.534
33594.070	600.32	600.52	0.04	-0.20	-0.96	-1.534
33265.258	0.27	0.25	0.21	0.02	6.94	6.471
33596.168	600.30	600.22	0.28	0.09	6.94	6.471
33923.385	1200.32	1200.21	0.29	0.11	6.94	6.471
34139.516	1600.33	1600.18	0.33	0.15	6.96	6.471
34460.798	2200.35	2200.19	0.34	0.17	6.96	6.471
34673.075	2600.36	2600.19	0.35	0.17	6.97	6.470
34988.711	3200.37	3200.22	0.33	0.16	6.99	6.471
35507.524	4200.36	4200.25	0.28	0.11	6.99	6.471
36017.634	5200.34	5200.26	0.24	0.08	6.99	6.471
36519.417	6200.30	6200.26	0.20	0.04	6.99	6.470
36017.736	5200.34	5200.46	0.04	-0.12	6.99	6.470
35507.672	4200.35	4200.53	-0.01	-0.18	7.00	6.470
34988.878	3200.37	3200.53	0.01	-0.16	7.01	6.471
34673.244	2600.35	2600.49	0.04	-0.14	7.01	6.471
34460.965	2200.34	2200.47	0.05	-0.13	7.01	6.470
34139.675	1600.33	1600.45	0.05	-0.13	7.01	6.470
33923.532	1200.31	1200.45	0.05	-0.13	7.01	6.471
33596.287	600.30	600.40	0.09	-0.10	7.01	6.471
33267.234	0.27	0.23	0.15	0.04	17.24	16.481
33598.204	600.31	600.22	0.19	0.09	17.24	16.481
33925.473	1200.34	1200.23	0.20	0.11	17.24	16.481
34141.639	1600.36	1600.22	0.22	0.13	17.24	16.481
34462.971	2200.38	2200.24	0.22	0.14	17.24	16.481
34675.283	2600.40	2600.26	0.21	0.14	17.24	16.481
34990.966	3200.43	3200.30	0.18	0.13	17.24	16.481
35509.859	4200.44	4200.36	0.11	0.08	17.24	16.481
36020.045	5200.43	5200.39	0.06	0.04	17.24	16.481
35509.954	4200.43	4200.54	-0.07	-0.11	17.24	16.481
34991.093	3200.43	3200.55	-0.06	-0.11	17.24	16.481
34675.423	2600.41	2600.52	-0.05	-0.12	17.24	16.481
34463.109	2200.39	2200.50	-0.04	-0.11	17.24	16.481
34141.793	1600.36	1600.51	-0.07	-0.16	17.23	16.481
33925.616	1200.34	1200.50	-0.07	-0.16	17.24	16.481
33598.319	600.32	600.43	-0.01	-0.12	17.23	16.481
33268.281	0.27	0.18	0.26	0.09	29.84	28.988
33599.337	600.32	600.21	0.24	0.11	29.85	28.988
33926.662	1200.35	1200.21	0.25	0.14	29.85	28.988
34142.864	1600.38	1600.19	0.27	0.18	29.85	28.988
34464.268	2200.41	2200.24	0.24	0.17	29.85	28.988
34676.650	2600.42	2600.31	0.16	0.11	29.85	28.988
34992.410	3200.46	3200.39	0.08	0.07	29.85	28.988
35511.426	4200.48	4200.51	-0.05	-0.03	29.85	28.988

Sensor Output	Standard	Sensor New_Coefs	Standard-Sensor Prev_Coefs	Standard-Sensor NEW_Coefs	Sensor_Temp	Bath_Temp
34992.495	3200.46	3200.56	-0.08	-0.09	29.84	28.989
34676.770	2600.43	2600.54	-0.07	-0.11	29.84	28.989
34464.420	2200.41	2200.52	-0.05	-0.11	29.84	28.988
34143.026	1600.38	1600.50	-0.03	-0.12	29.84	28.988
33926.827	1200.35	1200.52	-0.06	-0.17	29.84	28.988
33599.486	600.32	600.48	-0.03	-0.16	29.84	28.988
33268.375	0.27	0.35	0.08	-0.08	29.84	28.989



Pressure Calibration Report
STS Calibration Facility

SENSOR SERIAL NUMBER: 0830
CALIBRATION DATE: 10-JAN-2019
Mfg: SEABIRD Model: 09P CTD Prs s/n: 99676

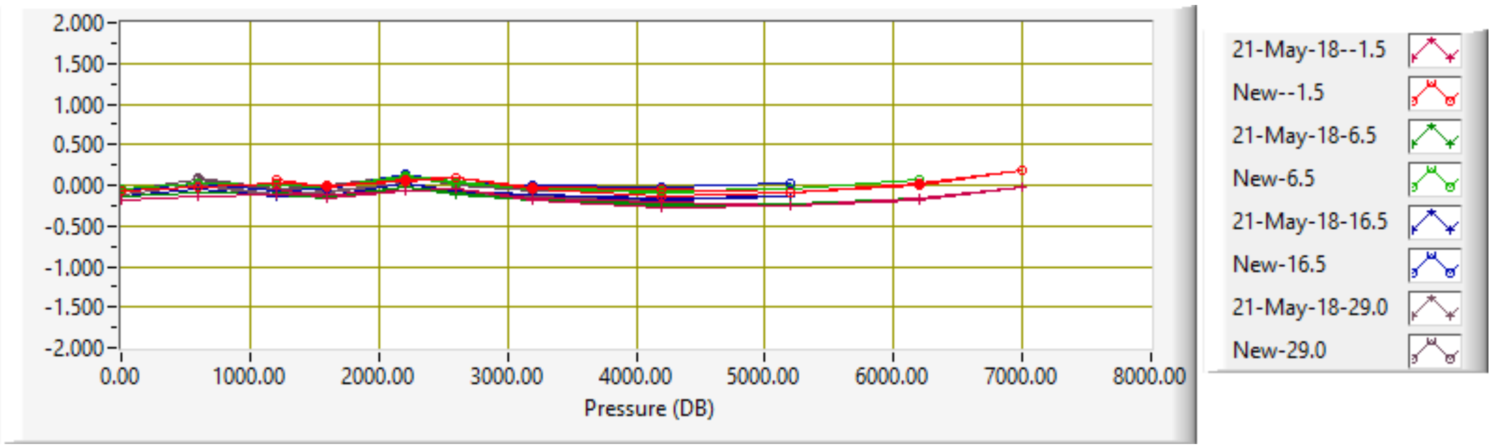
C1= -4.071254E+4
C2= -6.881146E-1
C3= 1.013208E-2
D1= 3.156099E-2
D2= 0.000000E+0
T1= 3.008941E+1
T2= -5.608424E-4
T3= 4.428700E-6
T4= -5.164714E-9
T5= 0.000000E+0
AD590M= 1.29036E-2
AD590B= -8.20188E+0
Slope = 1.00000000E+0
Offset = 0.00000000E+0

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	Standard	Sensor New_Coefs	Standard-Sensor Prev_Coefs	Standard-Sensor NEW_Coefs	Sensor_Temp	Bath_Temp
33239.765	0.27	0.34	-0.19	-0.08	-1.16	-1.534
33592.764	600.32	600.34	-0.14	-0.02	-1.16	-1.534
33941.622	1200.35	1200.33	-0.11	0.01	-1.16	-1.534
34171.986	1600.37	1600.37	-0.12	-0.00	-1.16	-1.534
34514.219	2200.41	2200.35	-0.07	0.06	-1.16	-1.533
34740.253	2600.42	2600.34	-0.05	0.08	-1.16	-1.534
35076.298	3200.45	3200.50	-0.18	-0.04	-1.16	-1.534
35628.272	4200.46	4200.60	-0.29	-0.14	-1.16	-1.534
36170.562	5200.48	5200.57	-0.25	-0.09	-1.16	-1.534
36703.647	6200.47	6200.48	-0.19	-0.01	-1.15	-1.534
37123.704	7000.44	7000.26	-0.02	0.18	-1.16	-1.534
36703.628	6200.46	6200.45	-0.17	0.02	-1.16	-1.534
36170.555	5200.47	5200.55	-0.25	-0.08	-1.16	-1.534
35628.232	4200.47	4200.53	-0.20	-0.06	-1.16	-1.534
35076.293	3200.46	3200.49	-0.16	-0.03	-1.16	-1.534
34740.251	2600.43	2600.34	-0.04	0.09	-1.16	-1.534
34514.215	2200.41	2200.34	-0.07	0.06	-1.16	-1.534

Sensor Output	Standard	Sensor New_Coefs	Standard-Sensor Prev_Coefs	Standard-Sensor NEW_Coefs	Sensor_Temp	Bath_Temp
34172.000	1600.37	1600.40	-0.15	-0.03	-1.16	-1.534
33941.588	1200.35	1200.27	-0.05	0.07	-1.16	-1.534
33592.756	600.32	600.33	-0.12	-0.01	-1.16	-1.534
33244.460	0.27	0.31	-0.15	-0.04	6.80	6.471
33597.455	600.30	600.29	-0.09	0.02	6.80	6.471
33946.344	1200.32	1200.32	-0.12	-0.00	6.80	6.471
34176.715	1600.33	1600.36	-0.15	-0.03	6.81	6.471
34518.914	2200.35	2200.25	-0.03	0.10	6.83	6.471
34745.005	2600.36	2600.32	-0.10	0.03	6.83	6.470
35081.020	3200.37	3200.41	-0.19	-0.04	6.83	6.471
35632.971	4200.36	4200.44	-0.25	-0.08	6.83	6.471
36175.276	5200.34	5200.39	-0.24	-0.05	6.85	6.471
36708.350	6200.30	6200.24	-0.16	0.06	6.86	6.470
36175.273	5200.34	5200.38	-0.23	-0.04	6.86	6.470
35632.967	4200.35	4200.41	-0.23	-0.06	6.86	6.470
35081.028	3200.37	3200.40	-0.18	-0.04	6.86	6.471
34745.016	2600.35	2600.32	-0.11	0.03	6.86	6.471
34518.927	2200.34	2200.24	-0.03	0.10	6.86	6.470
34176.731	1600.33	1600.34	-0.14	-0.02	6.86	6.470
33946.361	1200.31	1200.29	-0.09	0.02	6.87	6.471
33597.477	600.30	600.25	-0.06	0.05	6.88	6.471
33249.678	0.27	0.34	-0.13	-0.08	17.09	16.481
33602.679	600.31	600.30	-0.05	0.01	17.10	16.481
33951.626	1200.34	1200.41	-0.14	-0.07	17.10	16.481
34181.978	1600.36	1600.40	-0.13	-0.04	17.10	16.481
34524.178	2200.38	2200.27	0.02	0.11	17.10	16.481
34750.299	2600.40	2600.38	-0.08	0.02	17.11	16.481
35086.310	3200.43	3200.44	-0.12	-0.00	17.11	16.481
35638.291	4200.44	4200.47	-0.17	-0.03	17.11	16.481
36180.605	5200.43	5200.39	-0.13	0.03	17.11	16.481
35638.287	4200.43	4200.47	-0.17	-0.03	17.10	16.481
35086.301	3200.43	3200.43	-0.11	0.01	17.09	16.481
34750.291	2600.41	2600.38	-0.08	0.03	17.09	16.481
34524.167	2200.39	2200.26	0.03	0.13	17.09	16.481
34181.978	1600.36	1600.41	-0.13	-0.05	17.09	16.481
33951.621	1200.34	1200.40	-0.14	-0.06	17.09	16.481
33602.668	600.32	600.29	-0.04	0.03	17.09	16.481
33254.742	0.27	0.33	-0.12	-0.07	29.76	28.988
33607.745	600.32	600.25	0.01	0.07	29.76	28.988
33956.767	1200.35	1200.43	-0.15	-0.08	29.76	28.988
34187.115	1600.38	1600.38	-0.08	-0.00	29.76	28.988
34529.372	2200.41	2200.30	0.02	0.10	29.76	28.988
34755.519	2600.42	2600.43	-0.10	-0.01	29.76	28.988
35091.587	3200.46	3200.53	-0.17	-0.06	29.76	28.988
35643.604	4200.48	4200.54	-0.19	-0.06	29.76	28.988

Sensor Output	Standard	Sensor New_Coefs	Standard-Sensor Prev_Coefs	Standard-Sensor NEW_Coefs	Sensor_Temp	Bath_Temp
35091.569	3200.46	3200.50	-0.14	-0.03	29.76	28.989
34755.503	2600.43	2600.40	-0.07	0.03	29.76	28.989
34529.368	2200.41	2200.30	0.02	0.11	29.76	28.988
34187.109	1600.38	1600.37	-0.07	0.00	29.76	28.988
33956.748	1200.35	1200.40	-0.12	-0.05	29.76	28.988
33607.731	600.32	600.22	0.03	0.10	29.75	28.988
33254.733	0.27	0.32	-0.11	-0.06	29.75	28.989



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SENSOR SERIAL NUMBER: 0197
CALIBRATION DATE: 21-Feb-19

SBE 43 OXYGEN CALIBRATION DATA

COEFFICIENTS:		NOMINAL DYNAMIC COEFFICIENTS	
Soc = 0.7027	B = 4.2608e-004	D1 = 1.92634e-4	H1 = -3.300000e-2
Voffset = -0.7719	C = -4.1978e-006	D2 = -4.64803e-2	H2 = 5.00000e+3
Tau20 = 1.28	E nominal = 0.036		H3 = 1.45000e+3
	A = -1.0210e-002		

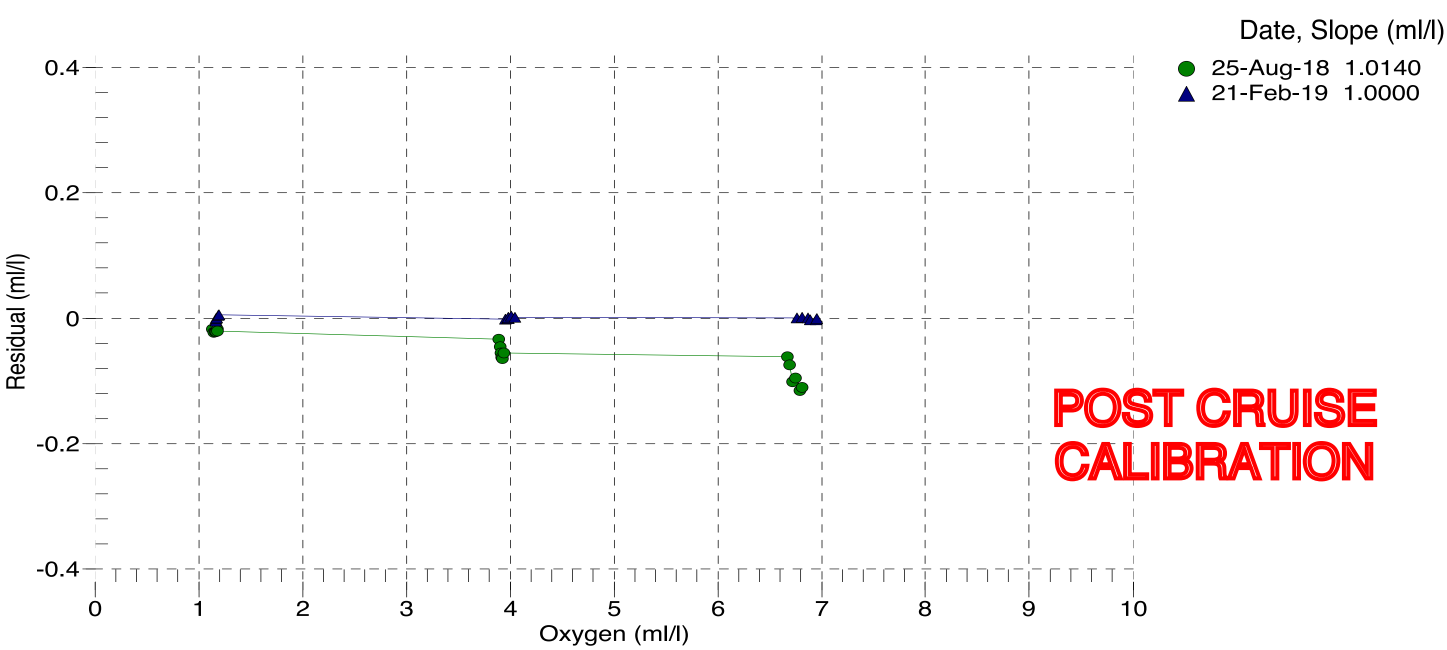
BATH OXYGEN (ml/l)	BATH TEMPERATURE (° C)	BATH SALINITY (PSU)	INSTRUMENT OUTPUT (volts)	INSTRUMENT OXYGEN (ml/l)	RESIDUAL (ml/l)
1.16	2.00	0.00	0.946	1.16	-0.00
1.17	6.00	0.00	0.971	1.16	-0.00
1.17	12.00	0.00	1.009	1.17	-0.00
1.18	20.00	0.00	1.054	1.18	0.00
1.19	26.00	0.00	1.086	1.19	0.00
1.19	30.00	0.00	1.107	1.20	0.01
3.96	2.00	0.00	1.365	3.96	-0.00
3.97	6.00	0.00	1.453	3.97	-0.00
3.98	12.00	0.00	1.578	3.98	-0.00
3.98	20.00	0.00	1.728	3.99	0.00
4.01	26.00	0.00	1.833	4.01	0.00
4.04	30.00	0.00	1.902	4.05	0.00
6.76	2.00	0.00	1.786	6.77	0.00
6.81	6.00	0.00	1.940	6.81	0.00
6.87	12.00	0.00	2.164	6.87	0.00
6.89	20.00	0.00	2.424	6.89	-0.00
6.95	30.00	0.00	2.711	6.95	-0.00
6.95	26.00	0.00	2.609	6.95	-0.00

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

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

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

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



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SENSOR SERIAL NUMBER: 3521
CALIBRATION DATE: 22-Feb-19

SBE 43 OXYGEN CALIBRATION DATA

COEFFICIENTS:
Soc = 0.5383
Voffset = -0.4829
Tau20 = 1.68

A = -4.4808e-003
B = 1.8574e-004
C = -2.5719e-006
E nominal = 0.036

NOMINAL DYNAMIC COEFFICIENTS
D1 = 1.92634e-4
D2 = -4.64803e-2

H1 = -3.300000e-2
H2 = 5.00000e+3
H3 = 1.45000e+3

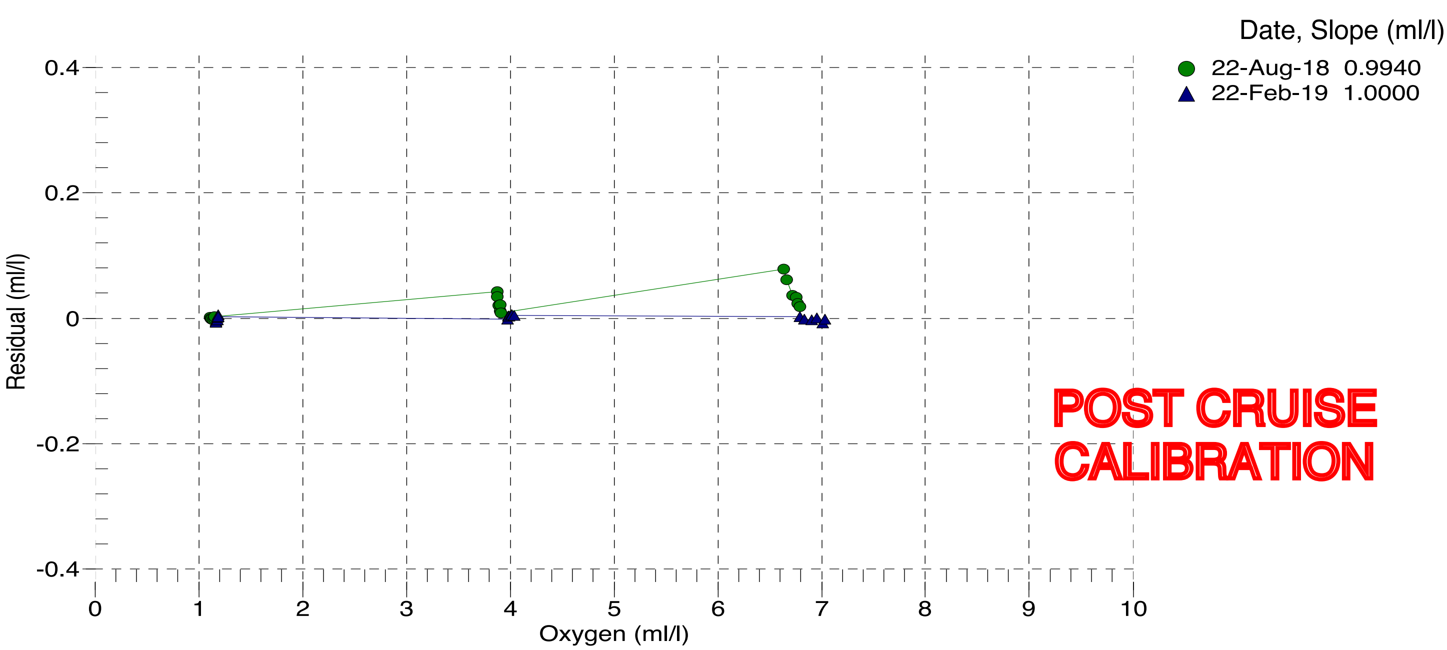
BATH OXYGEN (ml/l)	BATH TEMPERATURE (° C)	BATH SALINITY (PSU)	INSTRUMENT OUTPUT (volts)	INSTRUMENT OXYGEN (ml/l)	RESIDUAL (ml/l)
1.17	6.00	0.00	0.736	1.16	-0.00
1.17	2.00	0.00	0.708	1.16	-0.01
1.18	12.00	0.00	0.782	1.18	-0.00
1.18	20.00	0.00	0.840	1.18	0.00
1.19	30.00	0.00	0.919	1.20	0.01
1.19	26.00	0.00	0.888	1.19	0.00
3.97	2.00	0.00	1.252	3.97	-0.00
3.98	6.00	0.00	1.351	3.98	0.00
3.99	12.01	0.00	1.499	3.99	0.00
4.01	20.00	0.00	1.700	4.02	0.01
4.01	26.00	0.00	1.848	4.02	0.01
4.04	30.00	0.00	1.956	4.04	0.00
6.79	2.00	0.00	1.797	6.79	0.00
6.83	6.00	0.00	1.971	6.83	-0.00
6.91	12.03	0.00	2.240	6.90	-0.00
6.95	20.00	0.00	2.589	6.95	0.00
7.01	26.02	0.00	2.862	7.01	-0.01
7.03	30.00	0.00	3.045	7.03	-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



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SENSOR SERIAL NUMBER: 2818
CALIBRATION DATE: 27-Feb-19

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

COEFFICIENTS:

```
g =   -1.02057891e+001
h =    1.39840972e+000
i =    4.29914931e-004
j =    5.57631793e-005

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

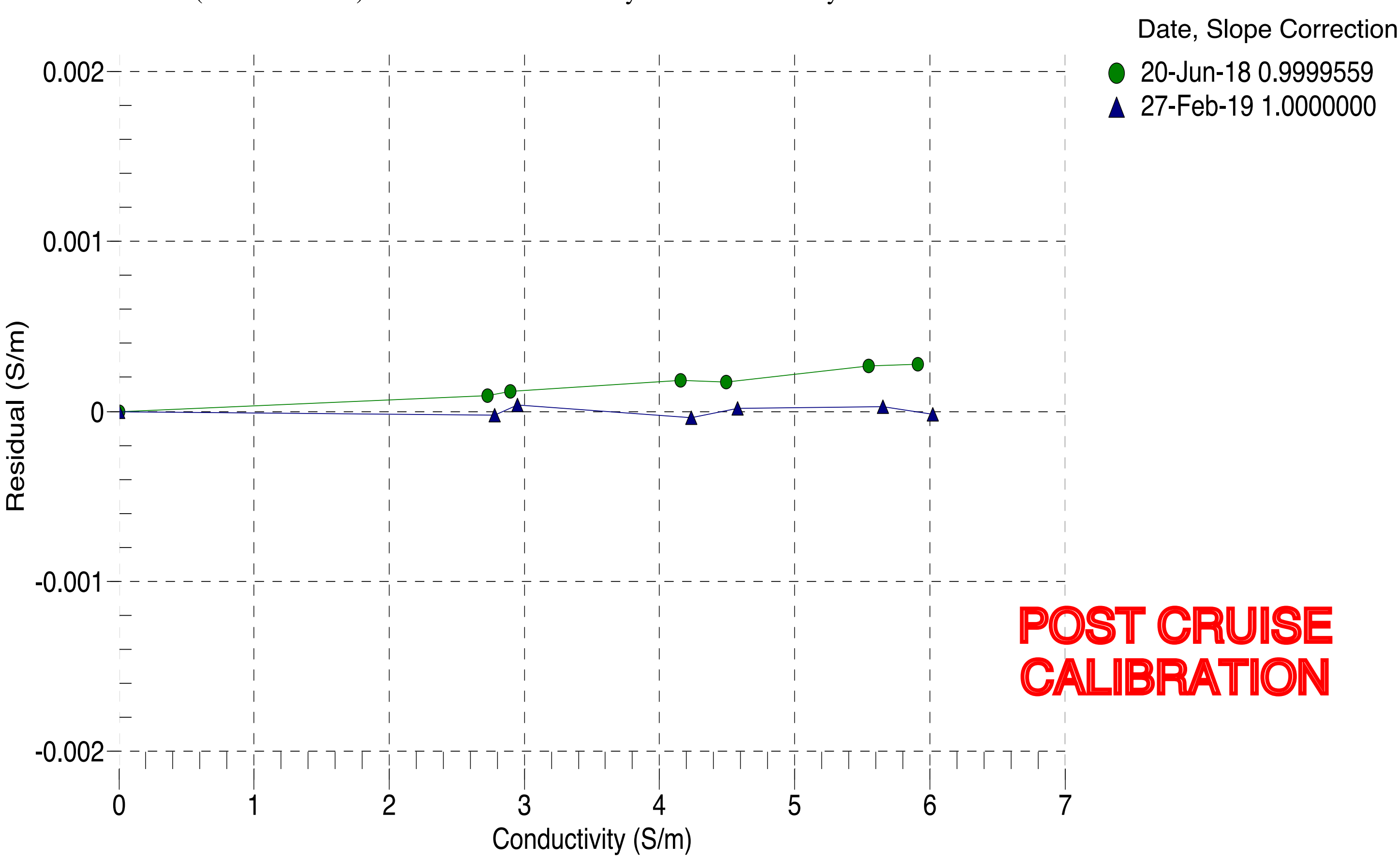
BATH TEMP (° C)	BATH SAL (PSU)	BATH COND (S/m)	INSTRUMENT OUTPUT (kHz)	INSTRUMENT COND (S/m)	RESIDUAL (S/m)
0.0000	0.0000	0.00000	2.69999	0.00000	0.00000
-1.0001	34.4960	2.78116	5.20703	2.78113	-0.00002
0.9999	34.4948	2.95108	5.32196	2.95112	0.00004
15.0000	34.4931	4.23614	6.12090	4.23610	-0.00004
18.5000	34.4913	4.57988	6.31742	4.57990	0.00002
29.0000	34.4850	5.65413	6.89520	5.65416	0.00003
32.5000	34.4734	6.02292	7.08257	6.02290	-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



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SENSOR SERIAL NUMBER: 2659
CALIBRATION DATE: 01-Jun-18

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

COEFFICIENTS:

```
g =  -9.74805118e+000
h =   1.18346247e+000
i =  -2.95638100e-004
j =   6.57176492e-005

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

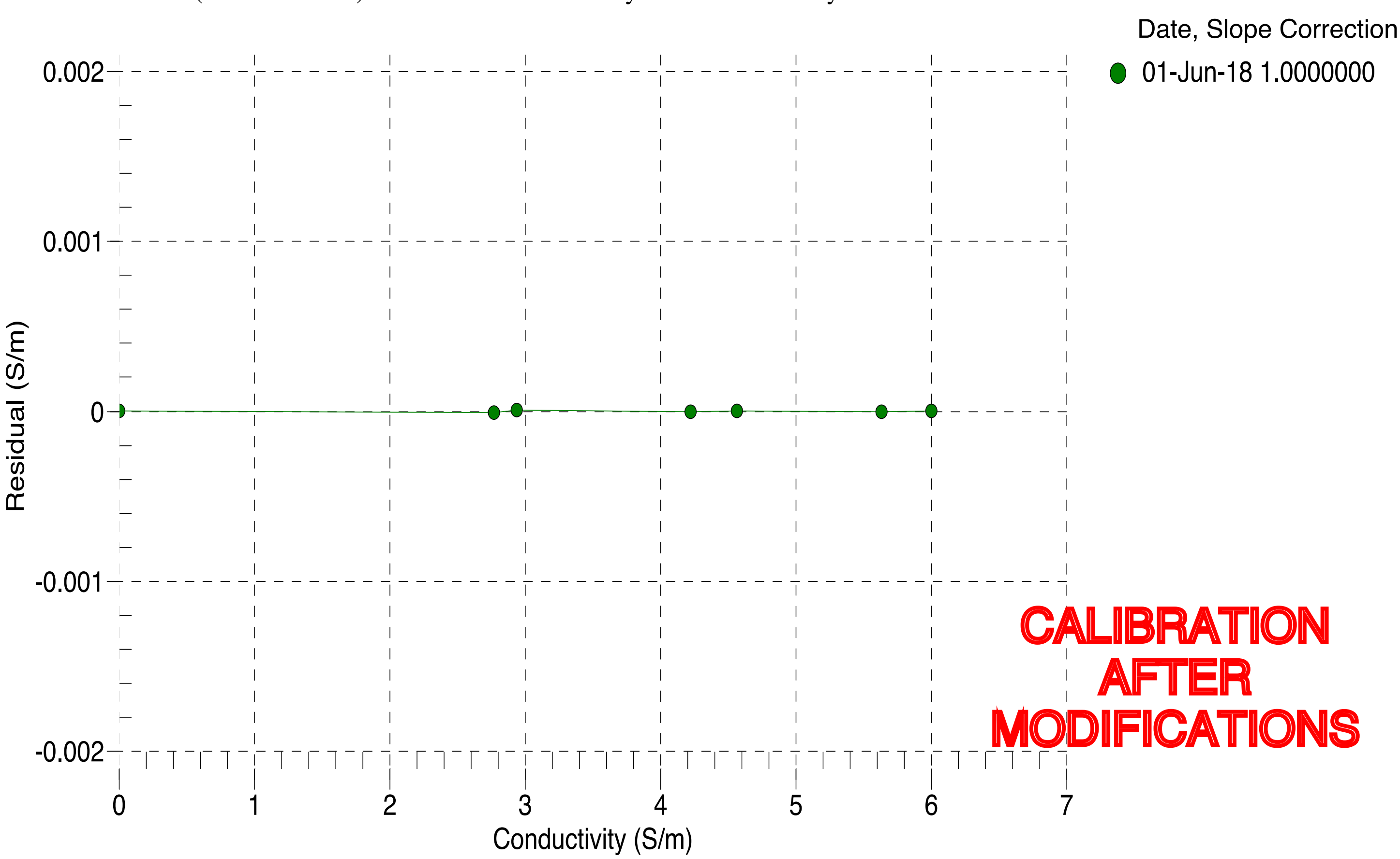
BATH TEMP (° C)	BATH SAL (PSU)	BATH COND (S/m)	INSTRUMENT OUTPUT (kHz)	INSTRUMENT COND (S/m)	RESIDUAL (S/m)
0.0000	0.0000	0.00000	2.87037	0.00000	0.00000
-1.0001	34.3728	2.77215	5.62580	2.77214	-0.00001
1.0000	34.3732	2.94167	5.75155	2.94168	0.00001
14.9999	34.3728	4.22291	6.62472	4.22291	-0.00000
18.5000	34.3718	4.56572	6.83937	4.56572	0.00000
29.0000	34.3653	5.63670	7.47004	5.63670	-0.00000
32.4999	34.3515	6.00402	7.67432	6.00402	0.00000

f = Instrument Output (kHz)

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

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

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



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SENSOR SERIAL NUMBER: 2319
CALIBRATION DATE: 27-Feb-19

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

COEFFICIENTS:

```
g =  -1.04151078e+001
h =   1.51411415e+000
i =  -4.18289952e-004
j =   1.13946323e-004

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

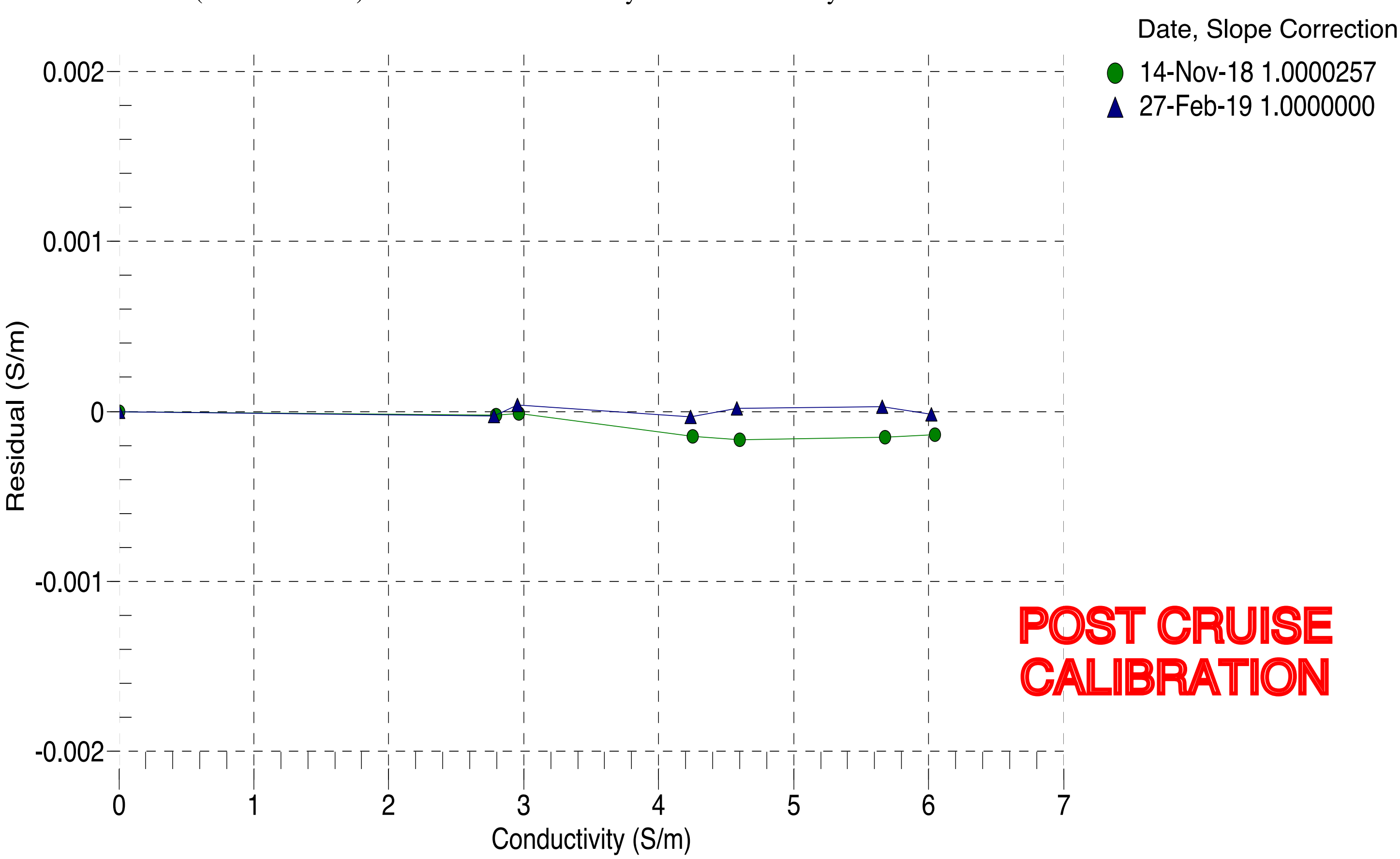
BATH TEMP (° C)	BATH SAL (PSU)	BATH COND (S/m)	INSTRUMENT OUTPUT (kHz)	INSTRUMENT COND (S/m)	RESIDUAL (S/m)
0.0000	0.0000	0.00000	2.62300	0.00000	0.00000
-1.0001	34.4960	2.78116	5.02332	2.78113	-0.00003
0.9999	34.4948	2.95108	5.13367	2.95112	0.00004
15.0000	34.4931	4.23614	5.90110	4.23610	-0.00003
18.5000	34.4913	4.57988	6.08994	4.57990	0.00002
29.0000	34.4850	5.65413	6.64526	5.65416	0.00003
32.5000	34.4734	6.02292	6.82538	6.02290	-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



POST CRUISE CALIBRATION

Temperature Calibration Report
STS Calibration Facility

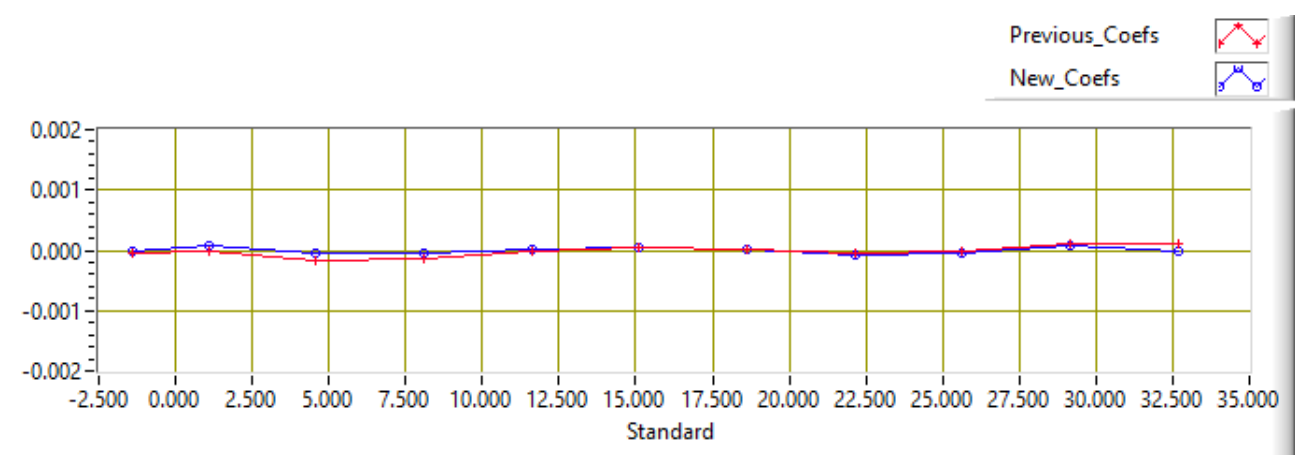
SENSOR SERIAL NUMBER: 0105
CALIBRATION DATE: 04-Mar-2019
Mfg: SEABIRD Model: 35
Previous cal: 29-Aug-18
Calibration Tech: CAL

ITS-90_COEFFICIENTS
a0 = 5.921489433E-3
a1 = -1.661897735E-3
a2 = 2.351748134E-4
a3 = -1.287474061E-5
a4 = 2.691712738E-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
920470.0482	-1.4127	-1.4127	-0.00006	-0.00003
823375.6818	1.0847	1.0846	-0.00003	0.00008
705619.7740	4.5916	4.5917	-0.00018	-0.00005
606269.5237	8.0993	8.0994	-0.00014	-0.00004
522235.5299	11.6094	11.6094	-0.00002	0.00002
451208.0674	15.1108	15.1108	0.00004	0.00005
390701.1883	18.6230	18.6229	0.00003	0.00002
339233.7454	22.1328	22.1329	-0.00006	-0.00007
295300.4338	25.6443	25.6444	-0.00003	-0.00004
257744.9889	29.1535	29.1534	0.00011	0.00008
225506.1253	32.6661	32.6661	0.00011	-0.00003



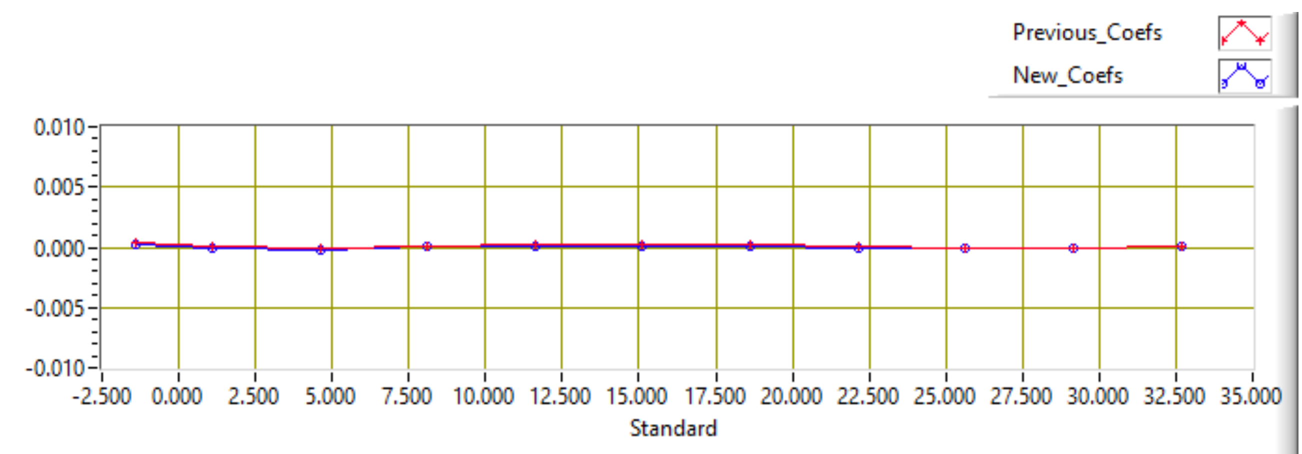
Temperature Calibration Report
STS Calibration Facility

SENSOR SERIAL NUMBER: 5844
CALIBRATION DATE: 11-Feb-2019
Mfg: SEABIRD   Model: 03
Previous cal: 22-Aug-18
Calibration Tech: CAL

ITS-90_COEFFICIENTS	IPTS-68_COEFFICIENTS ITS-T90	
g = 4.36555702E-3	a = 4.36575808E-3	
h = 6.30030565E-4	b = 6.30238331E-4	
i = 2.00794160E-5	c = 2.01103820E-5	
j = 1.50503934E-6	d = 1.50638442E-6	
f0 = 1000.0	Slope = 1.0	Offset = 0.0

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

SBE3 Freq	SPRT ITS-T90	SBE3 ITS-T90	SPRT-SBE3 OLD_Coefs	SPRT-SBE3 NEW_Coefs
3079.9071	-1.4182	-1.4184	0.00046	0.00017
3260.5884	1.0867	1.0868	0.00008	-0.00014
3526.3126	4.5938	4.5940	-0.00007	-0.00021
3807.4353	8.1022	8.1022	0.00014	0.00003
4104.4831	11.6121	11.6121	0.00017	0.00008
4416.9426	15.1133	15.1131	0.00022	0.00013
4746.9501	18.6245	18.6244	0.00018	0.00008
5093.6792	22.1321	22.1322	0.00004	-0.00005
5458.3609	25.6446	25.6447	-0.00004	-0.00012
5840.5159	29.1534	29.1535	-0.00007	-0.00011
6241.2069	32.6651	32.6650	0.00009	0.00012



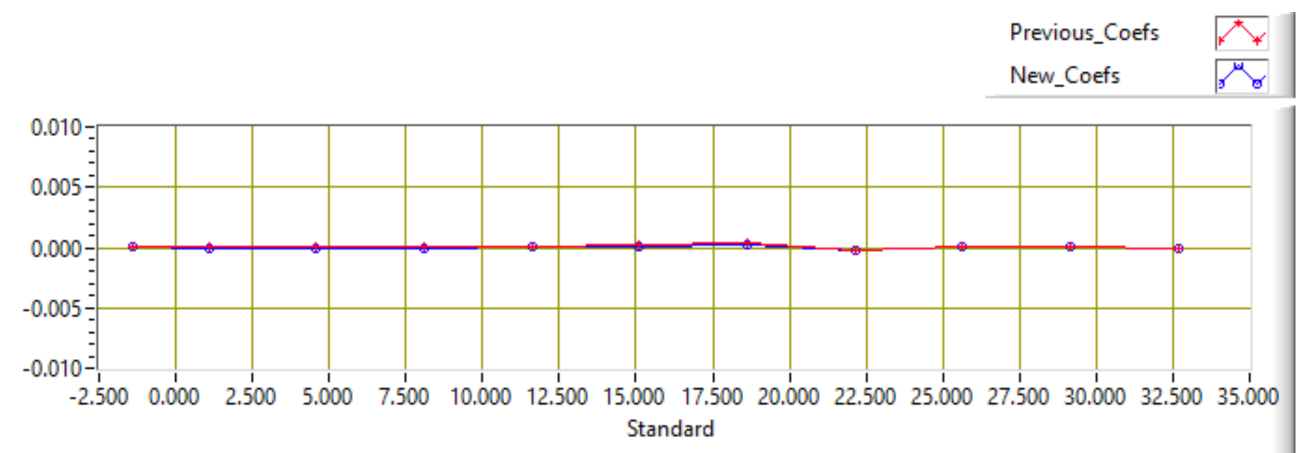
Temperature Calibration Report
STS Calibration Facility

SENSOR SERIAL NUMBER: 2380
CALIBRATION DATE: 12-Feb-2019
Mfg: SEABIRD   Model: 03
Previous cal: 02-Jul-18
Calibration Tech: CAL

ITS-90_COEFFICIENTS	IPTS-68_COEFFICIENTS ITS-T90	
g = 4.34120280E-3	a = 4.34139563E-3	
h = 6.42213468E-4	b = 6.42422652E-4	
i = 2.40474717E-5	c = 2.40799887E-5	
j = 2.31110902E-6	d = 2.31269974E-6	
f0 = 1000.0	Slope = 1.0	Offset = 0.0

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

SBE3 Freq	SPRT ITS-T90	SBE3 ITS-T90	SPRT-SBE3 OLD_Coefs	SPRT-SBE3 NEW_Coefs
2908.5057	-1.4218	-1.4218	0.00011	0.00005
3076.7271	1.0830	1.0830	0.00004	-0.00004
3323.9997	4.5902	4.5902	0.00004	-0.00007
3585.3945	8.0984	8.0984	0.00013	0.00000
3861.4170	11.6088	11.6087	0.00015	0.00002
4151.3728	15.1084	15.1084	0.00017	0.00004
4457.6510	18.6217	18.6215	0.00032	0.00019
4779.2928	22.1319	22.1322	-0.00019	-0.00030
5116.9997	25.6445	25.6444	0.00013	0.00006
5470.8469	29.1556	29.1555	0.00007	0.00004
5841.4151	32.6681	32.6681	-0.00004	-0.00001



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Pressure Test Certificate

Test Date: **2018-11-14**

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

Sensor Information:

Replaced the main piston "O"-Rings.

Model Number: **SBE-5T**

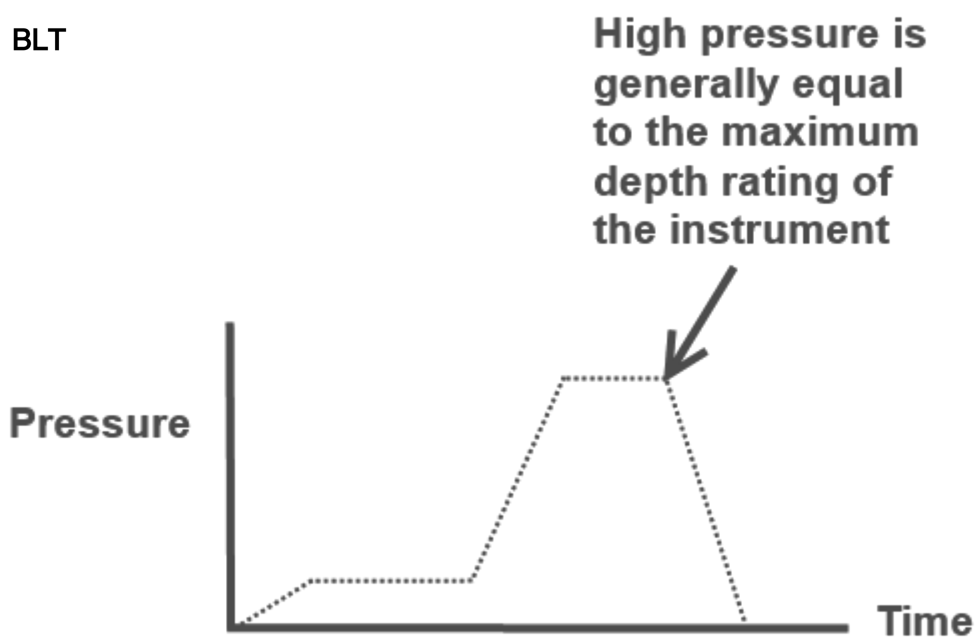
Serial Number: **5124**

Pressure Test Protocol:

Low Pressure Test: **50**	PSI	Held For:	**15**	Minutes
High Pressure Test: **10000**	PSI	Held For:	**30**	Minutes

Passed Test: **True**

Tested By: **BLT**



Typical Test Profile

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Pressure Test Certificate

Test Date: **2018-11-14**

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

Sensor Information:

Model Number: **SBE-5T**

Serial Number: **1892**

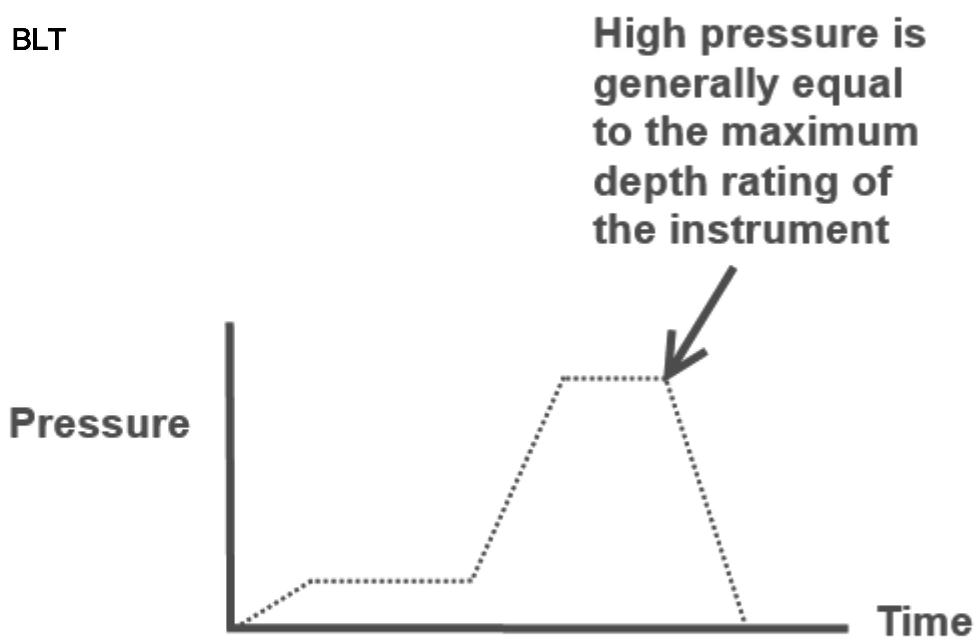
Replaced the main piston "O"-Rings.
Replaced main housing.

Pressure Test Protocol:

Low Pressure Test:	**50**	PSI	Held For: **15**	Minutes
High Pressure Test:	**10000**	PSI	Held For: **30**	Minutes

Passed Test: **True**

Tested By: **BLT**



Typical Test Profile

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

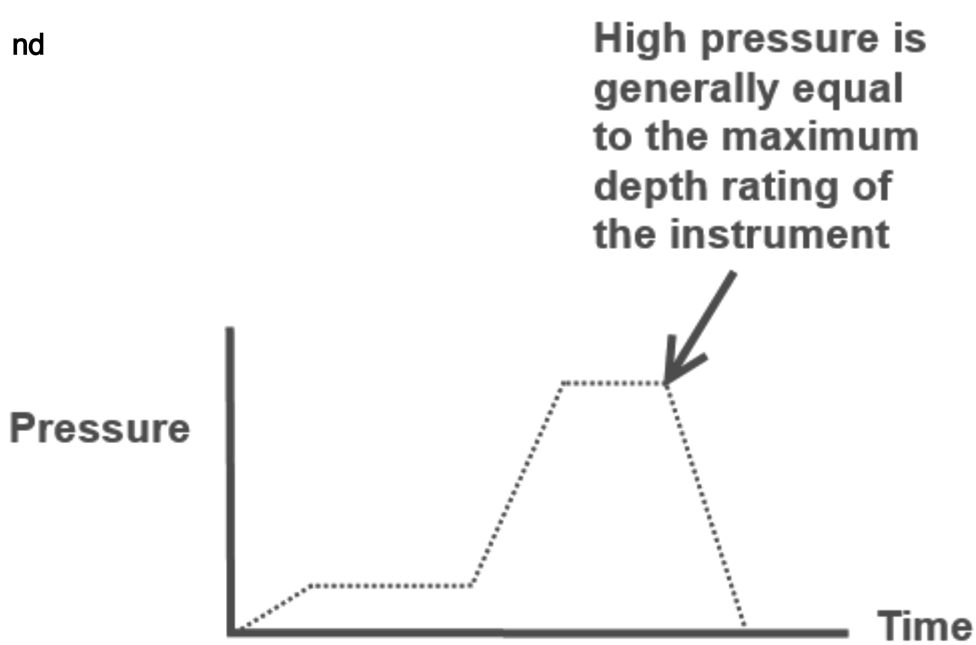
Serial Number: 8692

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



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Pressure Test Certificate

Test Date: **2018-11-14**

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

Sensor Information:

Model Number: **SBE-5T**

Serial Number: **8691**

Replaced the main piston "O"-Rings.
Replaced end cap.

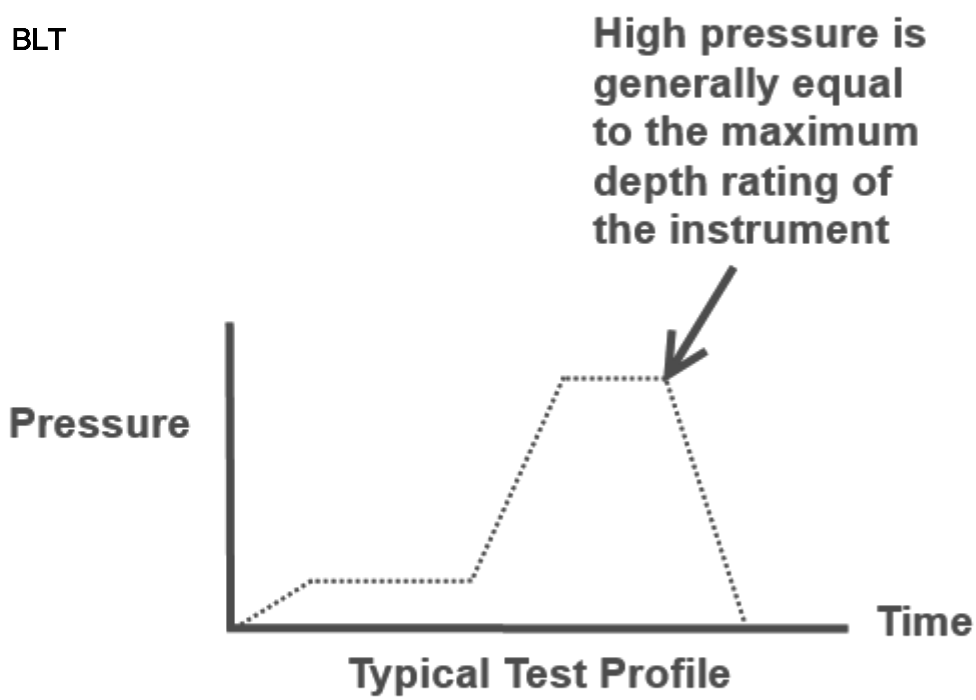
Pressure Test Protocol:

Low Pressure Test: **50** PSI Held For: **15** Minutes

High Pressure Test: **10000** PSI Held For: **30** Minutes

Passed Test: **True**

Tested By: **BLT**



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CCHDO Data Processing Notes

- **File Submission** **Kenneth Jackson**

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