Cruise Report of the 2017 P06E US GO-SHIP Reoccupation

Release Draft 1

Kevin Speer

Nov 20, 2017

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CHAPTER

ONE

GO-SHIP P06E 2017 HYDROGRAPHIC PROGRAM

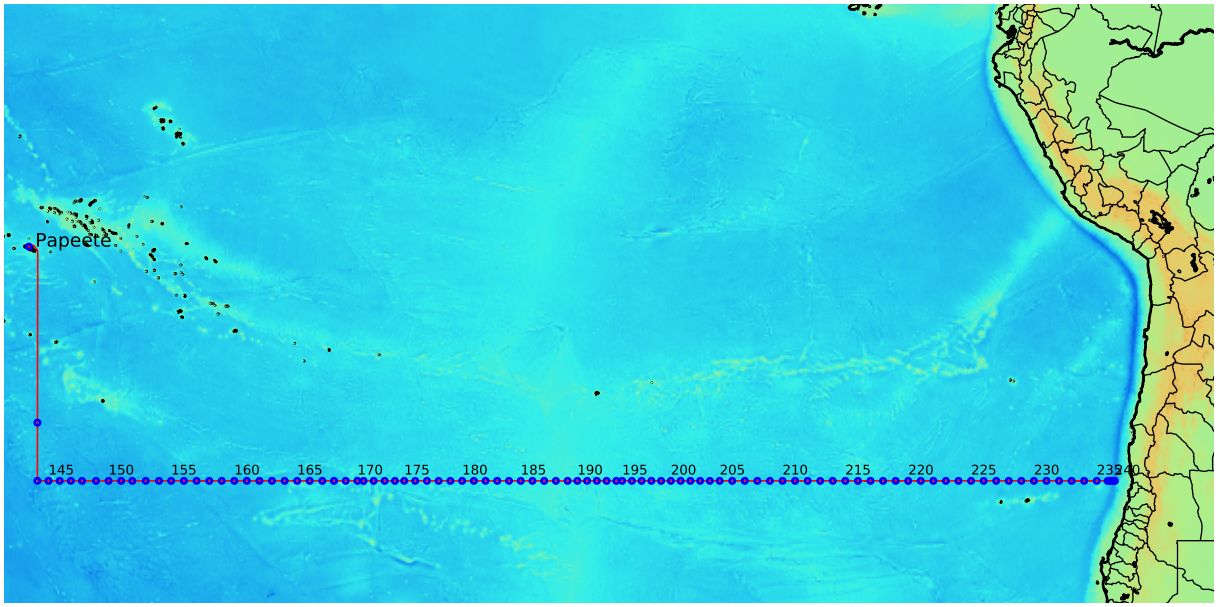

Fig. 1.1: Cruise track of P06E 2017

The Pacific Ocean P06E repeat hydrographic line was reoccupied for the US Global Ocean Carbon and Repeat Hydrography Program. Reoccupation of the P06E transect occurred on the RVIB Nathaniel B Palmer from August 20, 2017 to September 30, 2017. The survey of P06E 2017 consisted of *CTDO*, rosette, *LADCP*, chipod, water samples and underway measurements. The ship departed from the port of Papeete on the island of Tahiti, French Polynesia and completed the cruise in the port of Valparaiso, Chile.

A total of 106 stations were occupied with one CTDO/rosette/LADCP/chipod package. 106 stations and 106 CTDO/rosette/LADCP/chipod casts including 2 test casts were performed. The stations were, for the most part, a reoccupation of P06E 2009 and detailed in the following sections. 31 Argo/O_2 floats were deployed on P06E 2017 and detailed in the *Float Deployments* section of the cruise report. 4 *SOCCOM* floats were deployed on P06E 2017 and are detailed in the *SOCCOM floats* section of the cruise report. 6 drifters were deployed on P06E 2017 and are detailed in the *Drifter Deployments* section of the cruise report.

CTDO data and water samples were collected on each CTDO, rosette, LADCP, and chipod cast, usually within 10 meters of the bottom. Water samples were measured on board for salinity, dissolved oxygen, nutrients, *DIC*, pH, total alkalinity and *CFCs*/*SF6*. Additional water samples were collected and stored for shore analyses of Nitrate δ^{15}N and δ^{18}O, *DOC*/*TDN*, 13C/14C, *POC*, *HPLC*, *DOP*, *DON*, cell counts, *DOP*, *DIP*, *POP*, particulate ATP, and dissolved ATP.

A sea-going science team assembled from 11 different institutions participated in the collection and analysis of this

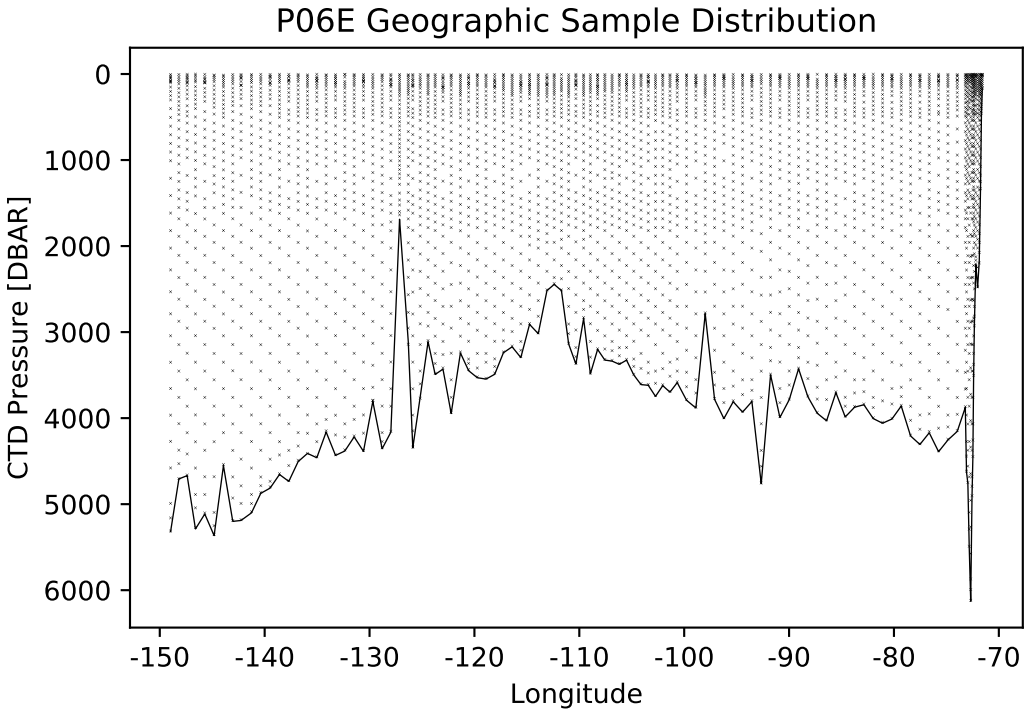

Fig. 1.2: Distribution of samples by longitude.

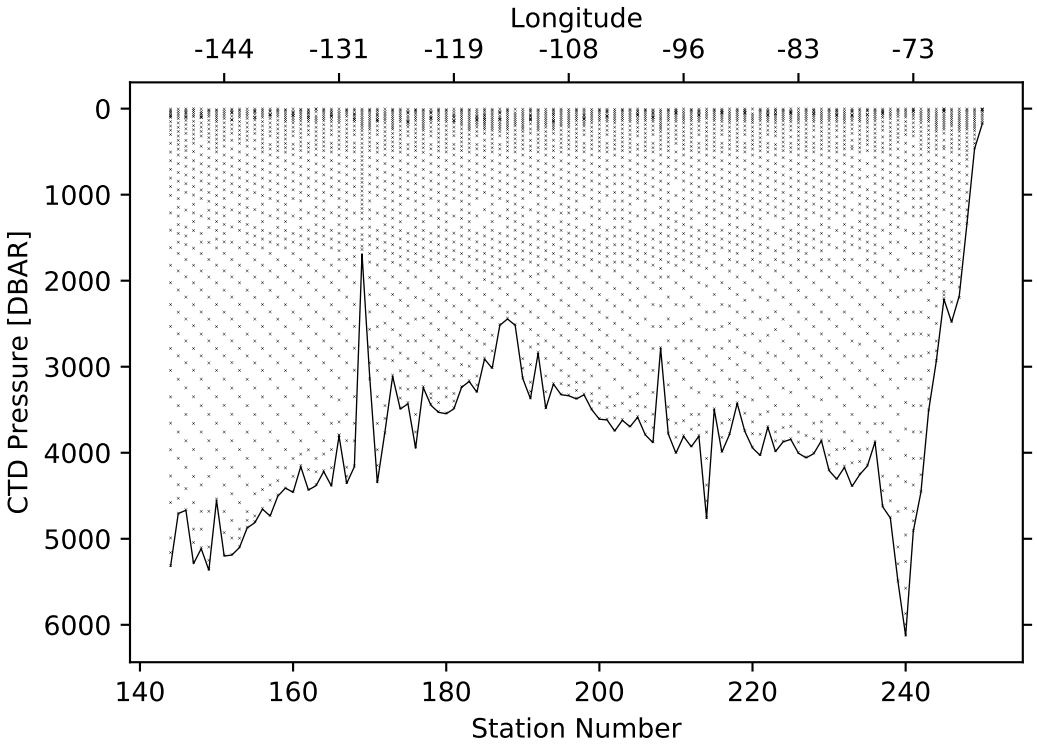

Fig. 1.3: Distribution of samples by station number.

data set. The programs, principal investigators, science team, responsibilities, instrumentation, analysis and analytical methods are outlined in the following cruise document.

1.1 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)	*PMEL*, *AOML*, *NOAA*	Richard Feely, Rik Wanninkhof	Richard.A.Feely@noaa.gov, Rik.Wanninkhof@noaa.gov
Underway Temperature, Salinity, and pCO_2	*AOML*, *NOAA*, *ASC*	Rik Wanninkhof, *ASC*	Rik.Wanninkhof@noaa.gov, admin@nbp.usap.gov
Total Alkalinity, pH	*U Miami*	Frank Millero	fmillero@rsmas.miami.edu
ADCP	*UH*	Eric Firing	efiring@soest.hawaii.edu
LADCP	*LDEO*	Andreas Thurnherr	ant@ldeo.columbia.edu
CFCs, *SF6*	*U Miami*, *UT*	Rana Fine, Dong-Ha Min	rfine@rsmas.miami.edu, dongha@mail.utexas.edu
DOC, *TDN*	*UCSB*	Craig Carlson	carlson@lifesci.ucsb.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
Nitrate $\delta^{15}N$ and $\delta^{18}O$	*Princeton*	Daniel Sigman	sigman@princeton.edu
DON and DOP	*FSU*	Angela Knapp	anknapp@fsu.edu
Cell counts, *DOP*, *DIP*, *POP*, particulate ATP, and dissolved ATP	*U Miami*, *RSMAS*	Kimberly Popendorf	kpopendorf@rsmas.miami.edu
Optical profilers, profiling radiometer and above water radiometer, *POC*, *CDOM*, *DOC*, *TDN*, FlowCAM, Oxygen primary productivity, *HPLC* pigments	*NASA*	Antonio Mannino	antonio.mannino-1@nasa.gov
Argo Floats	*UW*, *UCSD*, *SIO*	Steve Riser, Dean Roemmich, John Gilson	riser@ocean.washington.edu, droemmich@ucsd.edu, jegilson@gmail.com
SOCCOM Floats	*UW*, *UCSD*, *SIO*	Steve Riser, Lynne Talley	riser@ocean.washington.edu, ltalley@ucsd.edu
Surface Drifters	*NOAA*, *AOML*	Shaun Dolk	Shaun.dolk@noaa.gov
Underway Bathymetry and Meteorological Data	*ASC*	*ASC*	admin@nbp.usap.gov

1.2 Science Team and Responsibilities

Duty	Name	Affiliation	Email Address
Chief Scientist	Kevin Speer	*FSU*	kspeer@fsu.edu

Continued on next page

Table 1.1 – continued from previous page

Duty	Name	Affiliation	Email Address
Co-Chief Scientist	Lena Schulze	*FSU*	lschulze@fsu.edu
CTD Watchstander, Nitrate δ^{15}N and δ^{18}O, *DOP*	Dario Marconi	*Princeton*	dmarconi@princeton.edu
CTD Watchstander	Luz Zarate-Jimenez	*TAMU*	luzareli@tamu.edu
CTD Watchstander, Chipods	Sherry Chou	*UH*	wawa.sherry@gmail.com
Chilean Observer, CTD Watchstander	Rudolph Herbstaedt Gomez	*UNAB*	r.herbstaedtgomez@uandresbello.edu
CTD Watchstander	Cristobal Aguilera	*UdeC*	cris.aguilera.bravo.90@gmail.com
Nutrients, *ODF* supervisor, *SOCCOM* floats	Susan Becker	*UCSD ODF*	sbecker@ucsd.edu
Nutrients	David Cervantes	*UCSD ODF*	d1cervantes@ucsd.edu
CTDO Processing, Database Management	Joseph Gum	*UCSD ODF*	jgum@ucsd.edu
Salts	Kenneth Jackson	*UCSD ODF*	k3jackson@ucsd.edu
Salts	Kelsey Vogel	*UCSD STS*	kdvogel@ucsd.edu
Dissolved O_2, Database Management	Andrew Barna	*UCSD ODF*	abarna@ucsd.edu
Dissolved O_2	John Ballard	*UCSD ODF*	jrballard@ucsd.edu
SADCP, *LADCP*, floats and drifters	Elizabeth Simons	*FSU*	egs07d@my.fsu.edu
DIC, underway pCO2	Julian Herndon	*PMEL*	julian.herndon@noaa.gov
DIC	Jackie Long		
CFCs, SF6	David Cooper		davidcooper59@gmail.com
CFCs, SF6	Charlene Grall	*U Miami*	cgrall@rsmas.miami.edu
CFCs, SF6 student	Lucie Knor	*UH*	luciek@hawaii.edu
Total Alkalinity	Ryan Woosley	*U Miami*	rwoosley@rsmas.miami.edu
Total Alkalinity	Fen Huang	*U Miami*	fhuang@rsmas.miami.edu
pH, cell counts, *DOP*, *DIP*, *POP*, particulate ATP, dissolved ATP	Kaycie Lanpher	*U Miami*	klanpher@rsmas.miami.edu
DOC, *TDN*, Radio Carbon	Chance English	*UCSB*	cje@umail.ucsb.edu
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Ocean Optics	Scott Freeman	*NASA*	scott.a.freeman@nasa.gov
Ocean Optics	Michael Novak	*NASA*	michael.novak@nasa.gov
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Marine Technician	Rich Thompson	*ASC*	mt@nbp.usap.gov
Marine Technician	Shannon Zellerhoff	*ASC*	mt@nbp.usap.gov
Marine Technician	Rosemary McGuire	*ASC*	mt@nbp.usap.gov
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Electronic Technician	Julian Race	*ASC*	et@nbp.usap.gov
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Network Administrator	Richard Jeong	*ASC*	admin@nbp.usap.gov

1.3 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 pressure sensor and housing unit with dual exhaust, dual pumps, dual

temperature, a reference temperature, dual conductivity, dissolved oxygen, transmissometer, chlorophyll fluorometer and backscatter meter, oxygen optode, and altimeter. LADCP and chipods 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 vertically 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. The fluorometer, oxygen optode, and altimeters were mounted vertically inside the bottom ring of the rosette frames. The 150 KHz bi-directional Broadband LADCP (RDI) unit was mounted vertically on the bottom side of the frame. 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.

Equipment	Model	S/N	Cal Date	Stations	Responsible Party
Rosette	36-place	Yellow	_	144-250	*STS*/*ODF*
CTD	SBE9+	1281	_	144-250	*STS*/*ODF*
Pressure Sensor	Digiquartz	136428	Apr 10, 2017	144-250	*STS*/*ODF*
Primary Temperature	SBE3+	35844	Apr 11, 2017	144-250	*STS*/*ODF*
Primary Conductivity	SBE4C	43399	Apr 7, 2017	144-250	*STS*/*ODF*
Primary Pump	SBE5	51646	_	144-250	*ASC*
Secondary Temperature	SBE3+	32309	Apr 18, 2017	144-250	*STS*/*ODF*
Secondary Conductivity	SBE4C	42819	Apr 11, 2017	144-250	*STS*/*ODF*
Secondary Pump	SBE5	55644	_	144-250	*ASC*
Transmissometer	Cstar	CST-1803DR	Sep 16, 2016	144-250	*TAMU*
Fluorometer Chlorophyll and Backscatter	WetLabs	FLBBRTD-3698	Sep 23, 2014	144-250	*U Maine*
Primary Dissolved Oxygen	SBE43	431138	July 6, 2017	144-250	*ODF*
Oxygen Optode	RINKO	0297	Apr 7, 2017	144-250	*STS*/*ODF*
Reference Temperature	SBE35	0035	Apr 13, 2017	144-250	*STS*/*ODF*
Carousel	SBE32	1178	_	144-250	*STS*/*ODF*
Altimeter	Valeport 500	51520	_	144-250	*ASC*

The DUSH5 baltic room winch deployment system was successfully used for all stations. The rosette system was suspended from a UNOLS-standard three-conductor 0.322" electro-mechanical sea cable. The sea cable was terminated at the beginning of P06E 2017.

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. LADCP technician would check for LADCP battery charge, prepare instrument for data acquisition and disconnect cables. The chipod battery was monitored for charge and connectors were checked for fouling and connectivity. Every 20 stations, the transmissometer windows were cleaned and an on deck blocked and un-blocked voltage readings were recorded prior to the cast. 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 essentially the reverse of launching. The rosette, CTD and carousel were rinsed with fresh water frequently. CTD maintenance included flushing fresh water through both plumbed sensor lines between casts. The rosette was routinely examined for valves and o-rings leaks, which were maintained as needed.

Some complications were overcome to complete CTDO/rosette/LADCP/chipod station casts for P06E 2017. Storms caused casts to proceed slower than normal, limiting deployment speed to 20 meters per minute for the first 1000 meters on some stations during storms. Adverse weather conditions caused surface bottles (nominal 5 meters) to be fired on the fly, instead of soaking for 30 seconds. Part way through the cruise the LADCP dipped unacceptably low to the rails upon which the rosette was mounted. Different solutions were tried before settling on a set of aluminum skids u-bolted onto the rosette frame to gain clearance for the LADCP. Spare nylon fishing line used for bottle lanyards were also rigged to support the weight of the LADCP. One skid blocked an LADCP head, so the LADCP was rotated in order to have the bad, unusable head pointed at the skid. The other skid was covered in black tape to minimize reflection of light off of the aluminum for the FLBB mounted next to it. The black tape helped until it peeled away, at

which point the data became more noisy.

CHAPTER

TWO

CRUISE NARRATIVE

A hydrographic survey (P06, Leg 2) was conducted in the South Pacific Ocean from 20 August – 30 Sept. 2017 aboard the RV Ice Breaker Nathaniel B. Palmer. Leg 2 is the continuation of Leg 1, which arrived in Papeete, French Polynesia on 17 Aug. 2017. A total of 107 CTD casts, with a 36 bottle rosette, LADCP and other instruments were occupied on a transect running along 32° 30'S, from 148.97 W, almost due south of Papeete, Tahiti, to Valparaiso, Chile.

CTD casts normally went to 10-12 meters above the seafloor. During a few casts, the CTD was stopped slightly higher due to wave action; similarly, some of the "surface" bottles nominally at 5m depth were made at 10m, or, as the console operators became familiar with the process, fired at 5m depth on the fly (only in conditions where the MT would not stop the package at shallow depths). In addition to the (pair of) CTD sensors, two oxygen sensors, upward and downward looking lowered acoustic doppler current profilers (LADCPs), a transmissometer, a fluorometer (including backscatter sensor), Chipods unit, and an altimeter were mounted onto the rosette frame.

Other work was done by the NASA group with 200m optical properties casts and water sampling. Float and drifter deployments continued on Leg 2, with a total of 16 UW Argo floats, 15 SIO Argo floats, 4 SOCCOM floats, and 6 NOAA drifters deployed on Leg 2.

Salinity and dissolved oxygen, nutrients (nitrate, nitrite, phosphate, silicate), total CO_2/TCO_2 (dissolved inorganic carbon/DIC), pH, total alkalinity, and transient tracers (chlorofluorocarbons/CFCs and sulfur hexafluoride/SF_6) were analyzed onboard.

Additional samples were collected for onshore analysis: dissolved organic carbon (DOC), dissolved organic phosphorus (DOP), radiocarbon (δ^{13}C/δ^{14}C), nitrogen and oxygen isotopes of nitrate (δ^{15}N, δ^{18}O), phytoplankton pigment using high performance liquid chromatography (HPLC), and particulate organic carbon (POC).

Underway measurements included GPS navigation, EM 112 multibeam and Knudsen bathymetry, ADCP, meteorological parameters, and sea surface measurements (including temperature, conductivity/salinity, dissolved oxygen, fluorescence, pCO2 and gravity.

2.1 Narrative

The Leg 2 science party assembled in Papeete, Tahiti to meet the ship upon its arrival on August 17, 2017. The primary task for Leg 2 was to complete the transect of CTD/rosette casts beginning at Australia and ending at Chile.

As the equipment and lab supplies were already set up for Leg 1 in Sydney, the amount of preparation required in port for the scientific program was limited to some shipping and receiving and the new activity of the NASA team. Technical work on the Palmer is supported by the Contractor (ASC) and new technicians arrived for Leg 2, including 3 new Marine Technicians for CTD operations. Departure went smoothly, leaving the dock at 1100 on the 20 Aug. 2017. A 4 day steam to the first station on Leg 2 allowed new science crew members time to get their sea legs, adjust to the ship's schedule, take part in safety drills and become familiar with the ship's operations.

A test cast was carried out just outside French EZZ to exercise the system and provide clean water for the chemists. The first station on the line, Stn. 144, was a repeat of the last station of Leg 1, on 24 Aug. NASA operations were tested and programmed for the time slot between local 1000-1400 to catch the high sun angles.

On 25 Aug Stn. 147 waves occasionally entered the Baltic room during the CTD cast. In order to save time, bottle firing stops were aborted about halfway up and Niskins were closed on the fly. While not normal procedure for bottle stops, the impact on sampling and calibration was relatively minor. As a result of wind and waves, on 26 Aug 2017 the ship steamed at 4kn to Stn 148, to re-evaluate situation at 0600, a roughly 12 hour delay. The problem is not simply wave height but cross-chop – waves that appear from an angle to the prevailing direction and enter the Baltic room uninvited. The situation was more manageable at daylight and operations continue in the morning. Early on 1 Sept., CTD ops were again on standby with winds at 40kn and waves of 15-20 ft. Again the decision was made to wait and re- evaluate the situation during the daylight hours. The situation and safety of the CTD package and operators in the Baltic room was regularly evaluated with winds continuing at 20-25 kt with 10-15ft, choppy seas. On 2 Sept. at the 0000 evaluation on bridge, the decision was made to open the Baltic room door at 0545 and check for waves entering the room. With winds and waves down, CTD operations proceeded normally after that.

Over time the LADCP showed some tendency to slip down and touch the railing system put in place to receive the CTD package into the Baltic room. After some iteration, an agreement was reached to attach an aluminum bar with stainless u-bolts to the base of the CTD frame. The fluorometer and altimeter were moved to avoid being blocked. The new arrangement did not result in an increase in the rotation of the package during the casts.

Weather built again 18 Sept., with the occasional waves entering Baltic room. Operations continued, however, with the surface bottle taken on the fly. As on Leg 1, winch speeds were generally slowed in the upper ocean to accommodate wave motion and reduce wire tension.

Up on reaching the Chile Trench on September 26, 2017, station spacing was significantly tighter, between 3.5 – 7.5 nm, to resolve complicated flow and smaller scale chemical property variations along the eastern boundary and in the trench. In total, 15 stations were occupied across the trench and onto the shelf reaching 71.585 W and a water depth of 200m. To allow water samples to be analyzed between stations, a minimum wait time of 2 hours was implemented between each station.

The merging of CTD ops and NASA ops went well due the flexibility of the NASA group on the time of day constraint for the deployment of their instruments. The Baltic room winch performed well, bottle trips and water sampling had essentially no problems, and as a whole the new CTD package was very successful.

Station spacing on Leg 2 ranged from a few miles in the trench, to as much as 45nm. Aside from a limited area above the eastern flank of the EPR, most stations in the interior had a 45nm spacing. This was larger than the spacing on Leg 1, and the previous occupation in 2009/2010. Spacing was increased owing to fewer available days and a longer track compared to leg 1; 41 days were allocated to Leg 2, versus 46 days on Leg 1, and the distance along the line was about 900nm longer on Leg 2 than Leg 1. The number of stations per day actually available for work, obtained by subtracting the steam time along the line, produces a similar rate on both legs (c. 5 stations per day available on the P06 line). Another factor was the enhanced sampling at the eastern boundary. If we had chosen not to do this, and given the time constraints, the interior spacing in the Chile Basin portion of the track could have been reduced somewhat, to about 40 nm. Resolution of the eastern boundary circulation was deemed a higher priority.

Data quality was examined together with the CTD Watchstanders to help the students gain some insight to the measurements made during the cruise. Students were assigned properties and plotted sections and property relations to try to understand the distributions, recognize real ocean features and more subtle differences due to sensor behavior or the various factors involved with chemical analysis, for instance the temperature of the autosal room (which varied with time). No unusual data quality issues were found and the overall quality is very high.

CTD operations ended on Stn. 250 at 0830 29 Sept. 2017, water sampling continued another hour or so; chemical analysis continued through the rest of the day, and packing commenced. NASA carried out a final optical set of casts from 1030-1130 at which point science operations ended (1200 was the final deadline for science operations in order for the ship to prepare for entry to the port). Leg 2 ended at Valparaiso, Chile on 30 Sept. 2017.

2.2 Preliminary Science remarks

P06 was first occupied during WOCE in 1992 over the course of 3 legs, with stops at Easter Island and Tahiti, then again in 2003, and once more in 2009- 2010. Not too far to the north, the SCORPIO section at 28 S also traversed this territory in 1967. Motivated by the potential for climate change effects, GO-SHIP is re-occupying the line 50 years after the SCORPIO expedition to investigate changes in circulation and ocean properties, in particular those related to the carbon system, and to improve sampling where possible and practical.

Leg 2 entered the P6 line over the western flank of the East Pacific Rise (EPR), well to the east of the deep western boundary current system above the Kermadec Trench. Previous analysis of the WOCE P6 line by Wijffels et al (2001) showed broad southward deep and bottom water flow in this region, with little indication of net meridional flow at shallower levels.

A layering of deep water masses was found at the crest of the EPR. We were able to occupy an axial valley station, possibly for the first time on P6, determined to the best of our abilities from Etopo1 bathymetry, and interpreted with the help of our Chilean observer who is a marine geologist. No obvious properties anomalies were evident from the preliminary data, but a distinctive, 200m thick mixed-layer was observed with the characteristics of water found within a nearby fracture zone on the eastern flank. Above the mixed layer, water properties indicate regional western flank water masses, switching back to eastern conditions farther up the water column.

The SCORPIO observations revealed a broad, weak northward flow at 43 S and to a lesser extent at 28 S in the deep water below 2000m depth, above the eastern flank of the EPR. New hints of higher oxygen within the bottom topography might suggest control on the route taken by this flow. Similarly, indications of bottom water flow occurred here and there along the route down the eastern flank.

The eastern South Pacific Ocean shows an extraordinary stacking of salinity and oxygen extrema in the upper 1500m or so. These increase in magnitude toward the east, arising from the combination of biological activity and eastern boundary currents bringing properties both southward and northward along the slope. The termination of the shallow oxygen minimum is rather abrupt, and tentative results suggest a balance between eastward advection and eddy mixing.

2.3 Acknowledgments

The professionalism of the analysis groups enabled steady progress and mutual aid when needed. The CTD Watch-standers did an excellent job, even as their assignments multiplied over the course of the cruise. We extend our sincere thanks to MLT Lindsey Ekern for sampling help. Joaquin Chaves shared his enthusiasm for optical measurements in a science presentation. Thanks also to Jim Swift, Lynne Talley, Tomomi Ushii, Sabine Mecking, and Isa Rosso for pre-cruise help and suggestions. NSF and NOAA are acknowledged for funding provided to the GO-SHIP program. Pre-cruise planning was done in collaboration with ASC (Adam Jenkins and Brad Fabling). ASC was also responsible for marine operations while at sea, and we appreciate the support we received from the Marine Projects Coordinator Ken Vicknair and ASC techs, with the deployment and recovery of the rosette and the repair of the LADCP cable. Captain Brandon Bell (ECO) and the crew helped to maintain smooth vessel operations throughout.

CHAPTER

THREE

CTDO AND HYDROGRAPHIC ANALYSIS

PIs

- Susan Becker
- James Swift

Technicians

- Joseph Gum

3.1 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 10 meters. The CTD sensor pumps were configured to start 10 seconds after the primary conductivity cell reports salt water in the cell. The CWO checked the CTD data for proper sensor operation, waited for sensors to stabilize, and instructed the winch operator to bring the package to the surface in good weather or no more than 5 meters in high seas. The winch was then instructed to lower the package to the initial target wire-out at no more than 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 water.

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

3.2 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 106 CTD stations were occupied including one test station. A total of 106 CTDO/rosette/LADCP/chipod casts were completed. 106 standard CTDO/rosette/LADCP/chipod casts and one test cast completed with a single 36-place (CTD #1281) rosette was used for all station/casts.

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 P06E 2017 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.

3.3 Pressure Analysis

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

The Paroscientific Digiquartz pressure transducer S/N: 831-99677 was calibrated on November 17th, 2015 at the SIO Calibration Facility. 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.

- CTD Serial 1281-99677; Station Set 144 - 250

	Start P (dbar)	End P (dbar)
Min	0.0	-0.1
Max	0.3	0.2
Average	0.2	0.1
Applied Offset		0.1081

An offset of 0.1081 was applied to every cast performed by CTD 1281. On-deck pressure reading for CTD 1281 varied from 0.0 to 0.3 dbar before the casts, and -0.1 to 0.2 dbar after the casts. Before and after average difference was 0.2 and 0.1 dbar respectively. The overall average offset before and after cast was 0.1081 dbar.

3.4 Temperature Analysis

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

The pre-cruise laboratory calibration coefficients were used to convert SBE3plus frequencies to ITS-90 temperature. Additional shipboard calibrations were performed to correct 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.

$$T_{cor} = T + D_1P_2 + D_2P + D_3T_2 + D_4T + \text{Offset}$$

$$T_{90} = T + tp_1P + t_0$$

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

Corrected temperature differences are shown in the following figures.

The 95% confidence limits for the mean low-gradient (values -0.002°C $\leq$ T1-T2 $\leq$ 0.002°C) differences are $\pm$0.0077°C for SBE35RT-T1, $\pm$0.0077°C for SBE35RT-T2 and $\pm$0.0055°C for T1-T2. The 95% confidence limits for the deep temperature residuals (where pressure $\geq$ 2000dbar) are $\pm$0.00081°C for SBE35RT-T1, $\pm$0.00094°C for SBE35RT-T2 and $\pm$0.00079°C for T1-T2.

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

- The SBE35RT sensor memory was partially full, and there are partial data reported for casts on station 148.
- Rough weather caused tripping on the fly for the surface bottle on many stations, leading to some surface SBE35RT averaging periods out of the water.

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

3.5 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.

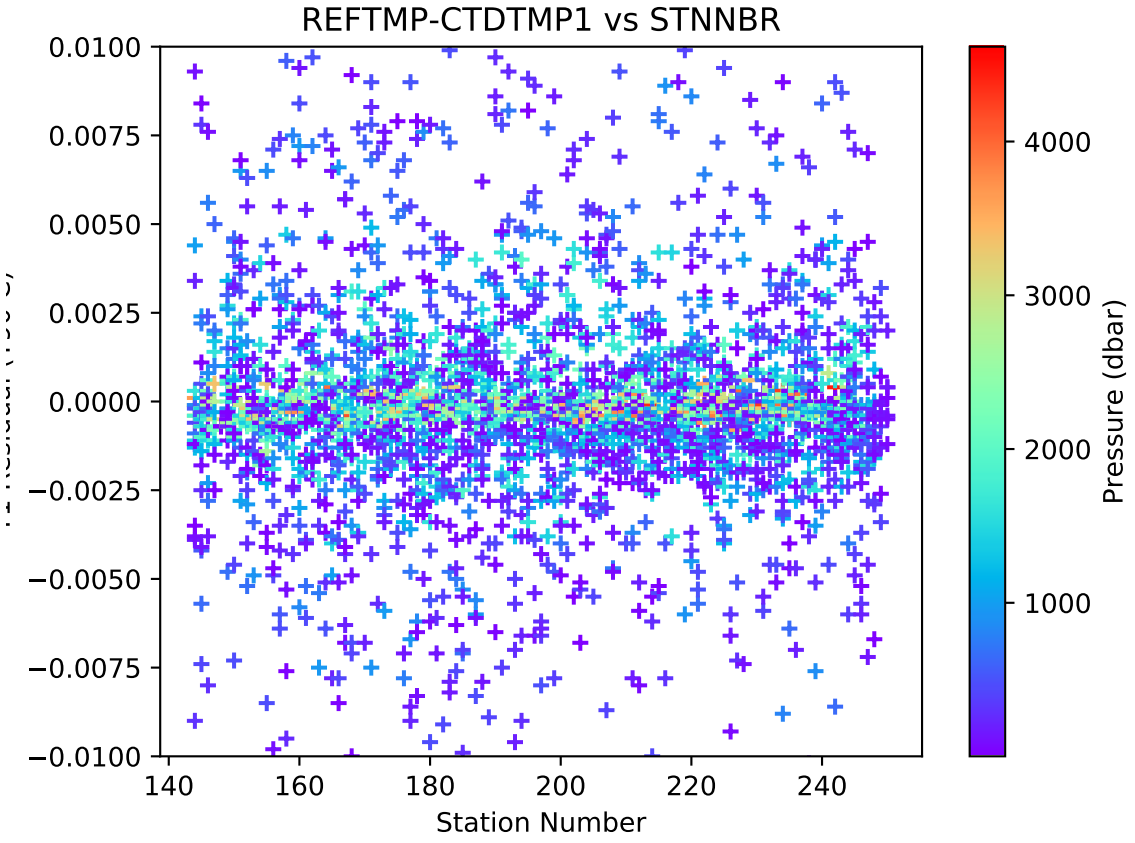


Fig. 3.1: SBE35RT-T1 by station (-0.002°C $\leq$ T1-T2 $\leq$ 0.002°C).

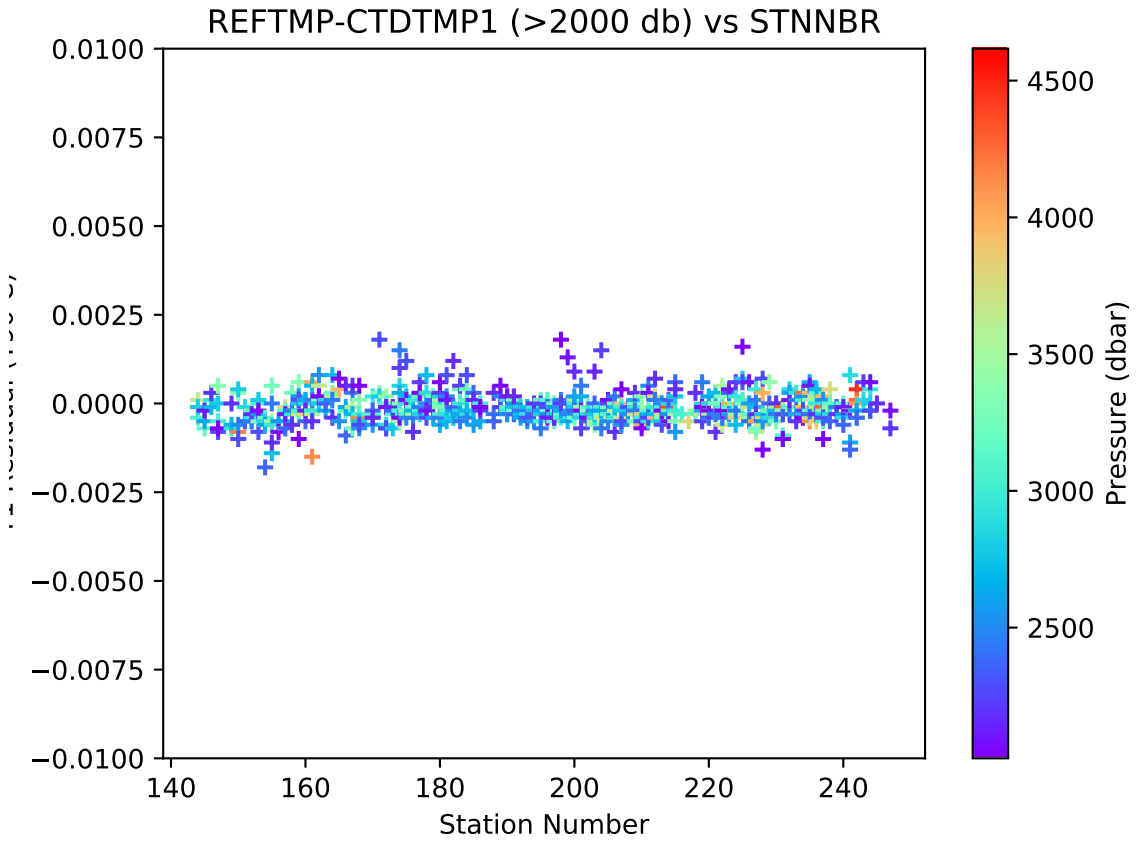


Fig. 3.2: Deep SBE35RT-T1 by station (Pressure $\geq$ 2000dbar).

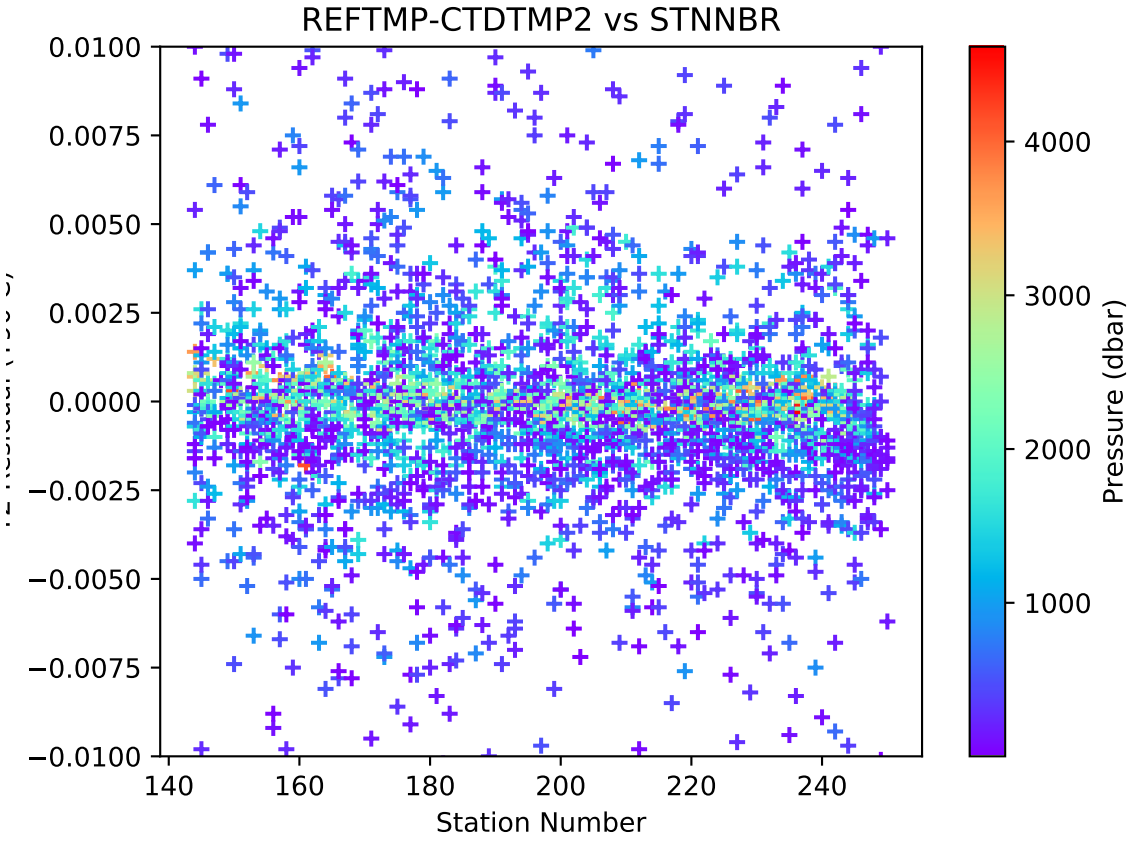


Fig. 3.3: SBE35RT-T2 by station (-0.002°C $\leq$ T1-T2 $\leq$ 0.002°C).

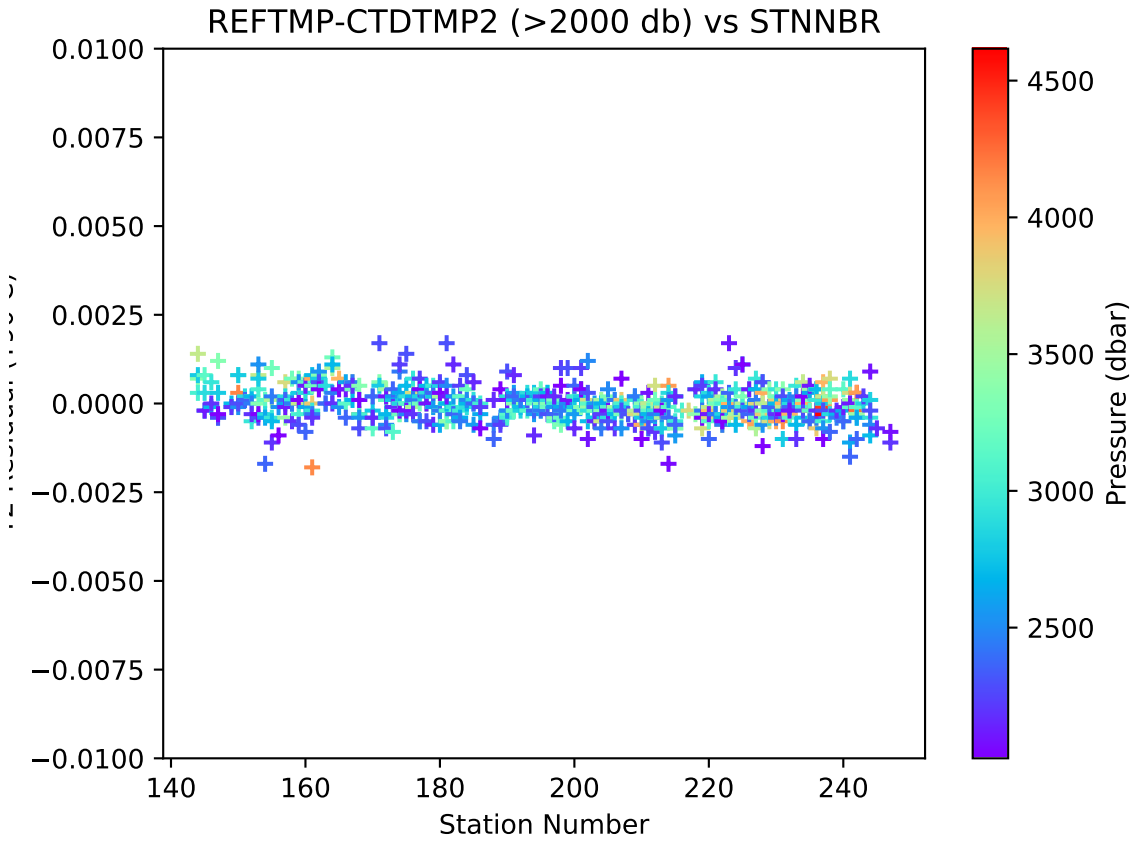


Fig. 3.4: Deep SBE35RT-T2 by station (Pressure $\geq$ 2000dbar).

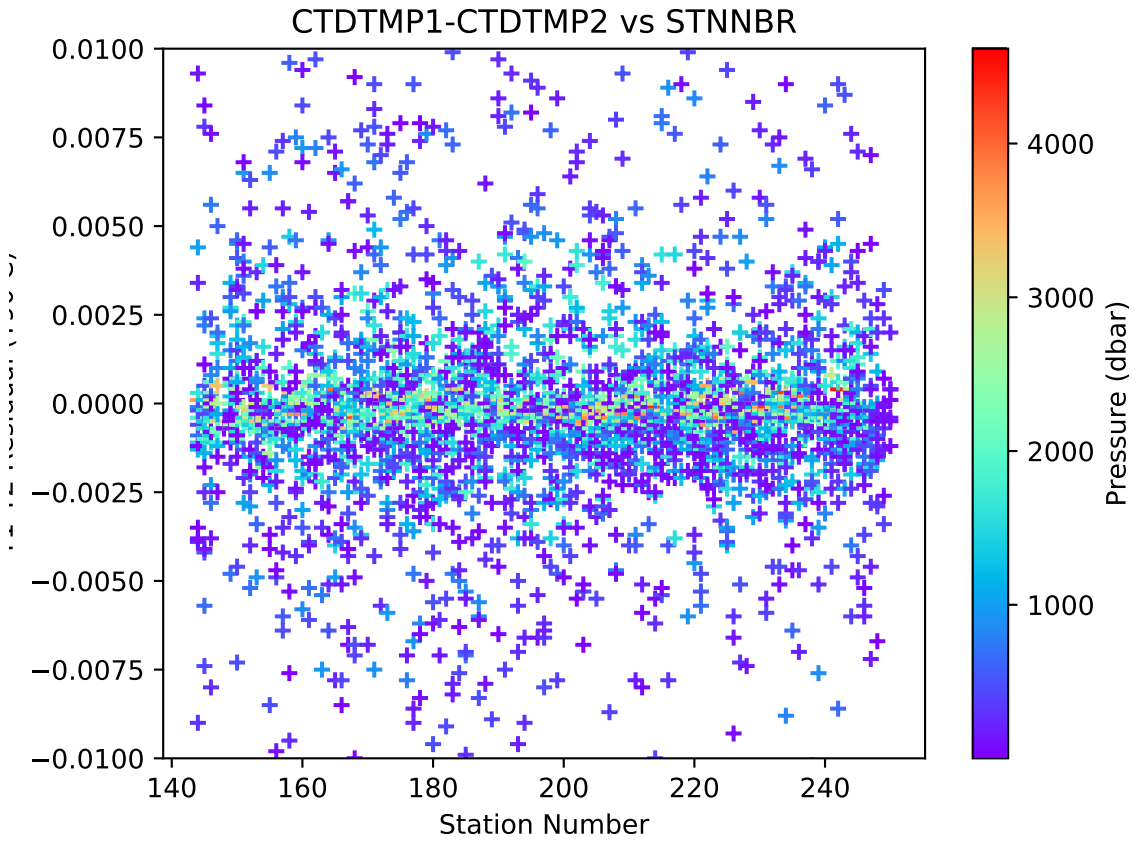


Fig. 3.5: T1-T2 by station (-0.002°C $\leq$ T1-T2 $\leq$ 0.002°C).

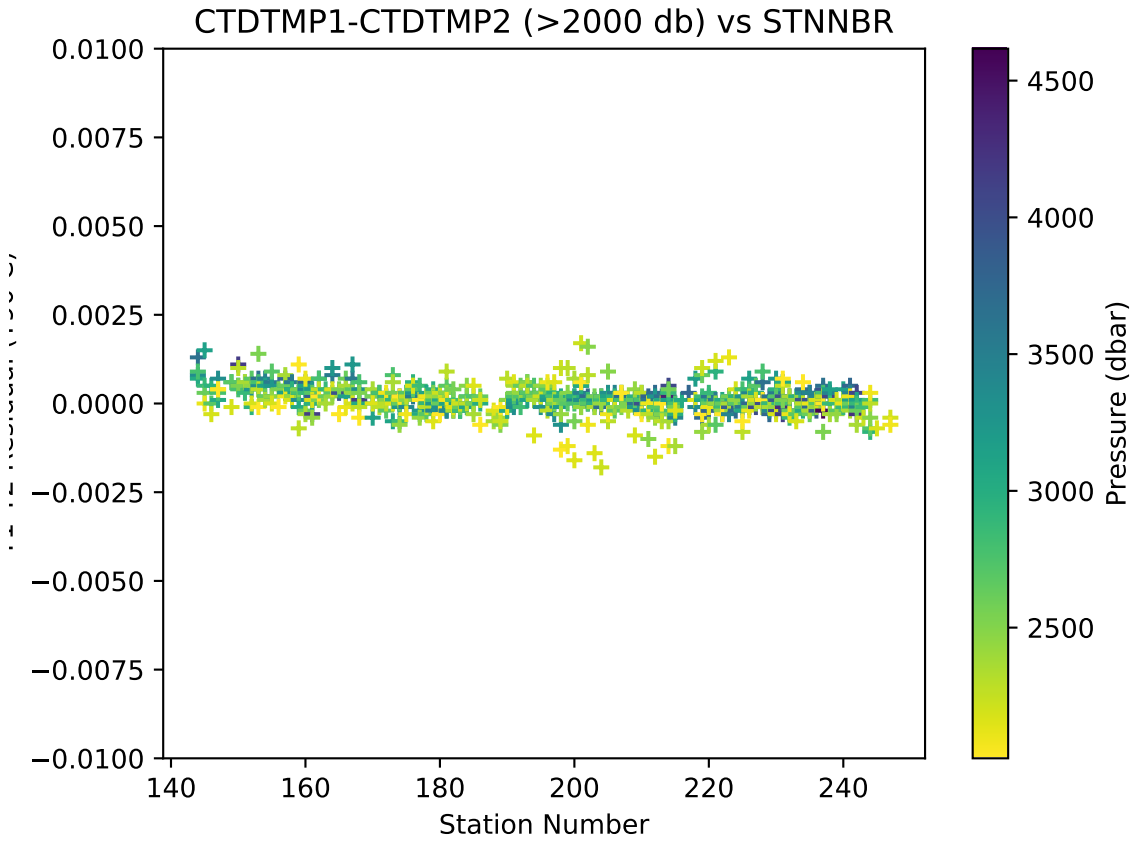


Fig. 3.6: Deep T1-T2 by station (Pressure $\geq$ 2000dbar).

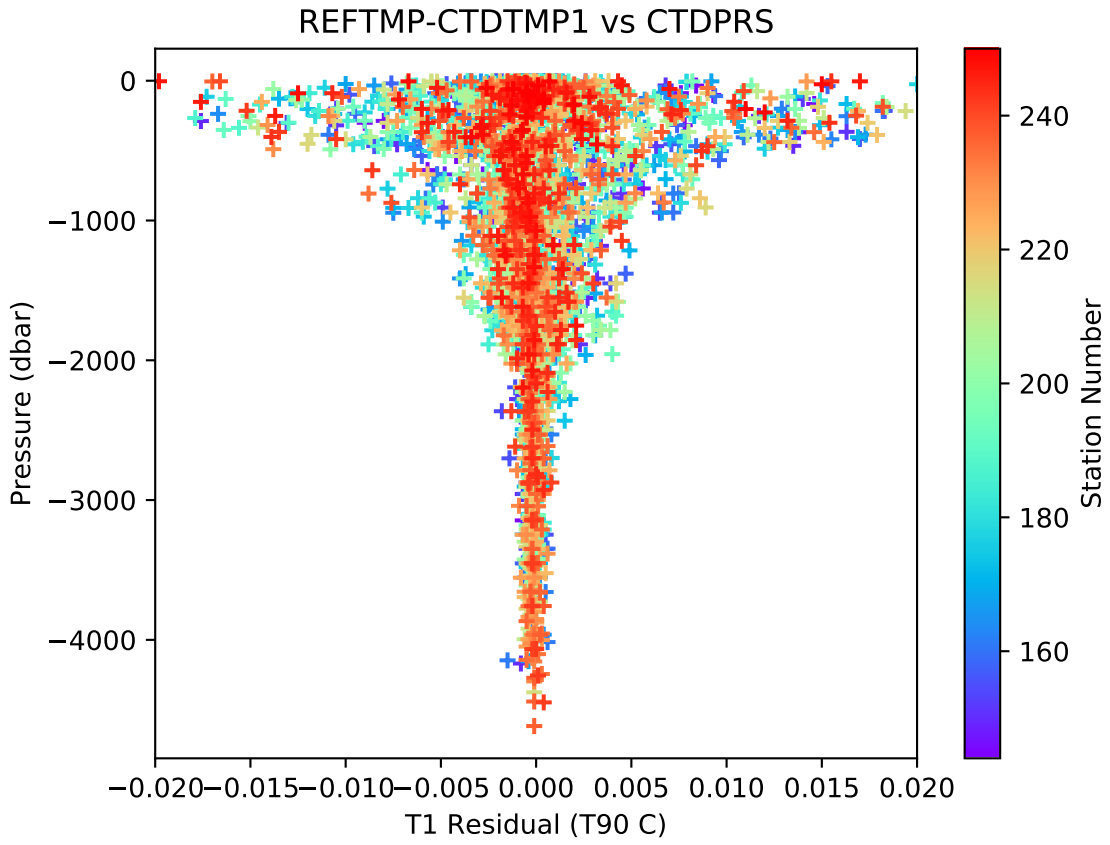


Fig. 3.7: SBE35RT-T1 by pressure (-0.002°C $\leq$ T1-T2 $\leq$ 0.002°C).

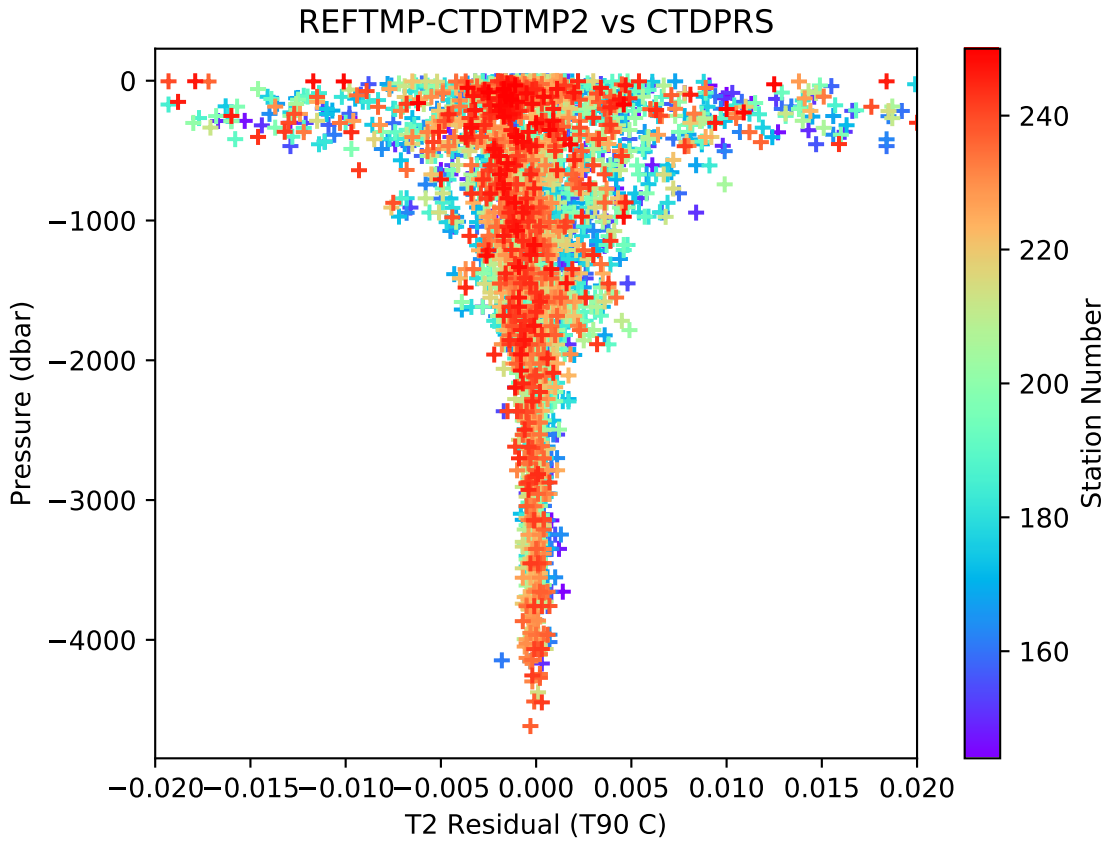


Fig. 3.8: SBE35RT-T2 by pressure (-0.002°C $\leq$ T1-T2 $\leq$ 0.002°C).

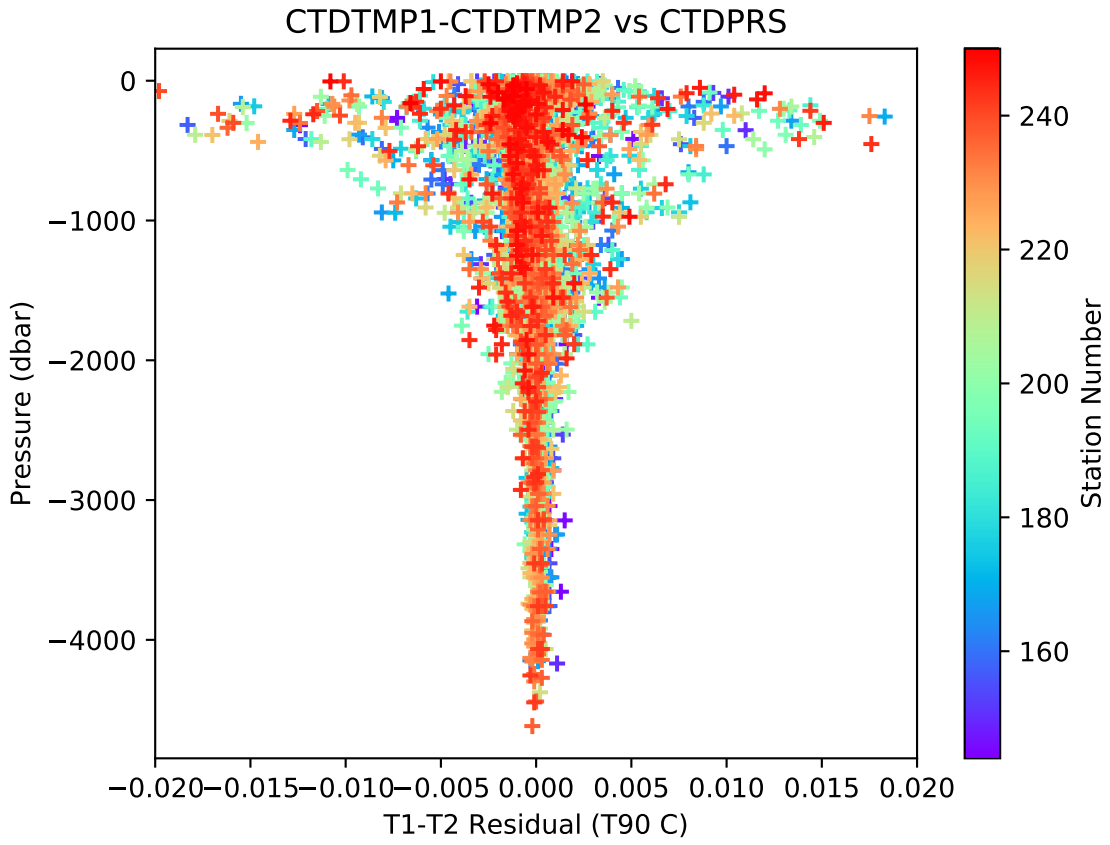


Fig. 3.9: T1-T2 by pressure (-0.002°C $\leq$ T1-T2 $\leq$ 0.002°C).

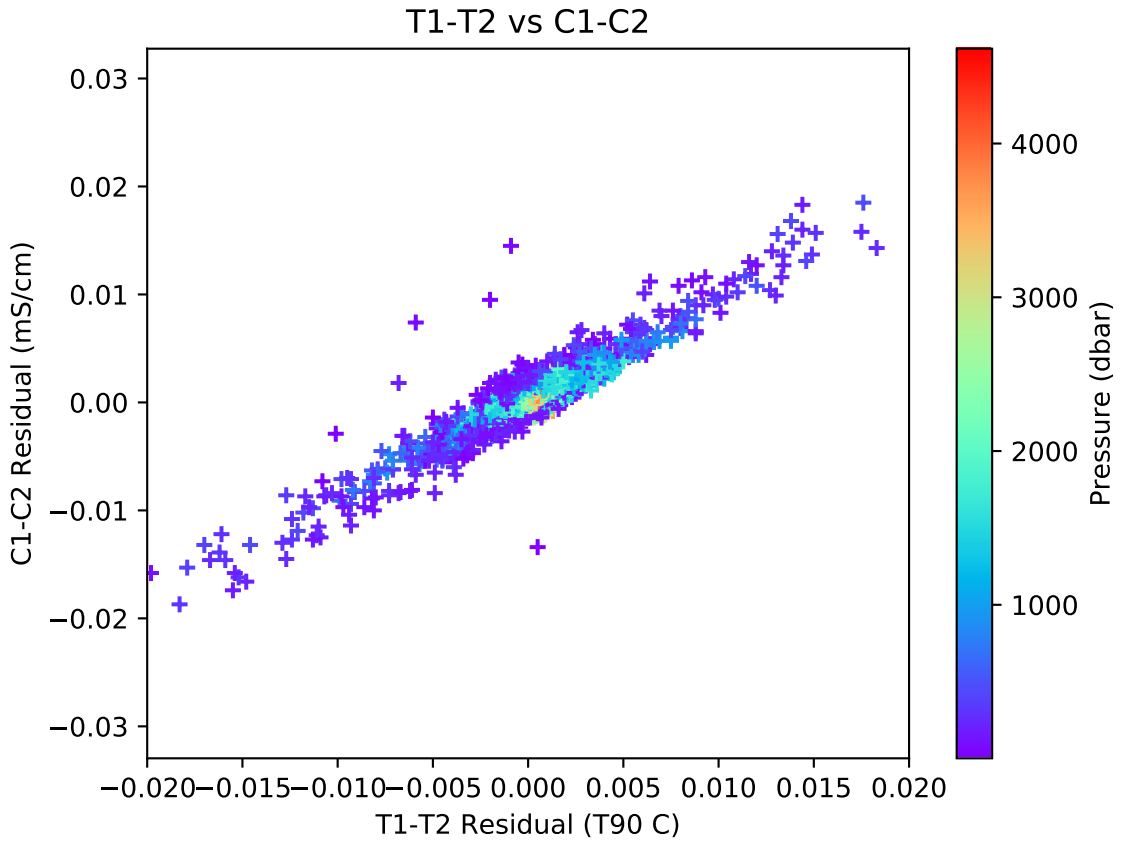


Fig. 3.10: Coherence of conductivity differences as a function of temperature differences.

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.

Uncorrected conductivity comparisons are shown in figures *Uncorrected CBottle - C1 by station (-0.002 mS/cm BTLCOND-C1 0.002 mS/cm).* through *Uncorrected C1-C2 by station (-0.002 mS/cm C1-C2 0.002 mS/cm).*.

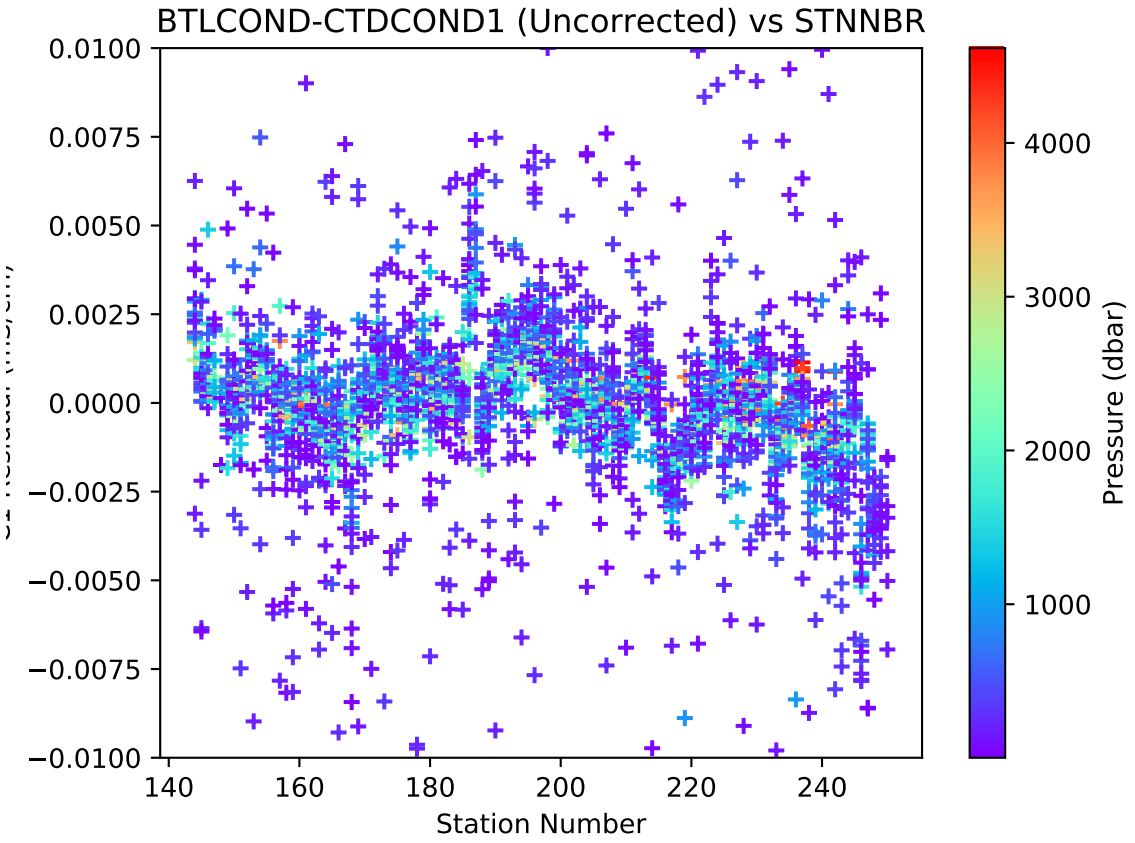


Fig. 3.11: Uncorrected C_{Bottle} - C1 by station (-0.002 mS/cm $\leq$ BTLCOND-C1 $\leq$ 0.002 mS/cm).

The residual conductivity differences after correction are shown in figures *Corrected CBottle - C1 by station (-0.002 mS/cm BTLCOND-C1 0.002 mS/cm).* through *Corrected C1-C2 by conductivity (-0.002 mS/cm C1-C2 0.002 mS/cm).*.

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

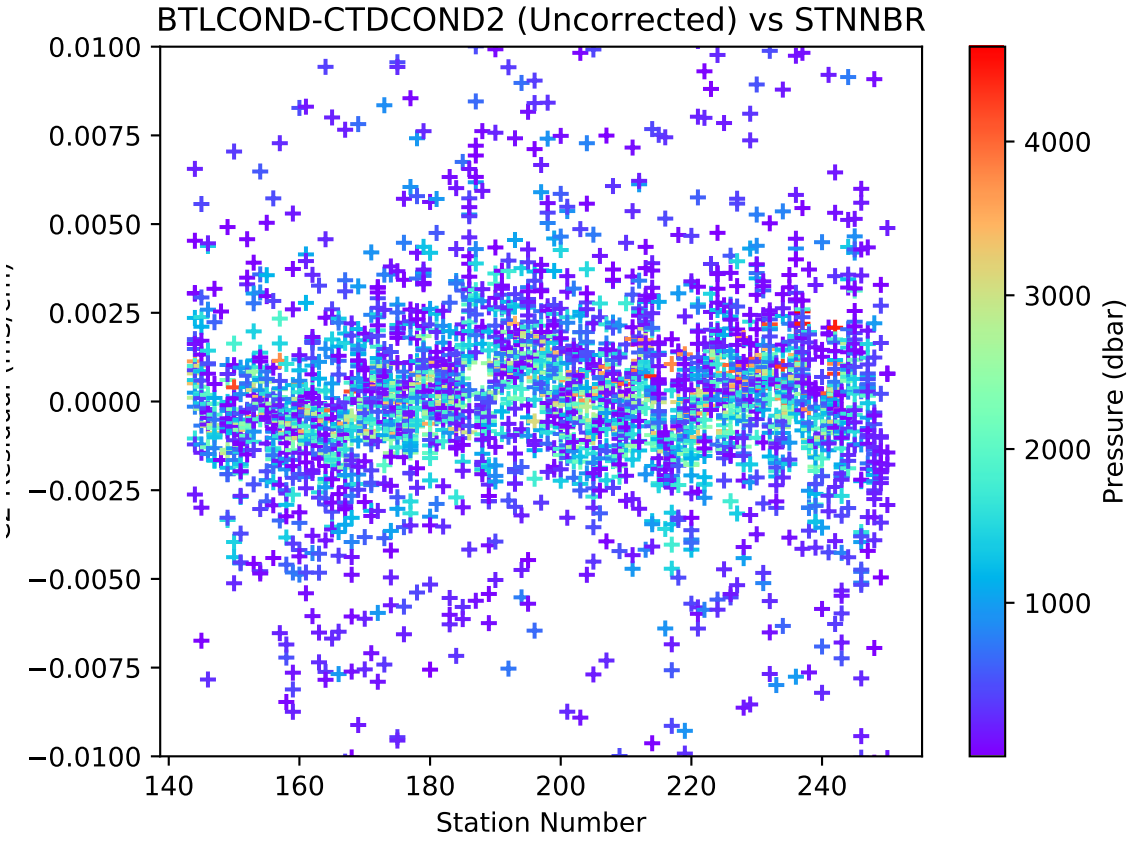


Fig. 3.12: Uncorrected C_{Bottle} - C2 by station (-0.002 mS/cm $\leq$ BTLCOND-C2 $\leq$ 0.002 mS/cm).

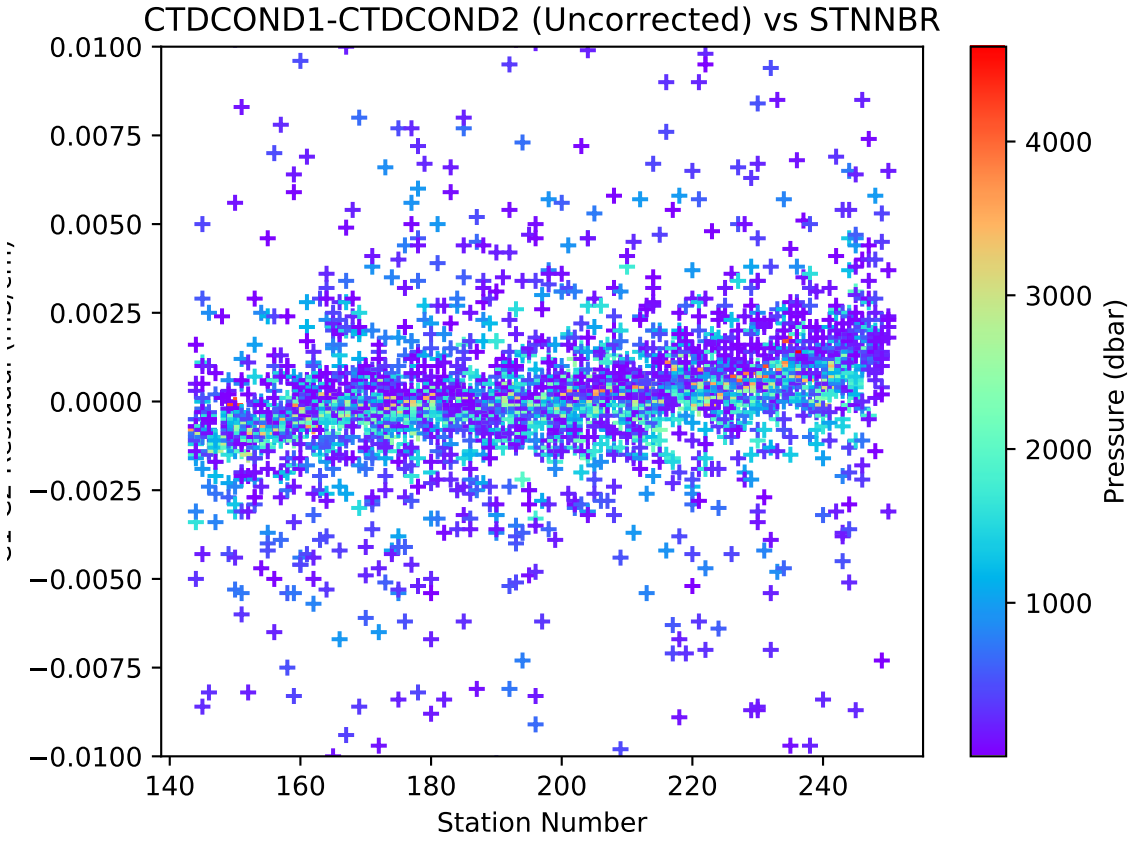


Fig. 3.13: Uncorrected C1-C2 by station (-0.002 mS/cm $\leq$ C1-C2 $\leq$ 0.002 mS/cm).

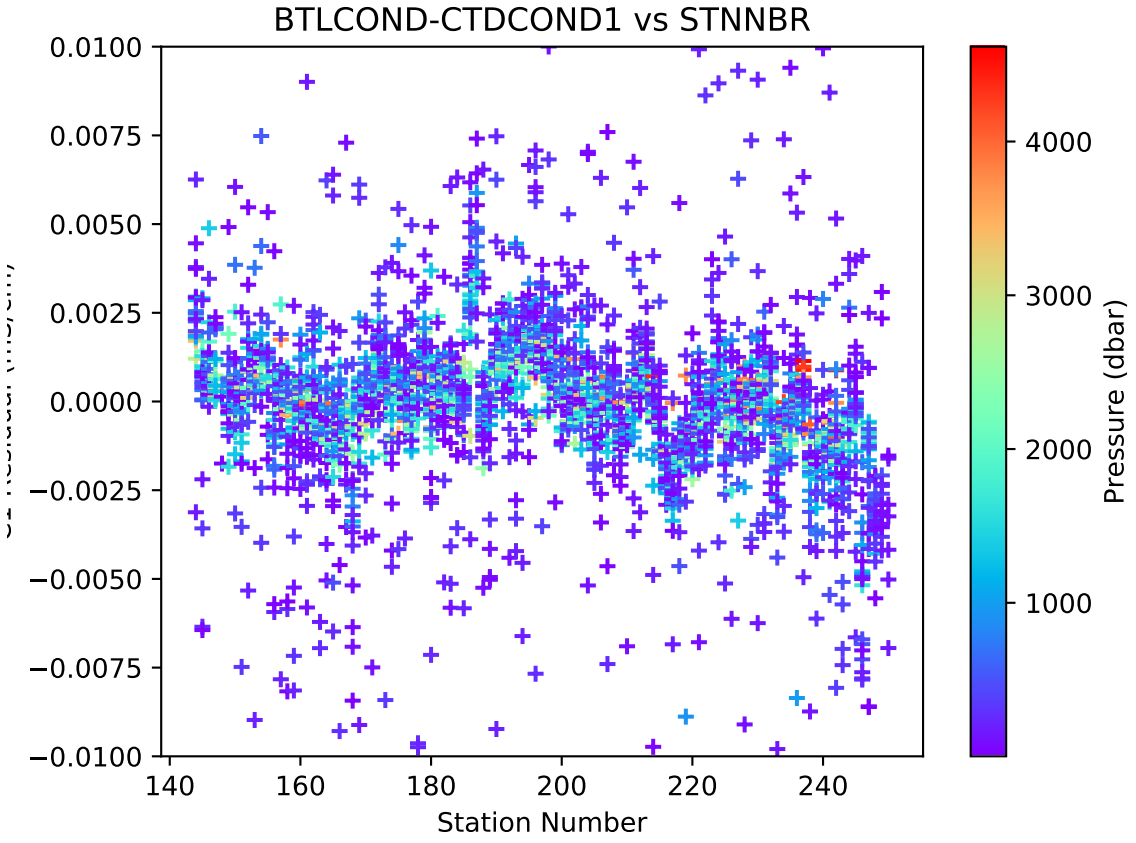


Fig. 3.14: Corrected C_{Bottle} - C1 by station (-0.002 mS/cm $\leq$ BTLCOND-C1 $\leq$ 0.002 mS/cm).

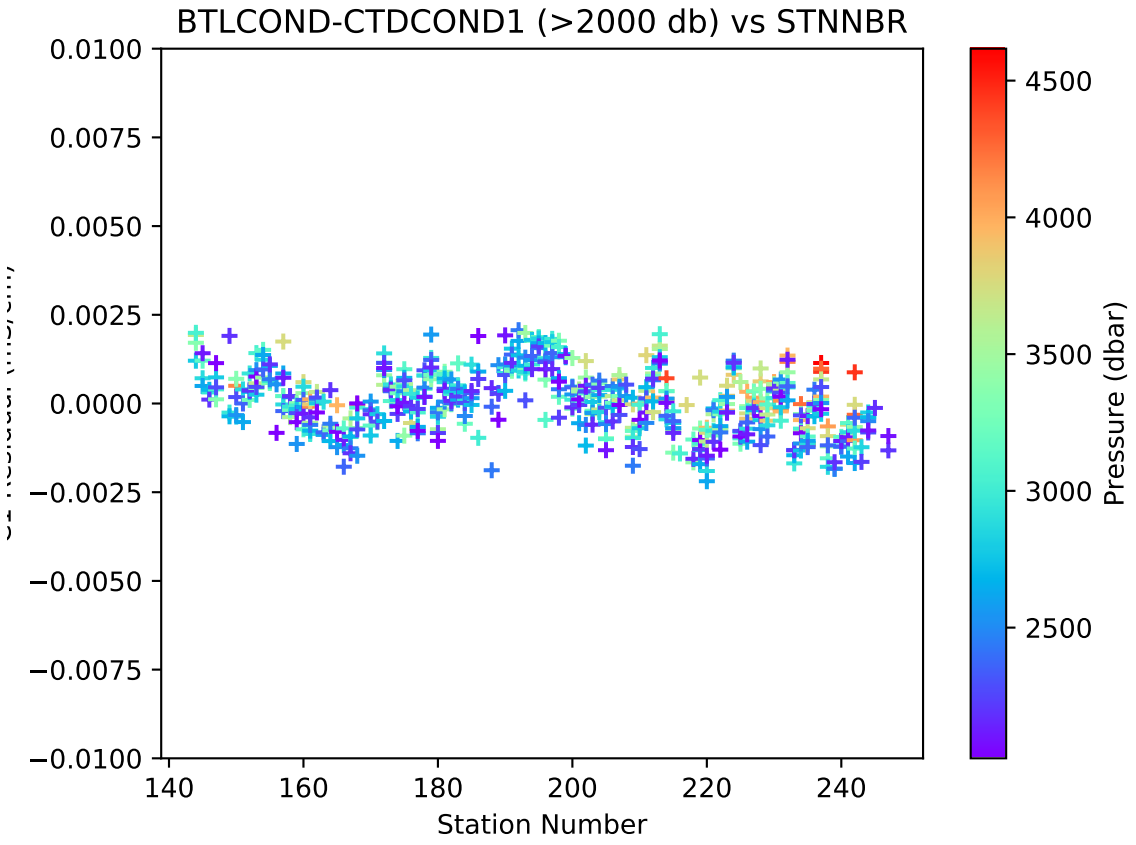


Fig. 3.15: Deep Corrected C_{Bottle} - C1 by station (Pressure >= 2000dbar).

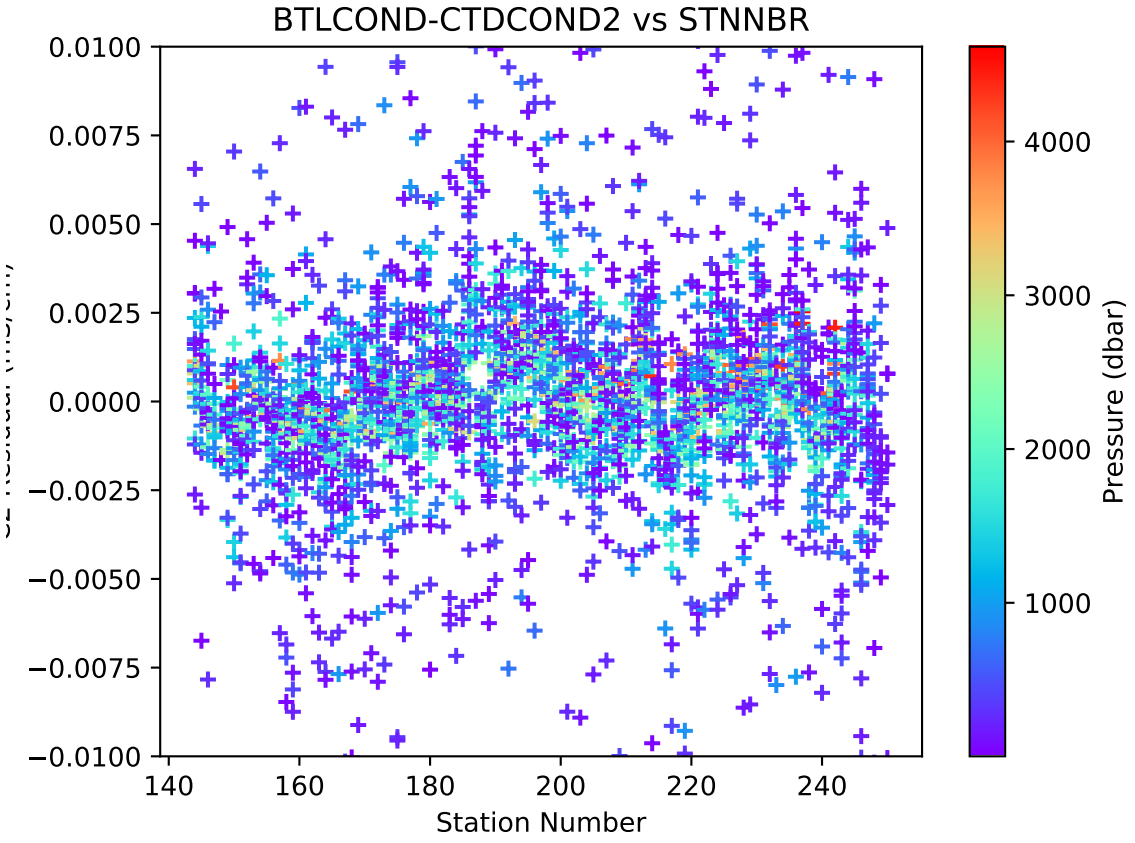


Fig. 3.16: Corrected C_{Bottle} - C2 by station (-0.002 mS/cm $\leq$ BTLCOND-C2 $\leq$ 0.002 mS/cm).

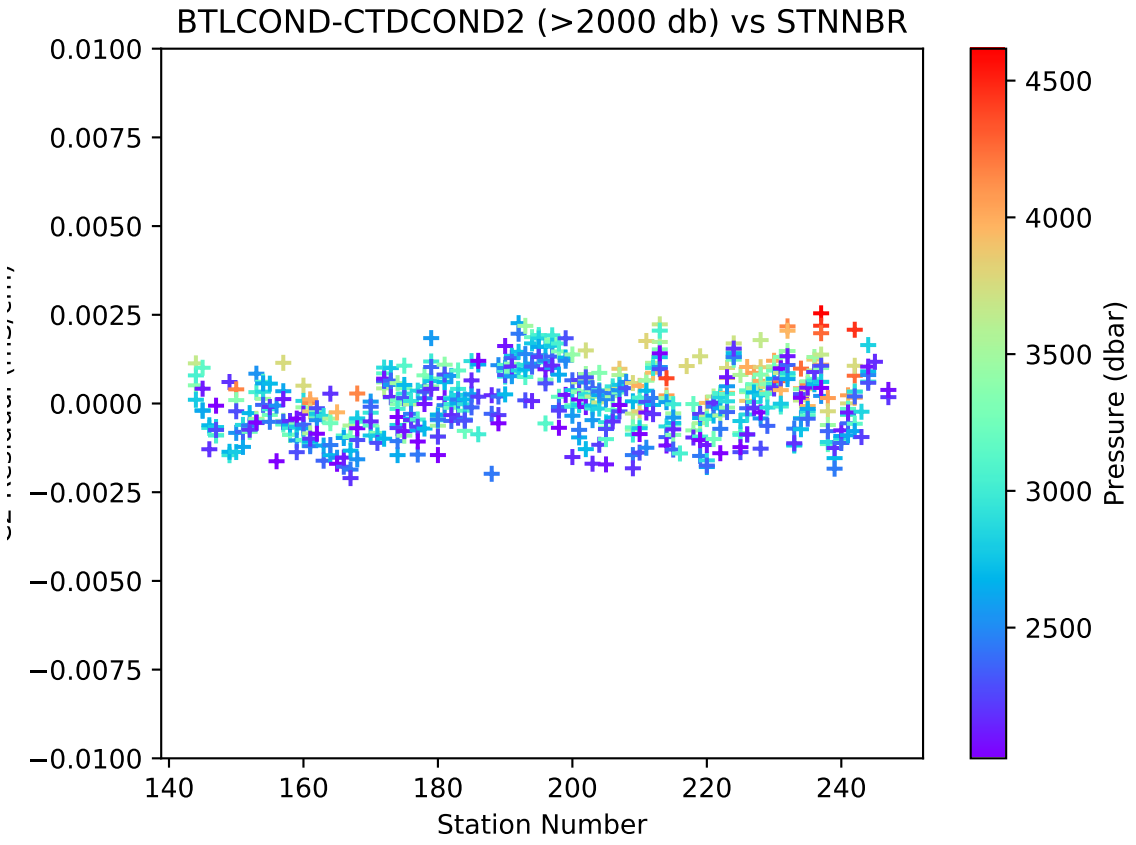


Fig. 3.17: Deep Corrected C_{Bottle} - C2 by station (Pressure >= 2000dbar).

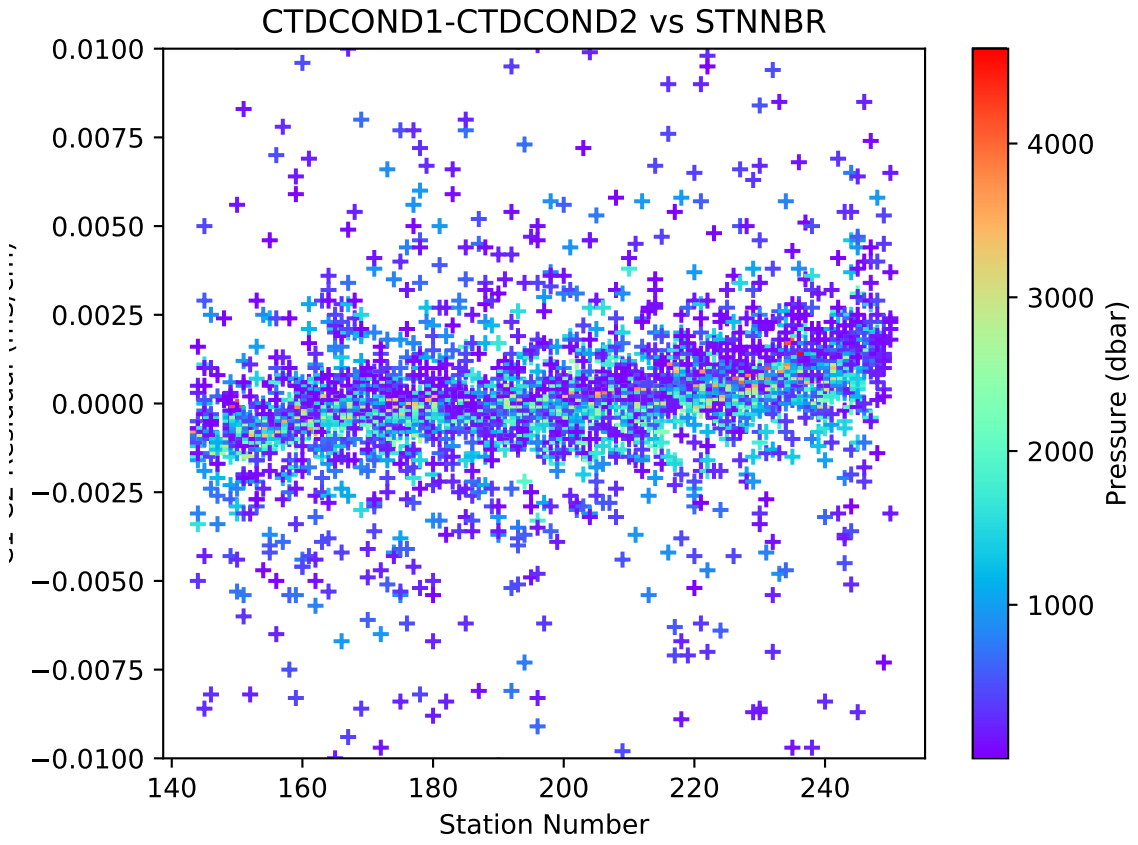


Fig. 3.18: Corrected C1-C2 by station (-0.002 mS/cm $\leq$ C1-C2 $\leq$ 0.002 mS/cm).

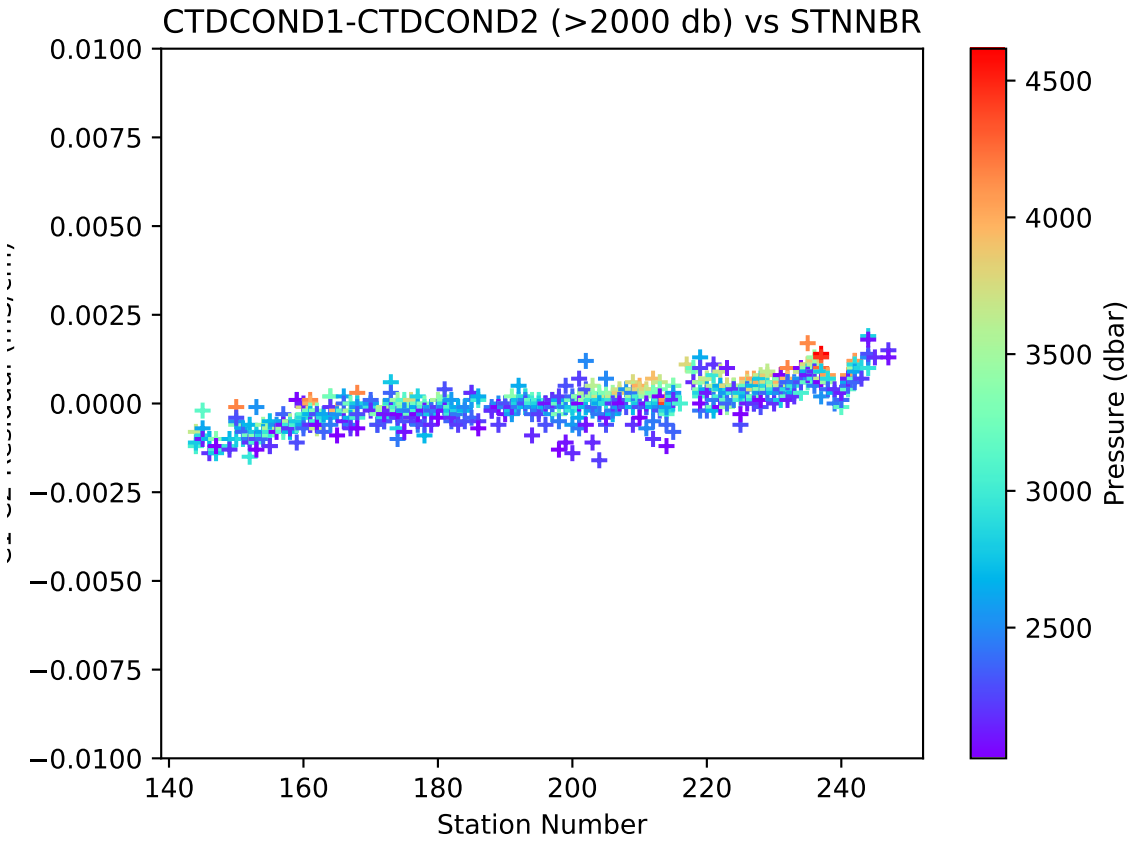


Fig. 3.19: Deep Corrected C1-C2 by station (Pressure >= 2000dbar).

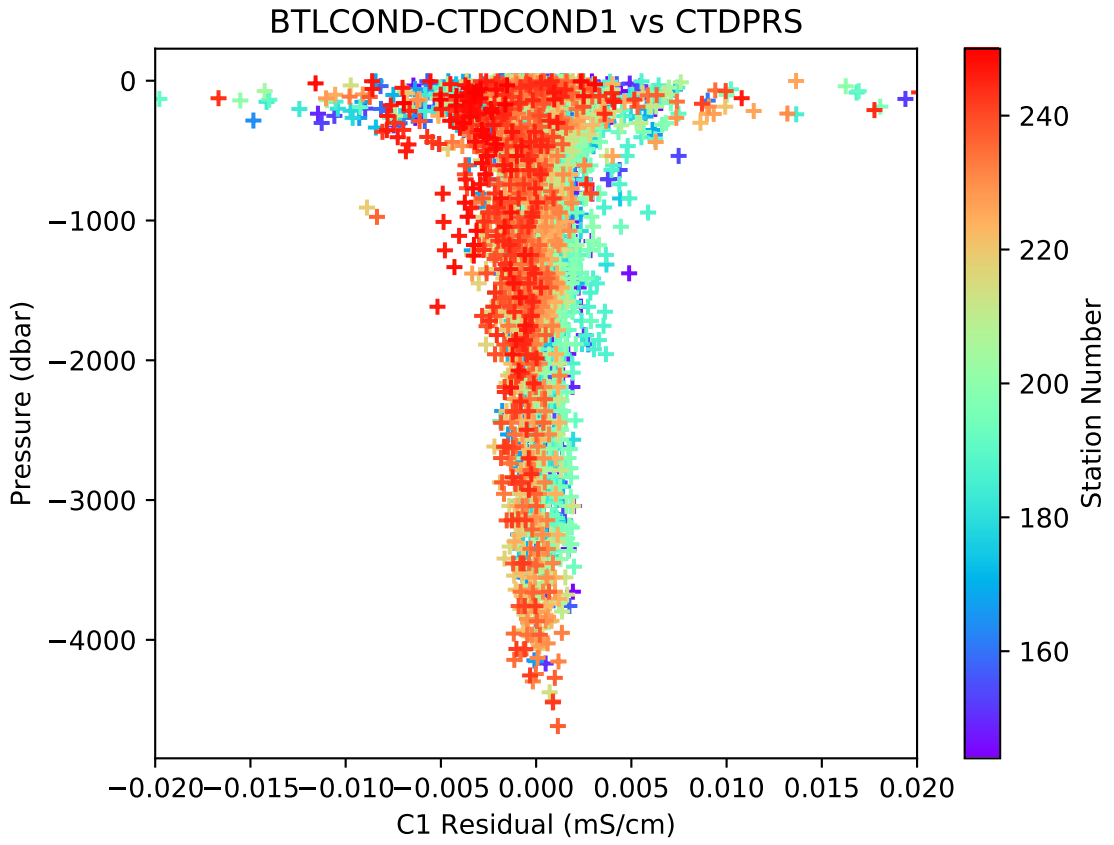


Fig. 3.20: Corrected C_{Bottle} - C1 by pressure (-0.002 mS/cm $\leq$ BTLCOND-C1 $\leq$ 0.002 mS/cm).

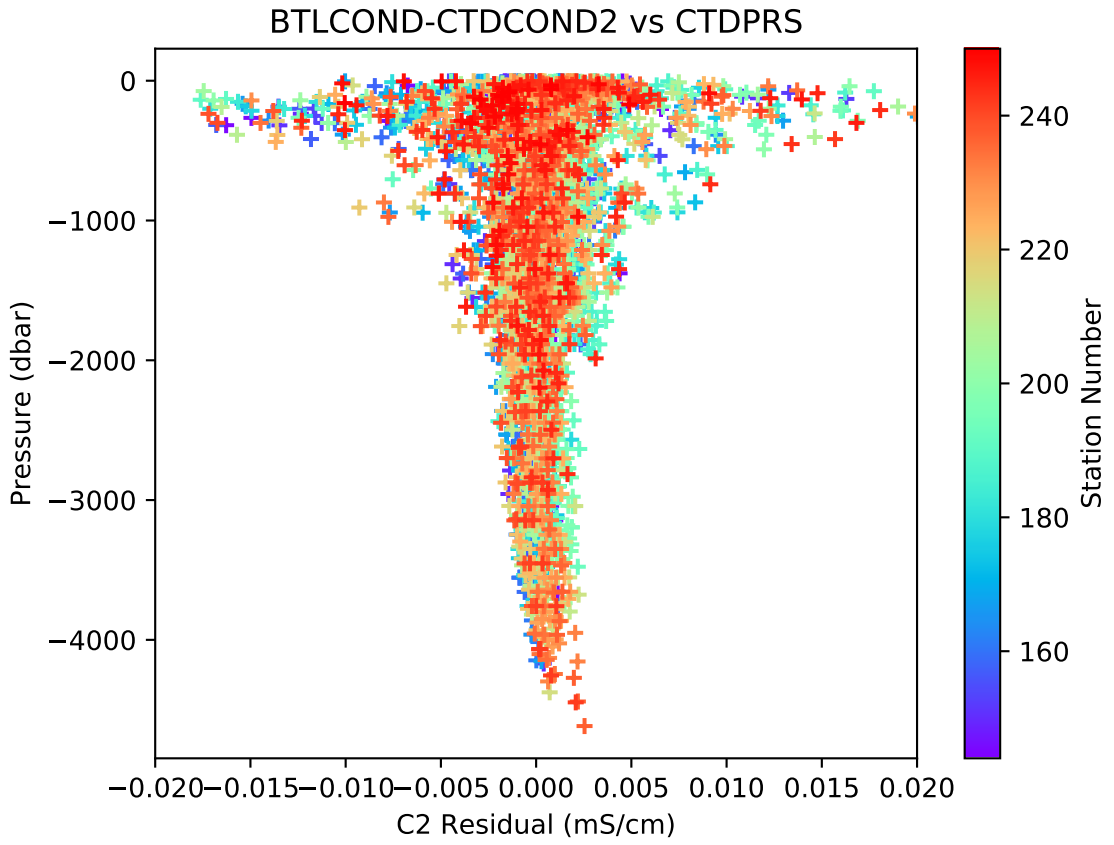


Fig. 3.21: Corrected C_{Bottle} - C2 by pressure (-0.002 mS/cm $\leq$ BTLCOND-C2 $\leq$ 0.002 mS/cm).

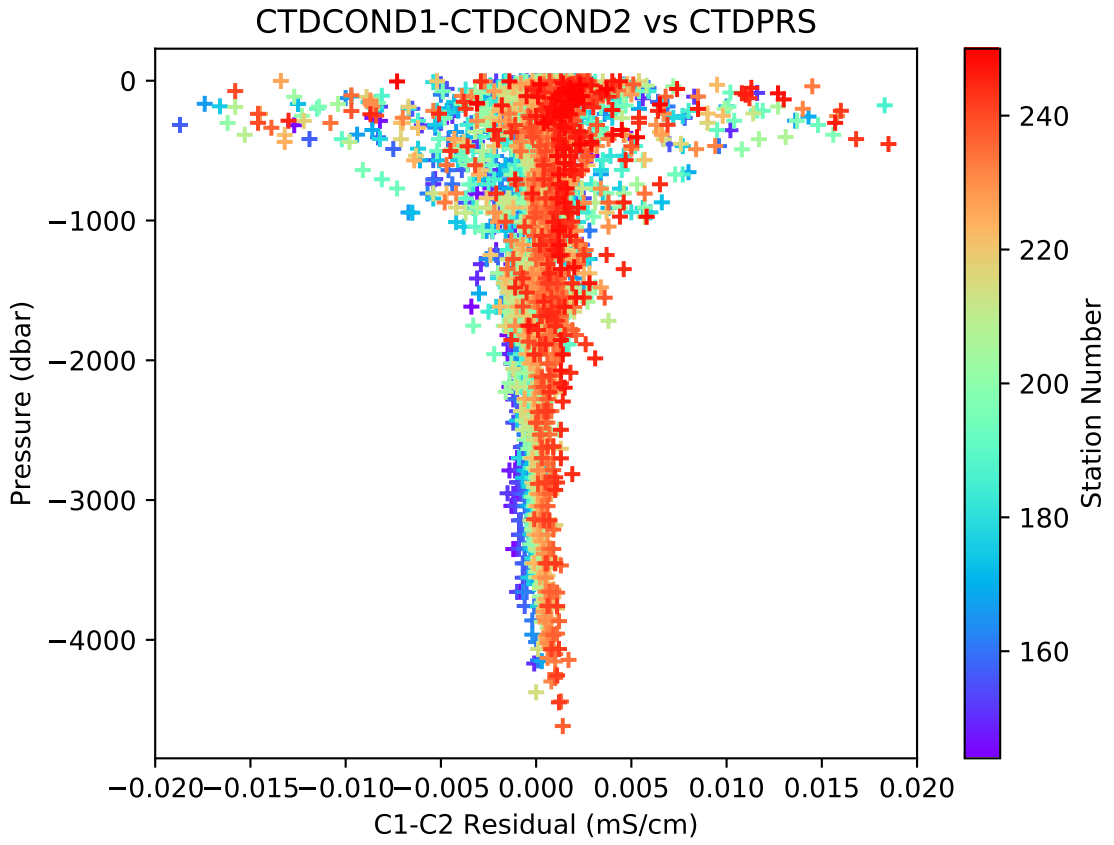


Fig. 3.22: Corrected C1-C2 by pressure (-0.002 mS/cm $\leq$ C1-C2 $\leq$ 0.002 mS/cm).

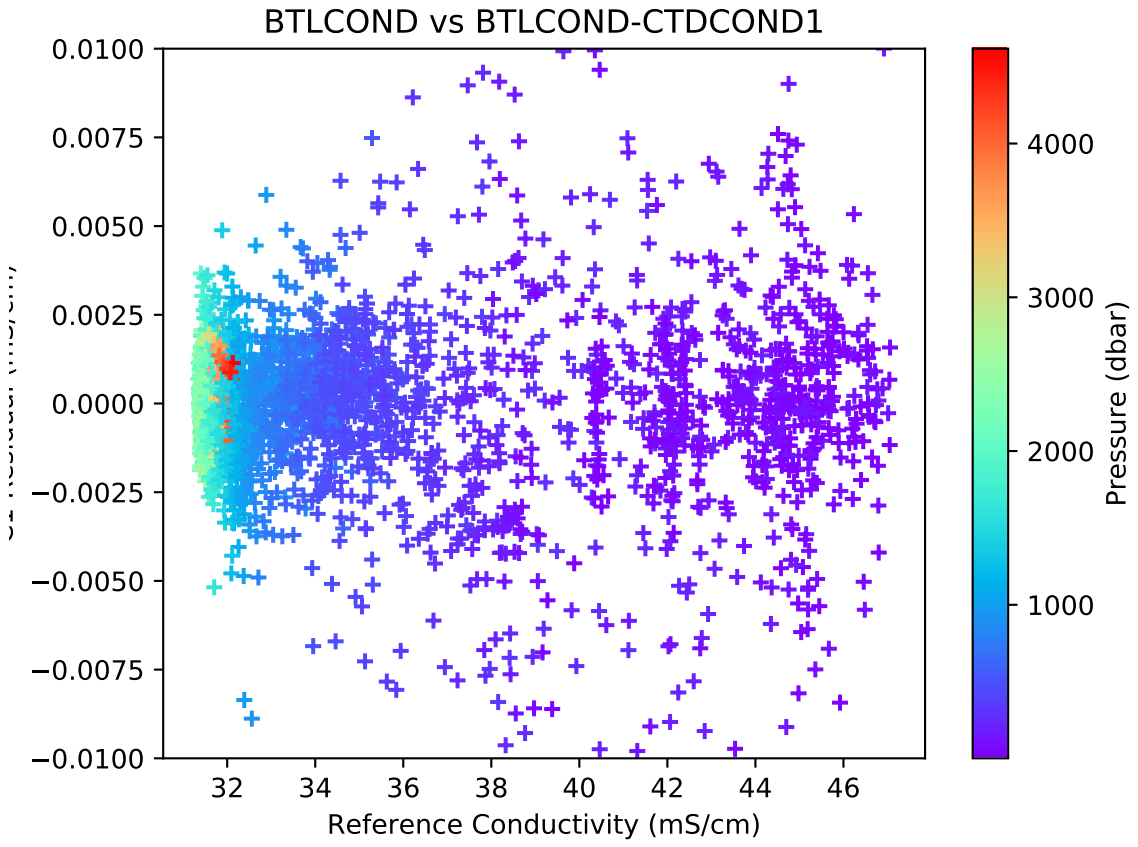


Fig. 3.23: Corrected C_{Bottle} - C1 by conductivity (-0.002 mS/cm $\leq$ BTLCOND-C1 $\leq$ 0.002 mS/cm).

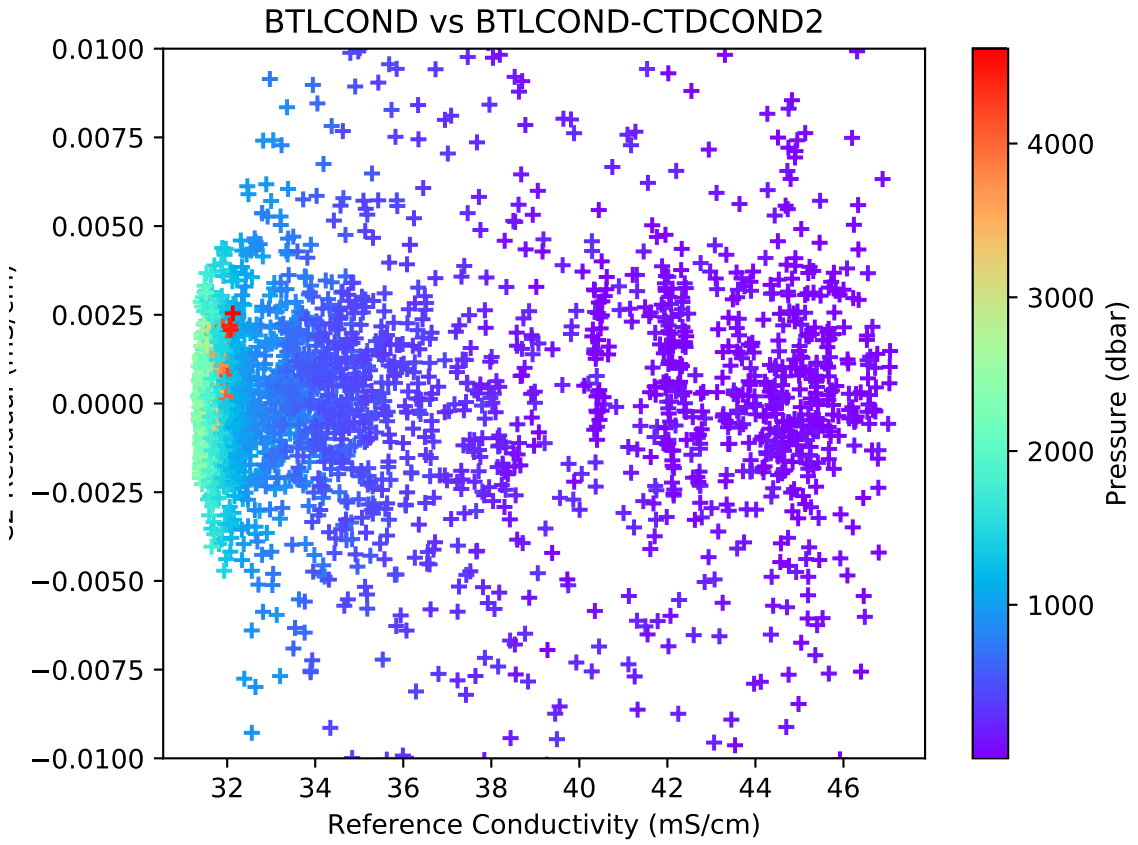


Fig. 3.24: Corrected C_{Bottle} - C2 by conductivity (-0.002 mS/cm $\leq$ BTLCOND-C2 $\leq$ 0.002 mS/cm).

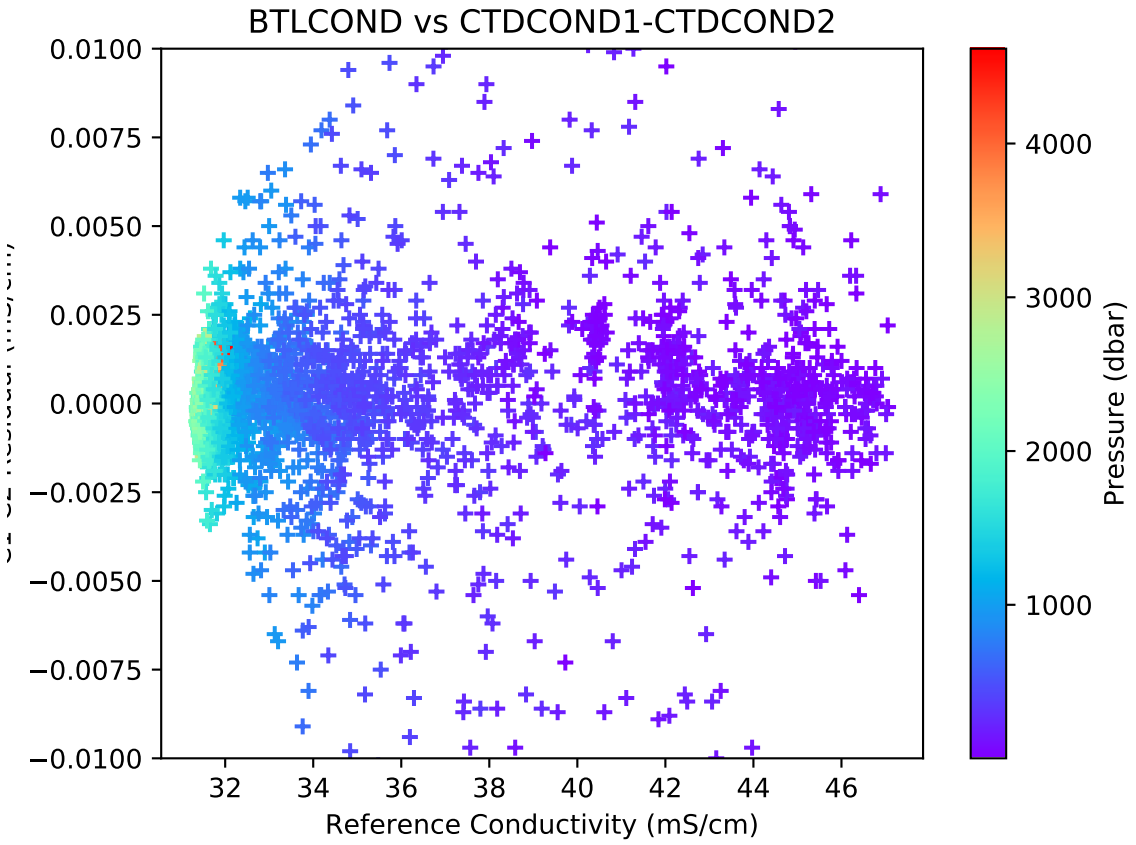


Fig. 3.25: Corrected C1-C2 by conductivity (-0.002 mS/cm $\leq$ C1-C2 $\leq$ 0.002 mS/cm).

published in the APPENDIX of this report.

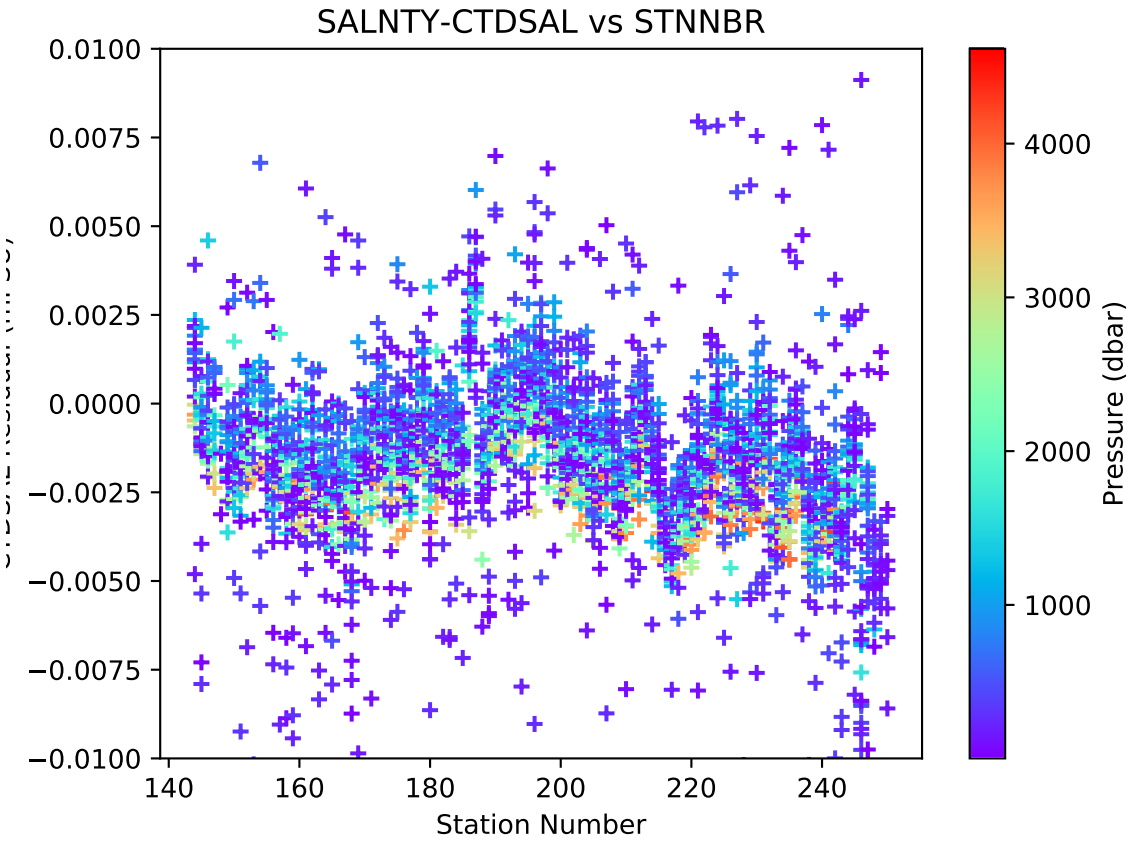


Fig. 3.26: Salinity residuals by station (-0.002 mPSU $\leq$ SALNTY-C1SAL $\leq$ 0.002 mPSU).

The 95% confidence limits for the mean low-gradient (values -0.002 mPSU $\leq$ T1-T2 $\leq$ 0.002 mPSU) differences are $\pm$0.0051 PSU for salinity-C1SAL. The 95% confidence limits for the deep salinity residuals (where pressure $\geq$ 2000dbar) are $\pm$0.0021 PSU for salinity-C1SAL.

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

- 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.

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

3.6 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.

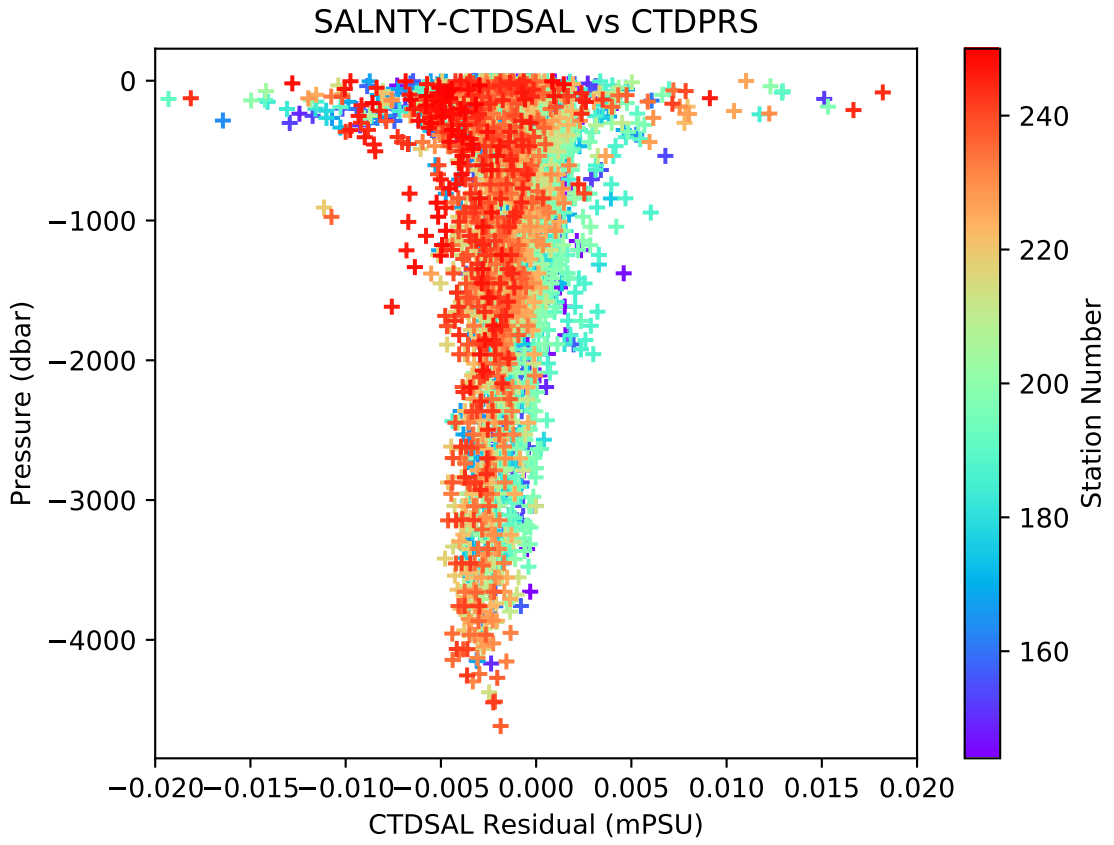


Fig. 3.27: Salinity residuals by pressure (-0.002 mPSU $\leq$ SALNTY-C1SAL $\leq$ 0.002 mPSU).

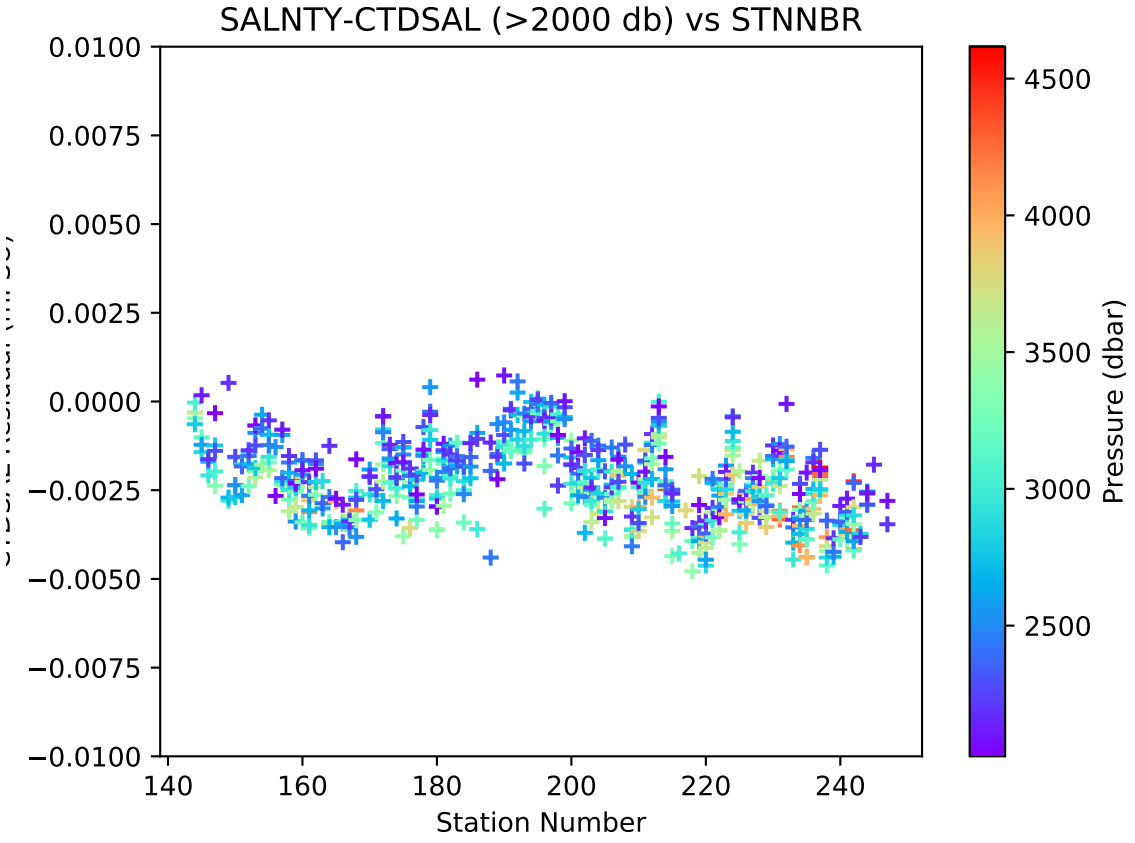


Fig. 3.28: Deep Salinity residuals by station (Pressure >= 2000dbar).

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 *[Millard82]* and Owens *[Owens85]* 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 response 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-response low-pass filtered temperature (°C)
- T_s Short-response 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 response coefficients

CTD dissolved O_2 residuals are shown in the following figures *O2 residuals by station (-0.01 µmol/kg OXYGEN-BTLOXY 0.01 µmol/kg).* through *Deep O2 residuals by station (Pressure >= 2000dbar).*.

The second standard deviations of 9.04 (µmol/kg) for all dissolved oxygen bottle data values and 2.45 (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.

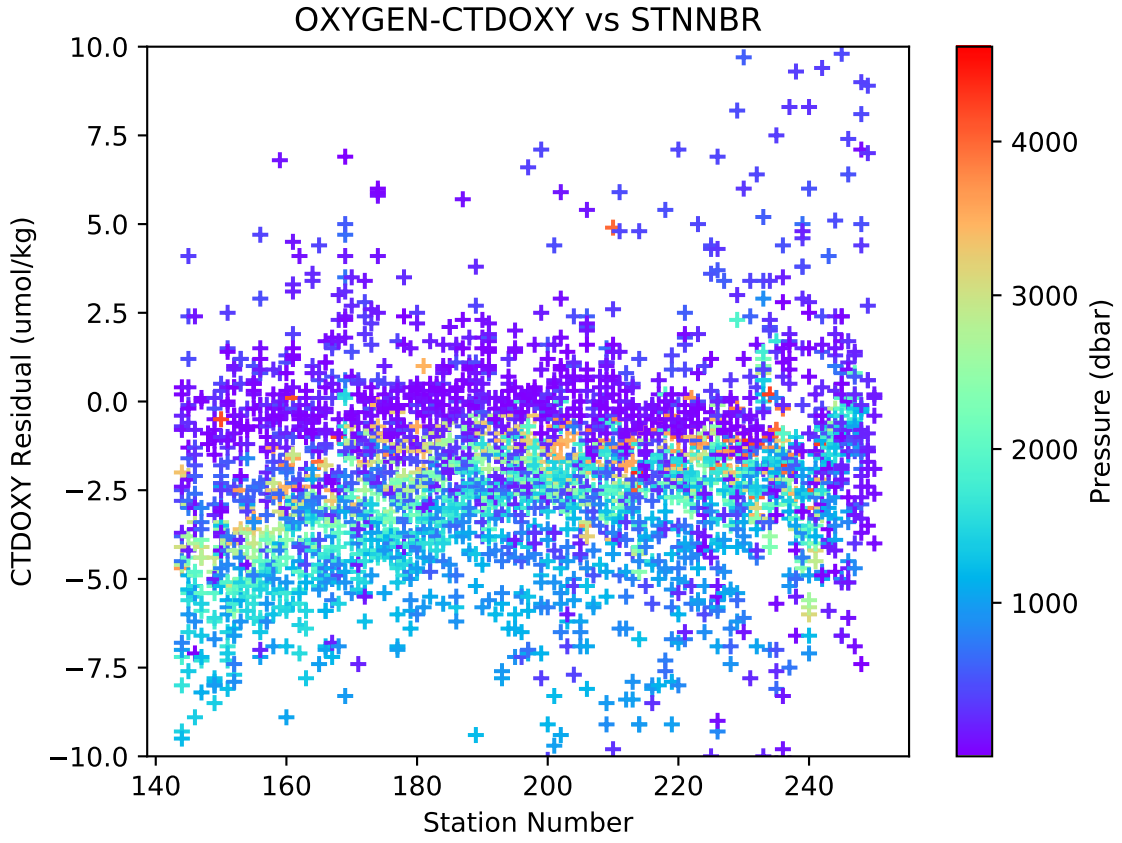


Fig. 3.29: O_2 residuals by station (-0.01 µmol/kg $\leq$ OXYGEN-BTLOXY $\leq$ 0.01 µmol/kg).

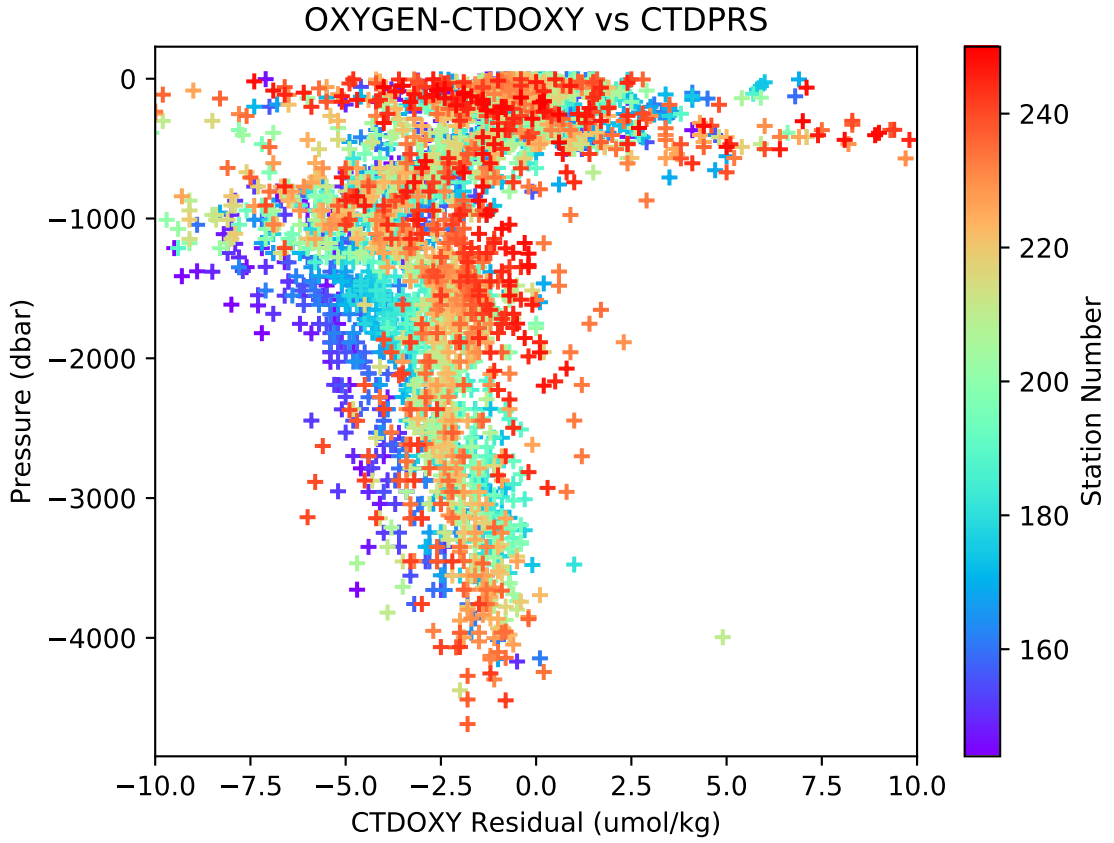


Fig. 3.30: O_2 residuals by pressure (-0.01 µmol/kg $\leq$ OXYGEN-BTLOXY $\leq$ 0.01 µmol/kg).

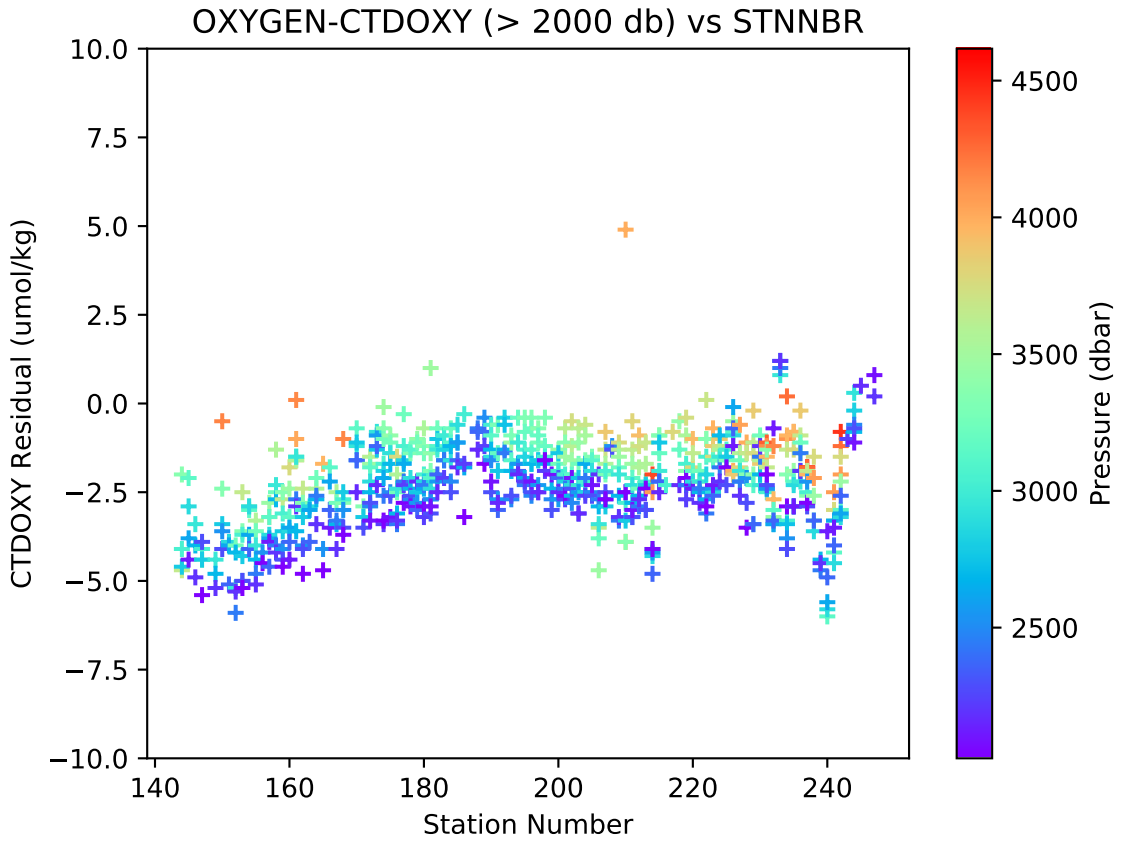


Fig. 3.31: Deep O_2 residuals by station (Pressure >= 2000dbar).

- New software used to fit the data is not working as intended, and the data will be re-fit post cruise after a thorough checking of the code.

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.

CHAPTER

FOUR

SALINITY

PIs

- Susan Becker
- James Swift

Technicians

- Kelsey Vogel
- Kenneth Jackson

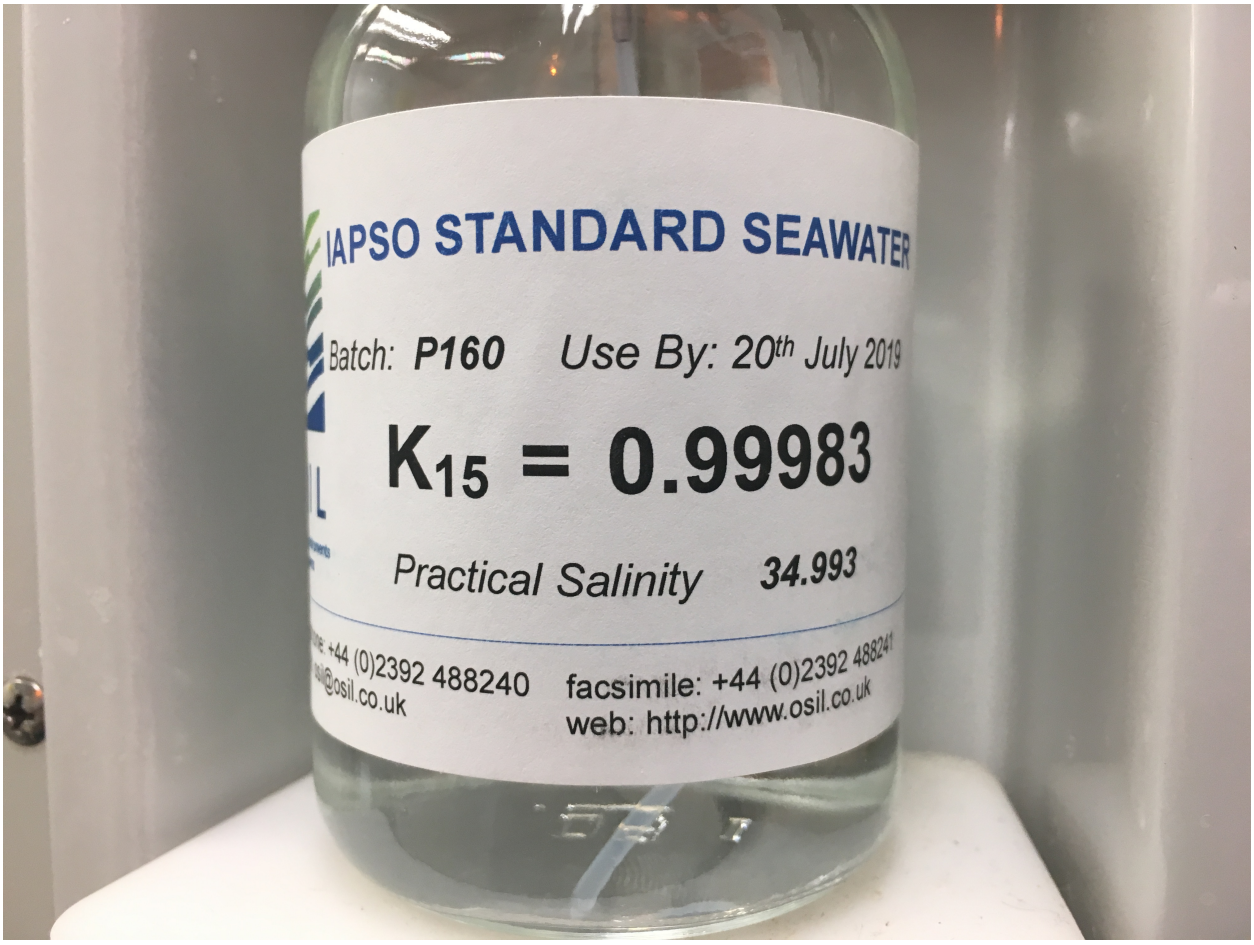
4.1 Equipment and Techniques

Two Guildline Autosals, model 8400B salinometer (S/N 69-180) and model 8400A salinometer (S/N 57-526) located in salinity analysis room, were used for all salinity measurements. Autosal model 8400B was serviced prior to NBP1701 and remained on ship. Autosal model 8400A was serviced prior to P06W and sent with other equipment in June. The salinometer readings were logged on a computer using in house LabView program developed by Carl Mattson. The Autosal water bath temperature was set to 24°C. The laboratory's temperature was also set and maintained to 22°C. This is to ensure stabilize reading values and improve accuracy. Salinity analyses were performed after samples had equilibrated to laboratory temperature range of 22-25°C, usually 6 hours after collection. The salinometer was standardized for each group of samples analyzed (usually 2 casts and 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. Prior to each run a sub-standard flush, approximately 200 ml, of the conductivity cell was conducted to flush out the DI water used in between runs. 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-160 was used to standardize all casts.

4.2 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


IAPSO STANDARD SEAWATER
Batch: P160
Use By: 20th July 2019
K15 = 0.99983
Practical Salinity 34.993
facsimile: +44 (0)2392 488241
web: http://www.osil.co.uk

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.

4.3 Narrative

Autosal 69-180 was used to perform the salinity analysis for the entirety of P06E. Throughout the cruise, there were several issues found in regards to the salinometer. During station 170 (2017-09-05) and the running of the salts from station 168, Autosal 69-180 stopped pumping water due to salt buildup in the sampling tube. As a result, sample 13 from that cast was aborted and the clogged tubing was replaced by new Tygon tubing of similar length. From that point on, only one box was run at a time until it was certain that there were no adverse effects from the tubing change; it was found to be safe to run two boxes at a time starting from the analysis of the salts from station 173 onwards (2017-09-07). During station 174 (2017-09-06), lint, or some other form of buildup was found to be collecting inside of the sampling chamber and getting stuck on the platinum sensors of the Autosal. This problem was addressed by flushing the chamber multiple times with DI water, soapy water, a small amount of NaOH and DI water, then a small amount of isopropyl alcohol and DI water, and then thoroughly rinsed with DI water to flush the tubing and chambers clean, in that order. This process removed most of the buildup, however some still remained in the chamber. During Station 175 (2017-09-06), salt run 172, the ending standard looked bad with a conductivity ratio that read 1.99977 when it was expected to have read somewhere around 1.99966. The chambers were flushed again with DI water and the conductivity ratio was measured with a reading of ~0.0205. From that point on, all salt sampling runs were ended by multiple flushes of the chamber with DI water until it read a conductivity ratio of ~0.0030-0.0040 in efforts to prevent salt buildup and other forms of sample contamination. It was also noted that during station 191 (2017-09-11) that there was a buildup of some sort of brown residue in some of the bottles (boxes S and X) that were subsequently cleaned out.

Room and bottle temperature proved difficult to keep consistent throughout the cruise, causing certain changes to be made throughout P06E. Towards the beginning of the leg, on station 170 (2017-09-05), the thermometer of the of the Autosal was found to have a temperature offset of anywhere between 1.5 to 1.7°C and the room temperature was adjusted in order to compensate. The initial room temperature was set to 22°C, raised to 23°C, and subsequently raised to 24°C. Temperature fluctuations also were observed during this leg. Room temperature was noted before analyzing a box of salts and these temperatures ranged from 22.4°C (analysis of Station 172, 2017-09-07) to 26.5°C (analysis of Station 190, 2017-09-12), this and sample time, resulted in fluctuations of bottle temperatures when ran. These bottle temperatures at the time of sampling, ranged from 22.4°C (analysis of Station 175, 2017-09-08) to 26.0°C (analysis of Station 200, 2017-09-14).

CHAPTER

FIVE

NUTRIENTS

PIs

- Susan Becker
- James Swift

Technicians

- Susan Becker
- David Cervantes

5.1 Summary of Analysis

- 3660 samples from 107 ctd stations
- The cruise started with new pump tubes and they were changed prior to stations 163, 198 and 223.
- 5 sets of nitrate, phosphate, and silicate Primary/Secondary standards were made up over the course of the cruise.
- 3 sets of Primary and 26 sets of Secondary nitrite standards were made up over the course of the cruise.
- The cadmium column efficiency was checked periodically and ranged between 94%-100%. A new column was put on if the efficiency fell below 97%.

5.2 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 GO-SHIP repeat hydrography manual (Hydes et al., 2010) *[Hydes2010]*.

5.3 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 540nm. 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 l liter volume. Add 5ml of 2% CuSO4 solution to this NH4Cl stock. This should last many months.

5.4 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 (880nm after station 59, see section on analytical problems for details).

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.

5.5 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.

5.6 Sampling

Nutrient samples were drawn into 40 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.

5.7 Data Collection and Processing

Data collection and processing was done with the software (ACCE ver 6.10) 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.

5.8 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). Batches of LNSW were used on the cruise. Batches of LNSW, were collected. 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)	NH_4 (uM)
0	0.0	0.0	0.0	0.0	0.0
3	15.50	1.2	60	0.50	2.0
5	31.00	2.4	120	1.00	4.0
7	46.50	3.6	180	1.50	6.0

5.9 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	36.05	0.20
PO_4	2.53	0.01
SIL	113.7	0.9

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]* and Sato *[Sato2010]*. RMNS batch BV 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	36.14	0.07	36.19
PO_4	2.56	0.01	2.56
Sil	104.9	0.4	104.6
NO_2	0.06	0.00	0.05

5.10 Analytical Problems

No major analytical problems.

CHAPTER

SIX

OXYGEN ANALYSIS

PIs

- Susan Becker
- James Swift

Technicians

- Andrew Barna
- John Ballard

6.1 Equipment and Techniques

Dissolved oxygen analyses were performed with an SIO/ODF-designed automated oxygen titrator using photometric end-point detection based on the absorption of 365nm wavelength ultra-violet light. The titration of the samples and the data logging were controlled by PC LabView software. Thiosulfate was dispensed by a Dosimat 765 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 approximately 0.012N, and thiosulfate solution approximately 55 gm/l. Pre-made liquid potassium iodate standards were run every day (approximately every 4-5 stations), unless changes were made to the system or reagents. Reagent/distilled water blanks were determined every day or more often if a change in reagents required it to account for presence of oxidizing or reducing agents.

6.2 Sampling and Data Processing

3661 oxygen measurements were made. Samples were collected for dissolved oxygen analyses soon after the rosette was brought on board. Using a silicone drawing tube, nominal 125ml volume-calibrated iodine flasks were rinsed 3 times with minimal agitation, then filled and allowed to overflow for at least 3 flask volumes. The sample drawing temperatures were measured with an electronic resistance temperature detector (RTD) embedded in the drawing tube. These temperatures were used to calculate umol/kg concentrations, and as a diagnostic check of bottle integrity. Reagents ($MnCl_2$ then NaI/NaOH) were added to fix the oxygen before stoppering. The flasks were shaken twice (10-12 inversions) to assure thorough dispersion of the precipitate, once immediately after drawing, and then again after about 30-40 minutes.

The samples were analyzed within 2-14 hours of collection, and the data incorporated into the cruise database.

Thiosulfate normalities were calculated for each standardization and corrected to 20°C. The 20°C normalities and the blanks were plotted versus time and were reviewed for possible problems. The blanks and thiosulfate normalities for each batch of thiosulfate were stable enough that no smoothing was necessary.

6.3 Volumetric Calibration

Oxygen flask volumes were determined gravimetrically with degassed deionized 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 volumetric flasks used in preparing standards were volume-calibrated by the same method, as was the 10 ml Dosimat buret used to dispense standard iodate solution.

6.4 Standards

Liquid potassium iodate standards were prepared in 6 liter 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 oxidizing and reducing impurities prior to use.

6.5 Narrative

Since the analytical equipment from the Sydney to Papeete leg was to continue on leg 2, no set up was nessessary in Papeete. A limited supply of Oxygen Standards meant the rig was not regularary standardized durring the transit from station 143 to Papeete, the entire 4 day port period, and the transit back to the P06 section line. While the period between standaridzation was long (aprox. 10 days) the change in thiosulfate normality was within the day to day allowed change. Saples taken from the underway system were stored until the first station occupation at which time they were analysed.

The normality of the thiosulfate was monitored daily. Each 1L batch of thiosulfate was very stable, the difference between the highest and lowest measured thiosulfate normality for the entire lifetime of a batch never even exceded the allowed daily change.

A few samples were lost due to errors made by the analysts: accidentally dumping an unanalysed sample, not adding enough acid to dissolved the precipitant. In a region of especailly low (~10 µmol/lg) oxgeyn off the coast of Chile, extra care was taken to eleminate microbubbles and minimize the time between the opening of a niskin and the fixing of the oxygen sample.

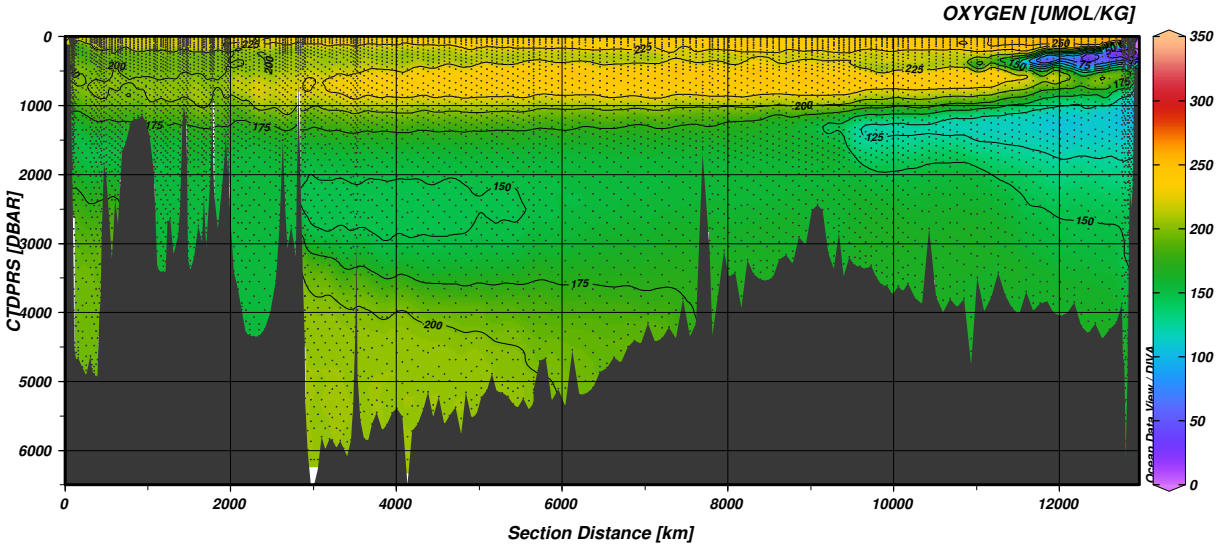


Fig. 6.1: Oxygen section for P06

CHAPTER

SEVEN

TOTAL ALKALINITY

PI

- Andrew G. Dickson – Scripps Institution of Oceanography (P06W)
- Frank J. Millero – University of Miami, Rosenstiel School of Marine and Atmospheric Science (P06E)

Technicians

- Manuel Belmonte (P06W)
- Derek Smith (P06W)
- Ryan Woosley (P06E)
- Fen Huang (P06E)

7.1 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 $\leq$ 10–4.5 at 25°C and zero ionic strength) over proton donors (acids with K > 10–4.5) in 1 kilogram of sample.

7.2 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 0.04 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.

7.3 Sample Collection

Samples for total alkalinity measurements were taken at all P06W Stations (1-143) except for stations 16, 20, 56, 60, 69 and 72. Two Niskin bottles at each station were sampled twice for duplicate measurements except for stations where 24 or less Niskin bottles were sampled. 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 0.12 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 RTE water bath.

7.4 Problems and Troubleshooting

The RVIB Nathaniel B. Palmer is a fantastic research vessel. However, our electrodes appeared to continually pick up larger than expected interference from the lab's neighboring instruments or the ship itself. Electrode plots could show increased electrode sensitivity over time. Luckily, enough electrodes were brought on P06W and replacing them minimized bad measurements. Any unusual measurements (poor electrode plot / profile outlier) were reran when possible. No such interference occurred on P06E and the same electrode was used for the entire leg.

Normally after samples are collected, they are placed into a water bath to equilibrate the sample temperature near 20°C, the temperature at which the sample is measured. This is normally fine when the lab temperature is within 2°C of 20°C. The lab temperature for P06W ranged from 19°C to 25°C due to some air conditioning issues. At the beginning of the cruise, before the air conditioning was fixed, lab temperatures ranged from 20°C to 25°C. Once the air conditioning was fixed, the temperature ranged from 19°C to 22°C. This constantly delayed the titration start times. To remedy the situation, we equilibrated the sample temperatures to about 22.5°C at the start of the cruise and 20°C after the lab temperatures were more stable. This strategy enabled most of the sample temperatures to not exceed a 0.2°C range while being titrated. During P06E temperature control was not an issue.

Throughout the cruise, varying issues resulted from the Sample Delivery System. At the start of the cruise (during station 5), Sample Delivery System B would not fill the pipette completely so it was replaced with Sample Delivery System A. About a third of the way into the leg (before station 55), a shift in Sample Delivery System A's delivery volume was noticed causing smaller samples sizes to be dispensed: A calibration using a manual pipette resolved this issues. Once again, towards the end of the leg (during station 140) Sample Delivery Station A's dispensed volume shifted and another calibration was performed. No volume recalibration was required during P06E. Lastly, throughout the cruise, the Sample Delivery System's program would freeze in Deliver Sample mode or Prepare Pipette mode and caused a few sample bottles to be emptied. This resulted in lost samples due to the novice operators. Despite these issues, a minimal amount of samples were lost, and the amount of samples that were suspected of being low in volume were reran or flagged if a rerun was not possible.

7.5 Quality Control

Dickson laboratory Certified Reference Material (CRM) Batch 165 and 166 was used to determine the accuracy of the total alkalinity analyses. The total alkalinity certified value for this batch is:

- Batch 165 2214.09 $\pm$ 0.41 μmol/kg (32;16)
- Batch 166 2212.56 $\pm$ 0.39 μmol/kg

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 station analyzed resulting in 380 reference material analyses. The measured total alkalinity value for each batch is:

P06W

- Batch 165 2213.37 ± 3.94 μmol kg-1 (179) [mean ± std. dev. (n)]

And for Po6E

- Batch 165: 2212.72 1.92 μmol kg-1 (163) [mean ± std. dev. (n)]
- Batch 166: 2210.62 2.10 μmol kg-1 (26) [mean ± std. dev. (n)]

If greater than 24 Niskin bottles were sampled at a station, two Niskin bottles on that station were sampled twice to conduct duplicate analyses. If 24 or less Niskin bottles were sampled at a station, only one Niskin on that station was sampled twice for duplicate analyses.

The standard deviation for the duplicates measured are: For P06W: ± 3.52 µmol kg–1 (196) [± std. dev. (n)] For P06E. ± 0.95 µmol kg–1 (196) [± abs std. dev. (n)]

The total alkalinity measurements for each P06W stations have not been compared to measurements taken from the neighboring P06W 2017 stations and the P06W 2009 stations of similar if not identical coordinates.

3136 total alkalinity values were submitted for P06W and 2,808 for P06E. The total alkalinity of the entire transect is shown as a section in *P06W Alkalinty Section*. No corrections have been applied therefore this data should be considered preliminary until a more thorough analysis of the data can take place on shore.

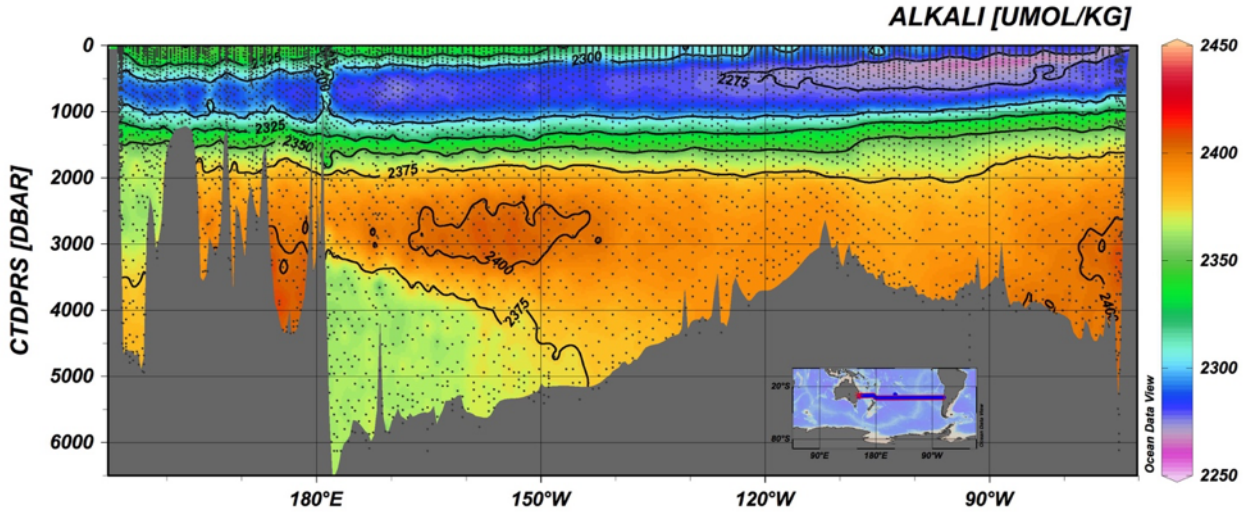


Fig. 7.1: P06W Alkalinty Section
Section of total alkalinity along P06W (Stations 1 to 143).

CHAPTER

EIGHT

DISSOLVED INORGANIC CARBON (DIC)

PIs

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

Technicians

- Julian Herndon (UW/NOAA/PMEL)
- Jacki Long (UM)

8.1 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 310 ml borosilicate glass bottles using silicone tubing. The flasks were rinsed three times and filled from the bottom with care not to entrain any bubbles, overflowing by at least one-full volume. The sample tube was pinched off and withdrawn, creating a ~6 ml headspace, followed by 0.12 ml of saturated $HgCl_2$ solution which was added as a preservative. The sample bottles were then sealed with glass stoppers lightly coated with Apiezon-L grease and were stored at room temperature for a maximum of 12 hours.

8.2 Equipment

The analysis was done by coulometry with two analytical systems (PMEL 1 and PMEL2) used simultaneously on the cruise. Each system consisted of a coulometer (CM5015-O UIC Inc) coupled with a Dissolved Inorganic Carbon Extractor (DICE). 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 (PMEL 1 and PMEL 2) were set up in the aft dry lab onboard the RVIB Nathaniel B. Palmer.

8.3 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.

8.4 DIC Calculation

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

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

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

The instrument has a salinity sensor, but all DIC values were recalculated to a molar weight (µmol/kg) using density obtained from the CTD's salinity. The DIC values were corrected for dilution due to the addition of 0.12 ml of saturated $HgCl_2$ used for sample preservation. The total water volume of the sample bottles was 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 ($\pm$ SD) correction was 0.86 $\pm$ 1.08 µmol/kg for PMEL 1 and 1.43 $\pm$ 1.57 µmol/kg for PMEL 2.

The coulometer cell solution was replaced after 25 – 28 mg of carbon was titrated, typically after 9 – 12 hours of continuous use. The average ($\pm$ SD) blanks for PMEL 1 and PMEL 2 were 15.6 $\pm$ 3.94 and 17.9 $\pm$ 4.17 counts, respectively.

8.5 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 165 CRM value. The CRM certified value for this batch is 2064.33 µmol/kg.

The precision of the two DICE systems can be demonstrated via the replicate samples. Approximately 10% of the niskins sampled were duplicates taken as a check of our precision. These replicate samples were interspersed throughout the station analysis for quality assurance and integrity of the coulometer cell solutions. The average absolute difference from the mean of these replicates is 0.76 µmol/kg.

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.

Table 1: PO6 Leg 2 Calibration data. Includes results up to station #238 of a total of 250 stations. The additional stations should not significantly change these reported values.

UNIT	L Loop	S Loop	Pipette	Ave CRM1	Std Dev	Avg rep. diff.
PMEL 1	1.003407	1.007279	27.5812 ml	2064.43, N= 61	1.08	0.74
PMEL 2	1.004569	1.002407	26.3417 ml	2065.05, N= 52	1.57	0.78

8.6 Underway DIC Samples

Underway samples were collected from the flow thru system in the Hydro Lab during transit after departing Tahiti. Discrete DIC samples were collected approximately every 4 hours. A total of 16 discrete DIC samples were collected.

8.7 Summary

The overall performance of the analytical equipment during the second leg of PO6 was very good. Including the duplicates, 3,256 samples were analyzed from 107 CTD casts and underway sampling for dissolved inorganic carbon (DIC). The distribution of DIC with depth along the second leg of PO6 2017 cruise track can be seen in Figure 1. The DIC data reported to the ODF database directly from the ship are to be considered preliminary until a more thorough post-cruise data quality review can be completed ashore.

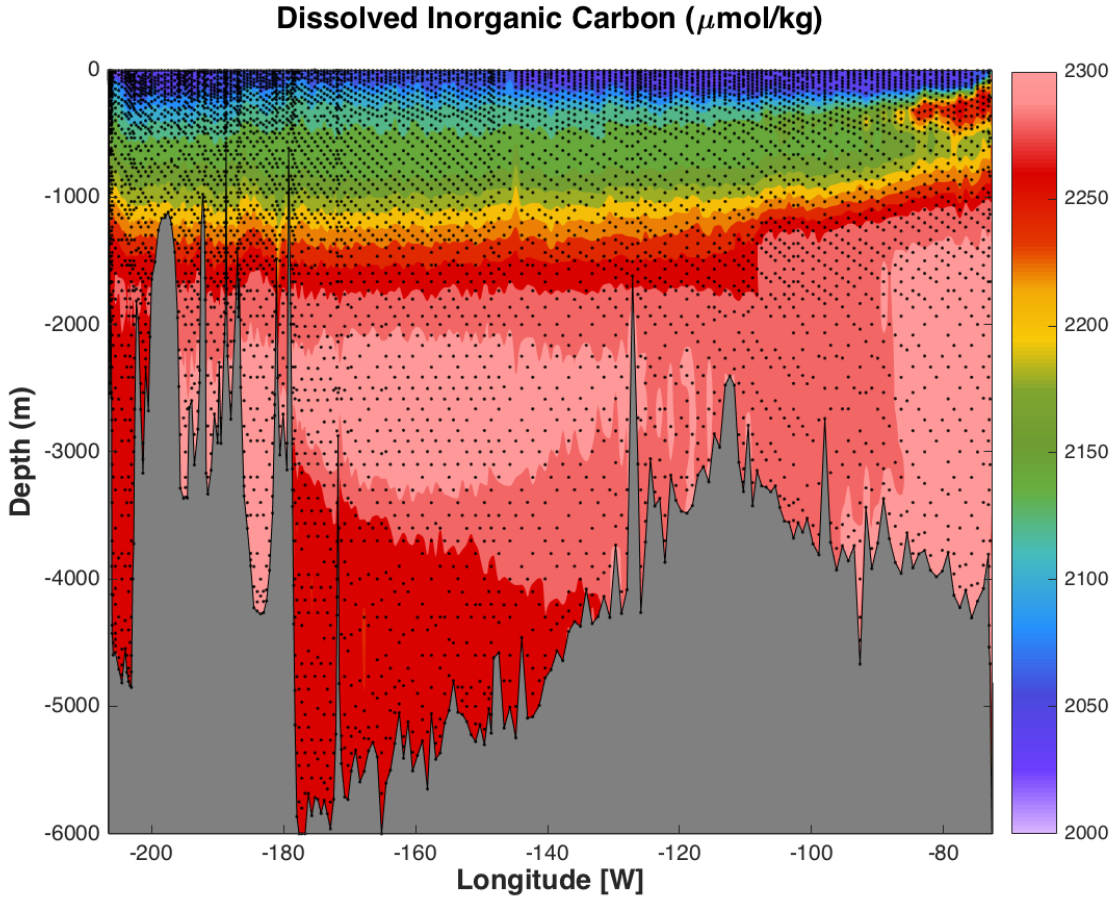


Fig. 8.1: Dissolved Inorganic Carbon. Preliminary data from Leg1 and Leg2 of PO6 2017 up to station #238. An additional 12 stations (not included here) were conducted in the Chile Trench. Courtesy of Ms. Luz Zarate, Texas A&M University.

CHAPTER

NINE

DISCRETE PH ANALYSES (TOTAL SCALE)

PI

- Dr. Andrew Dickson (P06W)
- Frank J. Millero (P06E)

Technicians

- Stephanie Mumma (P06W)
- Kaycie B. Lanpher (P06E)

9.1 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 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.

9.2 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 NESLAB RTE-7 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 immediately after the spectrophotometric measurements were taken. The indicator meta-cresol purple (mCP) was 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 conductivity sensor on the CTD.

9.3 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 four batches were used during P06, Leg 1. 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 7.75, 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]*.

9.4 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:

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

9.5 Problems and Troubleshooting

Many of the samples had a high dissolved gas content and degassed when brought to room temperature. This could be clearly seen in the formation of bubbles inside the sealed sample bottles and in the spectrophotometric pH system (Kloehn syringe pump, sample tubing, and the 10 cm cell). Bubbles were especially difficult to eliminate in the Kloehn syringe pump, which would accumulate large bubbles at the top after running a number of samples from each station. Efforts were made to reduce bubble formation by verifying all pump fittings were tight, slowing down the speed of the syringe pump, and holding samples below 25°C. When bubbles formed during station analysis, they were cleared by the aforementioned methods between samples. Bubbles were also cleared from the syringe by flushing with ethanol, followed by DI water. This method of flushing with ethanol and DI water proved to be effective and removed bubbles when accumulated. These bubbles appeared to have no affect on the samples' pH values.

On two occasions near the beginning of the P06W, the valve on the Kloehn syringe pump appeared to be "sticking" in between ports, resulting in cross-port contamination of the measured sample. The spare Kloehn pump was installed and this issue was not encountered again. The two affected Niskin samples were measured again from the original sample bottles with good results. The Labview software that controls the automated pH system crashed once during P06W, resulting in the loss of data for one measurement. The uncorrected pH values were documented in the pH lab notebook. This sample was run again and the resulting pH value for the second analysis was used for data submission.

9.6 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 165 (provided by Dr. Andrew Dickson, UCSD). Two duplicate and two replicate measurements were performed on every station when at least twenty-three Niskins were sampled. If less than twenty-three Niskins were sampled, only one duplicate and one replicate measurement were performed. CRMs were measured at the beginning and ending of each day.

The precision statistics for P06W are:

Duplicate precision	± 0.00057 (n=206)
Replicate precision	± 0.00039 (n=244)
B165	7.7598 ± 0.00104 (n=78)
B165 within-bottle SD	± 0.00026 (n=78)

The precision statistics for P06E are:

Duplicate precision	± 0.00048 (n=201)
B165	7.7085 ± 0.00085 (n=140)

3478 pH values were submitted for P06W, and 2808 on P06E. 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. The preliminary pH of the entire transect is shown as a section in Fig. 9.1.

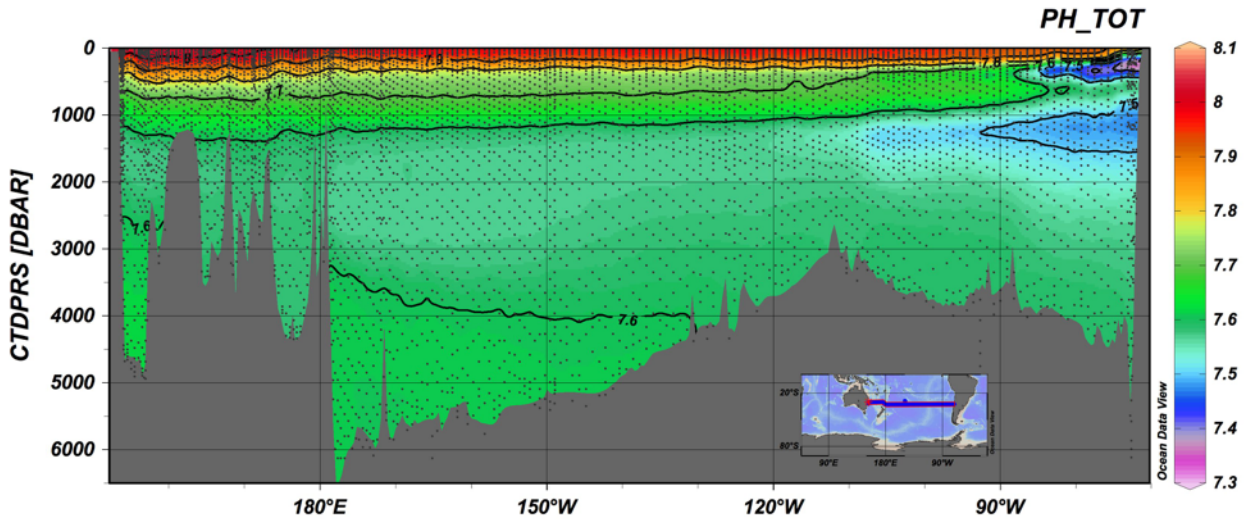


Fig. 9.1: Section of preliminary pH measurements on the total scale along P06 cruise track.

CHAPTER

TEN

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

Analysts

- Jim Happell
- David Cooper
- Kelly McCabe

10.1 Sample Collection

All samples were collected from depth using 10.4 liter Niskin bottles. None of the Niskin bottles used showed a CFC contamination throughout the cruise. All bottles in use remained inside the CTD hanger between casts.

Sampling was conducted first at each station, according to WOCE protocol. This avoids contamination by air introduced at the top of the Niskin bottle as water was being removed. A water sample was collected from the Niskin bottle petcock using viton tubing to fill a 300 ml BOD bottle. The viton tubing was flushed of air bubbles. The BOD bottle was placed into a plastic overflow container. Water was allowed to fill BOD bottle from the bottom into the overflow container. The stopper was held in the overflow container to be rinsed. Once water started to flow out of the overflow container the overflow container/BOD bottle was moved down so the viton tubing came out and the bottle was stoppered under water while still in the overflow container. A plastic cap was snapped on to hold the stopper in place. One duplicate sample was taken on every other station from random Niskin bottles. Air samples, pumped into the system using an Air Cadet pump from a Dekoron air intake hose mounted high on the foremast were run when time permitted. Air measurements are used as a check on accuracy.

10.2 Equipment and Technique

CFC-11, CFC-12, and SF6 were measured on 129 0f 143 stations for a total of 3500 samples. Salt water flooded the analytical system just after analyzing station 48, which was the cause of most of the missed stations, although some of the added stations with very short station spacing were also skipped. Analyses were performed on a gas chromatograph (GC) equipped with an electron capture detector (ECD). Samples were introduced into the GC-EDC via a purge and dual trap system. 202 ml water samples were purged with nitrogen and the compounds of interest were trapped on a main Porapack N/Carboxen 1000 trap held at ~ -20°C with a Vortec Tube cooler. After the sample had been purged and trapped for 6 minutes at 250ml/min flow, the gas stream was stripped of any water vapor via a magnesium perchlorate trap prior to transfer to the main trap. The main trap was isolated and heated by direct resistance to 180°C. The desorbed contents of the main trap were back-flushed and transferred, with helium gas, over a short period of time, to a small volume focus trap in order to improve chromatographic peak shape. The focus trap was Porapak N and is held at ~ -20°C with a Vortec Tube cooler. The focus trap was flash heated by direct resistance to 180°C to release the compounds of interest onto the analytical pre-columns. The first precolumn was a 5 cm length of 1/16" tubing packed with 80/100 mesh molecular sieve 5A. This column was used to hold back N_2O and keep it from entering the main column. The second pre-column was the first 5 meters of a 60 m Gaspro capillary column

with the main column consisting of the remaining 55 meters. The analytical pre-columns were held in-line with the main analytical column for the first 50 seconds of the chromatographic run. After 35 seconds, all of the compounds of interest were on the main column and the pre-column was switched out of line and back-flushed with a relatively high flow of nitrogen gas. This prevented later eluting compounds from building up on the analytical column, eventually eluting and causing the detector baseline signal to increase.

The samples were stored at room temperature and analyzed within 24 hours of collection. Every 12 to 18 measurements were followed by a purge blank and a standard. The surface sample was held after measurement and was sent through the process in order to "restrip" it to determine the efficiency of the purging process.

10.3 Calibration

A gas phase standard, 33780, was used for calibration. The concentrations of the compounds in this standard are reported on the SIO 2005 absolute calibration scale. 5 calibration curves were run over the course of the cruise. Estimated accuracy is $\pm$ 2%. Precision for CFC-12, CFC-11, and SF_6 was 1.2%, 1.6% and 2.5% respectively. Estimated limit of detection is 1 fmol/kg for CFC-11, 3 fmol/kg for CFC-12, and 0.1 fmol/kg for SF6

CHAPTER

ELEVEN

DISSOLVED ORGANIC PHOSPHORUS

PI

- Daniel Sigman (Princeton University)

Technician

- Dario Marconi

Marine dissolved organic matter (DOM) is considered a primary substrate for heterotrophic microbes, but can also be used by some nutrient-limited phytoplankton that especially consume dissolved organic phosphorus (DOP) when phosphate (PO_4) is scarce. However, very few measurements of surface ocean DOP concentration have been made, which limits our understanding the extent to which DOP is utilized by phytoplankton. The goal of this data collection is to increase the spatial coverage of DOP measurements to constrain the use of DOP as a nutrient source supporting export production and di-nitrogen fixation in the global marine environment.

DOP samples were collected from the upper 300 meters at stations with about two-degree longitude spacing. A total of 350 samples from 35 stations were collected. All samples were hand filtered through Whatman 25mm Puradisc 0.2µm PES filters. The syringe and filter were rinsed with 40mL of seawater before each 60mL HDPE bottle was rinsed once with 40mL of filtered seawater. All samples were stored onboard at -20°C to preserve for land based analysis.

Analysis: All samples will be analyzed for total dissolved P (TDP) using the high temperature combustion magnesium sulfate oxidation techniques modified according to Monaghan and Ruttenberg *[Monaghan1999]*. DOP concentration will be reported as the difference between the TDP concentration and the PO_4 concentration determined onboard by ODF.

CHAPTER

TWELVE

NITRATE δ^{15}N AND δ^{18}O

PIs

- Daniel Sigman (Princeton University)

Technician

- Dario Marconi

Nitrate (NO_3^-) is the dominant dissolved inorganic form of nitrogen in the oceans. As a macro-nutrient, nitrate is depleted in the surface due to biological consumption and abundant in the ocean interior due to remineralization. The dual isotopes of NO_3^- (δ^{15}N and δ^{18}O) allow us to constrain the utilization and consumption processes controlling the nitrogen cycle within the South Pacific Subtropical Gyre.

Nitrate δ^{15}N samples were collected from all depths at about every two degrees of longitude. Two 60mL samples were collected from each niskin bottle fired in the shallowest six depths. One 30mL sample was taken from all other depths. All samples collected above 400 meters were hand filtered with a BD 60mL Luer-Lok tip syringe and a 25mm Puradisc 0.2µm PES filter. The syringe and filter were rinsed with 40mL of seawater before each HDPE (both 60mL and 30mL) bottles were rinsed once with half their full volume of filtered seawater. The samples were stored onboard at -20°C to preserve for land based analysis.

Analysis: The denitrifier method *[Casciotti2002] [Sigman2001]* will be used to analyze NO_3^- δ^{15}N and δ^{18}O. Briefly, this method converts all NO_3^- to nitrous oxide (N_2O) via denitrifying bacteria before the sample is analyzed by an IRMS.

CHAPTER

THIRTEEN

DISSOLVED ORGANIC CARBON AND TOTAL DISSOLVED NITROGEN

PI

- Craig Carlson (UCSB)

Technician

- Chance English

Analysts

- Keri Opalk
- Elisa Halewood

Support NSF

13.1 Project Goals

The goal of the DOM project is to evaluate dissolved organic carbon (DOC) and total dissolved nitrogen (TDN) concentrations along the P06 zonal transect (30 to 32.5°S & 153°E to 72°W). During the P06 cruise Leg 1 (July – Aug 2017), casts were specifically targeted in order to overlap with the TCO_2 sampling program.

13.2 Sampling

DOC profiles were taken at approximately every other station from 26 of 36 niskin bottles ranging the full depth of the water column (68 stations; ~1800 DOC and 600 TDN samples. DOC samples were passed through an inline filter holding a combusted GF/F filter attached directly to the Niskin for samples in the top 500 m of each cast. This was done to eliminated particles larger than 0.7 µm from the sample. Samples from deeper depths were not filtered. Previous work has demonstrated that there is no resolvable difference between filtered and unfiltered samples in waters below the upper 500 m at the µmol kg^{-1} resolution. 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 50 µL of 4N Hydrochloric acid and stored at 4°C on board. Samples were shipped back to UCSB for analysis via high temperature combustion on Shimadzu TOC-V or TOC L analyzers.

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

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

13.3 Standard Operating Procedure for DOC Analyses- Carlson Lab UCSB

DOC samples will be analyzed via high temperature combustion using a Shimadzu TOC-V or Shimadzu TOC-L at an in shore based laboratory at the University of California, Santa Barbara. The operating conditions of the Shimadzu TOC-V have been slightly modified from the manufacturer's model system. The condensation coil has been removed and the headspace of an internal water trap was reduced to minimize the system's dead space. The combustion tube contains 0.5 cm Pt pillows placed on top of Pt alumina beads to improve peak shape and to reduce alteration of combustion matrix throughout the run. CO_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]*).

13.4 DOC calculation

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

13.5 Standard Operating Procedure for TDN analyses- Carlson Lab UCSB

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

13.6 TDN calculation

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

CHAPTER

FOURTEEN

CARBON ISOTOPES IN SEAWATER (14/13C)

PI

- Ann McNichol (WHOI)

Technician

- Chance English

A total of 27 samples were collected from 24 stations along Leg 1 of the P06 zonal transect (30-32.5°S & 153°E to 72°W). Samples were taken from only the surface bottle (~ 5m) at each station with approximately 2.5 degrees of spacing between each station. Duplicates were made at three separate stations. Samples were collected in 500 mL airtight glass bottles. Using silicone tubing, the flasks were rinsed 2 times with seawater from the surface niskin. While keeping the tubing at the bottom of the flask, the flask was filled and flushed by allowing it to overflow 1.5 times its volume. Once the sample was taken, about 10 mL of water was removed to create a headspace and 120 µL of 50% saturated mercuric chloride solution was added to the sample. To avoid contamination, gloves were used when handling all sampling equipment and plastic bags were used to cover any surface where sampling or processing occurred.

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

FIFTEEN

MARINE MICROBES, PHOSPHORUS, AND METABOLIC ENERGY POTENTIAL

PI

- Kimberly J Popendorf

Cruise Participant

- Kaycie B Lanpher

Important factors for ocean productivity are the relative availability of nutrients and the generation and storage of metabolic energy to convert these nutrients into biomass. Adenosine triphosphate (ATP) is a primary energy trafficking molecule and plays a key role in providing intracellular energy for metabolism. We are investigating ATP, as a measure for metabolic energy potential, relative to other biogeochemical parameters: biomass, community composition, and nutrient resources in two dissolved phosphorus pools. These comparisons will address the relationship between energy compounds and biomass with the availability of nutrient resources. We will be testing the hypothesis that the allocation of energy compounds as a fraction of biomass will have an inverse relationship with nutrient concentrations and will vary across a latitudinal gradient and within depth profiles. We collected data across the P06 transect in the Southern Pacific Ocean with depth profiles of the upper 200 m for cell counts and concentrations of dissolved organic phosphorus (DOP), dissolved inorganic phosphorus (DIP), particulate organic phosphorus (POP), particulate ATP, and dissolved ATP. From the cross correlations of these data we will explore the variation in microbial allocation to energy storage, the role of DOP in supporting the microbial community, and the relationship between microbial abundance and the dissolved and particulate phosphorus pools.

Samples were collected at 12 stations, 6 depths per station with a maximum at 215 m, and 3 times using the ship's flow-through system, spread out across the transect. Water was collected in a 250 mL HPDE bottle at the CTD rosette for total dissolved phosphorus (TDP), which was immediately placed in the freezer to be analyzed on land. Additionally, 2 L of water was collected from the same niskin bottles on the CTD. From this, 2 mL was taken in duplicate from each bottle and put into two cryogenic vials containing 0.5% formaldehyde final concentration. These cryogenic vials were placed in the refrigerator for 30 minutes before being stored in a dewar containing liquid nitrogen to return to the lab for analysis of cell counts. Then, 1 L of each sample was filtered using a 47mm, 0.3 um glass fiber filter. Each of those filters were boiled for 5 minutes in a 20mM Tris buffer and then frozen and returned to the lab for analysis of particulate ATP. The filtrate from three of those filters was also frozen for land-based analysis of dissolved ATP. The remaining 1 L for each sample was then filtered using the 47 mm, 0.3 um glass fiber filters, the filters were rinsed with 1 mL of 0.17 M sodium sulfate before being stored in combusted foil and placed in a liquid nitrogen dewar and returned to the lab for land-based analysis of particulate organic phosphorus (POP).

CHAPTER

SIXTEEN

NASA OCEAN BIOLOGY/BIOGEOCHEMISTRY PROGRAM

NASA Goddard Space Flight Center, Ocean Ecology Laboratory, Field Support Group

Participating team members:

- Joaquín E. Chaves
- Scott A. Freeman
- Michael G. Novak

The NASA Goddard Space Flight Center (GSFC), Field Support Group participated in the 2017 P06 Leg 2 GO-SHIP campaign on board the R/V Nathaniel B. Palmer. The campaign departed from the Papeete, French Polynesia, on August 20, 2017, and arrived in Valparaiso, Chile, on September 30, 2017. Measurements were mainly conducted along 32.5° S just south of the South Pacific Gyre, starting at approximately 149° W, along a zonal west-to-east transect ending at ~74° W off the coast of Chile.

16.1 NASA Science Objectives

The P06 campaign presented a valuable opportunity to collect in-water optical measurements concurrently with phytoplankton pigments and other biogeochemical parameters to support NASA's satellite ocean color validation across a wide dynamic range of water optical properties. The P06 line traversed from the clear, oligotrophic Gyre, to the hypertrophic waters of the Chile upwelling system. Pigment and biogeochemical samples were also collected concurrently with the deployment of SOCCOM biogeochemical ARGO floats to support their calibration.

16.1.1 Phytoplankton pigments and taxonomy, and biogeochemical measurements

Near-surface samples (~2 m) were collected for measure the concentration of phytoplankton pigments using high performance liquid chromatography (HPLC), particulate organic carbon (POC), particulate inorganic carbon (PIC), dissolved organic carbon (DOC), and spectral particulate ($a_{\mathrm{p}}(\lambda)$), and CDOM ($a_{\mathrm{g}}(\lambda)$) absorptions. Samples for the determination of phytoplankton species composition and cell abundance were also collected and preserved for later analysis. A FlowCam imaging flow cytometer (Fluid Imaging Technologies, Inc., Scarborough, ME) was used to quantitatively image live phytoplankton cells for taxonomic classification and enumeration. For the parameters above, surface samples were collected with a peristaltic pump outfitted with an acid-clean silicon rubber hose deployed over the side while on station. Additional subsurface samples from two depths within the photic zone (< 200 m) were collected from the CTD rosette at stations where concurrent optical measurements were conducted. The depths for these subsurface samples were chosen based on the location of the chlorophyll maximum. Niskins bottles were fired at and above the chlorophyll maximum, the latter depth was determined by the inflection point of the chlorophyll fluorescence above the maximum. All filtration and cold sample preservation were conducted on board. Samples were transported to NASA-GSFC for further analyses. An inventory of all samples collected for each parameter is presented in Table 16.1.

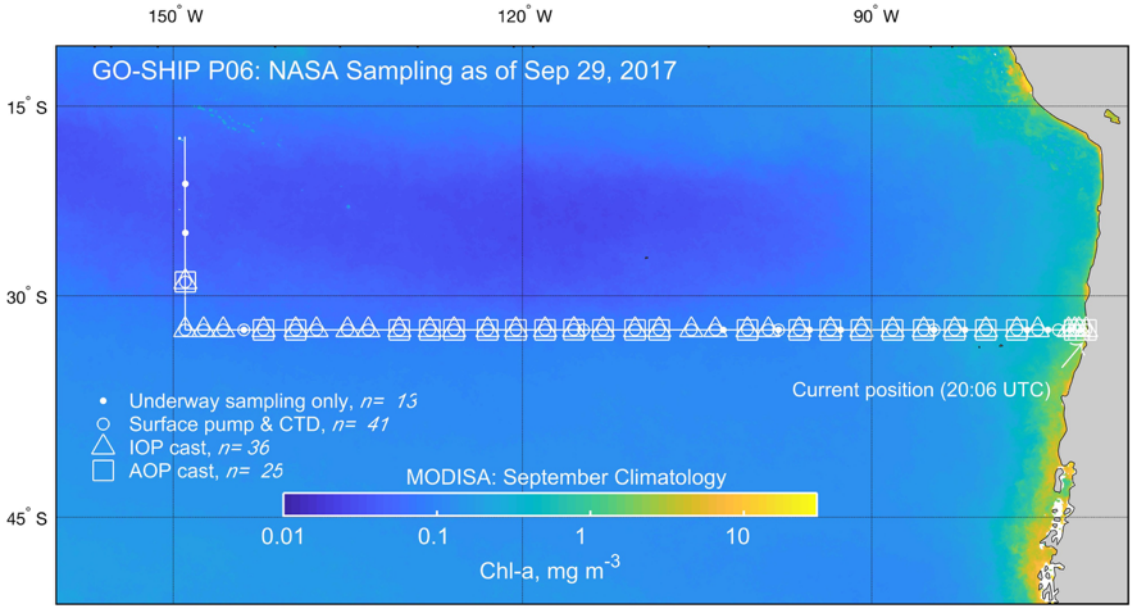


Fig. 16.1: Summary of NASA's sampling during GO-SHIP P06, 2017.

16.1.2 In-Water Optical Measurements (AOPs, IOPs)

The package to measure inherent optical properties (IOPs) was equipped with two attenuation and absorption spectrometers (ac-s, ac-9; WET Labs, Inc.). The ac-9 was equipped with a 0.2 um pre-filter to allow the in-situ measurement of spectral particulate absorption ($a_p(\lambda)$). The IOP package also included two scattering meters (bb-3, VSF-9; WET Labs, Inc.), and a Sea Bird SBE 49 CTD. The ac-s and ac-9 meters measure absorption and attenuation (and total scattering by difference) at 90 and 9 wavelengths, respectively, between 400 and 740 nm, while the bb-3 measures backscatter at 3 wavelengths and 117°. The VSF-9 measures scattering at 9 angles from 60° to 170° at 532 nm. The package performed casts down to 200m depth at 36 stations during the campaign (Table 16.2).

Apparent optical properties (AOPs), both downwelling irradiance ($E_d(\lambda)$) and upwelling radiance ($L_u(\lambda)$), were measured using a Satlantic, Inc., HyperPro radiometer system and/or a Biospherical Instruments C-OPS system. For both instrument systems, incoming solar irradiance ($E_s(\lambda)$) was measured with a matching reference radiometer. The HyperPro system measured radiance and irradiance at 255 wavelengths between 305 and 1140 nm, while the C-OPS measured the same parameters at 19 wavelengths between 305 and 900 nm. AOP measurements were conducted once daily within $\pm$ 2 h of local solar noon when weather conditions permitted down to the 20% of surface light level.

Additionally, we conducted solar radiometry at 10 stations using a Microtops Sun Photometer. The Microtops is a small, handheld instrument, which measures solar radiance at five wavelengths. These data will be incorporated into NASA's AERONET database.

16.1.3 Underway IOP Measurements

During the entire campaign, with the exception of the transit through the French EEZ, we conducted IOP measurements with an underway system that included an ac-s meter, a VSF-3 scattering meter, a bb-3 scattering meter, and a chlorophyll fluorometer. All the above instruments in the underway system are from WET Labs, Inc. A Turner integrated cavity absorption meter (ICAM) also provided absorption data at 9 wavelengths. In addition to the optical instruments, the system included a SeaBird SBE45 thermosalinograph and a Sequoia Inc. valve flow control unit, which switched hourly between whole seawater and 0.2 um filtered water to measure a_p. Twice per day, distilled water was run through the entire system to calibrate the optical instruments.

Table 16.1: Biogeochemical samples collected during the P06 campaign by the NASA team.

Parameter	Number of samples
a_p	213
a_g	122
DOC	301
HPLC pigments	226
POC	646
PIC	137
Phytoplankton abundance, taxonomy	108
Total	1753

Table 16.2: Inherent optical properties (IOPs) instrument casts during the P06 GO-SHIP campaign.

Date, UTC yyyymmdd	Beg time, UTC	Duration	End time, UTC	Station	Latitude	Longitude
20170824	00:05:26	00:10:41	00:16:07	902	-28.9596	-148.9672
20170824	00:23:01	00:30:00	00:53:01	902	-28.9596	-148.9672
20170824	22:19:54	00:30:16	22:50:10	144	-32.4996	-148.9693
20170825	20:28:41	00:29:32	20:58:13	146	-32.5009	-147.3892
20170826	20:27:47	00:29:05	20:56:52	148	-32.5001	-145.709
20170828	18:40:19	00:21:25	19:01:44	152	-32.5032	-142.2516
20170829	22:24:34	00:20:14	22:44:48	155	-32.4992	-139.4796
20170830	20:15:00	00:34:56	20:49:56	157	-32.5003	-137.6989
20170831	19:22:55	00:19:03	19:41:58	160	-32.5001	-135.0277
20170902	17:32:45	00:22:20	17:55:05	162	-32.4998	-133.2433
20170903	18:52:53	00:15:48	19:08:41	165	-32.4998	-130.5776
20170904	19:59:07	00:20:58	20:20:05	168	-32.5003	-127.9669
20170905	17:18:56	00:20:14	17:39:10	171	-32.501	-125.8766
20170906	19:03:54	00:20:58	19:24:52	175	-32.5	-122.9989
20170907	17:35:59	00:19:19	17:55:18	178	-32.4997	-120.5564
20170908	18:25:35	00:19:34	18:45:09	181	-32.4998	-118.0661
20170909	21:14:20	00:23:04	21:37:24	184	-32.4896	-115.5716
20170910	18:56:35	00:20:28	19:17:03	187	-32.5001	-113.0855
20170911	18:17:36	00:20:06	18:37:42	191	-32.5001	-110.3258
20170912	18:03:34	00:21:51	18:25:25	194	-32.5	-108.256
20170913	18:52:25	00:26:43	19:19:08	198	-32.5	-105.4966
20170914	18:54:19	00:26:28	19:20:47	201	-32.5002	-103.4259
20170915	19:49:13	00:23:12	20:12:25	205	-32.5005	-100.6656
20170916	15:29:38	00:24:19	15:53:57	207	-32.5002	-98.8853
20170917	15:06:44	00:19:53	15:26:37	210	-32.5004	-96.2146
20170918	15:57:44	00:20:38	16:18:22	213	-32.4998	-93.544
20170919	17:00:21	00:22:07	17:22:28	216	-32.5031	-90.8778
20170920	17:25:56	00:22:16	17:48:12	219	-32.4999	-88.205
20170921	15:12:56	00:22:22	15:35:18	222	-32.4999	-85.5353
20170922	15:47:19	00:21:52	16:09:11	225	-32.5008	-82.8655
20170923	16:25:33	00:21:32	16:47:05	228	-32.5002	-80.1938
20170924	16:39:59	00:22:34	17:02:33	231	-32.5002	-77.5246
20170925	13:20:32	00:20:35	13:41:07	233	-32.4997	-75.7453
20170926	15:44:33	00:32:15	16:16:48	237	-32.5004	-73.0834

Continued on next page

Table 16.2 – continued from previous page

Date, UTC yyyymmdd	Beg time, UTC	Duration	End time, UTC	Station	Latitude	Longitude
20170927	15:34:50	00:25:36	16:00:26	241	-32.5001	-72.5573
20170928	16:45:02	00:24:58	17:10:00	245	-32.5	-72.1956
20170929	13:32:31	00:10:31	13:43:02	250	-32.5005	-71.585
20170929	13:48:52	00:22:06	14:10:58	250	-32.5172	-71.585

Table 16.3: Apparent optical properties (AOPs) instrument casts during the P06 GO-SHIP campaign.

Date, UTC yyyymmdd	Beg time, UTC	End time, UTC	Station	Latitude	Longitude	Sky conditions, % clouds
20170823	21:15:00	21:25:00	902	-28.9638	-148.9673	100
20170823	21:26:00	21:30:00	902	-28.9638	-148.9673	60
20170828	19:07:00	19:22:00	152	-32.5032	-142.2516	50
20170829	22:07:00	22:20:00	155	-32.4992	-139.4796	100
20170903	19:15:27	19:17:25	165	-32.4998	-130.5776	60
20170903	19:17:32	19:25:00	165	-32.4998	-130.5776	60
20170904	20:26:49	20:41:22	168	-32.5003	-127.9669	40
20170905	17:39:03	17:40:21	171	-32.501	-125.8766	10
20170906	19:35:14	19:45:43	175	-32.5	-122.9989	30
20170907	18:12:00	18:14:00	178	-32.4997	-120.5564	10
20170907	18:14:00	18:18:00	178	-32.4997	-120.5564	10
20170908	18:53:00	19:12:00	181	-32.4998	-118.0661	80
20170909	20:37:48	21:05:00	184	-32.4896	-115.5716	30
20170910	19:25:42	19:41:27	187	-32.5001	-113.0855	60
20170911	18:52:25	19:04:08	191	-32.5001	-110.3258	10
20170912	18:53:38	18:45:35	194	-32.5	-108.256	30
20170915	20:24:25	20:31:05	205	-32.5005	-100.6656	80
20170917	15:32:56	15:36:41	210	-32.5004	-96.2146	40
20170917	15:47:00	15:50:42	210	-32.5004	-96.2146	40
20170918	16:26:28	16:38:05	213	-32.4998	-93.544	30
20170919	17:37:59	17:46:28	216	-32.5031	-90.8778	30
20170920	17:56:45	18:19:43	219	-32.4999	-88.205	80
20170920	17:56:45	18:19:43	219	-32.4999	-88.205	80
20170921	15:47:37	16:03:20	222	-32.4999	-85.5353	100
20170921	15:47:37	16:03:20	222	-32.4999	-85.5353	100
20170922	16:22:07	16:33:07	225	-32.5008	-82.8655	100
20170923	16:57:17	17:06:51	228	-32.5002	-80.1938	100
20170924	17:03:52	17:12:40	231	-32.5002	-77.5246	20
20170927	16:31:32	16:43:45	241	-32.5001	-72.5573	40
20170928	17:23:11	17:36:41	245	-32.5	-72.1956	40
20170929	14:20:04	14:30:13	250	-32.5172	-71.585	100

CHAPTER

SEVENTEEN

LADCP

PI

- Dr. Andreas Thurnherr

Cruise Participant

- Elizabeth Simons

LADCP was collected during full depth CTD casts at all stations by Elizabeth Simons and Lena Schulze. Preliminary processing and QC was made on board by Elizabeth Simons. Approximately every 5 casts or when data was questionable post-processed data was sent to Andreas Thurnherr for further review and QC.

17.1 LADCP system configuration

An upward-looking (UL) and a downward-looking (DL) ADCPs 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 the rosette bottom center bar.

A star cable was used to connect both UL and DL LADCPs to the battery and deck/connection cables.

While on deck, two communications and one power cable ran from the aft dry lab to the baltic room where the ctd package rested while on 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.

Two different ADCP instruments were used during the cruise. The Teledyne RDI WHM150 (S/N:24544) as DL and the Teledyne RDI WHM300 (S/N:24997) as the UL. The battery package was a Deepsea Power and Light SB 48 V/16 A (S/N: 01283). 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.

DCP programming and data acquisition were carried out by Elizabeth Simons and Lena Schulze using the LDEO Acquire software running on a MAC computer. Prior to each cast, the corresponding command files were send to both the UL and DL ADCPs, 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 the baltic room to the dry aft lab. The battery remained connected to the charger between stations. The battery pack was periodically vented manually to prevent pressure build up. Log files were kept for each cast with LADCP and CTD information to ensure all steps were made properly.

17.2 Problems/Setup changes

The battery package from Leg 1 was overcharging and needed to be vented after every cast so it was replaced after the test cast (902). After station 161 a pigtail connection between the on deck power and star cable was crushed while landing the rosette on deck. It was replaced with a spare before station 162, and more fully secured. After the initial stations, it was noted that the DL instrument was seated lower on the rosette. It turned out that the bracket the instrument was attached to was slightly twisted and tilting the DL forward, bringing it closer to the floor. After a rough landing on deck due to rough seas, skids were attached to the bottom of the rosette cage, gaining enough clearance for the heads of the DL to clear the floor. The DL was rotated so the broken beam 3 was looking at the top of the skid to reduce signal contamination in the working heads.

Communication issues with the LADCP started early, with multiple files created for the UL instrument and occasional trouble interacting with the both the UL and DL. It was assumed that the star cable was faulty, but working. An extra star cable was hand carried to the ship for Leg 2, and held in reserve for when the cable on the rosette failed completely. After station 219, the star cable was replaced with the new cable.

At the beginning of station 220 there were problems with power to the instruments and on recovery the UL and DL would not communicate using either LADCP2 command or interact2 command. Partial communication was restored before station 221, however due to time constraints only the DL was set-up to record. Once on board after station 221, troubleshooting found a bad link between the UL and UL deck cables through the replacement star cable. The star cables were switched again, with the original faulty, but working cable reattached on the rosette. The broken star cable was found to have a bad RS232 wire on the UL connected side of cables. This was repaired by the ETs (Sheldon Blackman and Julian Race) on board, bypassing the faulty section on the cables. The original star cable remained in place on the rosette, with the repaired replacement as a back-up. After the last cable switch, the original star cable operated acceptably.

- Station 144: Manually downloaded data.
- Station 175: Manually downloaded data.
- Station 183: No UL data.
- Station 194: Difficulty communicating.
- Station 200: Manually downloaded data.
- Station 214: Difficulty communicating with UL.
- Station 219: Communication issues and multiple files were downloaded.
- Station 220: Manually downloaded data.
- Station 221: Only DL data.

Multiple stations had multiple files associated with the UL. Some were the result of user error, usually disconnecting direct power before comms were established, others were caused for unknown reasons.

17.3 Data Processing and Quality Control

The ADCP data was processed daily by Elizabeth Simons 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 5 stations or when questionable profiles were observed.

Available for download at http://www.ldeo.columbia.edu/LADCP

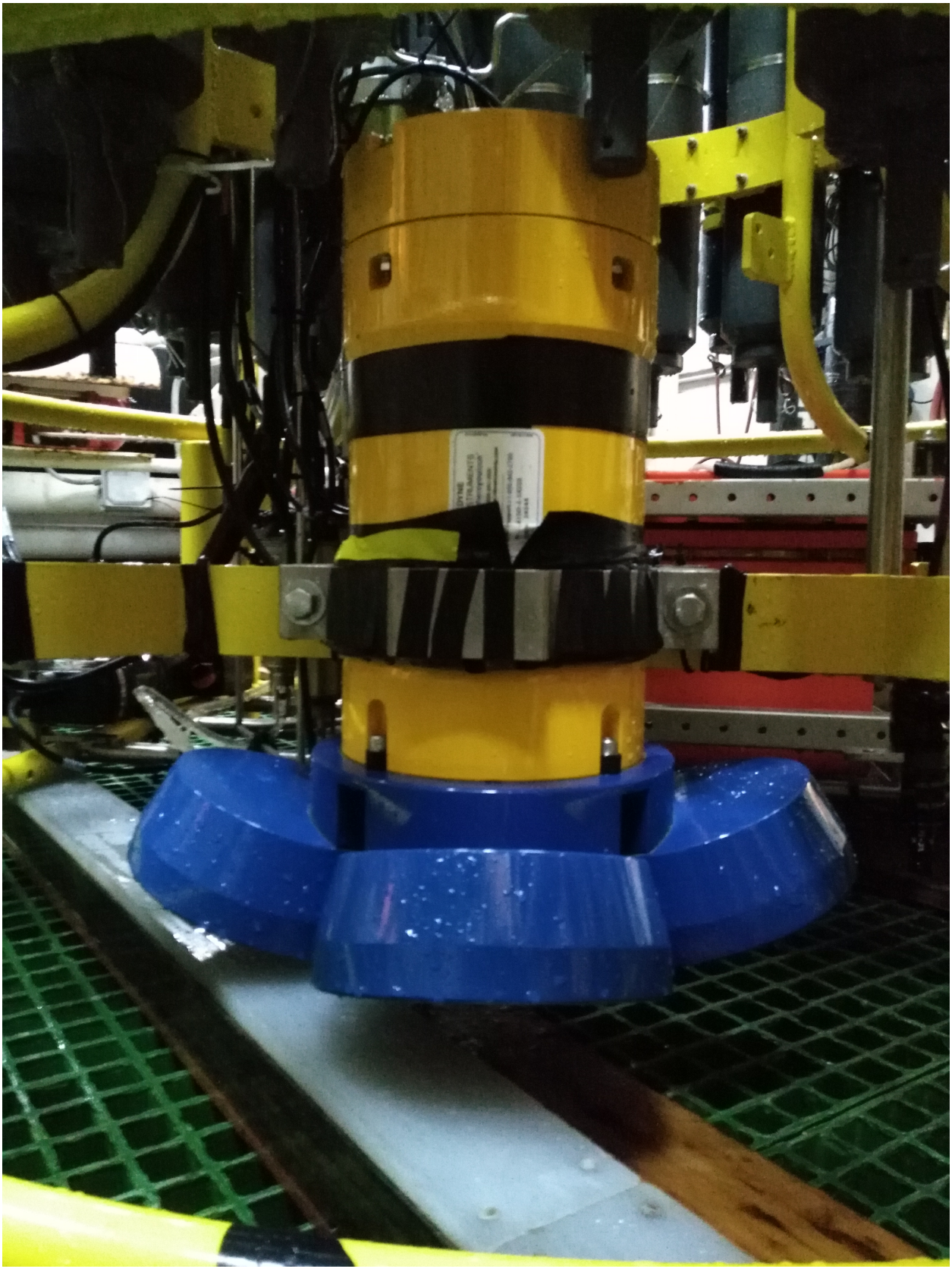


Fig. 17.1: Downward looking ADCP

Fig. 17.2: Upward looking ADCP

CHAPTER

EIGHTEEN

CHIPODS

PI

- Jonathan Nash

Cruise Participants

- Ratnaksha Lele
- Sherry Chou

18.1 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.

18.2 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	Station Numbers
2025	Ti 44-7	Up	1-143, 902, 144-168
2030	Ti 44-11	Up	1-107, 169-250
2032	Ti 44-15	Down	1-143, 902, 144-172
2027	Ti 44-3	Down	173-250
2027	Ti 44-3	Up	112-143, 902
2026	Ti 44-2	Up	144-146
2031	Ti 44-6	Up	147-250

Fig. 18.1: Chipod pressure case attached on the rosette

18.3 Data

18.3.1 Leg 1

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 once every day to ensure proper functioning and data collection. SN2030 was replaced by SN2027 before cast 112 due to problems with file acquisition and communicating with the device possibly due to a memory card issue. SN2030 memory card and batteries were replaced soon after.

18.3.2 Leg 2

On 8/24/17 we had a test cast at Station 902. Loggers SN2025 (uplooker), SN2027 (uplooker), and SN2032 (downlooker) were deployed. For this test cast logger SN2027 recorded zeros for temperature and acceleration values, and the other two loggers recorded normal looking data. Logger SN2027 was switched out and SN2026 took its place (batteries inside the units were switched because those from SN2027 were newer). For the first CTD cast, at Station 144, logger SN2026 recorded normal temperature values but the acceleration values were low compared to the other units. The problem continued during the next 2 CTD casts (Stations 145-146). Logger SN2026 was switched out and SN2031 took its place starting with Station 147. Data from the 4th CTD cast of Leg 2, at Station 147, looked fine for all three deployed loggers: SN2025, SN2031, and SN2032 (except that there are vertical lines in the plots for data from SN2032 at 3:30 on 08/26/17).

Loggers SN2032 and SN2025 both had problems on 09/2/17 and didn't record data for Stations 164-168; they both show corrosion on usb connector plug (pictures were sent to June Marion).

On 9/6/17 logger SN2032 couldn't communicate with computer and it was switched out with SN2027.

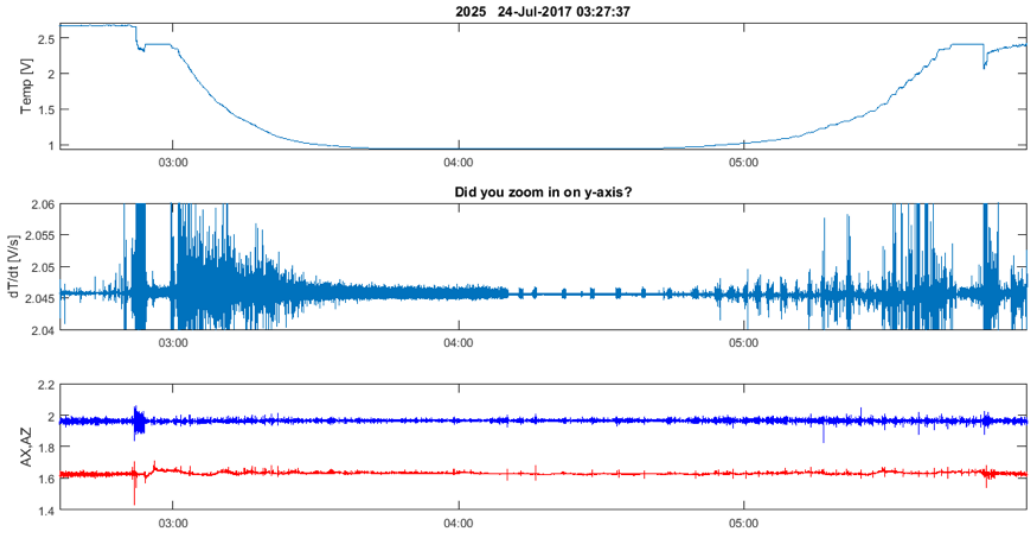


Fig. 18.2: A typical plot of chipod raw data

Chipod sensors seemed to be working fine and loggers were recording data, but there were continued problems with downloading data. The computer program for getting data from loggers froze often, especially with logger SN2031 (uplooker). Logger SN2031 did not record data for Stations 185-188. Frequency of downloading data was decreased, as advised by Jonathan Nash.

On 9/19/17, data was retrieved from logger SN2027, but there were multiple problems with the other 2 loggers. Logger SN2031 froze the computer program but did not need to be power-cycled; files 78-79 showed incorrectly large maximum time values but otherwise the data seemed fine - this had happened before and reloading the file had removed the problem.

Logger SN2030 (uplooker) froze the computer program and then did not record data for Stations 215-216. On 9/29/17 data was successfully downloaded from all 3 loggers after the last cast.

Status of Spares Logger SN2026 recorded low acceleration values, it was switched out (with SN2027) on 8/24/17.

Logger SN2025 might have had a faulty memory card, it was switched out (with SN2030) on 9/6/17 and a new memory card was installed.

The “insides” of SN2026 and SN2025 were switched because SN2026 had a newer usb plug but unidentified hardware issue, and this way SN2026 was ready to use.

Logger SN2032 was switched out (with SN2031) on 9/6/17 due to problem recording data (possibly related to corroded usb plug).

Summary Data was attained by (at least one) uplooking chipod for all stations. For the downlooking chipod there is no data for Stations 164-172.

CHAPTER

NINETEEN

FLOAT DEPLOYMENTS

During P06E 2017 a total of 35 profiling floats were deployed, which were part of several programs: 16 UW Argo, 15 SIO SOLO II, and 4 biogeochemical SOCCOM floats. Elisabeth Simons was responsible for all deployments, recording and communicating their deployment details to the various PIs of the programs. The assistance from the ASC marine technicians was necessary for all deployments, first because it was required for any operation on the back deck, and second in order to reduce any possible difficulties with the floats' deployment. Each deployment occurred with the use of line strung to the float, with one end of the line tied to a cleat and the other held by the technician. Deployments were always done on departure from a CTD station while the ship was steaming at 1 knot. Before the deployment, the marine technician communicated with the bridge to disengage the propeller on the side of the deployment, in order to avoid any risk of having the float going through the propeller. The cruise participant was primarily responsible for deployments, with additional assistance from CTD watchstanders. Elisabeth Simons oversaw operations on the midnight to noon watch, while Lena Schulze oversaw operations on the noon to midnight watch.

A 10-day cycle is set for the UW Argo, SOLO II, and SOCCOM floats: after an initial dive to a parking depth of 1000m, the floats drift for 10 days with the ocean currents at this depth; after a subsequent dive to 2000m, the floats then ascend to the surface, during which data are collected. The 2000m-surface data profiles are then sent to shore via satellite, using an antenna located at the top of the float. Measurements comprehend temperature, salinity, pressure and additional biogeochemical measurements for the SOCCOM type.

The SIO Deep SOLO profiling floats have a different cycle: they dive down to the full ocean depth and drift at 5000 dbar, or 500 dbar shallower than the bottom, with a cycle of approximately 15 days, in order to balance data collection with battery life.

Each of these floats was self-activating, so no initial operations where required before their deployment to activate them, except for the case of Deep SOLO floats for which John Gilson sent some commands few hours before their deployment.

In the following, each float program is discussed.

19.1 SOCCOM floats

PIs

- Steve Riser
- Ken Johnson
- Lynne Talley

Two 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. So far, SOCCOM has 86 active floats, and the data are available to the public at http://soccom.princeton.

edu/content/float-data. The floats are equipped with CTD, oxygen (Anderaa optode 4330), nitrate (MBARI/ISUS), FLBB bio-optical (Wetlabs) and pH (Deep-Sea DuraFET) sensors. Data acquisition is made available through Iridium Satellite communication and GPS.

Rick Rupan and Andrew Meyer (UW) tested each float (for both leg 1 and leg 2 of the P06 occupation) at the beginning of the voyage during the port call in Sydney, Australia. They found a malfunction on one of the floats assigned to leg 2, and this float has been sent back to UW for investigation and repair.

Before the deployment of each float, the fluorometer/backscatter and the pH sensors were carefully cleaned using lens paper, 99% isopropyl alcohol and DI water. The procedure required the use of a line strung through the deployment collar of the float. Each deployment occurred on the starboard side, mid-ship, while the ship was steaming at no more than 1 kn. No issues were encountered during the deployments.

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 2500m. Samples for HPLC and POC analyses were taken from the Niskin bottles, tripped as duplicates, at the surface and at the chlorophyll maxima depths. These samples will be sent to the U.S., where NASA (HPLC) and UCSB (POC) groups will perform the analyses. On board, only the filtration of the samples was required. Full-depth samples of other ocean properties (salts, pH, nitrate, oxygen) were collected and analyzed by the different groups on board, in order to calibrate the floats' sensors. In particular, pH samples were collected and analyzed by personnel from U Miami, Millero lab; dissolved inorganic carbon samples by personnel from AOML and PMEL; oxygen, nitrate and salinity samples by the ODF group at SIO.

After the deployment, the cruise participant recorded the details and sent them to the SOCCOM PIs. The location and date of the float deployments are indicated in the table below, with hull and serial numbers, list of parameters measured by the floats and the CTD cast at the location of deployment. Both floats have reported their first profiles and their sensors are working well.

Table 19.1: summary of the deployment details of the four SOCCOM floats

Float I.D.	Inst./Prog.	Date (UTC)	Lat	Lon	P06 Stn	Depth	Confirm (Y/N)
12396(2)	SOCCOM	31/08/17 23:45	32 30S	135 01.65W	160	4375	Y
8204(2)	SOCCOM	10/9/17 04:52	32 29.887S	114 44.59W	185	2800	Y
12369	SOCCOM	22/09/17 03:17	32 30.00S	084 37.746W	223	3930	Y
12540(4)	SOCCOM	26/09/17 06:50	32 30.0737S	073 57.8215W	235	4100	Y

19.2 SIO floats

PIs

- Dean Roemmich
- John Gilson

15 SIO SOLO II floats were deployed during the cruise. The SIO SOLO II are part of a global 3°x3° array. The float is programmed to do a first dive, and to come back to the surface after one hour. The data of this first dive are used by the SIO team to check that the float is working correctly. We have received confirmation that all the floats have reported correctly after one hour, and their data look good.

These floats were deployed in their original bio-degradable cardboard boxes, as requested, in order to prevent any damage. Two bands of soluble PVA tape were placed around the box, in order to hold it together. 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 at the top, and then secured on the other end to a cleat.

Each deployment proceeded smoothly, with the exception of SIO float 8568. A stabilizing disk was lost on 8568. This float's water release did not function properly so the float was released under rougher conditions. After each deployment, the details were recorded by the scientist responsible for the deployment and sent to John Gilson by the cruise participant. The location and date of the SIO float deployments are indicated in the table below, with serial numbers, CTD cast at the location of deployment and name of the personnel who deployed the floats.

Table 19.2: summary of the deployment details of the 15 SIO SOLO II floats

Float I.D.	Date (UTC)	Lat	Lon	P06 Stn	Depth	Confirm (Y/N)
8556	25/08/17 21:04	32 30.0948S	147 23.3340W	146	4570	Y
8557	28/08/17 14:12	32 30.0316S	143 02.5397W	151	5100	Y
8558	30/08/17 11:47	32 29.9881S	138 35.3137W	156	4575	Y
8559	3/9/17 19:26	32 30.3797S	130 34.5309W	165	4115	Y
8560	5/9/17 11:11	32 29.894S	126 18.517W	170	3134	Y
8562	6/9/17 23:26	32 30.0057S	122 59.6086W	175	3550	Y
8563	8/9/17 13:37	32 30.0023S	118 53.7286W	180	3500	Y
8564	10/9/17 12:09	32 30.0098S	113 54.7810W	186	2960	Y
8565	11/9/17 08:09	32 30.0378S	111 42.2823W	189	2472	Y
8566	12/9/17 18:49	32 30.4237S	108 15.6862W	194	3209	Y
8567	15/09/17 14:30	32 30.00S	102 44.131W	202	3686	Y
8568	18/09/17 16:38	32 30.358S	093 32.839W	213	3710	Y
8569	19/09/17 17:40	32 30.1856S	090 52.669W	216	3910	Y
8570	21/09/17 02:08	32 30.0902S	87 19.0324	220	3870	Y
8571	25/09/17 05:13	32 30.0787S	076 38.1230W	232	3966	Y

19.3 UW floats

PI Steve Riser

16 UW floats have been deployed during P06 leg 1, as part of the global Argo array. Rick Rupan and Andrew Meyer had tested the floats, during the port call in Sydney, Australia. The floats were all successfully deployed, with no issues. After the deployment, the details were recorded by the scientist responsible for the deployment and sent to Steve Riser, Dana Swift and Rick Rupan by the cruise participant. 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 19.3: summary of the deployment details of the 16 UW floats

Float I.D.	Date (UTC)	Lat	Lon	P06 Stn	Depth	Confirm (Y/N)
12444(9)	27/08/17 06:48	32 29.863S	144 49.334W	149	6185	Y
6963(5)	29/08/17 08:36	32 30.015S	141 15.559W	154	5000	Y
12643(9)	31/08/17 05:52	32 29.85S	136 48.421W	158	4421	Y
12550	4/9/17 12:05	32 30.0057S	128 47.8830W	167	4279	Y
12426(10)	6/9/17 01:05	32 30.015S	125 10.11W	172	3750	Y
12374(6)	7/9/17 14:03	32 30.0137S	121 20.1727W	177	3190	Y
12420(10)	9/9/17 06:00	32 29.85S	117 14.01W	182	3300	Y
12428(11)	10/9/17 19:45	32 30.01S	113 06.84W	187	2400	Y
12770(6)	11/9/17 22:35	32 29.944S	110 19.511W	191	3350	Y
12611(11)	13/09/17 08:30	32 29.8814S	106 52.4863W	196	3278	Y
12626(12)	16/09/17 15:50	32 30.0169S	098 53.1386W	207	3820	Y
12623(12)	17/09/17 15:55	32 30.4816S	096 13.5855W	210	3940	Y
12608(13)	19/09/17 08:56	32 29.9966S	091 45.9192W	215	3480	Y
12644	20/09/17 09:26	32 30.1707S	089 05.7669W	218	3380	Y
12609	21/09/17 19:45	32 30.00S	085 31.96W	222	3720	Y
11096(14)	22/09/17 20:11	32 30.00S	082 51.899W	225	3730	Y

CHAPTER

TWENTY

DRIFTER DEPLOYMENTS

PI

- Shaun Dolk (*AOML*)

Cruise Participants

- Elizabeth Simons

Six drifters were deployed on P06E 2017 for the Global Drifter Program. Elizabeth Simons was responsible for deployment of the drifters, and the CTD watchstanders of each shift helped with the deployment. Secondary assistance was provided by ASC Marine Technicians.

The simple deployment process involved: (1) removing the plastic wrapping from the drifter; (2) carrying the drifter to the back deck; (3) deployment of the drifter, after received confirmation from the bridge; (4) recoding of the deployment details. In case two deployments were required at the same location, the drifter release occurred with 30 seconds of distance between each other, in order to avoid any entanglement amongst the drifters' drogues. After the deployment, the scientist responsible for the operation recorded the details from the monitor in the wet lab, wrote them in the log sheet and Elizabeth Simons sent the details to Shaun Dolk at AOML. The Table below reports the details for each deployment.

Table 20.1: Table of deployments of the six drifters

Float I.D.	Date (UTC)	Lat	Lon	P06 Stn	Depth
64829530	25/08/17 12:24	32 30.073S	148 10.879W	145	4603
64831280	19/09/17 17:40	32 30.1856S	090 52.669W	216	3910
64829550	20/09/17 01:50	32 30.08S	089 58.95W	217	3713
64829040	20/09/17 18:09	32 30.005S	088 12.299W	219	3680
64828490	21/09/17 10:10	32 30.0263S	086 25.5327W	221	3960
64828500	22/09/17 03:29	32 30.00S	084 37.753W	223	3950

CHAPTER

TWENTYONE

STUDENT STATEMENTS

21.1 Cristobal Aguilera

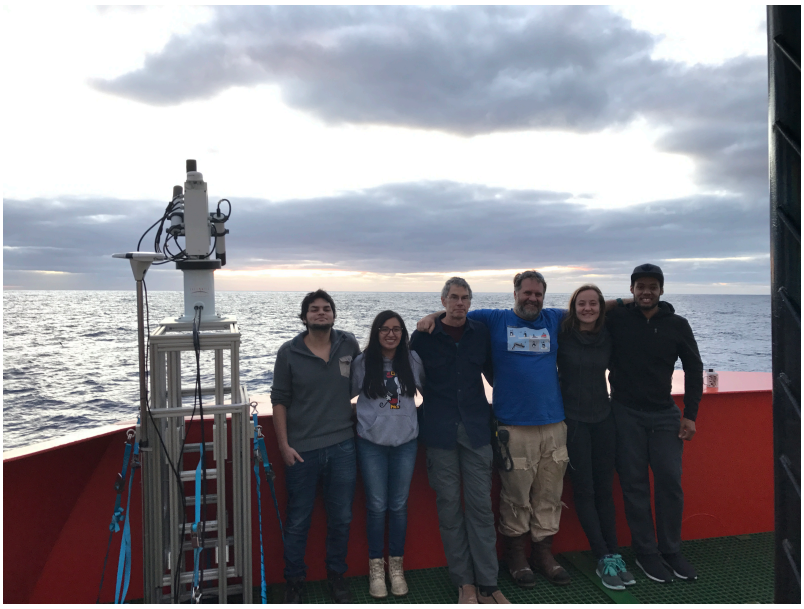


Fig. 21.1: In the picture, from left to right: me, Luz, Dr. Speer, Rich (MT), Lucie (fellow student), and Kenny.

I guess I could say I got into this cruise for pure chance, or sheer luck. My advisor was supposed to come, but he couldn't find the time: too many obligations and duties. After him, his right hand man was the next on the line, but he couldn't either, for the same reasons. So here I am, almost at the end of this fantastic experience! I had high expectations for what this cruise would be, but they were far surpassed. I have met a lot of fun people onboard the Nathaniel B. Palmer, and a 40 days long ship adventure is something to be lived! I actually didn't even realize how the days passed by: it looked like we were just starting, and now we are a few miles from land. Part of that may be due to the huge amount of work to be done; no rest for CTD watchstanders! (Not to mention the super fun ping-pong tournament!!) But I think it's just that when you enjoy what you do, time flies. I'd like to mention my fellow watchstanders Luz, Kenny, Dario, Rudi and Cherry, they were all really nice and spending time and working with them was easy and rewarding.

On a more academic side, this cruise experience will undoubtedly leave its mark in my academic life. As a physical oceanographer in formation, this hands-on experience has helped me to get a better understanding on how the oceanographic data is acquired. On campus, we students are often used to only use the data, without thinking or taking into consideration how the data was collected, where does it come from. Being outside, on the actual open ocean, has given me a different perspective, has helped me to set the idea that data are not just numbers in a matrix. Great efforts must

be done to acquire it, and good quality data is not being produced by itself. As part of my duties onboard, I had to make some plots of the data we were collecting. Here is an example of what we have been up to:

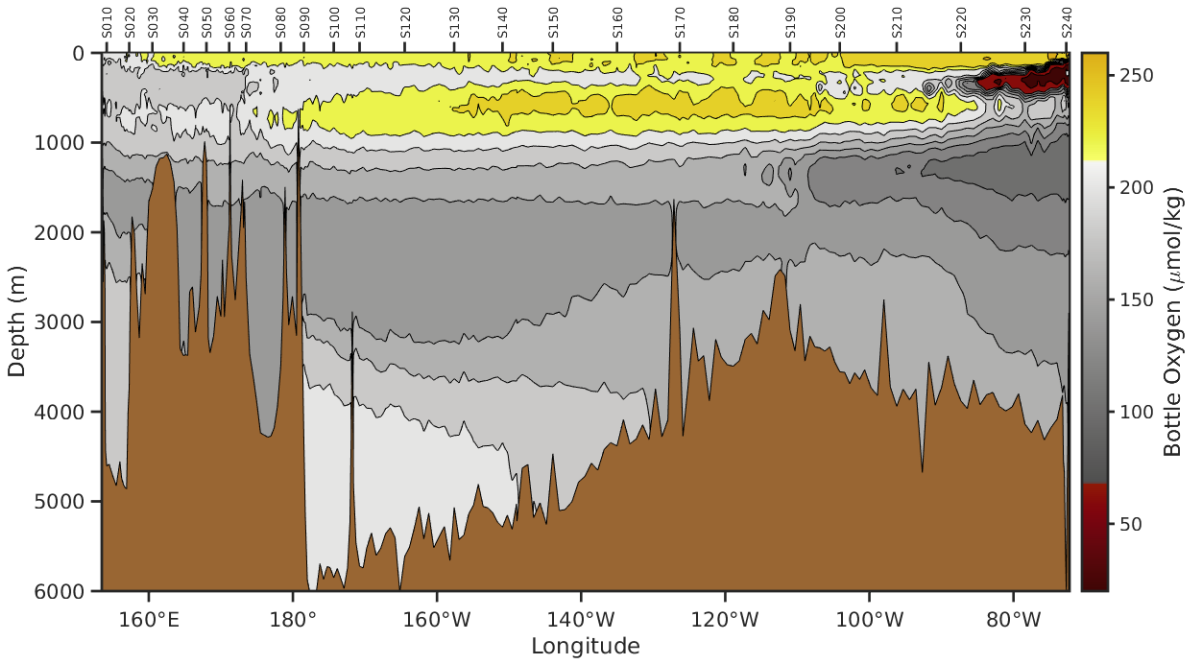


Fig. 21.2: Cross-section of the bottle dissolved oxygen concentration along 32.5ºS

As some final words, I just want to point out that this was a great experience overall, I have made links and bounds that will remain in time, and I have actually been lucky enough to get a master's degree thesis project off this journey, in collaboration with Dr. Kevin Speer. So there is no doubt for me that it was definitely worth it!

21.2 Dario Marconi

Take a walk on the wild side.... I started the cruise that I was seek as I have never been. When Ken was taking my temperature on Day 1 I thought: well, I guess that my time on the ship finishes now. Nope, the antibiotics did their job. I recovered, lost weight and I leave the ship in great shape. Thanks Ocean to clean my body and make my mind sharper: "mens sana in corpore sano". Thanks to my team: Lena, Rudi and Cherry. I return home with an amazing dataset for nitrate isotope analyses. In my previous work I studied Nitrogen fixation in the Atlantic, a basin that does not host significant rates of water column denitrification. It's now time to use my tool bag in the Pacific where N fixation and denitrification are co-occurring in the same basin. Buon vento to whom will sail on the NBP in the next future!

21.3 Lucie Knor

GO-SHIP P06E from Pape'ete to Valparaíso was my first experience at sea, and a wonderful one at that. I helped David Cooper and Charlene Grall with sampling and analysis of chlorofluorocarbons (CFCs) and sulfur hexafluoride (SF6), anthropogenic gaseous compounds that are used as tracers for ocean circulation and ventilation. I learned how to sample CTD casts for volatile gases, and how to measure CFCs and SF6 using a gas chromatograph. Throughout both smooth routine and white-knuckle troubleshooting, I was impressed with David and Charlene's patience and insight, and I consider myself lucky to have learned from them.

Fig. 21.3: Photo: Joaquín Chaves

The 42 days on the Nathaniel Palmer made me realize that I have chosen the right field, and I want to thank GO-SHIP for providing me with the opportunity to get to this very satisfying conclusion. My traveling companions all had interesting things to say about their various projects, from nitrate isotopes and dissolved organic carbon to Pacific water masses and ocean color remote sensing. I especially enjoyed hearing about the on-the-ground research for NASA's earth observing satellites.

I'm looking forward to crossing paths again with the scientists and crew I got to know on this adventure.

21.4 Luz Zarate-Jimenez

First of all, I would like to extend my gratitude for the opportunity to participate on this oceanographic research cruise. This at-sea experience has broadened my vision, allowing me to interact with and learn from researchers in different fields and made me appreciate the opportunity of being part of an international effort to improve the understanding of the ocean and its variability. The scientific team and crew of the vessel were beyond professional at all times and shared the common goal of creating a successful oceanographic expedition. Being surrounded by such knowledgeable and committed scientists enhanced my interest in learning more and participating actively within the scientific community.

Part of my duties as watch-stander included preparing the rosette before every cast to ensure the proper collection of water, monitoring the deployment and descent of the CTD, communicating with the winch operators to adjust speed, recording depths of interest (including O2 minimum and maximum and chlorophyll maximum), as well as firing the Niskin bottles using the right depth scheme. Once the rosette was on board, I supported the sampling personnel serving as "sample cop", helping to ensure that each research group was able to get the water they needed. With practice, being a CTD operator along with Cristobal Aguilera was enjoyable and fun. Keeping track of the changes in temperature, salinity, and oxygen both vertically (depth) and horizontally (west to east transect), provided us with enough material to have discussions about the variations that we were observing. Most of the time, these discussions were led by Dr. Kevin Speer, whom I will always remember for being a challenging mentor from whom I have learned a lot during these last weeks.

Dr. Kevin encouraged critical thinking among the students. One of my favorite activities was spending time with

Dr. Speer and Cristobal looking at the bathymetric plots to decide the best location and estimate the timing for the next station. Also, Dr. Speer kept the watch-standers engaged with the data analyzed by the chemists. To do so, we helped produce different sections for the properties being analyzed during the cruise, so that the chemists could detect important changes or problems with the data as we continued our transect along the 32ºS line. Some of these properties included salinity, temperature, oxygen, alkalinity, pH, and dissolved inorganic carbon.

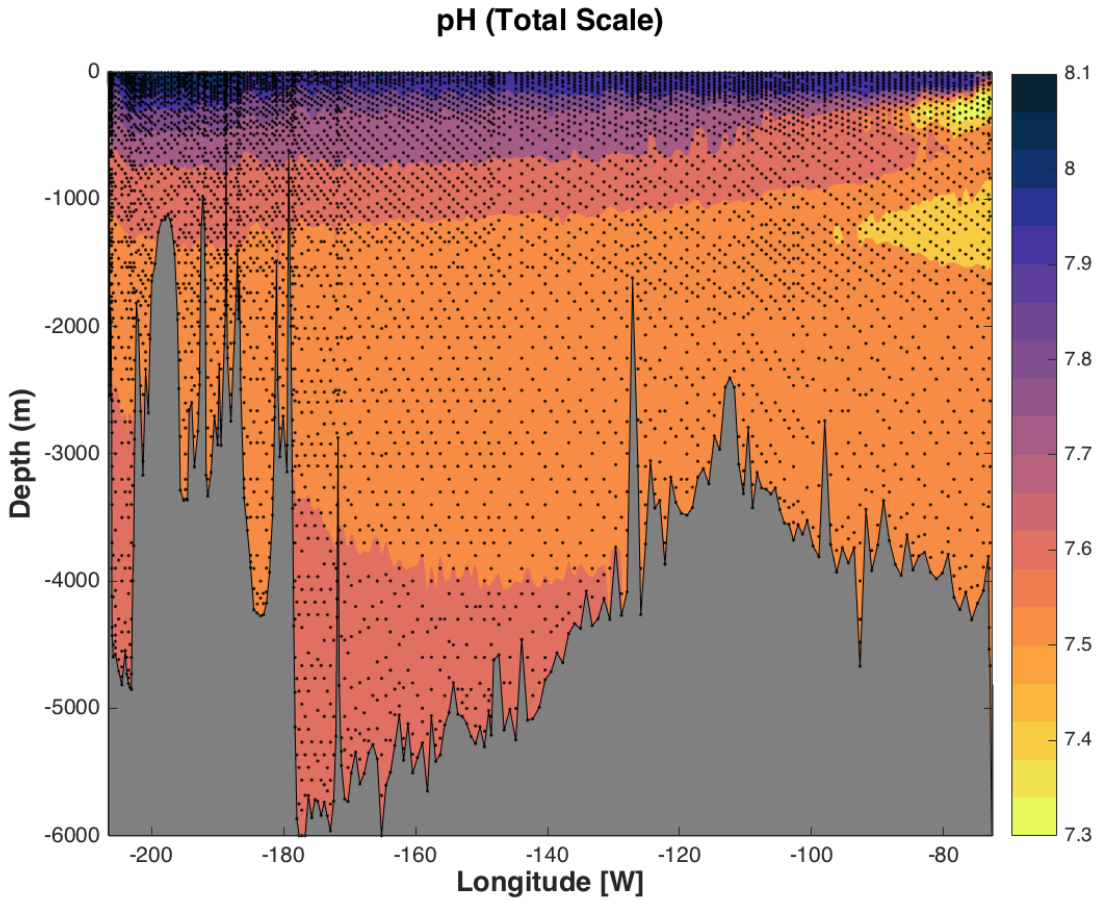


Fig. 21.4: Cross-section of the pH concentration along the 32.5ºS

This cruise represented a great opportunity to grow personally and professionally. Cristobal Aguilera, Elizabeth Simons, and Dr. Dario Maconi were great support when coding. As a geophysicist, I enjoyed the talk given by Rudolph Herbstaedt Gomez, where he explained to us the main features of the East Pacific Rise. I wish I had spent more time with the people from the other shift. However, I had the chance of learning from my fellow watch-stander's culture, and enjoy getting to talk in Spanish with Sherry Chou, who was always willing to have a conversation.

21.5 Rudolph Herbstaedt Gomez

I went on the GO-SHIP-P06 LEG 2 cruise as a Chilean National Observer. However, for the most part I was included in the students' activities. Given that I am in my senior year and have already taken all my course work, this cruise helped me to see from a broad perspective the interactions between different subjects I have studied. It was a great opportunity to deepen my understanding on different natural phenomena, particularly from a physical oceanography point of view. As a geology major, learning about oceanography was something absolutely new.

During this cruise, I served as a CTD watchstander and helped collect alkalinity water samples. I had the privilege of working with wonderful people who taught me how to use the equipment and were always willing to help me whenever it was needed. For these reasons, I am very thankful for all the scientific team for involving me in their research and paper discussions, which helped me get involved in the research that was taking place on the ship.

Like every science student, curiosity is innate to me. In this case, I learned a lot about the Pacific Ocean, and its relationship with global scale processes. Although geology and oceanography are different research areas, I realized that there is a significant connection between them. Lastly, I must say that this experience has increased my appreciation for those who work at sea, both the ship crew who impacted my daily life, and the science staff who contribute to enhance our understanding of the behavior of the ocean.

21.6 Sherry Chou

While I have been on four other research ships for different projects, this cruise on the RVIB Nathaniel B. Palmer for GO-SHIP P06E has been the longest and the most rewarding. Previously I had experienced a variety of serious problems during research cruises, and signing up for this opportunity was my way of giving ocean field work one more (perhaps last) chance. I told myself that no matter what happens I will be able to get through it, and that alone will be a worthwhile experience. I was often thinking about it like a marathon, something seemingly intimidating but very feasible to accomplish, with patience and perseverance. Like a marathon, signing up was the hardest part in many ways.

In spite of my positive self-talk, I was rather anxious prior to the start of the cruise. Luckily, we had a few days in port so I came on the ship early and asked around for help to get settled in. Everyone was very nice and understanding, and slowly but surely I got adjusted to ship life and trained for my new responsibilities.

From the start there were a variety of problems with the chipods, and troubleshooting them and replacing malfunctioning parts was sometimes tiring, but also a great learning opportunity. Jonathan Nash and June Marion always replied to my inquiries promptly, even late at night, and gave me lots of encouragement. While at first I was slightly overwhelmed at the idea of being the "expert" on the ship, slowly I became confident that I could take care of these instruments and the important data they were collecting. The training session with Ratnaksha Lele from Leg1, and the consistent and reliable support from Jonathan and June were central to my climbing quickly along the learning curve. Also invaluable was knowing that I could rely on the expertise and help of the Marine and Electronics techs and the Chief-Scientists when needed.

For my other two duties, as CTD Watchstander and "sample cop", there were many others who shared the responsibilities, and I witnessed the beauty of the scientific process at work. I think central to the scientific method is the idea that humans are fallible, and human error is inevitable. However, we can minimize the impact of human error, by implementing a careful protocol. For the most important tasks we often have many people checking on each other, catching each other's mistakes. Mistakes were frequent, by almost everyone, but they did not compromise the integrity of the data. Everything was carefully and honestly noted. Along these lines, I was also greatly impressed with the protocol for sampling water from the rosette. There was a specific order which was understood and accepted, and everyone followed the protocol. These are principles which are central to science, common place even, but I couldn't help but think how wonderful it would be if other aspects of society worked so rationally and cooperatively, that it could be common place in our everyday lives.

On the purely scientific level, I totally geeked out after our first sampling session, where I recorded the temperature measured from water collected from the Niskin bottles. After about an hour of writing down very similar numbers, the numbers started jumping dramatically. It was the thermocline, which I have known about for the last eight years, but which I was vicariously "experiencing" for the first time. I was really excited, and I couldn't stop telling everyone about it, including to Dad back home. It's like the first time I pointed a telescope at a random spot in the night sky, and saw light from Jupiter and its moons. I felt the thrill of discovery in both cases, and very close to nature and its beautiful mysteries.

I learned that there are some things which need to be experienced first hand, in situ, in real time, and that scientific discovery is what I hope to have the privilege to be a part of for the rest of my life. I have to thank GO-SHIP and my

advisor for this opportunity. It has been one of the most special experiences of my life.

APPENDIX

A

ABBREVIATIONS

ADCP Acoustic Doppler Current Profiler

AOML Atlantic Oceanographic and Meteorological Laboratory - *NOAA*

AP Particulate Absorbtion Spectra

APL Applied Physics Laboratory

ASC Antarctic Support Contract

AWI Alfred Wegener Institute - Alfred-Wegener-Institut, Helmholtz-Zentrum für Polar- und Meeresforschung

Bigelow Bigelow Laboratory for Ocean Sciences

CDOM Chromophoric Dissolved Organic Matter

CFCs Chlorofluorocarbons

CTDO Conductivity Temperature Depth Oxygen

DIC Dissolved Inorganic Carbon

DIP Dissolved Inorganic Phosphorus

DOC Dissolved Organic Carbon

DON Dissolved Organic Nitrogen

DOP Dissolved Organic Phosphorus

ECO Edison Chouest Offshore

ENSTA ENSTA ParisTech

ETHZ Edgenössische Technische Hochschule Zürich

FSU Florida State University

HPLC High-Performance Liquid Chromatography

JAMSTEC Japan Agency for Marine-Earth Science and Technology Kokuritsu-Kenkyū-Kaihatsu-Hōjin Kaiyō Kenkyū Kaihatsu Kikō

LDEO Lamont-Doherty Earth Observatory - Columbia University

LADCP Lowered Accoustic Doppler Profiler

MBARI Monterey Bay Aquarium Research Institute

NASA National Aeronautics and Space Administration

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 - *NOAA*

POC Particulate Organic Carbon

POM Particulate Organic Matter

POP Particulate Organic Phosphorus

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

UCI University of California Irvine

U Colorado University of Colorado

UCSB University of California Santa Barbara

UCSD University of California San Diego

UdeC University of Concepción, Chile

UH University of Hawaii

U Maine University of Maine

U Miami University of Miami

UNAB Universidad Nacional Andres Bello

UNSW University of New South Wales

U Puerto Rico University of Puerto Rico

USAP United States Antarctic Program

USCG United States Coast Guard

USF University of South Florida

UT University of Texas

UW University of Washington

UWA University of Western Australia

U. Wisconsin University of Wisconsin

VUB Vrije Universiteit Brüssel

WHOI Woods Hole Oceanographic Institution

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APPENDIX

B

BOTTLE QUALITY COMMENTS

APPENDIX

C

CALIBRATION DOCUMENTS

Sea-Bird Electronics, Inc.

13431 NE 20th Street, Bellevue, WA 98005-2010 USA

Phone: (+1) 425-643-9866 Fax (+1) 425-643-9954 Email: seabird@seabird.com

SENSOR SERIAL NUMBER: 2569
CALIBRATION DATE: 20-Sep-16

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

COEFFICIENTS:

```
g =  -1.04785719e+001
h =   1.58738716e+000
i =   9.17747073e-005
j =   9.25102032e-005

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

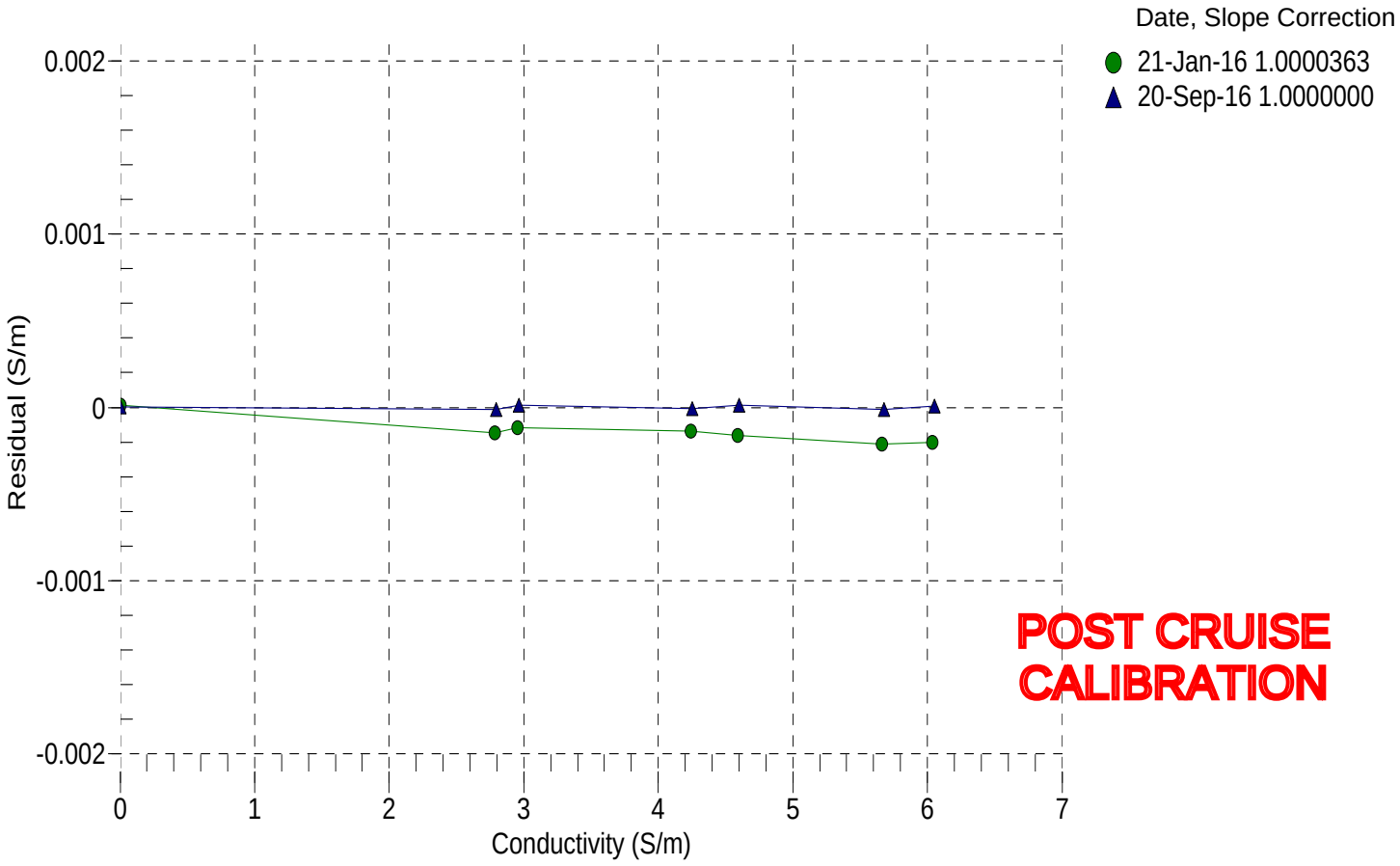
BATH TEMP (° C)	BATH SAL (PSU)	BATH COND (S/m)	INSTRUMENT OUTPUT (kHz)	INSTRUMENT COND (S/m)	RESIDUAL (S/m)
0.0000	0.0000	0.00000	2.56859	0.00000	0.00000
-1.0000	34.6548	2.79278	4.91464	2.79277	-0.00001
1.0000	34.6551	2.96350	5.02254	2.96351	0.00001
15.0000	34.6566	4.25409	5.77286	4.25408	-0.00001
18.5000	34.6563	4.59943	5.95753	4.59944	0.00001
29.0001	34.6543	5.67877	6.50068	5.67876	-0.00001
32.5001	34.6476	6.04990	6.67716	6.04991	0.00001

f = Instrument Output (kHz)

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

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

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



Sea-Bird Electronics, Inc.

13431 NE 20th Street, Bellevue, WA 98005-2010 USA

Phone: (+1) 425-643-9866 Fax (+1) 425-643-9954 Email: seabird@seabird.com

SENSOR SERIAL NUMBER: 2819
CALIBRATION DATE: 11-Apr-17

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

COEFFICIENTS:

```
g =  -9.85851217e+000
h =   1.38071290e+000
i =   3.34284591e-004
j =   4.61675746e-005

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

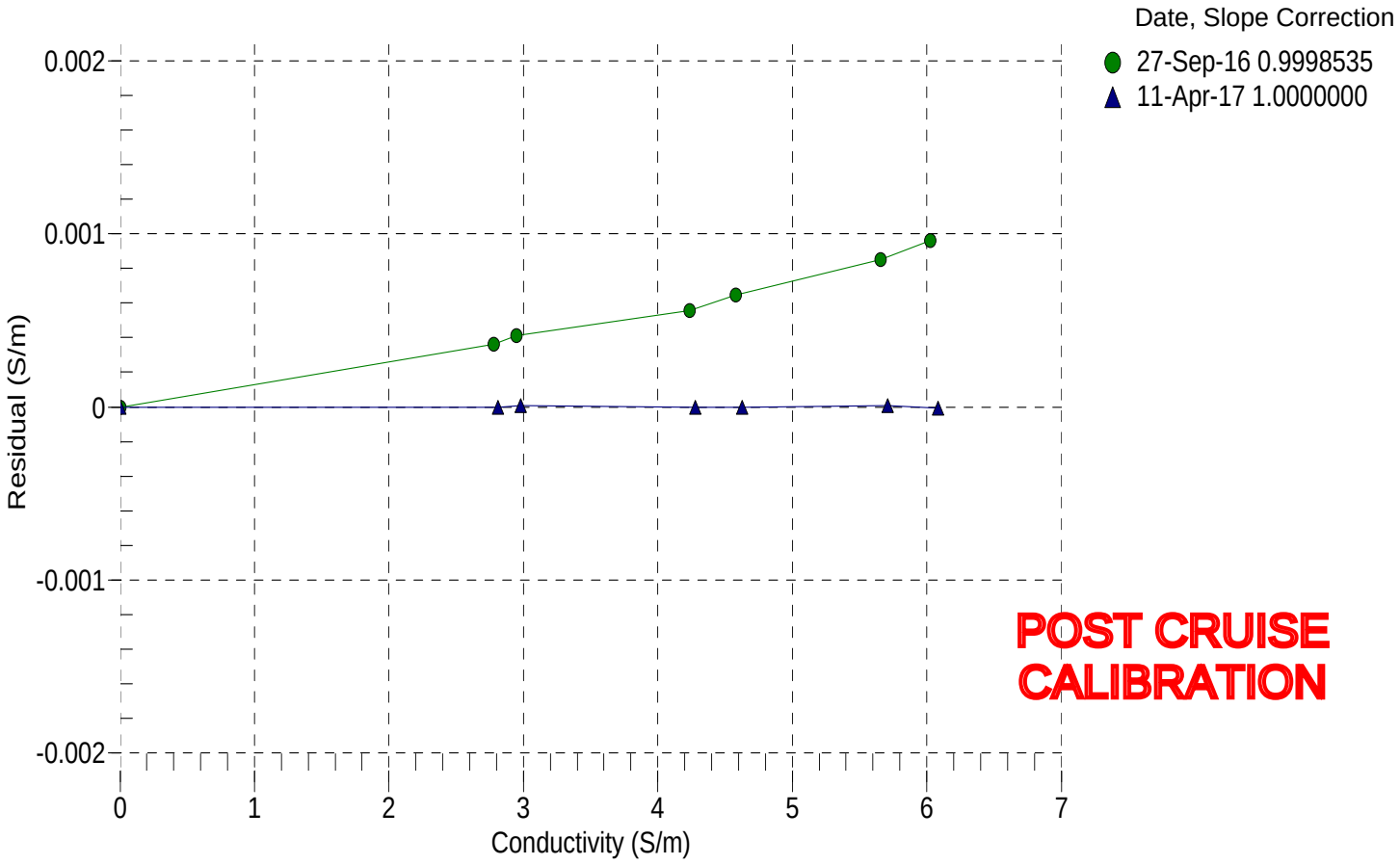
BATH TEMP (° C)	BATH SAL (PSU)	BATH COND (S/m)	INSTRUMENT OUTPUT (kHz)	INSTRUMENT COND (S/m)	RESIDUAL (S/m)
0.0000	0.0000	0.00000	2.67093	0.00000	0.00000
-1.0000	34.8911	2.81004	5.23758	2.81003	-0.00000
1.0000	34.8911	2.98175	5.35456	2.98175	0.00001
15.0000	34.8899	4.27968	6.16707	4.27968	-0.00000
18.5000	34.8883	4.62689	6.36676	4.62689	-0.00000
29.0000	34.8798	5.71155	6.95350	5.71155	0.00001
32.5000	34.8640	6.08337	7.14346	6.08336	-0.00001

f = Instrument Output (kHz)

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

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

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



Sea-Bird Electronics, Inc.

13431 NE 20th Street, Bellevue, WA 98005-2010 USA

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SENSOR SERIAL NUMBER: 3399
CALIBRATION DATE: 07-Apr-17

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

COEFFICIENTS:

```
g =  -9.89936522e+000
h =   1.49747858e+000
i =  -2.33267274e-003
j =   2.62671888e-004

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

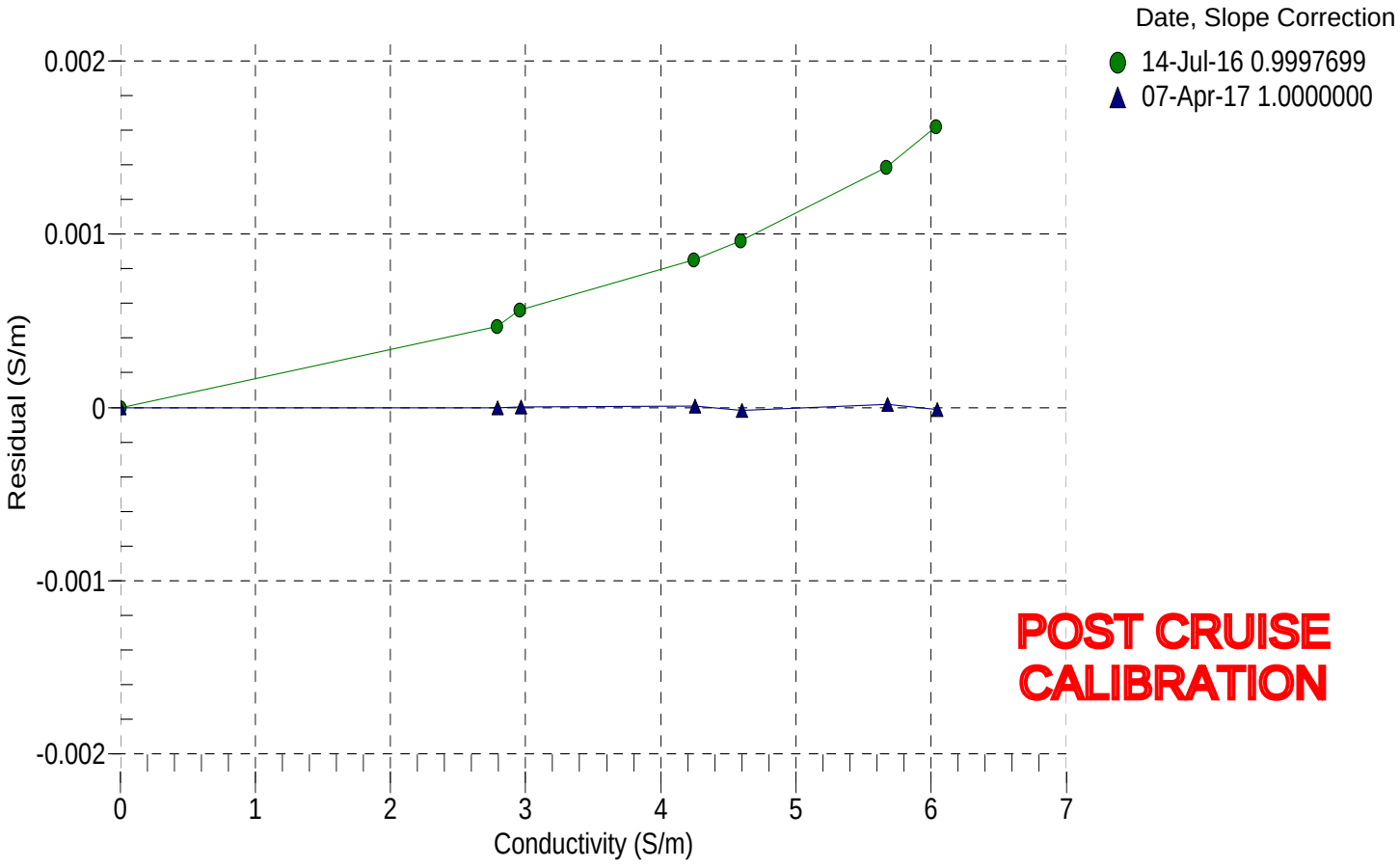
BATH TEMP (° C)	BATH SAL (PSU)	BATH COND (S/m)	INSTRUMENT OUTPUT (kHz)	INSTRUMENT COND (S/m)	RESIDUAL (S/m)
0.0000	0.0000	0.00000	2.57479	0.00000	0.00000
-1.0000	34.6606	2.79320	5.03482	2.79320	-0.00000
1.0000	34.6613	2.96398	5.14715	2.96398	0.00000
15.0001	34.6616	4.25465	5.92723	4.25466	0.00001
18.5000	34.6605	4.59993	6.11892	4.59991	-0.00002
29.0000	34.6522	5.67846	6.68203	5.67848	0.00002
32.5001	34.6389	6.04856	6.86446	6.04854	-0.00001

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



PO Box 518
620 Applegate St.
Philomath, OR 97370

(541) 929-5650
Fax (541) 929-5277
www.wetlabs.com

Scattering Meter Calibration Sheet

9/23/2014
Wavelength: 700 S/N FLBBRTD-3698

Use the following equation to obtain either digital or analog "scaled" output values:

$\beta(\theta_c)$ m^{-1} sr^{-1} = Scale Factor x (Output - Dark Counts)

• **Scale Factor for 700 nm**	=	1.662E-06 ($m^{-1}sr^{-1}$)/counts	1.362E-03 ($m^{-1}sr^{-1}$)/volts
• **Output**	=	meter output counts	meter output volts
• **Dark Counts**	=	43 counts	0.0708 volts
Instrument Resolution	=	1.0 counts 1.0651 mV	1.66E-06 ($m^{-1}sr^{-1}$)

Definitions:

- **Scale Factor**: Calibration scale factor, $\beta(\theta_c)$/counts. Refer to User's Guide for derivation.
- **Output**: Measured signal output of the scattering meter.
- **Dark Counts**: Signal obtained by covering detector with black tape and submersing sensor in water.

Instrument Resolution: Standard deviation of 1 minute of collected data.

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www.wetlabs.com

ECO Chlorophyll Fluorometer Characterization Sheet

Date: 9/23/2014 S/N: FLBBRTD-3698

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

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

	Analog		Digital	
Dark counts	0.057	V	40	counts
Scale Factor (SF)	6	µg/l/V	0.0072	µg/l/count
Maximum Output	4.99	V	4130	counts
Resolution	0.7	mV	1.0	counts
Ambient temperature during characterization			21.5	°C

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

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

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

Resolution: Standard deviation of 1 minute of collected data.

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

Temperature Calibration Certificate

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

1. Equation

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

2. Coefficients

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

3. Calibration results

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

4. Verification

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

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

Examined K. Shimotsu

Approved A. Fukuoka

Dissolved Oxygen Calibration Certificate

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

1. Equation

DO[%] =G+H × P'

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

2. Coefficients

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

3. Verification

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

Acceptance: ±0.5% of full scale

Test for DO 0 %

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

Test for DO 100 %

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

Examined R. Kashida

Approved A. Fukuoka

Sea-Bird Electronics, Inc.

13431 NE 20th Street, Bellevue, WA 98005-2010 USA

Phone: (+1) 425-643-9866 Fax (+1) 425-643-9954 Email: seabird@seabird.com

SENSOR SERIAL NUMBER: 0255
CALIBRATION DATE: 07-Apr-17

SBE 43 OXYGEN CALIBRATION DATA

COEFFICIENTS:
Soc = 0.4872
Voffset = -0.5143
Tau20 = 1.19

A = -3.9824e-003
B = 2.2613e-004
C = -3.7106e-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

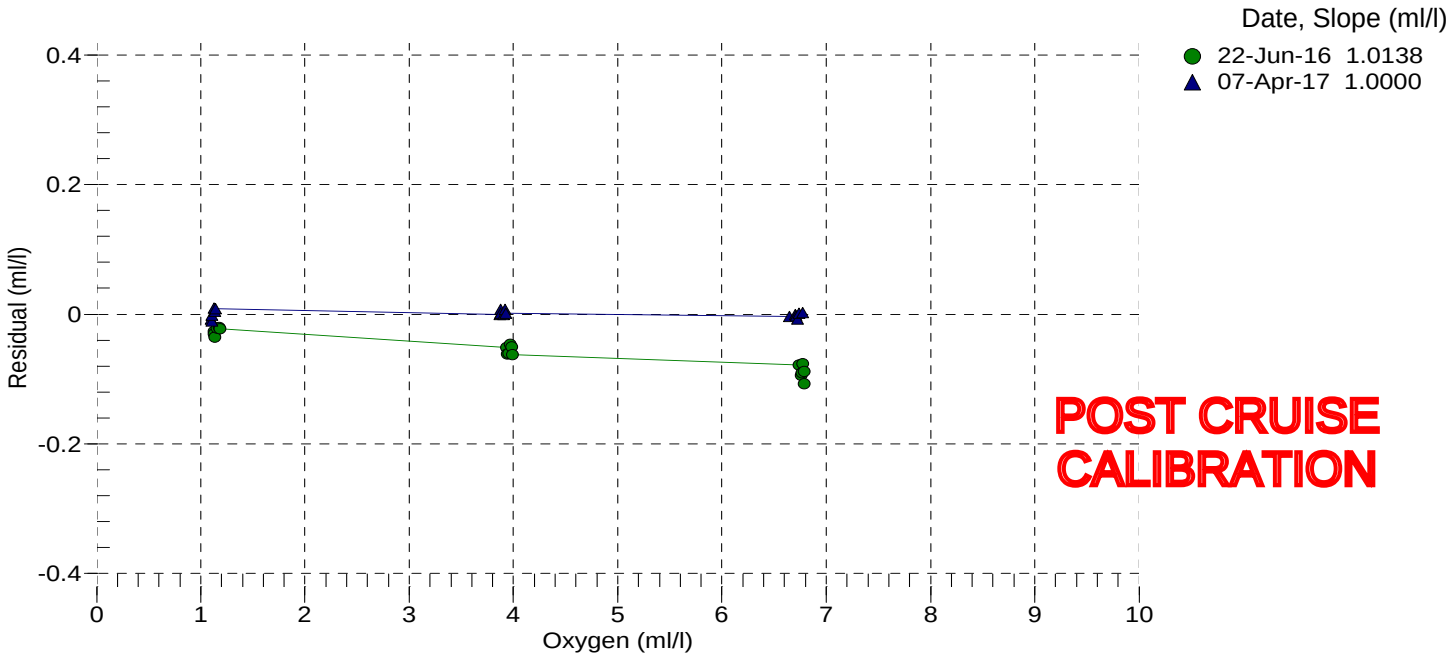
BATH OXYGEN (ml/l)	BATH TEMPERATURE (° C)	BATH SALINITY (PSU)	INSTRUMENT OUTPUT (volts)	INSTRUMENT OXYGEN (ml/l)	RESIDUAL (ml/l)
1.10	6.00	0.00	0.777	1.09	-0.01
1.10	2.00	0.00	0.748	1.09	-0.01
1.10	12.00	0.00	0.821	1.10	-0.00
1.13	26.00	0.00	0.932	1.14	0.01
1.13	20.00	0.00	0.888	1.14	0.00
1.14	30.00	0.00	0.969	1.15	0.01
3.87	6.00	0.00	1.442	3.87	-0.00
3.87	20.00	0.00	1.791	3.88	0.01
3.88	12.00	0.00	1.593	3.88	0.00
3.90	2.00	0.00	1.348	3.90	-0.00
3.92	26.00	0.00	1.957	3.93	0.01
3.93	30.00	0.00	2.063	3.93	0.00
6.65	30.00	0.00	3.135	6.64	-0.00
6.70	12.00	0.00	2.378	6.70	-0.00
6.71	26.00	0.00	2.978	6.70	-0.00
6.72	20.00	0.00	2.723	6.72	-0.01
6.74	2.00	0.00	1.955	6.74	0.00
6.77	6.00	0.00	2.138	6.78	0.00

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

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

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

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



Sea-Bird Electronics, Inc.

13431 NE 20th Street, Bellevue, WA 98005-2010 USA

Phone: (+1) 425-643-9866 Fax (+1) 425-643-9954 Email: seabird@seabird.com

SENSOR SERIAL NUMBER: 0275
CALIBRATION DATE: 30-Mar-17

SBE 43 OXYGEN CALIBRATION DATA

COEFFICIENTS:
Soc = 0.5402
Voffset = -0.4998
Tau20 = 1.21

A = -3.6705e-003
B = 1.9061e-004
C = -2.9805e-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

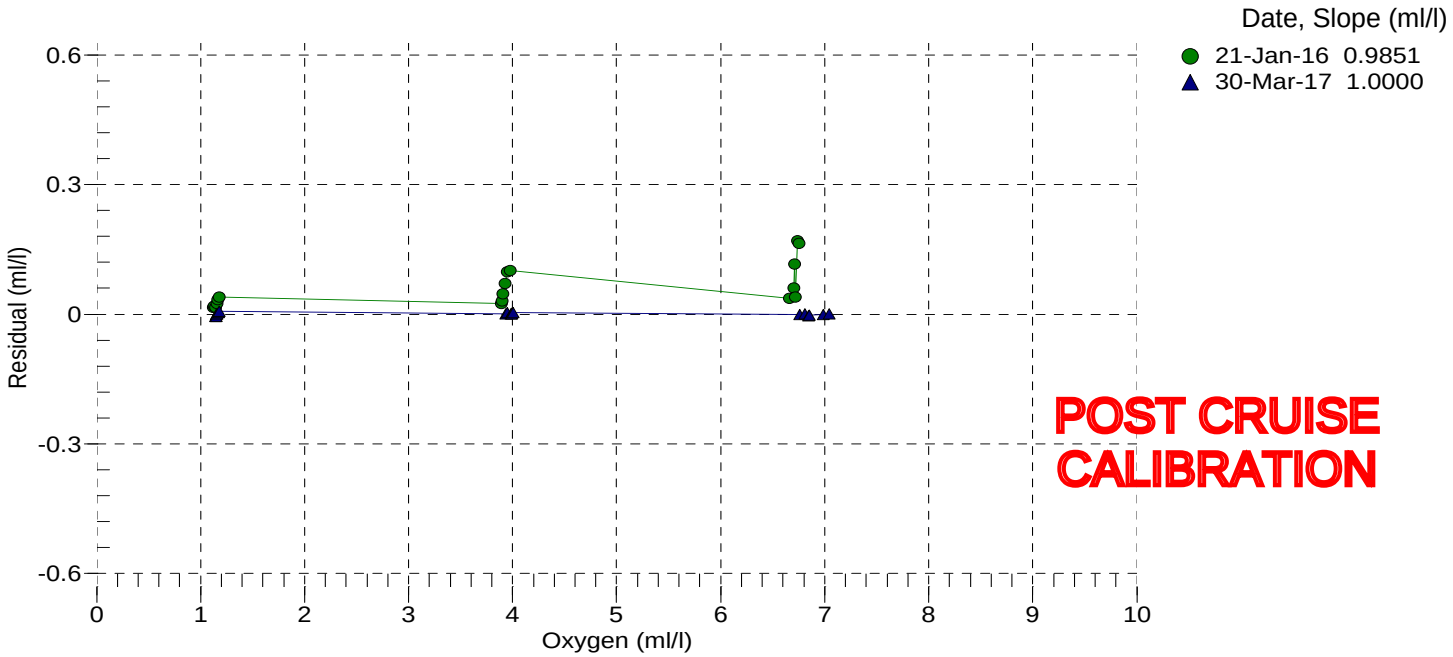
BATH OXYGEN (ml/l)	BATH TEMPERATURE (° C)	BATH SALINITY (PSU)	INSTRUMENT OUTPUT (volts)	INSTRUMENT OXYGEN (ml/l)	RESIDUAL (ml/l)
1.14	2.00	0.00	0.719	1.14	-0.00
1.15	12.00	0.00	0.788	1.15	-0.00
1.15	6.00	0.00	0.747	1.15	-0.00
1.16	20.00	0.00	0.844	1.16	0.00
1.17	26.00	0.00	0.889	1.17	0.00
1.18	30.00	0.00	0.922	1.18	0.01
3.93	2.00	0.00	1.258	3.94	0.00
3.95	6.00	0.00	1.353	3.95	0.00
3.98	20.00	0.00	1.684	3.98	0.00
3.99	26.00	0.00	1.826	3.99	0.00
3.99	12.00	0.00	1.501	3.99	0.00
4.01	30.00	0.00	1.931	4.01	0.00
6.76	2.00	0.00	1.801	6.76	-0.00
6.81	6.00	0.00	1.971	6.81	0.00
6.85	30.00	0.00	2.941	6.84	-0.00
6.85	12.00	0.00	2.219	6.85	-0.00
6.99	20.00	0.00	2.576	6.99	-0.00
7.04	26.00	0.00	2.840	7.04	0.00

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

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

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

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



Sea-Bird Electronics, Inc.

13431 NE 20th Street, Bellevue, WA 98005-2010 USA

Phone: (+1) 425-643-9866 Fax (+1) 425-643-9954 Email: seabird@seabird.com

SENSOR SERIAL NUMBER: 1136
CALIBRATION DATE: 11-Apr-17

SBE 43 OXYGEN CALIBRATION DATA

COEFFICIENTS:
Soc = 0.4514
Voffset = -0.5352
Tau20 = 2.29

A = -3.2659e-003
B = 2.0102e-004
C = -3.4120e-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

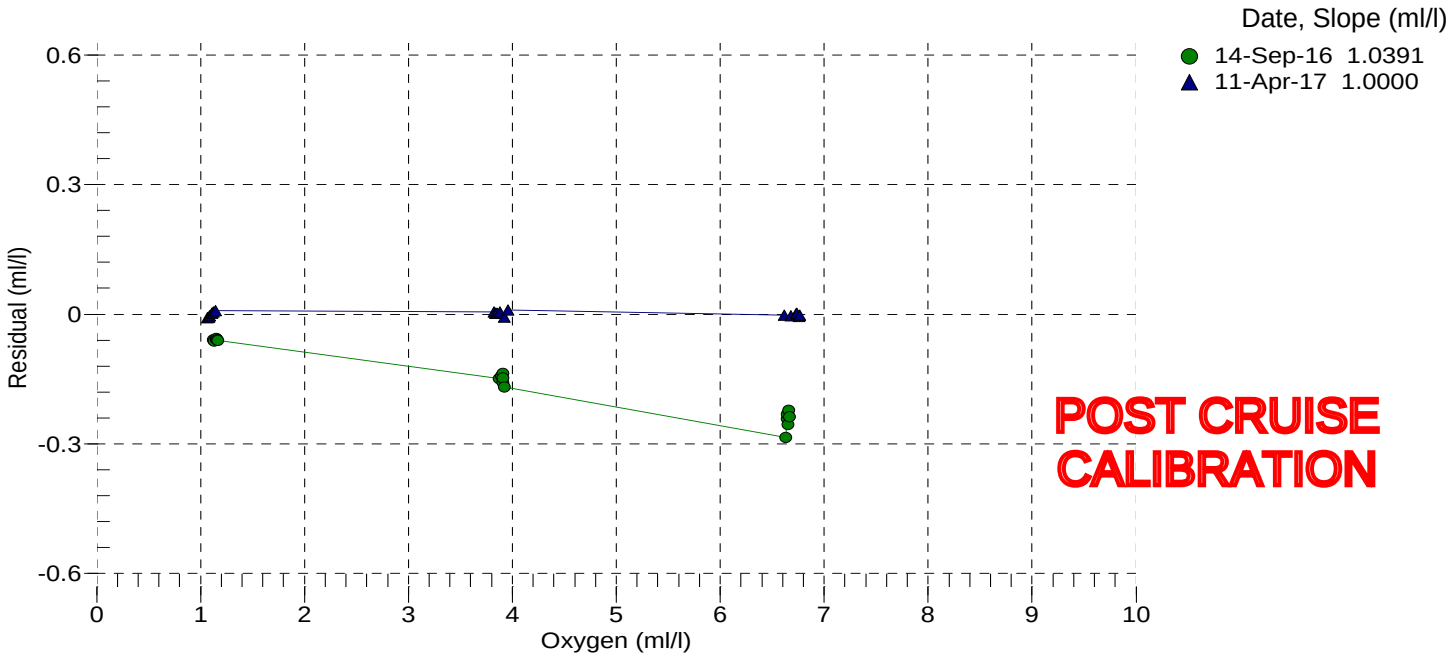
BATH OXYGEN (ml/l)	BATH TEMPERATURE (° C)	BATH SALINITY (PSU)	INSTRUMENT OUTPUT (volts)	INSTRUMENT OXYGEN (ml/l)	RESIDUAL (ml/l)
1.07	2.00	0.00	0.779	1.06	-0.01
1.08	6.00	0.00	0.811	1.07	-0.01
1.08	12.00	0.00	0.858	1.08	-0.00
1.11	20.00	0.00	0.926	1.11	0.00
1.13	26.00	0.00	0.980	1.13	0.01
1.14	30.00	0.00	1.022	1.15	0.01
3.83	2.00	0.00	1.418	3.83	0.01
3.84	6.00	0.00	1.525	3.84	0.00
3.85	12.00	0.00	1.685	3.85	0.00
3.88	20.00	0.00	1.904	3.88	0.00
3.92	26.00	0.00	2.078	3.92	-0.01
3.96	30.00	0.00	2.214	3.97	0.01
6.61	2.00	0.00	2.057	6.61	-0.00
6.68	12.00	0.00	2.528	6.67	-0.00
6.73	6.00	0.00	2.269	6.73	0.00
6.74	20.00	0.00	2.910	6.74	0.00
6.76	30.00	0.00	3.390	6.75	-0.01
6.76	26.00	0.00	3.197	6.76	-0.00

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

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

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

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



Sea-Bird Electronics, Inc.

13431 NE 20th Street, Bellevue, WA 98005-2010 USA

Phone: (+1) 425-643-9866 Fax (+1) 425-643-9954 Email: seabird@seabird.com

SENSOR SERIAL NUMBER: 0080
CALIBRATION DATE: 04-Feb-17

SBE 43 OXYGEN CALIBRATION DATA

COEFFICIENTS:
Soc = 0.5761
Voffset = -0.5113
Tau20 = 1.48

A = -4.1846e-003
B = 1.6396e-004
C = -2.5621e-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

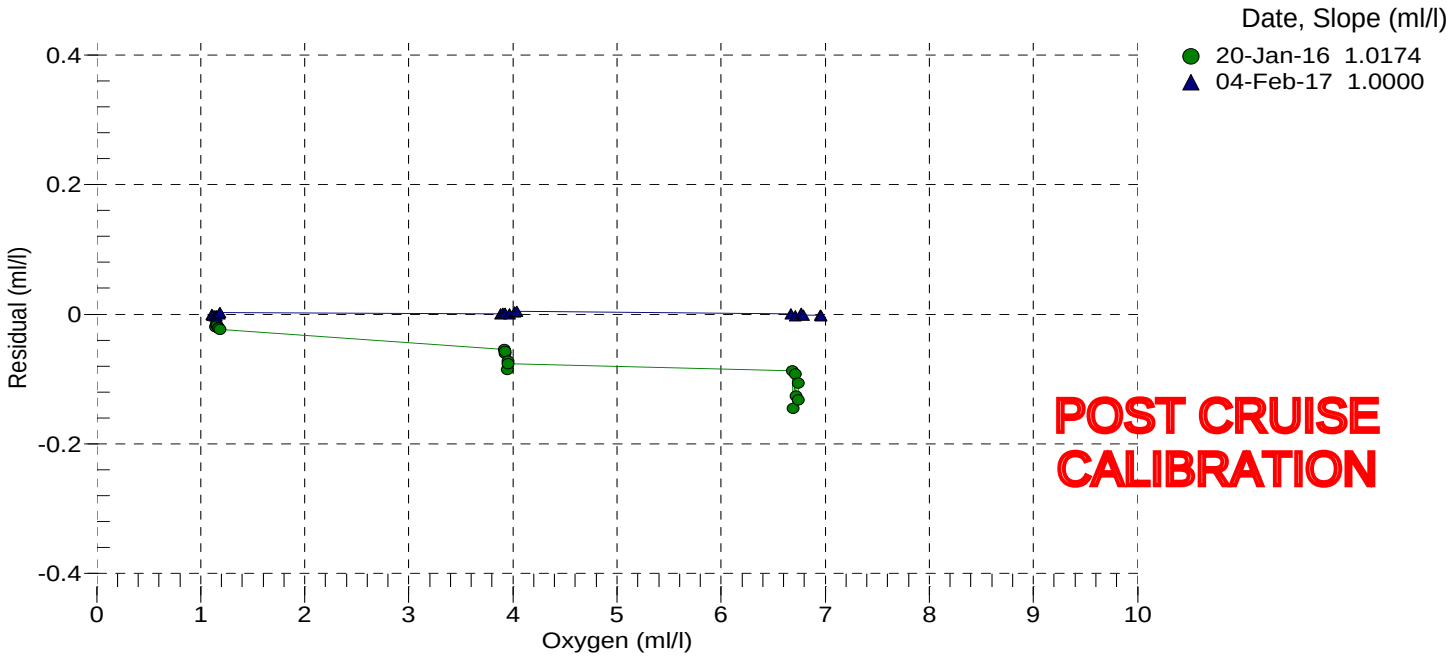
BATH OXYGEN (ml/l)	BATH TEMPERATURE (° C)	BATH SALINITY (PSU)	INSTRUMENT OUTPUT (volts)	INSTRUMENT OXYGEN (ml/l)	RESIDUAL (ml/l)
1.11	2.00	0.00	0.712	1.11	-0.00
1.12	12.00	0.00	0.777	1.12	-0.00
1.13	6.00	0.00	0.741	1.13	-0.00
1.15	20.00	0.00	0.838	1.15	-0.00
1.18	26.00	0.00	0.888	1.18	0.00
1.18	30.00	0.00	0.920	1.19	0.00
3.89	2.00	0.00	1.214	3.89	0.00
3.90	6.00	0.00	1.305	3.91	0.00
3.92	12.00	0.00	1.443	3.92	0.00
3.97	20.00	0.00	1.637	3.97	0.00
4.02	26.00	0.00	1.795	4.02	0.00
4.04	30.00	0.00	1.903	4.04	0.00
6.67	2.00	0.00	1.718	6.67	0.00
6.71	6.00	0.00	1.875	6.71	-0.00
6.77	12.00	0.00	2.119	6.77	0.00
6.79	20.00	0.00	2.437	6.79	-0.00
6.95	26.00	0.00	2.732	6.95	-0.00
6.96	30.00	0.00	2.908	6.96	-0.00

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

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

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

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



Pressure Calibration Report
STS/ODF Calibration Facility

SENSOR SERIAL NUMBER: 1281
CALIBRATION DATE: 10-APR-2017
Mfg: SEABIRD Model: 09P CTD Prs s/n: 136428

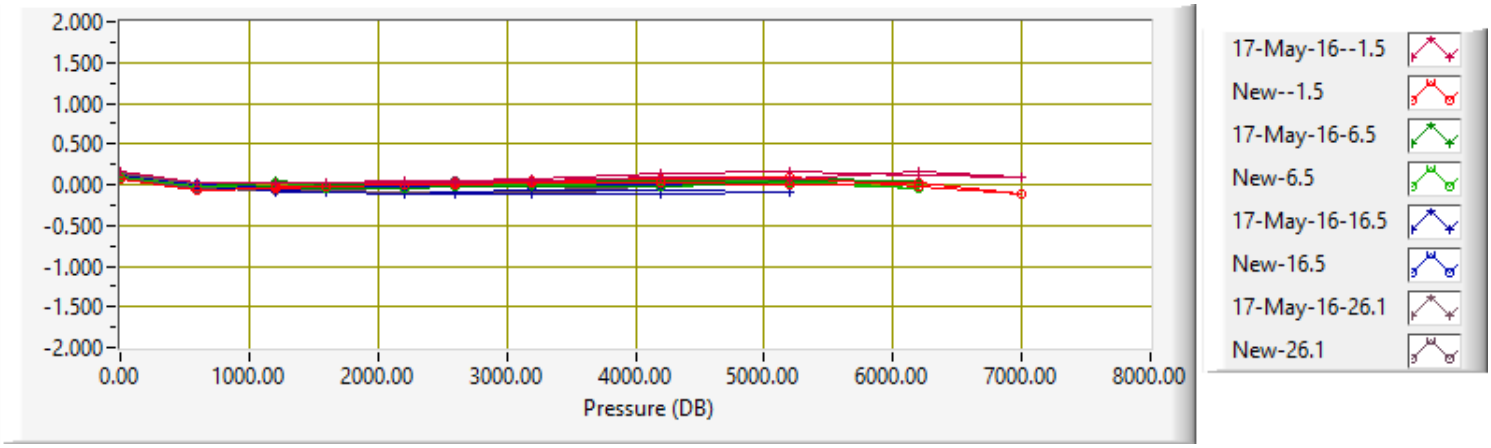
C1= -4.160528E+4
C2= -4.007210E-1
C3= 1.424636E-2
D1= 3.538591E-2
D2= 0.000000E+0
T1= 3.014002E+1
T2= -3.931397E-4
T3= 3.774435E-6
T4= 1.842545E-8
T5= 0.000000E+0
AD590M= 1.27846E-2
AD590B= -9.25586E+0
Slope = 1.00000000E+0
Offset = 0.00000000E+0

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

Sensor Output	Standard	Sensor New_Coefs	Standard-Sensor Prev_Coefs	Standard-Sensor NEW_Coefs	Sensor_Temp	Bath_Temp
33184.184	0.26	0.19	0.17	0.06	-0.62	-1.530
33529.145	600.32	600.38	0.02	-0.06	-0.64	-1.530
33870.005	1200.36	1200.39	0.02	-0.04	-0.64	-1.530
34095.080	1600.39	1600.41	0.02	-0.03	-0.64	-1.530
34429.524	2200.43	2200.44	0.03	-0.01	-0.65	-1.530
34650.420	2600.45	2600.46	0.03	-0.01	-0.66	-1.530
34978.750	3200.49	3200.48	0.05	0.01	-0.68	-1.530
35518.180	4200.52	4200.49	0.08	0.03	-0.68	-1.530
36048.293	5200.54	5200.55	0.08	-0.01	-0.68	-1.530
36569.432	6200.54	6200.52	0.16	0.02	-0.68	-1.530
36980.245	7000.53	7000.64	0.08	-0.12	-0.68	-1.530
36569.450	6200.54	6200.56	0.12	-0.02	-0.68	-1.530
36048.243	5200.54	5200.46	0.17	0.08	-0.68	-1.530
35518.149	4200.52	4200.44	0.13	0.08	-0.69	-1.530
34978.728	3200.49	3200.45	0.07	0.04	-0.69	-1.530
34650.397	2600.45	2600.44	0.05	0.01	-0.69	-1.530
34429.496	2200.43	2200.42	0.04	0.01	-0.69	-1.530

Sensor Output	Standard	Sensor New_Coefs	Standard-Sensor Prev_Coefs	Standard-Sensor NEW_Coefs	Sensor_Temp	Bath_Temp
34095.056	1600.39	1600.41	0.02	-0.02	-0.69	-1.530
33869.978	1200.36	1200.39	0.03	-0.03	-0.69	-1.529
33529.090	600.32	600.33	0.07	-0.01	-0.70	-1.530
33187.363	0.26	0.17	0.17	0.08	7.28	6.479
33532.336	600.32	600.34	0.03	-0.02	7.28	6.479
33873.234	1200.36	1200.40	-0.02	-0.04	7.28	6.480
34098.329	1600.39	1600.44	-0.04	-0.05	7.28	6.480
34432.800	2200.43	2200.48	-0.05	-0.05	7.28	6.479
34653.693	2600.45	2600.47	-0.02	-0.01	7.28	6.479
34982.050	3200.49	3200.50	-0.02	-0.01	7.28	6.479
35521.518	4200.52	4200.53	-0.01	-0.02	7.28	6.479
36051.617	5200.54	5200.52	0.05	0.01	7.28	6.480
36572.822	6200.54	6200.58	0.04	-0.04	7.29	6.479
36051.601	5200.54	5200.50	0.08	0.04	7.28	6.480
35521.479	4200.52	4200.47	0.06	0.05	7.28	6.479
34982.024	3200.49	3200.45	0.03	0.04	7.28	6.479
34653.681	2600.45	2600.45	-0.00	0.01	7.28	6.479
34432.769	2200.43	2200.43	0.00	0.00	7.28	6.479
34098.310	1600.39	1600.40	-0.00	-0.02	7.28	6.480
33873.193	1200.36	1200.33	0.06	0.03	7.28	6.479
33532.319	600.32	600.31	0.06	0.01	7.27	6.479
33190.565	0.26	0.16	0.13	0.10	17.28	16.489
33535.570	600.32	600.33	-0.02	-0.01	17.28	16.489
33876.498	1200.36	1200.38	-0.08	-0.03	17.29	16.489
34101.601	1600.39	1600.40	-0.08	-0.02	17.28	16.489
34436.101	2200.43	2200.45	-0.11	-0.02	17.28	16.489
34657.028	2600.45	2600.46	-0.11	-0.01	17.29	16.489
34985.419	3200.49	3200.50	-0.13	-0.01	17.28	16.490
35524.921	4200.52	4200.52	-0.11	-0.00	17.29	16.489
36055.082	5200.54	5200.54	-0.10	-0.00	17.29	16.489
35524.892	4200.52	4200.46	-0.06	0.05	17.28	16.489
34985.391	3200.49	3200.45	-0.07	0.04	17.29	16.489
34657.021	2600.45	2600.45	-0.10	0.00	17.28	16.489
34436.101	2200.43	2200.45	-0.11	-0.02	17.28	16.489
34101.601	1600.39	1600.40	-0.09	-0.02	17.27	16.489
33876.501	1200.36	1200.39	-0.09	-0.04	17.27	16.490
33535.571	600.32	600.33	-0.03	-0.01	17.27	16.489
33192.637	0.26	0.20	0.15	0.06	26.53	26.092
33537.680	600.32	600.36	-0.00	-0.04	26.55	26.093
33878.643	1200.36	1200.41	-0.06	-0.06	26.57	26.093
34103.774	1600.39	1600.43	-0.07	-0.04	26.59	26.093
34438.308	2200.43	2200.47	-0.09	-0.04	26.59	26.093
34659.257	2600.45	2600.47	-0.09	-0.02	26.61	26.093
34987.677	3200.49	3200.50	-0.09	-0.01	26.62	26.093
35527.229	4200.52	4200.49	-0.07	0.03	26.64	26.093

Sensor Output	Standard	Sensor New_Coefs	Standard-Sensor Prev_Coefs	Standard-Sensor NEW_Coefs	Sensor_Temp	Bath_Temp
34987.649	3200.49	3200.44	-0.03	0.05	26.64	26.093
34659.234	2600.45	2600.41	-0.03	0.04	26.66	26.093
34438.300	2200.43	2200.43	-0.05	-0.00	26.67	26.093
34103.776	1600.39	1600.40	-0.04	-0.02	26.68	26.093
33878.645	1200.36	1200.38	-0.02	-0.02	26.69	26.093
33537.688	600.32	600.33	0.03	-0.01	26.69	26.093
33192.651	0.26	0.17	0.17	0.08	26.69	26.093



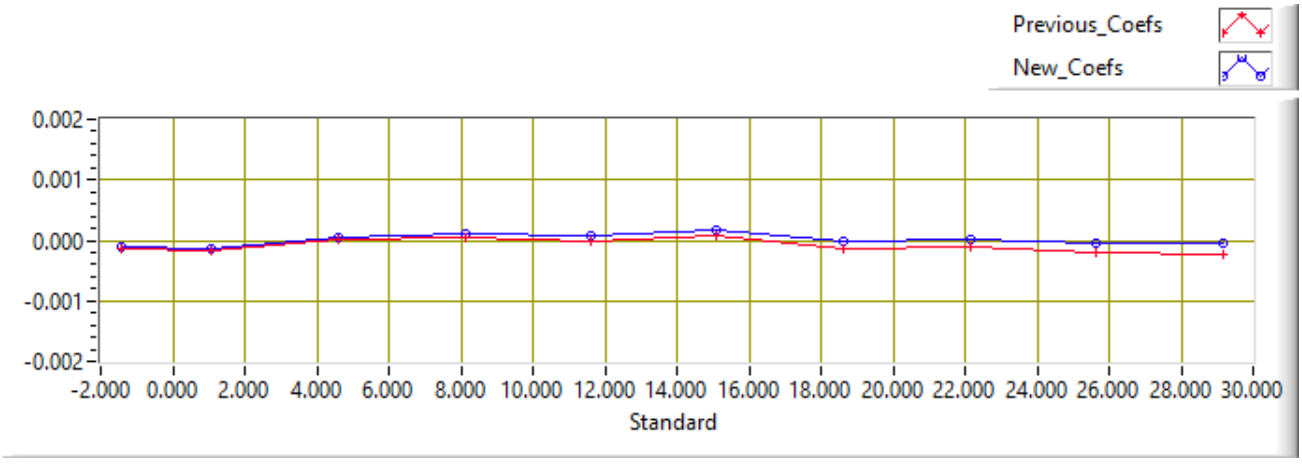
Temperature Calibration Report
STS/ODF Calibration Facility

SENSOR SERIAL NUMBER: 0035
CALIBRATION DATE: 13-Apr-2017
Mfg: SEABIRD Model: 35
Previous cal: 29-Aug-16
Calibration Tech: CAL

ITS-90_COEFFICIENTS
a0 = 4.208496100E-3
a1 = -1.124111980E-3
a2 = 1.735065310E-4
a3 = -9.702815440E-6
a4 = 2.086576170E-7
Slope = 0.999995
Offset = -0.000024

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
-1.4135	-1.4136	-1.4135	-0.00013	-0.00011
1.0905	1.0903	1.0904	-0.00017	-0.00014
4.5965	4.5965	4.5964	0.00002	0.00006
8.1039	8.1040	8.1039	0.00005	0.00011
11.6134	11.6134	11.6133	-0.00001	0.00007
15.1146	15.1146	15.1145	0.00008	0.00017
18.6277	18.6275	18.6276	-0.00014	-0.00003
22.1350	22.1349	22.1349	-0.00012	0.00002
25.6458	25.6456	25.6456	-0.00019	-0.00004
29.1546	29.1544	29.1544	-0.00023	-0.00006
29.1546	29.1544	29.1544	-0.00023	-0.00006



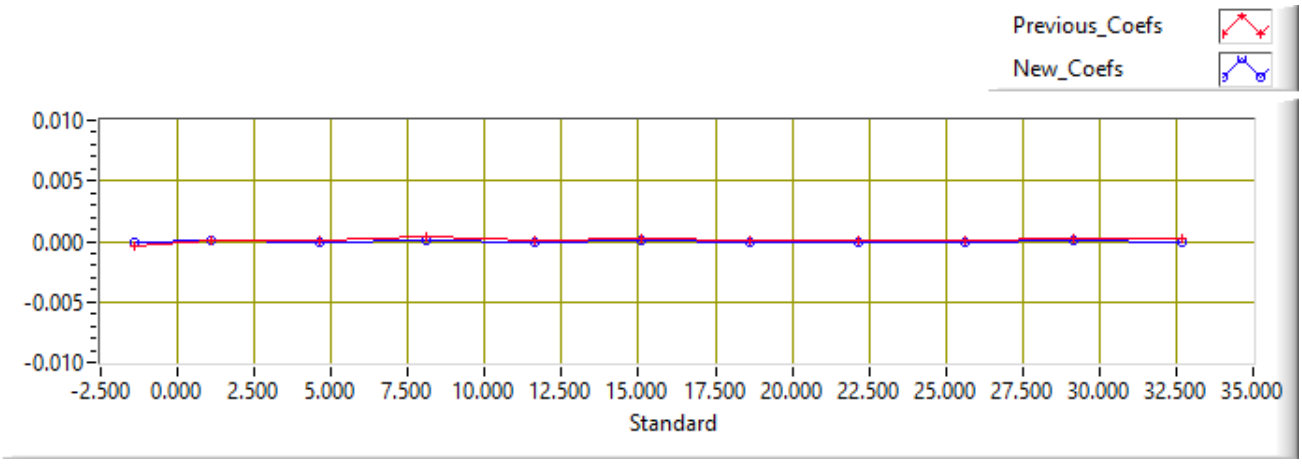
Temperature Calibration Report
STS/ODF Calibration Facility

SENSOR SERIAL NUMBER: 2309
CALIBRATION DATE: 18-Apr-2017
Mfg: SEABIRD Model: 03
Previous cal: 10-Mar-17
Calibration Tech: CM

ITS-90_COEFFICIENTS IPTS-68_COEFFICIENTS
g = 4.35795296E-3 a = 4.35815123E-3
h = 6.45303354E-4 b = 6.45514766E-4
i = 2.44482718E-5 c = 2.44810575E-5
j = 2.39242392E-6 d = 2.39402502E-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
2976.6396	-1.4141	-1.4141	-0.00035	-0.00004
3148.2115	1.0899	1.0898	0.00004	0.00010
3400.3783	4.5960	4.5962	0.00004	-0.00013
3666.9010	8.1039	8.1038	0.00038	0.00013
3948.1828	11.6126	11.6127	0.00015	-0.00010
4243.8071	15.1136	15.1135	0.00031	0.00011
4555.7929	18.6256	18.6256	0.00009	-0.00005
4883.2295	22.1342	22.1342	0.00002	-0.00006
5226.9845	25.6450	25.6450	0.00003	-0.00004
5586.7653	29.1520	29.1518	0.00029	0.00015
5963.8548	32.6640	32.6640	0.00025	-0.00007



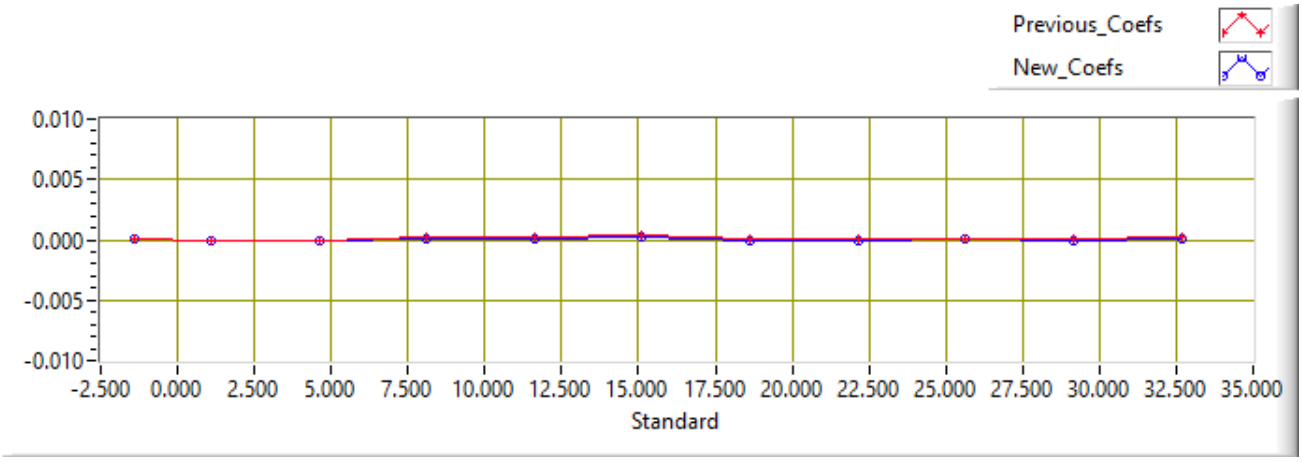
Temperature Calibration Report
STS/ODF Calibration Facility

SENSOR SERIAL NUMBER: 5844
CALIBRATION DATE: 11-Apr-2017
Mfg: SEABIRD Model: 03
Previous cal: 12-Sep-16
Calibration Tech: CAL

ITS-90_COEFFICIENTS	IPTS-68_COEFFICIENTS ITS-T90	
g = 4.36572108E-3	a = 4.36592217E-3	
h = 6.30346756E-4	b = 6.30554579E-4	
i = 2.02981226E-5	c = 2.03291260E-5	
j = 1.55658300E-6	d = 1.55793676E-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
3080.3281	-1.4132	-1.4133	0.00004	0.00012
3260.9407	1.0907	1.0908	-0.00010	-0.00012
3526.5836	4.5966	4.5967	0.00000	-0.00010
3807.6759	8.1044	8.1044	0.00019	0.00003
4104.6790	11.6137	11.6136	0.00020	0.00003
4417.1410	15.1148	15.1146	0.00036	0.00019
4747.1574	18.6258	18.6259	0.00006	-0.00010
5093.9888	22.1346	22.1347	0.00009	-0.00005
5458.5531	25.6460	25.6460	0.00014	0.00001
5840.6669	29.1545	29.1545	0.00011	-0.00005
6241.4164	32.6667	32.6666	0.00024	0.00004



PO Box 518
620 Applegate St.
Philomath, OR 97370

WET Labs

(541) 929-5650
Fax (541) 929-5277
www.wetlabs.com

C-Star Calibration

Date 9.16.16 S/N# CST-1803DR Pathlength 25 cm

	Analog output	Digital output	
V_d	0.008 V	0 counts	
V_{air}	4.813 V	15801 counts	
V_{ref}	4.699 V	15426 counts	
Temperature of calibration water			21.4 ℃
Ambient temperature during calibration			21.6 ℃

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

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

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

V_d Meter output with the beam blocked. This is the offset.

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

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

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

Ambient temperature: meter temperature in air during the calibration.

V_{sig} Measured signal output of meter.

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V

W